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PREFACE

The Spiral Reader is a measuring machine designed to measure the starlike patterns of bubble chamber events. It operates on line with a small computer for control and data collection. A radially oriented image of a slit rotates around the machine center with continuously increasing radius. In this way the slit traces out a spiral in the image plane of the film. The light blocked by a section of a track covering the slit produces a signal which is used to record in polar co-ordinates the position of the track segment. The pulse contains information also on the blackness of the track which is related to the velocity of the particle.

The concept and first design of the Spiral Reader comes from Alvarez' group in Berkeley. Towards the end of the 1960th a number of bubble chamber groups in Europe and in Israel arranged to get a Spiral Reader either by purchase from industry (SMB-SCANIA, Jönköping, Sweden) or by laboratory design and construction. In this way several slightly different Spiral Readers are in use. They have, however, the main principles in common.

It was felt that an organized exchange of experiences and ideas for further development among experts could be fruitful and beneficial both to those working with and those using Spiral Readers. To this end a three day symposium was organized in Stockholm at the Institute of Physics in May 1972. Most of the papers presented are collected in this report. The capability of the Spiral Reader for fast and precise measurements was well demonstrated during the symposium as well as its potential for improvements in the area of ionization measurements. The credit for the success of this first European Symposium on Spiral Readers goes to all participants for their reports and the lively discussions, which we unfortunately cannot reproduce in this report. I wish to thank all people who helped to run the symposium and acknowledge the cooperation of CERN which made this report possible. Finally, I wish to express thanks to my fellow members of the organizing committee, Dr. R. Budde and Dr. S.O. Holmgren.

Gösta Ekspong

Stockholm, June 1972.
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PRESENT PERFORMANCE OF THE WEIZMANN INSTITUTE-TECHNION SPIRAL READER SYSTEM

Weizmann Institute-Technion SR Collaboration(*)

Presented by E. E. Ronat
Weizmann Institute of Science, Rehovot, Israel

1. General Description

We describe in this paper the present performance of the Spiral Reader, which is a collaboration project between the Weizmann Institute and the Technion. Our Spiral Reader (SR) is based on the mechanical-optical hardware identical to the Berkeley SR II. The control electronics, interface to the PDP-9 computer, and on-line software were completely designed and implemented by our group. The whole system was briefly described previously\textsuperscript{1,2}. Figure 1 shows an overall view of our SR.

In very broad terms the timetable of the SR project was as follows:

Mid 1968 - General planning and placement of order for the mechanical-optical hardware
1969 - Design and construction of electronics; design and writing of on-line and off-line software
1970 - Testing and running-in of whole system
1971 - Beginning of production measurement

The Spiral Reader was built by a quite small subgroup of the experimental high energy group - and there was at no time a special group involved exclusively with the SR problems. During the construction and testing phase the whole manpower involved was approximately the following: 1.5 physicists, 1.5 senior programmers, 1 engineer, 2 technicians. Only during later running-in period and during production did a larger number of physicists and programmers get partly involved in the different aspects of the analysis system. Thus the relatively small number of people involved in the project required a careful assignment of priorities, and a number of important improvements and developments had to be postponed until proper manpower was available.

One has to mention that a special problem, was incurred by the off-line computer. All off-line programs were originally run on a home built GOLEM A computer (roughly IBM 7094 equivalent) and the proper conversion of the programs had to be made. Very early though, the GOLEM became overloaded and an IBM 370/165 was obtained. Thus another major reconversion of programs had to be achieved (during 1971) and this severely taxed our limited manpower and caused delays to several projected developments.

2. Performance

The first experiment which is being performed by our Spiral Reader is π\(^+-\)p interactions at 5 GeV/c, taken with the SLAC S2\textsuperscript{m} Bubble Chamber on 46 mm single-strip film.

We measure all nuclear interactions except 2-prongs (of which a sample was measured). Until how we measured approximately 140,000 events. Of these we consider about 100,000 measurements completely good. The unacceptable measurements were performed during the running-in and early production phase when improvements were still being continuously performed. Also during this early phase - the off-line computer was completely over-loaded and only a very small fraction of the measurements could be run. Thus as we had no good check on the quality of measurements, a sizeable number was lost due to hardware malfunctioning before it was detected.

Of the acceptable measurements we have a DST of 41,000 events, and some preliminary results will be discussed in Section 3. The rest of the measured events are in the stage of being processed, through the analysis programs.

The present measuring rate on our Spiral Reader is 40-50 events/hour. The total average weekly rate for a 16 shift week is about 3,000 events/week.

The measuring process at the moment includes manual measurements of 4 fiducials and full crutch pointing. This means that one crutch point is placed on every track. This procedure, while quite time consuming during measurement was considered helpful for the success of events through POOH.

A significant increase in the rate of measurement is expected in the coming months due to 3 main causes:

(a) Introduction of minimum crutch points instead of full crutch pointing. With proper training of our measurers, no significant increase of loss in POOH should occur while increasing the speed of measuring by 30-40%.

(b) Introduction of the software for semi-automatic fiducial measuring (see Section 7), by performing a small spiral around each fiducial. This may again increase the rate by 20-30%.

(c) Further training of our measurers, and reducing down time of the SR.

The success rate of the SR measurements through the various off-line programs POOH, TP and SQUAW is summarized in Table 1 for a sample of 5239 events. The overall success rate of 73% is very comparable to that of manual machines (even though they have no POOH failures). This figure for the overall success rate holds also for a much larger sample of 59,077 events, as is shown in Table 2 (Item IV).

It should be noted that the 27% which fail, include 5% of operator rejects, which are classified in Table 1a. The operator rejects are events rejected by the SR operator before their measurement and are presumably unbiased rejects. As these events were not even measured, the 3rd column of Table 1 summarizes the success rates of measurement excluding the operator rejects.

The events that failed POOH-TP-SQUAW were sent to remeasurement on the SR. A sample of the results of SR remeasurements are summarized in Table 3. It is seen that POOH-TP-SQUAW failure went up from 27% to about 44%. It should be noted, though, that in this sample operator rejects were sent back to remeasurement too and these will usually be rejected again by the operator. Thus normally the POOH-TP-SQUAW rejects are expected to be considerably smaller than 44% and it is planned to do the 2nd measurements on the SR.
Table 1. Success of SR Measurements

Sample: 20 rolls, 5259 events; measured: Feb-March 1972

<table>
<thead>
<tr>
<th></th>
<th>No. Events</th>
<th>Fraction Total (%)</th>
<th>Fraction of Non-Operator Reject (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful SQUAW</td>
<td>3820</td>
<td>73.0</td>
<td>76.9</td>
</tr>
<tr>
<td>SQUAW Failure</td>
<td>405</td>
<td>7.7</td>
<td>8.2</td>
</tr>
<tr>
<td>TP Failure</td>
<td>218</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>POOH Failure</td>
<td>533</td>
<td>10.2</td>
<td>10.6</td>
</tr>
<tr>
<td>Operator Rejects</td>
<td>265</td>
<td>5.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5239</td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Table 1a. Operator Rejects

<table>
<thead>
<tr>
<th>Reason</th>
<th>No. Events</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong Event Type</td>
<td>81</td>
<td>1.5</td>
</tr>
<tr>
<td>Vertex Obscured</td>
<td>53</td>
<td>1.0</td>
</tr>
<tr>
<td>Out of Fiducial Volume</td>
<td>26</td>
<td>0.5</td>
</tr>
<tr>
<td>Fiducial Not Measurable</td>
<td>20</td>
<td>0.4</td>
</tr>
<tr>
<td>No Event on Frame</td>
<td>14</td>
<td>0.3</td>
</tr>
<tr>
<td>Others</td>
<td>71</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>265</td>
<td>5.0%</td>
</tr>
<tr>
<td>Status</td>
<td>No. Events</td>
<td>%</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------------</td>
<td>----</td>
</tr>
<tr>
<td><strong>I. Automatic Decision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33033</td>
<td>32639</td>
<td>55.2</td>
</tr>
<tr>
<td><strong>II. Physicist Decision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32022 Ionization Convergence Failure</td>
<td>221</td>
<td>0.4</td>
</tr>
<tr>
<td>32025 &quot;Bad&quot; Hypothesis has better (x^2_{\text{bub}}) by 2</td>
<td>403</td>
<td>0.7</td>
</tr>
<tr>
<td>32033 No acceptable ionization (x^2)</td>
<td>2272</td>
<td>3.8</td>
</tr>
<tr>
<td>32044 Too many ambiguities (≥ 3)</td>
<td>1371</td>
<td>2.3</td>
</tr>
<tr>
<td>32045 Resolvable ambiguities</td>
<td>3506</td>
<td>5.9</td>
</tr>
<tr>
<td>32066 Too many 4C (≥ 2)</td>
<td>323</td>
<td>0.5</td>
</tr>
<tr>
<td>32077 Reduced ND</td>
<td>69</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>III. Physicist Reject</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31022 Ionization Convergence failure</td>
<td>106</td>
<td>0.2</td>
</tr>
<tr>
<td>31025 &quot;Bad&quot; Hypothesis has better (x^2_{\text{bub}})</td>
<td>769</td>
<td>1.3</td>
</tr>
<tr>
<td>31033 No acceptable ionization (x^2)</td>
<td>229</td>
<td>0.4</td>
</tr>
<tr>
<td>31044 Too many ambiguities (≥ 4)</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>31055 Resolvable ambiguities</td>
<td>157</td>
<td>0.3</td>
</tr>
<tr>
<td>31066 Too many 4C</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>31077 Reduced ND</td>
<td>182</td>
<td>0.3</td>
</tr>
<tr>
<td>31088 Kinematic fails</td>
<td>773</td>
<td>1.3</td>
</tr>
<tr>
<td>Unmeasureable and</td>
<td>33</td>
<td>0.1</td>
</tr>
<tr>
<td>Wrong Event Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IV. POOH, TP, SQUAW Fail</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Operator Rejects</td>
<td>16007</td>
<td>27.0</td>
</tr>
<tr>
<td></td>
<td><strong>59077</strong></td>
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### Table 3. Remeasurements Results

10 Rolls; 2nd Measurement

<table>
<thead>
<tr>
<th>Status</th>
<th>No. Events</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Auto Decision</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33033</td>
<td>606</td>
<td>39.0</td>
</tr>
<tr>
<td>II. Send to Physicist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30022 Ionization Convergence fail</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>30025 &quot;Bad&quot; Hypothesis has better $\chi^2_{\text{pub}}$ by 2</td>
<td>33</td>
<td>2.1</td>
</tr>
<tr>
<td>30033 No acceptable ionization $\chi^2$</td>
<td>40</td>
<td>2.6</td>
</tr>
<tr>
<td>30044 Too many ambiguities ($\geq$ 3)</td>
<td>49</td>
<td>3.2</td>
</tr>
<tr>
<td>30055 Resolvable ambiguities</td>
<td>75</td>
<td>4.8</td>
</tr>
<tr>
<td>30066 Too many 4C</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>30077 Reduced ND</td>
<td>13</td>
<td>0.8</td>
</tr>
<tr>
<td>30088 Kinematic Fails</td>
<td>55</td>
<td>3.4</td>
</tr>
<tr>
<td>POOH, TP, SQ-Fail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ Operator Reject</td>
<td>677</td>
<td>43.5</td>
</tr>
<tr>
<td></td>
<td>1554</td>
<td></td>
</tr>
</tbody>
</table>

$^a$These numbers include all the operator rejects of measurement 1. In normal operation, operator rejects will not be sent to remeasurement, thus significantly decreasing these failures.
Malfunction of the hardware can occur, such that it does not put the SR out of operation but still produces poor measurements. In order to avoid loss of measurements from this cause, a sample of each day's measurement is examined within 24 hours. The following criteria are applied:

(a) The POOH success rate is required to be above 85% and overall success above 65%.
(b) The beam FRMS is required to peak below ~5.5 least counts.
(c) The beam pulse height is required to be concentrated between 19-23.

In case of failure of any of these criteria, the measurement is stopped and the SR is turned over to the maintenance crew.

A reasonable amount of our effort went into program development and logistic setup for a system that could handle the 200,000-400,000 measurements per year. For this purpose bookkeeping program JUNGLE was developed which keeps the status of all the events and controls the events sent to measurement; it also receives feedback from the program SELECT as to which measurements were put on DST and which failed inside the system and for what reason.

Rather careful procedures had to be setup for the daily debug checking of a sample of measurements (described above), as well as for the complete production running and proper tape storage.

3. Results

The first measurements of our Spiral Reader were performed on an experiment of $\pi^+ p$ interactions at 5 GeV/c.

We shall show some results of 4-prong interactions from this experiment, based on a preliminary DST of about 40,000 events (after physicist checking, but no remeasurement).

A. Reaction $\pi^+ p \rightarrow p\pi^+\pi^-\pi^-$ (4C, 9620 events).

Figure 2 shows the invariant mass of $p\pi^+$. Figure 3 shows the invariant mass of $\pi^+\pi^-$ when the other $p\pi^+$ combination is the $\Delta^{++}$ region. There are seen clear signals for the $\Delta^{++}(1236)$, $\rho^0$ and $f^0$, and both location of these resonances and their widths corresponds to presently acceptable values.

B. Reaction $\pi^+ p \rightarrow p\pi^+\pi^+\pi^0$ (IC1, 12,300 Events).

The distribution of $M(\pi^+\pi^-\pi^0)$ is shown in Figure 4. The $(\pi^+\pi^-\pi^0)$ invariant mass, when produced with a $\Delta^{++}$ is shown in Fig. 5, in 10 MeV intervals. The narrow $\eta$ and $\omega$ mesons appear as very prominent features, and are at their correct central values, with widths which are somewhat better than for hand measurements.

4. Quality of Measurements.

The invariant mass distributions of the $\pi^+ p$ 5 GeV/c experiment (Figures 2-5) provide some evidence that the SR measurements are "reasonable". The distribution of the FRMS (= deviations from fitted tracks projected onto the film) of a sample of measurements is shown in Fig. 6. They peak between 2-3 least counts (4-6 microns) and are somewhat better than FRMS deviations obtained on a manual measuring machine for the same film.

In order to investigate in detail the quality of measurements of the SR a sample of the film was measured by a Vanguard manual measuring machine. The hand measurements were passed through the identical TP geometry program as the SR measurements. We compared in detail the geometry results of all tracks of 1450 events.
For all events we looked at a quantity \( q_{SR} - q_{VU} / q \) where \( q \) was the momentum, phi and dip of each track as measured by the SR and the Vanguard. For all outgoing tracks these distributions were reasonably centered on 0 with widths of about 1. On the other hand the beam distribution showed small shifts corresponding to about 30 MeV on the momentum and about 0.1° on the dip. We also examined the pulls of about 9600 4C events and they show qualitatively similar effects.

While we do not yet understand the exact source of this beam shift, we are now conducting an investigation in order to understand it and eliminate it. In order to correct the measurements already made we use the following procedures in SQUAW: (a) the values of the beam momentum and dip are modified by a small correction factor (this was not yet done on the events on our present DST), (b) a beam averaging calculation is done (following a LRL procedure) where the measured beam values are averaged with a beam mapping based on 4C fits where the beam was unconstrained.

Possible sources for the observed beam shift and ways of improvement that are being looked into are the following:

(a) Film tension. LRL found out that the tension under which the film is kept during measurement could cause such distortions and suggested methods to eliminate it.

(b) Improved calibration. The calibration could be improved by (i) better parameterization of the fit, and by (ii) investigating the effect of the differences in the tension under which calibration plate and usual film are measured. (iii) Furthermore, we are now doing a separate calibration in each of the 3 views - while previously calibration was performed in view 3 only.

(c) Investigation of the vacuum of the three film gates, and its improvement.

We also compared the overall results of passage through off-line programs of hand-measurements (Vanguard) and SR measurements on a sample of events. The TP+SQUAW failure was 13% on the hand measurement 10% on SR measurements. Of the 586 events which passed successfully the whole analysis system, in 88% there was agreement between the Vanguard and SR measurements. Of the remaining 12%, further reexamination showed that in about 8.5% the SR assignment was considered correct, in 1.5% the Vanguard was correct and in 2% it was undecided (hardship cases).

5. Calibration

For calibration we use the LRL "Chicken-walk" film-strip of a pattern of 7 x 15 crosses at 15° to the radial direction. The calibration film is just placed in the film gate and is not attached to the film transport system and therefore not subject to the same tensions as the real film during measurements.

The calibration program CALB originates from the CERN program SCALP with considerable modifications. The input is completely rewritten to conform to our SR output. The fit itself is performed to a 17 parameter function which is similar to the LRL formulation. It was found that some of these parameters have only a minor effect in the fit in most cases. A study is presently being done on improvements on the parametrization of the fit.

For each calibration measurement we take 7 spiral runs. Originally we calculated 7 complete fits (and sets of parameters) corresponding to these separate spiral-runs. We subsequently found out that the fit was very considerably improved when all the fits of the 7 spirals are being used together. Thus we are now performing a grand fit to all hits
for all 7 spirals for each cross. In this way there are typically about 130-140 hits on each cross. We pick up on calibration about 90 crosses. (The others are beyond the range of the spiral or not enough hits are obtained on it). We pay especial attention to there not being any "fractional" crosses being picked up as these can distort the fit considerably. In making the grand fit to all hits, we obtain $\chi^2$ of typically 500-600 for about 90 points and 17 parameters. For this purpose our $\chi^2$ is defined as the sum of differences between the fit and the expected position of the cross (i.e. the error is set arbitrarily to $\Delta=1 \mu c. = 2 \text{ microns}$). This means that typical residuals on the coordinates of each cross are about 1.5-2.0 least counts on $x$ and $y$.

We have not made as yet a comprehensive study of systematics of the residuals from the fit to the calibration pattern, but this problem is under study.

An interesting point was found in relation to the $x$-$y$ measurement of the crosses. A feature of the calibration programs allows several measurements of the $x$-$y$ coordinates of the calibration plate crosses to be made by the SR stage just prior to making the spiral run - then calculating the average position. Alternately the cross positions were measured on a Vanguard measuring machine and introduced as data into the CALB program. It turned out that the $\chi^2$ of a fit based on the Vanguard measurement of the crosses is significantly better than when using the SR measured $x$-$y$ coordinates of the crosses.

6. Ionization Measurement and Auto Decisions

In our Spiral Reader the pulse height of each hit is digitized into 32 levels, and output in 5 bits (i.e. $PH \leq 31$). The discriminator level commonly used is 7. In the program POOH the $PH$ data for all points of each track with radius $\leq 3500$ R-counts (i.e. about 5000 microns on film), are used to calculate an average $PH$ for the track. Typically one gets $PH = 30$ for stopping tracks and 20-22 for beam tracks.

In SQUAW, for each hypothesis a fit is made to the pulse height data and an ionization $\chi^2$ is obtained. Our treatment follows generally the LRL procedure. All 3 views are used as independent data. Before making the fit a check is made of the consistency of the 3 views, and views that are very inconsistent are not used. The fit is made by first obtaining the projected bubble density $\alpha$ for each track in each view (taking into account different aspect angles for the 3 views). Then all tracks are fit simultaneously for each kinematic hypothesis where the functional form of the "predicted" PH (PHP) is:

$$\text{PHP} = \text{PHMAX} \left[ 1 - \left( 1 - \frac{\text{PHMIN}}{\text{PHMAX}} \right)^\alpha \right]$$  

and the quantity fitted is PHMIN. PHMAX is the average PH of stopping protons (29.5 is used in our experiment). The $\chi^2$-ionization ($= \chi^2_{\text{bub}}$) is obtained from minimization of difference of measured and predicted heights.

The distribution of $\chi^2$-ionization for a typical sample of 4-prong events is shown in Fig. 7.

It was found that the Spiral Reader pulse height measurement consistently underestimated the ionization of low momentum tracks ($p \leq 150$ MeV) and consequently gave very poor $\chi^2_{\text{bub}}$ for these events. As such tracks are distinguishable kinematically (by range), we introduced a recent modification which excludes such tracks from the $\chi^2_{\text{bub}}$ calculation.
Our SELECT program, which follows SQUAW, subsequently uses the $\chi^2$-ionization value for deciding on the automatic selection of the SQUAW hypothesis. The SELECT program makes one of the following decisions:

a. Event is unique (1 hypothesis put on DST).

b. Event is intrinsically ambiguous (several hypotheses sent onto DST).

c. Event is doubtful (referred to physicist for final decision).

The criteria developed for the program SELECT are hopefully general, but the specific values of the quantities mentioned below refer to our $\pi^+p$ experiment at 5 GeV/c.

The main procedure of the program SELECT in making decisions is as follows:

1. The kinematic results of SQUAW are examined. Here a $P_{\chi^2}$ cutoff is applied, missing mass hypotheses are rejected if a higher constrain corresponding fit exists, and a minimum value of missing mass is required for genuine missing mass hypotheses.

2. The hypothesis with the minimum $\chi^2$-ionization is required to be below a specified value (we require $\chi^2_{\text{bub}} \leq 1.5 \cdot (3 \cdot NTK - 1)$, where $NTK$ is the number of tracks in the fit). If not the whole event is put in category (c) and sent to the physicist.

3. Assuming that condition 2 holds, the other hypotheses are classified as to whether they fall within $KQ$ units of $\chi^2$-ionization ($KQ = 4$ in our experiment) of the hypothesis with minimum $\chi^2$-ionization. Those that differ from the minimum $\chi^2$-ionization by more than $KQ$ are rejected. Those that fall within the range $KQ$ are classified "potentially ambiguous".

4. The event is examined whether at this stage it falls into one of a number of potentially troublesome categories. These include: more than 2-fold ambiguous, more than one 4C hypothesis, reduced number of kinematic degrees of freedom, or a better $\chi^2_{\text{bub}}$ (by 2 units) of one of the kinematically rejected hypotheses (this indicates possibility of a higher constrained fit not having succeeded for various reasons). These cases are sent to the physicist for examination.

5. Finally those events in the "potentially ambiguous" class are now further analyzed by the program to determine whether they are "intrinsically" ambiguous, or whether a physicist could resolve them on the scanning table. Events where a physicist could make a decision include those cases in which the SR did not measure ionization on one or more tracks (short tracks, flares, discrepancies between PH on different views causing rejection, etc.). These tracks could be crucial for the decision. Therefore, the program looks at the separate hypotheses of the "potentially ambiguous" events track by track; if different mass assignments on any track causes its predicted ionization to be different by more than a factor FI (in our experiment $FI = 1.3$) that event is sent to the physicist as a resolvable ambiguity. If on the other hand in no case do different mass assignments cause a different predicted ionization by more than factor FI, the event is classified as "intrinsically ambiguous" and put in category (b) above.

The events sent to the physicist, or any other event can be forced into any kinematically accepted decision by an overriding decision card which SELECT recognizes.

We tested this system on a sample of 1106 events. These events were fully physicist checked, and then the physicist decisions were compared against the automatic decisions of SELECT. Those cases of disagreement were again examined very carefully to determine
whether the automatic decision or the physicist were right. The results were as follows:

89 events (8%) - had disagreements. Of these
23 events (2.1%) - SR was considered mistaken; of these again only
9 events (0.9%) involved wrong unique hypotheses.
66 events (6%) - the physicist was considered mistaken; of these
26 events (2.4%) involved wrong unique hypothesis.

After the comparison was made, several criteria of SELECT were improved, which
should result in even considerably smaller SR errors. On the other hand while some of
the physicist errors could be attributed to inexperience or carelessness, we believe
that the study shows conclusively that basically the number of SR auto-decision errors
are smaller than if checking were fully done by physicists.

The distribution of the hypothesis with the best $\chi^2_{bub}$ versus the next best $\chi^2_{bub}$ on
a sample of events is shown in Fig. 8. The comparison of the predicted versus measured
pulse height is shown in Fig. 9.

The results of the Auto-decision systems for the approximately 40,000 events on the
DST are shown in Table 2 (for first measurement). We note that about 18% of all events
were sent to the physicist. About 4% of these events were rejected by the physicist.
They include possible strange events (not all strange hypotheses were included in SQUAW),
possible Dalitz pairs which were not yet treated properly in SQUAW, as well as candidates
for remeasurement. Of those 13.7% of the events resolved by the physicist, the biggest
category are status 32055 (resolvable ambiguity), 32033 (no acceptable ionization $\chi^2$)
and 32044 (too many ambiguities). The improved treatment of curly tracks, described
above would considerably lower the number of events of status 32033 and allow them to
go into the automatic decision category.

In Table 3 are shown the results of a sample of SR remeasurements; for this sample
all events that did not get on the DST were sent for remeasurement (including operator
rejects). About 55% of events successfully passed POOH, TP, SQUAW (and were not rejected
by operator), compared to 73% for the 1st measurement. The fraction sent to the physicists
for final decision is roughly the same (these have status words of "30,000" because they
were not yet looked at by the physicist). Consequently we are now doing all 2nd measure-
ments on the Spiral Reader.

Further improvements of ionization measurements being planned are as follows. Each
hit on our Spiral Reader is composed of 4 PDP-9 words. Of these one word is reserved to
get the pulse width at half-height. When this feature will be fully implemented we
could calculate a quantity proportional to the pulse area. This will then permit us to
use the pulse heights from a much longer section of track and thus improve considerably
the evaluation of the ionization. That is expected to decrease considerably the number
of events sent to the physicist as resolvable ambiguities and as too many ambiguities
(status 32044, 32055).
7. **Further Developments.**

Plans for future development of our Spiral Reader System include the following items:

A. **Hardware**
   1. Electronics for measurement of the pulse width of half height. This is expected to improve considerably the ionization measurement.
   2. A new cage of handling 35 mm single-strip film.
   3. A new cage and film transport for handling 35 and 50 mm 3-strip film.
   4. Additional buttons and control for handling chopping and negative crutch points.
   5. Electronics for pulse treatment of bright-field film.

B. **Software**
   1. Software to support new hardware features above (specifically items A1, A3).
   2. Semi-automatic fiducial measurement. We plan to perform a spiral scan of each fiducial of approximately 5 pitches (≈ 300 msec) - thus yielding about 10 points on each leg of the fiducial. A best fit to their intersection (similar to fit of crosses in the calibration program) will yield the best position of the fiducial. This scheme is intended to substantially increase the speed of measurement of fiducials, increase the accuracy of the measurement and reduce fatigue of the measurer. In this scheme the stage will be driven to the prestored approximate location of the fiducials by the computer, where the spiral will be performed (also by computer) without the necessity of operator interference. Preliminary results of calculated positions of the fiducials yield generally better reproducibility than hand-measurement of the fiducial location.
   3. Improved treatment of filter and match - in particular handling of crutch points, overlapping tracks and matching procedures.

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**References**

Figure Captions

Fig. 1. Overall view of the Weizmann Institute-Technion Spiral Reader.

Fig. 2. $M(p\pi^+)$ for reaction $\pi^+p \rightarrow p\pi^+\pi^+\pi^-$, 5 GeV/c.

Fig. 3. $M(\pi^+\pi^-)$ for reaction $\pi^+p \rightarrow p\pi^+\pi^+\pi^-$, 5 GeV/c, when $p\pi^+$ is in $\Lambda^{**}$ resonance.

Fig. 4. $M(\pi^+\pi^-\pi^0)$ for reaction $\pi^+p \rightarrow p\pi^+\pi^+\pi^-\pi^0$, 5 GeV/c.

Fig. 5. $M(\pi^+\pi^-\pi^0)$ for reaction $\pi^+p \rightarrow p\pi^+\pi^+\pi^-\pi^0$, 5 GeV/c when $p\pi^+$ is in $\Lambda^{**}$ resonance.

Fig. 6. FRMS (= film deviations from fitted tracks) distribution for $\pi^+p \rightarrow p\pi^+\pi^+$

5 GeV/c.

Fig. 7. Distribution of ionization $\chi^2$, for 4 prong events.

Fig. 8. "Best" hypothesis is the physicist decision based on scanning table. The scatter plot shows the $\chi^2$-ionization for "best" hypothesis versus the next best $\chi^2$-ionization. Those events falling within the broken lines are sent to physicist for decision, unless the ionization ratios of all corresponding tracks is less than 1.3.

Fig. 9. Distribution of predicted pulse height versus measured pulse height on tracks of hypotheses chosen by physicist. Broken lines represent typical errors.
\[ \pi^+ p \rightarrow p \pi^+ \pi^+ \pi^-, 5 \text{ Gev}/c \]

\[ \text{MASS } p-\pi^+ \pi^- \text{ BOTH} \]

9620 events

\[ \pi^+ p \rightarrow p \pi^+ \pi^+ \pi^-, 5 \text{ Gev}/c \]

\[ \text{MASS } \pi^+ \pi^- \text{ IN DELTA} \]

4960 events

**Fig. 2**

**Fig. 3**
\[ \pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^0, 5 \text{ GeV/c} \]

MASS \( \pi^+ \pi^- \pi^0 \)

12300 events

\[ \pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^0, 5 \text{ GeV/c} \]

MASS \( \pi^+ \pi^- \pi^0, p\pi^+\text{in}\Delta^+ \)

7058 events

Fig. 4

Fig. 5
Fig. 8

Fig. 9
STATUS REPORT OF THE CERN-LSD SYSTEM

CERN-LSD Group
(presented by J.-C. Gouache)

1. INTRODUCTION

This first paper is intended to serve as a general frame for the following reports. It gives an overall view of the construction of the LSD (short for "Lecteur à Spirale Digitisée") and of the operation of the whole system at CERN. Most of the points and figures just mentioned here will be dealt with in detail in the next papers.

No attempt is made to give a precise description of the machines - this can be found in references 1, 2, 3 and 4 - we simply emphasize the main differences with the other devices of this type.

Before we go into the details of this status report we would like to stress the following point: experiments at CERN are carried out in two departments; the Department of Physics II concentrates on bubble chamber physics and half of the events measured there are processed on the LSD's. This already gives an idea of their importance in the CERN production systems.

2. HISTORICAL SURVEY

The studies for the construction of a Spiral Reader at CERN as a joint project with the Collège de France began in November 1966. The design of the LSD was intended to be as close as possible to the Berkeley machine but finally evolved into the complete redesign of the following items:

- the cone-periscope system was put vertical instead of horizontal and the photomultiplier outside the periscope assembly;
- the system for automatic measurement of fiducial marks was designed to measure 4 marks/picture instead of 2;
- the PDP-4 was replaced by a PDP-9;
- the spiral scan radius was increased from 40 cm in space to 72 cm;
- the optical path was simplified in the sense that the light did not go through any plane parallel plate (except film gate) on the main path from film to cone-periscope;
- the film transport had to accommodate film from the 2 m or 80 cm HBC's, i.e. 50 or 35 mm unperforated film (measurement of 70 mm film was not required);
- the electronics was entirely redesigned for integrated circuits.

In April 1969 the LSD 1 (Fig. 1) produced its first event digitizing and test production could be started. The digitizing logic and pulse analysis system were closely derived from the Berkeley machine and the periscope slit dimensions were then 260 x 17 μ in the
film plane. The first experiment to be measured was Exp. 30, \( \pi^- p \) at 3.9 GeV/c, topologies 200 and 400 only. At the end of April 1970, this first experiment was successfully completed with the measurement of 33,000 events. A detailed account of this first year of production, of the difficulties encountered and their solutions is given in ref. 5. In the meantime, in November 1969, the autofiducial system had been put into operation and this increased the measuring rate by a factor 3 (from 20 to 60 events/hour). This first experiment consisted partially of events already measured on manual machines (IEP) and was essentially intended to assess the quality of LSD data.

The second experiment was started in May 1970 (Exp. 36, again \( \pi^- p \) at 3.9 GeV/c, but all topologies except 200) and until June 1971, 120,000 events (out of which 40,000 were measured twice) had been processed, corresponding to the measurement of 200,000 vertices. This experiment was originally intended to investigate the alleged split of the A2 meson, to study the \( \omega \) interference and the B meson, but finally extended its scope to a general study of production mechanisms. In the meantime, towards March 1971, the very first investigations to get ionization information from the pulse height measurements were initiated on selected event samples using the method then currently in use at Berkeley and at the Weizmann Institute. This study was carried further with the next experiment to convince ourselves of the reliability of pulse height measurements. The study was sufficiently well advanced to use ionization in production for the second half of the experiment.

This third experiment was Exp. 28, a formation experiment, \( K^- p \) between 1.45 and 1.86 GeV/c, all topologies. It lasted from July to December 1971 and yielded 68,000 events (out of which 12,000 were measured twice) corresponding to the measurement of 115,000 vertices. It was intended essentially for phase shift analysis, hence the large amount of remeasurements.

The last experiment started in February 1972 (\( K^- p \) at 4.2 GeV/c, all topologies except 200 and 400). It is intended to be the first very large statistics \( K^- \) experiment. One expects to obtain a total of 3 million photographs (the exposure would then correspond to 200 events/\( \mu b \)) which should lead to the measurement of a total of 1,500,000 events on LSD's. Besides the study of the \( \Xi^* \) resonance (\( \approx 50,000 \) strangeness-2 final states expected) one intends to perform all K induced physics in the intermediate region. At this date (May 1972) 40,000 events are already on DST, corresponding to the measurement of 75,000 vertices.

Since we have mentioned the existence of two LSD's, let us review briefly the construction of LSD 2 (fig. 2).

Already in the fall 1969 the spare parts for LSD 1 were being used to perform different tests which had proven to be necessary from the experience gained with the first machine and the difficulties encountered. Since this set-up essentially consisted of the machine framework carrying a cone-periscope assembly, it was, in some early reports, referred to as "Test C-P" (Cone-Periscope).

The first item to be tested was a new type of Automatic Gain Control referred to as AGC 2 (as opposed to AGC 1 on the LSD 1). It could accept background variations in a ratio 1:50 (resp. 1:10 for AGC 1).
The second item was an integrator, primarily intended to replace the pulse height by a pulse area estimate to improve the ionization information. It turned out to be extremely useful in the treatment of broad pulses, as encountered during calibration and with highly curved tracks but its influence on ionization estimate still remains to be investigated.

Other pieces of hardware, such as a new type of analog-to-digital converter, a new pulse discrimination logic, a new photomultiplier etc. were also tested. At the same time, studies to increase the amount of light coming to the periscope in order to be able to reduce the slit width (thus improving ionization measurement) without deteriorating the signal to noise ratio, led to the replacement of both semi-transparent mirrors. All these results are discussed in detail in the next reports on hardware improvements.

In the meantime, in June 1971, an X-Y stage was added to "Test C-P" and, in August 1971, a slow film transport. After the completion of the system for automatic measurement of the fiducial marks and debugging of the control program towards the beginning of 1972, it was then officially labelled LSD 2.

Up to now, it has measured a total of 15,000 events from Exp. 42. These events have already been measured on LSD 1 and are intended to check the consistency between both machines. This comparison is still under way but everything seems to indicate that LSD 2 will be in a position to take over the full production load when LSD 1 is turned off for a long maintenance in July 1972. From October 1972 onwards, both machines are expected to be run together.

3. PERFORMANCE

3.1 Production

Fig. 3 shows the overall production of LSD 1 since April 1969. Based on 1971 production and extrapolating the figure for the beginning of 1972, the typical yearly production should now amount to 200,000 to 250,000 vertices. The speed has also constantly increased; it seems to level off at 70 vertices/hour but it is obviously correlated to the topologies measured, to the beam density and to the operator's performance. The maximum speed obtained up to now on a 2 hour shift is 120 vertices/hour. To appreciate this figure one should keep in mind that the absolute maximum velocity of the machine lies between 150 and 180 vertices/hour. The total number of events processed on LSD 1 at this date is 320,000 (resp. 430,000 vertices).

Fig. 4 shows the actual measuring time, i.e. the time during which one actually measures events (thus excluding breakdowns, film and magnetic tape handling, calibration, tests etc.). Again a typical yearly figure can be estimated to lie between 3,500 and 4,000 hours of measuring time on a total of 5,000 hours foreseen (corresponding to a typical percentage of 75%). The LSD 1 has been measuring events during 8,000 hours but the machine has been running during 11,000 hours since April 1969.
The difference between foreseen time and measuring time can be accounted according to the following table (typical values):

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>film and magnetic tape change calibration, etc.</td>
<td>7%</td>
</tr>
<tr>
<td>preventive maintenance</td>
<td>4%</td>
</tr>
<tr>
<td>test (including title measurements)</td>
<td>7%</td>
</tr>
<tr>
<td>breakdown</td>
<td>7%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25%</strong></td>
</tr>
</tbody>
</table>

3.2 Quality

For the current experiment (Exp. 42; all events, except 600's are multi-vertex events) one can give the following figures:

- passed events (i.e. go directly onto DST)        40%
- check events (i.e. come back to the scanning table because of ambiguous kinematical hypotheses) 40%
- failed events:
  - geometry 13%
  - kinematics 7%

One should note that these numbers are obtained without using ionization. Preliminary results for Exp. 42 seem to indicate that ionization should reduce the number of check events by a factor 2 and the number of hypotheses for the remaining check events by a factor 3.

4. Production Operation

Fig. 5 shows a flow diagram of the production operation of LSD 1 for Exp. 42. Its most characteristic feature is the time scale. As can be seen, a complete measurement cycle does not take more than 60 hours. In other words, within 3 days, a film is measured, the output tapes are processed through THRESH-GRIND-SLICE on the CDC 65-600, the CHECK events are identified, the remeasurements are prepared and the physicist gets a pre-DST. At this stage already, most of the tests on physical quantities can be carried out.

The procedure has become necessary by the very type of experiment performed namely the processing of 1,500,000 events out of 3,000,000 photographs. It allows to split the whole experiment into a series of "sub-experiments", not longer than 8 weeks, corresponding to the standard interval between two long maintenance periods on the LSD. Remeasurements are typically performed during the last 1½ week of this period. At this level real physics analysis can already be started and then proceed in parallel with the measurements.

This procedure has been implemented and operated up to now with the direct participation of programmers and physicists. We are now in the process of delegating more and more of this responsibility to assistant staff and are making efforts to get a smooth and well
coordinated operation of the whole chain, in order to leave the physicists free for other
tasks.

4.1 Preparation of input

The high processing rates reached by 2 LSD's in production are such that the classical
scanning had to be given up and a more efficient system implemented. Recently (May 1972),
6 Shiva scanning tables have been connected on-line to a PDP-11 computer. The data (roll,
frame, topology) are entered via a keyboard and the grid is replaced by a line of 24 push-
bUTTONS located on the table about 30 cm in front of the operator. These buttons have
dimensions corresponding to the size of the TV screen on the LSD, thus ensuring a good
positionning for the measurement.

After different consistency checks, the data are output onto a DEC-tape which is used
to produce the usual INDEX tape and the LSD input tape. Paper, pencil and scan-cards have
thus been entirely eliminated.

The scanning operation itself has been simplified as much as possible. The only item
which has been added to the usual information is the number of kinks.

Besides the improvement in reliability and the reduction in cost, the scanning speed
has increased by a factor of 2 (from 32 to 60 events/hour, thus almost reaching the average
speed of one LSD).

4.2 Organization of measurements

4.2.1 LSD operation

A typical measuring period lasts 8 weeks between two maintenance periods of 1 week.
One measures 5 days/week, 24 hours/day. Each week, a preventive maintenance is performed,
typically during 5 hours.

The measurement is presently organized in 2 hour shifts. The operators are the same
as for scanning and identification, and are supervised in all their activities by the same
coordinators.

The maintenance is performed by one electronics technician "on call", 24 hours a day.

4.2.2 Measuring sequence

A detailed description of the measuring sequence is given in ref. 1 We would simply
like to mention here that the number of "special" buttons has been cut down to a minimum
in order to increase the speed and to reduce the number of operator errors.

Three "special" buttons are left:

- Button A : this point must be reconstructed in space
- Button B : this point is a help to the filter program
- Button C : ignore the digitizings beyond this point.
4.3 Quality control of the output

4.3.1 Hardware checks

During the weekly preventative maintenance all the standard test programs are run before the machine is delivered to the production. These programs cover the PDF-9, the magnetic tape units and the LSD hardware. The production control program also performs, on-line, a series of consistency checks.

Some parameters computed by the calibration program have been shown to be particularly sensitive to the machine status. Their behaviour is carefully registered and the engineers are informed whenever their value reaches a given threshold. As an example, we might mention the average RMS deviation of the digitizings for all crosses, the reconstruction of a radial line on the square grid, and the average pulse width and pulse height on individual crosses.

4.3.2 Check of the operator's measurements

After one week, the number of events measured by each operator is sufficient to perform a statistics on his performance. For instance, the speed, the percentage of tracks lost per topology, the ratio of the number of useful crutch points to their total number etc.

At the sub-experiment level (8 weeks) one computes the operator's effective speed expressed in "good" events/hour. A "good" event is defined as an event which has passed the whole program chain (geometry and kinematics). This latter figure really expresses the operator's performance.

4.3.3 Check of the measurement quality

The geometry output allows to verify several quantities such as the residuals on the fiducial marks, the track residuals and the beam parameters (1/p, θ, φ).

The kinematics output serves to produce the plot shown on fig. 6. It should be emphasized that this plot is updated each week and thus ensures that the whole chain, from film to DST, is working properly.

5. CREDITS AND ACKNOWLEDGEMENTS

The LSD system is the result of a group effort and this is why all the papers presented at this Symposium are signed "CERN-LSD Group".

Although the present development and maintenance team consists of about 12 persons, here is the list of people who have either participated at some stage in the construction or have contributed in some fashion to the success of the LSD system at CERN:
Finally one should not forget to pay the proper credit to the continued efforts of our operators and their supervisors to achieve a high rate of measurement and to develop both machines into an efficient production system.

REFERENCES


2) Project LSD (Spiral Reader) Electronique by P. Nappéy, CERN/D.Ph.II/INSTR 69-5, 28 April 1969.


FIGURE CAPTIONS

Fig. 1  Overall view of LSD 1

Fig. 2  Overall view of LSD 2

Fig. 3  Production of LSD 1

Fig. 4  Measuring time on LSD 1

Fig. 5  Flow diagram of production operation for Exp. 42

Fig. 6  Physical distributions for the system's quality control.
Fig. 3

Fig. 4
Fig. 5
IONISATION MEASUREMENTS AND THEIR TREATMENT AT CERN - LSD1

CERN-LSD Group (presented by Ph. Gavillet)

Since July 1971, the ionisation information provided by the LSD in the form of the pulse height obtained when the slit passes over a track, has been used to identify the particles whose tracks have been measured (Ref. 1,2). The method for processing the ionisation was originally similar to that developed at Berkeley (Ref. 3). The results obtained with this method, prompted a detailed investigation of the characteristics of the ionisation data before it was attempted to improve the reliability of this data by special modifications of the hardware.

This study, as well as the processing method finally adopted, will be presented. The results show that the main disturbing effects originate either from the chamber and the film or from the hardware and that it is possible to correct them off line. As a consequence a very satisfactory resolution power is obtained.

1. MEASUREMENT OF IONISATION AT THE LSD:

The LSD pulse height depends essentially on the optical characteristics of the film and the bubble density of the track considered (see appendix A). From the latter dependence, one can derive the ionisation of a track. For this purpose the analog signal is converted into a digital value covering an interval of (0-31)x4 units. At the hardware level, certain precautions undertaken assure that only useful information is provided.

1.1 Conditions for acquisition of the ionisation data

The CERN LSD1 is currently equipped with an automatic gain control circuit (AGCI : ref 4) and a slit of 600x80 μ. Pulses whose height is less than a given digital threshold, are interpreted as originating from parasitic digitizings and are thus rejected.

The filter program provides, for each track in each view, pulse heights as well as the measurement scatter about the mean values. Two types of average are transmitted:

a) $<\phi_H>$ for $500 \, C_R < R < 3500 \, C_R$. 1 R-count is equivalent to 2.86μ in the film plane. The interval chosen corresponds to 0.85 cm on film. This is 11 cm in space for a flat track in the middle of the 2 m HBC.

b) $<\phi_H>$ for $500 \, C_R < R < 9500 \, C_R$, after correction of the damping effect due to the slit-track angle.

Only the first average has so far been used in order to simplify the study of all possible effects. We thus hope that, in the 11 cm interval, any effect will be fairly constant. However a semi-empirical correction is applied to the pulse height of the curved
tracks. Tracks with high curvature (momentum less than 100 MeV/c) whose ionisation information is likely to be unreliable, are neglected.

The track length interval (on the film 0.85 cm long) is covered by 20 spirals. During these 20 revolutions of the cone, the slit swept over \((20 \times 600)/2.8 = 0.43\) cm of the flat track, which is 50% of the total track length interval. Combining all three views, the percentage seen by the slit raises to about 75%. Obviously the measurements on the three views are correlated, since certain track sections may have been measured twice or threefold on the different views.

For a track with minimum ionisation (approx. 15 bubbles/cm), the total number of bubbles detected is \((15 \times 11) \times 0.50 = 83\) bubbles. The statistical error in the counting is \((83)^{-1/2} = 11\%\). The precision of the pulse height as given by the A/D converter is 1/32 or about 3%. The precision of the mean pulse height is about the same. Thus the resolution limit that we could hope to obtain, taking into account the statistical error and the electronic accuracy, is about 1 : 1.25, at two standard deviations confidence level.

1.2 Characteristics of the ionisation data

The data come from an experiment at the 2m CERN HBC exposed to a 4.2 GeV/c K⁻ beam. All the topologies except for 200 and 400 were measured (the topology 201 accounts for approximately 60% of all topologies.) The following study was made on a sample of 1403 events from a single roll. Investigations on larger scale event samples are currently being pursued.

1.2.1 Characteristic distributions of the pulse heights.

The fig. 1 shows the distributions of the mean pulse heights of beam tracks as given by the L.S.D. The distributions are gaussian with a slight accumulation towards larger values (superimposed beams). Their width is about 6.5 PH (pulse height) units. The corresponding resolution ranges from 1 to 1.6, which is much lower than the theoretical resolution limit established above. Any effect originating from the position of the event within the chamber will broaden these distributions. Fig. 2 gives the same distributions for slow protons. The statistics is low but one can estimate the width to about 8 PH units. Contrary to the beam tracks, the proton tracks are not unidirectional. An azimuthal dependence of the pulse height may therefore explain why the distribution width for slow protons is larger than that for beam tracks.

Anyway, the fact that the spread of measurements is considerably larger than expected, leads us to conclude that certain non statistical effects are present. The classical distribution of the mean pulse height as a function of the ionisation, shown in fig. 3 confirms this assumption.
1.2.2 Variation of pulse height with the position in the chamber.

Fig. 4 shows, for each view, the variation of beam track pulse height as a function of the longitudinal coordinate X in the chamber, from the entry (-70 cm), to the exit (+70cm). There is a clear dependence. Three bumps are visible. They coincide rather well with the central area of the three vertical flashes placed behind the chamber. The position of camera 1 and 3 are symmetrical with respect to the chamber's horizontal medium plane, whilst camera 2 is placed at the entry side of the chamber. This explains the variations between view 2 and view 1, respectively view 3. Fig. 5 shows the classical curve giving the optical density of the film as function of the logarithme of the exposure. On this curve we marked the optical densities of the background $D_B$ and of the bubble $D_F$, for the peripheral area (subscript 1) and the central area (subscript 2) of a flash region. The difference $(D_B^2 - D_F^2)$ is larger than $(D_B^1 - D_F^1)$, due to the non-linearity of the curve. As a consequence, the pulse height is larger in the central area. It shall be pointed out that with a background density from the linear portion of the curve in fig.5, the difference $D_B - D_F$ would remain constant and hence would be absorbed by the AGC, which is particularly designed to operate on that linear portion.

In so far, the flash intensity has been kept constant during the ($K^- p$ 4.2 GeV/c) experiment, one could correct, "off line", for the effect observed. Fig. 6 shows the pulse heights distributions of the beam tracks after such a correction. Their width is reduced to 5 PH units.

Other distributions such as $PH = F(Y)$ show no peculiarity. In this case, the above stated X-dependence could be considered as the main film effect.

1.2.3 Azimuthal variation of the pulse height.

Fig. 7 gives the variation of the pulse height of a beam and of a dark (ionisation ~ 2-3) tracks as a function of their angular orientation in the cone image plane. This distribution has been obtained by an angular variation of the orientation (in steps of $10^0$) of both a single beam track and a dark track about a fixed point on the track. This point could thus be considered as the vertex point. A sinusoidal variation is clearly visible. It is independent of the pulse height and reaches about 20% of the average beam track pulse height.

Although the various LSD mirrors produce polarisation of the incident height on the cone, we expect these effects to be compensated by the AGC. However, the minimum and maximum values of the PH coincide relatively well with the minimum and maximum of the height intensity, taking into account the geometrical position of the mirrors. This problem is actually under study. An explanation seems to be possible by assuming parasite light to fall upon the slit and impeding a complete normalisation by the AGC.

We verified that the effect remains constant, as long as the geometrical configuration of the mirrors does not change. This is true for a larger period of time than is required to measure an experiment. So one can correct for this effect by some empirical function.
1.2.4 Input data of the fitting program

The input data of the ionisation fitting program are the pulse height corrected for film-chamber and LSD effects as described above. A consistency criterion between the pulse heights of the same track in different views is also applied in order to eliminate erratic measurements (For instance: tracks superimposed on one or several views).

The test is applied on pulse heights calculated in space

\[ PH_S = PH/RFAC \]

RFAC Stereoscopic factor.

Further, pulse heights are normalized to the average level of views. For three views measurements, every PH deviating for more than 15\% from the average is rejected. If only two measurements are available, they are kept in the fit if they differ by less than 6\% of their average.

2. IONISATION TREATMENT:

The processing of the ionisation information consists in comparing the measured (and corrected) mean pulse height of each track to the theoretical prediction made from the different possible mass assignments, in order to select the right hypothesis.

2.1 Pulse height parametrisation and fitting procedure

Appendix A gives the derivation of the theoretical LSD pulse height. It depends on the optical densities of bubble and film and on the bubble density. For a given track on a given frame one can write:

\[ PH \sim (1 - \lambda^{-\gamma d}) \]

\( \gamma \) : bubble density per unit length

\( d \) : bubble image diameter.

A suitable parametrisation of the predicted pulse height for track \( i \), in view \( j \) has been derived (ref.3):

\[ PH_{ij} = PH_{\text{MAX}, j} \left[ 1 - \left( \frac{PH_{\text{MAX}, j} - PH_{\text{MIN}, j}}{PH_{\text{MAX}, j}} \right)^{i_{ij}} \right] \]

\[ = PH_{\text{MAX}, j} \left[ 1 - K_{ij}^{i_{ij}} \right] \]

as well as a more sophisticated formula:

\[ PH_{ij} = PH_{\text{MAX}, j} \left[ 1 - \left( \frac{PH_{\text{MAX}, j} - P_{ij}}{PH_{\text{MAX}, j}} \right) \left( \frac{PH_{\text{MAX}, j} - PH_{\text{MIN}, j}}{PH_{\text{MAX}, j} - P_{ij}} \right)^{i_{ij}} \right] \]
\[ I_{ij} = \text{RFAC}_{ij} / \beta_1^2 \]

\[ \text{RFAC}_{ij} : \text{stereoscopic factor} \]

\[ \beta_1^2 = p_1^2 / (m_1^2 + p_1^2) \text{ velocity factor} \]

\( \text{PHMAX}_j, \text{PHMIN}_j \) are parameters depending on the chamber film conditions and the LSD setting, but otherwise constant if the AGC is in a condition to work effectively. \( P_0 \) is an offset parameter which could in principle vary from film to film.

In these conditions a good estimator of the goodness of the measured pulse height of a given kinematically acceptable mass assignment is the chi-square function:

\[ x^2 = (P_{\text{meas}} - P_{\text{pred},j}^T G^{-1} (P_{\text{meas}} - P_{\text{pred},j}) \]

The covariance matrix \( G \) contains off-diagonal terms which are non zero due to the fact that the same bubbles are measured on the three views. The correlations are however randomised by various factors (crossing tracks, background of the film) which vary from view to view and are difficult to parametrise.

We have chosen at the expense of a loss of information, to consider the measurements in the 3 views as independent, and to further take the non diagonal matrix \( G \) as the unit matrix multiplied by a constant. For each hypothesis we then build the estimator:

\[ x^2_{\text{Hyp}} = \frac{1}{\sigma} \sum_{j} \left[ P_{\text{meas},ij} - P_{\text{pred},ij}^{\text{Hyp}} \right]^2 \]

\( \sigma : \text{constant internal error} \)

The \( x^2 \) is further minimized (see appendix B) to allow for fluctuations in some of the LSD parameters. Presently \( \text{PHMIN} \) could vary in the fit. The set of minimum \( x^2 \) so obtained are then combined in a decision algorithm, whose outline follows. Call \( P_j^H \) the probability associated to \( x^2_{\text{Hyp}} \). We form the compound "probability".

\[ P^H = \prod_{j=1,n} P_j^H \]

\( n : \text{number of useful views} \)

A mass assignment is said to be compatible with the observed pulse height measurement if \( P_j^H > \text{constant } K_1 \) and at least one of the \( P_j^H \) is bigger than a constant \( K_2 \). Furthermore the mass assignment \( A \) is discarded versus \( B \) if:

\[ P_j^B / P_j^A > N \]

For the current production under the present LSD setting we use the following set of constants and initial values.

\( P_0 = 0, 0, 0 \)

\( \text{PHMIN} = 50, 50, 50 \)

\( \text{PHMAX} = 80, 80, 80 \)

\( \sigma = 4 \)

\( K_1 = .01 \)

\( K_2 = .05 \)

\( N = 2.5 \)
2.2 Results and resolution

We give here the results for our 1403 events sample. The events are divided into 876 events with only one type of kinematical hypothesis (PASS events) and 527 events with more than one type of hypothesis and normally sent for identification (CHECK events).

Fig. 8 shows the probability distribution of the PASS events for each view. These distributions are flat with a slight accumulation at the low probability values corresponding to events for which the pulse height measurements are poor or biased (beam tracks superimposed) and sometimes missing (two point tracks).

The distributions of the parameter $R_j$ for all the hypothesis attempted are given in fig. 9. They are gaussian and their width represent about 20% of the mean value. This indicates that the fluctuation interval of the fitted parameter $PHM_{ij}$ is not too large. Let us further note that the $R$ mean values are identical for views 1 and 3, whilst the value for view 2 is a little larger (therefore the ratio $PHMIN/PHMAX$ is greater for this view). The resolution must therefore be better in this view. This is because the film background is normally blacker in view 2. The optical density of the background and the bubble are therefore on the linear part of the curve $D = f(\log E)$ (fig. 5), hence the contrast is at its maximum.

Now, the figures of merit for this method at the energy considered may be summarized by counting the events:

- completely resolved
- partially resolved (more than one hypothesis left)
- with no decision at all
- with decisions disagreeing with the visual identification.

Table 1 gives in a matrix form the number of hypothesis remaining after ionization decision, versus the number of kinematically possible hypotheses, for the CHECK events. One sees that about 50% of these events are completely resolved. For the remaining events 2/3 of the kinematically ambiguous hypotheses are eliminated (2/3 of the identification work done). The events with no decision represent about 2% of the overall sample. They are events either with a suspicious kinematics, either with poor pulse height measurements. The wrong decisions represent about 1.5% of all CHECK events i.e. 0.5% of all events (which is of the same order of magnitude as the human error in the visual identification).

Since the amount of wrong decisions has to be reduced as much as possible we give and discuss some extra precautions which can be taken in order to minimize this figure.

- Cut on the number of degrees of freedom for the fit: Fig. 10 shows the average number of unsolved hypotheses after ionisation decision, as a function of the number of degrees of freedom for the fit. For poorly constrained fits one sees that the resolution power is very weak. Moreover, about 20% of the wrong decisions are of this type so one could easily apply a cut on the number of degrees of freedom without loosing too much in resolution.
- Cut on the dip angle: Very dipping tracks may give pulse height measurements very unreliable either because they are completely black or because, on the contrary, they are clear, much clearer than would be expected from their momentum (Peyrou's track). This type of track should be excluded by a cut on the dip angle.

- Reject of superimposed beam tracks that give wrong pulse height measurement (but consistent from view to view) and could further induce wrong decisions.

If we express the resolution in classical terms, i.e., the ionization that one could distinguish from a minimum ionizing track (I = 1) at two standard deviations, we obtain the following figures:

- Theoretical limit combining the statistical and electronic fluctuations 1/1.25
- Resolution obtained using the rough LSD pulse height 1/1.6
- Resolution obtained using the corrected LSD pulse height 1/1.35

The resolution reached is quite satisfactory and we have consequently decided to introduce this procedure in the kinematics program used in production.

3. DISCUSSION AND FUTURE:

In the present situation, the resolution obtained is not very far from the theoretical limit. This proves that the main effect from the film and LSD have been detected and corrected and that the simple formula chosen (Po = 0) is fairly close to reality. However some further steps have still to be taken in order to improve the flexibility and reliability of the method. The improvements to be made concern both the hardware and the model.

3.1 Hardware improvements

The azimuthal and axial corrections now made to the pulse height may reach together 20 to 30. For the time being it seems unrealistic to use a larger track length which would require other corrections (slit-track angle effect). The azimuthal and axial effects have to be eliminated at their source.

The first effect as observed on LSD1 is presently under study but seems to have disappeared on LSD2.

The axial effect comes from the film. It could be minimized during the run by tuning the flash intensity until the optical density of the film background reaches the linear part of the curve D = f(\log E). One should stress that these conditions correspond for a given film to the best bubble/background contrast which is very desirable for scanning, measuring or usual identification. It should be pointed out that poorly optimized illumination can be improved at the development stage but only to a fairly limited extent because of the risk of damaging the film chemical background. This kind of precautions has been taken for the second run of the experiment (Kp, 4.2 GeV/c).
3.2 Model improvements

The improvements to the procedure adopted should primarily go in the direction of assuring the same resolution for any roll measured at any time. This means that the fixed input parameters must either be updated when the film-LSD conditions change, or be suppressed or fitted.

We have already started to fit both PHMIN and PHMAX. This has been achieved in two similar ways. First we just form the new $\chi^2$

$$\chi^2_{\text{new}} = \chi^2_{\text{old}} + \frac{(\text{PHMAX} - \text{PHMAX}_0)^2}{\sigma^{'2}}$$

PHMAX$_0$ = (80,80,80)

$\sigma'$ : variation interval for PHMAX

This allows PHMAX to change and thus compensates possible film-hardware variations and at the same time absorbs the slight saturation effect visible on fig.11 where we put the fitted curve on the distribution PH = f(I).

We have also investigated possibility of completely fitting PHMAX after linearisation of the theoretical pulse height formula and have obtained the same results. When fitting PHMIN and PHMAX one should at the same time relate to then all the others input parameters ($K_1$, $K_2$, $\sigma$) which is rather easy.

The updating (instead of the fitting) of the input parameters could be done in a simple way. It is sufficient, at the geometry level, to produce the pulse height distributions of the beam and slow proton tracks to immediately get a good approximation of PHMIN and PHMAX for given film-LSD conditions.

A small investigation that could be made to improve the resolution is, to study in more detail the internal error of the pulse height. It is now taken as a constant but it clearly depends on the pulse height. The form of this dependence could be extracted from pulse height distributions for tracks of different ionizations and put back into the fit.

3.3 Future developments

On the CERN LSD2, we use a slit 1000 x 40 $\mu$m which reduces the statistical error. Moreover an integrator is added behind AGC2. It gives a signal proportional to the pulse area and hence independent of the slit-track angle.

This solution should allow to use a longer length of track without any further correction. This should significantly improve the resolution, and especially for the fast tracks.
APPENDIX A - DERIVATION OF THE THEORETICAL PULSE HEIGHT

The LSD pulse height is supplied from the AGC by the A/D converter. The AGC is designed to provide a pulse height proportional to the relative variation of the light flux transmitted when the slit crosses a track.

$S_b$: Area covered by bubbles
$S$: Area of the slit ($a \times b$)
$T_b$: Mean light transmission of a bubble
$T_f$: Mean light transmission of the film background.

$T_b$ is assumed to be constant but this is not strictly true in the areas where the bubbles are superimposed.

The different light flux are:

$\phi_b = (S - S_b)T_f + S_bT_b$ flux when crossing a track
$\phi_f = ST_f$ original flux through the slit

The pulse height provided by the AGC is such that:

$$PH = \frac{\phi_f - \phi_b}{\phi_f} = \frac{S_b}{S} \times \frac{(T_f - T_b)}{T_f}$$

Or, using the optical density ($D = \log_{10}\left(\frac{1}{T}\right)$)

$$PH = \frac{S_b}{S} (1 - e^{-a(D_b - D_f)}) = K \frac{S_b}{S}$$

$D_b$: optical density of the bubble
$D_f$: optical density of the film background
$a = 2.3$

For a given bubble density, $S_b$ is constant on the average. In that case we see that PH is an increasing function of the difference $(D_b - D_f)$. If $D_b$ and $D_f$ are on the linear part of the curve $D = f(\log E)$, this difference is maximum (maximum contrast). Then any variation in the light intensity leaves it constant. Consequently the pulse height delivered by the AGC also remains constant.

Calculation of the geometrical term $S_b/S$

Let us consider a slit narrower than the track and define $g$ to be the mean gap between bubbles. The mean bubble density is $\gamma = 1/g$. When the slit crosses a track we count $n$ bubbles when the average is $\bar{n}$. The inverse probability to find a distance $\Delta x$ without bubble is $(1 - \Delta x/g)$. 
The probability of \( n' \) consecutive intervals of length \( \Delta x \) without bubble i.e. no bubble in the finite distance \( t = n'\Delta x \) is:

\[
P(t) = \lim_{n' \to \infty} (1 - \frac{t}{n'\Delta x})^{n'} = e^{-t/\Delta x}
\]

\[
\frac{e^{-t/\Delta x}}{\Delta x} \text{ is the normalized law}
\]

If \( n \) is the number of bubbles (or intervals) in the slit, the number of bubbles spaced by more than \( t_{\text{min}} = d \) (bubble diameter) is:

\[
* \quad n_1 = n \int_{d}^{\infty} P(t)dt = n \int_{d}^{\infty} \frac{e^{-t/\Delta x}}{\Delta x} dt = n e^{-d/\Delta x}
\]

The area covered by these bubbles is:

\[
S_1 = n_1 \Delta x = n \Delta x e^{-d/\Delta x}
\]

The number of overlapping bubbles \((t < d)\) is obviously:

\[
n_2 = n(1 - e^{-d/\Delta x})
\]

The corresponding area covered is:

\[
S_2 = \int_{0}^{d} n(t) \Delta x dt = \int_{0}^{d} \frac{n e^{-t/\Delta x}}{\Delta x} \Delta x dt
\]

\[
S_2 = na [g(1 - e^{-d/\Delta x}) - d e^{-d/\Delta x}]
\]

The total area covered by the bubbles is:

\[
S_b = S_1 + S_2 = nag (1 - e^{-d/\Delta x})
\]

Hence:

\[
P_H = K \cdot \frac{n \gamma b}{\Delta x} (1 - e^{-d/\Delta x})
\]

Therefore, for a track with bubble density \( \gamma = 1/g \), the LSD pulse height, when the slit counts \( n \) bubbles for an average of \( \bar{n} = \gamma b \) is:

\[
P_H = \frac{n}{\gamma b} (1 - e^{-\gamma d}) [1 - e^{-a(D_b - D_f)}]
\]

The average pulse height is:

\[
P_H = (1 - e^{-\gamma d}) [1 - e^{-a(D_b - D_f)}]
\]
APPENDIX B - CONVERGENCE ALGORITHM

The minimized $\chi^2$ has for each view the form:

$$\chi^2 = \frac{1}{\sigma^2} \sum_i [PH_i - \text{PHMAX} (1 - R) I_i]^2$$

We define $A = \frac{\sigma^2}{2} \chi^2$ and calculate the derivatives:

$$\frac{\partial A}{\partial R} = \sum_i [PH_i - \text{PHMAX} (1 - R) I_i] \text{PHMAX}.I_i.R_i^{I_i - 1}$$

$$\frac{\partial^2 A}{\partial R^2} = \sum_i ((PH_i I_i R_i^{I_i - 1})^2 + [PH_i - \text{PHMAX} (1 - R I_i)]) \text{PHMAX}(I_i - 1)R_i^{I_i - 2}$$

We then proceed by means of successive iterations assuming that the variation of $A$ is linear near the minimum. In that case:

$$R^{v+1} = R^v - \left( \frac{\partial^2 A}{\partial R^2} \right)^{-1} \frac{\partial A}{\partial R} \quad v = \text{iteration index}$$

The starting value is $R^0 = 0.4$. The convergence is defined by

$$\left| \frac{R^{v+1} - R^v}{R^{v+1} - R^v} \right| < 0.01$$

We iterate at least once and at the most five times. If, during the iterations, $\chi^2(v + 1) > \chi^2(v) + 0.05$, we abandon the procedure which is then declared non convergent.

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Table 1
Average pulse height distributions for beams (no correction) (1403 events)

Fig. 1
Uncorrected PH distributions for 65 slow protons

**View 1**

**View 2**

**View 3**

**Fig. 2**
uncorrected PH = F (Ionisation)

VIEW 1

Fig. 3
PH (beams) = F(X position) in chamber

VIEW 1

VIEW 2

VIEW 3

X apex (chamber)

Fig. 4
Fit view by view
Probability distribution for 876 unambiguous events

Fig. 8
Distribution of $R = (1 - \frac{PH_{min}}{PH_{max}})$ (all hypotheses)

Fig. 9
Number of hypotheses left after ionization fit
(3 views together)

Fig. 10
The Paris College de France Spiral Reader was built in collaboration with the CERN L.S.D.I\(^{(1)}\). It was completely assembled at end of 1970. The test and adjustment period take end at middle 1971 when the first experiment for physics started to be measured.

Until now about 56,000 events was measured in part for test (10,000) and for physic.

The machine is equiped to measure 35 mm and 50 mm films. The transformation take few days (2 to 3) and are discrbed by M. Forlen\(^{(2)}\).

Presently the machine is working 97 hours per week with the help of 8 operators. Each of them works 2.5 hours/day. Two techniciens (electronic and mechanic + optic) have the charge to keep the machine in operation.

Early in the morning (5 o'clock) a more trained operator put the machine in work and eventually can make same adjustments. In the night an extra technicien has the responsibility of the L.S.D.

Two half time students have the charge of program development (Asterix, Pooh, Sable).

A full time physicist has the responsability of the organisation.

It is given in this report some detail about the test done on the machine, our calibration procedure, the experiments actually an measurement stage and the one planed for future, the rate, problems, software and hardware development.

1. **TESTS**

After usual hardware tests made with on line program (RAVEN) it was done:

- a calibration several time a week to see the variation of the machine as function of time. It is reported\(^{(3)}\) in this conference the detailed results of our calibration evolution.

- a remeasure of 3000 2 and 4 prongs events from $\bar{p}p$ annihilation at rest already measured on the Collège de France F.S.D few years ago. A comparison of the results got from the 2 measurement machines and for the same events was done at geometry and kinematic level. It was found that for this type of events, the efficiency and the quality of the measurements was in agreement. More detail on this study are reported by C. Ghesquière\(^{(4)}\).

- a measurement of 4000 events $\bar{p}p$ annihilations into 2 and 4 prongs at 480 MeV/c to study the best digitisation conditions of the machine for a 120 000 events $\bar{p}p$ in formation experiment (0 to 1.1 GeV/c $\bar{p}p + n$ π annihilations).

- a test of 3000 events of $\pi^-$ d → 3 prongs or 3 prongs + slow proton at 9 GeV/c to check the quality and efficiency of the L.S.D. system for high energy tracks. This experiment
represent more than 40,000 events and is done for the L.P.N.H.E. (Paris 6) group, the results were found satisfactory and are reported by M. Baubillier(5).

- a remeasure of several houndred of $\bar{p}p \rightarrow$ 4 prongs at 1.6 GeV/c already measured on the SMP system of the L.P.N.H.E. group.

2. CALIBRATIONS

As it is shown in reference 3 the calibration results during more than 6 month are stable. But it is also known that a regular calibration is necessary to check this stability as function of in time. So it was decided to make a calibration 2 to 3 time a week.

The following chicken pass are used.

- a large circular chicken pass with crosses distance equal to .7 cm
- a smaller rectangular grid with crosses distance equal to 1.0 cm
- a simple 5 mm square grid. The digitizings come from straight lines, etch with good accuracy and some 30 µm wide.

In the square grid the angle of intersection between slit and straight line varies from zero to maximum (45° for the moment), in the calibration pattern by definition the slit always intersects at 20°.

Three independent measurements are done for each of these artificial patterns and immediately analysed.

3. RATES AND PROBLEMS

In figure 1 are given the number of events measured per week, the percentage of measurement time/week and the operator speed as function of time.

One see that the mean speed is relatively slow compared to results reached on other machines. It does not come from fiducial measurement, our efficiency is larger than 90 %. But it is strongly function of the experiment and the quality of the films. As it is known the speed decrease with the number of points taken in the XY coordinate system. For the experiment actually measured 2 to 3 such points are taken per view.

It can also be seen from figure 1 that 30 % of the measurement time is lost (30 hours in mean per week). For a typical week the repartition of this lost time is :

- film change (7) 5 hours
- calibration (2) 1 "
- start of the machine 6 "
- maintenance + tests 4 "
- time lost by operators 5 "
- machine breaks + adjustments 10 "
An effort is made to reduce the start time of the machine, in near future the machine will not be cut during night (0\textsuperscript{30} - 5 o'clock).

The strongest problems come from encoders shifts and especially the 0 encoder. Brenner counting is an other big problem but is now quite solved by using infrared lamps and detectors.

4. EXPERIMENTS FOR PHYSIC

During 1971 about 20.000 $\overline{p}\ p \rightarrow 2$ and 4 prongs annihilations at 480 MeV/c was measured. The optical quality of the films was very poor, so a high rejection rate was obtained (30 to 40% of events with too few tracks). Detailed analysis of these events is in progress.

In November 1971 started the measurement of $\pi^- \ d \rightarrow 3$ and 4 prongs 9 GeV/c interactions. 26,200 events was measured.

In view to measure 5000 multivertex $\overline{p}\ p$ events at 1.6 GeV/c. 1300 such events were measured before the March shut down and transformation of the machine for 35 mm film.

The machine now measure a first part of the formation experiment (60,000 events). During the two first month 20,000 events have been measured.

Table 1 summarizes all these numbers.

In Table 2 are given the next experiment which are planned to be measured on the L.S.D. In total 230,000 events are expected to be measured during the two next years.

5. SOFTWARE AND HARDWARE DEVELOPMENTS

To try to reduce the number of points to be taken in XY coordinate system it will by used in a near future a Tetronix 612 display, which will also by used as a 4002 system replacing the teletype.

In June a new AGC will be used, the photomultiplier changed by a more sensitive one. All these modifications have been taken from studies made in CERN.

For the moment no ionization is used from the machine and no serious study made.

6. CONCLUSION

The limited number of person working around the machine does not allow us to be 100\% efficient and very fast in analysing the measurements.

The off line program come from CERN but have to be adapted for our experiments what sometimes take very long.
### Table 1

Experiments measured on the machine

<table>
<thead>
<tr>
<th>Momentum GeV/c</th>
<th>Reactions</th>
<th>Number of events</th>
<th>Time taken</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$\bar{p}\ p \rightarrow 4\ \pi$</td>
<td>4000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.48</td>
<td>$\bar{p}\ p \rightarrow 2\ and\ 4\ \pi$</td>
<td>4000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>$\pi^-\ d \rightarrow 3\pi$ and $3\pi p$</td>
<td>3000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.48</td>
<td>$\bar{p}\ p \rightarrow 4\ \pi$</td>
<td>12000</td>
<td>sept-oct. 71</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>$\pi^-\ d \rightarrow 3\pi$ and $3\pi p$</td>
<td>26200</td>
<td>nov 71 - march 72</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>$\bar{p}\ p \rightarrow V^0, V^{\pm} K\pi$</td>
<td>1300</td>
<td>march 72</td>
<td></td>
</tr>
<tr>
<td>.63</td>
<td>$\bar{p}\ p \rightarrow 4\ \pi$</td>
<td>11200</td>
<td>April 72</td>
<td></td>
</tr>
<tr>
<td>.56</td>
<td>$\bar{p}\ p \rightarrow 4\ \pi$</td>
<td>8000</td>
<td>May 72</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

Future experiments to be measured on the L.S.D

<table>
<thead>
<tr>
<th>Momentum</th>
<th>Reactions</th>
<th>NB of Events</th>
<th>Scheduled date</th>
</tr>
</thead>
<tbody>
<tr>
<td>.4 - .8</td>
<td>$\bar{p}\ p \rightarrow 4\ \pi$</td>
<td>60000</td>
<td>April-Sept 72</td>
</tr>
<tr>
<td>9.0</td>
<td>$\pi^-\ d \rightarrow 3\pi$ and $3\pi p$</td>
<td>20000</td>
<td>Oct - Nov 72</td>
</tr>
<tr>
<td>1.6</td>
<td>$\bar{p}\ p \rightarrow V^0, V^{\pm} K\pi$</td>
<td>5000</td>
<td>Nov - Dec 72</td>
</tr>
<tr>
<td>.75</td>
<td>$\bar{p}\ p \rightarrow 6$ prongs and $V^0 K\pi$</td>
<td>120000</td>
<td>Déc 72</td>
</tr>
<tr>
<td>1.3 - 1.6</td>
<td>$\bar{p}\ p \rightarrow 6$ prongs</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td>.4 - .8</td>
<td>$\bar{p}\ p \rightarrow 4$ prongs</td>
<td>60000</td>
<td></td>
</tr>
<tr>
<td>.4 - .8</td>
<td>$\bar{p}\ p \rightarrow 2$ prongs</td>
<td>120000</td>
<td></td>
</tr>
</tbody>
</table>

### ACKNOWLEDGEMENTS

Have also participated to this work and to discussions, M. Forlen, C. Kaspiengeas, A. Abbes, M. Huiban, L. Guiguicellemi, M. Bravard, C. Chêssquire.
STATUS REPORT OF THE DANISH-SWEDISH SPIRAL READER — JUNE 1972

S. Berglund, S-O. Holmgren and P. Lundborg,
Danish-Swedish Spiral Reader Project, Inst. of Physics, The University of Stockholm,
Sweden.

The discussion about a Nordic center for automatic high statistic measurements
of BC-pictures started already in 1964

Several systems were discussed but the final choice on the part of Denmark and
Sweden fell on the Spiral Reader System. Work was spent in the Spiral Reader
Purchasers Group during 1967
and a contract was signed with SAAB-SCANIA AB Jan. 25,1968

The delivery time was 18 months.

The Board of DSSLP (The Danish-Swedish Spiral Reader Project) was formed April 10, 1968
by:
Prof. J.K. Bøggild, chairman
Prof. G. Ekspong, v. chairman
Dr. K-H. Hansen
Prof. G. von Dardel
Mr. O. Obling
Dr. G. Funke repl. by prof. B.E.Y. Svensson
Dr. B. Ronne, secretary

The SRS-1 (Spiral Reader SAAB) was installed at the Institute of Physics, University of
Stockholm April 1970

The acceptance test was signed Dec. 1970

Personnel:
Project leader: J. Hooper 1/7-68 – 30/6-71
S-O. Holmgren 1/7-71

Engineer: S. Berglund 15/9-68

Off-Line Programmer/ L. Granström 1/11-68 – 31/1-71
Physicist P. Lundborg 1/2-71
As can be seen there is no separate on-line programmer post in spite of the fact that
SAAB took no formal responsibility for software in the contract. The effort on the
on-line programmes has been made by J. Hooper for our controlprogramme SLINKS and by
J. Hooper and B. Angelstrand SAAB, for the maintenance programmes MAGPIE and RAVEN.
This will be discussed in a separate contribution. In the off-line programming a great
part of the work especially on POOH has been made by Eric Dahl-Jensen and other members
of the Copenhagen High Energy group. This will also be discussed in a separate contri-
bution.

Last years operation

The measurements on the first experiment (19 GeV pd) started in June 1971.
The first time up to beginning of Oct. 1971
was characterized by serious reject problems in POOH. These were solved during this period by several improvements among which

Increased sensitivity (valid pulse logic)
Changes in POOH
New slit mask
were the most important. After that we have a through put of ∼80-90%.

The second great problem dealt with during the year was distortion effects.
This problem has been worked at since Dec. 1971
During the last months we have April–May 1972
arrived at sufficient understanding of this problem to be able to make the necessary correction of the data. This will be described in a separate contribution to this symposium.

In order to obtain sufficient precision it has been necessary to make some improvements of the hardware.
The coupling between the θ-scaler and the cone was rebuilt and later adjusted twice.
The cone periscope assembly was rebalanced June 1971 March 1972
Except for these things, some "worn out" electronic components and a few minor mechanical break downs the machine hardware has not caused serious trouble.

**Experiments and measurements**

The number of event measured in the 19 GeV/c pd experiment is ~16000 events
Most of these will be useful for Physics with the geometrical corrections mentioned.

Scanned experiment which will be measured
19 GeV/c pd 25000 events
Multiprong 19 GeV/c pp 6000 events
9 GeV/c pp 25000 events

We are currently measuring 10-14 hours/day and the measuring speed is 20-50 events/hour which implies 2000-3000 events/week when everything goes smoothly.
TECHNICAL DESCRIPTION OF SRS - SPIRAL READER SAAB

S. Berglund, S-O. Holmgren and P. Lundborg,
Danish-Swedish Spiral Reader Project, Inst. of Physics, The University of Stockholm, Sweden.

Introduction

Until now 4 systems have been delivered from SAAB, Sweden - Stockholm-Copenhagen, Vienna, Saclay, Serpukhov.

SRS uses the wellknown method invented in 1958 by B. McCormick in Alvarez group (Berkeley) to scan with a radially oriented slit in a spiral centered on vertex. During the scan the system stores polar coordinates for hits on the tracks.

The system includes a computer (PDP-9) with magnetic tape units for controlling the measuring procedure and storing data from the event.

SRS is in principal identical to CERN-L.S.D. In the realization of the system some changes have been done.

Electrically SRS is almost identical to CERN-L.S.D. with AGC 1. Exceptions are: Film-transport electronics, manual control of X-Y stage, power-supplies and some other power units.

The mechanical design of SRS is different from other Spiral Readers. In the following essential data for the different subsystems will be given and a more detailed presentation of some units.

Data for the main subsystems

X-Y system
Linearity: Within 2 microns over 7.5 cm
Perpendicularity: 20 microns over 20 cm
Least count: 2 microns
Max speed: 10 cm/sec
Platen driven by ball-screws directly coupled to printed circuit motors.
Position control: Speed-ball connected to "spill-pulse" circuit.
Cone-Periscope system
Periscope: Vertically driven by ball-screw directly coupled to printed circuit motor.
Max speed: 10 cm/sec
Least count: 8 microns
Periscope travel: 15 cm
PM-tube mounted in the pushrod to the periscope
Cone: Vertically suspended in preloaded ball-bearings.
Rotation speed: 900 rpm
Angular resolution: 10 sec of an arc

Film transport system
Max speed: 100 m/min.
Spool-capacity: 300 m
Transport time: 1 frame 3 sec, 10 frames 5 sec, 25 frames 8 sec.
Position control: Brenner mark detection and capstan pulse detection (resolution 0.24 mm)
System adaptable to 35, 50 and 70 mm films.

Fiducials
Four fiducials measured in one sweep
Slit dimension: 20 x 5000 microns

Optics
The optical system consists of the following elements (Fig. 4):
Projection lamp: Xenon lamp 450 W
Condensor system
Cold mirror
Condensor lens
2 clamping plates: One on each side of the film, 10 mm.
Beamsplitter: 50 % refl., 50 % transmission
Objectiv: Schneider Repro-Claron (303 1:9)
Beamsplitter: 40 % refl., 60 % transmission.
Cone mirror
Pick up slit: 700 x 80 µ
Fiber optic
Plexiglas rod
PM-tube: Philips XP 1110, placed inside the push-rod to the periscope

Above presented elements refers to the measuring channel. For presentation of the event to the operator the system has one objective and 2 mirrors for presentation on the operators table (magnification 10 times) and a hair-cross mirror, objectiv and TV-camera (magnification 200 time) for precise setting.
Film Drive System

The mechanical part of the film drive system consist of two identical but mirrored units on each side of the machine. The film reels are placed in boxes that are slaved to the Y-system by belts from the Y-motor to ball-screws connected to the boxes. Each film have 2 printed circuit motors, a system of rollers for guidance of the film, tachogenerator, forcctransducer and reel diameter sensors to control the servoloop. A brenner mark detection system is used to detect the frames and a capstan with code disc and pulsedetectors is used to control small movements of the film.

Control logic

The control logic consists of:
Command register with input and output gates connected to the I/o buffer
8-bit device selector
Interrupt and skip logic

Command and status register

<table>
<thead>
<tr>
<th>Bit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Auto = 1 Manual = 0</td>
</tr>
<tr>
<td>1</td>
<td>Capstan pulse flag</td>
</tr>
<tr>
<td>2</td>
<td>Brenner mark flag</td>
</tr>
<tr>
<td>3</td>
<td>&quot;Film stopped and clamped&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Capstan pulse interrupt enable</td>
</tr>
<tr>
<td>5</td>
<td>Brenner mark interrupt enable</td>
</tr>
<tr>
<td>6</td>
<td>&quot;Film stopped and clamped&quot; interrupt enable</td>
</tr>
<tr>
<td>7</td>
<td>Not used</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>- = 1, + = 0</td>
</tr>
<tr>
<td>14</td>
<td>MSB</td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>LSB</td>
</tr>
</tbody>
</table>

Connected to interrupt line

Velocity (1's complement)
Device selectors

51  Film 1
52  Film 2
53  Film 3

Instructions:

SOUF1  705104  Set Ones  To upper bits (0-8)
SZUF1  705102  Set Zeroes  from AC bits 9-17
SOLF1  705124  Set Ones  To Lower bit (p-17)
SZLF1  705122  Set Zeroes  from AC bits 9-17
RCRF1  705172  Read Command and Status Register
SKGF1  705101  Skip if no enabled flag on
SKBF1  705121  Skip if not brner mark flag
SKPF1  705141  Skip if not capstan pulse flag
SKCF1  705161  Skip if not "film stopped and clamped" interrupt enable

For film 2 and 3 the 1's in the instruction will be replaced by 2 and 3.

Motion control

Speed command comes to the system via D/A-converters under computer-control or from speed ball or a potentiometer under manual control. Speed command is compared with information about actual speed and this error-signal is then compensated with information from radius sensors and source transducers. The signal is then fed to one pre-amplifier and power amplifier for each motor. That part have current feed-back to get good linearity between voltage and torque. The power amplifier are controlled by pulse-width modulated current in the same fashion as in the X-Y DC-Servo system.

Brenner-mark detectors

This system have 4 markdetectors and one referensdetector. A logic circuit sets a flag when the conditions for a brenner-mark are fullfilled. The system can be switched to detect brenner-marks on one side of the film or the other or both.
Capstan pulse system

With this system it is possible to detect small movements of the film. The codedisc connected to the capstan gives pulses that sets a flag in the register for a movement of 0.24 mm. This can be used to define the stop distance after detecting a brenner mark.

Film clamping system

When all films are set to Auto and Zero-speed is commanded the film will be clamped between the two glass-plates. A registerbit "Film stopped and clamped" will be set.

References:
G.V. Butler: Spiral Reader Electronics - Description and Specifications UCID-2842 101.10.1966
G.V. Butler: Spiral Reader Control proposal, UCLRL 1967
SAAB-SCANIA AB, Sweden: Technical description of SRS

Figure captions
1 Block diagram
2-3 Mechanical assembly
4 Optical path
5-6 Film transport system
Fig. 5

Fig. 6
STATUS REPORT ON THE SACLAY SPIRAL-READER
B. GANDOIS, M. JACQUET, J.C. MICHAU, M. LEVI, D. REVEL.
COMMISSARIAT A L'ENERGIE ATOMIQUE
Centre d'Etudes Nucléaires de SACLAY
Département de Physique des Particules Elémentaires.

Our Spiral Reader (serial number 3 in SAAB's production) has been delivered in June 1971 and was mounted on its site in July. During the first month of operation we made several precision tests and for that purpose measured a batch of about 1000 two-prong events produced by 4 GeV incident pions, previously processed through our HPD. The results obtained from these test events will be given in an other paper.

Since August 1971 we are routinely measuring four-prong events from a 4 GeV/c incident negative pions experiment and until now we have processed some 60,000 events.

We are working now 5 days/week and 16 hours a day at a speed of about 60 events an hour. We plan to increase or working time to 20 hours a day.

Except in case of machine breakdown which is always possible, the systematic maintenance of the Spiral Reader takes place every monday morning (4 hours) and during this same time we measure 8 times our chicken walk plate to calibrate the system.

These measurement are a good check on the working status of the machine. We would like first to present a normal GW calibration result.

As you can see on fig. 1 our calibration residues after transformation of the \( \phi \) system in \( xy \) system are small. The order of magnitude varies from about \( 3 \mu \) to \( 15 \mu \) in the worst case.

On view basis of these results we feel unnecessary to incorporate a correction map in the filtening programme.

Another good check on the stability and on the good working conditions of the Spiral Reader consists in supperposing 2 crosses of the CWP with the RAVEN test programme. (for exemple crosses 29 and 37) by folding the \( \phi \) display around 180° line. A perfect superposition of the digitisations of the legs of three crosses is a powerful test of the correct alignment of the \( \phi \) scaler axis with the rotation and optical axis.
On Fig. 2 we present the time evolution of the radial and tangential residues as calculated every week since August 1971. As you can see these values are extremely stable except for a period in November 1971 and February 1972 when we had to dismount and adjust the coupling between the Q scaler and the cone.
AVERAGE CALIBRATION - RESULT S.R. SACLAY

Fig. 1

TIME EVOLUTION ON CALIBRATION S.R. SACLAY

I STATISTICAL ERROR ON ONE POINT

Fig. 2
FIDUCIALS MEASUREMENTS ON COLLEGE DE FRANCE
SPIRAL READER AND PARTIAL RESULTS ON \( \pi^- D \) EVENTS AT 9 GeV/c

M. Baubillier, M.C. Cousinou, M. Rivoal, L. De Billy.
L.P.N.H.E. - Université Paris VI-FRANCE

1. Introduction

In order to examine the reaction \( \pi^- d \rightarrow d\pi^+\pi^- \) at 9 GeV/c, we have measured 25,000 3 and 4 prong events on the CDF Spiral Reader. For this run, optic titles had been derived from CERN HPD fiducial measurements and we treated a part of digitisations with them. Results were rather unsatisfactory and we hoped to improve them by measuring the fiducial marks on the L.S.D.

2. Analysis of fiducial measurements

A sample of about 60 frames, distributed over the whole run, was selected. In each view 30 fiducial marks were measured. We have made the average of these measurements in the following manner: for every frame we determined the linear transformation between the reference plane of a measured view and the reference plane of a "standard frame" which was fixed before. All fiducials of the view were transformed and deviations from the "standard" calculated. If more than 4 fiducials of a view showed large deviations, the view was rejected. Then the average of the accepted measurements was used as input for PYTHON. In order not to risk to work with a faulty "standard frame", we used 10 different "standard frames" and averaged the corresponding titles.

3. Comparison of different optic titles

We notice that the results of PYTHON differ very much according to formulae used to correct lens-distortions. We test the following two distortions formulae:

\[
\begin{align*}
x & = (1 + a_1 x + a_2 y + a_3 r^2) x \\
y & = (1 + a_1 x + a_2 y + a_3 r^2) y + a_4 x^2
\end{align*}
\]

Danny formula

\[
\begin{align*}
x & = x + a_1 x^2 + a_2 xy + a_3 r^2 + a_4 x^2
\end{align*}
\]

Henry formula

Fig. 1 shows the differences between the coordinates on the chamber and the reconstructed \((x,y)\) coordinates on the 3 views for fiducial marks on plane 2 for these two formulae. It is clear that reconstruction is improved by using Henry formula. The 4 fiducial marks measured with each event determine a rectangle. On Fig. 2 one may see how the reconstruction of this rectangle varies according to the optic titles used. One may see that by using LSD titles the reconstruction is better.

Then we compared the results for 455 events geometrically reconstructed using the two sets of titles obtained and the last Cern version of the POOH program. The following table shows the main differences observed.
<table>
<thead>
<tr>
<th></th>
<th>DANNY</th>
<th>HENRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>measured events</td>
<td>455</td>
<td>455</td>
</tr>
<tr>
<td>good events</td>
<td>360 - 79,1 %</td>
<td>367 - 80,6%</td>
</tr>
<tr>
<td>number of tracks</td>
<td>2038</td>
<td>2038</td>
</tr>
<tr>
<td>lost tracks</td>
<td>102 - 5 %</td>
<td>95 - 4,7 %</td>
</tr>
<tr>
<td>doublet tracks</td>
<td>602 - 29,5%</td>
<td>422 - 20,7%</td>
</tr>
<tr>
<td>Mean Residual on beam</td>
<td>5,9 µ</td>
<td>5,6 µ</td>
</tr>
<tr>
<td>Mean Residual on tracks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p &lt; 1 GeV/c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Residual on tracks</td>
<td>8,9 µ</td>
<td>7,5 µ</td>
</tr>
<tr>
<td>p &gt; 1 GeV/c</td>
<td>7,3 µ</td>
<td>6,1 µ</td>
</tr>
</tbody>
</table>

This leads us to choose the titles fitted with "Henry" formula.

Figure 3 shows the residual distributions of the tracks. On figure 4 we present the beam momentum LSD measurements obtained for 3 and 4 prongs events compared to the same quantity measured with conventional digitizing devices (IEP).

The deviation appears to be larger for the LSD data than for the IEP data. This is also true when one study the grind output. For instance figure 5 and 6 show squared missing masses for π⁰ and neutrons.

4- Conclusion

It appears to be necessary to measure the fiducials marks, which are used to calculate geometry titles, on the Spiral Reader; as, in that manner, much of the machine-dependent distortions are corrected. The previous results show, also, how important is the choice of the parametrization expression for the non linear distortions.

Nevertheless, it seems that the improvement is not sufficient and that the LSD output are more distorted than the IEP output.
Figure Captions

1. Differences between coordinates of fiducial marks of the chamber window (plane 2) and reconstructed \((x,y)\) coordinates from measurements of fiducial marks on the three views.

2. Comparison between theoretical and reconstructed coordinates of fiducial marks.

3. Tracks residuals (24 master points)

4. Beam momentum

5. \((\text{missing mass})^2\)

6. ""
Fig. 1

Fig. 2

The dimensions of the rectangle are approximately (130/35 cm)
Fig. 3

Fig. 4
\[(\text{Missing Mass})^2 = (\pi^o)^2\]

LSD (DANNY)

68 events

0.5 1.0 1.5 GeV/\(c^2\)

6 under 18 over

LSD (HENRY)

69 events

0.5 1.0 1.5 GeV/\(c^2\)

6 under 18 over

IEP measurements

1263 events

0.5 1.0 1.5 GeV/\(c^2\)

126 under 284 over

Fig. 5

\[(\text{Missing mass})^2 = (\text{neutron})^2\]

LSD (DANNY)

49 events

0.5 1.0 1.5 GeV/\(c^2\)

2 under 9 over

LSD (HENRY)

57 events

0.5 1.0 1.5 GeV/\(c^2\)

2 under 9 over

IEP measurements

100 events

0.5 1.0 1.5 GeV/\(c^2\)

5 under

Fig. 6
CALIBRATION, PRECISION AND STABILITY AT THE COLLEGE DE FRANCE SPIRAL READER.

L. Dobrzynski, Collège de France, Paris, France.

The stability of the machine is tested daily and weekly:

- every day a set of random events (5-10) measured the day before are completely analyzed by the filtering program. The lost tracks if any, the two views tracks, high helix fit RMS tracks... are looked in detail. Rarely the losses can be attributed to the machine itself.

- two to three times a week the calibration procedure is performed and a comparison with the past done.

The precision studies (or artificial patterns and bubble chamber film events) show that random errors can be brought well below the level of conventional hand measuring apparatus. The remaining systematic errors do not reach the magnitude of the X-Y least count (2 μ).

About 26000 measurements of 3 prongs and 3 prongs + short proton from π⁻ d 9 GeV/c interactions and 20000 measurements of 4 prongs from π⁻ p annihilations at 630 MeV/c and 560 MeV/c are available to judge filtering and reconstruction capabilities.

Preliminary results on precision and rejection rates are presented in this study.

1. CHARACTERISTICS OF THE MACHINE.

The speeds of the 5 R ramps for π⁻ d experiment are 40, 60, 120, 120, 200 and 30, 40, 60, 200, 200 for the π⁻ p one.

The standard Collège de France AGC is used. The PM is a 1110 Philips. The power of the Xenon lamp is 550 watts.

The slit dimension are 600 x 50 μm.

2. CALIBRATION.

The mapping function of the polar onto the cartesien system is obtained by measuring a special calibration pattern on a glass plate containing crosses with X-Y positions measured to 1μm accuracy and "visible" to the rotating slit.

Digitizing on these crosses seen from the center at 20° angle are histogrammed and fitted, values for the centres of crosses are transformed into the X-Y system using an analytic function (5 or 12 parameters), adding as option linearly interpolated correction terms corresponding to the residuals of the calibration fit. The transformation from the
plate's own X-Y system to that of the L.S.D is obtained from X-Y measurements on five
crosses of the pattern.

3. PRECISION STUDIED IN MEASUREMENTS OF ARTIFICIAL PATTERNS.

L.S.D. precision has been looked at by measurements on patterns (glass and film
plates).

1/ Reproducibility.

Four type of artificial lines have been used: digitizings obtained on a simple 5 mm
square grid, with the spiral centred on one of the intersection point, digitizings and
circular and rectangular calibration grid and digitizings from 67 radial line seen by the
slit at 0°.

In either case the digitizings come from straight lines etched with good accuracy
and some 30 μm wide. In the square grid the angle of intersection between slit and straight
line varies from zero to maximum (about 45° with the slit actually used). In the calibra-
tion patterns by definition the slit always intersects at 20°. In both case sections of
straight lines up to 10 mm long are obtained by first histogramming and then fitting.

a) Squared grid

The results are given in figure 1 and can be summarized like this

- at zero intersection angle between slit and line the RMS error of a single digitizing
  is about ± 2 μm independant of R (figure 2).
- with increasing angle the RMS error remain constant until 15° and equal to ± 3 μm
  than it increase. At 20° it is ± 12 μm and ± 20 μm at 30°.

b) Radial line

To check if there are no problem in the R, θ plane, we have digitized a set of
67 radial lines the angular distance between two consecutive line is of 1000 to 2000
θ counts. The digitizings of each line have been fitted in R, θ plane with a 3 parameters
θ₀, α, β formula of the type

θ = θ₀ + α + β/R

For each line about 100 digitizings were used for the fit. The mean deviation for
all the lines from digitizings to fitted course is centred at zero. What indicate no
systematic distorsions in R, θ plane.

The standard deviation being 2 less count θ. No particular distorsions could be
detected for any θ.

These results are stable for several consecutive spirals and function of time.
c) Systematic distortions between the polar and cartesian systems

It is looked at the some digitizings obtained from artificially etched straight lines on the calibration grids and the 5 mm square grid.

a) Calibration grid

For the calibration grid some 20 digitizings are usually obtained on each arm of each cross and used to determine the centre of the cross with a statistical precision of about ±2.0 μm in the radial and ±0.6 μm in tangential direction (1.2 μm and 0.4 μm for the rectangular grid). The overall RMS for all the digitizings used for the cross reconstructions is 4.2 μm (2.0 for the rectangular grid).

We have not been able to produce an analytic mapping function from R θ to X-Y which reaches the precision expected from the above numbers. Residuals after any such attend go as height as 30 μ with a 5 parameters transformation formula and 13 μ with a 12 parameters transformation formula (15 μ for the rectangular grid with a 9 parameters transformation formula) and their rms value comes out at best ±11 μm R and 4 μm R θ (tangential) (8 μm and 4.7 μm for the rectangular grid).

For the production of events for the physics the residual are not used for the moment. It was check that on straight line no improvement is found when they was used.

b) Square grid

Figure 3 shows the rms residual after a fit of a straight line performed on the 0° angle line of the squared grid. The overall RMS of the fits is 2 μm. No systematic shifts are apparent.

4. PRECISION AS FUNCTION OF TIME.

Figure 4 shows the variation of the RMS of a straight line fit thought the 0° line of the square grid. During several month its variation is very small (around 2 μm).

Figure 5 gives the RMS of the digitizings used to obtain all the crosses of the calibrations grid. Over more than 6 months it remained around 4 μm.

Figure 5 shows the mean radial and tangential residual obtained using a 5 parameters fit. The variation as function of time is very small.

The same observation come out from the variation of the 12 parameters calibration fit as function of time figure 7 to 17.

5. MEASUREMENTS ON BUBBLE CHAMBER FILMS.

Two experiments have been possessed on the machine in a large extend. 26000 π⁻ d 9 GeV/c interactions and 20000 p p annihilations at 630 and 560 MeV/c have been measured. The first was measured for a L.P.N.H.E. (Paris 6)group and the result will be reported by M. Baubillier, the second for Collège de France physicist. Unfortunately for this last no
precise efficiency ratio exist for the moment because the filtering program is still into adjustment.

Two fact can be pointed out from our preliminary studies.

1/ For the $\pi^-$ d experiment it was very usefull to produce a set of optical tittles done on the L.S.D. With a set of tittles done on the CERN H.P.D. the deviation of the measured fiducial marks to the tittle values was as large as 150 $\mu$m on film. These deviation were reduced to 20-30 $\mu$m with the new set. A special care was also necessary to choose the distorsion formula for optical tittles the worst formula gives 30% of doublets (tracks reconstructed with 2 views only) the best gives 12% what can be consi-
dered as acceptable.

2/ The helix fit RMS deviations are in agreement with what one expect for a good precision experiment. This RMS for 9 GeV/c $\pi^-$ beam tracks is of the order of 3 $\mu$m (for more detail see M. Baubillier talk) Figure 18 shows the helix fit RMS for $\bar{p}$ beam tracks (630 MeV/c) and for secondary tracks (mean momentum about 350 MeV/c). One see that these distributions peaks respectively at 6 $\mu$m what for low momentum tracks with large coulomb scattering contributions, is satisfactory.

3/ It was analysed about 50 no interacting 9 GeV/c $\pi^-$ beam tracks. Figure 19 displays in R, $\theta$ frame the digitizings for these tracks on view 1, 2 and 3. A simple 2 parameters fit was performed ($\theta = \theta_0 + \alpha r$). The dispersion for $\alpha$ is small (2.4 $10^{-3}$) for a mean value of $\alpha = 24.1$ $10^{-3}$, 23.1 $10^{-3}$, 22.4 $10^{-3}$ for view 1, 2, 3. The statistical error on $\alpha$ is $10^{-3}$.

The overall dispersion of all the 50 tracks is $10$ leascount $\theta$ independant of $R$ ($R > 500$ counts). For a radius of 13000 it correspond to a dispersion of $6$ $\mu$m what on a track of 30 to 50 $\mu$m wide is relatively good.

ACKNOWLEDGEMENTS

Have also participeted to this work and to discutions M. Forlen, C. Raspiengeas, A. Abbes, M. Huiban, L. Guiguellemi, M. Bravard, C. Chesquier.
Fig. 1

Fig. 2

Fig. 3
Fig. 8

Fig. 9

Fig. 10

Fig. 11
CALIBRATION, PRECISION AND SYSTEMATIC ERRORS OF CERN-LSD's

CERN-LSD Group (presented by Ph. Gavillet)

SUMMARY

Precision, detection of systematic errors largely depend on the calibration of the LSD. Since the beginning of its operation a special effort has been put at CERN on this crucial point\(^1\). The overall procedure for calibration remains basically the same but many features have been changed and some modifications have improved the stability and ensured an excellent control.

The treatment of the pulse on hit of a calibration cross, which almost completely directs the quality of the results, is not easy near the centre where these pulses are different from measurement pulses. Different solutions have been adopted to eliminate this difficulty.

It seems very useful to systematically check the calibration by applying the outcoming parameters to the digitizings from artificial lines. In addition, some precaution has to be taken in the calibration program. One describes these points and presents results on beam-track measurements. A more detailed analysis of the LSD performance on bubble chamber film is discussed in the report "Some considerations of space reconstruction precision" of this conference.

1. CALIBRATION CONDITIONS

The LSD has two different co-ordinate systems, one is cartesian, the other is polar. Thus the measurement information is mixed and to handle it, one must know the relation between the two systems.

1.1 Calibration procedure

Calibration is performed to give:

- the relation between the \((R,\theta)\) and \((XY)\) co-ordinate systems;
- the inaccuracy inherent to each system.

It consists of:

- the measurement of a pattern of 177, 20° angle crosses 7 mm spaced and pointing towards the centre\(^*)
- the fit of the classical relation between polar and cartesian systems depending on the characteristic parameters of the LSD.

\(^*)\) The X-Y position of the crosses on the glass plate has been measured with a very high accuracy \((1\mu)\). The transformation to the X-Y LSD system is performed by measuring five crosses during calibration. The RMS residual of this fit is about \(5\mu\) and represents essentially the operator setting error.
It provides:
- The parameters \((R_c, R_0, \Theta_0, X_0 Y_0)\) for processing the data in the filter program;
- Fit residuals interpreted as giving the inaccuracy of the two systems (local non-linear distortion) and used to correct each digitizing by a linear interpolation.

1.2 Treatment of calibration pulses

The theoretical width of a pulse at its base is given by:

\[
W(\alpha) = \text{stg} \alpha + d + a \cos \alpha
\]

\(a\) track width, \(d\) slit length
\(a\) slit-track angle, \(d\) slit width

The theoretical ratio of pulse heights at zero angle and \(\alpha\) angle is: \((\alpha/\alpha)\sin \alpha\). So, for a slit \(1000 \times 50u^2\) the calibration pulse is about four times broader and four times smaller than a radial track pulse. As a consequence the noise is twice more important (fig. 1).

On LSD1, the width of a pulse is taken at one digital step from the top. If the noise amplitude reaches one digital step, the width transmitted may be wrong. On fig.1 one sees how difficult it is to determine the right width of a calibration pulse near the centre, where the pulse is broad. As a result, one experimentally finds an artificial pulse displacement in the centre region. The calibration fit (rotation, translation and magnification) cannot take this effect into account. It then appears as extra-components added to the normal \(XY\) fit residuals and the application of the calibration parameters to the digitizing of an artificial straight line, leads to a distortion in the opposite direction.

Currently, the machine is tuned in order to correctly digitize a real track; calibration is performed in the same hardware conditions.

To correct the noise negative effects we preferred to study its origine. Two types of solutions have been chosen for each LSD.

**LSD1:**

We simply took a smaller and broader slit \(600 \times 80u^2\) whose effect is to give a quasi-triangular calibration pulse. The top of this pulse is then rather well defined even in the presence of noise.

**LSD2:**

We kept a slit \(1000 \times 40u^2\), more efficient for filtering and ionization measurements. An integrator is added behind the AGC. It gives a pulse whose height is proportional to the original pulse area and hence independent of the slit-track angle. The width is given at the base of the pulse.
1.3 Processing of the spirals in the calibration program

The calibration program $\text{SCALP}^2$ is basically the same for all the SPINAL READER users. We have only changed the procedure of treatment of the consecutive spirals in order to make sure that the starting values of the parameters in the linearized fit are good. This becomes necessary if one considers that the $R_0$ parameter, very influential in the central region, is the only parameter which could normally change when the periscope reference head is replaced. To illustrate the importance of the starting value of $R_0$, (fig.2b) shows a reconstructed straight line obtained by using a calibration for which the operator positionning was, on purpose, bad and the input $R_0$, $150$ R counts far from the correct value. One sees a clear central distortion of the order of $8\mu$. The fig.2a shows the same line, from the same calibration but with the correct $R_0$ value. The origine of the distortion comes from the fact that the translation $R-R_0$ made in the program displaces the central digitizings, non radially, if the centre of the spiral does not coincide with the centre of the calibration pattern. As a consequence the central crosses are artificially displaced and distortion appears in this region.

To prevent such an effect, we use the first spiral to fit good input parameters. These parameters are then applied to the three spirals which are averaged. Fig.2c shows the straight line corresponding of the bad positionning and the wrong $R_0$ value. The iteration procedure has eliminated the effect described.

1.4 Calibration results

The quality and stability of the calibration results are nearly the same for both LSD's. Table 1 gives the main figures. One sees that:

- The RMS scatter of all the useful digitizings on the crosses is $2\mu$;
- The resulting statistical precision on the cross center is less than $1\mu$ ($0.7\mu$ in the radial direction, $0.25\mu$ in the tangential direction);

In spite of this very good precision, it remains systematic effects. Fit residuals are as large as $30-40\mu$. Their RMS values are of the order of $10\mu$ ($R$ direction) and $5\mu$ ($\theta$ direction). One takes these effects into account by correcting each digitizing using a linear interpolation between residuals. It is worthwhile to note that we did not try to find a mapping function from $R-\theta$ to $X-Y$ system for practical reasons. An analytical function takes some time to be correctly adjusted and its validity period is short (few months) due to the necessary changes on the hardware (mirror on the cone, for instance). Besides this, the standard analysis of the map of residuals is very useful to detect hardware effects such as bad centering of the $\Theta$-encoder, slit eccentricity, local optical distortions, etc.

For three successive spirals, the RMS error on regularly spaced co-ordinates are of the order of $3\mu$ and $2\mu$ in the $R$ and $R-\theta$ directions respectively. The statistical error on the cross centre being so small, these values correspond almost entirely to the operator setting error. One randomizes these errors by frequent calibrations over one experiment.
1.5 Calibration in time

It is rather difficult to compare different calibrations at long time intervals, because of the normal changing conditions of the hardware such as the periscope reference head, already mentioned. We presently calibrate every two days. The resulting parameters are used for the corresponding production.

For a period of fifteen days the RMS error for one spiral is 6.6μ and 2.5μ in the R and Rθ directions respectively. Subtracting the time independent error established above (3μ, 2μ) one sees that the precision for such a period is 5.8μ and 1.5μ (R, Rθ). The major error is radial which is not very consequent, so one could conclude that the reproducibility is very good.

Over longer periods the variation of the parameters R₀, Rc, θ₀, X₀, Y₀ is checked and any abnormal evolution is immediately reported to the engineers.

2. CALIBRATION AND PRECISION CHECKS ON ARTIFICIAL PATTERNS

The example given above shows the importance of verifying the quality of a calibration, on artificial straight line. This allows to detect any hardware trouble and check of the information coming from broad calibration pulses.

2.1 Measurement of a square grid

A square grid made of 30μ lines spaced by 5 mm is measured. One fits a straight line through the digitizings of the whole line and through 5 mm segments. The outcoming results are the followings:

- For a zero slit-line angle, the RMS error on a single digitizing is 1μ and does not depend on R;
- The overall RMS scatter for the radial line is 1.5μ, very close to what we would expect from the statistical fluctuation (1μ) and the cross detection error (.25μ). A slight systematic shift of the order of 1μ is visible just in the central region. This effect comes from the difficulty of correctly analysing the calibration pulses in this region. The consequence of an effect of this type on tracks, is analyzed in section 3.

One should mention that the square grid also provides other information, for instance:

- The reconstruction of the grid lines without using the calibrations residuals will reflect any hardware effect by looking at the distortions. Fig.3 gives the behaviour of the radial line for a given cone mirror.
- The study of the pulse height distributions as function of the angle θ and the radius R provides information for correcting ionization measurements. In the present situation, a calibration cycle consists of three spirals on the calibration grid and three spirals on the square grid. The same program treats, first the chicken path, then the square grid as a check of the calibration results. This procedure is not too heavy and very safe.
2.2 Measurement of a star pattern

A more detailed analysis of the characteristics of the pulses in the plane is achieved by measuring a star pattern with 36 arms, 35μ width, every 10°. It is used whenever important modifications are made, in order to make sure that for radial tracks the pulse height remains independent of R and θ. The statistical RMS deviation of 2μ on each leg confirms that the same precision is obtained in any direction.

3. TRACK MEASUREMENTS

Some tests are made regularly either to observe the effect of possible calibration distortions on tracks, or at the beginning of a bubble chamber run, to give an idea of the quality of the pictures.

3.1 Influence of calibration on tracks

Since the parameters (1/p, λ, θ) of beams are well defined from the run conditions, the measurement of primary tracks allows to observe the influence of the calibration. Fig.4a shows the beam momentum on an experiment Kp (1.760 GeV/c) as a function of the abscissa x of the interaction point in the chamber (x entry = -70 cm). This distribution is broader at the low x values. If one uses, in the filter program, a calibration which produces a central distortion of 4μ as in fig.2b one obtains a non uniform distribution (fig.4b). The systematic error introduced can be estimated by:

\[ \frac{Δp}{p} = \frac{ΔR}{R} \approx \frac{ε}{f} \]

R (cm) radius of curvature = \( \frac{P(\text{GeV/c})\cos λ}{0.5 \ H(kG)} \)

f (cm) Sagitta \( f = \frac{L^2 \ \cos^2 λ}{8 \ R} \)

ε (cm) error on sagitta

L (cm) Track length

\[ \frac{Δp}{p} \approx \frac{8 \ \epsilon}{L^2} (\cos \ λ \approx 1) \]

For ε = 50μ (4μ on 2m HBC film) and L = 30 cm: \( \frac{Δp}{p} \approx 1.5 \% \). The errors on the angles λ, θ are:

\[ Δθ \approx \frac{ε}{(L \ \cos λ)^{3/2}} \]

\[ Δλ \approx \frac{ε}{\sqrt{\cos \ λ} / L^{3/2}} \]

They could reach 0.5 mm and have to be taken into account especially in the reconstruction of short, fast connecting tracks (e decay).

3.2 Precision on beam tracks

One measures beam tracks and fits circle through the digitizings in the film plane. This test is made at the beginning of a run when geometrical titles are not available, in order to get information on the picture quality (bubble density, film optical conditions, possible track distortions).
For Exp. 42 (K^- p 4.2 GeV/c) measurements have been made on beam tracks, in space 80 cm long. The estimated multiple scattering error is 2µ. The mean scatter of master points along the fitted circle was 3.5µ. The statistical error on the master points is less than 1µ so the remaining inaccuracy came either from calibration or possible chamber distortions present at the time of the run. Others more complete tests are made over short and long periods of measurements.

* * *

REFERENCES


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Table 1
R = constant

α = 0°
0.1 ms/cm
0.5 V/cm

α = 20°
0.1 ms/cm
0.1 V/cm

Fig. 1

Fig. 2
Fig. 3

Fig. 4
1. INTRODUCTION

The CERN K⁻ Group has for the past year been using the CERN LSD1 to measure 2m HBC film. A very considerable proportion of the events measured are multi-vertex topologies, involving one or more V⁺ or V⁻ decay vertices. Unlike the simpler topologies measured hitherto on this machine, the present data require, for proper physical interpretation, as much care in treating the secondary vertices as in the treatment of the primary vertices. The analysis of these event measurements by the standard CERN program sequence of POOH, MATCH, THRESH, and GRIND has unsurprisingly revealed some shortcomings in the treatment of LSD measurements. We have studied, among other subjects, the treatment of two point tracks. A natural consequence of this study is a clearer understanding of the spatial reconstruction precision one can obtain from measurements of 2m HBC film. I present here some facets of these studies which are peculiar to the LSD measurements.

Most of the ideas presented here have arisen in the course of talks with various CERN colleagues. I acknowledge especially the benefit of conversations with R.K. Böck, Ph. Gavillet, R.J. Hemingway and E. Pagiola.

2. TRACK MEASUREMENTS

It is required for the purpose of kinematic fitting to express the geometrical parameters of the space track helices (curvature, azimuth and dip) for each measured track at each vertex to which that track is linked.

For the vast majority of charged tracks, one has point measurements on the orbit images in each of several stereoscopic views. These image measurements are used to reconstruct in a standard fashion an approximation of the space helix, from which the required values and errors of the helix parameters at the vertex point are extracted. For these tracks, a precise space position estimate for the vertex point is not needed, and practically any vertex reconstruction algorithm is adequate. The track parameters and errors are evaluated at the point of closest approach of the reconstructed helix to the estimated vertex position. Vertex position misestimates of the order of hundreds of microns are found to introduce negligible differences in the parameters furnished to the kinematics program. This remains true even in the case of rather short tracks, with unmeasurable curvature, whose only important variables are the angles.

Quite different conditions apply to two point tracks, such as V⁻ "tracks", or very short charged tracks. These tracks are constructed as the line joining the two reconstructed space vertex points. Clearly, the ability to do this reconstruction with precision is much more important for these classes of tracks.
The $V^0$ problem is common to all classes of measuring engines. In most cases both the $V$ origin and decay point are fairly well defined and easily measurable, and thus again the reconstructed end points are fairly insensitive to the reconstruction method. It has been noted that as the distance between the vertices becomes large, the kinematic fits become generally less acceptable. It is easy to understand this; for very long tracks, the angle errors estimated from the end point stated errors become very small. For these tracks, small systematic effects such as optical constants misdetermination or fiducial image mis-measurement come to dominate the angle precision determination. In the past, this problem has been solved in an ad hoc manner by imposing lower limits on the permissible position or angle errors.

In the case of charged vertex-connecting tracks, for most machines other than the CERN LSD, if the track is longer than about 1 cm in space, it is probable that track points are measured and the helix reconstruction is done. For tracks shorter than this, the position error limits yield fairly large angular errors on the two point vertex link, largely obscuring any small position misdeterminations.

The CERN LSD1 furnishes a much larger fraction of charged vertex links as two point tracks. This is a fairly direct consequence of a number of hardware and programming decisions.

- In the first 1 cm of film around the spiral center, there are 20 sweeps of the slit.
- At the time of filtering at one vertex, the co-ordinates of other vertices of the event are not accessible to the current program.
- No track is furnished to the geometry program unless there are at least 7 points found.
- One often discards the first and last found track points, to minimize the track distortions that arise when one track is followed past its real end and onto another track.

The result is that few tracks within the first 10 radial sweeps are found and communicated from the filtering stage to the geometry. In the current case, with the 2m chamber, 1 cm on film corresponds to 13 cm in the X-Y plane at the middle of the chamber. Finally, we find that essentially all charged tracks shorter than 6 cm in space, and 50% of tracks between 6 and 9 cm in space, are measured as two point tracks. The kinematics results are therefore much more sensitive to the vertex point reconstruction algorithms than in most measuring systems.

3. POINT RECONSTRUCTION

The conclusion of the previous section stems from the various hardware and program decisions listed. Were these to be changed, we could expect to decrease the sensitivity of the kinematics results on the point measurements, through a significant shortening of the average measured two point track length. We have however about $10^5$ event measurements
already in hand, so it seemed desirable to study the point reconstruction techniques in the hopes of improving these. This study has been carried far enough so that our kinematic results have been considerably improved. This study has been described in an informal K

CERN note

1). The details are not of direct interest here: the conclusions will only be summarized.

When we measure a vertex in a view, we collect data on the film image positions of the fiducial marks, the vertex image point, and points on the various track images associated with the vertex. The fiducial measurements are used to transform the film measurements to the "standard frame", where corrections to the measurements to account for the various optical distortions are applied. We may now construct the space vertex point by locating that point which, when projected on the each of the views, yields the minimum sum of the weighted quadratic residuals to the measured, transformed image points and to the extrapolated track image plane curves. To assign errors to the co-ordinates of these reconstructed points, we must be able to properly weight the point and curve contributions, to compute the effect of errors on the standard frame transformation, and finally understand the quality of the optical distortion constants.

We may study the fiducial measurement precision in a number of different ways.

(i) It has been shown that the ability of the LSD to reproduce fiducial co-ordinates in repeated measurements of a given frame is characterizable by a rms scatter of about 2μ on film.

(ii) Measurement, in the manual mode, of all visible fiducials in many different frames of a given view of a particular roll yields a fiducial position rms scatter of about 10μ on film.

(iii) Measurement, in the automatic mode, of the four "event" fiducials, when compared to the expected positions in the standard frame, yields a rms scatter of about 8μ. The corresponding figures for HPD measurements of the same film are all between 1 and 3μ. Thus, observations ii) and iii) seem to arise from measurement point setting error rather than film systematics. There do not seem to be any gross systematic discrepancies; the average frame, constructed from the manual measurements used in ii) above, maps onto its HPD twin with a rms scatter of about 1μ, and the event measurement distributions iii) seem to be fairly well centered about zero.

The fiducial measurements are compared to their expected positions in the standard frame, and a transformation is constructed whose most important elements are a translation, a rotation, and a magnification. We measure four fiducials in the 2m film. Using the figures given above, we predict a translational error of about 5μ, and a magnification error (δ1/1) equal to a rotational error (δθ) of about 1.5 x 10^{-4}. There is no way to measure the rotational or translational errors directly. We may however infer the magnification error from the rms scatter of magnifications required to transform the event frames onto the standard frame. In the case of the LSD, this is found to be between 1.5 and 2 x 10^{-4}, as
expected. The corresponding HPD figure is 0.6 x 10^-4, again indicating that the LSD figure is a measurement scatter and not a property of the film.

In reconstructing a single point according to the outlined algorithm, rotational and magnification errors do not enter; these measurement errors leave the track image intersection points invariant. Only the translational errors enter directly, as they break the projective correspondence between the triad of image points.

It has been found that we obtain understandable point reconstruction stereo chi-squared distributions, account being taken of the fiducial transformation: translational uncertainties, if we use only the extrapolated plane curve track orbit images, with an uncertainty of 5μ in the plane curve radius. If we use the vertex point measurements, an error of at least 9μ is needed to characterize most measurements, while a noticeable fraction of all point reconstruction chi-squares remain far too large to be reasonable. It is obvious that this is just a reflection of the operator's inability to set on an obscure vertex image point in some or several views to a precision described by a circular 9μ setting error. We therefore are abandoning the use of point measurements in the vertex reconstruction for all but stopping points or o-prong or very small angle V decays.

We should note here that there is no evidence in our analysis for inadequate optical constants. The fit of the averaged frame from the measurements in ii) above yielded a film fit rms fiducial projection scatter of 3μ. We see no need on the basis of our point reconstruction chi-squared distributions for anything but the demonstrated fiducial transformation errors.

In the past, it has been found necessary to impose lower limits on the space co-ordinate errors of (δX = 100μ, δY = 100μ, δZ = 700μ). These errors correspond to about an 8μ film circular setting error. With our new technique, with errors assigned by the image aspect, we find typical space errors of the order of (δX = 110μ, δY = 40μ, δZ = 350μ) (X is the beam direction). This then represents a marked improvement in the point reconstruction position. There are further refinements that may allow a further decrease by about a factor of 1/3 in the δz value, but these do not here concern us.

4. TWO POINT TRACK DIRECTIONS

We have reviewed the single point location status in the previous section. We are however only interested in the relative location of two points. We might characterize the two points with the 6 space parameters (X_1, Y_1, Z_1, X_2, Y_2, Z_2). For our purposes, it is more convenient to use (X_1, Y_1, Z_1, L, Λ, φ), where (L, Λ, φ) are the length and direction of the space link between the two vertex points.

We see that the standard frame translational measurement error now contributes only to (X_1, Y_1, Z_1) errors. These translational errors do not affect in any direct fashion the position of vertex 2 relative to vertex 1. However, the rotational and magnification errors
in each view do generate measurement uncertainties in \((L, \Lambda, \phi)\). This error matrix depends on the orientation and length of the vertex link, and serves to fundamentally limit our ability to measure angles and lengths of two point tracks. The calculation of this error matrix, assuming a three view measurement, is given in the Appendix. Using the figures \((\delta L/L) = (\delta \theta) = 2.5 \times 10^{-4}\), for a flat track the limit on the azimuthal precision is found to be about \(0.5 \times 10^{-3}\). This effect then becomes important for two point tracks of about 8 cm, and dominant for tracks longer than about 10 cm. Obviously, the \(V^0\) tracks are the ones affected. This is comforting; we have already remarked that angle resolution limits have in the past had to be imposed on long \(V^0\)’s.

5. RESULTS AND CONCLUSIONS

Our modified procedures are being very carefully examined by detailed inter-comparison of the new with the old results. A considerable improvement in the quality of kinematics results is already evident. The total rate of kinematic ambiguities is lower, a higher fraction of events yield constrained fits, and the errors on missing variables are found to be smaller. There remain some problems. One constraint events have much the same kinematic chi-squared results. The average chi-square change per event for 1c fit is + 0.08 and for highly constrained fits, + 1.05.

I feel that the fact that more events fit is evidence that the vertex link direction calculation is now done better. I interpret the increase in the chi-squares for highly constrained events as evidence that there remain further effects that contribute to decrease the directionia precision of LSD measurements. More work remains to be done.

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1) CERN/D.Ph.II/KI' GROUP 72-3 (internal Note) "Vertex Point Reconstruction and two point track handling for LSD Measurements of 2m HBC film", J.P. Berge.
CALCULATION OF THE LINK VARIABLE ERRORS

We have vertex points in space \((X_1, Y_1, Z_1)\) and \((X_2, Y_2, Z_2)\). We construct the link variables

\[
L = \left[ (X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2 \right]^{1/2}
\]

\[
\Lambda = \tan^{-1} \left[ \frac{(Z_2 - Z_1)}{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \right]^{1/2}
\]

\[
\phi = \tan^{-1} \left[ \frac{(Y_2 - Y_1)}{(X_2 - X_1)} \right]
\]

(A.1)

We wish to compute the error matrix on these link variables arising from fiducial transformation errors in the magnification <\(\delta l/l\)> and the rotation <\(\delta \theta\)> for each view.

We shall assume 3 views, and we shall work in the approximation of first order optics. This approximation is extremely good, as we are only estimating errors rather than central values.

We then simply write down all the terms necessary to construct the transformation Jacobian

\[
J = \frac{\delta(L, \Lambda, \phi)}{\delta(l, \theta, K)} \quad (\text{here } K \text{ is a view index})
\]

Consider view \(K\): The image co-ordinates in the standard (pin hole, optic axis) system of the two vertex points are

\[
\xi_nK = \frac{(X_n - A_K)}{M(Z_n)}, \quad \eta_nK = \frac{(Y_n - B_K)}{M(Z_n)}
\]

(A.2)

with \(M(Z_n) = D_0 - \frac{Z_n}{\nu H}, \quad D_0 = \sum_{med} \frac{D_n}{\nu_e}\)

here \(n\) is a vertex index, \(k\) is a view index, \((A_K, B_K)\) are the camera X-Y co-ordinates, and \(D_n\) is the on-axis optical distance from the lens to the hydrogen-glass interface of the window. The vertex Z coordinate is taken as negative, according to the THRESH convention.

It remains now to compute the various differentials: let \(a_\Lambda\) be \(\xi_K\) or \(\eta_K\). Then

\[
\frac{\partial L}{\partial a_\Lambda} = \frac{1}{L} \left[ (X_2 - X_1) \frac{\partial X_1}{\partial a_\Lambda} + (Y_2 - Y_1) \frac{\partial Y_1}{\partial a_\Lambda} + (Z_2 - Z_1) \frac{\partial Z_1}{\partial a_\Lambda} \right] = \left[ \cos \Lambda (\cos \phi \frac{\partial X_2}{\partial a_\Lambda} + \sin \phi \frac{\partial Y_2}{\partial a_\Lambda}) + \sin \lambda \frac{\partial Z_2}{\partial a_\Lambda} \right]
\]

\[
\frac{\partial \Lambda}{\partial a_\Lambda} = \frac{1}{L} \left[ \cos \Lambda \frac{\partial Z_2}{\partial a_\Lambda} - \sin \Lambda (\cos \phi \frac{\partial X_2}{\partial a_\Lambda} + \sin \phi \frac{\partial Y_2}{\partial a_\Lambda}) \right]
\]

(A.3)

\[
\frac{\partial \Lambda}{\partial a_\phi} = \frac{1}{l_{XY}} \left[ \cos \phi \frac{\partial Y_2}{\partial a_\Lambda} - \sin \phi \frac{\partial X_2}{\partial a_\Lambda} \right]
\]

We invert the ray equation results A.2 and compute

\[
\frac{\partial X_2}{\partial a_\lambda} = (M(Z_2) \frac{\partial \xi}{\partial a_\lambda} - \frac{\xi}{\nu_H} \frac{\partial Z_2}{\partial a_\lambda}) \frac{\partial Z_2}{\partial a_\lambda} \quad \frac{\partial Z_2}{\partial a_\lambda} = (M(Z_2) \frac{\partial \eta}{\partial a_\lambda} - \frac{\eta}{\nu_H} \frac{\partial Z_2}{\partial a_\lambda})
\]

(A.4 a,b)

To estimate \(Z_2\), we need to combine the measurements in two views. Working in first order optics, we see that
\[ Z_2(IK) = -\eta_H \left[ \frac{d_{IK}}{d_{z2IK}} - D_0 \right] \]

Here

\[ d_{IK} = \sqrt{(A_1 - A_K)^2 + (B_1 - B_K)^2} \]

and

\[ d_{(2)IK} = \sqrt{(\xi_{2I} - \xi_{2K})^2 + (\eta_{2I} - \eta_{2K})^2} = \frac{1}{M(z_{2K})} d_{IK} \]

To an excellent approximation,

\[ Z_2 = \frac{1}{3} \left[ z_{2(12)} + z_{2(13)} + z_{2(23)} \right] \]

Set \( \cos \psi_{IK} = \frac{(A_I - A_K)}{D_{IK}} \), the stereo axis angle for the stereo system (K, I).

\[ \sin \psi_{IK} = \frac{(B_I - B_K)}{D_{IK}} \]

Then

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = M(z_{2K}) \left\{ \left( \frac{\cos \psi_{IK}}{D_{IK}} + \frac{\cos \psi_{IJ}}{D_{IJ}} \right) (M(z_{2K}) \frac{\alpha_{2K}}{\alpha_\lambda}) + \left( \frac{\sin \psi_{IK}}{D_{IK}} + \frac{\sin \psi_{IJ}}{D_{IJ}} \right) (M(z_{2K}) \frac{\alpha_{2K}}{\alpha_\lambda}) \right\} \]

There remains only

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = M(z_{2K}) \frac{\alpha_{2K}}{\alpha_\lambda} \]

for \( \alpha_\lambda = \xi_K \),

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = (X_2 - M(z_{2K}) Y_1) - A_K \left( \frac{Z_2-Z_1}{M(z_{2K}) X_1} \right) \]

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = (Y_2 - M(z_{2K}) X_1) - B_K \left( \frac{Z_2-Z_1}{M(z_{2K}) Y_1} \right) \]

for \( \alpha_\lambda = \theta_K \),

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = (X_2 - M(z_{2K}) Y_1) + A_K \left( \frac{Z_2-Z_1}{M(z_{2K}) X_1} \right) \]

\[ \frac{\alpha_{2K}}{\alpha_\lambda} = (Y_2 - M(z_{2K}) X_1) + B_K \left( \frac{Z_2-Z_1}{M(z_{2K}) Y_1} \right) \]

Thus, we evaluate the derivatives A5, A4 and A3 for each view, to construct the transformation Jacobian \( J_{ij} \), a 3 x 6 matrix. We then compute the 3 x 3 error matrix \( G_{ij} \) on the link variables by forming the matrix product

\[ G_{ij} = J_{ik} J_{iu} H_{ku} \]

where \( H_{ku} \) is the 6 x 6 diagonal matrix with alternate diagonal terms

\[ \sigma_M^2 = \langle (\delta t/L)^2 \rangle \quad \text{and} \quad \sigma_\theta^2 = \langle (\delta \theta)^2 \rangle \]

These, we have taken as being equal, with \( \sigma_M = \sigma_\theta = 2.5 \times 10^{-4} \).

This matrix \( G_{ij} \) is finally added to the link variable error matrix computed in the normal way from the co-ordinates and the errors of the two vertices in question.
CALIBRATION OF THE DANISH-SWEDISH SPIRAL READER (SAAB-TYPE)

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Introduction

The Danish-Swedish Spiral Reader is no 1 of the four machines constructed and manufactured so far by SAAB-SCANDIA in Jönköping. The principal design and performance is described in the status report\(^1\). The purpose of this paper is to describe and discuss methods for the correction of geometrical distortions in this machine. Unlike in many other installations it was decided in an early stage to make the subtraction \(\theta_{\text{trailing}} - \Delta \theta/2\) in the on-line computer. This subtraction did not work correctly for the last buffer in each spiral. This problem obscured for some time the real distortion effects. The picture has now become more clear and we believe that we can separate systematic and random errors with sufficient confidence.

Chicken Walk Calibration

The calibration method using glass plate with a so called chicken walk pattern has been extensively used. Two types of patterns have been used both made by J. Heidenhain after drawings from CERN\(^2\). The currently used one has 177 crosses the positions of which are known by microscope measurements.

The CERN program SCALP\(^3\) has been used for the analysis of the measurements. Fig. 1 shows a typical result of the calculations for one spiral. In the use of this calibration method it was found essential that the slit is not too long and that it has an even sensitivity.

A simple method has been used to measure the sensitivity along the slit. A dark mask with a approx. 25 microns wide slit along the Y-axis has been placed in the optical path. The periscope is stopped and rotated so that the image of the light slit is perpendicular to the pick-up slit. The X-stage is then moved and the current from the PM-tube is plotted. Fig. 2a shows a typical plot from SRS-1. A mask is then placed over the slit to select a good part of the slit. If the sensitivity curve is not symmetric this can introduce a systematic difference between measuring on CW-crosses and straight lines or high energy track. The straight line will not be affected by an unsymmetric sensitivity-curve but Fig. 2b, 2c shows qualitatively the distortions on CW-crosses.
Beam track measurements at 19 GeV/c

The film currently measured on the Danish-Swedish Spiral Reader is from a 19 GeV/c pd experiment in CERN 2 m BC.

When measuring beam momentum in this experiment we locate a bubble in the middle of a noninteracting beam track and center the spiral on the same bubble in the three views. These measurements are then processed in the filter and geometry programmes POOH(4) and THRESH(5).

When comparing the distribution of \( \frac{1}{\rho} \) (\( \rho \) = radius of curvature of helix fit in THRESH) for the backward and forward part of the track a highly significant shift in the mean values is found. The distributions are shown in Fig. 3 and in Fig. 4 results from the same film measured on a conventional ENETRA-machine is shown.

The widths of the distributions are almost the same, which indicates that the effect is due to some stable systematic error. The size of the effect could be estimated in the following way:

Nominal momentum 19.2 GeV gives \( \frac{1}{\rho} = \frac{0.3 \times 17.34}{19.2 \times 10^3} = 27.094 \times 10^{-5} \text{ cm}^{-1} \)

\[ \text{Sagitta } S = \frac{L^2}{8R} = \frac{27.094 \times 10^{-5}}{8} \times 60^2 = 1210 \mu \text{ in space = } \frac{1210}{14} = 86 \mu \text{ on film} \]

Magnification is \( \sim 14 \)

The full effect is around 7% and if we assume the effect to be equally shared (in fact it is not) between incoming and outgoing track it implies an effect of 3 \( \mu \text{m} \) in sagitta over full radius (50 000 \( \mu \) ) that is 1.5 least count in xy.

When fitting the \((r, \theta, \tau, x, y)\)-transformation parameters \((r_o, \theta_o, r_{\text{count}}, x_o, y_o)\) from chicken walk measurements one gets residuals in \( x \) and \( y \) for each cross fitted.

These residuals should in principle contain the systematic effects not taken into account by the transformation but of course also random fluctuations from measurements.

It is customary to make a table of these residuals and use it to correct the measurements in the xy-system before entering the geometry calculations in THRESH.

This has been tried on the beam track measurements but with no satisfactory effect on the curvature difference between the forward and backward parts of the track.
Measurements of artificial straight lines and comparisons with chicken walk measurements

We have to our disposal a glass-plate with engraved straight lines in a square grid. These lines are measured in the same way as the CW-plate i.e. with constant low periscope speed (110 counts/rev).

The points on the lines in the SR x and y direction are filtered out and fitted to straight lines in a computer programme LINES\(^6\).

Fig. 5 shows the residuals from such a fit along the x-axis (beam direction made on measurements taken at the time of the mentioned beam track measurements. Each point is the average residual over 500 r-count ("5 digitizings) and four spirals are superimposed.

The profile of the line shows a distortion which has a curvature of the right sign and size to account for the systematic effect on beam track measurements.

The figure also shows that the random spread of the measurement around the average profile is smaller than the systematic effect. This offers a possibility to separate the systematic effect from the random spread.

To purify the systematic effect a table of mean residuals from four spirals is determined. This table of residuals is then applied as a correction to 12 spirals including the four first ones. The measurements are spread over a period of one week. As can be seen from Fig. 6 there is no detectable systematic effect left after this correction and the random spread appears to be the same along the line. The projection of this plot is given in Fig. 7. The standard deviation in this distribution is 0.5. When single digitizings are used we find a standard deviation of 0.9 counts. These measurements are made on an ideal straight and sharp line which is free from Coulomb error. We therefore claim that the setting error attributed to the machine itself on a single digitizing amounts to 1.8 \(\mu\mbox{m}\).

To investigate how much of the systematic effect could be attributed to the measured line itself the line was turned 180\(^0\). Fig. 8 and 9 shows results from normal and rotated line position and the differences are indeed small which justifies our assumption that the line itself is straight enough not to need any separate correction. This is also supported by measurements in the SR xy system.

An interesting question is now "how does these result compare with the result from CW measurement". Fig. 10 shows the y-residuals of the crosses along the x-axis taken from a CW measurement done at the same time as the line measurement in Fig. 5. In principle these points should fall on top of the lines profile (a rotation around the origin is allowed due to possible small differences in \(\theta_0\)). As can be seen from the figures the two profiles agree in some rough sense but the CW measurements do not reproduce the finer details like the curved distortion on each side of vertex and especially not near
the vertex. The reason for this could be speculated on but in fact the measurements are radically different.

The angle between the slit and the straight line or fast track is 0° while in the CW measurements it varies between 30° and 20°. Another dubious point is the definition of the CW-pattern which is calibrated in one way (microscope measurements probably concerning only the central region of the crosses) and measured on SR in another (here the central regions of the crosses are excluded).

**Application of line-residuals to beam track measurements**

As mentioned the profile of the residuals in the line measurements could account for the distortion of curvature of beam tracks. This has been verified by making a correction in POOH where the residuals from the line measurements are used instead of those from the CW calibration. The result of this is shown in Fig. 11 where \( \frac{1}{\rho} \) from THRESH is plotted after correction. As could be seen in this figure the residuals from LINES seem to correct fully the observed systematic effect.

An obvious shortcoming of this method is that we have only the possibility to measure in two orthogonal directions x and y, since we cannot turn the plate. The variation over 90° can be seen from Fig. 12 which shows the residuals from the line in y-direction. Fig. 13 shows this line with corrections from the x-line and here we see that some of the structure still remains. On the other hand for real measurements the distortions is very important only for the fastest tracks and those are emitted in a narrow angular cone (\( \theta \leq \tan^{-1} \frac{P_0}{P} \), \( P_0 \sim 0.350 \text{ GeV/c} \) \( P_{\text{max}} \sim 1.0 \text{ GeV/c} \)), and within this the variation of the distortion is not expected to be significant.

As can be seen from Fig. 3, 4 and 11 the standard deviations in \( \frac{1}{\rho} \) in SR measurements and the ENETRA measurements are of the same size (\( \sigma \frac{1}{\rho} \sim 0.6 \times 10^{-5} \text{ cm}^{-1} \)). The average track length measured on the SR is 62 cm in the chamber while for the ENETRA-measurements (10 points/track) the corresponding length is 75 cm. In production measurements on ENETRA one usually pulls only 5 points/track. This implies that the SR gives considerably smaller random errors in production measurements compared to an ENETRA provided the measured track lengths are the same.

**Hardware cause of the distortion**

When investigating possible hardware causes for the described effects we turned the lens by 180°. The measurements in terms of lines residual and beam track radius are shown in Figures 14-15. Here the picture is radically different and the distortion is much
smaller. This indicates that the systematic distortion observed is of an optical nature and that it probably concerns both the lens and some mirror(s). One disadvantage with this lens position is that due to some strange reason it introduces a very disturbing astigmatic distortion in the autofiducial plane and we are afraid that this could ruin our autofiducial measurements.

Another reason for continuing the investigation of the original lens position is that we have a large sample of non-processed measurements waiting for the distortion problems to be solved.

Conclusion and future developments

The investigations presented in this paper are not complete and we will continue and elaborate more on some details in the nearest future.

The results obtained so far are however encouraging and we feel that with a combination of calibration from CW-measurements and systematic corrections along the lines presented here we are able to measure as high a momentum as 19 GeV/c in the 2 m BC with satisfactory results. This, according to our experience, is impossible with CW-calibration only, even if the CW-residuals are used.

Further on the random fluctuation or setting error obtained when systematic effects are removed; 1.8 \( \mu \)m on single points and 1 \( \mu \)m on master points is a surprisingly good number which seems to be well matched with the intrinsic setting error on real tracks in CERN 2 m HBC. This latter setting error seems to be caused by the bubble growth and is \( \sim 2.3 \mu \)m for "normal" flash delay\(^7\).
Figure Captions:

Fig. 1 A typical result of SCALP calculations on one spiral of chicken walk measurements.

Fig. 2 Slit sensitivity
2 a: Full slit
2 b: Masked slit
2 c-d: Qualitative distortion of CW-crosses as a consequence of uneven slit sensitivity.

Fig. 3 Distribution of $\frac{1}{2}$ from SR-measurements of non-interacting beam tracks (19 GeV/c proton%).
3 a: Forward part.
3 b: Backward part.

Fig. 4 Same as Fig. 3 but measured with ENETRA.

Fig. 5 Residuals from fit of straight line measurements in beam direction.

Fig. 6 Residuals from fit of corrected straight line measurements. 12 spirals are superimposed.

Fig. 7 Projection of residuals from Fig. 6.

Fig. 8 Residuals from fit of straight line measurements. The line was oriented in "normal" position (beam direction).

Fig. 9 Same as Fig. 8 but the line rotated 180°.

Fig. 10 Y-residuals from SCALP on CW-crosses situated in the beam direction. Data taken at the same time as those of Fig. 5.

Fig. 11 Same as Fig. 3 but raw data corrected with residuals from line measurements.

Fig. 12 Residuals from fit of straight line measurements in SR Y-direction (L beam)

Fig. 13 Same as Fig. 12, but data corrected with residuals from X-direction (same correction as in Fig. 6).

Fig. 14 Residuals from fit of straight line measurements with the SR-lens rotated 180°.

Fig. 15 Same as Fig. 3 but measured with the SR-lens rotated 180°.
References


4. POOH is the name of the off-line filter programme for the SR. The version used by DSSL is derived from an early Stanford version and is described by E. Dahl-Jensen in a contribution to ESRS, Stockholm.


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Table 3

| Parameter | Value
|-----------|------
| a         | 0.2368
| b         | 0.357
| c         | 0.4789
| d         | 0.5901

Correlation Matrix

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<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
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<td>0.32</td>
<td>0.18</td>
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<td>0.45</td>
</tr>
<tr>
<td>d</td>
<td>0.18</td>
<td>0.23</td>
<td>0.45</td>
<td>1.00</td>
</tr>
</tbody>
</table>

No. of Crosses Measured: 228. Used in Fit: 167
Chi-square found: 1.78698
Map and Nip: a = 3.0

Residual in X and Theta After Fit: 1.00 2.22
Highest Residual in X = 3.08 at Cross 167
Highest Residual Found: 3.08

Fig. 1
Residuals from fit of straight line measurements

Residuals from fit of "corrected" straight line measurements

Fig. 5

Fig. 6
\[
\langle \frac{x}{y} \rangle = 27.05 \times 10^{-5} \text{ cm}^3
\]
\[
\sigma_y = 6.0 \times 10^{-6} \text{ cm}^3
\]

\[
\langle \frac{x}{y} \rangle = 26.90 \times 10^{-5} \text{ cm}^3
\]
\[
\sigma_y = 6.2 \times 10^{-5} \text{ cm}^3
\]
Fig. 13

Residuals from fit of "corrected" straight line measurements

Fig. 14

Residuals from fit of straight line measurements
Fig. 15
ON-LINE PROGRAMMING

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I. Introduction:

Our control program ZOO was written for a PDP-9 computer. The coding was done by using most of DEC's utilities, like the Text Editor for creating the source files of subroutines, the Assembler MacroA-9 (a restricted version of Macro-9) the debugging aid D.D.T., the relocatable linking loader of the keyboard Monitor System (KBM-9), and the UPDATE for building a library of subroutines in binary mode.

The fact that all subroutines were stored on DEC tapes, enables us to modify easily any section of the program, without affecting the performance of the entire control program.

The program occupies: 4K words of instruction


2K " for buffers

1K " common area, working space

1K " KBM resident (reserved for future developments)

It should be emphasized that the KBM was used only in the preexecution phases of the program. Once execution started the on-line program was completely stand-alone. Thus we wrote our own special purpose and compact handlers for DEC tape, Magnetic tape and teletype. Furthermore, during the execution phase the resident monitor area (1K) could be overlaid by storage space, (e.g. buffers), and thus no serious loss of storage resulted from use of the monitor system.

In designing our program we have tried to learn from all examples, to make it as simple as possible from all points of view, namely:

(a) No sophistication in the management, no Executives which control queue of tasks, software priorities etc. We have just used a simple sequential set of operations, out of which simultaneous jobs are handled via API handlers.
(b) Simple, straightforward I/O organization, 3 record types for the 3 different data structure. No circular buffering, we use double buffers instead.

(c) Since we have not used external assembler, all subroutines are kept in a file organization on DEC tape, and the program is loaded from a dump area of a DEC tape.

All these could, to some extent, slow the operation, but we feel confident that is only a small fraction of the "real things" (like fiducials and CPTS).

II. Program Structure:

The program consists of 6 major blocks:

(1) MAIN - Initializes S.R. activities, sets API trap addresses, readies I/O devices, checks various reference marks, calibrates fiducials, gets date, time, operator information, roll, tape, etc.

(2) LION - Controls all measurements. Calls upon XYLAM to perform 3 views measurements. ID information is read from DEC, film is moved to picture and stage is brought approximately to 1st fiducial.

(2) XYLAM - Measures one vertex at a time in the following sequence:
(a) 4 fiducials are measured by a push button, after stage was driven automatically to the expected position.

(b) Stage moves to vertex, vertex scan starts after manual adjustment, future vertex calculation is done, while the Q channel fills one buffer, the other is being written on tape, in addition the data is being displayed on the scope at the same time and various checks are being made.

(c) Crutch points measurements on all tracks, part of which are driven as flagged cpts, namely stage is driven to the expected position.

(4) Device handlers - Closed subroutines to handle the various devices of the S.R., including their API service sections

(5) PILM - A collection of special functions, which could be entered by hitting (ALT) key and typing a letter. These functions can
perform remeasurements, handle rejects, sign-in, sign-off, device checkout, fiducial calibration, data display, magnetic tape operation, etc.

In other words it can "Interrupt" the regular flow of program and perform some function and resume its flow afterwards.

(6) **Utilities** - Arithmetic functions, formating routines, etc.

**I/O Structure:**

(a) Input from DEC tape, 40 words per event: ID, VERTEX, CODES, when a new ID is to be read, it is already found in buffer, and the program initiates another read.

(b) Output on a 7-track, IBM compatible magnetic tape. Up to few months ago we were using 556 bpi without any trouble. We have switched to 800 bpi in order to have only 1 magnetic tape per roll, and we tolerate up to 3-4 parity errors per roll.

We have 3 types of records:

- **ID** - 24 words, scan information
- **Q** - 524 " 512 data (128 hits) + 12 Header
- **FVC** - 56 " Fiducials, Vertex, Crutch points

Each record has a type signature, which identifies it, together with its length. The records are written as independent physical records, and this makes it easy to read it, without any need for deblocking, unpacking, etc. On the other side, it occupies more space on tapes, and after 2 years of operation the number of tapes is quite large. This is solved by an extra operation in the long chain of analysis, namely 5-6 tapes are being stored on one 1600 bpi, 9 track tape, after all the data was checked.

**IV. Timing of Operations:**

The following table shows how much time is consumed at each phase of measurement. All numbers are given for 3 views: (each view is approximately 1/3 of the time).
1) Film movement, view switching, event verification 14 sec.
2) 4 Fiducials measurement 14 sec.
3) Vertex drive, adjustment and scan 19 sec.
4) Crutch points taken on all tracks (4 prong) 28 sec.
   75 sec.

We are confident that we can easily improve this situation by taking minimum cpts (30% better) and by using semiautomatic fiducial measurement, so that we could reach a time of about 45 sec/event.

V. Diagnostic Routines and External Utilities:

We have a local version of RAVEN, called OREV. It is an adaptation of LRL’s routines, though vastly altered and expanded to accommodate the various changes in the Q-channel logic.

We have introduced some extra features which provide us with more useful functions:

Controlling the ramping (periscope movements), collecting data on a magnetic tape, dumping or printing interesting parts of a buffer, and also the possibility to magnify selected areas according to radius range.

Our library of utilities includes some packages which can perform data transfer from the following devices:

Magnetic tape to DEC and vice versa
DISK to magnetic tape " " "
OFF-LINE PROGRAMMING

I. POOH:

We have started with an old version of LRL POOH (FILTER+MATCH) which ran on a 360 IBM, and was adapted to our local GOLEM. Since then it was modified quite extensively along 2 major lines, using an IBM 370/165 computer just recently installed.

(1) Our local data structure and the different machine parameters have dictated natural line of modifications. More debug aids, reject handling, more switches for skipping, selecting various types of events. Our calibration library file resides on a direct access device and is being updated by our CALB program. By using Fortran instruction one gets access to the proper deck of calibration by reading a directory record which points to the proper location on disk. (See Define File instruction in IBM's FORTRAN IV MANUAL).

(2) Improvements along the developments made by LRL in their NU-POOH. We have introduced the following items:

(a) Averaging 40 points per track into 12
(b) Better tracking out and in.
(c) Data checking, like monotony, bad points.
(d) Better matching routines.

We intend to introduce very soon the following features:

CLEANUP routines for dropping points from PH average calculation, when it belongs to 2 tracks simultaneously.

We have not to-date used the REDO feature because of various reasons (these events often failed in kinematics). But we intend to reactivate it soon. (A 5% gain in POOH success rate is expected).

Long chopping and negative cpts handling will be introduced, once the extra hardware is implemented.

Our program occupies 250K bytes under FORTRAN H (OPT=2) compiler, including buffers and plotting routines. It runs with 95% cpu utilization,
and process 30 events/minute. Most of the code is in Fortran, with very little assembler code (mainly for non standard I/O).

2 seconds per event is an overall average for our data, but obviously for a 10 track/view event, it will run up to 4-5 seconds, spending most of the time in MATCH. Let us look at the various POOH rejects chosen from a sample of 5000 events. POOH FAILURES: NO BEAM TRK WAS FOUND .1%
PARITY ERROR (ON INPUT) .5%
TOO FEW TRACKS 1.0%
NO MATCH 8.6%
TRACK FAILED VOLUME .15%
NO EVENT TYPE IN DICTIONARY .2%

II. TVGP-SQUAW (GEOMETRY & KINEMATICS)

We are using a version which is very close to LRL's SIOUXC. 12% of our events fail in these sections of the system. 5% of them are due to non beam events (we are using strict criteria in this particular experiment), and 3% are events with unacceptable $\chi^2$. The rest 4% are mainly from Geometry failure for various reasons like: Bad points scatter, wrong curvature, etc. For some time we had troubles with handling short tracks, and stopping tracks. We have solved it completely by introducing LRL's TYPE 4 tracks (kinematical variables are azimuth, slope and momenta). Some of the unacceptable $\chi^2$ were solved by introducing Dalitz Pair handling. The event type is reduced once a pair is detected. These 2 programmes are running independently in core.

180K is occupied by TVGP and 240K by SQUAW. We have attached to SQUAW a SQHIST section which gives us histograms of various quantities, like $\chi^2$, beam distributions, pulls, and also a summary of failures and successes. These 2 programmes are 99% cpu bound and their corresponding rates are 120 events/minute for TVGP and 80 events/minute for SQUAW.

To sum it up, we have for the 3 big programmes the following timings:

<table>
<thead>
<tr>
<th>Programme</th>
<th>Rate</th>
<th>Time/Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>POOH</td>
<td>30 Events/minute</td>
<td>2 sec/event</td>
</tr>
<tr>
<td>TVGP</td>
<td>120 &quot;</td>
<td>1/2 &quot;</td>
</tr>
<tr>
<td>SQUAW</td>
<td>80 &quot;</td>
<td>3/4 &quot;</td>
</tr>
</tbody>
</table>

Total $3 \frac{1}{4}$
ON-LINE SOFTWARE FOR THE CERN SPIRAL READERS

CERN-LSD Group (presented by Mrs. L. Zanello)

1. ON-LINE COMPUTER CONFIGURATION

Each of the two CERN Spiral Readers is connected to a DEC PDP-9 with 8K of core, 1 usec cycle time; single address, fixed-length words; program interrupt facility with single priority level; one accumulator; real time clock.

Peripherals include:
- a 10 cps send-receive teletype
- a 300 cps paper tape reader
- a 50 cps paper tape punch
- two magnetic tape units
- a storage display.

The LSD2 configuration is more powerful, including also four DEC-tape units and the Extended Arithmetic Element, i.e. fixed point hardware multiply/divide, long shifts, access to a second register. The display is also different for the two machines, LSD1 having a RM 564 Tektronix storage oscilloscope, and LSD2 a 611 Tektronix storage display. The difference is not only in screen size and control instruction set, but also in interrupt facility.

2. DEFINITION OF "ON-LINE" SOFTWARE

We conventionally classify "on-line" all the LSD software necessary to produce a magnetic tape with LSD digitizations. In other words, software is "on-line" if it would change with the on-line computer. This includes not only the measurement control program, but also software for machine reliability tests, machine calibration, data quality control, hardware debugging etc.

3. PROGRAMS DESCRIPTION

3.1 ASTERIX - The on-line control program

ASTERIX is the control program for event measurement. It occupies all the available 8K of core; 2K of data buffers are obtained by overlaying part of the coding after its execution. ASTERIX's basic purposes are:

- to control the measurement sequence, making it as far as possible automatic and checking the operator's actions;
- to monitor the status of the machine, checking its conditions against some standard ones. These are determined periodically through calibration procedures;
- to perform some book-keeping activities (count number of events per operator's shift, numbers of events on tape, etc.), printing on the teletype the relevant information.
ASTERIX can be divided in the following sections:

**Initialization**
- Determine calibration constants for stage, periscope and autofiducial system.

**Input**
- Search input device for a given event, read scanning information for this event and type it on the teletype.

**Event measurement**
- Calculate approximate vertex position for each view, digitize all view-vertices for a given event, control measurement of special points.

**Device handling**
(a) Stage: move stage to a given destination, change view etc.;
(b) magnetic tape: read/write, backspace, endfile etc.;
(c) film transport: move one or more films to a given frame;
(d) display: control scaling and displaying of digitized points;
(e) teletype: type messages, octal or decimal numbers and single characters on the teletype; accept input from keyboard.

**Operator interaction**
- Accept operator's commands and initiate appropriate action: view re-measurement, event reject, topology change, etc.

**Fiducial measurement**
(a) Manual: move stage to approximate fiducial position, store operator's measured co-ordinates;
(b) automatic: sweep over fiducial areas, collect and sort points, reconstruct cross center for each fiducial.

**Information request**
- Request from the operator time of day, tape number, roll, frame...

**Interrupt handling**
- Decode interrupt source; if legal dispatch to appropriate handler; process interrupt as directed, clear flags and restore normal program sequence.

**Utilities**
- Double precision integer divide/multiply, word shift, illegal instruction handling, generation of a given time delay etc.

Note that this separation is a logical, rather than a physical one: there is more interaction and overlapping between different sections than there may seem from this classification.
ASTERIX is essentially experiment independent; a few new features have however been added for an experiment with large statistics and frequently complicated topologies: measurement of special points has been simplified for the operator, in order to increase speed and reduce errors, and the possibility of topology change has been introduced to avoid event re-measurement in case of obvious scanning error. Other recent facilities added are: the possibility to update a half-filled output tape, and the conversion of point co-ordinates to a cartesian system before displaying.

This last feature gives the operator a better control on measurement quality, and makes it easier to spot hardware failures. It has also proved useful for machine tune-up during measurement of calibration patterns.

3.2 **STEP - The general hardware test program**

STEP was born from a nucleus of small hardware test programs, written during the construction of LSD1 as an aid to the engineers.

In STEP, these have been organized in a systematic way and completed, so that every part of the machine, except the data channel, can undergo a complete test. The data channel requires more extensive checks, and a special program exists for it.

STEP is divided in two main parts:

- **SCOUT** checks all the IOT instructions, assuming only that the CAF (clear all flags) instruction is working. It tests therefore the interface electronics and its communication with the computer;

- **TRIAL** checks the conditions of the physical devices, and their communication with the electronics.

The devices tested are:

- x stage
- y stage
- periscope
- film transport
- auto-fiducials
- display.

For x-y stage and periscope, the command and status register is tested: the command bits are checked to produce the appropriate action if set on by program, the status bits are checked to see if the corresponding physical condition is present when the bit is on. Scalers are checked by verifying the up-down counters and the reproducibility of the scaler value on the same reference mark. Other tests include: check that an interrupt occurs if and only if the corresponding physical condition is present and the appropriate bit of the command and status register is set; check that incompatible physical conditions are not present at the same time; check that the relative position of limit switches and reference marks is correct, etc.
For film transport, each bit of the command and status register is controlled, for the three views. For the auto-fiducials a complete calibration of each fiducial can be requested by the operator, selecting the view and the cross. For the display STEP checks that it can be cleared, and filled with random points covering the entire screen.

3.3 RAVEN - The data channel test program

RAVEN allows the operator to transfer in core the digitizing corresponding to the first 1500 points of the spiral, and to display them in various forms.

The desired program action is selected by teletype. The operator can choose to display the midpoint of all data either in polar or in cartesian coordinates; he can display leading edge, trailing edge, midpoint or any combination of these; magnify or demagnify any part of the display; rotate right or left by a specified amount; display only data which falls within the histogram region of the off-line filter program; mark all points with a selected pulse height; output a scaled histogram of pulse heights for the points currently on the display; calculate and output the number of times each bit in the word is on, for 1000 points; superimpose points for different spirals on the same display; display only points with pulse height in a given interval; type out the co-ordinates, the pulse height and the pulse width for all points on the display. A special precision display of straight lines is provided; it is used to adjust the ACC parameters without waiting for the off-line calibration program response to each change.

3.4 WOODSTOCK - The data quality control program

WOODSTOCK allows the operator to perform the same checks as RAVEN, but on digitizings stored on magnetic tape; it is therefore used for control of measurement quality prior to more extensive off-line analysis.

The user can request the program to search the tape for a specified event and display the first valid vertex for this event.

From this point, the program functions in the same way as RAVEN.

WOODSTOCK has proved particularly useful for a detailed analysis of events rejected by the filter program. While it does not provide at present any rescue procedure, it can help to improve the understanding between measuring machine and filter program.

4. PRESENT ORGANIZATION OF ON-LINE SOFTWARE, PROBLEMS, AND SOME PROPOSED SOLUTIONS

The development of on-line software faces two basic difficulties, which we believe to be intrinsic to any configuration of the type we have: one is lack of computer time for software development and the other limitation of core size.

Having no-time sharing facilities, the control computer is, under normal circumstances, unavailable for program development; as a consequence, we tend to shift all the handling of on-line software on an off-line computer. This has the extra advantage of allowing the use of a more powerful assembly language than it would be possible on the small computer:
labelled and blank COMMON, conditional assembly, direct reference to global symbols, macro instructions, DATA statements, are commonly utilized. Having virtually no restrictions in the symbol table size, the program can be partitioned into logical segments, rather than into the largest units allowed by the symbol table size.

Another advantage of the present organization is that it minimizes compatibility problems between the two machines, arising not only from differences in the computer configuration, but also in the measuring machine hardware.

Programs are created as source files on DEC-tape; edited and updated through DEC's standard Display Editor, then transferred to magnetic tape. This tape is used as input to a chain of FORTRAN programs, running on the CDC 6000, producing as output PDP9 binary code in relocatable form. The steps of the chain are the following:

- resolve conditional assembly: this means that alternative groups of instructions are included in the source file, depending on the value of parameters given on data cards. As an example, if a multiplication or division is necessary, the program would include calls to the corresponding subroutines, if assembled for LSD1, and the machine instructions themselves if assembled for LSD2;

- expand macro instructions: beside the normal machine instructions, our assembly language allows user defined macros, each macro summarizing a group of machine language instructions. During this step, macros are substituted with their full expansion, with the actual parameters replacing the formal parameters used in the macro definition;

- translate the assembly code into relocatable binary, with its relocation information, to be used by a linking loader. This step produces a program listing and a binary tape.

The binary tape is loaded on the PDP9 via a linking loader, which can produce a memory map and cross reference table. The result of this pass is absolute code, that can be dumped on magnetic tape as core image.

If the available machine time is further reduced, as the LSD2 is put in full scale production, the editing phase may also be transferred off-line, provided that an interactive display editor becomes available on the new 7600 system.

This program organization, while helpful with regard to the machine time problem, does not improve the situation of core size limitation. Taking the example of the control program, we have noted that it remains basically unchanged for different experiments: it should be added that this is partly due to lack of computer memory. The program has a natural tendency to grow, for the following reasons:

- as rare hardware failures occur, which are discovered only at level of the filter or geometry program, one notices that they could have been spotted on-line if appropriate checks were included in the control program;

- measurement speed can be increased by simplifying the operator's task; this also reduces re-measurements due to operator's fault, but it correspondingly complicates the program logic;
- it would be convenient to perform data quality tests during measurement, according to the philosophy to reject an event as soon as possible in the chain.

One can answer the growing need for memory space with coding optimization; this has however the disadvantage of making the program difficult to understand to all but its author, and of increasing debugging difficulties.

So, we are adopting the overlay system solution, that is, to keep in core at any time only what is needed, with a simple mechanism to load program segments in the same area. In the final organization, not only the control program, but all the on-line software will be integrated into one large system, with facility to load at any time during measurement a hardware test segment, execute it, and resume normal measurement.

The overlay system provided by DEC being too large for our memory size, we decided to write our own system, rather than try to adapt the existing one.

The basic idea is the following:
A program to be executed under this system must be divided into:
- one segment including all the coding that must be resident throughout execution (Type 0 segment);
- any number of segments which can overlay each other (Type 1 segments).

The segments for all programs are assembled as separate files and stored on magnetic tape in relocatable binary. One special segment precedes all the others: it is called the Monitor, and it is common to all programs. Its function is to control the loading in core of segments, and to provide basic facilities such as teletype I/O, arithmetic functions, interrupt handling etc.

The next pass is to transform the relocatable binary segments in absolute binary code, storing it on DEC-tape. The program that does this is called the Loader; the procedure is as follows:

The Loader is read in high core from paper tape; it loads in low core the first segment (Monitor), constructing a table of External Symbols, that is, symbols which may be referenced by other segments. The absolute code for the Monitor and the table are then copied on DEC-tape.

The Loader is now read in low core from paper tape. It requests from the operator the type of next segment:
- if it is a Type 0, it is loaded starting from the first free location above the Monitor. Its external symbols are added to those of the Monitor, as they may be referenced by the Type 1 segments. The segment and the complete External Symbols Table are then written on DEC-tape;
- if it is a Type 1, it is loaded starting from the first free location above the corresponding Type 0 segment. References to global symbols defined either in the Monitor or in the Type 0 segment are filled in. The absolute code is then transferred to DEC-tape. This procedure continues until the operator signals that loading is finished.

As each segment is written out, the Loader keeps track of its position on DEC-tape by attaching to the segment name its starting block number. Other information collected by the Loader is: the number and names of all Type 1 segments connected to a given Type 0 segment, the length of each Type 0 segment etc. All this information is stored in a system table and written on block 0 of the DEC-tape at the end of the loading.

The execution procedure is as follows:
- read the Monitor in core, using a bootstrap absolute loader; control is automatically transferred to a Keyboard Listener;
- select the desired Type 0 segment by typing its name;
- start execution.

Any Type 1 segment needed is automatically loaded from the DEC-tape by the Monitor.

A special teletype key (CNTL C) allows the user to return to the Monitor at any time during execution, and to request another Type 0 segment. Another key (ALT Mode) can be used to restart the current Type 0 segment.

Two interesting features of this overlay scheme should be mentioned: one is the possibility of saving on DEC-tape a block of information obtained through the execution of a segment; the other, the fact that communication is allowed between segments of different type in both directions.

The first feature is used to preserve up-to-date values of calibration constants, eliminating the need to recalculate them at each new loading. The second is useful to allow for instance different interrupt handling in the different programs, by instructing the Monitor to pass control to user-written subroutines.

An update procedure is under study, that will allow changing only one segment without having to recreate the entire DEC-tape. It is obvious that if the changed segment is a Type 0, all its attached Type 1 will have to be reloaded, owing to the possible change of External Symbols addresses.

The net gain in computer memory obtained with the overlay system depends on the program structure: it is maximum for a program like STEP, essentially modular in its structure; less for the control program, unless error handling and other rarely used features are put in their own segment. However little need be said as to the other advantage of the system, that is, its flexibility: a simplified version of the off-line machine calibration program, track following, more stringent fiducial consistency checks, first approximation geometry checks, can be added without great programming effort.
5. **POSSIBLE TRENDS IN ON-LINE SOFTWARE IMPROVEMENT: AN EXAMPLE**

Basic on-line software for the LSD is now fully developed and we are beginning to explore possible future additions. Which of these will be worth implementing in any particular installation will depend upon such factors as the hardware configuration, the cost of off-line computer time etc.

An interesting example of such an addition is contained in a pilot study of a simple track-following method. The aim was the early identification of events which would be rejected at the histogramming stage of the off-line program. On-line recognition of such events would enable immediate recovery by re-measurement or the addition of special points.

The scheme used was a variant of the "stringing" method and functions as follows:

Starting at zero radius and continuing until the fifth spiral, each digitizing is treated as a potential track start. If it is genuinely a track start there should be on the subsequent spiral another digitizing with a similar angle, pulse width and pulse height. If the program finds such a point it searches the next spiral for a point associated with the existing track members. This process continues from spiral to spiral until the limit of the histogram region is reached. The association of points is then stopped and a string of pointers to the track members is stored. Various routines are included in the program to reject spurious digitizings, hop over holes in valid tracks, avoid wrong directions when two tracks cross, etc.

Some typical results, as they could appear to the operator, are shown in Fig. 4.

The initial results of the study were not promising. For example, the program found the tracks of a two-prong event in only 50% of the tries. However, since that time, some hardware improvements (Geissler; this symposium) have resulted in better quality digitizings. The performance of our prototype stringing program is correspondingly improved: (two-prong events are found with 80% reliability). We therefore suggest that development in this direction would be profitable, particularly for users with spare on-line core and high off-line overheads.

**ACKNOWLEDGEMENTS**

We would like to thank all members of the Spiral Reader group for many helpful discussions and suggestions; G. Pichon and H. Klein for the important part they played in the development of the overlay system.

A special acknowledgement goes to G. Brandon, until recently in charge of the on-line LSD software, whose work and ideas form the base of most development described in this paper.
FIGURE CAPTIONS

Fig. 1  The LSD 'chicken path' calibration plate displayed in polar (left) and in cartesian coordinates.

Fig. 2  The LSD 'IEP-grid' calibration plate displayed in polar (left) and in cartesian coordinates.

Fig. 3  An event displayed in polar (left) and in cartesian coordinates.

Fig. 4  Typical results of the on-line track-following routine.
Fig. 1. The LSP 'chicken path' calibration plate, displayed in polar (left) and in cartesian coordinates.
Fig. 2 The LSD 'IEP-grid' calibration plate displayed in polar (left) and in cartesian coordinates.
Fig. 3. An event displayed in polar (left) and in cartesian coordinates.
Fig. 4  Typical results of the on-line track-following routine.
MAGPIE
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MAGPIE is the name of the on-line system used for testing the mechanical and electrical components of the SRS. The programme consists of a large number of routines testing individual functions which are tied together by a TELETYPE control routine. The intention has been to give the operator maximum control from the keyboard. MAGPIE tests all the functions of the SRS except the detailed study of the pulse data from the R-Θ digitizer which is the domain of an updated version of RAVEN, the original BERKELEY programme for this purpose.

In common with the other on-line SRS programmes, MAGPIE includes teletype calls which load the other programme, or loads itself from Dectape, making use of the Dectape bootstrap loader DECCONTROL.

MAGPIE consists of three main sections:
1) Test routines for all the main electronic and mechanical functions.
2) A small routines block for testing specific minor functions and for trouble-shooting.
3) An utility section, containing a PATCH routine to enable the operator to make temporary modifications to MAGPIE from the keyboard, and dumping routines for records (blocks) from MAGPIE and D3CTAPE.

A detailed description of the whole programme is available in the "MAGPIE OPERATOR MANUAL" (SAAB-SCANIA, JÖNKÖPING, 1971).

1) THE TEST Routines:
The greater part of MAGPIE consists of the test routines listed in TABLE 1.

a) Periscope and X-Y stage tests.
The most important of these, from the maintenance point of view, is the logic test (7) which checks both the mechanical functions and the interface hardware. Each computer order is performed in turn and checked to see that the unit has responded as it should. Other tests check the stability of the coordinate system and the functioning of the limit stops which prevent the unit from running off the ends of its guides in the event of an electrical or programming error. The
velocity test provides an easy method of checking the relationship between programmed and actual velocities, and the acceleration test, which can output its results either in the form of a curve (teletype or display) or a table, between any two preset velocities, has proved to be particularly valuable in optimizing the control routines used by SLINKS.

b) Film Transport Tests.
The three films drives are handled individually. The logic tests are very similar those used for the X,Y & P systems. Tests specific to the film drives are the one that tests Brenner mark detection, by using the pulse count capstan to measure the distances between brenner marks, and the routines which measure the accuracy with which the film can be positioned by the computer, and the magnitude of the drift which can occur when the film is not clamped.

c) Data Channel Logic Test.
This routine checks the function of the data channel interface. After testing the individual functions (loading registers, interrupts, etc.), data transfer into the machine, and channel flipping, are tested by making use of the CHKD order which simulates a valid pulse signal from the R-E hardware. MAGPIE does not contain routines for more detailed investigation of the functioning of the track detection system as these were already available in RAVEN.

d) Film Number Display Test.
Enables the operator to check that the digits actually displayed correspond to the digits specified by the programme. When all the digits have been displayed and checked the TV display monitor is switched over to the vertex camera.

e) Buttons & View Sensors Test.
Checks the functioning of the buttons as they are pressed by the operator with and without interrupts on. The view sensor test moves the Y stage occurs its whole range and the view sensors are continuously monitored. If at some point no view sensors are on a "G" (gap) will be typed, while the occurrence of two simultaneous view sensor flags will cause "O" (overlap) to be typed. At the end of the run a line containing the start and end coordinates of each view is typed.

f) Autofiducial Test.
Apart from testing the functioning of the interface electronics this routine also checks that light signals falling on the P.M. slits are properly registered and transferred to the computer.

g) Oscilloscope Display Test.
A number of patterns are generated and displayed on the oscilloscope screen. The scope controls should be adjusted to provide correct in-
tensity, focusing and centering on the screen. The DAC's linearity may be checked, and the storage and erase functions are exercised.

2) **THE SMALL Routines.**

The small routines section contains at present 29 routines devised for more detailed investigations of the hardware and/or calibration measurements. The routines at present included are those which were found to be most useful during the construction and commissioning of the SRS. Typical examples are routines which send a signal to cover specified interface register at regular intervals, to provide input for the service engineers scope, and, at that other extreme, a routine which makes a single sweep across the fiducials and stores the raw AF data so that it may be dumped on the teleprinter, and used as input for the first stage of an AF calibration, as well as for a detailed check of the hardware function.

3) **Utility Section.**

MAGPIES utility section contains routines for dumping specified records (blocks) from the IBM compatible mag. tape and from the DEC tape units. The third routine in this section is a teletype PATCH routine to enable the operator to modify the contents of any location(s) in core memory while running the programme. This facility has proved very useful and convenient when tracing faults of a more exotic nature, as one can either modify a suitable small routine or create a new one for the specific purpose in hand.
Table 1

1) Periscope and X-Y stage Tests
   1. Acceleration Test
   2. Velocity Test
   3. Limit Stop Distance Test
   4. Reference Mark Stability Test
   5. Count Flag Test
   6. a) Stage Flag Test
       b) Periscope Velocity Ramp Calibration and Exit Timing
   7. Logic Test

2) Film Transport System Tests
   1. Acceleration Test
   2. Velocity Test
   3. Distance between Brenner Marks
   4. Drift of Stopping Position
   5. Stopping Accuracy
   6. Velocity and Timing Test
   7. Logic Test

3) Data Channel Test

4) Film Number Display Test

5) Button and View Sensor Test

6) Auto-Fiducial Test

7) Oscilloscope Display Test
AUTOMATIC MEASUREMENT OF SIX FIDUCIALS ON HBC 200 FILM.

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The Spiral Reader (SAAB) was originally designed and built to measure four fiducials in a single sweep. The hardware is equipped with four pairs of slits, corresponding to the four fiducials to be measured, and 8 light pipes and P.M. tubes, one for each slit. The design implicitly assumes that the fiducials lie approximately on lines across the film (at right angles to the long axis), but the distances between the members of each of the two pairs, and along the film between the pairs, are adjustable.

More recently, studies of small distortion effects which are important when the beam energy is near the top end of the PS scale, have demonstrated that a considerable improvement in the accuracy of the measurements can be obtained if more than four fiducials are measured. To achieve this on the SRS poses several problems and three possible solutions have been examined:

1) Measure four automatically and two manual.

2) Extend hardware with two extra slit pairs, and the corresponding photomultipliers and electronics.

3) Rewrite the programme to make a double sweep. This only works if the film has two pairs of fiducials with very closely the same distance between them.

Solution (1) is obviously a temporary expedient, and it was used for some time in the summer and autumn of 1971, while a more permanent solution was being found.

Solution (2) is probably the best and most general solution in the long run, but it demands a very considerable redesign of the A.F. plate and slit mounting system, mechanical space considerations making a simple modification and extension of the existing system difficult.

Solution (3) was possible on newer film from the 2 m CERN HBC, as here there were two pairs of fiducials with the same distance between them. It was therefore decided to rewrite the auto-fid. control section in SLINKS, MAFIA, to provide two sweeps, the first of which measures four fids., the second measuring the remaining two. The inter-fid distances for the first 4 are checked in the normal way, making use of all six distances. The second sweep makes use of data from only two pairs of slits

Fig. 1.
(UL & UR). After calculating the two intersections for the measured fids the values, found in the first sweep, for LL and LR are placed in the appropriate address to make a complete set of four fiducials for pairing and matching. The complete set of interfid distances examined (lL) can be seen in fig. 1. After PAIRED and MATCH have been performed on the data from the second sweep, MANFID is called as usual to check that all six fiducials have been successfully found. Any that have not been found may now be measured manually. If more than one fid is lost in either sweep the operator will be asked to re-measure all four or two normally.

Finally, the routine SKEW is called to correct for small rotations of the fiducials w.r.t. the sweep axis. SKEW takes care both of innate rotations which vary from fiducial to fiducial, and of rotations due to wandering of the film in the holder. (We have found the rotation angles to be very small). No correction is at present made for nonorthogonality of the cross arms.

In connection with rewriting MAFIA, a couple of auxiliary routines have been written to assist in calibration and checking work. The first, MAFIA DEBUG, is designed as a patch to SLINKS and exists in form of a binary tape which can be loaded over SLINKS. It provides data dumps at various stages throughout the processing of the fiducial data (which ones are obtained may be controlled from the AC switches) and/or a punched tape containing labelled auto-manual differences for calibrating individual light pipe distances. (These depend slightly on the quality of the fiducials).

The second routine merely provides a means of extracting histograms and statistical data rapidly for the 36 quantities dumped on paper tape by MAFIA DEBUG during a calibration run. One would normally have data from ca. 100 x 3 views.
THE SCANDINAVIAN POOH

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The Scandinavian version of POOH originates from the famous Berkeley-version. It was found as a card deck on a shelf in Copenhagen, brought to our IBM 7094, compiled and slowly turned into a working program, initially by testing it on CERN SR-data and later on output from the Scandinavian SAAB-SR. The program has during the past years undergone a high number of changes, many of them being of technical art, but most of the modifications have been applied to increase detection efficiency, cleanliness of found solutions and also, which is important for this type of program, execution speed.

The present version of our POOH is installed on the Copenhagen UNIVAC 1106, the Stockholm CDC 3600 and on the Vienna IBM 7040. On all these computers it is overlayed - on the UNIVAC it occupies \( \approx 26 \) K words (42 K words, when not overlayed) with the following overlay structure (schematic):

```
  INIT
  | READ
  | HIST
  | TRACK
  | CRUTCH +
  FILTER
  | OWL
  | DEBUG +
  MATCH
  | SETUP
  | TESTS
  | OUTPUT
  | ALEX
  | TPOT

+) Only called in when needed.

POOH is (at least in principle) fully built out to handle up to four vertices and it also possesses a REDO facility (see later).
It will be impossible to describe all the smaller or greater improvements we have implemented (a description and full list is of course available for those interested) so here a few features of the program that might or might not differ from other versions will be presented.

**Histogramming.**

Histogramming is performed with rather few (~200) non-overlapping bins. In the case that a binslope contains more than a preset number of digitizing (e.g. 22) a routine RESOLVE is called. It splits the binslope up in 5 smaller bins, each with 3 subslopes. In this way, it can resolve tracks that are near each other in angle and momentum.

Normally, 10 points out of 18 possible are requested to form a track. The point distribution of HIST-found tracks is shown in fig. 1 for all tracks and (shaded) for matching tracks.

In order to obtain better starting parameters for tracking and also to improve the reject rate for spurious tracks a two-stage RMS limit method was introduced. So in verifying a track through the FIT-procedure it is first tried to establish a track which passes a low RMS-limit (e.g. 0.25 track widths) within the allowed number of points. If this fails the track is accepted anyway if its RMS is below a second limit (e.g. 0.50 track widths). The higher limit is necessary to catch low momentum tracks with high multiple scattering. The distribution of RMS at the HIST-stage is shown in fig. 2.

It has been found that a track often fails the $\beta$-test because a spurious digitizing near to the vertex has gone on the track. Therefore, in case the track fails the $\beta$-test, the innermost point of the track is removed (if enough points still remains to allow this) and the track is given another try.
Tracking

During tracking a narrow angular interval is used in order to reduce tracking time and also to avoid mistracking. The angular interval is determined from the slope of the track and from the requirement that the next point on the track must be found within a preset number of revolutions (normally 7) following the last point added.

Crutch points

If a track is sought in HUNNY from a crutch-point a radius interval for 8 possible digitizings is computed. Then 5 digitizings are required to form a track in the subsequent histogramming and also here a binslope is split up in 15 smaller binslopes if more than a certain number of digitizings (e.g. 14) are found within a normal binslope.

If the innermost edge of the radius interval falls outside the upper limit for HIST, no $\beta$-term is used in the fit as experience has shown that a $\beta$-term often leads to a faulty track.

Sometimes a HUNNY-found track cannot be tracked sufficiently near to the vertex because of a narrow crossing of two tracks. In such cases COMBIN is called to try to match the HUNNY-track to an already found HIST-track. If such a match can be found the two tracks are combined.

Tracks can be marked with an anticrutch-point (ACPT) to signal POOH that this track should not be used. This facility is in particular useful to discriminate against electron-pairs and V-zeroes that point directly to the vertex. It is also useful to erase tracks, not belonging to the event, that physically pass near to the vertex. An ACPT is normally only needed in one of the views, if applied in two views one is safeguarded against formation of unwanted doublets.
It is often wanted to extend high momentum tracks beyond the SR-range. This can be done by adding long crutch points (LCPT) to one of the tracks. They are normal CPT's with radii greater than SR-maximum. The LCPT's are added as x-y points to the track at OWL time.

End of filter stage

If a view-vertex contains more than 15 tracks and the end of the filter-stage, JACOB is called to choose the 15 "best" tracks based on an empirical function in which track-length, magnitude of RMS and $\beta$-term and on whether or not a crutch-point has been associated to the track.

Master points (usually 12) are built up by REDUCE. REDUCE first removes a number of points (depending on track length - $\sim 4$ for full length) that have too large deviates to the overall fit. The master points are then formed from digitizing in equidistant intervals averaged with respect to the fitted parameters and weighted by radius of each digitizing. Labelled points are naturally not touched by this procedure.

Track match

The track match proper has not undergone much change from its original structure except on adoption to the CERN 2m HBC. Multi-vertex features have been completely revised and seem to work reliably for up to four vertices. Match time for manyprong events has been greatly reduced by improved logic in the match-steering routine ALEXB. Output formats have been changed to fit the standard CERN TC chain.

Doublets

A doublet facility has been introduced in track-match. All possible doublet matches are stored in a special control array. Found and accepted triplets are erased from this array. In case a full triplet solution cannot be found at a
vertex, fx. if a triplet is missing, a beam track not found or if charge is not conserved, then the doublet array is examined in order to find a high quality doublet to become part of the solution. Only one doublet track is allowed at each vertex.

**Redoing**

If a vertex contains a doublet REDO is called to try to find the missing track. The half digested data from all view-vertices are stored on the drum-file. If REDO is called, the relevant view-vertex is called in from this file. A prediction of angle and slope of the missing track is made by projecting the track from the two views where the track exists into the third view. Then a narrow path is laid around the predicted track position and the track is sought by fitting all digitizings within the path. If a new track is found it is checked and added to the track bank and the track match is entered once again.

**Timing**

The average time spent per event (3-4 groups) is 12 secs. on our UNIVAC 1106. Differential timing can be read below:

<table>
<thead>
<tr>
<th>Task</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEYORE, READIN, FIT</td>
<td>12%</td>
</tr>
<tr>
<td>HIST, PIGLET, FIT</td>
<td>27%</td>
</tr>
<tr>
<td>TRACK, HFALMP</td>
<td>31%</td>
</tr>
<tr>
<td>ELIM</td>
<td>5%</td>
</tr>
<tr>
<td>TIGGER, GORSE, HUNNY</td>
<td>6%</td>
</tr>
<tr>
<td>OWL, REDUCE</td>
<td>10%</td>
</tr>
<tr>
<td>MATCH</td>
<td>5%</td>
</tr>
<tr>
<td>REDO</td>
<td>4%</td>
</tr>
</tbody>
</table>

**Transmission and reject rates**

(Based on last 1400 3-4 groups processed)

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events accepted</td>
<td>91.6%</td>
</tr>
<tr>
<td>Events rejected (POOH)</td>
<td>8.4%</td>
</tr>
<tr>
<td>Category</td>
<td>Percentage</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>No track match:</td>
<td>3.0%</td>
</tr>
<tr>
<td>Not enough tracks:</td>
<td>2.9%</td>
</tr>
<tr>
<td>Charge not conserved:</td>
<td>0.7%</td>
</tr>
<tr>
<td>Beam track not accepted:</td>
<td>1.6%</td>
</tr>
<tr>
<td>Other rejects:</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td><strong>8.4%</strong></td>
</tr>
<tr>
<td>REDO called:</td>
<td>16.9%</td>
</tr>
<tr>
<td>REDO found missing track:</td>
<td>9.6%</td>
</tr>
<tr>
<td>REDO failed (remaining doublets):</td>
<td>7.3%</td>
</tr>
</tbody>
</table>
Three essential features characterise the 81 cm HBC pictures: which are actually undermeasurement on our machine.

1) The length of the tracks is rarely greater than 40 cm, so it was decided to increase the number of points on the tracks at small radius, by using small speed variations for the three first ramps (30, 40, 60) until 17, 9216 counts, than rise it as fast as possible.

2) Large variation in the ionization of minimum ionization tracks (9 - 13), brings large gaps without digitizations.

3) The background variation from one view to another is important. Usually 1000, 2000, 3000 are the number of digitizations on views 1, 2 and 3. So the percentage of useful digitizations is small.

According to remarks 1 and 2 the limit of the histogram region was largely reduced (1250 counts instead of 2000 currently used) and the gap function was increased until 35 (currently 10). More over the number of points necessary to accept a track as good is recalculated in each view as function of the number of digitizations in the histogram region. This number varies between 4 and 12.

Recovery system.

The percentage of good events for physics of our system (L.3.D. + filtering program) is now of the order of 70 to 80 % according to the quality of the roll. This is insufficient for our experiment so it is necessary either to remeasure 30 % of all events, or to imagine a recovery system. Such a system is under development. It consist of several stages of recovery.

1st stage.

Too much candidates are found by the filtering program and wrong tracks have been chosen. In this case a system of select cards is used to indicate to the program which tracks have to be taken in a second run of the event.
2\textsuperscript{nd} stage.

Very often tracks are only found in one view, and lost in the other ones because either too large gaps were present on it, or large confusions were present in the track region, or the track was underdigitized... Then with the same select card system, it is possible to indicate in which region of θ, and in which limit of θ, the track should be found. Than it is sufficient to built a road over all R and accept the track which agrees with what is expected.

3\textsuperscript{rd} stage.

The second level of recovery can be directly applied to each event by requiring that all tracks from view 1 should be found in view 2 and 3, and all tracks from view 2 should be present in view 3. Only tracks common to 2 views at least are kept for thresh-match. This should increase the percentage of 3 views tracks. For the moment this percentage is between 60 and 80 \% of all tracks.

4\textsuperscript{th} stage.

It is an extension of the third. Now if there are tracks found on view 3 (2) and which have not been found on view 2 or 1, a redo is done on the view where the track was not found. This procedure require the possibility to reach to the digitizings from all views of an event what is not easily possible with the normal tape system. An extension of memories for the program is necessary what can be obtained on our 6600 CDC either by writting all digitizings on disk and requiring a fast access to it or by dissociating the Pooh and thresh-match parts of the program.

For the moment only the 1\textsuperscript{st} stage of the system works, the other ones are under development.
1. **INTRODUCTION**

The LSD chain of programs has already measured about 300,000 events and is at present being used to measure a 1,500,000 events experiment from the CERN 2m HBC (K⁺ at 4.2 GeV/c).

One can say therefore that the programs have achieved production status.

2. **CALIBRATION**

Since the LSD has two independent coordinate systems, an x-y system and a polar system, one has to know exactly the mapping function of one onto the other. This is obtained by measuring a special calibration pattern on a glass plate containing crosses "visible" to the rotating slit. Digitizings on these crosses are identified in the R-θ system by histogramming and fitting.

The calibration program SCALP¹, computes values for the centres of crosses. Their transformation into the x-y system of the LSD is then obtained by fitting an analytic function.

To take account of the systematic distortions between the polar and cartesian systems, the calibration program outputs the fitted parameters and also the residuals for each cross after the fit.

All this information is used by the filtering program to convert into x-y the averaged digitizings kept on the acceptable tracks.

The systematic errors are reduced by averaging the calibration results from several spirals and they are randomized over an experiment by frequent calibrations.

3. **OFF-LINE PROCESSING**

In normal production, the measurement of a film on the LSD and its complete processing by the programs (filtering, track-match, geometry kinematics and decision) do not take longer than 60 hours.
At present these programs are grouped into two modules:
- 1 module POOH-MATCH-THRESH (filtering, track-match, geometry)
- 1 module GRIND-SLICE     (kinematics, decision)

which are done consecutively in the same job (fig. 1).

The input of the POOH-MATCH-THRESH program consists of:
- the digitizing tapes provided by the LSD on one hand
- title cards on the other

There is a double output:

a) a printed output (fig. 2) including a line per event with
- some scanning information (identification of the event, primary vertex, grid, topology)
- information concerning measurement (operator number, measurement date)
- a reminder of any errors encountered during the processing of the event with an indication of the program in which they have been detected
- counters giving:
  - the ordinal number of the event in relation to the start of the job
  - its position on the input tape
  - its position on the output tape
  - in case of trouble, the number of an error detected by the system and for which a recovery procedure is planned (passage to the next event).

It is possible to have a more explicit printed output, on paper or microfilm, by means of special title cards.

b) A binary output tape consisting of one record per event handled.

The structure of this record is very similar to that provided by the standard geometrical reconstruction program (THRESH) used at CERN. Only some information, which is useful for the statistical program, as well as two ionization words per track have been added to this standard structure.

This magnetic tape is then re-read, with new title cards, by the CRACE program (GRind And slice) which performed the kinematic study of the events, chooses in some cases between the various possible kinematic hypotheses and creates pre-DST (Data Summary Tape).
Alongside this pre-DST the GRACE program also provides:

- a printed output consisting of one line per event (similar to that provided by the POOH-MATCH-THRESH program and recalling the results of the kinematic hypothesen tried)
- binary cards (SURVEY cards) later used for providing statistics on the experiment in progress.

A more explicit printed output facilitating the identification later on of events which are ambiguous may be commanded by means of control cards.

Besides the 2 sets of programs used daily in normal production, there are statistical programs which are run regularly throughout an experiment.

One of them, the main purpose of which is to control measurements, operates on the basis of the POOH-MATCH-THRESH output tapes. Besides statistics per operator and per film, it also gives some distributions on the residues of the fiducial marks and tracks.

The other program, designed to provide complete statistics on the experiment in progress, operates on the basis of the SURVEY tapes regularly produced from the SURVEY cards given by the GRACE program.

All these programs are done on the CDC 6600.

The POOH-MATCH-MASS dependent THRESH program (with a 4K digitizing buffer) takes 45K of memory in its production version.

Observed execution times are about 2.5 sec/ev for single vertex events.

An overlay version, with debug facilities including (R-0) plots on paper or micro-film is used in test. This overlay version takes 35K of memory in the CDC 6600.

4. POOH FILTERING PROGRAM

The filtering program used at CERN is mainly based on the filtering part of Berkeley's program POOH 2) The track-match is the same as used for HPD minimum guidance digitizings.

4.1 Principle of the POOH program

The filtering program exploits the fact that the event tracks start from zero radius and are arcs of circles. If you examine a display graph of the polar data plotted in rectangular space, with the azimuth taken as the X-axis, and the radial coordinate as the Y-axis, you can see that the desired track points are colinear and extend down into the region of small radius (fig. 3). A histogram of the data in the region of small radius provides a powerful technique for localizing the desired track points.
Once a track is roughly determined in this way, very selective fitting criteria are sufficient to isolate the remaining length of the track. This procedure is, however, inadequate in the case of very short tracks. In this case the operator who is using the LSD provides some additional data points, called "crutch points", which help the filtering program to find the particular track. The operator's help is also solicited by the program in certain cases of confusion or in order to be able to reconstruct with accuracy certain physical points.

On the CERN LSD, the operator has 3 buttons at his disposal, which enable him to measure special points on certain tracks. These points are measured in the (x,y)-system used for measuring the vertex and the fiducial marks.

A CPT button, which can be used in two distinct ways:

- either to help the program when there is considerable confusion. The point will then be taken as far as possible along the track after the area of confusion;
- or if a very short curved track is likely not to be sufficiently digitized in order to be able to filtered (but for which one would nevertheless like to know the curvature) as an artificial measurement of the track. In this case, the operator would measure not one but two such points on the track and in the histogramming region (≈ 5.5mm in film plane). The measurement of these points will then be re-requested automatically by the ASTERIX program (on line program) on the other views of the same vertex. From these two points and from the vertex, you then have an indication of the curvature of the track even if it is not sufficiently digitized.

An STP button, which is designed to measure the break-points as well as the secondary vertices in the case of V charged events. In this case it is used only during the measurement of the primary vertex, since once this vertex has been measured, it forms the break-point of the connecting tracks on the other vertices.

An END button, which is a cut-off (to stop the track following). It is less used than the above buttons and is mainly required in the case of secondary or charged exchange interactions.

4.2 Main stage in POOH

The main stages in the processing of a "view-vertex" in POOH are the following:

a) Reading, decoding and test for the validity of the information provided for this view-vertex.
After this phase in the processing, the digitizations retained are stored in the "blank COMMON" at the rate of one word (60 bits) per digitizing according to the following format.

<table>
<thead>
<tr>
<th>6 bits</th>
<th>15 bits</th>
<th>16 bits</th>
<th>5 bits</th>
<th>1</th>
<th>17 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0</td>
<td>R</td>
<td>Δθ/2</td>
<td>PH</td>
<td>P</td>
<td>W</td>
</tr>
<tr>
<td>59</td>
<td>53</td>
<td>38</td>
<td>22</td>
<td>17</td>
<td>16</td>
</tr>
</tbody>
</table>

A series of very fast small functions, written in machine language, then provide access to any part of the information contained in a digitizing through its location address in the "blank COMMON". In this way one is able to restrict to a minimum the size of the program buffers since you only work with addresses which can be packed at a rate of several per word without considerably increasing the programs run-time.

b) **Track Initialization**

This initialization, as mentioned above, is done by a system of variable-slope histograms relating only to a small part of the digitizings around the measured vertex.

When an interval for a given slope is found which contains sufficient points in order to be able to forecast the presence of a track, we attempt to fit to these points an equation of the following form:

\[ \theta = \theta_o + \alpha R + \beta R + \gamma R^3 \]  
(equation of a circle in polar coordinates)

where

- \( \theta_o \) represents the angle made with the \( \theta \)-axis by the tangent to the track at the vertex
- \( \alpha \) is a direct function of the track curvature
- \( \beta \) is a measurement of the distance from the track to the vertex
- \( \gamma \) is a function of \( \alpha \) (\( \gamma = -1/3 \, \alpha^3 \))

This fit linear in \( \theta_o \), \( \alpha \), \( \beta \), \( \gamma \) is done by a least squares method. Validity tests relating to the RMS of the fit, the value of the \( \beta \) term representing the distance at which the candidate track would pass from the vertex, the maximum deviation of a track point in relation to this fit etc. are clearly performed before accepting the feasibility of such a candidate track.

c) before carrying out the track following, we first try to eliminate certain candidate tracks which could have been detected several times. The same track may in fact have been detected several times for consecutive slopes and intervals.

d) Suitable track candidates are then followed out from the vertex.

Each time a new point is added to a track, the previous fit of this track is re-adjusted in order to allow for the information provided by this new point. The process continues until no more points can be added to the track being investigated.
We then try to match the special points measured by the operator to the tracks already found.

If there are special points left which could not be matched to the tracks already found, we try to find the tracks passing through these points by again using a system of variable-slope histograms. These histograms are applied locally around the special point investigated. The track candidates first initialized are then followed towards the vertex, then from the vertex towards the special point and if necessary beyond by the same routines as those used in the above stages.

Refiltering of all or part of the view-vertex if the number of tracks found at this processing level is lower than the number of tracks expected according to the topology.

Master points creation

The acceptable digitizings on tracks are averaged to give a maximum of 12 master points. These points are then converted into (x, y) by applying the calibration parameters and residuals. Before setting-up the master points of a track, any suspect digitizings are first suppressed (deviations, pulse height or width too far from the normal). These investigations are carried out locally in order to take into account the normal development of the information along the track.

It is at this processing level that any short curved tracks, measured by the operator with 2 CPT in the histogram region (and not sufficiently digitized for filtering), are artificially re-created (in x, y) and an ionization information is added to each "long track".

Before being transmitted to the next part of the program, the tracks are first rearranged according to the quality criterion.

Tracks to which a special point measured by the operator has been attached, are placed at the top of the tracks retained.

For the others, quality calculated is a function

- of its number of points;
- of the RMS of the fit;
- of the distance at which the track passes the vertex.

\[ Q = \omega_1 \cdot \text{RMS} + \beta^2 + 2 \cdot n \]

where:

- \( \omega_1 \) is a weight applied to the RMS of the fit and given in the titles
- \( \beta \) is the \( \beta \) of the fit, corrected in order to allow for the \( X_0, Y_0 \) parameters of the calibration, and normalized in track width (divided by a \( R \cdot \Delta \theta \) product).
- \( n \) is the number of track points
- \( \omega_2 \) is a weight given in the titles
4.3 Main features of the program

4.3.1 Tracks Initialization

A method of variable-slope histograms is used to initialize both the tracks which leave the vertex and those which are capable of passing through a special point measured by the operator.

The calling sequence for the histogramming routines must specify:

- The limits in $R$ (RREG, REND) and $\theta$ (TBEG, TEND) of the digitizings to be histogrammed.
- The origin in $R$ of the axis on which the digitizings for a given slope are projected.
- The maximum slope to be histogrammed. This number depends on the curvature of the minimum track momentum for a given experiment.
- The number of $\theta$ variation intervals to be studied for a given slope.
- The width of a $\theta$ variation interval.
- The number of points which must fall within an interval for this interval to be considered capable of containing a track.

In order to construct the histograms and to analyse them, we use a set of four routines:

- An initialization routine which subjects the digitization to be histogrammed to certain preliminary transformations intended to speed-up the processing in the routine which constructs and analyses the histograms.
- A histogramming routine for locating the track candidates.
- An elimination routine designed to avoid certain useless fits (local maxima procedures).
- A routine designed to locate the digitizings of the candidates retained and then to try on them a linear fit of the equation $\theta = \theta_0 + aR + b/R + cR^3$ by a least squares method.

a) Preparation of the histograms

The initialization routine begins by searching for the indices of the first and last digitizations included in the area to be histogrammed. It then defines the initial slope to be histogrammed and the slope variation to be used between the various histograms.

This slope-variation is selected as a constant in order to provide better overlapping between various slopes investigated.

$$\tan (a + \Delta a) = \tan a + \Delta \tan \frac{\Delta a}{\text{constant}}$$

For example, consider the initialization of tracks near the vertex (fig. 4).

In this case we study all the digitizings with a radius between the 2 limits $R_1$ and $R_2$ and these digitizings are projected on the axis $R = R_2'$. 
The lower limit of this R variation zone is not selected at the origin of the R in order to take into account the fact that the information provided by the LSD is inaccurate near the vertex (pulse centers poorly defined).

If in the \((R, \theta)\) plane we consider the projection at an angle \(\alpha\) (in relation to the vertical) of a point \(M(R, \theta)\) on an axis \(R = R_2\), the distance \(AB\) of this projection to an axis \(\theta = \theta_0\) is given by:

\[
AB = (\theta - \theta_0) - CM = (\theta - \theta_0) + (R - R_2) \tan \alpha
\]

The projection \(AB\), for an angle \((\alpha + \Delta \alpha)\) will be given by:

\[
AB = (\theta - \theta_0) + (R - R_2) (\tan \alpha + \tan \Delta \alpha)
\]

or

\[
AB = \frac{AB + (R - R_2) \tan \Delta \alpha}{\text{constant}}
\]

As the slope variation \(\tan \Delta \alpha\) is constant, it can be seen that for a given digitizing we move from one projection to another by adding a simple constant:

\[
(R - R_2) \tan \Delta \alpha.
\]

Therefore, in the initialization routine, the projection of all the digitizings following a given slope may be calculated and the histogramming routine will then only have simply additions to make in order to move from one slope to another.

If you wish to speed up this routine even more, it is possible to avoid negative interval numbers and to foresee the case of tracks consisting of two parts with \(\theta\) separated by \(2\pi\) by duplicating the digitizings with a \(\theta\) between 0 and \(2 \pi \) \((R_2 - R_1) \tan \alpha_{\text{max}}\) (hatched area A copied into hatched area B). This is done by adding \(2\pi\) to the \(\theta\) of these digitizings.

The origin for the calculation of the interval numbers will then be taken according to the axis \(\theta_0 = (R_2 - R_1) \tan \alpha_{\text{max}}\) instead of \(\theta = 0\) and we shall be interested only in the interval numbers in the range \(i_1 = \frac{2(R_2 - R_1) \tan \alpha_{\text{max}} + 1}{\omega}\) and \(i_2 = i_1 + n\) instead of \([1, n]\)

where
- \(\omega\) is the width of an interval
- \(n\) is the number of intervals between 0 and \(2\pi\)

The histogramming routine will then only have to test the validity of the interval numbers calculated (which can never be negative) provided that a slightly larger histogram buffer size is included:

\[
n + \frac{3(R_2 - R_1) \tan \alpha_{\text{max}}}{\omega}\]

instead of \(n\)
At each digitizing i of the region to be histogrammed, the histogram preparation routine therefore matches 2 quantities:

\[
X_i = \frac{(R_i - R_2)}{\omega} \text{tg } \Delta \alpha = \text{constant}
\]

\[
Y_i = \frac{(a_i - a_0) + (R_i - R_2) \text{tg } (-a_{\text{max}})}{\omega} + 1
\]

\(y(i)\) provides directly the number of the interval containing the projection of the digitizing i following the angle \(-a_{\text{max}}\).

The histogramming routine will work on these quantities \(x(i), y(i)\) rather than on the digitizings themselves. The digitizing addresses are retained in the least significant part of the \(x(i)\).

b) Histogramming routine

In this form the computation of the histogram is very simple and very fast since it no longer requires any test on the indices containing the point projections and since for a given point these indices may be deduced from one another (when the slope has changed) by simple addition.

For each slope the histogramming routines does two loops:

- One over the digitizings which determine the number of points falling within each of the histogrammed intervals and prepares the projection for the next slope

\[
\text{DO 10 I = 1, NDIG loop on the digitizings}
\]

\[
J = Y(I) J = \text{number of the interval into which the digitizing I for the given slope is projected}
\]

\[
\text{KPT(J) = KPT(J) + 1 Counter of the number of points falling within the interval J}
\]

\[
10 Y(I) = Y(I) + X(I) \text{Preparation of the projections for the next slope.}
\]

- The other loop, on the intervals to be investigated \((i_1 \text{ to } i_2)\) sets up, for each interval containing a sufficient number of points, a word containing:

  - the ISL number of the given slope
  - the J index of the interval concerned
  - the number KPT(J) of points found in this interval.

These 3 pieces of information are distributed in the word in the following way:

<table>
<thead>
<tr>
<th>12 bits</th>
<th>12 bits</th>
<th>12 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>KPT(J)</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISL</td>
</tr>
</tbody>
</table>
Due to the extremely concise nature of the content of these 2 loops, they may be written in machine language in a number of instructions which is smaller than the size of the stack of the CDC 6600. In this way an extremely fast histogramming routine is obtained and the computing time required for this track initialization procedure is correspondingly short.

c) **Elimination of duplicate candidates**

After the above stage we are left with a set of track candidates including several which represent the same track detected for similar slopes and intervals.

If we express, in a rectangular system, the contents of the intervals investigated, versus the histogram slopes, we can see the possibility of limiting, by simple study of the local maxima, the number of these candidates to be sent to the fit procedure (fig. 5).

d) **Final fit**

The constituent digitizings for the candidates left at the end of the above stage are found by mean of a routine in machine language and a linear fit of the equation

$$\theta = \theta_0 + aR + b/R + cR^2$$

is tried on them by a least squares method.

### 4.3.2 Rescue

We can have a refiltering of all or part of a "view-vertex" if the number of tracks found is lower than the number of tracks expected according to the topology.

Certain cases may occur requiring additional processing of this type:

a) Certain special points could not be matched to the tracks found and new tracks could not be initialized from these points. In this case, we repeat the track initialization procedure, after considerably enlarging certain tolerances. In fact, the recovery of tracks passing through these points is essential for the processing since we know a priori that such tracks do pass through these points and that the event could therefore not be complete if they were not recovered.

b) The beam, in the case of filtering of the event primary vertex, has not been found or has been poorly detected. For a given experiment, the beam is a particular track with very well defined and predictable filtering characteristics ($\theta_0$ and $a$ parameters of the fit), which makes it easy to recognize.

In fact, the $a$ parameter (representing the track curvature) is quite stable provided that the beam is sufficiently long for the fit made on its digitizings to be sufficiently well defined. (For experiment 42, $K^- p$ at 4.2 GeV/c now being measured at CERN a is of the order of $-0.05$).
It's localization in the (R,θ) diagram may also be determined with quite good accuracy as a function of the distance between the vertex measured and a given fiducial mark.

In fact, if the distribution of theθo of the beams from an experiment are expressed in as a function of the distances Xv-Xp between the vertex measurements and a given fiducial mark, an appreciably linear distribution is obtained (fig. 6).

This rough linear approximation

θo = m(Xv - Xp) + h

is sufficient to define a fairly narrow window to contain the beam and thus limit the cost o of any refiltering of this beam.

c) The number of secondary tracks filtered is lower than the number of tracks expected from the topology. The view-vertex is then fully refiltered with new parameters and enlarged tolerances.

Unlike cases a) and b) which are local refiltering procedures, the latter case corresponds to overall refiltering. Although it is generally very powerful when required, it has the disadvantage of not being controllable. In fact, it is performed taking into account only the information provided for that view-vertex. A procedure is now being developed where tracks found on the other views of the same vertex will be taken into account. This will be done on the CDC 7600. The great possibilities offered by the LCM (Large Core Memory) will then be used to retain, throughout the processing of an event, all the digitings and tracks found on the various views and any refiltering will then be made easier and, above all, controlled.

4.3.3. Ionization Information

An ionization information is attached to each "long track" in a form of a word with the following structure:

<table>
<thead>
<tr>
<th>15 bits</th>
<th>15 bits</th>
<th>15 bits</th>
<th>15 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>σōPH₂</td>
<td>PH₂</td>
<td>σōPH₁</td>
<td>PH₁</td>
</tr>
</tbody>
</table>

where:

\[ PH₁ = 4. + \sum_{i=1}^{n} PH₁ \]

\[ σōPH₁ = 4 \sqrt{\sum_{i=1}^{n} PH₁^2 - (\sum_{i=1}^{n} PH₁)^2/n} \]

\[ n-1 \]
Computations are done with all the track digitizings with a radius of between 500 and 3,500 l.c \( (1 \, l.c = 2.86 \mu) \)
and:

\[ \Phi_2 \text{ and } \sigma_{\Phi_2} \]
are computed in the same way but this time with all the digitizings for which:

\[
\begin{cases}
500 \leq R_i \leq 9500 \, l.c \\
|\xi| < 0.2
\end{cases}
\]

(\( \xi \) = angle intersection of the slit with the track)

If \( \xi \) is expressed as a function of the track fit parameters in the system \((R, \theta)\), we have:

\[ \tan \xi = (\theta_0 - \theta_1) + 2\theta/R_i - 2\gamma R_i^3 \]

in fact, taking an equation curve \( \theta = f(R) \), the angle made by the tangent at a point on this curve with a radial direction passing through this point is given by:

\[ \tan \xi = -R \frac{d\theta}{dR} \]

Taking the track fit formula used in POOH,

\[ \theta_1 = \theta_0 + aR_1 + \beta/R_i + \gamma R_i^3 \quad (1) \]

we then obtain:

\[ \tan \xi = -R_1 \left[ a - \frac{\beta}{R_i^2} + 3\gamma R_i^2 \right] \]

or:

\[ \tan \xi = -aR_1 + \frac{\beta}{R_i} - 3\gamma R_i^3 \]

hence, by substituting \( aR_1 \) by its expression obtained from equation (1).

\[ \tan \xi = (\theta_0 - \theta_1) + 2\theta/R_i - 2\gamma R_i^3 \]

4.3.4 Master Points

A maximum of 12 master points per track is computed in \((R, \theta)\) on each of the tracks remaining at the end of POOH.

If \( \theta_0, a, \beta \) et \( \gamma \) are the parameters of the best fit,

\[ \theta(R) = \theta_0 + aR + \beta/R + \gamma R^3 \]
obtained on all the points of a track, we then define the coordinates of a "master point" as:

\[ R_{\text{avg}} = \frac{\sum_{i=1}^{n} R_i}{n} \]
\[ \theta_{\text{avg}} = F(R_{\text{avg}}) + \theta' \]

where:
- \( n \) is the number of points averaged over the region concerned (each region has the same number of periscope revolutions except for the last which consists only of the last point found on the track)
- \( F(R) = aR + \frac{\theta}{R} + \gamma R^3 \)
- \( \theta' \) is the track's initial angle which minimizes the \( x^2 \) for these points

\[ x^2 = \sum_{i=1}^{n} \frac{(R_i \Delta \theta_i)^2}{R_i} \]
\[ x^2 = \sum_{i=1}^{n} \frac{R_i^2 \left( \theta_i - (F(R_i) + \theta') \right)^2}{R_i} \]
\[ \frac{dx^2}{d\theta'} = -2 \sum_{i=1}^{n} \frac{R_i \left( \theta_i - (F(R_i) + \theta') \right)}{R_i} \]
\[ \frac{dx^2}{d\theta'} = 0 \Rightarrow \theta' = \frac{\sum_{i=1}^{n} R_i^2 \left( \theta_i - F(R_i) \right)}{\sum_{i=1}^{n} R_i^2} \] (fig. 7)

5. CURRENT DEVELOPMENT

The set of programs currently used on the CDC 6600 for handling the events measured on the LSD is being re-written in order to take into account, both the new opportunities offered by the CDC 7600 (particularly the large core memory) and those provided by the new programming system HYDRA \(^3,4\) developed at CERN.

The main objective of HYDRA is to provide production programs which can be adapted to the user requirements to the experiment and to the machine configuration including software, without significant overhead. To this end, programs are made up of modules (called processors) which communicate with each other through a simple interface expressed in terms of data blocks set up in a dynamic storage. Processors are easily exchangeable units to allow for alternatives. Processors are kept free to all possible except from non-calculational tasks such as input-output, error recovery, memory management, etc. A set of "Hydra system routines" is provided to look after such tasks.
REFERENCES

1) E. Eichmann, SCALP - The Spiral Reader Calibration Program. CERN/D.Ph.II/PROG 69-2.

2) G. Lynch et al. (Berkeley) POOH - Scrapbook.

3) HYDRA - Modular Programs for Bubble Chamber Data Analysis


FIGURE CAPTIONS

Fig. 1 Block diagram of the LSD program chain.

Fig. 2 Printed output of the POOH-MATCH-THRESH program (in production mode).

Fig. 3 Typical spiral reader digitizing for a 2-prong $\nu^0$ event (microfilm output from POOH).
   Fig. 3a - Primary vertex with the 3 event tracks found by POOH
   Fig. 3b - Secondary vertex with the 2 $\nu^0$ tracks found by POOH

Fig. 4 Explanation of the tracks initialization procedure when used near the vertex.

Fig. 5 Example of elimination of duplicate tracks found by histogramming, by a local maxima procedure.

Fig. 6 Distribution of the $\theta_v$ of the beams as a function of the distance $x_v - x_F$ between the vertex measurements and a given fiducial mark, for the experiment 42 (K$^-$p at 4.2 GeV/c).

Fig. 7a Filtering of the 2 tracks of a $\nu^0$.

Fig. 7b Corresponding digitization, and master points calculated by POOH.
Fig. 1

Fig. 2
**EXP 42 (K^+ p 4.2 GeV/c)**

\[ \theta(\text{beam}) = m(X_y - X_f) + h \]

\[ m = 0.068 \]
\[ h = 77560. \]

Fig. 6
LINES: A COMPUTER PROGRAMME FOR THE ANALYSIS OF SPIRAL READER MEASUREMENTS OF STRAIGHT LINES


Introduction

The purpose of the program LINES is to analyse data from straight line measurements from a spiral reader. By studying the residuals to a fitted line important information about distortions and other systematic effects can be obtained. The residuals might also be useful for the correction of event measurements since they contain detailed information about the distortion in narrow radial intervals. The programme also offers the possibility of making circle fits. The distortions on the Danish-Swedish Spiral Reader are however not fully described by simple circles which can be shown with a statistical significance test of the residuals from such a fit.

The measurement procedure

The measurement is performed in almost the same way as a chicken walk measurement. The glass plate with the engraved lines is placed in the position of the lower clamping plate. The orientation of the plate is such that the lines go in the direction of the X and Y axes respectively. The spiral is centered on the intersection between the lines, and the speed of the periscope is kept constant at 110 counts/rev. The operator puts four crutch points, two on each side of the vertex, on either the line in the X-direction or on the one in the Y-direction. This makes it possible to study how well one can expect that a crutch point falls on a track in a real event measurement.

Filtering of the data

The first step in the filtering procedure is to select digitizings in a θ-interval that is big enough to ensure that all digitizings belonging to the line fall inside the interval but narrow enough to prohibit too many spurious digitizings to be selected. The programme then fits a straight line \( y = ax + b \) to the selected points the coordinates of which have been transformed from \( R \) and \( θ \) to \( X \) and \( Y \). Points with a residual of 15 counts or more are removed and the line is refitted until all points fall within the limits. Normally only two or three points out of 160 are thrown away. Because of the difficulty to fit a line in the direction of the Y-axis where \( a \) becomes infinity, the fits are performed in a system that has been rotated 45° with respect to the SR-system.
Least square fits of the lines taken two by two

While in the first fit procedure each of the four lines was treated separately they are in the final fit combined two by two i.e. the forward and backward lines in the X-direction and the left and right going lines in the Y-direction are fitted together. The advantage of this joint fit is that also e.g. slit offset effects can be studied and also included in the residual table. The total number of points along such a line is about 350 and standard deviation before any correction is applied is about 2 xy counts.

Residual plots

One of the main reasons for starting the line measurements and for putting effort into the program LINES was that we felt that a straight line is an object that resembles a beam-track more than e.g. a series of crosses. By studying the distortion of a straight line important knowledge about the distortion of the beam tracks\(^{(1)}\), could be gained. To make these studies possible and fruitful it is necessary to extract the significant information and present it in such a form that it is easy to see what is systematic effects and what is random fluctuations.

We have found that a plot on the line printer of the mean residual over an interval of 500 r-counts i.e. 4-5 points gives a good picture of the systematic effects, an example is given in Fig. 1. The effect of the averaging is that random fluctuations become less important so that the systematic effects can be seen more clearly. The interval is small enough to make variations of the distortion inside the interval unimportant and all important details can thus be displayed in such a plot. The advantages of this method for studying distortions compared to the chicken walk one are obvious. In the chicken walk method an average is taken over an interval of 2000 r-counts which is so big that important details will be lost. It is for instance impossible to describe the rather sharp hook in a region from 250-2250 r-counts by measuring a cross the center of which is at 2500 r-counts and the length of which is 2100 r-counts. That the residuals from LINES when applied to real measurements give good results for \( \frac{1}{\rho} \) is shows in the report on calibration\(^{(1)}\).

Correction of measurements by the use of residuals from LINES

The residuals from LINES do of course not contain any information about radial distortions. This is not a serious disadvantage since the accuracy in the radial direction is of almost no importance in real event measurements compared to the importance of having good accuracy in the \( \theta \)-direction. Because of this the residuals from LINES are applied as corrections not on the transformed X-Y co-ordinates, which is customary when applying
the chicken walk residuals from SCALP\(^{(2)}\), but on the raw \( \theta \) value. The residual value \( \Delta Y \) corresponding to the actual \( R \)-value is calculated by linear interpolation between the values on each side and a small angle \( \Delta \theta = \Delta Y / R \) is added to or subtracted from the raw \( \theta \) value, depending on whether or not the point is in the forward or backward cone. This method has turned out to give good results both for other measurements on the straight lines themselves than those upon which the correction table was based and for beam track measurements at 19 GeV/c. A disadvantage with this method is that it can only be used in the forward and backward directions and in the directions perpendicular to these. This difficulty might be overcome by the use of a plate with several lines in a star pattern or if the straight line could be rotated in its holder.

References


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TRACK COMPARISON OF HPD AND SPIRAL READER MEASUREMENTS.

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Before starting the first production run of the Spiral Reader Saab (1) at Saclay a test run was made to get a better understanding of this system and as far as possible to find out its shortcomings by measuring bubble chamber film.

A sample of about 1000 2-prong events produced by a beam of 4 GeV/c negative pions interacting in the CERN 2-meter hydrogen bubble chamber, has been processed through the HPD road guidance and the SRS systems. In order to attempt this comparison a set of 857 events was selected according to the following requirements: a/ for each system the best optical titles and calibration parameters have been used b/ for each event the three tracks had to be accurately (2) reconstructed by the geometry program: mass dependent THRESH.

Here we restrict ourselves to discussing the geometrical parameters of the negative incident (3) track, namely the reciprocal of the radius 1/ρ, the dip-angle λ and the azimuthal-angle θ.

Before comparing the precision it is very important to make sure that there are no systematic differences in the track parameters.

A two-dimensional plot of the azimuthal angle θ is shown in Fig. 1. The X-axis represents the HPD measurements and the Y-axis those of the SRS. If both measurements are identical the points should fall on either side of the 45° solid line. A similar result is observed in the plot of 1/ρ in Fig. 2 with some discrepancies which will be discussed below. The 1/ρ distribution for the two systems is shown in Fig. 3. It can be seen that a/ the peaks are centered at the same value b/ the SRS peak is roughly
thinner and more symmetrical than this of the HPD c/ the distribution tails are wider for the HPD.

The scatter plot of Fig. 4 (1/\rho_{HPD} - 1/\rho_{SRS} VS 1/\rho_{SRS}) does not show any correlation between the radius difference and the SRS radius. On the other hand one can observe in Fig. 5 a striking correlation between 1/\rho_{HPD} - 1/\rho_{SRS} and 1/\rho_{HPD} . Indeed the positive and negative tails of the 1/\rho_{HPD} - 1/\rho_{SRS} distribution are respectively associated with the high and low values of the 1/\rho_{HPD} distribution. This means that the HPD system involves a distortion for some tracks which are correctly measured by SRS. It has been checked that these tracks had large internal errors : \Delta \rho, \Delta \lambda, \Delta \phi .

The shape of the 1/\rho_{HPD} - 1/\rho_{SRS} distribution is shown in Fig. 6. The mean value is compatible with zero as expected and the step size being \(3\times10^{-6}\) cm\(^{-1}\) which is roughly equivalent to a 10 MeV/c momentum, this yields a FWHM of about 60 MeV/c momentum.

The distributions of the angular parameters \(\lambda\) and \(\phi\) are shown in Figs. 7 and 8. They are rather identical for SRS and HPD. Instead of the rough azimuthal angle (in Fig. 2 a very similar shape for both systems was seen) the \(\phi_0\) angle which is the \(\phi\) angle at the entry of the bubble chamber has been plotted.

In order to assess the measurement quality it is useful to study the internal errors. This error is calculated by the least squares fitting method of the geometry program and takes into account every type of error: optical, measurement, chamber and film distortions, multiple scattering, etc...

But everything else being equal the comparison of internal errors is meaningful for both systems. The \(\Delta \rho, \Delta \lambda, \Delta \phi\) distributions are shown in Figs. 9, 10, 11, respectively. They share common features: for every internal error, the most likely SRS value is higher than the HPD one and the tail of every distribution is wider for the HPD than for the SRS.

The comparison of track lengths is shown in the scatter plot of Fig. 12. The X-axis gives the lengths of the HPD system, the Y-axis those of the SRS system and the 45° solid line represents equal lengths. It turns out that there
are two clouds of points. The first one gives the upper limit of track length which can be measured in the CERN 2-meter chamber with the SRS. This value is roughly 68 cm in the middle plane of the chamber. The second one which is far above the solid line means that on the average the SRS measures longer tracks than the HPD. Indeed in the HPD road guidance system there is no digitizing beyond the last premeasured point on the track.

The usual way of checking the measurement precision is to study the track average residual. This is the RMS deviation of the measured points from the projection of the fitted ones on the film plane. The scatter diagram of Fig. 13 gives the result. The HPD values are given by the X-axis and the SRS one by the Y-axis. It is obvious that the density of points is more crowded above than below the 45° line. The projection on the two axes are shown in Fig. 14. The mean values of the residue distributions are 1.5μ and 2.5μ for HPD and SRS respectively, and there is a significant overflow in the HPD distribution.

Another way of comparing the precision is to look at the relative internal error distribution Δl/l_0/l which is shown in Fig. 15 for both systems. The population of points is slightly more to the left of the 45° solid line, and this result is obviously in agreement with the previous one, since the internal error is related to the residue.

According to the previous results, this conclusion can be drawn: the HPD measurements seem to be more precise than those of the SRS. But this statement must be qualified by the following comments. In both systems the tracks are reconstructed in the geometry program by using twelve master points. It is worth pointing out that those averaged points are computed, for instance in a production run for a 70 cm track, with about 60 SRS and 600 HPD rough digitizings. Besides it was previously shown that about half of the events had measured lengths which were between 70 and 100 cm in HPD and which were limited to less than 70 cm in SRS. Moreover it is well known that the error in momentum of a track has two components arising from a/multiple coulomb scattering b/mea-
suring process. For a given momentum the first one increases with a decreasing number of points while the second one decreases with an increasing length. As a result it could be misleading to readily assert that the HPD measurements are really much more precise compared to those of the SRS.

(1) Hereafter referred to as SRS.
(2) Without any kind of THRESH errors.
(3) Comparing the positive and negative secondary tracks give quite similar results.
Fig. 3
Fig. 4

Fig. 5
INCIDENT TRACKS: 857 events

underflow = 26
overflow = 21

$\frac{1}{\rho_{HPD}} - \frac{1}{\rho_{SRS}}$

Fig. 6
Fig. 7

Fig. 8
Fig. 9

Δ (1/ρ)_HPD  overflow = 68
Δ (1/ρ)_SRS  overflow = 33

Fig. 10

INCIDENT TRACKS 857 events

λ_SRS  underflow = 10  overflow = 6
λ_HP  underflow = 14  overflow = 11
INCIDENT TRACKS  857 events

Δλ_{SRS}  overflow = II
Δλ_{HPD}  overflow = 45

Fig. 11
1. **Introduction**

   About 4000 events of the type $p^+ p \rightarrow 2$ and 4 prongs, at rest were selected according to usual selection rules involving: a restricted fiducial volume allowing sufficient track length, not too many incident tracks, no black spots on picture, good Brenner marks. A special criterion rejected events with a visible kink on secondaries, nevertheless some of them have shown up in the process of track following, which were undetected by eye.

   The films involved were the 35 mm wide of the 80 cm Saclay bubble chamber. They were old and have been used so many times on several devices that the whole run was plagued with heavy scratches making the digitization quite uneasy; very often long scratches generated fake straight tracks.

   Though the measurement was made on about 2000 two prongs and 2000 four prongs events, only the last ones which gave appreciable number of 4 and 1 constraint fit were fully processed and the results presented will be restricted to these ones.

2. **Parameters Used for Digitization**

   - Least count in $R$ and $\theta$ are standard
     
     \[ \Delta R = 2.85 \mu \text{ on film} \]
     \[ \Delta \theta = 48.5 \times 10^{-6} \text{ rad.} \]

   - Spiral increment.

   The tracks being rather short: on the average 14 mm on film, the spiral had a slow step at the center, fast on the outside. The curve below display the ($R$, $\Delta R$/turn) used.
Total number of revolution by spiral was 110 (6.5 sec for a complete sweep) but useful points were on the average 50/tracks.

- Slit used was 320 x 18 μ on film - meaning ≈ 5 bubbles in the slit for a minimum ionizing particle parallel to the glasses.

- Fiducials marks were faint and they usually required a manual measurement - residual on fiducials after adjustment were about 6 μ on the film.

- Distortion due to film transport were carefully checked with film transport operating normally, or without tension. A stretch of about 0.3 °/° was observed along the axis of the film but no differential effect (transverse/longitudinal) was detected within the accuracy of the stage.

- The calibration used a small grid of 51 crosses. The full correction with 5 terms in polynomial expansion of distortion and an interpolation map for residuals was applied although it has been shown later that no correction at all give approximately the same results: the dispersion averaged 2 μ, maximum 4 μ on a reconstructed straight line.

3. CHECK OF THE APPARATUS

Here we stand from a physicist's joint of view, eager the get precise measurement within the limits needed by the experiment, reliability and stability of the apparatus in time. Systematics errors if exist should be well known as to be taken care of in the later stage of exploitation.

- Stability:

The check of stability has been done on the calibration parameters. Calibration were frequent, 1/day at the beginning, later it was found that 1/3 day were sufficient. Fig. 1 display some of the main parameters but at longer intervals. But for some of them subject to mechanical readjustment (X₀, Y₀, R₀) they all show up very stable.

- Detection ability:

Stopping p have the nice feature that they give tracks in flat distribution in all direction of space, thus providing a nice way to check the ability of the apparatus to have a uniform detection probability. Although this last point cannot be disconnected from the performances of the geometry program behind.

In Fig. II is displayed a (φ, sinλ) scatter plot with both φ and sinλ projection for secondary tracks. Both distribution should normally be flat.

Zone A is slightly overcrowded showing an excces of unrecognized beam tracks, confused with secondary ones. This is an important point for this experiment that the beam is so poorly defined in direction, that automatic finding has high failure. Otherwise sinλ histogram exhibits a small depletion on very forward (backward) tracks, sinλ ≈ ± 1. This is
a common feature due to both shortness of the projection of these tracks and difficulty for geometrical reconstruction to converge.

- Precision.

Precision has finally been tested on projected residus of tracks after geometrical reconstruction.

To stay in agreement with H.P.D. reconstruction, the mass dependent THRESH was not used. Hence with very low energy tracks, ranging from 200 to 800 MeV/c, systematic errors may appear, but they must hopefully be the same in both cases.

Fig. III display a scatter plot of average residuals, $\sigma$, as a function of curvature $C$. With no mass dependent helix fit the dispersion normally increase with $C$. The average 6 $\mu$ residual compete rather well with conventional hand measurement - it is only slightly over the 5 $\mu$ obtained with H.P.D.

In Fig. IV a scatter plot of residual $\sigma$ as a function of $\sin\lambda$ is shown. There is no significant correlation between $\sigma$ and $\sin\lambda$, but for the region $\sin\lambda$ close to 0, where some unidentified beam track are introduced among secondaries, and such stopping track are much farther from the circular helix than other ones.

- Rejection rate:

Up to the geometrical reconstruction, the rejection rate appears to be 22%. This rate is defined as the ratio of events where at least one track is missing, over total events processed. This provides in fact a lower limit for rejection rate - indeed tracks can be mismatched or wrongly associated with vertex, making the measurement useless.

If rejection rate includes all rejects, up to the output of kinematics, where all unsuccessful physical hypothesis lead to remeasurement, than we raise the rejection rate up to 33%. Same events on H.P.D. with premeasurement have given a 35% rejection rate, thus making the efficiencies comparable.

4. DIRECT COMPARISON WITH H.P.D. MEASUREMENT

- Geometry level.

A track to track comparison is made on a limited number of tracks, mainly due to the difficulty to establish the real one to one correspondance between tracks which are labeled in different order.

The following serie of figures show the result of comparison.

Fig. V : scatter plot of curvature difference $(C_{HPD} - C_{LSD})$ as a function of H.P.D curvature $C_{HPD}$. The mean relative external error is about 2.5%, pictured as the slopy lines - "normal" tracks, shown as dots are normally distributed within these errors. Crosses correspond to tracks of widely different measured length, where the 2.5% definition no longer holds.
Fig. VI: Scatter plot of dip angle difference \( (\lambda_{HPD} - \lambda_{LSD}) \) as a function of \( \lambda_{HPD} \). Here again the distribution of differences agrees rather well with the average external error of \( 8.10^{-3} \) rad.

Fig. VII: Scatter plot of azimuthal angle difference \( (\phi_{HPD} - \phi_{LSD}) \) as a function of \( \phi_{HPD} \).

The distribution of differences is compatible with the external estimated error \( 7.10^{-3} \) rad. nevertheless the centre of the distribution shows a systematic display of about \( 4.10^{-3} \) rad.

A more careful examination shows that the shift is mainly due to the tracks in the vicinity of \( \phi = 2.5 \) rad. Those are in fact beam tracks, and we have to admit that if some systematic rotation of all tracks appear in the reconstruction, this effect is much more effective on the highly curved, highly ionizing particles such as stopping \( \bar{p} \), and cannot be discarded if the informations were to be entered as fitted parameters. Fortunately in this experiment \( \bar{p} \) measurement is only used as an external check of stopping probability where the \( \phi \) does not enter.

Fig. VIII: Scatter plot of measured length on both apparatus. It is to be feared indeed that the systematic cut off of digitization when the relative angle of the slit with respect to the track tangent becomes larger than \( \approx 20^\circ \), may shorten systematically the effective measurement length.

This effect is indeed apparent for \( L \) greater than 20 cm. Under that it is rather the contrary, showing that the ability to discriminate a track in region where contrast becomes very poor is slightly better for an automatic detection device than for a human operator making premeasurement.

Fig. IX: Scatter plot of residual dispersion after fit for both apparatus. Dots show tracks where measured length can compare within \( \pm 10\% \). Crosses when outside this range.

H.P.D. dispersion are roughly 20 % lower than L.S.D. ones, going from \( \sim 5 \mu \) to \( \sim 7 \mu \), which is not significantly worst for the experiment. Very large \( 0 \) (over \( 15 \mu \)) are eventually due to stopping beam tracks and some undetected small kinks on the tracks.

Kinematic level.

Statistical errors:

The events have been processed into GRIND with identical pointing errors (60 \( \mu \)). The probability distribution for 1 and 4 constraint fit for L.S.D. (Fig. X) compared to the same one for H.P.D. (Fig. XI) show that in the case of L.S.D., errors are may be slightly underestimated and contamination of multipion events in 1 C fit is larger in L.S.D.
Systematics errors:

The histograms of missing mass squared for 4 C fit (Fig. XIII) and 1 C fit (Fig. XIV) are not significantly displaced from their theoretical values, respectively 0.0 and 0.02 GeV$^2$/c$^4$ although in the case of missing π$^+$ the appreciation of the center is difficult.

Nevertheless in the case of 4 C fit the distribution around 0.0 is not very gaussian like, indicating possible systematic errors.

Physical hypothesis:

Comparison can be done at two stages, first on global results at the end of the chain, next on what is exactly the content of the intersection of results.

Gross results of H.P.D are the relative ratios

\[
\begin{array}{c|c|c|c}
& \pi^+ \pi^+ \pi^- \pi^- & \pi^+ \pi^+ \pi^- \pi^0 & \pi^+ \pi^+ \pi^- \pi^- M M (\text{multineutral}) \\
\hline
17\% & 44\% & 39\%
\end{array}
\]

whereas L.S.D. is giving

\[(14.5 \pm 1.1)\% / (44 \pm 2.1)\% / (41 \pm 2)\%.
\]

Compatible but for the 4 \(\pi\).

Check on the intersection give the results gathered in the following table I.

Numbers in boxes are percentages.

| Table 1 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|               | L.S.D.          | \(\pi^+ \pi^- \pi^- \pi^+\) | \(\pi^+ \pi^+ \pi^- \pi^0\) | \(\pi^+ \pi^+ \pi^- \pi^- M M\) | No physics |
| H.P.D.        |                 | (=)                  | (#)                   | (=)                  | (#)                   |
| \(\pi^+ \pi^- \pi^- \pi^+\) | 12.3            |                      |                     |                     |                     |
| \(\pi^+ \pi^+ \pi^- \pi^0\) | 0.32            | 33.7                 | 3.90                | 0.97                | 0.97                |
| \(\pi^+ \pi^+ \pi^- \pi^- M M\) | 0.97            | 0.32                 | 30.1                | 4.85                |                     |
| No physics    | 0.64            | 0.32                 |                      |                     | 2.26                |

Hypothesis type are flagged (=) or (#). The sign (=) meaning that inside the event, all tracks have their parameters equal within twice the estimated errors. And sign (#) when at least one of the track parameter is outside twice the estimated error.

The boxes edged in black are thus the common part of the two measurement as the number of (#) does not exceed the tolerance for a normal distribution.

Hatched boxes are events satisfying different hypothesis according to the measurement, although the track parameters are very close. They represent a small set, compatible with a 3 standard deviation effect.
Of a greater concern are the cross hatched boxes giving a normal H.P.D hypothesis and "No Physics" in L.S.D. No Physics meaning that all kinematical hypothesis lead to absurdities: f.e. negative missing energy, negative missing mass square ... Most of these events come probably from a bad track association, especially when doublets instead of triplets have been associated, and also of beam track confused with secondary. Nevertheless the effect is striking on a constraint fit which are more sensitive.

If all "No Physics" events are remeasured, which is currently made, the measurements agree within 95%.

V. CONCLUSION

A 95% overlap is not bad and close to the one obtained on a cross check measurement on the H.P.D's of CERN and C.D.F.

The lack of flagging of the incident $\bar{p}$, whereas at the premeasurement level the efficiency of identification was nearly 100%, is a cause of reject not negligible. A noticable gain could be the use of ionization information as the $\bar{p}$ track are black.

The track association is left to the MATCH procedure. The success of which is greatly enforced by the full detection of all tracks on all view. The gain in accuracy is not striking but the mismatching is greatly reduced. This can be achieved in making a uniform detection probability on the three views. That point was not easy due to the large variation in contrast between views.

The calibration grid is probably too small for long tracks, but in this case it looks sufficient and we do not even need the complete set of corrections in order to obtain good results.

One of the main difference with H.P.D. measurement is the number of fiducials measured, which were currently 6 to 8 in H.P.D.; furthermore, due to the failure of automatic detection of fiducials we had to rely heavily on hand pointing, this could increase the inaccuracy of measurement and be partly responsible of the increase of the track residues.

In spite of these restrictions the apparatus give reasonable results in this range of energy and we can rely on its measurement as much as on the one given by the H.P.D. The measurement rate on L.S.D. was of the order of 25 ev$/s$/hour, the slowing down was mainly due to the poor training of operators at the early stage of exploitation, the difficulty to identify the proper vertex among an average of 4 in a very restricted fiducial region and eventually an unusually large number of crutch, end and stopping point. The H.P.D rate was more like 35 ev$/s$/hour, there the rate was cut down by an abnormal scan on each picture.
AKNOWLEDGMENTS:

The operating crew was mainly composed at this time of M. Forlen, Lai Van Thap and C. Raspiengeas.

We like to thank all members of our computational electronic and mechanical departments who helped us to put the L.S.D. in operation.

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FIGURE CAPTIONS — (For full commentary on figures see the text).

Fig. I  Evolution of main calibration parameters extended over 6 month.

Fig. II Scatter plot (φ, sinλ) for secondary.

Fig. III Scatter plot (σ, C) residus as a function of curvature

σ in μ/film, C in cm⁻¹.

Fig. IV Scatter plot (σ, sinλ)

σ in μ/film.

Fig. V Scatter plot (ΔC, C_HPD)

ΔC and C in cm⁻¹.

Two slopping lines at ± 2.5 %.

Fig. VI Scatter plot (Δλ, λ_HPD)

Units: radians.

Fig. VII Scatter plot (Δφ, φ_HPD)

Dots are normal tracks, crosses are tracks with λ > 70°.

Fig. VIII Scatter plot (L_{LSD}, L_{HPD})

Both measured length in cm. in space.

Fig. IX Scatter plot (σ_{LSD}, σ_{HPD})

Residuals on film after geometrical reconstruction in μ/film.

Dots when \( \frac{L_{LSD}}{L_{HPD}} = 1 \pm 0.1 \)

Cross when \( \frac{L_{LSD}}{L_{HPD}} \neq 1 \pm 0.1 \)

Fig. X Probability distribution 4 C and 1 C fit.

L.S.D measurement. Pointing error 6 μ/film.

Fig. XI Probability distribution 1 C fit on H.P.D.

Fig. XII Withdrawn

Fig. XIII Missing mass squared distribution - 4 C fit on L.S.D

Fig. XIV Missing mass squared distribution - 1 C fit and No fit on L.S.D.

Hatched part are 1 C fit.
\[ \Delta C = \text{Courbure}_{HPD} - \text{Courbure}_{LSD} \]

Fig. 5

\[ \Delta \lambda = \lambda_{HPD} - \lambda_{LSD} \]

Fig. 6
\[ \Delta \psi = \psi_{\text{HPD}} - \psi_{\text{LSD}} \]

**Fig. 7**

**measured length LSD / measured length HPD**

**Fig. 8**
Fig. 14
ON LINE PREFILTERING AND IMPROVED DATA COLLECTION ON L.S.D.


I. INTRODUCTION

When looking at the evolution of automatic or quasi automatic measurement devices, H.P.D's mainly, one may discover several trends on the most convenient, if not the most logical use of these apparatus, which arose when those where handed to physicist for operation.

I may try to summarize some of them, which may have some relation with the proposed improvements. In no way I mean to exhaust the list of possibilities.

- Avoid cumbersome tape storage and handling :
  1 tape means between 200 and 300 ev's on L.S.D.

- Avoid to much processing time on large computer. Filtering phase is roughly
  2 sec/ev on 6600 CDC.

- Have a quick answer as to the quality of the measurement, if not the complete
  kinematic answer at least some knowledge of how will behave the filter.

- In a direct relation with the preceding I avoid if possible all lengthy remeasure-
  ment procedure, i.e. be able to take quick rescue action, either help to filter or
  decision for immediate remeasurement.

On L.S.D. we have the advantage to have already "on line" an operator and a slave display which are in fact the way by which H.P.D and C.R.T type users interact with their filter programs, but unfortunately the filter is not included in the PDP9 on line control.

The question is such: could we introduce and at what expense, a way to help the ope-
  rator to take a decision ? It looks like the prefiltering may bring a realistic solution
  and at the same time it can reduce substantially the amount of data transmitted on tape
  and save some C.P. and P.P. time in further analysis.

II. PREFILTERING PROCESSES PRINCIPLES.

The goal of prefiltering is to keep and transmit to tape all good points and as little as possible background. Roughly speaking there are at maximum 3000 digitization/picture 4 to 500 belong really to signal, the other are rubbish, if the transmission could be reduced to some 500 to 1000 point, this will already be an appreciable gain.

We can use the nice property that on the (R, θ) plot the signal is roughly constituted locally by points aligned, this is true within the uncertainty on the center of the track, whereas the background is more or less evenly scattered or appreciably different from being aligned.
The problem is then to resolve the scatter plot in a set of small segments and transmit only the points belonging to these segments. Of course points could belong to two segments at the same time, but the separation will occur at the off-line stage.

III. PROPOSITIONS FOR REALISATION.

The prefiltering process could be summarized in the next scheme:

![Diagram](image)

Of course in the process we want to waste the minimum of time for machine operation and not delay the data transfer more than a second or so.

- Hardware solution: One of the first ideas for the prefiltering unit was to use, as it is done in the initial stage of POOH, rotating histograms over several revolutions of the periscope (8 to 10). This could be realised by hardware using shift registers now commonly available realizing for instance a matrix of bits 4050 x 10, the binning is then 1 radius step in R, and 32 counts in θ. Now by shifting on the rows and summing on the columns as illustrated for instance in fig. 1, one could obtain maxima and detect track candidates choosing a convenient threshold.

The method has been efficiently simulated on CDC 6600. A good efficiency of detection of signal, about 1 signal point/1.4 background point has been found using 8 consecutive radii and 30 0 counts/bins, on real digitization and a threshold > 5 bcts, but good efficiency according to the type of digitization means versatility in the choice of bin width, number of spiral turns, threshold, all things that cannot so easily be adjusted in hardware.

About the rapidity of extracting the signal, it must be remembered that these shift register can be piloted easily at 20 MHz. The full exploration of a 10 rows matrix, over 100 directions in both side takes only 0.8 sec. and can be processed in real time parallel to data acquisition as soon as enough information is provided to fill the matrix.
Nevertheless in spite of all the attractive features of the realisation of such a
gadget the price and the effort to be put in may be not worth the benefit of it if some
easiest way can be found, and we think that the PDP9 itself can be used efficiently
to preselect the signal.

Software solution: The acquisition of 3000 points is indeed stretched over about 5 sec.
A 3 words transmission into memory core takes about 15 μsec. total
3000 points take 45 msec. Only a very small fraction of the time is the computer busy
for data input an lot of time is available for computation.

Following the prefiltering technics developed on the C.d.F. H.P.D. by H. Videau
we will define for every point of the field (R_i, θ_j) a weight proportional to the proba-
bility to belong to the signal. We use for algorithm to define the weight the quasi alli-
gment of track

\[ \frac{θ_{i+1} - θ_i}{R_i + R_i+1} = C \pm \delta_i \ldots \]

δ_i stand for an dispersion on the centre of the track, δ_i can be variable according
to the value of R_i, and \((R_i - R_{i+1}) = C^\text{te}\). Of course we know also that we are looking for
tracks elements within reasonable limits for the slope, so the constant C
should have some upper (and lower) bounds.

The weight will be defined by the number of points satisfying the criteria when the
test is extended over some range if R_i.

To picture this suppose the scatter plot (R, θ) in fig. II, the weight is in fact
defined as the sum of the number of points in excess of 2 contained in all boxes
which contain the point, and the test is applied over 4 consecutives values of R and all
points corresponding to N < 2 are discarded as they just define an initial box.

The programming logic is rather simple. The coordinates θ_j = (θ_{LSD} - Δθ_{LSD}) are
already disposed in increasing order for each R_i, and origin of each new R_i line can be
easily defined by a table of indices for example.

The procedure is assessed further in Table 1.

The procedure use only elementary operations : addition, substraction, test on positive
or negative values, jump, transfers, all operations that are very fast on PDP9 and do not
need too much memory core.

The process described has been simulated on 6600 and in fact used up to the complete
filtering of tracks, using sequences of 8 rows and restricting δ in several steps. It
shows that prefiltering could be very efficient using δ = 8 counts and |C| < 200 δ counts.
The selected points could be entered directly in a \(\chi^2\) fit of a straight line after track
to track association. The points belonging to 2 tracks in crossing regions are just over
weighted, but this is more an advantage their a drawback of the method.

The limitation imposed over C reduces greatly the number of points to explore per
line to a few ones. Indeed the knowledge of the anterior research always guide us in
the actual one. Suppose indeed that at some stage of the game association has been found
between point
Table I

<table>
<thead>
<tr>
<th>R_1</th>
<th>θ_{2,1}</th>
<th>θ_{2,2}</th>
<th>θ_{2,3}</th>
<th>θ_{2,4}</th>
<th>θ_{2,5}</th>
<th>θ_{2,6}</th>
<th>θ_{2,7}</th>
<th>θ_{2,8}</th>
<th>\cdots</th>
<th>\cdots</th>
</tr>
</thead>
</table>

Starting point

\[ \downarrow \]

Limits imposed by \( C_{\text{min,max}} \)

<table>
<thead>
<tr>
<th>R_2</th>
<th>θ_{3,1}</th>
<th>θ_{3,2}</th>
<th>θ_{3,3}</th>
<th>θ_{3,4}</th>
<th>θ_{3,5}</th>
<th>θ_{3,6}</th>
<th>θ_{3,7}</th>
<th>θ_{3,8}</th>
<th>\cdots</th>
<th>\cdots</th>
</tr>
</thead>
</table>

Test: \( (θ_{3,1} - θ_{2,1}) = (θ_{2,3} - θ_{1,2}) + δ \)

\[ \downarrow \]

Limits imposed by \( C_{\text{min,max}} \)

<table>
<thead>
<tr>
<th>R_3</th>
<th>θ_{4,1}</th>
<th>θ_{4,2}</th>
<th>θ_{4,3}</th>
<th>θ_{4,4}</th>
<th>θ_{4,5}</th>
<th>θ_{4,6}</th>
<th>θ_{4,7}</th>
<th>θ_{4,8}</th>
<th>θ_{4,9}</th>
<th>\cdots</th>
<th>\cdots</th>
</tr>
</thead>
</table>

Test: \( (θ_{4,1} - θ_{3,1}) = 2 (θ_{2,3} - θ_{1,2}) + 2δ \)

\[ \downarrow \]

Limits imposed by \( C_{\text{min,max}} \)

<table>
<thead>
<tr>
<th>R_4</th>
<th>W_{4,2} = W_{1,2} + 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W_{4,3} = W_{4,3} + 1</td>
</tr>
<tr>
<td></td>
<td>W_{4,5} = W_{4,5} + 1</td>
</tr>
</tbody>
</table>

Start next with \( θ_{1,3} \)
% on line 1
m on line I + 1
n on line I + 2

(\$, m, n, I) meaning the rank of the point on the line, or rank of line.

Next research will start from point \$ + 1 on line I, but there is no use to explore all points of I + 1 line. Experimentally we have seen that starting from (m - 1) up to the point given by the limit C is enough, that means 2 or 3 points on I + 2. The same for I + 2, starting from (n - 1), only 2 or 3 points are explored. This means a big saving of time.

When applying this method abruptly we see that the region of large R, when we enter the zone of dense beams for instance, leads to many alignments, i.e. to too many weighted points. It is why the method should be applied in three stages. Suppose for instance a complete spiral of 60 turns. I suggest to distinguish 3 zones.

Zone A: turn 1 to 4
B: " 4 to 18
C: " 18 to 60

In A: alignments are spoiled by vertex mispointing keep all points.
In B: roughly this correspond to the histogramming zone of POOH + apply the full research.
In C: explore C keeping only as starting points the ones who have got a high enough weight on line 18, so you follow only the good track candidates.

IV. EXPLOITATION OF THE PREFILTERING.

At the end or at some intermediate time of the prefiltering process we dispose of a large buffer of digitizations, each one has on weight attributed. Incidentally we could use for instance the 3 upper bits of \$R/2 to keep record of this weight. The following steps are then.

1) Display all points with \$ > some cut off : the operator instead of looking at a mess of points where it can barely distinguish the tracks, sees only selected candidates and can evaluate at a quick glance if there are enough, too few or too many and eventually react immediately for instance too many tracks : warn for better AGC adjustment.
   too few : put crutch points on tracks.
   remeasure with some adjustment.

If this is not a check of the intrinsic precision of the apparatus, at least it is a good check of the detection ability and may avoid many feedback of events. The apparent waste of time due to the time spend for decision of operator, could be largely compensated by the reduced number of remeasurement.
2) Transmit on tape all selected points if quality looks good, only reduced number of points are written, except may be in some cases where full transmission is asked for. The data points are reduced by a factor 4 to 10 in many cases so cutting the output tape handling at many stages.

3) Off line filtering is greatly improved:
- Reduced data input storage and P.P: time.
- Elimination of practically all initial stage of track research and track following in POOH, gain may be of the order of 1 sec. of 6600/evts, without accounting for remeasurement avoided.
- Avoid as much as possible mismatching of tracks. MATCH failures have mainly two causes:
  1/ Too many tracks as input, the association is then lengthy and may lead to wrong ones.
  2/ Too few tracks: only doublet association are then found and they lead to wrong answers too.

  The ability of the operator to immediately have an idea of the input to match is probably the more efficient way to prevent these errors.

CONCLUSION.

The prefiltering is probably a sound improvement of the apparatus and does not involve too much effort.

Keeping in mind that the use of computational facilities is probably the cheapest and most efficient way to proceed, still several solutions can be found and deserve a careful study of the economics of the problem in parallel with the technical studies.

There is no doubt that the realisation requires a Buffer memory able to contain part or total of digitisation and some memory disponible for programming. I have no answer so far what either an 8 K extension of PDP9 memory or use of overlay on DECTAPE, are best solution.

Financial aspects have also different faces, on one side there is certainly a capital investment in equipment, on the other side gain in computer time, but the comptability of computer time differs widely according to the situation, gain in operator time, gain in magnetic tape, and at last gain in satisfaction of the physicist.

I am slightly biased for this argument to be the real strong and overwhelmingly decisive, unfortunately I must recognise that finance department are sometimes conflicting with this point of view.

So far no beginning of realisation has been attempted for the proposed scheme, only simulation at the level of the 6600 has shown how efficient it can be.
AKNOWLEDGEMENTS:

I like to thank B. Equer and H. Videau who have initiated the work on prefiltering on the H.P.D. at Collège de France and gave me the idea to introduce it at the L.S.D. level, and G. Fontaine for helpful discussion.

Thanks to M. Bravard and L. Guglielmi who have done the programming and to L. Dobrzynski and M. Forlen for advices.
Fig. 1

Initial content

\[
\begin{array}{cccc}
1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 \\
\end{array}
\]

Row sum → 2 2 2 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

→ No track detected

1st shift

4 right →
3 up → 1 1 1 1 1
2 up → 1 1 1 1 1
1 up → 1 1 1 1 1
0 → 1 1 1 1 1

Row sum → 2 1 1 1 1 1 2 1

5 1 ← 1 Track detected

2nd shift

8 right →
6 up → 1 1 1 1 1
4 up → 1 1 1 1 1
2 up → 1 1 1 1 1
0 → 1 1 1 1 1

Row sum → 1 1 1 3

4 3 1 2 ← 1 good track
2 false tracks

(Detected or not according to the threshold)
Fig II

θ

This box is outside the C limit

absolute limit for C

θ_{1,i} - θ_{2,i}
SOME IMPROVEMENTS OF THE LSD OPTICAL SYSTEM

CERN-LSD Group (presented by K.K. Geissler)

SUMMARY

The overall efficiency of the optical system of the LSD has been reviewed with reference to its influence on the signal-to-noise ratio of the track detector output signal and found to be not optimal. The improvements undertaken are aimed at raising the quality of the output signal of the photomultipliers by supplying them with the maximum possible light intensity, thus reducing the influence of the Schottky shot noise on the signal quality to a tolerable level. This was done using two types of mirror coatings which are radically different from the existing ones. Further measures consisted of changing the type of cone/periscope PM, raising the Xenon lamp current to its rated value and using specially selected filters.

The definition of the spectral transmittance curves of the coatings was based on information given by the lens manufacturer SCHNEIDER & Co. about the chromatic aberrations of the projection lens, as they occur in the LSD machine.

The theoretical forecast for the result of this improvement study is a factor of 2.5 for the S/N ratio of the track signal and a factor of about 3 for the S/N ratio of the fiducial signal.

INTRODUCTION

In the course of a program to convert the "Test CP" into LSD2-Pollux, the somewhat noisy output signal from the cone/periscope assembly photomultiplier ("track PM") was found to be partly due to the track detector PM XP 1110 in use at that time. It was decided to replace it by the type XP 1002 which has a S-20 trialkali photocathode.
The study about optimisation revealed furthermore that the existing arrangement favoured the fiducial detector PM to an unduly high extent at the cost of the track detector PM. Some details show this:

1. Slit surfaces
   - dimensions of track slit: 1000μ × 50μ;
   - dimensions of fiducial slit: 3000μ × 100μ;
   i.e. a ratio of 1:6

2. Light guides
   - 300 + 900mm for tracks; transmission 30%;
   - 500mm for fiducials; transmission 55%;
   i.e. a ratio of 1:1.8

3. Splitting ratio of large mirror
   - reflectance at 480mm (for track detector) = 40%
   - transmittance at 480mm (for fiducial detector) = 60%
   i.e. a ratio of 1:1.5

This results in a total "favouring" factor of

1: (6 × 1.8 × 1.5) = 1:16

as far as the luminous flux upon the two PMs is concerned.

A direct consequence of this large factor was the following. The 8 fiducial PMs and the single track PM were supplied by a common high voltage source. When the Xenon lamp current was raised in order to improve the track signal quality, the fiducial PMs very soon were overcharged. Consequently, the lamp current was set at 19A, far below the rated value of 25A.

The main task yet was the determination of the coatings for the two splitter mirrors. These are:

1. The "small splitter", which is 150mm in diameter, 15 mm thick and splits away the light for the operator's table;
2. The "large splitter", which is 400mm in diameter, 30mm thick and splits the light between cone/periscope image plane and fiducials/TV image plane.

TRANSMISSION CHARACTERISTICS OF THE OPTICS AND PM RESPONSE

From the point of view of PM sensitivity the different optical devices used in the LSD are "hostile". This is not bad engineering but a natural fact and shall be outlined in some detail.

The spectral response curves of the S-11 and S-20 photocathodes (shown in fig. 1) peak at wavelengths ranging from 380nm to 420nm. The standard Cs$_3$Sb-O composition of the S-11 shows a steep descent towards longer wavelengths, while the trialkali composition Na$_2$K$_3$Sb-Cs of the S-20 has lower values of the photoelectric work function than the S-11 and thus shows an appreciable sensitivity in the red spectral region (50% at 600nm compared to 12% of the S-11; see fig. 1). It is logical to concentrate on the blue and violet spectral region when designing an optical device for use with a photomultiplier. The relative spectral transmission curves of the optical components in the LSD (fig. 2) show increasing absorption towards shorter wavelengths. Fig. 3 shows the overall spectral transmission curve of all optical components which are common to both image planes on either side of the large splitter. The light guides are taken with their respective PMs to form the "detector units".

In order to obtain information upon which to base a decision about the splitting ratio, the relative spectral distribution of the radiant output of the Xenon lamp has been evaluated from OSRAM calibration curves and is plotted in fig. 4. The total product of

\[
\text{Xenon lamp} \quad \times \quad \text{light guide transmission} \quad \text{(fig. 4)} \quad \text{times} \quad \text{(fig. 2)}
\]
times PM spectral sensitivity (fig. 1)
times overall transmission (fig. 3)

yields the two curves in fig. 5, which show the relative spectral response of the two PMs involved. These curves are "maximum curves" in the sense that they are obtained

- for the fiducial PM with small splitter $R = 100\%$
  and large splitter $R = 0\%$
- for the track PM with small splitter $R = 100\%$
  and large splitter $R = 100\%$

Both PMs show peak response at 470nm. The peaks are due to the 470nm peak in the output power curve of the Xenon lamp. The absorption and reflection losses encountered in the combination of a 300mm and a 900mm light guide in front of the track PM are obviously responsible for the remarkably inferior response of the track PM, at least in the region of peak response.

There is still one peculiarity to be explained that would help in the understanding of the characteristic behaviour of a PM which is illuminated with light of a certain wavelength.

The radiant cathode sensitivity $E(\lambda)$ in mA/watt is defined as

$$E(\lambda) = \frac{I_K}{P} \% \lambda Q(\lambda)$$

that is, photocurrent per radiant power $P$ having a wavelength $\lambda$.

Thus $E(\lambda)$ is valid information only for particular wavelengths, since the radiant power $P$ as well as the quantum efficiency $Q(\lambda)$ have to be specified for these wavelengths.

It is customary for photocathode sensitivities to be quoted as luminous sensitivity in units of $\mu$A/lumen, since the lumen is related to the human eye and covers a wide spectral range.
A source with an emission spectrum $W(\lambda)$ gives rise to a luminous flux of $dF$ lumens in the wavelength region $\lambda$ to $\lambda + d\lambda$:

$$dF \propto V(\lambda) \ W(\lambda) \ \lambda$$

$V(\lambda)$ is the relative response of the standard eye and provides the reference to the human eye.

When a light source with the emission spectrum $W(\lambda)$ cited above irradiates a photosensitive surface with a flux in the wavelength region $\lambda$ to $\lambda + d\lambda$, the current $di_k$ would be:

$$di_k \propto \omega \lambda W(\lambda) d\lambda$$

or

$$di_k \propto \lambda Q(\lambda) W(\lambda) d\lambda$$

In our case the value $W(\lambda)$ is obviously given by the spectral distribution curve of the Xenon lamp (figure 4) whereas the term $\lambda Q(\lambda)$ is given by the relative spectral response curves in fig. 1. It is thus clear that the PM output current is proportional to the area under the spectral sensitivity curve in the $S$ versus $\lambda$ plot shown in fig. 5.

Finally, the actual values of cathode sensitivities as given in the data sheets were obtained using a tungsten ribbon lamp at $2857^\circ K$, which resembles very closely a black-body radiator, whose emission data $W(\lambda)$ are tabulated.

The expression for the cathode sensitivity $S$ in $\mu A$/lumen

$$S = \frac{C_1 \int E(\lambda) \ W(\lambda) \ d\lambda}{C_2 \int V(\lambda) \ W(\lambda) \ d\lambda}$$

may be evaluated by numerical integration using calibrated values of $E(\lambda)$ for a particular tube and tabulated data for $V(\lambda)$.

The statement of cathode sensitivity in $\mu A$/lumen makes it difficult to compare two cathodes having appreciably different spectral
responses. In particular, the fact that the emission spectrum for a 2857\textdegree K black body peaks at a wavelength of 1000nm (1 micron) may result in a disproportionate increase in photosensitivity for a small extension of the long wavelength tail of the quantum efficiency curve. The two types of PM used in the LSD are a good illustration of this fact:

<table>
<thead>
<tr>
<th></th>
<th>XP 1110</th>
<th>XP 1002</th>
<th>mA/watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>radiant sensitivity at 420nm,</td>
<td>60</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>luminous sensitivity</td>
<td>60</td>
<td>150</td>
<td>(\mu A/\text{lumen})</td>
</tr>
</tbody>
</table>

**PERFORMANCE OF THE SCHNEIDER REPRO-CLARON**

A particular study of the degradation of image quality due to geometrical and chromatic aberrations introduced by the 4.5mm thick glass plate in the film gate seemed appropriate as well. These aberrations are likely to occur since the spherical aberrations are a function of the index of refraction which in turn varies with the wavelength of the light used for projection.

The manufacturer of the lens, J. SCHNEIDER, Bad Kreuznach, helped by running a special computer program and supplied all relevant data in the form of a computer print-out from which the following comments are extracted (examples are shown in figs 6 and 7).

For a 0\% - 100\% step function in the object plane the program computed the energy distribution in the image plane for a magnification of 2.8. This was given for both sagittal and meridional (tangential) orientation of the step function with respect to the optical axis and for varying

- image plane positions (\(\Delta s' = 0, -2.5, \text{ and } -5\text{mm}\));
- colours (blue, 480nm; green, 546nm; red, 644nm);
- off-axis distances in the image plane (0, 40, 80, 120, 160mm).
The sketch shall illustrate this:

In the case where the object is a straight line one superposes this step function with its inverse function, as shown by the solid and dashed lines in fig. 8a. When overlapped properly so that the ideal width $W_i$ in the image plane is equal to object width times magnification, one can obtain the real image by multiplying the appropriate distribution curves (as shown in fig. 8a by the dotted curve).

A certain "smear-out" or broadening of the line image can be seen. To extract useful information about this "smear-out", the distribution curves have been cut at 10% height and thus the value $W$ was found, which is proportional to the total width (at 10% height) since the ideal width $W_i$ is constant, see fig. 8a. This value $W$ is evidently a representative measure of the quality and sharpness of the projected image under the various conditions involved.

It should be mentioned that the data in the computer output is derived by purely geometrical ray computing and thus is of only limited significance, although adequate for our purposes. The interpretation of the results is restricted to blue and green light, where the PMSs are most sensitive. Furthermore, only sagittal lines are studied since these are equivalent to radially oriented tracks from a vertex. In the particular case of the fiducial arms, some reference to the related case of meridional oriented lines will be made.
There are two regions of chief interest:

(i) vertex region, i.e. optical axis
(ii) fiducial region, i.e. 160mm off-axis

(i) The interest stems from the fact that in this region the measurements of track ionisation are made and therefore highest image quality is needed.

(ii) The fiducial region is a very critical one:

- it is far away from the optical axis;
- the fiducial arms are not radially oriented, but under angles from 35° to 65° referred to a radial line. This introduces an appreciable amount of aberration coming from the "meridional case". Figs 6 and 7 will illustrate this. The right hand side diagram in fig. 7 shows the original information which indicates a 40μ displacement at 50% step height for the tangentially oriented edge image, while the dotted curve in fig. 8b shows the energy distribution for a 60μ thick line image (tangentially oriented) composed in the manner described above.
- The large 45° splitter mirror of 30mm thickness created additional coma and chromatic aberrations. These particular non-symmetrical conditions are currently under study at SCHNEIDER. Definite results are not yet available, but preliminary information indicates that the coma effect is larger than the chromatic aberrations.

The information about the performance of the Repro-Claron supplied by SCHNEIDER & Co is plotted in fig. 9a. For the two wavelengths blue (480nm, dashed lines) and green (546nm, solid lines) the "pulse width W" is plotted versus different focal plane positions Δs'. The different off-axis distances (in the image plane) are inserted in the curves as a parameter. The pulse width W is to be taken in a relative sense and serves only for the purpose of comparison.
W is taken arbitrarily at 10% step height and does not relate to any absolute value. For instance, if it were taken at 50% step height, W would be equal to zero.

Evidently the highest line image quality is obtained with green light. Three cases may be distinguished:

1. At Δs' = -2.5mm the smallest line image is given on the optical axis (0mm) but the width increases with increasing radius of the spiral, up to 40μ for 160mm off-axis distance.

2. At Δs' = -4mm the initial width is larger but there is no variation of width for green light from 0 to 80mm and for blue light only modest variation occurs. For greater radii the width increases but in a less pronounced fashion.

3. At Δs' = -5mm the variation of width over the entire range of off-axis distances is smallest, but the initial width is double that of case 1.

The general requirements to be fulfilled for track images are:

1. Sharpness;
2. High signal-to-noise ratio, i.e. high light level.

Comments on these two points are:

1a. Sharpest images (for ionisation measurements) are needed only for image plane off-axis distances 0 to 40mm, for larger distances the requirements are less stringent.

2a. More light for the track PM means less relative noise and thus clearer, more reliable pulses, even when track images are slightly broader than in the optimal case.
A compromise has been found with light of 500nm wavelength (blue-green) that yields for the track image a reasonably small width around the optical axis (0 to 40mm) as well as modest increase for larger distances (compare fig. 9b and the two vertical arrows there).

Logically the wavelength region around 470nm will now be used to illuminate the fiducial detectors. The V-slits of the pick-up system are at fixed positions so that no pulse width variations will occur. The best image plane will be set for each V-slit independently. The dashed line in fig. 9b indicates that at $\Delta s' = -6.5$nm the pulse width $W$ for the fiducial marks may be the same as for the tracks. Of course, the influence of the large 45° splitter mirror (coma, chromatic aberration) was not taken into account, this will change the entire situation as may be deduced from fig. 8b.

THE MIRROR COATINGS

When it comes to specifying the spectral characteristic of the mirror coatings one should remember that it is the area under the spectral sensitivity curve of the track detector unit that counts, since it is directly related to PM output current.

Now we are obliged to operate the track detector unit within a narrow spectral region. It is therefore logical to split the available light spectrally and not (as is normal) to split the intensity. In other words: The mirror coating must have the characteristics of a bandpass frequency filter, whose reflectance is ideally 100% for the specified spectral region and whose transmittance is ideally 100% for the rest of the spectrum.

For obvious reasons of human engineering this cannot be applied to the small splitter which transmits the light to the operator's table. In this case a more or less neutral splitter has to be specified.
In close cooperation with BALZERS, Liechtenstein the two types of coatings were specified and manufactured by them. The small splitter is treated on the first surface with a standard TRANSFLEX TF-TS2T-65 coating and with a "short IRALIN" as antireflection coating on the second surface. "Short" in this context means that the standard IRALIN spectral curve has been shifted by 30 to 40nm towards shorter wavelengths.

The large splitter was coated with a specially developed type of many-layer dielectric coating which is based on the standard type "DC GRÜN", but differs in that it is centered at 505nm and reflects as much as 98% of the light at this wavelength. The "full-width-half-magnitude" value is about 60nm. For the other spectral region of interest, 400 to 470nm (fiducials), the transmittance is 80% on average with a peak transmittance of 91% for 430 to 455nm. From 560nm to the red end of the spectrum the transmittance is about 90% (TV camera). These curves are shown in fig. 10, together with the curves for the hitherto applied oxide coated neutral splitters.

The second surface of the large splitter is coated with a "short" GE DO type double-layer antireflection coating, since the multi-layer type IRALIN would have been extremely difficult to apply homogenously on such a large substrate.

Finally, the mirror strip inside the cone has been given another coating. Instead of ALFLEX A (R = 88% at 500nm) a SILFLEX coating with protective SIO coating (R = 98% at 500nm) was applied.

**RESULTS**

The final results obtained by taking into account the reflectances and transmittances of the two new splitter mirrors are given in the following figures.
The solid curve in fig. 11 gives the relative spectral sensitivity of the track PM (XP 1002, S-20), while the dashed curve indicates the actual spectral response of the track PM (XP 1110, S-11) in LSDl. The dashed curve was calculated in the same way as the solid curve, using the R/T ratio of the old mirror set and the lower relative radiant output of the Xenon lamp. The dotted curve will be mentioned in the section Outlook. There is no need to use a colour filter - the coating of the large splitter behaves already as expected as a very efficient broadband interference filter.

It is evident that the new PM response will result in a remarkable increase in output current and thus in a much less noisy output signal than that given by the area under the dashed curve. The signal-to-noise ratio will improve by a factor of 2 or more.

The solid curve in fig. 12 shows the relative spectral sensitivity of the fiducial PM (XP 1110, S-11) and again the actual operating conditions are given by the dashed curve. Here as well a striking increase in PM output current is to be seen. Hitherto a SPECIVEX 540 B filter was used. At the wavelength of its peak transmission (540nm) the relative sensitivity of the XP 1110 is already as low as 45%. Due to the favouring of the fiducial/TV image plane it was not obvious that the subsequent attenuation of the surplus light by the filter was at the cost of the cone/periscope image plane which thus responded with a poor signal-to-noise ratio.

The dotted continuation of the solid curve is that portion which will be cut away by the filter FITC-3 special, developed by BALZERS and shown in fig. 15. Since the aberrations introduced by the large splitter are not yet known, it will be decided by direct experiment on the machine whether this filter is to be applied or not.

Two curves for the final relative spectral sensitivity of the vidicon are shown in fig. 13. The reasoning is the same as for
the fiducial filter. So once more, the unknown chromatic aberrations introduced by the large splitter leave the decision to a direct experiment on the LSD, as to whether a sharper image on the TV is produced by green light of 550nm (using the BALZERS filter FILTRAFLEX DT GRÜN, see fig. 15) or by blue light of 470nm (using the fiducial filter FITC-3 special see fig. 15). Both methods are acceptable, the relative spectral sensitivity of the vidicon being 70% for blue and 100% for green light.

The two circles in fig. 9a marked "TV" indicate for the pulse width W a best value of 10µ for the green light (540nm) and 20µ for the blue light (480nm).

The relative spectral distribution of the light falling through the small splitter upon the operator's table is shown in fig. 14. A first test with a small glass plate sample of TRANSFLEX-65 showed better results than would have been expected from fig. 14. The reason is perhaps that compared with the relative spectral sensitivity of the human eye the two peaks at 470nm and 620nm are sensed with 10% and 40% only of the relative response of the eye. The light on the projection table appears slightly reddish instead of snow white and that is all. This appears to be acceptable since the operator did not complain about eye strain.

OUTLOOK

In the course of this study it became apparent that further improvements are possible, which would not necessitate any change in the design or construction of the machine.

The first case where an appreciable improvement in performance could still be gained concerns again the large splitter mirror. Some brief details shall explain this.
A dielectric mirror is produced by stacking optical interference films in such a way that alternate layers of dielectric materials with low refractive index and high refractive index are deposited. This particular coating is called a quarter-wave stack because the films all have the same optical thickness of a quarter of a wavelength at the "tuned" wavelength. The spectral region of high reflectance of the coating is called a "stopband".

There are three characteristic points of some importance with such a stopband:

1. The centre wavelength can be chosen at will, since the optical thickness is controlled accordingly during the evaporation process.

2. Adding extra pairs of layers of the two dielectric materials increases the maximum reflectance, but the spectral width of the stopband is unchanged.

3. The spectral width of the stopband depends only on the refractive index of the two films that are used in the stack and is independent of the number of layers.

After discussion with BALZERS it became clear that by applying a material with a different high refractive index the spectral width of the stopband on the large splitter could be increased from 60nm to 90nm. This leads to the first proposal for eventual further improvements of the track PM output signal:

- A stopband from 480nm to 570nm. This spectral width would include the green portion of the spectrum which is found to be best suited from the point of view of image quality.

The second proposal concerns an optical element which did not seem to promise much improvement: the light guides. Replacing the ordinary light guides currently used in the cone/periscope system by SCHOTT ZM2 4x4mm image guides for instance would result in an appreciably
higher luminous flux. An ordinary short fiber light guide has a transmittance not higher than 60%, mainly due to reflection losses at the entrance and exit surface and the "filling factor" encountered when putting loose fibers together into a bundle. The greater packing density of the regularly structured image guide results in a higher filling factor. Instead of the existing transmittance of the 300mm + 900mm combination

\[ 60\% \times 50\% = 30\% \]

one would find

\[ 75\% \times 60\% = 45\%. \]

This is equivalent to 50% more light for the track PM.

By combining these two effects the dotted response curve in fig. 11 was obtained.

THE IMPORTANCE OF ANTIREFLECTION COATINGS

On the second surface of both the small and the large splitter mirror an antireflection coating has been deposited. Why do these coatings have to be "short" coatings? Alternatively, why are their spectral reflectance curves shifted towards the blue end of the spectrum?
This simple sketch demonstrates for an uncoated glass plate that reflection from first and second surface is of almost equal intensity.

The principal point with antireflection coatings is therefore: They must be of highest efficiency, i.e. minimum reflectance in that particular spectral region, where the first surface coating is of low reflectance. In other words: The parasitic light of the second surface ghost image cannot penetrate the first surface coating when its reflectance is high.

These are exactly the conditions we meet with the large splitter. The following table shows values extracted from figs 10 and 16.

<table>
<thead>
<tr>
<th>wavelength</th>
<th>450</th>
<th>470</th>
<th>500</th>
<th>620</th>
<th>nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>small splitter, $R_S$</td>
<td>50</td>
<td>60</td>
<td>65</td>
<td>50</td>
<td>%</td>
</tr>
<tr>
<td>large splitter, $R_L$</td>
<td>10</td>
<td>20</td>
<td>98</td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td>IRALIN, $r_S$</td>
<td>0.1</td>
<td>0.12</td>
<td>0.16</td>
<td>0.14</td>
<td>%</td>
</tr>
<tr>
<td>GEDO, $r_L$</td>
<td>0.6</td>
<td>0.6</td>
<td>0.65</td>
<td>1.2</td>
<td>%</td>
</tr>
</tbody>
</table>

Fig. 17 sketches the situation in the LSD machines and shows the fractions of the normalised incident light intensity appearing at the various places.

For the case of the track PM the attenuation of the ghost images by the AR coatings is shown in table 2. Of real importance for the cone/periscope system are the "blue and red ghosts" from the large splitter (1.72% and 1.72%), where $R_L$ is only 10%!
The results are weighted with appropriate S values from fig. 5 and are thus directly related to the final spectral sensitivity curve of the track PM in fig. 11.

<table>
<thead>
<tr>
<th>wavelength</th>
<th>450</th>
<th>470</th>
<th>500</th>
<th>620</th>
<th>nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>no AR coatings</td>
<td>1.72</td>
<td>1.67</td>
<td>0.5</td>
<td>1.72</td>
<td>%</td>
</tr>
<tr>
<td>with AR coatings</td>
<td>0.27</td>
<td>0.25</td>
<td>0.05</td>
<td>0.5</td>
<td>%</td>
</tr>
<tr>
<td>weight S</td>
<td>9</td>
<td>15</td>
<td>10</td>
<td>6</td>
<td>%</td>
</tr>
<tr>
<td>final &quot;ghost intensity&quot;</td>
<td>0.02</td>
<td>0.04</td>
<td>0.004</td>
<td>0.03</td>
<td>%</td>
</tr>
</tbody>
</table>

Referred to a 100% spectral response of the track PM due to the primary image the response due to the parasitic light from the ghost image could be reduced by the AR coatings to 0.8%.
FIGURE CAPTIONS

Fig. 1 Relative spectral response curves for the S-11 and S-20 PM photocathode and the vidicon.

Fig. 2 Relative spectral transmission of different optical elements of the LSD.

Fig. 3 Overall relative spectral transmission curve of all optical elements shown in fig. 2, including a cold mirror in the light house beneath the film. This mirror is not shown in fig. 2.

Fig. 4 Relative and absolute spectral density distribution of an OSRAM Xenon arc lamp XBO 450 W.

Fig. 5 Relative spectral sensitivity curves for the fiducial PM XP 1110 and the track PM XP 1002.

Fig. 6 Example of the SCHNEIDER computer output concerning chromatic aberrations of the Repro-Claron 305mm, f:9; Left hand diagram shows "pulse width W" of 10μ for green light on the optical axis.

Fig. 7 Same as fig. 6. Right hand diagram shows chromatic variation of geometrical aberrations for a tangentially oriented step function at 160mm distance from the optical axis.

Fig. 8 Energy distribution in the 2.8x enlarged image of a 0%-100% step function and superposition of a step function with its inverse function to form the image of a line which is (in the object plane) of width W_1/2,8.

fig. 8a: case of a radially oriented line on the optical axis;
fig. 8b: case of a tangentially oriented line at a distance of 160mm from optical axis.

Fig. 9a Plot of "pulse width W" versus displacement of focal plane Δs'. The inserted numbers indicate off-axis distances in the image plane for green light (546nm, solid lines) and blue light (480nm, dashed lines).
Fig. 9b  Conditions chosen from fig. 9a for operation of the LSD.  
Wavelength of "fiducial light": 470nm;  
Wavelength of "track light": 505nm.

Fig. 10  Reflectance curves for the small and large splitter.  
Solid curves - new mirrors;  
Dashed curves - old mirrors.

Fig. 11  Final relative spectral sensitivity curve for the track PM  
XP 1002, S-20.  
Solid curve - new mirror set;  
Dashed curve - old mirror set;  
dotted curve - proposed future improvement.

Fig. 12  Final relative spectral sensitivity curve for the fiducial  
PM XP 1110, S-11.  
Solid curve - new mirror set;  
Dashed curve - old mirror set;  
Dotted curve - cut-away portion of the solid curve.

Fig. 13  Final relative spectral sensitivity curve for the vidicon.  
Solid curve - with filter FILTRAFLEX DT-GRÜN;  
Dashed curve - with filter FITC-3 special.

Fig. 14  Spectral distribution curve for the light falling on the  
operator's table.

Fig. 15  Spectral transmittance curves for the three BALZERS filters  
used in the LSD2.

Fig. 16  Residual reflectance of the second surface of a glass plate  
coated with three different types of AR coatings.  
Solid curve - single layer of MgF₂ (SG5);  
Dashed curve - double layer (short GEFO);  
Dotted curve - multi-layer (short IRALIN).
Fig. 17 Sketch of the repartition of light in the LSD machines. Intensities of the primary and ghost images at the various places are given as fractions of the normalised incident light intensity. Transmission through the small splitter: Operator's table; Transmission through the large splitter: Fiducials and TV; Reflection at the large splitter: Cone/periscope system.
Fig. 6

Fig. 7
Fig. 8

Fig. 9
FILM'S MEASUREMENTS OF 80 cm CHAMBER.

1. HARDWARE

   To adapt L.S.D. at 80 cm chamber:

   a) it is necessary to turn vacuum buffer to ninethy degrees and change felt plate.

   It is also necessary to change some rollers and the press-spools.

   For brener detection, diodes must be permutated.

   Indeed, detector can be used in 35 or 50 mm.

   The difference between the two photo-diode supports, is made in such way that we obtain a correct stop with the same positionning distance.

   Thus, in case of 35 mm film, the reference photo-diodes are the one of 50 mm and inversely.

   Nota. The 35 mm spools are loaded at opposite side that the 50 mm one ; this because of the brener marks configuration.

   b) For autofiducials, the mecanical building of rear panel do not allow to adjust the slits directly on the four crosses such as in 50 mm.

   A software solution has been found for this operation.

   However, the slits must be adjusted in Y in such a way that crosses pass throught the slits by a X platen transfer.

2. SOFTWARE

   a) The spools being loaded at opposite side that for 50 mm films, the positionning must be made with inversion of direction.

   Therefore, to move the film to "N" frames, the computer must set (N + 2) frames and fall over the flip-flop of inversion of direction at (N + 1) brener mark. At this time the signal of delayed flip-flop complements the speed's bytes to make the inversion of direction.

   In practice, only four instructions "S.Z.L" must be changed "S.N.L." in the subrou-
tine "Galere".

   b) Auto fids

   The slits being adjusted, the constants between slits and optical axis must be changed.
Then, the transfer to put the lower crosses on their slits and upper on their ones, must be measured (about 70,000 counts). This value must be set in "Asterix" like a constant.

During the transfer the slits are occulted by anything and pass in dark of press-film.

Therefore, it is necessary to mask the fiducials by software system during the transfer and to enable data acquisition during the sweep.

MEASUREMENT'S SEQUENCE

In a first pass the X platen explores all the frame to find the four crosses; then it sweeps the lower crosses through their slits and after the transfer, the upper ones.

ACKNOWLEDGEMENTS

I thank Mrs M.J. Blin and Mr. M. Bravard for their participation to the realisation of this work.
HARDWARE IMPROVEMENTS ON THE TWO CERN LSD SYSTEMS

CERN-LSD Group (presented by E. Rosso)

INTRODUCTION

The different methods to check the status of the machine are the following:

1) The on-line test program STEP and RAVEN etc. (ref. 1)
2) The output of the calibration program SCALP (ref. 2)
3) The statistical effects in the production.

These investigations have led us to a series of conclusions and this paper describes
the different improvements which have been implemented on LSD 1 whenever possible or on
LSD 2 whenever a long study or careful checks have been necessary.

We shall limit ourselves to discuss the improvements in the mechanics and in the elec-
tronics, the optics developments have been presented in another paper (ref. 3).

1. MECHANICS IMPROVEMENTS

1.1 Machine Alignment

Due to the fact that the machine framework is made of welded iron plates, a correct
alignment is a critical operation: this problem is much easier to solve in the case of
cast iron blocks. However, to make these inconstant misalignment tolerable, we have taken
at CERN the following steps.

a) Periscope and periscope motor have been coupled by means of a knee-cap.
b) A certain amount of backlash has been allowed between the cone and the encoder. For this reason the star cotter system (which blocked the two items rigidly) has been discarded and a single cotter system introduced, which
allows an easy re-alignment of the cone-encoder axes.

However, we noticed that even if the alignment of the axes is made with the utmost
measurable precision, after about 2000 hours of operation, the remaining mis-alignment has
caused either:

a) $\theta$ error, due to the azimuthal backlash between the cotter and the encoder
housing, or, if the cotter is too rigid in the cotter slot,
b) The coming into contact of the two glass discs, due to a stress between fixed
and rotary parts of the encoder
In order to eliminate these troubles, we use an elastic cotter which allows a slight radial movement without azimuthal backlash.

1.2 Cone-periscope system on LSD 2.

Let us remind that cone and periscope on LSD 1 have been manufactured using "Anticorodal" blocks, thermically stabilized, rectified and hardened by an oxydizing treatment : the periscope was guided by a metal bushing.

To obtain more robustness and less friction for the second machine, we used iron blocks and a slide gear system which assures a backlash free guidance of the periscope.

1.3 Adjustable slit position on LSD 2.

Analysing the RAVEN displays and the colibration results on LSD 1, we realized (Ref. 4) the importance of accurately positioning the slit. So we supplied the LSD 2 with an adjustable slit support.

1.4 Adjustment of the periscope linear encoder position.

On LSD 2 we installed a new linear encoder and reference mark system : both gratings are carried by the same strip of glass. So, in order to adjust the value of the \( R_0 \) parameter (which plays an important role in the calibration (ref. 5), we have mounted the Heidenhain head on a vertical high precision slide-rail, controlled by micrometric screws (fig. 1).

1.5 Periscope linear potentiometer.

A linear potentiometer, mounted on the periscope, is used by the manual periscope position servo and the AGC circuit. Fig. 2 shows an elastic mechanical element which allow, without damaging the potentiometer, a further movement of the periscope even if cursor reaches its lower limit.

2. ELECTRONICS IMPROVEMENTS

2.1 Noise.

The greatest troubles we had on LSD 1 were connected with the superimposition of noise to the measurement pulses. So we studied in detail the different effects of the noise, its sources and the possibilities to eliminate them.

2.1.1 Principal effects of noise

The pulse analysis system is closely derived from the Berkeley design (Ref. 6). However, the valid pulse criterion, based on the number of digital steps counted before and
Fig. 1
after the pulse top, consists of 5 up-5 down OR 3 up-5 down (instead of 5 up-5 down). The noise presence causes the following effects:

a) The 0 coordinate, if we measure it at 1 step from the top (LSD 1), may be wrong if the noise level exceeds 1 step (150 mV) (fig. 3).
b) Due to the fact that the up (respect. down) counter is reset by each down (respect. up) count, we might lose good pulses, particularly those having a small pulse height (6-7 counts).
c) In the cone plane, the image of the sides of the film gate is not completely dark, due to the presence of shifted ghost image (ref. 3).

Since the light intensity of the ghost image is in the order of a few percent of the directly projected image, the AGC attempts to normalise the noise. Thus a lot of spurious digitizing are created.

2.1.2 Noise sources.

The total noise is attributable to several noise sources:

a) Schotky noise of the photomultiplier (PM)
b) Secondary emission in the photomultiplier.
c) Spurions pulses, which are induced in the cable connecting PM and VA.
d) Thermal noise of the electronic components.
e) Noise from the ground of the common power supplies.
f) Induced noise from ground loops.
g) Induced noise from parasitic fields acting on electronic circuits.

2.1.3 Means to overcome the noise.

2.1.3.1 Filter systems

The first attempt to extract the useful pulses out of the noise was made by an electronic filter circuit (Ref. 7).

It happened that at small radii already the filter delayed, due to its RC time constant, the useful pulses. It was not possible to correct this delay effect entirely by software corrections. At large radii the equivalent frequencies of the pulses are in the range of the noise frequencies and it was thus, by principle, impossible to filter out the useful pulses.

Thus the efforts to reduce the noise figures were controled on the principal noise sources as mentioned under 2.1.2.

2.1.3.2 Several ways to reduce the noise.

a) Schottky noise was appreciably reduced by using a photomultiplier with appropriate photocathode (S-20) and by using newly developed types of splitting mirrors (see the previous paper).
$R = \text{constant}$

$\alpha = 0^\circ$

0.1 ms/cm

0.5 V/cm

$\alpha = 20^\circ$

0.1 ms/cm

0.1 V/cm

Fig. 3
b) The effect of secondary emission of the first dynodes of the dynode chain was reduced by the application of the highest possible voltages, stabilized by Zener diodes.

c) Voltage divider network and video-amplifiers were put into the PM housing directly to provide the shortest possible connections. This enables to normalize the pulses prior to their transfer over relatively long cables. However, the AGC circuit has been installed very close to the video-amplifier.

d) Advancement in the state-of-the-art of integrated circuits allows a wider choice in the field of the low-noise operational amplifiers.

e) Each analog circuit cord is equipped with its own power supply. Transfer of analog signals to the logic circuits is done by means of differential amplifiers with high common mode rejection ratio.

f) Ground loops have been avoided by connecting all ground lines to a common ground point in a star-like manner.

g) All analog circuits including the analog to digital converter (ADC) were carefully shielded.

All the corrections mentioned have been applied to LSD 2, while LSD 1, working with a simple $\sin^2$-filter, got only those improvements mentioned under c), d), e) and f). The output signals of the VA, shown in fig. 4, allow to assess the improvements obtained on both machines.

2.2 Analog circuits development

2.2.1 AGC circuits

The pulse height of the VA output signal is affected by variations of backround density on the film, which are essentially due to:

a) Uneven illumination of the film

b) Partial azimuthal polarization around the optical axis

c) Uneven illumination of the chamber

The AGC has been especially designed to eliminate these effects. The basic operation carried out by both AGC circuits, may be described as the calculations of the signal-to-background ratio (see fig. 5).

The aim to obtain (for a given radial track) the relation

$$\frac{I_1}{F_1} = \frac{I_2}{F_2} = \text{const.}$$

(1)

The AGC perfoms the above division and outputs analog signal. Relation (1) means that the AGC correct only linear variations between the VA pulse height and the background amplitude.
LSD1
PM : XP1110
0.2 ms/cm
1V/cm
Old configuration

LSD2 and
LSD1 new configuration
PM : XP1110
0.2 ms/cm
0.5V/cm

LSD2
PM : XP1002
0.2 ms/cm
0.5V/cm

Fig. 4
Until now, two non linear effects have been detected:

i) A spurious light may come onto the slit. It could be generated either by light sources other than the xenon lamp or by diffraction of tracks on the film.

ii) The optical density of bubbles or background on the film does not lie on the linear portion of the curve in the plot film density versus logarithm of the exposure (fig. 6).

Let us remind the following definitions:

a) Film optical transmission is given by the ratio of the light passing through the film to the light incident on the film.

b) Film optical density.

c) Film exposure E is the incident energy per unit surface.

Let us define a radial particle track.

\[ A_s \] the total slit area
\[ A_b \] the slit area covered by bubbles.

Consider two different illumination conditions:

Condition 1.

Background: exposure \( E_{f1} \), transmission \( T_{f1} \) and, from b), density \( D_{f1} = - \log T_{f1} \)

Bubbles: exposure \( E_{b1} \), transmission \( T_{b1} \), density \( D_{b1} = - \log T_{b1} \)

The ratio of the signal amplitude \( I_1 \) to the background amplitude \( F_1 \) may be expressed as:

\[
\frac{I_1}{F_1} = \frac{A_b}{A_s} \frac{T_{b1}}{T_{f1}} + \frac{(A_s - A_b)}{A_s} \frac{T_{f1}}{} = \frac{A_b}{A_s} \left( \frac{T_{b1}}{T_{f1}} - 1 \right) + 1
\]  \hspace{1cm} (2)

Condition 2.

Background: exposure \( E_{f2} \), transmission \( T_{f2} \), density

\[ D_{f2} = - \log T_{f2} \]

Bubbles: exposure \( E_{b2} \), transmission \( T_{b2} \), density \( D_{b2} = - \log T_{b2} \)

Similarly the ratio of the signal amplitude \( I_2 \) to the background amplitude \( F_2 \) is given by:

\[
\frac{I_2}{F_2} = \frac{A_b}{A_s} \frac{T_{b2}}{T_{f2}} + 1
\]  \hspace{1cm} (3)
To obtain a correct signal normalization by the AGC in both conditions, relation (1) must be satisfied, i.e.

\[
\frac{A_b (T_{b1} - T_{f1})}{A_s T_{f1}} + 1 = \frac{A_b (T_{b2} - T_{f2})}{A_s T_{f2}} + 1
\]

(4)

\[
\frac{T_{b1} - T_{f1}}{T_{f1}} = \frac{T_{b2} - T_{f2}}{T_{f2}}
\]

\[
\frac{T_{b1}}{T_{f1}} = \frac{T_{b2}}{T_{f2}}
\]

If we now take the logarithm

\[
\log \frac{T_{b1}}{T_{f1}} = \log \frac{T_{b2}}{T_{f2}}
\]

\[
D_{f1} - D_{b1} = D_{f2} - D_{f1}
\]

\[
D_{b2} - D_{b1} = D_{f2} - D_{f1}
\]

\[
\Delta D_b = \Delta D_f
\]

(4')

Consider fig. 8: the slope \( \gamma \) of the curve density versus logarithm of exposure is defined as:

\[
\gamma = \frac{\Delta D}{\Delta \log E}
\]

(5)

If we assume that the chamber is such that

\[
E_{b2} = K E_{b1} \quad \quad E_{f2} = K E_{f1}
\]

(6)

Then

\[
\log \frac{E_{b2}}{E_{b1}} = \log \frac{E_{f2}}{E_{f1}} = \log K = K'
\]

\[
\log E_{b2} - \log E_{b1} = \log E_{f2} - \log E_{f1}
\]

\[
\Delta \log E_b = \Delta \log E_f = K'
\]

(6')
AGC 2

Fig. 8
Relation (5) applied to the bubbles and to the background gives:

\[ \gamma_b = \frac{\Delta D_b}{\Delta \log E_b} \quad \text{and} \quad \gamma_f = \frac{\Delta D_f}{\Delta \log E_f} \]

Introducing (4) and (6) in (7) we obtain.

\[ \gamma_b = \gamma_f = \text{const.} \quad (8) \]

If \( \gamma_b \) is different from \( \gamma_f \) or spurious light is not proportional to the background density, the AGC, is good as it may be, will not be able to correctly perform the division in relation (1).

Referring to i) we have tried to protect the slit from the external light, however it was impossible to eliminate all the spurious light so, especially on LSD 2, we have attempted to reduce this effect to a minimum by using a narrow slit and to keep it constant in order to make a software correction possible (ref. 5).

The effect described in ii) may be entirely eliminated by appropriate film exposure and development.

2.2.2 AGCI and AGC2 (figs. 7 and 8)

Due to the fact that the AGCI performances were not entirely satisfactory by ionization measurement (see paper on ionization) AGC2 was designed and mounted on LSD 2.

The following comparison shows the drawbacks of AGCI and the improvements brought by AGC2.

<table>
<thead>
<tr>
<th>AGCI (ref. 8)</th>
<th>AGC2 (ref. 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Allows density background variations in a range of 1 : 10</td>
<td>Allows density background variations in a range of 1 : 50</td>
</tr>
<tr>
<td>2. Performs the I/F division by means of an &quot;open loop&quot; circuit. Precision depends on the variation law of the source driven resistance of the FET performing the division.</td>
<td>Performs the I/F division by means of a &quot;closed loop&quot; analog divider. The quotient is screwed to a reference value ( V_o ) by the feed-back loop.</td>
</tr>
<tr>
<td>3. Memorizes a constant value of the background ( F ), at the pulse detection time. But, during the pulse, the background slope may be different from zero (fig. 9). In this case the input amplitude will not reach after the pulse, the memorized value. In this case, the pulse detection circuit will not be reset.</td>
<td>Memorizes amplitude and slope of the background. Sums the first one with the integral of the second one. If during the pulse derivative of the background is constant (fig. 10) the denominator ( F ) may be considered as following the background slope. In any case, the pulse detection circuit will be reset.</td>
</tr>
</tbody>
</table>
4. Is not equipped with a safety system blocking the discriminator in the case of a step background variation (black flare on the film etc).

5. Its tuning is not easy due to interdependence of the different potentiometers.

Is equipped with a safety system blocking the feedback loop if the pulse width detected is 2-3 times larger than expected. This safety is served to the spiral radius. Is tuned by 4 independent potentiometers.

Fig. 11 demonstrates the efficiency of AGC 2 versus AGC1.

2.3 **ADC circuits on LSD1 and LSD2**

2.3.1 **Basic principles of LSD1 ADC (fig. 12)**

A counter (CTR) controls a Digital to Analog Converter (CDA). An operational amplifier adds the output voltages of the CDA and of the track pulse. The output of this amplifier is given by:

\[ S = K \cdot (\text{CDA output} + \text{track PH}) \]

The CDA pulse being positive and the track pulse negative, this amplifier allows to detect the sign of slope variations of the track pulse:

- **UP** → positive output voltage
- **DOWN** → negative output voltage
Two comparators having one a slightly positive and the other a slightly negative reference voltage, assure the shaping of the UP and DOWN signals. These signals control a clock and the sign of the counter increment. Clock gives pulses only in presence of an UP or a DOWN condition.

If there are no track pulses or the two pulses have the same amplitude, the clock is blocked. When several flip-flops of the CTR change state at the same time (for instance when the counter contents goes from $7_8$ to $8_9$), one base parasites on the CDA output.

2.3.2 Basic principles of ADC2 (fig. 13)

With the 5 bits giving the PH one can determine a maximum PH value of $37_{10} = 31_{8}$; for this reason in this converter we utilize 31 comparators (fig. 14) - Each comparator gives a step of PH.

These comparators receive on "non inverting input" the AGC output and on "inverting input" a reference voltage more or less high according to the rank of the comparator.

The reference voltage is $+5V$. Each step will therefore have an amplitude of $\frac{5}{31} \approx 160 \text{ mV}$.

We use both the direct and the complemented output of the comparators, in order to realise a decoding giving two square waves A and B (fig. 15), deployed by $90^\circ$, but whose phase changes with UP or DOWN condition:

- decoding $\bar{A}B + AB$ gives the weight $2^0$
- voltage B gives the weight $2^1$
- decoding $(4.\bar{8}) + (12.\bar{1}6) + (20.24) + 28$ gives the weight $2^2$
- decoding $(8.\bar{1}6) + 24$ gives the weight $2^3$.
- comparator 16 gives directly the weight $2^4$.

The detection of the relative position of leading and trailing edges of waves A and B permits to obtain the UP and DOWN conditions as well as the clocks UP and DOWN (figs. 16 and 17).

2.4 Integrator

Let us consider the PH: it is dependent from the angle slit-track, so that the information useful for the ionization is given by the first 13cm in space of the tracks. In order to be independent from this angle, we equipped LSD2 with an integrator, which gives a pulse whose PH is proportional to the area of the AGC pulse (fig. 18).
Comparateurs

A
B

CAD 2
Courbes pour impulsion saturante

Fig. 15
INTEGRATOR

\[ \alpha \neq 0 \quad \alpha = 0 \]

Fig. 18
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A POSSIBLE IMPROVEMENT ON TRACK DETECTION
BY VARIATION OF THE SLIT LENGTH

CERN-LSD Group (presented by K.K. Geissler)

To date, all Spiral Readers operate with a slit of fixed dimensions. It may be replaced by another of different dimensions, yet its length cannot be altered during the periscope movement.

The slit should fulfil two contradictory requirements:

i) In the vertex region it has to be narrow and long in order to accomplish a filtering function, i.e. detect only those tracks that belong to the vertex and omit particularly beam tracks passing very near to the vertex;

ii) Far away from the vertex it ought to be shorter in order to improve the track detectability, especially when the subtended angle between track and slit becomes larger than 20°.

Normally one tries to meet both requirements by a compromise in the slit dimensions, depending on track sizes, curvatures etc.

In a 1971 internal CERN report E. Rossa emphasized already the usefulness of a variable slit length.

The following proposal concerns an arrangement that allows the reduction of the slit length at any moment during the periscope movement, thus enabling to operate in the vertex region with a long slit and in the far field with a shorter one. Moreover, this could be installed without excessive modifications to the existing periscope assembly or photomultiplier housing. The basic arrangement would simply consist of a fiber optics face plate for the slit, a double light guide, a two-arm relay light guide and a shutter. It would operate as follows:

- The light falling upon the slit is separated into two channels by using a double light guide composed of two distinct light guides, each having a square shaped end face as shown in fig. 1. Each light guide picks up the light falling through the corresponding areas of the slit (which touches the end faces) and transmits it separately to the PM. Blocking the light coming through one of the light guides by a shutter is equivalent to a reduction of the slit length by an amount determined by the partition ratio at the entrance end.

A fiber optics face plate is the best suited substrate for the slit. It may be cut, ground, polished and anti-reflection coated like a solid piece of glass, but essential for the set-up is the fact that regardless of its physical thickness the optical thickness is
zero. Square shaped pieces of fiber plates may be ground on two lateral faces to be used afterwards as references for the exact positioning of the slit. Fastening and adjustment of the plate in the periscope will be done by screws as is done in the existing machines.

In contact with the rear surface of the fiber plate will be the rigid fused end of a double light guide, consisting of two image guides ZM1, 2x2 mm of SCHOTT. These are called "raw bundles" which have only one end fused into a rigid rod. The rest of the length is left as a free-moving bundle. This is of particular interest since it allows the exit end to be given a special shape. For the considered application two such raw bundles are fused together at their rigid ends and then bent by 90°, as shown in fig. 1. The two bundles terminate in two concentric bushings, where one bundle is distributed concentrically around the other, inner bundle. This arrangement will keep the two light transmission channels separate during the rotation of the cone.

The relay light guide from the optical link within the periscope to the PM has to be made in a similar way, i.e. with a concentric entrance end and a two-arm exit end. Both arms will illuminate the same PM.

The shutter will block the light coming through one of the two channels. The type of shutter remains to be determined. One possibility is a liquid crystal shutter as they are coming of age now. The rise times of liquid crystal cells of 6μ active thickness are in the range of 1 to 5 ms. They require only a few μA at 20 V for excitation. A drawback of these cells is that they do not show an opaqueness of 100% when activated. At saturation they still scatter about 7% of the incident light in a forward direction, i.e. onto the PM, where it would raise the background noise level.

If this is intolerable, a shielded electromechanical shutter with a black teflon blade could be used instead. The activation time to fully retract the blade can be made to be in the range of 1 ms, which is equivalent to an angle of about 6° of one spiral.

Some additional points, directly related to the foregoing set-up, are mentioned briefly below:-

- Cutting the slit length also involves cutting the light flux falling upon the PM. The AGC will compensate for this effect.

- Cutting the slit length from one end only by an amount ΔL will shift the midpoint of the slit by ΔL/2 and will thus alter the radius of the subsequent spirals by ΔR. If, for instance, 400μ are cut away at the upper end of a slit of 1000μ length, the new radius R' will be

\[ R' = R - ΔR = R - \frac{ΔL}{2} = R - 25 \text{ least counts} \]
with the least count of the radius coordinate being 8µ. The off-line software can easily take care of this effect.

- Cutting the slit length can be done at any radius. It is sufficient to add to the control program a few statements which will give a hardware instruction to actuate the shutter when the preset radius is reached.

- By proper adjustment of the fiber plate in front of the double light guide any amount of slit length reduction can be set. After this setting a recalibration of the radius is necessary.
FIRST DIGITIZATIONS OF 12" ANL BUBBLE CHAMBER PICTURES ON CERN LSD2

CERN-LSD Group (presented by E. Rosso)

Recently a certain number of large bubble chambers have been started into production; in the near future a few more (in particular BEBC) will be operational.

Thus we decided to study the possibilities of digitizing dark field frames on CERN LSD's. Both the AGC1 and the AGC2 were unable to discriminate and normalize pulses generated by transparent tracks: a complete new design was so compulsory.

A first test circuit has been already achieved and mounted on LSD2 to digitize frames from the 12" ANL bubble chamber.

An old AGC2 circuit has been modified in order to allow a ratio I/F larger than 1 (ref. 1). It should be noted that this test has been introduced in the general planning foreseen for the tuning of the LSD2; all other parameters of the machine were therefore the same used for production of experiment 42 with 2 meter chamber film (slit 1000 x 40 \( \mu \)m\(^2\), integrator, etc.). Even if limited, the results so far obtained, have been very encouraging (figs.1, 2).

In a near future a new AGC circuit will be designed, especially for dark field film; we shall besides try to optimize the optical, mechanical and electronic parameters of the machine as a function of the tracks thickness and radius of curvature.

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SOME DIGITIZATIONS FROM ARCONNE 12\' BC ON SRS

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Sweden.

A first test has been performed to measure on film from BC with light tracks on dark background.

An inversion and a bias of the PM-tube-current is introduced to get voltage-levels and peaks acceptable for the A.G.C. (Fig. 1). Fig. 2-5 shows some examples of track configurations and corresponding R-\( \theta \)-plots. The events are scanned out to \( \approx 2 \) cm on the film. Slit dimensions in this test was 700x80 \( \mu \) and the pulse-acceptance-criteria had to be set very sensitive to detect the tracks and therefore also much noise is detected.

By selecting a longer and narrower slit and making some adaptations of the A.G.C. it seems possible to measure this sort of film on S.R.S.