At the Argonne meeting of October 1968, we reported on
two experiments in progress using the Columbia HPD in the
pattern recognition mode.\textsuperscript{1,2} After three additional months
of intensive production running, our IBM 7094 was replaced
by an IBM 360/91. Between computer center system shakedown
(OS/MVT with LASP) and our own reprogramming effort, it was
October 1969 before we achieved a production state on the /91.
Our purpose here is to bring the Argonne report up to date
with regard to the two experiments, and describe a third
projected experiment in some detail. A short summary of
these experiments is shown in Table I.

The processing chain is similar in each case. The HPD
is run under control of the 360/91, the digitizing for one
frame being retained in core until the processing cycle is
complete. Each scan is processed by the track-following
program\textsuperscript{3}, now being run in a new Fortran version. The
segments generated are then "linked" into maximal length
strings and the strings from the normal and orthogonal scans
are "merged" to form complete tracks. This marks the end of
the on-line processing cycle and the master point measurements
for each track, along with the associated hit-count information

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are output to the "abstract tape" for further (experiment dependent) processing, generally on the 360/44. Track-following and its supporting programs are overlayed into a region of 65 K words, exclusive of the digitizing buffer. The entire on-line cycle takes about 7 CPU seconds. The real time distribution of the 7 seconds is governed by use of a dynamic priority scheme, so that the HPD uses no more than 25% of the available CPU time during periods of continuous demand.

I. THE $K_\pi$ BRANCHING RATIO EXPERIMENT

This experiment is now essentially complete. A preliminary result will be presented at the Washington Meeting of the American Physical Society (April 1970). The experiment has proceeded as described at the Argonne Conference.¹

II. STUDY OF $\Sigma$ LEPTONIC DECAYS

The automatic scan and measurement of $\Sigma$ decays which was reported at Argonne last year has just been resumed after reprogramming for the 360/91. Rates and efficiencies on the 360/91 seem to be nearly the same as were reported at Argonne for the system using an IBM 7094. The automatic system is designed to find and measure decays of the $\Sigma^+$ and $\Sigma^-$ produced by a stopping $K$ beam in the Brookhaven 30 in. hydrogen bubble chamber. Only those events consistent with the very rare decay mode $\Sigma \rightarrow n\nu$ and inconsistent with the two body decay $\Sigma \rightarrow n\pi$ are passed on for final identification by a hand scanner and further analysis.
A problem in this experiment has been that $\Sigma^+$ and $\Sigma^-$ events are often confused by the system. A $\Sigma^+$ decay misidentified as a $\Sigma^-$ often meets the criteria for a candidate for the decay $\Sigma^- \rightarrow n e \bar{\nu}$, and floods the output sample with unwanted events to be weeded out by hand. This problem has been considerably reduced in the past year, to the point that for every 100 true $\Sigma^-$ events successfully measured, a sample of only 11 events is presented in the output for hand weeding. The final identification of unwanted events by hand is very fast.

III. STUDY OF $\omega^0 \rightarrow 2\pi$ DECAYS

The new experiment is concerned with the $2\pi$ decay mode of the $\omega^0$ particle. The $\omega^0$ particles are produced in the reaction $K^- p \rightarrow \omega^0 \Lambda^0$ with the incoming $K^-$ beam at 1.75 BeV momentum. The experiment was run in the Columbia-Brookhaven 31-in. bubble chamber at the AGS. There have been 860,000 pictures taken so far.

The events have a two-prong with an associated vee topology on the film. The expected number of frames with events is 200,000 per $10^6$ pictures, the expected number of $\omega^0 \Lambda^0$ events being 20,000.

The primary reason for the use of the HPD in this experiment is the large number of frames to be measured. To minimize processing time, however, the HPD will process only those frames with an event. The pre-scanning will be done manually. It will be necessary for the HPD to scan all three views of a selected frame in both the normal and the
orthogonal modes. The digitizings are input to the track-following program, the output of which is raw data for the event recognition program.

The track following program used in this experiment is the same as we used in the past and has been described in detail previously.

The off-line processing is carried out on a separate computer, an IBM 360/44, in two main steps:

Step 1. **One View Processing**

Each view is processed independently at this stage, the goal being to remove segments that are not part of an event. The procedure is as follows:

a. Using the fiducials found by the HPD, the tracks are transformed into the front glass coordinate system. A maximum of five evenly spaced points are selected along each track. Approximately 150 track segments enter here, 120 of which come from the normal scan.

b. The pseudo track segments due to fiducials and the edge of the chamber are removed from the sample. They amount to about 20 tracks.

c. Using a fiducial volume, the remaining tracks are classified according to their end points. Class 4 tracks are deleted here. Class 3 tracks are kept here and deleted after links. Class 1 and Class 2 tracks are potential candidates for events. A circle is fitted to Class 1 and Class 2 tracks. A straight line fit is used for the shorter ones.
<table>
<thead>
<tr>
<th>Classification Code</th>
<th>Meaning</th>
<th>Aprox. No. per View</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both end points inside F.V.</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>One end point inside F.V.</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Both end points outside and all points outside</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Both end points outside and at least 1 point inside</td>
<td>15</td>
</tr>
</tbody>
</table>

The end point of a track that falls within the fiducial volume is entered into a 20 x 80 grid. Each box covers 1 cm² in space and has a capacity of 5 entries. Class 1 tracks contribute 2 entries while Class 2 tracks contribute 1. The information is as follows:

1. Track number.

2. A code to distinguish the two end point entries of a Class 1 track.

3. A code to distinguish the direction in which the track points.
d. The grid of Section C is used to "link" and "merge" tracks with no overlap. Each track is extrapolated by an amount depending on its length and radius. This is done to avoid uncertain extrapolation.

The criteria for a "link" or "merge" are:

1. When extrapolated to a line halfway between the endpoints, the tracks must have a lateral displacement smaller than some cutoff value.
2. An overall circle fit to both tracks must have a small rms deviation. If a "link" produces a through track, the resultant track is eliminated. About 30 links/frame-view are made.

e. A search is made for possible overlapping segments from the normal and orthogonal scans. This happens about 2-3 times/view. Such overlapping segments are merged here.

f. The raw average points of the remaining tracks (∼ 25 per frame) form the output for step 1. The execution time for step 1 is 0.95 sec per view.

Step 2. Three Dimensional Reconstruction and Event Finding

The output of Step 1 from the three views form the input to this stage. The processing is as follows:

a. The tracks in each view are separated into beam-like and non-beam-like. Only the non-beam-like tracks (∼ 10 per view) are used in the event finding phase.

b. A pair of views are considered at a time. Tracks of one view are "matched" with those of the other. For a successful "match" the following criteria must be satisfied:
1. Tracks must have the same sign of curvature.
2. They must overlap, when projected on a common line perpendicular to their intercamera direction.
3. Their lengths must be either greater than 6 cm or be comparable. The ratio \((l_1 - l_2)/(l_1 + l_2)\) is used as a measure.
4. Three "corresponding" points are formed. They are spaced evenly along the shorter track. The calculated depth \((z)\) for these points must be within chamber limits.
5. The dip angles for the two sections (points 1–2 and 2–3) are computed with their difference, \(\delta(\tan(\lambda))\). The approximate angle between the track and the intercamera direction is computed \((\phi)\). The quantity \(|l\delta(\tan(\lambda))\sin\phi|\) is used as a measure of correspondence for the pair, where \(l =\) length of the track. For matching tracks the maximum combined length from the two views is used. A helix is computed to represent the track in space. About 30 such helices are formed per frame.

c. Matching tracks in 3 views are formed out of the 2-view sample above. A consistency check of the helices involved is made here. Three view "matches", whenever made, replace their corresponding two-view "matches". This reduces the number of helices somewhat. The output consists of a number of tracks in 3 dimensions.
d. All intersecting helices are examined. They represent potential two-prong or vee candidates. For two helices to intersect, their projections on the front glass must meet (x-y) and their depth (z) must agree within narrow limits.

ACKNOWLEDGEMENTS

We wish to thank F.C. Sake and R. Pisani for their invaluable help in the areas of systems programming and computer operations, respectively.

REFERENCES


<table>
<thead>
<tr>
<th>Experiment</th>
<th>Reaction</th>
<th>Energy</th>
<th>Chamber</th>
<th>Topology</th>
<th>Rate</th>
<th>Events Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) $K_1^{--}\pi^+/K_1^{-}\pi^0$</td>
<td>$K^-p-K^0n$</td>
<td>1.75 BeV/c</td>
<td>31 in.</td>
<td>—</td>
<td>300 fr/hr</td>
<td>500,000 frames</td>
</tr>
<tr>
<td>2) $\Sigma$ - leptons</td>
<td>$K^-\Sigma^\pm_{\pi}$</td>
<td>at rest</td>
<td>30 in.</td>
<td>—</td>
<td>100 evs/hr</td>
<td>30,000 events</td>
</tr>
<tr>
<td>3) $\omega - 2\pi$</td>
<td>$K^-\Lambda^0\omega$</td>
<td>1.75 BeV/c</td>
<td>31 in.</td>
<td>—</td>
<td>100 evs/hr</td>
<td>200 frames</td>
</tr>
</tbody>
</table>
DISCUSSION

A. WERBROUCK (Torino): How expensive is this operation in time and memory space in the two computers involved?

C. BALTAY: The 360/44 is a 32 K machine with 32-bit words, and the program pretty much fills that, and takes 4 or 5 seconds an event. On the 360/91, the program is of the order of 400,000 bytes (100,000 words), it demonstrates Parkinson's Law beautifully; the same program that fitted into the 7094, 32 K, now takes that much space on the 91, just because we have the space.

W. SLATER (UCLA): Why do you use the 360/91 for the HPD on-line work?

C. BALTAY: Economics and politics. We wanted our own small on-line computer but the economics of the situation prevented us, and Columbia insisted that we use the 360/91. We cannot really complain; we are on-line and are using 25% of the CPU day and night, when it is running.

R. ROYSTON (SCS): Are you using 25% of all CPU time, or are you using 25% of usefully available CPU time?

C. BALTAY: When the 91 is up and running, we are on-line and are using 25%; in other words we use something like 3 seconds out of 12.

R. ROYSTON (SCS): The rest of the world is getting considerably less than 75%, then?

C. BALTAY: No. This is CPU time.

D. BURD (Columbia): At present our CPU is under-utilized. We are in fact limited by our inability to read cards into the system, set-up tapes, get print-outs, etc., fast enough to keep the CPU busy.

R. ROYSTON (SCS): Let us have another try. Are other people doing three times as much as you, or just about as much as you, with the rest of the time idle?

C. BALTAY: That is hard to establish, as far as I can tell. Usually when we are on, we are not slowing other people down, although at peak times, when they throw us off, the throughput increases somewhat. It is on the borderline. I think that when the machine is normally used, we are not costing anything, but when the machine is very heavily used, we are. Is this an answer to your question?

R. ROYSTON (SCS): It is an involved question.
J. MULVEY (Oxford): What is the time required to make the 3D-Match of the 30 or more tracks?

C. BALTAY: That is done on the 360/44, and takes 2-3 seconds per triad.

G. BROWNING (Glasgow): What configuration has the Columbia 360/91?

D. BURD (Columbia):

Configuration of 360/91 at Columbia


Running under OS/MVT + LASP (the system uses 650 K bytes) with the following configuration of peripherals:

- 2 card reader/punches
- 11 tape units (mixed 7 and 9 tracks)
- 4 high speed line printers
- 2 set-up disk drives (IBM 2311)
- 3 on-line disk units - 4 drives each (IBM 2314)
- 2 drums - for system use only (IBM 2301)
- 1 on-line CRT display unit (IBM 2250)
- 1 data cell (for remote job entry users)
- 1 off-line microfilm plotter (SC 4060)

HPD connected to a selector subchannel of the multiplexor via an IBM 2701.

Remote job entry: Numerous

Typewriter + CRT terminals supported under the CLEO system