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A SYSTEM OF 4400 SILICON MICROSTRIPS READOUT WITH
ANALOG MULTIPLEXED ELECTRONICS USED IN THE WA75 EXPERIMENT

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ABSTRACT

We describe an array of 16 planes of Microstrip Silicon Detectors used in the SPS-WA75 experiment. Its aim was to give predictions on the localization of interactions of 350 GeV/c particles in a thick emulsion target, together with a 3-dimensional reconstruction of the secondary tracks. It is shown that the detector array contributes to the vertex location errors by $\pm 20 \mu\text{m}$ and $\pm 500 \mu\text{m}$, respectively transverse to and along the beam direction. Mechanical layout and electronics are presented. All strips are analogically read-out, using a pulse stretching method which allows a serial-parallel multiplexing of 32 channels, and therefore lowers the electronics cost. Operation and detector performances are described with a study of clustered events.

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1. INTRODUCTION

Photographic emulsion used as a target and detector has, so far, the best tridimensional resolution to observe the decays of heavy flavour particles. As the production cross section of these particles is very small ($\leq 1 \mu\text{b}$), only a highly irradiated emulsion ($2000 \text{ particles/mm}^2$) combined with a selective trigger can render a search effective. The immediate drawback of these conditions is that the emulsion scanning becomes very laborious unless the interaction vertex of the triggered event can be predicted with sufficient accuracy.

To this end, two systems, a beam hodoscope and a vertex detector have been constructed for the WA75 [1] experiment which was operational at the CERN-SPS during summer 1983 and spring 1984. The main goal of the experiment was to observe the decay of beauty particles in a photographic emulsion stack 2 or 4 cm thick, recording only those events in which one or more muons are detected in the final state. Recently, an event with associated production of two beauty particles, both decaying into charm particles was observed [2].

The Beam Hodoscope (BH) and Vertex Detector (VD) form two separate arrays, consisting of planes of Microstrip Silicon Detectors (MSD), 16 planes in all, placed respectively upstream and downstream of the target.

Their main aim is to:

- (a) provide a precise prediction, of the impact point of a beam particle transverse to the beam (BH);
- (b) determine the interaction vertex location along the beam by reconstruction of the trajectories of the emitted secondary particles and provide an event topology to be compared with the one found in the emulsion (VD).

The detector design constraints have been dictated by the following experimental conditions:

- (a) Due to the problem of multiple scattering in the thick target, it is not intended to use the (VD) to find secondary vertices, for which task the emulsion is much more powerful (micron resolution and a grain density of 250 dots per mm). Hence, Monte-Carlo simulations have shown that the resolution achieved by 50 μ m strip detectors can fulfill the requirements on primary vertex localization.
- (b) Charged secondaries produced by 350 GeV/c pions are emitted in a forward cone of ± 3 degrees and their average multiplicity is about 12. This means that transverse detector dimensions of moderate size (10-40 mm) are capable of intercepting most of the secondary tracks. In addition, larger mwpc's record tracks at larger angles which miss the silicon detectors (VD). The essential feature required from the detectors is obviously an excellent multitrack resolution: the intrinsic capability of a (MSD) is as good as its strip width. In practice, ambiguous cases might occur when two adjacent hits are generated either by a single inclined track or a genuine double track: a dedicated study of the cluster size as a function of the angle of the track is presented in sect. 5.
- (c) Regarding the electronics, no fast decision is expected from the (MSD) arrays. The "event trigger" signal (muon(s) detection) is available at the control room 160 ns after the passage of the particle; the number of events to be recorded ranges from 10 to 100 per second, depending on the trigger selection. The beam rate is 10^5 /s in a spot size of 2 mm (FWHM).
- (d) In such a fixed target setup, contrary to the situation in colliding beam experiments, little constraints are imposed on the transverse dimensions of the detector arrays. However, along the beam direction, as our main trigger is based on muon detection, a distance as short as possible has to be maintained between the target and the downstream muon filter, in order to minimize the contribution of π and K decays. Given the limited space available, the compactness of the (VD) along the beam is of primary importance.

2. DETECTORS AND LAYOUT

In order to retain a valid vertex prediction, a tridimensional matching has to be performed between the track pattern found in the emulsion and the one reconstructed in the (VD). Monte-Carlo optimization led us to the configuration shown in fig. 1. To facilitate correlation between track projections and to obtain a good spatial reconstruction, two pairs of orthogonal planes (UV) (numbered 12,14,15,16), rotated by 45° with respect to the standard (Y,Z) planes were introduced in the (VD). The 50 μm , (UV) planes at the end of the setup, resolve tracks in the cone where the track density is largest. The center of the target is located at 65 mm from the first V.D. plane. The main parameters are summarized in table 1. This setup represents in total 1200 and 3200 strips in the (BH) and (VD) respectively.

2.1 Detectors and connections

The detectors are made^(*) from a n-doped silicon crystal, 300 μm thick. Their resistivity ranges from 3 to 7 $\text{k}\Omega\text{ cm}$. The p^+ diode structure is made with the process of passivated ion implantation [3]. The polarization voltage was applied on the side opposite to the diode structure. No special protective coating was applied.

The detectors are glued on a first support made of fibreglass epoxy, 1.6 mm thick. This support acts as a fan-out circuit to adapt the high strip density to a sizeable connector. Odd and even strips are fanned out on opposing ends. The silicon strips are connected^(*) to the circuit traces by ultrasonic-bonding. Mylar screens protect the detectors from the light, and are also used to allow a flushing with dry Nitrogen.

The length of the connection from a strip to an electronic input is constituted of traces on the fan-out circuit about 60-80 mm long plus 80-120 mm of very flexible wire to the preamplifiers: in fact, all the electronics and cables are mounted on a frame F (figs 2 and 3).

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mechanically independent from the base plate P supporting the detectors. The only junction between these two parts is made of these flexible wires, not influencing the detector alignment.

2.2 Alignment

The problem is to control the relative positions and orientations of the three reference frames attached to the (BH), target mover and (VD) as all information must match the reconstructed vertex unambiguously. Due to the lever arms in presence, the detectors have to be positioned with an accuracy of a few microns. Two additional constraints result from the fact that, as seen in fig. 3, (BH) and (VD) are independent objects, separated by the Target Mover (TM); the B.H. has to be displaced to change emulsion stacks.

The alignment procedure is such that we always keep the possibility to measure the position of the detectors in absolute value with respect to a stable reference, controlling any eventual shift or tilt. We proceed as follows (figs 2 and 3):

- (a) A detector is mounted on each side of a steel support plate S, one with the strips vertical and the other with the strips horizontal. Two perpendicular edges of this plate (dotted lines)(fig. 2) are carefully machined, all the plates being rectified as a block. Each detector is now aligned in such a way that its first strip is placed parallel to the corresponding edge of the S plate and at a known distance. An accuracy and reproducibility of $\pm 2 \mu\text{m}$ is achieved and found to be stable over long periods.
- (b) Each S plate is then fixed to a rigid base plate B by means of three "manipulators" M [4]. They consist of thin bars tightly screwed to the S plate and the base plate, leaving no freedom for the S plate to move in its own plane unless compressing the bars. A displacement can however be induced by bending one of the bars by means of the dedicated screw V (fig. 2). A movement of $\pm 50 \mu\text{m}$ amplitude in a direction parallel to the bar can be achieved, for two turns of the screw. The base plates are placed on three spheres, with plane, cone and V contacts, ensuring a reproducible positioning of the arrays.

(c) The reference is composed of two granite blocks B1, B2 adjusted on a granite table T in such a way that their top and lateral faces, ref. H and ref. V, each coincide in a same plane. This is possible as B1 and B2 originate from the same block, machined as a "parallel"^(*) and cut thereafter into two. It is then possible to move a measuring device^(**) along the edge defined by these two faces and, with the manipulators, adjust successively all the S plates in such a way that (a) their lateral edges are vertical and at a known distance from ref. V, (b) their horizontal edges are at a known distance from ref. H. It is then always possible to control these distances. A reproducibility of $\pm 2 \mu\text{m}$ in an alignment can be obtained. The room temperature is stabilized to within $\pm 1^\circ\text{C}$.

3. ELECTRONICS

The signal generated by a Minimum Ionizing Particle (MIP) traversing a 300 μm thick silicon detector is a current pulse generated by the collection of an average of $2.4 \cdot 10^4$ electrons/holes. The collection lasts for about 20 ns, in a totally depleted detector. Such a small deposited charge, about 4 fC, requires a low noise preamplification, achieving an equivalent noise charge figure of $1500 e^-$ (0.25 fC) RMS or less.

Fully efficient detection of a single hit, where the energy is released into a single cell, is certainly achievable with signal to noise ratio $(S/N) \geq 10$, figure to be increased as detection of partial deposit is desired in case of inclined tracks traversing two adjacent cells. If a digital readout method were to be chosen in a system involving several thousands of channels, problems might be anticipated, arising from amplification spread, offset and threshold inhomogeneities, unless some effort is devoted to components selection or individual channel adjustments.

(*) "parallel": block having its opposite faces flat and parallel two-by-two within a tolerance of 3 μm .

(**) 3 Heidenheim linear sensors, 2 horizontal and 1 vertical.

Therefore we chose to develop an analog readout chain, which allows:

- (a) a safe control of individual thresholds, achieved at the expense of a more cumbersome software, as the noise and DC-offset levels of every channel have to be monitored from pedestals measurements (sect. 4.1);
- (b) additional dE/dx information, useful for detailed analysis such as clustering, non-resolved tracks etc.

A low cost realisation was made possible by implementating a multiplexed readout.

3.1 Principle of operation

The basic idea is to use a Track and Hold (T/H) circuit to stretch the peak amplitude of the preamplifier pulse for a time long enough to allow multiplexed readout, saving therefore a large amount of Analog to Digital Converters (ADC's).

The electronic chain is composed of two parts:

- (a) close to the detector: integrating preamplifier, track and hold circuit, analog multiplexer, driving amplifier;
- (b) at the counting room: receiving amplifier, ADC and buffer memory.

The block diagram and timing are shown in figs 4 and 5. In order to cope with the T/H bandwidth, the fast current pulse issued from the detector, is slowed down by an integration such that rise and fall times of 60 and 200 ns are achieved. An external device, scintillators or silicon plates, can then send early enough a signal to all the channels, which stretches the peak values (if correctly timed) for a few hundred nanoseconds. This signal, called Short Hold (SH) has a fixed duration and acts as an analog delay, during which the physics decision whether or not to accept the event is taken. In case of a positive answer, the hold time can be extended up to hundreds of microseconds without significant loss ($< 1\%$ after 100 μs) and the multiplexer starts reading the channels. If the event is not accepted, the stretched pulses are automatically reset to

quiescent line by the falling edge of the SH pulse. Thirty-two channels are read by a multiplexer^(*), operated from an addressing unit (CAMAC). This unit drives in parallel as many blocks of 32 channels as necessary within the system. The signals from the MPX outputs, that are now DC levels, are sent via a driving amplifier and 50 Ω coaxial cable (small number!) to the control room to be digitized. A single unit CAMAC card contains 6 converters^(**) handling 192 channels. A line receiver before each ADC permits gain and offset adjustments. Each ADC is followed by a First-In-First-Out (FIFO) memory^(***) where data is stored after each conversion.

After the MPX scanning is over, FIFO's containing the odd and even channels are respectively daisy-chained so that the data is ready to be read via CAMAC as 16 bit words, containing in the lower bits (1-8) the digitized pulse heights of odd numbered channels and the upper ones (9-16), the even channels. A complete cycle lasts for 120 μ s, independent of the number of channels. This time is small compared to the usual interrupt handling time of the main data acquisition system, which was of the order of 1 ms (PDP 11/44).

Finally, we can make a few remarks about the dead time introduced by operating in track and hold mode.

The short hold duration must be 100 ns plus the delay to obtain a physics decision, the latter being 300 ns for this experiment, leading to a dead time of 400 ns during which the (T/H) circuits cannot accept another event. In addition, as seen in fig. 6(e), when the short hold is reset, an oscillation of the zero base line occurs at the outputs of the (T/H) circuits for about 300 ns. An event occurring during this time can be dangerously altered. For these reasons, any reduction of the (SH) rate is profitable. In this experiment, we are interested in the interaction, being only $6 \div 10\%$ of the total beam rate.

(*) MPX: Analog Devices AD 7506.

(**) ADC: TRW 1001J, 8 bits, 400 ns conversion time, range: 500 mV.

(***) FIFO: AM 2813 ADC, 8 bits, 32 words deep.

Therefore the (SH) is generated by a "multiplicity trigger"^(*) situated behind the target, making the (SH) dead time negligible. The occupation time of an electronic channel for non interacting particles (no SH) is given by the rate per strip, also a factor 100 smaller than the beam rate.

3.2 Preamplifier

The electronic diagram of the preamplifier is shown in fig. 7, the various pulse shapes in fig. 6. Two channels, including preamplifier and T/H are implemented according to a thick hybrid technology^(**) on a ceramic support, 1 x 2 inches size. Electronic performances are discussed in sect. 4.

A box of 60 x 90 x 200 mm³ in size houses 96 channels, including their multiplexers, hold and driver circuits. Pulsing capability for test and calibration purposes is achieved by means of a common strip capacitively coupled to all the inputs. Detectors of 200 (or 400) strips are equipped with one (or two) boxes at each end of their S. plates. A "plane" of eight hundred channels is easily implemented covering 60 mm along the beam line. A complete array (200 strips) is shown in fig. 8. The cost of an electronic channel, from the detector to the computer interface is 35 SF, based on a production of 5000 channels (1982 price).

4. OPERATION AND PERFORMANCE OF THE ELECTRONICS

4.1 Operation

The "hit" patterns are obtained from the analog data by applying threshold cuts, defined at the software level according to the following steps:

(*) It was composed of 4 silicon plates 14 x 14 mm², 400 μ m thick having the advantage on a scintillator of reducing the amount of matter and avoiding the transit time delay of a photomultiplier.

(**) Telecontrolli-Napoli.

- (a) the short hold signal must first be timed with respect to the peak amplitude of the analog pulse. This can be achieved either with a pulse generator or with particles;
- (b) pedestal distributions recorded previously, provide a map of mean pedestal values $PED(i)$ and corresponding RMS, $SIG(i)$ for every channel i ; $SIG(i)$ is taken as a characteristic noise level. Then any signal of amplitude $A(i)$ is considered as a "hit" whenever

$$(A(i) - [PED(i) + N * SIG(i)]) > 0.$$

The expression in brackets is the software threshold defined for every channel, having a resolution of 0.5 ADC bin adjustable, according to the N value. For analog measurements, the electronics gain normalization is obtained by using for every channel the slopes of the linearity curves recorded in pulser mode as weight factors.

4.2 Hold delay scan and input capacitance sensitivity

This scan allows the adjustment of the hold delay in order to stretch the pulses at their maximum amplitude. A step pulse is applied at the inputs of the preamplifiers through a common strip capacitance. By varying the relative timing of the hold signal with respect to this step pulse, the mean shape of the output pulse can be scanned: in fact, this provides the track mode response of the chain (fig. 6(d)). A unique value of the hold delay was found convenient to operate the whole system.

The results shown in fig. 9 have been obtained at various capacitance input configurations. Fig. 10 shows that within a range of 1-15 pF, the preamp response is characterized by a decrease of the output pulse amplitude but keeping a constant noise level.

The electric cross talk is estimated by pulsing a single channel with and without a detector being connected. An induction level of about 10% of the input pulse is found on the two first adjacent strips, due to capacitive coupling on the detector surface. This level is still 6-7% on the strips next to the first adjacent, because coupling occurs between

traces adjacent on the fan-out board as detector strips of same parity are read at one side of the detector. Neither the strip widths (50, 100, 200 μm), nor the bias voltage have much influence on the induction level. The response of the chain has an overall linearity of $\pm 2\%$ in the 8 bit ADC range.

This offers a detection capability of 3 (MIP) per strip with a response still proportional to the deposited energy.

4.3 Noise and output sensitivity

By means of the four distributions shown in fig. 11, we gather the 192 mean values of respectively, pedestal, signal, noise levels and noise to signal ratios, measured at every strip of a detector (in this case: 50 μm . $V_{\text{pol}} = 90 \text{ V}$). The level and noise to signal distributions were measured for an output signal comparable to the one recorded with M.I.P. (~ 25 ADC bin).

The mean values of these distributions were taken as characteristic figures for the status of every detector. For example, in normal running conditions, the means of the noise distributions for the 16 planes ranged between 1.1 and 1.4 ADC bin (table 2).

As expected, the pedestal and signal distributions show rather important spreads, 20 to 30%: this does not affect the detection efficiency as (a) threshold definition takes into account the pedestal level for every strip and (b) there is usually a correlation between noise and gain, a high noise corresponding to a higher gain. These curves reflect the spread in gain of the various electronic components. Preamplifiers were easily selected using the signal to noise distributions.

An essential point was to get a good time stability of the pedestal values: this was found to be excellent, about .4 times the (RMS) of any pedestal distribution, over a period of a few weeks, provided that temperature is kept stable and grounding problems are well stabilized. This behaviour would allow the use of any fast "zero suppression" unit leading to a large reduction of the volume of recorded data.

5. DETECTOR MEASUREMENTS

5.1 General behaviour of the detectors

The detectors have now been used for three years, totalizing about 5000 hours of operation. They were operated essentially in extracted SPS or PS beams under moderate irradiation conditions typically 10^5 - 10^6 /s/few mm^2 . In the WA75 experiment the detectors were flushed with dry N_2 because they were maintained at 12°C and $\sim 80\%$ humidity, conditions needed for the emulsion target.

Detectors of 100 and 200 μm strip width ($40 \times 40 \text{ mm}^2$) showed a remarkably stable total bias current, ranging from 0.2 to 0.8 μA at 60V. We observed higher current with the 50 μm detectors, some of them being unstable. In some cases, the current source was found to be the 2 or 3 strips at the edge of the detector: rendering these strips floating was sufficient to operate again in good conditions, the noise level being unaffected. In other cases, the detector had to be cured by heating up to 80°C , but it might be possible that the leakage current originates partially from the support itself. Let us remark that the 50 μm detectors are of lower resistivity (3 $\text{k}\Omega\cdot\text{cm}$) than the 100-200 μm elements; they were then operated at higher bias voltage (90-100V).

5.2 Analysis of the results - definitions

Most of the results described below were obtained using the complete setup, properly aligned, and exposed to a π^- (or μ) beam with energies between 200-350 GeV/c.

Hit patterns of a given plane, which are analysed below, are those associated with a track reconstructed using the complementary subset of detectors (reference). Every pattern is described in terms of clusters. They are referred to as:

C1H1, C1H2, C1HN: a single cluster formed of respectively 1, 2, >2 contiguous hit strips;

C2: more than one cluster of any size.

The track coordinate in any plane is defined as the middle of the cluster. The residual is then calculated at the detector plane under study as the difference between the measured coordinate and the one predicted from the track reconstructed in the reference. In addition to threshold conditions, the residual must be smaller than two strips width in order to be associated with a track.

5.3 Residuals

Distributions of residuals are shown in fig. 12 for various reference configurations and strip width values. They include events of any cluster size. The shape of these distributions depends strongly upon the combination of beam divergence and set up geometry in use: in an extreme case of no divergence, the residuals should be restricted within a single bin of arbitrarily small extension. Both beam divergence and presence of ClH2 clusters render the distribution more and more "continuous". In figs 12(a) and (b), we show such examples of "quantized" histograms, the beam divergence being in this case as small as 12 μ rad r.m.s. In (a) the reference structure (50 μ m planes) is observed after propagation in a 200 μ m plane as four separated peaks; in (b) obtained with 50 μ m planes, geometry and ClH2 clustering are responsible for the 2 satellites, ± 25 μ m apart from the main peak. A divergence of 1. mrad r.m.s. was used in the distribution (c); now a "box" profile is observed, with about 90-95% of the events having their residuals comprised within plus or minus half a strip width. The source of the remaining fraction could possibly be ClH2 events where only one hit was recorded (sect. 5.5).

In 50 μ m pitch detectors, the "r.m.s. value" of distributions such as (c) in fig. 12 is of 18 μ m, leading to a resolution for a single plane of 14 μ m r.m.s., i.e. $50 \mu\text{m}/\sqrt{12}$ as expected.

This residual method was used to check the relative positions of the beam hodoscope and vertex detector by selecting various combinations of 3 planes. In fact, the peak position in a residual distribution of 3 planes is known to be a linear function of the transverse positions of these planes. Being centered around zero indicates that the three detectors are aligned.

5.4 Working conditions

The operating threshold is chosen by looking at the fraction of multi clusters C2 (fig. 13) most often resulting from a good hit in conjunction with hits from noisy channels. A value $N = 5$ for the threshold was adopted in data taking mode.

The polarization voltage must be set at such a value that the detector is fully depleted in order to collect the entire deposited ionization. Two methods were used:

- (a) Measuring mean pulse height of selected ClH1 events as a function of the polarization voltage, V_{pol} . A plateau should be reached when full depletion is achieved.
- (b) Rising V_{pol} decreases the strip capacitance because the depletion depth varies as $\sqrt{V_{pol}}$. Accordingly, the response to cathode pulsing will decrease and reach a plateau at full depletion.

The results shown in fig. 14 indicate that the expected behaviour is observed in detectors of 100 and 200 μm strip widths where the depletion is reached at 60 V, but that it is less pronounced in case of 50 μm pitch. The most probable values of the Landau spectra are also found to be different from one detector to another (fig. 15). This can be attributed to the different configurations and trace widths on the various fan-outs boards influencing the input capacitances, to which the preamp response has been shown to be very sensitive. The Landau spectra values were found stable and independent of the set of electronics used. A summary of the detector measurements is found in table 2.

5.5 Efficiency, cluster size, Landau spectra

Fig. 16 shows the efficiencies and fractions of ClH1, ClH2 of various detectors as a function of the threshold (N).

The quoted inefficiencies originate mostly from unbonded strips and not from threshold effects as long as N is smaller than 8.

The measurements of the fraction of ClH2 show the following features:

- (a) The fraction decreases when the threshold is increased. The absence of a plateau at the lowest threshold values indicates that the efficiency of detecting both hits of any ClH2 produced is not 100%.
- (b) The ClH2 fraction ranges from 10 to 15% at the operational threshold ($N = 5$) for 200, 100 and 50 μm strip width detectors.

The Pulse Height (PH) and pedestal distributions for the ClH1 selected events originating from a single strip are presented in fig. 17(a). Figs 17(b) and 17(c) are normalised PH spectra involving several strips (sect. 4.1): Fig. 17(b) shows the PH spectrum for the ClH1 events; fig. 17(c) the total PH of the adjacent strips for the ClH2 events. It can be seen that the tail of the spectrum for ClH2 events is more populated and extends to higher values than for the ClH1 events (see next section).

5.6 Zone of signal sharing between strips

The fraction of ClH2 that is observed incites to check the validity of taking the track coordinate as the middle of a cluster (assumption 1). For this purpose, the residuals for the ClH2 events are calculated under the assumption 2, that the track coordinate corresponds to the middle of the strip having the largest pulse height. Moreover, the ClH2 events are split into two classes, depending on whether the total pulse height is smaller or larger than twice the peak value (respectively (a) and (b) in fig. 18). The distributions are shown for 3 different detectors in fig. 18.

When small pulse heights are selected, the distributions are clearly split into two peaks, the distance between each maxima and the origin being of half the strip width of the detector under study. It means that the track passes in reality in the boundary zone between the 2 strips of the cluster, justifying assumption, 1. On the other hand, distributions centered around the origin are found when large pulse heights are selected. As the assumption 2 is now satisfied, the occurrence of such ClH2 events could be attributed to a track passing through about the middle of a strip but

inducing the adjacent hit by cross-talk. This can also account for the long tail observed in the ClH2 spectrum: the highest amplitudes are not belonging any more to the ClH1 distribution but appears in the ClH2 tail, enhanced by the cross talk contribution. Their fraction amounts to be about 10-20% of the ClH2 class, that is 1-3% of all events (respectively for 200 μm to 50 μm pitch detectors). Let us mention also that the ClH3 fraction typically ranges between 0.3-0.8%.

In conclusion, the assumption of taking the track coordinate in the middle of the cluster is valid in our system except for 1-3% of the cases where a high pulse height value in one strip could indicate a possible cross-talk on an adjacent one.

Two simple observations allow a rough estimate of the extension of the detector zone where the signal sharing occurs. As the cluster size fractions are measured under uniform density irradiation, the product of the ClH2 fraction with the corresponding strip width gives us the following first order estimates: $\pm 8 \mu\text{m}$, $\pm 13 \mu\text{m}$ and $\pm 16 \mu\text{m}$ for increasing strip widths. A second way is provided by the width of the ClH2 residual distributions, giving respectively (fig. 18): $\pm 7 \mu\text{m}$, $\pm 15 \mu\text{m}$, $\pm 22 \mu\text{m}$ values comparable to the previous estimate. Let us remark that these results were obtained with very parallel beam conditions (r.m.s. beam divergence of about 10 μrad), rendering negligible the contribution to the error of the reference detectors.

The collection and diffusion mechanisms of the ionization contribute only for a few micrometers to the size of the sharing zone, as shown in [5]. In our detectors, these sizes are found larger and pitch dependent. The predominant cause is then a charge sharing effect determined by the electrode configuration. This is supported by fig. (19) where the ratio $(\text{PH left})/(\text{PH left} + \text{PH right})$, correctly normalized, is plotted versus the coordinate and shows the expected correlation in the narrow sharing zone.

5.7 Inclined tracks

The ClH2 fraction was also measured by rotating a 200 μm detector in a beam with a divergence smaller than 1 mrad. Fig. 20 shows that the ClH2 fraction stays about constant for angles around the normal smaller than $\pm 6^\circ$ and increases at larger values when each of the two parts of the ionized deposition are detectable in the two adjacent strips. This measurement is compared to a Monte-Carlo simulation where only the detector efficiency for ionized segment is taken into account on the basis of geometrical sharing. A reasonable agreement is found at angles larger than 7° , when a sensitivity to a 1/4 of the total ionization length is taken as a limit to generate a hit above threshold. This angular limit also provides another estimate of the sharing zone found to be $\pm 25 \mu\text{m}$.

6. VERTEX RECONSTRUCTION AT WA75

From the residual distributions shown before, it was then possible to locate interactions with errors of $\pm 20 \mu\text{m}$ transverse to the beam, error propagation taken into account.

The procedure for finding vertices along the beam (with the VD) will be described elsewhere in the case of the WA75 experiment where complex vertex topologies are involved. We shall only mention runs intended to calibrate the position of the stack along the beam. For this purpose, two 1 mm thick iron plates, separate by 37.1 mm were mounted in place of the emulsion target. Cuts were imposed to reject interactions originating from the upstream silicon planes and only events with 4 to 20 space tracks were retained. The distribution of the coordinate of the reconstructed vertex along the beam is shown in fig. 21, for the upstream and downstream plate separately: a FWHM of 2.0 and 1.2 mm can be estimated respectively. The difference in the FWHM of the two distributions reflects the effect of "target to first VD plane distance" as well as the multiple scattering in the downstream plate. The distance between the two peaks agrees within .1 mm with the distance separating the two plates.

Fig. 22 shows the distributions of the number of space tracks reconstructed in the VD, in the emulsion and their correlation in case of a 350 GeV/c pion irradiation. The reconstructed space tracks were 9.2 on

TABLE 1

Detector geometry

Detector (fig. 1)	Strip Width μm	Width mm	Strip Length mm	# Strips per detector
1,2,3,4,5,6	50	10	30	200
7,8,15,16	50	20	20	400
9,10	100	40	40	400
11,12,13,14	200	40	40	200
A		10	10	1
B		14	14	1

TABLE 2

Summary of detector measurements

Detect.	Vpol. [V]	R k Ω /cm	I μA	SIG ADC bin	Landau (C1H1)			C1H2 C1H1%	efficiency %
					Mean ADC bin	Peak ADC bin	FWHM ADC bin		
1	90	3.0	0.12	1.2	19.1	18	9	10.6	0.978
2	90	3.0	0.76	1.3	26.2	24	10.5	15.4	0.990
3	90	3.0	0.34	1.3	23.8	22	10.5	12.6	0.984
4	90	3.0	0.60	1.2	21.3	20	11	13.4	0.998
5	90	3.0	0.13	1.3	23.5	22	11	14.2	0.984
6	90	3.0	0.55	1.2	20.8	19	10	12.1	0.995
7	90	3.7	0.46	1.2	22.3	20	10	12.2	0.985
8	90	4.0	1.42	1.2	21.7	20	10	15.2	0.993
9	60	7.0	0.39	1.3	22.9	21	10	12.7	0.990
10	60	7.0	0.41	1.3	25.4	23	11	13.0	0.990
11	60	8.8	0.34	1.4	30.9	28	14	6.2	0.990
12	60	8.8	0.36	1.4	28.8	25	13	9.0	0.972
13	60	6.8	0.84	1.4	30.4	28	13	8.1	0.996
14	60	8.2	0.37	1.3	26.0	22	11	8.0	0.998
15	90	4.0	1.9	1.2	19.6	18	8	12.8	0.978
16	90	4.0	5.3	1.2	18.8	18	8	12.6	0.934

FIGURE CAPTIONS

- Fig. 1 Detector array, lateral view. Dimensions are shown in table 1. A is the beam trigger and B is the multiplicity trigger.
- Fig. 2 Front view of the Beam Hodoscope. Electronic boxes are indicated. B1, B2: granit blocks; P: base plate; S: detector support plate; M: manipulator operated by the screw V; F: frame for electronics.
- Fig. 3 Side view of the Beam Hodoscope and the Vertex detector surrounding the Target Mover (TM). The length of the block B1 is 50 cm. T is the main granite table.
- Fig. 4 Block diagram of the analog multiplexed chain. PTH-2 cards are not shown on the even strips side. This diagram corresponds to 192 channels.
- Fig. 5 Schematic timing diagram of pulse stretching by a short hold signal.
- Fig. 6 Different pulse shapes measured on the PTH-2 card:
 (a) input step;
 (b) at the emitter of the second BFS 17 transistor (fig. 7);
 (c) at the T/H input (3) (fig. 7);
 (d) at the T/H output in track mode;
 (e) and (f) at the T/H output in short and long hold mode, respectively.
- Fig. 7 Electronic diagram of the PTH-2 card with 2 channels; resistor values are in $k\Omega$; capacitors values, except for those indicated, are 22 nF.
- Fig. 8 (top) A detector of 192 strips, mounted on a support plate, and its associated electronics: preamplifier/multiplexer boxes and ADC card.

FIGURE CAPTIONS (Cont'd)

(bottom) WA75 telescopes. The beam hodoscope is moved backward from the target. An S plate with an uncovered detector is seen in the forefront. The vertex detector is partially shown in the back.

Fig. 9 (a) Linearity curves and (b) pulse shapes for various input capacitances.

Fig. 10 Response to an input charge equivalent to the charge deposited by a MIP versus the input capacitance (a) peak amplitude (b) RMS noise detector: 50 μm pitch - 30 mm length.

Fig. 11 Distributions of the mean values of 192 strips (50 μm detector) of: (a) pedestal levels; (b) RMS of pedestal distributions; (c) response to an input signal equivalent to a MIP; (d) signal to noise ratio $V_{\text{pol}} = 90 \text{ V}$.

Fig. 12 Residual distributions: (a) plane No. 11-200 μm with reference No. 2-4-6 (50 μm planes); (b) plane No. 6-50 μm with reference No. 2-4-7 (50 μm planes); (c) plane No. 3-50 μm with reference No. 1-5-8 (50 μm planes). The beam divergence is respectively of 10 μrad and 0.9 mrad in (a), (b) and (c).

Fig. 13 Efficiency and fractions of multi-clusters versus threshold. The noise contribution is suppressed when $N \geq 4$ (50 μm detector, $V_{\text{pol}} = 90 \text{ V}$). The remaining events correspond to multi track configurations.

Fig. 14 Depletion curves in a 200 μm detector.

- (a) Landau peak of C1H1 events;
- (b) pulsing of the back plane.

Fig. 15 Mean values of Landau spectra versus V_{pol} . C1H1 events are selected. Detectors No. 1,6,7 are 50 μm pitch, No. 9, 100 μm , No. 12: 200 μm .

FIGURE CAPTIONS (Cont'd)

Fig. 16 Fractions of cluster size 2 events (C1H2) versus threshold:

(a) 100 μm pitch detector $V_{\text{pol}} = 60 \text{ V}$;

(b) 50 μm pitch detector $V_{\text{pol}} = 90 \text{ V}$;

(c) same as (b) at various V_{pol} .

Fig. 17 Landau distributions (π , 10 GeV/c):

(a) single strip (200 μm , 60 V) with pedestal distribution;

(b) C1H1 selected events from several strips with normalization of electronic gains;

(c) C1H2 selected events: sum of PH of the two adjacent strips.

Fig. 18 Distributions of the residuals for selected C1H2 events (cluster size 2), assuming the track coordinate corresponds to the middle of the strip having the largest PH

(a) total PH is smaller than 2 x (Landau peak value);

(b) total PH is greater than 2 x (Landau peak value).

Plane numeration is found in fig. 1 No. 4, 9, 11 have respectively 50, 100, 200 μm pitch.

Fig. 19 Test of a "charge division" sharing of the signal in C1H2 events. A linear dependance of $\text{PH}_l / (\text{PH}_l + \text{PH}_r)$ versus the coordinate is expected. The slope of the distribution in the range (0.1-0.9) is 0.13/10 μm with a correlation factor of 0.75 (66 measurements, confidence level > 99%).

FIGURE CAPTIONS (Cont'd)

Fig. 20 Fraction of cluster size 2 events (C1H2) measured versus the angle between the beam and the normal to the detector (origin $\sim 339^\circ$). The open circles are calculated under the assumption of a geometrical sharing in two segments l_1, l_2 of the ionization and a threshold value proportional to $L/4$ (no signal sharing zone between two strips as in hatched area).

Fig. 21 (a) Test target array for vertex location with VD. Iron 1 mm thick spaced by 37.1 mm.

(b) Distributions of the coordinates of the vertices along the beam.

(c),(d) enlargements of the two distributions, respectively left and right peaks.

Fig. 22 Vertex finding in an emulsion exposed to a 350 GeV/c beam. For every reconstructed vertex, the number of space tracks found in the VD (a) and in the emulsion (b); (c) correlation between (a) and (b).

Fig. 1

Fig. 2

ITEM	DESCRIPTION	QUANTITY	UNIT	REMARKS
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...
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97	...	...	...	...
98	...	...	...	...
99	...	...	...	...
100	...	...	...	...

Centre (main) 'insane' (0&0)

Centre Varies coil

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 22