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A HIGH RESOLUTION BEAM TELESCOPE BUILT WITH DOUBLE SIDED SILICON STRIP DETECTORS

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Abstract

A compact and portable beam telescope has been built using four 1.92 x 1.92 cm^2 double sided silicon microstrip detectors with 50 μm read-out pitch. Tests using 50 GeV pions have shown that the beam position can be defined with a precision of 3 μm and 6 μm on the p-side and n-side respectively with an overall detection efficiency of 93.0%.

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1) Introduction

Silicon strip detectors are used in high energy physics for their excellent spatial resolution. This resolution depends on many parameters: the silicon detector characteristics, the read-out pitch, the presence of intermediate floating strips, the coupling with the read-out electronics and the noise level of the read-out electronics.

In principle, it should be possible to estimate the influence of any of these parameters on the detector performance. In reality, when a new silicon microstrip device has been designed and built, the spatial resolution can be exactly established only by a careful study in a beam test. This requires a beam defining telescope with better resolution than expected for the device under test, i.e. a few microns. In contrast, the beam test time allocation is generally limited and only a small fraction of it can be spent on commissioning the beam defining apparatus.

Therefore, availability of a well tested, high resolution beam defining apparatus, complete with trigger and data acquisition, which is both easy to transport and quick to install, is highly desirable.

We have built a beam telescope to meet these requirements. To achieve the needed spatial resolution, double sided silicon microstrip detectors, with 50 μm read-out pitch were used. The compactness and transportability were obtained through an appropriately modular design and with a versatile data acquisition in VME standards.

In this paper, we describe the adopted solution for the beam telescope and present the measurements of the signal to noise ratio, the spatial resolution, and the detection efficiency, as obtained in a test beam at the X7 experimental area at CERN SPS West Area

2) Module Description

The basic telescope element was a module. The set-up described in this note consisted of 4 modules, referred to in the following as D1, D2, D3 and D4. All the system, however, was designed so that the number of modules could easily be increased should more redundancy be required in the beam track definition. A picture of the module is shown in fig. 1.

2.1) Silicon Detector

The active area consisted of a double sided microstrip high

resistivity silicon detector, 300 μm thick, with an effective sensitive area of 1.92 x 1.92 cm^2.

These detectors were designed by the PISA group [1] and were produced by CSEM, (Neuchatel, CH) according to a fabrication process developed in collaboration by INFN Pisa and CSEM. In effect, these small detectors came from the production made for the L3 vertex detector [2] and were provided by the Perugia group.

The p-side of the detector had p$^+$ implantation strips every 25 μm and a read-out pitch of 50 μm. This left one floating strip between two connected strips which improved the position resolution by exploiting the capacitive charge division. The n-side, had n$^+$ implantation strips every 50 μm, interleaved with p$^+$ blocking strips. The n-side strips were perpendicular to the p-side strips. Each detector had 385 read-out strips on each side. A guard ring surrounded the strips on both sides.

The detectors were tested for leakage current and interstrip resistance. Those used had typically a total leakage current of about 30 nA, a strip leakage current of about 20 pA, an interstrip resistance on the n-side exceeding 0.5 GΩ, and a depletion voltage between 10 and 30 V.

2.2) Front-end Electronics

The strips were read-out using the VIKING amplifier-multiplexer chips [3]. These are 128 channel VLSI CMOS chips developed at CERN. The chip has a 50 μm input channel pitch matching the detector strip pitch. Each channel contains a charge amplifier followed by a CR-RC shaper and a hold circuit. The output information is serialised, i.e. all the 128 inputs are multiplexed into one output line.

A test set-up was implemented in our laboratory to test the general functionality of the chips. Only chips passing the test were accepted for module construction.

The detector strips were capacitively coupled to the input of the amplifier-multiplexer chip, using a custom 128 channel capacitor chip built on a quartz substrate, also with a read-out pitch of 50 μm. Each channel comprises a 150 pF capacitor and protection diodes against capacitor breakdown. The chip was designed for the L3 vertex detector and produced by CSEM [2].

To equip the 385 strips of each detector side, three capacitor chips and three VIKING chips were necessary, leaving only one unconnected strip at each detector edge. The three VIKING chips are directly glued, and their control and output pads bonded, on

ceramic hybrids [4] which provide steering signals, power, mechanical support as well as heat dissipation.

A standard repeater card [4], was positioned close to each hybrid and was electrically connected to them by thin kapton cables, 4 cm long. This card provided the bias voltage to the detector and power and control signals to the hybrid. It also distributed the output signals to the digitising electronics.

Two hybrids and two repeater cards were used for each detector, one for the p-side, the other for the n-side.

2.3) Assembling

All the elements of a module were mounted onto a 12.5 x 12.5 cm^2 G10 frame, 1 cm thick. A square window was cut out and grooves were machined to allow insertion of the silicon and hybrids respectively, as shown in fig. 1 and fig. 2. The window was positioned with respect to four reference marks to insure that all four modules were identical. The frame was designed to have the p-side electronics on one face and the n-side ones on the other face, at 90° with respect to the p-side electronics.

The silicon was cut to 2.3 x 2.3 cm^2, around the 1.92 x 1.92 cm^2 sensitive area, leaving 3.5 mm space for gluing on the two edges where no hybrids would be placed and 0.3 mm space on the other two. The silicon was glued to the shaped edges of the window taking care to position the detector with respect to the reference marks with a microscope.

In order to facilitate the module assembly, the three capacitor chips and the ceramic hybrid were first glued on a vetronite substrate. This substrate was settled in the grooves of the frames and was aligned relative to the detector and held in position by two small screws.

Finally, the VIKING chip inputs were microbonded to the capacitor chips and these to the detector strips [5].

2.4) Power Supply and Read-out Configurations

The detector strips were biased by applying voltage to the guard ring on both the p-side and n-side [6]. A positive floating voltage was applied to the n-side referred to the p-side. To prevent the n-side coupling capacitors from having a potential difference equivalent to the bias voltage, the n-side electronics was referred to the n-side bias voltage. A decoupler circuit was applied to feed the control signals to the n-side repeater card and to get the analog

output signals. Optical decouplers were used on the control digital lines and 1 μF blocking capacitors for the analog signal outputs.

Detectors were biased in pairs (D1-D2 and D3-D4), and the relative front-end electronics were powered in parallel.

In this way, the front-end electronics of the two p-sides (n-sides) of each pair operated at the same floating potential. This allowed the read-out of the six VIKING chips belonging to the p-sides (n-sides) of each detector pair to be serialised on a single output line, properly connecting the corresponding repeater cards. Only 4 output lines were required (see fig. 4). Each line served 768 strips. In addition, only two distinct high voltage, low current, channels were needed to bias the detectors, while eight distinct low voltage channels were required to power the front-end electronics and the two n-side decouplers. The power and the bias voltage were provided by a computer controlled modular power supply system [7].

3) Telescope Layout

The layout of the telescope is shown in fig. 3. The four modules were mounted on a horizontal aluminium platform, 1.5 cm thick, by means of aluminium supports 17 cm high. Since the G10 frame was sufficiently rigid to be self-supporting, no additional mechanics was required. The two repeater cards of each module were also mounted on the G10 frame. All the fixing holes, both on the frame and the platform, were precisely machined so that a relative alignment of silicon detector within ± 200 μm could be achieved.

In the reference system shown in fig. 3 the beam was along the z axis, and the double sided detector was installed such that the p-side strips measured the y coordinate and the n-side ones the x coordinate.

Along the 85 cm long platform, the four modules D1 to D4, were positioned at 5, 10, 70 and 75 cm from the platform front edge. These positions could easily be changed using a set of precision holes every 2.5 cm along the z axis.

Four small plastic scintillator counters, two before and two after the silicon detector modules were also mounted on the platform in order to define the trigger for the silicon detector. These counters defined a beam region of 1.5 x 1.5 cm^2 aligned with the four silicon detectors.

The platform was mounted on a movable remote controlled table which permitted translation in x and y with a minimum step of 1 mm to allow the positioning of the trigger scintillators on the beam.

The set-up was completed by a movable and rotatable support for holding the device under test. This support had micrometric remote controlled x-y movement and a manual angular rotation. The maximum excursion was 40 cm in x and cm 25 cm in y with a minimum step of 20 µm and an angular rotation of 360° with a minimum step of 0.3°.

4) Data Acquisition and Beam Test Set-up

The general layout of the digitising and read-out electronics is shown in fig. 4.

The acquisition system, which performed data taking and on-line monitoring, was based on the VME standard. The VME system crate contains a processor module, one sequencer [8] and four digitising Sirocco VME modules [9], one for each line coming from the four detectors.

The Siroccos were read-out by the FIC8234 VME processor [10], running the OS9 operating system. It was used both for reading the data from detectors and for network communication via the TCP/IP protocol.

The data acquisition was based on a "producer-consumer" architecture, using the ALEPH Buffer Manager [11] installed in the processor. The "producer" program initialises the VME crate, prepares the sequencer and Siroccos for running, reads the data from the detectors and writes them into a buffer. The "consumer" program reads the events asynchronously from this buffer and prepares the data in BOS banks [12] .

During the beam spill, the data collected were stored in a 1 Mbyte area in the processor's memory. Between bursts, these data were transferred over the network to a VAX station 4000/60 where they were stored on disk. The synchronisation of the VAX and processor was accomplished with the ALEPH Message System [13], which uses TCP/IP protocol for inter-task communication. At the end of the run, the data was stored on a Digital audio tape (DAT).

Data quality monitoring was provided on-line using the same VAX and processor configuration. An analysis program running with low priority on the FIC8234 processed about 5% of the events from the buffer. This task prepared rough pedestal estimates, as well as histograms of raw data, pedestals and pedestal subtracted data. These histograms were transfered to the VAX, where they could be displayed using the ALEPH Presenter Software [14].

The telescope was installed in the X7 experimental area at CERN SPS West Area and used in the ALEPH vertex detector prototype

beam test to define the beam particle track. The prototype [15], having 1536 channels digitised by two Siroccos, was read and monitored by the same software programs. Data were taken with a 50 GeV pion beam.

The trigger to the sequencer was provided by a coincidence between the four scintillator counters on the platform. The waiting time for data capture [3], was set to 1.6 μs after the trigger.

About 10 events per spill were taken. A total of about 110K events were written on tapes.

5) Signal to Noise Analysis and Results

The algorithms used in the data analysis are described in detail in [15]. We simply recall that the signal of the i-th strip (PH_i) is extracted from raw information (ADC_i) by subtracting the pedestal (PED_i) and the common mode noise (CM_i):

$$PH_i = ADC_i - PED_i - CM_i$$

The pedestal for each strip is evaluated as the average of ADC counts using the first 50 events, and then it is continually updated. The common mode represents the joint shift of the signal in a group of strips belonging to the same read-out unit typically caused by low frequency pickup. It was computed, event by event, as the average value of signals for groups of 32 strips situated on the same physical amplifier chip. In both cases, strips which may have real signal, i. e. those with signal to noise ratio greater than 3, were excluded from the calculation.

The strip noise is defined as the root mean square of PH_i values and is computed also in two steps: it is initialised with the following 100 events and then it is continuously updated.

The noise level for all strips observed for a typical run of about 2 hours is shown in fig. 5 for D3. Fig. 6 shows, channel by channel, the strip contents in a typical event, again for D3.

Once the signal and noise for each strip of a detector side was calculated, a search for clusters of adjacent strips having the characteristic structure of a minimum ionising particle (m.i.p.) was made. First, for each side of a detector, all strips were scanned to identify the cluster seeds, i.e. strips with a signal to noise ratio (S/N) > 2.5. In a group of 11 strips centred on the seed, the strip having the maximal S/N was taken as the central strip if the S/N was greater than 12. The cluster is then formed from the central strip and strip to left and right until a strip falls below the cut S/N > 3.

The number of strips belonging to the cluster defines the cluster extent (E).

These cuts were chosen in order to include the maximum signal and to reduce the relative number of one strip clusters which have poor spatial resolution.

The cluster signal (S_{cl}) and the cluster noise (N_{cl}) were defined as:

$$S_{cl} = \sum_{cluster} PH_i, \qquad N_{cl} = \sqrt{\frac{1}{E} \sum_{cluster} N_i^2}$$

The cluster noise and m.i.p. cluster signal distributions are shown in fig. 7 for both side of D3. As expected, the signal has a very clean Landau distribution. The scatter plot of the cluster signals on the p-side and the n-side in the same event, is shown fig. 8. A linear correlation between the two signals is evident, as expected for double sided detectors.

The S_{cl}/N_{cl} distribution for the same detector is shown in fig. 9 both for n-side and p-side. All the other detectors have very similar distributions. Peak and mean values for cluster m.i.p. signal and S_{cl}/N_{cl} for all detectors are given in Table1, together with the mean and rms values of the cluster noise.

Side	Detector	Noise		m.i.p. signal		S/N	
		mean (in ADC	rms counts)	peak (in ADC	mean counts)	peak	mean
p-side	D1	1.5	0.4	64.2	77.9	46.9	51.4
	D2	1.8	0.2	120.4	139.8	64.6	74.4
	D3	1.7	0.2	109.6	130.4	66.8	77.5
	D4	1.7	0.4	100.2	118.4	62.3	70.3
n-side	D1	0.6	0.3	28.6	34.6	54.2	60.8
	D2	0.8	0.2	42.5	56.6	52.5	61.7
	D3	1.2	0.2	55.9	84.6	51.7	64.9
	D4	1.4	0.3	68.6	92.1	46.8	60.1

Table 1: Mean and r.m.s. values of cluster noise, peak and mean values for cluster m.i.p. signal and S_{cl}/N_{cl} for both side of the four detectors.

The signal to noise ratio for the p-side, has a peak value around 60 and an average value around 70 for all modules except D1. These values are completely in agreement with those quoted in

[16], where similar but smaller detectors (1 x 1 cm^2) and the same read-out electronics were used. A lower signal to noise ratio was found on the D1 p-side. This is due, as we found after the beam test, to a improper tuning of the control voltage of the VIKING chips.

On the n-side, the average signal to noise ratio has a typical value around 60. The lower value on n-side, with respect to the p-side, is expected due to the lower parallel resistance of the bias resistor on this side. A small degradation can also be due to the decoupler electronics.

6) Spatial Resolution

An alignment algorithm [17], used the local coordinates of the four double sided detectors to determine their position with respect to a common reference system. The spatial resolution was evaluated from track residuals remaining after aligning the detectors.

Assuming the beam track to be a straight line, the alignment algorithm searched, using an iterative procedure, for the displacements and rotations of each detector which minimised the residuals, i.e. the difference between the measured track position and the straight line hypothesis. Only displacement and rotation in the plane perpendicular to the beam line (xy plane) were considered, as translations along the beam line (z axis) were assumed to be negligible with respect to the spacing between the planes.

For each module and for both sides, the position of the track was calculated from the cluster information using a simple center of gravity algorithm. The track position was calculated as the mean of the strip coordinates weighted by the corresponding signal. The average number of strips in a cluster was 2.5 on the p-side, 2.9 on the n-side, while 96.0% on the p-side and 98.8% on the n-side clusters had more than 1 strip. A typical distribution of the number of strips belonging to a cluster is shown in fig. 10 for D3 both for p-side and n-side.

Typical residual distributions are shown in fig 11. These are for both D3 coordinates. A gaussian fit is superimposed. The sigma of the residual distributions for all detector and sides are listed in Table 2.

The corresponding intrinsic resolution, also given in Table 2, is calculated from the residual taking into account the propagation of the line fit error and multiple coulomb scattering errors. The line fit error was estimate to be about 6 μm in x and 3 μm in y, while

multiple scattering error was zero for D1, negligible for D2, and about 2.5 μm in D3 and D4 due to the presence of the VDET200 prototype in between.

	σ_{res} (μm)		σ_{int} (μm)	
	x	y	x	y
D1	9.2	3.3	6.9	2.6
D2	8.4	3.5	6.0	2.6
D3	8.7	5.1	6.0	3.1
D4	9.9	6.2	6.2	3.1

Table 2: Sigmas (σ_{res}) of the residual distribution and the intrinsic resolutions (σ_{int}) corrected for line fit and multiple scattering errors for both side of the four detectors.

The intrinsic position resolution obtained for a single plane is about 3 μm in y and 6 μm in x. The poorer resolution on x coordinate reflects the bigger strip pitch (50 μm) on the n-side with respect to that on the p-side (25 μm). Moreover, similar resolution was obtained for detectors with different S/N demonstrating that it is dominated by the strip pitch and not by the noise.

7) Efficiency

In order to determine the hit efficiency for the p-side (n-side) of each detector, we selected a sample of events having clusters on the three p-sides (n-sides) of the other detectors. We fit a track through them and look for the fourth cluster in a window of ±100 μm around the track intersection with the fourth layer. The presence of noise, dead or disconnected channels was taken into account. These bad channels amounted to about 0.6 % for each detector side.

The detector efficiency was determined by the same procedure but requiring a particle detected if a cluster pair (one for the p-side, one for the n-side) in the fourth detector was found within ±100 μm around the track intersection.

The hit efficiencies were found to be generally better than 99.7%, while the detector efficiency was generally better than 99.4%. The telescope detection efficiency can be defined as the product of the four detector efficiency and was found to be 97.6% which became 93.0% if the small inefficiencies due to noise, dead or disconnected

channels are included. The quoted efficiencies are independent of small changes in the cut values used in cluster definition.

8)   Conclusions

A high resolution silicon telescope has been built which allows a beam track definition with a spatial resolution of 3 μm and 6 μm in p-side and n-side respectively, with an overall detection efficiency of 93.0%. The telescope has been installed and successfully operated in the X7 line at CERN SPS during the ALEPH microvertex upgrade beam test. The setting up and the commissioning of the telescope was fast and easy. In general, the hardware and software systems performed well with a data taking efficiency close 100%.

9)   Acknowledgements

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FIGURE CAPTIONS

Fig. 1) A picture of a complete module. Detector, capacitor chips and VIKING chips can be easily recognised.

Fig. 2) Prospective view of a G10 frame. An appropriate design of the window edges allows the reading of strips by positioning the read-out electronic on both frame faces.

Fig. 3) Overview of telescope.

Fig. 4) Layout of the data acquisition system.

Fig. 5) Noise levels as function of strip number for D3 on p-side a) and n-side b) in a typical run of about 2 hours. Bars indicate the r.m.s. fluctuations.

Fig. 6) Strip contents in a typical event for D3 on p-side a) and n-side b).

Fig. 7) Cluster noise and cluster m.i.p. signal distributions for p-side a) and n-side b) in D3.

Fig. 8) Signal correlation between the n-side and p-side for D3.

Fig. 9) Cluster signal to noise distribution for p-side a) and n-side b) for D3.

Fig. 10) Distribution of number of strips per cluster for D3 on n-side a) and p-side b).

Fig. 11) Distributions of the difference between the straight line hypothesis and measured track position (residual) in the D3 detector, a) for x coordinate (n-side) and b) for y coordinate (p-side) with a superimpose gaussian fit.