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(on behalf of the DELPHI MICROVERTEX Collaboration)

MEASUREMENT OF SPATIAL RESOLUTION AND CHARGE COLLECTION IN DOUBLE SIDED DOUBLE METAL SILICON MICROSTRIP DETECTORS

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MEASUREMENT OF SPATIAL RESOLUTION AND CHARGE COLLECTION IN DOUBLE SIDED DOUBLE METAL SILICON MICROSTRIP DETECTORS

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Spatial resolution and charge collection in double sided silicon microstrip detectors have been measured in a 100 GeV negative pion beam, at the CERN SPS. The detectors were prototypes, designed for use in the upgrade of the Microvertex detector of the DELPHI experiment. They had integrated coupling capacitors and polysilicon resistors and a second metal layer on the n-side in order to route the signals at the end of the detectors. They have been manufactured with the use of different techniques to insulate the strips on the ohmic side (field plates and p stops) . Their performance and the dependence of their spatial resolution on the signal to noise ratio, readout pitch and particle incidence angle are presented.

1. Introduction

The DELPHI experiment at LEP planned to extend the excellent performance of its silicon strip Microvertex detector [1] from two to three coordinates, in order to increase the efficiency for identification and reconstruction of heavy flavour final states, by means of high precision three dimensional tracking.

For that reason, double side double metal silicon strip detectors have been developed. Double sided detectors can provide two dimensional information, without increasing the material in the sensitive region. Double metal layers route signals from transverse strips out to the ends of the silicon detectors, permitting the readout electronics to be kept outside of the tracking volume.

A variety of prototypes, manufactured by SINTEF (Oslo, Norway), Hamamatsu Photonics K.K. (Japan) and VTT (Finland), has been evaluated as part of the upgrading program. In the following, the description of these silicon sensors is reported and their performance, as measured in a testbeam, is discussed.

2. Detectors description

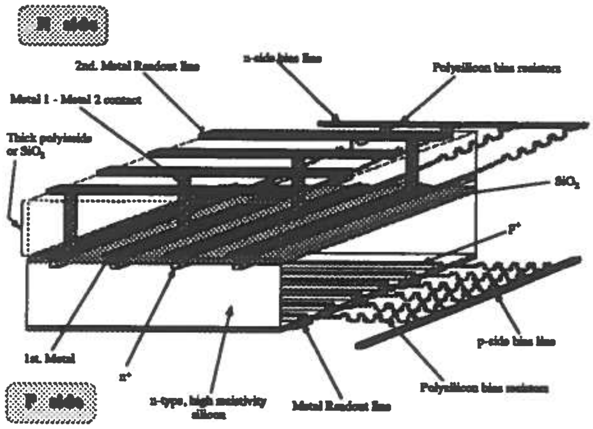

Figure 1. Layout of a double sided double metal silicon microstrip detector, with field plate separation

The junction side of the silicon detectors is a high resistivity n type detector with p^+ diodes, AC coupled to their metal readout lines, with coupling capacitors integrated into the detector, in order to avoid pedestal shifts due to varying strip leakage currents. The capacitors are formed by growing a thin oxide ($\sim$ 200 nm) onto the diodes, before the final metallization step in the processing. On the ohmic side, n$^+$ strips are implanted, at an angle of 90^0 to the p^+ strips, but the positive

Table 1
Silicon detectors characteristics

	P side	*N side*			
		SINTEF-1	SINTEF-2	HPK	VTT
n^+ strips separation		Field plates	Field plates	p stops	Field plates
Dimensions [cm]		5.04 × 1.92	5.8 × 3.2	5.8 × 3.2	7.9 × 2.1
Diffusion strip pitch [μm]	25	35	42.5, 85	42	50, 100
Readout strip pitch [μm]	50	35, 70	42.5, 85	84	50, 100
Al strip layer 1 width [μm]	8	15	16	8	17
Al strip layer 2 width [μm]		5	6.5	6	5
Insulator		Polyimide	Polyimide	SiO_2	SiO_2
Insulator thickness [μm]		2.3	5	5	2
Readout channels		387	640, 640	640	384
Multiplexing		3	2 (1)	1	3
Capacitance [pF]	1.1/cm	27.3	28.1 (19.6) *	19.5	17.5
S/N (perpendicular tracks)		12 *	26 (26) *	16	24

* = Flipped module + p side

charge present in the silicon oxide after the passivation process induces a layer of electrons at the surface. This electron accumulation layer represents a conductive path between the strips, which must be interrupted in order to achieve good strip insulation. This layer is broken in two different ways: with 'p stops' and 'field plates'. In the 'p stops' technique an implant of p$^+$ type silicon is placed between the n$^+$ strips, while in the 'field plates'[2] solution, the capacitively-coupled metal readout line, which is held at ground, is made wider than the implant. The field from the edges of this line breaks the electron accumulation layer. Integrated coupling capacitors are used also on the n-side. On both sides the individual strips are biased by a common bias line via polysilicon resistors, integrated on the silicon.

The readout of n^+ strips is performed at the same edge of the silicon sensors where the readout of p^+ strips is located, routing the signals with a second layer of metal readout lines, separated from the metal lines sitting on the n^+ strips by a thick insulating layer, in which holes are opened to allow for the contacts. This second layer of metal lines is also designed to multiplex the signals from two or three strips into a single readout line, since the number of n^+ strips is larger than the number of readout channels. The distance between strips multiplexed into the same readout line is always larger than two cm, then a possible ambiguity, when these detectors are installed in DELPHI, is very rare.

The cross section of one of the double sided double metal detectors, with field plate separation, is shown in fig. 1. The specifications for some of the prototypes, developed at various stages of the R&D project and tested in a test beam, are described in table 1.

For all the silicon sensors, the p-side includes diodes with 25 μm pitch, every second of which is readout. The diodes are parallel to the long side of the detectors and, when in DELPHI, they are used to measure the $R\phi$ coordinate, transverse to the beam direction. On the n-side, different values for the pitch between the n^+diodes, have been tested, as well as different insulator material and tickness and different metal lines widths.

3. Test beam setup

Tests [3] have been performed at CERN, in the West Area at the SPS, using a pion beam, with 100 GeV/c momentum. To provide a precise particle track reconstruction, a beam telescope has been used [4]. It consisted of eight single sided silicon strip detectors, mounted in pairs, four measuring the x coordinate and four the y coordinate. The double sided detectors have been mounted on a rotating support in the centre of the telescope. Data have been taken first with particles at normal incidence, then the detector under test

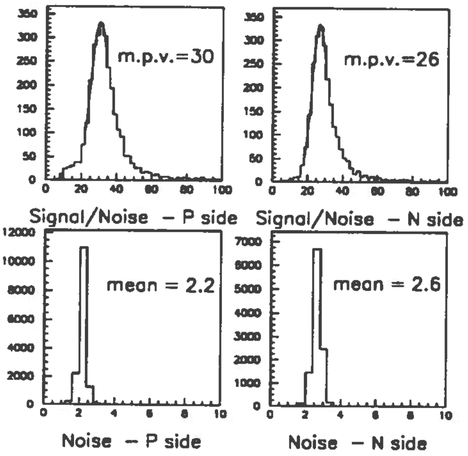

Figure 2. Signal to Noise ratio for a) p-side and b) n-side, for a SINTEF-2 detector. Most probable values are indicated. Noise for c) p-side and d) n-side (arbitrary units).

has been rotated by a variable angle, to test the ohmic side behaviour for particles at large incidence angle [1].

In some cases, the double sided detectors to be tested have been arranged to form a prototype of DELPHI Microvertex detector half module, consisting of a pair of double sided detectors with strips wire bonded in a flipped way, such that the p^+ strips of one detector are daisy chained to the n^+ strips of the other. In this way the input capacitance to the readout electronics is equalized on the two sides.

The detectors under test have been readout on both sides with custom designed VLSI chips MX6 [5], produced in a 3 μm CMOS technology. The measured noise performance of this chip is: $ENC = [340 + 20 \times C]e^-$, where C is the capacitance at the input in pF. Multiplexed analog signals from the silicon detectors have been read out and digitized by six VME SIROCCO units.

4. Detector Performance

Usable strip signals have been determined by subtraction of mean pedestals from the observed raw signals, taking into account possible event-by-event common mode variations. The pedestal and noise have been continuously updated using a digital filter. Dead and noisy strips have been neglected. A cluster has been defined as a set of adjacent strips, in which the central strip has S/N larger than 3, neighbouring strips has S/N larger than 1.5 and the sum of S/N of all the individual channels is larger than 6.

In figure 2 the total cluster pulse height normalized to single strip noise for p-side and n-side of SINTEF-2 detector is shown for perpendicular particles, together with the strip noise on both sides. It should be noted the noise is higher on ohmic side, due to the additional capacitance introduced by second metal layer and two fold multiplexing. The most probable values of S/N distributions are 30:1 for p-side and 26:1 for n-side.

In table 1, most probable S/N values are summarized. They are the result of various factors.

SINTEF detectors have been mounted in pairs to form a half module, then their noise contains also a contribution from daisy chained p-strips while the others have been tested individually. The noise depends on the input capacitance, the bias resistors and leakage current. The first and major contribution has been reduced by increasing the thickness of insulator between the two metal layers. It can be noted that, in similar conditions, the multiplexing introduces an additional capacitance and larger noise (see SINTEF-2).

For a given particle incidence angle, i.e. for a given amount of ionization released in the silicon, the signal decreases for larger diode pitch or when floating strips are present, due to capacitive coupling to the back side. In figure 3 the total charge of the clusters as a function of the interstrip position is shown for p-side (a), n-side with 42.5 μm pitch (b), n-side with 85 μm pitch (c) and the charge correlation between p-side and 85 μm n-side (d), for SINTEF-2 detectors. It can be noted a $\sim$ 5 % loss in the central region between two consecutive readout strips of p-side, where there is a floating strip, no charge loss for 42.5 μm n-side, a $\sim$ 15 % in the centre of interstrip region for 85 μm n-side. To solve this problem, larger pitches can be obtained connecting together two diodes, as done in successive production.

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[1] The angle θ is defined between the particle direction and the normal to the detector surface

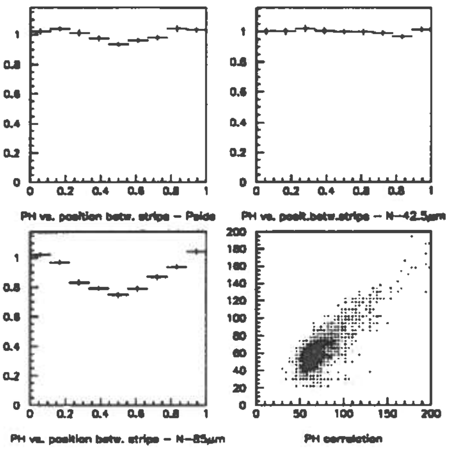

Figure 3. Total charge of the clusters as a function of interstrip region for a) p-side; b) n-side pitch=42.5 μm; c) n-side pitch=85 μm. Readout strips are positioned at 0 and 1. d) Charge correlation between p and n-side (85 μm), for a prototype SINTEF-2 detector.

At larger incidence angles, the S/N increases as $1/cos(\theta)$, due to larger path in the silicon.

5. Intrinsic resolution

Two different algorithms are applied to evaluate the hit position, depending on the readout pitch and particle incidence angle. For perpendicular incidence, since most of the charge released by the passing particle is collected by two strips, the impact position is reconstructed by interpolation of the two highest consecutive signals of the cluster and correcting for non linear charge sharing [6].

For inclined particles, the charge is collected over a region approximately given by $d \times tan(\theta)$, where d is the silicon detector thickness. When this region is larger than the readout pitch, only the two edge strips of the cluster carry information on the position of the passing particle. Then an algoritm based on the mean of the positions of these two edge strips is used, corrected by the difference in their pulse heights [4]. This algorithm is very sensitive to the precise definition of cluster width.

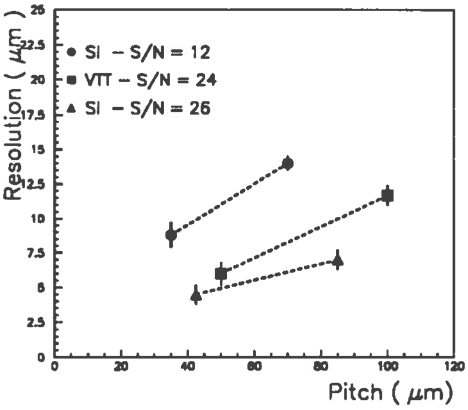

Figure 4. N-side hit precision for perpendicular particles.

The resolution of the detector under study is measured by fitting the distribution of the residual between the coordinate measured by the detector and the one predicted by the telescope. Then the particle track extrapolation uncertainty (~ 4 μm), determined by intrinsic precisions and geometry of telescope planes and by multiple scattering, is subtracted.

In figure 4 the resolution is presented for the ohmic side of tested detectors, for perpendicular incidence. The dependence from readout pitch and S/N is shown.

Figure 5 shows the hit precision as a function of particle angle, for SINTEF-1 detectors, with a S/N ~ 12, on both sides. On the p-side the resolution improves with the angle, taking advantage of the increased path in the silicon. On n-side, the best resolution is obtained at angles slightly larger than 0^0, where a maximal ratio of two strips clusters to single strip and three strips clusters exists, because, due to small particle inclination, a better charge sharing exist between two consecutive readout strips. At angles larger than ~ 20^0, better precision is obtained with a larger pitch than with a smaller one. This is due to the fact that, at larger angles, the charge is spread over a wider region. If the charge is collected by a large number of strips, this reflects into a poor S/N_{strip}, causing difficulties in the discrimination between signal and noise and the

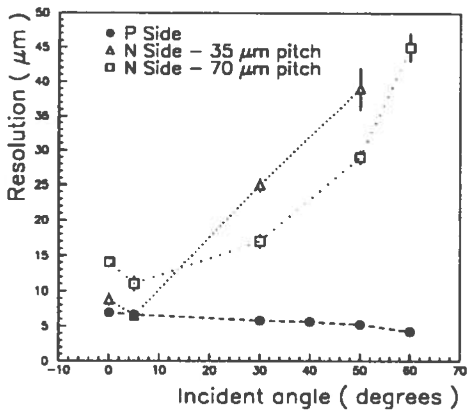

Figure 5. Hit precision as a function of particle incidence angle for a prototype SINTEF detector (S/N ~ 12).

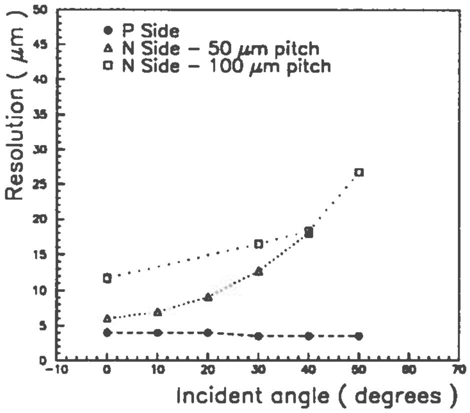

Figure 6. Hit precision as a function of particle incidence angle for a VTT detector (S/N ~ 24).

definition of cluster width. This can be better understood from the results obtained for a detector having higher S/N (~ 24). The intrinsic resolution is improved and the angle, at which the precisions obtained with the two different pitches are equivalent, is ~ 40^0, larger than in previous case (fig. 6). After normalization for different pitch, higher S/N results in a more precise definition of the cluster, mainly for small pitch at large angle, when the charge is spread over many strips.

6. Conclusions

The signal to noise performance of various prototypes of double side double metal silicon strip detectors has been studied. It has been found high quality double sided double metal silicon strip detectors can be manufactured and they work reliably.

Their intrinsic resolution has been measured as a function of various parameters, as the S/N, the diode pitch and the particle incidence angle. On the p-side the intrisic resolution is ~ 5 μm and slightly improving with the particle incidence angle, taking advantage on the increased path in the silicon.

On the n-side, the resolution is degraded with increased particle incidence angle, since the charge is spread over a wider region. A variable diode pitch is desiderable, in order to match the cluster width and to keep the spread of the charge over a limited number of strips. This results in a better signal to noise ratio for the single strip such that cluster width can be more correctly defined, allowing a high precision to be reached.

The intrinsic resolution is adequate for the use of these detectors in the upgrade of the DELPHI Microvertex detector [7].

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