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(on behalf of the DELPHI MICROVERTEX Collaboration)

**THE DELPHI MICROVERTEX DETECTOR WITH DOUBLE SIDED
READOUT**

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THE DELPHI MICROVERTEX DETECTOR WITH DOUBLE SIDED READOUT

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The silicon strip Microvertex detector of the DELPHI experiment has been upgraded from two coordinates ($R\phi$) to three coordinates ($R\phi$ and z), without increasing the material in the active volume. This has been achieved using AC coupled double sided silicon strip detectors, with a second metal layer routing the signals from z strips to the ends of the detector modules.

The detector description and its performance from the 1994 LEP run are reported.

1. Introduction

The DELPHI experiment at LEP had a silicon microvertex detector installed since the beginning. Initially consisting of two layers of $R\phi$ ¹ readout, it was upgraded to three layers in 1991, when the radius of the beampipe was reduced from 7.8 cm to 5.5 cm. This detector is described in [1], and had a single hit precision of about 8 μm , averaged over all incidence angles and cluster sizes and including alignment uncertainties, and an impact parameter resolution determined from hadronic Z^0 decays of $\sqrt{(69/p_t)^2 + 24^2} \mu\text{m}$, with p_t in GeV/c, in the plane transverse to the beam.

Since the typical track p_t at LEP is low ($\leq 1\text{-}2$ GeV/c), the momentum dependent term, which is due to multiple scattering in the beam pipe and detector material, dominates the impact parameter resolution. When considering any change to the detector, it is therefore very important that the material is not increased.

The new detector described here has been equipped with double sided silicon strip detectors. They have a second metal layer which routes the z signals to the same edge, where the $R\phi$ strips are readout, thus allowing the readout electronics to remain outside the active volume. Thus it achieves its goal of adding information about previously unmeasured coordinate without degrading the excellent resolution obtained before.

2. General layout and Detector characteristics

As for the previous silicon strip Microvertex detector, the new one consists of three concentric layers of Si microstrip detectors at average radii of 6.3 cm (Closer layer), 9 cm (Inner layer) and 10.9 cm (Outer layer), covering the central region of the DELPHI detector surrounding the beam pipe. Each layer has 24 modules with about 1^o azimuthal overlap. This high modularity has been chosen to avoid the $R\phi$ intrinsic resolution degradation by inclined tracks. The overlap region was designed to improve the relative alignment of neighbouring modules. Each module consists of two electrically independent half modules, each of them built up of two silicon strip detectors. Detector pairs are wire bonded in series and read out at the full module ends, by custom designed VLSI chips MX6 [2], 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.

Out of the three layers, the closest to and further from the beam line have been equipped with double sided silicon strip detectors, while the intermediate layer has single sided detectors, already described in [1].

The junction side of the double sided silicon detectors is a n type detector with p^+ diodes, AC coupled to their metal readout lines, with coupling capacitors integrated into the detector, in

¹ R, ϕ are defined in the plane transverse to the beam, $+z$ is coincident with the electron beam direction.

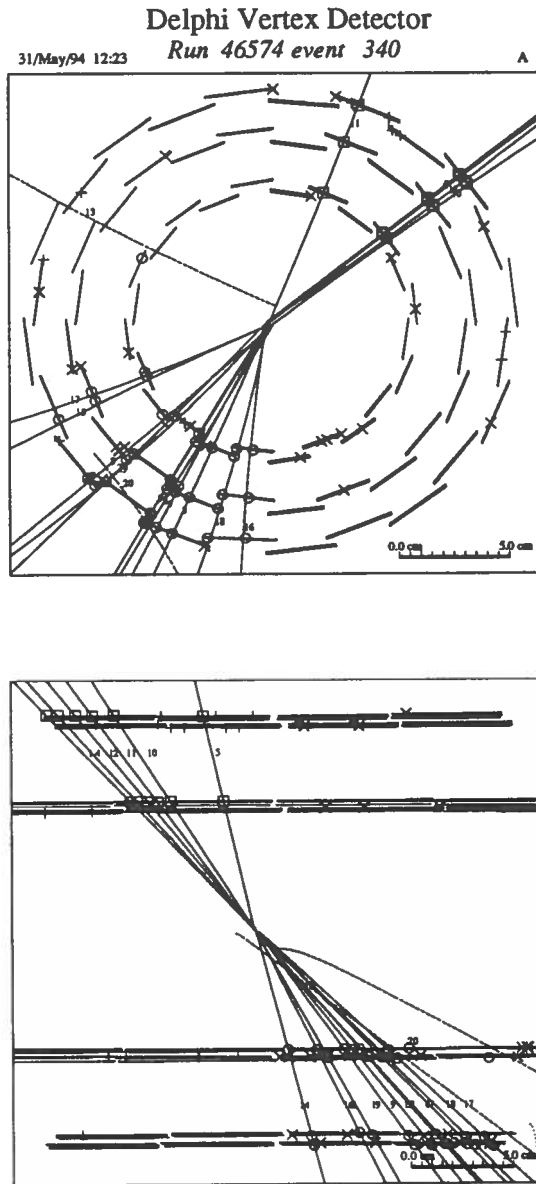


Figure 1. The $R\phi$ and the z projection of one hadronic event from a Z^0 decay observed in the new DELPHI Microvertex detector. Circles and squares indicate silicon hits associated to tracks, crosses correspond to unassociated hits.

order to avoid pedestal shifts due to varying strip leakage currents. The capacitors are formed by growing a thin oxide (~ 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° to the p^+ strips, but the positive 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 isolation. This layer is broken in two different ways: with 'p stops' for the Outer layer ² and 'field plates' for the Closer ³. In the 'p stops' technique an implant of p^+ type silicon is placed between the n^+ strips, while in the 'field plates' solution [3], 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 detectors 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.

The specifications for these detectors are described in table 1.

The p-side includes diodes with $25 \mu\text{m}$ pitch, every second of which is readout. The diodes are parallel to the long side of the detector and used to measure the $R\phi$ coordinate. On the n-side, there is not a single pitch between the n^+ diodes, but it varies, increasing with the angle of tracks crossing the silicon. In this case, since the charge is spread over a wider region, a larger pitch is needed in order to obtain optimal resolution [4].

Detectors with smaller pitch have the signals from two or three strips multiplexed on one single readout line of the second metal layer. Informa-

²manufactured by Hamamatsu Photonics K.K., Japan.

³manufactured by SINTEF, Oslo, Norway.

Table 1
Silicon detectors characteristics

	Closer (SINTEF)		Outer (HPK)	
Polar angle acceptance	$25^\circ < \theta < 155^\circ$		$44^\circ < \theta < 136^\circ$	
Thickness [μm]	307		320	
Dimensions [cm^2]	$7.9 \times 2.1; 6.3 \times 2.1$		5.75×3.2	
Leakage current [μA]	< 10		< 1	
	<i>P side</i>	<i>N side</i>	<i>P side</i>	<i>N side</i>
Diffusion strip pitch [μm]	25	49.5, 99, 150	25	42, 84
Readout strip pitch [μm]	50	49.5, 99, 150	50	42, 84
Diffusion strip width [μm]	6	8	12	14
Al strip layer 1 width [μm]	8	17	8	8
Al strip layer 2 width [μm]		9		6
Insulator (4-5 μm)		Polyimide		SiO_2
Coupling capacitance [pF/cm]	10-20	20-50	10	20
Polysilicon resistance [$\text{M}\Omega$]	4-25	4-25	> 10	> 20
Defects, pinholes...	0.3%	0.3%	$< 1\%$	$< 1\%$

tion from other tracking detectors of DELPHI is used to resolve this ambiguity.

Double sided silicon detectors are 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 capacity for the readout electronics is equalized on the two sides and the polarity of the signals solves the ambiguity between the two detectors.

All the modules, after production, were over-biased at 90 V (current bias voltage during data taking was 65 V) to provoke the creation of pinholes in weak places. If a pinhole was produced, the bond between the interested channel and the chip was removed. Out of 125952 readout channels, only 23 pinholes were developed in Closer layer and 13 in the Outer, none after the installation.

3. Detector Performance

The new Microvertex detector has been working reliably, in the DELPHI experiment at LEP, since the beginning of 1994 data taking period, during which time some $1.5 \times 10^6 Z^0$ decays were recorded. Figure 1 shows a hadronic Z^0 decay. The $R\phi$ view is similar to the one used in the previous detector, but now a precise z view has been added. The signal to noise of the detector (defined as the total cluster pulse height divided by the rms noise of a single readout channel) is

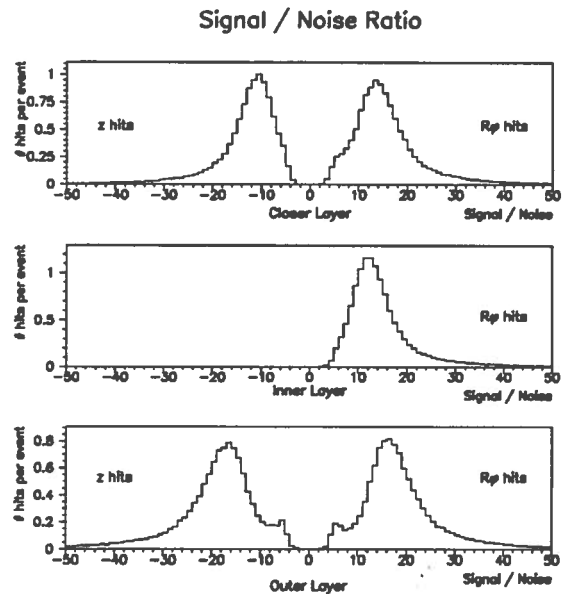


Figure 2. The signal to noise ratio per layer, normalized to perpendicular incidence. z hits are plotted with negative signal over noise.

shown in figure 2, for the three layers. It has been corrected to normal incidence, reducing by a factor $\sin \theta$, where θ is the polar angle of the track to which the hit is associated, to take account of the fact that tracks passing through the silicon at larger incident angles have a longer path through the silicon, and thus leave a larger signal. Hits in z have negative signal to noise ratio. For the Outer layer, the signal to noise is 17 : 1 for both z and $R\phi$ hits, while for the Closer layer the values are slightly lower, around 13 : 1 for the $R\phi$ hits and 11 : 1 for the z hits. The difference in signal to noise between the $R\phi$ and the z hits for the Closer layer is caused by the 7.9 cm long and three fold multiplexing n-side inducing a larger noise than the 6 cm n-side. The signal to noise of the Inner layer is 12 : 1 on average.

3.1. Efficiency

A first measurement of the relative efficiency of the new Microvertex detector has been obtained from the first hadronic events taken by DELPHI in 1994. At present, while the detector is still taking data, it is not yet possible to calculate an absolute efficiency for each layer, as there are inefficiencies in the association of hits to tracks due to uncertainties still present in the alignment.

There are three sectors which show inefficiencies in $R\phi$: in two cases these are problems with the connection of the n-side bias voltage; the third case is caused by high noise on one side of one of the half modules. In addition, one chip from one Inner layer module is dead. In z , three sectors show inefficiencies: (the same) two sectors which have problems with the n-side bias connection, and a third sector which is run lower than its full strip separation voltage to keep its noise within acceptable levels.

In total, these effects render 2.1 % of the Closer layer, 0.2 % of the Inner layer and 1.0 % of the Outer layer inoperational.

3.2. Hit Precision

Since the detector has a large overlap within a given layer, the intrinsic spatial resolution can be obtained from the residual distributions of tracks passing through the overlapping region between two neighbouring sectors. The track is defined by

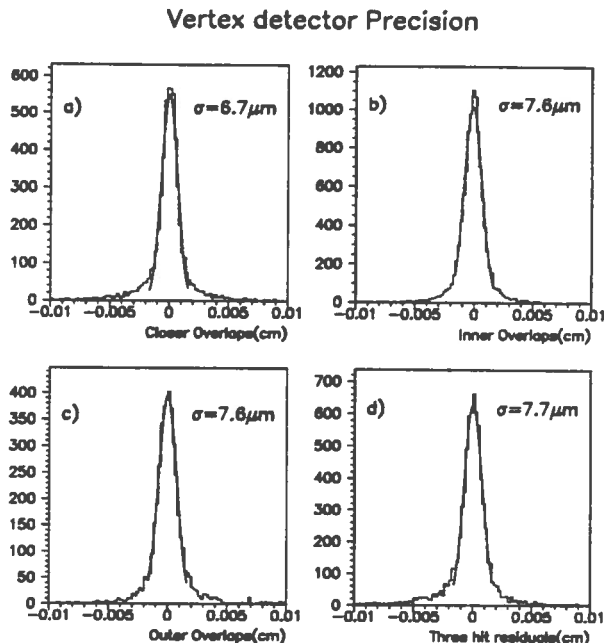


Figure 3. $R\phi$ residual distributions for a) Closer overlap tracks, b) Inner overlap tracks and c) Outer overlaps tracks. Also shown are d) the Inner layer residuals for tracks with hits in all layers. Each residual is normalized by the necessary geometric factor to exhibit the single hit precision for that layer of the vertex detector.

a hit in one of the two sectors of the overlap and a hit in one of the other layers, while the hit on the other sector of the overlap is used to evaluate the residual.

Figure 3 shows the $R\phi$ residual distributions of tracks passing through overlaps in all layers averaged for all sectors and track incident angles. The obtained precision is 6 - 8 μm . For $Z^0 \rightarrow \mu^+\mu^-$ decays, the missed distance between the two muon tracks has a measurement dispersion of 30 μm in $R\phi$, when the muon energy is constrained to the beam energy. This implies an impact parameter asymptotic resolution of $\sim 21 \mu\text{m}$, well reproducing the result obtained with previous Microvertex detector.

Figure 4 a shows the z residuals for the Outer

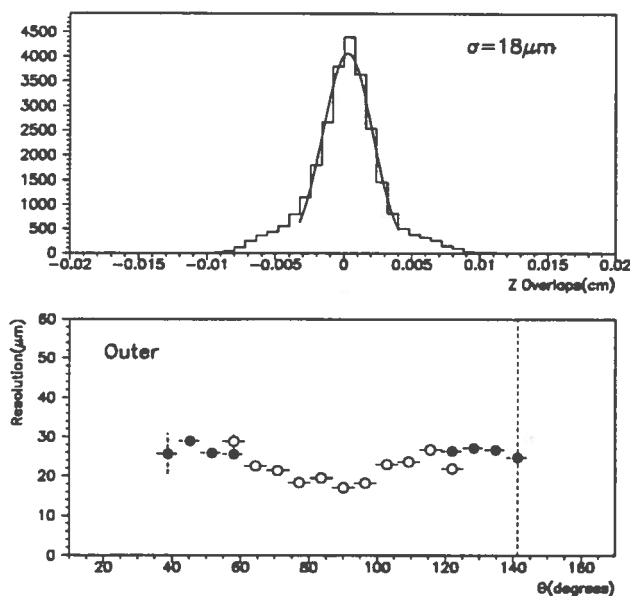


Figure 4. a) z residuals for the Outer layer, averaged over all angles. b) Outer layer z resolution as a function of the track incident angle. The closed circles represent the region where the pitch was doubled. Results are preliminary, since obtained before final alignment.

layer, before the z alignment has been finalized. The residual width corresponds to a single hit precision of $18 \mu\text{m}$.

As described in previous sections, the z strip pitches vary for different track incident angles. Even without the final alignment, it is already possible to see the advantages of changing the n-side readout pitch to match the cluster widths. Figure 4 b shows the Outer layer single hit precision as a function of the track incident angle. The closed circles represent the region where the pitch was doubled.

4. Conclusions

A new Microvertex detector, upgraded from $R\phi$ to $R\phi$ and z readout, has been constructed and installed in the DELPHI experiment. This new detector uses newly developed double sided sili-

con microstrip detectors, in which the routing of signals from the z strips to the end of the detectors is achieved with a second metal layer on the detector surface and no additional material in the active region.

The detector has been operating successfully since the start of the 1994 LEP run. The fraction of inactive channels is less than 2%. The most probable signal to noise ratios for minimum ionizing particles measured with Z^0 decay tracks, are 17 for both z and $R\phi$ in Outer layer detectors and 11 and 13 respectively in Closer layer detectors.

An intrinsic resolution of $6-8 \mu\text{m}$ in $R\phi$ has been measured, while, based on a preliminary alignment, a precision of $18 \mu\text{m}$ in z has been presently shown averaged over all incidence angles. This should improve to the expected $11 \mu\text{m}$ precision once the alignment has been refined using charged particle tracks from the data.

The goal of maintaining the $R\phi$ performance, while adding a precise position measurement also along the beam direction, has been achieved.

Aknoledgements

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