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A SILICON PAD SHOWER MAXIMUM DETECTOR FOR A "SHASHLIK" CALORIMETER

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Abstract

The structure of the calorimeters built with the "Shashlik" technique [1] allows the insertion of tracking detectors within the sampling structure, in order to improve the accuracy in the determination of the showering particle direction and to enhance the e-π separation ability. The new luminosity monitor of the DELPHI detector at LEP was equipped with two planes of silicon pad detectors placed at a depth of 4 and 7.4 radiation lengths.
A description of the silicon detectors is given, together with the results from the exposure to a test beam.

I. Introduction

A new forward electromagnetic calorimeter, STIC (Small Angle TIle Calorimeter) [2], built with the "Shashlik" technique, was installed in the DELPHI detector during the 1993-94 shutdown. It is made of 2 cylinders, positioned at $\pm$ 2.2 m from the interaction point, which cover the angular regions between 29 and 180 mrad around the beam axis. Each cylinder consists of 47 sandwiches made of 3.4 mm thick continous lead plates and 3 mm thick scintillator tiles. It is segmented in towers, projective to the interaction point, each covering 22.5° in the azimuthal angle ϕ and 3 cm in radius.

The scintillation light is carried to the readout tetrodes by 1 mm diameter wavelength shifting (WLS) fibers which cross the tiles with a density of 0.79 fiber/cm^2. The "Shashlik" technique gives the calorimeter a very good spatial uniformity, but makes it practically impossible, for mechanical reasons, to obtain multiple longitudinal shower sampling.

The projectivity of STIC prevents the reconstruction of the shower axis. At LEP200 an angular precision of approximatively 10 mrad in the measurement of the direction of the showering particle would allow to reject backgrounds from beam halo and to identify correctly events with only one photon in the final state.

For that reason the STIC detector was equipped with two planes of silicon pad detectors [3], positioned at a depth of 4 and 7.4 radiation lengths inside the calorimeter. Radially the covered region starts at 71.5 mm (73.0 mm) from the beam axis and extends up to 174.2 mm (178.3 mm) for the first (second) plane.

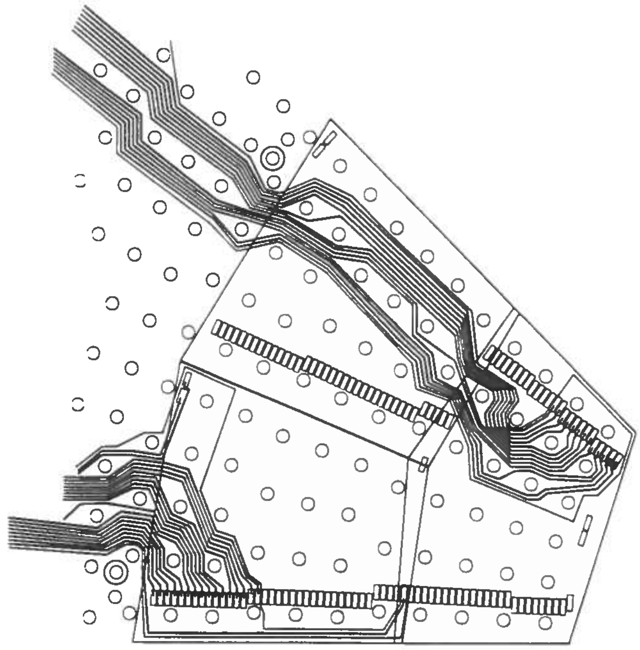

Figure 1: **Layout of a 45° ϕ-wedge of the detector showing the holes for the fibers and the connections to the Kapton cables (the strip structure is not shown).**

The two planes are slightly different to match the projective geometry of the STIC calorimeter.

Each plane consists of a 3.5 mm thick aluminum support onto which 1 mm thick ceramic tiles, fixed by 2 screws, are accurately aligned by means of 3 dowels. The silicon pads are attached, with conductive glue, onto a metallized area of the ceramic which is used to provide the backplane biasing voltage to the diodes.

Each silicon detector is made of 300 μm thick, high resistivity n-type silicon, with p-type strips implanted on the front and a n$^+$ layer on the back. The strips cover 22.5° in ϕ and have a radial pitch of 1.712 mm (1.754 mm) for the first (second) plane.

The radial granularity has been determined after simulation studies [4] in order to optimize the spatial resolution.

In both planes the silicon detectors are arranged in two concentric crowns. Each 45° ϕ-wedge is made out of 3 silicon wafers: an inner wafer which includes two 22.5° ϕ-wedges, each with 24 strips; and two outer wafers, each covering one 22.5° ϕ-wedge with 36 strips (see fig. 1).

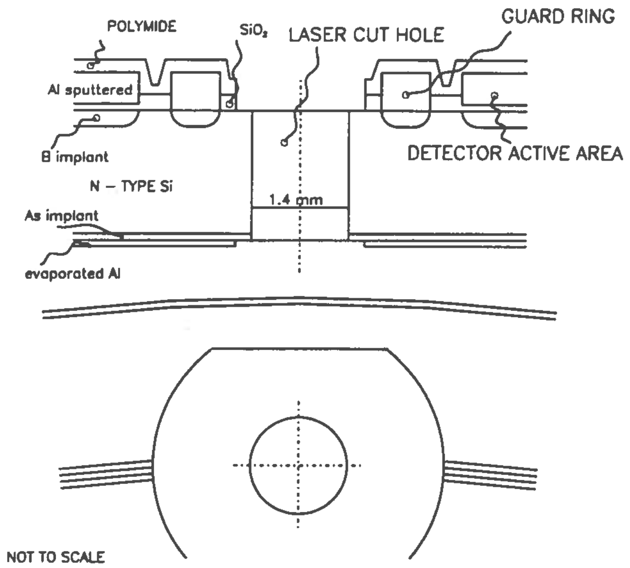

Figure 2: **Layout of the region surrounding a hole.**

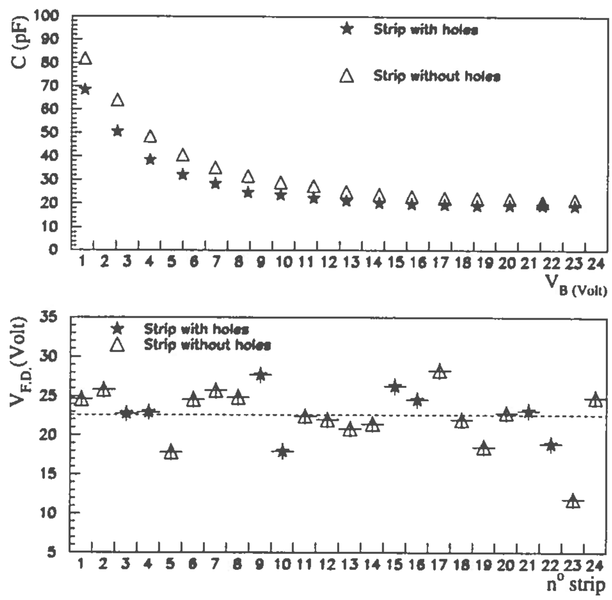

Figure 3: **A comparison of the capacitance (a) and of the full depletion voltage (b) between strips with and without holes.**

The most challenging problem in the detector construction was to make in the silicon 1.4 mm diameter holes to let through the WLS fibers of the calorimeter readout.

Three different techniques for making the holes were tested: laser cutting, ultrasonic grinding and chemical etching. All three techniques gave satisfactory mechanical results, however the best quality to price performance was obtained using laser cutting [1].

The obtained precision in the hole diameter is better than 10 μm. The implanted strip is protected by a guard region which extends for 300 μm. The total passivated zone around a hole has a diameter of about 3 mm. The position of the holes is always between 2 strips, in order to keep the strip continuity. The layout of the region surrounding the holes is shown in fig. 2.

To evaluate possible damage to the substrate, the strips with and without holes were compared [5]. Neither the capacitance nor the full depletion voltage differ, apart from purely geometrical effects, as can be seen from fig. 3. A special production of wafers without holes showed leakage currents comparable to the final detectors with holes.

The strips are AC coupled to the readout and biased by means of a FOXFET (Field OXide Field Effect Transistor) [6] scheme. Each strip acts as an independent source, while the gate and the drain are common.

The drain is put at the same voltage as the preamplifier (5 V) to avoid current flow in case of damage to the decoupling capacitance. Depending on the detector, a voltage varying between 30 V and 50 V is applied to the backplane, in order to achieve the full depletion and to compensate for the voltage drop between the strip and the drain. An aluminum pad is provided for charge collection on each strip. Two aluminum wires, 33 μm in diameter, are used to bond each pad to a copper track deposited on a flexible cable, 35 cm long, which bring the signals to the outer edge of the calorimeter (see fig. 1).

The cable is made of 50 μm Kapton [2] substrate, 35 μm copper tracks and 50 μm protective coating.

Each 45^0 ϕ-wedge of a silicon plane is connected to a Microplex 4 (MX4), 128 channels charge amplifier with multiplexed output, designed by the Rutherford Appleton Laboratories (UK) [7]. The dynamic range is equivalent to 500 MIP, to be compared with the highest signal produced in a strip by a 45 GeV elec-

[1] MICRON Semiconductor Ltd., UK.

[2] manufactured by Du Pont.

tromagnetic shower, which amounts to 70 MIP in the first plane and 60 MIP in the second plane, as determined by Monte Carlo simulation. The signals from the strips are sampled and stored twice, once before the LEP beam crossing and once after all the charge in the silicon has been collected, and the difference between the two measurements is sent to a differential amplifier. The technique of double sampling provides a suppression of the common mode spurious signals induced at the detector level.

A special hybrid fanin, designed and manifactured at CERN, matches the 0.5 mm track input pitch on the Kapton cables to the 44 μm pitch of the MX4 chip. It consists of a ceramic substrate on which a 1 μm aluminum layer is evaporated under vacuum and then printed by chemical etching. The connections between the Kapton cables and the tracks on the fanin are made by connectors [3], soldered onto the fanin. Owing to the difficulties of soldering directly on the aluminum tracks, solder pads were made by evaporating in sequence a layer of cromium and a layer of gold, each less than 1 μm thick. The solder joint proved to be the weakest point of the front end electronics, giving unstable contacts in 10-15 % of the cases, because of the weak adhesion of the gold layer to the substrate. Some alternatives to the chromium-gold layer are presently under study, in order to provide a more reliable soldering technique.

The output signals from the amplifiers are sent to the control room via a 8-to-1 analog multiplexer. The data from each detector are clocked, at a 1 MHz frequency, into a Sirocco IV Fastbus module [8], where they are digitized by a flash ADC.

II. Results from a test beam

The data reported on here were collected in July 1994, using a STIC calorimeter exposed to a 45 GeV electron test beam .

Both the silicon detectors and the readout chain were the same which are used inside DELPHI.

Pedestal runs were taken between the test beam runs to monitor the noise in a systematic way. The data showed the presence of a coherent noise source which produces a common shift of the baseline for the strips read out by the same MX4.

From the pedestal runs the noise correlation coefficients between the various strips were determined.

To subtract the noise on an event by event basis the following procedure was adopted:

1. determination of the region with the maximum signal;
2. evaluation of the coherent noise from the neighbouring strips, read out by the same preamplifier;
3. subtraction of the noise from the signal, using the correlation coefficients calculated in the pedestal runs.

The measured signal over noise ratio is about 40, for a 45 GeV electromagnetic shower, in the strip with the maximum energy deposition.

The radial position of the incoming particle was estimated, in both silicon planes, by means of a center of gravity method applied to the 5 strips around the shower maximum, without correcting for possible strip to strip gain variations.

As can be seen in fig. 4, the transverse profiles of the shower, measured by the 2 silicon planes, agree well with the predictions of a simulation based on the GEANT program [9].

The best method to take into account systematic effects, like the biases caused by the centre of gravity estimator, the presence of the holes in the strips and inaccuracies in the calibration, is still under study. Nevertheless we can correlate the measurements of the two planes and estimate what is achievable in terms of angular resolution in the determination of the shower axis.

Due to the alignement of the beam along the STIC projective structure, the distribution of the difference between the radial positions reconstructed by the two silicon planes provides a measurement of the angular resolution in the reconstruction of the showering particle direction. The 630 μm spread of the distribution in fig. 5, evaluated from the FWHM, translates into an angular resolution of 13 mrad, since the distance of the two silicon planes is 51.7 mm.

The non gaussian tails of the distribution are probably due to the systematics mentioned above.

Taking these factors into account, the resolution compares well with the 10 mrad resolution aimed to in the proposal [10].

Figure 6 compares the radial shower profiles for a Bhabha event at LEP, measured by the STIC calorimeter and by the two silicon planes, in order to show the improvement, in terms of spatial resolution, due to the silicon pad detectors.

[3]ELCO®, series 6200-6201

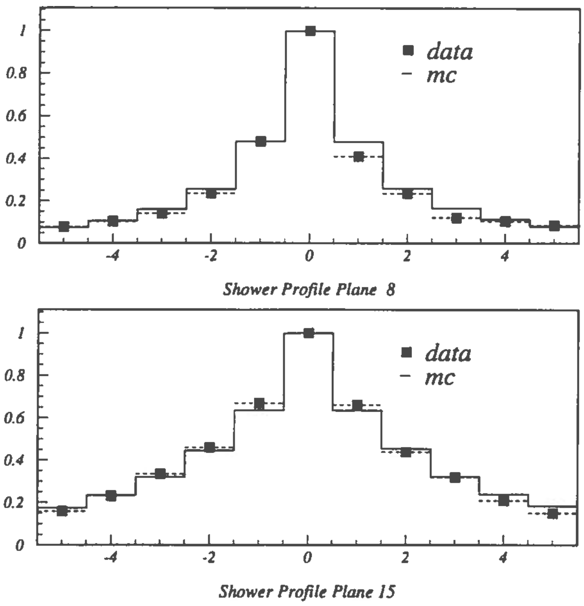

Figure 4: Transverse shower profiles, for 45 GeV electrons, in the 1^{st} (at 4 X_0 inside the calorimeter) and 2^{nd} (at 7.4 X_0 inside the calorimeter) silicon planes. The test beam data and the results of a simulation are compared.

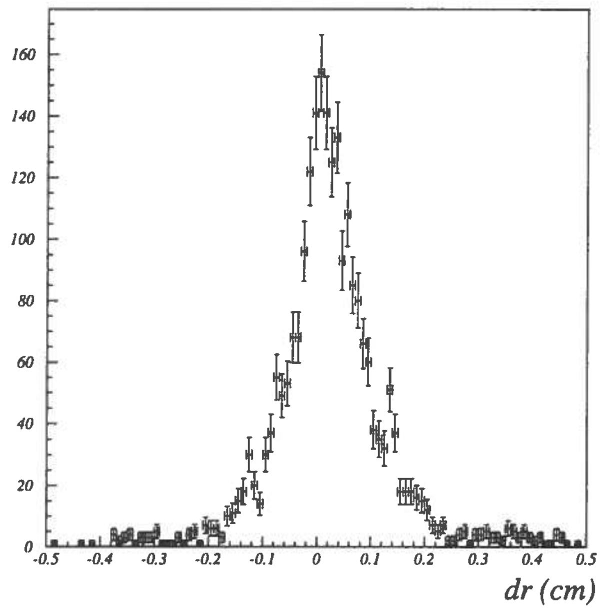

Figure 5: Difference between the radial positions reconstructed in the two silicon planes.

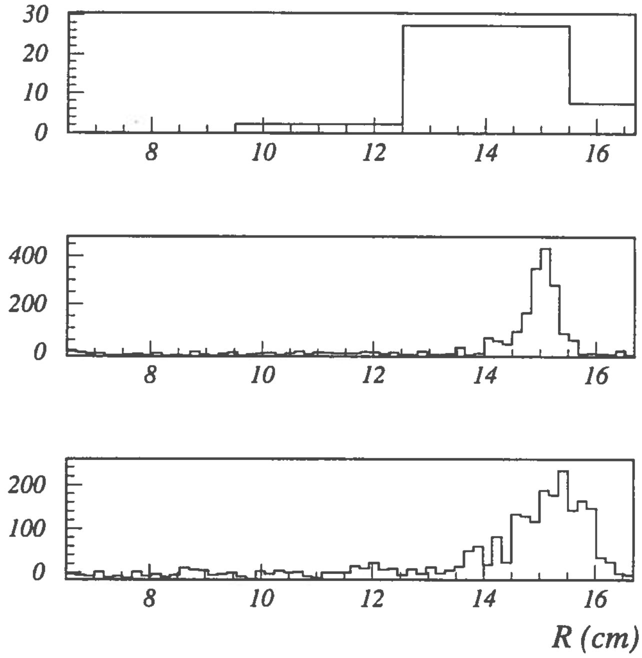

Figure 6: Transversal shower profiles, measured by the STIC calorimeter and by the two silicon planes, for a typical Bhabha scattering event at LEP. The vertical axis shows the pulse height in arbitrary units.

III. Conclusions

We have built a new type of silicon detector matched to the calorimeter Shashlik structure.

It provides a mesaurement of the direction of the incoming particle with an accuracy of about 13 mrad, making possible for DELPHI, in the LEP200 phase, the rejection of backgrounds from beam halo and the correct identification of events with only one photon in the final state.

IV. Acknowledgements

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