4 Particle Physics at LHC/CMS

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4.1 Silicon Microstrip Telescope

To study the performance of pixels foreseen for the CMS microvertex detector we have built in our mechanical workshop a precision beam defining telescope (fig. 4.1). This device was described in details in last year's annual report. It is made of 4 modules, each containing two 32×32 mm^2 single-sided microstrip silicon wafers manufactured by SINTEF (Oslo), one providing the x-coordinates and the other the y-coordinates. A microstrip detector contains 1280 strips with a pitch of 25 μm. Every second strip is connected to the readout electronics and the charge collected by the floating strips induces a charge on the readout strips by capacitive coupling. The readout is triggered by upstream and downstream scintillation counters. The signals from the 640 active strips are amplified and stored in VA2 Viking chips (shaping time 2.3 μs). The analog charge is then read out sequentially and stored in Flash ADC's (CAEN VME V550). The data acquisition is controlled by a PC running Labview. The total length of the telescope is 59 cm. The space between the two upstream and the two downstream modules (35 cm) is used e.g. for the pixel detector prototype mounted on a rotating support.

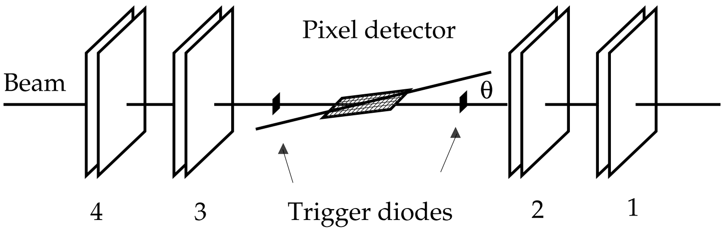

Figure 4.1: Sketch of the microstrip telescope.

The telescope was exposed to a 100 GeV muon beam at the SPS. A signal to noise ratio of 130 for minimum ionizing particles was achieved. The hit coordinates were determined accurately by measuring the energy deposits shared between adjacent strips. The precise alignment was achieved by software with a large number of passing muons. Preliminary results for the resolution were already reported in last year's annual report. Each readout plane provides the x or y coordinates of a traversing particle with a resolution of $\sigma = 1.8$ μm. The coordinates of a track hitting the test device in the center of the telescope can be determined with a precision of $\sigma \simeq 1\mu$m [1].

4.2 Pixels

The final design of the CMS pixel detector was submitted to CERN in 1998 [2]. The barrel detector is made of three cylindrical layers, 53 cm long with radii of 4, 7 and 11 cm, the first layer being used only during initial low luminosity runs. The support structures are made of tubes providing cooling to - 10° with C_6F_{14}, connected with carbon fibre blades and supported at both ends by carbon fibre rings.

Each layer is made of two half-cylinders to allow insertion into the CMS detector. Figure 4.2 shows a full size prototype of one of the supporting half cylinders which was built in our mechanical workshop. The prototype uses titanium tubes and a ceramic substrate. The former will be replaced by aluminium and the latter will be replaced by carbon fibres to minimize multiple scattering. A cooling manifold is available at each end within the carbon fibre end flanges.

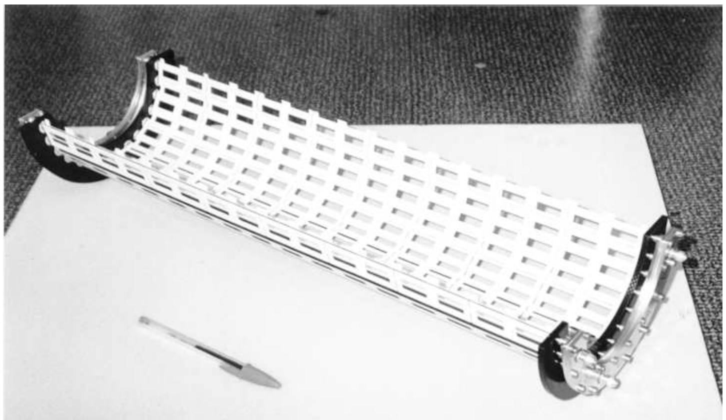

Figure 4.2: Full scale prototype of the mechanical support structure for one of the CMS pixel detectors.

A pixel unit cell contains 53 $\times$ 52 pixels. The dimensions of the (square) pixels have been increased from 125 μm in the original proposal to 150 μm. Two rows of 8 cells build a module and a row of 8 modules builds a facet of length 53 cm and width 1.75 cm. The total number of pixels to be read out is about 3×10^7. The bulk material is n-type and the pixel implants are n^+.

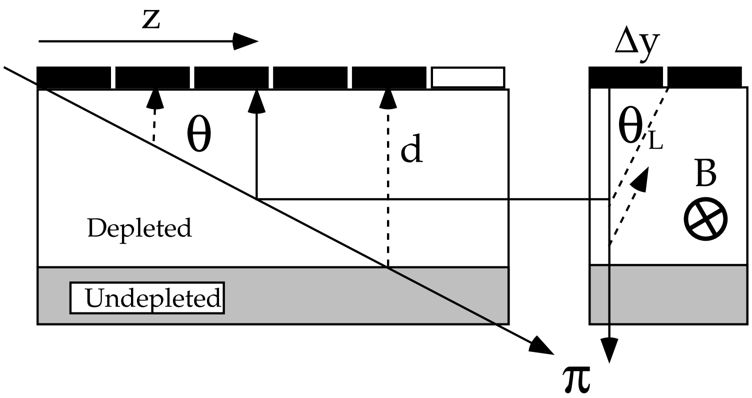

Figure 4.3: a) Measurement of the depletion depth with particles traversing the detector at a known grazing angle θ. The first and last row of fired pixels determine the depletion thickness d; (b) In the presence of a longitudinal magnetic field the charge migrates towards the adjacent column under the angle θ_L.

In the high rate environment of LHC, type inversion will occur, the bulk material then acting as p-type. These radiation defects will slowly reduce the depletion thickness for a given bias voltage. We therefore measured in spring 1998 at CERN [1] the depletion depth for the two prototype pixel detectors that were manufactured earlier by CSEM in Neuchâtel, one of which had been irradiated at PSI with $6{\times}10^{14}$ pions/cm^2. This flux corresponds to

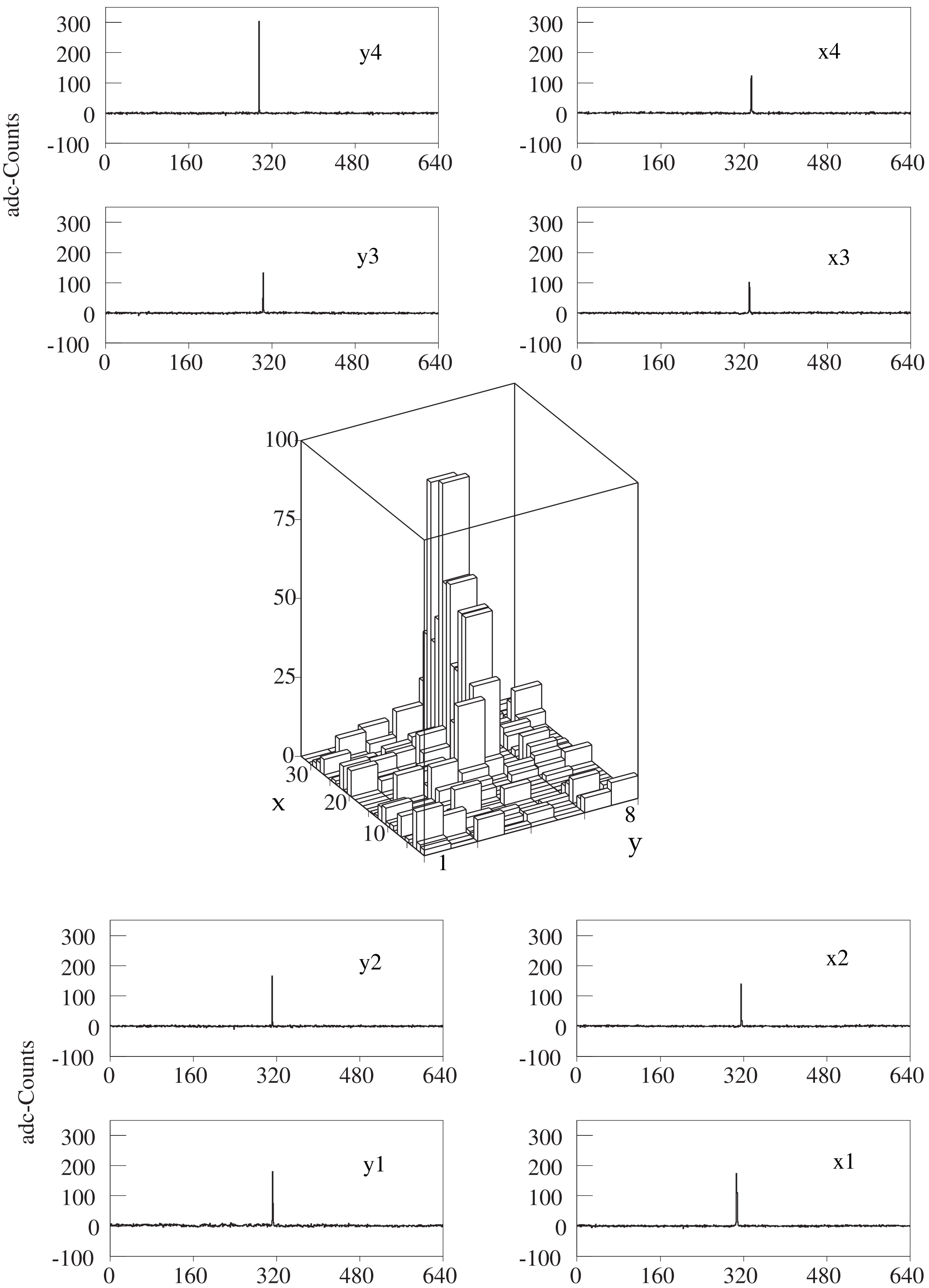

Figure 4.4: Typical pion track detected by the eight microstrip detectors in coincidence with the pixel device. The figure shows the distributions of charge deposits as a function of position after pedestal subtraction.

the operation of the pixel device at the radius of 7 cm during 6 years at the maximum LHC luminosity. The irradiation was performed in late 1996 and the detector was subsequently stored at a temperature of 3°C. To minimize multiple scattering effects the measurements were made at the SPS in a 225 GeV π^+ beam. The detectors had 8 columns and 32 rows of silicon pixels each covering a surface of 125 $\times$ 125 μm^2 (thickness 285 μm), leading to an active area of 1$\times$ 4 mm^2. The pixel detector was positioned horizontally at the center of the microstrip telescope, so that pions would traverse the detector at a grazing angle $\theta = 8°$ (see fig. 4.1). The depletion thickness could be measured by counting the number of hit pixels along the beam direction (fig. 4.3a). The apparatus was immersed in a longitudinal magnetic field provided by two Helmholtz coils to also measure the Lorentz angle, as will be explained below.

The readout electronics was triggered by two 2 $\times$ 2 mm^2 silicon diodes placed immediately upstream and downstream of the pixel detector. For the pixel readout we used the same Flash ADC system as for the telescope. The precise orientation of the pixel detector (e.g. the angle θ) was determined with the telescope using straight tracks and comparing the predicted entrance coordinates with the measured ones. Figure 4.4 shows a typical track detected by the eight silicon layers of the telescope and the corresponding energy deposits in the fifth column of the pixel detector. The average signal over noise ratio ($\sim$ 130) for the silicon strips is much larger than for the pixels ($\sim$ 5) due to the much longer integration time.

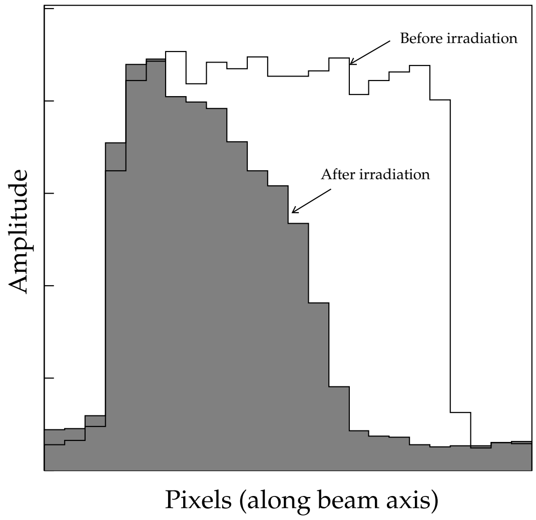

Figure 4.5: Amplitude distribution along the beam axis as a function of pixel row. The grey histogram shows the reduction in depletion depth due to radiation damages.

Figure 4.2 shows the amplitude distribution (without magnetic field) along the beam direction before and after irradiation. The typical "road" length of 18 pixels before irradiation corresponds to a depletion depth of 285 μm (achieved with a bias voltage of - 144 V), in accord with the physical thickness of the detector. For the irradiated detector the significantly shorter road length indicates a depletion thickness of about 164 $\pm$ 17 μm (bias voltage of -300 V), 18 months after irradiation. A similar measurement performed at PSI immediately after irradiation led to a depletion length of about 150 μm. The smooth decrease of the collected charge along the road is due to trapping of the charge carriers by defects, an effect that is proportional to the total drift length.

The angle θ being small we assume the electric and magnetic fields to be orthogonal. Due to deflection in the magnetic field the charge carriers do not move along the electric field lines but drift at an angle θ_L, the Lorentz angle, towards the adjacent column (fig. 4.3b). The charge deposit is therefore shared among (mostly two) adjacent pixels. Figure 4.2 shows the pixel roads for the two detectors in a longitudinal magnetic field of $\pm$ 3 T. One observes the increasing charge collection with road length - hence depth - by the adjacent left or right columns, depending on the sign of the magnetic field.

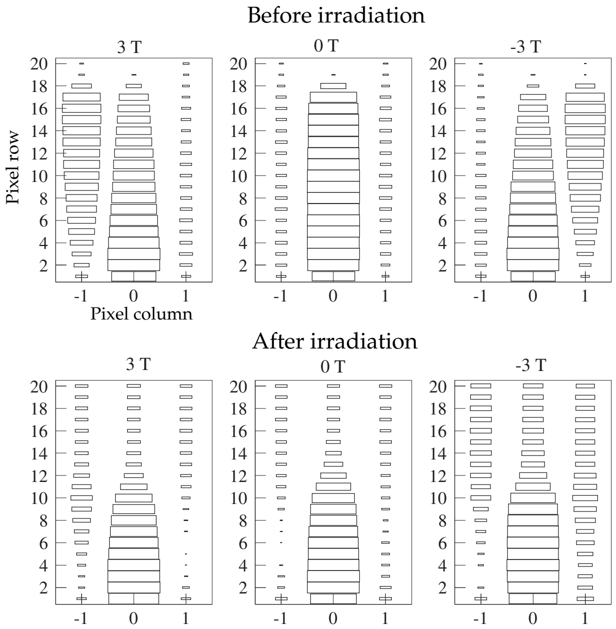

Figure 4.6: Energy deposits in a longitudinal magnetic field of 0 and ± 3 T. The pions enter the pixel detectors in the central column at the bottom of the figures. The size of the box is proportional to the charge deposited in each pixel. The distance between the (square) pixels is 125 μm.

The Lorentz angle was measured by finding the coordinate z of the pixel row for which the charge collected between the main and adjacent pixels are equal (see fig. 4.3b). This corresponds to charge reaching the readout surface between two pixels. The coordinate Δy of the impinging track was determined by the telescope and θ_L could be calculated from the relation $\tan\theta_L = \Delta y/z \tan\theta$. We found a Lorentz angle of (13.1 ± 1.1) ° at 2 T before irradiation and (12.3 ± 2.7) ° after irradiation, which does not indicate a strong dose dependent effect. These figures are also in agreement with an earlier measurement from our group [3].

In conclusion, the depletion thickness and the Lorentz angle for irradiated detectors will be sufficiently large to permit charge sharing among adjacent pixels in the 4 T field of the CMS detector. In 1999 we will proceed with beam tests of a novel pixel sensor designed by the Zurich group. So far the pixel signals were fed to the preamplifiers through readout strips, while in the final CMS device the pixels will be connected to the chips through indium bumps [2]. The first indium bump bonded pixels will be exposed to our test beam facility this year.

References

[1] M. Glättli, Diplomarbeit, Universität Zürich (1998)

[2] Technical Design Report of the CMS Tracker, CERN/LHCC 98-6 (1998)

[3] R. Kaufmann, Diplomarbeit, Universität Zürich (1997)