4 Particle Physics at LHC/CMS

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In last year's annual report we announced that we had joined the LHC/CMS Collaboration at the Large Hadron Collider at CERN [1]. B-physics at LHC, on which we plan to concentrate, requires a good reconstruction capability for secondary vertices from B-decays. We are therefore contributing to the inner tracker, in particular the silicon pixel detector, its readout system and the mechanical support structure. We also participate in the design and construction of the microstrip gas chambers.

4.1 Pixel Detector

The barrel pixel detector is made of 2 cylindrical layers, 65 cm long, with 55 million pixels (125×125 μm^2) at a radial distance of 77 mm and 117 mm from the beam axis. The pixels are arranged in rows of detectors along the beam direction (z), each detector containing a double row of 64×64 pixels. The position resolution will be improved by comparing the energy deposits from the electron cloud on adjacent pixels. The goal is to achieve a position resolution of σ=15 μm in both $r\phi$ and z.

During two beam periods at CERN we tested two prototypes (manufactured by CSEM in Neuchâtel) for the silicon pixel detector. The detectors (fig.4.1) were made of n-doped 4×8 mm^2 silicon wafers with a thickness of 300 μm and a sensitive pixel area of 1×4 mm^2 containing 256 pixels (32×8) with a size of 125×125 μm^2. The pixel cells were connected to two Premux128 readout chips (2×128 channels), one on each side of the detector.

The first beam test, with preliminary results presented in last year's annual report, was performed at the CERN-SPS with 50 GeV pions to measure the position resolution [2]. In the 4 T magnetic field of CMS (which is perpendicular to the electric field in the silicon detector) the electron cloud does not follow the electric field lines but migrates at an angle of $\sim 35^\circ$ with respect to the field lines (the so-called Lorentz angle). The charge deposit is therefore shared among several adjacent pixels forming a cluster (fig. 4.2), a property that can be used to improve on the position resolution.

Since no magnet was available for this test, data were taken at different detector inclination angles with respect to the beam axis to simulate the Lorentz angle in the magnetic field of CMS. The signal to noise ratio was about 30. The cluster charge and size as a function of tilt angle were measured and found to correspond to expectations from simple geometry. The energy loss distribution for different tilt-

Figure 4.1: Sketch of one of the detectors equipped with its readout electronics. The pixels in the lower half are staggered to improve the position resolution by charge sharing on adjacent pixels.

angles ($0° - 45°$) is shown in fig. 4.3. As expected, the mean of the distribution moves to higher energies with increasing angles. Figure 4.4 shows cluster sizes (averaged over many events) for the two extreme angles $0°$ and $45°$. The cluster size (typically 1 pixel for normal incidence) increases with tilt angle (typically 3 pixels at $45°$).

In this first attempt the data collection efficiency was rather poor due to the large beam spot compared to the detector size. A good definition of the incident π tracks with silicon microstrip detectors was also not possible due to heavy multiple scattering effects from other detectors tested in the same beam. An algorithm was used instead to measure the spatial resolution without tracking [3], employing charge sharing between pixels: For a traversing charged particle leaving a signal in only one pixel, the spatial resolution is determined by the pixel pitch divided by $\sqrt{12}$ (in our case $\sim 36\ \mu$m). If, however, the charge Q is deposited in two adjacent pixels (left (L) and right (R)) the fraction of charge deposited in, say the right pixel, is

$$\eta = \frac{Q(R)}{Q(R) + Q(L)}. \tag{4.1}$$

The η distribution can be measured with many events (see fig. 4.5 below). For a given passing particle the impact point between the two pixels can then be obtained by integrating the η distribution up to the measured η. The position resolution was measured as a function of tilt angle [2]. We obtained $\sigma = 13\ \mu$m for a tilt angle of $35°$, which corresponds to the Lorentz angle in the CMS magnetic field of 4 T.

Figure 4.2: In a magnetic field the charge is spread over several pixels.

The second beam test was performed in May 1996 in a strong magnetic field [4] with 225 GeV/c pions. We also improved on the data collection efficiency by a factor of ten by using triggering diodes of the size of the pixel detector. The purpose of this run was to measure the Lorentz angle and the position resolution in the magnetic field. Figure 4.5 shows the η distribution at normal incidence for 0, 2 and 3 T. The intensity in the central region ($0 < \eta < 1$) grows with increasing field due to the increase in charge sharing between adjacent pixels. The 2 T data points taken with our 300 μm thick prototype correspond to 4 T for the 150 μm thick detectors foreseen at CMS. For 2 T we find a position resolution of $\sigma = 16.4 \pm 1.5$ μm which agrees with the expected 15 μm assumed in the CMS proposal.

The Lorentz angle at 2 and 3 T was determined by measuring the cluster size as a function of inclination angle. The cluster size with tilted detectors increases (or decreases) in the presence of the magnetic field (depending on the field polarity) and hence depends on the tilt angle and on the Lorentz angle. In addition, the longer drift length in the magnetic field (see fig. 4.2) increases the transverse diffusion width. A model parametrization taking into account the three effects was developed with Monte-Carlo data [4]. The model, the simulation for the expected Lorentz angles and the data agree reasonably well (fig. 4.6). A fit of the model function to the data (fig. 4.5) then permits the determination of the Lorentz angle. Alternatively, the parameters of the simulation can be adjusted to fit the data. We find:

$$\begin{aligned} \Theta_L &= 15.5^\circ \pm 2.4^\circ \text{at 2 T}, \\ \Theta_L &= 23.6^\circ \pm 2.1^\circ \text{at 3 T}, \end{aligned} \tag{4.2}$$

in fair agreement with expectations (18.6°, resp. 26.8°) from the known electron mobility in silicon. The slightly smaller experimental values may indicate a contribution from drifting holes.

The readout system (based on Sirocco II flash ADC's) was also purchased by the Zurich group and the data acquisition system (based on a VME FIC 8234 processor)

Figure 4.3: Energy loss distribution for different detector tilt angles ($0° - 45°$) fitted by Landau distributions (curves).

was developed [4]. To alleviate the difficulties with multiple scattering from other detectors in the beam we are constructing in the workshop of our Institute our own defining telescope made of 8 planes of single-sided microstrip detectors providing a position resolution of 6 μm, equipped with trigger diodes of the size of the pixel detectors. In 1998 we will then perform further measurements at 300 GeV in a magnetic field of 2 to 3 T to measure the resolution and Lorentz angles using irradiated detectors. The devices must survive fluences of the order 10^{15} particles/cm^2, corresponding to about 5 years of LHC running. Preliminary tests at PSI with fluences over 10^{14} protons/cm^2 were encouraging.

4.2 Microstrip Gas Chambers

The ongoing research and development work for microstrip gas chambers is described in section 5.4 below, because a part from building up the necessary infrastructure within our institute [5, 6], we are concentrating on the prototypes for the HERAB experiment.

Figure 4.4: Normalized two-dimensional pixel energy distribution, averaged over many events for normal incidence (a). In (b) the detector was tilted by 45° around the i axis.

Figure 4.5: left: η-distribution measured for different magnetic fields: - O T, - - 2 T, ... 3 T. Right: Cluster-sizes vs. tilt angle with fits; $*$: 0 T, $\circ$ 2 T, $\times$: 3 T.

References

[1] The Compact Muon Solenoid, Technical Proposal, CERN/LHCC/P1, 1994.

[2] V. Dubacher, "Test of silicon pixel detector with 50 GeV pions", Diploma work, Universität Zürich, 1996.

[3] E. Belau et al., Nucl. Instr. Meth. 214(1983)253.

[4] R. Kaufmann, "Performance of a silicon pixel detector in a magnetic field", Diploma work, Universität Zürich, 1997.

[5] "An electrical method for detecting anode breaks on micristrip gas chamber plates", A. Maag, Diploma Thesis, Universität Zürich (1997).

Figure 4.6: Simulated cluster-sizes for different fields ($\triangle$). The curves are the model fits to the simulated data. The measured cluster sizes with errors are also shown.

[6] "Clean Room Instrumentation for Microstrip Gas Chamber Scanning: An Optical Microscope with Computer Controlled Positioning and Position Recording", P. Robmann, S. Steiner and T. Walter, University of Zürich Report HERAB–01/97.