The ALICE forward multiplicity detector

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The ALICE experiment is designed to study the properties of hadron and nucleus collisions in a new energy regime at the Large Hadron Collider at CERN. A fundamental observable in such collisions is the multiplicity distribution of charged particles. A forward multiplicity detector has been designed to extend the charged particle multiplicity coverage of the ALICE experiment to pseudorapidities of $-3.4 < \eta < -1.7$ and $1.7 < \eta < 5.0$. This detector consists of five rings, each containing 10240 Si strips, divided into sectors comprised of Si sensors bonded and glued to hybrid PC boards equipped with radiation hard preamplifiers. The output of these preamplifiers is multiplexed into custom-made fast ADC chips located directly behind the Si sensors on the detector frame. These ADCs are read out, via optical fibers, to a data acquisition farm of commodity PCs. The design and characteristics of the ALICE Forward Multiplicity Detector will be discussed.

1. PHYSICS MOTIVATION

The ALICE experiment at the LHC will study interactions in high-energy hadron and nucleus collisions ($\sqrt{s_{NN}} = 5.5$ TeV) at the LHC. The goal of the experiment is to study the properties of matter created in high energy collisions of nuclei directed at establishing if an extended region of deconfined matter was created [1]. A range of observables must be measured to establish the state of matter created in these collisions.

One important observable is the multiplicity distribution of charged particles produced in the collision. This distribution characterizes both the number of charged particles produced in the collision and the direction where the particles were emitted. Fig. 1 shows the charged particle multiplicity acceptance as a function of pseudorapidity (η) in ALICE. The Forward Multiplicity Detector, FMD, increases this acceptance to $-3.4 < \eta < 5.0$.

2. FMD CONSTRUCTION

The FMD consists of a set of 5 rings of silicon strip detectors placed at 3 distances from the nominal collision point to extend the pseudorapidity coverage of ALICE [2]. A picture of the layout of the FMD in the ALICE coordinate system is shown in Fig. 2. Each silicon ring contains 10 or 20 silicon sensors as shown in Fig. 3. To better resolve individual particles at higher particle densities (expected in more forward regions), the strip width (radially) in the inner sensors is half of the strip width in the outer sensors.

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*For the full list of ALICE authors and acknowledgments, see appendix 'Collaborations' of this volume.

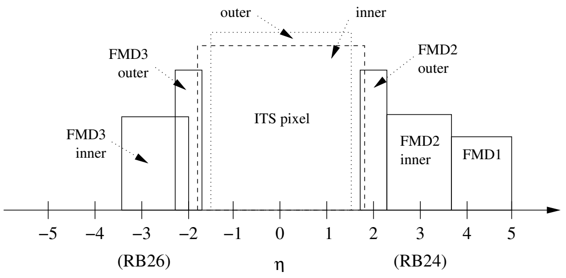

Figure 1. Pseudorapidity (η) acceptance of the FMD. The FMD extends the pseudorapidity coverage of the ALICE midrapidity detectors (dashed and dotted lines here) to be $-3.4 < \eta < 5.0$.

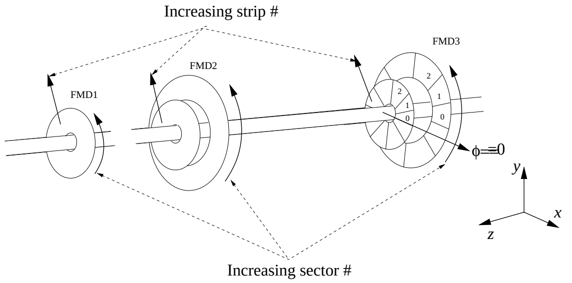

Figure 2. Physical layout of the FMD in the ALICE coordinate system. FMD1 is located 320 cm in front of the nominal collision point and has only an inner ring. FMD2 and FMD3 are located approximately 80 cm in front of and behind the nominal collision point and have both an inner and outer ring.

Each ring has 10240 silicon strips. The size of the silicon detectors is determined by the silicon production process. The number of strips per sensor has been chosen so that the number of particles per strip is, on average, approximately 1 per event.

3. SILICON MODULES AND READOUT

The basic silicon sensor is a 300 μm thick piece of n-type silicon with p+ type implants. Fig. 4 shows the cross-section of a silicon sensor. Each p+ implant is connected through a bias resistor to a bias ring. During operation, high voltage (greater than 70V) is applied to an aluminum surface on the back of the silicon bulk (where no p+ implants exist) and the bias ring is left grounded. This depletes the silicon bulk of thermal electron-hole pairs that would dominate the readout noise in an unbiased sensor. Readout lines are capacitively coupled to the p+ implants. When a particle traverses the silicon bulk, electron hole pairs are created and the signal is transferred to the readout lines, which only run over the top of their own pads to ensure that cross-talk is minimized.

A silicon module is made by glueing the strip side of a silicon sensor to a hybrid card with 250-500 μm spacers separating them. The module is then electrically connected via wire bondings (512 for outer sensors and 1024 for inner sensors) at the periphery of the silicon sensor and hybrid card. The hybrid card contains VA1_3 preamplifier chips [3] to integrate, shape, and hold the readout signals from the silicon sensors. The VA1_3 preamplifier chip is a radiation hard version of the VA family [4] of preamplifier chips which uses 0.35 μm technology [5]. Each chip has 128 channels. Hybrid cards for inner sensors, therefore, contain 8 chips while hybrid cards for outer sensors contain 4 chips. The VA chips are designed to have low noise, high gain, and a dynamic range of 0-20 MIPS.

When a collision occurs, particles traverse the silicon leaving signals which are collected by the VA chips. After a fixed time, (between 1.2 and 2.0 μs) determined by the tuned

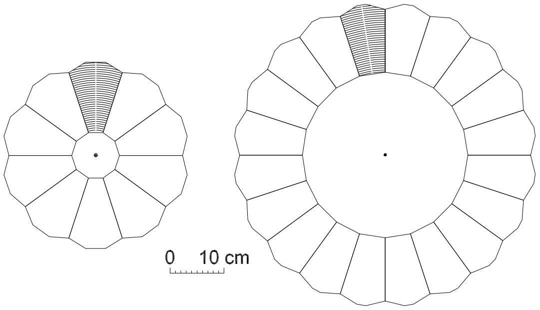

Figure 3. Geometry of each FMD ring type (inner and outer). An inner FMD ring has an inside radius of 4.2 cm and an outside radius of 17.2 cm and contains 10 silicon sensors each with 1024 silicon strips. An outer FMD ring has an inside radius of 15.4 cm and an outer radius of 28.4 cm and contains 20 silicon sensors each with 512 silicon strips.

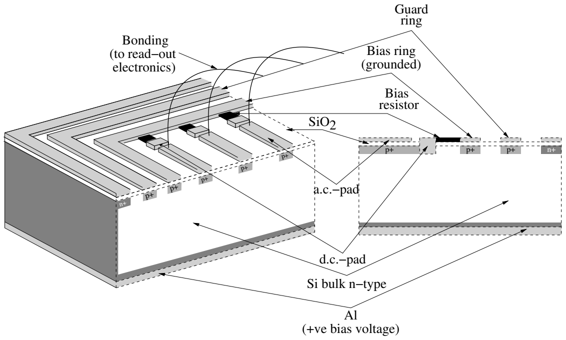

Figure 4. A schematic view of the corner of a silicon sensor. High voltage is applied to the bottom Al layer to deplete the silicon bulk of thermal electron-hole pairs. Signals are read out through AC coupled readout lines.

shape of the output signal from the preamplifiers, the VA chips hold the level of their signals. These signals are then multiplexed out to an ALTRO ADC [6] on a nearby board (less than 30 cm away to reduce noise) and are digitized. A readout control unit (RCU [7]) then transmits this information over fiber optic links to a PC farm which will collect and assemble the data into an event if the event is desired to be recorded.

4. PERFORMANCE

A prototype inner silicon module has been constructed. The main contributions to the noise arise from thermal current fluctuations in the preamplifier chips, silicon bulk, and bias resistors. The signal to noise has been estimated to be between 65 and 57 depending on the length of the strip being considered.

The prototype module has been tested at the ASTRID facility at the University of Århus in Denmark. The prototype module was put into a high energy (680 MeV) electron beam and data were collected. Fig. 5 shows a sample of the data taken in that test beam for a single strip. A minimum ionizing signal peak can be seen in the raw signal. However, a large number of signals are observed with energies between the noise level and the 1 MIP peak. Fig. 6 shows the correlation between the energy deposited in two adjacent silicon strips. The sharing of energy from a single particle among the two strips can be clearly seen. If the signal in both pads is required to be above the noise level (0.4 fC in this case), the resultant distribution of summed energy from the adjacent pads fits a Landau distribution well. If signals which could have been shared with neighboring channels are excluded by requiring that only small amounts of energy (on the order of the noise level) are recorded in adjacent strips, the number of signals between the noise peak and the 1 MIP peak is drastically reduced. After this cut, a clear signal peak is evident and the signal to noise of the detector can be calculated. A resultant signal to noise ratio of 60:1 is measured. This signal peak also displays properties of a Landau distribution, but retains some features of residual sharing.

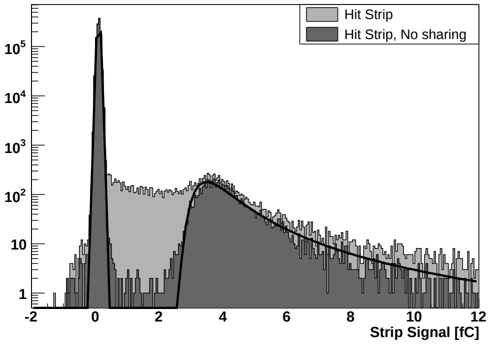

Figure 5. Data taken from detection of 680 MeV electrons impinging on an FMD silicon module for a single silicon strip. While a MIP signal can be seen in raw data, the exclusion of hits with energy shared between adjacent strips makes the MIP much more distinct. The line is a fit to Gaussian noise plus a Landau signal distribution.

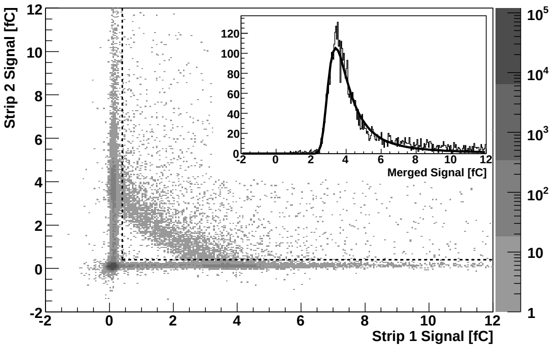

Figure 6. Correlation of energy deposited in 2 adjacent silicon strips. A clear band of shared energy representing $E_1 + E_2 =$ 1 MIP can be seen. The inset picture is the distribution of $E_1 + E_2$ if the energy in each strip is required to be above 0.4 fC, represented by the dashed lines in the larger picture. The distribution of $E_1 + E_2$ is fit to a Landau distribution.

The FMD detector works according to specifications with excellent signal to noise characteristics. Hit sharing will have to be dealt with in order to properly assess the number of particles impinging on the detector, but the performance of the detector is ideal for performing the physics desired in ALICE.

REFERENCES

1. "ALICE Technical Proposal", CERN/LHCC 95-71
2. "ALICE Technical Design Report on Forward Detectors: FMD, T0, V0", CERN-LHCC-2004-025
3. Ideas ASA, "`VA1_3`",
   Draft document, see `http://fmd.nbi.dk/fmd/VA1_3-draft-v0r94.pdf` .
4. Ideas ASA, `VA1_prime2`,
   `http://www.ideas.no/products/ASICs/VAfamily.html` .
5. A. Yokoyama *et al.*, IEEE Trans. Nucl. Sci. **48** (2001) 440.
6. R. Esteve Bosch, A. Jimenez de Parga, B. Mota and L. Musa, IEEE Trans. Nucl. Sci. **50** (2003) 2460.
7. R. Esteve Bosch *et al.*, Proc. 8th Workshop on Electronics for LHC Experiments, Colmar 9–13 September 2002.