A Multiplicity-Vertex Detector for the PHENIX Experiment at RHIC

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Abstract

A Multiplicity-Vertex Detector (MVD) has been designed, and is in construction for the PHENIX Experiment at the Relativistic Heavy Ion Collider (RHIC). The 35,000 channel silicon detector is a two-layer barrel comprised of 112 strip detectors, and two disk-shaped endcaps comprised of 24 wedge-shaped pad detectors. The support structure of the MVD is very low mass, only 0.4% of a radiation length in the central barrel. The detector front-end electronics are a custom CMOS chip set containing preamplifier, discriminator, analog memory unit, and analog to digital converter. The system has pipelined acquisition, performs in simultaneous read/write mode, and is clocked by the 10MHz beam crossing rate at RHIC. These die, together with a pair of commercial FPGA's that are used for control logic, are packaged in a mutlichip module (MCM).The MCM will be fabricated in the High-Density-Interconnect (HDI) process. The prototype MCM design layout is described.

1. THE DETECTOR

The MVD will be installed into the PHENIX experiment at The RHIC Collider in early 1999. The main physics goals of the detector are to provide a multiplicity measurement, $dN/d\eta$, to the PHENIX Level-1 trigger and to measure fluctuations within the multiplicity distribution on an event-by-event basis. Such fluctuations are a potential signal associated with the formation of a Quark-Gluon-Plasma. The MVD has the largest rapidity coverage of any of the subsystems in the experiment at $\eta = 5$. The detector has full azimuthal coverage with good granularity and is capable of reconstructing the collision vertex to better than 2 mm.

The MVD is a clam-shell design, constructed in two-halves to close about the beampipe (see figure 1). Not shown in the figure is the double-skin rf enclosure that encloses the detector. The 75 cm long central barrel of the detector is comprised of two layers of silicon strip detectors located at 5 and 7.5 cm from the beam. The strips are oriented orthogonal to the beam directions, and each detector is read out independently. There are 256 strips on each strip detector at 200 μm strip-pitch. The inner detectors are 5.3 cm wide by 5.2 cm long, and the outer detectors are 5.3 wide by 7.45 cm long. The strips are ac-coupled on the detector. The integrated coupling capacitor is approximately 200 pF, corresponding to a dielectric thickness of 200 nm between the implant and the readout electrode. The biasing of the strips is through polysilicon resistors. The resistance values on the prototype detectors average 5 MΩ. The strips are coupled to the front-end electronics through kapton cables. The length of the cable varies with the detector position in ϕ, the azimuthal coordinate, with the longest cable being 19 cm.

On each end of the central barrel there is a silicon disk comprised of twelve wedge-shaped pad detectors. Each pad detector has 252 elements (see figure 2). The size of the pads increases from the inner to the outer radius of the wedge. The smallest element is 2 x 2 mm, and the largest is 4.5 x 4.5 mm. The pads are also ac-coupled. The ratio of the area of the readout electrode to the area of the pad is held roughly constant. We have measured the coupling capacitor values, and they range from approximately 200 to 2000 pF from the smallest to the largest element, respectively.

We have produced the pad detector in a single-metal and a double-metal version. We will choose one of these technologies after they are fully tested. A 4 μm layer of silicon dioxide separates these two metal layers on the double-metal design. Metal two is used to route the pad outputs to bond pads at the outer radius of the detector where the electronics are located. The issue that will drive our choice will be the amount of crosstalk we measure between metal-one and metal two. If we choose the single-metal version, the trace routing will be done on a separate kapton cable. Micron

Semiconductor is producng both the strip and the pad detectors [1].

2. SUPPORT STRUCTURE

The total allowed mass budget of the MVD is very restrictive. This is especially true in the central barrel region of the detector which shadows the acceptance of the PHENIX electron-arms. In order to minimize the mass we have used low density rohacell foam wherever possible. The radiation length of this foam is 545 cm.

The unit mechanical support of the barrel is called a c-cage. The cage is machined from a laminated block of rohacell-71 foam. Strip detectors are glued to three outer and three inner faces of the cage. The cages are assembled contiguously along the z-axis, registered to each other with plastic tubing, and held in

place under spring-loaded compression. Twelve of these cages form one-half of the barrel. The total average radiation length in the central barrel is 1%; 0.4% for the support, rf enclosure and kapton cables, and 0.6% for the two layers of silicon.

We have done extensive testing of the materials properties of the rohacell in the lab. It is well-known that rohacell is hydroscopic, and therefore it is essential to understand the relationship between humidity and the potential distortions and stresses induced into the mechanical support. Although we intend to operate the MVD in a humidity and temperature controlled environment, we accept the possibility of occasional failures in the control system. Details of our lab studies can be found elsewhere [2], but in summary, we found the c-cage shape to be relatively stable, especially with silicon panels glued to the faces. We examined the behavior of the cages over the range of relative humidity from 30-80 percent, where the higher value corresponds to loss of environmental control in the detector, and the lower value to nominal ambient conditions. The silicon panels constrain the tendency of the cage to curl inward with increasing humidity. The constraint induces stress into the silicon-to-foam glue joints. We used finite element modeling to quantify the stress. We discovered that the stress depends on the glue thickness and type. If the glue joint was made thin enough, the stresses levels could exceed the tensile strength of the rohacell. Although this would not lead to immediate failure of the joint, it might cause the joint to fail after repeated cycling. A 125 μm thick layer of araldite glue, however, is adequate to reduce the stresses below the failure level of the rohacell and the silicon.

We have also tested surface coating materials, and found that a thin, 12 μm layer of parylene, vacuum deposited uniformly on the surfaces of the cage lengthens the diffusion constant of water into the foam by a factor of two. This effectively gives us additional time to re-establish environmental control following a failure.

Finite element analysis was also run to determine the maximum deflection of the assembled half-barrel due the loading of the silicon and gravity. The maximum occurs, as expected, midway along the length of the barrel and is predicted to be 16 μm. We measured this in the lab on a full-scale model, and found the measurements to be consistent with the prediction. The deflection is well within our mechanical tolerance.

3. COOLING

Air has been chosen as the cooling medium for the detector front-end electronics. Again, this choice has been driven by the need for a minimum mass design [3]. Each strip detector is connected to a 1.7 mm thick alumina substrate front-end module through a kapton cable. The location of the relatively thick substrates below the central barrel puts them out of the most sensitive region in regards to background production into the central arms. The power budget on each substrate is 2.3 W. The electronics modules are arranged in six rows, each row comprised of twelve substrates, in a cooling plenum manufactured out of rohacell-71 foam. A thermal model was created to simulate the cooling system. Calculated results from that model indicate that to maintain a maximum temperature of 40° C at any die surface, it is necessary to blow 20° C air at approximately 9 m/s through the plenum. These predictions are consistent with measurements made in the lab using a realistic physical model. There are two main reasons why air performs efficiently in our design. First, the multichip-module process that we employ embeds the die into the substrate, which provides excellent thermal contact. Secondly, the alumina substrate does a good job of spreading the heat across the entire surface of the 5 x 5 cm substrate. The maximum temperature differential across the surface of the MCM is calculated to be 3° C.

4. ELECTRONICS

The beam crossing rate at the RHIC accelerator is roughly once every 100 ns. Stop-and-read electronics are not fast enough to keep up with this rate and would impose the loss of events from adjacent crossings. The MVD front-end has been designed to be alive for each crossing. The architecture is pipelined and runs simultaneous read/write operations at the full 10 MHz beam frequency.

The front-end electronics are built in a 1.2 μm CMOS process. The basic functional units of the chain are preamplifier, discriminator, analog memory (AMU), correlator, and analog to digital converter (ADC). The entire

chain is designed for a power dissipation of 6 mW per channel [4].

The preamp is a charge integrating amplifier with a gain of 20 mV/fC. The rise time is 60 ns, and the peak output is held fixed and sampled. There is a discriminator on each channel. The discriminator threshold is adjustable down to 1/4 MIP. The discriminator outputs of each of the 256 channels associated with a given detector are summed, and this sum, containing the multiplicity, is sent to the Level-1 trigger every crossing. The AMU stores the amplifier output level every crossing and is 64 channels deep. When a trigger is received from Level-1, both the cell that is time stamped to the trigger, and the previous AMU-cell are presented sequentially to the correlator. The correlator reconstructs the preamplifier output voltage by comparing the difference of the stored voltage on the two cells. This level is then digitized in a 10-bit Wilkinson ADC.

In addition to the custom die, there are two Xilinx field-programmable-gate-arrays on the front-end. One of these provides the address list management of the AMU, and the other controls the distribution of clocks, dac settings and other control functions. The two die add 750 mW to each 256 channel module.

5. BEAM TEST RESULTS

Each element of the front-end has been prototyped in 8-channel versions. We recently instrumented 32 channels each of two MVD silicon strip detectors, and tested them at the AGS at Brookhaven National Lab in a secondary beamline that provided a minimum ionizing beam flux. The setup consisted of an upstream finger scintillator that covered the instrumented section of the strips, the two strip detectors, one behind the other, and a downstream coincidence paddle. The two scintillators defined the trigger. The trigger rate to strip rate ratio was about 50:1.

The electronics die were packaged in commercial ceramic packs and interconnected on a standard G-10 printed circuit board. The silicon detectors were both outer layer types, with 7.5 cm long strips. The kapton cable connecting the strips to the readout boards was 19 cm.

The test successfully demonstrated the operation of the entire electronics chain. We measured the signal-to-noise (S/N) on the output of the preamplifier to be about 15:1. Figure 3 shows the ADC distribution from a single silicon strip, including charge-shared events. The shape of the Landau is well resolved, though the absolute separation of signal to noise is not as good as we would like. The ratio of the Landau peak to the one-sigma width of the residual noise distribution is about 6:1, whereas our goal is to achieve 10:1. Part of the noise width is due to a known problem in the

version of the ADC we used for the test that had a noisy ramp. This problem has been solved in a subsequent layout. The greater noise contribution is, we feel, due to coupling of the fast clocks on the PCB into the ADC. In particular, we feel the problem is exacerbated by the long trace lengths that carry these clock signals.

The platform that we will use in the MVD is a multichip module (MCM). The process we will employ is called the high density interconnect (HDI) process [5]. In this process wells are milled out of an alumina substrate, and the bare die are placed into these wells. The machining is done so that the surface of thedie is coplanar with the un-milled surface of the substrate. A polyimide layer is placed over the surface and holes are laser drilled through the layer, directly over the die bond pads, and the contact to the pad is made by aluminization. Multiple layers are built up of trace, power and ground. We have laid out a four layer MCM. The first layer routes the analog signal traces . The second layer is a power plane split between analog and digital. The third layer routes the digital traces. The final layer is a split ground plane. The 32 channel prototype is functionally identical to the chain we used in the beam test, with the exception that we are using the improved ADC. The clock traces are several times shorter than the PCB counterpart. This fact, together with the direct contacts to the die pads, and the excellent analog to digital isolation that is achieved in the HDI process, should significantly reduce the system noise. The MCM design is complete and ready for fabrication. It will be tested later this year.

A. Acknowledgement

6. REFERENCES

[1] Micron Semiconductor Ltd., Lancing, England.
[2] E. Bosze et al., PHENIX Note, PHENIX_MVD_95_11
[3] J.S. Lock et al., Nucl. Instr. and Meth. A345 (1994) 284.
[4] C.L. Britton et al., Proc. of the 1st Workshop on Electronics for LHC Experiments, Lisbon, Portugal (1995) 84.
[5] The high Density Interconnect Process is liscensed to Lockheed Martin, Moorestown, NJ, USA.

752mm

R 290mm

R 236mm
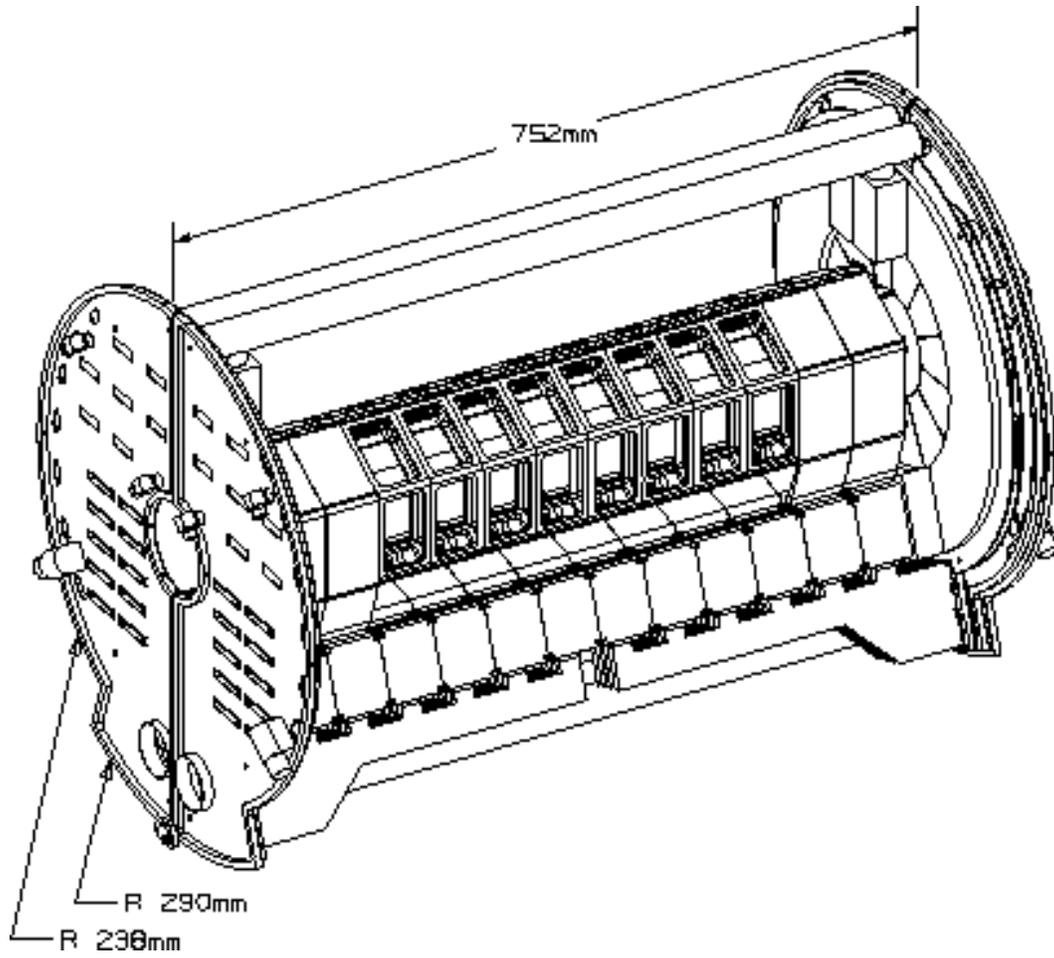
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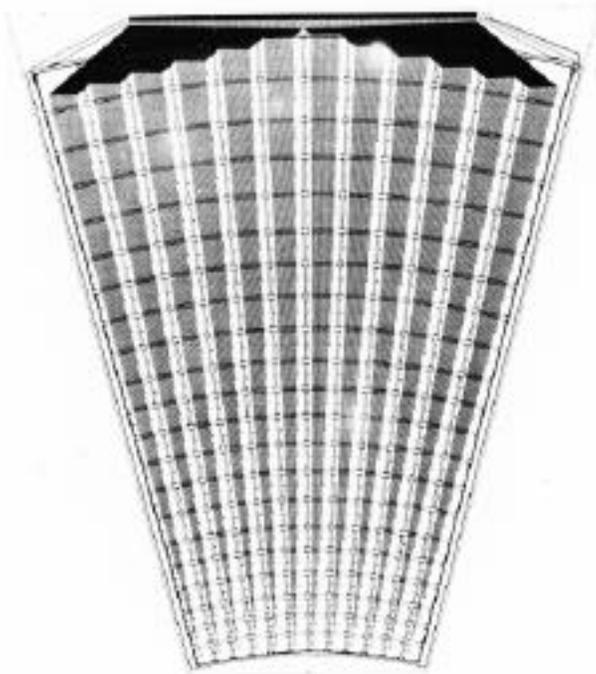
Figure 2. The MVD double-metal pad detector
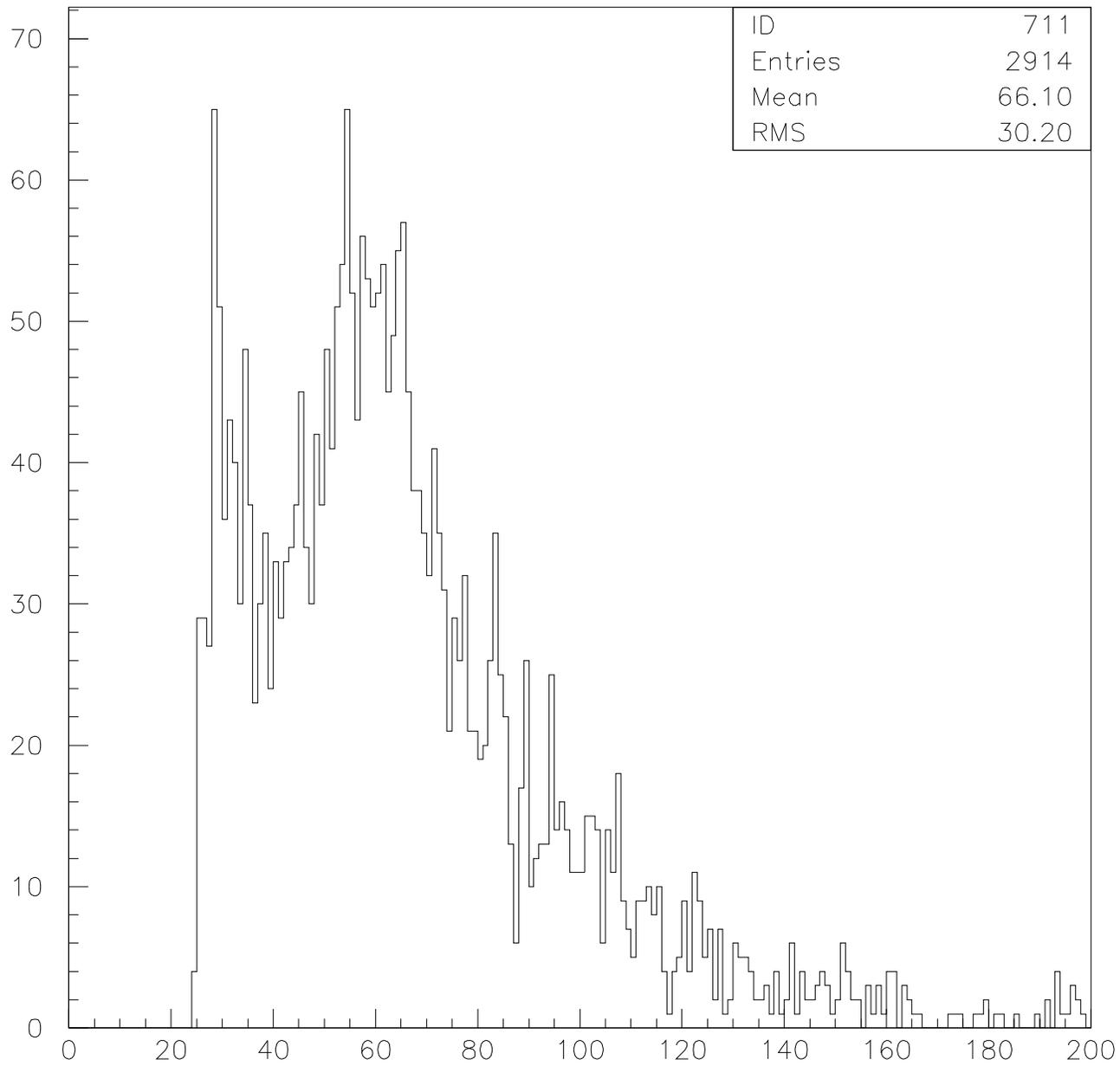
Figure 3. Landau distribution from a single strip.