Simulations of the Performance of the MVD in PHENIX

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Abstract

The PHENIX Multiplicity Vertex Detector (MVD) provides event characterization, a centrality trigger, collision vertex position, and measures fluctuations in charged particle multiplicities. The design criteria include a large rapidity coverage, good azimuthal coverage and granularity, minimizing material in the electron arm acceptance, and minimizing costs. The MVD contains two concentric barrels of Si strip detectors with two disk-shaped Si pad detector endcaps. Simulations will show that the vertex position can be located to within a few hundred microns using hits in the barrels. A channel multiplicity signal is formed for use in the Level-1 trigger. The effect of the expected discriminator performance on this trigger signal will be shown. The pad and strip detectors are read-out with identical electronics. The influence of the performance of the electronics on the detector's performance will be discussed.

I. INTRODUCTION

The Multiplicity Vertex Detector (MVD) is the inner-most detector in PHENIX, an experiment currently under construction at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The MVD consists of two concentric 64 cm long barrels of silicon strip detectors (300μm thick and 200μm pitch) around the beam pipe and two disk-shaped endcaps of silicon pad detectors at z = $\pm$35cm, where z is along the beam axis. Each barrel layer has six azimuthal segments. The two barrel layers are mounted on a common support structure made of light-weight, rigid Rohacell foam. Each endcap is composed of 12 wedges. Each wedge is subdivided into 21 (radial) $\times$ 12 (azimuthal) = 252 pads. The size of the pads increases from $\approx 2 \times 2$ mm at the innermost radius to 4.5×4.5 mm at the outermost radius. This variation keeps the average occupancy about the same in all pads.

In addition to minimum cost, the design criteria include a large rapidity coverage, good azimuthal (ϕ) coverage and granularity, and minimizing material in the electron arm acceptance. The MVD is intended to provide event characterization, a collision vertex position, a centrality trigger, and a measurement of charged particle multiplicity distributions.

The single-event coverage about midrapidity is five units in pseudorapidity ($\eta \equiv -\ln(\tan(\theta/2))$) for the inner barrel layer and four units in η for the outer barrel layer; the η coverage for event-averaged quantities is extended due to the variation of the vertex position along the direction of the colliding beams (σ = 22 cm). The disk-shaped endcaps cover $1.71 < |\eta| < 2.56$ for an event occurring at z=0. The inner barrel and the endcaps have complete azimuthal angle coverage. The outer MVD barrel has a hole for $|z| < 21$cm in the upper 2/3 of the azimuthal coverage. This hole was introduced in order to minimize background in the electron arms of PHENIX. The electron arms will measure e^+e^- pairs produced in the nuclear collisions. These measurements are difficult because of the small number of pairs produced in the collisions compared to the number of other particle types. The measurement is further complicated by e^+e^- pairs produced by background processes. The MVD (and any other material in the interaction region) can be a source of background via pair production ($\gamma \rightarrow e^+e^-$) in the MVD. The size of the hole in the outer layer of the MVD represents a compromise between minimizing background and maximizing the MVD's efficiency.

As the detector in PHENIX with the largest coverage in rapidity, the MVD will be used to characterize events. This includes measuring the total multiplicity of charged particles and the distribution of the particles in η and ϕ ($dN/d\eta d\phi$). The vertex position can be located using hits in the barrel for z positions between -40 and +40cm, which covers the majority of the length of the interaction region (σ = 22 cm). The multiplicity (centrality) trigger is formed using the sum of silicon channels above a threshold corresponding $\approx$ 1/3 of the signal from a minimum-ionizing particle (MIP).

II. MVD FEM

Both the pad and strip detectors are read-out with identical electronics, which are optimized for minimum size, power dissipation and cost. The total silicon channel count is 34,720. The front-end modules (FEM) for the MVD are packaged on multi-chip modules (MCM), each containing the electronics, readout, and control for 256 channels of silicon. Each MCM contains 8 32-channel TVG-32 preamp/discriminator ASIC's [3], 8 32-channel analog memory unit (AMU)/ADC ASIC's [4], and two Xilinx field programable gate arrays (FPGA). One

FPGA is an address list manager (ALM) [2], which provides simultaneous read/write control, cell over-write protection for both Level-1 trigger decision delay and digitization latency, and reordering of AMU addresses following conversion. The second FPGA (called the heap manager) provides control signals to the front-end electronics, collects and transmits the digitized data, and manages the slow serial interface and command interface to the FEM [1].

The preamp/AMU/ADC chain, controlled by the heap manager and the ALM, provide the information from which the MVD's online and offline software find the vertex position and $dN/d\eta d\phi$. The weighted summed-current output from the discriminator provides a count of all silicon channels with signals greater than the discriminator threshold ($\approx$ 1/3 MIP). This is used to construct a channel-multiplicity count which is used in the PHENIX Level-1 multiplicity trigger.

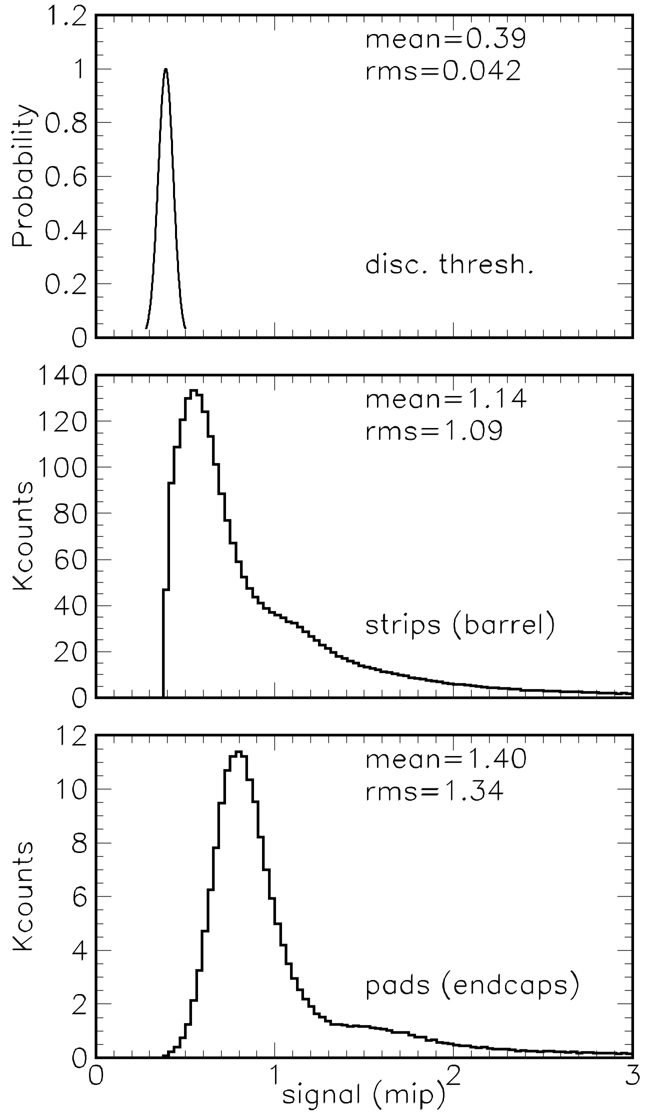

Figure 1: Results from simulations of the MVD with a range of event multiplicities included. The plot for the strips combines the inner and outer barrels. The plot for pads combines the north and south detectors.

III. RESULTS

The Level-1 trigger signal is intended to give the channel count in the MVD. Since most produced particles hit the MVD's inner barrel, this is a good measure of the event multiplicity. The ideal discriminator would give an accurate channel-count. The problem is complicated by variations (Landau fluctuations) in particle energy loss, noise in the system, and channel-to-channel variations in the discriminator threshold. The discriminator thresholds would ideally be the same for each channel. However, studies of the Phenix discriminators have shown that the actual thresholds vary slightly from channel to channel. The average threshold was 25 mV with an rms variation of 2.7 mV. All channels tested had thresholds between 18 and 32 mV. When combined with the charge gain of the preamplifiers (16mV/fC) and the average charge created by a single MIP (4 fC), the threshold variation can also be expressed as 0.39 MIP with an rms variation of 0.042 MIP and all values between 0.28 and 0.50 MIP.

A Geant-based [5] simulation of the effect of channel-to-channel variations in the discriminator performance was done to determine the effect on the PHENIX level-1 trigger. Figure 1 shows the assumed distribution of discriminator thresholds in the top panel. The middle panel shows the energy loss per strip in the MVD barrel. The bottom panel shows the energy loss per pad in the endcap detectors. In each case, the horizontal axis is in MIPS instead of ADC channels.

Using the set of discriminator thresholds, the overall efficiencies (fraction of channel which had a real hit which caused a signal about the discriminator threshold) are slightly less than 1. Part of the problem is that a MIP is defined as the average signal from a minimum ionizing particle. The actual energy loss distribution has a long ("Landau") tail with very high energy loss values. The result is the the mean is significantly larger than the most probable energy loss distribution. In other words, the peak of the distribution is at less than 1 mip. For the pad detectors, the average energy loss in a channel is actually slightly larger than the energy loss from a particle at normal incidence since most particles have an incident angle of a few 10's of degrees. The result is a typical signal slightly larger than 1 mip – which is normally defined for normal incidence into a 300 micron detector. For the strip detectors most particles enter the detector at a very large angle relative to the normal. The result is that the energy loss in a given strip corresponds to the energy loss in about 200 microns of Si (the strip pitch). This results in smaller signals than for pads. On the other hand, the average occupancy of the pads is relatively high for high multiplicity events – causing many strips to have multiple hits per channel. This increases the efficiency of the discriminator (because the signals are twice as large) at high occupancy/multiplicity values.

These simulations included a simulation of noise in the MVD. The noise was assumed to be present at a level of 0.1mip (sigma) in all channels – whether or not they had a real hit. This degrades the resolution for channels with a real hit and occaisonally causes the resulting signal to be less than the discriminator threshold. For channels with no hit, it means that

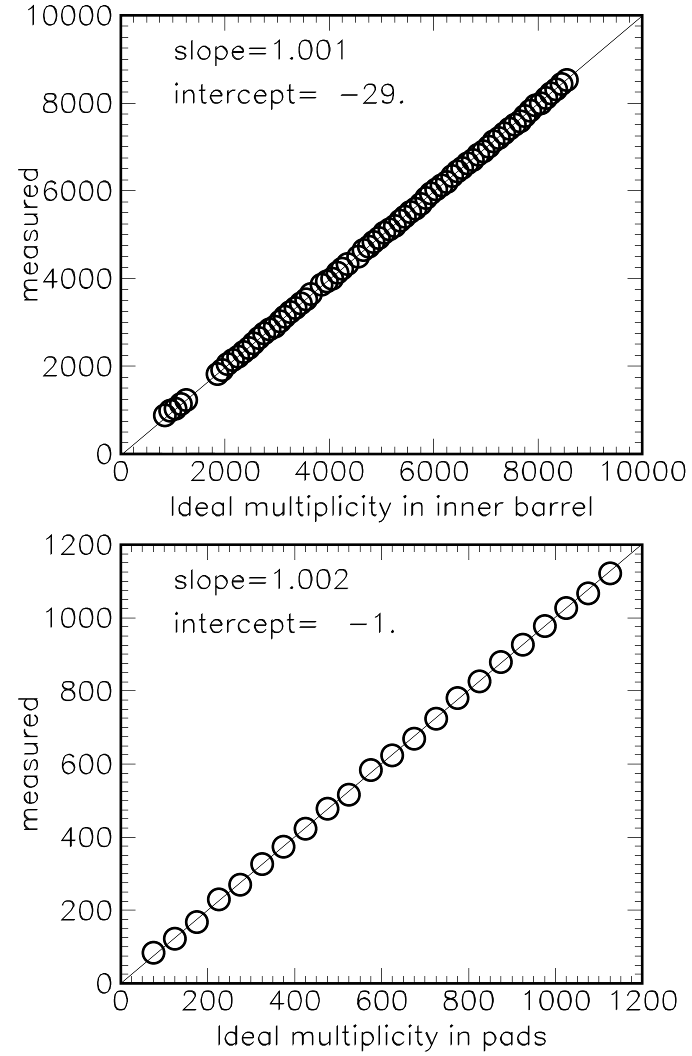

Figure 2: The ideal multiplicity vs. the number of hits assuming the performance of our discriminators. The two plots show the performance of the inner MVD barrel and the MVD pad detectors.

there is a pedestal with a width of 0.1mip (sigma) and a mean of 0. This allows some channels to be above the discriminator threshold even without a hit.

Using discriminator threshold which varied from channel-to-channel as shown in the top panel of figure 1, two-dimensional plots were created. Each pair of plots shows the ideal number of channels hit on the horizontal axis and the number we would measure with our discriminator performance on the other axis. The ideal multiplicity is the result we would get with a perfect (no channel to channel variations) discriminator set at 0.39 mip – it is plotted on the horizontal axis. The number of hits assuming the performance of our discriminators is shown on the vertical axis. The two plots show the performance of the inner MVD barrel and the MVD pad detectors. For the strip detector, the true number of channels hit is not the number of particles in the event since most particles hit many strips. A perfect discriminator would appear on these plots as 45 degree lines (slope =1) with an intercept of zero and a width of zero. Figure 2 shows calculations for higher multiplicity events (from 12% to 100% of the central Au+Au multiplicity).

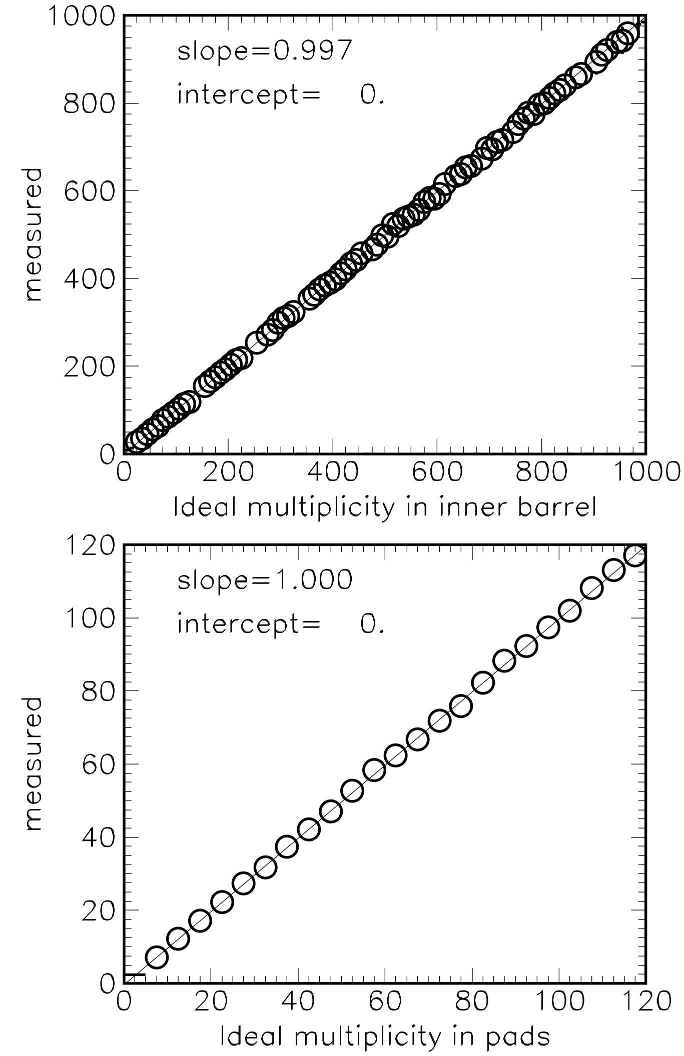

Figure 3: The ideal multiplicity vs. the number of hits assuming the performance of our discriminators. The two plots show the performance of the inner MVD barrel and the MVD pad detectors. This plot uses lower multiplicity events than figure 2.

The same type of calculations have been done with lower multiplicities. In this case between 0.1% and 10% of the full Au+Au multiplicity was assumed. Figure 3 shows the results of these calculation.

The lines shown in figures 2 and 3 are fits to the data. These slopes of these lines are very close to 1 and the intercepts are close to zero. This means that the channel-to-channel variations are not large enough to affect the performance of the PHENIX level-1 trigger.

Cost considerations did not allow us to build a true tracking vertex detector (which would have required many more channels). However, several algorithms which can find the vertex have been developed. Among them is the "pseudo-tracking" algorithm. This algorithm takes every combination of pairs of hits on the same azimuthal segment of the MVD as a potential track. The pair of hits is projected back to the beam axis to find the vertex for a track which hit these

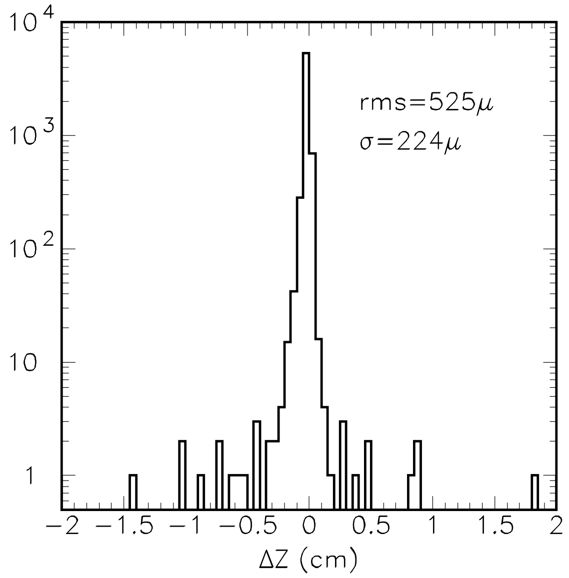

Figure 4: The resolution (difference between the true and calculated vertex position) of the pseudo-tracking method for vertex finding.

two locations. For each of these possible vertex locations, a channel in a histogram is incremented. Most pairs of hits do not correspond to a real track. However, when all pairs are considered, the true vertex location appears more frequently than the other locations. This can be used to find the vertex position. Figure 4 shows the resolution of this vertex finding algorithm for simulated Au+Au events from the Hijing event generator [6]. In most cases, the z position of the vertex is found to within a few hundred microns. The calculation shown in figure 4 assumed signal/noise = 10.

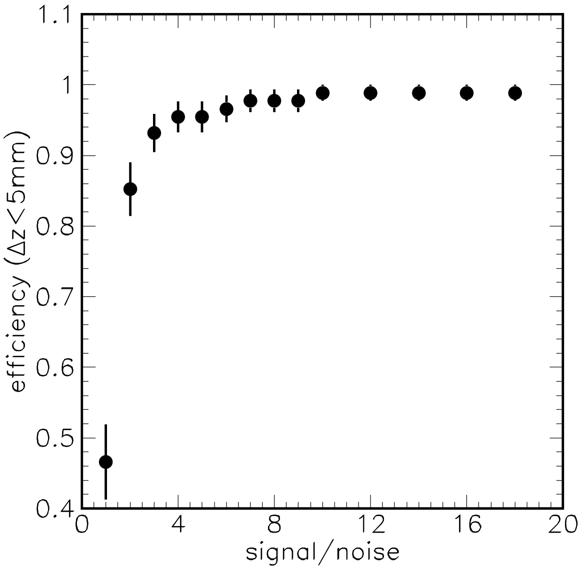

Figure 5: The efficiency (fraction of events for which the vertex-finding algorithm found the vertex to within 5mm of the true value) of the vertex-finding algorithm vs. the signal to noise assumed in the simulation. The simulation used 90 central events from the Hijing event generator [6] for each point.

Electronic noise degrades the performance of the vertex finding algorithms. We expect to achieve signal/noise of 10 or better in the final MVD electronics. Figure 5 shows the efficiency of the vertex-finding algorithm as a function of the signal to noise assumed in the simulations. The definition of the signal to noise is based on the signal for a MIP. Given signal to noise x, the noise is (1 MIP signal)/x. This value is then used as the standard deviation of a gaussian noise distribution. The noise values selected from this distribution are added to the "true" signal to get the "measured" signal. Figure 5 shows that the vertex-finding efficiency is high as long as the signal to noise is better than ≈ 6.

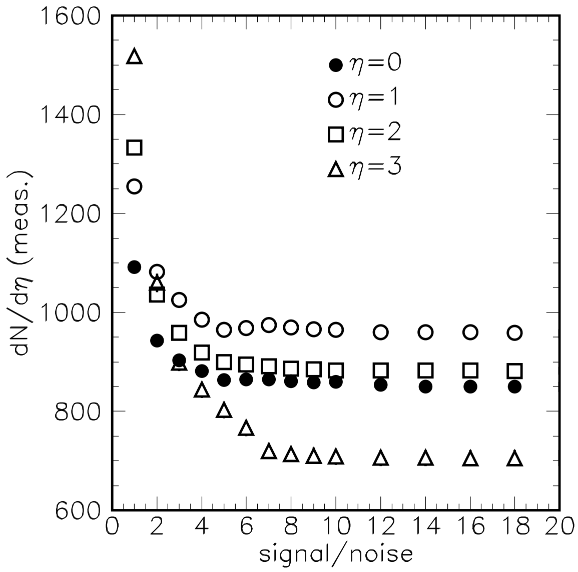

Figure 6: "Measured" dN/dη as a function of the signal/noise value assumed in the simulations. Results for four values of η are shown — η = 0, 1, 2, 3.

Calculations of $dN/d\eta$ (the number of charged particles per unit pseudo-rapidity) use the ADC signals in the detector to estimate the number of particles. The accuracy of these calculations depends on low noise, the linearity of the electronics, and good calibrations. Figure 6 shows more results from the simulations of the effects of signal/noise on the MVD's performance. The plot shows the variation in dN/dη as the assumed signal to noise is changed. For very low signal to noise values, the dN/dη values increase. This is a consequence of noise-induced false hits in the detector. From this, we conclude (as with the vertex finding algorithms) that the dN/dη performance is not effected significantly for signal/noise values larger than ≈ 8.

IV. CONCLUSIONS

Simulations show that the performance of the MVD electronics should be sufficient to meet its performance criteria. The MVD Level-1 trigger is sensitive to the performance on the discriminators. Simulations of the effect of the expected discriminator performance (as well as better and worse than expected performance) on the Level-1 trigger have shown that the discriminator performance is good enough for our purposes. The position of the vertex can be found to within a few hundred microns with a vertex-finding efficiency close to 100% as long as the signal to noise is around 10/1 – as we expect it to be. Calculations of $dN/d\eta$ are also insensitive to the signal to noise in the electronics if it is 10/1.

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