Test of a GEM Detector in the PHENIX Experiment at RHIC

B.Azmoun, N.Smirnov, S.P.Stoll, C.L.Woody

***Abstract*—GEM detectors can serve as high precision tracking detectors in a variety of high energy and nuclear physics experiments. However, relativistic heavy ion experiments can potentially provide not only very high track multiplicities, but also severe background conditions for operating GEM detectors. To study their use under these conditions, a test was carried out of a three stage GEM detector in the PHENIX experiment at RHIC. The detector was placed in a region close to the collision point inside the PHENIX Central Spectrometer and operated during full luminosity gold-gold collisions. Results are given on the stability of operation and the sensitivity of the detector to beam related backgrounds using both Argon/CO_2 and pure CF_4 gas mixtures.**

I. Introduction

THERE has been a strong increase in interest in the use of Gas Electron Multiplier (GEM) detectors for charged particle tracking in both high energy and nuclear physics experiments [1]. Both the PHENIX and STAR experiments at RHIC plan to use GEM detectors as part of their upgrade program to improve both particle identification and tracking in the high multiplicity environment of relativistic heavy ion collisions at RHIC. However, while the total interaction rate in heavy ion collisions at RHIC is relatively low (< 10 KHz minimum bias rate for gold-gold collisions at the full luminosity of 2 x 10^{26} cm^2s^{-1}), the particle multiplicity is quite high ($dN_{ch}/dy \sim 650$), and the spectrum of produced particles is fairly soft ($<p_T> \sim 300$ MeV/c). This results in a high density of charged tracks, as well as soft background particles (both charged and neutral) in any detector placed close to the interaction region.

PHENIX plans to use GEMs in both a Hadron Blind Detector (HBD) [2] to be used for low energy electron identification, and for charged particle tracking in the central region [3]. In order to study how these detectors might be affected by the high multiplicity and soft background environment at RHIC, a small triple GEM detector was placed at a distance of ~50 and ~250 cm from the beam pipe in four different orientations, within the interaction region in the Central Magnetic Spectrometer in PHENIX. The purpose was to study its gain stability and performance, as well as its sensitivity to background particles produced in this region. In order to compare the direct affects of the beam on the GEM performance, back to back data were acquired with the beam ON and OFF. Results will be given on gain stability and background sensitivity using both Ar/CO_2 and pure CF_4 gas mixtures.

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B.Azmoun, S.P.Stoll and C.L.Woody are with Brookhaven National Laboratory, Upton, NY (E-mail: woody @bnl.gov).

N.Smirnov is with the Physics Department, Yale University, New Haven CT.

II. Experimental

The triple GEM detector consisted of three GEM foils that were arranged in a configuration shown in Fig. 1. The foils, which measured 10x10 cm^2, were produced at CERN with standard bi-conical tapered holes, and were segmented into four strips in order to reduce the amount of stored energy in case of sparking. The GEM stack was mounted on a 1" thick stainless steel flange, but the top of the detector was enclosed with a thin Lucite ring and a .003" mylar window, thus allowing low

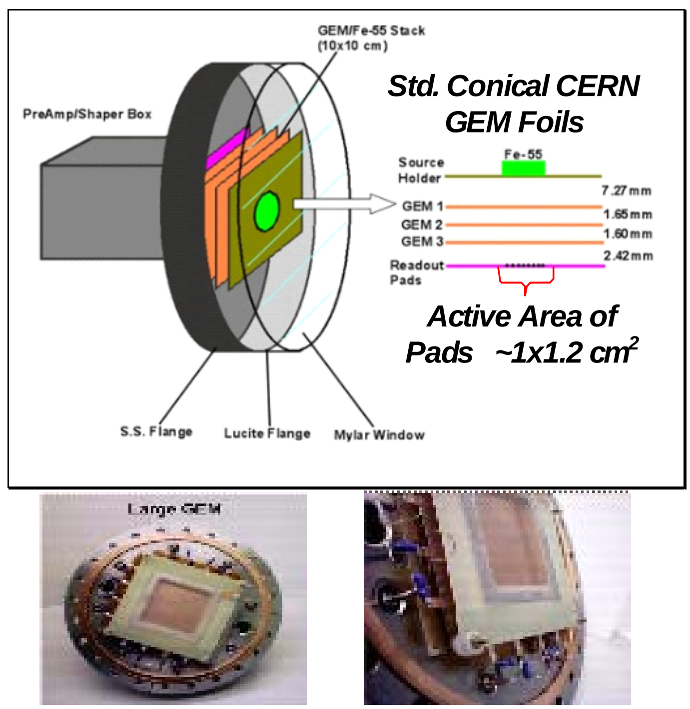


Fig. 1 GEM detector used for the beam test in PHENIX. The front window was constructed out of thin mylar, mounted on a Lucite flange to allow soft particles to pass through, simulating the actual final detector configuration.

energy particles to pass through into the detector volume. This arrangement simulates the geometry of the planned upgrade detectors in PHENIX.

A small 250 μCi ^{55}Fe source was mounted inside the detector that was used to measure and monitor the gas gain. Fig. 2 shows the ^{55}Fe spectrum measured in the lab prior to the test. The detector easily achieved a gas gain of ~ $6x10^3$ in Ar/CO_2 (70/30) (4.0 grade) and $3x10^3$ in pure CF_4 (6.0 grade). In fact, higher gains could also be achieved, but these gains are sufficient for the eventual planned detector operation, and it was felt that one should be conservative and not try and push the gain too high in these initial tests. The FWHM energy resolution for the ^{55}Fe peak was ~13% in Ar/CO2 (70/30), as measured in the lab.

The field configuration applied across the GEM stack throughout all of the tests was as follows: Ar/CO_2: 0.5kV/cm (drift gap), 2.5kV/cm (transfer gap 1), 3.0kV/cm (transfer gap 2), and 3.5kV/cm (induction gap); CF_4: 0.5kV/cm (drift gap), 2.5kV/cm (transfer gap 1), 3.5kV/cm (transfer gap 2), and 5.0kV/cm (induction gap). As a general rule, to avoid the gain instabilities associated with charging up effects from the GEM foils, the HV was applied at least 45 minutes prior to data taking. Typical gain variations after this initial charge-up period are ± 10%

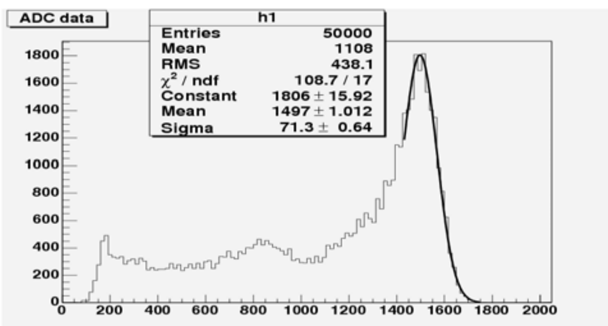


Fig. 2 ^{55}Fe spectrum taken in the lab in Ar/CO_2 (70/30). The gas gain was ~ $6x10^3$ @ΔV=360V, and the FWHM energy resolution of the photopeak was ~ 13%.

The detector was first tested in a location close to the north pole tip of the PHENIX Central Magnet, as depicted in Fig. 3.

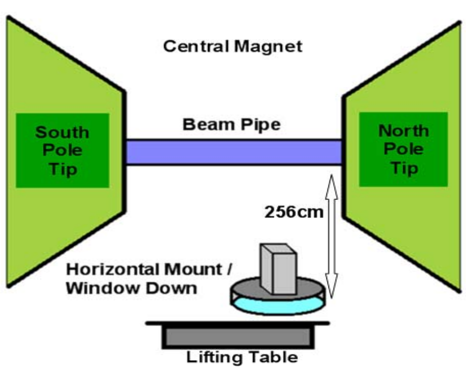


Fig. 3 GEM detector mounted in the first of four orientations near the interaction region of the PHENIX detector, with the window at 256cm from, and facing away from the beam pipe.

Before the beam was turned on, a gain curve was generated once the detector was mounted in place to insure consistent and proper operation. The following plot in Fig. 4 compares gain data taken in the lab versus data acquired while the detector was in the first orientation within PHENIX.

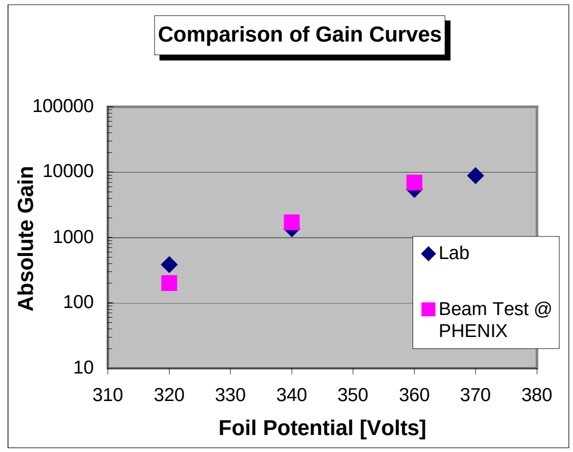


Fig. 4 Comparison of gain curves taken in the lab and in the first orientation within PHENIX, with the beam off.

The pole tips are potentially a source of soft background particles (mainly albedo) produced by the large flux of high energy hadrons that impinge upon them. However, the detector operated smoothly at full RHIC luminosity at an initial gain of ~ $2x10^2$ (at a foil potential of ΔV=320V) in Ar/CO_2 without sparking or discharge. Unfortunately, the beam was lost before the foil potential could be raised to the nominal operating value of 360V, but another spectrum was produced at ΔV=360V at a gain of $6.5x10^3$ with the beam off. This spectrum is depicted in Fig. 5, and shows very consistent results with respect to the spectrum produced in the lab, albeit with some loss in resolution (~13% in lab versus ~18% in PHENIX). Before the beam was lost, the gain remained stable to within ±10% over the course of several hours, which is consistent with what was observed in the lab.

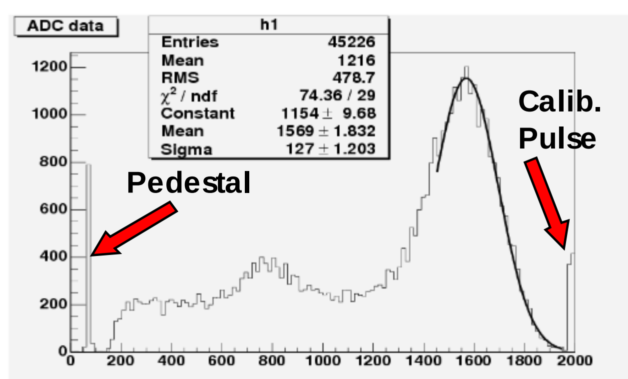


Fig. 5 ^{55}Fe spectrum taken inside the PHENIX Central Magnet with no beam (just after the beam dump). The gas gain in Ar/CO_2 (70/30) was ~ $7x10^3$ @ ΔV=360V, and the energy resolution was ~ 20%.

The implications of this initial test are significant and include the following: 1) the detector electronics was not affected by the presence of the ambient magnetic field, 2) the detector easily passed a simple survival test with beam ON and *during* a beam dump, 3) the behavior of the detector is exactly reproducible after exposure to the beam, and 4) at 256cm away, there is little or no sensitivity to background.

Next, the orientation of the detector was changed and brought closer to the beam pipe as depicted in Fig. 6, below.

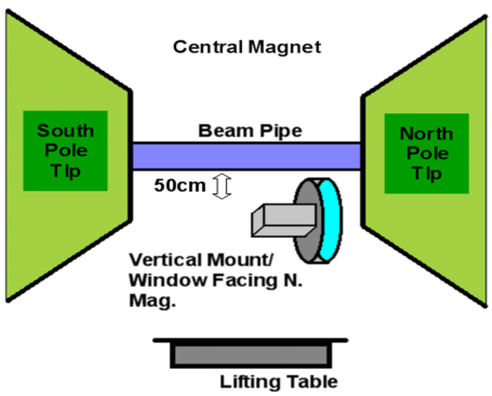


Fig. 6 Detector mounted in 2nd orientation, at 50cm from the beam pipe with the mylar window facing the magnet pole tip.

Again, the detector seemed operational in all respects, even in close proximity to the beam pipe. The beam OFF spectrum was very similar to the lab results, with a gain of 6.8×10^3 @ΔV=360V, and a resolution of ~19%. After the beam was turned on, a spectrum was taken and showed similar results, but with some added background, as seen below in Fig. 7.

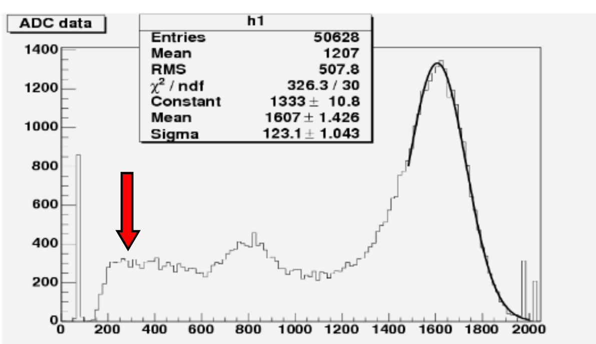


Fig. 7 Spectrum taken in orientation #2with beam ON shows some additional background. The gain was ~6.2×10^3 @ΔV=360V, and the resolution was 19%.

While the ^{55}Fe source provided a means to measure and monitor the gain, the resulting spectrum does not provide an adequate means to measure the detector response in coincidence with beam-beam collisions. To study this, the response of the detector was also measured in time with a minimum bias interaction trigger. Due to the very small solid angle of the instrumented part of the detector (only ~ 1.2 cm^2 at ~ 50 cm), the in-time interaction rate for this trigger was very low. Approximately 4.4% of the total number of interactions produced some signal in the detector above pedestal with the detector mounted in orientation #2, and filled with Ar/CO_2 (70/30). This was roughly a factor of three higher than expected, according to the calculated flux of charged particles through this small solid angle, indicating that the detector was in fact sensitive to additional background in coincidence with our minimum bias trigger.

The detector was then moved to the third orientation inside the Central Magnet, depicted in Fig. 8, with the mylar window facing up towards the beam pipe. The distance to the beam pipe was ~ 50 cm, which is the expected position and approximate orientation of the future PHENIX HBD detector. The detector was tested with both Ar/CO_2 (70/30) and pure CF_4 in this location.

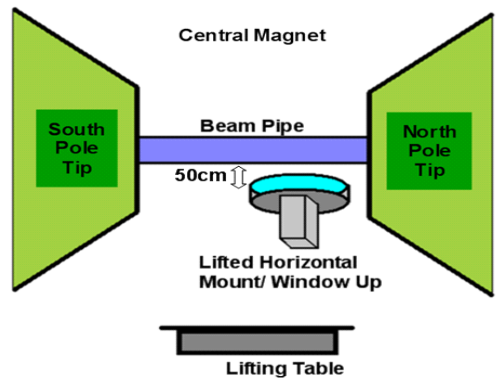


Fig. 8 Detector mounted in 3rd orientation, with the mylar window at 50cm from, and facing the beam pipe.

The resulting spectrum in this position, using Ar/CO2 (70/30) @ΔV=360V is given below and shows a marked increase in background once the beam is turned on. However, the added background is of fairly low energy and doesn't obscure the main ^{55}Fe photopeak. The beam-beam triggered data produced 4.6% of the total hits above pedestal, in a data run made just prior to the one corresponding to the spectrum below.

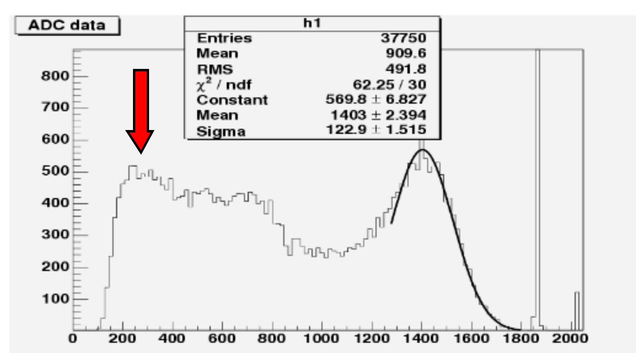


Fig. 9 ^{55}Fe spectrum taken inside the PHENIX Central Magnet at full RHIC luminosity, facing up towards the beam pipe. Note the increase in low energy background compared to Fig. 7. The gas gain in Ar/CO_2 (70/30) was ~ 5.5×10^3 @ΔV=360V, and the energy resolution was ~ 22%.

During the same beam fill, the gas was switched to pure CF_4. After a sufficient purging period, the first spectrum at ΔV=495V was produced, shown below in Fig 10. Although some background persists, its amplitude relative to the main peak is significantly smaller with respect to earlier Ar/CO_2 spectra. Also, in the beam-beam triggered data, only 2.7% of total hits were above pedestal.

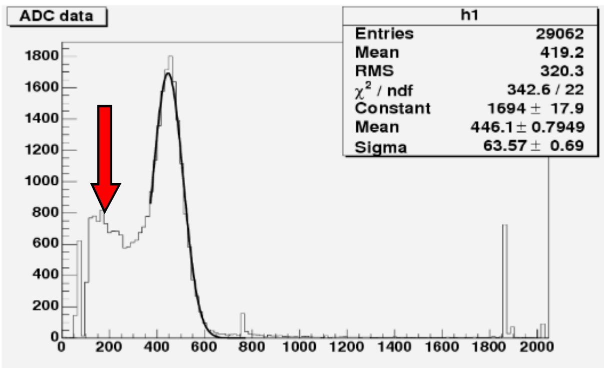


Fig. 10 ^{55}Fe spectrum taken inside the PHENIX Central Magnet at full RHIC luminosity with the mylar window facing up towards the beam pipe. The gas gain in pure CF_4 was ~ $3.3x10^3$ @ΔV=495V and the energy resolution was ~ 40%. Background levels are relatively low.

Upon repeating the measurement during a following beam fill, we observed that the low energy background increased dramatically, as depicted in Fig. 11. The photopeak became obscured and the number of hits above pedestal jumped to 5.1%.

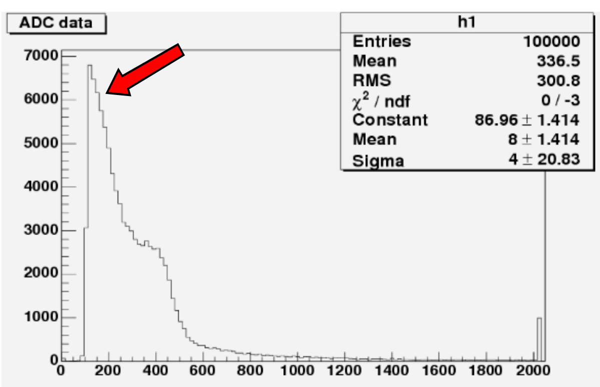


Fig. 11 ^{55}Fe spectrum taken inside the PHENIX Central Magnet at full RHIC luminosity with the mylar window facing up towards the beam pipe, produced during a following beam fill. The background levels dominate the spectrum. ΔV=495V.

We were able to verify that this behavior was not due to any sparking or discharge within the detector chamber. Nevertheless, we recycled the HV during the same data run, and another spectrum was produced half an hour later, as shown in Fig. 12. This spectrum is almost identical to the original spectrum shown in Fig. 10.

The change in background levels observed in all of the ^{55}Fe spectra produced thus far (in particular in orientation #4), in addition to the changing number of hits above pedestal in each of the beam-beam triggered data, could be attributed to changes in beam conditions and background. Since each ^{55}Fe spectrum is produced in self-triggered mode, this data is sensitive to background from all sources reaching the detector, whereas data acquired with the beam-beam trigger is only sensitive to background in coincidence with real beam collisions. Although at the moment it is unclear whether the fluctuating background levels observed above originate from changes in the beam conditions or some other source, the important implication is that aside from one short-lived anomaly and some added background, the GEM behaved normally, as it would have in the lab.

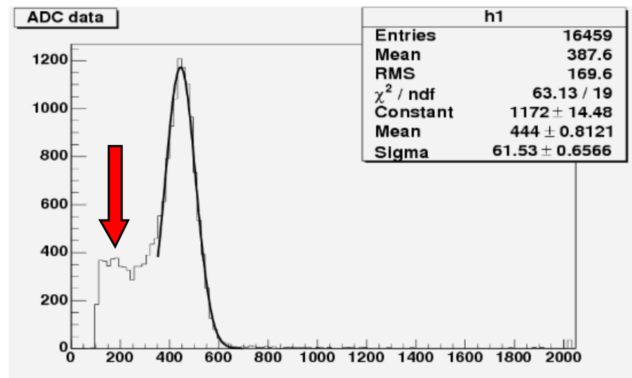


Fig. 12 ^{55}Fe spectrum taken inside the PHENIX Central Magnet at full RHIC luminosity with the mylar window facing up towards the beam pipe, produced during same fill. The gas gain in pure CF_4 was ~ $3.1x10^3$ @ΔV=495V and the energy resolution was ~ 39%. Background levels are again small.

Finally, the detector was mounted in one last configuration, 226cm away from the beam pipe, in the same orientation, as shown in Fig. 13. Only CF_4 is used as the working gas of the detector in this configuration.

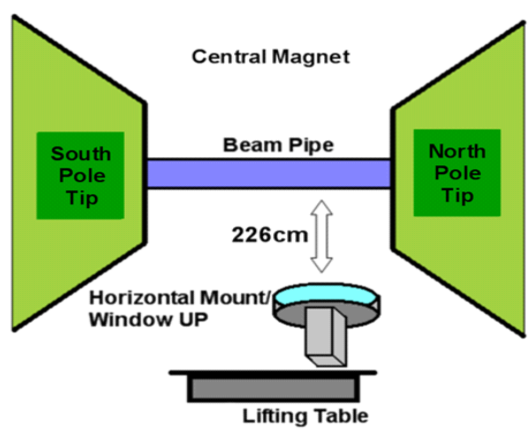


Fig.13: Detector mounted in 4th orientation, with the mylar window at 226cm from, and facing the beam pipe.

The spectrum, taken with the beam on, shows a significant reduction in the background rate, as one would expect being much farther away from the beam pipe. In addition, the number of hits above pedestal in the beam-beam triggered spectrum is only 0.22%. The gain is once more well within expected limits, at $3.2x10^3$, and the resolution is consistent with previously measured spectra, at 36%.

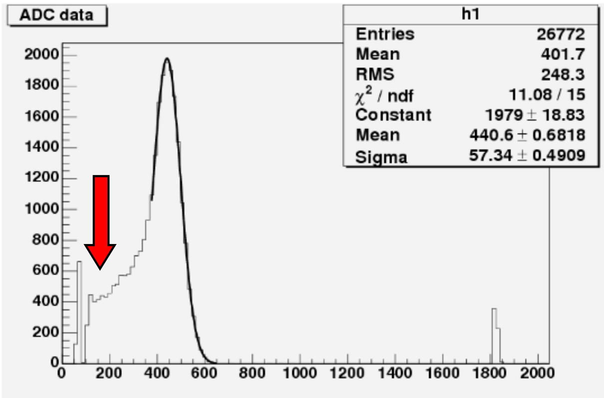
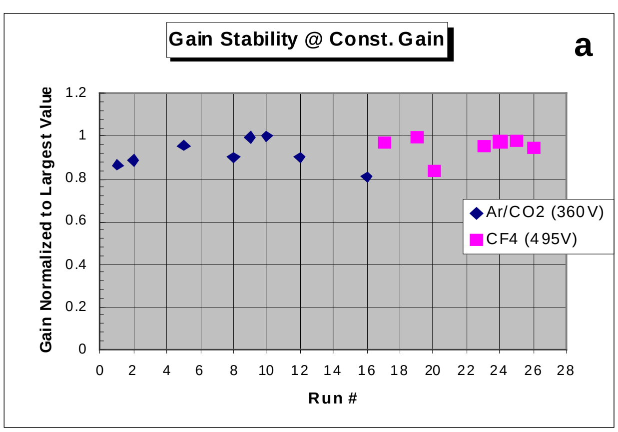


Fig. 14 ^{55}Fe spectrum taken inside the PHENIX Central Magnet at full RHIC luminosity with the mylar window facing up towards the beam pipe, but 256 cm away. The gas gain in pure CF_4 was ~ $3.2x10^3$ @ΔV=495V and the energy resolution was 36%. Background levels are too small to be visible.

Considering the absence of any detected background in the first orientation, the results here strongly suggest a true correlation between the level of detected background and the proximity of the detector to the beam pipe. According to the results obtained while the detector was in orientations 2 and 3, it is apparent that further study is needed to accurately quantify the levels of this background near the beam pipe.

Fig. 15 shows the trend in the absolute gain and the FWHM % resolution as a function of run number. It is clear from both plots that the overall behavior of the detector in terms of gain and resolution was quite stable throughout all the tests. The gain remained stable to within ±10%, as expected from experience in the lab. The resolution as measured in PHENIX also showed quite stable results, aside from two instances where the resolution became worse. However, in both of these instances, the resolution was calculated from data taken shortly after the HV was turned on, and therefore the poorer resolution may be attributed to residual charge-up effects in the GEMs.



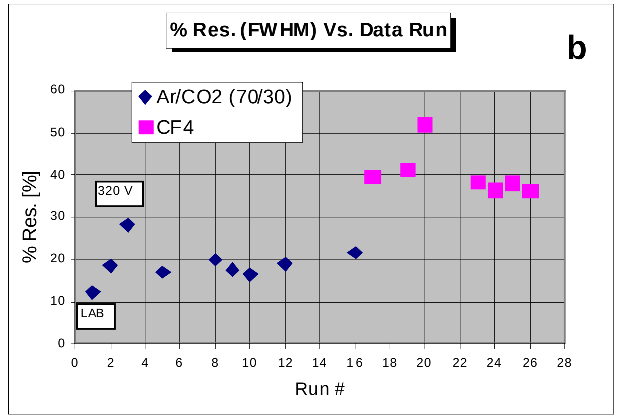


Fig. 15 Plots of the absolute gain (a) and FWHM % resolution (b) vs. data run #. The gain is constant to within ±10% as expected, and the resolution is almost as consistent aside from two points.

SUMMARY

The triple GEM detector performed smoothly within the PHENIX IR using both Ar/CO_2 (70/30) and CF_4 working gases and exhibited no sparking or excessive gain instabilities. The operation of the GEM and the associated electronics were not hindered by the presence of the ambient magnetic field generated by the central magnet within the IR. However, in close proximity to the beam pipe (50cm), the detector was sensitive to beam related background, although this background corresponded to low energy pulses, derived from a primary charge of about 100 electrons or less. The detector seemed to be less sensitive to this background with pure CF_4, although the observed increase in background levels with the use of Ar/CO2 may have been related to changing beam conditions. This is in light of the fact that the dE/dx value for MIPs in CF_4 is ~7.0keV/cm, and ~1.4keV/cm in Ar/CO_2 (70/30). Although the detector did behave unusually at one point, the behavior was short lived and again may have been related to unusual beam conditions. The fundamental implication of these tests is that the incorporation of a GEM detector among the inner PHENIX detectors is quite feasible when considering how stable the GEMs' performance was in such a high multiplicity environment.

III. REFERENCES

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[3] C.L.Woody, *Upgrade Plans for PHENIX*, Proceedings of the 18th International Workshop on Nuclear Dynamics, (2002) pp 331-339.