A GEM based Muon Tracker for CBM experiment at FAIR

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A Gas Electron Multiplier(GEM) based micropattern gas detector has been envisaged for a Muon tracker for the CBM experiment at FAIR. The choice of the detector technology is guided by the stringent requirements of rate capability, radiation hardness among other stringent requirements expected in the CBM experiment. Several 10 cm x 10 cm multi-GEM prototypes have been built at VECC and tested with radioactive sources and proton and pion/muon beams. A charged particle detection efficiency of more than 90 % has been obtained using conventional electronics as well as using a self triggered mode of readout.

1. Introduction

The Compressed Baryonic Matter(CBM) experiment[1] is a fixed target experiment planned at the upcoming FAIR facility at GSI, Darmstadt. It aims to study the heavy ion collisions in the energy range 8-35 AGeV/n. A layout of the detectors in CBM is shown in Figure 1. The goal in CBM is to study the properties of matter at extreme conditions of high baryon densities and moderate temperatures. The main physics goals include search for the deconfinement phase transitions at high net-baryon densities, study of chiral symmetry restoration, search for the critical end point and study of the nuclear equation of state. One of the key probes that can address these issues is the measurement of the rare probes such as J/Ψ, Ψ' among others via their leptonic decay channels. The Indian collaboration in CBM has proposed to build a large acceptance muon detector system for addressing these issues by exploring the decay via the dimuonic channel.

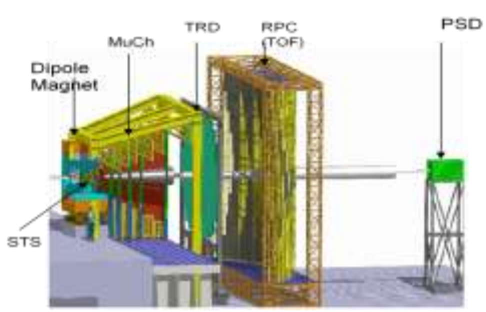

Fig.1 Layout of CBM detector

2. Muon Tracker Layout, Design Considerations, Technology options.

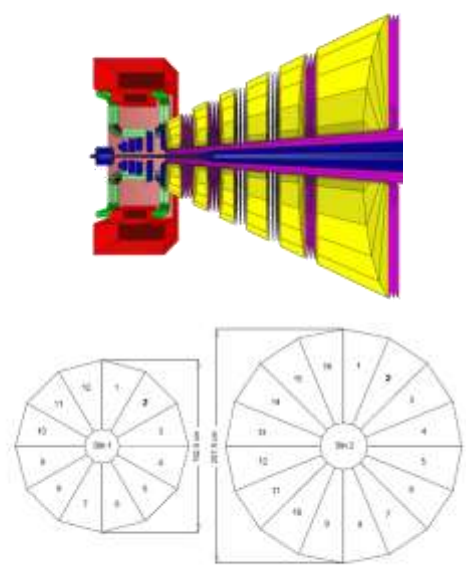

Fig.2 (top) Layout of MUCH (bottom) Segmentation of the detector plane in form of sectors for first two stations.

Located at a distance of about 1.25 m from the collision vertex and spanning a conical angle of about 50 degrees, the challenges in Muon Detection @ CBM are as follows,

- The detector should be able to cope up with a high collision rate of ~ 10 MHz. This high luminosity facilitates the measurement of rare probes mentioned above.
- Detector granularity should be high to cater to a hit of about 1 hit/sq.cm
- The detector should be resistant to high dose of neutrons, photons and heavy ions.
- Large acceptance detector – should have modular arrangement.
- Collecting data in a self triggered mode, which is the data taking mode for all CBM detectors.

Besides all these, the essential criterion is that the detector should have high charged particle detection efficiency and good position resolution. The layout of the CBM muon tracker, commonly referred to as Muon Chambers (MUCH), is shown in the Fig. 2(top). The main task of MUCH is to identify the dimuon signals arising from the decay of the low mass vector mesons and charmonia produced in the heavy ion collisions. The full version of the MUCH system consists of six alternating layers of absorbers and triplets of tracking chambers. This geometrical layout was arrived at after rigorous GEANT3 simulation using CBMROOT[2]. Each detector layer is divided into several sector shaped modules as shown in Fig.2(bottom). The readout plane in each module consists of progressively increasing pad layout, with the minimum pad size being 3 mm x 3 mm. These granularities were optimized by studying the reconstruction efficiencies and the corresponding signal-to-background ratios of the particle species mentioned above [3].

Several technology options have been considered. Owing to a harsh radiation environment and large size of the chambers required option of using silicon detectors for MUCH would not be practicable. Use of detectors based on semiconductor technology is also not a suitable option as ageing can be a serious issue due to high luminosity. Gas based detectors are most suited for this purpose. However, the conventional wire chambers cannot cope up with the specified high rates, as the gain is known to drop at such high rates[4]. Gas detectors based on micropattern technology, i.e. GEM(Gas Electron Multiplier), THGEM and micromegas are known to have stable gains at high rates[5,6]. GEM based detectors are already employed or being implemented in many high energy physics experiments such as COMPASS[7], HBD[8], LHCb[9], CMS[10]. At VECC, we are involved in the design and development of a GEM based detector for the first few planes of MUCH, where the hit density is high as mentioned above.

GEM is made out of a 50 micron thin polyimide foil, coated with a thin layer of copper on both surfaces. Holes of about 50 microns in diameter are then chemically etched in this foil at a pitch

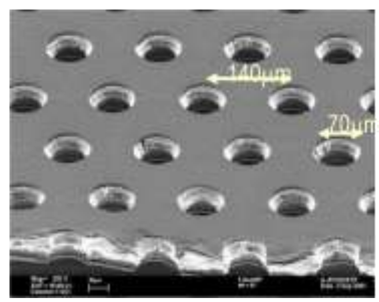

Fig.3 Magnified picture of a cutout of GEM foil

of about 140 microns. Fig.3 shows a magnified image of a cutout of a typical GEM foil. By applying a voltage (ΔV~500 volts) across the two conducting surfaces, a very high field region is created inside the holes. A primary electron which drifts towards this hole undergoes amplification inside these and produces an avalanche of electrons. Multiple layers of GEM can be added in cascade thus producing more and more amplification, leading to an enhanced signal which is collected from the readout pads placed just below the bottom of the last GEM, as schematically shown in Fig. 5. More GEM layers implies more and more amplification stages. Higher gains with lesser ΔV across each GEMs can thus be achieved, with a reduced spark probability. But the detector costs also increases proportionately. So as a compromise based on the stability of the detector, a triple GEM configuration is nowadays commonly employed. Each of the GEM layers is powered by using a

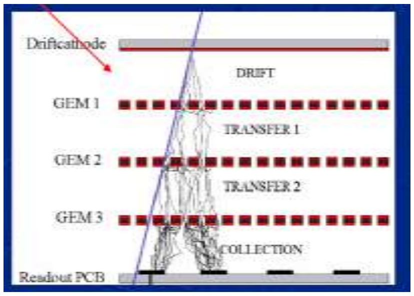

Fig.5 Schematic layout of the working of a multilayered GEM chamber

single resistive chain. The advantage with GEM detectors is that the readout plane is decoupled from the bias voltage, thus drastically minimizing the damage to the Front End readout Electronics from sparks. This is not the case in micromegas, where one has to adopt more complex techniques to bypass or reduce these sparks.

3. Prototype Chamber Fabrication

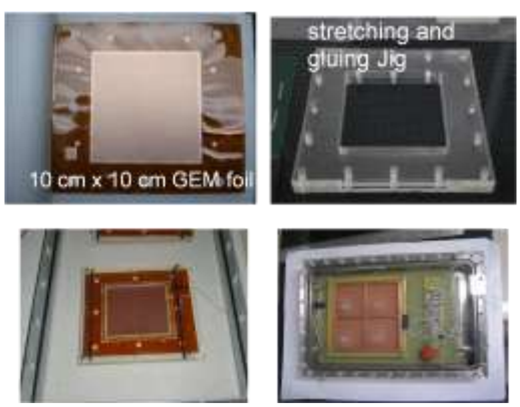

Fig.6 Fabrication of the prototype and schematic arrangement of prototype chamber assembly

The first GEM chambers at VECC, were built from scratch, using a 10 cm x 10 cm GEM foil. In VECC lab, it was stretched using thermal techniques and G10 frames were then glued on the top and bottom surfaces. The entire operation is schematically shown in Fig.6. The successful test results using ^{55}Fe source was reported in[11]. For later tests, we have used CERN made, framed GEMs of 10 cm x 10 cm for our detector R&D.

Several multiGEM chambers, mainly triple GEM chambers have been thus assembled and tested[12]. The schematic of assembly of such a prototype for beamtests is shown in the Fig.7. A Perspex frame of 12 cm x 12 cm x 10 mm and sealed from the top by a drift plane housed three GEMs stacked with a drift gap of 3-6 mm, transfer gap of 1 mm between the GEMs and a gap of 1.5 mm from the readout plane. The HV box was placed outside this gas tight volume and appropriate copper inserts carried the connections inside.

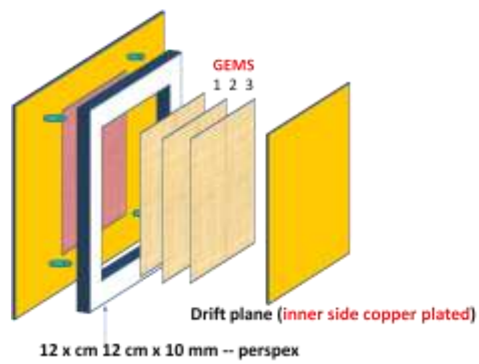

Fig.7 Schematic arrangement of prototype chamber assembly

4. Test Results

(a) Test with ^{55}Fe and with cosmics.

Using standard NIM based ORTEC-make modules in lab, the response to ^{55}Fe spectra for a triple GEM chamber is shown in Fig.7(left) and

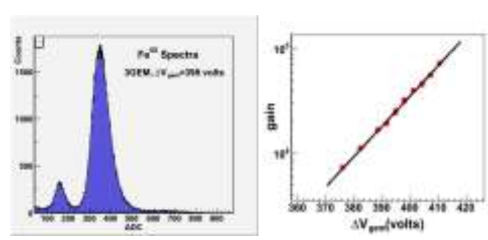

Fig. 7 (left) ^{55}Fe spectra, (right) triple GEM gain vs. ΔV_{gem}

the corresponding gain plot is shown on the right. Gains of the order of 10^5 have been reached corresponding to the maximum ΔVgem as shown in the right side plot. A multilayered readout PCB having 512 pads was fabricated and a triple GEM detector with active area 100 sq. cm. was assembled and put to test with cosmic muons in VECC lab. All the readout pads were shorted together to get one output from the detector. The amplified signal was then fed to an MCA or the coincidence unit as the case maybe. The pulse height spectra fitted to a Landau distribution is shown in the Fig.8 for two different voltages.

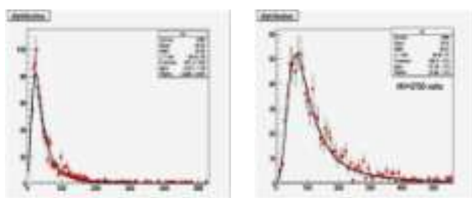

Fig. 8 Pulse height spectra from cosmic muons for two different bias voltages.

The MIP detection efficiency was measured by counting the number of detector pulses from a sample of muon triggers obtained by coincidence counts from three scintillator detectors. The efficiency increases with high voltage and is found to saturate around 95 %.

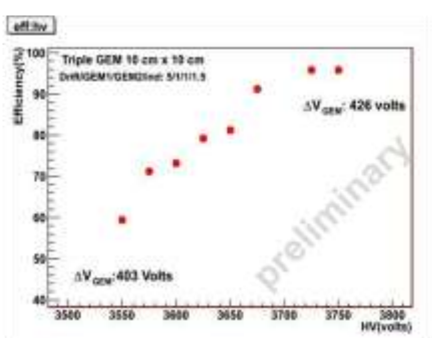

Fig.9 Efficiency of cosmic MIPs vs high voltage

(b) Test with nXYTER, a self triggered readout board

Data in CBM will be acquired in a self triggered mode. The schematic of working of such a detector is shown in Fig. 10.

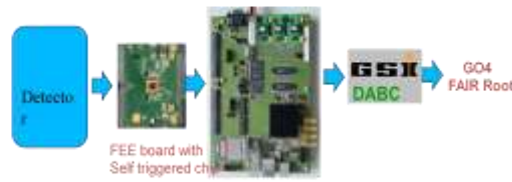

Fig.10, Schematic of data acquisition in a self triggered system.

The detector signal is readout by a self triggered Front End Electronics(FEE), which is nXYTER [13]in our case. This is a 32 MHz readout ASIC, being developed at GSI, for use in the actual CBM experiment. This is then controlled via a Readout Controller (ROC) and finally the data acquired by the CBM-DAQ is written to a PC. Data is collected in a free streaming mode, and time stamps of all the hits are recorded. Events are reconstructed offline by appropriately grouping the detector hits based on their timestamps.

Fig. 11 picture of a 512 pad, triple GEM chamber under test at COSY at Juelich.

Several triple GEM prototypes each of 100 sq-cm area have been tested with proton, pions and muon beams to understand the detailed response of the detector in terms of efficiency, cluster size, uniformity among others. Multi-layered readout planes varying in number of pads were fabricated depending upon the granularity adopted. Using a self triggered readout system the goal was to optimize the detector geometry parameters and readout characteristics and arrive at an appropriate operating voltage of a triple GEM chamber. One such chamber consisting of 512 readout pads each of 3 mm x 3 mm dimension was assembled at VECC. We have

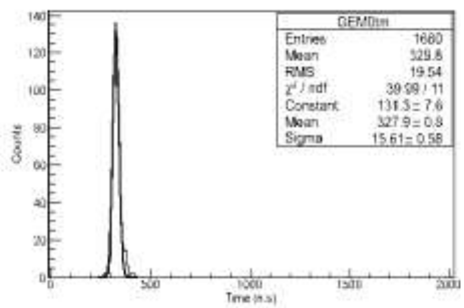

Fig.12 Typical timing difference spectra(between GEM hits and beam trigger) from the prototype chamber.

mostly adopted a resistive divider for powering the three GEMs. However, more recently we have also tested chambers using individual powering scheme wherein each of the GEM plane is supplied voltage individually. Fig.11 shows the picture of one such detector under test at COSY accelerator facility at Juelich. The signal from the pads were read out via four Front End Boards(FEBs), each consisting of one nXYTER chip. A premixed gas mixture of Ar/CO_2 in the ratio 70/30 was used for all our tests.

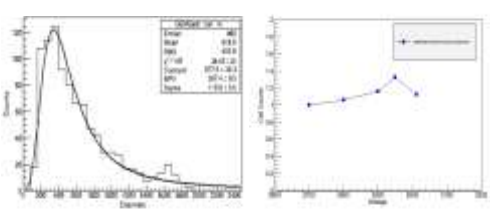

Fig.13. Pulse height spectra for 150 GeV/c muon beam(left) and cluster size(right).

The distribution of the timing difference when the detector sees the correlated signal with respect to the trigger is shown in Fig.10. It shows a narrow profile with an RMS of <20 ns. All detector hits falling within a time window of 200 ns was considered to be a valid muon track hit. The pulse height corresponding to the muon beam and fitted to a Landau distribution function is shown in Fig. 13. Data at varying GEM voltages were taken for two different resistive divider configurations. The variation of efficiency with GEM voltage is shown in Figure 13. The efficiency of charged particle detection for the two cases obtained in a time window of 200ns, is found to reach a value >95%. Design and assembly of a large size GEM chamber with an active area of 30 cm x 30 cm based on sector pad layout is underway.

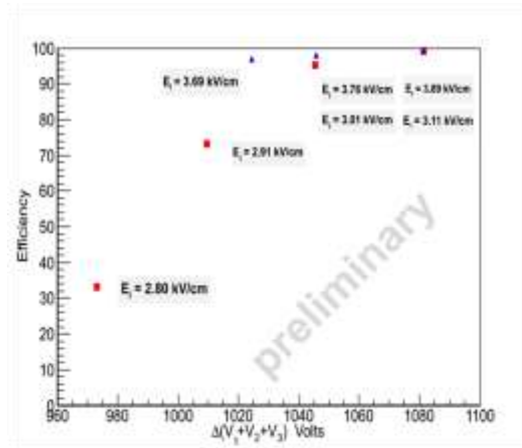

Fig. 14. Variation of Efficiency with GEM voltage

5. Summary and Outlook

A detector based on micropattern technology, namely GEMs, has been proposed for the first few stations of MUCH in CBM, where the paticle density is very high. We have built several multiGEM 10 cm x 10 cm prototype chambers at VECC. These have been tested with radioactive sources and proton, pion and muon beams. Several beamtest of the prototype chambers have been conducted and the response of the chamber to MIPs have been studied. A high charged particle detection efficiency > 90% have been obtained and the cluster size is also close to 1, thus meeting the desired criteria of the detector. More optimization in the biasing scheme of the detector and test for rate capability is underway. The next step now would be to make a 30 cm x 30 cm large size chamber and test the uniformity of response. The goal is also to optimize the techniques of stretching and gluing of large size GEMs, which is still an evolving issue.

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