Development and performance studies of GEM based tracking detectors for the Compressed Baryonic Matter (CBM) experiment at FAIR

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CBM is a fixed target heavy-ion experiment at the FAIR facility of GSI Darmstadt Germany. This experiment aims to study the Quantum Chromodynamics (QCD) matter at high net-baryon densities and moderate temperature by colliding heavy-ion beams in the energy range of 2-14 AGeV at the SIS100 setup. The main physics goal of the CBM is to study the equation of state at high net-baryon densities and measure the rare diagnostic probes such as multi-strange hyperons, charmed particles, and vector mesons decaying into lepton pairs with unprecedented precision and statistics [1]. The di-lepton physics is the central part of the CBM experiment as they are sensitive diagnostic probes for the condition inside the fireball. Measurements of di-leptons (J/ψ, ρ, ω, ϕ) will provide information on the temperature and lifetime of the fireball, chiral symmetry restoration, and in-medium properties of the vector mesons. The production cross-section of these particles is very small at FAIR energies and is termed as rare probes. The unique feature of CBM is that it will be operated at an unprecedented interaction rate up to 10 MHz, which will open the possibility to measure these rare probes with high statistics. The di-muon measurements at CBM will be carried out using a Muon Chamber (MuCh) system, which consists of alternating layers of segmented absorbers and detector stations. This novel scheme of using segmented absorbers allows the detection of muon tracks in a broad momentum range. The particle rates (400 kHz/cm^2 (inner region) for minimum bias Au+Au collisions at 10 AGeV) and radiation doses for the first two stations of MuCh will be very high. Fast and high rate detectors which can work in such harsh environments and can cope up with high interaction rates are needed. A gaseous detector based on GEM technology will be used for the first two stations. The work in this thesis is dedicated to building and studying the performance of real-size triple GEM prototypes.

During the R & D phase, several triple GEM prototypes detectors ($\sim$100 cm^2 to $\sim$1900 cm^2) were built and tested with radioactive sources (X-rays and β-rays) in the laboratory and with particle beams at different accelerator facilities. In all these tests, two types of readout chains were used namely, conventional (NIM-based) and self-triggered (n-XYTER and STS/MuCh-XYTER [2]). Basic characteristic measurements in terms of efficiency, cluster size, time resolution, gain, etc. for small size as well as with real-size prototype detectors have been carried out in the laboratory and in different accelerator facilities. In the laboratory, for small size prototype, the efficiency was measured with self-triggered readout and an efficiency of $\sim$95% was observed. It varies within 5% throughout the active region of the detector.

Real-size chambers were built at VECC using standard NS-2 technique with a gap configuration of 3/2/2/2 and with novel optocoupler-based [6] HV biasing scheme. Trapezoidal-shaped single mask GEM foils were used with the top surface of each foil being segmented into 24 divisions. The readout consists of pads with progressively increasing size from $\sim$4 mm to $\sim$17 mm. The active area

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of each of the detector is about 1900 cm^2. Rigorous Quality Assurance (QA) test of foils and other components were done before the detector assembly. All these modules were tested with an X-ray source in the laboratory to ascertain the overall proper functioning of the detectors. The effects of the environmental parameters such as Temperature and Pressure on normalized detector gain with time were observed to be within 5%. The real-size module was also tested with proton beams of momentum 2.36 GeV/c at the COSY accelerator facility in Jülich. Using n-XYTER chip as readout electronics, a charged particle detection efficiency higher than ∼95% was observed. The variation in efficiency with the incoming particle rate (with the maximum rate reaching up to 2.8 MHz/cm^2) was found to be about 2% [5].

Real-size prototype detectors were tested with a spray of particles from nucleus+nucleus collisions, as the case would be in the actual CBM experiment, for the first time at CERN-SPS, and more rigorously in mCBM (mini-CBM) experiment at GSI [3, 4]. The mCBM experiment has been set up at the SIS18 facility of GSI to test the simultaneous response from different detector regions of any subsystems and also a correlated response between different subsystems in high rate nucleus+nucleus collisions. Two real-size modules were commissioned in mCBM as part of the mMuCh system. The data at mCBM have been acquired using the actual CBM DAQ and electronics. The detector gain, as calculated using MPV of the cluster charge, was found to be about 3.1 k at $\Delta V_{GEM(sum)}$ of ∼1072 V which matched within 15% with the gain value measured in the lab using 5.9 keV X-ray source. Zone-wise relative gain of the detector module was measured and it is observed to vary within 15% over the full active area of the detector. The uniformity as measured from the time resolution map involving large number of pads/channels over entire detector area was observed to vary within 4-5 ns. In free-streaming data, for the first time using different detectors in mCBM, event building was performed offline by grouping time stamps of the detector hits. A clear spatial correlation between the hits of GEM1 & GEM2 and between GEM & TOF modules have been observed, conveying an effective event reconstruction. This clearly demonstrates the time-synchronous behavior of two different detectors or, for that matter, even two different subsystems employing entirely different detector technologies and readout electronics. A straight line track fitting has been carried out using TOF detectors and GEM detectors event-by-event. Track residuals have been measured at the different granularity regions of the GEM modules. Average particle rates were measured for various beam intensities and a linear response has been observed.

The performance of MuCh detectors in simulation has been systematically studied by implementing realistic detector digitization parameters, such as mean gas gain and spot radius of the avalanche, for central Au+Au collisions at 8 AGeV beam energy. The main observation from this exercise is that the ω reconstruction efficiency saturates at a mean gas gain of about 3.5 k and remains unaffected by the change in spot radius.

Based on the performance and test results of the detector modules discussed in this thesis, we expect that GEM-based detectors of MuCh should be able to carry out the intended measurements in CBM.

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