Large area BM@N GEM detectors

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Abstract. Baryonic Matter at Nuclotron (BM@N) is a fixed target experiment at the NICA accelerator complex in JINR aimed to study nuclear matter in relativistic heavy ion collisions. Detectors based on Gas Electron Multipliers (GEM) are used for the central tracking system of the BM@N experiment, which is located inside the BM@N analyzing magnet. The structure of the GEM detectors and the results of study of their characteristics are presented. The performance of seven GEM detectors integrated into the BM@N experimental setup and data acquisition system is briefly reviewed.

1. Introduction

The study of nuclear matter properties under extreme conditions is one of the most rapidly developing areas of modern physics. The first experiment at the accelerator complex of NICA-Nuclotron – BM@N is aimed to study nuclear-nuclear (up to “gold-gold”) collisions at high densities. The main goal of the experiment is to study the interactions of relativistic heavy ion beams with fixed targets. Experimental interest is focused on hadrons with strangeness, which are produced in collisions and do not exist in the initial state of two colliding nuclei. Measurements will be carried out at the BM@N experimental setup, located at the extracted beam of the Nuclotron. The Nuclotron heavy ion beam energy range corresponds to $\sqrt{s_{NN}} = 2.3 \div 3.5$ GeV. It suites to studies of strange mesons and multi-strange hyperons which are produced in nucleus-nucleus collisions close to the kinematic threshold. The maximum yield in the hyper-nuclei production predicted by the thermal model [1] is also close to the Nuclotron energy range.

A scheme of the BM@N experimental setup for heavy ion physics program that starts in 2021 is shown in Fig. 1. The experiment combines both high precision track measurements with time-of-flight information for particle identification and calorimetry for the analysis of the collisions centrality. The magnetic field of the analyzing magnet can be set up to 1 T to get the optimal detector acceptance and momentum resolution for different reactions and beam energies.

The charged particle momentum and multiplicity are measured with the set of Gas Electron Multipliers (GEM) located inside the analyzing magnet. Double-sided silicon strip-detectors (FwdSi, STS) are installed between the GEM tracker and the target to improve the track and vertex reconstruction in heavy ion collisions. The outer tracking system consists of six planes of cathode strip chambers (CSC). It is situated outside the magnetic field and is intended to precise parameters of tracks, obtained in GEM detectors inside the analyzing magnet. Beside improvement of particles momentum identification, refined track in CSC is used to find corresponding hits in ToF-400 and ToF-700 time-of-flight systems.

A vacuum beam pipe will be integrated into the experimental setup to minimize the amount of scattering material on the way of heavy ions.

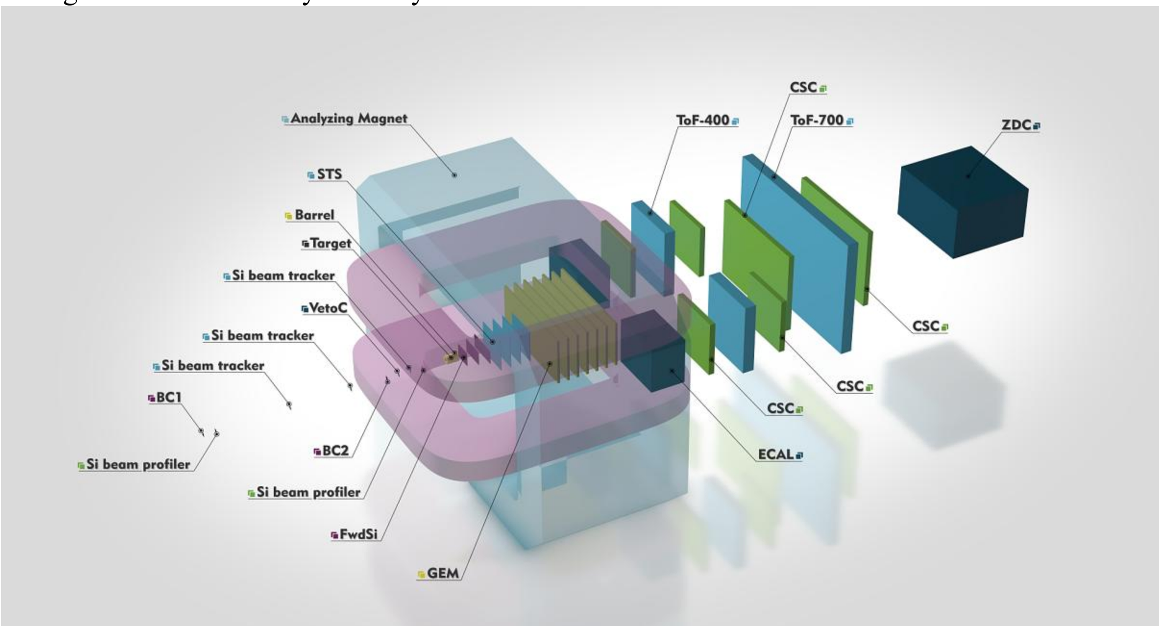

Figure 1. Schematic view of the BM@N experimental setup: FwdSi – Forward double-sided silicon strip-detectors, STS – Silicon Tracking System; GEM – Gas Electron Multipliers, CSC – Cathode Strip Chambers, ToF-400, ToF-700 – Multi-gap Resistive Plate Chambers, ECAL – Electromagnetic Calorimeter, ZDC – Zero Degree Calorimeter.

2. GEM tracking system

The tracking system of the BM@N experiment will provide precise momentum measurements of the cascade decays products of multi-strange hyperons and hyper-nuclei produced in central Au-Au collisions. The full configuration of central tracking system consists of 14 GEM detectors (Fig. 2):

- 7 GEM detectors of the size 163×45 cm^2 – above the vacuum beam pipe;
- 7 GEM detectors of the size 163×39 cm^2 – below the vacuum beam pipe.

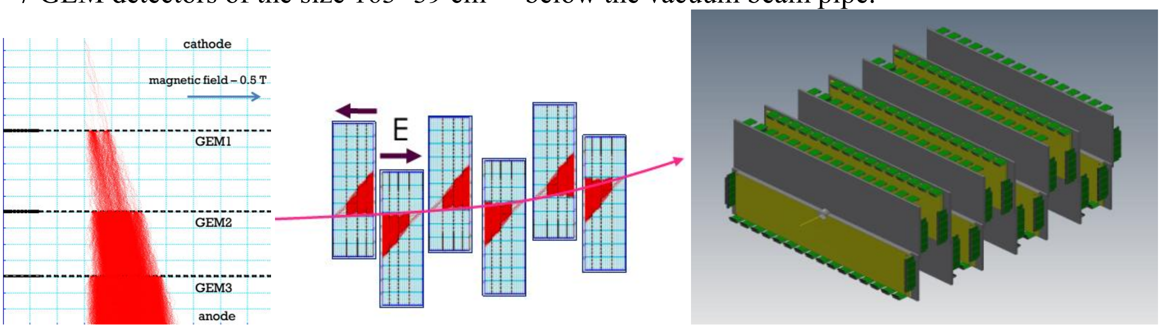

Figure 2. a) The electron avalanche in triple GEM cascade in magnetic field; b) illustration of avalanches evolution in GEM planes with opposite directions of electric fields; c) scheme of the GEM full planes configuration inside the magnet.

To separate positively and negatively charged particles and to measure their momentum the central tracking system is located inside the analyzing magnet. Since the magnetic field is perpendicular to the electric field direction in the GEM, electron avalanche in GEM gas gaps drifts at some angle (the Lorentz angle) with respect to the normal to the readout board (Fig. 2a). The electron drifts result in a displacement of the collected charge is called a Lorentz shift. The shift value depends on the field strength and gas properties. To eliminate a systematic shift of the reconstructed tracks in the magnetic field, GEM detectors are rotated so that neighboring planes have opposite directions of the electric field (Fig. 2b). The scheme of the GEM full planes configuration inside the magnet is shown in Fig. 2c.

For today seven GEM detectors of the size 163×45 cm^2 are installed into the BM@N setup for technical runs with the deuteron, carbon, argon and krypton beams in 2016-2018. Three detectors of the size 163×39 cm^2 are tested with cosmic rays in 2019. Full configuration is planned to be integrated into experimental setup in the beginning of 2020.

3. BM@N GEM construction

Due to the construction features of the BM@N beam channel two sizes of detectors are foreseen to cover the maximum possible geometrical acceptance within the experiment dimensions. Both 163×45 cm^2 and 163×39 cm^2 BM@N GEM detectors are produced at CERN PH Detector Technologies (DT) and Micro-Pattern Technologies (MPT) workshop. Each detector consists of three GEM multipliers, with the following gaps between the electrodes: the drift gap of 3 mm, the first transfer gap of 2.5 mm, the second transfer gap of 2 mm and the induction gap of 1.5 mm, as it is shown in Fig. 3a. To ensure effective operation and reduce both the energy and probability of discharge an optimization of the electric field applied to the GEM gas gaps was performed [2]. There is a hole of 80 mm in diameter in the central region of the GEM detectors in order to install a vacuum beam pipe for heavy ion beam particles. The rigidity and support of the GEMs is achieved by using two honeycomb plates.

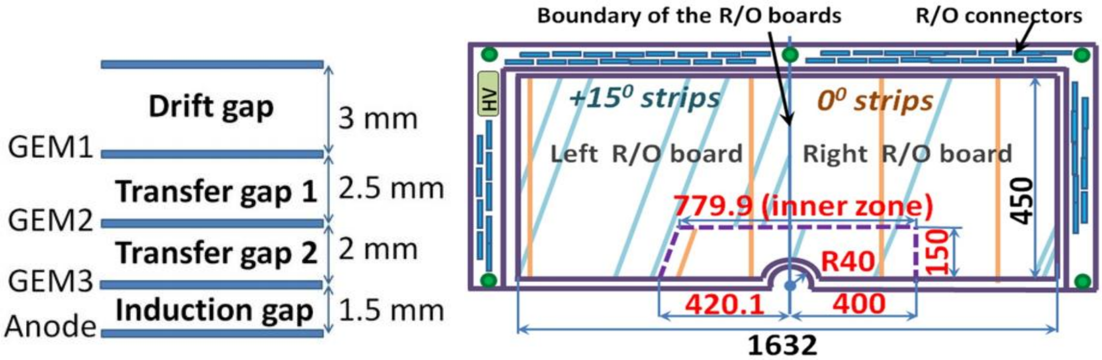

Figure 3. a) Schematic cross section of BM@N triple GEM detector; b) 163×45 cm^2 readout board design.

3.1. Readout board design

A two-dimensional projective readout of the electron charge signal is performed on a readout board with two sets of parallel metal strips (Fig. 3 b). The inclination angles of bottom layer strips (X coordinate) and top layer strips (X′ coordinate) to the vertical axis are 0 and 15 degree, respectively. The widths of the X and X′ strips are 680 and 160 µm, correspondingly. The strip pitch is 800 µm for both layers. Because of a large multiplicity of charged particles near the beam line, the readout layer is divided into the outer and the inner ("hot") zones.

3.2. GEM foil sector design

Both 163×45 cm^2 and 163×39 cm^2 GEM foils are divided into sectors. Each sector is individually powered through high value protection resistors in order to reduce the energy stored in the foil. For the first produced chamber the design with vertical sectors was chosen (Fig. 4 left). It results in regular dips in occupancy distribution for X strips (Fig. 5 left). The dips coincide with the corresponding non-active borders of sectors. In the dip region the degradation of particle reconstruction accuracy is observed. To improve the detector resolution over X coordinate the horizontal sector design was adopted (Fig. 4 right). The occupancy distribution for X strips for horizontal sector design is shown in Fig. 5 right.

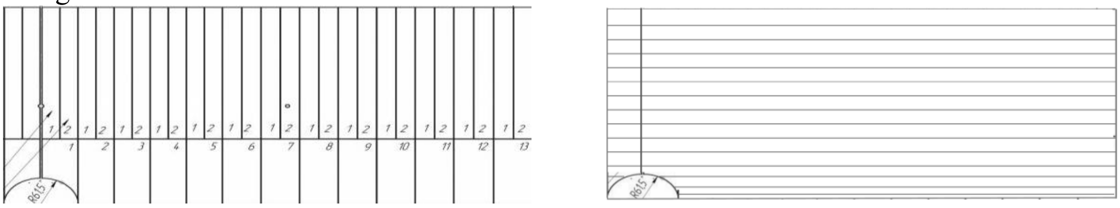

Figure 4. Vertical (left) and horizontal (right) sectors.

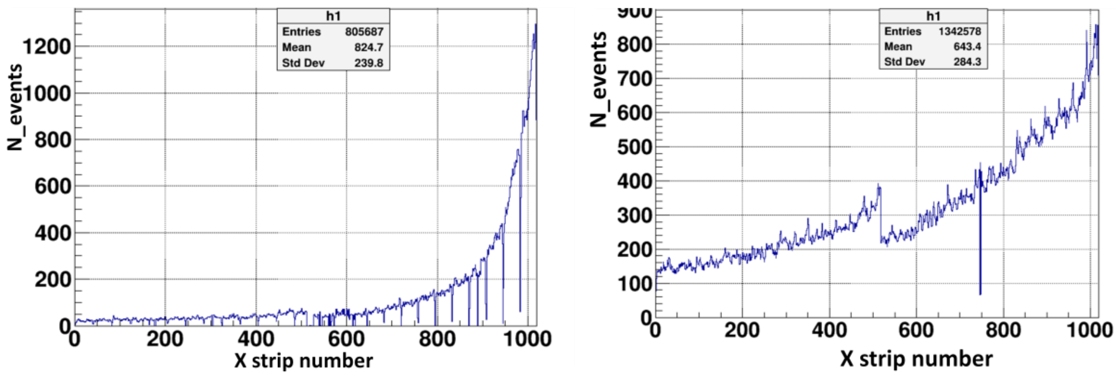

Figure 5. Occupancy distributions for X strips for vertical and horizontal sector design.

4. FEE and DAQ

GEM front-end electronics is based on the charge sensitive preamplifier chip VA163 (IDEAS) [3]. The chip has 32 channels. Each channel contains a charge sensitive preamplifier, a shaper with 500 ns peaking time and a sample-hold circuit. An analog multiplexer with 32 inputs allows performing serial readout channel by channel.

Chips are joined in groups of 4 in one front-end board. The multiplexed data from each board are transmitted through 13 m of twisted pair flat cable to the 12-bit analog-to-digital converter (ADC) readout by the BM@N data acquisition system [4].

For heavy ion beam program new fast FEE is planned to be integrated. Two ASICs (VMM3 [5] and TIGER [6]) with capability to measure both time and amplitude information are considered.

5. Study of GEM characteristics

To provide stable operation of detectors as part of experimental setup careful studies of detectors characteristics were performed. Stand for cosmic rays and radioactive source tests was developed. Gas gain as a function of the current in the high voltage divider for different gas mixtures was measured [2], the operational gains were determined.

5.1. GEM response uniformity

Studies with 163×45 cm^2 GEM chamber irradiated by ^{106}Ru radioactive source were performed to measure the response uniformity across the detectors (Fig. 6). Gas gain was measured for 62 points, which were chosen uniformly over the surface of the chamber (Fig. 6 left). The position of the points is shown on XY plane of the distribution. The value of uniformity across the detector is ±25% (Fig. 6 right). The gap in 3D plot corresponds to the hole for vacuum beam pipe.

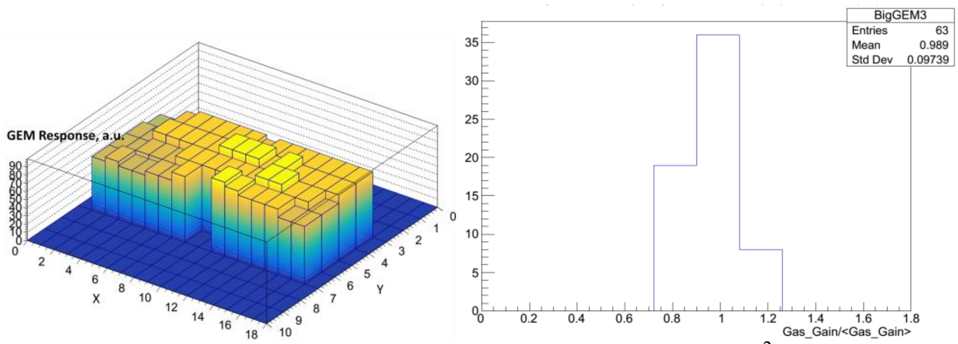

Figure 6. Gas gain uniformity measurements for 163×45 cm^2 GEM chamber. Left: Response uniformity 3D plot. Right: Gas gain distribution normalized on average gas gain.

5.2. GEM spatial efficiency

Studies of spatial efficiency of 163×45 cm^2 GEM chambers with different foil sector design were performed on cosmic ray stand. The average efficiency inside sectors is around 99%. Non-efficient areas correspond to sector borders (Fig. 7).

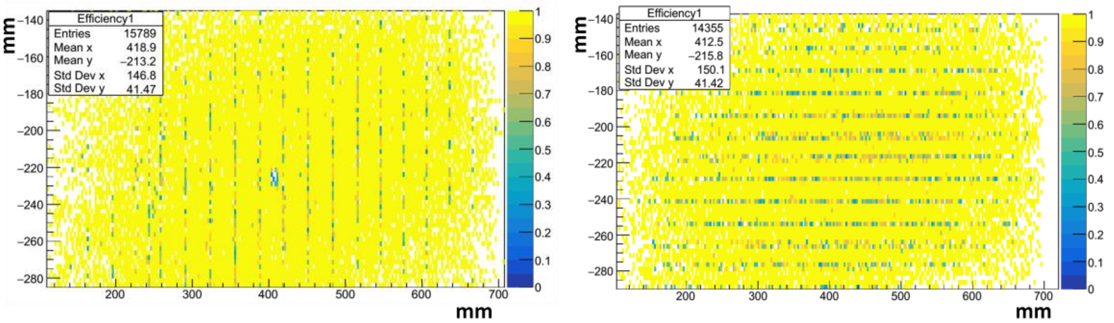

Figure 7. Spatial efficiency for vertical (left) and horizontal (right) foil sector design.

6. Beam results

First beam tests of GEM chambers were performed in 2016 with the deuteron beam at the Nuclotron accelerator. GEM chambers were filled with Ar(70)/CO2(30) gas mixture. To measure the spatial accuracy of GEM detectors, distributions of hit deviations from the reconstructed tracks (the hit residuals) were calculated. The obtained standard deviation of the Gaussian fit is 670 μm (see Fig. 8 left).

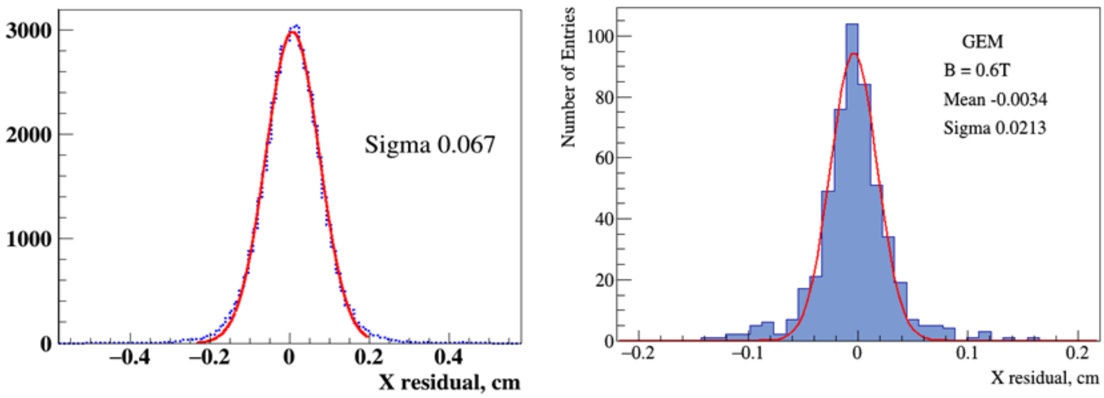

Figure 8. GEM hit residuals for magnetic field of 0.6 T for different gas mixtures and different values of the electric field in drift gaps.

At the Ar and Kr beam tests in 2018 the value of electric field in drift gaps of GEM chambers was increased to 1.5 kV/cm, the gas mixture was changed to Ar(80)/C4H10(20). That caused the three times decrease of the Lorentz shift value of the electrons avalanche. Hit residuals standard deviation of the Gaussian fit is 220 μm (see Fig. 8 right).

7. Conclusions

GEM detectors of the BM@N central tracking system have been assembled and studied at the d, C, Ar, Kr beams of the Nuclotron accelerator. The measured parameters of the GEM detectors are consistent with the design specifications. Seven GEM chambers with the size of 1632×450 mm^2 are the biggest GEM detectors presently produced in the world. Full configuration is planned to be integrated to the BM@N experimental setup in the beginning of 2020.

References

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