Conference Paper

Triple GEM tracking detectors for the BM@N experiment

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Abstract

BM@N (**B**aryonic **M**atter at the **N**uclotron) is the fixed target experiment aimed to study nuclear matter in the relativistic heavy ion collisions at the Nuclotron accelerator in JINR. The BM@N tracking system is based on Gas Electron Multipliers (GEM) detectors, mounted inside the BM@N analyzing magnet. The structure of the GEM detectors and the results of study of their characteristics are presented. The GEM detectors are integrated into the BM@N experimental setup and data acquisition system. The results of the first test of the GEM tracking system in the technical run with the deuteron beam are shortly reviewed.

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1. Introduction

The BM@N (Baryonic Matter at the Nuclotron) is the first experiment at the accelerator complex of NICA-Nuclotron [1]. The main purpose of the BM@N experiment is to investigate properties of nuclear matter under extreme density and temperature. The Nuclotron beam energy range corresponds to $\sqrt{s_{NN}}$ = 2.3–3.5 GeV, which is of great interest for scientific studies, but still poorly investigated.

A scheme of the BM@N experimental setup is shown in Figure 1. The experiment combines 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 varied up to 1 T. The charged particle momentum and multiplicity are measured with the set of Gas Electron Multipliers (GEM) located inside the analyzing magnet and by the Drift Chambers (DCH) situated outside the magnetic field. Double-sided Silicon Micro-strip Sensors (SiMS) are installed between the GEM tracker and the target to improve the track and vertex reconstruction.

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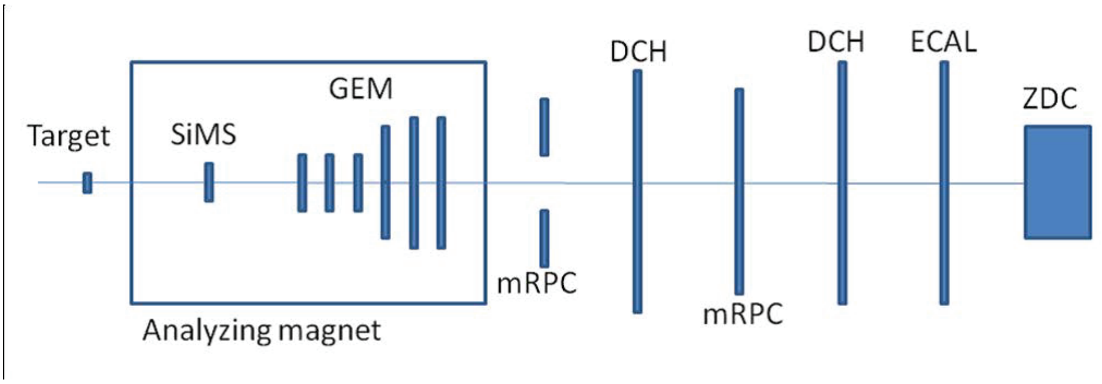

Figure 1: Schematic view of the BM@N experimental setup: SiMS - Silicon Micro-strip Sensors, GEM - Gas Electron Multipliers, mRPC - Multi-gap Resistive Plate Chambers, DCH - Drift Chambers, ECAL - Electromagnetic Calorimeter, ZDC - Zero Degree Calorimeter.

2. BM@N tracking system

Physics measurements will be performed in conditions of high beam intensities up to 10^6 ions per second in collisions with large multiplicity of charged particles. This requires the use of detectors with the capacity to resolve multiple tracks produced at very high rate. Detectors based on the GEM technology posses all the mentioned characteristics combined with the capability of stable operation in a strong magnetic field. For this reason, two coordinate GEM detectors were chosen for the central part of the tracking system. At present, the GEM tracking system of the BM@N experiment consists of five GEM detectors of the size of 66×41 cm^2 (small GEM detectors) and two GEM detectors of the size of 163×45 cm^2 (big GEM detectors). These detectors were installed into the BM@N set-up for technical runs with the deuteron beam in December 2016 and with the carbon beam in spring 2017.

2.1. GEM detector technology and construction

One GEM foil is made of thin Kapton foil coated on both sides with copper electrodes and perforated by a large number of holes (manufactured by CERN PH Detector Technologies (DT) and Micro-Pattern Technologies (MPT) workshop) [2]. When the GEM foil is placed between a drift cathode and a readout anode plate and a potential is applied between the two sides of the foil, it behaves like a charge amplifier. It is possible to use several GEM foils to achieve gains appropriate for efficient detection of minimum ionizing particles. A BM@N GEM detector contains three GEM multipliers, stretched with screws with non-glued technology. Schematic cross section of the GEM detector is shown in Figure 2. Different transfer gaps are performed in order to optimize charge load on GEM2 and GEM3. The size of induction gap was chosen to achieve required value of electric field at minimal applied high voltage.

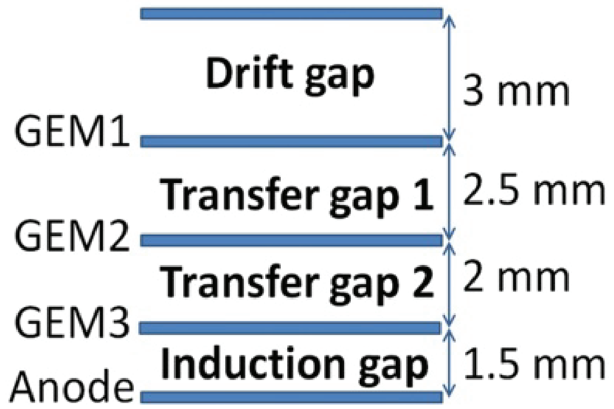

Figure 2: Schematic cross section of BM@N triple GEM detector.

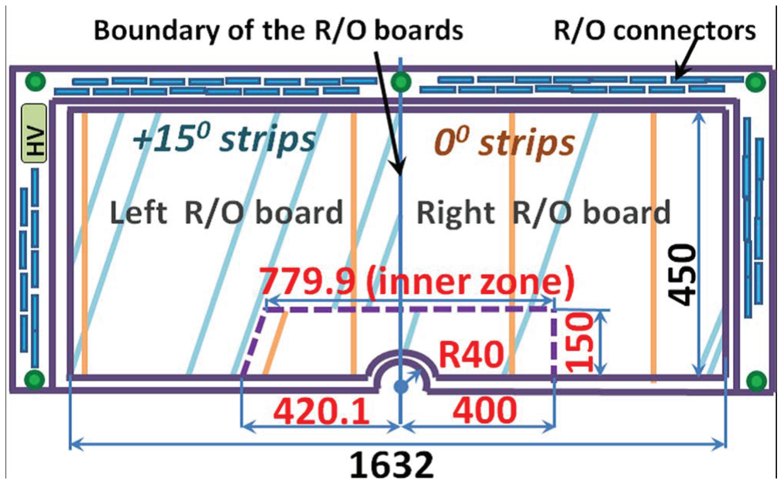

Figure 3: Schematic view of the big GEM detector readout board.

A two-dimensional projective readout of the electron charge signal is performed on a multilayer readout board with two types of straight parallel metal strips. Their inclination angles to the vertical axis are 0 (X coordinate) and 15 (X′ coordinate) degrees. The total number of readout channels of the GEM detector system is about 3×10^4. A scheme of the big GEM readout plane is shown in Figure 3.

2.2. FEE and DAQ

Front-end electronics is based on the charge sensitive pre-amplifier chip VA162 (IDEAS) [3]. The chip has 32 channels. Each channel contains a charge-sensitive preamplifier, a shaper with 2 μs peaking time and a sample-hold circuit. An analog multiplexer with 32 inputs allows one to perform serial read-out channel by channel. Chips are joined in groups of 4 in one front-end board. The multiplexed data from each board are transmitted through 13m of twisted pair flat cable to the 12-bit analog-to-digital converter (ADC) readout by the BM@N data acquisition system [4].

2.3. GEM gas gain measurements

The measured amplification and conversion factor of the VA162 chip and ADC chain is 3.3 ADC counts per fC. The gas gain of the GEM detector should be around 3×10^4, in order to achieve a satisfactory signal to threshold ratio (around 20) at the working threshold value 4.5 fC and thus the signal 90 fC for minimum ionizing particles.

Measurements of the gas gain as a function of the current in the high voltage divider, designed for the BM@N GEM detectors, were performed using the small GEM detector equipped with the calibrated VA162 FEE irradiated with Fe55 radioactive source (see Figure 4). The measurements show, that operational gain of 3×10^4 for the $Ar(90)/C_4H_{10}(10)$ gas mixture is achieved at a significantly lower value of the divider current compared to the $Ar(70)/CO_2(30)$ gas mixture.

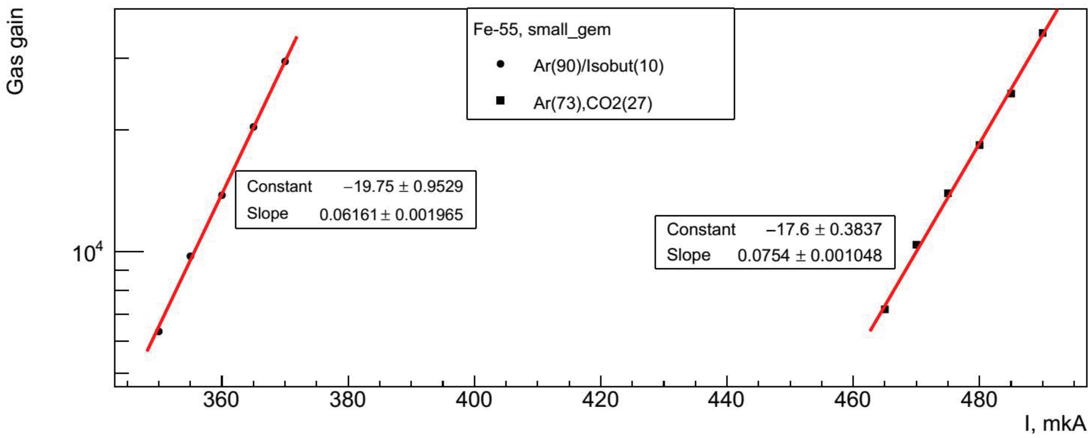

Figure 4: The GEM gas gain for the $Ar(70)/CO_2(30)$ and $Ar(90)/C_4H_{10}(10)$ gas mixtures as a function of the current in the high voltage divider.

3. Beam results

For the first beam tests with the deuteron beam 7 GEM chambers were arranged in 6 planes as it is shown in Figure 1. The left and right parts of the Big GEM detectors were treated as independent detectors. The main goal of the tests was to study the performance of the GEM detectors and the FEE and readout electronics as a part of the

BM@N experimental setup. The measurements were made within the magnetic field varied from 0 up to 0.9 T.

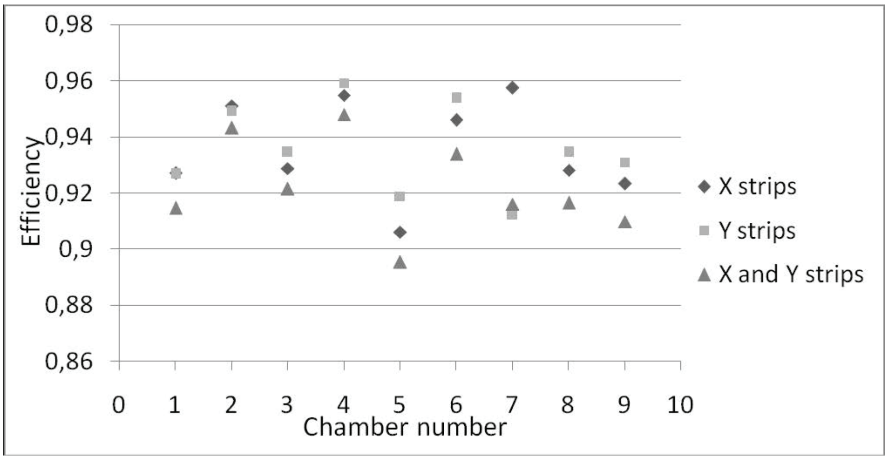

Figure 5: The GEM chamber efficiencies measured in the deuteron beam run in December 2016.

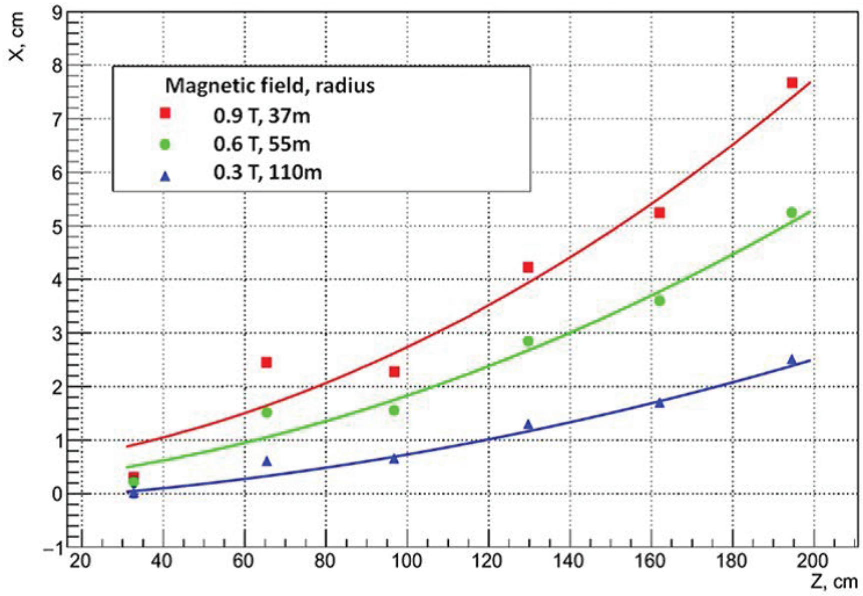

Figure 6: The average trajectories of the deuteron beam and the average Lorentz shifts of an electron avalanche in 6 GEM planes measured for three values of the magnetic field.

After track reconstruction procedure, the track detection efficiency of the GEM chambers was calculated. For the efficiency determination four GEM planes were used as reference detectors and two other were tested. The magnetic field was switched off. The efficiency of the chambers under study was defined from the presence of a cluster with a center of gravity within ±2mm of the predicted position. The efficiencies are presented in Figure 5 for the vertical X strips, the inclined X′ ("Y") strips and for the coincidence of the X and X′ ("Y") strips. The difference in efficiencies can be explained by the dispersion of FEE amplification factor and by the spatial response non-uniformity of some chambers.

The average shifts of the electron avalanche in the direction perpendicular to the magnetic field (Lorentz shift) were measured from the deviation of hits from the averaged trajectory of the beam as it is illustrated in Figure 6. Subsequent GEM planes had opposite directions of the electric field in the detectors. For first two chambers the Lorentz shift value exceeds the average shift by factors 2–3 due to insufficient rigidity of the support construction of these chambers. That leads to an enlargement of the drift gap due to gas flow, which in turn leads to an increase of the Lorentz shift of the electron avalanche.

Coordinate and momentum resolutions were calculated using data, collected without target and with magnetic field of 0.79 T. Gaussian fit of hit residuals distribution (Figure 7) gives the standard deviation of 0.067, which conform to the Monte-Carlo simulation. Momentum resolution for deuteron beam (9.7 GeV/c) is ~9% (Figure 8). The resolution for protons from deuteron defragmentation is ~6%.

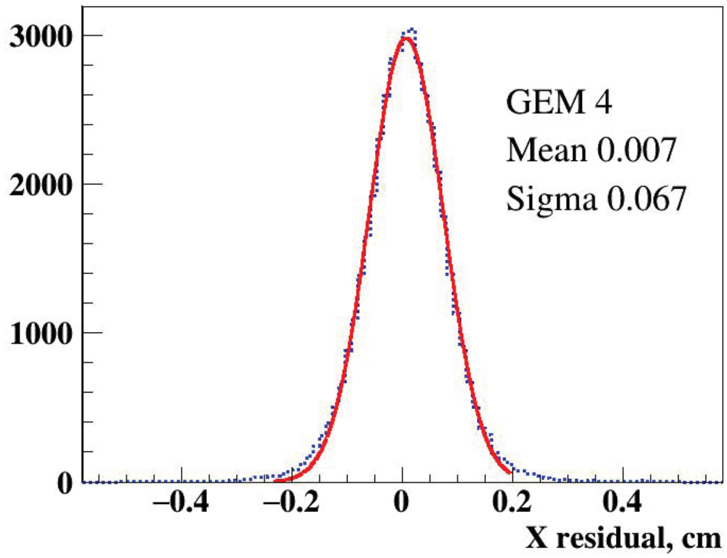

Figure 7: GEM hit residuals for experimental data. Magnetic field 0.79 T.

4. Conclusions

Seven triple GEM detectors of the BM@N tracker system have been assembled and studied in the deuteron beam of the Nuclotron accelerator. They comprise one third of the central tracking system of the BM@N experiment. Detectors, readout electronics, cables and readout services were successfully integrated into the BM@N experimental setup and tested during the technical run in December 2016. The measured parameters of the GEM detectors are consistent with the design specifications.

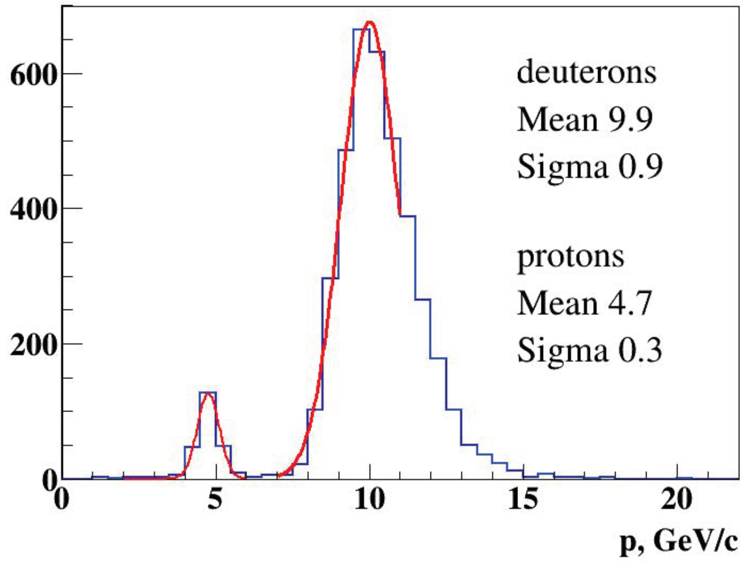

Figure 8: Momentum resolution for deuteron beam ~9%. Momentum resolution for proton spectators ~6%.

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