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Track reconstruction and GEM detector performance in BM@N experiment

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Abstract

BM@N experiment tracking system consists of Multiwire Proportional Chambers (MWPC), Gas Electron Multiplier (GEM) and Drift Chambers (DCH). It is used for trajectories reconstruction of charged particles. GEM detector is located inside the magnet and plays crucial role in track reconstruction. Algorithm of track reconstruction is described. GEM detector performance (efficiency and spatial resolution) is presented.

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1. Introduction

BM@N (Baryonic Matter at Nuclotron) is the first experiment at the accelerator Complex of NICA-Nuclotron-M. The Nuclotron will provide a variety of beams from protons to gold ions with the kinetic energy of ions ranging from 1 to 6 GeV per nucleon. The maximum kinetic energy for ions with the ratio of the charge to the atomic weight (Z/A) of 1/2 is 6 GeV per nucleon. The main goals of the experiment are the investigation of nuclear equation-of-state, study of the in-medium properties of hadrons, production of (multi)-strange hyperons at the threshold and search for hypernuclei.

Final BM@N setup includes detectors:

- MWPC chambers used as beam trajectory detectors;
- DCH situated outside the magnetic field;
- time-of-flight detectors based on multi-gap resistive plate chambers (mRPC-1,2) with a strip readout permit to differentiate various hadrons (π, K, p);
- zero-degree calorimeter (ZDC) is designed for the analysis of the collision centrality by measuring the energy of forward-going particles etc al.[1].

New experimental data with a high detector resolution is needed in order to disentangle different theoretical predictions [2]-[3] and for physics purposes. The performance of tracking detectors (MWPC, GEM, DCH) with experimental data will be described in this article.

2. Beam momentum estimation

The reconstruction of the momentum of charged particles is necessary for identification of strange hyperons production. In last runs (winter and spring 2017) two multiwire proportional chambers [4] were located on the beam before the magnet. In each MWPC station there are 6 planes: two X, two U and two V-planes. Three double-coordinate planes are at an angles 0°, $\pm 60^{\circ}$. Resolution is $d/\sqrt{12} = 0.72$ mm for wire pitch d = 2.5 mm. After the straight line fitting, we obtained the beam parameters trajectory up to the magnet [5].

Drift chambers are located after the magnet and have 4 double-coordinate planes with wire angles 0°, 90°, $\pm 45^{\circ}$. Analogous straight line fit in the drift chambers provide track parameters after the magnetic field.

Charged particles are deflected by a magnetic field and the beam parameters take a different values. The beam momentum is calculated by knowing the integral of the magnetic field. The following formula is used for calculation of beam momentum:

$$P_{beam} = \frac{0.3 * \int Bdl}{\sin \alpha_{out} - \sin \alpha_{in}}$$

where α_{in} - angle of beam before magnet, α_{out} - angle of beam after magnet, $\int Bdl$-magnet field integral [Tl*m] and 0.3 is the coefficient for transferring Tl*m to GeV/c. The results are calculated for two beam energy values: 4.5 GeV/nuclon and 3.5 GeV/nuclon (figure 1). The expected momentum values are 10.7 GeV/c and 8.7 GeV/c, respectively.

Carbon ion beam momentum is estimated with a good accuracy (2.2% at maximum value of the magnetic field).

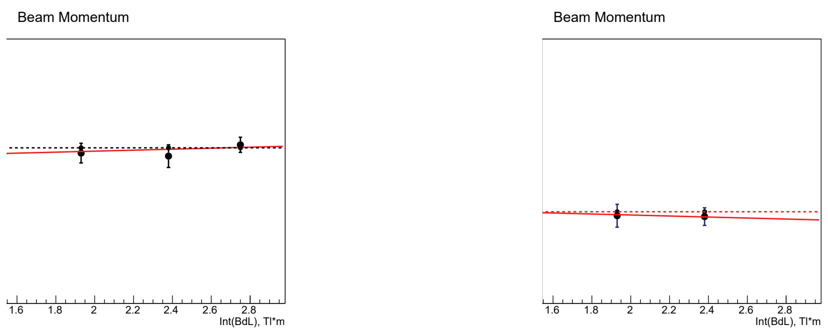

Figure 1: Two beam energy values: 4.5 GeV/nuclon (left) and 3.5 GeV/nuclon (right). The expected beam momentum value is indicated by dotted lines. Solid lines are experimental data.

3. Algorithm of track-segment building reconstruction of a charged particles without magnetic field.

The central tracker is based on the GEM coordinate detectors, that sustain high multiplicities of particles. The analyzing magnet has an aperture around one meter and magnetic field up to 0.8 T. Presently nine stations of the GEM detectors are installed into the magnet. "Middle" GEM detector size is 66 x 41 cm^2 and "large" GEM detector size is 163 x 45 cm^2. Each station has two-coordinate readout with the X and X' (inclined to $\pm 15^{\circ}$) strips. Pitch is 800 μm.

GEM detector [6] consists of anode and cathode planes with additional planes, which have holes, between them. An electron avalanche is produced by charged particles that pass through the gas volume. This electron avalanche is amplified after each plane with holes. Each anode plane consists of strips. An electron avalanche is accumulated on a group of anode strips. Cluster is a group of united fired strips. The coordinate of the reconstructed hit is determined by the formula of the center of gravity:

$$x_c = \frac{\sum_{i=1}^{n} x_i A_i}{\sum_{i=1}^{n} x_i}$$

where n is the cluster width, x_i and A_i are the coordinate and amplitude on the signal of the fired strip respectively, x_c is the center of gravity. Which we used as a measurements.

The algorithm includes consistent steps. Candidates for the track-segment are built from at least 4 hits in layers of X-strips from different stations. The linear track on X-coordinate is extrapolated to the remaining stations.

In each station we have measurement or expected X-hit. It is needed for matching with second (X') coordinate. In the result we obtain spatial track-candidate on both (X and X') coordinates. Among all track candidates we selected the one with the most hits and the lowest value of χ^2/ndf for linear 2-dimensional fit.

One spatial track-segment for testing the algorithm and calculating the efficiency was used. GEM hit efficiency per layer is calculated for events where track-segments were reconstructed and defined as ratio: Number of the reconstructed hits in a layer/Number of track-segments.

4. Testing of algorithm with Monte-Carlo data in GEM detector

The algorithm of efficiency calculation was tested using a generator with an established efficiency per layer 90%. The obtained averaged efficiency is close to established number (figure 2,left). Dependence of efficiency vs background and generator with background = 5 hits per layer are presented on the figure 2,right.

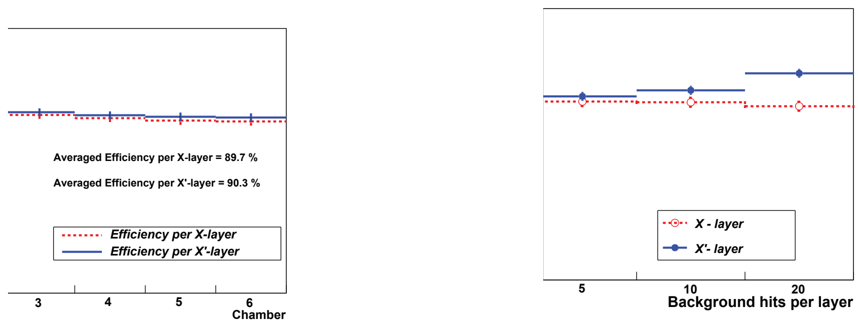

Figure 2: Calculated efficiency per layer (left) and dependence of efficiency vs background hits per layer (right) with Monte-Carlo data

5. GEM tracking with Nuclotron data

On the figure 3 it is shown GEM hit efficiency per layer with Nuclotron data for different gas mixtures: Ar + CO_2 on the left and Ar + Isobutane on the right picture. Efficiency per layer is quite high = 92-95 %. The difference between the two gas mixtures is 2-3 %.

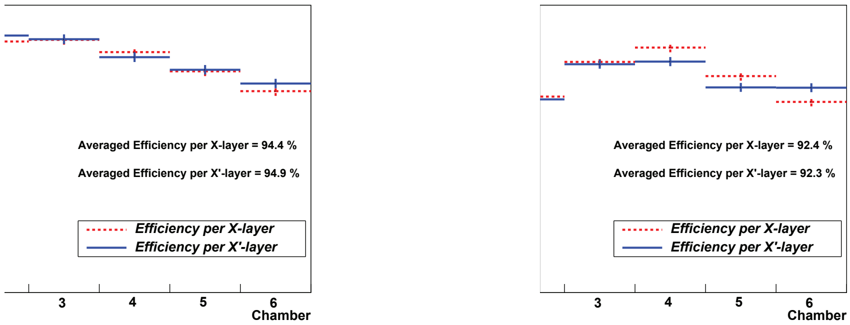

Figure 3: Efficiency per layer with Nuclotron data for two gas mixtures: Ar+CO_2 (left) and Ar+Isobutane (right)

For two gas mixtures cluster width is different. For Ar + CO_2 gas mixture cluster width is 2.3 hits on average (figure 4, left). Most clusters have only one strip. For Ar + Isobutane gas mixture cluster width is 3 hits (we have mainly 2-3 strip clusters)(figure 4, right).

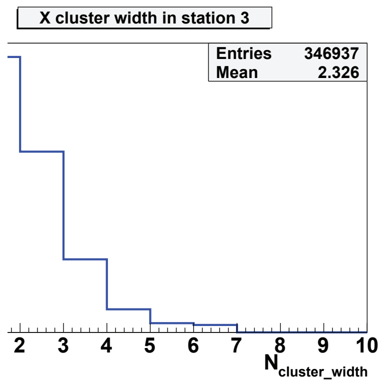

Figure 4: Cluster width for two gas mixtures: Ar+CO_2 (left) and Ar+Isobutane (right)

6. GEM spatial resolution with Nuclotron data

Spatial resolution was calculated from residuals between measurements and fitted line predictions in each layers. Spatial resolution for gas mixtures Ar + CO_2 is presented on the figure 5. For one strip clusters resolution is estimated as for uniform distribution [7] $d/\sqrt{12} = 231\mu$m with pitch 800 μm. Obtained resolution is about 200 μm and similar to this number. Spatial resolution for gas mixture Ar + Isobutane is presented on the figure 6. Obtained resolution (100 μm) is much better than that for Ar + CO_2 gas mixture.

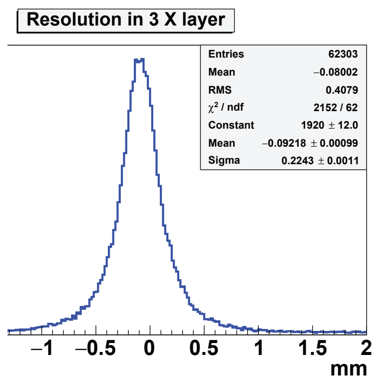

Figure 5: GEM Chamber 3 X and X′ resolution with data for Ar+CO_2 gas mixture

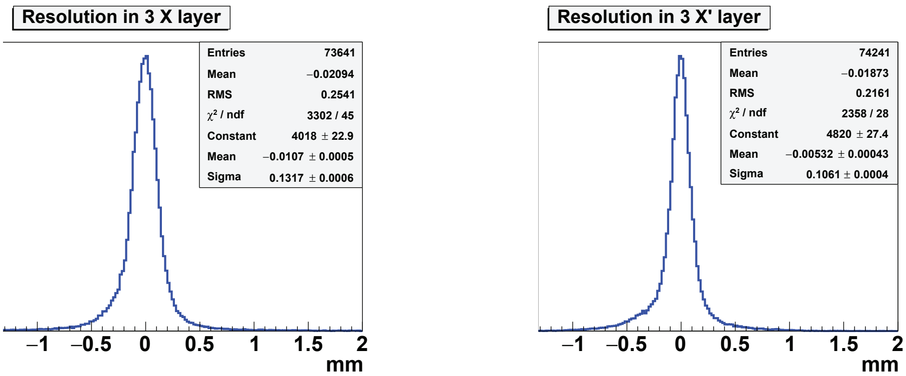

Figure 6: GEM Chamber 3 X and X' resolution with data for Ar+Isobutane gas mixture

7. Conclusions

General tracking includes external (MWPC and DCH) and internal (GEM) detectors. Using of external detectors beam momentum estimation precision resolution is 2.2 % for the maximum value of the magnetic field.

GEM detector performance in BM@N experiment with Nuclotron data without magnetic field was studied. For GEM detectors we obtained:

- Satisfying hit efficiency per layer 92-95%;
- Spatial resolution around 200 μm with gas mixture Ar + CO_2;
- Good spatial resolution 90 - 120 μm with gas mixture Ar + Isobutane.

The next step will be to calculate the parameters of the track in runs with the magnetic field, mainly the momentum of the charged particles in the main tracker (GEM).

This is one of the main objectives of the BM@N experiment. This work and its continuation are mainly aimed at maximizing the effectiveness of obtaining the physical results with present and future experimental data. The next step is the development of an algorithm for reconstructing the trajectory in an inhomogeneous magnetic field.

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