Joint Institute for Nuclear Research
Veksler and Baldin laboratory of High Energy Physics

Final report on the summer student program

Track reconstruction in GEM Detectors for the BM@N Experiment

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Participation period:
July 01 - August 19

Dubna, 2016

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Abstract

Experimental data from GEMs(Gaseous Electron Multipliers) from run 4 (June 2016) of the BM@N experiment was analyzed. Coordinates of hits were reconstructed in each GEM. An algorithm of building linear track segments in GEM stations was implemented. GEM position alignment was performed using the data from events without magnetic field with precision in the order of 0.1 mm. Lorenz shift was estimated using data from events with magnetic field. Efficiencies of each strip layer of GEM detectors were calculated.

1 Introduction

1.1 The experimental setup

BM@N (Baryonic Matter at Nuclotron) is the first experiment at the accelerator complex of NICA Nuclotron.

The main goals of the experiment[1] 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 hyper-nuclei.

The schematic view of the NICA-Nuclotron complex and the position of the BM@N setup are presented in figure 1.

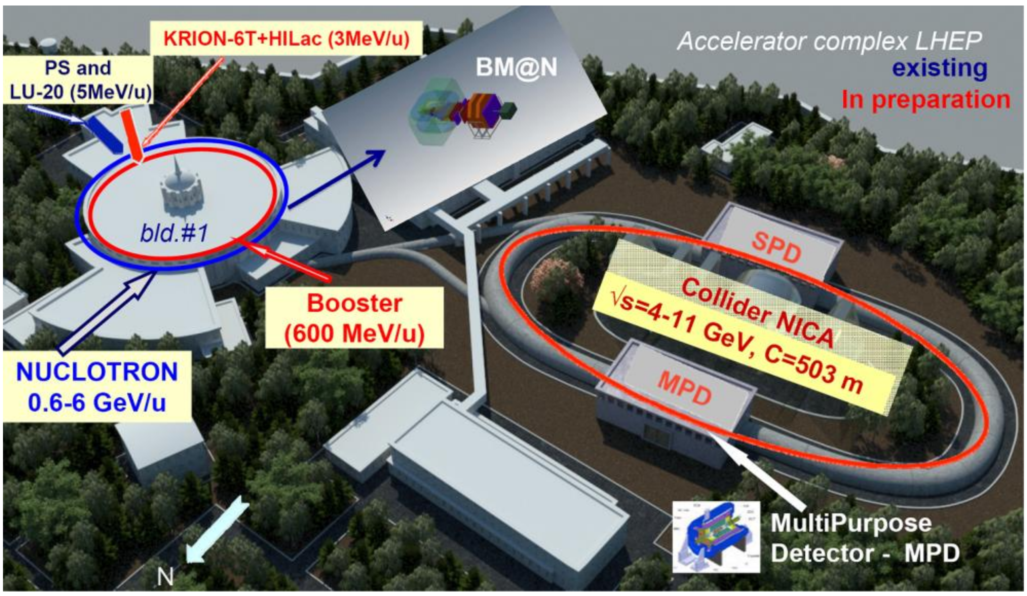


Figure 1. Schematic view of the NICA-Nuclotron complex and the position of the BM@N setup.

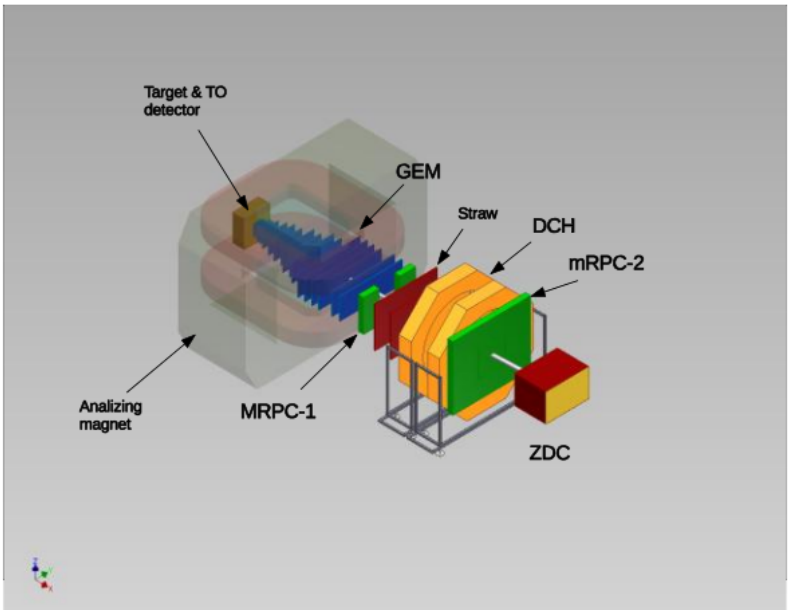


Figure 2. Schematic view of the BM@N setup

The sources of light and heavy ions, the beam Booster, Nuclotron accelerator and NICA collider are shown. A sketch of the proposed experimental setup is shown in figure 2.

The charged track momentum and multiplicity is measured with the set of GEM detectors located inside the analyzing magnet and drift chambers (DCH) situated outside the magnetic field.

Run 4 was the first run of the BM@N experiment with the GEM detectors in operation. The configuration of GEM tracker in run 4 (June 2016) was based on seven GEM planes.

At the second stage of the BM@N experiment in 2020, at least four planes of two-coordinate silicon strip detectors will be installed between the GEM tracker and the target to improve the track reconstruction in Au+Au collisions.

The geometry of the setup in run 4 is presented in Figure 3.

A photo of GEM configuration inside the magnet is presented in Figure 4.

Figure 4. Photo of configuration of GEMs in Run 4

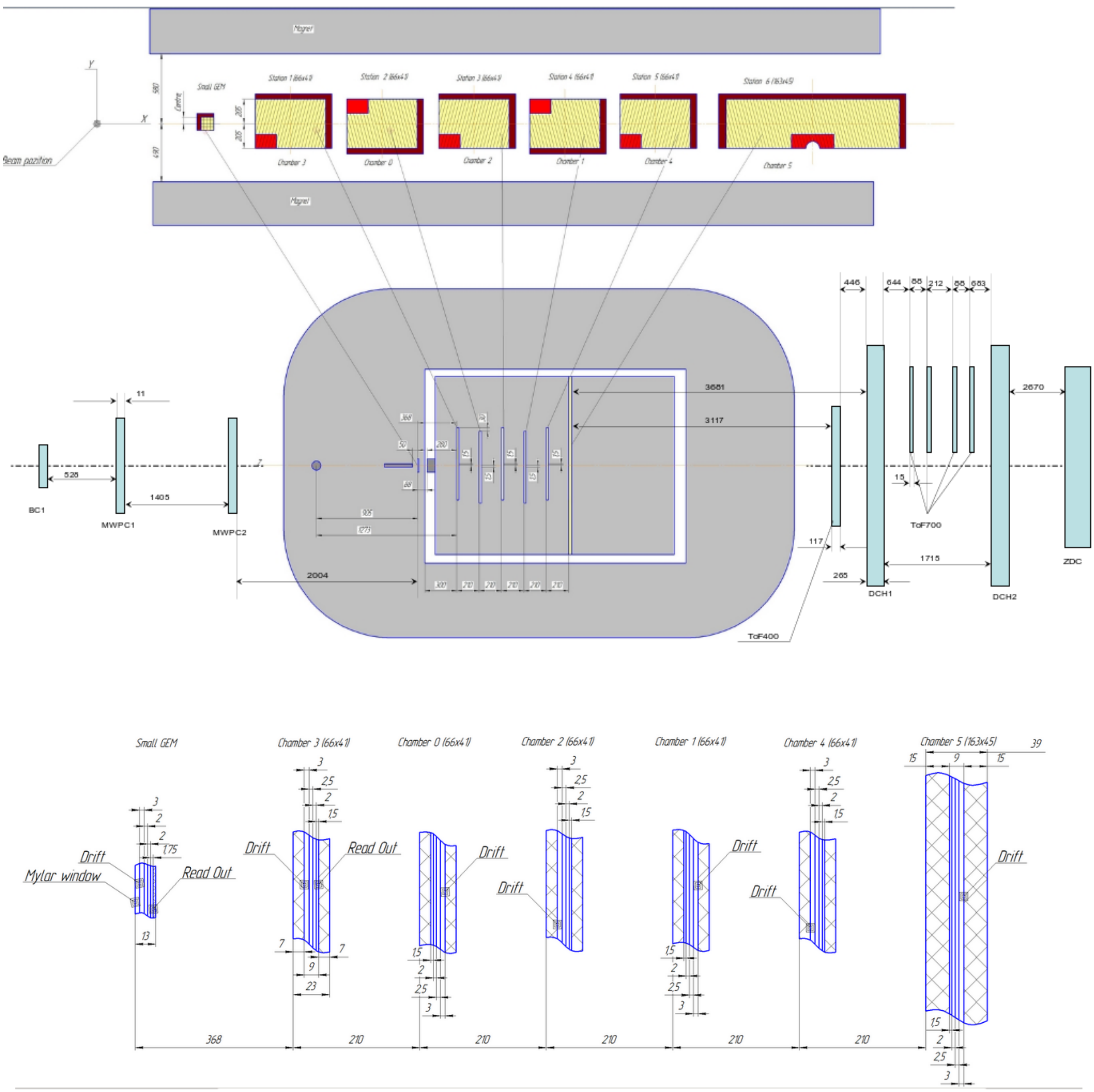


Figure 3. Run 4 geometry

1.2 Structure of Gaseous Electron Multiplier (GEM)

The microscopic structure of one GEM layer and the transverse structure of the triple GEM detector are shown in figure 5.

Each GEM detector has two-coordinate strips: 0 degree to the vertical axis (X) and +15 degree (X+) or -15 degree (X-) with a pitch of 800 microns. The largest GEM detector has the size of 163 to 45 cm^2. The first small GEM detector has two-coordinate X/Y readout (0/90 degree to the vertical axis) and a strip pitch of 400 microns.

Electrons produced by ionization in the upper gas volume drift into the holes, multiply in the high field region near the holes and drift towards the readout plane.

Due to the tight structure the GEM detectors are operational in the strong magnetic field and can sustain fluxes up to 10^6 particles per cm^2.

In magnetic field electron readout position is shifted due to Lorenz force (Lorenz shift). The Lorenz shift in GEM detector was simulated using Garfield++ toolkit[2][3]. Simulated electron tracks and X readout position are shown in Figure 6.

1.3 Structure of the experimental data

Experimental data is stored using BmnGemDigit class[3]. Each lighted strip is represented by one BmnGemDigit. Each BmnGemDigit contains:

- number of fired strip
- number of station from which the signal was received; signals from left and right parts of the large GEM are stored separately
- amplitude of the signal (pedestals were subtracted)

2 Hit production

In order to get hit coordinates from array of BmnGemDigits, adjacent strips were combined into clusters. For several reasons, however, the straightforward algorithm had to be corrected. Large clusters (with cluster width, or number of strip in it, more than 6) were divided in such way that each local signal maximum corresponds to one hit. As the occupancy graphs (Figure 7) show, some strips have significantly lower occupancy, consequently, the two clusters on both sides of these channels should be counted as one and amplitude of the signal in the disabled strip should be restored.

Narrow ranges with reduced number of hits in the middle of the X-coordinate distributions (left plots) are caused by lower efficiency of the readout electronics. Occupancy in left part of the Large GEM is smaller because the beam crosses the right part of the detector.

The width of the coordinate distributions reflects the transverse spread of the deuteron beam.

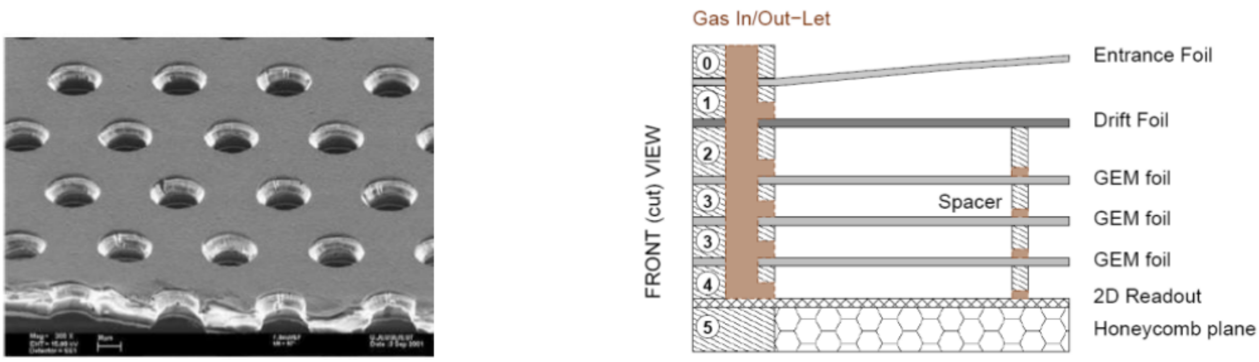
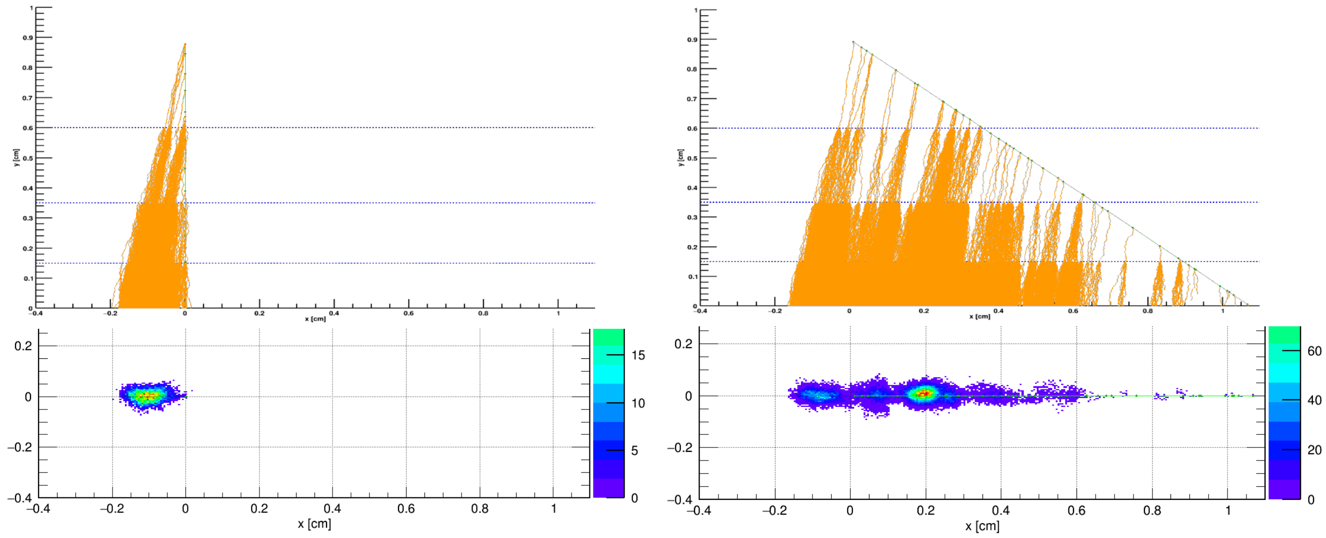


Figure 5. Structure of GEM



(a) Incident angle of the particle is 0 °

(b) Incident angle of the particle is 50 °

Figure 6. Electron tracks and X readout position in GEM

After mentioned problems were taken into consideration, the hit coordinates were calculated using the "center-of-gravity" approximation:

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

where n is the cluster width, x_i and A_i are the coordinate and amplitude of the signal of the lighted strip respectively, x_c is the "center of gravity". This approximation, however, cannot be used with clusters near the edge of a detector. In this case our approximation gives false result and the hit is assigned to the maximum of the cluster. The typical cluster width is 2-3 strips per cluster (Figure 8).

3 GEM position alignment on tracks without magnetic field

In order to make position alignment, track segments were built using the following algorithm. Firstly, segment candidates consisting of 3 hits in X strip layers from different stations were built. The linear track in X-Z plane was then extrapolated to the remaining stations, and each hit close to the extrapolated track, was added to the track candidate. 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. Tracks with less than 4 hits in X strip layer are considered unreconstructable and therefore are not selected.

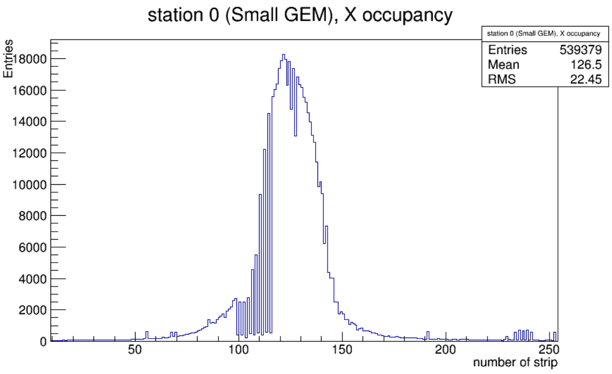
After finding track segment in X-Z plane, Y coordinate for each hit in X+/X- strip layer can be calculated. Using the described algorithm for the Y coordinates of the hits, tracks segments in 3-dimensional space were made. The used hits are then removed and the algorithm is run until all reconstructable tracks are found.

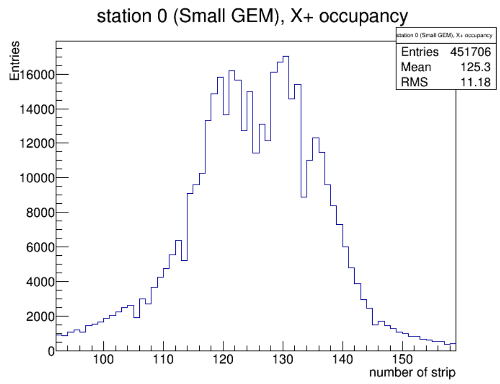
The track segments were then fitted with the 3-dimensional line fit:

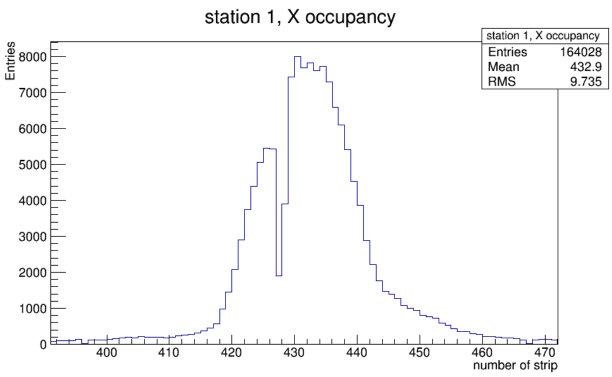
$$x_i = a_x z_i + b_x$$

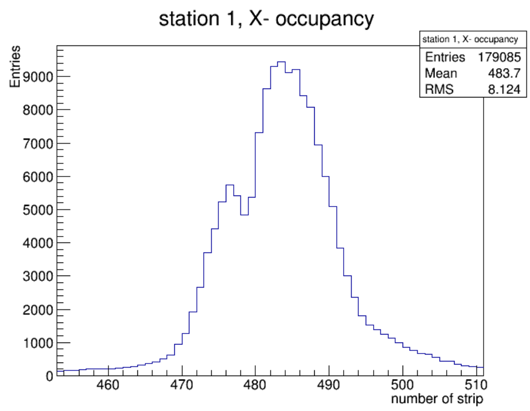
$$y_i = a_y z_i + b_y$$

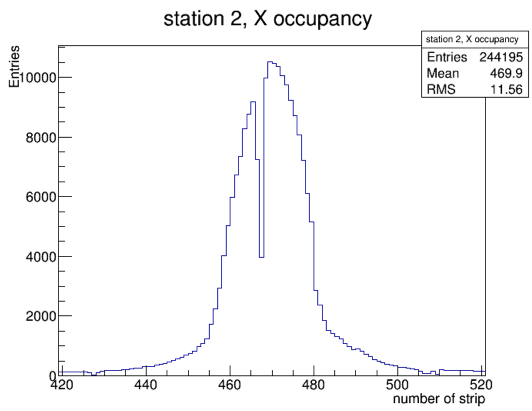
where x_i, y_i, z_i are coordinates of each hit, and a_x, a_y, b_x, b_y are the coefficients. Residuals between fitted coordinate and real hit were then obtained. The fit did not include the hit for which the residual was calculated. The obtained residuals after the alignment are shown in figure 9.

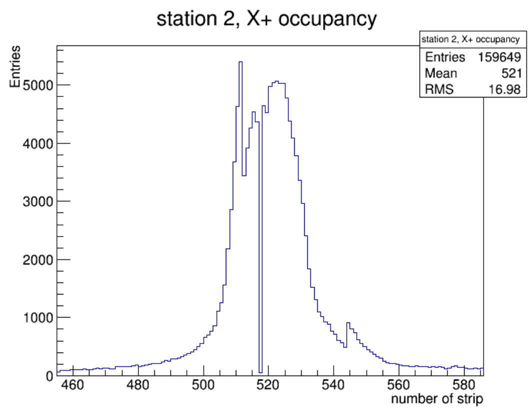

station 0 (Small GEM), X occupancy
Entries 539379
Mean 126.5
RMS 22.45
Entries
number of strip

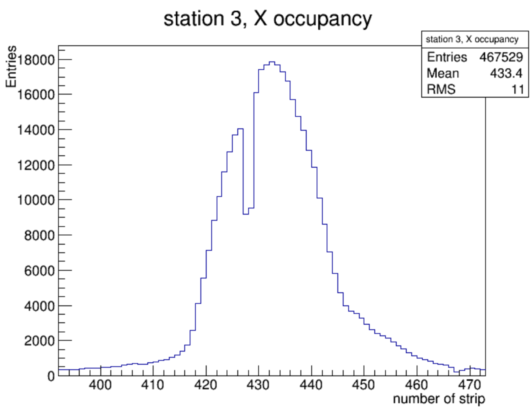

station 0 (Small GEM), X+ occupancy
Entries 451706
Mean 125.3
RMS 11.18
Entries
number of strip

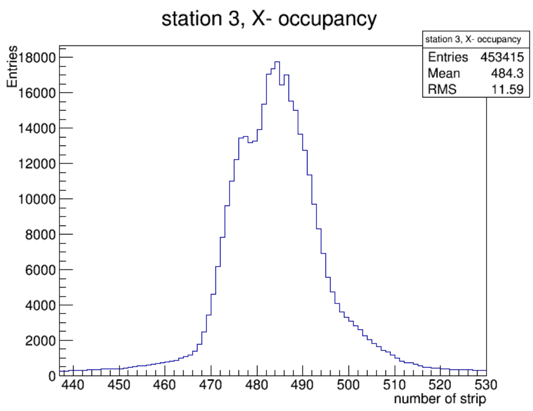

station 1, X occupancy
Entries 164028
Mean 432.9
RMS 9.735
Entries
number of strip


station 1, X- occupancy
Entries 179085
Mean 483.7
RMS 8.124
Entries
number of strip


station 2, X occupancy
Entries 244195
Mean 469.9
RMS 11.56
Entries
number of strip


station 2, X+ occupancy
Entries 159649
Mean 521
RMS 16.98
Entries
number of strip


station 3, X occupancy
Entries 467529
Mean 433.4
RMS 11
Entries
number of strip


station 3, X- occupancy
Entries 453415
Mean 484.3
RMS 11.59
Entries
number of strip

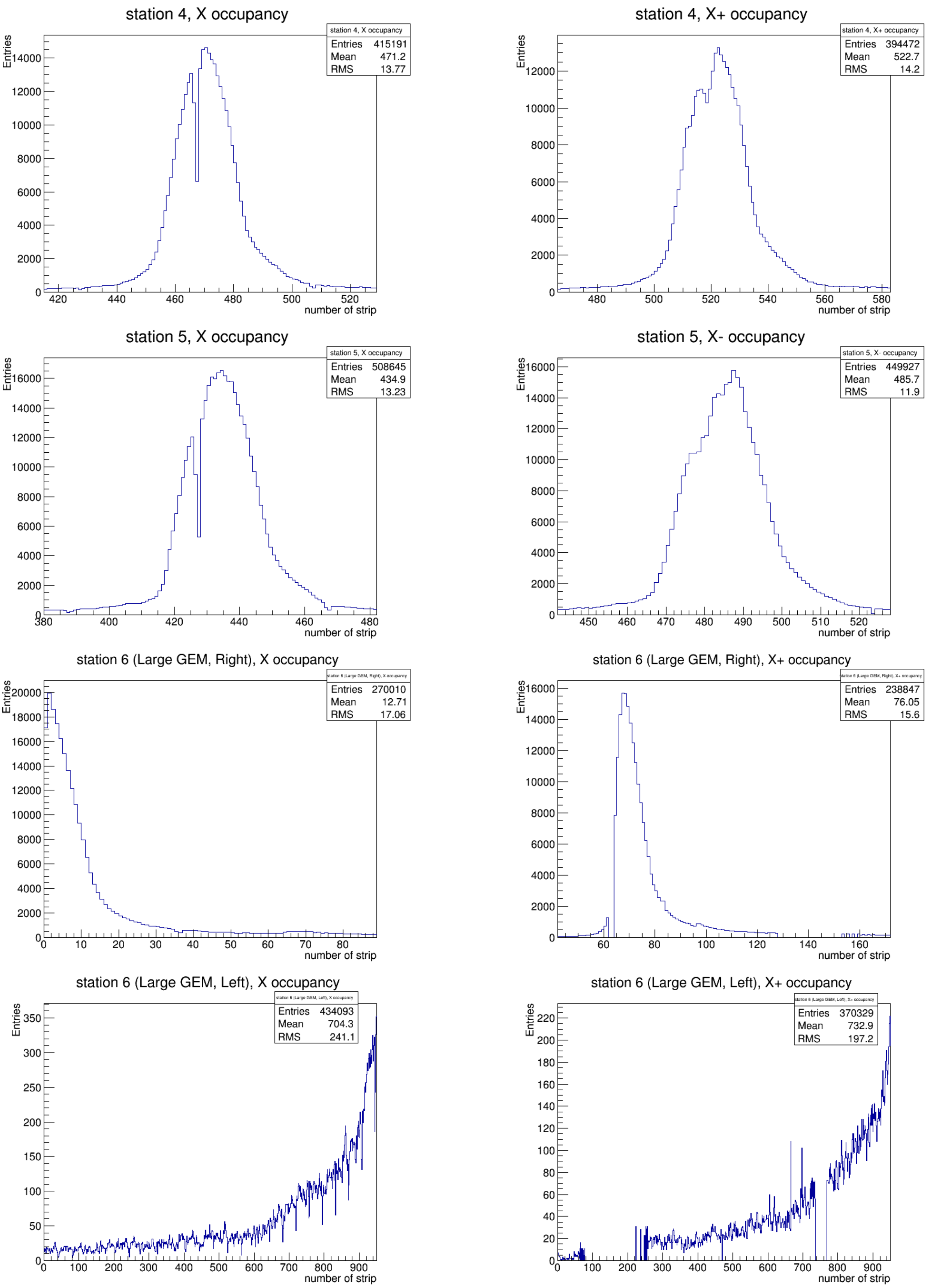


Figure 7. Strip layer occupancies, run without magnetic field

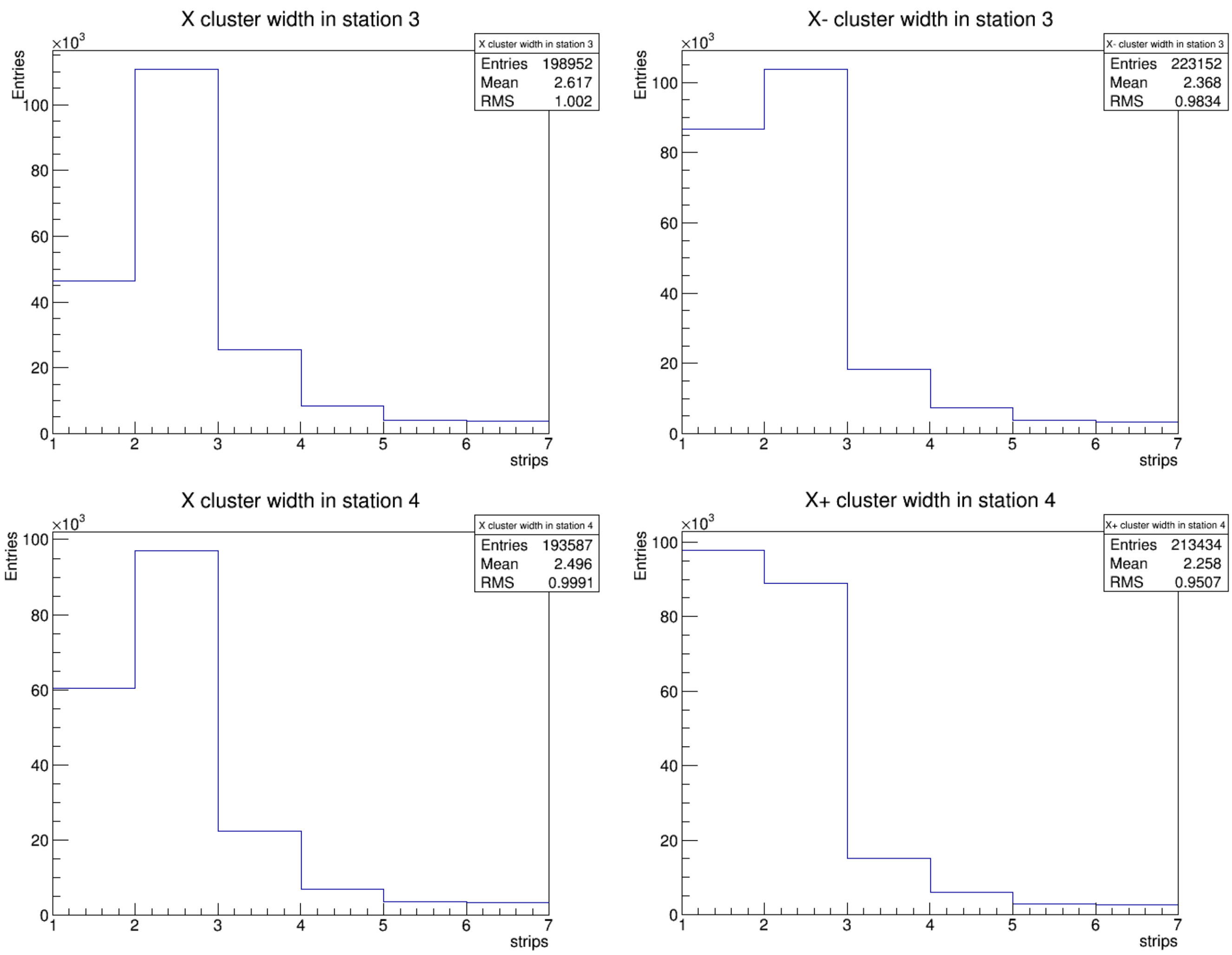
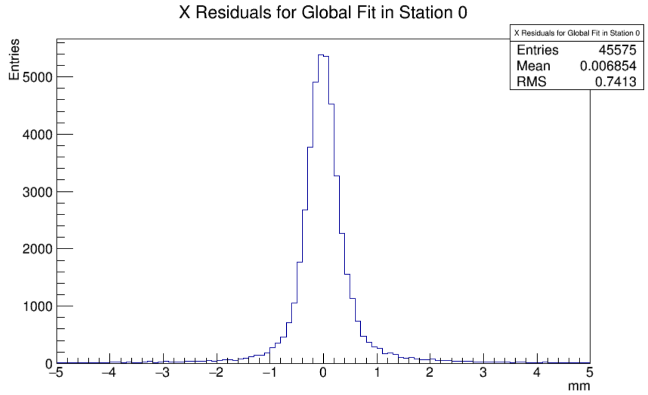
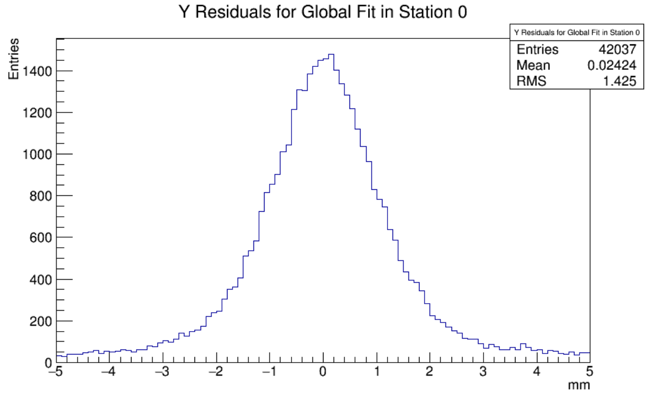
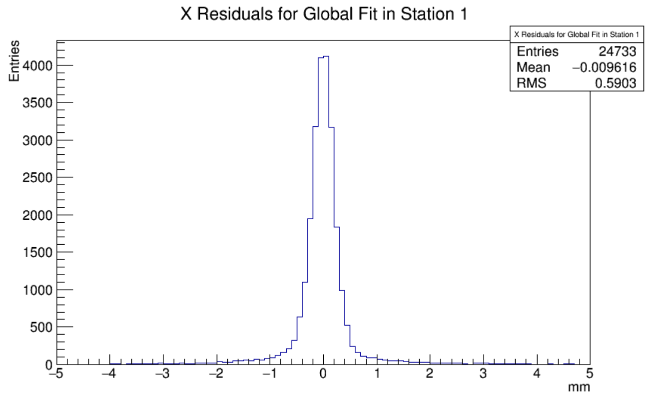
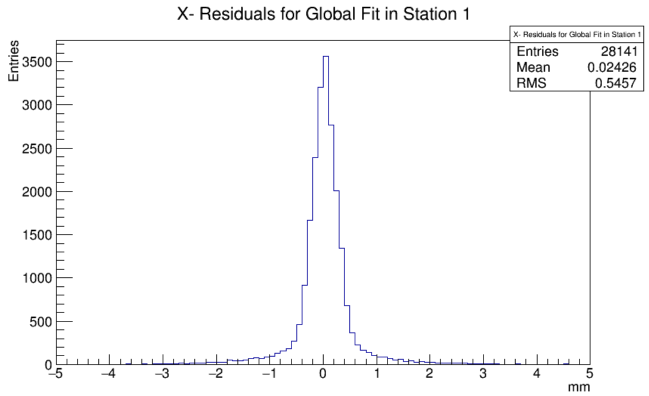


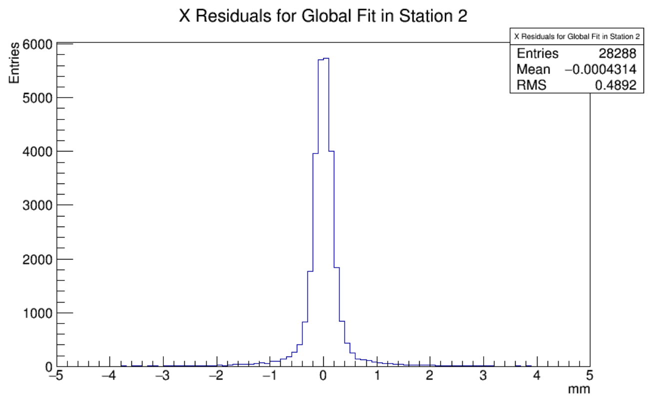
Figure 8. Cluster width in stations 3 and 4

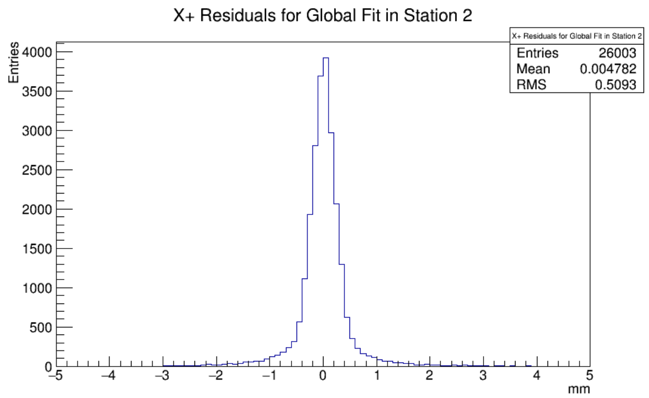


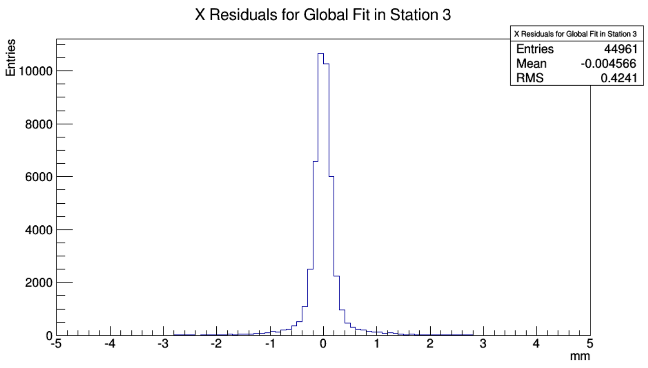


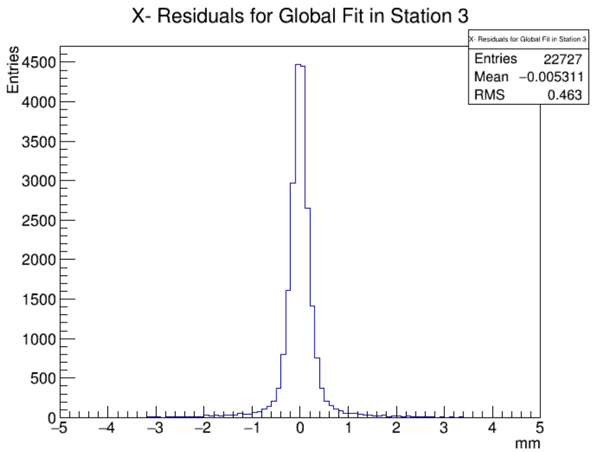












These are the shifts in GEM positions that were applied in addition to experiment geometry (Figure 3):

station	0	1	2	3	4	5	6(R)	6(L)
X shift, mm	-27.77	+0.27	+0.43	-0.20	-0.30	+0.30	-29.19	-27.41
Y shift, mm	-0.34	+1.68	-1.17	+1.00	-0.35	+0.35	-20.65	-23.02

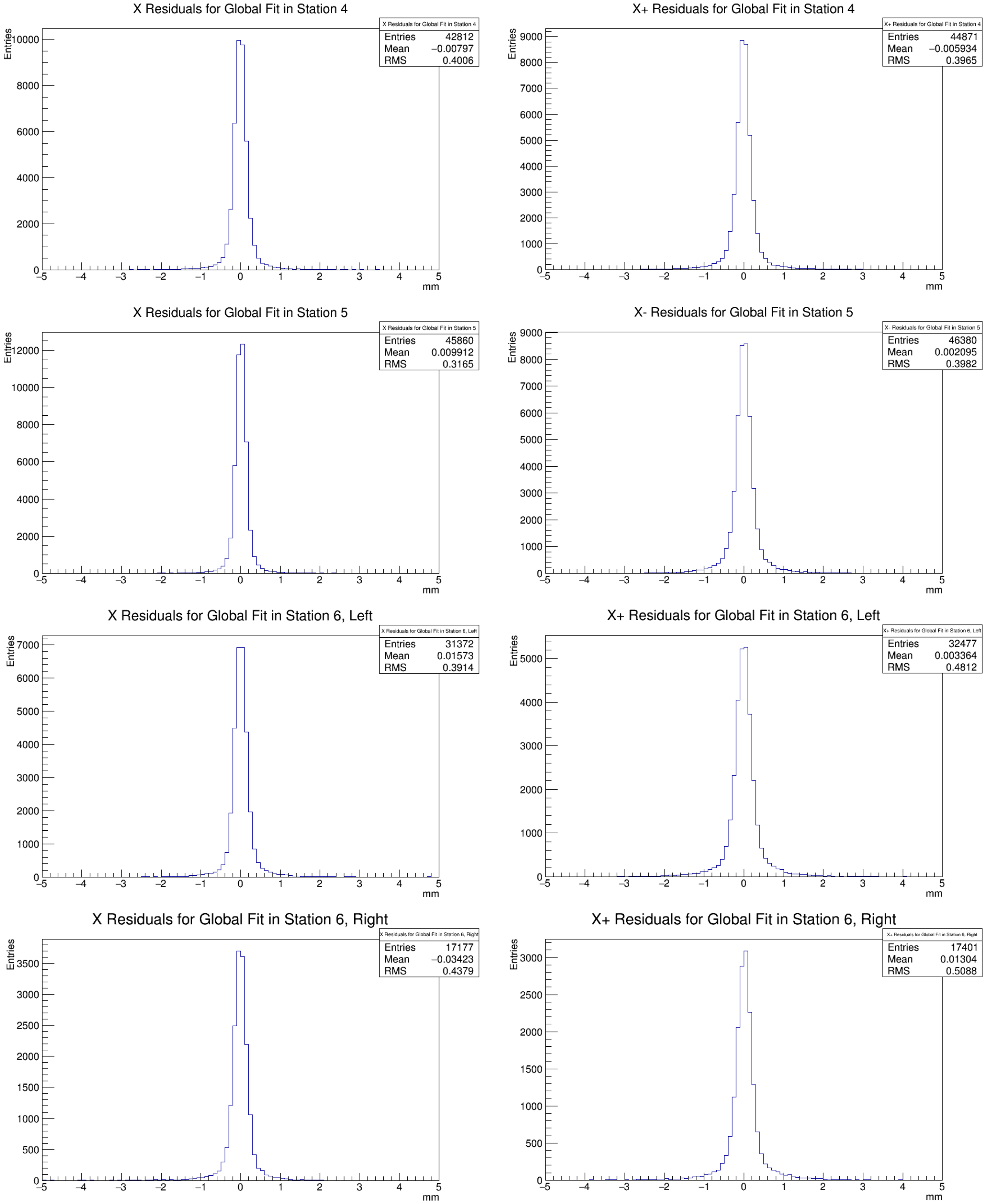


Figure 9. Residuals for alignment on tracks without magnetic field

4 Alignment on events with magnetic field

As we previously discussed in chapter 1, the X coordinate of electron readout is shifted in magnetic field. Thus, we should take it into consideration when performing alignment in magnetic field.

Additionally, the described algorithm of finding track segments should be corrected. After a candidate into track segment is selected, hits are assigned to it according to the road-following algorithm: with the knowledge of existing hits and considering the curvature of the track close to constant, other hits in the expectation region are being picked. Then, among all the track candidates with most hits the one with the lowest value of χ^2/ndf for parabolic 2-dimensional fit is selected. The adding of X+/X- is made analogically to the case with linear tracks. The built track is then fitted using the following 5-parameter approximation:

$$x_i = a_x z_i^2 + b_x z_i + c_x$$

$$y_i = b_y z_i + c_y$$

The magnetic field is significantly inhomogeneous in proximity of 0,1 and 2 stations, thus, only hits in the remaining stations (3,4,5,6) were taken into account while applying the global fit.

The direction of the applied electric field and the direction of the Lorentz shift is opposite for every second GEM detectors. This fact was used in the analysis to estimate the absolute value of the Lorentz shift.

The Lorenz shift was estimated to be about 0.8 mm. Residuals considering this shift are shown in Figure 10.

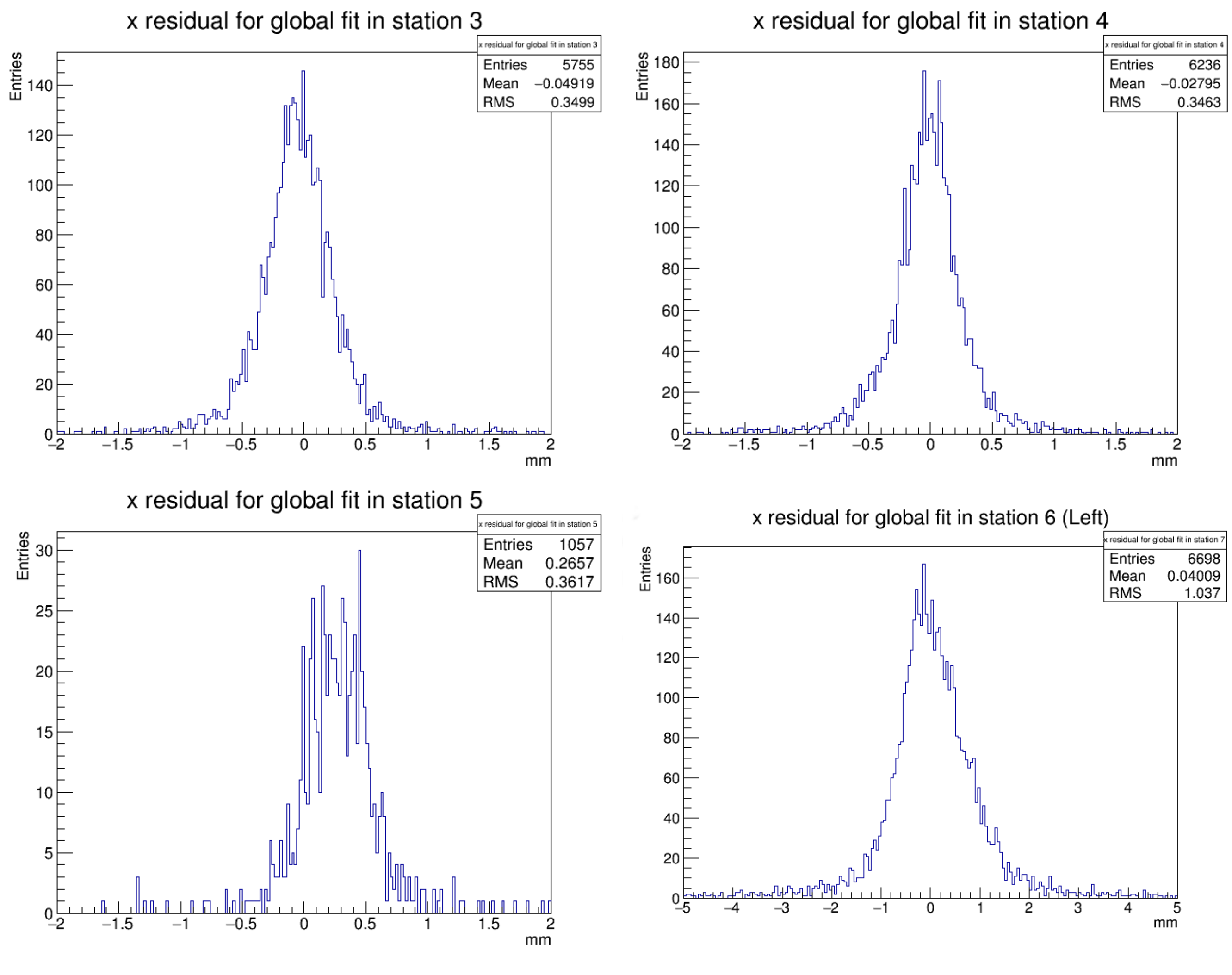


Figure 10. Residuals for alignment in magnetic field

5 Efficiencies

Using the built track segments we calculated efficiency of strip layers of each detector.

In run 65 (without magnetic field and without target) during some periods of time some detectors were disabled (Figure 11) due to trip in the high voltage circuit. Relative low values of the GEM coordinate efficiency are due to the reduced high voltages applied to the GEM detectors in the first run of their operation.

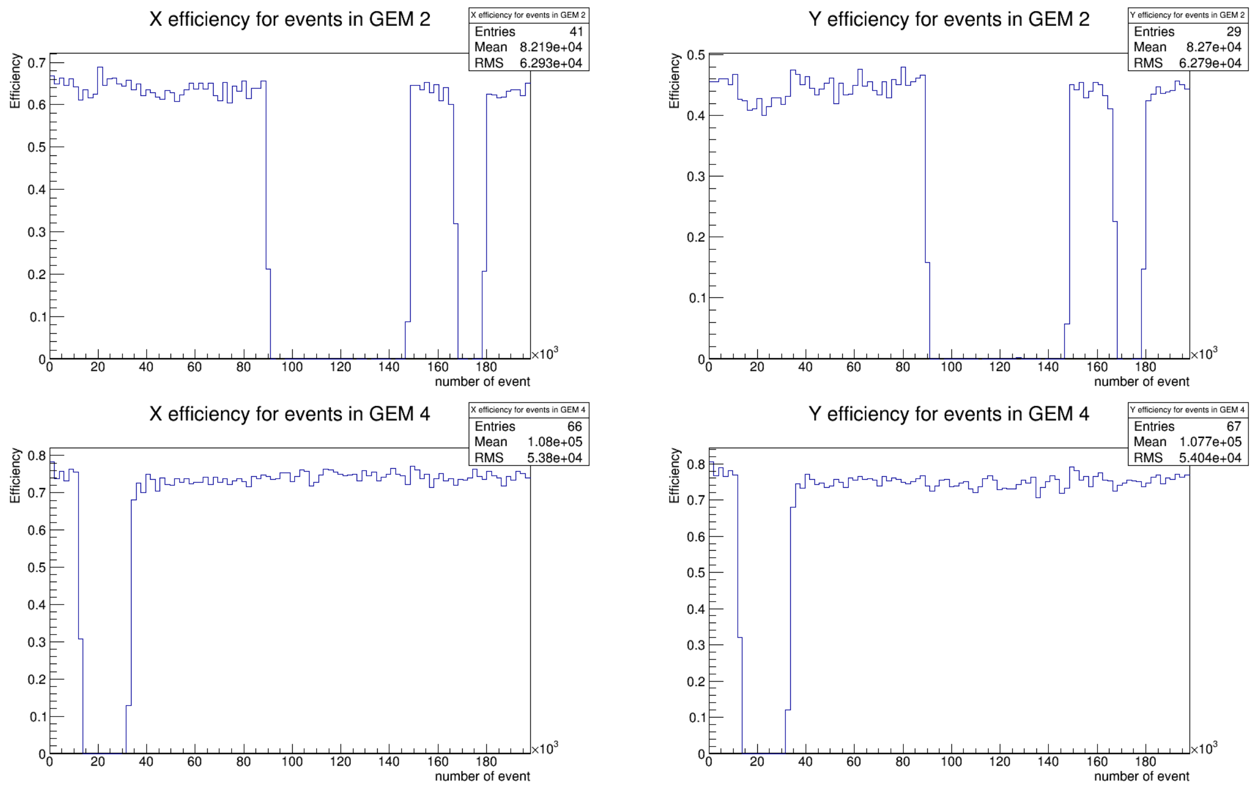


Figure 11. Station efficiency vs. number of event

This was taken into consideration while calculating the efficiencies (Figure 11)

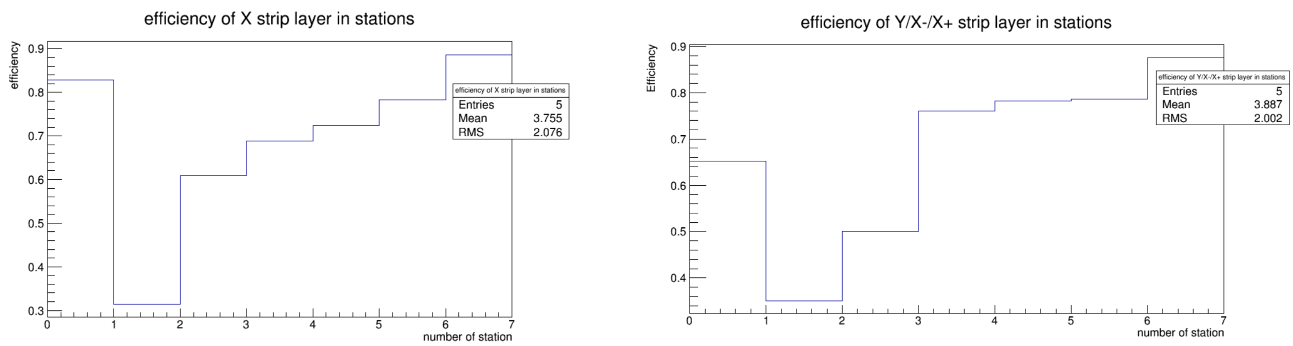


Figure 12. Strip layer efficiencies

6 Discussion

The work on experimental data of technical run described in this report is essential for the preparation for the future runs of the BM@N experiment. The next step will be calculation of the track parameters in runs with magnetic field, mainly momentum of the beam particles. Reconstruction of momentum of incident particles is necessary for obtaining information on production of strange hyperons, which is one of the primary goals of the BM@N experiment.

This work and its continuation is mainly aimed at maximizing the efficiency of obtaining physical results of the future runs. One of the key characteristics of the efficiency of the experiment is track reconstruction efficiency, which, in turn, heavily depends on the algorithms of finding tracks segments, as well as the efficiency of GEMs. Thus, another thing that should be focused on in the future is the algorithm of track reconstruction in an inhomogeneous magnetic field.

Finally, ways of estimating errors should also be reconsidered. For each cluster in a GEM strip layer its coordinate should be calculated as accurately as possible. This can be achieved by considering the distribution of signal amplitudes in the cluster.

Acknowledgements

I would like to thank M.N. Kapishin for inviting me in the Summer Student Programme organized by the JINR University Center. This was an amazing experience for me and I really enjoyed being part of such a great team. Of course, I wouldn't have been able to do this work without guidance of V.V. Paltchik and technical assistance of V.V. Lenivenko. I would also like to thank S. Merts for providing support.

I want to express my gratitude to the University Center of JINR for giving me the opportunity to participate in the Summer Student Programme and the management of Veksler and Baldin Laboratory of High Energy Physics for providing financial support.

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