**JOINT INSTITUTE FOR NUCLEAR RESEARCH**

Veksler and Baldin Laboratory of High Energy Physics


**FINAL REPORT ON
THE START PROGRAMME**

# GEM efficiencies corrections in Monte-Carlo simulation for 4.5 GeV carbon-nucleus interactions at the BM@N experiment


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# Contents

**Abstract**

Heavy ion collisions at high energies provide a unique opportunity to study the nuclear matter under extreme density and temperature. These extreme conditions are well suited to the investigation of the compressibility of the nuclear matter, in particular, the stiffness of the nuclear equation-of-state (EOS). The theoretical models suggest different possible scenarios for these modifications, so that new experimental data with high resolution and statistics are needed in order to disentangle the different theoretical predictions. The BM@N experiment (Baryonic Matter at the Nuclotron) aims to studying collisions of the elementary particles and ions with fixed targets. In such heavy ion collisions, nucleons are excited to baryonic resonances, which decay by the emission of lighter baryons and mesons. In this report, it was considered the Run-6 data processing of the BM@N experiment at 4.5 GeV beam energy. The data taking was prepared on the carbon (C) beam with four fixed targets: C, Al, Cu, Pb. The main task of the current work was to apply the calculated efficiencies of the GEM detectors from the physical data to the Monte-Carlo (MC)simulation by using the same method as it was done for the 4.0 GeV beam energy MC dataset. It is a necessary step for the preparation of the MC simulation which will be in good agreement with the data for future analysis flow.

# 1 Introduction

The research program on heavy-ion collisions at the Nuclotron of the Joint Institute for Nuclear Research includes investigation of the reaction dynamics and nuclear EOS, study of the in-medium properties of hadrons, production of (multi)- strange hyperons at the threshold and search for hyper-nuclei. The BM@N experiment is the first experiment which was held at Nuclotron. It is schematic 3D-view of BM@N setup are presented on Fig.2. BM@N aims at studying collisions of the elementary particles and ions with a fixed target at energies (laboratory system) up to 4 GeV per nucleon (for $^{79}$Au) [1]. The BM@N facility is one of the main element of the first stage of the NICA collider complex development (Fig.1) to study hot and dense matter in heavy ion collisions.

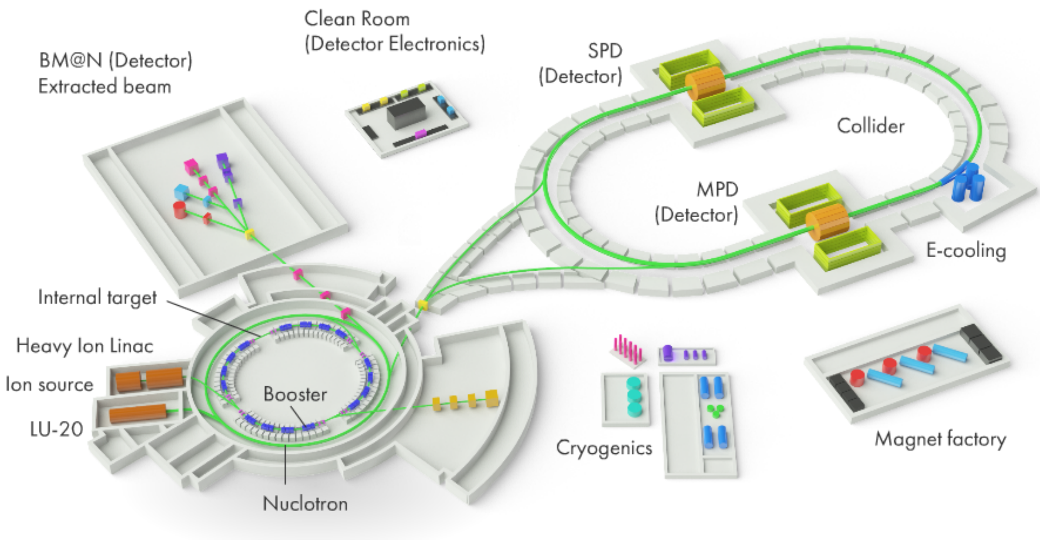


Figure 1: NICA collider complex at JINR

In Run-6 the configuration of thr BM@N setup consists of a large-acceptance dipole magnet with a magnetic field up to 1.2 T. Inside the magnet a target is placed and along with it there are inner tracking detector modules based on one plane of a forward silicon detector (Si) and 6 GEM (Gas Electron Multiplier) detector stations. The outer tracking module consists of Drift Chambers (DCH), Time-of-Flight detectors (TOF), Cathode Strip Chamber (CSC) and ZDC (Zero-Degree Calorimeter) to identify and measure the particles [2–4]. The GEM is a type of gaseous ionization detector which collects electrons released by ionizing radiation, guiding them to a region with a large electric field, and thereby initiating an electron avalanche.

For Run-6 of BM@N, the magnetic field at the center of the analyzing magnet was 0.61 T and the tracking stations were arranged so that the beam passed through their centers (Fig.2). The 6 GEM stations were combined from 5 GEM detectors with the size of 66×41 $cm^2$ and 2 GEM detectors with the size of 163×45 $cm^2$.

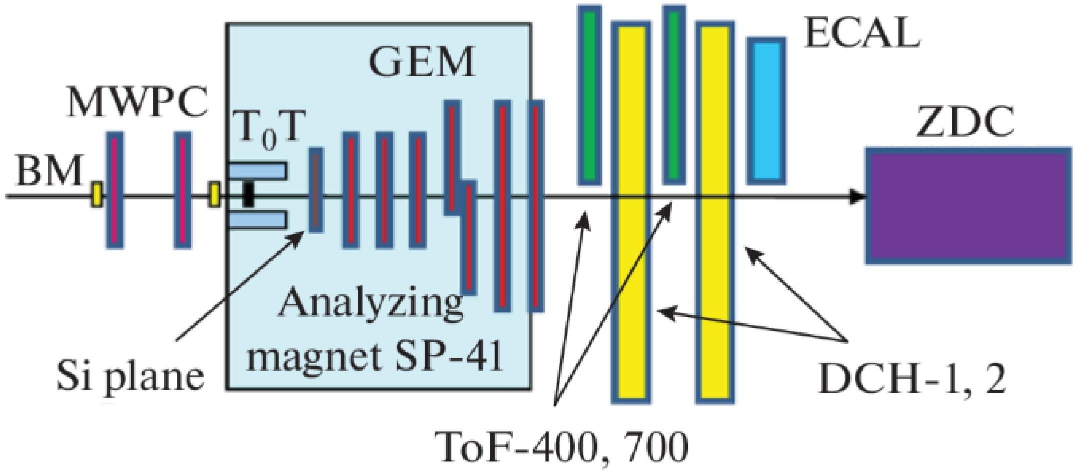


Figure 2: Schematic view of the BM@N setup in the carbon beam run (RUN 6)

# 2 GEM efficiencies analysis for the Run-6 at energy 4.5 GeV

This Run-6 was performed on a carbon (C) beam with various fixed targets, respectively, reactions C+C, C+Al, C+Cu, C+Pb at collision energies of 4.0 and 4.5 GeV. Below, all studies will be presented for the energy 4.5 GeV. The main goal of the Run-6 analysis is to measure the yields of $\Lambda^0$ hyperons and compare the obtained results with theoretical models. The main task of the current work consists of analyzing of the GEM detectors efficiencies in physical and MC datasets, comparison and applying necessary efficiencies corrections from the data to MC simulation for the MC/data matching.

## 2.1 GEM efficiencies in physical data

To obtain the GEM detector efficiencies from the physical data we used the BmnRoot framework script which on output make a set of reconstructed tracks' dataset for each of the 6 GEM detector planes. The selection cut for "good" selected tracks was 3>= hits per track in GEM detectors planes. After each GEM plane was divided into 180x45 cells (along X & Y coordinates) and at the output of script the efficiencies in each cell was recorded in file. For working we had two main script throughout the process(and this was the case for every generated data files, this is because of the big number of files we are working with). The first script mainly contained the location of the input, output data and the C++ script which passed input and output data locations, the second script contained the number of runs for every target during the process. we passed every run number to the first script that must be processed. Data for all targets were processed for every GEM station. Then we need to unite the data from every run number for every station. Two-dimensional efficiencies distributions for 6 GEM stations measured with experimental tracks for different targets are presented on Figs.[3-6].

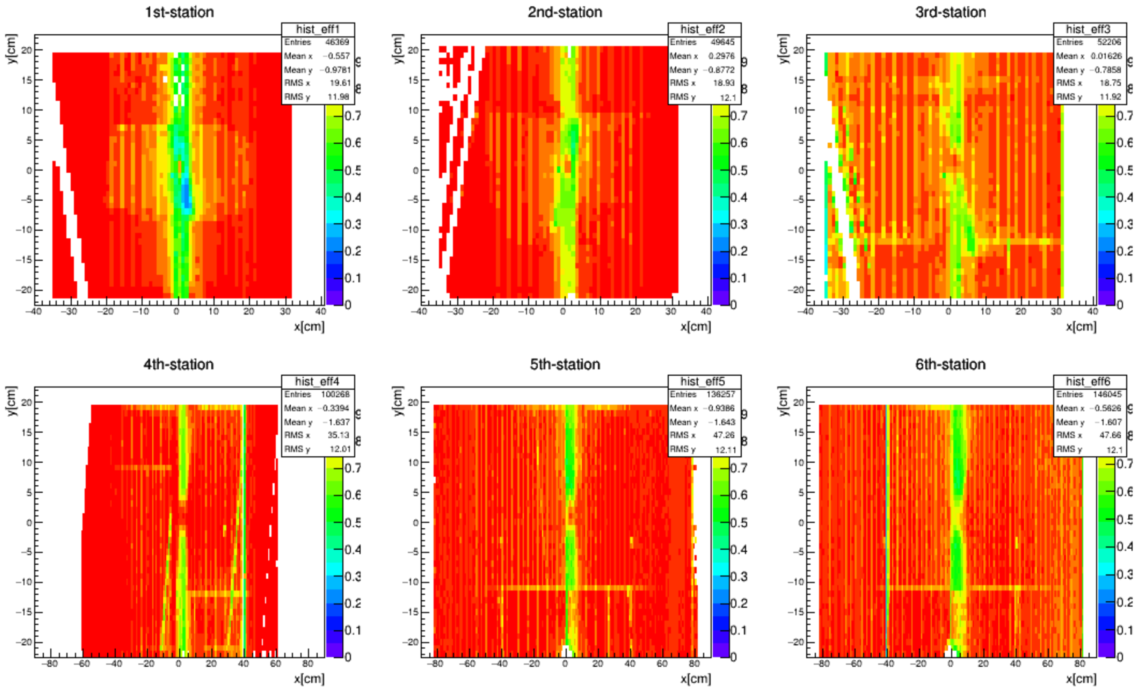


Figure 3: 2-D X/Y DATA efficiency distribution in 6 GEM stations for C+Al

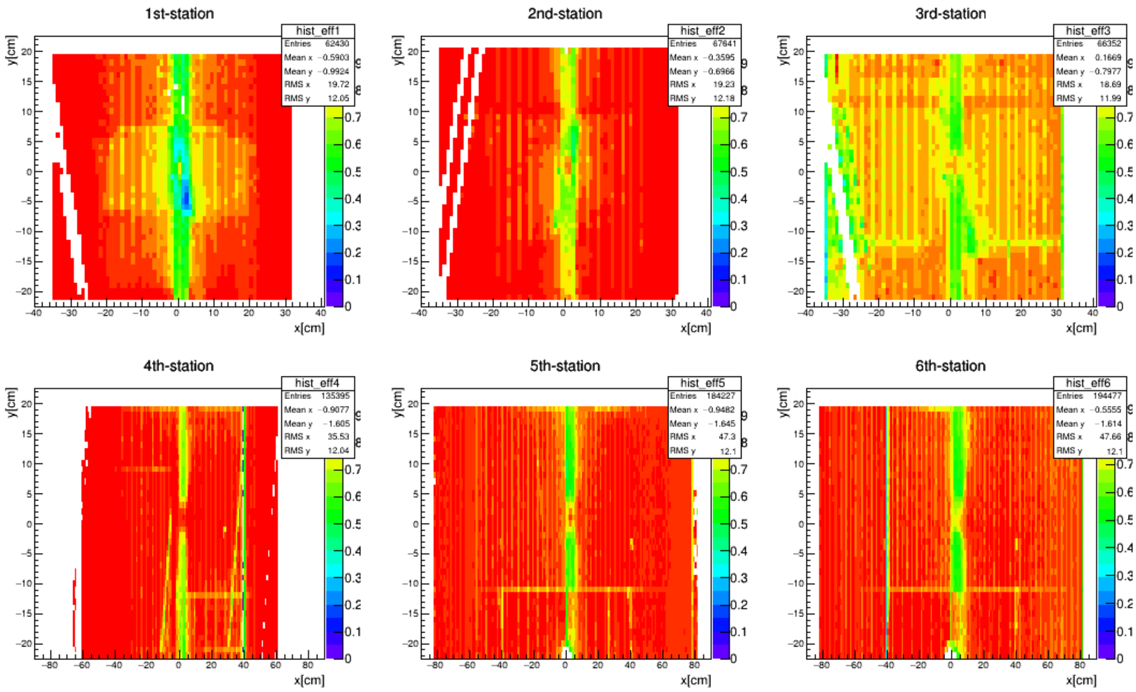


Figure 4: 2-D X/Y DATA efficiency distribution in 6 GEM stations for C+Cu

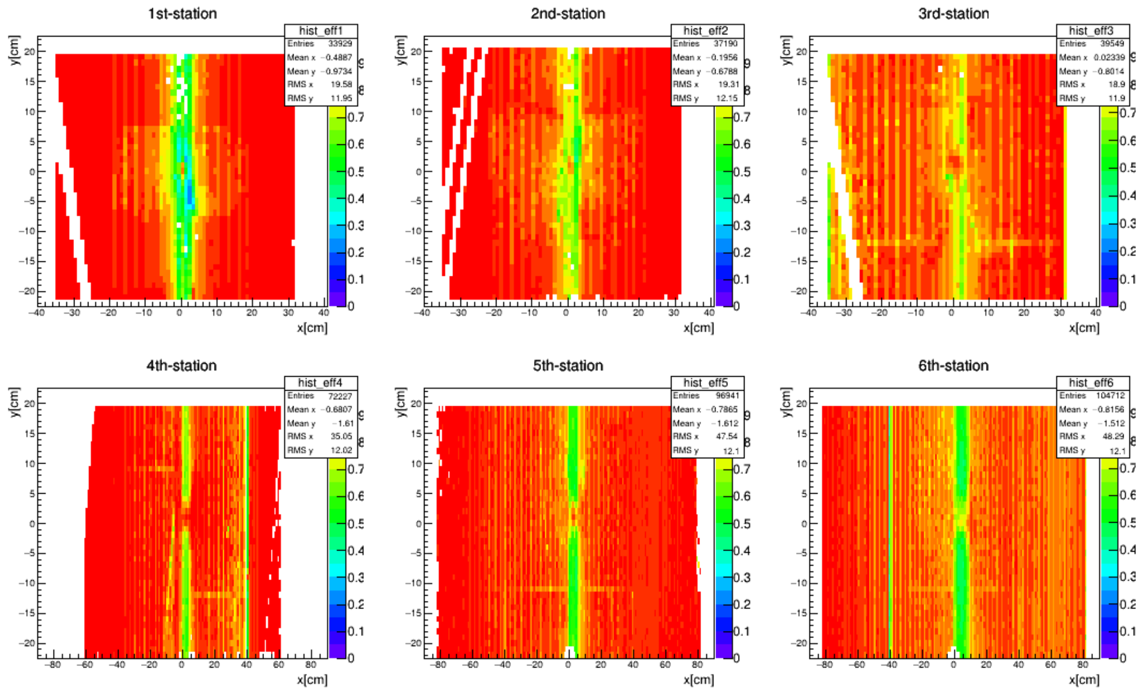


Figure 5: 2-D X/Y DATA efficiency distribution in 6 GEM stations for C+C

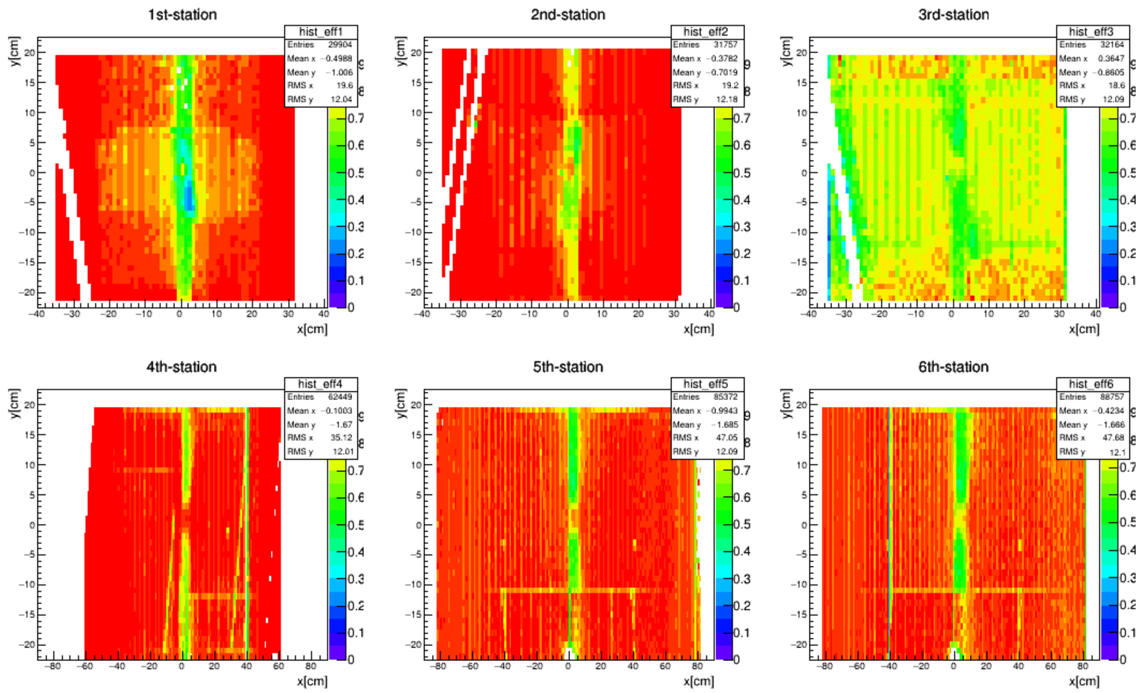


Figure 6: 2-D X/Y DATA efficiency distribution in 6 GEM stations for C+Pb

## 2.2 GEM efficiencies in Monte-Carlo sample

The Monte Carlo event samples of C+A collisions were produced with the DCM-QGSM event generator. The passage of particles through the setup volume was simulated with the GEANT4 program integrated into the BmnRoot software framework. To speed up the simulation, dependencies of the Lorentz shifts and the charge distributions on the readout planes on the drift distance were parameterized and used in the GEM digitization part of the BmnRoot package.

To work with generated Monte-Carlo data we need the same thing as we did in case of data, we need two scripts. But in MC we don't have a run number, instead we have a set of 50 files for every target. The 2-D X/Y distributions of GEM efficiencies for MC sample for 4 different targets are presented on Figs.[7-10].

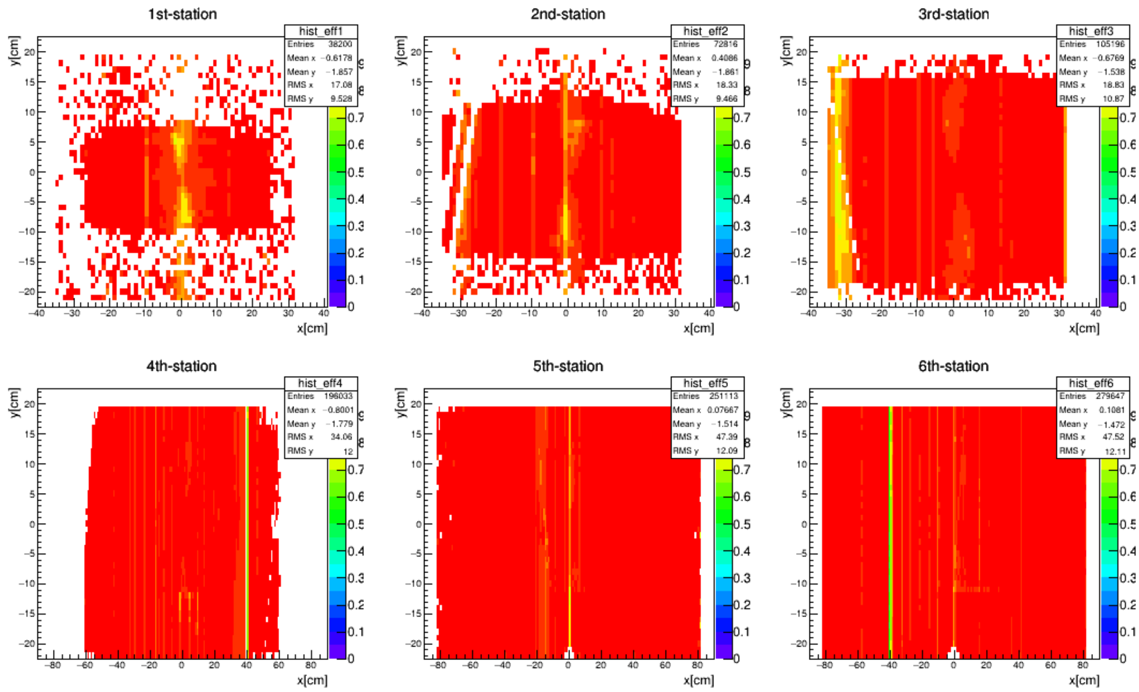


Figure 7: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Al

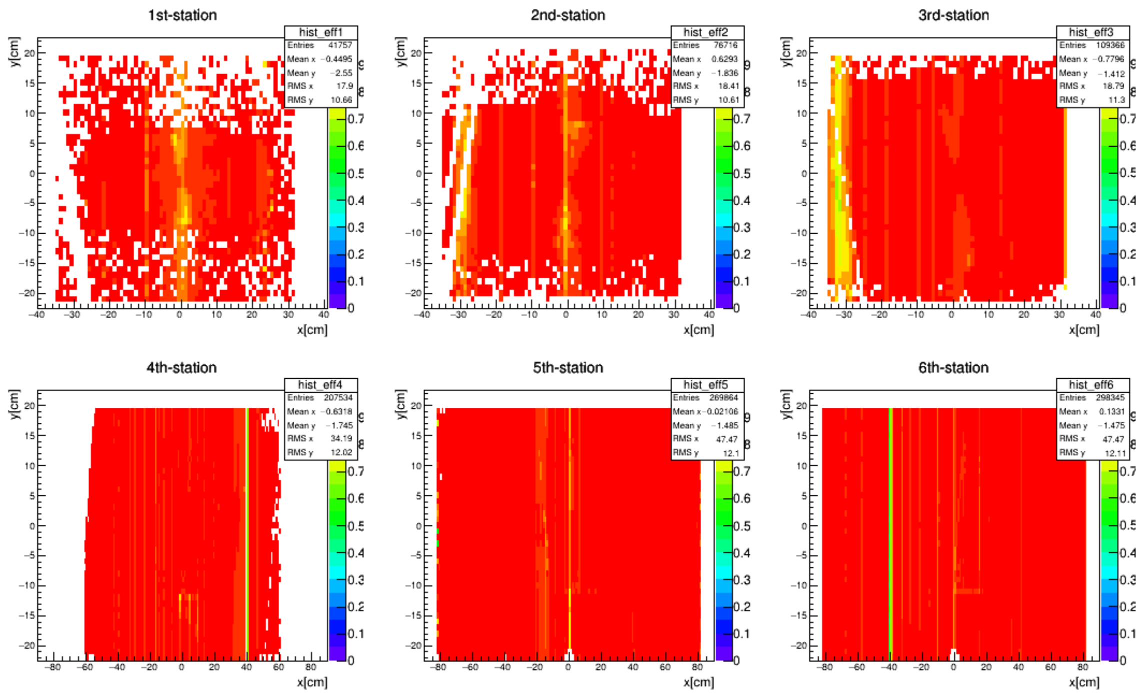


Figure 8: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Cu

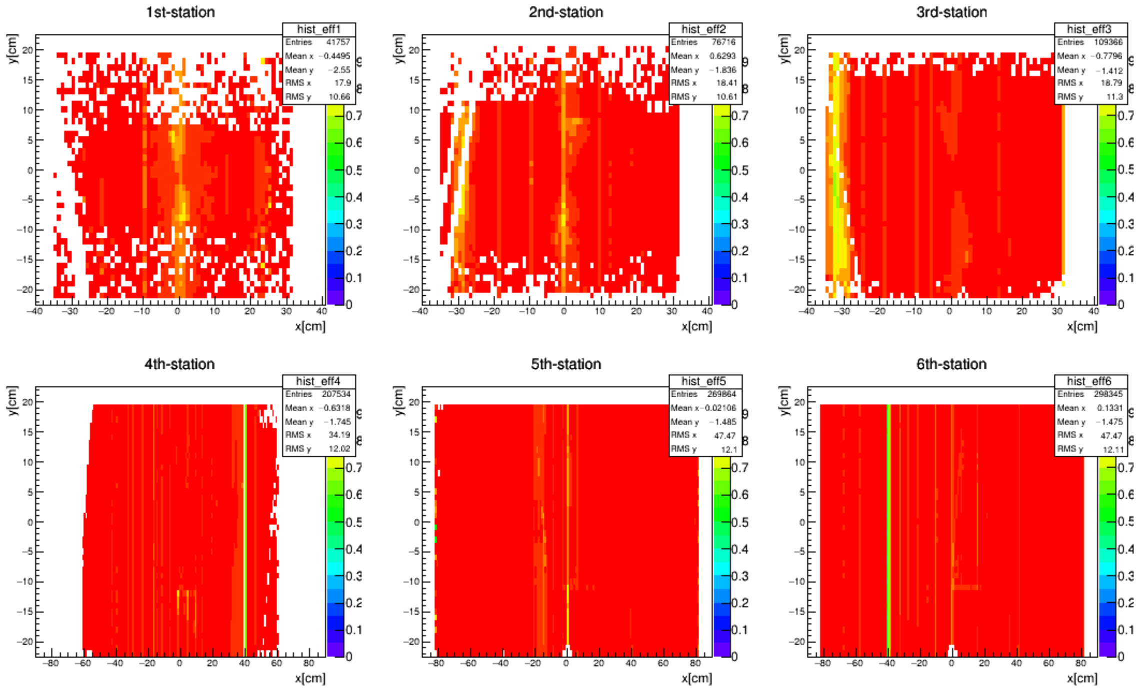


Figure 9: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+C

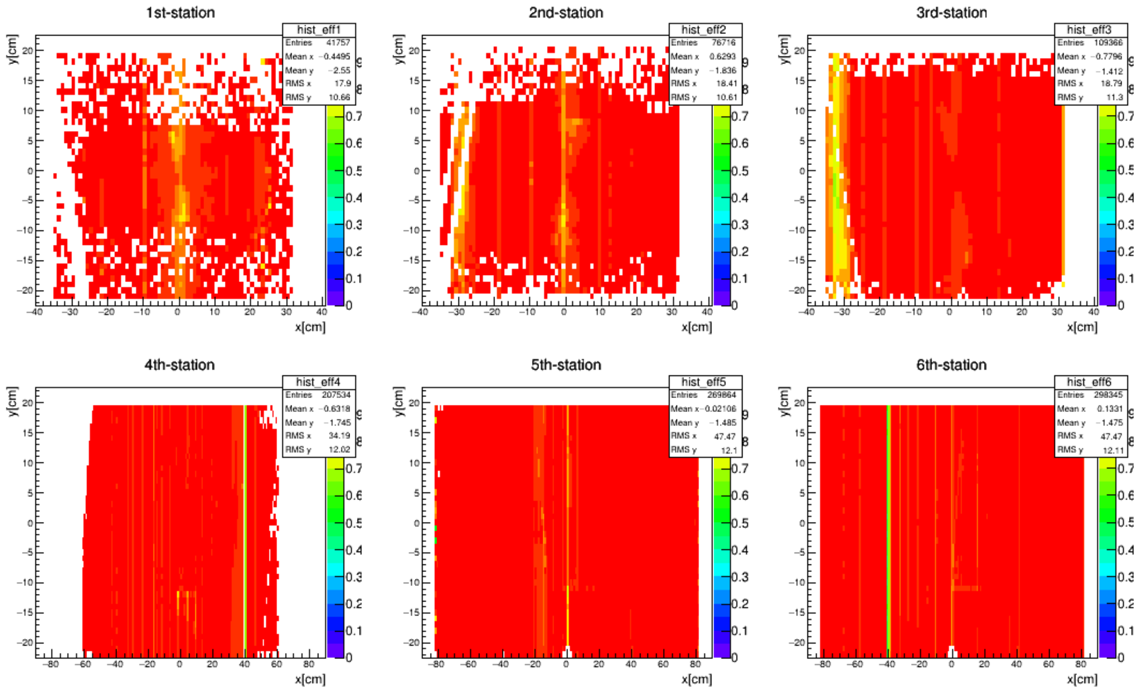


Figure 10: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Pb

## 2.3 Integral efficiencies distributions for MC/data comparison

As we can see from the Figs.[3-10] the GEM efficiencies in MC dataset don't correspond to the efficiencies in data for the relevant targets. To get better information readability for the MC and data efficiency distributions comparison, the 1-dimensional integral (along X-axis) for each GEM station for each target was calculated and plotted on Figs.[11-14]. MC efficiencies are shown in red lines, data in blue. All distributions were normalized for each bin. Comparing the MC efficiencies with data, we will notice that in the MC simulation efficiencies are more idealized in comparison to the physical data.

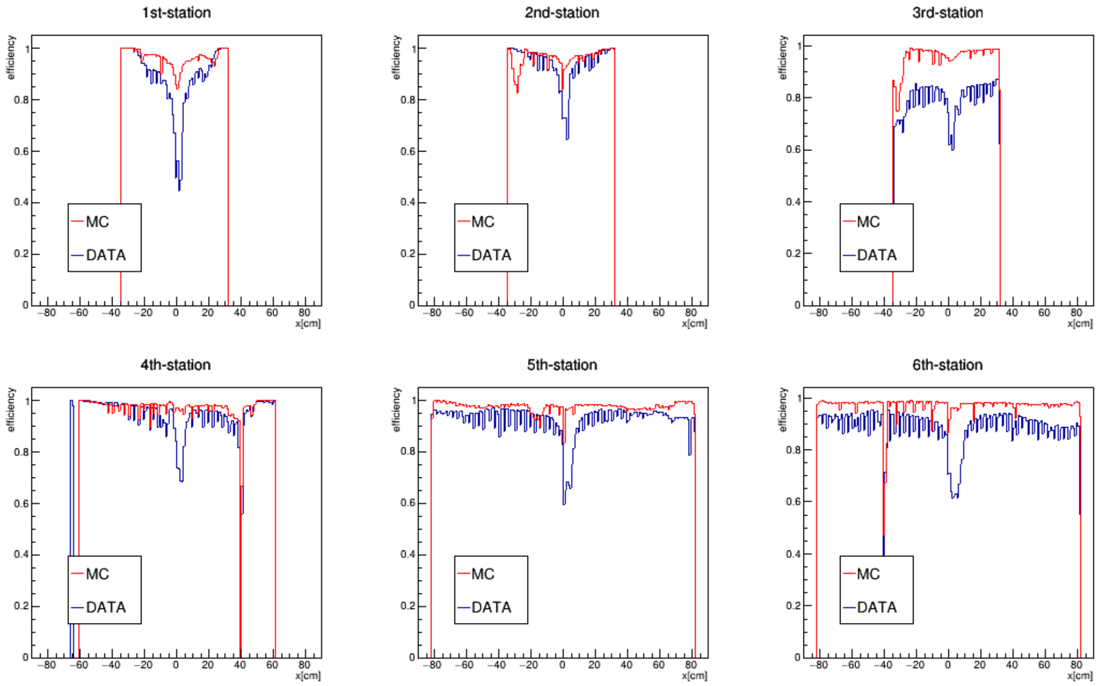


Figure 11: MC (red) and Data (blue) 1-D efficiency distributions for C+Al

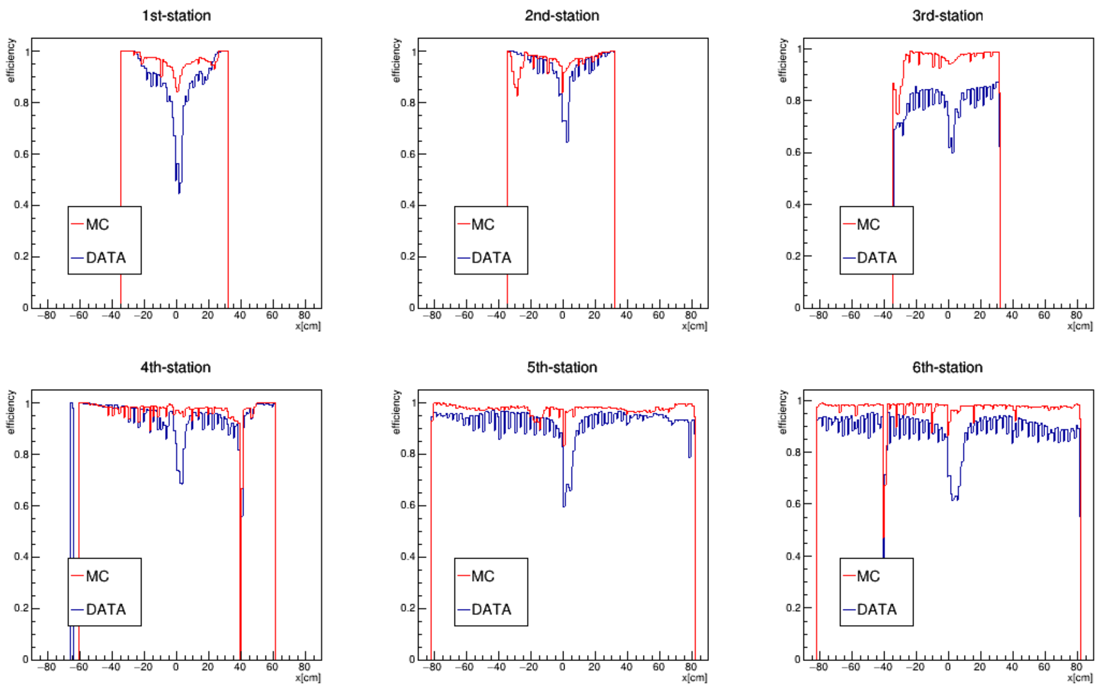


Figure 12: MC (red) and Data (blue) 1-D efficiency distributions for C+Cu

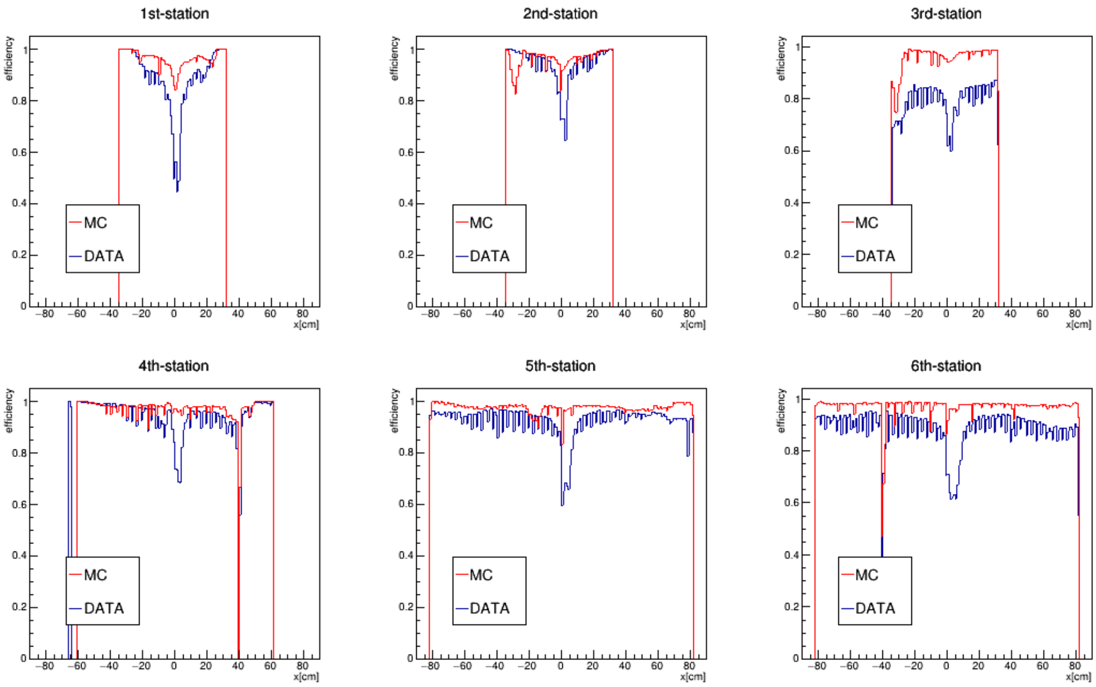


Figure 13: MC (red) and Data (blue) 1-D efficiency distributions for C+C

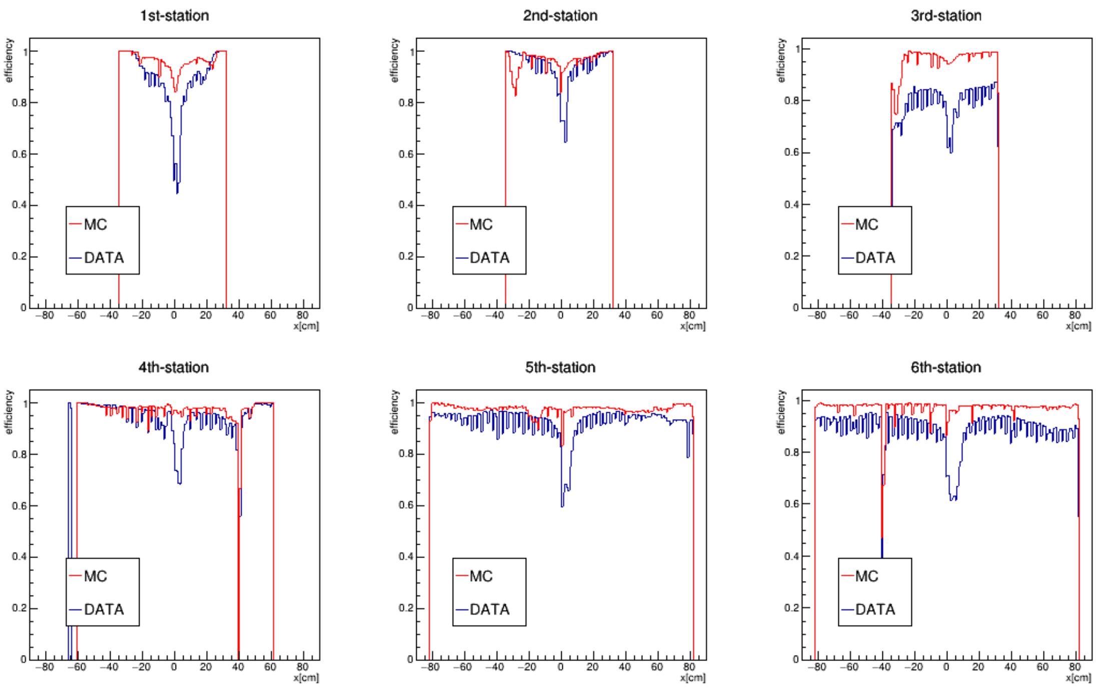


Figure 14: MC (red) and Data (blue) 1-D efficiency distributions for C+Pb

## 2.4 GEM efficiencies corrections

For a good agreement between data and Monte-Carlo data sets, we must apply the same values of efficiencies from the data to the MC. For this task, BmnRoot code was modified using the same algorithm for applying corrections which was used for the MC simulation data at 4.0 GeV beam energy. This algorithm is an iterative method for applying corrections. As a result of this approach, two iterations of corrections were made, the results of which are presented on the Figs.[15-18] for different targets. Here, 1-dimensional plots are presented. Red line corresponds to the MC data without any efficiencies corrections, green line corresponds to efficiencies after first iteration of corrections and the blue one corresponds to the results after the second iteration of efficiency corrections. Data corresponds to the dark green line.

As we can see that the efficiencies in Monte-Carlo samples after the second iteration are close enough to data. To check this, the 2-D X/Y distributions after the second iteration of the correction procedure for MC data were plotted (Figs.[19-22]) and compared with efficiencies obtained from the data (Figs.[3-6]).

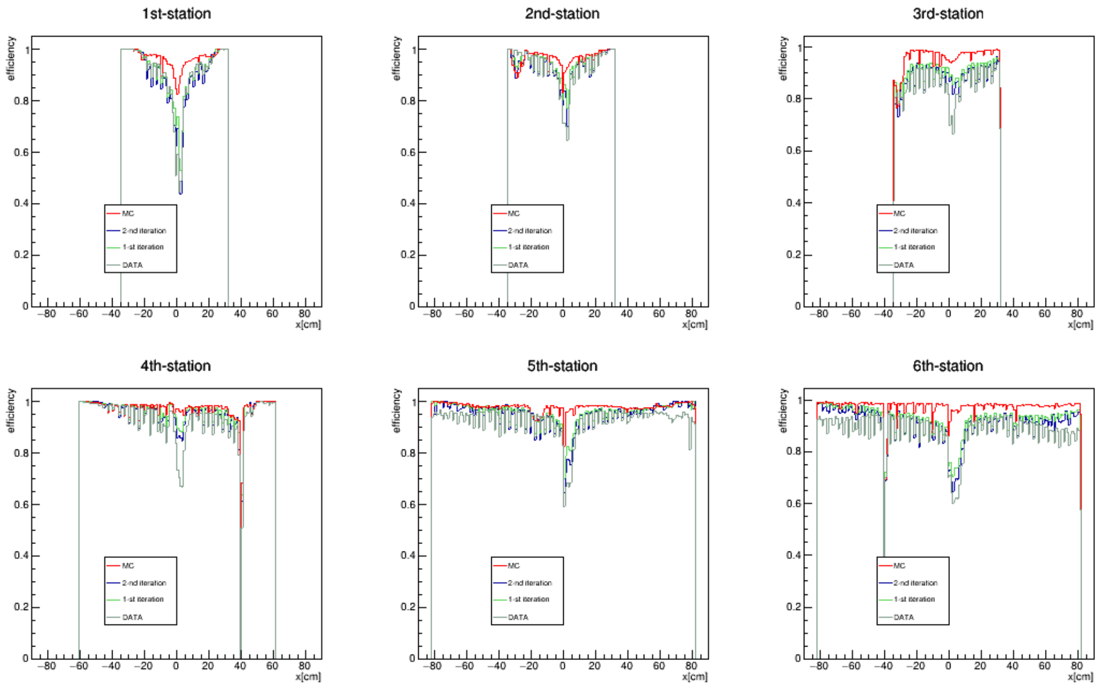


Figure 15: 1-D efficiency distributions in 6 GEM stations for C+Al

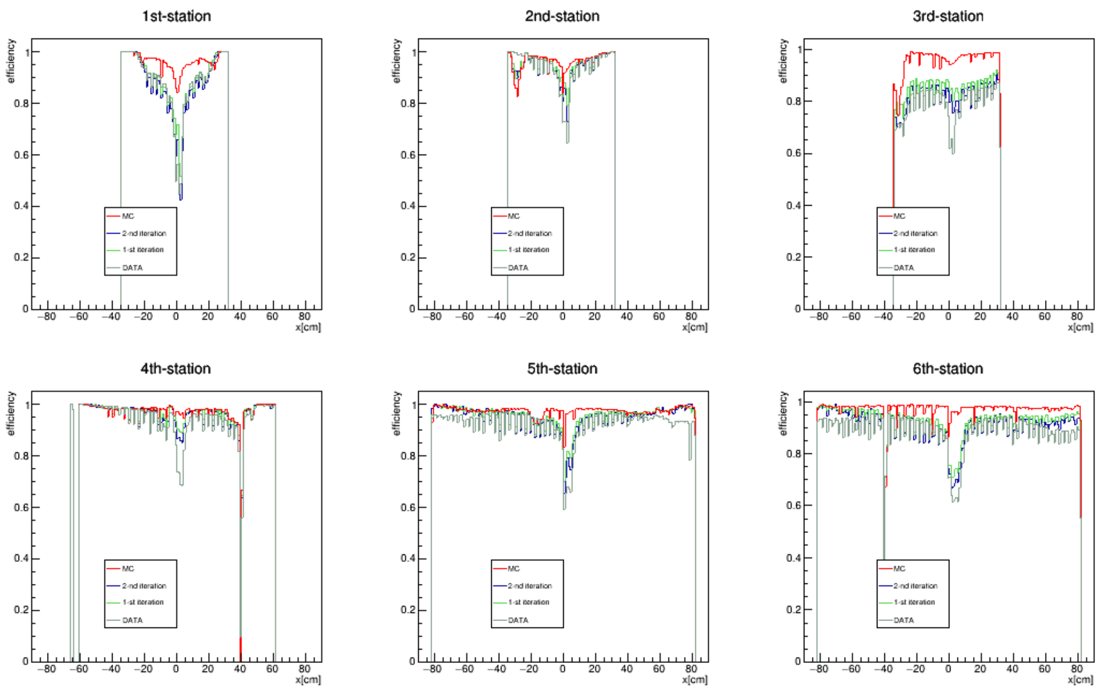


Figure 16: 1-D efficiency distributions in 6 GEM stations for C+Cu

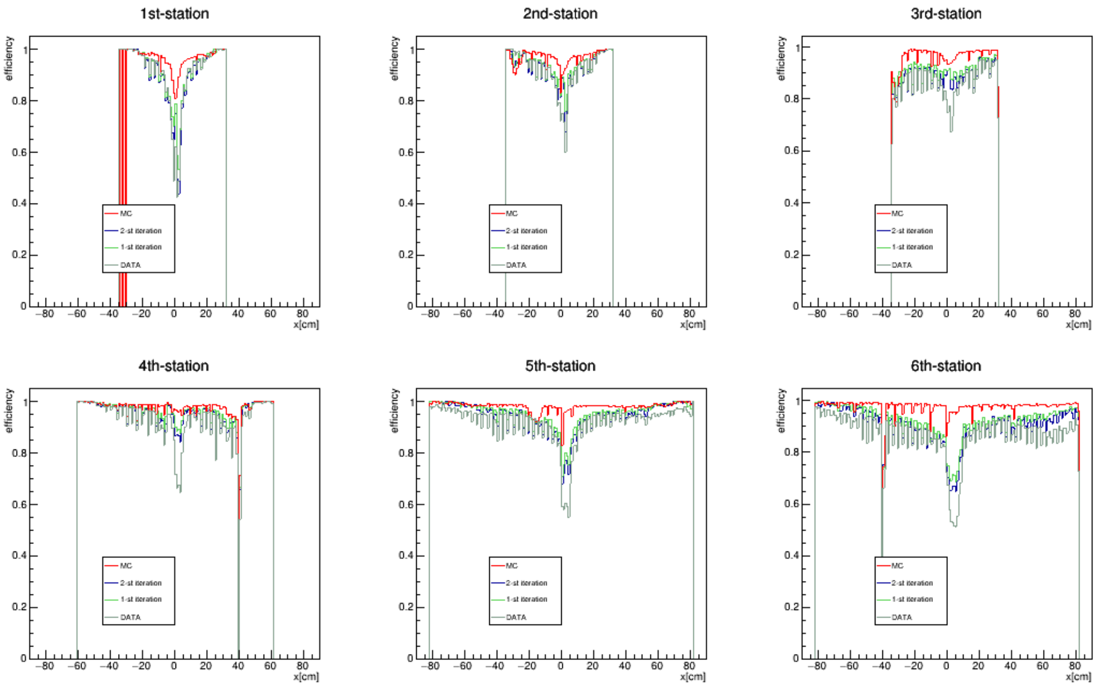


Figure 17: 1-D efficiency distributions in 6 GEM stations for C+C

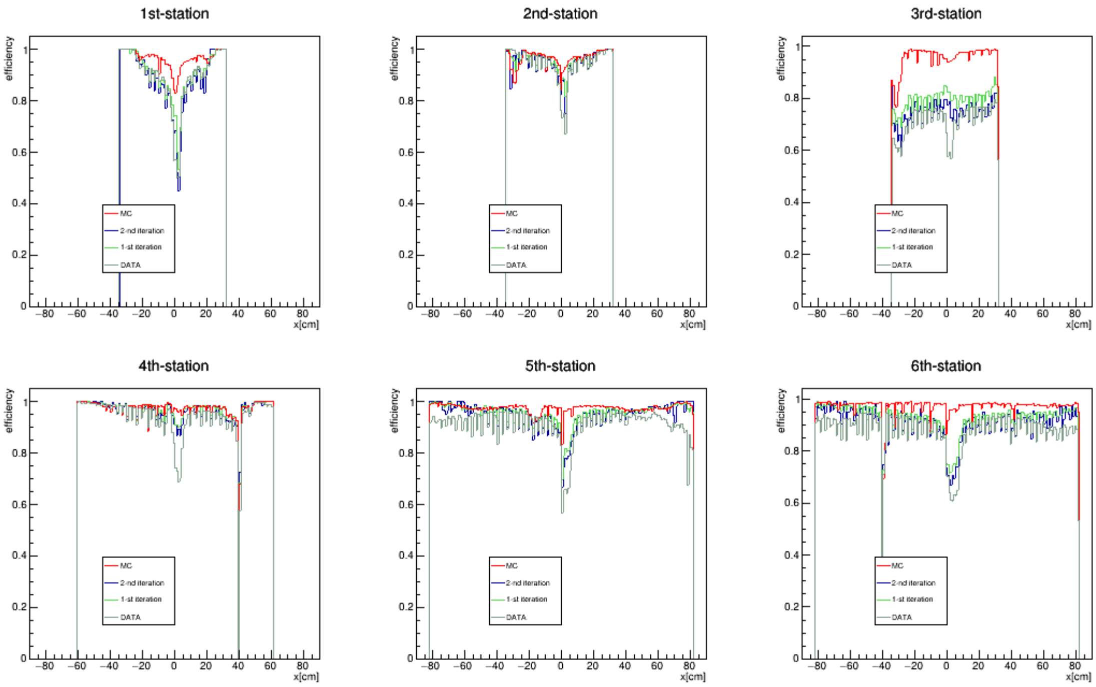


Figure 18: 1-D efficiency distributions in 6 GEM stations for C+Pb

After the second correction, the third iteration step of correction procedure was done checking for convergence of the applied method. The obtained result shows that further iterations of the method don't give much improvement to the final result.

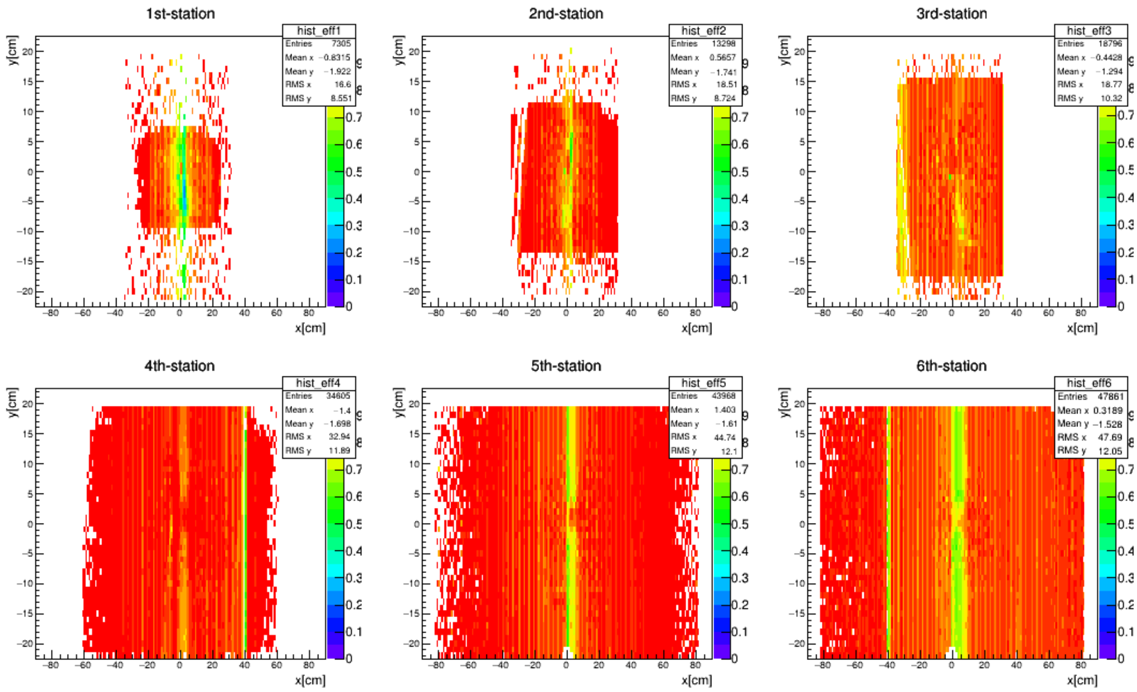

Figure 19: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Al

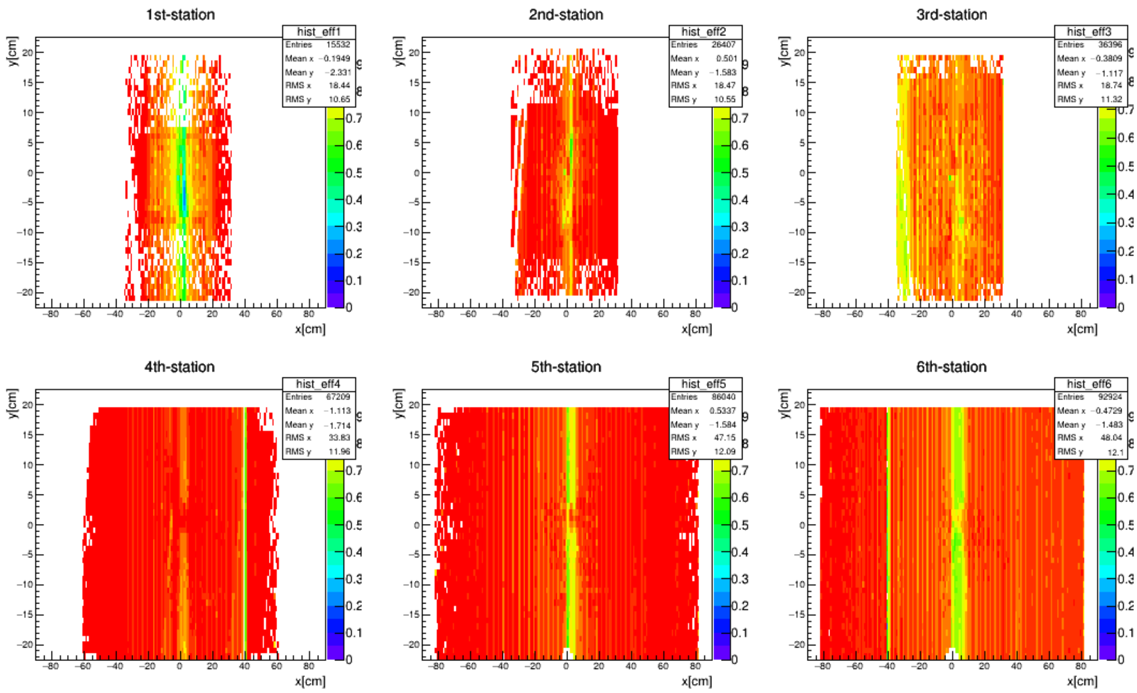

Figure 20: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Cu

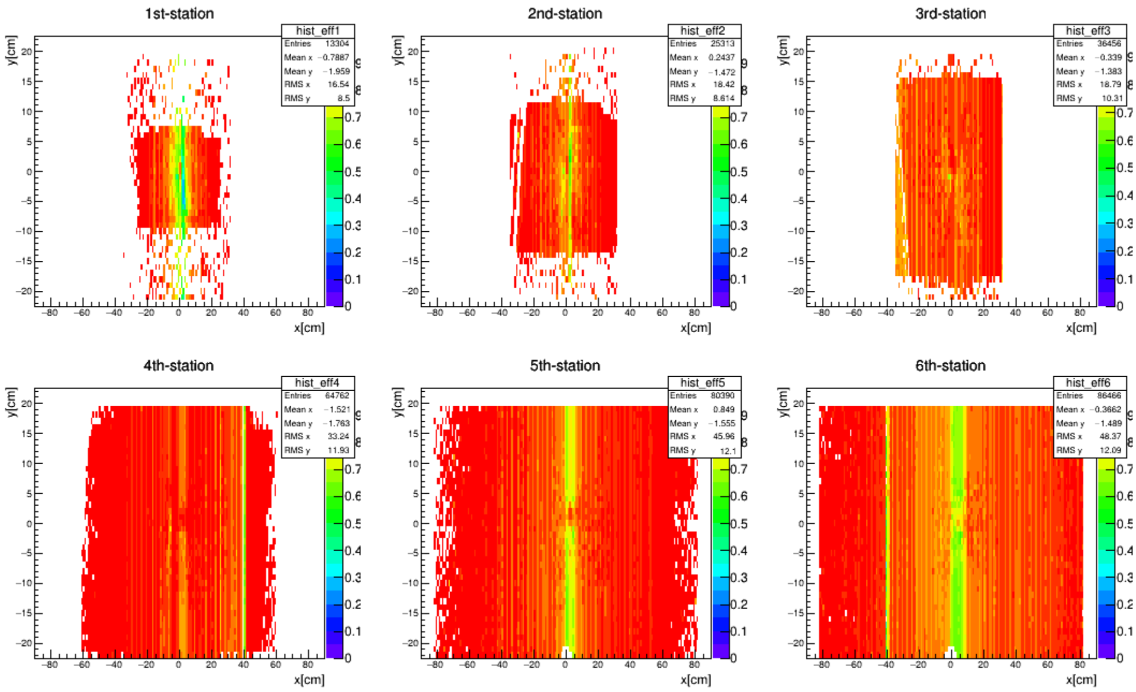


Figure 21: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+C

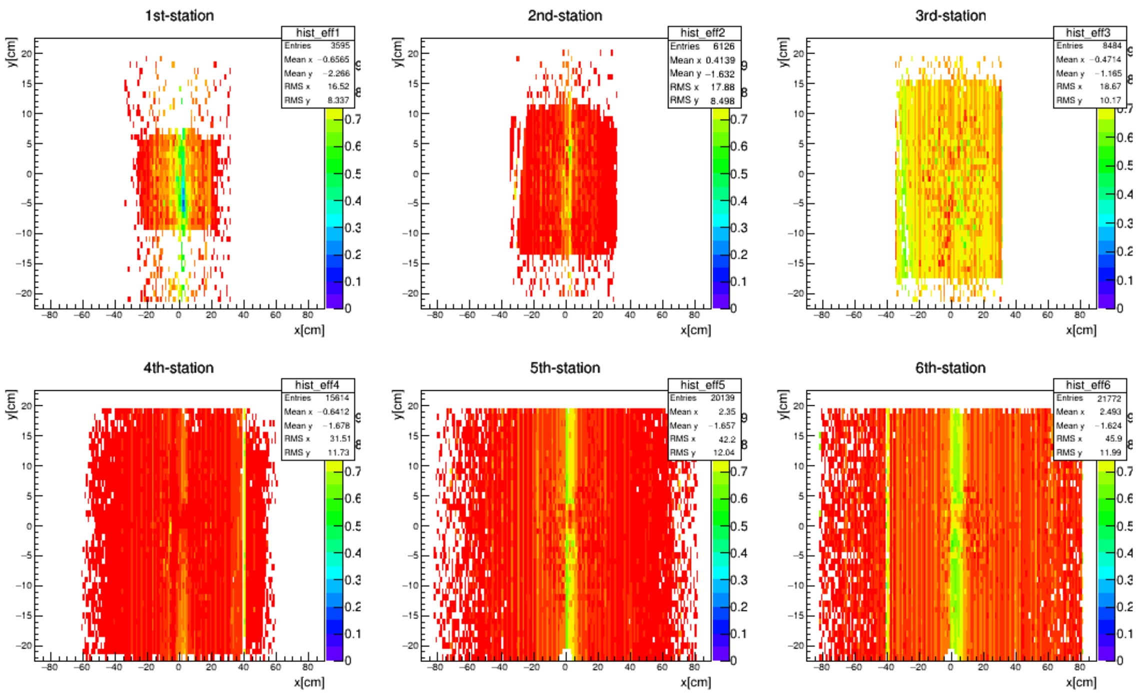


Figure 22: 2-D X/Y MC efficiency distribution in 6 GEM stations for C+Pb

# 3 Conclusion

GEM efficiencies corrections method for Monte-Carlo simulation was learned and applied to the GEM detector for 4 different targets for the Run-6 dataset in BM@N experiment. For the purpose of this study, the BmnRoot framework structure was learned and accordantly modified. Two iterations of the correction method were applied and the close matching between efficiencies in physical and

Monte-Carlo data was obtained. For parallel data processing, the main work principles of the NICA (JINR) cluster were studied. During the task implementation, new ROOT package methods were learned.

# 4 Acknowledgement

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# References

[1] D. Baranov, M. Kapishin, E. Kulish, A. Maksymchuk, T. Mamontova, G. Pokatashkin, I. Rufanov, V. Vasendina, and A. Zinchenko. First Results from BM@N Technical Run with Deuteron Beam. *Phys. Part. Nucl. Lett.*, 15(2):148–156, 2018.

[2] Batyuk, Pavel, Gertsenberger, Konstantin, Merts, Sergey, and Rogachevsky, Oleg. The bmnroot framework for experimental data processing in the bm@n experiment at nica. *EPJ Web Conf.*, 214:05027, 2019.

[3] J. Adams et al. Experimental and theoretical challenges in the search for the quark–gluon plasma: The STAR collaboration's critical assessment of the evidence from RHIC collisions. *Nuclear Physics A*, 757(1-2):102–183, 2005.

[4] K. Adcox et al. Formation of dense partonic matter in relativistic nucleus–nucleus collisions at RHIC: Experimental evaluation by the PHENIX collaboration. *Nuclear Physics A*, 757(1-2):184–283, 2005.