JOINT INSTITUTE FOR NUCLEAR RESEARCH

Laboratory of Hight Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Development and implementation of data recovery and analysis methods with MWPC

Student:

Daniil Usov

Saint-Petersburg State University

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Supervisor:

Merts S.P.

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1. Abstract

BM@N experiment is a part of the NICA acceleration complex. BmnRoot software is used to process it, however, not all detectors are included in the reconstruction chain. One of them is Multi-Wire Proportional Chamber (MWPC).

The purpose of this work is to describe detector geometry and develop an algorithm for track reconstruction.

2. Introduction

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex designed at the Joint Institute for Nuclear Research (Dubna, Russia) to study properties of dense baryonic matter. BM@N experiment (Baryonic Matter at the Nuclotron) has the purpose of studying the collisions of elementary particles and ions with a fixed target. The BM@N setup consists of the set of detectors for track and energy measurements for further particle identification (Fig. 1).
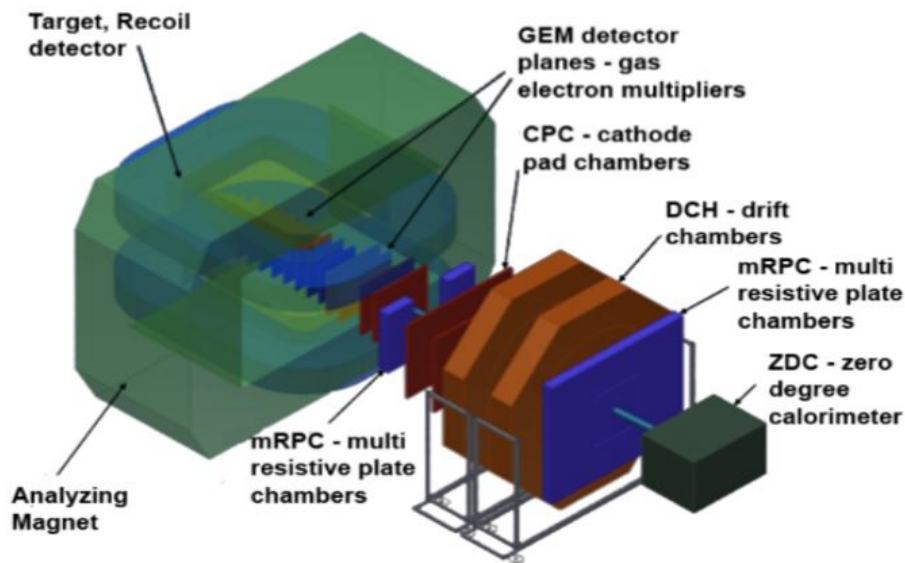

Figure 1. Three-dimensional view of the BM@N facility.

3. BmnRoot framework

BmnRoot framework is used for the BM@N experiment processing. It provides a powerful tool for detector performance studies, event simulation and development of algorithms for reconstruction and physics analysis of data of fixed

target events registered by the BM@N facility. The BmnRoot is implemented in the programming language C++ and based on the ROOT environment and the object-oriented framework FairRoot.
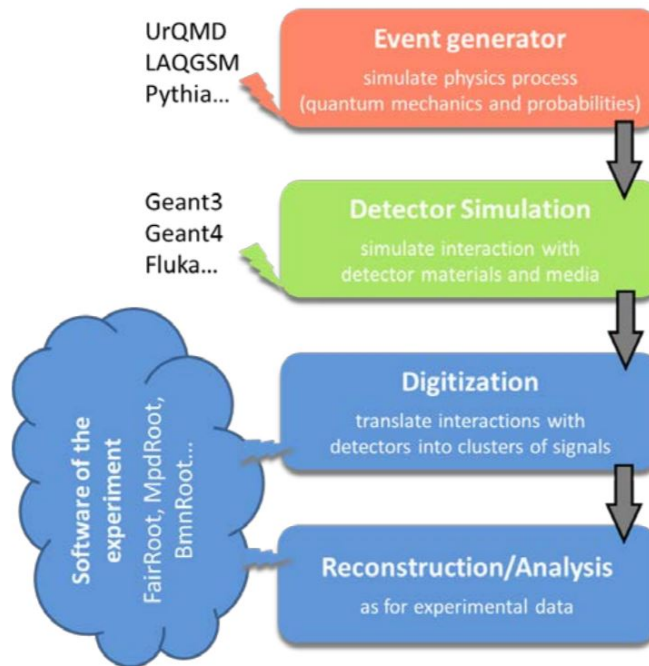

Figure 2. Simulation and analysis steps of high energy physics experiment.

The detector inclusion in the simulation and reconstruction chain can be divided into several stages:

- Creating geometry of detector to describe particle interactions with the detector;

- Digitization – transformation of simulated data into detector signals;

- Development of particle track reconstruction algorithms.

4. Multi-Wire Proportional Chamber

Multi-Wire Proportional Chambers are used to determine the trajectory of a particle beam. The detector is a chamber filled with a mixture of gases, in which anode wires are located between the cathode planes (Fig. 3). Upon entry, a charged particle causes ionization of the gas, and generated electrons, under the action of the electric field of the chamber, trigger the wire closest to the particle's trajectory.
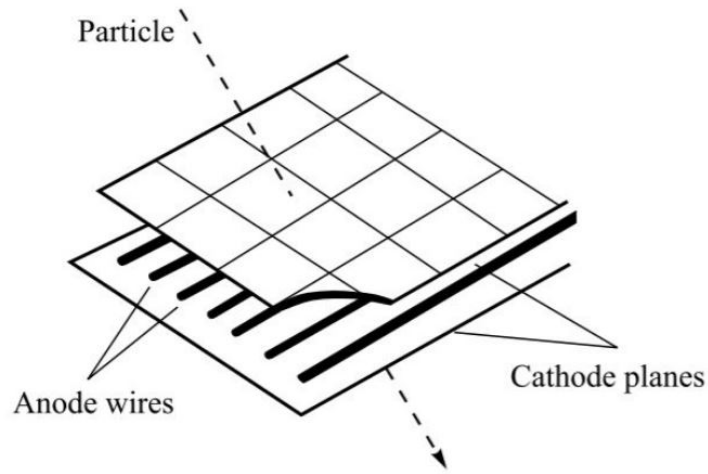
Figure 3. Structure of MWPC.

In the BM@N experiment, the MWPC detector consists of 6 flat planes, each of which consists of 96 wires. Each plane is rotated by an angle of 60° relative to the previous one. Distance between wires in one plane is equal to dw = 2.5 mm, and between planes in one chamber is 10 mm. In a cartesian coordinate system, the z axis is perpendicular to the planes. The coordinate system of the detector is shown in Fig. 4. In this representation, the planes have the sign "+" or "−" depending on the increasing or decreasing numbers of wires along the coordinate axis. For convenience, two axes U and V, perpendicular to the wires in the planes u_+ and v_+, are added.
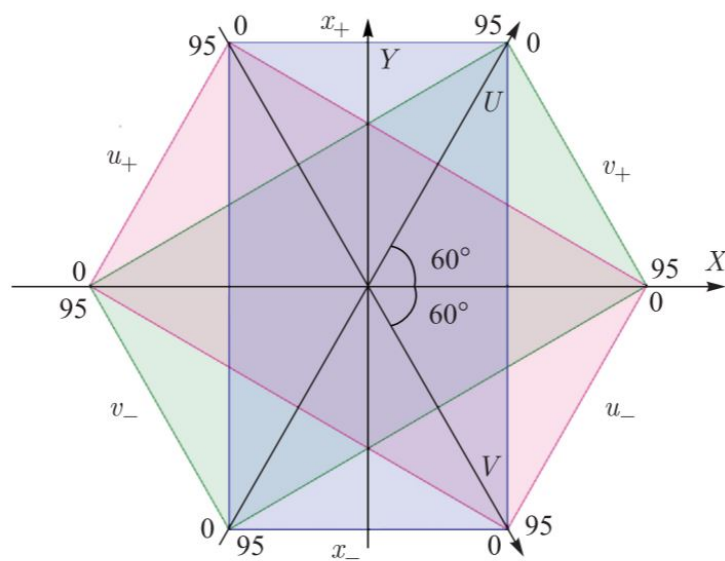

Figure 4. Coordinate system of detector.

Detectors are located before the magnet, so trajectories of particles can be approximated by straight lines.

5. Detector geometry

Simulation process requires the description of detector geometry, its proportions, materials and location. The ROOT geometry package is used for these purpose. It is a tool to build, browse and visualize detector geometries. Previous version of MWPC geometry described only active parts involved in the interactions, but detector contains frames in which new particles may appear, and this should be taken into account (Fig. 5).
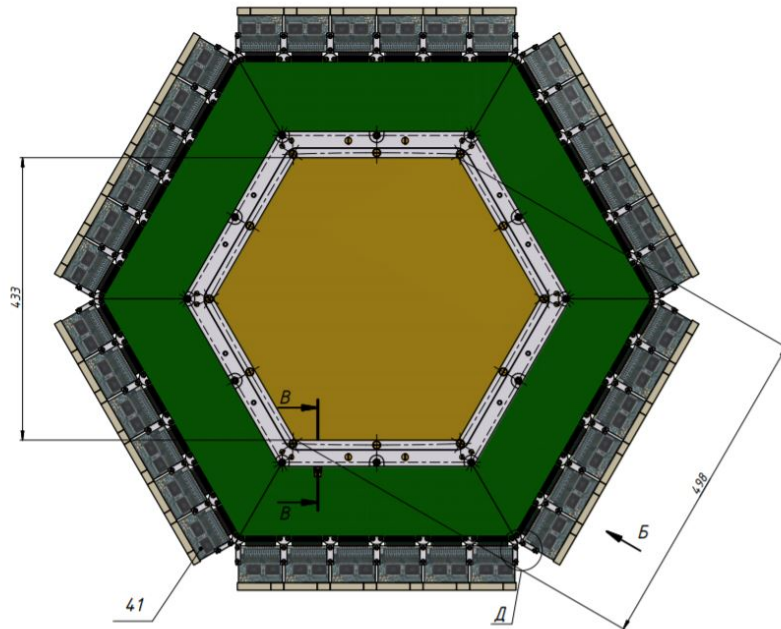

Figure 5. Scheme of MWPC.

The current version of the geometry includes aluminum frames around the detector and layers of copper and fiberglass on both sides of the stations. Comparison of detector models:
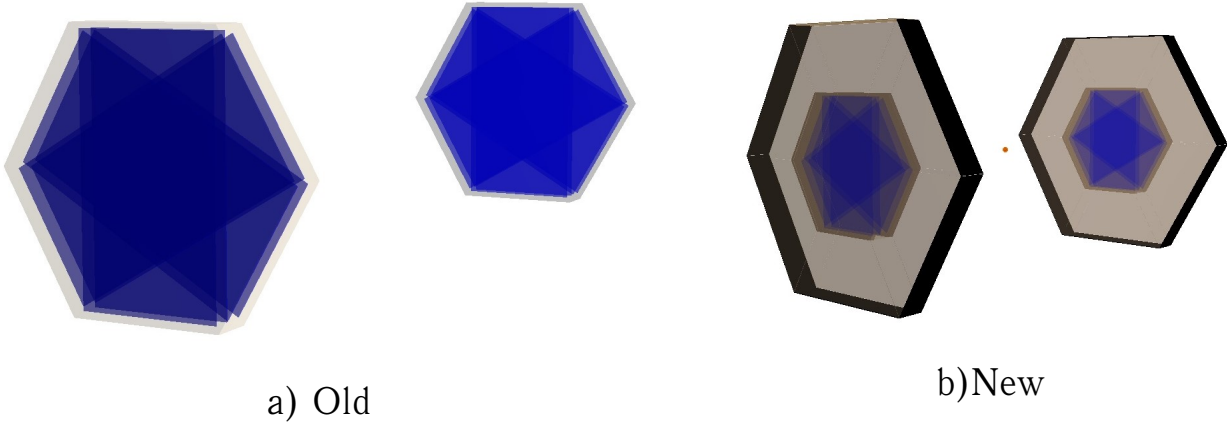
a) Old

b)New

Figure 6. Comparison of detector models.

To quantify the effect of additional materials, a macro testGeometry.C was written. It finds secondary tracks formed in the stations and calculates their parameters, such as initial coordinates and momentum. The result can be seen in the Fig. 7- 9. 100000 events of 10 particles in each were simulated.
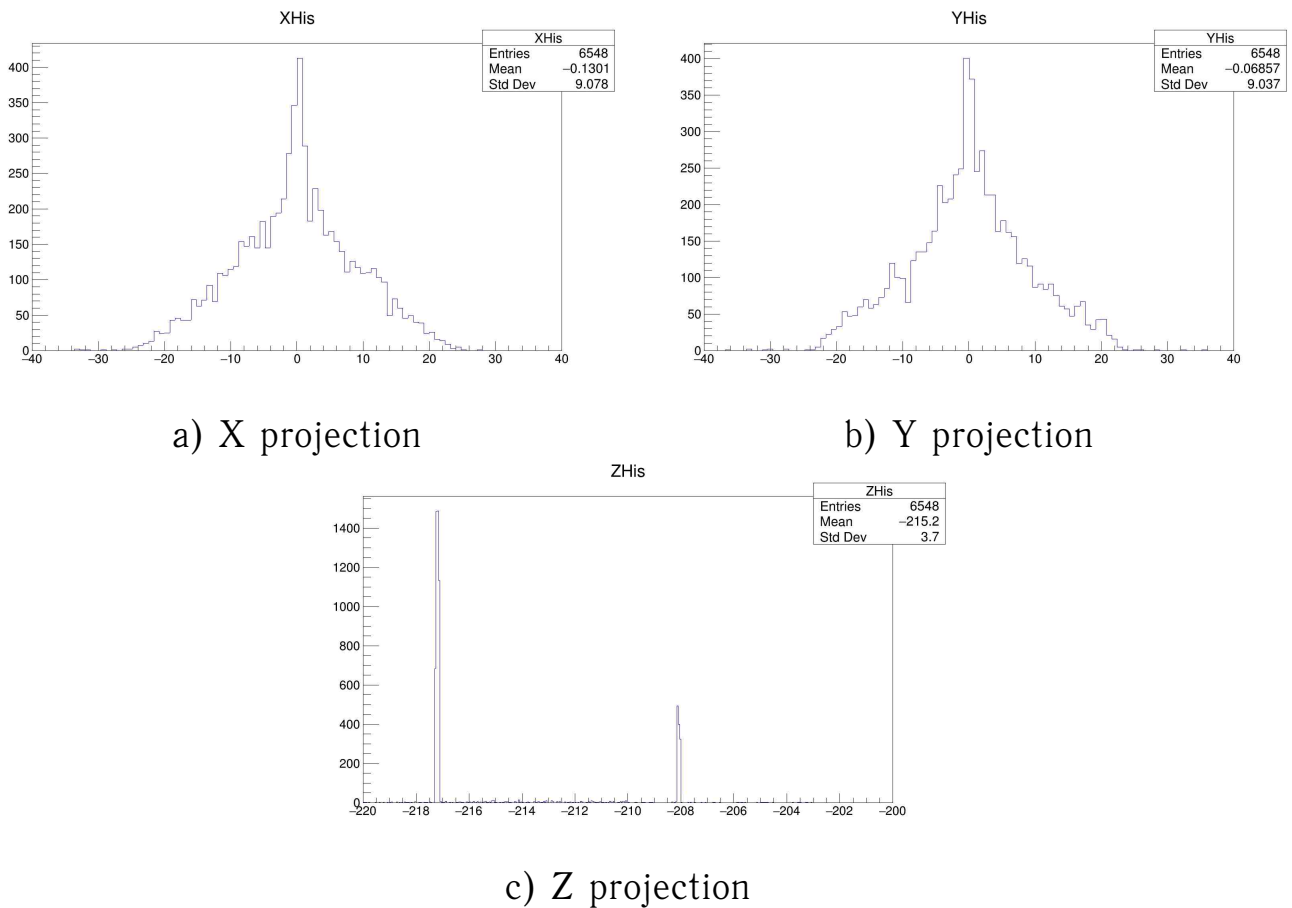

a) X projection

b) Y projection

c) Z projection

Figure 7. Histograms of distribution of the number of new particles by coordinates X, Y and Z.

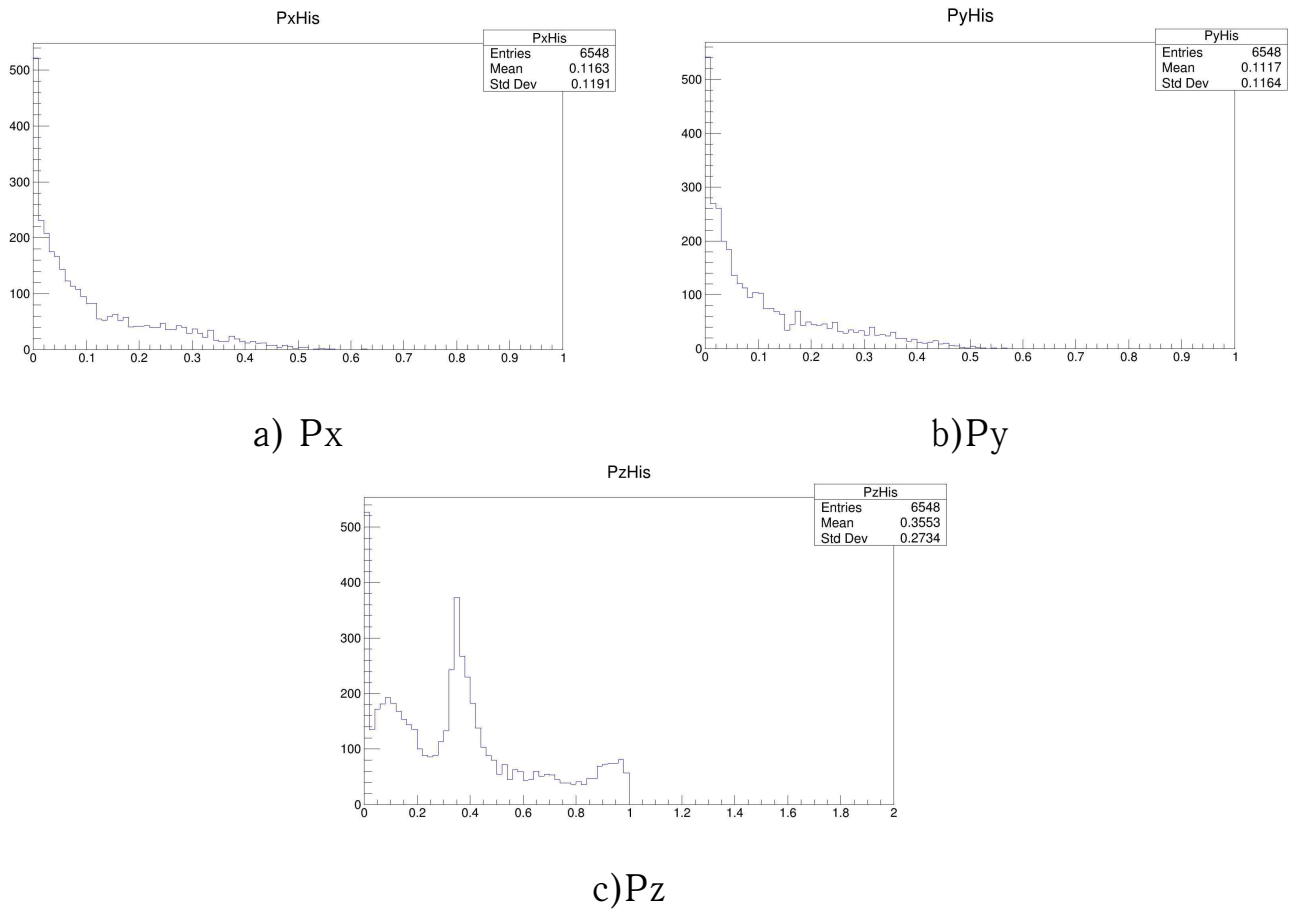a) Px   b)Py

c)Pz

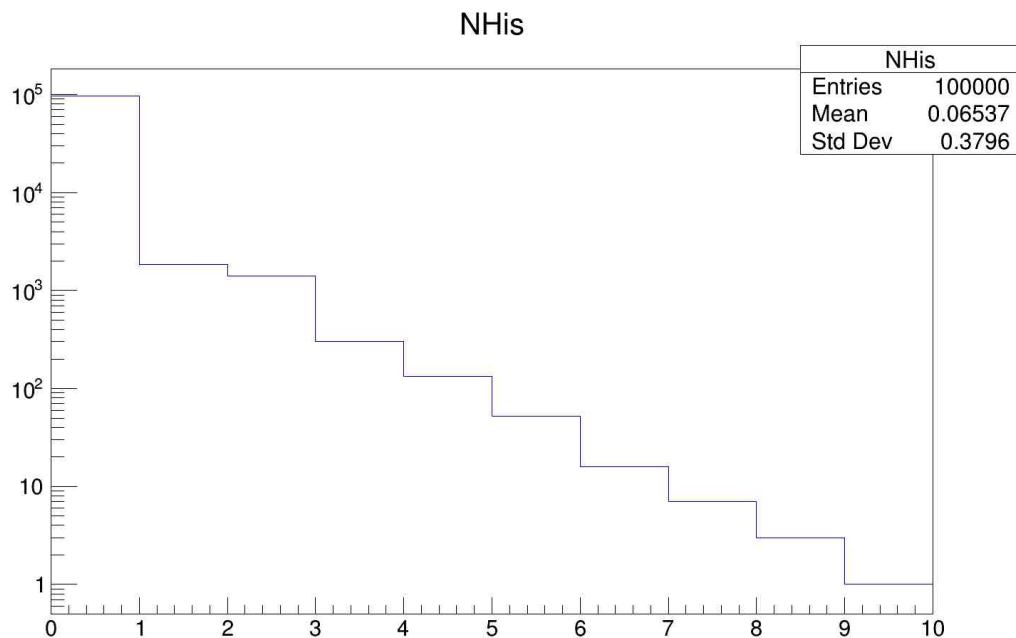Figure 8. Histograms of distribution of the number of new particles by projections of momentum.

Figure 9. Histogram of distribution of the number of events by number of new particles in them.

Based on these graphs, we can conclude that most of particles are formed in

the fiberglass protective layer on two sides of the chamber.

6. Digitizing

The main task of reconstruction is the processing of experimental data. However, for further tests of track reconstruction, the processing of simulated data is also important. They should be brought in the same form that the experimental ones have. For this, the BmnMwpcDigitizer class was written.

The coordinate data obtained during the simulation must be digitized, that is, presented as a discrete set of wire numbers and detector planes. Based on the geometry of the detector, this can be done by rounding to integers the following expressions for different planes:

$$n_{x_+} = \frac{x}{d_w} + 47,5 \tag{1}$$

$$n_{u_+} = \frac{u}{d_w} + 47,5 \tag{2}$$

$$n_{v_-} = 47,5 - \frac{v}{d_w} \tag{3}$$

$$n_{x_-} = 47,5 - \frac{x}{d_w} \tag{4}$$

$$n_{u_-} = 47,5 - \frac{u}{d_w} \tag{5}$$

$$n_{v_+} = 47,5 + \frac{v}{d_w} \tag{6}$$

$d_w = 2,5$ мм —distance between neighbor wires in one plane.

The BmnMwpcDigitizer class is created as a inheritor of the FairTask class. At each reconstruction step, the ProcessPoints method is called, during which the coordinates of the particles entering the detector are taken from the tree of simulated data, the numbers of wires and planes are calculated, and then they are written to the BmnMwpcDigits branch of the output reconstruction tree.

7. Hit reconstruction

The next step is creating three-dimensional reconstructed points - hits, on which tracking will be built. The BmnMwpcHitMaker class was written. Tracks are built on three hits obtained from 6 values of the detector wire numbers, one from each plane.

The intersections of wires on planes 0-1, 2-3 or 4-5 are converted into a hit, the z coordinate of which is taken as the average between the coordinates of the planes, and the remaining coordinates are calculated based on the detector geometry:

$$\left.\begin{aligned} x &= (n_{x_+} - 47,5)d_w \\ u &= (n_{u_+} - 47,5)d_w \\ y &= \frac{2u - x}{\sqrt{3}} \end{aligned}\right\} \quad \text{Hit 1}$$

$$\left.\begin{aligned} v &= (47,5 - n_{v_-})d_w \\ x &= (47,5 - n_{x_-})d_w \\ y &= \frac{x - 2v}{\sqrt{3}} \end{aligned}\right\} \quad \text{Hit 2}$$

$$\left.\begin{aligned} u &= (47,5 - n_{u_-})d_w \\ v &= (n_{v_+} - 47,5)d_w \\ x &= u + v \\ y &= \frac{2u - x}{\sqrt{3}} \end{aligned}\right\} \quad \text{Hit 3}$$

The result of BmnMwpcDigitizer and BmnMwpcHitMaker classes work can be seen in following histograms of the distribution of the number of particles by wire numbers of digits and coordinates of hits:
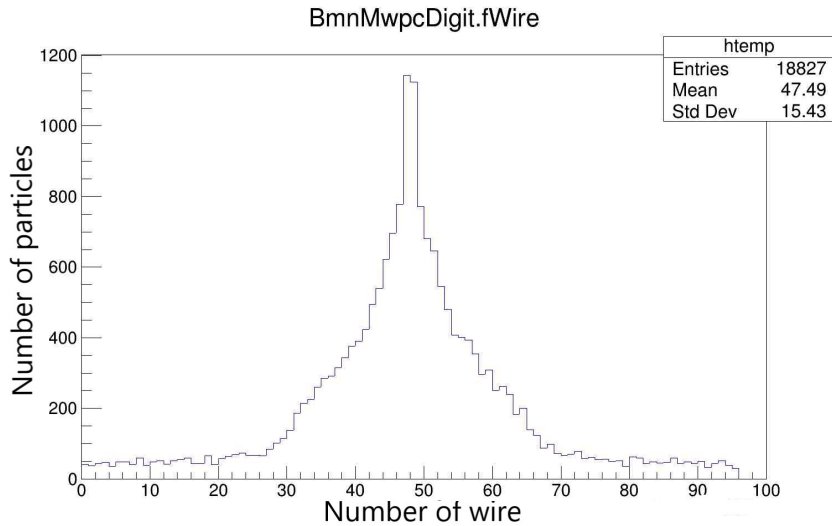

Figure 10. Histogram of distribution of the number of new particles by wire numbers of digits.
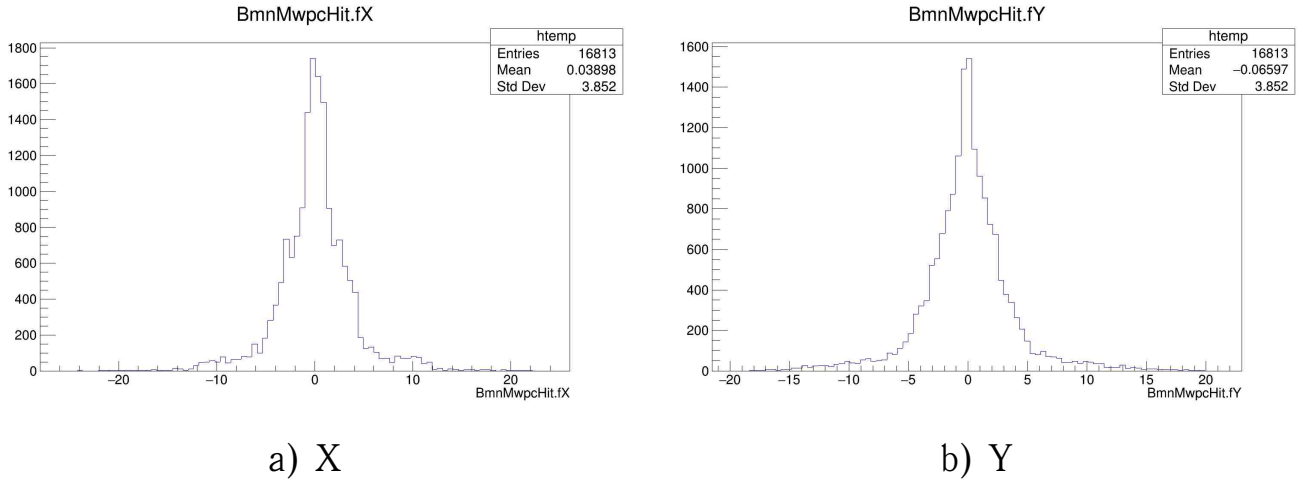
a) X   b) Y

Figure 11. Histograms of distribution of the number of new particles by X and Y hit coordinates.

8. Track reconstruction algorithm

Particle tracks are built on three hits. The BmnMwpcTracking class was written. At the beginning, the data read from the BmnMwpcHits branch is sorted in three planes corresponding to different z coordinates. Further, all combinations of hits from different planes are approximated by straight lines using the least squares method and the best ones are selected from them by the chi-squared test.

The following functional is getting minimized:

$$\Sigma \frac{d_i^2}{\sigma^2} \longrightarrow min$$

where d_i is the difference between coordinates of hits and approximated coordinates in the i-th plane, $\sigma = \frac{d_w}{\sqrt{12}} = 0.072$ cm is the standard deviation. Example of reconstruction tracks in two projections XZ and YZ:
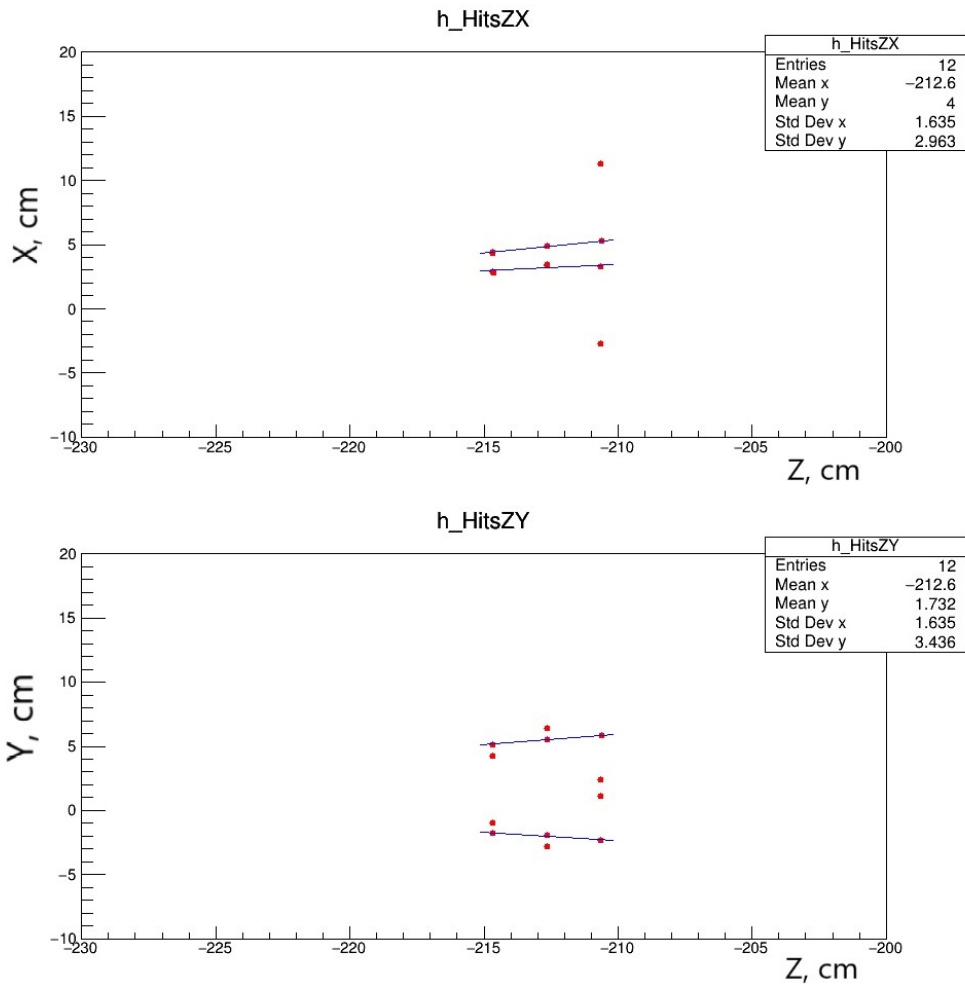
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Figure 12. Approximation of hits in the chamber.

It is possible to compare hits and simulated points by passing the point index to the hit. Residuals of point and hit coordinates:
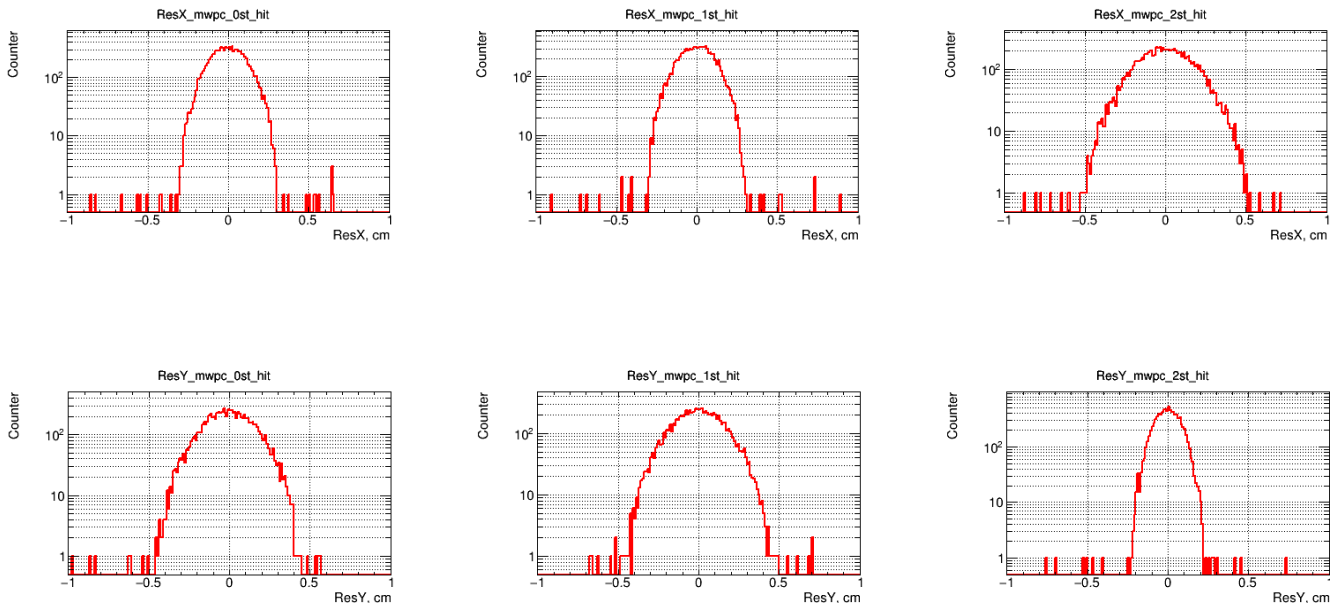

Figure 13. Residuals of point and hit coordinates for 1 particle in event.
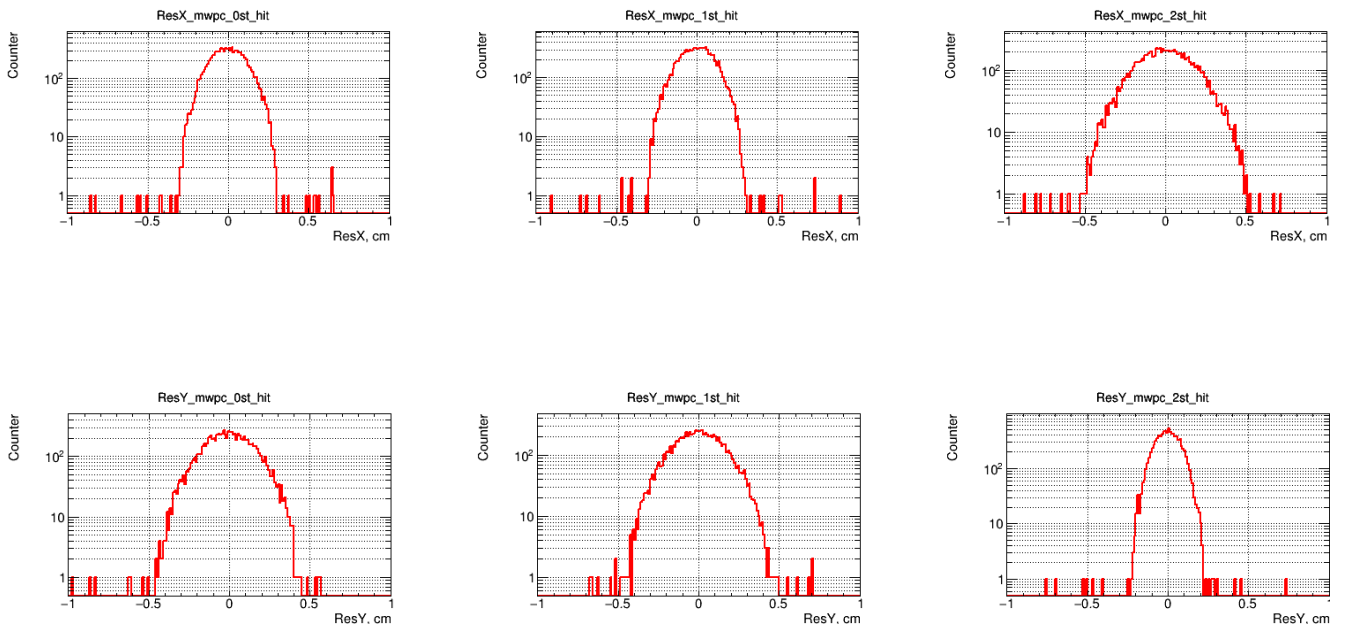
Figure 14. Residuals of point and hit coordinates for 3 particle in event.

If in a track more than 60% of hits refer to one simulated track, then reconstruction considered as correct. The efficiency of the algorithm for tracks reconstruction for 1, 2, and 3 simulated tracks in an event, depending on polar angle θ and pseudorapidity $\eta = -ln(tan(\frac{\theta}{2}))$, presented in Fig. 15 – 17:
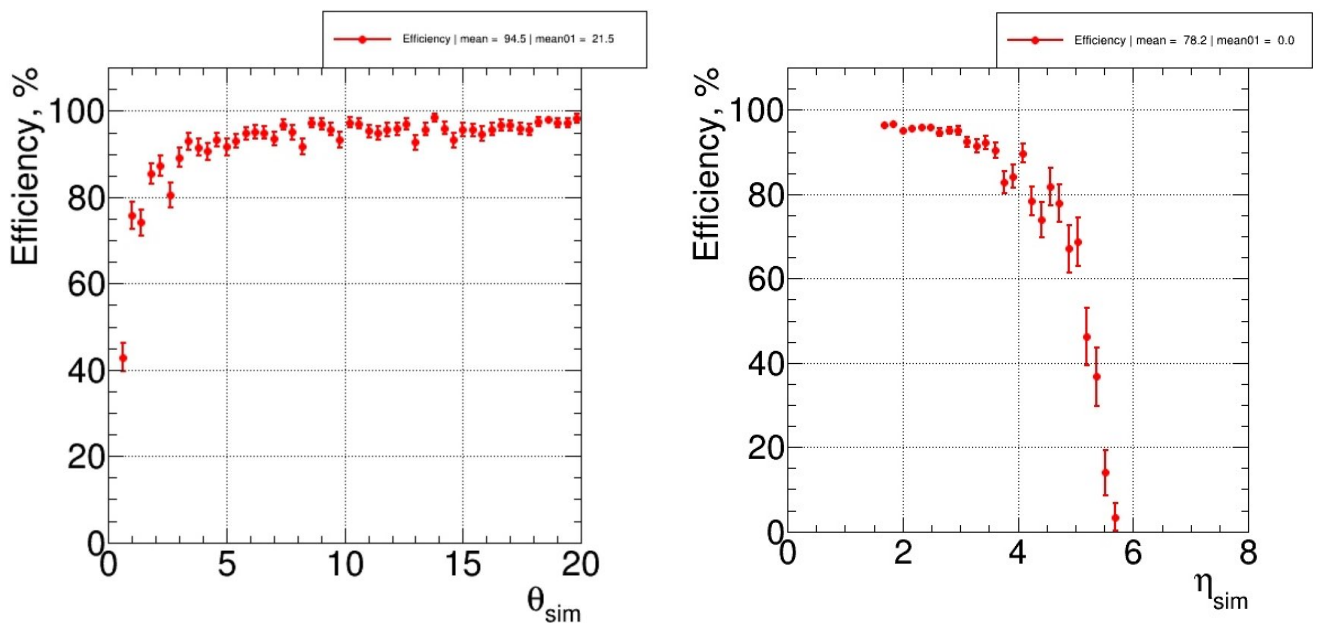

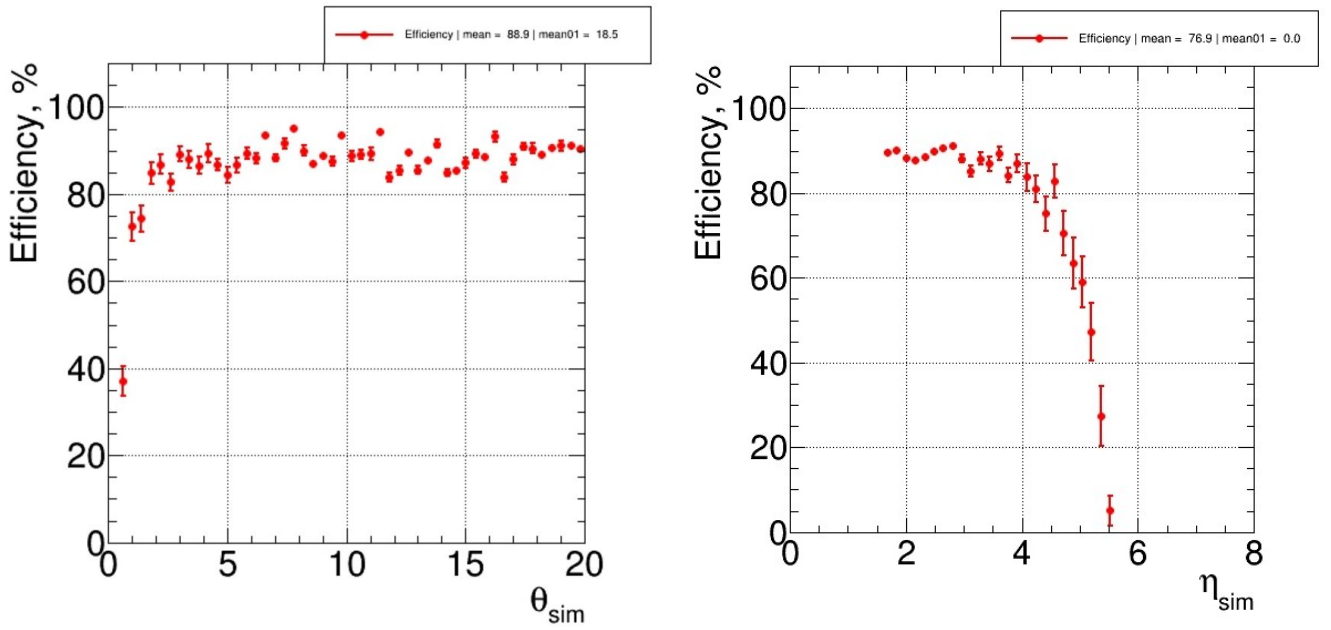Figure 15. Efficiency of track reconstruction for 1 particle in event.

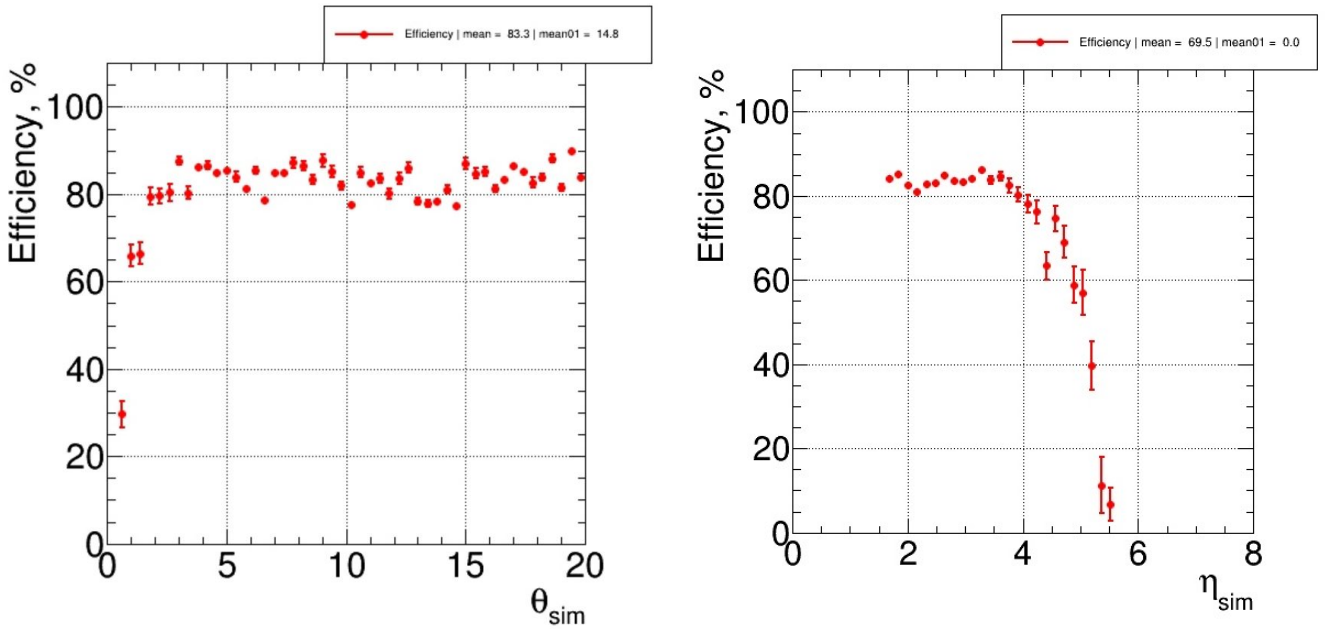Figure 16. Efficiency of track reconstruction for 2 particle in event.

Figure 17. Efficiency of track reconstruction for 3 particle in event.

9. Merger between tracks in system of chambers

After building tracks in proportional chambers, it is necessary to combine them. Tracks are extrapolated to two planes corresponding to $Z_1 = \frac{3Z_{ch1}+Z_{ch2}}{4}$ and $Z_2 = \frac{Z_{ch1}+3Z_{ch2}}{4}$. The best set of tracks is located at the minimum average distance between extrapolated coordinates with a small difference in angle. Then this set of two tracks is converted into a new single one. Example of merger between tracks in two chambers in two projections XZ and YZ:
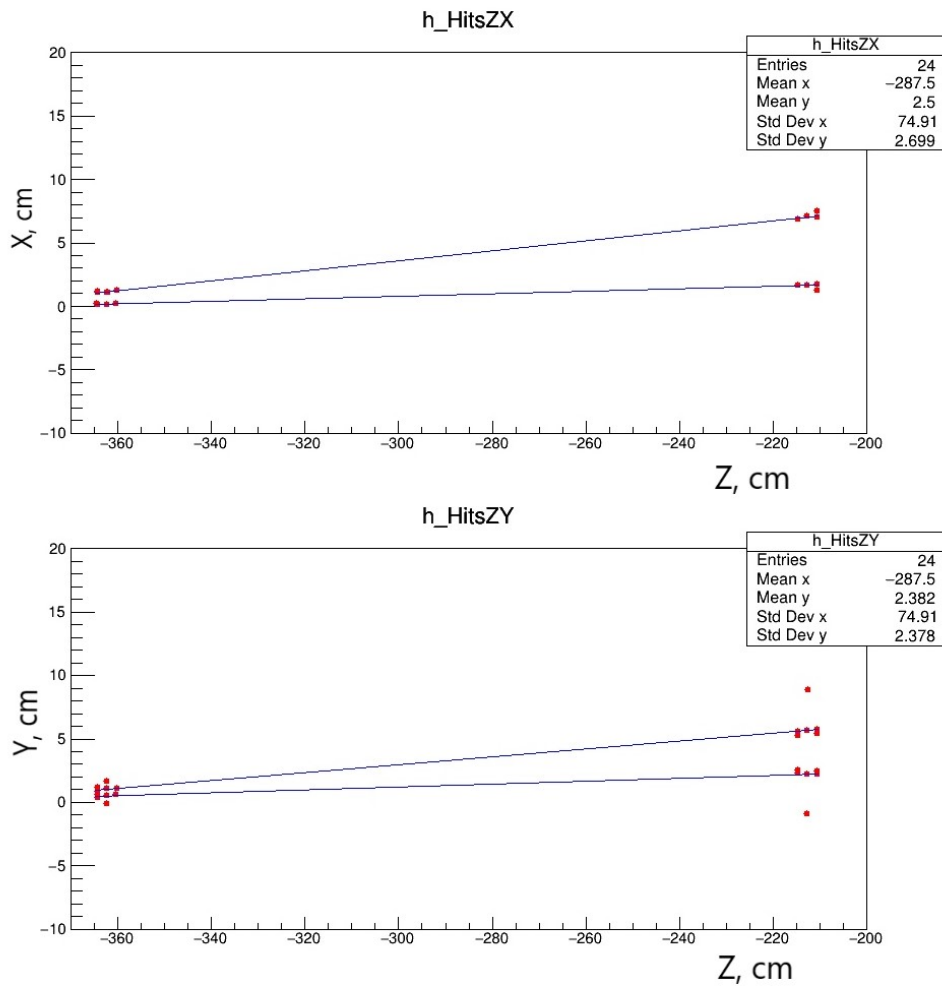
Figure 18. Tracks in system of chambers.

The efficiency of the algorithm for tracks reconstruction for 1, 2, 3 and 5 simulated tracks in an event, depending on polar angle θ and pseudorapidity η, presented in Fig. 19 – 22:
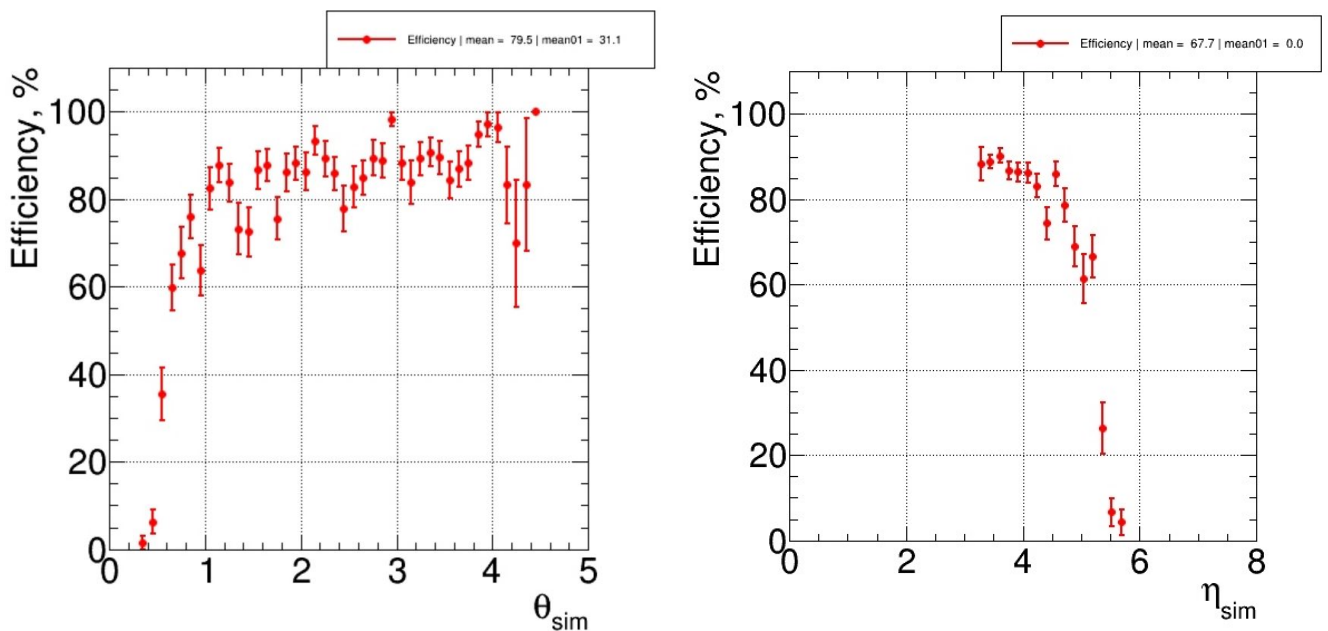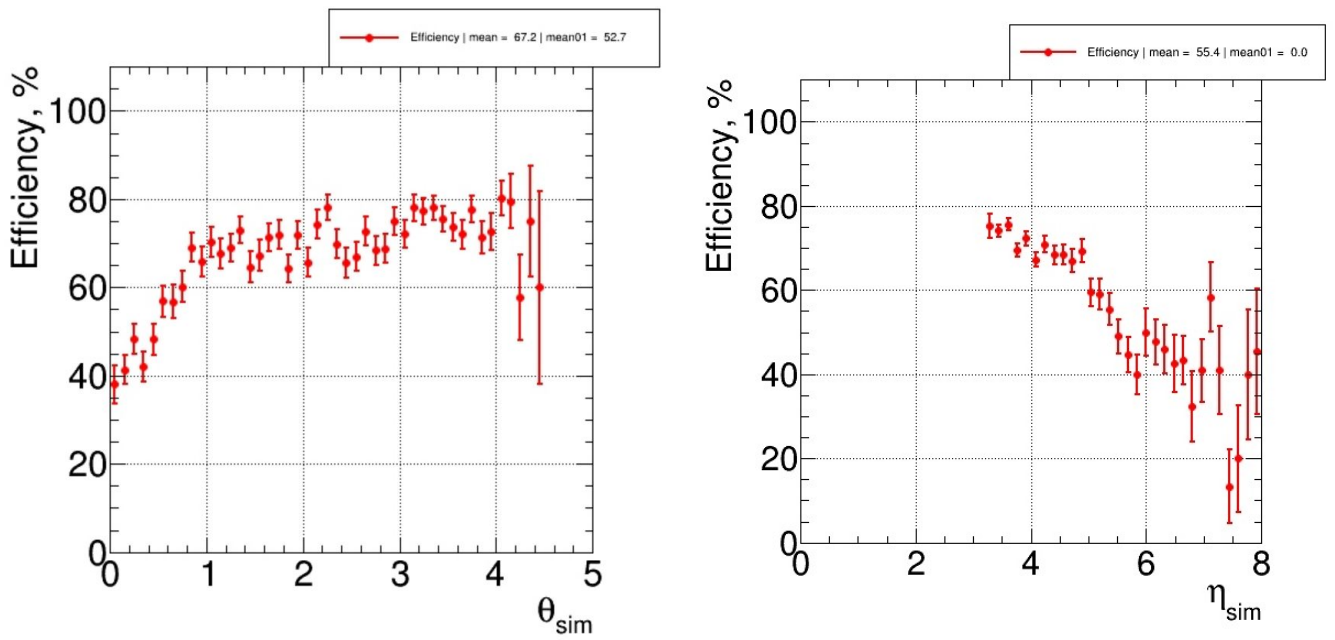

Figure 19. Efficiency of track reconstruction for 1 particle in event.

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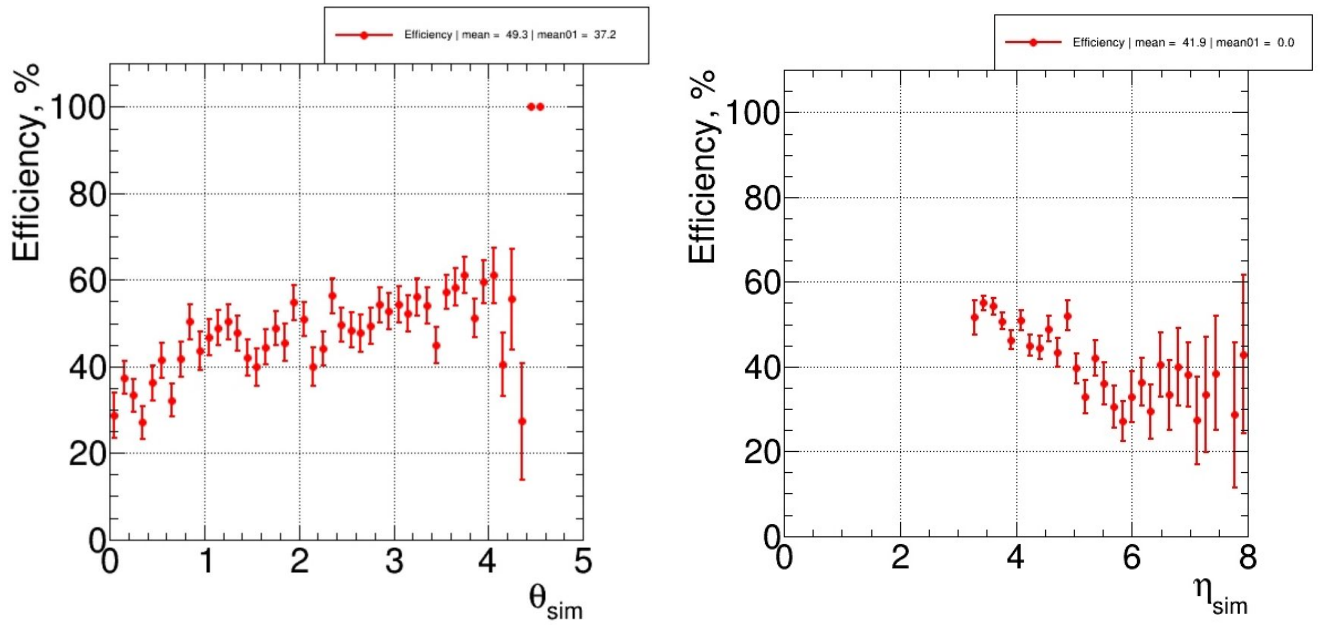Figure 20. Efficiency of track reconstruction for 2 particle in event.

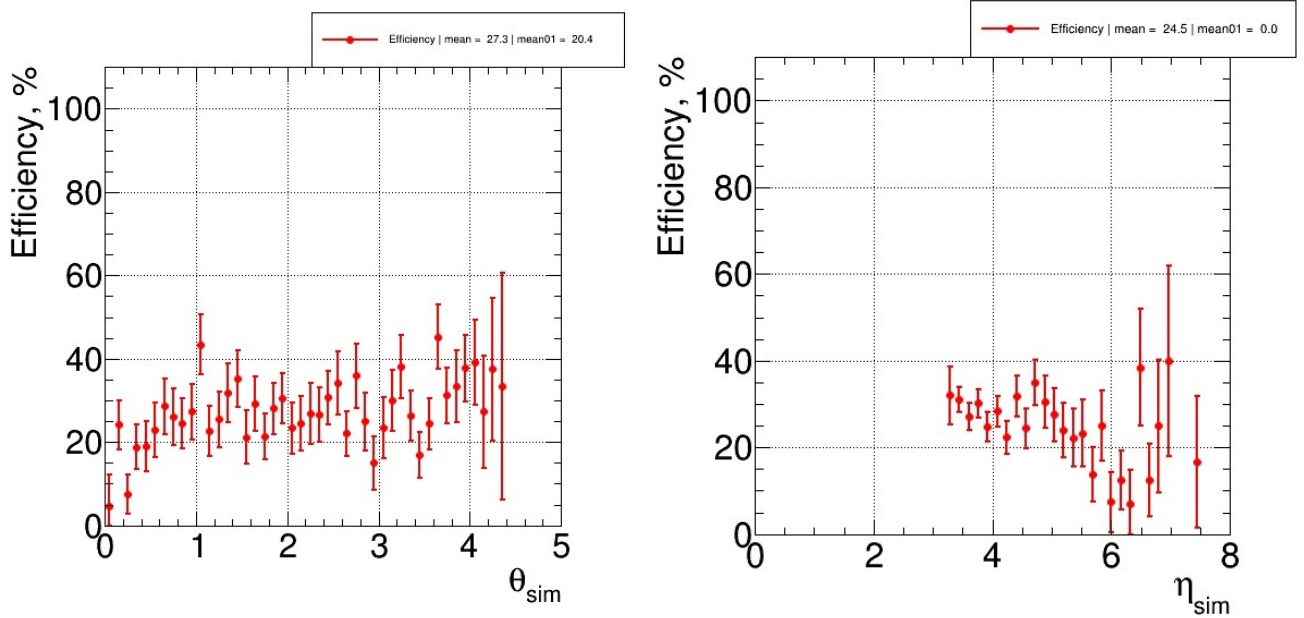Figure 21. Efficiency of track reconstruction for 3 particle in event.

Figure 22. Efficiency of track reconstruction for 5 particle in event.

Macro bmn_qa_generator also allows to compare and visualize the parameters of tracks, such as angles, pseudorapidity and length:
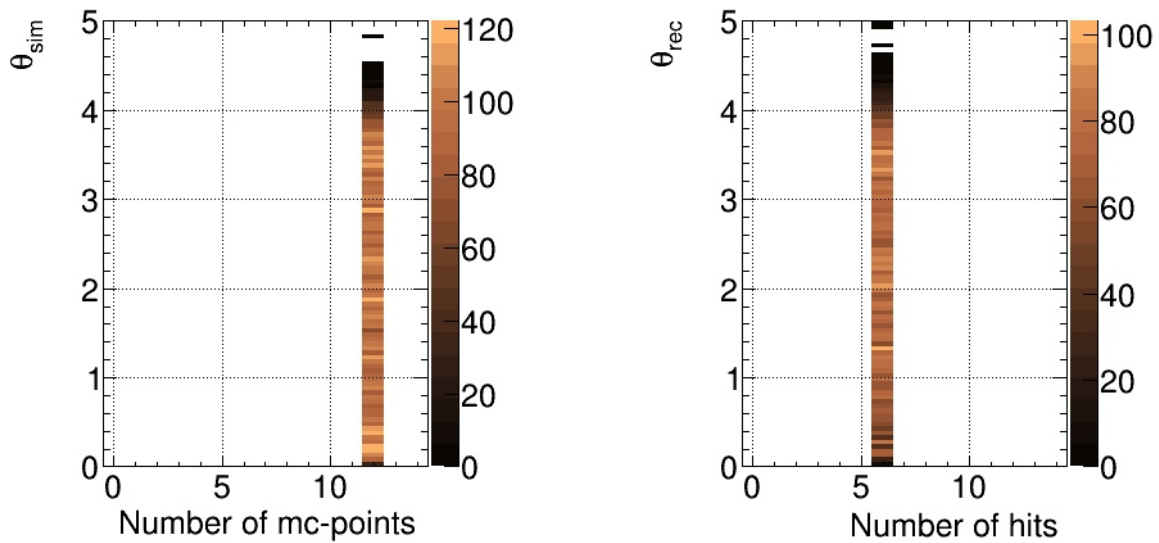

Figure 23. Comparison of polar angles of simulated and reconstructed tracks.
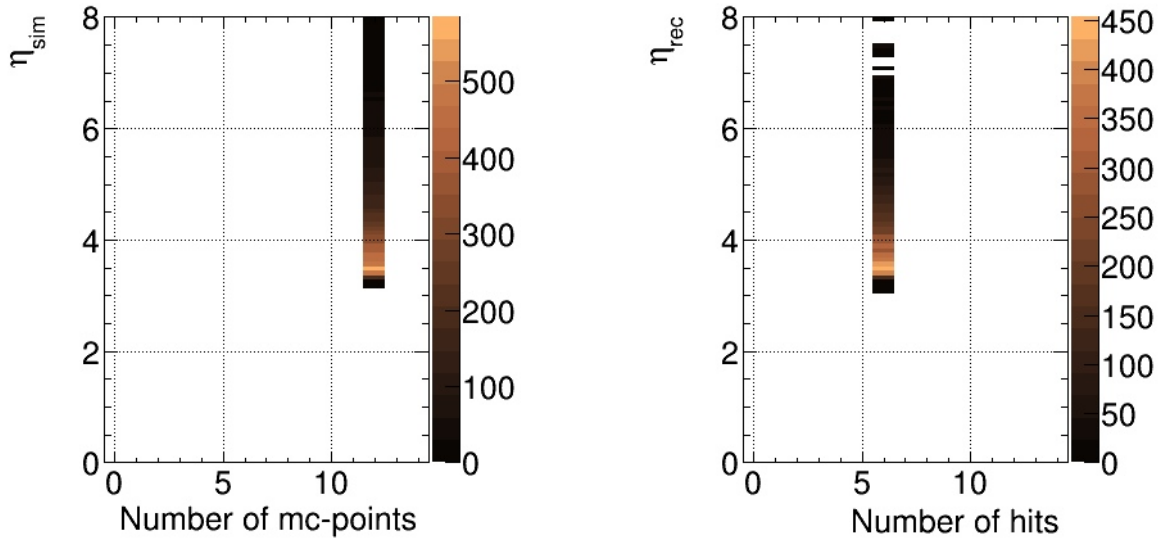
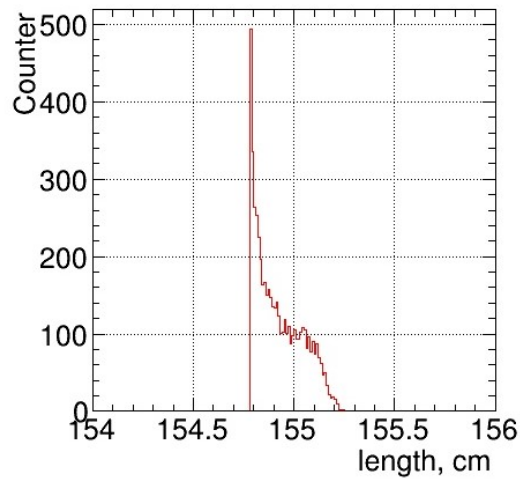Figure 24. Comparison of pseudorapidity of simulated and reconstructed tracks.

Figure 25. Length of reconstructed tracks.

10. Conclusion

The geometry of the detector MWPC was described and the contribution of the surrounding materials was evaluated. It turned out that the material around the detector has a small effect on the appearance of new particles in it. Classes for digitizing the simulated data and finding reconstructed dimensional points - hits, on which tracking is built, were written. Track reconstruction algorithm and an algorithm for merging tracks in a camera system have been developed.

References

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[2] В. В. Ленивенко, В. В. Пальчик - Реконструкция траекторий заряженных частиц в системе многопроволочных пропорциональных камер эксперимента BM@N. Письма в ЭЧАЯ. 2018. Т. 15, №6(218). С.512-527.

[3] CERN. ROOT. An Object-Oriented Data Analysis Framework. 2013.

[4] Rafa-l Bielski - HrbDecoder documentation. JINR Summer Student Programme project report.

[5] K. V. Gertsenberger - The Unified Database For The Fixed Target Experiment Bm@N. JINR, 2016.