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Veksler and Baldin Laboratory of High Energy Physics

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SUMMER STUDENT PROGRAM

Λ^0 hyperon reconstruction quality assurance in the BM@N experiment

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Contents

Abstract

The paper is devoted to the problem of implementation the quality assurance visualization for Λ^0 reconstruction in the BM@N experiment at NICA project. The module implemented deals with the information obtained from Monte Carlo simulation, as well as with the information obtained from existing algorithms of Λ^0 hyperon reconstruction. The module plots vivid histograms to empower one to study how a geometry of experiment is good for Λ^0 reconstruction, and how Λ^0 reconstruction algorithms are efficient upon a fixed geometry.

Introduction

The BM@N experiment

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 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, short from Baryonic Matter at the Nuclotron, presented in the figure 1, 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 Au79+). The BM@N facility is one of the main elements of the first stage of the NICA collider development to study hot and dense matter in heavy ion collisions [2]. Figure 2 presents the three-dimensional scheme of the BM@N facility. It proposed to study the elementary

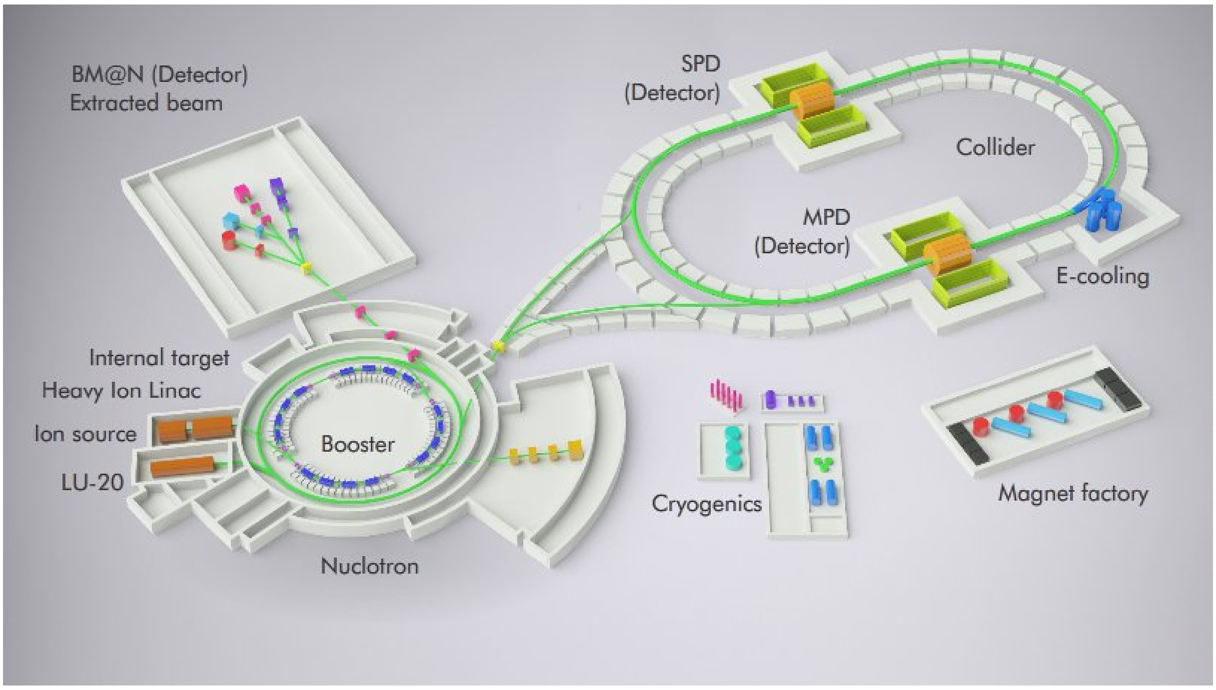

Figure 1: The BM@N experiment at extracted Nuclotron beam

reactions (p + p, p + n) and cold nuclear matter (p + A), the properties of dense baryonic matter in heavy ion collisions with fixed target, in-medium effects, hypermatter production, strangeness and hadron femtoscopy. Particle yields, ratios, transverse momentum spectra, rapidity and angular distributions, as well as fluctuations and correlations of hadrons will be studied as a function of the collision energy and centrality.

In the gold ion collisions with a gold target at these energies, very high multiplicity can be reached, and the BM@N facility should identify the particles produced with high efficiency and estimate their parameters with high precision for the full study of this hot matter. For this purpose, the BM@N combines high precision track measurements with the time-of-flight information for particle identification registered by detectors and total energy measurements for event characterization. The BM@N setup divides the detectors for particle identification into "near to magnet" and "far from magnet" to measure particles with low as well as high momenta [1].

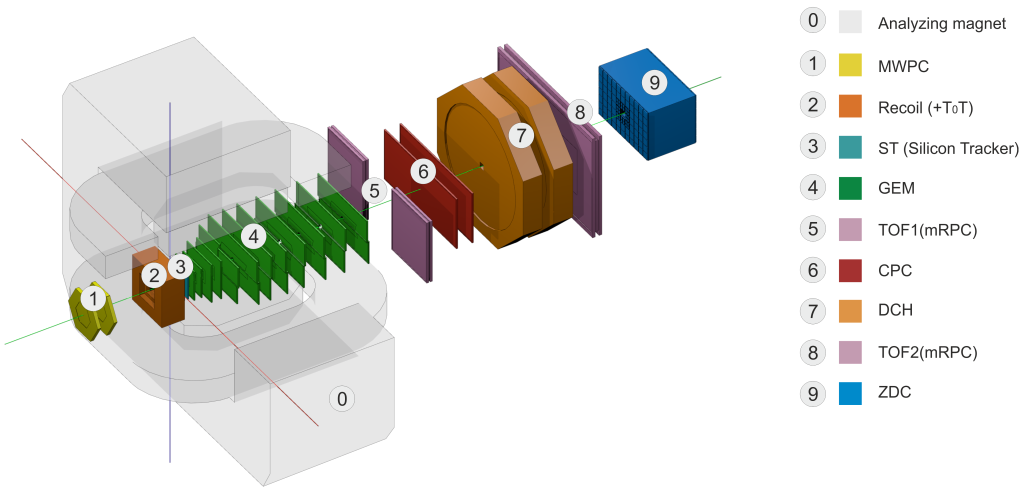

Figure 2: Three-dimensional view of the BM@N facility

The BmnRoot framework

The software and computing parts of the BM@N project are responsible for the activities including design, evaluation and calibration of the detector; storing, access, reconstruction and analysis of the data; and development and maintenance of a distributed computing infrastructure for physicists engaged in these tasks. To support the BM@N experiment, the software framework BmnRoot is developed. It provides a powerful tool for detector performance studies, event simulation, and development of algorithms for reconstruction and physics analysis of data of the fixed target events registered by the BM@N facility. BmnRoot is implemented in the programming language C++ and based on the ROOT environment and the object-oriented framework FairRoot (for the FAIR experiment at GSI Institute).

The flexibility of the framework is gained through its modularity. The physics and detector parts could be written by different groups. In the applied framework, the detector response simulated by a package currently based on the Virtual Monte Carlo concept allows switching simulation between Geant3, Geant4 and Fluka transport packages without changing the user code. For a realistic simulation of various physics processes, an interface to the event generators for nuclear collisions, e.g. UrQMD, Pythia and FastMC, is provided. One can easily choose between different modules, e.g. event generators. The same framework – BmnRoot is used to define the experimental setup, provides simulation, reconstruction, and physics analysis of simulated and experimental data. Using the same internal structure the user can compare easily at any time the real data with the simulation results [1].

Λ^0 reconstruction

High density barionic matter can be obtained under conditions available for NICA project and it makes possible for Quark-Gluon Plasma to be studied there, which is one of the the most significant aims of experiments at the facility. Theory predicts that the strangeness would enhance in heavy-ion induced interactions, and consequently the study of strange particles in these processes might be of interest as an increase of strangeness might serve as a signature for deconfinement phase transition to the state of quark-gluon plasma. Particularly, being able to detect Λ^0 hyperons would provide an opportunity to indicate this phase transition [3]. This hyperon is neutrally charged and, consequently can not be registered by detectors currently used in the BM@N. Nevertheless, this particle has a relatively small half-life (about $2.6 * 10^{-10}$s) and, consequently, could be reconstructed by it's decay products. Dominating decay channels are $p + \pi^-$ (64%) and $n + \pi^0$(36%). The former engenders two charged particle, so that both of them may be detected. Different algorithms of particles reconstruction have been already implemented in BmnRoot as well as Λ^0 reconstruction algorithm, which is based on the former. However, reconstruction algorithms require a set of tests before they can be used in physical analysis. One of ways to perform it is Monte-Carlo simulation. A number of events is simulated and output digital signals are used as an input for reconstruction algorithms instead of experimental data. This approach gives one an opportunity to compare reconstructed particle tracks with them simulated, this procedure being called a quality assurance. A tracking quality assurance responsible for testing single particles reconstruction have already been implemented, but that for Λ^0 reconstruction have not. Consequently, this is the objective of this student summer practice program.

Quality assurance

The Λ^0 quality assurance module was implemented as a separate class *BmnLambdaQa* inherited from *FairTask*, so that it could be called in *bmn_qa_generator.C* macro in the same way all other existing quality assurance modules are called.

An information in the BM@N experiment is stored in files with an extension .root called root trees as they consist of branches containing different parts of information desired to be stored in a file. Hence, the first step is to read these root files containing simulated and reconstructed information properly. Pointers to branches required are set by *FairRootManager*, each branch containing a number of entries. After that, an instance of *BmnHistManager* is used, which has a variety of methods for creating different types of histograms and filling them, the latter being done in bodies of different loops entry by entry.

To output an information recorded to the histogram manager *BmnLambdaQaReport* class was created. It inherits from *BmnSimulationReport*, which is capable of writing data to *.png* and *.html* files, containing plotted histograms and text information. *BmnLambdaQa* class constructor has two specific input bool parameters, the first of them presets if the class would read *evetest.root* file with results of Monte-Carlo simulation, the second if reconstruction file *bmndst* should be read. If it is pointed to use MC file, it conducts a geometry analysis and reconstruction analysis with Monte-Carlo input data, if it is asked to use reconstruction file, it conducts a reconstruction analysis with reconstruction input data. If both of them are pointed to use, also reconstruction analysis with matches between Monte-Carlo and reconstruction data is carried out.

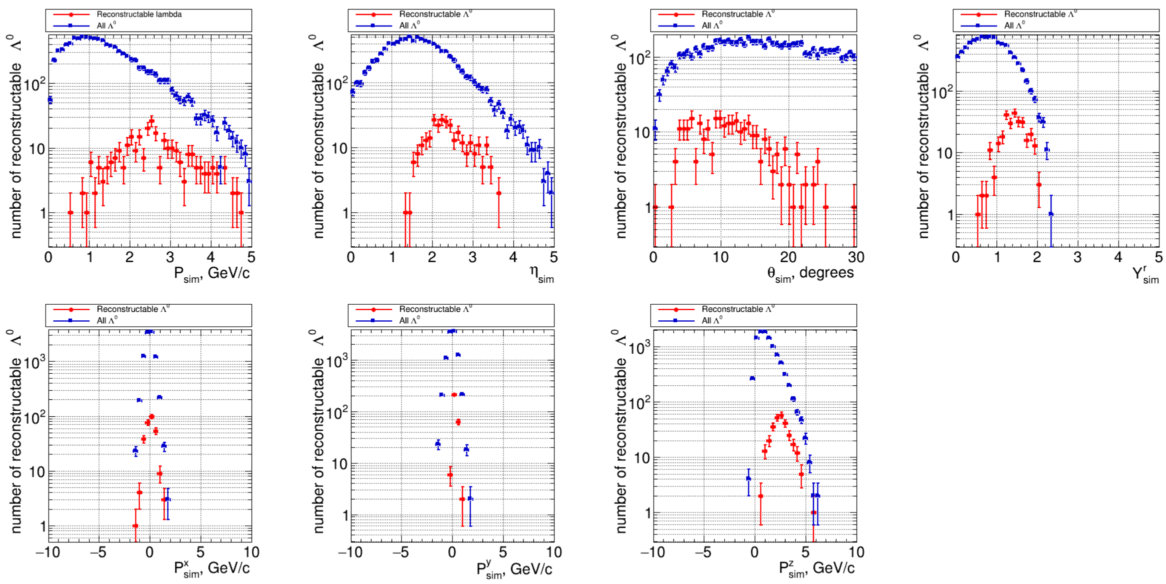

Figure 3: Λ^0 One-dimensional geometry analysis histograms

Geometry analysis

The first part of quality assurance module works with the output of *run_sim_bmn.C* macro used for simulation and outputs the information about the number of reconstructable Λ^0 to a set of *.jpg* files

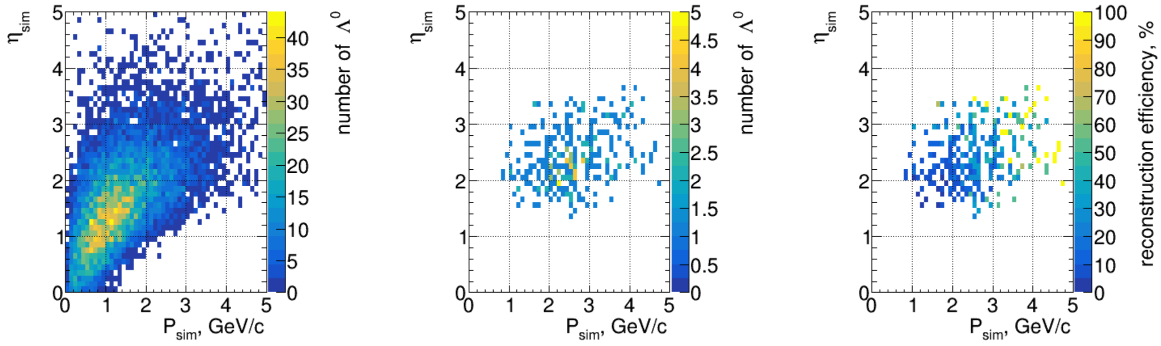

Figure 4: Λ^0 Two-dimensional geometry analysis histograms

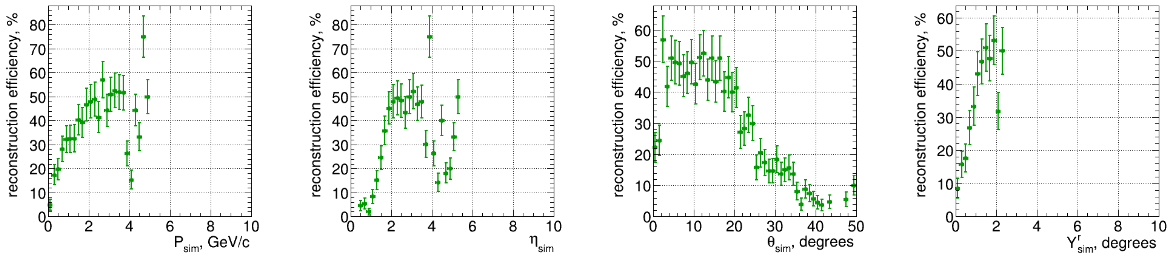

Figure 5: Reconstructive protons geometrical efficiency

and one *.html* file uniting them all and overall information in the header. The criterion for charged particle to be reconstructable is to have at least four hits. Since Λ^0 is reconstructed by its charged decay products, it requires both decay products to have four hits to be called reconstructable. The constructor of *BmnLambdaQa* class takes a key as a parameter to set whether these four hits can be obtained only on GEM detectors or silicon stations would give valid hits as well. Output of the module also includes an information about the total amount of Λ^0 simulated and a geometrical efficiency calculated as a ratio of a number of reconstructable particles to an overall number of them simulated. This data is printed in numerical format in the header file created and as a set of histograms depicting momentum, pseudorapidity, angle, rapidity and momentum axial projections distributions of number of reconstructable Λ^0, overall numbers of them plotted on the same figures and their ratio called efficiency(Figure 3). Moreover, some of these distributions are plotted in two dimensional form as well(Figure 4). All histograms given in this paper were obtained on simulation with *LAQGSM* generator, *Geant3* transport package and geometry of the BM@N experiment in the spring of 2018.

In addition, similar histograms were plotted for p and π^- being a product of Λ^0 decay. For these particles a total amount of them being Λ^0 decay products is taken as a divisor to calculate the geometrical efficiency.

The number of reconstructable particles upon a fixed event generator and other simulation utilities should be assigned entirely by a geometry. This is the reason why it is called the geometrical analysis. Histograms plotted in this part of *BmnLambdaQa* class should help one to understand how a disposition of detectors in an experiment is good in terms of detecting Λ^0.

Reconstruction analysis

The second part of the module conducts an analysis of Λ^0 reconstruction algorithms implemented in *BmnTwoParticleDecay* class and macros used to run it with options required. If *BmnLambdaQa* class was presetted to use Monte-Carlo data and the output file of the algorithm in *BmnTwoParticleDecay* applied to them exists, a reconstruction analysis for simulated data is conducted. The results are the number of reconstructed particle pairs, the number of them being actual decay products of the same Λ^0, and a set of histograms illustrating various invariant mass distributions in one-dimensional (Figure 6) and two-dimensional forms. The final stage of two-particle decay reconstruction algorithms is applying various conditions on kinematic and geometrical parameters of candidate pairs called cuts. In order to empower one to improve the cuts in terms of the Λ^0 reconstruction efficiency, the module plots invariant mass distributions both before and after applying cuts (Figures 7, 8). All these information might be used to study how good is algorithm of two particle decay reconstruction regardless of single particle decay reconstruction algorithms.

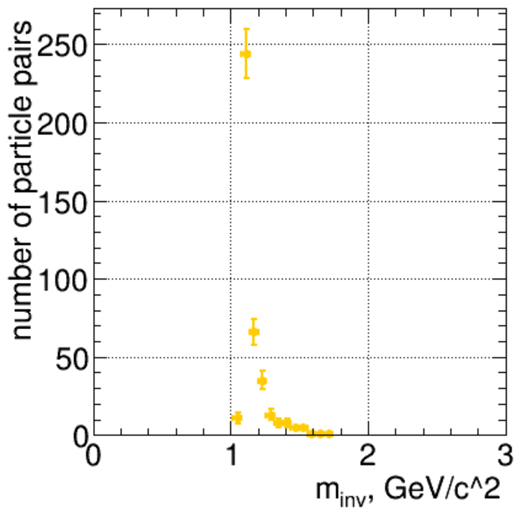

Figure 6: Invariant mass distribution for reconstructed particle pairs from MC data

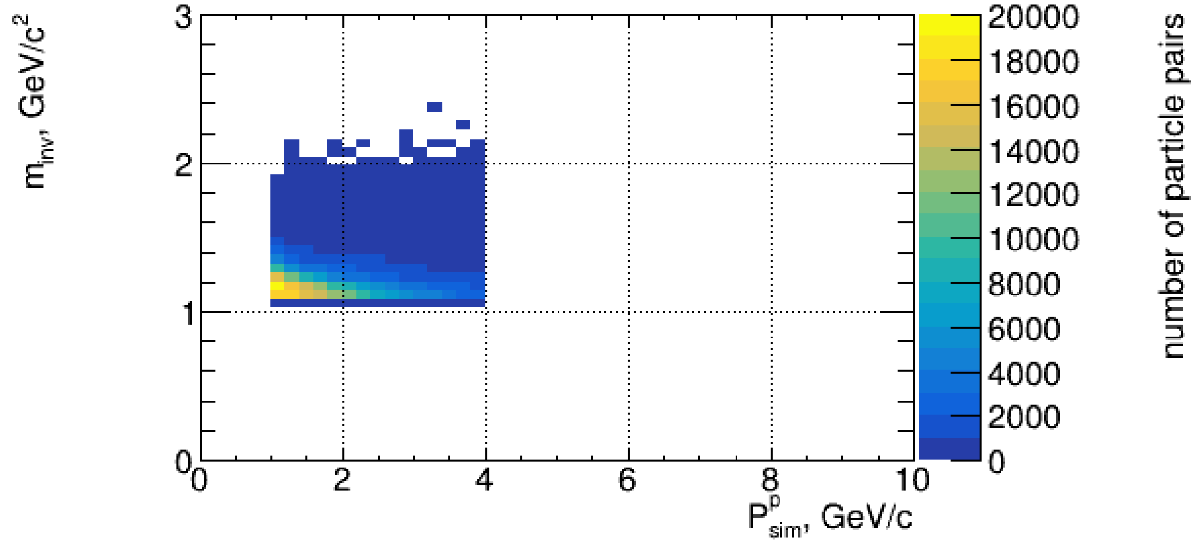

Figure 7: Two-dimensional invariant mass distribution before applying cuts

Reconstruction data can be obtained after applying *BmnTwoParticleDecay* to the output of *run_reco_bmn.C*. If reconstruction data is used similar distributions are plotted, with all variables being taken from the reconstruction. In case of experimental data, when there are no simulated data, it is impossible to find the number of reconstructed particle pairs corresponding to decayed Λ^0.

However, provided both simulation and reconstruction files are given, it is possible to extract a lot of information about particle pairs reconstructed with single particle reconstruction data as input, since it is possible to match reconstructed tracks to them simulated. In that case, it prints the number of reconstructed particle pairs corresponding to the same Λ^0, the number of them not corresponding to the

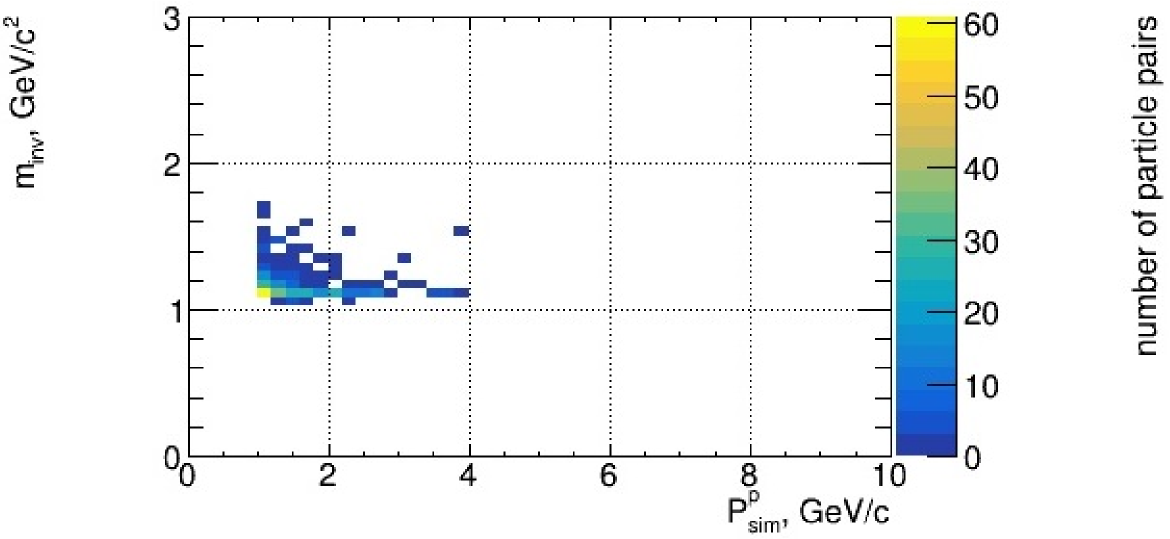

Figure 8: Two-dimensional invariant mass distribution after applying cuts

same Λ^0, and the number of simulated Λ^0 that have not been reconstructed. Moreover, it plots various parameter distributions like in the geometry analysis for primary particle pairs with matched simulated Λ^0 and a few distributions for simulated Λ^0 without matched reconstructed one. This part could be used to estimate how good is the entire Λ^0 reconstruction system would perform when it is used to reconstruct the experimental data.

Testing the quality assurance system

To make sure, that the quality assurance system implemented works correctly it was applied to a set of simulations. Histograms and text information obtained were checked on being in agreement with the general sense. For all of particles studied geometrical efficiency increased with momentum, pseudorapidity and rapidity, and decreased with angle to Z-axis, and all invariant mass distributions reached their maxima near 1.115 GeV/c^2, being a mass of Λ^0. Moreover, this module was applied to simulations with geometries of runs occurred in the spring of 2017 and in the spring of 2018 with aim to compare geometrical efficiencies. The difference between geometries in these runs was in adding two additional silicon stations. The comparison carried out showed a slight increase of the geometrical efficiency (Figures 9, 10).

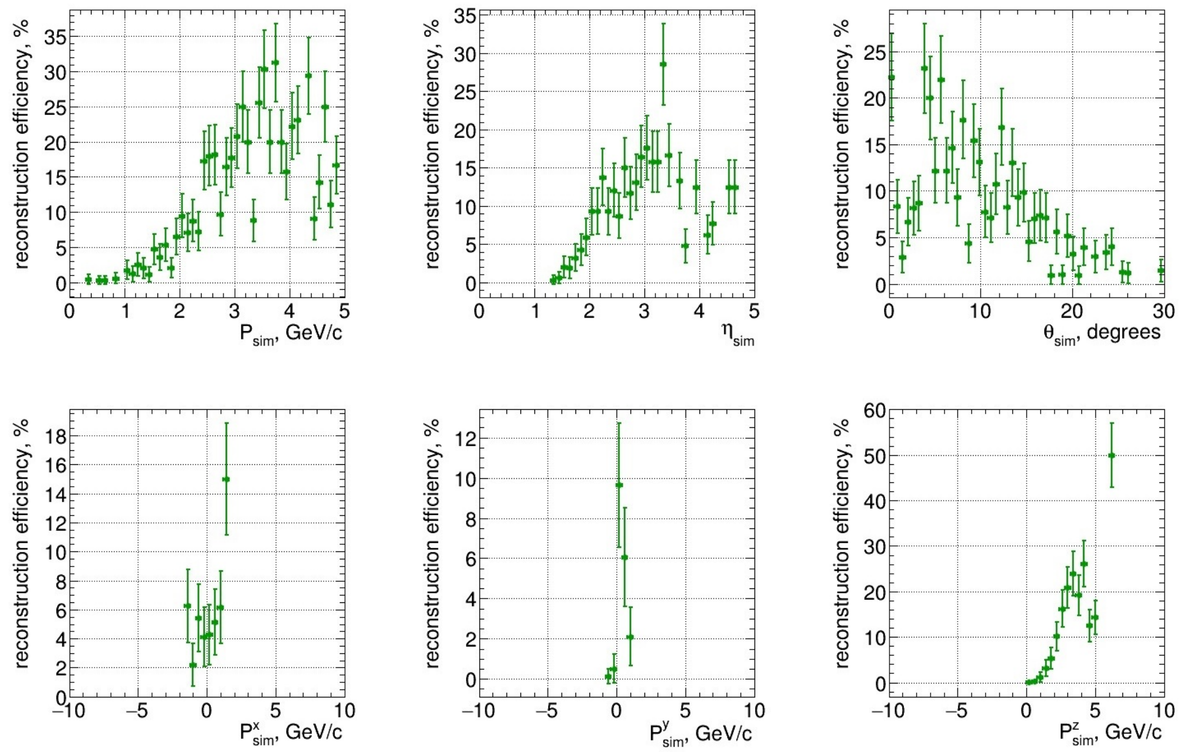

Figure 9: Λ^0 geometrical efficiency for run in the spring of 2017

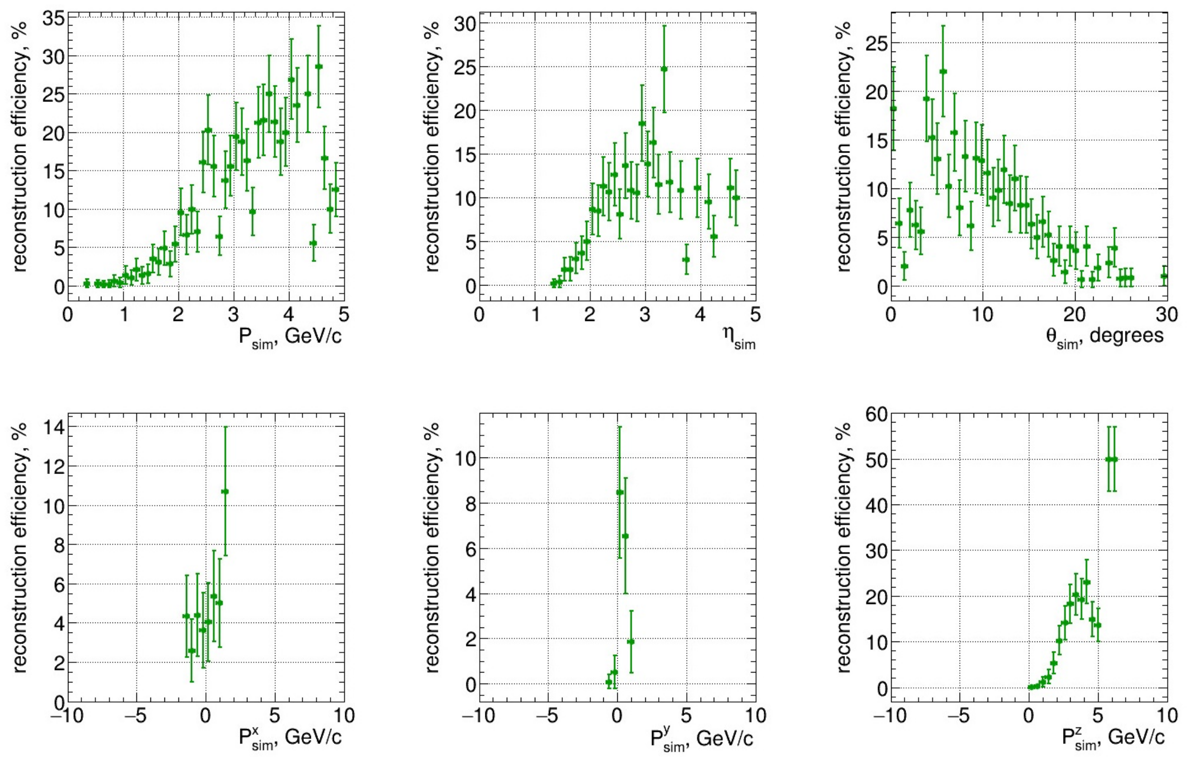

Figure 10: Λ^0 geometrical efficiency for run in the spring of 2018

Conclusion

The module of quality assurance for Λ^0 reconstruction was implemented. It is capable of conducting geometry analysis without reconstruction data and reconstruction analysis whether it takes simulated particle tracks as input or them reconstructed. Output information of this module do not seem to be in contradiction with the general sense. This system might help both for improving the geometry for Λ^0 reconstruction and to test algorithms for its reconstruction. Moreover, this system might be relatively easily generalized to test a geometrical efficiency and a reconstruction efficiency for any two particle decay. Particularly, it is expected to be applied for K_S^0 reconstruction in the foreseeable future.

References

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