JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Modeling of Beam-monitoring detector for MPD (Multi-Purpose Detector)

Supervisor: Dr. Oleg Vasilievich Rogachevsky
Student: Demezhan Myktybekov, Kazakhstan
Al-Farabi Kazakh National University
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Abstract

Beam monitoring detector in MPD experiment is essential to determine centrality and plane of the event for nucleus-nucleus interaction in the MPD detector. The results of beam-monitoring detector simulation and data analyzing in MPDROOT are written in this report.

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1 Physics objectives of the NICA project

The global scientific goal of the NICA/MPD project is to explore the phase diagram of strongly interacting matter in the region of highly compressed baryonic matter. Such matter could exist in neutron stars and in the core of supernova explosions, while in the early Universe we meet the opposite conditions of very high temperature and vanishing baryonic density [1]. In terrestrial experiments, high-density nuclear matter can transiently be created in a finite reaction volume in relativistic heavy ion collisions. In these collisions, a large fraction of the beam energy is converted into newly created hadrons, and new color degrees of freedom may be excited [2]. The properties of excited resonances may noticeably be modified by the surrounding hot and dense medium. At very high temperature or density, this hadron mixture melts and their constituents, quarks and gluons, form a new phase of matter, the quark-gluon plasma. Different phases of strongly interacting matter are shown in the phase diagram of figure 1.

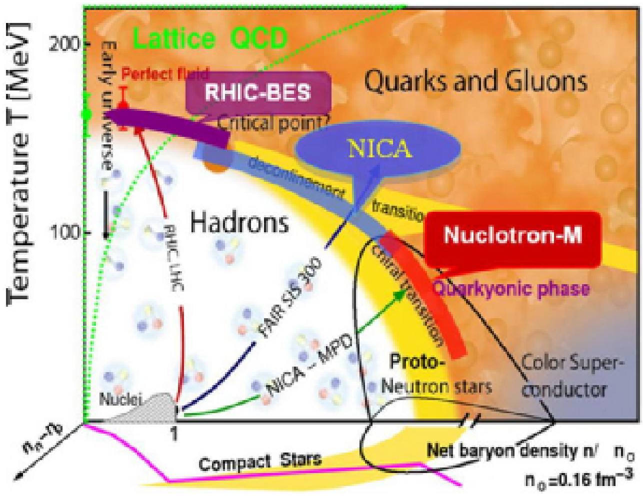


Figure 1: The phase diagram of strongly interacting QCD matter. Phase boundaries, critical end-point, and conjectured dynamical trajectories for an expansion stage are plotted as well.

The major goal of the NICA/MPD Project is the study of in-medium properties of hadrons and the nuclear matter equation of state, including a search for possible signals of deconfinement and/or chiral symmetry restoration phase transitions and the QCD critical endpoint in the region of the collider energy $\sqrt{s_{NN}} = 4 - 11$ GeV. Due to the high complexity of this task and large uncertainty in the predicted signals, an accurate scanning of the considered phase diagram domain in collision energy, impact parameter, and system size is utterly needed [3].

2 MpdRoot framework and MPD detectors simulation

The software framework for the MPD experiment (MpdRoot) is based on the objectoriented framework FairRoot and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data [4]. The basement of MpdRoot shown in figure 2.

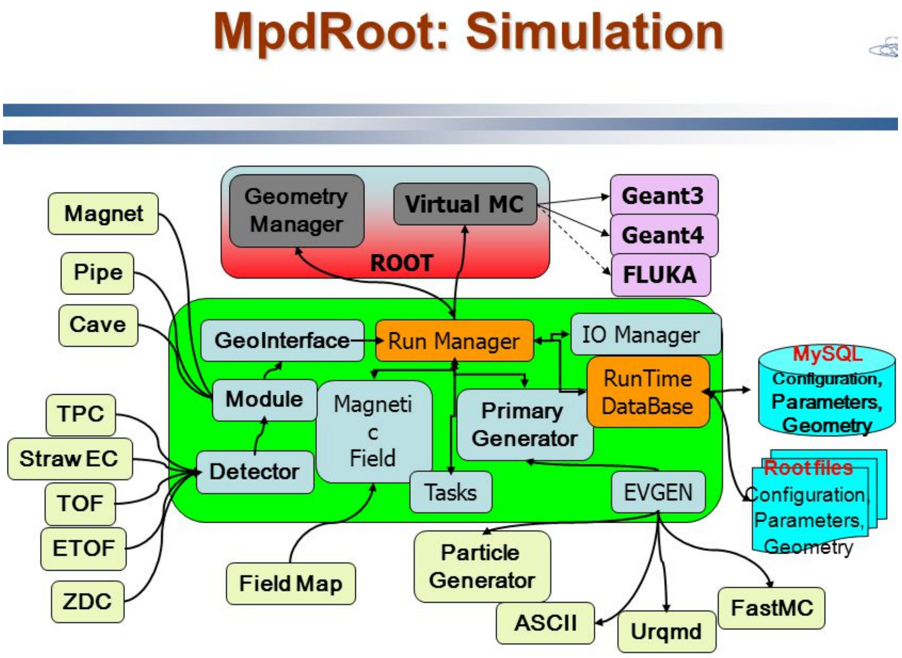


Figure 2: MpdRoot Design

The FairRoot project started in 2003/2004 as a software framework for the CBM experiment at GSI/FAIR [5]. FAIRROOT is ROOT - based platform involving all instruments for simulations data analyzing and transferring as GEANT3, Virtual Monte-Carlo,GEANT4, UrQMD and other. It became very useful for researches in high energy physics, therefore NICA project joined FAIR global research program in 2006. One of the design goals of FairRoot was to provide flexibility to the users, i.e. it should be possible to do for example simulations with different detector configurations or to test different tracking algorithms during the reconstruction without recompiling the code [6]. The basement of Fairroot shown in figure 3.

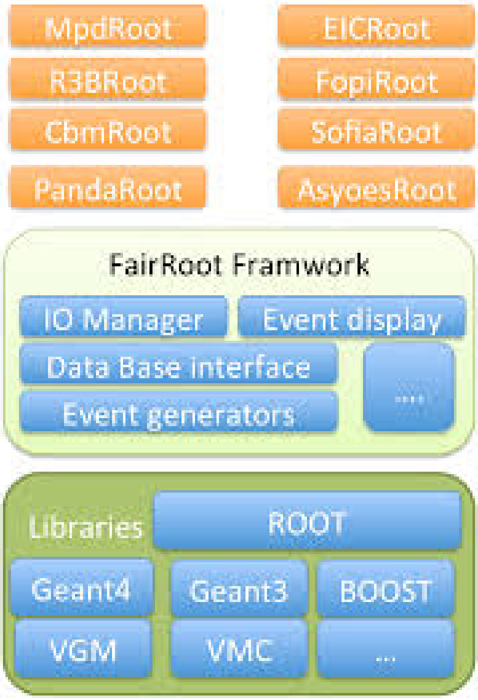


Figure 3: FairRoot Software Design

ROOT is an object-oriented program and library developed by CERN. It was originally designed for particle physics data analysis and contains several features specific to this field, but it is also used in other applications such as astronomy and data mining [7]. A typical application developed for researches in high energy physics (more details in figure ??. is used to process both real and simulated data, consisting of many events having the same data structure and assumed to be statistically independent [8]. In addition, complementary information is also needed to analyze the data, for example detector parameters (geometry, read-out powering and configuration, magnetic field maps, etc.) or input settings of the simulation engines. Such values do not change at the event scale. Rather, they have a slower evolution that defines a much coarser granularity: a run is defined by a set of events with constant settings [9]. The packages provided by ROOT include those for:

- Histogramming and graphing to view and analyze distributions and functions,
- curve fitting (regression analysis) and minimization of functionals,
- statistics tools used for data analysis,
- matrix algebra,
- four-vector computations, as used in high energy physics,

- standard mathematical functions,
- multivariate data analysis, e.g. using neural networks,
- image manipulation, used, for instance, to analyze astronomical pictures,
- access to distributed data (in the context of the Grid),
- distributed computing, to parallelize data analyses,
- persistence and serialization of objects, which can cope with changes in class definitions of persistent data,
- access to databases,
- 3D visualizations (geometry),
- creating files in various graphics formats, like PDF, PostScript, PNG, SVG, LaTeX, etc.
- interfacing Python and Ruby code in both directions,
- interfacing Monte Carlo event generators. [10]

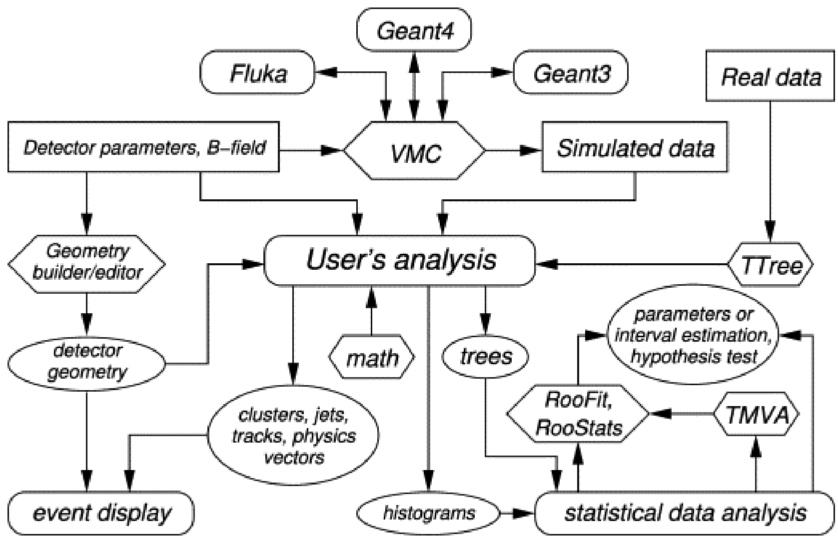
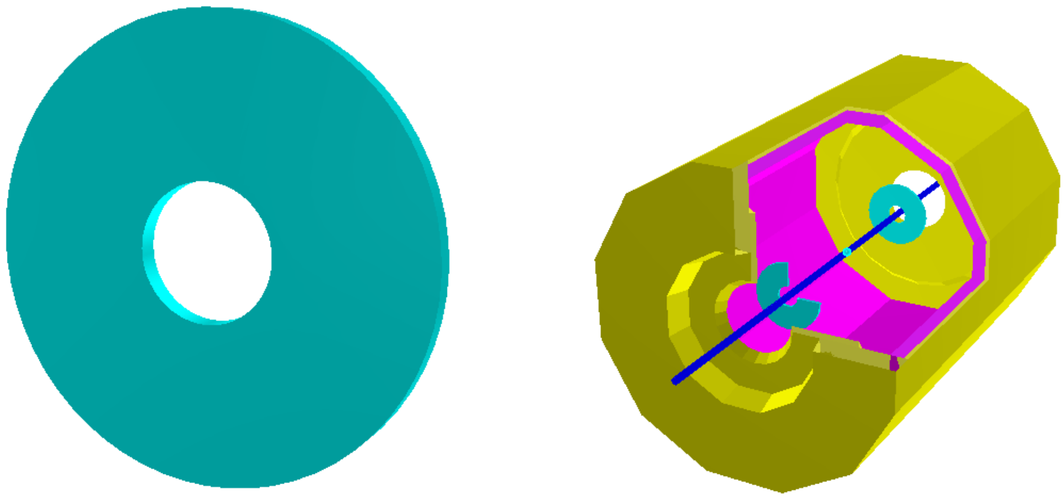


Figure 4: Example of typical usage of ROOT.

3 Beam-monitoring Detector

Simulation of the BMD detector has been done in MpdRoot with using of GEANT4 transport code. The Beam-monitoring detector is shown in the figure 5 as a whole disk from scintillation material with inner and outer radius as 150 and 500 mm. The main goal of BMD is monitoring and analyzing the beam, therefore BMD disks are set in two sides off the interaction point on the distance 1735 mm from the center.

Generated particles data were provided using a Ultra relativistic Quantum Molecular Dynamics (UrQMD) [11] generator on 10000 events of Au+Au collisions at the energy $\sqrt{s_{NN}} = 9$ GeV.



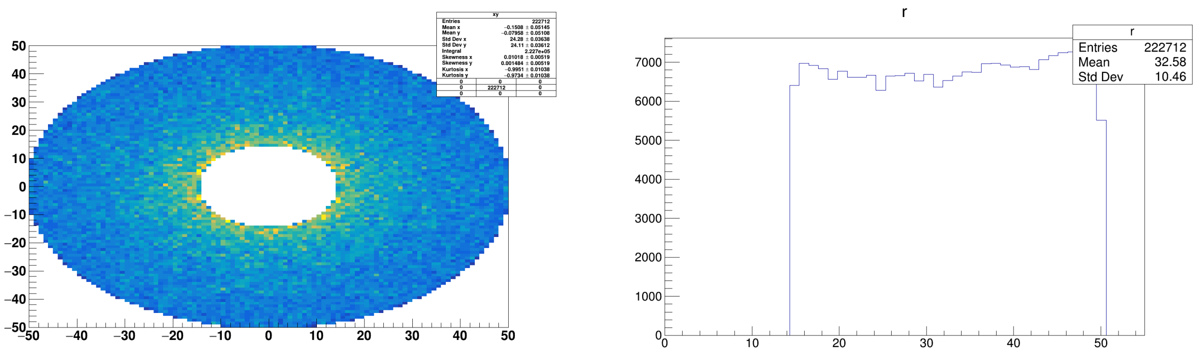
a b

Figure 5: The Geant geometry model of BMD.

Monte Carlo methods (or Monte Carlo experiments) are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. Their essential idea is using randomness to solve problems that might be deterministic in principle. They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other approaches. Monte Carlo methods are mainly used in three problem classes: [12] optimization, numerical integration, and generating draws from a probability distribution.

In physics-related problems, Monte Carlo methods are useful for simulating systems with many coupled degrees of freedom, such as fluids, disordered materials, strongly coupled solids, and cellular structures. In a Monte Carlo simulation, a random value is selected for each of the tasks, based on the range of estimates. The model is calculated based on this random value. The result of the model is recorded, and the process is repeated. A typical Monte Carlo simulation calculates the model hundreds or thousands of times, each time using different randomly-selected values. The simulation gives a large number of results from the model, each based on random input values. These results are used to describe the likelihood, or probability, of reaching various results in the model.

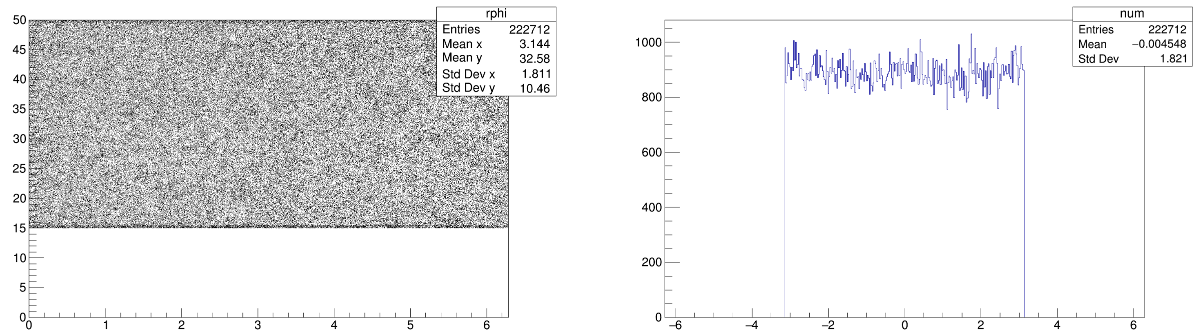
All simulated data saved in one macros: it linked with many classes in ROOT and draws histograms, records all particle numbers with their PDG codes and gives full description of events. The plane distribution is shown in figure 6(a). Smooth blue color means that all particles are evenly distributed in the plane of detector. The figure 6(b) shows an even particle distributions by radius.



a b

Figure 6: Plane distribution of Monte-Carlo points in BMD; left - XY plane , right - r

The particle distributions have to be even also by ϕ angle. This distribution shown in figure 7.



a b

Figure 7: The angle distribution of BMD detector: left - ϕ, right - θ

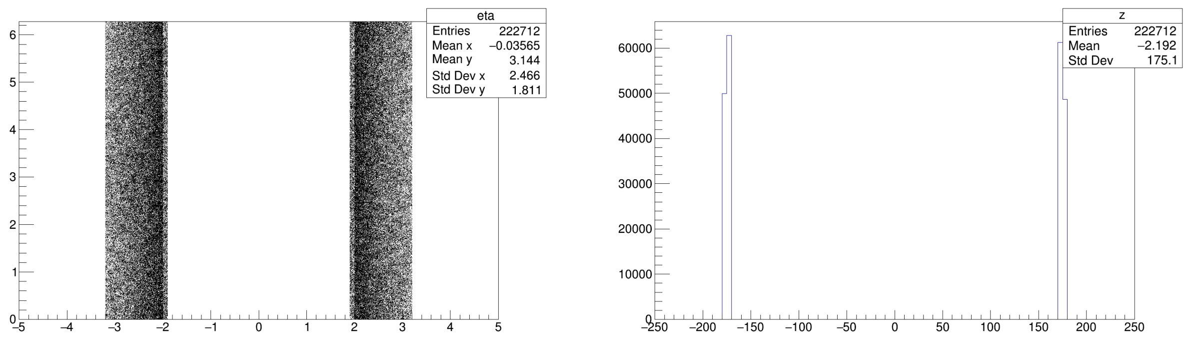
The next parameter is rapidity. The rapidity is monotonically increasing velocity function that tends to infinity when the velocity of the particle approaches the speed of light.

$$Y = \frac{1}{2}\ln\left(\frac{E + pcos\theta}{E - pcos\theta}\right) \tag{1}$$

where θ is a polar angle. Pseudorapidity is the function of angles of expansion:

$$\eta = -\frac{1}{2}\ln\left(\tan\left(\frac{\theta}{2}\right)\right) \tag{2}$$

Pseudorapidity and z-axis distributions of particles are given in figure 8.



a

b

Figure 8: Distribution of Monte-Carlo points for particles in BMD: left - rapidity, right - Z coordinate

The Monte Carlo particle numbering is intended to facilitate interfacing between event generators, detector simulators, and analysis packages used in particle physics [14]. The results of the Monte-Carlo Simulation also can be given in the type of particles. Using a class of MpdROOT <FairMCTrack.h> its possible to get the PDG codes of particles and their mother ID's. The distribution of PDG codes of particles detected on BMD shown in the figure 9.

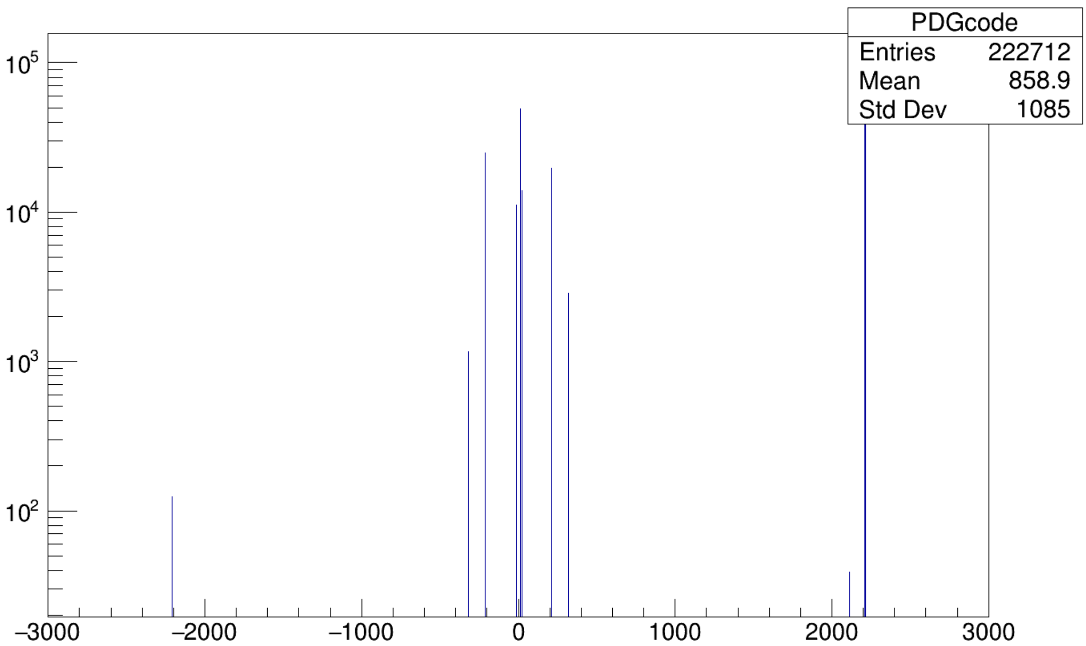


Figure 9: Particle PDG codes distribution, crossing BMD

Conclusion

During the Summer Student Program in the Joint Institute for Nuclear Research I have studied classes in MpdROOT to analyze events in Beam-Monitoring detector. Different variables distributions were used to study properties of the BMD: MC poins radius, azimutal anglrs ϕ, pseudorapidity η, PDG code, Z, XY coordinates. All of these distributions are shown in this report.

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