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FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Generation and reconstruction simulation of Lambda particles in MPD detector

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Abstract

The generation, transport, identification, and track reconstruction of lambda particles in the NICA-MPD tracking system is performed. The vertex reconstruction capability of the Time Projection Chamber (TPC) - Inner Tracking System (ITS) complex is assessed by means of MpdROOT software simulations. It was thoroughly studied and assimilated the previously existing codes, in order to adapt them to the specificity of our study cases. The calculation of the detection efficiency of lambda hyperons for two thousands central Au + Au collisions at $\sqrt{S_{NN}}$ = 9 GeV was performed giving acceptable results.

Introduction

The study of strongly interacting matter under extreme conditions is one of the most exciting and demanding goals of modern nuclear physics. The recent discoveries of neutron stars mergers and supermassive neutron stars drives us to the understanding of the high-density baryonic matter, as well as its equation of state and the microscopic degrees of freedom. High-energy heavy ions collisions offer the possibility to study the new phases of matter such as quark-gluon plasma, which may feature characteristic structures such as a first order phase transition with a region of phase coexistence and a critical endpoint. The experimental discovery of these prominent landmarks of the QCD phase diagram would be a major breakthrough in our understanding of the properties of nuclear matter, with fundamental consequences for our knowledge on the structure of neutron stars and the dynamics of neutron star collisions. It is with these objectives that the major heavy-ions accelerator Nuclotron-based Ion Collider fAcility (NICA) is being constructed by the Joint Institute for Nuclear Research (JINR) in Dubna, Rusia [1].

The Multi-Purpose Detector (MPD) is one of two major particle detector based at NICA, aimed to study the properties of hot and dense and dense nuclear matter formed in central heavy nucleus. Models predict that in such reactions heavy quarks generated in initial nucleons impacts carry information about the excited nuclear medium at an early stage of its formation [2]. Therefore, heavy quarks are expected to be important probes of medium dynamics in strongly interacting matter [3]. Measuring the yields of particles with heavy flavours in a wide range of transverse momentum is important for understanding the critical phenomena during anticipated phase transitions in nuclear matter.

In order to register these flavoured particles with decays lengths ranging from tenths of millimeters to hundreds of micrometers, it is needed the use of vertex detectors with high spatial resolution located as close as possible to the point of particle generation. For the identification of secondary particle decays, the MPD experiment will consist of a Time Projection Camera (TPC), together with an Inner Tracking System (ITS). The good spatial resolution and high bandwidth of the ITS pixel sensors, together with its high level of segmentation per pixel allows installing detectors of this type at distances of several centimeters from the interaction point without risking their overload. The ITS-TPC installation will make possible the detection of short-lived nucleus-nucleus products with the maximum efficiency.

It is the goal of this work to assess the identification capability of the ITS-TPC tracking system for lambda particles generated in central Au+Au collisions at $\sqrt{S_{NN}}$ = 9 GeV.

MPD tracking system

The main MPD tracking detector is the TPC that provides the precise reconstruction of particle tracks and their momenta in the central rapidity region. It also identifies the charge of the particles by their measured energy losses [4]. In order to achieve the reliable identification of short-lived hadrons, the TPC will be supplemented with the ITS, the main purpose of which will be increasing the accuracy of reconstruction of the coordinates of primary interaction and secondary vertices of unstable particle decays as well as the reduction of the threshold of registration of charged particles with small transverse momenta.

The MPD ITS is to be build based on MAPs technology with a sensor thickness of 50 μm. In ITS the pixel sensors will be grouped onto modules and super modules. They will be located along the surfaces of coaxial cylinders around the interaction diamond of the NICA collider beams. It is expected that the radiation thickness of carbon-composite structures of the pixel-detector support, cooling system, and the detectors themselves will not exceed 1% of the radiation length, to reduce the influence of multiple scattering on the ITS resolution.

The free space for installation of ITS is limited on the inside by the beam pipe diameter which can vary from 40 to 60 mm and, on the outside, by the TPC inner diameter of 50 cm. These limitations together with the defined size of the MAPS to be used result in ultra-light carbon fiber support structure with five-layer version of the vertex detector general view of which is depicted in Fig. 1. Two ITS outer layers will be built from the ladders equipped with sensors with a sensitive matrix of 15 x 30 mm^2 containing 512 x 1024 pixels. The ladders of three inner layers will contain new generation MAPS with larger area and reduced thickness, which will be installed in the ITS, when it will be possible to reduce the diameter of the MPD beam pipe to the optimal value of 40 mm [5].

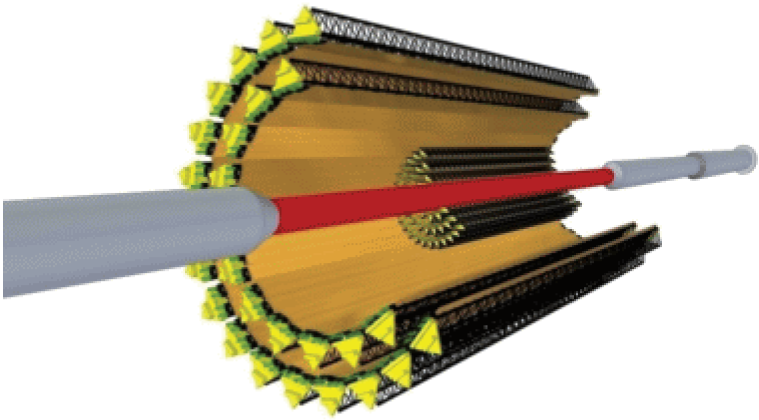

Fig. 1. View of the Inner Tracking System and the beam pipe of the MPD.

Particle reconstruction method

The yields of flavoured particles generated in nucleus-nucleus collisions at NICA collider energies ($\sqrt{S_{NN}}$ = 4 - 11 GeV) will be measured at the MPD facility by registering charged products of their hadron decays. The evaluation of the identification ability of the MPD tracking system to reconstruct the decay vertices of strange and charmed particles was carried out in the MpdROOT software object-oriented environment [6], the main interfaces and components of which are shown in Figure 2. The Monte Carlo transport of the particle events delivered by the event generator via MPD track detectors was carried out using the GEANT4 software package integrated in MpdROOT. At the transport step detector responses (hits) were created, then, with this, the charged particle tracks were reconstructed with the help of the Kalman filter method [7]. The tracks coordinates were determined from the column and row number of the pixel hit by the transported particle.

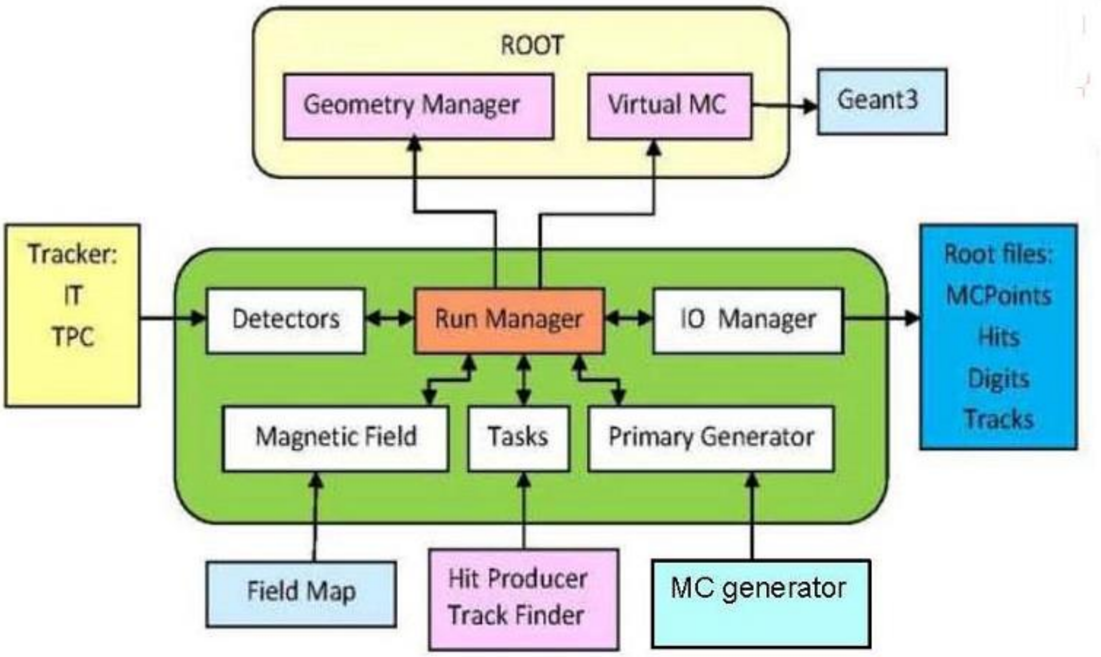

Fig. 2. The software environment of MpdROOT.

To generate events of nucleus-nucleus collisions with the creation of strange and charmed particles at the energies of the NICA collider, the QGSM event generator, based on the quark-gluon string model [8], was used.

The track reconstruction procedure used in the calculations of the efficiency of extracting strange and charmed particles includes two stages: track finding [7] and track fitting [9]. The track finding is based on the Kalman filter algorithm. The algorithm starts with selecting a cluster in the initial layer of detectors and attaches the cluster in the next layer repeating the procedure layer by layer. The tracks found in the TPC over a large number (about 40) of clusters are then extended to the vertex detector. After the candidate tracks that match all possible combinations of different clusters in the same layers are selected, they are fitted to choose the best track with the minimum value of χ^2.

In nucleus-nucleus collisions events involving the birth of a large number of primary particles, the background for physical signals corresponding to the true decays of short-lived particles is a large number of random combinations of tracks that do not correspond to a real particle. In order to achieve a significant suppression of such combinatorial background, it is necessary to use strict criteria for selecting useful events. The topology of decay of short-lived particles into charged hadrons dictates the selection criteria with the following parameters:

- the distance of closest approach between the decay-product tracks and the primary interaction vertex of colliding nuclei (dca);
- the distance between the daughter tracks at the vertex of the mother particle decay (distance);
- the path of the mother particle from the point of its generation to the point of its decay (path);
- the angle between the vector connecting the primary and the secondary vertices and the vector of the reconstructed momentum of the mother particle (angle).

The values of the above mentioned selection parameters and the values of χ^2 for the decay product tracks are optimized together for each particle type based on the requirement of maximum significance $S/\sqrt{S+B}$, where S and B are the number of signal and background events, respectively.

The decay of short-lived hadrons were identified by appearance of the peak corresponding to the mother particle in the invariant mass spectrum of its decay products along a fixed hadron channel. The MC identification of the tracks was used to discern the decay products; in the real experiment, the identification will be based on information about the time of flight from the TOF detectors and the specific energy losses of the particle in the TPC.

Reconstruction of Lambda particles

The detection of strange hyperons is based on the precise reconstruction of the Λ particle through its decay products. Therefore the high efficiency of the Λ reconstruction is a good criterion of the identification capability of a tracking system. Because the Λ particle is relatively long-lived, it is easier to reconstruct the vertex of its decay. In addition, large multiplicity of Λ baryons in heavy nucleus collisions at the NICA collider energy makes it easier to extract the signal from the combinatorial background. Table 1 shows some of the properties of the Λ particle.

The first stage of the work was dedicated to the study and assimilation of the simulation codes, the changing of running parameters, the way they are connected to each other and the manipulation of the input/output files. The simulation procedure is first formed by the generation code, in which the initial particle energy, the number of events and the randomly distribution of initial momentum can be set in convenience. Then, there is the MC background generation code, where are set the QGSM generator, the detector geometry and the decay mode of the studied particle, it is here where the transportation and decay of particles is done. Later, the reconstruction code is used to estimate, by means of the Kalman filter, the particle's tracks, using the output data from the previous step. Afterwards it was used the analysis script, where the chosen topological cuts were applied to the reconstruction results to discern the real lambda decay events from the combinatorial background. Finally it was used a last script to do the fitting and drawing of the invariant mass spectrum of the daughter particles (π^- , p).

Table 1. Lambda particle properties

Rest mass (MeV/c^2)	Decay length cτ (mm)	Quark content	Electric charge	J^P	Main decay channel	BR (%)
1115.68 ± 0.01	78.9	uds	0	½+	π^- + p	63.9

Reconstruction of Λ hyperons was performed in 2000 central Au + Au collisions at $\sqrt{S_{NN}}$ 9 GeV simulated using DQGSM generator. In order to extract the signal in the invariant mass spectrum M (π^- ; p) of Λ decay products, the following criteria, represented in Fig. 3, were used:

- dca(π) > 0.3 cm;
- dca(p) > 0.3 cm;
- dca(Λ) < 0.5 cm;
- λ(Λ) > 0.0 cm;
- θ < 0.009 rad.

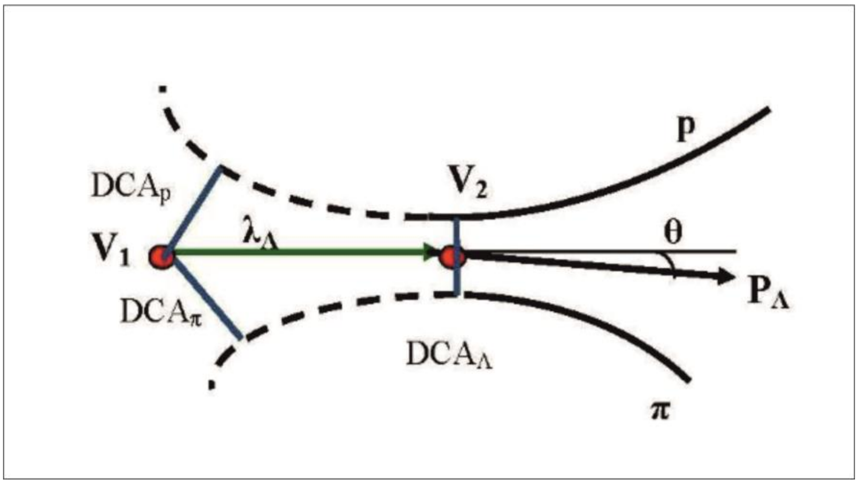

Fig. 3. Schematic representation of track reconstruction and topological cut for Λ particle decay.

In Figure 4, it is shown the invariant mass spectrum of the Λ decay products without applying the above-mentioned cuts.

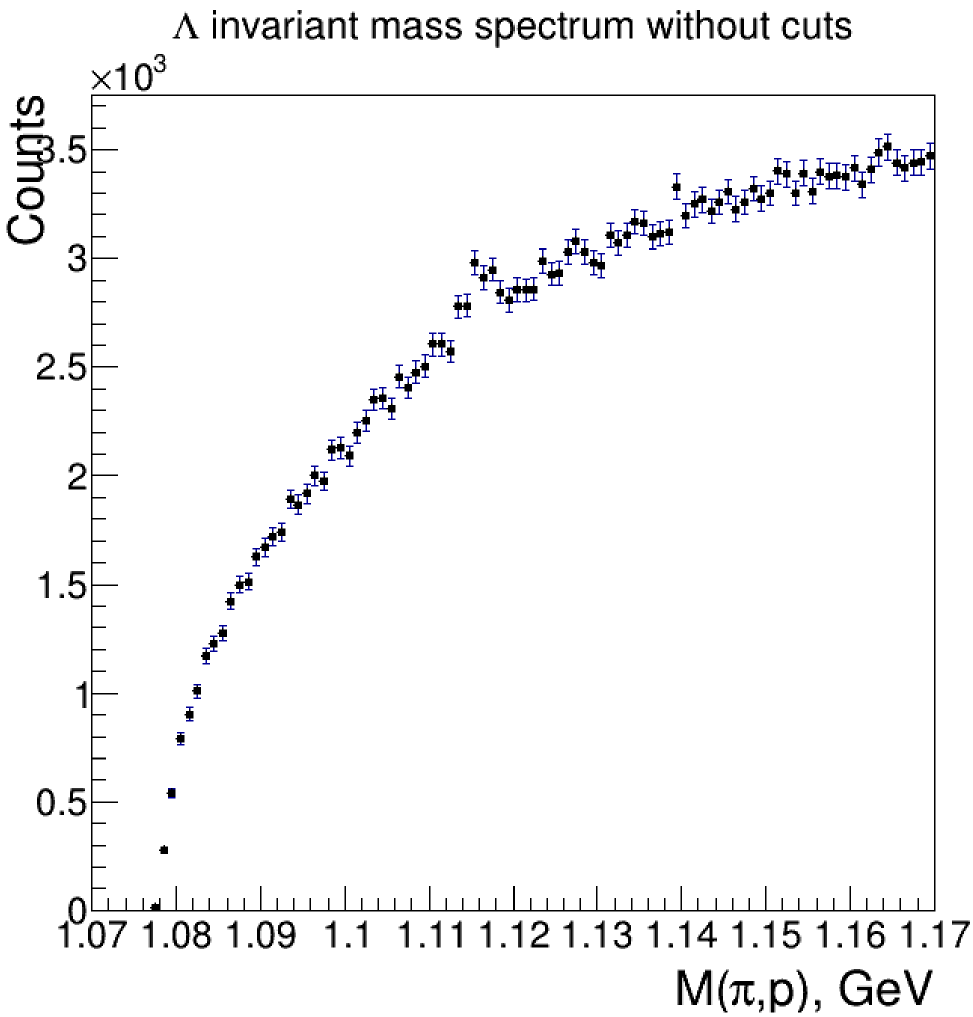

Fig. 4. Invariant mass spectrum of Λ decay products with no topological cuts.

In order to extract the signal (S) corresponding to Λ hyperon, the range near the peak of the obtained spectrum, which centroid corresponds to the tabular value of the Λ mass, was approximated by the sum of a Gaussian with third order polynomial function. The area under the polynomial function in the interval ± 3σ around the peak determines the level of the background (B), and the integration of the Gaussian distribution in the same interval provides an estimate of the number of reconstructed Λ hyerons.

Figure 5 shows the reconstruction results after applying the topological cuts. As can be seen, the values of significance 16.2 and signal to noise ratio 4.6, together with a detection efficiency of 5.4%, were obtained. It is also notable the good agreement between the mass of the reconstructed Λ baryons, 1.11563 ± 0.00002 GeV/c^2, and its corresponding PDG value (Table 1).

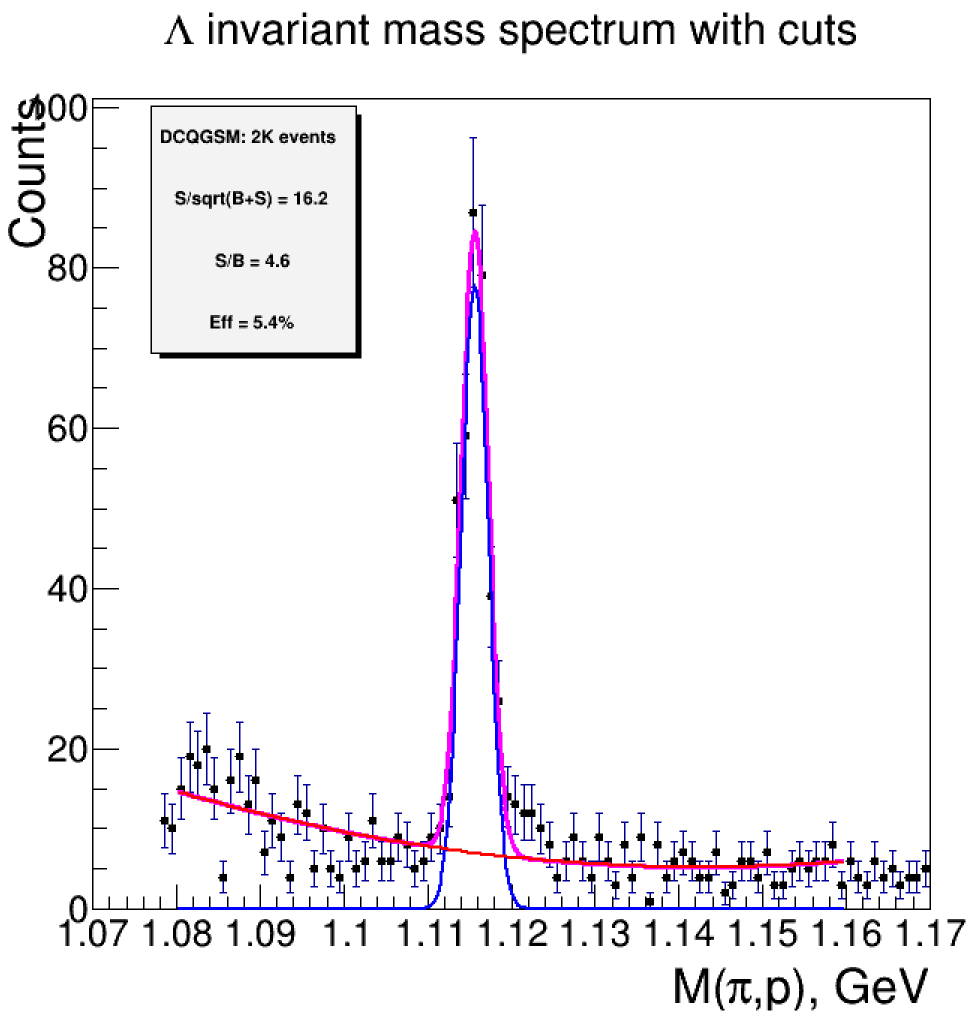

Fig. 5. Signals of Λ-hyperons in the invariant mass spectrum M(π^-,p) extracted from 2k Au + Au collisions at $\sqrt{S_{NN}}$= 9 GeV (purple line - full spectrum, blue line - signal, red line - residual combinatorial background)

Conclusions

The identification simulation of Lambda particle by the MPD tracking system, which is formed by a time projection chamber and a vertex detector based in pixel sensors, was carried out. The detection efficiency, the significance level and he signal to noise ratio were calculated, with acceptable results, improvable through a better selection of cuts and higher statistics. It is shown the suitability of the method for the reconstruction of charmed hadrons, such as D^0 and D^+ mesons, significant particles for the study of the early stages of the quark gluon plasma in heavy ions collisions. It is also intended to continue this study with the implementation of the new design of ITS and the comparison, by means of the here explained methods, with the previous geometry.

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