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Performance studies for strange hadron flow measurements in CBM at FAIR

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Abstract

Measurements of the directed and elliptic flow of strange and multi-strange hadrons are an important part of the physics program of the Compressed Baryonic Matter experiment (CBM) at the future accelerator complex FAIR in Darmstadt, Germany. We present recent results from the CBM performance studies for measurements of the directed (v_1) flow of strange hadrons, Λ and K_s^0. For performance studies we use CbmRoot environment for Monte-Carlo simulations and event reconstruction. Heavy-ion collisions at the FAIR beam energy of E_{beam} = 10 GeV per nucleon are simulated using the UrQMD event generator. Kalman Filter Particle Finder (KFParticleFinder) package is utilized for hyperon reconstruction via their weak decays, and the Projectile Spectator Detector (PSD) and Silicon Tracking System (STS) are used for centrality and event plane estimation. Effects due to non-uniformity of the CBM detector response in flow studies are investigated using the Qn-vector corrections framework originally developed for ALICE experiment at the LHC.

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1. Introduction

The Compressed Baryonic Matter experiment [1] at the future FAIR facility is dedicated to studies of QCD phase diagram at high baryonic densities and moderate temperatures produced in heavy-ion collisions. A very high collision rate up to 10 MHz is expected at CBM and continuous streaming readout is proposed.

It was shown recently by studies from the RHIC BES program that $dv_1/dy|_{y=0}$ and the difference between v_2 of particles and antiparticles in the $\sqrt{s_{NN}}$ region of a few GeV are of great interest for understanding a pattern of the phase transition between quark-gluon and hadronic matter [2]. Precision measurements of these observables in CBM experiment will be a significant step forward in exploration of the QCD phase diagram in the region of a $\sqrt{s_{NN}}$ = 2-5 GeV.

2. Simulation setup

10 AGeV Au-Au collisions are simulated with the UrQMD generator (version 3.4) [3] and the GEANT3 transport code. MDV, STS, RICH, TDR, TOF and PSD hits are simulated, then reconstructed into tracks and clusters and processed into reduced analysis tree within CbmRoot.

Three CBM detectors are of special importance for this performance study. The STS [4] and MVD detectors, located in the central rapidity region, are used for track reconstruction and identification as well as for event plane determination and centrality estimation. PSD detector [5] located in the forward rapidity region is used for spectator detection, event plane determination and centrality estimation. PSD geometry used in the simulations is: 44 modules 20 × 20 cm^2 covering full azimuthal angle with three groups of modules. The beam pipe hole is 10 cm.

3. Strangeness reconstruction in CBM

The KF (Kalman Filter) Particle Finder algorithm [6] is used to identify Vo decays (Λ, $\bar{\Lambda}$, K_s^0) in the reconstruction. Invariant mass distributions for (Anti)Λ and K_s^0 are shown at Fig. 1.

4. Centrality determination in CBM

Centrality is needed to obtain event classes for different impact parameter b intervals. In CBM the centrality can be calculated with the PSD energy, the STS track multiplicity or a combined 2D distribution [7]. For 1D distributions the fitting procedure with Negative Binomial Distribution is used [8]. N_{coll} and N_{part} parameters are obtained with Glauber Monte-Carlo model [8]. For 2D distributions an iterative procedure is used for profiling, fitting, perpendicular profiling. It was shown [7] that by using a combined 2D estimator one can improve impact parameter resolution for central collisions (0-30% centrality). In the studies reported here we have used STS tracks multiplicity as the estimator for event centrality.

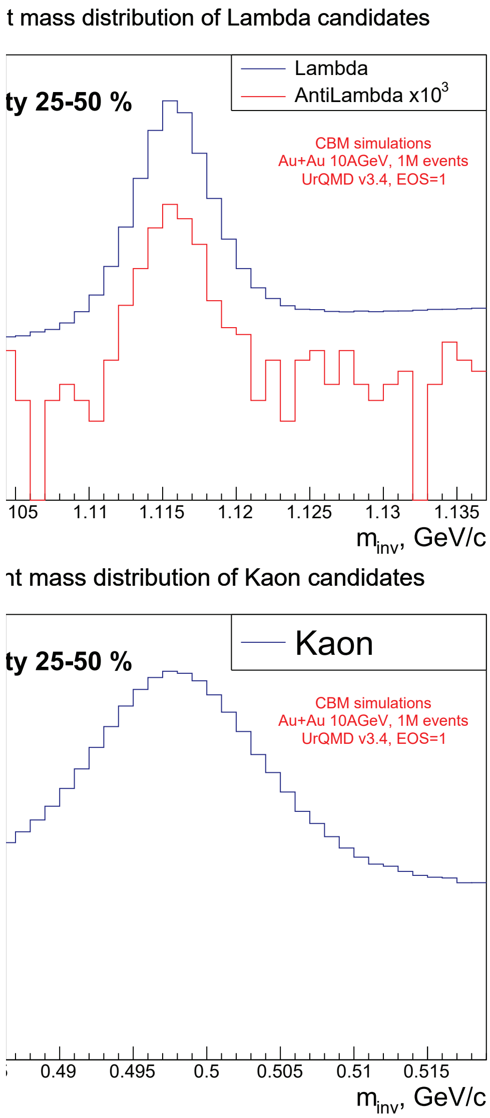

Figure 1: Invariant mass distributions for Λ and $\bar{\Lambda}$ (left) and K_s^0 (right) for centrality 25-50%.

5. v_n extraction procedure

Anisotropic transverse flow is the effect of azimuthal anisotropic particle production with respect to the reaction plane (1).

$$\frac{dN}{d(\varphi - \Psi_{RP})} \sim 1 + 2\sum_{n=1} v_n(p_T, \eta)\cos[n(\varphi - \Psi_{RP})], \tag{1}$$

The scalar product (SP) method is used to extract the flow coefficients v_n, eq. (2). In this method Q-vectors defined in (2) of subevents corresponding to 3 groups of PSD modules or STS subevents separated in rapidity are correlated with particle's unit vector. For the correction of the finite resolution a factor R is used to obtain true v_n values [9].

$$Q_{n,j} = \sum_{i=1}^{M} e^{nj\varphi_i}; v_n^{obs} = \langle\langle u_{ij} Q_j \rangle\rangle; v_n^{true} = v_n^{obs}/R; j \in \{x, y\}. \tag{2}$$

The invariant mass method to separate flow contribution of decaying particles from flow of combinatorial background is implemented: v_n is calculated for each bin in invariant mass as well as the signal to background ratio. v_n of the combinatorial background is estimated in the regions outside of the mass peak and v_n of the signal is obtained with formula (3).

$$v_n^S = v_n^{meas} + \frac{Bg}{S}(v_n^{meas} - v_n^{Bg}), \tag{3}$$

where Bg and S are Background and Signal values, respectively, in the invariant mass distributions.

In experiment non-uniformity of detectors' acceptance leads to distortions of the Q-vector distributions. We utilize Q-vector Corrections framework [10] which implements corrections for these effects, such as gain equalization, recentering, alignment. In this study recentering correction is applied to the Q-vectors of each subevent.

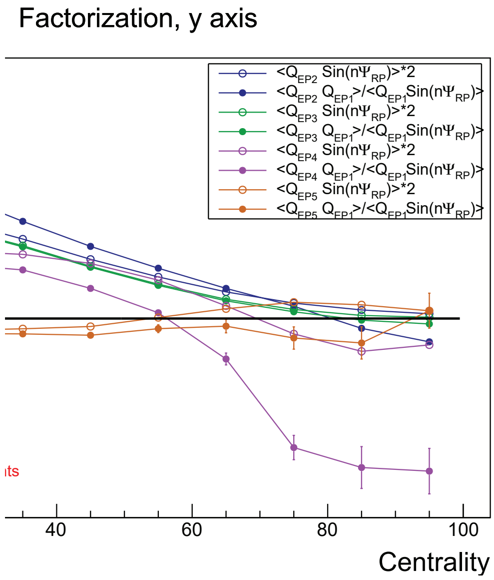

Figure 2: $\langle Q_i Q_j \rangle / \langle Q_j \sin(n\Psi_{RP}) \rangle$ and $2\langle Q_i \sin(n\Psi_{RP}) \rangle$ compared for: EP1 – central, EP2 – middle, EP3 – outer PSD modules, EP4 – STS forward ($1.53 < y < 3.06$, $0.3 < p_T < 2$ GeV/c), EP5 – STS backward ($0 < y < 1.53$, $0.3 < p_T < 2$ GeV/c).

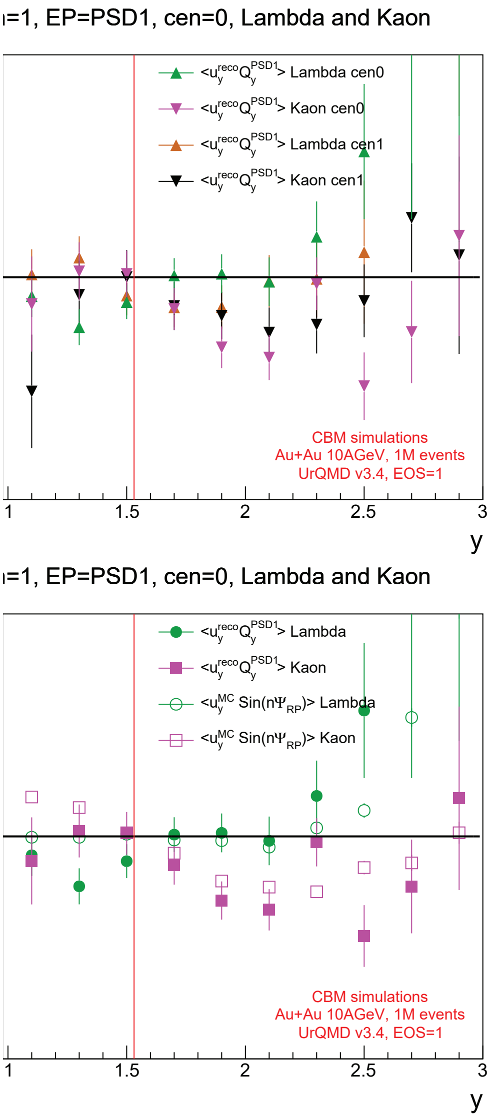

Figure 3: Left: $v_1(y)$ for Λ and K_s^0 for centralities 0-25% and 25-50%. Right: $v_1(y)$ for Λ and K_s^0 from the MC and reco particles correlated with RP and Q-vectors from PSD1 subevent.

6. Results

A dedicated study was performed to check if eq.(4) is true or breaks due to non-flow effects and momentum conservation law. For simplicity, vectors $Q_{n,j}$ defined in eq.(2) are scribed as Q_j taking into account that we used only 1st harmonic here.

$$\frac{\langle Q_i Q_j \rangle}{\langle Q_j \sin(n\Psi_{RP})\rangle} \stackrel{?}{=} 2\langle Q_i \sin(n\Psi_{RP})\rangle \quad (4)$$

Correlations between Q-vectors from PSD and STS subevents as well as correlations of Q-vectors and reaction plane angle are shown on Fig. 2. One can see that factorization is kept only for $\langle Q_1 Q_3 \rangle$ for mid-central collisions. The mixed harmonics procedure to calculate the resolution factor is necessary to obtain the correct value from observables.

Directed flow (v_1) of Λ and K_s^0 extracted for MC and reco particles is shown on Fig. 3. $v_1(y)$ for two centrality classes (0-25% and 25-50%) are also shown on Fig. 3. Flow dependence obtained with SP method differs from model distribution both for Λ and K_s^0.

7. Conclusions

First performance studies with the UrQMD model and the CbmRoot detector response simulations were carried out. Collective flow methods are implemented to extract directed flow of Λ baryons and K_s^0 mesons in Au+Au collisions with 10 AGeV energy expected at the future SIS100 accelerator in several centrality classes.

We observe the difference between model distributions and the ones obtained with PSD Q-vectors due to Q-vector factorization breaking.

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