Conference Paper

CBM performance for anisotropic flow measurements

V. Klochkov[1,2] and I. Selyuzhenkov[1,3]

[1]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, Darmstadt, Germany
[2]Goethe University Frankfurt, Max-von-Laue-Straße 1, Frankfurt am Main, Germany
[3]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia

Abstract

Compressed Baryonic Matter experiment (CBM) at FAIR has a potential of discoveries in the area of QCD phase diagram with high net baryon densities and moderate temperatures. Anisotropic transverse flow is one of the key observables to study the properties of matter created in heavy-ion collisions. CBM performance for anisotropic flow measurements is studied with Monte-Carlo simulations of gold ions at SIS-100 energies using heavy-ion event generators. Different combinations of the CBM detector subsystems are used to investigate the possible systematic biases in flow measurement and to study effects of detector azimuthal non-uniformity. Resulting performance of the CBM for flow measurements is demonstrated for directed flow of identified charged hadrons as a function of rapidity and transverse momentum in different centrality classes.

Corresponding Author:
V. Klochkov
v.klochkov@gsi.de

I. Selyuzhenkov
ilya.selyuzhenkov@gmail.com

Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

1. Introduction

Due to the interaction among particles produced in a heavy-ion collision, the initial spatial asymmetry in the overlap region of the collision leads to the asymmetry in the direction of the particle's transverse momenta. The asymmetry can be measured via azymutal distributions of produced particles with respect to the initial symmetry plane (reaction plane, RP) spanned by the impact parameter and the beam direction. For a given reaction plane angle in the laboratory frame (Ψ_{RP}) the azimuthal angle (ϕ) distribution of the particle momenta can be decomposed as:

$$\rho(\phi - \Psi_{RP}) = \frac{1}{2}\left(1 + \sum_{n=1}^{\infty} v_n \cdot \cos\left(n(\phi - \Psi_{RP})\right)\right). \tag{1}$$

Flow coefficients v_n quantify the the asymmetry in a given harmonics in the Fourier expansion of the distribution. Magnitude of v_n depends of the system size, energy, centrality and other event and particle properties.

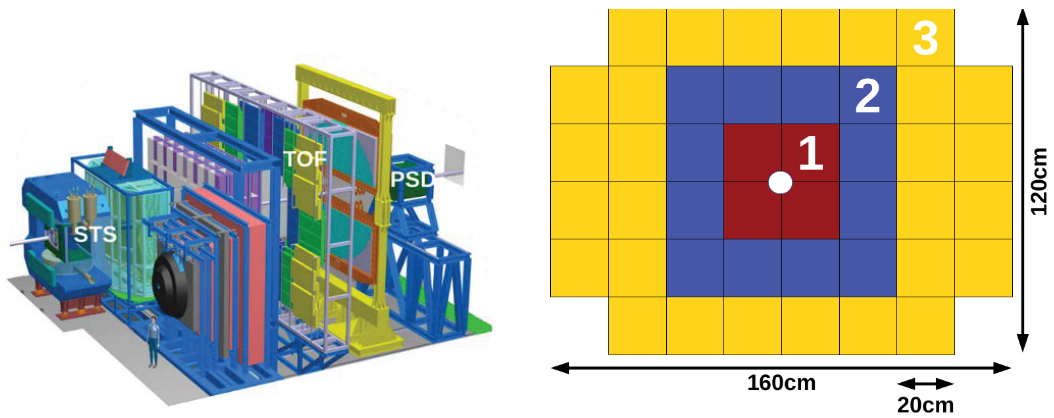

Figure 1: Left: layout of the CBM experiment. Right: transverse to the beam layout of the PSD modules. Colors show module subgroups used in the analysis: PSD1, PSD2 and PSD3.

2. CBM simulation setup

CBM is a future fixed target experiment at FAIR. Its detector subsystems are shown in figure 1 *(left)* and includes Superconducting Dipole Magnet [1] (maximal magnetic field is 3.25 T), Micro-Vertex Detector (MVD), Silicon Tracking System (STS) [2], Ring Imaging Cherenkov Detector (RICH) [3], Transition Radiation Detector (TRD), Time-of-Flight Wall (TOF) [4], Electromagnetic Calorimeter (ECal) and Projectile Spectator Detector (PSD) [5]. Tracking detectors MVD and STS have an acceptance in polar angle (Θ) $2.5^{\circ} < \Theta < 25^{\circ}$. The PSD has 44 modules elongated in x direction and covers the range in x (y) of $0.21^{\circ} < \Theta < 5.7^{\circ}$ (4.3°) at a distance of 8 m from the target which is optimized [5] for FAIR energy range $\sqrt{s_{NN}}$=2.7-4.8 GeV. The PSD has a 10 cm hole in the center which is needed to avoid radiation damage at high beam intensities expected at CBM. It is sensitive to spectator fragments (central modules) and produced particles (outer modules).

A sample of 5M Au+Au collisions with beam momentum of 10 AGeV simulated with UrQMD event generator [6] was used for the analysis. PSD was shifted horizontally in the transverse plane by 11 cm which account for the beam deflection in magnetic field with a bending power of 1 Tm. CBMROOT release JUL17 [7] is used to simulate the detector response to particles transported with GEANT3 [8] through the CBM setup. Charge particles tracks are reconstructed in STS and MVD. The PSD modules were grouped into PSD1, PSD2 and PSD3 subgroups as shown in the figure 1 *(right)*.

3. Event, track and centrality selection

Events with a good primary vertex reconstruction quality (χ^2/NDF < 3) were selected. Event multiplicity (M_{trk}) calculated from tracks with a good quality fit (χ^2/NDF < 3)

DOI 10.18502/ken.v3i1.1776

and a number of hits associated to the track more than 70% out of the total possible number for this track. Particle idetification was done using MC-true information.

Event classification (centrality determination) is performed following the procedure described in Ref. [9, 10]. Figure 2 *(left)* shows the result of the event classification procedure using the multiplicity distribution of charged particles reconstructed in the CBM STS.

4. Performance for anisotropic transverse flow measurement

To estimate the reaction plane orientation it is common to use the azimutal asymmetry of particle production in the transverse plane to the beam direction. Due to the momentum transfer between participants and spectators, the spectators (fragments of projectile and target nuclei) are deflected in the course of the collision. For non-central collisions, the asymmetry of the initial energy density in the transverse plane is expected to be aligned in the direction of the reaction plane, and thus the spectator deflection direction is likely to be correlated with the impact parameter (or reaction plane) direction. One can estimate the reaction plane angle with spectators detected in the PSD and extract flow of produced particles detected in the STS with respect to this plane.

The asymmetry of the measured distributions is described in terms of two dimensional vectors u_1, q and Q determined event-by-event from the STS tracks and groups of PSD modules (sub-events):

$$Q = \frac{1}{E} \sum_i E_i \, n_i \; ; \quad q = \frac{1}{M} \sum_i u_{1,i} \; ; \quad u_{1,i} = \{\cos\phi_i, \sin\phi_i\} \; , \tag{2}$$

where the unit vector n_i points to the center of the i-th PSD module, E_i is the energy deposition in the i-th module and $E = \sum_i E_i$ is the total energy of the PSD sub-event. For each particle track i reconstructed with the STS a 1-st harmonic unit vector $u_{1,i}$ is defined. The STS q-vectors were calculated in 0.2 wide slices of rapidity using Eq. (2) where M is the number of particle tracks in a given slice of rapidity.

Independent estimates of the Q-vector correction factors $C^A_{1,i}\{B,C,D\}$ and flow harmonics $v_{1,i}\{A,B\}$ can be obtained using mixed garmonics method as follows:

$$v_{1,i}\{A,B\} = \frac{2\langle q_i Q_i^A \rangle}{C^A_{1,i}\{B,C,D\}} \; ; \quad C^A_{1,i}\{B,C,D\} = \sqrt{2\frac{\langle Q_i^{A,1} Q_i^{B,1} \rangle \langle Q_i^{A,1} Q_i^{C,1} Q_i^{D,2} \rangle}{\langle Q_i^{B,1} Q_i^{C,1} Q_i^{D,2} \rangle}} \; . \tag{3}$$

Using second harmonic in Eq. 3 allows to reduce non-flow correlations (e. g. contribution due to total momentum conservation). Imperfect acceptance and efficiency of

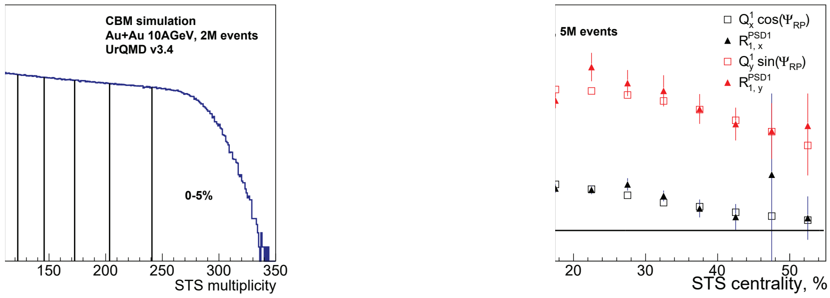

Figure 2: Left: multiplicity distribution of charged particles produced in minimum bias Au+Au collisions at 10 AGeV and reconstructed in the CBM STS. The vertical lines mark event (centrality) classes. Right: resolution correction factors $R_{1,i}$ obtained with PSD1 sub-event using mixed harmonics method.

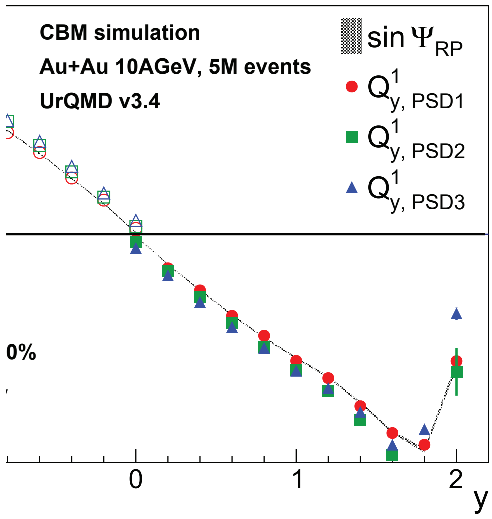

Figure 3: Directed flow of negatively charged pions for the 20-40% centrality class obtained using the y components of the PSD Q-vectors. The open points have been reflected anti-symmetrically relative to zero rapidity.

the detector bias the azimuthal angle distribution of measured particles. A correction procedure for the Q-vectors was proposed in Ref. [11]. This procedure is implemented in a software framework (QnCorrections framework) [12].

Figure 2 *(right)* shows the resolution correction factors for Q_y-vector components defined for three PSD sub-events: central (PSD1), middle (PSD2), and outer (PSD3) module groups.

Results for negatively charged pions directed flow calculated for 5M selected Au+Au collisions at 10 AGeV and the event plane estimates from the combined PSD are shown in Fig. 3. Directed flow as a function of rapidity was measured for the 20-40% event (centrality) class, which is compared with that calculated using MC-true reaction plane angle. At the moment no p_T-dependent acceptance and efficiency correction was applied to the extracted value of v_1, which is a subject of a future work.

5. Summary and outlook

Reaction plane reconstruction with mixed harmonic method is implemented and results compared to direct calculations from the model. π^- directed flow with event plane from PSD was calculated. CBM detector system allows to reconstruct flow coefficients with high precision. In future we plan to include particle identification with TOF and study flow coefficients for other harmonics with different particles (pions, protons, kaons).

6. Acknowledgments

This work was partially supported by the Ministry of Science and Education of the Russian Federation, grant N 3.3380.2017/4.6, and by the National Research Nuclear University MEPhI in the framework of the Russian Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013).

References

[1] A Malakhov *et al.* [CBM Collaboration], CBM SDM TDR, `https://repository.gsi.de/record/109025`

[2] J Heuser *et al.* [CBM Collaboration], STS TDR, `http://repository.gsi.de/record/54798`

[3] C Höhne *et al.* [CBM Collaboration], RICH TDR, `http://repository.gsi.de/record/65526`

[4] N Herrmann *et al.* [CBM Collaboration], TOF TDR, `http://repository.gsi.de/record/109024`

[5] F Guber *et al.* [CBM Collaboration], PSD TDR, `http://repository.gsi.de/record/109059`

[6] M Bleicher *et al.*, J. Phys. G 25, 1859 (1999) doi:10.1088/0954-3899/25/9/308 [hep-ph/9909407].

[7] CBMROOT, JUL17 release, `https://redmine.cbm.gsi.de/projects/cbmroot/repository/show/release/JUL17`

[8] R Brun, F Bruyant, M Maire, A C McPherson and P Zanarini, CERN-DD-EE-84-1.

[9] V Klochkov and I Selyuzhenkov, Performance of centrality determination in heavy-ion collisions with the CBM experiment, GSI Scientific Report 2015

[10] Klochkov *et al.* [CBM Collaboration], J. Phys. Conf. Ser. 798, no. 1, 012059 (2017).

[11] I Selyuzhenkov and S Voloshin, Phys. Rev. C 77, 034904 (2008)

[12] V Gonzalez J Onderwaater and I Selyuzhenkov, Detector non-uniformity corrections for collision symmetry plane estimates, GSI Scientific Report 2015