Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Performance for proton anisotropic flow measurement of the CBM experiment at FAIR

To cite this article: O Golosov *et al* 2020 *J. Phys.: Conf. Ser.* **1690** 012104

Performance for proton anisotropic flow measurement of the CBM experiment at FAIR

O Golosov[1], V Klochkov[2,3], E Kashirin[1] and I Selyuzhenkov[1,2] for the CBM Collaboration

[1] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute) Moscow, Russia
[2] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[3] Eberhard Karls University of Tübingen, Tübingen, Germany

E-mail: oleg.golosov@gmail.com

Abstract. The Compressed Baryonic Matter experiment (CBM) performance for proton anisotropic flow measurements is studied with Monte-Carlo simulations using collisions of gold ions at lab momentum of $12A$ GeV/c employing DCM-QGSM-SMM heavy-ion event generator. Realistic procedures are used for centrality estimation with the number of registered tracks and particle identification with information from Time-Of-Flight detector. Variation of directed flow estimates depending on various combinations of PSD modules is used to evaluate possible systematic biases due to collision symmetry plane estimation.

1. Introduction

The Compressed Baryonic Matter experiment (CBM) at FAIR is designed to study the phase diagram of strongly-interacting matter in the area of moderate temperatures and high net baryon densities with heavy ion collisions at beam momenta of 3.3–$12A$ GeV/c per nucleon ($\sqrt{s_{NN}}$=2.9–4.9 GeV). One of the most important observables to probe the properties of matter created in these collisions is anisotropic transverse flow. In heavy ion collisions spatial asymmetry of initial energy density in the overlap region is converted due to interaction between produced particles to the asymmetry in final momentum distribution of collision products. This momentum asymmetry allows to constrain the transport parameters of the matter created in heavy-ion collisions. It is quantified by the coefficients v_n in a Fourier decomposition of the azimuthal distribution of produced particles direction [1]:

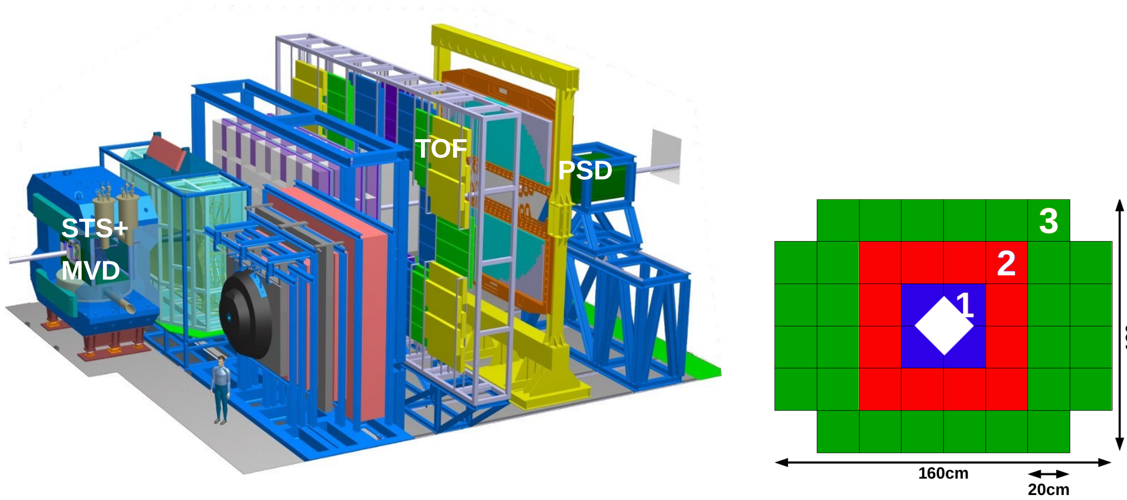
$$\rho(\varphi - \Psi_{\mathrm{RP}}) = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\varphi - \Psi_{RP})\right]\right). \quad (1)$$

The Fourier decomposing is performed relative to the reaction plane spanned by the impact parameter and the beam. In the experiment reaction plane angle Ψ_{RP} can be estimated using the azimuthal distribution of produced particles or deflection of spectator fragments. Magnitude of v_n depends on the colliding system size and energy, centrality and other event and particle properties.

2. CBM layout and simulation setup

The Compressed Baryonic Matter (CBM) is a future fixed target experiment at the currently constructed FAIR facility. The relevant detector subsystems (figure 1 (a)) used in this analysis include [2] Micro-Vertex Detector (MVD), Silicon Tracking System (STS), and a forward hadron calorimeter called the Projectile Spectator Detector (PSD).

The MVD and STS were used to obtain information about particle momenta and define centrality classes with track multiplicity, TOF for particle identification, PSD for reaction plane estimation. Twelve layers of silicon sensors of MVD and STS detectors cover the acceptance in polar angle of $2.5° < \Theta < 25°$. Hadron calorimeter PSD (figure 1 (b)) is situated at a distance of 8 m from the target which is optimized for FAIR energy range and is shifted horizontally in the transverse plane by about 10 cm to account for the beam deflection by the magnetic field with bending power of 1 Tm. The PSD consists of 44 modules and covers polar angles $0.21° < \Theta < 5.7°$ (4.3°) in x (y) directions. A 20 cm hole in its center will allow to avoid radiation damage at high beam intensities expected at CBM.



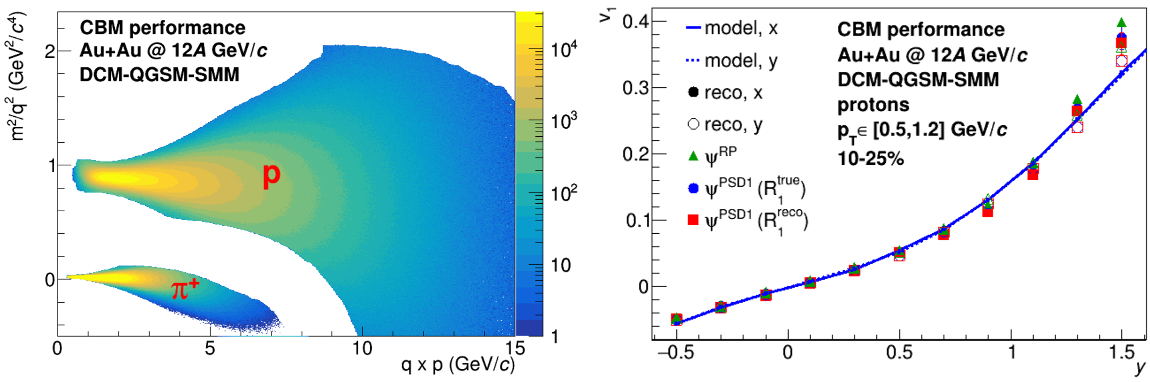
(a) (b)

Figure 1. (a): layout of the CBM experiment. (b): transverse to the beam layout of the PSD modules. Colors show module groups used in the flow performance study: PSD1 (central), PSD2 (middle) and PSD3 (outer).

Analysis of the directed flow was performed using a sample of 5M Au+Au collisions at beam momentum of $12A$ GeV/c produced with DCM-QGSM-SMM event generator (see [3, 4] and references therein). Detector response was simulated using GEANT4 transport code embedded in the CbmRoot framework along with the reconstruction software.

3. Analysis description

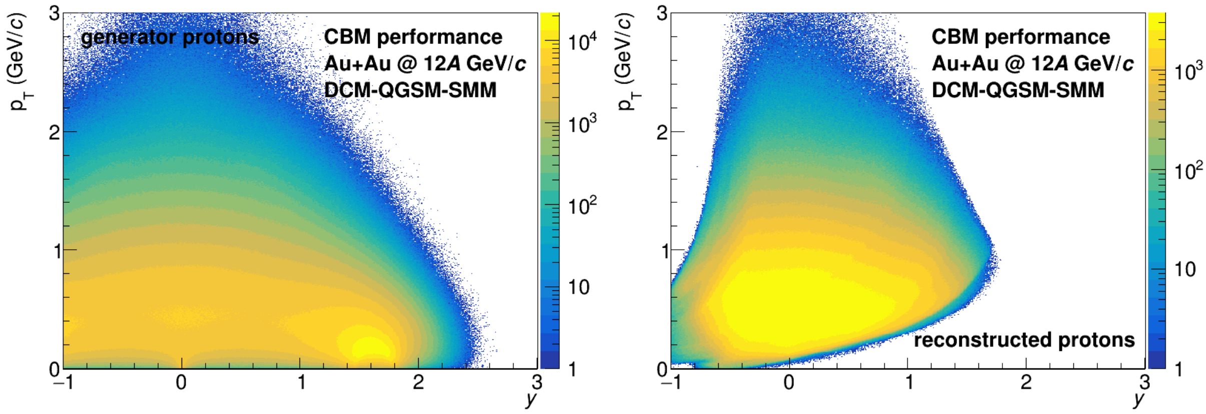
Events with high quality of primary vertex reconstruction (χ^2/NDF < 3) were selected. Only tracks with good quality fit to primary vertex ($\chi^2 < 18$) and distance to the matched TOF hit less then 1.5 cm were used in the analysis. Centrality determination was performed using the multiplicity of tracks registered in MVD and STS as described in [5]. Particle identification was based on track charge, momentum and time of flight information and utilizes Bayesian approach described in [6]. Figure 2 (a) shows the distribution of squared mass versus momentum for reconstructed tracks identified as protons and positive pions with purity higher than 90%.



(a) (b)

Figure 2. (a): distribution of squared mass versus momentum for selected protons and positive pions (purity $> 90\%$). (b): Directed flow v_1 of identified protons extracted relative to reaction plane or symmetry plane from PSD1 with the use of true and reconstructed resolution. Lines show the values obtained from the generator input.

Figure 3 shows the distribution of transverse momentum versus rapidity for generator protons (a) and selected proton tracks (b). To minimize the effect of finite efficiency on reconstructed flow values the analysis was performed in kinematic regions with higher tracking efficiency: $p_T \in [0.5, 1.2]$ for rapidity-differential and $|y| \in [0.3, 0.4]$ for p_T-differential calculations.



(a) (b)

Figure 3. Distribution of transverse momentum versus rapidity for generator protons (a) and identified proton tracks (b).

4. Flow extraction

Directed flow v_1 is reconstructed from the correlation of two-dimensional flow vectors $\mathbf{q_1}$ and $\mathbf{Q_1}$. The $\mathbf{q_1}$ vector is calculated event-by-event from the azimuthal angles ϕ_i of tracks identified as protons:

$$\mathbf{q_1} = \frac{1}{M}\sum_{i=1}^{M} \mathbf{u_{1,i}}, \quad \mathbf{u_{1,i}} = (\cos\phi_i, \sin\phi_i), \tag{2}$$

where M is the number of identified proton tracks in the event, i track index. The spectator symmetry plane is estimated with the $\mathbf{Q_1}$ direction determined from the azimuthal asymmetry of the energy deposition in different PSD subevents (see figure 1 (b)):

$$\mathbf{Q_1}^{\mathrm{PSD_A}} = \frac{1}{E_{\mathrm{PSD_A}}} \sum_{i=1}^{N_A} E_i \mathbf{n_i}, \quad E_{\mathrm{PSD_A}} = \sum_{i=1}^{N_A} E_i, \tag{3}$$

where the unit vector $\mathbf{n_i}$ points in the direction of the center of i-th PSD module, E_i is the energy deposited in it, A denotes the PSD subevent used for event plane estimation, N_A - number of modules in this subevent.

Due to rectangular shape of the transverse layout of the detectors and presence of magnetic field the azimuthal acceptance of the CBM tracking system and the PSD are non-uniform in the transverse plane, which introduces substantial bias in flow measurements. Non-uniformity may vary with event and track properties. These effects were corrected for using a data-driven procedure [7] as implemented in the QnTools framework [8] which is an extension of the QnCorrections [9] framework originally developed for ALICE experiment at the LHC. Recentering, twist and rescaling corrections were applied as a function of time and collision centrality for $\mathbf{Q_1}$ and $\mathbf{q_1}$-vectors and for $\mathbf{q}$-vectors additionally as a function of track transverse momentum and rapidity.

Independent estimates of directed flow v_1 are obtained with the scalar product method using x and y components of flow vectors and different symmetry plane sources:

$$v_{1,i}\{A\} = \frac{2\langle q_i Q_{1,i}^A \rangle}{R_{1,i}^A\{B,C,D\}}, \tag{4}$$

where $i = x, y$ are $\mathbf{q_1}$ and $\mathbf{Q_1}$ components, A, B, and C are different PSD subevents, and D is the $\mathbf{Q_1}$-vector calculated with the STS tracks. Symmetry plane resolution correction factors $R_{1,j}^A\{B,C,D\}$ were calculated with the 4-subevent method, which reduces the bias from additional correlations between PSD subevents.

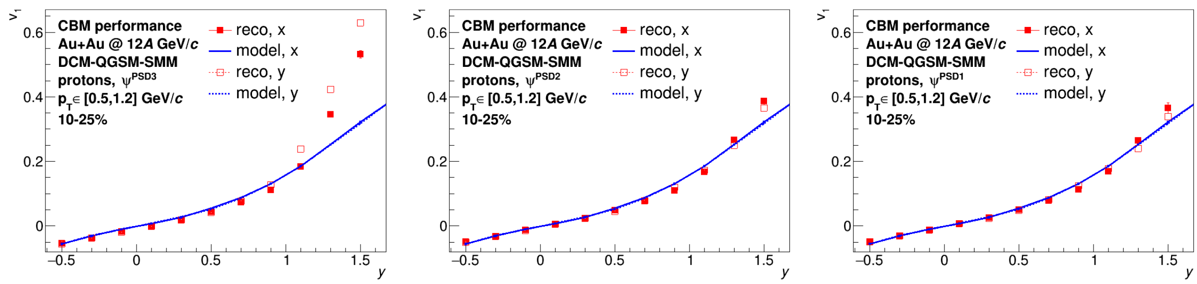
5. Flow performance

Figure 2 (b) shows proton directed flow as a function of rapidity for the 10–25% centrality class. Dependencies obtained using information from Monte-Carlo simulation (lines) are compared with the calculations based on reconstructed tracks relative to:

- true reaction plane (green triangles)
- symmetry plane reconstructed using four central modules of forward hadron calorimeter (PSD1) with:
  - true resolution based on generator information about reaction plane angle (blue circles)
  - fully data driven result for resolution calculation (red squares).

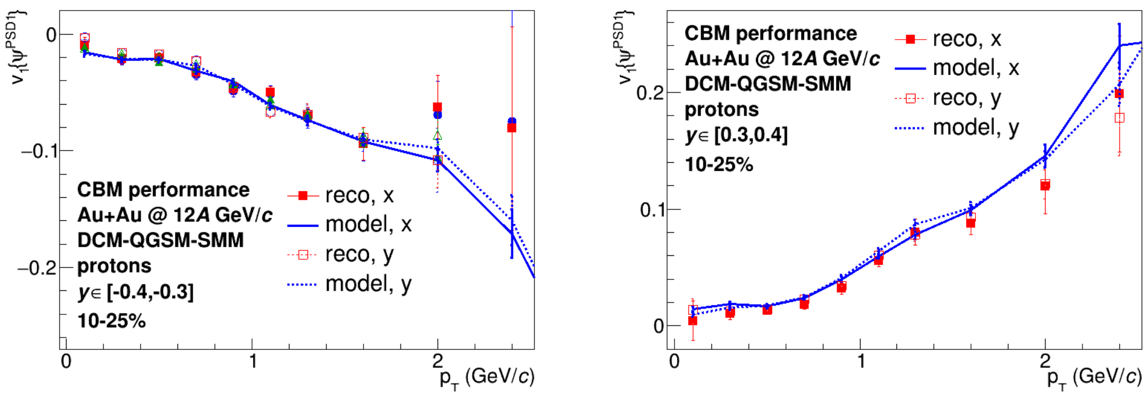
Solid lines (filled markers) show results obtained with x components of $\mathbf{q_1}$ and $\mathbf{Q_1}$ vectors, dashed lines (empty markers) represent the y component. Good agreement is observed between generator input and all the three variants of reconstructed values in a wide rapidity range.

Figure 4 presents the effect of choice of symmetry plane source. True dependencies are compared with calculations relative to symmetry planes reconstructed using different groups of PSD modules (see figure 1 (b)). One can see that with the shift to more peripheral modules for symmetry plane estimation (from PSD1 to PSD3) additional correlations arise at higher rapidity reducing the agreement of reconstructed flow values with the generator input.



(a) (b) (c)

Figure 4. Directed flow of protons as a function of rapidity extracted relative to symmetry plane estimates from PSD1 (a), PSD2 (b) and PSD3 (c) subevents. Centrality 10-25%. Lines show the values obtained from the generator input.



(a) (b)

Figure 5. Directed flow of protons as a function of transverse momentum in the backward (a) and forward (b) rapidity range (10–25% centrality class). Lines show the values obtained using true information in the Monte-Carlo simulations.

6. Summary and outlook

Performance for directed flow measurement for protons relative to the projectile spectator symmetry plane in Au+Au collisions at 12A GeV/c are presented as a function of transverse momentum and rapidity. Realistic procedures for centrality determination and particle identification are used. Corrections are applied to account for effects of the detector azimuthal non-uniformity. Good agreement has been shown between reconstructed and input values of directed flow in case symmetry plane is estimated from the most central group of PSD modules. The use of more peripheral groups of PSD modules for symmetry plane estimation leads to additional correlations in the higher rapidity range. Future plans include application of efficiency correction and study of performance for measurement of higher order anisotropic flow with more particle species (protons, kaons, lambda).

Acknowledgments

The work is supported by the Ministry of Science and Higher Education of the Russian Federation, Project "Fundamental properties of elementary particles and cosmology" No 0723-2020-0041, the Russian Foundation for Basic Research (RFBR) funding within the research project no. 18-02-40086, the European Union's Horizon 2020 research and innovation program under grant agreement No. 871072, 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] Voloshin S A, Poskanzer A M and Snellings R 2010 *Relativistic Heavy Ion Physics* ed Stock R (Berlin: Springer-Verlag Berlin Heidelberg) chap Collective phenomena in non-central nuclear collisions, pp 293–333 (*Preprint* 0809.2949)
[2] Ablyazimov T *et al.* (CBM Collaboration) 2017 *Eur. Phys. J.* A **53** 60 (*Preprint* 1607.01487)
[3] Baznat M, Botvina A, Musulmanbekov G, Toneev V and Zhezher V 2020 *Phys. Part. Nucl. Lett.* **17** 303–24 (*Preprint* 1912.09277)
[4] Botvina A *et al.* 1995 *Nucl. Phys.* A **584** 737–56
[5] Klochkov V and Selyuzhenkov I (CBM Collaboration) 2017 *J. Phys. Conf. Ser.* **798** 012059
[6] Anticic T *et al.* 2017 *CBM Progress Report 2016* ed I Selyuzhenkov and A Toia (Darmstadt: GSI) URL http://repository.gsi.de/record/201318
[7] Selyuzhenkov I and Voloshin S 2008 *Phys. Rev.* C **77** 034904 (*Preprint* 0707.4672)
[8] URL https://github.com/HeavyIonAnalysis/QnTools
[9] URL https://github.com/FlowCorrections/FlowVectorCorrections