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Using multiplicity of produced particles for centrality determination in heavy-ion collisions with the CBM experiment

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Abstract. The evolution of matter created in a heavy-ion collision depends on its initial geometry. Experimentally collision geometry is characterized with centrality. Procedure of centrality determination for the Compressed Baryonic Matter (CBM) experiment at FAIR is presented. Relation between parameters of the collision geometry (such as impact parameter magnitude) and centrality classes is extracted using multiplicity of produced charged particles. The latter is connected to the collision geometry parameters using Monte-Carlo Glauber approach.

1. Introduction

The Compressed Baryonic Matter (CBM) is a future fixed target experiment at the new accelerator complex FAIR in Darmstadt, Germany [6]. Physics program of CBM includes investigation of the QCD phase diagram at high net baryon densities in the beam momentum range 3.3 – 12 AGeV/c for heavy nuclei.

Observables which are sensitive to the properties of the strongly interacting matter created in heavy-ion collision depend on its initial geometry (see e.g. [1,2]). Theoretically, initial geometry can be described by parameters such as impact parameter (b), number of binary nucleon-nucleon collisions (N_{coll}) and number of participating nucleons (N_{part}). To characterize initial geometry in the least dependent way on experimental conditions a concept of centrality is introduced. Collision centrality, C_b , is defined as a percentage of a total inelastic nucleus-nucleus cross-section, σ_{inel}^{AA} :

$$C_b = \frac{1}{\sigma_{inel}^{AA}} \int_0^b \frac{d\sigma}{db'} db', \quad (1)$$

where b is impact parameter and $d\sigma/db$ is differential cross-section of $A + A$ collision.

Experimentally collision geometry might be characterized by the measured multiplicity of produced charged particles. All collisions are grouped into centrality classes according to their



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multiplicity value. Events with the value of centrality class close to 0% correspond to the most central collisions with the highest multiplicity. The same collisions correspond to the range of impact parameter values close to zero. Relation between collision geometry and experimentally measured multiplicities is commonly evaluated with the Monte-Carlo Glauber approach [3, 5].

The CBM experiment provides two ways for centrality determination: with track multiplicity of produced charged particles and/or energy of the projectile spectators. In these proceedings the aspects of centrality determination with multiplicity are discussed.

2. Procedure for multiplicity based centrality determination

Centrality defined by the produced particle multiplicity can be calculated according to the following formula:

$$C_M = \frac{1}{\sigma_{inel}^{AA}} \int_M^{\infty} \frac{d\sigma}{dM'} dM', \quad (2)$$

where M is a number of produced charged particles which defines a given centrality. Distribution of the impact parameter values and charged pion multiplicity is presented in figure 1.

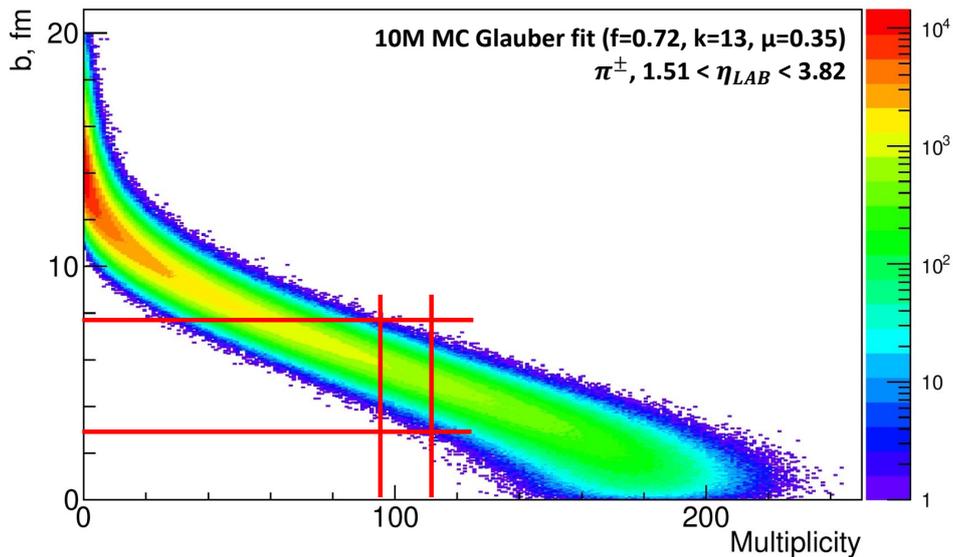


Figure 1. Distribution of the impact parameter values and charged pion multiplicity. Red lines shows mapping of centrality class determined by multiplicity to the corresponding range of impact parameter.

Due to the spread of impact parameter values at a given multiplicity there is an ambiguous mapping between centrality values C_M defined by equation (2) and the values of C_b given by equation (1). Therefore one can relate the impact parameter and multiplicity only on average by introducing centrality classes (see red lines in figure 1). In real experiment one needs a model to map a centrality class defined from measured multiplicity to the range of impact parameter values (or other collision geometry parameters). In this work Monte Carlo Glauber model is used for description of the initial state of a heavy-ion collision. The MC-Glauber model makes the following assumptions [3, 4]:

- The nucleus-nucleus collision is treated as a sequence of independent binary nucleon-nucleon collisions defined by a nucleon-nucleon inelastic cross-section

- Initial position of individual nucleons is sampled using Monte-Carlo simulations from a Woods-Saxon nuclear density function:

$$\rho(r) = \frac{\rho_0}{1 + \exp(\frac{r-R}{a})}, \quad (3)$$

where ρ_0 is a normalization coefficient, r is a distance to nucleus center, R is a radius of nucleus, parameter a is a skin depth. In present analysis: $R = 6.38 fm$, $a = 0.535 fm$ [3].

- Individual nucleons are moving along the straight line trajectories during the collision process

Multiplicity of produced charged particles is modeled using collision geometry parameters (N_{part}, N_{coll}) sampled with the MC Glauber model. A number of produced particles is calculated as $M_G = \sum_{a=1}^{N_a} M_a$, where M_a is a number of particles produced from individual source (ancestor) "a" and N_a is the total number of sources (ancestors). To evaluate N_a a two-component model is used. In this model soft interactions contribute to the multiplicity dependence as N_{part} , while hard process as N_{coll} :

$$N_a = f N_{part} + (1 - f) N_{coll}, \quad (4)$$

For each ancestor "a" the number of produced particles M_a is sampled according to the Negative Binomial Distribution (NBD) with mean parameter μ and width parameter k :

$$P_{\mu,k}(n) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{(\mu/k)^n}{(\mu/k+1)^{n+k}}, \quad (5)$$

where $P_{\mu,k}(n)$ is the probability that the ancestor will produce n particles.

Then free parameters are fixed by scanning the phase space of k and f to find a minimum of χ^2 value between the simulated MC-Glauber multiplicity distribution and experimental measured one. A value of μ is defined by the method of golden section for each pair of f and k on the grid.

This procedure is implemented in the CentralityFramework software package [10] which was originally developed for CBM.

3. Results

The CBM tracking system includes MVD (Micro-Vertex Detector) and STS (Silicon Tracking System) with a polar angle acceptance of $2.5^\circ < \theta < 25^\circ$ which are located inside the magnetic field [7] (see figure 2). The MVD and STS are used for reconstruction of the charged particles tracks from which one can calculate multiplicity of the produced charged particles.

In this analysis we used one million of Au+Au collisions with the beam momentum of 12 AGeV/ c simulated with the UrQMD event generator [8,9]. To replicate the CBM tracking system acceptance only charged hadrons generated with UrQMD with the $2.5^\circ < \theta < 25^\circ$ in the laboratory frame were accepted for the centrality analysis. To avoid bias in the centrality determination due to admixture of the collision spectators only charged pions were used for multiplicity calculation.

The cross section of inelastic nucleon-nucleon interaction was set to 30 mb [11].

The k and f values with minimal χ^2 were found by generating 10^7 MC-Glauber events and sampling distribution of M_G for each point of the parameter phase space. The grid of the parameter phase space was: $k \in [1, 30]$ with a step of 1, $f \in [0, 1]$ with a step of 0.02. Fit range included only region with pion multiplicity above 50.

Results for the best fit are shown on figure 3.

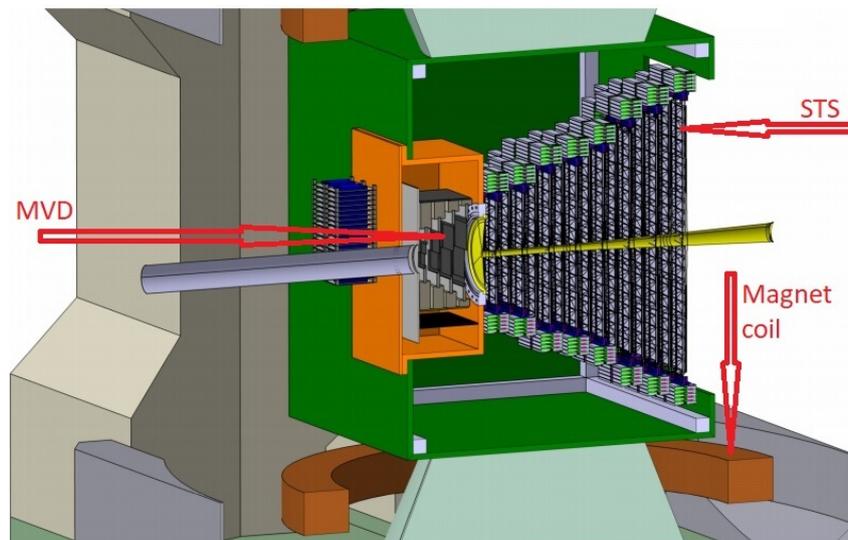


Figure 2. Geometry of the CBM tracking system located with the dipole magnet [7].

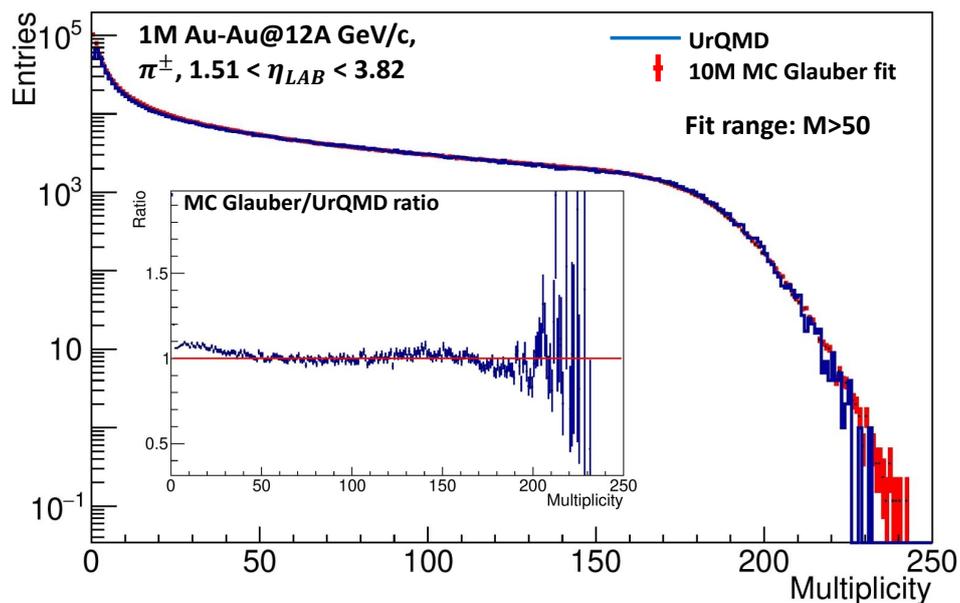


Figure 3. Result for the best fit of the charged pion multiplicity distribution in the CBM acceptance from the UrQMD model.

The fit reproduces multiplicity distribution in the whole fit range with $\chi^2/NDF = 0.93 \pm 0.14$. The optimal parameters are $f = 0.72, k = 13$ and $\mu = 0.35$. Using best fit parameters the average values and the distribution width of initial geometry parameters (b , N_{part} , and N_{coll}) for each centrality class was extracted. The result for impact parameter b is shown in figure 4.

The anticorrelation between impact parameter and multiplicity for the MC-Glauber best fit is shown in figure 3.

We observe small (1-2%) difference between average impact parameter values obtained separately from UrQMD and MC Glauber model.

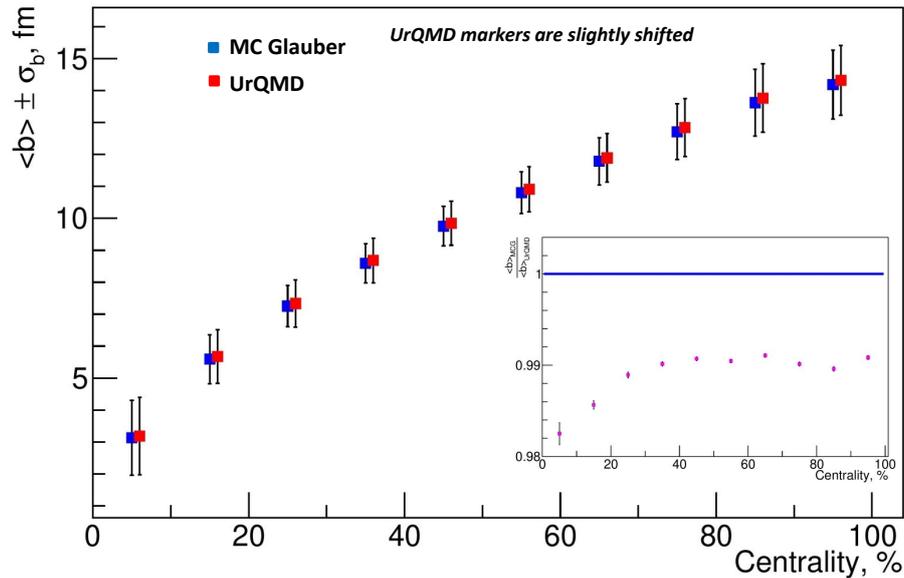


Figure 4. Average impact parameter and the distribution width for different centrality classes.

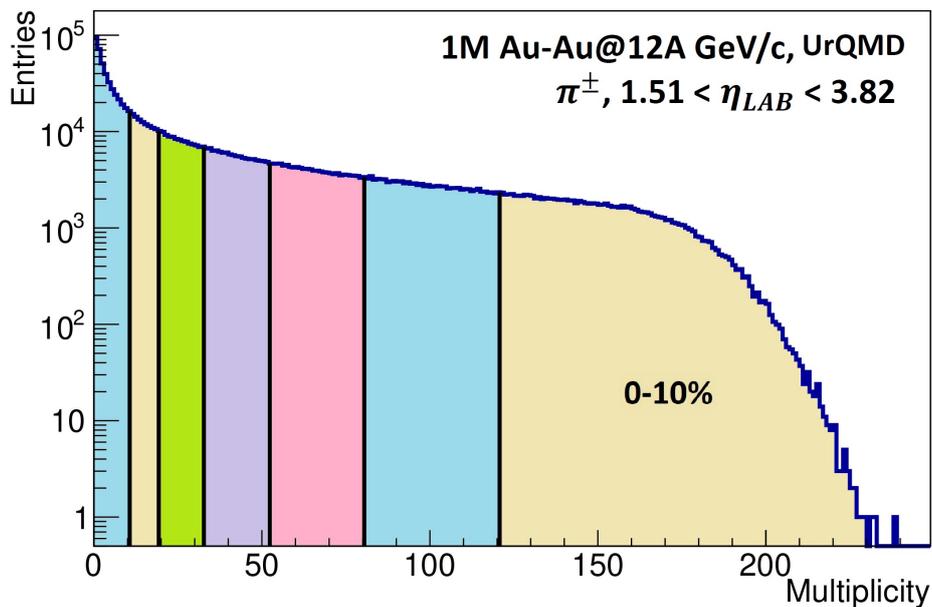


Figure 5. Multiplicity distribution and corresponding centrality classes.

4. Summary

Procedure for centrality determination based on charged hadron multiplicity is established for the Compressed Baryonic Matter (CBM) experiment at FAIR. Connection between parameters of the collision geometry (such as b , N_{coll} and N_{part}) and centrality classes is extracted within the UrQMD model using multiplicity of produced charged pions. The Monte-Carlo Glauber model is used to map the multiplicity of charged pions generated with the UrQMD model in the CBM acceptance to the average values and the distribution width of b , N_{coll} and N_{part} in a given centrality class.

Acknowledgments

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