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HIGH ENERGY PHYSICS

CENTRALITY DETERMINATION IN 15 GeV/u Au-Au COLLISIONS IN CBM EXPERIMENT*

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Abstract. The aim of our analysis is to study the feasibility of centrality determination in 15 GeV/u Au-Au collisions in CBM experiment. We use two independent centrality estimators, the charge particle multiplicity and the forward energy carried by nucleons spectators. Correlation between these estimators is made and for each centrality class the average of the number of participants and the number of binary collisions have been estimated based on Glauber Monte Carlo model.

Key words: heavy ion collisions, centrality, Glauber Monte Carlo model.

1. INTRODUCTION

When two nuclei collide they can overlap more or less. The degree of overlapping is called centrality. If the overlap region is large the number of nucleons which interact inelastically, called participants, is important and the system formed is a hot and highly compressed system. Depending on initial energy of the nuclei the quark-gluon plasma (QGP) is expected to occur [1]. There are many experimental signals for QGP and recently many efforts have been made to analyze experimental data obtained in relativistic heavy ion collisions in order to search for these signals [4]. It is obvious that the properties of the matter formed after collision depend not only on initial energy but also on centrality. This is one of the reasons why the analysis of the experimental data is made in so called centrality bins.

From geometrical point of view the centrality is correlated with the impact parameter. In each inelastic collision of two heavy ions approximated as hard spheres their centers are separated by some distance, *b*. This distance is called

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impact parameter. When the impact parameter is very small, $b \approx 0$, we have head-on collisions, the overlap region between nuclei is large and the number of inelastic interactions or the number of participants is maximal. This fact is correlated with high particles multiplicity M or high energy deposited in transverse direction. In the other limit, when the impact parameter is $b \approx (R_1+R_2)$, we have the case of peripheral collisions. In this case, the number of participant nucleons is very small and the energy transported in forward direction by spectators is important.

The impact parameter describes, therefore, the initial collision geometry, but, similarly to the number of participants, N_{part} , or the number of binary collisions, N_{coll}, or the total inelastic nucleus-nucleus cross-section, σ_{inel}, it can not be measured directly [6, 8, 15].

From the experimental point of view, we use the concept of centrality as a criterion to divide and analyse data. The connection with quantities like impact parameter or number of participants is made by models like Glauber model [16, 14].

If we have, for example, a distribution of charged particle multiplicity determined event-by-event in an experiment, $\mathrm{d}N/\mathrm{d}M$, and the total integral of the distribution is known, the centrality is calculated by binning the distribution on the basis of the fraction of the total integral starting with the high multiplicity.

$$\frac{\int_{n1}^{\infty} \frac{\mathrm{d}N}{\mathrm{d}M}\mathrm{d}M}{\int_{0}^{\infty} \frac{\mathrm{d}N}{\mathrm{d}M}\mathrm{d}M} = c_1, \tag{1}$$

The centrality class $c_1 - c_2$ is defined by the boundaries n_1 and n_2 of the multiplicity which satisfies the relation (1).

This analysis describes the possibility of centrality determination in 15 GeV/u Au-Au collisions in CBM experiment setup using for simulations the CBMROOT framework. In our approach first the centrality class was determined and then, based on the Glauber Monte Carlo model, the impact parameter, the number of participants and the number of binary collisions [6, 8, 16] were estimated.

2. CBM EXPERIMENT SET-UP

The Compressed Baryonic Matter – CBM [5] experiment is a fix target heavy-ion experiment designed to investigate the proprieties of highly compressed baryonic matter produced in nucleus-nucleus collisions at SIS100 and SIS300 accelerator of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany [2]. The goal of the experiment is to explore the phase diagram of nuclear matter at very high net baryonic densities and moderate temperatures. In the beam energy range between 10 and 40 GeV/u the QCD phase diagram is only little explored and the approach adopted by the CBM experiment towards this goal is to measure simultaneously observables which are sensitive to high density effects and phase transitions in this region. For the study of the particle phase-space distributions and collective flow it is very important to develop reliable techniques for determination of the collisions centrality and reaction plane angle [2].

For centrality determination the experimental set-up includes two detectors, namely: the Silicon Tracking System (STS) and the Projectile Spectator Detector (PSD). The STS detector will be used basically to perform a measurement of the charge particle trajectories in the magnetic field of a dipole up to emission angles of 25^{o} and consists of low-mass silicon micro-strip detectors. The PSD is a compensator hadronic calorimeter and it is used for centrality determination, reaction angle plane determination and fluctuations measurements [2].

CBM detectors for particle identification are a RICH and a transition radiation detector (TRD) for electrons [3], a time-of-flight (TOF) wall for hadron identication, and an electromagnetic calorimeter (ECAL) for the measurement of direct photons in selected regions of phase space.

From practical point of view, the centrality can be determined using the charge particles multiplicity measured by STS which depends monotonically on the number of nucleons participants or using the forward energy carried by nucleon spectators measured by PSD or from correlations between these two detectors. In Figure 1 we show the experimental setup for centrality determination.

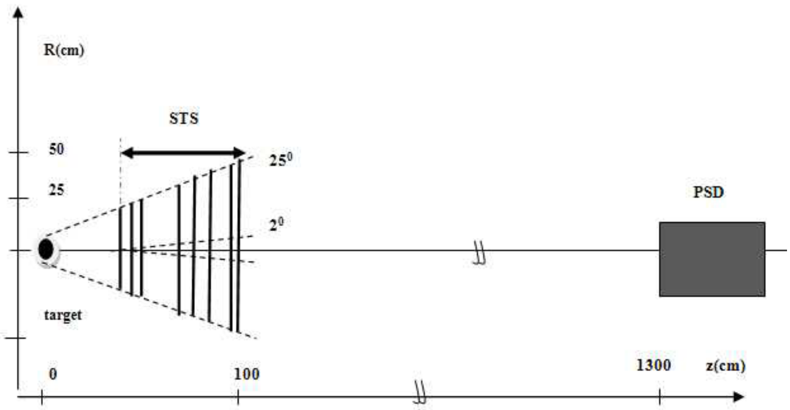

Fig. 1 – STS and PSD detectors used in centrality determination in CBM experiment.

3. SIMULATIONS RESULTS

Because the detectors are still under construction, our analysis refers to simulations using CBMROOT [13] framework. This framework is specifically designed for CBM experiment and incorporates UrQMD as generator [9, 10], GEANT4 for transport [11] and ROOT [12] for data analysis. Our discussion is based on 10000 minimum bias events at 15 GeV/u Au-Au collisions generated and analyzed in this framework.

Using the methodology explained briefly in introduction we show in the figures below the distribution of charge multiplicity in STS and respectively the distribution of forward energy in PSD, as well as the delimitations of the centrality classes using each of these detectors.

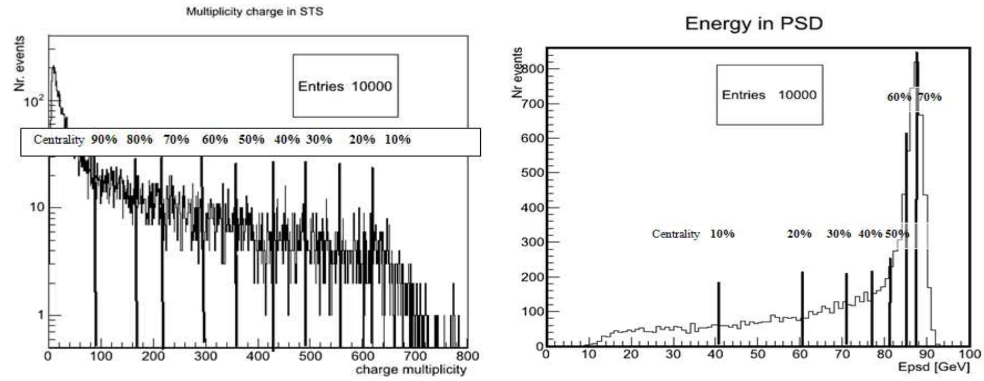

Fig. 2 – The class centrality determination using the charge multiplicity measured in STS (left) and the energy deposited in PSD (right).

Correlation between total energy deposited in PSD and the charge multiplicity in STS provided another method to cross-check the centrality determination. In this case the centrality domains are defined as percentile of the total hadronic cross section:

$$\int_{Ch_{STS,i}} \int_{E_{PSD,i}} \frac{\mathrm{d}^2\sigma}{\mathrm{d}Ch_{STS}\,\mathrm{d}E_{PSD}} = c_i \sigma_{tot}\,, \qquad (2)$$

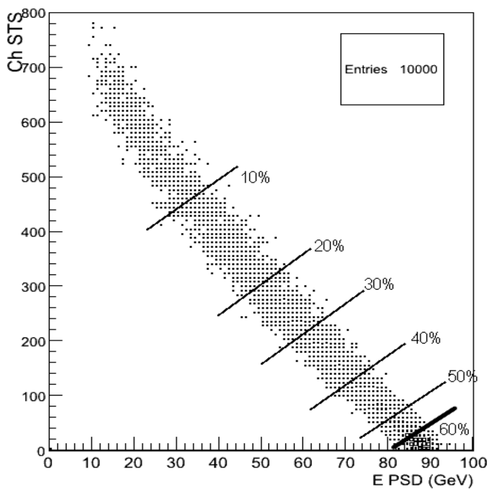

Fig. 3 – STS – PSD correlations.

4. GLAUBER MONTE CARLO MODEL

The Glauber Monte Carlo (MC) model treats the nucleus-nucleus collisions as a process of multiple nucleon-nucleon collision. The nucleons in the two colliding nuclei, taking into account that, in our case, is a fix target experiment, are randomly distributed as a spherically symmetric two-parameter Woods-Saxon nuclear density profile [6, 8, 14]:

$$\rho(r) = \rho_0 \frac{1 + w(r/R)^2}{1 + e^{\frac{r-R}{a}}}, \tag{3}$$

Our Woods-Saxon parameters for Au nucleus are the following: $R \approx 6.38$ Fm, for the radius, $a = 0.54$, for the surface thickness, $w = 0$ and $\rho_0 = 0.17$ Fm^{-3}. The two nuclei are separated by the impact parameter b, which is determined by sampling the distribution $(\mathrm{d}N/\mathrm{d}b) \approx b$ in the region $0 \le b \le b_{\max} = 15.82$ fm. We assume that two nucleons from two different nuclei collide if their transverse distance satisfies the relation:

$$d \le \sqrt{\frac{\sigma_{NN}}{\pi}}, \tag{4}$$

where σ_{NN} is the inelastic nucleon-nucleon cross section. For 15 GeV/u Au-Au collisions we take $\sigma_{NN} = 31.2$ mb. In these conditions we perform simulations of 100 000 events using GLISSANDO MC package [4] and the outputs are summarized in the table below.

Table 1

Correlations between centrality classes, impact parameter, number of participants and number of binary collisions for our case

Centrality %	b [fm]	$< N_{part} >$	$< N_{coll} >$
0 - 10	0-4.56	266.8	1717.5
10 - 20	4.56-6.43	192.4	1110.7
20 - 30	6.43-7.82	137.3	708.3
30 - 40	7.82-9.03	95.2	433.4
40 - 50	9.03-10.08	62.1	245.9
50 - 60	10.08-11.07	38.0	127.7
60 - 70	11.07-11.94	21.05	57.9
70 – 80	11.94-12.77	11.02	24.4
80 - 90	12.77-13.64	5.00	8.5

The number of binary collisions is calculated assuming that in a collision of two identical nuclei the average number of collisions per participant scales on the length $l \approx N_{part}^{1/3}$, taking into account the interaction volume along the beam direction, so that the number of binary collisions is $N_{coll} \approx N_{part}^{4/3}$. In Fig. 3 are shown the correlations between centrality classes and the impact parameter calculated by Glauber MC model using GLISSANDO code [7]. If from experimental point of view we have well defined centrality domains considering the Glauber model we can map these domains with the impact parameter and with the average number of participants and with the average number of binary collisions. By calculating the integral of the distribution shown in Fig. 3 we can estimate the total geometric cross-section for Au-Au collision at 15 GeV/u energy. In our case this is 6.424 barn.

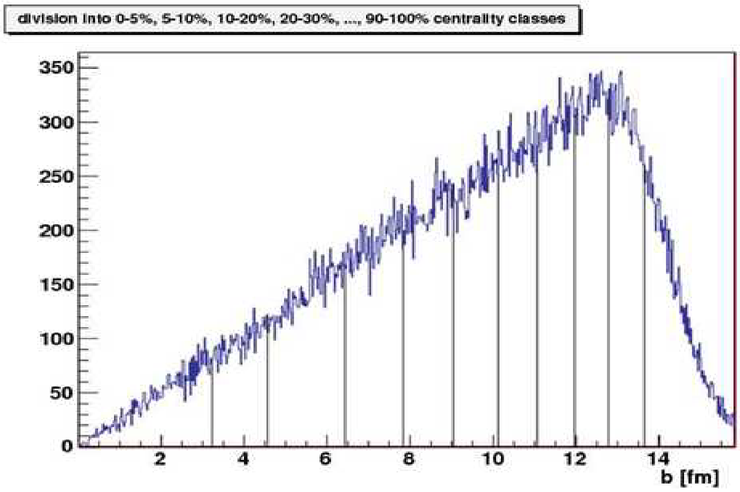

Fig. 4 – Correlation between centrality class and the impact parameter from Glauber MC calculations.

As we can see from Figs. 2 and 3 for large values of the impact parameters, which correspond to peripheral collisions, there are important uncertainties in defining the class centrality, mainly related to fluctuations. These could be important in these situations.

4. CONCLUSIONS

The centrality is estimated using quantities varying monotonically with the impact parameter like charge multiplicity or the forward energy. After the construction of the multiplicity distribution or of the forward energy distribution using a mapping procedure with Glauber model we can make predictions about the values of the impact parameter or of the number of participants for a defined centrality class. The total geometrical cross section for the Au-Au nuclei can be calculated also from the integral of the distributions shown in Fig. 3.

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