Energy Dissipation and Charged Particle Densities in Heavy Ion Collisions

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Introduction

Pseudorapidity density of charged particles is one of the key observables to characterise the multiparticle production in high energy particle and nuclear collisions. In this report, we use the model [1] which considers the secondary particle production based on the constituent quark picture combined with Landau relativistic hydrodynamics [2]. Within this model, the particle production in nuclear and nucleon collisions is basically driven by the amount of the initial effective energy deposited by the participants, quarks or nucleons. In $pp/\bar{p}p$ collisions, a single constituent (or dressed) quark from each nucleon takes part in a collision and rest are considered as spectators. In the most central nuclear collisions, the participating nucleons are considered colliding by all three constituent quarks from each nucleon which makes the whole energy of the colliding nucleons available for the particle production. Thus, one expects that bulk observables measured in the head-on heavy-ion collisions at the c.m. energy per nucleon, $\sqrt{s_{NN}}$, to be similar to those from $pp/\bar{p}p$ collisions but at a three times larger c.m. energy i.e. $\sqrt{s_{pp}} \simeq 3\sqrt{s_{NN}}$.
Within the framework of this model, one can find the relation between charged particle rapidity density per participant pair $\rho(y) = (2/N_{part})dN_{ch}/dy$ at mid-rapidity (y=0) in heavy ion collisions and that in $pp/\bar{p}p$ collisions as [1]

$$\rho(0) = \rho_{pp}(0)\,\frac{2N_{ch}^{AA}}{N_{part}\,N_{ch}^{pp}}\sqrt{1-\frac{4\,\ln 3}{\ln(4m_p^2/s_{NN})}} \quad (1)$$

Here, $N_{\rm part}$ is the number of participants, $N_{\rm ch}$ and $N_{\rm ch}^{pp}$ are the mean multiplicities in nucleus-nucleus and nucleon-nucleon collisions, respectively.
The centrality is closely related to the number of nucleon participants determined using a Monte Carlo Glauber calculations so that the largest number of participants contribute to the most central

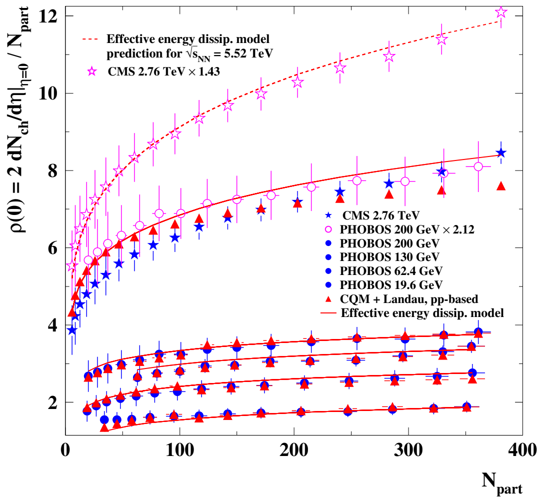

FIG. 1: The charged particle pseudorapidity density at midrapidity per participant pair as a function of the number of participants, $N_{\rm part}$. The solid circles and solid stars are experimental measurements from RHIC and LHC respectively. The solid triangles show the calculations by Eq. (2) using $pp/\bar{p}p$ data. The lines represent the effective energy dissipation approach predictions based on the hybrid fit to the c.m. energy dependence of the midrapidity density in central heavy-ion collisions shown in Fig.2. The open circles show the PHOBOS measurements at $\sqrt{s_{NN}}$ = 200 GeV multiplied by 2.12, while the open stars show the CMS measurements multiplied by 1.43.

heavy-ion collisions. Hence the centrality is related to the energy released in the collisions, *i.e.* the effective energy, ε_{NN}, which, in the framework of the model, can be defined as a fraction of the c.m. energy available in a collision according to the centrality, α:

$$\varepsilon_{NN} = \sqrt{s_{NN}}(1-\alpha). \quad (2)$$

Conventionally, the data are divided into classes of centrality, or centrality intervals, so that α is the average centrality for the centrality interval, *e.g.* $\alpha = 0.025$ for $0-5\%$ centrality, which refers to the 5% most central collisions. Then, for the effective c.m. energy ε_{NN}, Eq. (1) reads:

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$$\rho(0) = \rho_{pp}(0)\,\frac{2N_{\rm ch}}{N_{\rm part}\,N_{\rm ch}^{pp}}\sqrt{1-\frac{2\ln 3}{\ln(2m_p/\varepsilon_{NN})}}\,,$$
$$\varepsilon_{NN} = \sqrt{s_{pp}}/3\,, \qquad (3)$$

where $N_{\rm ch}$ is the mean multiplicity in central nucleus-nucleus collisions measured at $\sqrt{s_{NN}} = \varepsilon_{NN}$. The rapidity density $\rho_{pp}(0)$ and the multiplicity $N_{\rm ch}^{pp}$ are taken from the existing data or, where not available, calculated using the corresponding experimental c.m. energy fits, and, according to the model, the calculations are made at $\sqrt{s_{pp}} = 3\,\varepsilon_{NN}$. The $N_{\rm ch}$ values are as well taken from the measurements in central heavy-ion collisions wherever available, while for the non-existing data the "hybrid" fit [3] combining the linear logarithmic and power-law regularities is used.

Analysis

In the framework of the model, we calculate the centrality dependence of the charged particle midrapidity density using Eq. (3) to reproduce the centrality data shown in Fig. 1. The calculations are shown by solid triangles. One can see that within this model where the collisions are derived by the centrality-defined effective c.m. energy ε_{NN}, the model calculations are in very good overall agreement with the measurements independent of the collision energy. Given the obtained agreement between data and the model and considering the similarity put forward for ε_{NN} and $\sqrt{s_{NN}}$, one would expect the measured centrality data at ε_{NN} to follow the $\sqrt{s_{NN}}$ dependence of the midrapidity density in the most central nuclear collisions.
In Fig. 2, the measurements of the charged particle pseudorapidity density at midrapidity in head-on nuclear collisions are plotted against the $\sqrt{s_{NN}}$ from a few GeV at GSI to a few TeV at the LHC along with the centrality data, shown as a function of ε_{NN}. The centrality data effective-energy dependence follow well the data on the most central collision c.m. energy behaviour. We fit both the head-on collisions and centrality data by the hybrid fit function. One can see that hybrid fit to centrality data (solid line) is very close to fit to head-on data (dashed line). From this one can conclude that the model well reproduces the data under the assumption of the effective energy deriving the multiparticle production process pointing to the similarity in all the data from peripheral to the most central measurements to follow the same energy behaviour. From the fit, we estimate the midrapidity density value to be of about 12.0 in the most central collisions at $\sqrt{s_{NN}} = 5.52$ TeV shown by solid circle in Fig. 2.

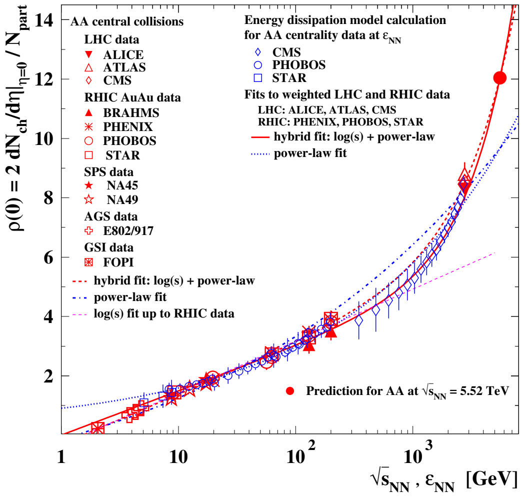

FIG. 2: The charged particle pseudorapidity density per participant pair at midrapidity as a function of c.m. energy per nucleon, $\sqrt{s_{NN}}$, in central nucleus-nucleus (AA) collisions (shown by large symbols), and as a function of effective c.m. energy, ε_{NN} (Eq. (2)), for AA collisions at different centrality (small symbols).

Now, using the effective c.m. energy approach, we apply the obtained hybrid function fit of the midrapidity density measured in head-on collision data (dashed line in Fig. 2), to the centrality data, shown in Fig. 1 as a function of N_{part}. The calculations are shown by the solid lines. One can see that the model well describes the measurements and actually follows the predictions by Eq.(3), except the LHC data, where it is better than the calculations of Eq.(3). Similarly to the above calculations for the existing data on the N_{part}-dependence of the midrapidity density, we made the predictions for the forthcoming heavy-ion collisions at $\sqrt{s_{NN}} = 5.52$ TeV. The predictions are shown by the dashed line in Fig. 1, where the centrality and N_{part} values are taken as in the 2.76 TeV data shown.
Similar observations are made for the transverse energy midrapidity density measurements as soon as the centrality data is recalculated for the c.m. effective energy [4]. The centrality data are found to well complement the central collision measurements c.m energy behaviour.

References

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