# UNIVERSALITY OF PARTICLE PRODUCTION AND ENERGY BALANCE IN HADRONIC AND NUCLEAR COLLISIONS*

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The multihadron production in $AA$ and $pp/\bar{p}p$ collisions is studied by exploring the collision-energy and centrality dependencies of the mean multiplicity in the existing data. The study is performed in the framework of the recently proposed effective-energy approach which combines the constituent quark picture and Landau hydrodynamics counting for the centrality-defined effective energy of participants. The multiplicity energy dependence and the pseudorapidity spectra from the most central nuclear collision data are well-reproduced. The study of the multiplicity centrality dependence reveals a new scaling between the measured pseudorapidity spectra and the calculations. Using this scaling, called the energy balanced limiting fragmentation scaling, the pseudorapidity spectra are well-reproduced for all centralities. A similarity in the multiplicity energy dependence in the most central collisions and centrality data is shown. Predictions are drawn for the mean multiplicities to be measured in hadronic and heavy-ion collisions at the LHC.

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**1.** In this report, we discuss our recent results on the universality of multiparticle production in nucleus–nucleus ($AA$) and hadronic interactions in view of a new scaling obtained [1]. The study exploits concept of effective energy [2] employed for the data interpreted in terms of the approach of the dissipating energy of quark participants [3, 4], or, for brevity, the participant dissipating energy (PDE) approach. The PDE study [2] shows complementarity of the midrapidity pseudorapidity and transverse energy densities in non-central and head-on $AA$ collisions. Here, in the framework of the PDE approach, we extend the previous studies of the charged particle mean multiplicity [3, 4] to LHC energies.

In the framework of PDE approach, which combines the constituent quark picture and the relativistic Landau hydrodynamics [5], one can calculate multiplicity $N_{\rm ch}$ at a given rapidity density $\rho(0)$ at $\sqrt{s_{NN}}$, and rapidity density $\rho_{pp}(0)$ and the multiplicity $N_{\rm ch}^{pp}$ at $3\sqrt{s_{NN}}$, as

$$2N_{\rm ch}/N_{\rm part} = N_{\rm ch}^{pp}\rho(0)/\rho_{pp}(0)\sqrt{1-2\ln 3/\ln(4.5\sqrt{s_{NN}}/m_p)}\,, \quad \sqrt{s_{NN}} = \sqrt{s_{pp}}/3\,. \tag{1}$$

Further development [2] treats this dependence in terms of centrality. The centrality is related to $N_{\rm part}$ and, then, to the amount of the energy released in the collision, *i.e.*, to the effective energy, $\varepsilon_{NN}$. Within the PDE approach, $\varepsilon_{NN}$ can be defined as a fraction of the c.m. energy available in a collision according to the centrality, $\alpha$ [1],

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

Then, for the effective c.m. energy $\varepsilon_{NN}$, Eq. (1) reads

$$2N_{\rm ch}/N_{\rm part} = N_{\rm ch}^{pp}\rho(0)/\rho_{pp}(0)\sqrt{1-2\ln 3/\ln(4.5\varepsilon_{NN}/m_p)}\,, \quad \varepsilon_{NN} = \sqrt{s_{pp}}/3 \tag{3}$$

with $\rho(0)$ being the midrapidity density in central $AA$ collisions at $\sqrt{s_{NN}} = \varepsilon_{NN}$.

**2.** Figure 1 (left) shows the c.m. energy dependence of the multiplicity measured in head-on $AA$ collisions and the fits made in the energy range of $\sqrt{s_{NN}} = 2$ GeV to 2.76 TeV. We fit the head-on data by the "hybrid" fit function which combines the 2nd-order logarithmic from RHIC and the power-law dependence obtained at the LHC. We show also the $\log^2(s_{NN})$-fit [3, 4] and the power-law fit. One can see that the power-law fit well describes the data similar to the hybrid fit up to the LHC data. However, the 2nd-order log-polynomial lies below the data for $\sqrt{s_{NN}} > 200$ GeV. This

[1] Conventionally, the data are divided into centrality intervals, so that $\alpha$ is the average centrality per centrality interval, *e.g.* $\alpha = 0.25$ for the centrality interval of 20–30% centrality.

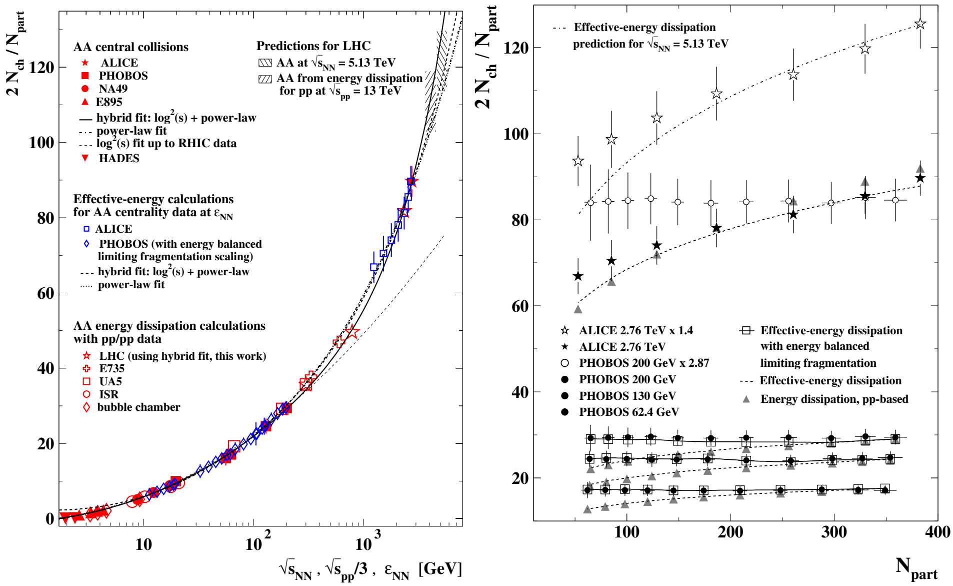

Fig. 1. Left: The energy dependence of the charged particle mean multiplicity per participant pair. Right: The $N_{\rm part}$-dependence of the charged particle mean multiplicity per participant.

observation supports a possible transition to a new regime in $AA$ collisions at $\sqrt{s_{NN}}$ of about 1 TeV, as indicated earlier [2]. One can see that the calculated $2N_{\rm ch}/N_{\rm part}$ values, using Eq. (1), follow the measurements from $AA$ collisions at $\sqrt{s_{NN}}$ from a few GeV up to the TeV LHC energy. This points to the universality of the multiparticle production in the different types of collisions.

In Fig. 1 (right), we show the $N_{\rm part}$-dependence of $2N_{\rm ch}/N_{\rm part}$. One can see that the $\varepsilon_{NN}$-calculations well reproduce the LHC data. For the RHIC data, however, the difference between the calculations and the measurements is visible already for medium centralities. These observations are also interrelated with the difference observed in the measurements at RHIC *vs.* those from the LHC. This becomes even clearer when the 200 GeV PHOBOS data are scaled to match the ALICE highly central collision data.

**3.** The observed differences in the pseudorapidity density spectra are investigated in the context of the PDE picture. The calculations within the PDE approach reproduce the pseudorapidity density distribution in most central $AA$ interactions in the full $\eta$ range, while in the case of non-central $AA$ interactions, the calculations underestimate the distribution in the higher $\eta$ region. To understand the difference between experimental measurement and PDE-based calculations in non-central collisions, a new scaling called *energy balanced limiting fragmentation scaling* introduced based on assumption of the similarity of the fragmentation region of the measured distribution in the beam rest frame, and that determined from the calculations by using the effective energy. The revealed scaling allows us to reproduce the pseudorapidity density distributions independently of the centrality of collisions and, then, to correctly describe the centrality independence of the mean multiplicity measured at RHIC. Moreover, this finding provides a solution to the RHIC "puzzle" of the difference between the centrality independence of the mean multiplicity *vs.* the monotonic decrease of the midrapidity pseudorapidity density with the increase of centrality. The mean multiplicity is shown to get a fraction of additional contribution to account for the balance between the collision c.m. energy shared by all nucleons and the effective energy of the participants. However, the midrapidity pseudorapidity density is fully defined by the effective energy of colliding participants.

We observed that the multiplicity measurements at the LHC are well-reproduced without the energy balanced additional contribution, so one can conclude that in heavy-ions collisions at the LHC at TeV energies, the multihadron production obeys a head-on collision regime, for all the centrality intervals measured. This points to apparently different regimes of hadroproduction occurring in heavy-ion collisions with $\sqrt{s_{NN}}$ between a few hundred GeV and TeV energies. This observation supports a similar conclusion made above, which is suggested from the observation of a change of the functional type of the fit needed to describe the energy behaviour as soon as the LHC data are included, see Fig. 1. Further details of the present work can be found in reference [1] and references therein.

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