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Effective Energy Dissipation and Particle Production in Heavy-Ion Collisions

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ABSTRACT

The dependencies of charged particle pseudorapidity density and transverse energy pseudorapidity density at midrapidity on the collision energy and on the number of nucleon participants, or centrality, measured in nucleus-nucleus collisions are studied in the energy range spanning a few GeV to a few TeV per nucleon. The model, which considers the multiparticle production process being derived by the dissipating effective energy of participants, is used based on the earlier proposed approach combining the constituent quark picture together with Landau relativistic hydrodynamics shown to interrelate the measurements from different types of collisions. Within this approach, the midrapidity pseudorapidity density dependence on the number of participants in heavy-ion collisions from RHIC to LHC energies are found to be well described in terms of effective energy defined as a centrality-dependent fraction of a collision energy. For both variables studied, the effective energy approach reveals a similarity in the energy dependence obtained for the most central collisions and the centrality data in the entire range of energy studied. Predictions are made for the investigated dependencies for the forthcoming higher energy measurements in heavy-ion collisions at the LHC.

Introduction

Here, we study global observables such as charged particle multiplicity and transverse energy using the energy dissipation model of constituent quark participants[1]. Within this model, the secondary particle production is basically driven by the amount of the initial effective energy deposited by participants, quarks or nucleons, into the Lorentz contracted overlap region. In pp/ppbar collisions a single constituent (or dressed) quark from each nucleon takes part in a collision and rest are considered spectators. Thus, the effective energy for the production of secondary particles is the energy carried by a single quark a pair i.e. 1/3 of the entire nucleon energy. In the most central heavy-ion collisions, one considers all three constituent quarks from each nucleon participate in the collision. Therefore, the entire energy of the colliding nucleons (participants) is available for the particle production. Thus, one expects that the bulk observables in the most central heavy-ion collisions at the c.m. energy per nucleon, $\sqrt{s_{NN}}$, to be similar to those in pp/ppbar collisions but at a three times larger c.m. energy i.e. $\sqrt{s_{pp}} = 3\sqrt{s_{NN}}$.

Combining the above discussed ingredients of the constituent quark picture and Landau hydrodynamics [2], one obtains the relationship between charged particle rapidity density per participant pair, $\rho(\eta)=(2/N_{part})dN_{ch}/d\eta$ at midrapidity ($\eta \approx 0$) in heavy-ion collisions and that in pp/ppbar collisions:

$$\frac{\rho(0)}{\rho_{pp}(0)} = \frac{2N_{ch}}{N_{part}\,N_{ch}^{pp}}\sqrt{\frac{L_{pp}}{L_{NN}}}\ . \qquad (1)$$

Here, N_{part} is the number of participants, N_{ch} and N_{ch}^{pp} are the mean multiplicity in nucleus-nucleus and nucleon-nucleon collisions, respectively. $L = \sqrt{s}/2m$ with 'm' being the proton mass, m_p in nucleus-nucleus collisions and the constituent quark mass in pp/ppbar collisions which is set to $m_p/3$. According to the model, we estimate Eq.(1) for the rapidity density $\rho(0)$ and the multiplicity N_{ch} at $\sqrt{s_{NN}}$ and the rapidity density $\rho_{pp}(0)$ and multiplicity N_{ch}^{pp} at $3\sqrt{s_{NN}}$:

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

Here, we extend the above-discussed model to the midrapidity pseudorapidity density dependence on the number of (nucleon) participants. We consider this dependence in terms of centrality α, related to the energy released in the collisions, i.e. the effective energy, ε_{NN}, in the framework of the effective energy model:

$$\varepsilon_{NN} = \sqrt{s_{NN}}\,(1-\alpha). \qquad (3)$$

For the effective c.m. energy ε_{NN}, Eq.(2) reads:

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

where N_{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_{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 $\sqrt{s_{pp}} = 3\,\varepsilon_{NN}$.

N_{ch} values are as well taken from the measurements in central heavy-ion collisions where available, while for the non-existing data the "hybrid" fit [3] combining the linear logarithmic and power-law regularities is used.

Charge Particle Pseudorapidity Density

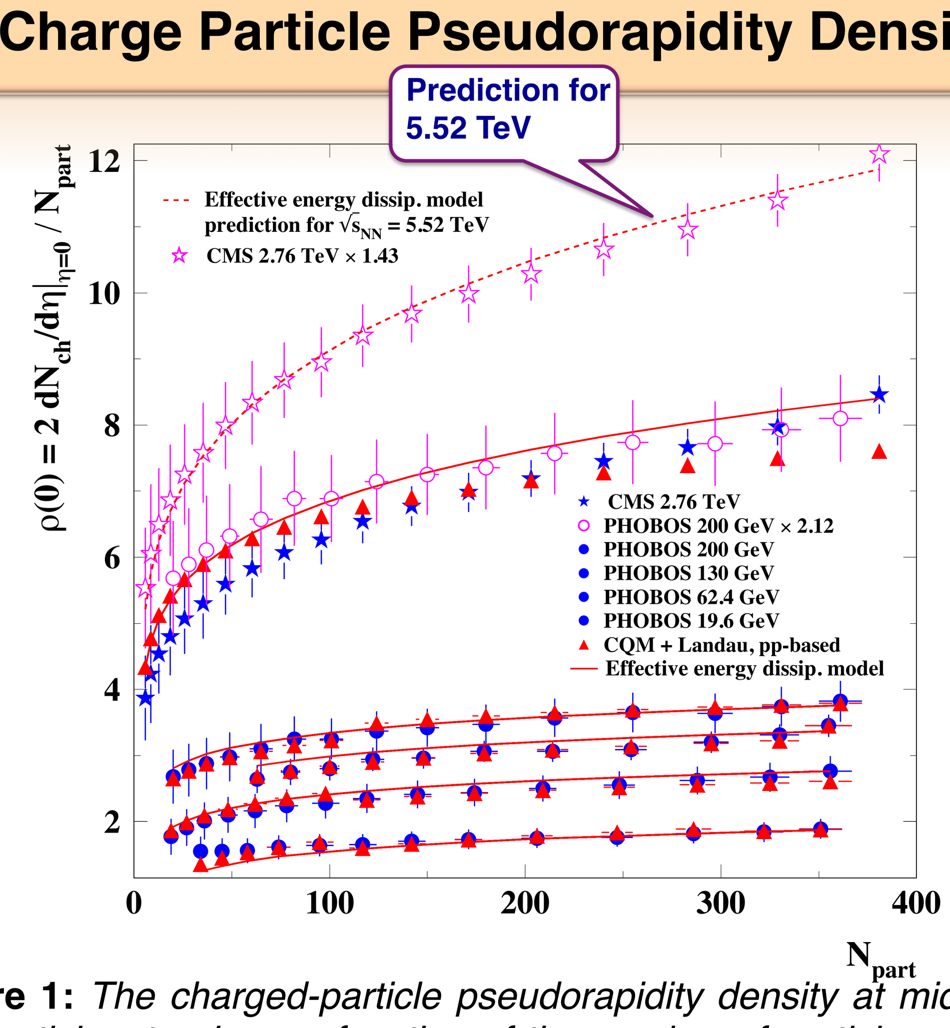

Figure 1: *The charged-particle pseudorapidity density at midrapidity per participant pair as a function of the number of participants N_{part}, measured in heavy-ion (AA) collisions up to LHC energies and calculated from pp/ppbar data using Eq.(4). The lines show the dissipation energy calculations.*

Within this model, where the particle production is derived by the centrality-defined effective c.m. energy ε_{NN}, the calculations are in very good overall agreement with the measurements independent of the collision energy.

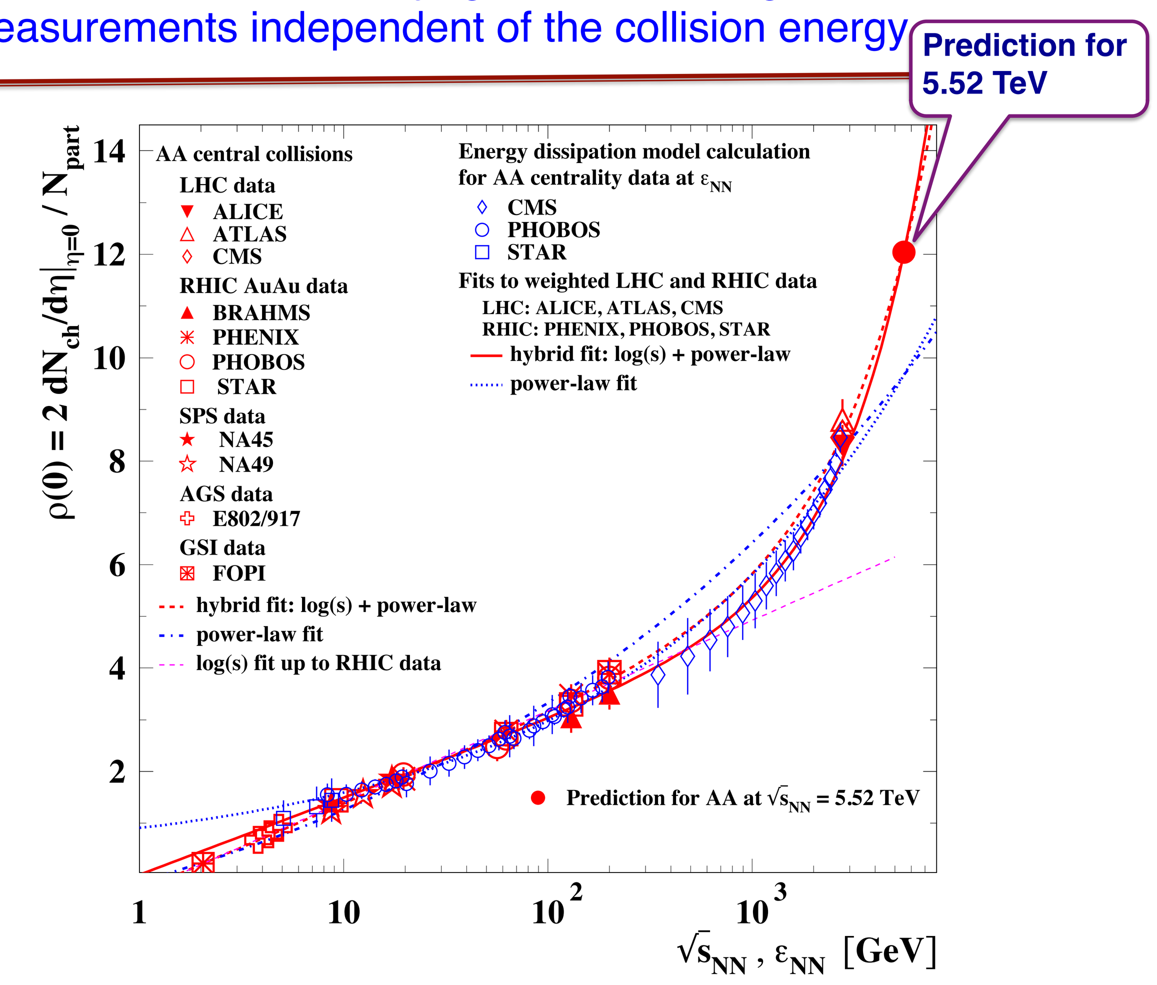

Figure 2: *The pseudorapidity density of charged particles per participant pair at midrapidity as a function of c.m. energy per nucleon, $\sqrt{s_{NN}}$, in central nucleus-nucleus (AA) collisions and as a function of effective energy, ε_{NN}, in centrality data measured up to LHC energy.*

Central data fit:

$$\rho(0) = -0.327 + 0.381\ln(s_{NN})$$
$$\rho(0) = -2.955 + 2.823\,s_{NN}^{0.087}$$
$$\rho(0) = -0.306 + 0.364\ln(s_{NN}) + 0.001\,s_{NN}^{0.5}$$

Centrality data fit:

$$\rho(0) = -0.244 + 0.663\,\varepsilon_{NN}^{0.308}$$
$$\rho(0) = -0.002 + 0.646\ln(\varepsilon_{NN}) + 0.0003\,\varepsilon_{NN}^{1.158}$$

Given an 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 (head-on)*** 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 most ***central*** collision data c.m. energy behaviour.

Transverse Energy Pseudorapidity Density

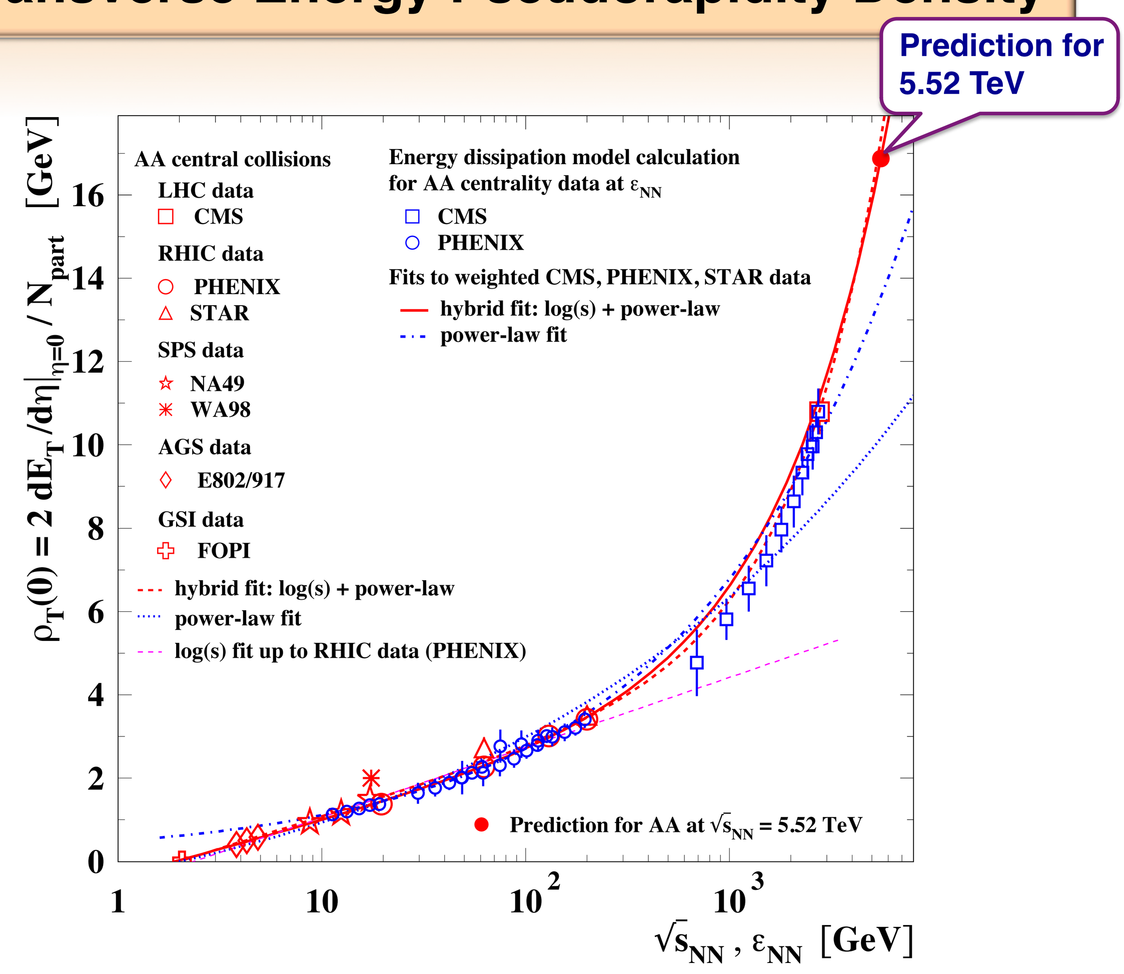

Figure 3: *The transverse energy pseudorapidity density of charged particles per participant pair at midrapidity as a function of c.m. energy per nucleon, $\sqrt{s_{NN}}$, in central nucleus-nucleus (AA) collisions and as a function of effective energy, ε_{NN}, in centrality data measured up to LHC energy.*

Effective c.m. energy approach is also applied to the pseudorapidity density of the **transverse energy** at midrapidity, $\rho_T(0) = (2/N_{part})dE_T/d\eta$ at $\eta \approx 0$. The ***centrality*** data effective-energy dependence **follow well** the most ***central*** collision data c.m. energy behaviour.

Central data fit:

$$\rho_T(0) = -2.29 + 1.97\,s_{NN}^{0.107}$$
$$\rho_T(0) = -0.447 + 0.327\ln(s_{NN}) + 0.002\,s_{NN}^{0.5}$$

Centrality data fit:

$$\rho_T(0) = -0.09 + 0.40\,\varepsilon_{NN}^{0.20}$$
$$\rho_T(0) = -0.387 + 0.574\ln(\varepsilon_{NN}) + 0.011\,\varepsilon_{NN}^{0.818}$$

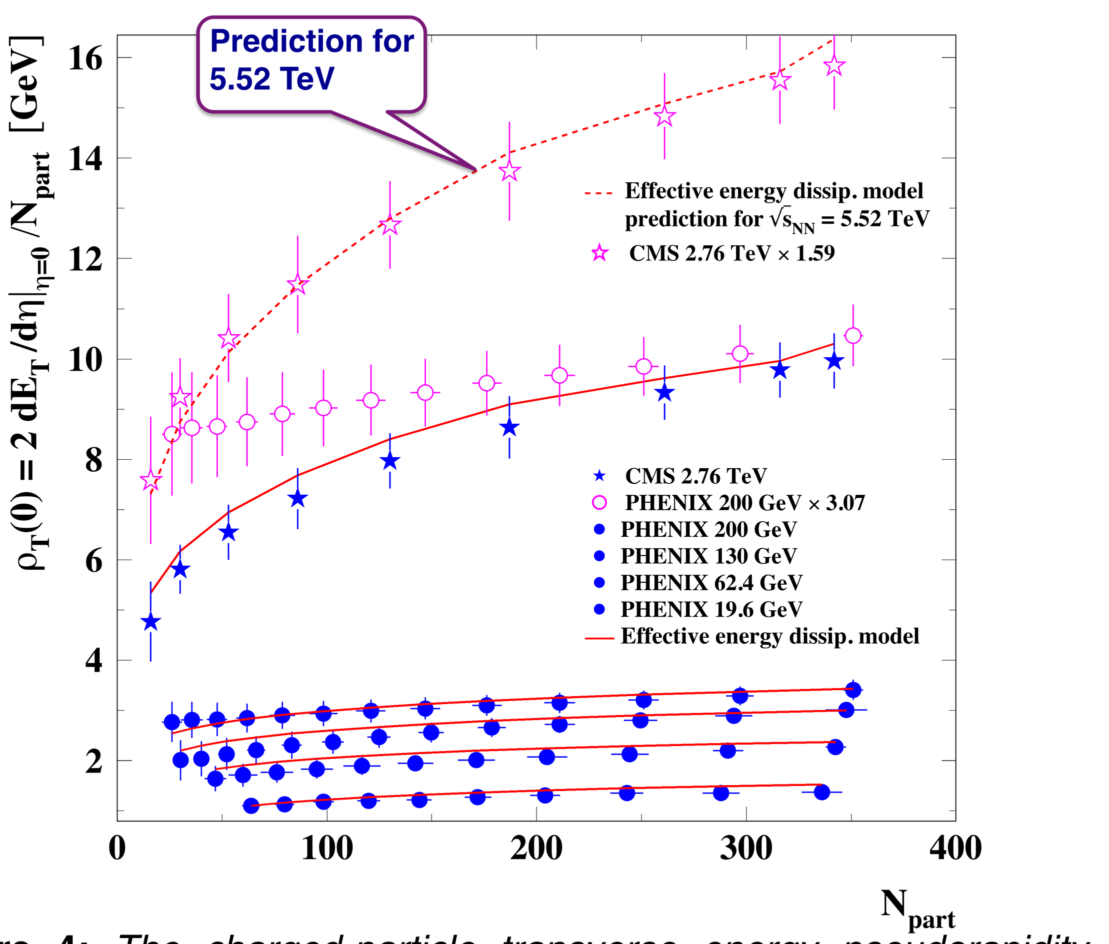

Figure 4: *The charged-particle transverse energy pseudorapidity density at midrapidity per participant pair as a function of the number of participants. The lines show the dissipation energy prediction.*

Transverse energy pseudorapidity density at RHIC show much less decrease as the centrality increases (more peripheral data), than that observed for the LHC data.

Considering the transverse energy production is derived by the centrality-defined effective c.m. energy, ε_{NN}, the calculations show very good overall agreement with the measurements independent of the collision energy.

Summary

The dependences of midrapidity pseudorapidity density of charged particles and of the transverse energy on the collision c.m. energy and on the number of participants measured in nucleus-nucleus collisions in the entire available energy range are analyzed within the framework of the energy dissipation model. The following observations are made.

- Pseudorpaidity density at midarpidity data are well reproduced in terms of the effective c.m. energy.
- The head-on collision and centrality-dependent data follow a similar energy dependence obtained for the head-on collisions as soon as the centrality data is rescaled to the effective energy. A possible transition to a new regime at ~1 TeV is indicated.
- The hybrid fit to the energy-dependence of the central collision measurements is found to reproduce well the dependence of the midrapidity density on the number of participants within the effective energy approach.
- Similar conclusions are made for the transverse-energy midrapidity density measurements.
- The predictions based on the effective energy dissipation model are made for Pb+Pb 5.52 TeV forthcoming LHC measurements for the c.m. energy and the centrality dependences.

References:

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