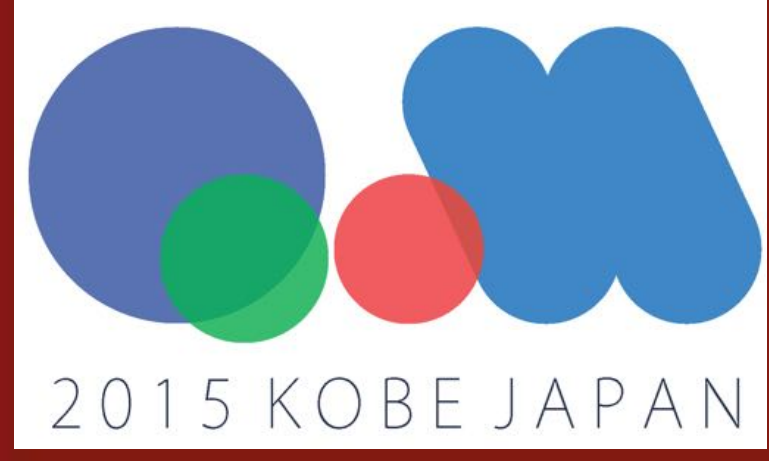


Universality of particle production and energy balanced in hadronic and nuclear collisions



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Abstract

Universality of multihadron production in AA and pp interactions is studied using collision energy and centrality dependence of the charged particle mean multiplicity data in the entire available energy range. The study is based on the participant effective-energy approach combining the constituent quark picture and Landau relativistic hydrodynamics and relating hadronic and nuclear collisions. The energy dependence of the multiplicity of head-on AA collisions are shown to be well produced. The multiplicity centrality dependence reveals a new scaling between the measured and calculated pseudorapidity spectra. Using this scaling, called the energy balanced limiting fragmentation scaling, the pseudorapidity spectra are described for all centralities. This elucidates the centrality dependence differences of multiplicity at RHIC and LHC as well as between the midrapidity density and multiplicity measured at RHIC. A new regime in AA collisions is indicated at ~ 1 TeV. Predictions are made for the multiplicities in pp and AA collisions at LHC.

1. Introduction

We study **charge particle multiplicity** in the framework of the **quark participant dissipating effective-energy approach** [1]. Within this approach, **the secondary particle production is basically driven by the amount of the initial effective energy deposited by constituent quarks into the Lorentz-contracted overlap region**. This resembles Landau relativistic hydrodynamical description of high-energy multiparticle production. In pp/pp collisions a single constituent (or dressed) quark from each nucleon is assumed to take part in a collision and rests considered spectators. Thus in **pp/pp** collisions, the effective energy for the production of secondary particles is assumed to be the energy carried by **a single quark a pair** i.e. $\sqrt{s_{pp}}/3$. 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/pp collisions but at a three times larger c.m. energy** i.e. $\sqrt{s_{pp}} = 3\sqrt{s_{NN}}$. Combining the constituent quark picture and the 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/pp collisions:

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

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/pp collision and is set to $m_p/3$. Solving Eq.(1) for multiplicity N_{ch} at a given rapidity density $\rho(0)$ at $\sqrt{s_{NN}}$, and the rapidity density $\rho_{pp}(0)$ and the multiplicity N_{ch}^{pp} at $3\sqrt{s_{NN}}$, one finds:

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

Extending this approach to the number of (nucleon) participants or centrality α , related to the energy released in the collision, we introduce the term of **the effective energy, ϵ_{NN}** , which reads:

$$\epsilon_{NN} = \sqrt{s_{NN}} (1 - \alpha) \quad (3)$$

Then, Eq.(2) reads:

$$\frac{2N_{ch}}{N_{part}} = N_{ch}^{pp} \frac{\rho(0)}{\rho_{pp}(0)} \sqrt{1 - \frac{2\ln 3}{\ln(4.5\epsilon_{NN}/m_p)}}, \quad \epsilon_{NN} = \sqrt{s_{pp}}/3. \quad (4)$$

Here $\rho(0)$, the midrapidity density in the most central nucleus-nucleus collisions measured at $\sqrt{s_{NN}} = \epsilon_{NN}$. 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 $\sqrt{s_{pp}} = 3\epsilon_{NN}$.

Recently [1], the $\sqrt{s_{NN}}$ -dependence of **the midrapidity pseudorapidity density and the transverse energy density in the midrapidity of charged particles** measured in the head-on nucleus-nucleus collisions and the centrality dependence of these two variables approach have been shown to be well described within the dissipating participant effective energy approach.

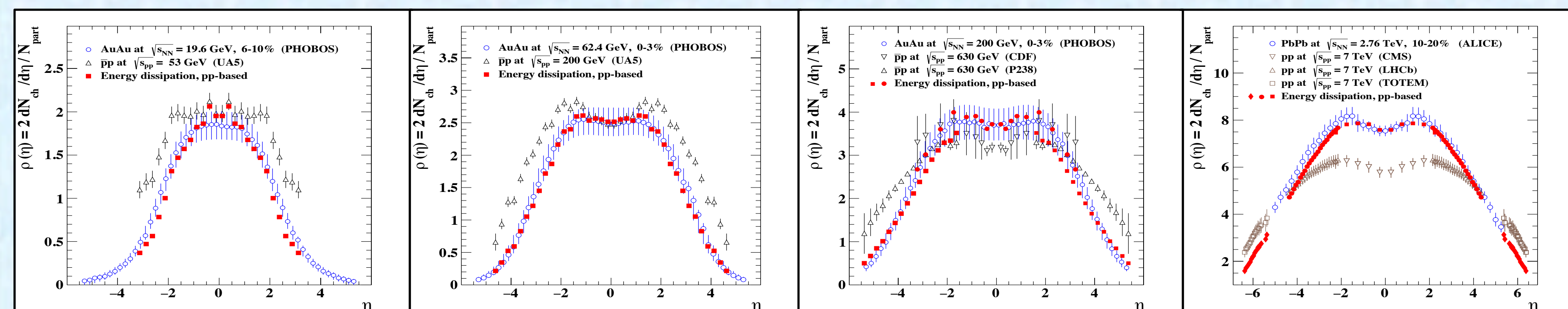
4. Energy balanced limiting fragmentation

We introduce **a new scaling, called the energy balanced limiting fragmentation scaling**, which leads to the **scaling between the measured pseudorapidity distribution and that distribution calculated using the dissipating participant effective-energy approach**. **Using this scaling, a complementarity of the multiplicities in head-on nuclear collisions and centrality data is obtained.**

Within the considered approach of constituent quarks and the Gaussian form of the pseudorapidity distribution in Landau hydrodynamics, the relationship between the pseudorapidity density distributions $\rho(\eta)$ and $\rho_{pp}(\eta)$ reads:

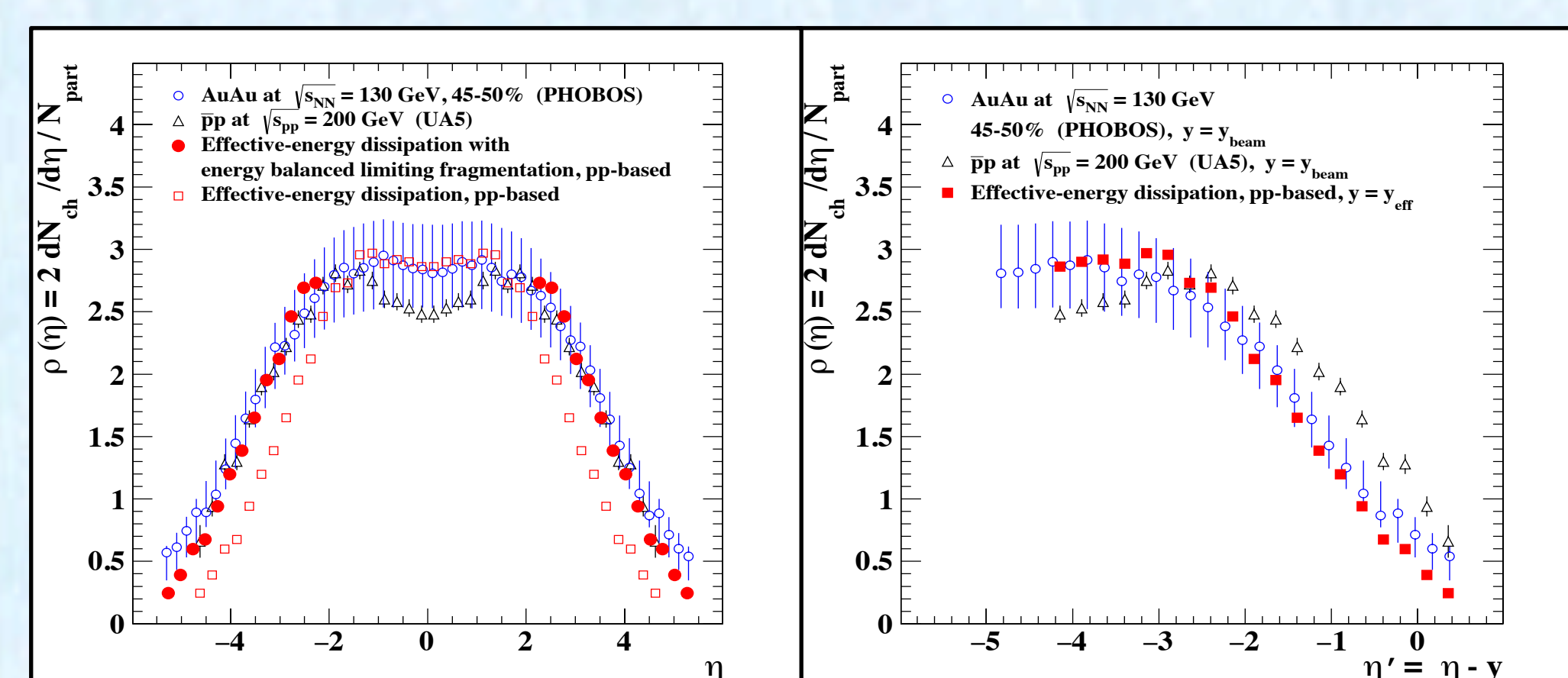
$$\frac{\rho(\eta)}{\rho_{pp}(\eta)} = \frac{2N_{ch}}{N_{part} N_{ch}^{pp}} \sqrt{1 + \frac{2\ln 3}{L_{NN}}} \exp\left[\frac{-\eta^2}{L_{NN}(2 + L_{NN})/\ln 3}\right] \quad (5)$$

Following heavy-ion distributions are calculated based on the $\rho_{pp}(\eta)$ spectra.



✓ Calculations for high-central collisions, are in very good agreement with the measurements. Minor deviations are due to some mismatch between $\sqrt{s_{pp}}$ and $3\sqrt{s_{NN}}$ (or $3\epsilon_{NN}$) and due to a slight non-centrality.

✓ At LHC energy, pp measurements from three different experiments are used to reproduce AA data.



✓ The newly calculated distribution $\rho(\eta)$ needs to be shifted by the difference ($y_{eff} - y_{beam}$) in the fragmentation region: $\eta \rightarrow \eta - (y_{eff} - y_{beam}) = \eta - \ln(1 - \alpha)$. This represents the energy balanced limiting fragmentation scaling

✓ The shift adds the needed energy balanced ingredient to the calculations providing the description of the measured pseudorapidity density distribution in the full η range in non-central heavy-ion collision

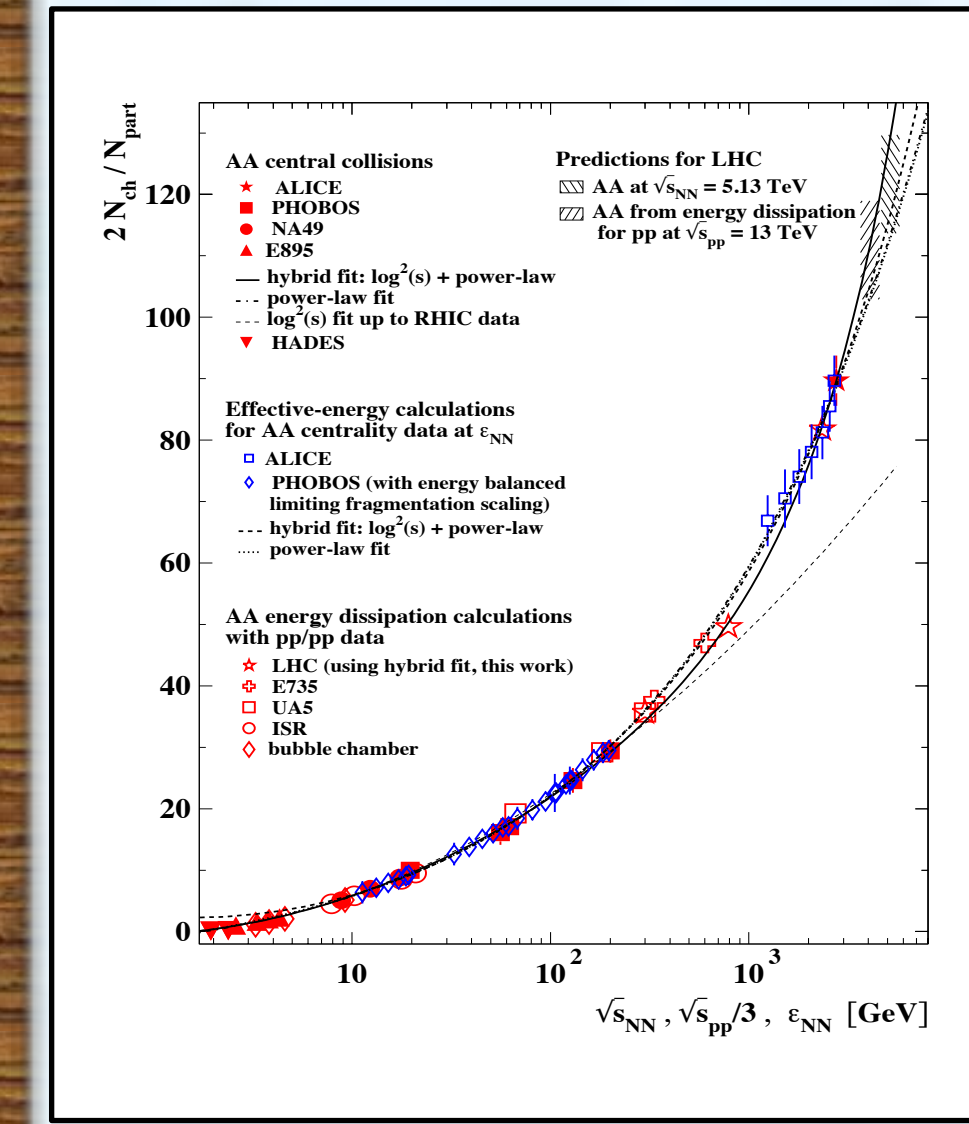
✓ **With the new scaling, which adds a needed ingredient to balance the energy of a collision and of nucleon participants, one successfully reproduces the measured $\rho(\eta)$ distribution for all centralities**

✓ Calculations for **non-central** collisions, agree well with the measurements in the central η region while fall below the data outside this region

✓ Within the effective-energy approach, one expects the **limiting fragmentation scaling** of $\rho(\eta)$ (fragmentation area of $\rho(\eta)$ independence of collision energy in the beam/target rest frame) **measured at $\sqrt{s_{NN}}$ to be similar to that of the calculated distribution but taken at the effective energy ϵ_{NN} , i.e. $\eta \rightarrow \eta - y_{eff}$, where $y_{eff} = \ln(\epsilon_{NN}/m_p)$**

✓ The measured distribution $\rho(\eta)$ is shifted by the beam rapidity, y_{beam} , while the calculated distribution is shifted by $y_{eff} = \ln(\epsilon_{NN}/m_p)$ and becomes a function of $\eta' = \eta - y_{eff}$

2. Energy dependence



✓ Hybrid [3] and power-law fits show a good agreement with AA data and are almost indistinguishable

✓ LHC data departs from \log^2 polynomial fit at $\sqrt{s_{NN}}$ about 1 TeV, indicates a **possible transition to a new regime** in heavy-ion collisions

✓ Charged particle mean multiplicity **calculations** for AA data by Eq. (2), using the pp/pp measurements, **follow the heavy-ion measurements**

✓ The centrality data show the energy dependence **similar** to head-on data as soon as the centrality data are considered in terms of the effective energy. The RHIC data are recalculated by using the energy balanced limiting fragmentation scaling (see Section 3)

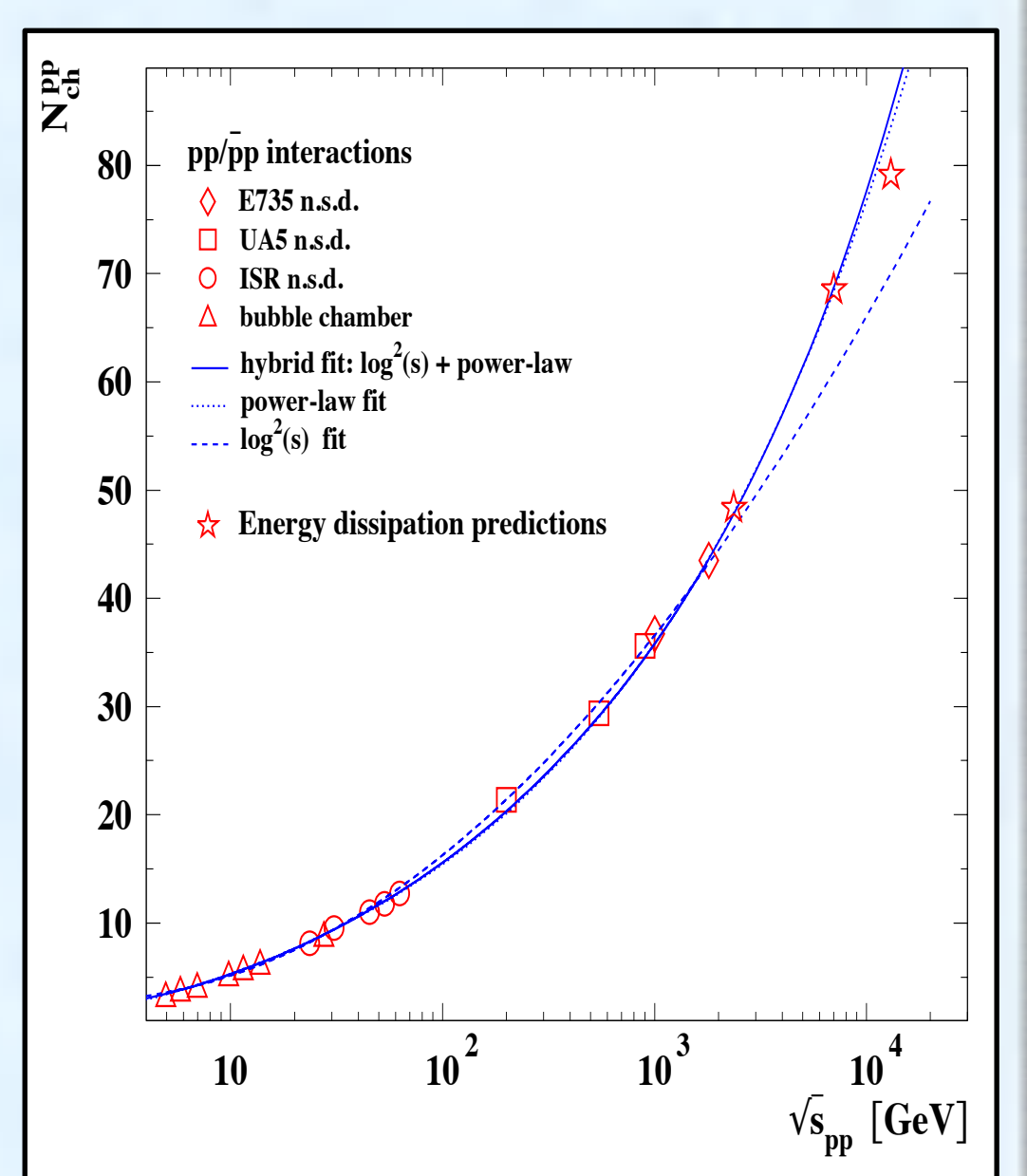
Prediction for heavy-ion collisions at $\sqrt{s_{NN}} = 5.13$ TeV and the expectation at $\sqrt{s_{pp}} = 13$ TeV are shown.

✓ The power-law and hybrid fit functions show nice agreement with data and are seen to overlap up to $\sqrt{s_{pp}} = 10$ TeV

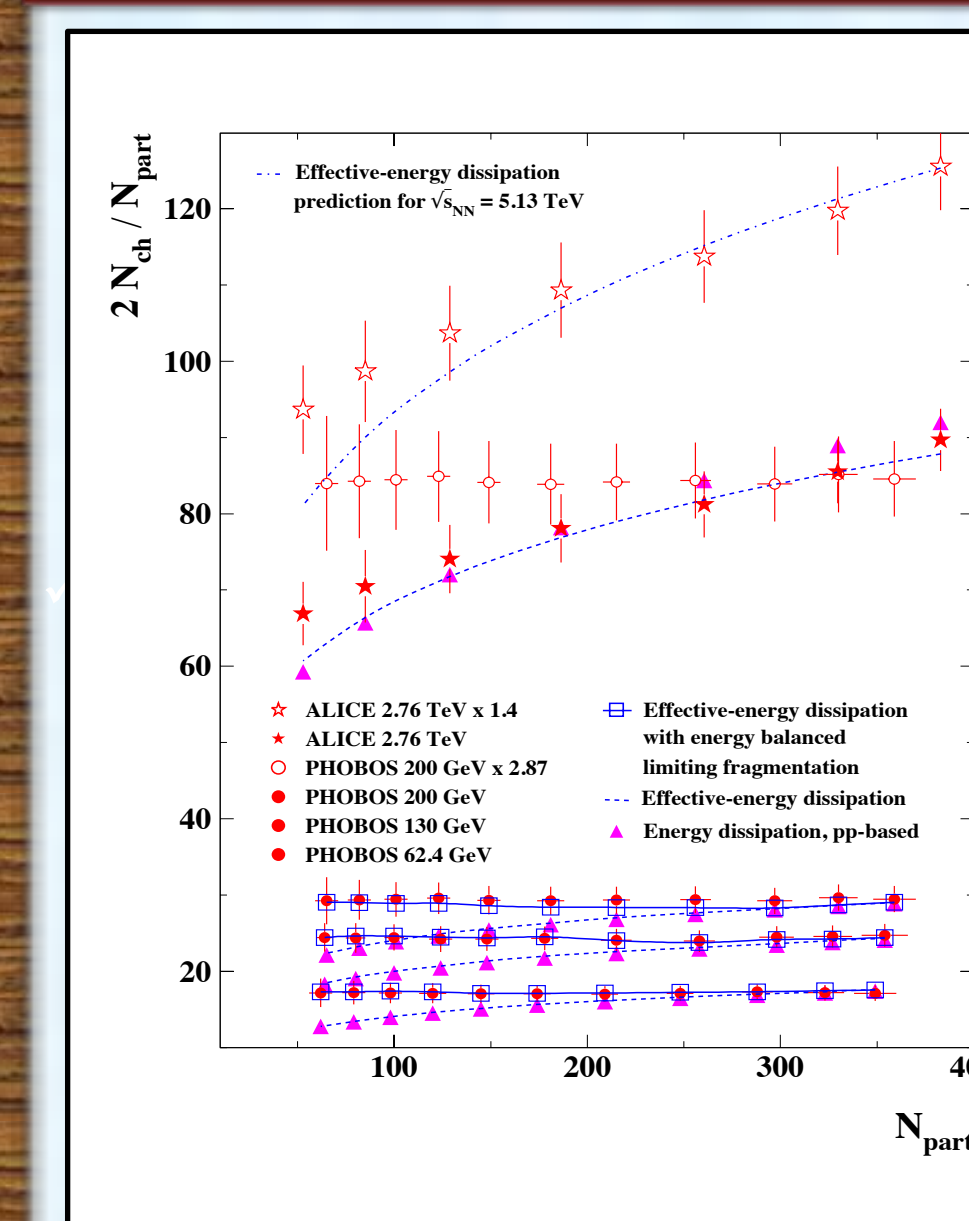
✓ \log^2 - polynomial fit function is also very close to the power-law fit even for $\sqrt{s_{pp}} > 2$ TeV

✓ **No change** in the multihadron production in pp interactions up to the top LHC energy in contrast to a new regime possibly occurred at $\sqrt{s_{NN}} \approx 1$ TeV in heavy-ion collisions

✓ **pp participant dissipating energy approach predictions are given**



3. Centrality dependence



✓ The dotted lines represent the calculations from the effective-energy approach

✓ The **calculations**, driven by the centrality-defined effective c.m. energy ϵ_{NN} , well **reproduce** the LHC data

✓ RHIC data show a significant **difference** with the calculations **for peripheral collisions**

✓ **The difference between RHIC data and calculations is explained by including the energy balanced limiting fragmentation scaling (see Section 4)**

Summary

The charged particle mean multiplicity $\sqrt{s_{NN}}$ and N_{part} dependencies measured in the entire available energy range are investigated in AA collisions within the framework of the effective energy dissipation approach. The calculations are made based on the data from pp/pp interactions pointing to the universality of multiparticle production in different types of collisions. The conclusions are as follows.

✓ The AA measurements are well reproduced under the assumption of the effective energy deriving the multiparticle production process and pointing to the same energy behaviour for all types of heavy-ion collisions, from peripheral to the most central collisions

✓ A **new scaling, called the energy balanced limiting fragmentation scaling**, which takes into account the balance between the collision energy and the energy shared by the participants, is introduced

✓ Energy balanced limiting fragmentation scaling provides a solution of 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

✓ Under the concept of the effective energy and using the energy balanced limiting fragmentation scaling, the centrality data are found to follow the head-on collisions $\sqrt{s_{NN}}$ dependence

✓ A possible transition to a new regime at $\sqrt{s_{NN}} \sim 1$ TeV is indicated

✓ Predictions are made for heavy-ion and pp collisions for upcoming collision energies at the LHC

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