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

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E.K.G. Sarkisyan, A.N. Mishra, R. Sahoo, A.S. Sakharov
arXiv:1405.2819

MOTIVATION

- Bulk observables - *mean multiplicity and rapidity densities* - control parameters of the formation and evolution of the collision initial state

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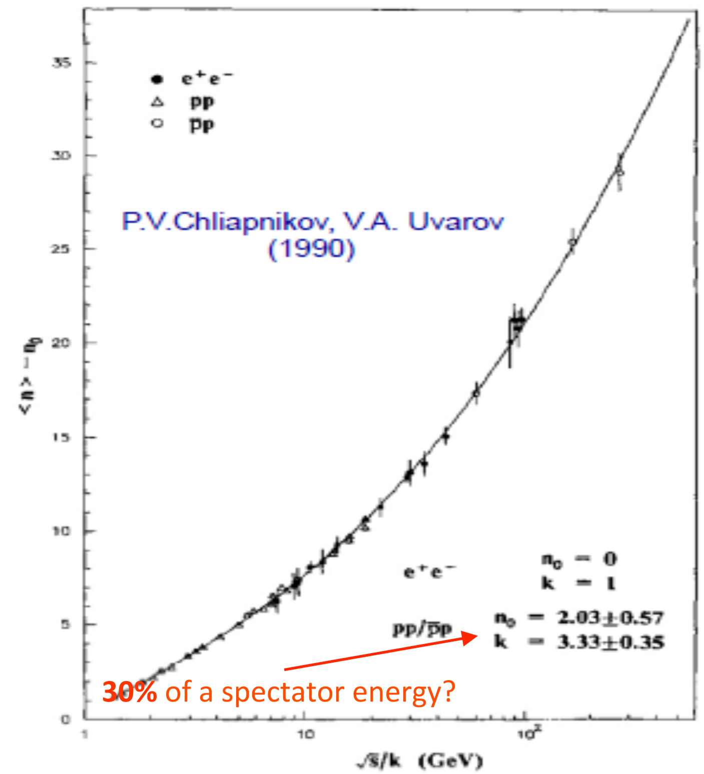

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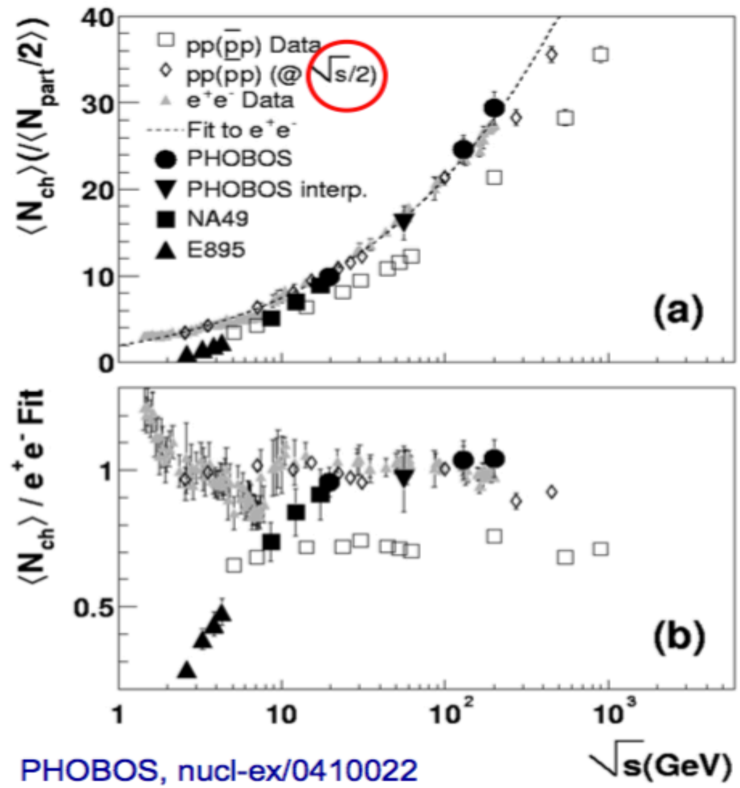

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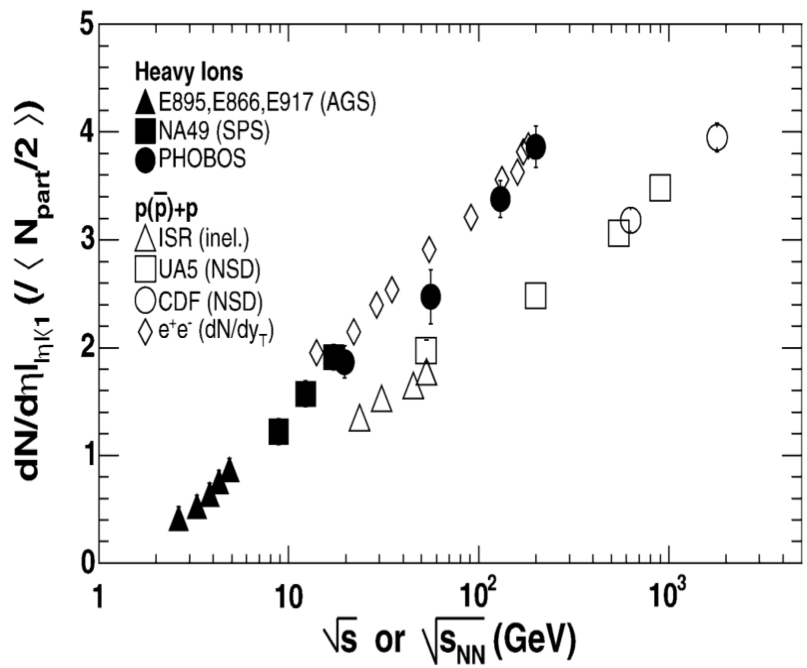
- **pp *midrapidity density* does *not* obey a similar scaling**

Not the same scaling for both variables and for different types of Interactions



Energy Scaling vs. Types of Collisions

- e^+e^- (structureless particles) annihilation - the ***total*** interaction energy is deposited in the initial state

- pp (superposition of three pairs of constituents) collision - only the energy of the interacting ***single quark pair*** is deposited in the initial state

- Both *multiplicity* and *midrapidity density* should be similar in pp at c.m. energy $\sqrt{s_{pp}}$ and e^+e^- at c.m. energy $\sqrt{s_{ee}} \approx \sqrt{s_{pp}}/3$

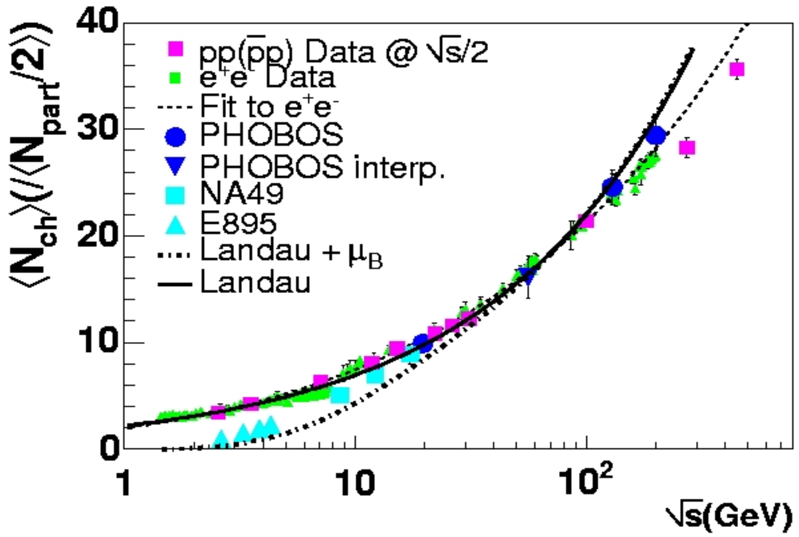
- Head-on heavy ion collisions: ***all three quarks*** participate nearly simultaneously and deposit their energy coherently into initial state

- ***Both multiplicity* and *midrapidity density* should be similar in pp at c.m. energy $\sqrt{s_{pp}}$ and head-on AA at c.m. energy $\sqrt{s_{NN}} \approx \sqrt{s_{pp}}/3$**

E. Sarkisyan & A. Sakharov (2004) : dissipating energy participants

Hydrodynamics of Collisions

- Two head-on colliding Lorentz-contracted particles stop within the overlapped zone
  - Formation of fully thermalized initial state at the collision moment
  - The decay (expansion) of the initial state is governed by relativistic hydrodynamics - Landau model (1953)



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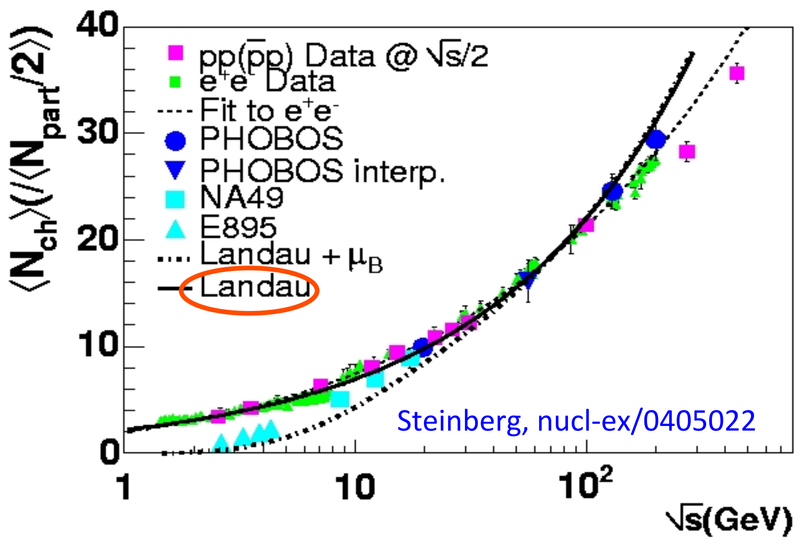

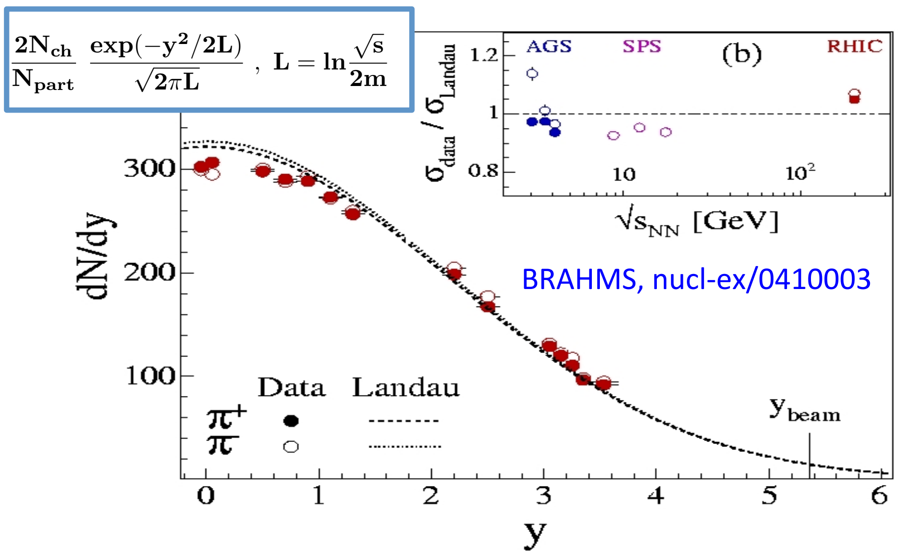

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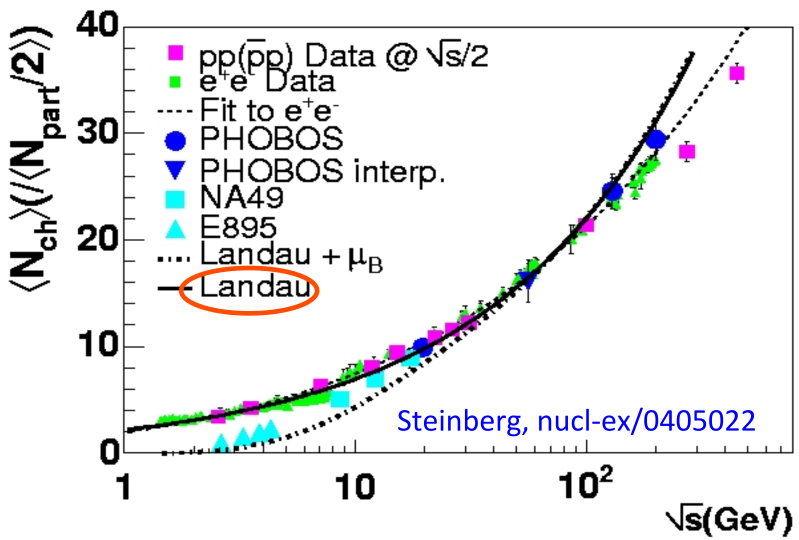

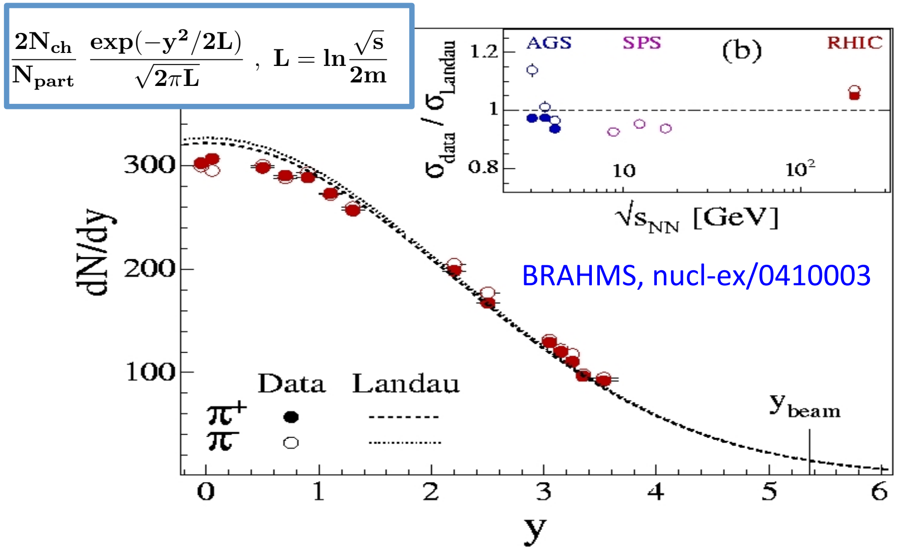

The production of secondaries is defined by the energy deposited into the initial state

Hydrodynamics & Effective Energy

From **Landau Hydrodynamics**

$$\frac{\mathbf{2N_{ch}}}{\mathbf{N_{part}}} = \mathbf{N_{ch}^{pp}} \frac{\rho(\mathbf{0})}{\rho_{\mathbf{pp}}(\mathbf{0})} \sqrt{\frac{\mathbf{L_{NN}}}{\mathbf{L_{pp}}}}, \quad \mathbf{L} = \ln \frac{\sqrt{\mathbf{s}}}{\mathbf{2m}}$$

Landau Hydrodynamics + Constituent Quark approach:

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

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Effective Energy:

Effective energy can be calculated as following:

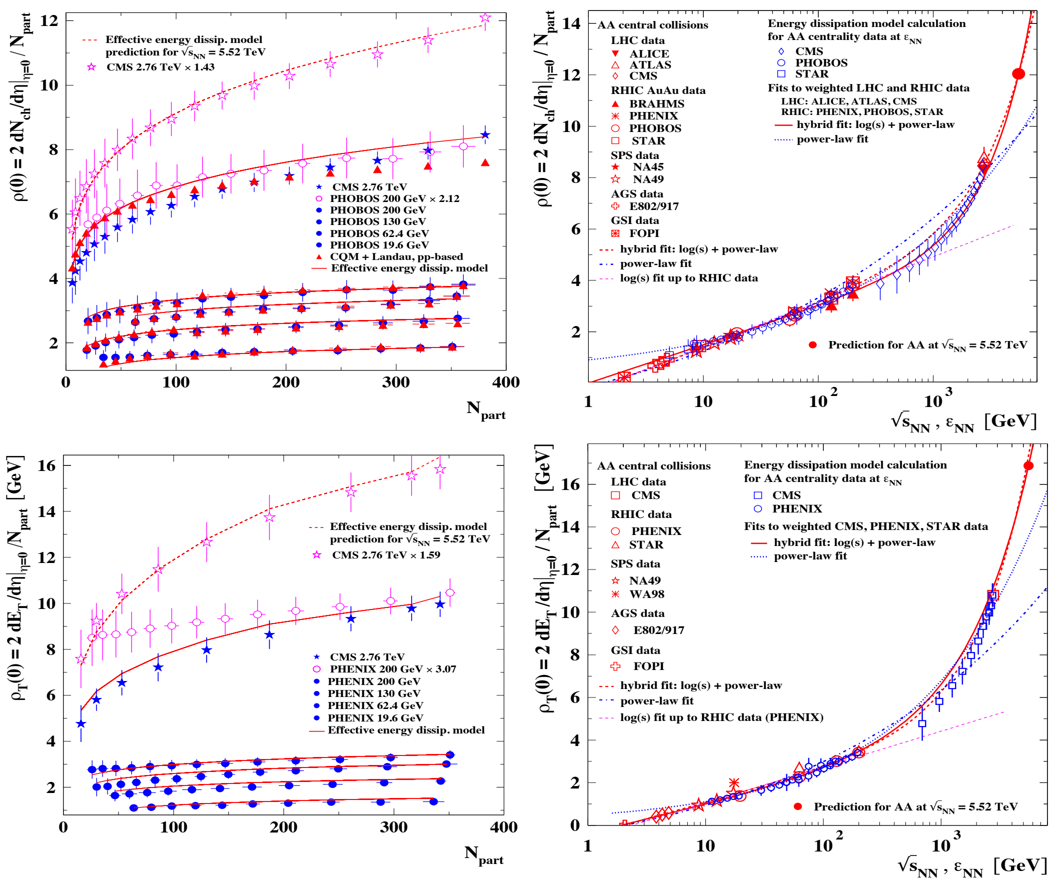
$$\epsilon_{NN} = \sqrt{s_{NN}}(1 - \alpha)$$

Here α is centrality percentile.

e.g. For 0-5% central collision α = 0.025

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

Pseudorapidity and E_T Midrapidity Densities

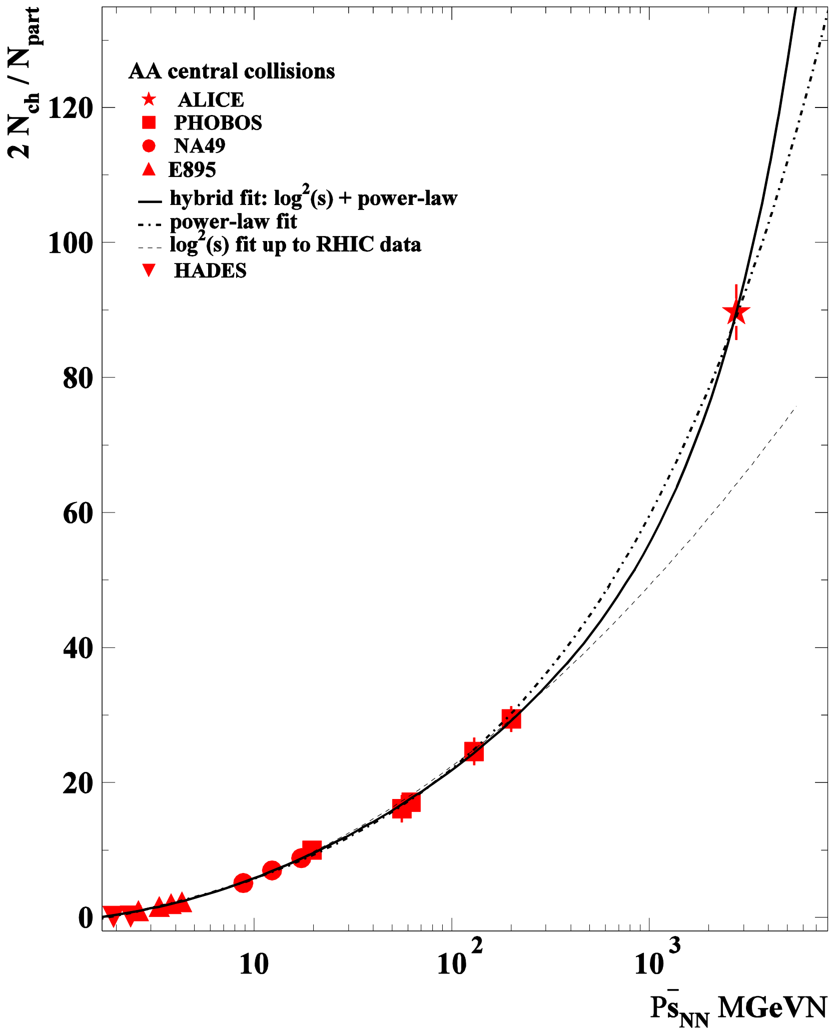


- **CQM+Landau calculations have a very good agreement with data**
- Effective energy dissipation well *explains* the centrality behaviour
- **Similarity** in the data *from peripheral to the most central* collisions: all the data follow the same (effective) energy behavior
- The combined data indicate possible transition to a new regime at $\sqrt{s_{NN}}$=0.5-1.0 TeV

Effective energy approach provides a good description of *both* the pseudorapidity and transverse energy densities at midrapidity in heavy-ion collisions

ANM, R Sahoo, EKG Sarkisyan, AS Sakharov, Eur.Phys.J. C 74 (2014) 11, 3147

Mean Multiplicity Energy Dependence



- Hybrid and power-law functions provide good fits for *all available AA data* and are almost indistinguishable up to LHC energy
- 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

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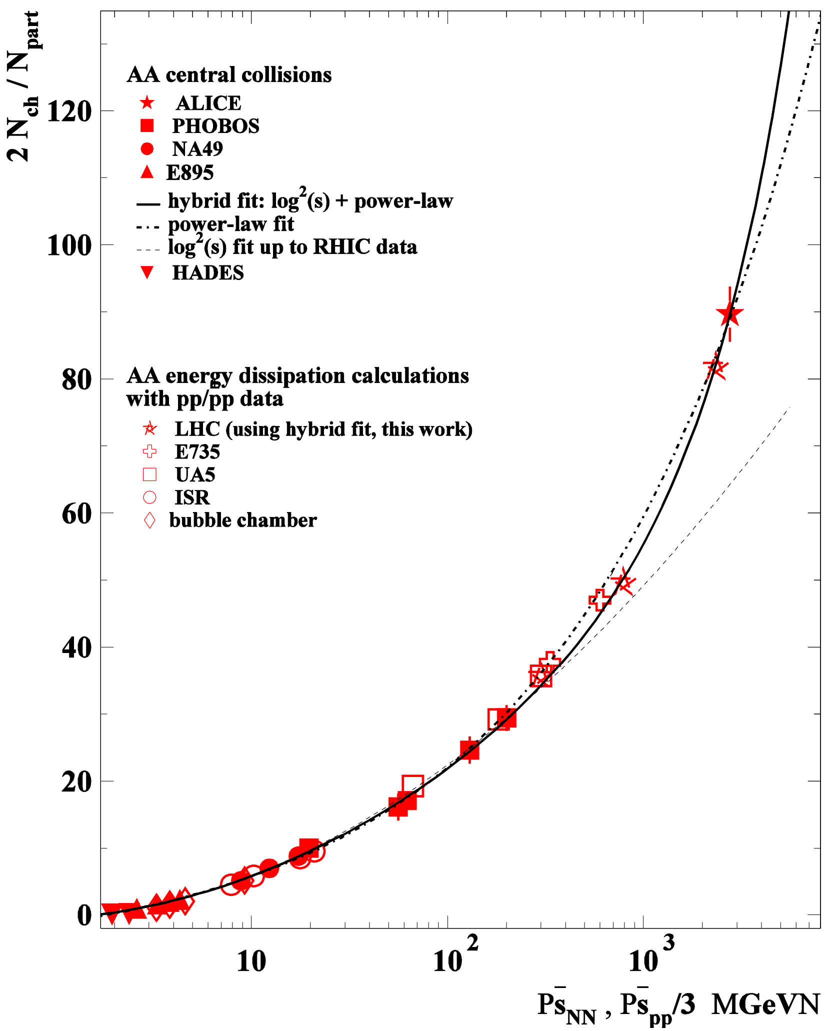

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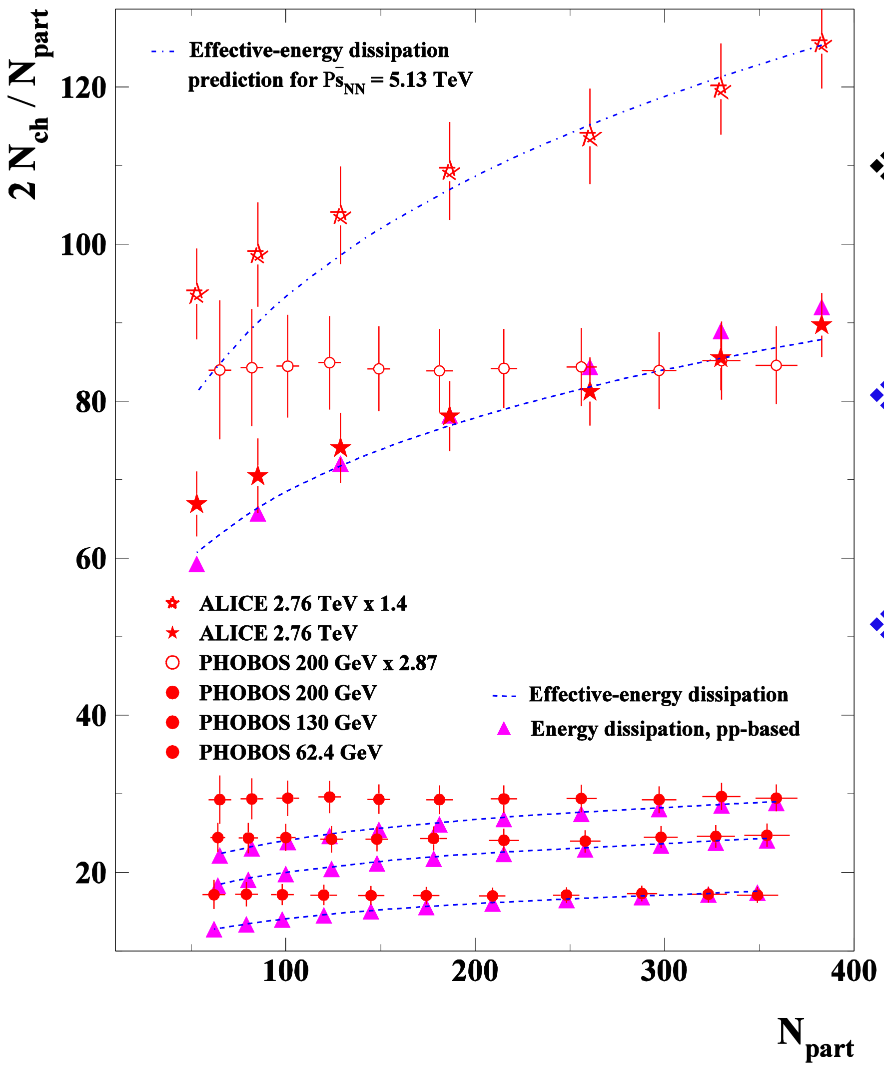
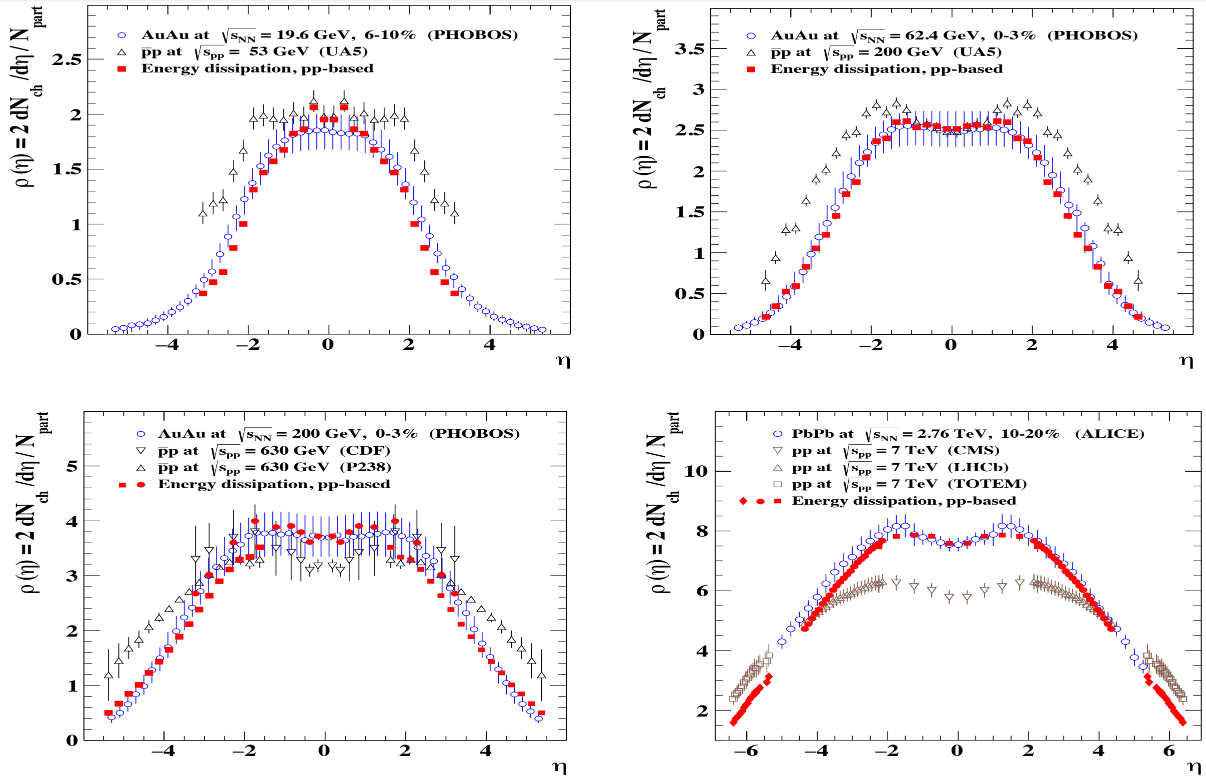
- LHC data departs from $\log^2$-polynomial fit at $\sqrt{s_{NN}}$ about 1 TeV, indicates **a possible transition to a new regime** in heavy-ion collisions
- Charged particles mean multiplicities *calculated* from the dissipation energy approach for AA data, using the pp/ppbar measurements, **well describe** the heavy-ion measurements

Mean Multiplicity 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

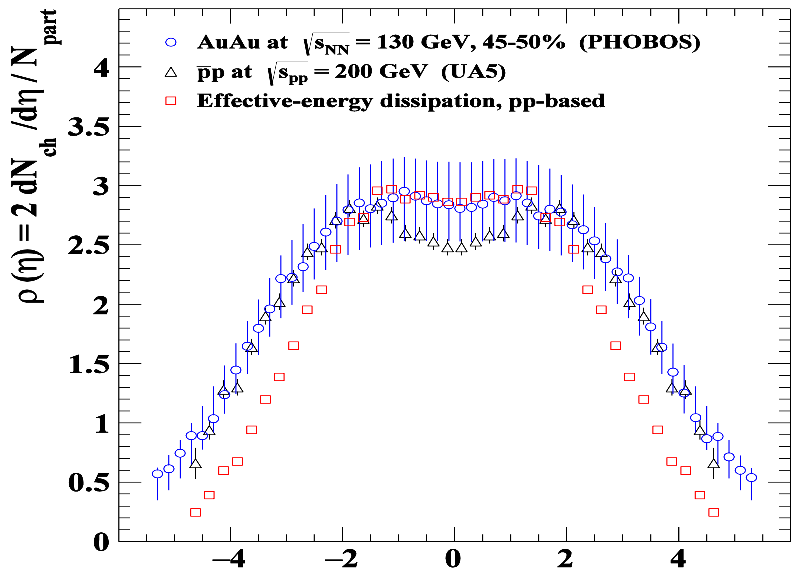
Pseudorapidity Distributions: Most Central Collisions



- ❖ Calculations for high-central collisions, are in **very good agreement** with the measurements.

- ❖ At **LHC** energy, pp measurements from the three different experiments are used and shown to **reproduce** AA data

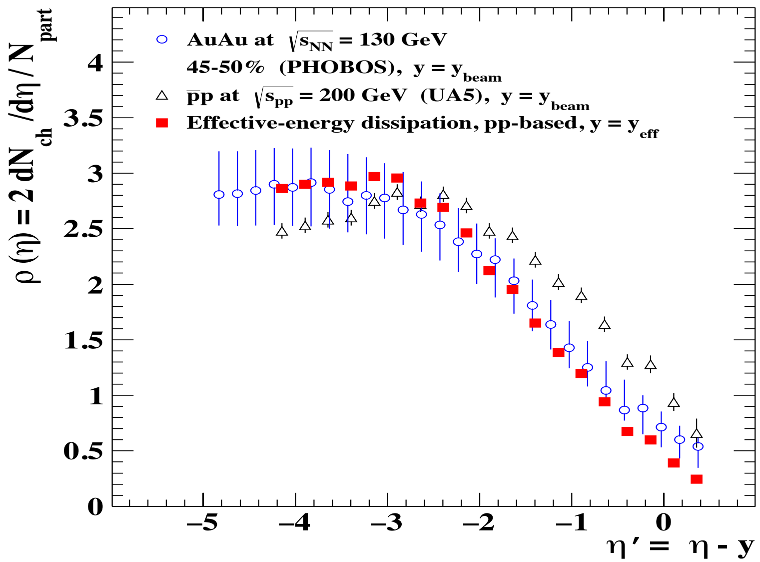
Pseudorapidity Distributions: Non-central Collision



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

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

Energy Balanced Limiting Fragmentation



❖ The *measured* distribution $\rho(\eta)$ is shifted by the *beam rapidity, y_{beam}*, while the **calculated** distribution is shifted **by $y_{eff} = \ln(\varepsilon_{NN}/m_p)$** and becomes a function of $\eta' = \eta - y_{eff}$. Then **the distributions coincide** as expected.

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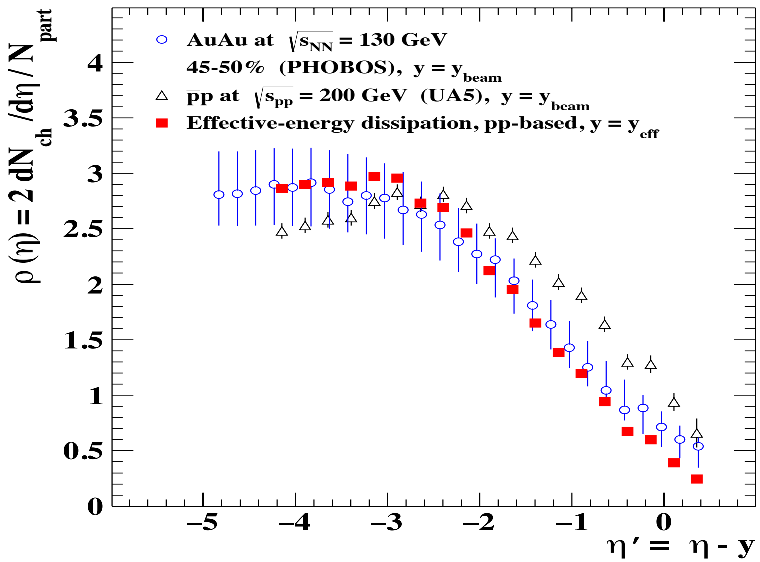
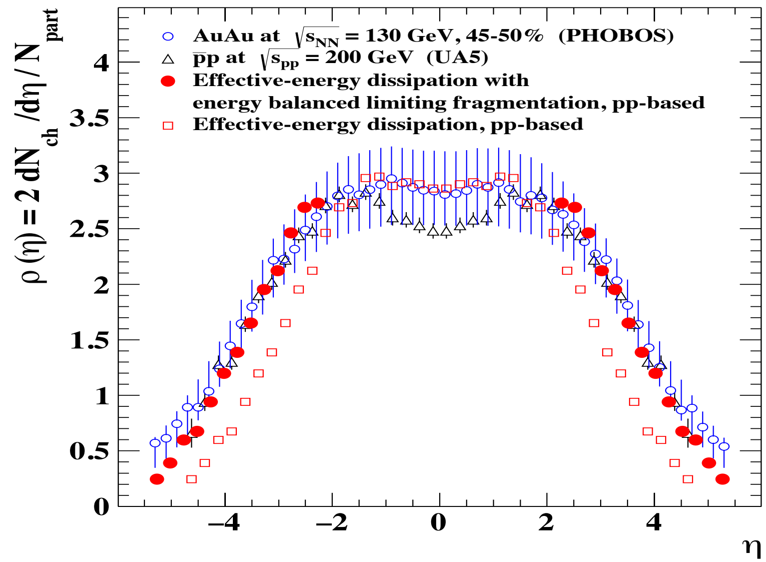
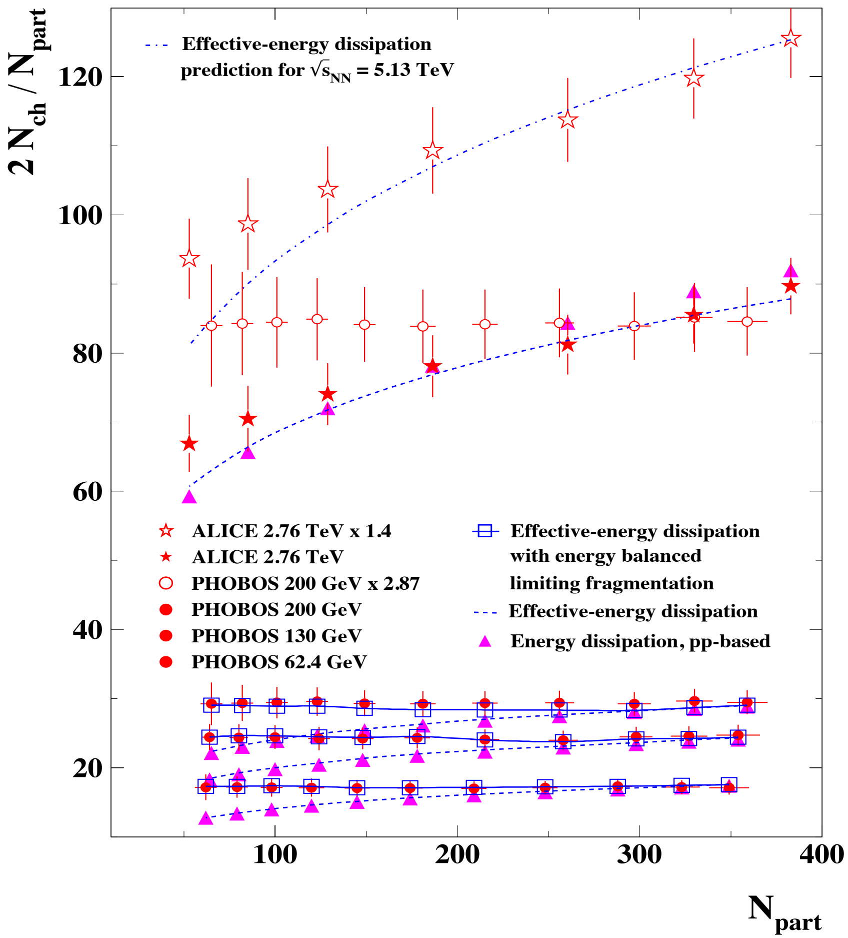




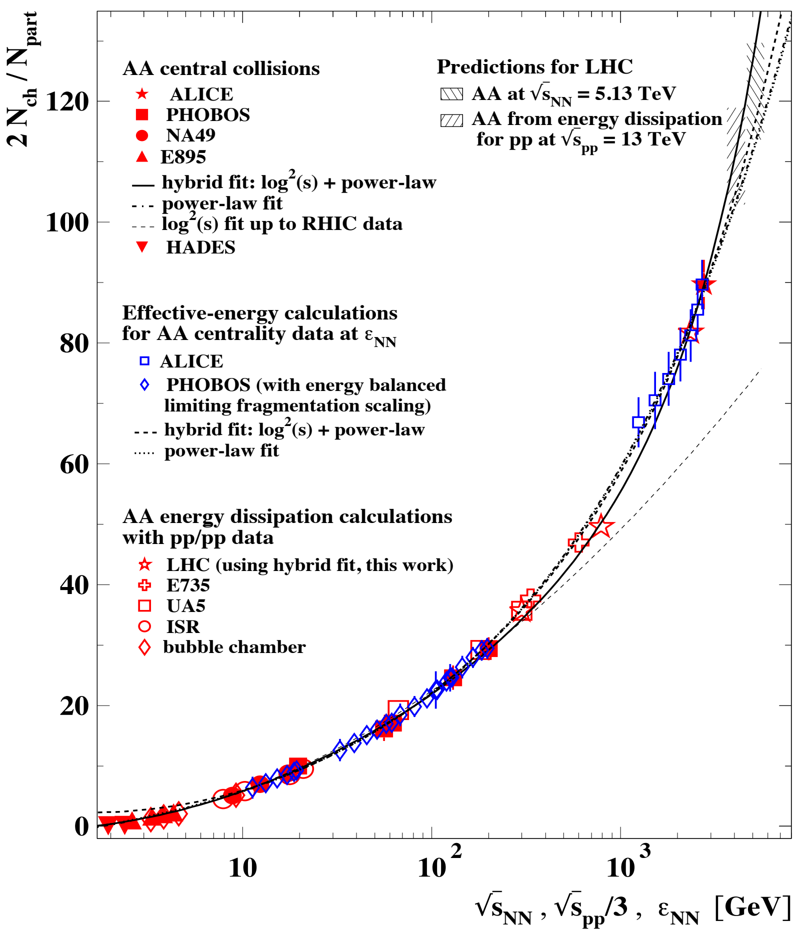
- The *measured* distribution ρ(η) is shifted by the *beam rapidity, y_{beam}*, while the **calculated** distribution is shifted **by $y_{eff} = \ln(\varepsilon_{NN}/m_p)$** and becomes a function of $\eta' = \eta - y_{eff}$. Then **the distributions coincide** as expected.
- The *newly calculated* distribution ρ(η) needs to be shifted by the difference $(y_{eff} - y_{beam})$ in the fragmentation region: $\eta \rightarrow \eta - (y_{eff} - y_{beam}) = \eta - \ln(1 - \alpha)$.
- These represent **the *energy balanced* limiting fragmentation scaling** phenomena

Mean Multiplicity Centrality Dependence: Energy Balanced Limiting Fragmentation



- 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**

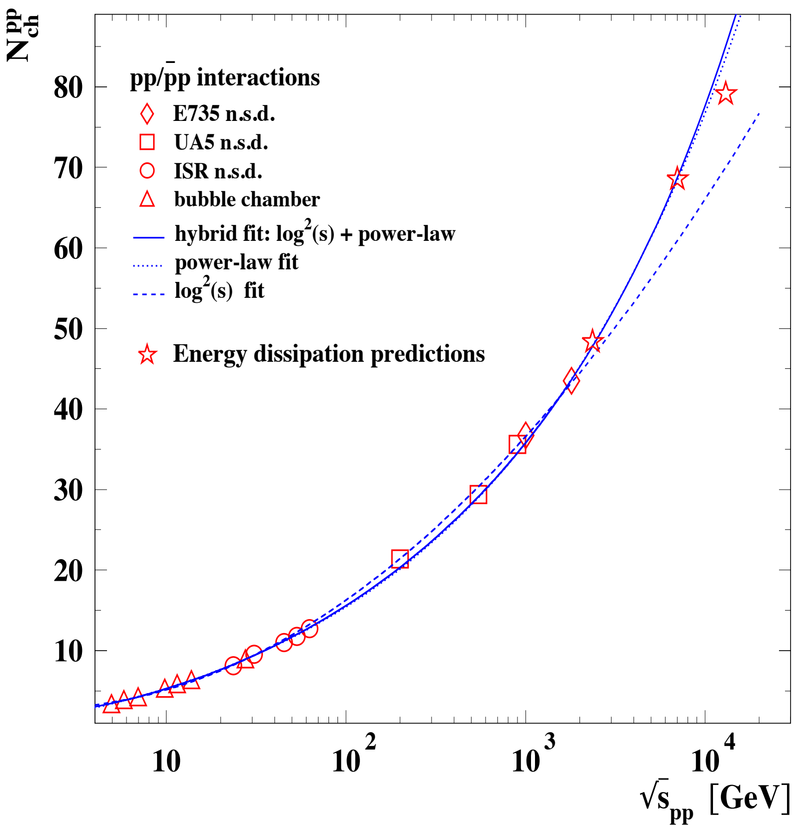
Mean Multiplicity Energy Dependence



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

- *Hybrid 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 particles mean multiplicities *calculated* from the dissipation energy approach for AA data, using the pp/ppbar measurements, **well describe** 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**

Mean Multiplicity Energy Dependences in pp Interactions



- *The power-law and hybrid* fit functions **fit well** the data in the **entire c.m. energy** region 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**

Summary and Conclusions

- **The AA multiplicity 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 $\sqrt{s_{NN}}$ ~1 TeV is indicated
- ***Predictions* are made** for *heavy-ion and pp collisions* for upcoming energies at the ***LHC***


Thank you