Saturation - "bottom-up"

hadron multiplicities at LHC

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- motivation -

Does parton saturation at high density explain hadron multiplicities at LHC ?

[R. B., A. H. Mueller, D. Schiff, D. T. Son, arXiv:1103.1259]

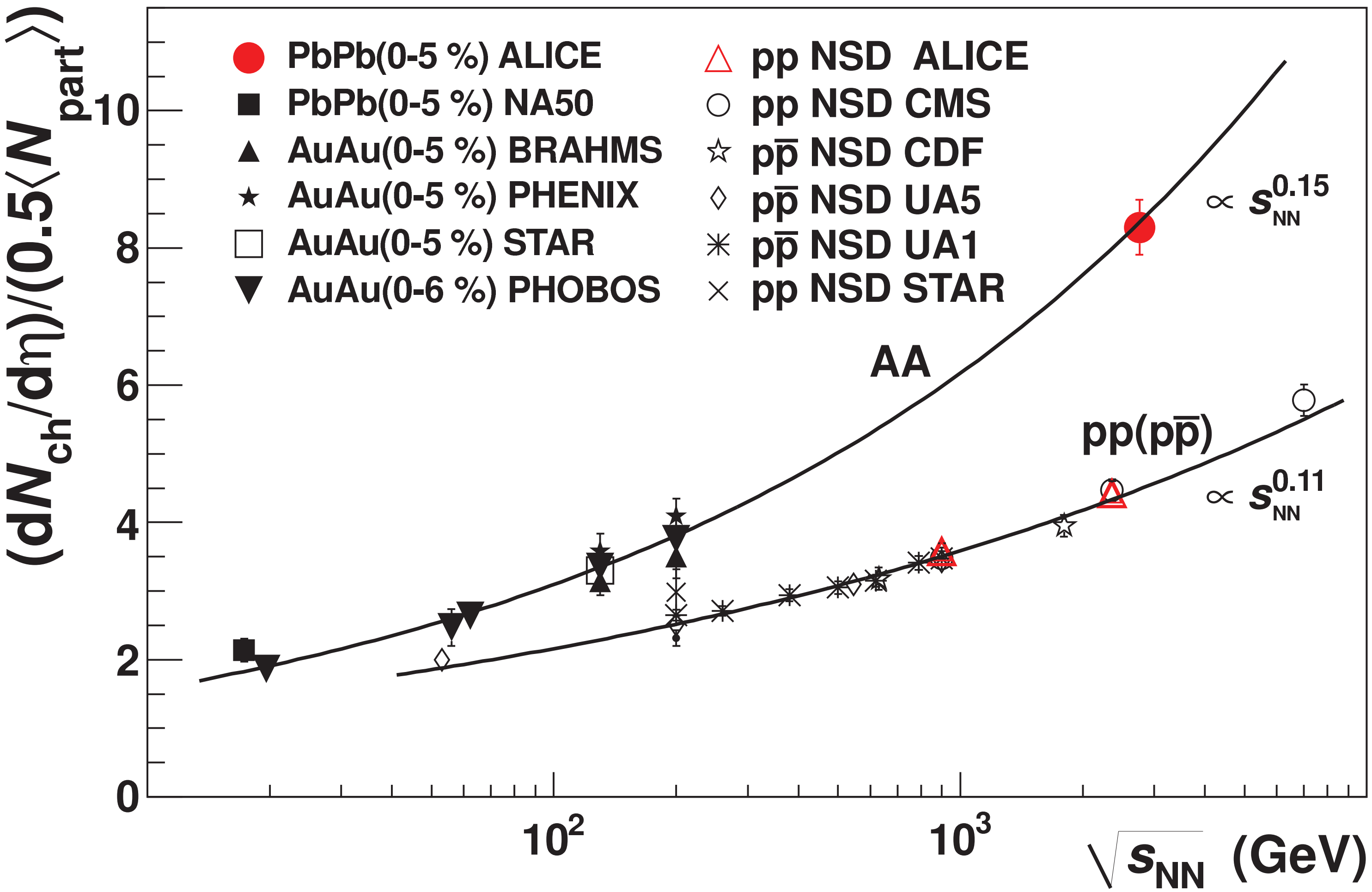
charged-particle multiplicities measured in central heavy ion collisions at high energies may not *directly* be determined by the initial conditions as given by saturation models, but in addition by the way gluons are thermalized

this process - "bottom-up" like equilibration due to nonconservation of the number of gluons, i.e. due to entropy production - may fill the gap between the multiplicities expected e.g. from saturation models and the ones measured by the ALICE Collaboration in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

[The ALICE Collab., arXiv: 1011.3916 and 1012.1657]

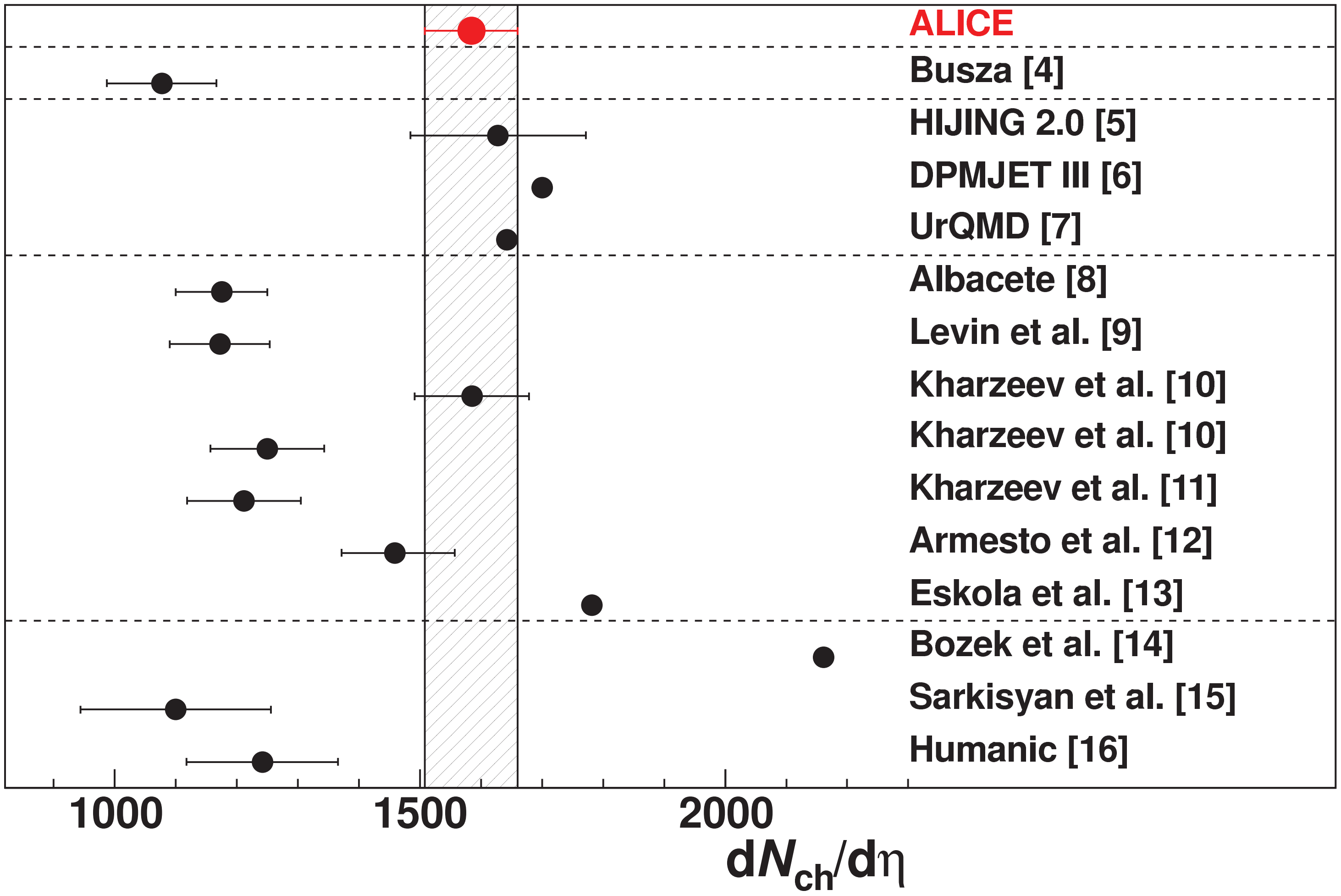
ENTROPY GENERATION CONNECTS COLORED GLASS INITIAL CONDITIONS TO FINAL STATE MULTIPLICITIES

multiplicities [ALICE Collab.]



Charged particle pseudo-rapidity density per participant pair for central nucleus–nucleus as a function of s_{NN}

multiplicities



Comparison of the ALICE measurement with model predictions. Dashed lines group similar theoretical approaches

- "bottom-up" scenario -

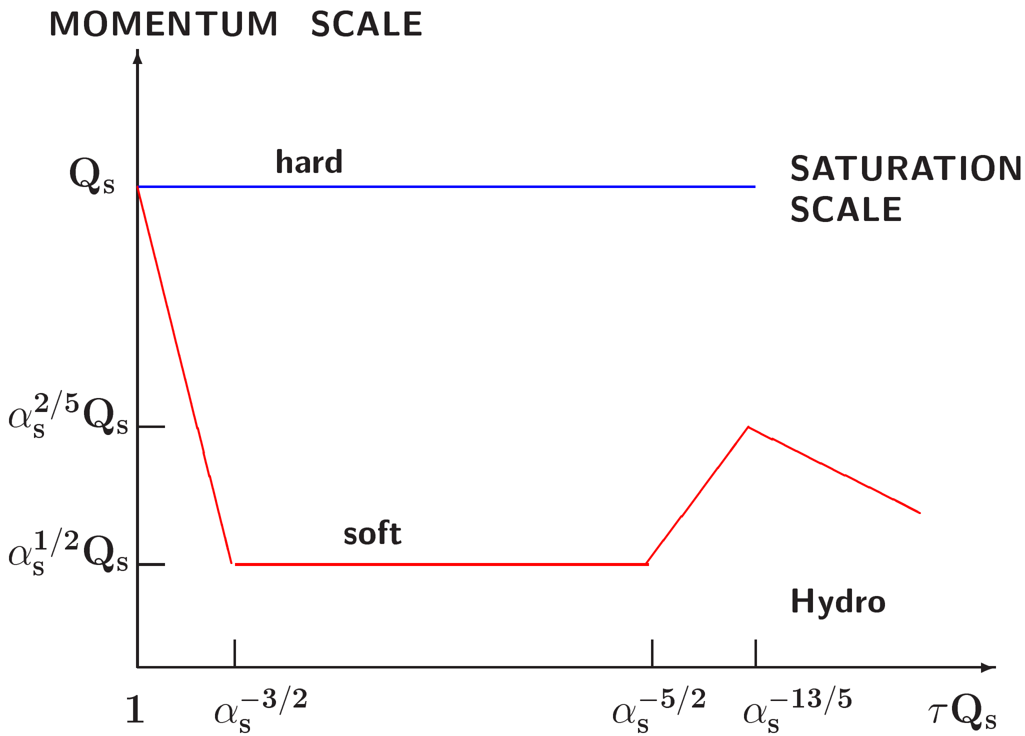
characterized by the fact that hard gluons are degrading, soft ones are formed and start to dominate the system

NOTE: the original "bottom-up" picture does not account for the physics of plasma instabilities in the early stages of thermalization which changes the stages to thermalization: most of the entropy of the final system is generated around $\tau \equiv \alpha_s^{-5/2} Q_s^{-1}$, not very much different from the "original" equilibration time

$$\tau_{eq} = c_{eq}\, \alpha_s^{-13/5} Q_s^{-1}$$

providing explicit quantitative predictions for particle multiplicities in this scenario we go as much as possible beyond the parametric estimates - the main drawback of the model are two theoretically undetermined constants c_{eq} and c

bottom-up scenario



characteristic momentum scales for the "bottom-up" scenario

- gluon densities -

ratio R of the number of soft versus hard initial gluons

parametrically estimated in terms of the gluon densities $n_{soft}(\tau)$ and $n_{hard}(\tau)$, respectively,

$$R = [n_{soft}(\tau)(Q_s\tau)]|_{\tau_{eq}} \;/\; [n_{hard}(\tau)(Q_s\tau)]|_{\tau_0} \sim \alpha_s^{-2/5}$$

i.e.

$$R \simeq 0.13\, c^2\, c_{eq}^4 \alpha_s^{-2/5}(Q_s^2)$$

an illustrative numerical example for plausible $O(1)$ estimates for the constants:

$$c \simeq 2.4\ (\pm 0.2), \quad c_{eq} \simeq 1.1\ (\pm 0.1)$$

should encourage to obtain numerical values beyond this "guess"

- input -

ratio $R(2.76\ TeV)$ for the LHC energy at $\sqrt{s} = 2.76\ TeV$ is estimated by taking the ALICE value

$$dN_{ch}/d\eta = 1584 \pm 4(stat) \pm 76(sys)$$

and as a reference value for the CGC initial state configuration
[J. L. Albacete, arXiv:1010.6027],

$$dN_{ch}/d\eta\ (2.76\ TeV) = 1175 \pm 75$$

which underpredicts the ALICE value
gives the estimate

$$R(2.76\ TeV) \simeq 1.35\ (\pm 0.15)$$

together with RHIC data and the parametrizations at $\sqrt{s_0} = 130\ GeV$:

$$Q_s^2 = (s/s_0)^{\lambda/2}\ Q_{s0}^2, \ \ \lambda = 0.25, \ \ Q_{s0}^2 = 2\ GeV^2, \ \alpha_s = 0.35$$

and

$$Q_s^2\ (2.76) = 4.3\ GeV^2, \ \ \alpha_s = 0.3$$

- result and prediction -

the estimates give $\tau_{eq} \simeq 2.2\ fm$ and $T_{eq} \simeq 490\ MeV$ at the LHC energy $\sqrt{s} = 2.76\ TeV$, to be reasonable values in the framework of pQCD

at the higher energy at $\sqrt{s} = 5.5\ TeV$ we expect, using
$Q_s^2 = 5.1\ GeV^2,\ \alpha_s = 0.29,\ R(5.5\ TeV) \simeq 1.38,$

$$dN_{ch}/d\eta \simeq 1910\ (\pm 50)$$

enhancing the CGC value by J. L. Albacete [arXiv: 1010.6027]

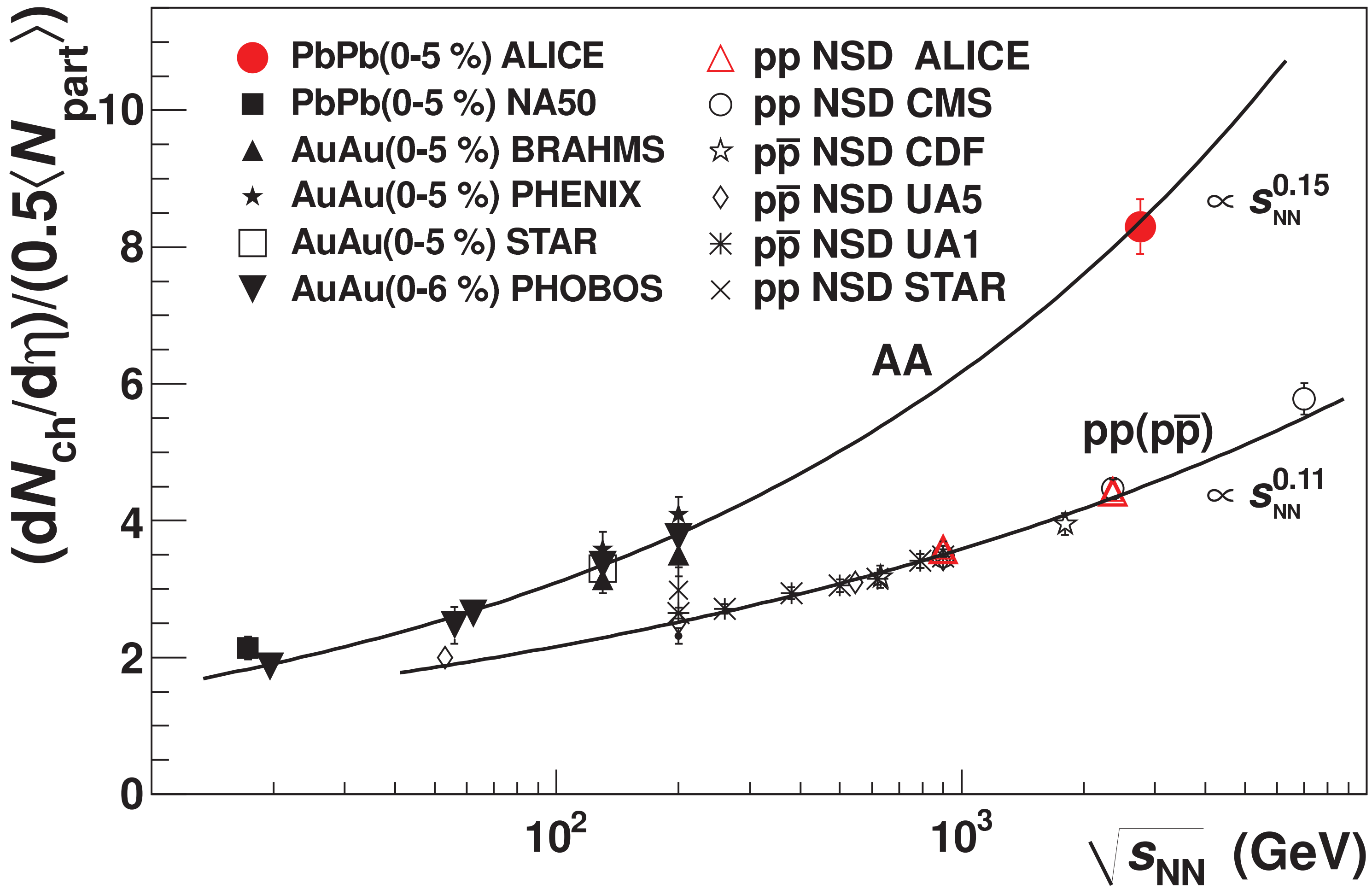
$$dN_{ch}/d\eta = 1390 \pm 95$$

with $N_{part} = 381$ (taken at $2.76\ TeV$) gives

$$\frac{2}{N_{part}} dN_{ch}/d\eta \simeq 10.0$$

in agreement with the ALICE fit using the proportionality $\propto s^{0.15}$

multiplicities [ALICE Collab.]



Charged particle pseudo-rapidity density per participant pair for central nucleus–nucleus as a function of s_{NN}

dependence on number of participants

surprising fact [J. Schukraft, arXiv:1103.3474]:
the shape of the centrality dependence of $\frac{dN_{ch}}{d\eta}$ at LHC
is practically identical to Au - Au at RHIC (at least for $N_{part} > 50$)

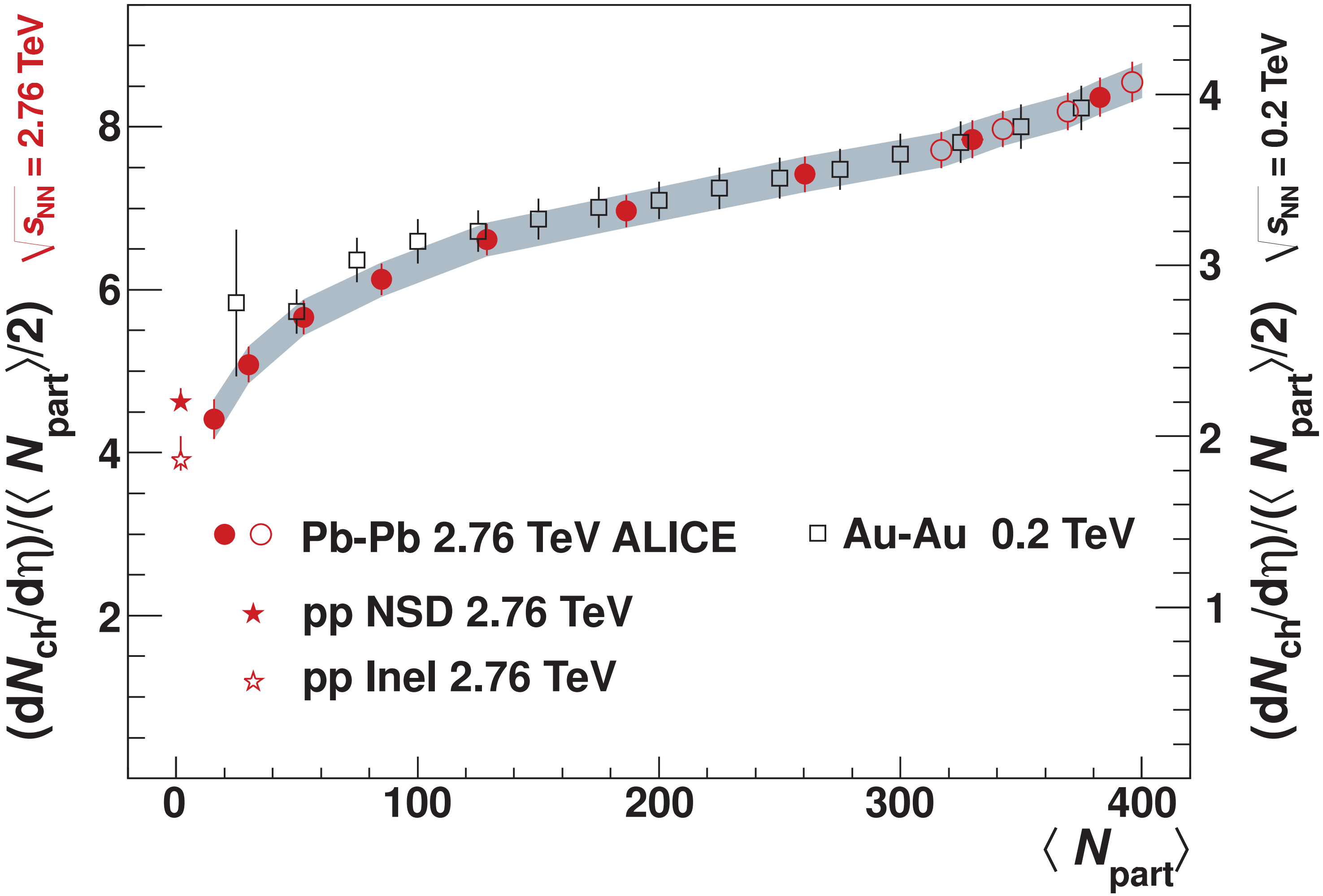
- numerically small dependence on saturation scale Q_s:

$$\langle \frac{2}{N_{part}} \frac{dN_{ch}}{d\eta} \rangle \approx \left(\frac{\sqrt{s}}{\sqrt{s_0}} \right)^{\lambda} \left[\ln \frac{Q_s^2(s,b)}{\Lambda_{QCD}^2} \right]^{7/5}$$

and

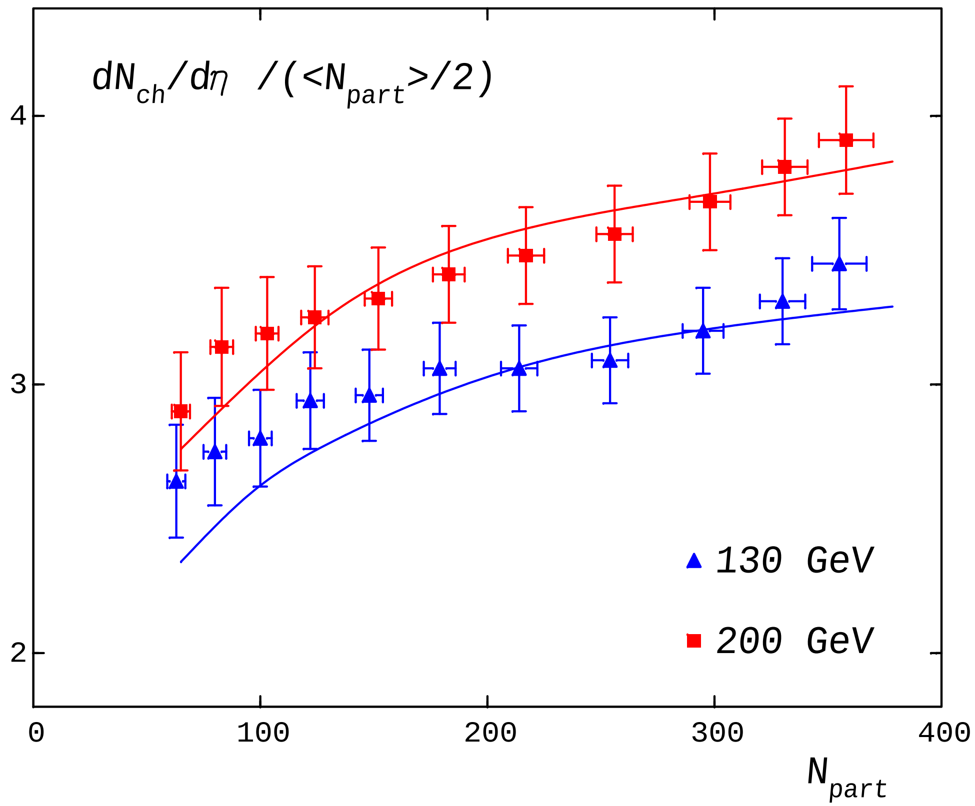
$$Q_s^2(s,b) \simeq \frac{4\pi^2 N_c}{N_c^2 - 1} \, \alpha_s(Q_s^2) \, xG(x, Q_s^2) \, \frac{\rho_{part}(\vec{b})}{2}$$

NOTE: for $60 < N_{part} < 200$ there is a trend that the shape at 2.76 TeV is flatter than the one at 200 GeV



Dependence on the number of participants for Pb-Pb collisions (LHC) and Au-Au collisions (RHIC) - scale difference of a factor 2.1

N_{part} dependence



scaled density as a function of N_{part} at $\sqrt{s} = 130$ and 200 GeV. Data from PHOBOS Collab.