Towards A Universal Law of Particle Production in Heavy-Ion Collisions

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Outline:

- Global Observables: E_T and N_{ch}
- Nuclear Overlap Model
- Results and Discussion
- Summary

A Word of Caution: This is a work done for my Ph.D. Project Work.

Global Observables: E_T and N_{ch}

✍ E_T measurement gives an idea of the energy density of the produced fireball.

✍ Is heavy-Ion Collision a simple superposition of pp collision ? $dE_T/d\eta$ studied as a function of collision centrality may give the answer.

✍ Particle production mechanism in both Nucleon and Quark participant framework.

Nuclear Overlap Model

Mean number of participants in the collisions of a nucleus *A* and a nucleus *B* with impact parameter *b* is:-

$$N_{N-part,AB} = \int d^2s \;\; T_A(\vec{s})\left\{1-[\frac{\sigma_{NN}T_B(\vec{s}-\vec{b})}{B}]^B\right\} + \int d^2s \;\; T_A(\vec{s})\left\{1-[\frac{\sigma_{NN}T_A(\vec{s}-\vec{b})}{A}]^A\right\}$$

Where $$T(\vec{b}) = \int dz \;\; n_A(\sqrt{b^2+z^2})$$

Probability of having a Nucleon-Nucleon collision within the transverse area element *db*.

For 2.76 TeV at LHC:-

σ_{NN} = 64 mb or Nucleon participant

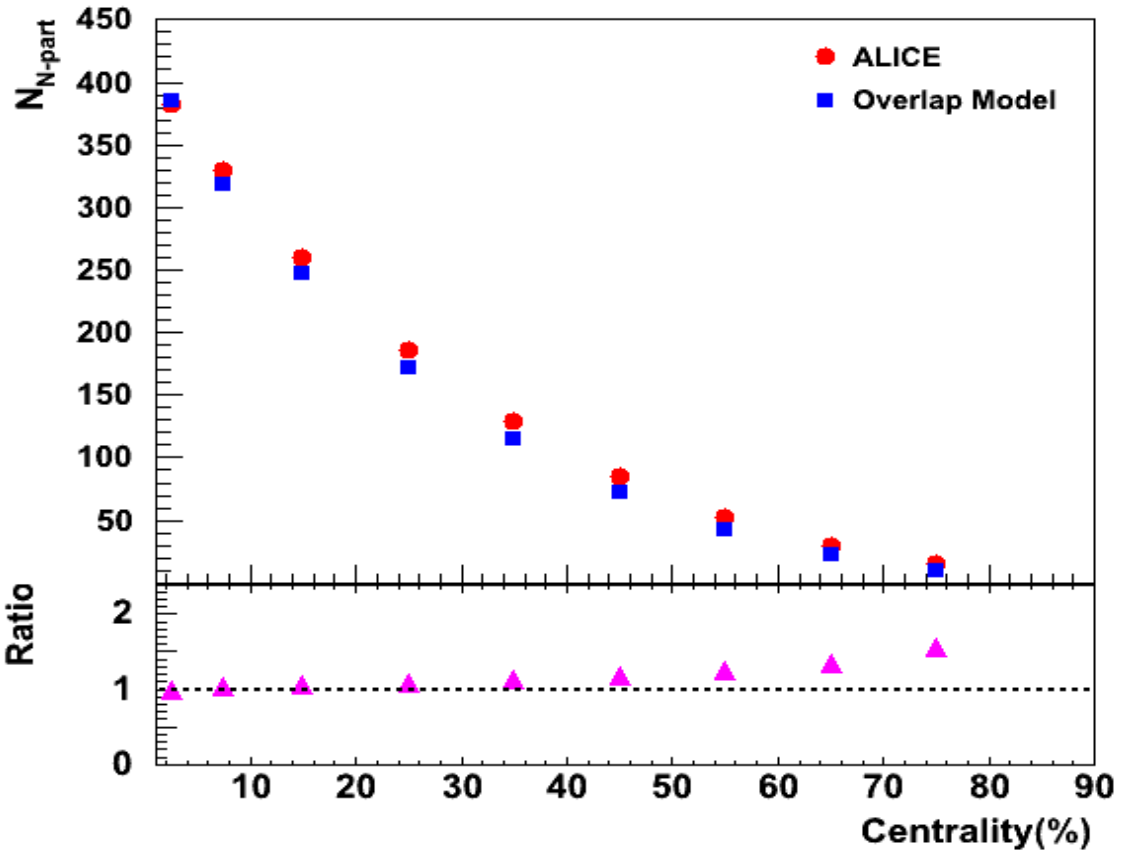
σ_{NN} = 64/9 ~ 7.1 mb for Quark participant

Nuclear Density (n_0) = 0.17 fm^{-3} for Nucleon participant

Quark Density (n_q) = ($3xn_0$)= 0.51 fm^{-3} for Quark participant

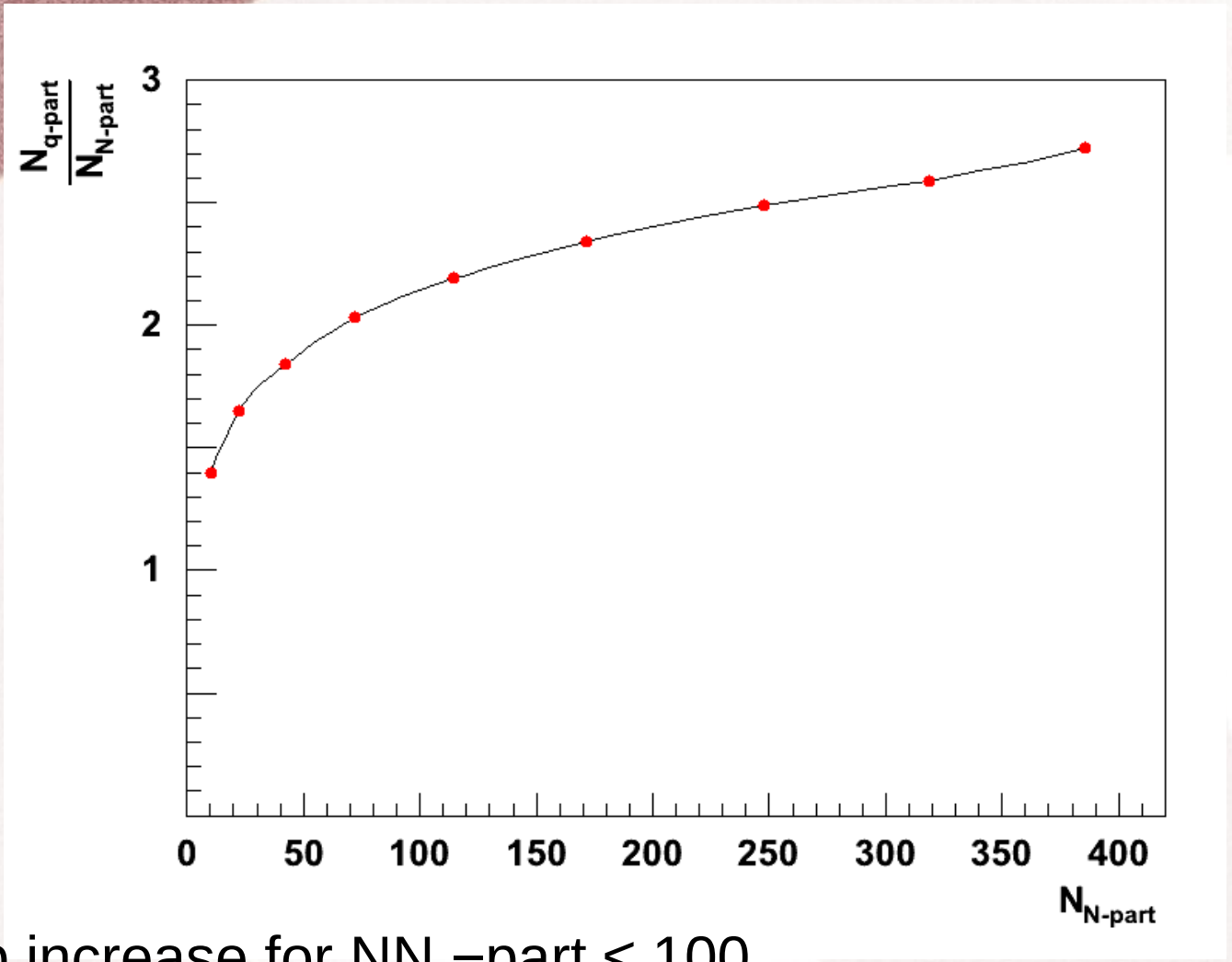
Overlap Model *Vs* ALICE estimates

Phys. Rev. Lett. 106, 032301 (2011), ALICE Collaboration



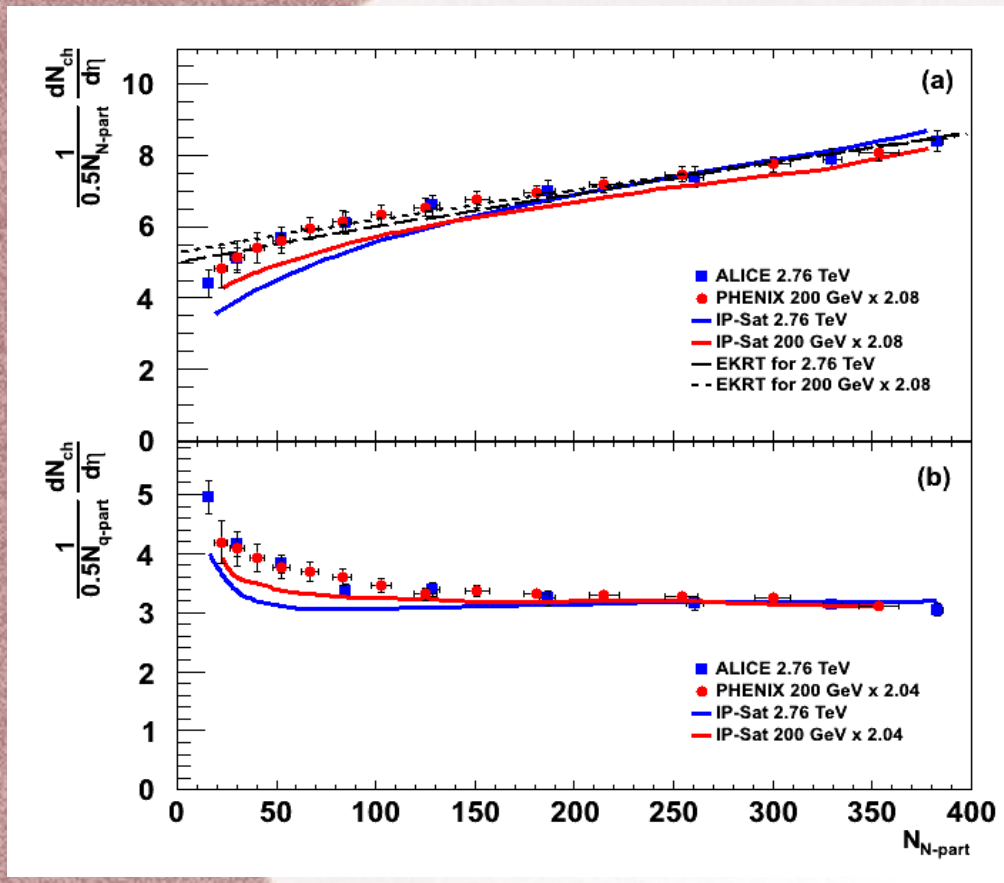
➔ Overlap model has very good agreement with ALICE estimatation.

Ratio of $N_{q\text{-part}}$ and $N_{N\text{-part}}$



- ✓ Sharp increase for NN −part ≤ 100.
- ✓ Linear monotonic rise going from peripheral to central collisions.
- ✓ This behavior is purely geometrical in nature.

Centrality Dependence of N_{ch}



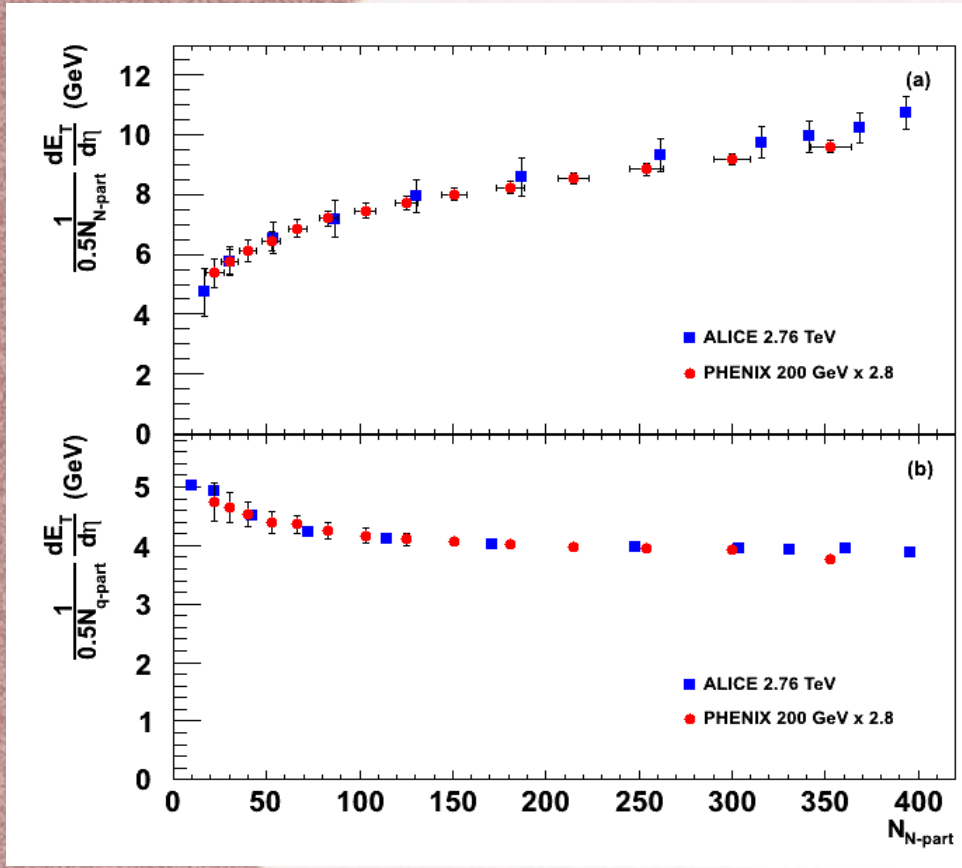
For $N_{N\text{-part}}$
Centrality dependent behaviour

For $N_{q\text{-part}}$
Centrality independent behaviour

Particle production is better described in terms of contituent quarks rather than nucleon participants.

Hence it make sense to consider partons as the source of particle production than nucleons.

Centrality Dependence of E_T



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Centrality dependent behaviour

For $N_{q\text{-part}}$
Centrality independent behaviour

Particle production is better described in terms of contituent quarks rather than nucleon participants.

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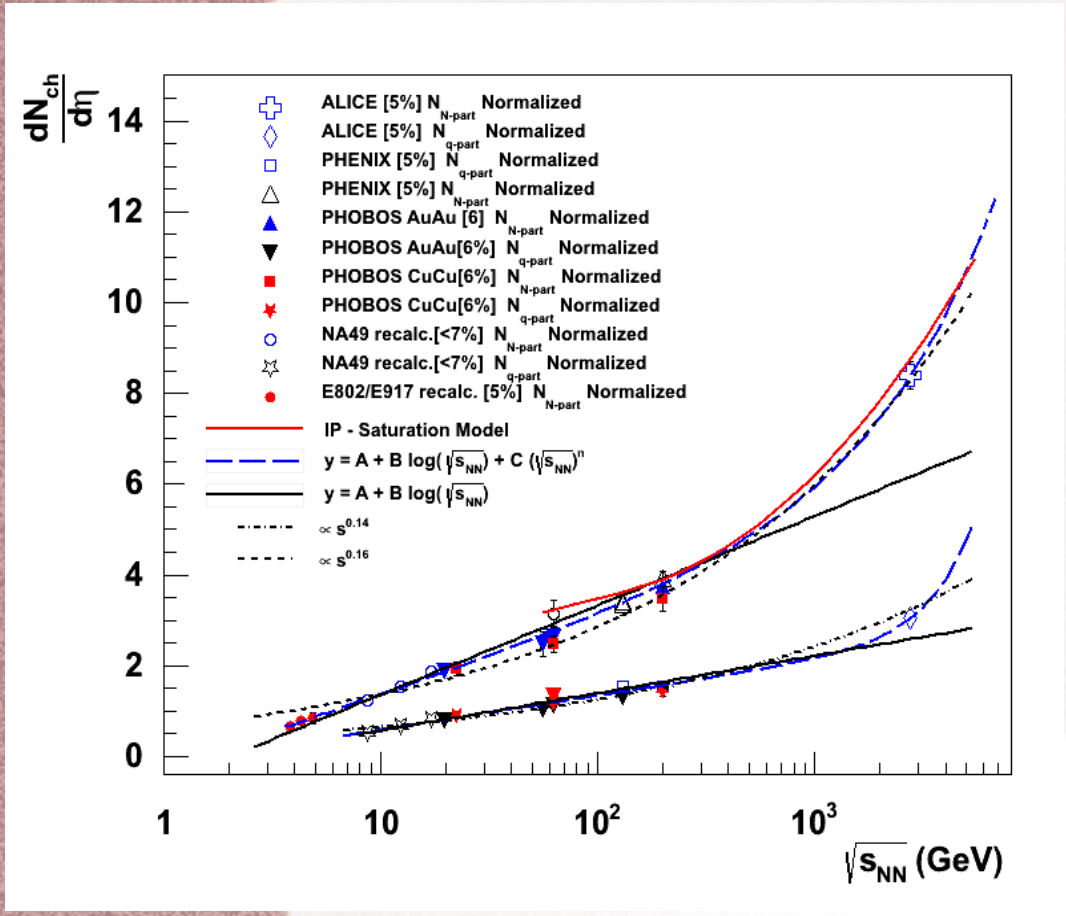
Collision Energy Dependence of N_{ch}



For $N_{N\text{-part}}$

- Logarithmic function does not discribe LHC data.
  (missmatch with LHC data is 26%).
- Power law function discribes RHIC and LHC data but overestimates low energy measurements.

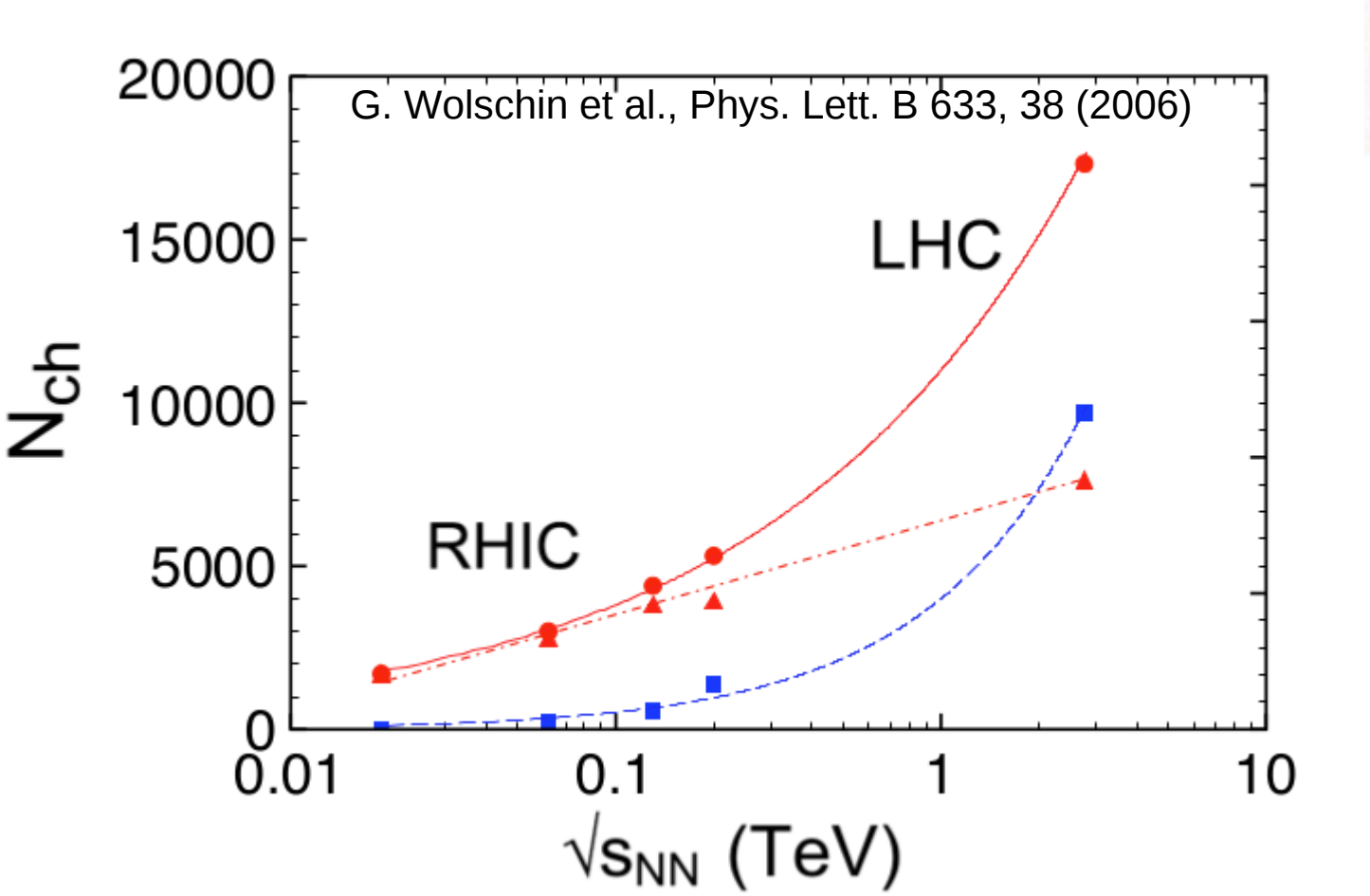
For $N_{q\text{-part}}$

- Logarithmic function discribe whole range of energies with little deviation towards LHC energy.
- Power law function discribes whole data sets

Hybrid function describes whole range of energy for both Npart and Nqprt normalized data.

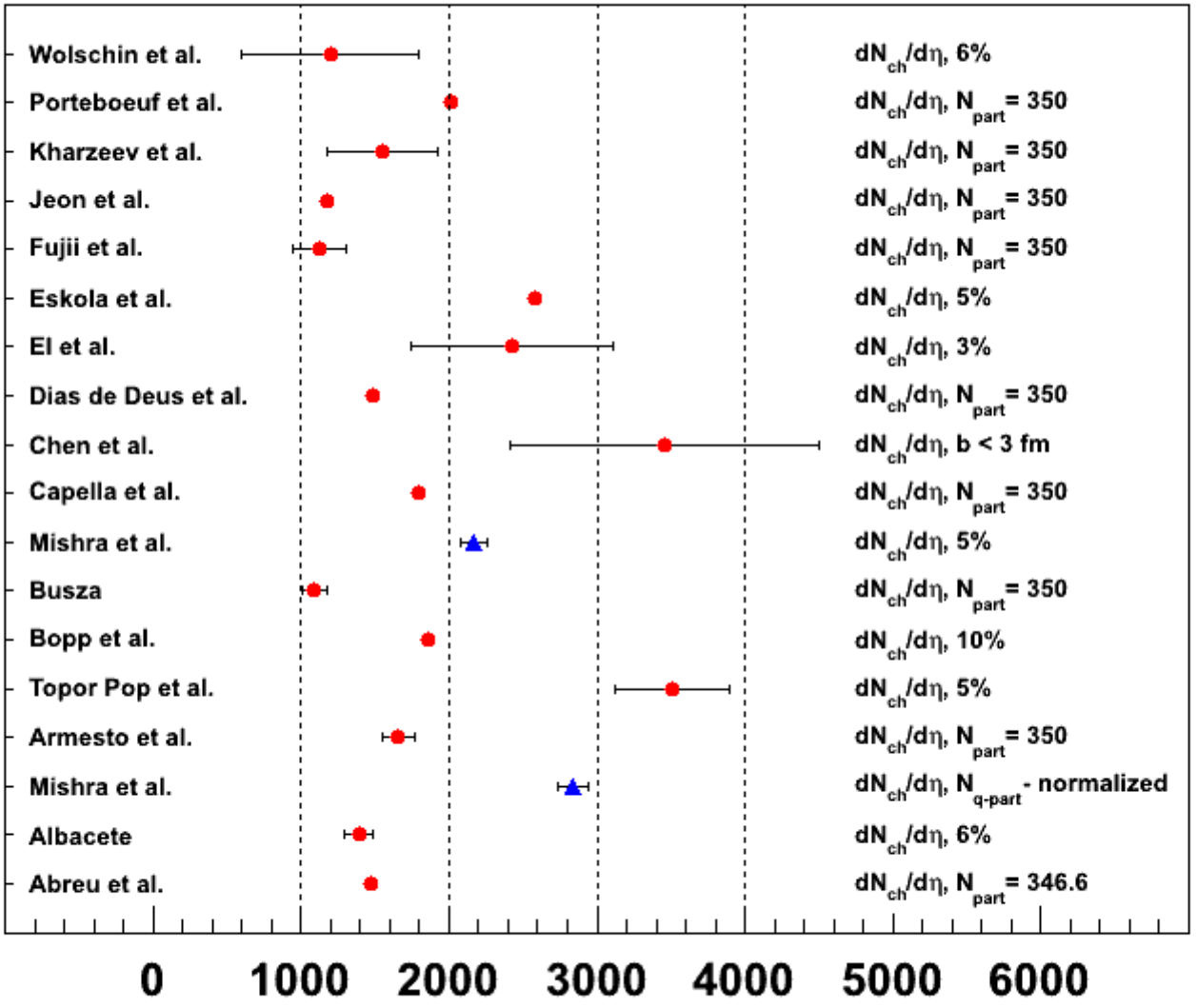
IP-saturation model prediction is also shown.

Motivation of Hybrid function

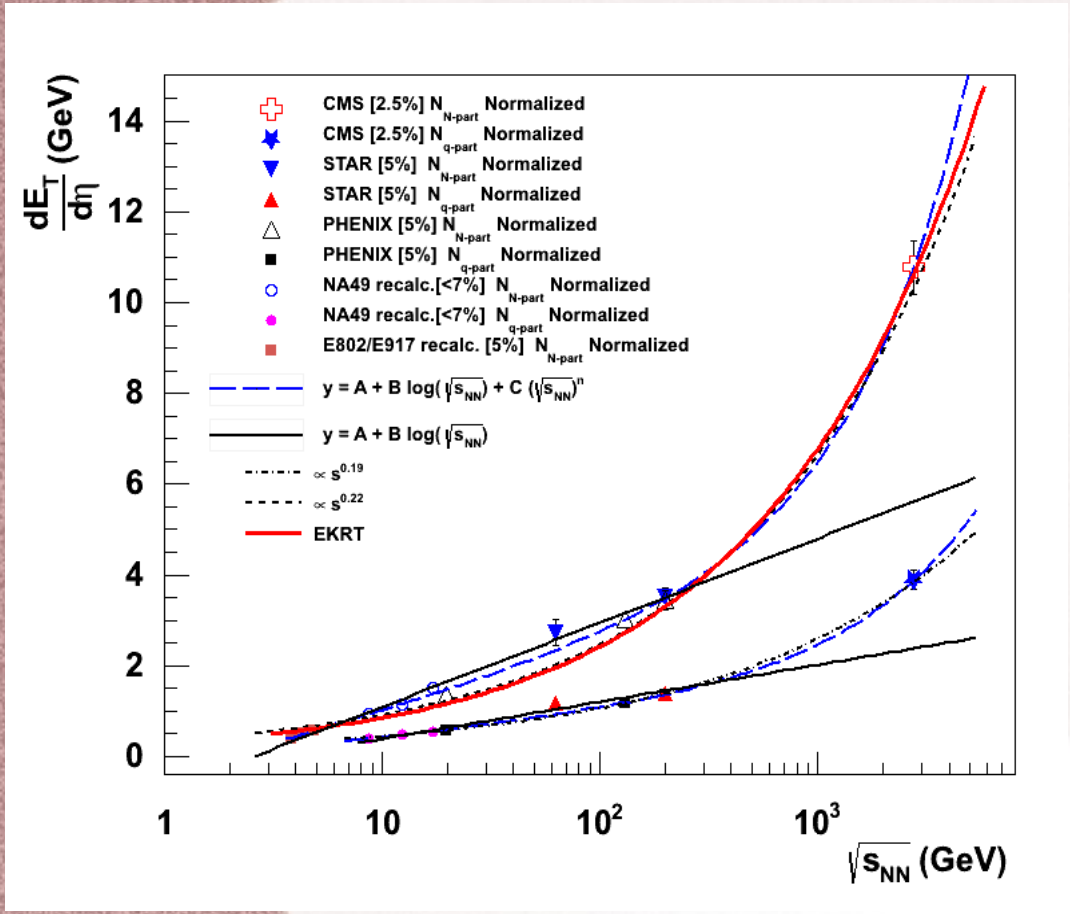


- ✓ RHIC and LHC multiplicity could be explained by the combination of a mid-rapidity gluonic source and a fragmentation source in the framework of Relativistic Diffusion Model (RDM).
- ✓ Mid-rapidity gluonic sources predict a power-law type behavior.
- ✓ Fragmentation sources predict a logarithmic behavior.

Prediction for Pb+Pb 5.5 TeV Collision



Collision Energy Dependence of E_T



For $N_{N\text{-part}}$

- Logarithmic function does not discribe LHC data.
  (missmatch with LHC data is 47%).
- Power law function discribe RHIC and LHC data but overestimates low energy measurements.

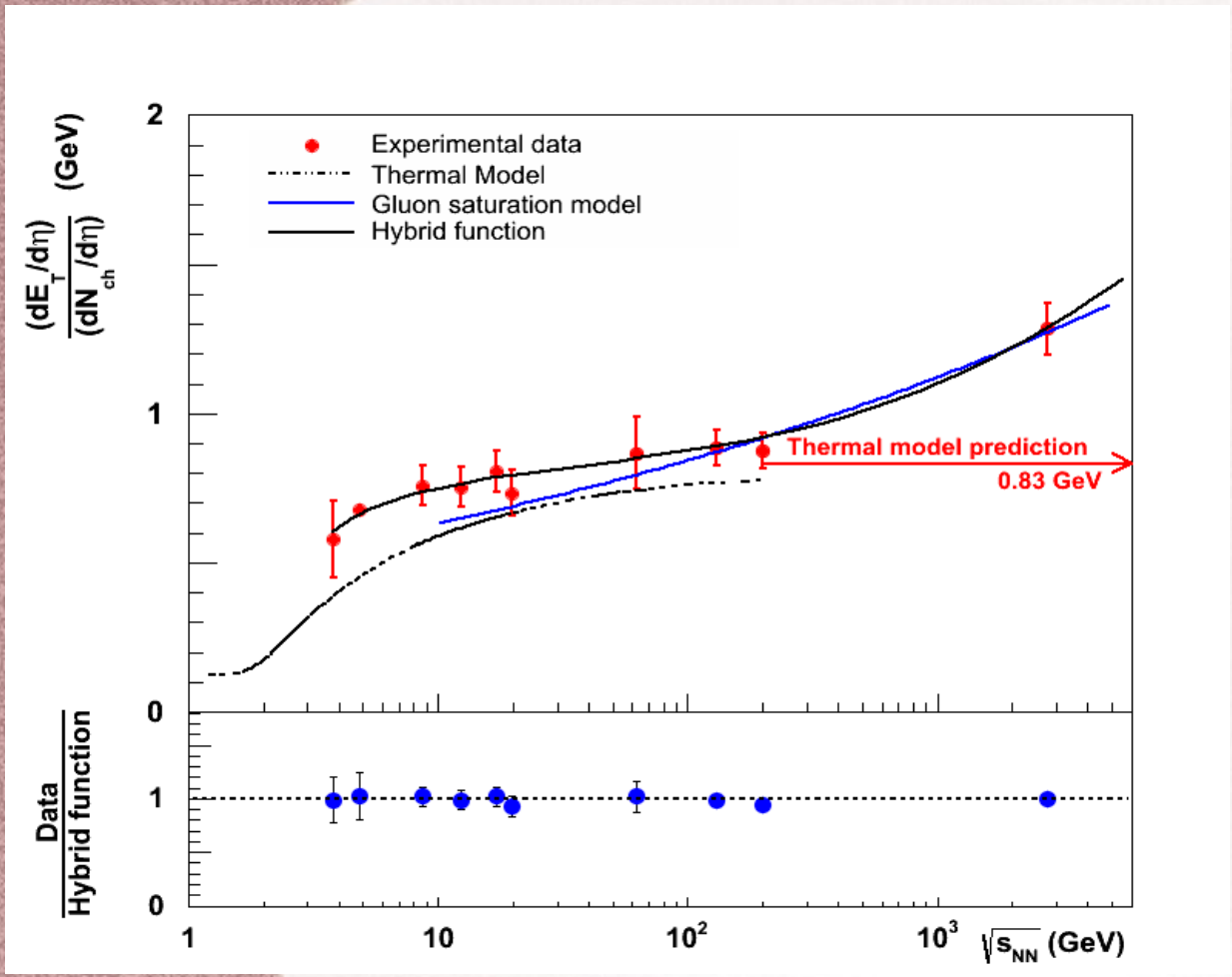
For $N_{q\text{-part}}$

- Logarithmic function does not discribe LHC data.
- Power law function discribe whole data sets

Hybrid function describes the experimental data for the whole range of energy for both Npart and Nqprt normalization.

EKRT model prediction is also shown.

Collision energy dependence of E_T/N_{ch}



- ✓ E_T/N_{ch} is a measure of the internal presure in the ultra dence matter produced in heavy-ion collisions.
- ✓ Statistical Hadron Gas Model (SHGM) very well discribes the the data upto top RHIC energy.
- ✓ SHGM predicted that at energies higher to top RHIC energy E_T/N_{ch} will be saturated at 0.83 GeV.

- ✓ This rise in E_T/N_{ch} could be understood from the gluon saturation.
- ✓ The number of gluons increases with increase in collision energy.
- ✓ At very high energy, the gluon creation and annihilation balance out leading to a saturation in gluon number.

$$E_T \propto Q_s^3$$

$$N_{ch} \propto Q_s^2$$

$$\Longrightarrow \quad \frac{E_T}{N_{ch}} = Q_s$$

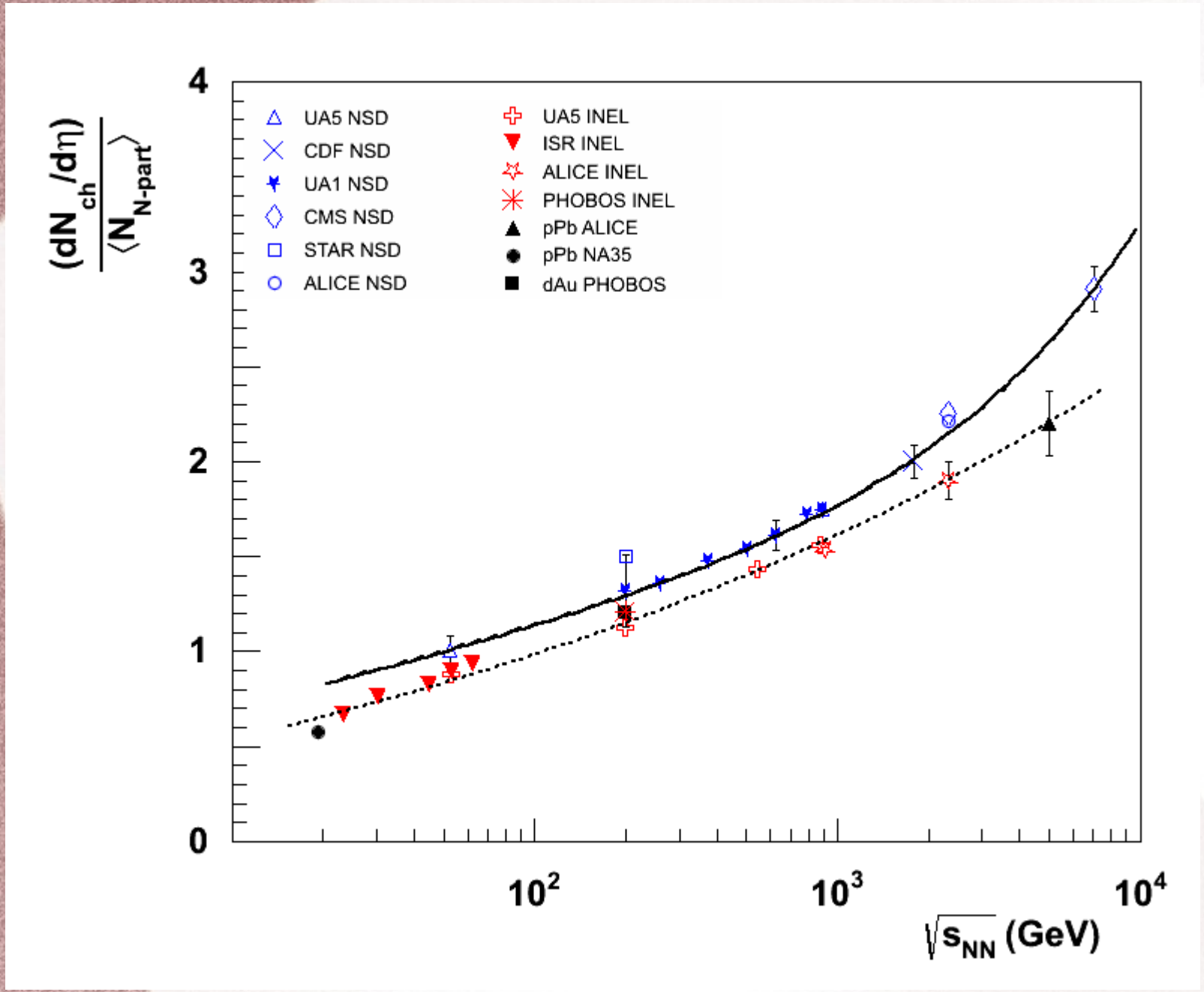
$$Q_s \propto \left(\sqrt{s}\right)^{\lambda}$$

$$\frac{E_T}{N_{ch}} = Q_s = k\left(\sqrt{s}\right)^{\lambda}$$

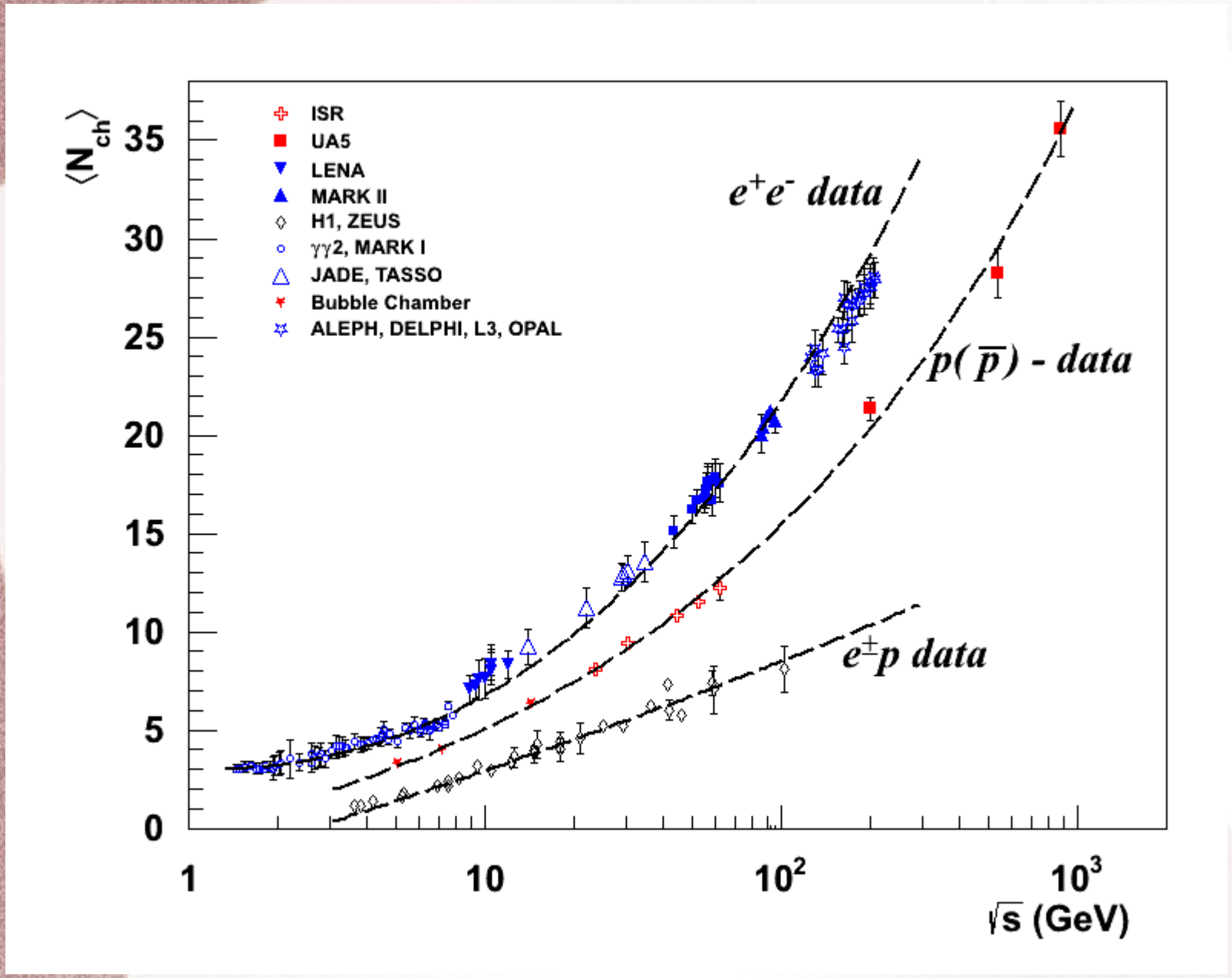
Where k & λ are constant

λ = 0.12 obtained from fitting, which lies between λ = 0.15 (IP-sat model prediction) and λ = 0.11 (b-CGC model prediction)

pp and pPb


$(dN_{ch}/d\eta)/\langle N_{N\text{-}part}\rangle$
4
3
2
1
0
UA5 NSD
CDF NSD
UA1 NSD
CMS NSD
STAR NSD
ALICE NSD
UA5 INEL
ISR INEL
ALICE INEL
PHOBOS INEL
pPb ALICE
pPb NA35
dAu PHOBOS
10^2
10^3
10^4
$\sqrt{s_{NN}}$ (GeV)

Elementry Particle



Summary

✍ Centrality and energy dependence of $dE_T/d\eta$ and $dN_{ch}/d\eta$ are studied in nucleon and constituent quark frameworks.

✍ Neither logarithmic function nor power law function describes the energy dependence of $N_{N\text{-}part}$ normalized $dN_{ch}/d\eta$.

✍ A hybrid function (Logarithmic + Power law) describes data at all energies and collision species (elementary, pp, pA and AA collisions).

✍ Based on gluon saturation, EKRT model describes the high energy data for E_T quite well but underestimates the low energy data.

✍ The predicted values of E_T, N_{ch}, E_T/N_{ch} for 5.5 TeV Pb+Pb collisions are 3056 ± 44 GeV, 2836 ± 73 and 1.49 ± 0.05 GeV respectively.

✍ Need of new / modified phenomenological models to explain E_T/N_{ch} values at higher energies: not explained by SHGM.

Acknowledgement

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Thank You