First results on the event-by-event study in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76TeV

EbyE

S. Jena for the ALICE Collaboration

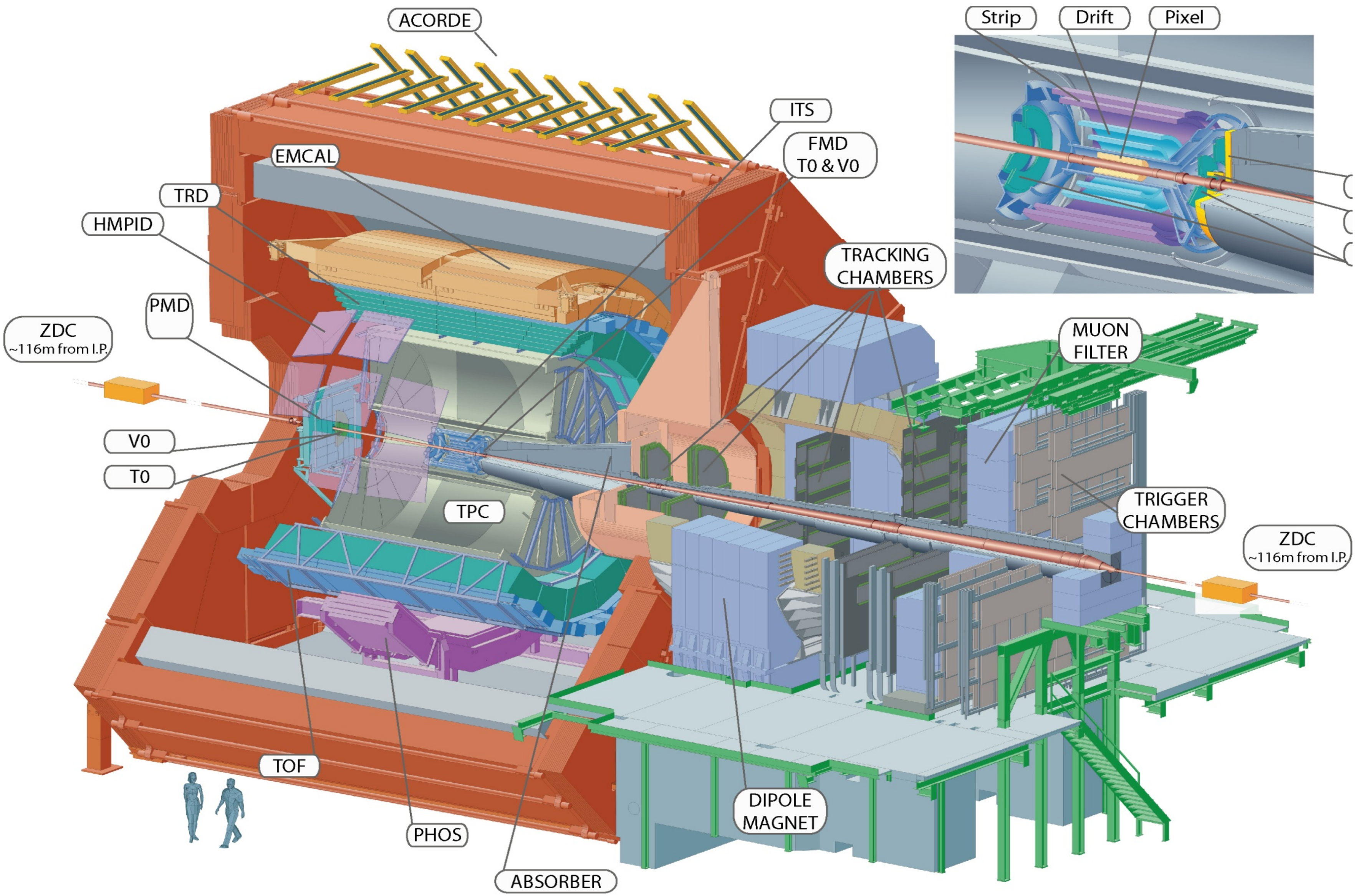
Motivation

- The presence of the phase transition can manifest itself by characteristic behavior of several observables which may vary dramatically from one event to the other.
  - Thus the study of various quantities on an event-by-event basis offers the possibility for studying the QGP phase transition and the nature of the QGP matter.
- The challenge of event-by-event studies is to disentangle between the two components having a statistical and a dynamical origin. The latter consists of
  - fluctuations which do not change event-to-event, e.g. those from Bose-Einstein (BE) correlations, resonance decays, etc.
  - the fluctuations which have a new physics origin and may vary from event-to-event.

- $\langle p_T \rangle$ fluctuations
- Net charge fluctuations
- Multiplicity fluctuations
- Fluctuations in particle ratios
- Long range correlations
- Balance functions
- Higher Moments
- Temperature Fluctuations

S. Jeon and V. Koch. 85, 2076 (2000);V. Koch, M. Bleicher, and S. Jeon, Nucl. Phys. A698, 261 (2002). M. Asakawa, U. Heinz, and B. Müller, Phys. Rev. Lett. 85, 2072 (2000); S.A. Voloshin, V. Koch and H.G. Ritter 1999 Phys. Rev. C 60 024901; M.A. Stephanov, K. Rajagopal and E.V. Shuryak 1998 Phys. Rev. Lett. 81 4816-4819

ALICE: Experimental Setup



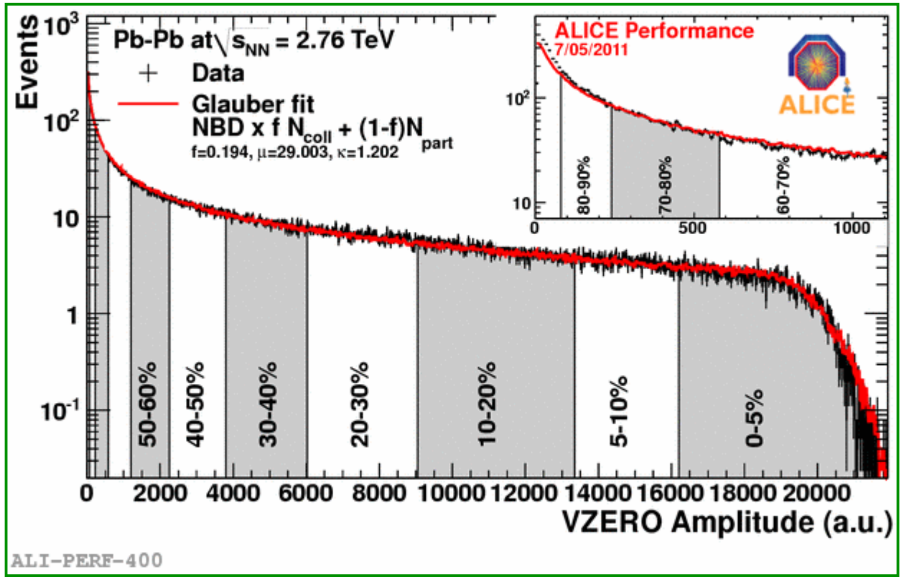
Analysis details

- The large particle production at the LHC allows to make precision event-by-event measurements.

- Analysis of pp @ $\sqrt{s}$ = 0.9, 2.76 and 7 TeV and Pb—Pb events @ $\sqrt{s_{NN}}$ = 2.76 TeV
  - Event sample split in two sets having different magnetic field polarities (results used for the systematic uncertainties)
- The trigger consists of the following criteria :
  - two pixel chips hit in the outer layer of the SPD,
  - signal in VZERO-A detector,
  - signal in VZERO-C detector.

- Due to the nature of the studies, applying corrections is highly non-trivial; we need to have the acceptance corrections under control:
  - The TPC tracks provide a uniform acceptance with minimal corrections
  - Disadvantage: contamination from secondaries
    - Investigated by varying the cut on the distance of closest approach (results used for the systematic uncertainty).

- The centrality is selected using the VZERO amplitude as the default estimator
  - Centrality bins: 0-5%, 5-10%, 10-20%,…, 70-80%
  - Different centrality estimators (TPC tracks, SPD clusters) :
    - Results used for the systematic uncertainty



- $<p_T>$ Fluctuations
- Net Charge Fluctuations

Transverse momentum fluctuations

- Event-by-event fluctuations of mean transverse momentum contain information on the dynamics and correlations in pp and heavy-ion collisions.
- Reference measurements in pp serve as a baseline with 'known' physics like p_T correlations due to resonance decays, HBT, (mini-)jets etc.
- In heavy-ion collisions, fluctuations may also be related to other effects like a critical behaviour of the system in the vicinity of a phase boundary or the onset of thermalisation of the system.
- The tool used to quantify the fluctuations is the 2-particle correlator:

$$C_m = \left\langle \Delta p_{T,i}, \Delta p_{T,j} \right\rangle = \frac{1}{\sum_{k=1}^{n_{ev}} N_k^{pairs}} \sum_{k=1}^{n_{ev}} \sum_{i=1}^{N_k} \sum_{j=i+1}^{N_k} \left(p_{T,i} - \langle p_T \rangle_m \right) \left(p_{T,j} - \langle p_T \rangle_m \right)$$

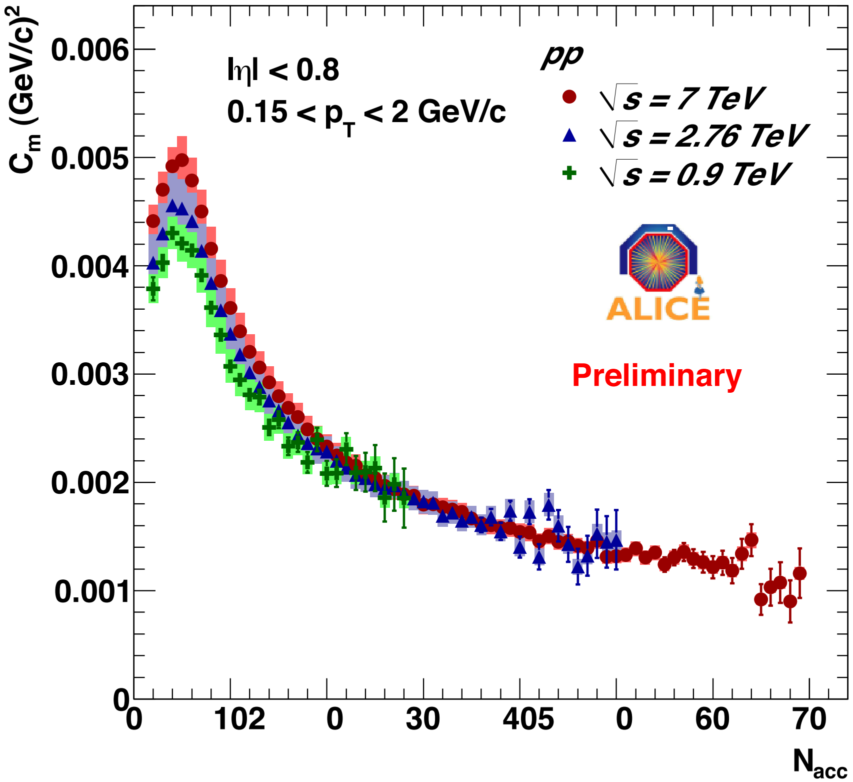
M.A. Stephanov, K. Rajagopal and E.V. Shuryak 1998 Phys. Rev. Lett. 81 4816-4819

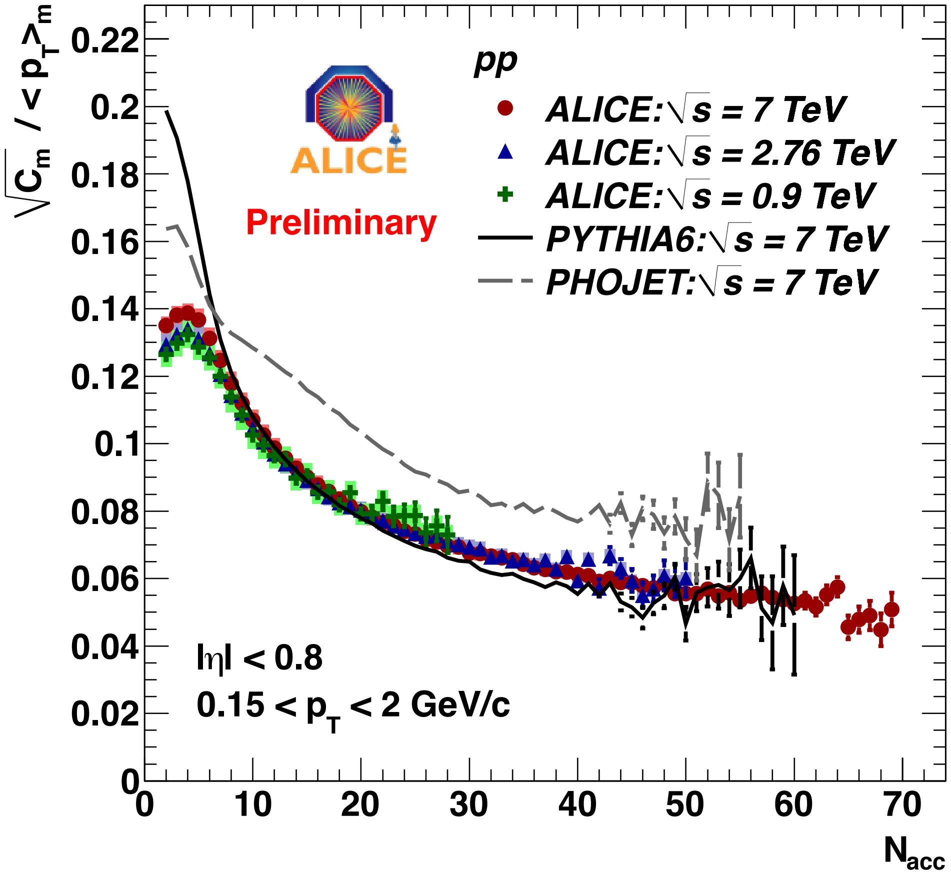
S.A. Voloshin, V. Koch and H.G. Ritter 1999 Phys. Rev. C 60 024901

$\langle p_T \rangle$ denotes average p_T of per event

Transverse momentum fluctuations in pp

- Significant non-statistical fluctuations
  - 'Dilution' with multiplicity
- Moderate energy dependence of the 2-particle correlator

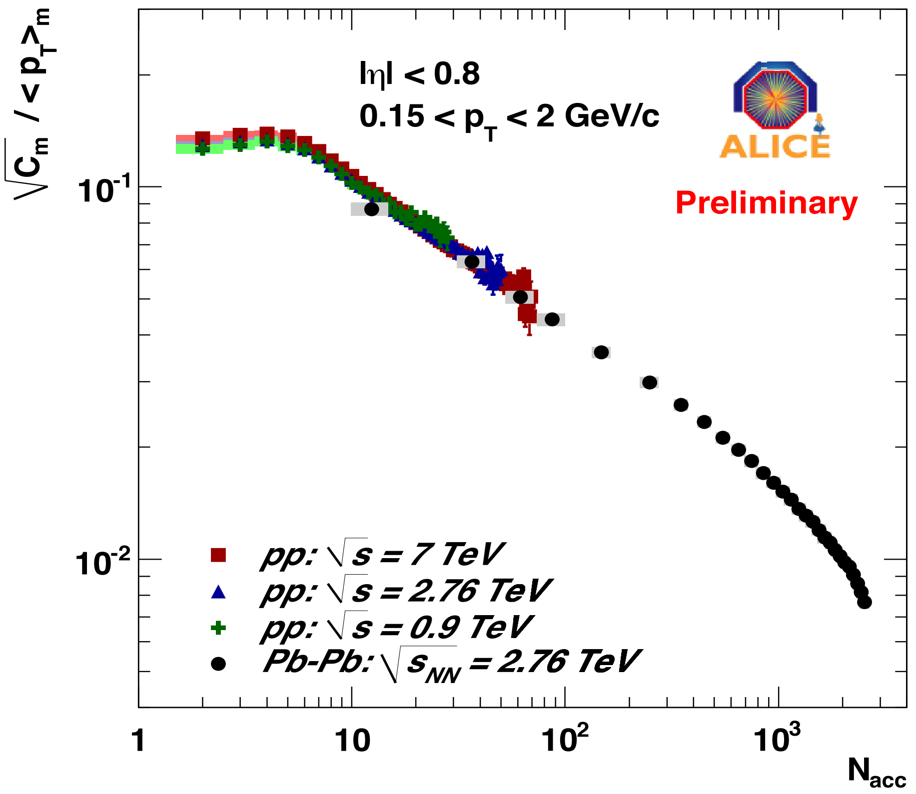


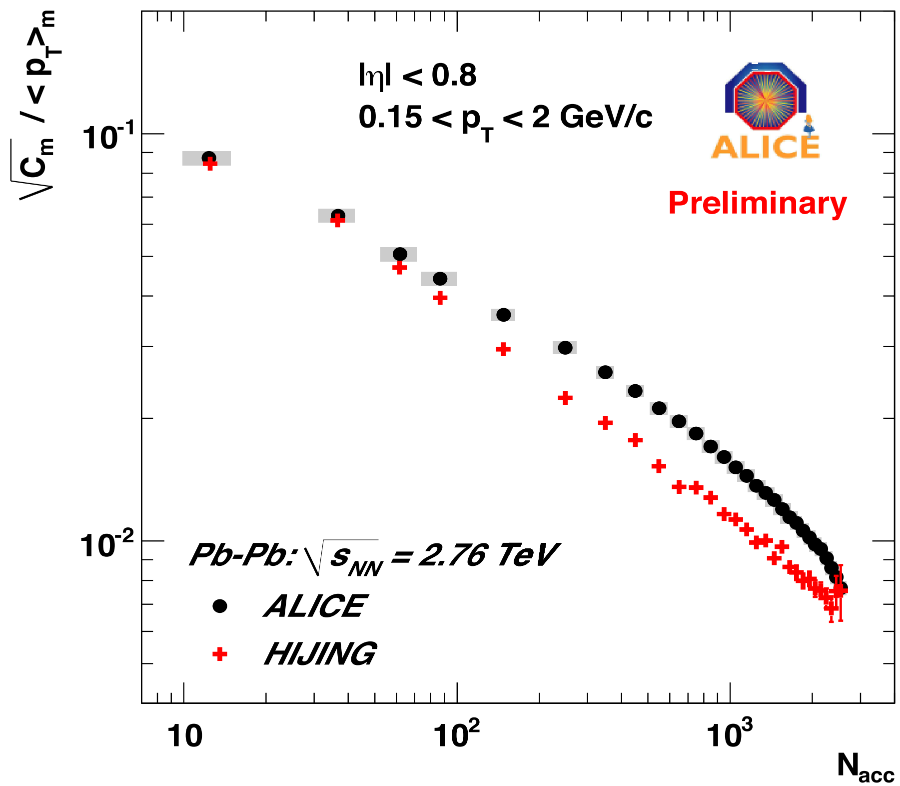


- ❑ Good description of the relative fluctuations by PYTHIA
  - ○ Discrepancies at low multiplicities (N_{acc} < 7)
- ❑ Poor description by PHOJET

Transverse momentum fluctuations in Pb—Pb

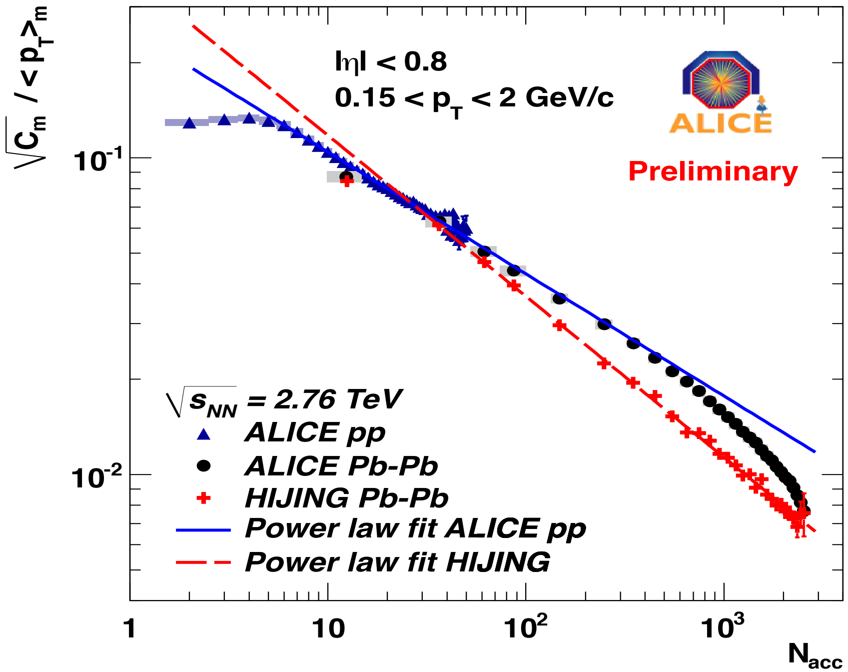
- Same trend as in pp
  - Significant fluctuations in the peripheral bins. The magnitude decreases from peripheral to central collisions
- pp and peripheral Pb—Pb indicate a common scaling





- Experimental values are not described by HIJING.
  - HIJING shows significant non-statistical fluctuations with a decreasing trend as a function of centrality

Transverse momentum fluctuations: Data vs models

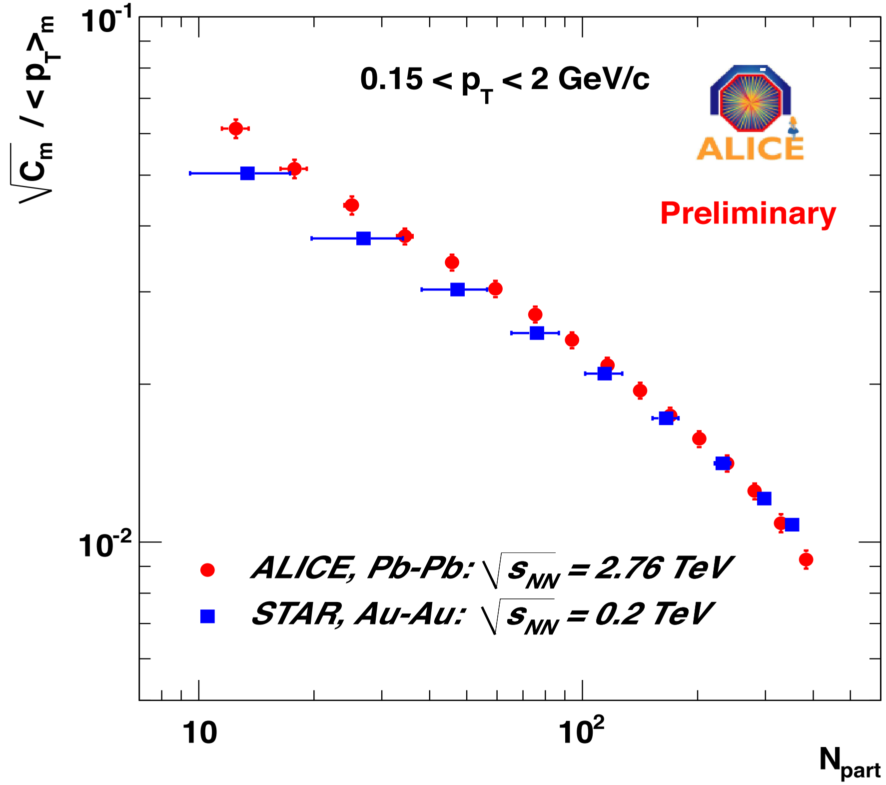


$(N_{acc} \approx 600 \approx 30\text{-}40\%$ centrality)

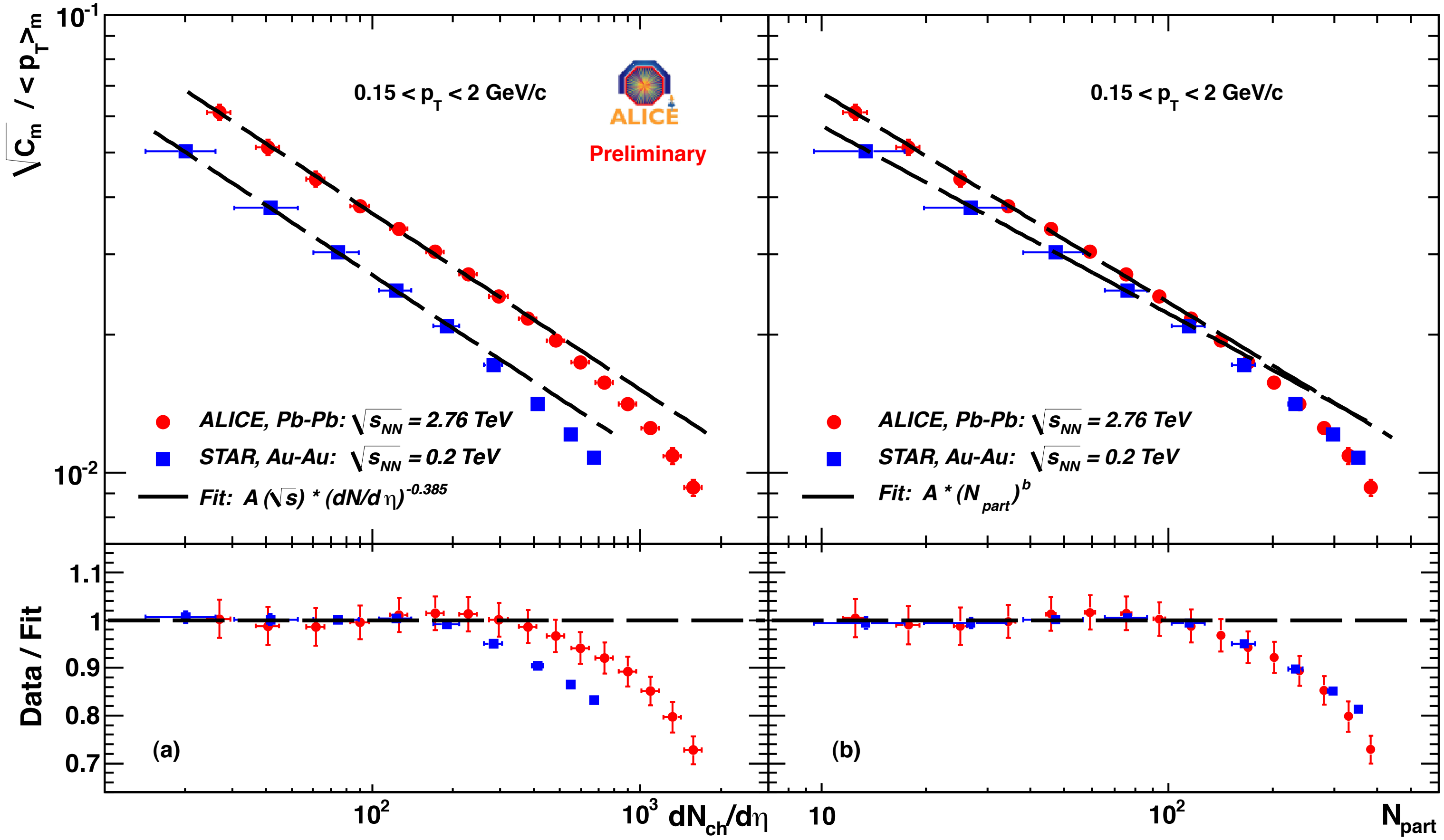
- Fit the pp baseline with a power law from $N_{acc.} > 8$
- The fit with the same parameters describes the Pb—Pb points up to 30—40% centrality bin.
  - Moving to more central collisions leads to significant additional reduction of the relative fluctuations

$$f(N_{acc.}) \sim (N_{acc.})^{a}$$

- LHC and RHIC data demonstrate a similar slope
- ALICE data indicate an additional reduction of the relative fluctuations in central collisions



Transverse momentum fluctuations: LHC vs RHIC

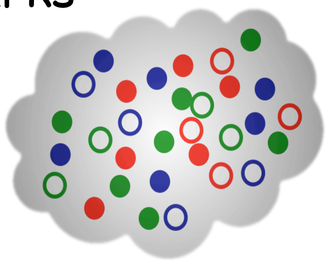


- The relative fluctuations for both energies are described well by the pp baseline fit from peripheral up to mid-central collisions
- RHIC data were explained in terms of percolation of strings, thermalization and deconfinement
- We need to have a model incorporating the two important contributions: jets and flow

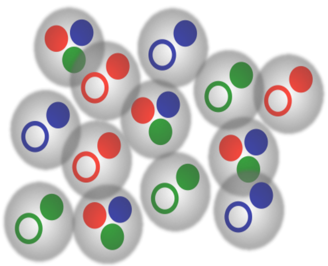
- $\langle p_T \rangle$ Fluctuations
- Net Charge Fluctuations

Charge fluctuations

- In the presence of the QGP, the relevant carriers of the charge are the quarks



QGP: Charge unit = fractional



Hadron Gas: Charge unit = 1

Hadron Gas: $q = \pm 1 \qquad q^2 = 1$

QGP: $q = \pm\frac{1}{3};\frac{2}{3} \qquad q^2 = \frac{1}{9};\frac{4}{9}$

- Charge fluctuations depend on the squares of the charges and hence strongly depend on which phase they originate from.
- The measure of the net charge fluctuations should not be sensitive to:
  - Volume fluctuations (i.e. fluctuations in the impact parameter)

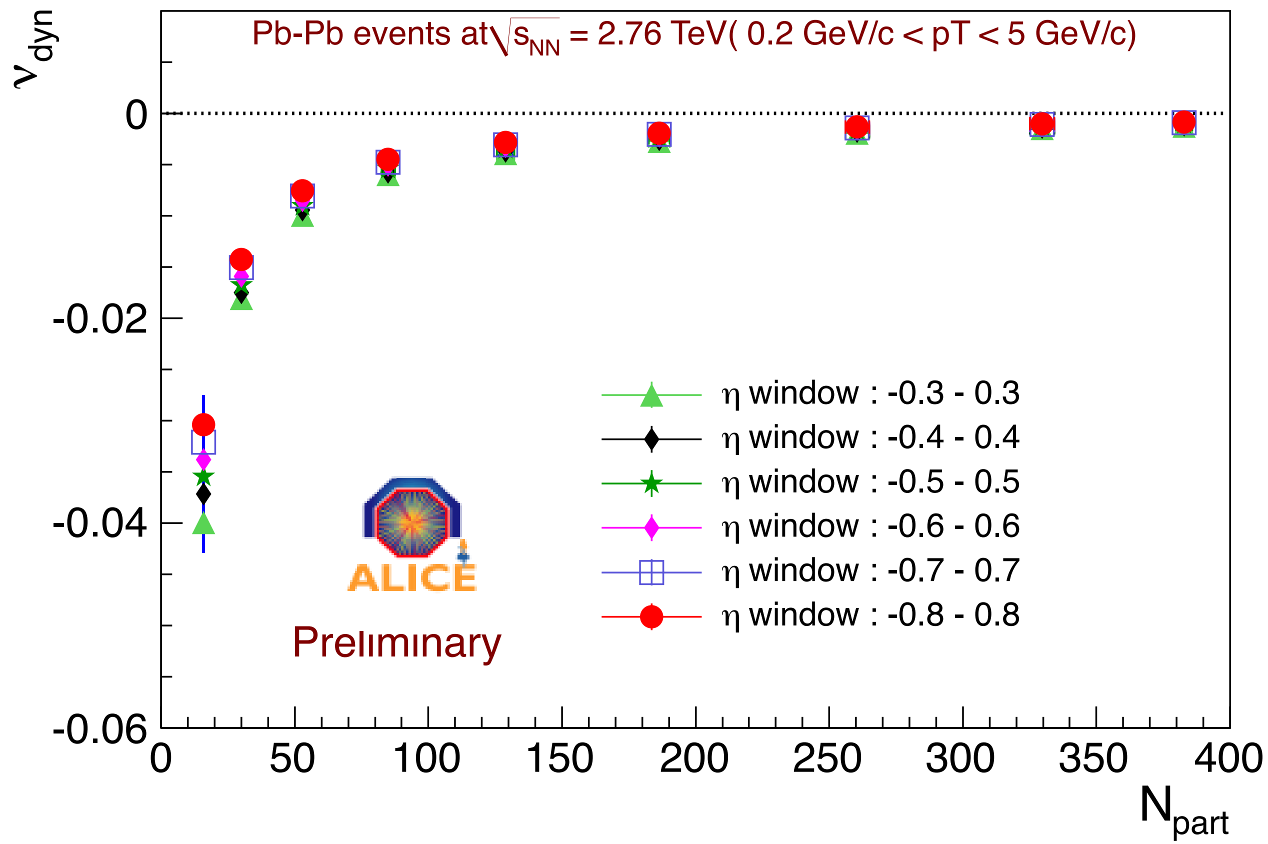
- The tool used to quantify the fluctuations is the ν_{dyn}. which is not sensitive to detector effects, provided that the detection efficiency is uniform over the measured kinematic range:

$$\nu_{(+-,dyn.)} = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_+N_-\rangle}{\langle N_+\rangle\langle N_-\rangle}$$

S. Jeon and V. Koch. 85, 2076 (2000);V. Koch, M. Bleicher, and S. Jeon, Nucl. Phys. A698, 261 (2002). M. Asakawa, U. Heinz, and B. Müller, Phys. Rev. Lett. 85, 2072 (2000);

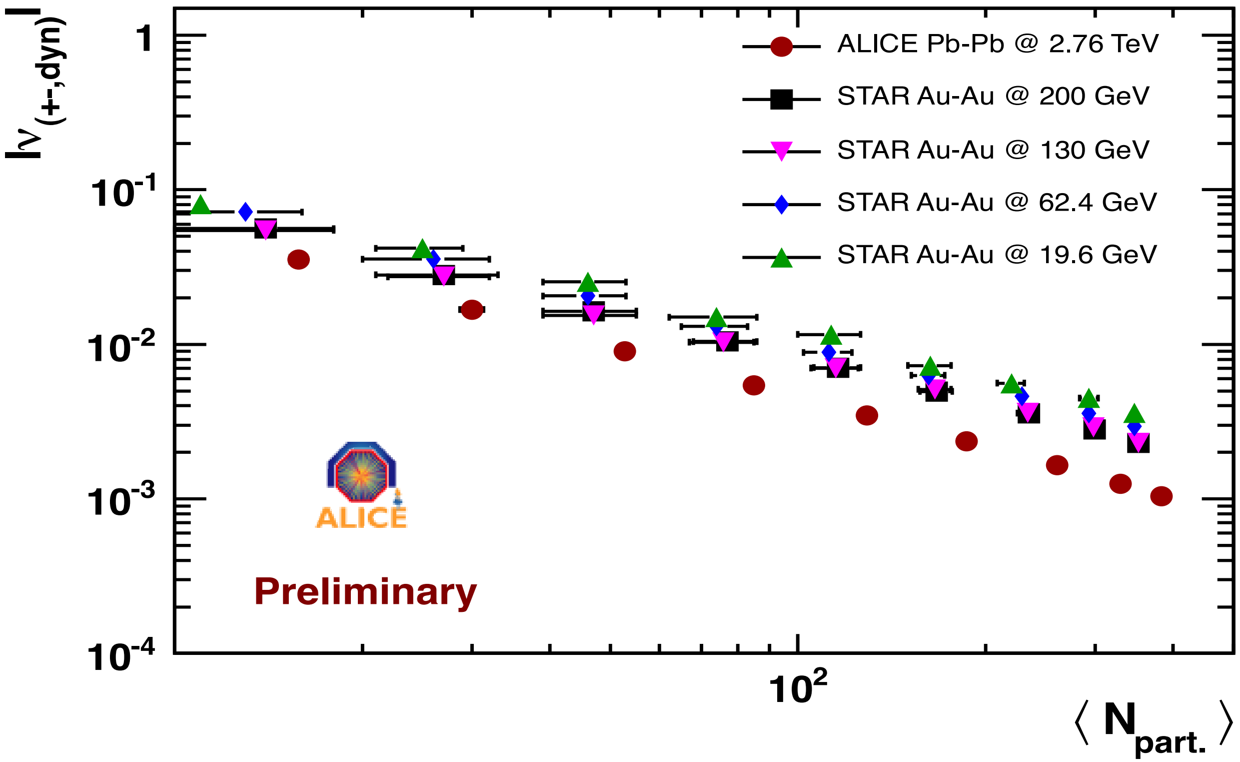
Centrality Dependence of $\nu_{(+-,dyn.)}$

$\nu_{(+-,dyn.)}$ for different centralities and pseudo-rapidity windows.



- Smooth evolution of the $\nu_{(+-,dyn.)}$ as a function of N_{part}
- The centrality dependence shows a saturation pattern

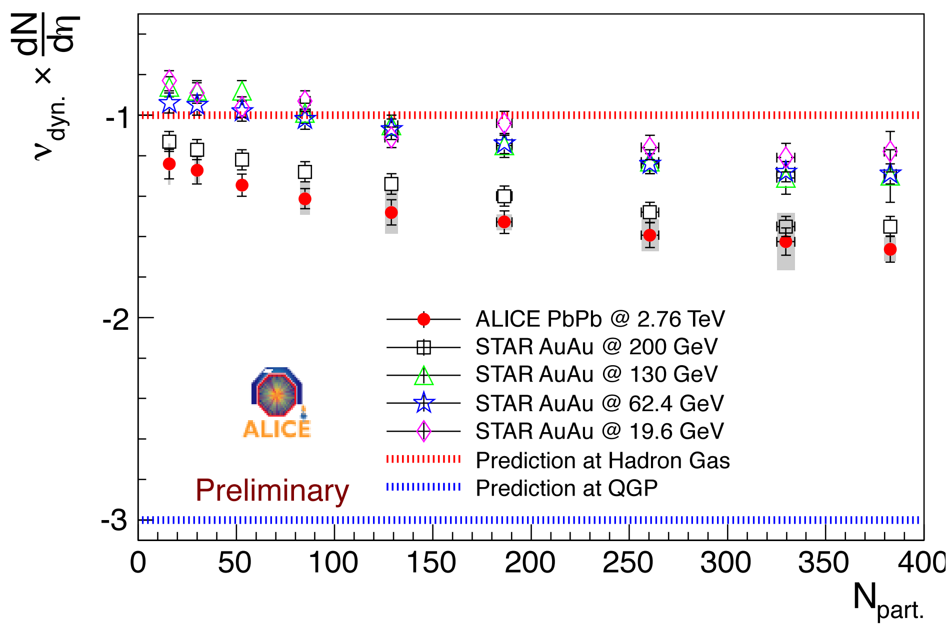
Comparison with lower energies

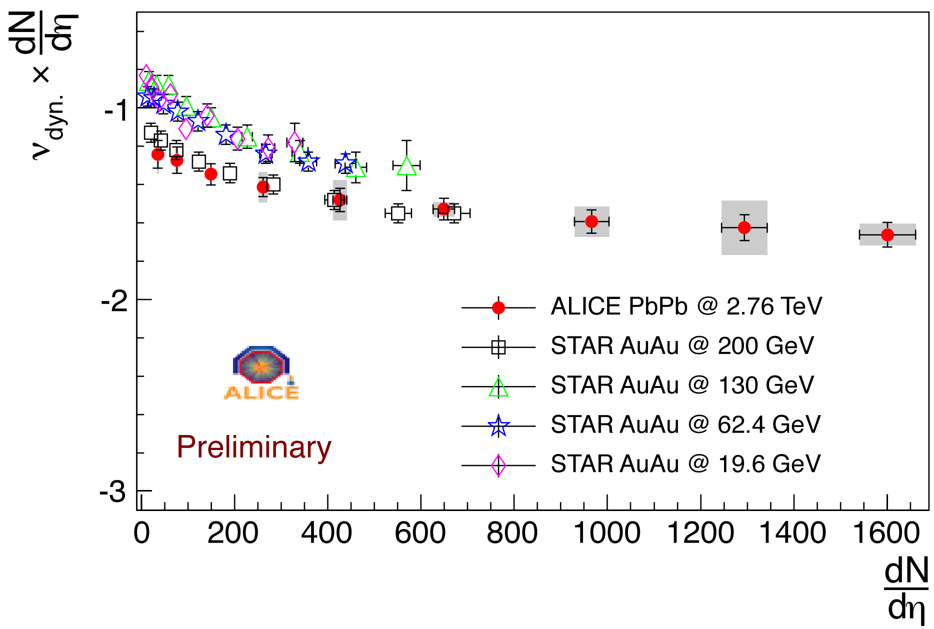


- The ALICE points, when plotted vs N_{part}, demonstrate a lower value of $|\nu_{(+-,dyn.)}|$ for each centrality bin.
- $|\nu_{(+-,dyn.)}|$ decreases from peripheral to central collisions

Looking for the proper scaling

- Observed centrality dependence of the scaled (with $dN/d\eta$) $\nu_{(+-,dyn.)}$
- In case of independent nucleon-nucleon collisions, the scaled $\nu_{(+-,dyn.)}$ should not show any dependence on centrality





- Indication of a change in the collision dynamics when going from peripheral to central collisions.

Attempt to trace the initial fluctuations

According to Shuryak and Stephanov, the initial fluctuations are diluted by the final state interactions and the limited experimental acceptance

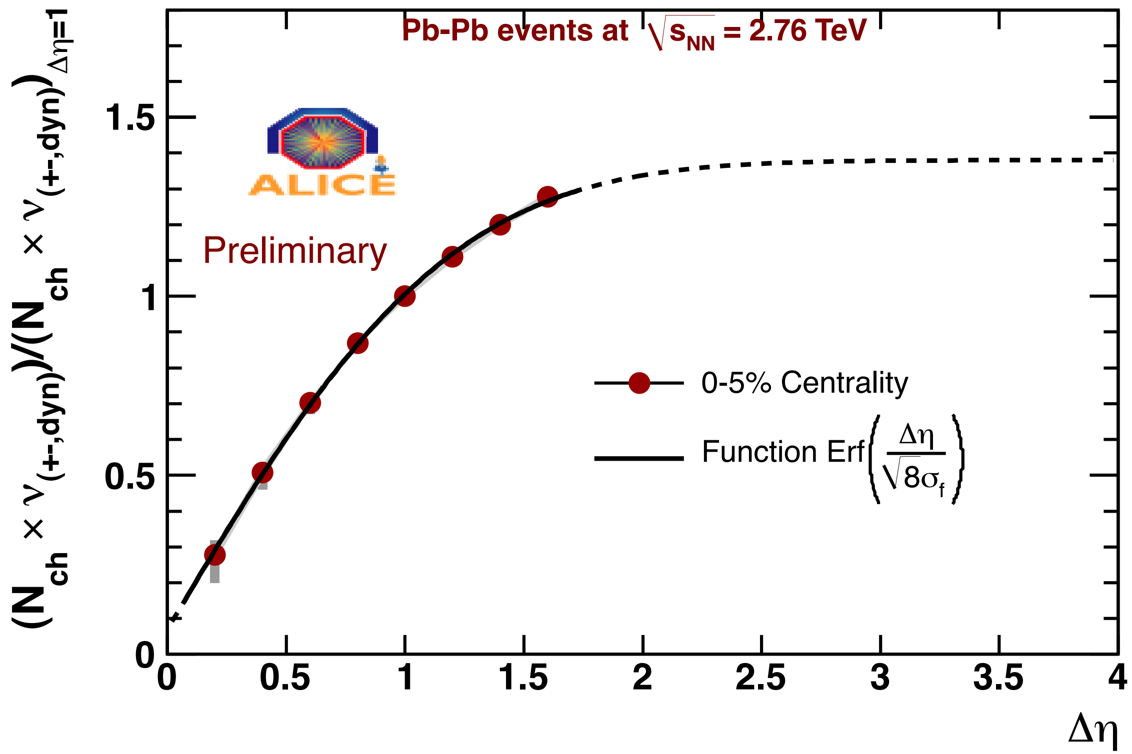
Ref: 10.1103/PhysRevC.63.064903

The fitted parameter for 0-5% centrality are found to be:

$P[0] = 0.068 \pm 0.025$

$P[1] = 1.311 \pm 0.023$

$P[2] = 0.467 \pm 0.021 = \sigma_f$



From here we can see that the correlation increases with $\Delta\eta$ and the curve saturates at a value of $\Delta\eta \sim 3.0$.

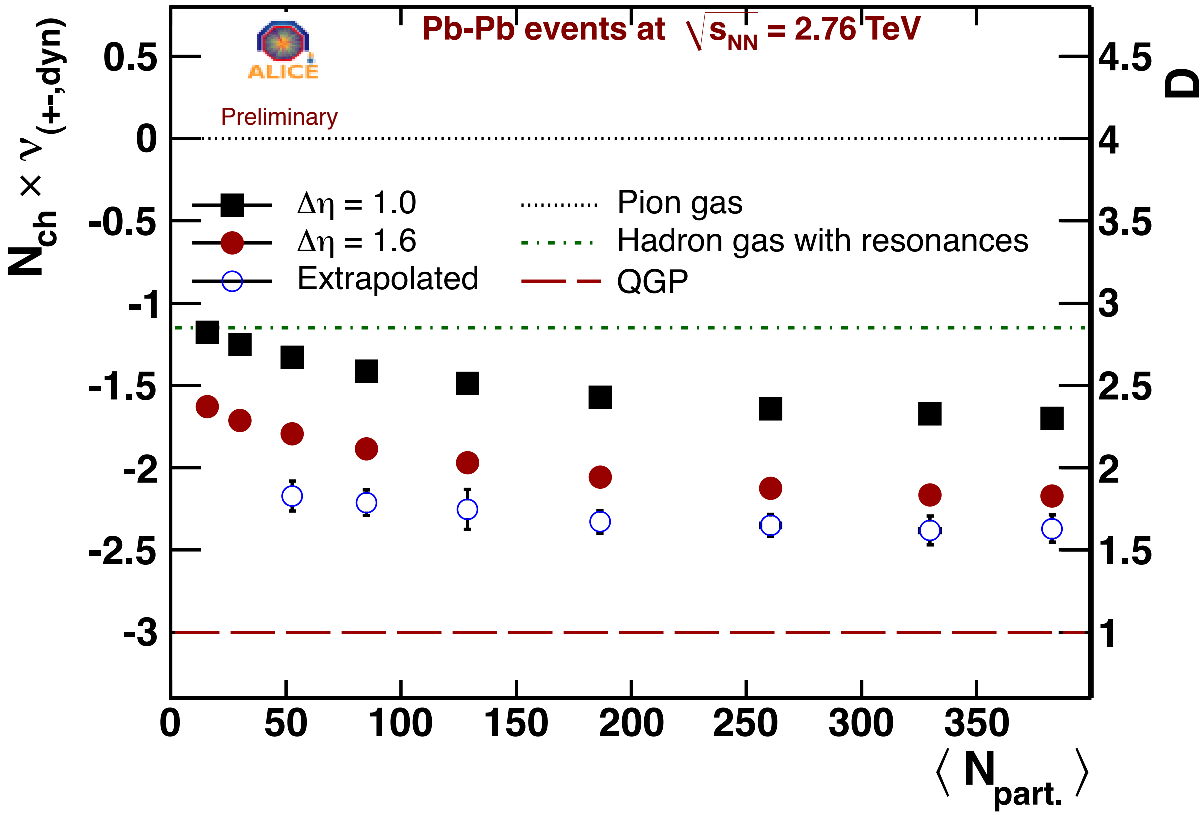
Comparison with theory

S. Jeon and V. Koch,
Phys. Rev. Lett. **85**, (2000) 2076

$$D = 4\frac{\left\langle (\delta Q)^2 \right\rangle}{N_{ch}}$$

$$D \approx \langle N_{ch} \rangle \langle \Delta R^2 \rangle \approx \begin{cases} 4, (\pi - gas) \\ 3, (hadron - gas) \\ 1, (QGP) \end{cases}$$

$$N_{ch} \times \nu_{(+-,dyn.)} \approx D - 4$$



- Black solid squares are for the $\Delta\eta = 1$ and solid circle is for $\Delta\eta = 1.6$, and open circle is extrapolated value at saturation.
- The experimental values are closer to the QGP prediction.
- Global Charge Conservation is not taken care of.

Summary

- The event-by-event studies at the LHC with the ALICE experiment have been performed for first time.

- The transverse momentum fluctuations demonstrate:
  - a universal scaling with energy in pp collisions,
  - a nice evolution of the relative fluctuations from pp to peripheral Pb—Pb collisions with an additional reduction for the more central events,
  - the centrality dependence of the fluctuations can't be described by HIJING.
- The charge fluctuations indicate:
  - A further reduction of the magnitude of the fluctuations measured in $\nu_{(+-,dyn.)}$. going from RHIC to LHC,
  - A change in the collision dynamics when $\nu_{(+-,dyn.)}$. is scaled with dN/dη,
  - The resulting fluctuations have a magnitude closer to the expected value for a QGP phase transition.
- More things to come:
  - Balance functions ➔ time of hadronization, radial flow
  - Identified particle ratios
  - long range correlations