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

Panos Christakoglou[1]
for the ALICE Collaboration

[1]Nikhef

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

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

- ALICE has a detailed ebye physics program under way
  - Charge fluctuations (+ higher moments)
  - Transverse momentum fluctuations
  - Multiplicity fluctuations
  - Balance functions
  - Identified particle ratios
  - long range correlations

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

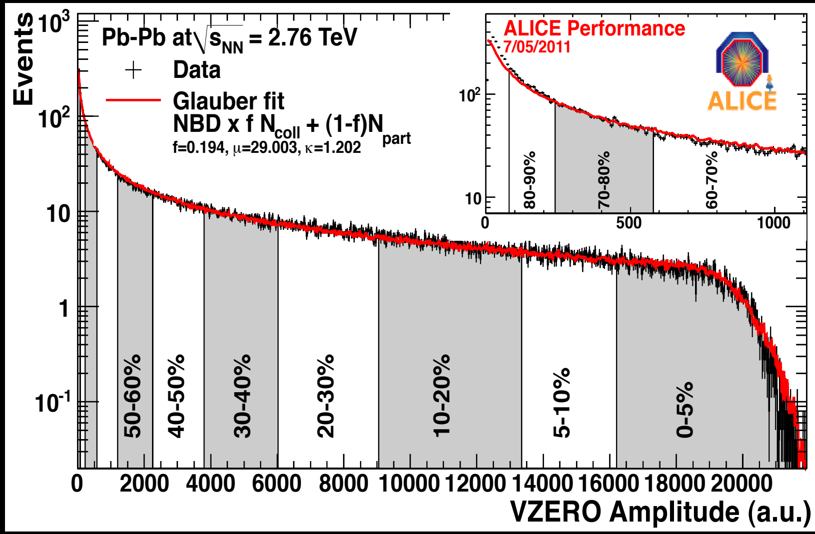
- ALICE has a detailed ebye physics program under way
  - Charge fluctuations (+ higher moments)
  - Transverse momentum fluctuations
  - Multiplicity fluctuations
  - Balance functions
  - Identified particle ratios
  - long range correlations

Studies in ALICE: Analysis details

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

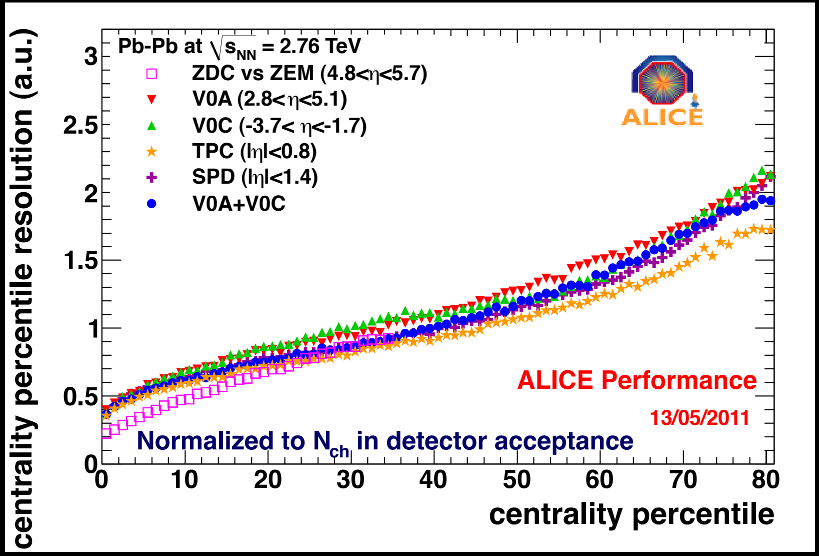


Studies in ALICE: Analysis details

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



- Possibility to have really fine bins in centrality, reducing the fluctuations due to the impact parameter

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.

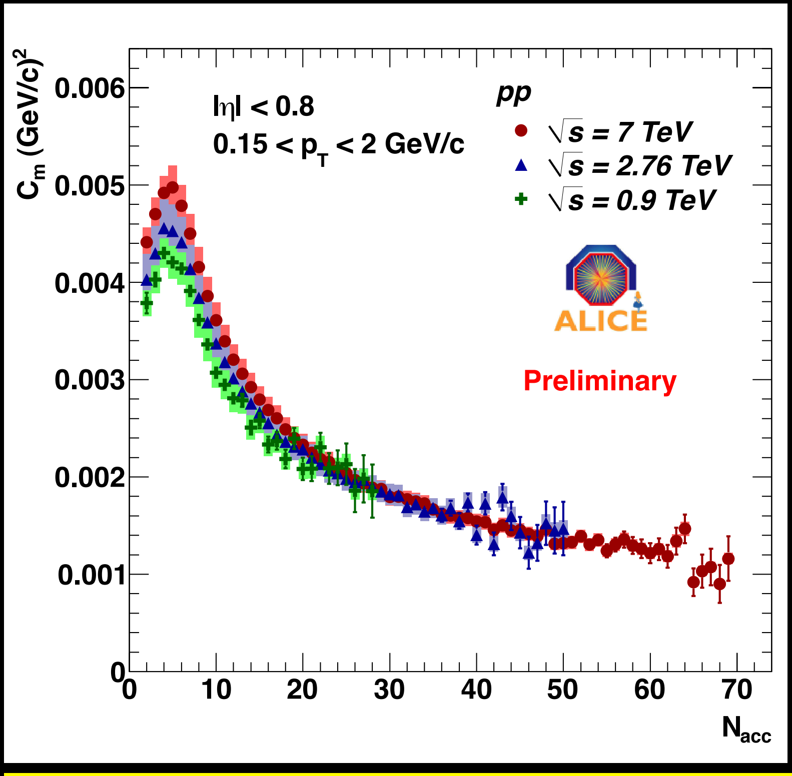
- The tool used to quantify the fluctuations is the 2—particle correlator:

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

  - C_m = 0 in the presence of stat. fluctuations

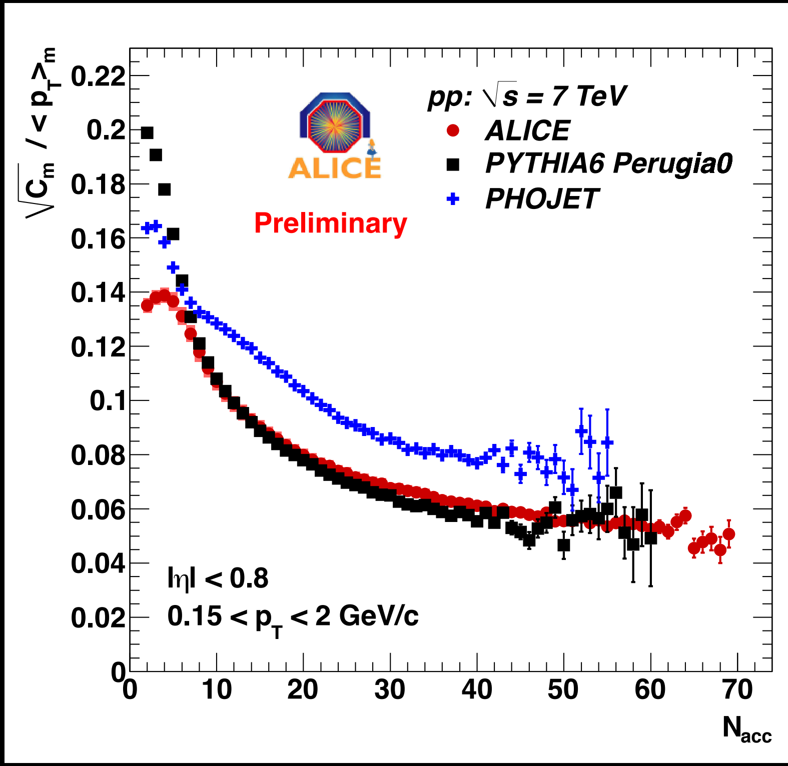
Transverse momentum fluctuations in pp

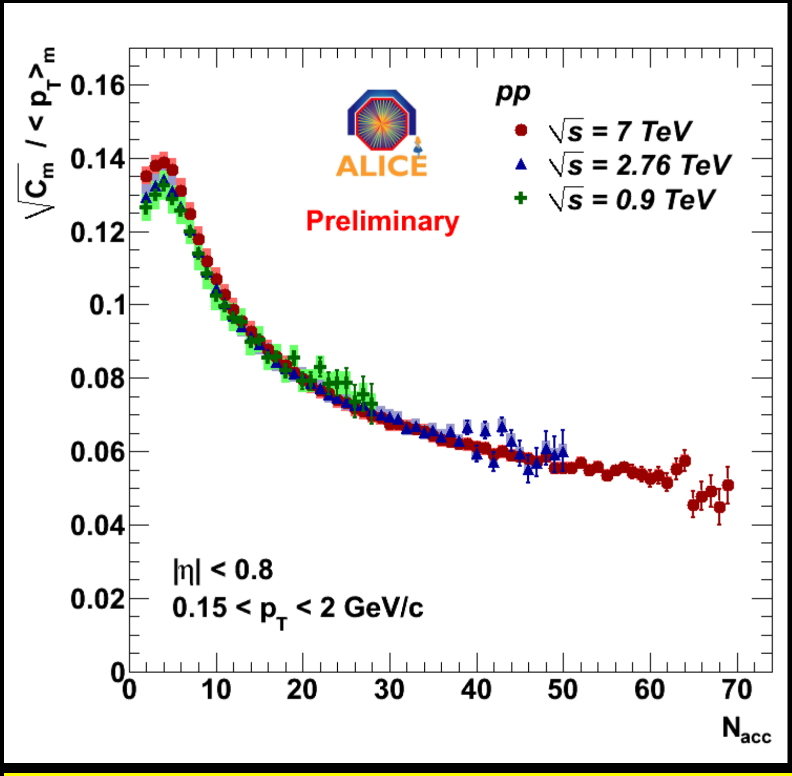
- Significant non-statistical fluctuations
  - 'Dilution' with multiplicity
- Moderate energy dependence of the 2-particle correlator



Transverse momentum fluctuations in pp

- Significant non-statistical fluctuations
  - 'Dilution' with multiplicity
- No apparent energy scaling of the relative fluctuations

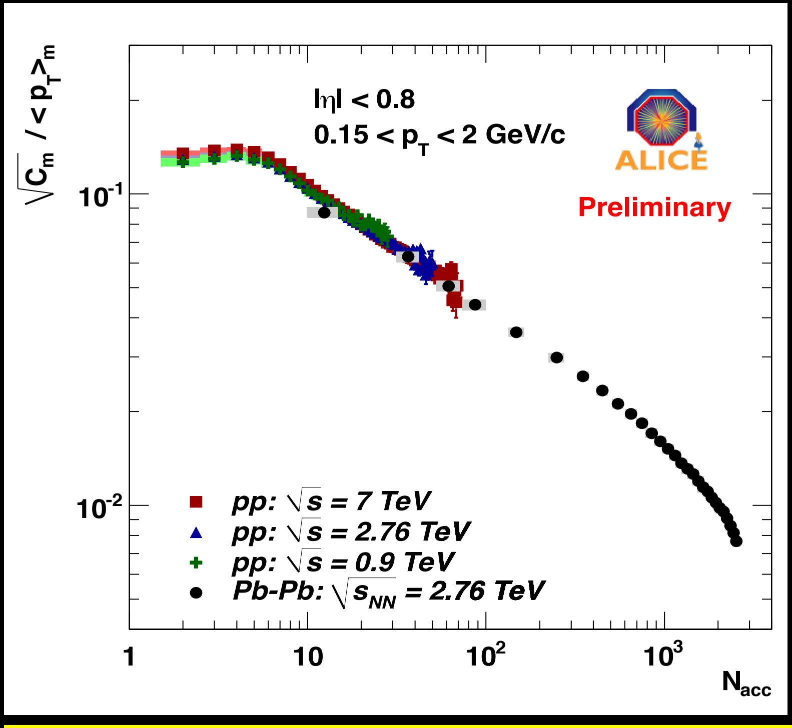


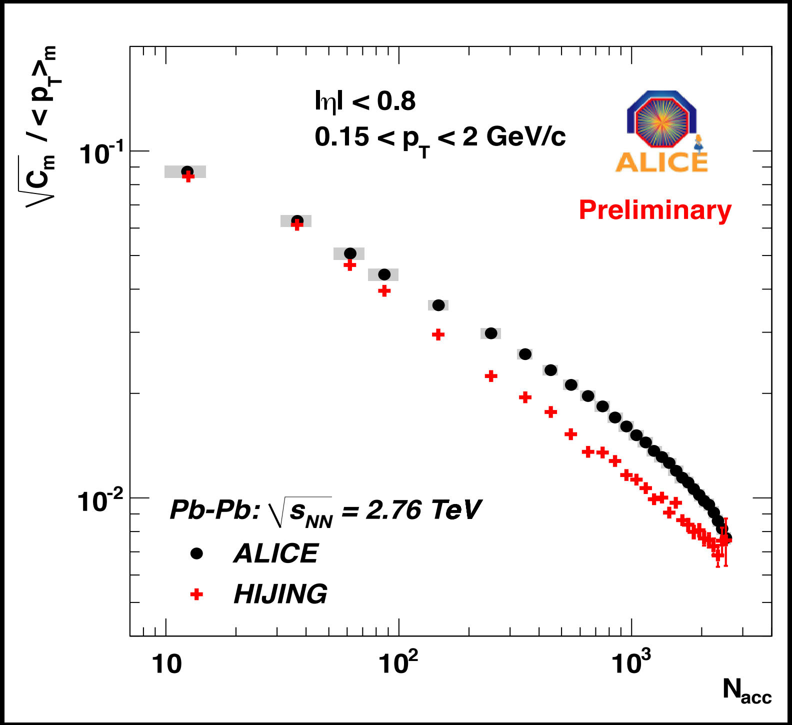


- Good description of the relative fluctuations by PYTHIA
  - Discrepancies at low multiplicities (N_{acc} < 7)
- Poor description by PHOJET

Transverse momentum fluctuations in Pb—Pb

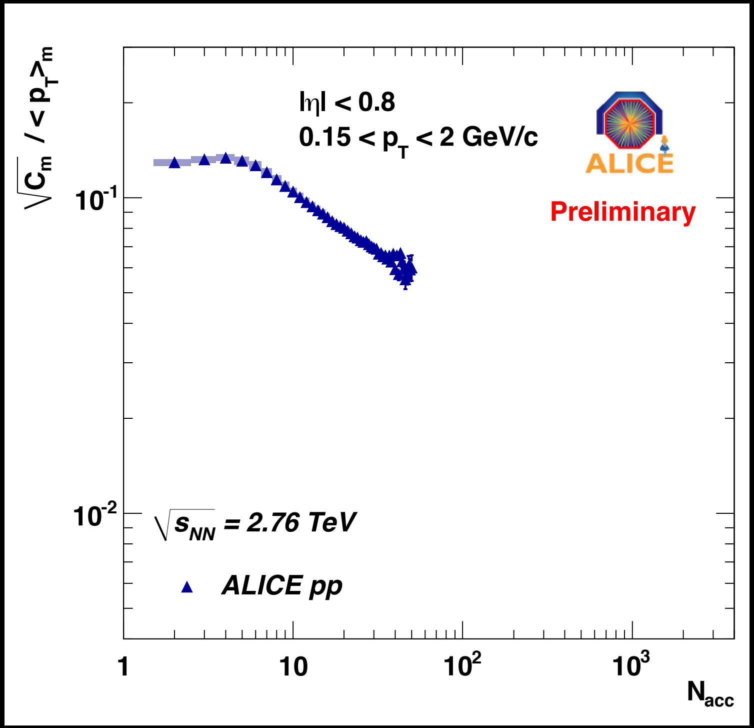
- Same trend as in pp
  - Significant fluctuations in the peripheral bins the magnitude of which is decreasing when moving to more central collisions
- pp and peripheral Pb—Pb indicate a common scaling





- Experimental values are not described by HIJING both in magnitude and in their centrality dependence
  - HIJING points show also significant non-statistical fluctuations with a decreasing trend vs centrality

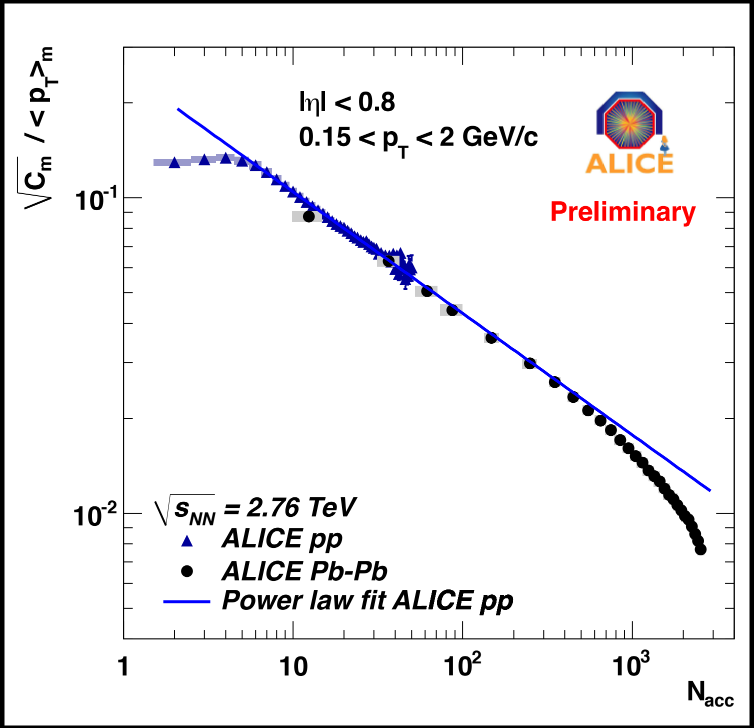
$$f(N_{acc.}) \sim (N_{acc.})^{a}$$



Transverse momentum fluctuations: Data vs models

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

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

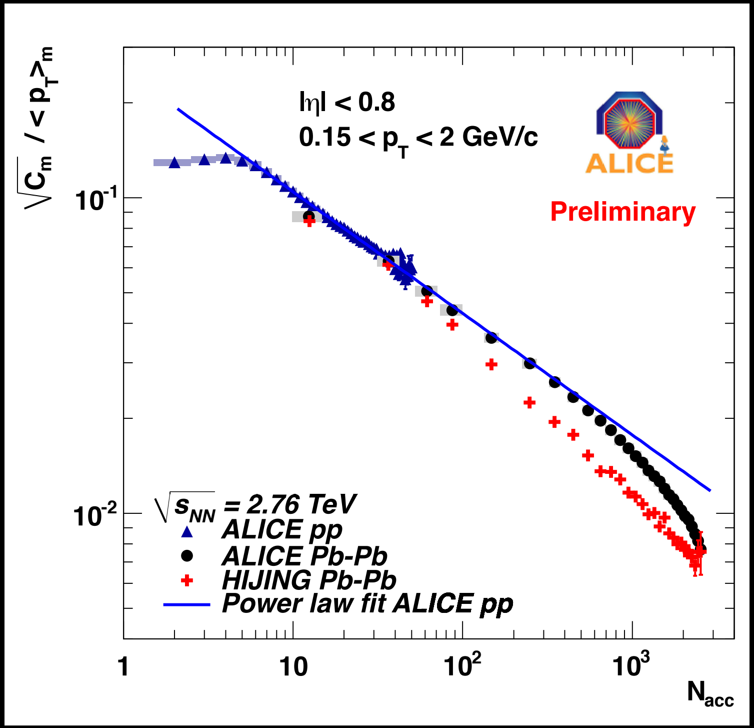


Transverse momentum fluctuations: Data vs models

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

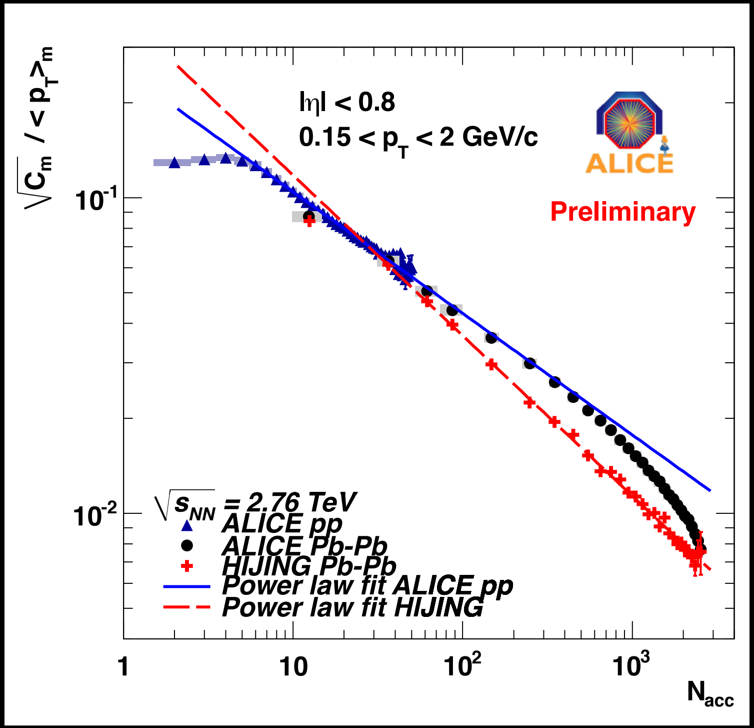
$$f(N_{acc.}) \sim (N_{acc.})^{a}$$

- HIJING points deviate following their own monotonic decrease with centrality



Transverse momentum fluctuations: Data vs models

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

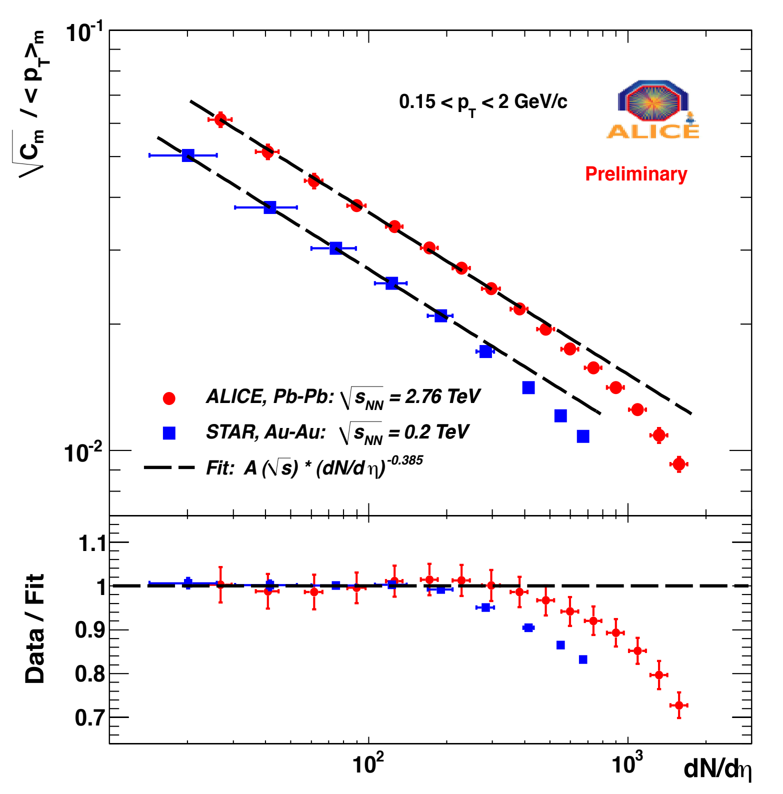


$$f(N_{acc.}) \sim (N_{acc.})^{a}$$

- HIJING points deviate following their own monotonic decrease with centrality
- Different slopes between experimental data points and HIJING
- No indication for a deviation from the power law fit for central collisions in HIJING

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, deconfinement
- We need to have a model incorporating the two important contributions: jets and flow



Charge fluctuations

- In the presence of the QGP, the relevant carriers of the charge are the quarks
- Thus in the QGP phase, the unit of charge is 1/3 while in the hadronic phase, the unit of charge is 1.
- 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)
  - detector effects

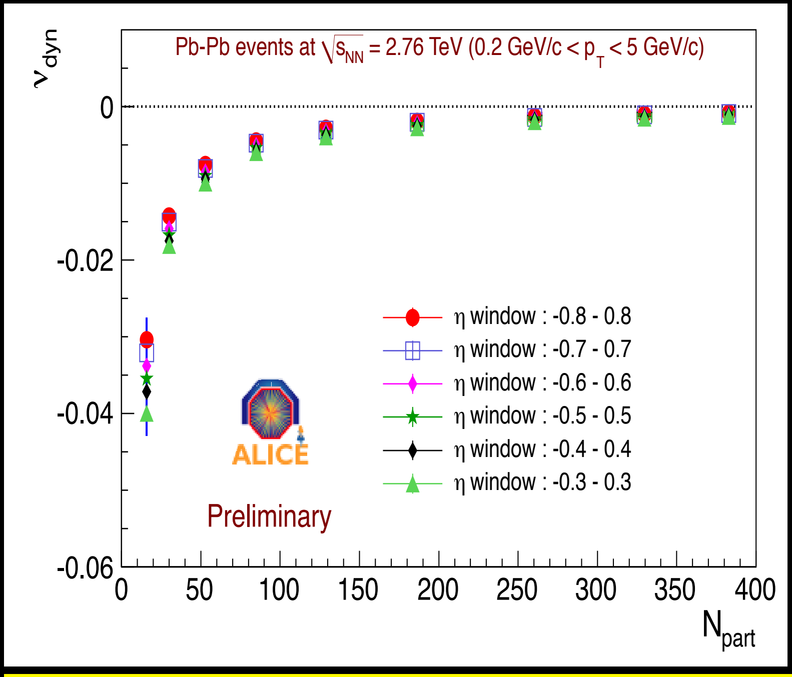
- The tool used to quantify the fluctuations is the $v_{dyn.}$ which is not sensitive to detector effects, provided that the detection efficiency is uniform over the measured kinematic range:

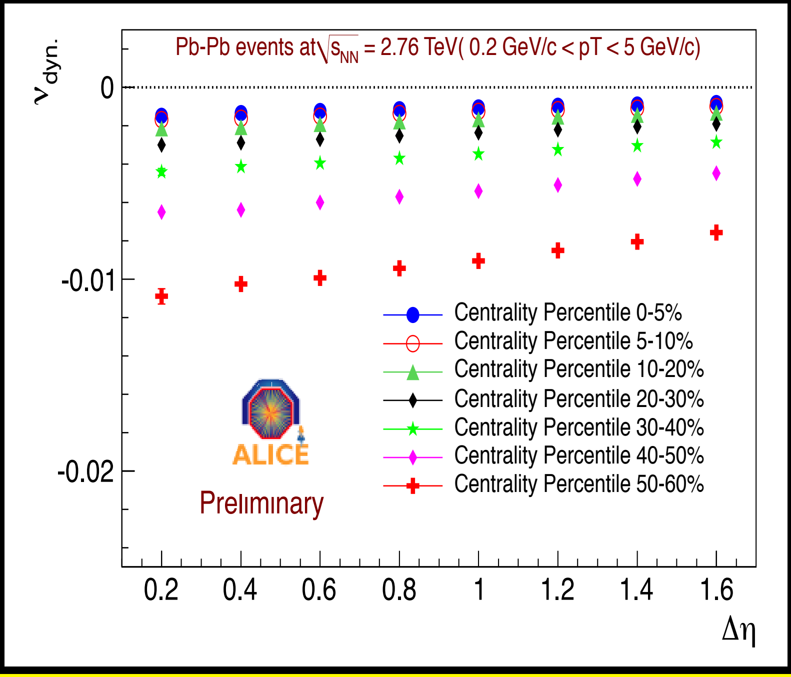
$$v_{(+-,dyn.)} = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_+N_-\rangle}{\langle N_+\rangle\langle N_-\rangle}$$

C. Pruneau, S. Gavin and S. Voloshin, Phys. Rev. C**66**, (2002) 044904

Charge fluctuations: Centrality dependence

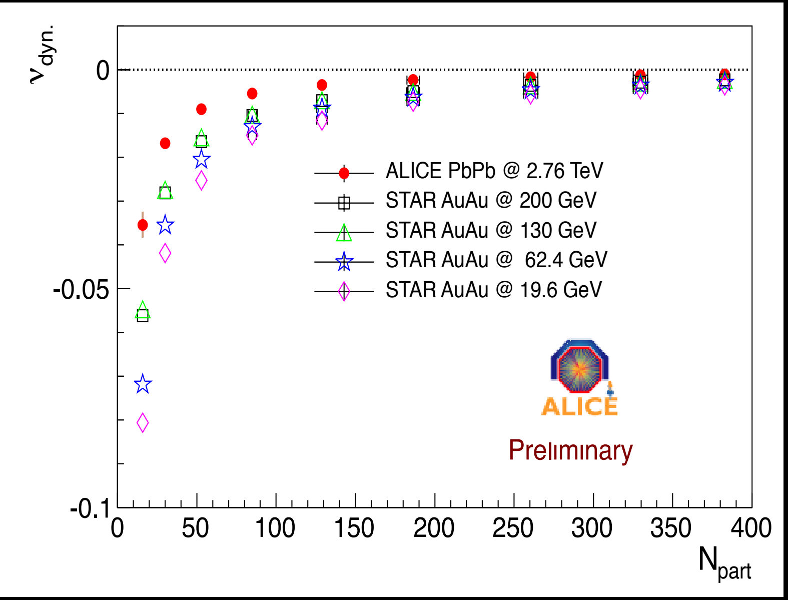
- v_{dyn} studied for different centralities and pseudo-rapidity windows.
- The centrality dependence shows a saturation pattern, already observed at RHIC.
  - $|v_{dyn.}|$ decreases when moving from peripheral to central collisions
  - Can this be attributed to the larger yield of resonances that don't contribute to the charge fluctuations but only to the multiplicity?
- Relative decrease in $\Delta\eta$ of the $|v_{dyn.}|$ twice as much in central than in peripheral collisions

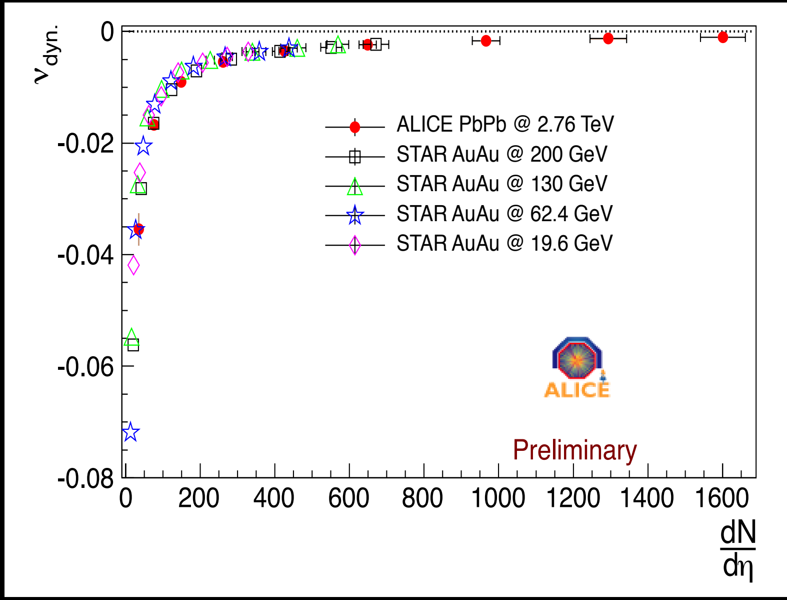




Charge fluctuations: LHC vs RHIC

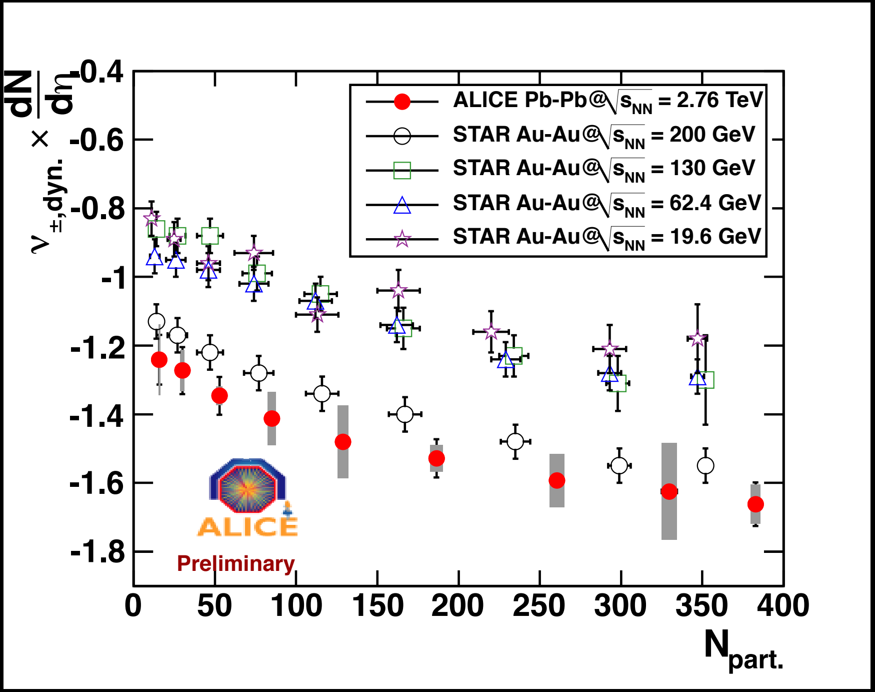
- Nice evolution of the $\nu_{dyn.}$ as a function of the centrality
- The ALICE points, when plotted vs N_{part}, demonstrate a higher value of $\nu_{dyn.}$ for each centrality bin.
- When plotted against the pseudo-rapidity density, there is a nice agreement between the LHC peripheral and mid-peripheral and the RHIC mid-peripheral and central points.
  - The ALICE points extend further in dN/dη, exhibiting an additional reduction of the fluctuations.





Charge fluctuations: Looking for the proper scaling

- Observed centrality dependence of the scaled (with the dN/dη) v_{dyn}
  - In case of independent nucleon-nucleon collisions, then the scaled $v_{dyn.}$ should not show any dependence on centrality
  - Indication of a change in the collision dynamics when going from peripheral to central collisions.
- Additional 7.5% reduction of the fluctuations compared to the highest RHIC energy.



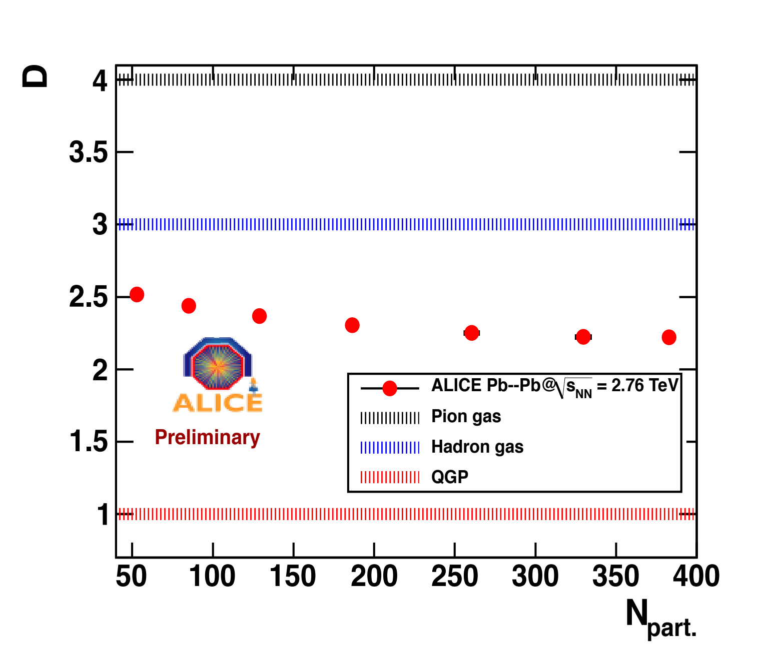
Charge fluctuations: Comparison with theory

- Initial estimate by Jeon and Koch about the values of the parameter D in case of a pion gas and the QGP phase.
- The relevant values were further refined by the same authors taking into account the contributions from resonances.
- The experimental values are larger than the QGP prediction (ideal QGP) but still lower than the expectation for a hadron gas with the inclusion of resonances

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

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

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



Charge fluctuations: Comparison with theory

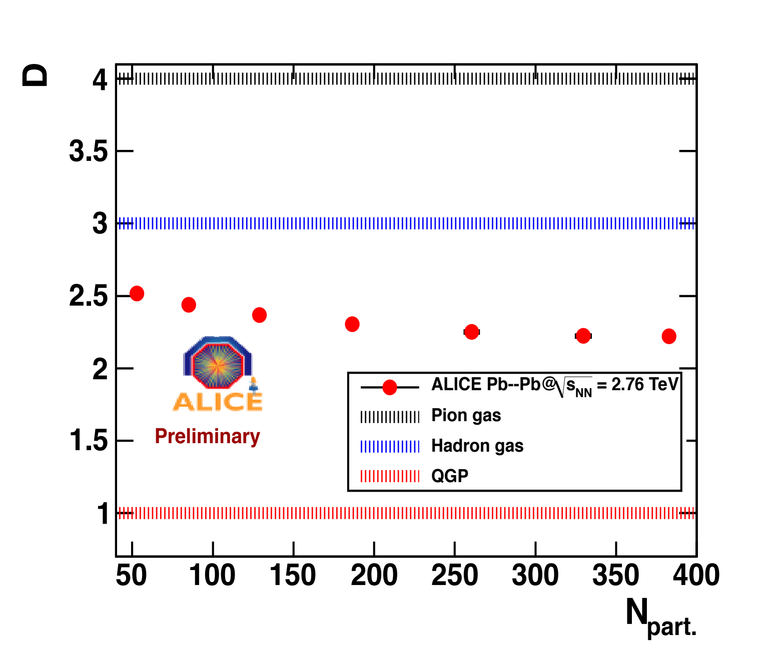
- Initial estimate by Jeon and Koch about the values of the parameter D in case of a pion gas and the QGP phase.
- The relevant values were further refined by the same authors taking into account the contributions from resonances.
- The experimental values are larger than the QGP prediction (ideal QGP) but still lower than the expectation for a hadron gas with the inclusion of resonances

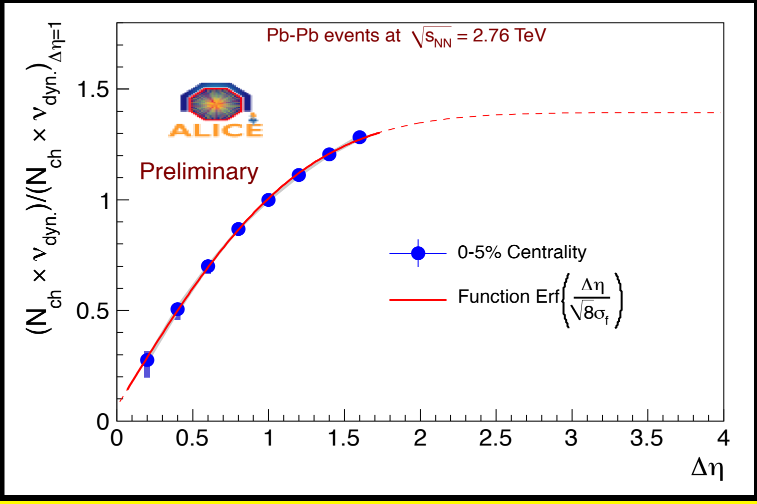
S. Jeon and V. Koch, Phys. Rev. Lett. **85**, (2000) 2076

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

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

- Initial fluctuations diluted by the hadronization and the final state interactions
- Introduction of the diffusion parameter to trace the initial magnitude of the fluctuations





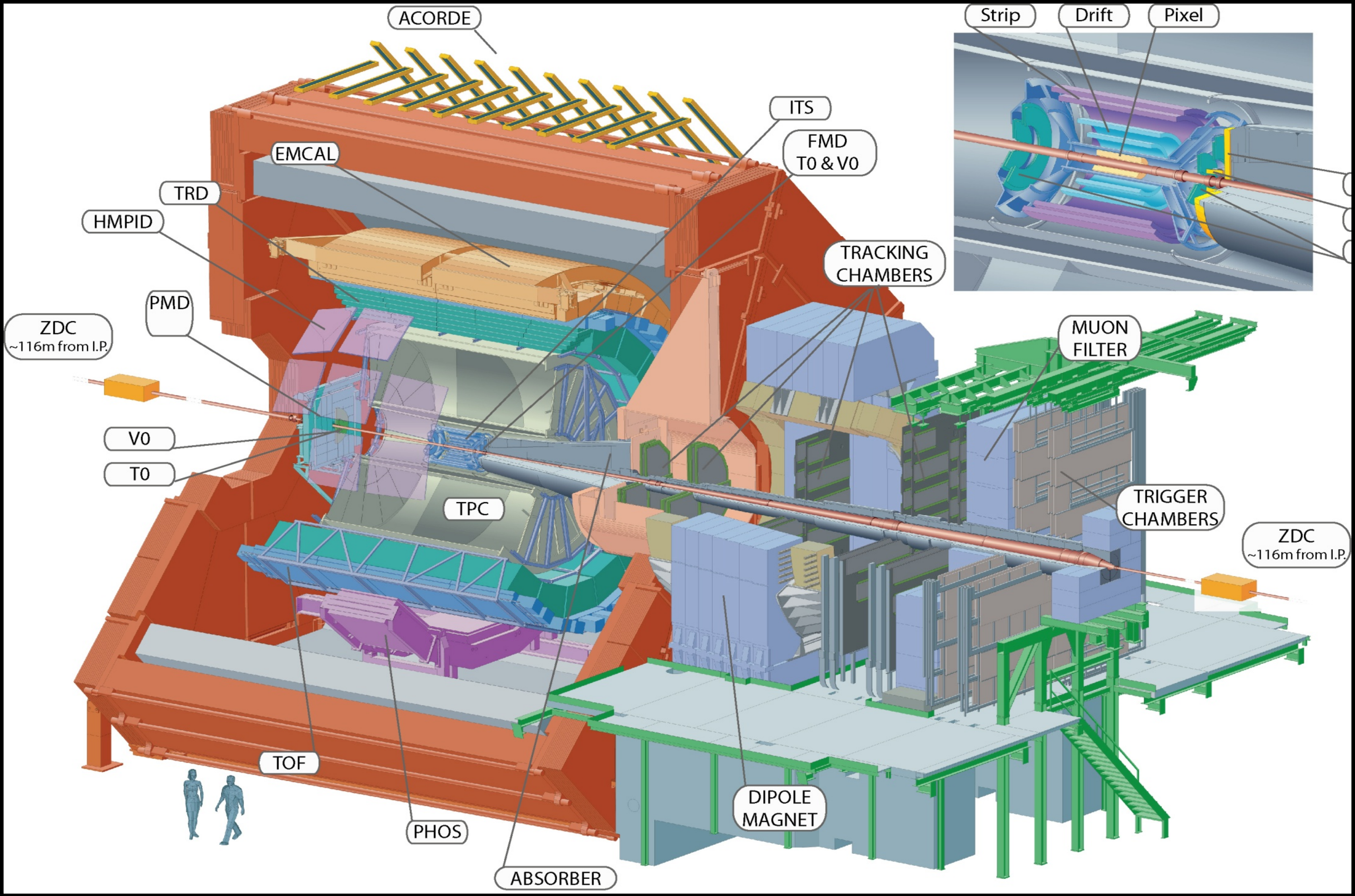
E. V. Shuryak and M. A. Stephanov, Phys. Rev. *C63*, (2001) 064903
M. Aziz and S. Gavin, Phys. Rev. *C70*, (2004) 034905

Summary and outlook

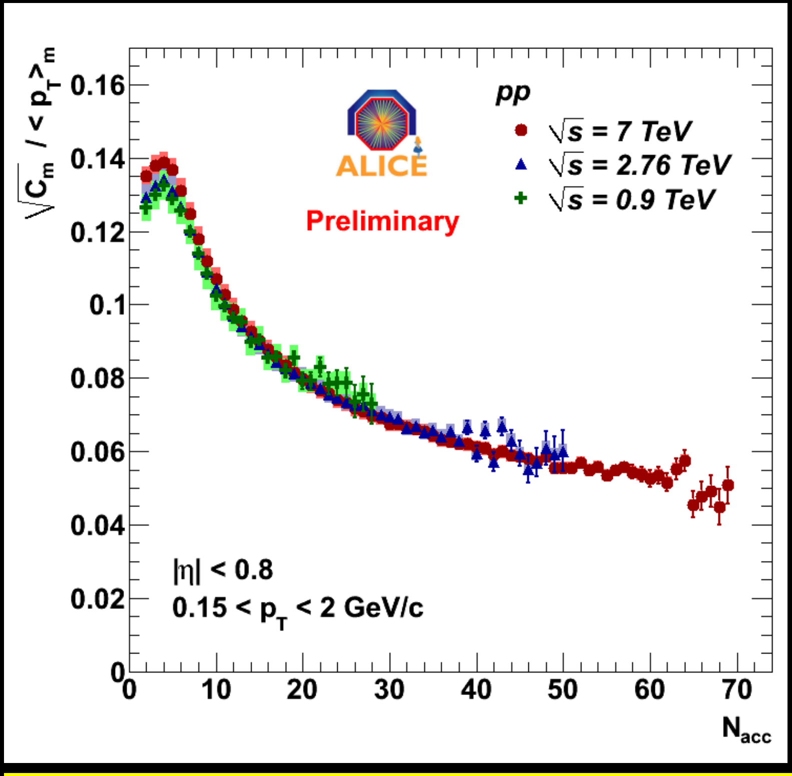
- First ebye observables studied at the LHC with the ALICE experiment in pp collisions @ $\sqrt{s}$ = 0.9, 2.76 and 7 TeV and Pb—Pb events @ $\sqrt{s_{NN}}$ = 2.76 TeV
- The transverse momentum fluctuations demonstrate:
  - a universal scaling with energy in pp collisions,
  - a nice evolution of the relative fluctuations from pp to mid-peripheral Pb—Pb collision with an additional reduction for the more central events,
  - the centrality dependence of the fluctuations can't be described by standard models (i.e. 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 the dN/dη,
  - the resulting fluctuations have a magnitude which resides between the expectations from theory for a hadron gas with the inclusion of resonances and the corresponding value for a QGP phase transition.
    - Important to get a description of the dilution of the initial fluctuations due to the final state effects
- More things to come:
  - Balance functions ➔ time of hadronization, radial flow
  - Identified particle ratios
  - long range correlations

BACKUP

ALICE: Experimental setup

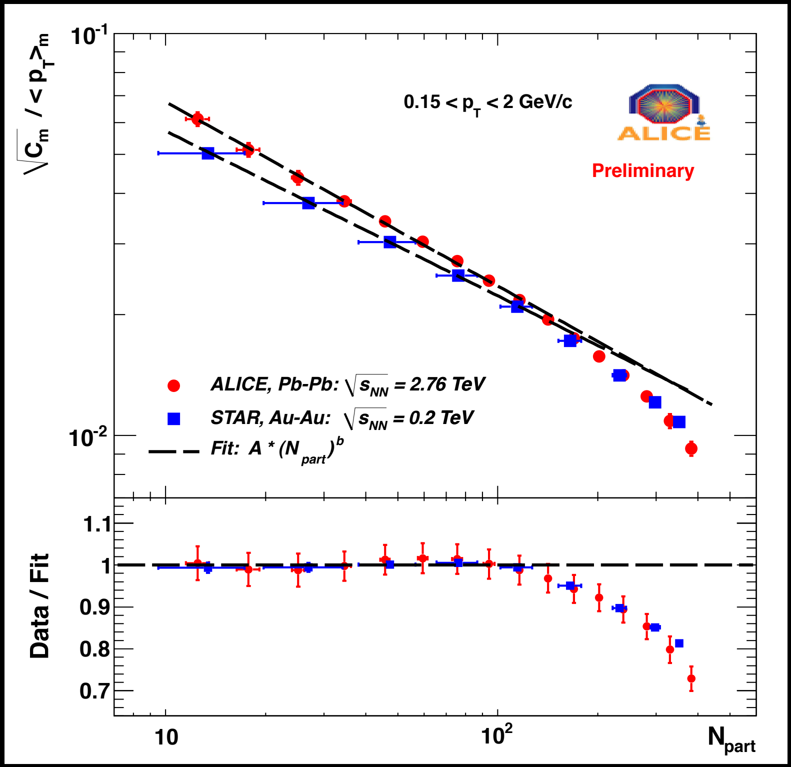


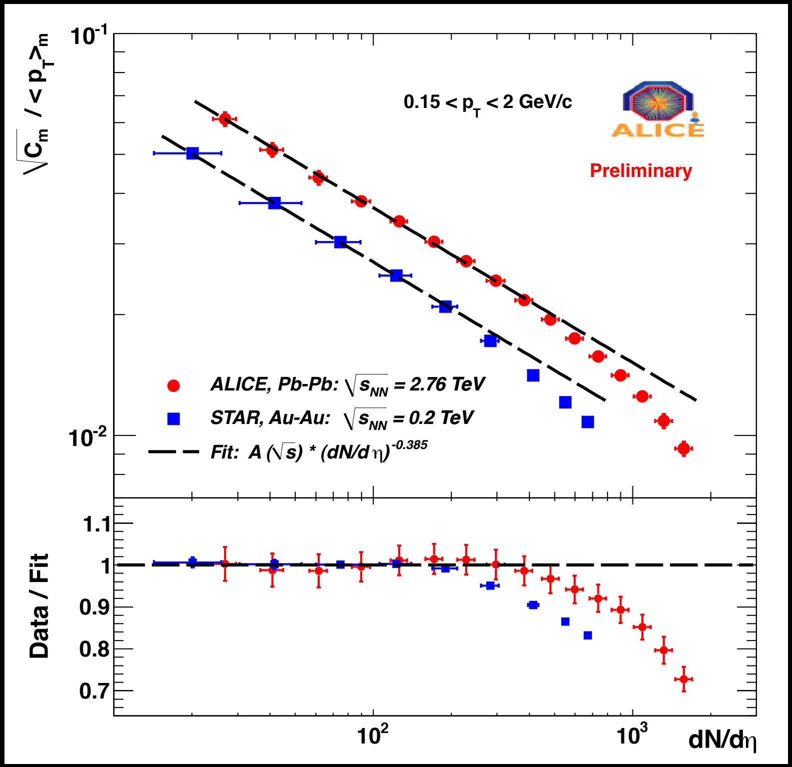
- Significant non-statistical fluctuations
  - 'Dilution' with multiplicity
- Moderate energy dependence of the 2-particle correlator
- No apparent energy scaling of the relative fluctuations



Transverse momentum fluctuations: LHC vs RHIC

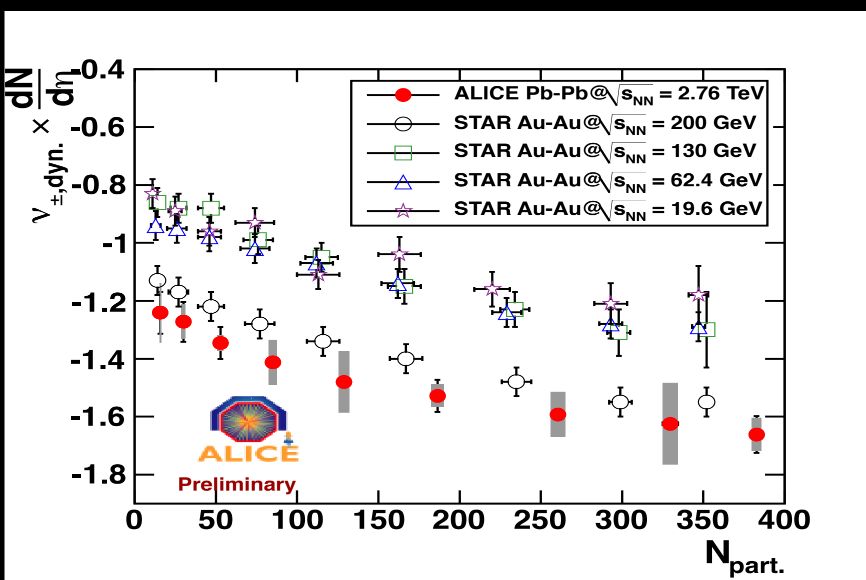
- The relative fluctuations for both energies are described well by the pp baseline fit from peripheral up to mid-central collisions
- RHIC data were explained in terms of percolation of strings, thermalization, deconfinement
- We need to have a model incorporating the two important contributions: jets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

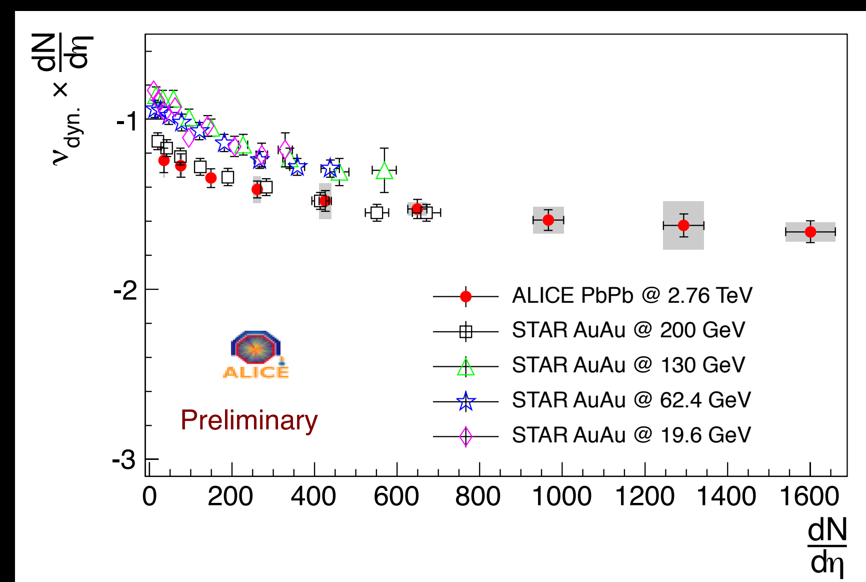




Charge fluctuations: Looking for the proper scaling

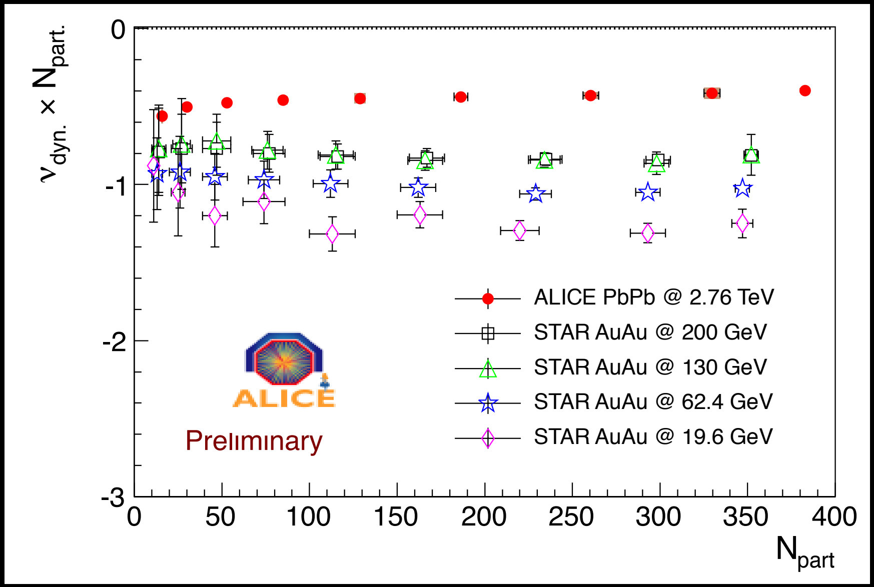
- Observed centrality dependence of the scaled (with the dN/dη) ν_{dyn}
  - In case of independent nucleon-nucleon collisions, then the scaled $\nu_{dyn.}$ should not show any dependence on centrality
  - Indication of a change in the collision dynamics when going from peripheral to central collisions.
- Additional 7.5% reduction of the fluctuations compared to the highest RHIC energy.

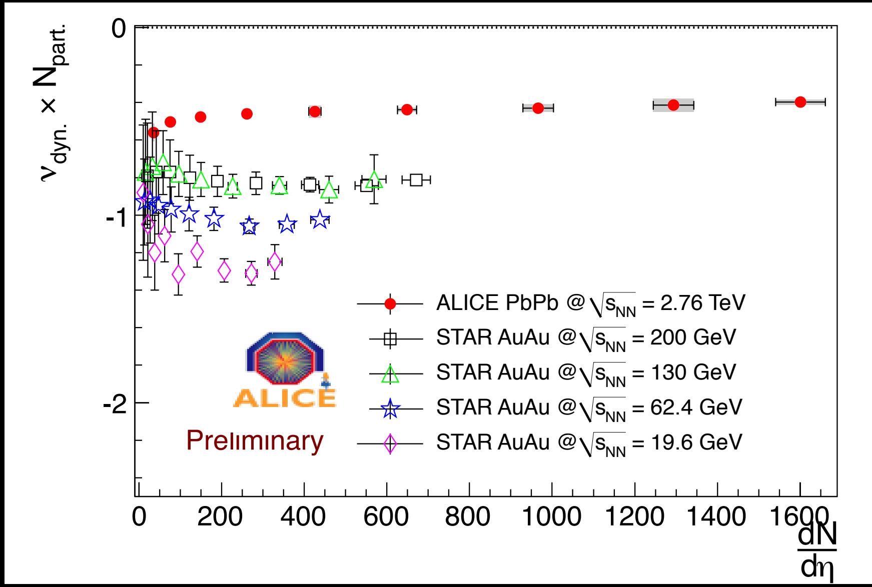




Charge fluctuations: Looking for the proper scaling

- No centrality dependence of the scaled (with the number of participants) vdyn
- Fluctuations/participant show no centrality dependence?
- A strong energy dependence is observed





Charge fluctuations: Attempt to trace the initial fluctuations

- Several attempts were made 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.
- Based on a refined formulation of the previous idea, Gavin et al. introduced the notion of the causal diffusion