Event-by-event mean p_T fluctuations in pp and Pb-Pb collisions measured with ALICE at the LHC

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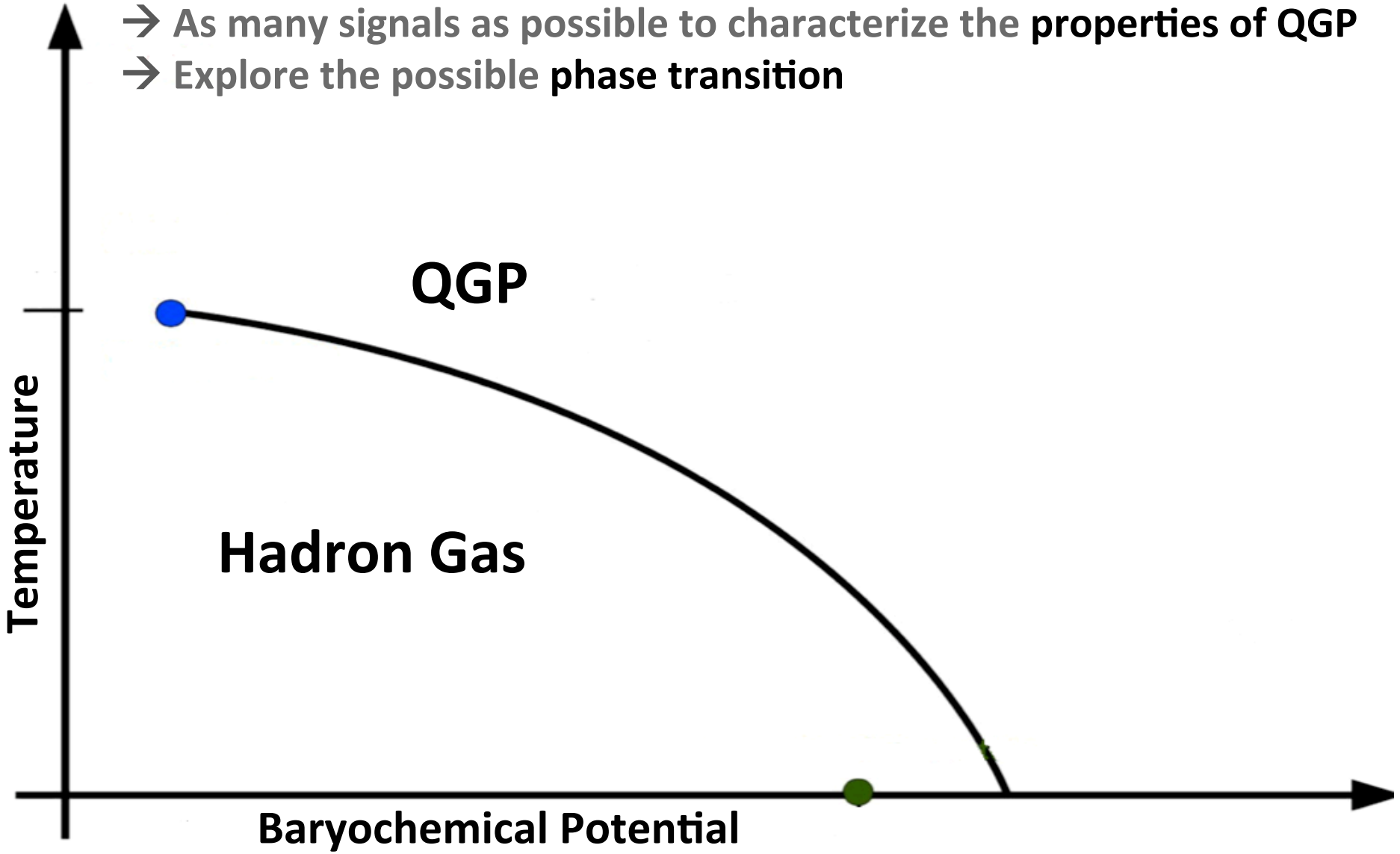
on behalf of the ALICE Collaboration

WWND, Colorado, USA
28.01.2015

GOETHE UNIVERSITÄT FRANKFURT AM MAIN
IKF Institut für Kernphysik Frankfurt
H-QM Helmholtz Research School Quark Matter Studies
ALICE

→ As many signals as possible to characterize the **properties of QGP**

→ Explore the possible **phase transition**



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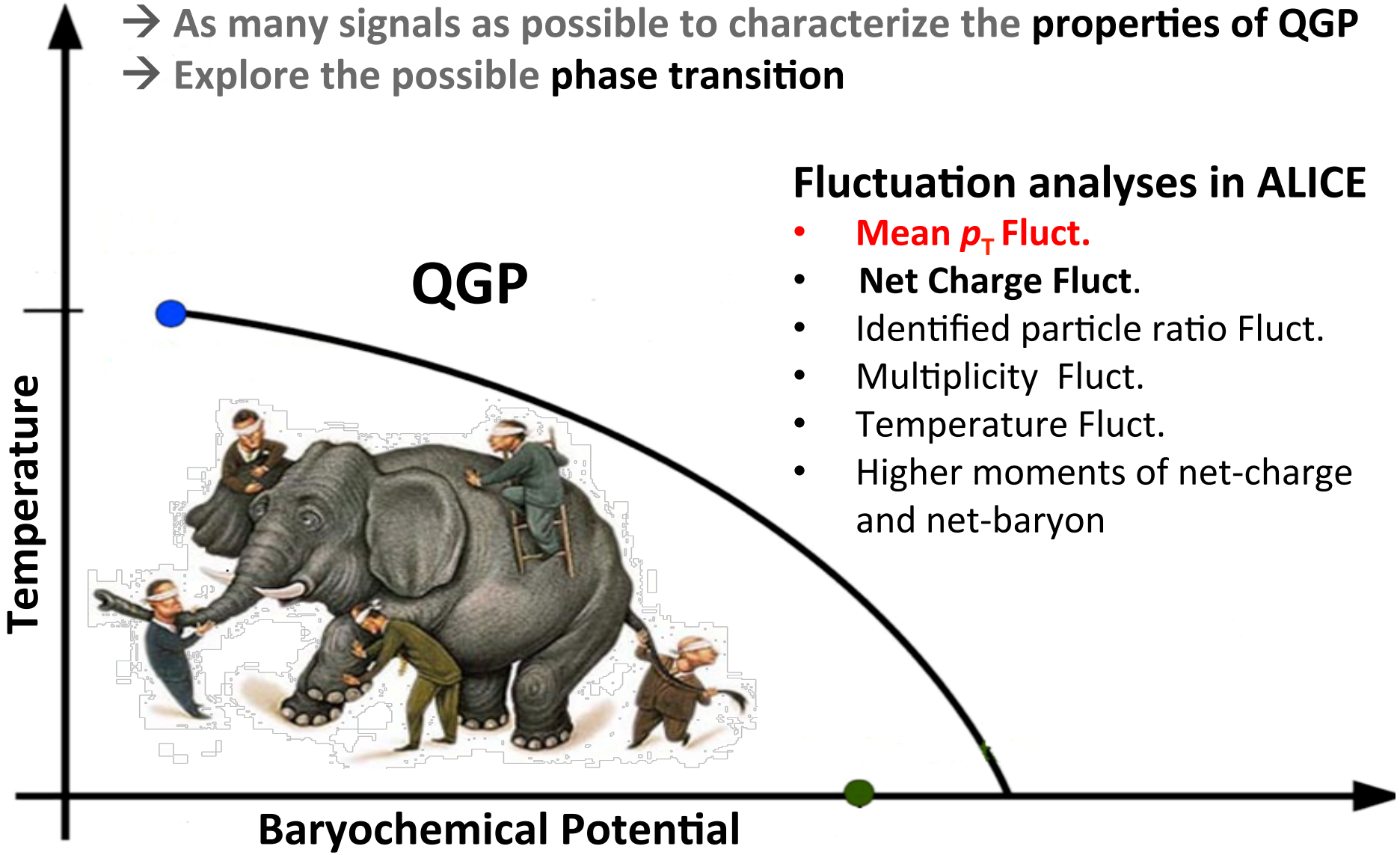


Fluctuation analyses in ALICE

- **Mean p_T Fluct.**
- **Net Charge Fluct**.
- Identified particle ratio Fluct.
- Multiplicity Fluct.
- Temperature Fluct.
- Higher moments of net-charge and net-baryon

OUTLINE

Introduction

- Motivation → **Why ?**
- **A L**arge **I**on **C**ollider **E**xperiment, **ALICE**

Event-by-event mean p_T fluctuations

- Observable: Two-Particle Correlator → **How ?**
- Physics Messages → **What ?**
  - pp Results
  - Pb-Pb Results
- Summary

MOTIVATION

Fluctuations: Statistical → Independent particle production

Dynamical → Source of physical phenomena

pp Collisions

- QGP is not expected
- Minijet production
- Resonance decays
- …

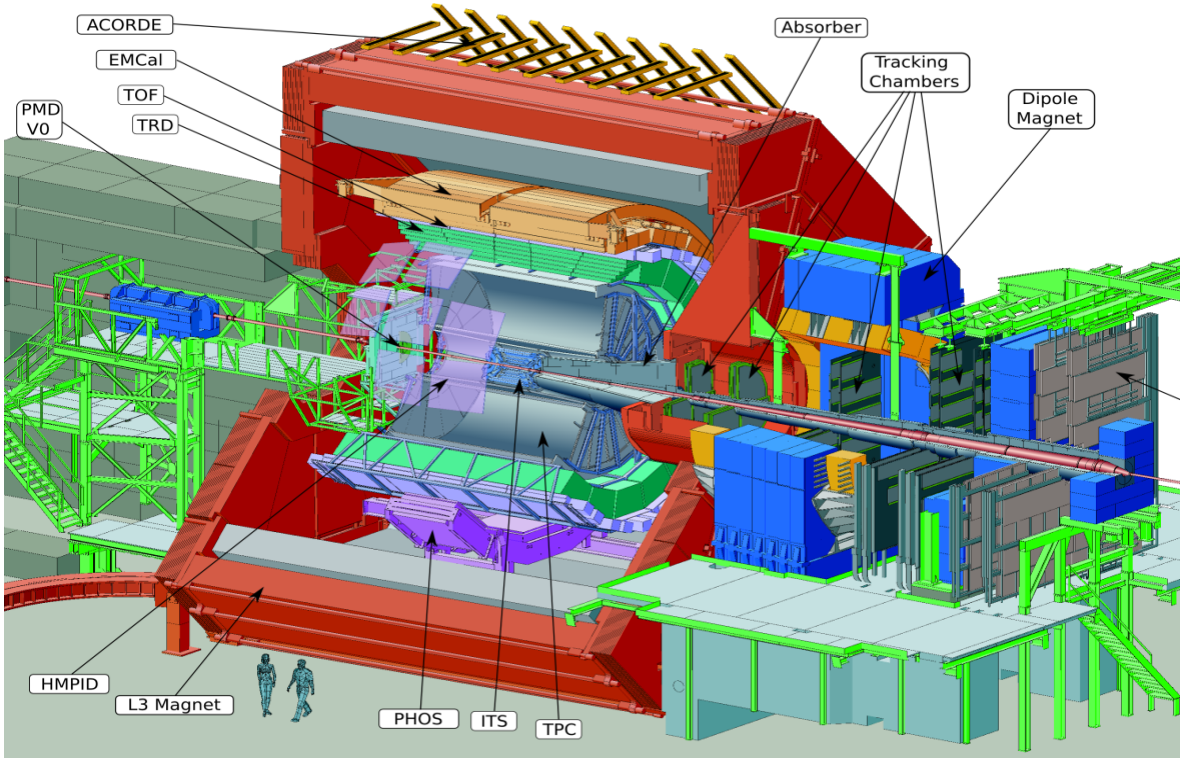
✧ **Important as reference measurement**

Pb-Pb Collisions

- **QGP is expected**
- Phase transition
- Initial State Fluctuations
- Collectivity
- Thermalization
- …

Energy and Multiplicity Dependence

ALICE Detector Setup



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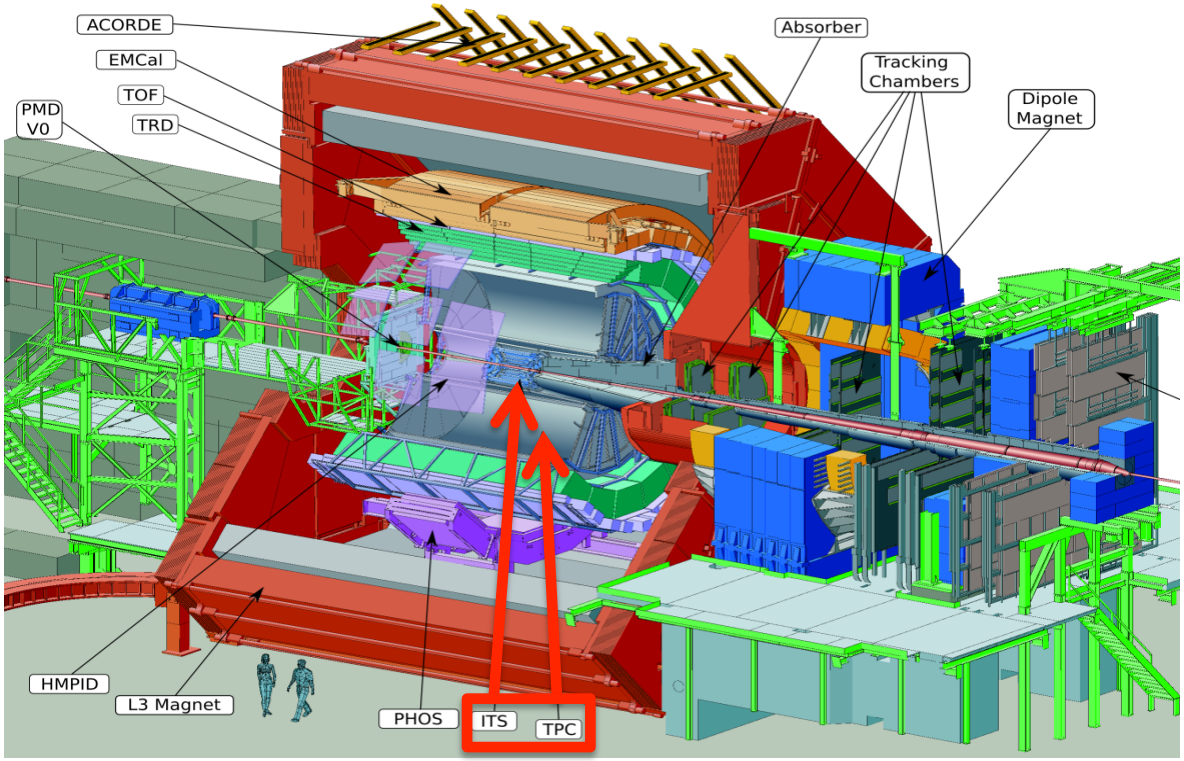

Main detectors used in the analysis

- **T**ime **P**rojection **C**hamber **(TPC)** → Tracking and Vertex
- **I**nner **T**racking **S**ystem **(ITS)** → Vertex

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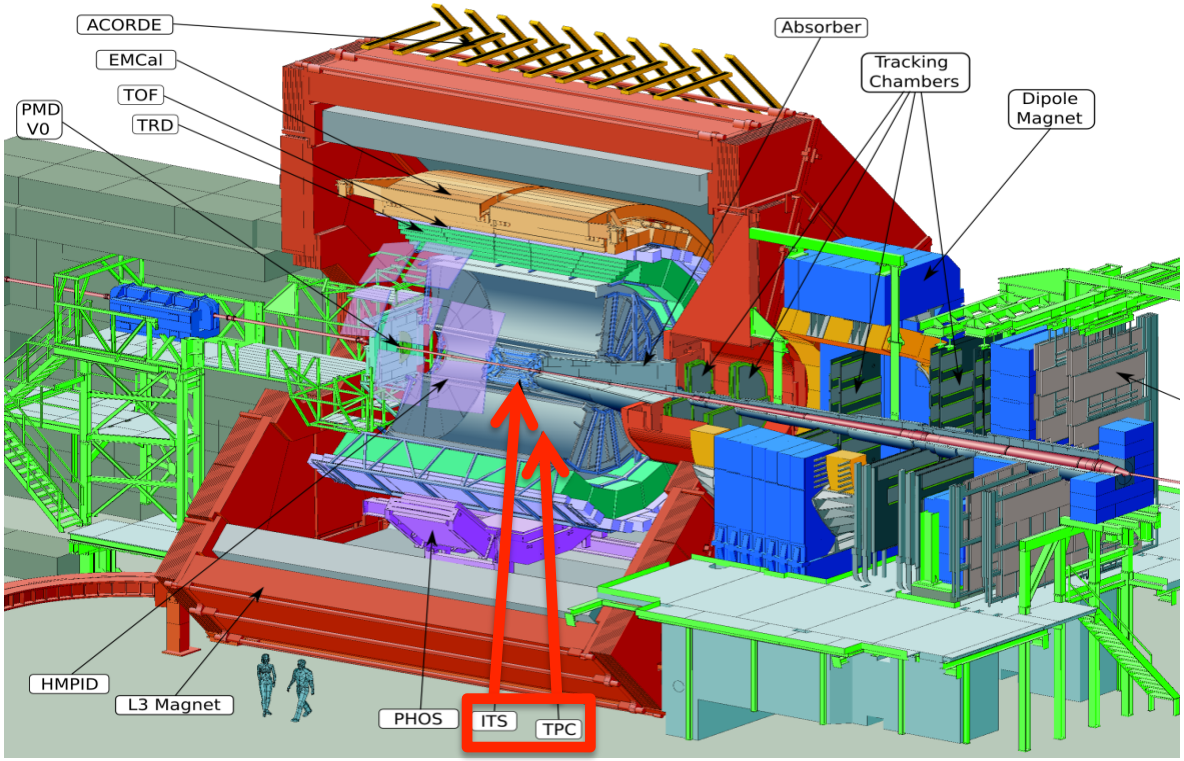

Data Sets

pp Collisions :

√s =0.9 TeV, 6.9 M events

√s =2.76 TeV, 66 M events

√s =7 TeV, 290 M events

Pb-Pb Collisions

√s =2.76 TeV, 19 M events

Acceptance:

✓ $|\eta|<0.8$

✓ $0.15 < p_T < 2$ GeV/c

Main detectors used in the analysis

- **T**ime **P**rojection **C**hamber **(TPC)** → Tracking and Vertex
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Observable: Two-Particle Correlator

Definition: The mean of covariances of all particle pairs i and j

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

n_{ev} : Number of events

N_k : Number of tracks in event k

$N_k^{pairs} = 0.5 \cdot N_k \cdot \left(N_k - 1 \right)$: Number of pairs in event k

$M(p_T)$: Mean p_T of all tracks in all events

$$C = 0$$

(Statistical Fluctuations)

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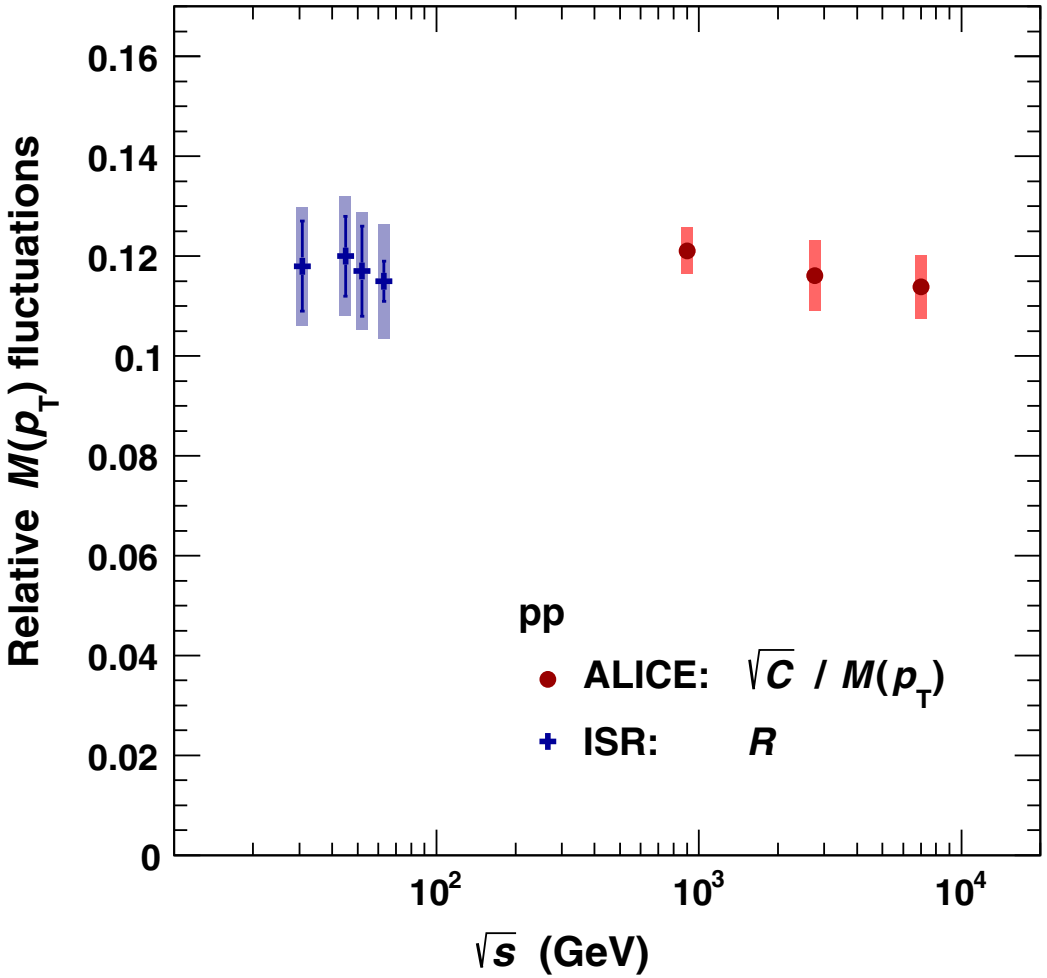
$$\frac{\sqrt{C}}{M(p_T)}$$

Energy and Multiplicity Dependence

pp Results

pp Results: Energy Dependence

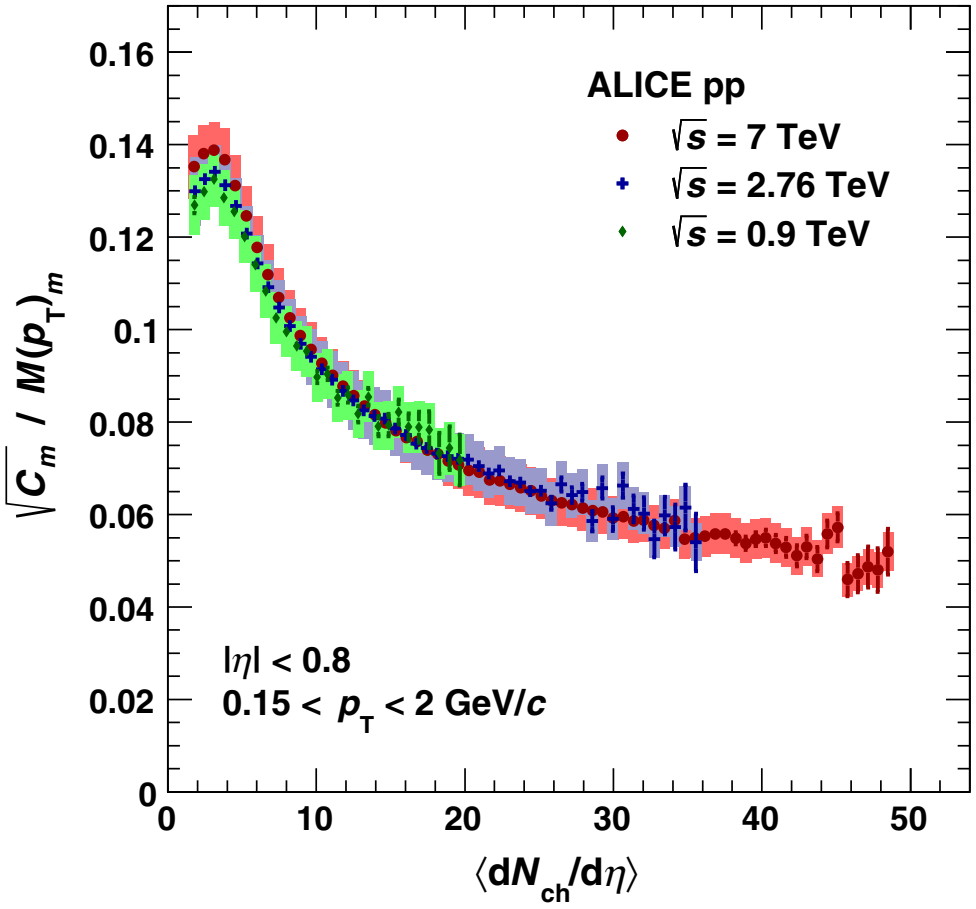


- ✓ **C>0** → Significant dynamical fluctuations
- ✓ **No significant dependence** over a large range of collision energies

ISR: Phys. Lett. B 123 (1983) 467
ALICE: Eur. Phys. J. C 74 (2014) 3077

pp Results: Multiplicity Dependence

→ **First measurement of mean p_T fluctuations as a function of multiplicity in pp collisions!**



- ✓ C_m>0 → Significant dynamical fluctuations
- ✓ Strong decrease with charged particle multiplicity
- ✓ No significant collision energy dependence

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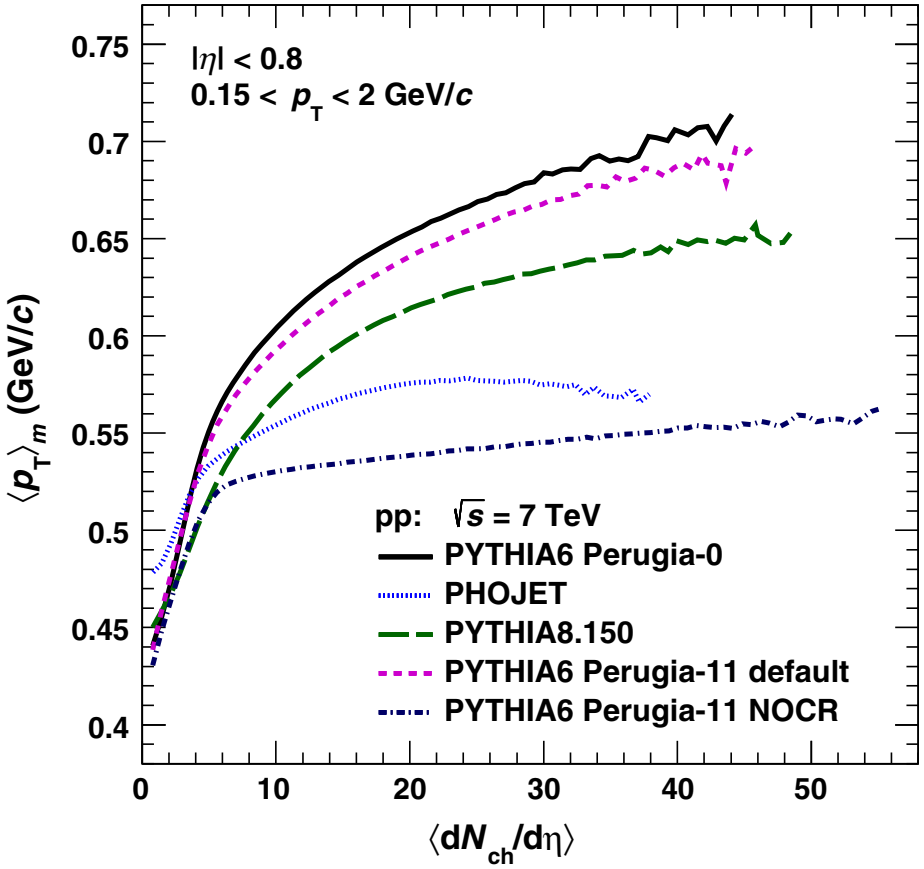
pp Results: Multiplicity Dependence

Monte Carlo (MC) Generators



→ **MC generators yield qualitatively different results for mean p_T** for the multiplicity dependence

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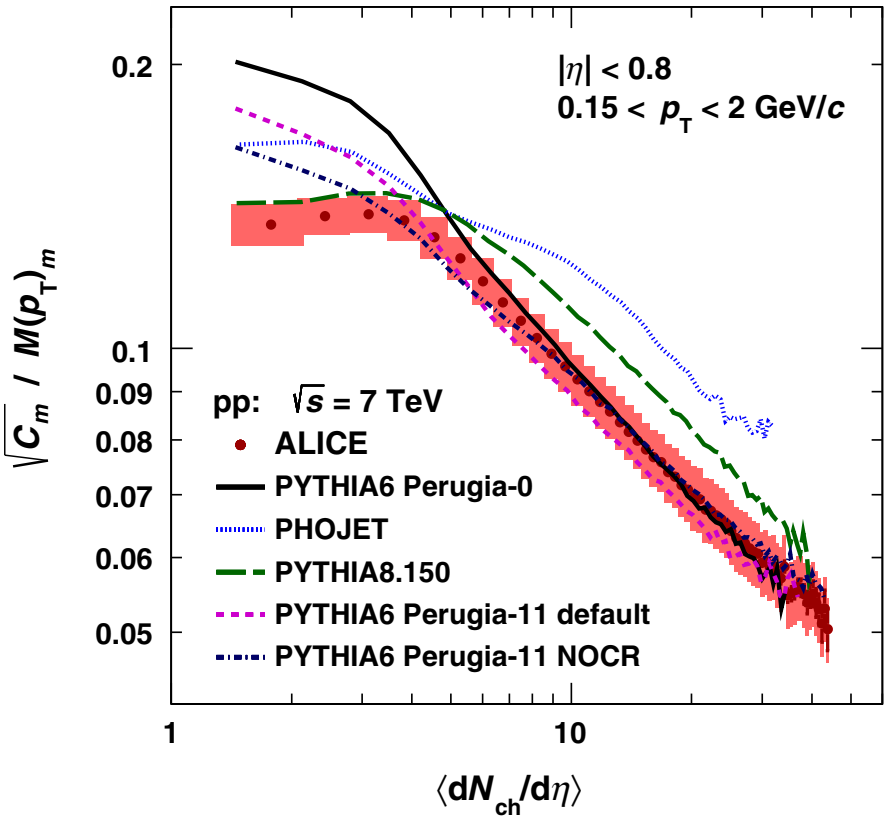
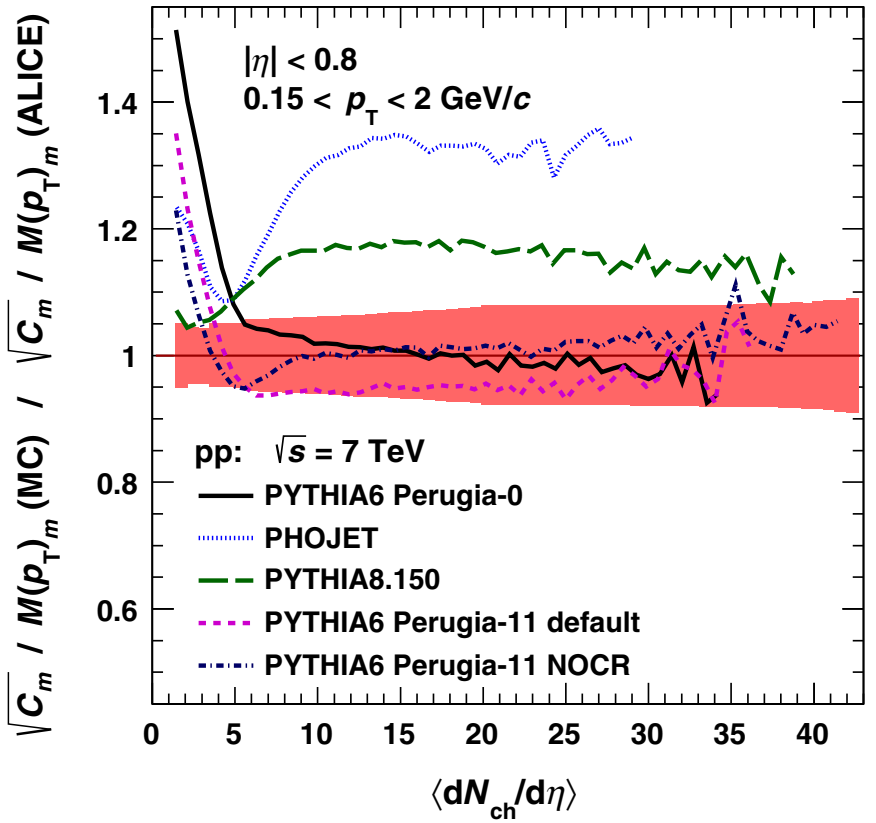
pp Results: Multiplicity Dependence

MC Generators vs Data





- Reasonable description by most of the generators for charged particle multiplicities larger than 5

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pp Results: Multiplicity Dependence

What else to say ?

1. High-multiplicity events in pp collisions at LHC energies are driven by **multi-parton interactions (MPIs).**
2. **Color reconnection (CR)** is the driving mechanism in PYTHIA for the increase of mean p_T as a function of multiplicity.
3. **Power-law dependence** (in $5 < \langle dN_{ch}/d\eta \rangle < 30$):

$$\sqrt{C_m} / M(p_T)_m \propto \langle dN_{ch}/d\eta \rangle^b \Rightarrow b = -0.431 \pm 0.022$$

→ All PYTHIA tunes (including the one with NOCR) show a similar power-law index as the data.

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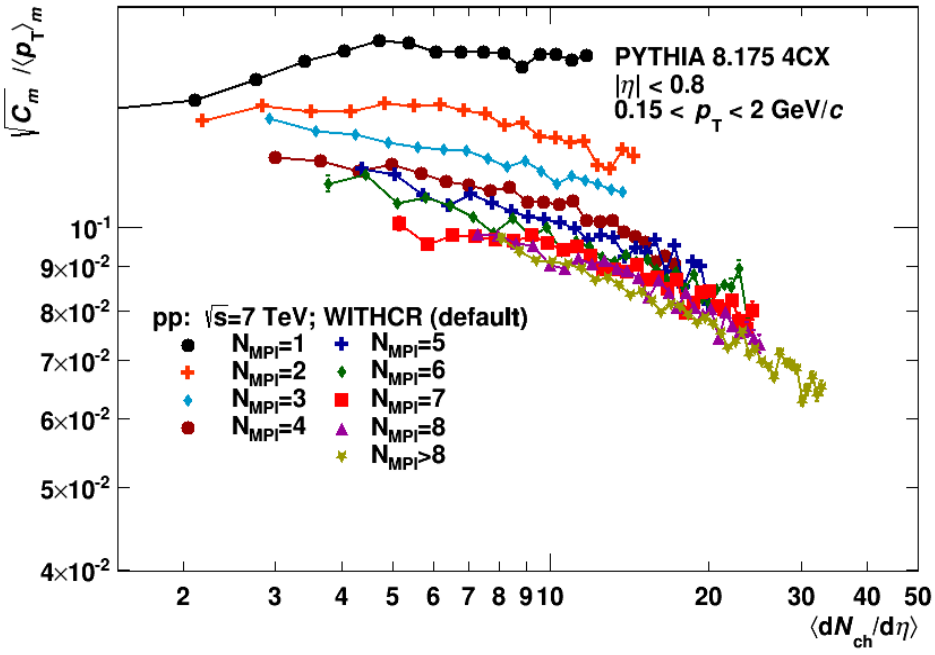
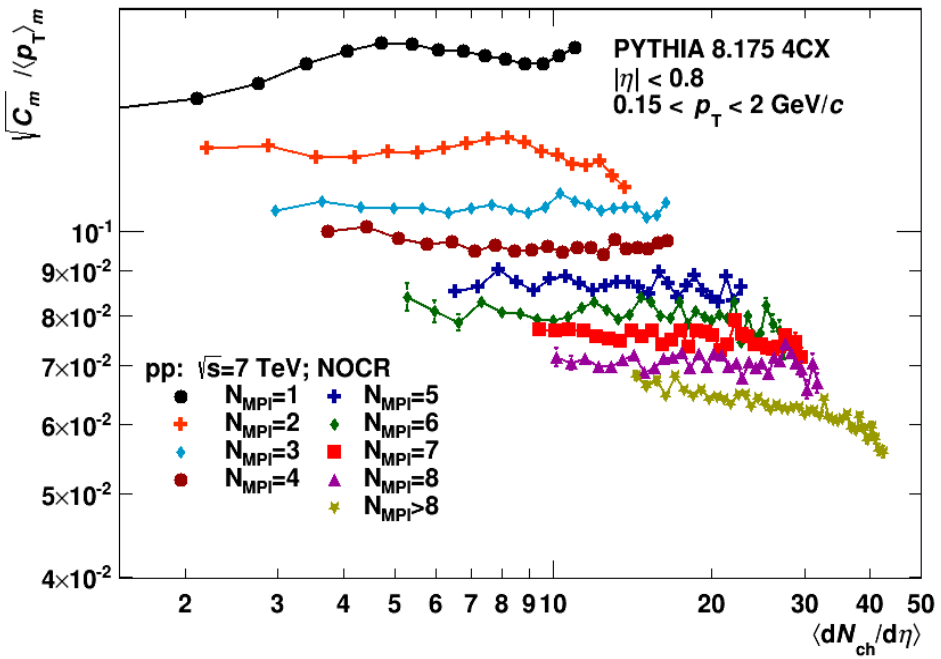
Deviation from ***b* = –0.5** indicates that the observed multiplicity dependence **does not follow a simple superposition scenario**, contrary to what might be expected for independent MPIs

pp Results: MPI study with PYTHIA

→ **Differential study of different N_{MPI} with PYTHIA tunes w and w/o CR**



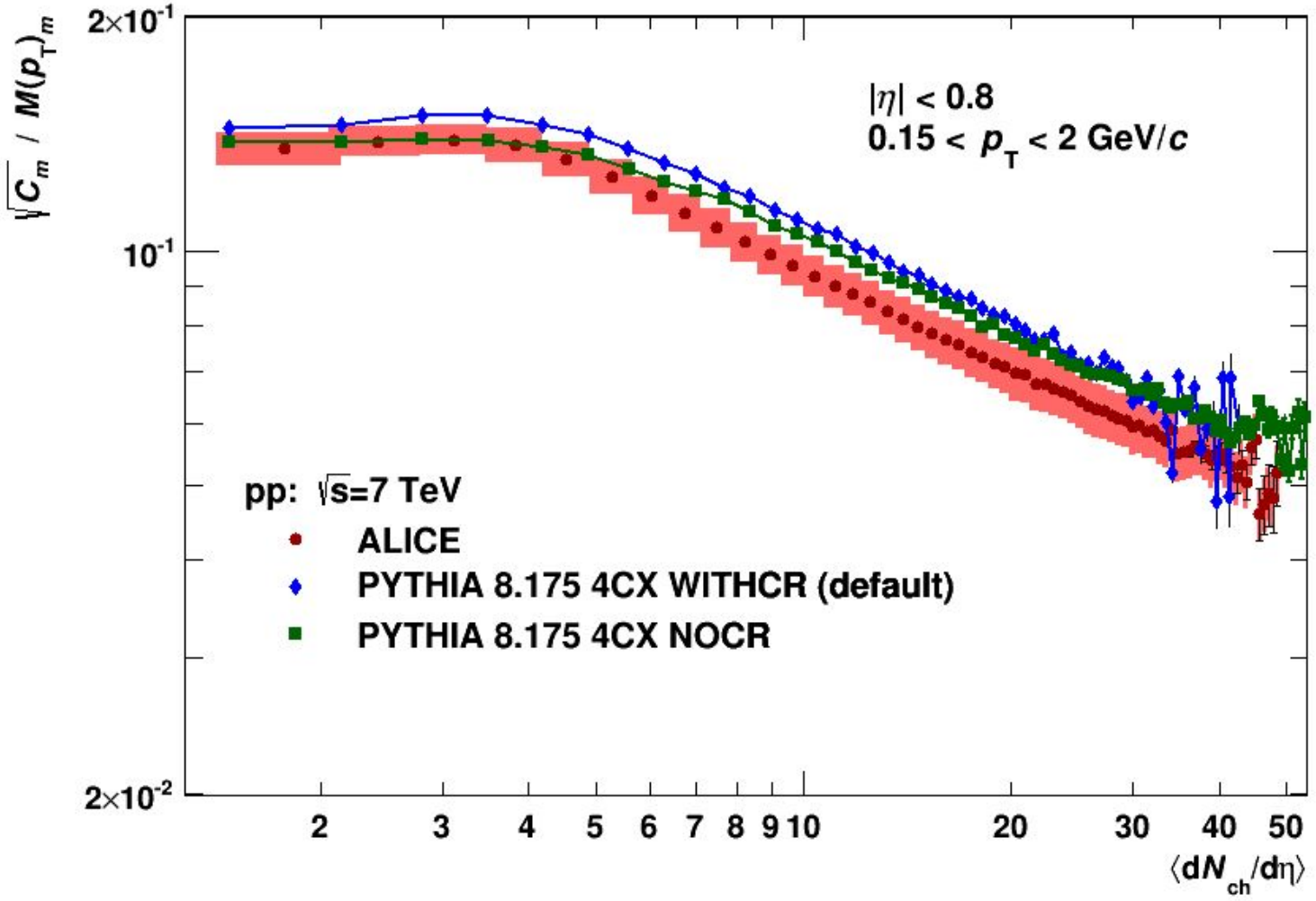


→ **Both**: similar behavior for $N_{MPI}=1$

→ **WITHCR**: decrease with multiplicity

→ **NOCR**: flat behavior with multiplicity

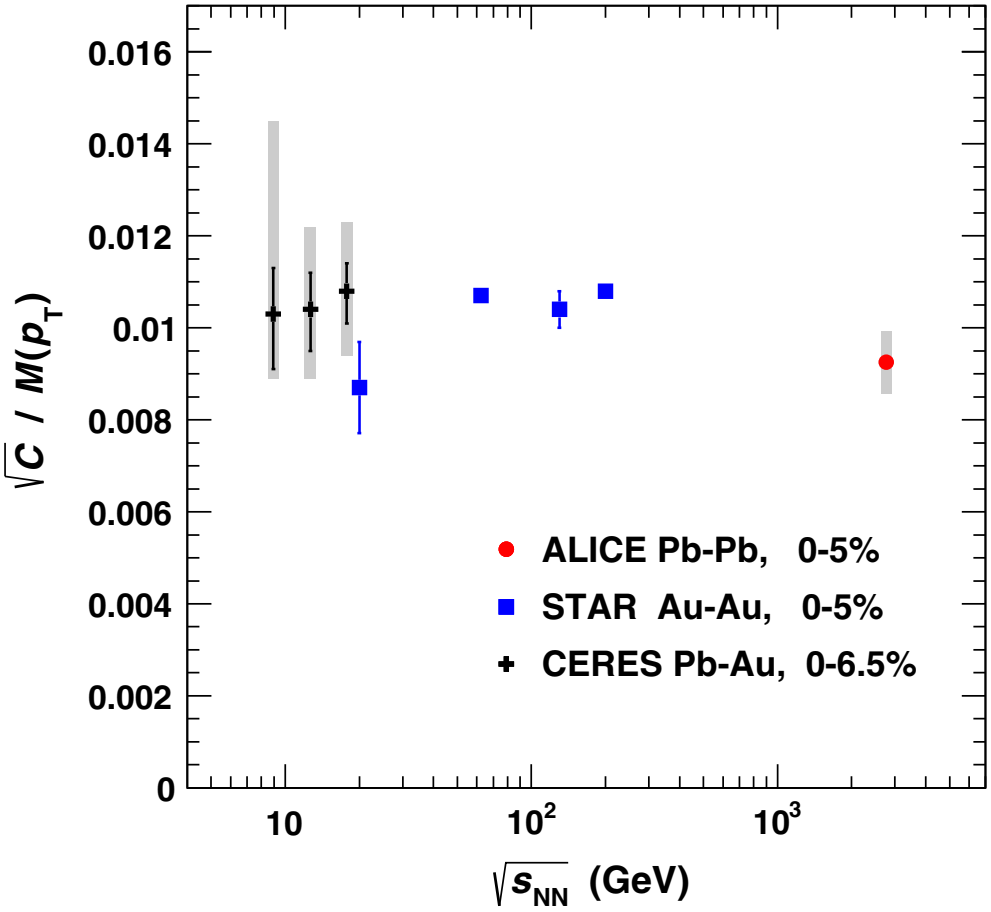
pp Results: MPI study with PYTHIA



→ Both tunes w and w/o CR show similar behavior in case of inclusive N_{MPI} scenario

Pb-Pb Results

Pb-Pb Results: Energy Dependence



- ✓ **C>0 → Significant dynamical fluctuations**
- ✓ **No significant dependence** on collision energies

CERES: Nucl. Phys. A **811**, 179–196
STAR: Phys. Rev. C **72**, (2005) 044902
ALICE: Eur. Phys. J. C 74 (2014) 3077

Pb-Pb Results: Multiplicity Dependence

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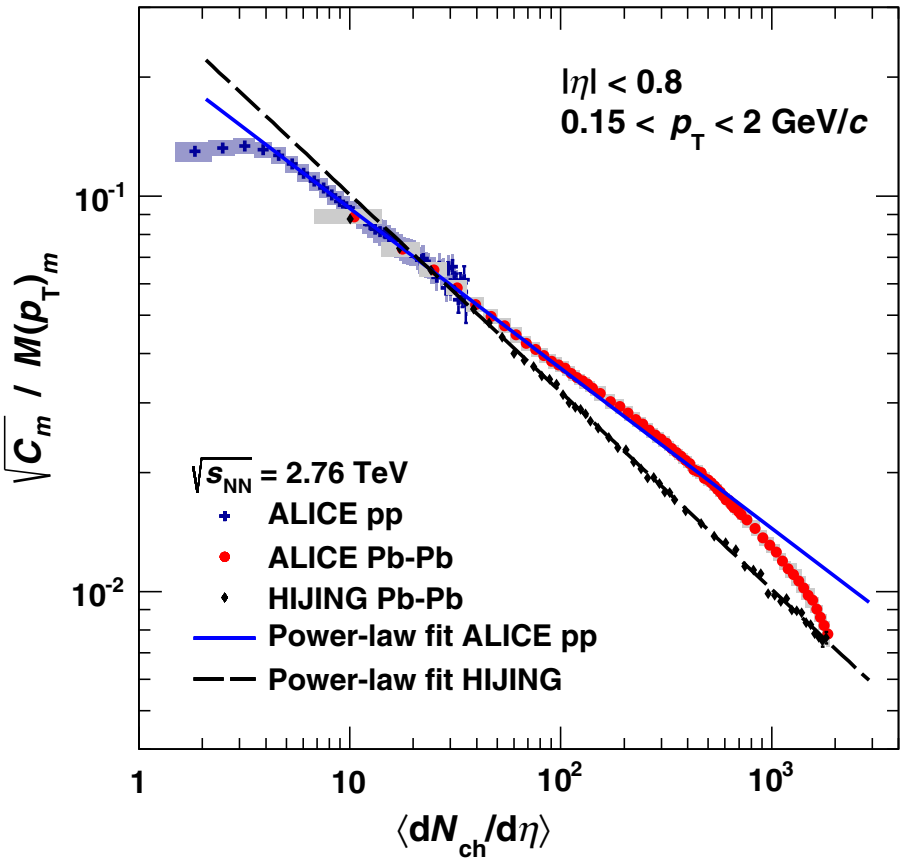

✓ **Significant decrease with multiplicity**

Pb-Pb Results: Multiplicity Dependence

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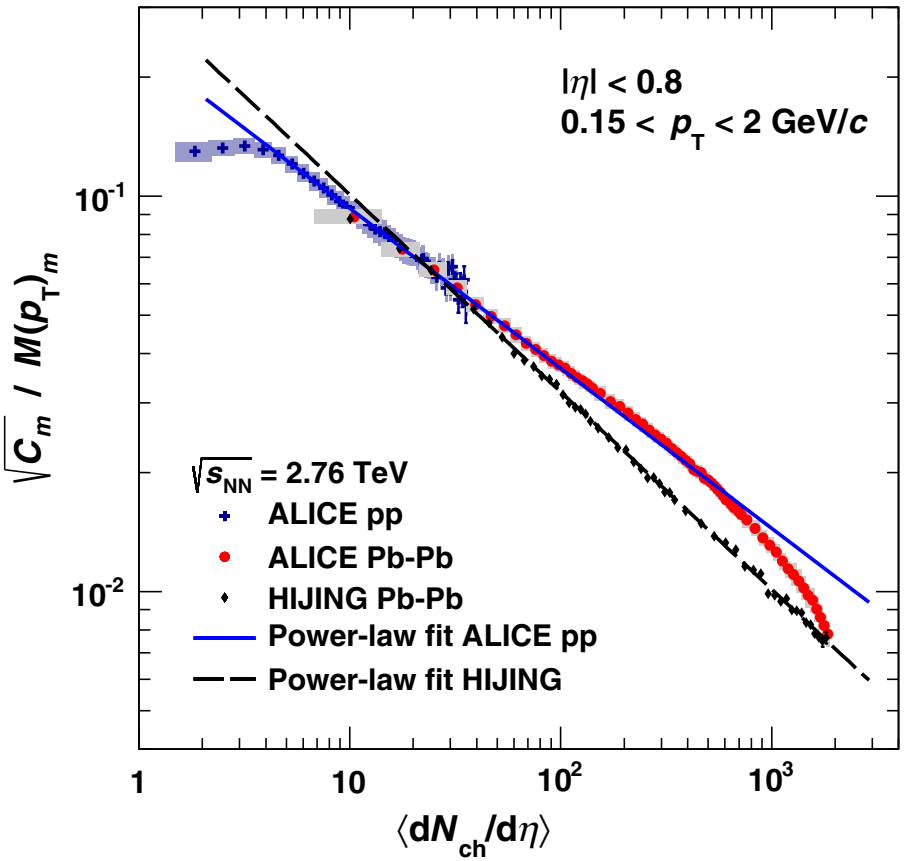
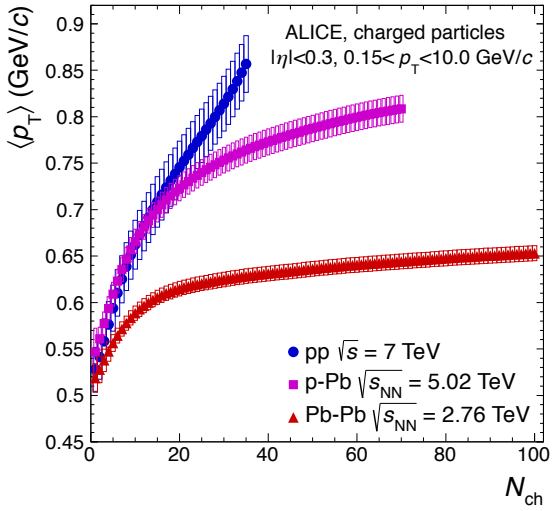


- ✓ **Significant decrease with multiplicity**
- ✓ **Peripheral Pb-Pb** (<$dN_{ch}/d\eta$><100) is in good agreement with pp
  - ➢ b=-0.405±0.002(stat.) ±0.036(syst.)



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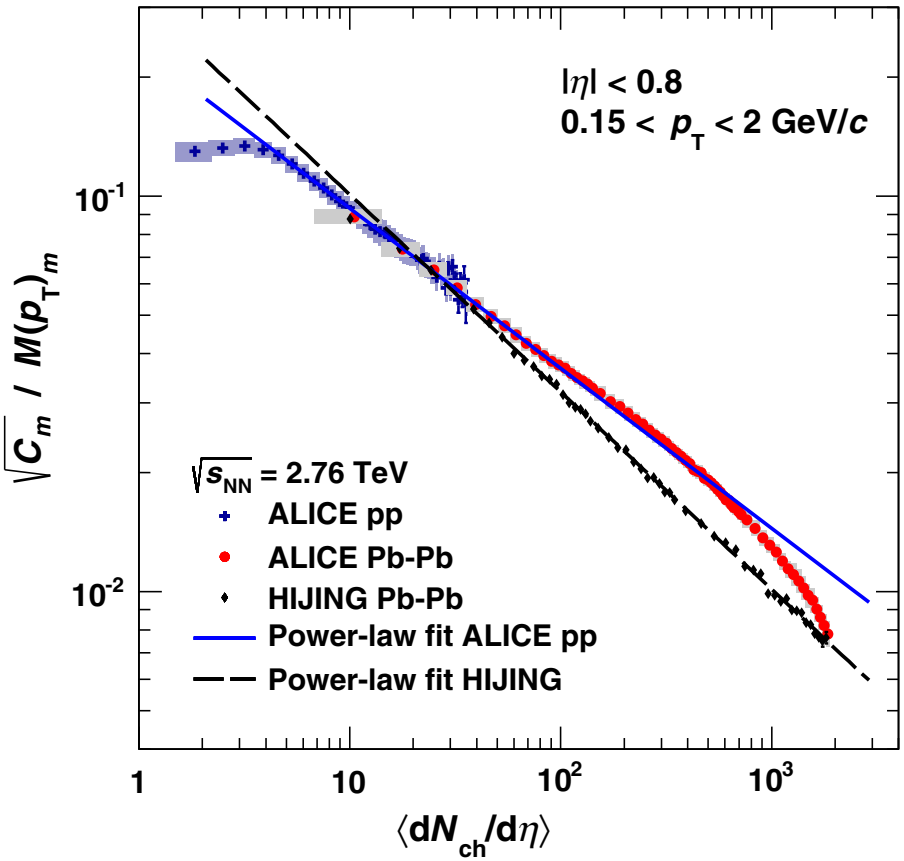

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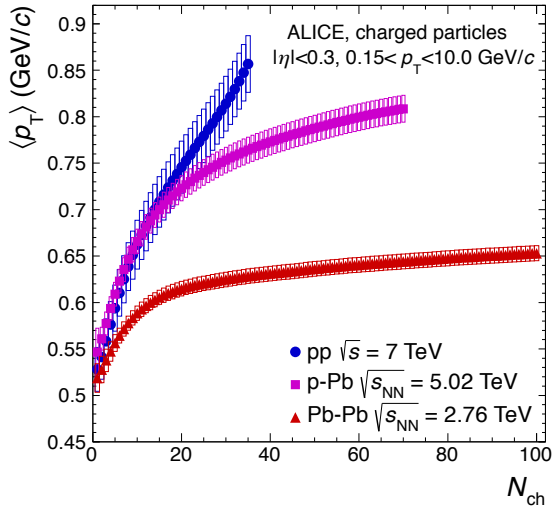

- ✓ **Deviation in central Pb-Pb**
  - ➢ $100 < \langle dN_{ch}/d\eta \rangle < 500$; enhancement
  - ➢ $\langle dN_{ch}/d\eta \rangle > 500$ (centralities <40%) **strong reduction**

Pb-Pb Results: Multiplicity Dependence

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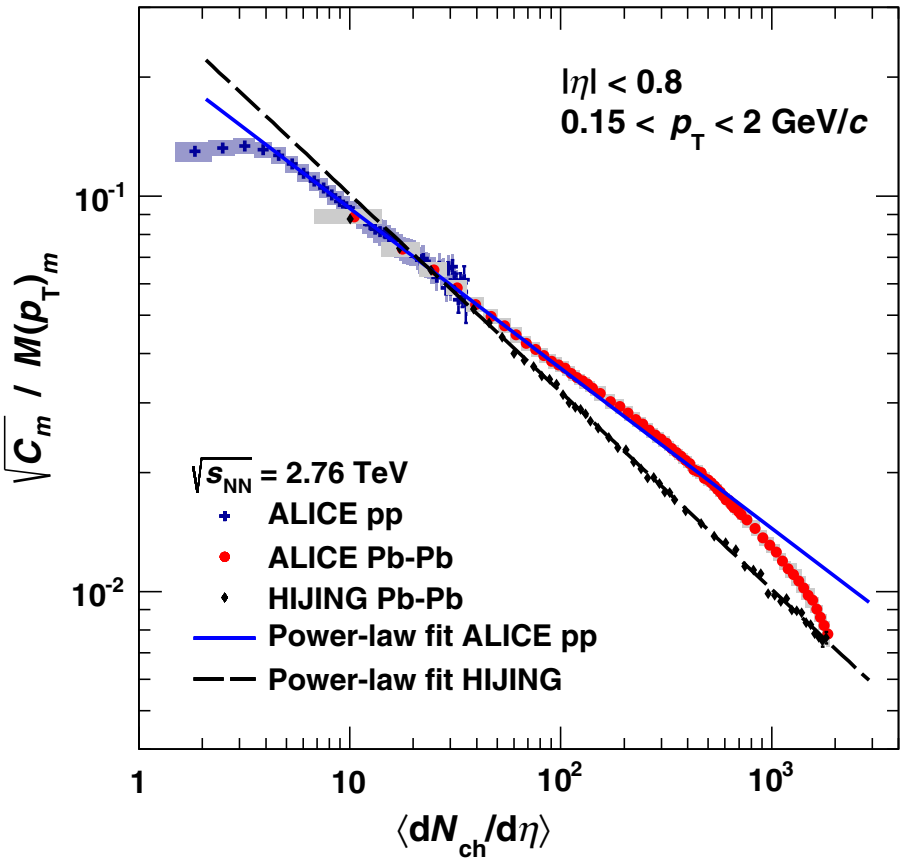

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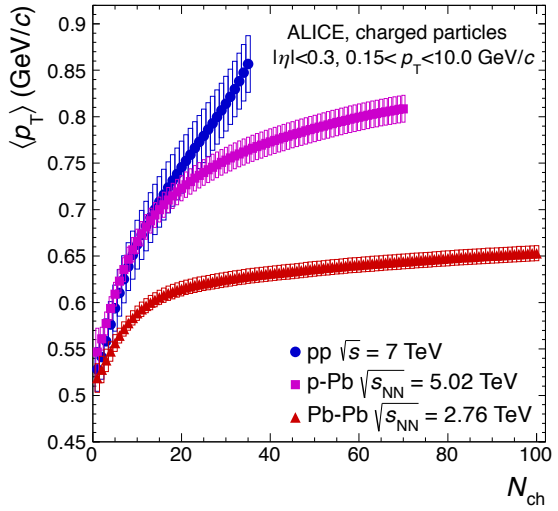
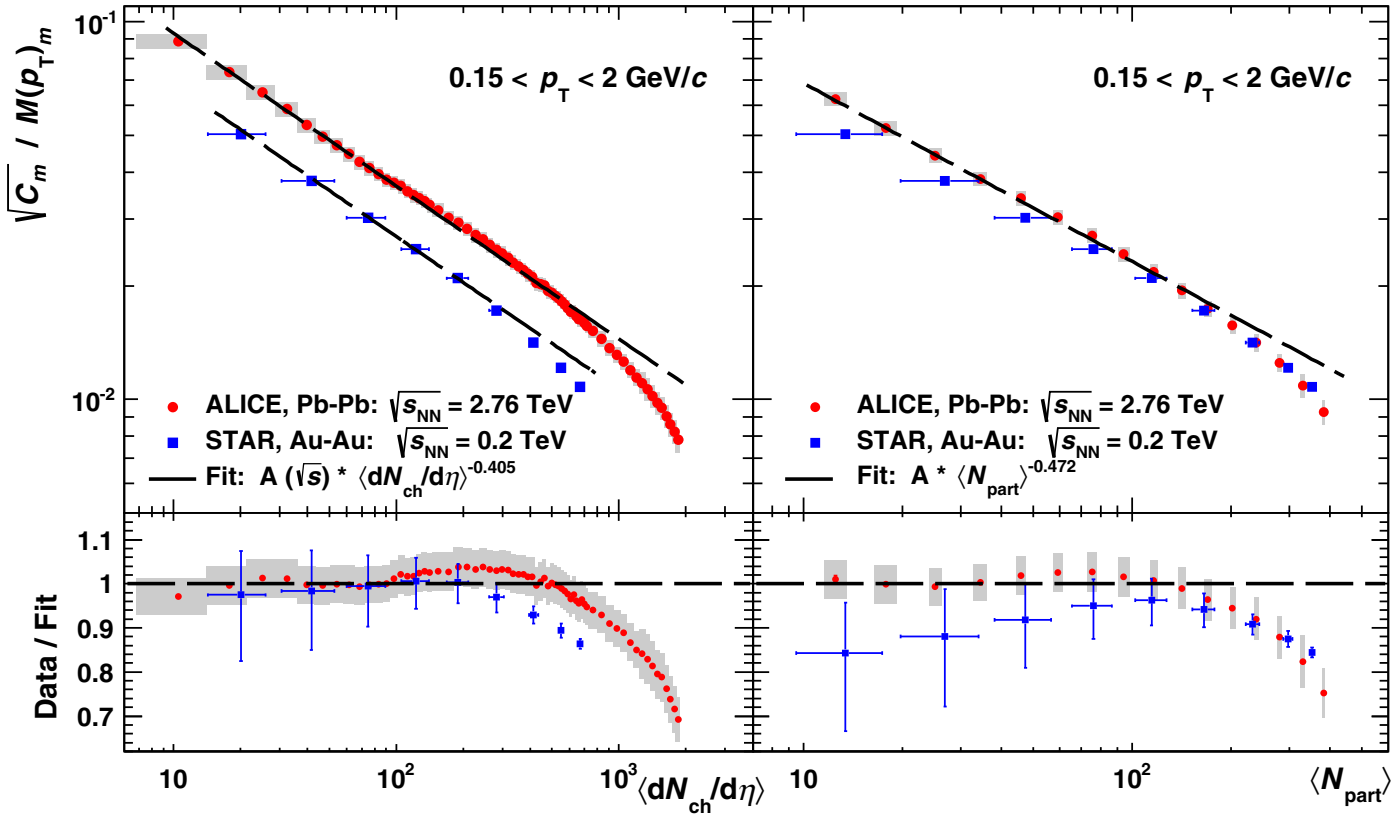


- ✓ **HIJING does not describe data**
  - ➢ b=-0.499±0.003(stat.) ±0.005(syst.)
  - ➢ superposition model of independent pp collisions.
- ✓ **Deviation in central Pb-Pb**
  - ➢ 100< <$dN_{ch}/d\eta$> <500 ; enhancement
  - ➢ <$dN_{ch}/d\eta$> >500 (centralities <40%) **strong reduction**

Pb-Pb Results: Multiplicity Dependence

Comparison to STAR results in Au–Au collisions



- ✓ **Similar scaling** with <$dN_{ch}/d\eta$> (b=-0.405)
- ✓ Similar decrease in **central collisions**
- ✓ No significant enhancement in **semi-central** events

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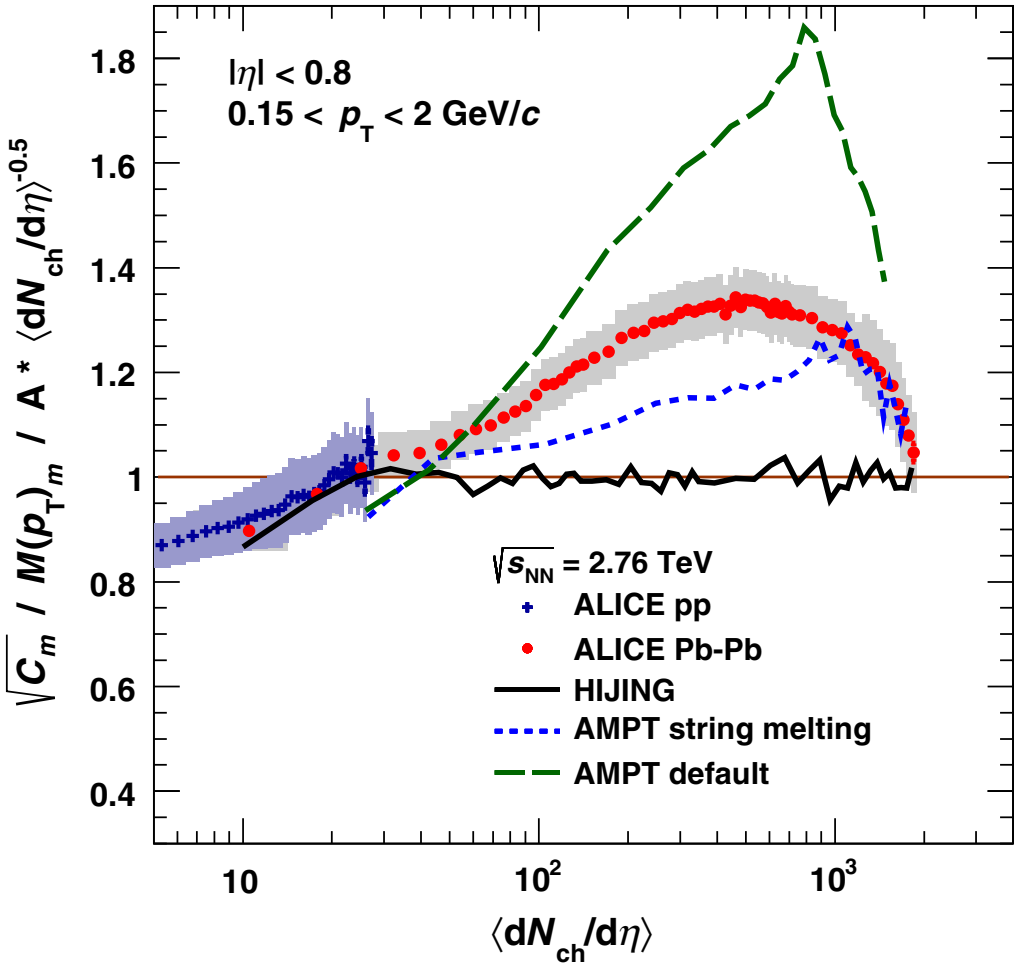
- ✓ Agreement within the large uncertainties on <N_{part}> in STAR (b=-0.472)
- ✓ Points to a relation between the observed fluctuation patterns and the **collision geometry**

Pb-Pb Results: Multiplicity Dependence

MC Generators vs Data



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Pb-Pb Results: Multiplicity Dependence

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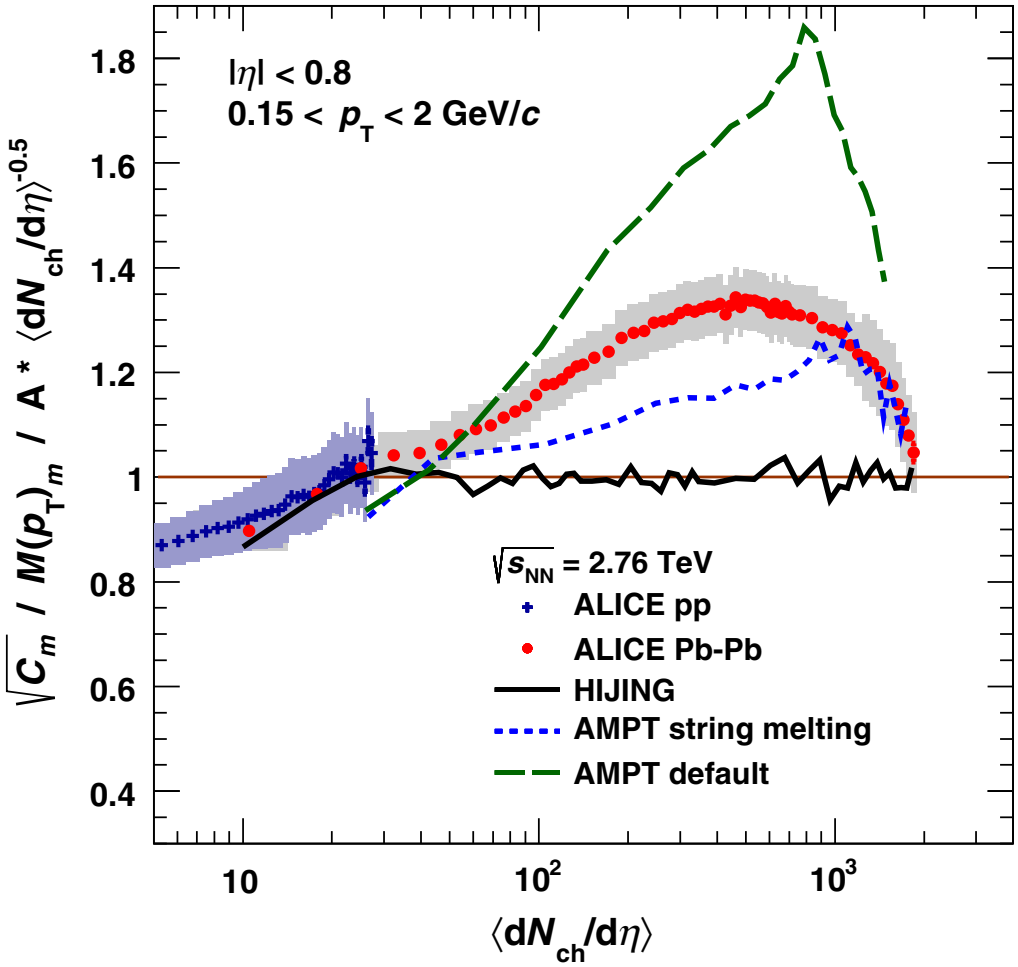

- ✓ **HIJING** :
  - ➢ **$\langle dN_{ch}/d\eta \rangle$ < 30**: agrees well with pp and Pb-Pb results.
  - ➢ **$\langle dN_{ch}/d\eta \rangle$ > 30**: **does not agree** with data **(b=-0.5)**

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Pb-Pb Results: Multiplicity Dependence

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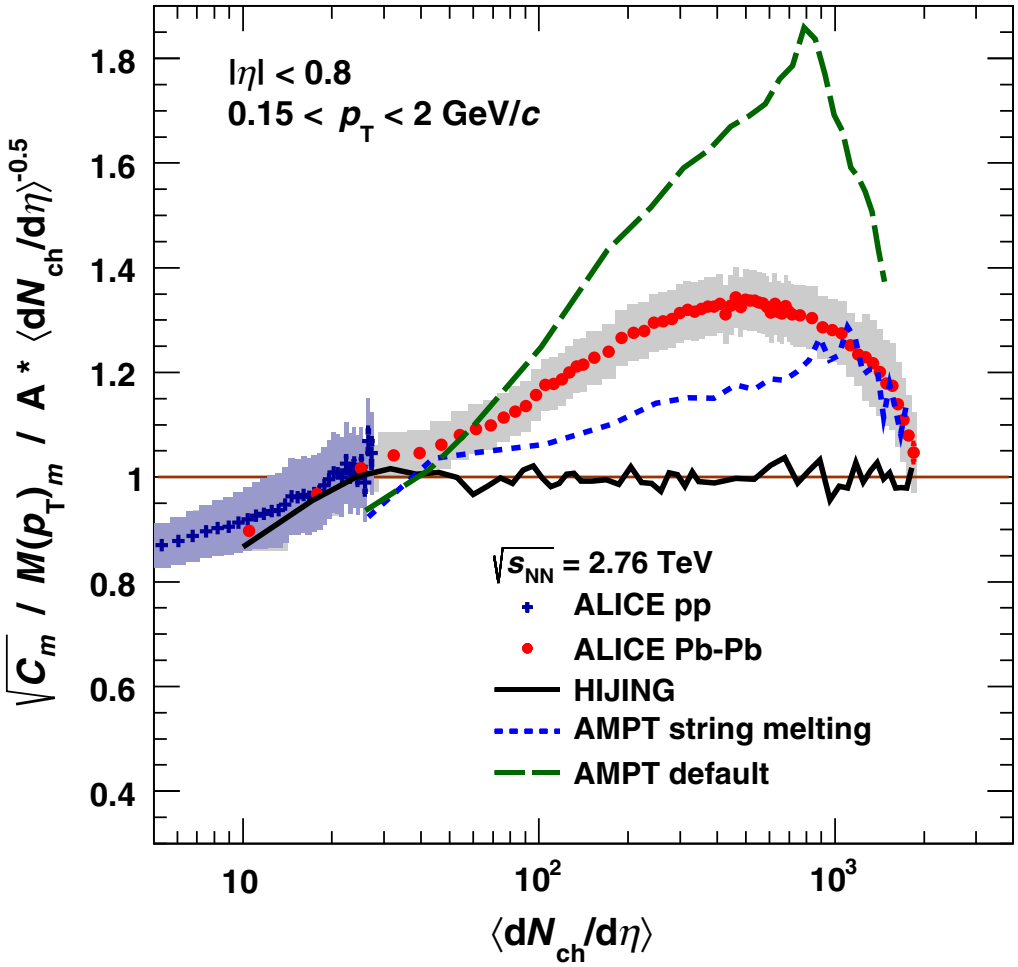

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  - ➢ **$\langle dN_{ch}/d\eta \rangle$ > 30**: **does not agree** with data **(b=-0.5)**
- ✓ **AMPT** (both versions):
  - ➢ Includes initial state density fluctuations and their effect on the development of **collectivity**
  - ➢ **Increased fluct. on top of HIJING** except for peripheral collisions
  - ➢ Pronounced **fall-off in central collisions**
  - ➢ **Qualitative agreement** with the data but **fail in terms of absolute values**

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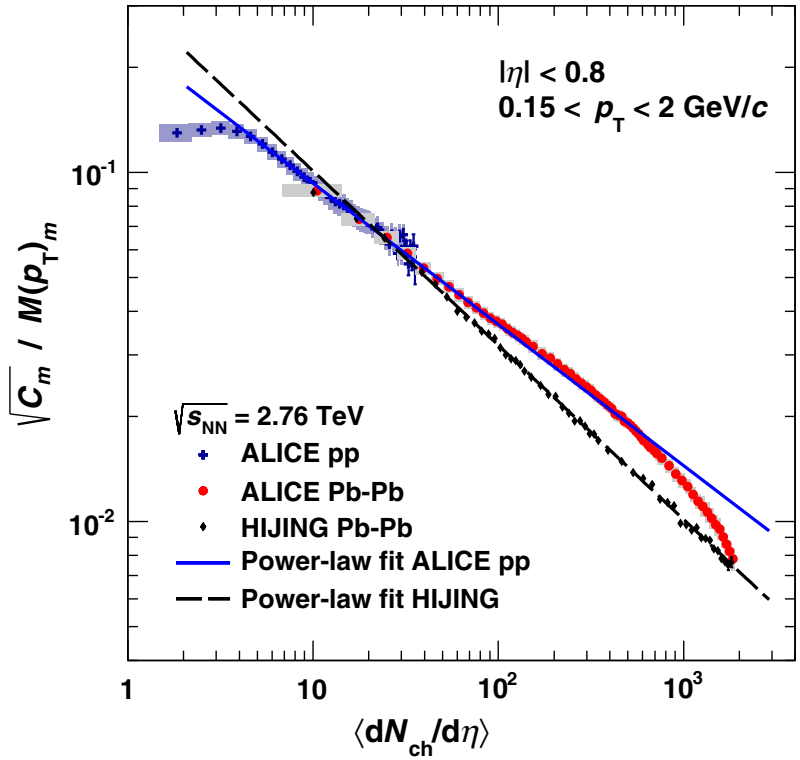
SUMMARY

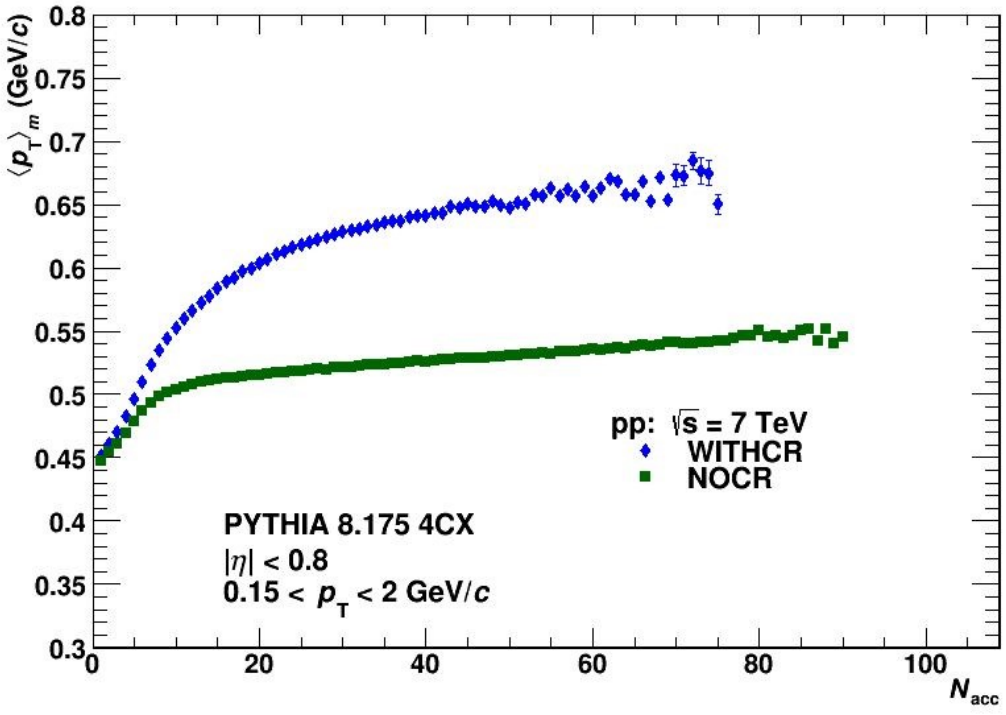
- ✓ Mean p_T fluctuations **provide valuable information on collision dynamics.**
- ✓ **Significant dynamical fluctuations** decreasing with multiplicity observed in pp and Pb–Pb collisions.
- ✓ **No significant energy dependence** found in pp and Pb–Pb collisions.
- ✓ **Peripheral Pb–Pb collisions agree with pp** extrapolation while **central Pb–Pb deviates significantly**.
- ✓ Monte Carlo generators:
  - ➢ **pp:** described rather well
  - ➢ **Pb–Pb:** not described by **HIJING**, but qualitatively by **AMPT.**

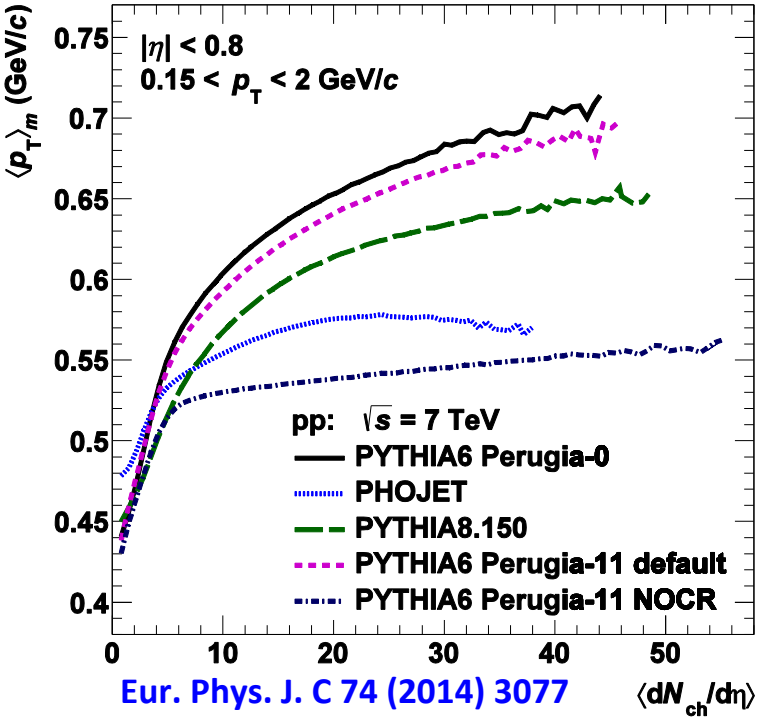


- ✧ Connection between the p_T fluctuations and azimuthal correlations, and their relation to the **initial state fluctuations**.

BACKUP

<p_T> as function of multiplicity





❖ Behavior in PYTHIA8 4CX is very similar to PYTHIA6 Perugia-11

Net Charge Fluctuations

QGP → q = ±(1/3), ±(2/3)
Hadron Gas → q = ±1

$$NCF \sim q^2 \Rightarrow NCF_{QGP} < NCF_{HG}$$

Observable

$$D = \langle N_{ch} \rangle \langle \delta R^2 \rangle \approx 4 \frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

$$R = N_+ / N_-$$
$$Q = N_+ - N_-$$

- **Distinguish phases**

$$D \approx \begin{cases} 4, & HG \\ 3, & HRG \\ 1-1.5, & QGP \end{cases}$$

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

- **Global Charge conservation**

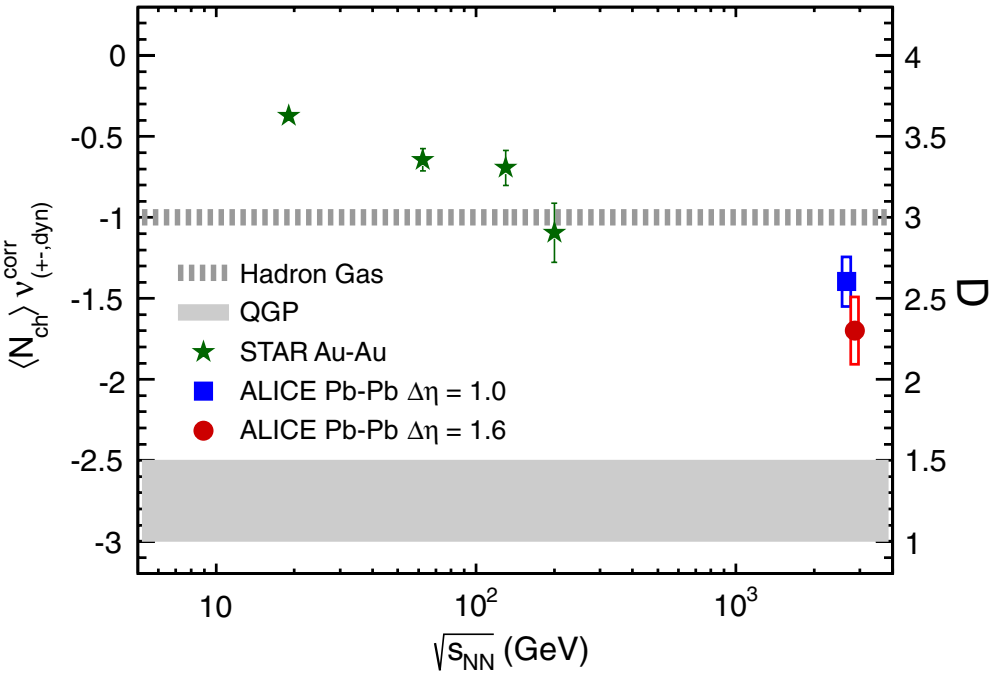
$$\nu^{corr}_{(+-,dyn)} = \nu_{(+-,dyn)} + \frac{4}{\langle N_{total} \rangle}$$

- **Independent of detector efficiency** under uniform phase space coverage.

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

Energy and multiplicity dependence

NCF: Energy Dependence

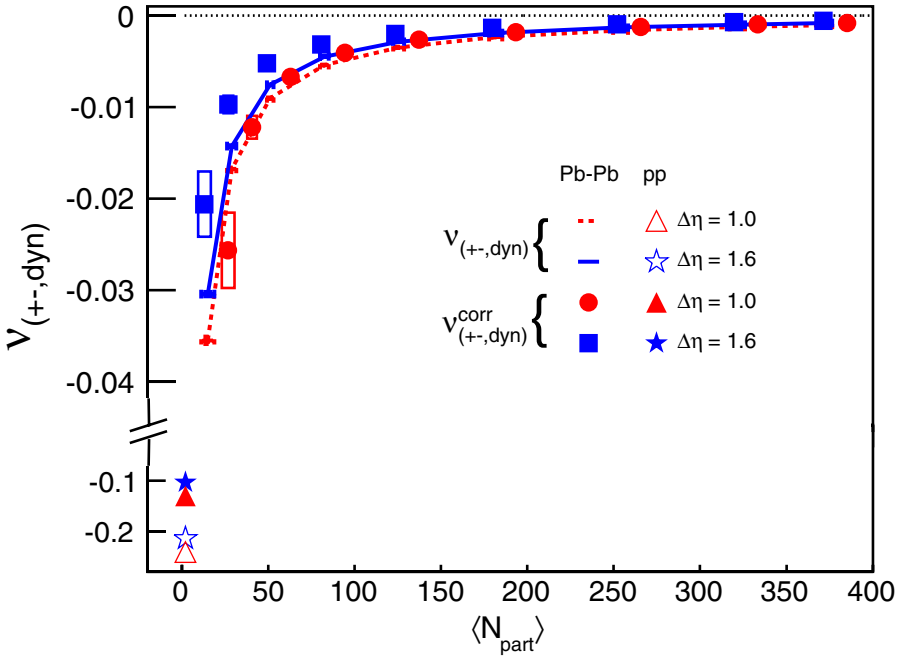


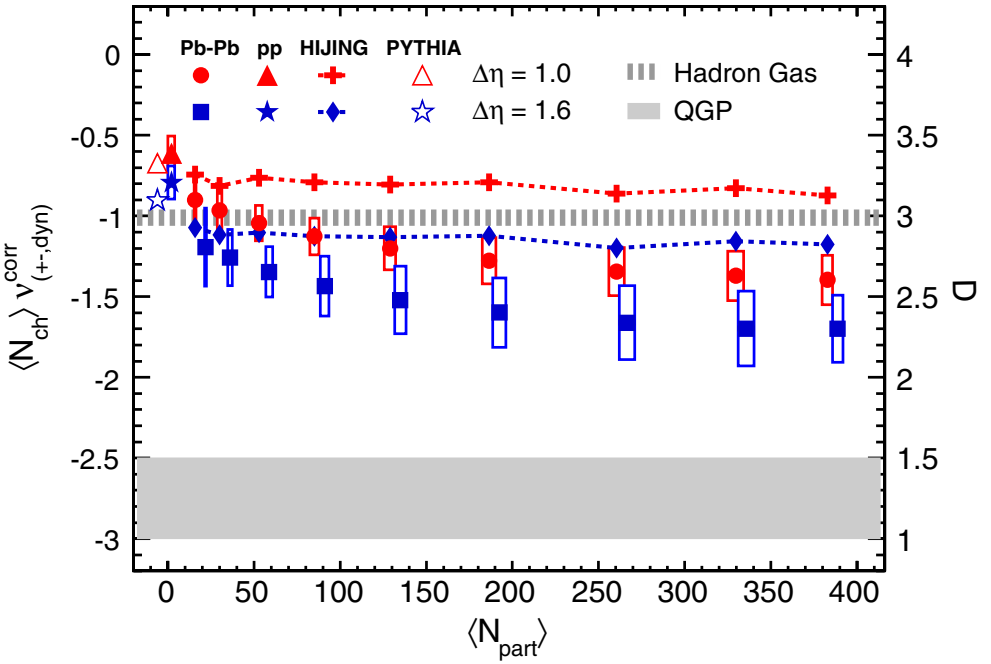
- Comparison of **most central events**
- Both results from the STAR and ALICE are presented for **Δη = 1** after the **correction for charge conservation**.

- ✓ **Decreasing trend with increasing beam energy**
- ✓ **STAR data**: close to prediction for Hadron gas
- ✓ **ALICE data**: in between HRG and QGP predictions
  - for **Δη** = 1.6 closer to QGP

STAR: Phys. Rev. C 79, 024906 (2009).
ALICE: PRL 110, 152301 (2013)

NCF: Multiplicity Dependence





- **ν_{dyn}<0** → dominance of correlation term. → Unlike sign pairs more correlated, between HRG and QGP expectation
- **Pseudorapidity dependence** → diffusion in rapidity during system evolution (hadronization to kinetic freeze-out) can dilute measured fluctuations ($\Delta\eta=1$ → $|\eta|<0.5$)
- **HIJING:** little or no centrality dependence (close to HRG)

BALANCE FUNCTIONS

Charge Correlations

$$B_{+-}(\Delta\eta) = \frac{1}{2}\left(C_{+-}(\Delta\eta) + C_{-+}(\Delta\eta) - C_{--}(\Delta\eta) - C_{++}(\Delta\eta)\right)$$

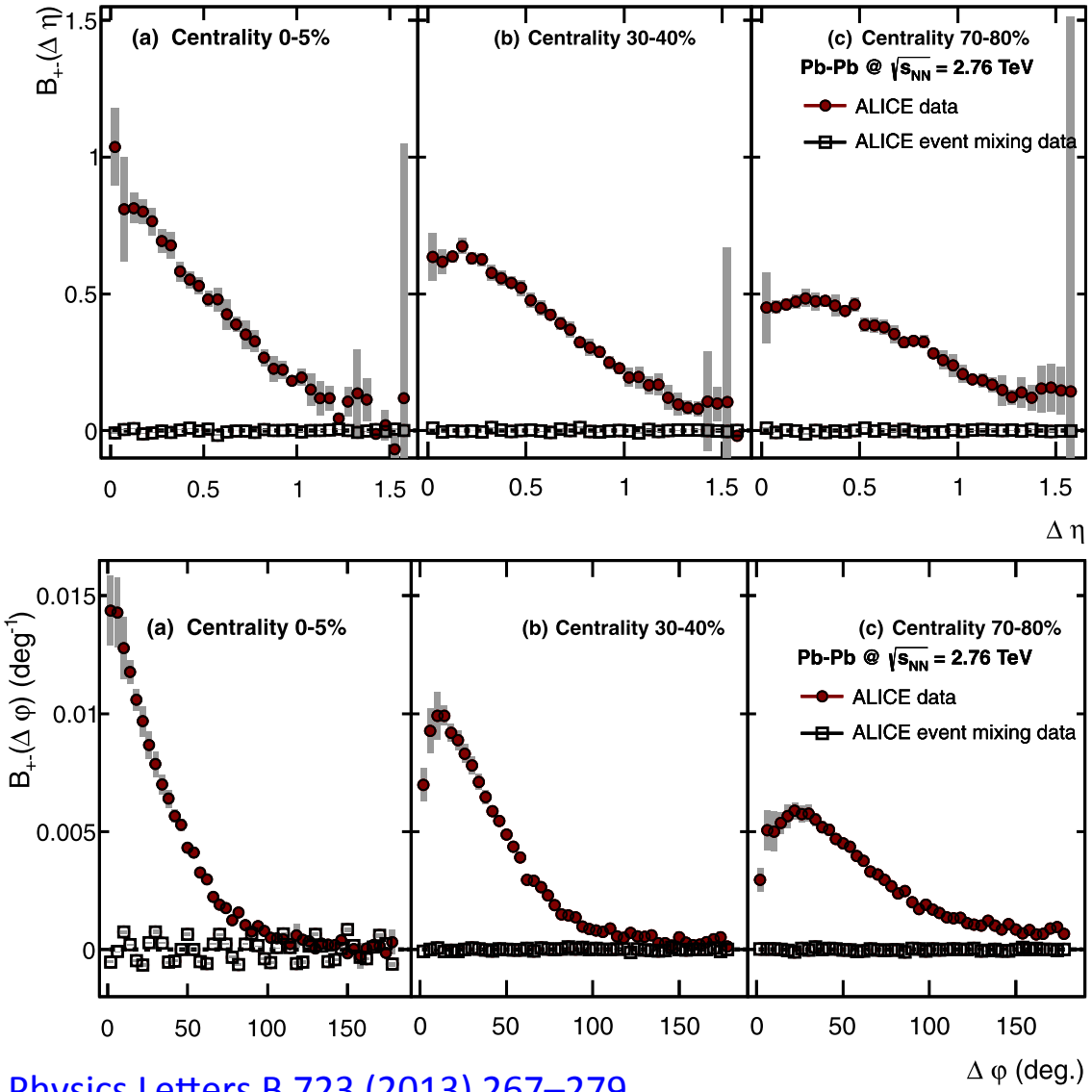
$$C_{+-} = \left(\frac{N_{+-}}{N_{+}}\right) / f_{+-}$$

Particle pair density normalized to the number of trigger particles

Detector acceptance and efficiency

- The width of the balance function distribution can be used to quantify how tightly the balancing charges are correlated
- **Narrower distr.** → Creation of balancing charges **close to the end of the evolution**.
  Larger width → Creation of balancing charges **at the first stages of the evolution**

Pb-Pb Results: Centrality Dependence



- ✓ Balance function gets **narrower for more central collisions** for both Δη and Δφ.
  → **Reduction of fluctuations**
- ✓ Balance functions for **mixed events fluctuate around zero** as expected for a totally uncorrelated sample where the **charge is not conserved**.

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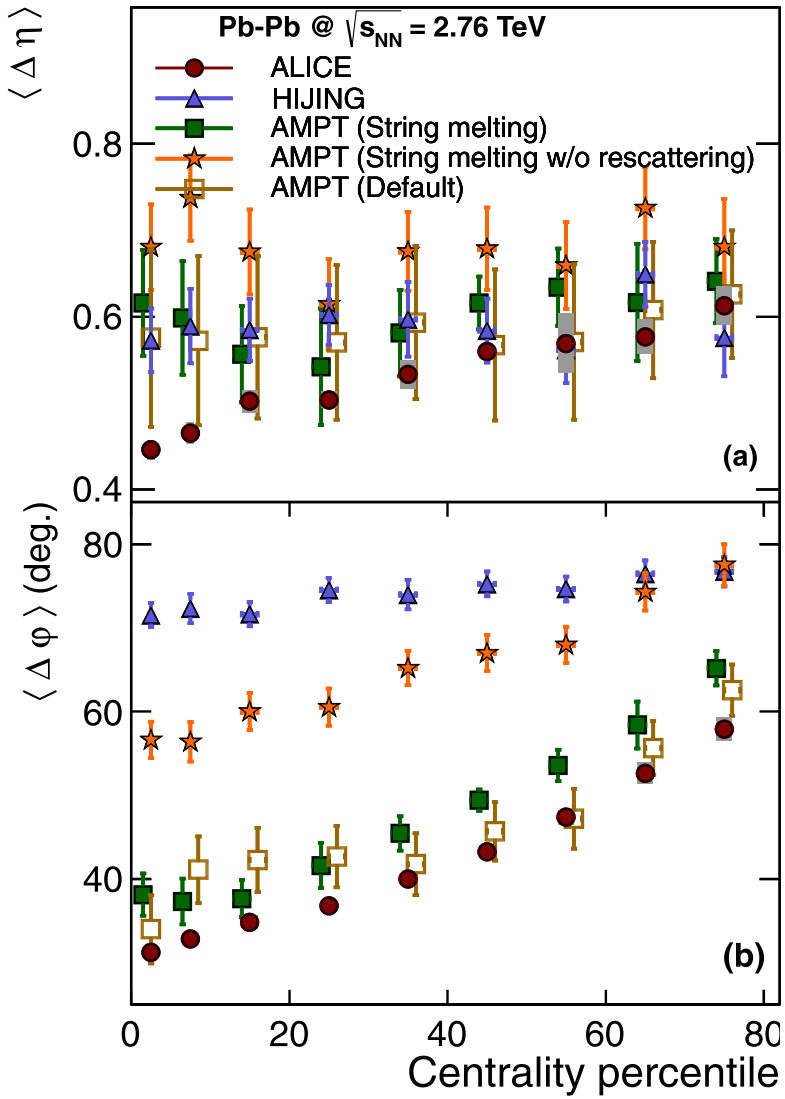
Pb-Pb Results: Model Comparison



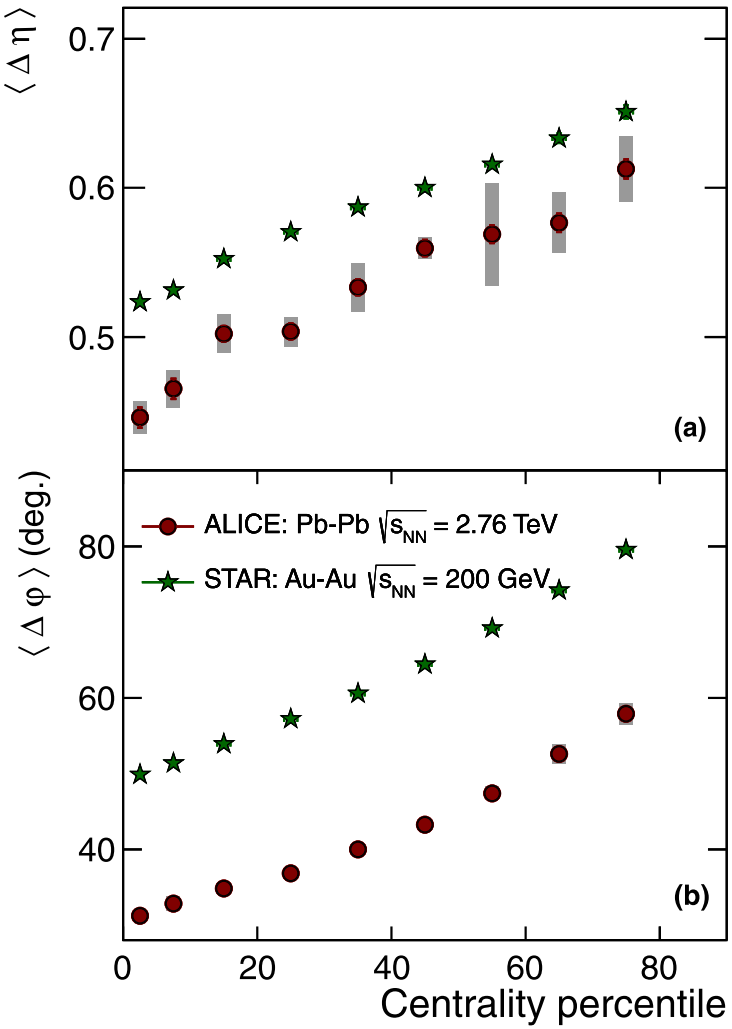
✓ **HIJING:**

- **Does not reproduce** the observed centrality dependence of the width in either projection
- **Not just a simple superposition** of single pp collisions

✓ **AMPT:**

- Agrees qualitatively with the centrality dependence of Δφ but fails to reproduce the dependence of Δη.

Pb-Pb Results: Energy Dependence



- ✓ Similar centrality dependence
- ✓ Balance function width is significantly narrower at the LHC
  - ➢ larger radial flow at LHC with respect to RHIC

ALICE: Physics Letters B 723 (2013) 267–279
STAR: Phys. Rev. C 82 (2010) 024905.