Higher-order event-by-event mean-p_T fluctuations in pp and A–A collisions with ALICE

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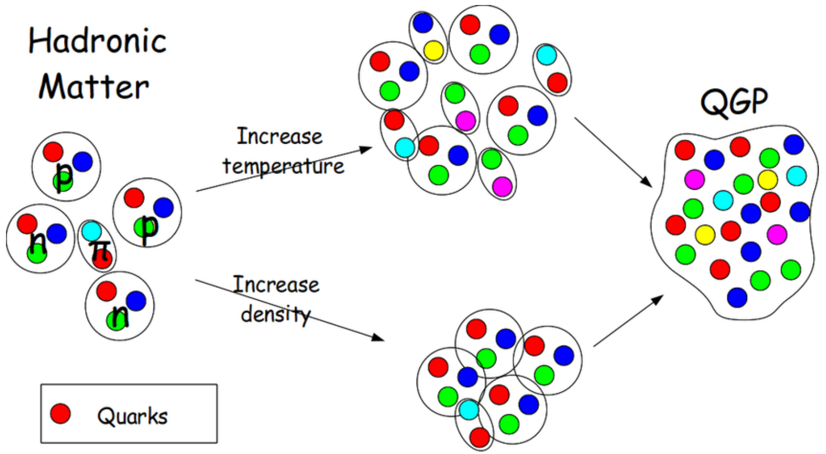
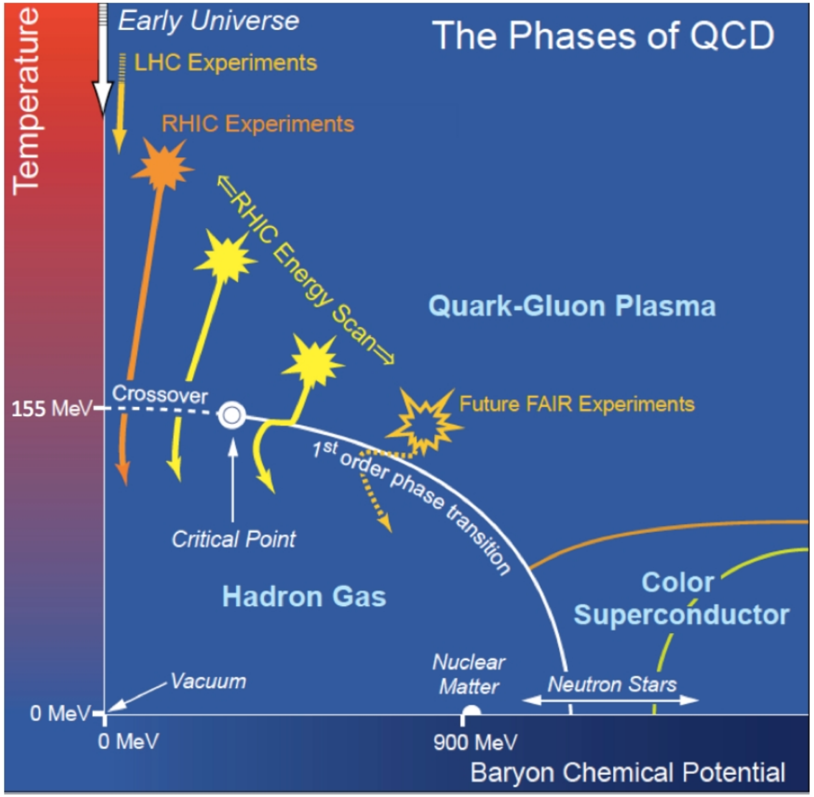
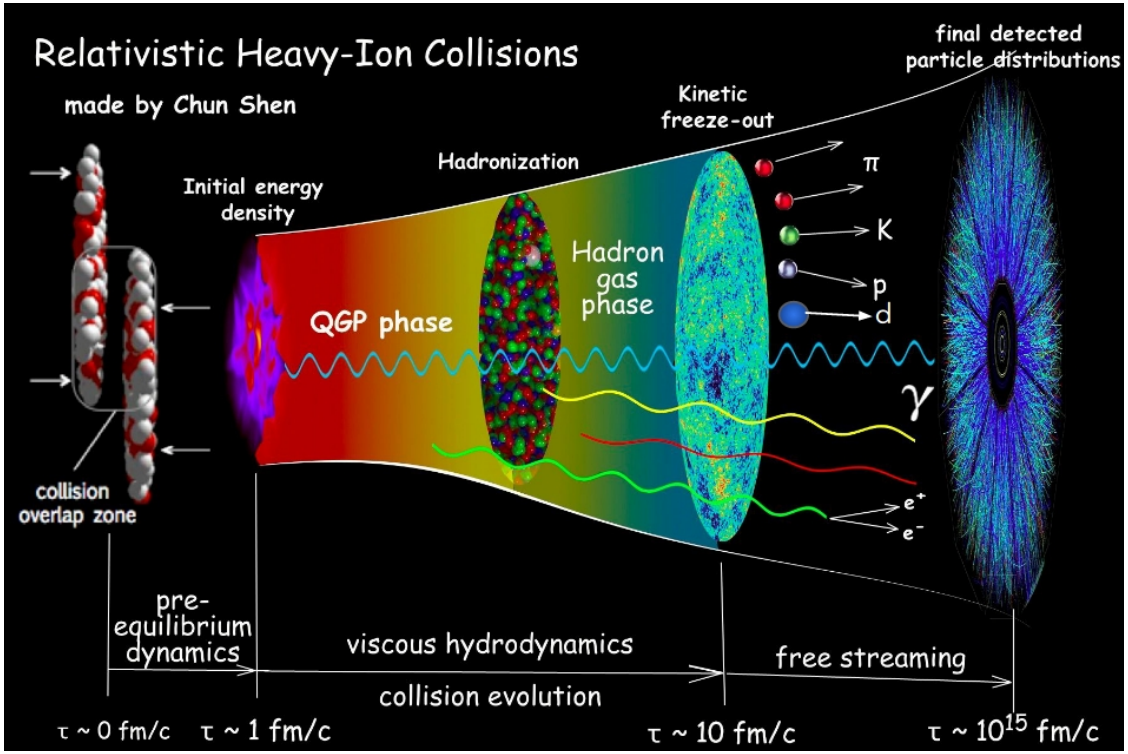
Introduction





- Our goal is to study the properties of strongly interacting matter
- Quark–gluon plasma: deconfined phase of quarks and gluons
- Phase transition at LHC (low baryonic density region)
  – smooth crossover: similar to early universe
  (~few μs after the Big Bang)

Time evolution of heavy-ion collision



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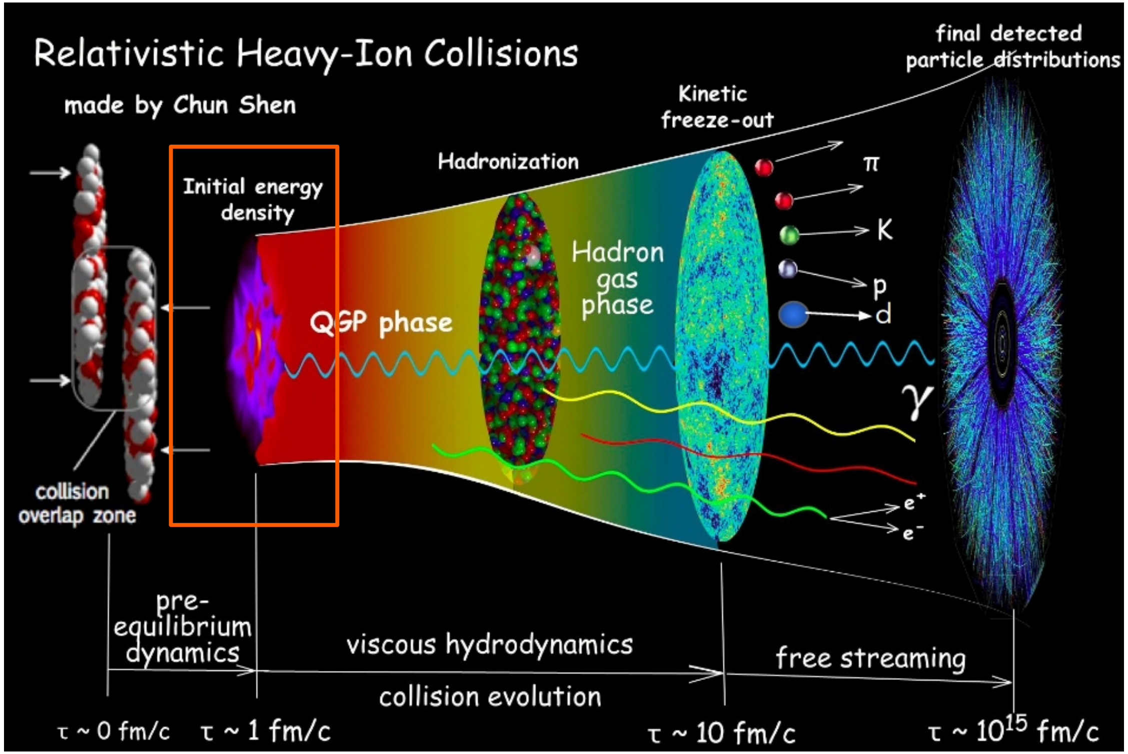

Participating nucleons collide, generate entropy and produce a nuclear matter with non uniform energy density

- Probe the initial energy fluctuations

Event-by-event fluctuation

Event-by-event analysis is more sensitive to changes of state in the system than inclusive analysis

- Observable is measured in each event, fluctuation of the observable around their mean value is studied over the ensemble of events

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$$p_{\mathrm{T}} = \sqrt{p_x^2 + p_y^2}$$

Event-by-event mean-p_{T}:

$$\boxed{\langle p_{\mathrm{T}} \rangle = \frac{1}{N} \sum_{i=1}^{N} p_{\mathrm{T},i}}$$

N = total number of tracks in an event

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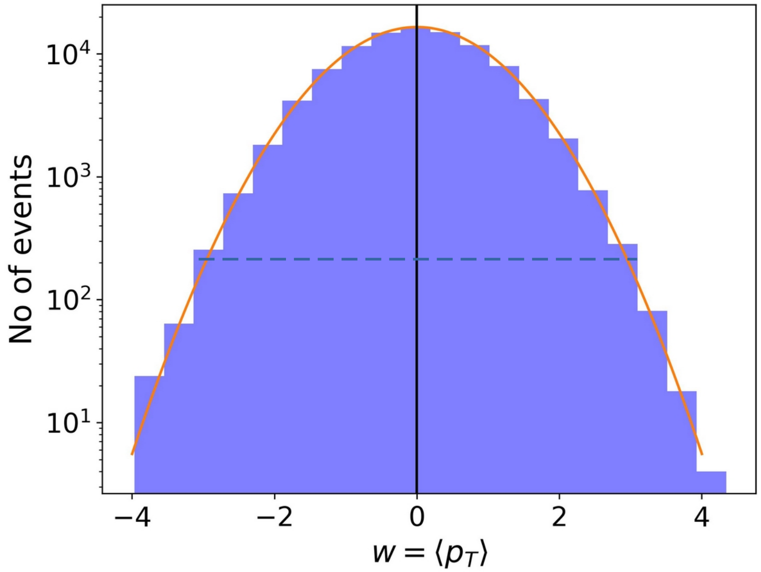
mean = $\langle w \rangle$



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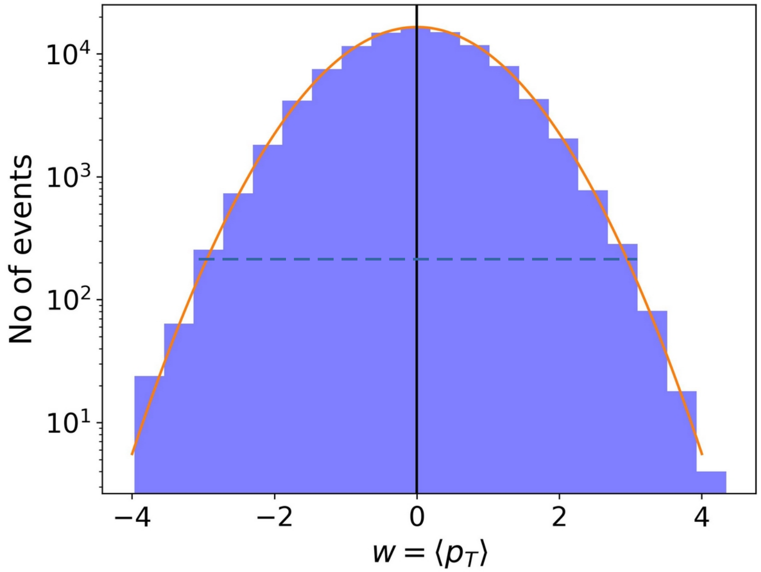


mean = ⟨w⟩

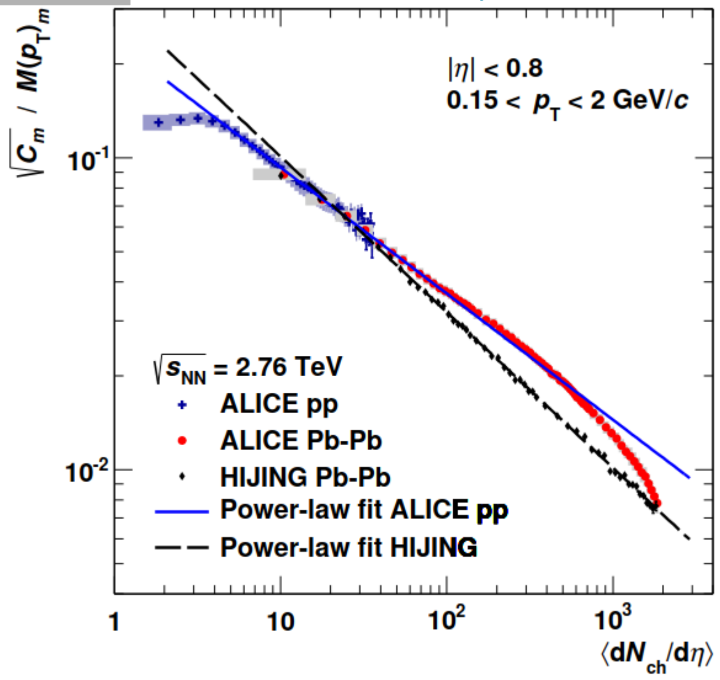
Fluctuation ⟶ variance = ⟨(δw)²⟩ ; δw = w-⟨w⟩

Measurement of $\langle p_T \rangle$ fluctuations

Fluctuation of mean-p_T ($\langle p_T \rangle$) distribution is measured in the experiments upto second order only

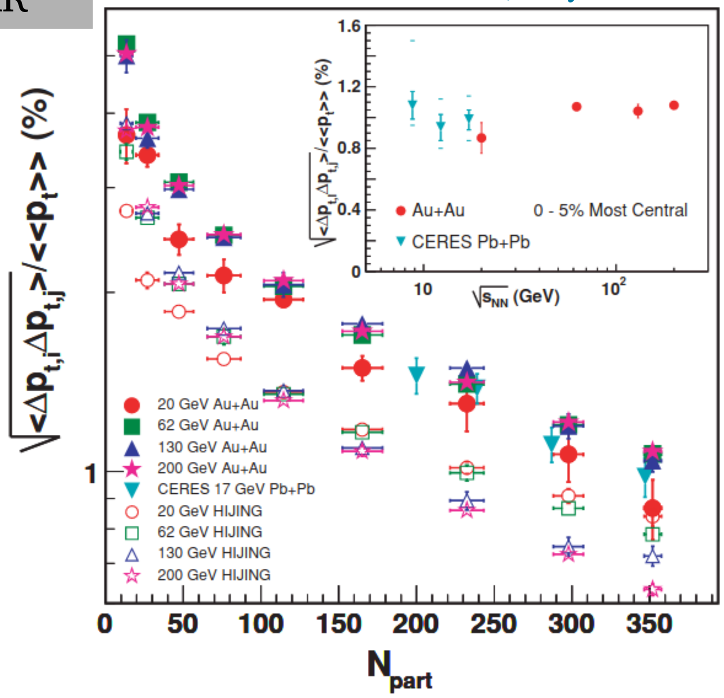
ALICE

ALICE, Eur. Phys. J. C (2014) 74:3077



STAR

STAR, Phys. Rev. C 72, 044902



$$C_m \sim \langle \Delta p_{\mathrm{t,i}} \Delta p_{\mathrm{t,j}} \rangle \longrightarrow \text{Fluctuation of } \langle p_T \rangle$$

$$M(p_{\mathrm{T}})_m \sim \langle \langle p_t \rangle \rangle \longrightarrow \text{Mean of } \langle p_T \rangle$$

Higher order fluctuation

- Moments and cumulants are mathematical measures of "shape" of a distribution, which probes fluctuations of an observable

- Higher order fluctuations of a distribution are accessed by higher order moments

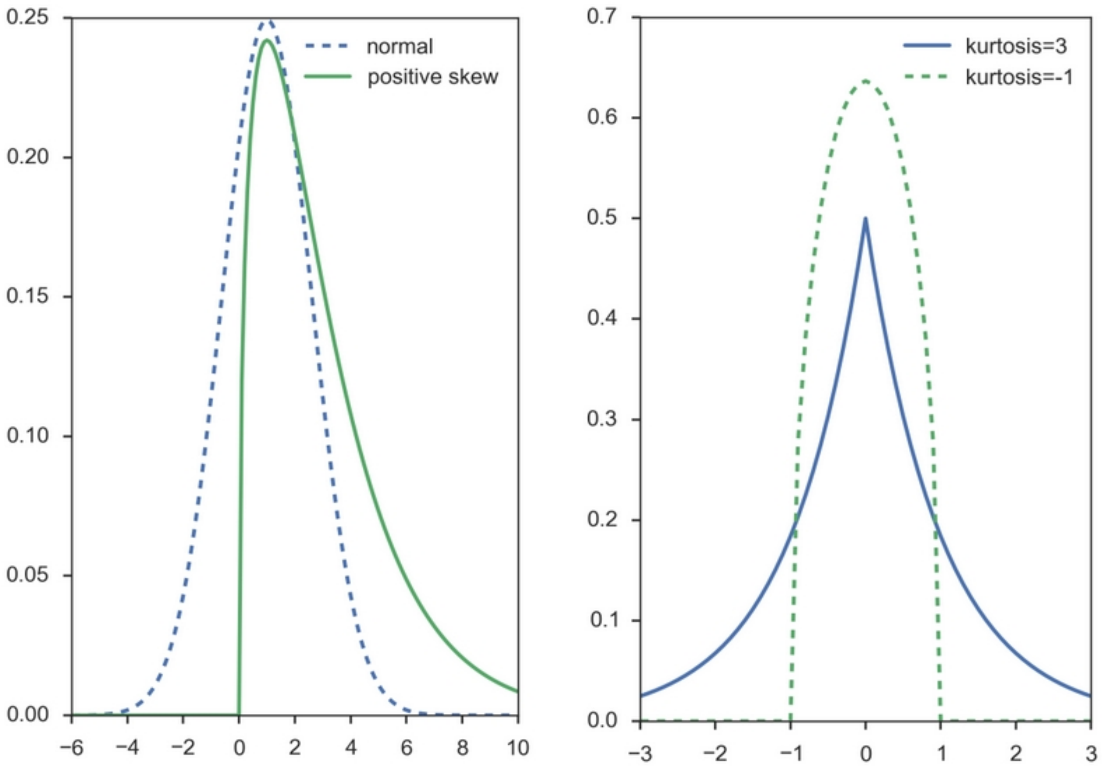
$$\mu_n = \langle(\delta w)^n\rangle \; ; \; \delta w = w - \langle w \rangle$$

where, n is the order of moment

- 3rd moment μ_3 probes skewness
- 4th moment μ_4 relates to kurtosis

Skewness $\longrightarrow$ asymmetry

Kurtosis $\longrightarrow$ sharpness

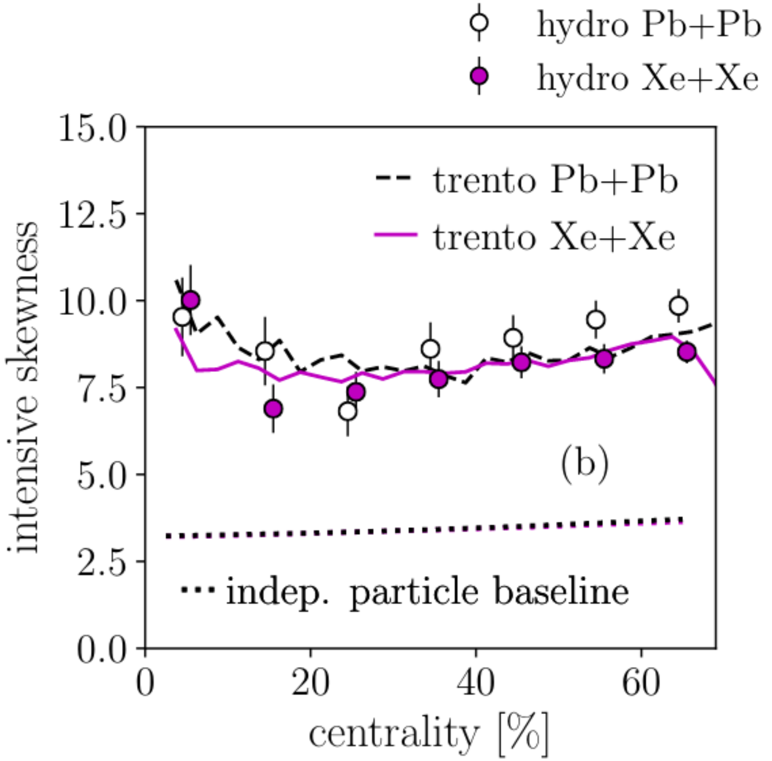


Motivation

Skewness of the $\langle p_T \rangle$ fluctuations can probe hydrodynamic behaviour in heavy-ion collisions

G. Giacalone et al., Phys. Rev. C 103, 024910 (2021)

- Hydrodynamical calculations predict positive skewness
- Attributes its origin to the fluctuations of initial energy of the fluid when hydrodynamic expansion starts
  - sensitive to the early thermodynamics of the QGP
  - direct way to observe initial-state fluctuations
- Measurements will strongly constrain the modeling of the initial stages in hydrodynamic studies



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Intensive skewness

$$\boxed{\Gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_i \Delta p_j \Delta p_k \rangle \langle\langle p_T \rangle\rangle}{\langle \Delta p_i \Delta p_j \rangle^2}}$$

G. Giacalone et al., Phys. Rev. C 103, 024910 (2021)

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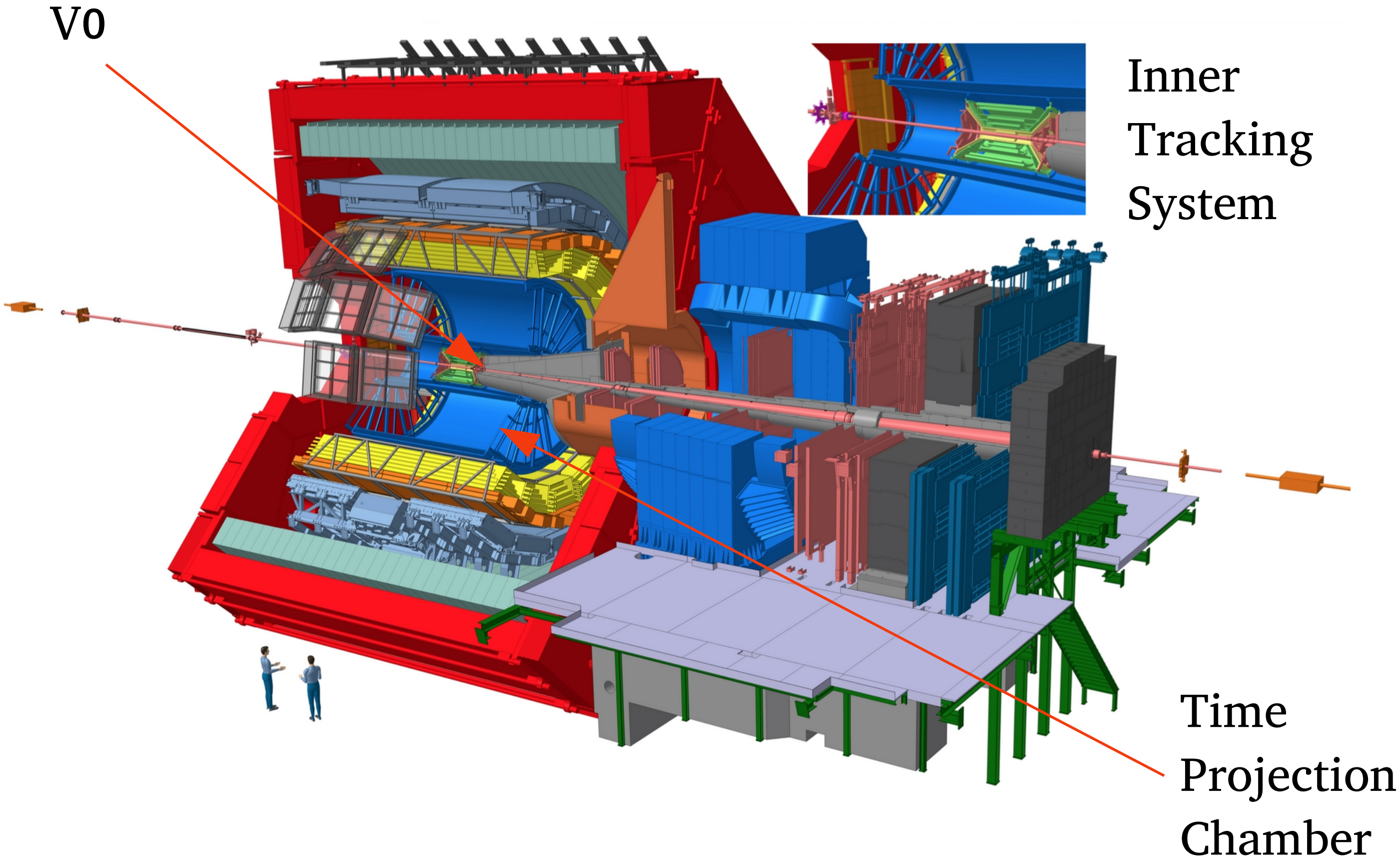
Kurtosis

- Ratio quantities are robust against detection inefficiencies

Experimental setup - ALICE detector



Inner Tracking System (ITS)

- tracking, vertexing

Time Projection Chamber (TPC)

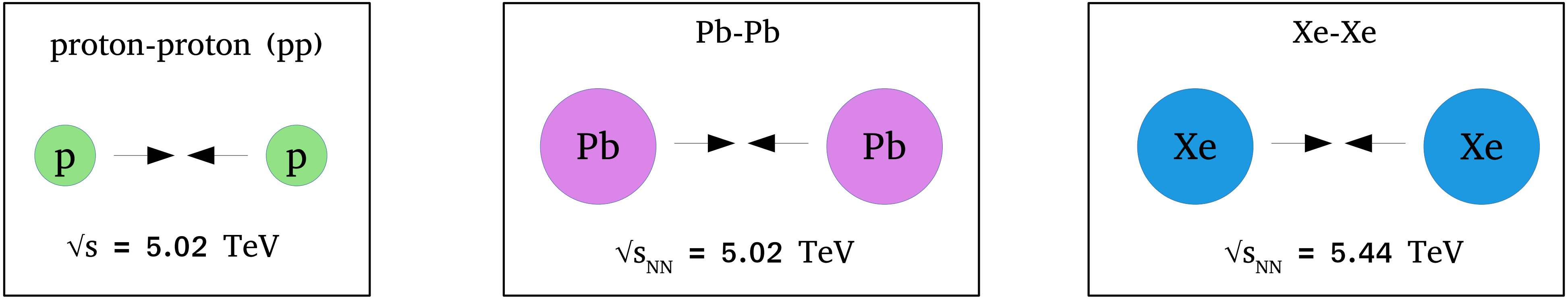
- tracking and particle identification via dE/dx in the TPC gas mixture

V0 Scintillators

- trigger and centrality estimation

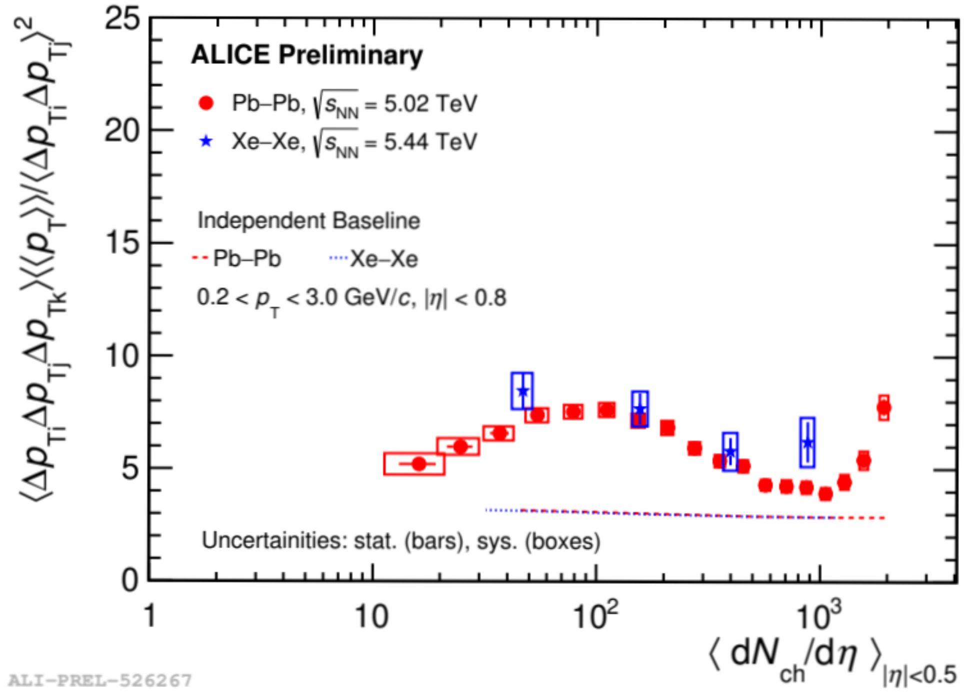
Analysis details

Higher order fluctuations of $\langle p_T \rangle$ distribution are measured in different collision systems at LHC energies



- Charged particle tracks with $0.2 < p_T$ [GeV/c] < 3.0 and pseudorapidity $|\eta| < 0.8$ are selected in each event
- Observables are calculated in different centrality classes estimated by V0 detector

Skewness of $\langle p_T \rangle$



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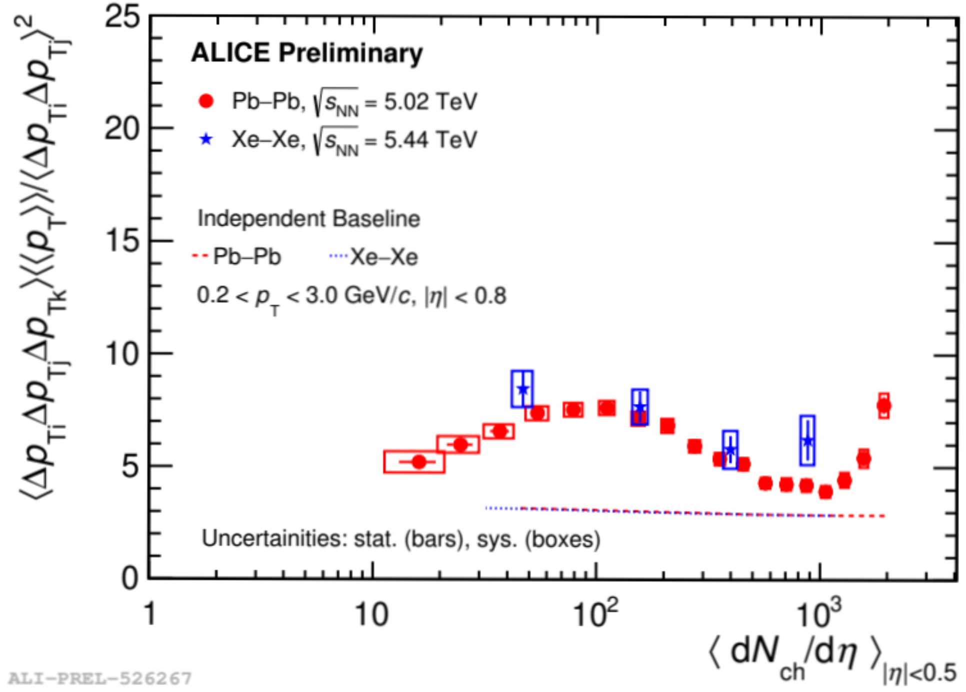

Baseline is provided by the distribution of $\langle p_T \rangle$ for mixed events

- intensive skewness for mixed events is given by

$$\Gamma_{\text{independent}} = \frac{\langle (p_T - \langle p_T \rangle)^3 \rangle \langle p_T \rangle}{\langle (p_T - \langle p_T \rangle^2) \rangle^2}$$

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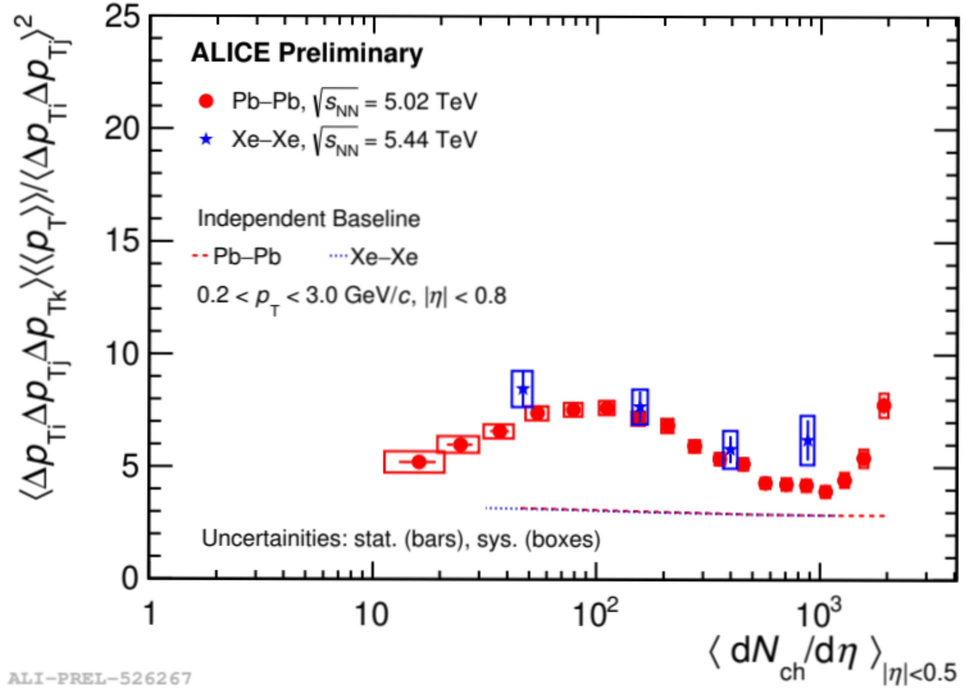

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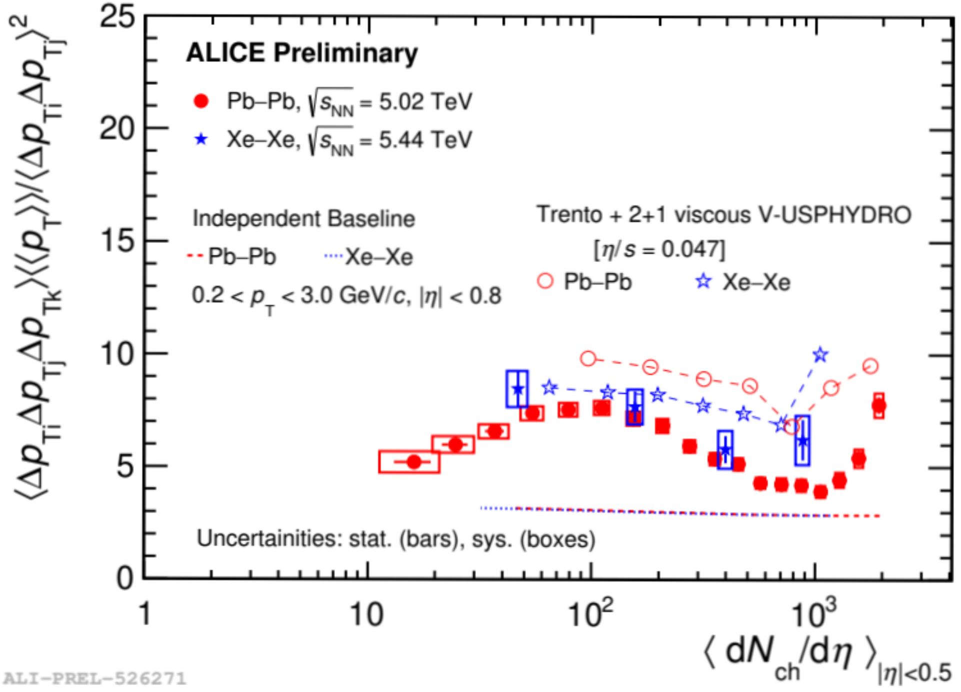

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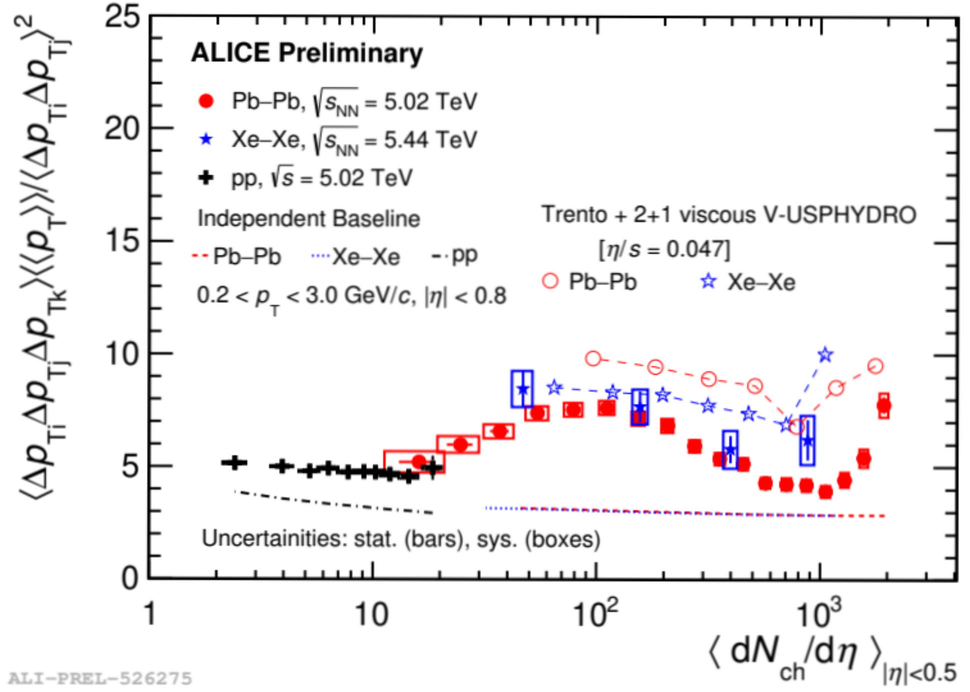

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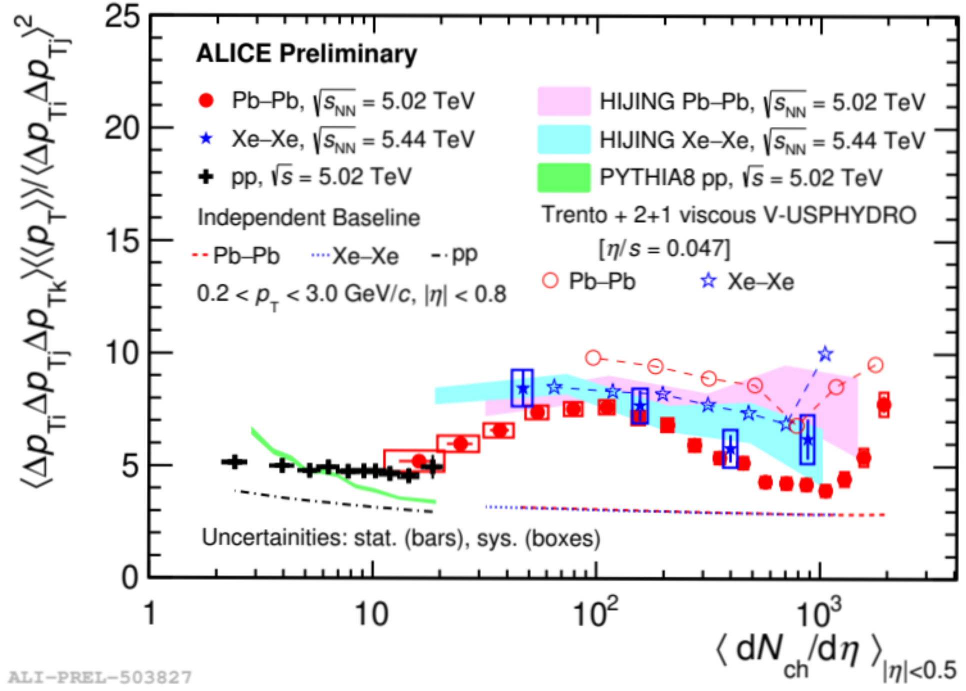

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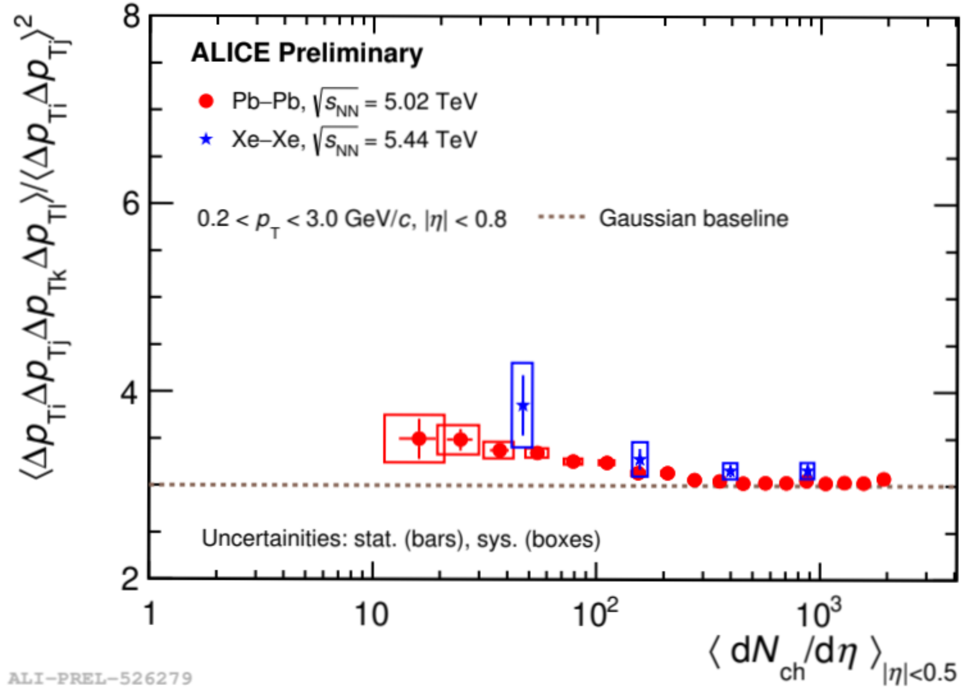
- Hydrodynamic model results overestimate data
- Results in pp collisions show an excess of the intensive skewness over the corresponding baseline
- Due to large uncertainities in HIJING results for A-A systems, no firm conclusion could be drawn and PYTHIA for pp fails to describe the behaviour of data

Kurtosis of $\langle p_T \rangle$



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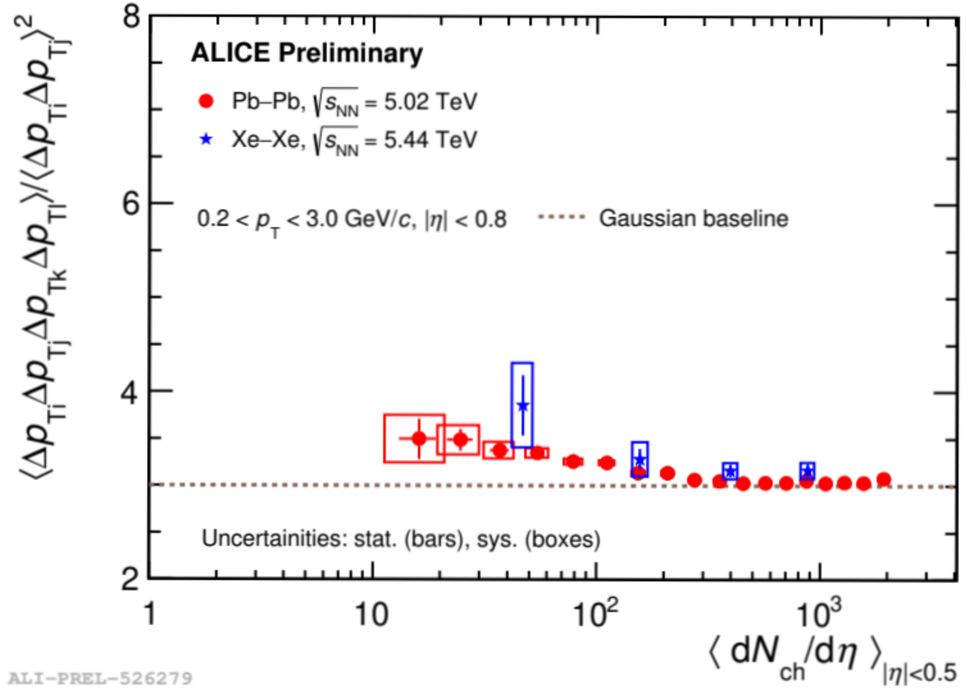

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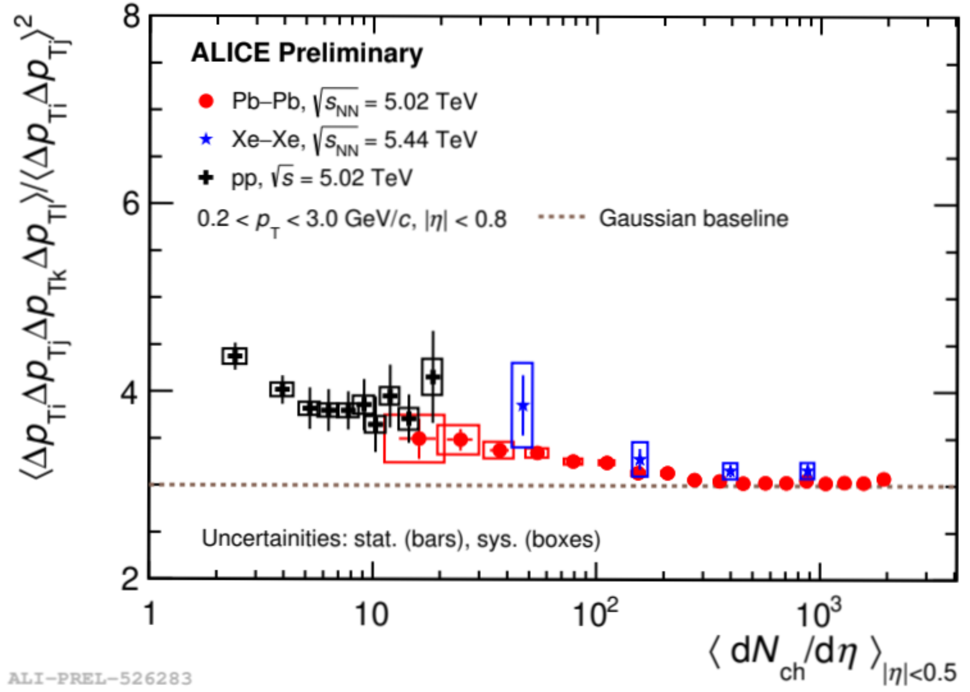

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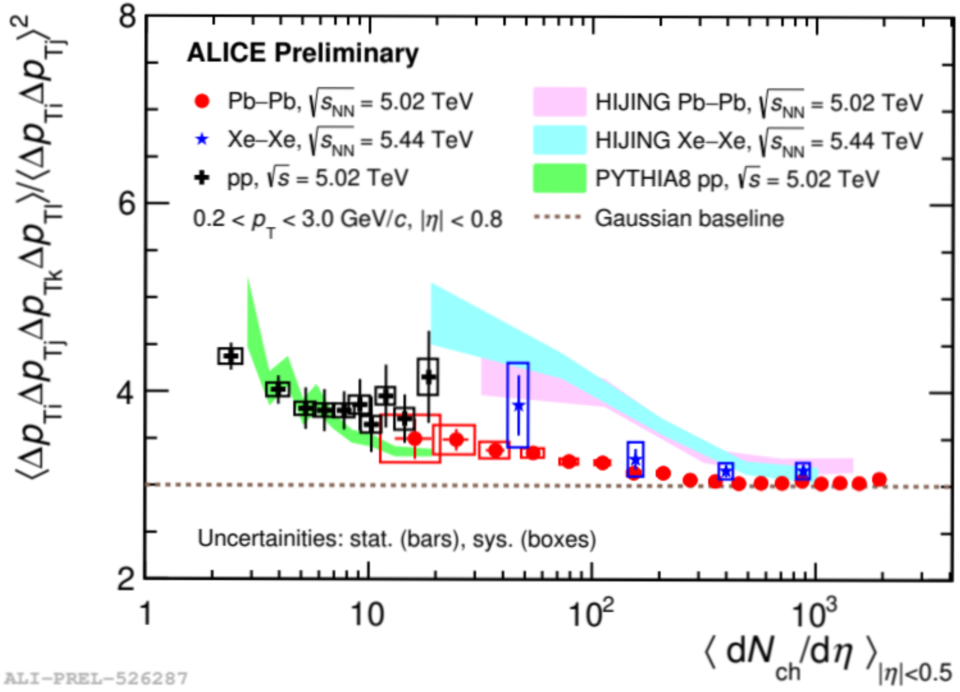

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- Approaches Gaussian baseline at high multiplicity in A–A collisions
- Results in pp collisions remain consistently above the Gaussian baseline indicating that it is a more correlated system
- Models qualitatively describe data but there is no quantitative agreement

Summary

- First measurements of skewness and kurtosis of $\langle p_{T} \rangle$ distributions in pp, Pb-Pb and Xe-Xe collision at LHC energies.

- **Positive** intensive skewness in A-A collisions show **significant excess over independent baseline** – existence of hydrodynamic evolution in the system.

- Measurements in pp collisions and HIJING show an excess of intensive skewness compared to their corresponding baselines.

- Measure of the dynamic kurtosis may help **distinguish particle production** mechanism in different system.