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

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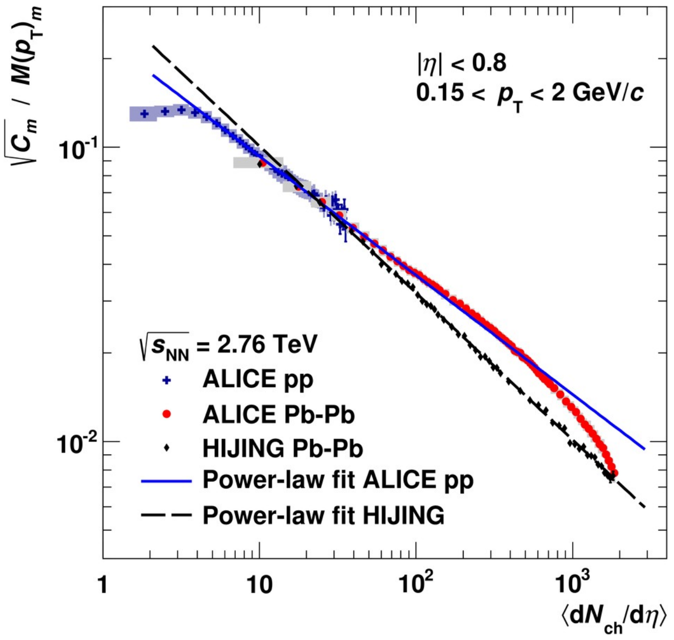
Motivation

- Event-by-event mean transverse momentum ($\langle p_T \rangle$) fluctuations:
  - related to correlations in particle production
  - provide evidence for the production of QGP

Henning Heiselberg, Physics Reports 351 (2001) 161-194

previous measurement of event-by-event $\langle p_T \rangle$ fluctuation up to second order only

Second order event-by-event $\langle p_T \rangle$ fluctuation relative to $\langle p_T \rangle$ as a func. of $\langle dN_{ch}/d\eta \rangle$



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

- Skewness of the $\langle p_T \rangle$ fluctuations can probe hydrodynamic behaviour in A–A collisions
  - Hydrodynamics predicts **positive skewness**
    - attributes its origin to the **fluctuations of 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

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

What is the skewness of $\langle p_T \rangle$ distribution in A–A, what about pp ?

Observables

$\langle p_T \rangle$ correlators: **extract dynamical information** of $\langle p_T \rangle$ fluctuation

→ $$\langle \Delta p_i \Delta p_j \rangle = \left\langle \frac{\sum_{i,j,i\neq j}^{N_{\mathrm{ch}}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)}{N_{\mathrm{ch}}(N_{\mathrm{ch}}-1)} \right\rangle_{\mathrm{ev}}$$ $\sim \mu_2$

→ $$\langle \Delta p_i \Delta p_j \Delta p_k \rangle = \left\langle \frac{\sum_{i,j,k,i\neq j\neq k}^{N_{\mathrm{ch}}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)(p_k - \langle\langle p_T \rangle\rangle)}{N_{\mathrm{ch}}(N_{\mathrm{ch}}-1)(N_{\mathrm{ch}}-2)} \right\rangle_{\mathrm{ev}}$$ $\sim \mu_3$

→ $$\langle \Delta p_i \Delta p_j \Delta p_k \Delta p_l \rangle = \left\langle \frac{\sum_{i,j,k,l,i\neq j\neq k\neq l}^{N_{\mathrm{ch}}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)(p_k - \langle\langle p_T \rangle\rangle)(p_l - \langle\langle p_T \rangle\rangle)}{N_{\mathrm{ch}}(N_{\mathrm{ch}}-1)(N_{\mathrm{ch}}-2)(N_{\mathrm{ch}}-3)} \right\rangle_{\mathrm{ev}}$$ $\sim \mu_4$

where, μ_n is the n$^{\mathrm{th}}$ order moment of $\langle p_T \rangle$

$\langle p_T \rangle$ fluctuation

→ **Statistical** information

→ **Dynamical** information
e.g., resonance decays, jets, quantum correlation, temperature fluctuation, $\boxed{\text{hydrodynamic flow of initial energy}}$

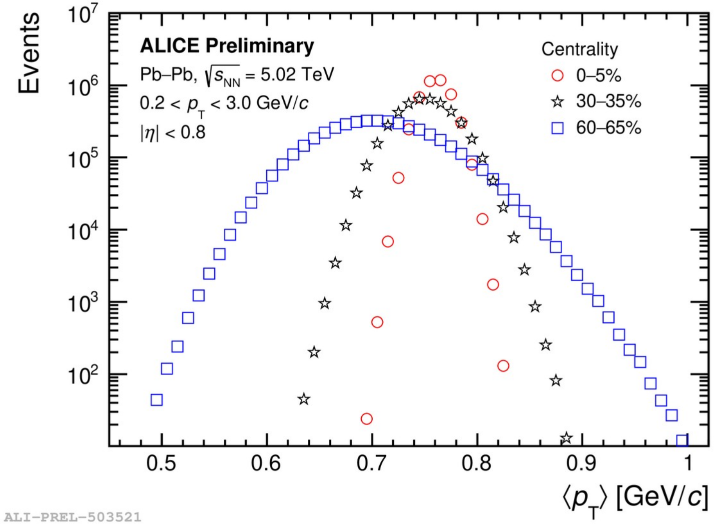
Intensive skewness $\sim$ **independent of N_{ch}**

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

Dynamic kurtosis $\sim$ **$1/N_{\mathrm{ch}}$**

$$\kappa_{\langle p_T \rangle} = \frac{\langle \Delta p_i \Delta p_j \Delta p_k \Delta p_l \rangle}{\langle \Delta p_i \Delta p_j \rangle^2}$$

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



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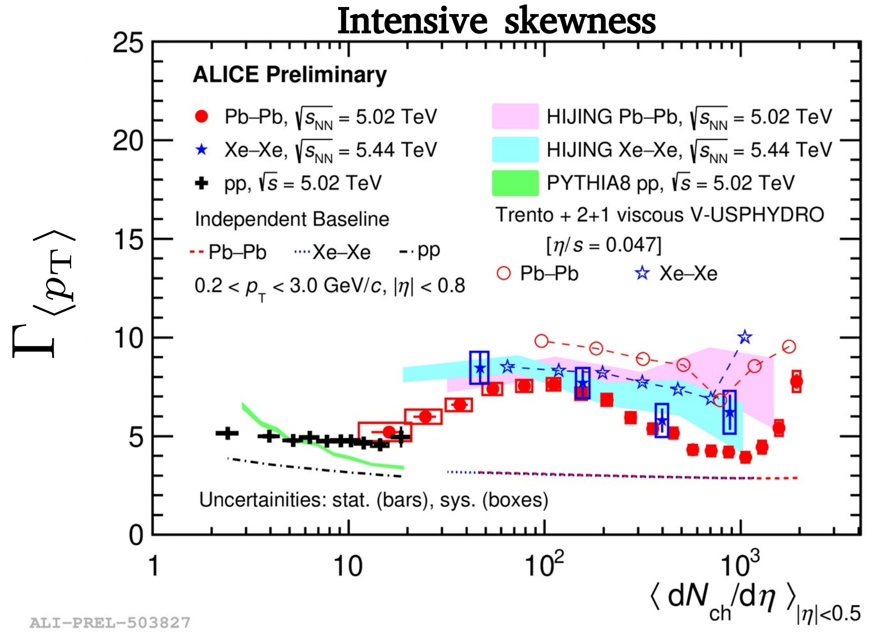
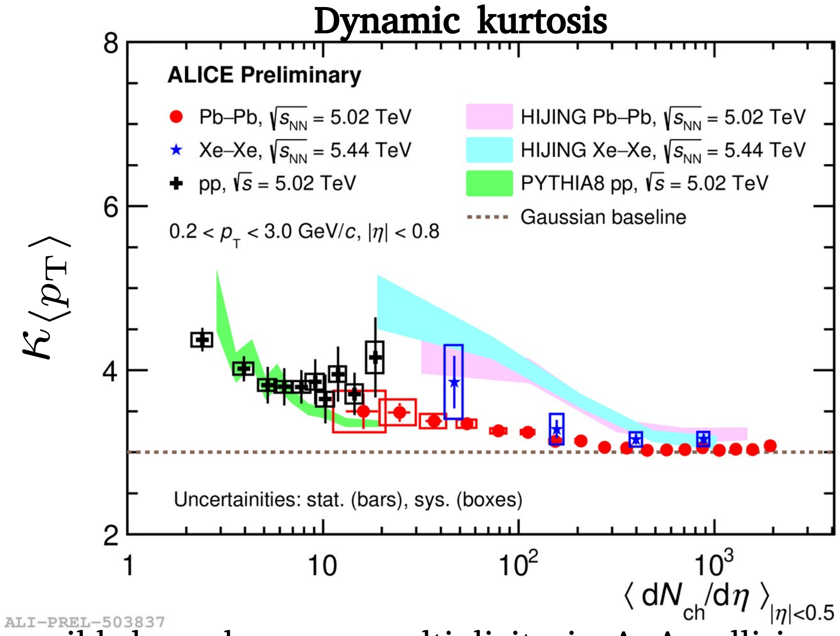
Results: Skewness and kurtosis of $\langle p_T \rangle$



- **positive skewness** excess from its baseline value observed in A–A collisions
- indicates **hydrodynamic evolution in A–A system**
- **pp** collisions and **models without hydrodynamics** also show excess of the intensive skewness over corresponding baselines
- comparable to hydrodynamic model predictions

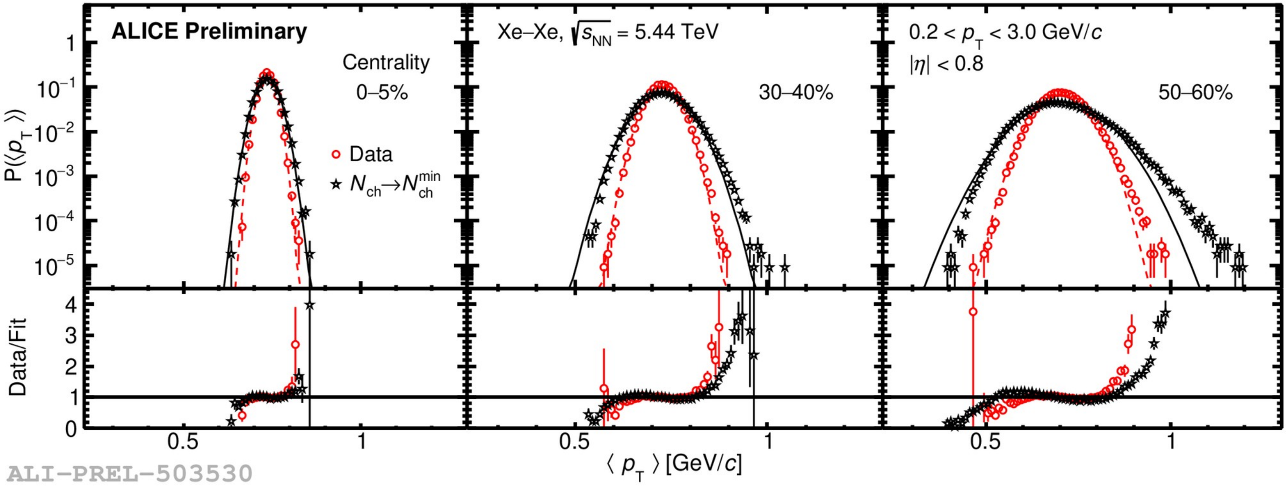


- mild dependence on multiplicity in A–A collisions
- approaches **Gaussian** baseline at **high multiplicity** in A–A collisions
- pp collisions remain consistently above the Gaussian baseline indicating that it is a more correlated system
- HIJING qualitatively describes data but shows **no quantitative agreement**

Skewness of $\langle p_T \rangle$- is it trivial?

$$\langle p_{\mathrm{T}} \rangle = \frac{\sum_{i=1}^{N_{\mathrm{ch}}} p_i}{N_{\mathrm{ch}}}$$

Does the fluctuations of e-by-e $\langle p_T \rangle$ arise from trivial stochastic effects of multiplicity (N_{ch})?



- Black points: Distributions obtained by fixing N_{ch} to N_{ch}^{min} (*) in a given centrality class, to disentangle statistical fluctuations of N_{ch}. Black and red dashed lines indicate Gaussian fit.

  *N_{ch}^{min} is the minimum number of charged particle per event for a centrality class

$\langle p_T \rangle$ distribution continues to have a positive skew even after removing the stochastic effect of N_{ch}, which shows that the skewness is not a trivial consequence of e-b-e N_{ch} fluctuations

Summary :

- First measurement of skewness and kurtosis of $\langle p_T \rangle$ in pp, Pb–Pb and Xe–Xe collisions at LHC energies.
- **Positive** intensive skewness in A–A collisions shows **significant excess from its independent baseline** – existence of hydrodynamic evolution in the system.
- Measurements in **pp** collisions and **HIJING** simulations also show excess of intensive skewness over their corresponding baselines.
- Measurement of the dynamic kurtosis may help **distinguish particle production** mechanisms in different systems.

THANK YOU