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

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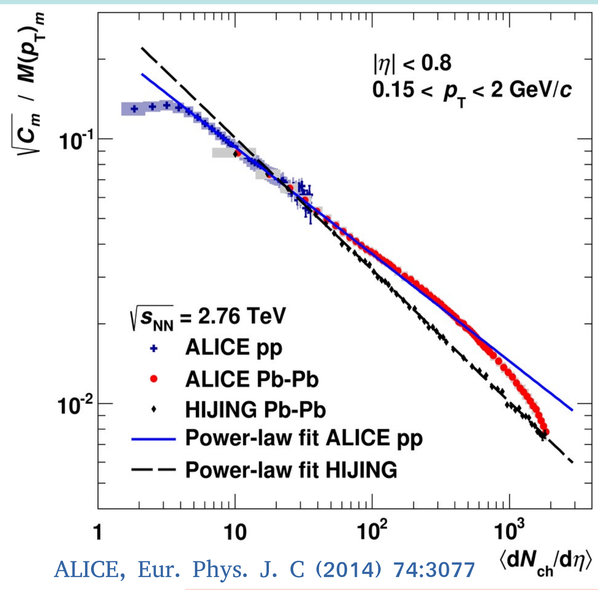
1. Motivation

Mean transverse momentum ($\langle p_T \rangle$) fluctuations are related to correlations in particle production and provide evidence for the production of quark-gluon plasma

Skewness of the $\langle p_T \rangle$ fluctuations can probe hydrodynamic behaviour in A–A collisions

- Hydrodynamics predicts positive skewness
- related to initial state energy density fluctuations
- measurements will strongly constrain the modeling of the initial stages in hydrodynamic studies

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



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

2. Observables

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

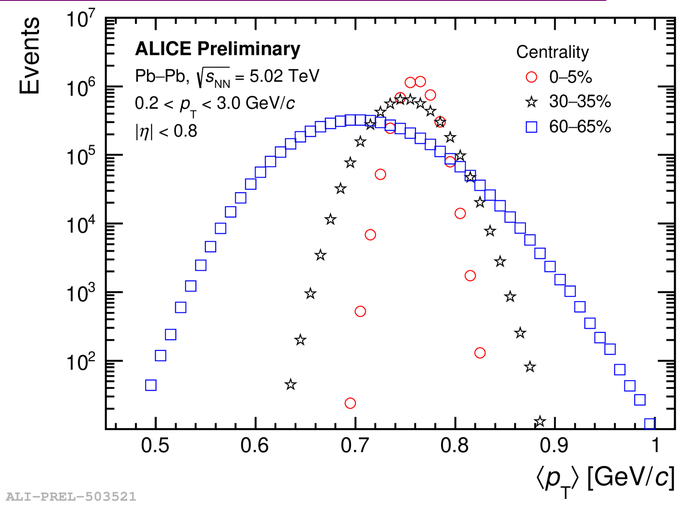
- $\langle \Delta p_i \Delta p_j \rangle = \left\langle \frac{\sum_{i,j,i\neq j}^{N_{ch}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)}{N_{ch}(N_{ch}-1)} \right\rangle_{ev}$ $\sim \mu_2$
- $\langle \Delta p_i \Delta p_j \Delta p_k \rangle = \left\langle \frac{\sum_{i,j,k,i\neq j\neq k}^{N_{ch}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)(p_k - \langle\langle p_T \rangle\rangle)}{N_{ch}(N_{ch}-1)(N_{ch}-2)} \right\rangle_{ev}$ $\sim \mu_3$
- $\langle \Delta p_i \Delta p_j \Delta p_k \Delta p_l \rangle = \left\langle \frac{\sum_{i,j,k,l,i\neq j\neq k\neq l}^{N_{ch}} (p_i - \langle\langle p_T \rangle\rangle)(p_j - \langle\langle p_T \rangle\rangle)(p_k - \langle\langle p_T \rangle\rangle)(p_l - \langle\langle p_T \rangle\rangle)}{N_{ch}(N_{ch}-1)(N_{ch}-2)(N_{ch}-3)} \right\rangle_{ev}$ $\sim \mu_4$

Intensive Skewness, 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, proportional to $1/N_{ch}$

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



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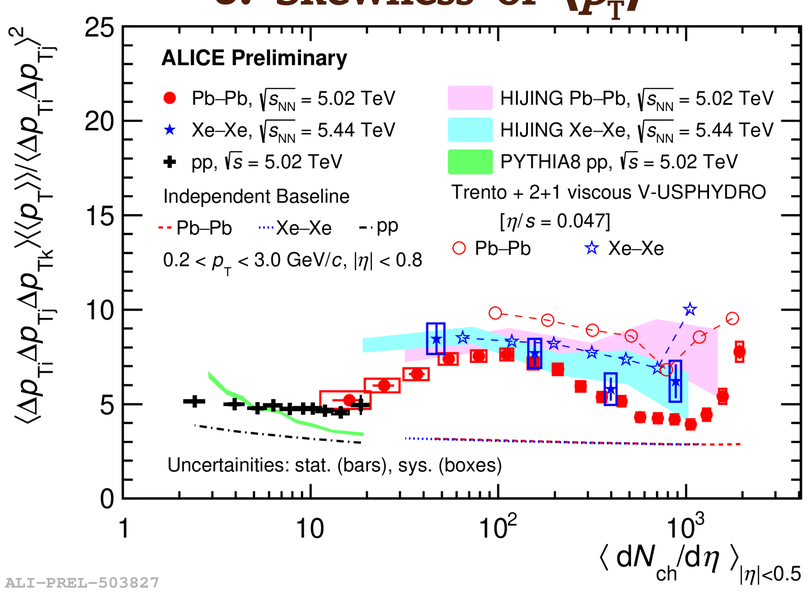
Dynamical information e.g., resonance decays, jets, quantum correlations, temperature fluctuation, hydrodynamic flow of initial energy

3. Skewness of $\langle p_T \rangle$



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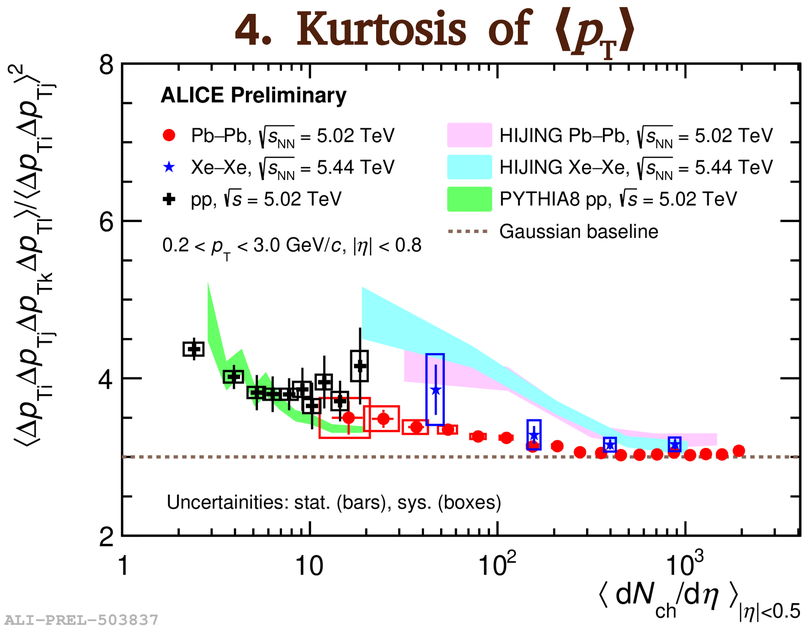
- positive skewness excess in A-A collisions compared to the independent baseline
- indicates hydrodynamic evolution in A–A system
- pp collisions and models without hydrodynamics also show excess of the intensive skewness over corresponding baselines
- qualitative agreement with the hydrodynamic model predictions

4. Kurtosis of $\langle p_T \rangle$



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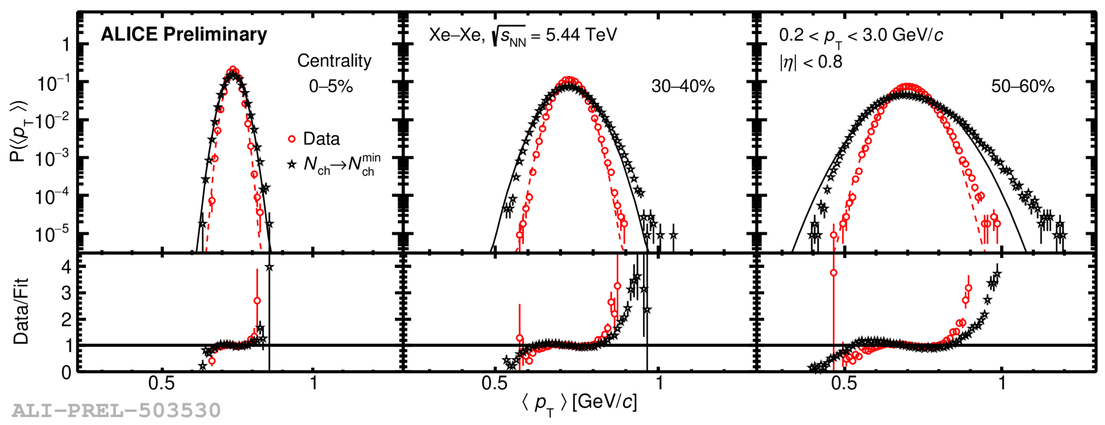
- mild dependence on multiplicity in A–A collisions
- approaches Gaussian baseline at high multiplicity in A–A collisions
- pp collisions remain consistently above the Gaussian baseline indicating that it is a correlated system
- HIJING qualitatively describes the data but shows no quantitative agreement

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

$$\langle p_T \rangle = \frac{\sum_{i=1}^{N_{ch}} p_i}{N_{ch}}$$

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



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- Black points: Distributions obtained by fixing N_{ch} to N_{ch}^{min} (minimum number of charged particle per event). Black and red dashed lines indicate Gaussian fit.

$\langle p_T \rangle$ distribution has a positive skewness 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

6. Summary

- First measurement of skewness and kurtosis of $\langle p_T \rangle$ in pp, Pb–Pb and Xe–Xe collisions at LHC energies.
- Positive 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.

7. References

[1] H. Heiselberg, Physics Reports 351 (2001) 161-194
[2] G. Giacalone et al., Phys. Rev. C 103, 024910 (2021)

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