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 fluctuations:
- related to correlations in particle production
- provide evidence for the production of QGP
- previous measurement of event-by-event \( \langle p_T \rangle \) fluctuation up to second order only

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

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


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

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

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

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<\!\langle p_T \rangle\!> \text{ correlators: extract dynamical information of } <\!\langle p_T \rangle\!> \text{ fluctuation}

\[
\langle \Delta p_i \Delta p_j \rangle = \left\langle \frac{\sum_{i,j,i \neq j}^N (p_i - <p_T>) (p_j - <p_T>)}{N_{ch}(N_{ch}-1)} \right\rangle_{ev} \sim \mu_2
\]

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

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

\[
\Gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_i \Delta p_j \Delta p_k \rangle / \langle \langle p_T \rangle \rangle}{\langle \Delta p_i \Delta p_j \rangle^2}
\]

\[
K_{\langle p_T \rangle} = \frac{\langle \Delta p_i \Delta p_j \Delta p_k \Delta p_l \rangle}{\langle \Delta p_i \Delta p_j \rangle^2}
\]


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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

Intensive skewness

\[ \Gamma(p_T) \]

\[ \langle dN_{ch}/d\eta \rangle_{|\eta|<0.5} \]

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

Dynamic kurtosis

\[ K(p_T) \]

\[ \langle dN_{ch}/d\eta \rangle_{|\eta|<0.5} \]

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

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

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

ALICE Preliminary

**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.

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