Skewness of event-by-event $\langle p_T \rangle$ distribution of charged particles at LHC energies with ALICE

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Introduction

In ultrarelativistic heavy-ion collisions, a hot and dense nuclear state of matter known as the quark–gluon plasma (QGP) is formed, in which quarks and gluons are no longer confined within hadrons. The space–time evolution of the QGP is known to be governed by hydrodynamic equations of state. In a recent publication [1], it was suggested that skewness of event-by-event (e-by-e) mean transverse momentum ($\langle p_T \rangle$) distribution can help to study the hydrodynamic behaviour of the system produced in heavy-ion collisions. Hydrodynamic simulations predict that the $\langle p_T \rangle$ fluctuations are positively skewed, larger than in the independent particle emission scenario. The skewness of the $\langle p_T \rangle$ fluctuations has been related to the fluctuations of initial state energy density. Event-by-event fluctuations in the initial state of a collision arise due to fluctuations in the positions of participating nucleons. In this work, the first measurements of skewness of e-by-e $\langle p_T \rangle$ distribution are presented, as a function of average charged-particle pseudorapidity density $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$ in pp collisions at $\sqrt{s} = 5.02$ TeV and Pb–Pb (Xe–Xe) collisions at $\sqrt{s_{NN}} = 5.02\ (5.44)$ TeV using the data recorded by the ALICE [2] detector.

The mean transverse momentum of particles in an event is defined as $\langle p_T \rangle = (1/N_{ch}) \sum_{i=1}^{N_{ch}} p_{T,i}$ where N_{ch} is the number of particles and $p_{T,i}$ is the transverse momentum of the ith particle in that event. This quantity fluctuates from event to event in a given collision centrality. The fluctuations of $\langle p_T \rangle$ involve a purely statistical component and a dynamic (non-statistical) component. The statistical component arises from the stochastic effect of multiplicity (N_{ch}), while the dynamic component may come from correlations among particles, produced by different particle production processes. To analyze the fluctuations of $\langle p_T \rangle$, the two-particle and three-particle p_T correlators

$$\langle \Delta p_{Ti} \Delta p_{Tj} \rangle = \left\langle \frac{Q_1^2 - Q_2}{N_{ch}(N_{ch} - 1)} \right\rangle - \left\langle \frac{Q_1}{N_{ch}} \right\rangle^2, \tag{1}$$

$$\begin{aligned} \langle \Delta p_{Ti} \Delta p_{Tj} \Delta p_{Tk} \rangle &= \left\langle \frac{Q_1^3 + 2Q_3 - 3Q_1 Q_2}{N_{ch} - 1)(N_{ch} - 2)} \right\rangle + 2 \left\langle \frac{Q_1}{N_{ch}} \right\rangle^3 \\ &\quad - 3 \left\langle \frac{Q_1}{N_{ch}} \right\rangle \left\langle \frac{Q_1^2 - Q_2}{N_{ch}(N_{ch} - 1)} \right\rangle, \end{aligned} \tag{2}$$

are used [1], where $Q_n = \sum_{i=1}^{N_{ch}} p_{T,i}^n$ and the angular brackets $\langle \cdot \rangle$ represent average over events. These correlators are by construction zero for a purely statistical distribution. For the study of skewness, a new observable, Γ_{p_T}, named as intensive skewness introduced in Ref.[1] is used. It is defined as

$$\Gamma_{p_T} = \frac{\langle \Delta p_{Ti} \Delta p_{Tj} \Delta p_{Tk} \rangle \langle \langle p_T \rangle \rangle}{\langle \Delta p_{Ti} \Delta p_{Tj} \rangle^2}, \tag{3}$$

where $\langle \langle p_T \rangle \rangle = \left\langle \sum_{i=1}^{N_{ch}} p_{T,i}/N_{ch} \right\rangle$. The baseline for intensive skewness of $\langle p_T \rangle$ distribution considering independent particle production, is provided by

$$\Gamma_{independent} = \frac{\langle (p_T - \langle p_T \rangle)^3 \rangle \langle p_T \rangle}{\langle (p_T - \langle p_T \rangle)^2 \rangle^2}, \tag{4}$$

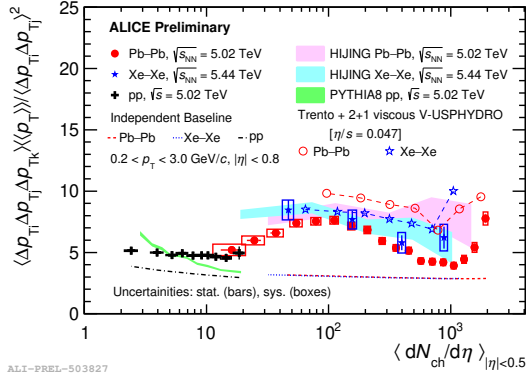[*]Electronic address: swati.saha@niser.ac.in

FIG. 1: Itensive skewness vs. $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle_{|\eta|<0.5}$ in pp, Pb–Pb and Xe–Xe collisions are shown with their corresponding independent baselines by different colors. The predictions from PYTHIA 8 and HIJING are represented with colored bands. The open markers represent the hydrodynamic model of Pb–Pb and Xe–Xe collisions obtained from [1].

where angular brackets denote an average over p_{T} intervals with the weight $\mathrm{d}N/\mathrm{d}p_{\mathrm{T}}$. It is calculated for different collision systems, using the available data on $\mathrm{d}N/\mathrm{d}p_{\mathrm{T}}$ for the corresponding system at ALICE.

Analysis details

The events used in this analysis for the three systems are selected using a minimum bias (MB) trigger that requires at least one hit in both V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$) detectors [2]. All charged particles that are within the kinematic range of pseudorapidity, $|\eta| < 0.8$, and transverse momentum, $0.2 < p_{\mathrm{T}} < 3.0$ GeV/c, are used to calculate the intensive skewness as a function of multiplicity. The multiplicity of an event is determined using V0M (V0A+V0C) estimator.

Results

Figure 1 shows the intensive skewness ($\Gamma_{p_{\mathrm{T}}}$) measured in pp, Pb–Pb and Xe–Xe collisions as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle_{|\eta|<0.5}$. A positive skewness of $\langle p_{\mathrm{T}} \rangle$ is observed across all systems. The values of $\Gamma_{p_{\mathrm{T}}}$ in Pb–Pb and Xe–Xe collisions are found to be larger than their in-

dependent baselines, which indicates that the skewness of the $\langle p_{\mathrm{T}} \rangle$ fluctuation is significantly larger than if the particles were produced independently. Hydrodynamic model calculations [1] show similar magnitude of $\Gamma_{p_{\mathrm{T}}}$ as measured in data, but the model slightly overestimates the data. The measurement in pp collisions also shows excess of intensive skewness over its corresponding baseline. These results are compared with HIJING model predictions for Pb–Pb (Xe–Xe) collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ (5.44) TeV. In HIJING model, no hydrodynamic evolution is incorporated, yet positive intensive skewness higher than the baseline value is observed. The results in pp collisions are compared with the PYTHIA 8 model. The model calculations are comparable to the data and larger than the baseline.

In conclusion, the predicted positive skewness of e-by-e $\langle p_{\mathrm{T}} \rangle$ distribution for heavy-ion collisions is observed in both Pb–Pb and Xe–Xe collisions at the LHC. This verifies that the system produced in these collisions evolves hydrodynamically. However, pp collisions, where hydrodynamic evolution is not expected to be dominant, as well as non-hydro models such as HIJING and PYTHIA 8 (shown here) are found to show the same feature. The measured intensive skewness in Pb–Pb and Xe–Xe collisions show no significant system dependence for $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle_{|\eta|<0.5} < 400$. For higher multiplicity, a slight difference is observed between Pb–Pb and Xe–Xe collisions, which might be related to nuclear deformation. Since the uncertainties in the Xe–Xe results are large due to limited number of events, no firm conclusion on this aspect could be drawn.

Acknowledgments

References

[1] G. Giacalone *et al.*, *Phys. Rev. C* **103** (2021) 024910.

[2] ALICE Collaboration, *JINST* **3** (2008) S08002.