PROCEEDINGS OF SCIENCE

Skewness of event-by-event $\langle p_{\mathrm{T}} \rangle$ distribution of charged particles at LHC energies with ALICE

Swati Saha (for the ALICE Collaboration)[a,*]

[a] *National Institute of Science Education and Research, Jatni 752050, India*
Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai 400094, India

E-mail: swati.saha@cern.ch, swati.saha@niser.ac.in

The study of fluctuation in event-by-event mean transverse momentum ($\langle p_{\mathrm{T}} \rangle$) is considered a useful tool to understand the dynamics of the system produced in the ultrarelativistic collisions. The measurement of skewness of $\langle p_{\mathrm{T}} \rangle$ can help in probing hydrodynamic behavior of the system and can be a direct way of observing initial-state fluctuations. Recent measurement of skewness of $\langle p_{\mathrm{T}} \rangle$ distribution as a function of average charged particle density in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV recorded by ALICE is presented. For the baseline study, the analysis is also performed in pp collisions at $\sqrt{s}$ = 5.02 TeV. The measurements are compared to hydrodynamic model calculations and results from Monte Carlo event generators.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)1157

1. 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 equation of state [1]. In a recent publication [2], it was suggested that skewness of event-by-event (e-by-e) mean transverse momentum ($\langle p_{\rm T}\rangle$) distribution can help to study the hydrodynamic behaviour of the system produced in heavy-ion collisions. Hydrodynamic simulations predict that the $\langle p_{\rm T}\rangle$ fluctuations are positively skewed, larger than in the independent particle emission scenario. The skewness of the $\langle p_{\rm T}\rangle$ 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 $\langle p_{\rm T}\rangle$ distribution are presented as a function of average charged-particle pseudorapidity density $\langle {\rm d}N_{\rm ch}/{\rm d}\eta\rangle_{|\eta|<0.5}$ in pp collisions at $\sqrt{s}$ = 5.02 TeV and Pb–Pb (Xe–Xe) collisions at $\sqrt{s_{\rm NN}}$ = 5.02 (5.44) TeV using the data recorded by ALICE [3].

The mean transverse momentum of particles in an event is defined as $\langle p_{\rm T}\rangle = (1/N_{\rm ch})\sum_{i=1}^{N_{\rm ch}} p_{{\rm T},i}$, where $N_{\rm ch}$ is the number of particles and $p_{{\rm T},i}$ is the transverse momentum of the $i^{\rm th}$ particle in that event. This quantity fluctuates from event to event in a given collision centrality. The fluctuations of $\langle p_{\rm T}\rangle$ involve a purely statistical component and a dynamic (non-statistical) component. The statistical component arises from the stochastic effect of multiplicity ($N_{\rm ch}$), while the dynamic component may come from correlations among particles, produced by different particle production processes. To analyze the fluctuations of $\langle p_{\rm T}\rangle$, the two-particle and three-particle $p_{\rm T}$ correlators [2]

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

$$\langle \Delta p_{{\rm T}i}\Delta p_{{\rm T}j}\Delta p_{{\rm T}k}\rangle = \left\langle \frac{Q_1^3 + 2Q_3 - 3Q_1Q_2}{N_{\rm ch}-1)(N_{\rm ch}-2)}\right\rangle + 2\left\langle \frac{Q_1}{N_{\rm ch}}\right\rangle^3 - 3\left\langle \frac{Q_1}{N_{\rm ch}}\right\rangle\left\langle \frac{Q_1^2 - Q_2}{N_{\rm ch}(N_{\rm ch}-1)}\right\rangle, \tag{2}$$

are used, where $Q_n = \sum_{i=1}^{N_{\rm ch}} p_{{\rm T},i}^n$ and the angular brackets represent average over events. These correlators are by construction zero for a purely statistical distribution. For the study of skewness, a new observable, $\Gamma_{p_{\rm T}}$, named as intensive skewness introduced in Ref. [2] is used. It is defined as

$$\Gamma_{p_{\rm T}} = \frac{\langle \Delta p_{{\rm T}i}\Delta p_{{\rm T}j}\Delta p_{{\rm T}k}\rangle\langle\langle p_{\rm T}\rangle\rangle}{\langle \Delta p_{{\rm T}i}\Delta p_{{\rm T}j}\rangle^2}, \tag{3}$$

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

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

where angular brackets denote an average over $p_{\rm T}$ intervals with the weight ${\rm d}N/{\rm d}p_{\rm T}$. It is calculated for different collision systems, using the available data on ${\rm d}N/{\rm d}p_{\rm T}$ for the corresponding system at ALICE [4–6].

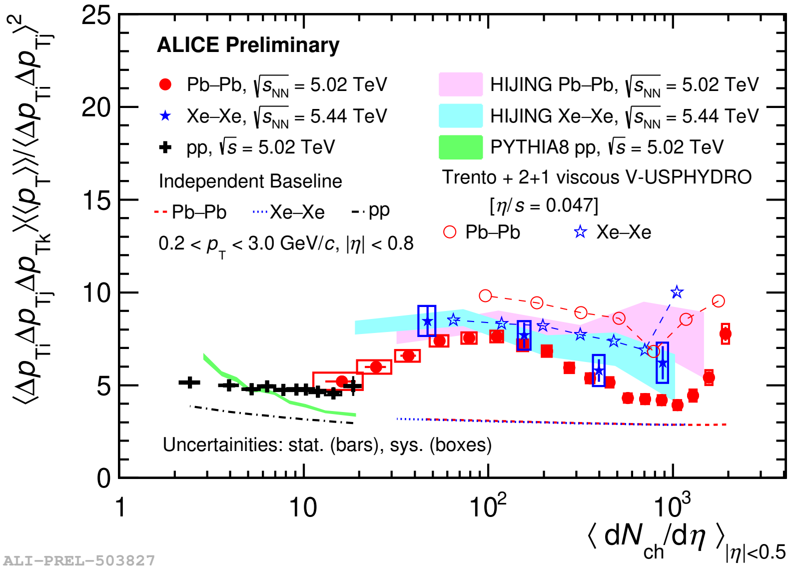

Figure 1: Intensive skewness vs. $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$ in pp, Pb–Pb, and Xe–Xe collisions (full markers) shown with the corresponding independent baselines (dotted lines). The predictions from PYTHIA 8 and HIJING are represented with colored bands. The open markers denote hydrodynamic calculations for Pb–Pb and Xe–Xe collisions obtained from Ref. [2].

2. Analysis details

The events used in this analysis for the three collision 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 [3]. All charged particles that are within the kinematic range of pseudorapidity, $|\eta| < 0.8$, and transverse momentum, $0.2 < p_T < 3.0$ GeV/c, are used to calculate the intensive skewness as a function of multiplicity. The multiplicity of an event is estimated from the energy deposition measured in the V0 detector.

3. Results

Figure 1 shows the intensive skewness (Γ_{p_T}) measured in pp, Pb–Pb, and Xe–Xe collisions as a function of $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$. A positive skewness of $\langle p_T \rangle$ is observed across all systems. The values of Γ_{p_T} in Pb–Pb and Xe–Xe collisions are found to be larger than their independent baselines, which indicates that the skewness of the $\langle p_T \rangle$ fluctuation is significantly larger than if the particles were produced independently. Hydrodynamic model calculations [2] show similar trends of Γ_{p_T} as those from data, but they overestimate the magnitude. The measurement in pp collisions also shows an excess of intensive skewness over its corresponding baseline. These results are compared with HIJING model predictions for Pb–Pb (Xe–Xe) collisions at $\sqrt{s_{NN}}$ = 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 event generator. The model calculations are comparable to the data and larger than the baseline.

4. Conclusion

In conclusion, the predicted positive skewness of e-by-e $\langle p_{\rm T} \rangle$ 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. For pp collisions, where a hydrodynamic evolution is not expected, a positive skewness is also observed. Non hydrodynamic models such as HIJING and PYTHIA 8 show the same feature. The measured intensive skewness in Pb–Pb and Xe–Xe collisions shows no significant system dependence for $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle_{|\eta|<0.5} < 400$. For higher multiplicities, 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 data sample, no firm conclusion on this aspect could be drawn.

References

[1] D. H. Rischke *et al.*, "Relativistic hydrodynamics for heavy ion collisions. 1. General aspects and expansion into vacuum", *Nucl. Phys. A* 595 (1995) 346-382.

[2] G. Giacalone *et al.*, "Skewness of mean transverse momentum fluctuations in heavy-ion collisions", *Phys. Rev. C* 103 (2021) 024910.

[3] ALICE Collaboration, K. Aamodt *et al.*, "The ALICE experiment at the CERN LHC", *JINST* 3 (2008) S08002.

[4] ALICE Collaboration, S. Acharya *et al.*, "Transverse momentum spectra and nuclear modification factors of charged particles in pp, p–Pb and Pb–Pb collisions at the LHC", *JHEP* 11 (2018) 013.

[5] ALICE Collaboration, S. Acharya *et al.*, "Transverse momentum spectra and nuclear modification factors of charged particles in Xe–Xe collisions at $\sqrt{s_{\rm NN}}$ = 5.44 TeV", *Phys. Lett. B* 788 (2019) 166-179.

[6] ALICE Collaboration, S. Acharya *et al.*, "Charged-particle production as a function of multiplicity and transverse spherocity in pp collisions at $\sqrt{s}$ = 5.02 and 13 TeV", *Eur. Phys. J. C* 79 no. 10, (2019) 79:857.

PoS(ICHEP2022)1157