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Event-by-event fluctuations of mean transverse momentum in Pb–Pb and Xe–Xe collisions with ALICE

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The article presents studies of event-by-event fluctuations in the mean transverse momentum, $\langle p_{\mathrm{T}} \rangle$, of charged particles in Pb–Pb and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV, respectively, with the ALICE detector at the LHC. Significant dynamical fluctuations, indicative of correlated particle emission, are observed in both collision systems. Central Pb–Pb and Xe–Xe collisions exhibit a decrease in fluctuations compared to peripheral collisions, aligning qualitatively with prior measurements in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. The findings are compared with the results from the HIJING model. A deviation from a simple superposition scenario, wherein final state particles arise from the superposition of emitting sources, is observed.

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1. Introduction

The investigation of fluctuations in the event-wise average transverse momentum (p_{T}) of particles generated in nuclear collisions holds significant importance, as it serves as a probe for the transition from a quark-gluon plasma (QGP) to a hadron gas (HG). These fluctuations are anticipated to exhibit sensitivity to temperature fluctuations which are directly proportional to the heat capacity of the hot QCD medium [1], within the produced matter. Predictions suggest that temperature fluctuations will experience a pronounced increase near the critical point and during the phase transition due to rapid changes in the medium's heat capacity [1]. This study measures event-by-event fluctuations in the mean transverse momentum, $\langle p_{\mathrm{T}} \rangle$, for charged particles produced in Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. With the help of the ALICE detector at the LHC, the study explores these fluctuations as a function of charged-particle multiplicity. The primary objectives are to investigate the evolution of the $\sqrt{\Delta p_{\mathrm{Ti}} \Delta p_{\mathrm{Tj}}}/\langle\langle p_{\mathrm{T}} \rangle\rangle$ correlator strength with beam energy and to determine whether this evolution can be quantitatively understood based on existing models.

2. Analysis details

The results presented in this proceeding are obtained from the analysis of Pb–Pb collision run at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and the Xe–Xe collision run at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV collected with the ALICE detector [4] in 2015 and 2017, respectively. The data collection employed minimum bias (MB) triggers based on V0 detectors (V0A and V0C) and the Inner tracking system (ITS). Charged particles, measured at central rapidity using the ITS and Time-Projection-Chamber (TPC), were further categorized into classes based on equal fractional cross-sections in both Pb–Pb and Xe–Xe collisions, using charged particle multiplicities measured from V0 detectors. These classes served to map centrality to charged particle multiplicity. The analysis focused on particles with pseudorapidities $|\eta| < 0.8$ and transverse momentum $0.15 < p_{\mathrm{T}} < 2$ GeV/c. Such low p_{T} threshhold was essential due to the sharp decline in tracking efficiency at very low transverse momentum. Meanwhile, the higher p_{T} cut aimed to ensure the analysis of soft particles in the "bulk", minimizing contributions from jet fragmentation. To maintain uniform tracking efficiency, the analysis was constrained to events with a reconstructed primary event-vertex within 10 cm of the nominal interaction point along the beam direction ($|Vz| < 10$ cm).

2.1 Observable

The observable used in this analysis is the two-particle correlator which is calculated on an event by event basis using the following equation:

$$\langle \Delta p_{\mathrm{Ti}} \Delta p_{\mathrm{Tj}} \rangle = \left\langle \frac{\sum_{i,j \neq i} (p_{\mathrm{Ti}} - \langle\langle p_{\mathrm{T}} \rangle\rangle)(p_{\mathrm{Tj}} - \langle\langle p_{\mathrm{T}} \rangle\rangle)}{N_{\mathrm{ch}}(N_{\mathrm{ch}} - 1)} \right\rangle. \tag{1}$$

Here, p_{Ti} and p_{Tj} are the transverse momenta of i^{th} and j^{th} particle of an event in a particular multiplicity bin, where $N_{\mathrm{ch}}(N_{\mathrm{ch}} - 1)$ represents the number of particle pairs. Here $\langle\langle p_{\mathrm{T}} \rangle\rangle$ is the average of the $\langle p_{\mathrm{T}} \rangle$ over events within the same multiplicity bin, where, $\langle p_{\mathrm{T}} \rangle = \frac{\sum_{i=1}^{N_{\mathrm{ch,k}}} p_{\mathrm{Ti}}}{N_{\mathrm{ch,k}}}$. p_{Ti} is

the transverse momentum of $i^{\rm th}$ particle in the event k and $N_{\rm ch,k}$ represents the charged-particle multiplicity of the event. The above equation is simplified as,

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

where, $Q_{\rm n} = \sum_{i=1}^{N} (p_{Ti})^n$.

3. Results and discussion

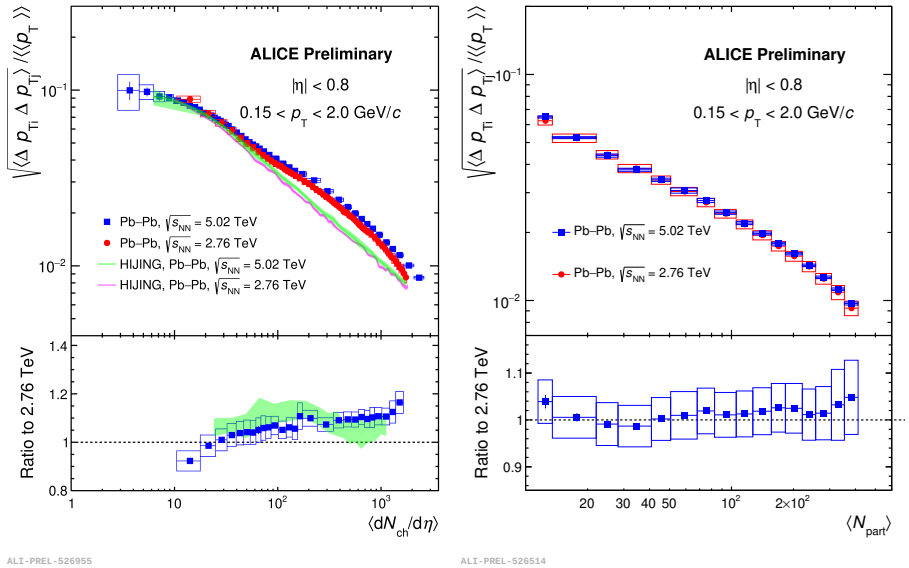

Figure 1: Event-by-event fluctuations of mean transverse momentum, in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 and 5.02 TeV and their model comparisons with HIJING as a function of $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle$ (left panel) and as a function of $\langle N_{\rm part} \rangle$ (mean number of participants-right plot)

The left panel of Fig. 1 shows the event-by-event fluctuations of $\langle p_{\rm T} \rangle$ in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 [2] and 5.02 TeV, represented by the dimensionless quantity $\sqrt{\langle \Delta p_{\rm Ti} \Delta p_{\rm Tj} \rangle}/\langle \langle p_{\rm T} \rangle \rangle$ and their model comparisons with HIJING model [3]. Significant dynamical fluctuations are observed for both collision energies, which decreases with increasing multiplicity i.e., when compared to peripheral collisions, the fluctuationa are much reduced in the central collisions for all systems and energies. For Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, the value of the correlator is found to be greater in comparison to earlier results produced in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Clear deviation of the experimental data from the HIJING model indicates a deviation from a simple superposition scenario. This indicates that the final state particle production in heavy-ion collisions at the LHC can not be described by a mere superposition of independent particle-emitting sources. The stronger decrease of fluctuations in high multiplicity bins, is one of the main effects of Pb-Pb collisions. This can be attributed to radial flow and other final state effects.

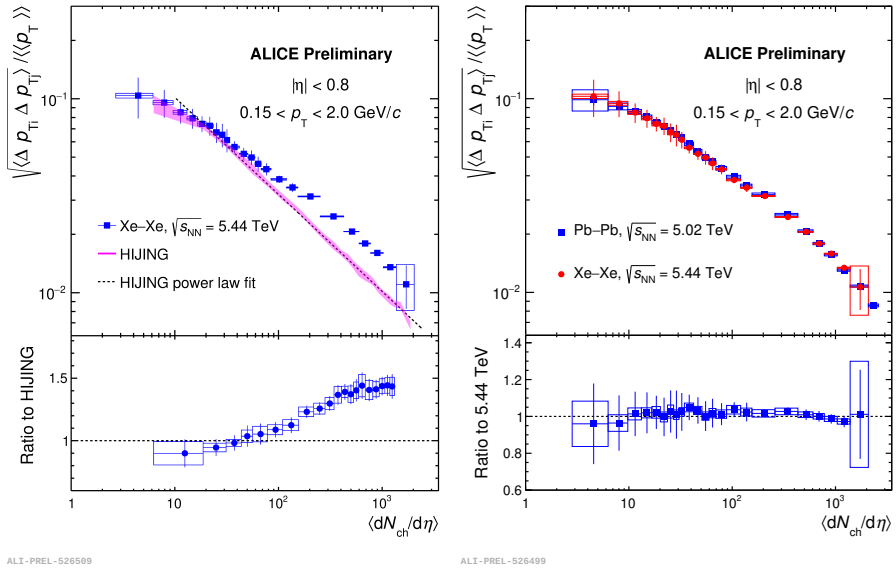

Figure 2: Event-by-event fluctuations of mean transverse momentum, Left panel: In Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV and comparisons with HIJING mode, right panel: In Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV

However, according to the right panel of Fig. 1, the dependence on collision energy is reduced when the correlator is studied as a function of the mean number of participants, $\langle N_{\mathrm{part}} \rangle$. The bottom panel shows the ratio of the measurements at 5.02 and 2.76 TeV and it is found to be consistent with unity. This suggests that for a given initial-state overlap geometry, the correlator strength is independent of collision energy. Hence, the results from Fig. 1 might indicate that the strength of correlator is influenced by final state effects at different energies

The left panel of Fig. 2 compares event-by-event $\langle p_{\mathrm{T}} \rangle$ fluctuations in Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV with HIJING model. Deviation from the HIJING model as well as from the power law fit is observed. The right panel of Fig. 2 shows the comparison of event-by-event fluctuations of $\langle p_{\mathrm{T}} \rangle$ in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV. Results of both the systems are found to agree with each other.

4. Conclusions

Investigation of event-by-event $\langle p_{\mathrm{T}} \rangle$ fluctuations in charged particles from Pb–Pb and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and $\sqrt{s_{\mathrm{NN}}}$ = 5.44 TeV, respectively, reveals notable dynamical variations. The study, conducted as a function of charged-particle multiplicity, underscores a significant reduction in fluctuations in central collisions compared to peripheral ones. Across all systems and energies, there is a distinct deviation from a simple superposition scenario, as depicted by the HIJING model. This deviation challenges the notion of final state particles arising solely from a superposition of independent particle-emitting sources.

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