Event-by-event fluctuations of mean transverse momentum in pp, Xe–Xe and Pb–Pb collisions with ALICE at the LHC

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Introduction and motivation

In heavy-ion collisions, event-by-event measurements play a crucial role in understanding the high-energy nuclear interaction dynamics and the quark-gluon plasma (QGP) properties. Depending on the impact parameter of an event (an interaction between two heavy ions like lead or Xenon nuclei at extremely high energies) the collisions can be categorised into central, semi central or peripheral collisions. In the Large Hadron Collider (LHC), about $\sim 10^4$ particles are produced per event. This number is large enough to analyse the desirable physical quantity on an event-by-event basis. Studies of event-by-event fluctuations of event-wise observables measured in heavy-ion collisions are of great interest given they probe the phase transition from quark–gluon plasma (QGP) to hadron gas [1]. Of particular interest are fluctuations of the average transverse momentum (p_{T}) of particles detected, event-by-event, in a specific kinematic range. These fluctuations are expected to be sensitive to energy fluctuations, and arguably, temperature variations of the produced matter in these collisions. In turn, the magnitude of these fluctuations is nominally proportional to the heat capacity of the hot QCD medium. As such, the temperature fluctuations are predicted to sharply increase in the vicinity of the critical point and in this part of QCD phase diagram, a rapid change in the heat capacity of the medium near the phase transition is expected. $\langle p_{\mathrm{T}}\rangle$ fluctuations are also highly sensitive to the presence of collective effects and the onset of thermalization in mesoscopic systems [1]. Measurements of $\langle p_{\mathrm{T}}\rangle$ fluctuations are thus an essential tool to achieve a better understanding of the hot and dense matter produced in heavy-ion collisions. The observable studied in this thesis is the two particle correlator, $\sqrt{\langle \Delta p_{\mathrm{T},1}\Delta p_{\mathrm{T},2}\rangle}/\langle\langle p_{\mathrm{T}}\rangle\rangle$. In small collision systems, one expects that the magnitude of the correlator should be explained by processes such as string fragmentation, hadronic resonance decays, as well as jets. On the other hand, correlations in large collision systems should depend on the number of individual nucleon–nucleon (or parton–parton) collisions and also depends on whether these produce collective phenomena or feature re-scatterings of the particles they produce. For collisions involving independent nucleon–nucleon collisions, one expects that the strength of the correlator should evolve in inverse proportion to the number of sources of correlated particles. This translates into an inverse dependence of the magnitude of the correlator on the produced particle density, $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$. Although prior observations of $\sqrt{\langle \Delta p_{\mathrm{T},1}\Delta p_{\mathrm{T},2}\rangle}/\langle\langle p_{\mathrm{T}}\rangle\rangle$ at RHIC and LHC have shown that the magnitude of this correlator does in fact decrease monotonically from peripheral to central collisions, a sizeable deviation from the trivial $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ scaling behavior was observed in semi-central to central collisions of large systems [1]. The above phenomenon motivated the results shown in this thesis. The goals of the measurements of event-by-event fluctuations of $\langle p_{\mathrm{T}}\rangle$ are to examine how the strength of the correlator evolves with collision energy and system size, and determine whether this evolution can be understood quantitatively based on existing models. Additionally, given the presence of jet constituents is likely

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to influence the magnitude of measured correlations, particularly in small collision systems, this work also includes an analysis of the strength of the $\sqrt{\langle \Delta p_{\mathrm{T},1}\Delta p_{\mathrm{T},2}\rangle}/\langle\langle p_{\mathrm{T}}\rangle\rangle$ correlator based on the transverse shape of events measured in pp collisions.

Results and discussion

For the first time, the magnitude of two particle correlator is measured as a function of the charged particle density in pp collisions at $\sqrt{s} = 5.02$ TeV, Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV, and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The strength of the two particle correlator is found to be non-vanishing and exhibit an approximate power law dependence on the produced charged particle density. Fluctuations of the event-by-event $\langle p_{\mathrm{T}}\rangle$ are found to be non-Poissonian and exhibit a strong dependence on the particle density in all collision systems.

The measured evolution of two particle correlator with $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ for Pb–Pb and Xe–Xe collisions is compared with calculations based on the HIJING and AMPT model using the default mode and the mode with string melting. The magnitude of two particle correlator computed with HIJING exhibits a simple power law behavior. This power law dependence and exponent value are consistent with the behavior expected for a system consisting of a simple superposition of nucleon–nucleon collisions without re-scattering of the secondaries as modelled by HIJING. One finds, however, that while the evolution of the correlator measured in both Pb–Pb and Xe–Xe approximately follows the HIJING power-law fit in the range $10 < \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle < 50$, it clearly deviates from this simple trend at $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle > 50$. This indicates that the final state particle production in heavy ion collisions cannot be described by a mere superposition of independent particle-emitting sources.

The evolution of the strength of the two-particle correlator with $\langle \mathrm{dN_{ch}}/\mathrm{d}\eta\rangle$ in pp collisions at $\sqrt{s} = 5.02$ TeV for different spherocity classes has also been reported in this thesis. Jetty events exhibit larger $\langle p_{\mathrm{T}}\rangle$ fluctuations than the isotropic events. The correlator strength is enhanced significantly by the presence of jets in the events. It is known that jets are quenched in high multiplicity region, thus fewer particles from jets are expected to be detected as compared to the system without jet quenching. Since jets are missing or suppressed, the correlator is expected to be reduced relative to perfect scaling. On the contrary, an increase in the correlator strength for the jetty events relative to the spherocity integrated pp collisions suggest that the results seen in A–A collisions are not driven directly by the suppression of jets. Thus the presence of jets in central A–A collisions are not expected to have a significant contribution to the strength of the correlator.

The thesis also explores on study of multiplicity dependence of heavy flavor production [2, 3] and multiplicity and transverse spherocity dependence of $\langle p_{\mathrm{T}}\rangle$ fluctuations of charged particles in pp collisions at $\sqrt{s} =$ 7 and 13 TeV [4] using different modes of colour reconnection and rope hadronization in PYTHIA.

Summary

Studies based on the thesis found that the final state particle production in Xe–Xe and Pb–Pb collisions are non-Poissonian in nature and cannot be described by a mere superposition of independent particle-emitting sources. Also, the presence of jets in central Pb–Pb collisions are not expected to have a significant contribution to the strength of the correlator rather this feature most likely arises from the presence of collective flow.

References

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