Collective dynamics of heavy ion collisions in ATLAS

Helena Santos*, on behalf of the ATLAS Collaboration

Laboratório de Instrumentação e Física Experimental de Partículas, LIP
Av. Prof. Gama Pinto 2, Lisbon, Portugal

* helena@lip.pt

50th International Symposium on Multiparticle Dynamics (ISMD2021)
12-16 July 2021
doi:10.21468/SciPostPhysProc.10

Abstract

The latest measurements of collective behaviour in a variety of collision systems with the ATLAS detector at the LHC, including pp collisions at 13 TeV, Xe+Xe collisions at 5.44 TeV, and Pb+Pb collisions at 5.02 TeV, are presented. They include v_n-[p_{T}] correlations, which carry important information about the initial-state geometry of the quark-gluon plasma and can shed light on any quadrupole deformation in the Xe nucleus, and measurements of flow decorrelations differential in rapidity, which probe the longitudinal structure of the colliding system. These measurements furthermore provide stringent tests of the theoretical understanding of the initial state in heavy ion collisions.

Received 22-11-2021
Accepted 31-03-2022
Published 11-08-2022
Check for updates
doi:10.21468/SciPostPhysProc.10.034

1 Introduction

Heavy-ion collisions at the LHC produce the quark-gluon plasma (QGP) whose space-time evolution is described by hydrodynamics [1]. Owing to strong event-by-event density fluctuations in the initial state, the space-time evolution of the QGP also fluctuates event by event. These fluctuations lead to correlations of particle multiplicity in momentum space in both the transverse and longitudinal directions with respect to the collision axis. Studies of particle correlations in the transverse plane reveal strong harmonic modulation of the particle densities in the azimuthal angle, $\frac{dN}{d\phi} \equiv \frac{N_0}{2\pi}(1+2\sum_{n=1}^{\infty} v_n \cos(n(\phi-\Phi_n)))$, where v_n and Φ_n represent the magnitude and event plane angle[1] of the n^{th}-order azimuthal flow vector $V_n = v_n e^{in\Phi_n}$.
The GLAUBER Monte Carlo model [2] is used to obtain a correspondence between the total transverse energy deposited in the ATLAS [3] forward calorimeter (FCal) and the sampling fraction of the total inelastic A+A cross-section, allowing the setting of the centrality percentiles.

[1]The event plane is defined by the beam direction and by the direction of the impact parameter b.

2 v_n-$[p_\mathrm{T}]$ correlations

The goal of this measurement is to understand the system size dependence, and in particular the role of the Xe nucleus deformation, through comparisons between Pb+Pb and Xe+Xe collisions results. Model calculations show that V_n are proportional to the eccentricities $\mathcal{E}_n$ for n = 2, 3, and 4 in central collisions [4]. Correlated fluctuations between the $\mathcal{E}_n$ and the system size in the initial state are expected to generate dynamical correlations between v_n and $[p_\mathrm{T}]$ in the final state. The correlator $\rho(v_n^2,[p_\mathrm{T}]) = cov(v_n^2,[p_\mathrm{T}])/(\sqrt{(}var(v_n^2))\sqrt{(}c_k))$, where $[p_\mathrm{T}]$ is the average transverse momentum of particles in each event and c_k is the variance of $[p_\mathrm{T}]$, is shown in Figure 1. A smaller magnitude of $\rho(v_2^2,[p_\mathrm{T}])$ in Xe+Xe collisions is observed in all centrality range and there is a significant difference in the $N_\mathrm{rec}^\mathrm{ch}$-based and ΣE_T-based (number of reconstructed charged particles and sum of the transverse energy depositions in the FCal, respectively) centrality binning. These systematic differences are much smaller in $\rho(v_3^2,[p_\mathrm{T}])$. The models TRENTO+HYDRO [6] and CGC+HYDRO [7] do not capture the trends in the data, either qualitatively or quantitatively. Although the correlations between v_n and $[p_\mathrm{T}]$ are sensitive to the nuclear deformations in the initial state, centrality fluctuations need to be taken into account in the understanding of the nuclear deformation effects on the Xe+Xe results [5].

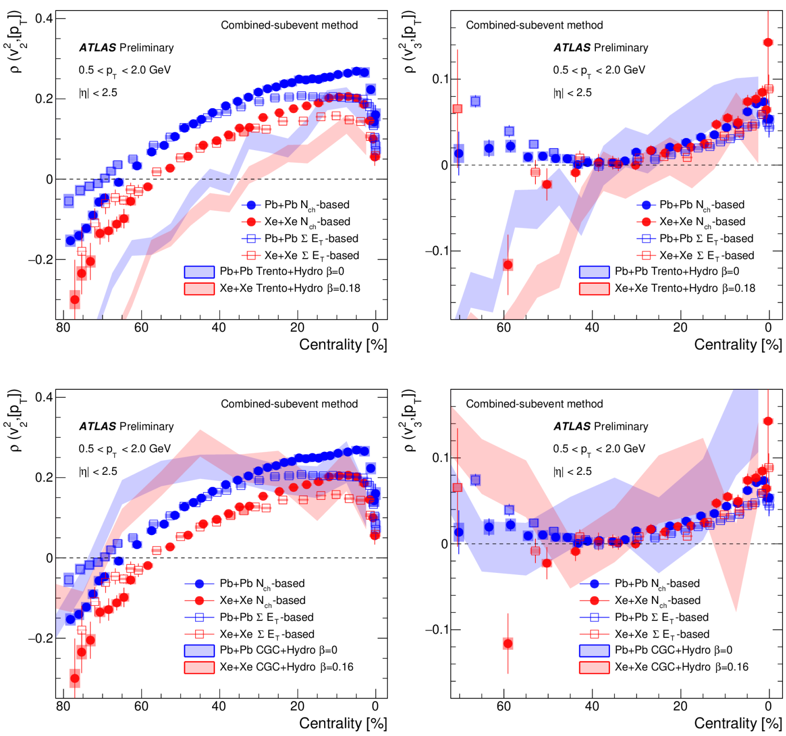

Figure 1: $\rho(v_2^2,[p_\mathrm{T}])$ (left) and $\rho(v_3^2,[p_\mathrm{T}])$ (right) as a function of the collisions centrality in Pb+Pb (blue symbols) and Xe+Xe (red symbols) collisions obtained using $N_\mathrm{rec}^\mathrm{ch}$-based (closed symbols) and ΣE_T-based (open symbols) event averaging procedure for charged particles in 0.5< p_T <2 GeV [5]. They are compared with a hydrodynamical model calculation based on Trento initial condition [6] (top) and with a calculation based on a three-dimensional initial condition dynamically generated from gluon saturation models [7] (bottom). The error bars and boxes on the data points regard statistical and systematic uncertainties, respectively. The width of the bands represent the statistical uncertainties of the models.

3 Longitudinal decorrelation dynamics

The longitudinal flow decorrelations are studied using the product of the particles weighted flow vectors $q_n(\eta) = \Sigma_j w_j e^{in\phi_j}/(\Sigma_j w_j)$ in the Inner Detector [3] and $q_n(\eta_{\rm ref})$ in the FCal, averaged over events in a given centrality interval. The $r_{n|n}(\eta)$ correlator, which quantifies the decorrelation between η and -η, and the slope parameter F_2, which is obtained via a simple linear regression of the $r_{n|n}(\eta)$ data, are shown in Figure 2 for Xe+Xe collisions. The $r_{2|2} > r_{3|3} > r_{4|4}$ decrease linearly with η and F_2 shows a strong centrality dependence, being smallest in the 20–30% centrality interval and larger towards more-central and more-peripheral collisions. This strong centrality dependence is due to the average elliptic geometry in mid-central collisions, which dominates v_2 and makes this coefficient less sensitive to decorrelations, while the fluctuation-driven collision geometries dominate in central and peripheral collisions [8].

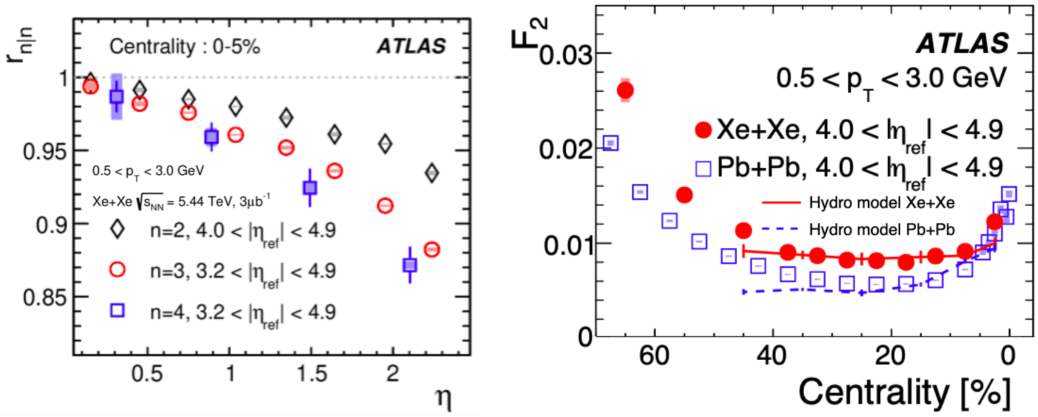

Figure 2: Left panel: $r_{2|2}$, $r_{3|3}$ and $r_{4|4}$ as a function of η in Xe+Xe collisions for six centrality intervals. The $|\eta_{\rm ref}|$ stands between 4.0< $|\eta_{\rm ref}|$ <4.9 for $r_{2|2}$, and 3.2< $|\eta_{\rm ref}|$ <4.9 for $r_{3|3}$ and $r_{4|4}$. The error bars and boxes regard statistical and systematic uncertainties, respectively. Right panel: The F_2 compared between Xe+Xe and Pb+Pb collisions as a function of centrality. The error bars and shaded boxes on the data represent statistical and systematic uncertainties, respectively [8] . The results from a hydrodynamic model are shown as solid lines (Xe+Xe) and dashed lines (Pb+Pb) with the vertical error bars representing statistical uncertainty of the predictions [9] .

Funding information The author acknowledges the financial support of Fundação para a Ciência e a Tecnologia (FCT) through FCT Researcher contracts CEECIND/03346/2017 and CERN/FIS-PAR/0002/2019.

References

[1] C. Gale, S. Jeon and B. Schenke, *Hydrodynamic modeling of heavy-ion collisions*, Int. J. Mod. Phys. A **28**, 1340011 (2013), doi:10.1142/S0217751X13400113.

[2] M. L. Miller, K. Reygers, S. J. Sanders and P. Steinberg, *Glauber Modeling in High-Energy Nuclear Collisions*, Annu. Rev. Nucl. Part. Sci. **57**, 205 (2007), doi:10.1146/annurev.nucl.57.090506.123020.

[3] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, J. Inst. **3**, S08003 (2008), doi:10.1088/1748-0221/3/08/S08003.

[4] F. G. Gardim, F. Grassi, M. Luzum and J.-Y. Ollitrault, *Mapping the hydrodynamic response to the initial geometry in heavy-ion collisions*, Phys. Rev. C **85**, 024908 (2012), doi:10.1103/PhysRevC.85.024908.

[5] ATLAS Collaboration, *Measurement of flow and transverse momentum correlations in Pb+Pb collisions at* $\sqrt{s_{\mathrm{NN}}} = 5.02$ *TeV and Xe+Xe collisions at* $\sqrt{s_{\mathrm{NN}}} = 5.44$ *TeV with the ATLAS detector*, ATLAS-CONF-2021-001.

[6] G. Giacalone, *A matter of shape: seeing the deformation of atomic nuclei at high-energy colliders*, arXiv:2101.00168.

[7] G. Giacalone, B. Schenke and C. Shen, *Observable Signatures of Initial State Momentum Anisotropies in Nuclear Collisions*, Phys. Rev. Lett. **125**, 192301 (2020), doi:10.1103/PhysRevLett.125.192301.

[8] ATLAS Collaboration, *Longitudinal Flow Decorrelations in Xe+Xe Collisions at* $\sqrt{s_{NN}}$*=5.44 TeV with the ATLAS Detector*, Phys. Rev. Lett. **126**, 122301 (2021), doi:10.1103/PhysRevLett.126.122301.

[9] X.-Y. Wu, L.-G. Pang, G.-Y. Qin and X.-N. Wang, *Longitudinal fluctuations and decorrelations of anisotropic flows at energies available at the CERN Large Hadron Collider and at the BNL Relativistic Heavy Ion Collider*, Phys. Rev. C **98**, 024913 (2018), doi:10.1103/PhysRevC.98.024913.