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Is hadronic flow produced in p–Pb collisions at the Large Hadron Collider?

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Abstract

Using the Ultra-relativistic Quantum Molecular Dynamics (`UrQMD`) model, we investigate the azimuthal correlations in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. It is shown that the simulated hadronic p–Pb system can not generate the collective flow signatures, but mainly behaves as a non-flow dominant system. However, the characteristic $v_2(p_{\rm T})$ mass-ordering of pions, kaons and protons is observed in `UrQMD` simulations, which is the consequence of hadronic interactions and not necessarily associated with strong fluid-like expansions.

The relativistic heavy ion collisions at the Large Hadron Collider (LHC) have provided strong evidences for the creation of the Quark–Gluon Plasma (QGP). One of the crucial observables is the azimuthal anisotropy of the transverse momentum distribution for produced hadrons [1], usually characterized by the Fourier flow-coefficients [2]. The second Fourier flow-coefficient v_2 is called elliptic flow, which has been systematically measured and studied at the LHC [3]. These results, together with the comparisons to theoretical model calculations, provides important information on the Equation of State (EoS) and the transport properties of the QGP. The azimuthal correlations in $\sqrt{s_{\rm NN}} = 5.02$ TeV p–Pb collisions were also measured at the LHC with the original purposes of providing reference data for the high

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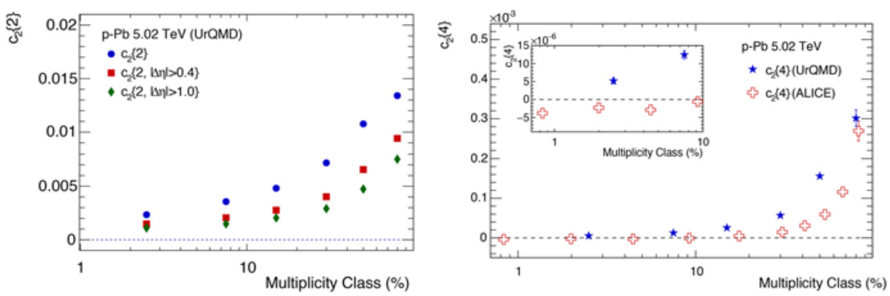

Figure 1: Multiplicity class dependence of $c_2\{2\}$ (left) and $c_2\{4\}$ (right).

energy Pb–Pb collisions. However, a large amount of unexpected collective behaviors have been discovered [9] and the results can be semi-quantitatively described by (3+1)-d hydrodynamic simulations [4,5]. It might suggest that the large collective flow has been developed in the small p–Pb systems. In this study [6], we utilize a hadron cascade model Ultra-relativistic Quantum Molecular Dynamics (`UrQMD` version 3.4) [7] to simulate the evolution of the hadronic matter and then study the azimuthal correlations of final produced hadrons.

Figure 1 (left) presents the centrality dependence of the 2-particle cumulant $c_2\{2\}$ from `UrQMD` model. With various pseudorapidity gaps, $c_2\{2\}$ exhibits decreasing trends from low multiplicity events to high multiplicity events. As the pseudorapidity gap increases, the magnitudes of $c_2\{2\}$ become weaker for `UrQMD`. These results agree with the suppression of the so-called non-flow effects, which is the azimuthal correlations not associated with the symmetry plane. When the pseudorapidity gap $|\Delta\eta|$ is larger than 1.0, $c_2\{2\}$ from `UrQMD` still presents strong centrality dependence, showing a typical non-flow behavior. It indicates that `UrQMD` hadronic expansion could not generate enough flow in a small p–Pb system, and non-flow effects still dominate the 2-particle correlations even with $|\Delta\eta| > 1.0$. To better understand the hadronic systems simulated by `UrQMD`, we investigate the 4-particle cumulant of the second Fourier flow-coefficient $c_2\{4\}$, which is less sensitive to non-flow effects. Figure 1 (right) shows that the $c_2\{4\}$ measurement exhibits a transition from positive to negative values for the most central collisions, indicating the creation of flow-dominated systems in the high multiplicity events. However, $c_2\{4\}$ calculations from `UrQMD` simulations keep positive for all available multiplicity classes, including central collisions. As a result, real values of $v_2\{4\}$ can not be extracted. This comparison further illustrates the difference between the p–Pb systems created

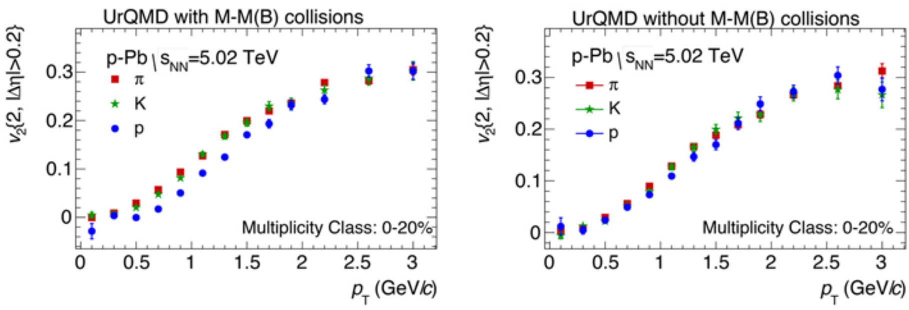

Figure 2: $v_2(p_\mathrm{T})$ of pions, kaons and protons in p–Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV, calculated from `UrQMD` with (left) and without (right) M-M and M-B collisions.

in experiment and simulated by `UrQMD`. Without the contributions from the initial stage and/or the QGP phase, the measured flow-like 4-particle correlations in high multiplicity events can not be reproduced by a microscopic transport model with only hadronic scatterings and decays.

In addition, the characteristic feature of $v_2(p_\mathrm{T})$ mass-ordering among pions, kaons and protons was observed in p–Pb collisions [9]. This mass ordering feature is similar with what observed in Pb–Pb collisions [10] and can be roughly reproduced by hydrodynamic calculations [4,5]. It was token as a strong evidence for the collective expansion of the p–Pb systems created in $\sqrt{s_\mathrm{NN}} = 5.02$ TeV collisions. Figure 2 shows that a clear v_2 mass-ordering among pions, kaons and protons below 2 GeV is also observed in `UrQMD`. Such mass-ordering pattern, caused by only hadronic interactions, qualitatively agrees with the ALICE measurement [9].In `UrQMD`, the unknown hadronic cross sections are calculated by the additive quark model (`AQM`) through counting the number of constituent quarks within two colliding hadrons. As a result, the main meson-baryon (M-B) cross sections from `AQM` are about 50% larger than the meson-meson (M-M) cross sections, leading to the v_2 splitting between mesons and baryons after the evolution of hadronic matter. It is also observed in Fig. 2 (right) that when switch off the M-B and M-M interaction channels in `UrQMD`, the v_2 mass-ordering almost disappears. The comparison of Fig. 2 (left) and (right) illustrates that the hadronic interactions could lead to a v_2 mass-ordering feature, even for small p–Pb systems without enough flow generation.

In summary, using `UrQMD` hadron cascade model, we studied azimuthal correlations in p–Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV. It is found that hadronic interactions alone could not generate sufficient collective flow as observed in experiment. In order to fit the azimuthal correlations measurements, the contributions from the initial stage and/or the QGP phase can not be neglected. In addition, we extended our study of azimuthal correlations to identified hadrons. A v_2 mass-ordering was generated by `UrQMD`, which is similar to the ALICE measurements. This characterize feature is mainly caused by hadronic interactions. The experimentally observed v_2 mass-ordering alone is not necessarily explained as a flow signal associated with the strong fluid-like expansions.

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