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Collective Effects in the Interactions of Small Systems on the RHIC

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Abstract—It has long been believed that small colliding systems (p + Au, d + Au, ^{3}He + Au) are can only be used to study the collective effects of cold nuclear matter. However, recent studies on the RHIC and LHC accelerators indicate there are flowlike collective effects characterized by the high multiplicity of charged particles produced in these collisions. Whether these effects result from the hydrodynamic expansion of a dense and hot thermalized medium or are caused by the initial state remains an open question. This work reports the results from measuring flow characteristics in d + Au and ^{3}He + Au collisions at an energy of 200 GeV in the PHENIX experiment on the RHIC collider. Attempts to describe the results theoretically are discussed.

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INTRODUCTION

Recent measurements in the ATLAS [1], CMS [2], and ALICE [3] experiments on the LHC (CERN) revealed azimuthal correlations between charged hadrons separated by several units in rapidity ($|\eta| \gg 1$) in $p + p$ and $p + A$ collisions. Similar correlations were observed in selecting events with high multiplicities of secondary particles. Earlier, correlations similar to these were observed only in collisions of heavy relativistic nuclei ($A + A$) on the RHIC and LHC accelerators and were attributed to the development of a collective flow. The flow developed due to the spatial anisotropy of the overlap region of colliding heavy nuclei. Intense interactions inside the arising system and its rapid thermalization resulted in spatial anisotropy being transformed into the momentum anisotropy of the produced particles, observed as a collective flow. Measuring the fluxes in collisions of heavy relativistic particles showed that a strongly interacting quark–gluon plasma (QGP) with properties of a perfect fluid was produced [4]. Even more unexpected was the observation of azimuthal correlations in $p + p$ and $p + A$ interactions, which were never thought to be candidates for QGP formation and study. Similar azimuthal correlations between hadrons categorized according to speed were observed later in d + Au collisions at an energy of $\sqrt{s_{NN}}$ = 200 GeV on the RHIC [5]. An attempt was made to study correlations in ^{3}He + Au collisions at the same energy in order to obtain systematic knowledge of the phenomenon. The $p + p$, $p + A$, d + Au, and ^{3}He + A collisions differ by the spatial anisotropy of the region of nuclear overlap. If the observed correlations are indeed related to the development of a collective flow, they must be sensitive to the initial geometry of the interacting system.

ELLIPTIC FLOWS

Figure 1 shows the results from measuring elliptic flows (v_2) as functions of transverse momentum p_T during investigations of central d + Au collisions (0–5 and 0–20%) at an energy of $\sqrt{s_{NN}}$ = 200 GeV and p + Pb collisions at an energy of $\sqrt{s_{NN}}$ = 5.02 TeV on the RHIC and LHC accelerators. The measurements are compared to theoretical calculations based on hydrodynamics [6]. The observed mass dependences of the elliptic flows are similar to those in collisions of heavy nuclei. The theoretical calculations also describe the experimental data well.

A set of experimental data on ^{3}He + Au collisions was recently accumulated in the PHENIX experiment [7]. The results from their analysis for coefficients v_2 and v_3 of the charged particles are shown in Fig. 2. The data are shown for 0–5% central ^{3}He + Au collisions at an energy of $\sqrt{s_{NN}}$ = 200 GeV. The results from theoretical calculations using the SONIC model [8], the Glauber model with hydrodynamic development [9], the AMPT model [10], the Super Sonic model [11], and the IP-Glasma model with hydrodynamic development [12] are also presented. The theoretical calculations describe the experimental data to differing degrees. Azimuthal correlations between particles are observed in 5% of the most central ^{3}He + Au collisions at an energy of $\sqrt{s_{NN}}$ = 200 GeV. This result is in good agreement with the earlier measurements in d + Au

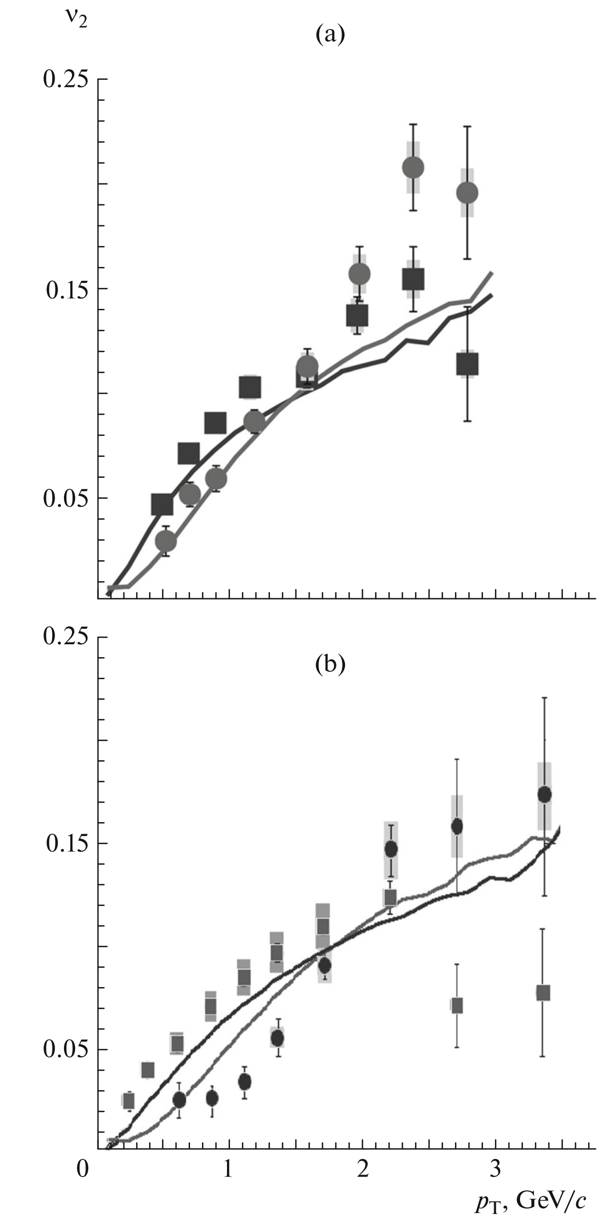

Fig. 1. Elliptic flow v_2 measured as a function of transverse momentum p_T for pions (■) and protons (●) on (a) the RHIC and (b) the LHC. Lines represent theoretical calculations.

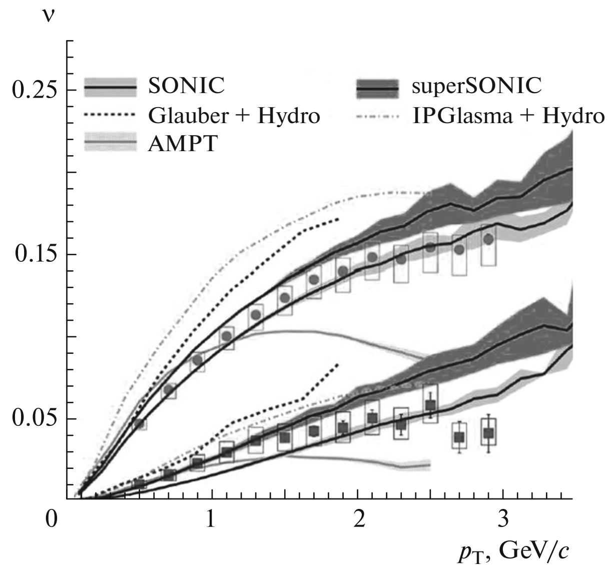

Fig. 2. Coefficients v_2 (●) and v_3 (■), measured as functions of transverse momentum p_T for charged particles in ^{3}He + Au collisions at an energy of $\sqrt{s_{NN}}$ = 200 GeV on the RHIC. Lines are theoretical calculations.

collisions at the same energy. The observation of such correlations could indicate that a collective flow develops during interactions between light and heavy nuclei at RHIC energies.

CONCLUSIONS

The geometrical effects the initial state has on the properties of particles produced in collisions of small systems is clearly observed on the RHIC. Evidence of this is the positive values of coefficients v_2 and v_3 for charged particles in nuclear d + Au and ^{3}He + Au collisions at an energy of $\sqrt{s_{NN}}$ = 200 GeV. The ability of hydrodynamics-based theoretical models to describe the observed effects could indicate the formation of a collective flow in collisions of small systems.

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