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Collective phenomena in high-energy nuclear collisions

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Abstract

I review experimental studies of collective phenomena in $p + \mathrm{A}$ and $\mathrm{A} + \mathrm{A}$ collisions presented in the Quark Matter 2014 conference.

Keywords: Heavy-ion collisions; Fluctuations; Correlations; Collective flow; Ridge

1. Introduction

The goal of high-energy nuclear experiments is to understand the properties of the QCD matter created in the heavy-ion collisions. Most progress to this end has been obtained from study of collective flow phenomena, which are sensitive to the dynamics of the system at various stages of the space–time evolution. Extensive measurements of various flow observables in $\mathrm{A} + \mathrm{A}$ collisions at RHIC and the LHC, in combination with successful modeling by relativistic viscous hydrodynamics, have placed important constraints on the transport properties and initial conditions of the produced matter [1,2].

Recently, qualitatively similar collective behaviour has also been observed in high-multiplicity $p + \mathrm{A}$ collisions [3]. Current debate is focused on the effective mechanism behind the apparent collectivity in these small systems: Is it initial state effect, final state effect, or both?

This contribution reviews the new results from $p + \mathrm{A}$ and $\mathrm{A} + \mathrm{A}$ collisions from RHIC and the LHC, obtained with various flow observables. I first summarize experimental progresses in

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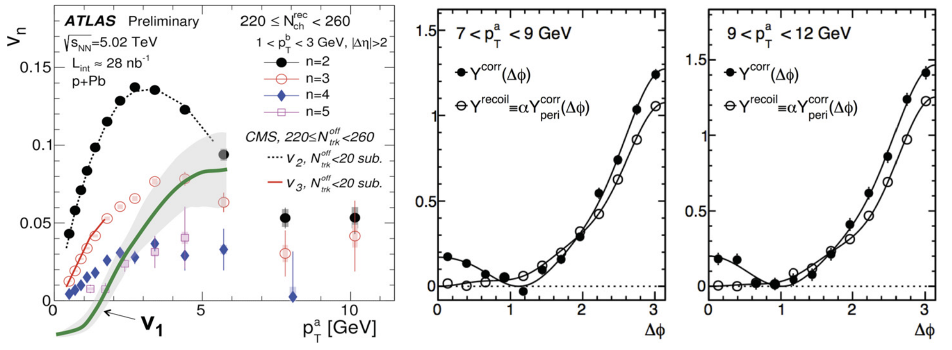

Fig. 1. The $v_n(p_T)$ with $n = 2$ to 5 for pairs with $|\Delta\eta| > 2$ [4]. An overlay sketch of rapidity-even v_1 data is also shown. Results are compared to the CMS data with comparable multiplicity.

studying the collectivity in small collision systems. I then make a few remarks on flow results in A + A collisions that I personally found interesting. This is followed by a focused discussion of the event-by-event (EbyE) flow fluctuations measurements in A + A collisions. Finally I discuss open issues and future physics opportunities.

2. Collectivity in small systems

The observation of collective behaviour in high-multiplicity p + A collisions [3] came as a surprise, since the transverse size of the produced system was thought to be too small for the hydrodynamic description to work. Experimentalists attempt to elucidate this puzzle by mapping out the detailed properties of the azimuthal harmonics in p + A collisions and comparing with those in peripheral A + A collisions.

Fig. 1(a) shows the first five azimuthal harmonics v_1 to v_5 as a function of p_T in high-multiplicity p + Pb collisions, obtained from a two-particle correlation (2PC) method [4]. The away-side and near-side short-range correlations have been estimated from events with low multiplicity and subtracted. The v_n magnitude is largest for $n = 2$, and decreases with increasing n. All v_n increase with p_T up to 3–5 GeV and then decrease, but remain positive at higher p_T. It is interesting that the v_2 and v_3 values are sizable at $p_T > 8$ GeV (3–5%), reflecting a significant near-side ridge regardless of the recoil subtraction procedure as shown in the right panels of Fig. 1. This may be the first indication of a small azimuthal anisotropy of jet yield in high-multiplicity p + Pb collisions.

Fig. 1 also shows an overlay sketch of the preliminary rapidity-even v_1 [4]. The values of v_1 are comparable to v_3 at $p_T \sim 4$ GeV, albeit with larger uncertainties since they are directly sensitive to the recoil subtraction.

Multi-particle cumulants beyond 2PC have been argued to be able to distinguish the correlation arising from collective dynamics from those arising from sources involving few particles. CMS presents a detailed measurement of multi-particle cumulants $v_2\{4\}$, $v_2\{6\}$ and $v_2\{8\}$, as well as Lee–Yang Zero (LYZ) method $v_2\{LYZ\}$ in p + Pb or Pb + Pb collisions [5]. The different methods agree within ±10% over a broad multiplicity range in each collision system (Fig. 2), confirming the collective nature of the observed correlations in both systems. The apparent difference from $v_2\{2\}$ reflects the fluctuations either present in the initial geometry or generated in the collective expansion.