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d + Au hadron correlation measurements from PHENIX

Anne M. Sickles, for the PHENIX Collaboration

Physics Department, Brookhaven National Laboratory, Upton, NY, United States

HIGHLIGHTS

- A significant v_2 is observed for hadrons in d + Au collisions at RHIC.
- The first observation of a long range ridge correlation in d + Au collisions is observed.
- Approximate scaling of v_2 with the participant eccentricity is observed for Au + Au, d + Au, p + Pb and Pb + Pb collisions.

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ABSTRACT

Recent observations of extended pseudorapidity correlations at the LHC in p + p and p + Pb collisions are of great interest. Here we present related results from d + Au collisions at PHENIX. We present the observed v_2 and discuss the possible origin in the geometry of the collision region. We also present new measurements of the pseudorapidity dependence of the ridge in d + Au collision. Future plans to clarify the role of geometry in small collision systems using ^{3}He + Au collisions are discussed.

The highly asymmetric nuclear collisions d + Au and p + Pb have been studied at ultra-relativistic energies primarily to establish a baseline of cold nuclear matter effects in heavy ion collisions. In 2003 measurements from RHIC [1–4] conclusively established that the jet quenching observed at RHIC [5] was due to a final state effect in the hot nuclear matter rather than an initial state effect.

In heavy ion collisions at both RHIC and LHC the properties of the matter are understood to be described by hydrodynamics with a very small sheer viscosity to entropy density ratio, η/s [6]. The η/s is constrained via measurements of Fourier coefficients of the azimuthal distribution of particles

E-mail address: anne@bnl.gov.

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(v_N, where N is the order of the Fourier coefficient). Measurements of the particle pair correlations in heavy ion collisions have been well described by products of the same v_N [7,8]. One prominent feature of these correlation functions is the so-called *ridge* a long range in pseudorapidity, small $\Delta\phi$ correlation resulting from the sum of positive v_N correlations around $\Delta\phi = 0$.

Surprisingly, a similar long range correlation was seen in very high multiplicity p + p collisions at the LHC [9] where a hydrodynamical system was not generally expected to be created. Recently, at the LHC a double ridge structure has been observed also in p + Pb collisions at 5.02 TeV [10,11]. Once the jet and dijet correlations were subtracted out the residual distribution was largely described by a $\cos 2\Delta\phi$ modulation. Extractions of v_2 resulted in values with a similar magnitude to those in heavy ion collisions [10,11], which was suggestive of a similar hydrodynamic origin. However, such correlations were also expected from the Color Glass Condensate model [12].

Given these exciting discoveries at the LHC, it was of course natural to ask if such effects could be seen in d + Au collisions at RHIC and what could be understood about the physical origin of these effects from the comparison between RHIC and LHC measurements. A large sample of d + Au collisions at $\sqrt{s_{NN}} = 200$ GeV was taken in 2008. Here, we report on measurements by the PHENIX collaboration using that data.

1. Midrapidity correlations

PHENIX has measured charged hadron azimuthal angular pair correlations in central (the top 5% of centrality) and peripheral (50%–88% centrality) d + Au events at $\sqrt{s_{NN}} = 200$ GeV. The correlations for a selection of p_T combinations are shown in the left panel of Fig. 1. The trigger particle is always $0.5 < p_T < 0.75$ GeV/c and partner particle p_T ($p_{T,a}$) is varied. In order to reduce same side jet contributions a $\Delta\eta$ separation greater than 0.48 is required between the particles. The difference of the central and peripheral correlations, $\Delta Y(\Delta\phi)$, is also shown. An extraction of the second Fourier component, c_2 is overlaid. The curve describes the data well. The c_2 values, as a function of the p_T of the partner are shown in the right panel of Fig. 1. c_2 reaches a maximal value of about 1% at around $p_{T,a} = 1.5$ GeV/c. Also shown on the same Figure is the third Fourier coefficient, c_3; this is consistent with zero in the measured p_T range. Predictions ΔY at RHIC in the Color Glass Condensate model have been made [13].

PHENIX lacks the pseudorapidity acceptance necessary to completely suppress same side jet correlations (which are a small $\Delta\phi$ and small $\Delta\eta$ effect) in these correlations. In order to constrain the possible effects of jet correlations in the observed signal we repeat the same procedure with d + Au events generated with HIJING [20]. The results of this study are also shown in the right panel of Fig. 1. c_2 in HIJING is consistent with zero and much smaller than that observed in the data. Additionally, we have tested the sensitivity to the $|\Delta\eta|$ cut used by varying it from the nominal 0.48 value to 0.36 and 0.60; no significant change in the extracted c_2 value is observed. A direct measure of the large $\Delta\eta$ correlations will be discussed in Section 2.

The factorization assumption [21,22,7],

$$c_N\left(p_{T,trig}, p_{T,a}\right) = v_N\left(p_{T,trig}\right) v_N\left(p_{T,a}\right), \tag{1}$$

is used to extract the single particle anisotropies, v_2, which are shown in Fig. 2. v_2 rises with p_T reaching a maximal value of about 15%. Also shown on the plot are hydrodynamic calculations from three groups [15,16,18,19]. All three calculations agree rather well with the data. Refs. [15,16,18] use $\eta/s = 0.08$. The calculation in Ref. [19] is for ideal hydrodynamics.

Since the c_3 values observed are not significantly larger than zero, it is not possible to extract $v_3\,(p_T)$ from the current data. However, it is possible to turn a calculation for $v_3\,(p_T)$ into $c_3\left(p_{T,a}\right)$, which is shown in Fig. 1 for the calculation in Refs. [15,16]. The calculation agrees well with the data.

In order to investigate the possible relationship between the geometry of the collision system and the observed v_2 we compare the v_2 values (at $p_T \approx 1.4$ GeV/c) scaled by estimates of the initial state second order eccentricity, ε_2. The v_2/ε_2 values are shown as a function of $dN_{ch}/d\eta$ at mid-rapidity in Fig. 3 for d + Au, p + Pb, Au + Au and Pb + Pb collisions. The ε_2 values are from a Glauber Monte Carlo calculation v_2/ε_2 consistent between central d + Au and midcentral p + Pb (systems which have a similar $dN_{ch}/d\eta$) despite the factor of 25 difference in collision energy. The ε_2 value in central d + Au