BNL-113367-2016

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*Submitted at the 25th International Conference on
Ultra-Relativistic Nucleus-Nucleus Collisions*

December 1, 2016

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**U.S. Department of Energy
USDOE Office of Science (SC),
Nuclear Physics (NP) (SC-26)**

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PHENIX results on centrality dependence of yields and correlations in d +Au collisions at $\sqrt{s_{NN}}=200$ GeV

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Abstract

PHENIX has measured the transverse momentum (p_T) spectra and two particle angular correlations for high p_T particles in d +Au collisions at $\sqrt{s_{NN}}=200$ GeV using the RHIC Year-2008 run data. The azimuthal angle correlations for two particles with a large rapidity gap exhibit a ridge-like structure. Using the π^0 s reconstructed in the EMCal, we have successfully extended the p_T reach of the correlation up to 8 GeV/c. We find that the azimuthal anisotropy of hadrons found at low p_T persists up to 6 GeV/c with a significant centrality and p_T dependence, similar to what was observed in A+A collisions.

Keywords: Quark-gluon plasma, small systems, collective flow, high momentum hadrons

1. Introduction

The small collision systems such as p/d +A collisions have been considered a good laboratory to quantify cold nuclear matter effects, a necessary baseline for understanding the effects of the hot and dense medium produced in A+A collisions. The observation of the ridge-like structure in the long-range azimuthal correlations in p +Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV at the LHC [1, 2], however, called into question the view of such systems as consisting merely of cold nuclear matter. The study at the LHC was followed by the PHENIX experiment at RHIC, and a finite v_2 of hadrons in 0-5 % central d +Au collisions using both the two-particle angular correlation method and the event-plane method were shown [3, 4]. These observations led the community to explore any phenomena found in A+A collisions, in p/d +A collisions. Recently, interest has focused on the high p_T region in the small systems. If the collective behavior in low p_T is hydrodynamic, the phenomena should cease at higher p_T [5, 6], while a CGC-motivated model would produce a correlation even at high p_T [7]. The hydrodynamical scenario would also suggest that the energy loss of hard scattered partons may occur in the small systems, and result in small but sizable anisotropy of the particle emission at high p_T . The recent PHENIX measurement of the reconstructed jets in minimum bias d +Au collisions at $\sqrt{s_{NN}}=200$ GeV shows little or no modification of their production rates compared to those expected from p + p collisions within the experimental uncertainty, while a strong centrality dependence in the rates has been observed [8]. Extending the measurement of v_n (or c_n) to high p_T may contribute to understanding the

¹For the full PHENIX Collaboration author list and acknowledgments, see Appendix “Collaboration” of this volume

interplay of high p_T particles and the possible medium created in the $d+Au$ collisions. We show the latest results on the azimuthal angle correlation of pairs of hadrons with a large rapidity gap in $d+Au$ and $p+p$ collisions.

2. Analysis

PHENIX recorded an integrated luminosity of 80 nb^{-1} in $d+Au$ collisions and 5.2 pb^{-1} in $p+p$ collisions in the RHIC Year-2008 run. The events were triggered by Beam-Beam counters (BBC) located at $3.1 < |\eta| < 3.9$ covering the full azimuth. The detailed description of the PHENIX detector system can be found elsewhere [9]. The long-range two particle correlation functions were constructed by pairing the charged hadrons in the mid-rapidity region ($|\eta| < 0.35$, defined as CNT) with the energy deposited in towers of Muon Piston Calorimeter (MPC) sitting either south ($-3.7 < \eta < -3.1$) or north ($3.1 < \eta < 3.9$). Figure 1(a) show the position of each PHENIX detector component in the $\phi - \eta$ coordinate. Note that the MPC south

Fig. 1. (a, left) Configuration of PHENIX detector in $\phi - \eta$ coordinate. (b, right) Two particle angular correlation functions using charged hadrons measured in CNT, and tower energies measured in MPC south detector in 0-5 % $d+Au$ collisions.

(MPCs) sits in the Au-going direction, which see more multiplicity in case of $d+Au$ collisions, while the MPC north (MPCN) sits in the d -going direction. For the higher p_T , we substituted the charged hadrons with π^0 s measured by the electromagnetic calorimeter (EMCal) through the $\pi^0 \rightarrow \gamma\gamma$ channel. We defined the $\gamma\gamma$ invariant mass region of $0.12 - 0.16 \text{ GeV}/c^2$ as the π^0 region. There is a combinatoric background underneath the π^0 peak, and we accounted for this contribution in the systematic uncertainty estimate. We applied different energy thresholds for MPC tower energies between charged hadrons and π^0 s; we used 3 GeV when associating with charged hadrons and 0.3 GeV for π^0 s.

After constructing correlation functions, we fitted them with Fourier series for quantifying their shape:

$$\frac{dN}{d\Delta\phi} = N_0 + 2c_1 \cos(\Delta\phi) + 2c_2 \cos(2\Delta\phi) + 2c_3 \cos(3\Delta\phi) + 2c_4 \cos(4\Delta\phi)$$

where c_n can be written as $c_n = v_n(\text{MPC}) \times v_n(\text{CNT})$. In the following section, we show the correlation functions as well as the c_n 's obtained from the fit.

3. Results and discussion

In Figure 1(b), we show the correlation functions for charged hadrons in CNT associated with MPCs for 0-5 % $d+Au$ collisions, together with the ones in $p+p$ collisions as reference. Comparing to the $p+p$ collision case, the correlation functions for $d+Au$ collisions have peaks on the near side ($\Delta\phi \sim 0$), which is well described by a second order Fourier term. The peaks become much prominent as one goes to higher p_T . It was found that the similar correlation is seen for CNT-MPCN correlation for the same centrality,

but the magnitude is much smaller. Solid lines show the total fit to the Fourier series as described in the previous section, while the dotted lines show each term of the series. Using π^0 's in CNT, we have successfully extended our measurement in p_T compared to that from charged hadrons as shown in Figure 2(a). The near

Fig. 2. (a, left) Two particle angular correlation functions using π^0 reconstructed in CNT, and tower energies measured in MPC south detector in 0-5 % $d+Au$ collisions. (b, right) c_2 values obtained from Fourier series fit to the π^0 -MPCs correlation functions.

side peaks are clearly seen up to $p_T \sim 6$ GeV/c, while the magnitudes decrease with p_T . The definition of the lines are the same as Figure 1(b). In order to quantify the line shape of the correlation functions, we plotted the c_2 from the Fourier series for various centralities in $d+Au$ collisions as a function of p_T of π^0 , together with that in $p+p$ collisions. The result is shown in Figure 2(b). The bottom panel show the relative systematic uncertainty for the data points shown in the top panel. The main component of the uncertainty is from the uncertainty of the correlation between the combinatoric background under π^0 and MPCs. As was seen in the correlation functions, the c_2 s are decreasing as a function of p_T . Due to the large magnitude of c_2 in $p+p$ collisions, the c_2 s from $d+Au$ collisions look similar. However, there is a clear centrality dependence of the c_2 ; higher c_2 values are seen in more central collisions.

The c_1 is the dipole component and primarily results from back-to-back jet contribution or energy conservation of the system. Therefore, we assume that c_1 can be a proxy for primordial multiplicity-related effects and we “normalize” c_2 with it so that we can more directly compare various centralities in $d+Au$ and $p+p$ collisions. With this idea in our mind, we computed $-c_2/c_1$ as shown in Figure 3(a). The bottom panel is showing the systematic uncertainty as similarly defined as in Figure 2. Note that both statistical and systematic uncertainties are smaller in $-c_2/c_1$ compared to $-c_2$, because some of the uncertainties in c_2 and c_1 are correlated and can be canceled out in the ratio. This way, we clearly see the centrality dependent change of Fourier coefficients, which approach to the $-c_2/c_1$ in $p+p$ collisions in more peripheral collisions. Assuming $c_3 = c_4 = 0$ and requiring $(\partial^2/\partial\Delta\phi^2)(dN/d\Delta\phi) = 0$ results in $-c_2/c_1 = 0.25$ which is also shown on Figure 3(a) as a dotted line. If the points are above this line, the distribution shows a “hill”, while the distribution shows a “valley” if the points are below. We found that $c_3 = c_4 = 0$ is a very good assumption in $d+Au$ and $p+p$ collision case. As we see in the correlation functions, the hill persists up to ~ 6 GeV/c for 0-5 % $d+Au$ collisions. Finally, we show the CNT-MPCN correlation for a comparison, again using π^0 's in CNT in Figure 3(b). Although the finite $-c_2/c_1$ and their slight centrality dependence are seen, the trend is very different compared to the one from CNT-MPCS. This shows the ridge-like structure is asymmetric in rapidity. This result is consistent with previous PHENIX results as well as the recent STAR publication [10].

These results show that the p_T and centrality dependence of the ridge-like structure in $d+Au$ collision resembles what was observed in A+A collisions, indicating the possibility that both collective behavior and differential energy loss play a role also in $d+Au$ collisions. The result may contribute to understanding the

Fig. 3. $-c_2/c_1$ values obtained from Fourier series fit to the π^0 -MPCS (a, left) and π^0 -MPCN (b, right) two particle angular correlation functions.

centrality dependence of the reconstructed jets [8].

4. Summary

In these proceedings, the latest results on two particle angular correlations for high p_T particles in $d+Au$ collisions at $\sqrt{s_{NN}}=200$ GeV are shown. We find that the azimuthal angle correlations for two particles with a large rapidity gap exhibit a ridge-like structure mainly coming from the collective nature of the system. Using the π^0 s reconstructed in the EMCal, we have successfully extended the p_T reach of the correlation up to 8 GeV/c. We find that the azimuthal anisotropy of hadrons found at low p_T persists up to 6 GeV/c with a significant centrality and p_T dependence, similar to what was observed in A+A collisions.

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