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 $\pi^0$ 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:

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. After the the ridge-like structure in the long-range rapidity correlation in $p+Pb$ collisions at $\sqrt{s_{_{NN}}} = 5.02$ TeV at the LHC was reported [1, 2], however, the systems can no longer be considered as a simple 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

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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 that of 5.2 pb$^{-1}$ in $p+p$ collisions in RHIC Year-8 run. The events were triggered by Beam-Beam counter (BBC) located at 3.1 < $|\eta|$ < 3.9 covering the full azimuth. The detail description of the PHENIX detector system is found in a literature [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 the towers of Muon Piston Calorimeter (MPC) sitting either south (-3.7 < $\eta$ < -3.1, Au-going direction, which has more multiplicity, in case of charged hadrons measured in CNT, and tower energies measured in MPC south detector in 0-5% $\phi$ invariant mass region of 0.12-0.16 GeV/$c^2$ through the $\gamma\gamma$ channel. We defined the $\gamma\gamma$ invariant mass region of 0.12-0.16 GeV/$c^2$ as the $\pi^0$ region. There is a combinatoric background underneath the $\pi^0$ peak, and we accounted for this contribution in systematic uncertainty estimate. We applied different energy thresholds for MPC tower energy between charged hadrons and 0.3 GeV for $\pi^0$.

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

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

where $c_n$ can be written as $c_n = v_n(MPC) \times v_n(CNT)$. 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 (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 at near side ($\Delta \phi \sim 0$), which is well described by a second order Fourier term. The peaks become much prominent as going 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 \( \pi^0 \) in CNT, we have successfully extended our measurement in \( p_T \) compared to that from charged hadrons as shown in Figure 2(a). The peaks at near side are clearly seen up to \( p_T \sim 6 \text{ GeV/c} \), while the magnitudes decrease with \( p_T \). The definition of the lines are 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 fit for various centralities in \( d+Au \) collisions as a function of \( p_T \) of \( \pi^0 \), 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 combinatoric background under \( \pi^0 \) 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 as going to more central collisions.

The \( c_1 \) is the dipole component and primarily resulted in from back-to-back jet contribution or energy conservation of the system. Therefore, we assume that \( c_1 \) can be a proxy of primordial multiplicity-related effect and “normalize” \( c_2 \) so that we can compare apple-to-apple level among 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, as going to more peripheral collisions. Assuming \( c_3 = c_4 = 0 \) and requiring \( (d^2F/d\phi^2)(dN/d\phi) \) \( \equiv \) 0 result in \( -c_2/c_1 \sim 0.25 \) which is also shown on Figure 5(a) as a dotted line. If the points are above this line, the distribution shows “hill”, while the distribution shows “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 \( \sim 6 \text{ GeV/c} \) for 0-5 \% \( d+Au \) collisions. Finally, we show the CNT-MPCN correlation for a comparison, again using \( \pi^0 \) 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 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 \( \sqrt{s_{NN}} = 200 \text{ GeV} \) are shown. We found that the azimuthal angle correlations for two particles with a large rapidity gap exhibits a ridge like structure mainly coming from the collective nature of the system. Using the \( \pi^0 \) reconstructed in the EMCal, we have successfully extended the \( p_T \) reach of the correlation up to 8 GeV/c. We found that the azimuthal anisotropy of hadrons found in 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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