Dihadron correlations in d+Au collisions from STAR

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Abstract

Dihadron correlations are reported for peripheral and central d+Au collisions at √s_{NN} = 200 GeV from STAR. The ZYAM background subtracted correlation yields are larger in central than peripheral collisions. The difference is mainly caused by centrality biases to jet-like correlations. Fourier coefficients of the raw dihadron correlations are also reported. It is found that the first harmonic coefficient is approximately inversely proportional to event multiplicity, whereas the second harmonic coefficient is approximately independent of event multiplicity.

Keywords: d+Au, dihadron correlations, ridge

1. Introduction

Normally, d+Au (and pp and pA) collisions are used as reference to heavy-ion collisions. For example, d+Au data were essential in establishing jet-quenching at RHIC—the observed high-p_T suppression [1][2] is not due to initial-state differences in parton distributions inside proton and nucleus but final-state parton-parton interactions and partonic energy loss [3][4]. This, in part, led to the paradigm of strongly interacting quark-gluon plasma [5].

Surprisingly, a long-range pseudorapidity (Δη) dihadron correlations at small azimuthal difference (Δφ) was observed, above a uniform background, at high p_T in high-multiplicity pp collisions at the LHC [6]; it was later observed in p+Pb collisions at essentially all p_T and multiplicity (except very low multiplicity) [7][8][9]. This motivated further studies of those small-system collisions,
beyond just for their use as reference to heavy-ion collisions.

In fact, prior to the ridge observation in small systems at the LHC, dihadron correlations were extensively studied in $d+Au$ collisions at RHIC [10, 11]. No ridge correlations were observed in $d+Au$. The $d+Au$ dihadron collisions were similar to those in $pp$ collisions, although slight modifications were seen. A difference was observed by using the cumulant variable between $pp$ and $d+Au$ collisions [12], qualitatively consistent with a slight difference in dihadron jet-like correlations.

A similar long-range correlation had been observed before in heavy-ion collisions—called the ridge—after a subtraction of elliptic anisotropy background [13, 10, 14]. The heavy-ion ridge correlations were attributed primarily to triangular anisotropy [15]. The similarity of the ridge suggests that elliptic anisotropy may be responsible for the ridge in $pp$ and $p+Pb$ collisions. In fact, hydrodynamic calculations with event-by-event geometry fluctuations can qualitatively and semi-quantitatively describe the observed ridge in $pp$ and $p+Pb$ collisions [16, 17, 18]. Whether the experimentally measured azimuthal anisotropies are of hydrodynamic flow origin remains a quantitative open question.

Hydrodynamic flow is not the only explanation for the $pp$ and $p+Pb$ ridge correlations. They can also be described by the Color Glass Condensate, where two-gluon density is relatively enhanced at small $\Delta \phi$ over a wide range of $\Delta \eta$ [19, 20, 21, 22].

Recently, a back-to-back double ridge was observed by subtracting dihadron correlations in peripheral $p+Pb$ collisions from that in central collisions [8, 9]. If jet correlations—dominating the away-side dihadron correlations at large $\Delta \eta$—are equal between peripheral and central collisions, then the observed double ridge would be indication of new physics. Jet correlations are due to hard-scattering and are not expected to differ over $p+Pb$ collision centrality, except that the centrality definition, usually by measured multiplicity in the final state, can bias events with varying magnitudes of jet correlations. Such biases were estimated to be 10-20% [8, 9], indicating that the observed double ridge may indeed be due to new physics other than jets.
PHENIX analyzed their $d+Au$ data using the same technique of “central − peripheral” dihadron correlations in their limited $\Delta \eta$ acceptance of $|\Delta \eta| < 0.7$ with the central arm detector [23]. They observed a double ridge in their “central − peripheral” dihadron correlations. It is unclear how much centrality biases there are on jet correlations within the PHENIX acceptance.

STAR, with its large acceptance, is suitable to investigate centrality biases to dihadron correlations. In fact, motivated by the LHC ridge observations, STAR investigated dihadron correlation in centrality differentiated $d+Au$ data. No obvious ridge was observed. The recent development of LHC and PHENIX data called for a more detailed study of the STAR data. This contribution reports the status of such a study.

2. Data Sample

The data presented here were taken during $d+Au$ run in 2003 [24]. The coincidence of the signals from the Zero Degree Calorimeters (ZDC) and the Beam-Beam Counters (BBC) selects minimum-bias (MB) events of $d+Au$ collisions. Events used in this analysis are required to have a primary vertex position $|z_{\text{vtx}}| < 30$ cm from the TPC center. A total of approximately 10 million events were used. Particle tracks are required to have least 25 (out of maximum possible 45) hits and a distance of closest approach to the primary vertex within 3 cm.

Three quantities were used to define $d+Au$ centrality: charged particle multiplicity within $|\eta| < 1$ measured by the TPC, charged particle multiplicity within $-3.8 < \eta < -1.8$ measured by the FTPC in the Au-beam direction (FTPC-Au) [24], and neutral energy measured in the ZDC of the Au-beam direction (ZDC-Au). The correlations between any two of the three measurements are shown in Fig.1. Positive correlations are observed but the correlations are quite broad. The same percentile centralities defined by different centrality measures correspond to significantly different event samples of $d+Au$ collisions.
Figure 1: Correlations between three centrality measures: TPC multiplicity ($|\eta| < 1$), FTPC-Au multiplicity ($-3.8 < \eta < -2.8$), and ZDC-Au neutral energy.

3. Data Analysis

Two sets of dihadron correlations are analyzed: TPC-TPC correlations where the trigger and associated particles are both from the TPC within $|\eta| < 1$, and TPC-FTPC correlations where the trigger particle is from the TPC and the associated particle is from either the FTPC-Au within $-3.8 < \eta < -2.8$ or the FPTC-d within $2.8 < \eta < 3.8$. The $p_T$ ranges of trigger and associated particles reported here are both $1 < p_T < 3$ GeV/c. The associated particle tracking efficiency of $85\% \pm 5\%$ (syst.) is corrected. The correlations are normalized per trigger particle.

The two-particle acceptance correction is obtained from the mixed-events technique. The mixed events are required to be within 5 cm in $z_{vtx}$, with the same multiplicity (for the TPC and FTPC-Au centrality measures) or within ZDC-Au ADC-Sum 10-size bins (for the ZDC-Au centrality measure). The mixed-events acceptance are normalized to 100% at $\Delta \eta = 0$ for TPC-TPC correlations and at $\Delta \eta = \pm 3$ for TPC-FTPC correlations.

Figure 2 shows the two-particle acceptance corrected dihadron correlations in $(\Delta \eta, \Delta \phi)$ in peripheral and central $d+$Au collisions. In the rest of this article, correlation functions projected onto $\Delta \phi$ and $\Delta \eta$ are studied. Two approaches are taken to analyze the correlation functions. One is to analyze the correlated yields after subtracting a uniform combinatorial background. The background is normalized by the Zero-Yield-At-Minimum (ZYAM) assumption [25]. The
other is to decompose the correlation functions into Fourier series and study the Fourier coefficients. No background subtraction is required.

Systematic uncertainties are assessed by varying the ZYAM normalization $\Delta \phi$ range from the default of 0.4 to 0.2 and 0.6 radian. In addition a 5% systematic uncertainty from the tracking efficiency is applied on the correlated yield. For the Fourier coefficients, the systematic uncertainties are expected to be small compared to statistical uncertainties, but a thorough study of systematic uncertainties has not been done yet.

4. Results on correlated yields

Figure 3 shows the TPC-TPC $\Delta \phi$ correlations in three ranges of $\Delta \eta$. Both peripheral and central collisions are shown; centrality is determined by the FTPC-Au. It is observed that the correlated yields are larger in central than peripheral $d+Au$ collisions.

In order to investigate the source of the difference between central and peripheral collisions, $\Delta \eta$ correlations for near side ($|\Delta \phi| < 0.8$) and away side ($|\Delta \phi - \pi| < 1$) are shown in Fig. 4. The near-side correlations exhibit a Gaussian peak and the away-side correlations are approximately uniform. Gaussian+constant fits to the near-side correlations indicate a difference of 20% in the Gaussian area between central and peripheral collisions. The difference between central and peripheral collisions, shown in the right panel of Fig. 4, ex-
Figure 3: Dihadron $\Delta \phi$ correlations in three ranges of $\Delta \eta$ in peripheral (black) and central (red) $d$+Au collisions. Trigger and associated particles are both from TPC ($|\eta| < 1$) and $1 < p_T < 3$ GeV/c. Centrality is determined by FTPC-Au ($-3.8 < \eta < -2.8$) multiplicity. The arrows indicate ZYAM normalization locations. Error bars are statistical and boxes indicate systematic uncertainties.

Figure 4: Dihadron $\Delta \eta$ correlations for near side (red) and away side (blue) in peripheral (left panel) and central (middle panel) $d$+Au collisions, and their “central – peripheral” differences (right panel). Trigger and associated particles are both from TPC ($|\eta| < 1$) and $1 < p_T < 3$ GeV/c. Centrality is determined by FTPC-Au ($-3.8 < \eta < -2.8$) multiplicity. Error bars are statistical and boxes indicate systematic uncertainties.

hibits a near-side Gaussian peak and an approximate uniform away-side. These resemble the jet-correlation features, suggesting that the “central – peripheral” difference is mainly due to a difference in jet-like correlations. This difference is most likely caused by biases in the centrality determination—although FTPC-Au is used for centrality which is 3 units away from the correlation measurement, away-side jet-correlations can still contribute to the overall multiplicity in FTPC-Au.
Figure 5: Fourier coefficients of $\Delta \phi$ correlation functions vs. $\Delta \eta$ in peripheral (black) and central (red) $d+Au$ collisions. Trigger and associated particle $p_T$ are both $1 < p_T < 3$ GeV/$c$. Centrality is determined by TPC multiplicity (left panel) and FTPC-Au multiplicity (right panel). Error bars are statistical.

5. Results on Fourier coefficients

Figure 5 shows the second harmonic Fourier coefficients, $V_n = \langle \cos n \Delta \phi \rangle$ ($n = 2$), as a function of $\Delta \eta$ for both peripheral and central collisions. The third harmonic Fourier coefficient ($n = 3$) is consistent with zero. The centrality is determined by TPC in the left panel and FTPC-Au in the right panel; thus in the left panel the data points above $|\Delta \eta| > 2$ (from TPC-FTPC correlations) are more relevant because they are less biased by the centrality measure, and in the right panel those at $|\Delta \eta| < 2$ (from TPC-TPC correlations) are more relevant. The Fourier coefficients decrease with increasing $|\Delta \eta|$. This is consistent with a jet-like contribution to be primarily responsible for the measured $V_2$.

Figure 6 shows the Fourier coefficients, $V_1$ and $V_2$. ($V_3$ is consistent with zero.) Four ranges of $\Delta \eta$ are shown, from left to right, for TPC-FTPC-Au, TPC-TPC with negative $\Delta \eta$, TPC-TPC with positive $\Delta \eta$, and TPC-FTPC-$d$ correlations. Results with all three centrality determinations are shown, plotted at the corresponding measured mid-rapidity charged particle multiplicity density $dN/d\eta$. The $V_1$ is observed to approximately vary as $(dN/d\eta)^{-1}$, while the $V_2$ is approximately independent of $dN/d\eta$. $V_2$ is finite at all measured $\Delta \eta$; it is larger at mid-rapidity than forward/backward rapidities; $V_2$ from TPC-FTPC-$d$ correlation may be even larger than that from TPC-FTPC-Au correlation.

In fact, the Fourier coefficients of the “central – peripheral” correlations
Figure 6: Fourier coefficients of $\Delta \phi$ correlation functions vs. event multiplicity in $d+$Au collisions for four ranges of $\Delta \eta$ (as indicated in legends). Results from all three centrality definitions are shown. Trigger and associated particle $p_T$ are both $1 < p_T < 3$ GeV/c. Error bars are statistical.

Figure 7: Difference between dihadron $\Delta \phi$ raw correlations in central and peripheral collisions, corresponding to those in Fig. 3.

There are no different from those of the peripheral and central collisions. See Fig. 7, which shows the difference between the raw correlation functions in central and peripheral collisions corresponding to those in Fig. 3. This fact is governed by simple mathematics. However, the underlying physics mechanisms for the large Fourier coefficients of the “central − peripheral” correlations are not entirely clear. Whether there are additional sources, except the aforementioned difference in jet-like correlations due to centrality biases, remains an open question. One of the future studies is to better quantify the centrality biases to jet-like correlations, and then investigate any additional physics mechanisms for the “central − peripheral” difference.

6. Summary

Dihadron $\Delta \phi$ and $\Delta \eta$ correlations are reported for peripheral and central $d+$Au collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR. The ZYAM background
subtracted correlation yields are larger in central than peripheral collisions. The “central − peripheral” differences resemble jet-like correlations, Gaussian peaked on the near side and approximately uniform on the away side. The difference is mainly caused by difference in jet-like correlations due to centrality biases. Fourier coefficients of the raw dihadron correlations are also reported. The first harmonic coefficient is found to be approximately inversely proportional to event multiplicity. The second harmonic coefficient is found to decrease with $\Delta \eta$, but finite at forward/backward rapidity of $|\Delta \eta| \approx 3$; it is approximately independent of the event multiplicity.

The large acceptance of STAR allows detailed investigation of dihadron correlations and their centrality biases. The $d+Au$ data seem to be mainly consistent with jet phenomenology. The next step is to quantify “central − peripheral” differences caused by centrality biases, and hopefully isolate possible additional contributions unrelated to jets.

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