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**Citation**

**As Published**
http://dx.doi.org/10.1016/j.physletb.2015.02.068

**Publisher**
Elsevier

**Version**
Final published version

**Accessed**
Sat Dec 15 19:49:25 EST 2018

**Citable Link**
http://hdl.handle.net/1721.1/97063

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Effect of event selection on jetlike correlation measurement in $d + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV

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http://dx.doi.org/10.1016/j.physletb.2015.02.068
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A B S T R A C T

Dihadron correlations are analyzed in $\sqrt{s_{NN}} = 200$ GeV $d + Au$ collisions classified by forward charged particle multiplicity and zero-degree neutral energy in the Au-beam direction. It is found that the jetlike correlated yield increases with the event multiplicity. After taking into account this dependence, the non-jet contribution on the away side is minimal, leaving little room for a back-to-back ridge in these collisions.

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neutral energy (measured by ZDC-Au). The mixed-event correlations are normalized to 100% at $\Delta N = 0$.

Dihadron correlations, after combinatorial background subtraction, are often used to study correlations originating from jets [3]. However, other correlations than jets are also present, such as resonance decays. The parts of the dihadron correlations used for the jet study are therefore referred to as "jetlike" correlations in this Letter. In order to obtain jetlike correlations in $d + Au$ collisions, a uniform combinatorial background is subtracted. The background normalization is estimated by the Zero-Yield-At-Minimum (ZYAM) assumption [8,27]. After the corrected yield distribution is folded into the range of $0 < \Delta \phi < \pi$, ZYAM is taken as the lowest yield average over a $\Delta \phi$ window of $\pi/8$ radial width. The ZYAM systematic uncertainty is estimated by the yields at the ZYAM $\Delta \phi$ location averaged over ranges of width of $\pi/16$ and $3\pi/16$ radians. We also fit the $\Delta \phi$ correlations by two Gaussians (with centroids fixed at 0 and $\pi$) plus a pedestal. The fitted pedestal is consistent with ZYAM within the statistical and systematic errors because the near- and away-side peaks are well separated in $d + Au$ collisions.

Fig. 1(a) and 1(b) show the correlated yield densities per radian per unit of pseudorapidity as a function of $\Delta \eta$ for both the near-side ($|\Delta \phi| < \pi/3$) and away-side ($|\Delta \phi - \pi| < \pi/3$) ranges in (a) low and (b) high FTPC-Au multiplicity collisions. Both the trigger and associated particle $p_T$ ranges are $1 < p_T < 3$ GeV/c. The ZYAM background estimate is done for individual $\Delta N$ bins separately. The statistical errors of the data points include point-to-point statistical errors from the ZYAM values, since each $\Delta N$ bin has its own ZYAM value. The near-side yields exhibit Gaussian peaks and the away-side yields are approximately uniform in $\Delta \eta$.

A Gaussian-$t$-pedestal function $Y_{\text{jetlike}} \propto \exp\left(-\frac{(\Delta \eta)^2}{2\sigma^2}\right) + C$ fits to the near-side data are superimposed in Fig. 1(a, b) as solid curves, and the fit parameters are listed in Table 1. The Gaussian area $Y_{\text{jetlike}}$ measures the near-side jetlike correlated yield per radian. The fits indicate a ratio $\alpha = Y_{\text{jetlike}}^{\text{high}} / Y_{\text{jetlike}}^{\text{low}} = 1.29 \pm 0.05$ (stat.) $\pm 0.02$ (syst.) of jetlike yields in high to low FTPC-Au multiplicity collisions. For ZDC-Au event selection, the jetlike ratio parameter is $\alpha = 1.13 \pm 0.05$ (stat.) $\pm 0.03$ (syst.). The $\alpha$ parameter for events selected by FTPC-Au multiplicity is further from unity compared to $\alpha$ for events selected by ZDC-Au energy. The ratios of the away-side correlated yields are $1.32 \pm 0.02$ (stat.) $\pm 0.01$ (syst.) for FTPC-Au multiplicity and $1.22 \pm 0.02$ (stat.) $\pm 0.01$ (syst.) for ZDC-Au energy selected events respectively. The correlated yield ratios are similar (within 2 standard deviations) between the near and away side, consistent with back-to-back jet correlations. In addition, the near-side Gaussian peak is wider in high- than in low-multiplicity collisions. A similar broadening of jetlike peak was previously observed in $d + Au$ collisions compared with that in $p + p$ collisions [21].

In previous studies, dihadron correlations in low-multiplicity events are subtracted from high-multiplicity events. The residual correlation is often attributed to non-jet origins assuming jetlike correlations are equal in high- and low-multiplicity collisions [13]. The differences between high and low FTPC-Au multiplicity events from our data are shown in Fig. 1(c). A constant fit to the near- and away-side difference gives a $\chi^2/\text{ndf} = 50/9$ and 6.4/9, respectively, while a Gaussian fit to the near side gives $\chi^2/\text{ndf} = 2.3/8$. These differences resemble jetlike correlation features, consistent with a Gaussian peak on the near side and a uniform distribution on the away side. They therefore suggest that the difference is likely of jetlike origin.

As a first attempt to "address" the jetlike correlated yield difference, the jetlike ratio parameter $\alpha$ is applied as a scaling factor to the low-multiplicity data before it is subtracted from the high-activity data. This procedure assumes that the away-side correlated yield scales with the near-side one, which is based on momentum conservation arguments. The resulting subtracted data are shown in Fig. 1(d). The shape of the near-side difference is the result of subtracting a narrow Gaussian from a wide one of equal area offset by a pedestal. On the away side, once the low-multiplicity data are scaled up, the correlated yields are consistent between high- and low-multiplicity collisions as shown by the open circles in Fig. 1(d). This suggests that the away-side difference between high- and low-multiplicity events may be primarily due to a difference in jetlike correlations.

As seen in Table 1, the fit pedestal values of $C$ also shows dependence on event activity. Finite correlated yields above ZYAM exist on the near side at large $\Delta \eta$, where the near-side jet contribution should be minimal. This large $\Delta \eta$ correlation data will be studied elsewhere [28].

To investigate further the influence of event selection on jetlike correlations, Fig. 2(a) shows $Y_{\text{jetlike}}$ as a function of the event activity, represented by the uncorrected charged hadron multiplicity $dN/dy$ at midrapidity, in events selected according to the FTPC-Au multiplicity (solid squares) and ZDC-Au neutral energy (open squares), respectively. Five event samples are selected by each multiplicity, corresponding to 60–100%, 40–60%, 20–40%, 10–20%, and 0–10% events. The systematic uncertainties are obtained from Gaussian fits to the $\Delta \eta$ correlations, as in Fig. 1, varied by the ZYAM systematic uncertainties. Fig. 2(a) shows that the near-side jetlike correlated yield has a smooth linear dependence on event activity. Qualitatively similar behavior is also observed at the LHC [29]. Such a dependence is not observed in the HIJING [30] simulation of $d + Au$ collisions at RHIC as illustrated by the curve in Fig. 2(a). The HIJING calculations are scaled down such that the lowest multiplicity bin matches the real data. The multiplicity dependence of the jetlike yield is clearly different for the HIJING simulations.

The jetlike ratio $\alpha$ parameter can quantify the effect of the event selection on jetlike correlations. Fig. 2(b) shows the $p_T$ dependence of the $\alpha$ parameter. The systematic uncertainties are given by ZYAM uncertainties as in Fig. 2(a). Two sets of data points are shown: one (solid circles) has the trigger $p_T$ fixed to $0.5 < p_T < 1$ GeV/c and shows the $\alpha$ parameter as a function of the associated particle $p_T$ with bin of 0.5 GeV/c. This trigger $p_T$ range is similar to $0.5 < p_T^{(p)} < 0.75$ GeV/c used by PHENIX [13]. The $\alpha$ parameter is larger than unity and relatively insensitive to $p_T^{(p)}$ for this particular $p_T^{(p)}$ choice. The other set of points (solid triangles) shows $\alpha$ as a function of $p_T^{(p)}$ with a fixed $p_T^{(p)}$ of $0.5 < p_T^{(p)} < 1$ GeV/c. In this case, the $\alpha$ parameter decreases with $p_T^{(p)}$.

There could be multiple reasons for the event-selection effects on jetlike correlations. One could be a simple selection bias due to auto-correlation: if the away-side jet contributes to the total FTPC-Au multiplicity, high FTPC-Au multiplicity events would preferen-
Fig. 1. The dihadron correlated yield normalized per radian per unit of pseudorapidity as function of $\Delta \eta$ in $d+$Au collisions on the near ($|\Delta \phi| < \pi/3$, solid circles) and away side ($|\Delta \phi - \pi| < \pi/3$, open circles). Shown are the (a) low and (b) high FTPC-Au activity data, and the high-activity data after subtracting the (c) unscaled and (d) scaled low-activity data. Trigger and associated particles have $1 < p_T < 3$ GeV/c and $|\eta| < 1$. The Gaussian pedestal fit to the near side is superimposed as the solid curves. Error bars are statistical and boxes indicate the systematic uncertainties.

Fig. 2. (a) The near-side jetlike correlated yield obtained from Gaussian fit as in Fig. 1 as function of the uncorrected $dN/d\eta$ at midrapidity measured in the TPC. Two event selections are used: FTPC-Au multiplicity (filled squares) and ZDC-Au energy (open squares). The curve is the result from a HIJING calculation. (b) The ratio of the correlated yields in high over low FTPC-Au multiplicity events as a function of $p_T^{20}$ ($p_T^{21}$) where $p_T^{21}$ ($p_T^{20}$) is fixed. Error bars are statistical and caps show the systematic uncertainties.

Slightly select jets either of larger energy or happening to fragment into more particles. However, such an auto-correlation bias is not observed in the HIJING model implementation as clearly shown in Fig. 2(a). Event-activity dependent sampling of jet energies could also be caused by other physics origins; for example, there could be positive correlations between particle production from jets and from underlying events. The dependence of jetlike correlations at midrapidity on forward event activity could be driven by such mechanisms as initial-state $k_T$ effects or final-state jet modifications by possible medium formation [3,4] in the small $d+$Au collision system.

The PHENIX experiment reported a double-ridge difference in the dihadron $\Delta \phi$ correlations between high- and low-activity events in the acceptance range $0.48 < |\Delta \eta| < 0.7$ with event activity defined by total charge in the BBC at $-3.9 < \eta < -3$ [13]. Fig. 3(a) shows the STAR data analyzed in a similar acceptance of $0.5 < |\Delta \eta| < 0.7$ for high and low-activity events defined by the FTPC-Au which has similar $\eta$ coverage as PHENIX’s BBC. The systematic uncertainties shown by the histograms are the quadratic sum of those due to efficiency and ZYAM, as well as the ZYAM statistical error, because it is common for all $\Delta \phi$ bins. The correlated yields are larger in high- than in low-activity collisions on both the near and away side as previously discussed. The difference of the raw associated yield (i.e. no ZYAM subtraction) in high-activity events minus the jetlike correlated yield (i.e. with ZYAM subtraction) in low-activity events is shown in Fig. 3(b) by the open points. The systematic uncertainties are the quadratic sum of the statistical and systematic uncertainties on ZYAM of the low-activity data. The additional 5% efficiency uncertainty is not shown because it is an overall scale not affecting the shape of the dihadron correlation, therefore not affecting the physics conclusions. Back-to-back double ridges are apparent and are qualitatively consistent with the PHENIX observation [13]. However, the double-ridge structure is largely due to the residual jetlike correlation difference as demonstrated by our data above. Interpreting the double ridges as solely due to non-jet contributions in high-activity data is therefore premature.

Again, to account for the jetlike correlation difference, one may multiply the ZYAM-subtracted low-activity data by the jetlike ratio $\alpha$ parameter before subtraction. Fig. 3(b) shows, as the solid points, the raw associated particle yield (i.e. no ZYAM subtraction) in the high FTPC-Au multiplicity data after subtracting the $\alpha$-scaled jetlike correlated yield (i.e. with ZYAM subtraction) in the low-multiplicity data. The systematic uncertainties include the
propagated total error from ZYAM as well as the fit error on $\alpha$. The near-side difference is non-zero above the underlying event baseline for the $\Delta\eta$ range used. This is because this simple $\alpha$ scaling does not account for the observed broadening of the near-side jetlike peak from low- to high-activity collisions, although the jetlike yield difference has been taken care of. This causes a significantly larger difference in the intermediate range of $0.5 < |\Delta\eta| < 0.7$. When $\Delta\eta$ range closer to zero is used, e.g., $|\Delta\eta| < 0.3$, the jetlike difference is damped (below the baseline) on the near side after $\alpha$ scaling. This is shown by the negative solid data points at $\Delta\eta \sim 0$ in Fig. 1(d). Barring from the difference caused by the broadening, there is a finite pedestal value from the near-side Gaussian+pedestal fit that increases with event activity as aforementioned. This pedestal difference remains in the near-side peak in Fig. 3(b).

After the jetlike contribution is removed by the scaled subtraction, the away-side difference is significantly diminished. The results are similar using the ZDC-Au event activity. This suggests that any possible contribution from non-jetlike long-range correlations, such as the back-to-back ridge, is small. Although it does a better job of removing jetlike contributions than a simple subtraction of low-activity from high-activity data, the scaled subtraction may not completely remove the jetlike contributions. This is so for two reasons. One, the away-side jetlike yield in a given $p_T$ range may not strictly scale with the near-side one between high- and low-activity collisions, depending on the details of dijet production and fragmentation. Two, the jetlike correlation shapes, being different on the near side, can also be different on the away side, e.g., due to increasing $k_T$ broadening (or acoplanarity) with event activity.

In summary, dihadron correlations are measured at midrapidity using the STAR TPC as function of the forward rapidity event activity in $d + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. The event activity is classified by the measured FTPC-Au forward charged particle multiplicity or the ZDC-Au zero-degree neutral energy. The correlated yields are extracted by subtracting the estimated background using ZYAM. It is found that the correlated yield is larger in high- than in low-activity collisions and the $\Delta\eta$-dependence of the observed yield difference resembles jetlike features, suggesting a jetlike origin. There could be multiple reasons for the difference, ranging from simple auto-correlation biases to physical differences between high- and low-activity $d + Au$ collisions. The away-side correlation difference is significantly diminished after scaling the low-activity data by the ratio of the near-side jetlike correlated yields. Our data demonstrate that the dihadron correlation difference between high- and low-activity events at RHIC is primarily due to jets. In $d + Au$ collisions at RHIC such event-selection effects on jetlike correlations must be addressed before investigating possible non-jet correlations such as anisotropic flow.

**Acknowledgements**

We thank the RHIC Operations Group and RCF at BNL, the NERSC Center at LBNL and the Open Science Grid consortium for providing resources and support. This work was supported in part by the Offices of NP and HEP within the U.S. DOE Office of Science, the U.S. NSF, the Sloan Foundation, the DFG cluster of excellence ‘Origin and Structure of the Universe’ of Germany, CNRS/IN2P3, STFC and EPSRC of the United Kingdom, FAPESP CNPq of Brazil, Ministry of Ed. and Sci. of the Russian Federation, NNSFC, CAS, MoST, and MoE of China, GA and MSMT of the Czech Republic, FOM and NWO of the Netherlands, DAE, DST, and CSIR of India, Polish Ministry of Sci. and Higher Ed., Korea Research Foundation, Ministry of Sci., Ed. and Sports of the Rep. of Croatia, Russian Ministry of Sci. and Tech., and RosAtom of Russia.

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