Energy and system dependence of high-\(p_T\) triggered two-particle near-side correlations

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Abstract. Previous studies have indicated that the near-side peak of high-\(p_T\) triggered correlations can be decomposed into two parts, the Jet and the Ridge. We present data on the yield per trigger of the Jet and the Ridge from \(d + Au\), \(Cu + Cu\) and \(Au + Au\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV and 200 GeV and compare data on the Jet to PYTHIA 8.1 simulations for \(p + p\). PYTHIA describes the Jet component up to a scaling factor, meaning that PYTHIA can provide a better understanding of the Ridge by giving insight into the effects of the kinematic cuts. We present collision energy and system dependence of the Ridge yield, which should help distinguish models for the production mechanism of the Ridge.

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1 Introduction

Previous studies in \(Au + Au\) collisions at \(\sqrt{s_{NN}} = 200\) GeV demonstrated that the near-side peak in high-\(p_T\) triggered correlations can be decomposed into two structures. The Jet is narrow in both azimuth (\(\Delta \phi\)) and pseudorapidity (\(\Delta \eta\)), similar to what is observed in \(d + Au\), while the Ridge is narrow in azimuth but broad in pseudorapidity. The Jet component is similar to that expected from vacuum fragmentation, whereas the Ridge has properties similar to the bulk \([1,2]\). Comparing data from \(Au + Au\) and \(Cu + Cu\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV and \(\sqrt{s_{NN}} = 200\) GeV tests whether these conclusions hold for other collision systems and energies.

Several mechanisms have been proposed for the production of the Ridge \([3,4,6,7]\). These models have yielded few calculations which can be directly compared to data, in part because of the large number of factors which must be considered when theoretically calculating the experimentally measured quantities. The results presented here should provide a good test of models for the production of the Jet and Ridge because trends expected with changing collision energy and in nuclei collided in a given model should be easier to calculate theoretically.

2 Method

Data from the STAR detector from year 3 \(d + Au\) collisions as \(\sqrt{s_{NN}} = 200\) GeV, year 4 \(Au + Au\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV and \(\sqrt{s_{NN}} = 200\) GeV, and year 5 \(Cu + Cu\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV and \(\sqrt{s_{NN}} = 200\) GeV were used for the comparison of collision systems and energies. Details of the STAR detector can be found in \([8]\). The primary detector used for these analyses was the STAR Time Projection Chamber (TPC).

A high transverse momentum (\(p_T\)) particle is selected and the distribution of other particles in the event relative to that trigger particle in azimuth (\(\Delta \phi\)) and pseudorapidity (\(\Delta \eta\)) \(\frac{dN}{d\Delta \phi d\Delta \eta}\) was determined. The \(p_T\) of the trigger and associated particles was restricted in order to reduce the soft background; unless otherwise mentioned 1.5 GeV/c < \(p_T^{\text{associated}}\) < \(p_T^{\text{trigger}}\) and 3.0 < \(p_T^{\text{trigger}}\) < 6.0 GeV/c. \(\frac{dN}{d\Delta \phi d\Delta \eta}\) is normalized by the number of trigger particles. This was corrected for the single particle efficiency and for detector acceptance, which is dependent on the collision system and energy, \(p_T\), \(\Delta \eta\), \(\Delta \phi\), and collision multiplicity. Except for studies of \(N_{\text{part}}\) dependence, the \(Cu + Cu\) data at both energies are for 0-60% centrality, \(Au + Au\) data at \(\sqrt{s_{NN}} = 62.4\) GeV are for 0-80% centrality, and \(Au + Au\) data at \(\sqrt{s_{NN}} = 200\) GeV are for 0-10% centrality. \(d + Au\) data are minimum bias.

The yield measured is the number of particles associated with the trigger particle within limits on \(p_T^{\text{associated}}\) and \(p_T^{\text{trigger}}\). The Ridge was previously observed to be roughly independent of \(\Delta \eta\) within the acceptance of the STAR TPC \([2]\). To extract the yield it is assumed that the Ridge is independent of \(\Delta \eta\). Previous studies have demonstrated that the Jet component extends to \(|\Delta \eta| = 0.75\) in the \(p_T\) range studied here and that limited detector acceptance limits studies to \(|\Delta \eta| < 1.75\) \([1,2,9]\). To determine the Jet yield \(Y_{\text{Jet}}\), the projection of the distribution of particles \(\frac{dN}{d\Delta \phi d\Delta \eta}\) is taken in two different ranges in pseudorapidity:
\[
\frac{dY_{\text{trigger}}}{d\Delta\phi} = 1/N_{\text{trigger}} \int_{-0.75}^{-1.75} \frac{d^2N}{d\Delta\phi d\Delta\eta} d\Delta\eta \\
+ 1/N_{\text{trigger}} \int_{0.75}^{1.75} \frac{d^2N}{d\Delta\phi d\Delta\eta} d\Delta\eta
\]

where the former contains only the Ridge and the latter contains both the Jet and the Ridge. The jet-like yield on the near-side is the integral over \(-1 < \Delta\phi < 1:\n
\[Y_{\text{Jet}} = \frac{1}{N_{\text{trigger}}} \int_{-1}^{1} (dY_{\text{Jet+Ridge}} - 0.75 dY_{\text{Jet}}) d\Delta\phi.\]

The factor in front of the second term is the ratio of the \(\Delta\eta\) width in the region containing the Jet and the Ridge to the width of the region containing only the Ridge. With this method for subtracting the Ridge contribution to \(Y_{\text{Jet}}\), the systematic errors due to \(v_2\) cancel out assuming that \(v_2\) is roughly independent of \(\Delta\eta\), a reasonable assumption in the mid-rapidity range \(|\eta| < 1\) based on the available data \([11, 12]\). It is also assumed that the Ridge is independent of \(\Delta\eta\).

To determine \(Y_{\text{Ridge}}\), the integration is done over the entire \(\Delta\eta\) region to minimize the effects of statistical fluctuations in the determination of the background:

\[Y_{\text{Ridge}} = 1/N_{\text{trigger}} \int_{-1}^{1} \int_{-1.75}^{-0.75} \frac{d^2N}{d\Delta\phi d\Delta\eta} d\Delta\phi d\Delta\eta - Y_{\text{Jet}}.\]

The integration over \(\Delta\phi\) is done by fitting a Gaussian to the near-side. This partially compensates for a detector effect which causes lost tracks at \(\Delta\phi \approx 0\) and \(\Delta\eta \approx 0\); this effect is less than 10% in the \(p_T\) range studied here \([10]\).

The raw signal has a background due to particles correlated indirectly with each other in azimuth due to their correlation with the reaction plane. This random background is given by

\[dN_{\text{back}} = B(1 + 2(v_2^{\text{trigger}})(v_2^{\text{associated}}) \cos(2\Delta\phi))\]

where \(v_2\) is the second order harmonic in a Fourier expansion of the momentum anisotropy relative to the reaction plane, and must be subtracted in order to study the component associated with the jet. Systematic errors come from the errors on \(B\), \(v_2^{\text{trigger}}\), and \(v_2^{\text{associated}}\). It is assumed that \(v_2\) is the same for events with a trigger particle as for minimum bias events and that \(v_2\) is roughly independent of \(\Delta\eta\). For each data set \(v_2(p_T)\) was fit in centrality bins to determine \((v_2^{\text{trigger}})}\) and \((v_2^{\text{associated}}).\)

Details of the \(v_2\) subtraction for \(Au + Au\) collisions at \(\sqrt{s_{NN}} = 200\) GeV are given in \([11]\) and for \(Cu + Cu\) collisions at \(\sqrt{s_{NN}} = 200\) GeV in \([9]\). For \(Cu + Cu\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV, the \(v_2\) using the reaction plane as determined from tracks in the Forward Time Projection Chamber was used as the nominal value and the lower bound was determined from a multiplicity-dependent approximation as described for \(\sqrt{s_{NN}} = 200\) GeV in \([9]\). For \(Au + Au\) collisions at \(\sqrt{s_{NN}} = 62.4\) GeV, \(v_2\) and its systematic errors were taken from \([13]\). B is fixed using the ZYAM method \([14]\).

PYTHIA 8.1 was used to simulate \(p + p\) collisions for comparisons to \(Y_{\text{Jet}}\). A trigger particle was selected and the distribution of particles in azimuth was calculated, as in the experimental measurements. The yield was determined as the number of charged hadrons in the range \(-1 < \Delta\phi < 1\). For comparisons to data identical limits on \(p_T^{\text{trigger}}\) and \(p_T^{\text{associated}}\) were applied. The minimum \(p_T\) is the parameter in PYTHIA for the transverse momentum in the hard subprocess \([15]\). A minimum value of \(p_T = 0.1\) GeV/c was used and \(10^8\) events were simulated to ensure that the minimum \(p_T\) did not affect the yield and that the statistical error was negligible. It was not necessary to study the distribution of particles in pseudorapidity since there is no Ridge in PYTHIA.

3 Results

3.1 The Jet

Fig. 1 compares the dependence of \(Y_{\text{Jet}}\) on \(p_T^{\text{trigger}}\) for all systems and energies to the yield from PYTHIA 8.1 scaled by 2/3. An overall scaling factor of 2/3 was applied to the PYTHIA yields to match the data. The need for the scaling factor implies that PYTHIA assumes that too many particles are produced in hard processes, however, kinematic effects should still be reflected accurately in PYTHIA. The scaled PYTHIA yield describes the shape of the \(p_T^{\text{trigger}}\) dependence well, with a few deviations at lower \(p_T^{\text{trigger}}\). PYTHIA describes the energy dependence of \(Y_{\text{Jet}}\) well, indicating that the energy dependence can be explained as a \(pQCD\) effect. If \(Y_{\text{Jet}}\) is dominated by \(pQCD\) effects, deviations from PYTHIA at lower \(p_T\) would be expected. No system dependence is observed in the data, as would be expected for an effect dominated by \(pQCD\).

The dependence of \(Y_{\text{Jet}}\) on \(p_T^{\text{associated}}\) is shown in Fig. 2. As in Fig. 1 the scaled PYTHIA yield describes the shape of the data well and there is no system dependence. The inverse slope parameters from exponential fits to the data and to PYTHIA shown in Tab. 1 likewise support independence on collision system. Slight deviations from the
The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data. For fits of data in Fig. 2, the inverse slope parameter from PYTHIA scaled by 2/3. The inverse slope parameters from fits of an exponential to the data and to PYTHIA are given in Table 1. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.

The $J_{pt}$ dependence of $Y_{Jet}$ at $\sqrt{s_{NN}} = 62.4$ GeV and $d + Au$, $Cu + Cu$, and $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV is shown in Tab. 1. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.

The $N_{part}$ dependence of the $Y_{Jet}$ for $Cu + Cu$ and $Au + Au$ at $\sqrt{s_{NN}} = 62.4$ GeV and $d + Au$, $Cu + Cu$, and $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.

The $N_{part}$ dependence of the $Y_{Jet}$ for $Cu + Cu$ and $Au + Au$ at $\sqrt{s_{NN}} = 62.4$ GeV and $d + Au$, $Cu + Cu$, and $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.

The $N_{part}$ dependence of the $Y_{Jet}$ for $Cu + Cu$ and $Au + Au$ at $\sqrt{s_{NN}} = 62.4$ GeV and $d + Au$, $Cu + Cu$, and $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.

The $N_{part}$ dependence of the $Y_{Jet}$ for $Cu + Cu$ and $Au + Au$ at $\sqrt{s_{NN}} = 62.4$ GeV and $d + Au$, $Cu + Cu$, and $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3. The inverse slope parameter for fits of data in Fig. 2 is a measure of the distribution of particle energies. The slope parameter from fits of data in Fig. 2 is higher than that of the data.
The data from $d + Au$, $Cu + Cu$, and $Au + Au$ and $\sqrt{s_{NN}} = 62.4$ GeV and $\sqrt{s_{NN}} = 200$ GeV demonstrate that the $Jet$ shows no system dependence. In addition, the collision energy dependence of $Y_{Jet}$ is described well by PYTHIA even at fairly low $p_T$ and the $p_T^{trigger}$ and $p_T^{associated}$ dependencies agree with PYTHIA up to a scaling factor, with a few deviations at lower $p_T$. This implies that the dominant production mechanism of the $Jet$ is fragmentation. Deviations from PYTHIA may imply modifications of the $Jet$ in $A + A$ collisions. It also implies that PYTHIA or other models can be used to determine the effect of the kinematic cuts on $p_T^{trigger}$ on the $z_T$ and jet energy distribution, which could be very useful for the theoretical interpretation of the $Ridge$.

$Y_{Ridge}$ is smaller at lower collision energies and increases with system size independent of collision system. There is no dependence on the collision system. Data on the collision energy and system dependence could provide a robust test of models, and comparisons of $Y_{Jet}$ to PYTHIA imply that the effects of the kinematic cuts on the distribution of jet energies can be inferred from PYTHIA.

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