System Size and Energy Dependence of Jet-Induced Hadron Pair Correlation Shapes in Cu+Cu and Au+Au Collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV.

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Comets,24 P. Constantin,23,33 M. Csanád,15 T. Csörgő,27 J.P. Cussonneau,53 T. Dahms,52 K. Das,17 D. David,5 F. Deák,15 M.B. Deaton,1 K. Dehmelt,16 H. Delagrave,53 A. Denisov,20 D. d’Enterria,11 A. Deshpande,56 J.E. Desmond,5 A. Devissems,52 O. Dietzsch,49 A. Dion,50 M. Donadelli,49 J.L. Drachenberg,4 O. Draper,31 A. Drees,52 A.K. Dubey,59 A. Durum,20 D. Dutta,4 V. Dzhurighthouse,6,54 Y.V. Efremenko,41 J. Egdemir,52 F. Ellingson,10 W.S. Eman,6 A. Enokizono,19,32 H. En'yo,45,46 B. Espagnon,42 S. Essimi,56 K.O. Eyser,6 D.E. Fields,39,46 C. Finck,53 M. Finger,17,24 M. Finger,7,24 F. Fleuret,31 S.L. Fokin,29 B. Forestier,34 B.D. Fox,46 Z. Fraenkel,59 J.E. Frantz,11,52 A. Franz,5 A.D. Frawley,17 K. Fujiwara,45 Y. Fukao,30,45 S.-Y. Fung,6 T. Fusayasu,38 S. Gadrat,54 I. Garishvili,54 F. Gastineau,53 M. Germain,53 A. Glenn,16,54 H. Gong,52 M. Gouin,31 J. Gosset,13 Y. Goto,45,56 R. Gruber de Cassagnac,31 N. Grau,23 S.V. Greene,57 M. Grosse Perdekamp,21,46 T. Gunji,9 H.-A. Gustafsson,35 T. Hachiya,19,45 A. Hadj Henni,53 C. Haegemann,39 J.S. Haggerty,5 M.N. Hagiwara,1 H. Hamagaki,9 R. Han,43 A.G. Hansen,31 H. Harada,19 E.P. Hartouini,52 K. Haruna,19 M. Harvey,5 E. Hashum,35 K. Hasuko,45 R. Hayano,9 M. Heffner,32 T.K. Hemmick,52 T. Hester,6 J.M. Heuser,45 X. He,18 P. Hidas,27 H. Hiejima,21 J.C. Hill,23 R. Hobbs,39 M. Hohlmann,16 M. Holzmeyer,7 W. Holzmann,51 K. Honma,19 B. Hong,28 A. Hoover,40 T. Horaguchi,45,46,55 D. Hornback,54 M.G. Hur,25 T. Ichihara,45,46 V.V. Ikonomov,29 K. Inami,30,45 M. Inaba,56 Y. Inoue,47,45 M. Inuzuka,9 D. Isenhower,1 L. Isegihara,1 M. Ishihara,45 T. Isobe,9 M. Issah,5 A. Isupov,24 B.V. Jacak,52 J. Jia,11,52 J. Jin,11 O. Jinnouchi,45,46 B.M. Johnson,5 S.C. Johnson,32 K.S. Joo,47 D. Jouan,42 F. Kajihara,9,45 S. Kameni,9,58 N. Kamihara,45,55 J. Kamin,52 M. Kameta,46 J.H. Kang,60 H. Kanou,54,55 K. Katou,58 T. Kawabata,9 T. Kawagishi,56 D. Kawall,46 A.V. Kazantsev,29 S. Kelly,10,11 B. Khachatryan,44 J. Kikuchi,58 D.H. Kim,37 D.J. Kim,60 E. Kim,50 G.-B. Kim,31 H.J. Kim,60 Y.-S. Kim,25 E. Kinney,10 A. Kiss,15 E. Kistenev,5 A. Kiyomichi,45 J. Klay,32 C. Klein-Boesing,36 H. Kobayashi,46 L. Kochenda,44 V. Kochetkov,20 R. Kohara,19 B. Komkov,44 M. Konno,56 D. Kotchetkov,6 A. Kozlov,59 A. Král,12 A. Kravitz,11 P.J. Kroon,5 J. Kubart,7,22 C.H. Kuberg,46,54 J.G. Kunde,33 N. Kurihara,9 K. Kurita,45,47 M.J. Kweon,28 Y. Kwon,54,60 G.S. Kyle,40 R. Lacey,51 Y.-S. Lai,11 J.G. Lajoie,23 A. Lebedev,23 Y. Le Bornec,42 S. Leckey,52 D.M. Lee,33,56 K. Lee,50 T. Lee,50 M.J. Leitch,33,54 M.A.L. Leite,49 B. Lenzi,49 H. Lim,50 T. Liška,12 A. Litvinenko,24 M.X. Liu,33 X. Li,8 X.H. Li,6 B. Love,57 D. Lynch,5 C.F. Maguire,57 I.Y. Makdisi,5 A. Malakhot,74 M.D. Malik,39 V.I. Malkin,29 Y. Mao,43,45 G. Martinez,53 L. Mašek,7,22 H. Masui,56 F. Matathias,11,52 T. Matsubara,9,58 M.C. McCain,1,21 M. McCumber,52 P.L. McGaughey,33 Y. Miake,56 P. Mikes,7,22 K. Miki,56 T.E. Miller,57 A. Milov,52 S. Mioduszewski,5 G.C. Mishra,18 M. Mishra,3 J.T. Mitchell,5 M. Mitrovski,51 A.K. Mohanty,4 A. Morreale,6 D.P. Morrison,5 J.M. Moss,33 T.V. Moukhova,29 D. Mukhopadhyay,57,59 M. Muniruzzaman,6 J. Murata,47,45 S. Nagamiya,26 Y. Nagata,56 J.L.L. Nagle,10,11 M. Naglis,59 I. Nakagawa,45,46 Y. Nakamiya,19 T. Nakamura,19 K. Nakano,45,55 J. Newby,32,54 M. Nguyen,52 B.E. Norman,33 A.S. Nyanin,29 J. Nystrand,35 E. O'Brien,6 S.X. Oda,32 C.A. Ogilvie,22 H. Ohnishi,45 I.D. Ojha,3,57 H. Okada,30,45 K. Okada,45,46 M. Oka,56 O.O. Omiwade,1 A. Oskarsson,35 I. Otterlund,53 M. Ouchida,19 K. Oyama,9 K. Ozawa,5 R. Pak,5 D. Pai,57 59 A.P.T. Palounek,33 V. Pantuev,52 V. Papavassiliou,40 J. Park,50 W.J. Park,28 S.F. Pate,40 H. Pei,23 V. Penev,24 J.-C. Peng,21 H. Pereira,31 V. Peresedov,24 D.Y. Peressouk,49 A. Pierson,39 C. Pinkenburg,5 R.P. Pisani,5 M.L. Purschke,4 A.K. Purwar,33,52 J.M. Qualls,1 H. Qu,18 J. Rak,23,39 A. Rakotozafindrabe,31 I. Ravinovich,59 K.F. Read,41,54 S. Rembeczki,16 M. Reuter,52 K. Revers,36 V. Riabov,44 Y. Riabov,44 G. Roche,34 A. Romana,31 M. Rosati,33 S.S.E. Rosendahl,35 P. Rosnet,34 P. Ruikoyatkin,24 V.L. Rykov,45 S.S. Ryu,60 B. Sahlmueller,36 N. Saito,30,45,46 T. Sagakuchi,5,59,58 S. Sakai,56 H. Sakata,19 V. Samsonov,44 L. Sanfratello,39
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Heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) produce QCD matter at enormous energy density [1], exceeding that required for a phase transition to partonic, rather than hadronic, matter. The produced matter exhibits collective motion [2] and is opaque to scattered quarks and gluons. The opacity is observed via suppression of high momentum hadrons and intermediate energy dijets [3], and provides clear evidence of large energy loss by partons (quarks or gluons) traversing the medium. A key question is how the hot, dense medium transports the deposited energy.

As partons fragment into back-to-back jets of hadrons, angular correlations of the hadrons are used to study medium effects upon hard scattered parton pairs. Hadron pairs from the same parton appear at \( \Delta \phi \sim 0 \) (the near-side), while those with one hadron from each parton in the hard scattered pair appear at \( \Delta \phi \sim \pi \) (the away-side). For brevity, we will refer to these dijet induced dihadron azimuthal correlations with the abbreviation "dijet correlations".

Of great interest are intermediate transverse momentum \( (p_T) \) hadrons, as they can arise from intermediate energy dijets [3], and provide new parameters to quantify this shape modification [4, 5, 6, 7]. This Letter introduces new parameters to quantify this shape modification and reports their dependence on collision energy, system size, transverse momentum and centrality measured by the PHENIX experiment at RHIC.

We present azimuthal angle correlations of intermediate transverse momentum \( (1 - 4 \text{ GeV/c}) \) hadrons from dijets in \( \text{Cu+Cu} \) and \( \text{Au+Au} \) collisions at \( \sqrt{s_{NN}} = 62.4 \text{ and } 200 \text{ GeV} \). The away-side dijet induced azimuthal correlation is broadened, non-Gaussian, and peaked away from \( \Delta \phi = \pi \) in central and semi-central collisions in all the systems. The broadening and peak location are found to depend upon the number of participants in the collision, but not on the collision energy or beam nuclei. These results are consistent with sound or shock wave models, but pose challenges to Cherenkov gluon radiation models.

PACS numbers: 25.75.Dw
nucleons \( N_{\text{part}} \) are determined using the Beam-Beam Counters (BBCs) and Zero Degree Calorimeters [11].

Relative azimuthal distributions \( Y_{\text{same}}(\Delta \phi) \) between "trigger" hadrons with \( 2.5 < p_T < 4 \) GeV/c and "associated" hadrons with \( 1 < p_T < 2.5 \) GeV/c are formed. We correct their shape for the non-uniform azimuthal acceptance of the PHENIX central arms by using the mixed event pairs \( Y_{\text{mixed}}(\Delta \phi) \) [11] from the same data sample:

\[
C(\Delta \phi) = \frac{Y_{\text{same}}(\Delta \phi)}{Y_{\text{mixed}}(\Delta \phi)} \times \frac{\int Y_{\text{mixed}}(\Delta \phi) d\Delta \phi}{\int Y_{\text{same}}(\Delta \phi) d\Delta \phi} \tag{1}
\]

Extensive Monte-Carlo simulations were performed to ensure that the true pair distribution shape is recovered through this procedure.

In Au+Au and Cu+Cu collisions, hadrons have an azimuthal correlation with the reaction plane orientation \( \Phi_{\text{RP}} \) which is proportional to \( 1 + 2v_2 \cos(2(\phi - \Phi_{\text{RP}})) \). This generates a significant correlated background to our dijet source \( J(\Delta \phi) \) of azimuthal correlations:

\[
C(\Delta \phi) = b_0(1+2 \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \cos(2\Delta \phi)) + J(\Delta \phi) \tag{2}
\]

The charged hadron \( \langle v_2 \rangle \), where \( \langle \cdot \rangle \) signifies an event average, was measured through a reaction plane analysis using the BBCs \( 3 < |y| < 4 \) as in [11,12].

Hadrons have also a much smaller fourth order azimuthal correlation with the reaction plane orientation. Its effect was studied with the Au+Au data at 200 GeV by including the corresponding \( 2 \langle v_4^{\text{assoc}} \rangle \langle v_4^{\text{trigg}} \rangle \cos(4\Delta \phi) \) component in the background term of Eq. [2] where the \( \langle v_4 \rangle \) values have also been measured through the reaction-plane analysis [12]. No significant \( v_4 \) systematic effects on the shape of the dijet correlations were found.

The background subtraction generates point-by-point (\( \Delta \phi \) dependent) systematic errors from \( \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \) uncertainty and an overall (\( \Delta \phi \) independent) systematic error from \( b_0 \) uncertainty. The sources of \( \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \) uncertainty are the \( \langle v_2 \rangle \) systematic error [10], dominated by the reaction plane resolution uncertainty, the \( \langle v_2 \rangle \) statistical error, and the systematic error from the \( \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \approx \langle v_2^{\text{assoc}} \rangle \cdot \langle v_2^{\text{trigg}} \rangle \) factorization approximation made in Eq. [2]. The latter is estimated to be at most 5% of the \( \langle v_2 \rangle \) product for the most central events.

The \( b_0 \) uncertainty is estimated by using three independent methods to calculate \( b_0 \). The first, called Zero Yield At Minimum (ZYAM), assumes that there is a region in \( \Delta \phi \) where the dijet source of particle pairs is negligible. \( b_0 \) is varied until the background component in Eq. [2] matches the measured correlation \( C(\Delta \phi) \) at some value of \( \Delta \phi \). In the second method a functional form for \( J(\Delta \phi) \) is added to the background, and the sum fitted to the measured correlation with \( b_0 \) as a free parameter. Motivated by the theoretical ideas discussed in the introduction, we use a function that contains a near-side Gaussian, and two symmetric away-side Gaussians:

\[
J(\Delta \phi) = G(\Delta \phi) + G(\Delta \phi - \pi - D) + G(\Delta \phi - \pi + D) \tag{3}
\]

While the choice of this functional form is not unique, it does provide a reasonable fit to the measured correlations, as shown by the dotted line in Fig. 1. The parameter \( D \), or peak angle, is motivated by an attempt to describe the away-side dijet correlation in terms of its symmetry around \( \Delta \phi \sim \pi \). We note that it also tends to absorb any non-Gaussian character of the dijet correlation. The third method is independent of the measured \( C(\Delta \phi) \). We calculate \( b_0 = \xi(\langle n_{\text{trigg}} \rangle \langle n_{\text{assoc}} \rangle \langle n_{\text{same}} \rangle) \) with hadron production rates measured from all events within each centrality class and scale by the same-event pair rate. \( \kappa \) is a correction for pair-cut bias and \( \xi \) is a correction for residual correlations due to averaging production rates from events of different multiplicity within the same centrality class [13].

As shown in Table I for the Au+Au data at 200 GeV, there are slight \( b_0 \) variations depending on which method is used to extract its value. However, the resulting shape of the dijet correlations is essentially independent of these variations.

| Centrality | 60-90% | 70-90% | 80-90% | 90-100% | 10-20% | 15-25% | 20-30% | 25-35% | 30-40% | 35-45% | 40-50% | 45-55% | 50-60% | 60-70% |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| ZYAM \( b_0 \) | 0.861 | 0.942 | 0.960 | 0.971 | 0.982 | 0.988 | 0.985 | 0.982 | 0.979 | 0.975 | 0.972 | 0.969 | 0.965 | 0.962 |
| fit \( \delta b_0 \) | -0.003 | -0.003 | -0.006 | -0.028 | -0.035 | -0.022 | -0.021 | -0.019 | -0.017 | -0.015 | -0.013 | -0.011 | -0.009 | -0.007 |
| comb. \( \delta b_0 \) | -0.086 | -0.013 | -0.004 | +0.002 | +0.001 | +0.001 | +0.000 | +0.001 | +0.002 | +0.003 | +0.004 | +0.005 | +0.006 | +0.007 |

Figure 1 summarizes the extraction with the ZYAM method of the dijet correlations using the central (0-5%) Au+Au data at \( \sqrt{s_{NN}} = 200 \) GeV: the measured correlation is shown with squares, the background term with a full line, and the background subtracted dijet correlation with circles for values and boxes for the point-by-point systematic errors. The systematic errors are correlated since they depend on the same parameter - the \( \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \) uncertainty. For clarity, \( J(\Delta \phi) \) is shifted up by \( b_0 \), shown with dashed line, hence its amplitude should be read from the right axis. We note that, in this case, the measured correlation is flat near \( \Delta \phi \sim \pi \), even before any background subtraction. Due to the cosine modulation of the background, a local minimum should develop at \( \Delta \phi \sim \pi \) in the dijet away-side correlation.

Figure 2 shows a central and a peripheral dijet correlation for each colliding system and energy. A remarkable away-side feature in central and semi-central collisions (< 40%) is the peak location away from \( \Delta \phi = \pi \), and the appearance of a local minimum at \( \Delta \phi = \pi \). To quantify the significance of this minimum in the Au+Au data at 200 GeV, we have studied how much \( \langle v_2^{\text{assoc}} \rangle \langle v_2^{\text{trigg}} \rangle \) would need to change for the away-side to be flat. For the four most central bins (0-5%, 5-10%, 10-20%, and 20-
is defined here as all $\Delta \phi$ values above the dijet function $J(\Delta \phi)$ minimum, typically one rad. We extract these statistics on only the away-side jet peaks in $J(\Delta \phi)$; possible jet-associated flat underlying distributions, which are highly sensitive to the uncertainty in $b_0$ and precluded by the ZYAM assumption, are not included.

The rms and kurtosis centrality dependence is shown in Fig. 3(a). The rms increases with centrality, indicating broadening of the away-side dijet correlation, while the kurtosis decreases from the value characteristic of a Gaussian shape (three), suggesting a flattening of its shape beyond an increase in the Gaussian width.

TABLE II: Dependence of away-side shape parameters on associated hadron $p_T$ in central (0-20%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for $3 < p_T^{\text{assoc}} < 5$ GeV/c. First error is statistical and second error is systematic.

| $p_T^{\text{assoc}}$ | D [rad] | rms [rad] | kurtosis |
|---------------------|---------|-----------|----------|
| 1-1.5               | 1.04±0.03±0.03 | 1.02±0.02±0.05 | 1.68±0.04±0.10 |
| 1.5-2               | 1.07±0.04±0.04 | 1.06±0.02±0.05 | 1.58±0.05±0.10 |
| 2-2.5               | 1.05±0.03±0.06 | 1.08±0.04±0.08 | 1.38±0.11±0.12 |
| 2.5-3               | 1.07±0.06±0.06 | 1.09±0.07±0.07 | 1.35±0.17±0.12 |
| 3-5                 | 0.88±0.13±0.16 | 1.01±0.11±0.14 | 1.31±0.23±0.25 |

The peak angle D centrality dependence, extracted by fitting dijet correlations with Eq. 3(b) is shown in Fig. 3(b). It is consistent with zero radians in d+Au and peripheral nuclear collisions, but rapidly grows to a value around one radian in central nuclear collisions. Some deviation from zero radians of the peak angle may be
related to slight non-Gaussian shapes of the dijet correlations even without medium modification. This can be seen in the kurtosis values for d+Au and peripheral nuclear collisions, which have values somewhat lower than three. For details on dijet correlations in d+Au see [11]. The systematic errors in Fig. 3 come exclusively from \(v_2\) uncertainty. No apparent dependence of rms, kurtosis, or peak angle \(D\) on collision energy or species is observed.

Table II shows the dependence of the away-side shape parameters on the associated hadron \(p_T\) in the Au+Au data at 200 GeV for a 0-20% centrality bin, \(3 < p_T^{\text{trig}} < 5\) GeV/c, and the following \(p_T^{\text{assoc}}\) bins: 1 – 1.5, 1.5 – 2, 2 – 2.5, 2.5 – 3, and 3 – 5 GeV/c. The peak angle \(D\) and the rms have no \(p_T\) dependence, while the kurtosis is consistent with a slow decrease with \(p_T\).

Several phenomenological models for modification of the away-side jet have been proposed; all involve a strong response of the medium to the traversing jet. Bow shocks propagating as sound, or density, waves in the medium to the traversing jet. Bow shocks away-side jet have been proposed; all involve a strong reflect sound waves and cause a second away-side peak sound identically zero. This region was postulated [4] to a hadron gas and quark-gluon plasma [4]. A first or- 

"If the peak indeed arises from a sound wave, its location at approximately the same angle as seen in the data [4, 15]. If the peak may also arise from Cherenkov gluon radiation [4]. Such a mechanism should disappear for high energy gluons, implying that the peak angle \(D\) should gradually approach zero with increasing momentum of associated hadrons. Table II shows that this is not supported by the data. The medium may induce gluon radiation at large angles by mechanisms other than Cherenkov radiation [7, 8]. Such models can reproduce the observed peak if the density of scattering centers is large and the gluon splitting sufficiently asymmetric [7]. However, the predicted radiation is very sensitive to the treatment of geometry, expansion and radiative energy loss framework used. Our detailed measurements constrain the options.

An important issue is whether the density wave correlations can survive the underlying medium expansion. It was shown that the interplay of the longitudinal expansion and limited experimental \(\eta\) acceptance preserves, and even amplifies, the signal of directed collective exi- 

tations [15]. However, the creation of a shock wave consistent with our data requires that 75-90% of the jet’s lost energy be transferred to the collective mode [4, 15, 17].

We have presented azimuthal angle correlations of intermediate transverse momentum hadrons from dijets in Cu+Cu and Au+Au collisions at \(\sqrt{s_{NN}} = 62.4\) and 200 GeV. The away-side dijet correlation is seen to be broadened, non-Gaussian and peaked away from \(\Delta \phi = \pi\) in central and semi-central collisions. The away-side shape depends on the number of participants in the collision, and not on the beam nuclei or energy. The general features of the observed shape can be qualitatively accounted for by a number of phenomenological models, all having in common a strong medium response to the energy deposited by the traversing parton. The systematic data presented here provide quantitative tests that could discriminate between these models.

We thank the staff of the Collider-Accelerator and Physics Departments at BNL for their vital contributions. We acknowledge support from the Department of Energy and NSF (U.S.A.), MEXT and JSPS (Japan), CNPq and FAPESP (Brazil), NSFC (China), MSMT (Czech Republic), IN2P3/CNRS and CEA (France), BMBF, DAAD, and AvH (Germany), OTKA (Hungary), DAE (India), ISF (Israel), KRF and KOSEF (Korea), MES, RAS, and FFAE (Russia), VR and KAW (Sweden), U.S. CRDF for the FSU, US-Hungarian NSC-OTKA-MTA, and US-Israel BSF.

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[1] K. Adcox et al., Nucl. Phys. A 757, 184 (2005).

[2] S. S. Adler et al., Phys. Rev. Lett. 91, 182301 (2003).

[3] S. S. Adler et al., Phys. Rev. Lett. 91, 072301 (2003); S. S. Adler et al., Phys. Rev. C 69, 034910 (2004).

[4] J. Casalderrey-Solana, E. V. Shuryak and D. Teaney, Nucl. Phys. A 774, 577 (2007) and hep-ph/0511263.

[5] J. Ruppert, B. Mueller, Phys. Lett. B 618, 123 (2005).

[6] V. Koch, A. Majumder, and X.-N. Wang, Phys. Rev. Lett. 96, 172302 (2006).

[7] A. D. Polosa and C. A. Salgado, hep-ph/0607295.

[8] I. Vitev, Phys. Lett. B 630, 78 (2006).

[9] J. Adams et al., Phys. Rev. Lett. 95, 152301 (2005).

[10] S. S. Adler et al., Phys. Rev. Lett. 97, 052301 (2006).

[11] K. Adcox et al., Phys. Rev. C 69, 024904 (2004).

[12] H. Masui, nucl-ex/0510018. M. D. Oldenburg, J. Phys. G 31, S437 (2005) and nucl-ex/0412001.

[13] S. S. Adler et al., Phys. Rev. C 71, 051902 (2005).

[14] S. S. Adler et al., Phys. Rev. C 73, 054903 (2006).

[15] T. Renk and J. Ruppert, hep-ph/0605339.

[16] J. J. Friess, S. S. Gubser, G. Michalogiorgakis and S. S. Pufu, hep-th/0607022.

[17] A. K. Chaudhuri and U. W. Heinz, Phys. Rev. Lett. 97, 062301 (2006).