PHENIX measurement of jet properties and their modification in heavy-ion collisions

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Abstract. The properties of jets produced in $p+p$, $d+Au$ and $Au+Au$ collisions at $\sqrt{s_{NN}}$=200 GeV are studied using the method of two particle correlations. The trigger particle is assumed to be a leading particle from a high p_T jet while the associated particle is assumed to come from either the same jet or the away jet. From the angular width and yield of the same and away side correlation peaks, the parameters characterizing the jet properties are extracted.

The high-p_T particle yield measured at RHIC ($\sqrt{s_{NN}}$=130 and 200 GeV) was found to be strongly suppressed in $Au + Au$ central collisions [1]. Furthermore, the measurement of high-p_T particle yield in $d+Au$ induced collisions [2] confirmed that the suppression can be fully attributed to the final state interaction of high-energy partons with an extremely opaque nuclear medium [3]. Parton propagation through the excited nuclear medium should be accompanied by stimulated gluon radiation, which results in the modification of fundamental properties of hard-scattering such as broadening of parton transverse momentum k_T [4, 5] and modification of jet fragmentation [6]. Thus the measurement of jet fragmentation properties in heavy ion collisions, compared to the results for $p + p$ collisions, should provide more detailed insight into the process of formation and materialization of excited nuclear medium.

1. Jet angular correlations

We explore the systematics of jet fragmentation by the method of two-particle azimuthal correlations. This method, which worked well at ISR energies ($\sqrt{s}$=63 GeV) and below [7], is an alternative method to the full jet reconstruction when the use of the latter is difficult or impossible due to high-multiplicities, as in heavy ion collisions.

Jets are produced by the hard scattering of two partons [8, 9]. Two scattered partons propagate nearly back-to-back in azimuth from the collision point and fragment into the jet-like spray of final state particles (see embedded schematics on Fig. 1 where only one fragment of each parton is shown). These particles have a momentum $\vec{j}_T$ perpendicular to the partonic transverse momentum, with component j_{Ty} projected

§ For the full PHENIX Collaboration list and acknowledgments, see Appendix “Collaborations” of this volume onto the azimuthal plane. The magnitude of $\langle j_T \rangle$ measured at lower energies has been found to be $\sqrt{s}$ and p_T independent [7].

Despite the naive expectation of parton collinearity in the transverse plane, it was found that each of the partons carry the effective transverse momentum $\vec{k}_T$, originally described as "intrinsic" [10]. The measurement of net transverse momenta $\langle p_T^2 \rangle_{pair} = 2 \cdot \langle k_T^2 \rangle$ of diphoton, dimuon or dijet over the wide range of $\sqrt{s}$ in $p{+}p$ collisions gives $\langle k_T \rangle$ as large as 5 GeV/c [11]. Clearly, this value can not be attributed to the intrinsic transverse momentum given by the constituent quark mass ($\approx$300 MeV/c) and the NLO re-summation techniques has to be invoked [12].

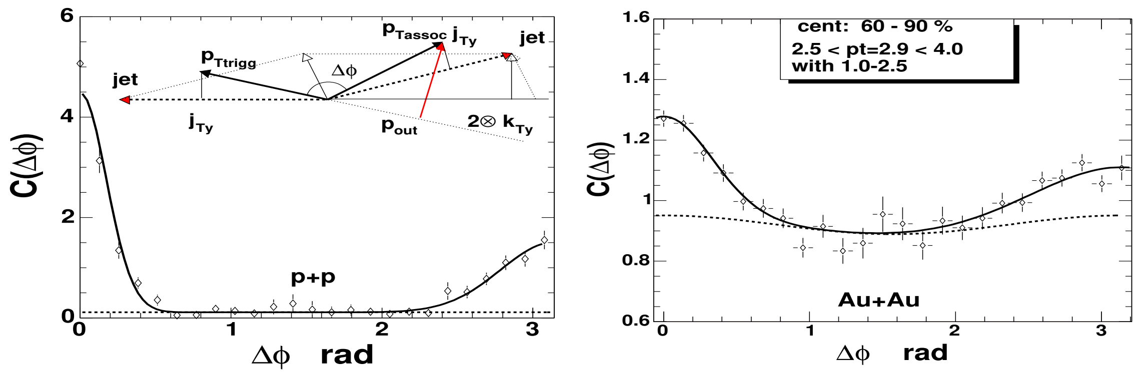

Figure 1. *Left:* Measured correlation functions in $p+p$ collisions for both particles in the $3.0 < p_T < 4.0$ range. Solid line corresponds to the fit of the two Gaussian functions representing the intra-jet and inter-jet correlation. Dashed line represents the uncorrelated background distribution. *Right:* The correlation functions from $Au+Au$ data with $2.5 < p_{Ttrig} < 4.0$ and $1.0 < p_{Tassoc} < 2.5$. The dashed line represent the $cos(2\Delta\Phi)$ background distribution and the solid line represent the contribution of jet correlations.

The analysis uses two-particle azimuthal correlation functions (CF) to measure the distribution of the azimuthal angle difference ($\Delta\phi = \phi_1 - \phi_2$) between pairs of charged hadrons (see Fig. 1). The correlation function is defined as $C(\Delta\phi) = \mathcal{N} \cdot \frac{N_{cor}}{N_{uncor}}$ where N_{cor} and N_{uncor} are the observed $\Delta\phi$ distributions of charged particle pairs in the same or mixed events, respectively and $\mathcal{N}$ is the normalization factor.

We fit the measured CF by two gaussians, one for the near-side component (around $\Delta\phi = 0$) and one for the far-side component (around $\Delta\phi = \pi$), and a constant for the uncorrelated pairs in case of $p+p$ and $d+Au$ collisions. In case of $Au+Au$ correlation functions, the background distribution has a "harmonic" form $1 + 2a_2^2 \cos(2\Delta\phi)$ with a_2 as a free parameter.

For two-particles with average transverse momenta $\langle p_{Ttrig} \rangle$ and $\langle p_{Tassoc} \rangle$ from the same jet, the width of the near-side correlation, σ_N, can be related to $\langle |j_{Ty}| \rangle$ as

$$\langle |j_{Ty}| \rangle \approx \sqrt{\frac{2}{\pi}} \frac{\langle p_{Ttrig} \rangle \langle p_{Tassoc} \rangle}{\sqrt{\langle p_{Ttrig} \rangle^2 + \langle p_{Tassoc} \rangle^2}} \sigma_N \tag{1}$$

if we assume $\langle |j_{Ty}| \rangle \ll \langle p_{Ttrig} \rangle$ and $\langle |j_{Ty}| \rangle \ll \langle p_{Tassoc} \rangle$. In order to extract $\langle k_T \rangle$ from the width of the away-side peak width σ_F, we started with the relation between $\langle |p_{out}| \rangle$, the average transverse momentum component of the away-side particle $\vec{p}_T$ perpendicular to trigger particle $\vec{p}_{Ttrig}$ in the azimuthal plane, and k_{Ty} given in [7], [10]. We note however, that [10] explicitly neglected $\langle z_{trig}\rangle = \langle p_{Ttrig}/p_{Tjet}\rangle$ in the formula at ISR energies, where $\langle z_{trig}\rangle \simeq 0.85$, while it is not negligible at $\sqrt{s_{NN}}$=200 GeV. Taking $\langle z_{trig}\rangle$ into account we derived

$$\langle|k_{Ty}|\rangle\langle z_{trig}\rangle = \frac{1}{x_h\sqrt{2}}\sqrt{\langle p_{Tassoc}\rangle \sin^2\sqrt{\frac{2}{\pi}}\sigma_F - (1+x_h^2)\langle|j_{Ty}|\rangle^2} \qquad (2)$$

where $x_h = \langle p_{Tassoc}\rangle/\langle p_{Ttrig}\rangle$. Equation (2) indicates that in order to extract the magnitude of $\langle|k_{Ty}|\rangle$ the external knowledge of the $\langle z_{trig}\rangle$ is needed. We have analyzed the p_T-dependence of the π^0 invariant cross section measured in $p+p$ collisions [13]. In the $p_T > 3$ GeV/c region where the power law function with the power of $n = 8.05\pm0.06$ provides the best description of the data, we assumed that the final state parton distribution function has the same shape as the π^0 invariant cross section and we found $\langle z\rangle_{p_T>3}$=0.75±0.05. Knowing $\langle z_{trig}\rangle$, σ_N and σ_F and using (1), (2) the $\langle|j_{Ty}|\rangle$ and $\langle|k_{Ty}|\rangle$ can be calculated. The results for $p+p$ and $d+Au$ are shown on Fig. 2 .

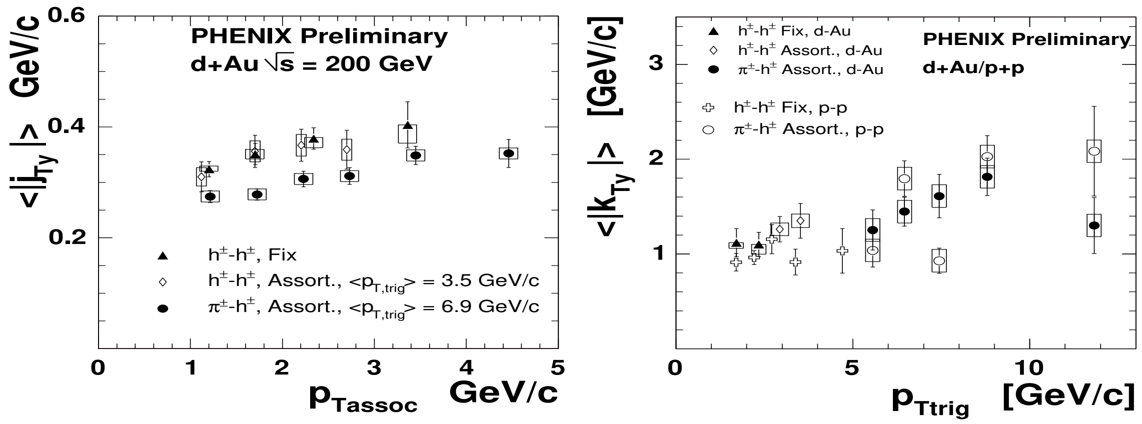

Figure 2. *Left:* Extracted values of $\langle|j_{Ty}|\rangle$ as a function of p_{Tassoc} in $d+Au$. *Right:* Variation of $\langle|k_{Ty}|\rangle$ with p_{Ttrig} for $p+p$ and $d+Au$. Boxes drawn around the data points indicate the systematic error bars.

The $\langle|j_{Ty}|\rangle$ and $\langle|k_{Ty}|\rangle$ values are extracted using "fixed" and "assorted"-p_T correlation technique. The former method explores the correlation between particle pairs of the similar values of p_{Ttrig} and p_{Tassoc} whereas the assorted method uses asymmetric pairs. The values of $\langle|j_{Ty}|\rangle$ in $p+p$ and $d+Au$ data are in good agreement and the average value $\langle|j_{Ty}|\rangle$=324±6 MeV/c ($\langle j_T\rangle=\frac{\pi}{2}\langle|j_{Ty}|\rangle$=510±10 MeV/c) has been obtained. Within the systematic and statistical errors it is not clear whether or not the $\langle k_T\rangle$ values follow the rising trend seen at lower energies [7]. Nonetheless, averaging the $h^\pm-\pi^\pm$ and $h^\pm-h^\pm$ data over p_{Ttrig} in case of $p+p$ data we found $\langle|k_{Ty}|\rangle_{pp}$=1.08±0.05 GeV/c ($\sqrt{\langle k_T^2\rangle}\,_{pp}=\sqrt{\pi}\langle|k_{Ty}|\rangle_{pp}$=1.92±0.09 GeV/c) and for $d+Au$ data $\langle|k_{Ty}|\rangle_{dAu}$=1.36±0.07±0.12 GeV/c ($\sqrt{\langle k_T^2\rangle}\,_{dAu}$=2.42±0.12±0.21 GeV/c).

A similar analysis has been done also for $Au+Au$ data for various collision centralities, characterized by the average number of participants $\langle N_{part}\rangle$. We have studied the angular width and the associated yield per trigger particle for $2.5<p_{Ttrig}<4.0$ GeV/c and $1.0<p_{Tassoc}<2.5$ GeV/c . However, in this case, there is no justification of using $D(z)$ extracted from $p+p$ data so we report only $\langle z_{trig}\rangle\langle|k_{Ty}|\rangle$ (see Fig. 3). Whereas the $\langle|j_{Ty}|\rangle$ values shows essentially no dependence on N_{part}, the away-side width and $\langle z_{trig}\rangle\langle|k_{Ty}|\rangle$ reveals a rather dramatic raising trend compared to $p+p$ and $d+Au$ indicating strong final state partons' interaction with nuclear medium.

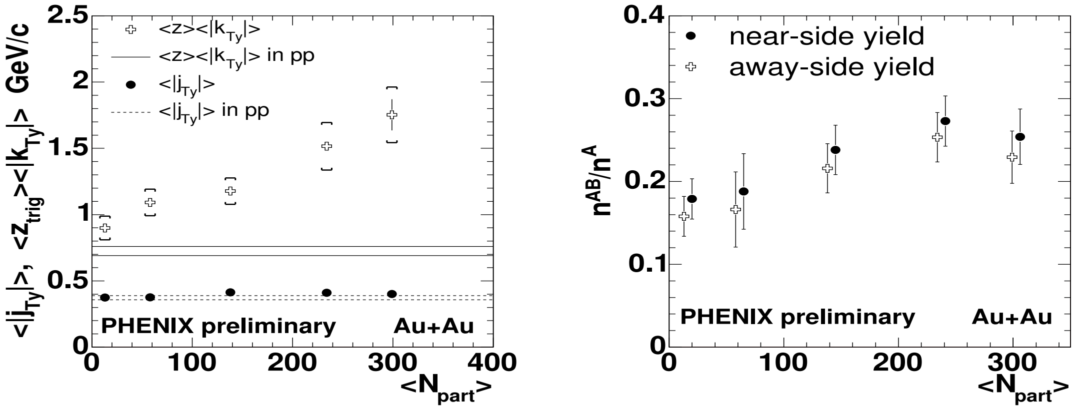

Figure 3. *Left:* Centrality dependence of the $\langle j_T\rangle$ and $\langle z_{trig}\rangle\langle|k_{Ty}|\rangle$in $Au+Au$ for $2.5<p_{Ttrig}<4.0$ GeV/c and $1.0<p_{Tassoc}<2.5$ GeV/c The dashed and solid lines represent the values of $\langle|j_{Ty}|\rangle$ and $\langle z_{trig}\rangle\langle|k_{Ty}|\rangle$ measured in $p+p$ data. Brackets indicate the systematic error bars. *Right:* Associated near-side (solid circles) and away-side (hollow crosses) yield of $1.0<p_{Tassoc}<2.5$ GeV/c particles per trigger particle found in the p_T-bin $2.5<p_{Ttrig}<4.0$ GeV/c . Errors are dominated by systematic error.

The associated near and away-side yields in $Au+Au$ are found to be rather constant or slightly rising with centrality in contrast of measurement done at higher p_{Ttrig}-range [14]. This observation seems to indicate strong jet rescattering rather than the full jet absorption in neclear medium.

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