Probing Cold and Hot, Dense Nuclear Media Via High-p_T Jets with Di-hadron and γ-hadron Correlations at PHENIX

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With the recent high statistics Au+Au and Cu+Cu runs at RHIC, it has become possible to systematically study jet properties in several different colliding systems with potentially different final state interactions. In this talk we present results from high-p_T di-hadron and γ-hadron correlations from p+p, d+Au, Cu+Cu, and Au+Au collisions where jets in vacuum, cold nuclear matter, and hot, dense nuclear matter are studied.

1. Introduction

One of the most celebrated results from the first three years of RHIC is the suppression of single high-p_T particle production in central Au+Au collisions due to jet suppression [1]. The effect of jet suppression was dramatically seen in two-particle correlations where the away-side jet in central Au+Au collisions was largely extinguished [2] and its shape modified [3]. These observations are consistent with calculations from parton energy loss via gluon bremsstrahlung when the parton traverses a medium with a large gluon density of $dN_g/dy \sim 1000$ [4]. Further, the same single particle suppression and away-side jet suppression is not present in d+Au collisions [5] meaning that it is the final state interactions in the central Au+Au collisions that suppress the jets. With the recent high-statistics Au+Au and Cu+Cu runs it is becoming possible to do more detailed studies of the away-side jet modification with two-particle correlations.

Two-particle correlations are measured in the PHENIX central spectrometer arms and are defined as

$$C\left(\Delta\phi\right) \propto \frac{dN_{real}/d\Delta\phi}{dN_{mix}/d\Delta\phi} \propto \frac{1}{N_{trig}}\frac{dN}{d\Delta\phi} \qquad (1)$$

where $dN_{real}/d\Delta\phi$ are the event pair distribution and the $dN_{mix}/d\Delta\phi$ are the mixed event distributions where each particle of the pair is chosen from a random event. The mixed event distributions correct for the non-uniform pair acceptance of the PHENIX central arms. These correlation functions can be turned into a pair per trigger distribution, $1/N_{trig}dN/d\Delta\phi$ where the normalization is dependent on the acceptance and the efficiency [6]. Two particle correlations exhibit two peaks at $\Delta\phi$=0 (near) and $\Delta\phi$=π(away) which represent correlations within the same jet and between di-jets respectively. In A+A
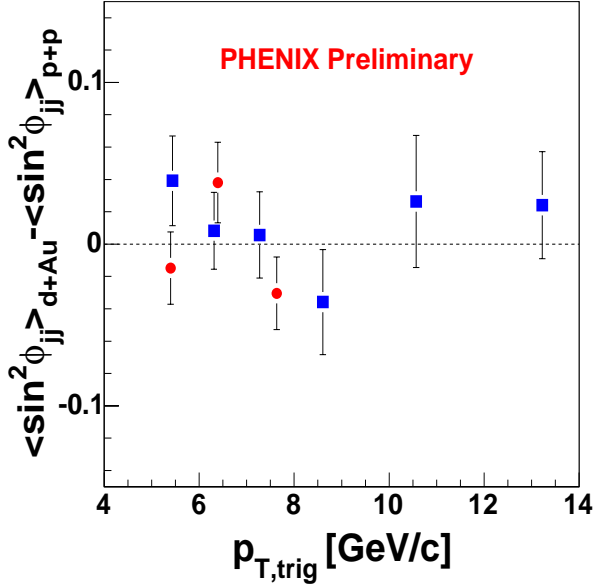

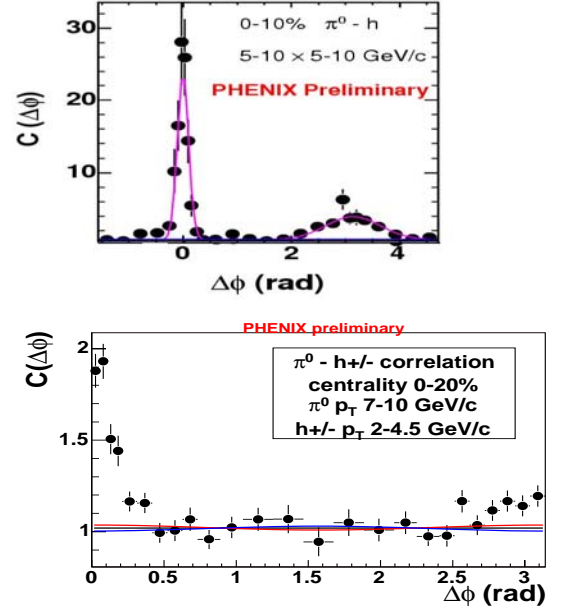Figure 1. Difference of $\sin^2\phi_{\mathrm{jj}}$ between p+p and d+Au.

Figure 2. $\pi^0 - h$ correlations in Cu+Cu (top) and Au+Au (bottom) collisions.

collisions elliptic flow is also present which causes a harmonic modulation of the isotropic background.

2. Jets in p+p and d+Au Collisions

Due to intrinsic k_T and hard and soft gluon radiation, parton-parton collisions are not necessarily collinear in the nucleon-nucleon center-of-mass frame. As a result, the outgoing di-jets are acoplanar, not back-to-back. Acoplanarity of the di-jets can be determined by the angle between the jets. Assuming independent fragmentation one can write $\Delta\phi_F = \Delta\phi_N + \phi_{jj}$, where $\Delta\phi_F$ is the angle between the fragments of the di-jets, $\Delta\phi_N$ is the angle between the fragments of the jets, and ϕ_{jj} is the angle between the di-jets. These three angles are statistically independent and so one can find

$$\left\langle \sin^2\phi_{\mathrm{jj}} \right\rangle = \frac{\left\langle \sin^2\Delta\phi_{\mathrm{F}} \right\rangle - \left\langle \sin^2\Delta\phi_{\mathrm{N}} \right\rangle}{1 - 2\left\langle \sin^2\Delta\phi_{\mathrm{N}} \right\rangle} \tag{2}$$

The terms on the right side are fixed by the RMS widths of the near- and away-side correlations.

In d+Au collisions multiple scattering, which is responsible for Cronin enhancement [5], should increase this acoplanarity of the di-jets. Fig. 1 shows the difference of $\sin^2\phi_{\mathrm{jj}}$ in d+Au and p+p collisions as a function of the trigger p_T where the trigger is either a charged (squares) or neutral (circles) pion. These data are consistent with no difference between p+p and d+Au, which constrains the amount of di-jet broadening from the cold nuclear medium at RHIC.
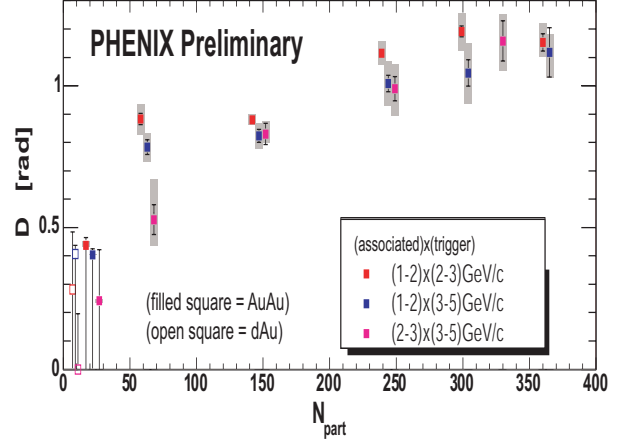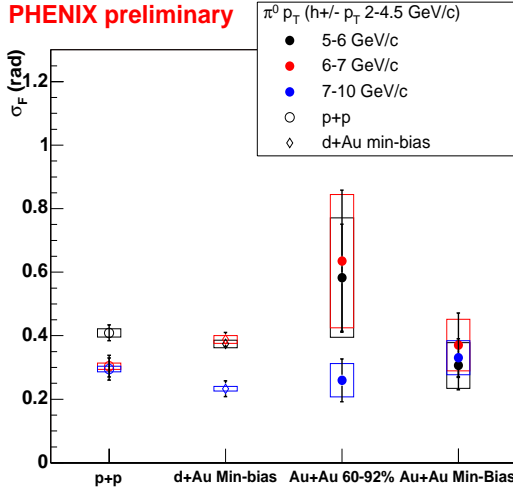
Figure 3. Away-side widths of the high-p_T jet distribution in Au+Au collisions.

Figure 4. N_{part} dependence of splitting angle from Au+Au correlations.

3. Jets in A+A Collisions

With the recent high-statistics Cu+Cu and Au+Au runs, data is available to extended jet correlations to higher p_T (> 5 GeV) than previously measured. The upper panel of Fig. 2 shows an example of a Cu+Cu π^0-h correlations in the 10% most central events. These correlations are normalized so that the vertical scale is the signal-to-background of the jets. There is a large S/B and the near- and away-side jet distributions are observed. The lower panel of Fig. 2 also shows high-p_T π^0-h correlations in Au+Au collisions for the 20% most central collisions where the away-side jet observable at 20% S/B. We extract the away-side widths and compare them to the widths from p+p and d+Au collisions (Fig. 3). The widths are consistent between p+p and Au+Au for this $p_{T,trig}$ range.

At lower momentum ($p_{Ttrig} < 5$ GeV) the jet shape becomes modified such that a local minimum appears at $\Delta\phi=\pi$. This has spurred theoretical interest in Mach cones or Cerenkov-like radiation [7] as possible physical mechanisms which could produce such a structure. Experimentally we study this shape quantitatively by parameterizing the away-side shape as two Gaussians with similar width but offset symmetrically about $\Delta\phi=\pi$ by a splitting angle D.

$$C_{away}\left(\Delta\phi\right) = \exp\left(\frac{-\left(\Delta\phi - \pi - D\right)^2}{2w^2}\right) + \exp\left(\frac{-\left(\Delta\phi - \pi + D\right)^2}{2w^2}\right) \tag{3}$$

Fig. 4 shows the angle D as a function of N_{part} for different low-p_T h-h correlations. There is a smooth increase of D at peripheral collisions to an apparent saturation at central collisions. We also observe that the lowest p_T combination is systematically higher than the two higher p_T ranges. Low-p_T correlations have also been performed in Cu+Cu at $\sqrt{s} = 200$ GeV and Au+Au at $\sqrt{s} = 62$ GeV. These correlations exhibit the same away side shape structure as seen in Au+Au. Fig. 5 shows the same D parameter as a function
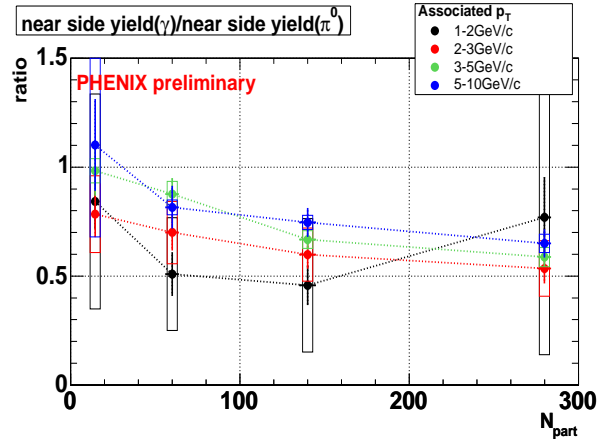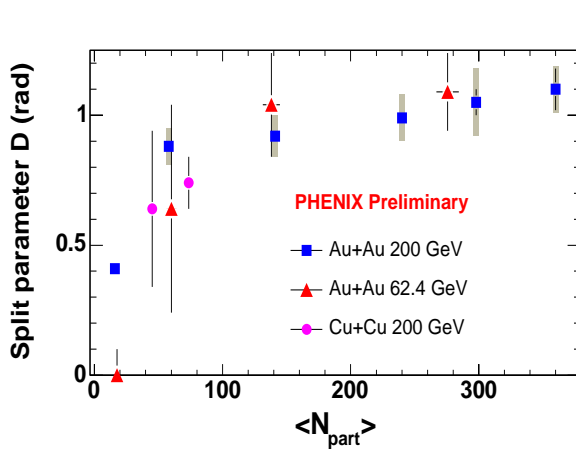
Figure 5. Energy and system-size dependence of the splitting angle.

Figure 6. Ratio of near angle yields with inclusive γ triggers to π^0 triggers.

of N_{part} for the different collision systems. All of the systems follow N_{part} scaling and, within errors, the angle D is independent of colliding energy.

An ideal probe for the jet modification in medium is the use of prompt γ-h correlations. PHENIX has shown a factor of 2 excess of photons above the hadronic decay background above 5 GeV/c in the most central Au+Au collisions consistent with prompt γ production as calculated by pQCD [8]. We have analyzed inclusive γ-h correlations. The near angle region of these correlations are populated by decay and prompt γ triggers. Fig. 6 shows the associated particle yield per trigger in the near-side from inclusive γ triggers compared to π^0 triggers. One sees a decrease in the ratio with centrality consistent with the fraction of prompt-γ increasing at the higher centralities.

PHENIX has measured jet correlations in p+p, d+Au, Cu+Cu, and Au+Au at low- and high-p_T. Little difference between p+p and d+Au di-jet acoplanarity is seen. We observe in Cu+Cu and Au+Au collisions an away-side jet widths that are similar to p+p. At lower-p_T a strong away-side modification is seen and the shape seems to scale with N_{part}. Finally, we have shown evidence that in central Au+Au collisions we are sensitive to prompt γ-h correlations.

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