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Jets and Jet-like Correlations in Heavy Ion and p+p Collisions at PHENIX

Christopher Pinkenburg* **for the PHENIX Collaboration**

Brookhaven National Laboratory
E-mail: pinkenburg@bnl.gov

Jets from heavy ion collisions provide a measurement of the medium-induced parton energy loss and the in-medium fragmentation properties. The medium modification effects are determined by comparing to a $p+p$ baseline measurement, but the high multiplicity background in a heavy ion collision inhibits the direct application of traditional jet reconstruction techniques and novel approaches are needed to deal with this environment. Alternatively, angular correlations between the hadronic fragments of energetic partons can be used to understand the hot dense matter produced in relativistic heavy ion collisions. The yield and shape modifications of the away side peaks as function of transverse momentum compared to $p+p$ has been interpreted as a medium response to parton energy loss. Direct photon–hadron correlations are another excellent channel to study jets from heavy ion collisions. Photons do not interact strongly with the medium and thus the photon approximately balances the momentum of the opposing jet, allowing the measurement of the effective modification to the fragmentation function through jet energy loss in the medium.

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*Speaker.

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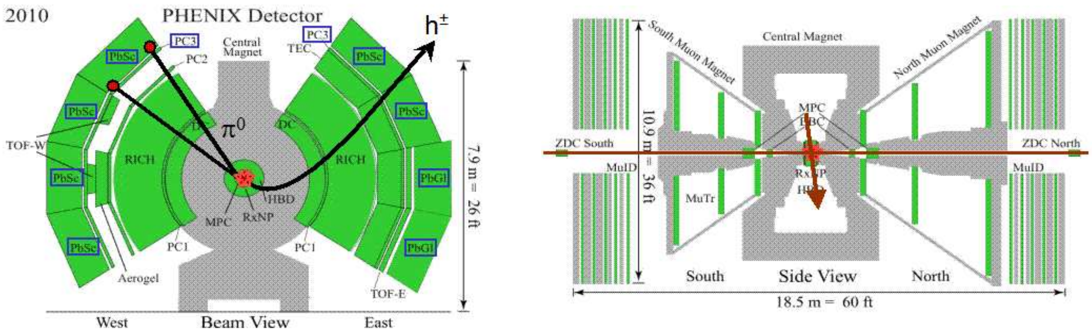

Figure 1: Overview of the PHENIX experiment as configured in 2010.

1. Experimental Setup

Fig 1 shows the PHENIX detector as it was configured in 2010. The spectrometer used in the presented analysis each cover $|\eta|$<0.35 and $\Delta\phi$=$\pi/2$. Charged particles are detected with a tracking system which employs a drift chamber in each arm with a set of pixel pad chambers (PC1) directly behind them. The momentum resolution is $\Delta p/p = 0.7\% \pm 1.0\% p$. Secondary tracks from albedo, conversions and decays are suppressed by matching tracks to hits in a second pad chamber (PC3). Photons are detected by finely segmented electromagnetic calorimeters which allow the reconstruction of π^0 and η mesons in the 2γ channel out to p_T of 20 GeV/c. Details of the setup can be found in [1].

2. π^0–Hadron Correlations

Angular correlations between the hadronic fragments of energetic partons are an essential tool for understanding the hot dense matter produced in relativistic heavy ion collisions. The shape of the relative azimuthal angular distribution and the yield of jet like fragment pairs in central *Au*+*Au* collisions can deviate significantly from those of *p*+*p* collisions. These deviations are expressed in terms of the nuclear modification factor R_{AA} or the nuclear jet suppression factor I_{AA}. The nuclear modification factor R_{AA} is a single particle spectrum normalized to *p*+*p*, the nuclear jet suppression factor I_{AA} is the integrated yield in a $\Delta\phi$ range of two particle angular correlations normalized to *p*+*p*. Deviations from unity are an indication of nuclear effects.

In moderate p_T ranges ($\sim$ 2-5 GeV/c) a pronounced away side peak broadening[2] and shape modification[3, 4] has been observed. Fig 2 left shows the per trigger jet pair yield for various π^0 trigger and $h^\pm$ p_T combinations in *p*+*p* and the 20% most central *Au*+*Au* collisions. The widths on the near side are comparable over the full p_T range, the yields show a slight enhancement at lower p_T in *Au*+*Au* over *p*+*p*. On the away side one observes strongly broadened jet peaks for low p_T in *Au*+*Au* evolving into peaks of similar shape to *p*+*p* but with strongly suppressed yields. Fig 2 right shows the away side jet yield modification I_{AA} in central collisions. The values decrease with increasing p_T of the associated particles but stay above the R_{AA} of π^0 mesons[5].

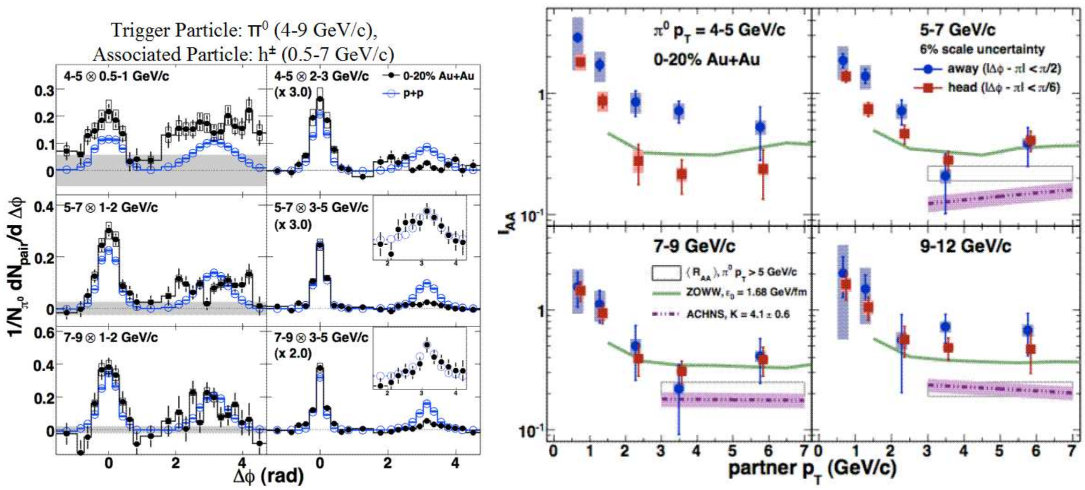

Figure 2: Left panel: Per trigger jet pair yield vs. $\Delta\phi$ for selected π^0 trigger and $h^{\pm}$ partner p_T combinations in $Au+Au$ and $p+p$ collisions. For shape comparison insets show away side distributions scaled to match at $\Delta\phi = \pi$. Right panel: Away–side I_{AA} vs. $h^{\pm}$ partner momentum for a narrow "head" $|\Delta\phi - \pi| < \pi/6$ and the entire away side $|\Delta\phi - \pi| < \pi/2$. For comparison, π^0 R_{AA}[5] bands are included for $p_T > 5GeV/c$

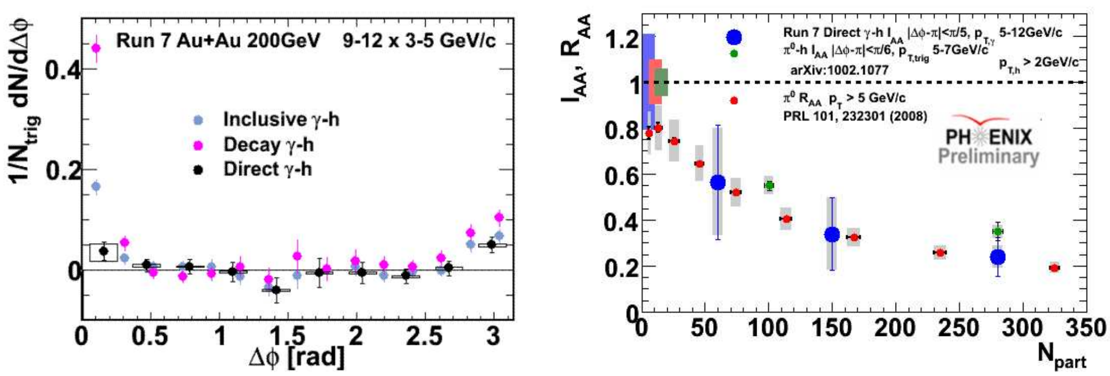

Figure 3: Left panel: Azimuthal correlations of charged hadrons with all photons, decay photons and direct photons in central Au+Au collisions. Right panel: Nuclear modification factor for direct photon–hadron correlations compared to π^0–hadron correlations and to the single $\pi^0 R_{AA}$ as function of the number of participants

3. Direct Photon–Hadron Correlations

Photons do not carry color charge and hence have only a small cross section for interacting with the dense mater created in in heavy ion collisions. Unlike hadron–hadron correlations, direct photon–hadron correlations are therefore unbiased by the path length of the trigger particle in the medium. The dominant source of direct photons is the QCD compton scattering process $q + g \rightarrow q + \gamma$. The photon momentum is balanced by that of the recoil quark and the level of suppression can be related to the energy loss of a parton of known initial momentum. For this reason the γ+jet channel at leading order has been considered the golden channel to study parton energy loss[6]. The experimental challenge is to separate the direct photons from the large background of photons

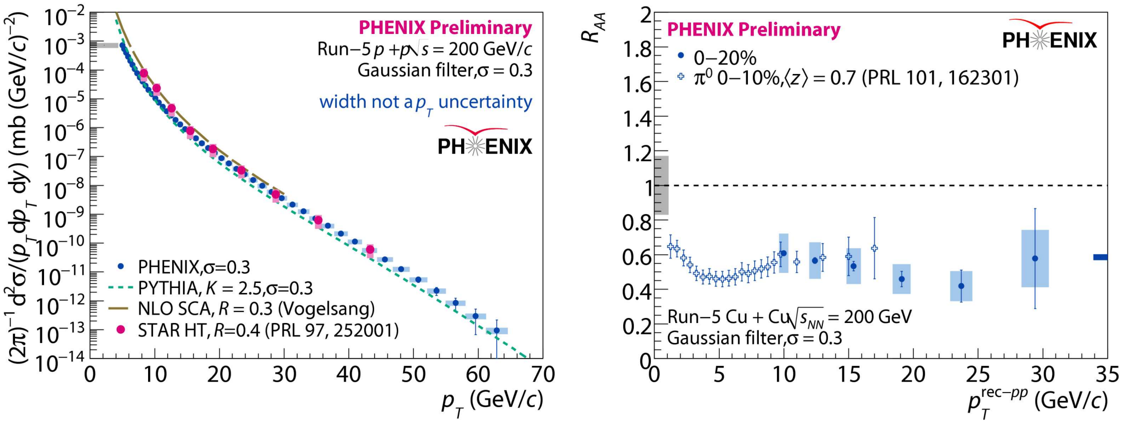

Figure 4: Left panel: Invariant jet cross section spectrum as function of p_t for p+p at $\sqrt{s} = 200GeV$ compared to measurements by the STAR collaboration, a next to leading order calculation from [9] and Pythia. Right panel: R_{AA} of fully reconstructed jets in central $Cu+Cu$ collisions at $\sqrt{s} = 200GeV$ compared to the measured R_{AA} of π^0

produced by hadron decays. This background is subtracted statistically using the measured direct photon cross section and a detailed detector simulation to determine the decay photon–hadron correlations[7]. Fig 3 left shows examples of azimuthal correlations for direct photons as well as the corresponding total and decay photon correlations used in the statistical subtraction. The right panel shows the nuclear modification factor I_{AA} which is the ratio of the away side yield in Au+Au to p+p as function of centrality. Within uncertainties it is consistent with I_{AA} for π^0–hadron correlations[8] and the R_{AA} for single π^0's[5]

4. Jet Reconstruction

Direct jet reconstruction in heavy ion collisions at RHIC energies poses challenging problems. The jet signal is easily lost in the high multiplicity of the underlying events which in addition give rise to fake jets [10]. The limited acceptance of the PHENIX detector introduces additional complications. Jets are reconstructed using a Gaussian filter algorithm described in [11]. It employs an angular weighting to differentiate jets from background fluctuations and to mitigate finite acceptance effects. Comparisons with other jet reconstruction algorithms using PYQUEN[12] and Q-PYTHIA[13] as jet quenching models exhibit no jet definition dependent effects within systematic uncertainties. The quality of the jet reconstruction is shown in Fig 4 left which shows the invariant jet cross section as function of p_T for $p+p$ at $\sqrt{s} = 200GeV$. Jets in $Cu+Cu$ at $\sqrt{s} = 200GeV$ show a considerable suppression comparable to the R_{AA} of π^0 mesons[14]

5. Conclusion

We have presented an overview of jets and jet like correlations in PHENIX in $p+p$ and heavy ion collisions. All measurements show strong modifications in central collisions. The observed suppression level in $Cu+Cu$ at $\sqrt{s} = 200GeV$ is comparable between π^0 mesons and reconstructed jets. Work is underway to measure the medium modification to the fragmentation function. The run this year employs a silicon vertex tracker which should enable us to separate mesons containing c and b quarks, shedding light on the medium effects on heavy quarks.

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