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PHENIX measurement of direct photon-triggered two-particle correlations in heavy ion collisions and its implication for medium-induced energy loss.

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Direct photon-hadron correlations are an excellent probe for QCD effects, including parton energy loss in the Quark-Gluon Plasma. At leading order, direct photons balance the p_T of the away-side jet. In addition, as a colorless probe, direct photons do not interact strongly with the colored medium providing a less biased trigger than a single high-p_T hadron. PHENIX has measured direct photon-triggered two-particle azimuthal correlations in a variety of collision systems at $\sqrt{s} = 200$ GeV. In d+Au collisions, no modification of the per-trigger pair yields compared to p+p collisions was observed constraining the amount of cold nuclear matter effects in such collisions. In A+A collisions, direct photons have been identified statistically, as well as using an isolation cut. Combining data sets from different collisions systems allows us to quantify the transition from suppression at high z_T ($= p_T^h/p_T^\gamma$) to the enhancement of low z_T particles relative to p+p, and to study this transition as a function of trigger p_T. Integrating per-trigger yields in different ranges of the away-side gives insights on the redistribution of energy within the jet. The implication for our understanding of energy loss mechanisms will be discussed.

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1. Introduction

Experiments and theoretical analyses have shown that a plasma of quarks and gluons created in relativistic heavy ion collisions exhibits remarkable properties, including opacity to traversing quarks and gluons. However, the exact mechanism for energy loss by these partons in quark gluon plasma and transport of the deposited energy within the plasma is not yet well understood. Experimental probes to address this question include correlations among particles arising from initial hard partonic scattering. Correlations of direct photons with hadrons are of particular interest.

Direct photons do not interact via the strong force and are produced via the quantum chromodynamics analog of Compton scattering at leading order. In the limit of negligible initial transverse momentum, the final state quark and photon are emitted back-to-back in azimuth with the photon balancing the transverse momentum of the jet arising from the quark. Consequently, measuring the correlation of high momentum direct photons with opposing hadrons allows investigation of quark gluon plasma effects upon transiting quarks and their fragmentation into jets of hadrons.

In this talk we present new PHENIX results on direct photon-hadron correlations in d+Au and Au+Au collisions at $\sqrt{s} = 200$ GeV.

2. Direct photon-hadron correlations measurement in PHENIX

The measurements in this paper use the PHENIX central spectrometers [1]. Two particle correlations are constructed by pairing photons measured in the Electromagnetic Calorimeter (EMCal) with charged hadrons reconstructed in the Drift Chambers (DC) and Pad Chambers (PC) The acceptance in rapidity is $|\eta| < 0.35$, while each spectrometer arm covers 90^o in azimuth. Beam-Beam counters (BBC) located at 1.44 meters from the center of the interaction region, cover rapidity range from 3.0 to 3.9 and full azimuthal angle. They are used to determine the collision centralities and event vertex position.

We aim to quantify the modification of the jet fragmentation function $D(z)$ in Au+Au and d+Au collisions, compared to the p+p baseline. The jet fragmentation function describes the probability of an outgoing parton to yield a hadron with momentum fraction $z = p_{hadron}/p_{parton}$. Assuming that the intrinsic k_T of partons in a nucleon has a negligible effect, then $z_T = p_T^h/p_T^\gamma$ can be used to approximate z. In order to focus on the low z_T region we use the variable $\xi = ln(1/z_T)$.

A more detailed description of the analysis procedure can be found in [2] and [3].

Fig. 1 shows azimuthal angular distributions of hadrons associated with direct photons of $5 < p_T < 7$ GeV/c, in the 0-10% most central Au+Au collisions (black circles) and in p+p collisions (open blue squares). The plots are shown for different ξ ranges.

The fragmentation function is obtained by integrating the per-trigger yield of hadrons in the azimuthal angle region $|\Delta\phi - \pi| < \pi/2$ rad and is shown in Fig. 2 as a function of ξ for p+p, d+Au and Au+Au collisions.

3. The results

$I_{AA} = Y_{AA}/Y_{pp} \approx D_{AA}(z)/D_{pp}(z)$, where Y_{AA} and Y_{pp} are per trigger yields of hadrons in nucleus-nucleus and proton-proton collisions correspondingly, is a nuclear modification factor

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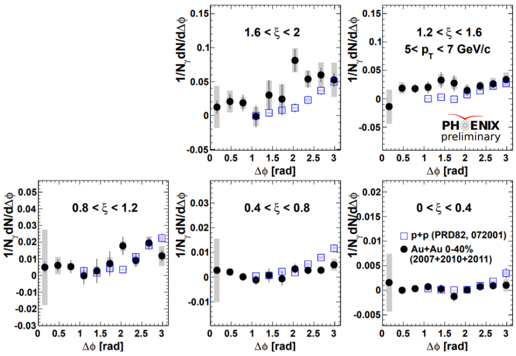

Figure 1: Per trigger yields of hadrons as a function of the angle between the hadron and the trigger photon.

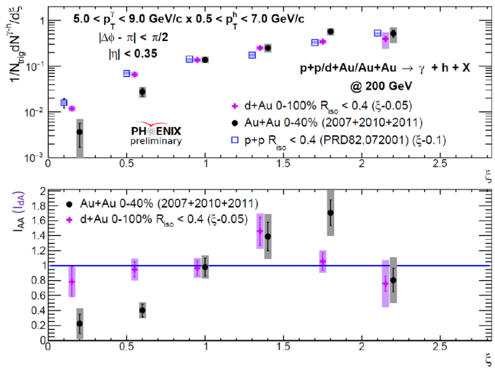

Figure 2: Effective fragmentation function (top) and nuclear modification factor (bottom) as a function of ξ.

which quantifies the difference between the fragmentation functions in Au+Au and p+p. In the absence of in-medium modifications, I_{AA} should be equal to 1. The nuclear modification factor I_{AA} is shown in Fig. 3 as a function of ξ for three different trigger photon p_T ranges. While the associated hadron yields are smaller than those in p+p at low ξ, the appearance of extra particles at higher ξ is observed for triggers with p_T of 5-7 GeV/c. A qualitatively similar increase of I_{AA} with ξ is visible for the 7-9 GeV/c p_T bin.

In order to investigate where the energy deposited in the plasma goes, we study the dependence of I_{AA} on the integration range in azimuthal opening angle. The hadron yields are integrated in two narrower angular ranges on the away side $|\Delta\phi - \pi| < \pi/3$ *rad* and $|\Delta\phi - \pi| < \pi/6$ rad. The resulting I_{AA} values are shown in Fig. 4 for all three photon p_T bins. The enhancement over p+p is largest for 5-7 GeV/c triggers, and for the full away-side integration range. The suppression observed at low ξ and low trigger photon p_T is similar for the different integration regions, suggesting that the jet core is suppressed, and the enhancement exists at large angles.

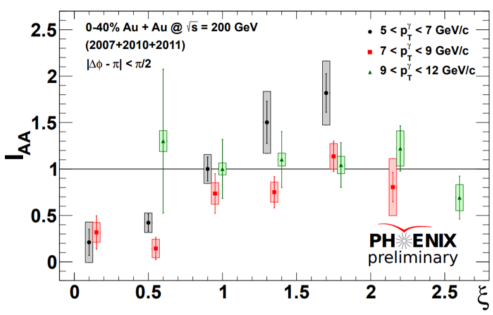

Figure 3: Two particle nuclear modification factor I_{AA} as a function of ξ.

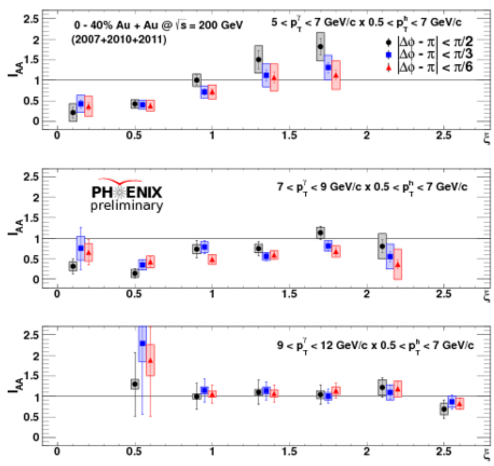

Figure 4: I_{AA} as a function of ξ for different trigger p_T and integration range.

Whether or not I_{AA} becomes significantly larger than unity - what we have been referring to as enhancement - there is a tendency for I_{AA} to increase with increasing ξ. To quantify this, we calculate the weighted averages of I_{AA} values above and below $\xi = 1.2$. The ratio for each integration range is plotted in Fig. 5, as a function of the trigger photon p_T. The enhancement is largest for softer jets and for the full away-side integration range, implying that jets with lower energy are broadened more than higher energy jets.

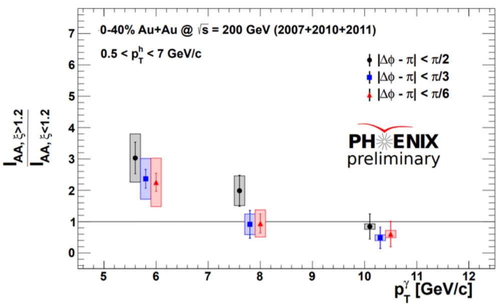

Figure 5: Ratio of I_{AA} at large and small ξ as a function of trigger p_T for different integration ranges.

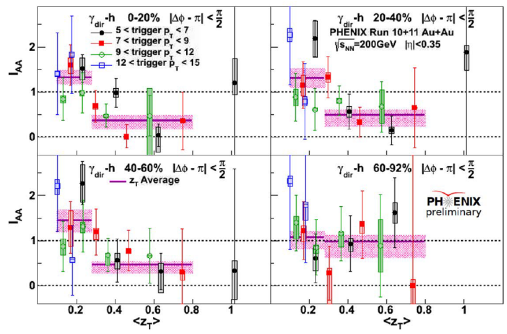

Figure 6: Average nuclear modification factor I_{AA} as a function of z_T for different centralities in Au+Au collisions.

3.1 Centrality dependence

Adapting the isolation cone method for use in Au+Au collisions allowed us to improve the precision of direct photon-hadron correlation measurements and determine the centrality dependence of the nuclear modification factor. Fig. 6 shows I_{AA} as a function of mean z_T for four different centrality bins. The nuclear modification factors I_{AA} were averaged above and below $z_T = 0.3$ as is shown by purple bands in this figure. These averages were used to study suppression/enhancement as a function of collision centrality.

The average I_{AA} is shown in the top panel of Fig. 7 for two z_T ranges as a function of centrality expressed as the number of participants N_{part}. While at low z_T the average I_{AA} is consistent with one, for the high z_T bin there is a clear decrease of the average I_{AA} with increasing centrality. The bottom panel of this figure shows the double ratio of I_{AA} at low and high z_T. A statistically significant monotonic increase in suppression is seen as the collision centrality increases.

Fig. 8 shows the comparison of the average two-particle nuclear modification factor I_{AA} and the single particle nuclear modification factor R_{AA} for π^0 in Au+Au collisions as a function of centrality. Similar suppression is observed in both cases.

4. Conclusions

Direct photon-hadron correlations are a powerful tool for studying QCD.

d+Au collisions show no significant modification of fragmentation function compared to p+p, which indicates that possible CNM effects are small.

In Au+Au collisions enhancement at low z_T (high ξ) and suppression at high z_T (low ξ) is observed. Suppression increases monotonically with centrality. Enhancement is largest for a broad

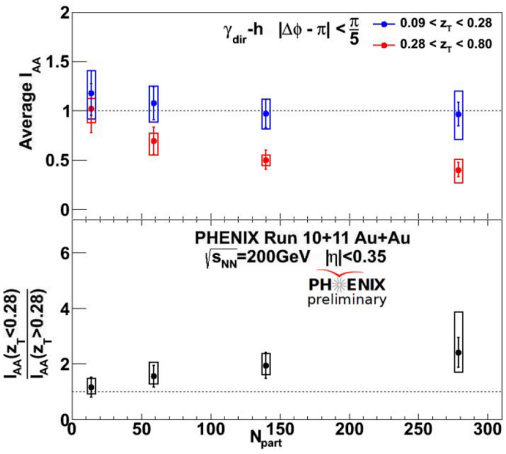

Figure 7: Average I_{AA} as a function of centrality expressed as the number of participants for two different z_T ranges (top) I_{AA} double ratio (bottom).

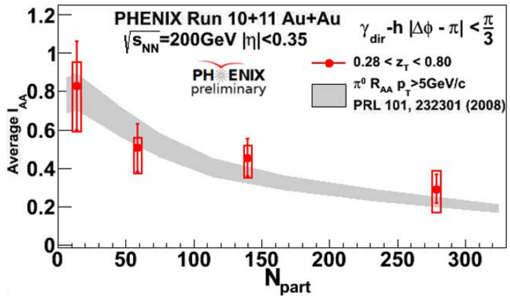

Figure 8: Comparison of average I_{AA} for direct photon-hadron correlations and single particle nuclear modification factor R_{AA} for π^0.

integration region and for soft hadrons. Transition from suppression to enhancement appears to occur at fixed hadron p_T. All this suggests medium response dominated processes.

Two-particle nuclear modification factor I_{AA} for direct photon-hadron correations and single particle nuclear modification factor R_{AA} for π^0 are consistent in Au+Au collisions.

More measurements are expected to come from PHENIX soon. Large Au+Au data sets from 2014 and 2016 are currently being analyzed.

References

[1] K. Adcox et al., NIM A499 469-479 (2003)

[2] A.Adare et al., Phys. Rev. **C86** 024909 (2012)

[3] A. Adare et al., Phys. Rev. **C80** 024908 (2009)