Production of Direct Photons, π^0's, and η's in p+p and Au+Au Collisions at RHIC

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Abstract. The PHENIX experiment at RHIC has measured neutral pion, eta, and direct photon production in $\sqrt{s_{NN}} = 200$ GeV p+p and Au+Au collisions. The neutral pion and direct photon yields in p+p collisions are well described by NLO pQCD predictions. In Au+Au collisions the neutral pion yield is suppressed as compared to expectations from p+p collisions, with a suppression which increases with increasing nuclear overlap. However, the direct photon yield shows no centrality dependent suppression, indicating that the pion suppression is due to a final state effect, such as parton energy loss in the excited final state.

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INTRODUCTION

The most dramatic observation from experiments at the Relativistic Heavy Ion Collider (RHIC) is the strong suppression of the yield of hadrons at large transverse momenta ($p_T > 2$ GeV/c) in central Au+Au collisions, as compared to measured yields in $p+p$ collisions scaled by the number of binary nucleon-nucleon collisions [1, 2, 3, 4]. This effect was predicted to result from the energy loss of hard-scattered partons propagating through the high density matter created in heavy ion collisions [5]. It was later proposed that the observed hadron suppression could be an initial-state effect due to saturation of the initial parton distributions in large nuclei [6]. Measurement of direct photon production allows a rather definitive discrimination between initial- and final-state suppression due to the fact that photons, once produced, are essentially unaffected by the surrounding matter. Hence photons produced directly in initial parton scatterings will not be quenched unless the initial parton distributions are suppressed in the nucleus. In fact, the direct photon yield may be enhanced in *AA* collisions [7] due to various processes such as momentum broadening of the incoming partons, additional fragmentation contributions [8, 9], or additional scatterings in the thermalizing dense matter of the final state.

The results described here were obtained with the PHENIX experiment at RHIC. Photons were measured with the PHENIX electromagnetic calorimeter subsytem located in the central arms of PHENIX. Each arm covers 90^o in ϕ with $|y| < 0.35$. The neutral pion and eta yields were extracted from their two-photon decay branch via a photon-pair invariant mass analysis. Further details may be found in [3, 10, 11, 12].

RESULTS

The completely corrected inclusive photon yields are compared to the expected yields of background photons from hadronic decays in the left panel of Fig. 1 for minimum bias Au+Au collisions (0-92% of the geometric cross section) and for five centrality selections. The decay photon calculations are based on the measured π^0 and η spectra [3, 12] assuming m_T-scaling for all other radiative decays (η',K^0_s,ω). The comparison is made as the ratio of measured (inclusive) γ/π^0 and calculated background γ/π^0 since many uncertainties, such as the energy scale, cancel to varying extent in the ratio. Since the π^0 spectra of the background calculations are taken to be the same as the measured spectra any significant deviation of the double ratio above unity indicates a direct photon excess. In Fig. 1 an excess is observed at high p_T with a magnitude that increases with increasing centrality of the collision. The extracted direct photon spectra as a function of centrality are shown in the right panel of Fig. 1. The curves shown in Fig. 1 are NLO pQCD $p+p$ predictions [12] scaled by the number of binary nucleon-nucleon collisions corresponding to the chosen centrality selection. The NLO pQCD predictions are found to be consistent with the observed direct photon yields.

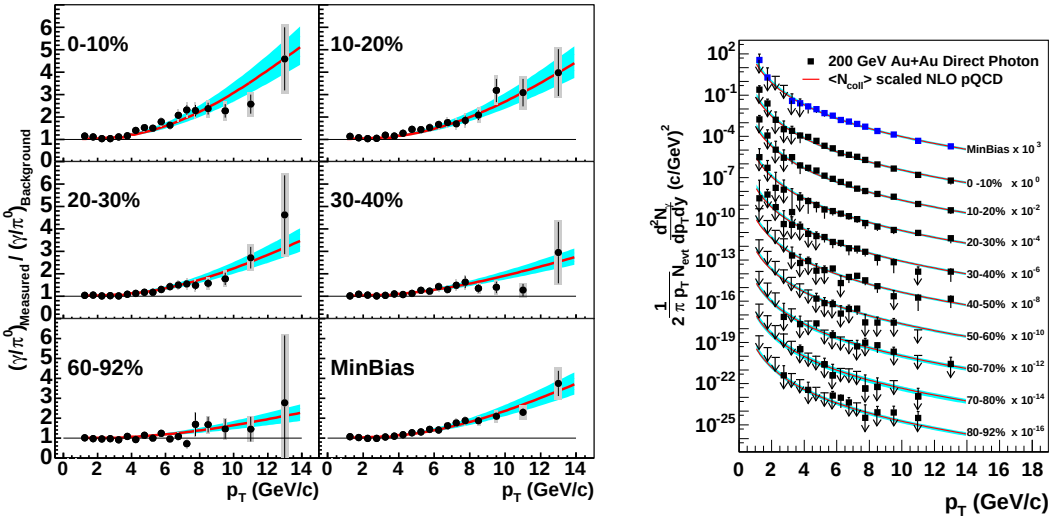

FIGURE 1. Left: Double ratio of measured $(\gamma/\pi^0)_{\text{Measured}}$ invariant yield ratio to the background decay $(\gamma/\pi^0)_{\text{Background}}$ ratio as a function of p_T for minimum bias and for five centralities of Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (0-10% is the most central). Statistical and total errors are indicated separately on each data point by the vertical bar and shaded region, respectively. The solid curves are the ratio of NLO pQCD predictions to the background photon invariant yield based on the measured π^0 yield for each centrality class. The shaded region around the curves indicates the variation of the pQCD calculation for scale changes from $p_T/2$ to $2p_T$, plus the $\langle N_{coll}\rangle$ uncertainty. Right: Direct γ invariant yields as a function of transverse momentum for 9 centrality selections and minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The vertical error bar on each point indicates the total error. Arrows indicate measurements consistent with zero yield with the tail of the arrow indicating the 90% confidence level upper limit. The solid curves are NLO pQCD predictions.

Medium effects in *AA* collisions are often presented using the *nuclear modification factor* given as the ratio of the measured *AA* invariant yields to the yield per $p+p$ collision times the average number of nucleon-nucleon collisions $\langle N_{coll}\rangle$ in the centrality

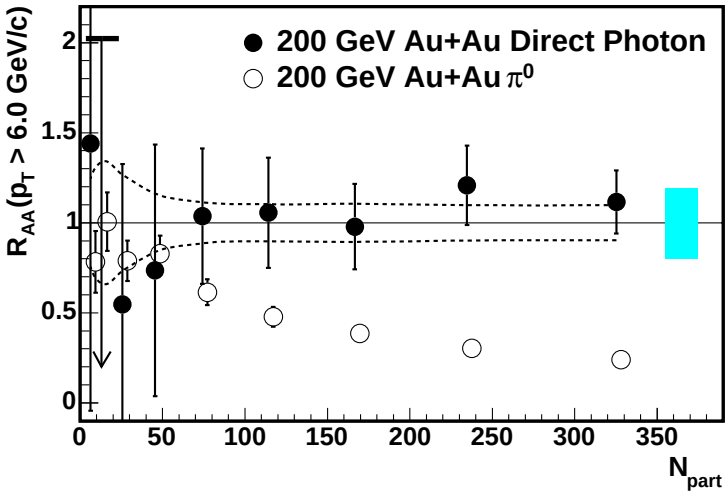

FIGURE 2. Ratio of Au+Au yield to $p+p$ yield normalized by the number of binary nucleon collisions as a function of the number of participating nucleons N_{part} for direct γ (closed circles) and π^0 (open circles) yields integrated above 6 GeV/c. The $p+p$ direct photon yield is taken as the NLO pQCD prediction. The error bars indicate the total error excluding the error on $\langle N_{coll}\rangle$ shown by the dashed lines and the scale uncertainty of the NLO calculation shown by the shaded region at the right.

bin under consideration:

$$R_{AA}(p_T) = \frac{(1/N_{AA}^{evt})\, d^2N_{AA}/dp_T dy}{\langle N_{coll}\rangle/\sigma_{pp}^{inel} \times d^2\sigma_{pp}/dp_T dy}. \quad (1)$$

The deviation of $R_{AA}(p_T)$ from unity provides a measure of the deviation of AA data from an incoherent superposition of NN collisions.

The centrality dependence of $R_{AA}(p_T > 6 \text{ GeV}/c)$ for high transverse momentum direct photons are shown in Fig. 3 and compared to the result for π^0 production. Unlike the π^0 production which shows a suppression which increases with Au+Au collision centrality, the high p_T direct photon yield is consistent with the NLO pQCD predictions scaled by the number of nucleon-nucleon collisions.

The p_T dependence of the direct photon $R_{AA}(p_T)$ for central Au+Au collisions is shown in Fig. 3 and compared to the π^0 $R_{AA}(p_T)$. Unlike the suppression observed for π^0 production, the direct photon yield is observed to scale with the number of collisions, within errors, over the full p_T range.

SUMMARY AND CONCLUSION

The PHENIX experiment at RHIC has measured π^0, η, and direct photon production in $p+p$ and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The π^0 and direct photon yields in $p+p$ collisions are well-described by NLO pQCD predictions. As a function of collision centrality in Au+Au collisions, the π^0 yield is suppressed in comparison to the yield expected from $p+p$ collisions scaled by the number of binary nucleon-nucleon collisions, with a suppression which increases with increasing centrality and

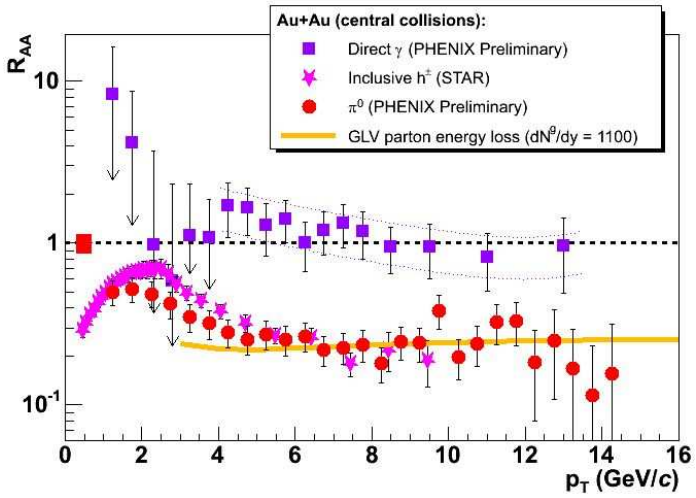

FIGURE 3. Ratio of Au+Au yield to $p+p$ yield normalized by the number of binary nucleon collisions as a function of p_T for direct γ (squares) and π^0 (circles) yields for the 10% most central Au+Au collisions. The $p+p$ direct photon yield is taken as the NLO pQCD prediction with scale variation indicated by the dashed lines. The error bars indicate the total error excluding the error on $\langle N_{coll} \rangle$ shown by the shaded region $R = 1$. The scale uncertainty of the NLO calculation is shown by the dashed lines about the γ result. Results for non-identified hadrons from STAR [13] are also shown (stars). Hadron energy loss calculations [14, 15, 16] are shown by the solid curve.

that is essentially independent of p_T at high p_T. In contrast, the direct photon yield is observed to scale with the number of binary nucleon-nucleon collisions with a yield that is consistent with the NLO pQCD predictions. The results clearly indicate that the hadron suppression observed in central Au+Au collisions is a consequence of the dense matter produced in the final state.

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