PHENIX Direct Photons in 200 GeV p+p and Au+Au Collisions

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Abstract.
We present the first positive direct photon ($\gamma$) results in Au+Au at $\sqrt{s_{NN}} = 200$ GeV along with initial p+p results at the same energy. The p+p result is found to be consistent with NLO perturbative QCD (pQCD) predictions within its large uncertainties. In central Au+Au collisions, an excess over expected background as large as 200-300% is observed from transverse momentum ($p_T$) 4-12 GeV/c. This large signal is shown to be consistent with the scaled pQCD $\gamma$ prediction, together with suppression of meson background sources.

1. Introduction

The study of hard scattering processes is a large and important part of the RHIC program. So far only hadronic production has been measured, but hard prompt photons are anticipated to provide complementary information.

Hard $\gamma$ production is dominated by gluon Compton scattering where an incoming quark and gluon interact to yield a photon and another quark. While this process has the same initial state as other hard parton-parton interactions, its final state has an outgoing $\gamma$ which suffers no fragmentation and thus carries information that is cleaner and less complicated than jet-forming color charged counterparts. Hence, hard $\gamma$'s provide an excellent probe to study nucleon gluon structure in p+p collisions. Furthermore in A+A collisions, the photons should not be distorted by the dense color fields of any media formed, once produced.

Direct photon measurements are considered difficult because of a large background of meson decay photons relative to signal. This background peaks at $p_T$ below $\sim$4GeV and makes measurements there most difficult. Consequently, our Au+Au results are not currently precise enough to distinguish the expected thermal component [1] above this background or even newly proposed sources of $\gamma$ enhancement [2] since each are expected to be significant only in similar low $p_T$ regions as the background. At higher $p_T$ however, the already observed suppression of background mesons should result in a large intrinsic signal to background, if the hard $\gamma$ are indeed unmodified. This would be

§ For the full PHENIX Collaboration author list and acknowledgments, see Appendix ”Collaborations” of this volume.
interesting by itself, and would also support the claim that jet quenching suppression is an effect of the final, and not the initial state.

2. Data analysis and results

The data shown here was taken in the 2001 RHIC run 2 with the standard PHENIX setup as in [3] and [4]. Especially important to this analysis are: 1) the Electromagnetic Calorimeter (EMCal) which detects photon showers and 2) The use of EMCal high $p_T$ triggers. For this analysis, a new set of Au+Au data corresponding to 55M sampled events, obtained with a high $p_T$ trigger that had 100% efficiency for $p_T \geq 5$ GeV/c, was combined with the 30M minimum bias events of [3], while the p+p data set consisted of 35M triggered events. [3] and [4] also describe the underlying $\pi^0$ analyses as well other details of the statistical direct photon search technique we employ for this analysis.

To measure the total inclusive single photon spectrum, EMCal showers are counted in each $p_T$ bin, with shower shape and timing cuts applied to reduce the hadronic shower contributions. The remaining charged track contamination is estimated by measuring distance correlations from Pad Chamber charge particle veto hits. $n/\pi$ contamination is estimated from the PHENIX measurements of $p/\bar{p}$ (with isospin feed-down modifications) and a full GEANT simulation using FLUKA. Total hadron contamination to the photon spectra peaks at 18-25% for low values of $p_T (<\sim 3$ GeV) due to the contracted hadronic shower response of the calorimeters, and is estimated with a $p_T$-independent upper limit of 5-15% above $\sim 6$ GeV/c. In p+p, we make a further cut for background reduction which removes $\pi^0/\eta \rightarrow \gamma\gamma$ photons in $\gamma$ pairs with invariant mass near the $\pi^0$ or $\eta$ mass. Corrections for acceptance, energy smearing, detector multiplicity skew, conversion loss, and other effects then follow.

The expected background from photonic meson decay to this inclusive spectrum is calculated using simple kinematic decay simulations. To estimate the contributing meson sources, $m_T$ scaling based on $\pi^0$ is used with normalization ratios from high $p_T$ world averages [4] and additionally for $\eta$ ($0.55$), from our corroborating preliminary measurements. The ratio of measured to expected background photons is made such that an excess $> 1$ is interpreted as the direct photon contribution. In order to cancel certain systematic errors, we divide by the final $\pi^0$ spectrum both the photon measurement (using $\pi^0$ data points) and background expectation (using a $\pi^0$ fit). This makes a double ratio interpreted in the same way.

Results are shown in the figures (1,2,3). The major systematic uncertainties come from the efficiency determination (10%), the $\pi^0$ peak extraction (9%), and the hadron contamination (12-7%). For p+p, the excess ratio is then applied back to the inclusive photons creating the invariant spectrum of direct photons. All results are compared to pQCD direct $\gamma$ predictions [6], scaled by nuclear thickness ("$N_{coll}$") and combined with our decay background calculations for Au+Au.
3. Results and Conclusion

A large and significant photon excess above meson decay background, attributable to direct photons, is found in central Au+Au events. The very high intrinsic signal to background ratio at the highest $p_T$ is a new phenomenon. The size of the signal is found to be consistent with the nuclear thickness-scaled pQCD expectation, given the previously observed level of suppression for mesons at RHIC \cite{3}. Since peripheral events lack the same suppression, the signal in these events becomes undetectable within the current uncertainties. The invariant spectrum of direct photons obtained for p+p collisions is also found to be qualitatively consistent with the same expectation within its large uncertainties.

These observations imply the presence of a medium in central Au+Au collisions which quenches hard partons but does not affect hard photons. This is exactly the behavior predicted for color dense matter like the QGP \cite{7}. Since hard production rates for mesons and photons are determined by the initial state, the photon observations, like those from studies of d+Au hard probes, indicate that such a medium exists only in the final state. Future PHENIX work in making the $\gamma$ measurements more precise at lower $p_T$ values will be able to address other QGP predictions such as modified thermal production and other enhancement.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Direct $\gamma$ excess double ratio and cross section in 200 GeV p+p collisions. The cross section is compared to pQCD \protect\cite{6} for scale factors $\mu = 0.5p_T, 1.0p_T, 2.0p_T$.}
\end{figure}

\begin{thebibliography}{99}
\bibitem{1} T. Peitzmann, M. Thoma, Phys. Rept. \textbf{364} (2002) 175
\bibitem{2} R. J. Fries, B. Muller and D. K. Srivastava, Phys. Rev. Lett. \textbf{90}, 132301 (2003) [arXiv:nucl-th/0208001].
\bibitem{3} S. S. Adler \textit{et al.}, Phys. Rev. Lett. \textbf{91}, 072301 (2003).
\bibitem{4} K. Reygers [PHENIX Collaboration], Nucl. Phys. A \textbf{715}, 683 (2003) [arXiv:nucl-ex/0209021].
\bibitem{5} WA80 Collaboration, R. Albrecht et al., Phys. Lett. B \textbf{361}, 14 (1995)
\bibitem{6} S. Catani, M. L. Mangano, P. Nason, C. Oleari and W. Vogelsang, JHEP \textbf{9903}, 025 (1999) / Private Communication \texttt{arXiv:hep-ph/9903436}.
\bibitem{7} X. N. Wang and Z. Huang, Phys. Rev. C \textbf{55}, 3047 (1997) \texttt{arXiv:hep-ph/9701227}.
\end{thebibliography}
Figure 2. Photon excess double ratio for the most central Au+Au bin, compared to pQCD (see text) for different scale factors as indicated. The dot-dash curve represents the expected excess if there were no suppression of the meson decay background. All uncertainties are expressed in the vertical error bars. Horizontal error bars represent only the bin width.

Figure 3. Photon excess double ratio for remaining Au+Au centralities compared to pQCD as in Fig. 2.