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Direct Photon Measurement at RHIC-PHENIX

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1. Introduction

The suppression of high transverse momentum ($p_T$) hadrons in central Au+Au collisions called as “jet quenching” has been of great interest since its first discovery by the PHENIX experiment at RHIC \cite{1}. The question has been asked, however, whether or not the phenomenon is attributed to energy loss of hard-scattered partons in a hot and dense medium (final state effect).

Photons are excellent probes for extracting the direct information of where they are produced because they do not interact strongly with medium once produced. Thus, they are expected to provide hints to answer questions of whether the jet quenching is due to initial or final state effect. The leading process of photon production is dominated by compton scattering of quarks and gluons ($qg \to q\gamma, g\gamma$) and the annihilation of quarks and antiquarks ($q\bar{q} \to g\gamma$), and the next leading process is dominated by bremsstrahlung and fragmentation.

In this report, the latest results on direct photon measurement from the PHENIX experiment are shown, and the source of photons is discussed.

2. Detector and Analysis

The description of PHENIX detector can be found in the literature \cite{2}. In this analysis, electromagnetic calorimeter (EMCal) was used for measuring the energy of photons. The EMCal consists of six lead-scintillator sandwich type calorimeters and two lead-glass homogeneous type calorimeters. The drift chambers and pad chambers were used to track charged particles to estimate charged hadron contamination in EMCal clusters.

The analysis of direct photons requires determining background photons decaying from known hadronic sources such as $\pi^0$ and $\eta$. PHENIX has measured the $p_T$ spectra of $\pi^0$ up to 13 GeV/c in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV \cite{3,4}. The momentum spectra of $\eta$ and other hadronic sources were estimated by using a fit to $\pi^0$ $p_T$ spectrum and applying $m_T$ scaling: $p_T \to (p_T^2 - M_\pi^2 + M_\eta^2)^{1/2}$. The normalization factor of $h/\pi^0$ at $p_T = \infty$ is obtained either from simulation or measurement. In case of $\eta$, $h/\pi^0$ was measured to be $0.45 \pm 0.05$. The number of photons decaying from known hadronic sources are then obtained from these spectra.

The inclusive photon spectra were reconstructed by applying several photon ID cuts on the measured cluster energy distributions, and correcting for hadron contamination and PID efficiency. The photon PID is realized by consisting likelihood functions from several quantities measured by EMCal such as shower shape or ratio of energies among towers, and by applying thresholds to them. It resulted in a significant reduction of hadronic clusters in the sample. Since the ratio of $\gamma$ to $\pi^0$ cancels their common systematic errors, the excess of the measured photon over the estimated background photon is evaluated in terms of $R_\gamma \equiv (\gamma/\pi^0)_{\text{measured}}/(\gamma/\pi^0)_{\text{estimated}}$ (double ratio). The direct photon spectra are extracted as $\gamma_{\text{direct}} = (1 - R_\gamma^{-1}) \cdot \gamma_{\text{measured}}$. The final systematic errors on the spectra are at the level of $\sim 15-20 \%$ \cite{5}.

3. Results

Fig. \textsuperscript{1} shows the $\gamma/\pi^0$ double ratios over various centralities in Au+Au collisions together with next-to-leading order (NLO) pQCD calculation scaled by the number of binary collisions shown in solid lines \cite{6}. The shaded bands on the data points show the systematic errors, and the bars are the statistical errors. The shaded bands around the lines show the uncertainty of the pQCD calculation. The magnitude of the excess at and above $p_T \sim 4$ GeV/c increases with increasing centrality of collisions, and is consistent with the calculation. Fig. \textsuperscript{2} shows the direct photon spectra extracted as described in the previous section. The lines show the same NLO pQCD calculation scaled by the number of binary collisions. It is clearly seen that all nine centralities including minimum bias are well described by the calculation. Fig. \textsuperscript{3} shows nuclear modification factor $R_{AA}$ as a

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{\(\gamma/\pi^0\) double ratios in Au+Au collisions.}
\end{figure}
function of centrality, represented by $N_{\text{part}}$. The $R_{AA}$ is defined as:

$$R_{AA} = \frac{1}{N_{\text{coll}}} \frac{d^2N_{AA}}{d^2p_T dy}$$

The dotted lines show the uncertainty on the number of binary collisions, and the boxes show the uncertainty of the NLO pQCD calculation. The open circles are for $\pi^0$ (open), and direct photons (solid).

From these results, we conclude that the hard scattering process at the initial stage follows the number of binary collisions scaling, and a large suppression of high $p_T$ $\pi^0$ is attributed to the final state interaction with a dense medium.

4. Beyond hard process photons

There have been several theoretical predictions on photon contributions on top of hard process. Fig. 4 shows a comparison of 0-10% central PHENIX data with a model including jet-photon conversion process. The jet-photon conversion is expected to occur, in the existence of QGP, by a secondary interaction of a hard scattered parton with thermal partons in the medium [8]. In this plot, hard process is calculated in leading-order pQCD with primordial $k_T$, and the next-leading-order contribution is partly compensated by bremsstrahlung process indicated in dotted lines. Although the pQCD calculation does not take full NLO processes into account, and therefore there is a possibility of underestimating the hard process contributions, the result suggests that the amount of the signal seen in $p_T$ region of 4-6 GeV/c is related with the existence of QGP.

5. Conclusion

Direct photon measurements in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV from the PHENIX experiment at RHIC are presented. The yields for $p_T > 6$ GeV/c are found to be consistent with NLO pQCD calculation scaled by the number of binary collisions. The result confirmed that the photons observed are produced through a hard scattering process in the initial stage, and the suppression of high $p_T$ hadrons is attributed to a final state effect.

References