Systematic Study of High-$p_T$ Direct Photon Production with the PHENIX Experiment at RHIC

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Abstract. When studying the initial state and evolution of the matter created in relativistic heavy ion collisions, high-$p_T$ direct photons are a powerful probe. They are created in initial hard processes and in parton fragmentation, and possibly in interactions of partons with the hot and dense medium. We present systematic measurements of high-$p_T$ direct photon production in $\sqrt{s_{NN}} = 200$ GeV $p+p$ and $Au+Au$ collisions. The nuclear modification factor of direct photons is shown for $5 < p_T < 18$ GeV/$c$, and at very high transverse momenta it seems to be below unity in the most central $Au+Au$ collisions.

1. Introduction

Direct photons are a powerful probe to study the initial state of matter created in relativistic heavy ion collisions since photons do not interact strongly once produced. They are emitted in all stages of the collision: in the initial state where photon production can be described by NLO pQCD, in the Quark-Gluon Plasma (QGP), dominated by thermal emission, and in the final hadron-gas phase [1]. In addition, high transverse momentum ($p_T$) photons are expected to be produced by the interaction of jet partons with dense matter.

The direct photon yields measured in RHIC-Year2 heavy ion collisions by the PHENIX experiment are in good agreement with a NLO pQCD calculation scaled by the number of binary nucleon collisions within experimental errors and theoretical uncertainties [2]. While this suggests that the initial hard scattering probability is not reduced, the direct photon yield measured in Au+Au collisions is in principle expected to be suppressed compared to binary scaled NLO pQCD calculations, because direct photons in the calculation consist of prompt photons produced directly in hard scattering and jet fragmentation photons from hard scattered partons which in turn would be suppressed due to the jet-quenching effect. The agreement with NLO pQCD calculations can just be a coincidence caused by mutually counterbalancing effects of

‡ For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume
Compton-like scattering of the jet partons with the medium, often referred to as jet-photon conversion [3] and energy loss of jet partons themselves. In order to study this effect for direct photon in the dense matter, it is important to measure the nuclear modification factor ($R_{AA}$) of direct photon using $p+p$ data as a reference rather than NLO pQCD calculations as done in earlier publications.

The PHENIX experiment [4] can measure photons with two types of highly segmented electromagnetic calorimeters (EMCal) [5]. One is a lead scintillator sampling calorimeter (PbSc), and the other is a lead glass Cherenkov calorimeter (PbGl).

For the measurement of direct photons presented here, the conventional subtraction method has been used. $\pi^0$ and $\eta$ mesons are reconstructed via their two-photon decay mode. The $p_T$ spectra of direct photons are obtained by subtracting the spectra of decay photons from the $p_T$ spectra of inclusive photons. The decay photons were estimated based on the measured $\pi^0$ and $\eta$ spectra.

2. Result on $\sqrt{s} = 200$ GeV $p+p$ collisions

The direct photon spectra in $\sqrt{s} = 200$ GeV $p+p$ collisions based upon RHIC-Year3 data have been published in [6]. The new large amount of data recorded by PHENIX in RHIC-Year5 ($\int L = 3.8 \text{ pb}^{-1}$) makes it possible to extend the $p_T$ range of the direct photon cross-section. The left panel of Fig. 1 shows the preliminary result for direct photon cross-section in $\sqrt{s} = 200$ GeV $p+p$ collisions. A NLO pQCD predictions [7], using
CTEQ 6M parton distribution functions and the BFG II parton to photon fragmentation function, with three theory scales ($\mu$) are shown as well. The data are consistent with the NLO pQCD calculation within the uncertainties.

For the measurement of the $R_{AA}$ in Au+Au, the direct photon cross-section in p+p collisions is parameterized. The right panel of Fig. 1 shows how well the parameterization describes the direct photon cross-section. The NLO pQCD calculations are also shown. Although the theoretical calculation can reproduce the experimental data within the uncertainties, the mean points of the data are systematically larger than the calculation.

3. Result on $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions

PHENIX recorded high-statistics Au+Au data in RHIC-Year4 ($\int L = 241 \mu$b$^{-1}$). The new data allow us to measure direct photons and to evaluate their nuclear modification up to very high-$p_T$. Owing to the strong suppression of neutral hadrons in heavy ion collisions [3], the signal-to-noise ratio of direct photons is better for extraction at high-$p_T$ ($p_T > 5$ GeV$/c$). The direct photon excess ratio ($R = \gamma_{\text{all}}/\gamma_{\text{bg}}$) is about 3 at $p_T = 10$ GeV$/c$ in the most central (0-10 %) Au+Au collisions. The left panel of Fig. 2 shows direct photon spectra as a function of $p_T$ for nine centralities and minimum bias of Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The spectra shown here are obtained using only the PbSc calorimeter. The solid curves show the binary scaled fit to the p+p direct photon data.

The $R_{AA}$ is defined as:

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_Td\eta}{\langle T_{AA}(b) \rangle d^2\sigma_{pp}/dp_Td\eta},$$

where the numerator is invariant direct photon yield in unit rapidity in Au+Au collisions and the denominator is the expected yield from p+p collisions scaled by the nuclear overlapping function ($\langle T_{AA}(b) \rangle = \langle N_{\text{coll}}(b) \rangle / \sigma_{pp}$) in Au+Au. If the reaction is just the superposition of hard scatterings, unmodified by nuclear effects, the $R_{AA}$ is unity.

The right panel of Fig. 2 shows $R_{AA}$ of direct photons using the p+p reference as a function of $p_T$ in the most central (0-10 %) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, in comparison to several theoretical expectations [9, 10, 11]. $R_{AA}$ of direct photons seems to be below unity at very high-$p_T$ ($p_T > 14$ GeV$/c$). None of the theoretical calculations reproduces $R_{AA}$ in the full $p_T$ range. Jet-photon conversion is not taken into account in Arleo’s calculation [11], and so-called isospin effect is not taken into account in Turbide et al.’s calculation [10]. In order to measure $R_{AA}$ of direct photons more precisely at very high-$p_T$, it is necessary to measure high-$p_T$ direct photon with the PbGl calorimeter, which can provide same measurement with different systematics that would give more detailed insight of the high-$p_T$ direct photons.
4. Summary

The measurements of high-$p_T$ direct photons in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are presented. The direct photon signal is extracted as a function of the Au+Au collision centrality and $R_{AA}$ is calculated with p+p direct photon data. The $R_{AA}$ of very high-$p_T$ direct photon seems to be below unity in the most central collisions.

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