Prompt Photon Production at RHIC and LHC

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We calculate prompt photon production rates at relativistic heavy ion collisions at RHIC and LHC. We include the full NLO diagrams as well as nuclear shadowing and medium induced energy loss effects. We show that energy loss effects are important and reduce the cross section by almost an order of magnitude at $p_t = 3$ at LHC and by $\sim 30\%$ at RHIC.

1 Introduction

Prompt photons have been the subject of considerable theoretical and experimental work in heavy ion collisions. They are thought to be a excellent probe of the Quark Gluon Plasma, possibly formed at relativistic heavy ion collisions performed at RHIC and under construction at LHC. Prompt photons, once produced, do not interact strongly and escape the formed media without further interactions and therefore carry valuable information about the early stages of the heavy ion collisions.

In addition to providing valuable information about the early stages of a heavy ion collisions, prompt photons are also an important background to other sources of photon production, for example, photons produced from a thermal bath or photons coming from pion decays. In order to separate out these different photons, one needs to understand and reliably calculate prompt photon production cross section.

In calculating prompt photon production in high energy nuclear collisions, it is quite typical to take the leading order (LO) cross sections for the partonic subprocesses and convolute them with the appropriate distribution and fragmentation functions. To take into account hogher-order corrections, the K-factor is introduced. In this work, we use the latest available NLO results for prompt photon production in hadronic collisions and modify the initial state parton distribution and final state parton fragmentation functions in order to take nuclear effects into account[1]. We show that the K-factor is large and p_t dependent and that nuclear effects reduce the cross section by a large amount.

2 Nuclear cross sections

In pQCD, the inclusive cross section for prompt photon production can be written as a convolution of parton densities with the hard scattering cross section and the parton to photon fragmentation function:

$$E\frac{d^3\sigma^{AB}}{d^3p_\gamma}(\sqrt{s},p_t) = \int dx_a \int dx_b \int dz \sum_{i,j}^{partons} F_i^A(x_a,Q^2)F_j^B(x_b,Q^2)D^{\gamma/c}(z,Q_f^2)E_\gamma \frac{d^3\hat{\sigma}_{ij\to cX}}{d^3p_\gamma} \tag{1}$$

where the $F_i^A(x,Q^2)$ is the i-th parton distribution in a nucleus and $D^{\gamma/c}(z,Q_f^2)$ is the photon fragmentation function in a nuclear environment. The parton distribution functions in a nucleus, $F_i^A(x,Q^2)$ include shadowing. In this work we used the parameterization of nuclear shadowing due to Benesh, Qiu and Vary[2]. In this parameterization, the nuclear distribution functions are given by $f^A(x,Q^2) \equiv S(x,A)\,f(x,Q^2)$ where $f(x,Q^2)$ is the parton distribution function in a proton and $f^A(x,Q^2)$ is the parton distribution function in a nucleus. The shadowing function $S(x,A)$ is given by

$$S(x,A) = \left\{ \begin{array}{ll} \alpha_3 - \alpha_4 x & x_0 < x \leq 0.6 \\ (\alpha_3 - \alpha_4 x_0)\frac{1+k_q\alpha_2(1/x-1/x_0)}{1+k_q A^{\alpha_1}(1/x-1/x_0)} & x \leq x_0 \end{array} \right\} \tag{2}$$

This parameterization seems to provide a good description of the available data on nuclear shadowing. There is also a more recent parameterization available[3] which includes Q^2 dependence of shadowing. In Fig. (1) we show the shadowing function.

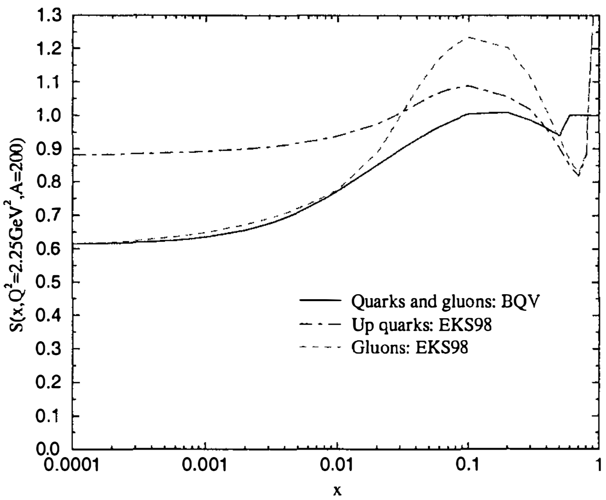

Figure 1: The nuclear shadowing ratio as parameterized by BQV and EKS.

We also include the medium induced energy loss effects by using the energy loss model of Huang, Sarcevic and Wang[4]. In this model, a parton traversing the nuclear mdeium, a quark gluon plasma, multiply scatters from the quarks and gluons in the medium and radiates away energy. This multiple scattering is taken into account by modifying the final state parton photon fragmentation function.

$$zD_{\gamma/a}(z, \Delta L, Q_f^2) = \frac{1}{C_N^a} \sum_{n=0}^{N} P_a(n) \left[z_n^a D^0_{\gamma/a}(z_n^a, Q_f^2) + \sum_{j=1}^{n} \bar{z}_a^j D^0_{\gamma/g}(\bar{z}_a^j, Q_f^2) \right] \tag{3}$$

where $z_n^a = z/(1 - (\sum_{i=0}^{n} \epsilon_i^a)/E_t)$, $\bar{z}_j^a = zE_t/\epsilon_j^a$ and $P_a(n)$ is the probability that a parton of flavor a traveling a distance ΔL in the nuclear medium will scatter n times. It is given by

$$P_a(n) = \frac{(\Delta L/\lambda_a)^n}{n!} e^{-\Delta L/\lambda_a}, \tag{4}$$

and $C_N^a = \sum_{n=0}^{N} P_a(n)$.

The first term in Eq. (3) corresponds to the fragmentation of the leading parton a with reduced energy $E_t - \sum_{i=0}^{n} \epsilon_a^i$ after n gluon emissions and the second term comes from the j-th emitted gluon having energy ϵ_a^j where ϵ_a^j is the energy loss of the parton a after j-th scattering given by[5] $\epsilon_a^j = \alpha_s \sqrt{\mu_a^2 \lambda_a E_a^j}$ where E_a^j is the energy of the parton a after j scatterings, λ_a is the inelastic mean free path of parton a and μ_a^2 represent a screening mass generated by the plasma and serves as an infrared cut off.

In Fig. 2 we show our results for the invariant photon cross section as a function of photon p_t for RHIC at $\sqrt{s} = 130$ GeV. The effects of nuclear shadowing and energy loss on the nuclear cross sections are shown separately as well as combined. We take $\mu = 1$ GeV and $\lambda_q = \lambda_g = 1 fm$. We find that the nuclear shadowing and the parton energy loss effects result in about 18% suppression of the cross section at $p_t = 3$ GeV and about 4% at $p_t = 10$ GeV.

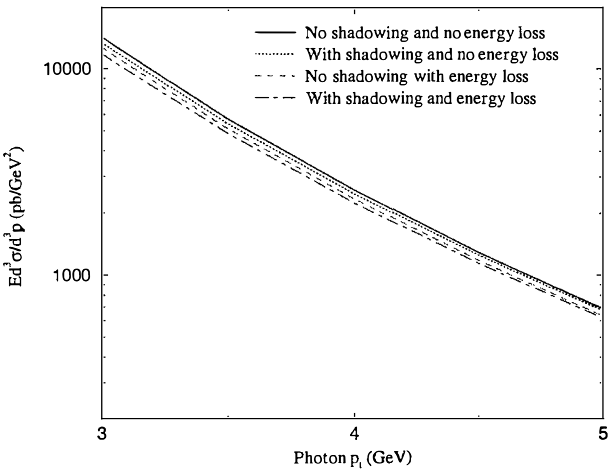

Figure 2: Prompt photon cross section at central rapidity at $\sqrt{s} = 130$ GeV.

In Fig. 3 we show the same cross section as in Fig. 2. for RHIC at the higher energy of $\sqrt{s} = 200$ GeV, expected to be reached experimentally sometime this year. As expected, the nuclear effects, shadowing and the parton energy loss become more important at higher energies.

At $p_t = 3$ GeV, there is about 30% suppression of the photon cross section while at $p_t = 10$ GeV it is a 7% effect. We expect that this effect can be observed experimentally at RHIC without ambiguity.

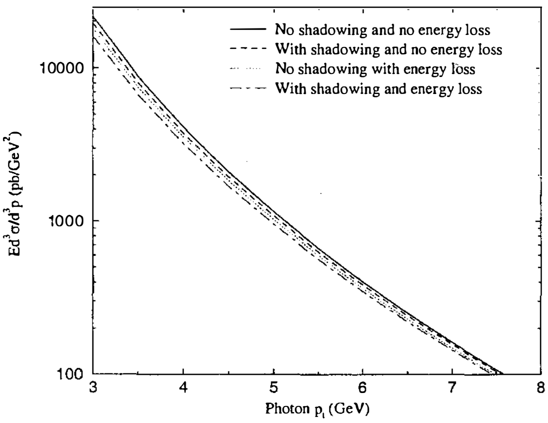

Figure 3: Prompt photon cross section at central rapidity at $\sqrt{s} = 200$ GeV.

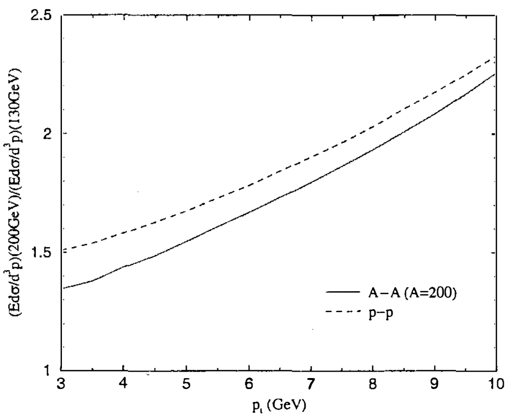

Figure 4: Ratio of hadronic and nuclear cross sections at $\sqrt{s} = 130$ GeV and $\sqrt{s} = 200$ GeV.

In Fig. 4 we show the ratio of hadronic and nuclear cross sections at different RHIC energies of $\sqrt{s} = 130$ GeV and $\sqrt{s} = 200$ GeV. By measuring this ratio one reduces the theoretical as well experimental uncertainties such as scale dependence of cross sections and systematic errors. Clearly, nuclear effects are especially important at lower p_t where the measurements are expected in the near future.

In summary, we have calculated the prompt photon production cross section for heavy-ion collisions at RHIC including the next-to-leading order corrections, $O(\alpha_{em}\alpha_s^2)$, nuclear shadowing effect and the final state parton energy losses. We have found that higher-order corrections, even relative to leading order plus the bremsstrahlung, are large and depend on p_t of the photon. We have also shown that nuclear effects are significant and can be as much as 30% at $\sqrt{s} = 200$ GeV.

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