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Di-photon correlations in p+A collisions at the LHC

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Abstract

We study the long-range in rapidity near-side and away-side azimuthal collimation, the so-called ”ridge” structure for di-photon correlations in high-energy proton-nucleus (p+A) collisions. We show that based on the initial-state Color-Glass-Condensate at leading-log approximation, the ridge-like structure for di-photon correlations disappears at the LHC energies. Nevertheless, the near-side and away-side correlations coming from the remanent of double and single fragmentation contributions respectively, survive upto $\Delta\eta \approx 1 \div 3$ in rapidity interval between two produced photons at RHIC and the LHC. Therefore, an experimental observation of ridge-like structure in di-photon correlations at the LHC similar to the one observed in di-hadron correlations in p+p(A) collisions, may suggest that final-state effects play important role in the formation of the ridge.

Keywords: CGC, Di-photon, Ridge, Proton-nucleus collisions

1. Introduction

The discovery of the so-called ridge phenomenon, namely the long-range in rapidity near-side ($\Delta\phi \approx 0$) di-hadron correlations in high-multiplicity events selection in both proton-proton (p+p) and proton(duetron)+nucleus collisions at the LHC and RHIC [1], triggered an on-going debate about the underlying dynamics of high-multiplicity events. Both the initial-state Color-Glass-Condensate (CGC) [2, 3, 4, 5, 6] and the final-state hydrodynamic [7] approaches provide a good description of the same phenomenon. It is thus an open question whether the ridge phenomenon in p+p(A) collisions mainly come from initial-state or final-state effects; and if the ridge is a universal phenomenon, for all different two-particle productions in p+p(A) collisions.

It is believed that prompt photons, do not participate in the final-state interactions and can be considered as a good probe of the initial-stage of collisions. Moreover, in contrast to gluons, prompt photons do not scatter on the target gluon field, but rather decohere from the projectile wavefunction due to scattering of the quarks. Therefore, di-photon correlations can be considered as a golden channel to probe intrinsic correlations of partons in the hadronic and nuclear wavefunctions, and can provide vital information to address whether it is the initial or final state effects that play dominant role in formation of the ridge collimation in p+p(A) collisions.

In our hybrid approach for di-photon production [8, 9], the projectile proton is assumed to be in dilute regime (as one may expect to be so at forward rapidities) and is consequently treated in standard parton model approach, while the target is treated as a CGC object at forward rapidities. Therefore, we have here only one saturation scale and our calculation should be applicable to minimal bias events in p+Pb collisions and a more significant fraction of p+p events than those exhibiting di-hadron ridge correlations. In this sense the di-photon correlations is a much cleaner probe of initial state effects compared to di-hadrons, as it does not require modelling of rare fluctuations leading to high multiplicity events which are theoretically not well understood. This is one of main differences between our approach and the approach of Ref. [5] where the exis-

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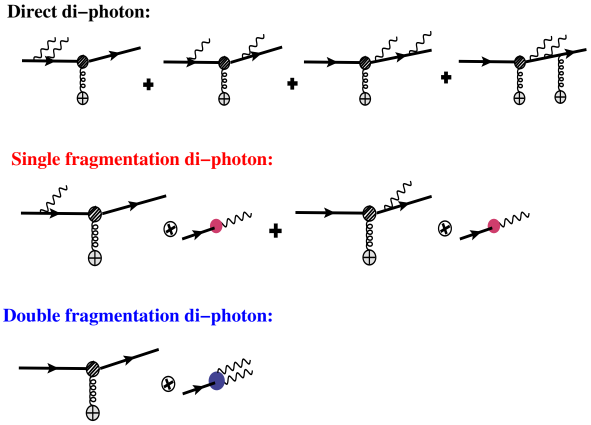

Figure 1: Typical CGC diagrams contributing to the inclusive prompt di-photon-quark production at leading-order in quark-nucleus collisions. The typical single and double fragmentation diagrams are also shown. The black blob denotes the interaction of a quark to all orders with the background field via multiple gluon exchanges. Note that the last right diagram on the top panel (direct di- photon) does not contribute at high energy.

tence of two saturation scales in the problem (for the projectile proton and the target) in p+Pb collisions at forward rapidities, is essential in order to find a good fit to the di-hadron ridge data.

2. Main formulation: factorization

The inclusive prompt di-photon production $h + A \to \gamma_1 + \gamma_2 + X$ in high-energy dilute-dense scatterings was recently calculated in the CGC approach [8, 9] where in the leading order approximation, at forward rapidity, a valence quark of the projectile hadron emits two photons with momenta k_1 and k_2 via Bremsstrahlung and the produced di-photon+jet is then put on shell by interacting coherently over the whole longitudinal extent of the target, see Fig. 1. The inclusive di-photon differential cross-section at leading-log approximation can be written in the following factorization form [8, 9],

$$\frac{d\sigma^{pA\to\gamma(k_1)\gamma(k_2)X}}{d^2\mathbf{b}\,d^2\mathbf{k}_{1T}\,d\eta_1\,d^2\mathbf{k}_{2T}\,d\eta_2} = \alpha_{em}^2\int_{x_q^{min}}^{1} dx_q f_q(x_q,\mu_I^2) \int d^2\mathbf{l}_T \mathcal{H}\left(\mathbf{k}_{1T},\mathbf{k}_{2T,}\mathbf{l}_T,\zeta_1,\zeta_2\right) N_F(l_T,x_g), \qquad (1)$$

where the function $N_F(l_T, x_g)$ is the correlator of two light-like fundamental Wilson lines in the background of the color fields of the target, and it encodes the small-x dynamics of the target [10]. The dipole amplitude $N_F(l_T, x_g)$ depends on the total transfer transverse momentum to target l_T and the fraction of light-cone momentum of target taken away by the exchange gluons x_g. At large N_c the dipole amplitude is obtained via the Balitsky-Kovchegov evolution equation [11]. The matrix function $\mathcal{H}$ depends on the transverse momenta of produced photons $\mathbf{k}_{1T}$, $\mathbf{k}_{2T}$ and the light-cone fractions of momentum of projectile taken away by two photons ζ_1, ζ_2. The matrix functional $\mathcal{H}$ is fairly lengthy and can be found in Ref. [9]. In Eq. (1), $f_q(x_q, \mu_I^2)$ denotes the parton distributions function (PDF) in the projectile hadron which depends on factorization scale μ and the parameter x_q defined as the ratio of the incoming quark to the projectile nucleon energy. The summation over quark and anti-quark flavor is implicit in Eq. (1). The matrix functional $\mathcal{H}$ includes the single and double fragmentation photon contributions, corresponding to the kinematics where only one emitted photon or both emitted photons are almost collinear with the outgoing quark, see Fig. 1. Note that both single and double fragmentation di-photon contributions, as well direct di-photon part are sensitive to the saturation dynamics via a convolution with the dipole amplitude $N_F(l_T, x_g)$, see Eq. (1).

The lower limit of integral x_q^{min} in the factorization Eq. (1) and light-cone variables x_g, ζ_1, ζ_2 are obtained via the energy-momentum conservation relations [8, 9]:

$$\begin{aligned}
x_g &= \frac{1}{x_q s}\Big[\frac{k_{1T}^2}{\zeta_1} + \frac{k_{2T}^2}{\zeta_2(1-\zeta_1)} + \frac{|\mathbf{l}_T - \mathbf{k}_{1T} - \mathbf{k}_{2T}|^2}{1-\zeta_1-\zeta_2+\zeta_1\zeta_2}\Big],\\
\zeta_1 &= \frac{k_1^+}{p^+} = \frac{k_{1T}}{x_q\sqrt{s}}e^{\eta_1},\\
\zeta_2 &= \frac{k_2^+}{p^+ - k_1^+} \approx \frac{k_2^+}{p^+} = \frac{k_{2T}}{x_q\sqrt{s}}e^{\eta_2},\\
x_q^{min} &= Max\left(\frac{k_{1T}e^{\eta_1}}{\sqrt{s}}, \frac{k_{2T}e^{\eta_2}}{\sqrt{s} - k_{1T}e^{\eta_1}}\right),
\end{aligned} \qquad (2)$$

where $\sqrt{s}$ is the nucleon-nucleon center-of-mass energy. η_1 and η_2 are rapidities of the produced photons. The azimuthal correlation of the produced di-photon is defined via

$$C_2(\Delta\phi, k_{1T}, k_{2T}, \eta_1, \eta_2) = \frac{d\sigma^{pA\to\gamma(k_1)\gamma(k_2)X}}{d^2\mathbf{k}_{1T}d\eta_{\gamma_1}d^2\mathbf{k}_{2T}d\eta_{\gamma_2}}[\Delta\phi] \Big/ \int_0^{2\pi} d\Delta\phi \frac{d\sigma^{pA\to\gamma(k_1)\gamma(k_2)X}}{d^2\mathbf{k}_{1T}d\eta_{\gamma_1}d^2\mathbf{k}_{2T}d\eta_{\gamma_2}} - C_{ZYAM}, \qquad (3)$$

where $\Delta\phi$ denotes the azimuthal angle between the two produced photons in the plane transverse to the collision axis.

3. Results and Conclusion

We first focus on the prompt di-photon correlations in quark-nucleus (q+A) collisions. The near-side and