PROCEEDINGS OF SCIENCE

Study of prompt photon production at the CERN LHC energies

G. Sampaio dos Santos,[a,*] **G. Gil da Silveira**[a,b] **and M. V. T. Machado**[a]

[a] *Universidade Federal do Rio Grande do Sul,*
9500 Ave. Bento Gonçalves, Porto Alegre, Brazil

[b] *Universidade do Estado do Rio de Janeiro,*
524 St. São Francisco Xavier, Rio de Janeiro, Brazil

E-mail: gss.fisica@gmail.com, gustavo.silveira@ufrgs.br, magno.machado@ufrgs.br

A study on the prompt photon production considering *pp* and *pA* collisions at the LHC energy regime is performed. Predictions for the differential cross section as well as the nuclear modification factor are calculated based on the QCD color dipole framework. The results are directly compared to the measurements provided by the CMS and ATLAS Collaborations as a function of the photon transverse momentum at different rapidity bins.

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*Speaker

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1. Prompt photon production in pp/pA collisions within the color dipole framework

The study of the prompt photon production can be treated within the QCD color dipole approach, where the prompt photon emission is pictured as a quark/antiquark electromagnetic bremsstrahlung [1], which exchange one gluon with the target. Thus, one can interpret the real photon radiation process by means of $q\bar{q}$ dipole scattering off the target. The differential cross section for prompt photon production in pp collisions as a function of the photon rapidity y^{γ} and transverse momentum p_T is obtained by convoluting the proton structure function F_2^p with the partonic cross section:

$$\begin{aligned} \frac{d^3\sigma\,(pp \to \gamma X)}{dy^{\gamma} d^2\vec{p}_T} &= \frac{\alpha_{em}}{2\pi^2} \int_{x_1}^{1} \frac{d\alpha}{\alpha} F_2^p\left(\frac{x_1}{\alpha}, \mu^2\right) \left\{ m_q^2 \alpha^4 \left[\frac{\mathcal{I}_1}{(p_T^2 + \varepsilon^2)} - \frac{\mathcal{I}_2}{4\varepsilon} \right] \right. \\ &+ \left. [1 + (1-\alpha)^2] \left[\frac{\varepsilon p_T\, \mathcal{I}_3}{(p_T^2 + \varepsilon^2)} - \frac{\mathcal{I}_1}{2} + \frac{\varepsilon\, \mathcal{I}_2}{4} \right] \right\}. \end{aligned} \quad (1)$$

The Eq. (1) contains the Hankel integral transforms of order 0 ($\mathcal{I}_{1,2}$) and order 1 ($\mathcal{I}_3$) given by

$$\mathcal{I}_1 = \int_0^{\infty} dr\, r J_0(p_T\, r) K_0(\varepsilon\, r)\, \sigma_{dip}(x_2, \alpha r), \quad (2)$$

$$\mathcal{I}_2 = \int_0^{\infty} dr\, r^2 J_0(p_T\, r) K_1(\varepsilon\, r)\, \sigma_{dip}(x_2, \alpha r), \quad (3)$$

$$\mathcal{I}_3 = \int_0^{\infty} dr\, r J_1(p_T\, r) K_1(\varepsilon\, r)\, \sigma_{dip}(x_2, \alpha r). \quad (4)$$

Furthermore, α denotes the fraction of the quark momentum carried by the photon, while the momentum fractions $x_{1,2}$ have the form $x_{1,2} = \frac{p_T}{\sqrt{s}} e^{\pm y^{\gamma}}$, being $\sqrt{s}$ the collision center-of-mass energy. In the Hankel transforms, we have the auxiliary variable $\epsilon^2 = \alpha^2 m_q^2$, where $m_q = 0.2$ GeV. Considering nuclear high-energy collisions, the QCD nuclear effects take place, in specific those derived from nonlinear gluon recombination and multiple parton scattering. Essentially, within the color dipole framework, the nuclear effects can be evaluated in two forms: via the geometric scaling (GS) property from parton saturation models or in terms of the Glauber-Gribov (GG) approach for nuclear shadowing. We consider the state-of-art of phenomenological models to the dipole-nucleus amplitudes N_A, which take into account the impact parameter dependence or geometric scaling. We apply the GS approach based on Ref. [2], which assumes that the GS establishes an A-dependence in the scattering cross section. Hence, the proposed GS considers that the nuclear effects are absorbed into the saturation scale and on the nucleus transverse area, $S_A = \pi R_A^2$, in correlation to the proton case, $S_p = \pi R_p^2$, where the nucleus radius is given by $R_A \simeq 1.12 A^{1/3}$ fm. Therefore, it is necessary to replace the proton saturation scale, $Q_{s,p}$, by the corresponding nuclear saturation scale, $Q_{s,A}$, consequently,

$$Q_{s,A}^2 = Q_{s,p}^2 \left(\frac{A\pi R_p^2}{\pi R_A^2} \right)^{\Delta}, \qquad N_A(x, r, b) = N(rQ_{s,p} \to rQ_{s,A}), \quad (5)$$

where $\Delta = 1 + \xi$ with $\xi = [(1-\delta)/\delta]$. The quantities $\delta = 0.79$ and $\pi R_p^2 = 1.55$ fm^2 have been determined by data [2]. Then, the prompt photon production cross section in pA collisions assuming the GS phenomenon is obtained as follows,

$$\frac{d^3\sigma(pA \to \gamma X)}{dyd^2\vec{p}_T} = \left(\frac{S_A}{S_p}\right) \frac{d^3\sigma(pp \to \gamma X)}{dyd^2\vec{p}_T}\bigg|_{Q^2_{s,p} \to Q^2_{s,A}} . \quad (6)$$

On the other hand, based on the GG approach that accounts the multiple elastic scattering diagrams associated to the dipole-nucleus interaction, the nuclear scattering cross section reads [3],

$$\sigma^{nuc}_{dip}(x, \vec{r}; A) = 2 \int d^2b \left\{1 - \exp\left(-\frac{1}{2}\sigma_{dip}(x, r)T_A(b)\right)\right\}, \quad (7)$$

where σ_{dip} represents the dipole-proton cross section, and T_A is the nuclear thickness function, usually calculated by considering a Woods-Saxon distribution. In this scenario, we replaced $\sigma_{dip} \to \sigma^{nuc}_{dip}$ in Eqs. (2-4).

In this particular framework the dipole cross section is a essential quantity to perform a calculation that can be compared to experimental measurements. Here we will employ parameterizations for σ_{dip} that are based on the gluon saturation assumption and its respective parameters are adjusted with the HERA data. Namely, the GBW [4] and BUW [5] approaches have the general expression

$$\sigma_{dip}(x, \vec{r}; \gamma) = \sigma_0 \left[1 - \exp\left(-\frac{r^2 Q_s^2}{4}\right)^{\gamma_{\text{eff}}}\right], \qquad Q_s^2(x) = \left(\frac{x_0}{x}\right)^{\lambda}, \quad (8)$$

where Q_s is the saturation scale. The GBW model considers the following set of parameters [6]: $\sigma_0 = 27.32$ mb, $x_0 = 0.42 \times 10^{-4}$, and $\lambda = 0.248$. In particular, GBW assumes $\gamma_{eff} = 1$, while BUW considers that the effective anomalous dimension is given by

$$\gamma_{\text{eff}} = \gamma_s + (1 - \gamma_s)\frac{(\omega^a - 1)}{(\omega^a - 1) + b}, \quad (9)$$

with $\omega \equiv p_T/Q_s$ and $\sigma_0 = 21$ mb, $x_0 = 3.04 \times 10^{-4}$, $\lambda = 0.288$, $a = 2.82$, and $b = 162$. Usually, analyzing the nuclear effects is made by measuring a nuclear modification factor, R_{pA}. Here it is determined as the ratio of pA to pp cross sections properly scaled with the correspondent mass number A of the target nucleus,

$$R^{\gamma}_{pA}(y, p_T) = \frac{d^3\sigma(pA \to \gamma A)/dy^{\gamma} d^2\vec{p}_T}{A \cdot d^3\sigma(pp \to \gamma p)/dy^{\gamma} d^2\vec{p}_T}. \quad (10)$$

In what follows we will show our results and compare them with the data from the LHC collider.

2. Results

Figure 1 shows the results for the inclusive prompt photon cross sections in pp collisions at $\sqrt{s} = 13$ TeV compared to the measurements obtained by the CMS Collaboration [7] in two distinct rapidity bins: $1.57 < |y^{\gamma}| < 2.1$ and $2.1 < |y^{\gamma}| < 2.5$. The GBW and BUW approaches delivery slightly different results taking $p_T < 300$ GeV. Apparently, in such p_T domain, the GBW and BUW parameterizations improve the data description, although we can not constrain between the models. On the other hand, the GBW predictions are similar to the BUW one considering the spectrum from

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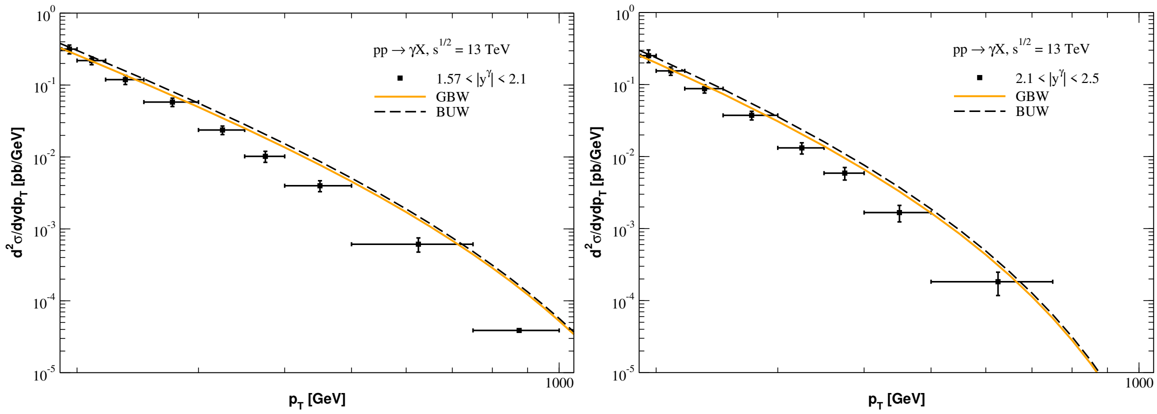

Figure 1: Prompt photon production cross section in pp collisions at $\sqrt{s}$ = 13 TeV.

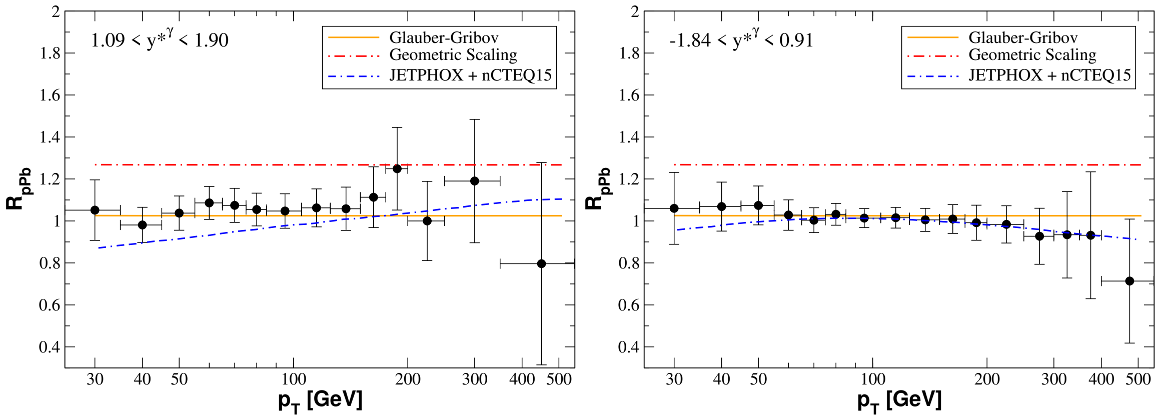

Figure 2: R_{pPb} in terms of p_T for a forward and backward rapidity bins at $\sqrt{s}$ = 8.16 TeV.

p_T > 300 GeV. This is indeed expected since $\gamma_{\rm eff}$ at large p_T is identical in both models, namely $\gamma_{\rm eff}$ = 1. However, at very forward rapidity, the GBW and BUW approaches are able to predict the correct shape and normalization concerning the p_T-spectrum.

The results regarding the nuclear modification factor in pPb collisions at $\sqrt{s}$ = 8.16 TeV in terms of p_T and $y^{*\gamma}$, the center-of-mass rapidity, are shown in Fig. 2, where the predictions are compared to the measurements provided by the ATLAS experiment [8]. Moreover, we include the results with pQCD at NLO level obtained by the JETPHOX Monte Carlo and nCTEQ15 nuclear PDF [9] in order to compare with our predictions considering only the GBW model as input. The nuclear modification factor measured is consistent with unity, implying that the magnitude of nuclear effects for the prompt photon production in pPb collisions becomes negligible. Furthermore, while the GG approach predicts quite small nuclear effect, the GS results suggest $R_{pPb} > 1$. Within the GS approach, the nuclear ratio is given as follows,

$$R^{\gamma}_{pA} \approx \left(\frac{A\pi R_p^2}{\pi R_A^2}\right)^{\xi}, \tag{11}$$

with $\xi \simeq 0.27$. Consequently, this reproduces numerically $R_{pPb} \simeq 1.3$ regarding any value of

p_T. The main uncertainty present in the GS approach is associated to $Q^2_{s,A}$, and in Ref. [10] we determined this uncertainty as ~20%. Lastly, the GG results are equivalent to those obtained by Monte Carlo simulation.

3. Conclusions

We show that the prompt photon production can be properly addressed within the dipole framework without any free parameter. Moreover, the GBW and BUW models tend to provide predictions that reasonable describe the data in large p_T. Additionally, we estimate the R_{pA} for prompt photon production at the LHC kinematic regime selecting different rapidity bins. We evaluate the influence of nuclear effects introduced by Glauber-Gribov and geometric scaling considering the p_T-spectrum of the prompt photon production. Our predictions do not suggest a strong suppression as a result of gluon saturation effects. Moreover, the GG estimates are quite similar to those given by JETPHOX Monte Carlo with nCTEQ15.

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