η_c photoproduction at LHC energies

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Introduction

In this contribution, we study the inclusive and diffractive η_c photoproduction in pp and pPb ultra-peripheral collisions (UPC's) at the LHC Run II energies. In a hadron-hadron UPC, is well known that the hadrons can act as sources of almost real photons allowing the study of photon-photon and photon-hadron interactions. Our goal is the study of the η_c production in photon-gluon and the photon-Pomeron subprocesses using the nonrelativistic QCD formalism (NRQCD). In this formalism, the photon-hadron process can be factorized in terms of the short distance coefficients for the photon-gluon subprocess (perturbatively calculated) and long distance matrix elements, related to the formation of the quarkonium at the final state, which are extracted from global analysis of the quarkonium data. As the photoproduction of η_c is a purely color octet contribution, this process is a probe of the color octet mechanism. In our analysis, we present our predictions for the rapidity distributions and total cross sections for the η_c photoproduction. A comparison with the predictions for the η_c production in photon-photon and exclusive photon-hadron interactions is presented.

η_c production at photo-induced processes

Let us consider an ultraperipheral collision (impact parameter $> R_{h_1} + R_{h_2}$) between two fast hadrons. In this regime we can factorize the cross section for the η_c production in hh collisions in terms of the equivalent flux of photons of the hadron projectile and the photon-hadron cross section. The rapidity distribution for quarkonium photoproduction in hadron-hadron collisions is given by[1]

$$\frac{d\sigma_{hh}}{dY}(Y) = n_{h_1}(Y)\sigma_{\gamma h_2}(Y) + (1 \longleftrightarrow 2\,; Y \to -Y) \tag{1}$$

where $n(Y)$ is the photon spectrum associated to the proton or nucleus which is dependent of the choice of the form factor. For protons as source of photons we use the dipole form factor, while, for Pb we have used the hard sphere form factor (according to the Ref.[1]). Besides that, the rapidity variable is related to the photon energy ω by $\omega = (M_{\eta_c}/2)\exp(Y)$. This approximation allows us to study the η_c production as a photo-induced process.

In order to study the inelastic η_c photoproduction in the process $\gamma + p \to \eta_c + X$, we will use the NRQCD formalism, which allows us to factorize the subprocess $\gamma + g \to \eta_c + g$ in two different steps: (i) the heavy pair production (perturbative), and (ii) the η_c formation, which is a nonperturbative process. Firstly, for the inclusive process[1,2] $\gamma + p \to \eta_c + X$, the cross section is given by

$$\sigma(\gamma + h \to \eta_c + X) = \int dz dp_T^2 \frac{xg(x,Q^2)}{z(1-z)}\frac{d\sigma}{d\hat{t}}(\gamma + g \to \eta_c + g) \tag{2}$$

where $z \equiv (p_{\eta_c}.p)/(p_\gamma.p)$ (fraction of the photon energy carried away by the η_c in the hadron rest frame), with p_{η_c}, p and p_γ being the four momentum of the η_c, hadron and photon, respectively. p_T is the magnitude of the η_c transverse momentum and $g(x,Q^2)$ is the gluon distribution function, for which we have used the CTEQ6LO parametrization (Ref.[3]) assuming that $Q^2 = 4m_c^2$. For the diffractive case we have used the diffractive PDF (Ref.[4]). The integration limits are taken so that $z < 1$ and $p_T^2 \geq 1$ GeV^2. The associated partonic differential cross section $d\sigma/d\hat{t}$ is given by[2]

$$\frac{d\sigma}{d\hat{t}} = \frac{1}{16\pi\hat{s}^2}F(^{2S+1}L_J^{[8]}) \times \langle\mathcal{O}(^{2S+1}L_J^{[8]})\rangle\ , \tag{3}$$

where $F(^{2S+1}L_J^{[8]})$ are the perturbative coefficients and $\langle\mathcal{O}(^{2S+1}L_J^{[8]})\rangle$ are the long distance matrix elements, obtained from experimental data of the quarkonium production. In this process, there are contributions from $^1S_0^{[8]}$, $^3S_1^{[8]}$ and $^1P_1^{[8]}$ states (Ref.[2]). Here we have used the $F(^{2S+1}L_J^{[8]})$ from Ref.[2] and the updated values for $\langle\mathcal{O}(^{2S+1}L_J^{[8]})\rangle$ from Ref.[5].

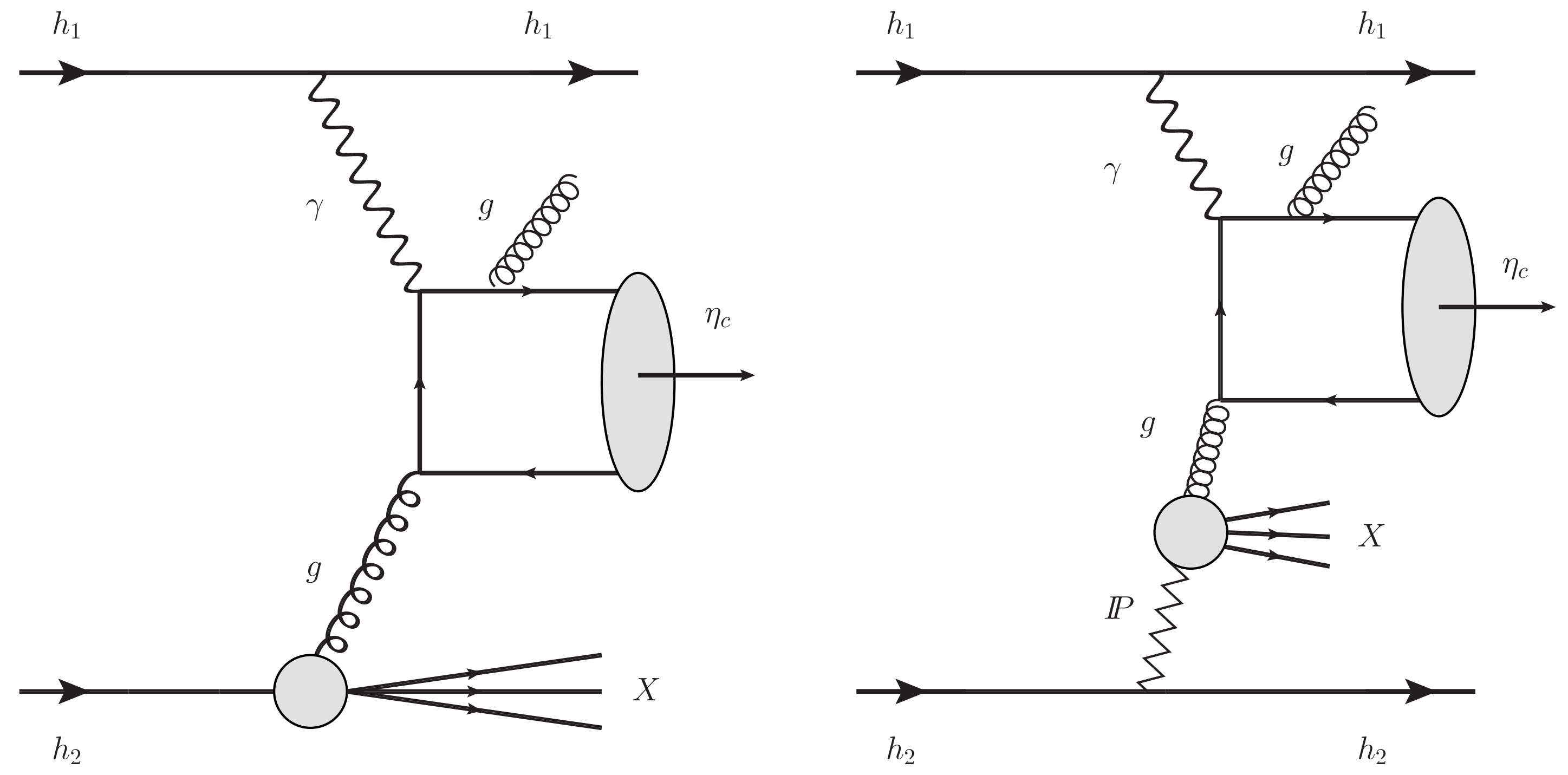

Figure 1: Feynman diagrams for η_c photoproduction.

Results

In the Figure 2 we present our predictions for the rapidity distribution (pp at $\sqrt{s} = 13$ TeV and pA at $\sqrt{s} = 8.1$ TeV). As expected, the rapidity distributions in pp collisions are symmetric in $Y = 0$, while in the pA case are asymmetric because the dominance of the γp interactions when the nucleus is acting as a source of photons. The bands presented are due to the uncertainty of the long distance matrix elements (Ref[5]). Moreover, the inclusive production is about 10 times larger than the diffractive production.

In the Table 1 we present our predictions for the total cross sections for the η_c photoproduction. For comparison, we present the predictions for the η_c photoproduction due to $\gamma\gamma$ and $\gamma\mathbb{O}$ mechanisms, from Refs.[1,6]. Here it is important to emphasize that the $\gamma\mathbb{P}$ diffractive, the $\gamma\gamma$ and the $\gamma\mathbb{O}$ processes are characterized by two rapidity gaps at the final state.

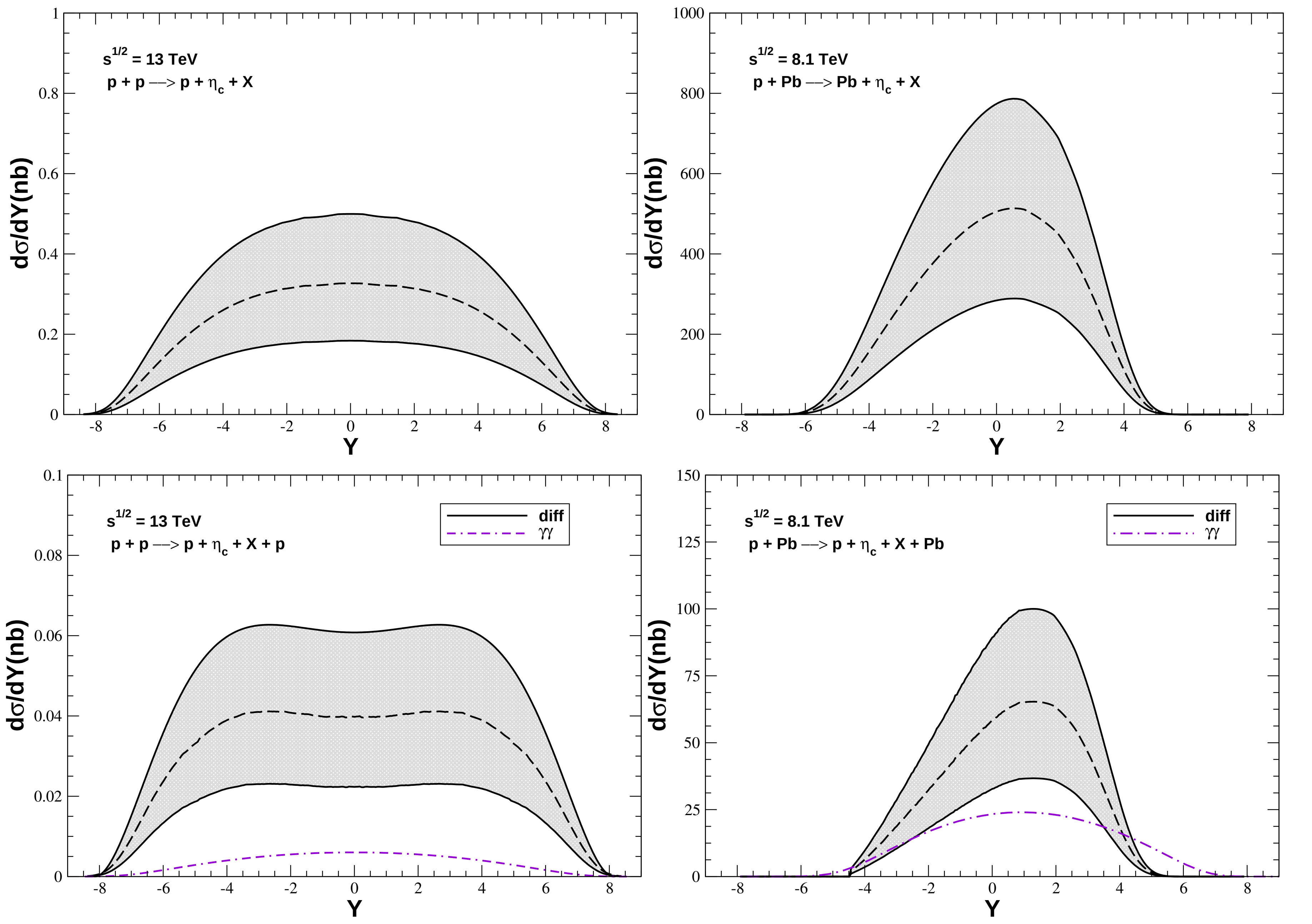

Figure 2: Rapidity distribution for the η_c photoproduction. Upper row: inclusive photoproduction in pp collisions (left panel) and pA collisions (right panel). Lower row: diffractive photoproduction in pp collisions (left panel) and pA collisions (right panel)

	γp inclusive	$\gamma\mathbb{P}$ diffractive	$\gamma\gamma$ exclusive	$\gamma\mathbb{O}$ exclusive
pp ($\sqrt{s} = 13$ TeV)	3.492 nb	0.501 nb	0.059 nb	0.013 nb
pPb ($\sqrt{s} = 8.1$ TeV)	3.194 μb	0.351 μb	0.182 μb	0.032 μb

Table 1: Total cross section for the η_c photoproduction. Here we also present the η_c productions due to $\gamma\gamma$ and $\gamma\mathbb{O}$ mechanisms from Refs.[1,6].

Conclusions

The photo-induced processes at LHC have been a powerful tool to study the hadronic structure and the QCD dynamics in different processes. In this contribution, we have studied the η_c photoproduction in the NRQCD formalism. Following the Ref.[2] , this process is a pure color octet and, therefore, it is a probe of the color octet mechanism. Moreover, it is important to note that the diffractive, $\gamma\gamma$ and $\gamma-$Odderon mechanisms are characterized by two rapidity gaps at the final state. In particular, the detection of the exclusive ($\gamma-$Odderon) mechanism would be a direct probe of the perturbative Odderon. Since the diffractive and $\gamma\gamma$ processes are backgrounds for the $\gamma-$Odderon process, the knowledge of their magnitudes can be useful for experimental analysis. Finally, the magnitude of the cross sections presented here, show that this study is feasible at LHC energies.

Acknowledgements

This work is partially financed by CNPq, CAPES and FAPERGS, Brazil.

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