Multiple photon production in double parton scattering at the LHC

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Abstract. The high density of gluons in the initial state of hadronic collisions at LHC implies that the probability of multiple parton interactions within one proton-proton collision increases. In particular, the probability of having two or more hard interactions in a collision is not significantly suppressed with respect to the single interaction probability. In this contribution we study for the first time the production of prompt photons in double parton scattering processes. In particular, we estimate the rapidity distribution for the double Compton process, which leads to two photons plus two jets in the final state. Besides, we study the production of three and four photons in the final state, which are backgrounds to physics beyond the Standard Model.

1. Introduction

Multiple photon production in hadronic collisions is a very interesting subject once it provides opportunities to study the predictions of the Standard Model, besides being background to Beyond Standard Model Physics. Recent studies predict the cross sections for $2\gamma$, $3\gamma$ and $4\gamma$ production in single parton scattering (SPS) processes [1, 2, 3]. Here we estimate the production of the same final states considering double parton scattering (DPS) processes. In particular, the final states are $2\gamma + 2\text{jets}$, $3\gamma + 1\text{jet}$ and $4\gamma$.

Multiple parton interactions in one proton-proton collision were already predicted in previous studies [4, 5], but with the energies available in colliders at those times, its contributions were suppressed with respect to the single scattering. However, due to the high energy regime reached at the LHC, the high density of partons in the initial state of hadronic collisions leads to the increase of the multiple parton interaction probability and, for some processes, double parton scattering, which can be described perturbatively, is also significant. This new perspective has motivated the rapid development of the theory of the DPS with several estimates of the cross section for different processes in the recent years [6, 7, 8, 9].

In a double parton scattering one can have, within one hadron-hadron collision, two partons from each colliding hadron interacting via two parton-parton interactions that happen almost independently. Figure 1 shows a general SPS process where one parton from each hadron interacts to form a final state, while in figure (2) one has a double partonic interaction generating a final state. Those final states do not have to be equivalent, but might be competitive. The main goal of the present work is to estimate the rapidity distribution for the production of prompt photons in DPS processes.
2. Theoretical framework

In the case where the two hard scatterings are independent and the same goes for the two incoming partons in each hadron, the DPS cross section can be written as

$$\sigma_{DPS} = \frac{C}{\sigma_{eff}} \sigma_{SPS}^1 \sigma_{SPS}^2$$ \hspace{1cm} (1)

where $C$ is a combinatorial factor which accounts for distinguishable ($C = \frac{1}{2}$) and indistinguishable ($C = 1$) final states, and $\sigma_{eff}$ is a normalization cross section representing the effective transverse overlap of partonic interactions that produce the DPS process. Its value is estimated through a fit to experimental data [10, 11]. Also, $\sigma_{SPS}^1$ and $\sigma_{SPS}^2$ characterize the cross sections for the two hard scattering processes, and can be written (in LO) as usual

$$\sigma_{SPS} = \sum_{a,b,c,d} \int dx_a dx_b f_a^A (x_a, Q^2) f_b^B (x_b, Q^2) \hat{\sigma} (ab \to cd)$$ \hspace{1cm} (2)

where $f_i^h (x_i, Q^2)$ are the parton distribution functions (here we use the CTEQ6L parametrization [12]) and $\hat{\sigma}$ are the partonic cross sections for the contributing subprocesses.

Considering the production of at least one photon in each partonic subprocess, and using the same assumptions as in eq. (1), one can write a similar formula for the differential distributions,

$$\frac{d\sigma_{DPS}}{d\eta_1 dp_1T dp_2T} = \frac{C}{\sigma_{eff}} \frac{d\sigma_{SPS}^1}{d\eta_1 dp_1^2T} \cdot \frac{d\sigma_{SPS}^2}{d\eta_2 dp_2^2T}$$ \hspace{1cm} (3)

where $\eta_i$ and $p_iT$ are the rapidity and transverse momentum of one of the photons produced in each SPS process, for which one has

$$\frac{d\sigma_{SPS}}{d\eta dp_1^2T} = \sum_{a,b,c,d} \int_{x_{a,min}}^{1} dx_a f_a^A (x_a, Q^2) f_b^B (x_b, Q^2) x_a x_b \frac{d\hat{\sigma}}{d\eta} (ab \to \gamma d)$$ \hspace{1cm} (4)

where $x_T = \frac{2p_T}{\sqrt{s}}$, $x_b = \frac{x_a x_T e^{-\eta}}{2x_a - x_T e^{-\eta}}$, $x_{a,min} = \frac{x_T e^{-\eta}}{2 - x_T e^{-\eta}}$. Also, $\frac{d\hat{\sigma}}{d\eta}$ are the leading-order partonic cross sections for the relevant subprocesses [13]. Integrating equation (3) over the transverse momenta $p_1T$ and $p_2T$, one obtains the rapidity distributions

$$\frac{d\sigma_{DPS}}{d\eta_1 d\eta_2} = \frac{C}{\sigma_{eff}} \frac{d\sigma_{SPS}}{d\eta_1} \cdot \frac{d\sigma_{SPS}}{d\eta_2}$$ \hspace{1cm} (5)
In what follows we estimate the $2\gamma + 2\text{jets}$ production considering the DPS process, taking into account that in the two SPS processes we have two Compton $(gq \rightarrow \gamma q)$ scatterings, which is the dominant mechanism [14]. The corresponding diagram is shown in figure 3. In the case of $3\gamma + 1\text{jet}$ production we assume that $\sigma^{DPS}(pp \rightarrow 3\gamma X) \propto \sigma^{SPS}(pp \rightarrow \gamma X)\sigma^{SPS}(pp \rightarrow \gamma \gamma X)$, and one typical diagram is shown in figure 4. Similarly, for $4\gamma$ production we assume that $\sigma^{DPS}(pp \rightarrow 4\gamma X) \propto \sigma^{SPS}(pp \rightarrow 2\gamma X)\sigma^{SPS}(pp \rightarrow 2\gamma X)$. For the sake of comparison, we show in figure 5 some typical SPS processes producing $4\gamma$, and in figure 6, some typical DPS processes leading to the same final states. In this work we use the aproximation $\sigma_{\text{eff}} = 15\text{mb}$ as in Ref. [6]. For the combinatorial factor we use $C = \frac{1}{2}$ for double Compton and four-photon production, and $C = 1$ for three-photon production.
Figure 7. Rapidity distributions for the LHC energies of $\sqrt{s} = 8$ TeV and 14 TeV.

3. Results
Our results for the multiple photon production at LHC energies using the DPS formalism are presented in figure 7, where we show the rapidity distributions for $2\gamma + 2\text{jets}$ (top lines), $3\gamma + 1\text{jet}$ (middle lines) and $4\gamma$ production (bottom lines) at $\sqrt{s} = 8$ TeV and $\sqrt{s} = 14$ TeV. The final state $2\gamma + 2\text{jets}$ have the larger cross sections, which are somewhat flat in the rapidity region considered and peaks around $10^3$ pb. For $3\gamma + 1\text{jet}$ and for $4\gamma$, the maximum values of the cross sections are above $10^1$ pb and $10^{-2}$ pb, respectively. These results indicates that measurements of DPS mechanism for multiple photon production are feasible to be measured at the LHC. In order to do so, it is important, however, that one finds the appropriate regions of phase space where the DPS processes could be distinguished from the same final states coming from SPS processes.

4. Summary
In this contribution we obtain, for the first time, results for multiple photon production in DPS processes. We show predictions for rapidity distributions for $2\gamma + 2\text{jets}$, $3\gamma + 1\text{jet}$ and $4\gamma$ final states at the LHC energies of $\sqrt{s} = 8$ TeV and 14 TeV. Our results show that all this processes have relevant cross sections, which indicates that they are feasible to be measured once one finds kinematic regions where they can be distinguished from the same final states coming from SPS processes. This is particularly important in experimental analyses of the multiple photon production as an observable to test the Standard Model and probe possible scenarios for Beyond the Standard Model Physics.

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