PROCEEDINGS OF SCIENCE

Production of W^+W^- pairs via subleading processes at the LHC

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We discuss many new subleading processes for inclusive production of W^+W^- pairs not included in the literature so far. We focus mainly on photon-photon induced processes. We include elastic-elastic, elastic-inelastic, inelastic-elastic and inelastic-inelastic contributions. The inelastic photon distributions in the proton are calculated in two different ways: naive approach used already in the literature and using photon distributions by solving special evolution equations with the photon being a parton in the proton. The results strongly depend on the approach used. We also calculate the cross section for single-diffractive production of W^+W^- pairs including pomeron and subleading reggeon exchanges in the Ingelman-Schlein model. The H1 diffractive parton distributions are used in the calculations. The results are compared to the results of elastic-inelastic (inelastic-elastic) $\gamma\gamma$ processes.

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1. Introduction

The $\gamma\gamma \to W^+W^-$ process is interesting by itself as it can be used to test the Standard Model and any other theories beyond the Standard Model. The photon-photon contribution for the purely exclusive production of W^+W^- was considered recently in the literature [1, 2]. The exclusive diffractive mechanism of central exclusive production of W^+W^- pairs in proton-proton collisions at the LHC (in which diagrams with an intermediate virtual Higgs boson as well as quark box diagrams are included) was discussed in Ref. [3] and turned out to be negligibly small. The diffractive production and decay of the Higgs boson into the W^+W^- pair was also discussed in Ref. [4]. The W^+W^- pair production signal would be particularly sensitive to New Physics contributions in the $\gamma\gamma \to W^+W^-$ subprocess [1, 2]. A similar analysis has been considered recently for $\gamma\gamma \to ZZ$ [5]. Corresponding measurements would be possible to be performed at ATLAS or CMS provided the very forward proton detectors are installed [6]. This would be a valuable supplement of the so far accepted scientific program.

We concentrate on inclusive production of W^+W^- pairs. The inclusive production of W^+W^- has been measured recently with the CMS and ATLAS detectors [7, 8]. The total measured cross section with the help of the CMS detector is 41.1 $\pm$ 15.3 (stat) $\pm$ 5.8 (syst) $\pm$ 4.5 (lumi) pb, the total measured cross section with the ATLAS detector with slightly better statistics is 54.4 $\pm$ 4.0 (stat.) $\pm$ 3.9 (syst.) $\pm$ 2.0 (lumi.) pb. The more precise ATLAS result is somewhat bigger than the Standard Model predictions of 44.4 $\pm$ 2.8 pb [8]. The Standard Model predictions do not include several potentially important subleading processes. We review several processes which have been ignored in the present Standard Model predictions. We will answer the question whether they can be responsible for the present disagreement between the state-of-art predictions and new experimental data. Some of the not included processes were already discussed separately. One of such examples is double parton scattering (DPS)

2. Inclusive production of W^+W^- pairs

The dominant contribution of W^+W^- pair production is initiated by quark-antiquark annihilation [9]. The gluon-gluon contribution to the inclusive cross section was calculated first in Ref. [10].

Therefore in the following for a comparison we also consider quark-antiquark and gluon-gluon components to the inclusive cross section. They will constitute a reference point for our calculations of the two-photon contributions.

2.1 $\gamma\gamma \to W^+W^-$ mechanism

In this section, we briefly discuss the inclusive $\gamma\gamma \to W^+W^-$ induced mechanisms. We shall calculate the contribution to the inclusive $pp \to W^+W^-X$ process for the first time in the literature.

If at least one photon is a constituent of the nucleon then the mechanisms presented in Fig.1 are possible. In these cases at least one of the participating protons does not survive the W^+W^- production process. In the following we consider two different approaches to the problem.

An approach how to include photons into inelastic processes was proposed some time ago by Martin, Roberts, Stirling and Thorne in Ref. [11]. In their approach the photon is treated on the

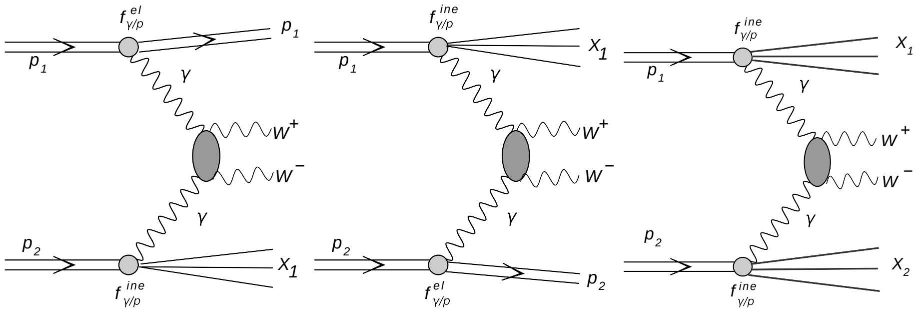

Figure 1: Diagrams representing inelastic photon-photon induced mechanisms for the production of W^+W^- pairs.

same footing as quarks, antiquarks and gluons. They proposed a QED-corrected evolution equation for the parton distributions of the proton [11].

In leading order approximation the corresponding triple differential cross section for the inelastic-inelastic photon-photon contribution can be written as usually in the parton-model formalism:

$$\frac{d\sigma^{\gamma_{in}\gamma_{in}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} x_1\gamma_{in}(x_1,\mu^2)\, x_2\gamma_{in}(x_2,\mu^2)\, \overline{|\mathcal{M}_{\gamma\gamma\to W^+W^-}|^2}\,. \tag{2.1}$$

The above contribution includes only cases when both nucleons do not survive the collision and the nucleon debris is produced instead. The case when at least one nucleon survives the collision has to be considered separately. Corresponding contributions to the cross section can then be written as:

$$\frac{d\sigma^{\gamma_{in}\gamma_{el}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} x_1\gamma_{in}(x_1,\mu^2)\, x_2\gamma_{el}(x_2,\mu^2)\, \overline{|\mathcal{M}_{\gamma\gamma\to W^+W^-}|^2}\,,$$
$$\frac{d\sigma^{\gamma_{el}\gamma_{in}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} x_1\gamma_{el}(x_1,\mu^2)\, x_2\gamma_{in}(x_2,\mu^2)\, \overline{|\mathcal{M}_{\gamma\gamma\to W^+W^-}|^2}\,,$$
$$\frac{d\sigma^{\gamma_{el}\gamma_{el}}}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} x_1\gamma_{el}(x_1,\mu^2)\, x_2\gamma_{el}(x_2,\mu^2)\, \overline{|\mathcal{M}_{\gamma\gamma\to W^+W^-}|^2}\,, \tag{2.2}$$
(2.3)

for the inelastic-elastic, elastic-inelastic and elastic-elastic components, respectively. In the following the elastic photon fluxes are calculated using the Drees-Zeppenfeld parametrization [12], where a simple parametrization of the nucleon electromagnetic form factors is used.

In the case of resolved photons, the "photonic" quark/antiquark distributions in a proton must be calculated first. This can be done by the convolution

$$f^{\gamma}_{q/p} = f_{\gamma/p} \otimes f_{q/\gamma} \tag{2.4}$$

which mathematically means:

$$x f^{\gamma}_{q/p}(x) = \int_x^1 dx_\gamma f_{\gamma/p}(x_\gamma,\mu_s^2) \left(\frac{x}{x_\gamma}\right) f\left(\frac{x}{x_\gamma},\mu_h^2\right)\,. \tag{2.5}$$

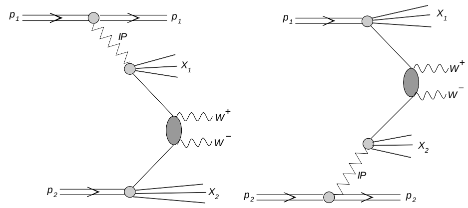

Figure 2: Diagrams representing single diffractive mechanism of the production of W^+W^- pairs.

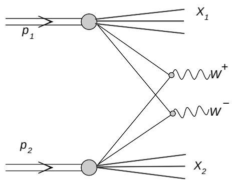

Figure 3: Diagram representing double parton scattering mechanism of the production of W^+W^- pairs.

Diffractive processes for W^+W^- production were not considered so far in the literature but are potentially very important.

In this approach one assumes that the Pomeron has a well defined partonic structure, and that the hard process takes place in a Pomeron–proton or proton–Pomeron (single diffraction) or Pomeron–Pomeron (central diffraction) processes. The mechanism of single diffractive production of W^+W^- pairs is shown in Fig.2.

In the present analysis we consider both pomeron and subleading reggeon contributions. The corresponding diffractive quark distributions are obtained by replacing the pomeron flux by the reggeon flux and quark/antiquark distributions in the pomeron by their counterparts in subleading reggeon(s). The other details can be found in [13]. In the case of pomeron exchange the upper limit in the integration over the momentum fraction carried by the pomeron/reggeon in the convolution formula is 0.1 for pomeron and 0.2 for reggeon exchange. In our opinion, the Regge formalism does not apply above these limits.

Up to now we have assumed Regge factorization which is known to be violated in hadron-hadron collisions. It is known that these are soft interactions which lead to an extra production of particles which fill in the rapidity gaps related to pomeron exchange.

If rapidity gap (gaps) is required (measured) then one has to include absorption effects in the formalism of the resolved pomeron/reggeon which can be interpreted as a probability of no extra soft interactions leading to a distruction of rapidity gap.

The diagram representating the double parton scattering process is shown in Fig.3.

The cross section for double parton scattering is often modelled in the factorized anzatz which in our case would mean:

$$\sigma^{DPS}_{W^+W^-} = \frac{1}{\sigma^{eff}_{qq}} \sigma_{W^+} \sigma_{W^-} \; . \tag{2.6}$$

The factorized model (2.6) can be generalized to more differential distributions (see e.g. [14, 15]). For example in our case of W^+W^- production the cross section differential in W boson

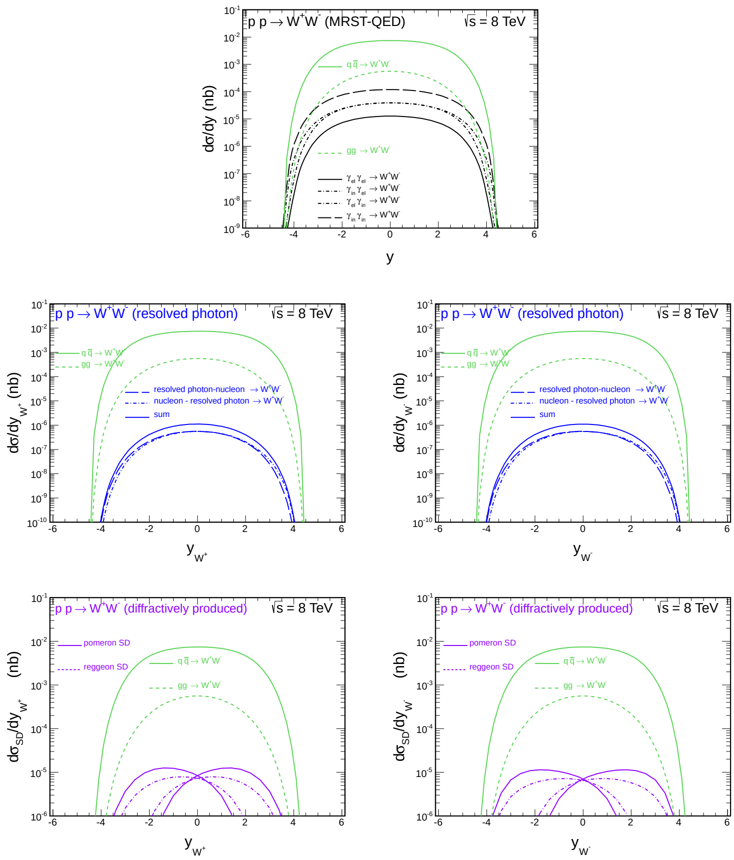

Figure 4: Rapidity distribution of W bosons for $\sqrt{s}$ = 8 TeV. The top panel shows contributions of all photon-photon induced processes, the middle panels resolved photon contributions and the bottom panels distributions of the diffractive contribution. The diffractive cross section has been multiplied by the gap survival factor S_G^2 = 0.03 as needed for the requirement of rapidity gaps.

rapidities can be written as:

$$\frac{d\sigma^{DPS}_{W^+W^-}}{dy_+ dy_-} = \frac{1}{\sigma^{eff}_{qq}} \frac{d\sigma^+_W}{dy_+} \frac{d\sigma^-_W}{dy_-} \ . \qquad (2.7)$$

3. Results

The distribution in W boson rapidity is shown in Fig.4. We show separate contributions discussed in the present paper. The diffractive contribution is an order of magnitude larger than the resolved photon contribution. The estimated reggeon contribution is of similar size as the pomeron contribution. The distributions of W^+ and W^- for the double-parton scattering contribution are different and, in the approximation discussed here, have shapes identical to those for single production of W^+ and W^-, respectively. It would therefore be interesting to obtain separate distributions for W^+ and W^- experimentally.

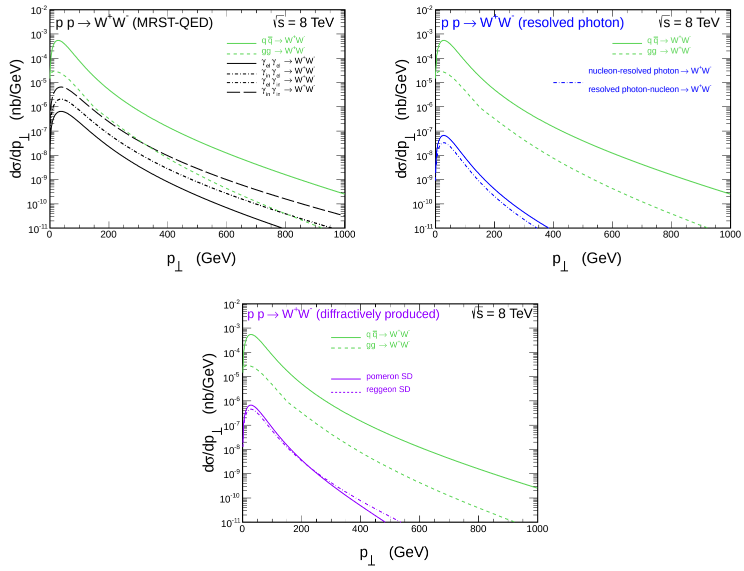

Figure 5: Transverse momentum distribution of W bosons for $\sqrt{s}$ = 8 TeV. The left-top panel shows all photon-photon induced processes, the right-top panel resolved photon contributions and the bottom panel the diffractive contribution. The diffractive cross section has been multiplied by the gap survival factor $S_G^2 =$ 0.03.

In Fig.5 we present distributions in the transverse momentum of W bosons. All photon-photon components have rather similar shapes. The photon-photon contributions are somewhat harder than those for diffractive and resolved photon mechanisms.

4. Conclusions

We have calculated for the first time a complete set of photon-photon and resolved photon-(anti)quark and (anti)quark-resolved photon contributions to the inclusive production of W^+W^- pairs. The photon-photon contributions can be classified into four topological categories: elastic-elastic, elastic-inelastic, inelastic-elastic and inelastic-inelastic, depending whether proton(s) survives (survive) the emission of the photon or not. The elastic-inelastic and inelastic-elastic contributions were calculated here for the first time. The photon-photon contributions were calculated as done in the past e.g. for the production of pairs of charged Higgs bosons or pairs of heavy leptons beyond the Standard Model, and within the QCD-improved method using MRST(QED) parton distributions. The second approach was already applied to the production of Standard Model charged lepton pair production and $c\bar{c}$ production. In the first approach we have obtained: $\sigma_{ela,ela} > \sigma_{ela,ine} = \sigma_{ine,ela} > \sigma_{ine,ine}$. In the more refined second approach we have got $\sigma_{ela,ela} < \sigma_{ela,ine} = \sigma_{ine,ela} < \sigma_{ine,ine}$. The two approaches give quite different results. In the first (naive) approach the inelastic-inelastic contribution is considerably smaller than the elastic-inelastic or inelastic-elastic ones. In the approach when the photon distribution in the proton undergoes QCD $\otimes$ QED evolution, it is the inelastic-inelastic contribution which is the biggest out of the four contributions. This shows that including the photon into the evolution equation is crucial. This is also a lesson for other processes known from the literature, where photon-photon processes are possible. This includes also some processes beyond the Standard Model mentioned in this paper.

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