PROCEEDINGS OF SCIENCE

Subleading processes in production of W^+W^- pairs in proton-proton collisions

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We discuss new subleading processes for inclusive production of W^+W^- pairs. 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. The resolved photon contribution was calculated in addition and found to be small. We also calculate the cross section for single-diffractive production of W^+W^- pairs including pomeron and reggeon exchanges in the Ingelman-Schlein model. Finally we only mention here about double parton contribution which is interesting by itself.

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1. Introduction

We shortly review several subleading processes in the production of W^+W^- pairs in proton-proton collisions [1]. The $\gamma\gamma \to W^+W^-$ process, one of them, is interesting by itself as it can be used to test the Standard Model and any other theories beyond the Standard Model. 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. [2] 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. [3]. The W^+W^- pair production signal would be particularly sensitive to New Physics contributions in the $\gamma\gamma \to W^+W^-$ subprocess [4, 5]. A similar analysis has been considered recently for $\gamma\gamma \to ZZ$ [6]. Corresponding measurements would be possible at ATLAS or CMS provided very forward proton detectors are installed. 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.

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].

Here we discuss the inclusive $\gamma\gamma \to W^+W^-$ induced mechanisms. We 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 Ref.[1] we considered two different approaches to the problem: naive and QCD improved.

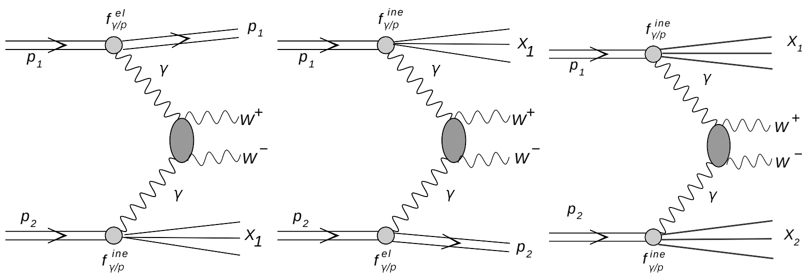

Figure 1: Diagrams representing inelastic photon-photon induced mechanisms for the production of W^+W^- pairs.

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 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 photon-photon contribution can be written as usually in the parton-model formalism:

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

where i,j = elastic,inelastic. 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

$$xf^{\gamma}_{q/p}(x) = \int_x^1 dx_\gamma f_{\gamma/p}(x_\gamma,\mu_s^2)\left(\frac{x}{x_\gamma}\right) f\left(\frac{x}{x_\gamma},\mu_h^2\right)\,. \tag{2.2}$$

Diffractive processes for W^+W^- production were not considered in the literature before Ref.[1] but are potentially very important. In the standard Ingelman-Schlein diffractive 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). All 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.

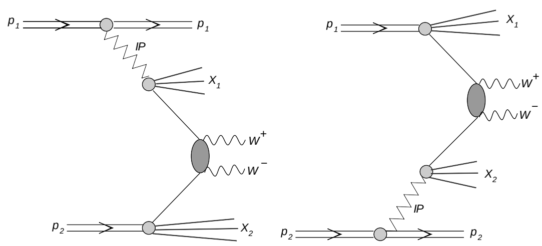

Figure 2: Diagrams representing single diffractive mechanism of the production of W^+W^- pairs.

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. The absorption effects are included here by multiplaying the cross section by so-called gap survival factor.

The diagram representating the double parton scattering process is shown in Fig.3 and the corresponding dynamics was discussed in [1].

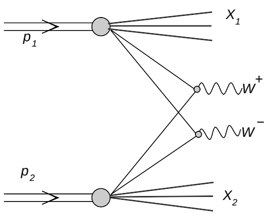

Figure 3: Diagram representing double parton scattering mechanism of the production of W^+W^- pairs.

3. Results

In Fig.4 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.

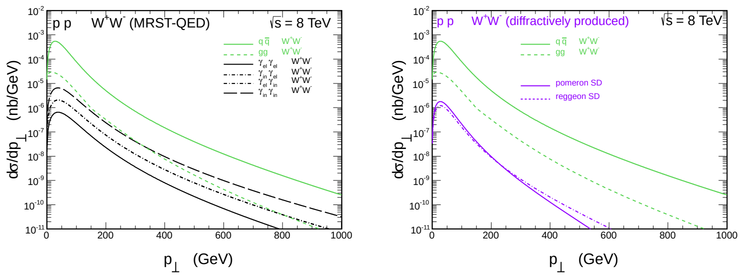

Figure 4: Transverse momentum distribution of W bosons for $\sqrt{s} = 8$ TeV. The left panel shows all photon-photon induced processes, the right panel the diffractive contribution. The diffractive cross section has been multiplied by the gap survival factor $S_G^2 = 0.03$.

We show also our predictions obtained with the NNPDF2.3 QED photon distributions [14], (see Fig.5). In the left panel of Fig.5 we concentrate on the biggest inelastic-inelastic contribution. We show the statistically most probable result (middle dashed line) as well as one-sigma uncertainty band (shaded area). The uncertainty band is very large. This demonstrates that it is very difficult to obtain the photon distributions from fits to experimental data. We have checked that limiting to -2.5 $< y_W <$ 2.5 the uncertainty band becomes relatively smaller. However, here we are interested mostly in the contribution in the whole phase space, so we leave more detailed studies for future investigations. The NNPDF distributions differ from those obtained with the MRST2004 QED photon distributions at large rapidities. In the right panel we show results for the elastic-inelastic and inelastic-elastic components. The most probable result obtained with the NNPDFs is similar as that for the MRST QED distributions. The elastic-inelastic and inelastic-elastic contributions differ one from the other more for the NNPDF than for the MRST case. The uncertainty bands (not shown) are also rather broad, but slightly narrower than in the case of inelastic-inelastic component.

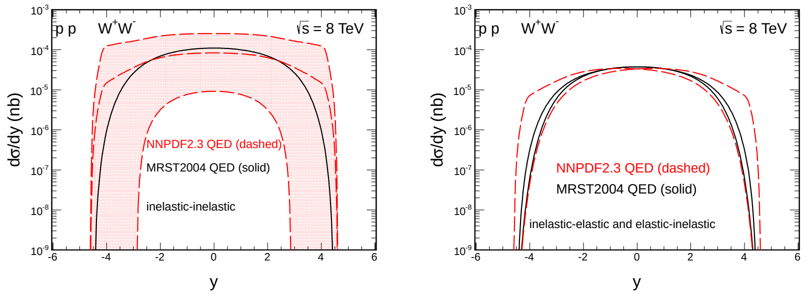

Figure 5: Rapidity distribution of W bosons for $\sqrt{s}$ = 8 TeV for photon-photon components with the NNPDF2.3 QED set. In the left panel we show the dominant inelastic-inelastic component. In addition we show uncertainty band as obtained from the NNPDF framework (one sigma). The right panel shows elastic-inelastic and inelastic-elastic components obtained with the NNPDF2.3 QED set.

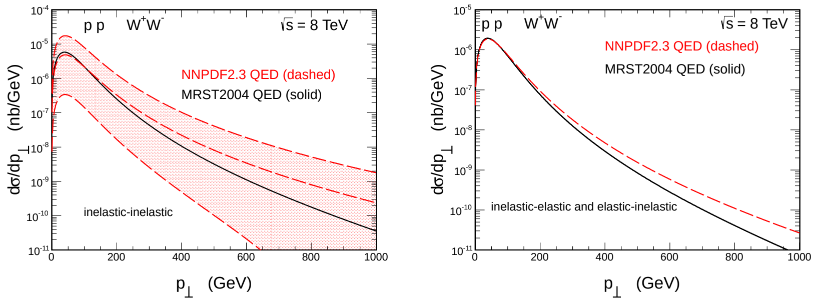

Figure 6: Transverse momentum distribution of W bosons for $\sqrt{s}$ = 8 TeV for photon-photon components with NNPDF2.3 QED set. In the left panel we show the dominant inelastic-inelastic component. In addition we show uncertainty band as obtained from the NNPDF framework (one sigma). The right panel shows elastic-inelastic (inelastic-elastic) components obtained with NNPDF2.3 QED set.

In Fig.6 we show distributions in transverse momentum of W bosons for photon-photon components obtained with the NNPDF photon distributions [14]. In the left panel we show the dominant inelastic-inelastic component and in the right panel elastic-inelastic (= inelastic-elastic) components. The uncertainty band is very large, especially at large transverse momenta.

Concerning the searches for anomalous $\gamma\gamma WW$ coupling without proton tagging as performed by the D0 and CMS collaborations, the ratios of the inelastic-inelastic, elastic-inelastic and inelastic-elastic contribution to the elastic-elastic one are crucial.

4. Conclusions

We have discussed nonleading, usually ignored contributions to the production of W^+W^- pairs.

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 for the first time in Ref.[1]. The photon-photon contributions were calculated in Ref.[1] within the QCD-improved method using MRST(QED) and NNPDF parton distributions. The approach was already applied before to the production of charged lepton pairs and $c\bar{c}$ pairs. In this approach we have got $\sigma_{ela,ela} < \sigma_{ela,ine} = \sigma_{ine,ela} < \sigma_{ine,ine}$.

We have shown in Ref.[1] that including the photon into the evolution equation gives different results than obtained with more simplified approaches. 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 our paper.

We have also discussed single and central diffractive contribution and a contribution of resolved photons. Especially the single diffractive contribution can be large. It is ignored, however, in the present analyses. Similar situation is for double parton scattering, only mentioned here (for details see [1]).

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