

# Diffractive pQCD mechanisms of exclusive production of $b\bar{b}$ dijets and $W^+W^-$ pairs in proton-proton collisions

Antoni Szczurek<sup>1,2</sup>

<sup>1</sup>Institute of Nuclear Physics PAN, ul. Radzikowskiego 152, PL-31-342 Kraków, Poland

<sup>2</sup>Rzeszów University, ul. Rejtana 16, PL-35-959 Rzeszów, Poland

DOI: <http://dx.doi.org/10.3204/DESY-PROC-2012-02/261>

We discuss central exclusive production of  $W^+W^-$  pairs in proton-proton collisions at LHC. Predictions for the total cross section and differential distributions in transverse momentum of  $W^\pm$  and  $WW$  invariant mass are presented. We discuss both  $\gamma\gamma \rightarrow W^+W^-$  mechanism as well as a new mechanism of exclusive diffractive production. The amplitude for the latter process is calculated in the Durham model. We compare the two (QED and QCD) types of contributions. The diffractive contribution is only a small fraction of fb compared to the  $\gamma\gamma$  contribution which is of the order of 100 fb. This opens a possibility of searches for anomalous four-boson  $\gamma\gamma W^+W^-$  coupling due to physics beyond Standard Model.

## 1 Introduction

The  $\gamma\gamma \rightarrow W^+W^-$  process is interesting reaction to test the Standard Model and any other theory beyond the Standard Model. The linear collider would be a good option to study the couplings of gauge bosons in the future. For instance in Ref.[1] the anomalous coupling in locally  $SU(2) \times U(1)$  invariant effective Lagrangian was studied. Other models also lead to anomalous gauge boson coupling.

It was discussed recently [3, 4, 5] that the  $pp \rightarrow ppW^+W^-$  reaction is a good case to study experimentally the  $\gamma W^+W^-$  and  $\gamma\gamma W^+W^-$  couplings almost at present. Only photon-photon contribution for the purely exclusive production case was considered so far.

Central exclusive production has been recently an active field of research [6]. The exclusive reaction  $pp \rightarrow pHp$  has been intensively studied by the Durham group [7]. This study was motivated by the clean environment and largely reduced background due to a suppression of  $b\bar{b}$  production as a consequence of the  $J_z = 0$  rule in the forward limit. During the conference some results for the  $b\bar{b}$  production were shown.

In this communication, we discuss exclusive production of  $W^+W^-$  pairs in high-energy proton-proton collisions. The original results have been presented recently in [2]. The  $pp \rightarrow pW^+W^-p$  process going through the diffractive QCD mechanism with the  $gg \rightarrow W^+W^-$  subprocess naturally constitutes an irreducible background for the exclusive electromagnetic  $pp \rightarrow p(\gamma\gamma \rightarrow W^+W^-)p$  process. We discuss the contribution of the diffractive mechanism which could potentially shadow the photon-photon fusion.

## 2 Diffractive mechanism

A schematic diagram for central exclusive diffractive production of  $W^\pm W^\mp$  pairs in proton-proton scattering  $pp \rightarrow pW^\pm W^\mp p$  is shown in Fig. 1.

The amplitude of the diffractive process at high energy is written as:

$$\mathcal{M}_{\lambda_+ \lambda_-}(s, t_1, t_2) \simeq i s \frac{\pi^2}{2} \int d^2 \mathbf{q}_{0\perp} V_{\lambda_+ \lambda_-}(q_1, q_2, k_+, k_-) \frac{f_g(q_0, q_1; t_1) f_g(q_0, q_2; t_2)}{\mathbf{q}_{0\perp}^2 \mathbf{q}_{1\perp}^2 \mathbf{q}_{2\perp}^2}, \quad (1)$$

where  $\lambda_\pm = \pm 1, 0$  are the polarisation states of the produced  $W^\pm$  bosons, respectively,  $f_g(r_1, r_2; t)$  is the off-diagonal unintegrated gluon distribution function (UGDF).

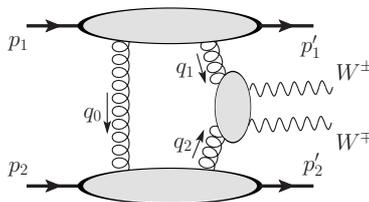


Figure 1: Diagram for the central exclusive diffractive  $WW$  pair production in  $pp$  collisions.

The  $gg \rightarrow W_{\lambda_+}^+ W_{\lambda_-}^-$  hard subprocess amplitude  $V_{\lambda_+ \lambda_-}(q_1, q_2, k_+, k_-)$  can be formally written as

$$V_{\lambda_+ \lambda_-} = n_\mu^+ n_\nu^- V_{\lambda_+ \lambda_-}^{\mu\nu} = \frac{4}{s} \frac{q_{1\perp}^\nu}{x_1} \frac{q_{2\perp}^\mu}{x_2} V_{\lambda_+ \lambda_-, \mu\nu}, \quad q_1^\nu V_{\lambda_+ \lambda_-, \mu\nu} = q_2^\mu V_{\lambda_+ \lambda_-, \mu\nu} = 0, \quad (2)$$

where  $n_\mu^\pm = p_{1,2}^\mu / E_{p, cms}$  and the center-of-mass proton energy  $E_{p, cms} = \sqrt{s}/2$ .

There are two types of diagrams entering the hard subprocess amplitude: triangles and boxes [2]. The corresponding amplitudes have been calculated using the Mathematica-based FormCalc (FC) package. The details are explained in [2].

The bare amplitude above is subjected to absorption corrections that depend on the collision energy and typical proton transverse momenta. The bare cross section is usually multiplied by a rapidity gap survival factor which we take the same as for the Higgs boson and  $b\bar{b}$  production to be  $S_g = 0.03$  at the LHC energy.

The diffractive  $WW$  CEP amplitude (1) described above is used to calculate the corresponding cross section. In order to make the calculation feasible we simplify the calculation limiting to the forward region. The calculation in the full phase space is obtained by assuming exponential dependence in  $t_1$  and  $t_2$  and assuming no correlation between outgoing protons. In such an approximate calculation the phase space integral reduces to four dimensions [2].

## 3 Electromagnetic mechanism

In this section we briefly discuss the  $\gamma\gamma \rightarrow W^+W^-$  mechanism. Here we limit to only Standard Model amplitude. The relevant subprocess diagrams are shown in Fig. 2. The cross section for the subprocess can be expressed in terms of Mandelstam variables.

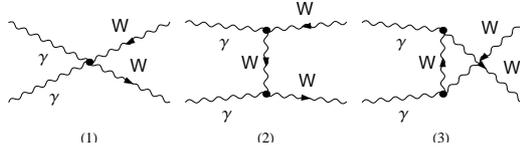


Figure 2: The Born diagrams for the  $\gamma\gamma \rightarrow W^\pm W^\mp$  subprocess.

Since we concentrate on the diffractive mechanism the cross section for the  $\gamma\gamma$  mechanism is calculated in approximate way.

To calculate differential distributions the following parton formula is used

$$\frac{d\sigma}{dy_+ dy_- d^2 p_{W\perp}} = \frac{1}{16\pi^2 \hat{s}^2} x_1 f_1^{WW}(x_1) x_2 f_2^{WW}(x_2) \overline{|\mathcal{M}_{\gamma\gamma \rightarrow W^+W^-}(\hat{s}, \hat{t}, \hat{u})|^2}, \quad (3)$$

where  $x_{1,2}$  are momentum fractions of the fusing gluons.

In our evaluations we use the Weizsäcker-Williams equivalent photon fluxes of protons from Ref. [8].

## 4 Results

In Fig. 3 we show distribution in  $W^+$  ( $W^-$ ) transverse momentum. The distribution for exclusive diffractive production is much steeper than that for the electromagnetic contribution. The diffractive contribution peaks at  $p_{t,W} \sim 25$  GeV. This is somewhat smaller than for the  $\gamma\gamma \rightarrow W^+W^-$  mechanism where the maximum is at  $p_{t,W} \sim 40$  GeV. The exclusive cross section for photon-photon contribution is at large transverse momenta  $\sim 1$  TeV smaller only by one order of magnitude than the inclusive  $gg \rightarrow W^+W^-$  component shown for comparison.

Fig. 4 shows distribution in the  $W^+W^-$  invariant mass which is particularly important for the New Physics searches at the LHC [3]. The distribution for the diffractive component drops quickly with the  $M_{WW}$  invariant mass. For reference and illustration, we show also distribution when the Sudakov form factors in off-diagonal UGDF's is set to one. As can be seen from the figure, the Sudakov form factor lowers the cross section by a large factor. The damping is  $M_{WW}$ -dependent as can be seen by comparison of the two curves. We show the full result (boxes + triangles) and the result with boxes only which would be complete if the Higgs boson does not exist. At high invariant masses, the interference of boxes and triangles decreases the cross section even more. The distribution for the photon-photon component drops very slowly with  $M_{WW}$  and at  $M_{WW} > 1$  TeV the corresponding cross section is even bigger than the  $gg \rightarrow W^+W^-$  component to inclusive production of  $W^+W^-$ .

## 5 Summary

Recently ([2]) we have calculated the QCD diffractive contribution to the exclusive  $pp \rightarrow pW^+W^-p$  process for the first time in the literature with the full one-loop  $gg \rightarrow W^+W^-$

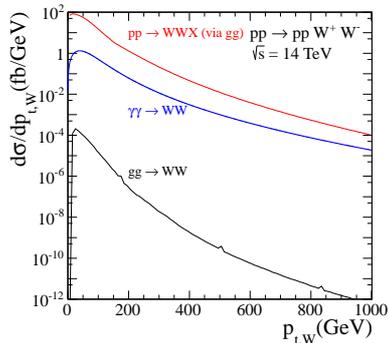


Figure 3: Distribution in transverse momentum of one of the  $W$  bosons. The diffractive contribution is shown by the bottom solid line while the  $\gamma\gamma \rightarrow W^+W^-$  contribution by the middle solid line. The top solid line corresponds to the inclusive gluon-initiated  $pp \rightarrow W^+W^-X$  component.

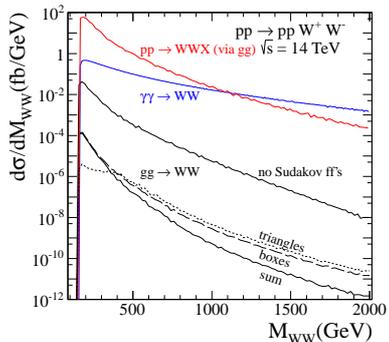


Figure 4: Distribution in  $W^+W^-$  invariant mass. We show both the QCD diffractive contribution and the  $\gamma\gamma \rightarrow W^+W^-$  contribution. The result when the Sudakov form factor is put to one is shown for illustration. The most upper curve is for the inclusive gluon-initiated  $pp \rightarrow W^+W^-X$  component.

matrix element. The full amplitude is a sum of two mechanisms. First component is a virtual (highly off-shell) Higgs boson production and its subsequent transformation into real  $W^+W^-$  pair. Second component relies on the formation of intermediate quark boxes.

We have made first evaluation of differential distributions using amplitudes in the forward limit “corrected” off-forward via a simple exponential (slope dependent) extrapolation. Distributions in  $W$ -boson transverse momentum and  $W^+W^-$  pair invariant mass has been presented here for illustration. The contribution of triangles (with the intermediate s-channel Higgs boson) turned out to be smaller than the contribution of boxes. These results have been compared with the results obtained for purely electromagnetic photon-photon fusion. We have shown that the diffractive contribution is much smaller than the electromagnetic one. There are several reasons of the suppression. Since here we have focused on large invariant masses of the  $W^+W^-$  system, rather large  $x$  gluon distributions enter the calculation of the diffractive amplitude.

The gluon densities at such large invariant masses, i.e. large  $x_1$  and  $x_2$ , are rather small. Furthermore relative to the electromagnetic process the diffractive contribution is strongly damped by the Sudakov form factor, soft gap survival probability and optionally (if Higgs boson exists) by the interference of box and triangle diagrams.

In summary, we have given a new argument for the recent idea that the  $pp \rightarrow ppW^+W^-$  reaction is a good place for searches beyond Standard Model as far as four-boson (anomalous) coupling is considered.

## 6 Acknowledgements

I am indebted to Piotr Lebedowicz and Roman Pasechnik for collaboration on the issues presented here. I wish to thank the organizers for perfect organization of DIS2012. My stay during the conference in Bonn was supported from a polish grant DEC-2011/01/B/ST2/04535.

## References

- [1] O. Nachtmann, F. Nagel, M. Pospischil and A. Utermann, Eur. Phys. J. **C45** (2005) 679; Eur. Phys. J. **C46** (2006) 93.
- [2] P. Lebedowicz, R. Pasechnik and A. Szczurek, arXiv.1203.1832 [hep-ph].
- [3] O. Kepka and C. Royon, Phys. Rev. **D78** (2008) 073005;  
E. Chapon, C. Royon and O. Kepka, Phys. Rev. **D81** (2010) 074003.
- [4] N. Schul and K. Piotrkowski, Nucl. Phys. B (Proc. Suppl.) **179-180** (2008) 289;  
T. Pierzchała and K. Piotrkowski, Nucl. Phys. B (Proc. Suppl.) **179-180** (2008) 257.
- [5] M. Maniatis, A. v. Manteuffel and O. Nachtmann, Nucl. Phys. B (Proc. Suppl.) **179-180** (2008) 104.
- [6] M. G. Albrow, T. D. Coughlin and J. R. Forshaw, Prog. Part. Nucl. Phys. **65** (2010) 149.
- [7] V. A. Khoze, A. D. Martin and M. G. Ryskin, Phys. Lett. **B401** (1997) 330;  
V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. **C14** (2000) 525;  
V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. **C19** (2001) 477 [Erratum-ibid. **C20** (2001) 599];  
V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. **C23** (2002) 311;
- [8] M. Drees and D. Zeppenfeld, Phys. Rev. **D39** (1989) 2536.