HIGH ENERGY PHOTON INTERACTIONS AT THE LHC*

T. PIERZCHALA AND K. PIOTRZKOWSKI†

Département de Physique, Université Catholique de Louvain,
Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve, Belgium

Potential for studying high-energy photon interactions at the LHC, as the associated WH photoproduction, or two-photon production of W boson pairs, is discussed. The role of the forward proton detectors in selection of such events is briefly described.

1. Introduction

First collisions of 7 TeV protons at the CERN Large Hadron Collider are expected in 2008, when studies of interactions of proton constituents, quarks and gluons, at unprecedented energies will begin. However, protons are charged particles, and a significant fraction of *pp* collisions will involve high-energy interactions of photons exchanged by one, or both incoming protons. Most of the time such protons will stay intact and will be scattered at very small angles. However, thanks to significant proton energy losses, tagging the high-energy photon-photon and photon-proton interactions by dedicated forward detectors becomes possible [1]. Hence, by adding such detectors to the ATLAS and CMS experiments one can extend their physics reach and effectively convert the LHC into a high-energy photon-photon or photon-proton collider. The same tagging technique can be used to select diffractive interactions at high luminosity [2]. Assuming validity of the equivalent photon approximation (EPA [3]) one can relate, using the effective luminosity spectrum S, the *pp* and $\gamma\gamma$ cross sections by $\sigma_{pp} = \int dW\, S\, \sigma_{\gamma\gamma}$, where integration is taken over the $\gamma\gamma$ center of mass energy W, and S is a convolution of photon fluxes of two protons. The effective luminosity of the tagged two-photon collisions, reaches a fraction of 1% of the *pp* luminosity for W > 100 GeV, where $W\,[\mathrm{TeV}] \cong 14\sqrt{x_1 x_2}$, and x_1, x_2 are fractional energy losses of the two scattered protons. Similarly, one can identify photoproduction processes at the LHC. In this case, the effective luminosity and

* This work is partially supported by FNRS and its associated funds (IISN and FRIA) and by an Inter-University AP Programme subsidised by the Belgian Federal Science Policy Office.
† Contact person: krzysztof.piotrzkowski@fynu.ucl.ac.be.

the energy of photon-parton collisions are even higher. For example, in Fig. 1, the effective luminosity spectra of photon-gluon collisions are shown assuming the tagged photon energy range, $0.01 < x < 0.1$, and $0.005 < x_g < 0.3$ range for the gluon Bjorken-*x* (MRST 2001 pdf taken at $Q^2 = 10000\ GeV^2$). One sees, for example, that the luminosity of photon-gluon collisions at W > 300 GeV is almost 30% of the *pp* luminosity!

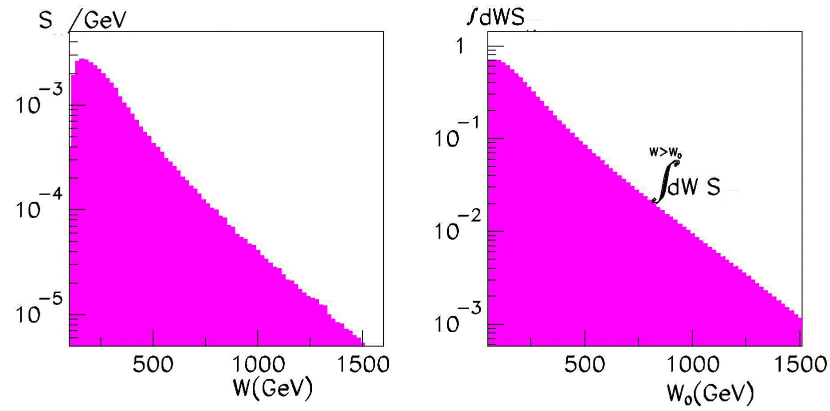

Figure 1. Effective luminosity spectrum S of the photon-gluon collisions (left plot); and the integrated S, starting from the minimal cms photon-gluon energy W_0 (right plot).

2. Benchmark processes at the LHC

To understand better the physics potential of the photons interactions at the LHC the following processes have been calculated using Calchep package [4], with the implemented EPA in *pp* collisions:

- $\gamma p \to WqX$, with cuts on the final state quark $p_T > 2$ GeV, $|\eta| < 2.5$
- $\gamma p \to \bar{t}tX$, with $p_T(X) > 3$ GeV
- $\gamma p \to \gamma/ZWX$, with $p_T(\gamma/Z) >$ 3GeV, $p_T(X) > 3$ GeV, $|\cos(\theta_{\gamma/Z,X}| < 0.99$
- $\gamma p \to WHX$ (for $M_H = 120$ GeV and 200 GeV), with $p_T(X) > 3$ GeV
- $\gamma\gamma \to W^+W^-$
- $\gamma\gamma \to \mu^+\mu^-$, with $p_T(\mu) > 2$ GeV, and $|\eta(\mu)| < 2.5$

The cuts have been usually applied to simulate a minimal impact of the detector acceptance, and for a couple of cases to stabilize results numerically. In Fig. 2, the differential cross-sections, at the *pp* level, are shown for these processes, as a function of the cms energy in $\gamma\gamma$ and photon-parton collisions, respectively. In Fig. 3, the integrated cross-sections are shown as a function of the minimal cms energy W_0; in addition, the number of events for the integrated *pp* luminosity of 30 fb^{-1} is shown. As expected from the photon luminosities, the statistics of these electroweak processes is significant. Apart from the low-mass muon pairs, the highest cross-section of about 40 pb is obtained for the single W boson photo-

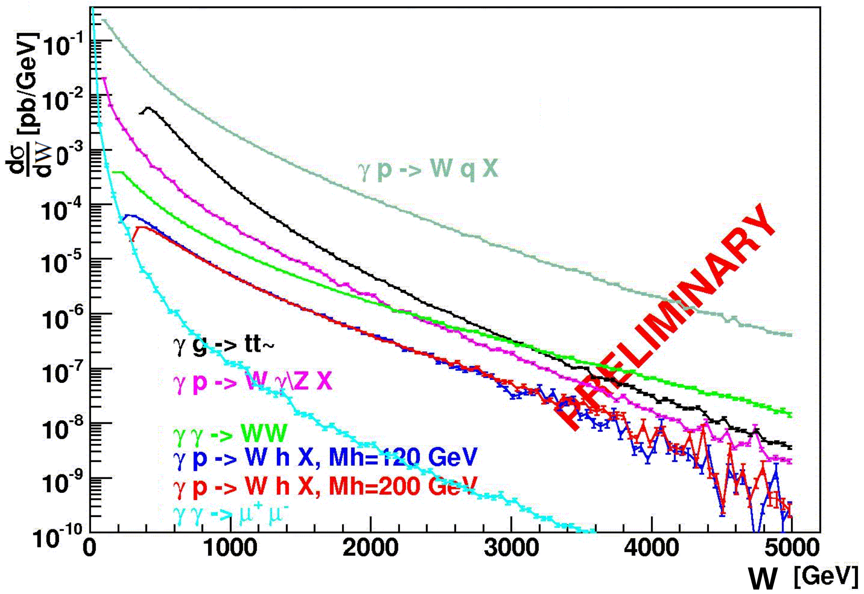

Figure 2. Differential cross-sections (at *pp* level) for processes described in the text, as a function of the cms energy in photon-photon and photon-parton collisions, respectively.

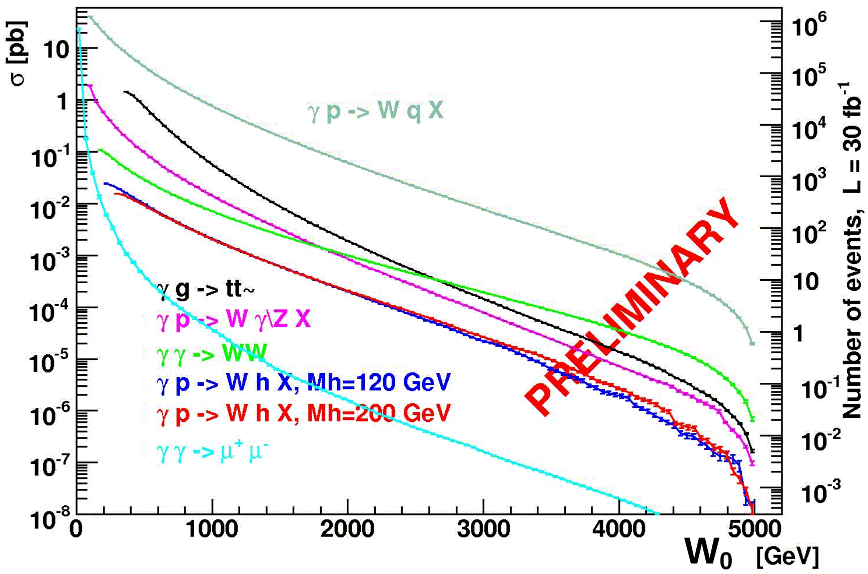

Figure 3. Cross-sections (at *pp* level), and number of events (for the *pp* integrated luminosity of 30 fb^{-1}), for processes described in the text, as a function of the minimal cms energy in photon-photon and photon-parton collisions, respectively.

production. One should note that a large cross-section of about 1 pb is expected for W > 1 TeV, so very interesting studies will be possible already using initial low luminosity samples. It is therefore not surprising that the cross-section for associated WH photoproduction is significant, above 20 fb for the SM light Higgs boson[c], and contrary to the *pp* case, the top pair production of 1.5 pb is not so overwhelming. Therefore, the top background will be much less severe, allowing for a complementary measurement of the WH production (provided sufficient luminosity), and in addition interesting studies of the top photoproduction will be possible even at initial luminosities. Finally, the two-photon W^+W^- exclusive production has the total cross-section of more than 100 fb, and a very clear signature. Its cross-section is still about 10 fb for $W_0 > 1$ TeV showing sensitivity for physics beyond the SM. On the other hand, the two-photon dimuon production will be an excellent calibration process, with very well known cross-section from QED, and an extremely clear signature of the exclusive, back-to-back dimuons in the central detectors.

3. Outlook

These initial studies of photon induced high-energy interactions at the LHC show very interesting prospects. One should stress that apart from the spectacular exclusive muon pairs, all the other considered final states contain at least one W boson. It means that even using the nominal triggers one will be efficiently selecting also photon events.

However, for the final selection, and in particular for the suppression of huge inclusive *pp* backgrounds, tagging photon events by forward proton detectors is mandatory. In addition, it will improve the reconstruction of events by using the measured momenta of the forward-scattered protons. This will lead to very clean samples, in particular for the exclusive two-photon production – for example, for the fully leptonic decays of W pairs the final state will consist of two forward protons, two very high p_T central leptons of opposite sign, large missing energy and nothing else. Selection of such events should be therefore possible even at the nominal LHC luminosity.

References

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[c] Note: WH photoproduction constitutes about 2% of the total inclusive WH production at the LHC!