EXCLUSIVE PRODUCTION AT CMS*

Marek Walczak

on behalf of the CMS Collaboration

Institute of Experimental Physics, Faculty of Physics, University of Warsaw
Pasteura 5, 02-093 Warszawa, Poland

(Received May 5, 2016)

I briefly introduce so-called central exclusive production. I mainly focus on the example analyses that have been performed in the CMS experiment at CERN. I conclude with ideas and perspectives for future work that will be done during Run 2 of the LHC. I pay special attention to the ultra-peripheral collisions.

DOI:10.5506/APhysPolB.47.1751

1. Introduction

Central exclusive production (CEP) is a process in which the colliding hadrons stay intact after the interaction and the information on the whole final system is obtained. For the collision of two protons, CEP can be written as

$$pp \to pXp\,,$$

where X is a produced colour-singlet particle. This process is illustrated in Fig. 1. Exclusive production provides a very clean environment that enables, for example, the measurement of quantum numbers (*e.g.* the spin and parity) of produced resonance states. In order to recognise exclusive production, it is necessary to check if there is activity in the very forward (high η) region of the detector, as the proton remnants would be mostly contained in these regions, if it dissociates. Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider at CERN has high coverage in the forward region [1] (see Fig. 2), and is successfully used for studying those processes [2–4].

* Presented at the Cracow Epiphany Conference on the Physics in LHC Run 2, Kraków, Poland, January 7–9, 2016.

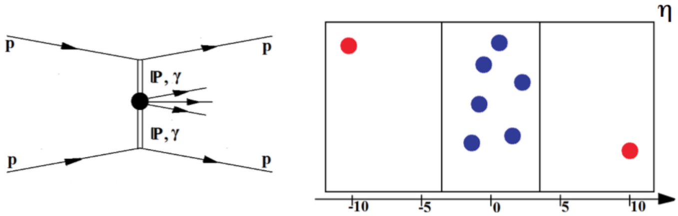

Fig. 1. Central exclusive production. On the left-hand side, there is a Feynman diagram showing the exchange of gamma particles or Pomerons between the two protons. As shown in the right panel, the produced state is observed in the central part of the detector (multiple dots in central rapidity region) and the intact protons go into the forward region and, in general, are not observed (dots in the forward region).

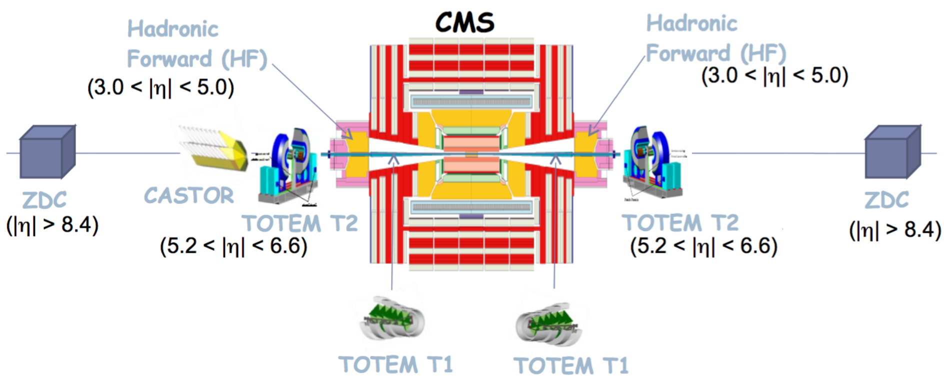

Fig. 2. Forward sub-detectors in the CMS. On both sides, there are HF, TOTEM and ZDC detectors. CASTOR is installed on one side only.

2. Analyses at CMS

In this section, I will present two studies that were done with the use of Run 1 data collected by the CMS experiment.

2.1. Exclusive $\gamma\gamma \to \mu^+\mu^-$ production

In this analysis, the cross section for the exclusive two-photon production of muon pairs was calculated with the use of data at $\sqrt{s} = 7$ TeV for the integrated luminosity of 40 pb^{-1} from 2010. The sample contained about 80% of events with pileup over 1. The Feynman diagrams for considered processes are shown in Fig. 3. The dissociative processes are the background for the exclusive process. The selected events were required to have the reconstructed invariant mass of the muon pair above 11.5 GeV. The transverse momentum of the muons was required to be $p_T(\mu) > 4$ GeV and pseudorapidity $|\eta(\mu)| < 2.1$. In order to measure exclusive and semi-exclusive contributions, the MC sample was fit to the data (see Fig. 4).

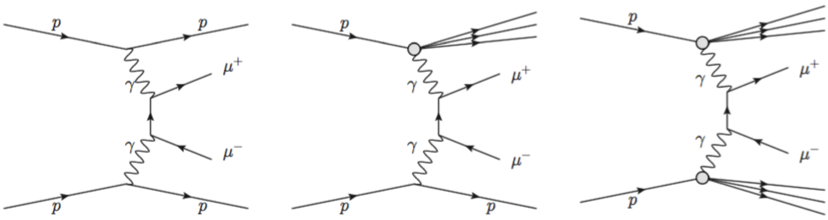

Fig. 3. Feynman diagrams for the two-photon production of muon pairs in pp collisions. The left diagram illustrates exclusive production, the diagram in the centre is the semi-exclusive process with single proton dissociation, and the right is the semi-exclusive process with double proton dissociation.

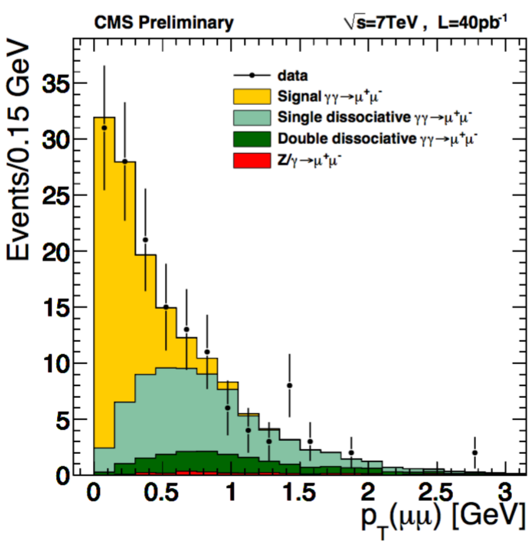

Fig. 4. The histograms show the result of fitting the MC simulated $p_T(\mu\mu)$ distribution to the data (points with error bars). The simulation was done with the use of the LPAIR event generator.

The resulting visible cross section from a fit to the $p_T(\mu^+\mu^-)$ distributions $\sigma(pp \to p\mu^+\mu^-p) = 3.38^{+0.58}_{-0.55}(\text{stat.}) \pm 0.16(\text{syst.}) \pm 0.14(\text{lumi.})$ pb. The corresponding ratio of the measured to the predicted cross section is $0.83^{+0.14}_{-0.13}(\text{stat.}) \pm 0.04(\text{syst.})$.

2.2. Search for central exclusive $\gamma\gamma$ production and observation of central exclusive e^+e^-

In this study, a sample of 36 pb^{-1} recorded by the CMS experiment in 2010 at $\sqrt{s} = 7$ TeV has been used to calculate the cross section for the exclusive $\gamma\gamma$ production. The diagram of this process is illustrated in Fig. 5. The selection of events requires two photon candidates, each with transverse energy $E_{\rm T} > 5.5$ GeV and pseudorapidity $|\eta| < 2.5$. There should be no other particles detected in the pseudorapidity region $|\eta| < 5.2$. As in the previous study, the colliding protons stay intact, or dissociate, and escape along the beam and are not detected. As a cross-check, the cross section for the exclusive e^+e^- production has also been obtained. This analysis requires one positron and one electron, and uses the same cuts as above.

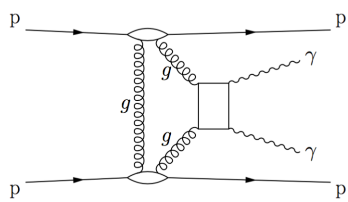

Fig. 5. Figure shows the dominant diagram for central exclusive $\gamma\gamma$ production in pp collisions.

No diphoton candidate passed all the selection criteria, therefore, only an upper limit on the cross section was set at $\sigma(\gamma\gamma) < 1.30$ pb with 95% confidence level (see Fig. 6). In the case of the exclusive e^+e^- production,

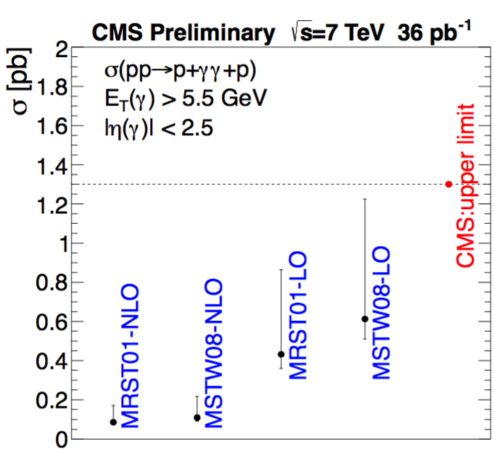

Fig. 6. Comparison of the cross section for central exclusive $\gamma\gamma$ production between the measurement with 36 pb^{-1} of integrated luminosity data and four different theoretical predictions.

17 candidates on a background of 0.84 ± 0.28 (stat.) were observed. The theoretical prediction is 16.5 ± 1.7(theo.)± 1.2(syst.) events, in a good agreement with the data, indicating that the used method was proper.

3. Ultra-peripheral collisions

The accelerated protons and ions carry an electromagnetic field, which is a source of photons. A photon generated by one of these hadrons can interact with another photon (or with a parton inside a hadron from the second beam) producing a wide variety of particles. Ultra-peripheral collisions (UPCs) refer to nuclear collisions where the impact parameter b is larger than the sum of the radii R of the nuclei; the impact parameter is simply the transverse distance between the centres of the nuclei (see Fig. 7). The hadrons do not collide head on, they pass close one to another. Due to their electric field, they exchange a very energetic photon. These events offer a unique opportunity to study fundamental aspects of QED and QCD via photon-induced processes. As can be seen in Fig. 8, the UPC events are capable of probing hadrons at small Bjorken-$x < 10^{-2}$ [4], where the effect of nuclear shadowing is present. This effect has been recently confirmed by the ALICE Collaboration by measuring ultra-peripheral exclusive J/ψ production [5]. Therefore, further analysis by other experiments and with the use of processes including other particles in the final state (*e.g.* exclusive Υ photoproduction) are of a great interest for the heavy-ion community.

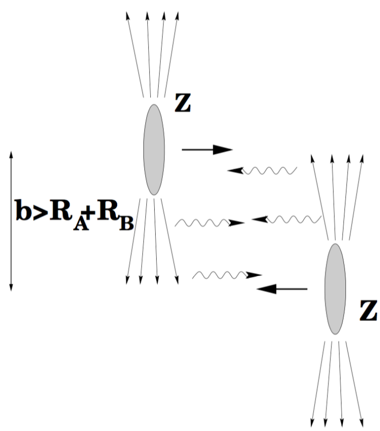

Fig. 7. A representation of an ultra-peripheral collision. The pancake-like shape of the nuclei is due to relativistic Lorentz contraction.

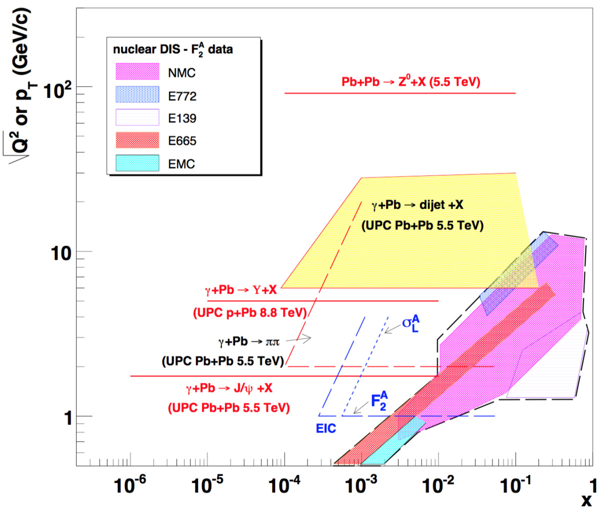

Fig. 8. The kinematic range in which UPCs at the LHC can probe gluons in protons and nuclei in quarkonium production, dijet and dihadron production. The Q^2 value for typical gluon virtuality in exclusive quarkonium photoproduction is shown for J/ψ and Υ. For comparison, the kinematic ranges for J/ψ at RHIC, F_2^A and σ_L^A at eRHIC and Z^0 hadron production at the LHC are also shown [4].

4. Conclusions

In conclusion, I introduced the field of the exclusive production. The installation of the very forward detectors FP420 in cryogenic region of the LHC will broaden the spectrum of analyses that can be done at the CMS. These processes offer an ideal way to study, for example, the properties of the Higgs boson and to search for the Supersymmetry, in particular with future high-luminosity LHC.

This work was supported by the National Science Centre (Poland) grants 2012/07/E/ST2/01406 and 2014/14/M/ST2/00428.

REFERENCES

[1] CMS Collaboration, *JINST* **3**, S08004 (2008).

[2] CMS Collaboration, *J. High Energy Phys.* **1201**, 052 (2012).

[3] CMS Collaboration, *J. High Energy Phys.* **1211**, 080 (2012).

[4] A.J. Baltz *et al.*, *Phys. Rep.* **458**, 1 (2008).

[5] V. Guzeya, E. Kryshena, M. Strikmanb, M. Zhalova, *Phys. Lett. B* **726**, 290 (2013).