PROCEEDINGS OF SCIENCE

PoS(EPS-HEP2011)327

Measurement of the differential isolated prompt photon production cross section in pp collisions at 7 TeV center-of-mass energy

Nicolas Chanon[*†]
Institute for Particle Physics, ETH Zürich
E-mail: nicolas.pierre.chanon@cern.ch

In this paper we present two measurements : the measurement of the differential cross section for the inclusive production of isolated prompt photons [1], and the measurement of the production of pairs of prompt isolated photons [2] in proton-proton collisions at a centre-of-mass energy of 7 TeV with the Compact Muon Sollenoid (CMS) detector at the Large Hadron Collider (LHC). A data sample corresponding to an integrated luminosity of 36 pb^{-1} is analyzed. The next-to-leading-order perturbative QCD calculations are consistent with the measured differential cross section for the inclusive photon production, while the diphoton differential cross-section shows a discrepancy for regions of the phase space where the two photons have an azimuthal angle difference $\Delta\phi < 2.8$.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

[*]Speaker.
[†]for the CMS Collaboration

1. Introduction

The measurement of isolated prompt photons production in proton-proton collisions provides a test of perturbative quantum chromodynamics (pQCD). A comprehensive understanding of inclusive photon and photon pair production is also important as it represents a major background in certain searches for rare or exotic processes, such as the production of a light Higgs boson, extra-dimension gravitons, and some supersymmetric states.

The CMS detector consists of a silicon pixel and strip tracker surrounded by a crystal electromagnetic calorimeter (ECAL) and a brass/scintillator sampling hadron calorimeter (HCAL), all in an axial 3.8 T magnetic field provided by a superconducting solenoid. The muon system is composed of gas-ionization detectors embedded in the steel return yoke of the magnet. A more detailed description of CMS can be found elsewhere [3]. In the CMS coordinate system, θ and ϕ respectively designate the polar angle with respect to the counterclockwise beam direction, and the azimuthal angle. The pseudorapidity is defined as $\eta = -ln[tan(\theta/2)]$. The distance in the (η, ϕ) plane is defined as $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$. The electromagnetic calorimeter, which plays a major role in this measurement, consists of nearly 76 000 lead tungstate crystals. It is divided into a central part (barrel) covering the region $|\eta| < 1.48$ and forward parts (endcaps) extending the coverage up to $|\eta| < 3$. A preshower detector, consisting of two planes of silicon sensors interleaved with 3 radiation lengths of lead, is placed in front of the endcaps to cover the pseudorapidity region $1.65 < |\eta| < 2.6$.

Photon candidates are reconstructed by clustering the energy deposited in the ECAL [4, 5] crystals. CMS is equipped with a versatile trigger to adapt to the LHC steady increase in instantaneous luminosity. Inclusive photon analysis uses four settings with different photon E_T threshold (20,30,40,70 GeV) while the diphoton measurement uses three settings requiring two photons with a threshold of either 15 GeV or 17 GeV in E_T. Both measurements are using similar identification criteria applied offline. The deposits in the calorimeters have to be consistent with an electromagnetic shower, using the spread along η of the energy clustered in the ECAL (referred to as $\sigma_{\eta\eta}$), and on the ratio H/E of the energies measured in the HCAL and ECAL (loose selections of [5]). An isolation energy requirement is applied on the sum of the transverse momenta of charged particles measured by the tracker, the sum of the transverse energy deposits in the HCAL and ECAL, defined within a cone in the (η, ϕ) plane around the photon direction. To discriminate against electrons, it is required to have no track with hits in the first layer of the tracker along the photon direction. After these identification requirements, it remains a non-negligible background of boosted neutral mesons decaying into two photons (reconstructed as a single one), therefore one needs to subtract the background component on a statistical basis.

2. Measurement of the Cross Section for the Inclusive Production of Isolated Photons [1]

To discriminate statistically the signal from the remaining background, the inclusive photon measurement uses two complementary methods. The first method relies on E_T/p_T, the ratio of the E_T measured in the ECAL to the p_T measured in the tracker for converted photons [4, 6], and is more competitive at low E_T. For an isolated prompt photon, the sum of the p_T of the conversion tracks is on average the same as the energy deposited in the ECAL, while for photons produced from the decay of π^0 and η in jets it underestimates the energy collected in the ECAL. The second method relies on *ISO*, which is the sum of the isolation energies measured with the tracker, ECAL and HCAL, and is more competitive at high E_T. For a signal photon, only underlying event, pile-up, and detector noise may contribute to the *ISO*, while for a background photon an additional contribution comes from the particles accompanying the π^0 or η inside the jet. In each method, the number of signal events is obtained by fitting the distribution of the discriminating observable as the sum of two components: signal and background.

The selection efficiency is the product of the photon reconstruction, trigger and identification efficiencies. The trigger efficiency is evaluated from $Z \to ee$ data events, the reconstruction efficiency is estimated from simulation. The cluster shape and isolation selection efficiency are taken from simulation and corrected for data to Monte-Carlo difference in $Z \to ee$ events. The conversion selection efficiency is measured in data using the *ISO* method before and after the conversion selection. The electron veto efficiency is measured in $Z \to \mu\mu\gamma$ data events. The shapes of the signal and background distributions are taken from simulation and the systematic uncertainties estimated running toy Monte-Carlo experiments using the difference between Monte-Carlo and data. The overall uncertainty for the conversion method is about 15%, the biggest contribution being the uncertainty on the conversion selection. For the isolation method the biggest uncertainty comes from the signal and background shapes and the overall uncertainty is about 20-35% at low E_T and close to 7-10% at higher E_T, depending on the η region. Measured differential cross-section and uncertainties of the two methods are statistically combined [7]. Cross-sections measured in the range $21 < E_T < 400$ GeV for four η regions are compared fig. 1 with NLO pQCD predictions from JETPHOX [8] and found to be in agreement in the whole E_T and η range of the measurement.

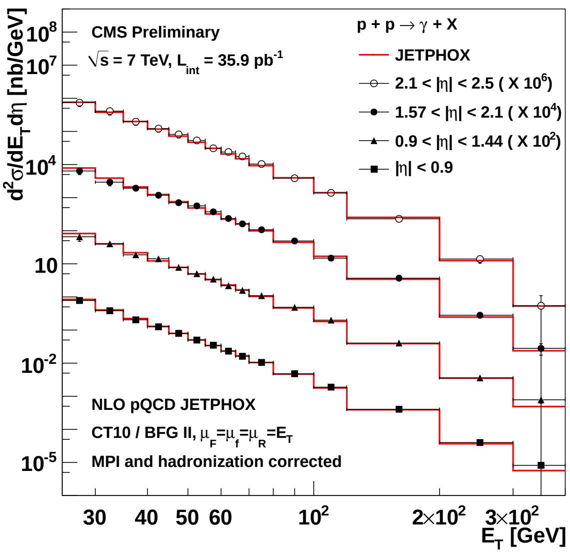

Figure 1: Measured isolated prompt photon differential cross sections (markers) as a function of E_T in the four η regions and the predictions from JETPHOX [8] 1.3.0 using the CT10 PDFs [9] (histograms).

3. Measurement of the Production Cross Section for Pairs of Isolated Photons [2]

The measurement is performed in the kinematical range $E_T > 23, 20$ GeV, $|\eta| < 2.5$ and $R > 0.45$. An isolation variable I based on the energy in the ECAL is used to statistically estimate the fraction of signal diphoton events among the selected candidates. It is defined as the sum of the transverse energy of the ECAL deposits with $E_T > 300$ MeV (to minimise the electronic noise and the dependence on the energy deposited by minimum-ionising particles), within a hollow cone centred on the photon impact point. Contributions to the value of I for signal photons come from pileup and underlying-event. The signal shape is measured from random cones method, measuring I at the same η as the photon candidate and at a random ϕ, and the uncertainty estimated from the difference of I with $Z \to ee$ and $W \to e\nu$ events. The background shape is extracted by selecting photon candidates with one impinging track hitting the isolation cone, and the systematic uncertainty obtained from the difference with two impinging tracks. The signal yield is obtained by a simultaneous fit of I for both selected photons.

The trigger and reconstruction efficiencies are estimated from simulation. The cluster shape and isolation selection efficiency and their uncertainties are estimated from the data to Monte-Carlo difference in $Z \to ee$ events. The efficiency for the requirement to have no impinging tracks within the isolation cone is estimated from data using a random-cone technique. The overall systematic uncertainty from the I distributions on the integrated cross section is about 8%, and varies from 4 to 27% on the differential cross sections, depending on the bin. A 4% uncertainty is assigned to the integrated luminosity. Measured differential cross-sections are compared fig. 2 with NLO theoretical calculations performed using DIPHOX [10] and GAMMA2MC [11] following PDF4LHC procedure [12] for four observables: the diphoton invariant mass $m_{\gamma\gamma}$, the azimuthal angle difference $\Delta\phi_{\gamma\gamma}$, the diphoton transverse momentum $p_{T,\gamma\gamma}$ and the scattering angle in Collins-Soper frame $cos(\theta^*) = tanh(\Delta Y_{\gamma\gamma}/2)$. The theoretical predictions underestimate the measured cross section for $\Delta\phi_{\gamma\gamma} < 2.8$, due to missing higher order corrections. This kinematical region, with the requirements of $E_T > 20$ and 23 GeV on the two photons, is responsible for the shoulder around 40 GeV in the diphoton differental p_T distribution, and also populates the region below 30 GeV in the diphoton mass distribution.

4. Conclusions

In this paper we presented two measurements of photon processes in proton-proton collisions at a centre-of-mass energy of 7 TeV with an integrated luminosity of 36 pb^{-1}. The measurement of the differential cross section for the production of isolated prompt photons has been performed in the range $25 < E_T < 400$ GeV in four bins of pseudo-rapidity up to $|\eta| < 2.5$. The prompt photon yield is measured via two methods which are combined: the ratio of the energy measured in the electromagnetic calorimeter to the momentum measured in the tracker for converted photons, and the isolation measured in the tracker and calorimeters. Predictions from the NLO pQCD are found to agree with the measured cross section within uncertainties. The integrated and differential production cross sections for isolated photon pairs have been measured in the kinematical range $E_T > 23, 20$ GeV, $|\eta| < 2.5$ and $R > 0.45$. The background from hadron decay products was estimated with a statistical method based on an electromagnetic energy isolation variable. Whereas

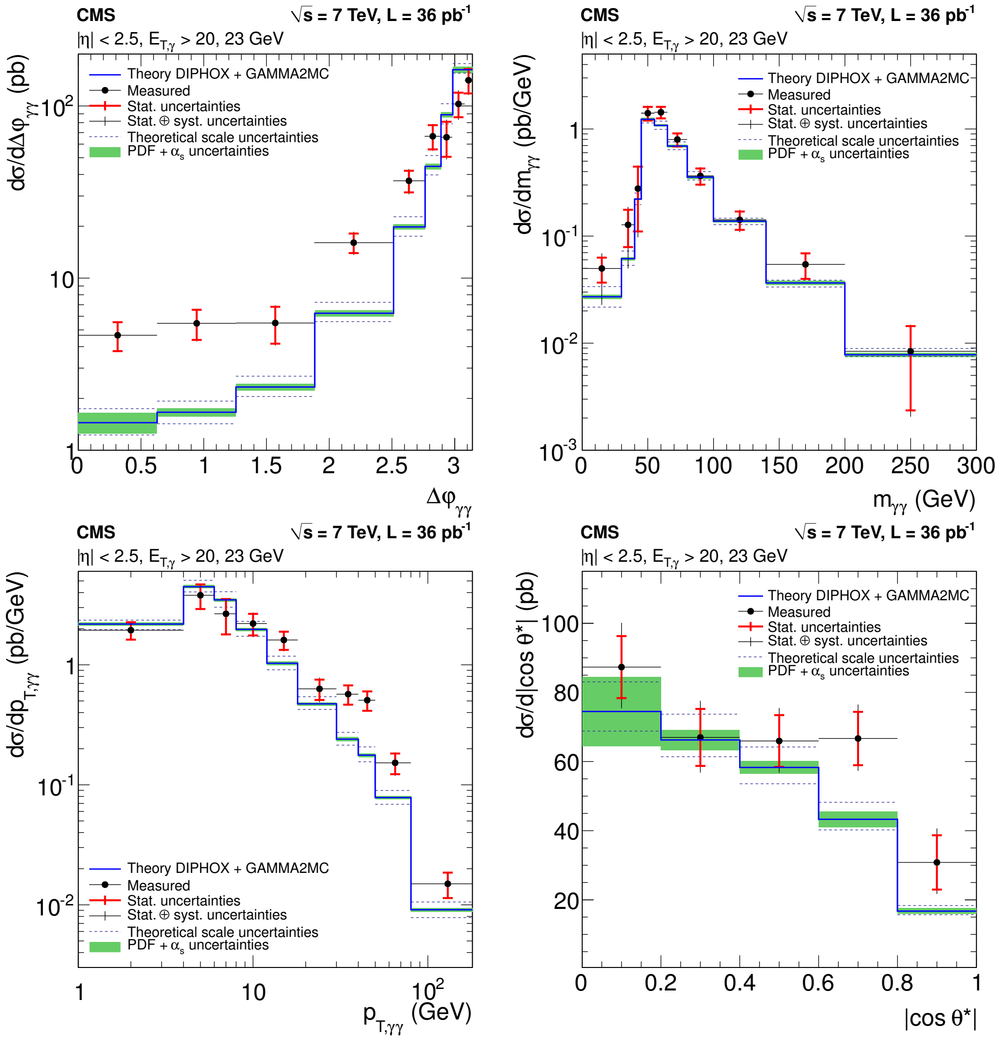

Figure 2: Diphoton differential cross section as a function of $\Delta\phi_{\gamma\gamma}$ (top left), $m_{\gamma\gamma}$ (top right), $p_{T,\gamma\gamma}$ (bottom left) and $cos(\theta^{*})$ (bottom right) from data (points) and from theory (solid line).

there is an overall agreement between NLO predictions and data for the diphoton mass spectrum, the theory underestimates the cross section in regions of the phase space where the two photons have an azimuthal angle difference $\Delta\phi < 2.8$.

References

[1] CMS Collaboration, *Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV*, Phys. Rev. D **84** (2011) 05201, [arXiv:1108.2044]

[2] CMS Collaboration, *Measurement of the Production Cross Section for Pairs of Isolated Photons in pp collisions at $\sqrt{s}$ = 7 TeV*, submitted to JHEP, [arXiv:1110.6461].

[3] CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST **03** (2008) S08004.

[4] CMS Collaboration, *Photon Reconstruction and Identification at CMS*, PAS-EGM-10-005 (2010).

[5] CMS Collaboration, *Isolated Photon Reconstruction and Identification at CMS*, PAS-EGM-10-006 (2010).

[6] N. Marinelli, *Track finding and identification of converted photons*, CMS-NOTE-2006-005, (2006).

[7] L. Lyons, D. Gibaut, and P. Clifford, *How to Combine Correlated Estimates of a Single Physical Quantity*, Nucl. Instrum. Meth. A **270** (1988) 110.

[8] S. Catani, M. Fontannaz, J. P. Guillet et al., *Cross section of isolated prompt photons in hadron-hadron collisions*, JHEP **05** (2002) 028, [arXiv:hep-ph/0204023].

[9] H.-L. Lai, M. Guzzi, J. Huston et al., *New parton distributions for collider physics*, Phys. Rev. D **82** (2010) 074024, [arXiv:1007.2241].

[10] T. Binoth et al., *A full next-to-leading order study of direct photon pair production in hadronic collisions*, Eur. Phys. J. C **16** (2000) 311, [arXiv:hep-ph/9911340].

[11] Z. Bern, L. J. Dixon, and C. Schmidt, *Isolating a light Higgs boson from the di-photon background at the LHC*, Phys. Rev. D **66** (2002) 074018, [arXiv:hep-ph/0206194].

[12] M. Botje et al., *The PDF4LHC Working Group Interim Recommendations*, arXiv:1101.0538.