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CMS results on exclusive and diffractive production

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Abstract. We present recent CMS measurements of diffractive and exclusive processes, using data collected at 7 TeV at the LHC. Measurements of soft single- and double-diffractive cross sections are presented, as well as measurements of photon-induced processes including studies of exclusive WW production via photon-photon exchange.

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INTRODUCTION

A significant fraction of the total inelastic proton-proton cross section at high energies can be attributed to diffractive interactions, characterized by the presence of at least one large rapidity gap (LRG) in the final state. The LRG, defined as a region in pseudorapidity devoid of particles, is presumed to be formed by a color-singlet exchange carrying quantum numbers of the vacuum, often referred to as Pomeron (IP). Figure 1 shows the main types of diffractive processes: single dissociation (SD), double dissociation (DD) and central dissociation (CD).

Inclusive diffractive interactions have been traditionally described by models based on Regge theory. These phenomenological models suffer from large uncertainties when extrapolated to higher energies and need additional tuning at the LHC. Experimental results from LHC run I are therefore crucial for tuning the models. Moreover, measurements of the particle yields and their associated kinematic distributions can provide a better understanding of the mechanisms of hadron production in high-energy interactions and on the relative role of soft and hard processes.

Another class of processes with a LRG in the final state is exclusive $\gamma\gamma$ production of lepton (W) pairs, $pp \rightarrow pp l^+ l^-$ ($pp \rightarrow pp W^+ W^-$), with l being a muon or an electron.

This paper reviews recent results on diffractive and exclusive processes obtained by the CMS experiment at the LHC. Early data collected in 2010, when the LHC was running in a low pile-up scenario, was used for a selection based on the LRG signature. For exclusive $\gamma\gamma$ production, the larger 2011 data sample was used.

Detectors used for the studies were the tracking devices and calorimeters in the central region ($|\eta| < 2.4$ and $|\eta| < 3$, respectively, η being the pseudorapidity variable), Hadron-Forward calorimeters (HF) covering the region of $3 < |\eta| < 5$ on both sides of the interaction point, and the Beam Shower Counters (BSC) attached to the front of the HF detectors.

DIFFRACTIVE CROSS SECTIONS

Diffractive cross sections were measured [1] using a low pileup sample with $16.2 \mu\text{b}^{-1}$ integrated luminosity. This sample was collected at $\sqrt{s} = 7$ TeV during the 2010 commissioning period. The online and offline event selection before the LRG cut provided a minimum-bias sample corresponding to the inelastic cross section, limited to the acceptance of the CMS detector ($|\eta| \leq 4.7$). The PYTHIA8-MBR (Minimum Bias Rockefeller) Monte Carlo [2] was used for the acceptance calculation and for the background subtraction. The 4C tune [3] of PYTHIA was instead used as a systematic check. Data belonging to two different experimental topologies, depending on the position of the gap, were used: forward pseudorapidity gap reconstructed at the edge of the detector on the negative η -side; central pseudorapidity gap reconstructed in the detector around $\eta \approx 0$. The first topology is related to the variables η_{min} , defined as the lowest η of the particle candidates in the central detector. The central-gap topology is described by $\Delta\eta^0 = \eta_{max}^0 - \eta_{min}^0$, with η_{max}^0 (η_{min}^0) the closest-to-zero value of the pseudorapidity of the particle candidate on the positive (negative) η side of the detector.

FIGURE 1. Schematic diagrams of (a) non-diffractive, $pp \rightarrow X$, and diffractive processes with (b) single dissociation, $pp \rightarrow Xp$ or $pp \rightarrow pY$ (not shown), (c) double-dissociation, $pp \rightarrow XY$, and (d) central dissociation, $pp \rightarrow pXp$. The $X(Y)$ represents a dissociated-proton or a centrally-produced hadronic system.

FIGURE 2. Detector level η_{min} (left) and $\Delta\eta^0$ (right) distributions for the minimum-bias sample compared to predictions of the PYTHIA8-MBR simulation, shown separately for the different processes and normalized to the luminosity of the data.

The distributions of η_{min} and $\Delta\eta^0$ are shown in Fig.2 for the selected sample compared to MC predictions. The data are dominated by ND events. Diffractive events appear as a flattening of the exponential distributions and populate the regions of high η_{min} and $\Delta\eta^0$, hence cuts on $\eta_{min} > -1$ and $\Delta\eta^0 > 3$ were imposed.

The SD and DD cross sections were extracted from the negative-side-gap sample. They are shown in Fig. 3 left and right respectively as a function of the variable ξ , which represents the longitudinal momentum loss of the incoming proton and is related to the mass of the dissociated system, M_x , by $\xi = M_x^2/s$, with s the center-of-mass energy squared.

Figure 3 also shows a comparison of the measured cross sections with predictions from the theoretical models used in PYTHIA8-MBR, PYTHIA6 [4] and PYTHIA8-4C simulations. In the case of PYTHIA8-MBR the predictions are given for two values of the ε parameter of the Pomeron trajectory, $\alpha(t) = 1 + \varepsilon + \alpha't$. The SD data are well described by either versions of the MBR model, while the DD cross section prefers a smaller intercept. The other two models cannot describe the falling behaviour of the SD cross section.

Since it is not possible to measure the whole mass of the diffractively dissociated system due to the limited coverage of the detector in the forward region, one can alternatively measure the size of the corresponding pseudorapidity gap. In each reconstructed event of the central-gap sample, the largest gap between each edge of the detector and the position in η of the first particle found moving away from the edge is designated as the largest forward rapidity gap, $\Delta\eta^F$. The unfolded and fully corrected differential cross section of the forward gap size is shown and compared to a previous ATLAS measurement [5] in Fig. 4. The green band represents the total systematic uncertainty of the CMS measurement (included in the error bands in ATLAS case). It must be said that the hadron level definition is not quite the same as CMS gap starts at $|\eta| \approx 4.7$, whereas ATLAS cross section is given for $|\eta| < 4.9$. The CMS result extends the ATLAS measurement by 0.4 unit of gap size.

FIGURE 3. The SD (left) and DD (right) cross sections as a function of ξ compared to the MC predictions described in the text.

FIGURE 4. Differential cross section of the forward rapidity gap size, $d\sigma/d\Delta\eta^F$, compared to the ATLAS measurement described in the text.

TWO-PHOTON PRODUCTION OF W PAIRS

Measurements of the two-photon production of W^+W^- pairs at the LHC, $pp \rightarrow pW^+W^-p$, provide unique sensitivity to the anomalous quartic gauge coupling of the W boson [6]. The electroweak sector of the Standard Model (SM) predicts three and four point vertices with the gauge bosons. Deviation from the SM are predicted by theories where more generic couplings are taken into account. In this study [7], a genuine anomalous quartic gauge coupling is introduced via an effective lagrangian with two additional dimension-6 terms containing the parameters a_0^W and a_C^W [8]. The anomalous coupling makes the $\gamma\gamma \rightarrow WW$ cross section increase quadratically with energy, therefore a dipole form factor is introduced to preserve unitarity:

$$a_{0,C}^W \rightarrow a_{0,C}^W(W_{\gamma\gamma}^2) = a_{0,C}^W \left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda^2} \right)^{-2}, \quad (1)$$

where Λ is the energy cutoff scale ($\Lambda \rightarrow \infty$ implies no form factor) and $W_{\gamma\gamma}$ is the two-photon center-of-mass energy. Since the energy scale and exact form of the new physics that enters to regulate the cross section is unknown, in the current study both a scenario with $\Lambda = 500$ GeV and another without dipole form factors are considered.

Since both very forward scattered protons escape detection, the signal signature is a primary vertex from the dilepton pair with no other tracks, with large transverse momentum and large invariant mass. The same signature is also accessed via proton-dissociative production, in which one or both of the incident protons dissociate into a low-mass system that escapes detection. In order to avoid large backgrounds from other processes, the unlike-dilepton final state $\gamma\gamma \rightarrow W^+W^- \rightarrow \mu^\pm e^\mp \nu\bar{\nu}$ was selected over 5.05 fb^{-1} collected by the CMS experiment in 2011 at $\sqrt{s} = 7$ TeV. A

control sample $pp \rightarrow p^* \mu^+ \mu^- p^*$, where p^* are dissociated protons, was used to validate the selection and to estimate the proton-dissociative contribution. The dominant backgrounds due to inclusive $W^+ W^-$ and $\tau^+ \tau^-$ production were then constrained using control regions with low $p_T(\mu^\pm e^\mp)$ or a low-multiplicity requirement on the extra tracks originating from the dilepton vertex. In a region sensitive to SM $\gamma\gamma \rightarrow W^+ W^-$ production, with $p_T(\mu^\pm e^\mp) > 30$ GeV, two events were observed, with a signal expectation of 2.2 ± 0.4 events and a background expectation of 0.84 ± 0.15 events. The significance of the signal is around one standard deviation, with a 95% CL upper limit on the SM cross section of 10.6 fb. In the tails of the $p_T(\mu^\pm e^\mp)$ distribution ($p_T(\mu^\pm e^\mp) > 100$ GeV), where the SM contribution is expected to be small, no events were observed. A limit is set on the partial cross section times branching fraction within the acceptance of $p_T(\mu, e) > 20$ GeV, $|\eta(\mu, e)| < 2.4$, $p_T(\mu^\pm e^\mp) > 100$ GeV at 95% CL:

$$\sigma(pp \rightarrow p^* W^+ W^- p^* \rightarrow p^* \mu^\pm e^\mp p^*) < 1.9 \text{ fb}.$$

We use this subsample to set limits on the anomalous quartic gauge coupling parameters, which results in values of the order of $1.5 \times 10^{-4} \text{ GeV}^{-2}$ for a_0^W/Λ^2 and $5 \times 10^{-4} \text{ GeV}^{-2}$ for a_c^W/Λ^2 , assuming a dipole form factor with the energy cutoff scale at $\Lambda_{\text{cutoff}} = 500$ GeV. These limits are approximately 20 times more stringent than the best limits obtained at the Tevatron [9], and approximately two orders of magnitude more stringent than the best limits obtained at LEP [10]. With no form factors, the limits would be of order 10^{-5} and below. Should proton taggers be available in CMS, the uncertainty on the proton-dissociation contribution would be reduced and the limits would still improve.

CONCLUSIONS

We have presented recent CMS measurements of diffractive and exclusive processes, using data collected at 7 TeV at the LHC.

Diffractive cross sections have been measured as a function of the longitudinal momentum loss of the incoming proton (ξ), for a low pileup data sample with $16.2 \mu\text{b}^{-1}$ integrated luminosity collected in 2010. Comparison of the measured cross sections with predictions from the theoretical models favors the PYTHIA8-MBR model over other models.

A search for exclusive two-photon production of $W^+ W^-$ in the $\mu^\pm e^\mp$ channel has also been performed using 5.05 fb^{-1} of data collected by the CMS detector in 2011. In a region sensitive to SM $\gamma\gamma \rightarrow W^+ W^-$ production, with $p_T(\mu^\pm e^\mp) > 30$ GeV, two events were observed, with a signal expectation of 2.2 ± 0.4 events and a background expectation of 0.84 ± 0.15 events. The significance of the signal is around one standard deviation, with a 95% CL upper limit on the SM cross section of 10.6 fb. In the region with $p_T(\mu^\pm e^\mp) > 100$ GeV where the SM contribution is expected to be small, no events were observed, and a limit were on anomalous quartic gauge coupling parameters which are approximately 20 times more stringent than the best limits obtained at the Tevatron, and approximately two orders of magnitude more stringent than the best limits obtained at LEP.

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