The Compact Muon Solenoid Experiment
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Soft and Hard Diffraction with CMS

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Abstract

The observation of diffraction at the LHC with the CMS detector, at $\sqrt{s} = 7$ TeV, is presented, along with a comparison of the data with the predictions of the PYTHIA6, PYTHIA8 and PHOJET generators. The observation of diffractive W and Z boson production is also presented, and its fraction is measured in a sample of large rapidity gap events, based on the description of the POMPYT generator.

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Soft and Hard Diffraction with CMS

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Keywords: CMS, diffraction, rapidity gaps

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INTRODUCTION

This paper presents the observation of a diffractive signal dominated by the inclusive single-diffractive (SD) reaction, $pp \rightarrow Xp$ [1], as well as that in which X includes a W or Z boson (i.e. diffractive W/Z production) [2]. Diffractive events can be described in terms of a colourless exchange with the vacuum quantum numbers (the “Pomeron”). In these events, the final-state hadrons are well separated in rapidity (“large rapidity gap”, LRG) from the outgoing proton, which is not detected. Inclusive diffractive events are in general of a *soft* nature and are well described in the context of Regge theory (see e.g. [5, 6]). Conversely, *hard-diffractive* events, in which a hard scale is present, can be described in the framework of QCD, in terms of diffractive structure functions and, in analogy to the usual parton distribution functions, by diffractive PDFs (dPDFs).

The analysis is based on the data collected by the CMS experiment during the year 2010, at a centre-of-mass energy of 7 TeV. The data are compared to simulated events obtained from the PYTHIA6 [7], PYTHIA8 [8] and PHOJET [9, 10] event generators. Diffractive events with a hard sub-process are simulated with the POMPYT generator [11]. The detailed simulation of the CMS detector response is based on GEANT4 [12]. Simulated events were processed and reconstructed in the same manner as collision data.

EXPERIMENTAL APPARATUS

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [4]. The central feature of the CMS apparatus is a superconducting solenoid, of 6 m internal diameter. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass-scintillator hadronic calorimeter (HCAL). Muons are measured in gaseous detectors embedded in the iron return yoke. CMS has extensive forward calorimetry. The forward part of the hadron calorimeter, HF, covers the pseudorapidity region $2.9 < |\eta| < 5.2$. The very forward angles are covered by the CASTOR ($-6.6 < \eta < -5.3$) and Zero Degree ($|\eta| > 8.3$) calorimeters, which were however not used in the present analysis. Two elements of the CMS monitoring system, the Beam Scintillator Counters (BSC) and the Beam Pick-up Timing eXperiment (BPTX) devices, were used to trigger the CMS readout. The two BSC are sensitive in the $|\eta|$ range from 3.23 to 4.65. The two BPTX [4] are designed to provide precise information on the bunch structure and timing of the incoming beam.

EVENT SELECTION

To select inclusive diffractive events, the CMS readout was triggered by a signal in any of the BSC scintillators, coincident with a signal from either of the two BPTX detectors, indicating at least one bunch crossing the interaction point (IP). Offline, BPTX signals were required from both beams passing the IP, in conjunction with a signal in either of the BSCs. In addition, a primary vertex was required close to the IP; at least four tracks were required in the vertex

fitting. Beam-halo event candidates, as well as beam-scraping events, in which long horizontal sections of the pixel tracker are hit, were rejected. Events were also rejected if large signals consistent with noise in HCAL were identified.

The identification of W bosons required the presence of isolated electrons and muons with transverse-momentum (p_T) greater than 25 GeV with pseudo-rapidity $|\eta| < 1.4$, and the missing transverse momentum, reconstructed from a combination of measurements from the tracker and the calorimeters [3], greater than 30 GeV. The transverse mass was further required to be greater than 60 GeV. Analogously, the selection of Z bosons required two isolated electrons or muons with opposite charge with $p_T > 25$ GeV, at least one of them at $|\eta| < 1.4$. The reconstructed invariant mass of the di-lepton system was further required to lie between 60 and 120 GeV. Events were selected online by requiring a high transverse momentum electron or muon. The trigger efficiency for signal events is above 99%. In order to reject events with additional pp interactions in the same bunch crossing (i.e. *pile-up*), only events with a single reconstructed vertex were selected. The primary vertex is matched to the lepton track along the z axis. The pile-up vertex reconstruction efficiency is determined from the simulation to be $\sim 72\%$, while the reconstruction inefficiency due to merged vertices is estimated to be around 3.3%.

RESULTS

Events passing the inclusive selection described in the previous section are plotted as a function of the variable $E \pm p_z \equiv \sum (E_i \pm p_{z,i})$ (Figure 1, left panel), where the sum runs over all calorimeter towers, including HF. This variable approximately equals twice the Pomeron energy; the plus (minus) sign applies to the case in which the proton emitting the Pomeron moves in the $+z$ ($-z$) direction. Diffractive events cluster at very small values of $E \pm p_z$, reflecting the peaking of the cross section at small ξ , the proton fractional energy loss in single-diffractive events. Diffractive events also appear as a peak in the zero-energy bin of the deposited energy distribution in HF (E_{HF}), on either the HF at forward rapidities (HF+) or the HF at negative rapidities (HF−), reflecting the presence of a large rapidity gap (LRG) extending over HF+ or HF− (Fig. 1, right panel).

The data are compared with the predictions of PYTHIA6 and PYTHIA8, as well as PHOJET. A clear diffractive contribution is evident. The bands in all cases illustrate the effect of a 10% energy scale uncertainty in the calorimeters and should be taken as a rough estimate of the systematic uncertainty due to the current imperfect understanding and simulation of the detector.

FIGURE 1. Distributions of the accepted events as a function of $E + p_z$ (left) and $E_{\text{HF}+}$ (right). Similar distributions are obtained for the symmetric $E - p_z$ and $E_{\text{HF}-}$. The predictions of PYTHIA6, PYTHIA8 and PHOJET are also shown, normalised to the data. The distributions are uncorrected. The vertical bars indicate the statistical uncertainty of the data. The bands illustrate the effect of a 10% energy scale uncertainty in the calorimeters.

In the left panel of Figure 2, the distribution of the energy deposited in HF is shown for events in which a W boson is identified, decaying in the muon channel. The data are compared with the predictions of PYTHIA6, as well as PYTHIA8. Large discrepancies between the data and the different models are observed. Events with zero energy deposition reflect the presence of large rapidity gap (LRG) extending over HF. The corrected fractions of W and Z events with a LRG are found to be, respectively, $1.46 \pm 0.09(\text{stat.}) \pm 0.38(\text{syst.})\%$ and $1.57 \pm 0.25(\text{stat.}) \pm 0.42(\text{syst.})\%$, where the results for the electron and muon decay channels are combined.

The distribution of the selected W candidate events with a LRG is shown in the right panel of Fig. 2 as a function of the signed charged lepton rapidity η_{lepton} , defined to be positive when the observed gap and the lepton are in the same hemisphere and negative otherwise. The data show that charged leptons from W decays are found more often in the

hemisphere opposite to the gap. The corresponding asymmetry is $-21.0 \pm 6.4\%$. In the case of Z events, the rapidity of the lepton pair is used instead and an asymmetry of $-20 \pm 16\%$ is observed. The asymmetry seen in the data agrees well with the POMPYT simulation of diffractive W/Z events. A fit from the predictions of POMPYT and the PYTHIA6 non-diffractive simulation results in a fraction of diffractive events of $50.0 \pm 9.3(\text{stat.}) \pm 5.2(\text{syst.})\%$ in the selected sample.

FIGURE 2. Left: Distribution of the $W \rightarrow \mu\nu$ candidate events as a function of the energy deposition in HF. The predictions of PYTHIA6, with different tunes, and PYTHIA8 are also shown. Right: Signed lepton rapidity distribution in W events with a LRG (see text). Electron and muon channels are combined. The fit result for the combination of the PYTHIA6 (ProQ20 tune) and POMPYT predictions is shown as the dotted line. Fit results of the non-diffractive component using different PYTHIA6 tunes are also shown.

SUMMARY

Evidence of the observation of diffraction at the LHC, at 7 TeV center-of-mass energy, has been presented. Diffractive events appear as a peak at small values of the variable $E \pm p_z$, which is proportional to ξ , the proton fractional energy loss, reflecting the $1/\xi$ behaviour of the diffractive cross section. Diffractive events also appear as a peak in the energy distribution of the forward calorimeter HF, reflecting the presence of a rapidity gap over HF.

Events associated to W and Z boson production with a LRG have been observed. A large asymmetry in the signed charged lepton (η_{lepton}) distribution is observed. This asymmetry is well described by the prediction of the POMPYT generator. The diffractive component in the LRG event sample is determined to be $50.0 \pm 9.3(\text{stat.}) \pm 5.2(\text{syst.})\%$ and provides the first evidence of diffractive W/Z production at the LHC.

REFERENCES

1. CMS Collaboration, PAS-FWD-10-007 (2010).
2. CMS Collaboration, PAS-FWD-10-008 (2010).
3. CMS Collaboration, PAS-PFT-10-002 (2010).
4. CMS Collaboration, JINST **3** (2008) S08004.
5. P. D. B. Collins, Cambridge University Press, Cambridge, 1977.
6. K. Goulianos, Phys. Rep. **101** (1983) 169.
7. T. Sjostrand, S. Mrenna and P. Skands, JHEP **0605** (2006) 026.
8. T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. **178** (2008) 852.
9. F. W. Bopp, R. Engel and J. Ranft, arXiv:hep-ph/9803437.
10. R. Engel, J. Ranft and S. Roesler, Phys. Rev. D **52** (1995) 1459.
11. P. Bruni and G. Ingelman, Phys. Lett. B **311**, 317 (1993).
12. S. Agostinelli *et al.* [GEANT4 Collaboration], Nucl. Instrum. Meth. A **506** (2003) 250.