The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

07 December 2012 (v4, 20 December 2012)

CMS results on soft and hard diffraction

Ada Solano for the CMS Collaboration

Abstract

Recent CMS results on soft and hard diffraction are discussed, including inclusive diffraction, hard-diffractive dijet production, and W and Z boson events with pseudorapidity gaps.

Presented at *Diffraction 2012: International Workshop on Diffraction in High-Energy Physics*

CMS results on soft and hard diffraction

Ada Solano, on behalf of the CMS Collaboration

University of Torino and INFN-Torino, via Giuria 1, I-10125 Torino

Abstract. Recent CMS results on soft and hard diffraction are discussed, including inclusive diffraction, hard-diffractive dijet production, and W and Z boson events with pseudorapidity gaps.

Keywords: LHC, CMS, QCD, Diffraction, Rapidity gaps

PACS: 01.30.Cc; 12.38.Qk; 13.85.Qk; 14.70.Fm

FORWARD INSTRUMENTATION AND DIFFRACTION AT CMS

A substantial fraction of pp interactions consists of diffractive reactions, $pp \rightarrow pXp$ or $pp \rightarrow Xp$ or $pp \rightarrow XY$, characterized by the fact that the incoming proton(s) emerge from the interaction intact, or excited into a low mass state Y, with an energy loss of only a few per cent. Diffractive processes, as described by Regge theory, are dominated by a t -channel exchange with vacuum quantum numbers, the so-called pomeron, now also understood in terms of partons from the proton.

The absence of colour flow between the proton(s) and the system X results in the topological signature of these events, i.e. no hadrons produced in a large rapidity range adjacent to the scattered proton(s), leading to the so-called Large Rapidity Gap (LRG). The principal way of selecting diffractive events is thus looking for a large gap in the rapidity distribution of the hadronic final state. This needs the best possible coverage of the experimental apparatus in the forward regions, at high rapidities. On the other hand, in pp collisions large rapidity gaps can be destroyed by soft multi-parton interactions, leading to the suppression of the observed diffractive cross section, and the suppression factor, called rapidity gap survival probability, needs to be measured experimentally. Moreover, at high luminosities the overlapping of several events for a given bunch crossing (pile-up, PU) strongly affects the LRG signature since the gap is filled in, limiting the available statistics to a small amount of low PU data. A way to overcome this problem would be to measure the scattered proton(s) with near-beam taggers. These detectors are presently under discussion by both collaborations ATLAS and CMS.

CMS forward instrumentation. The CMS experiment [1], primarily designed for efficient detection of high transverse momentum particles produced at central rapidities, is characterized by a superconducting solenoid producing a strong magnetic field of 3.8 T. Within the field volume are the silicon pixel and strip trackers, 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, consisting of steel absorbers and embedded radiation-hard quartz fibers, covers the range in pseudorapidity $\eta = -\ln[\tan(\theta/2)]$ equal to $2.9 < |\eta| < 5.2$. Further coverage in the

FIGURE 1. Distributions of events as a function of (a) $E \pm p_z$ and (b) E_{HF-} (from [2]).

forward region is provided by the CASTOR ($5.2 < |\eta| < 6.6$) and ZDC ($|\eta| > 8.3$) calorimeters, which were however not used in the analyses presented here. 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 read-out. The two BSC are sensitive for $3.23 < |\eta| < 4.65$ and are designed to provide hit and coincidence rates. The two BPTX are designed to provide precise information on the bunch structure and timing of the incoming beams.

Observation of diffraction in pp collisions at 7 TeV. The observation of a diffractive signal [2] in pp collisions at 7 TeV centre-of-mass energy complements that of ref. [3], where the 900 and 2360 GeV data are discussed. The analysis is based on a small fraction ($\sim 20\mu\text{b}^{-1}$) of 2010 data, which were taken at low instantaneous luminosity such that the probability of PU events was negligible ($\sim 0.5\%$).

Evidence for diffraction, dominated by the inclusive single-diffractive (SD) reaction $pp \rightarrow Xp$, is obtained by looking at the following variables: (i) $E \pm p_z = \Sigma(E_i \pm p_{z,i})$, where the sum runs over all calorimeter towers, including HF; this variable approximately equals twice the pomeron energy, with the plus (minus) sign for the case in which the proton emitting the pomeron moves in the $+z(-z)$ direction; (ii) E_{HF} (N_{HF}), the energy deposition (multiplicity of towers) in HF. In order to discriminate signal from noise, the energy thresholds used in the calorimeters were 1.5 GeV for the barrel region, 2 GeV for the endcap regions and 4 GeV for HF.

Single-diffractive events cluster at small values of the variable $E \pm p_z$ (Fig. 1a), 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 zero-energy bin (Fig. 1b) and zero-multiplicity bin of the corresponding distributions for the forward calorimeters HF+ and HF-, reflecting the presence of a rapidity gap extending over HF.

EVIDENCE FOR HARD DIFFRACTION

Diffractive reactions are predominantly soft but can also occur in the presence of a hard scale, as observed at UA8, HERA and Tevatron. The hard scale may be provided by jets, heavy quarks or the W or Z boson mass and allows perturbative QCD (pQCD) to be used. Such hard-diffractive processes can be described in terms of the convolution

FIGURE 2. (a) $\tilde{\xi}$ distribution before and after the η_{max} (η_{min}) cut; (b) dijet differential cross section as a function of $\tilde{\xi}$ (from [4]).

of hard scattering cross sections, calculable in pQCD, and diffractive parton distribution functions (dPDFs), which can be interpreted as proton PDFs under the condition that the proton remains intact. The dPDFs have been determined by the HERA experiments by means of QCD fits to inclusive diffractive deep inelastic ep scattering data, and have been successfully used to describe different hard-diffractive processes in ep collisions.

Diffractive dijet production. Diffractive dijet production [4] has been studied with a sample of 2.7 nb^{-1} of 2010 data, taken at low instantaneous luminosity such that the average number of PU events is estimated to be 0.09. Events were selected with at least two jets with transverse momentum $p_T > 20 \text{ GeV}$ and axes in the range $|\eta| < 4.4$. To enhance the diffractive contribution, the requirements $\eta_{max} < 3$ ($\eta_{min} > -3$) were applied, with η_{max} (η_{min}) the pseudorapidity of the most forward (backward) particle-flow (PF) object. This selection is equivalent to imposing a gap of at least 1.9 units in the HF acceptance, with no PF objects with energy $E > 4 \text{ GeV}$ in the calorimeter.

The differential cross section for dijet production has been measured as a function of $\tilde{\xi}$, a variable that approximates the fractional momentum loss of the proton in SD events. Figure 2a shows the $\tilde{\xi}$ distribution before and after the η_{max} (η_{min}) cut. Data were fitted to different combinations of non-diffractive (ND) and SD Monte Carlo (MC) generators to extract their relative contribution. A combination of PYTHIA6 Z2 ND and POMPYT SD, scaled by a factor 0.23, results in the best description of the data. As shown in Fig. 2a, the low- $\tilde{\xi}$ region, dominated by diffraction, is mostly unaffected by the cut.

The corrected inclusive dijet cross section has been extracted in the first three bins and is plotted in Fig. 2b, compared to the predictions of non-diffractive (PYTHIA6 Z2 and PYTHIA8 tune 1) and diffractive (POMPYT SD, POMWIG SD and PYTHIA8 SD+DD) MC generators, along with that of the diffractive NLO calculation based on POWHEG (first bin only). The contribution of SD MC models is needed to describe the low- $\tilde{\xi}$ data, and is evidence of diffractive dijet production. However, the ratio of the measured cross section to that expected from MC simulations is 0.21 ± 0.07 in the first bin. This ratio can be taken as an upper limit of the rapidity gap survival probability, not simulated by the considered MCs. Assuming the amount of proton-dissociative events in the data to be 41%, this upper limit can be turned into an estimate of the rapidity gap survival probability of 0.12 ± 0.05 , which becomes 0.08 ± 0.04 if POWHEG is used.

FIGURE 3. Signed lepton pseudorapidity distribution in W events with a LRG signature (from [5]).

W and Z boson events with a pseudorapidity gap. The presence of a diffractive component in the production of single W and Z boson events [5] has been studied in a sample of 36 pb^{-1} of 2010 data, taken with increasing instantaneous luminosity. To account for the PU events, the data sample was subdivided into three periods with different luminosity conditions. To limit the PU, events with more than one vertex were rejected. W bosons were selected in the decay channels $W \rightarrow l\nu$, with the isolated lepton (e or μ) having $|\eta| < 1.4$ and $p_T > 25 \text{ GeV}$, and an event missing energy $E_T > 30 \text{ GeV}$. Z bosons were selected in the decay channels $Z \rightarrow ll$, with two isolated leptons of opposite charge and $p_T > 25 \text{ GeV}$, of which at least one within $|\eta| < 1.4$, and the reconstructed invariant mass of the dilepton system in the range $60 < M_{ll} < 120 \text{ GeV}$.

To select LRG events, the energy deposition in either the forward calorimeters HF+ and HF- was required to be less than 4 GeV, imposing a gap of at least 1.9 units in the HF acceptance. Evidence for a diffractive component in these LRG events is obtained from the observation that the majority of the charged leptons from the W(Z) decays are found in the hemisphere opposite to the gap. Figure 3 shows the signed lepton pseudorapidity distribution of W LRG events, with the η_l sign defined to be positive when the gap and the lepton are in the same hemisphere and negative otherwise. A large asymmetry is observed, which is predicted by POMPYT, in contrast to the various non-diffractive PYTHIA MC tunes. When fitting the observed asymmetry in LRG events with an admixture of diffractive (POMPYT) and non-diffractive (PYTHIA) events, the diffractive component is determined to be $50.0 \pm 9.3(\text{stat.}) \pm 5.2(\text{syst.})\%$, thus providing the first evidence for diffractive W production at the LHC. A comparable but statistically less significant asymmetry is seen in Z events with large pseudorapidity gaps.

REFERENCES

1. CMS Collaboration, S. Chatrchyan et al., JINST 3 (2008) S08004
2. CMS Collaboration, CMS PAS FWD-10-007 (2010)
3. CMS Collaboration, CMS PAS FWD-10-001 (2010)
4. CMS Collaboration, CMS PAPER FWD-10-004 (2010)
5. CMS Collaboration, S. Chatrchyan et al., Eur. Phys. J. C72 (2012) 1839