The Compact Muon Solenoid Experiment
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Diffraction with CMS

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Abstract

The observation of inclusive diffraction at LHC with the CMS detector at $\sqrt{s} = 900$ GeV and 2360 GeV is presented, along with a comparison of the data with the predictions of the PYTHIA and PHOJET generators

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Abstract. The observation of diffraction at LHC with the CMS detector at $\sqrt{s} = 900$ and 2360 GeV is presented, along with a comparison of the data with the predictions of the PYTHIA and PHOJET generators.

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, $pp \rightarrow Xp$. In these events, the final-state hadrons are well separated in rapidity ("large rapidity gap", LRG) from the outgoing proton, which is not detected. A comparison of the data with some of the available Monte Carlo models is performed. The analysis is based on the data collected by the CMS experiment in December 2009, which correspond to an integrated luminosity of approximately $10 \mu\text{b}^{-1}$ at a centre-of-mass energy of 900 GeV and $0.4 \mu\text{b}^{-1}$ at 2360 GeV [1].

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [2]. 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 [2] are designed to provide precise information on the bunch structure and timing of the incoming beam.

EVENT SELECTION

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); these conditions are the same as those used in [3].

Offline, BPTX signals were required from both beams passing the IP, in conjunction with a signal in either of the BSCs (the coincidence of the BSCs would have suppressed SD signals). In addition, a primary vertex was required close to the IP; at least three 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 numbers of events after the cuts are 207345 and 11848 at $\sqrt{s} = 900$ and 2360 GeV, respectively. The residual contamination due to collisions between beam protons and residual gas molecules in the beam-pipe was estimated to be less than 1% from a sample of events from non-colliding bunches.

MONTE CARLO SIMULATION AND ACCEPTANCE

The data are compared to simulated events obtained from the PYTHIA6 [4] and PHOJET 1.12-35 [5, 6] event generators processed through a simulation of the CMS detector response. Unless otherwise stated, PYTHIA tune D6T is used in the following.

The detailed Monte Carlo (MC) simulation of the CMS detector response is based on GEANT4 [7]. Simulated events were processed and reconstructed in the same manner as collision data.

Figure 1 shows the acceptance for SD events as a function of the generated value of ξ , the fractional energy loss of the scattered proton (i.e. the fraction of the incoming proton energy carried by the Pomeron), at 900 and 2360 GeV. This acceptance includes the effects of all the selection cuts applied. The figure also shows the generator-level ξ distributions, which peak at low ξ and have an approximately $1/\xi$ behaviour. The acceptance for low- ξ events is small since at low M_X (i.e. low ξ , $\xi = M_X^2/s$) the system X may escape undetected. The selection efficiency for SD events is about 20% according to PYTHIA and about 35% according to PHOJET; for non-diffractive (ND) events it is about 85% for both generators.

FIGURE 1. Acceptance for SD events, after the selection cuts, as a function of the generated value of ξ for the 900 GeV data (left) and for the 2360 GeV data (right), obtained with PYTHIA and PHOJET. The generator-level ξ distributions of SD events are shown in the insert.

RESULTS

The selected events are plotted as a function of the following variables:

- $E \pm p_z \equiv \sum (E_i \pm p_{z,i})$, 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 . Since it is not possible, on an event-by-event basis, to determine which is the proton emitting the Pomeron, the distributions from the data contain an admixture of "wrong-sign" events for which the proportionality between ξ and $E \pm p_z$ does not hold;
- E_{HF} (N_{HF}), the energy deposition (multiplicity of towers) in HF. Here diffractive events appear as a peak in the zero-energy bin of either the HF at forward rapidities (HF+) or the HF at negative rapidities (HF-), reflecting the presence of a large rapidity gap extending over HF+ or HF-.

Figure 2 shows the distributions of the events as a function of $E + p_z$. The bands 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. At both energies, a clear diffractive contribution is evident. The data are compared with the predictions of PYTHIA (tune D6T) and PHOJET. The agreement is reasonable, with PYTHIA describing the ND part of the data better than PHOJET.

FIGURE 2. Distributions of the accepted events as a function of $E + p_z$ at 900 GeV (left) and 2360 GeV (right). The predictions of PYTHIA 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.

To enhance the diffractive component in the data, a cut was applied to the HF energy sum. As an example, the right panel of Fig. 3 shows the $E_{\text{HF}-}$ distribution for events in which the energy sum in HF+ was $E_{\text{HF}+} < 8$ GeV (900 GeV data), while the left panel shows the event distribution when no selection was made. This cut mainly selects single-diffractive events with a LRG over HF+. The system X is thus boosted towards the negative z direction. The figure also compares the data with PYTHIA and PHOJET in this region. PHOJET agrees better with the data.

FIGURE 3. Distributions of $E_{\text{HF-}}$ before (left) and after (right) the requirement of $E_{\text{HF+}} < 8$ GeV for the 900 GeV 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. The data are compared to both PYTHIA and PHOJET, normalised to the data.

SUMMARY

Evidence of the observation of single-diffraction at the LHC has been presented, both at 900 and at 2360 GeV. Single-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. Single-diffractive events also appear as a peak in the energy and multiplicity distributions of the forward calorimeter HF, reflecting the presence of a rapidity gap over HF.

The data have been compared to PYTHIA6 and PHOJET. PYTHIA6 gives a better description of the non-diffractive component of the data, while PHOJET reproduces the diffractive contribution more accurately.

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