The Compact Muon Solenoid Experiment
Conference Report

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Diffraction at CMS

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Abstract

The measurement of the inelastic cross section and the observation of diffraction at 7 TeV with the CMS detector are presented. The results are compared with the predictions of the PYTHIA6, PYTHIA8 and PHOJET generators.

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DIFFRACTION AT CMS

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1 Introduction

This paper presents the results on the measurement of the pp inelastic cross section [1], as well as the observation of a diffractive signal dominated by the inclusive single-diffractive reaction $pp \rightarrow Xp$ [2,3]. 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 [4], PYTHIA8 [5] and PHOJET [6] event generators. Diffractive events with a hard sub-process are simulated with the POMPYT generator [7].

2 CMS Detector

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [8]. 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 $2.9 < |\eta| < 5.2$. 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.

3 Inelastic cross section measurement

A new method to measure the inelastic pp cross section has been developed based on the assumption that pile-up events are randomly distributed according to a Poisson probability. This method relies only on the accurate knowledge of the CMS tracking system and it does not depend upon a specific Monte Carlo simulation. The number of inelastic proton-proton (pp) interactions in a given bunch crossing follows a Poisson probability distribution:

$$P(n) = \frac{(L \cdot \sigma)^n}{n!} e^{-L \cdot \sigma}, \quad (1)$$

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Figure 1: Fraction of events with n pile-up events as a function of luminosity. The dotted line is a Poisson fit.

Figure 2: Compilation of total inelastic pp and $p\bar{p}$ cross section values. CMS analysis uncertainty is shown in dark blue while the model-dependent extrapolation is shown in light blue (dark green and light blue for ATLAS). Picture layout and data points courtesy of [10].

where L is the bunch crossing luminosity and σ the total inelastic pp cross section.

The true pile-up distributions are obtained by performing a bin-by-bin correction of the measured vertex distributions with the efficiency values obtained with Monte Carlo. Then, each pile-up distribution is fitted with a Poisson function, eq. 1, as shown in Figure 1.

The measurements obtained in this analysis can be used to estimate the value of the total inelastic pp cross section using MC dependent extrapolation factors:

$$\sigma_{inel}(pp) = 68 \pm 2.0(\text{syst.}) \pm 2.4(\text{lumi}) \pm 4(\text{ext.}) \text{ mb.} \quad (2)$$

Figure 2 shows how this value compares with previous pp and $p\bar{p}$ measurements and with the ATLAS results [9].

4 Observation of diffraction

Figure 3 (left) shows the distribution of the selected events as a function of $\sum(E \pm p_Z)$, 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. 3, 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 3: Distributions of the accepted events as a function of $E + p_Z$ (left) and E_{HF+} (right). 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.

The selected sample of W events with a LRG is shown in Fig. 4, 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.

5 Summary

A new method to measure the inelastic pp cross section has been developed based on the assumption that pile-up events are randomly distributed according

Figure 4: Signed lepton rapidity distribution in W events with a LRG. 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.

to a Poisson probability. The model-dependent value of the extrapolated total inelastic pp cross section is $\sigma_{inel}(pp) = 68 \pm 2.0(\text{syst.}) \pm 2.4(\text{lumi}) \pm 4(\text{ext.}) \text{ mb}$

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.

A large asymmetry is observed when comparing the number of events with the charged lepton (from the W (Z) decay) in the opposite and same hemisphere as the rapidity gap. Such an asymmetry is predicted by the diffractive POMPYT MC, in contrast to the various non-diffractive PYTHIA MC tunes.

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