# Soft Diffraction at CMS

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**Abstract.** The observation of a diffractive signal dominated by the inclusive single diffractive dissociation reaction pp → pX is presented. The analysis is based on a fraction of the data collected by the CMS experiment in 2010 and corresponds to an integrated luminosity of 10, 0.4 and 20 $\mu b^{-1}$ at 0.9, 2.36 and 7 TeV, respectively. Detector level distributions are compared to fully simulated and reconstructed Monte Carlo predictions obtained with the PYTHIA6, PHOJET and PYTHIA8 generators.

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## INTRODUCTION

A substantial fraction of the total proton-proton cross section is due to diffractive reactions. Diffractive events can be described in terms of a colourless exchange with the vacuum quantum numbers (the "Pomeron") and notably no color. As a consequence, the two (groups of) final-state hadrons are well separated in rapidity ("large rapidity gap", LRG). The quantitative description of soft-diffraction still largely relies on Regge theory (see e.g. [1, 2]). The observed energy dependence of the inclusive single-diffractive cross section is however weaker than that expected by Regge theory. [1] The modeling of soft diffraction is in general generator specific. Therefore, defining and constraining diffractive interactions and their evolution with $\sqrt{s}$ is an important ingredient in the understanding and tuning of minimum-bias at the LHC.

## THE CMS DETECTOR

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [5]. The CMS detector comprises the tracking system in the central part (-2.5< $|\eta|$ <2.5) and the calorimetry system in the pseudorapidity range -5< $|\eta|$ <5, where the forward region (2.9 < $|\eta|$ < 5.2) is covered by the hadronic forward calorimeter (HF). Two elements of the CMS monitoring system are used to trigger the CMS readout; the Beam Scintillator Counters (BSC) designed to provide hit and coincidence rates and two Beam Pick-up Timing eXperiment (BPTX) devices designed to provide precise information on the bunch structure and timing of the incoming beam.

[1] A fact ascribed to "shadowing" corrections due to soft re-scattering between the protons, which slow down the scattered proton and fill the rapidity gap, thereby decreasing the visible diffractive cross section.

## EVENT SELECTION

BPTX signals were required from both beams passing the IP in conjunction with a signal in either of the BSCs; this cut selects approximately 99% of the inelastic events and about 70-80% of the SD events (the estimated fraction depends slightly on the MC generator used). A good quality primary vertex was required, which selects approximately 90-95% of the inelastic events; the fraction of SD events which pass this selection is about 35% according to PYTHIA6, 52% according to PHOJET and 58% according to PYTHIA8. The number of events after all cuts is 1030752. The data considered were taken at low instantaneous luminosity. The probability of additional interactions in a given bunch crossing was negligible (of order 0.5%).

## MONTE CARLO SIMULATION AND ACCEPTANCE

The data are compared to simulated events obtained from the MC generators PYTHIA6, version 6.422 [6], tune D6T [7] [2]; PYTHIA8, version 8.135 [8], tune 1; and PHOJET1.12-35 [9] processed through a detailed simulation of the CMS detector response. Figure 1 shows the acceptance for SD events as a function of the generated value of $\xi$, the fractional energy loss of the scattered proton (i.e. the fraction of the incoming proton energy carried by the Pomeron)[3] . The figure also shows the

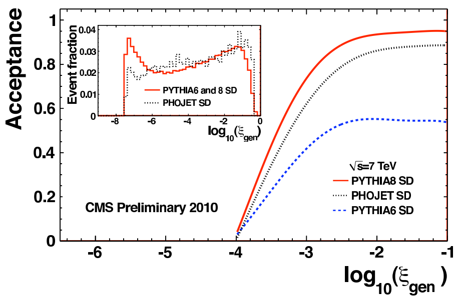


**FIGURE 1.** Acceptance for SD events, after the selection cuts, as a function of the generated value of $\xi$ obtained with PYTHIA6, PYTHIA8 and PHOJET. The generator-level $\xi$ distributions of SD events are shown in the insert (the PYTHIA6 and PYTHIA8 distributions are identical); their area is normalised to unity over the full $\xi$ range

generator-level $\xi$ distributions, which peak at low $\xi$ and have an approximately $1/\xi$ behaviour; the PYTHIA6 and PYTHIA8 distributions are identical. The acceptance for low-$\xi$ events is small since at low $M_X$ (i.e. low $\xi$ , $\xi = M_X^2/s$) the system X may escape undetected. The acceptances predicted by PHOJET and PYTHIA8 are close and higher than that predicted by PYTHIA6. The difference between the PYTHIA6 and PYTHIA8

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[2] The tunes DW, CW, Perugia-0 (P0) and Z1 have been studied but are not shown here and can be found in [3] and [4].

[3] This and all following distributions are presented for 7 TeV, the corresponding results with 0.9 TeV and 2.36 TeV are equivalent and can be found in [3].

acceptances (in spite of the identical $\xi$ distribution) reflects the different simulation of the diffractive system fragmentation in the two generators as well as the absence of hard-diffractive processes in PYTHIA6.

## RESULTS

Energy and longitudinal momentum conservation can be used to show that $E \pm p_z = \Sigma(E_i \pm p_{z,i})$, where the sum runs over all calorimeter towers, 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 $\xi$.

Figure 2 shows the distributions of the selected events as a function of $E + p_z$ and the track multiplicity obtained from the tracking system. The distributions are uncorrected for acceptance as well as detector and reconstruction efficiencies. They are compared to the predictions of PYTHIA6, PHOJET and PYTHIA8. In the $E + p_z$ variable a clear diffractive contribution is evident. The band illustrates the effect of a 10% energy scale uncertainty in the calorimeters. The agreement is reasonable for PYTHIA6 and it is worse for PYTHIA8 and PHOJET. The track multiplicity distribution is described well by PYTHIA8; PYTHIA6 and PHOJET have a poor description specially of the high multiplicity tails. The expected SD components is also indicated showing considerable higher activity for PYTHIA8 and PHOJET compared to PYTHIA6.

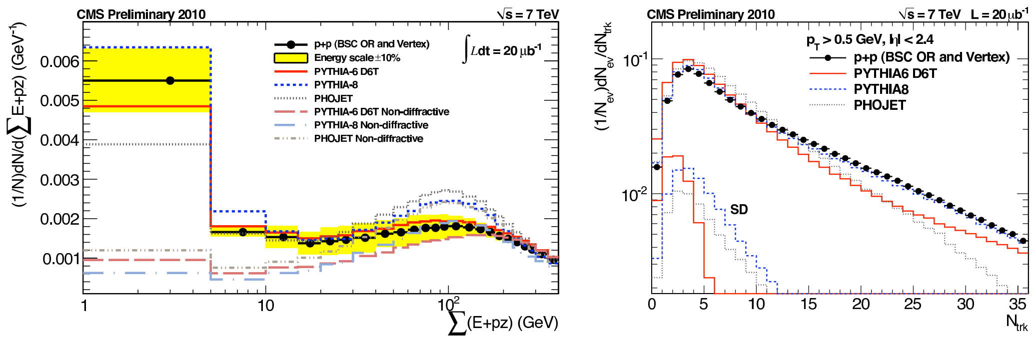


**FIGURE 2.** Distribution of $E + p_z$ (left) and track multiplicity (right) of all the accepted events. The band illustrates the effect of a 10% energy scale uncertainty in the calorimeters. The distributions are uncorrected. The predictions of PYTHIA6, PYTHIA8 and PHOJET are shown, normalized to the data. The SD contribution is also indicated.

To enhance the diffractive component in the data, a cut was applied to the HF energy sum. As an example, Figure 3 shows the $E - p_z$ and track multiplicity distributions for events in which the energy sum in HF+ was $E_{HF+} < 8$ GeV. This cut mainly selects single-diffractive events with a LRG over HF+. The system X is thus boosted towards the negative z direction. The comparison of the data with PYTHIA6, PYTHIA8 and PHOJET shows that PHOJET gives a fair description of the data in the high-mass diffractive systems i.e. at large values of $E - p_z$ while PYTHIA6 and PYTHIA8 perform significantly worse. The track multiplicity is well reproduced by PYTHIA8 and PHOJET whereas PYTHIA6 has a considerably softer spectrum than data.

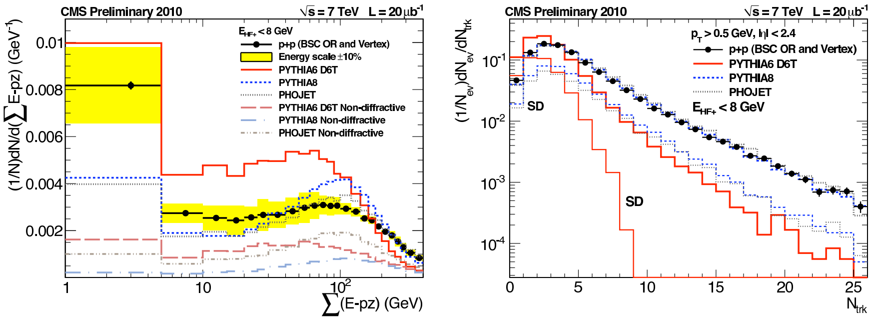


**FIGURE 3.** Distribution of $E - p_z$ (left) and track multiplicity (right) after the requirement of $E_{HF+} < 8$ GeV. The band illustrates the effect of a 10% energy scale uncertainty in the calorimeters. The distributions are uncorrected. The predictions of PYTHIA6, PYTHIA8 and PHOJET are shown, normalized to the data. The SD contribution is also indicated.

# CONCLUSIONS

Evidence of the observation of SD reactions at the LHC has been presented. SD events appear as a peak at small values of the variable $E \pm p_z$. The uncorrected data has been compared to PYTHIA6, PYTHIA8 and PHOJET after simulation of the detector response. The inclusive distributions have been studied in the central region of the detector through the track multiplicities and in the forward region through the $E \pm p_z$ variable. The data is best described by PYTHIA8 in the central region and by PYTHIA6 in the forward region. The description of the diffractive component is studied by enhancing the data sample with events which have a LRG on one side of the detector, finding that PYTHIA8 and PHOJET give an accurate description of data in the central part while in the forward region they only describe the tails of the distribution. Even though several of the considered simulations describe accurately some distributions, none of them manages to describe all the features of the data in its entirety.

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