Probing hard diffraction with CMS

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The cross section for dijet production in pp collisions at $\sqrt{s} = 7$ TeV is presented as a function of $\tilde{\xi}$, a variable that approximates the fractional momentum loss of the scattered proton in single-diffractive events. The observation of W and Z boson production with a pseudorapidity gap in the final state is also presented.

1 Introduction

This paper presents a measurement of the dijet production cross section as a function of a variable, denoted $\tilde{\xi}$, which approximates the fractional momentum loss of the scattered proton in single-diffractive (SD) reactions, $pp \to Xp$ [1]. The observation of W and Z events associated with pseudorapidity gaps is also discussed. According to a Monte Carlo model, these events can be interpreted as due to diffractive W/Z production [2].

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 [5] and Pythia8 [6] event generators. Diffractive events with a hard sub-process are simulated with the Pompyt [7] and Pomwig [8] generators, as well as Pythia8. Diffractive dijet events were also generated at next-to-leading (NLO) accuracy using the Pomweg [9] framework. These generators were used with diffractive parton distributions (dPDFs) from the same fit to diffractive deep inelastic scattering data (H1 Fit B) [10].

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 $2.9 < |\eta| < 5.2$. In the current analysis only the region $3.0 < |\eta| < 4.9$ was used, thus restricting the data to a region of well understood reconstruction efficiency.

2 Event selection

To select dijet events, at least one jet with uncorrected transverse momentum (p_T) greater than 6 GeV was required at the trigger level. Offline, events were selected with two jets with $p_T >$ 20 GeV, in the pseudorapidity region $-4.4 < \eta^{\mathrm{jet}(1,2)} < 4.4$. Jets were reconstructed with the anti-k_T jet-finding algorithm with radius parameter $R = 0.5$. The diffractive contribution was enhanced by requiring the pseudorapidity of the event most forward (backward) reconstructed object $\eta_{\max}$ ($\eta_{\min}$), using a particle-flow algorithm which combines measurements from the tracker and the calorimeters [3], to be $\eta_{\max} < 3$ ($\eta_{\min} > -3$). This selection corresponds to imposing a pseudorapidity gap of at least 1.9 units in the HF acceptance. It rejects most of events with additional *pp* interactions in the same bunch crossing (i.e. *pile-up*).

The identification of W bosons required the presence of isolated electrons and muons with transverse-momentum (p_T) greater than 25 GeV with pseudorapidity $|\eta| < 1.4$, and the missing transverse momentum, reconstructed from a particle-flow algorithm, 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 pile-up events, a single reconstructed vertex was required.

3 Results

The dijet production cross section is measured as a function of the variables $\tilde{\xi}^{+}$ and $\tilde{\xi}^{-}$, defined as $\tilde{\xi}^{\pm} = C \, \frac{\sum(E^i \pm p_z^i)}{\sqrt{s}}$, where E^i and p_z^i are the energy and longitudinal momentum of each reconstructed particle-flow object, respectively, and the sum runs over all objets measured in the detector. The constant C is a correction factor determined from the MC. The results as a function of $\tilde{\xi}^{+}$ and $\tilde{\xi}^{-}$ were averaged, and presented as a function of $\tilde{\xi}$. The reconstructed $\tilde{\xi}$ distribution is shown in the left panel of Figure 1. The results are presented both when not applying the $\eta_{\max} < 3$ ($\eta_{\min} > -3$) selection and when this condition was required. This pseudorapidity gap selection rejects events at high values of $\tilde{\xi}$, while the region of low $\tilde{\xi}$, where the diffractive contribution dominates, is only marginally affected. The shape of the distributions can be described by a combination of diffractive (Pompyt) and non-diffractive (Pythia6, Tune Z2) MC simulated events. The data collected correspond to an integrated luminosity of 2.7 nb^{-1}.

The right panel of Fig. 1 shows the differential cross section for dijet production as a function of $\tilde{\xi}$, where the measured number of dijet events in each bin was corrected by a factor which includes the effects of the geometric acceptance of the apparatus as well as unfolding corrections to account for the finite resolution of $\tilde{\xi}$, as well as p_T^{jet} and η^{jet}, and the trigger efficiency. A correction for the effect of pile-up was also applied. At hadron-level, $\tilde{\xi}^{+}$ and $\tilde{\xi}^{-}$ are defined analogously from the energy and longitudinal momentum of each final-state particle with $-\infty < \eta < 4.9$ for $\tilde{\xi}^{+}$ and $-4.9 < \eta < +\infty$ for $\tilde{\xi}^{-}$. In the region of low $\tilde{\xi}^{\pm}$ this variable is a good approximation of ξ for single-diffractive events. The data are compared to the predictions of non-diffractive (Pythia6, Tune Z2 and Pythia8, Tune 1) and diffractive (Pompyt SD, Pomwig SD, Pythia8 SD+DD) MC models, as well as the NLO calculation based on Pomweg. The contribution of SD MCs is needed to describe the low-$\tilde{\xi}$ data. They predict however more events than are observed, by a factor of about 5 in the lowest $\tilde{\xi}$ bin[1]. The ratio of the measured cross section to that expected by diffractive MCs in Fig. 1 can be taken as an upper limit of the rapidity-gap survival probability.

[1]The normalisation of the SD+DD Pythia8 prediction disagrees with that of Pompyt and Pomwig. This is a consequence of the different modelling of diffraction in these generators: while they all use the same H1 dPDFs, the parametrisation of the Pomeron flux in Pythia8 is different, and notably not that used in [10].

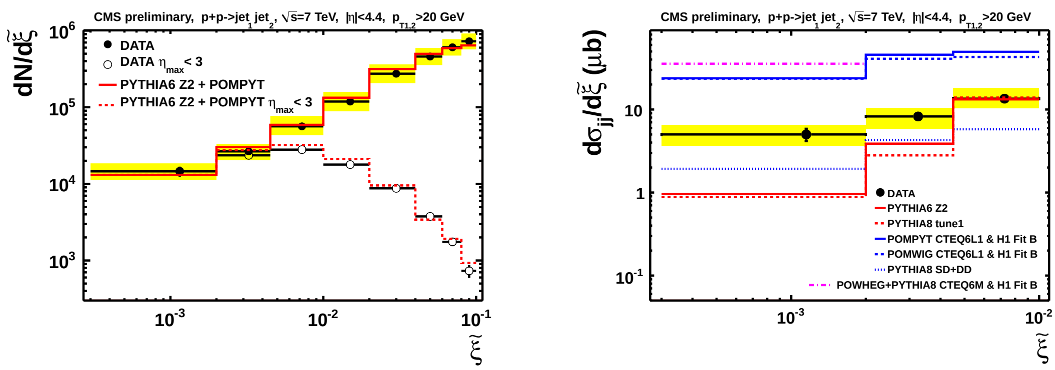

Figure 1: Left: Reconstructed $\tilde{\xi}$ distributions compared to MC predictions including diffractive dijet production (Pythia6 + Pompyt) without (solid line) and with (dashed line) the $\eta_{\max} < 3$ ($\eta_{\min} > -3$) condition. The MC diffractive dijet contribution has been scaled by a factor of 0.23, obtained from a fit to the data. Right: The differential cross section for dijet production as a function of $\tilde{\xi}$ for jets with $-4.4 < \eta < 4.4$ and $p_T > 20$ GeV. The points are plotted at the centre of the bins. The predictions of non-diffractive and diffractive MC generators are also shown (see text). The error bars indicate the statistical uncertainty and the band represents the jet and calorimeter energy-scale uncertainties added in quadrature.

In the left panel of Figure 2, the distribution of the energy deposited in HF is shown for events in which a W boson decaying in the muon channel is observed. 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 a pseudorapidity gap extending over HF. The fractions of W and Z events with a pseudorapidity gap 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 a data-driven pile-up correction has been applied. The results for the electron and muon decay channels are combined. The data collected correspond to an integrated luminosity of 36 pb^{-1}.

The distribution of the selected W candidate events with a pseudorapidity gap is shown in the right panel of Fig. 2 as a function of the signed charged lepton pseudorapidity η_ℓ, 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 of 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.

4 Summary

The differential cross section for dijet production as a function of $\tilde{\xi}$, a variable that approximates the fractional momentum loss of one of the protons in single-diffractive processes, has

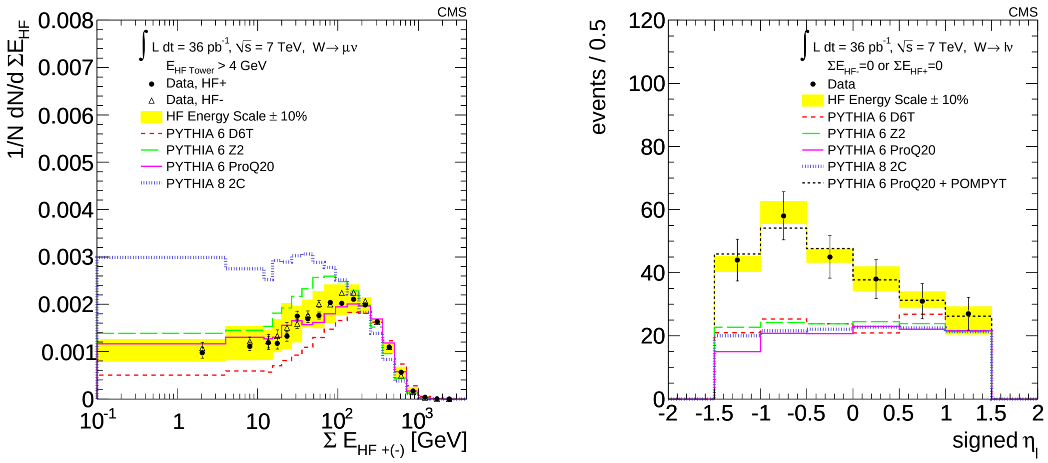

Figure 2: Left: Distribution of the $W \to \mu\nu$ candidate events as a function of the energy deposition in HF. The predictions of Pythia6, with different tunes, and Pythia8 are also shown. Right: Signed lepton pseudorapidity distribution in W events with a pseudorapidity gap (see text). Electron and 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.

been measured with the CMS detector for events with at least two jets with $p_T > 20$ GeV in the pseudorapidity region $-4.4 < \eta < 4.4$. The results are compared to diffractive and non-diffractive MC models. The low-$\tilde{\xi}$ data are dominated by diffractive dijet production. Diffractive generators based on dPDFs from the HERA experiments overestimate the measured cross section and their normalisation needs to be scaled down by a factor which can be interpreted as the effect of the rapidity-gap survival probability.

The production of W and Z bosons with a pseudorapidity gap in the final state has been observed. In these events, a large asymmetry in the signed charged lepton (η_ℓ) distribution is seen. This asymmetry is well described by the prediction of the Pompyt generator. The diffractive component in the rapidity-gap 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.

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