The Compact Muon Solenoid Experiment

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Jet Production in the Very Forward Direction at 13 TeV with CMS

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Jet Production in the Very Forward Direction at 13 TeV with CMS

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Abstract. The new frontier collision energy $\sqrt{s} = 13$ TeV of the Large Hadron Collider (LHC) at the Run II has important key points in particle physics. Forward jets, abundantly produced in proton-proton (pp) collisions, are useful tools to test Quantum Chromodynamics (QCD) predictions at low values of parton momentum fraction x . Measurement of the differential inclusive jet production cross section in the very forward direction is a powerful benchmark to study multiple partonic interactions (MPI) in pp collisions. The very forward jet measurement is performed with the CMS detector in a special early run at 13 TeV taken with $B = 0$ T. The results are corrected to stable particle level and compared to several Monte Carlo (MC) model predictions.

INTRODUCTION

Quantum Chromodynamics (QCD) is the fundamental theory to describe the strong interactions of hadrons. Inclusive jet production ($p + p \rightarrow \text{jet} + X$) is one of the most abundant processes at hadron colliders and can be used to test predictions of perturbative QCD (pQCD). Such processes cause a huge background for many new physics searches with the Large Hadron Collider (LHC) which is basically a QCD machine. Hence the modelling of such processes should be carried out precisely. The underlying event (UE), multiple parton interactions (MPI) and minimum-bias particle production measurements are needed to be understood carefully in order to have constraints on the QCD background. Hence, to perform measurements with inclusive jets in the very forward direction play an important role for QCD model predictions. The collimated sprays of hadrons, i.e. jets, are essential for studying both the hard and non-perturbative QCD effects as well as the proton structure. The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) parton evolution equations and collinear factorization theorem [1, 2, 3, 4] are commonly used for describing the proton collisions by the Monte Carlo (MC) event generators. Balitsky-Fadin-Kuraev-Lipatov (BFKL) [5, 6, 7] or the Ciafaloni-Catani-Fiorani-Marchesini (CCFM) [8, 9, 10, 11] equations are the alternative models of parton dynamics.

EXPERIMENTAL APPARATUS

The central feature of the Compact Muon Solenoid (CMS) detector is a superconducting magnet providing magnetic field of 3.8 T. The silicon pixel tracker, strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL) are located within the field volume. ECAL is made of $PbWO_4$ crystals and covers pseudorapidity range $|\eta| < 3.0$. The HCAL calorimeter is a sampling brass/scintillator which also covers the range $|\eta| < 3.0$. A detailed description of the CMS detector can be found in Ref. [12].

The CASTOR calorimeter which covers the very forward pseudorapidity range $-6.6 < \eta < -5.2$ is located only on the minus side of CMS. The CASTOR very forward calorimeter is made of quartz plates embedded in tungsten absorbers providing a fast collection of the Cherenkov light. The calorimeter is segmented in 14 longitudinal (z -modules) and 16 azimuthal (ϕ -sectors) channels. The first two front channels have half the absorber thickness of the others and are used to detect electromagnetic showers. The CASTOR calorimeter was not precisely centered around

the beam pipe during the data taking period. The position of CASTOR is determined with an uncertainty in x and y -positions of each hemispheres of better than 2 mm. A small tilt or rotation of the hemispheres is neglected.

RESULTS

The measurements of double-differential inclusive jet cross sections as a function of the jet transverse momentum p_T and the jet rapidity y are performed by CMS with proton-proton collisions at $\sqrt{s} = 8$ TeV [13] and $\sqrt{s} = 13$ TeV [14]. The jets in both analyses are reconstructed with the anti- k_t jet clustering algorithm. The cone size parameter $R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.7$ is used for previous measurement whereas for the latter $R = 0.4$ and $R = 0.7$ are used. Figure 1 (left) shows the double differential inclusive jet cross section measured as a function of transverse momentum p_T and rapidity y at 8 TeV. The results are compared to the NLO theory prediction, based on the CT10 PDF set. The data are found to be consistent with the theory predictions. Five different parton density functions are considered and amongst all the CT10 and NNPDF3.0 [16] PDF sets are observed to have good agreement with the measurements. The double-differential inclusive jet cross section measurements at $\sqrt{s} = 13$ TeV is shown in Figure 1 (right). The results are compared to the NLOJET++ predictions based on the CT14 [17] PDF set, corrected for non-perturbative (NP) and electroweak effects (EWK). The data and predictions are observed to have a consistency within a wide range of $114 \text{ GeV} < p_T < 2 \text{ TeV}$.

FIGURE 1. Double differential inclusive jet cross sections measured at $\sqrt{s} = 8$ TeV (left) [13] and $\sqrt{s} = 13$ TeV (right) [14].

A measurement of the very forward differential jet production cross section in the pseudorapidity interval $-6.6 < \eta < -5.2$ is performed with pp collision data collected at $\sqrt{s} = 13$ TeV [18]. During the data taking period the CMS solenoid was not switched on, i.e. $B = 0$ T. In the event selection an unbiased trigger with the requirement of the presence of two colliding bunches is used. In addition further cleaning is applied to remove noise events.

In order to reconstruct the jets in CASTOR a three step procedure is applied. Two steps are devoted for clustering and the last one is for the noise rejection. First the malfunctioning channels in each azimuthal sector are excluded and the remaining channels are used for the reconstruction of calorimeter towers. Then, the jets in CASTOR are reconstructed with the anti- k_t jet algorithm using the radius parameter of $R = 0.5$. Assembly of jets is done from CASTOR calorimeter towers which are assigned to have $\eta = -5.9$ corresponding to the center of the calorimeter acceptance. The quantity to measure is chosen as transverse momentum p_T which is obtained with the conversion of clustered jet energy E_{jet} by the factor $\cosh(5.9)$, $p_T = E/\cosh(-5.9)$, and the mass of particles is neglected. Because the CASTOR calorimeter cannot measure the jet angle within its acceptance, the conversion of E_{jet} to p_T causes increased migration effects. These migration effects are corrected during the unfolding procedure.

All the detector effects are taken into account for correcting the data to the stable particle level. In order to determine event-selection efficiencies and to make correction to the stable particle level the response of all detectors is simulated using the GEANT4 [19] framework. The measurement is then compared to the MC models as well as the ultra-high energy cosmic ray model predictions EPOS-LHC [20] and QGSJETII.4 [21]. EPOS-LHC, is a phenomenological model based on a parton-level Gribov-Regge field theory [22] implementation whereas QGSJETII.4 is

a more theory-motivated model implemented using Pomeron-tree and -loop diagrams calculated at all orders. EPOS-LHC and QGSJETII.4 model predictions are based on DGLAP parton evolution equation and are recently tuned with the LHC data taken at $\sqrt{s} = 8$ TeV. Furthermore, PYTHIA6 tune Z2*, PYTHIA8 tune Monash, PYTHIA8 tune CUETP8M1 [23] and PYTHIA8 MBR [24] are also used. The used PYTHIA tunes utilize the DGLAP evolution equations in order to describe the parton showers.

Various systematic uncertainty sources are considered and the very forward jet p_T spectra, reconstructed from the calorimeter energies, are corrected. The most dominant uncertainty source is the energy scale of CASTOR (CES) which has an exceeding 50% impact on the final jet cross section. Model dependence, the second dominant source, has an effect of 20 to 50%. Figure 2 (left) shows the comparison of final corrected differential very forward jet cross section as a function of p_T to different model predictions. The systematic uncertainty bands are added quadratically on top of the previous one. The jet yield normalized by the number of jets in the range $3 < p_T < 13$ GeV is shown in Figure 2 (right). Figure 3 (left) shows the comparison of the corrected differential jet cross section with the various PYTHIA tunes. A similar comparison is also performed for the jet yield normalized by the number of jets with the different PYTHIA tunes as shown in Figure 3. Generally, a consistency between the data and all the models used in the analysis is observed within the experimental uncertainties. A slight overprediction of the cross section is observed in all the PYTHIA tunes. However, the cosmic ray models EPOS-LHC and QGSJETII.4 are found to underpredict the cross section. Overall the PYTHIA tunes reproduce the shape of the distribution well. However, EPOS-LHC and QGSJETII.4 tend to have softer shape than the data observed. The presented results show a moderate sensitivity to the underlying PDF set of the model, however, show high sensitivity to MPI.

FIGURE 2. Left: The final corrected differential very forward jet cross section as a function of p_T . Right: The jet yield normalized by the number of jets [18].

SUMMARY

The CMS experiment is extensively studying new kinematic regions of QCD in proton-proton collisions, available at the LHC with data from Run II. In particular, several measurements performed with forward jets as well as low- p_T jet final states to probe the low- x region. The very forward inclusive jet cross section measured in proton-proton collisions with a center-of-mass energy of $\sqrt{s} = 13$ TeV is presented. Within the current experimental uncertainties however, which are dominated by the jet energy scale, all models are able to describe the data.

FIGURE 3. Comparison of the PYTHIA8 tune CUETP8M1 with different PDF sets (CTEQ6.1 and HeraPDF) with final corrected differential very forward jet cross section (left) and the jet yield normalized by the number of jets (right) [18].

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