The Compact Muon Solenoid Experiment

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Forward and Small- x QCD Physics Results from CMS Experiment at LHC

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Abstract

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Forward and Small- x QCD Physics Results From CMS Experiment at LHC

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INTRODUCTION

The production of jets with large transverse momenta p_T in high energy proton-proton (pp) collisions originates from a scattering of partons which is well-described within the theory of strong interactions, QCD. The cross section of such a pp collision process is factorized in a convolution of the cross section for a partonic sub-process and the parton distribution functions (PDF). The advantage of jets is to include more particles originating from the outgoing partons, whereas single charged hadrons carry only a fraction of the parent parton momentum. On the other hand, jets are sensitive to the underlying event (UE) activity, consisting of particles originating from multiple partonic interactions (MPI) and initial and final state radiation (ISR and FSR). The measurements based on leading particles and leading jets are therefore complementary. Multijet measurements allow further features of QCD to be investigated and studied. In this paper, the recent CMS results on diffraction, soft QCD and forward physics, and discuss their comparison to predictions of various theoretical models are reviewed.

THE CMS DETECTOR

The CMS experiment is ideally suited to carry out the above mentioned studies. A detailed description of the CMS detector can be found in [1]. The main feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter. Within the magnet volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter, and the brass and scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke of the magnet. The tracker measures charged particles within $|\eta| < 2.4$. It has 1440 silicon pixel and 15148 silicon strip detector modules, arranged in 14 tracking layers. The barrel region of the CMS pixel detector consists of three layers very close to the beamline. In addition to the barrel and endcap detectors, CMS has extensive forward calorimetry. The forward component of the hadron calorimeter, HF ($2.9 < |\eta| < 5.2$), consists of steel absorbers with embedded radiation-hard quartz fibers, providing fast collection of Cherenkov light. The very forward angles are covered at one end of CMS ($6.6 < \eta < -5.2$) by the CASTOR calorimeter, made of quartz plates embedded in tungsten absorbers, segmented in 16 ϕ -sectors and 14 z-modules.

RESULTS

The diffractive dissociation cross sections measurements in pp collisions at $\sqrt{s} = 7$ TeV are performed in the kinematic regions defined by the masses M_X and M_Y of the two final-state hadronic systems separated by the largest rapidity gap in the event [2]. Differential cross sections are measured as a function of $\xi_X = M_X^2/s$ in the region $5.5 < \log_{10} \xi_X < 2.5$, for $\log_{10} M_Y < 0.5$, dominated by single dissociation (SD), and $0.5 < \log_{10} M_Y < 1.1$, dominated by double dissociation (DD). The discrimination between the above two M_Y regions is performed by means of the CMS forward calorimeter. The measured cross sections compared to the various MC predictions. The extrapolation is carried out using the predictions of PYTHIA8 MBR event generator tune. The extrapolated SD and DD cross sections thus obtained are $\sigma^{SD} = 8.84 \pm 0.08(\text{stat})_{-1.38}^{+1.49}(\text{syst})_{-0.37}^{+1.17}(\text{extrap})$ mb and $\sigma_{DD} = 5.17 \pm 0.08(\text{stat})_{-0.57}^{+0.55}(\text{syst})_{-0.51}^{+1.62}(\text{extrap})$ mb, respectively, and shown on Fig. 1 compared to other measurements and models as a function of $\sqrt{s}$. The MC predictions show that in the pseudorapidity range covered by the measurement, $|\eta| < 4.7$, a large fraction of nondiffractive events can be suppressed by means of the largest pseudorapidity gap $\Delta\eta^F > 3$ requirement.

FIGURE 1. Single (double) dissociation cross sections as a function of collision energy measured in pp and $p\bar{p}$ collisions compared to model predictions. Left: Total SD cross section for $\xi < 0.05$. Right: total DD cross section for $\Delta\eta > 3$.

The underlying event activity is measured by using a leading charged particles with $p_T > 0.5$ GeV and $|\eta| < 2$ at the CMS detector in pp collisions at $\sqrt{s} = 2.76$ TeV [3]. The charged particle jets and charged particles produced at central pseudorapidity ($|\eta| < 2$) with transverse momentum larger than 1 GeV and 0.5 GeV, respectively, are used to study the UE properties. The center-of-mass energy dependence of the UE activity in the transverse region is presented on Fig. 2 (left) as a function of p_T^{jet} for $\sqrt{s} = 0.9, 2.76$ and 7 TeV. A fast rise with increasing center-of-mass energy of the activity in the transverse region is observed for the same value of the leading charged-particle jet. All presented model tunes predict a center-of-mass energy dependence consistent with that of the data.

At high centre-of-mass energies the gluonic parton densities become large at low values of longitudinal momentum fraction. Hence, the probability to have more than one partonic interaction becomes non-negligible, leading to the production of pairs of different flavoured jets via double parton scattering (DPS). A measurement of the production cross section of events with at least four jets, two of them initiated by a b-quark, has been performed as a function of the transverse momentum p_T and pseudorapidity η , together with the correlations in azimuthal angle and the p_T -balance among the jets [4]. The variable ΔS is defined as the azimuthal angle between the light jet pair and the b-jet pair, where the direction of a jet pair is defined by the vector sum of their transverse momenta. The measured cross section as a function of ΔS is shown on Fig. 2 (right). None of the models describes the data well. Models underestimate the region at values of $\Delta S < 2$ and do not follow well the decreasing shape towards lower values. This study shows the need for MPI contributions in the simulation in order to describe correlation observables between jets. The sensitivity on DPS is investigated in events with the $\gamma + 3$ jets final state in pp collisions at $\sqrt{s} = 7$ TeV [5]. $\gamma + 3$ jets events are analyzed with the help of the azimuthal angular differences for the di-jet pair and the balance in transverse momentum of the photon-jet and di-jets pairs. The predictions of PYTHIA 8, MADGRAPH+PYTHIA 8 and SHERPA are compatible with the measured distribution. Switching off the MPI simulation for MADGRAPH+PYTHIA and SHERPA causes about 5 – 10% differences. The reason the MPI causes only small changes in ΔS is due to various background components which reduce the possible sensitivity for the DPS signal contribution.

The azimuthal angle decorrelations have also been studied [6] in events with jets most forward and backward

FIGURE 2. Left: Comparison of the particle density in the UE in the transverse region where the leading charged-particle jet available in the event at $\sqrt{s} = 0.9, 2.76$ and 7 TeV, as a function of p_T^{jet} . Right: Normalized cross sections unfolded to the stable particle level as a function of ΔS , compared to predictions of the various MC models. The lower panel shows the ratios of the predictions to the data. The yellow band represents the total uncertainty.

in rapidity (Mueller- Navalet, MN dijets), using 5 pb^{-1} of the 2010 data at $\sqrt{s} = 7$ TeV. Jets with $p_T > 35$ GeV and $|y| < 4.7$ were considered. The requirement of two jets with similar p_T suppresses contributions in the DGLAP scheme, which is based on p_T ordering. The BFKL equation predicts a strong rise of additional parton radiation with an increase of rapidity span of the event. Thus the study of azimuthal decorrelation of dijets as a function of rapidity separation may reveal effects beyond the DGLAP description. The azimuthal decorrelation angle measurements, $\Delta\phi_{dijet}$, its average cosines, $C_n = \langle \cos(n(\pi - \phi_{dijet})) \rangle$, and their ratios have been performed in bins of rapidity separation between the jets, Δy , reaching up to $\Delta y = 9.4$ for the first time. Fig. 3 (left) shows the normalized $\Delta\phi_{dijet}$ distribution for $3 < \Delta y < 6$, compared to various DGLAP based MC generators. The ratios of cosines are expected to be more sensitive to BFKL effects, because of cancellation of DGLAP contributions. The measured C_2/C_1 ratio is presented in Fig. 3 (right), showing that the NLL BFKL calculations describe the data well; the DGLAP based predictions are not able to describe the C_2/C_1 distribution.

FIGURE 3. Left: The azimuthal angle $\Delta\phi_{dijet}$ between MN jets in the rapidity interval. Right: The ratio of average cosines C_2/C_1 in bins of Δy .

The measurement of pseudorapidity distribution of charged hadrons is the first physics result obtained at the LHC in pp collisions at 13 TeV [7]. The data sample used for this analysis was obtained while the magnet was off. The yield of primary, charged long-lived hadrons produced in inelastic pp collisions was determined in the central region of the CMS pixel detector ($|\eta| < 2$) using both hit pairs and reconstructed tracks. Fig. 4 (left) shows the density distributions of charged hadrons in the region $|\eta| < 2$ for inelastic pp events. In the range $|\eta| < 0.5$ the charged-hadron multiplicity density is $dN_{ch}/d\eta = 5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$. The result is compared to predictions from MC event generators and to similar measurements performed at lower collision energies. The center-of-mass energy dependence of $dN_{ch}/d\eta$ is shown in Fig. 4 (right). The predictions of PYTHIA8 (tunes CUETP8S1 and CUETP8M1) [8] and EPOS LHC event generators are consistent with the measurement in the central region. However, EPOS LHC provides a better description for the measurements in the wider η range.

FIGURE 4. Left: Distributions of pseudorapidity density of charged hadrons in the region $|\eta| < 2$ in inelastic pp collisions at 13 TeV compared to PYTHIA8 CUETP8S1 and EPOS LHC. Right: Center-of-mass energy dependence of $dN_{ch}/d\eta$ including measurements at lower center-of-mass energy.

SUMMARY

LHC has completed Run I data taking period and opened a new era. Jets are the excellent tools to study QCD due to their large production cross sections at LHC. The CMS Collaboration has an active forward and small- x physics program. In the present talk, an extensive list of recent results concerning diffractive cross sections, four-jet cross sections, underlying event properties have been reviewed, together with the first physics results at the highest-ever LHC energy on charge particle pseudorapidity distributions.

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REFERENCES

- [1] S. Chatrchyan *et al.* [CMS Collaboration], JINST **3** S08004 (2008).
- [2] V. Khachatryan *et al.* [CMS Collaboration], Phys. Rev. D **92**, 012003 (2015).
- [3] V. Khachatryan *et al.* [CMS Collaboration], JHEP **1509**, 137 (2015).
- [4] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-FSQ-13-010, (2014).
- [5] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-FSQ-12-017, (2015).
- [6] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-FSQ-12-002, (2013).
- [7] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **751**, p.143-165 (2015).
- [8] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-GEN-14-001, (2014).