PROCEEDINGS OF SCIENCE

Nucleon Structure and Soft QCD from CMS

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Recent results on nucleon structure, and measurements of soft and small-x QCD and diffractive processes, performed with the CMS and TOTEM experiments, are presented. The results are compared to theoretical predictions, as implemented in various Monte Carlo simulations, as well as to other measurements. These studies are useful to test predictions based on perturbative and non-perturbative QCD techniques and provide valuable input for tuning of Monte Carlo event generators.

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1. Introduction

Soft Quantum Chromodynamics (QCD) physics is a domain of particle physics which is characterized by a low momentum transfer, typically a low transverse momentum, (p_T) . It is usually used to describe that part of the scattering which dominates at soft scales and where perturbative QCD cannot be applied. In this document, recent CMS [1] and TOTEM [2] measurements on the nucleon structure and soft QCD physics and their comparisons with various theoretical model predictions are presented.

2. DPS study using inclusive four jets process

Due to the complex structure of nucleons, it is possible to have more than one parton-parton interaction within the same proton-proton (pp) collision. Double parton scattering (DPS) corresponds to events where two hard parton-parton interactions occur in single pp collisions. A study of inclusive four-jet production in pp collisions at a center-of-mass energy of 13 TeV is presented [3]. Two phase space regions defined by selections on jet transverse momentum (p_T) are used. In region I, the four leading jets within pseudorapidity $|\eta| < 4.7$ are required to exceed p_T thresholds of 35, 30, 25, and 20 GeV. Asymmetric thresholds have been chosen over symmetric ones because the latter tend to dampen the DPS contribution with respect to the single parton scattering (SPS) fraction. The ΔS (azimuthal angle between the hardest and the softest jet pair) distribution is obtained for region II, with p_T thresholds of 50, 30, 30, and 30 GeV.

The ΔS distribution is less affected by different parton shower implementations. The DPS tune CDPSTP8S1-4j agrees very well with the shape, whereas all other models underestimate the data at low ΔS, indicating a possible need for more DPS contribution.

The DPS contribution is extracted by means of a template fit to the data, using distributions for SPS obtained from Monte Carlo event generators and a DPS distribution constructed from inclusive single-jet events in data. Figure 1 shows the results for σ_{eff} extracted with the models that are based on the recent CP5 and CH3 tunes and where the hard MPI have been removed. All results, except for the values obtained with the NLO $2 \to 2$ models, agree with the measurement performed by the ATLAS collaboration at a center-of-mass energy of 7 TeV, where a σ_{eff} equal to $14.9^{+1.2}_{-1.0}$(stat)$^{+5.1}_{-3.8}$(syst) mb was found, while none agree with the value of $21.3^{+1.2}_{-1.6}$ mb from the CMS measurement at a center-of-mass energy of 7 TeV, which is more in line with the results obtained with some of the models based on older underlying event (UE) tunes.

3. DPS study using inclusive Z+jets process

A first measurement is performed to explore observables sensitive to the presence of DPS using Z+jets process with the CMS detector at $\sqrt{s} = 13$ TeV, where the Z boson decays into two oppositely charged muons [4]. For the consistency with previous DPS measurements, jets are required to have a lower p_T threshold of 20 GeV.

The production cross sections in the fiducial region are measured to be 158.5 ± 0.3 (stat) ± 7.0 (syst) ± 1.2 (theo) ± 4.0 (lumi) pb for Z + $\geq$ 1 jet events and 44.8 ± 0.4 (stat) ± 3.7 (syst) ± 0.5 (theo) ± 1.1 (lumi) pb for Z + $\geq$ 2 jets events. The measured cross sections are described, within uncertainties, by various simulations except for the MG5_aMC + PYTHIA 8 (with DPS specific CDPSTP8S1-WJ tune). The cross section of the DPS-specific tune is predicted 10% higher than the measured cross section.

Figure 2 shows the differential cross section measurement as a function of $\Delta\phi$ between the Z boson and the leading jet. The Z+jets calculation of MG5_aMC + PYTHIA 8 without MPI is lower than the measurement by 50% at lower $\Delta\phi$ indicating sensitivity of this distribution to MPI. Different MC event generators describe, within uncertainties, the differential cross section as a function of $\Delta\phi$ except for the MG5_aMC + PYTHIA 8 predictions with the DPS-specific tune CDPSTP8S1-WJ, which shows a deviation up to 10–20%, but correctly describes the shape of the observable (not shown in Figure). The presented results will be a significant input to further improve the DPS-specific tunes and a global tune in combination with other soft QCD measurements in pp interactions at TeV scale.

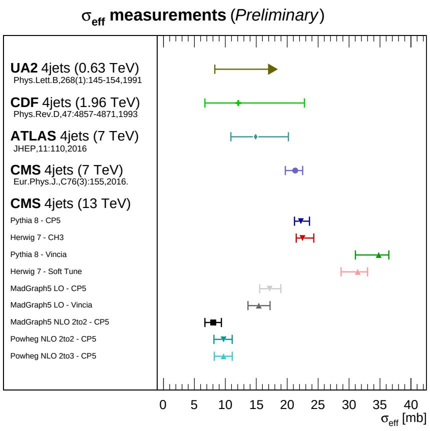

Figure 1: Comparison of the values for $\sigma_{\rm eff}$ extracted from data. The results from four-jet measurements performed at lower center-of-mass energies are shown alongside the newly extracted values [3].

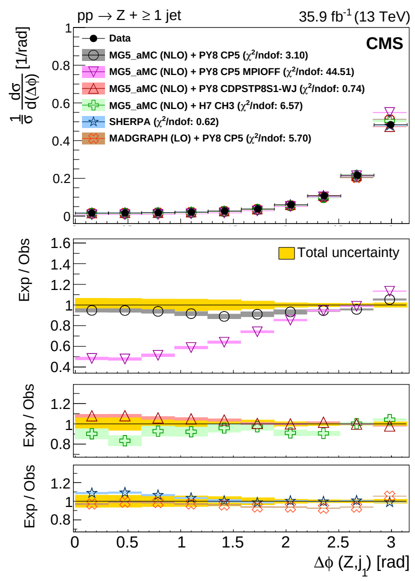

Figure 2: Differential cross sections as a functiona of $\Delta\phi$ between the Z boson and the leading jet for Z + $\geq$ 1 jet events. In the bottom panels, the total uncertainty for data is indicated by the solid yellow band centred at 1. [4].

4. Hard color singlet exchange in dijet events

One of the processes sensitive to Balitsky-Fadin-Kuraev-Lipatov (BFKL) dynamics [5] is the production of two jets separated by a large rapidity interval devoid of particle activity, known as Mueller-Tang jets [6] or jet-gap-jet events. The CMS detector with its unprecedented center-of-mass energy and large detector coverage in rapidity provides an ideal tool for testing BFKL dynamics and understanding the role of diffraction at large momentum transfers in strong nuclear interactions.

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The study [7] is performed with the low instantaneous luminosity data collected in pp collisions at $\sqrt{s}$ = 13 TeV by the CMS and TOTEM experiments. The fraction of jet-gap-jet events to events where the two jets have similar kinematics, f_{CSE}, is measured as a function of the η difference between the leading two jets, $\Delta\eta_{\mathrm{jj}}$, and the p_{T} of the sub-leading jet ($p_{\mathrm{T}}^{\mathrm{jet2}}$) (Figure 3). An increase with $\Delta\eta_{\mathrm{jj}}$ and a weak dependency on $p_{\mathrm{T}}^{\mathrm{jet2}}$ are observed. The present analysis sets a constraint on the theoretical treatment of rapidity gap survival probability.

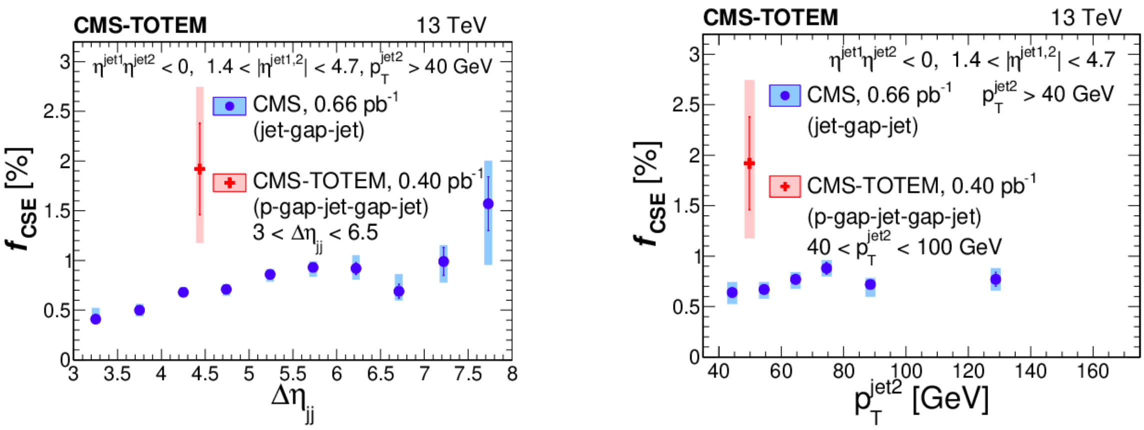

Figure 3: Gap fraction, f_{CSE}, measured as a function of $\Delta\eta_{\mathrm{jj}}$ and $p_{\mathrm{T}}^{\mathrm{jet2}}$ in inclusive dijet events and in dijet events with a leading proton [7].

5. Summary

An overview of soft QCD and diffractive measurements has been presented. CMS and TOTEM has a rich physics program which is a perfect testing ground for soft QCD models. A good modelling of soft QCD is crucial for many more complex analyses, e.g. precision measurements of the top quark mass. While the existing soft measurements already challenge the models, there are plenty of possibilities to guide theory with new measurements.

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