PROCEEDINGS OF SCIENCE

Double parton scattering studies in CMS

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Recent results of the study of double parton scattering with the CMS experiment using states with a Z boson and jets, and with four jets will be presented.

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1. Introduction

Events in which two hard parton-parton interactions occur within a single proton-proton (pp) collision are referred to as double-parton scattering (DPS). Under the assumption of transverse and longitudinal factorization of the two single parton interactions, the DPS cross section can be written as:

$$\sigma_{AB}^{DPS} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}} \tag{1}$$

where A and B denote the single parton scattering (SPS) processes, and σ_A and σ_A their respective SPS cross sections. The factor 'm' is unity if processes A and B are the same, and n = 2 if A ≠ B. The parameter σ_{eff} is related to the extent of the parton distribution in the plane orthogonal to the direction of motion of the protons. In this document, recent CMS [1] measurements on the study of DPS using states with a Z boson and jets, and with four jets 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. 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 ($\sqrt{s}$) of 13 TeV is presented [2]. 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 $2 \rightarrow 2$ models, agree with the measurement performed by the ATLAS collaboration at a $\sqrt{s}$ of 7 TeV, where a σ_{eff} equal to $14.9^{+1.2}_{-1.0}(\text{stat})^{+5.1}_{-3.8}(\text{syst})$ mb was found, while none agree with the value of $21.3^{+1.2}_{-1.6}$ mb from the CMS measurement at a $\sqrt{s}$ 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 the Z+jets process with the CMS detector at $\sqrt{s}$ = 13 TeV, where the Z boson decays into two

oppositely charged muons [3]. 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 + ≥ 1 jet events and 44.8 ± 0.4 (stat) ± 3.7 (syst) ± 0.5 (theo) ± 1.1 (lumi) pb for Z + ≥ 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 are 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.

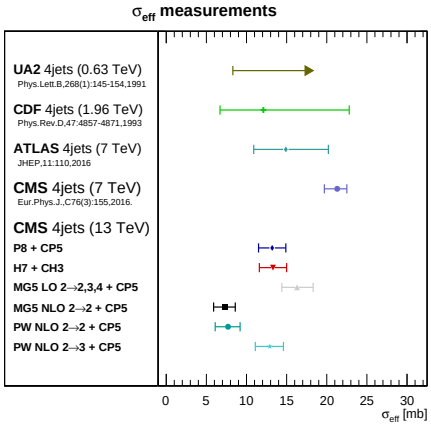

Figure 1: Comparison of the values for σ_{eff} extracted from data. The results from four-jet measurements performed at lower $\sqrt{s}$ are shown alongside the newly extracted values [2].

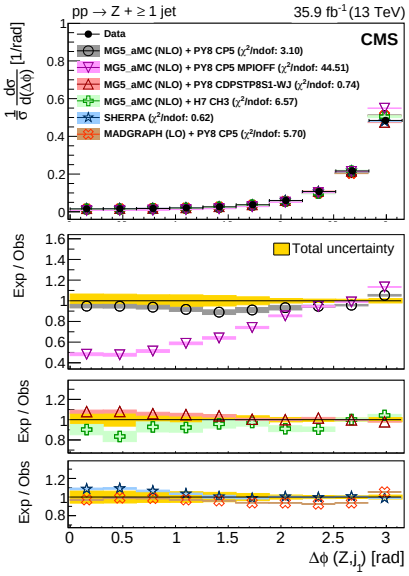

Figure 2: Differential cross sections as a functiona of $\Delta\phi$ between the Z boson and the leading jet for Z + ≥ 1 jet events. In the bottom panels, the total uncertainty for data is indicated by the solid yellow band centred at 1. [3].

4. Summary

An overview of recent DPS measurements performed at CMS has been presented. The DPS measurements with 4-jets and Z+jets processes demonstrate the need for further development of

models in few areas. Apart from theoretical work and the work related to the development of MC tunes, new phase-space regions or variables sensitive to DPS effects are being identified and explored and their study is being pursued with more data from the LHC.

References

[1] CMS Collaboration, "The CMS Experiment at the CERN LHC," JINST **3** (2008) S08004

[2] CMS Collaboration, "Study of double-parton scattering in the inclusive production of four jets with low transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV," arXiv:2109.13822 (submitted to JHEP).

[3] CMS Collaboration, "Measurements of Z bosons plus jets using variables sensitive to double parton scattering in pp collisions at 13 TeV," arXiv:2105.14511 (accepted by JHEP).

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