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Double Parton Scattering Studies at the Large Hadron Collider using the CMS detector

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Double Parton Scattering Studies at the Large Hadron Collider using the CMS detector

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Abstract. The high parton densities at the Large Hadron Collider lead to a probability of occurrence of two or more parton-parton scatterings within a hadron collision. The possibility of two hard parton-parton scatterings in a hadron collision is known as double parton scattering (DPS). The study of DPS processes, being performed using the various final states at different collision energies using the CMS detector at the Large Hadron Collider, has been presented. The DPS processes play an important role in hadron collisions as they act as a background to new physics searches. The study of DPS processes provides information on the parton-parton correlations and parton distributions in a hadron.

Keywords: QCD, Hadron Physics, parton distribution

1 Introduction

The hard scattering between the partons from the colliding hadrons is characterized by the presence of a particle or a cluster of particles with large mass or large transverse momentum (p_T). At high energy collisions, the parton densities are large enough to cause a significant probability for two or more parton-parton scatterings within the same hadron-hadron collision, known as multiple parton interactions (MPI). Exactly two hard parton-parton scatterings in a proton-proton (pp) collision leads to DPS, a subset of MPI.

A number of DPS measurements are performed using events from pp and $p\bar{p}$ collisions in different final states and at different centre-of-mass energies, e.g., measurements with multi-jet final-states at $\sqrt{s} = 63$ GeV, 630 GeV, 1.8 TeV and 7 TeV [1–4]; in $\gamma + 3$ jets events at $\sqrt{s} = 1.8$ TeV, 1.96 TeV and 7 TeV [5–7]; in W production associated with jets at $\sqrt{s} = 7$ TeV [8, 9]; in same-sign WW events at $\sqrt{s} = 8$ TeV [10] are available.

The effective cross section (σ_{eff}) for a hadron-hadron collision is defined as the measure of the transverse distribution of partons inside the colliding hadrons and their overlap in a collision. This paper presents the measurement of σ_{eff} using the study of double parton scatterings being done with data collected by the

CMS detector [12] using the $W + 2\text{-jet}$ process at $\sqrt{s} = 7$ TeV, and same-sign WW process at $\sqrt{s} = 8$ TeV.

2 DPS using same-sign W boson pairs

A useful feature of same-sign W boson pair production is the cross section, which is comparable for DPS and SPS, whereas in opposite-sign W pair production the cross section for SPS events dominates over the DPS one by a bigger factor. This analysis studied DPS events with two same sign muons and two respectively associated neutrinos in the final state at 8 TeV [10]. The data sample corresponds to an integrated luminosity of 19.7 fb^{-1} . In case of DPS the two W bosons are produced in first approximation independent of each other, and they are expected to be randomly distributed in the azimuthal plane and with less p_T as compared to SPS production. Hence, the muons produced from DPS are less boosted as compared to the leptons produced from SPS and there would not be any correlation between the two muons in the azimuthal plane. After several control and validation studies, a Multi-Variate Analysis (MVA) using a Boosted Decision Tree (BDT) has been performed in order to improve sensitivity to DPS events with respect to a single observable study. The idea is to use the BDT estimator to get a response shape with the highest possible DPS sensitivity; therefore many sensitive kinematic observables have been put into the BDT training process. The BDT response is studied on top of the same-sign offline base selection and results.

The upper limit on the WW production cross section by DPS is observed to be 1.12 pb, which is calculated using the ratio of the measured DPS yield with respect to the yield expected from Monte Carlo (computed using CLs method based on modified frequentist approach). The lower limit on σ_{eff} is calculated to be 5.91 mb, which is consistent with the previous measurements.

3 DPS using W + 2-jet events

The study of DPS using $W + 2\text{-jet}$ events at a centre-of-mass energy of 7 TeV, collected by the CMS detector in 2011, has also been performed [9]. The data sample corresponds to an integrated luminosity of 5 fb^{-1} . Events with a W boson, reconstructed from the muon and missing transverse energy information, are required to have exactly two jets. The determination of the effective cross section (σ_{eff}) requires the measurement of the fraction of DPS events in the selected sample of $W + 2\text{-jet}$ events (f_{DPS}). For the measurement of f_{DPS} the correlation observables, sensitive to DPS, are investigated. It is observed that the simulations of $W + \text{jets}$ events with MADGRAPH5 + PYTHIA8 (or PYTHIA6) and NLO predictions of POWHEG2 + PYTHIA6 (or HERWIG6) provide a good description of the observables, and describe the data only if multiple parton interactions are included. The standalone PYTHIA8, due to missing higher order processes, is not able to provide a good description of the selected data events.

The fraction of DPS in selected $W + 2$ -jet events is extracted using DPS signal, and single parton scattering (SPS) background templates produced by simulations. The obtained value of the DPS fraction is 0.055 ± 0.002 (stat.) ± 0.014 (syst.). The σ_{eff} is calculated to be 20.7 ± 0.8 (stat.) ± 6.6 (syst.) mb. This measured value of σ_{eff} is also found to be consistent with the PYTHIA8 model predictions.

4 Conclusions

A firm decision of the invariance of the effective cross section with respect to centre-of-mass energy can not be drawn due to large systematic uncertainties. The low sensitivity of the correlation observables, used to extract the fraction of DPS in the selected sample, is one of the reason behind the large systematic uncertainties. Therefore, it is required to look for new channels as well as new observables with enhanced sensitivity to DPS [11]. For the proper understanding of invariance of the effective cross section, it is required to perform the measurement with same final state at different centre-of-mass energies. The ongoing LHC run at a center-of-mass energy of 13 TeV will be important for the study of invariance of the effective cross section.

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