

Chapter 2

Double Parton Scattering Studies via Di-boson Processes Using the CMS Detector at LHC

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2.1 Introduction

In high energy proton-proton (pp) collisions at LHC, due to the composite nature of protons, it is possible to have two or more distinct hard parton-parton interactions occurring simultaneously in a single pp collision. At fixed final state invariant masses, such cross sections tend to increase with collision energy because partons with successively lower momentum fraction x and rapidly varying flux, are being probed [1]. Multiple soft parton-parton collisions are called multiple parton interactions (MPI), while those in which only a single pair of partons produce a hard scattering are referred as single parton scattering (SPS) [2]. Large hadronic activity is observed in the soft regime, characterized by small transverse momenta (p_T) of the produced particles. For relatively large p_T values, the observation of MPI will mostly focus on two simultaneous scatterings, i.e. on double parton scattering (DPS) [3–5].

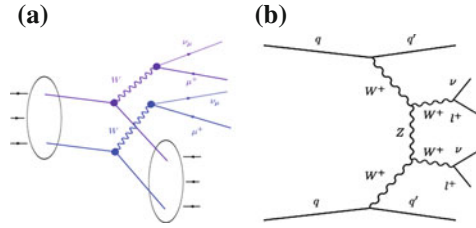
In this paper, we present a study of double parton scattering in same-sign W pair production in pp collisions at $\sqrt{s} = 8$ TeV with the CMS detector, with fully leptonic final state. Our signal events consists of two same-sign electrons plus large missing transverse energy (E_T^{miss}). Two separate hard scatterings during a single pp collision produce two W bosons, which further decay to two electrons and two neutrinos as shown in Fig. 2.1.

This study was conducted on behalf of CMS Collaboration

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Fig. 2.1 Typical diagrams for production of same-sign WW events from **a** double parton scattering (DPS) and **b** single parton scattering (SPS)



2.2 Effective Cross Section

The cross section for a DPS process involving A and B can be written as:

$$\sigma(A+B) = \frac{m * \sigma(A) * \sigma(B)}{\sigma_{\text{eff}}},$$

where $\sigma(A)$ and $\sigma(B)$ are cross sections for processes “A” and “B” respectively and “m” is the symmetry factor, $m = \frac{1}{2}$, for identical processes otherwise unity. Given that one hard scattering occurs, the probability of the other hard scattering is proportional to the flux of accompanying partons; these are confined to the colliding protons, and therefore their flux should be inversely proportional to the transverse area (cross section) of a proton. Various measurements in pp and p \bar{p} collisions at $\sqrt{s} = 63$ GeV [6], 630 GeV [7], and 1.8 TeV [8] are consistent with a DPS contributions to multijet final states, as well as to $\gamma + 3$ -jet events at $\sqrt{s} = 1.8$ TeV [9] and 1.96 TeV [10]. Recently, the ATLAS and CMS Collaborations have carried out the DPS measurements using W + 2-jet events at $\sqrt{s} = 7$ TeV [11, 12]. From the available measurements, a firm conclusion on the energy dependence of σ_{eff} cannot be drawn due to the large systematics associated to the model dependence [13].

DPS also constitutes a background to new physics searches [14–16] and to any high-precision measurement of standard model processes, as it cannot be unambiguously separated from single hard scattering contribution. It is therefore mandatory to provide a measurement as much model independent as possible, to constraint σ_{eff} in the view of the incoming LHC run at 13 TeV.

2.3 Signal and Background Processes

A useful feature of the same-sign W boson pair production is the cross section, which is 10^{-4} nb, comparable for DPS and SPS, whereas opposite-sign WW production cross section for SPS events dominates over the DPS ones by a factor of 10^2 . In addition, same-sign SPS events are produced with additional jets, a clear topological discrimination between the two mechanisms [3]. Major sources of background (in addition to the irreducible WW production from SPS) are expected from:

- WZ, ZZ and $W\gamma^*$: Their cross section is higher than the DPS cross section by a factor of 10^2 , their contribution has to be controlled.
- W + jets, $t\bar{t}$ + jets, Drell-Yan and QCD Multijets: These backgrounds originate due to misidentified electrons from other final states in the detector. These background have a very large cross section as compared to DPS processes (upto a factor of 10^5).

2.4 Investigation of DPS Sensitive Variables at Generator Level

Generator level studies are performed to investigate kinematic variables, that could help us to discriminate our signal from background processes. These studies are performed by selecting only those events having two same-sign W bosons, decaying to two same sign electrons. For same-sign W pair production from DPS, the two W bosons are produced in first approximation independent of each other, and are expected to be randomly distributed in the azimuthal plane and they present, as general features, less transverse momentum (p_T) as compared to SPS production. The electrons produced from DPS are less boosted as compared to the electrons produced from SPS and there would not be any correlation between the two electrons in the azimuthal plane (Fig. 2.2). The final state electrons can be studied using several observables. The scalar sum of transverse momentum of two electrons and their p_T can be used for the discrimination purpose. For the same reason the azimuthal separations between the electron direction and E_T^{miss} have been studied as well. The invariant transverse mass of an electron and E_T^{miss} and the invariant transverse mass of two lepton system are studied since they are sensitive to energy imbalance in the two W boson system (Figs. 2.3 and 2.4).

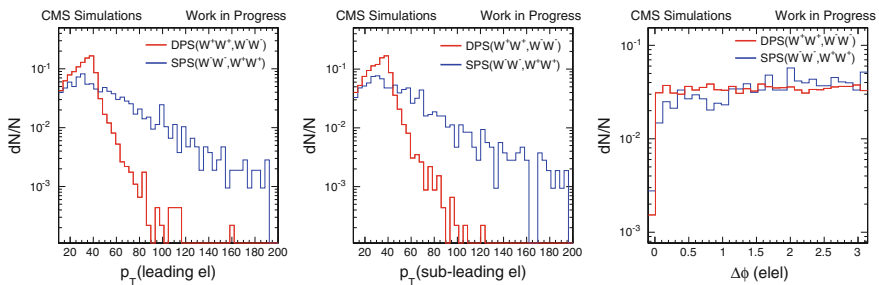


Fig. 2.2 p_T distributions at generator level for electrons in SPS and DPS processes (leading, sub-leading electron), transverse angular separation between the two same sign electrons respectively

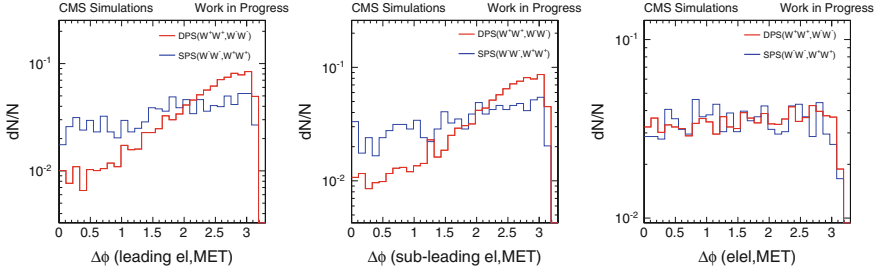


Fig. 2.3 Distributions showing azimuthal separation between E_T^{miss} and leading electron; sub-leading electron and E_T^{miss} ; azimuthal separation between two electrons respectively for DPS and SPS events

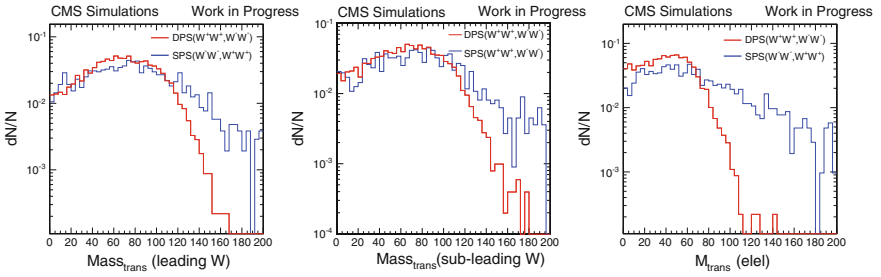


Fig. 2.4 Distributions showing transverse invariant mass of E_T^{miss} and leading electron; E_T^{miss} and sub-leading electron; two electrons invariant transverse mass for DPS and SPS events

2.5 Summary

Generator level studies are performed for DPS and SPS MC samples. DPS sensitive observables are being investigated, which could discriminate DPS from other background processes. All the variables reported are expected to show good discrimination of DPS events from other background processes. Detector level studies for DPS studies in di-electron, di-muon and electron-muon final state are going on. We will further investigate DPS sensitive observables at detector level to extract σ_{eff} .

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