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Measurement of the double parton scattering in W + 2 jets production at $\sqrt{s}$ = 7 TeV with the ATLAS detector

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Abstract. The presence of the double parton scattering in proton-proton collisions at $\sqrt{s}$ = 7 TeV has been measured by the ATLAS detector at the LHC. The analyzed dataset corresponds to an integrated luminosity of 36 pb^{-1}. The process under study is the production of a W boson in association with exactly two jets. W boson decays in either the electron or muon channel. The fraction of double parton scattering events was found to be 0.08±0.01(stat.)±0.02(syst.) for jets with transverse momentum p_T > 20 GeV and rapidity $|y|$ < 2.8. The double parton scattering scaling factor σ_{eff} was evaluated to 15±3(stat.)$^{+5}_{-3}$(syst.) mb.

1 Introduction

The Double Parton Interaction (DPI) is a special process occurring in hadron-hadron collisions, in which two partons from one hadron interacts independently with partons from the other hadron. The high-energy proton-proton collisions at the LHC allow a study of these processes at much higher rate than ever before and especially at higher transverse momenta of the detected particles. Previous experiments investigated DPI contributions to 4-jet [1–3] or γ + 3-jet [4–6] final states. The ATLAS collaboration has investigated the production of W bosons in association with exactly two jets [7], where the W boson decaying in the electron or muon channel is assumed to be produced in a completely independent parton interaction than the two jets. For this case, the inclusive cross section can be written using full factorization of double parton distribution functions as

$$\sigma^{\text{DPI}}_{W+2\text{j}} = \frac{\sigma_{W+0\text{j}}\sigma_{2\text{j}}}{\sigma_{\text{eff}}}. \tag{1}$$

The denominator, σ_{eff}, has the meaning of an effective area which scales the probability of the occurrence of the secondary hard scatter given the primary one. Since the measured values of σ_{eff} lie between 5 and 20 mb, i.e. much below the geometric transverse area of the proton or inelastic cross section, a proton is mostly modeled having a smaller hard core surrounded by softer partons.

This paper presents a brief description of the σ_{eff} measurement using the ATLAS detector [8]. The analysis used the entire 2010 ATLAS data corresponding to an integrated luminosity of about 36 pb^{-1}. Events were selected if they contained exactly one isolated lepton, an electron (e) or a muon (μ), and two anti-k_t jets (j_1,j_2) with R = 0.4. In addition, a set of further requirements had to be fulfilled to accept an event to the W + 2-jet data sample:

$$\begin{aligned} p_T^e &> 20 \text{ GeV} \quad , \quad |\eta^e| < 2.47, \\ p_T^\mu &> 20 \text{ GeV} \quad , \quad |\eta^\mu| < 2.4, \\ p_T^{\text{j}_1,\text{j}_2} &> 20 \text{ GeV} \quad , \quad |y^{\text{j}_1,\text{j}_2}| < 2.8, \\ \text{E}_T^{\text{miss}} &> 25 \text{ GeV} \quad , \quad \text{m}_T^W > 40 \text{ GeV}, \end{aligned}$$

where m_T is the transverse mass of the W boson reconstructed from the charged-lepton transverse momentum (p_T) and missing transverse energy in the detector (E_T^{miss}). The restrictions of the lepton pseudorapidity (η) and jet rapidity (y) ranges are given by the detector design.

2 Strategy of the analysis

The method of the evaluation of σ_{eff} is very straightforward. First, one can replace each term for cross section in Eq. (1) by the ratio of number of appropriate events and the accelerator- and detector-related parameters of type

$$\sigma = \frac{N}{\mathcal{A}C\epsilon\mathcal{L}}. \tag{2}$$

Parameter $\mathcal{A}$ represents the geometrical acceptance of the detector, C denotes the correction for unfolding to the particle level including reconstruction effects, ϵ is the trigger efficiency and $\mathcal{L}$ stands for the integrated luminosity. Second, the unknown number of DPI events in the total W + 2-jet data sample is expressed as

$$N^{\text{DPI}} = f_{\text{DP}}N^{\text{tot}}. \tag{3}$$

Since the most of the parameters cancel in the ratio and $\epsilon_{2\text{j}} = 1$, the final formula

$$\sigma_{\text{eff}} = \frac{1}{f_{\text{DP}}} \frac{N_{W+0\text{j}}}{N^{\text{tot}}_{W+2\text{j}}} \frac{N_{2\text{j}}}{\mathcal{L}_{2\text{j}}} \tag{4}$$

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contains only a single parameter requiring further analysis, the fraction of DPI events f_{DP}. In order to obtain the luminosity and the event numbers, appropriate event selections have been prepared for the W + 2-jet, W + 0-jet and 2-jet final states. One should note that W events were required to contain exactly one reconstructed primary vertex and the di-jet data sample corresponded only to the early low-luminosity 2010 ATLAS data. The aim was to avoid the dependence of the σ_{eff} measurement on pile-up collisions. On the other hand, the entire 2010 ATLAS data set was used for the extraction of f_{DP} and thus it has to accommodate a further correction for pile-up estimated using Monte Carlo simulations.

3 f_{DP} extraction

Firstly, all the physics processes contributing to the W + 2-jet production have to be taken into consideration. Using Monte Carlo simulations, we have found that the main component of the data sample was created in an inclusive single parton interaction (SPI) producing W boson and two additional jets. This process may proceed either as an exclusive SPI process, where the two jets are directly related to the primary scatter, or as an exclusive DPI process described in the introduction. All the other mechanisms producing an isolated lepton and two jets are taken as an unwanted background and their estimated contributions are subtracted from the ATLAS data. Therefore, the term $N^{\mathrm{tot}}_{W+2\mathrm{j}}$ corresponds only to the inclusive SPI W + 2-jet production.

Second, the event topology has to be investigated in order to distinguish the exclusive SPI and exclusive DPI events. At the Monte Carlo level, there are several kinematic variables whose distributions slightly differ for these two types of events. These are transverse momentum of W boson or leading jet, missing transverse energy in the event, and the azimuthal angle between the two jets. However, all these variables can not be reconstructed at the detector level with the desired accuracy. The most suitable quantity is the normalized jet pair transverse momentum imbalance defined as

$$\Delta^{\mathrm{n}}_{\mathrm{jets}} = \frac{|\vec{p}^{\,\mathrm{j}_1}_{\mathrm{T}} + \vec{p}^{\,\mathrm{j}_2}_{\mathrm{T}}|}{|\vec{p}^{\,\mathrm{j}_1}_{\mathrm{T}}| + |\vec{p}^{\,\mathrm{j}_2}_{\mathrm{T}}|}. \quad (5)$$

The distribution of $\Delta^{\mathrm{n}}_{\mathrm{jets}}$ for the ATLAS data normalized to unity is compared to the normalized template distributions, which model the shape of the $\Delta^{\mathrm{n}}_{\mathrm{jets}}$ distributions for exclusive SPI (template A) and exclusive DPI events (template B). The aim of the comparison is to find the best linear combination of these two templates in the form of (1-f_{DP}) A + f_{DP} B, which fits the ATLAS data for the minimal χ^2.

Since the DPI process composes of two independent parton processes, W + 0-jet and di-jet productions, and the studied variable $\Delta^{\mathrm{n}}_{\mathrm{jets}}$ depends only on the two jets, the modeling of exclusive DPI events was done simply by taking the exclusive di-jet ATLAS data (for the entire year of 2010). Two jets coming from the same interaction of type QCD 2→2 tend to be back-to-back oriented and balanced in their p_{T}. Therefore, the domain of the DPI events is the low $\Delta^{\mathrm{n}}_{\mathrm{jets}}$ region.

On the other hand, the exclusive SPI events tend to contain jets much closer to each other. One can observe a sharp peak of number of events in the $\Delta^{\mathrm{n}}_{\mathrm{jets}}$ distribution for $\Delta^{\mathrm{n}}_{\mathrm{jets}} \to 1$. The modeling of exclusive SPI events was done using Monte Carlo simulations. In the context of this analysis, the exclusive SPI events are allowed to contain additional parton interactions, which do not produce partons with transverse momentum larger than maximal cut $p^{\mathrm{max}}_{\mathrm{T}}$. Thus, the measurable jets are supposed to be initiated by partons coming from the primary interaction.

The combination of programs Alpgen [9], Herwig v6.510 [10] and Jimmy v 4.31 [11] (A+H+J) was used for the main modeling of exclusive SPI events, where the parton-level cut was set to

$$p^{\mathrm{max}}_{\mathrm{T}} = 15 \text{ GeV}. \quad (6)$$

A theoretical uncertainty of the f_{DP} parameter was obtained partially by varying the $p^{\mathrm{max}}_{\mathrm{T}}$ cut between 10 and 17.5 GeV. Figure 1 shows the wide range of $p^{\mathrm{max}}_{\mathrm{T}}$ tested for the fitting procedure, using Monte Carlo (MC) inclusive SPI events, in order to optimize this cut with respect to the true value of $f^{\mathrm{P}}_{\mathrm{DP}}$ counted from generator record at parton level. One can see that the cut $p^{\mathrm{max}}_{\mathrm{T}}$ = 15 GeV corresponds to value of $f^{\mathrm{MC}}_{\mathrm{DP}}$ closest to the parton-level $f^{\mathrm{P}}_{\mathrm{DP}}$.

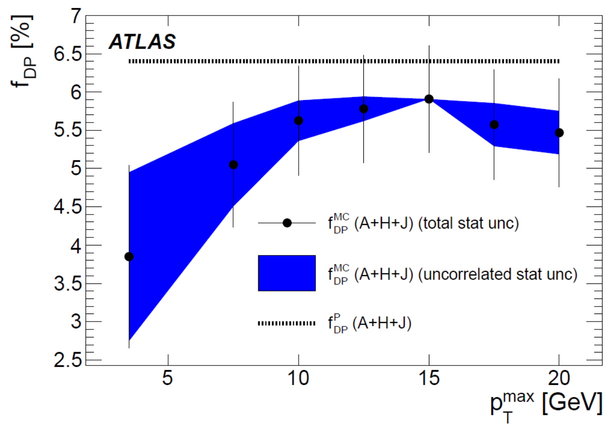

Figure 1. Values of the f_{DP} fraction obtained by fitting of the Monte Carlo simulated data as a function of the transverse momentum cut applied on the scattered partons coming from QCD interactions additional to the primary W boson production [7]. The blue band illustrates the statistical uncertainties related to the one for the reference sample for $p^{\mathrm{max}}_{\mathrm{T}}$ = 15 GeV.

In addition, an alternative modeling of exclusive SPI events was done using Sherpa generator v1.31 [12], where the generation of additional hard parton interactions was completely switched off. The comparison of the results for the fit using Sherpa and A+H+J events served for the evaluation of the other part of the theoretical uncertainty.

4 Result

Figure 2 shows the result of the best linear combination of the two templates fitted to the ATLAS data. One can clearly see the shapes of the two templates and their region of domain. Despite the contribution of template B is not large, the template A alone would not fit the data well.

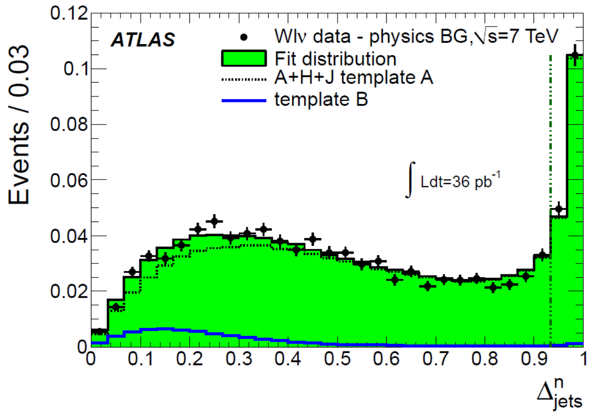

Figure 2. Distributions of Δ^{n}_{jets} for the background-subtracted ATLAS data and the result of the best combination of templates A (SPI-like events) and B (DPI-like events) [7]. Both, data and fit distributions, were normalized to unity. Two right-most bins were excluded from the fit due to the high collinearity of the two jets.

Since both ATLAS and A+H+J simulated events may contain an arbitrary number of primary vertices, a correction for the effect of pile-up collisions had to be added to the final result. This correction was estimated using Monte Carlo simulations and its statistical uncertainty was included into both statistical and systematic uncertainties of the f_{DP} factor. The fraction of DPI events in the total W + 2-jet data sample was found to be

$$f_{\text{DP}} = 0.076 \pm 0.013(\text{stat.}) \pm 0.018(\text{syst.}). \qquad (7)$$

Besides the theoretical uncertainty described above, the systematic uncertainty reflects also the experimental uncertainties in the jet energy scale and resolution, physics background modeling and lepton response. Since σ_{eff} is a quantity primarily defined at parton level, the fitting procedure was repeated also for A+H+J simulated events containing one primary vertex. The result for $f^{\text{MC}}_{\text{DP}}$ was compared to the parton level one, f^{P}_{DP}, obtained directly from generator record. It was concluded that the results for f_{DP} at detector and parton level should differ at most by 10% from each other. The fraction of DPI events was also obtained via the fitting procedure using the unfolded ATLAS data. This hadron level f_{DP} was also found within 10% from the detector level value.

In order to evaluate σ_{eff} using Eq. (4), the number of low-luminosity di-jet events had to be multiplied by a correction factor. The W + 2-jet event selection includes the jet-lepton isolation condition removing jets from the analysis and thus the number of simple di-jet events should be smaller. Monte Carlo-based analysis estimated this suppression factor to be 0.96 with almost negligible uncertainty. The number of di-jet events in the low-luminosity data sub-sample was taken to be $N_{2\text{j}} = 9488$ corresponding to the integrated luminosity of 184 μb^{-1}. The systematic uncertainty of the luminosity measurement was around 3%. The ratio $N_{W+0\text{j}}/N_{W+0\text{j}} = 23$ was determined with an uncertainty of around 5% due to the lepton response and background modeling uncertainties. These numbers lead to the result for the DPI effective cross section

$$\sigma_{\text{eff}} = 15 \pm 3(\text{stat.})^{+5}_{-3}(\text{syst.})\ \text{mb} \qquad (8)$$

for proton-proton collisions at $\sqrt{s} = 7$ TeV. This value is consistent with results from previous measurements at CERN and Fermilab.

5 Summary

These proceedings summarize the ATLAS measurement of double parton interactions contributing to the production of exactly two jets in association with W boson in proton-proton collisions at a center-of-mass energy $\sqrt{s} =$ 7 TeV. The entire 2010 ATLAS data corresponding to an integrated luminosity of 36 pb^{-1} was used. The fraction of DPI events within the background-subtracted data set was found to be around 8% using the normalized jet-pair transverse momentum imbalance distribution, which is sensitive to the event topologies typical for single and double parton scattering. Even though the value of the DPI event fraction depends on the choice of the studied phase space, the final result for σ_{eff} is assumed to be both process and kinematic region independent. The central value of σ_{eff} was measured to be 15 mb, which corresponds to the previous experiments very well.

References

[1] T. Akesson *et al.* [AFS Collaboration], Z. Phys. C **34** (1987) 163.

[2] J. Alitti *et al.* [UA2 Collaboration], Phys. Lett. B **268** (1991) 145.

[3] F. Abe *et al.* [CDF Collaboration], Phys. Rev. D **47** (1993) 4857.

[4] F. Abe *et al.* [CDF Collaboration], Phys. Rev. D **56** (1997) 3811.

[5] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **81** (2010) 052012.

[6] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **83** (2011) 052008.

[7] ATLAS Collaboration, New J. Phys. **15** (2013) 033038.

[8] ATLAS Collaboration, JINST **3** (2008) S08003.

[9] M. L. Mangano *et al.*, JHEP **0307** (2003) 001.

[10] G. Corcella *et al.*, JHEP **0101** (2001) 010.

[11] J. M. Butterworth *et al.*, Z. Phys. C **72** (1996) 637.

[12] T. Gleisberg *et al.*, JHEP **0902** (2009) 007.