PROCEEDINGS OF SCIENCE

Measurements of the production of jets in association with a W or Z boson with the ATLAS detector

Marisa Sandhoff*
on behalf of the ATLAS Collaboration
Bergische Universitaet Wuppertal
E-mail: sandhoff@physik.uni-wuppertal.de

The production of jets in association with vector bosons is an important process to study QCD in a multi-scale environment at the LHC. The ATLAS collaboration has performed a first measurement of Z+jets cross sections in 85 pb^{-1} of proton – proton collision data taken in 2015 at centre-of-mass energies of 13 TeV. In data corresponding to 4.6 fb^{-1} at a centre-of-mass energy of 7 TeV, the collaboration has measured the production of W+jets events and the cross section ratio of W+jets and Z+jets events. The measurements are compared to state-of-the-art QCD calculations and Monte Carlo simulations.

XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects
11-15 April, 2016
DESY Hamburg, Germany

*Speaker.

PoS(DIS2016)123

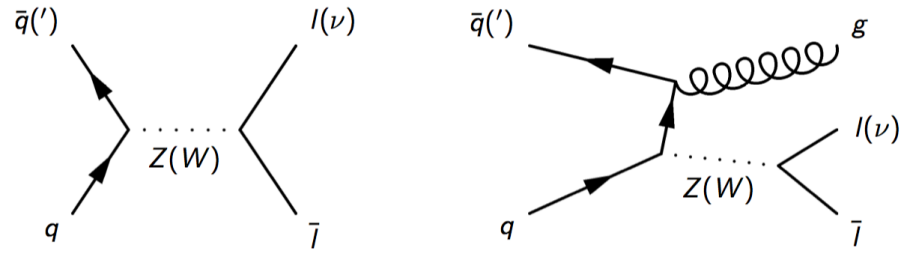

Figure 1: Feynman diagrams for W+jets and Z+jets production. These diagrams are shown as an example for Feynman diagrams, which are valid for both W+jets and Z+jets production.

Introduction

The production of the weak vector bosons $W^{\pm}$ and Z in association with jets is an important standard candle at hadron colliders for studying quantum chromodynamic (QCD) and electroweak (EWK) processes. The leptonic final states with one (for $W^{\pm}$) or two (for Z) isolated charged leptons with high transverse momentum, p_{T}, offer a clean experimental signature where the production of the vector bosons themselves defines a clear energy scale.

In addition, W/Z+jets events are important background processes, for example to Higgs boson studies, top-quark physics and searches for new phenomena. Therefore, a good knowledge of these events is crucial.

Another aspect in studying W+jets and Z+jets events is the fact that events of both types are very similar. Most Feynman diagrams occur in both, W+jets and Z+jets production, thus in first approximation the event properties are expected to be the same. Fig. 1 shows as an example two Feynman diagrams, which are valid for both W+jets and Z+jets production.

There are only small known differences: the mass of the W boson is smaller than the mass of the Z boson, a different coupling (pure V-A for the W boson, a combination of V-A and V+A for the Z boson) and the initial-state quarks in the hard-scattering process need to be different. But the jet production associated to the boson production is identical. As a consequence, by studying the ratio of W+jets and Z+jets events, most systematic uncertainties cancel out, such as the uncertainty on the jet energy scale or the modelling of the hadronization. Thereby more precise tests of pertubative QCD are possible.

ATLAS [1] has measured the production of Z+jets events [2] at a centre-of-mass energy of 13 TeV based on a dataset recorded between June 13th and July 16th 2015, corresponding to an integrated luminosity of 85 pb^{-1}. The production cross section of W+jets events [3] and the ratio of cross sections of W+jets and Z+jets events [4] was measured at a centre-of-mass energy of 7 TeV using the entire 2011 dataset delivered by the LHC, which corresponds to an integrated luminosity of 4.6 fb^{-1}.

The event selection was chosen according to the expected event signatures and is summarized in Table 1.

Applying the in Table 1 mentioned W+jets and Z+jets event selections to the dataset, data distributions at reconstruction level are obtained. In order to compare the results to theoretical predictions at particle level, the expected background event yields have to be subtracted and then

W selection	Z selection	jet selection
one lepton (e or μ) $p_{\mathrm{T}}^{\mathrm{l}} > 25$ GeV $\lvert\eta^{\mathrm{l}}\rvert < 2.4$ for e (2.47 for μ)	two leptons (e or μ) $p_{\mathrm{T}}^{\mathrm{l}} > 25$ GeV same flavour oppositely charged $\lvert\eta^{\mathrm{l}}\rvert < 2.4$ for e (2.47 for μ)	Anti-kt jet algorithm, R=0.4 $p_{\mathrm{T}}^{\mathrm{jet}} > 30$ GeV $\lvert\eta^{\mathrm{jet}}\rvert < 4.4$ ($\lvert\eta^{\mathrm{jet}}\rvert < 2.5$ for Z+jets@13TeV)
$E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV $m_{\mathrm{T}} > 40$ GeV	66 GeV $< m_{\mathrm{ll}} <$ 116 GeV $\Delta R_{\mathrm{ll}} > 0.2$	
		overlap removal: ΔR(lepton, jet) < 0.5

Table 1: Kinematic event selection criteria for W $\rightarrow$ lν + jets and Z $\rightarrow$ ll + jets events.

the data distributions are corrected for the detector effects. The correction is implemented by using the iterative Bayesian method of unfolding as introduced in Ref. [5]. Afterwards, electron and muon channels are combined using the procedure described in Refs. [6,7]. At the end, these results are compared to theoretical predictions.

1. Z+jets production at $\sqrt{s} = 13\,\mathbf{TeV}$

In 2015, Run2 of the LHC was launched after the first long shutdown. One of the first measurements was the cross section of Z+jets events. The left side of Fig. 2 shows the detector-level results of the inclusive jet-multiplicity distribution for Z$\rightarrow$e$^+$e$^-$ events. A clean signal selection and a good agreement of data and simulation is observed. The result at particle level after applying correction factors is shown on the right side of Fig. 2. The measurement already reaches a precision of 20 % for events with four additional jets. Both, Sherpa 2.1 [8, 9] and Madgraph [10] describe the data well.

2. W+jets production at $\sqrt{s} = 7\,\mathbf{TeV}$

Figure 3 shows the cross section measurement results of W $\rightarrow$ lν events at a centre-of-mass energy of 7 TeV at particle level as a function of the inclusive jet multiplicity. On the left side the distribution itself is presented, on the right side the ratios of the various predictions to the data are shown. A good agreement for all jet multiplicities is observed for BLACKHAT+SHERPA [11–13]. Both ALPGEN [14] and SHERPA 1.4 show a good agreement for jet multiplicities of up to four jets. For five and more jets ALPGEN underestimates the data, SHERPA overestimates them. MEPS@NLO [8, 9] and HEJ [15, 16] reveal a comparable level of agreement like BLACKHAT+SHERPA.

3. The ratio W+jets and Z+jets production at $\sqrt{s} = 7\,\mathbf{TeV}$

In Fig. 4 the cross-section ratio of W+jets and Z+jets events as a function of the leading jet p_{T} is shown for events with at least one jet (left), at least two jets (center) and at least three jets

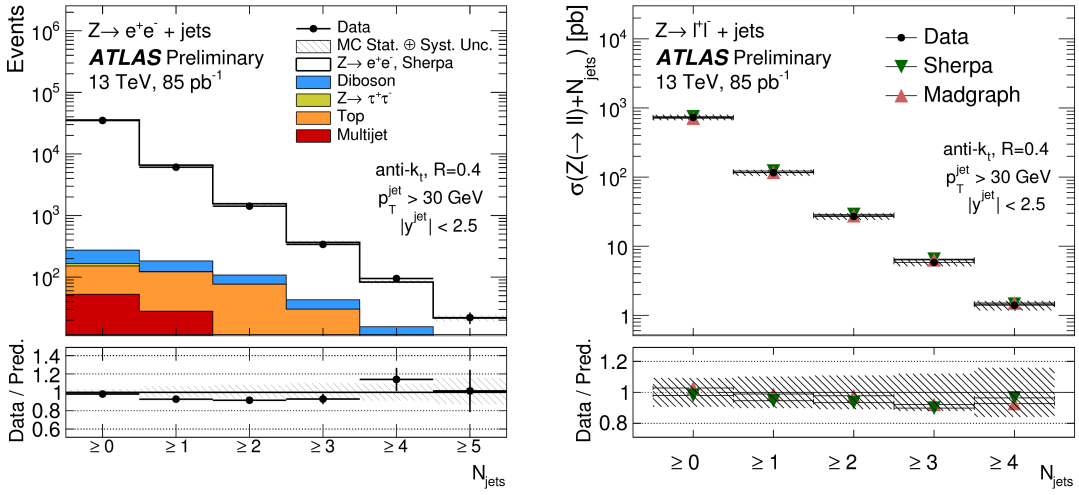

Figure 2: Left side: Inclusive jet multiplicity in the Z→ e$^+$e + jets selection. Systematic uncertainties for the signal and background distributions are combined in the shaded band, and the statistical uncertainty is shown on the data points. Luminosity and theoretical uncertainties are not included. Right side: Combined Z→l$^+$l$^-$ plus ≥N jets fiducial cross sections. Results are reported at the Born level and compared to predictions from Sherpa and MadGraph. The hatched error band corresponds to the total uncertainty of the results: systematic, statistical, and luminosity uncertainties for the fiducial cross section results [2].

(right). The ratio is calculated after applying all corrections, but before estimating the systematic uncertainties. Thus, the calculation of the systematic uncertainties profits from the positive correlations between numerator and denominator. The upper plot shows the cross section ratio itself, the three lower plots show the ratio of the predicted cross section ratio devided by the measured cross section ratio for different predictions.

Due to the higher Z-boson mass compared to the W-boson mass a higher jet p_{T} in Z+jets events is expected. But the more additional jets are produced in the event, the more unimportant this mass difference is expected to be. Thus the leading jet p_{T} is expected to be more similar for W and Z events the more additional jets are produced. This is confirmed in Fig. 4. The slope of the cross section ratio flattens with increasing jet multiplicity. All predictions describe the flattening slope of the ratio for increasing jet multiplicity well.

For small jet p_{T} all predicted shapes show different trends compared to the measurement. The best agreement is achieved for ALPGEN, the most pronounced discrepancy can be seen for BLACKHAT+SHERPA.

Conclusion

The Z+jets cross section was measured by the ATLAS collaboration based on proton–proton collisions at a centre-of-mass energy of 13 TeV with an integrated luminosity of 85 pb^{-1} recorded in the summer of 2015. The cross sections for events with up to four jets were measured with a precision of 10 % to 20 % and compared to theoretical predictions at particle level. Based on the entire 2011 dataset of proton–proton collisions at a centre-of-mass energy of 7 TeV with an

integrated luminosity of 4.6 fb^{-1} ATLAS has measured the W boson plus jets production cross section with up to seven jets. The results were compared to various theoretical predictions. Also the cross section ratio of W+jets and Z+jets production was measured. This measurement profits from large cancellations of experimental systematic uncertainties and non-pertubative QCD effects due to W+jets and Z+jets events being very similar.

References

[1] ATLAS Collaboration, 2008 JINST 3 S08003.

[2] ATLAS Collaboration, ATLAS-CONF-2015-041, http://cds.cern.ch/record/2048104.

[3] ATLAS Collaboration, Eur. Phys. J. C (2015) 75:82.

[4] ATLAS Collaboration, Eur. Phys. J. C (2014) 74:3168.

[5] G. D'Agostini, Nucl. Instrum. Meth. A 362 (1995) 487

[6] A. Glazov, AIP Conf. Proc. 792 (2005) 237

[7] H1 Collaboration F. D. Aaron, et al., Eur. Phys. J. C 63 (2009) 625, arXiv:0904.0929 [hep-ex]

[8] T. Gleisberg et al., J. High Energy Phys. 0902 (2009) 007, arXiv:0811.4622 [hep-ph]

[9] S. Hoeche, F. Krauss, M. Schonherr, and F. Siegert, J. High Energy Phys. 1304 (2013) 027, arXiv:1207.5030 [hep-ph]

[10] J. Alwall et al., JHEP 1407 (2014) 079, arXiv:1405.0301[hep-ph]

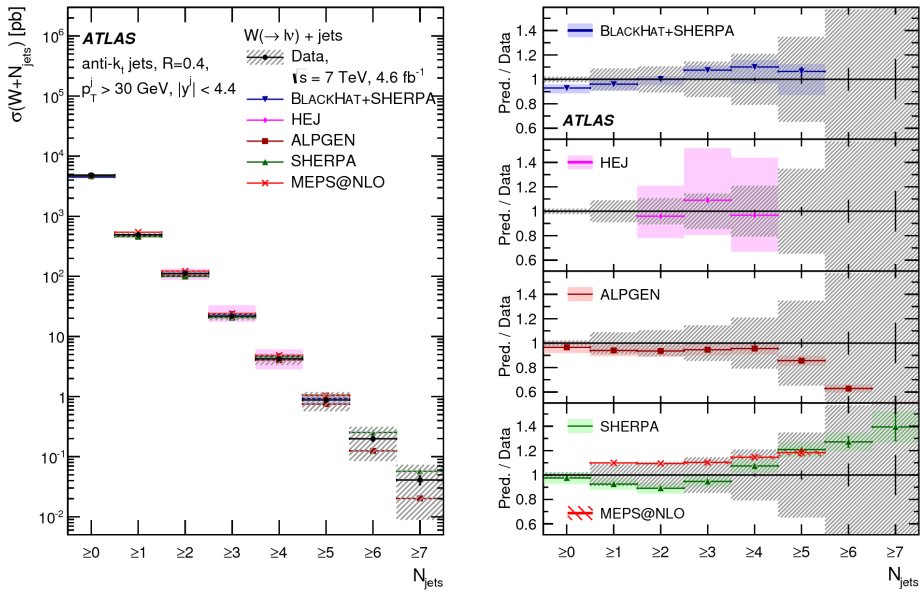

Figure 3: Cross section for the production of W+jets as a function of the inclusive jet multiplicity. For the data, the statistical uncertainties are shown by the vertical bars, and the combined statistical and systematic uncertainties are shown by the black-hashed regions. The data are compared to predictions from BLACKHAT+SHERPA, HEJ, ALPGEN, SHERPA and MEPS@NLO. The left-hand plot shows the differential cross sections and the right-hand plot shows the ratios of the predictions to the data [3].

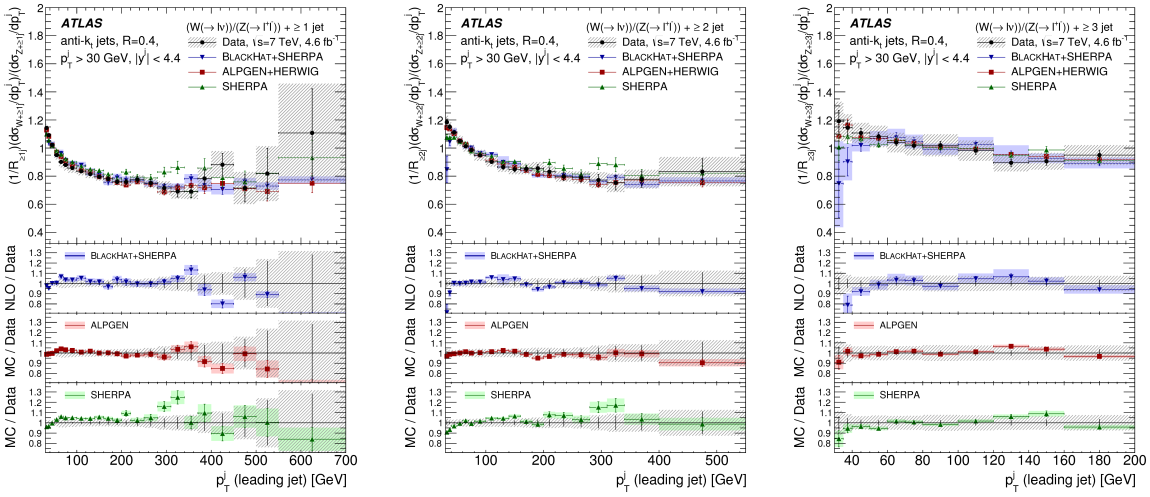

Figure 4: The ratio of W+jets and Z+jets production cross sections, Rjets, versus the leading-jet transverse momentum for Njets ≥ 1 (left), ≥ 2 (center) and ≥ 3 (right). The electron and muon channel measurements are combined as described in the text. Ratios of the BLACKHAT+SHERPA NLO calculation and the ALPGEN and SHERPA generators to the data are shown in the lower panels. Vertical error bars show the respective statistical uncertainties. The hatched error band shows statistical and systematic uncertainties added in quadrature for the data. The solid error bands show the statistical uncertainties for the ALPGEN and SHERPA predictions, and the combined statistical and theoretical uncertainties for the BLACKHAT+SHERPA prediction [4].

[11] Z. Bern et al., Phys. Rev. D 88 (2013) 014025, arXiv:1304.1253 [hep-ph]

[12] C. Berger et al., Phys. Rev. D 80 (2009) 074036, arXiv:0907.1984 [hep-ph]

[13] C. Berger et al., Phys. Lett. 106 (2011) 092001, arXiv:1009.2338 [hep-ph]

[14] M. L. Mangano et al., J. High Energy Phys. 0307 (2003) 001, arXiv:hep-ph/0206293

[15] J. R. Andersen, T. Hapola, and J. M. Smillie, J. High Energy Phys. 1209 (2012) 047, arXiv:1206.6763 [hep-ph]

[16] J. R. Andersen, T. Hapola, and J. M. Smillie, J. High Energy Phys. 1001 (2010) 039, arXiv:0908.2786 [hep-ph]