EPJ Web of Conferences **129**, 00002 (2016) DOI: 10.1051/epjconf/201612900002
QCD@Work 2016

Z/W + jets production at 8/13 TeV in CMS

Kadir Ocalan[1,⋆] for the CMS Collaboration

[1] *Necmettin Erbakan University, Faculty of Aviation and Space Sciences, Koycegiz Campus, Meram, 42090 Konya, Turkey*

Abstract. The production of vector bosons (Z and W) in association with jets provides a stringent test of perturbative QCD and is a background process in searches for new physics. Differential cross section measurements of vector bosons produced in association with jets and heavy flavour quarks in proton-proton collisions at center of mass energies of 8 TeV and 13 TeV in the CMS experiment at the LHC are presented. The measurements are compared to next-to-leading order calculations and event simulations that devise matrix element calculations interfaced with parton showers.

1 Introduction

The production of vector bosons (Z and W) in association with jets is an important Standard Model (SM) benchmark providing precision tests for perturbative Quantum Chromodynamics (pQCD) calculations and inputs for improving parton distribution functions (PDFs). Vector boson and associated jets (V+jets) data can be used for testing Monte Carlo (MC) based event generators. Productions of V+jets constitute prominent background for several SM processes such as Higgs boson production in association with a vector boson, single top production, top pair production, and vector boson fusion. Moreover, studies of V+jets are important for modelling backgrounds for beyond the SM (BSM) searches such as supersymmetry (SUSY) and dark matter.

In V+jets measurements, Z and W bosons are reconstructed through their leptonic decays ($Z/\gamma^* \rightarrow l^+l^-$, $W \rightarrow l\nu$) and their productions in association with jets are characterised by measured differential cross sections as a function of various observables including jet multiplicity and kinematics, angular correlations, and invariant masses. Measured V+jets distributions are unfolded to particle level for detector effects and compared to several theoretical predictions. The theoretical predictions include leading order (LO) and next-to-leading order (NLO) matrix element (ME) calculations interfaced with parton showers (PS) and NLO and next-to-next-to-leading order (NNLO) fixed order calculations. In this report, the latest results on the V+jets production are reviewed based on mostly 8 TeV and 13 TeV proton-proton (pp) collisions data recorded by the Compact Muon Solenoid (CMS) detector [1] at the CERN Large Hadron Collider (LHC).

2 Z + jets differential cross sections

The differential cross sections of Z boson production in association with jets, in the dimuon and dielectron decay channels [2] and in the dimuon decay channel for an extended jet rapidity region [3],

⋆e-mail: kadir.ocalan@cern.ch

are measured in pp collisions at a center-of-mass energy of $\sqrt{s} = 8$ TeV. The data sample used corresponds to an integrated luminosity of 19.6 fb^{-1} collected by the CMS detector. The differential cross sections are measured in a phase space where transverse momenta and pseudorapidities of leptons and jets are required as $p_T(l) > 20$ GeV and $p_T(\text{jets}) > 30$ GeV and $|\eta(l, \text{jets})| < 2.4$ ($|y(\text{jets})| < 4.7$ in the extended measurement). The measured differential cross sections are compared to predictions by MADGRAPH5 [4] (+ PYTHIA 6 [5]) tree level ME event generator at LO accuracy and by SHERPA 2 [6] ME event generator at NLO accuracy up to 2 partons, where both generators are interfaced for PS. The total cross section for MADGRAPH5 is normalised to the NNLO cross section computed with FEWZ [7]. The predictions are generally able to describe data within uncertainties, however as shown in figure 1 (left), MADGRAPH5 shows deviation from data for a range of 150–450 GeV and SHERPA 2 slightly underestimates data for the first leading jet p_T.

The first differential cross section measurement of Z+jets at 13 TeV is performed in the dimuon decay channel using pp collisions data corresponding to an integrated luminosity of 2.5 fb^{-1} [8]. The analysed Z+jets events are required to have isolated muon pairs with $p_T(\mu) > 20$ GeV and $|\eta(\mu)| < 2.4$ and jets with $p_T(\text{jets}) > 30$ GeV and $|y(\text{jets})| < 2.4$. The measured differential distributions are compared to predictions by MADGRAPH5_aMC@NLO [9], interfaced with PYTHIA 8 [10] for PS and hadronization, at NLO accuracy up to 2 additional partons merged using FxFx scheme [11] and by an NNLO fixed order calculation [12, 13] for Z + 1 jet production. The MADGRAPH5_aMC@NLO and NNLO predictions show remarkable agreement with data on the first leading jet p_T as shown in figure 1 (right).

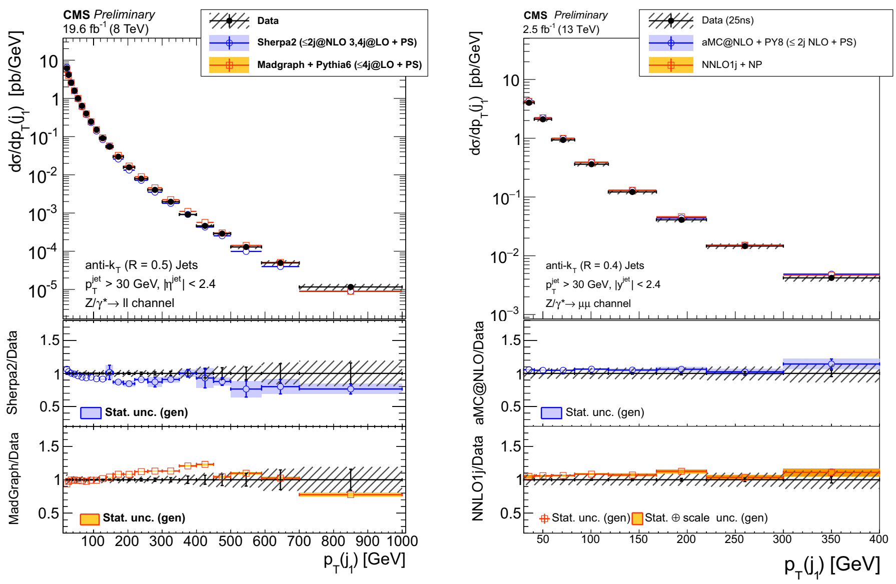

Figure 1. Left: 8 TeV Z+jets differential cross section measurement as a function of the first jet p_T compared to the SHERPA 2 and MADGRAPH5 predictions. Right: 13 TeV Z+jets differential cross section measurement as a function of the first jet p_T compared to the MADGRAPH5_aMC@NLO and Z + 1 jet NNLO predictions. Error bars around the experimental points show the statistical uncertainty, while the crosshatched bands indicate the statistical and systematic uncertainties added in quadrature. The color filled band around the NNLO prediction shows the statistical and systematic uncertainties added in quadrature, while representing only the statistical uncertainty of the generated sample for the other predictions.

3 W + jets differential cross sections

The measurement of the differential cross sections for W boson production in the muon decay channel and jets is presented with data corresponding to an integrated luminosity of 19.6 fb^{-1} recorded by the CMS detector at $\sqrt{s} = 8$ TeV [14]. W+jets events are selected by the requirements for single muons with $p_T(\mu) > 25$ GeV and $|\eta(\mu)| < 2.1$ and jets with $p_T(\text{jets}) > 30$ GeV and $|\eta(\text{jets})| < 2.4$, in addition to W boson transverse mass requirement of $M_T(\text{W}) > 50$ GeV. Differential distributions are measured as a function of several observables including the jet kinematics and angular correlations among the jets and the muon. Such angular distributions are sensitive to the modelling of higher order corrections and parton emissions. The measured W+jets cross sections are compared to the predictions of MADGRAPH5 (+ PYTHIA 6) tree level LO, MADGRAPH5_aMC@NLO (+ PYTHIA 8) merged NLO up to 2 partons, and SHERPA 2 multileg NLO (+ BLACKHAT [15, 16]) MC generators and the fixed order theoretical predictions provided by BLACKHAT + SHERPA [17] at NLO accuracy. The NNLO calculation [18, 19] in pQCD for W + 1 jet production is also provided. The predictions from MADGRAPH5, MADGRAPH5_aMC@NLO, SHERPA 2, and NNLO calculation show reasonable agreement with data within uncertainties for the H_T variable (defined as scalar sum of jets p_T) for one inclusive jet production, while BLACKHAT + SHERPA systematically underestimates data as shown in figure 2 (left). The measured differential cross section as a function of azimuthal separation between the first leading jet and the muon is well described by the multileg LO and NLO predictions, however fixed order NLO shows lower trend in describing data as shown in figure 2 (right).

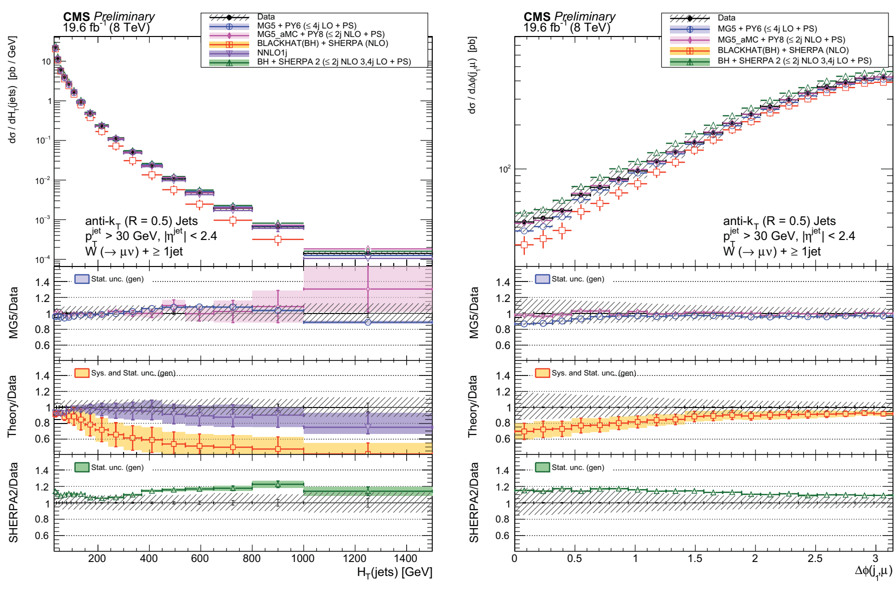

Figure 2. W+jets differential cross section measurement as a function of H_T for one inclusive jet production (left) and azimuthal correlation between the first jet and the muon (right). The measured distributions are compared to several predictions including W + 1 jet NNLO for H_T variable. Black circular markers with the grey hatched band represent the data measurement and its total experimental uncertainty. The color filled bands around the BLACKHAT + SHERPA and NNLO predictions show their statistical and systematic uncertainties added in quadrature, while representing only the statistical uncertainty of the generated sample for the other predictions. BLACKHAT + SHERPA and NNLO are corrected for non-perturbative effects.

4 Z + b jets cross sections

Associated production of a vector boson and heavy flavour jets is sensitive for probing heavy quark content in the proton and constitutes important background processes to Higgs studies and BSM searches. The production of a Z boson in association with at least one jet originating from a b quark is measured in pp collisions at $\sqrt{s}$ = 8 TeV [20]. Cross sections are measured from data collected by the CMS, for a total integrated luminosity of 19.6 fb^{-1}, using Z boson decays into electron or muon pairs, and identified b quark jets. Z+b jets events are required to have leptons with $p_{\mathrm{T}}(l) > 20$ GeV and $|\eta(l)| < 2.4$ and b-tagged jets with $p_{\mathrm{T}}(\mathrm{b}) > 30$ GeV and $|\eta(\mathrm{b})| < 2.4$. The fiducial cross sections for Z boson in the combined lepton channel with at least one and two b jets are measured. The differential cross sections for the cases of at least one and two b jets are measured as a function of observables characterising the b jet and Z boson kinematics. Moreover, the ratios of differential cross sections for the associated production with at least one b jet and with any jet inclusive in flavour are also measured. The measurement results are compared to the theoretical predictions including MADGRAPH5 (+ PYTHIA 6) tree level LO generator and POWHEG [21–23] (+ PYTHIA 6) NLO, testing two different flavour schemes for the choice of initial state partons as the four-flavour scheme (4FS) [24] and the five-flavour scheme (5FS) [25]. The differential cross sections for Z+b jets and the cross section ratios for the associated one inclusive b jet and any jets are better described by the predictions using 5FS approach than 4FS as shown in figure 3.

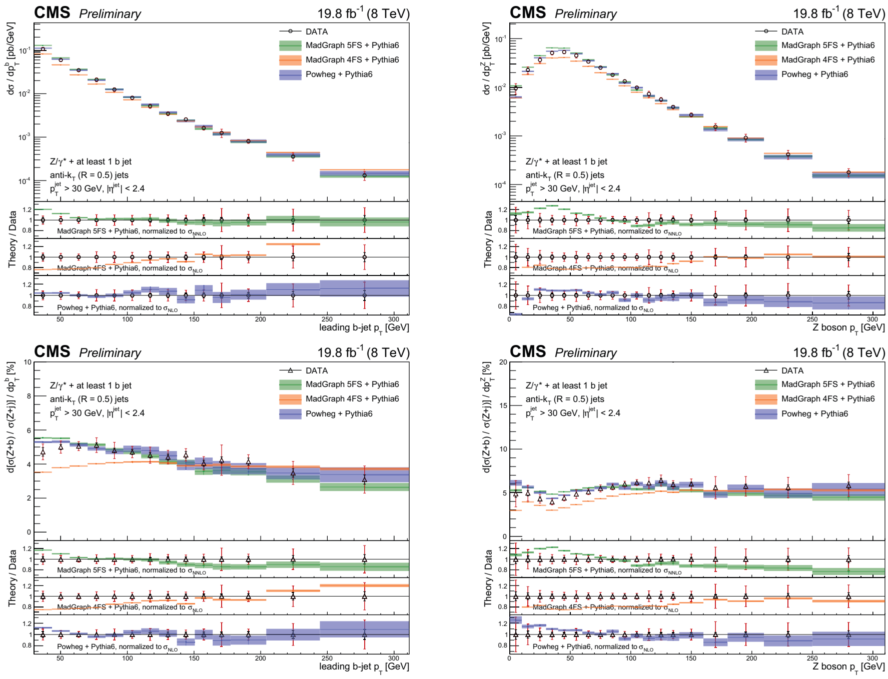

Figure 3. Differential Z+1 b jet cross sections as a function of p_{T} for the leading b jet and Z boson (top) and the cross section ratios for p_{T} of the leading b jet and Z boson between Z+1 b jet and Z+jets (bottom). The measured distributions are compared with the MADGRAPH5 (4FS and 5FS) and POWHEG (5FS) theoretical predictions. For each data point the statistical and the total (statistical plus systematic) uncertainty are represented by the double error bar. The width of shaded bands represents the statistical error on the theoretical predictions.

5 W + 2 b jets cross section

The production cross section of the W boson in association with two b jets (W+b$\bar{b}$) is measured using a data sample of pp collisions collected by the CMS experiment at $\sqrt{s}$ = 8 TeV [26]. The data sample corresponds to an integrated luminosity of 19.8 fb^{-1}. The W bosons are reconstructed using their leptonic decays to muons ($W \to \mu\nu$) and electrons ($W \to e\nu$). The W+b$\bar{b}$ events are required to have leptons with $p_T(l) > 30$ GeV and $|\eta(l)| < 2.1$ and exactly two b-tagged jets with $p_T(b) > 25$ GeV and $|\eta(b)| < 2.4$ in the signal region and extracted using a likelihood fit to $M_T(W)$. The measured cross section in the combined lepton channel, $\sigma(pp \to W(l\nu) + b\bar{b}) = 0.69 \pm 0.02(\text{stat.}) \pm 0.11(\text{syst.}) \pm 0.07(\text{theo.}) \pm 0.02(\text{lumi.})$ pb, is compared to theoretical predictions of MADGRAPH5 (+ PYTHIA 6) using both 4FS and 5FS, MADGRAPH5 (+ PYTHIA 8) using 4FS, and MCFM [27, 28] NLO. The predicted cross sections agree each other and are consistent with the measured cross section within one standard deviation as shown in figure 4.

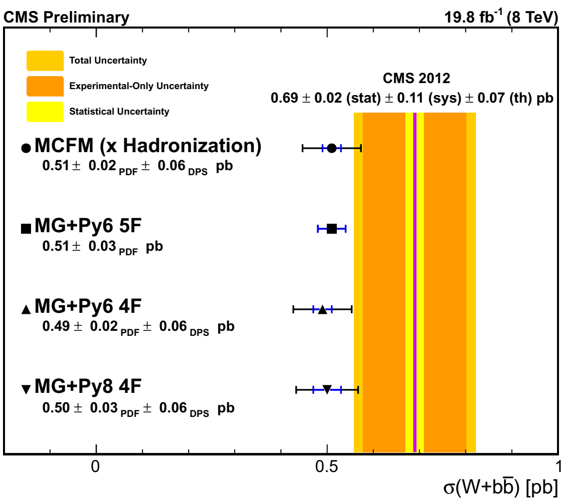

Figure 4. Comparison between the measured W+b$\bar{b}$ cross section and various theoretical predictions. The blue error bars on the predictions represent the uncertainty in the given sample associated with PDF choice and the black bars represent the total uncertainty. The effects of double parton scattering (DPS) are not included in the generated samples of the predictions except MADGRAPH5 + PYTHIA6 (5F), so the extra DPS factor is included to account for the DPS effect in the theoretical cross section predictions.

6 Conclusions

The CMS collaboration has explored V+jets productions including Z and W bosons in the most relevant areas using 8 TeV and recently 13 TeV pp collisions data at the LHC. The measured cross sections differential in various observables are confronted by several predictions based on multileg LO and NLO ME + PS generators and NLO and NNLO fixed order calculations. The V+jets measurements including associated heavy flavour jets provide unique tests for pQCD calculations to high precision and inputs for tuning MC based event generators with constant developments. Overall, the differential cross section distributions measured as a function of the observables are well modelled by the predictions. NLO ME + PS and fixed order NNLO predictions show good agreement with data distributions, while LO (ME + PS) predictions show some discrepancies. In the associated heavy flavour jets measurements, Z+b jets data spectra are better described by the predictions using 5FS approach. The measured W+b$\bar{b}$ fiducial cross section is in agreement with the SM predictions. The CMS physics program will continue delivery of V+jets results with higher precision using 13 TeV pp collisions data.

The author acknowledges the financial support for the conference by Necmettin Erbakan University Scientific Research Projects Unit (BAP) under the AGED1 project with number 162518001-211.

References

[1] The CMS Collaboration, JINST **3**, S08004 (2008).
[2] The CMS Collaboration, CMS-PAS-SMP-13-007, (2014).
[3] The CMS Collaboration, CMS-PAS-SMP-14-009, (2014).
[4] J. Alwall et al., JHEP **1106**, 128 (2011).
[5] T. Sjostrand et al., JHEP **0605**, 026 (2006).
[6] T. Gleisberg et al., JHEP **0902**, 007 (2009).
[7] R. Gavin et al., Comput. Phys. Commun. **182**, 2388-2403 (2011).
[8] The CMS Collaboration, CMS-PAS-SMP-15-010, (2015).
[9] J. Alwall et al., JHEP **07**, 079 (2014).
[10] T. Sjostrand et al., Comput. Phys. Commun. **178**, 852-867 (2008).
[11] R. Frederix and S. Frixione, JHEP **12**, 061 (2012).
[12] R. Boughezal et al., Phys. Rev. Lett. **116**, 152001 (2016).
[13] R. Boughezal, X. Liu, and F. Petriello, arXiv:1602.08140 (2016).
[14] The CMS Collaboration, CMS-PAS-SMP-14-023, (2016).
[15] C. Berger et al., Nucl.Phys.Proc.Suppl. **183**, 313-319 (2008).
[16] C. Berger et al., Nucl.Phys.Proc.Suppl. **205-206**, 92-97 (2010).
[17] C. F. Berger et al., Phys. Rev. D. **80**, 074036 (2009).
[18] R. Boughezal et al., Phys. Rev. Lett. **115**, 062002 (2015).
[19] R. Boughezal, X. Liu, and F. Petriello, arXiv:1602.06965 (2016).
[20] The CMS Collaboration, CMS-PAS-SMP-14-010, (2015).
[21] P. Nason, JHEP **0411**, 040 (2004).
[22] S. Frixione, P. Nason and C. Oleari, JHEP **0711**, 070 (2007).
[23] S. Alioli et al., JHEP **1006**, 043 (2010).
[24] F. F. Cordero et al., Phys. Rev. D. **80**, 034015 (2009).
[25] J. M. Campbell et al., Phys. Rev. D. **69**, 074021 (2004).
[26] The CMS Collaboration, CMS-PAS-SMP-14-020, (2016).
[27] J. M. Campbell and R. Ellis, Nucl. Phys. Proc. Suppl. **205**, 10 (2010).
[28] S. Badger, J. M. Campbell, and R. Ellis, JHEP **03**, 027 (2011).