Vector Boson + Jets Production at CMS

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/182

Recent measurements of the production cross section of a vector boson in association with jets and a vector boson in association with heavy flavour quarks in proton-proton collision are presented. The collisions were recorded at $\sqrt{s} = 7$ and 8 TeV with the CMS detector at the LHC, for an integrated luminosity of 5.2 and 19.7 fb^{-1} respectively.

1 Introduction

Measurements of the production cross section of a vector boson in association with jets (V+jets, $V = W, Z, \gamma$) and a vector boson in association with heavy flavour quarks (V+HF) are fundamental tests of perturbative quantum chromodynamics (pQCD). These V+jets and V+HF productions also constitute important backgrounds to searches for rare standard model processes and to searches for particles predicted by new physics. With the LHC proton-proton collision data taken in 2011 and 2012, the CMS collaboration [1] measured the V+jets cross section to higher energies and jet multiplicities compared to previous results from CMS. The rapidity distributions in V+jet events and ratios of the cross sections of Z/γ^* plus jets and photon plus jets events are also measured to provide additional sensitivities to parton distribution functions (PDFs) and higher order effects.

Besides testing pQCD, measurements of W and Z production with b hadrons (Z+b and W+b) are particular important for searches of new particles. For Z+b process, both cross section and angular distribution are measured. For W+b process, previous measurements concentrating on W-boson production with at least one observed b-quark jet have shown various levels of agreement with theoretical calculation. The CMS measurement provides a complementary approach focusing on the observation of W-boson production with two well-separated b-quark jets. The study of associated production of a W boson and a charm (c) quark (W+c) production provides direct access to the strange-quark content of the proton. More precise knowledge of the PDFs is essential for many present and future precision analyses.

2 Vector boson + jets

The production cross sections of a photon and one or more jets in the final state with various angular configurations are sensitive to contributions from the QCD hard-scattering subprocesses and to PDFs of the proton. The main background for these processes comes from the decay of neutral hadrons into nearly collinear pairs of photons. These background is estimated using a data-driven method which exploits the distribution of energy in the vicinity of the photon. The measurement is performed in four regions of pseudorapidity for the photon and two regions of pseudorapidity for the leading-transverse-momentum jet [2]. This kinematic region corresponds to x and Q^2 region of $0.002 \lesssim x \lesssim 0.4$ and $1600 \leq Q^2 \leq 9\times10^4$ GeV^2. Results are compared to theoretical predictions from the SHERPA [3] leading-order QCD event generator and the next-to-leading-order(NLO) perturbative QCD calculation from JETPHOX [4]. The predictions are found to be consistent with the data over most of the examined kinematic region.

Compared to γ+jets process, Z/γ^*+jets process has a much cleaner signature. Z/γ^*+jets cross sections with jet multiplicity up to six and seven for $\sqrt{s} = 7$ and 8 TeV respectively are measured [5],[6]. The differential cross section as a function of the transverse momentum of the leading jet is shown in Figure 1. The differential cross section as a function of jet multiplicity and H_T, the scalar sum of jet transverse momenta is also measured. The experimental results and their NLO theoretical predictions are generally consistent within uncertainties.

The measurements of the production cross section of W+jets events have a larger data-sample size however also higher systematic uncertainties compared to measurements of Z+jets events. The higher systematic uncertainties are mainly from a lager background contamination from $t\bar{t}$ decay. The data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV was collected and corresponds to an integrated luminosity of 5.0 fb^{-1}. The measured cross sections [7] are compared to predictions from MADGRAPH [8] + PYTHIA [9] and SHERPA, and to NLO calculations from BLACKHAT+SHERPA [10]. The differential cross section as a function of the transverse momentum of the leading jet is displayed in Figure 1. The differential cross section are found to be in agreement with the predictions for most kinematic region.

The angular distributions of Z/γ^*+jet events and γ+jet events are measured with $\sqrt{s} = 7$ TeV data [11]. The rapidity of a particle is defined as $y = (1/2)\ln[(E+p_z)/(E-p_z)]$, where E is the energy and p_z is the momentum component along the direction of the counterclockwise circulating proton beam. The invariant rapidity difference can be written in terms of the measured quantities y_V and y_{jet} as $y_{\text{dif}} = |y_V - y_{\text{jet}}|/2$. The quantity $y_{\text{sum}} = |y_V + y_{\text{jet}}|/2$ is the boost from the laboratory frame to the center-of-mass frame of the V and jet. The distribution in y_{sum} depends mainly on the PDFs , while the distribution in y_{dif} reflects the leading order partonic differential cross section. The distribution for the sum of the V and jet rapidity is shown in Figure 1. It is best described by hybrid calculations that employ NLO PDF.

The measurement of the cross section ratio of Z/γ^*+jets and γ+jets provides an important information about possible contributions of large logs in higher-order effects. This measurement used data collected at $\sqrt{s} = 7$ TeV [12]. The results are compared to leading order prediction from MADGRAPH. The prediction agrees with data in shape, but overestimates the ratio.

3 Vector boson + heavy quarks

The measurement of the cross sections for the production of a Z boson in association with at least two b-jets is displayed in Figure 2 [13]. The measurement is of particular importance for search of higgs production associated with a Z boson. The result is compared to MADGRAPH in the five-flavour scheme, where b quarks are assumed massless, and the four-flavour scheme, where massive b quarks are used, as well as with the NLO predictions from amc@nlo [14]. With the tracker only b-tag, angular separation of the b hadrons and the Z boson is measured in [15]. The azimuthal separation($\Delta\phi$) between the b hadrons compared to theory is shown in Figure 2. Some differences are found between predictions and data in collinear region.

The production cross section for a W boson and two b-jets is measured at $\sqrt{s} = 7$ TeV [16].

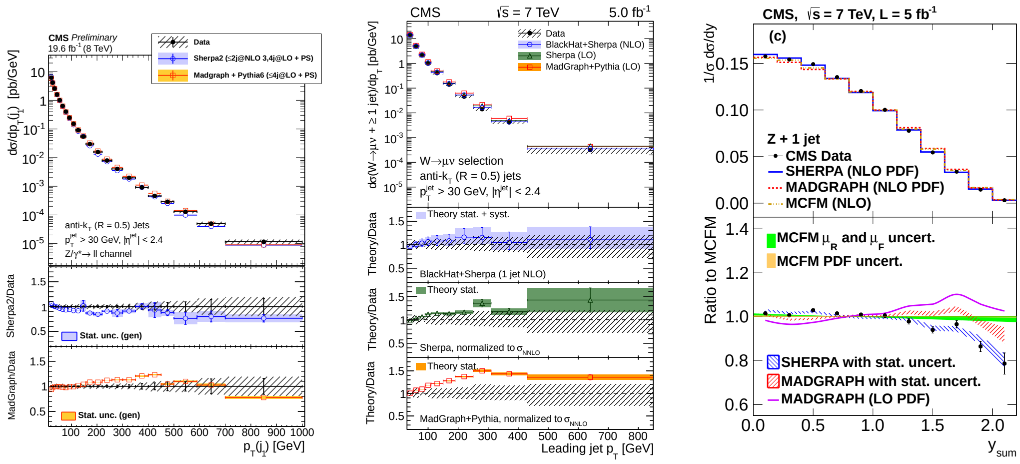

Figure 1: Differential cross sections of Z+jets at $\sqrt{s} = 8$ TeV(left) and W+jets at $\sqrt{s} = 7$ TeV(center) as a function of the transverse momentum of the leading jet. The distribution of y_{sum} in Z+jet channel(right).

Previous studies from hadron colliders are concentrated on W-boson production with at least one observed b-quark jet. Different level of agreements with theory is found in these analyses. The study of W boson and exactly two b-jets hence complements previous measurements. The measured fiducial cross section is in agreement with NLO prediction from MCFM at parton level.

The study of associated production of a W boson and a charm quark at hadron colliders provides direct access to the strange-quark content of the proton. The good measurement of charmquark jet charge is utilized in this measurement to disentangle the W+c signal component from most of the background processes [17]. The measured total cross section is compared with next-to-leading order calculation from MCFM [18] using four PDF sets, which is shown in Figure 2. Measurement of the cross section ratio of $\sigma(W^+ + \bar{c})/\sigma(W^- + c)$ is a test of $s - \bar{s}$ asymmetry hypothesis. The measured cross section ratios are around 95%. This result does not favour such hypothesis although the measurement is still dominated by experimental uncertainties.

4 Conclusion

Recent CMS results of V+jets and V+HF productions have been presented. Besides the measurements from different final states, new results also extend the kinematic coverage of previous measurements and probe additional observables. Overall, NLO predictions agree with the data rather well for most of the V+jets processes. Some disagreements exist for the variables sensitive to higher order term such as H_T. Some differences remain between theory and measurements in the production of V+HF such as angular distribution of the Z+b-jets process and differential cross section of W+chram process. These results provide input to MC tools and background estimation of different standard model measurements and beyond standard model searches.

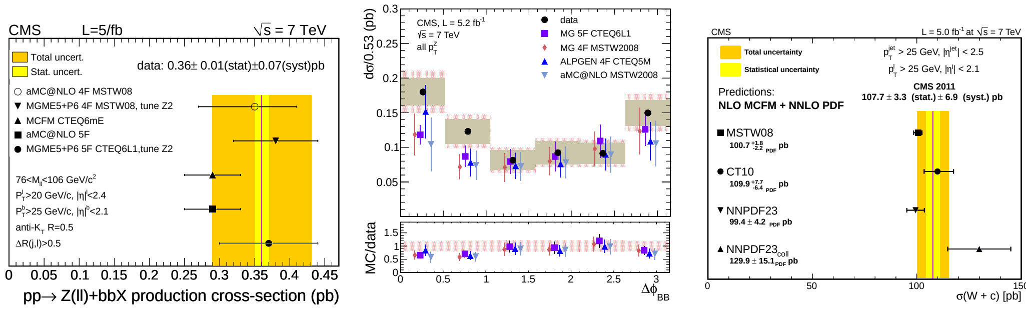

Figure 2: Cross sections for the production of a Z boson with at least two b-jets(left). Differential cross sections as a function of ϕ difference between two b quarks(center). Total cross section of W+c production compared with NLO MCFM using four different PDF sets(right).

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