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Measurement of electroweak gauge boson production in association with jets at ATLAS

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We present the latest results of electroweak gauge boson interactions in association with jet activities with the ATLAS detector at the LHC experiment, using proton-proton collision data from LHC Run-2 operating at center-of-mass energy of 13 TeV. The fiducial cross sections are measured as function of different kinematic variables in multiple channels, in comparison with theory predictions

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1 Introduction

The Standard Model (SM) of particle physics has endured as the framework describing the fundamental constituents of matter and their interactions. One of its essential components is the unification of two of the four fundamental forces (electromagnetic and weak forces) into the electroweak interaction. The electroweak sector is mediated by gauge bosons (the W and Z bosons for the weak force, and the photon for the electromagnetic force).

Multi-Boson interactions are one of the most important Standard Model (SM) processes to be measured at the Large Hadron Collider (LHC) [1] with ATLAS detector [2]. The precise measurements of gauge boson production do not only provide a better understanding of SM and beneficial to the constraints of fundamental parameters of SM especially in the electroweak sector, but also provide a solid estimation of SM backgrounds for Beyond SM (BSM) new physics searches such as Axion-Like particles (ALP) and EFT interpretations. At the same time, the precise measurement of electroweak gauge boson in association with jets can be used to test fixed-order perturbative QCD calculations and predictions. As an important part in LHC physics, it also helps to improve our understanding of Parton Density Functions (PDF). This proceeding will introduce various results of electroweak gauge boson interactions, applied with different experimental methodologies.
[a]

2 Differential measurement of $Z + b$-jets at high p_T

The measurements of cross sections for the production of a leptonic decays of Z boson in association with a large-radius jet in pp collisions at $\sqrt{s} = 13$ TeV at ATLAS with 36 fb^{-1} is

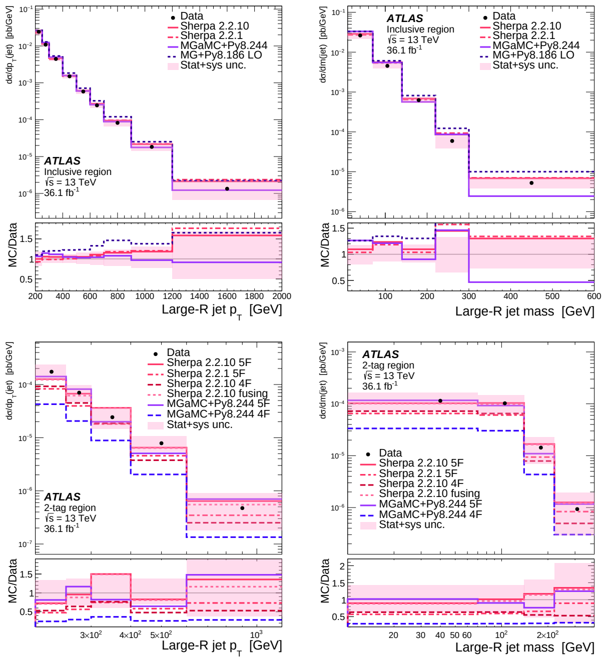

Figure 1 – The measured differential cross sections as function of Large-R jet p_T and mass, compared with different predictions in both regions and different flavor number scheme in 2-tag region.

presented here. This measurement is beneficial for the study of b-flavor component of Parton Density Functions (PDFs) by discriminating the effect of b-quark PDF of the proton. And it plays a crucial role in testing of perturbative QCD such as gluon splitting and NLO effects. Two flavor number schemes are studied and compared. One is the four-flavor number scheme (4FNS) by setting b-quark density to zero in the PDF. In this scheme, the perturbative generation of b-quark coming from the gluon splitting, and the signature of such process is that 4FNS always has at least two participating b-quarks. By contrast, the other one is five-flavor number scheme (5FNS) that the PDF evolution can generate initial-state b-quarks, and only one b-quark can participate the hard scatter. [4]

Two different regions are defined to perform the measurement. The "2-tag" region is defined as a subset of "inclusive" region by requiring that the large-R jet contains exactly two b-tagged jets. "Same Flavor and Opposite Sign" requirement helps to select signal events containing a leptonic decaying Z boson in association with a large-R jets.

The measured fiducial cross sections are consistent with the SM predictions in both region. MadGraph5_aMc@NLO + PYTHIA8 well described all distribution shape and other predictions have mis-modelling of QCD activities is observed from inclusive region, and in the 2-tag region, good shape agreement between the measured data and all MC models is also observed but 4FNS underestimates the rate of $b\bar{b}$ boosted-jet production from Figure 1.

3 Differential measurement of W boson in association with a charm hadron

The production of a W boson in association with a single charm quark is studied using 140 fb^{-1} of $\sqrt{s} = 13$ TeV in ATLAS [3]. A special strategy is applied in this study by identifying the charm quark as a charmed hadron which is reconstructed with a secondary-vertex fit method. As the dominant production mode that 90% of this signature produced by a s-quark initiated process at LO, it is sensitive to s-quark PDF and beneficial for constraining PDF uncertainties. This measurement is performed relies on the signature that W boson is reconstructed from the decay to either an electron or a muon plus the missing transverse momentum, and the charmed meson is also reconstructed from $D^+ \to K^-\pi^+\pi^+$ and $D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$ in different

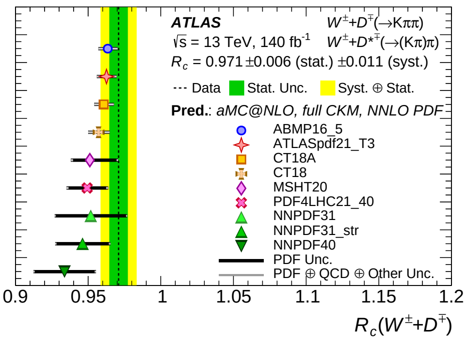

Figure 2 – Measured fiducial cross section ratio, $R_C^{\pm}$, compared with different PDF predictions. $R_C^{\pm}$ is defined as $\sigma(W^+ + D^-)/\sigma(W^- + D^+)$ in two decay channels.

Channel	$\sigma_{\text{fid}}^{\text{OS-SS}}(W+D^{(*)}) \times B(W \to \ell\nu)$ [pb]
W^-+D^+	50.2 ± 0.2 (stat.) $^{+2.4}_{-2.3}$ (syst.)
W^++D^-	48.5 ± 0.2 (stat.) $^{+2.3}_{-2.2}$ (syst.)
W^-+D^{*+}	51.1 ± 0.4 (stat.) $^{+1.9}_{-1.8}$ (syst.)
W^++D^{*-}	50.0 ± 0.4 (stat.) $^{+1.9}_{-1.8}$ (syst.)
	$R_c^{\pm} = \sigma_{\text{fid}}^{\text{OS-SS}}(W^++D^{(*)})/\sigma_{\text{fid}}^{\text{OS-SS}}(W^-+D^{(*)})$
$R_c^{\pm}(D^+)$	0.965 ± 0.007 (stat.) ± 0.012 (syst.)
$R_c^{\pm}(D^{*+})$	0.980 ± 0.010 (stat.) ± 0.013 (syst.)
$R_c^{\pm}(D^{(*)})$	0.971 ± 0.006 (stat.) ± 0.011 (syst.)

Figure 3 – The measured fiducial cross sections in different channels and their ratios.

fiducial regions.

The signal is extracted by measuring the difference between the numbers of Opposite-Sign (OS) and Same-Sign (SS) $W + D^{(*)}$ candidates which can effectively control and estimate the contribution of backgrounds. The experimental precision of these measurements is comparable to the PDF uncertainties and smaller than the total theory uncertainty. Consistence (shown in Figure 2 and Figure 3) exists with NLO prediction accuracy and indicates $s - \bar{s}$ asymmetry is small. At the same time, this measurement provides useful constraints for global PDF fits.

4 Differential measurement of $Z\gamma$+jets

The differential measurement of $Z\gamma$ in association with jet activities [5] are first measured at ATLAS with full Run2 data. With a relative large cross section but small background contributions, this measurement can be used to constrain parameters of the SM Lagrangian, test fixed-order QCD calculations with resummation of Sudakov logarithms and also sensitive to the parton distribution functions (PDFs).

This measurement focuses on analyzing such process with its unique signature : charged leptonic decays of Z boson plus an Initial State Radiation (ISR) photon. $m_{ll} > 40$ GeV is required to avoid low mass resonance, and $m_{ll} + m_{ll\gamma} > 182$ GeV requirement helps to suppress events with Final State Radiation (FSR) photon. In this measurement, variables that represent the hard scale of the process are "Hard variables", and "Resolution variables" means the variables sensitive to additional QCD variations. Both "Hard variables" and "Resolution variables" are measured in this analysis. Good agreement observed between the measured data and SM prediction as shown in Figure 4.

The measured fiducial cross sections are consistent (shown in Figure 5) with SM predictions within experimental uncertainties at NNLO accuracy, jet activities are also generally well described with some trends observed in the different predictions.

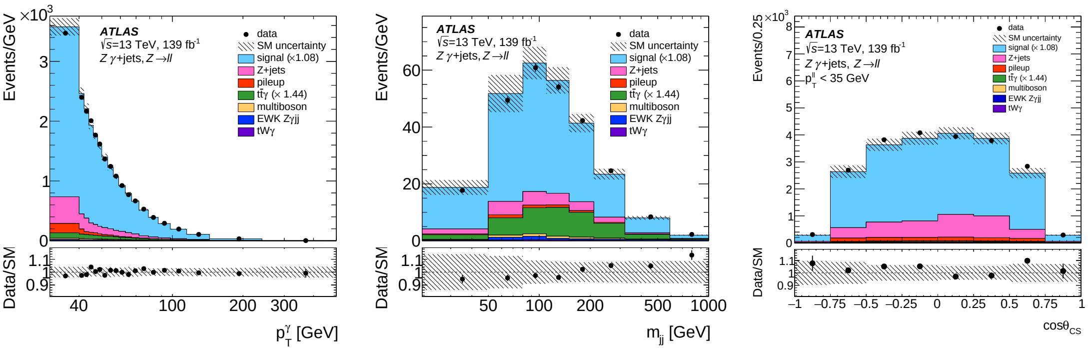

Figure 4 – The comparison between the measured data and MC simulation in the signal region.

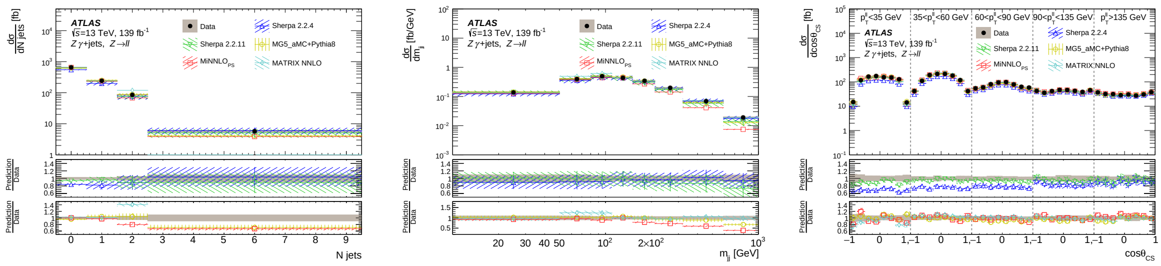

Figure 5 – Measured differential cross section as function of N_{jets}, m_{jj} and $cos\theta_{CS}$.

5 Summary

Recent progresses from ATLAS experiment of gauge boson production in association with jets are presented here, which intensively improved the understanding of the electroweak sector of SM. Fiducial cross sections of multiple processes have been measured and provide a solid test of SM parameters with consistence observed within experimental uncertainties. Such measurements are crucial for the understanding of perturbative QCD which can be used as the guideline for MC simulation and modelling. As the important background for BSM and Higgs measurement, the precise measurement of such processes helps to understand irreducible background and work as sensitive probes to BSM physics as well.

We do believe and look forward to that with the development of the measurement of gauge boson interaction, the new techniques will be pushed forward and more precise results can be achieved with the benefits of the increase of luminosity, especially for rare processes.

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