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Measurements of vector-boson scattering with the ATLAS experiment

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Measurements of diboson final states with two energetic jets allow the exploration of the electroweak production mechanism of the Standard Model using the data collected at the LHC. The ATLAS collaboration recently released new measurements exploiting Wγ, opposite sign WW and WZ final states, with the W and Z decaying leptonically. Observation of the electroweak production has been claimed in the first two channels. Inclusive and differential cross section measurements in phase spaces enhanced in the vector-boson scattering component have been performed. The growing interest in the constraint of the effective field theory operators motivated to perform interpretation in these final states.

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[*] Speaker

1. Introduction

The diboson physics program at the LHC represents a crucial test of the Standard Model (SM); a significant amount of measurements has been released from the ATLAS collaboration [1] with the interest in probing higher and higher p_{T} ranges. The vector boson scattering (VBS) mechanism is a key component of the electroweak (EWK) production of two bosons in association with two jets; it allows the direct probing of the electroweak symmetry breaking (EWSB) and it represents a portal to new physics.

2. Experimental and theoretical challenges

A typical VBS diagram and its experimental signature are shown in Fig. 1. The topology is characterized by two additional and energetic jets in the forward region and the hadronic component of the central activity (not related to the bosons) is low; these represent the two key discriminating features for this process. The EWK diboson production is a rare process [2], the VBS component cannot be directly measured due to the gauge invariance and the interference with the other EWK diagrams; the interference with the QCD part also deserves some treatment. From the theoretical point of view, in addition to the need to ensure the gauge invariance, the predictions play a role in terms of NLO corrections and the modeling of discriminating variables [3], [4].

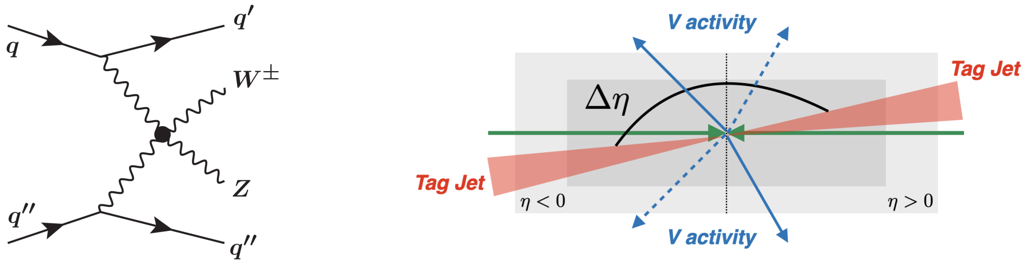

Figure 1: Typical VBS diagram with the quartic vertex of SM gauge bosons (left) [5]; schematic representation of a typical reconstruction of EWK VV+jj event with the ATLAS detector (right).

3. Observation of EWK diboson production in assosiation with two jets

The observation of the EWK diboson production in association with two jets has been claimed by the ATLAS collaboration in the Wγ+jj channel with 6.3 σ observed [6] and in the opposite sign WW+jj channel with 7.1 σ observed [7]. The Wγ is a clean final state due the presence of one lepton from the W and one photon; a typical VBS selection is applied with requirements on the invariant mass (m_{jj}) and the pseudo-rapidity difference ($\Delta\eta_{\mathrm{jj}}$) of the jets. After the full event selection, the QCD Wγ production represents the main and irreducible background; other contributions from non-prompt and fakes and top production also contribute, Fig. 2. VBS analyses usually rely on two key points. Firstly, relevant kinematic variables are used to define signal regions (SRs) and control regions (CRs), to enhance the contribution of the signal, to better constraint the amount of the background and to extrapolate it from CR to SR. This analysis uses a four-region based strategy with two variables, the multiplicity of jets reconstructed in the central region

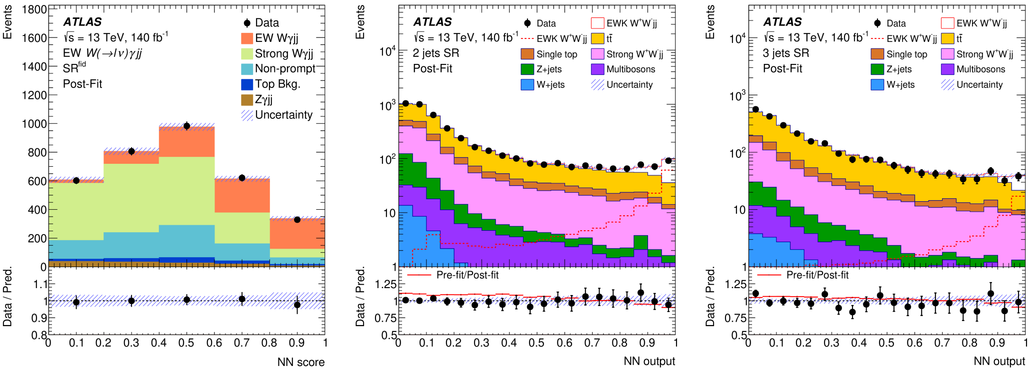

Figure 2: Distributions of data and MC prediction for the the expected SM processes of the final discriminant used in the Wγ+jj (left) [6] and opposite sign WW+jj 2-jets (middle) and 3-jets (right) SRs [7].

$N_{\text{jets}}^{\text{gap}}$ and the centrality of the lepton-photon system relative to the forward jets, j_1 and j_2, defined as $\xi_{l\gamma} = \left|(y_{l\gamma} - \frac{(y_{j_1}+y_{j_2})}{2})/(y_{j_1} - y_{j_2})\right|$. The second point is to build Machine Learning (ML) discriminants in the SR to enhance further the separation between signal and background relying on all the kinematic information in the phase space. The fiducial phase space for the opposite sign WW requires, instead, two opposite charges for an electron and a muon. The signal is enhanced with a centrality requirement and b-veto is applied to reduce the top production background. A dedicated CR (reverting the b-veto) is used to constraint this process; the other main background is represented by the QCD production of WW+jj. A ML approach is used; since the jets pairing has some intrinsic inefficiency, a looser phase space with at least three jets is used to recover signal efficiency and rely on the ML to reject the background further. A crucial separation between signal and background is reached in the SR, Fig. 2, as well as a good modelling of the discriminant. The measurement of the cross section is $2.65^{+0.49}_{-0.46}$ fb and it is limited mainly by theory uncertainties, MC statistics and jets experimental uncertainties.

4. Cross section measurements

Inclusive cross sections for the EWK production are measured in the Wγ [6] and WZ [5] final states and they are 13.2 ± 2.5 fb and 0.37 ± 0.07 fb, respectively. The cross section is measured as a function of a relevant variable after an unfolding procedure; the truth to reco correction are estimated using the MC generator and iterative Bayesian unfolding is used. The result measured in the Wγ final state analysis, introduced in the previous section, is shown in Fig. 3 as a function of the m_{jj}; the impact of the uncertainties, that are mainly, modelling and jets, is also reported.

The WZ phase space requires exactly three leptons and a loose m_{jj} requirement. The QCD WZ+jj production represents an irreducible background; an additional lepton is required to build a CR to constrain the ZZ production and b-jets are required to build b-CR and constrain the tt+V process. A ML approach is used for the final discriminant; a BDT is trained in SR to enhance the EWK WZ+jj vs the other backgrounds, a second one to separate the ttV and the tZj in the b-CR to constrain both of them in the same CR; an adversarial neural network is used to separate also the QCD WZjj in the SR. Both the EWK and the QCD components of the WZ+jj production are

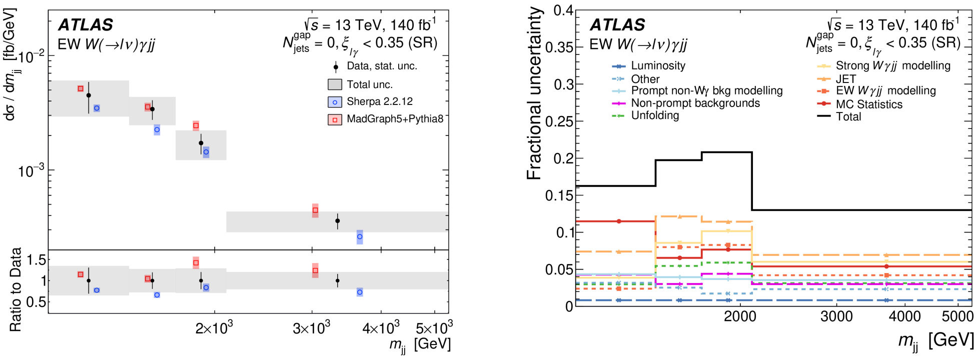

Figure 3: Differential cross section measured in data compared to Sherpa and MadGraph MC generators (left) and relative impact of the different source of uncertainties (right) as a function of the m_{jj} [6].

constrained in this measurement, mainly, in a couple of jets multiplicity bins and in three m_{jj} bins. The QCD component is overestimated in the MC prediction and it is scaled down by the measured 0.71 factor before the unfolding procedure. The unfolded data are compared to the EWK and QCD predictions, Fig. 4.

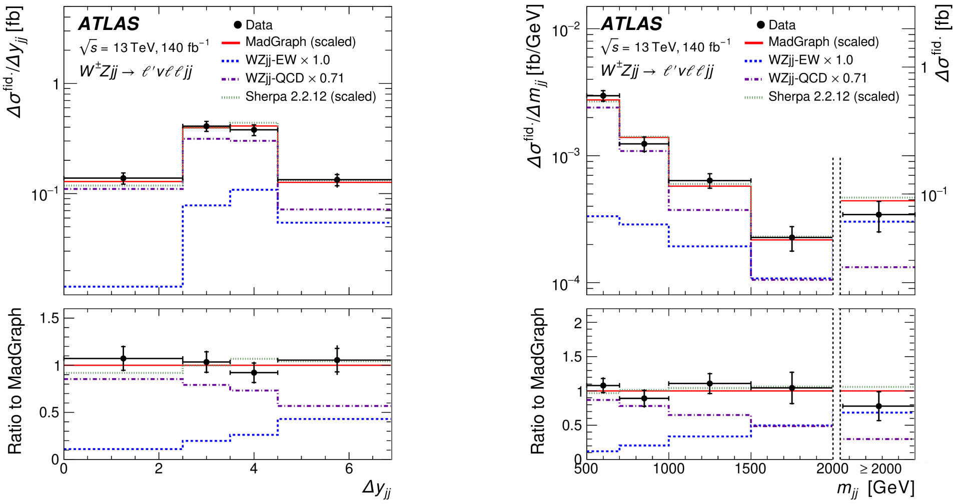

Figure 4: Differential cross section measured in data compared to Sherpa and MadGraph MC generators as a function of $\Delta\eta_{\text{jj}}$ (left) and mjj (right); the measurement is performed in inclusive QCD+EWK phase space [5].

5. EFT interpretation

The final states presented and, in general, VBS analyses, allow the constraint of new physics using a dim-8 EFT model [8]. The Lagrangian can be parameterised with additional terms written as operators, scalar, tensor or mixed; they affect the SM predictions usually at high momentum of the diboson system. The data in the tails are sensitive and can be interpreted in this theoretical framework; a clipping method is usually adopted to release results that guarantee the unitarisation as a function of the diboson system. Both the Wγ and the WZ analyses give interpretations covering a large set of operators; the WZ channel allows stronger constraints while the Wγ covers complemetary operators. The operators are constrained using the p_{T} of the lepton or of the jj system in the Wγ final state. In the WZ channel, a 2d fit approach is used combining the BDT score and the WZ transverse mass to enhance the sensitivity. Results for the T3 and T1 operators are shown in Fig. 5.

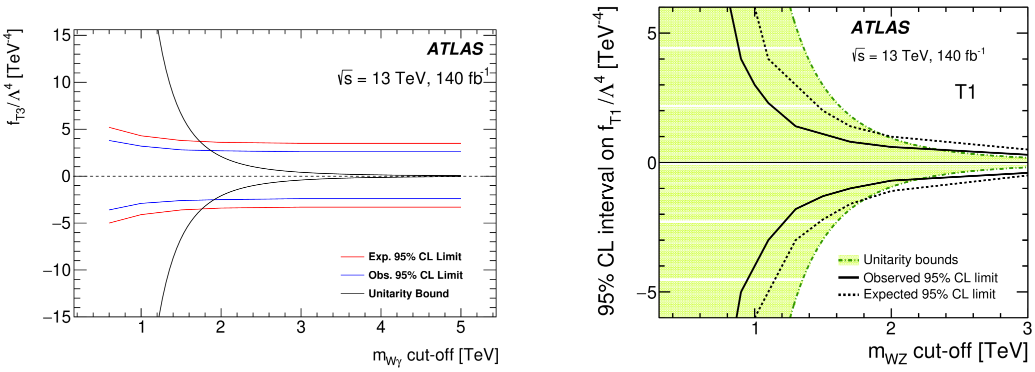

Figure 5: Limits on the Wilson coefficient as a function of the clipping value on the Wy invariant mass system and T3 operator (left) [6] and on the WZ invariant mass system and T1 operator (right) [5]; the expected and observed limits are compared with the unitarity bounds.

6. Summary

EWK measurements in VBS enhanced phase spaces are a crucial test of the EWK sector and all the challenges motivated the development of improvements in the analyses. The focus of this contribution has been on recent results in three final states, among the measurements available in many other analyses. Constraints on BSM using dim-8 EFT operator have been also presented.

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