PROCEEDINGS OF SCIENCE

Vector boson plus jets measurements at ATLAS / CMS / LHCb

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The study of vector boson production in association with jets (V+jets, where V = W, Z, γ) is a crucial component of the LHC physics program. These processes serve both as stringent tests of perturbative Quantum Chromodynamics (pQCD) and as important backgrounds in searches for new physics and precision measurements, including Higgs boson studies and top quark analyses. Precise modeling and measurement of V+jets final states provide valuable constraints on theoretical predictions and Monte Carlo (MC) event generators, especially in regions of high jet multiplicity or large transverse momentum. In this contribution recent V + jets measurements by the ATLAS, CMS and LHCb experiments are reviewd. These includes, the evidence of longitudinally polarised W bosons, the measurement of EW γ + jets production, cross section measurements for the production of of a W boson + high p_T jets and the search for rare decays $Z \to D^0\gamma$ and $W^+ \to D_s^+\gamma$.

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1. Introduction

At the LHC, spin-1 vector bosons — such as the W, Z, and γ— are produced in abundance in proton-proton collisions [1]. The study of their production in association with jets (V+jets) is a cornerstone of the LHC physics program, offering valuable insights into both the quantum chromodynamics (QCD) and electroweak (EW) sectors of the standard model (SM). In the QCD domain, V+jets processes provide a critical probe of the strong interaction. They are instrumental in constraining and refining parton distribution functions (PDFs), and serve as an essential input for the tuning of Monte Carlo (MC) event generators, which are indispensable for accurate theoretical predictions. Moreover, due to their high cross sections and kinematic similarity to many signals, V+jets processes represent significant backgrounds in searches for new physics and in precision SM measurements. From the electroweak perspective, V+jets measurements allow for the study of higher-order EW corrections and the interplay between QCD and EW effects. These processes are also sensitive to potential deviations from SM predictions, such as anomalous gauge couplings, making them a powerful tool for probing the gauge structure of the SM. This proceeding summarizes recent results on vector boson production in association with jets,

2. Evidence for Longitudinal Polarization in Same-Sign W Boson Scattering

A study of same-sign W boson pair production in association with two jets by the ATLAS experiment provides the first evidence for longitudinally polarized W bosons in vector boson scattering (VBS) [2]. The signal is categorized into three polarization states: both transverse (TT), one transverse and one longitudinal (TL), and both longitudinal (LL). The analysis is performed in the dileptonic channel using Sherpa 3.0 simulations as polarization templates. Events are selected with exactly two leptons, two jets with high invariant mass and separation, and significant missing transverse energy. Deep neural networks (DNNs) are employed to separate signal from background and to isolate polarization components. A shape-based maximum likelihood fit of the signal DNN scores provides evidence for the presence of longitudinally polarized W bosons. The measurement is statistically limited, indicating strong potential for improvement with future data.

3. Observation of Electroweak Photon Production in Association with Jets

CMS presented the first observation of EW photon production in association with two jets (γjj) at the LHC [3]. Despite its small cross-section, this process serves as a sensitive probe of the electroweak sector and anomalous triple gauge couplings. The primary challenge is the large QCD-induced photon production background, which is approximately 30 times more abundant than the EWK signal. Events are selected with two jets having large invariant mass and rapidity separation, and at least one photon with $p_T > 200$ GeV. A boosted decision tree (BDT) is trained to distinguish signal from background. The observed cross section agrees well with Standard Model predictions, with a relative uncertainty of approximately 15%. Differential cross sections are measured as a function of several observables, including the Zeppenfeld variable, dijet invariant mass, and photon p_T. While the modeling is generally accurate, discrepancies are observed in variables related to individual photons and jets. A rapidity gap analysis is also performed to study

color flow suppression between the tagging jets, confirming the VBF topology. Simulations with MadGraph5_aMC@NLO + Pythia8 show good agreement with data. An effective field theory (EFT) interpretation sets limits on operators affecting triple and quartic gauge couplings, using a DNN to distinguish EFT-like from SM-like events.

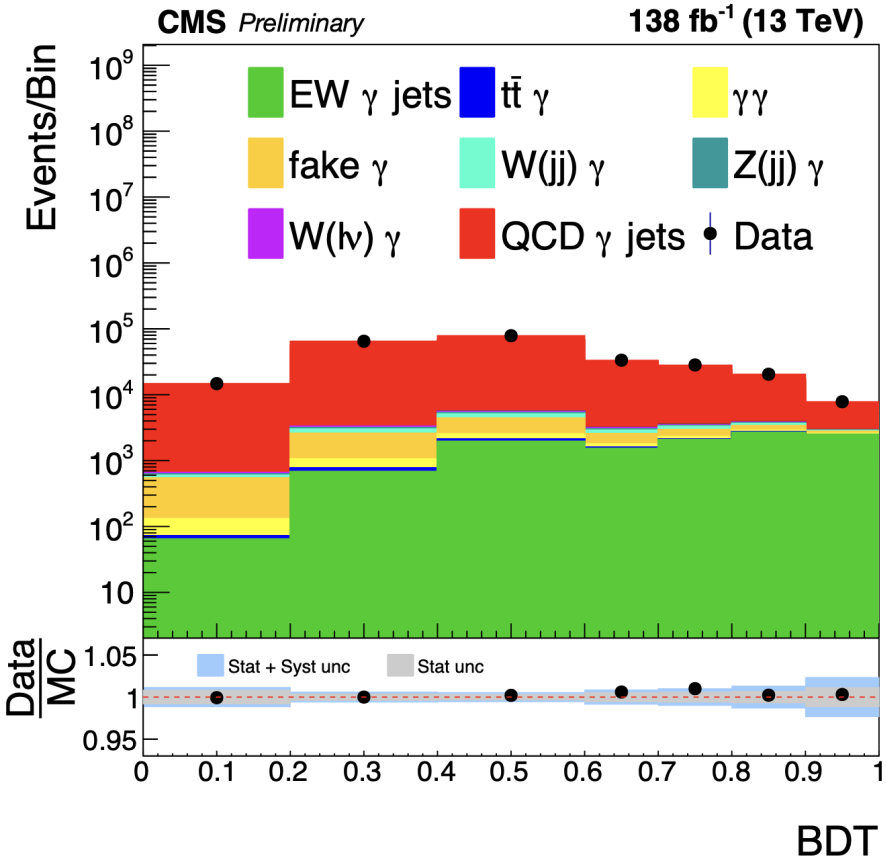

Figure 1: The postfit BDT output distribution. The data are compared to the sum of the signal and the background contributions. The black points with error bars represent the data and their statistical uncertainties, whereas the solid bands represent the statistical uncertainty in the combined signal and background expectations. The lower panel shows the ratio of the data to simulation.

4. Measurement of W Boson Production in Association with High-p_T Jets

The inclusive and differential cross sections of W boson production in association with high-p_T jets are measured by the ATLAS experiment [4], targeting events where the W boson decays leptonically and the leading jet has $p_T > 500$ GeV. Additional regions are defined to explore specific kinematic configurations: inclusive 2-jet, collinear, and back-to-back regions. State-of-the-art event generators (Sherpa 2.2.11 and MadGraph5_aMC@NLO + Pythia8) are compared with the data. Inclusive cross section measurements show that experimental uncertainties are smaller than theoretical ones. Fixed-order NNLO predictions from MCFM describe the data well, though inclusion of electroweak corrections leads to a 10% deficit. Differential measurements are

performed as functions of the lepton–jet angular separation, the p_T ratio of the $\ell\nu$ system to the jet, and the dijet invariant mass. Results confirm collinear enhancements in W+jets production and serve as stringent tests of higher-order predictions. Sherpa provides better modeling in the boosted regime, although theoretical uncertainties remain larger.

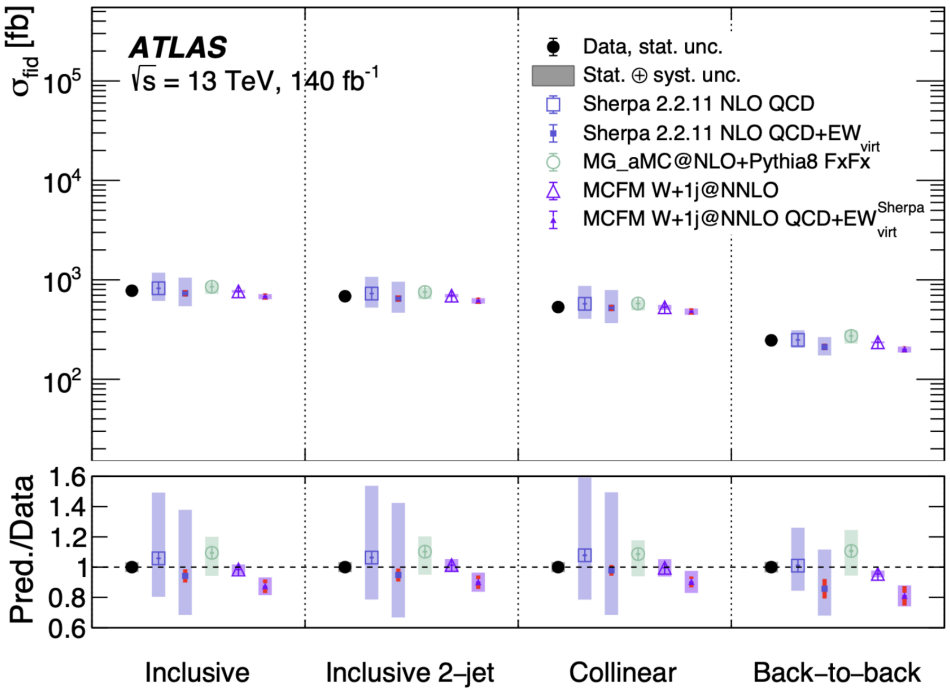

Figure 2: Measured fiducial cross-sections in each signal region are shown with total uncertainties (solid dots and error bands) and statistical uncertainties (small error bars). Various theoretical predictions (NLO, NLO+EWvirt, NNLO) are overlaid with their corresponding uncertainties: QCD scale and PDF for NLO, electroweak scheme variations for NLO+EWvirt, and MCFM-based uncertainties for NNLO. Shaded areas indicate total theoretical uncertainty, while error bars show electroweak correction uncertainties.

5. Search for Rare Decays of W and Z Bosons to D Mesons and Photons

Using the LHCb detector, a search is conducted for the rare decays $W \to D_s\gamma$ and $Z \to D^0\gamma$ [5]. These processes are highly suppressed in the Standard Model and have not been observed. For $Z \to D^0\gamma$, the D^0 meson is reconstructed from two tracks with $p_T > 0.5$ GeV, at least one with $p_T > 5$ GeV. The photon is required to have $E_T > 15$ GeV. The Z candidate mass must lie between 30 and 130 GeV. The $W \to D_s\gamma$ channel uses similar criteria, with the D_s reconstructed from three tracks. Background modeling is performed using mass sidebands and a KDE-based pseudo-data generation approach. A pseudo-mass fit is used to extract yields, and upper limits are set at 95% confidence level. The limit obtained for the W boson decay is the most stringent to date. With upcoming upgrades to the LHCb detector, sensitivity to such rare processes is expected to improve significantly.

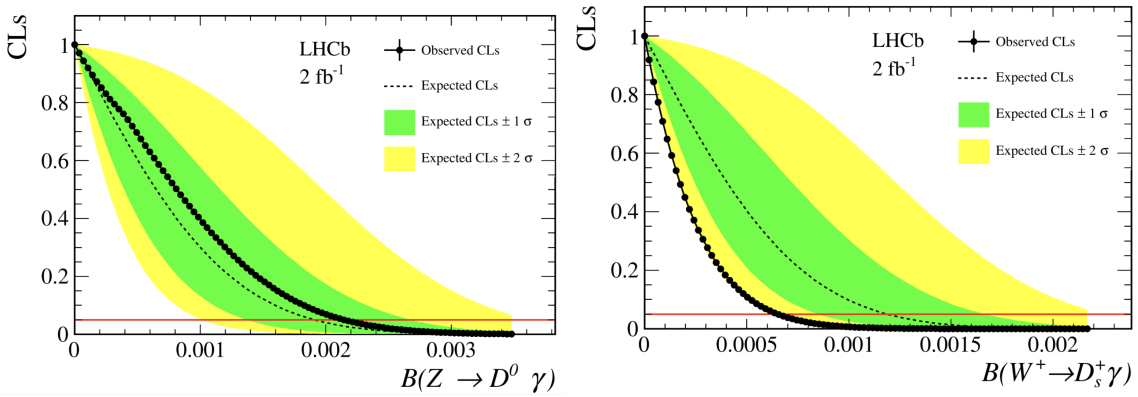

Figure 3: Upper limits on branching fractions of the (left) $W^+ \to D_s^+\gamma$ and (right) $Z \to D^0\gamma$ decays.

Conclusion

Studies of vector boson production in association with jets have been presented. The recent measurements by ATLAS, CMS, and LHCb—including evidence for longitudinally polarized W bosons, electroweak γ+jets production, high-p_{T} W+jets cross sections, and searches for rare decays such as $Z \to D^0\gamma$ and $W^+ \to D_s^+\gamma$—represent significant progress in testing the Standard Model at high precision. These results provide critical input for tuning Monte Carlo event generators. Looking ahead, further measurements at higher luminosities and in extended phase space will be essential for refining theoretical predictions and enhancing the sensitivity of searches for new physics at the LHC.

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