PROCEEDINGS OF SCIENCE

Associated production of a vector boson and jets at CMS

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The production cross section of highly boosted vector bosons (V = W, Z or γ) recoiling against jets is studied, with CMS data, differentially as function of the transverse momentum and angular correlations of the final state particles. The measurements are confronted with different state-of-the-art theory predictions that include next-to-leading order calculations and matrix-element plus parton shower event simulations.

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1. Introduction

Vector bosons (Z / W / γ) produced in association with jets provide a way to test pertubative Quantum Chromodynamics (pQCD) predictions to high precision. Small theoretical uncertainty on the production and small experimental uncertainty on the selection of vector boson plus jets processes make it possible to study higher order pertubative effects and parton distribution functions (PDFs). Moreover, the vector boson + jets are important for modeling backgrounds for beyond the Standard Model (BSM) searches and Higgs studies.

In this report, more recent mesurements of vector boson in association with jets are overviewed based on mostly 7 TeV proton-proton collisions data collected by the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) [1]. Comparisons of measured values with predictions by both Monte Carlo (MC) generators and next-to-leading order (NLO) calculations are discussed.

2. Z/γ + 1 jet rapidity distributions

Rapidity distributions of events containing either a Z boson or a photon with exactly one jet are measured by using a data sample collected with the CMS detector at $\sqrt{s}$ = 7 TeV corresponding to an integrated luminosity of 5.0 fb^{-1} [2]. Data individual rapidity distributions of the boson and the jet are found to be in agreement with NLO predictions (by MCFM [3] for Z + jet part and by Owens [4] for γ + jet part), SHERPA [5], and MADGRAPH [6]. However, theory predictions for the sum (y_{sum} = $|y_{Z/\gamma} + y_{jet}|$ / 2) and the difference (y_{dif} = $|y_{Z/\gamma} - y_{jet}|$ / 2) in rapidities of the two final-state objects exhibit discrepancies with data. Particularly, NLO QCD calculations and two common MC event generators using different methods to match matrix-element partons with parton showers, appear inconsistent with Z + 1 jet data as well as with each other as shown in Figure 1.

3. γ + jets differential production cross section

A measurement of the triple-differential production cross section in photon + jets final states is performed by using a data sample of 2.14 fb^{-1} integrated luminosity collected by CMS at $\sqrt{s}$ = 7 TeV [7]. Phase space of reconstructed photons and jets cover a pseudorapidity range of $|\eta|$ < 2.5 and transverse momenta in the range 40 < p_T^{γ} < 300 GeV and p_T^{jet} > 30 GeV, respectively. The measurements are compared to theoretical predictions from the SHERPA leading-order QCD MC event generator and the NLO perturbative QCD calculation by JETPHOX [8]. The predictions show agreement with data over most of the examined kinematic region except for cases of photons measured in the largest pseudorapidity region (2.1 < $|\eta^{\gamma}|$ < 2.5) as observed from the data / theory ratio comparisons in Figure 2.

4. Z + jets differential production cross section

In this study, a measurement of differential production cross sections for the Z boson and associated jets is presented with data corresponding to a total integrated luminosity of 4.9 fb^{-1} recorded

by CMS at $\sqrt{s}$ = 7 TeV [9]. The differential production cross sections of Z boson candidates in both dielectron and dimuon channels in association with jets are measured as functions of exclusive / inclusive jet multiplicities up to 6 jets, transverse momentum and pseudorapidity for the four most energetic jets, and scalar sum of jet transverse momenta (H_T) for jet multiplicity (N_{jets}) $\geq$ 1, 2, 3, and 4. MC event generators at leading-order (SHERPA and MADGRAPH plus PYTHIA 6 [10]) and NLO calculation (POWHEG-BOX [11] plus PYTHIA 6) show satisfactory agreement with data on all measured distributions. MC predictions tend to underestimate data on jet multiplicities within uncertainties as can be interpreted from the left plot of Figure 3.

5. W + jets differential production cross section

The measurement of the production cross section for W + jets processes in muon channel is presented with data corresponding to an integrated luminosity of 5.0 fb^{-1} recorded by CMS at $\sqrt{s}$ = 7 TeV [12]. Differential distributions are given as a function of several variables similar to the previous work [9] inculding also the difference in azimuthal angle between each jet and the muon. The predictions from MC generators (MADGRAPH + PYTHIA and SHERPA at leading-order) and the NLO calculations from BLACKHAT + SHERPA [13] are observed to be describing the measured cross sections reasonably well. MC predictions tend to overestimate data on jet multiplicities within uncertainties as opposed to the case in the previous study [9], which can be seen from the right plot of Figure 3.

6. Z + 2 jets electroweak production cross section

The measurement of the electroweak production cross section of Z boson with two forward / backward jets is presented [14] based on a data sample recorded by the CMS experiment at $\sqrt{s}$ = 8 TeV with an integrated luminosity of 19.7 fb^{-1}, in paralel to the previous study of the same kind performed at $\sqrt{s}$ = 7 TeV [15]. In this study, different methods are used to extract the signal including a data-driven approach that models the QCD Z + dijet background based on γ + dijet events. The cross section for this process is measured in both dielectron and dimuon final states in the kinematic region of dilepton invariant mass $m_{ll} > 50$ GeV, dijet invariant mass $m_{jj} > 120$ GeV, and pseudorapidity $|\eta_j| < 5.0$. The combination of measured cross sections in dimuon channel yields $\sigma = 226 \pm 26_{stat} \pm 35_{syst}$ fb, which is in agreement with the theoretical cross section.

7. Other results

In addition to the above studies, Z + jets azimuthal correlations and event shapes [16], Z + 2 jets electroweak production cross section at $\sqrt{s}$ = 7 TeV [15], W + jets dijet mass spectrum [17], and W + 2 jets double parton scattering [18] measurements have been performed as part of the CMS Physics program regarding vector boson and associated jets productions.

8. Summary

In the CMS experiment, Z / W / γ + light jets productions are explored in the most relevant areas with 7 TeV data. Overall, good agreements between data and predictions including MC

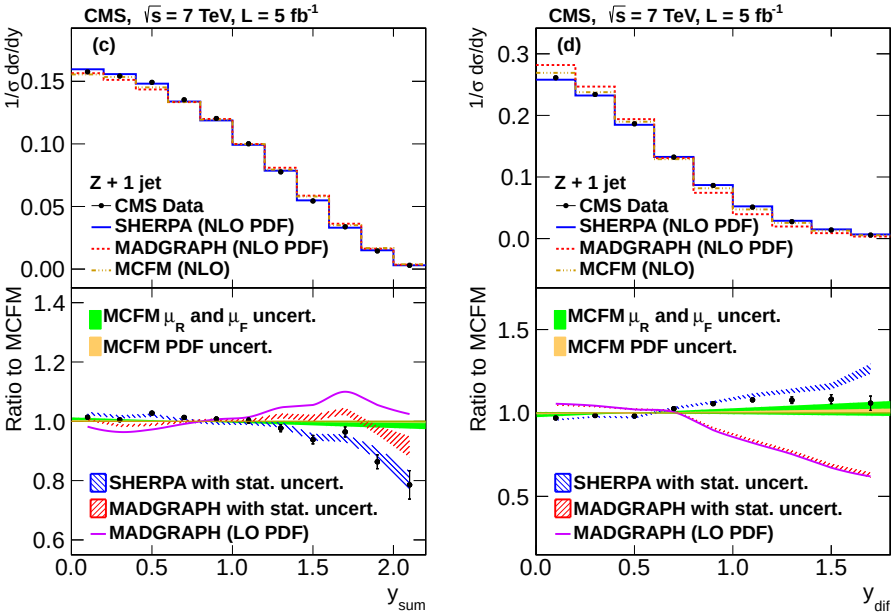

Figure 1: Distributions for the sum (left) and the difference (right) rapidities in Z + 1 jet data, normalized to unity. The data are shown after correcting for efficiency and resolution, and displayed with statistical and systematic uncertainties combined in quadrature. The ratio error bars include MCFM statistical uncertainties folded with data statistical and systematic uncertainties.

event generators and NLO calculations are observed in all measurements briefly overviewed in this report. However, discrepancies observed in some cases which point to a need for more detailed understanding of the differences between generator implementations, matching schemes, and so on. In combination with the ongoing analyses of the 8 TeV dataset, CMS Standard Model vector boson plus jets physics program will provide an excellent benchmark to tune the predictions and prepare for the next LHC run.

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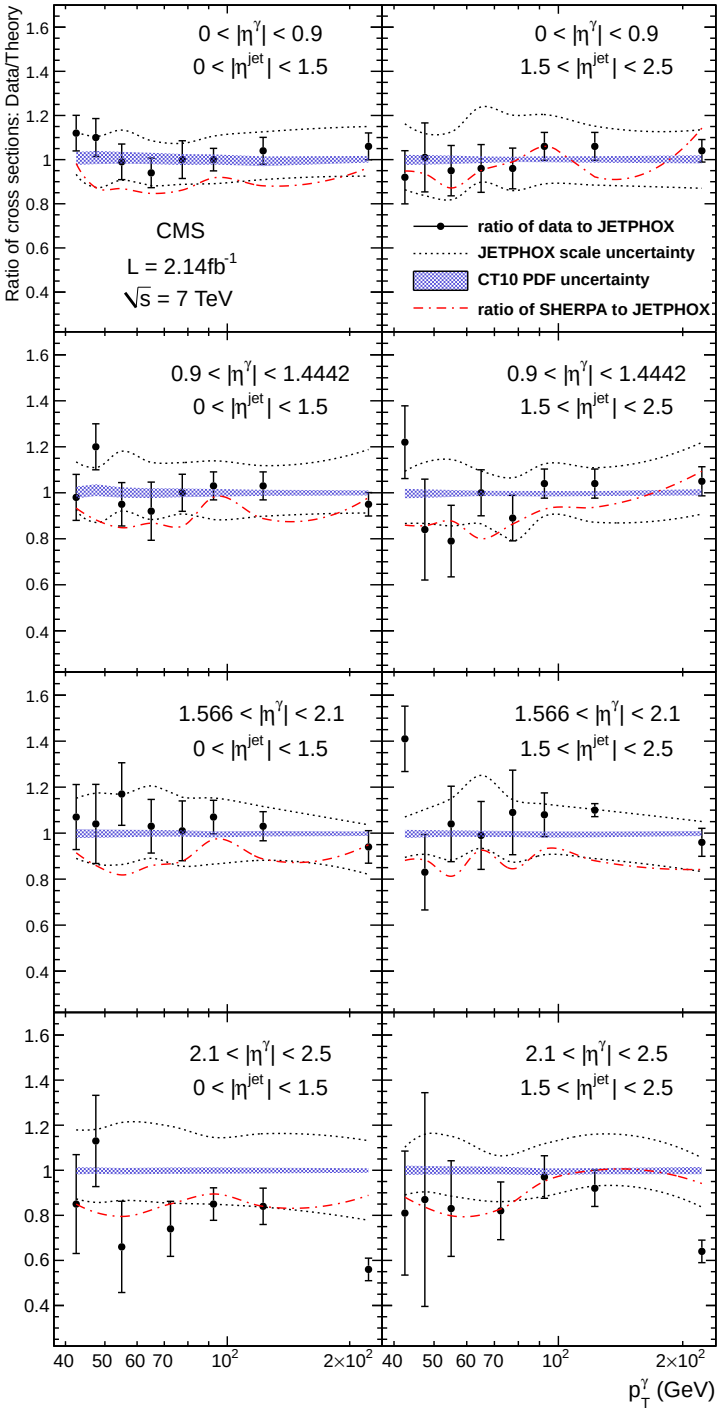

Figure 2: The ratios of the measured triple-differential cross sections to the NLO prediction by JETPHOX in 8 different photon and jet pseudorapidity regions. The vertical lines on the points show the statistical and systematic uncertainties added in quadrature.

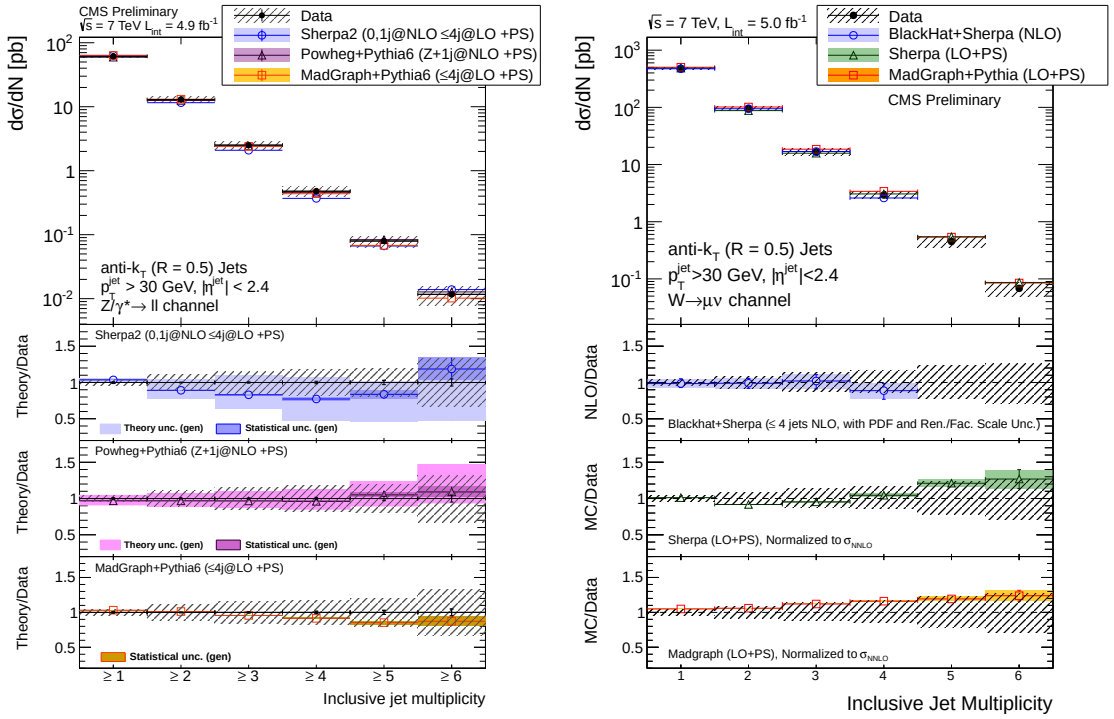

Figure 3: On the left, inclusive jet multiplicity distribution for the Z + jets processes is displayed with comparisons to SHERPA, POWHEG-BOX and MADGRAPH predictions. Error bars around the experimental points represent the statistical uncertainty, while crosshatched bands represent statistical plus systematic uncertainty. On the right, inclusive jet multiplicity distribution for the W + jets processes is shown with comparisons to the predictions of MADGRAPH + PYTHIA, SHERPA, and BLACKHAT + SHERPA. Black circular markers with the gray hatched band represent the data measurement and its uncertainty. Overlaid are the MC predictions together with their statistical uncertainties error bars. In both distributions, lower plots show the ratio of each prediction to data.

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