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Jets produced in association with W and Z bosons in CMS

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Summary. — The measurement of W and Z plus jets final states at the LHC allows for stringent tests of perturbative QCD calculations in the context of the Standard Model and is sensitive to the possible presence of new physics. A study of jet production in association with a vector boson in proton-proton collisions at a 7 TeV center-of-mass energy is presented, using data collected with the CMS detector. The measured jet multiplicity distributions, corrected for efficiency and unfolded for detector effects, are compared with theoretical predictions. The study includes the measurement of the normalized inclusive rates of jets and of the ratio W/Z. A test of the jet multiplicity scaling at $\sqrt{s} = 7\,\text{TeV}$ is also presented.

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1. – Introduction

The study of W and Z vector boson production in association with hadronic jets ($V +$jets) in proton-proton collisions represents an important test of perturbative QCD calculations. The production cross section of a Z(W) boson has been calculated at Next-to-Leading-Order (NLO) precision for events with up to 4 associated jets. The uncertainties related to such calculations are not negligible due to their intrinsic complexity and to the uncertainties about the partonic distribution functions of the proton. Moreover, $V +$jets processes represent an irreducible background to some important Standard Model Higgs boson decay channels, to the study of top quark processes and to interesting searches for new physiscs. A good understanding of these processes is thus of primary importance in all those fields. We measured $V +$jets cross sections in order to provide an experimental test of the theoretical predictions at the center of mass energy $\sqrt{s} = 7\,\text{TeV}$ of the Large Hadron Collider (LHC). The dataset used for this analysis [1] corresponds to the data collected by the Compact Muon Solenoid (CMS) [2] experiment during the 2010 data-taking period and consists of an integrated luminosity of $(35.9 \pm 1.4)\,\text{pb}^{-1}$.

2. – Event selection

The interesting events for this analysis are selected by means of a dedicated path of the CMS trigger system, designed to select events containing at least a well isolated single lepton. A trigger-level threshold on the transverse momentum of 17(15) GeV for electrons (muons) has been used. The events with a positive trigger flag undergo the standard reconstruction process: electron and muon tracks are built with a Gaussian-Sum-Filter procedure and a Kalman filter respectively, while the collection of hadronic jets is built up with a clustering algorithm starting from Particle Flow candidate particles. Isolated leptons are removed from the jet collection. We require reconstructed leptons to have a transverse momentum $p_T > 20\,\mathrm{GeV}$, to be in the electromagnetic calorimeter acceptance ($|\eta| < 1.4442$ and $1.566 < |\eta| < 2.5$) and to be matched to a trigger candidate. Eventually, we apply selection cuts to a set of variables inherent to the signal quality and isolation of leptons in the detector and we reject spurious leptons from photon conversions. The set of selection cuts has been optimized on a simulated data sample for the signal efficiency to be roughly equal to 80%. Events with two selected leptons in the invariant mass window $60\,\mathrm{GeV} < m_{ll} < 120\,\mathrm{GeV}$ are used to build the Z sample, while events with a single selected lepton with transverse mass $m_T > 20\,\mathrm{GeV}$ are used to build the W sample. The hadronic jets from the standard clustering algorithm are tuned to the correct energy scale (JES) and corrected for pile-up contributions. We eventually compute the jet multiplicity with a threshold on the transverse jet energy $E_T > 30\,\mathrm{GeV}$.

3. – Simulation

Monte Carlo $V +$ jets events are produced with the matrix element *MadGraph* [3] generator at parton level. *MadGraph* is able to compute the matrix element for events with a vector boson and up to 4 outgoing partons. The final states are then processed with the parton shower technique by means of the *PYTHIA* [4] generator. A similar procedure is used to generate the top quark background processes, while QCD, γ+jets and minimum bias events processes are completely generated within the *PYTHIA* framework. Particle crossing and detection through the CMS detector is simulated within the *Geant4* [5] framework. The comparison between experimental and simulated data shows indeed a good agreement of the jet multiplicity distributions up to four associated jets.

4. – Detection efficiency and signal extraction

In order to get the correct measurement of the $V +$jets cross sections, it is necessary to accurately estimate the detection efficiencies of the lepton decay products of the Z boson. All the efficiencies are measured with a data-driven *Tag&Probe* method which exploits the invariant mass distribution of the two selected leptons around the Z mass value. We extract the signal and background components via an unbinned extended Maximum-Likelihood fit: both the signal and background distribution fractions are modelled with analytical functions [6]. The efficiency-corrected jet multiplicity distribution has been treated with an unfolding technique in order to deconvolve the detector effects and to provide the corresponding particle-level distribution.

The same *Tag&Probe* fitting technique has been exploited to extract the signal yield from the raw Z sample, where the background is very little. The background component is more prominent in the W sample, with a large fraction of both QCD and $t\bar{t}$ events not

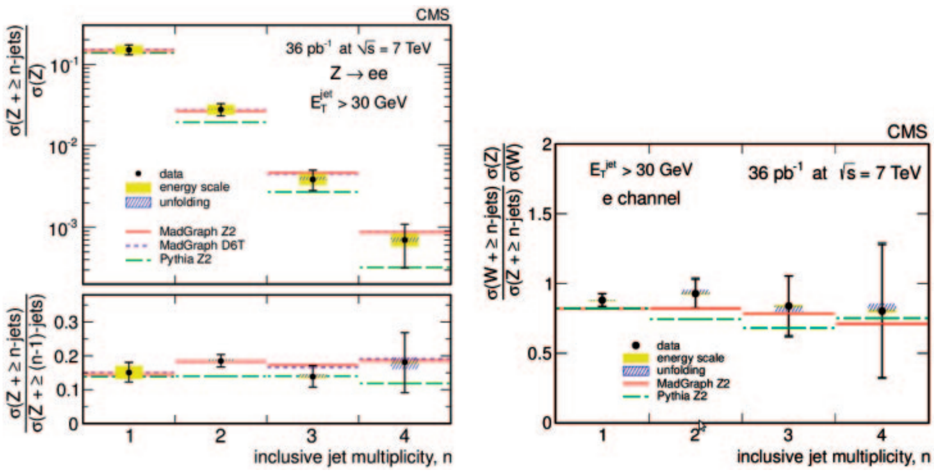

Fig. 1. – Left: exclusive Z+jets cross sections in the electron decay channel. The bottom part of the plot shows the behaviour of the cross section scaling: $\sigma(V+\geq n \text{ jets})/(V+\geq (n-1) \text{ jets})$. Right: values of the W/Z ratio: $\sigma(W+\geq n \text{ jets})/\sigma(Z+\geq n \text{ jets})$ in the electron channel.

eliminated by the selection cuts. A special template is used to fit the transverse mass distribution of the decay lepton in different channels of b-tagged jet multiplicity.

5. – Results

We have measured the exclusive vector boson cross sections with respect to the associated number of jets, providing the results for the following ratios (fig. 1): $\sigma(V+\geq n \text{ jets})/\sigma(V)$ and $\sigma(V+\geq n \text{ jets})/(V+\geq (n-1) \text{ jets})$. In particular, the second ratio describes the scaling of the cross section as a function of the jet multiplicity and is predicted to be constant by NLO calculations. In order to probe for eventual deviations from the theory we have compared the scaling with a linear function and the resulting angular coefficient is compatible with zero. Thus we have no evidence, with the available amount of data, of significative deviations from the theoretical predictions. Eventually, we computed the ratio between W and Z exclusive cross sections: $\sigma(\mathrm{W}+\geq n \text{ jets})/\sigma(\mathrm{Z}+\geq n \text{ jets})$. The result of this ratio is essentially independent from the associated number of jets, in good agreement with Standard Model predictions.

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