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CMS CR -2009/191

The Compact Muon Solenoid Experiment

Conference Report

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21 July 2009

Measurement of W and Z production in association with jets with CMS detector.

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Abstract

We present a feasibility study of the Z and W boson production in association with jets with the first LHC data recorded by CMS detector with pp collisions at $\sqrt{s} = 10$ TeV.

Presented at *IFAE 2009,15-19/April/2009,Bari,Italy,30/06/2009*

1 Introduction

The study of vector boson ($VB = W, Z$) production in association with jets at the LHC represents one of the challenges in the physics program of the first run. The VB + jets events represent the benchmark channels to provide stringent tests of the perturbative QCD predictions within the Standard Model (SM). The VB + high jet multiplicity states, moreover, represent one of the main backgrounds for searches. Within the SM the VB + n jets cross section is $\mathcal{O}(\alpha_s)$. The $VB + n$ jets over $VB + (n+1)$ jets yield ratio is expected to be constant as a function of n[1, 2]. QCD predicts for the W+jets and Z+jets very similar accompanying final states as one would naively expect, resulting in a double ratio $C_W/C_Z \equiv \frac{\mathrm{W+njets/W+(n+1)jets}}{\mathrm{Z+njets/Z+(n+1)jets}}$ consistent with 1, independent of jet multiplicity.

The purpose of the Z+jets measurement (*candle*) is to measure the ration $Z + n$ jets over $Z + (n+1)$ at different multiplicities to investigate the correctness of the theoretical prediction, select a pure Z+jets sample that can be used for detector and physics commissioning and to probe the existence of new physics (NP) processes with multijets and a real Z boson in the final state. The purpose of the measurement of double ratio C_W/C_Z (*ratio*) is to investigate to what extent it is independent of jet multiplicity and to provide a method of determining the W+jets absolute rate normalization in the higher jet multiplicities, given the absolute rate of Z+jets events. A strong dependence of the double ratio on the number of jets could be an indication of NP.

2 The CMS detector and Event Simulation

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [3]. The central feature of the CMS apparatus is a superconducting solenoid, of 6 m internal diameter. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass-scintillator hadronic calorimeter (HCAL). Muons are measured in gas chambers embedded in the iron return yoke. Besides the barrel and endcap detectors, CMS has extensive forward calorimetry. The $W(\rightarrow\ell\nu) + n$-jets events ($\ell = e, \mu$) and $Z(\rightarrow\ell\ell) + n$-jets events ($\ell = e, \mu$) are studied with Monte Carlo simulation, using the MADGRAPH [4] event generator, based on a leading-order calculation of the matrix element (ME). ME calculation is performed for final states with at most four primary partons. PYTHIA [5] is used for the parton shower, hadronization and the underlying event description. A large background component for this analysis comes from QCD multijet production. These events are generated with PYTHIA. The $t\bar{t}$+jets and single top backgrounds are generated with MADGRAPH interfaced with PYTHIA.

3 Event reconstruction and selection

The events are filtered through the CMS trigger system according single lepton paths studied for low luminosity running (L=10^{32}cm$^{-2}s^{-1}$). The offline reconstruction is applied to identify isolated electrons and muons. Additional tracks and calorimetric towers respect the primary leptons are also reconstructed. The VB candidates are formed from the full combinatorial of leptons in the event and a set of selection requirements is applied to increase the signal over background ratio (consistency of lepton with event primary vertex, strict lepton identification, veto on additional leptons). Jets are formed and the events are streamed in datasets according to the n inclusive jet multiplicity ($\geq n$). While the Z sample is pure and fully characterized by the invariant mass $m_{\ell\ell}$, the W sample is largely polluted both by multijet backgrounds not containing a real W boson, as well as $t \rightarrow Wb$ decays. To tag a W boson candidate we form its transverse mass m_T^W using the lepton p_T and the transverse calorimetric energy imbalance (MET) computed from the calorimeter towers. An extended and unbinned maximum likelihood (ML) fit to the Z mass or to the W transverse mass is used to determine the signal yield for each jet multiplicity and the fit results are used to measure the $VB + n$ jets over $VB + (n+1)$ jets ratio and the C_W/C_Z double ratio. In the W case, the extra information on the efficiency of a selection on a transverse and longitudinal impact parameters of jets is used in the ML fit to improve the W/t separation. The measurement of *candle* Z+jets keeps the selection as efficient as possible, while for the W+jets over Z+jets *ratio* the Z boson definition is synchronized with the W one, resulting less efficient with respect the *candle* analysis. The jet counting is done using “raw” calo-jets and track-jets reconstructed from calorimeter towers and tracks respectively using the Seedless Infrared Safe Cone (SISCone) jet algorithm [6] with a cone size $R_{cone} = 0.5$ in the ($\eta \times \phi$) space. The two sets of jets allow for probing different parts of the phase space ($p_T > 30$ GeV/c and $p_T > 15$ GeV, respectively) and are independent in terms of detector effects.

4 The Z+n jets over Z+$n+1$ jets yield ratio

Applying the candle Z+jets selection we expect, in 100 pb^{-1} of data collected by CMS at $\sqrt{s} = 10$ TeV, 4007 $\pm$ 37, 555 $\pm$ 14, 72 $\pm$ 5, 11 $\pm$ 2 events for $Z(\rightarrow \mu\mu)$ + $\geq$ 1, 2, 3, 4 calo-jet respectively, with a background dominated by QCD and $t\bar{t}$ events in the interval $60 < m(\ell\ell) < 110$ GeV/c^2 ($\ell = e, \mu$). Using the track-jet counting we achieve about double the signal events, with even better signal/background ratio. We expect similar yields in the electron final state. The ML fit allows to measure the Z+jets signal up to 4 jets in both final states. The fit results on 100 pb^{-1} Monte Carlo sample is shown in Fig. 1 for $Z(\rightarrow \mu\mu/ee)$ + 4 track-jets. The functional form of the $m(\ell\ell)$ for

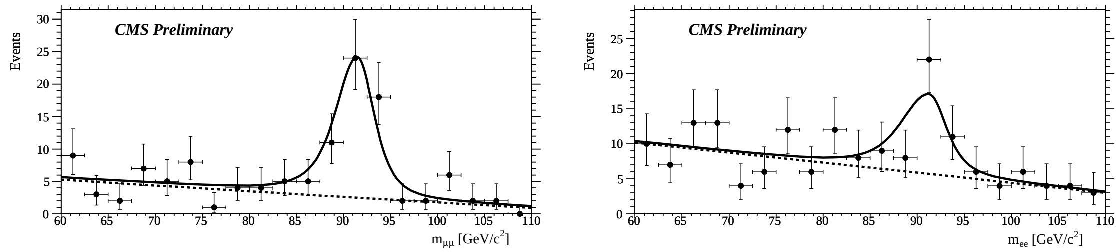

Figure 1: Invariant mass $m(\mu\mu)$ (left) and $m(ee)$ (right) for $Z+ \geq 4$ track-jets events selected in a simulated sample equivalent to 100 pb^{-1}.

signal and background are obtained from inclusive (very clean) Z analysis and from a sample obtained from data inverting the lepton isolation criteria (dominated by QCD), respectively.

With the ML fit to the four different jet multiplicity samples we measure the yields of Z+n jets as a function of jet multiplicity. Defining C as the Z+n jets over $Z + (n{+}1)$ jets yield ratio, we expect C to be independent of n, within errors. Thus physically C represents the cost of adding an extra jet to Z+n jet production at some fixed order in α_s. We find that the test can be performed already with a data sample 100 pb^{-1} (Fig. 2 for Z + calo-jets).

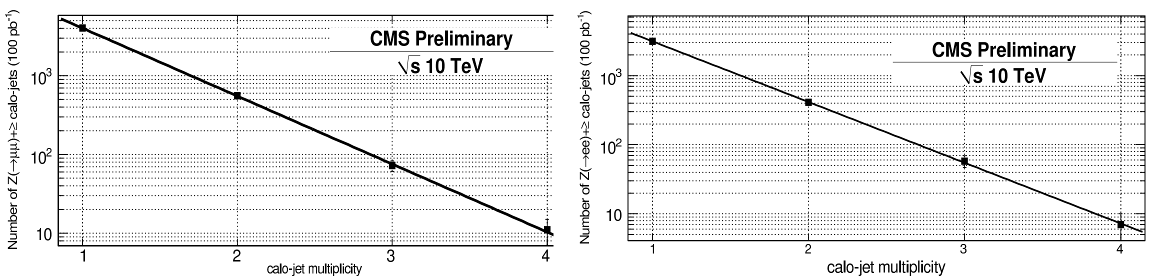

Figure 2: The $(dN/d\mathrm{n_{jet}})$ distributions and exponential fit for $Z(\rightarrow \mu\mu)+$ calo-jets (left) and $Z(\rightarrow ee)$ (right).

5 The W + n jets to Z + n jets ratio

In the case of the double ratio measurement C_W/C_Z a tighter selection to reduce the higher QCD backgrounds in the W sample is applied to the highest p_T lepton of the Z candidate, while keeping the one on the other lepton relaxed. With this strategy we achieve most of the cancellation between the W and Z efficiency in the C_W/C_Z ratio. We expect 21897 $\pm$ 95, 2922 $\pm$ 35, 389 $\pm$ 13, 54 $\pm$ 5 $W(e\nu)+ \geq$ 1, 2, 3, 4 calo-jets events in 100 pb^{-1} of integrated luminosity. For the $W(\mu\nu)$ final state we expect similar yields. In the case we use the track-jet counting we expect about three times the signal yield, with a better signal/noise ratio. Due to the tighter requirements, we expect about half of the Z+jets events with respect to the *candle* selection. In Fig. 3 we show the m_T^W for $W+ \geq$ 3 track-jets.

We find that C_{VB} is constant for all types of jet counting and for both the W+jets electron (muon) selection and Z+jets dielectron (dimuon) selection. Further we find that the double ratio C_W/C_Z is consistent with 1 within the precision obtained independent of the jet definition: 1.04 ± 0.08 (1.04 ± 0.04) for $VB(e)$ + calo-jets (track-jets) and 0.93 ± 0.06 (1.04 ± 0.03) for $VB(\mu)$ + calo-jets (track-jets). Results are not affected by correcting for the selection efficiency within each jet multiplicity bin.

Assuming that we find a constant ratio in the data, we would use the VB $+ \geq 1$ jet and VB $+ \geq 2$ jet yields

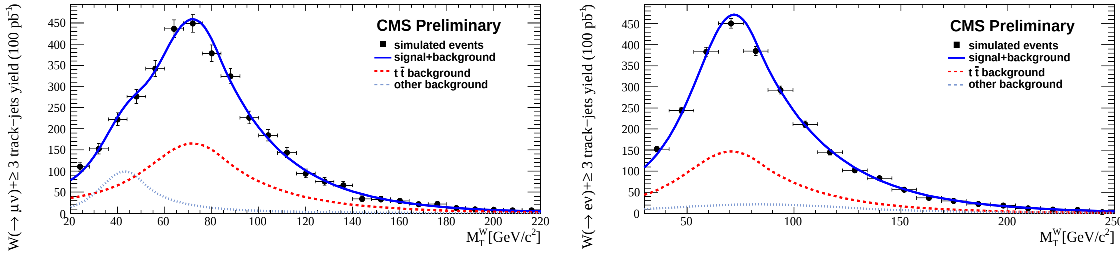

Figure 3: Transverse mass $m_T^W(\mu\nu)$ (left) and $m_T^W(e\nu)$ (right) for $Z+\geq 3$ track-jets events selected in a simulated sample equivalent to 100 pb^{-1}.

to predict the yields for higher jet multiplicities. These yields would then be used to perform a test of the SM, and to provide a data-based estimate of the VB+jets backgrounds to other SM processes as well as searches for new physics. With 100 pb^{-1} we expect to predict $W+\geq 3$ (4) jets with up to half (one fifth) the statistical uncertainty with respect the direct measurement in both muon and electron final state. Moreover the contributions of systematic uncertainties (luminosity, parton distribution functions, detector efficiency) are largely suppressed in the double ratio.

6 Conclusions

We have presented the feasibility study of the Z + n jets over Z + (n+1) jets ratio, verifying its constancy in n as predicted by QCD within the expected uncertainties of 100 pb^{-1} of data with CMS detector at LHC pp collisions with $\sqrt{s}=10$ TeV. We have also presented the study of W+jets over Z+jets ratio production, showing its constancy in n and its predictive power of $W+\geq$ 3,4 jets, which is the background to SM processes as well as NP searches.

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