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Diboson production at CMS

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We present an analysis strategy based on Monte Carlo simulations for measuring the WW and WZ production cross sections in pp collisions with the CMS detector. We describe suitable requirements for background reduction and data-driven methods to estimate the remaining backgrounds. We report the event yields and statistical and systematic uncertainties that we expect to achieve with a few hundred inverse picobarns of data.

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1. Introduction

The Compact Muon Solenoid (CMS) detector [1] at the CERN pp Large Hadron Collider (LHC) [2] is a general purpose detector consisting of a pixel and silicon-strip tracker (SST) immersed in a 3.8 T axial magnetic field provided by a superconducting solenoid, a scintillating $\mathrm{PbWO_4}$ crystals electromagnetic calorimeter (ECAL), and a brass-scintillator hadronic calorimeter (HCAL). A forward calorimeter (HF) covers the region at large pseudorapidity to $|\eta| = 5.2$. Muons are measured in layers of three types of gaseous detectors installed in the iron yoke: Drift Tubes (DT), Cathod Strip Chambers (CSC), and Resistive Plate Chambers (RPC). Since March 2010 the LHC is providing pp collision at an unprecedented center of mass energy of $\sqrt{s} = 7$ TeV, and physics results from these collisions data have been released [3]. It is expected that the CMS detector will collect, by the end of 2011, an integrated luminosity on the order of 100 pb^{-1}.

Measurements of diboson production at LHC will probe the Standard Model (SM) at the TeV energy frontier and will search for evidence of new physics. In the SM, the WW and WZ production rate is sensitive to the WWZ and $\mathrm{WW}\gamma$ triple gauge couplings. Physics beyond the SM could enhance the production cross section thanks to anomalous vector boson couplings [4]. From an experimental perspective, diboson channels represent a source of background for Higgs and Supersymmetry searches, thus the production cross sections need to be precisely understood. Recent measurements have been published by Tevatron experiments [5], [6], [7], [8].

In this article we present analysis strategies for measuring WW and WZ processes at CMS. They have been developed on signal and background Monte Carlo (MC) samples processed with the full simulation of the CMS detector.

2. Study of WW production

WW events are reconstructed in decay modes where each W boson decays leptonically. The final state is characterized by the presence of a lepton pair ($\mathrm{e^+e^-}$, $\mu^+\mu^-$, or $\mathrm{e}\mu$) plus large missing transverse energy (MET) due to the undetected neutrinos [9]. The background sources are $\mathrm{W}+$jets, Drell-Yan, $t\bar{t}$ and tW events, and other diboson channels (WZ and ZZ).

To be selected as WW candidates, events must contain two identified leptons of opposite charge and with transverse momentum $p_T > 20\ \mathrm{GeV}/c$. To suppress background events with leptons originating from jets, it is required that both leptons must satisfy an optimized isolation criterion. To suppress top quark background, no reconstructed jets with transverse energy $E_T > 20$ GeV must be present in the pseudorapidity region $|\eta| < 3$. To suppress Drell-Yan background in the $\mathrm{e^+e^-}$ or $\mu^+\mu^-$ modes, the event MET must be > 45 GeV. In addition, if the invariant mass $m_{\ell\ell}$ of the lepton pair is between 76 and 106 GeV/c^2 the event is rejected. In order to reject Drell-Yan events in the tail of the MET distribution, an event veto is applied, which is based on the values of the following observables: the acoplanarity angle α, defined as $\alpha = |\pi - \phi_{\mathrm{MET}} - \phi_{\ell\ell}|$ with ϕ_{MET} and $\phi_{\ell\ell}$ representing MET and di-lepton azimuthal angles respectively; the $\mathrm{MET}/p_T^{\ell\ell}$ ratio, where $p_T^{\ell\ell}$ is the di-lepton transverse momentum. The event is vetoed if $\alpha < 0.25$ and $\mathrm{MET}/p_T^{\ell\ell} < 0.6$. Discrimination of signal events against the $\mathrm{Z} \to \tau^+\tau^-$ background is obtained by requiring that the transverse component of the MET with respect to the closest lepton (if the azimuthal separation between the lepton and MET directions is $< 90^\circ$) must be > 20 GeV. Finally, a veto on events that

W + jets	3.11 ± 1.27
Wγ	1.55 ± 0.89
$t\bar{t}$	3.27 ± 0.38
tW	1.94 ± 0.20
$Z \to e^+e^-$	0.22 ± 0.22
$Z \to \mu^+\mu^-$	0.87 ± 0.39
$Z \to \tau^+\tau^-$	0.67 ± 0.39
WZ	0.97 ± 0.12
ZZ	0.32 ± 0.04
Total background	12.91 ± 1.72
WW signal	35.04 ± 1.13

Table 1: Total signal and background yields after the full selection of the WW analysis. The expectations are based on MC simulations, assuming an integrated luminosity of 100 pb^{-1} and pp collisions at $\sqrt{s} = 10$ TeV. The reported errors are the statistical uncertainties due to the MC statistics.

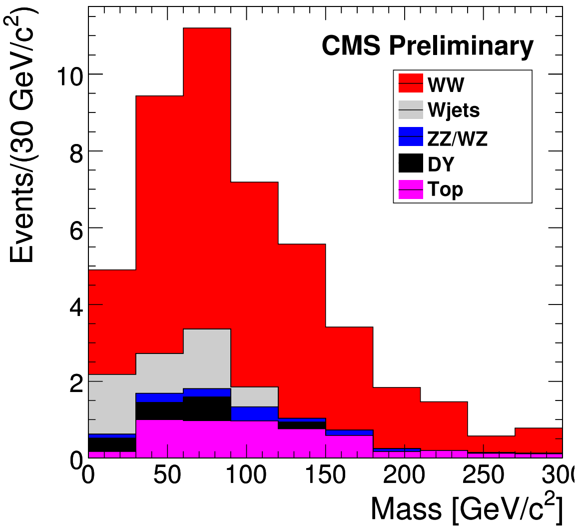

Figure 1: Invariant mass distribution for the lepton pair in WW candidate events. The expectation is based on MC simulations, assuming pp collisions at $\sqrt{s} = 10$ TeV. The MC is normalized to an integrated luminosity of 100 pb^{-1}.

contain an extra identified muon is applied, which suppresses poorly reconstructed Drell-Yan, WZ, and $t\bar{t}$ events.

The performance of the selection has been studied on MC simulated samples assuming $\sqrt{s} =$ 10 TeV. The signal and background events in a 100 pb^{-1} data sample which satisfy all of the above requirements are summarized in Table 1. About 35 WW signal events are selected, and most of the background comes from $t\bar{t}$ and W + jets events (almost 10% of the signal yield, respectively). The invariant mass distribution of the lepton pair in the selected candidate events is shown in Fig. 1.

Data-driven methods for determining the relevant backgrounds have been studied. The W +

jets background is determined by the "fake-rate" and the "isolation sideband" methods. The first method relies on estimating from a QCD control sample of the fake-rate probability for a loosely identified lepton to satisfy the full isolation and identification criteria of the WW selection. The second method relies on a fit to the isolation distribution of the leptons in the selected sample, with the signal shape being parameterized in data from a Z control sample, and the background shape from a QCD control sample. The top quark background is estimated by counting, in the sample of events rejected by the extra muon veto, the number of events which contain soft or non-isolated muons ("top-tagging" muons). This number is then divided by the probability to have a muon originating from jets in top decays, which is estimated from MC and cross-checked in data. Other backgrounds are estimated from MC with conservative systematic errors.

The signal yield after background subtraction has a 22% statistical+systematic uncertainty. The systematic error on signal efficiency determination is conservatively estimated as 14%, where the major contribution is due to the MET modeling in MC. Including the 10% uncertainty expected in the luminosity measurement, the total uncertainty on the WW cross section is 28%.

3. Study of WZ production

WZ events are reconstructed in decay modes where the W boson decays leptonically and the Z boson decays into a lepton pair. The final state is characterized by three leptons ($3e$, $2e1\mu$, $1e2\mu$, or 3μ) plus large MET due to the undetected neutrino [10]. The background can be divided in three categories: events without a genuine Z ($t\bar{t}$+jets and $\mathrm{W}+\mathrm{jets}$), events with a genuine Z plus a jet faking the lepton from the W decay (Z+jets), and genuine Z physics background (ZZ and Zγ processes).

To be selected as WZ candidates, events must contain at least three identified and isolated leptons, with transverse momentum $p_T > 15$ GeV$/c$. A pair of leptons with opposite charge and same flavour is associated to the Z decay and must have an invariant mass $m_{\ell\ell}$ in the $[81, 101]$ GeV$/c^2$ interval. The event is vetoed if additional di-leptons with invariant mass in a 20 GeV$/c^2$ interval around the nominal Z mass are found. The lepton not associated to the Z decay and with the highest p_T is associated to the W decay. It must have $p_T > 20$ GeV$/c$ and satisfy tight lepton identification criteria. The W candidate is identified by its transverse mass M_T, defined as $\mathrm{M}_T(\mathrm{W}) = \sqrt{2 \cdot \mathrm{MET} \cdot E_{T\ell} \cdot (1 - cos\Delta\phi_{\nu,\ell})}$, where $E_{T\ell}$ is the lepton transverse energy and $\Delta\phi_{\nu,\ell}$ is the azimuthal separation between MET and lepton directions. The event is selected if $\mathrm{M}_T >$ 50 GeV.

The performance of the selection has been studied on MC simulated samples assuming $\sqrt{s} =$ 14 TeV. The signal and background events in a 300 pb^{-1} data sample which satisfy all of the above requirements are summarized in Table 2. About 35 signal events are selected, and most of the background comes from Z+jets events (about 20% of the signal yield).

The dominant Z+jets background can be determined by the "matrix method" [11], a data-driven method which relies on the measurement of the probabilities for a loosely identified lepton in signal and background events to satisfy the tight identification requirements of the WZ selection. The probability for signal is measured in data with a Z control sample, while the probability for background is measured with $\mathrm{W}+\mathrm{jets}$ and QCD control samples. Other backgrounds are estimated

$t\bar{t}$+jets, W + jets	2.6 ± 0.7
Z+jets	6.8 ± 1.0
ZZ, $Z\gamma$	4.2 ± 0.3
WZ signal	34.9 ± 0.5

Table 2: Total signal and background yields after the full selection of the WZ analysis. The expectations are based on MC simulations, assuming an integrated luminosity of 300 pb^{-1} and pp collisions at $\sqrt{s} = 14$ TeV. The reported errors are the statistical uncertainties due to the MC statistics.

from MC with conservative systematic errors. Background with no genuine Z can be also estimated from the sidebands of the Z canditates invariant mass distribution.

The systematic error on the cross section measurement is on the order of 30% in each mode, slightly smaller than the statistical error. It includes the systematic error on the background subtraction (around 20%, depending on the mode), the systematic error on signal efficiency determination (about 10%, mostly due to the MET modeling in MC), and the 10% uncertainty of the luminosity measurement. It has been also estimated that less than 350 pb^{-1} of pp collisions data at $\sqrt{s} = 14$ TeV are needed, at 95% C.L., to achieve a 5σ measurement of the WZ production.

4. Conclusions

Analysis strategies for measuring WW and WZ production cross sections at CMS have been developed. It has been established that with an integrated luminosity of several hundred inverse picobarn it is possible to measure the WW production cross section with an uncertainty at the 30% level, and to provide a statistically significant measurement of the WZ channel. Although based on MC simulations assuming pp collisions at $\sqrt{s}$ greater than 7 TeV, these results are very encouraging and further studies are in progress within the CMS collaboration to optimize the strategies for analysis of 7 TeV collision data.

References

[1] CMS Collaboration, JINST **3** (2008) S08004.

[2] L. Evans and P. Bryant (editors), JINST **3** (2008) S08001.

[3] CMS Collaboration, accepted by Phys. Rev. Lett., `arXiv:1005.3299`.

[4] L.J. Dixon, Z. Kunszt, and A. Signer, Phys. Rev. **D 60** (1999) 114037.

[5] T. Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett. **104** (2010) 061803.

[6] V.M. Abazov et al. (D0 Collaboration), Phys. Rev. Lett. **103** (2009) 191801.

[7] A. Abulencia et al. (CDF Collaboration), Phys. Rev. Lett. **98** (2007) 161801.

[8] V.M. Abazov et al. (D0 Collaboration), Phys. Rev. **D 76** (2007) 111104(R).

[9] CMS Collaboration, CMS PAS EWK-09-002.

[10] CMS Collaboration, CMS PAS EWK-08-003.

[11] B. Abbot et al. (D0 Collaboration), Phys. Rev. **D 61** (2000) 072001.