Available on CMS information server

CMS NOTE 2011/XXX

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

June 25, 2012

Searches for beyond-the-standard model physics in events with a Z boson, jets and missing transverse energy

D. Barge, C. Campagnari, D. Kovalskyi, V. Krutelyov

University of California, Santa Barbara, USA

W. Andrews, G. Cerati, D. Evans, F. Golf, I. MacNeill, S. Padhi, Y. Tu, F. Würthwein, A. Yagil, J. Yoo

University of California, San Diego, USA

L. Bauerdick, K. Burkett, I. Fisk, Y. Gao, O. Gutsche, B. Hooberman, S. Jindariani, J. Linacre, V. Martinez Outschoorn

Fermi National Accelerator Laboratory, Batavia, Illinois, USA

Abstract

This note describes a search for beyond-the-standard model (BSM) physics in events with a leptonically-decaying Z boson, jets, and missing transverse energy ($\mathrm{E_T^{miss}}$). This signature is predicted to occur in several BSM scenarios, for example supersymmetric (SUSY) models. Two search strategies are pursued. The first is an inclusive approach which selects events with at least two jets and large $\mathrm{E_T^{miss}}$, produced in association with the Z$\rightarrow \ell\ell$ candidate. The second is a targeted search which focuses on a more exclusive signature topology that is motivated by SUSY models dominated by the electroweak charginos and neutralinos. The main backgrounds of SM $Z + \mathrm{jets}$ and $t\bar{t}$ production are estimated with the data-driven $\mathrm{E_T^{miss}}$templates technique and the opposite-flavor subtraction technique, respectively. No excesses above the SM expectations are observed. The results are interpreted in the context of simplified model spectra.

Contents

1 Introduction

This note presents two searches for beyond-the-standard model (BSM) physics in events containing a leptonically-decaying Z boson, jets, and missing transverse energy. This is an update of previous searches performed with 2011 data [1, 2]. The search is based on a data sample of pp collisions collected at $\sqrt{s} = 8$ TeV in 2012, corresponding to an integrated luminosity of 3.9 fb^{-1}.

The production of Z bosons is expected in many BSM scenarios, for example supersymmetric (SUSY) models. For example, Z bosons may be produced in the decays $\chi_2^0 \rightarrow Z\chi_1^0$ $\chi_1^0 \rightarrow Z\tilde{G}$, where χ_2^0 is the second lightest neutralino, χ_1^0 is the lightest neutralino, and $\tilde{G}$ is the gravitino. Such decays may occur in the cascade decays of the strongly-produced squarks and gluinos, or via direct production of the electroweak charginos and neutralino. Examples of such processes (see Fig. 1) are:

- strong production: $pp \rightarrow \tilde{g}\tilde{g} \rightarrow (q\bar{q}\chi_2^0)(q\bar{q}\chi_2^0) \rightarrow (q\bar{q}Z\chi_1^0)(q\bar{q}Z\chi_1^0) \rightarrow$ ZZ + 4 jets + $\mathrm{E_T^{miss}}$
- electroweak production: $pp \rightarrow \chi_1^{\pm}\chi_2^0 \rightarrow (W\chi_1^0)(Z\chi_1^0) \rightarrow$ WZ + $\mathrm{E_T^{miss}}$

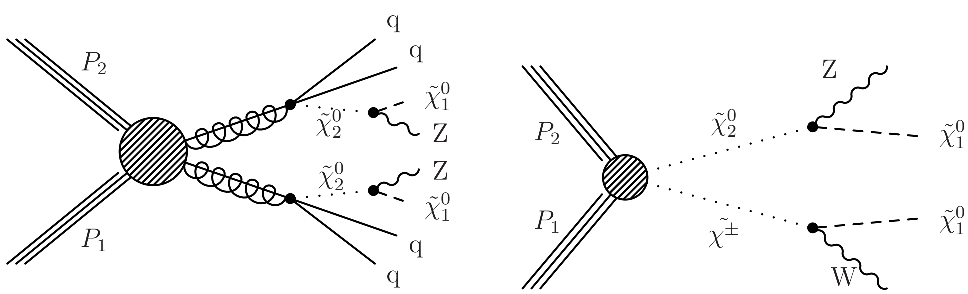

Figure 1: Examples of BSM physics signatures targeted in this search. In the left diagram, Z bosons are produced in the cascade decays of the strongly-interacting gluinos. In the right diagram, a Z boson is produced via direct production of the weakly-coupled charginos and neutralinos.

We thus pursue two strategies. The first is an inclusive strategy which selects events with a Z$\rightarrow$ $\ell\ell$ candidate, at least two jets, and large $\mathrm{E_T^{miss}}$. This strategy is useful for targeting, e.g., the production of Z bosons in the cascades decays of strongly-interacting particles as depicted in Fig. 1 (left). In the second strategy, we impose additional requirements which strongly suppress the backgrounds while retaining high efficiency for events with Z bosons produced via direct production of the weakly-coupled charginos and neutralinos. These two strategies are referred to as the "inclusive search" and the "targeted search," respectively.

After selecting events with jets and a Z$\rightarrow$ $\ell^+\ell^-$ ($\ell = e, \mu$) candidate, the dominant background consists of SM Z production accompanied by jets from initial-state radiation ($Z + \mathrm{jets}$). The $\mathrm{E_T^{miss}}$ in $Z + \mathrm{jets}$ events arises primarily when jet energies are mismeasured. The $Z + \mathrm{jets}$ cross section is several orders of magnitude larger than our signal, and the artificial $\mathrm{E_T^{miss}}$ is not necessarily well reproduced in simulation. Therefore, the critical prerequisite to a discovery of BSM physics in the $Z + \mathrm{jets} + \mathrm{E_T^{miss}}$ final state is to establish that a potential excess is not due to SM $Z + \mathrm{jets}$ production accompanied by artificial $\mathrm{E_T^{miss}}$ from jet mismeasurements. In this note, the $Z + \mathrm{jets}$ background is estimated with the $\mathrm{E_T^{miss}}$templates technique, in which the artificial $\mathrm{E_T^{miss}}$in $Z + \mathrm{jets}$ events is modeled using a $\gamma + \mathrm{jets}$ control sample. The second background category consists of processes which produce leptons with uncorrelated flavor. These "flavor-symmetric" (FS) backgrounds, which are dominated by $t\bar{t}$but also contain WW, DY$\rightarrow$ $\tau\tau$ and single top processes, are estimated using a data control sample of eμ events. Additional backgrounds from WZ and ZZ production are estimated from MC, after validation of the MC modeling of these processes using 3-lepton and 4-lepton data control samples.

2 Datasets and Triggers

In this section we list the datasets, triggers, and MC samples used in the analysis. For selecting signal events, we use dilepton triggers in the DoubleElectron, DoubleMu, and MuEG datasets. An event in the ee final state is required to pass the dielectron trigger, a $\mu\mu$ event is required to pass the dimuon trigger, while an eμ event is required to pass at least one of the two $e-\mu$ cross triggers. Our signal region consists of same-flavor (SF) ee and $\mu\mu$ events, while opposite-flavor (OF) $e\mu$ events are retained in a control sample used to estimate the FS contribution as described. A sample of $\gamma+\mathrm{jets}$ events, used as a control sample to estimate the $Z+\mathrm{jets}$ background, is selected using a set of single photon triggers. The golden json of June 15th, corresponding to an integrated luminosity of 3.9 fb^{-1}.

UPDATE LIST OF MC SAMPLES.

- Datasets
  - `/DoubleElectron/Run2021A-PromptReco-v1/AOD`
  - `/DoubleMu/Run2021A-PromptReco-v1/AOD`
  - `/MuEG/Run2021A-PromptReco-v1/AOD`
  - `/DoubleElectron/Run2021B-PromptReco-v1/AOD`
  - `/DoubleMu/Run2021B-PromptReco-v1/AOD`
  - `/MuEG/Run2021B-PromptReco-v1/AOD`
- Triggers
  - `HLT_Mu17_Mu8_v*`
  - `HLT_Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v*`
  - `HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL*`
  - `HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v*`
  - `HLT_Photon22_R9Id90_HE10_Iso40_EBOnly_v*`
  - `HLT_Photon36_R9Id90_HE10_Iso40_EBOnly_v*`
  - `HLT_Photon50_R9Id90_HE10_Iso40_EBOnly_v*`
  - `HLT_Photon75_R9Id90_HE10_Iso40_EBOnly_v*`
  - `HLT_Photon90_R9Id90_HE10_Iso40_EBOnly_v*`
- Good run list
  - `Cert_190456-195947_8TeV_PromptReco_Collisions12_JSON.txt`
- MC samples
  - `/DYJetsToLL_TuneD6T_M-50_7TeV-madgraph-tauola/Spring11-PU_S1_START311_V1G1-v1/AODSIM`

3 Selection

In this section, we list the event selection, electron and muon objects selections, jets, E_T^{miss}, and b-tagging selections used in this analysis. These selections are based on those recommended by the relevant POG's.

3.1 Event Selection

We require the presence of at least one primary vertex satisfying the standard quality criteria; namely, vertex is not fake, $\mathrm{ndf} \geq 4$, $\rho < 2$ cm, and $|z| < 24$ cm.

3.2 Lepton Selection

Because $Z \to \ell\ell$ ($\ell = e, \mu$) is a final state with very little background after a Z mass requirement is applied to the leptons, we restrict ourselves to events in which the Z boson decays to electrons or muons only. Therefore two same flavor, opposite sign leptons passing the ID described below are required in each event.

- $p_T > 20$ GeV and $|\eta| < 2.4$;
- Opposite-sign SF lepton pairs (OF eμ events are retained in a control sample used to estimate the FS contribution);
- For SF events, the dilepton invariant mass is required to be consistent with the Z mass; namely $81 < m_{\ell\ell} < 101$ GeV.

3.2.1 Electron Selection

The electron selection is the loose working point recommended by the E/gamma POG, as documented at [3]. We use PF-based isolation with a cone size of $\Delta R < 0.3$, using the effective area rho corrections documented at [4], and we require a relative isolation < 0.15. Electrons in the transition region defined by $1.4442 < |\eta_{SC}| < 1.566$ are rejected. The electron selection requirements are listed in Table 1 for completeness.

Table 1: Summary of the electron selection requirements.

Quantity	Barrel	Endcap
$\delta\eta$	< 0.007	< 0.009
$\delta\phi$	< 0.15	< 0.10
$\sigma_{i\eta i\eta}$	< 0.01	< 0.03
H/E	< 0.12	< 0.10
d_0 (w.r.t. 1st good PV)	< 0.02 cm	< 0.02 cm
d_z (w.r.t. 1st good PV)	< 0.2 cm	< 0.2 cm
$\|1/E - 1/P\|$	< 0.05 GeV^{-1}	< 0.05 GeV^{-1}
PF isolation / p_T	< 0.15	< 0.15
conversion rejection: fit probability	$< 10^{-6}$	$< 10^{-6}$
conversion rejection: missing hits	$leq1$	≤ 1

3.2.2 Muon Selection

We use the tight muon selection recommended by the muon POG, as documented at [5]. We use PF-based isolation with a cone size of $\Delta R < 0.3$, using the $\Delta\beta$ PU correction scheme, and we require a relative isolation of < 0.15. The muon selection requirements are listed in Table 2 for completeness.

3.3 Photons

As will be explained later, it is not essential that we select real photons. What is needed are jets that are predominantly electromagnetic, well measured in the ECAL, and hence less likely to contribute to fake MET. We select photons with:

- $p_T > 22$ GeV

Table 2: Summary of the muons selection requirements.

Quantity	Requirement
muon type	global muon and PF muon
χ^2/ndf	< 10
muon chamber hits	≥ 1
matched stations	≥ 2
d_0 (w.r.t. 1st good PV)	< 0.02 cm
d_z (w.r.t. 1st good PV)	< 0.5 cm
pixel hits	≥ 1
tracker layers	≥ 5

- $|\eta| < 2$
- $H/E < 0.1$
- No matching pixel track (pixel veto)
- There must be a pfjet of $p_T > 10$ GeV matched to the photon within $dR < 0.3$. The matched jet is required to have a neutral electromagnetic energy fraction of at least 70%.
- We require that the pfjet p_T matched to the photon satisfy (pfjet p_T - photon p_T) $>$ -5 GeV. This removes a few rare cases in which "overcleaning" of a pfjet generated fake MET.
- We also match photons to calojets and require (calojet p_T - photon p_T) $>$ -5 GeV (the same requirement used for pfjets). This is to remove other rare cases in which fake energy is added to the photon object but not the calojet.
- We reject photons which have an electron of at least $p_T > 10$ GeV within $dR < 0.2$ in order to reject conversions from electrons from W decays which are accompanied by real MET.
- We reject photons which are aligned with the MET to within 0.14 radians in phi.

3.4 MET

We use pfmet, henceforth referred to simply as $\mathrm{E_T^{miss}}$.

3.5 Jets

- PF jets with L1FastL2L3 corrections (MC), L1FastL2L3residual corrections (data)
- $|\eta| < 2.5$
- Passes loose PFJet ID
- $p_T > 30$ GeV for determining the jet multiplicity, $p_T > 15$ GeV for calculation of H_T
- For the creation of photon templates, the jet matched to the photon passing the photon selection described above is vetoed
- For the dilepton sample, jets are vetoed if they are within $dR < 0.4$ from any lepton $p_T > 20$ GeV passing analysis selection

References

[1] CMS Collaboration, “Search for physics beyond the standard model in events with a Z boson, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV,”, arXiv:1204.3774v1 [hep-ex].

[2] SUS-12-006, paper draft

[3] https://twiki.cern.ch/twiki/bin/viewauth/CMS/EgammaCutBasedIdentification

[4] https://twiki.cern.ch/twiki/bin/viewauth/CMS/EgammaEARhoCorrection

[5] https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideMuonId

[6] https://hypernews.cern.ch/HyperNews/CMS/get/SUS-12-007/32.html

[7] arXiv:1204.3774v1 [hep-ex]

[8] D. Barge, CMS AN-2011/464

[9] CMS Collaboration, *Search for supersymmetry in events with a Z boson, jets and momentum imbalance* PAS SUS-11-021

[10] CMS Collaboration, *“Measurement of the b-tagging efficiency using $t\bar{t}$ events”*, PAS BTV-11-003, in preparation.

[11] CMS Collaboration, *Performance of b-jet identification in CMS*, PAS BTV-11-001

[12] M. Narain for BTV POG, `https://indico.cern.ch/getFile.py/access?contribId=0&resId=1&materialId=slides&confId=163892`

[13] arXiv:1103.1348v1, D. Barge *at al.*, CMS AN-CMS2011/269.

[14] V. Pavlunin, Phys. Rev. **D81**, 035005 (2010).

[15] V. Pavlunin, CMS AN-2009/125

[16] A reference to the top paper, once it is submitted. Also D. Barge *et al.*, AN-CMS2010/258.

[17] Changes to the selection for the 38x CMSSW release are given in `https://twiki.cern.ch/twiki/bin/viewauth/CMS/TopDileptonRefAnalysis2010Pass5`.

[18] https://twiki.cern.ch/twiki/bin/viewauth/CMS/SimpleCutBasedEleID

[19] https://twiki.cern.ch/twiki/bin/viewauth/CMS/EgammaWorkingPointsv3

[20] D. Barge *at al.*, AN-CMS2009/159.

[21] B. Mangano *et al.*, AN-CMS2010/283.

[22] https://twiki.cern.ch/twiki/bin/viewauth/CMS/CrossSections_3XSeries, https://twiki.cern.ch/twiki/bin/view/CMS/ProductionSpring

[23] CMS Collaboration, “Measurement of CMS luminosity”, *CMS-PAS* **EWK-10-004** (2010).

[24] D. Barge *at al.*, AN-CMS2009/130.

[25] W. Andrews *et al.*, AN-CMS2009/023.

[26] D. Barge *at al.*, AN-CMS2010/257.

[27] L. Bauerdick *at al.*, AN-CMS2011/155.

[28] CMS-PAS-JME-10-010.

[29] arXiv:1103.6083v1, J. T. Ruderman, D. Shih

[30] H. Haber, G. Kane, Phys. Reports 117, Nos. 2-4 (1985) 75-263.

[31] http://cmssw.cvs.cern.ch/cgi-bin/cmssw.cgi/UserCode/SusyAnalysis/SLHAFILES/TChiwz/

[32] http://cmssw.cvs.cern.ch/cgi-bin/cmssw.cgi/UserCode/SusyAnalysis/SLHAFILES/TChizz/

[33] https://twiki.cern.ch/twiki/bin/viewauth/CMS/SWGuideLandS