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CMS NOTE 2011/XXX

The Compact Muon Solenoid Experiment

CMS Note

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

May 14, 2013

E_T^{miss} Templates Results and Additional Cross-checks for the Opposite-sign Same-flavor (“Edge”) Dilepton Analysis

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Abstract

The Aachen and ETH groups have reported an excess of events with low mass, opposite-sign same-flavor lepton pairs, commonly referred to as the “edge analysis.” In this note, we use the E_T^{miss} templates technique to estimate the Z background in the Z mass region for the two signal regions used in this analysis. This prediction is extrapolated to low mass to estimate the γ^*/Z contribution. Additional cross-checks are also presented.

Contents

1 Changes since previous version

- AN v2: Update the selection. For the high-E_T^{miss} signal region require both leptons to satisfy $p_T > 20$ GeV (previously the trailing lepton p_T threshold was 10 GeV). For both the low-E_T^{miss} and high-E_T^{miss} signal regions, we now quote the results in the "central region" and "inclusive region" defined by requiring both leptons to satisfy $|\eta| < 1.4$ and $|\eta| < 2.4$, respectively (4 total signal regions).

2 Introduction

The Aachen and ETH groups have reported an excess of events with low mass, opposite-sign same-flavor (OSSF) lepton pairs, as described in AN-2012/200 (Aachen) and AN-2012/231 (ETH). In Sec. 3 we define the signal regions used in the analysis and demonstrate the level of synchronization with the ETH and Aachen authors. In Sec. 4 of this note, we use the E_T^{miss} templates technique [1] to estimate the Z background in the Z mass region for the two signal regions used in this analysis. This prediction is extrapolated to low mass to estimate the γ^*/Z contribution. In Sec. 5 we cross-check the results of the nominal analysis based on dilepton triggers using single lepton triggers. **All results presented here are based on 9.2 fb^{-1}.**

3 Signal Regions and Synchronization Exercise

We begin by defining the signal regions used in the edge analysis, and demonstrating the level of synchronization with the results from the ETH and Aachen authors.

3.1 Signal Regions

The signal regions of the OSSF analysis are defined as:

- Low-E_T^{miss} signal region (ETH)
  - At least 3 jets ($p_T > 40$ GeV, $|\eta| < 3$)
  - $E_T^{miss} > 100$ GeV
  - 2 $p_T > 20$ GeV leptons with $|\eta| < 1.4$ (central signal region) or $|\eta| < 2.4$ (inclusive signal region)
- High-E_T^{miss} signal region (Aachen)
  - At least 2 jets ($p_T > 40$ GeV, $|\eta| < 3$) with scalar sum $H_T > 100$ GeV
  - $E_T^{miss} > 150$ GeV
  - 2 $p_T > 20$ GeV leptons with $|\eta| < 1.4$ (central signal region) or $|\eta| < 2.4$ (inclusive signal region)

This gives a total of four signal regions: low-E_T^{miss} central, low-E_T^{miss} inclusive, high-E_T^{miss} central, and high-E_T^{miss} inclusive. The edge signal regions are defined by requiring the lepton pair to have $20 < m_{\ell\ell} < 70$ GeV ("low-mass"), in this note we also examine the results in the $81 < m_{\ell\ell} < 101$ GeV ("on-Z") region.

3.2 Synchronization Exercise

We perform a synchronization exercise to make sure that we can reproduce the ETH/Aachen results. In Table 1 we compare our on-Z yields with those from the Aachen and ETH groups. In Table 2 we compare our low-mass yields with those from the Aachen and ETH groups. In general we are synchronized to within a few% in all channels.

Table 1: Summary of the synchronization exercise for the on-Z yields, obtained from the ETH/Aachen authors via private communication. The yields in the on-Z region are displayed for the low $\mathrm{E_T^{miss}}$ central and high $\mathrm{E_T^{miss}}$ inclusive signal regions.

low $\mathrm{E_T^{miss}}$ signal region (central)	UCSB-UCSD-FNAL	ETH Authors
ee	91	89
$\mu\mu$	102	102
eμ	130	130
high $\mathrm{E_T^{miss}}$ signal region (inclusive)	**UCSB-UCSD-FNAL**	**Aachen**
ee	61	60
$\mu\mu$	73	78
eμ	95	94

Table 2: Summary of the synchronization exercise comparing with Table 4 of SUS-12-019 v9. The yields in the low-mass region are displayed for the low $\mathrm{E_T^{miss}}$ and high $\mathrm{E_T^{miss}}$ signal regions, in the central and inclusive regions. The opposite-flavor prediction (OF) is the number of eμ events scaled by $R_{SF/OF} = 1.02$.

low $\mathrm{E_T^{miss}}$ signal region (central)	UCSB-UCSD-FNAL	SUS-12-019 v9 Table 4
SF	364	364
OF	265	264
low $\mathrm{E_T^{miss}}$ signal region (inclusive)	**UCSB-UCSD-FNAL**	**SUS-12-019 v9 Table 4**
SF	453	452
OF	368	367
high $\mathrm{E_T^{miss}}$ signal region (central)	**UCSB-UCSD-FNAL**	**SUS-12-019 v9 Table 4**
SF	168	174
OF	114	119
high $\mathrm{E_T^{miss}}$ signal region (inclusive)	**UCSB-UCSD-FNAL**	**SUS-12-019 v9 Table 4**
SF	217	222
OF	149	154

4 Results of the $\mathrm{E_T^{miss}}$ Templates Analysis

In this section, we use the $\mathrm{E_T^{miss}}$ templates technique to derive predictions for the Z background in the Z mass regions for the two signal regions used for the OSSF dilepton analysis. The background estimation methodology used in the $\mathrm{E_T^{miss}}$ templates analysis is described in AN-2012/254; this AN presents only details which differ from that reference. We then use the predicted Z background to derive an estimate of the low-mass γ^*/Z contribution, using an extrapolation technique commonly referred to as the "$R_{out/in}$" technique [2].

4.1 Background Estimation Methodology

The strategy is to select Z$\rightarrow \ell\ell$ candidates ($81 < m_{\ell\ell} < 101$ GeV) with jet requirements corresponding to the low-$\mathrm{E_T^{miss}}$ and high-$\mathrm{E_T^{miss}}$ signal regions, and compare the observed $\mathrm{E_T^{miss}}$ distribution to the sum of the predictions from the $\mathrm{Z+jets}$ background (from the $\mathrm{E_T^{miss}}$ templates method based on the $\gamma+\mathrm{jets}$ data control sample), the flavor-symmetric (FS) background predicted from eμ data events, and MC contributions from WZ/ZZ (for which the contribution to the FS background estimate is negligible), as well as the rare SM processes with Z bosons ($t\bar{t}$Z and ZZZ, ZZW, ZWW). The reader is referred to AN-2012/254 for details of the methods.

In order to adapt the $\mathrm{E_T^{miss}}$ templates method to predict the Z background in these regions, we make minor modifications to the procedure used in AN-2012/254. Specifically, we re-calculate the flavor-symmetric (FS) scaling factor K and change the binning used for the $\mathrm{E_T^{miss}}$ templates. The FS background is estimated using eμ events in data. To improve the precision of this background estimate, the dilepton mass requirement is not applied, and we apply a scaling factor K, which is the efficiency for eμ events to fall in the Z mass window, extracted from MC. The systematic uncertainty on K is assessed by comparing this quantity in data vs. MC. The values of K for various $\mathrm{E_T^{miss}}$ intervals for the high-$\mathrm{E_T^{miss}}$ region (using p_T > (20,10) GeV leptons and at least 2 jets) are shown in Fig. 1. Based on this plot we choose $K = 0.13 \pm 0.02$ for $\mathrm{E_T^{miss}}$ signal regions up to 200 GeV; for $\mathrm{E_T^{miss}}$ 200-300 GeV and $\mathrm{E_T^{miss}} > 300$ GeV we inflate the uncertainty to $K = 0.13 \pm 0.04$ and $K = 0.13 \pm 0.05$, respectively, due to the limited statistical precision. The values of K for the low-$\mathrm{E_T^{miss}}$ region (using p_T > (20,20) GeV leptons and at least 3 jets) are shown in Fig. 2. Based on this plot we choose $K = 0.14 \pm 0.02$ for $\mathrm{E_T^{miss}}$ signal regions up to 200 GeV; for $\mathrm{E_T^{miss}}$ 200-300 GeV and $\mathrm{E_T^{miss}} > 300$ GeV we inflate the uncertainty to $K = 0.14 \pm 0.03$ and $K = 0.14 \pm 0.07$, respectively. In addition, we change the jet p_T threshold for the $\mathrm{E_T^{miss}}$ templates jet multiplicity binning from 30 to 40 GeV, and change the H_T bins to (0,80,100,150,200,250,300,5000) GeV.

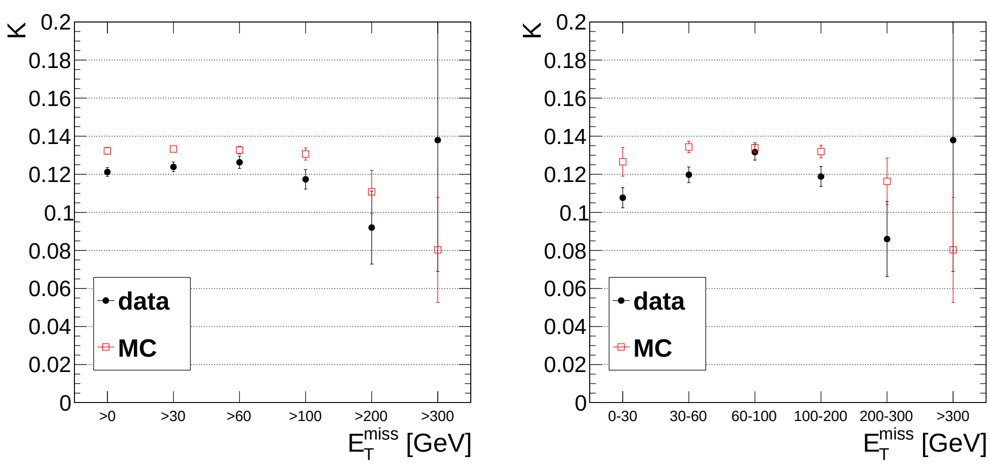


Figure 1: The efficiency for eμ events to satisfy the dilepton mass requirement, K, in data and simulation for inclusive $\mathrm{E_T^{miss}}$ intervals (left) and exclusive $\mathrm{E_T^{miss}}$ intervals (right) for the dilepton p_T > (20,10) GeV selection with at least 2 p_T > 40 GeV jets (used for the high $\mathrm{E_T^{miss}}$ signal region).

4.2 Results in Z Mass Window

The results of the low $\mathrm{E_T^{miss}}$ signal region are displayed in Fig. **??** and summarized in Table **??**, separately for the Run2012A+B data (5.1 fb^{-1}) and Run2012C data (4.1 fb^{-1}). In the Run2012A+B data, we observed a 1.6σ excess for $\mathrm{E_T^{miss}} > 100$ GeV, corresponding to the low $\mathrm{E_T^{miss}}$ signal region. However, this excess does not persist in Run2012C data, where we observe good agreement between the data and the predicted background. In the

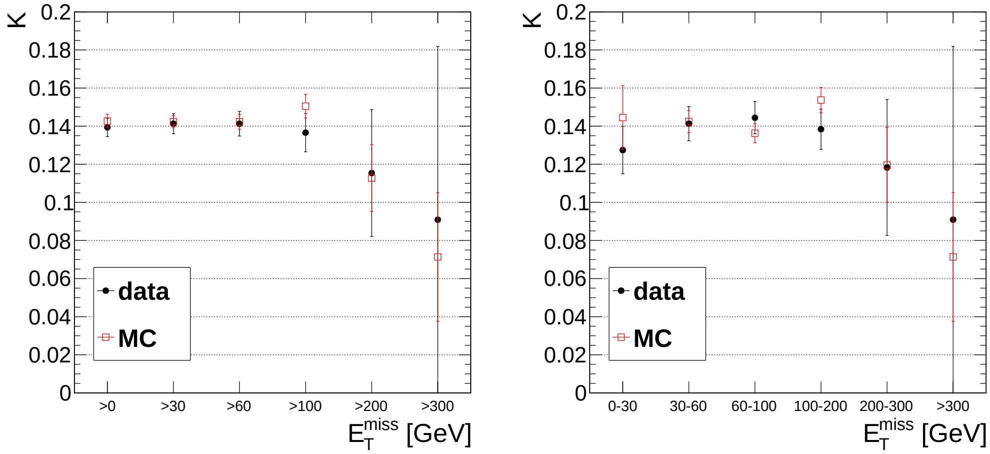


Figure 2: The efficiency for eμ events to satisfy the dilepton mass requirement, K, in data and simulation for inclusive $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ intervals (left) and exclusive $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ intervals (right) for the dilepton p_T $>$ (20,20) GeV selection with at least 3 p_T $>$ 40 GeV jets (used for the low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region).

combined Run2012A+B+C data (Fig. 3 and Table 3) we observe reasonable agreement over the full $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ range. In the $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV region we observe 288 events with a predicted background of 251 ± 33, representing an excess of 1.0σ.

The results of the high $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region are displayed in Fig. **??** and summarized in Table **??**, separately for the Run2012A+B data (5.1 fb^{-1}) and Run2012C data (4.1 fb^{-1}). In both periods we observe good agreement between the data and predicted background over the full $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ range. In the combined Run2012A+B+C data (Fig. 3 and Table 3) we observe reasonable agreement over the full $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ range. In the $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV region corresponding to the high $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region in the full sample, we observe 167 events with a predicted background of 177 ± 25 events, representing a deficit of -0.4σ.

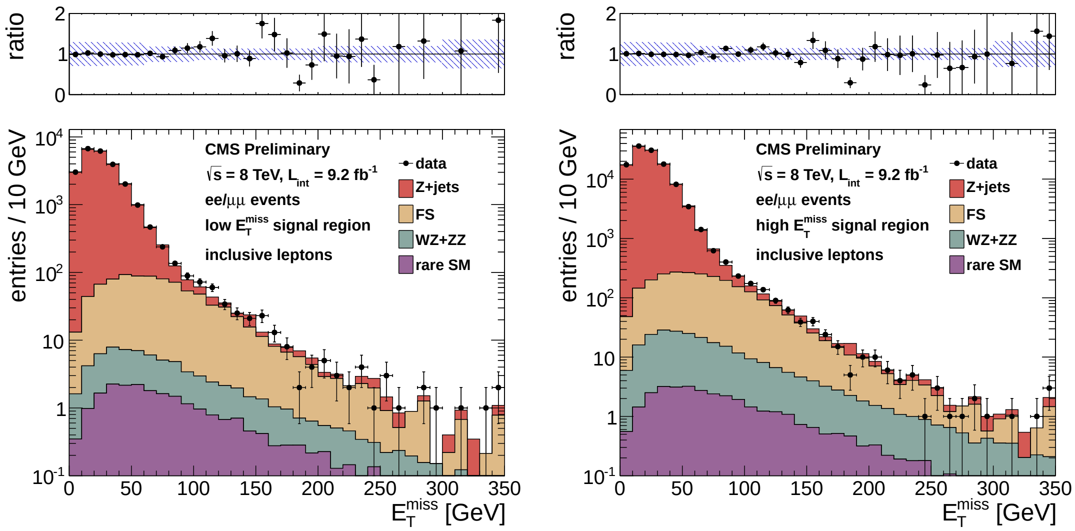
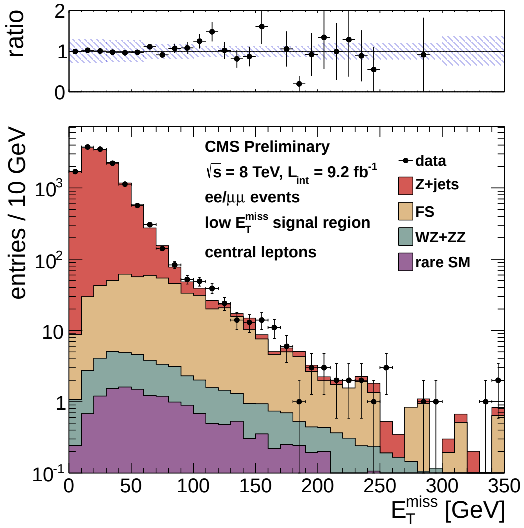


Figure 3: **Results of for the low $\mathrm{E_T^{miss}}$ (left) and high $\mathrm{E_T^{miss}}$ (right) signal regions with the inclusive lepton selection.** The observed $\mathrm{E_T^{miss}}$ distribution (black points) is compared with the sum of the predicted $\mathrm{E_T^{miss}}$ distributions from $\mathrm{Z + jets}$, flavor-symmetric backgrounds, WZ+ZZ backgrounds, and rare SM backgrounds. The ratio of observed to predicted yields in each bin is indicated. The error bars indicate the statistical uncertainty in the data and the shaded band indicates the total background uncertainty.

Table 3: **Results for the low $\mathrm{E_T^{miss}}$ signal region (top table) and high $\mathrm{E_T^{miss}}$ signal region (bottom table) with the inclusive lepton selection.** The total background is the sum of the $\mathrm{Z + jets}$ background predicted from the $\mathrm{E_T^{miss}}$ templates method ($\mathrm{Z + jets}$ bkg), the flavor-symmetric background predicted from eμ events (FS bkg), the WZ and ZZ backgrounds predicted from MC (WZ bkg and ZZ bkg) and the rare SM backgrounds. All uncertainties include both the statistical and systematic components. The Gaussian significance of the deviation between the data and total background is indicated for signal regions with at least 20 observed events.

	$\mathrm{E_T^{miss}} > 0$ GeV	$\mathrm{E_T^{miss}} > 30$ GeV	$\mathrm{E_T^{miss}} > 60$ GeV	$\mathrm{E_T^{miss}} > 100$ GeV	$\mathrm{E_T^{miss}} > 200$ GeV	$\mathrm{E_T^{miss}} > 300$ GeV
$\mathrm{Z + jets}$ bkg	23071 ± 6922	7456 ± 2238	673 ± 203	49.9 ± 16.4	4.4 ± 1.8	1.0 ± 0.6
FS bkg	807 ± 126	695 ± 108	457 ± 71	184 ± 29	14.1 ± 3.4	1.5 ± 0.9
WZ bkg	43.5 ± 30.5	35.1 ± 24.6	21.3 ± 14.9	10.0 ± 7.1	1.9 ± 1.7	0.4 ± 0.4
ZZ bkg	7.8 ± 3.9	7.0 ± 3.6	5.4 ± 2.8	3.3 ± 1.8	0.9 ± 0.8	0.2 ± 0.2
rare SM bkg	22.0 ± 11.0	19.0 ± 9.6	12.4 ± 6.3	6.3 ± 3.3	1.3 ± 1.1	0.3 ± 0.3
total bkg	23951 ± 6924	8213 ± 2241	1169 ± 216	253 ± 34	22.6 ± 4.4	3.5 ± 1.2
data	23999	8134	1217	288	26	4
significance	0.0σ	-0.0σ	0.2σ	0.9σ	0.5σ	

	$\mathrm{E_T^{miss}} > 0$ GeV	$\mathrm{E_T^{miss}} > 30$ GeV	$\mathrm{E_T^{miss}} > 60$ GeV	$\mathrm{E_T^{miss}} > 100$ GeV	$\mathrm{E_T^{miss}} > 150$ GeV	$\mathrm{E_T^{miss}} > 300$ GeV
$\mathrm{Z + jets}$ bkg	114401 ± 34322	30966 ± 9291	1905 ± 573	120 ± 38	26.2 ± 8.9	1.4 ± 0.7
FS bkg	2255 ± 373	1908 ± 316	1201 ± 199	436 ± 72	90.0 ± 15.3	2.9 ± 1.3
WZ bkg	182.7 ± 127.9	144.7 ± 101.3	81.8 ± 57.3	35.2 ± 24.7	13.9 ± 9.9	1.3 ± 1.3
ZZ bkg	35.9 ± 18.0	32.3 ± 16.2	23.9 ± 12.0	14.0 ± 7.1	6.7 ± 3.6	0.8 ± 0.8
rare SM bkg	33.5 ± 16.8	29.0 ± 14.6	19.5 ± 9.8	10.2 ± 5.2	4.5 ± 2.5	0.5 ± 0.5
total bkg	116908 ± 34324	33080 ± 9297	3231 ± 609	616 ± 86	141 ± 21	6.9 ± 2.2
data	116978	32796	3301	635	133	5
significance	0.0σ	-0.0σ	0.1σ	0.2σ	-0.4σ	-0.6σ



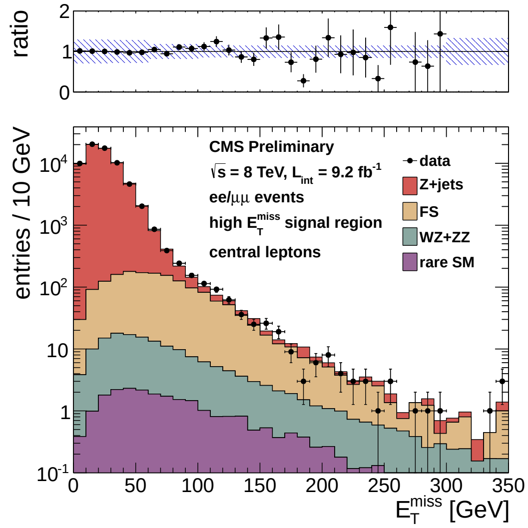


Figure 4: **Results of for the low E_T^{miss} (left) and high E_T^{miss} (right) signal regions with the central lepton selection.** The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions from $Z+\text{jets}$, flavor-symmetric backgrounds, WZ+ZZ backgrounds, and rare SM backgrounds. The ratio of observed to predicted yields in each bin is indicated. The error bars indicate the statistical uncertainty in the data and the shaded band indicates the total background uncertainty.

Table 4: **Results for the low E_T^{miss} signal region (top table) and high E_T^{miss} signal region (bottom table) with the central lepton selection.** The total background is the sum of the $Z+\text{jets}$ background predicted from the E_T^{miss} templates method ($Z+\text{jets}$ bkg), the flavor-symmetric background predicted from $e\mu$ events (FS bkg), the WZ and ZZ backgrounds predicted from MC (WZ bkg and ZZ bkg) and the rare SM backgrounds. All uncertainties include both the statistical and systematic components. The Gaussian significance of the deviation between the data and total background is indicated for signal regions with at least 20 observed events.

	$E_T^{miss} > 0$ GeV	$E_T^{miss} > 30$ GeV	$E_T^{miss} > 60$ GeV	$E_T^{miss} > 100$ GeV	$E_T^{miss} > 200$ GeV	$E_T^{miss} > 300$ GeV
$Z+\text{jets}$ bkg	13001 ± 3901	4247 ± 1275	392 ± 118	29.7 ± 9.7	2.6 ± 1.1	0.6 ± 0.4
FS bkg	528 ± 82	455 ± 71	301 ± 47	121 ± 19	9.6 ± 2.4	1.1 ± 0.7
WZ bkg	28.1 ± 19.7	22.7 ± 15.9	13.9 ± 9.8	6.8 ± 4.9	1.5 ± 1.4	0.4 ± 0.4
ZZ bkg	4.8 ± 2.5	4.4 ± 2.3	3.3 ± 1.8	2.1 ± 1.2	0.6 ± 0.6	0.1 ± 0.1
rare SM bkg	15.8 ± 8.0	13.7 ± 6.9	9.0 ± 4.6	4.8 ± 2.5	1.0 ± 1.0	0.3 ± 0.3
total bkg	13577 ± 3902	4743 ± 1277	719 ± 128	164 ± 22	15.3 ± 3.2	2.5 ± 0.9
data	13631	4688	773	192	18	3
significance	0.0σ	-0.0σ	0.4σ	1.1σ	0.5σ	0.3σ

	$E_T^{miss} > 0$ GeV	$E_T^{miss} > 30$ GeV	$E_T^{miss} > 60$ GeV	$E_T^{miss} > 100$ GeV	$E_T^{miss} > 150$ GeV	$E_T^{miss} > 300$ GeV
$Z+\text{jets}$ bkg	64824 ± 19448	17710 ± 5314	1119 ± 336	71.9 ± 22.4	15.8 ± 5.3	0.8 ± 0.4
FS bkg	1468 ± 243	1252 ± 207	793 ± 131	292 ± 49	62.1 ± 10.7	2.1 ± 1.0
WZ bkg	115.0 ± 80.5	91.3 ± 64.0	52.4 ± 36.7	23.3 ± 16.4	9.4 ± 6.7	1.0 ± 1.0
ZZ bkg	21.7 ± 10.9	19.7 ± 9.9	14.8 ± 7.5	8.8 ± 4.5	4.3 ± 2.4	0.5 ± 0.5
rare SM bkg	23.9 ± 12.0	20.8 ± 10.4	14.1 ± 7.1	7.5 ± 3.9	3.6 ± 2.1	0.5 ± 0.5
total bkg	66453 ± 19450	19094 ± 5318	1994 ± 363	403 ± 56	95.2 ± 14.1	4.9 ± 1.6
data	66521	18841	2062	421	92	4
significance	0.0σ	-0.0σ	0.2σ	0.3σ	-0.2σ	-0.4σ

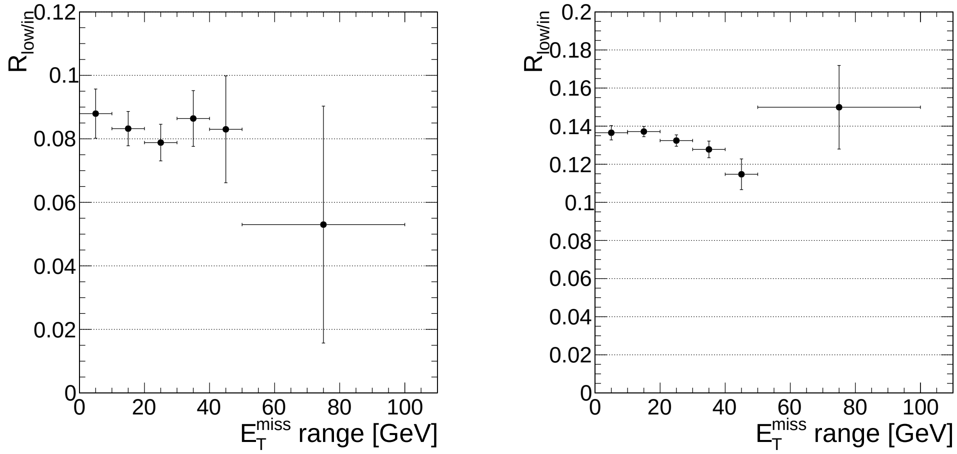


Figure 5: The ratio $R_{low/in}$ of low mass ($15 < m_{\ell\ell} < 70$ GeV) to on-Z ($81 < m_{\ell\ell} < 101$ GeV) events, as a function of the $\mathrm{E_T^{miss}}$ requirement. The left plot corresponds to the low $\mathrm{E_T^{miss}}$ signal region (2 p_T $>$ 20 GeV leptons with at least 3 jets), the right plot corresponds to the high $\mathrm{E_T^{miss}}$ signal region (p_T $>$ (20,10) GeV leptons with at least 2 jets).

4.3 Extrapolation to Low Mass to Estimate the γ^*/Z Contribution

Given a prediction for the Z background in the Z mass window, we can extrapolate to estimate the low mass γ^*/Z contribution. We extract the ratio $R_{low/in}$ of low-mass to on-shell Z events from data, correcting for the contribution from flavor-symmetric backgrounds, according to:

$$R_{low/in} = (N_{SF}^{low} - N_{OF}^{low})/(N_{SF}^{in} - N_{OF}^{in}). \tag{1}$$

Here SF and OF refer to the same-flavor and opposite-flavor data yields in the "low" ($15 < m_{\ell\ell} < 70$ GeV) and "in" ($81 < m_{\ell\ell} < 101$ GeV) dilepton mass regions. To predict the low-mass γ^*/Z contribution, we scale the total predicted Z background by this quantity, which is displayed in Fig. 5. Here we measure $R_{low/in}$ in several $\mathrm{E_T^{miss}}$ regions, and assess the uncertainty based on the variation with respect to $\mathrm{E_T^{miss}}$. Based on this plot we choose $R_{low/in} = 0.08 \pm 0.02$ for the low $\mathrm{E_T^{miss}}$ signal region and $R_{low/in} = 0.13 \pm 0.03$ for the high $\mathrm{E_T^{miss}}$ region.

We find the following results for the first 5.1 fb^{-1}. For the low $\mathrm{E_T^{miss}}$ signal region, the total predicted Z background in the Z mass region is 39 ± 9.6 (sum of the $\mathrm{Z + jets}$, WZ+ZZ, and rare SM backgrounds from Table **??**, $\mathrm{E_T^{miss}}$ $>$ 100 GeV region), resulting in a γ^*/Z prediction of 3.1 ± 1.1 events. For the high $\mathrm{E_T^{miss}}$ signal region, the total predicted Z background in the Z mass region is 30 ± 8.1 (sum of the $\mathrm{Z + jets}$, WZ+ZZ, and rare SM backgrounds from Table **??**, $\mathrm{E_T^{miss}}$ $>$ 150 GeV region), resulting in a γ^*/Z prediction of 3.8 ± 1.4 events.

We find the following results for the full 9.2 fb^{-1}. For the low $\mathrm{E_T^{miss}}$ signal region, the total predicted Z background in the Z mass region is 68 ± 17 (sum of the $\mathrm{Z + jets}$, WZ+ZZ, and rare SM backgrounds from Table 3, $\mathrm{E_T^{miss}}$ $>$ 100 GeV region), resulting in a γ^*/Z prediction of 5.4 ± 1.9 events. For the high $\mathrm{E_T^{miss}}$ signal region, the total predicted Z background in the Z mass region is 60 ± 16 (sum of the $\mathrm{Z + jets}$, WZ+ZZ, and rare SM backgrounds from Table 3, $\mathrm{E_T^{miss}}$ $>$ 150 GeV region), resulting in a γ^*/Z prediction of 7.9 ± 2.7 events.

4.4 Summary of Results

In this section we summarize the results for the 5.1 fb^{-1} Run2012A+B data (Table 5) and the 9.2 fb^{-1} Run2012A+B+C data (Table 6).

Table 5: Summary of results in 5.1 fb^{-1} 2012A+B data for the low-$\mathrm{E_T^{miss}}$ and high-$\mathrm{E_T^{miss}}$ signal regions (SR). In the Z mass region, the predicted Z background (Z bkg, sum of $\mathrm{Z + jets}$, WZ/ZZ, and rare SM processes with Z bosons), flavor-symmetric background (FS bkg), and total background (Total bkg) are indicated, and compared to the observed yield (Data). The Gaussian significance of the difference between the data and the total background is indicated. The predicted γ^*/Z contribution to the low-mass region (Low mass γ^*/Z bkg) is also indicated.

	Low-$\mathrm{E_T^{miss}}$ SR	High-$\mathrm{E_T^{miss}}$SR
Z bkg	39 ± 9.6	30 ± 8.1
FS bkg	99 ± 16	69 ± 12
Total bkg	138 ± 18	98 ± 14
Data	175	95
Significance	$+1.6\sigma$	-0.2σ
Low mass γ^*/Z bkg	3.1 ± 1.1	3.8 ± 1.4

Table 6: Summary of results in 9.2 fb^{-1} 2012A+B+C data for the low-$\mathrm{E_T^{miss}}$ and high-$\mathrm{E_T^{miss}}$ signal regions (SR). In the Z mass region, the predicted Z background (Z bkg, sum of $\mathrm{Z + jets}$, WZ/ZZ, and rare SM processes with Z bosons), flavor-symmetric background (FS bkg), and total background (Total bkg) are indicated, and compared to the observed yield (Data). The Gaussian significance of the difference between the data and the total background is indicated. The predicted γ^*/Z contribution to the low-mass region (Low mass γ^*/Z bkg) is also indicated.

	Low-$\mathrm{E_T^{miss}}$ SR	High-$\mathrm{E_T^{miss}}$SR
Z bkg	68 ± 17	60 ± 16
FS bkg	184 ± 29	117 ± 20
Total bkg	251 ± 33	177 ± 25
Data	288	167
Significance	$+1.0\sigma$	-0.4σ
Low mass γ^*/Z bkg	5.4 ± 1.9	7.9 ± 2.7

5 Cross-check with single lepton triggers

The nominal “edge analysis” is performed with dilepton triggers. An excess of SF vs. OF events may thus be observed if there were some inefficiency for the eμ triggers used in this analysis. In this section we provide a cross-check of the nominal analysis by including events collected with single lepton triggers. The relevant triggers are:

- ee channel
  - dilepton: `HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL`
  - single lepton: `HLT_Ele27_WP80`
- $\mu\mu$ channel
  - dilepton: `HLT_Mu17_Mu8` OR `HLT_Mu17_TkMu8`
  - single lepton: `HLT_IsoMu24` OR `HLT_IsoMu24_eta2p1`
- $e\mu$ channel
  - dilepton: `HLT_MuX_EleY_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL` (X,Y=17,8 OR 8,17)
  - single lepton: `HLT_Ele27_WP80` OR `HLT_IsoMu24` OR `HLT_IsoMu24_eta2p1`

In the nominal analysis based on dilepton triggers only, an ee event is required to satisfy the ee dilepton trigger, a $\mu\mu$ event is required to satisfy one of the two $\mu\mu$ dilepton triggers, and an eμ event is required to satisfy one of the two eμ dilepton triggers. Here we compare the results obtained from the nominal dilepton triggers with those obtained by requiring an OR of the dilepton and single lepton triggers. In this cross-check, an ee event is required to satisfy the ee dilepton trigger OR single electron trigger, a $\mu\mu$ event is required to satisfy one of the two $\mu\mu$ dilepton triggers OR one of the two single muon triggers, and an eμ event is required to satisfy one of the two eμ dilepton triggers OR the single electron trigger OR the single muon trigger. The results are summarized in Table 7. Including the single lepton triggers increases the yields in the ee, $\mu\mu$ and eμ final states by (1–7)%, and does not significantly alter the excess of SF vs. OF data yields.

Table 7: Summary of results comparing dilepton vs. dilepton OR single lepton triggers, for 5.1 fb^{-1}, in the low $\mathrm{E_T^{miss}}$ and high $\mathrm{E_T^{miss}}$ signal regions (SR). The ratio of the dilepton OR single lepton yield to the dilepton only yield is indicated, along with the excess of SF w.r.t. OF events.

Region	N_{ee}	$N_{\mu\mu}$	$N_{\mathrm{e}\mu}$	$N_{\mathrm{ee}} + N_{\mu\mu} - N_{\mathrm{e}\mu}$
Low $\mathrm{E_T^{miss}}$ SR and $20 < m_{\ell\ell} < 70$ GeV				
dilepton (nominal)	106	153	189	70 ± 21.2 (stat)
dilepton OR single lepton	112	155	199	68 ± 21.6 (stat)
ratio	1.06	1.01	1.05	
Low $\mathrm{E_T^{miss}}$ SR and $m_{\ell\ell} > 20$ GeV				
dilepton (nominal)	357	517	693	181 ± 39.6 (stat)
dilepton OR single lepton	368	534	739	163 ± 40.5 (stat)
ratio	1.03	1.03	1.07	
High $\mathrm{E_T^{miss}}$ SR and $15 < m_{\ell\ell} < 70$ GeV				
dilepton (nominal)	89	157	187	59 ± 20.8 (stat)
dilepton OR single lepton	93	160	197	56 ± 21.2 (stat)
ratio	1.04	1.02	1.05	
High $\mathrm{E_T^{miss}}$ SR and $m_{\ell\ell} > 15$ GeV				
dilepton (nominal)	258	380	527	111 ± 34.1 (stat)
dilepton OR single lepton	271	386	553	104 ± 34.8 (stat)
ratio	1.05	1.02	1.05	

Next, we compare the results obtained with the dilepton triggers to results obtained with single lepton triggers only. Since the single electron (single muon) triggers have p_T thresholds of 27 (24) GeV, we use a dilepton $p_T >$ (30,20) selection. The results are summarized in Table 8. Switching from dilepton to single lepton triggers alters the yields by (-2–5)%, and does not significantly alter the excess of SF vs. OF data yields.

Table 8: Summary of results comparing dilepton vs. single lepton triggers (with a dilepton $p_T >$ (30,20) GeV selection, for 5.1 fb^{-1}, in the low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ and high $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal regions (SR). The ratio of the single lepton trigger yield to the dilepton trigger yield is indicated, along with the excess of SF w.r.t. OF events.

Region	N_{ee}	$N_{\mu\mu}$	$N_{\mathrm{e}\mu}$	$N_{\mathrm{ee}} + N_{\mu\mu} - N_{\mathrm{e}\mu}$
Low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ SR and $20 < m_{\ell\ell} < 70$ GeV				
dilepton	95	135	169	61 $\pm$ 20.0 (stat)
single lepton	93	134	172	55 $\pm$ 20.0 (stat)
ratio	0.98	0.99	1.02	
Low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ SR and $m_{\ell\ell} > 20$ GeV				
dilepton	345	497	669	173 $\pm$ 38.9 (stat)
single lepton	346	499	700	145 $\pm$ 39.3 (stat)
ratio	1.00	1.00	1.05	
High $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ SR and $15 < m_{\ell\ell} < 70$ GeV				
dilepton	48	72	79	41 $\pm$ 14.1 (stat)
single lepton	47	72	81	38 $\pm$ 14.1 (stat)
ratio	0.98	1.00	1.03	
High $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ SR and $m_{\ell\ell} > 15$ GeV				
dilepton	197	270	367	100 $\pm$ 28.9 (stat)
single lepton	200	269	377	92 $\pm$ 29.1 (stat)
ratio	1.02	1.00	1.03	

6 Summary of Results

- We reproduce the yields in the Z mass region for the two signal regions of the OSSF edge analysis in the ee, $\mu\mu$ and eμ final states to within 3% of the ETH results for all channels.
- We have predicted the background in the Z mass regions of the two signal regions using the $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ templates technique:
  - In the low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region we observe 288 events and predict 251 $\pm$ 33 events.
  - In the high $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region we observe 167 events and predict 177 $\pm$ 25 events.
- We have extrapolated the predicted Z background to the low mass region to estimate the γ^*/Z background using the "$R_{out/in}$" technique:
  - In the low $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region we predict 5.4 $\pm$ 1.9 events.
  - In the high $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ signal region we predict 7.9 $\pm$ 2.7 events.
- We have verified that the excess of same-flavor vs. opposite-flavor dilepton events persists when using single lepton triggers.

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] CMS AN-2009/023. "A Method to Measure the Contribution of DY→ $\ell^+\ell$ to a dilepton + $\mathrm{E_T^{miss}}$ Selection."