



The Compact Muon Solenoid Experiment

CMS Note

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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.

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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. B 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, $|\eta| < 3$)
 - $E_T^{\text{miss}} > 100$ 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
 - $E_T^{\text{miss}} > 150$ 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 E_T^{miss} central and high E_T^{miss} inclusive signal regions.

low E_T^{miss} signal region (central)	UCSB-UCSD-FNAL	ETH Authors
ee	91	89
$\mu\mu$	102	102
$e\mu$	130	130
high E_T^{miss} signal region (inclusive)	UCSB-UCSD-FNAL	Aachen
ee	61	60
$\mu\mu$	73	78
$e\mu$	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 E_T^{miss} and high E_T^{miss} signal regions, in the central and inclusive regions. The opposite-flavor prediction (OF) is the number of $e\mu$ events scaled by $R_{SF/OF} = 1.02$.

low E_T^{miss} signal region (central)	UCSB-UCSD-FNAL	SUS-12-019 v9 Table 4
SF	364	364
OF	265	264
low E_T^{miss} signal region (inclusive)	UCSB-UCSD-FNAL	SUS-12-019 v9 Table 4
SF	453	452
OF	368	367
high E_T^{miss} signal region (central)	UCSB-UCSD-FNAL	SUS-12-019 v9 Table 4
SF	168	174
OF	114	119
high 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 E_T^{miss} Templates Analysis

In this section, we use the E_T^{miss} templates technique to derive predictions for the background in the on-Z region for the four signal regions used for the edge analysis. The background estimation methodology used in the 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 “ $R_{\text{out/in}}$ ” 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- E_T^{miss} and high- E_T^{miss} signal regions, and compare the observed E_T^{miss} distribution to the sum of the predictions from the four background categories:

- Z+jets background: the E_T^{miss} in Z+jets events is modeled using a data control sample of γ +jets events. These events are reweighted to account for different jet kinematics in Z+jets vs. γ +jets events using the “ E_T^{miss} templates” technique.
- Flavor-symmetric (FS) background: this background category is dominated by $t\bar{t}$, and consists of processes with equal rates for same-flavor (ee and $\mu\mu$) vs. opposite-flavor ($e\mu$) events. The FS background is predicted from the $e\mu$ data sample. The on-Z dilepton mass requirement is not applied to the $e\mu$ sample, and the predictions are scaled by K , the MC efficiency for $e\mu$ background events to satisfy the on-Z dilepton mass requirement.
- WZ/ZZ background: this background is predicted from MC, after validation in 3-lepton (WZ) and 4-lepton (ZZ) data control samples. The contributions from WZ and ZZ to the FS background estimate are negligible.
- Rare background: this background consists of processes with Z bosons ($t\bar{t}Z$ and ZZZ, ZZW, ZWW) that have small cross sections, and is estimated from MC.

In order to adapt the 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 FS scaling factor K and change the binning used for the E_T^{miss} templates. The details of the extraction of K are presented in App. A; to summarize, we use $K = 0.14 \pm 0.02$ for signal regions with inclusive leptons and $K = 0.15 \pm 0.02$ for signal regions with central leptons. In addition, we change the jet p_T threshold for the 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.

4.2 Results in Z Mass Window

The results of the for the signal regions with inclusive leptons are displayed in Fig. 1 and summarized in Table 3. The results of the for the signal regions with central leptons are displayed in Fig. 2 and summarized in Table 4. For all four signal regions, the observed E_T^{miss} distributions agree with the expected E_T^{miss} distributions for the sum of the backgrounds. The observed yields for the $E_T^{\text{miss}} > 100$ GeV (low- E_T^{miss}) and $E_T^{\text{miss}} > 150$ GeV (high- E_T^{miss}) requirements are consistent with the expected background yields within $\pm 1\sigma$. No evidence of a signal-like excess is observed in any region.

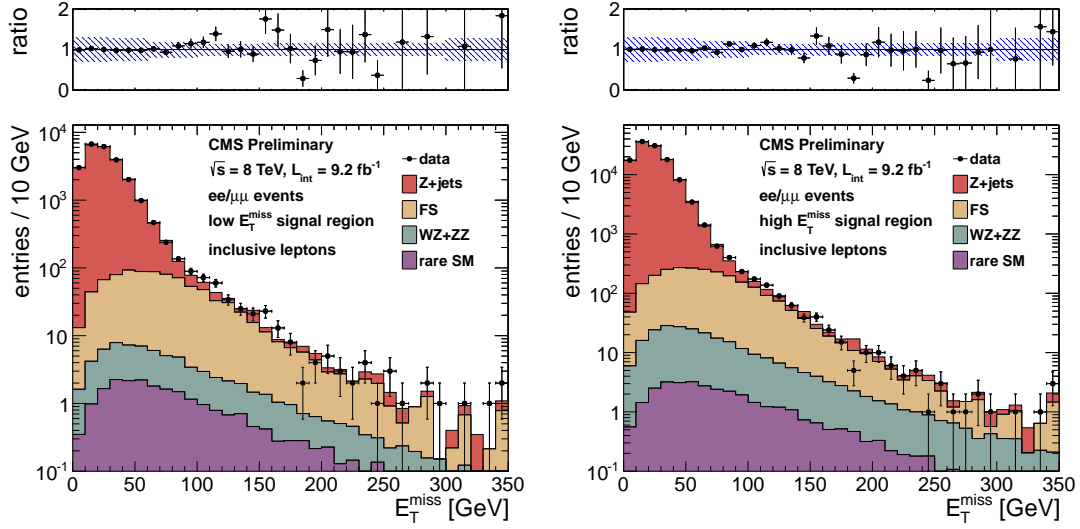


Figure 1: Results of for the low E_T^{miss} (left) and high E_T^{miss} (right) signal regions with the inclusive lepton selection. The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions from Z + jets , flavor-symmetric backgrounds, WZ+ZZ 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 E_T^{miss} signal region (top table) and high E_T^{miss} signal region (bottom table) with the inclusive lepton selection. The total background is the sum of the Z + jets background predicted from the E_T^{miss} templates method (Z + 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.

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	23071 ± 6922	7456 ± 2238	673 ± 203	49.9 ± 16.4	10.4 ± 3.6	1.0 ± 0.6
FS bkg	807 ± 126	695 ± 108	457 ± 71	184 ± 29	45.6 ± 7.5	1.5 ± 0.5
WZ bkg	43.5 ± 30.5	35.1 ± 24.6	21.3 ± 14.9	10.0 ± 7.1	4.4 ± 3.2	0.4 ± 0.4
ZZ bkg	7.8 ± 3.9	7.0 ± 3.6	5.4 ± 2.8	3.3 ± 1.8	1.7 ± 1.1	0.2 ± 0.2
rare SM bkg	22.0 ± 11.0	19.0 ± 9.6	12.4 ± 6.3	6.3 ± 3.3	2.8 ± 1.6	0.3 ± 0.3
total bkg	23951 ± 6924	8213 ± 2241	1169 ± 216	253 ± 34	64.8 ± 9.1	3.5 ± 1.0
data	23999	8134	1217	288	76	4
significance	0.0σ	-0.0σ	0.2σ	0.9σ	0.9σ	

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	114401 ± 34322	30966 ± 9291	1905 ± 573	120 ± 38	26.2 ± 8.9	1.4 ± 0.7
FS bkg	2255 ± 350	1908 ± 296	1201 ± 187	436 ± 68	90.0 ± 14.4	2.9 ± 0.8
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 ± 9296	3231 ± 605	616 ± 82	141 ± 20	6.9 ± 1.9
data	116978	32796	3301	635	133	5
significance	0.0σ	-0.0σ	0.1σ	0.2σ	-0.4σ	

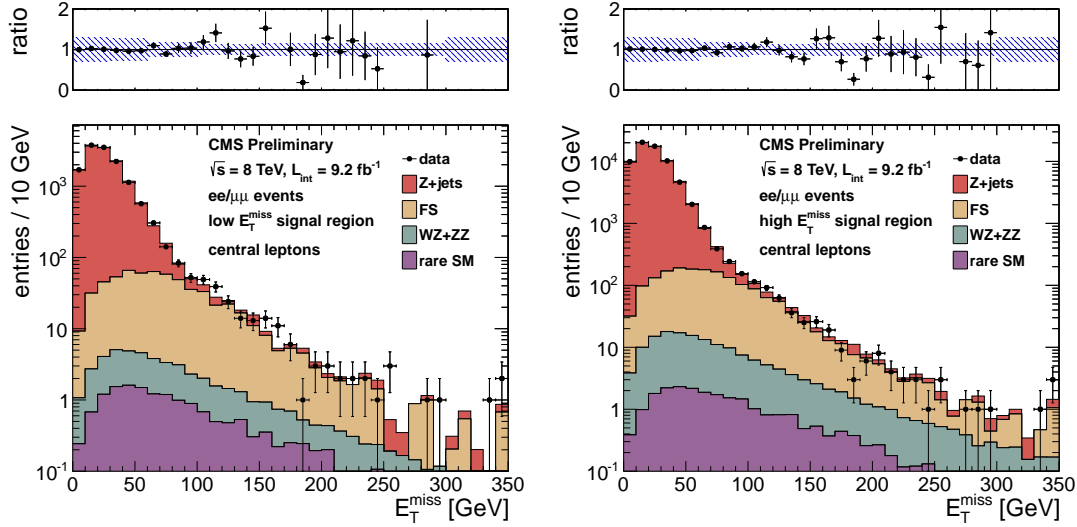


Figure 2: Results of for the low E_T^{miss} (left) and high E_T^{miss} (right) signal regions with the central lepton selection. The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions from Z + jets , flavor-symmetric backgrounds, WZ+ZZ backgrounds, 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 + jets background predicted from the E_T^{miss} templates method (Z + 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.

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	12984 ± 3896	4242 ± 1273	391 ± 118	29.6 ± 9.7	6.3 ± 2.2	0.6 ± 0.4
FS bkg	565 ± 83	487 ± 72	323 ± 48	129 ± 19	32.5 ± 5.2	1.2 ± 0.5
WZ bkg	28.1 ± 19.7	22.7 ± 15.9	13.9 ± 9.8	6.8 ± 4.9	3.1 ± 2.4	0.4 ± 0.4
ZZ bkg	4.8 ± 2.5	4.4 ± 2.3	3.3 ± 1.8	2.1 ± 1.2	1.1 ± 0.8	0.1 ± 0.1
rare SM bkg	15.8 ± 8.0	13.7 ± 6.9	9.0 ± 4.6	4.8 ± 2.5	2.3 ± 1.4	0.3 ± 0.3
total bkg	13598 ± 3897	4770 ± 1275	740 ± 128	173 ± 22	45.2 ± 6.3	2.6 ± 0.7
data	13631	4688	773	192	53	3
significance	0.0σ	-0.1σ	0.3σ	0.7σ	0.8σ	
	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	64775 ± 19433	17697 ± 5310	1118 ± 336	71.8 ± 22.3	15.8 ± 5.3	0.8 ± 0.4
FS bkg	1573 ± 231	1341 ± 197	850 ± 125	313 ± 46	66.5 ± 10.2	2.2 ± 0.7
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	66508 ± 19435	19170 ± 5314	2049 ± 360	424 ± 54	99.6 ± 13.7	5.1 ± 1.4
data	66521	18841	2062	421	92	4
significance	0.0σ	-0.1σ	0.0σ	-0.1σ	-0.5σ	

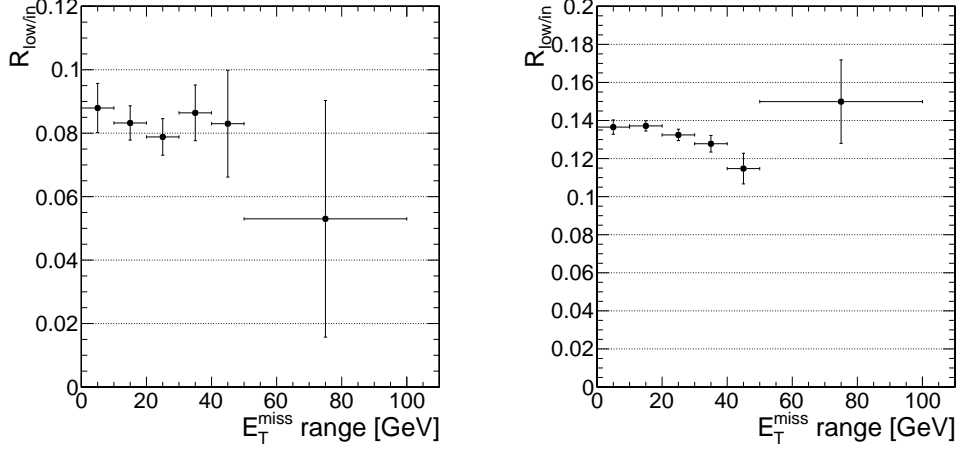


Figure 3: The ratio $R_{low/in}$ of low mass ($15 < m_{\ell\ell} < 70$ GeV) to on-Z ($81 < m_{\ell\ell} < 101$ GeV) events, as a function of the E_T^{miss} requirement. The left plot corresponds to the low E_T^{miss} signal region ($2 < p_T < 20$ GeV leptons with at least 3 jets), the right plot corresponds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

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

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. 3. Here we measure $R_{low/in}$ in several E_T^{miss} regions, and assess the uncertainty based on the variation with respect to E_T^{miss} . Based on this plot we choose $R_{low/in} = 0.08 \pm 0.02$ for the low E_T^{miss} signal region and $R_{low/in} = 0.13 \pm 0.03$ for the high E_T^{miss} region.

We find the following results for the first 5.1 fb^{-1} . For the low E_T^{miss} signal region, the total predicted Z background in the Z mass region is 39 ± 9.6 (sum of the Z + jets, WZ+ZZ, and rare SM backgrounds from Table ??, $E_T^{miss} > 100$ GeV region), resulting in a γ^*/Z prediction of 3.1 ± 1.1 events. For the high E_T^{miss} signal region, the total predicted Z background in the Z mass region is 30 ± 8.1 (sum of the Z + jets, WZ+ZZ, and rare SM backgrounds from Table ??, $E_T^{miss} > 150$ 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 E_T^{miss} signal region, the total predicted Z background in the Z mass region is 68 ± 17 (sum of the Z + jets, WZ+ZZ, and rare SM backgrounds from Table ??, $E_T^{miss} > 100$ GeV region), resulting in a γ^*/Z prediction of 5.4 ± 1.9 events. For the high E_T^{miss} signal region, the total predicted Z background in the Z mass region is 60 ± 16 (sum of the Z + jets, WZ+ZZ, and rare SM backgrounds from Table ??, $E_T^{miss} > 150$ 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- E_T^{miss} and high- E_T^{miss} signal regions (SR). In the Z mass region, the predicted Z background (Z bkg, sum of 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- E_T^{miss} SR	High- 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- E_T^{miss} and high- E_T^{miss} signal regions (SR). In the Z mass region, the predicted Z background (Z bkg, sum of 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- E_T^{miss} SR	High- 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 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 $e\mu$ 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 E_T^{miss} templates technique:
 - In the low E_T^{miss} signal region we observe 288 events and predict 251 ± 33 events.
 - In the high E_T^{miss} signal region we observe 167 events and predict 177 ± 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 E_T^{miss} signal region we predict 5.4 ± 1.9 events.
 - In the high E_T^{miss} signal region we predict 7.9 ± 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 $DY \rightarrow \ell^+ \ell^-$ to a dilepton + E_T^{miss} Selection.”

A Measurement of K

To measure the flavor-symmetric background (mostly $t\bar{t}$) in the Z mass window, we take the $e\mu$ yield without the on-Z mass requirement and scale this by the quantity K, which is the MC efficiency for the flavor-symmetric background to fall in the Z mass window. In this section we measure K from MC for the high- E_T^{miss} and low- E_T^{miss} signal regions, for central and inclusive leptons. The measurement is made in various E_T^{miss} regions, and the uncertainty is assessed based on comparison of K with the corresponding value extracted from data.

The values of K for the high- E_T^{miss} signal region are in Fig. 4 (inclusive leptons) and Fig. 5 (central leptons). The values of K for the low- E_T^{miss} signal region are in Fig. 6 (inclusive leptons) and Fig. 7 (central leptons).

For the inclusive leptons, we find that $K = 0.14 \pm 0.02$ for all E_T^{miss} regions up to $E_T^{\text{miss}} > 150$ GeV (the largest E_T^{miss} requirement used in the edge analysis) For the central leptons, we find $K = 0.15 \pm 0.02$.

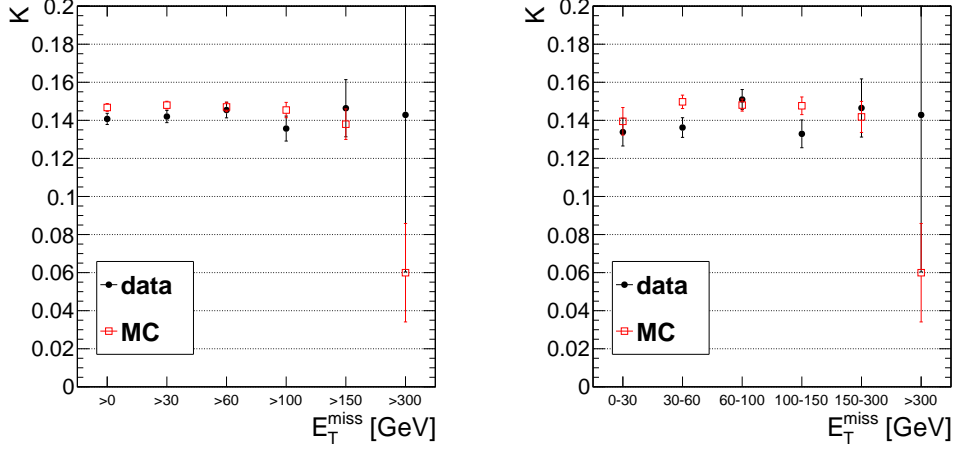


Figure 4: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the **high- E_T^{miss} signal region requirements and inclusive leptons**.

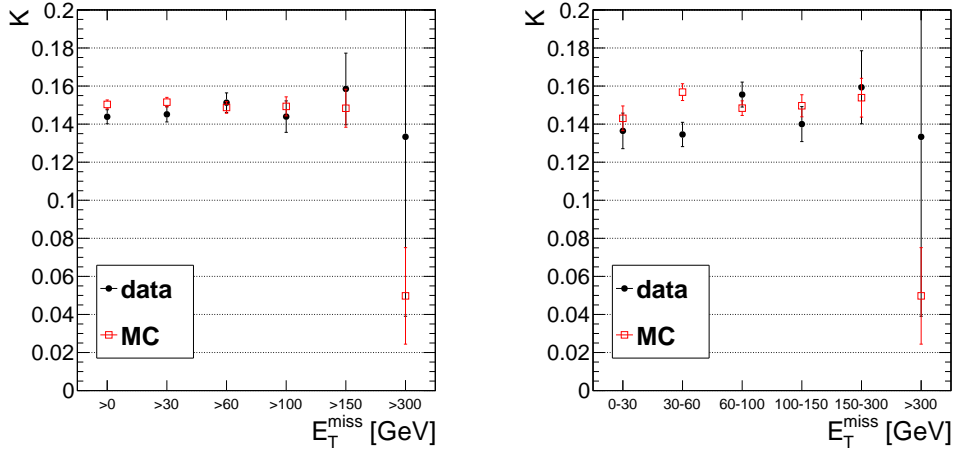


Figure 5: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the **high- E_T^{miss} signal region requirements and central leptons**.

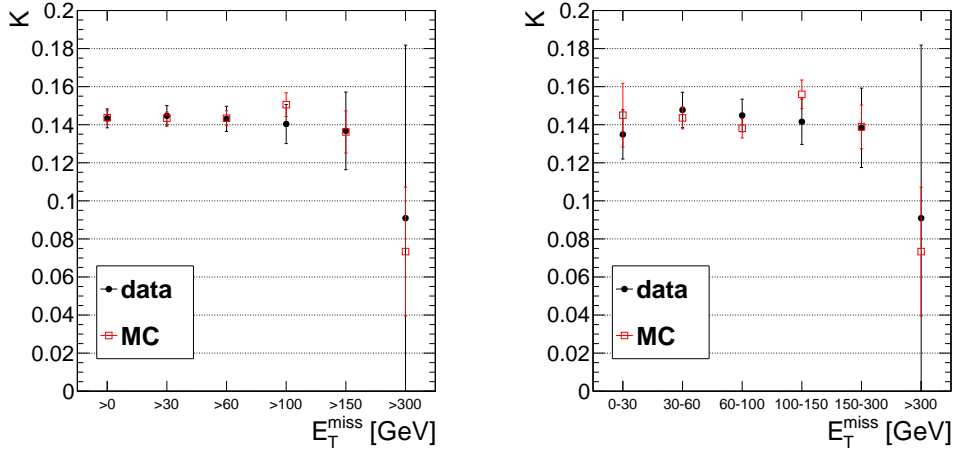


Figure 6: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the **low- E_T^{miss} signal region requirements and inclusive leptons**.

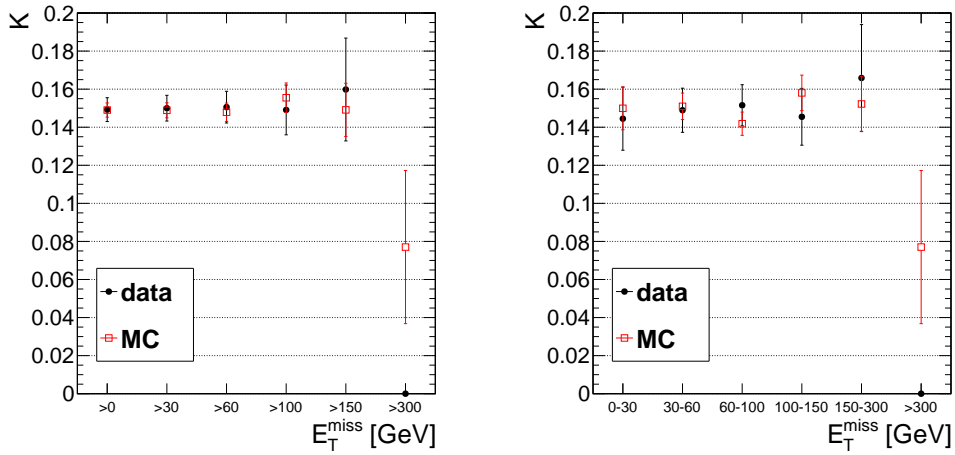


Figure 7: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the **low- E_T^{miss} signal region requirements and central leptons**.

B 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 $e\mu$ 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 $e\mu$ event is required to satisfy one of the two $e\mu$ 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 $e\mu$ event is required to satisfy one of the two $e\mu$ 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 $e\mu$ 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 E_T^{miss} and high 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}	$N_{\mu\mu}$	$N_{e\mu}$	$N_{ee} + N_{\mu\mu} - N_{e\mu}$
Low E_T^{miss} SR and $20 < m_{\ell\ell} < 70 \text{ GeV}$				
dilepton (nominal)	106	153	189	$70 \pm 21.2 \text{ (stat)}$
dilepton OR single lepton	112	155	199	$68 \pm 21.6 \text{ (stat)}$
ratio	1.06	1.01	1.05	
Low E_T^{miss} SR and $m_{\ell\ell} > 20 \text{ GeV}$				
dilepton (nominal)	357	517	693	$181 \pm 39.6 \text{ (stat)}$
dilepton OR single lepton	368	534	739	$163 \pm 40.5 \text{ (stat)}$
ratio	1.03	1.03	1.07	
High E_T^{miss} SR and $15 < m_{\ell\ell} < 70 \text{ GeV}$				
dilepton (nominal)	89	157	187	$59 \pm 20.8 \text{ (stat)}$
dilepton OR single lepton	93	160	197	$56 \pm 21.2 \text{ (stat)}$
ratio	1.04	1.02	1.05	
High E_T^{miss} SR and $m_{\ell\ell} > 15 \text{ GeV}$				
dilepton (nominal)	258	380	527	$111 \pm 34.1 \text{ (stat)}$
dilepton OR single lepton	271	386	553	$104 \pm 34.8 \text{ (stat)}$
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 E_T^{miss} and high E_T^{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}	$N_{\mu\mu}$	$N_{e\mu}$	$N_{ee} + N_{\mu\mu} - N_{e\mu}$
Low E_T^{miss} SR and $20 < m_{\ell\ell} < 70 \text{ GeV}$				
dilepton	95	135	169	$61 \pm 20.0 \text{ (stat)}$
single lepton	93	134	172	$55 \pm 20.0 \text{ (stat)}$
ratio	0.98	0.99	1.02	
Low E_T^{miss} SR and $m_{\ell\ell} > 20 \text{ GeV}$				
dilepton	345	497	669	$173 \pm 38.9 \text{ (stat)}$
single lepton	346	499	700	$145 \pm 39.3 \text{ (stat)}$
ratio	1.00	1.00	1.05	
High E_T^{miss} SR and $15 < m_{\ell\ell} < 70 \text{ GeV}$				
dilepton	48	72	79	$41 \pm 14.1 \text{ (stat)}$
single lepton	47	72	81	$38 \pm 14.1 \text{ (stat)}$
ratio	0.98	1.00	1.03	
High E_T^{miss} SR and $m_{\ell\ell} > 15 \text{ GeV}$				
dilepton	197	270	367	$100 \pm 28.9 \text{ (stat)}$
single lepton	200	269	377	$92 \pm 29.1 \text{ (stat)}$
ratio	1.02	1.00	1.03	