



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.

Contents

1	Introduction	3
2	Results of the E_T^{miss} Templates Analysis	3
2.1	Signal Regions	3
2.2	Synchronization Exercise	3
2.3	Background Estimation Methodology	3
2.4	Results in Z Mass Window	5
2.5	Extrapolation to Low Mass to Estimate the γ^*/Z Contribution	8
2.6	Summary of Results	10
3	Cross-check with single lepton triggers	11
4	Summary of Results	12

1 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. 2 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. 3 we cross-check the results of the nominal analysis based on dilepton triggers using single lepton triggers.

2 Results of the E_T^{miss} Templates Analysis

In this section, we use the 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 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].

2.1 Signal Regions

The two signal regions of the OSSF analysis are defined as:

- Low- E_T^{miss} signal region (ETH)
 - $2 p_T > 20$ GeV leptons with $|\eta| < 2.4$
 - At least 3 jets ($p_T > 40$ GeV, $|\eta| < 3$)
 - $E_T^{\text{miss}} > 100$ GeV
- High- E_T^{miss} signal region (Aachen)
 - leading lepton $p_T > 20$ GeV, trailing lepton $p_T > 10$ GeV, both with $|\eta| < 2.4$
 - At least 2 jets ($p_T > 40$ GeV, $|\eta| < 3$) with scalar sum $H_T > 100$ GeV
 - $E_T^{\text{miss}} > 150$ GeV

2.2 Synchronization Exercise

We perform a synchronization exercise to make sure that we can reproduce the ETH/Aachen results. In Table 1 we display the yields in the Z mass regions of the 2 signal regions and compare these to results from the ETH group. In general we are synchronized to 3% or better in all channels. Note that for the purposes of this exercise we include an additional dimuon trigger (HLT_Mu17_TkMu8) which is not yet included in the results quoted in Sec. 2.3-2.6. The inclusion of this trigger adds 3 $\mu\mu$ events in both the low E_T^{miss} and high E_T^{miss} signal regions.

Table 1: Summary of the synchronization exercise with the ETH group with 9.2 fb^{-1} . The yields in the Z mass region ($81 < m_{\ell\ell} < 101$ GeV) are displayed for the low E_T^{miss} and high E_T^{miss} signal regions.

low E_T^{miss} signal region	UCSB-UCSD-FNAL	ETH
ee	125	123
$\mu\mu$	166	164
$e\mu$	186	186
high E_T^{miss} signal region	UCSB-UCSD-FNAL	ETH
ee	75	72
$\mu\mu$	95	94
$e\mu$	113	113

2.3 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 Z + jets background (from the E_T^{miss} templates method based on the γ + jets data control sample), the flavor-symmetric (FS) background predicted from $e\mu$ 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 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 E_T^{miss} templates. The FS background is estimated using $e\mu$ 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 $e\mu$ 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 E_T^{miss} intervals for the high- 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 E_T^{miss} signal regions up to 200 GeV; for E_T^{miss} 200-300 GeV and $E_T^{\text{miss}} > 300$ 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- 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 E_T^{miss} signal regions up to 200 GeV; for E_T^{miss} 200-300 GeV and $E_T^{\text{miss}} > 300$ 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 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.

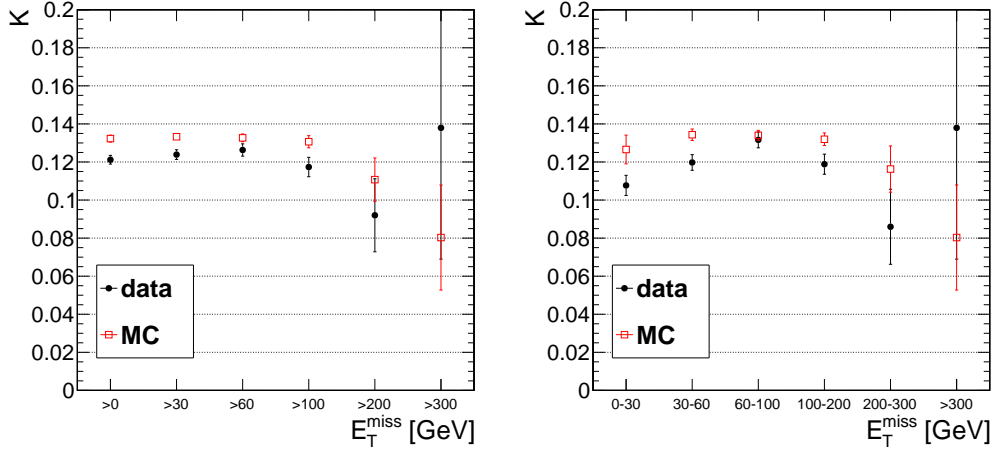


Figure 1: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the dilepton $p_T > (20,10)$ GeV selection with at least 2 $p_T > 40$ GeV jets (used for the high E_T^{miss}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

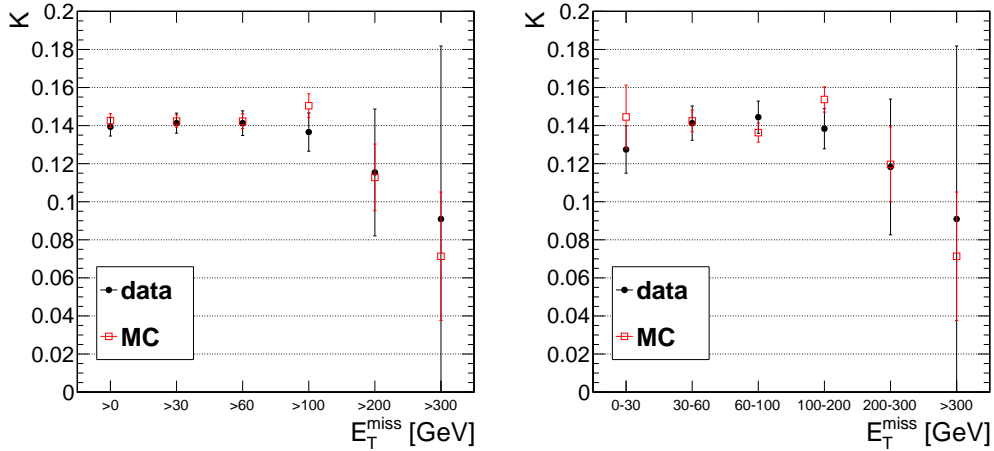


Figure 2: The efficiency for $e\mu$ events to satisfy the dilepton mass requirement, K , in data and simulation for inclusive E_T^{miss} intervals (left) and exclusive E_T^{miss} intervals (right) for the dilepton $p_T > (20,20)$ GeV selection with at least 3 $p_T > 40$ GeV jets (used for the low E_T^{miss}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

2.4 Results in Z Mass Window

The results of the low E_T^{miss} signal region are displayed in Fig. 3 and summarized in Table 2, 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 $E_T^{\text{miss}} > 100 \text{ GeV}$, corresponding to the low 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 combined Run2012A+B+C data (Fig. 5 and Table 4) we observe reasonable agreement over the full E_T^{miss} range. In the $E_T^{\text{miss}} > 100 \text{ GeV}$ region we observe 288 events with a predicted background of 251 ± 33 , representing an excess of 1.0σ .

The results of the high E_T^{miss} signal region are displayed in Fig. 4 and summarized in Table 3, 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 E_T^{miss} range. In the combined Run2012A+B+C data (Fig. 5 and Table 4) we observe reasonable agreement over the full E_T^{miss} range. In the $E_T^{\text{miss}} > 150 \text{ GeV}$ region corresponding to the high E_T^{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 .

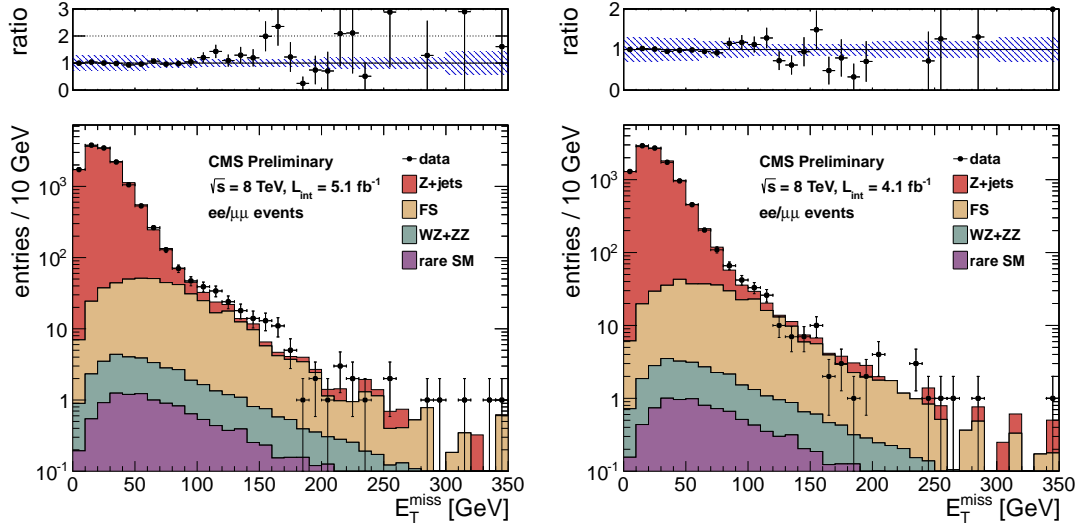


Figure 3: Results for the low E_T^{miss} signal region. The results for 5.1 fb^{-1} 2012A+B data are displayed on the left, the results for 4.1 fb^{-1} 2012C data are displayed on the right. The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions 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 2: Results for the low E_T^{miss} signal region. The results for 5.1 fb^{-1} 2012A+B data are displayed in the top table, the results for 4.1 fb^{-1} 2012C data are displayed in the bottom table. 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.

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 200 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	12870 ± 3862	4118 ± 1236	356 ± 107	27.5 ± 8.5	2.6 ± 1.1	0.3 ± 0.3
FS bkg	451 ± 70	389 ± 61	256 ± 40	99.1 ± 15.8	6.9 ± 1.8	1.0 ± 0.6
WZ bkg	24.1 ± 16.9	19.5 ± 13.7	11.8 ± 8.3	5.6 ± 3.9	1.1 ± 1.0	0.2 ± 0.2
ZZ bkg	4.3 ± 2.2	3.9 ± 2.0	3.0 ± 1.5	1.9 ± 1.0	0.5 ± 0.4	0.1 ± 0.1
rare SM bkg	12.2 ± 6.1	10.5 ± 5.3	6.9 ± 3.5	3.5 ± 1.8	0.7 ± 0.6	0.2 ± 0.2
total bkg	13362 ± 3862	4541 ± 1238	634 ± 115	138 ± 18	11.8 ± 2.5	1.8 ± 0.8
data	13412	4461	684	175	14	3
significance	0.0σ	-0.1σ	0.4σ	1.6σ	0.5σ	
	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 200 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	10203 ± 3061	3449 ± 1035	320 ± 97	20.5 ± 6.3	2.1 ± 0.6	0.8 ± 0.2
FS bkg	356 ± 56	307 ± 48	201 ± 32	84.5 ± 13.5	7.2 ± 1.9	0.6 ± 0.4
WZ bkg	19.4 ± 13.6	15.7 ± 11.0	9.5 ± 6.6	4.5 ± 3.2	0.9 ± 0.8	0.2 ± 0.2
ZZ bkg	3.5 ± 1.8	3.1 ± 1.6	2.4 ± 1.2	1.5 ± 0.8	0.4 ± 0.4	0.1 ± 0.1
rare SM bkg	9.8 ± 4.9	8.5 ± 4.3	5.5 ± 2.8	2.8 ± 1.5	0.6 ± 0.5	0.1 ± 0.1
total bkg	10592 ± 3062	3783 ± 1036	538 ± 102	114 ± 15	11.2 ± 2.2	1.8 ± 0.5
data	10587	3673	533	113	12	1
significance	-0.0σ	-0.1σ	-0.0σ	-0.0σ		

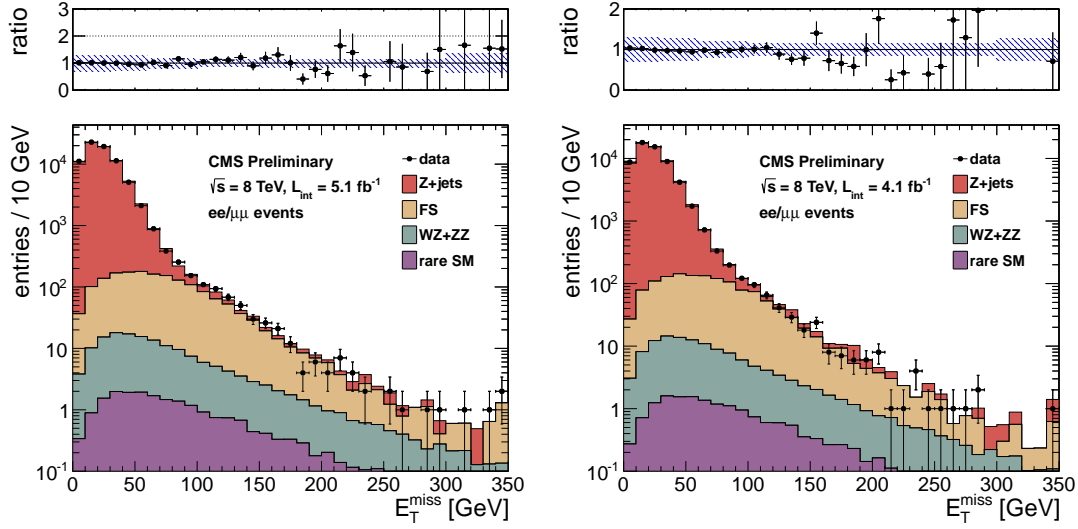


Figure 4: Results of for the high E_T^{miss} signal region. The results for 5.1 fb^{-1} 2012A+B data are displayed on the left, the results for 4.1 fb^{-1} 2012C data are displayed on the right. The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions 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 high E_T^{miss} signal region. The results for 5.1 fb^{-1} 2012A+B data are displayed in the top table, the results for 4.1 fb^{-1} 2012C data are displayed in the bottom table. 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	71975 ± 21593	19573 ± 5873	1182 ± 355	70.7 ± 21.4	13.6 ± 4.2	0.4 ± 0.4
FS bkg	1540 ± 255	1293 ± 214	823 ± 136	313 ± 52	68.6 ± 11.7	2.4 ± 1.1
WZ bkg	115.9 ± 81.2	91.8 ± 64.3	52.1 ± 36.5	22.4 ± 15.7	8.9 ± 6.3	0.8 ± 0.8
ZZ bkg	22.6 ± 11.3	20.3 ± 10.2	15.1 ± 7.6	8.8 ± 4.5	4.3 ± 2.3	0.5 ± 0.5
rare SM bkg	20.6 ± 10.3	17.9 ± 9.0	12.0 ± 6.1	6.3 ± 3.2	2.8 ± 1.5	0.3 ± 0.3
total bkg	73674 ± 21595	20996 ± 5877	2084 ± 382	421 ± 59	98.1 ± 14.2	4.5 ± 1.5
data	73711	20601	2121	446	95	4
significance	0.0σ	-0.1σ	0.1σ	0.4σ	-0.2σ	
	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
Z + jets bkg	57206 ± 17163	15965 ± 4790	1040 ± 313	68.3 ± 21.5	17.5 ± 6.0	1.4 ± 0.4
FS bkg	1206 ± 200	1015 ± 168	649 ± 108	244 ± 41	48.1 ± 8.3	1.3 ± 0.6
WZ bkg	93.2 ± 65.3	73.8 ± 51.7	41.9 ± 29.4	18.0 ± 12.7	7.1 ± 5.1	0.7 ± 0.7
ZZ bkg	18.2 ± 9.1	16.3 ± 8.2	12.1 ± 6.1	7.1 ± 3.6	3.4 ± 1.8	0.4 ± 0.4
rare SM bkg	16.6 ± 8.3	14.4 ± 7.2	9.7 ± 4.9	5.1 ± 2.6	2.3 ± 1.2	0.3 ± 0.3
total bkg	58541 ± 17164	17084 ± 4793	1753 ± 332	343 ± 48	78.4 ± 11.7	4.0 ± 1.1
data	58478	16494	1690	321	72	1
significance	-0.0σ	-0.1σ	-0.2σ	-0.4σ	-0.4σ	

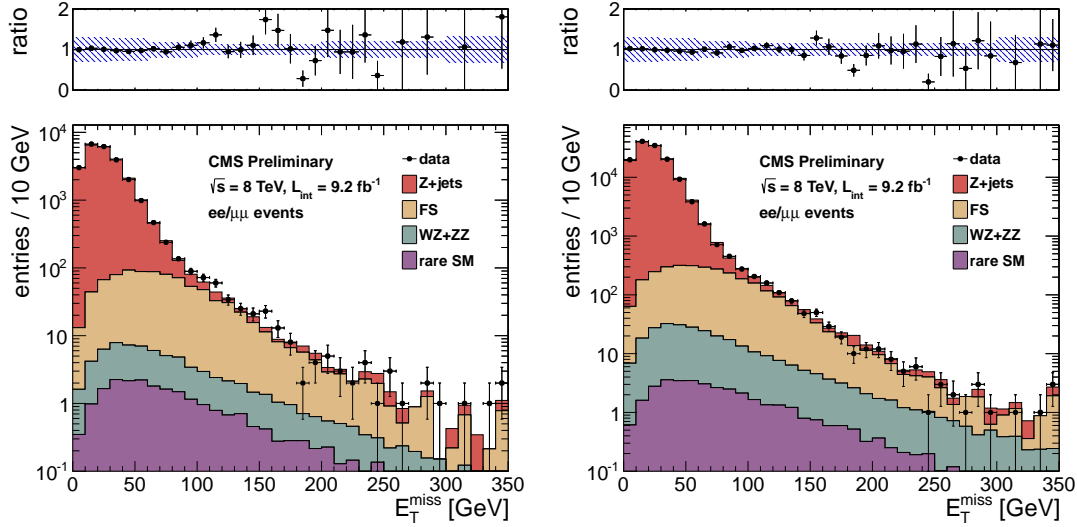


Figure 5: Results of for the low E_T^{miss} (left) and high E_T^{miss} (right) signal regions for the full 9.2 fb^{-1} sample. The observed E_T^{miss} distribution (black points) is compared with the sum of the predicted E_T^{miss} distributions from $Z + \text{jets}$, flavor-symmetric backgrounds, $WZ+ZZ$ 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). 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.

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 200 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
$Z + \text{jets}$ bkg	23072 ± 6922	7566 ± 2270	674 ± 203	47.9 ± 14.6	4.7 ± 1.6	1.1 ± 0.4
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	23952 ± 6923	8323 ± 2273	1170 ± 216	251 ± 33	22.8 ± 4.4	3.5 ± 1.1
data	23999	8134	1217	288	26	4
significance	0.0σ	-0.1σ	0.2σ	1.0σ	0.5σ	

	$E_T^{\text{miss}} > 0 \text{ GeV}$	$E_T^{\text{miss}} > 30 \text{ GeV}$	$E_T^{\text{miss}} > 60 \text{ GeV}$	$E_T^{\text{miss}} > 100 \text{ GeV}$	$E_T^{\text{miss}} > 150 \text{ GeV}$	$E_T^{\text{miss}} > 300 \text{ GeV}$
$Z + \text{jets}$ bkg	129184 ± 38756	35565 ± 10670	2225 ± 668	140 ± 43	31.6 ± 10.1	1.7 ± 0.6
FS bkg	2746 ± 454	2308 ± 382	1471 ± 243	557 ± 92	117 ± 20	3.7 ± 1.6
WZ bkg	209.2 ± 146.4	165.6 ± 115.9	94.1 ± 65.9	40.5 ± 28.4	16.0 ± 11.3	1.5 ± 1.5
ZZ bkg	40.8 ± 20.4	36.6 ± 18.4	27.2 ± 13.7	16.0 ± 8.1	7.7 ± 4.1	0.9 ± 0.9
rare SM bkg	37.2 ± 18.7	32.2 ± 16.2	21.7 ± 10.9	11.4 ± 5.8	5.1 ± 2.8	0.6 ± 0.6
total bkg	132217 ± 38759	38108 ± 10678	3839 ± 714	765 ± 106	177 ± 25	8.4 ± 2.5
data	132189	37095	3811	767	167	5
significance	-0.0σ	-0.1σ	-0.0σ	0.0σ	-0.4σ	

2.5 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 $R_{\text{low/in}}$ of low-mass to on-shell Z events from data, correcting for the contribution from flavor-symmetric backgrounds, according to:

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

Here SF and OF refer to the same-flavor and opposite-flavor data yields in the “low” ($15 < m_{\ell\ell} < 70 \text{ GeV}$) and “in” ($81 < m_{\ell\ell} < 101 \text{ GeV}$) 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. 6. Here we measure $R_{\text{low/in}}$ 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

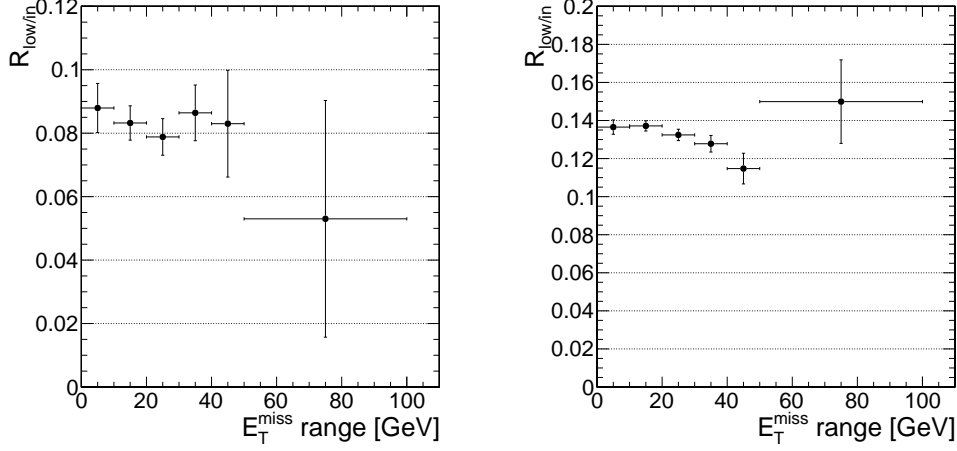


Figure 6: The ratio $R_{low/in}$ of low mass ($15 < m_{\ell\ell} < 70$ GeV) to on-Z ($81 < m_{\ell\ell} < 101$ GeV) events, as a function of the E_T^{miss} requirement. The left plot corresponds to the low E_T^{miss} signal region ($2 p_T > 20$ GeV leptons with at least 3 jets), the right plot corresponds to the high E_T^{miss} signal region ($p_T > (20,10)$ GeV leptons with at least 2 jets).

$R_{low/in} = 0.08 \pm 0.02$ 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 2, $E_T^{miss} > 100$ 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 3, $E_T^{miss} > 150$ 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 4, $E_T^{miss} > 100$ 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 4, $E_T^{miss} > 150$ GeV region), resulting in a γ^*/Z prediction of 7.9 ± 2.7 events.

2.6 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

3 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 $20 < m_{\ell\ell} < 70$ GeV				
dilepton	95	135	169	61 ± 20.0 (stat)
single lepton	93	134	172	55 ± 20.0 (stat)
ratio	0.98	0.99	1.02	
Low E_T^{miss} SR and $m_{\ell\ell} > 20$ GeV				
dilepton	345	497	669	173 ± 38.9 (stat)
single lepton	346	499	700	145 ± 39.3 (stat)
ratio	1.00	1.00	1.05	
High E_T^{miss} SR and $15 < m_{\ell\ell} < 70$ GeV				
dilepton	48	72	79	41 ± 14.1 (stat)
single lepton	47	72	81	38 ± 14.1 (stat)
ratio	0.98	1.00	1.03	
High E_T^{miss} SR and $m_{\ell\ell} > 15$ GeV				
dilepton	197	270	367	100 ± 28.9 (stat)
single lepton	200	269	377	92 ± 29.1 (stat)
ratio	1.02	1.00	1.03	

4 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 “ $R_{\text{out/in}}$ ” 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.”