Search for Supersymmetry at CMS in Events with Two Photons and Missing Transverse Energy at $\sqrt{s} = 13$ TeV (CADISUS-15-012)

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Supersymmetry (SUSY) and Gauge Mediated Supersymmetry Breaking (GMSB):

- Symmetry between SM bosons and fermions to supersymmetric fermions and bosons.
- Broken symmetry: otherwise the SM particle and its SUSY partner would have the same mass.
  - GMSB:
    - Ordinary gauge interaction is responsible for SUSY breaking.

![Diagram showing processes involving SUSY particles and their SM partners.](image)
Quantum Chromodynamics (QCD) background
- May have two real photons in the final state, or one or both coming from the electromagnetically-rich jet fragmentation mimicking the response of a photon.
- Missing transverse energy ($E_T^{\text{miss}}$ or MET) from object mis-measurement.

QCD Background
Most significant background as the QCD cross-section is enormous!

Electroweak (EWK) background
- SM process with neutrino in the final state.
- $W\gamma$, $W$-jets events where $W \to e\nu$ etc.

EWK Background
genuine $E_T^{\text{miss}}$, but very small background.

Other negligible contributions:
$Z\gamma\gamma \to \nu\nu\gamma\gamma$, $W\gamma\gamma \to l\nu\gamma\gamma$, $t\bar{t}\gamma\gamma$. 
Relevant Object Reconstruction:

**Candidate (Double Photon, \(\gamma\gamma\)) Sample**

- Define \(\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}\)
- Hadronic energy deposition (H)/electromagnetic energy deposition (E) < 0.05 around the photon object.
- Showershape in \(\eta\) direction should be consistent with electromagnetic shower.
- No hit in inner two layers of silicon pixel detector.
- The selected objects should be well isolated. Applied particle-flow based isolation.
- The photon selection follows medium cut based photon Id.

**Figure:** A sample photon deposition in the detector.
Control samples and Trigger:

Control samples for QCD background estimation:

**Electron (ee) Sample**
- Selection of electron: same as photon selection but requires hit in the silicon pixel detector.
- Two separated electrons having invariant mass within 75 to 105 GeV (within Z boson mass).

**Fake (ff) Sample**
- Comes primarily from electromagnetically rich jets whose fragmentation mimic the response of photons.
- The requirement of deposited transverse momenta by charged hadrons around the object within $\Delta R < 0.3$ or the showershape in $\eta$ direction (but **NOT** both) is orthogonal to that of photon selection.
- These samples don't have real $E_T^{miss}$, ideal for QCD background modeling.

Control sample for EWK background estimation:

**Electron-Photon (e\gamma) sample**: events with one electron and one photon.
- Real $E_T^{miss}$.

High Level Trigger:

- Two objects with leading object $p_T > 30$ GeV and sub-leading object $p_T > 18$ GeV.
- Showershape for each object must be less than 0.015 for the barrel and also $H/E < 0.1$.
- The objects should be isolated.
- Invariant mass $> 95$ GeV.
Missing Transverse Energy ($E_T^{\text{miss}}$ or MET):

- Imbalance in the total transverse momentum of particles before and after collision.
  - May be due to object mis-measurement.
  - Particles leaving the detector undetected.

**Definition**

\[ E_T^{\text{miss}} = - \sum_{i=1}^{n} \vec{p}_{Ti} \text{ where } i \text{ runs over all visible particles in the event.} \]

**$E_T^{\text{miss}}$**

Toughest thing to measure because it involves resolution of all the visible particles!

**Correction to $E_T^{\text{miss}}$:**

- Type 0 correction: correction on $E_T^{\text{miss}}$ to reduce the effect of pileup.
- Type 1 correction: the propagation of correction applied to the jets.
**Double-Photon Sample**

- Any double-photon sample selected will invariably contain jet-jet, photon-jet samples because of jet fluctuations appearing as photons.

- Very tough to simulate the $E_T^{miss}$ distribution when jets fluctuate and appear as photons, as resolution in measuring jets are poor.

- Even with events with two true photons, mis-measurement of the $E_T^{miss}$ possible due to the additional hadronic activity.

- Data-driven technique: control sample with $ee$ and $ff$ because they don’t have real $E_T^{miss}$.

- Control samples differ from candidate samples in hadronic activity.

### di-EM $p_T$:

- di-EM $p_T$ is defined as transverse momenta of two electromagnetic objects:
  \[ \vec{p}_T^{di-EM} = (\vec{p}_T^1 + \vec{p}_T^2) \]

  where $\vec{p}_T^1$ and $\vec{p}_T^2$ are the individual transverse momentum of the electromagnetic objects.

- This is a measure of hadronic recoil in the sample.
The primary QCD background estimate comes from the double electron sample.

The prediction from double fake samples used to cross check our double electron estimate.
$E_{\text{miss}}$ distribution between control and candidate samples can differ because of difference in jet multiplicity.

The energy resolution in an event where there are three jets having total $p_T$ of 100 GeV will be worse than that of an event where there is only one jet having $p_T$ of 100 GeV.

To extract any dependence of jet multiplicity with di-EM $p_T$ for ee sample, the jet multiplicity is plotted in bins of di-EM $p_T$. 

![Diagram showing jet multiplicity distribution and ratio for different channels.](image_url)
Effect of reweighting by jet multiplicity distribution:

To know the effect of jet multiplicity reweighting, we plot only di-EM $p_T$ reweighted $E_T^{\text{miss}}$ and jet multiplicity in bins of di-EM $p_T$ reweighted $E_T^{\text{miss}}$.

The ratio shows the effect of jet multiplicity reweighting is small.

Take the difference between only di-EM $p_T$ reweighted $E_T^{\text{miss}}$ and jet multiplicity in bins of di-EM $p_T$ reweighted $E_T^{\text{miss}}$ as one of our systematic uncertainties.

<table>
<thead>
<tr>
<th>$E_T^{\text{miss}}$ bin (GeV)</th>
<th>Expected QCD (from reweighted ee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 110</td>
<td>1.85 ± 0.96</td>
</tr>
<tr>
<td>110 – 120</td>
<td>1.53 ± 0.63</td>
</tr>
<tr>
<td>120 – 140</td>
<td>0.97 ± 0.62</td>
</tr>
<tr>
<td>&gt; 140</td>
<td>0.61 ± 2.15</td>
</tr>
</tbody>
</table>
Analysis Technique: Modeling EWK Background:

EWK Background:

- Coming mainly from $W\gamma$ sample where $W \rightarrow e\nu$ and electron is misidentified as photon, so we get double-photon final state.

To model the EWK background, need to find the electron-to-photon misidentification rate (fake rate) ($f_{e\rightarrow\gamma}$) and scale the electron-photon $E^\text{miss}_T$ distribution with it.

- $f_{e\rightarrow\gamma} = 0.021 \pm 0.002$
- $N_{\gamma\gamma} = \frac{f_{e\rightarrow\gamma}}{1-f_{e\rightarrow\gamma}} N_{e\gamma}$
- $M_{e\gamma} > 105$ GeV.

<table>
<thead>
<tr>
<th>$E^\text{miss}_T$ bin (GeV)</th>
<th>Expected EWK</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 110</td>
<td>0.41 ± 0.12</td>
</tr>
<tr>
<td>110 – 120</td>
<td>0.26 ± 0.09</td>
</tr>
<tr>
<td>120 – 140</td>
<td>0.54 ± 0.15</td>
</tr>
<tr>
<td>&gt; 140</td>
<td>1.03 ± 0.25</td>
</tr>
</tbody>
</table>
Analysis Technique: $E_T^{\text{miss}}$ Plot with Candidate and Modeled Background

**Remark:**
- Did not get significantly excess events over expected background in data.
- Put the limits on production cross sections.

<table>
<thead>
<tr>
<th>$E_T^{\text{miss}}$ bin (GeV)</th>
<th>Expected QCD+EWK</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 110</td>
<td>2.26 ± 0.96</td>
<td>4</td>
</tr>
<tr>
<td>110 – 120</td>
<td>1.79 ± 0.64</td>
<td>2</td>
</tr>
<tr>
<td>120 – 140</td>
<td>1.51 ± 0.64</td>
<td>2</td>
</tr>
<tr>
<td>&gt; 140</td>
<td>1.64 ± 2.16</td>
<td>1</td>
</tr>
</tbody>
</table>

Table: Expected and observed events for $E_T^{\text{miss}} > 100$ GeV
Efficiency $\times$ Acceptance is low for low gluino and neutralino masses, as here most of the photons fail to pass $p_T > 40$ GeV cut.
Conclusion:

- Full analysis done on 13 TeV data.
- Successfully modeled the background for the analysis.
- Did not observe any significantly excess event in the signal region.
- The analysis with 8 TeV data (integrated luminosity 19.6 fb$^{-1}$) set limits on gluino mass at 1.35 TeV (arxiv:1507.02898). With only 2.3 fb$^{-1}$ of 13 TeV data, the limits on gluino mass is extended to 1.65 TeV.
Thank You!
Back Up
Trigger:

- Primary analysis trigger: \texttt{HLT\_Diphoton30\_18\_R9Id\_OR\_IsoCalold\_AND\_HE\_R9Id\_Mass95\_v*}.
- Lead photon $p_T > 30$ GeV and trail photon $p_T > 18$ GeV.
- Leading leg has $L1$ seed, but sub-leading leg is unseeded.
- $M_{\gamma\gamma} > 95$ GeV.
- Photons must pass \_HE\_R9Id\_ and (\_R9Id\_ or \_IsoCalold\_).

<table>
<thead>
<tr>
<th>_R9Id_</th>
<th>R9 $&gt; 0.85$</th>
</tr>
</thead>
<tbody>
<tr>
<td>_IsoCalold_</td>
<td>$\sigma_{\eta\eta} &lt; 0.015$</td>
</tr>
<tr>
<td></td>
<td>ECAL Isolation $&lt; (6 + 0.012 \times p_T^\gamma)$</td>
</tr>
<tr>
<td></td>
<td>Track Isolation $&lt; (6 + 0.002 \times p_T^\gamma)$</td>
</tr>
<tr>
<td>_HE_R9Id_</td>
<td>H/E $&lt; 0.1$</td>
</tr>
<tr>
<td></td>
<td>R9 $&gt; 0.5$</td>
</tr>
</tbody>
</table>

High Level Trigger

- \texttt{HLT\_Diphoton30\_18\_R9Id\_OR\_IsoCalold\_AND\_HE\_R9Id\_Mass95\_v*}
- \texttt{HLT\_Diphoton30\_18\_R9Id\_OR\_IsoCalold\_AND\_HE\_R9Id\_DoublePixelSeedMatch\_Mass70\_v*}
- \texttt{HLT\_Diphoton30PV\_18PV\_R9Id\_AND\_IsoCalold\_AND\_HE\_R9Id\_DoublePixelVeto\_Mass55\_v*}
- \texttt{HLT\_Diphoton30EB\_18EB\_R9Id\_OR\_IsoCalold\_AND\_HE\_R9Id\_DoublePixelVeto\_Mass55\_v*}
Trigger efficiencies:

- Trigger requires two photons passing sub-leading filters and one photon passing leading filters.
- Total trigger efficiency $\epsilon_{\text{tot}} = \epsilon_{\text{lead, lead}} \times \epsilon_{\text{lead, sub}} \times \epsilon_{\text{sub, sub}}$
- $\epsilon_{\text{lead, lead}}$ means efficiency of leading photon passing leading filter.
- $\epsilon_{\text{lead, sub}}$ means efficiency of leading photon passing sub-leading filter.
- $\epsilon_{\text{sub, sub}}$ means efficiency of sub-leading photon passing sub-leading filter.

**Figure**: Efficiency of leading photon passing leading filter as function of photon $p_T$

**Figure**: Efficiency of leading photon passing sub-leading filter as function of photon $p_T$
Trigger efficiencies: Sub-leading photon

![Leading Efficiency](image1)

![Sub-Leading Efficiency](image2)

**Figure**: Efficiency of sub-leading photon passing leading filter as function of photon $p_T$

- We use the photon $p_T$ cut at 40 GeV.
- At this point, $\epsilon_{\text{lead,lead}} = 0.997$, $\epsilon_{\text{lead,sub}} = 0.995$
- $\epsilon_{\text{sub,sub}} = 0.994$, $\epsilon_{\text{tot}} = 98.6\%$

**Figure**: Efficiency of sub-leading photon passing sub-leading filter as function of photon $p_T$
Determine the ID efficiency of $e\gamma$ objects.

Photon efficiency $\epsilon_\gamma = \epsilon_\gamma^{MC} \times \frac{\epsilon_\gamma^{data}}{\epsilon_\gamma^{MC}}$

Computed the efficiency as a function of kinematic variables like: $E_T$, $|\eta|$, $\Delta R(\gamma, \text{jet})$.

Data used: DoubleEG streams (Run C and Run D)

Trigger used: \textit{HLT\_Diphoton30\_18\_R9Id\_OR\_IsoCaloId\_AND\_HE\_R9Id\_DoublePixelSeedMatch\_Mass70\_v*}

MC sample: DY\rightarrow ee sample ($DYToEE\_13\ TeV - amcatnloFXFX - pythia8$)

$\gamma$ selection:
- $|\eta| < 2.5$, $E_T > 25$ GeV for probe, $E_T > 35$ GeV for tag
- tagged photon passes tight photon selection
- probe efficiencies were computed for loose, medium and tight selections.
Overall scale factor $= 0.985 \pm 0.011$ (Official values: $0.983 \pm 0.012$).
Cross check on pure QCD background estimate:

- Fake samples are sideband to candidate sample.
- If there is no signal anywhere in the $E_T^{\text{miss}}$, expect the relative fraction of candidate and fake-fake sample should remain constant as a function of $E_T^{\text{miss}}$.
- We fit the $\gamma\gamma/ff$ ratio with a simple function (in the form $\exp(ax+b)$) in the control region ($E_T^{\text{miss}} < 100$ GeV).
- Extend this ratio in signal region and ratio $\times$ ff in one bin gives the double photon estimate coming from pure QCD in that bin.
- We take the overall normalization from fake sample and the distribution from loose fake samples.

Table: Estimation of QCD background for $E_T^{\text{miss}} > 100$ GeV using the ff control sample

<table>
<thead>
<tr>
<th>$E_T^{\text{miss}}$ bin (GeV)</th>
<th>Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 110</td>
<td>Di-EM $p_T$ reweighting method</td>
<td>1.97 ± 0.69</td>
</tr>
<tr>
<td></td>
<td>$\gamma\gamma/ff$ ratio method</td>
<td>1.12 ± 0.59</td>
</tr>
<tr>
<td>110 – 120</td>
<td>Di-EM $p_T$ reweighting method</td>
<td>1.12 ± 0.48</td>
</tr>
<tr>
<td></td>
<td>$\gamma\gamma/ff$ ratio method</td>
<td>0.61 ± 0.35</td>
</tr>
<tr>
<td>120 – 140</td>
<td>Di-EM $p_T$ reweighting method</td>
<td>1.53 ± 0.76</td>
</tr>
<tr>
<td></td>
<td>$\gamma\gamma/ff$ ratio method</td>
<td>0.68 ± 0.43</td>
</tr>
<tr>
<td>&gt; 140</td>
<td>Di-EM $p_T$ reweighting method</td>
<td>2.05 ± 1.32</td>
</tr>
<tr>
<td></td>
<td>$\gamma\gamma/ff$ ratio method</td>
<td>0.91 ± 0.70</td>
</tr>
</tbody>
</table>
Shape difference between $ee$ and $ff$ $E_T^{miss}$ distribution:

- Fit reweighted $ee$ and $ff$ $E_T^{miss}$ distribution with $x^{p_0} \times \exp(p_1 \cdot x^{p_2})$, where $p_0$, $p_1$ and $p_2$ are obtained from the fit in the range 70-300 GeV.
- Integrate each of the fits in the signal bins.
- Take the difference between the integrated results in each bin between $ee$ and $ff$.
- Uncertainty in the last bin is large because here the integration range is high.
Comparison of reweighted control samples and data $E_T^{miss}$

CMS Preliminary 2.3 fb$^{-1}$ (13 TeV)

Events/GeV

$\gamma\gamma$

reweighted ee

$\gamma\gamma$

reweighted ff

$E_T^{miss}$ (GeV)

Events/GeV

$\gamma\gamma$

reweighted ee

$\gamma\gamma$

reweighted ff

$E_T^{miss}$ (GeV)
Uncertainty in QCD background estimation:

Table: Shape uncertainty coming from the difference between the $ee$ and $ff$ $E_{T}^{\text{miss}}$ distributions for $E_{T}^{\text{miss}} > 100$ GeV

<table>
<thead>
<tr>
<th>$E_{T}^{\text{miss}}$ bin (GeV)</th>
<th>ee prediction</th>
<th>$ff$ prediction</th>
<th>difference</th>
<th>fractional difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 − 110</td>
<td>1.87</td>
<td>2.21</td>
<td>0.34</td>
<td>18.18%</td>
</tr>
<tr>
<td>110 − 120</td>
<td>1.16</td>
<td>1.30</td>
<td>0.14</td>
<td>12.07%</td>
</tr>
<tr>
<td>120 − 140</td>
<td>1.25</td>
<td>1.43</td>
<td>0.18</td>
<td>14.40%</td>
</tr>
<tr>
<td>&gt; 140</td>
<td>1.39</td>
<td>3.48</td>
<td>2.09</td>
<td>150.36%</td>
</tr>
</tbody>
</table>

Table: Systematic and Statistical Uncertainties from QCD Background Estimation

<table>
<thead>
<tr>
<th>$E_{T}^{\text{miss}}$ bin (GeV)</th>
<th>Systematic Uncertainty</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 − 110</td>
<td>Di-EM $p_{T}$ reweighting</td>
<td>15.11%</td>
</tr>
<tr>
<td></td>
<td>Jet multiplicity reweighting</td>
<td>33.77%</td>
</tr>
<tr>
<td></td>
<td>Shape difference between $ee$ and $ff$</td>
<td>18.18%</td>
</tr>
<tr>
<td></td>
<td>Statistical uncertainty of ee sample</td>
<td>30.81%</td>
</tr>
<tr>
<td>110 − 120</td>
<td>Di-EM $p_{T}$ reweighting</td>
<td>16.60%</td>
</tr>
<tr>
<td></td>
<td>Jet multiplicity reweighting</td>
<td>14.87%</td>
</tr>
<tr>
<td></td>
<td>Shape difference between $ee$ and $ff$</td>
<td>12.07%</td>
</tr>
<tr>
<td></td>
<td>Statistical uncertainty of ee sample</td>
<td>33.33%</td>
</tr>
<tr>
<td>120 − 140</td>
<td>Di-EM $p_{T}$ reweighting</td>
<td>33.31%</td>
</tr>
<tr>
<td></td>
<td>Jet multiplicity reweighting</td>
<td>29.39%</td>
</tr>
<tr>
<td></td>
<td>Shape difference between $ee$ and $ff$</td>
<td>14.40%</td>
</tr>
<tr>
<td></td>
<td>Statistical uncertainty of ee sample</td>
<td>41.75%</td>
</tr>
<tr>
<td>140 − $\text{Inf}$</td>
<td>Di-EM $p_{T}$ reweighting</td>
<td>39.37%</td>
</tr>
<tr>
<td></td>
<td>Jet multiplicity reweighting</td>
<td>20.34%</td>
</tr>
<tr>
<td></td>
<td>Shape difference between $ee$ and $ff$</td>
<td>150.36%</td>
</tr>
<tr>
<td></td>
<td>Statistical uncertainty of ee sample</td>
<td>70.98%</td>
</tr>
</tbody>
</table>
Other sources of systematic uncertainties:

Table: Summary of systematic uncertainties included in the determination of the expected exclusion contours.

<table>
<thead>
<tr>
<th>Systematic Uncertainty</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity</td>
<td>4.6</td>
</tr>
<tr>
<td>Photon Data/MC scale factor</td>
<td>2.4</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>0 - 23</td>
</tr>
<tr>
<td>Finite MC statistics</td>
<td>0 - 16</td>
</tr>
<tr>
<td>PDF error on cross section</td>
<td>13 - 22</td>
</tr>
</tbody>
</table>
Selection of objects: Muons and Jets

**Muon**
- $p_T > 30$ GeV.
- $|\eta| < 1.4442$.
- passes medium Id.

**Jets**
- $p_T > 30$ GeV and $|\eta| < 2.4$.
- Passes PFLooseId.
- Separated by $\Delta R > 0.4$ from all electrons, photons and muons.

### Table: Muon Medium Id

<table>
<thead>
<tr>
<th>1. Global muon</th>
<th>normalized $\chi^2 &lt; 3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized global-track $\chi^2$</td>
<td>$\chi^2$ LocalPosition $&lt; 12$</td>
</tr>
<tr>
<td>Tracker-Standalone position match</td>
<td>track Kink $&lt; 20$</td>
</tr>
<tr>
<td>Kick finder</td>
<td>$&gt; 0.303$</td>
</tr>
<tr>
<td>Segment compatibility</td>
<td>$&gt; 0.451$</td>
</tr>
<tr>
<td>2. Tight segment compatibility</td>
<td></td>
</tr>
</tbody>
</table>

---
Selection of objects: photon and electron

**Photon**
- $p_T > 40$ GeV
- Restricted to barrel region.
- passes medium Id.
- pixel seed $= 0$.

**Electron**
- Identical to photon selection except pixel seed match.

---

**Table: 25 ns Spring 15 Cut-based Medium Photon Id**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H/E</td>
<td>0.05</td>
</tr>
<tr>
<td>$\sigma_{\eta \eta \eta}$</td>
<td>0.0102</td>
</tr>
<tr>
<td>$\rho$ corrected charged hadron isolation</td>
<td>1.37</td>
</tr>
<tr>
<td>$\rho$ corrected neutral hadron isolation</td>
<td>$1.06 + 0.014 \times p_T + 0.000019 \times p_T^2$</td>
</tr>
<tr>
<td>$\rho$ corrected photon isolation</td>
<td>$0.28 + 0.0053 \times p_T$</td>
</tr>
</tbody>
</table>
Fake selection:

<table>
<thead>
<tr>
<th>Fake sample</th>
<th>Loose Fake sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T &gt; 40$ GeV</td>
<td>$p_T &gt; 40$ GeV</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>$H/E &lt; 0.05$</td>
<td>$H/E &lt; 0.05$</td>
</tr>
<tr>
<td>Photon isolation and neutral hadron</td>
<td>Photon isolation and neutral hadron isolation from ID not applied</td>
</tr>
<tr>
<td>isolation from ID applied</td>
<td>Passed pixel seed veto</td>
</tr>
<tr>
<td>Passed pixel seed veto</td>
<td>Passed pixel seed veto</td>
</tr>
<tr>
<td>$R9 &lt; 1.0$ and $\sigma_{i\eta_i\eta} &gt; 0.005$ to avoid spikes</td>
<td>$R9 &lt; 1.0$ and $\sigma_{i\eta_i\eta} &gt; 0.005$ to avoid spikes</td>
</tr>
<tr>
<td>$0.0102 &lt; \sigma_{i\eta_i\eta} &lt; 0.015$ XOR $1.37 &lt; Charged Isolation &lt; 15.0$</td>
<td>$0.0102 &lt; \sigma_{i\eta_i\eta} &lt; 0.020$ OR $1.37 &lt; Charged Isolation &lt; 40.0$</td>
</tr>
</tbody>
</table>
Subtraction of other contributions in control region:

- $t\bar{t}$ sample where top decays leptonically:
  - Will have two electrons and $E_T^{\text{miss}}$ due to neutrino.
  - In our ee control sample, we found $17.27 \pm 0.98$ events in the signal region from $t\bar{t}$.
  - We subtracted it’s shape.

- $Z + \text{jets}$ sample where $Z \rightarrow \nu \nu$
  - In tight fake sample, we found only 0.1 events in the signal region. We neglected this.
  - In loose fake sample, we found $15.8 \pm 0.9$ events in the signal region. We also subtracted this shape.
Fake rate calculation:

- We find the number of observed $Z \rightarrow ee$ events in the $ee$ mass spectrum as given by $N_{ee} = (1 - f_{e\rightarrow\gamma})^2 N_{trueZ}$ where $N_{trueZ}$ is the true number of $Z \rightarrow ee$ events.

- The observed $Z \rightarrow ee$ peak in the $e\gamma$ mass spectrum is given by $N_{e\gamma} = 2[f_{e\rightarrow\gamma}(1 - f_{e\rightarrow\gamma})]N_{trueZ}$.

- We used single electron trigger: HLT_Ele27_eta2p1_WPLoose_Gsf

- The factor of 2 comes because we do not distinguish between $e\gamma$ events where electron has higher $p_T$ compared to photon and vice versa.

- $f_{e\rightarrow\gamma} = N_{e\gamma}/(2N_{ee} + N_{e\gamma})$

- The number of events from the $e\gamma$ mass spectrum is given by $N_{e\gamma} = (1 - f_{e\rightarrow\gamma})N_{trueW}$ where $N_{trueW}$ is the true $W\gamma$ events.

- Then in the $\gamma\gamma$ sample, the number of $N_{\gamma\gamma}$ coming from $W$ background is given as: $N_{\gamma\gamma} = f_{e\rightarrow\gamma}N_{trueW} = N_{e\gamma}f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma})$. 
EWK Components:

\[ \frac{\text{Events}}{\text{GeV}} = 2.3 \text{ fb}^{-1} (13 \text{ TeV}) \]

**CMS Preliminary Data**

Combined GJet (0.7) and WG (0.3)

**Graph:**
- Data
- Combined GJet (0.7) and WG (0.3)
- WG_MC
- GJet_MC

**Axes:**
- Y-axis: Events/GeV
- X-axis: \( E_T^{\text{miss}} \) (GeV)
- Data/fit

**Legend:**
- Data
- Combined GJet (0.7) and WG (0.3)
- WG_MC
- GJet_MC
total events: 13852
- events having two photons ($p_T > 0, 0$) : 3960
- events having two photons ($p_T > 30, 18$) : 3477
- events having two photons ($mass > 95$) : 3508
- events having two photons ($mass > 95, p_T > 30, 18$) : 3461
- events having two photons ($mass > 105, p_T > 30, 18$) : 3454
- events having two photons ($mass > 105, p_T > 40, 40$) : 3435
Simplified model:

- a limited set of hypothetical particles and decay chains are introduced
- this is to produce a given topological signature such as the diphoton final state studied in this analysis
- For gluino mass of 1.6 TeV and neutralino mass of 600 GeV, the event yield in the signal region: 4.58 and last bin is 4.41.
Standard Model Production:

Figure: Higgs Boson decaying to two photons

Figure: Z boson decaying to electrons
Standard Model $W\gamma$ production, Feynman Diagrams: