Search for supersymmetry in final states with photons and missing transverse momentum in proton-proton collisions.

The CMS Collaboration

Abstract

Results are reported of a search for supersymmetry in final states with photons and missing transverse momentum in proton-proton collisions at the LHC. The data sample corresponds to an integrated luminosity of 35.9 fb\(^{-1}\) collected at a center-of-mass energy of 13 TeV using the CMS detector. The results are interpreted in the context of models of gauge-mediated supersymmetry breaking. Production cross section limits are set on gluino and squark pair production in this framework. gluino masses below 1.86 TeV and squark masses below 1.99 TeV are excluded at 95% confidence level.

Supersymmetry (SUSY), an extension to the Standard Model that aims to fill some of the gaps

But, how to find a sign of SUSY?

Models with General Gauge Mediated (GGM) SUSY breaking predict that neutralino decays into the lightest SUSY particles (gravitino) and photon.

Gravitino is stable and remains undetected.

If proton-proton collisions products SUSY particles there should be observed missing transverse momentum $p_T$.
Strategy of the analysis

Search for GGM SUSY in final states involving two photons and missing transverse momentum in CMS detector.

**Model framework:**

- T5gg model – gluino pair production
- T6gg model – squark pair production

**Data sample:**

- Real data: pp collisions $\sqrt{s}=13$ TeV, integrated luminosity of $35.9\,\text{fb}^{-1}$
- Monte Carlo: signal events - generated using the T5gg and T6gg simplified models. Gluino (squark) mass simulated in the range 1.4 to 2.5 (1.2 to 2.0) TeV in steps of 50 GeV. The neutralino masses range from 10 GeV up to the mass of the gluino or squark. Some other details about MC in the backup
Triggers

A two-tiered trigger system

Trigger is based on information from calorimeters and muon detectors and selects events containing candidate object (like energy clusters consistent with an electron, photon, missing transverse energy or jet)

Event rate ~100kHz

Here processors run a version of the full event reconstruction software.

A diphoton trigger – to collect the data (require photon with $p_T > 30$ GeV, combined invariant mass $m_{\gamma\gamma} > 95$ GeV and fulfilled requirement on isolation and cluster shape)

This trigger reduces the event rate to ~1kHz
Event selection

- Particle energy reconstructed via particle-flow event algorythm – using to the reconstruction information from all detector subsystems.

- **Photon** and **electron** candidates:
  - energy deposited in the ECAL has to be consistent with EM shower (+ energy deposited in HCAL <5% of energy deposited in ECAL)
  - $p_T > 40$ GeV
  - $|\eta| < 1.44$
  - $\Delta R > 0.3$ (isolation requirement)
  - electron orthogonal to photon (electron has to be matched to a pixel detector seed consistent with a track while photon should not)

- A misidentified “fake” (f) **photons** are selected as photons that satisfies looser requirements on photon and neutral-hadron $\Delta R$ and fails either the ECAL requirement or the charged-hadron $\Delta R$

Events are divided into four categories with two EM objects: $\gamma\gamma$, ee, ff, ey. $\Delta R>0.6$, invariant mass $>105$ GeV

- Events are rejected when there is a muon with $p_T>25$ GeV and $|\eta|<2.4$ that pass constraints on track quality and $\Delta R$. Also when there is additional electron with $p_T>25$ GeV, $|\eta|<2.5$ that fulfilled constraints on signal shape and $\Delta R$. 

**Background**

**QCD processes**
(i.e. direct diphoton events) can lead to production two photons and therefore mimic the signal topology if the hadronic activity in the event is mismeasured.

**Electroweak processes**
Processes that have genuine $\phi_T^{\text{mass}}$. Mainly from the production of neutrinos when an electron is misidentified as photon in $W \rightarrow e\nu$ decays.

**Z$\gamma\gamma$ events**
$Z\gamma\gamma$ events where $Z$ boson decays to two neutrinos, $Z \rightarrow \nu\bar{\nu}$.

The main source of background. Estimation is based on the ratio of the event yield from data in the $\gamma\gamma$ sample and $f\bar{f}$ control sample.

This background is calculated from signal plus background hypothesis based on the mass peaks from $Z$ boson in $ee$ and $e\gamma$ control samples.

This contribution from this small source is modelled via MC simulation.
The full background prediction and the measured distribution. Region below 100 GeV is dominated by background – control region. The likelihood fit is constructed from signal and background in the region above 100 GeV.

Last bin – 12 events obtained (expected from the background ~5.4)

95% confidence level upper limits on the gluino and squark pair production cross sections as a function of the mass pair values for the two models considered in this analysis.

- expected limit contours to exclude gluino (squark) mass up to 2.02 TeV (1.74 TeV).
- observed limit contours of exclusions for gluino (squark) mass up to 1.86 TeV (1.59 TeV).
Conclusions

The study concerned the search for general gauge-mediated supersymmetry breaking in proton-proton collisions with two photons and missing transverse momentum in the final state.

We still do not see any clear evidence on SUSY from this kind search but we significantly excluded bigger search region!

Main benefits of this CMS study from 2016:

Exclusion expected limits on masses at 95% confidence level $< 2.02$ TeV for gluino and $< 1.74$ TeV for squark. The analysis improves the observed limits of more than 300 GeV for each model with respect to the analysis performed by CMS detector in 2015.

Exclusion observed limits on masses at 95% confidence level $< 1.86$ TeV for gluino and $< 1.59$ TeV for squark. The analysis improves the observed limits by more than 200 GeV for each model with respect to the analysis performed by CMS detector in 2015.
Thank you for your attention :)}
Backup

- CMS 2016, Signal region in number

Table 2: Number of expected background and observed data events with 35.9 fb$^{-1}$ of 13 TeV data in the signal region prior to the fit defined in the text. The uncertainty in each expected background yield includes the statistical uncertainty and all of the systematic uncertainties described in Section 5 added in quadrature.

<table>
<thead>
<tr>
<th>$p_T^{\text{miss}}$ bin (GeV)</th>
<th>QCD</th>
<th>EWK</th>
<th>$Z\gamma\gamma$</th>
<th>Total background</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 115</td>
<td>99 ± 12</td>
<td>13.7 ± 4.2</td>
<td>1.3 ± 0.6</td>
<td>114 ± 13</td>
<td>105</td>
</tr>
<tr>
<td>115 – 130</td>
<td>32.8$^{+7.0}_{-5.7}$</td>
<td>9.0 ± 2.7</td>
<td>1.1 ± 0.6</td>
<td>42.9$^{+7.5}_{-7.0}$</td>
<td>39</td>
</tr>
<tr>
<td>130 – 150</td>
<td>18.8$^{+4.9}_{-3.4}$</td>
<td>7.4 ± 2.3</td>
<td>1.1 ± 0.6</td>
<td>27.3$^{+5.6}_{-4.1}$</td>
<td>21</td>
</tr>
<tr>
<td>150 – 185</td>
<td>9.9$^{+3.6}_{-3.4}$</td>
<td>6.1 ± 1.9</td>
<td>1.3 ± 0.7</td>
<td>17.4$^{+4.1}_{-3.5}$</td>
<td>21</td>
</tr>
<tr>
<td>185 – 250</td>
<td>3.1$^{+1.9}_{-1.7}$</td>
<td>5.8 ± 1.8</td>
<td>1.3 ± 0.6</td>
<td>10.2$^{+2.7}_{-2.6}$</td>
<td>11</td>
</tr>
<tr>
<td>≥250</td>
<td>1.0$^{+1.1}_{-0.9}$</td>
<td>3.3 ± 1.1</td>
<td>1.1 ± 0.6</td>
<td>5.4$^{+1.6}_{-1.5}$</td>
<td>12</td>
</tr>
</tbody>
</table>
Backup

- CMS 2015

integrated luminosity of 2.3 fb$^{-1}$

https://doi.org/10.1016/j.physletb.2017.04.005
Backup

- Monte Carlo
- MADGRAPH5_aMC@
  - NLO2.3.3 – signal sample simulations,
  - NLO2.4.2 – background sample simulation,
- PYTHIA 8.212 – signal and background processes and particles behaviour,
- PYTHIA – pileup simulation
- GEANT4 – detector response for background processes (CMS fast simulation for signal events)
Backup

- Uncertainty:
  - calculated for each contribution to the total background production (the largest from QCD processes: 7-79% in the signal region, EWK background <9% in the signal region)
  - fitting procedure: by comparing the primary prediction to the cross check prediction: 10-83% in the signal region
  - uncertainties of the signal efficiency (T5gg, T6gg signal size, photon identification and other)