Search for SUSY and UED in Final States with Photons and Missing Transverse Momentum with the ATLAS Detector with 1.07 fb$^{-1}$ of Data

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30 August 2011
Introduction

• Outline
  • Introduction to GMSB and UED
  • Event selection
  • Background modeling
  • Signal grids
  • Systematic uncertainties
  • Results and interpretation in the models

• Builds on 2010 analysis: arXiv:1107.0561v2 [hep-ex]
• Submitted to EPJC Letters
Gauge-Mediated SUSY Breaking (GMSB)

- A hidden sector is responsible for SUSY breaking.
- Standard gauge interactions transmit the SUSY breaking to the MSSM.
- Gauge interactions are flavor-blind: no flavor problem.
- Common Features:
  - Mass scale for the SUSY breaking is much lower than mSUGRA.
  - The LSP is the gravitino.
  - NLSP determines experimental signature.
Minimal and General Gauge Mediation

- **Minimal Gauge Mediation (MGM):**
  - Simple model with one mass scale for the symmetry breaking ($\Lambda$) and messengers of mass $M_{\text{mess}}$.
  - Gluinos much heavier than neutralinos because $M_a = \frac{\alpha_a}{4\pi} \Lambda$

- **General Gauge Mediation (GGM):**
  - “in the limit that the MSSM gauge couplings $\alpha_i \to 0$, the theory decouples into the MSSM and a separate hidden sector that breaks SUSY” ([arXiv:0801.3278v3 [hep-ph]](http://arxiv.org/abs/0801.3278v3))
  - The MGM mass hierarchy between gluinos and neutralinos is not required.
If $|M_1| \ll \mu$ and $|M_1| < |M_2|$, the NLSP is bino-like.

Assuming R-parity, two sparticles are produced, which cascade down to the bino NLSPs.

The bino decays to a photon or a $Z + \gamma$.

**Signature:** two high $p_T$ photons + $E_T^{\text{miss}}$
Introduction to Universal Extra Dimensions (UED) with One Extra Dimension

- **Universal**: ALL SM particles propagate into the extra dimensions with compactification scale $R$ ($1/R \sim 1$ TeV)

- quark and gluon KK excitations are pair produced, and cascade decay down to Lightest KK Particle: $\gamma^*$

- If the “thick brane”, where the SM particles propagate, is embedded in a larger space of $(4+N)$-dim (of size~$^{-1}$ ~ eV) where only gravitons propagate:
  - gravity mediated decays become possible: $\gamma^* \rightarrow \gamma + \text{Graviton}$

- Signature: two high $p_T$ photons + $E_T^{\text{miss}}$
Selection Criteria for the Summer 2011 Analysis: 1.07 fb\(^{-1}\)

- **Trigger:** 2 loose egamma objects, \(p_T > 20\) GeV
- **Require** two tight photons
  - \(p_T > 25\) GeV
  - \(|\eta| < 1.81\) but not in the crack region, \(1.37 < |\eta| < 1.52\)
  - Calorimeter iso: \(E_T (R < 0.2, \text{excluding core}) < 5\) GeV
    - corrected for energy leakage outside of core and pileup.
  - Not touching a problematic calorimeter area
- \(E_{T\text{miss}} > 125\) GeV, based on local-calibrated topoclusters + muons
- **primary vertex** with > 4 tracks
- **Reject events** with:
  - *bad* jets likely from noise, spikes, cosmics, beam background
  - photons that fail LAr cleaning or timing, or electrons that fail timing.
  - selected muon with \(|z_0| > 1\) mm or \(|d_0| > 0.2\) mm wrt PV
Discriminating Photons From Electrons

- Due to the many interaction lengths in front of the calorimeter, a large fraction of the photons convert.
- Standard way to discriminate photons from electrons—vetoing for hits or tracks—significantly lowers efficiency.
- Solution: reconstruct conversions:
  - 2-track conversion: two tracks with electron-like transition radiation, consistent with coming from a massless particle.
  - 1-track conversion: one track with electron-like transition radiation, with missing hits in initial live layers.
- Ambiguity resolution heuristic to choose electron/photon interpretation.
Background Modeling

- Most background is modeled from data
- Only model $E_T^{\text{miss}}$ distribution
  (inspired by similar searches at D0: [doi:10.1103/PhysRevLett.105.221802])
- **Instrumental $E_T^{\text{miss}}$ background**: $\text{di-}\gamma$, $\gamma+\text{jets}$, dijets
  - model using “QCD” and ee data samples
- **Genuine $E_T^{\text{miss}}$ background**:
  - electron faking photon: $W+\gamma$, $W+\text{jets}$, ttbar
    - model using $e\gamma$ data sample
  - irreducible: $Z + \gamma\gamma$, $W + \gamma\gamma$
    - from MC, scaled to NLO.
- **Cosmic background**: found to be negligible in signal
The QCD Control Samples

- Model SM $\gamma$-jets, dijets, and diphoton using a QCD control sample
  - Require two egamma objects with $p_T > 20$ GeV at trigger
  - **pseudo-photon**: passes loose but fails some tight criteria
  - sample definition: **at least one pseudo-photon**
  - Veto events with electrons that pass medium or two tight photons
  - Apply timing cut on pseudo-photons to suppress cosmics ($|t| > 10$ ns: veto event)
- Use $Z \rightarrow ee$ (0 jets) as alternate model in systematics studies.
  (It was found to model SM diphoton events well)
- Normalized in $E_T^{miss} < 20$ GeV range; systematic by varying 10 GeV
  subranges: 0-10 GeV, 1-11 GeV, ... 18-28 GeV
Real $E_T^{\text{miss}}$ background (electron faking photon)

- Use $\text{e}\gamma$ events from data.
  - Assumption: electron fakes a photon.
- Need to subtract out the Z and QCD contribution to avoid double-counting.
  - Use QCD sample normalized to $\text{e}\gamma$ in $E_T^{\text{miss}} < 20$ GeV,
  - $Z\rightarrow ee$ as systematic
- Scale the sample by the $e\rightarrow \gamma$ fake rate / electron efficiency.
  (~6% in barrel, 17% in endcaps)
- use MC normalized to data as systematic
The Experimental Results

**In Signal region \((E_T^{\text{miss}} > 125 \text{ GeV})\)**

**Total predicted background:**

\(4.1 \pm 0.6\text{(stat)} \pm 1.4\text{(syst)}\) events

**Total observed:**

5 events

### Statistical uncertainties only

<table>
<thead>
<tr>
<th>(E_T^{\text{miss}}) range</th>
<th>Data events</th>
<th>Total</th>
<th>Predicted background events</th>
<th>Expected signal events</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\text{GeV}])</td>
<td></td>
<td></td>
<td>QCD</td>
<td>(W/t\bar{t}(\to e\nu) + X)</td>
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<td>0 - 20</td>
<td>20881</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20 - 50</td>
<td>6304</td>
<td>5968 ± 29</td>
<td>5951 ± 28</td>
<td>13.3 ± 8.1</td>
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<tr>
<td>50 - 75</td>
<td>86</td>
<td>87.1 ± 3.3</td>
<td>60.9 ± 2.8</td>
<td>25.2 ± 1.7</td>
</tr>
<tr>
<td>75 - 100</td>
<td>11</td>
<td>14.7 ± 1.2</td>
<td>6.7 ± 0.9</td>
<td>7.4 ± 0.8</td>
</tr>
<tr>
<td>100 - 125</td>
<td>6</td>
<td>4.9 ± 0.7</td>
<td>1.6 ± 0.4</td>
<td>3.0 ± 0.5</td>
</tr>
<tr>
<td>(&gt; 125)</td>
<td>5</td>
<td>4.1 ± 0.6</td>
<td>0.8 ± 0.3</td>
<td>3.1 ± 0.5</td>
</tr>
</tbody>
</table>
GGM Signal Samples

- Created a 2D grid in gluino and Bino mass for GGM
- Turn off squark production for more independence to its mass
- $M_2 = 1.5 \text{ TeV}, \mu = 1.5 \text{ TeV}, \tan \beta = 2$
- $c_{\tau_{\text{NLSP}}} = 0.1 \text{ mm}$
  (allowed to increase somewhat in low Bino mass extension, but $< 1 \text{ mm}$)
- All soft parameters are set to 1.5 TeV
- Go down to a bino mass of 50 GeV.
- Use SUSPECT, SDECAY, and PYTHIA for event generation
- Use Prospino 2.1 for cross section calculation.
SPS8 and UED Grid Points

• SPS8: minimal GMSB (MGM) with
  • N_{\text{mes}}=1, \tan\beta=15, \mu>0, M_{\text{mes}}/\Lambda = 2
  • \Lambda \text{ varies in steps of 10 TeV in the range 50 - 250 TeV}
  • Use ISAJET for mass spectrum and decay table, then Herwig++ for generation.
  • Cross sections calculated with Prospino. K-factors are 1.1 – 1.5

• UED Simulated at various 1/R values
  • \Lambda R = 20, \ N = 6, \ M_D = 5 \text{ TeV}
  • Because only have LO calculations, do not include PDF and scale uncertainties

<table>
<thead>
<tr>
<th>Signal 1/R [GeV]</th>
<th>Cross section [pb]</th>
<th>\gamma\gamma \text{ B.R.}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.133</td>
<td>100%</td>
</tr>
<tr>
<td>1100</td>
<td>0.0521</td>
<td>95%</td>
</tr>
<tr>
<td>1200</td>
<td>0.0205</td>
<td>90%</td>
</tr>
<tr>
<td>1250</td>
<td>0.0129</td>
<td>83%</td>
</tr>
<tr>
<td>1300</td>
<td>0.00803</td>
<td>75%</td>
</tr>
<tr>
<td>1350</td>
<td>0.00498</td>
<td>67%</td>
</tr>
<tr>
<td>1400</td>
<td>0.00312</td>
<td>60%</td>
</tr>
<tr>
<td>1500</td>
<td>0.00120</td>
<td>50%</td>
</tr>
</tbody>
</table>
Systematics

- PDF errors are estimated by weighting 44 error PDFs from CTEQ6.6m and using the Hessian method.
- Scale: factorization and renormalization scale $\times 2$, $\times 1/2$.
- Photon ID/Iso: systematics related to data/MC differences and correction.
  - Also includes extra material.
- $E_T^{\text{miss}}$: due to topocluster energy scale and resolution uncertainties.
- Pileup uncertainty by varying MC pileup configuration.

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity</td>
<td>3.7%</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.6%</td>
</tr>
<tr>
<td>Photon identification</td>
<td>3.9%</td>
</tr>
<tr>
<td>Photon isolation</td>
<td>0.6%</td>
</tr>
<tr>
<td>Pileup</td>
<td>1.3%</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ reconstruction and scale</td>
<td>1.7%</td>
</tr>
<tr>
<td>LAr readout</td>
<td>1.0%</td>
</tr>
<tr>
<td>Signal MC statistics</td>
<td>2.9%</td>
</tr>
<tr>
<td>Total signal uncertainty</td>
<td>6.6%</td>
</tr>
<tr>
<td>PDF and scale</td>
<td>31%</td>
</tr>
<tr>
<td>Total</td>
<td>32%</td>
</tr>
</tbody>
</table>

Representative points:
- GGM with $m_{\text{gluino}}/m_{\text{neutralino}} = 800/400$ GeV
- SPS8 with $\Lambda = 140$ TeV
- UED with $1/R = 1200$ GeV
GGM Results

- $\text{CL}_s$ is used
- $\sigma < 25 - 44 \text{ fb}$ for GGM with
  - $m_{\text{bino}} = 150 \text{ GeV}$
  - $m_{\text{gluino}} = 400 \text{ GeV} - 1200 \text{ GeV}$

$\int Ldt = 1.07 \text{ fb}^{-1}$, $\sqrt{s} = 7 \text{ TeV}$

$M_{\text{gluino}} > 776 \text{ GeV}$
for $M_{\text{bino}} > 50 \text{ GeV}$
SPS8 Benchmark Result

- Using CLs
- $\Lambda > 145$ TeV at 95% CL ($\Lambda > 150$ TeV expected)
- D0 has set a limit of $\Lambda > 124$ TeV (arXiv:1008.2133v1)
- $\sigma < 27 – 91$ fb
- Best current limit.

\[ \int L d\tau = 1.07 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

$\Lambda$ [TeV]

$\sigma$ [fb]

$\tau_{\text{NLSP}} < 0.1$ mm

$M_{\text{mess}} = 2\Lambda, N=1, \tan\beta=15, c_{\tau_{\text{NLSP}}} < 0.1$ mm

$\text{SPS8 NLO cross-section}$

$\text{ATLAS Preliminary}$
UED Result and Statistical Interpretation

- $\text{CL}_s$ is used

- Model specific limit: $1/R > 1226 \text{ GeV}$ at 95% CL ($1/R > 1243 \text{ GeV}$ expected)

- Cross section limit: $\sigma < 15 - 27 \text{ fb}$

- Previous ATLAS limit: $1/R < 961 \text{ GeV}$
  [arXiv:1107.0561v2 [hep-ex]]

$$\int L \, dt = 1.07 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$$

$\text{ATLAS}$ Preliminary
Conclusion

• This is a search for GGM and UED events in the $\gamma \gamma + E_{T}^{\text{miss}}$ channel in 1.07 fb$^{-1}$ of data from 2011 at the LHC using the ATLAS detector.

• Background is estimated mainly from data:
  $4.1 \pm 0.6(\text{stat}) \pm 1.6(\text{sys})$ for $E_{T}^{\text{miss}} > 125$ GeV

• Number of observed events: 5:

• Results are interpreted for bino-like GGM, SPS8, and UED models:
  • GGM: $M_{\text{gluino}} > 776$ GeV for $M_{\text{bino}} > 50$ GeV
  • SPS8: $\Lambda > 145$ TeV
  • UED1/R > 1226 GeV
Backup
GGM Results with 2010 Data

- CL$_s$ is used: model-independent 95% CL upper limit of 3.0 events
- CMS results from: https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS10002/table_mass_limits.txt

\[
\begin{array}{cccccccc}
100 & 200 & 300 & 400 & 500 & 600 & 700 & 800 \\
\text{[GeV]} & & & & & & & \\
\end{array}
\]

\[
\begin{array}{cccccccc}
350 & 400 & 450 & 500 & 550 & 600 & 650 & 700 \\
\text{[GeV]} & & & & & & & \\
\end{array}
\]

\[
\begin{array}{cccccccc}
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1 & 1.2 & 1.4 & 1.6 & 1.8 & 2 \\
\text{Cross section [pb] 95% CL} & & & & & & & & & & & \\
\end{array}
\]

\[
\begin{array}{cc}
\int Ldt = 36\text{ pb}^{-1}, \sqrt{s} = 7\text{ TeV} & \tilde{\chi}_1^0 \text{ NLSP} \lesssim 0.1\text{ mm} \\
\end{array}
\]

\[
\begin{array}{c}
\text{ATLAS}
\end{array}
\]

\[
\begin{array}{c}
\text{CMS observed limit (35 pb}^{-1})
\end{array}
\]

\[
\begin{array}{c}
M_{\text{gluino}} > 560\text{ GeV}
\end{array}
\]

\[
\begin{array}{c}
\text{for } M_{\text{bino}} > 50\text{ GeV}
\end{array}
\]

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UED Result and Statistical Interpretation: 2010 Data

- $C_L$ is used: model-independent
  95% CL upper limit of 3.0 events

- Model specific limit:
  $1/R > 961$ GeV

- Cross section limit:
  $\sigma < 0.18 - 0.23$ pb

![Graph showing UED cross section limits and expected limits.](image)
Latest D0 Result (arXiv:1008.2133v1)

- In MGM, D0 set a limit of $m_\chi > 175$ GeV in SPS8 framework.
- Current ATLAS analysis, if interpreted in the SPS8 trajectory, would produce a limit of $m_\chi > 124$ GeV
- 210 pb$^{-1}$ would be needed to match the D0 sensitivity

- No excess of events with $E_T^{\text{miss}} > 50$ GeV
- Cross section limit between 0.3 and 1.1 pb at the 95% CL across.
- Extracted a contour while varying the gluino and squark masses
Older UED Results

- For UED, D0 set a limit of \( R^{-1} < 477 \text{ GeV} \)

- ATLAS set a limit of \( R^{-1} < 729 \text{ GeV} \)
GSMB and UED Photon $p_T$ distributions

![Graph showing event distributions for different models.]

$\int L dt = 1.07 \text{ fb}^{-1}$

- **Data 2011 ($\sqrt{s} = 7 \text{ TeV}$)**
- **GGM $m_{\tilde{g}} = 800 \text{ GeV}, m_{\tilde{\chi}} = 400 \text{ GeV} \times 100$**
- **SPS8 $\Lambda = 140 \text{ TeV} \times 100$**
- **UED $1/R = 1200 \text{ GeV} \times 100$**

**Event distributions**

*ATLAS Preliminary*
## isEM discriminating variables for photons

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>DV</th>
<th>Loose</th>
<th>Tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>$</td>
<td>\eta</td>
<td>&lt; 2.37, 1.37 &lt;</td>
<td>\eta</td>
</tr>
<tr>
<td>Hadronic leakage</td>
<td>Ratio of $E_T$ in the first sampling of the hadronic calorimeter to $E_T$ of the EM cluster (used over the ranges $</td>
<td>\eta</td>
<td>&lt; 0.8$ and $</td>
<td>\eta</td>
</tr>
<tr>
<td></td>
<td>Ratio of $E_T$ in all the hadronic calorimeter to $E_T$ of the EM cluster (used over the range $0.8 &lt;</td>
<td>\eta</td>
<td>&lt; 1.37$)</td>
<td>$R_{\text{had}}$</td>
</tr>
<tr>
<td>EM Middle layer</td>
<td>Ratio between the sum $E_{5x7}^2$ of the energies of the cells contained in a $3x7$ $\eta \times \phi$ rectangle (measured in cell units), and the sum $E_{7x7}^5$ of the cell energies in a $7x7$ rectangle, both centered around the cluster seed</td>
<td>$R_\eta$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Lateral width of the shower in the $\eta$ direction</td>
<td>$w_{\eta_2}$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Ratio between the sum $E_{3x3}^2$ of the energies of the cells contained in a $3x3$ $\eta \times \phi$ rectangle (measured in cell units), and the sum $E_{3x7}^2$ of the cell energies in a $3x7$ rectangle, both centered around the cluster seed</td>
<td>$R_\phi$</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>EM Strip layer</td>
<td>Lateral shower width for three strips around maximum strip</td>
<td>$w_{3,3}$</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total lateral shower width</td>
<td>$w_{3,\text{tot}}$</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fraction of energy outside core of three central strips but within seven strips</td>
<td>$F_{\text{side}}$</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips</td>
<td>$\Delta E$</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies</td>
<td>$E_{\text{ratio}}$</td>
<td>✓</td>
<td></td>
</tr>
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</table>
# Jet Cleaning

<table>
<thead>
<tr>
<th></th>
<th>Loose</th>
<th>Medium = Loose OR</th>
<th><em><strong>under discussion</strong></em> Tight = Medium OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEC spikes</td>
<td>HECf&gt;0.5 &amp;</td>
<td>HECQ</td>
<td>&gt;0.5 or</td>
</tr>
<tr>
<td>EM coherent noise</td>
<td>EMf&gt;0.95 &amp;</td>
<td>LArQ</td>
<td>&gt;0.8 &amp;</td>
</tr>
<tr>
<td>Non-collision background &amp; Cosmics</td>
<td></td>
<td>t</td>
<td>&gt;25ns or EMf&lt;0.05 &amp; Chf&lt;0.05 &amp;</td>
</tr>
</tbody>
</table>
The $e \rightarrow \gamma$ Fake Rate

- Use tag and probe based on Z events:
  - **tag**: Medium electron, $\text{etcone20\_corrected} < 5$ GeV, and fired $\text{g20\_loose}$
  - **probe**: egamma object that has fired $\text{g20\_loose}$
- Let $e =$ efficiency for true electron to satisfy electron criteria
- Let $f =$ efficiency for true electron to satisfy photon criteria
- The scale factor ($s$) that the eg sample needs to be scaled is then:
  \[
  s = \frac{f}{e} = \frac{N_{\text{pass photon}}/N_{\text{probe}}}{N_{\text{pass electron}}/N_{\text{probe}}} = \frac{N_{\text{pass photon}}}{N_{\text{pass electron}}}
  \]
- Background subtraction can be done on the numerator and denominator. Use a Voigt function + exponential.
Cosmic Background Estimate for 2010 analysis

- Estimated using real cosmic events triggered in empty bunches.
- Look for photons passing same $p_T$ and $\eta$ cuts, but no vertex or jet cleaning requirements
  - 7395 events with one loose photon, 63 with one tight
  - 2 events with two loose photons, 0 with two tight
    - Both two-loose photon events mass $E_{T_{miss}} > 125$ GeV
    - Estimate $0.017 \pm 0.012$ (statistical errors only) for two tight
- Scaling the results to the number of colliding bunches in our sample, and assuming all of the cosmics events would pass the $E_{T_{miss}}$ cut:
  - $0.079 \pm 0.056$ two-loose, $0.00068 \pm 0.00049$ two-tight events
  - Therefore apply tight timing to QCD $\gamma$, negligible for signal
### Table 4: The total LO and NLO cross sections and derived K factors for the SPS8 signal points.

<table>
<thead>
<tr>
<th>( \Lambda [\text{TeV}] )</th>
<th>( \sigma (\text{LO}) [\text{pb}] )</th>
<th>( \sigma (\text{NLO}) [\text{pb}] )</th>
<th>K factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>12.2</td>
<td>18.0</td>
<td>1.482</td>
</tr>
<tr>
<td>60</td>
<td>4.38</td>
<td>6.49</td>
<td>1.482</td>
</tr>
<tr>
<td>70</td>
<td>1.83</td>
<td>2.69</td>
<td>1.468</td>
</tr>
<tr>
<td>80</td>
<td>0.855</td>
<td>1.24</td>
<td>1.446</td>
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<tr>
<td>90</td>
<td>0.436</td>
<td>0.617</td>
<td>1.415</td>
</tr>
<tr>
<td>100</td>
<td>0.240</td>
<td>0.331</td>
<td>1.379</td>
</tr>
<tr>
<td>110</td>
<td>0.141</td>
<td>0.189</td>
<td>1.341</td>
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<tr>
<td>120</td>
<td>0.0867</td>
<td>0.113</td>
<td>1.302</td>
</tr>
<tr>
<td>130</td>
<td>0.0557</td>
<td>0.0707</td>
<td>1.271</td>
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<tr>
<td>140</td>
<td>0.0370</td>
<td>0.0459</td>
<td>1.241</td>
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<td>150</td>
<td>0.0252</td>
<td>0.0306</td>
<td>1.215</td>
</tr>
<tr>
<td>160</td>
<td>0.0176</td>
<td>0.0210</td>
<td>1.190</td>
</tr>
<tr>
<td>170</td>
<td>0.0125</td>
<td>0.0146</td>
<td>1.172</td>
</tr>
<tr>
<td>180</td>
<td>8.99\times10^{-3}</td>
<td>0.0104</td>
<td>1.158</td>
</tr>
<tr>
<td>190</td>
<td>6.57\times10^{-3}</td>
<td>7.49\times10^{-3}</td>
<td>1.141</td>
</tr>
<tr>
<td>200</td>
<td>4.83\times10^{-3}</td>
<td>5.47\times10^{-3}</td>
<td>1.131</td>
</tr>
<tr>
<td>210</td>
<td>3.58\times10^{-3}</td>
<td>4.02\times10^{-3}</td>
<td>1.123</td>
</tr>
<tr>
<td>220</td>
<td>2.68\times10^{-3}</td>
<td>2.99\times10^{-3}</td>
<td>1.114</td>
</tr>
<tr>
<td>230</td>
<td>2.02\times10^{-3}</td>
<td>2.23\times10^{-3}</td>
<td>1.107</td>
</tr>
<tr>
<td>240</td>
<td>1.53\times10^{-3}</td>
<td>1.68\times10^{-3}</td>
<td>1.100</td>
</tr>
<tr>
<td>250</td>
<td>1.16\times10^{-3}</td>
<td>1.27\times10^{-3}</td>
<td>1.096</td>
</tr>
</tbody>
</table>

### Table 5: UED signal cross sections and branching ratios for the \( \gamma\gamma \) final state for different \( \Lambda / R \) values, with \( \Lambda = 20 \), \( N = 6 \) and \( M_D = 5 \text{ TeV} \) for proton-proton collisions at \( E_{cm} = 7 \text{ TeV} \). MC samples (10000 events each) were produced for all \( \Lambda / R \) values.
Acceptance Systematics due to $E_{T}^{\text{miss}}$: 2010 analysis

• Reminder: we use a $E_{T}^{\text{miss}}$ based on the topocluster energies, corrected for muon terms.

• Method to determine systematics inspired from W/Z cross section and previous UED analyses.
  
  • Topocluster Energy Scale: scale topocluster energy by uncertainty
  
  • Smear $E_{\text{miss}}^{x}$ and $E_{\text{miss}}^{y}$ for uncertainty due to resolution
  
  • Underlying event uncertainty within statistical error of MC sample
  
  • Muon term uncertainty found to be negligible.

• Total uncertainty: 10.9% to 0.8% (GGM) and 2.1% to 0.9% (UED)
CMS Lepton-Photon

4. SUSY: diphoton + jet + Missing $E_T$

- **Gauge-Mediated SUSY Breaking:**
  - $\rightarrow$ LSP = Gravitino
  - $\rightarrow$ NLSP = Neutralino (and Chargino)
  - $\rightarrow$ NLSP $\rightarrow$ LSP + Photon or W or Z

<table>
<thead>
<tr>
<th>NLSP type</th>
<th>$\gamma + 3$ jets + $E_T^{miss}$</th>
<th>$\gamma\gamma + 3$ jets + $E_T^{miss}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bino</td>
<td>$\chi^0_1 \chi^0_1 \rightarrow \gamma + Z + \tilde{G}\tilde{G}$</td>
<td>$\chi^0_1 \chi^0_1 \rightarrow \gamma\gamma + \tilde{G}\tilde{G}$</td>
</tr>
<tr>
<td>Wino</td>
<td>$\chi^0_1 \chi^0_1 \rightarrow \gamma + Z + \tilde{G}\tilde{G}$</td>
<td>$\chi^0_1 \chi^0_1 \rightarrow \gamma\gamma + \tilde{G}\tilde{G}$</td>
</tr>
</tbody>
</table>

$m(\chi^0_1) \approx m(\chi^0_1)$

**co-NLSP's**

- **Consider both final states:**
  - Diphoton
  - Single photon (next slide)
4. SUSY: photon + jets + Missing $E_T$

- **Gauge-Mediated SUSY Breaking:**
  - $\text{LSP} = \text{Gravitino}$
  - $\text{NLSP} = \text{Neutralino (and Chargino)}$
  - $\text{NLSP} \rightarrow \text{LSP} + \text{Photon or W or Z}$

<table>
<thead>
<tr>
<th>NLSP type</th>
<th>$\gamma + 3 \text{ jets} + E_T^{\text{miss}}$</th>
<th>$\gamma\gamma + \text{jet} + E_T^{\text{miss}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bino</td>
<td>$\chi_1^0 \chi_1^0 \to \gamma + Z + \tilde{G}G$</td>
<td>$\chi_1^0 \chi_1^0 \to \gamma + \tilde{G}G$</td>
</tr>
<tr>
<td>Wino</td>
<td>$\chi_1^0 \chi_1^0 \to \gamma + Z + \tilde{G}G$</td>
<td>$\chi_1^0 \chi_1^0 \to \gamma + W + \tilde{G}G$</td>
</tr>
</tbody>
</table>

$\gamma, \geq 3 \text{ jets, MET} > 200 \text{ GeV}$

$m(\chi_1^0) \approx m(\chi_1^\pm)$

co- NLSP's

1 photon, $\geq 3$ jets

MET $> 200$ GeV
• Universal: ALL SM particles propagate into the extra dimensions ($\delta = 1; 1/R \sim 1\, \text{TeV}$)

• $n=1, 2, 3, \ldots$ Kaluza Klein (KK) excitations for each SM particle ($n=0$)

• $R$: compactification scale

• Mass degeneracy $m_n^2 = n^2/R^2 + m_{SM}^2$ lifted by radiative corrections.

• quark and gluon KK excitations cascade decay down to Lightest KK Particle: $\gamma^*$