NEGLECTED SUSY;
A PERSPECTIVE ON CURRENT SEARCHES

Based on unapproved CMS results, work and several conversations with M. Pierini, G. Rolandi, M. Lisanti, …

(I am the only one to blame)
SUMMARY

- One loophole and one handle
  - Natural SUSY searches
- My view of the future
IS THAT EVEN POSSIBLE?
RELAXING ASSUMPTIONS

- SUSY = MET + X
  (with notable exceptions diphotons, SS dileptons and multileptons)
RELAXING ASSUMPTIONS

- SUSY = MET + X
  (with notable exceptions diphotons, SS dileptons and multileptons)

- New physics = high scale = hard objects
RELAXING ASSUMPTIONS

- SUSY = $\not{E_T} + X$

  Reminder: $\not{E_T} = p_T$ of the stable particle

- New physics ~ high scale ~ hard objects or many soft objects
gluino AND stops AND higgsinos
NATURALNESS

gluino AND stops AND higgsinos

\[ M_3 \lesssim 1.3 \text{ TeV} \sin \beta \left( \frac{\log \Lambda/\text{TeV}}{3} \right)^{-1} \left( \frac{m_h}{125 \text{ GeV}} \right) \sqrt{\frac{10\%}{\Delta^{-1}}} \]

\[ \frac{\sigma(m_{g}=1.5 \text{ TeV})}{\sigma(m_{g}=1 \text{ TeV})} \sim 10^{-2} \]
gluino AND stops AND higgsinos

\[ t\bar{t}t\bar{t} + \chi^0\chi^0 \quad \leftrightarrow \quad b\bar{b}b\bar{b} + \chi^0\chi^0 \]

\[ \ldots, t\bar{t}b\bar{t}b + X, \ldots \]
gluino AND stops AND higgsinos

$\bar{t}s\bar{t}s\bar{b},qqqqqqq,...$
• SUSY configurations with low MET
  • RPV
  • Cascade decays or moderately squeezed spectrum
    • For very small mass splittings (for instance chargino-neutralino) $p_T$(mother) $\sim p_T$(daughter)
  • Partly visible decays of the lightest MSSM neutralino (NMSSM, gravitino LSP)
- SUSY configurations with low MET
  - RPV
  - Cascade decays or moderately squeezed spectrum
  - Partly visible decays of the lightest MSSM neutralino (NMSSM, gravitino LSP)
- High multiplicities
  - Jets from RPV, extra W's, Z's, h's, extra steps in the cascades
- Rare objects: leptons (details of the spectrum are important), photons
IT IS SO TYPICAL (HADRONIC)

- We are not always doing our best, even before ISR becomes important

<table>
<thead>
<tr>
<th>Signal region</th>
<th>$H_T$ [GeV]</th>
<th>$E_T^{\text{miss}}$ [GeV]</th>
<th>$N_{\text{bjets}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b-loose 1BL</td>
<td>$&gt; 400$</td>
<td>$&gt; 250$</td>
<td>$\geq 1$</td>
</tr>
<tr>
<td>1b-tight 1BT</td>
<td>$&gt; 500$</td>
<td>$&gt; 500$</td>
<td>$\geq 1$</td>
</tr>
<tr>
<td>2b-loose 2BL</td>
<td>$&gt; 400$</td>
<td>$&gt; 250$</td>
<td>$\geq 2$</td>
</tr>
<tr>
<td>2b-tight 2BT</td>
<td>$&gt; 600$</td>
<td>$&gt; 300$</td>
<td>$\geq 2$</td>
</tr>
<tr>
<td>3b 3B</td>
<td>$&gt; 400$</td>
<td>$&gt; 250$</td>
<td>$\geq 3$</td>
</tr>
</tbody>
</table>

CMS, $L_{\text{int}} = 4.98 \, \text{fb}^{-1}$, $\sqrt{s} = 7 \, \text{TeV}$

$p p \rightarrow \bar{q} q, \bar{q} \rightarrow t\bar{t} + \text{LSP}; m(\bar{q}) > m(q)$

~ $1/10$ in efficiency
We are not always doing our best, even before ISR becomes important.
We are not always doing our best, even before ISR becomes important.
ONE HANDLE
TWO HANDLES
### IN THE MATRIX

<table>
<thead>
<tr>
<th>Leptons</th>
<th>Jets</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>WHY NOT</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>IN PROGRESS</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>NEED EXTRA DISCRIMINATION (b-tagging)</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>≥ 9</td>
</tr>
</tbody>
</table>

\[ (N_l', N_J', N_b) \]
CAN IT WORK?

- Multi-jet background
  - Berends-Giele scaling + phenomenological correction from the Tevatron (essentially a fit to the data)
  - Prerequisite: separate W from Z from tt from QCD
  - Byproduct: first measurement of the scaling for tt
- Multi-b background
  - Assume MC has the $p_T$ and $\eta$ of the jets (almost) right
  - Correct MC for efficiencies measured on data ($p_T$-rel template fit)
MY VIEW OF THE FUTURE
EDEN

- Theory input
  - Dedicated searches to pursue outside of the grid
  - New dimensions for the grid
  - Simplified understanding of classes of models
EDEN

• Theory input
  • Dedicated searches to pursue outside of the grid
  • New dimensions for the grid
  • Simplified understanding of classes of models

• Experimental output
  • New physics discovery
EDEN

- **Theory input**
  - Dedicated searches to pursue outside of the grid
  - New dimensions for the grid
  - Simplified understanding of classes of models

- **Experimental output**
  - $N_{bkg}, \sigma_{bkg}, N_{data}$ (for each point in the grid) + public simulation
  - Likelihood (where doable)
THE PURGATORY

- Theory input
  - Dedicated searches to pursue outside of the grid
    - Ok: stops, long lived, ...
  - New “dimensions” for the grid
    - Ok: $\alpha_\tau$, jet substructure, ...
  - Simplified understanding of classes of models
    - Done for vanilla SUSY, but missing RPV, long lived and heavy colored objects travelling inside the detector
THE PURGATORY

● Experimental output
  - $N_{\text{bkg}}$, $\sigma_{\text{bkg}}$, $N_{\text{data}}$ (for each point in the grid) + public simulation
    - Strong opposition inside the collaborations
    - Next-to-ideal: fill the grid (not even analyses, just counting experiments) and give detector to generator curves → Razor example

● Likelihood (where doable)
  - “I'd be dead before [LHC experiment] releases a likelihood”. Anonymous
CONCLUSIONS

- There is a blind spot in our searches, but no fundamental obstacles (i.e. trigger) in front of us.
- In terms of discovery potential we are doing a great job, also thanks to cross feedback between theorists and experimentalists, but ...
- The future can be a much better place.
GLUINO 7 TeV

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections
CMS Preliminary, $\sqrt{s} = 8$ TeV, $L_{\text{int}} = 3.95$ fb$^{-1}$

Same Sign dileptons with btag selection

Exclusion $\sigma^{\text{prod}}_{\text{Exclusion}} = \sigma^{\text{NLO+NLL}} \pm 1\sigma$
## SRs FOR THE EXAMPLE ANALYSES

### ATLAS 1-2lepton

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Single electron or muon (+jet)</th>
<th>Missing $E_T$</th>
<th>Single electron or muon (+jet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{lep}$</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$p_T^e$ (GeV)</td>
<td>$&gt; 25$ (20)</td>
<td>$&gt; 25$ (20)</td>
<td>7 to 25 (6 to 20)</td>
</tr>
<tr>
<td>$p_T^\mu$ (GeV)</td>
<td>$&lt; 10$</td>
<td>$&lt; 10$</td>
<td>$&lt; 7$ (6)</td>
</tr>
<tr>
<td>$N_{jet}$</td>
<td>$\geq 3$</td>
<td>$\geq 4$</td>
<td>$\geq 2$</td>
</tr>
<tr>
<td>$p_T^{jet}$ (GeV)</td>
<td>$&gt; 100$, 25, 25</td>
<td>$&gt; 80$, 80, 80, 80</td>
<td>$&gt; 130$, 25</td>
</tr>
<tr>
<td>$p_T^{\text{add jet}}$ (GeV)</td>
<td>$&lt; 80$</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$E_T^{miss}$ (GeV)</td>
<td>$&gt; 250$</td>
<td>$&gt; 250$</td>
<td>$&gt; 250$, 300</td>
</tr>
<tr>
<td>$m_T$ (GeV)</td>
<td>$&gt; 100$</td>
<td>$&gt; 100$</td>
<td>$&gt; 100$, 100</td>
</tr>
<tr>
<td>$E_T^{miss}/m_{eff}$</td>
<td>$&gt; 0.3$</td>
<td>$&gt; 0.2$</td>
<td>$&gt; 0.3$</td>
</tr>
<tr>
<td>$m_{T_{\text{inc}}}$ (GeV)</td>
<td>$&gt; 1200$</td>
<td>$&gt; 800$</td>
<td>—</td>
</tr>
</tbody>
</table>

### ATLAS 1lepton+4jets

<table>
<thead>
<tr>
<th>Pre-selection</th>
<th>Signal Region name</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>no leptons, at least three jets, $p_T(j1) &gt; 130$ GeV, $p_T(j2,j3) &gt; 50$ GeV, $E_T^{miss} &gt; 130$ GeV, $E_T^{miss}/m_{eff} &gt; 0.25$, $\Delta\phi_{\text{min}} &gt; 0.4$</td>
<td>SR0-A1</td>
<td>at least one b-tag, $m_{eff} &gt; 500$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[0, \infty]$</td>
<td>SR0-B1</td>
<td>at least one b-tag, $m_{eff} &gt; 700$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[150, 200]$</td>
<td>SR0-C1</td>
<td>at least one b-tag, $m_{eff} &gt; 900$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[200, 275]$</td>
<td>SR0-A2</td>
<td>at least two b-tags, $m_{eff} &gt; 500$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[275, 375]$</td>
<td>SR0-B2</td>
<td>at least two b-tags, $m_{eff} &gt; 700$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[375, 500]$</td>
<td>SR0-C2</td>
<td>at least two b-tags, $m_{eff} &gt; 900$ GeV</td>
</tr>
<tr>
<td>$M_{T2}$ $[500, \infty]$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| one lepton, at least four jets $p_T(j1) > 60$ GeV, $p_T(j2,j3,j4) > 50$ GeV, $E_T^{miss} > 80$ GeV, $m_T > 100$ GeV, at least one b-tag | SR1-D | $m_{eff} > 700$ GeV |
| | SR1-E | $m_{eff} > 700$ GeV, $E_T^{miss} > 200$ GeV |
ATLAS MULTIJET

Signal region

<table>
<thead>
<tr>
<th>7j55</th>
<th>8j55</th>
<th>9j55</th>
<th>6j80</th>
<th>7j80</th>
<th>8j80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of isolated leptons (e, μ)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet $p_T$</td>
<td>$&gt; 55$ GeV</td>
<td></td>
<td>$&gt; 80$ GeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet $</td>
<td>\eta</td>
<td>$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of jets</td>
<td>$\geq 7$</td>
<td>$\geq 8$</td>
<td>$\geq 9$</td>
<td>$\geq 6$</td>
<td>$\geq 7$</td>
</tr>
<tr>
<td>$E_T^{\text{miss}} / \sqrt{H_T}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>