SUSY Status Report

David Stuart
UC Santa Barbara
SUSY Status Report?

Not yet.
SUSY Status Report?

Not yet. Check back next year.
SUSY Status Report? – a perturbative answer, 0\textsuperscript{th} order

“Squarks and gluinos excluded up to 1000 GeV…”

is a common sound bite.
Aug 27: LHC results put supersymmetry theory 'on the spot'

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.
SUSY Status Report? – a perturbative answer, 1\textsuperscript{st} order

Hadroproduction covered up to 500 or 1000 GeV
SUSY Status Report? – a reasonable answer

\( \tilde{g} \tilde{g} \) and \( \tilde{q} \tilde{g} \) covered up to \textit{maybe} 500 or 1000 GeV
SUSY Status Report? – a reasonable answer

\( \tilde{g} \tilde{g} \) and \( \tilde{q} \tilde{g} \) covered up to maybe 500 or 1000 GeV

stop pair production unprobed so far.
Workshop on Searches for Supersymmetry at the LHC
LNBL, October 19-21
Outline

1. *Some* experimental results

2. Theoretical issues and ideas

3. Outlook
Some experimental results…
All-hadronic searches:
All-hadronic searches: Compare CMSSM limits

Small difference at low m0, ±1σ bands differ at high m0.
### All-hadronic searches: Different cuts and variables

**arXiv:1109.6572; arXiv:1110.2299**

**Different search modes**
**Different kinematic variables**
**Different kinematic regimes**

\[ M_{\text{eff}} \approx \text{sum of all } p_T \]

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>( \geq 2)-jet</th>
<th>( \geq 3)-jet</th>
<th>( \geq 4)-jet</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_T^{\text{miss}} )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
</tr>
<tr>
<td>Leading jet ( p_T )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
<td>( &gt; 130 )</td>
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<tr>
<td>Second jet ( p_T )</td>
<td>( &gt; 40 )</td>
<td>( &gt; 40 )</td>
<td>( &gt; 40 )</td>
<td>( &gt; 80 )</td>
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<tr>
<td>Third jet ( p_T )</td>
<td>–</td>
<td>( &gt; 40 )</td>
<td>( &gt; 40 )</td>
<td>( &gt; 80 )</td>
</tr>
<tr>
<td>Fourth jet ( p_T )</td>
<td>–</td>
<td>–</td>
<td>( &gt; 40 )</td>
<td>( &gt; 80 )</td>
</tr>
<tr>
<td>( \Delta \phi(\text{jet, } E_T^{\text{miss}})_{\text{min}} )</td>
<td>( &gt; 0.4 )</td>
<td>( &gt; 0.4 )</td>
<td>( &gt; 0.4 )</td>
<td>( &gt; 0.4 )</td>
</tr>
<tr>
<td>( E_T^{\text{miss}} / m_{\text{eff}} )</td>
<td>( &gt; 0.3 )</td>
<td>( &gt; 0.25 )</td>
<td>( &gt; 0.25 )</td>
<td>( &gt; 0.2 )</td>
</tr>
<tr>
<td>( m_{\text{eff}} )</td>
<td>( &gt; 1000 )</td>
<td>( &gt; 1000 )</td>
<td>( &gt; 500/1000 )</td>
<td>( &gt; 1100 )</td>
</tr>
</tbody>
</table>

### Signal region

<table>
<thead>
<tr>
<th>7j55</th>
<th>8j55</th>
<th>6j80</th>
<th>7j80</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jet ( p_T )</strong></td>
<td>( &gt; 55 \text{ GeV} )</td>
<td>( &gt; 80 \text{ GeV} )</td>
<td></td>
</tr>
<tr>
<td>**Jet (</td>
<td>\eta</td>
<td>)**</td>
<td></td>
</tr>
<tr>
<td><strong>( \Delta R_{jj} )</strong></td>
<td></td>
<td></td>
<td>( &gt; 0.6 ) for any pair of jets</td>
</tr>
<tr>
<td><strong>Number of jets</strong></td>
<td>( \geq 7 )</td>
<td>( \geq 8 )</td>
<td>( \geq 6 )</td>
</tr>
<tr>
<td><strong>( E_T^{\text{miss}} / \sqrt{H_T} )</strong></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
# All-hadronic searches: Backgrounds

**arXiv:1109.6572; arXiv:1110.2299**

<table>
<thead>
<tr>
<th></th>
<th>≥ 2-jet</th>
<th>≥ 3-jet</th>
<th>≥ 4-jet, $m_{\text{eff}} &gt; 500$ GeV</th>
<th>≥ 4-jet, $m_{\text{eff}} &gt; 1000$ GeV</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma + \text{jets}$</td>
<td>32.3 ± 2.6 ± 6.9</td>
<td>25.5 ± 2.6 ± 4.9</td>
<td>209 ± 9 ± 38</td>
<td>16.2 ± 2.2 ± 3.7</td>
<td>3.3 ± 1.0 ± 1.3</td>
</tr>
<tr>
<td>$W + \text{jets}$</td>
<td>26.4 ± 4.0 ± 6.7</td>
<td>22.6 ± 3.5 ± 5.6</td>
<td>349 ± 30 ± 122</td>
<td>13.0 ± 2.2 ± 4.7</td>
<td>2.1 ± 0.8 ± 1.1</td>
</tr>
<tr>
<td>$t\bar{t} + \text{single top}$</td>
<td>3.4 ± 1.6 ± 1.6</td>
<td>5.9 ± 2.0 ± 2.2</td>
<td>425 ± 39 ± 84</td>
<td>4.0 ± 1.3 ± 2.0</td>
<td>5.7 ± 1.8 ± 1.9</td>
</tr>
<tr>
<td>QCD multi-jet</td>
<td>0.22 ± 0.06 ± 0.24</td>
<td>0.92 ± 0.12 ± 0.46</td>
<td>34 ± 2 ± 29</td>
<td>0.73 ± 0.14 ± 0.50</td>
<td>2.10 ± 0.37 ± 0.82</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>62.4 ± 4.4 ± 9.3</td>
<td>54.9 ± 3.9 ± 7.1</td>
<td>1015 ± 41 ± 144</td>
<td>33.9 ± 2.9 ± 6.2</td>
<td>13.1 ± 1.9 ± 2.5</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>58</td>
<td>59</td>
<td>1118</td>
<td>40</td>
<td>18</td>
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### Signal region

<table>
<thead>
<tr>
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<th>8j55</th>
<th>6j80</th>
<th>7j80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-jets</td>
<td>26 ± 5.2</td>
<td>2.3 ± 0.7</td>
<td>19 ± 4</td>
<td>1.3 ± 0.4</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow q\ell, \ell\ell$</td>
<td>10.8 ± 6.7</td>
<td>0^+0.3</td>
<td>6.0 ± 4.6</td>
<td>0^+0.13</td>
</tr>
<tr>
<td>$W + \text{jets}$</td>
<td>0.95 ± 0.45</td>
<td>0^+0.13</td>
<td>0.34 ± 0.24</td>
<td>0^+0.13</td>
</tr>
<tr>
<td>$Z + \text{jets}$</td>
<td>1.5^+1.8</td>
<td>-1.4</td>
<td>0^+0.75</td>
<td>0^+0.75</td>
</tr>
<tr>
<td><strong>Total Standard Model</strong></td>
<td>39 ± 9</td>
<td>2.3^+4.4</td>
<td>26 ± 6</td>
<td>1.3^+0.9</td>
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<tr>
<td><strong>Data</strong></td>
<td>45</td>
<td>4</td>
<td>26</td>
<td>3</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_{\text{BSM}} \times \epsilon / \text{fb}$</th>
<th>$\Lambda_{\text{BSM}}$</th>
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<td></td>
<td>$\sigma_{\text{BSM}} \times \epsilon / \text{fb}$</td>
<td>$\Lambda_{\text{BSM}}$</td>
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<tr>
<td><strong>Data</strong></td>
<td>45</td>
<td>16.3</td>
</tr>
<tr>
<td>$\sigma_{\text{BSM}} \times \epsilon / \text{fb}$</td>
<td>26.0</td>
<td>16.3</td>
</tr>
<tr>
<td>$\Lambda_{\text{BSM}}$</td>
<td>11.2</td>
<td>16.3</td>
</tr>
</tbody>
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*SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis*
All-hadronic searches: Varied cuts and variables

Different search modes
Different kinematic variables
Different kinematic regimes

HT ≈ sum of jet $p_T$s

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Baseline</th>
<th>Baseline</th>
<th>Baseline</th>
<th>Medium</th>
<th>High HT</th>
<th>High HT</th>
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</thead>
<tbody>
<tr>
<td>HT$&gt;$300</td>
<td>HT$&gt;$300</td>
<td>HT$&gt;$300</td>
<td>HT$&gt;$300</td>
<td>HT$&gt;$500</td>
<td>HT$&gt;$800</td>
<td>HT$&gt;$800</td>
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<tr>
<td>MET$&gt;$200</td>
<td>$\geq$ 3jets</td>
<td>$\geq$ 3jets</td>
<td>$\geq$ 3jets</td>
<td>HT$&gt;$500</td>
<td>HT$&gt;$800</td>
<td>HT$&gt;$800</td>
</tr>
<tr>
<td>p$_T$$&gt;$50</td>
<td>$\Delta\phi$ cuts</td>
<td>$\Delta\phi$ cuts</td>
<td>e/μ veto</td>
<td>MET$&gt;$350</td>
<td>MET$&gt;$200</td>
<td>MET$&gt;$500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
<th>Sum SM MC</th>
<th>QCD multijet (PYTHIA)</th>
<th>Z(νν)+jets (MG)</th>
<th>W(ℓν)+jets (MG)</th>
<th>tℓ (MG)</th>
<th>LM4 (PYTHIA)</th>
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</thead>
<tbody>
<tr>
<td>6377</td>
<td>6406</td>
<td>1143</td>
<td>1370</td>
<td>2963</td>
<td>930</td>
<td>1477</td>
</tr>
<tr>
<td>3408</td>
<td>3227</td>
<td>549</td>
<td>481</td>
<td>1365</td>
<td>832</td>
<td>1179</td>
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<tr>
<td>1640</td>
<td>1709</td>
<td>11.4</td>
<td>387</td>
<td>784</td>
<td>527</td>
<td>942</td>
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<tr>
<td>986</td>
<td>987</td>
<td>11.3</td>
<td>386</td>
<td>346</td>
<td>244</td>
<td>742</td>
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<tr>
<td>78</td>
<td>95</td>
<td>0.3</td>
<td>46.3</td>
<td>37.5</td>
<td>11.3</td>
<td>318</td>
</tr>
<tr>
<td>70</td>
<td>83</td>
<td>6.9</td>
<td>29</td>
<td>28</td>
<td>18</td>
<td>304</td>
</tr>
<tr>
<td>3</td>
<td>7.5</td>
<td>0.0</td>
<td>4.2</td>
<td>2.9</td>
<td>0.4</td>
<td>54</td>
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</tbody>
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SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis
All-hadronic searches: Kinematic comparisons

All-hadronic searches: Using the shape
arXiv:1109.2352, alphaT analysis
b-hadronic searches: Loosen kinematic cuts
ATLAS-CONF-2011-098

At least 3 jets, with $p_T>130,50,50$ (cf. 130,130)

Lepton veto

b-tag jets with $p_T>50$

$MET>130$, $\Delta \phi(jet,MET)>0.4$

$MET/m_{\text{eff}}>0.25$

$m_{\text{eff}}>500$ or $700$ (cf. 1000)

<table>
<thead>
<tr>
<th>Sig. Reg.</th>
<th>Data (0.83 fb$^{-1}$)</th>
<th>Top</th>
<th>W/Z</th>
<th>QCD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3JA (1 btag $m_{\text{eff}}&gt;500$ GeV)</td>
<td>361</td>
<td>$221^{+82}_{-68}$</td>
<td>$121 \pm 61$</td>
<td>$15 \pm 7$</td>
<td>$356^{+103}_{-92}$</td>
</tr>
<tr>
<td>3JB (1 btag $m_{\text{eff}}&gt;700$ GeV)</td>
<td>63</td>
<td>$37^{+15}_{-12}$</td>
<td>$31 \pm 19$</td>
<td>$1.9 \pm 0.9$</td>
<td>$70^{+24}_{-22}$</td>
</tr>
<tr>
<td>3JC (2 btag $m_{\text{eff}}&gt;500$ GeV)</td>
<td>76</td>
<td>$55^{+25}_{-22}$</td>
<td>$20 \pm 12$</td>
<td>$3.6 \pm 1.8$</td>
<td>$79^{+28}_{-25}$</td>
</tr>
<tr>
<td>3JD (2 btag $m_{\text{eff}}&gt;700$ GeV)</td>
<td>12</td>
<td>$7.8^{+3.5}_{-2.9}$</td>
<td>$5 \pm 4$</td>
<td>$0.5 \pm 0.3$</td>
<td>$13.0^{+5.6}_{-5.2}$</td>
</tr>
</tbody>
</table>
b-hadronic searches: Kinematic comparisons

ATLAS-CONF-2011-098

\[ m_{\text{eff}} \geq 1 \text{b} \quad \geq 2 \text{b} \]

\[ \text{MET} \geq 1 \text{b} \quad \geq 2 \text{b} \]
## b-hadronic searches: Varied cuts and variables

**PAS-SUS-11-005, PAS-SUS-11-006**

### HT and MET Search

- \( \geq 3 \) jets, with \( p_T > 50 \)
- Lepton veto
- \( b \)-tag jets with \( p_T > 30 \)
- \( \text{MET} > 200, \Delta \phi \) (normalized) > 4
- \( \text{HT} > 350 \) (loose) or 500 (tight)

### HT and MT2 Search

- \( \geq 4 \) jets, with \( p_T > 150, 100, 40, 40 \)
- Lepton veto
- \( b \)-tag jets with \( p_T > 50 \)
- \( \text{MT2} > 150, \Delta \phi(jet,\text{MET}) > 0.4 \)
- \( \text{HT} > 650 \)
b-hadronic searches: Results  
PAS-SUS-11-005, PAS-SUS-11-006

HT and MET Search

≥3 jets, with $p_T>50$

Lepton veto

b-tag jets with $p_T>30$

$MET>200$, $\Delta\phi$ (normalized) > 4

HT > 350

<table>
<thead>
<tr>
<th></th>
<th>$(H_T, E_T^{miss}) &gt; (350, 200)$ GeV</th>
<th>$(H_T, E_T^{miss}) &gt; (500, 300)$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≥ 1 b-jets</td>
<td>≥ 2 b-jets</td>
</tr>
<tr>
<td>Data</td>
<td>155</td>
<td>30</td>
</tr>
<tr>
<td>Total SM</td>
<td>183 ± 5</td>
<td>35.7 ± 1.3</td>
</tr>
<tr>
<td>$tt$</td>
<td>122 ± 2</td>
<td>28.9 ± 0.7</td>
</tr>
<tr>
<td>Single top</td>
<td>4.54 ± 0.38</td>
<td>0.77 ± 0.09</td>
</tr>
<tr>
<td>$W+J$ets</td>
<td>17.0 ± 2.1</td>
<td>1.21 ± 0.45</td>
</tr>
<tr>
<td>$Z \rightarrow \nu\bar{\nu}$</td>
<td>22.5 ± 0.5</td>
<td>2.23 ± 0.10</td>
</tr>
<tr>
<td>$Z/\gamma^* \rightarrow \ell^+\ell^-$</td>
<td>0.17 ± 0.17</td>
<td>0.01 ± 0.01</td>
</tr>
<tr>
<td>Diboson</td>
<td>0.69 ± 0.07</td>
<td>0.10 ± 0.02</td>
</tr>
<tr>
<td>QCD</td>
<td>16.4 ± 3.9</td>
<td>2.5 ± 0.9</td>
</tr>
<tr>
<td>SUSY LM9</td>
<td>147 ± 5</td>
<td>60.0 ± 2.5</td>
</tr>
</tbody>
</table>

SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis
b-hadronic searches: Results
PAS-SUS-11-005, PAS-SUS-11-006

HT and MET Search
≥3 jets, with $p_T>50$
Lepton veto
b-tag jets with $p_T>30$
MET>200, $\Delta \phi$ (normalized) > 4
HT > 350 (loose) or 500 (tight)
HT and MT2 Search
≥4 jets, with $p_T>150, 100, 40, 40$
Lepton veto
b-tag jets with $p_T>50$
MT2$>150$, $\Delta \phi(\text{jet,MET})>0.4$
HT $> 650$
ATLAS Preliminary

0 lepton, 3 jets
b-jet analyses

\[ m(\tilde{\chi}_1^0) = 60 \text{ GeV}, \quad m(\tilde{q}_{1,2}) \gg m(\tilde{g}) \]

CDF \( \tilde{b}_1 \tilde{b}_1 \): 2.65 fb\(^{-1}\)
D0 \( \tilde{b}_1 \tilde{b}_1 \): 5.2 fb\(^{-1}\)
CDF \( \tilde{g}\tilde{g} \rightarrow \tilde{b}_1 b \): 2.5 fb\(^{-1}\)

Reference point

\[ g \rightarrow \tilde{b}_1 \tilde{b}_1, \text{ forbidden} \]

L \( dt = 0.83 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]
b-hadronic searches: Limits
ATLAS-CONF-2011-098

ATLAS Preliminary

0 lepton, 3 jets
b-jet analyses

Observed 95% CL$_s$ limit

Expected CL$_s$ limit

$\tilde{g} \rightarrow 2b + \chi_1^0$, $m(\tilde{g}) >> m(\tilde{Q})$

$\sqrt{s} = 7$ TeV

$L dt = 0.83$ fb$^{-1}$
**b-hadronic searches: Limits**

PAS-SUS-11-005, PAS-SUS-11-006

**HT and MET Search**

**HT and MT2 Search**

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**Cross section UL at 95% CL [pb]**

- $\sigma^{\text{NLO-QCD}}$
- $3 \times \sigma^{\text{NLO-QCD}}$
- $\frac{1}{3} \times \sigma^{\text{NLO-QCD}}$

**95% CL upper limit on $\sigma$ (pb)**

- CMS Preliminary

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**SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis**
Multilepton searches
PAS-SUS-11-013

Low background SUSY search, including EWK gaugino pair-production

or

RPV

Separate search into multiple exclusive boxes by:

3 or 4 leptons; # taus; on/off-Z OSOF pairs; kinematics, HT and MET or ST (=m_{eff})

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**SUSY Multilepton 2011**
(based on 2010 Analysis)

**RPV/Exotic Multilepton 2011**

Oct 20, 2011

R. Gray, Rutgers University

Fedor Ratnikov (KIT)
Richard Gray (Rutgers)
Multilepton searches
PAS-SUS-11-013

53 exclusive regions

<table>
<thead>
<tr>
<th>Selection</th>
<th>N(τ)=0</th>
<th>N(τ)=1</th>
<th>N(τ)=2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>obs</td>
<td>expected SM</td>
<td>obs</td>
</tr>
<tr>
<td>≥FOUR Lepton Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET&gt;50, H_T &gt;200, noZ</td>
<td>0</td>
<td>0.003 ± 0.002</td>
<td>0</td>
</tr>
<tr>
<td>MET&gt;50, H_T &gt;200, Z</td>
<td>0</td>
<td>0.06 ± 0.04</td>
<td>0</td>
</tr>
<tr>
<td>MET&gt;50, H_T &lt;200, noZ</td>
<td>1</td>
<td>0.014 ± 0.005</td>
<td>0</td>
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<tr>
<td>MET&gt;50, H_T &lt;200, Z</td>
<td>0</td>
<td>0.43 ± 0.15</td>
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</tr>
<tr>
<td>MET&lt;50, H_T &gt;200, noZ</td>
<td>0</td>
<td>0.0013 ± 0.0008</td>
<td>0</td>
</tr>
<tr>
<td>MET&lt;50, H_T &gt;200, Z</td>
<td>1</td>
<td>0.28 ± 0.11</td>
<td>0</td>
</tr>
<tr>
<td>MET&lt;50, H_T &lt;200, noZ</td>
<td>0</td>
<td>0.08 ± 0.03</td>
<td>4</td>
</tr>
<tr>
<td>MET&lt;50, H_T &lt;200, Z</td>
<td>11</td>
<td>9.5 ± 3.8</td>
<td>14</td>
</tr>
<tr>
<td>THREE Lepton Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET&gt;50, H_T &gt;200, no-OSSF</td>
<td>2</td>
<td>0.87 ± 0.33</td>
<td>21</td>
</tr>
<tr>
<td>MET&gt;50, H_T &lt;200, no-OSSF</td>
<td>4</td>
<td>3.7 ± 1.2</td>
<td>88</td>
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<tr>
<td>MET&lt;50, H_T &gt;200, no-OSSF</td>
<td>1</td>
<td>0.50 ± 0.33</td>
<td>12</td>
</tr>
<tr>
<td>MET&lt;50, H_T &lt;200, no-OSSF</td>
<td>7</td>
<td>5.0 ± 1.7</td>
<td>245</td>
</tr>
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<td>MET&gt;50, H_T &gt;200, noZ</td>
<td>5</td>
<td>1.9 ± 0.5</td>
<td>7</td>
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<td>MET&gt;50, H_T &gt;200, Z</td>
<td>8</td>
<td>8.1 ± 2.7</td>
<td>10</td>
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<tr>
<td>MET&gt;50, H_T &lt;200, noZ</td>
<td>19</td>
<td>11.6 ± 3.2</td>
<td>64</td>
</tr>
<tr>
<td>MET&lt;50, H_T &gt;200, noZ</td>
<td>5</td>
<td>2.0 ± 0.7</td>
<td>24</td>
</tr>
<tr>
<td>MET&gt;50, H_T &lt;200, Z</td>
<td>58</td>
<td>57 ± 21</td>
<td>47</td>
</tr>
<tr>
<td>MET&lt;50, H_T &gt;200, Z</td>
<td>6</td>
<td>8.2 ± 2.0</td>
<td>90</td>
</tr>
<tr>
<td>MET&lt;50, H_T &lt;200, noZ</td>
<td>86</td>
<td>82 ± 21</td>
<td>2566</td>
</tr>
<tr>
<td>MET&lt;50, H_T &lt;200, Z</td>
<td>335</td>
<td>359 ± 89</td>
<td>9720</td>
</tr>
<tr>
<td>Totals 4L</td>
<td>13.0</td>
<td>10.4 ± 3.8</td>
<td>20.0</td>
</tr>
<tr>
<td>Totals 3L</td>
<td>536</td>
<td>539 ± 94</td>
<td>12894</td>
</tr>
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</table>
Multilepton searches
PAS-SUS-11-013

Diboson and ttbar from MC. Fake contributions measured in data.
Multilepton searches
PAS-SUS-11-013

Diboson and ttbar from MC. Fake contributions measured in data.

CMS Preliminary  \( \sqrt{s} = 7 \text{ TeV}, L_{\text{int}} = 2.1 \text{ fb}^{-1} \)  3 leptons: 2(e/\mu)+1\(\tau\) channels

- \(t\bar{t}\)
- WZ/ZZ
- \(t\bar{t}W/ t\bar{t}Z/ WWW\)
- Data-driven
- Bkg Uncertainties

[SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis]
Multilepton searches
PAS-SUS-11-013

Diboson and ttbar from MC. Fake contributions measured in data.
Fake contributions measured in data.
Multilepton searches
PAS-SUS-11-013

4 lepton backgrounds dominated by dibosons; taken from MC.
Multilepton searches
PAS-SUS-11-013

4 lepton backgrounds dominated by dibosons; taken from MC.
Multilepton searches
PAS-SUS-11-013

Kinematic consistency check: HT (pre-MET cut)
Multilepton searches
PAS-SUS-11-013

Kinematic consistency check: MET (pre-HT cut)
Multilepton searches
PAS-SUS-11-013

Kinematic consistency check: Njet (pT>40) after all cuts
NLO Theory for SUSY Searches

October 19, 2011
Zvi Bern, UCLA (on behalf of BlackHat)

BlackHat Collaboration current members:
ZB, L. Dixon, F. Febres Cordero, G. Diana, S. Hoeche, H. Ita, D. Kosower, D. Maitre, K. Ozren
Theory issues: NLO background predictions

Will be critical when we start to see excesses

Different theoretical predictions track each other. This conversion directly used by CMS in their estimate of theory uncertainty.
Theory ideas: Compressed spectra

For study: consider models that generalize mSUGRA by including a "compression factor" $c$. At the TeV scale:

$$M_1 = \left(\frac{1 + 5c}{6}\right) M_{\tilde{g}}, \quad M_2 = \left(\frac{1 + 2c}{3}\right) M_{\tilde{g}},$$

• $c = 0$ corresponds to mSUGRA.
• $c = 1$ is total compression (gauginos degenerate).

Also take $\tan \beta = 10$, $\mu > 0$, and squark masses

$$M_{\tilde{Q}} = 0.96 M_{\tilde{g}}.$$

Variable input parameters: $M_{\tilde{g}}$ (overall superpartner mass scale) and $c$ (compression factor).
Theory ideas: Compressed spectra

Masses of important superpartners, as a function of $c$, for $M_{\tilde{g}} = 700$ GeV:

- $\tilde{g}$
- $\tilde{q}$
- $\tilde{\tau}_1$
- $N_2, C_1$
- $N_1$
Theory ideas: Compressed spectra

For low compression, signal E (4 jets, inclusive $m_{\text{eff}}$) wins, but as the compression increases, B (3 jets) and then A (2 jets) take over.

---

**Heavy squarks**

- A (2 jets, $m_{\text{eff}} > 1000$) acceptance
- E (4 jets, $m_{\text{eff incl}} > 1100$) acceptance

- $M_{\text{Gluino}}$ values: 1000, 900, 800, 700, 600, 500, 400, 300
**Theory ideas: Compressed spectra**

Limits collapse for LSP mass above a couple hundred GeV. Efficiency at low $\Delta m$ is low and uncertain.

---

**CMS Preliminary**

$L_{int} = 1.1 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$

- \( pp \rightarrow \bar{g} \ g, \bar{g} \rightarrow 2b + \text{LSP}; m(\bar{g}) \gg m(g) \)

**Cross section UL at 95\% CL [pb]**

- $\sigma^{\text{prod}} = \sigma^{\text{NLO-QCD}}$
- $\sigma^{\text{prod}} = 3 \times \sigma^{\text{NLO-QCD}}$
- $\sigma^{\text{prod}} = 1/3 \times \sigma^{\text{NLO-QCD}}$
Suggestions:

- Require fewer jets (or lower $p_T$ threshold for subleading jets), but sum over more of them in defining $m_{\text{eff}}$.

AND/OR

- Choose lower cut on $m_{\text{eff}}$ (750 GeV?), and a higher cut on $E_T^{\text{miss}}/m_{\text{eff}}$ (0.35?) to compensate.

- Collect more data and be patient...
Theory ideas: GGM

David Shih

NLSP Collider Signatures

- In GGM, the NLSP can be (almost) anything in the MSSM

<table>
<thead>
<tr>
<th>NLSP type</th>
<th>Relevant final states (+MET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bino</td>
<td>$\gamma\gamma$, $\gamma$+jets</td>
</tr>
<tr>
<td>wino</td>
<td>$\gamma\ell$, $\gamma\gamma$, $\gamma$+jets, $\ell$+jets, jets</td>
</tr>
<tr>
<td>Z-rich Higgsino</td>
<td>$Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell'^+\ell'^-)$, jets</td>
</tr>
<tr>
<td>h-rich Higgsino</td>
<td>$b$-jets, jets</td>
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<tr>
<td>slepton</td>
<td>SS dileptons, multileptons, jets</td>
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<tr>
<td>squark/gluino</td>
<td>jets</td>
</tr>
<tr>
<td>stop</td>
<td>SS dileptons, $b$-jets, $\ell$+jets, $\ell$ + $b$-jets, $\bar{t}t$, jets</td>
</tr>
<tr>
<td>sbottom</td>
<td>$b$-jets, jets</td>
</tr>
</tbody>
</table>
Theory ideas: Naturalness

Motivation for Supersymmetry

- Beauty/String
- Gauge coupling unification
- SUSY
- Dark Matter
- Natural EWSB

Motivation that susy will be found at LHC

SUSY Status Report, D. Stuart, Nov. 2011, Hidden SUSY, UC Davis
Theory ideas: Naturalness

"Natural spectrum" is 15-20 years old; "We already bought something like this after LEP"
Theory ideas: Naturalness

SUSY Bull’s Eye

\[ 1500 \downarrow \tilde{\chi} \]

\[ 400 \downarrow \tilde{\tau}_{L,R}, \tilde{b}_L \]

\[ 120 \downarrow h \]

No wiggle room. Limits: sharply quantify tuning.

\[ \text{DISCOVERY} \rightarrow \text{EUPHORIA!} \]
Theory ideas: Naturalness

A Natural Spectrum

General “bottom-up” viewpoint

The “Nuclear Family” of the Higgs

\[ \tilde{h}_2^0 \]
\[ \tilde{h}_1^0 \]
\[ \tilde{h}_1^+ \]
\[ \tilde{t}_1 \]
\[ \tilde{b}_L \]
\[ \tilde{t}_2 \]

\[ \tilde{g} \]

\[ \tilde{q}_{1,2} \]
\[ \tilde{b}_R \]
\[ \tilde{\ell} \]

“Distant Cousins”

“ ’Natural spectrum’ is 15-20 years old”; “We already bought something like this after LEP”
SUSY Status Report? – a reasonable answer

\( \tilde{g} \tilde{g} \) and \( \tilde{q} \tilde{g} \) covered up to maybe 500 or 1000 GeV
stop pair production unprobed so far.
Conclusion

Tanya Sandoval
(Cambridge)
Additional slides…
Conclusion

\[ \sqrt{s} = 7 \text{ TeV}, \int L dt = 1.1 \text{ fb}^{-1} \]

- 2011 Limits
- 2010 Limits
- \( \tan \beta = 10, \ A_0 = 0, \ \mu > 0 \)

- CDF \( \tilde{g}, \tilde{q}, \tan \beta = 5, \mu < 0 \)
- D0 \( \tilde{g}, \tilde{q}, \tan \beta = 3, \mu < 0 \)
- LEP2 \( \tilde{\chi}_1^\pm \)
- LEP2 \( \tilde{l}^\pm \)

- MT2
- 1 Lepton
- SS Dilepton
- OS Dilepton
- \( g(1000) \text{ GeV} \)
- \( g(750) \text{ GeV} \)
- \( g(500) \text{ GeV} \)
- \( \alpha_T \)
Conclusion

Ranges of exclusion limits for gluinos and squarks, varying \( m(\tilde{\chi}^0) \)

- **T1**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0 \)
  - \( \alpha_T, 1.1 \text{ fb}^{-1}, \text{ gluino} \)

- **T1**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0 \)
  - MT2, 1.1 \text{ fb}^{-1}, \text{ gluino} \)

- **T2**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0 \)
  - \( \alpha_T, 1.1 \text{ fb}^{-1}, \text{ squark} \)

- **T1bbbb**
  - \( \tilde{g} \rightarrow b\tilde{\chi}^0 \)
  - \( E_T+b, 1.1 \text{ fb}^{-1}, \text{ gluino} \)

- **T1bbbb**
  - \( \tilde{g} \rightarrow b\tilde{\chi}^0 \)
  - MT2, 1.1 \text{ fb}^{-1}, \text{ gluino} \)

- **T1Lnu**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^\pm \)
  - di-lepton same sign, 0.98 \text{ fb}^{-1}, \text{ gluino} \)

- **T1Lh**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0 \)
  - di-lepton opposite sign, 0.98 \text{ fb}^{-1}, \text{ gluino} \)

- **T5zz**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0_2 \)
  - JZB, 0.191 \text{ fb}^{-1}, \text{ gluino} \)

- **T5zz**
  - \( \tilde{g} \rightarrow q\tilde{\chi}^0_2 \)
  - \( Z + E_T, 0.98 \text{ fb}^{-1}, \text{ gluino} \)

For limits on \( m(\tilde{g}), m(\tilde{g}) > m(\tilde{\chi}) \) (and vice versa), \( \sigma_{\text{prod}} = \sigma^{\text{NLO-QCD}} \).

\[
m(\tilde{\chi}^\pm), m(\tilde{\chi}_2^0) = m(\tilde{g}) + m(\tilde{\chi}^0).
\]

\( m(\tilde{\chi}^0) \) is varied from 0 GeV/\( c^2 \) (dark blue) to \( m(\tilde{g})-200 \text{ GeV}/c^2 \) (light blue).
Interpretation: PDF uncertainty at high mass
Steve Martin (NIU)