Search for SUSY in Gauge Mediated and Anomaly Mediated SB Models

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• GMSB searches at LEP/OPAL
• GMSB searches at Tevatron/DØ and prospects for Run II
• AMSB searches at LEP/Delphi
Gauge Mediated SUSY Breaking

- Alternative to gravity mediated SUSY breaking: Gauge interactions with messenger fields at a scale $M_{mess} \ll M_{Planck}$ are responsible for SUSY breaking.
- Gauge interactions are flavour blind, thus no FCNC (as in SUGRA models)
- The LSP is a Goldstone Fermion: Gravitino $\tilde{G}: M(\tilde{G}) \leq 1\text{keV}$
- The NLSP (next-to-lightest SUSY particle) is either the lightest neutralino (bino) or a charged slepton (mostly stau)
  $$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$$
  $$\tilde{l} \rightarrow l \tilde{G}$$
- The NLSP lifetime can range from 0 to $\infty$
  $\Rightarrow$ many different topologies

- Minimal set of parameters:
  - $\Lambda$: scale of SUSY masses
  - $M_{mess}$: messenger mass scale
  - $N_{mess}$: number of mess. fields
  - $\tan \beta$: ratio of Higgs v.e.v.
  - $|\mu|$: sign of higgs mass term
## GMSB Topologies

<table>
<thead>
<tr>
<th>NLSP</th>
<th>NLSP lifetime:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>short</strong></td>
<td><strong>medium</strong></td>
<td><strong>long</strong></td>
</tr>
<tr>
<td>stau, sleptons</td>
<td>2 leptons +</td>
<td>2 heavy,</td>
</tr>
<tr>
<td>(charged particles)</td>
<td>missing energy:</td>
<td>charged</td>
</tr>
<tr>
<td></td>
<td>(kinked tracks)</td>
<td>particles:</td>
</tr>
<tr>
<td>neutralino</td>
<td>2 photons +</td>
<td>missing</td>
</tr>
<tr>
<td>(neutral particles)</td>
<td>missing energy:</td>
<td>energy:</td>
</tr>
<tr>
<td></td>
<td>1 or 2 photons,</td>
<td>not pointing</td>
</tr>
<tr>
<td></td>
<td>not pointing to</td>
<td>to vertex:</td>
</tr>
</tbody>
</table>

**Tracker**  **Electromagnetic calorimeter**

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Neutralino NLSP: $\gamma\gamma$ Production

Signal: Pair prod. of acoplanar $\gamma\gamma$:

- Expected SM production:

- GMSB interpretation of CDF $ee\gamma\gamma E_T$ event excluded
- Within GMSB Snowmass Slope parameter set (used by DØ):
  
  $$M(\tilde{\chi}_1^0) > 100 \text{ GeV}, \quad M(\tilde{e}) > 130 \text{ GeV}$$
Stau NLSP

- Combination of four different analysis, sensitive to various stau life times
- Measurement: upper limit on the production cross section in the plane $M(\tau_1) - \tau_{\text{life}}$

$$M(\tau_1) > 87.6 \text{ GeV}$$

Lower stau mass limits obtained by comparison to theoretical predictions of cross section $M(\tau_1)$.
Inclusive Search for $\gamma \gamma$ Missing $E_T (\not{E}_T)$

- Dominating production channels at Tevatron: $\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{\pm}\tilde{\chi}_{2}$
- In case of Neutralino NLSP:

  $\text{gauginos} \rightarrow \tilde{\chi}_{1}^{0}\tilde{\chi}_{1}^{0} + W, Z, \gamma \rightarrow \gamma \gamma + \tilde{G}\tilde{G} + X$

- Analysis assumes short NLSP lifetime $\Rightarrow$ prompt decay
- 2 $\gamma$'s in central calorimeter ($|\eta| \leq 1.1$)
  - w. transverse energy $E_T > 20\text{GeV}$
  - $\gamma$-consistent shower shape
  - isolation requirement based on energy deposition
  - $e^\pm$ veto: no matched tracks
- Measurement of missing $E_T$ distribution of di-photon events

- $\gamma$ pointing using highly segmented LAr calorimeter and Preshower strips
- $\gamma$ vertex resolution (beam direction):
  - Calorimeter only: $\sigma_z \approx 15 \text{ cm}$
    - used in this analysis
  - Central Preshower: $\sigma_z \approx 2.2 \text{ cm}$
    - not fully commissioned yet, but good prospects for future analyses
Background Estimation

- **Background without true missing $E_T$:**
  - Dominating: QCD with direct photons or jets mis-identified as $\gamma$'s (due to leading $\pi^0$)
    - Contribution estimated using fake $\gamma\gamma$ sample: at least one $\gamma$ candidate fails shower shape requirement, normalized at low $E_T < 20$ GeV
  - Drell-Yan, electrons mis-identified as $\gamma$'s due to track reconstruction inefficiency

- **Background with true missing $E_T$ (from $\nu$):**
  - Dominating: $W\gamma \rightarrow e\nu\gamma$ (missed tracks)
    - $W$+jet $\rightarrow e\nu$+jet (jet faking $\gamma$)
    - Contribution estimated using $e\gamma$ sample and $e\rightarrow\gamma$ mis-identification probability derived from data

<table>
<thead>
<tr>
<th>$\gamma\gamma$ events</th>
<th>$E_t &gt; 25$ GeV</th>
<th>$E_t &gt; 30$ GeV</th>
<th>$E_t &gt; 35$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD (w. wrong $E_t$)</td>
<td>6.0 ± 0.8</td>
<td>2.5 ± 0.5</td>
<td>1.6 ± 0.4</td>
</tr>
<tr>
<td>e+$\nu$+$\gamma$/j</td>
<td>0.6 ± 0.4</td>
<td>0.2 ± 0.2</td>
<td>0.0 ± 0.2</td>
</tr>
</tbody>
</table>
Search for Excess in $E_T$ Spectrum

- No excess seen in missing $E_T$ distribution
- Signal efficiencies derived using Snowmass Slope for GMSB:
  \[ M_{mess} = 2\Lambda, \quad N_{mess} = 1, \]
  \[ \tan \beta = 15, \quad \mu > 0 \]
  - combined efficiency: \( \sim (7-10)\% \)
    for $E_T > 30$ GeV and $45 < \Lambda < 55$ TeV
    - including trigger and reconstruction efficiencies
- Upper limits on cross sections are calculated using bayesian approach with cut: \( E_T > 30\) GeV

Run 2 preliminary

Simulated Signal

\( \Lambda = 55\) TeV
\( \Lambda = 45\) TeV
\( \Lambda = 35\) TeV

MET, GeV

\( \gamma\gamma \) search region

QCD

MET, GeV
95% C.L. Limits
\[ \Lambda > 51 \text{ TeV} \]
\[ M(\tilde{\chi}_1^0) > 66 \text{ GeV} \]
\[ M(\tilde{\chi}_1^\pm) > 116 \text{ GeV} \]

- Comparing cross section limits with theoretical predictions:

- Measurement is based on luminosity \( L = 41 \text{ pb}^{-1} \)
- Results are approaching limits from Run I analyses based on \( \sim 100 \text{ pb}^{-1} \) (similar models)
  - DØ: \( M(\tilde{\chi}_1^0) > 77 \text{ GeV} \)
  - CDF: \( M(\tilde{\chi}_1^0) > 65 \text{ GeV} \)
Prospects for Tevatron Run II

- Prompt neutralino decays:
  - With $L = 2 \text{ fb}^{-1}$ discovery up to $M(\tilde{\chi}_1^0) \approx 165 \text{ GeV}, \ M(\tilde{\chi}_1^\pm) \approx 300 \text{ GeV}$
    (J. Qian, hep-ph/9903548 v2, similar model, but $\tan \beta = 2.5$)
  - LEP limit (from acoplanar $\gamma\gamma$ search):
    $M(\tilde{\chi}_1^0) > 100 \text{ GeV}, \ M(\tilde{\chi}_1^\pm) > 175 \text{ GeV}$

- Intermediate neutralino life-time
  - Sensitivity drops as NLSP decays outside detector
  - Larger sensitivity in photon+jets+$E_T$ channel

- Opal: for any NLSP life-time
  $M(\tilde{\chi}_1^\pm) > 100 \text{ GeV}$
Prospects for Stau NLSP Scenario

- High mass reach also in stau NLSP scenario
- Short-lived stau
  - Prompt decay
  - Standard SUSY searches: Tri-lepton or like-sign di-lepton signature
- Quasi-stable stau
  - Stau escapes detector
  - 2 $\mu$-like objects with large dE/dx

J. Qian: hep-ph/9903548 v2
• SUSY breaking is mediated by anomalies in the supergravity lagrangian
  ◆ Provides soft mass parameters in visible spectrum
  ◆ No need for messenger sector
  ◆ Flavour blind $\Rightarrow$ FCNC automatically suppressed
  ◆ But: need additional non-anomaly contribution to avoid tachyonic sleptons

• AMSB model is very predictive
  ◆ Defined by $m_{3/2}$, $m_0$, $\tan \beta$ and sign($\mu$)

• LSP: $\tilde{\chi}_1^0, \tilde{\nu}, \tilde{\tau}$

• Neutralino and chargino are gaugino-like and nearly mass degenerate
  \[ \Delta M = M(\tilde{\chi}_1^\pm) - M(\tilde{\chi}_1^0) < O(10 \text{ GeV}) \]
Small $\Delta M$ Chargino Search

- Problem: small $\Delta M$ means little visible energy.
- $\Rightarrow$ large background from $\gamma\gamma$-scattering
- Require ISR tag!
- Exclusion region depends on sneutrino mass.
  - Leptonic decay mode $\tilde{\chi}_1^{\pm} \rightarrow \bar{\nu}^{*} l^{\pm} \rightarrow \tilde{\chi}_1^0 \nu l^{\pm}$
  - important for small sneutrino masses

Delphi
Constraints on AMSB Parameter Region

- Combination of various analyses to constrain AMSB parameter space
  - LEP1 constrain (Z width)
  - SM Higgs search
  - Invisible Higgs search
  - Small $\Delta M$ chargino search
  - Search for $\tilde{\chi}_1^\pm \rightarrow \tilde{\nu} l^\pm$

- Parameter scan using Isajet:
  - $M(\tilde{\chi}) > 68 \text{ GeV}$
  - $M(\tilde{\nu}) > 98 \text{ GeV}$
  - $M(\tilde{l}) > 72 \text{ GeV}$
Summary and Outlook

• Many different topologies have been studied by the LEP experiments.
  - Combination of results is used to set limits for all NLSP lifetimes and to cover most of the kinematically accessible parameter space for the GMSB and AMSB scenarios.

• First results from Tevatron are approaching Run I limits with much smaller statistics.

• For GMSB models Tevatron has the potential to significantly improve lower limits on SUSY particle masses.

Many thanks to Christoph Rembser for the valuable discussion on the LEP results!