June 17-23, 2002, DESY Hamburg

Superymmetry and Unification of Fundamental Interactions
SUSY02 The 10th International Conference on

Outline:

- Accessible range of the parameter space
  - SUSY signature: „end-point“
  - Example of the GMSB search method in the CMS detector

- Nature of the NLSP
  - Phenomenological implications

Basics of Gauge Mediated Superymmetry Breaking Models

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Gauge Mediated Supersymmetry Breaking Models

\[ \Lambda \]

\textit{effective scale of SUSY breaking}

\textit{Super symmetry}

\textit{hidden sector}

\textit{messenger sector}

\[ N \]

\textit{singlets of SU(5)}

\textit{acquire mass} \( M \)

\textit{visible sector}

\textit{MSSM}
\[ \Lambda^2 \left( \frac{\Lambda^2 T_0}{\sqrt{\mu}} \right)^4 \simeq \frac{\sqrt{M^3}}{\sqrt{\mu}} = \sqrt{m} \quad \text{then gravitino: } V < W \sim 10^{-1000} \text{ TeV and } V > W \sim 10^{-4.2} \text{ TeV}. \]

Additionally, SUGRA particles masses are split by \( \tilde{g} \) (\( \tilde{g} \)) and sign(\( \eta \)).

\[ \sum < Z / W < g / q < h / q < f / q \]

\[ \text{Masses: } \tilde{N} \]

\[ \text{Masses: } \tilde{g} \]

\[ \text{Masses: } \tilde{f} \]

The larger number of couplings the heavier the stermions.

\[ \left[ \left( \frac{\mu}{\sqrt{\lambda}} \right) \right]^{C/2} \Lambda^2 \sum N Z = \sqrt{z} \sim \sqrt{w} \]

\[ V^{\frac{w}{2}} \tilde{N} = \sqrt{w} m \]

Two-loop correction - squarks and squarks of SUSY breaking in the hidden sector is transferred to the visible sector.
GMSB models are classified with respect to the sort of particle which decays to the stable - gravitino.

Candidates for the Next to the LSP:
- The lightest neutralino $\tilde{N}_1$
- The lightest right slepton $\tilde{\tau}_1$
- Generated sleptons $\tilde{\tau}_1 \tilde{\mu}_R \tilde{e}_R$, co-NLSP

{
\textsc{A.J.E.T. 5.73} – event generator with GMSB($\Lambda, M, N, \tan(\beta), \text{sign}(\mu)$) function

- Bottom interface added
- Calculation of models
- Wide range of parameter values

$\Lambda = 30$-1000 TeV, $M = 40$-30000 TeV, $\tan(\beta) = 1.5$-55, $\text{sign}(\mu) = \pm 1$
Next to the Lightest Supersymmetry Particle: NLSP

$\tilde{\tau}_1$

or

$\tilde{N}_1$
NLSP: slepton degeneracy

\[ \tilde{\tau}_1 \]

or

\[ \tilde{\tau}_1, \tilde{e}_R, \tilde{\mu}_R \] ?

\[ \tau_1 \]

\[ \mu_{eR}, \tilde{\mu}_R \]

\[ \tan \beta \leq 7 \]

\[ \text{sign}(\mu) = 1 \]

\[ \text{sign}(\mu) = -1 \]

\[ N = 3 \]

\[ \tan \beta = 10 \]

\[ \tan \beta = 15 \]

\[ \tan \beta = 20 \]

\[ \tan \beta = 30 \]

\[ \tan \beta = 40 \]

\[ \tan \beta = 55 \]
A decay cascade of the heavy sparticle with lepton emission causes a sharp end-point in the $M_{inv}$ of all combinations of opposite sign lepton pairs: $\mu^+\mu^- + e^+e^- - \mu^+e^- - e^+\mu^-$. A well-known edge originates from

\[
\tilde{N}_2 \rightarrow \tilde{l}_R + l \\
\tilde{l}_R \rightarrow \tilde{N}_1 + l
\]

if NLSP is the neutralino $\tilde{N}_1$

\[
M_{inv}(ll)_1 = \sqrt{m_{\tilde{N}_2}^2 - m_{\tilde{l}_R}^2} \sqrt{m_{\tilde{l}_R}^2 - m_{\tilde{N}_1}^2} / m_{\tilde{l}_R}
\]

\[
\tilde{N}_1 \rightarrow \tilde{l}_R + l \\
\tilde{l}_R \rightarrow \tilde{\chi} + l
\]

if NLSP is the slepton $\tilde{\tau}_1$ or/and $\tilde{\mu}_R$, $\tilde{\nu}_R$

\[
M_{inv}(ll)_2 = \sqrt{m_{\tilde{N}_1}^2 - m_{\tilde{l}_R}^2}
\]

Observability of the edge depends on:

- total $\sigma$ for the SUSY production
  - partial $\sigma$ for the neutralino production
- branching ratios of the end-point decays
  - sensitivity to the neutralino contents
- Anti-SM background cuts
End-point position in the parameter space

\[ \Lambda = 30 \text{ TeV}, N = 1, \text{sign}(\mu) = -1 \]

Neutralino NLSP

\[ \Lambda = 50 \text{ TeV}, N = 3, \text{sign}(\mu) = 1 \]

Slepton NLSP

\[ N^* \text{sign}(\mu) \]

\[ \log(\frac{M}{\Lambda}) \]

edge: \( M_{\text{inv}(ll)} > 0 \)

edge: \( M_{\text{inv}(ll)} > 0 \)
THIA 6.157 – event generator
SJet – fast detector simulation

Processes in pp collisions at $\sqrt{s}$ 14 TeV:
mum bias, bb, gamma, tt, W, WW, WZ, Z, ZZ

$$\int Ldt = 10 / \text{fb}$$

Processes simulated in several $\hat{p}_t$ intervals
(50k events each). The background simulation
took 520h 100 CPU 1GHz PC.

Samples merged proportionally to cross sections.

SM contribution to the total background
<table>
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<th>edge</th>
<th>slope [GeV]</th>
<th>[GeV]</th>
<th>[GeV]</th>
<th>[GeV]</th>
<th>[GeV]</th>
<th>(tan$\theta$)</th>
<th>sgn(T)</th>
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<th>GMSB</th>
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<td>$m_{\tilde{q}}$</td>
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<td>$m_{\tilde{l}}^R$</td>
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</tr>
</tbody>
</table>

Examples of selected GMSB models
CUT1: \( E_{\text{miss}} > 200 \text{ GeV} \)

CUT2: \( p_T \) 4th jet > 80 GeV

CUT3: 2 opposite sign leptons
Is the end-point detectable?
Evidence of the end–point

5σ evidence for the signal is:

150 lepton pairs for the edge mass below 100 GeV
30 lepton pairs for the edge mass above 100 GeV.

set of kinematical cuts was applied to each model and a detector efficiency was determined.

Detection efficiency is evaluated as a ratio of an excess $\mu^+\mu^- + e^+e^- - \mu^+\mu^- - e^+e^-$ events after and before all cuts corrected by the efficiency of the lepton pair selection (model dependent).

The CMS detector response was examined for several models fully simulated with the CMSJET.

Efficiency of the end–point detection in the CMS detector is not less than 15%
Determination of the end–point value

For each model–sample we fit a triangle–like function, which allows us to find end–point position.

Some models presence of the $Z^0$ peak distorts the picture (it can be used to uncover of the neutralino contents)

SY background may change the edge position.

Systematic uncertainty the end–point value amounts to few GeV with more sophisticated method could be improved.
Accessible region of the GMSB parameter space for neutralino NLSP, end–point 1

\[ M_{\text{inv}}(ll)_1 = \sqrt{m_{\tilde{N}_2}^2 - m_{\tilde{\tau}_R}^2 \sqrt{m_{\tilde{\tau}_R}^2 - m_{\tilde{N}_3}^2}} \]

The edge is detectable at 5\( \sigma \) level for \( \int L dt = 10/\text{fb} \)

\( \Lambda \leq 100 \text{ TeV} \) for \( N = 1 \)
Accessible region of the GMSB parameter space for slepton NLSP, end–point 2

$\Lambda=50 \text{ TeV, } N=3, \text{ sign}(\mu)=1$

$M_{inv}(ll)_2 = \sqrt{m_{N_1}^2 - m_{l_R}^2}$

The edge is detectable at the 5$\sigma$ level for $\int Ldt = 10$/fb if $\tan(\beta) < 30$

and

$\Lambda < 70 \text{ TeV for } N = 5$
$\Lambda < 90 \text{ TeV for } N = 4$
$\Lambda < 110 \text{ TeV for } N = 3$
$\Lambda < 130 \text{ TeV for } N = 2$

$\Lambda < 170 \text{ TeV for } N = 1$
only for $M/\Lambda < 1.15$
\( \Lambda = 30\text{-}200 \text{ TeV}, M = 40\text{-}30\text{,}000 \text{ TeV}, \tan \beta = 1.5\text{-}55, \text{sign}(\mu) = \pm 1 \)

\[ m_{\tilde{\tau}_1} < 350 \text{ GeV and } m_{\tilde{N}_1} < 500 \text{ GeV} \]
points enable to solve the puzzle of the SU5Y mass hierarchy.

The diellpoton edge does not determine the model unambiguously.

...evertheless the Nature is more sophisticated.

In $\frac{1}{3}$ % efficiency in the CMS detector, the end-point signature can be investigated using the diellpoton end-point signature.

For $\sqrt{s} > 10^{3}$

\[ \frac{N}{\ln N} > 1 \quad \text{and} \quad \tan(\theta) > 30 \]\n
for certain values of $\tan(\theta)$. \( \frac{N}{\ln N} \) for $N = 5', 4', 3', 2'$

\( \, \text{TeV} \)

For $\sqrt{s} > 10^{3}$, $70', 90', 110', 130', 100', 120', 130', 100', \text{TeV}$

determined the region of the GMSB parameter space.

Summary

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CMS