GMSB and heavy neutrinos at CMS

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Soltan Institute for Nuclear Studies, Warsaw

- Gauge Mediated Susy Breaking at CMS (a trailer)
  - Very short theoretical remainder
  - NLSP types and lifetimes
  - $\tilde{\chi}_1^0$ NLSP: non-pointing photons
  - $\tilde{\tau}_1$ NLSP: charged WIMPs

- Detection of heavy Majorana neutrinos and right-handed bosons
  (on behalf of CMS) analysis done by people from INR Moscow:
  S.N. Gninenko, M.M. Kirsanov, N.V. Krasnikov and V.A. Matveev
  - Heavy Majorana neutrino production and decay
  - Analysis path
  - Results

- Summary
Any (minimal) GMSB model is specified in terms of five + one parameters

\[ \Lambda, \ M_m, \ N, \ \tan \beta, \ \text{sgn}(\mu) + C_G \]

\( \Lambda \) is the effective visible sector SUSY breaking parameter which sets the overall mass scale for all the MSSM superpartners. Gaugino masses are proportional to \( N\Lambda \) and sfermion masses are proportional to \( \sqrt{N}\Lambda \).

\( M_m \) is the messenger scale which enters as the scale at which the boundary conditions for renormalization group evolution of the MSSM parameters are imposed.

The type of the NLSP depends mainly on the parameter \( N \).
The effective SUSY breaking order parameter $F_S$ felt by the messengers is, in general, lower than the ultimate underlying SUSY breaking order parameter $F$ which determines the Goldstino mass and (inversely proportional to the mass squared) coupling.

To account for this, a dimensionless factor

$$C_G = \frac{F}{F_S}$$

relating $F$ and $F_S$ may be introduced.

With all other MGM parameters fixed, $C_G$ may be used to control the NLSP decay length:

$$c\tau(\widetilde{X} \to X\widetilde{G}) \approx C_G^2 \left( \frac{1 \text{ m}}{\kappa} \right) \left( \frac{100 \text{ GeV}}{m_{\widetilde{X}}} \right)^5 \left( \frac{\sqrt{\Lambda \cdot M_m}}{1000 \text{ TeV}} \right)^4 \left( 1 - \frac{m_{\widetilde{X}}^2}{m_{\widetilde{X}}^2} \right)^{-4}$$
## Non-standard GMSB signatures

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Long-lived charged WIMPs
Long-lived charged WIMPs

muon track in the Drift Tubes

How charged WIMP would be seen in the drift tubes?
Long-lived charged WIMPs

muon track in the Drift Tubes

stau track in the Drift Tubes

\[ \delta t \]
Long-lived charged WIMPs

Charged WIMP could be seen as a track reaching muon chambers with a velocity depended delay $\delta_t$

$$\delta_t = t_{\beta<1} - t_{\beta=1} = \frac{L}{c} \left( \frac{1}{\beta} - 1 \right)$$

where $L$ is the flight distance.
Long-lived charged WIMPs

Detailed simulation in 1999 but instead of staus, delayed muon tracks and custom $\delta t$ determination was used [1].

$$\delta t \Rightarrow \frac{1}{\beta} \quad \Rightarrow \quad M^2 = \frac{(p/c)^2}{(1/\beta^2 - 1)}$$

Now: full detector simulation and charged WIMPs introduced to GEANT 4. Results at Physics at LHC, Cracow, July 2006
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Neutralino decays $\tilde{N}_1 \rightarrow \tilde{G} \gamma$
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In 1999 (Tampere contr.) only feasibility study at the generator level using parameterization of the CMS detector [http://cmsdoc.cern.ch/documents/99/cr99_019.pdf]
Neutralino decays $\tilde{N}_1 \rightarrow \tilde{G} \gamma$

Now: full detector simulation and standard reconstruction in the ECAL
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Now: full detector simulation and standard reconstruction in the ECAL

pointing photon

non-pointing photon

$E$ in the ECAL crystals
Neutralino decays $\tilde{N}_1 \rightarrow \tilde{G} \gamma$

Now: full detector simulation and standard reconstruction in the ECAL

E in the ECAL crystals

pointing photon

non-pointing photon

$\Delta t$ sensitivity range

$\Delta t$ estimate precision

results at Physics at LHC, Cracow, July 2006
Heavy Majorana neutrinos

In the analysis the left-right (LR) symmetric model is explored:

\[ SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1) \]

The model embeds the SM at the scale of the order of 1 TeV and naturally explains the parity violation in weak interactions as a result of the spontaneously broken parity.

It necessarily incorporates three additional gauge bosons \( W_R \) and \( Z' \) and the heavy right-handed Majorana neutrino states \( N \).

The \( N \) states can be the partners \( (N_l) \) of the light neutrino states \( \nu_l \ (l = e, \mu, \tau) \) and can provide their non-zero masses through the see-saw mechanism.
The cross sections of $pp \rightarrow W_R \rightarrow l + N_l + X$ (the process studied here), and $pp \rightarrow Z' \rightarrow N_l + N_l + X$ (where $N_l \rightarrow l + j_1 + j_2$) depend on

- the value of the coupling constant $g_R$,
- the parameters of the CKM mixing matrix for the right-handed sector,
- the $W_R - W_L$ and $Z' - Z$ mixing strengths,
- and the masses of the partners $N_l$ of the light neutrino state.

In the study presented here the mixing angles are assumed small, the right-handed CKM matrix is identical to the left-handed one and $g_R = g_L$. With these assumptions the $Z'$ is about 1.7 times heavier than $W_R$ and the production cross-section for $pp \rightarrow W_R \rightarrow eN_e$ is found to be at least one order of magnitude higher than for the $pp \rightarrow Z' \rightarrow N_eN_e$ process.

Finally it is assumed that only the lightest $M_{N_e}$ is reachable at the LHC.
The analysis is performed in the $M_{W_R}$, $M_{N_e}$ parameter space.

The benchmark point considered:
$M_{N_e} = 500 \text{GeV}$ and $M_{W_R} = 2000 \text{GeV}$.

The dependence of the
$\sigma(pp \rightarrow W_R) \times Br(W_R \rightarrow e^\pm N_e)$
on the heavy neutrino mass for different masses of $W_R$. 

$$pp \rightarrow W_R \rightarrow e + N_e$$
$$\downarrow$$
$$e + W_R$$
$$\downarrow$$
$$jj$$
The two major backgrounds considered in this study are:

- $Z$ + jets
- $t\bar{t}$

Offline selection:

- two isolated electrons; dielectron invariant mass $M_{ee}$ is required to be above 200 GeV
- at least two jets
- the $M_{eejj}$, ($W_R$ boson candidate) invariant mass is required to be above 1 TeV.

$M_{ejj}$ for the signal overlaid with the SM background (shaded histogram) when $M_{eejj} > 1$ TeV for 30/ fb
The total $W_R$ mass the reconstruction efficiency for $M_{W_R} = 2\text{TeV}$ and for neutrino masses above 500 GeV is between 20% and 25%.

while for for neutrino masses much smaller than the $W_R$ mass the reconstruction efficiency drops due to the significant overlap of the heavy neutrino decay products in $\eta - \phi$.

The $M_{eejj}$ for the signal overlaid with the SM background (shaded histogram) for 30/fb.
Results

With 30/fb a 5 sigma observation of $W_R$ and $N_e$ with masses up to 4 TeV and 2.4 TeV respectively can be achieved.

The signal at the benchmark point $W_R$ of 2 TeV and $N_e$ 500 GeV is observable already after one month of running at low luminosity.

CMS discovery potential of the $W_R$ boson and right-handed Majorana neutrinos of the Left-Right Symmetric model for the integrated luminosity $L_t = 30/fb$ (outer contour) and for $L_t = 1/fb$ (inner contour)
Conclusions

- Heavy Majorana neutrinos
  - With 30/fb a 5 sigma observation of $\bar{W}_R$ and $N_e$ with masses up to 4TeV and 2.4TeV respectively can be achieved.
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