General Gauge Mediation as a Collider Signature Generator: Selectron/smuon co-NLSP & Multi-lepton Final States at LHC

Diego Redigolo

Université Libre de Bruxelles (ULB) & International Solvay Institutes (ISI)

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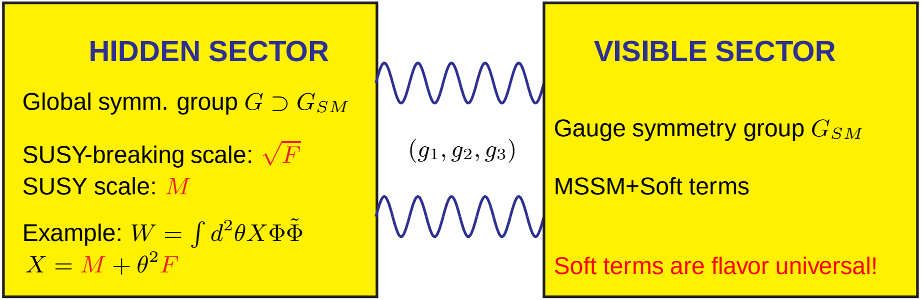
Credits:

- P. Grajek, A. Mariotti and D.R. arXiv:1303.0870 [hep-ph]
- K. De Causmaecker, J. D'Hondt, B. Fuks, A. Mariotti, K. Mawatari, C. Petersson and D. R. *work in progress*
- L. Calibbi, A. Mariotti, C. Petersson and D. R. *work in progress*

General Gauge Mediation

Meade Seiberg Shih '08



- $G_{SM} = U(1) \times SU(2) \times SU(3)$ with gauge couplings (g_1, g_2, g_3)
- Soft masses in GGM (at the messenger scale M)

$$m_{\lambda_i} = \frac{g_i^2}{(4\pi)^2} \Lambda_{G_i} \,, \qquad m_{sf}^2 = 2 \sum_{i=1}^{3} C_i k_i \frac{g_i^4}{(4\pi)^4} \Lambda_{S_i}^2 \qquad i = 1, \ldots 3;$$

- $3 + 3 + 1$ independent parameters: $(\Lambda_{G_i}, \Lambda_{S_i}, M)$

Universal property of Gauge Mediation spectra

- Gravitino always LSP: $m_{3/2} = F/\sqrt{3}M_{\mathrm{P}}$.
- The NLSP has a universal 2-body decay to SM partner + gravitino

$$\Gamma(\tilde{x} \to x\tilde{G}) = \frac{m_x^5}{16\pi(\sqrt{3}M_{\mathrm{P}} m_{3/2})^2} \text{ (prompt or delayed)} .$$

- Assuming R-parity all events would contain:
  - high p_T objects + MET
  - heavy long lived particles (colored, charged, or neutral)
- Most of the GGM collider phenomenology is determined by the nature of the NLSP and the production mechanism (Kats, Meade, Reece and Shih '11)

GGM as a powerful collider signature generator for LHC

Question: Status of GGM after the 125 GeV Higgs + Run I of LHC.

Is GGM still a powerfull collider signature generator?

What are the NLSP-type that can be realized in spectra with a 125 GeV Higgs?
Are there generic features of GGM spectra with a 125 GeV Higgs?

GGM vs Higgs

- A-terms are loop suppressed in the UV ⇒ generically $X_t/M_S \ll 1$ in the IR.
- Large M_S is the simplest solution to achieve a 125 GeV Higgs.
- Other directions: MSSM+extension of GGM ; extension of the MSSM+ GGM.

Large $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ in GGM:

- Case I: Large Λ_{G_3} (Large gluino mass in the UV).
- Case II: Large Λ_{S_3} (Large squark masses in the UV).

NLSP type and collider phenomenology in GGM   Grajek Mariotti and D.R. '13

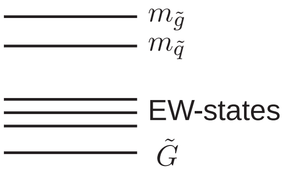
- No squarks NLSP
- Gluino is the only possible colored NLSP. Very constrained:
  - $jets +$ MET searches (prompt)
  - R-hadrons searches (long-lived)
- Any uncolored sparticle can be the NLSP in some region of the GGM parameter space

GGM realizations of Mini-Split spectra!

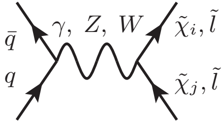
Arvanitaki, Craig, Dimopoulos, Villadoro '12; Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski '12;

Large $\Lambda_{G_3} \Rightarrow$

- Large $m_{\tilde g}$.
- Large $m_{\tilde q}$ from gluino mediation.

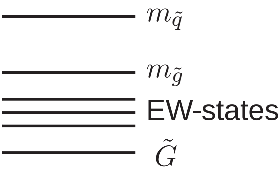


- Pure EW-production
- Low cross sections

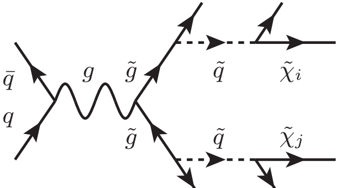


Large $\Lambda_{S_3} \Rightarrow$

- Large $m_{\tilde q}$.
- The gluino can be light (even NLSP).



- Colored production $m_{\tilde g} >$ EW STATES
- $4jets + X +$ MET



GGM+125 GeV Higgs as collider signature generator for pure EW-states.

Are there poorly explored SUSY spectra with a peculiar collider phenomenology that might be interesting for experimental searches?

An exotic case of Study:

Selectron/Smuon co-NLSP

- Departing from GGM. Yukawa-like interactions Hidden-Higgs sector:

$$\mathcal{W} = \int d^2\theta \, (\lambda_u H_u O_d + \lambda_d H_d O_u)$$

- Many theoretical motivation for these Extra-couplings:
  - They can generate μ and B_μ and associate them to the SUSY-breaking dynamics.
  - They are a key ingredient in “Large-A terms” model building. Shih's plenary talk

Generic consequence:

The Higgs soft terms are deformed with respect to the GGM ones.

GGM: $m^2_{H_u} = m^2_{H_d} = m^2_{E_L}$,

GGM+Yukawas: $m^2_{H_u} = m^2_{E_L} + \Delta^2_u$, $\quad m^2_{H_d} = m^2_{E_L} + \Delta^2_d$.

- Δ_d^2 induces a non-standard shift in the Yukawa contributions to the running of the slepton masses in the MSSM (Evans Morrissey and Wells '06).
- The effect is relevant only for the third generation: $y_\tau : y_\mu : y_e \approx m_\tau : m_\mu : m_e$.
- Tuning Δ_d^2 we can tune the 3rd/1st,2nd generation hierarchy

$$16\pi^2 \frac{d}{dt}(m^2_{\tilde{\tau}_R} - m^2_{\tilde{l}_R}) = 2(X_\tau + \Delta X_\tau)\,, \qquad \Delta X_\tau = 2|y_\tau|^2 \Delta_d^2\,.$$

- $\Delta X_\tau < 0 \Rightarrow \Delta_d^2 < 0$ can realize spectra with selectron/smuon co-NLSP.

$$\frac{m^2_{\tilde{\tau}_R} - m^2_{\tilde{l}_R}}{m^2_{\tilde{l}_R}} \approx -\frac{1}{4\pi^2}|y_\tau^2| \left(1 + \frac{m^2_{\tilde{l}_L}(M_{mess})}{m^2_{\tilde{l}_R}(M_{mess})}(2 + x_d^2)\right) \ln \frac{M}{M_{\rm SUSY}},$$

$$y_\tau \approx \frac{m_\tau \tan\beta}{v}\,, \qquad x_d^2 = \frac{\delta m_d^2}{m^2_{\tilde{l}_L}}\,.$$

- $|\Delta_d^2| > 2m^2_{\tilde{l}_L} + m^2_{\tilde{l}_R}$.
- The effect is enhanced for larger $\tan\beta$ and for longer running (larger M).
- For sizeable $\tan\beta$ we can account for the mixing in the stau mass matrix:

$$\delta^p = \frac{m_{\tilde{\tau}_1} - m_{\tilde{l}_R}}{m_{\tilde{l}_R}}$$

Consequences on the EWSB condition

- For large $\tan\beta$ the minimization condition simplifies to

$$\mu^2 \simeq -m_{H_u}^2 \qquad\qquad (m_{H_u}^2 < 0)$$

- Negative $m_{H_d}^2$ leads to light CP-odd Higgs (excluded by direct searches) and can destabilize the EWSB vacuum.

$$m_A^2 = 2\mu^2 + m_{H_u}^2 + m_{H_d}^2 \simeq -m_{H_u}^2 + m_{H_d}^2 < \mu^2$$

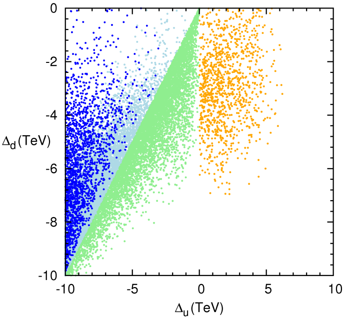
Are there escape solutions to the light CP-odd Higgs problem?

1. "tree level" solution:
   - Negative $m_{H_u}^2$ at M_{mess}.
   - Large μ + Dangerous UFB directions in the scalar potential (Evans Morrissey and Wells '09)
2. "radiative" solution:

$$16\pi^2 \frac{\mathrm{d}}{\mathrm{d}t}(m_{H_d}^2 - m_{H_u}^2) = 3(X_b - X_t) + X_\tau - \frac{6}{5} g_1^2 S \,.$$

$$X_t = 2|y_t|^2 (m_{H_u}^2 + m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2) + 2|y_t|^2 |A_t|^2$$

   - Positive $m_{H_u}^2$ at M_{mess} BUT either large $m_{\tilde{t}}$ or A_t at M_{mess}.



- $m^2_{H_{u,d}} = m^2_{\tilde{e}_L} + \Delta^2_{u,d}$
- REQUIREMENTS:
- All sparticles less than 10 TeV + LEP constraints
- $\delta^p > 10\%$
- CMS direct search bound in the plane $(m_A, \tan\beta)$

- BLUE REGION ("tree level" solution): $m^2_{H_u} < 0$ with $|m^2_{H_u}| \geq |m^2_{H_d}|$
- ORANGE REGION ("radiative" solution): $m^2_{H_u} > 0$
- GREEN REGION (intermediate): $m^2_{H_u} < 0$ with $|m^2_{H_u}| \leq |m^2_{H_d}|$

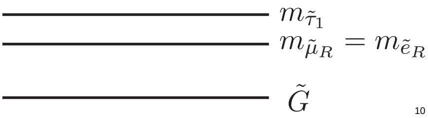
- Blue and Green region accessible with sfermion+gaugino mass unification and zero A-terms.
- Orange region needs either splitted colored spectrum or A-terms.

Work in progress

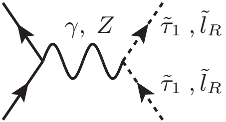
- Can we realize this corner of the parameter space via models of messengers?
- Are there extra constraints from global vacuum (meta)-stability?

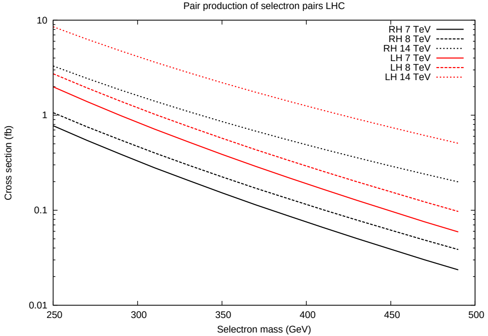
The (simplest) Simplified Model for Selectron/smuon co-NLSP

- The physics of the processes is determined by the mass splitting between the stau and the other sleptons δ^p



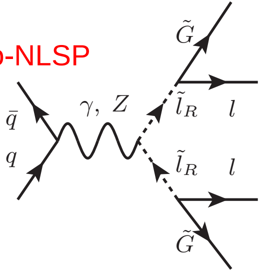
- The production cross section is completely determined by Drell-Yan production





- Three possible mass hierarchies:
  - Slepton co-NLSP: $m_{\tilde{\tau}_1} = m_{\tilde{l}_R}$
  - Stau-NLSP $m_{\tilde{\tau}_1} < m_{\tilde{l}_R}$
  - Selectron/smuon co-NLSP $m_{\tilde{\tau}_1} > m_{\tilde{l}_R}$
- The three configurations have different collider phenomenologies.

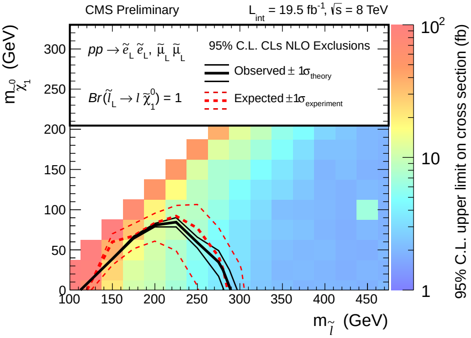
Slepton co-NLSP



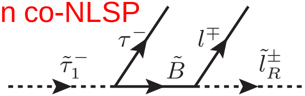
- Since mass degeneracy is assumed the best $\tilde{\tau}$ bound comes from pair produced sleptons.
- Bounds from CMS and ATLAS searches on OS-dileptons+ MET
- Large background from $WW + t\bar{t}$.
- M_{T_2} or $M_{C_\perp}$ variables to get rid of backgrounds.

Best bounds for GGM:

$m_{\tilde{l}_R} > 230$ GeV $m_{\tilde{l}_L} > 305$ GeV.



Selectron/smuon co-NLSP

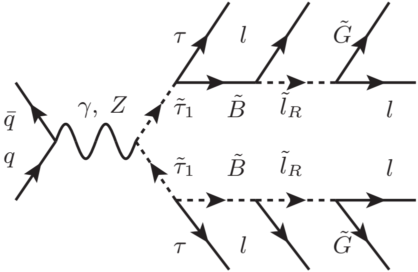


- $m_{\tilde\tau_1} > m_{\tilde l_R} + m_\tau$.
- Stau 3-body decay via off-shell Bino ($m_{\tilde B} = 500$GeV)

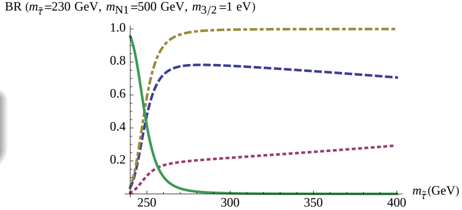
$$\tilde\tau_1^- \to \tau^- l^- \tilde e_R^+ \qquad \tilde\tau_1^- \to \tau^- l^+ \tilde e_R^- \,.$$

- 3-body decay VS 2-body decay $\tilde\tau_1^- \to \tau^- + \tilde G$
- There is a lower bound on the gravitino mass such that the 3-body decay dominate!

$$1 \text{ eV} < m_{\tilde G} < 10 \text{ eV}$$



$4l + 2\tau +$ MET final state from slepton pair-production!



Are there strongest bounds on $m_{\tilde{\tau}_1}$ from $4l$ + MET searches?

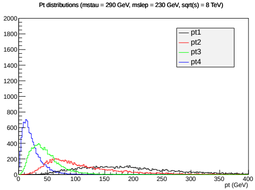
An *inefficient* example: The CMS Leptonic-RPV search

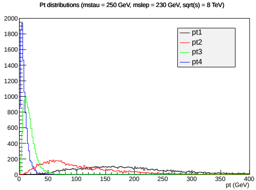
CUTS: $p_T > 20$ GeV 1st l $p_T > 10$ GeV other l.

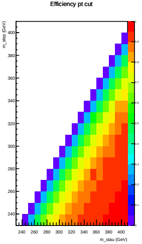
Z-veto to get rid of ZZ backgrounds.

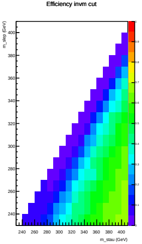
5 steps process:

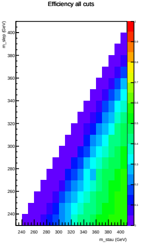
1. Characterizing of the final state
2. Looking for experimental searches with $4l$ + MET:
   - Leptonic RPV searches (ATLAS+CMS)
   - CMS inclusive search with 4 leptons
3. Reproducing the experimental analysis (kinematical cuts + isolation)
4. Computing the cut efficiencies
5. Reinterpret the search in our scenario

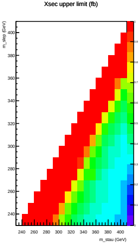












Concluding

Higgs at 125 GeV + Run I of LHC VS GGM+MSSM

- Colored states are strongly constrained
- We can relax some of the previous assumptions:
  - extensions of GGM+ MSSM
  - GGM+ extensions of the MSSM
  - hadronic RPV, compressed-spectra *(a lot of work to do!)*
- If we are lazy (i.e. *simple*)
  $\Rightarrow$ GGM realizations of Split-Susy spectra with (only) light EW states
- GGM as collider signature generator for EW states

A case of study: Selectron/Smuon co-NLSP

- Selectron/Smuon co-NLSP as the simplest scenario with $4l +$ MET final state
- This spectrum can be realized in weakly coupled model of GGM+Hidden-Higgs sector interactions *in progress...*
- Cornering the stau mass with $4l +$ MET searches. *stay tuned!*