Phenomenology of Gauge Mediation models at the LHC and future colliders

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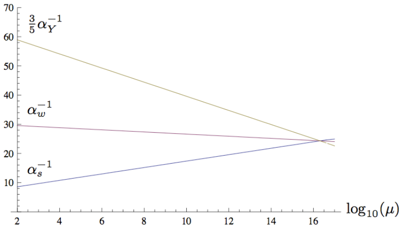
1. BSM → SUSY

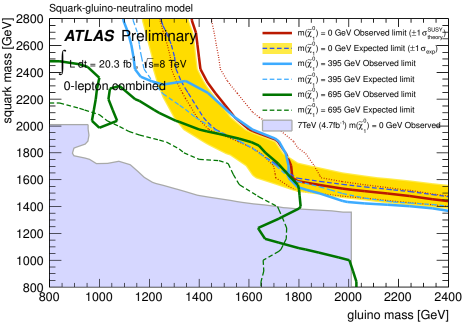
Still the best candidate for BSM is softly broken MSSM:

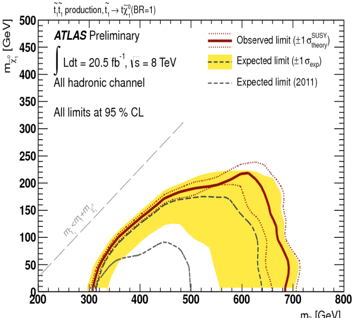
- solves problem of quadratic corrections to m_{h^0}
- dark matter candidate → LSP
- better unification of gauge couplings at 10^{16} GeV→ hint for GUT model



2. LHC searches for SUSY

- no SUSY signal so far
- relevant exclusions only for 1st and 2nd family
- still $\tilde{t}, \ldots$ can be as light as 500 GeV





ATLAS-CONF-2013-024

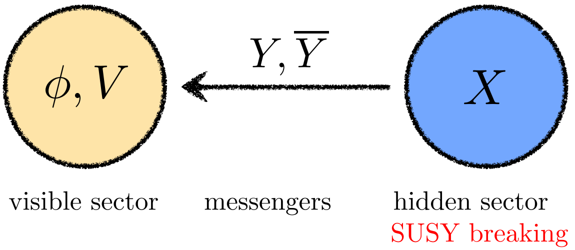
ATLAS-CONF-2013-047

3. SUSY challenges

Challenges:

- one needs additional sectors: SUSY breaking and mediation
- fine-tuning
- hard to explain the 750 GeV diphoton excess in the 13 TeV LHC data [Djouadi et al., arXiv:1605.01040]
- a lot of parameters (soft terms) $\rightarrow$ explain them using RGE and some simple set of initial conditions at high scale $\rightarrow$ GUT model

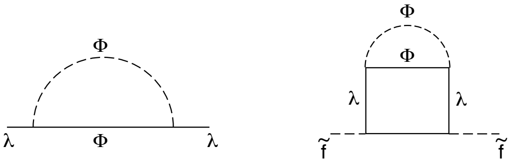
4. Gauge Mediated Supersymmetry Breaking



- perturbative coupling to spurion(s) $XY\overline{Y}$
- singlet $\langle X \rangle = M + \theta^2 F \to$ spontaneous SUSY breaking, $F/M \sim 10^5$ GeV
- messengers have large masses e.g. $M \sim 10^8 - 10^{14}$ GeV

5. Gauge Mediated Supersymmetry Breaking

[Giudice&Rattazzi, arXiv: 9801271]



- for $F/M^2 \ll 1$

$$M_r = N_Y \frac{g_r^2}{(4\pi)^2} \frac{F}{M}, \quad m_{\tilde{f}}^2 = 2 N_Y \sum_{r=1}^{3} c_2(f;r) \frac{g_r^4}{(4\pi)^4} \left(\frac{F}{M}\right)^2,$$

- soft terms are flavour universal
- spectrum depends on the details of the hidden and messenger sector
- bino or stau NLSP
- predictive but quite rigid scenario → more general approach?

6. Idea of General Gauge Mediation

[Meade et al., arXiv: 0801.3278]

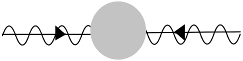
$$D^2\mathcal{J} = \overline{D}^2\mathcal{J} = 0 \;\longrightarrow\; \mathcal{J} = J + i\theta j - i\overline{\theta}\overline{j} - \theta\sigma^\mu\overline{\theta}j_\mu + \frac{1}{2}\theta^2\overline{\theta}\overline{\sigma}^\mu\partial_\mu j - \frac{1}{2}\overline{\theta}^2\theta\sigma^\mu\partial_\mu\overline{j} - \frac{1}{4}\theta^2\overline{\theta}^2\Box J$$

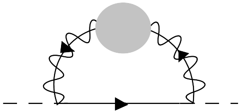
$$\langle j_\alpha(p) j_\beta(-p)\rangle = \epsilon_{\alpha\beta} M \widetilde{B}_{1/2}(p^2/M^2)$$

$$\langle j_\mu(p) j_\nu(-p)\rangle = -(p^2\eta_{\mu\nu} - p_\mu p_\nu)\widetilde{C}_1(p^2/M^2; M/\Lambda)$$

$$\vdots$$

$$K \supset g\int d^4\theta \mathcal{J} V$$





7. Parametrization of soft terms in GGM

- no need to specify hidden/messenger sector

$$M_r = g_r^2 M \widetilde{B}_{1/2}^{(r)}(0), \quad m_{\tilde{f}}^2 = \sum_{r=1}^{3} c_2(f;r) g_r^4 A_r M^2,$$

$$A_r = -\frac{1}{16\pi^2} \int dy \left(3\widetilde{C}_1^{(r)}(y) - 4\widetilde{C}_{1/2}^{(r)}(y) + \widetilde{C}_0^{(r)}(y) \right)$$

- 7 independent mass scales: $(\Lambda_{G_r}, \Lambda_{S_r}, M)$

$$M_r = \frac{g_r^2}{(4\pi)^2} \Lambda_{G_r}, \qquad m_{\tilde{f}}^2 = 2 \sum_{r=1}^{3} c_2(f;r) \frac{g_r^4}{(4\pi)^4} \Lambda_{S_r}^2$$

- standard GMSB

$$2\widetilde{B}_{1/2}^{(r)}(0)^2 = N_Y A_r$$

8. Universal features of GGM phenomenology

Assuming R-parity:

- all events contain high p_T objects +MET
- $\widetilde{G}$ is always LSP, $m_{\widetilde{G}} = F/\sqrt{3}M_P$
- NLSP $\widetilde{x}$ has a universal decay to SM partner x + gravitino $\widetilde{G}$

$$\Gamma(\widetilde{x} \to x\widetilde{G}) = \frac{m_x^5}{16\pi(\sqrt{3}M_P m_{\widetilde{G}})^2} \quad \text{(prompt or delayed)}$$

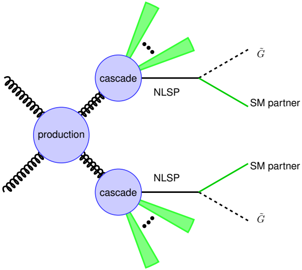
- mass sum rules: $\mathrm{Tr}(Ym^2) = \mathrm{Tr}[(B-L)m^2] = 0$

$$\begin{aligned} m_{H_u}^2 &= m_{H_d}^2 = m_L^2 \\ m_Q^2 - 2m_U^2 + m_D^2 - m_L^2 + m_E^2 &= 0 \\ 2m_Q^2 - m_U^2 - m_D^2 - 2m_L^2 + m_E^2 &= 0 \end{aligned}$$

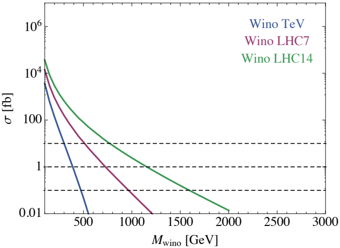
Phenomenology:

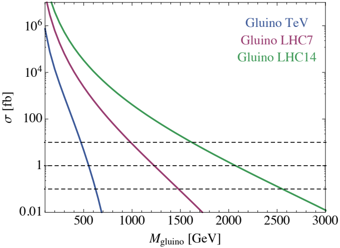
- does not depend on the details of the messenger/hidden sector
- mostly determined by the nature of the NLSP and the production mechanism

[Kats et al., arXiv:1110.6444]

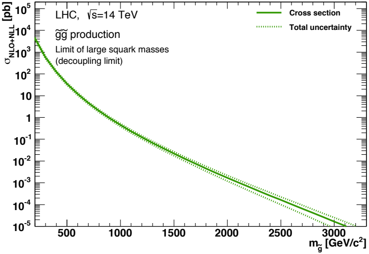


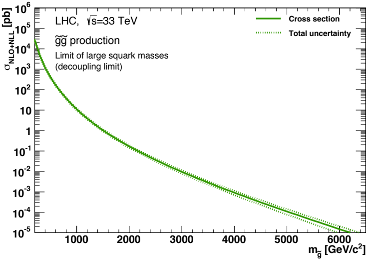
NLSP type	Relevant final states (+MET)
bino	$\gamma\gamma$, γ+jets
wino	$\gamma\ell$, $\gamma\gamma$, γ+jets, ℓ+jets, jets
Z-rich higgsino	$Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell'^+\ell'^-)$, SS dileptons, jets
h-rich higgsino	b-jets, SS dileptons, jets
chargino	SS dileptons, OS dileptons, ℓ+jets, jets
slepton	multileptons, SS dileptons, OS dileptons, ℓ+jets, jets
squark/gluino	jets
stop	SS dileptons, OS dileptons, b-jets, ℓ+jets, $\ell + b$-jets, $t\bar{t}$, jets
sbottom	b-jets, jets

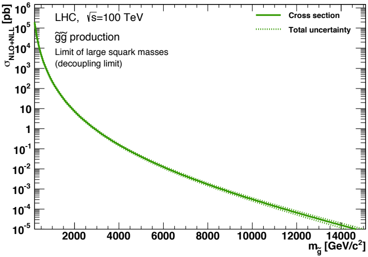




10. Collider signals

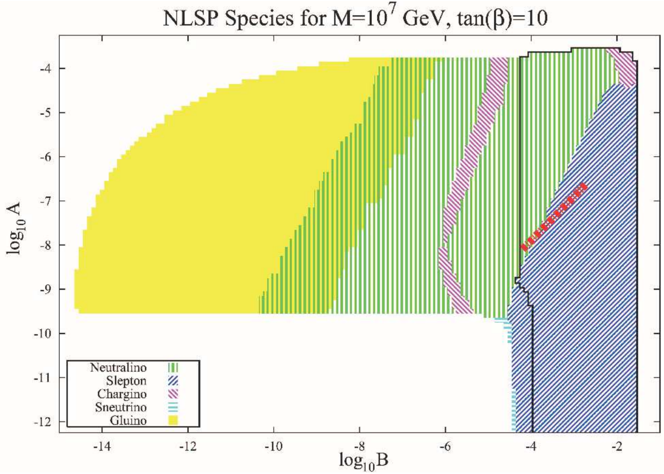






[Borschensky et al., arXiv:1407.5066]

11. NLSP vs. parameter space of GGM

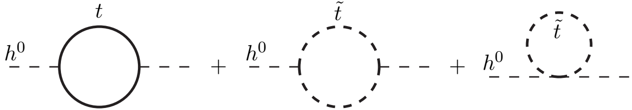


[Rajaraman et al., arXiv:0903.0668]

12. 1-loop corrections to m_{h^0}

- dominant contribution from top quarks and stops (due to $y_t \sim 1$):

$\Delta(m^2_{h^0}) =$



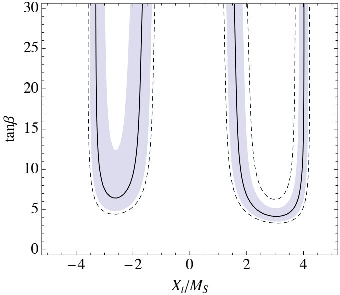
$$m^2_{h^0} = m_Z^2 \cos^2 2\beta + \frac{3 m_t^4}{4\pi^2 v^2}\left[\ln\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12 M_S^2}\right)\right] \approx (125\,\mathrm{GeV})^2,$$

$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$
$$X_t = A_t - \mu\cot\beta$$

Large A-terms or heavy stops!

A-terms:

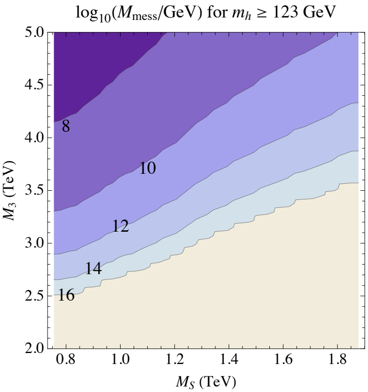
$$V_{\text{soft}} \supset y_t A_t H_u \widetilde{Q}_3 \widetilde{\overline{U}}_3 \longrightarrow y_t A_t h_0 \tilde{t}_1 \tilde{t}_2$$



Draper et al. 1112.3068

13. A-terms in GGM

- in GGM A-terms $= 0$ at messenger scale



[Draper et al., arXiv:1112.3068]

$$\mu \frac{dA_t}{d\mu} \sim y_t^2 A_t + g_3^2 M_3$$

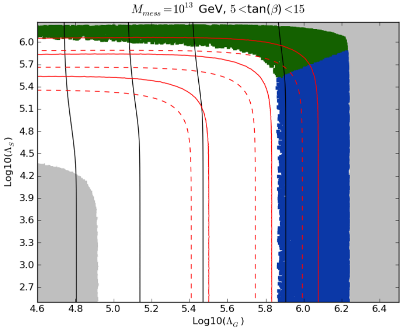
- hard to reconcile in GMSB
  - $m_{h^0} \gtrsim 123\,\mathrm{GeV}$
  - light stops
  - $M_{\tilde{g}} \lesssim 2.5\,\mathrm{GeV}$

14. GGM vs. Higgs mass

[Grajek et al., arXiv: 1303.0870]

Ensure $m_h \sim 125$ GeV through large $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$:

- large Λ_{G_3}
  - large $m_{\tilde{g}}$ and $m_{\tilde{q}}$ $\rightarrow$ colored sector typically beyond the reach of the LHC
  - pure EW production of sparticles, low cross-sections
- large Λ_{S_3}
  - large $m_{\tilde{q}}$
  - gluino can be light (even NLSP)
  - $4j + X +$ MET signal



- if $B_\mu = A_t = 0$ at messenger scale $\rightarrow$ always $m_{U_3} \gtrsim 1.5$ TeV [Knapen et al., arXiv: 1507.04364]

15. μ/B_μ problem in GGM

Problems:

- $A(M) = 0$, $B_\mu = 0$
- extra mechanism fo generation of μ/B_μ needed

Departing from GGM $\rightarrow$ Yukawa interactions between hidden and Higgs sector

$$W = \lambda_u H_u O_u + \lambda_d H_d O_d$$

Consequences:

- $m^2_{H_{u,d}} = m^2_{E_L} \pm \Delta^2_{u,d}$
- Any uncolored sparticle can be the NLSP in some region of the GGM parameter space
- selectron/smuon co-NLSP $\rightarrow$ $4l$+MET signal

16. Conclusions

Attractive features of General Gauge Meditation scenario:

- flavour universal soft terms
- relatively small number of parameters
- nicely fits in GUT scheme
- provides consistent benchmarks for many channels analyzed by the ATLAS and CMS