Phenomenology of GMSB-type unification models

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TJ & J. Pawełczyk, work in progress

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1. Outline

- $N = 1$ SUSY + $SU(5)$ + GMSB + additional couplings of messengers

  $\rightarrow$ specific pattern of soft terms

- confront it with ATLAS and CMS data

$$m_{h^0},\ \text{bounds on}\ m_{\tilde{g},\tilde{q}_{1,2}}$$

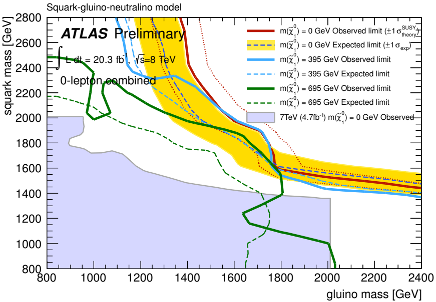
- and with flavour physics

$$\overline{K}^0 - K^0, \ldots \text{mixing}, \quad b \rightarrow s + \gamma, \quad l_i \rightarrow l_j + \gamma, \quad \ldots$$

1. LHC vs. MSSM

What do the LHC searches tell us about MSSM?

- no SUSY signal so far
- relevant exclusions only for 1st and 2nd family
- still $\widetilde{Q}_3, \ldots$ can be as light as 500 GeV



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BUT important information comes from Higgs mass measurement:

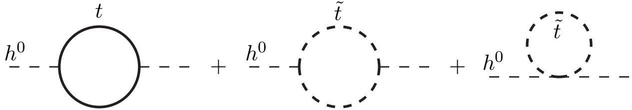
- $m \sim 125$ GeV $\rightarrow$ need for large loop corrections

ASSUME other MSSM Higgses are much heavier and masses of $\widetilde{Q}_{1,2}$ and $\widetilde{g}$ are bigger than 1.8 TeV.

2. 1-loop corrections to m_{h^0}

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

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



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

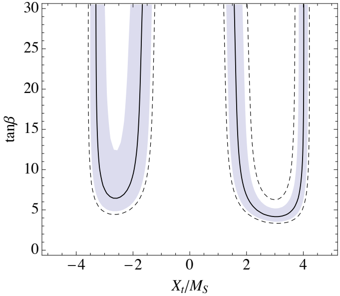
$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

$$X_t = A_t - \mu \cot\beta$$

Large A-terms or heavy stops!

A-terms:

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



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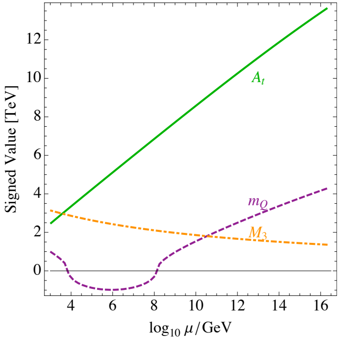
3. How to generate large A-terms?

- value of A-term gives initial condition for RGE evolution



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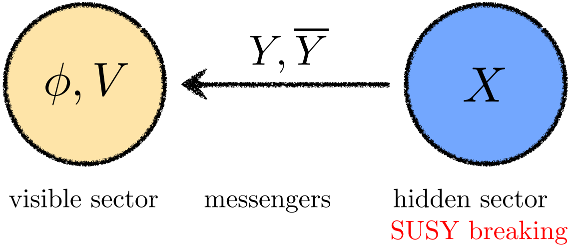
$$\mu \frac{dA_t}{d\mu} \sim y_t^2 A_t + g_3^2 M_3$$

- heavy $\widetilde{g}$ and RGE evolution from $M \gtrsim 10^{14}$ GeV
- or large A-terms at M

- how to get A-terms in GUT model?

Extended GMSB models (EGMSB)

5. SUSY breaking mediation



- singlet $\langle X \rangle = M + \theta^2 F \rightarrow$ spontaneous SUSY breaking

$$\xi = \frac{F}{M} \sim 10^5 \,\text{GeV}$$

- messengers have large masses e.g. $M \sim 10^{14}$ GeV
- mediation = interactions between $Y, \overline{Y}$ and other fields

6. Messenger couplings in EGMSB models

Focus on: $SU(5)$ unification model with

- matter Φ in $5, \overline{5}$ or 10
- pair of messengers: $\mathsf{Y} = (Y_5, Y_{\overline{5}})$
- allowed superpotential couplings $\Phi\mathsf{YY} + \Phi\Phi\mathsf{Y}$: $5\,10\,10, \quad \overline{5}\,\overline{5}\,10$

$$W_Y = hH_{\overline{5}}\phi_{10}Y_{\overline{5}} + \frac{1}{2}\lambda^{(1)}\phi_{10}\phi_{10}Y_5 + \lambda^{(2)}\phi_{\overline{5}}\phi_{10}Y_{\overline{5}} + \frac{1}{2}\lambda^{(3)}\phi_{10}Y_{\overline{5}}Y_{\overline{5}}$$

Flavour structure of couplings e.g.

$$h_i H_{\overline{5}}\phi_{10\,i}Y_{\overline{5}}, \qquad h = (h_1, h_2, h_3)$$

What are the soft terms?

7. Trilinear terms in EGMSB models

$$V \supset H_u Q_i (T_u)_{ij} \overline{U}_j + H_d Q_i (T_d)_{ij} \overline{D}_j + H_d L_i (T_e)_{ij} \overline{E}_j$$

- $T_{u,d,e}$ are 'partially aligned' to MSSM Yukawa matrices $y_{u,d,e}$
- e.g. if $W_Y = h_i H_{\overline{5}} \phi_{10_i} Y_{\overline{5}}$ then

$$\begin{aligned}
(T_u)_{ij} &= -\frac{\xi}{16\pi^2} h_i h_k^* (y_u)_{kj} \\
(T_d)_{ij} &= -\frac{\xi}{16\pi^2} \left[4 h_k h_k^* (y_d)_{ij} + h_i h_k^* (y_d)_{kj}\right] \\
(T_e)_{ij} &= -\frac{\xi}{16\pi^2} \left[4 (y_e)_{ij} h_k^* h_k + 2 (y_e)_{ik} h_k^* h_j\right]
\end{aligned}$$

8. A-terms in EGMSB models

$$V \supset H_u \widetilde{Q}_i (T_u)_{ij} \widetilde{\overline{U}}_j + H_d \widetilde{Q}_i (T_d)_{ij} \widetilde{\overline{D}}_j + H_d \widetilde{L}_i (T_e)_{ij} \widetilde{\overline{E}}_j$$

- $(T_{u,d,e})_{33} =: y_{t,b,\tau} A_{t,b,\tau}$

$$A_{t,b,\tau} \approx -\frac{\xi}{16\pi^2} C^{(t,b,\tau)} |h_3|^2$$

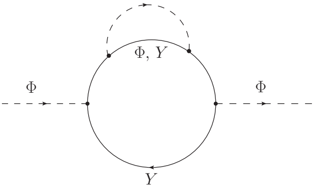
	$\lambda_{33}^{(1)}$	h_3	$\lambda_{33}^{(2)}$	$\lambda_3^{(3)}$
$C^{(t)}$	6	1	4	1
$C^{(b)}$	3	5	6	1
$C^{(\tau)}$	3	6	6	0

- A-terms
  - relevant to the m_{h^0}
  - may also lead to CCB
  - increase splitting of sfermion masses $m_{\widetilde{f}_{1,2}}$ without changing their average mass $\rightarrow \widetilde{f}_1$ may be tachyonic

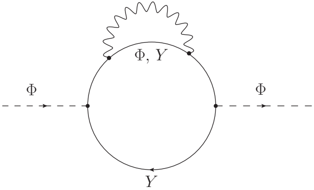
9. Soft masses in EGMSB models

- 2-loop contributions to soft masses

$$W_Y = h^{(I)}\Phi\mathsf{YY} + h^{(II)}\Phi\Phi\mathsf{Y}$$



$\sim h^4, h^3y, h^2y^2$



$\sim h^2g^2$

$$m^2_{\widetilde{\Phi},h} \sim \frac{\xi^2}{(4\pi)^4}(h^4 + h^3y - h^2y^2 - h^2g^2)$$

10. Soft masses when only $h \neq 0$

- squarks

$$(m^2_{\widetilde{Q}})_{ij} = \frac{\xi^2}{3840\pi^4}\Big[\delta_{ij}8\pi^2\left(\alpha_1^2+45\alpha_2^2+80\alpha_3^2\right) + h_i^* h_j\left(105|h_3|^2-4\pi(7\alpha_1+45\alpha_2+80\alpha_3)\right)\Big]$$

$$(m^2_{\widetilde{u}})_{ij} = \frac{\xi^2}{30\pi^4}\left[\delta_{ij}\pi^2\left(\alpha_1^2+5\alpha_3^2\right)-\delta_{i3}\delta_{j3}\frac{15}{64}|y_t|^2|h_3|^2\right]$$

$$(m^2_{\widetilde{d}})_{ij} = \frac{\xi^2}{120\pi^4}\left[\delta_{ij}\pi^2\left(\alpha_1^2+20\alpha_3^2\right)-\delta_{i3}\delta_{j3}\frac{75}{16}|y_b|^2|h_3|^2\right]$$

- sleptons

$$(m^2_{\widetilde{L}})_{ij} = \frac{3\xi^2}{160\pi^4}\left[\delta_{ij}\pi^2\left(\alpha_1^2+5\alpha_2^2\right)-\delta_{i3}\delta_{j3}\frac{5}{4}|y_\tau|^2|h_3|^2\right]$$

$$(m^2_{\widetilde{e}})_{ij} = \frac{\xi^2}{640\pi^4}\left[\delta_{ij}48\pi^2\alpha_1^2+h_i^* h_j(35\,|h_3|^2-12\pi\,(3\alpha_1+5\alpha_2))\right]$$

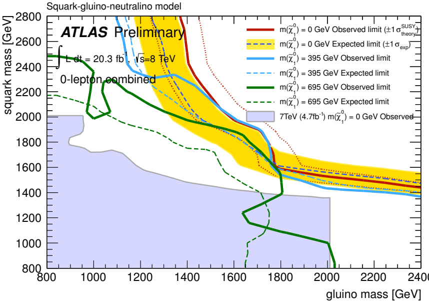
11. Scales of sparticles masses

- gluino mass M_3

$$M_3 = \frac{\alpha_3}{4\pi}\xi \gtrsim 1.8\,\text{TeV}$$

$$\downarrow$$

$$\boxed{\xi \gtrsim 2.3\cdot 10^5\,\text{GeV}}$$



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- squarks and sleptons average $(\text{mass})^2$

$$\overline{M}_{\tilde{q}} = \left(\frac{1}{6}\text{Tr}\, M^2_{\tilde{u}}\right)^{\frac{1}{2}} \approx \frac{\alpha_3}{\sqrt{6}\pi}\xi \gtrsim 3\,\text{TeV}, \quad \overline{M}_{\tilde{l}} \approx \frac{\sqrt{15}\alpha_2}{16\pi}\xi \gtrsim 0.6\,\text{TeV}$$

- lightest neutralino $\tilde{\chi}^0_1$ mass

$$m_{\tilde{\chi}^0_1} \sim \frac{\alpha_1}{4\pi}\xi \gtrsim 0.3\,\text{TeV}$$

12. FCNC effects

- Convenient parametrization of sfermion $(\text{mass})^2$ matrices

$$(M_u^2)_{ij} = \overline{M}_{\tilde{q}}^2 \begin{pmatrix} (\delta^u_{LL})_{ij} & (\delta^u_{LR})_{ij} \\ (\delta^u_{RL})_{ij} & (\delta^u_{RR})_{ij} \end{pmatrix}, \qquad (M_d^2)_{ij} = \ldots, \qquad (M_e^2)_{ij} = \ldots$$

- treat non-diagonal masses as additional interactions

- Left-Right sector

$$\delta^u_{LR} = \frac{1}{\overline{M}_{\tilde{q}}^2}(\frac{v_u}{\sqrt{2}}T_u^* - \mu m_u^\dagger \cot\beta), \quad |\delta^u_{LR}|_{i\neq j} \lesssim h^2 \frac{m_t}{\xi}\frac{1}{\alpha_3^2} \sim 0.1$$

$$\delta^d_{LR} = \frac{1}{\overline{M}_{\tilde{q}}^2}(\frac{v_d}{\sqrt{2}}T_d^* - \mu m_d^\dagger \tan\beta), \quad |\delta^d_{LR}|_{i\neq j} \lesssim h^2 \frac{m_b}{\xi}\frac{1}{\alpha_3^2} \sim 0.001$$

$$\delta^e_{LR} = \frac{1}{\overline{M}_{\tilde{l}}^2}(\frac{v_d}{\sqrt{2}}T_e^* - \mu m_e^\dagger \tan\beta), \quad |\delta^e_{LR}|_{i\neq j} \lesssim h^2 \frac{m_\tau}{\xi}\frac{10}{\alpha_3^2} \sim 0.01$$

Suppressed by $\frac{m}{\xi}$ $\rightarrow$ enough to satisfy experimental bounds on δ_{LR}

13. Bounds from meson mixing

On the other hand, Left-Left sector is constrained by meson mixing

$$\delta_{LL}^{u,d} \approx \frac{1}{\overline{M}_{\tilde{q}}^{2}} m_{\tilde{Q}}^{2},$$

- $\overline{D}^0 - D^0$ mixing:

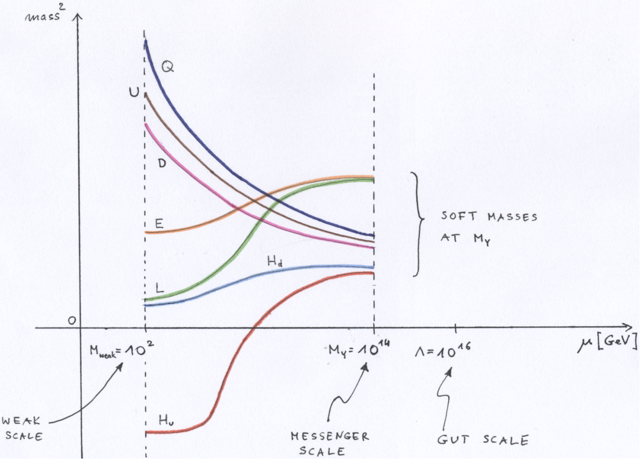
$$\begin{aligned}(\delta_{LL}^{u})_{12} &\approx \frac{h_1 h_2}{640\pi^2\alpha_3^2}(105|h_3|^2 - 96\cdot 4\pi\alpha_3)\\ &\approx 0.3 h_1 h_2 \lesssim 0.1 \longrightarrow \boxed{h_1 h_2 \lesssim 0.3}\end{aligned}$$

- $\overline{B}_{d,s}^0 - B_{d,s}^0$ mixing

$$\begin{aligned}(\delta_{LL}^{d})_{1j} &\approx \frac{h_1 h_j}{640\pi^2\alpha_3^2}(105|h_3|^2 - 96\cdot 4\pi\alpha_3)\\ &\approx 0.3 h_1 h_j \lesssim \begin{cases} 0.04 & j=2 \\ 0.1 & j=3 \end{cases} \longrightarrow \boxed{\begin{array}{l} h_1 h_2 \lesssim 0.1 \\ h_1 h_3 \lesssim 0.3 \rightarrow h_1 \lesssim 0.3 \end{array}}\end{aligned}$$

14. Top-down analysis

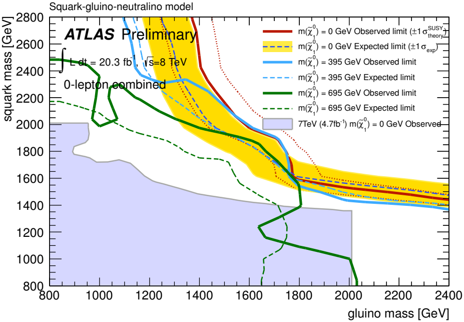
Reverse the initial problem and evolve parameters from M to EWSB scale:



15. Phenomenology

Find spectrum and check if phenomenology is correct i.e.

- $m_{h^0} \approx 125\,\mathrm{GeV}$
- no tachyons
- scalar potential bounded from below, no CCB
- a_μ, $b \to s\gamma$
- ATLAS bounds on gluino and squarks of 1. and 2. generation



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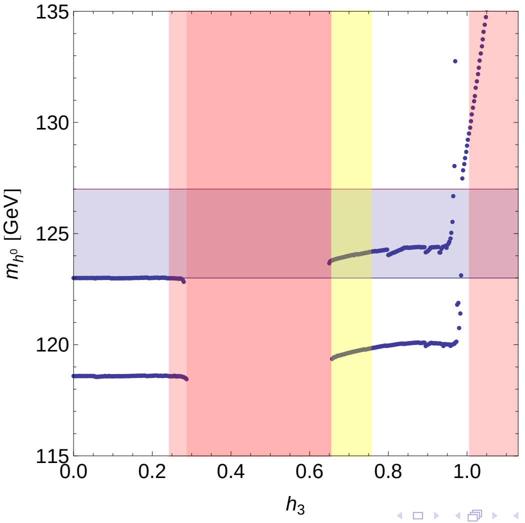
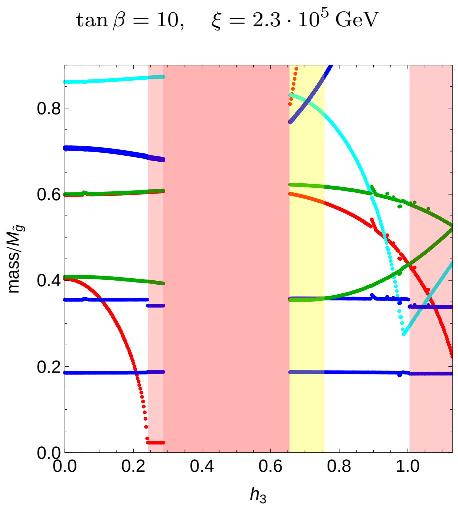
16. Higgs mass

$$\tan\beta = 10, \quad \xi = \begin{cases} 5.0 \\ 2.3 \end{cases} \times 10^5\ \text{GeV}$$



17. The lightest sparticles



- particles

$$\begin{array}{lcl} \widetilde{\chi}^0_{1,2,3,4},\ \widetilde{\chi}^{\pm}_{1,2} & - & \text{dark blue} \\ \widetilde{t}_{1,2} & - & \text{light blue} \\ \widetilde{\tau}_1, \widetilde{\tau}_2/\widetilde{\nu}_\tau & - & \text{red} \\ \widetilde{e}_1, \widetilde{e}_2/\widetilde{\nu}_e & - & \text{green} \end{array}$$

- $M_{\widetilde{g}} = 1.8$ TeV
- soft masses

$$\begin{array}{lcl} m^2_{\widetilde{u}} & \sim & -y_t^2 h_3^2 \\ m^2_{\widetilde{L}} & \sim & -y_\tau^2 h_3^2 \\ m^2_{\widetilde{e}} & \sim & h_3^2(35h_3^2 - 15 \cdot 4\pi\alpha_2) \end{array}$$

18. Conclusions

- Extended GMSB models naturally accommodate LR stops mixing
- trilinear terms generated by messenger couplings are 'partially aligned' to MSSM Yukawa matrices
- only mild hierarchy in messengers-matter couplings is necessary to satisfy FCNC constraints (meson mixing)
- EGMSB - large class of models with rich and interesting phenomenology, not fully explored yet