Natural SUSY and maximal stop mixing

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based on: M. Badziak, E. Dudas, M.O. and S. Pokorski, arXiv:1205.1675

Motivations for Split Sfermion Masses

- In SUSY models FCNC and CP violation problems may be substantially eased when the first two generation sfermions are heavy
- The LHC SUSY searches pushed up the masses of the 1st generation squarks above 1 TeV

- Naturalness arguments suggest that the third generation sfermions should be light
- Stops and sbottoms are quite weakly constrained by LHC

$\Rightarrow$ The tension between FCNC constraints and naturalness may be relaxed in Inverted Hierarchy (IH) scenarios, with the first two generations of squarks and sleptons much heavier than the third one

e.g. talk by Sabine Kraml at WG2 session

Inverted hierarchy of sfermion masses appears in some string models

e.g. Krippendorf et al. '12

and fermion mass models based on horizontal symmetries

Dudas et al. '95 '96, . . ., Craig et al. '12

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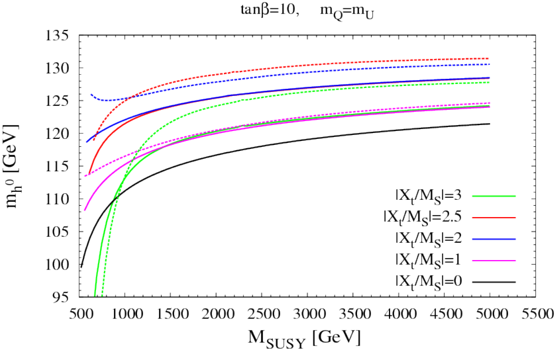
What are the predictions for the lightest Higgs boson mass in the MSSM with inverted hierarchy of sfermion masses?

Badziak, Dudas, M.O., Pokorski '12

Baer, Barger, Huang, Tata '12

The Higgs boson mass in the weak scale MSSM

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{\rm SUSY}^2}\right)\right]$$



$M_{\rm SUSY} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$

$X_t \equiv A_t - \mu/\tan\beta$

$X_t < 0$ solid lines

$X_t > 0$ dashed lines

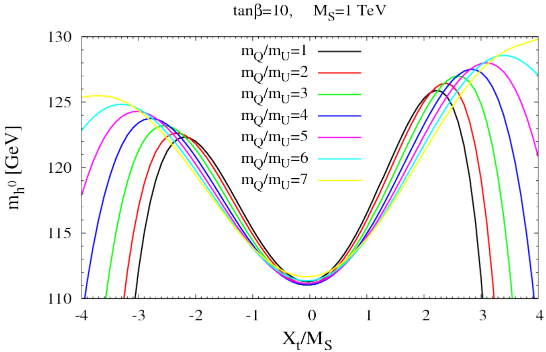
The Higgs mass of ~ 125 GeV requires:

- $M_{\rm SUSY} \gtrsim 1$ TeV and large stop-mixing $|X_t|/M_{\rm SUSY} \sim \mathcal{O}(2-2.5)$
- or $M_{\rm SUSY} \gg 1$ TeV

The Higgs boson mass in the weak scale MSSM

Bigger Higgs boson mass may be obtained if

- m_Q is substantially bigger than m_U
- the stop mixing parameter X_t is bigger than $\sim 2.5\, M_{\rm SUSY}$



Maximal Higgs boson mass increases by:

- 2 GeV if $m_Q/m_U \approx 5$ and $|X_t|/M_{\rm SUSY} \approx 3$
- 4 GeV if $m_Q/m_U \approx 7$ and $|X_t|/M_{\rm SUSY} \approx 4$

Large stop mixing and RGEs

From one-loop RGEs:

$$m_Q^2 \approx 3.1M_{1/2}^2 + 0.1A_0M_{1/2} - 0.04A_0^2 + 0.65m_0^2(3)$$
$$m_U^2 \approx 2.3M_{1/2}^2 + 0.2A_0M_{1/2} - 0.07A_0^2 + 0.35m_0^2(3)$$
$$A_t \approx -1.6M_{1/2} + 0.35A_0$$

How to get $A_t^2 \approx 6\, m_Q\, m_U$?

- Large (dominating) $M_{1/2}$ gives $A_t^2 \approx 0.9\, m_Q\, m_U$
- $m_0^2(3)$ contributions even worsen the situation
  ($m_0^2(3)$ is big e.g. in "focus point" scenarios)
- Only large initial value of $|A_0|$ may give $A_t^2/M_{\rm SUSY}^2 \sim 6$

Optimal stop-mixing requires very large $|A_0|$

e.g. for $M_{1/2} \approx m_0(3)$: $A_0 \approx -4M_{1/2}$ or $A_0 \approx 7.7M_{1/2}$

Large stop mixing and RGEs

1st/2nd generation sfermion masses enter the relevant RGEs at the two-loop level

$$m_Q^2 \approx 3.1M_{1/2}^2 + 0.1A_0M_{1/2} - 0.04A_0^2 + 0.65m_0^2(3) - 0.03m_0^2(1,2)$$
$$m_U^2 \approx 2.3M_{1/2}^2 + 0.2A_0M_{1/2} - 0.07A_0^2 + 0.35m_0^2(3) - 0.02m_0^2(1,2)$$
$$A_t \approx -1.6M_{1/2} + 0.35A_0$$

In the IH scenario, $m_0(1,2) \gg m_0(3)$, RG running of A_t can be disentangled from the running of stop masses.

- A_t can be enhanced by gluino contribution
- gluino contribution to the stop masses may be (partially) compensated by negative contributions from $m_0(1,2)$

No large initial A_0 required for optimal stop mixing

Large stop mixing and RGEs

Large stop mixing in IH scenario

Examples

- $M_{1/2} = m_0(3) \qquad m_0(1,2) = 10\, m_0(3) \qquad A_0 = -m_0(3)$

  $\Rightarrow |X_t| \approx 2.7\, M_{SUSY}$
- $M_{1/2} = m_0(3) \qquad m_0(1,2) = 10\, m_0(3) \qquad A_0 = 0$

  $\Rightarrow |X_t| \approx 1.9\, M_{SUSY}$
- $M_{1/2} = \frac{1}{2} m_0(3) \qquad m_0(1,2) = 5\, m_0(3) \qquad A_0 = 0$

  $\Rightarrow |X_t| \approx 2.2\, M_{SUSY}$

Stop mixing close to the optimal one is quite natural in IH scenario

even with vanishing initial A_0

Upper bounds on $m_0(1,2)$

Stop masses:

$$m_Q^2 \approx 3.1M_{1/2}^2 + 0.1A_0M_{1/2} - 0.04A_0^2 + 0.65m_0^2(3) - 0.03m_0^2(1,2)$$
$$m_U^2 \approx 2.3M_{1/2}^2 + 0.2A_0M_{1/2} - 0.07A_0^2 + 0.35m_0^2(3) - 0.02m_0^2(1,2)$$

Proper REWSB:

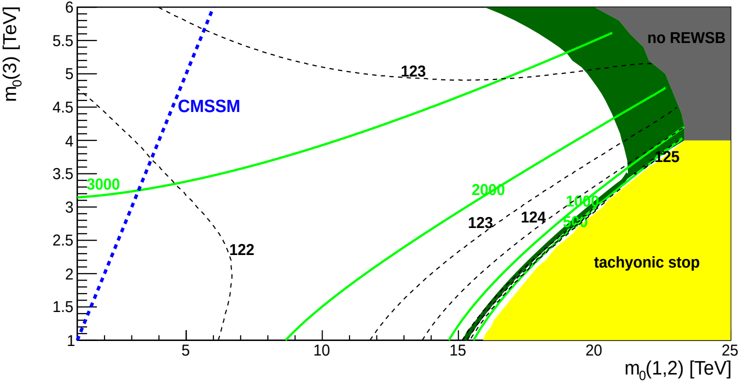
$$\mu^2 \approx 1.3M_{1/2}^2 + 0.1A_0^2 - 0.35M_{1/2}A_0 - 0.01m_0^2(3) - 0.006m_0^2(1,2)$$

For very large $m_0(1,2)$:

- stops are tachyonic
  maximal $m_0(1,2)/M_{1/2}$ increases with $m_0(3)/M_{1/2}$
- no correct REWSB is possible
  maximal $m_0(1,2)/M_{1/2}$ decreases with $m_0(3)/M_{1/2}$

Numerical results

$$M_{1/2} = 1.5 \text{ TeV}, \qquad A_0 = 0, \qquad \tan\beta = 10$$



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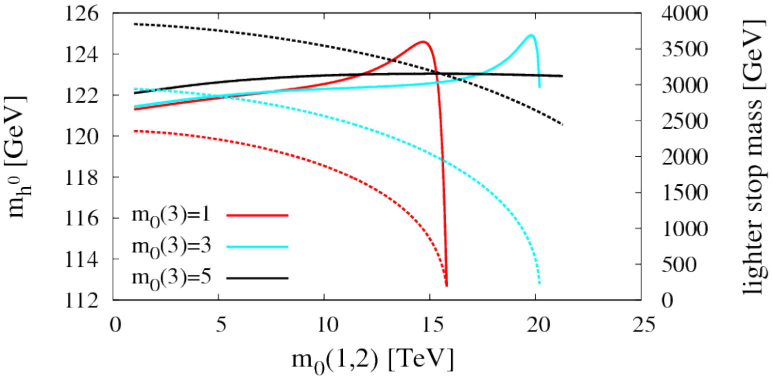
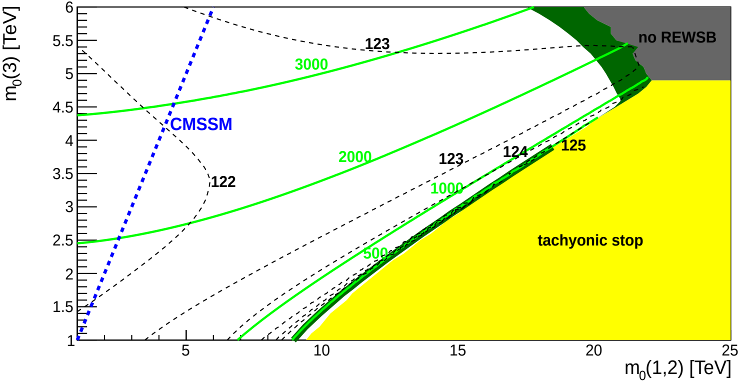


Numerical results

$$M_{1/2} = 1 \text{ TeV}, \qquad A_0 = -2 \text{ TeV}, \qquad \tan\beta = 10$$



Smaller $m_0(1,2)$, $M_{1/2}$ required to obtain a given Higgs mass if $A_0 < 0$

Numerical results

For heavy 1st/2nd generation sfermions
the lightest Higgs boson is generically relatively heavy

For instance, $m_0(1,2) > 15$ TeV implies $m_h \gtrsim 122$ GeV

The Higgs boson mass of 125 GeV may be obtained without very big fine tuning

- for $M_{1/2} \gtrsim 1.5$ TeV if $A_0 = 0$
- for $M_{1/2} \gtrsim 1$ TeV if $A_0 = -2$ TeV

m_h higher than 125 GeV may be obtained for bigger $M_{1/2}$ and/or $|A_0|$

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There are theoretical uncertainties in the calculation of Higgs boson mass

For example the leading 3-loop contribution is positive (at least in simple models) Kant et al. '10, Kant '11

Numerical results

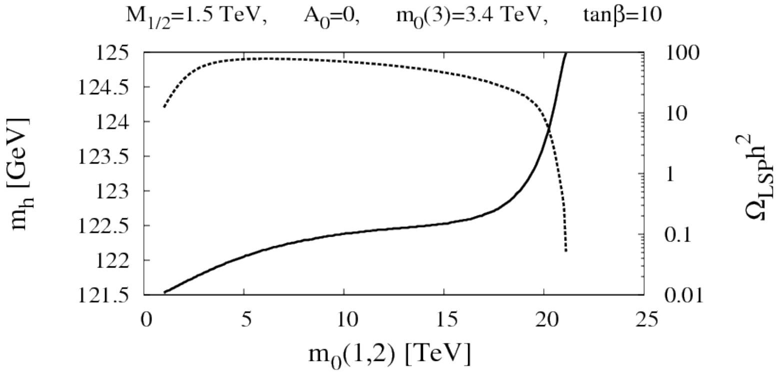
	Point A	Point B	Point C
$M_{1/2}$	1000	1500	1500
$m_0(3)$	3700	3400	3800
$m_0(1,2)$	17690	21070	22500
A_0	-2000	0	0
$\tan\beta$	10	10	10
μ	888	698	452
m_h	125	125	125.1
m_A	3541	3154	3477
$m_{\tilde{\chi}_1^0}$	444	647	448
$m_{\tilde{\chi}_1^\pm}$	812	700	455
$m_{\tilde{g}}$	2465	3530	3545
$m_{\tilde{t}_{1,2}}$	476, 1801	699, 1581	505, 1632
$m_{\tilde{b}_{1,2}}$	1784, 2926	1555, 2717	1610, 2933
$m_{\tilde{\tau}_1}$	3467	3108	3481
$\Omega_{DM}h^2$	0.111	0.118	0.021

Inverted Hierarchy and Dark Matter

In the IH scenario LSP can be a good dark matter candidate.

- Small $m_0(3)$: bino LSP, Stop-coannihilations may give correct $\Omega_{\rm LSP}$
- Intermediate $m_0(3)$: bino-higgsino LSP, $\Omega_{\rm LSP}$ may be correct
- Large $m_0(3)$: higgsino LSP, $\Omega_{\rm LSP}$ typically too small

Interesting correlation between $\Omega_{\rm LSP}$ and m_h



Conclusions

Properties of models with heavy sfermions of 1st/2nd generation

- SUSY FCNC and CP violation problems can be substantially eased
- Natural SUSY - fine tuning smaller than in CMSSM
- Large stop mixing is possible without large A_0
- Stop mixing close to the optimal one (giving maximal possible Higgs boson mass) emerges quite naturally from RGE running
- The lightest Higgs is generically heavy, in the vicinity of 125 GeV
- Lighter stop mass $\sim \mathcal{O}(0.5)$ TeV, gluino mass $\sim \mathcal{O}(2-3)$ TeV
- m_h may be bigger by a couple of GeV if m_Q is substantially bigger than m_U
- LSP can be a good dark matter candidate ($m_h - \Omega_{\rm LSP}$ correlation)