Fermi Scale & Light Higgsinos

Felix Brümmer, Wilfried Buchmüller

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Problem & Answer

- (theoretically) attractive extension of SM: SuSy

- no evidence for SuSy at LHC; gap between scale of electroweak symmetry breaking and SuSy threshold: at least factor 10

- fine tuning ?? look for convincing examples which explain `factor 10'!

- structure of MSSM: μ (preserves SuSy), gaugino and scalar mass terms (break SuSy)

- hypothesis: μ determines scale of electroweak symmetry breaking, scale of SuSy breaking happens to be higher (`factor 10'), without affecting electroweak symmetry breaking

- consequence: (only) light higgsinos in LHC range, rest heavy

Matching SM & MSSM

LHC: SM,

$$V = \; m^2 H^\dagger H + \frac{1}{2}\lambda \left(H^\dagger H\right)^2 \;\; ,$$

is correct up to maching scale (about 5 TeV), where (hopefully) matching to MSSM takes place:

$$V = \left(m_{H_u}^2 + |\mu|^2\right) H_u^\dagger H_u + \left(m_{H_d}^2 + |\mu|^2\right) H_d^\dagger H_d + B\mu \left(H_u^T i\sigma_2 H_d + \text{c.c.}\right)$$
$$+ \frac{1}{8}\left(g^2 + g'^2\right)\left(H_u^\dagger H_u - H_d^\dagger H_d\right)^2 + \frac{1}{2}\, g^2 \;\, H_u^\dagger H_d H_d^\dagger H_u$$

Rotate to light SM Higgs H and heavy 2nd doublet H':

$$H_u = \sin\beta \;\, H + \cos\beta \;\, i\sigma_2 H'^* \;\; , \quad H_d = \cos\beta i\sigma_2 H^* + \sin\beta H' \;\; ,$$

$$\tan 2\beta = \frac{2B\mu}{m_{H_u}^2 - m_{H_d}^2}$$

$$\lambda|_{M_S} = \; \frac{1}{4}\left(g^2 + g'^2\right)\cos^2 2\beta\big|_{M_S} \;\; , \quad m^2 = \ldots \;\; , \quad m'^2 = \ldots$$

Emergence of a little hierarchy

`Heavy' Higgs mass (126 GeV) suggests

$$|\cos 2\beta| \to 1 \ , \quad \tan\beta \gtrsim 10 \ ; \quad B\mu \ll m_{H_d}^2$$

matching relation

$$m^2 \simeq |\mu|^2 + m_{H_u}^2 + \frac{m_{H_u}^2 - m_{H_d}^2}{\tan^2\beta}$$

then requires (small scale of electroweak symmetry breaking):

$$\left|m_{H_u}^2\right| \ll m_{H_d}^2 \qquad \left(\to \tan\beta \simeq \frac{m_{H_d}^2}{B\mu}\right)$$

How is this possible (running down from GUT scale)?

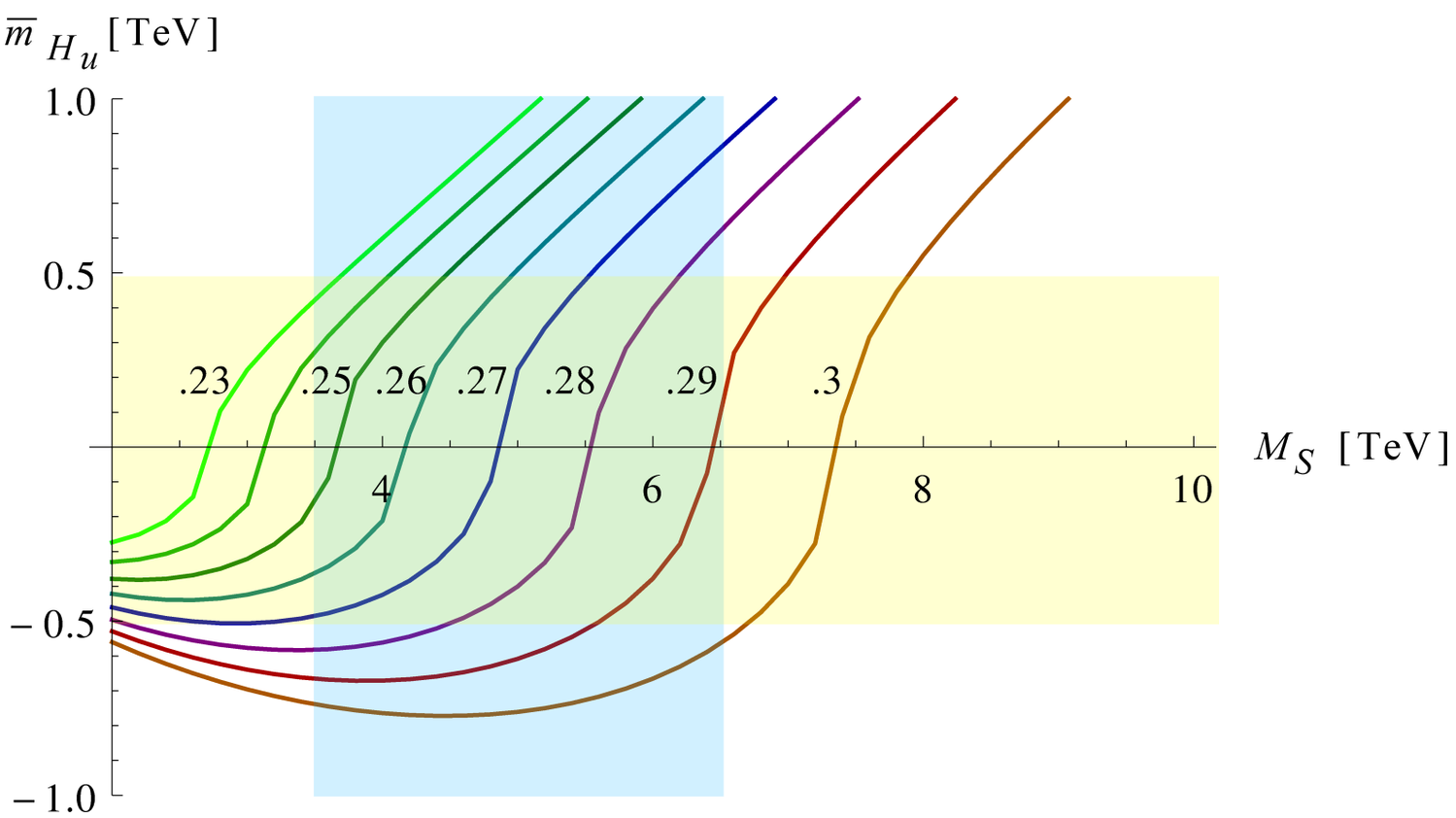
$$\begin{aligned} m_{H_u}^2\big|_{M_S} = &- 1.13\widehat{M}_3^2 - 0.11\widehat{M}_3\widehat{M}_2 + 0.22\widehat{M}_2^2 + 0.26\,\widehat{M}_3\widehat{A}_t + 0.07\,\widehat{M}_2\widehat{A}_t \\ &- 0.12\,\widehat{A}_t^2 + 0.67\widehat{m}_{H_u}^2 - 0.24\,\widehat{m}_{U_3}^2 - 0.33\widehat{m}_{Q_3}^2 \end{aligned}$$

Simplification (`universal' gaugino and scalar masses at GUT scale):

$$\bar{m}^2_{H_u}\big|_{M_S} = -1.08\, M^2_{1/2} + 0.33\, M_{1/2}\widehat{A}_t - 0.12\, \widehat{A}^2_t + 0.08\, m^2_0$$

Cancellation needed! Note different signs of gaugino and scalar mass terms (due to high matching scale!); cancellation can be achived for mass relation

$$M_{1/2} = \kappa\, m_0 \ , \qquad \frac{1}{5} \lesssim \kappa \lesssim \frac{1}{3}$$



Seesaw for the Fermi scale

Generation of μ (PQ breaking) and soft mass parameters (SuSy breaking):

$$M_{1/2} \sim m_0 \sim \frac{F_X}{M} \sim M_S \ , \quad \mu \sim \frac{Y^p}{M^{p-1}} \ ,$$

$$B\mu \sim \frac{Y^p}{M^p} F_X \sim \mu M_S \ , \quad |\mu|^2 \ll M_S^2 \ (\text{choice})$$

Resulting Higgs mass matrix ($\bar{m}_{H_u}^2 \simeq 0,\ m_{H_d} = \eta M_S,\ B\mu = \zeta |\mu| M_S,\ \zeta > \eta$):

$$m_H^2 = \begin{pmatrix} |\mu|^2 & \zeta |\mu| M_S \\ \zeta |\mu| M_S & \eta^2 M_S^2 \end{pmatrix}$$

Large and small eigenvalues:

$$m'^2 \simeq \eta^2 M_S^2$$

$$m^2 \simeq -\frac{(\zeta |\mu| M_S)^2}{\eta^2 M_S^2} = -\frac{\zeta^2}{\eta^2} |\mu|^2 < 0$$

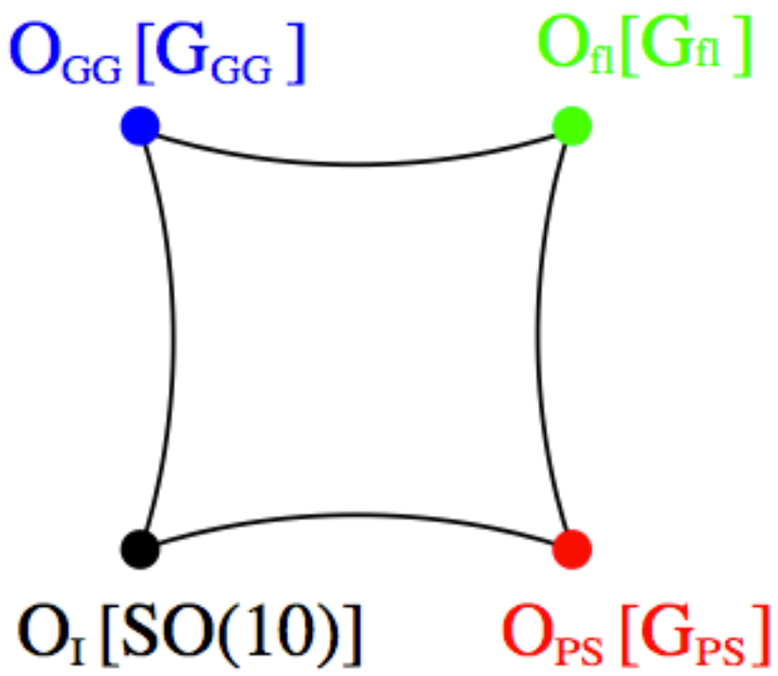
gives electroweak symmetry breaking

Gaugino mediation in 6 dimensions

bulk: 3rd generation and Higgs; branes: 1st & 2nd family and SuSy breaking on branes; SuSy mass spectrum determined by `naive dimensional analysis':

$$\kappa^2 = \frac{\ell_6}{\ell_4}\frac{1}{M_4 V_2^{1/2}} \simeq 0.06 \ , \quad M_{1/2} \sim \ 0.25\ m_0$$

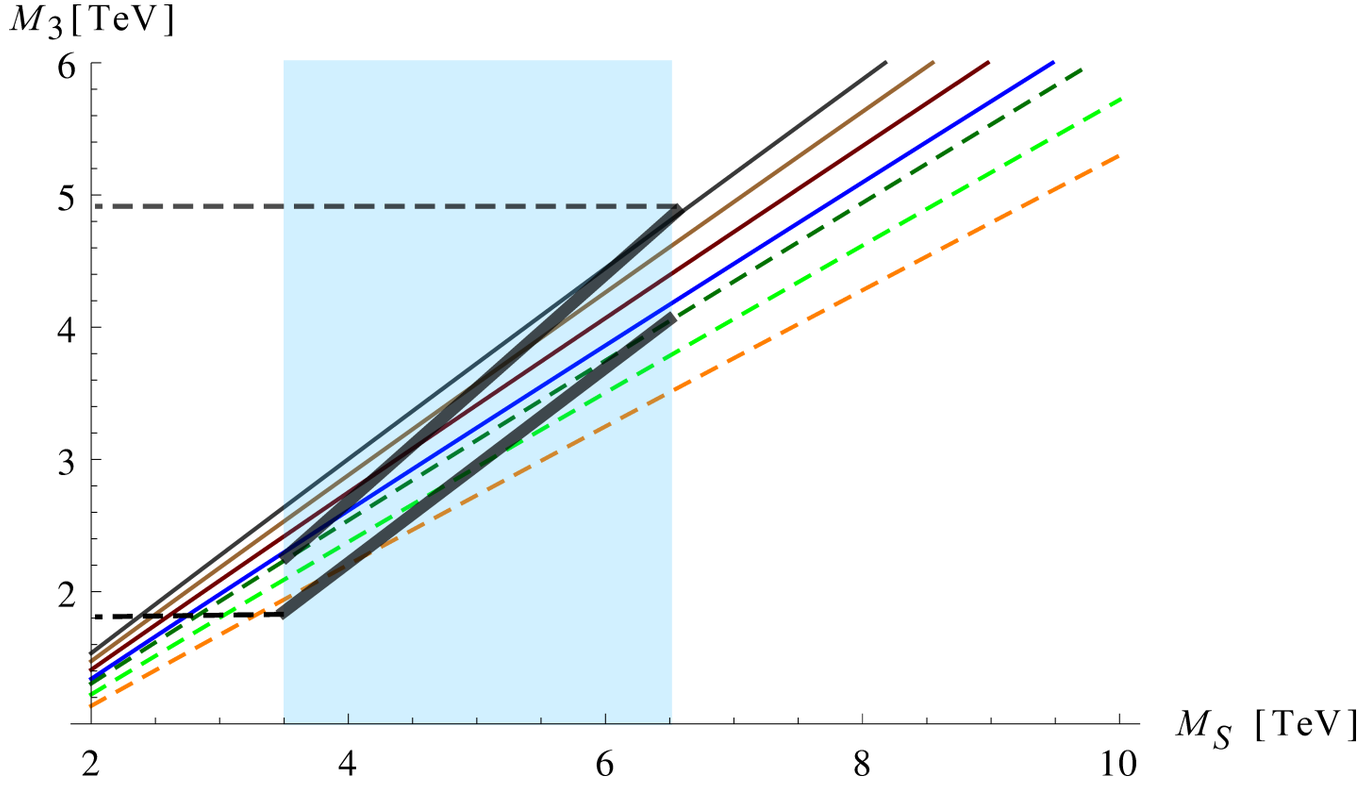
(used: $\ell_6 = 128\pi^3,\ \ell_4 = 16\pi^2,\ V_2^{-1/2} \simeq 5\times 10^{15}\,\mathrm{GeV}$)



SuSy mass spectra

Gluino and gravitino (LSP) masses:

$$2\ \mathrm{TeV} \lesssim M_3|_{M_S} \lesssim 5\ \mathrm{TeV}\ , \quad 40\ \mathrm{GeV} \simeq m_{3/2} \simeq 80\ \mathrm{GeV}$$



	light 1st & 2nd generation			heavy 1st & 2nd generation
	$M_S = 3.5$ TeV	$M_S = 5$ TeV	$M_S = 6.5$ TeV	$M_S = 5$ TeV
χ_1^0	127	109	141	185
χ_2^0	140	116	146	189
$\chi_1^\pm$	133	112	144	187
χ_3^0	430	700	990	1100
$\chi_4^0, \chi_2^\pm$	820	1300	1900	2100
H_0, A_0, $H^\pm$	4200	5900	7500	7200
$\tilde{g}$	2200	3500	4800	5600
$\tilde{u}_i$, $\tilde{d}_i$, $\tilde{c}_i$, $\tilde{s}_i$	1800 – 2000	2800 – 3000	3900 – 4100	3×10^4
$\tilde{t}_1$	3100	4500	5800	4400
$\tilde{t}_2$	4000	5600	7300	5900
$\tilde{b}_1$	4000	5700	7400	6000
$\tilde{b}_2$	4600	6500	8400	7400
$\tilde{\mu}_1$, $\tilde{e}_1$	350	560	800	3×10^4
$\tilde{\mu}_2$, $\tilde{e}_2$	610	1000	1400	3×10^4
$\tilde{\tau}_1$	4300	5900	7500	7400
$\tilde{\tau}_2$	4400	6000	7700	7500

Full spectra, depend on localization of 1st & 2nd generation relative to SuSy breaking; possibly `light' scalar leptons

Don't miss light higgsinos at the LHC!