A 124 GeV MSSM Higgs from high-scale gauge mediation

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DESY

Based on arXiv:1105.0802, 1201.4338
with W. Buchmüller

The little hierarchy problem in the MSSM

- Higgs mass $\gg$ Z mass in MSSM needs large radiative corrections...
- ...which require large stop masses or mixings
- Generically: Soft mass scale $\approx$ EWSB scale
- Soft mass scale $\gg$ EWSB scale requires fine-tuning

The little hierarchy problem in the MSSM

In MSSM ($\tan\beta$ large):

$$m_{h_0}^2 = m_Z^2 + \frac{3}{4\pi^2} y_t^4 v^2 \left(\log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2} \left(1 - \frac{A_t^2}{12\, m_{\tilde{t}}^2} \right) \right) + \dots$$

$$125^2 = 91^2 + 86^2$$

Want large soft mass scale: $m_{\text{soft}} \approx$ few TeV

But m_{soft} sets magnitude for parameters in Higgs potential:

$$m_Z^2 = -2\,|\mu|^2 - 2\, m_{H_u}^2$$

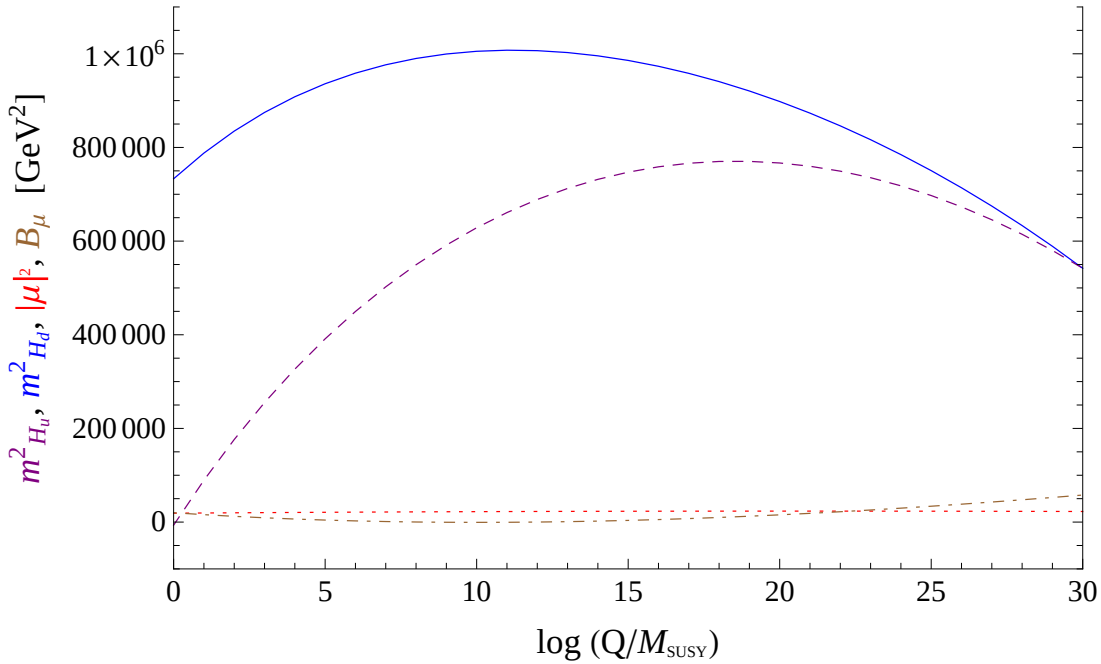
Large $m_{\text{soft}} \Rightarrow$ generically large $m_{H_u}^2 \Rightarrow$ large cancellation needed

Fine-tuning

What exactly is being fine-tuned?

$$m_Z^2 = -2\,|\mu|^2 - 2\,m_{H_u}^2$$

- either large $|\mu|^2$ cancels large $m_{H_u}^2$
- or μ small;
  RG running contributions to $m_{H_u}^2$ cancel among each other at EW scale



Focus point SUSY

Observation: → Feng/Matchev/Moroi '99
certain models predict cancellation

$$m_Z^2 = \left(-2|\mu|^2 - 2\,m_{H_u}^2\right)\Big|_{m_{\text{soft}}}$$

Focus point SUSY

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$$
\begin{aligned}
m_Z^2 &= \left(-2|\mu|^2 - 2\,m_{H_u}^2\right)\Big|_{m_{\text{soft}}} \\
&= \Big(-1.69\,|\mu|^2 + 2.25\,M_3^2 - 0.45\,M_2^2 - 0.01\,M_1^2 + 0.19\,M_2 M_3 + 0.03\,M_1 M_3 \\
&\quad + 0.74\,m_U^2 + 0.65\,m_Q^2 - 0.04\,m_D^2 - 1.32\,m_{H_u}^2 - 0.09\,m_{H_d}^2 \\
&\quad + 0.19\,A_0^2 - 0.40\,A_0 M_3 - 0.11\,A_0 M_2 - 0.02\,A_0 M_1 + \ldots\Big)\Big|_{M_{\text{GUT}}}
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Example: μ, M_i, A_0 small,
$m_U^2 = m_Q^2 = m_D^2 = m_{H_u}^2 = m_{H_d}^2 \equiv m_0^2$ at M_{GUT}:

m_0 can be several TeV, with its contribution to weak-scale $m_{H_u}^2$ still small

Our models: High-scale messenger gauge mediation

$$W = X\Phi\widetilde{\Phi}, \qquad \langle X \rangle = M + F\theta^2$$

As usual:

- SUSY breaking in hidden sector
- Messenger fields $\Phi, \widetilde{\Phi}$ charged under SM, couple to goldstino X
- Messenger loops induce soft terms
- Soft terms governed by discrete parameters: Messenger indices

Unusual:

- messenger mass scale is high, $M \lesssim M_{\text{GUT}}$
- large messenger multiplicities allowed
- incomplete GUT multiplets allowed
- gravity mediation induces μ, B_μ, A_0:
  all $\mathcal{O}(m_{3/2})$ with $m_{3/2} \sim 100$ GeV (by choice)

Focus points with high-scale gauge mediation

- N_3 pairs of colour triplet messengers
- N_2 pairs of weak doublet messengers
- N_1 pairs of hypercharged messengers with hypercharge ± 1
- goldstino X with $\langle X \rangle = M + F\theta^2, \quad M \lesssim M_{\text{GUT}}$

At scale M:

$$M_1 = \frac{6}{5} N_1 \, m_{\text{GM}} \,, \quad M_2 = N_2 \, m_{\text{GM}} \,, \quad M_3 = N_3 \, m_{\text{GM}}$$

$$m_Q^2 = \left(\frac{8}{3} N_3 + \frac{3}{2} N_2 + \frac{1}{25} N_1 \right) m_{\text{GM}}^2, \quad m_U^2 = \left(\frac{8}{3} N_3 + \frac{16}{25} N_1 \right) m_{\text{GM}}^2 \,,$$

$$m_D^2 = \left(\frac{8}{3} N_3 + \frac{4}{25} N_1 \right) m_{\text{GM}}^2 \,, \quad m_E^2 = \left(\frac{36}{25} N_1 \right) m_{\text{GM}}^2 \,,$$

$$m_{H_{u,d}}^2 = m_L^2 = \left(\frac{3}{2} N_2 + \frac{9}{25} N_1 \right) m_{\text{GM}}^2 \,,$$

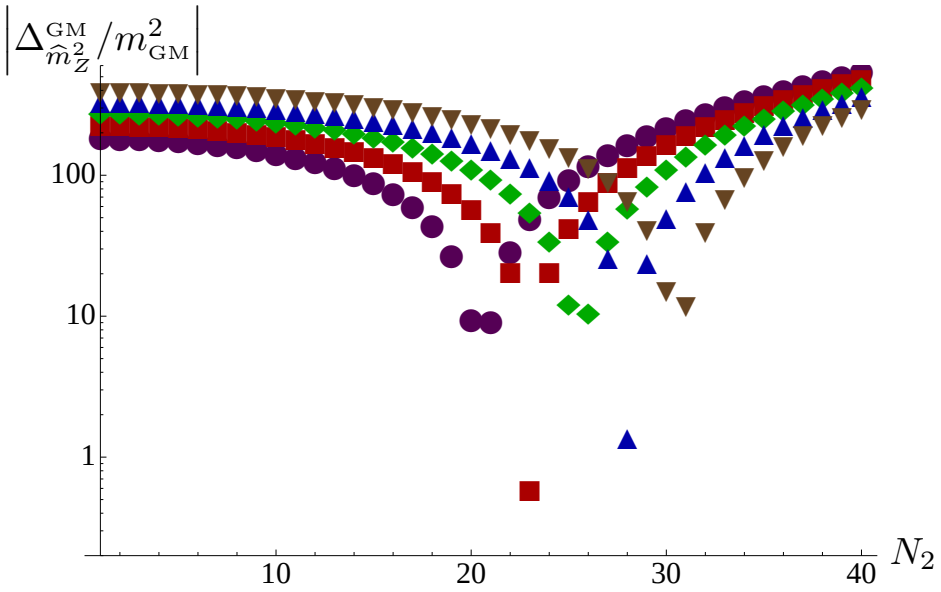
$$\text{where } m_{\text{GM}} \equiv \frac{g^2}{16\pi^2} \frac{F}{M} \sim m_{3/2} \,.$$

Focus points with high-scale gauge mediation

Contribution to m_Z^2 from gauge-mediated soft terms:

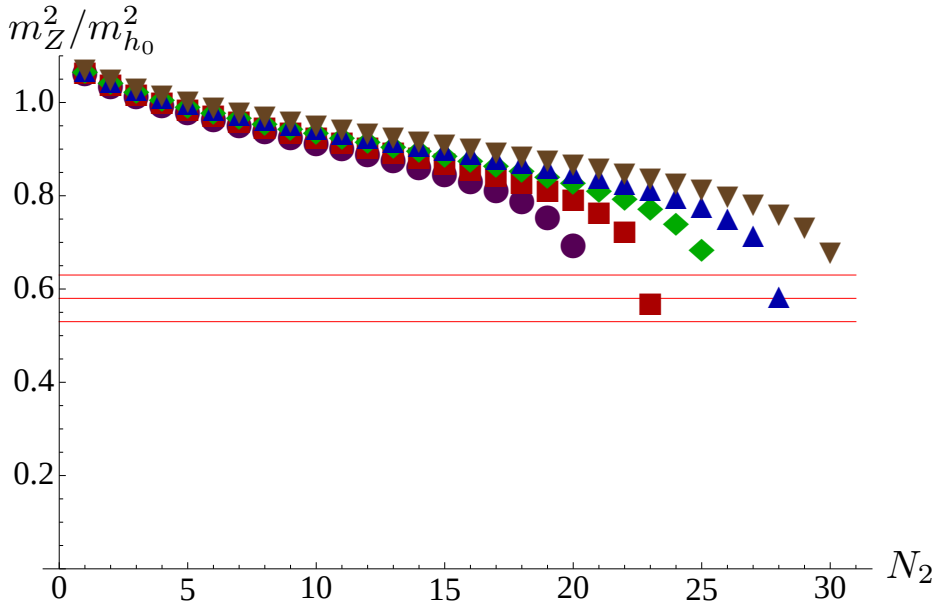
$$\begin{aligned}\Delta^{\mathrm{GM}}_{\widehat{m}_Z^2} = \big(&2.25\,N_3^2 - 0.45\,N_2^2 - 0.01\,N_1^2 \\ &+ 0.19\,N_2 N_3 + 0.04\,N_1 N_3 \\ &+ 3.80\,N_3 - 1.16\,N_2 - 0.01\,N_1\big)\, m^2_{\mathrm{GM}}\,.\end{aligned}$$

- N_1 influence small $\Rightarrow$ set $N_1 = N_2$
- N_2 and N_3 integers: scan over $N_3 = 8, 9, 10, 11, 12$:



Focus points with high-scale gauge mediation

- $(N_2, N_3) = (23, 9)$ or $(28, 11)$ lead to weak scale $\ll$ soft mass scale
- With $m_{\text{GM}} \simeq m_{3/2} \simeq m_Z$: can naturally have multi-TeV soft terms
- Helps pushing lightest Higgs mass above Z mass



Caveat: High sensitivity w.r.t. SM couplings and soft mass scale

Superparticle spectrum for $(N_1, N_2, N_3) = (28, 28, 11)$

particle	mass [GeV]
h_0	124
χ_1^0	164
$\chi_1^\pm$	166
χ_2^0	167
χ_3^0	2700
χ_4^0	4100
$\chi_2^\pm$	4100
H_0	2200
A_0	2200
$H^\pm$	2200
$\tilde{g}$	4200
$\tilde{\tau}_1$	1900
other sleptons	$2500 - 3600$
squarks	$2700 - 5000$

$$\tan\beta = 44$$

Phenomenological features

Cosmology:

- Gravitino LSP = dark matter
- Higgsino NLSP causes BBN problem;
  ameliorated by low relic density from chargino coannihilation

LHC:

- all coloured particles out of reach
- Higgsinos produced in EW processes, but buried under SM BG

  → Baer/Barger/Huang '11, Bobrovskyi/FB/Buchmüller/Hajer '11
- LC should at least discover higgsinos

Problems

Focus point is very sensitive:

- to subleading gravity-mediated soft terms
  (can be forbidden by symmetry – model dependent)
- to SM couplings: y_t, y_b, g^2_{GUT}
- to scale variations

Ultimately there should be no continuous parameters (e.g. in string model)

Conclusions

In models of high-scale gauge mediation, can have:

- large messenger multiplicities
- messengers in incomplete GUT multiplets
- subdominant but non-negligible gravity-mediated soft terms

Certain messenger multiplicites can lead to focus points:

- EWSB scale naturally $\ll$ soft mass scale
- soft mass scale can be multi-TeV: allows for 124 GeV Higgs
- LHC likely to find nothing but the Higgs in that case