Gauge Mediation with a small mu-term

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Outline

- 2 Problems with MGM
- Non-Minimal Gauge Mediation and the “little hierarchy” problem
- Solution to the mu-Problem (NMSSM)
- A Two-Singlet Model

Gauge Mediation

$$\int d^4\theta \phi^\dagger e^{2gV} \phi$$

Predictive: Typically a Small number of free parameters

Communicates SUSY breaking with Minimal Flavor Violation

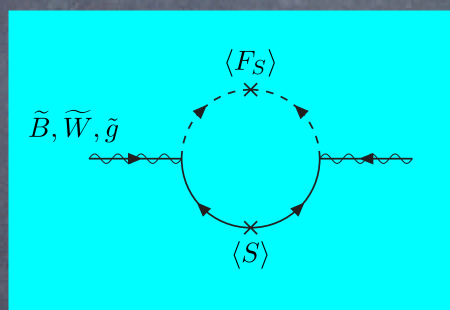
Minimal Gauge Mediation

$$W = \lambda' X \tilde{\phi} \phi$$

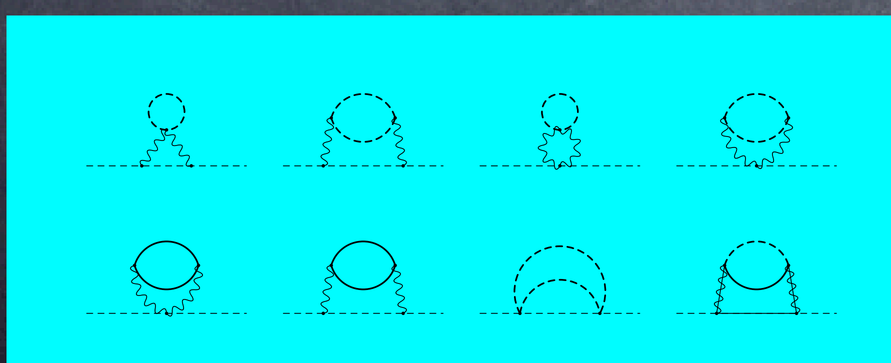
$$X = \langle X \rangle - \theta^2 F$$

$$m^2_{\psi_\phi} = \lambda'^2 \langle X \rangle^2$$

$$m^2_\phi = \begin{pmatrix} \lambda'^2 \langle X \rangle^2 & \lambda' F \\ \lambda' F & \lambda'^2 \langle X \rangle^2 \end{pmatrix}$$



$$M^{(r)}_\lambda = \frac{\alpha^{(r)}}{4\pi} \frac{F}{X}$$



$$m^2_f = 2 \sum_{r=1}^{3} C^r_f \left(\frac{\alpha^{(r)}}{4\pi} \right)^2 \frac{|F|^2}{|X|^2}$$

The mu-Problem in MGM

$$W = \mu H_D H_U$$

1) Gives mass to Charginos $m_{\chi_1^\pm} > 105\mathrm{GeV}$

2) EWSB in MGM demands: $\mu \sim \mathrm{TeV}$

Therefore it is natural to expect a Dynamical origin to the mu-term connected to SUSY Breaking

Gauge Mediation requires some extension to explain this

mu/B

Actually this is the "mu/B" Problem: often mu is easy to get but B is too big

Stability Requires $\Rightarrow$ $$m_{H_U}^2 + m_{H_D}^2 + 2\mu^2 > 2B$$

$$W = \eta X H_D H_U$$

$$\mu = \eta\langle X\rangle << B = \eta F$$

$$X = \langle X\rangle - \theta^2 F$$

$$\frac{B}{\mu} = \frac{F}{X} \sim 100\mathrm{TeV}$$

Gauge Mediation is incomplete and requires an extension

"Little Hierarchy" in MGM

Automatic Hierarchy $$\frac{\tilde{m}_{squark}}{\tilde{m}_{slepton}} \sim \left(\frac{4}{5}\right)^{\frac{1}{2}} \frac{g_3^2}{g_1^2} \sim 10.2$$

Experimental Bounds $$m_{\tilde{e}_R} > 73\text{GeV} \to m_{sq} > 750\text{GeV}$$

Radiative Corrections $$\delta m_{H_U}^2 = -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln(\lambda' \langle X \rangle / m_{\tilde{t}}) < -(600\text{GeV})^2$$

EWSB $$\frac{m_Z^2}{2} = \frac{m_{H_D}^2 - m_{H_U}^2 \tan\beta^2}{\tan\beta^2 - 1} - \mu^2$$

$$\mu^2 > (600\text{GeV})^2$$ $$T = \frac{\mu^2}{\frac{m_Z^2}{2}} \sim 89 \to 1\% \text{ Tuning}$$

A "Little Hierarchy" Relief

"Squashing" the sparticle spectrum is needed for lighter stops

$$m_{sq} \sim \frac{g_3^2}{16\pi^2}\Lambda_q$$

$$m_{sl} \sim \frac{g_1^2}{16\pi^2}\Lambda_\ell$$

$$\frac{m_{sq}}{m_{sl}} \sim \frac{g_3^2}{g_1^2}\left(\frac{\Lambda_q}{\Lambda_\ell}\right) \sim 3$$

"two-parameter Model" with Non-Minimal Messengers

S. Martin 98

$$W = (\lambda_1 X_1 + \lambda_2 X_2)\tilde{\phi}\phi$$

This fits into the broader framework of "General Gauge Mediation"

Meade, Seiberg, and Shih 08

Solving the mu Problem (NMSSM)

Ellis, Gunion, Haber, Roszkowski, Zwirner 89

$$W = \lambda N H_D H_U - \frac{\kappa}{3} N^3$$

$$\lambda \langle N \rangle = \mu$$

$$\lambda F_N = B$$

$$\frac{F_N}{\langle N \rangle} \sim 1\mathrm{TeV}$$

N is not the origin of Messenger mass

$$V^{(soft)} = m_N^2 |N|^2 + [\lambda A_\lambda N H_D H_U - \frac{\kappa}{3} A_\kappa N^3 + \mathrm{h.c.}]$$

Renormalization does not lead to stable vacuum

Murayama, Friedland, and de Gouvea 98

Again, more Dynamics needed to make this work.

Direct Couplings

Delgado/Giudice/Slavich (07)

$$W = X(\tilde{\phi}_1\phi_1 + \tilde{\phi}_2\phi_2) + \xi N \tilde{\phi}_2 \phi_1$$

$$m_N^2 = -\frac{16 g_3^2 \xi^2}{(16\pi^2)^2}\left|\frac{F}{X}\right|^2 \qquad 3A_\lambda = A_\kappa \sim \frac{-5\xi^2}{16\pi^2}\left|\frac{F}{X}\right|$$

Still need heavy stops to lift Higgs mass

$$\mu \sim 5\mathrm{TeV}$$

Re-thinking the mu problem in N-MGM

Messenger-Singlet Interactions induce positive 1-loop mass^2.

Dvali, Giudice, Rattazzi (96)

Delgado/Giudice/Slavich (07)

$$W = \xi N \tilde{\phi}_2 \phi_1 \quad \Rightarrow \quad m_N^2 = \frac{\xi^2}{(16\pi^2)} (\Lambda_1 - \Lambda_2)^2 g(x)$$

The NMSSM Singlet does NOT get a VEV in this way in Non-Minimal Gauge Mediation.

Large Quartic coupling

Nomura, Tweedie, Poland (06)

$$W = \lambda N H_D H_U \to \mathcal{L} \sim \lambda^2 |H_D H_U|^2$$

$$m^2_{Higgs} = m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$$

$$m^{(tree)}_{Higgs} > 114\text{GeV}$$

Need: $\langle N \rangle \ll m_n$

However, in the NMSSM $\kappa \langle N \rangle \sim m_n$

Two-Singlet Model

$$W = \eta_n N \tilde{\phi}_2 \phi_1 + \eta_s S \tilde{\phi}_1 \phi_2$$
$$+\lambda N H_D H_U - \frac{\kappa}{3} S^3$$

$$\left(\eta_s, \eta_n, \lambda, \kappa, \Lambda_q, \Lambda_\ell, \frac{M_1}{M_2} \right)$$

7 Parameter Model

Integrating out the messengers

$$W = \lambda N H_D H_U - \frac{\kappa}{3} S^3 + \tilde{\mu} S N$$

$$V^{(soft)} = m_N^2 |N|^2 + m_S^2 |S|^2 + [bSN - \lambda A_\lambda N H_D H_U - \frac{\kappa}{3} A_\kappa S^3 + \text{h.c.}]$$

Soft terms given by UV parameters:

$$\left(\eta_s, \eta_n, \lambda, \kappa, \Lambda_q, \Lambda_\ell, \frac{M_1}{M_2}\right) \Rightarrow (m_N^2, m_S^2, b, \tilde{\mu}, A_\lambda, A_\kappa)$$

Mixings

$$\epsilon = \frac{\eta_s}{\eta_n} < 1 \qquad m^2 = \frac{\eta_n^2}{(16\pi^2)}\Lambda^2$$

$$\begin{pmatrix} N & S \end{pmatrix} \begin{pmatrix} m^2 & \epsilon m^2 \\ \epsilon m^2 & \epsilon^2 m^2 \end{pmatrix} \begin{pmatrix} N \\ S \end{pmatrix}$$

$$\langle N \rangle \sim \frac{m\epsilon^2}{\kappa} \ll m_n \sim m$$

Now we can decouple the Singlet with small mu term if epsilon is small

Take: $\epsilon = .1$

Model Properties

1) 4 CP-even Higgs

$$\left(B = \lambda A_\lambda - \lambda \tilde{\mu} s - \frac{\lambda^2 v^2}{2} \sin 2\beta \right)$$

2) 3 CP-odd Higgs

3) 6 Neutralinos →

$$m_{\chi_1^0} \sim 43 - 53 \text{ GeV}$$

$$BR(h^0 \to b\bar{b}) < 0.1$$

4) Minimization conditions determine kappa

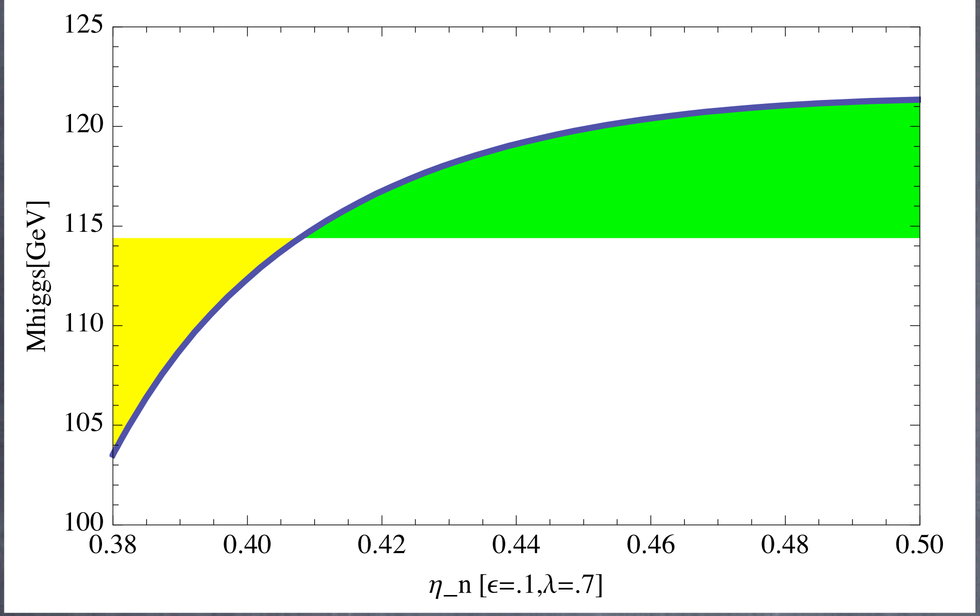
$$\left(\eta_s, \eta_n, \lambda, \kappa, \Lambda_q, \Lambda_\ell, \frac{M_1}{M_2} \right)$$

⇨ 6 Soft Parameters

⇩

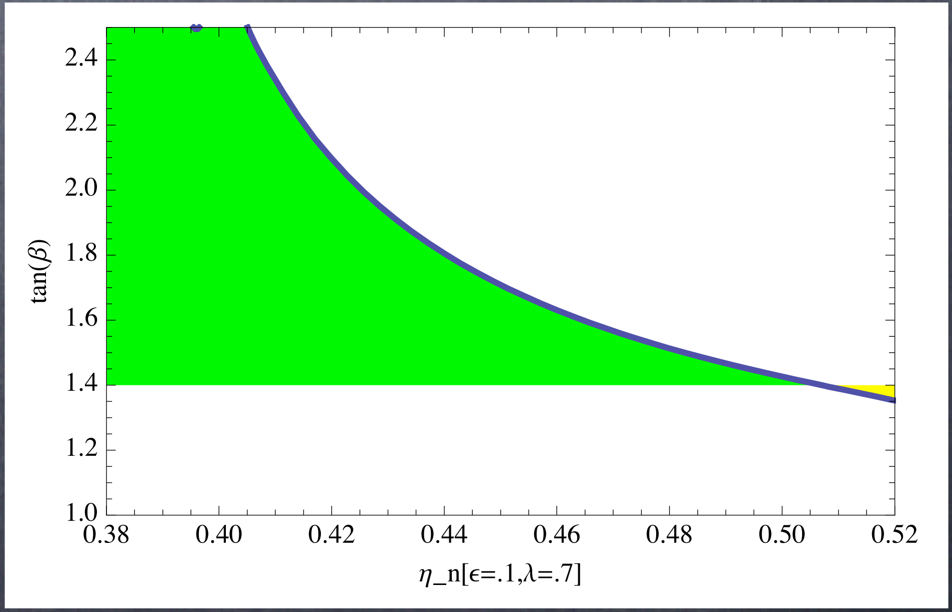
$$\tan\beta = \frac{v_u}{v_d}, \ m_{higgs}, \ \mu \text{ term}$$

$$\left(0.1\ \eta_n, \eta_n, 0.7, \kappa, 15 \text{ TeV}, 80 \text{ TeV}, \frac{1}{2} \right)$$



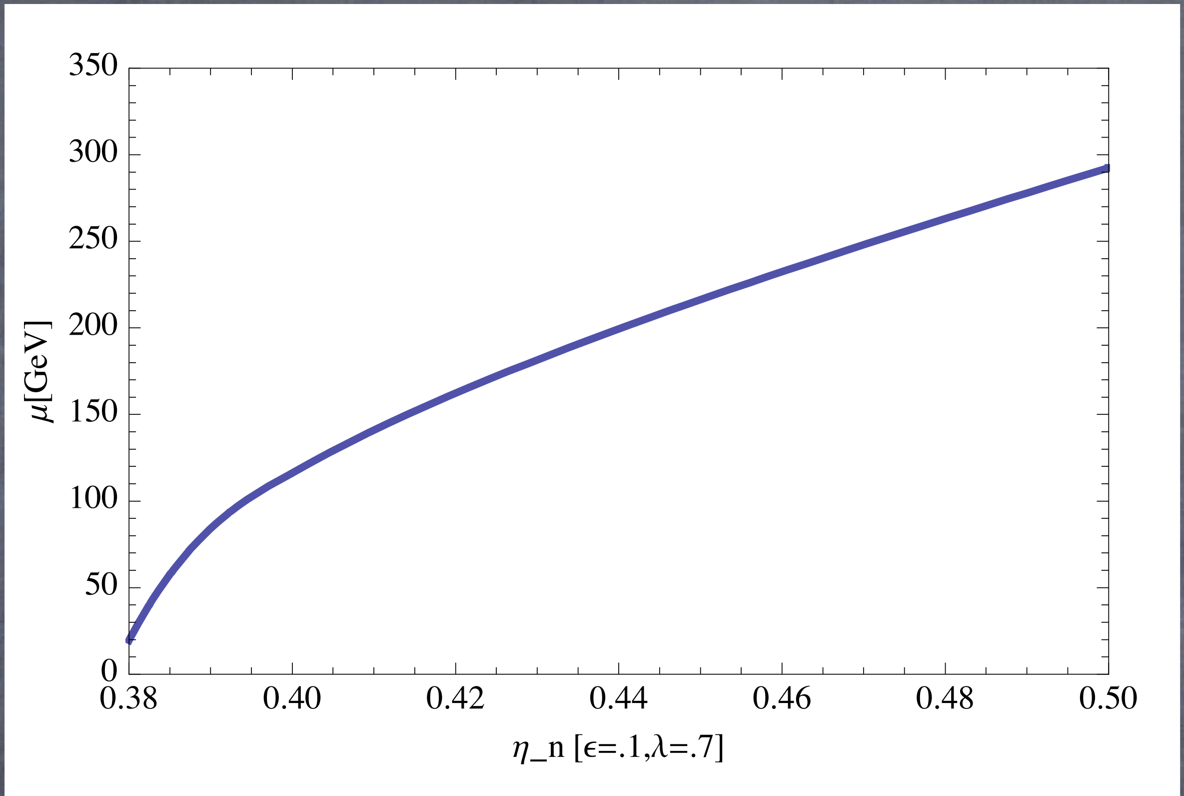
$$m_{Higgs} > 114.4 \text{ GeV}$$

$$\frac{\lambda_{GUT}}{4\pi} < 0.3$$



$$\eta_n = [0.41, 0.51]$$

Small mu term

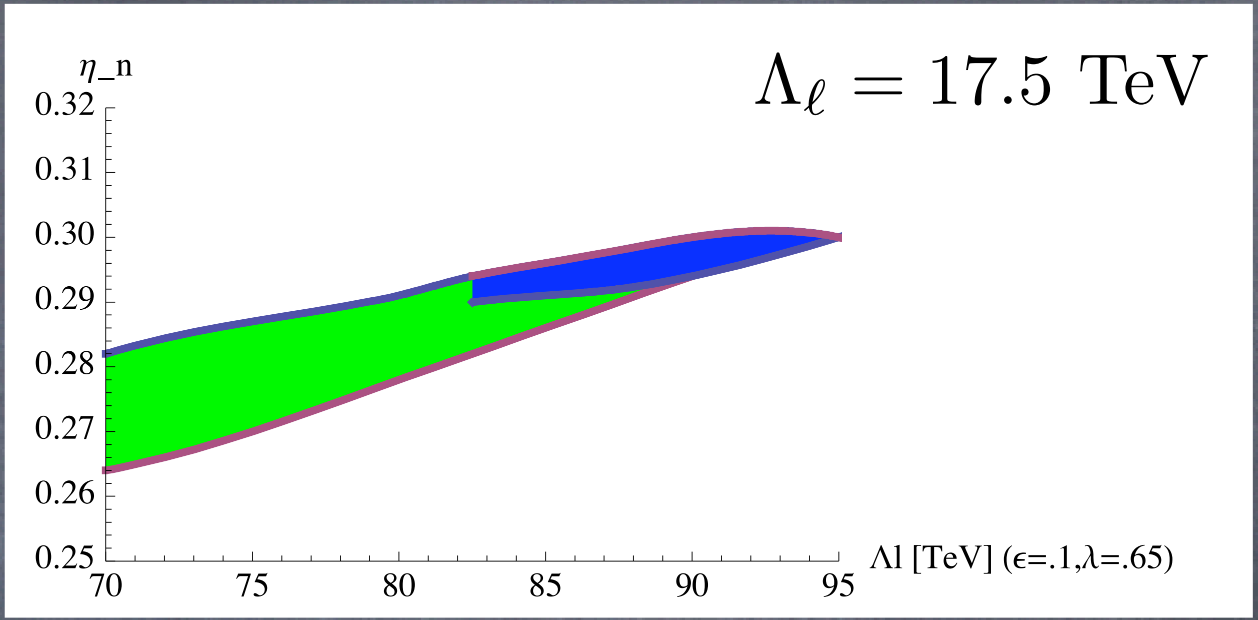


$$\mu = [120\ \text{GeV}, 300\ \text{GeV}]$$

Parameter Space

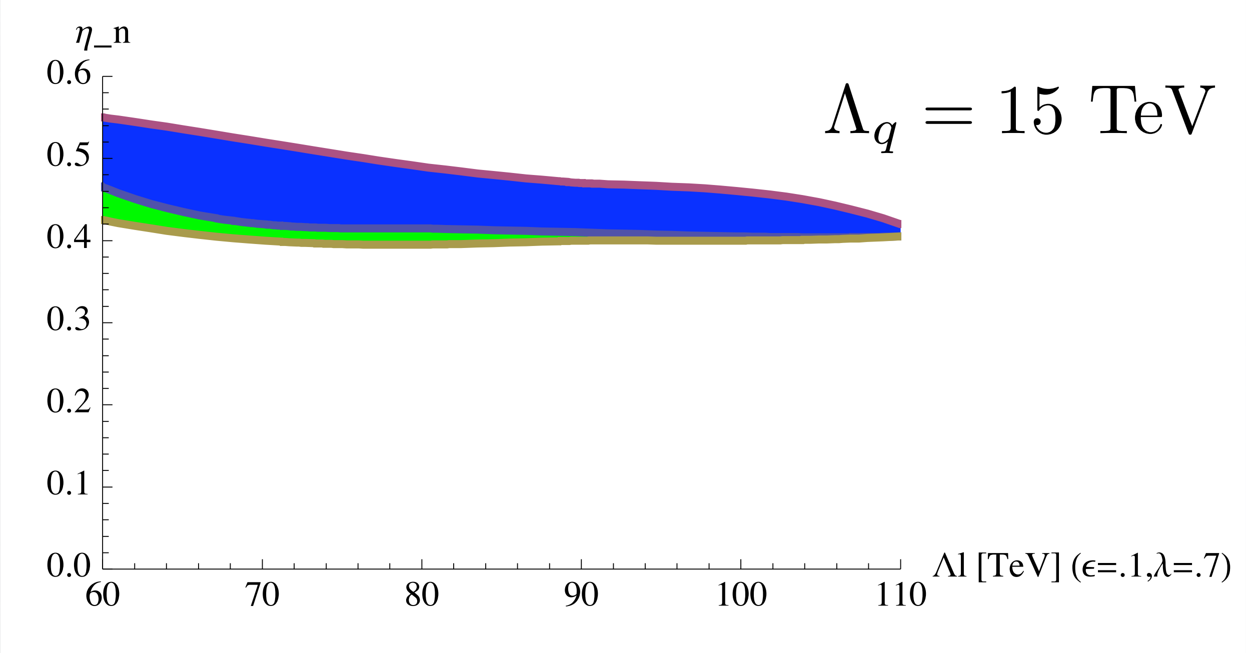
GUT Relations

tune: 3%



No GUT Relations

tune: 15%



Things that work out well

- sign of mu anti-correlated with gaugino mass
- B-term comes from A-term: unsupressed
- large quartic allowed due to second Singlet
- Stability Bound on kappa better than NMSSM

Conclusions

- small mu, light stops, Higgs above LEP bound are possible in Non-Minimal Gauge Mediation.
- Mixing can boost NMSSM's quartic corrections to the Higgs mass.
- Deviations from the 2 parameter model could change the situation.
- "Little Hierarchy" is less severe in these scenarios.