第二届中国LHC物理研讨会/北京大学

Higgs-messenger coupling extended Gauge mediated SUSY-breaking

based on arXiv:1610.06024 by ZF Kang &
Phys. Rev. D 86, 095020 (2012) by ZF Kang, T. Li, T. Liu, C. Tong and J. M. Yang.

Zhaofeng Kang(康昭峰), KIAS(韩国高等研究院), 10/25/2016

Outline

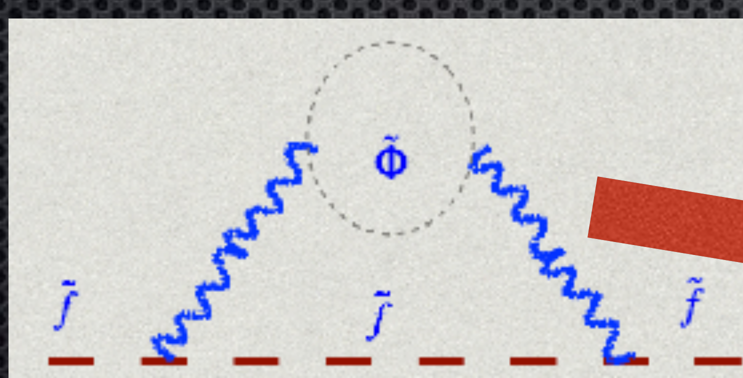
- GMSB: the good & the bad
- GMSB with H_u-messenger couplings
- GMSB with $H_{u,d}$-messenger couplings
- Conclusions

GMSB: gauge mediated SUSY-breaking

GMSB utilizes flavor universal of gauge interactions

- The best idea to overcome the flavor problem

hidden sector breaking SUSY, described by the spurion X=M+Fθ^2 → messenger sector $X\Phi\bar{\Phi}$ → A soft SUSY breaking sector in the MSSM automatically respects MFV



$$M_a = \frac{\alpha_a}{4\pi}\Lambda, \qquad (a = 1, 2, 3), \Lambda = \frac{F}{M}$$

$$m^2_{\phi_i} = 2\Lambda^2 \left[\left(\frac{\alpha_3}{4\pi}\right)^2 C_3(i) + \left(\frac{\alpha_2}{4\pi}\right)^2 C_2(i) + \left(\frac{\alpha_1}{4\pi}\right)^2 C_1(i) \right]$$

$$0\tilde{Q}H_u\tilde{U}^c + 0\tilde{Q}H_d\tilde{D}^c + 0\tilde{L}H_d\tilde{E}^c$$

GMSB: gauge mediated SUSY-breaking

Post h(125), awkward….

From P. Athron, J. h. Park, T. Steudtner, D. Stckinger and A. Voigt, 1609.00371

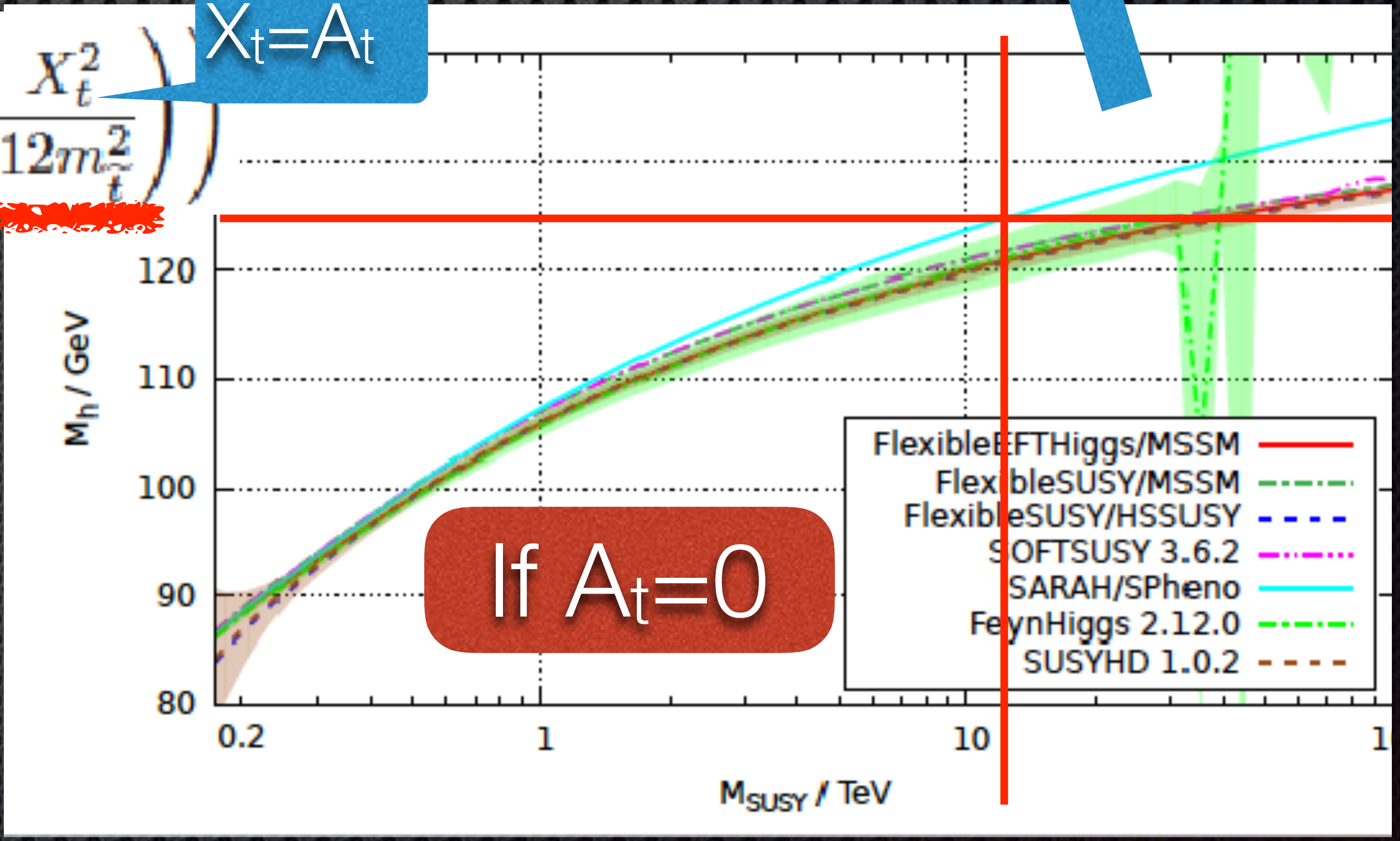
- VERY serious fine-tuning (at least in the MSSM)!

$$\delta_t^2 \simeq \frac{3m_t^4}{4\pi^2 v^2}\left(\log\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right)$$

$X_t = A_t$

$$\Delta m_{H_u}^2 \sim -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \log\frac{\Lambda_{UV}}{m_{\tilde{t}}}.$$

$$\frac{m_Z^2}{2} \simeq \frac{m_{H_d}^2 - \tan^2\beta\, m_{H_u}^2}{\tan^2\beta - 1} - \mu^2$$



If $A_t = 0$

- Fail in explaining $(g-2)_\mu$, because sleptons are very heavy!

GMSB: gauge mediated SUSY-breaking

Post h(125), awkward….

NOT mentioning to the long-standing μ/Bμ problem, that will be presented latter

HGMSB: GMSB with H_u-messenger couplings

Want a large A_t? Coupling H_u to messengers: $\lambda_u H_u \mathcal{O}_u$

- choosing messenger 10=(Q_Φ,U_Φ,E_Φ) of SU(5) with couplings

$$W_{10} = \lambda_u Q_\Phi H_u U_\Phi + \text{[illegible]} +$$
$$+ X \left(\lambda_Q Q_\Phi \overline{Q}_\Phi + \lambda_U \overline{U}_\Phi U_\Phi\right) + W_{\text{MSSM}},$$

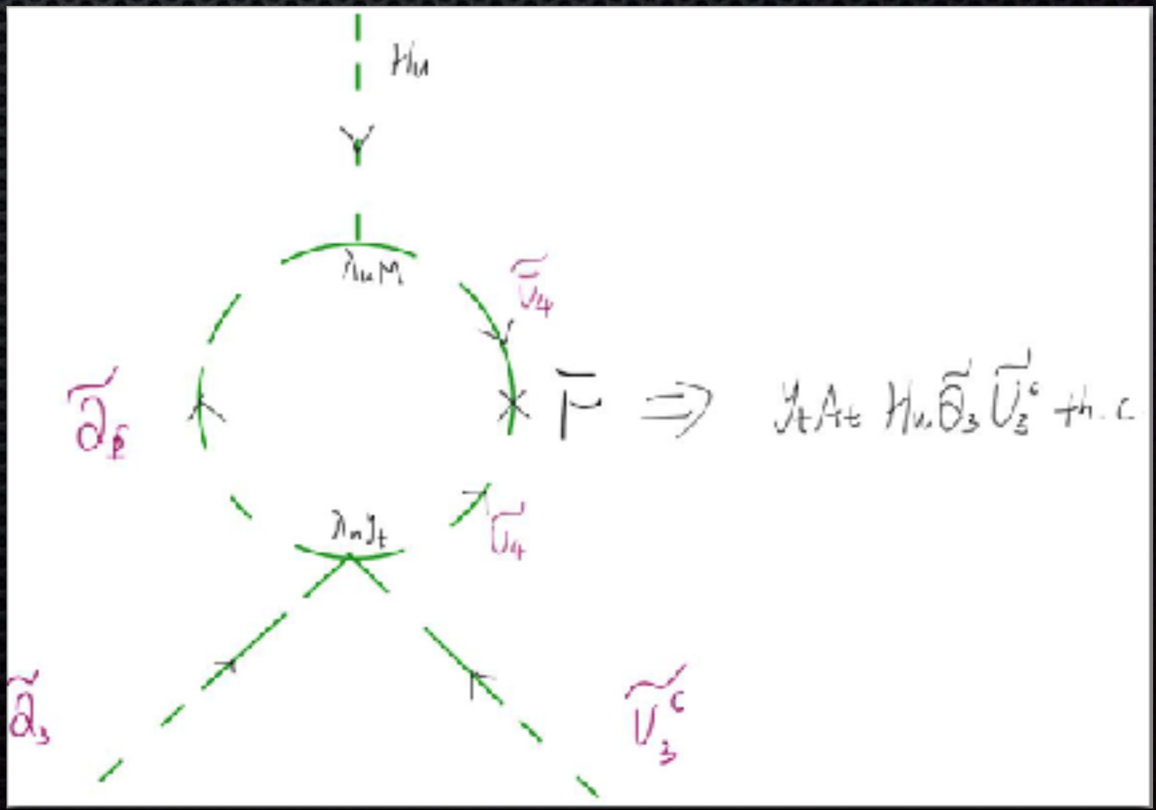
N_f sets of messengers

Z. Kang, T. Li, T. Liu, C. Tong and J. M. Yang, Phys.Rev. D 86, 095020 (2012).

Rev. D 86, 095020 (2012)

- Feymann digram demonstration of one-loop A_t

$$A_t = -N_m \alpha_u \Lambda \qquad N_m \equiv 3N_f$$
$$\Lambda \equiv F/(4\pi M) \sim \mathcal{O}(10\text{TeV})$$



HGMSB: GMSB with H_u-messenger couplings

Higgs-messenger **VS** matter-messenger coupling

J. L. Evans, M. Ibe, S. Shirai and T. T. Yanagida, Phys. Rev. D 85, 095004 (2012);
A. Basirnia, D. Egana-Ugrinovic, S. Knapen and D. Shih, JHEP 1506, 144 (2015)…

Although A_t also arises if the matters Q_3 /U_3 couple to messengers, HGMSB **naturally maintains MFV**, the most important feature of GMSB.

Moreover, HGMSB has the potential to be embedded in the framework which dynamically generates the μ term by coupling Higgs to the messengers, though the μ/Bμ problem

HGMSB: GMSB with $H_{u,d}$-messenger couplings

A_t/m_{H_u} problem: Not only a large A_u but also large m_{H_u}

- Soft parameters of Higgs and any MSSM fields coupling to Higgs acquire Yukawa-mediated SUSY-breaking effects
- Systematic calculation: wave function renormalization method

  G. F. Giudice and R. Rattazzi, Nucl. Phys. B 511 (1998)

$$\begin{aligned} \Delta m^2_{\tilde{Q}_3} &= -\frac{N_m}{3}\left(3\alpha_t\alpha_u + 3\alpha_b\alpha_d + \alpha_b\alpha'_d\right)\Lambda^2, \\ \Delta m^2_{\tilde{U}^c_3} &= -2N_m\alpha_t\alpha_u\Lambda^2, \\ \Delta m^2_{\tilde{D}^c_3} &= -2\frac{N_m}{3}\alpha_b(3\alpha_d + \alpha'_d)\Lambda^2. \end{aligned}$$

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- In particular, H_u receives a large & positive contribution

$$\begin{aligned} \Delta m^2_{H_u} = N_m\alpha_u\Big[&(N_m+3)\alpha_u \\ &-\frac{16}{3}\alpha_3 - 3\alpha_2 - \frac{13}{15}\alpha_1\Big]\Lambda^2 \end{aligned}$$

1. radiative EWSB probably fails
2. originally, cancelation between Yukawa and QCD gauge parts is the reason for introducing messenger 10

HGMSB: GMSB with $H_{u,d}$-messenger couplings

What if includes λ_d H_d $\mathcal{O}_d$?

- The model with $H_{u,d}$-messenger couplings:

$$W_{10} = \lambda_u Q_\Phi H_u U_\Phi + \lambda_d \overline{Q}_\Phi H_d \overline{U}_\Phi + \cdots + X\left(\lambda_Q Q_\Phi \overline{Q}_\Phi + \lambda_U \overline{U}_\Phi U_\Phi\right) + W_{\mathrm{MSSM}},$$

turned off before to avoid μ/Bμ problem

- Dynamically generate μ Hu Hd & Bμ Hu Hd at one loop with

$$\mu = f(\lambda_Q/\lambda_U) N_m \sqrt{\alpha_u \alpha_d}\Lambda,$$
$$B_\mu = f(\lambda_Q/\lambda_U) N_m 4\pi \times \sqrt{\alpha_u \alpha_d}\Lambda^2,$$

$$\sin 2\beta = \frac{2B_\mu}{m^2_{H_u} + m^2_{H_d} + 2\mu^2}$$

Great! It explains the the origin of μ, the unique massive coupling in MSSM superpotential

But Bμ has dimension 2! TOO BIG TO FILL the EWSB equation —— the μ/Bμ problem

HGMSB: GMSB with $H_{u,d}$-messenger couplings

Nonradiative EWSB as a common solution

- In the A_t/m_{H_u} problem we encounter a too large $m_{H_u}>0$, which hampers the conventional radiative EWSB

$$\frac{m_Z^2}{2} = -\mu^2 + \frac{m_{H_d}^2 - \tan^2\beta\, m_{H_u}^2}{\tan^2\beta - 1} \quad \Rightarrow \quad -\mu^2 - m_{H_u}^2 \approx m_Z^2/2,$$

- Similarly, in the μ/Bμ problem above we encounter a too large Bμ and thus EWSB fails:

$$\sin 2\beta = \frac{2B_\mu}{m_{H_u}^2 + m_{H_d}^2 + 2\mu^2}$$

C. Csaki, A. Falkowski, Y. Nomura and T. Volansky, Phys. Rev. Lett. 102 (2009) 111801.

Phys. Rev. Lett. 102 (2009) 111801

However, what if $m_{H_d}^2$ is NOT negligible ? ! ! $\Rightarrow$ Both equations can be satisfied by this large & positive $m_{H_d}^2$

HGMSB: GMSB with $H_{u,d}$-messenger couplings

Generate a huge $m^2_{H_d}$!!

- Include the "full" $H_{u,d}$-messenger couplings:

$$W_{10} = \lambda_u Q_\Phi H_u U_\Phi + \lambda_d \overline{Q}_\Phi H_d \overline{U}_\Phi + \frac{\lambda'_d}{2} E_\Phi H_d H_d + + X\left(\lambda_Q Q_\Phi \overline{Q}_\Phi + \lambda_U \overline{U}_\Phi U_\Phi\right) + W_{\rm MSSM},$$

messenger 10 admits such a term

$$\Delta m^2_{H_d} \approx \frac{N_m}{3}\alpha'_d\left(N_m\alpha'_d + 2N_m\alpha_d + 3\alpha_b - 3\alpha_2\right)\Lambda^2$$

$$\lambda'_d \simeq 1.7\left(\frac{\xi_S}{0.85}\frac{\tan\beta}{5}\frac{81}{N_m^2}\right)^{\frac{1}{4}}\left(\frac{\mu}{0.2\mathrm{TeV}}\frac{10\mathrm{TeV}}{\Lambda}\right)^{\frac{1}{4}}$$

HGMSB: GMSB with $H_{u,d}$-messenger couplings

Features of nonradiative EWSB

- A large m_{H_d}~10 TeV thus heavy H/A/H±

$$m_{H_d}^2 \simeq 2B_\mu / \sin 2\beta \approx \tan\beta B_\mu$$

H/A/H± at LHC

- Tanβ is favored to be not very large, thus alleviating the need for a superhuge $m_{H_d}^2$

$$m_{H_d}^2 / \tan^2\beta - m_{H_u}^2 \sim \mu^2$$

- A small μ is strongly favored, but:

1. a small μ term does not guarantee naturalness
2. cancelation is hidden between $m_{H_u}^2 > 0$ and $m_{H_d}^2$

HGMSB: GMSB with $H_{u,d}$-messenger couplings

Bonus: filling the $(g-2)_\mu$ discrepancy by light stau

- Nonradiative EWSB with a huge $m^2_{H_d}$ leads to

$$S = \mathrm{Tr}(Y_f \hat{m}^2_{\tilde{f}}) \sim m^2_{H_d}/2 > 0 \Rightarrow \frac{dm^2_{\tilde{L}}}{dt} = -\frac{1}{16\pi^2}\frac{3}{5}g_1^2 S + \ldots$$

Sparticles with negative hyper charge such as left-handed sleptons will be decreased significantly

so

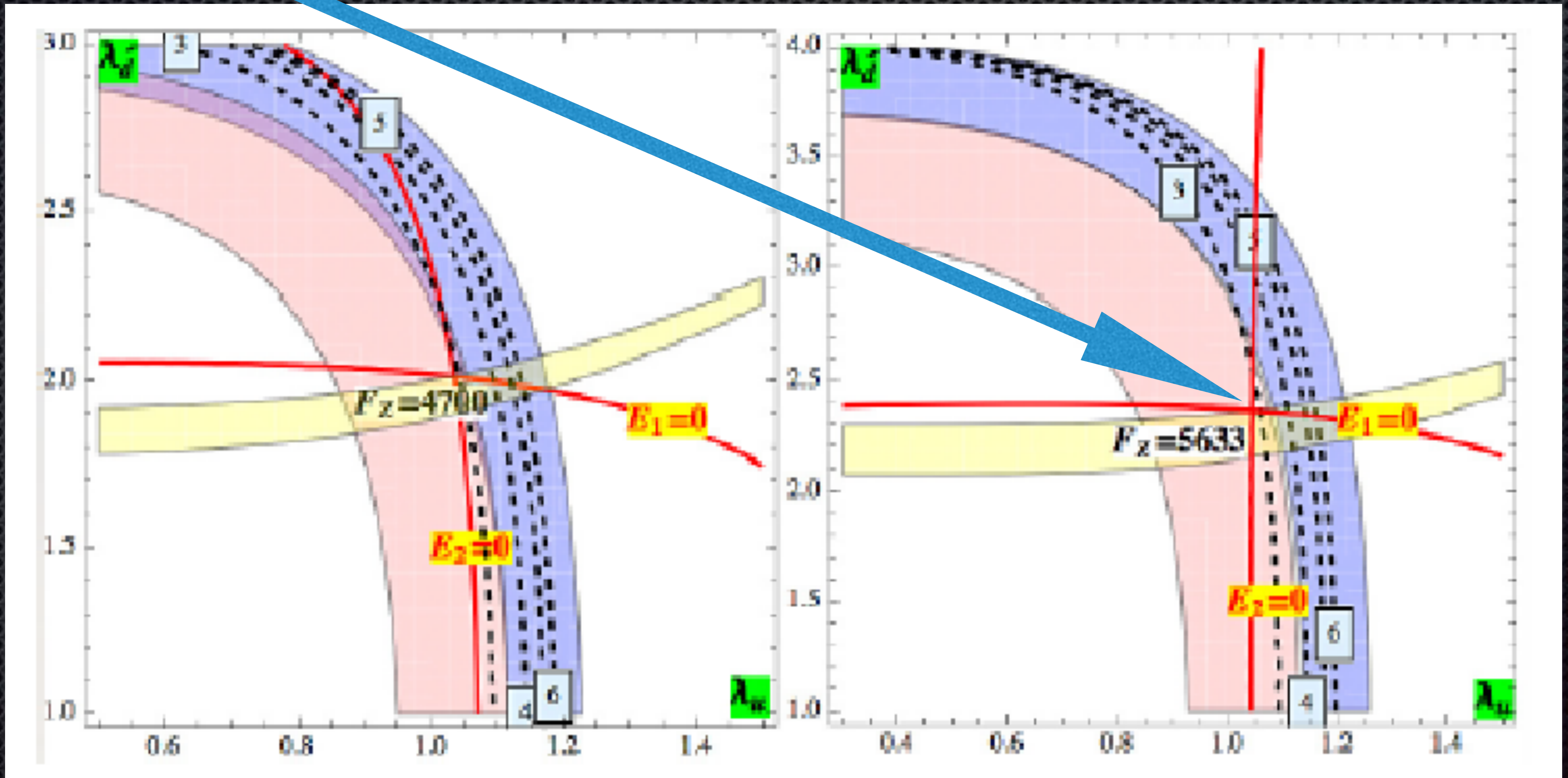
$\tilde{\nu}_\tau$ tends to the NLSP

$$\delta a_\mu \approx \frac{\alpha_2}{2\pi}\frac{m_\mu^2 M_{\lambda_2}\mu\tan\beta}{m^4_{\tilde{\nu}_\mu}}F_a\left(\frac{M^2_{\lambda_2}}{m^2_{\tilde{\nu}_\mu}}, \frac{\mu^2}{m^2_{\tilde{\nu}_\mu}}\right)$$

HGMSB: GMSB with $H_{u,d}$-messenger couplings

Two benchmarks with M=10^{12} GeV and 10^7 GeV

- The cross points of two red lines are the solutions to EWSB



and $m_{\tilde{\nu}_\tau} = 90.7(82.8)$ GeV, $m_{\tilde{\tau}} = 120.9(114.9)$ GeV, $m_{\chi_1} = 105.0(100.7)$ GeV and $m_{\chi_2} = 113.0(109.1)$ GeV.

$\delta a_\mu = 1.4 \times 10^{-9}(1.3 \times 10^{-9})$

HGMSB: GMSB with $H_{u,d}$-messenger couplings

A **light Higgsino & slepton world** for $(g-2)_\mu$

Light but quite dengnerate Higgsinos currently are hidden at LHC (missing energy+soft leptons/jets), even forever?

C. Han, D. Kim, S. Munir and M. Park, JHEP 1504,132 (2015).

Light sleptons are even less hopeful. But in one scenario where the sneutrino is not far above $m_Z/2$, the relatively hard leptons says from charginos still can be hunted, e.g.,

$$pp \to \chi^{\mp}\chi^{\pm} \to \tau^{+}\tau^{-} + \mathrm{MET}(= \tilde{\nu}_\tau \tilde{\nu}_\tau^*).$$

Conclusions

GMSB offer the best idea to organize soft SUSY, but it suffers the μ/Bμ problem, and serious fine-tuning problem post h(125)

HGMSB including both H_u&H_d coupling to messengers can address these problems, via nonradiative EWSB; as a bonus, the $(g-2)_\mu$ puzzle can be addressed, too.

The light Higgsino & slepton world satisfying $(g-2)_\mu$ can be tested in certain scenarios

Thank you for your attention!