GAUGE MEDIATION BEYOND MFV

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work in progress with L. Calibbi and P. Paradisi

MOTIVATION

Gauge Mediation very predictive
scenario of SUSY breaking

small A-terms $\longrightarrow$ need heavy SUSY spectrum for large Higgs mass

e.g. $M_S \approx 4\,\mathrm{TeV}$ for $m_h \approx 125\,\mathrm{GeV}$

MFV $\longrightarrow$ cannot have large FV effects

MOTIVATION

Evidence for direct CP violation in D decays

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = -0.0064 \pm 0.0014$$

Can be explained SUSY with "disoriented A-terms"

Giudice, Isidori, Paradisi '12

$$\Delta A_{CP}^{SUSY} \sim 0.6\% \, \frac{\mathrm{Im}(\delta^u_{LR})_{12}}{10^{-3}} \left(\frac{1\mathrm{TeV}}{\tilde{m}}\right)$$

Not possible in MFV: $(\delta^u_{LR})_{12} \sim 10^{-7}$

OUTLINE

- Minimally modify Gauge Mediation to get large non-MFV A-terms

→ can get large Higgs mass for light spectrum

Evans & al. '11 (MFV)

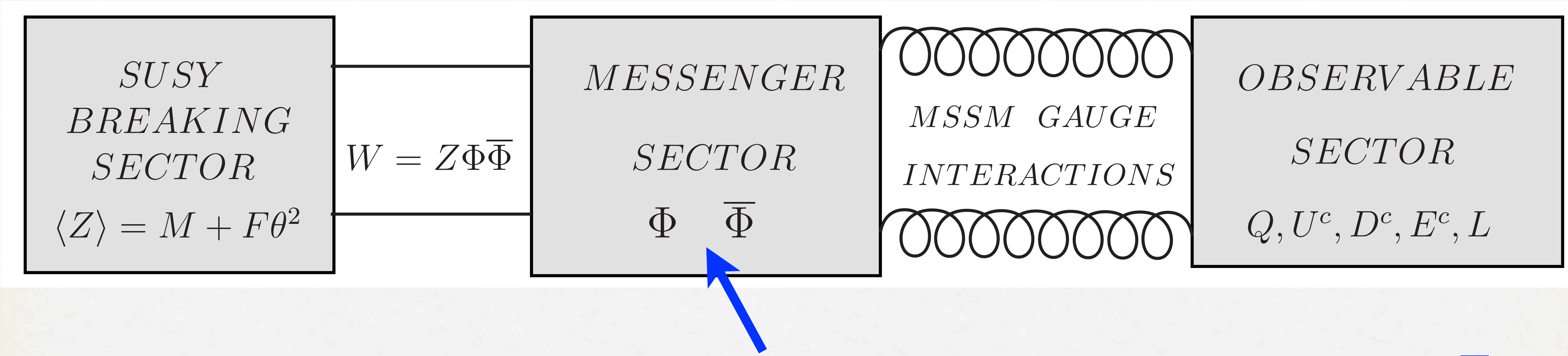
→ can account for ΔA_{CP}

Shadmi, Szabo '11 (slepton sector)

- Same field content as GM with one new coupling determining SUSY spectrum

- Rich flavor phenomenology controlled by full Yukawa structure

MINIMAL GAUGE MEDIATION



complete SU(5) multiplets: $N \times (\mathbf{5} + \overline{\mathbf{5}})$

1-loop gaugino masses $$M_a = N \frac{\alpha_a}{4\pi} \frac{F}{M}$$

2-loop sfermion masses $$\left(\tilde{m}_Q^2\right)_{ij} \sim \delta_{ij} \left(\frac{\alpha_a}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$$

A-terms vanish at messenger scale $$A = 0$$

MODIFIED SETUP

Allows for direct couplings of messenger to obs sector

$$W = Z\overline{\Phi}\Phi + Q_i U_j (y_{ij}^U H_u + \lambda_{ij}^U \Phi_D)$$

controlled by flavor symmetries:
parametrically suppressed as Yukawas $\lambda_{ij}^U \sim y_{ij}^U$

→ only $\lambda_{33}^U \equiv \lambda_U$ sizable

Can be motivated by symmetry: similar $\Phi_T, \overline{\Phi}_D, \overline{\Phi}_T$

HIGH ENERGY SPECTRUM

New contributions to soft terms controlled by $\lambda_U \sim y_t$

$$A^U_{ij} = -\frac{1}{16\pi^2}\frac{F}{M}\left[\delta_{i3}\, y^U_{3j}\, \lambda^2_U + \delta_{j3}\, y^U_{i3}\, 2\lambda^2_U\right]$$

$$A^D_{ij} = -\frac{1}{16\pi^2}\frac{F}{M}\left[\delta_{i3}\, y^D_{3j}\, \lambda^2_U\right]$$

$(F \ll M^2)$

negative

$$\Delta m^2_{H_u} = -\frac{1}{128\pi^4}\frac{F^2}{M^2}\lambda^2_U 9 y^2_t$$

$$\Delta m^2_{H_d} = -\frac{1}{128\pi^4}\frac{F^2}{M^2}\lambda^2_U \frac{3}{2} y^2_b$$

small for moderate tanβ

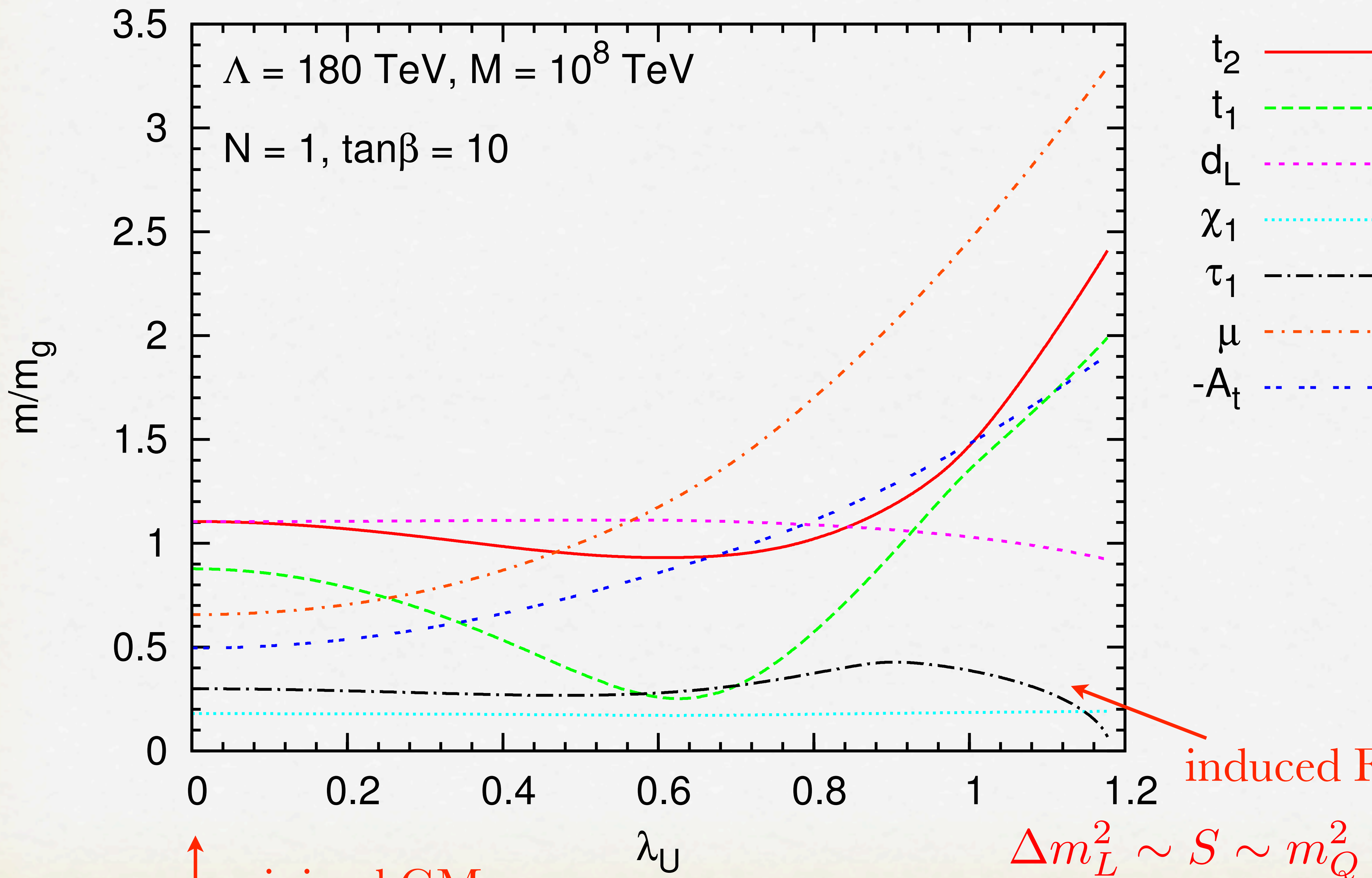
$$\Delta m^2_{U_3} = \frac{1}{128\pi^4}\frac{F^2}{M^2}\lambda^2_U\left(-\frac{13}{15}g^2_1 - 3g^2_2 - \frac{16}{3}g^2_3 + 6\lambda^2_U + y^2_b\right)$$

$$\Delta m^2_{D_3} = -\frac{1}{128\pi^4}\frac{F^2}{M^2}\lambda^2_U y^2_b$$

$$\Delta m^2_{Q_3} = \frac{1}{128\pi^4}\frac{F^2}{M^2}\lambda^2_U\left(-\frac{13}{30}g^2_1 - \frac{3}{2}g^2_2 - \frac{8}{3}g^2_3 + 3\lambda^2_U\right)$$

either sign

LOW ENERGY SPECTRUM



↑ minimal GM

induced FI term

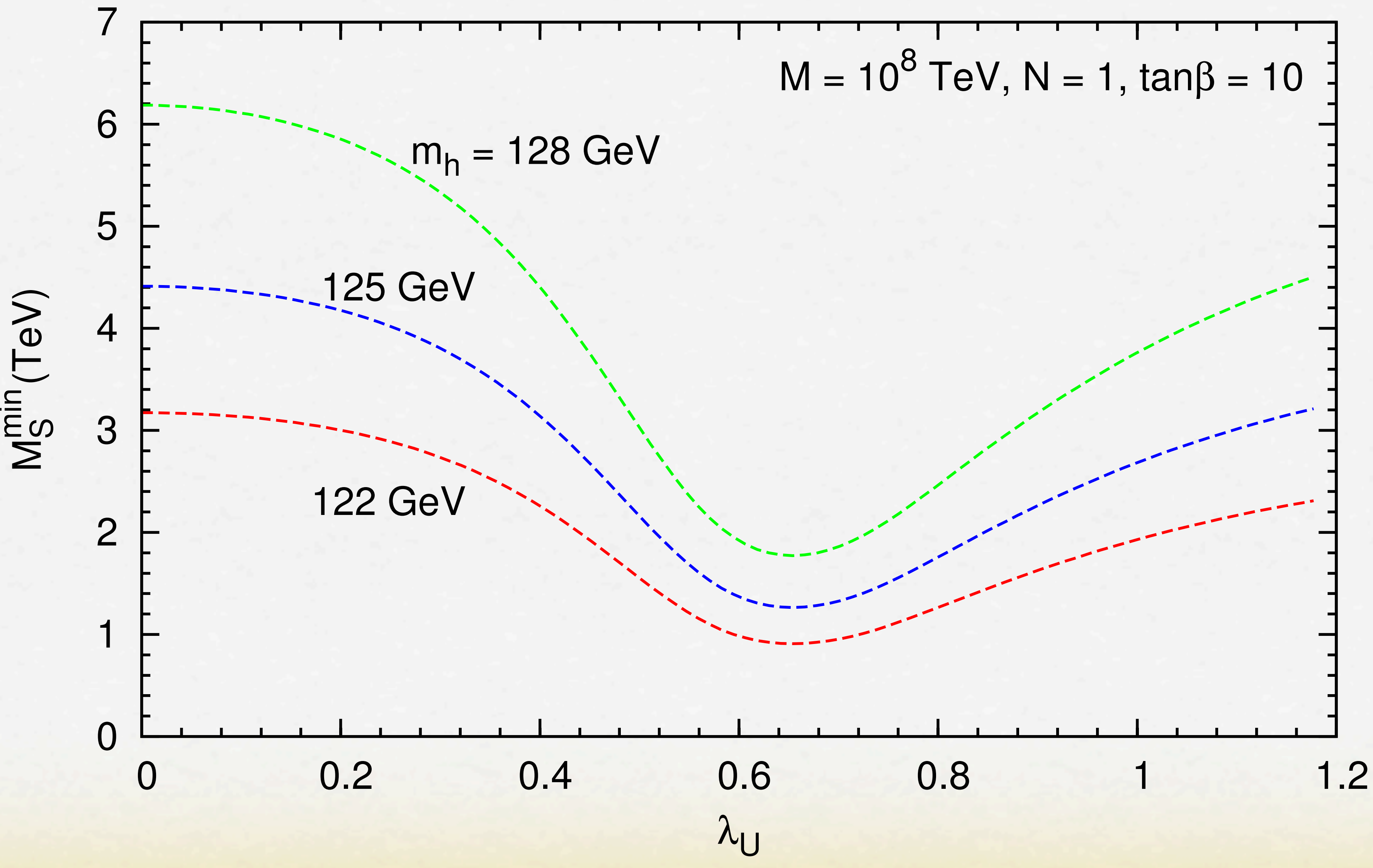
$\Delta m_L^2 \sim S \sim m_Q^2 - 2m_U^2$

HIGGS BOSON MASS

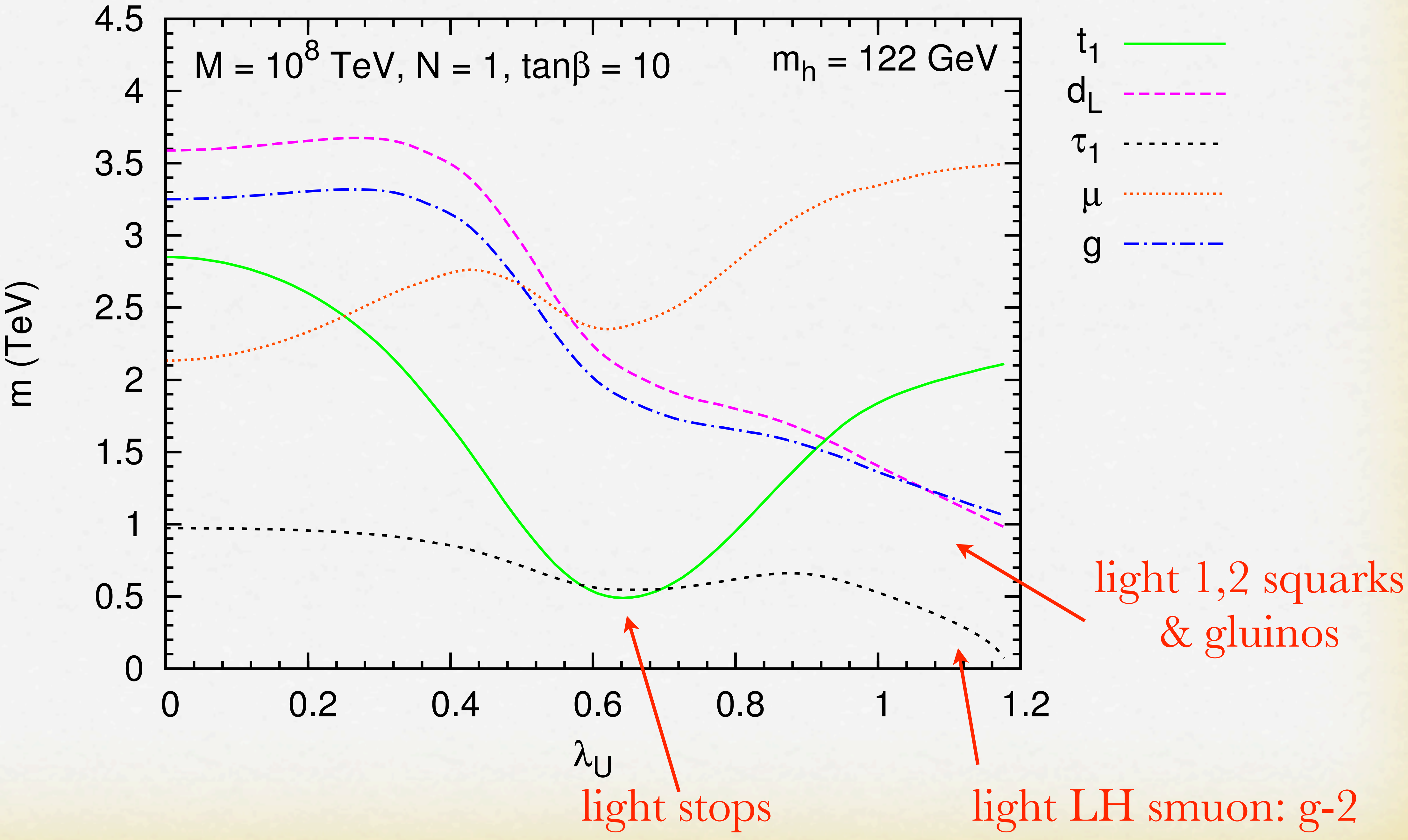
Vacuum stability:

$$A_t^2 + 3\mu^2 \leq 7.5\,(m_{Q_3}^2 + m_{U_3}^2)$$

$$\Delta m_h^2 = \frac{3m_t^4}{8\pi^2 v^2}\left(\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right)$$



SPECTRUM WITH LARGE m_h



FLAVOR STRUCTURE

go to convenient flavor basis: $y_D = y_D^{diag} \quad y_U = V_{CKM}^\dagger y_U^{diag}$

$$m_U^2 \sim \begin{pmatrix} m_0^2 & 0 & 0 \\ 0 & m_0^2 & 0 \\ 0 & 0 & m_0^2 \end{pmatrix} + \left(g^2 \lambda_U^\dagger \lambda_U + \ldots\right) m_0^2$$

minimal GM: MFV   new FV from $\lambda_U \sim y_U$

$$m_D^2 \sim \begin{pmatrix} m_0^2 & 0 & 0 \\ 0 & m_0^2 & 0 \\ 0 & 0 & m_0^2 \end{pmatrix} + \left((y_D^{diag})^\dagger \lambda_U \lambda_U^\dagger y_D^{diag}\right) m_0^2$$

≈ 0 for mod. tanβ

MASS INSERTIONS

$$(\delta^u_{LL})_{ij} \sim (\lambda_U)_{i3}(\lambda_U)^*_{j3}$$

$$(\delta^u_{RR})_{ij} \sim (\lambda_U)^*_{3i}(\lambda_U)_{3j}$$

$$(\delta^d_{LL})_{ij} \sim (\lambda_U)_{i3}(\lambda_U)^*_{j3}$$

$$(\delta^d_{RR})_{ij} \approx 0$$

CKM

$$(\delta^d_{LR})_{ij} \sim \frac{A}{\tilde{m}}(\lambda_U)_{i3}(\lambda_U)^*_{j3}\frac{(m_D^{diag})_{jj}}{\tilde{m}}$$

$$(\delta^u_{LR})_{ij} \sim \frac{A}{\tilde{m}}(\lambda_U)_{3i}(\lambda_U)^*_{3j}\frac{(m_U^{diag})_{ii}}{\tilde{m}}$$

$$(\delta^u_{LR})^{eff}_{ij} \equiv (\delta^u_{LL})_{ik}(\delta^u_{LR})_{kl}(\delta^u_{RR})_{lj}$$

$$(\delta^u_{LR})^{eff}_{ij} \sim \frac{A}{\tilde{m}}\frac{m_t}{\tilde{m}}(\lambda_U)_{i3}(\lambda_U)_{3j}$$

large effects only in up-sector!

FLAVOR PHENOMENOLOGY

bounds on δ's constrain parameters

$D-\overline{D}$ mixing $$(\lambda_U)^*_{31}(\lambda_U)_{32} \lesssim 6.0 \times 10^{-2}\left(\frac{M_S}{1\,\mathrm{TeV}}\right)$$

EDM $$(\lambda_U)_{13}(\lambda_U)_{31} \lesssim 1.7 \times 10^{-5}\left(\frac{M_S}{1\,\mathrm{TeV}}\right)\left(\frac{M_S}{A}\right)$$

$$(\delta^u_{LR})_{12} \sim 2.1 \times 10^{-3}\left(\frac{1\,\mathrm{TeV}}{M_S}\right)\left(\frac{A}{M_S}\right)\left(\frac{(\lambda_U)_{13}}{\lambda^3}\right)\left(\frac{(\lambda_U)_{32}}{\mathcal{O}(1)}\right)$$

$$(\delta^u_{LR})_{21} \sim 9.2 \times 10^{-3}\left(\frac{1\,\mathrm{TeV}}{M_S}\right)\left(\frac{A}{M_S}\right)\left(\frac{(\lambda_U)_{23}}{\lambda^2}\right)\left(\frac{(\lambda_U)_{31}}{\mathcal{O}(1)}\right)$$

large ΔA_{CP} easily possible for sizable RH rots!

SUMMARY

- introduce couplings of GM messenger to MSSM that are parametrically small as Yuks
  - → large misaligned A-terms
  - → light stops or light squarks, gluinos, sleptons
- can get large m_h with light, calculable spectrum
- flavor pheno depends on Yukawa structure
- only $\Delta C=1$ effects large, can account for ΔA_{CP}

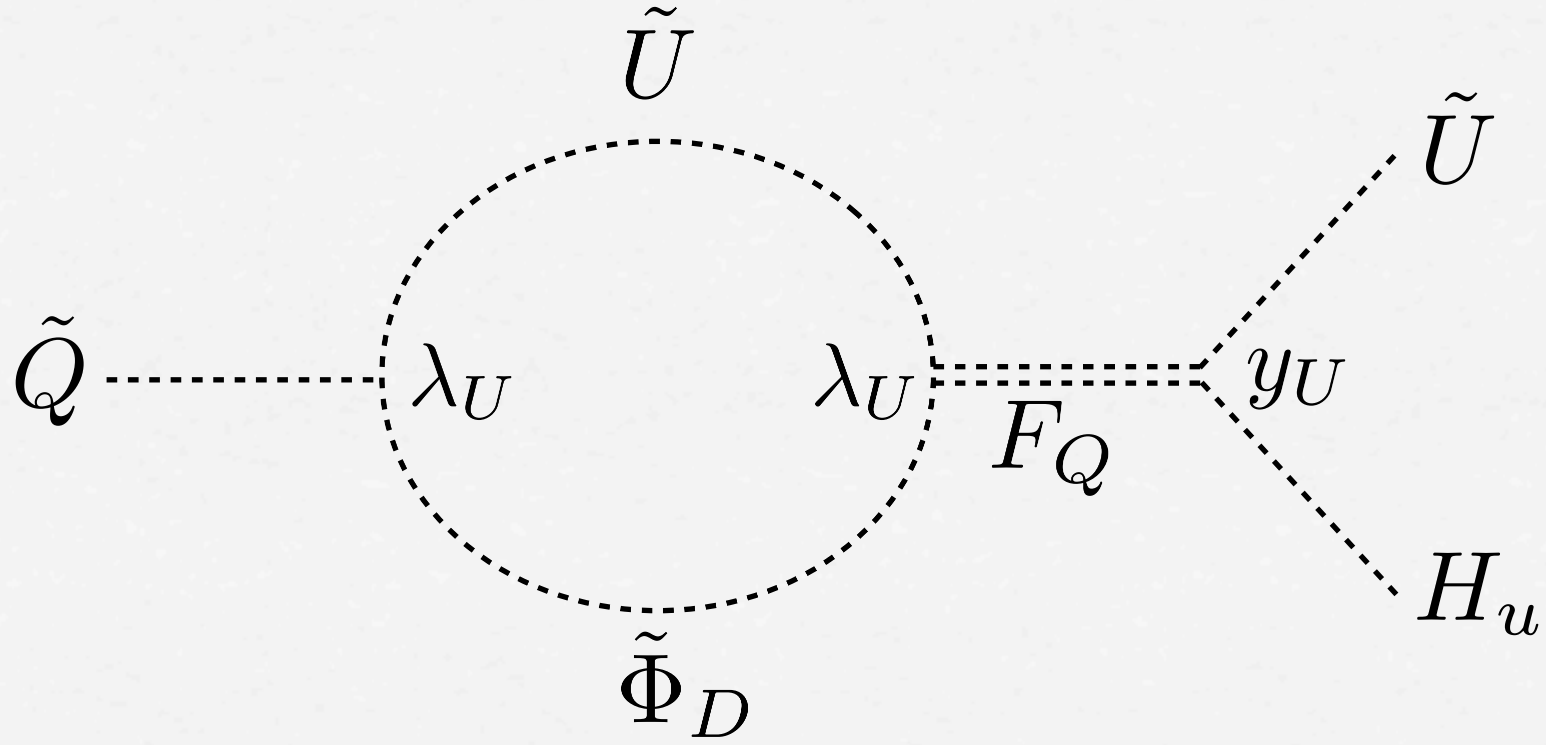
BACKUP

THEORETICAL MOTIVATION

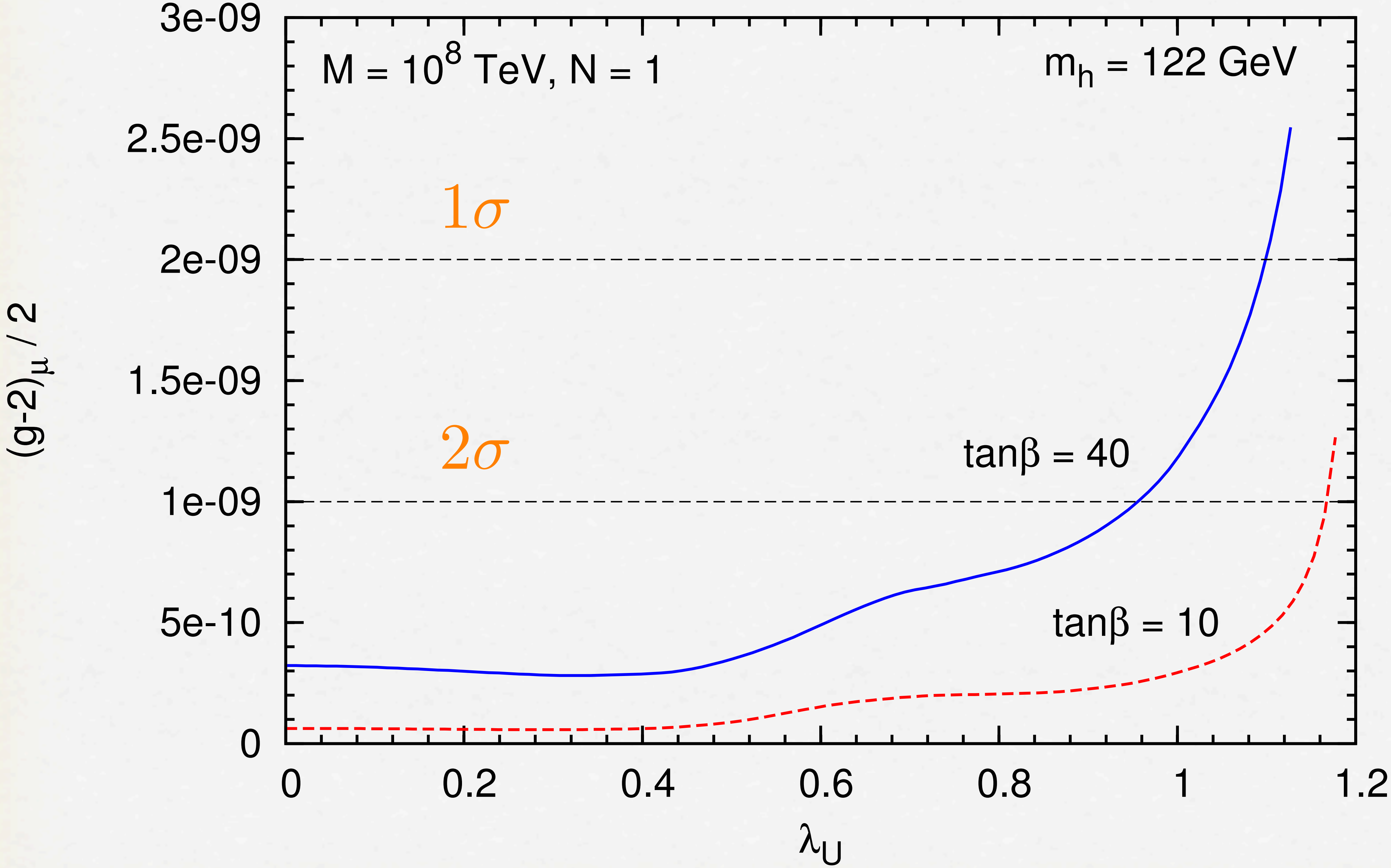
	$(\Phi_{D,T})_i$	$(\overline{\Phi}_{D,T})_i$	$(\Phi_D)_1$	$(\overline{\Phi}_D)_1$	$(\Phi_T)_1$	$(\overline{\Phi}_T)_1$	H_u	H_d	X	Q
U(1)	0	0	1	-1	0	0	1	1	0	$-1/2$

$$W = X \sum_{\alpha=1}^{N} (\overline{\Phi}_{D,T})_\alpha (\Phi_{D,T})_\alpha + (y_U)_{ij} Q_i U_j H_u + (y_D)_{ij} Q_i D_j H_d + (y_E)_{ij} L_i E_j H_d$$
$$+ (\lambda_U)_{ij} Q_i U_j \Phi_D$$

ORIGIN OF A-TERMS



G-2



also: Evans & al. ‘12

FULL FLAVOR STRUCTURE

$$\Delta m_U^2 \sim \frac{1}{(16\pi^2)^2}\frac{F^2}{M^2}\left(g^2\lambda_U^\dagger\lambda_U + \lambda_U^\dagger Y_U Y_U^\dagger \lambda_U + \lambda_U^\dagger\lambda_U\lambda_U^\dagger\lambda_U + Y_U^\dagger\lambda_U\lambda_U^\dagger Y_U\right)$$

$$\Delta m_Q^2 \sim \frac{1}{(16\pi^2)^2}\frac{F^2}{M^2}\left(g^2\lambda_U\lambda_U^\dagger + \lambda_U Y_U^\dagger Y_U \lambda_U^\dagger + \lambda_U\lambda_U^\dagger\lambda_U\lambda_U^\dagger + Y_U\lambda_U^\dagger\lambda_U Y_U^\dagger\right)$$

$$A_u \sim -\frac{1}{16\pi^2}\frac{F}{M}\left(\lambda_U\lambda_U^\dagger Y_u + Y_u\lambda_U^\dagger\lambda_U\right)$$

$$A_u^{eff} \sim -\frac{1}{16\pi^2}\frac{F}{M}\lambda_U\lambda_U^\dagger\left(\lambda_U\lambda_U^\dagger Y_u + Y_u\lambda_U^\dagger\lambda_U\right)\lambda_U^\dagger\lambda_U$$

$$(\delta^u_{RR})_{12} \sim (\lambda_U^*)_{31}(\lambda_U)_{32} \qquad (\delta^u_{LR})^{eff}_{11} \sim (\lambda_U)_{13}(\lambda_U)_{31}$$

$$(\delta^u_{LR})^{eff}_{12} \sim (\lambda_U)_{13}(\lambda_U)_{32}$$

BOUNDS ON MASS INSERTIONS

$(\delta^D_{XX})_{12}$	9.2×10^{-2} [Re]	1.2×10^{-2} [Im]
$\langle\delta^D_{12}\rangle$	1.9×10^{-3} [Re]	2.6×10^{-4} [Im]
$(\delta^D_{LR})_{12}$	5.6×10^{-3} [Re]	4.0×10^{-5} [Im]
$(\delta^U_{XX})_{12}$	1.0×10^{-1} [Re]	6.0×10^{-2} [Im]
$\langle\delta^U_{12}\rangle$	6.2×10^{-3} [Re]	4.0×10^{-3} [Im]
$(\delta^U_{LR})_{12}$	1.6×10^{-2} [Re]	1.6×10^{-2} [Im]
$(\delta^D_{XX})_{13}$	2.8×10^{-1} [Re]	6.0×10^{-1} [Im]
$\langle\delta^D_{13}\rangle$	4.2×10^{-2} [Re]	1.8×10^{-2} [Im]
$(\delta^D_{LR})_{13}$	6.6×10^{-2} [Re]	1.5×10^{-1} [Im]
$(\delta^D_{LR})_{11}$	2.0×10^{-6}	
$(\delta^U_{LR})_{11}$	3.0×10^{-6}	
$(\delta^E_{LL})_{12}$	2.8×10^{-3}	[5.7×10^{-4}]
$(\delta^E_{RR})_{12}$	2.3×10^{-2}	[4.6×10^{-3}]
$\langle\delta^E_{12}\rangle$	1.8×10^{-3}	[3.8×10^{-4}]
$(\delta^E_{LR})_{12}$	1.7×10^{-5}	[3.4×10^{-6}]

U(1) FLAVOR MODELS

$$\theta_{13}^{uL} \sim V_{ub} \sim \lambda^3$$

$$\theta_{13}^{uR} \sim \frac{m_u}{m_t|V_{ub}|} \sim \lambda^{4\div 5}$$

$$\theta_{23}^{uL} \sim V_{cb} \sim \lambda^2$$

$$\theta_{23}^{uR} \sim \frac{m_c}{m_t|V_{cb}|} \sim \lambda^{1\div 2}$$

↓

$$(\delta_{LR}^u)_{12} \approx 4 \times 10^{-4}$$

ΔA_{CP} in slight conflict with EDMs

Hiller, Nir '12

FLAVOR PHENOMENOLOGY

$\lambda \approx 0.23$

2 possible scenarios

A) $\theta_{23}^{uR} \sim \mathcal{O}(1) \qquad \theta_{13}^{uL} \sim \lambda^3 \qquad \theta_{13}^{uR} \lesssim \lambda^{4\div5}$

B) $\theta_{13}^{uR} \sim \lambda \qquad \theta_{23}^{uL} \sim \lambda^2 \qquad \theta_{13}^{uL} \lesssim \lambda^{6\div7} \qquad \theta_{23}^{uR} \lesssim \lambda$

Predict effects in chargino mediated ΔS=1 decays

$$BR(B_d \to \mu^+\mu^-) \sim \theta_{13}^{uL}$$
$$BR(B_s \to \mu^+\mu^-) \sim \theta_{23}^{uL}$$

$$BR(K \to \pi\nu\overline{\nu}) \sim \theta_{13}^{uL}\theta_{23}^{uL}$$

in progress...