Planck 2013

Bonn, May 22nd 2013

Gauge Mediation beyond Minimal Flavor Violation

Lorenzo Calibbi

ULB

based on arXiv:1304.1453, with Paride Paradisi and Robert Ziegler

Summary

• Gauge mediation (GM) is a predictive framework of communication of SUSY breaking to the visible sector, which is calculable in terms of few parameters

• A 126 GeV Higgs mass challenges minimal models of gauge mediation

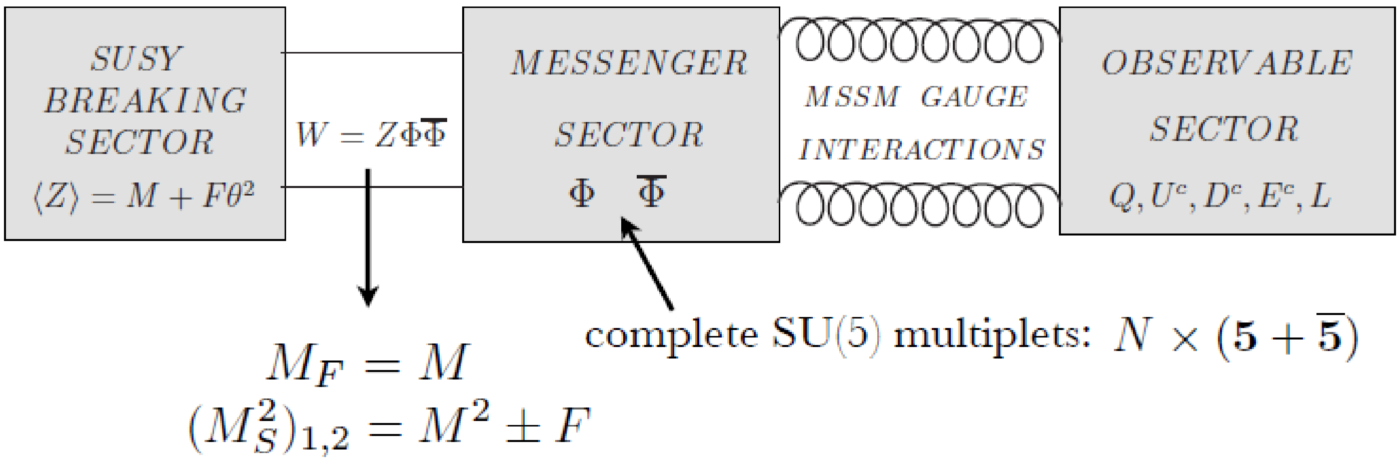
• Introducing GM messenger–matter couplings easily solves the problem

• The new couplings induce additional contributions to sfermion masses that can spoil the Minimal Flavor Violating structure of GM

• The departure from MFV is under control if the new couplings originate from the same flavor dynamics that gives rise to the Yukawa couplings

• This allows to embed simple flavor model (e.g. FN U(1)) in GM obtaining a built-in suppression of $\Delta F=2$ processes but still interesting deviations from MFV (e.g. large CP violation in charm decays).

Gauge-mediated SUSY breaking



$$M_i(M) = N \frac{\alpha_i(M)}{4\pi}\,\Lambda, \qquad \Lambda = \frac{F}{M},$$

$$m^2_{\tilde{f}}(M) = 2N \sum_{i=1}^{3} C_i(f)\,\frac{\alpha_i^2(M)}{(4\pi)^2}\,\Lambda^2, \qquad f = q,\, u,\, d, \ldots,$$

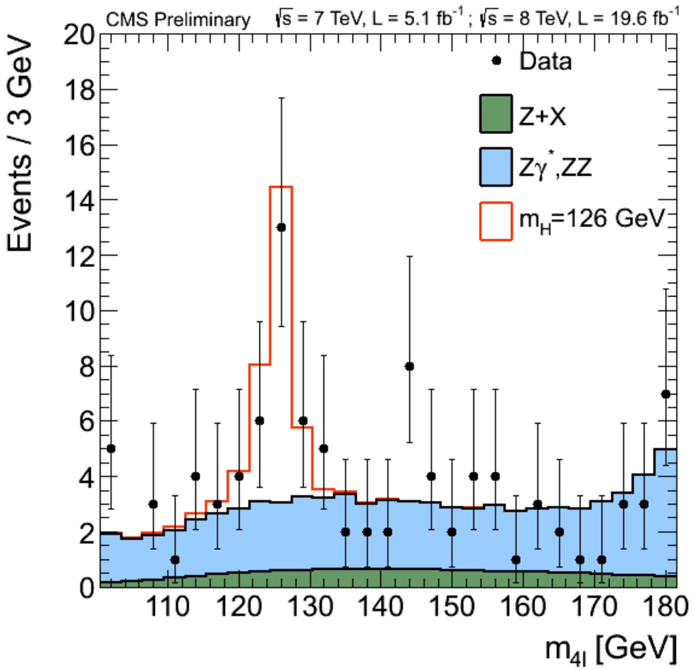
A-terms vanish at the mediation scale

Sfermion masses flavor universal → MFV at low energy

see Djouadi's talk

1-loop top-stop contribution (tree-level $m_h \leq M_Z$):

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



SUSY scale: $M_S \equiv \sqrt{\tilde{m}_{t_1}\tilde{m}_{t_2}}$

Stop LR mixing: $X_t \equiv A_t - \mu \cot\beta$

Maximized for: $|X_t/M_S| \approx \sqrt{6}$

Minimal GM, RGEs induce up to:

$$|A_t| \approx 0.5 \times M_S$$

⇨ heavy stops (3÷4TeV) required!

A solution: "Yukawa deflection"

Messengers have same quantum numbers of MSSM superfields.

Example: $5+\overline{5} \rightarrow H_u, H_d$

If no symmetry is introduced messenger-matter couplings are there!

⇒ New contributions to soft masses & A-terms at 1-loop

Dine Nir Shirman '96
Giudice Rattazzi '97
Chacko Ponton '01
...

Messengers in $5+\overline{5}$:

$$\Delta W = (\lambda_U)_{ij} Q_i U_j \Phi_{H_u} + (\lambda_D)_{ij} Q_i D_j \overline{\Phi}_{H_d} + (\lambda_E)_{ij} L_i E_j \overline{\Phi}_{H_d} + \frac{1}{2}(\kappa_{QQ})_{ij} Q_i Q_j \Phi_T + (\kappa_{UE})_{ij} U_i E_j \Phi_T + (\kappa_{QL})_{ij} Q_i L_j \overline{\Phi}_T + (\kappa_{UD})_{ij} U_i D_j \overline{\Phi}_T,$$

Extra symmetries can "shape" the superpotential

Messengers have same quantum numbers of MSSM superfields.

Example: $5+\overline{5} \rightarrow H_u, H_d$

If no symmetry is introduced messenger-matter couplings are there!

⇒ New contributions to soft masses & A-terms at 1-loop

Dine Nir Shirman '96
Giudice Rattazzi '97
Chacko Ponton '01
...

Example:

$$\Delta W = X\overline{\Phi}\Phi + (\lambda_U)_{ij} Q_i U_j \Phi_{H_u}$$

$$A_U = -\frac{\Lambda}{16\pi^2}\left(\lambda_U \lambda_U^\dagger y_U + 2\, y_U \lambda_U^\dagger \lambda_U\right)$$

$$A_D = -\frac{\Lambda}{16\pi^2}\,\lambda_U \lambda_U^\dagger y_D$$

The generated A_t can easily account for

$$m_h \approx 126 \text{ GeV}$$

Evans Ibe Yanagida '11, '12;
Kang et al. '12; Craig et al. '12;
Albeid Babu '12; Abdullah et al. '12;
Evans Shih '13

Flavor structure

$$\Delta W = X\overline{\Phi}\Phi + (\lambda_U)_{ij} Q_i U_j \Phi_{H_u}$$

New 2-loop contributions:

$$\Delta\tilde{m}^2_E = \Delta\tilde{m}^2_L = 0,$$

$$\Delta\tilde{m}^2_U = \frac{\Lambda^2}{128\pi^4}\Big[-\Big(\frac{13}{15}g_1^2 + 3g_2^2 + \frac{16}{3}g_3^2\Big)\lambda_U^\dagger\lambda_U + \lambda_U^\dagger y_U y_U^\dagger \lambda_U + \lambda_U^\dagger y_D y_D^\dagger \lambda_U$$
$$+ 3\,\lambda_U^\dagger\lambda_U\lambda_U^\dagger\lambda_U + 3\,\lambda_U^\dagger\lambda_U \mathrm{Tr}\,\lambda_U\lambda_U^\dagger - y_U^\dagger\lambda_U\lambda_U^\dagger y_U + 6 y_U^\dagger\lambda_U \mathrm{Tr}\, y_U\lambda_U^\dagger\Big],$$

$$\Delta\tilde{m}^2_D = -\frac{\Lambda^2}{128\pi^4} y_D^\dagger\lambda_U\lambda_U^\dagger y_D,$$

$$\Delta\tilde{m}^2_Q = \frac{\Lambda^2}{256\pi^4}\Big[-\Big(\frac{13}{15}g_1^2 + 3g_2^2 + \frac{16}{3}g_3^2\Big)\lambda_U\lambda_U^\dagger + 3\,\lambda_U\lambda_U^\dagger\lambda_U\lambda_U^\dagger + 3\,\lambda_U\lambda_U^\dagger \mathrm{Tr}\lambda_U\lambda_U^\dagger$$
$$+ 2\,\lambda_U y_U^\dagger y_U \lambda_U^\dagger - 2\, y_U\lambda_U^\dagger\lambda_U y_U^\dagger + 6 y_U\lambda_U^\dagger \mathrm{Tr}\,\lambda_U y_U^\dagger\Big],$$

$$\Delta m^2_{H_u} = -\frac{3\Lambda^2}{256\pi^4}\Big[2\,\mathrm{Tr}\, y_U\lambda_U^\dagger\lambda_U y_U^\dagger + \mathrm{Tr}\,\lambda_U\lambda_U^\dagger y_U y_U^\dagger\Big],$$

$$\Delta m^2_{H_d} = -\frac{3\Lambda^2}{256\pi^4}\mathrm{Tr}\,\lambda_U\lambda_U^\dagger y_D y_D^\dagger,$$

at the scale M

If λ_U anarchical matrix → flavor structure of GM completely spoiled

"Flavored Gauge Mediation"

Possible solution:

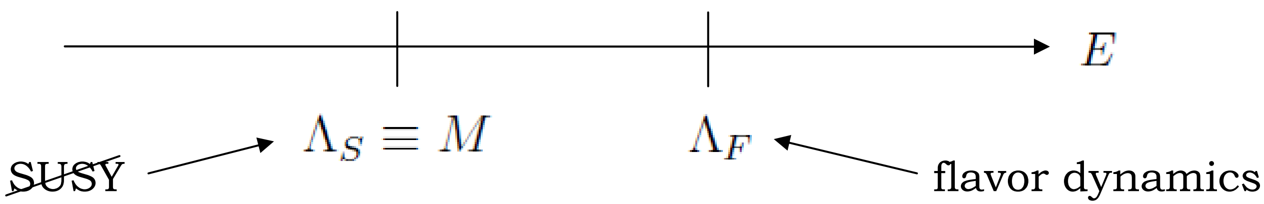
Shadmi Szabo '11

assuming λ_U controlled by the same dynamics that generate the Yukawas (e.g. same transformation properties of Φ and H_u under the FN flavor group)

$$(\lambda_U)_{ij} \sim (y_U)_{ij}, \quad (\lambda_D)_{ij} \sim (y_D)_{ij}, \quad (\lambda_E)_{ij} \sim (y_E)_{ij}$$

same hierarchical structure, but not aligned

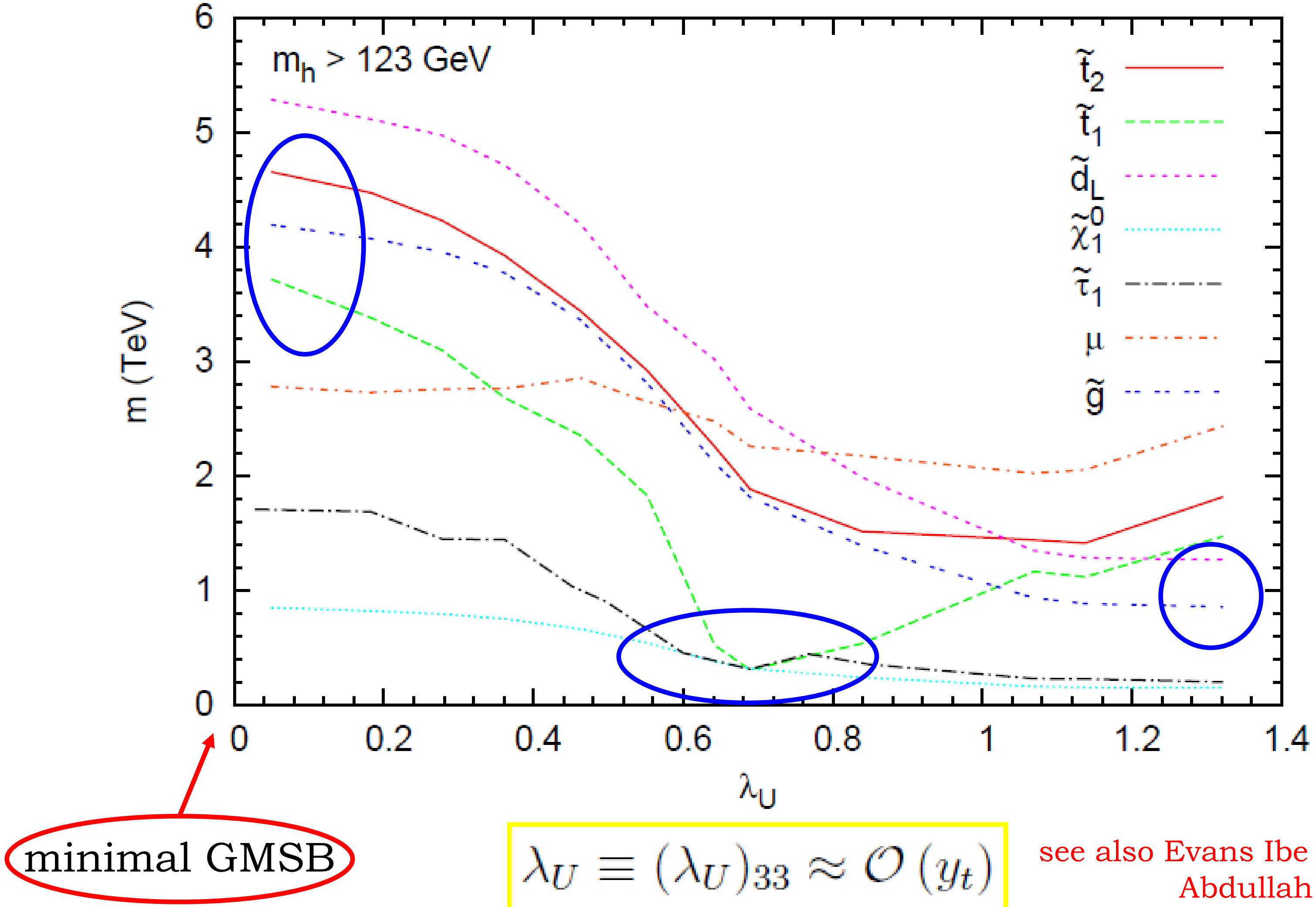
Scales:



- Framework suitable to embed models of flavor in gauge mediation
- Soft masses affected only through λ_U
- Departure from MFV under control, due to the loop origin of soft masses
- Just one additional parameter controls the spectrum deformation, "λ_t"

Lower bounds on SUSY masses

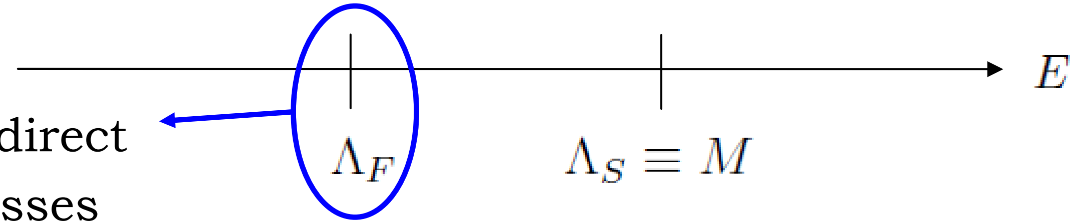
Imposing $m_h = (126 \pm 3)$ GeV ← theo uncert.



$$\lambda_U \equiv (\lambda_U)_{33} \approx \mathcal{O}(y_t)$$

see also Evans Ibe Yanagida '11, '12; Abdullah et al. '12

Comparison with flavor models



Flavor dynamics direct controls soft masses

Examples: Froggatt-Nielsen U(1), Partial Compositeness (PC)

$$(y_U)_{ij} \sim \epsilon^{Q_i+U_j} \qquad (y_D)_{ij} \sim \epsilon^{Q_i+D_j}$$

$K-\bar{K}$

$$\epsilon_K \sim (\delta^d_{LL})_{12}(\delta^d_{RR})_{12}$$

see Pokorski's talk

Keren-Zur et al. '12

U(1)

$$\epsilon^{q_1-q_2}\,\epsilon^{d_1-d_2} \sim \frac{y_d}{y_s}$$

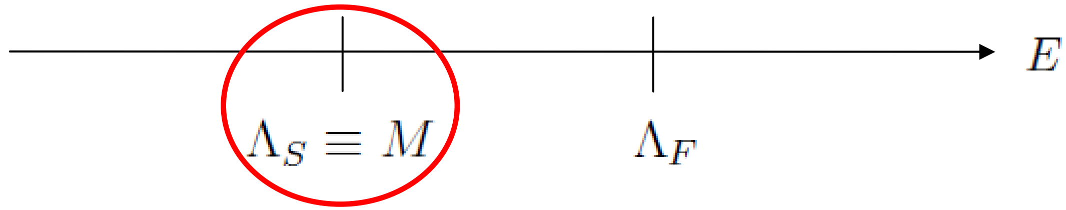
$$\tilde{m} \gtrsim \mathcal{O}(100)\ \text{TeV}$$

PC

$$\epsilon^{q_1+q_2}\,\epsilon^{d_1+d_2} \sim y_d\, y_s$$

$$\tilde{m} \gtrsim \mathcal{O}(1)\ \text{TeV}$$

Comparison with flavor models



In our case the flavor dynamics controls the soft terms only indirectly (via λs):

$$A_U \sim \lambda_D \lambda_D^\dagger y_U + \lambda_U \lambda_U^\dagger y_U + y_U \lambda_U^\dagger \lambda_U, \qquad A_D \sim \lambda_D \lambda_D^\dagger y_D + \lambda_U \lambda_U^\dagger y_D + y_D \lambda_D^\dagger \lambda_D,$$

$$\Delta \tilde{m}_Q^2 \sim \lambda_U \lambda_U^\dagger, \qquad \Delta \tilde{m}_U^2 \sim \lambda_U^\dagger \lambda_U, \qquad \Delta \tilde{m}_D^2 \sim \lambda_D^\dagger \lambda_D.$$

Flavor violating effects depend on the flavour model but:

Even with a U(1) symmetry, the suppression is as strong as in PC!

$$\epsilon_K \sim (\delta^d_{LL})_{12} (\delta^d_{RR})_{12} \sim \epsilon^{q_1+q_2}\, \epsilon^{d_1+d_2} \sim y_d\, y_s$$

Loop origin of soft masses acts as wave function renormalization

Comparison with flavor models

CKM

$\lambda_U,\ \lambda_D$ model

λ_U model

	MFV	PC	$U(1)$	$\text{FGM}_{U,D} + U(1)$	$\text{FGM}_U + U(1)$
$(\delta^u_{LL})_{ij}$	$V_{i3}V^*_{j3}y_b^2$	$V_{i3}V^*_{j3}(\epsilon^q_3)^2$	$\frac{V_{i3}}{V_{j3}}\vert_{i\leq j}$	$V_{i3}V^*_{j3}$	$V_{i3}V^*_{j3}$
$(\delta^d_{LL})_{ij}$	$V^*_{3i}V_{3j}$	$V^*_{3i}V_{3j}(\epsilon^q_3)^2$	$\frac{V_{i3}}{V_{j3}}\vert_{i\leq j}$	$V^*_{3i}V_{3j}$	$V^*_{3i}V_{3j}$
$(\delta^u_{RR})_{ij}$	$y^U_i y^U_j V_{i3}V^*_{j3}y_b^2$	$\frac{y^U_i y^U_j}{V_{i3}V^*_{j3}}(\epsilon^u_3)^2$	$\frac{y^U_i V_{j3}}{y^U_j V_{i3}}\vert_{i\leq j}$	$\frac{y^U_i y^U_j}{V_{i3}V^*_{j3}}$	$\frac{y^U_i y^U_j}{V_{i3}V^*_{j3}}$
$(\delta^d_{RR})_{ij}$	$y^D_i y^D_j V^*_{3i}V_{3j}$	$\frac{y^D_i y^D_j}{V^*_{3i}V_{3j}}(\epsilon^u_3)^2$	$\frac{y^D_i V_{j3}}{y^D_j V_{i3}}\vert_{i\leq j}$	$\frac{y^D_i y^D_j}{V^*_{3i}V_{3j}}$	$y^D_i y^D_j V^*_{3i}V_{3j}$
$(\delta^u_{LR})_{ij}$	$y^U_j V_{i3}V^*_{j3}y_b^2$	$y^U_j \frac{V_{i3}}{V^*_{j3}}$	$y^U_j \frac{V_{i3}}{V^*_{j3}}$	$y^U_j (V_{i3}V^*_{j3} + \frac{y^U_i y^U_i}{V_{i3}V^*_{j3}})$ $y^U_j \frac{V_{i3}}{V^*_{j3}}$	$y^U_j (V_{i3}V^*_{j3} + \frac{y^U_i y^U_i}{V_{i3}V^*_{j3}})$ $y^U_j \frac{V_{i3}}{V^*_{j3}}$
$(\delta^d_{LR})_{ij}$	$y^D_j V^*_{3i}V_{3j}$	$y^D_j \frac{V^*_{3i}}{V_{3j}}$	$y^D_j \frac{V_{i3}}{V^*_{j3}}$	$y^D_j (V^*_{3i}V_{3j} + \frac{y^D_i y^D_i}{V^*_{3i}V_{3j}})$ $y^D_j \frac{V^*_{3i}}{V_{3j}} y_b^2$	$y^D_j V^*_{3i}V_{3j}$

LL and RR suppressed as much as in partial compositeness (or even MFV)

Application: CP violation in charm decays

ΔF=2 processes are suppressed and FCNC mainly arise from LR up-sector

"Disoriented" A-terms naturally realized:

$$A^U_{ij} \sim y^U_{ij} \quad \text{but} \quad A^U_{ij} \not\propto y^U_{ij}$$

Giudice Isidori Paradisi '12

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

see Masiero's talk

$$a_f \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}, \quad f = K^+K^-, \pi^+\pi^-$$

$$\Delta a_{CP} \equiv a_{K^+K^-} - a_{\pi^+\pi^-} = -(0.68 \pm 0.15)\%$$

LHCb '11, CDF '12

Model prediction:

$$(\delta^u_{LR})^{eff}_{ij} \sim \frac{m_t(A - y_t^2 \mu^* / \tan\beta)}{\tilde{m}_Q \tilde{m}_U} (\lambda_U)_{i3} (\lambda_U)_{3j}$$

Application: CP violation in charm decays

ΔF=2 processes are suppressed and FCNC mainly arise from LR up-sector

"Disoriented" A-terms naturally realized:

$$A^U_{ij} \sim y^U_{ij} \quad \text{but} \quad A^U_{ij} \not\propto y^U_{ij}$$

Giudice Isidori Paradisi '12

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

see Masiero's talk

$$a_f \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}, \quad f = K^+K^-, \pi^+\pi^-$$

$$\Delta a_{CP} \equiv a_{K^+K^-} - a_{\pi^+\pi^-} = -(0.33 \pm 0.12)\%$$

naive average after LHCb '13

Model prediction:

$$(\delta^u_{LR})^{eff}_{ij} \sim \frac{m_t(A - y_t^2\mu^*/\tan\beta)}{\tilde{m}_Q \tilde{m}_U} (\lambda_U)_{i3}(\lambda_U)_{3j}$$

ΔF=2 processes are suppressed and FCNC mainly arise from LR up-sector

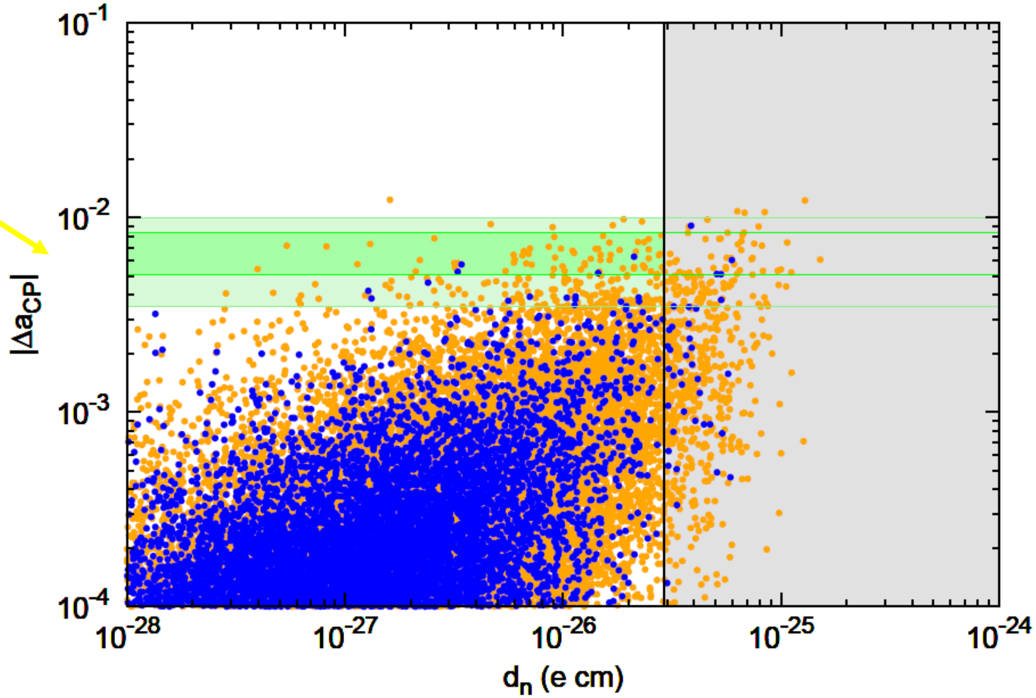
"Disoriented" A-terms naturally realized:

$$A^U_{ij} \sim y^U_{ij} \quad \text{but} \quad A^U_{ij} \not\propto y^U_{ij}$$

Giudice Isidori Paradisi '12

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

λ_U model + U(1) symm.



Easier than in PC: no flavor blind phases in soft terms!

Again my summary

• Gauge mediation (GM) is a predictive framework of communication of SUSY breaking to the visible sector, which is calculable in terms of few parameters

• A 126 GeV Higgs mass challenges minimal models of gauge mediation

• Introducing GM messenger–matter couplings easily solves the problem

• The new couplings induce additional contributions to sfermion masses that can spoil the Minimal Flavor Violating structure of GM

• The departure from MFV is under control if the new couplings originate from the same flavor dynamics that gives rise to the Yukawa couplings

• This allows to embed simple flavor model (e.g. FN U(1)) in GM obtaining a built-in suppression of $\Delta F=2$ processes and interesting deviations from MFV (e.g. large CP violation in charm decays).

λ_U-model setup

Messengers and Higgs distinguished by symmetry
that forbids mu-term: H chiral, **Φ** vectorlike

for N=1 only one messenger can couple to matter

- Forbid mu-term with U(1) (discrete subgroup)

	Φ_{H_u}	Φ_T	$\overline{\Phi}_{H_d}$	$\overline{\Phi}_T$	H_u	H_d	X	Q, U, D, E, L
$U(1)$	1	0	-1	0	1	1	0	$-1/2$

$$\begin{array}{c} \\ H_u \\ \Phi_{H_u} \end{array}\begin{array}{c} \begin{array}{cc} H_d & \overline{\Phi}_{H_d} \end{array} \\ \begin{pmatrix} 0 & X \\ 0 & X \end{pmatrix} \end{array} \xrightarrow{\text{redefine}} \begin{array}{c} \\ H'_u \\ \Phi'_{H_u} \end{array}\begin{array}{c} \begin{array}{cc} H_d & \overline{\Phi}'_{H_d} \end{array} \\ \begin{pmatrix} 0 & 0 \\ 0 & X \end{pmatrix} \end{array}$$

- Most general superpotential

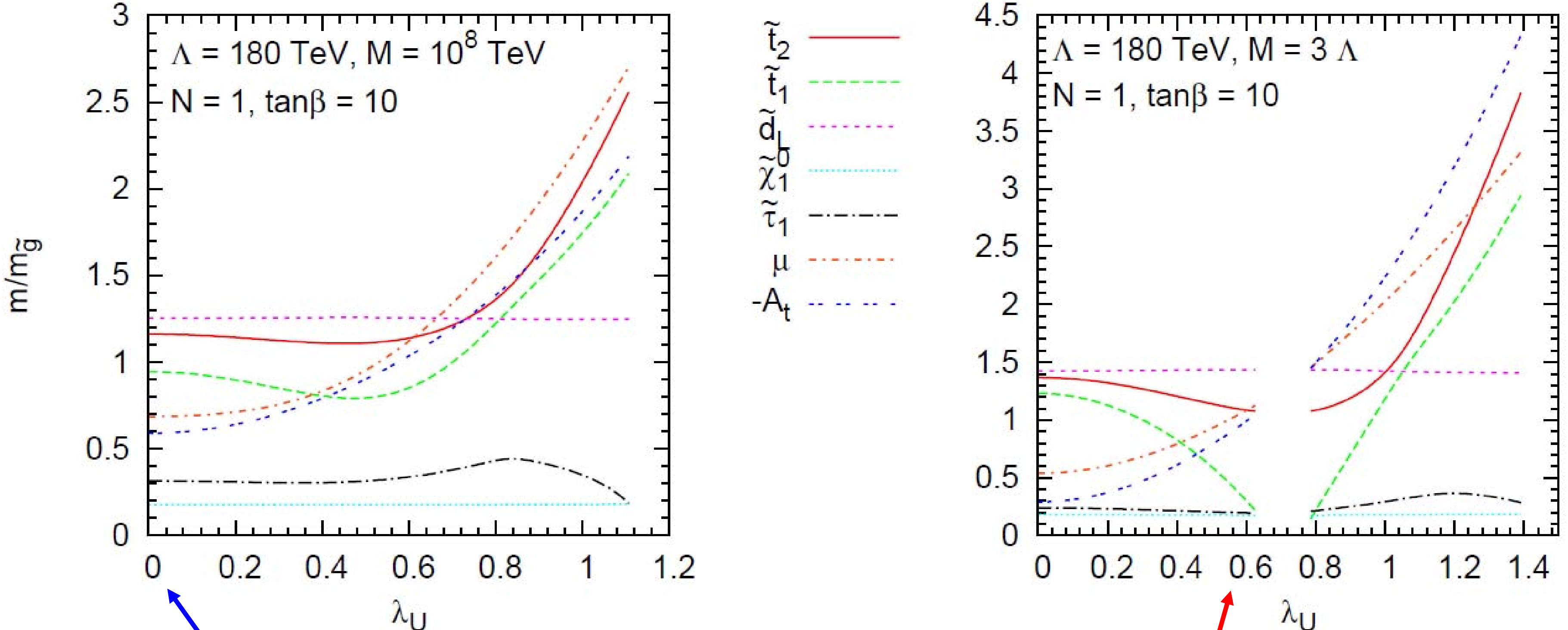
$$W = (y_U)_{ij} Q_i U_j H_u + (y_D)_{ij} Q_i D_j H_d + (y_E)_{ij} L_i E_j H_d$$
$$+ X\left(\overline{\Phi}_T \Phi_T + \overline{\Phi}_{H_d} \Phi_{H_u}\right) + (\lambda_U)_{ij} Q_i U_j \Phi_{H_u}$$

Spectrum deformation controlled by one parameter:

$$\lambda_U \equiv (\lambda_U)_{33} \approx \mathcal{O}(y_t)$$

see also Evans Ibe Yanagida '11, '12; Abdullah et al. '12

High-scale mediation: Low-scale mediation:



$\lambda_U = 0 \Longleftrightarrow$ minimal GM

negative 1-loop contr. effective

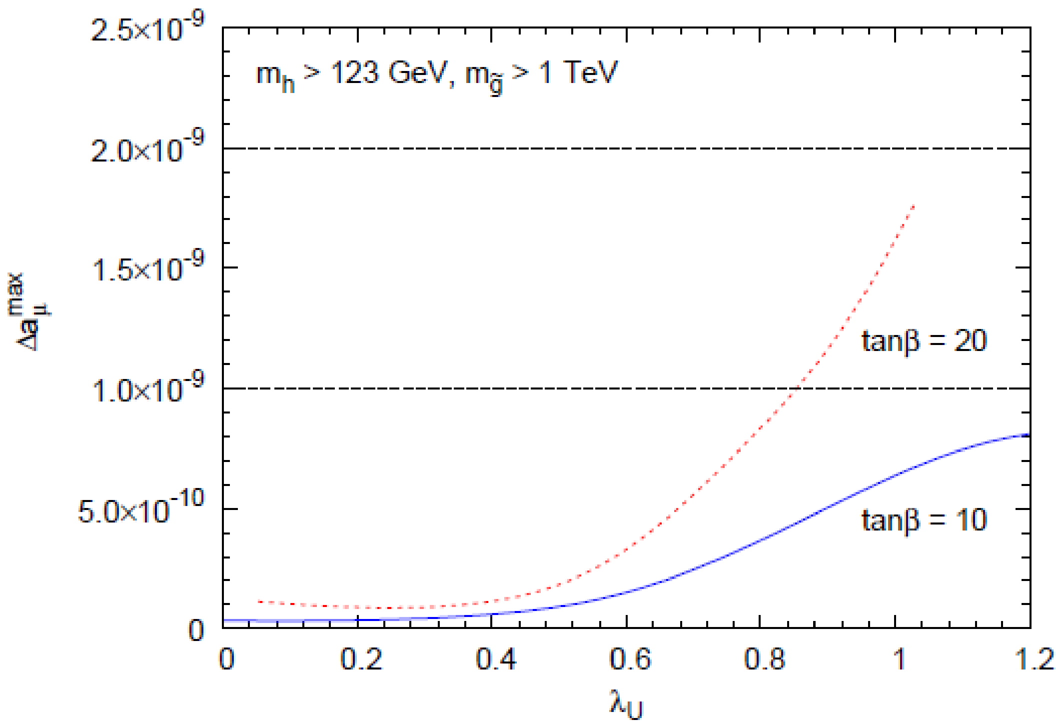
Slepton sector and g-2

$$16\pi^2 \frac{d}{dt}\tilde{m}^2_{L,E} \supset \frac{6}{5} g_1^2 \mathcal{Y}_{L,E} S \qquad\qquad S \sim \tilde{m}^2_{t_L} - 2\tilde{m}^2_{t_R}$$

Giudice Paradisi Strumia '12

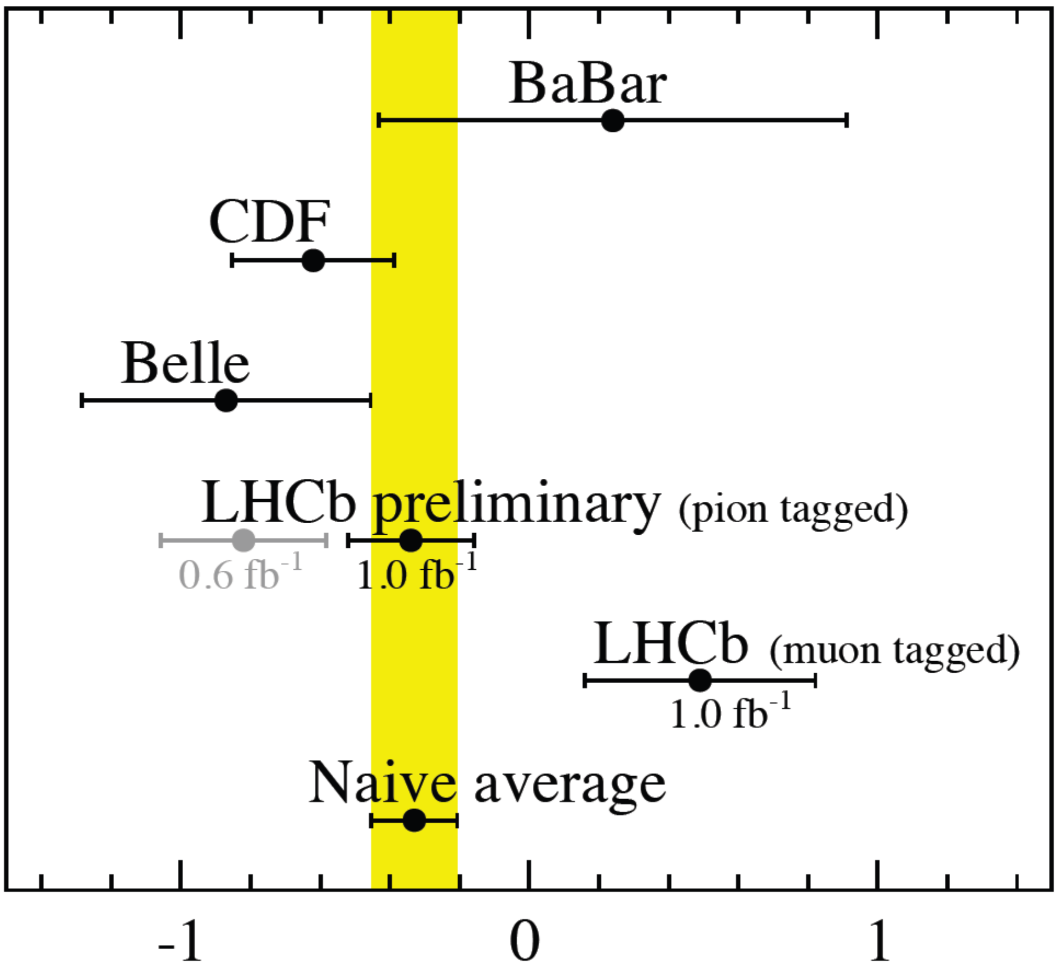
$$\mu \gg \tilde{m}_{\mu_L},\ \tilde{m}_{\mu_R}$$

$$\Delta a_\mu \approx 1 \times 10^{-9} \left(\frac{\tan\beta}{20}\right) \left(\frac{500\,\mathrm{GeV}}{\tilde{m}}\right)^2 \left(\frac{1}{8}\frac{10}{\mu/\tilde{m}} + \frac{\mu/\tilde{m}}{10}\right)$$



see also Evans et al. '12

Δa_{CP}: experimental situation



Naïve average*

$\Delta A_{CP} = (-0.33 \pm 0.12)\%$

*) Does not account for indirect CP violation.
No scaling of errors.

CERN-LHC seminar, 12 March 2013

Jeroen van Tilburg