Partially Composite *Supersymmetry*

Tony Gherghetta

UNIVERSITY OF MINNESOTA

Theory Institute in Particle Physics and Cosmology
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[Yusuf Buyukdag, TG, Andrew Miller: 1811.12388]

SUPERSYMMETRY:

complete theoretical framework for Beyond the Standard Model

- Stabilizes Planck/weak scale hierarchy
- Origin of electroweak symmetry breaking
- Dark matter
- Gauge coupling unification
- Low-energy limit of string theory

BUT where are the superpartners?!?

LHC:

gluino: $m_{\tilde{g}} \gtrsim 1970 \text{ GeV}$

stop: $m_{\tilde{t}} \gtrsim 1120\,\text{GeV}$

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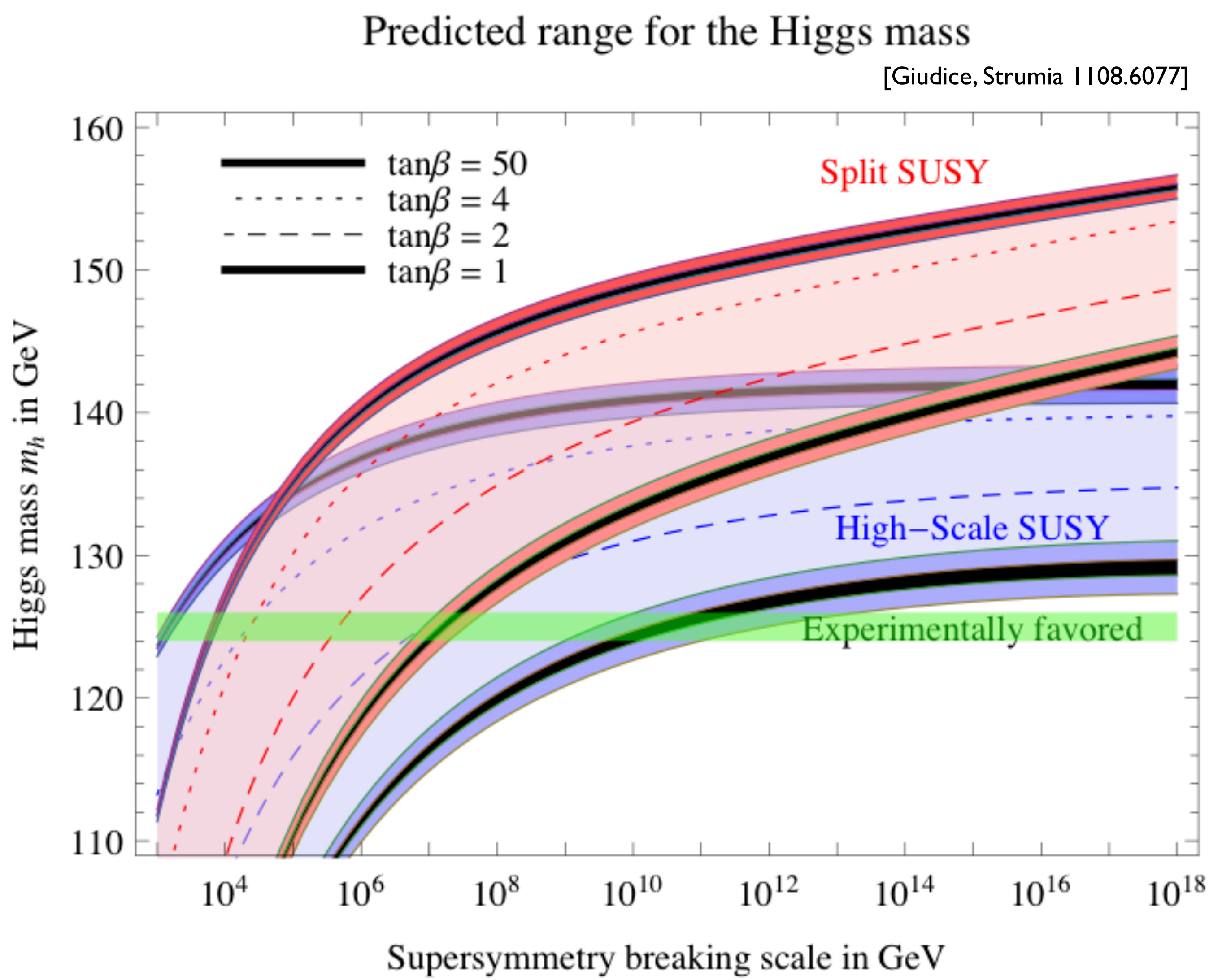
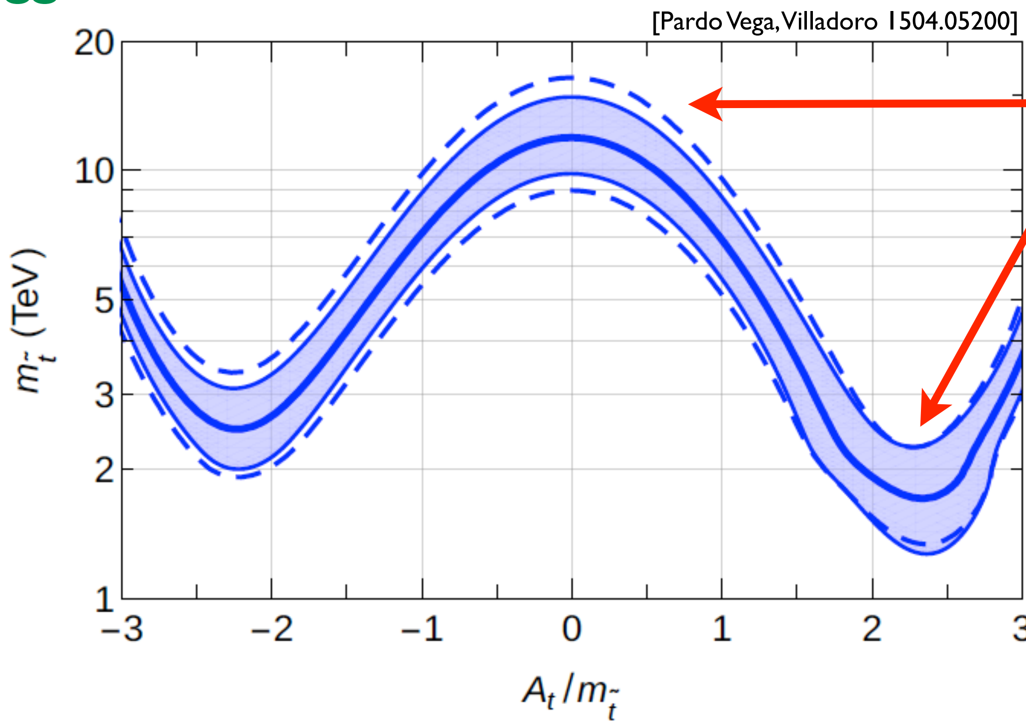


⇨ SUSY breaking scale $\lesssim 10^7$ GeV

Minimal SUSY requirements:

- Higgs mass



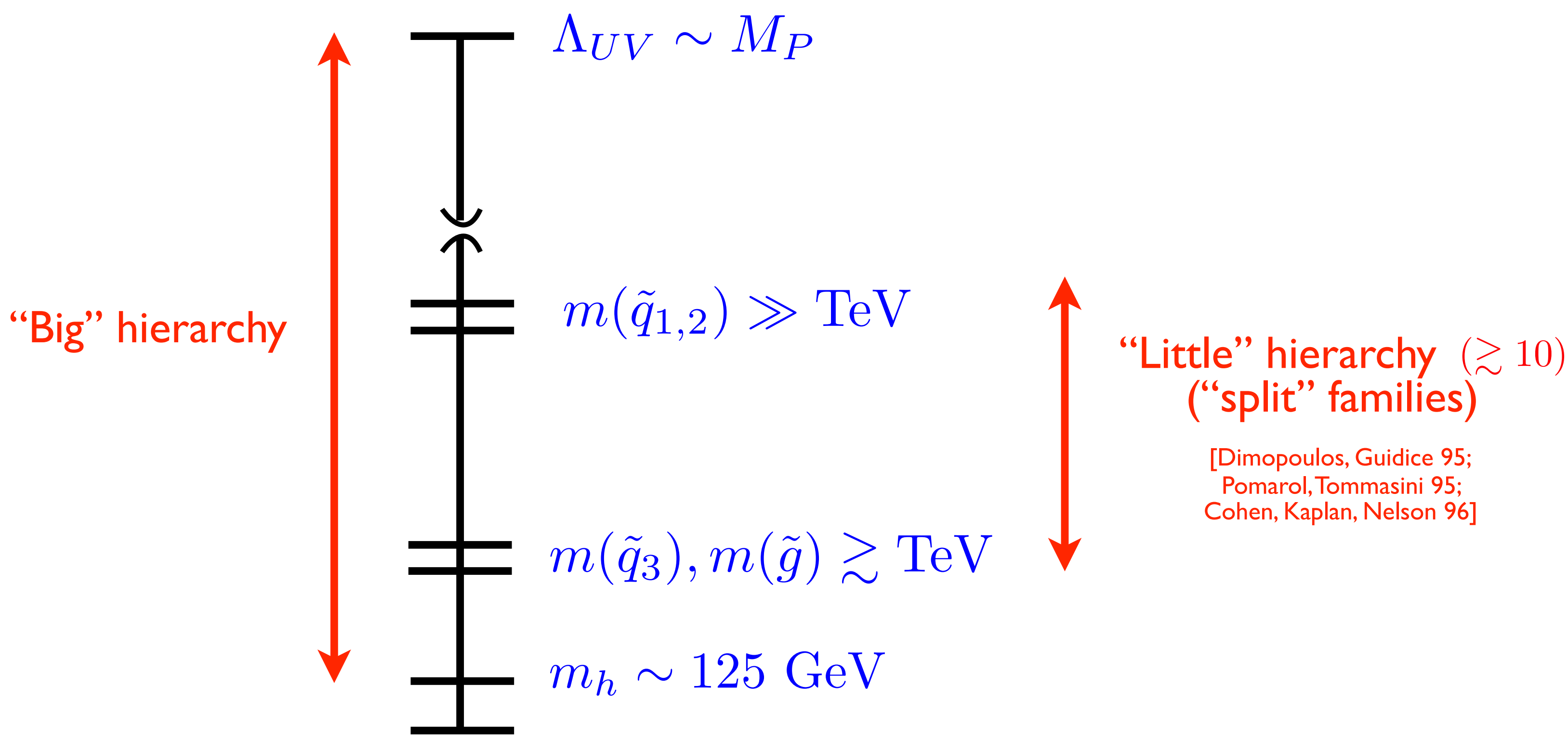
Requires ~10 TeV stops or large A-terms

- Supersymmetric flavor problem

$$\text{e.g. } \mathrm{K}-\bar{\mathrm{K}} \text{ mixing}: \quad \frac{\delta\tilde{m}^2_{ds}}{(10\ \mathrm{TeV})^2} \lesssim 10^{-2}\frac{(F/M)^3}{(10\ \mathrm{TeV})^3}$$

Requires heavy sfermions $\tilde{m}_{1,2} \gtrsim 100$ TeV

A possible minimal SUSY scenario:

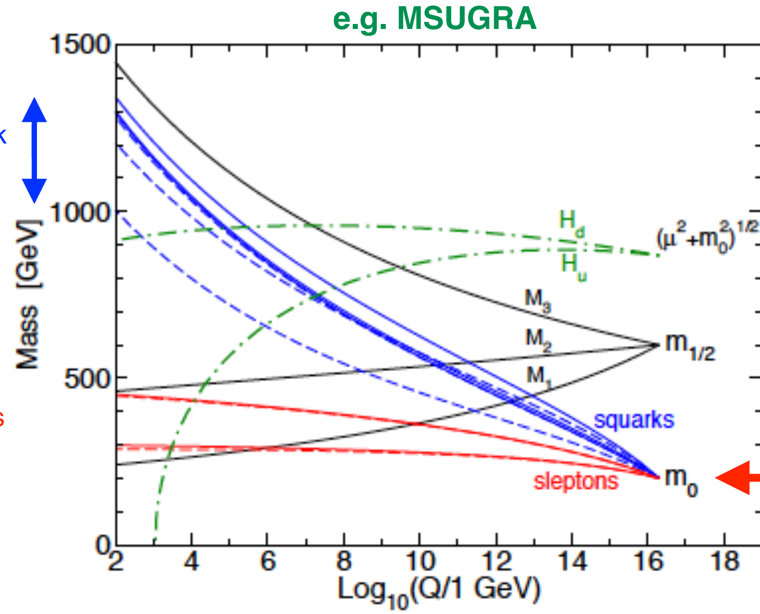


Can ***sfermion*** mass hierarchy $\left(\frac{\widetilde{m}_{1,2}}{\widetilde{m}_3} \gtrsim 10\right)$ be related to ***fermion*** mass hierarchy $\left(\frac{m_t}{m_{e,\mu}} \lesssim 10^5\right)$? *Yes!*

Pre-LHC

small squark hierarchy

light sleptons

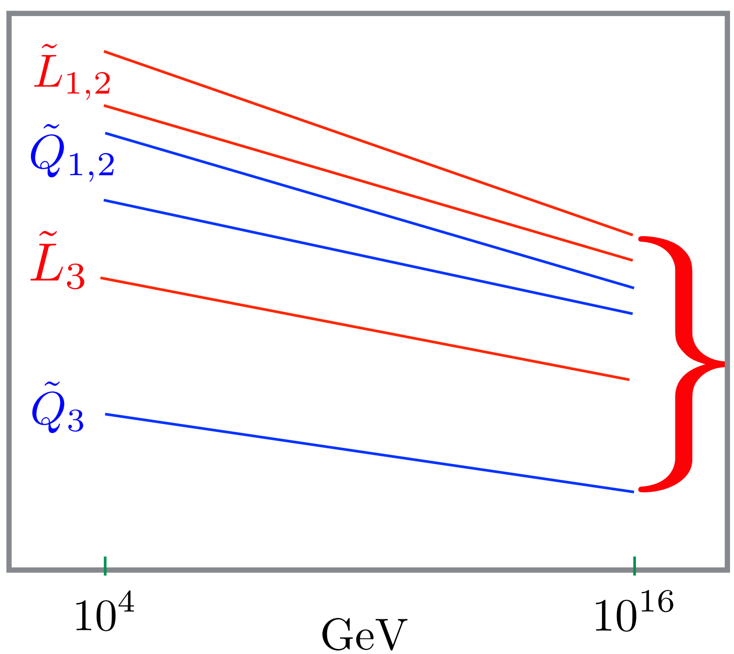


Universal boundary condition

Post LHC

heavy sleptons

large squark hierarchy



Flavor-dependent boundary conditions!

→ Determined by fermion masses!

[Related ideas: Dudas, Grojean, Pokorski, Savoy '96; Nelson, Strassler '00; Badziak, Dudas, Olechowski, Pokorski '12]

Partial Compositeness [Kaplan 91]

SM gauge field, Higgs and matter

A_μ, H, Ψ_i

strongly-coupled sector

$\mathcal{O}_i$

$$\mathcal{L}_{mix} = \lambda_F \Psi \mathcal{O}_\Psi + g_V A^\mu J_\mu$$

relative admixture controlled by dim $\mathcal{O}_i$

$$|\psi\rangle \sim a_e|\text{elementary}\rangle + a_c|\text{composite}\rangle$$

couples to elementary Higgs

couples to supersymmetry breaking from strong dynamics

Cases:

$a_e \gg a_c$ ⟶ $\dim(\Psi\mathcal{O}_\Psi) > 4$ "irrelevant" mixing

$a_e \ll a_c$ ⟶ $\dim(\Psi\mathcal{O}_\Psi) < 4$ "relevant" mixing

[Similar to $\gamma - \rho$ mixing which explains $\rho \to e^+e^-$ in QCD!]

Example: Fermion mixing

$$\mathcal{L}_\psi = i\psi^\dagger\bar{\sigma}^\mu\partial_\mu\psi - \frac{1}{\Lambda_{\rm UV}^{\delta-1}}\left(\psi\mathcal{O}_\psi^c + h.c.\right) \qquad (\dim\ \mathcal{O}_\psi^c = \frac{3}{2} + \delta)$$

anomalous dimension

$\Lambda_{IR} \ll \Lambda_{UV}$

$$\mathcal{L}_\psi = i\psi^\dagger\bar{\sigma}^\mu\partial_\mu\psi + i\psi^{\dagger(1)}\bar{\sigma}^\mu\partial_\mu\psi^{(1)} + i\psi^{\dagger c(1)}\bar{\sigma}^\mu\partial_\mu\psi^{c(1)}$$
$$- \varepsilon_\psi\Lambda_{\rm IR}\left(\psi\psi^{c(1)} + h.c.\right) - m_\psi^{(1)}\left(\psi^{(1)}\psi^{c(1)} + h.c.\right)$$

mass mixing!

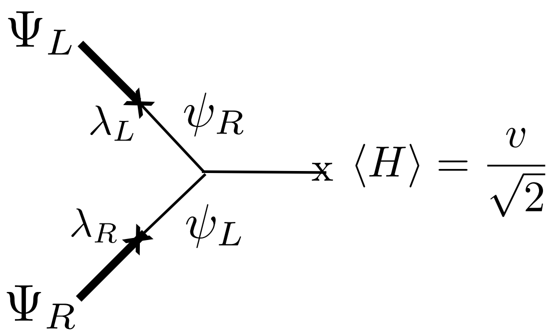
ε_ψ: Depends on δ

$m_\psi^{(1)} = g_\psi^{(1)}\Lambda_{\rm IR}$

$$|\psi_0\rangle \simeq \mathcal{N}_\psi\left\{|\psi\rangle - \frac{\varepsilon_\psi}{g_\psi^{(1)}}|\psi^{(1)}\rangle\right\}$$

Mass eigenstate is partially composite!

Explains the fermion mass hierarchy:



$$m_f \sim \lambda_L \lambda_R v$$

where $\lambda_{L,R} \sim \left(\frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}}\right)^{{\rm dim}\mathcal{O}_{L,R}-\frac{5}{2}}$

- Light fermions are mostly composite!

⇨ $\frac{3}{2} \leq {\rm dim}\ \mathcal{O}_{L,R} < \frac{5}{2}$ $\quad$ $({\rm or}\ 0 \leq \delta_{L,R} < 1)$ $\quad$ $({\rm dim}\ \mathcal{O}_{L,R} = \frac{3}{2} + \delta_{L,R})$

- Top quark is elementary

⇨ ${\rm dim}\ \mathcal{O}_{L.R} > \frac{5}{2}$ $\quad$ $({\rm or}\ \delta_{L,R} > 1)$

Supersymmetry breaking

Assume strong sector breaks supersymmetry: $\mathcal{X} = \theta\theta F_X$

GAUGINO:

linear supermultiplet $D^2\mathcal{J} = D^{\dagger 2}\mathcal{J} = 0$

$$\mathcal{L}_V = \left(\frac{1}{4}[W^\alpha W_\alpha]_F + h.c.\right) + 2\tilde{\varepsilon}_V [V\mathcal{J}]_D$$

$$\Rightarrow \quad |\lambda_0\rangle \simeq \mathcal{N}_V \left\{ |\lambda\rangle - \frac{1}{g_V^{(1)}\sqrt{2\zeta_V \log\left(\frac{\Lambda_{UV}}{\Lambda_{IR}}\right)}} |\lambda^{(1)}\rangle \right\}$$

← partially composite gaugino

SUSY breaking mass: $\frac{\xi_3}{2}\frac{g_V^{(1)2}}{\Lambda_{IR}}\left([\mathcal{X}W^{\alpha(1)}W_\alpha^{(1)}]_F + h.c.\right)$

$$\Rightarrow \quad M_\lambda \simeq \underbrace{g^2}_{\text{4D gauge coupling}} \xi_3 \frac{F_\mathcal{X}}{\Lambda_{IR}}$$

SFERMION:

$$\mathcal{L}_\Phi = \left[\Phi^\dagger\Phi\right]_D + \frac{1}{\Lambda_{\rm UV}^{\delta-1}}\left(\left[\Phi\mathcal{O}^c\right]_F + h.c.\right) \qquad (\dim\,\mathcal{O}^c = 1+\delta)$$

$$\Rightarrow \quad |\phi_0\rangle \simeq \mathcal{N}_\Phi\left\{|\phi\rangle - \frac{1}{g_\Phi^{(1)}\sqrt{\zeta_\Phi}}\sqrt{\frac{\delta-1}{\left(\frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}}\right)^{2(1-\delta)}-1}}\,|\phi^{(1)}\rangle\right\}$$

← partially composite sfermion

SUSY breaking: $\xi_4\frac{g_\Phi^{(1)2}}{\Lambda_{\rm IR}^2}\left[\mathcal{X}^\dagger\mathcal{X}\Phi^{(1)\dagger}\Phi^{(1)}\right]_D = \xi_4 g_\Phi^{(1)2}\frac{|F_\mathcal{X}|^2}{\Lambda_{\rm IR}^2}\phi^{(1)\dagger}\phi^{(1)}$

$$\Rightarrow \quad \widetilde{m}^2 \simeq \begin{cases} \frac{(\delta-1)}{\zeta_\Phi}\left(\frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}}\right)^{2(\delta-1)}\xi_4\frac{|F_\mathcal{X}|^2}{\Lambda_{\rm IR}^2} & \delta \geq 1 \\ \frac{(1-\delta)}{\zeta_\Phi}\xi_4\frac{|F_\mathcal{X}|^2}{\Lambda_{\rm IR}^2} & 0 \leq \delta < 1 \end{cases}$$

Hierarchical sfermion masses!

However for sufficiently large δ $\qquad \delta\widetilde{m}^2 \simeq \frac{g_i^2}{16\pi^2}M_{\lambda_i}^2$ $\qquad$ i.e. radiative corrections dominate

Critical value $(\delta\widetilde{m}^2 \simeq \widetilde{m}^2)$ $\qquad \delta^* \simeq 1 + \frac{\log\left(\frac{4\pi}{g_i}\log\left(\frac{\Lambda_{\rm UV}}{\Lambda_{\rm IR}}\right)\right)}{\log\left(\frac{\Lambda_{\rm UV}}{\Lambda_{\rm IR}}\right)}$

GRAVITINO:

$$-\frac{1}{4}\frac{W}{M_P^2}\,\psi_\rho\,[\sigma^\mu,\bar{\sigma}^\rho]\,\psi_\mu + h.c.$$

W = constant superpotential

$$\Rightarrow \quad m_{3/2} \simeq \xi_3 \frac{F_\chi}{\sqrt{3}M_P}$$

where $|F_\chi|^2 \frac{N}{16\pi^2} \simeq 3\frac{|W|^2}{M_P^2}$

HIGGSINO: [Kim, Nilles 84]

$$W_{KN} = \frac{\kappa_\mu}{2M_P} S^2 H_u H_d \quad \Rightarrow \quad \mu \simeq \frac{\kappa_\mu f^2}{2M_P}$$

where $\langle S \rangle \sim f$

Sfermion mass hierarchy:

$m_e \ll v$ ⇨ "relevant" mixing $(0 < \delta_e < 1)$ → "composite" electron

$m_t \sim v$ ⇨ "irrelevant" mixing $(\delta_t > 1)$ → "elementary" top quark

Yukawa couplings at IR scale:

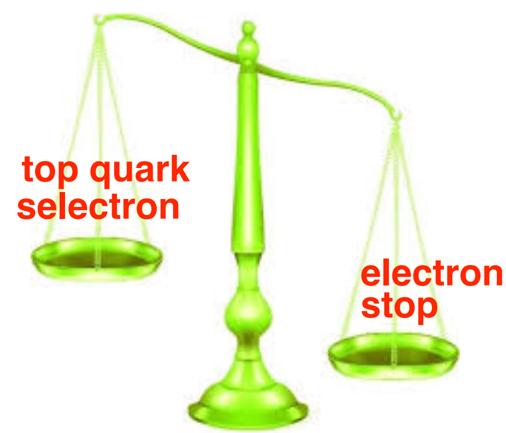
$$\frac{y_e}{y_t} \simeq \frac{1-\delta_e}{\delta_t - 1}\left(\frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}}\right)^{2(1-\delta_e)}$$

Partial compositeness explains Yukawa coupling hierarchy!

⇨

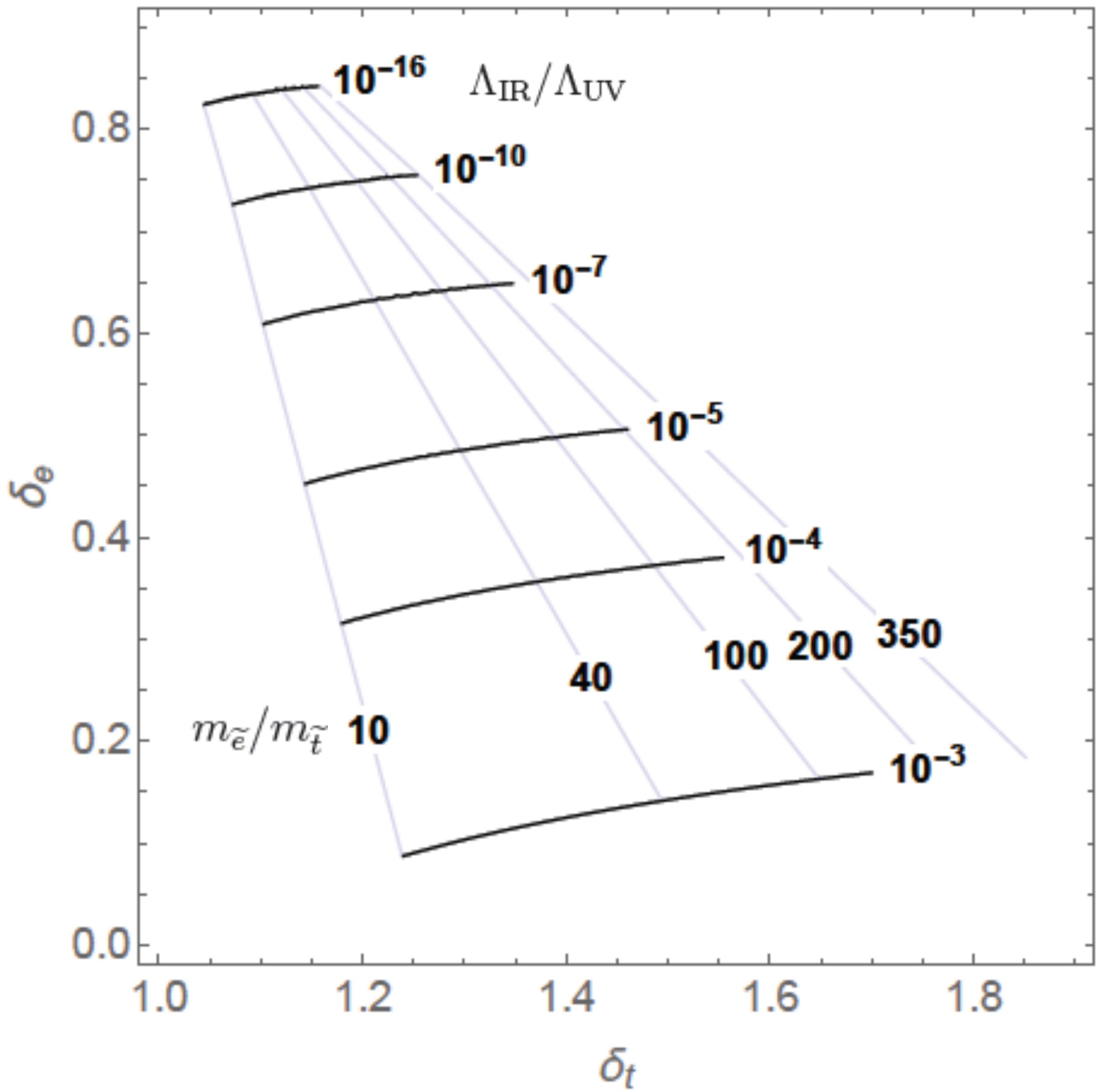
$$\frac{m^2_{\tilde{e}}}{m^2_{\tilde{t}}} = \begin{cases} \frac{1-\delta_e}{\delta_t-1}\left(\frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}}\right)^{2(1-\delta_t)} & \delta_t < \delta_t^* \,, \\ \frac{4\pi}{\alpha_3}(1-\delta_e)\log^2\left(\frac{\Lambda_{\rm UV}}{\Lambda_{\rm IR}}\right) & \delta_t \geq \delta_t^* \end{cases}$$

Partial compositeness predicts
inverted sfermion mass hierarchy!



Anomalous dimension contours

[Buyukdag, TG, Miller: 1812.12388]

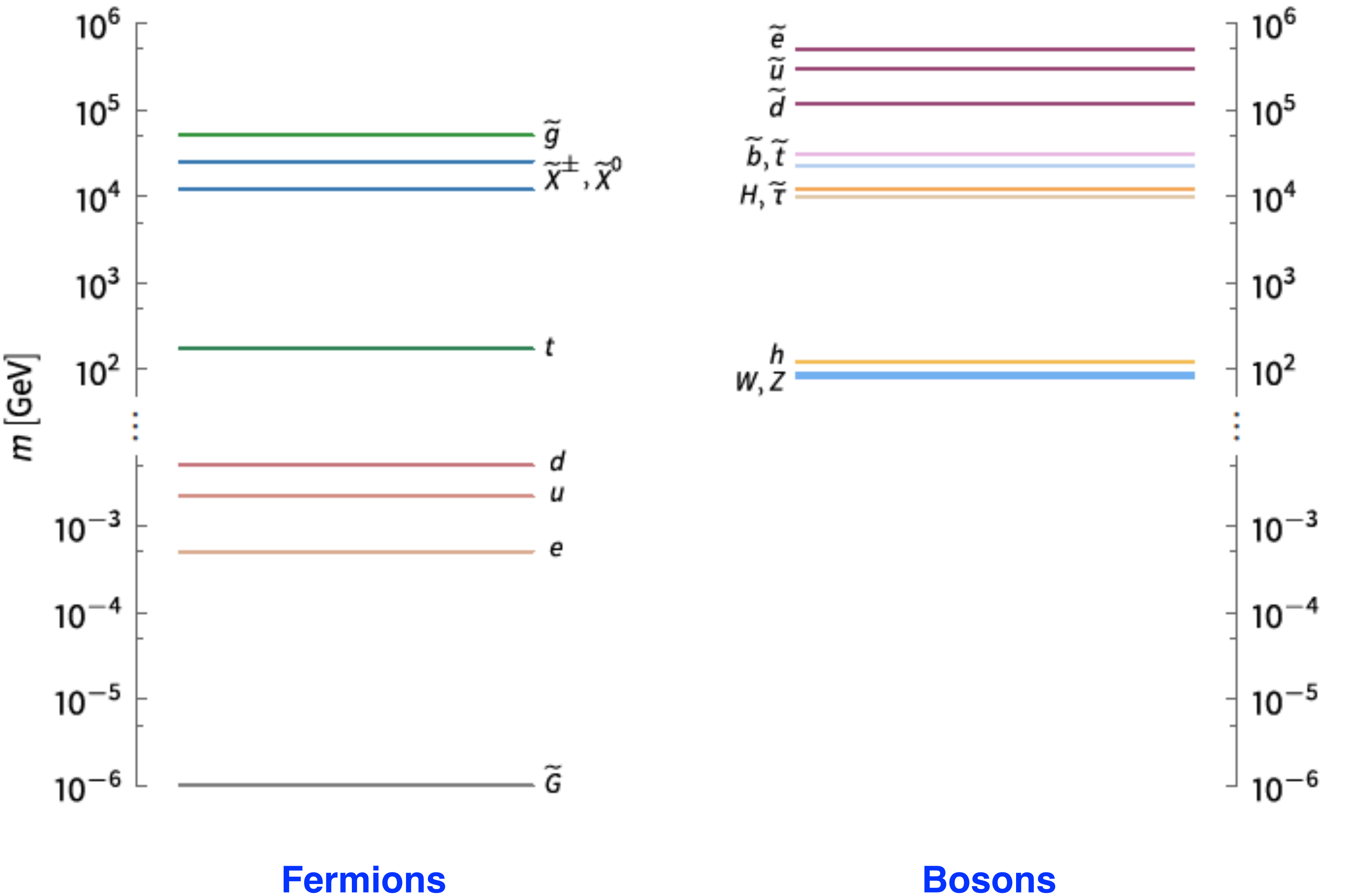


$\Lambda_{UV} = 10^{18}$ GeV, $\tan\beta = 3$

$M_{SUSY} = 50$ TeV

Partially Composite Spectrum

[Buyukdag, TG, Miller: 1811.12388]



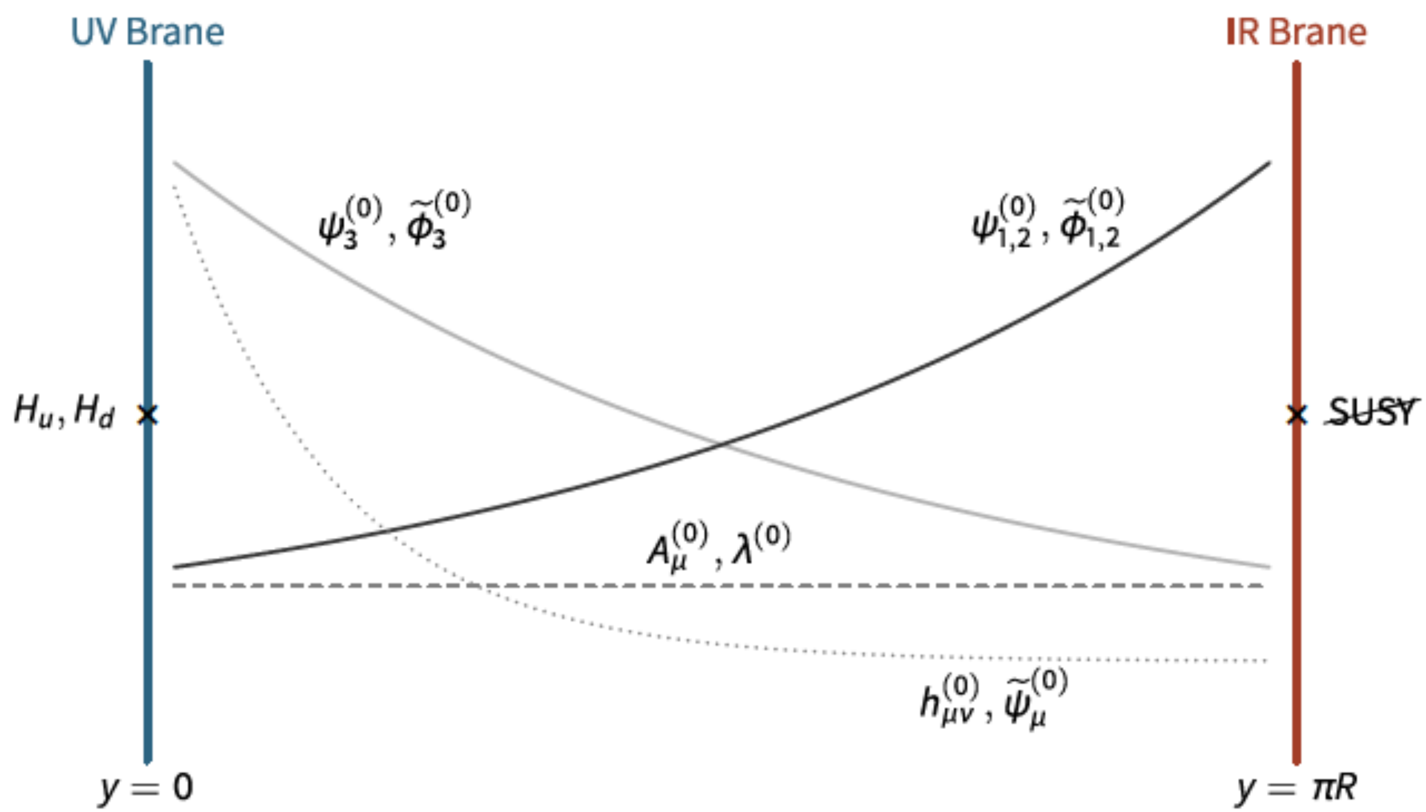
To model strong dynamics use AdS/CFT:

Partial Compositeness ⟺ 5D Localization in a slice of AdS

5D Model:

$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}\, dx^\mu\, dx^\nu + dy^2 \equiv g_{MN}\, dx^M\, dx^N$$

(k = AdS curvature)



Fermion mass hierarchy: [TG, Pomarol 00]

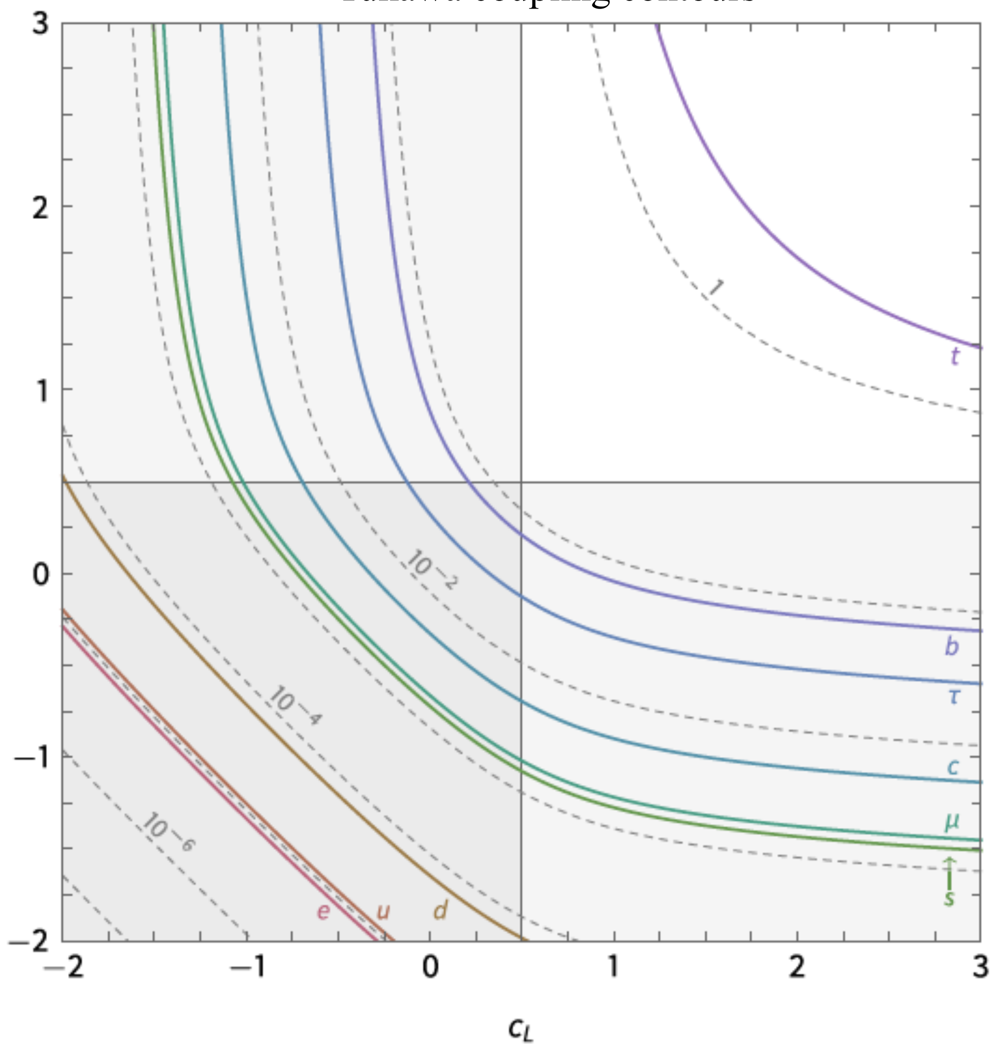
UV brane localized Higgs

$$S_5 = \int d^5x \sqrt{-g}\, Y_{ij}^{(5)} \left[\bar{\Psi}_{iL}(x^\mu, y)\, \Psi_{jR}(x^\mu, y) + h.c.\right] H(x^\mu)\, \delta(y) \equiv \int d^4x \left[y_{ij}\, \bar{\psi}_{iL}^{(0)}(x^\mu)\, \psi_{jR}^{(0)}(x^\mu)\, H(x^\mu) + h.c + \cdots\right]$$

$$\Rightarrow \quad y_{ij} = Y_{ij}^{(5)} \tilde{f}_{iL}^{(0)}(0)\, \tilde{f}_{jR}^{(0)}(0) = Y_{ij}^{(5)} k \sqrt{\frac{\frac{1}{2} - c_{iL}}{e^{2(\frac{1}{2} - c_{iL})\pi k R} - 1}} \sqrt{\frac{\frac{1}{2} + c_{jR}}{e^{2(\frac{1}{2} + c_{jR})\pi k R} - 1}}$$

$c_L, c_R =$ bulk mass parameters

Yukawa coupling contours



$$\Lambda_{\rm IR} = 2 \times 10^{16}\ {\rm GeV}$$
$$\tan\beta = 3$$
$$Y_{ij}^{(5)} k = 1$$

Supersymmetry breaking

IR brane spurion superfield: $X = \theta\theta F_X$ ➡ SUSY breaking scale: $F = F_X e^{-2\pi k R}$

Gaugino masses:

$X = \text{singlet}$ $$\int d^5x \sqrt{-g} \int d^2\theta \left[\frac{1}{2} \frac{X}{\Lambda_{UV} k} W^{\alpha a} W^a_\alpha + h.c. \right] \delta(y - \pi R)$$

4D gauge coupling

$$\Rightarrow \quad M_\lambda \simeq \frac{g_5^2 k}{2\pi k R} \frac{F}{\Lambda_{IR}} = \overbrace{g^2}\frac{F}{\Lambda_{IR}}$$

$X = \text{non singlet}$

$$\int d^5x \sqrt{-g} \int d^4\theta \left[\frac{1}{2} \frac{X^\dagger X}{\Lambda_{UV}^3 k} W^{\alpha a} W^a_\alpha + \text{H.c.} \right] \delta(y - \pi R)$$

$$\Rightarrow \quad M_\lambda \simeq \frac{g_5^2 k}{2\pi k R} \frac{F^2}{\Lambda_{IR}^3} = g^2 \frac{F^2}{\Lambda_{IR}^3}$$

⟵ Extra suppression $\frac{F}{\Lambda_{IR}^2}$

Gravitino mass:

$$\int d^5x \sqrt{-g} \left[\frac{1}{4} \frac{W}{M_5^3} \psi_\mu \left[\sigma^\mu, \bar{\sigma}^\nu\right] \psi_\nu + h.c. \right] \delta(y)$$

$$\Rightarrow \quad m_{3/2} \simeq \frac{F}{\sqrt{3} M_P}$$

where $|F|^2 \simeq 3 \frac{|W|^2}{M_P^2}$ for vanishing cosmological constant

Sfermion masses:

$$\int d^5x \sqrt{-g} \int d^4\theta \, \frac{X^\dagger X}{\Lambda_{\rm UV}^2 k} \Phi^\dagger \Phi \, \delta(y - \pi R)$$

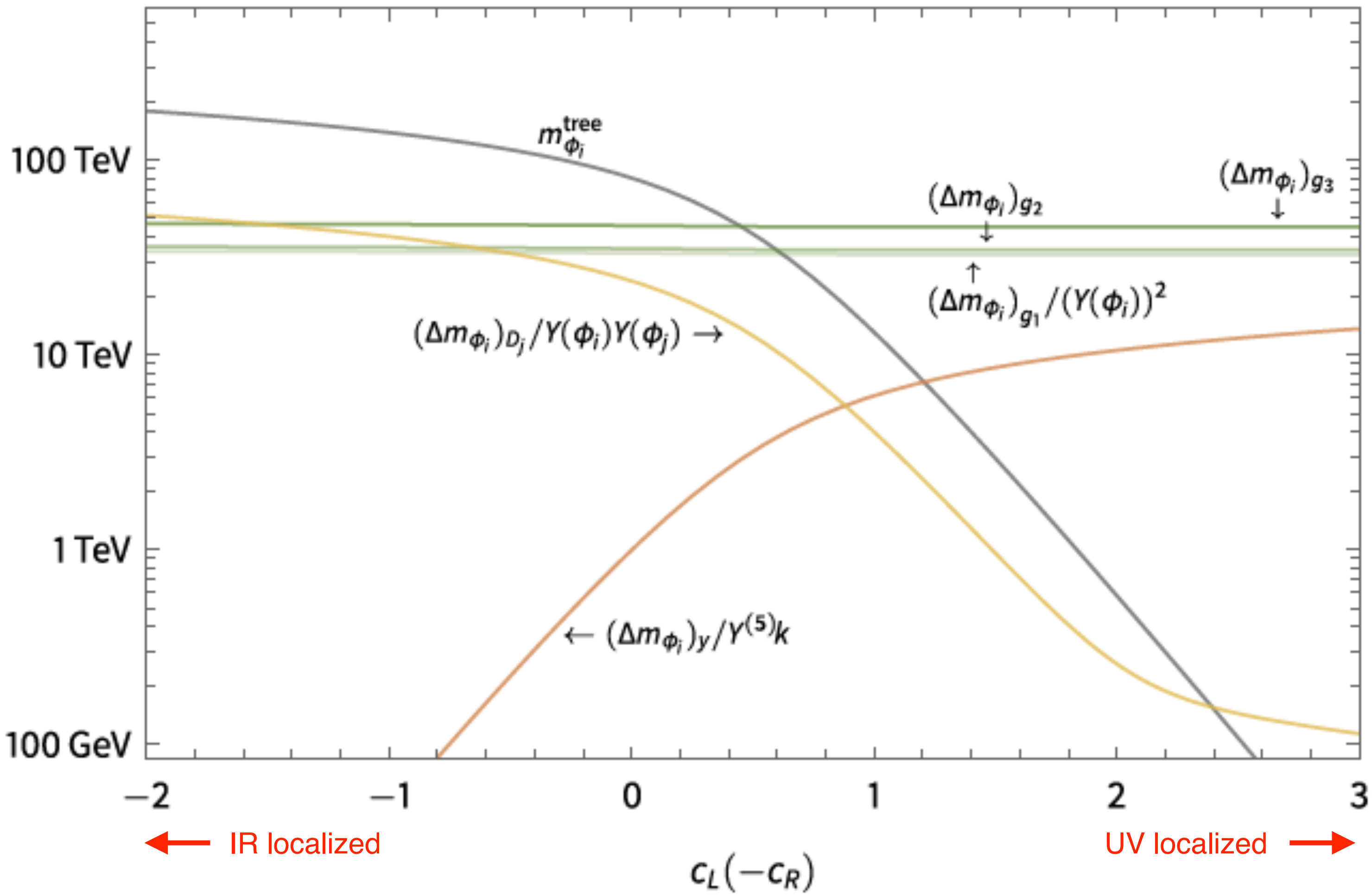
$$\Rightarrow \quad m^{\rm tree}_{\phi_{L,R}} \simeq \begin{cases} (\pm c - \frac{1}{2})^{1/2} \dfrac{F}{\Lambda_{\rm IR}} e^{(\frac{1}{2} \mp c)\pi k R} & \pm c > \frac{1}{2} \\ (\frac{1}{2} \mp c)^{1/2} \dfrac{F}{\Lambda_{\rm IR}} & \pm c < \frac{1}{2} \end{cases}$$

Flavor-dependent masses

Matches partial composite result using AdS/CFT dictionary: $\delta_i = |c_i \pm \frac{1}{2}|$

One-loop sfermion radiative corrections

[Buyukdag, TG, Miller: 1811.12388]



$$\Lambda_{\rm IR} = 2\times 10^{16}\ \text{GeV},$$
$$\sqrt{F} = 4.75\times 10^{10}\ \text{GeV}$$
$$\tan\beta = 3.$$

⇨ UV localized sfermions dominated by radiative corrections

Higgs sector:

Soft terms generated at one-loop (since Higgs is UV localized)

$$16\pi^2 m_{H_u}^2 = 6\, r_{g_2}^H g_2^2 M_2^2 + \frac{6}{5} r_{g_1}^H g_1^2 M_1^2 - 6\,\mathrm{Tr}\left[r_{y_{u_i}}^H y_{u_i}^2 \left(m_{\widetilde{Q}_i}^2 + m_{\widetilde{u}_i}^2 \right)\right] - \frac{3}{5} g_1^2 \Delta_S\,,$$

$$16\pi^2 m_{H_d}^2 = 6\, r_{g_2}^H g_2^2 M_2^2 + \frac{6}{5} r_{g_1}^H g_1^2 M_1^2 - 6\,\mathrm{Tr}\left[r_{y_{d_i}}^H y_{d_i}^2 \left(m_{\widetilde{Q}_i}^2 + m_{\widetilde{d}_i}^2 \right)\right] - 2\,\mathrm{Tr}\left[r_{y_{e_i}}^H y_{e_i}^2 \left(m_{\widetilde{L}_i}^2 + m_{\widetilde{e}_i}^2 \right)\right] + \frac{3}{5} g_1^2 \Delta_S\,,$$

$$16\pi^2 b = -\mu \left(6\, r_{\lambda_1}^b g_2^2 M_2 + \frac{6}{5} r_{\lambda_2}^b g_1^2 M_1 \right)\,,$$

EWSB:

$$m_{H_u}^2 + |\mu|^2 - b\cot\beta - \frac{1}{8}(g_1^2 + g_2^2) v^2 \cos 2\beta = 0$$

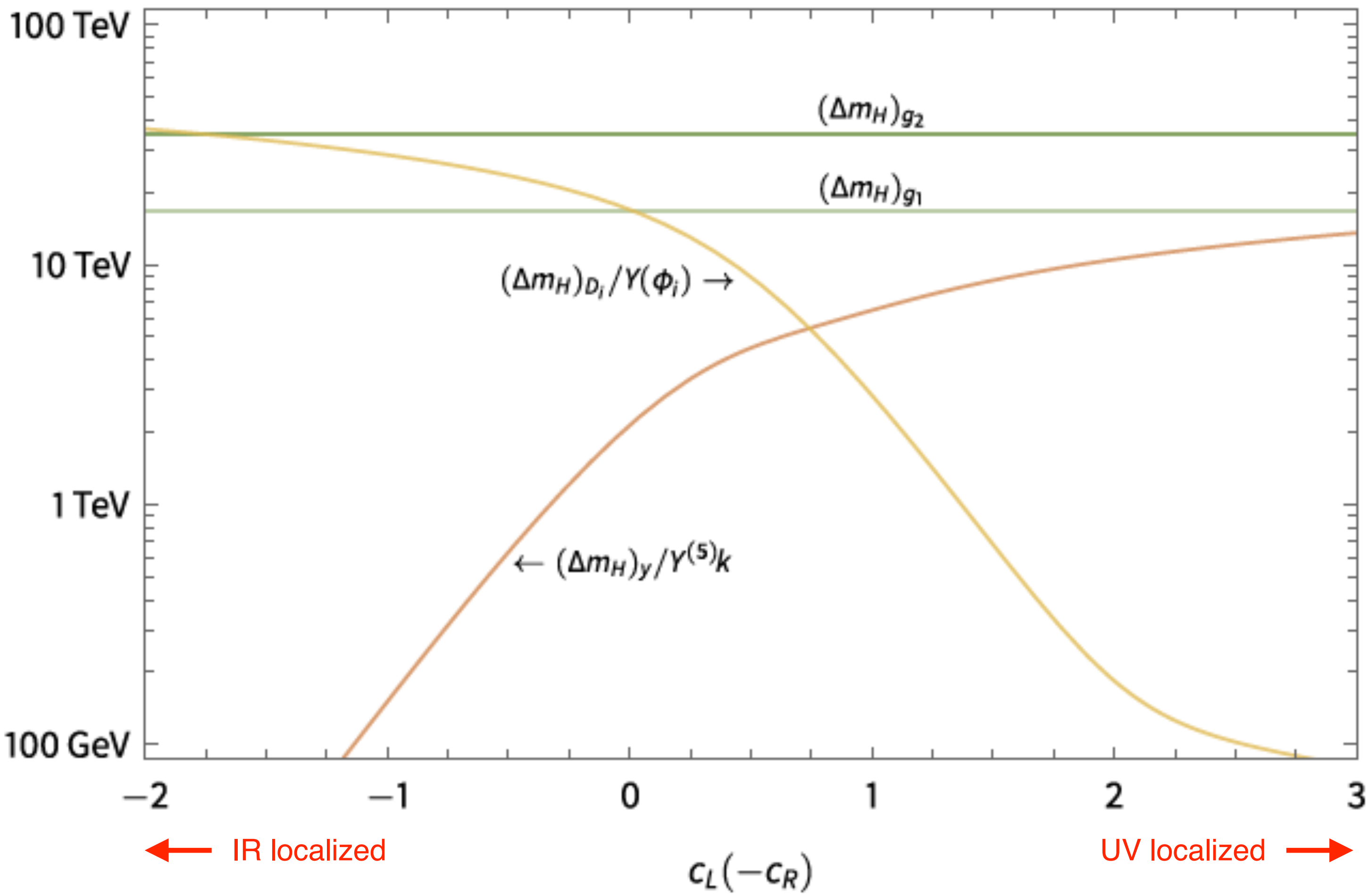
$$m_{H_d}^2 + |\mu|^2 - b\tan\beta + \frac{1}{8}(g_1^2 + g_2^2) v^2 \cos 2\beta = 0$$

$$\tan\beta \simeq \frac{(m_{H_d}^2 - m_{H_u}^2) + \sqrt{(m_{H_d}^2 - m_{H_u}^2)^2 + 4b^2}}{2b} + \mathcal{O}\left(\frac{v^2}{b}\right)\,,$$

$$|\mu|^2 \simeq \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} + \mathcal{O}(v^2)\,,$$

One-loop Higgs soft mass radiative corrections

[Buyukdag, TG, Miller: 1811.12388]



$\Lambda_{\rm IR} = 2\times 10^{16}$ GeV,

$\sqrt{F} = 4.75\times 10^{10}$ GeV

$\tan\beta = 3.$

Charge and Color breaking minima

Sfermions can receive negative mass-squared corrections from:

- Weak hypercharge D-term

$$16\pi^2(\beta_{m^2_{\phi_i}})_{\text{1-loop}} \supset \frac{6}{5}g_1^2\,Y(\phi_i)\,\text{Tr}\left[Y(\phi_j)\,m^2_{\phi_j}\right] \equiv \frac{6}{5}g_1^2\,Y(\phi_i)\,\mathcal{S}$$

where $\mathcal{S} = m^2_{H_u} - m^2_{H_d} + \text{Tr}\left[\mathbf{m}^2_{\tilde{\mathbf{Q}}} - \mathbf{m}^2_{\tilde{\mathbf{L}}} - 2\mathbf{m}^2_{\tilde{\mathbf{u}}} + \mathbf{m}^2_{\tilde{\mathbf{d}}} + \mathbf{m}^2_{\tilde{\mathbf{e}}}\right]$

- Bulk D-term (and Yukawa couplings)

$$(\Delta m^2_{\phi_i})_D = \frac{3}{5}g_1^2 Y(\phi_i)\sum_j Y(\phi_j)\,(\Pi_D^{\phi_i})_{\phi_j} \;\equiv -\frac{1}{8\pi^2}\frac{3}{5}g_1^2 Y(\phi_i)\,\Delta_{\mathcal{S}}$$

where $\Delta_{\mathcal{S}} = \sum_i Y(\phi_i)\,r^D_{\phi_i}\,m^2_{\phi_i} = \text{Tr}\left[r^D_{\tilde{Q}_i}m^2_{\tilde{Q}_i} - 2\,r^D_{\tilde{u}_i}m^2_{\tilde{u}_i} + r^D_{\tilde{d}_i}m^2_{\tilde{d}_i} - r^D_{\tilde{L}_i}m^2_{\tilde{L}_i} + r^D_{\tilde{e}_i}m^2_{\tilde{e}_i}\right]$

- 2-loop gauge boson [Arkani-Hamed, Murayama '97]

$$(16\pi^2)^2(\beta_{m^2_{\phi_i}})_{\text{2-loop}} \supset 4\sum_a g_a^4\,C_a(R_{\phi_i})\,\sigma_a\,;$$

where

$$\sigma_1 = \frac{1}{5}\left(3m^2_{H_u} + 3m^2_{H_d} + \text{Tr}\left[\mathbf{m}^2_{\tilde{\mathbf{Q}}} + 3\mathbf{m}^2_{\tilde{\mathbf{L}}} + 8\mathbf{m}^2_{\tilde{\mathbf{u}}} + 2\mathbf{m}^2_{\tilde{\mathbf{d}}} + 6\mathbf{m}^2_{\tilde{\mathbf{e}}}\right]\right),$$

$$\sigma_2 = m^2_{H_u} + m^2_{H_d} + \text{Tr}\left[3\mathbf{m}^2_{\tilde{\mathbf{Q}}} + \mathbf{m}^2_{\tilde{\mathbf{L}}}\right],$$

$$\sigma_3 = \text{Tr}\left[2\mathbf{m}^2_{\tilde{\mathbf{Q}}} + \mathbf{m}^2_{\tilde{\mathbf{u}}} + \mathbf{m}^2_{\tilde{\mathbf{d}}}\right].$$

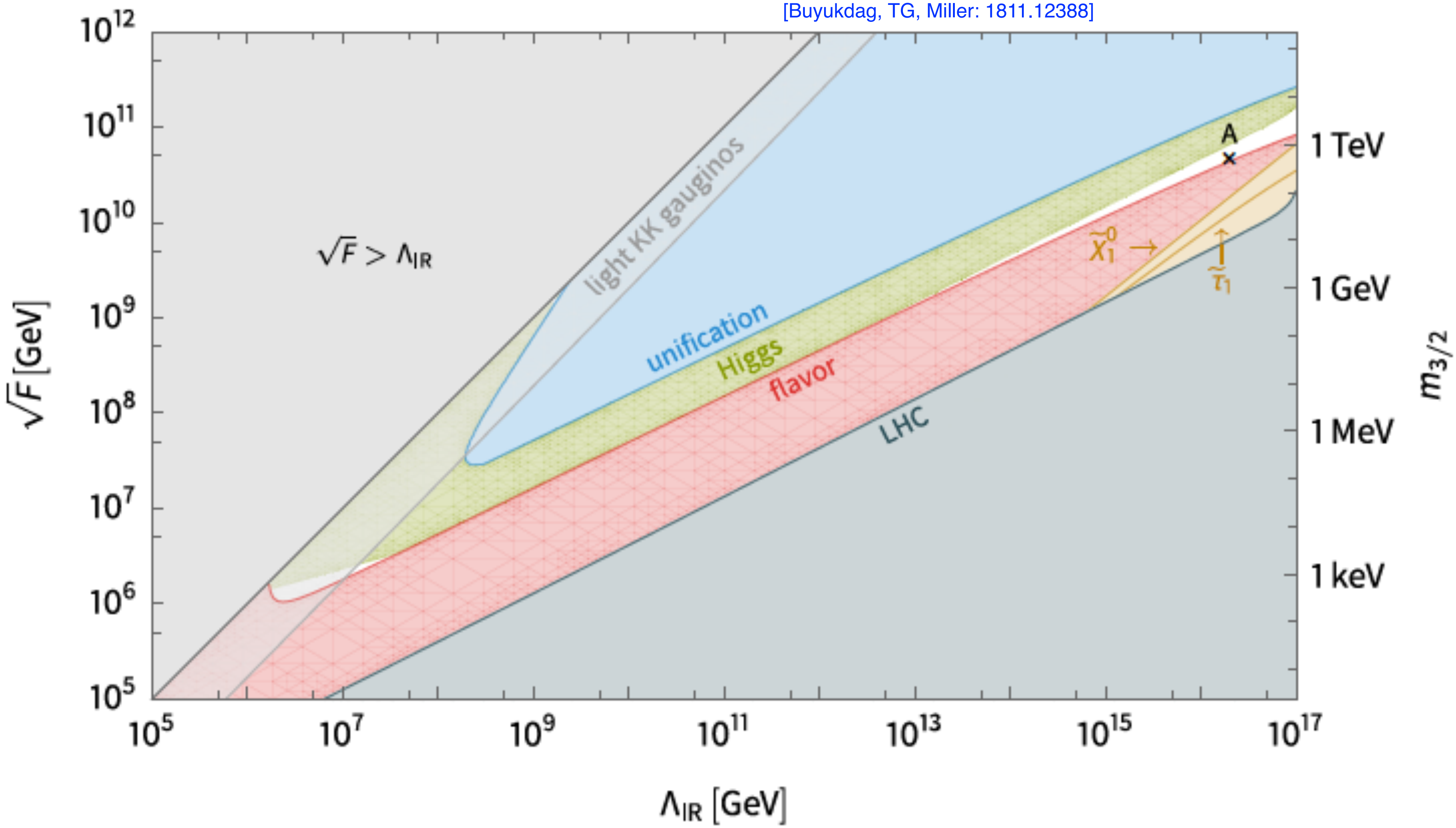
Phenomenological constraints

- Higgs mass $m_h \simeq 125 \text{ GeV}$
- Supersymmetric flavor problem $\tilde{m}_{1,2} \gtrsim 100 \text{ TeV}$
- Gauge coupling unification $|\mu| \sim M_\lambda \lesssim 100 \text{ TeV}$
- Gravitino Dark Matter $m_{3/2} \gtrsim \mathcal{O}(1)\,\text{keV}$
- Charge and color breaking minima $m^2_{\tilde{\phi}} > 0$

⇨ constrains $\sqrt{F}, \Lambda_{\text{IR}}$

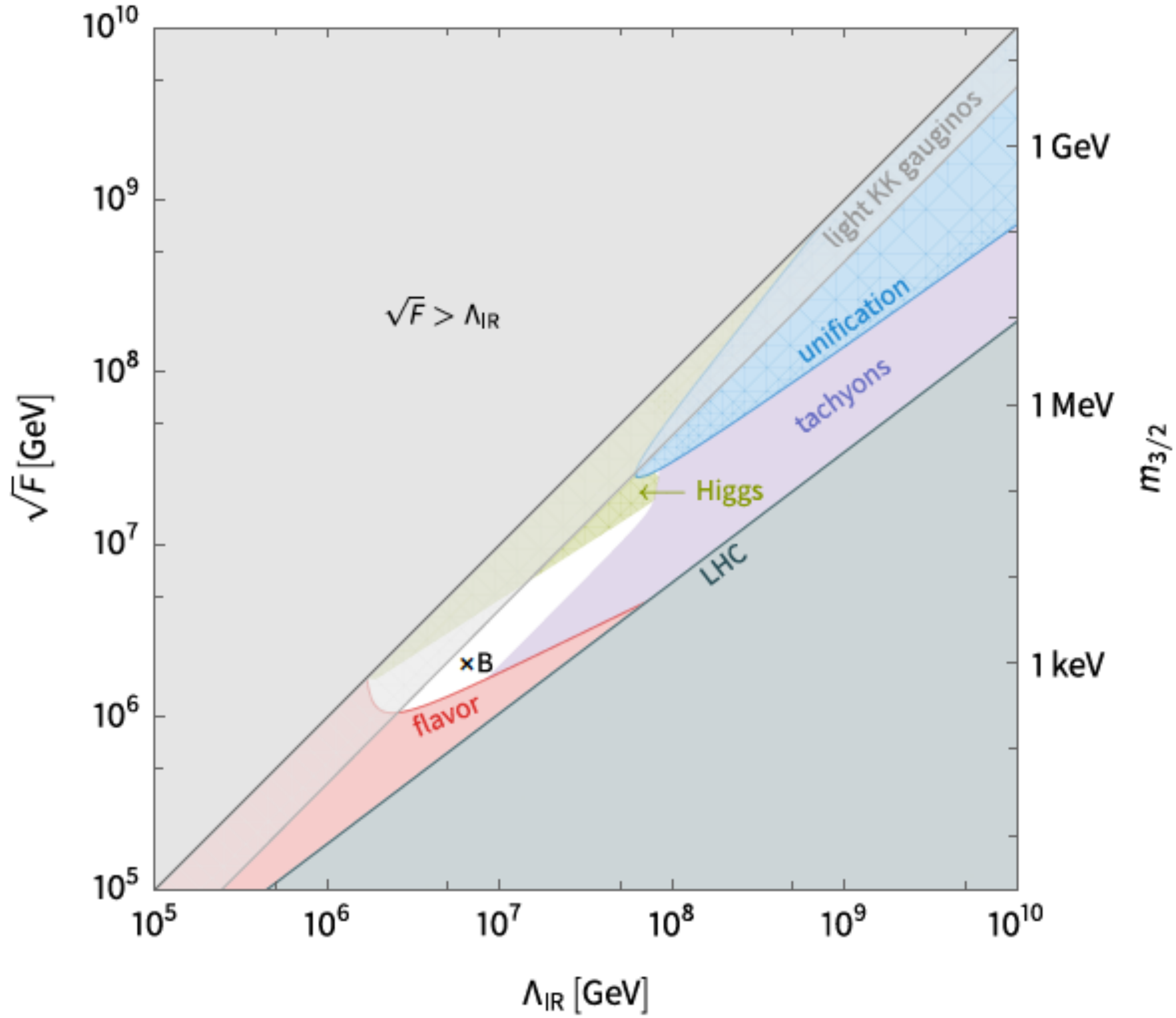
Parameter space constraints (singlet X spurion)

[Buyukdag, TG, Miller: 1811.12388]



Parameter space constraints (non-singlet X spurion)

[Buyukdag, TG, Miller: 1811.12388]

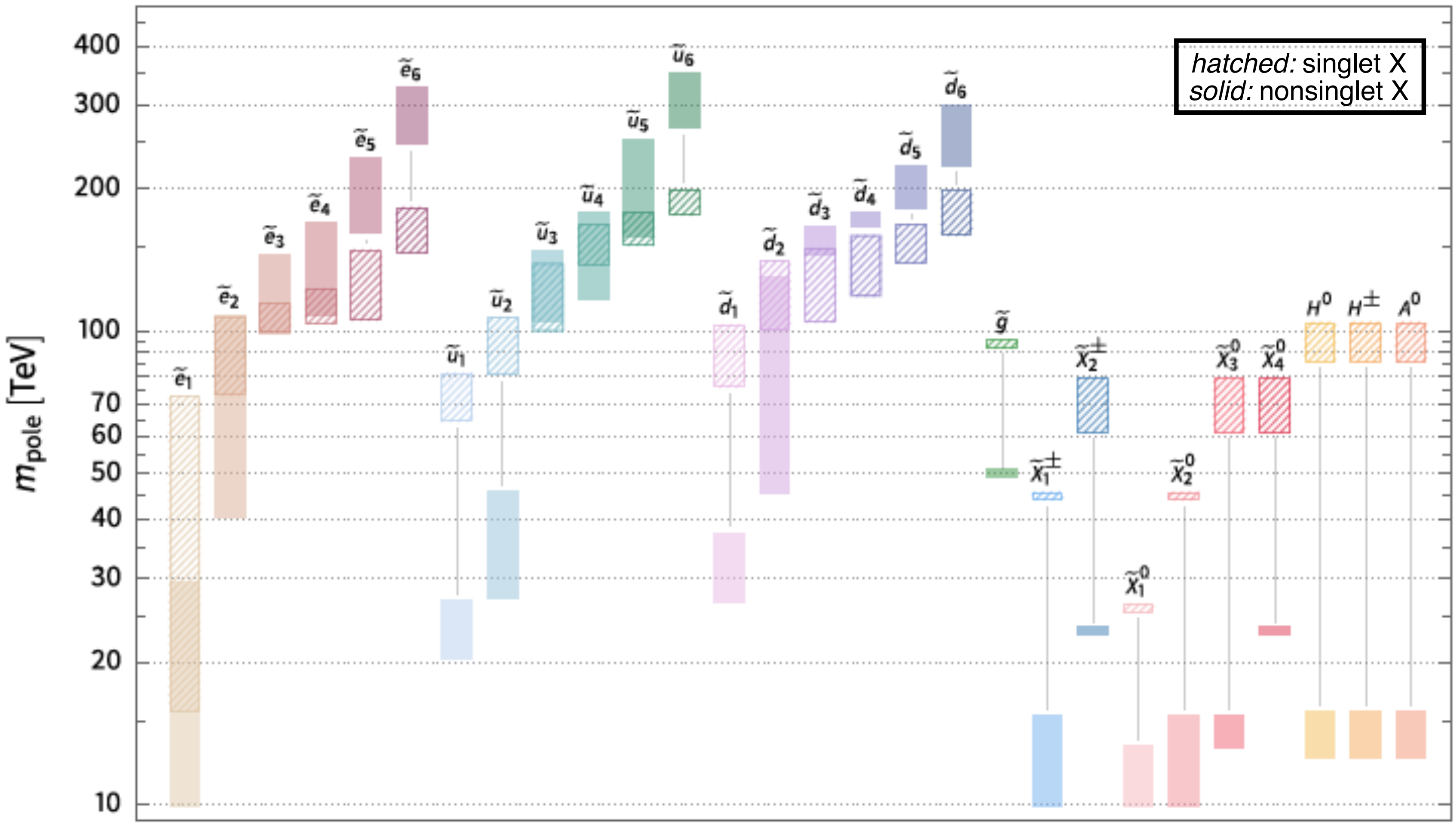


Two benchmark scenarios

	A	B
$\Lambda_{\rm IR}$	2×10^{16} GeV	6.5×10^{6} GeV
$\sqrt{F}$	4.75×10^{10} GeV	2×10^{6} GeV
$\tan\beta$	~ 3	~ 5
$\text{sign}\,\mu$	-1	-1
$Y^{(5)}k$	1	1
Spurion	singlet	non-singlet
$M_1(\Lambda_{\rm IR})$	52.9 TeV	14.60 TeV
$M_2(\Lambda_{\rm IR})$	50.7 TeV	22.9 TeV
$M_3(\Lambda_{\rm IR})$	49.85 TeV	38.94 TeV
$m_{3/2}$	535 GeV	1 keV

Superpartner spectrum

[Buyukdag, TG, Miller: 1811.12388



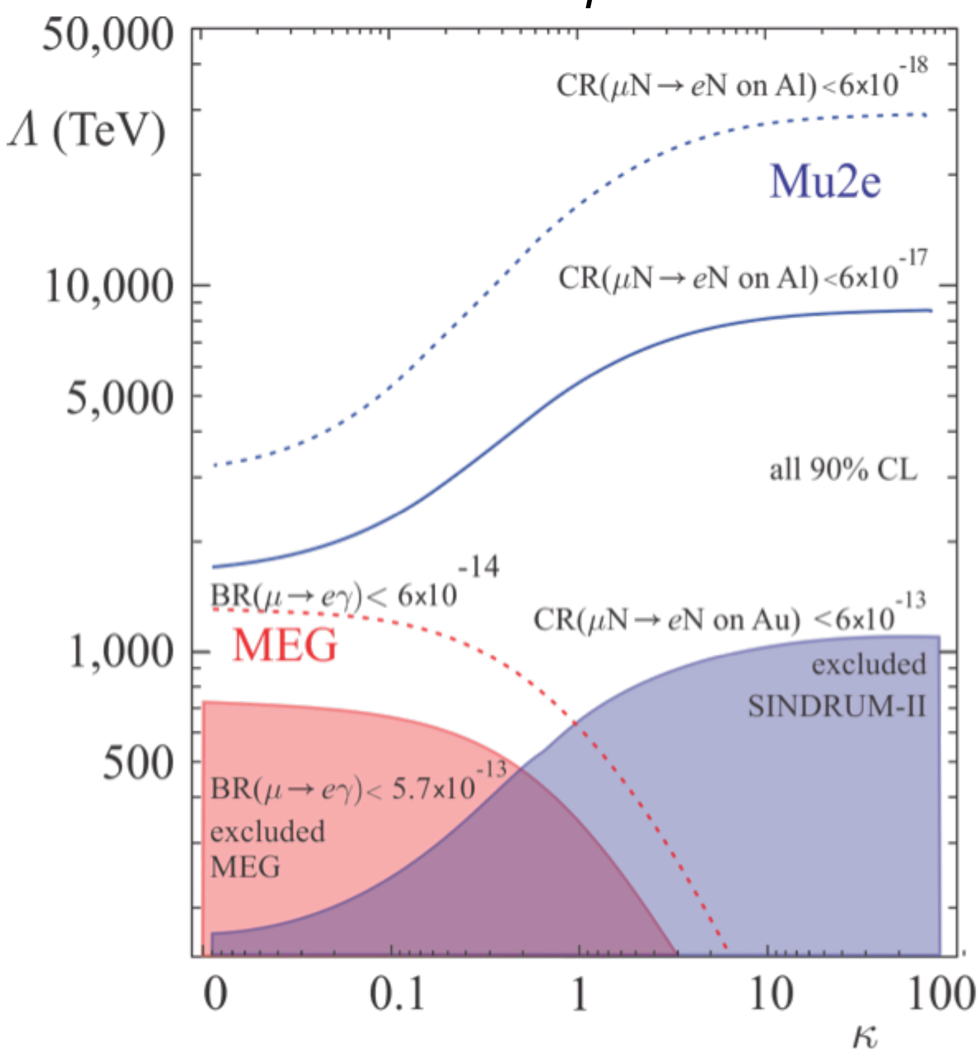
$$m_{\tilde{u}_6}/m_{\tilde{t}_1} \sim 3\ (18) \qquad m_{\tilde{u}_6}/m_{\tilde{\tau}_1} \sim 13\ (35)$$ for singlet (non-singlet)

Charged Lepton Flavor Violation

$$\mathcal{L}_{\rm soft} \supset \underbrace{\widetilde{m}^2_{ij}}\phi_i^\dagger \phi_j$$

not (flavor) diagonal ⇨ CLFV!

Mu2e experiment



$(\mu \to e\gamma)$ dipole term ⟵ ⟶ contact term $(\mu \to e)$

Current limits:

$\mathrm{BR}(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13}$ [MEG 2013]

$\mathrm{BR}(\mu\ \mathrm{Au} \to e\ \mathrm{Au}) < 7 \times 10^{-13}$ [SINDRUM-II 2006]

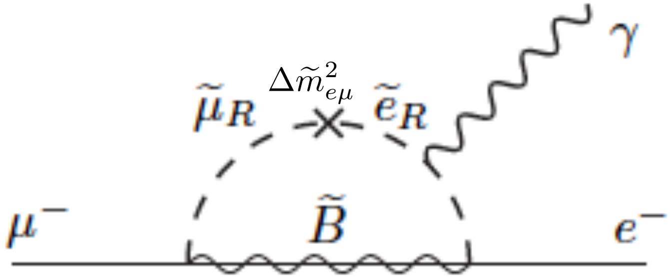
[compared to capture rate $\mu^- N \to \nu_\mu N'$]

$$\mathrm{BR}(\mu\ \mathrm{Al} \to e\ \mathrm{Al}) \sim 10^{-17}$$

$\sim 10^4$ improvement!

- Mu2e will probe values:
  $2000\ \mathrm{TeV} \lesssim \Lambda \lesssim 10000\ \mathrm{TeV}$

$\mu \to e\gamma$



$$\frac{1}{\Lambda^2} \sim \frac{eg^2}{16\pi^2 M^2_{SUSY}}\theta_{e\mu}$$

$$\text{where} \quad \theta_{e\mu} \sim \frac{\Delta\widetilde{m}^2_{e\mu}}{M^2_{SUSY}}$$

Mu2e $\Lambda \sim 2000 \text{ TeV}$ $\Rightarrow$ $\frac{\Delta\widetilde{m}^2_{e\mu}}{\widetilde{m}^2} \simeq 3\left(\frac{\widetilde{m}}{100 \text{ TeV}}\right)^2$

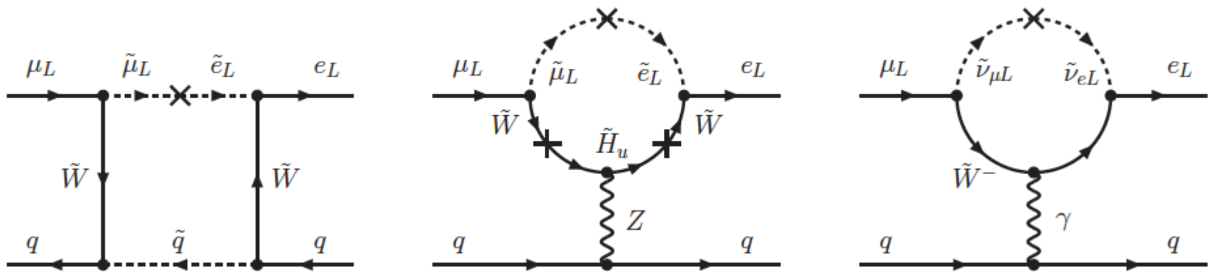
Partially-Composite Supersymmetry:

Can relate $\Delta\widetilde{m}^2_{e\mu}$ to fermion mass hierarchy — much more predictive!

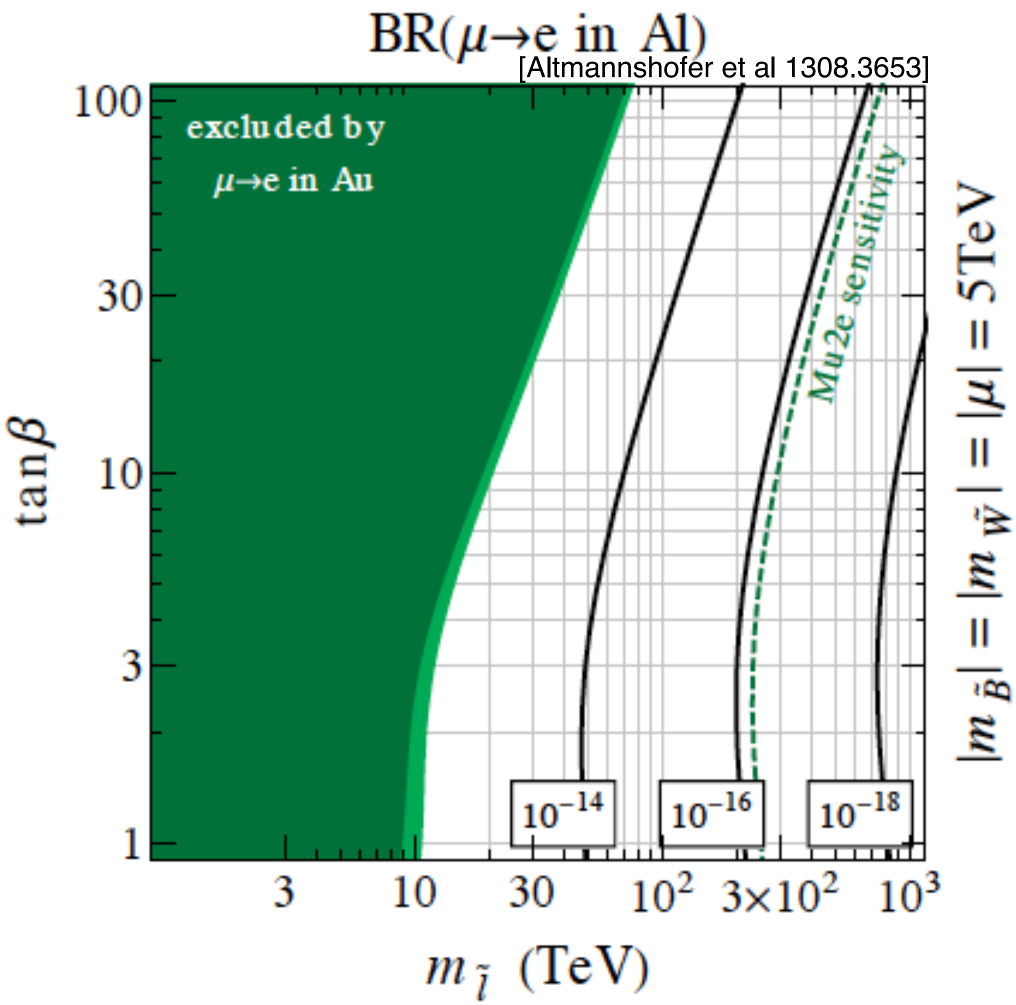
$$\widetilde{m}^2_{ij} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

[in preparation]

$\mu \to e$



Note: Penguin contributions are log enhanced



Anarchic sfermion mass matrix:

$$\tilde{m}^2_{ij} \sim \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

Mu2e can probe $\mathcal{O}(300\ \text{TeV})$ sleptons!

Partially Composite Supersymmetry: [in preparation]

Summary

- Partial compositeness relates fermion and sfermion mass spectrum

    --- Higgs/top quark = elementary

    --- First two generations = partly composite

    --- Hierarchies arise from order one anomalous dimensions

- Predicts *inverted* sfermion spectrum

    --- $20(65)\ \mathrm{TeV} \lesssim m_{\tilde{t}_1} \lesssim 27(80)\ \mathrm{TeV}$ or $150(250)\ \mathrm{TeV} \lesssim m_{\tilde{e}_6} \lesssim 180(330)\ \mathrm{TeV}$

    --- gravitino = dark matter

    --- long-lived (stau or neutralino) NLSP decay

- Sfermion flavor structure leads to specific flavor-violation processes (e.g Mu2e) or EDM

    --- work in progress