Flavorful Higgs and the g-2

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The 2021 CERN-CKC Theory Workshop:
BSM physics towards the end of the pandemic conference

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The SM flavor puzzle

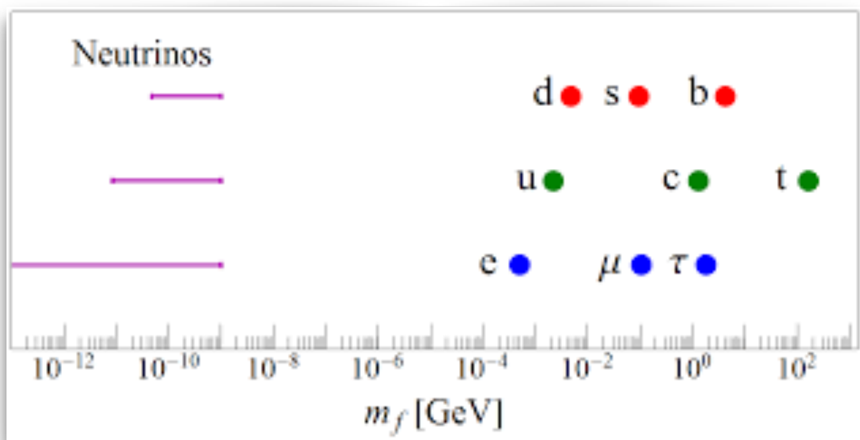
The SM **gauge Lagrangian** is invariant under 5 independent U(3) global rotations for each of the 5 independent fields:
U(3)⁵ global symmetry

$$\sum_{\psi=Q_L,u_R,d_R,L_L,e_R} \sum_{i=1,2,3} \bar{\psi}_i \not{D} \psi_i$$

flavor universality

The **Yukawa Lagrangian** breaks (part of) this global symmetry

$$\bar{Q}_L^i Y_D^{ij} d_R^j \Phi + \bar{Q}_L^i Y_U^{ij} u_R^j \tilde{\Phi} + \bar{L}_L^i Y_E^{ij} e_R^j \Phi + h.c.$$



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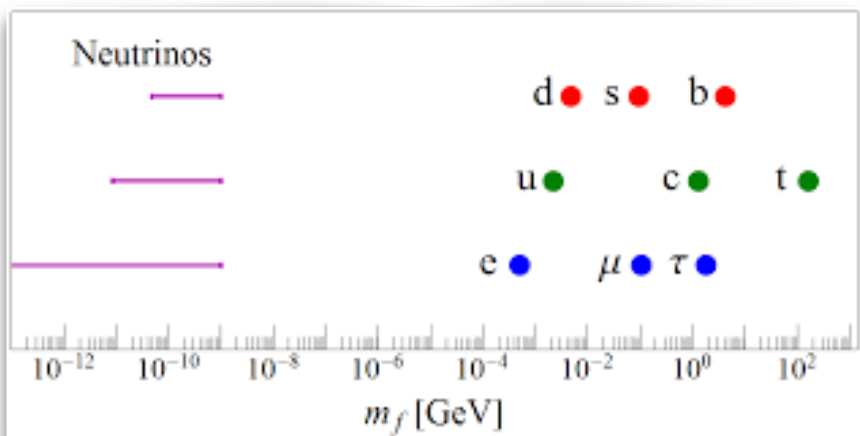


Hint for an approximate U(2)⁵ symmetry?
(1st-2nd vs. 3rd generation)

Experimental tests:
- Higgs coupling measurements!

Does New Physics affect the 2nd generation leptons?
- $(g-2)_\mu$ ← **for this talk**

$$R_K = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to K e^+ e^-)}, \quad R_{K^*} = \frac{\mathrm{BR}(B \to K^*\mu^+\mu^-)}{\mathrm{BR}(B \to K^* e^+ e^-)}$$

1. Higgs flavor measurements

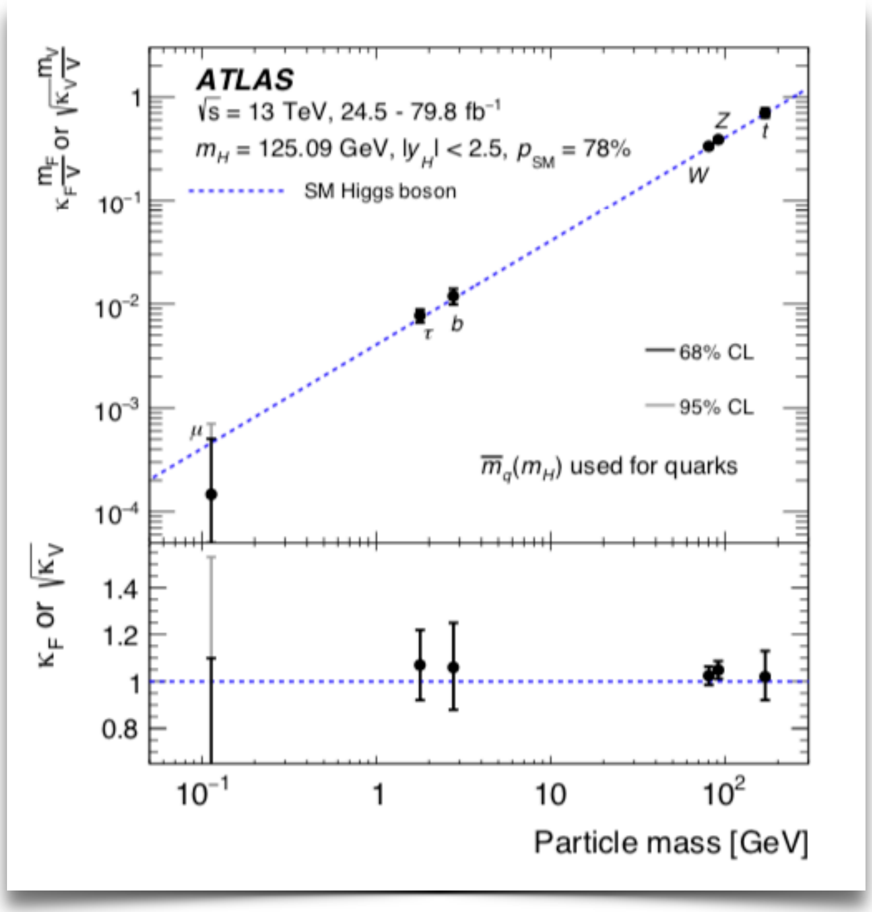
We do not know if the 125 GeV Higgs is coupled/gives mass to all flavors

Evidence for the Higgs decaying into muons!

$$\mu = 1.2 \pm 0.6$$ (ATLAS, 2007.07830)

$$\mu = 1.19^{+0.40}_{-0.39}(\mathrm{stat})^{+0.15}_{-0.14}(\mathrm{syst})$$ (CMS, 2009.04363)

the discovery is in reach of Run III



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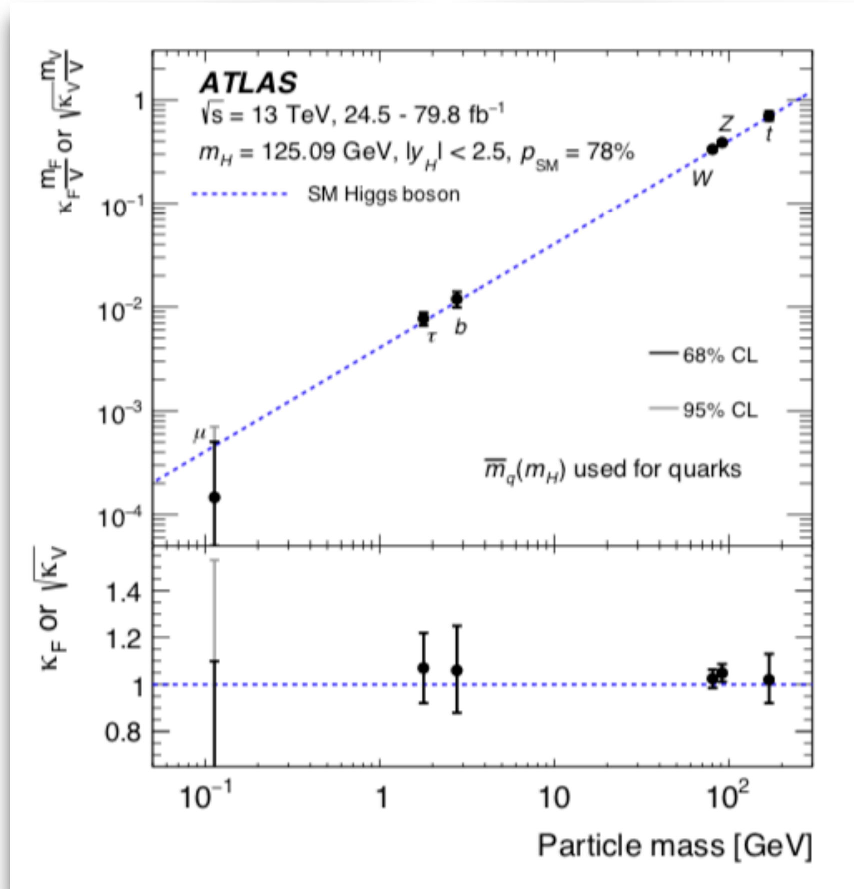


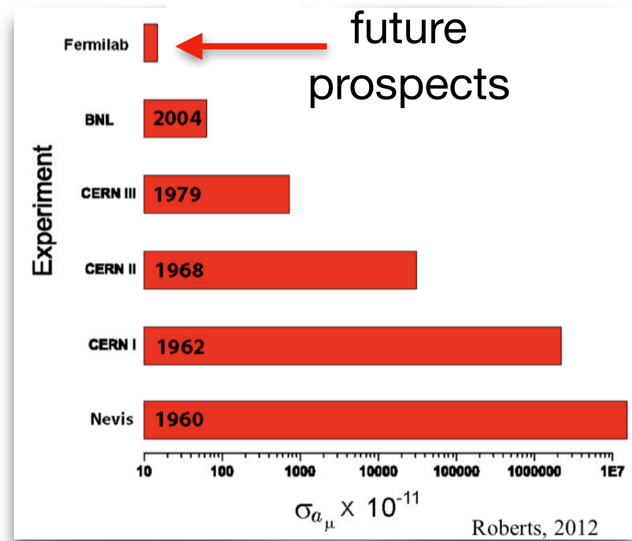
Several opportunities to test the charm Yukawa.
Goal: reach O(1) the SM Yukawa

Techniques include:

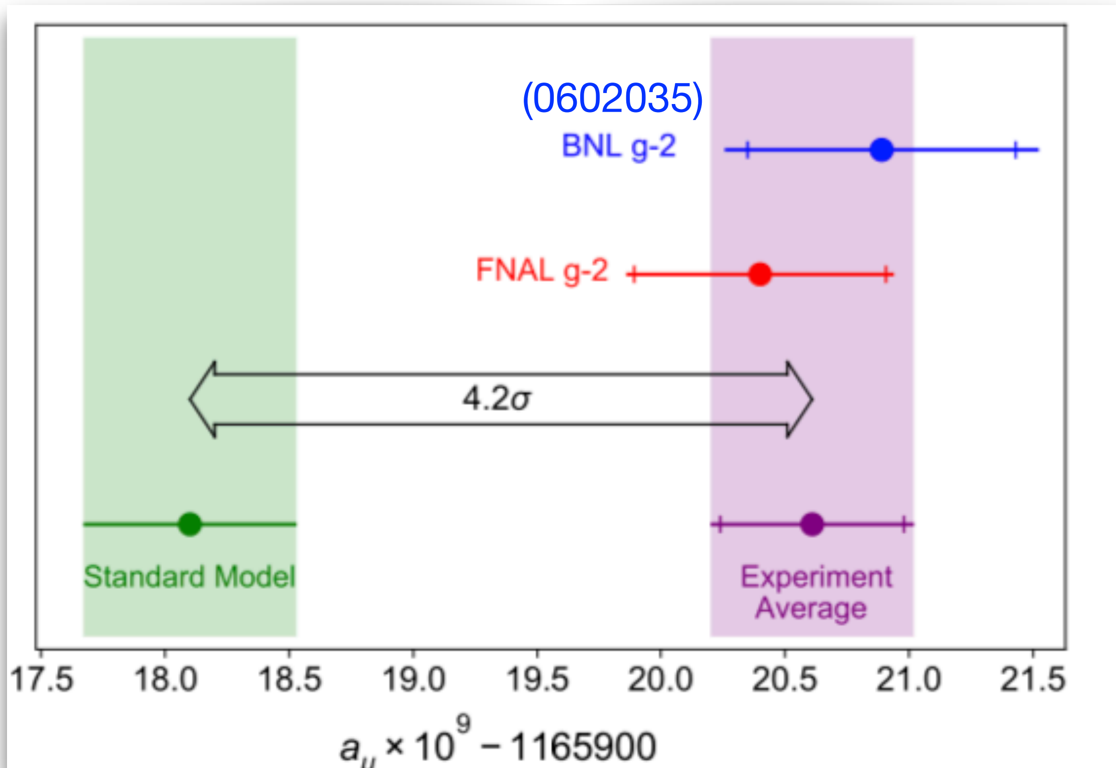
- Rare Higgs decays (Bodwin, Petriello, Stoynev, Velasco,1306.5770)
- Higgs + charm production (Brivio, Isidori, Goertz 1507.02916)
- Charge asymmetry in $W^\pm h$ production (Yu,1609.06592)

Lighter Yukawas are even more challenging

2. New results on $(g-2)_\mu$



g-2 collaboration at Fermilab, 2104.03281



$$\boxed{a_\mu(\mathrm{Exp}) - a_\mu(\mathrm{SM}) = (251 \pm 59) \times 10^{-11}}$$

chiral suppression in the SM prediction

0.46 part per million measurement!

Combination with BNL:
0.35 part per million

Fermilab future sensitivity:
~~0.1 part per million

BNL → now

3.7σ → 4.2σ

$(g\text{-}2)_\mu$ & the scale of New Physics

The **leading new physics operator** that modifies the anomalous magnetic moment of the muon and that respects the SM gauge symmetries:

$$\mathcal{H} = -\frac{C}{\Lambda_{\rm NP}^2} H(\bar{\mu}\sigma_{\alpha\beta}\mu)F^{\alpha\beta}$$

After electroweak symmetry breaking, this gives

$$\Delta a_\mu \sim C\frac{m_\mu v}{\Lambda_{\rm NP}^2} \sim 250 \times 10^{-11} \times C \times \left(\frac{100 \text{ TeV}}{\Lambda_{\rm NP}}\right)^2$$

<u>In principle,</u> one can probe extremely high scales with $(g\text{-}2)_\mu$

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In principle, one can probe extremely high scales with $(g\text{-}2)_\mu$

In practice, the Wilson coefficient C is typically tiny

Loop suppression, and suppression by the muon Yukawa (assuming minimal flavor violation)

$$C \sim \frac{1}{16\pi^2}\frac{m_\mu}{v} \sim 3 \times 10^{-6} \quad \Rightarrow \quad \Delta a_\mu \sim \frac{1}{16\pi^2}\frac{m_\mu^2}{\Lambda_{\rm NP}^2} \sim 250 \times 10^{-11} \times \left(\frac{170\ \text{GeV}}{\Lambda_{\rm NP}}\right)^2$$

Many explanations of $(g\text{-}2)_\mu$ predict **new physics not far above the electroweak scale** (or even considerably below...)

$(g\text{-}2)_\mu$ in the MSSM

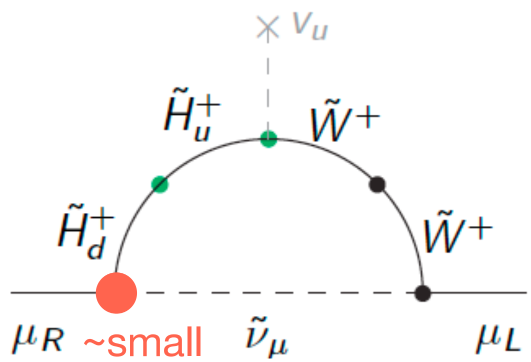
Electroweakino contributions

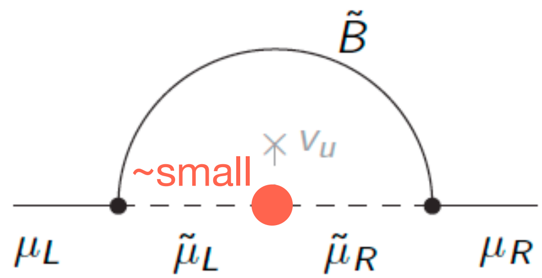
In the limit of degenerate SUSY masses and $m_Z \ll m_{SUSY}$:

$$\Delta a_\mu^{\tilde{W}} \sim \frac{5g^2}{192\pi^2} \frac{v^2}{m_{\tilde{\mu}}^2} \frac{M_2 \mu}{m_{\tilde{\mu}}^2} \frac{m_\mu^2}{v^2} \frac{t_\beta}{1+\epsilon_\ell t_\beta}$$

$m_{\tilde{\nu}} = m_{\tilde{\mu}}$

$$\Delta a_\mu^{\tilde{B}} \sim \frac{g'^2}{192\pi^2} \frac{v^2}{m_{\tilde{\mu}}^2} \frac{M_1 \mu}{m_{\tilde{\mu}}^2} \frac{m_\mu^2}{v^2} \frac{t_\beta}{1+\epsilon_\ell t_\beta}$$





Typically the Wino contributions are the dominant ones

tanβ enhancement of the muon Yukawa (chiral suppression is lifted)

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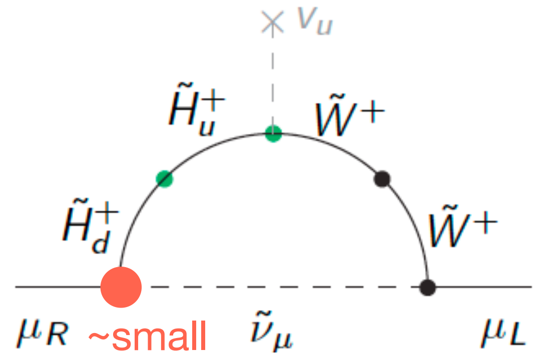

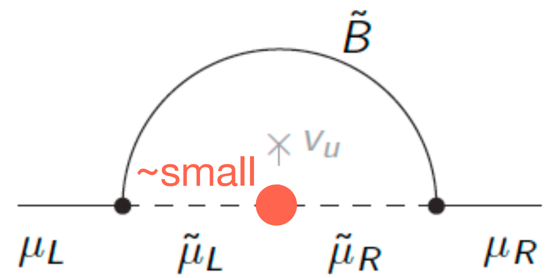

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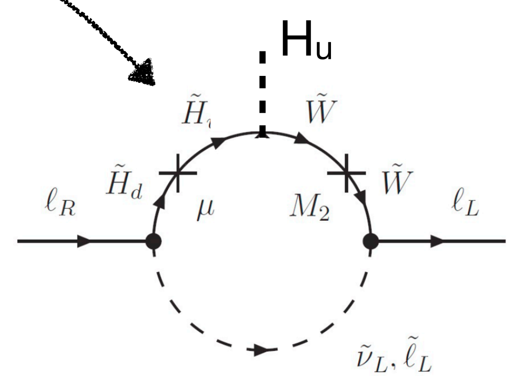
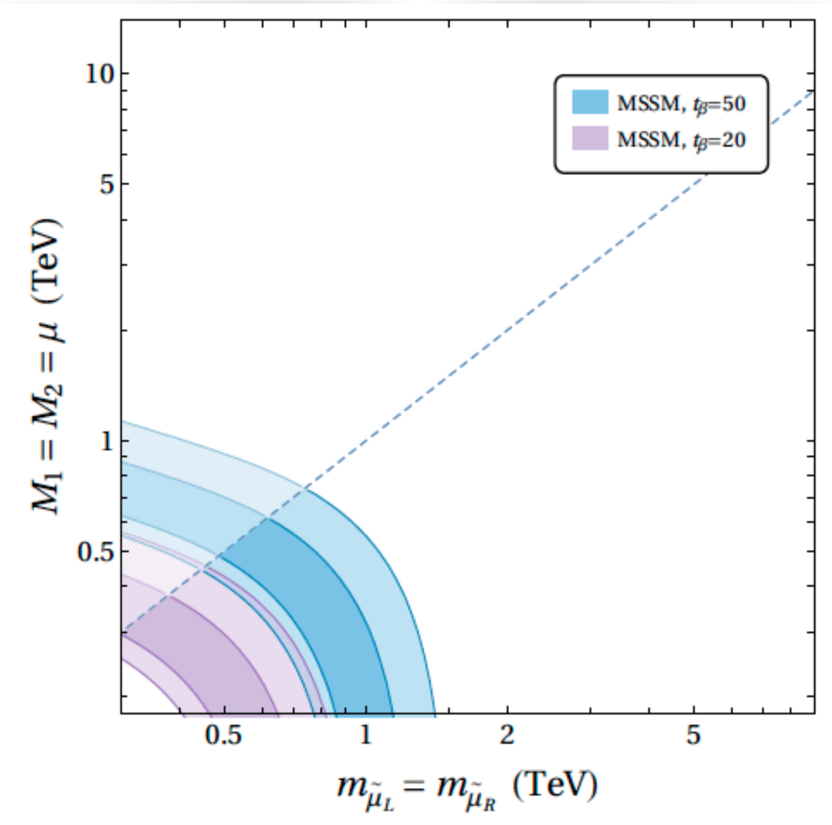


tanβ-enhanced threshold
corrections to the muon mass:
"wrong" Yukawa interaction:

$$y_\ell H_d \bar L E + \epsilon_\ell y_\ell H_u^\dagger \bar L E$$

$(g\text{-}2)_\mu$ in the MSSM, light SUSY

Altmannshofer, Gadam, SG, Hamer, 2104.08293



* (at least some) SUSY particles need to be **below 1 TeV** to explain the $(g-2)_\mu$ discrepancy

great news for colliders!

$$\Delta a_\mu \sim 260 \times 10^{-11} \times \left(\frac{\tan\beta}{50}\right)\left(\frac{500\ \text{GeV}}{m_{\text{SUSY}}}\right)^2$$

Larger values of tanβ are "dangerous":
Landau poles in bottom and tau Yukawas for tanβ>~70

$$Y_{\tau,b} = \frac{\sqrt{2}m_{\tau,b}}{v}\frac{\tan\beta}{1+\epsilon_{\tau,b}\tan\beta}$$

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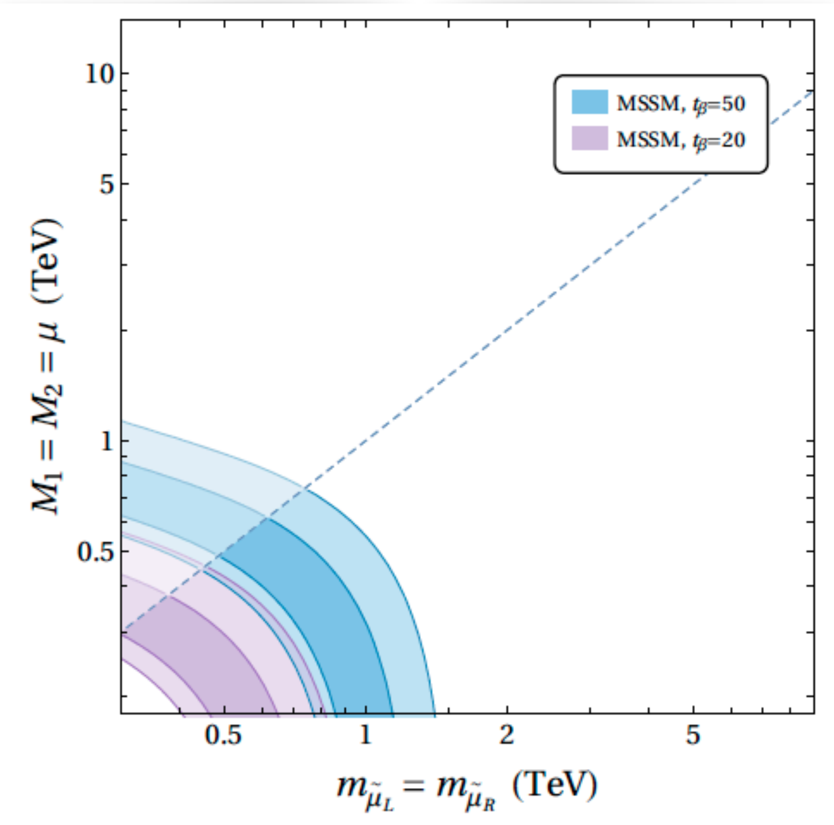

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- but why haven't we seen these particles at the LHC?

  * slepton masses as large as **~ 600 GeV** are now generically probed

  $$pp \to \tilde{\ell}\tilde{\ell} \to (\ell\chi_1)(\ell\chi_1)$$

  * squeezed spectra, $m_{\tilde{\ell}} - m_{\chi_1} \lesssim 30\text{GeV}$

  allow sleptons as light as **~ 250 GeV**

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Landau poles in bottom and tau Yukawas for tanβ>~70

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A flavorful 2HDM

Altmannshofer, SG, Kagan, Silvestrini, Zupan, 1507.07927

2 Higgs doublets H and H′ with vevs v and v′ and Yukawas Y and Y′

See also Ghosh et al., 1508.01501

$$\mathcal{L} = \bar{f} Y f H + \bar{f} Y' f H'$$

125 Higgs (h) Additional Higgses (H, A, H±)

we have one parameter, tanβ = v/v′, that can explain the hierarchy between 3rd and 2nd generation

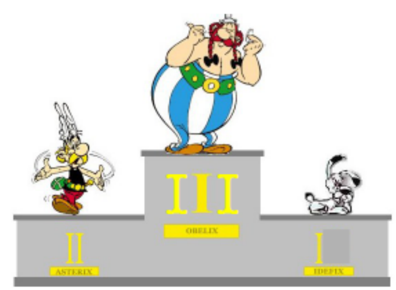
Fermions receive mass from both Higgs bosons

$$\mathcal{M} = vY + v'Y'$$

Invoke some mechanism such that the Yukawa Y is rank 1, while the Yukawa Y′ is generic (apart from 1st/2nd generation hierarchy)

Flavor-locking mechanism

(Altmannshofer, SG, Robinson, Tuckler, 1712.01847)



Something else Higgs Something else

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$$\mathcal{M}_0 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_\tau \end{pmatrix}, \quad \Delta\mathcal{M} = \begin{pmatrix} m_e & \mathcal{O}(m_e) & \mathcal{O}(m_e) \\ \mathcal{O}(m_e) & m_\mu & \mathcal{O}(m_\mu) \\ \mathcal{O}(m_e) & \mathcal{O}(m_\mu) & \mathcal{O}(m_\mu) \end{pmatrix}$$

Similar structure for the up quark sector. For the down sector:

$$\mathcal{M}_0 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_b \end{pmatrix}, \quad \Delta\mathcal{M} = \begin{pmatrix} m_d & \mathcal{O}(\lambda m_s) & \mathcal{O}(\lambda^3 m_b) \\ \mathcal{O}(m_d) & m_s & \mathcal{O}(\lambda^2 m_b) \\ \mathcal{O}(m_d) & \mathcal{O}(m_s) & \mathcal{O}(m_s) \end{pmatrix}$$

It also generates the correct CKM matrix

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Approximate U(2) symmetry

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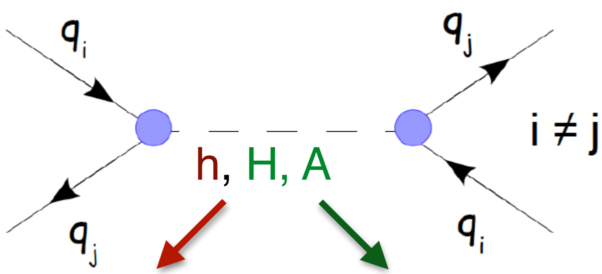
A protected flavor structure

Natural Flavor conservation is broken

$\Rightarrow$ Tree-level flavor changing Higgs couplings

(Y and Y' cannot be diagonalized simultaneously)



Going to 0 in the decoupling/ alignment limit

Always there

$\Downarrow$

Large New Physics effects in flavor transitions?

A protected flavor structure

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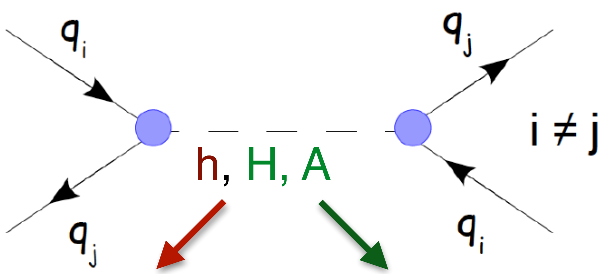
→ Tree-level flavor changing Higgs couplings

(Y and Y' cannot be diagonalized simultaneously)



Going to 0 in the decoupling/ alignment limit

Always there

↓

Large New Physics effects in flavor transitions?

Not necessarily! The rank 1 Yukawa couplings preserve a **SU(2)^5 flavor symmetry** for the light two generations of quarks and leptons

$$\begin{pmatrix} m_u & O(m_u) & O(m_u) \\ O(m_u) & m_c & O(m_c) \\ O(m_u) & O(m_c) & O(m_c) \end{pmatrix} \xrightarrow[\text{basis}]{\text{mass eigenstate}} \begin{pmatrix} m_u & O(\frac{m_u m_c}{m_t}) & O(m_u) \\ O(\frac{m_u m_c}{m_t}) & m_c & O(m_c) \\ O(m_u) & O(m_c) & O(m_c) \end{pmatrix}$$

$$\begin{pmatrix} m_d & V_{cd} m_s & V_{td} m_b \\ O(m_d) & m_s & V_{ts} m_b \\ O(m_d) & O(m_s) & O(m_s) \end{pmatrix} \xrightarrow[\text{basis}]{\text{mass eigenstate}} \begin{pmatrix} m_d & O(m_s V_{td}) & m_b V_{td} \\ O(m_d V_{ts}) & m_s & m_b V_{ts} \\ O(m_d) & O(m_s) & O(m_s) \end{pmatrix}$$

$$\begin{pmatrix} m_e & O(m_e) & O(m_e) \\ O(m_e) & m_\mu & O(m_\mu) \\ O(m_e) & O(m_\mu) & O(m_\mu) \end{pmatrix} \xrightarrow[\text{basis}]{\text{mass eigenstate}} \begin{pmatrix} m_e & O(\frac{m_e m_\mu}{m_\tau}) & O(m_e) \\ O(\frac{m_e m_\mu}{m_\tau}) & m_\mu & O(m_\mu) \\ O(m_e) & O(m_\mu) & O(m_\mu) \end{pmatrix}$$

The most stringent flavor constraints (1→2 transitions) can be avoided :

* $\mu \to e\gamma$
* D meson mixing
* Kaon mixing
* electron EDM

Flavor non universality

Comparing to the other flavor structures…

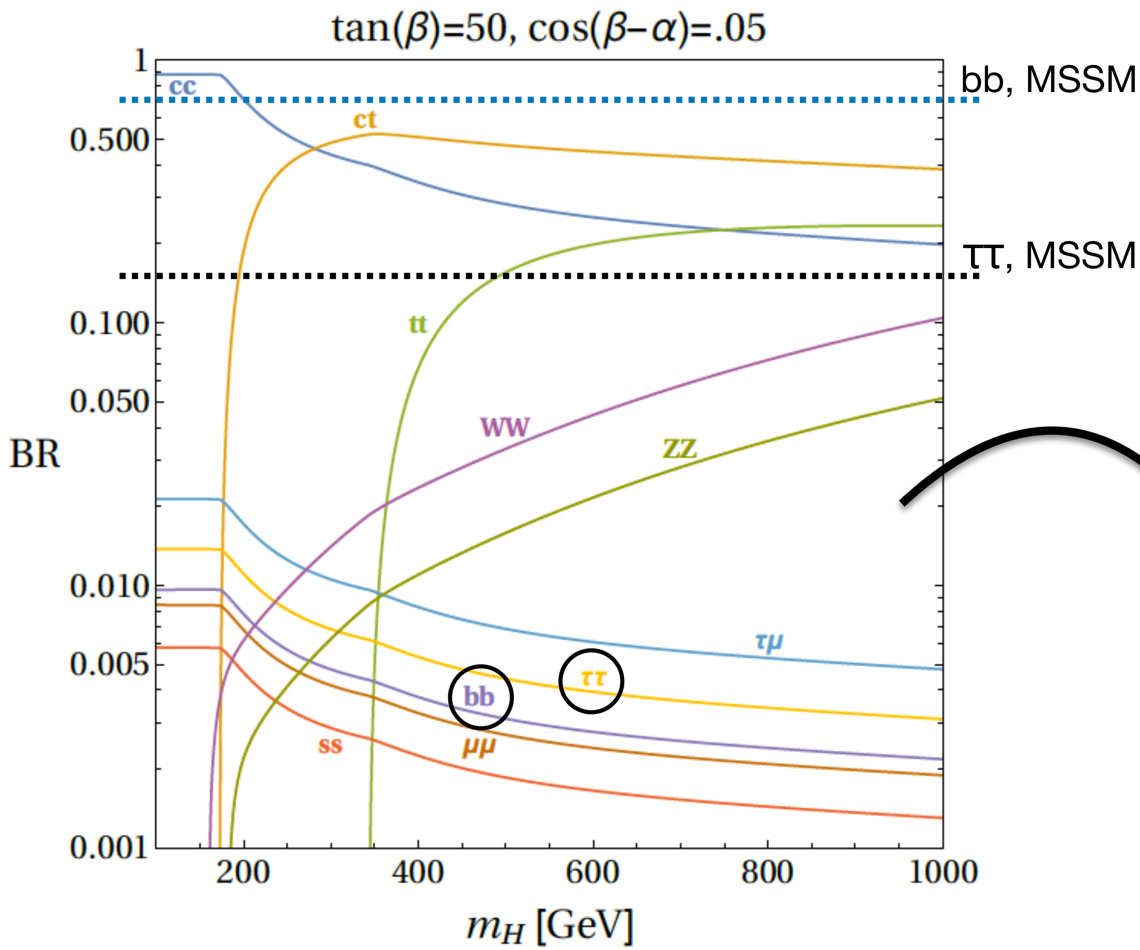
	W,Z κ_V^H	up quarks $\kappa_t^H, \kappa_c^H, \kappa_u^H$	down quarks $\kappa_b^H, \kappa_s^H, \kappa_d^H$	leptons $\kappa_\tau^H, \kappa_\mu^H, \kappa_e^H$
2HDM type 1	$c_{\beta-\alpha}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}$
2HDM type 2	$c_{\beta-\alpha}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}$	$t_\beta\frac{c_\alpha}{s_\beta}$	$t_\beta\frac{c_\alpha}{s_\beta}$
Flavorful 2HDM	$c_{\beta-\alpha}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}, t_\beta\frac{c_\alpha}{s_\beta}, t_\beta\frac{c_\alpha}{s_\beta}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}, t_\beta\frac{c_\alpha}{s_\beta}, t_\beta\frac{c_\alpha}{s_\beta}$	$\frac{1}{t_\beta}\frac{s_\alpha}{c_\beta}, t_\beta\frac{c_\alpha}{s_\beta}, t_\beta\frac{c_\alpha}{s_\beta}$

In the flavorful 2HDM there are additional corrections to the κ's of the order of $O(m_c/m_t)$, $O(m_s/m_b)$, $O(m_\mu/m_\tau)$

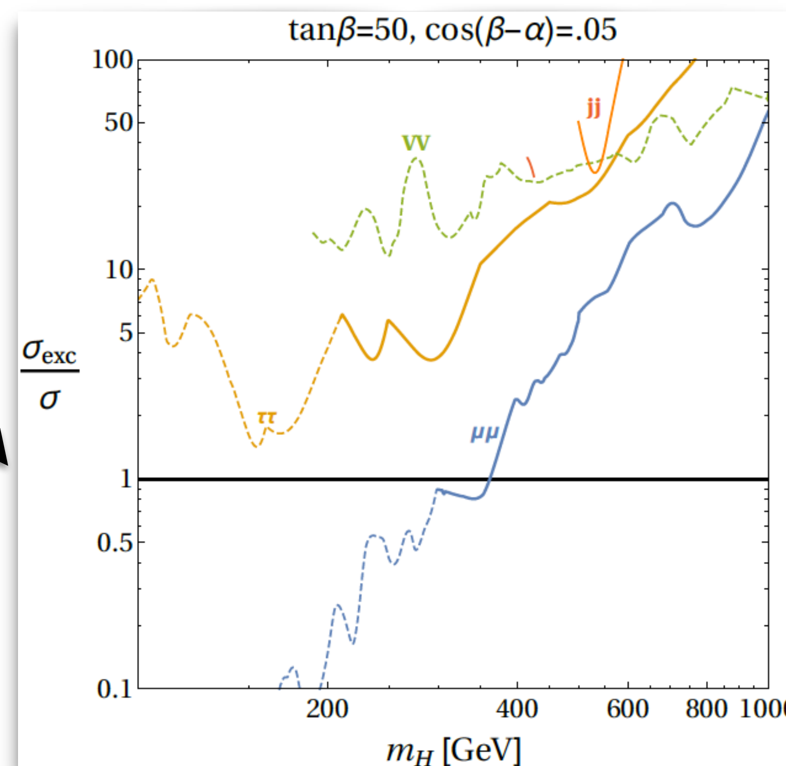
Hidden new Higgs bosons

Suppression of the main decay modes that are searched for at the LHC:

Altmannshofer, Eby, SG, Lotito, Martone, Tuckler, 1610.02398



weak bounds:



No bound beyond LEP for tanβ ≤ 10!

Similar message for the charged Higgs bosons

New heavy Higgs signature of the F2HDM

Several new signatures to look for:

H

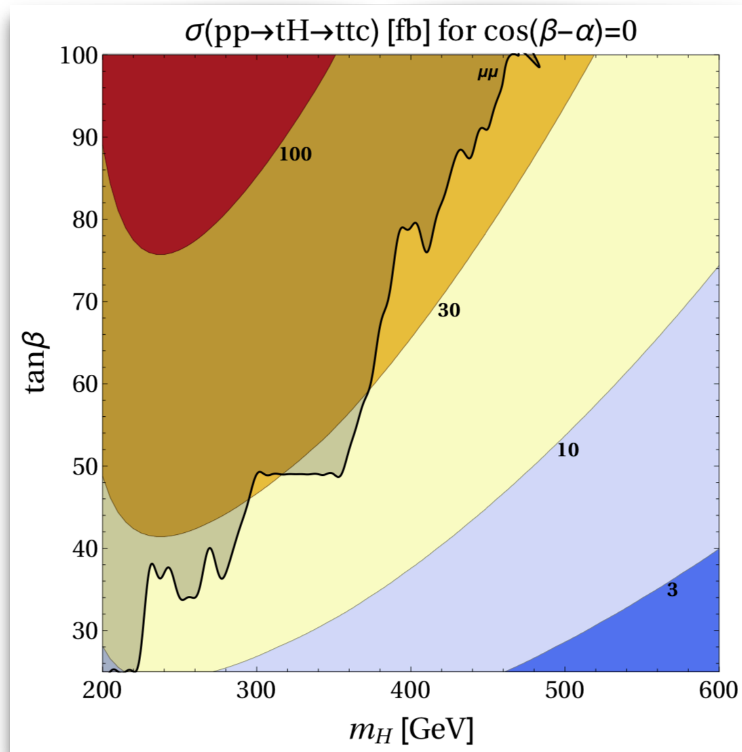
Top-charm resonances $\boxed{pp \to H \to tc}$

Boosted regime or leptonic top to trigger on the events.

Top-charm (or top-top) resonances

fully leptonic: $\boxed{pp \to t(c)H,\ H \to tc}$

same-charge dilepton plus bottom and charm jets



Tau-mu resonances $\boxed{pp \to t(c)H,\ H \to \tau\mu}$

Light di-jet resonances $\boxed{pp \to t(c)H,\ H \to cc}$

H±

Charm-bottom and charm-strange resonances (also above the top threshold). $\boxed{pp \to H^\pm \to cs,\ cb}$

Data scouting with bottom (charm)-tagging?

Altmannshofer, Eby, SG, Lotito, Martone, Tuckler, 1610.02398

The SUSY version of the F2HDM

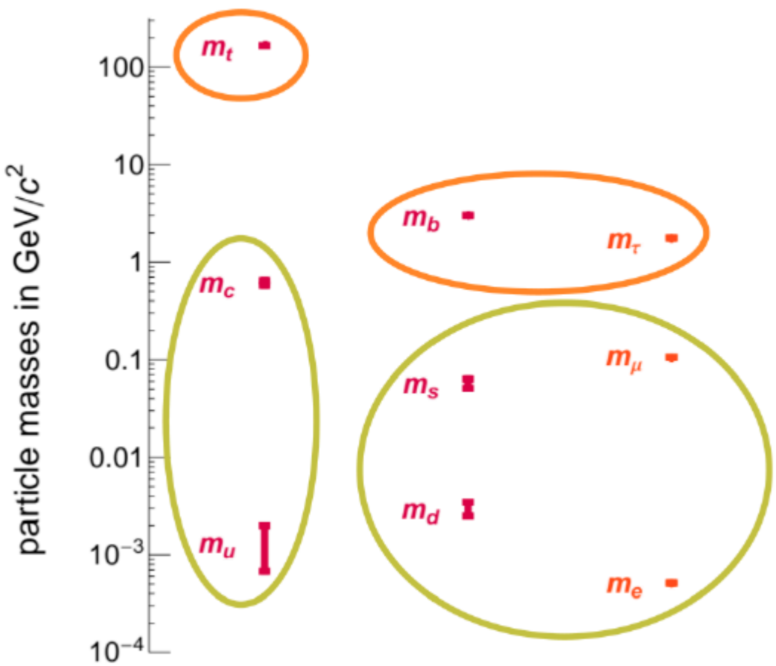
Altmannshofer, Gadam, SG, Hamer, 2104.08293

Anomaly cancellation → need four Higgs doublets: H_u, H_d, H'_u, H'_d

The superpotential is given by:

$$W = \mu_1 \widehat{H}_u \widehat{H}_d + \mu_2 \widehat{H}'_u \widehat{H}'_d + \mu_3 \widehat{H}'_u \widehat{H}_d + \mu_4 \widehat{H}_u \widehat{H}'_d$$
$$+ (Y_u \widehat{H}_u + Y'_u \widehat{H}'_u) \widehat{Q} \widehat{U}^c + (Y_d \widehat{H}_d + Y'_d \widehat{H}'_d) \widehat{Q} \widehat{D}^c + (Y_\ell \widehat{H}_d + Y'_\ell \widehat{H}'_d) \widehat{L} \widehat{E}^c$$

Let's call this framework "flavorful Supersymmetric SM" (FSSM)



from W. Altmannshofer

- Four μ terms
- Third generation gets mass from H_u, H_d
- First and second generation get mass from H'_u, H'_d

$$Y'_\ell \simeq \frac{\sqrt{2}}{v'_d} \begin{pmatrix} m_e & x_{e\mu} m_e & x_{e\tau} m_e \\ x_{\mu e} m_e & m_\mu & x_{\mu\tau} m_\mu \\ x_{\tau e} m_e & x_{\tau\mu} m_\mu & x_{\tau\tau} m_\mu \end{pmatrix}, \quad Y_\ell \simeq \frac{\sqrt{2}}{v_d} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_\tau \end{pmatrix}$$

Let us focus on the lepton sector…

Muon and smuon masses

Mass generation:

4 Higgs doublets participating to EWSB:

4 VEVs: v_u, v_d, v'_u, v'_d with $v_u^2+v_d^2+v'^2_u+v'^2_d=v^2$

Let's introduce the ratios $\tan\beta_u = \dfrac{v_u}{v'_u}$, $\tan\beta_d = \dfrac{v_d}{v'_d}$, $\tan\beta = \dfrac{v_u}{v_d}$

Muon and smuon masses

Mass generation:

4 Higgs doublets participating to EWSB:

4 VEVs: v_u, v_d, v'_u, v'_d with $v_u^2+v_d^2+v'^2_u+v'^2_d=v^2$

Let's introduce the ratios $\tan\beta_u = \frac{v_u}{v'_u}$, $\tan\beta_d = \frac{v_d}{v'_d}$, $\tan\beta = \frac{v_u}{v_d}$

$\tan\beta_d$

* controls the size of muon Yukawa (independently of the tau and bottom Yukawas)

$$Y'_{\mu\mu} = \frac{\sqrt{2}m_\mu}{v}\frac{\tan\beta\,\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d},\quad Y_\tau = \frac{\sqrt{2}m_\tau}{v}\frac{\tan\beta}{1+\epsilon_\tau\tan\beta}$$

Muon Yukawa can be O(1) without running into Landau poles

* boosts left-right mixing of smuons

$$M^2_{\tilde{\mu}} = \begin{pmatrix} m^2_{\tilde{\mu}_L} & -m_\mu\tan\beta\,\tan\beta_d\left(\mu_4+\frac{\mu_2}{\tan\beta_u}\right) \\ -m_\mu\tan\beta\,\tan\beta_d\left(\mu_4+\frac{\mu_2}{\tan\beta_u}\right) & m^2_{\tilde{\mu}_R} \end{pmatrix}$$

Chargino and neutralino spectrum

4 Higgsinos + Winos + Bino ➡ charginos + 6 neutralinos

Chargino mass matrix: $M_{\chi^\pm} = \begin{pmatrix} M_2 & \frac{g}{\sqrt{2}}v_u & \frac{g}{\sqrt{2}}v'_u \\ \frac{g}{\sqrt{2}}v_d & \mu_1 & \mu_3 \\ \frac{g}{\sqrt{2}}v'_d & \mu_4 & \mu_2 \end{pmatrix}$

It is convenient to first diagonalize the Higgsino block

$$\begin{pmatrix} \cos\theta_d & \sin\theta_d \\ -\sin\theta_d & \cos\theta_d \end{pmatrix} \begin{pmatrix} \mu_1 & \mu_3 \\ \mu_4 & \mu_2 \end{pmatrix} \begin{pmatrix} \cos\theta_u & \sin\theta_u \\ -\sin\theta_u & \cos\theta_u \end{pmatrix} = \begin{pmatrix} \mu & 0 \\ 0 & \tilde{\mu} \end{pmatrix}$$

Generically expect the rotation angles θ_u and θ_d to be O(1).

- Remaining off-diagonal entries are of the order of the electroweak scale and can be treated perturbatively.
- Analogous treatment for the neutralinos.
- The $\tilde{H}'_d$ component of the charginos and neutralinos can have O(1) coupling to muons.

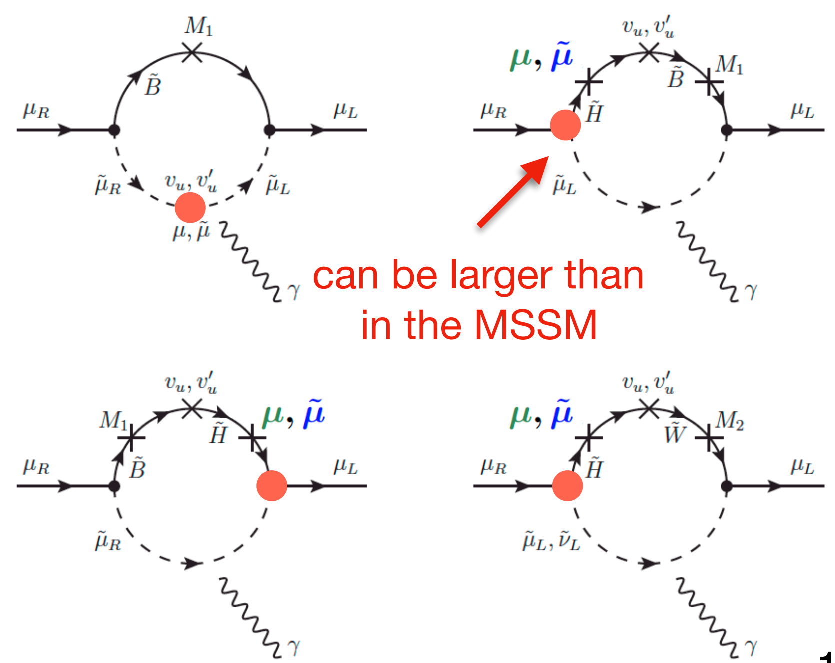
$(g\text{-}2)_\mu$ in the FSSM

Bino and Wino contributions have a structure that is analogous to the MSSM

$$\Delta a_\mu^{\tilde W} \sim \frac{5g^2}{192\pi^2}\frac{v^2}{m_{\tilde\mu}^2}\frac{M_2}{m_{\tilde\mu}^2}(\mu\sin\theta_d\cos\theta_u + \tilde\mu\cos\theta_d\sin\theta_u)\frac{m_\mu^2}{v^2}\frac{\tan\beta\,\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d}$$

$$\Delta a_\mu^{\tilde B} \sim \frac{g'^2}{192\pi^2}\frac{v^2}{m_{\tilde\mu}^2}\frac{M_1}{m_{\tilde\mu}^2}(\mu\sin\theta_d\cos\theta_u + \tilde\mu\cos\theta_d\sin\theta_u)\frac{m_\mu^2}{v^2}\frac{\tan\beta\,\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d}$$

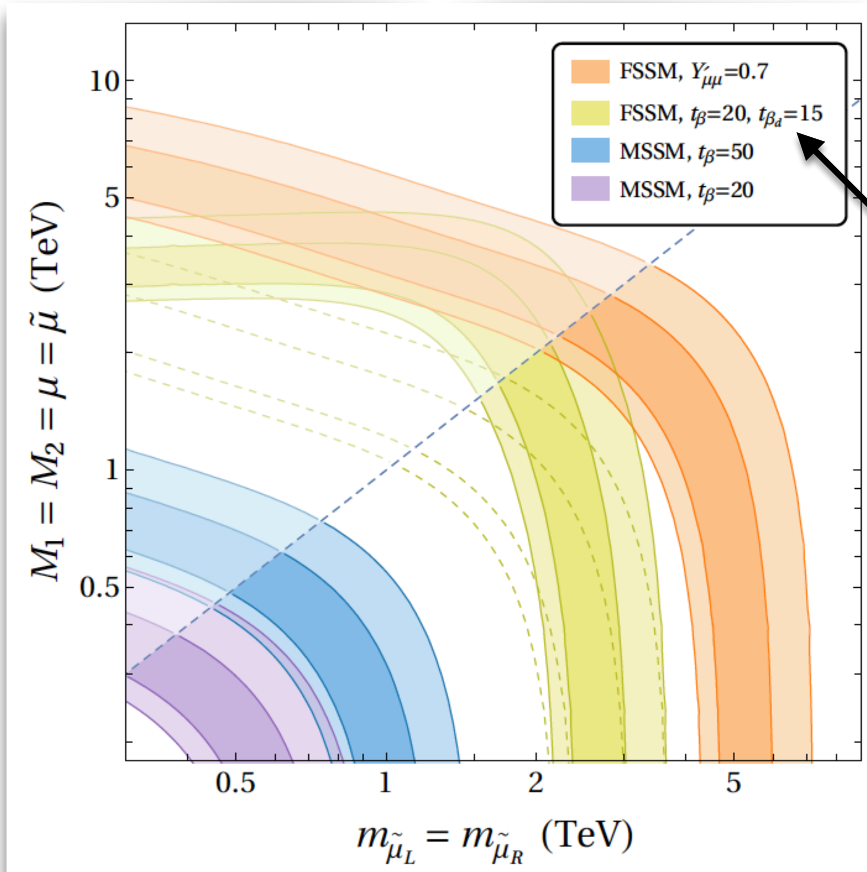
Contributions from the Higgsinos with mass μ and the Higgsinos with mass $\tilde\mu$



Main qualitative difference to the MSSM:
additional enhancement by $\tan\beta_d$

A heavier SUSY spectrum

Altmannshofer, Gadam, SG, Hamer, 2104.08293



Plot assumes O(1) Higgsino mixing:

$\theta_u = \theta_d = \pi / 2$

SUSY particles can be **several TeV** and can still explain the $(g-2)_\mu$ discrepancy

$$\boxed{\Delta a_\mu \sim 240 \times 10^{-11} \times \left(\frac{Y'_{\mu\mu}}{0.7}\right)\left(\frac{2.5\ \text{TeV}}{m_{\text{SUSY}}}\right)^2}$$

$$Y'_{\mu\mu} = \frac{\sqrt{2} m_\mu}{v} \frac{\tan\beta \tan\beta_d}{1 + \epsilon_\ell \tan\beta \tan\beta_d}$$

contrary to the MSSM,
muon mass threshold corrections can be large

$$\frac{\Delta m_\mu^{1-\text{loop}}}{m_\mu^{\text{tree}}} = \epsilon_\ell \tan\beta \tan\beta_d \simeq -0.54 \times \left(\frac{\tan\beta}{20}\right) \times \left(\frac{\tan\beta_d}{15}\right)$$

Other pheno implications of the model

Other **lepton g-2** are **<u>below</u>** experimental sensitivities:

$$\Delta a_e \simeq \frac{m_e^2}{m_\mu^2}\Delta a_\mu \simeq 5.8 \times 10^{-14} \times \left(\frac{\Delta a_\mu}{251 \times 10^{-11}}\right)$$

because of the approximate $SU(2)^2$ lepton flavor symmetry

$$\Delta a_\tau \sim \frac{m_\tau^2}{m_\mu^2}\frac{1}{\tan\beta_d}\Delta a_\mu \simeq 4.7 \times 10^{-8} \times \left(\frac{15}{\tan\beta_d}\right) \times \left(\frac{\Delta a_\mu}{251 \times 10^{-11}}\right)$$

Other pheno implications of the model

Other **lepton g-2** are **below** experimental sensitivities:

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Lepton flavor violation depends on unknown coefficients in the Yukawa couplings, Y'_{ll} but can get order of magnitude expectations:

$$Y'_\ell \simeq \frac{\sqrt{2}}{v'_d}\begin{pmatrix} m_e & x_{e\mu}m_e & x_{e\tau}m_e \\ x_{\mu e}m_e & m_\mu & x_{\mu\tau}m_\mu \\ x_{\tau e}m_e & x_{\tau\mu}m_\mu & x_{\tau\tau}m_\mu \end{pmatrix}$$

$$\begin{aligned}\mathrm{BR}(\tau\to\mu\gamma) &\simeq 24\pi^3\alpha_{\rm em}\frac{v^4}{m_\mu^4}(\Delta a_\mu)^2\left(x_{\tau\mu}^2+x_{\mu\tau}^2\right)\times\mathrm{BR}(\tau\to\mu\nu_\tau\bar{\nu}_\mu)\\ &\simeq 1.7\times 10^{-8}\times\left(\frac{\Delta a_\mu}{251\times 10^{-11}}\right)^2\left[\left(\frac{x_{\tau\mu}}{0.01}\right)^2+\left(\frac{x_{\mu\tau}}{0.01}\right)^2\right],\end{aligned}$$

constrained by BaBar and Belle: $\mathrm{BR}_{\rm exp} < 4.2 \times 10^{-8}$

$$\begin{aligned}\mathrm{BR}(\tau\to e\gamma) &\simeq 24\pi^3\alpha_{\rm em}\frac{v^4}{m_\mu^4}\frac{m_e^2}{m_\mu^2}(\Delta a_\mu)^2\left(x_{\tau e}^2+x_{\mu e}^2\right)\times\mathrm{BR}(\tau\to e\nu_\tau\bar{\nu}_\mu)\\ &\simeq 4.1\times 10^{-9}\times\left(\frac{\Delta a_\mu}{251\times 10^{-11}}\right)^2\left[\left(\frac{x_{\tau e}}{1.0}\right)^2+\left(\frac{x_{e\tau}}{1.0}\right)^2\right],\end{aligned}$$

($\mathrm{BR}_{\rm exp} < 3.3 \times 10^{-8}$) in reach of Belle II

Other pheno implications of the model

Other **lepton g-2** are **<u>below</u>** experimental sensitivities:

$$\Delta a_e \simeq \frac{m_e^2}{m_\mu^2}\Delta a_\mu \simeq 5.8\times 10^{-14}\times\left(\frac{\Delta a_\mu}{251\times 10^{-11}}\right)$$

because of the approximate SU(2)² lepton flavor symmetry

$$\Delta a_\tau \sim \frac{m_\tau^2}{m_\mu^2}\frac{1}{\tan\beta_d}\Delta a_\mu \simeq 4.7\times 10^{-8}\times\left(\frac{15}{\tan\beta_d}\right)\times\left(\frac{\Delta a_\mu}{251\times 10^{-11}}\right)$$

μ → e Lepton flavor violation is suppressed by the approximate SU(2)² lepton flavor symmetry

$$\begin{aligned}\mathrm{BR}(\mu\to e\gamma) &\simeq 24\pi^3\alpha_{\rm em}\frac{v^4}{m_\mu^4}\frac{m_e^2}{m_\tau^2}(\Delta a_\mu)^2\,(x_{e\tau}^2 x_{\tau\mu}^2 + x_{\mu\tau}^2 x_{\tau e}^2)\\ &\simeq 8.2\times 10^{-15}\times\left(\frac{\Delta a_\mu}{251\times 10^{-11}}\right)^2\left[\left(\frac{x_{e\tau}x_{\tau\mu}}{0.01}\right)^2+\left(\frac{x_{\mu\tau}x_{\tau e}}{0.01}\right)^2\right]\end{aligned}$$

Almost 2 orders of magnitude below the MEG bound

For further investigation

* Can the setup be consistently **extended to the quark sector**?

(It works well in the non-SUSY case. Constraints from meson mixing are under control
Altmannshofer, SG, Robinson, Tuckler 1712.01847)

* In a SUSY version, one expects **$\tan\beta \times \tan\beta_d$ enhanced** Higgsino contributions to **rare B decays** like $b \to s\gamma$ and $B_s \to \mu^+\mu^-$
  ⇒ possibly strong constraints on stop masses.

* One could try to **explain R_K and R_{K^*}** with Higgsino loops? (probably difficult)

* Quantify the effect of the extra Higgs bosons on **gauge coupling unification**

* Can one achieve 3rd generation Yukawa unification?
  What about **3rd+2nd generation Yukawa unification**?

Conclusions & outlook

Exp. motivations

- From Higgs coupling measurements, we do not yet know if the Higgs gives mass to all generation quarks and leptons
- Hints for New Physics coupled to muons? ($(g\text{-}2)_\mu$, R_K, R_{K^*})

Theory motivations

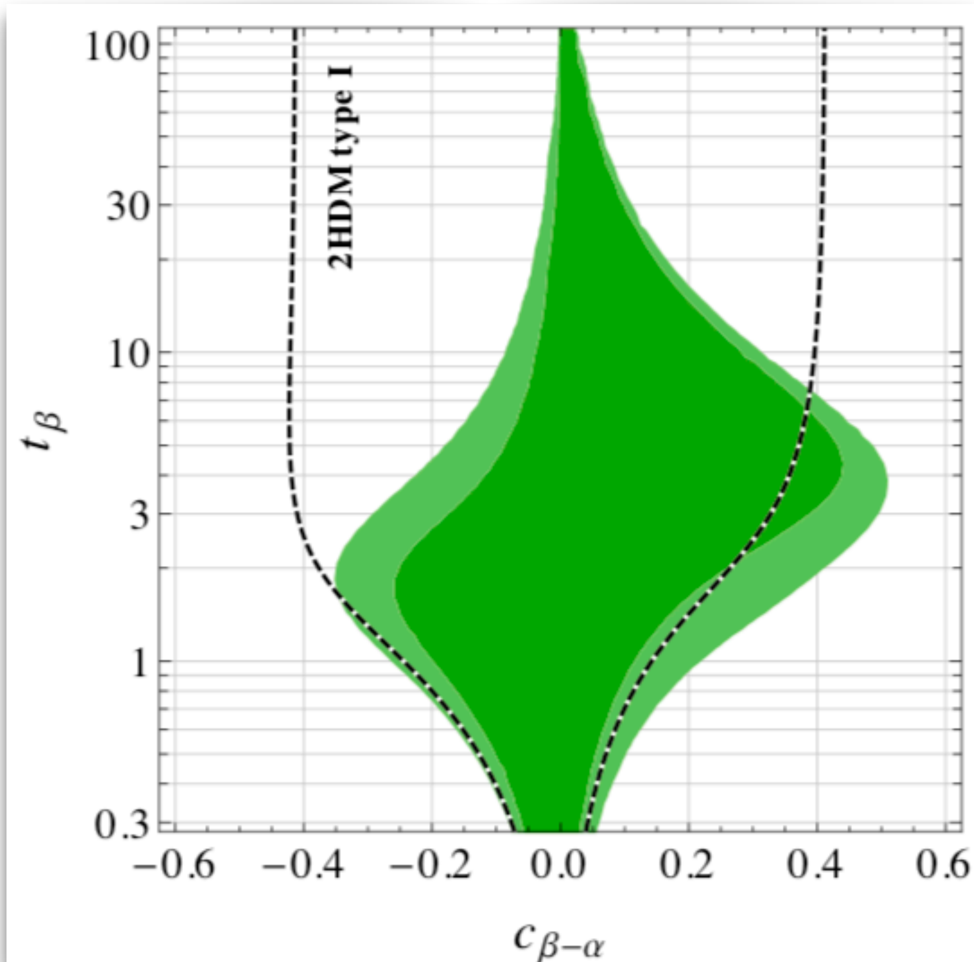
- The SM flavor puzzle

SUSY version of a flavorful electroweak symmetry breaking sector can accommodate Higgs bosons and Higgsinos with O(1) couplings to muons

- Model can explain $(g-2)_\mu$ with multi-TeV sleptons
- Predictions for other dipole transitions:
  - effects in anomalous magnetic moments of electron and tau below current sensitivities
  - Lepton flavor violating tau decays in reach of Belle II
  - $\mu \to e\gamma$ below current MEG sensitivity
- Extension to quark sector?

Higgs coupling constraints
for the flavorful 2HDM

Altmannshofer, Eby, SG, Lotito, Martone, Tuckler, 1610.02398



latest h → μμ results likely further constraint the allowed parameter space