BSM Higgs Bosons

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Summary

- Standard search strategies for additional Higgs bosons focus on 3rd gen. fermions (+ gauge bosons and Higgs)
- Many examples of models where other couplings dominate
  - coupling to 2nd (or even 1st) gen. could dominate $c\bar{c} \to H \to \mu\bar{\mu}$?
  - flavor violating couplings could be relevant $cg \to tH \to tt\bar{c}$? $\quad H \to \tau\bar{\mu}$?
  - exotic decays ($\to$ talk by Zhen Liu) neutralinos, staus, hidden sector glueballs, ...
- Keep open mind when searching for Higgs bosons!

Higgs and Flavor

Invariant under a $SU(3)^5 \times U(1)^5$ flavor symmetry

$$\mathcal{L}_{SM} \sim \Lambda^4 + \Lambda^2 H^2 + \lambda H^4 + \bar{\Psi} \not{D} \Psi + (D_\mu H)^2 + (F_{\mu\nu})^2 + F_{\mu\nu} \tilde{F}^{\mu\nu} + Y H \bar{\Psi} \Psi + \frac{1}{\Lambda} (LH)^2 + \frac{1}{\Lambda^2} \sum_i \mathcal{O}_i^{\text{dim6}}$$

Only renormalizable source of flavor breaking

No flavor without the Higgs in the Standard Model

But: minimal flavor breaking;
no flavor changing neutral currents at tree level (GIM)

Extended Higgs Sectors

Strong constraints from the ρ parameter
($I =$ weak isospin, $Y =$ hypercharge, $v =$ vacuum expectation value)

$$\rho = \frac{\sum_i (I_i(I_i+1) - Y_i^2) v_i^2}{\sum_i 2 Y_i^2 v_i^2} = \frac{m_W^2}{m_Z^2 c_W^2} = 1$$

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ρ is automatically 1 for $SU(2)$ singlets and doublets.

(Can be made 1 also for larger $SU(2)$ representations,
but in a non-trivial way)

$\rightarrow$ focus on singlets and doublets in the following

Flavor in Extended Higgs Sectors

Extended Higgs sectors often introduce new sources of flavor violation

Example: 2 Higgs Doublet Model contains two set of Yukawa couplings

$$Y_1 H_1 Q_L D_R + Y_2 H_2 Q_L D_R$$

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mass matrix for the quarks and Higgs couplings are given by different linear combinations of the two Yukawa couplings

$$\frac{m_d}{v} = Y_1 \sin\beta + Y_2 \cos\beta \quad , \quad g_{hdd} = Y_1 \cos\alpha - Y_2 \sin\alpha$$

in general, mass and coupling cannot be diagonalzied simultaneously
$\rightarrow$ flavor changing neutral currents at tree level
$\rightarrow$ very strong constraints e.g. from meson mixing

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Two options for "flavor safe" models

1) switch off one set of Yukawa couplings $\rightarrow$ natural flavor conservation
2) make the two sets proportional to each other $\rightarrow$ flavor alignment

Models with Natural Flavor Conservation

Four well explored types of 2HDMs.

Model	u_R^i	d_R^i	e_R^i
Type I	Φ_2	Φ_2	Φ_2
Type II	Φ_2	Φ_1	Φ_1
Lepton-specific	Φ_2	Φ_2	Φ_1
Flipped	Φ_2	Φ_1	Φ_2

Each set of fermions gets mass from only one Higgs boson

(Glashow, Weinberg '77)

$\rightarrow$ tree level FCNCs are avoided

Models with Flavor Alignment

Impose that both sets of Yukawa couplings are proportional to each other

(Pich, Tuzon 0908.1554)

$$Y_1 H_1 Q_L D_R + Y_2 H_2 Q_L D_R \quad \text{with} \quad Y_2 = c Y_1$$

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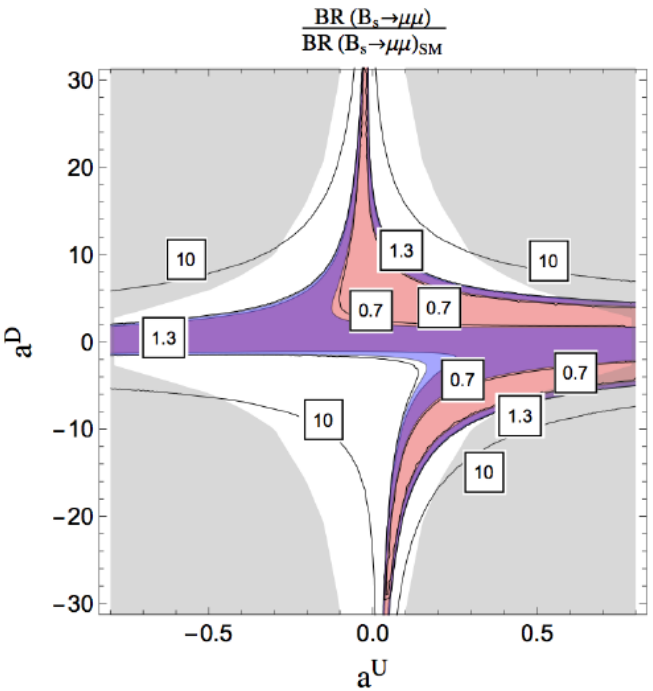
$\rightarrow$ tree level FCNCs are avoided
However: alignment is not stable under quantum corrections.

Aligning the Yukawa couplings at a particular energy scale will introduce flavor changing effects through RGE running.

flavor constraints can be important.

(Gori, Haber, Santos 1703.05873)



Modified $h(125)$ Couplings

	W,Z	up quarks	down quarks	leptons
	κ_V	κ_t, κ_c, κ_u	κ_b, κ_s, κ_d	κ_τ, κ_μ, κ_e
mixing with singlet				
2HDM type 1				
2HDM type 2				
lepton specific				
flipped				
aligned				

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	W,Z κ_V	up quarks κ_t, κ_c, κ_u	down quarks κ_b, κ_s, κ_d	leptons κ_τ, κ_μ, κ_e
mixing with singlet	c_α	c_α	c_α	c_α
2HDM type 1				
2HDM type 2				
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2HDM type 1	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$
2HDM type 2				
lepton specific				
flipped				
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flipped				
aligned				

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2HDM type 2	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{-s_\alpha}{c_\beta}$	$\frac{-s_\alpha}{c_\beta}$
lepton specific	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$	$\frac{-s_\alpha}{c_\beta}$
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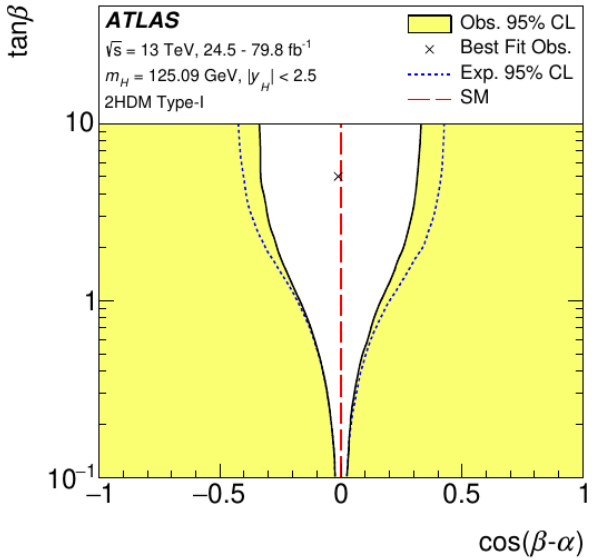
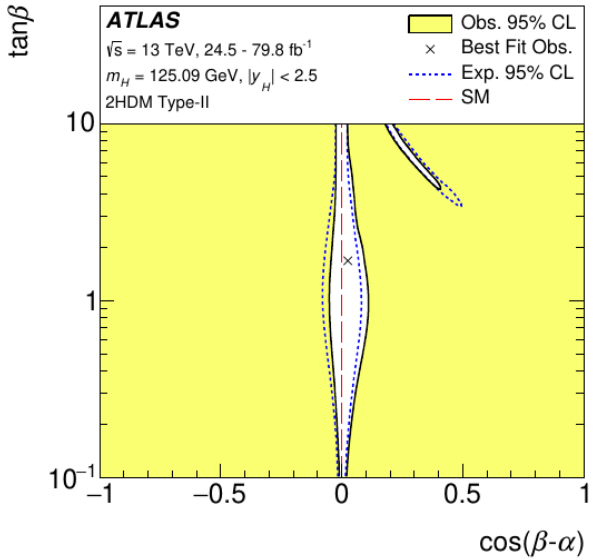
lepton specific	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$	$\frac{-s_\alpha}{c_\beta}$
flipped	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{-s_\alpha}{c_\beta}$	$\frac{c_\alpha}{s_\beta}$
aligned	$s_{\beta-\alpha}$	ξ_u^h	ξ_d^h	ξ_ℓ^h

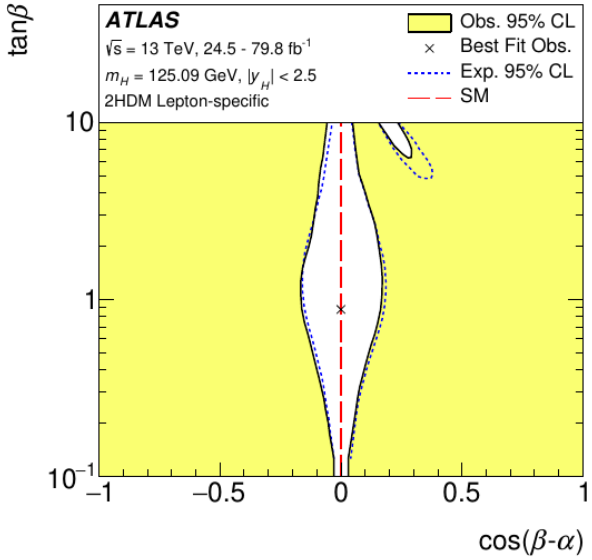
Constraints from $h(125)$ Measurements

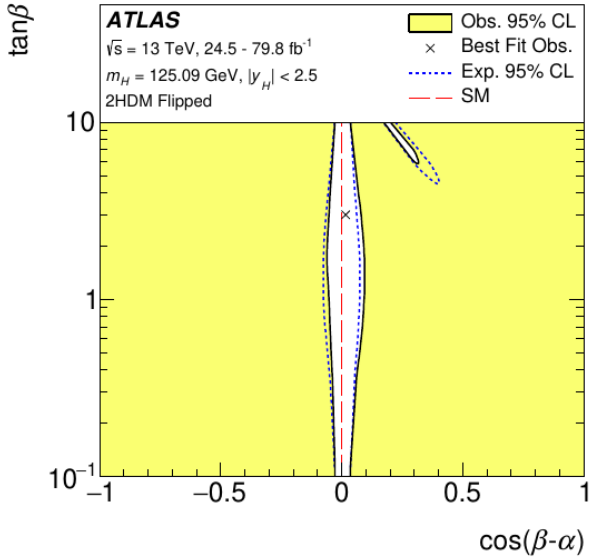


(a)



(b)





ATLAS 1909.02845

Modified Heavy Higgs Couplings

	W,Z κ_V	up quarks κ_t, κ_c, κ_u	down quarks κ_b, κ_s, κ_d	leptons κ_τ, κ_μ, κ_e
mixing with singlet				
2HDM type 1				
2HDM type 2				
lepton specific				
flipped				
aligned				

(in the Higgs alignment limit $\cos(\beta - \alpha) = 0$)

Modified Heavy Higgs Couplings

	W,Z κ_V	up quarks κ_t, κ_c, κ_u	down quarks κ_b, κ_s, κ_d	leptons κ_τ, κ_μ, κ_e
mixing with singlet	s_α	s_α	s_α	s_α
2HDM type 1				
2HDM type 2				
lepton specific				
flipped				
aligned				

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mixing with singlet	s_α	s_α	s_α	s_α
2HDM type 1	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$
2HDM type 2				
lepton specific				
flipped				
aligned				

(in the Higgs alignment limit $\cos(\beta - \alpha) = 0$)

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mixing with singlet	s_α	s_α	s_α	s_α
2HDM type 1	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$
2HDM type 2	0	$\frac{1}{t_\beta}$	t_β	t_β
lepton specific				
flipped				
aligned				

(in the Higgs alignment limit $\cos(\beta - \alpha) = 0$)

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2HDM type 1	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$
2HDM type 2	0	$\frac{1}{t_\beta}$	t_β	t_β
lepton specific	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	t_β
flipped	0	$\frac{1}{t_\beta}$	t_β	$\frac{1}{t_\beta}$
aligned				

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2HDM type 2	0	$\frac{1}{t_\beta}$	t_β	t_β
lepton specific	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	t_β
flipped	0	$\frac{1}{t_\beta}$	t_β	$\frac{1}{t_\beta}$
aligned	0	ξ_u^H	ξ_d^H	ξ_ℓ^H

(in the Higgs alignment limit $\cos(\beta - \alpha) = 0$)

Standard Search Strategies

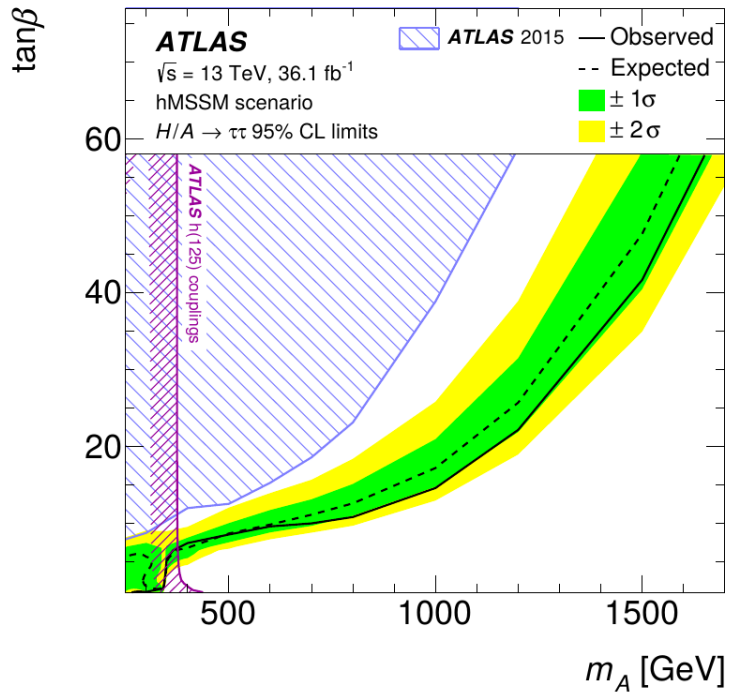
Focus on third generation fermions
top for small $\tan\beta$, bottom/tau for large $\tan\beta$

Production in association with bottom or top
Decay to top/bottom/tau

e.g. searches for MSSM Higgs bosons in large $\tan\beta$ regime:

$$pp \to bbH \to bb\tau\tau$$
$$pp \to H \to \tau\tau$$

ATLAS 1709.07242



(b) hMSSM scenario

Flavorful Two Higgs Doublet Models

Flavor Constraints

The strongest flavor constraints typically come from transitions between the second and first generation

$s \leftrightarrow d$: Kaon mixing

$d \leftrightarrow u$: D meson mixing

$\mu \leftrightarrow e$: $\mu \to e\gamma$, $\mu \to e$ conversion

Models with an $SU(2)^5$ flavor symmetry acting on the first two generations tend to be largely safe from flavor constraints

Implementation in a 2HDM Context

$$\lambda_{u_{1,2}} \sim \frac{\sqrt{2}}{v_{u_{1,2}}} \begin{pmatrix} m_u & m_u & m_u \\ m_u & m_c & m_c \\ m_u & m_c & m_c \end{pmatrix}, \qquad \lambda_{u_3} \sim \frac{\sqrt{2}}{v_{u_3}} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_t \end{pmatrix}$$

$$\lambda_{d_{1,2}} \sim \frac{\sqrt{2}}{v_{d_{1,2}}} \begin{pmatrix} m_d & \lambda m_s & \lambda^3 m_b \\ m_d & m_s & \lambda^2 m_b \\ m_d & m_s & m_s \end{pmatrix}, \qquad \lambda_{d_3} \sim \frac{\sqrt{2}}{v_{d_3}} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_b \end{pmatrix}$$

$$\lambda_{\ell_{1,2}} \sim \frac{\sqrt{2}}{v_{\ell_{1,2}}} \begin{pmatrix} m_e & m_e & m_e \\ m_e & m_\mu & m_\mu \\ m_e & m_\mu & m_\mu \end{pmatrix}, \qquad \lambda_{\ell_3} \sim \frac{\sqrt{2}}{v_{\ell_3}} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_\tau \end{pmatrix}$$

Suppression of FCNCs

$$\mathcal{M}_0^u \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_t \end{pmatrix} \;,\; \mathcal{M}_0^d \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_b \end{pmatrix} \;,\; \mathcal{M}_0^\ell \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_\tau \end{pmatrix}$$

The rank 1 Yukawa couplings preserve a $SU(2)^5$ flavor symmetry for the light two generations of quarks and leptons

Suppression of FCNCs

$$\mathcal{M}_0^u \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_t \end{pmatrix} , \quad \mathcal{M}_0^d \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_b \end{pmatrix} , \quad \mathcal{M}_0^\ell \simeq \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & m_\tau \end{pmatrix}$$

The rank 1 Yukawa couplings preserve a $SU(2)^5$ flavor symmetry for the light two generations of quarks and leptons

flavor violating transitions between 1st and 2nd generation are protected

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

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

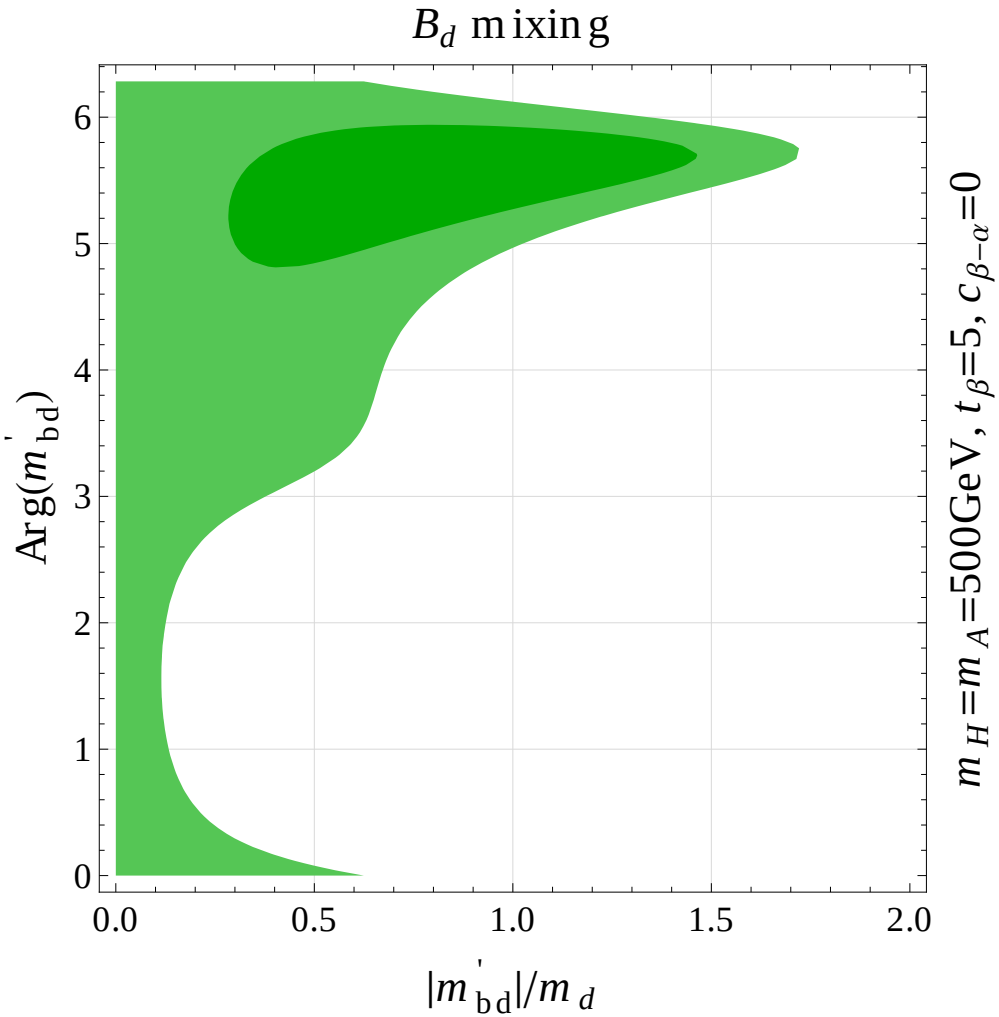
$$\begin{pmatrix} m_e & O(m_e) & O(m_e) \\ O(m_e) & m_\mu & O(m_\mu) \\ O(m_e) & O(m_\mu) & O(m_\mu) \end{pmatrix} \xrightarrow[\text{basis}]{\text{mass eigenstate}} \begin{pmatrix} m_e & O(\frac{m_e m_\mu}{m_\tau}) & O(m_e) \\ O(\frac{m_e m_\mu}{m_\tau}) & m_\mu & O(m_\mu) \\ O(m_e) & O(m_\mu) & O(m_\mu)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

Constraints from B_d mixing

$$\frac{M_{12}^{\rm NP}}{M_{12}^{\rm SM}} \propto \frac{m_{B_d}^2}{m_A^2} \tan^2\beta \frac{m'^*_{bd} m'_{db}}{m_b^2 (V_{tb} V_{td}^*)^2}$$

$m'_{db} \simeq m_b V_{td}^*$; $m'_{bd} \sim m_d$?

m'_{bd} can be of its "natural size"



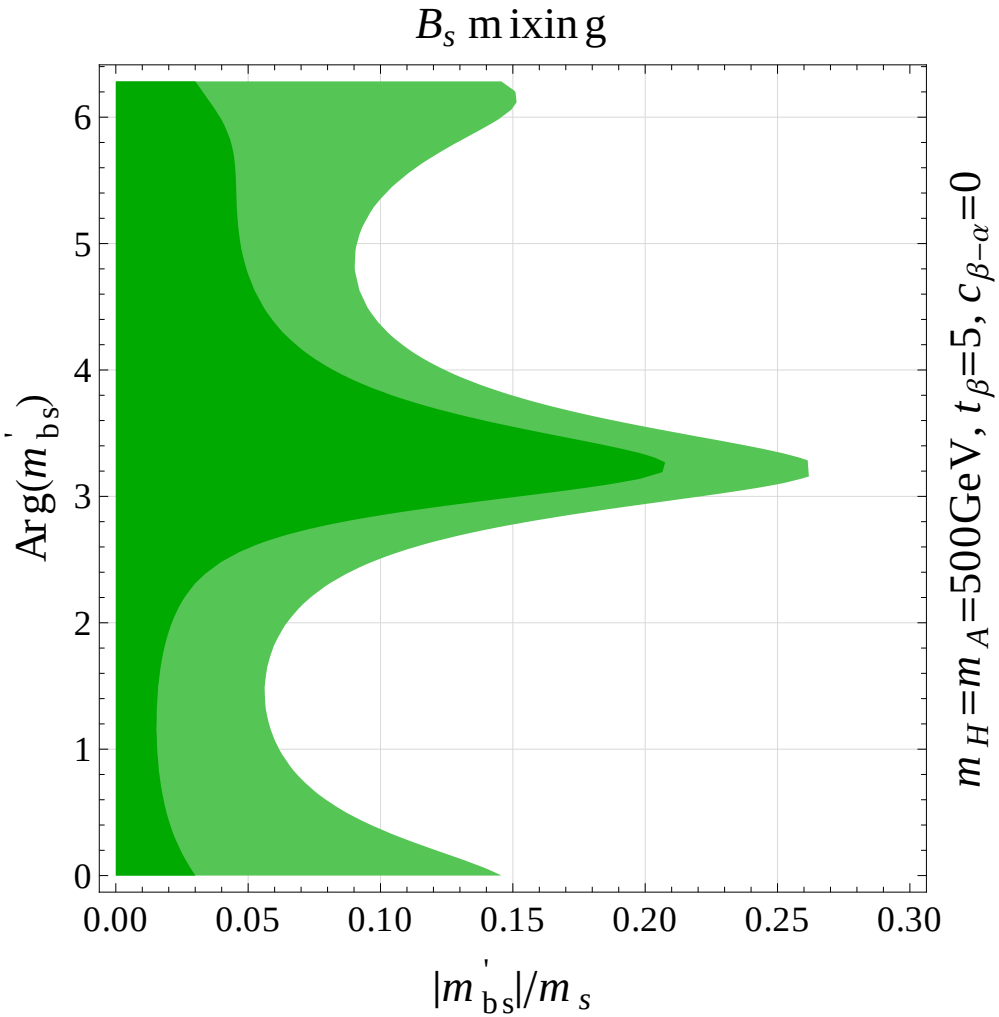
WA, Maddock 1805.08659

Constraints from B_s mixing

$$\frac{M_{12}^{\rm NP}}{M_{12}^{\rm SM}} \propto \frac{m_{B_s}^2}{m_A^2} \tan^2\beta \frac{m'^{*}_{bs} m'_{sb}}{m_b^2 (V_{tb} V_{ts}^*)^2}$$

$m'_{sb} \simeq m_b V_{ts}^*$; $m'_{bs} \sim m_s$?

m'_{bs} needs to be somewhat suppressed



WA, Maddock 1805.08659

Flavor Diagonal Couplings of the 125 GeV Higgs

Compare to other extended Higgs sectors

	W,Z κ_V	up quarks κ_t, κ_c, κ_u	down quarks κ_b, κ_s, κ_d	leptons κ_τ, κ_μ, κ_e
mixing with singlet				
2HDM type 1				
2HDM type 2				
flavorful 2HDM				

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mixing with singlet	c_α	c_α	c_α	c_α
2HDM type 1	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$
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flavorful 2HDM	$s_{\beta-\alpha}$	$\frac{c_\alpha}{s_\beta}, \frac{-s_\alpha}{c_\beta}, \frac{-s_\alpha}{c_\beta}$	$\frac{c_\alpha}{s_\beta}, \frac{-s_\alpha}{c_\beta}, \frac{-s_\alpha}{c_\beta}$	$\frac{c_\alpha}{s_\beta}, \frac{-s_\alpha}{c_\beta}, \frac{-s_\alpha}{c_\beta}$

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

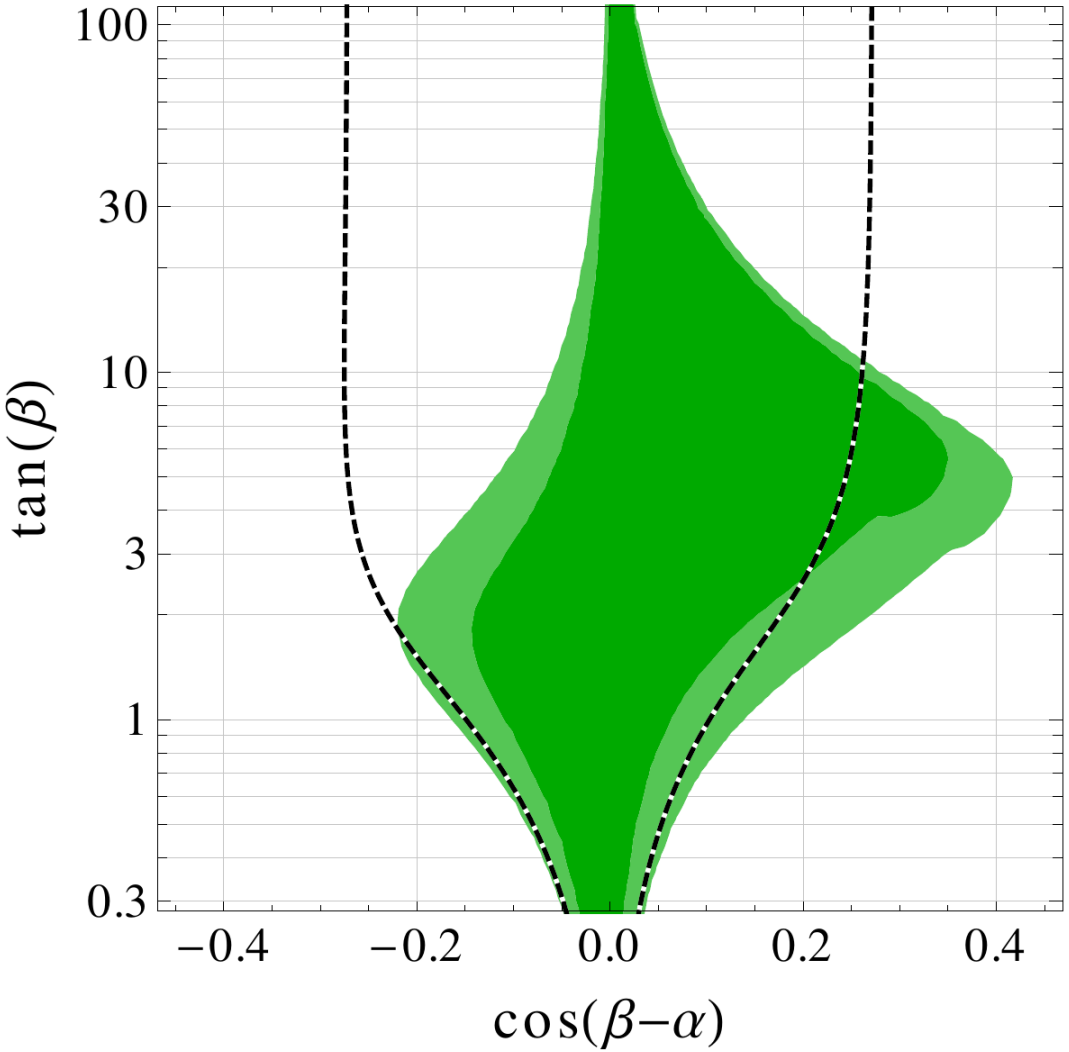
Constraints from Higgs Rates

measurements of Higgs rates constrain α/β parameter space

for low $\tan\beta$ expect constraints similar to 2HDM type 1

for large $\tan\beta$ couplings to charm and muons can be strongly enhanced

in the still allowed range, charm and muon couplings typically suppressed



WA, Maddock 1805.08659

Higgs Flavor Violation

generic expectations for lepton flavor violating Higgs decays

$$\text{BR}(h \to \tau\mu) \sim \frac{m_\mu^2}{3m_b^2} \sim 10^{-3}$$

$$\text{BR}(h \to \tau e) \sim \frac{m_e^2}{3m_b^2} \sim 10^{-7}$$

$$\text{BR}(h \to \mu e) \sim \frac{m_e^2 m_\mu^2}{3m_\tau^2 m_b^2} \sim 10^{-10}$$

WA, Gori, Kagan, Silvestrini, Zupan '15

Couplings of the Heavy Higgses

Compare neutral scalar couplings to other extended Higgs sectors

	W,Z	up quarks	down quarks	leptons
	κ_V	κ_t, κ_c, κ_u	κ_b, κ_s, κ_d	κ_τ, κ_μ, κ_e
mixing with singlet				
2HDM type 1				
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Compare neutral scalar couplings to other extended Higgs sectors

	W,Z κ_V	up quarks κ_t, κ_c, κ_u	down quarks κ_b, κ_s, κ_d	leptons κ_τ, κ_μ, κ_e
mixing with singlet	s_α	s_α	s_α	s_α
2HDM type 1	0	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$	$\frac{1}{t_\beta}$
2HDM type 2	0	$\frac{1}{t_\beta}$	t_β	t_β
flavorful 2HDM				

Couplings of the Heavy Higgses

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flavorful 2HDM	0	$\frac{1}{t_\beta}$, t_β, t_β	$\frac{1}{t_\beta}$, t_β, t_β	$\frac{1}{t_\beta}$, t_β, t_β

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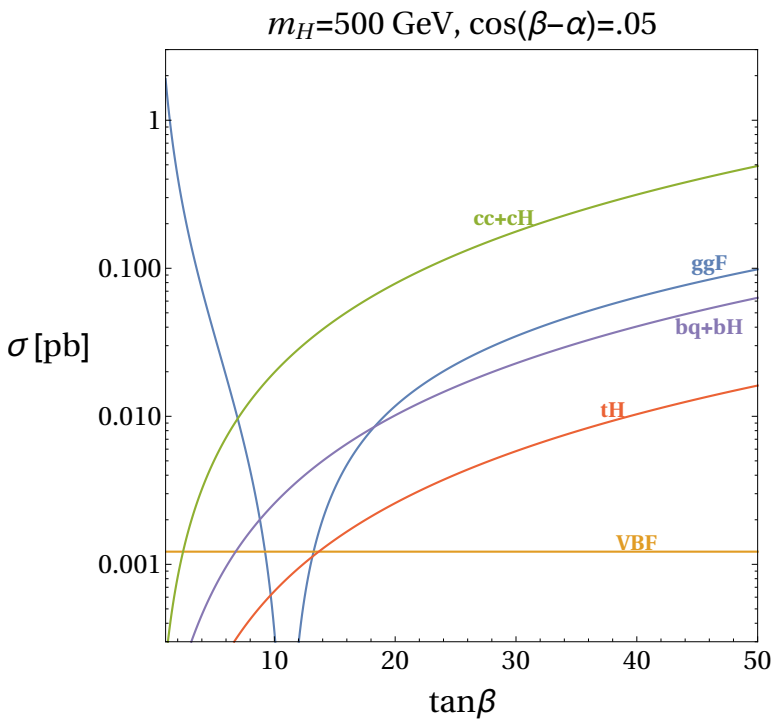
flavorful 2HDM	0	$\frac{1}{t_\beta}$, t_β, t_β	$\frac{1}{t_\beta}$, t_β, t_β	$\frac{1}{t_\beta}$, t_β, t_β

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

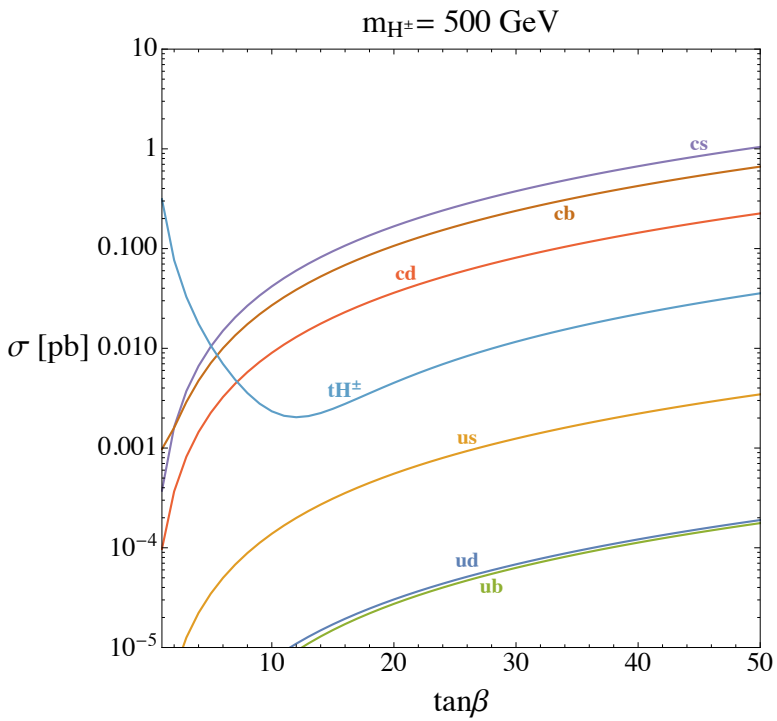
Heavy Higgs Production

most important production modes involve 2nd gen. fermions

neutral scalar



charged Higgs



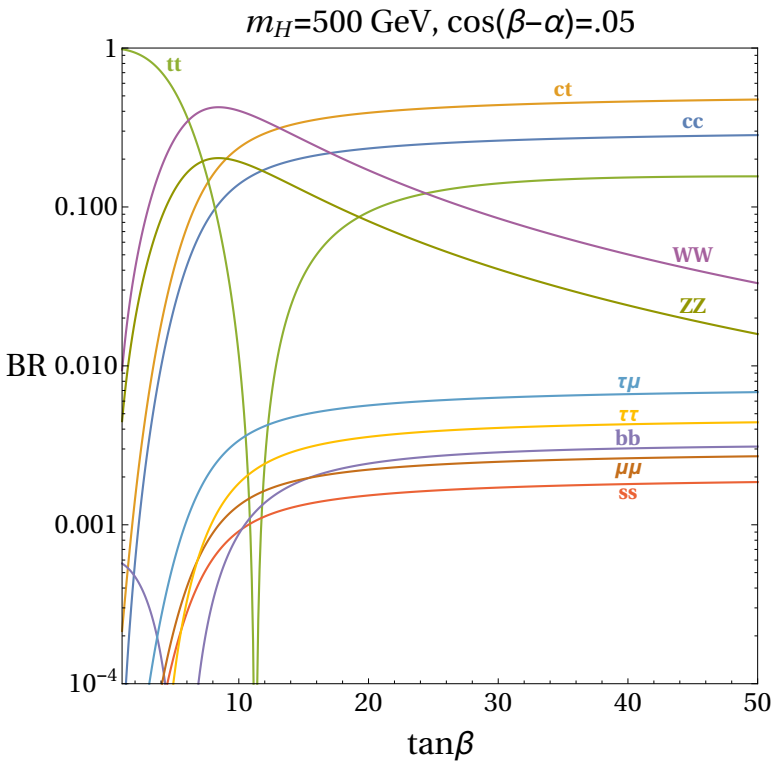
WA, Eby, Gori, Lotito, Martone, Tuckler '16

(in the plots, all $O(1)$ parameters in the mass textures are set $= 1$)

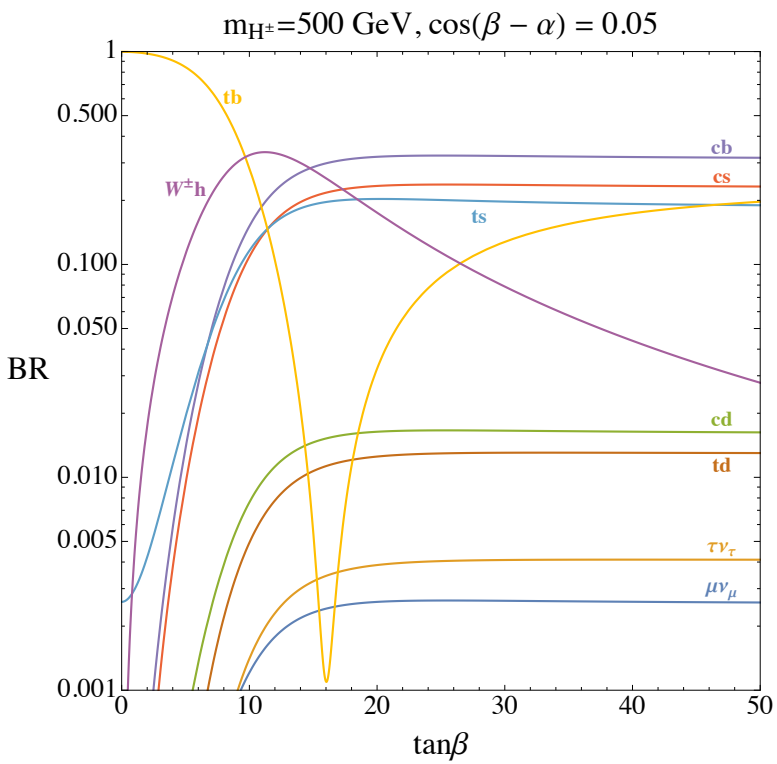
Heavy Higgs Decays

most important decay modes involve 2nd gen. fermions

neutral scalar



charged Higgs



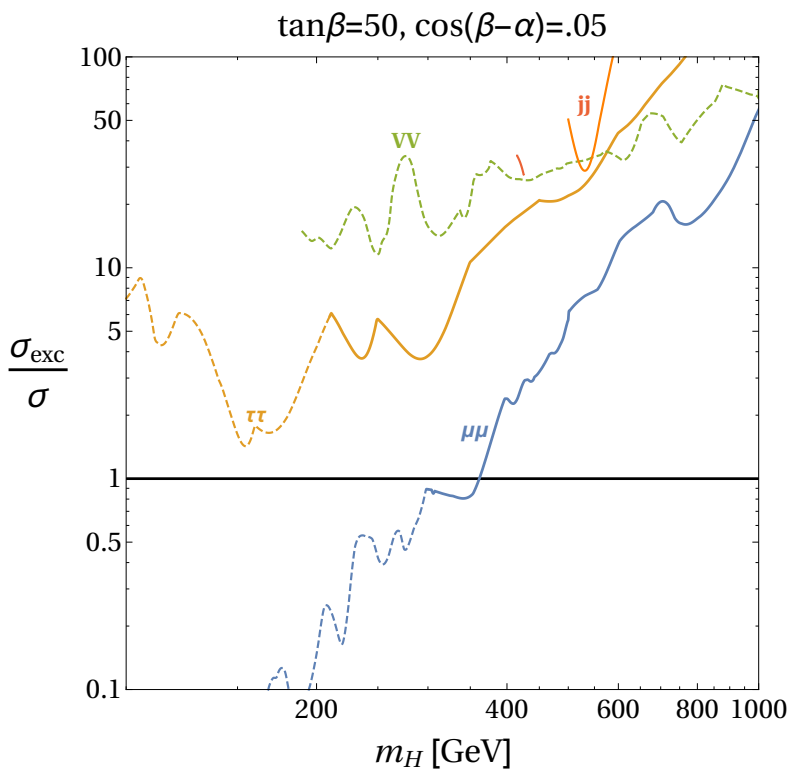
WA, Eby, Gori, Lotito, Martone, Tuckler '16

(in the plots, all $O(1)$ parameters in the mass textures are set $= 1$)

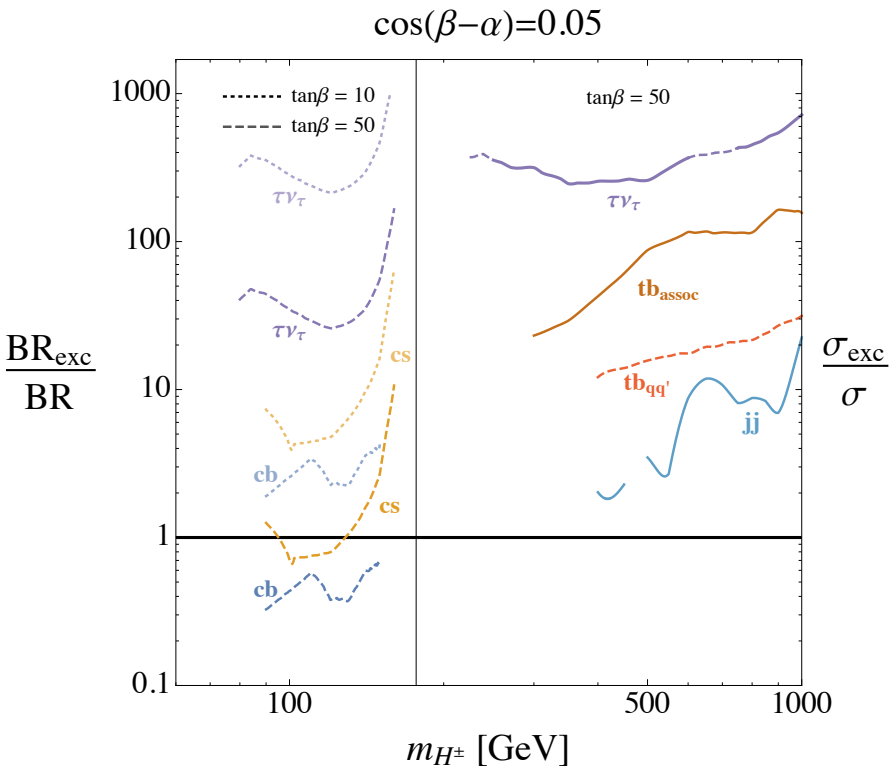
Current Exclusions

Strongest bounds currently from di-muon and di-jet resonance searches

neutral scalar

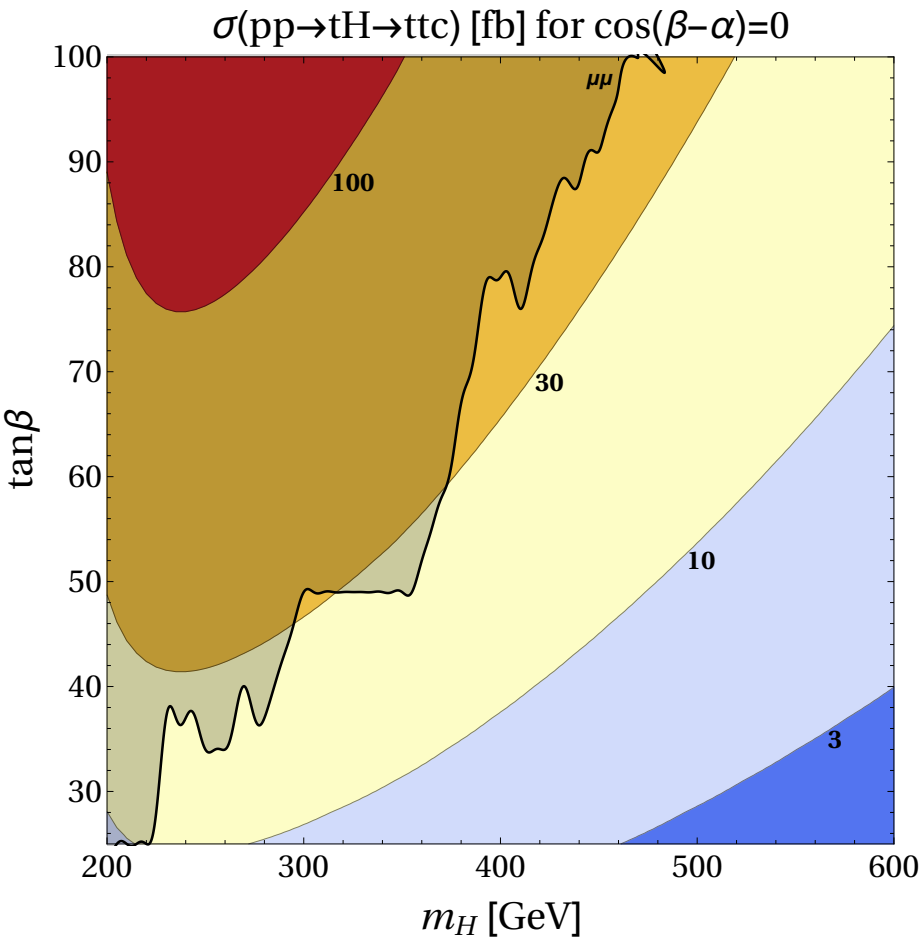


charged Higgs



WA, Eby, Gori, Lotito, Martone, Tuckler '16

Interesting Collider Signatures for Neutral Higgs



current most stringent constraint:
di-muon resonance searches
$pp \to H/A \to \mu^+\mu^-$
(gray shaded region)

Interesting signatures include:

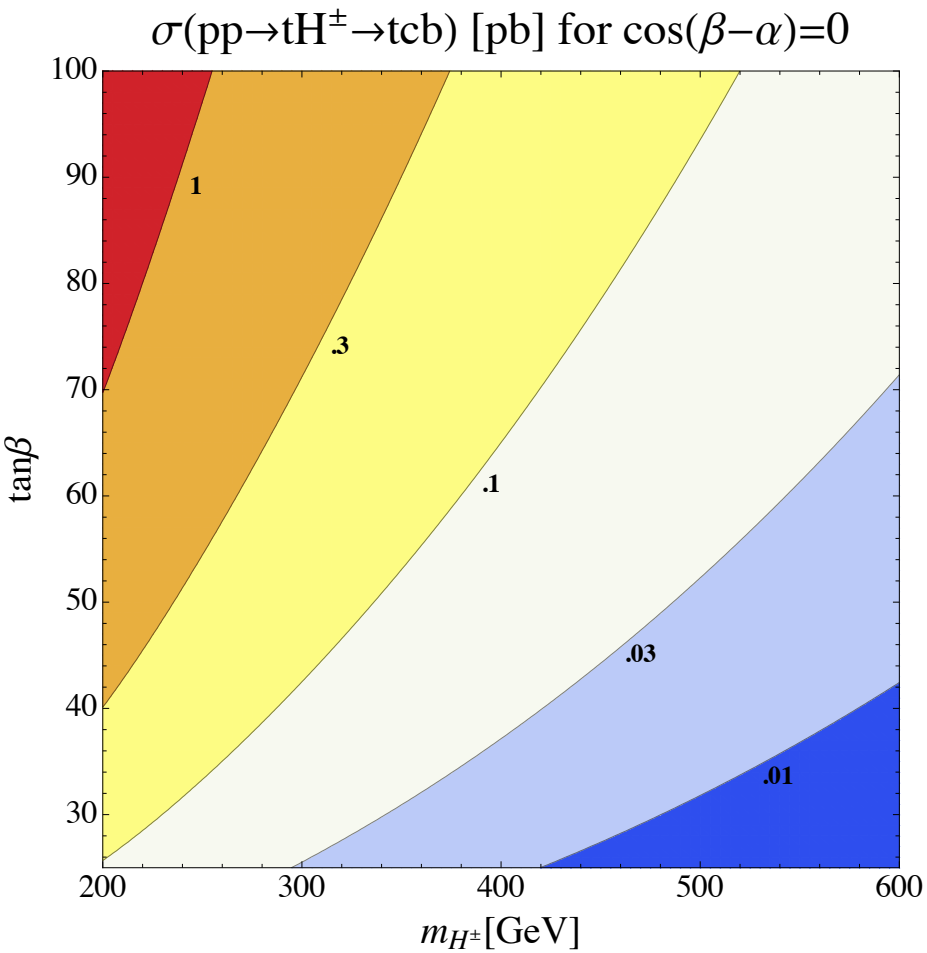
same sign tops
$pp \to tH/A \to tt\bar{c}$

di-jet resonances that are produced in association with a top
$pp \to tH/A \to tc\bar{c}$

flavor violating heavy Higgses
$pp \to H/A \to \tau\mu$
(see also Sher, Thrasher '16; Buschmann et al. '16)

WA, Eby, Gori, Lotito, Martone, Tuckler '16

Interesting Collider Signatures for Charged Higgs



di-jet resonance searches
$pp \to H^\pm \to jj$
are currently only sensitive for
very large $\tan\beta > 100$

Interesting signatures include:

di-jet resonances that are produced in association with a top

$pp \to tH^\pm \to tcb$
$pp \to tH^\pm \to tcs$

WA, Eby, Gori, Lotito, Martone, Tuckler '16

Full Classification of Flavorful Models

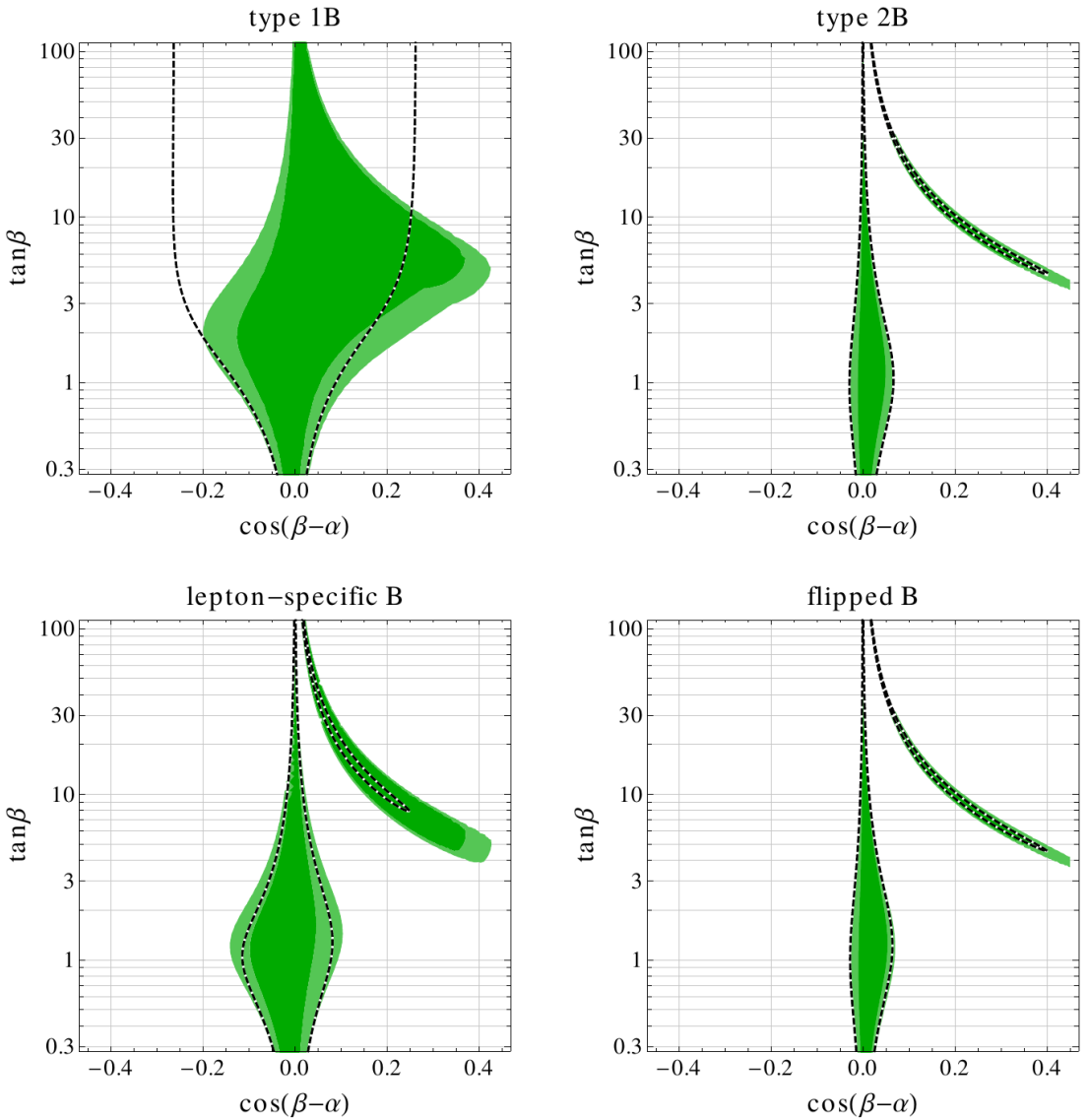
WA, Maddock 1805.08659

Model	$u_{1,2}$	u_3	$d_{1,2}$	d_3	$e_{1,2}$	e_R^3
Type 1A	Φ	Φ	Φ	Φ	Φ	Φ
Type 1B	Φ'	Φ	Φ'	Φ	Φ'	Φ
Type 2A	Φ	Φ	Φ'	Φ'	Φ'	Φ'
Type 2B	Φ'	Φ	Φ	Φ'	Φ	Φ'
Flipped A	Φ	Φ	Φ'	Φ'	Φ	Φ
Flipped B	Φ'	Φ	Φ	Φ'	Φ'	Φ
Lepton-Specific A	Φ	Φ	Φ	Φ	Φ'	Φ'
Lepton-Specific B	Φ'	Φ	Φ'	Φ	Φ	Φ'

(A = standard 2HDM; B = flavorful 2HDM)

Higgs Signal Strength Constraints

WA, Maddock 1805.08659



green:

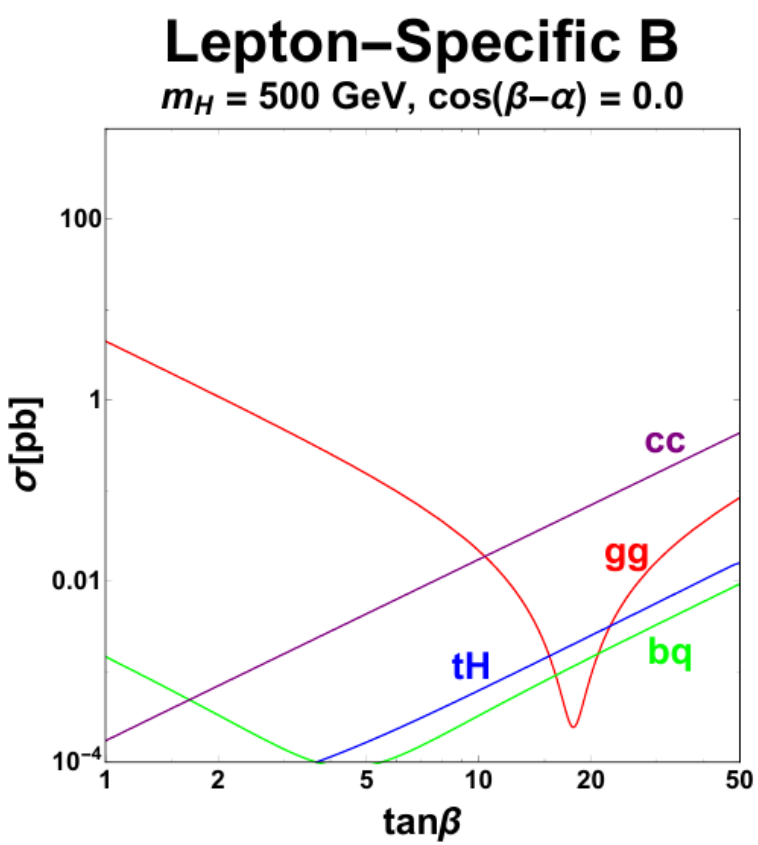
flavorful 2HDMs

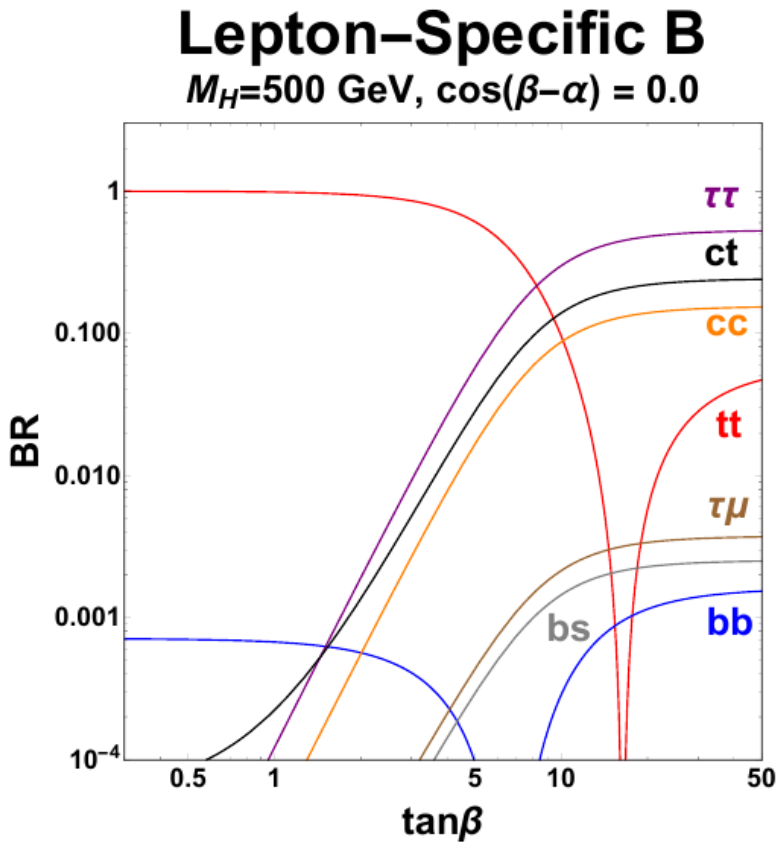
dotted:

standard 2HDMs

Example: Lepton-Specific B Model

WA, Maddock 1805.08659

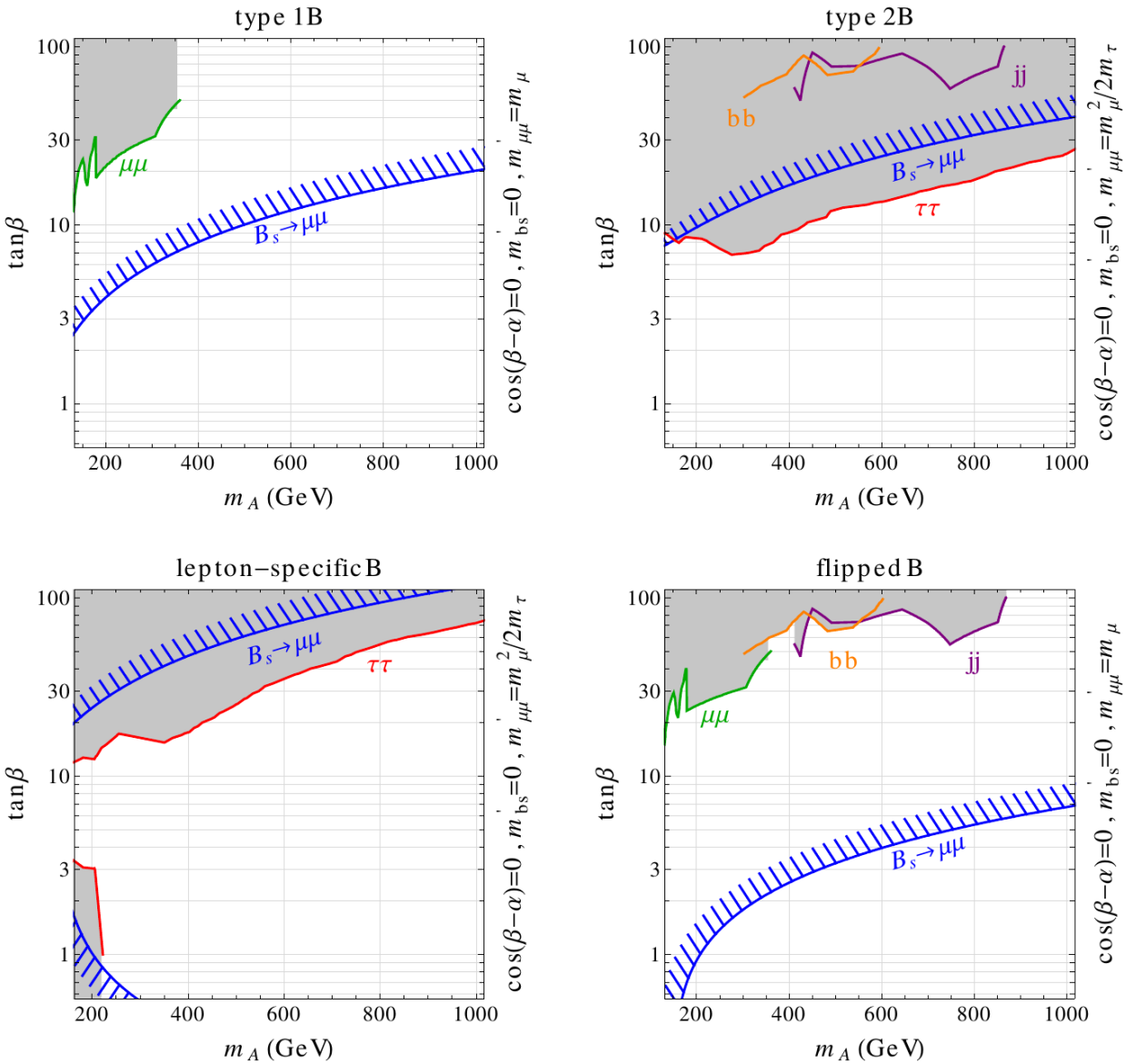




The “standard” lepton-specific model is largely unconstrained at the LHC.
In the flavorful version: sizable production from $c\bar{c}$.

Complementarity of Flavor and Direct Searches

WA, Maddock 1805.08659



In another variation of the models,
we shift the flavor violation
from the down quark sector into the up quark sector

(Flavor violation has to be somewhere
to reproduce the known CKM matrix)

Flavor violation in the Up Sector

WA, Maddock, Tuckler 1904.10956

$$v\lambda_u \sim v_w \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \epsilon^{|a|} & \epsilon^1 & 1 \end{pmatrix}, \qquad v'\lambda'_u \sim v_w \begin{pmatrix} \epsilon^8 & \epsilon^4 & \epsilon^3 \\ \epsilon^{|b|} & \epsilon^3 & \epsilon^2 \\ 0 & 0 & 0 \end{pmatrix},$$

$$v\lambda_d \sim v_w \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \epsilon^3 \end{pmatrix}, \qquad v'\lambda'_d \sim v_w \begin{pmatrix} \epsilon^7 & \epsilon^6 & 0 \\ \epsilon^{|c|} & \epsilon^5 & 0 \\ 0 & 0 & 0 \end{pmatrix},$$

Yukawa textures based on a U(1) flavor model

Flavor violation in the Up Sector

the largest coupling of the second doublet is to top-charm.

This implies:

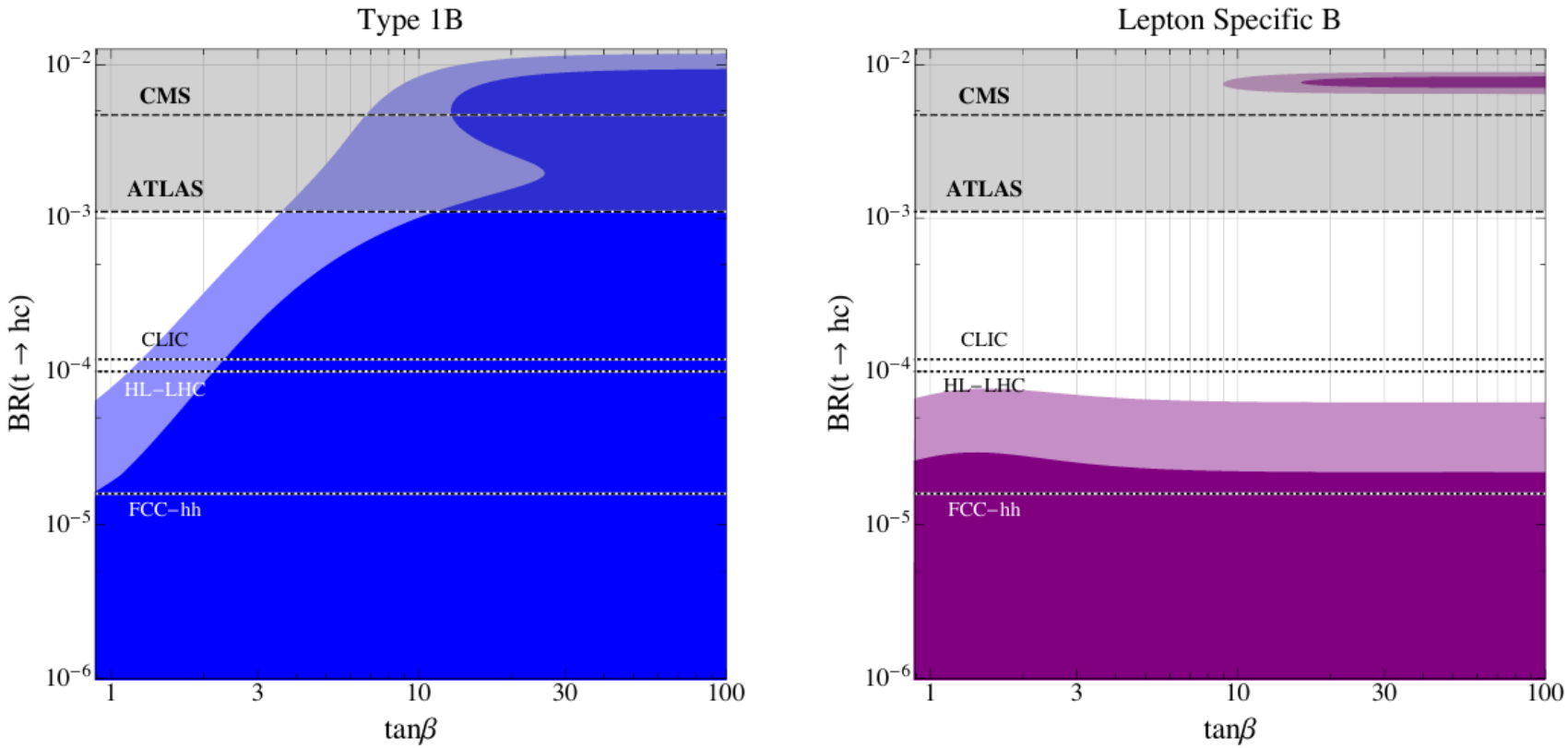
1) there can be sizable branching ratios of rare top decays $t \to hc$ (and $t \to hu$)

2) the dominant production of the heavy Higgs is in association with one top ($gc \to Ht$)

3) the by far dominant decay of the heavy Higgs is into top charm ($H \to tc$)

Rare Top Decays

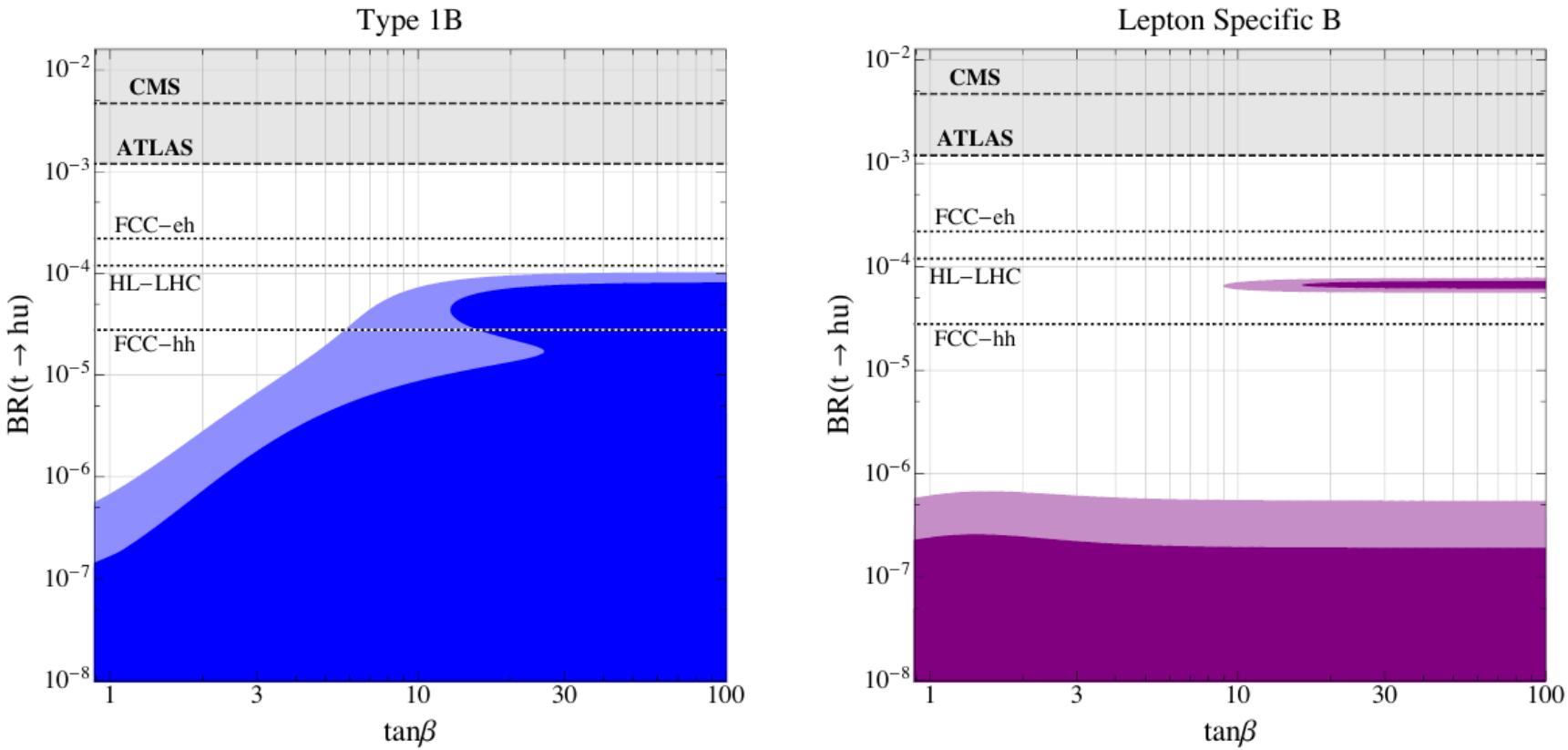
WA, Maddock, Tuckler 1904.10956



current constraints on $t \to hc$ already probe parameter space

Rare Top Decays

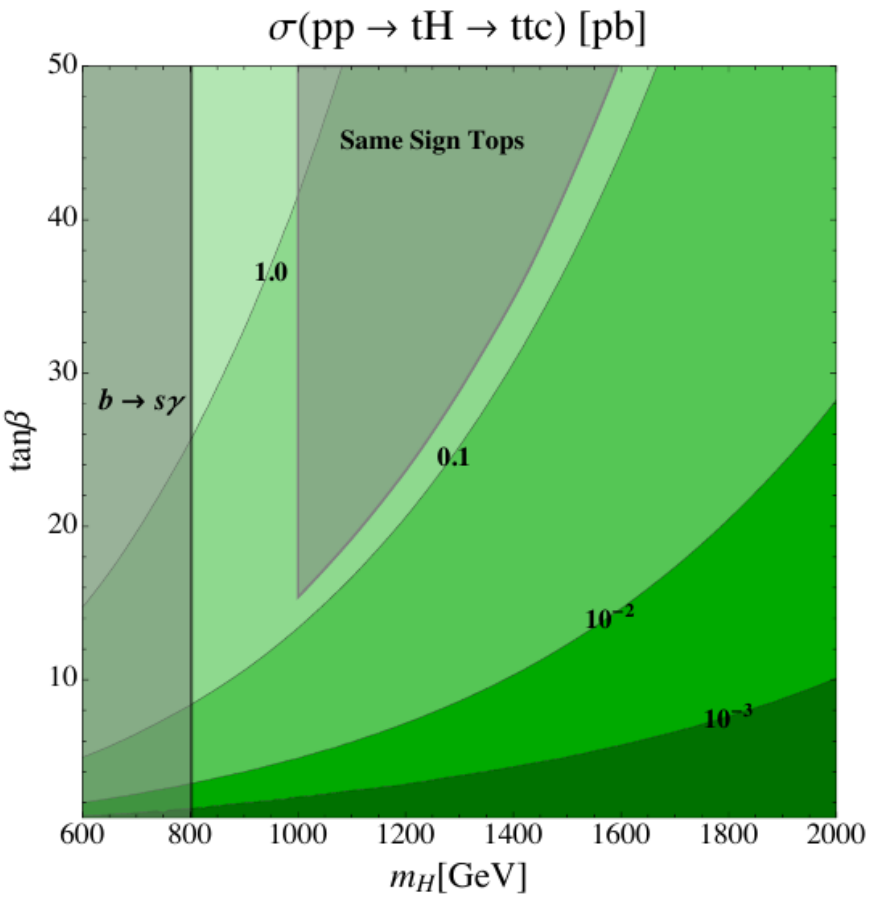
WA, Maddock, Tuckler 1904.10956



$t \to hu$ likely out of reach at the LHC

Most Prominent Signature: Same Sign Tops

WA, Maddock, Tuckler 1904.10956



existing same sign top searches already probe parameter space

Related Scenario: “Spontaneous Flavor Breaking”

Egana-Ugrinovic, Homiller, Meade 1908.11376, 1811.00017; also Knapen, Robinson 1507.00009

Design Yukawa sector such that Y_1 and Y_2 are not proportional to each other, but are diagonal in the same basis

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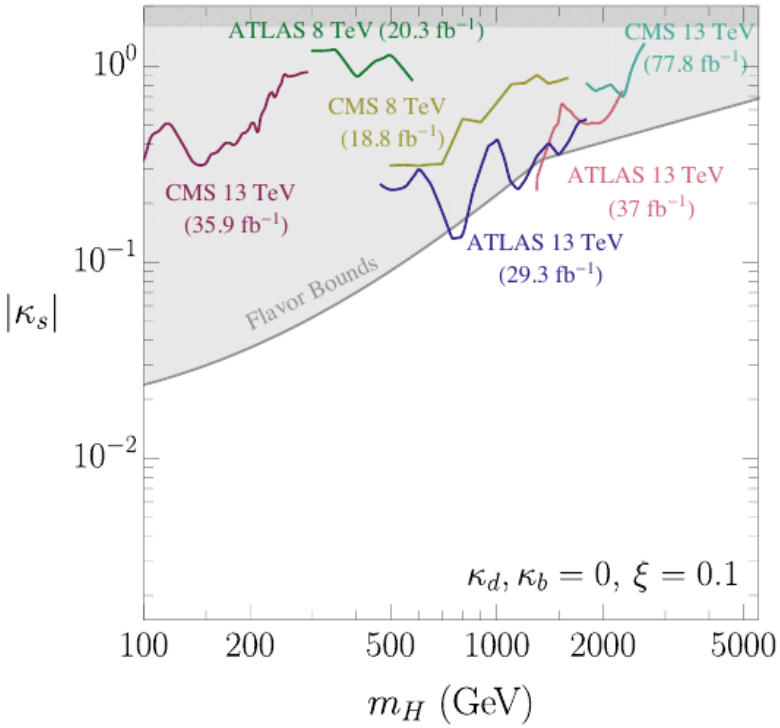
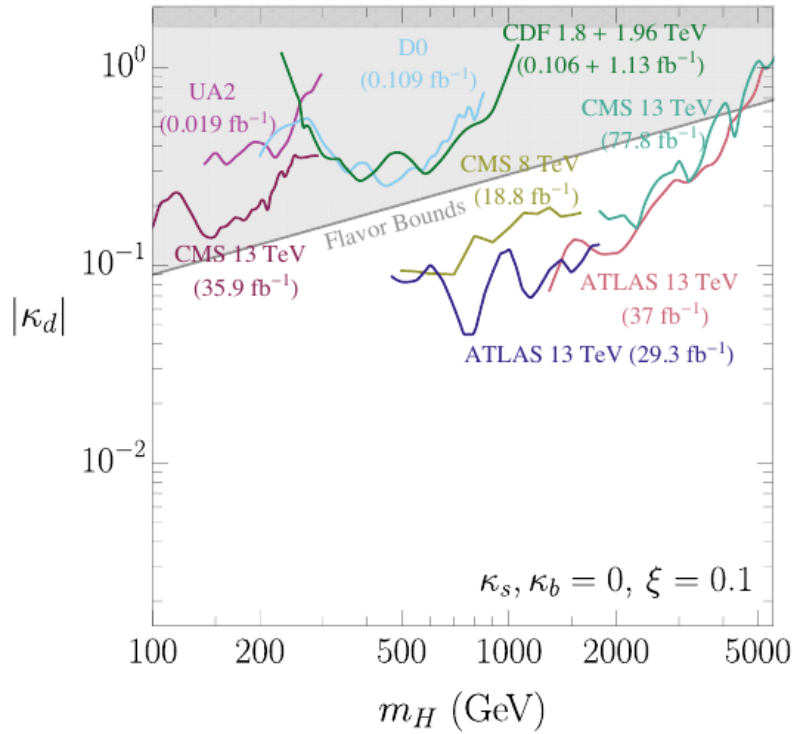
Design Yukawa sector such that Y_1 and Y_2 are not proportional to each other, but are diagonal in the same basis

Possible to design flavor specific Higgs boson



"strange quark philic" Higgs



"down quark philic" Higgs

Summary

- Standard search strategies for additional Higgs bosons focus on 3rd gen. fermions (+ gauge bosons and Higgs)
- Many examples of models where other couplings dominate
  - coupling to 2nd (or even 1st) gen. could dominate $c\bar{c} \to H \to \mu\bar{\mu}$?
  - flavor violating couplings could be relevant $cg \to tH \to tt\bar{c}$? $\quad H \to \tau\bar{\mu}$?
  - exotic decays ($\to$ talk by Zhen Liu) neutralinos, staus, hidden sector glueballs, ...
- Keep open mind when searching for Higgs bosons!