The role of flavor in heavy higgs searches

Stefania Gori
UC Santa Cruz

EF02 Meeting: Higgs and Flavor

September 3, 2020

Message(s) of this talk

1. There is a lot of room for new flavor structures in multi-Higgs models

2. If we focus on a Two Higgs Doublet Model (2HDM), new flavor models not based on a Z_2 symmetry and in agreement with flavor constraints can lead to

* weaker LHC bounds
* interesting new signatures for the LHC and future colliders

2HDMs with/without Z_2 symmetry

$$-\mathcal{L} = Y^u_{ij}\bar{u}_i H_u Q_j + \widetilde{\epsilon}^{u\dagger}_{ij}\bar{u}_i \tilde{H}_d Q_j - Y^d_{ij}\bar{d}_i H_d Q_j + \widetilde{\epsilon}^{d\dagger}_{ij}\bar{d}_i \tilde{H}_u Q_j$$
$$- Y^\ell_{ij}\bar{e}_i H_d L_j + \widetilde{\epsilon}^{\ell\dagger}_{ij}\bar{e}_i \tilde{H}_u L_j + h.c.$$

A (softly- broken) Z_2 symmetry can enforce some of these Yukawas to be 0

➡ Type I-IV 2HDMs

Natural Flavor Conservation (NFC) Ansatz:
all fermions of a given electric charge couple to no more than one Higgs doublet

Natural conservation laws for neutral currents*

Sheldon L. Glashow and Steven Weinberg
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138
(Received 20 August 1976)

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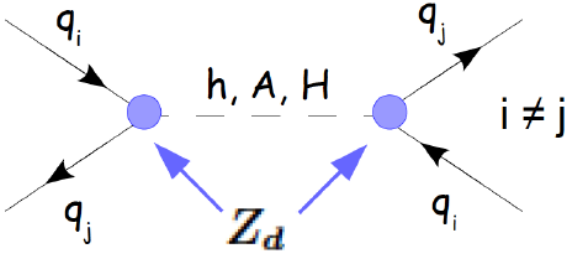
In the most general case, flavor changing neutral currents generated at the tree-level

$$\mathcal{H}^{\rm gen}_Y = \bar{Q}_L \left[\frac{\sqrt{2}}{v} M_d \Phi_v + Z_d \Phi_H\right] D_R + \text{h.c.}$$

$$\begin{cases} Z_d = c_\beta Y - s_\beta \widehat{\epsilon} \\ M_d = \dfrac{v}{\sqrt{2}}(c_\beta \widehat{\epsilon} + s_\beta Y) \end{cases}$$

$$\begin{pmatrix} \phi_v \\ \phi_H \end{pmatrix} = \begin{pmatrix} c_\beta & s_\beta \\ -s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} H_d \\ H_u \end{pmatrix}$$

$$\langle \Phi_v^\dagger \Phi_v \rangle = v^2/2, \qquad \langle \Phi_H^\dagger \Phi_H \rangle = 0$$



A few interesting flavor structures

A few flavor structures I have studied in the last few years:

1. Flavor aligned 2HDMs Pich, Tuzon, 0908.1554
2. Flavorful 2HDMs Altmannshofer, SG, Kagan, Silvestrini, Zupan, 1507.07927
3. Top specific 2HDMs Chiang, Fukuda, Takeuchi, Yanagida, 1507.04354

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→ Presented by D. Tuckler at the previous EF02 Higgs-flavor meeting

$$Y^u = a_U\, \widehat{\epsilon}^u$$
$$Y^d = a_D\, \widehat{\epsilon}^d$$
$$Y^\ell = a_\ell\, \widehat{\epsilon}^\ell$$

This structure leads to NO FCNCs at the tree-level

Note for the experts:
this structure is not stable under RGEs.
The most general stable structure is the Minimal Flavor Violating one

Main LHC pheno result:

The heavy Higgs branching ratios into bottoms, tops, and taus are independent.

There exist scenarios in which BR(H→bb)>>BR(H→ττ)

→ **Relaxed LHC bounds**

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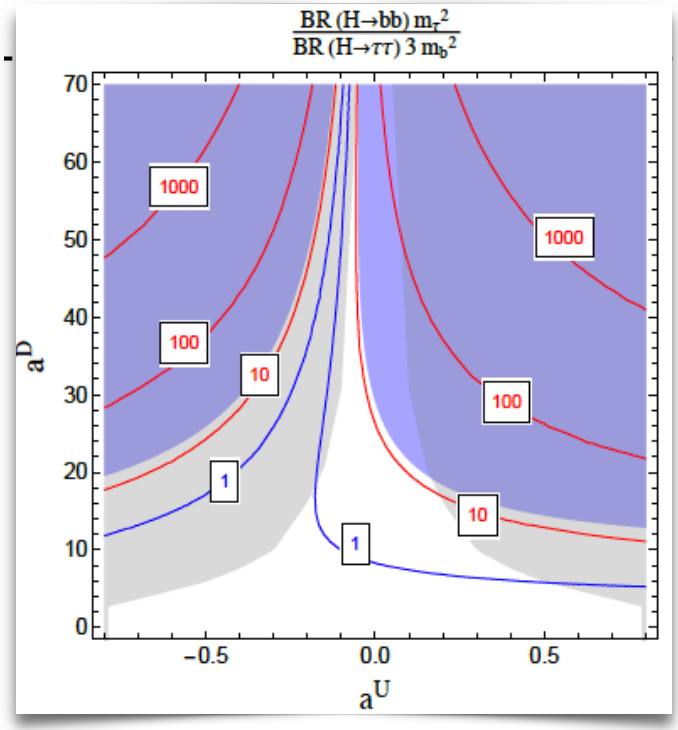

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Top-specific 2HDM

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$$- Y^\ell_{ij}\bar{e}_i H_d L_j + \widehat{\epsilon}^{\ell\dagger}_{ij}\bar{e}_i \tilde{H}_u L_j + h.c.$$

$$Y^u = \begin{pmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 0 & 0 & 0 \end{pmatrix} \quad \text{and} \quad \widehat{\epsilon}^{u\dagger} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \cdot & \cdot & \cdot \end{pmatrix}$$

H_u and H_d with PQ charges 0, –1, respectively;
t_R (and τ_R) with PQ charge -1

$$U_R\, v \left(Y^u \sin\beta + \hat{\epsilon}^{u\dagger}\cos\beta\right) U_L^\dagger = \mathrm{diag}(m_u, m_c, m_t) \equiv m^u$$

$$U_R \equiv \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\frac{\rho_u}{2} & \sin\frac{\rho_u}{2} \\ 0 & -\sin\frac{\rho_u}{2} & \cos\frac{\rho_u}{2} \end{pmatrix}$$

entering the CKM matrix

mixing angles in U_R can be as large as O(1)

Same structure in the lepton sector.
Down sector only coupled to H_d
(more stringent flavor constraints)

A new coupling structure

$$c_f^h = \frac{m_f}{\sqrt{2}v}\begin{cases} \sin(\beta-\alpha) + \left(\cot\beta - \frac{1-\cos\rho_u}{2}(\tan\beta+\cot\beta)\right)\cos(\beta-\alpha) & (\text{for } f=t)\,, \\ \sin(\beta-\alpha) - \left(\tan\beta - \frac{1-\cos\rho_u}{2}(\tan\beta+\cot\beta)\right)\cos(\beta-\alpha) & (\text{for } f=c)\,, \\ -\sin(\alpha)/\cos(\beta) & (\text{for } f=u) \end{cases}$$

$$c_{23}^h = \frac{m_t}{2\sqrt{2}v}(\cot\beta+\tan\beta)\cos(\beta-\alpha)\sin\rho_u$$

Flavor changing top-charm couplings

Breaking of lepton flavor universality

h^{SM}

$$c_f^H = \frac{m_f}{\sqrt{2}v}\begin{cases} \cos(\beta-\alpha) - \left(\cot\beta - \frac{1-\cos\rho_u}{2}(\tan\beta+\cot\beta)\right)\sin(\beta-\alpha) & (\text{for } f=t) \\ \cos(\beta-\alpha) + \left(\tan\beta - \frac{1-\cos\rho_u}{2}(\tan\beta+\cot\beta)\right)\sin(\beta-\alpha) & (\text{for } f=c) \\ \cos(\alpha)/\cos(\beta) & (\text{for } f=u) \end{cases}$$

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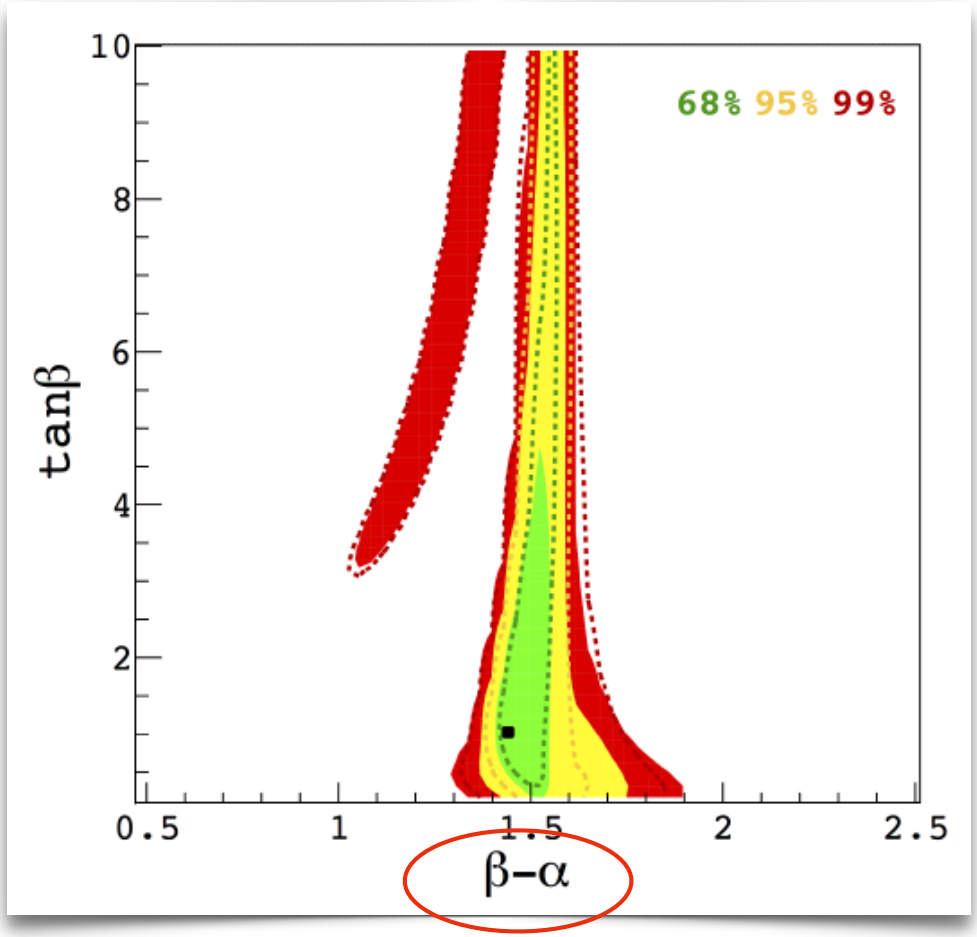
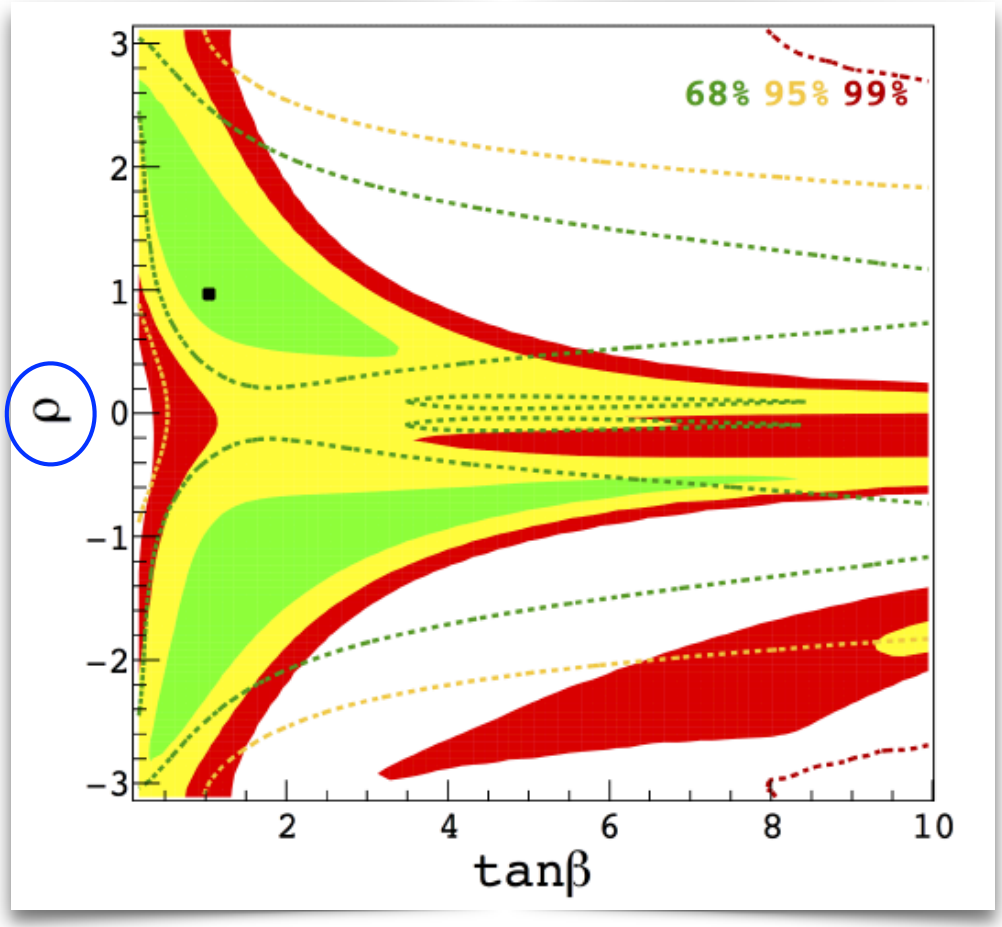
Present experimental constraints

SG, Grojean, Juste, Paul, 1710.03752





(2D marginalized posterior distributions)

Dashed lines: bound keeping into account only Higgs measurements

Heavy Higgs phenomenology

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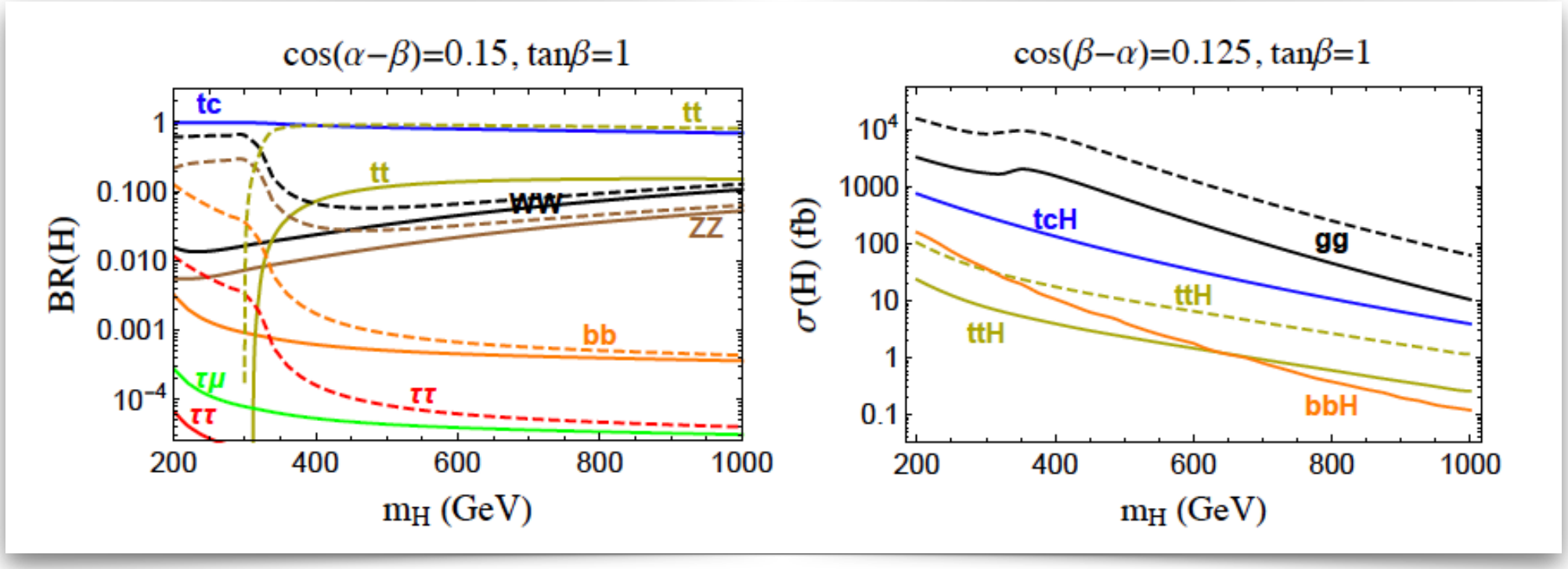
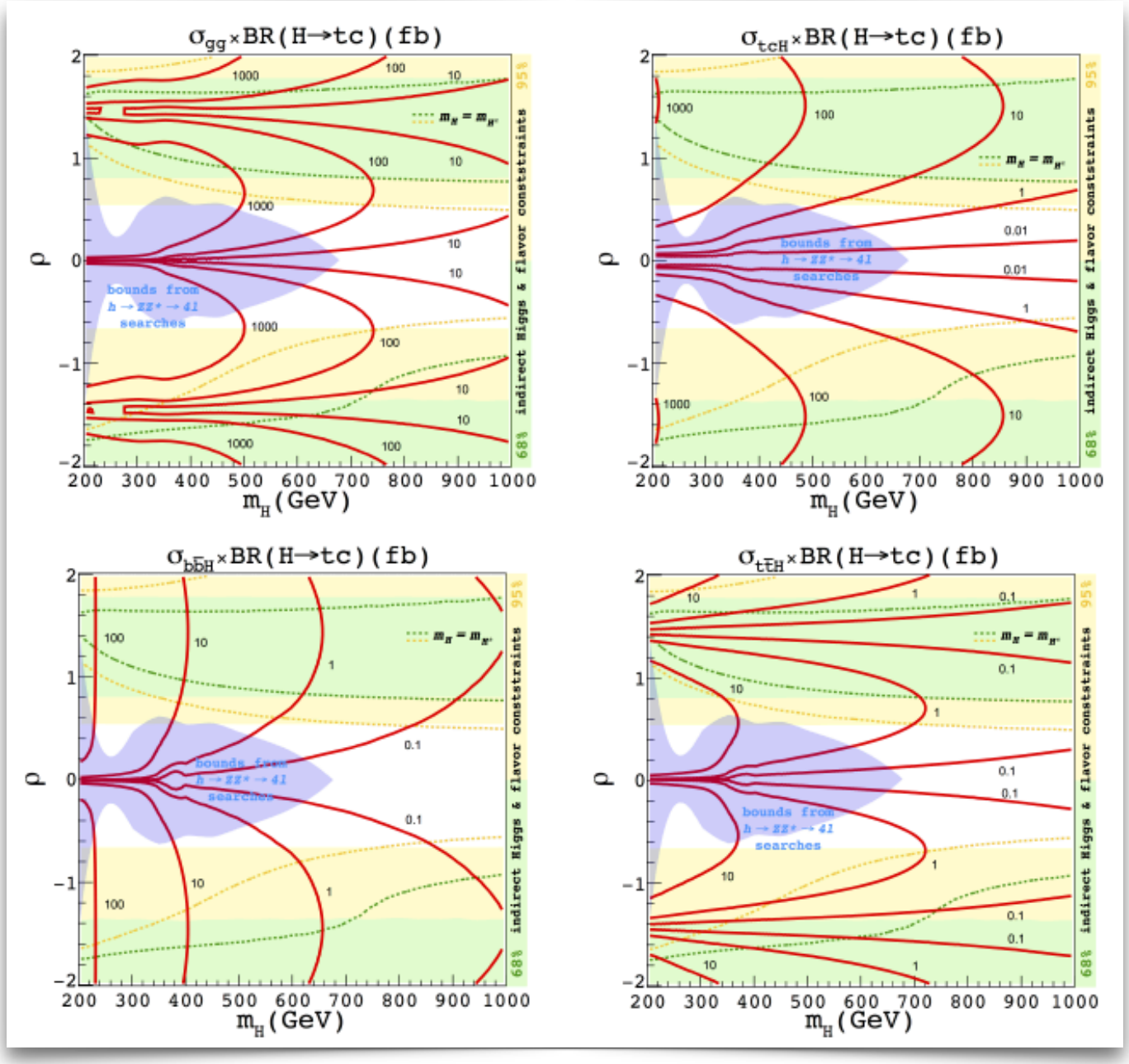


—— $\rho = 1$

····· $\rho = 0$

Cross sections for the LHC

Heavy Higgs phenomenology



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Charged Higgs phenomenology

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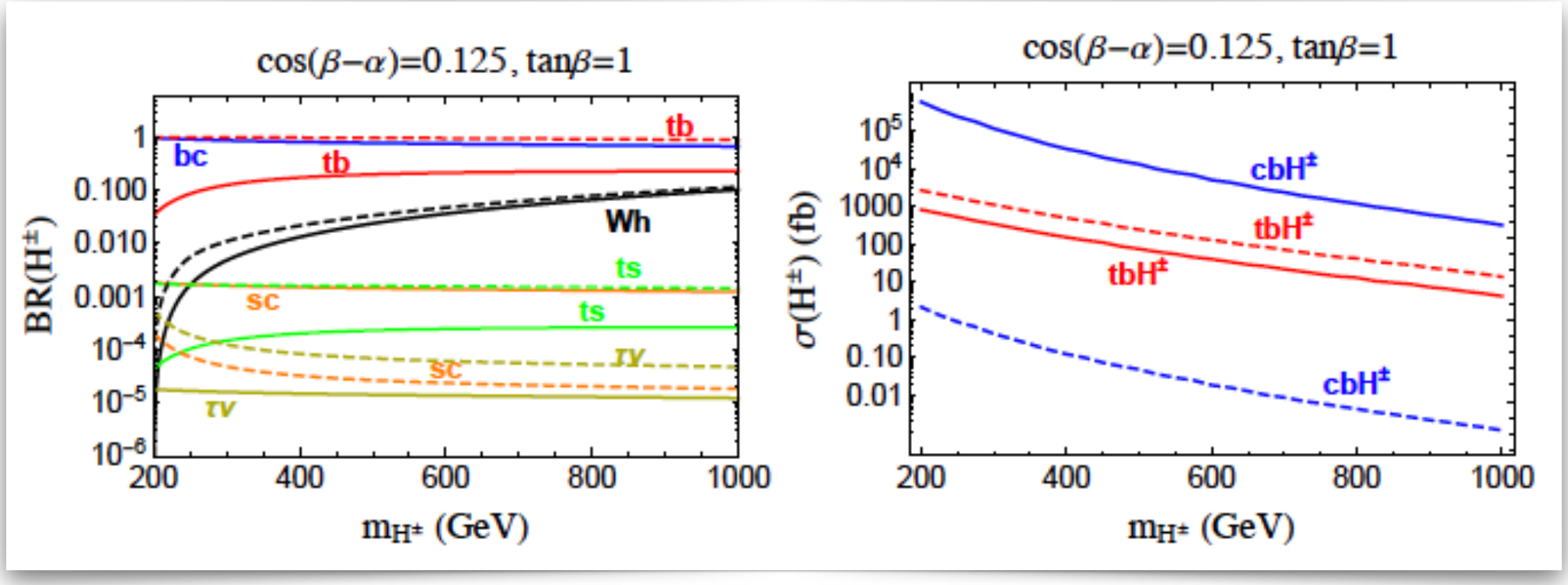

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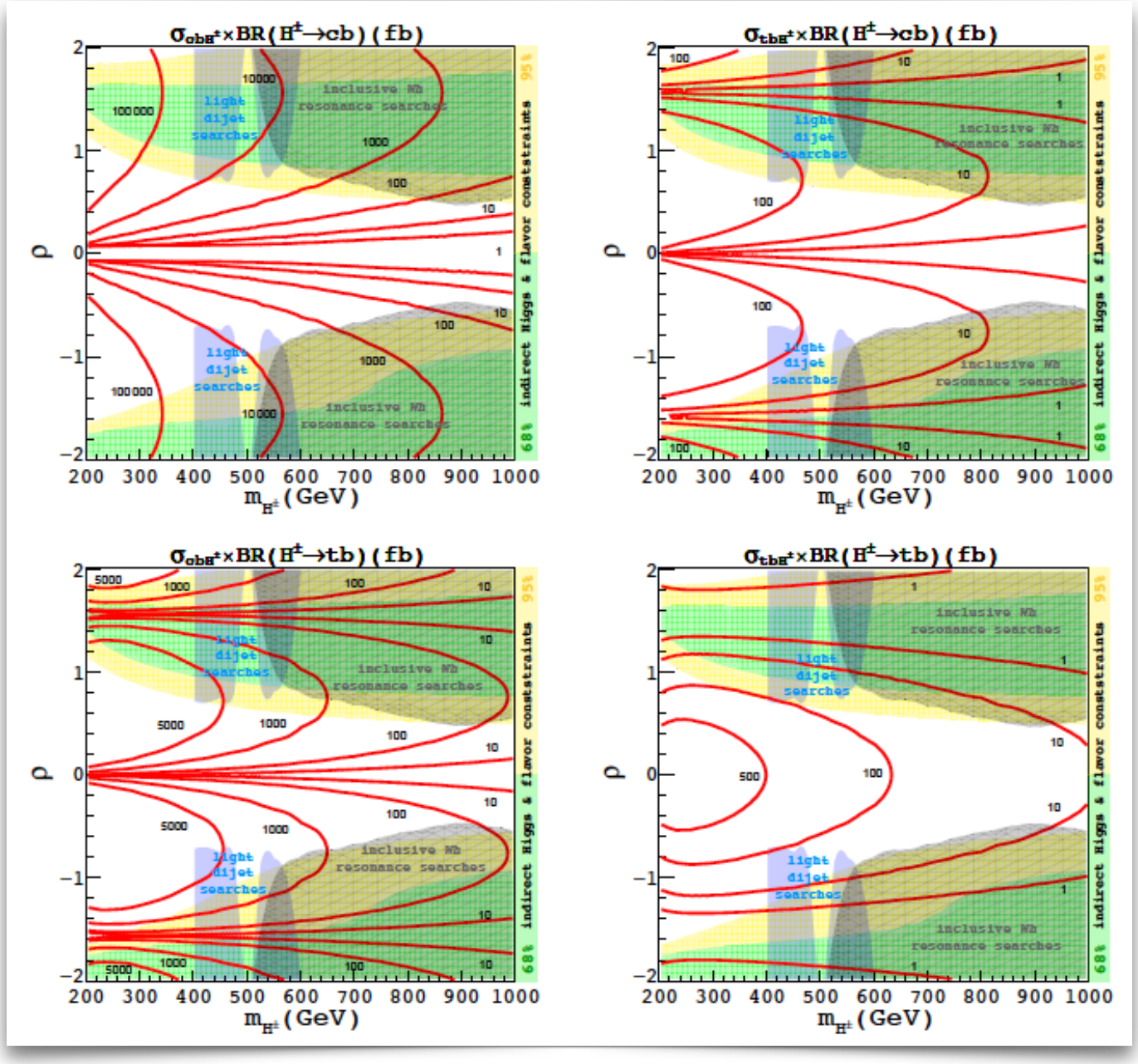

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Outlook

Let's go back to the "messages of the talk"…

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* interesting new signatures for the LHC and future colliders

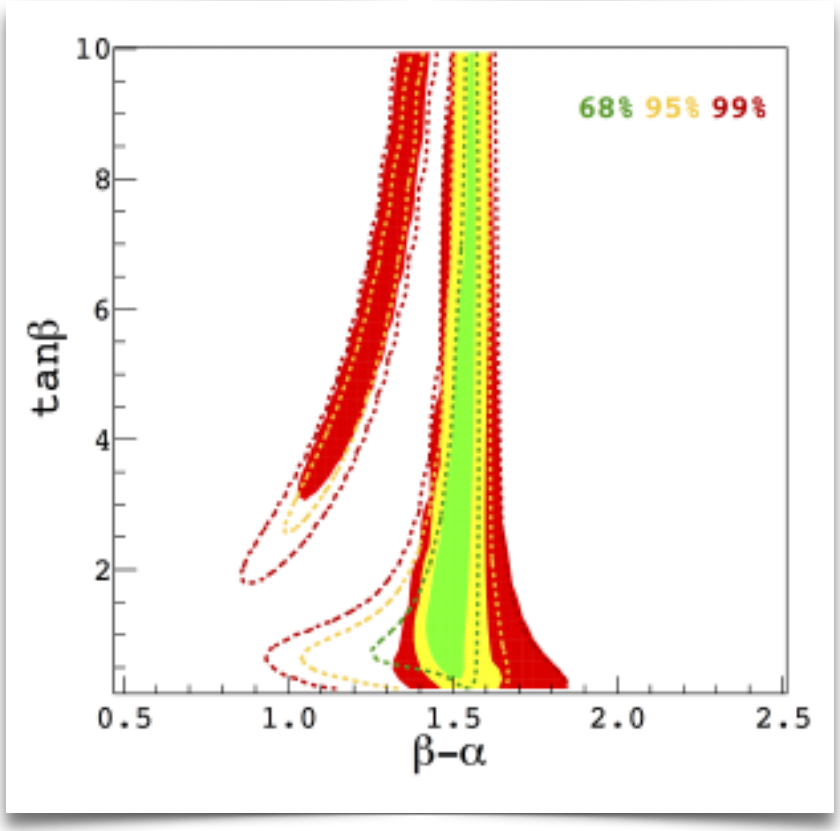
For the top specific 2HDM presented in this talk:
top enriched heavy Higgs signatures. E.g.

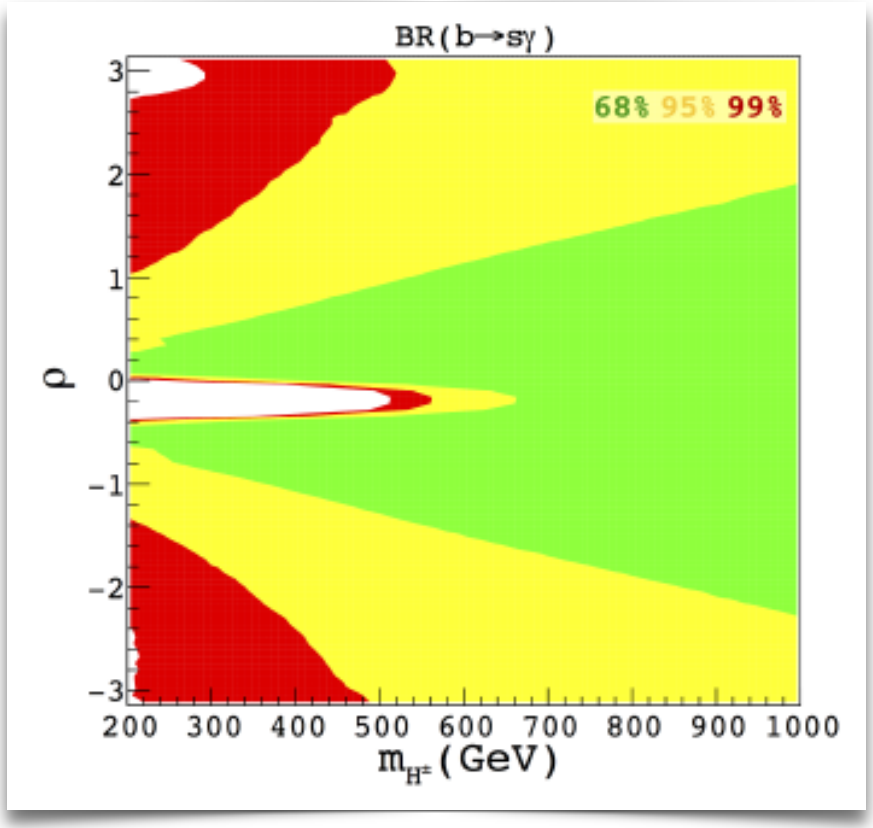
$$pp \to tcH,\ H \to tc \qquad pp \to H \to tc$$

$$pp \to tbH^{\pm},\ H^{\pm} \to cb$$

Flavor vs. Higgs constraints

SG, Grojean, Juste, Paul, 1710.03752





Solid contours:
only Higgs coupling measurements

Dashed contours:
Higgs couplings + t →ch, h →τμ

b →sγ