

# Flavor Changing Neutral Higgs Bosons Meet the Top and the Tau at Hadron Colliders

Chung Kao  
University of Oklahoma

<sup>†</sup>Presented at the European Physical Society Conference on High Energy Physics (EPS-HEP 2019), in Ghent, Belgium, July 12 (Friday), 2019.

# Introduction and Motivation

Das and Kao (1996)

- A special two Higgs doublet model explains why top quark is the most massive elementary particle by suggesting that it is the only fermion that couples to a Higgs doublet ( $\phi_2$ ) with a much larger VEV ( $v_2 \gg v_1$ ).
- This model leads to flavor changing neutral Higgs (FCNH) interactions and CP violation.
- Most LHC data are consistent with the Standard Model. FCNH interactions might lead to new physics beyond SM.

# A Special Higgs Model for the Top Quark

## 1 Introduction

In the Standard Model (SM) of electroweak interactions:

1. There is one Higgs doublet to generate mass for gauge bosons as well as for fermions. A neutral Higgs scalar ( $H^0$ ) remains after spontaneous symmetry breaking.
2. The top quark has a large mass because its Yukawa coupling with the  $H^0$  is large.<sup>†</sup>

In a special two Higgs doublet model, the top quark is much heavier than the other quarks and the leptons, because it is the only elementary fermion getting a mass from a much larger vacuum expectation value (VEV) of a second Higgs doublet.

This model has a few interesting features:

1. The ratio of the Higgs VEVs,  $\tan \beta \equiv |v_2|/|v_1|$ , is chosen to be large.
2. The Yukawa couplings of the lighter fermions are highly enhanced.
3. There are flavor changing neutral Higgs interactions.

---

<sup>†</sup>The mass of a fermion is equal to its Yukawa coupling with the  $H^0$  times the vacuum expectation value of the Higgs field,  $m = \lambda(v/\sqrt{2})$ .

## 2 Two Higgs Doublet Models

A two Higgs doublet model has doublets  $\phi_1$  and  $\phi_2$ . After spontaneous symmetry breaking, there remain five ‘Higgs bosons’:

1. a pair of singly charged Higgs bosons  $H^+$  and  $H^-$ ,
2. two neutral CP-even scalars  $H_1$  and  $H_2$ , and
3. a neutral CP-odd pseudoscalar  $A$ .

### 2.1 Yukawa Interactions

Several interesting two Higgs doublet models, with different Yukawa interactions between the fermions and the spin-0 bosons, have been suggested:

1. In Model I, the different mass scales of the fermions and the gauge bosons are set by the Higgs VEVs.<sup>‡</sup>
2. In Model II, one Higgs doublet couples to down-type quarks and charged leptons while another doublet couples to up-type quarks and neutrinos.<sup>§</sup>

---

<sup>‡</sup>H.E. Haber, G.L. Kane and T. Stirling, Nucl. Phys. **B161** (1979) 493.

<sup>§</sup>J.F. Donoghue and L.-F. Li, Phys. Rev. **D19** (1979) 945; L. Hall and M. Wise, Nucl. Phys. **B187** (1981) 397.

## 2.2 The Higgs Potential

In multi-Higgs doublet models, a discrete symmetry<sup>¶</sup> is usually required for flavor symmetry to be conserved. In two Higgs doublet models, this discrete symmetry is often chosen to be

$$\phi_1 \rightarrow -\phi_1, \quad \phi_2 \rightarrow +\phi_2. \quad (1)$$

If this discrete symmetry is only softly broken<sup>||</sup>: (a) Higgs boson exchange can generate CP violation, and (b) the flavor changing neutral Higgs interactions can be kept at an acceptable level.

The Higgs potential of a general two Higgs doublet model with the discrete symmetry softly broken,<sup>\*\*</sup> can be written as

$$\begin{aligned} V[\phi_1, \phi_2] = & m_1 \phi_1^\dagger \phi_1 + m_2 \phi_2^\dagger \phi_2 + \eta \phi_1^\dagger \phi_2 + \eta^* \phi_2^\dagger \phi_1 \\ & + \frac{1}{2} g_1 (\phi_1^\dagger \phi_1)^2 + \frac{1}{2} g_2 (\phi_2^\dagger \phi_2)^2 \\ & + g (\phi_1^\dagger \phi_1)(\phi_2^\dagger \phi_2) + g' (\phi_1^\dagger \phi_2)(\phi_2^\dagger \phi_1) \\ & + \frac{1}{2} h (\phi_1^\dagger \phi_2)^2 + \frac{1}{2} h^* (\phi_2^\dagger \phi_1)^2. \end{aligned} \quad (2)$$

<sup>¶</sup>S. L. Glashow and S. Weinberg, Phys. Rev. D15 (1977) 1958.

<sup>||</sup>G.C. Branco and M.N. Rebelo, Phys. Lett. B160 (1985) 117; J. Liu and L. Wolfenstein, Nucl. Phys. B289 (1987) 1.

<sup>\*\*</sup>S. Weinberg, Phys. Rev. D42 (1990) 860.

Introducing a transformation, which takes the Higgs doublets to their Higgs eigenstates ( $\Phi_1$  and  $\Phi_2$ ), we have

$$\begin{aligned} \begin{pmatrix} \Phi_1 \\ \Phi_2 \end{pmatrix} &= \begin{pmatrix} \cos \beta & \sin \beta e^{-i\theta} \\ -\sin \beta & \cos \beta e^{-i\theta} \end{pmatrix} \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}, \\ \Phi_1 &= \begin{pmatrix} G^+ \\ \frac{v+H_1+iG^0}{\sqrt{2}} \end{pmatrix}, \\ \Phi_2 &= \begin{pmatrix} H^+ \\ \frac{H_2+iA}{\sqrt{2}} \end{pmatrix}, \end{aligned} \tag{3}$$

where  $v = \sqrt{|v_1|^2 + |v_2|^2}$ , and

1.  $G^\pm$  and  $G^0$  are Goldstone bosons,
2.  $H^\pm$  are singly charged Higgs bosons,
3.  $H_1$  and  $H_2$  are CP-even scalars, and
4.  $A$  is a CP-odd pseudoscalar.

Without loss of generality, we will take  $v_1, v_2 \in \mathcal{R}$ , and

$$\langle \phi_1 \rangle = \frac{v_1}{\sqrt{2}}, \quad \langle \phi_2 \rangle = \frac{v_2 e^{i\theta}}{\sqrt{2}}.$$

In the Higgs eigenstates, the Higgs potential becomes

$$\begin{aligned}
 V[\Phi_1, \Phi_2] = & \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1 - \frac{v^2}{2})^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 \\
 & + \lambda_3(\Phi_1^\dagger\Phi_1 - \frac{v^2}{2})\Phi_2^\dagger\Phi_2 + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\
 & + \lambda_5(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2 - \frac{v^2}{2})(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1) \\
 & + (\lambda_6\Phi_1^\dagger\Phi_2 + \lambda_6^*\Phi_2^\dagger\Phi_1)(\Phi_1^\dagger\Phi_1 - \Phi_2^\dagger\Phi_2 - \frac{v^2}{2}) \\
 & + \frac{1}{2}\lambda_7(\Phi_1^\dagger\Phi_2)^2 + \frac{1}{2}\lambda_7^*(\Phi_2^\dagger\Phi_1)^2 \\
 & + \rho(\Phi_2^\dagger\Phi_2),
 \end{aligned} \tag{4}$$

where the parameters  $\rho$ ,  $v$  and  $\lambda_i$ ,  $i = 1$  through 5, are all real;  $\lambda_6$  and  $\lambda_7$  can be complex.

CP is violated if the imaginary part of  $\lambda_6$  or  $\lambda_7$  is nonvanishing.

There are two sources of CP violation in the Higgs potential:

1. the mixing of the  $A$  with the  $H_1$  and the  $H_2$ , and
2. the CP violating interaction of  $AH^+H^-$ .

### 3 Special Yukawa Interactions

We choose the Lagrangian density of Yukawa interactions to be of the following form

$$\begin{aligned}\mathcal{L}_Y = & - \sum_{m,n=1}^3 \bar{L}_L^m \phi_1 E_{mn} l_R^n - \sum_{m,n=1}^3 \bar{Q}_L^m \phi_1 F_{mn} d_R^n \\ & - \sum_{\alpha=1}^2 \sum_{m=1}^3 \bar{Q}_L^m \tilde{\phi}_1 G_{m\alpha} u_R^\alpha - \sum_{m=1}^3 \bar{Q}_L^m \tilde{\phi}_2 G_{m3} u_R^3 + \text{H.c.},\end{aligned}$$

where

$$\phi_\alpha = \begin{pmatrix} \phi_\alpha^+ \\ \frac{v_\alpha + \phi_\alpha^0}{\sqrt{2}} \end{pmatrix}, \quad \tilde{\phi}_\alpha = \begin{pmatrix} \frac{v_\alpha^* + \phi_\alpha^{0*}}{\sqrt{2}} \\ -\phi_\alpha^- \end{pmatrix}, \quad \phi_\alpha^- = \phi_\alpha^{+*}, \quad \alpha = 1, 2, \quad \text{and (5)}$$

$$L_L^m = \begin{pmatrix} \nu_l \\ l \end{pmatrix}_L^m, \quad Q_L^m = \begin{pmatrix} u \\ d \end{pmatrix}_L^m, \quad m = 1, 2, 3, \quad (6)$$

$l^m$ ,  $d^m$ , and  $u^m$  are the gauge eigenstates.

This Lagrangian respects a discrete symmetry,

$$\begin{aligned}\phi_1 &\rightarrow -\phi_1, \quad \phi_2 \rightarrow +\phi_2, \\ l_R^m &\rightarrow -l_R^m, \quad d_R^m \rightarrow -d_R^m, \quad u_R^\alpha \rightarrow -u_R^\alpha, \\ L_L^m &\rightarrow +L_L^m, \quad Q_L^m \rightarrow +Q_L^m, \quad u_R^3 \rightarrow +u_R^3.\end{aligned} \quad (7)$$

# The Higgs Basis

In the Higgs basis, the Higgs potential becomes

$$\begin{aligned} V[\Phi_1, \Phi_2] = & \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1 - \frac{v^2}{2})^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 \\ & + \lambda_3(\Phi_1^\dagger\Phi_1 - \frac{v^2}{2})\Phi_2^\dagger\Phi_2 + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\ & + \lambda_5(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2 - \frac{v^2}{2})(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1) \\ & + (\lambda_6\Phi_1^\dagger\Phi_2 + \lambda_6^*\Phi_2^\dagger\Phi_1)(\Phi_1^\dagger\Phi_1 - \Phi_2^\dagger\Phi_2 - \frac{v^2}{2}) \\ & + \frac{1}{2}\lambda_7(\Phi_1^\dagger\Phi_2)^2 + \frac{1}{2}\lambda_7^*(\Phi_2^\dagger\Phi_1)^2 \\ & + \rho(\Phi_2^\dagger\Phi_2). \end{aligned}$$

Where the parameters  $\rho$ ,  $v$  and  $\lambda_i$ ,  $i = 1$  through 5, are all real;  $\lambda_6$  and  $\lambda_7$  can be complex. CP is violated if the imaginary part of  $\lambda_6$  or  $\lambda_7$  is nonvanishing.

In this parameterization,  $\tan \beta$  can be written as

$$\tan \beta = \frac{\lambda_1 - \lambda_2}{\lambda_5} + \sqrt{1 + \frac{(\lambda_1 - \lambda_2)^2}{\lambda_5^2}}.$$

# Special Models for the Top Quark

- A Two Higgs doublet model for the top quark,  
Das and Kao (1996)
- Neutrino masses, mixing and leptogenesis in a two  
Higgs doublet model 'for the third generation',  
Atwood, Bar-Shalom, and Soni (2005)
- Flavor-Changing Neutral-Current Decays in Top-  
Specific Variant Axion Model,  
Chiang, Fukuda, Takeuchi, and Yanagida, (2015)

# A General Two Higgs Doublet Model

## Mahmoudi and Stal (2009)

- Let us express the general Yukawa interaction Lagrangian for neutral Higgs bosons as

$$\begin{aligned}\sqrt{2} \mathcal{L}_I^N = & \bar{U} [-\kappa^U s_{\beta-\alpha} - \rho^U c_{\beta-\alpha}] U h^0 + \bar{D} [-\kappa^D s_{\beta-\alpha} - \rho^D c_{\beta-\alpha}] D h^0 \\ & + \bar{U} [-\kappa^U c_{\beta-\alpha} + \rho^U s_{\beta-\alpha}] U H^0 + \bar{D} [-\kappa^D c_{\beta-\alpha} + \rho^D s_{\beta-\alpha}] D H^0 \\ & + \bar{U} [+i\gamma_5 \rho^U] U A^0 + \bar{D} [-i\gamma_5 \rho^D] D A^0\end{aligned}$$

where  $\kappa^f = \frac{\sqrt{2}m_f}{v}$ ,  $\tan \beta \equiv v_2/v_1$ , and  $v = \sqrt{v_1^2 + v_2^2}$ .

- There are 4 flavor conserving models with  $Z_2$  symmetries, such that  $\rho$ 's are related to  $\kappa$ 's in the following form [Barger, Hewett and Phillips, PRD 41 (1990) 3421.]:

Type				
	I	II	III	IV
$\rho^D$	$\kappa^D \cot \beta$	$-\kappa^D \tan \beta$	$-\kappa^D \tan \beta$	$\kappa^D \cot \beta$
$\rho^U$	$\kappa^U \cot \beta$	$\kappa^U \cot \beta$	$\kappa^U \cot \beta$	$\kappa^U \cot \beta$
$\rho^E$	$\kappa^E \cot \beta$	$-\kappa^E \tan \beta$	$\kappa^E \cot \beta$	$-\kappa^E \tan \beta$

- In a general model without  $Z_2$  symmetries,  $\rho$  matrices are free.

# The Decoupling Limit of 2HDM

Gunion and Haber (2003)

- In the decoupling limit of 2HDM, we expect
  - ▶  $M_h = O(v)$
  - ▶  $M_H, M_A, M_{H^\pm} = M_S + O(v^2/M_S)$
  - ▶  $|\cos(\beta - \alpha)| = O(v^2/M_S^2)$
  - ▶ If  $\cos(\beta - \alpha) = 0$ ,  $h^0$  becomes the SM Higgs boson.
- Recently, there has been interests in the 2HDM parameter space where the alignment is obtained without decoupling and without fine tuning where  $H^0$  and  $A^0$  can be light and  $h^0$  is like SM Higgs.  
Craig, Galloway, Thomas (2013); Carena et al. (2014)

# Constraints on FCNH Couplings

- ATLAS data (2018) have placed tight constraints on  $\lambda_{tc}$  and  $\lambda_{ct}$  with  $t \rightarrow ch^0 \rightarrow c\gamma\gamma$ 
  - ▶ the top decay should have  $B(t \rightarrow ch^0) < 0.16\%$ ,
  - ▶ or  $\lambda_{tch} < 0.077$ , with  $\lambda_{tch} = \rho_{tc} \cos(\beta-\alpha)$ ,
  - ▶ That leads to  $\lambda_{tch} \simeq 1.92 \times \sqrt{B(t \rightarrow ch^0)}$
- If we choose  $\rho$ -matrix to be Hermitian, then  $b \rightarrow s\gamma$  and  $B - \bar{B}$  mixing imply  $|\rho_{ct}| < 0.1$ .
- Thus we choose  $|\rho_{ct}| < 0.1$ , while  $|\rho_{tc}| < 1$ .

$$pp \rightarrow H^0, A^0 \rightarrow t\bar{c} + \bar{t}c + X$$

Physics Letters B 751 (2015) 135–142



Contents lists available at ScienceDirect

Physics Letters B

[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)



## Flavor changing heavy Higgs interactions at the LHC



Baris Altunkaynak<sup>a</sup>, Wei-Shu Hou<sup>b,\*</sup>, Chung Kao<sup>a</sup>, Masaya Kohda<sup>c</sup>, Brent McCoy<sup>a</sup>

<sup>a</sup> Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019, USA

<sup>b</sup> Department of Physics, National Taiwan University, Taipei 10617, Taiwan, ROC

<sup>c</sup> Department of Physics, Chung-Yuan Christian University, Chung-Li 32023, Taiwan, ROC

---

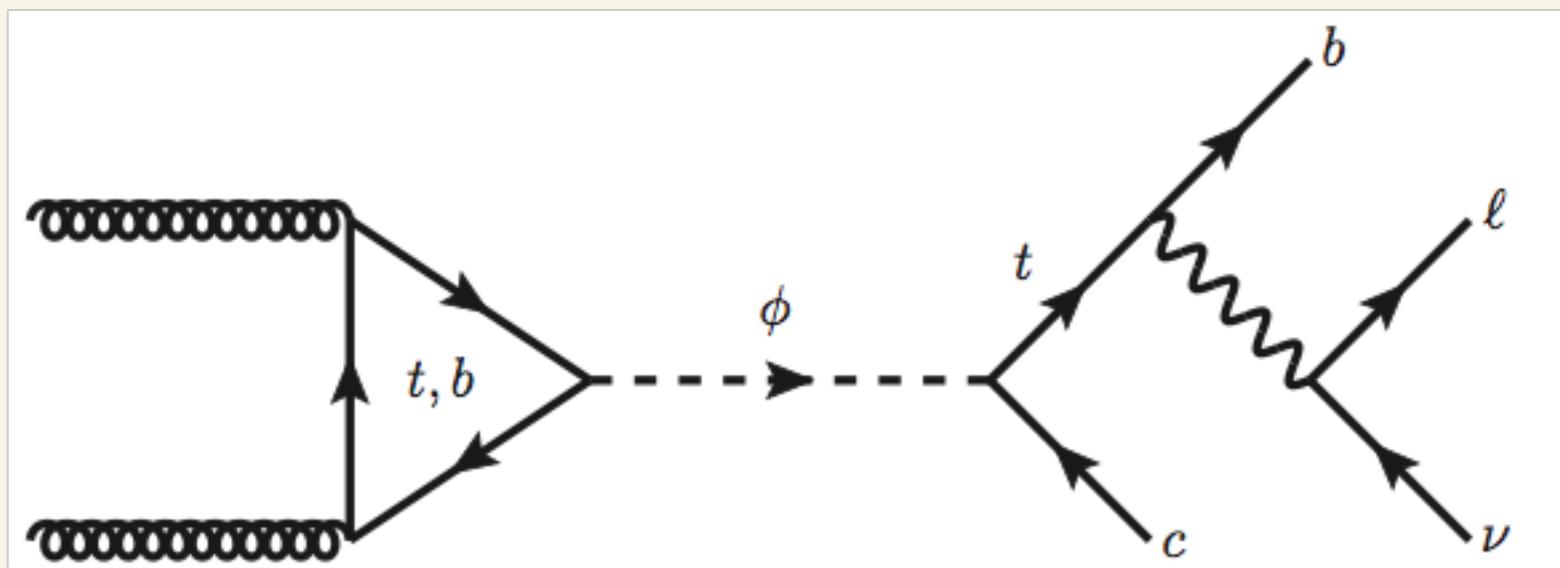
ARTICLE INFO

---

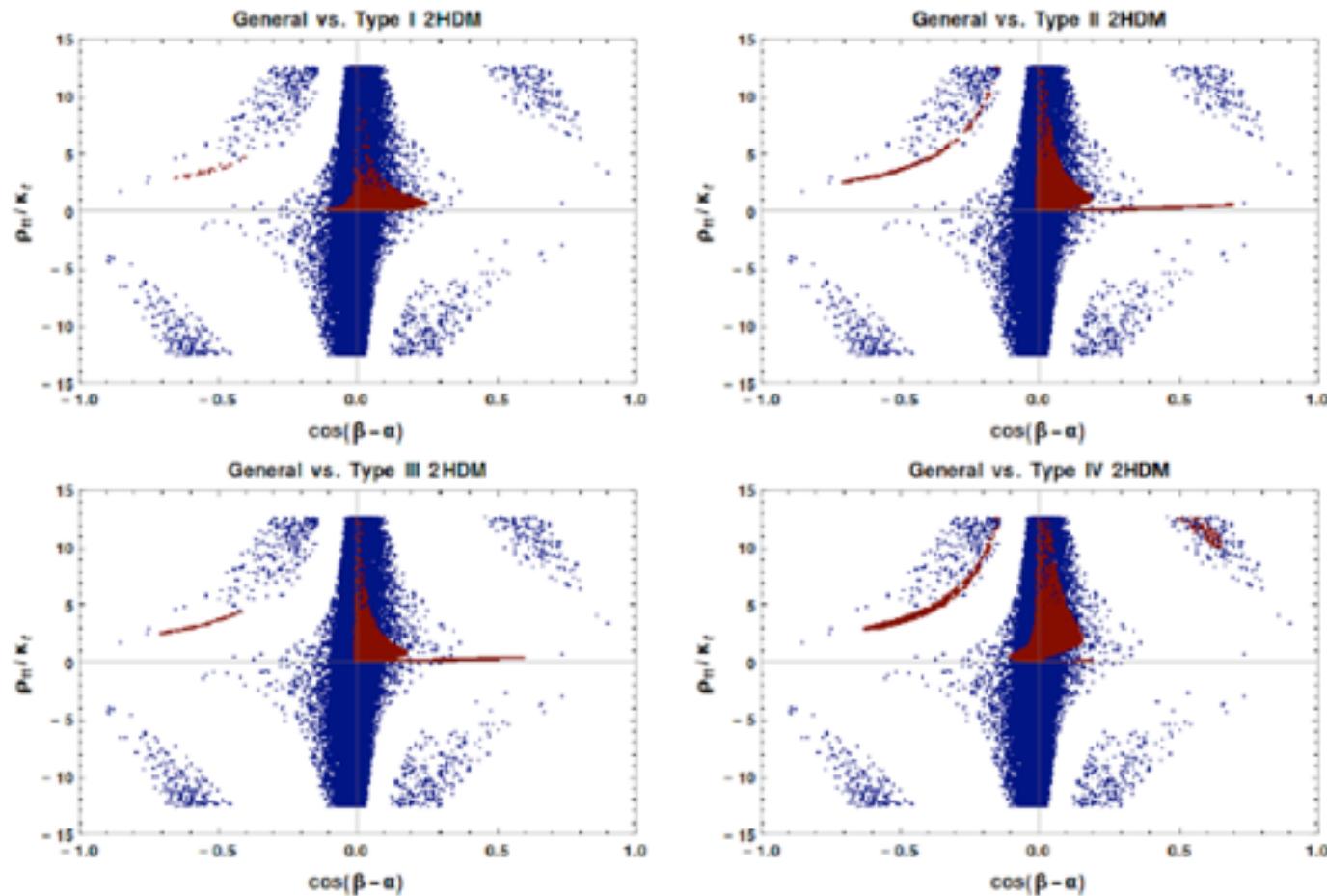
ABSTRACT

# The FCNH Signal of a Heavy Higgs boson at the LHC

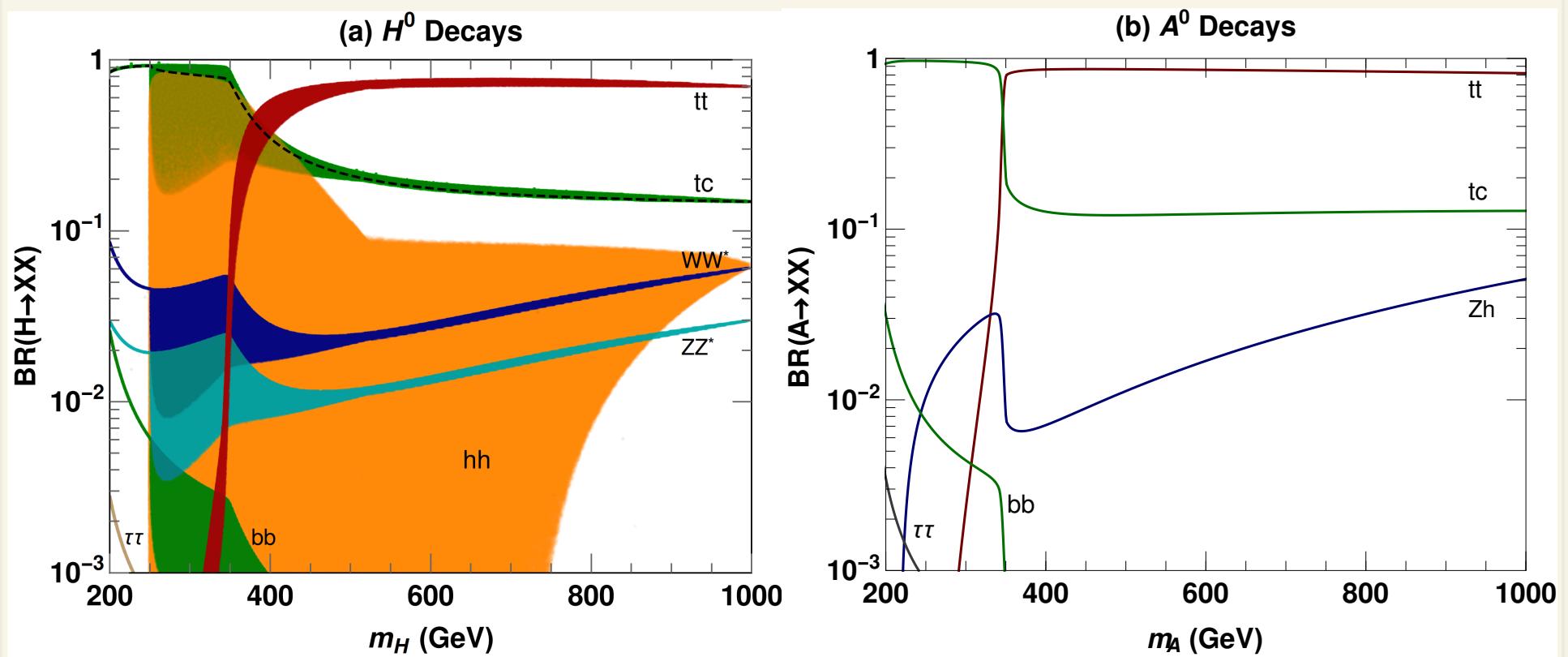
Let us consider a flavor changing neutral Higgs boson ( $\phi^0$ ) with  $M_\phi > M_h$ . It can be a CP-even scalar ( $H^0$ ) or a CP-odd pseudoscalar ( $A^0$ ) produced at the LHC followed by the Higgs decay into a top quark and a charm quark:



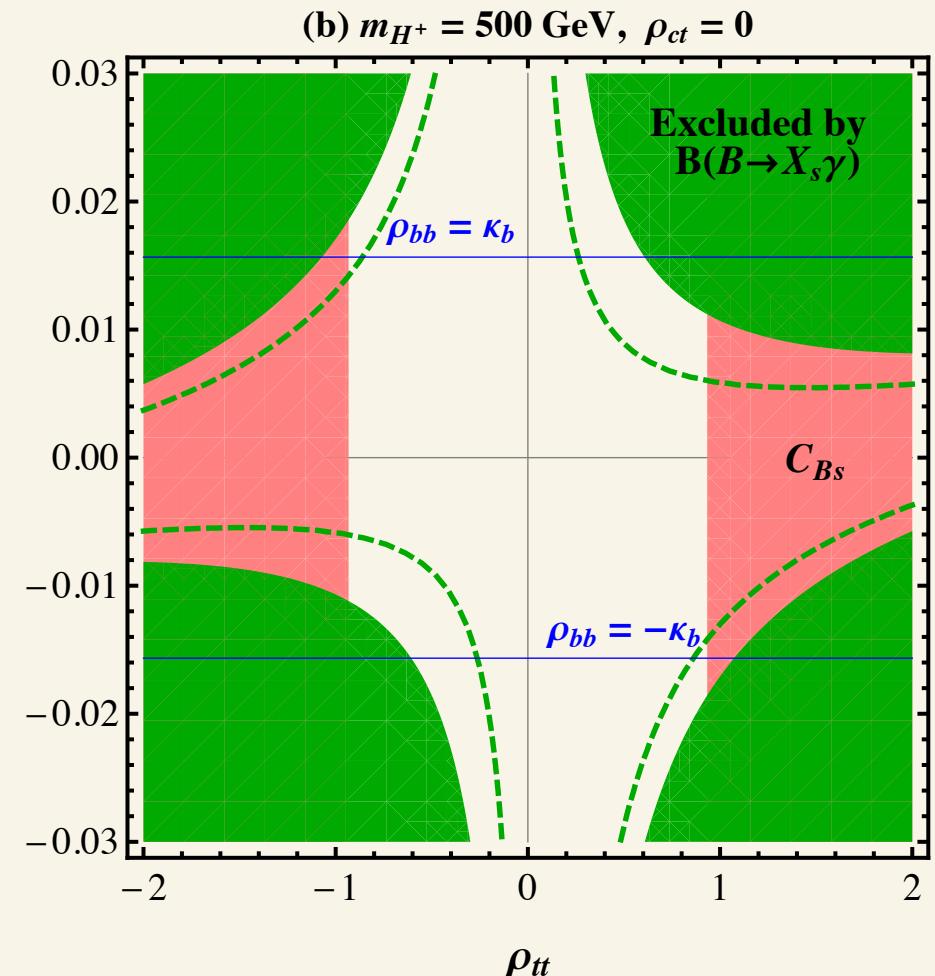
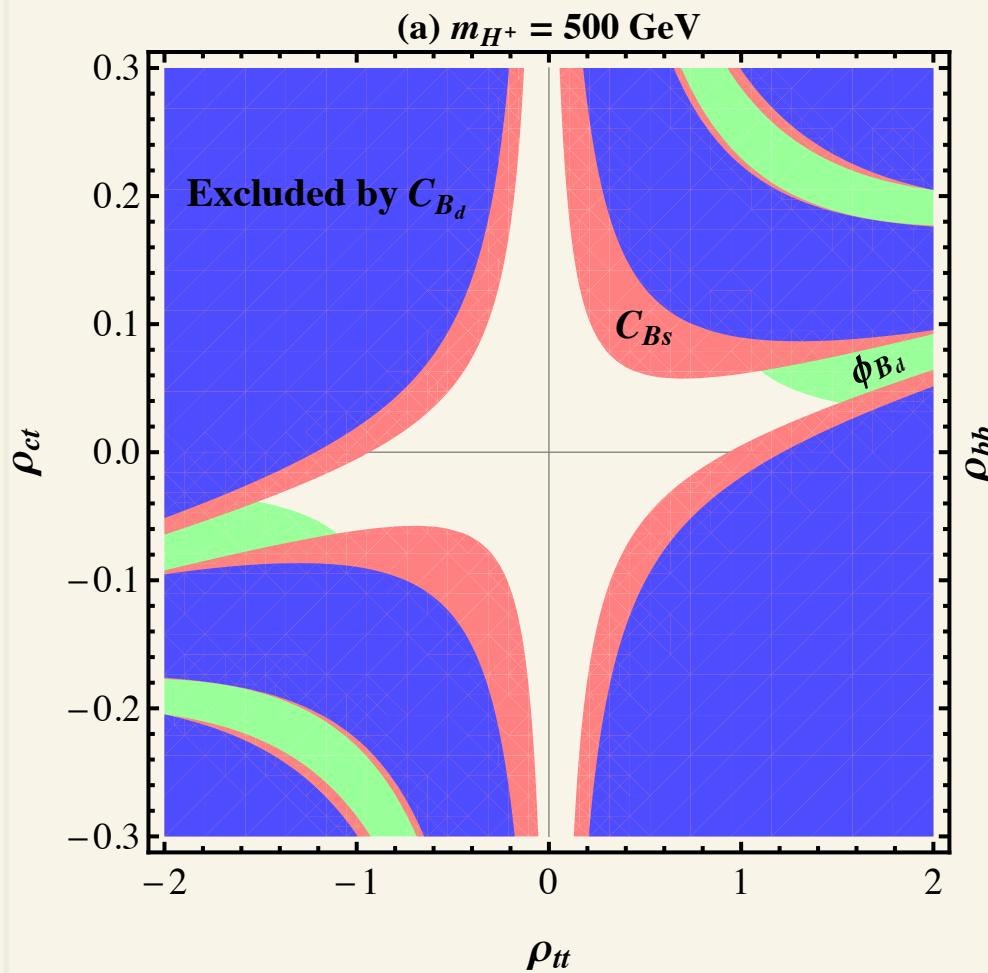
# ATLAS and CMS Signal Strength Measurements



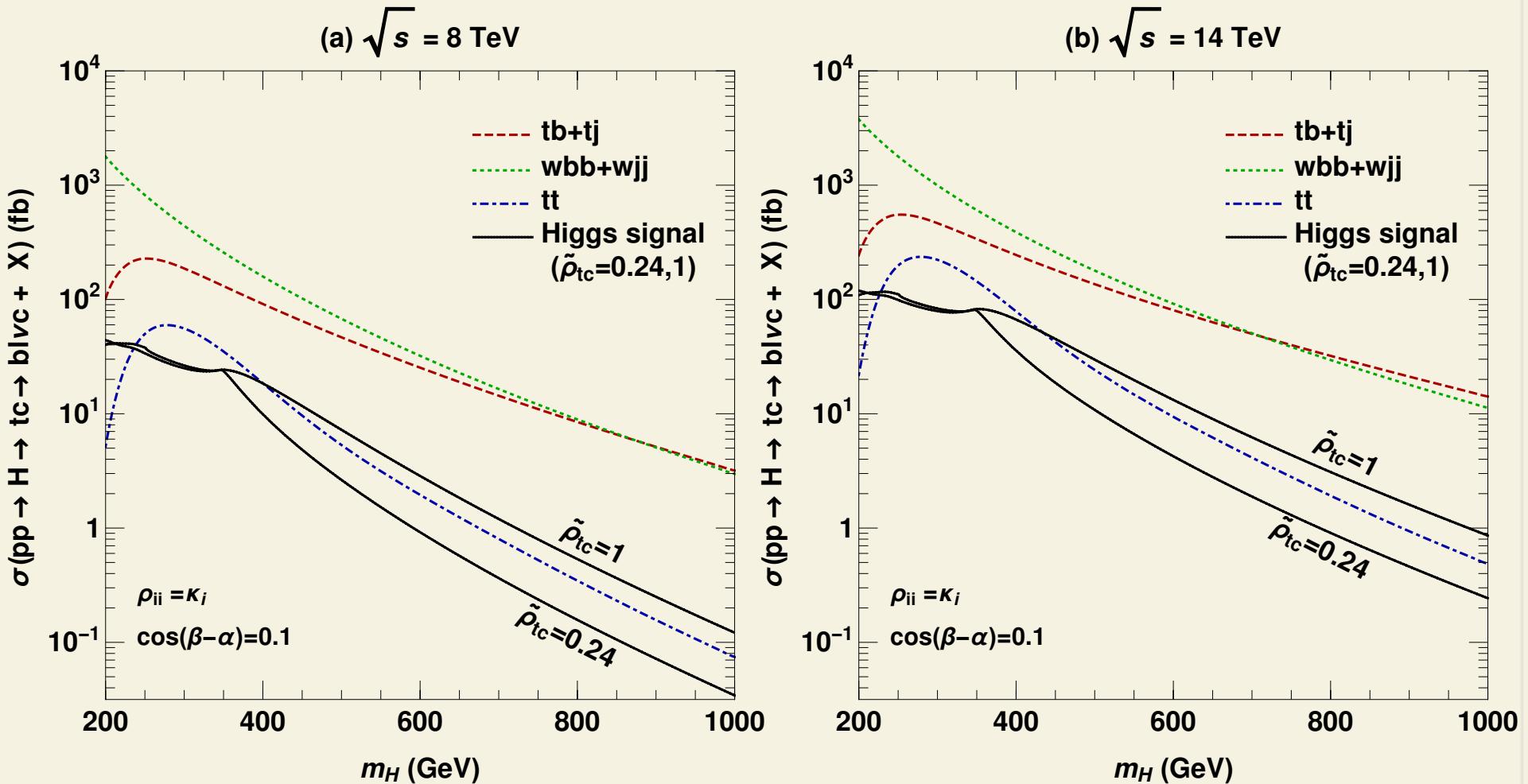
# Heavy Higgs Decay Branching Fractions



# Constraints from B Physics



# Signal and Background at the LHC



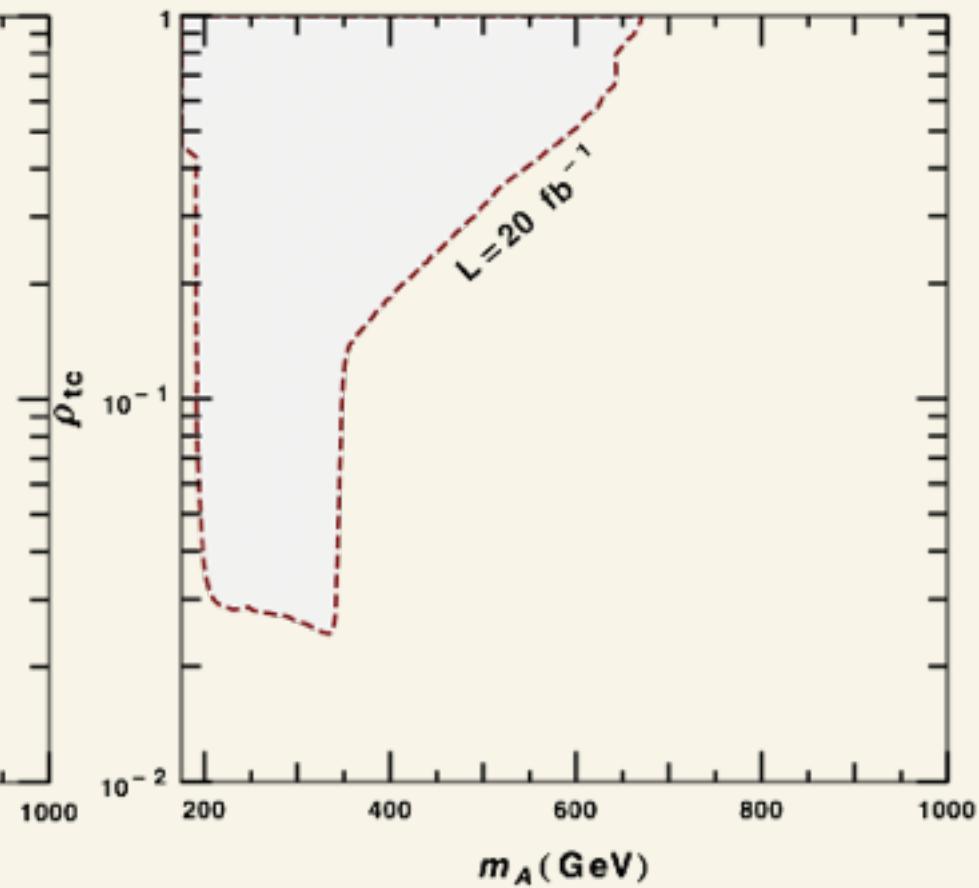
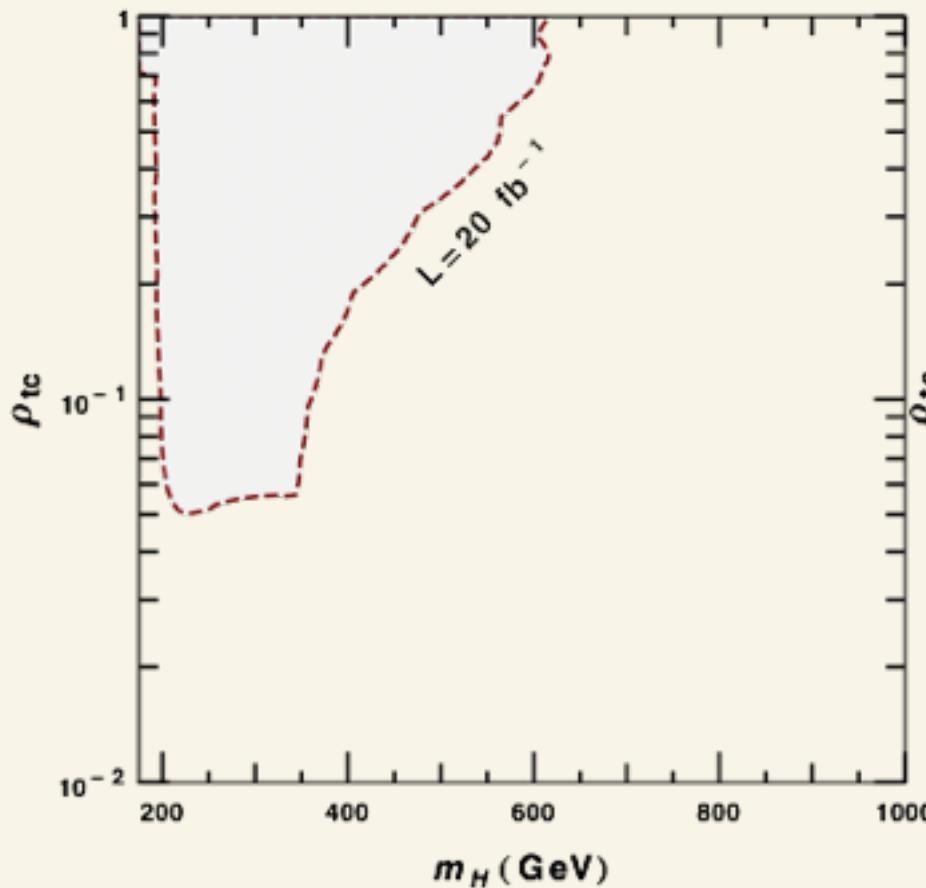
# Mass Reconstruction

We require that the reconstructed invariant masses should center around  $m_t$ ,  $m_w$ , and  $M_\phi$ .

- Assuming an on-shell  $W$ , we evaluate  $k_z$  of the neutrino with lepton momentum ( $p$ ) and missing transverse energy. Usually, there are two possible values for  $k_z$ . We select whichever leads to a better reconstruction of the top-quark mass:  $\text{Min}[m_t^2 - (k+p+p_b)^2]$ , and define the reconstructed top mass as  $M_{t^R} = M_{blv}$  such that  $|M_{blv} - m_t| < 0.15m_t$  or  $0.20m_t$ .
- The invariant mass of the top and the charm should have a peak near  $M_\phi$ :  $|M_{blvj} - m_\phi| < 0.15M_\phi$  or  $0.20M_\phi$ .

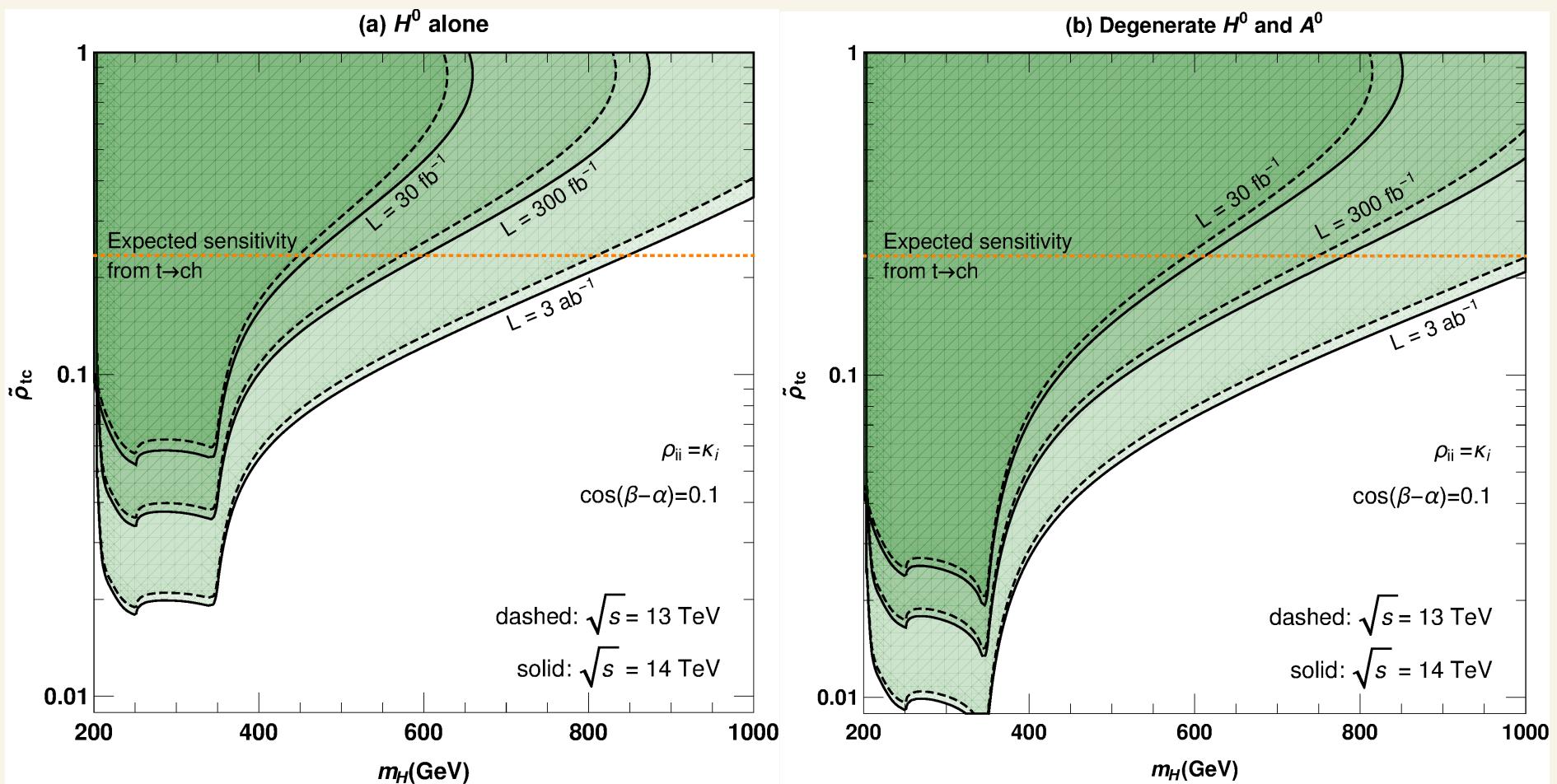
# Discovery Potential with 8 TeV

$\cos(\beta-\alpha) = 0.1$ ,  $\rho_{t\bar{t},bb,\tau\bar{\tau}} = K_{t\bar{t},bb,cc,\tau\bar{\tau}}$



# Discovery Contour at the LHC

## $\cos(\beta-\alpha) = 0.1$



# Conclusions

- It is of great interest to search for the link between the heaviest particle (top) and the mass giver (Higgs).
- It is a win-win strategy to search for the FCNH top decay  $t \rightarrow ch^0$  and the heavy Higgs decay  $H^0, A^0 \rightarrow t\bar{c} + t\bar{c}$ . In the decoupling limit, the production ( $gg \rightarrow H^0$ ) and the FCNH decay  $H^0 \rightarrow tc$  can be sustained by  $\sin(\beta-\alpha) \sim 1$ .
- The FCNH decay of heavy Higgs bosons will be observable for  $p_{tc} > 0.1$  and  $\cos(\beta-\alpha) \sim 0.1$  up to  $M_H = 800$  GeV with  $3000 \text{ fb}^{-1}$  of data.
- We might find out if nature chooses the same mechanism for electroweak symmetry breaking and tree-level FCNC.

$$pp \rightarrow H^0, A^0 \rightarrow \tau^- \mu^+ + \tau^+ \mu^- + X$$

Physics Letters B 795 (2019) 371–378



Contents lists available at ScienceDirect

Physics Letters B

[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)



## Flavor changing heavy Higgs interactions with leptons at hadron colliders



Wei-Shu Hou<sup>a</sup>, Rishabh Jain<sup>b</sup>, Chung Kao<sup>b</sup>, Masaya Kohda<sup>a</sup>, Brent McCoy<sup>b</sup>, Amarjit Soni<sup>c</sup>

<sup>a</sup> Department of Physics, National Taiwan University, Taipei 10617, Taiwan, ROC

<sup>b</sup> Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019, USA

<sup>c</sup> Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

---

ARTICLE INFO

---

ABSTRACT

# Flavor Changing Higgs Decays to $\tau\mu$

- Recent CMS data has set a limit on the branching fraction  $B(h \rightarrow \tau\mu) < 0.25\%$
- In a general 2HDM, the FCNH coupling of  $h\tau\mu$  is proportional to  $\cos(\beta-\alpha)$  while the FCNH couplings of  $H\tau\mu$  and  $A\tau\mu$  are proportional to  $\sin(\beta-\alpha)$ .
- In the decoupling limit or the alignment limit of 2HDMs, we expect  $\cos(\beta-\alpha) \sim 0$ , and  $\sin(\beta-\alpha) \sim 1$ .

$$pp \rightarrow H^0 \rightarrow WW + X$$

ATLAS Collaborations, JHEP 1803 (2018) 042

**Table 1**

Cross section of  $pp \rightarrow W^+W^- + X$  at  $\sqrt{s} = 14$  TeV and ATLAS limits at  $\sqrt{s} = 13$  TeV.

$M_H$ (GeV)	$\lambda_5 = 0$ (fb)	$\lambda_5 = -1$ (fb)	ATLAS limit (fb) [24]
300	$1.23 \times 10^3$	$1.98 \times 10^3$	$\leq 8.00 \times 10^3$
400	$7.17 \times 10^2$	$9.49 \times 10^2$	$\leq 1.30 \times 10^3$
500	$2.17 \times 10^2$	$2.47 \times 10^2$	$\leq 4.00 \times 10^2$

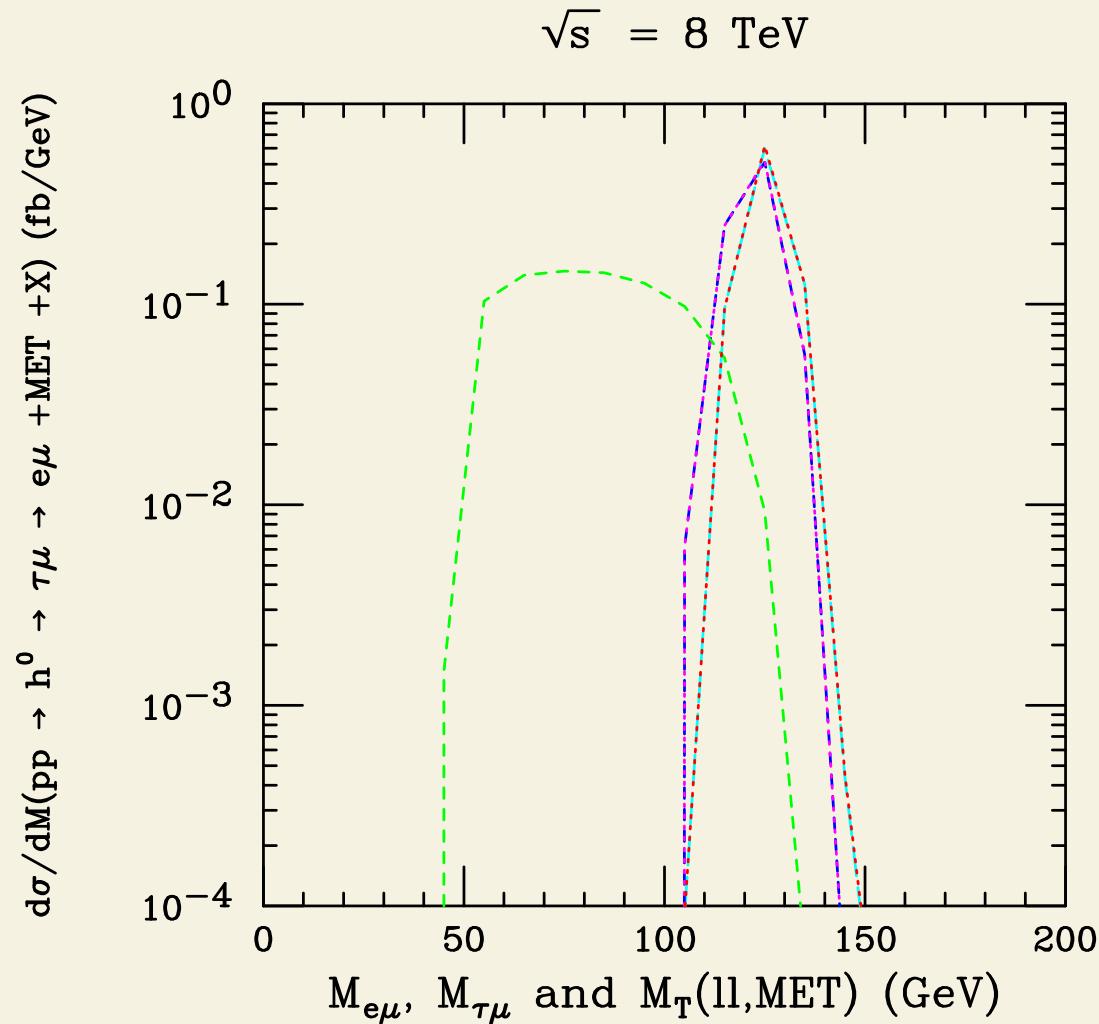
# Implications of $h \rightarrow \tau\mu$ from CMS Data

CMS arXiv:1502.07400; ATLAS arXiv:1508.03372;  
CMS arXiv:1712.07173

- CMS data in Run 1 had a  $2.4\sigma$  excess
  - ▶ Best fit branching fraction:  $0.84 \pm 0.38\%$
- It is compatible with  $1\sigma$  excess from ATLAS
  - ▶ Best fit branching fraction:  $0.77 \pm 0.62\%$
- The  $2.4\sigma$  excess is ruled out by 2016 CMS data
- An upper limit is set for  $B(h \rightarrow \tau\mu) < 0.25\%$

# Higgs to tau mu

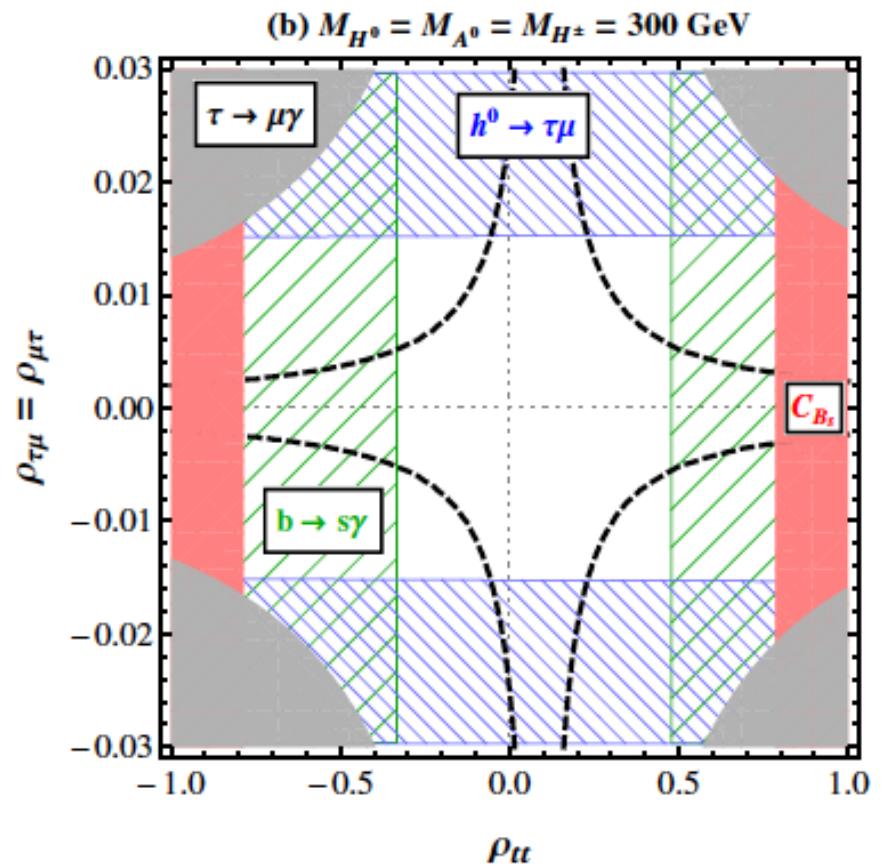
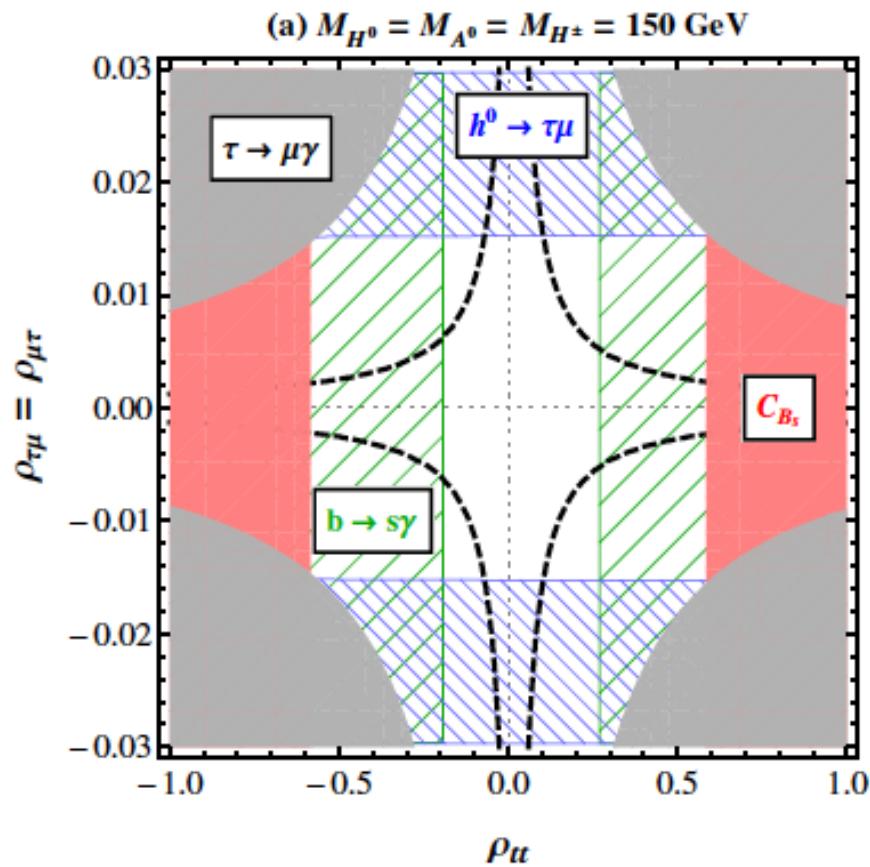
Hou, Jain, Kao, Kohda, McCoy, Soni (2018)



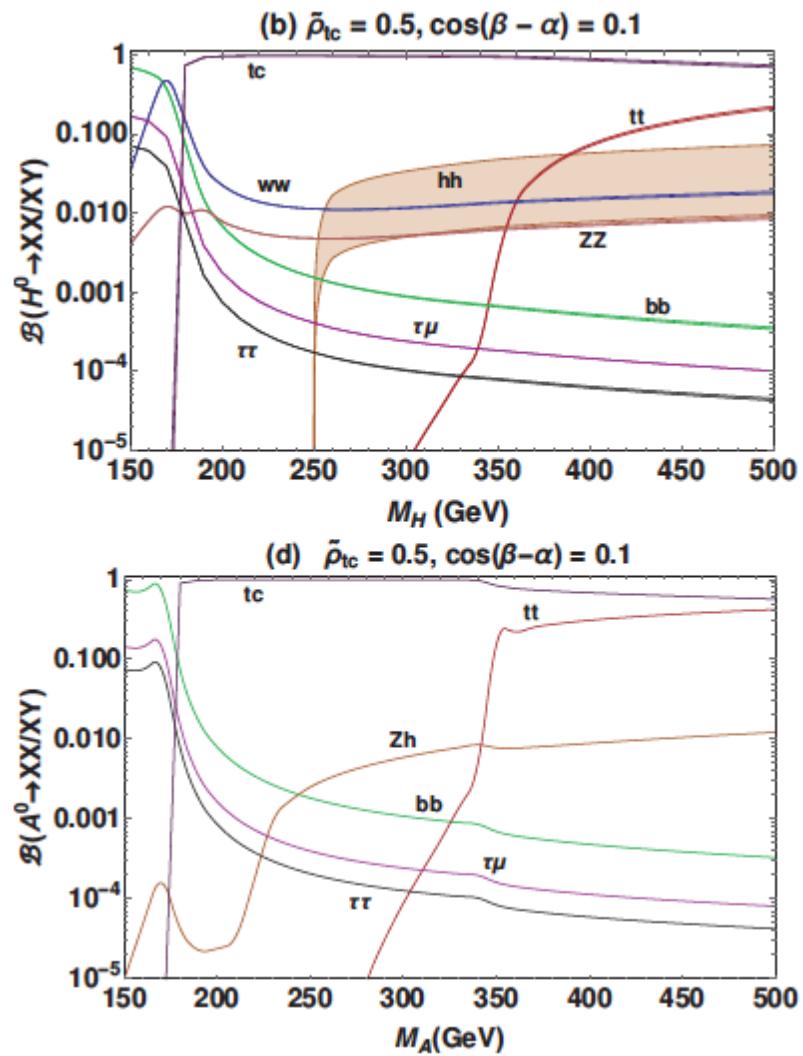
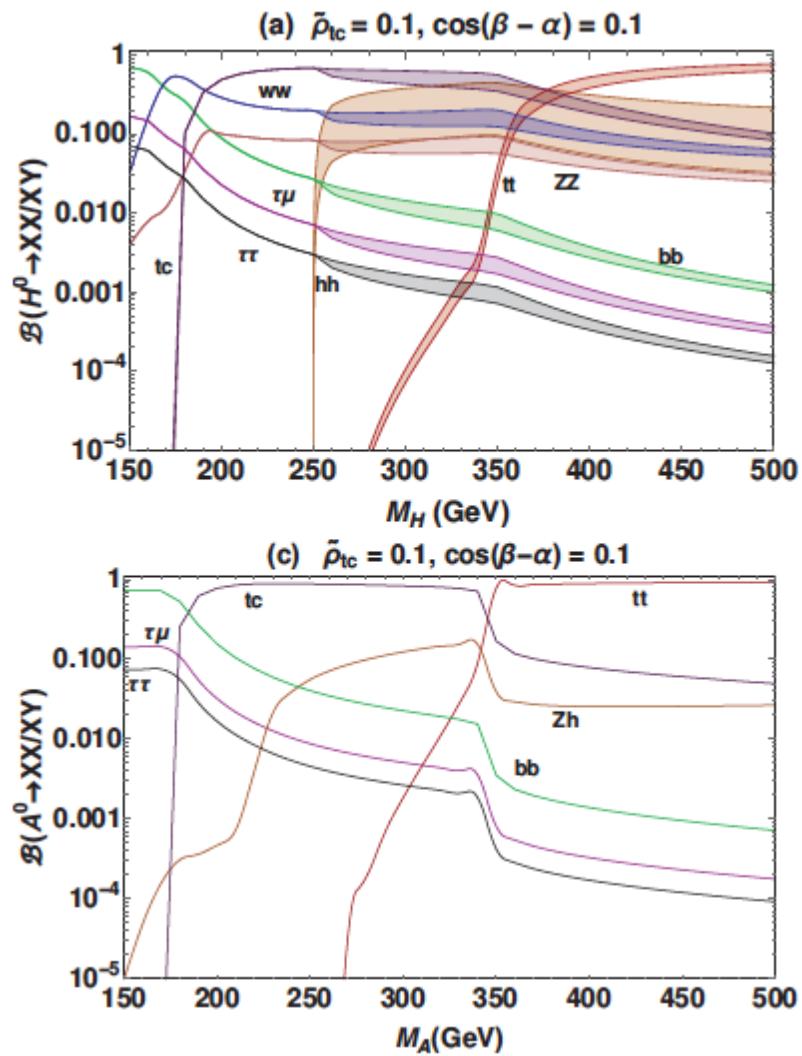
# Implication of New CMS Data

- CMS-HIG-17-001
- $B(h^0 \text{ to } \tau\mu) < 0.25\% \text{ at 95\% C.L.}$
- $(|Y_{\tau\mu}|^2 + |Y_{\mu\tau}|^2)^{1/2} < 1.43 \times 10^{-3}$
- For  $\cos(\beta-\alpha) = 0.1$ ,  $\rho_{\tau\mu} < 2 \times 10^{-2}$
- $g_{\tau\mu} = Y_{\tau\mu} = \rho_{\tau\mu} \cos(\beta-\alpha)/\sqrt{2}$

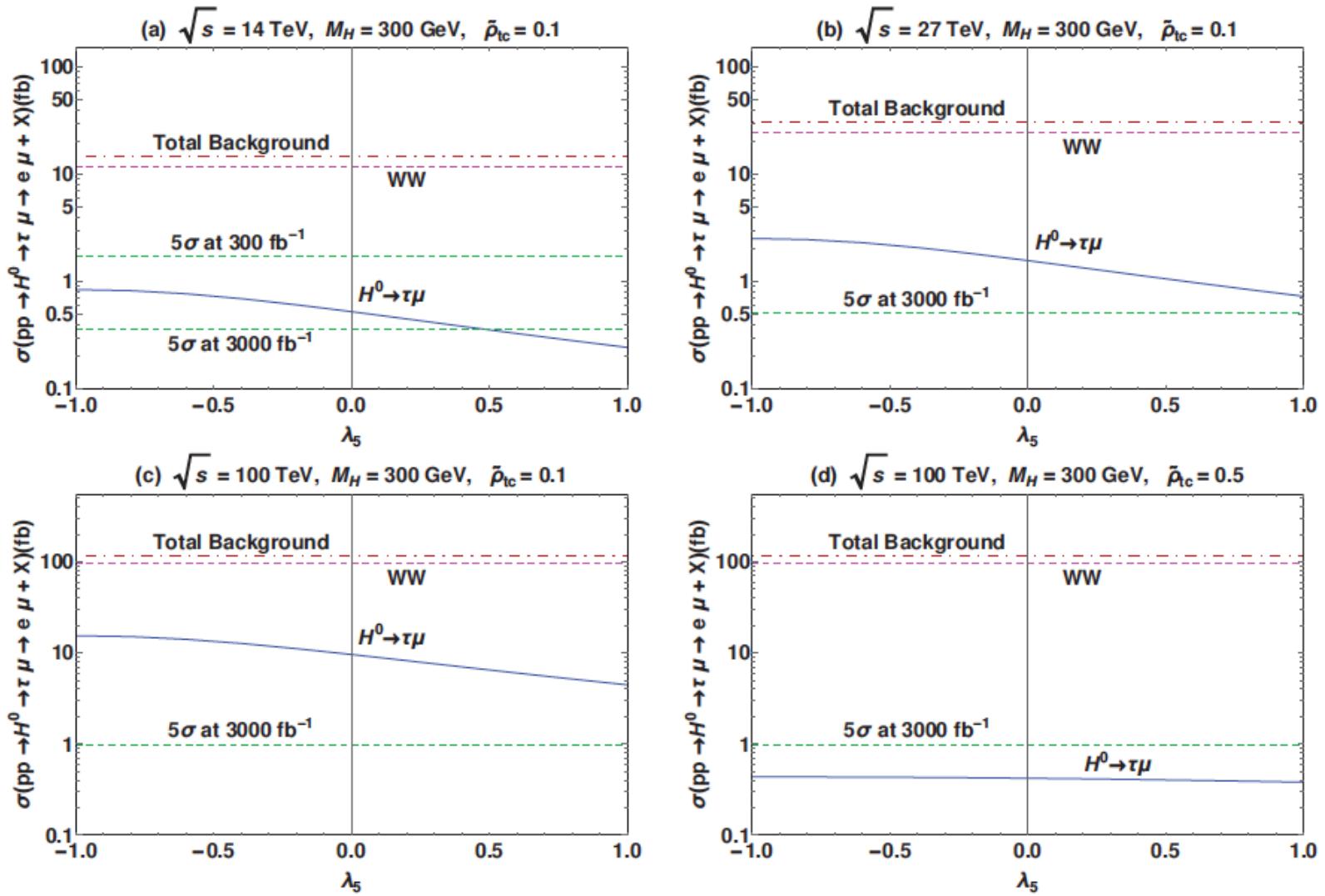
# Constraints on Parameters

$$\cos(\beta-\alpha) = 0.1$$


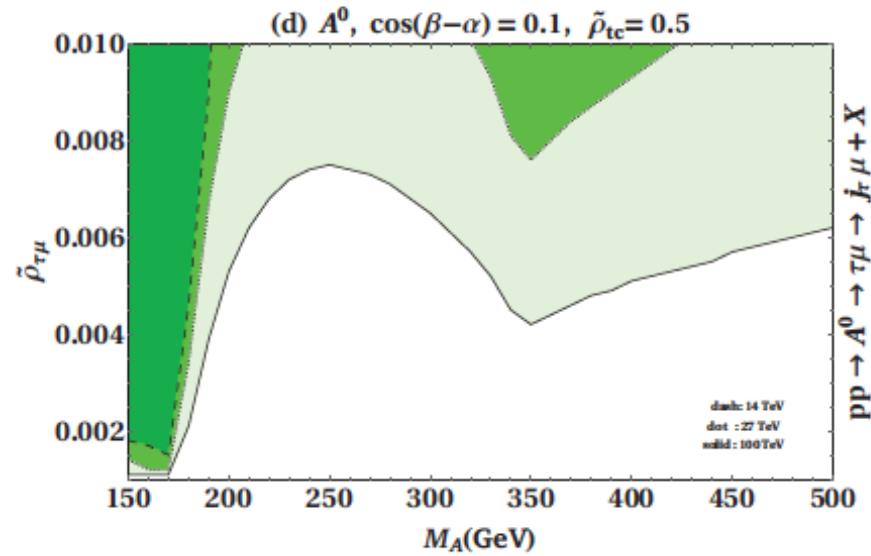
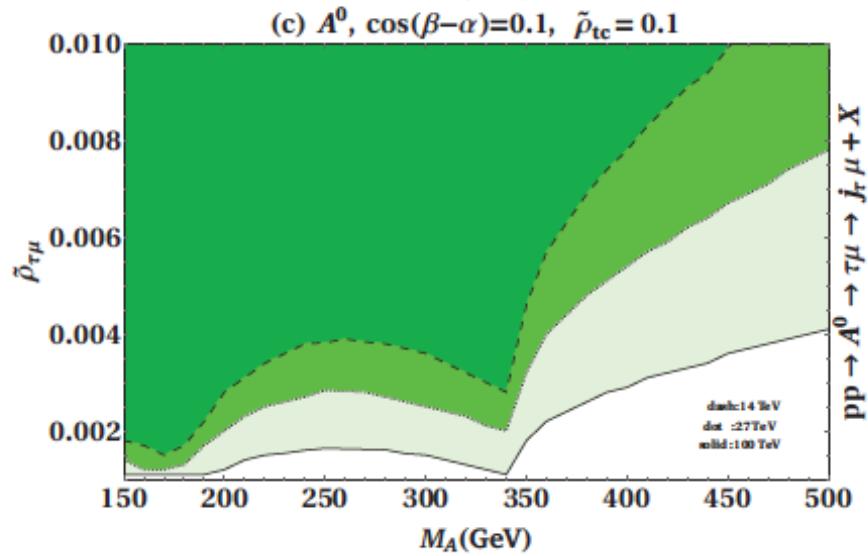
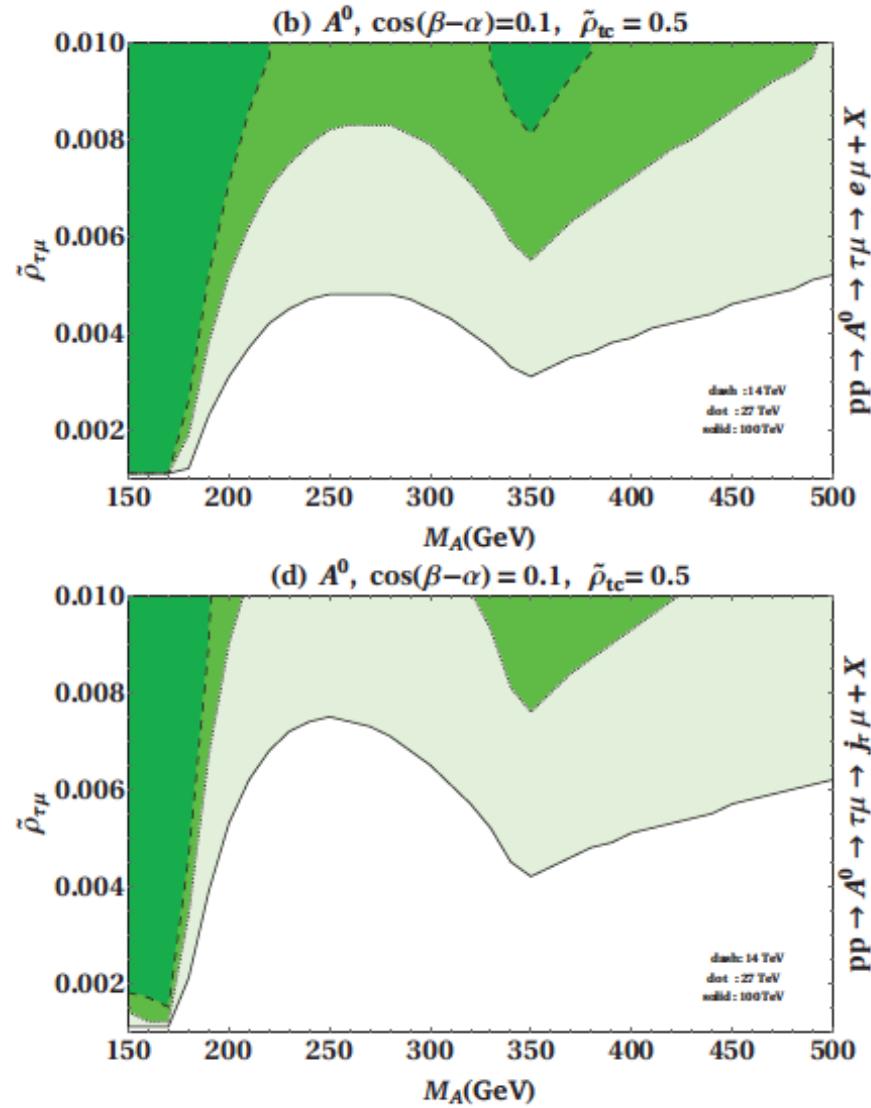
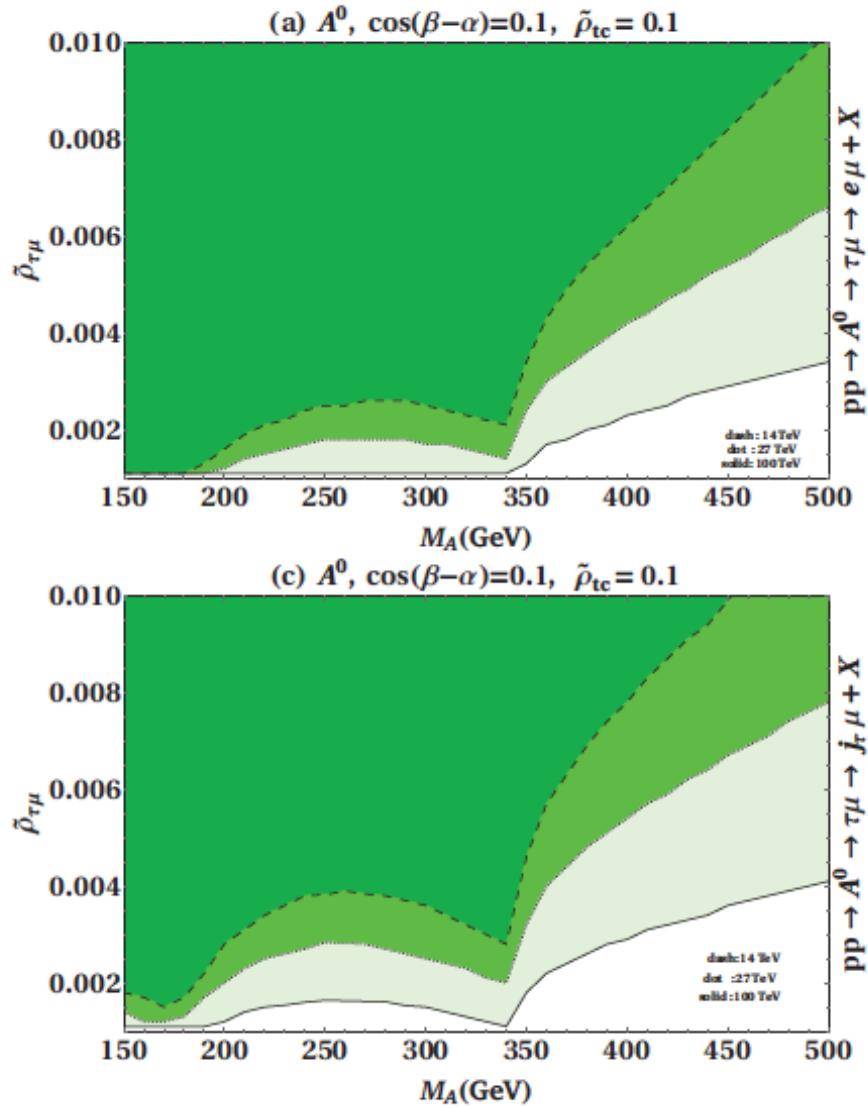
# Decay of Heavier Higgs Bosons



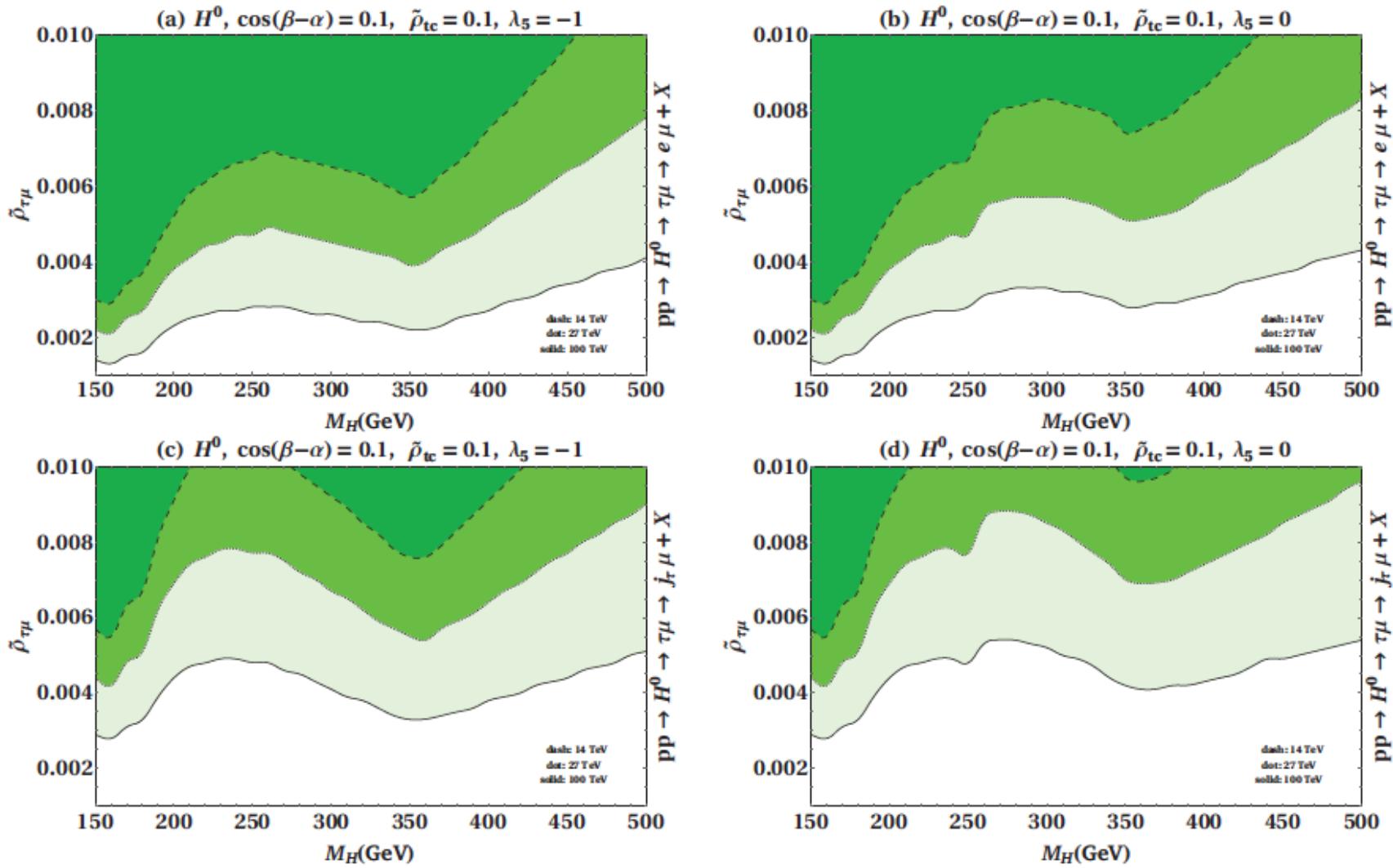
# Cross Section of the Higgs Signal



# Discovery Contours for the Pseudoscalar



# Discovery Contours for the Heavier Scalar



# Conclusions

- Strong experimental constraints exist for FCNH interactions, but third generation fermions might offer promising signatures for new physics at the LHC and future hadron colliders.
- In the general 2HDM, the coupling probed is  $\lambda_{h\tau\mu} = \rho_{\tau\mu} \cos(\beta-\alpha)$ , which is expected to be small in the alignment limit of  $\cos(\beta-\alpha) \rightarrow 0$ , where the light CP-even Higgs boson  $h^0$  approaches the standard Higgs boson.

# Conclusions

- The pseudoscalar  $A^0$  boson has FCNH coupling  $\lambda_{A\tau\mu} = \rho_{\tau\mu}$  that is independent of  $\cos(\beta-\alpha)$ , while the heavy CP-even scalar  $H^0$  has FCNH coupling  $\lambda_{H\tau\mu} = \rho_{\tau\mu} \sin(\beta-\alpha)$ .
- It should be noted that  $A^0$  is more promising than  $H^0$  because of its higher production cross section and fewer decay channels affecting its decay to  $\tau\mu$ , but  $H^0$  decay depends also on Higgs potential due to  $h^0h^0$  mode.