Flavor Changing Neutral Higgs Interactions with Top and Tau at the LHC

*presented at LHCP 2017 in Shanghai, China

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(d) $H^0 \to tc$ Signal

A general 2HDM is chosen to study FCNH interactions for neutral Higgs bosons. Since the ATLAS and CMS Higgs data favor a scalar with properties similar to the standard Higgs boson, and for simplicity, we choose $\cos(\beta-\alpha) = 0.1$ and 0.2 for case studies in the decoupling limit with heavy Higgs bosons $(H^0, A^0, H^\pm)$ almost degenerate.

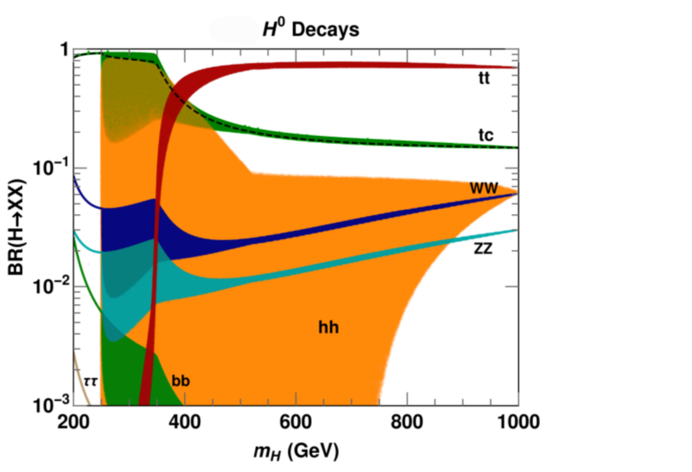

Figure 3: Branching fraction of the heavier Higgs scalar H^0 as a function of its mass with $\cos(\beta-\alpha) = 0.1$, $\tilde\rho_{tc} = 0.24$, and $\rho_{ii} = \kappa_i$ $(ii = tt,\ bb, \ldots)$ for diagonal couplings. We show the allowed regions when $\tan\beta$ and m_{12}^2 are varied (shaded regions) and the dashed curve is the $\mathcal{B}(H^0 \to tc)$ used for the LHC case study.

Gluon fusion $gg \to \phi^0$, $\phi^0 = H^0, A^0$ is the dominant Higgs production mechanism at the LHC. To study neutral Higgs decays, we scan over the parameters that satisfy stability, tree-level unitarity, and perturbativity, with mass parameters up to 2 TeV and $0.1 \le \tan\beta \le 50$. Branching fractions of the heavy Higgs scalar for several final states are presented in Fig. 3. We note that $H^0 \to h^0 h^0$ might offer great promise for Higgs pair discovery at the LHC.

(e) Physics Background

The dominant SM physics background to the final state of $bj\ell + \not{E}_T$ comes from $Wb\bar{b} + Wjj$, single top production $tb + tj$, and top pair production $(t\bar{t})$. Fig. 4 shows cross section of the Higgs signal $(H^0 \to t\bar{c} + \bar{t}c)$ as well as that of the physics background at the LHC with $\sqrt{s} = 14$ TeV. We consider $\tilde\rho_{tc} = \sqrt{\rho_{tc}^2 + \rho_{ct}^2}/2$, and choose two representative values $\tilde\rho_{tc} = 1$ as well as $\tilde\rho_{tc} = 0.24$ that is the future sensitivity of ATLAS to seach for $t \to ch^0 \to c\gamma\gamma$ with $\sqrt{s} = 14$ TeV and an integrated luminosity (L) of 3000 fb^{-1}.

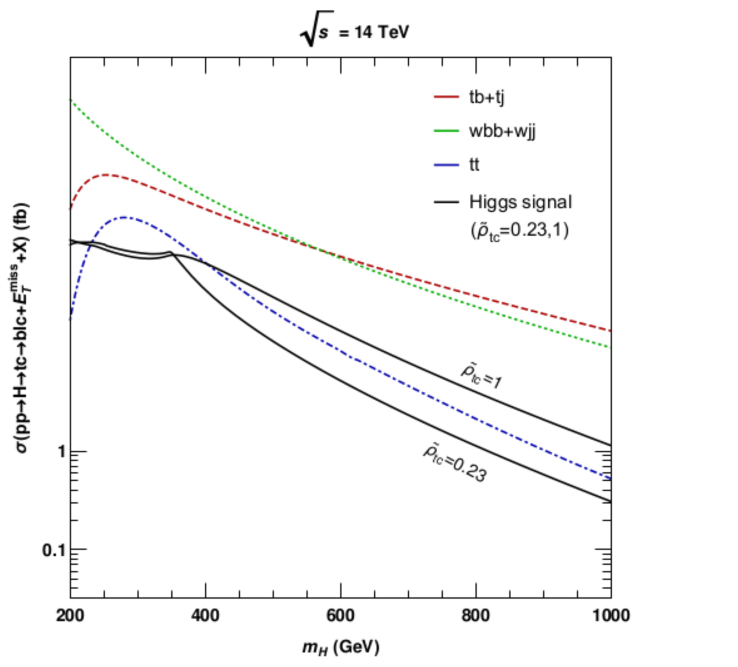

Figure 4: The cross section of the heavier Higgs scalar $\sigma(pp \to H^0 \to t\bar{c} + \bar{t}c \to bj\ell + \not{E}_T + X)$ (solid line) for $\sqrt{s} = 14$ TeV, $\tilde\rho_{tc} = 0.24,\ 1$ and $\cos(\beta-\alpha) = 0.1$. The dashed lines show the cross sections of the dominant physics background with K-factors, acceptance cuts, and tagging efficiencies.

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(a) Introduction

The discovery of a Higgs boson with mass $m_{h^0} \simeq 125$ GeV $< m_t$ [2], opens up the possibility of a $t \to ch^0$ decay indicating that there may be evidence for flavor changing neutral Higgs (FCNH) interactions. Since the branching fraction is small in the Standard Model (SM), $\mathcal{B}(t \to ch^0) \approx 3\times10^{-15}$ [3], any discovery of $t \to ch^0$ indicates physics beyond the SM [4-10]

To study FCNH interactions, we adopt a general two Higgs Doublet Model (2HDM) with the following Lagrangian involving Higgs bosons and Fermions,

$$\mathcal{L}_Y = \frac{-1}{\sqrt{2}}\sum_{F=U,D,L}\bar{F}\Big\{\left[\kappa^F s_{\beta-\alpha} + \rho^F c_{\beta-\alpha}\right]h^0 + \left[\kappa^F c_{\beta-\alpha} - \rho^F s_{\beta-\alpha}\right]H^0 - i\,\mathrm{sgn}(Q_F)\rho^F A^0\Big\}P_R F$$
$$- i\,\mathrm{sgn}(Q_F)\rho^F A^0\Big\}P_R F - \bar{U}\left[V\rho^D P_R - \rho^{U\dagger} V P_L\right]DH^+ - \bar{\nu}\left[\rho^L P_R\right]LH^+ + \mathrm{H.c.}, \qquad (1)$$

where $P_{L,R} \equiv (1 \mp \gamma_5)/2$, $c_{\beta-\alpha} = \cos(\beta-\alpha)$, $s_{\beta-\alpha} = \sin(\beta-\alpha)$, $\tan\beta = v_2/v_1$, and α is the mixing angle for the neutral Higgs scalars [19]. The κ matrice are diagonal, $\kappa^F = \sqrt{2}m_f/v$ with $v \simeq 246$ GeV while ρ are kept free and have both diagonal and off-diagonal elements. U, D, L and ν are vectors in flavor space $(U = (u,\ c,\ t)$, etc.). And h^0 and H^0 are CP-Even scalars $(m_h \le m_H)$, A^0 is a CP-odd pseudoscalar.

Since $g_{htc,h\tau\mu} \propto \cos(\beta-\alpha)$ and $g_{Htc,H\tau\mu} \propto \sin(\beta-\alpha)$, $H^0 \to tc$ and $H^0 \to \tau\mu$ are expected to be more promising in the decoupling limit with $\cos(\beta-\alpha) \to 0$ and $\sim (\beta-\alpha) \sim 1$. This study looks at the discovery potential of the LHC in the search for neutral Higgs bosons exhibiting such decays. We choose the top to subsequently decay into a b quark, a charged lepton (e or μ), and a neutrino, and in the leptonic channel with $\tau \to \ell\nu\nu, j_\tau\nu$. We evaluate production rates with full tree-level matrix elements for both the signal and the dominant physics background with optimized selection cuts and realistic b-tagging efficiencies. Promising results were obtained for the LHC with $\sqrt{s} = 13$ TeV and 14 TeV.

(g) LHC Discovery Potential

To study the discovery potential, we define the signal to be observable if the lower limit on the signal plus background is larger than the corresponding upper limit on the background with statistical fluctuations. This leads to the condition,

$$\sigma_S \ge \frac{N}{L}\left[N + 2\sqrt{L\sigma_B}\right], \qquad (2)$$

where $\sigma_{S(B)}$ is the signal (background) cross section and L the integrated luminosity. Choosing the parameter $N = 2.5$ corresponds to 5σ significance. For a large number of events $(N_B = L\sigma_B \gg 1)$, this requirement is equivalent to the statistical significance

$$N_{SS} = \frac{N_S}{\sqrt{N_B}} = \frac{L\sigma_S}{\sqrt{L\sigma_B}} \ge 5, \qquad (3)$$

where $N_{S(B)}$ is the number of signal (background) events. We present the LHC the discovery reach for the FCNH heavy Higgs with $\sqrt{s} = 13$ TeV and 14 TeV, for $\cos(\beta-\alpha) = 0.1$ and 0.2. Fig. 5 (a,c) are for the heavier scalar H^0 alone, whereas Fig. 5 (b,d) are for the degenerate case, for which the scalar H^0 and pseudoscalar A^0 signals are added together.

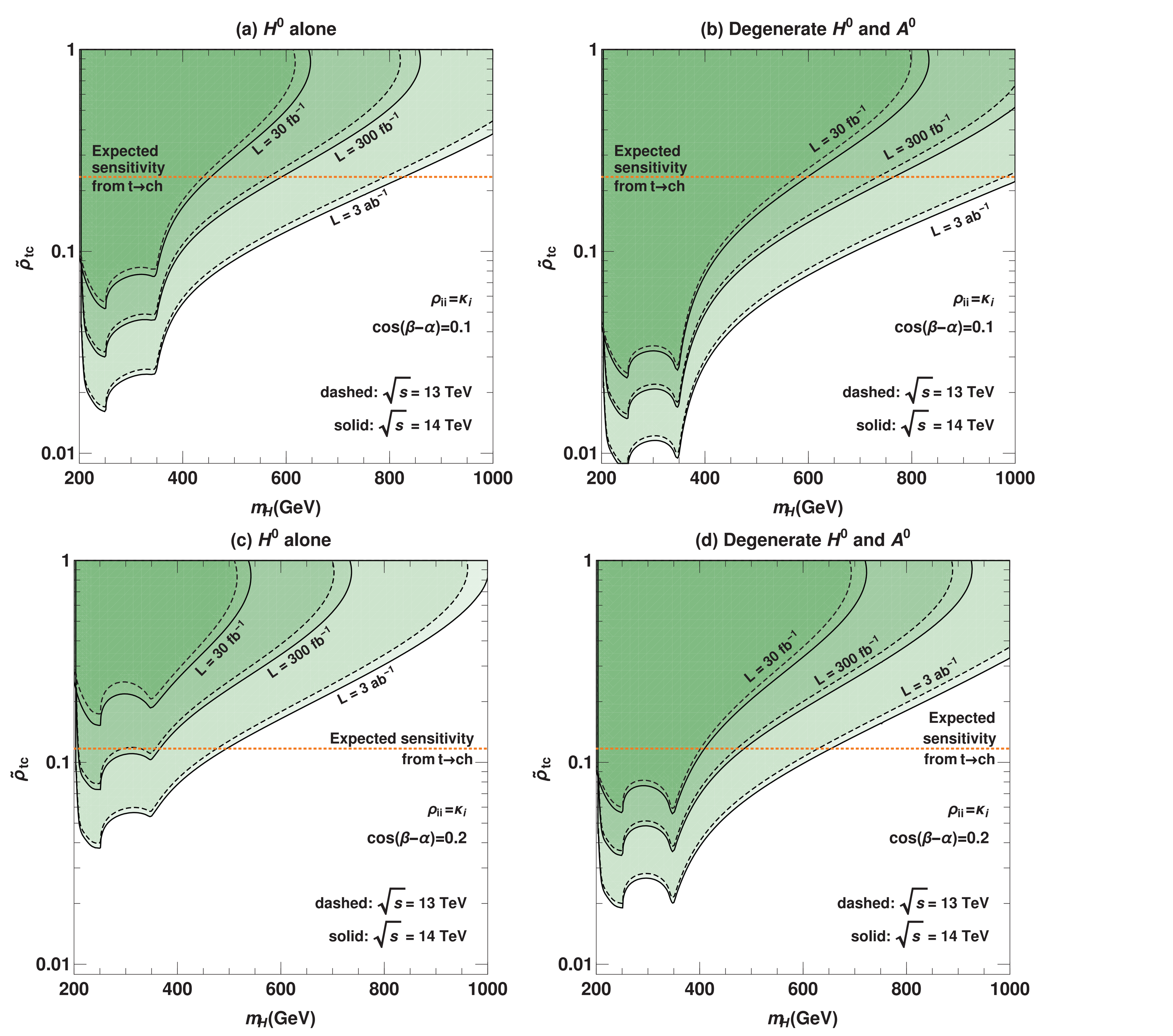

Figure 5: Discovery reach at 5σ in the $m_\phi - \tilde\rho_{tc}$ plane for $pp \to \phi^0 \to t\bar{c} + \bar{t}c \to bj\ell + \not{E} + X$ signal at the LHC with $\sqrt{s} = 13$ (14) TeV for dashed (solid) contours. (a) is for the heavier Higgs scalar H^0 and (b) is for the combined H^0 and A^0 signal assuming mass degeneracy for $\cos(\beta-\alpha) = 0.1$. (c) and (d) are analogous to (a) and (b) but for $\cos(\beta-\alpha) = 0.2$. The discovery region is the parameter space above the contours. Also shown is the future ATALS sensitivity at the 95% C.L. for $t \to ch^0 \to c\gamma\gamma$.

The FCNH decay of the heavy Higgs will be observable for $\cos(\beta-\alpha) = 0.1$ and $\tilde\rho_{tc} = 0.1$ up to $M_H = 800$ GeV with 3000 fb^{-1} of integrated luminosity. This result is robust against a small $\cos(\beta-\alpha)$, independent of the $t \to ch^0$ search, which becomes diminished. If $\tilde\rho_{tc} \gtrsim 0.5$, $\mathcal{B}(H^0 \to t\bar{c} + \bar{t}c)$ can become comparable to $\mathcal{B}(H^0 \to t\bar{t})$ or surpass it.

(b) Experimental Limits from $\tau \to \mu\gamma$

In general two Higgs doublet models with a large $\rho_{\tau\mu}$ or $\rho_{\mu\tau}$, results from $\tau \to \mu\gamma$ experiments provide strong constraint on ρ_{tt} as well as on $\rho_{\tau\mu}$. The sensitivity on ρ_{tt} comes from two-loop Barr-Zee diagrams. In Figure 1, we present allowed region in the $(\rho_{tt}, \rho_{\tau\mu})$ plane with constraints from BARBAR experiments, future sensitivity of Belle II, and CMS data for $h^0\tau\mu$ for $\rho_{tt} = \kappa_t$ and $\rho_{tt} = 0.5$.

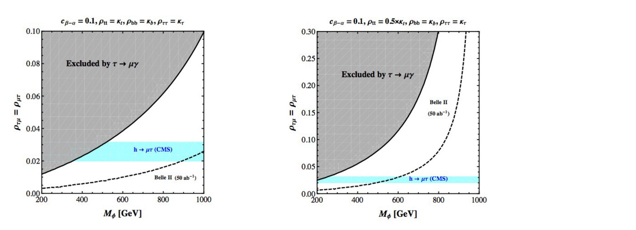

Figure 1: Allowed region in the $(\rho_{tt}, \rho_{\tau\mu})$ plane with $\rho_{\tau\mu} = \rho_{\mu\tau}$. Gray regions are excluded by the 90% CL limit from BARBAR: $B(\tau \to \mu\gamma) < 4.4\times10^{-8}$ [20]. Dashed lines represent future sensitivity by Belle II: $B(\tau \to \mu\gamma) < 3\times10^{-9}$ [21]. Light blue regions show the CMS 1σ range $B(h^0 \to \tau\mu) \simeq 0.84^{+0.39}_{0.37}\%$

(c) Constraints from B Physics

The FCNH coupling ρ_{ct} affects the H^+tq couplings. This effect contributes to FCNC processes with down-type quarks via H^+ and t loops. The constraints from $B_{d,s}$ mixing data are shown in Fig. 2 on the $(\rho_{tt} - \rho_{ct})$ plane with $m_{H^+} = 500$ GeV. In addition, experimental data of $\mathcal{B}(B \to X_s\gamma)$ place a strong limit on ρ_{bb}, as the effect of ρ_{bb} is enhanced by the chiral factor $\kappa_t/\kappa_b = m_t/m_b$. The constraints on ρ_{tc} has found to be $|\rho_{tc}| \lesssim 1.7$ for $m_{H^+} = 500$ GeV [22].

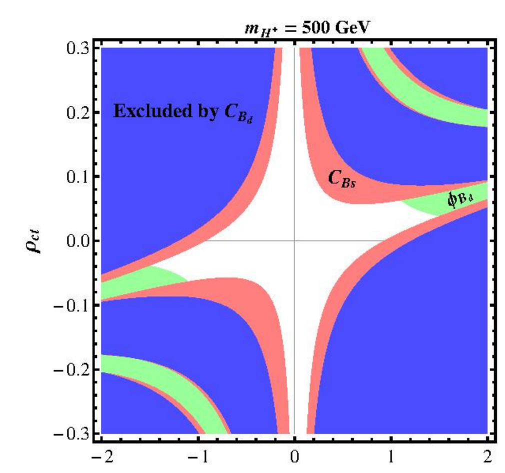

Figure 2: Allowed regions in the $\rho_{tt} - \rho_{ct}$ plane from $B_{d,s}$ − mixing for with shaded regions excluded at the 95% C.L. Blue (pink) regions by $C_{b_{d,s}}$, and the light-green regions by ϕ_{b_d}.

(f) Results for $h^0 \to \tau\mu$

Table 1 shows the cross section in fb of the $pp \to h^0 \to \tau\mu \to e\mu + X$ with all CMS acceptance cuts [13] for $g_{h\tau\mu} = \rho_{\tau\mu}\cos(\beta-\alpha)/\sqrt{2} = \sqrt{m_\tau m_\mu}/v \simeq 1.75\times10^{-3}$, dominant physics backgrounds are also presented.

Collider Energy	$h^0 \to \tau\mu$	$Z \to \tau\tau$	W^+W^-
8 TeV (CMS)	1.17	3.3	2.08
8 TeV (PM)	3.71	9.62	2.18
13 TeV (PM)	8.17	15.49	3.66
14 TeV (PM)	9.14	16.64	3.96

Table 1: $\sigma(pp \to h^0 \to \tau\mu \to e\mu + X)$[fb] for $\sqrt{s} = 8, 13$, and 14 TeV. PM means parton level cross section.

Our cross sections at the parton level for $h^0 \to \tau\mu$ and $Z \to \tau\tau$ are both significantly higher than CMS data. We plan to carry out Monte Carlo simulations for $H^0, A^0 \to \tau\mu$.

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