Charged Higgs Flavor Changing Current in $\tau \to \nu_X K P^0$

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September 13, 2010

=Collaboration=

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Introduction

- Search For Lepton Flavor Violation in B factories. (Belle, Babar).
- $\tau \to \mu P^0$ $\tau \to e P^0$ ($P^0 = \pi^0, \eta, \eta'$).
- Flavor Changing Neutral Current couplings of charged lepton sector in New Physics Models are constrained by these new upper limits for branching fractions.
- Examples of new physics models include super symmetric models, multi-Higgs doublet models etc.

Introduction (Continued.)

- We take two Higgs doublet models as example.
  In type (III) two Higgs doublet model, there are tree level FCNC in charged lepton sector.

  $$\tau \to l_X A \to l_X \bar{q} q \quad (X = e, \mu).(q = u, d, s).$$

  A is CP odd (pseudoscalar) Higgs bosons.
- The FCNC couplings are related to Flavor Changing Current in Charged Higgs (FCCC) interactions:

  $$\tau^- \to \nu_X H^- \to \nu_X K^- P^0.(X = e, \mu).(P^0 = \pi^0, \eta, \eta')$$

  H^- is charged Higgs boson.
- We study how large FCCC in the process $\tau \to K\pi^0\nu_X$ decay can be by considering the new limits on FCNC in charged lepton sector.

Experimental Limits on FCNC (Belle, Babar 2007)

Process	Belle[1](2007)	Babar[2] (2007)
$\tau \rightarrow e\pi^0$	0.8	1.4
$\tau \rightarrow \mu\pi^0$	1.2	1.1
$\tau \rightarrow e\eta$	0.92	1.9
$\tau \rightarrow \mu\eta$	0.65	1.3
$\tau \rightarrow e\eta'$	1.6	2.6
$\tau \rightarrow \mu\eta'$	1.3	2.0

Table: Upper limits on Branching fractions for $\tau \rightarrow l_x P^0$ decays: Unit$= 10^{-7}$.
[1] Y. Miyazaki et.al. (Belle) PLB 648,341 (2007). [2] B. Aubert et.al. (Babar) PRL 98,061803 (2007).

Constraints on FCNC couplings in two Higgs doublet model

Type III two Higgs doublet Model. Two VEVs of two Higgs is the origin of mass of leptons (m_l):

$$H_2 = e^{i\frac{\theta_{CP}}{2}} \begin{pmatrix} -\cos\beta H^+ \\ \frac{v_2+h_2-i\cos\beta A}{\sqrt{2}} \end{pmatrix}, \quad \tilde{H}_1 = i\tau_2 H_1^* = e^{-i\frac{\theta_{CP}}{2}} \begin{pmatrix} -\sin\beta H^+ \\ -\frac{v_1+h_1+i\sin\beta A}{\sqrt{2}} \end{pmatrix}.$$

$$-\mathcal{L} = y_{1ij}\overline{e_{Ri}}\tilde{H_1}^\dagger L_{Lj} + y_{2ij}\overline{e_{Ri}} H_2^\dagger L_{Lj} + \text{h.c.}.$$

$$m_l = V_R \frac{1}{\sqrt{2}}(-y_1 v_1 e^{i\frac{\theta_{CP}}{2}} + y_2 v_2 e^{-i\frac{\theta_{CP}}{2}}) V_L^\dagger$$

Neutral Higgs boson (A, h_1, h_2) couplings to leptons are not flavor diagonal.

$$\frac{g}{\sqrt{2}M_W} r_{2ij} m_{lj} = \left(V_L y_2^\dagger V_R\right)_{ij} e^{i\frac{\theta_{\rm CP}}{2}}$$

Relation between FCNC counpling and FCCC coupling

In general, FCNC couplings $r_{2ij} \neq 0$ may occur for neutral Higgs bosons (A,h_1, h_2) ($i, j = e, \mu, \tau$) (for $i \neq j$)

$$\mathcal{L}_{\rm NC} \quad = \quad -iA\frac{g}{2M_W}\{\frac{1}{\cos\beta}\overline{l_i}(m_l r_2^\dagger L - r_2 m_l R)_{ij} l_j + \tan\beta \overline{l_i} m_{li}\gamma_5 l_i\}$$

The FCNC couplings (r_{2ij}) of $l_j \to l_i A$ ($i \neq j$) are related to FCCC couplings $l_j \to \nu_i H^-$.

$$\mathcal{L}_{\rm CC} = \quad = \quad -\frac{g}{\sqrt{2}M_W} H^+ \overline{\nu_i}\{\delta_{ij}\tan\beta - \frac{r_{2ij}}{\cos\beta}\} m_{lj} R l_j$$

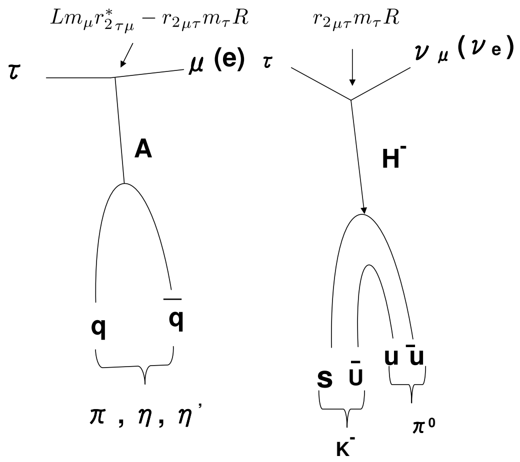


Figure: Lepton Flavor Violation due to Neutral Higgs (A) and Charged Higgs (H^-) exchanged processes

Constraints on FCNC couplings from $\tau \to l_X \pi^0$ decays.

Formulae for Branching fractions $l_X = e, \mu$.

$$Br(\tau \to l_X \pi^0) = \frac{p_{\pi^0}}{8\pi\Gamma_\tau}$$
$$\left(\frac{f m_{\pi^+}^2 m_\tau G_F}{\sqrt{2} M_A^2 \cos^2\beta}\right)^2 (\tan\beta\Delta_d - \cot\beta\Delta_u)^2$$
$$\{\frac{1+\delta_{l_X}^2 - \delta_{\pi^0}^2}{2}(|r_{2X\tau}|^2 + |r_{2\tau X}|^2 \delta_{l_X}^2) - \delta_{l_X}^2 (r_{2\tau X} r_{2X\tau} + h.c.)\}$$

$\delta_{lX} = \frac{m_{lX}}{m_\tau}$, $f =$ pion decay constant. $\Delta_{d(u)} = \frac{2m_{d(u)}}{m_u + m_d}$.
Requiring that the predictions are smaller than experimental upper limits:

$$Br(\tau \to l_X \pi^0) \leq Br^{\mathrm{UL}}_{\mathrm{exp.}},$$

the constraints on $|r_{2X\tau}|$ and $|r_{2\tau X}|$ can be obtained.

Allowed regions (shaded regions in figs.) on $(|r_{2X\tau}|, |r_{2\tau X}|)$ planes.

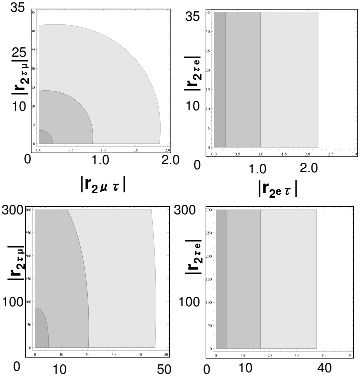


Figure: Upper panels from $\tau \to l_X \eta_8$ and down panels from $\tau \to l_X \pi^0$. $X = e$ for right. $X = \mu$ for left. $\tan\beta = 14.1$. M_A are $100, 200$ and 300 (GeV) from inner to outer.

Summary of the constraints

- $\tau \to l_X \eta$ gives more stringent constraint on $|r_{X\tau}|$ than that obtained from $\tau \to l_X \pi^0$. $\Delta_s \sim 26 > \Delta_d \sim 1.5, \Delta_u \sim 0.5$.

$$|r_{2\mu\tau}| < 0.9(\frac{M_A}{200})^2, |r_{2e\tau}| < 1(\frac{M_A}{200})^2,$$

$$Br(\tau \to l_X \pi^0) > \frac{p_{\pi^0}}{8\pi\Gamma_\tau} \left(\frac{f m_{\pi^+}^2 m_\tau G_F}{\sqrt{2} M_A^2 \cos^2\beta} \right)^2 (\tan\beta\Delta_d - \cot\beta\Delta_u)^2$$

$$\{\frac{1+\delta_{l_X}^2 - \delta_{\pi^0}^2}{2}(|r_{2X\tau}|^2 + |r_{2\tau X}|^2 \delta_{l_X}^2) - 2\delta_{l_X}^2 |r_{2\tau X} r_{2X\tau}|\}$$

$$Br(\tau \to l_X \eta_8) > \frac{p_\eta}{24\pi\Gamma_\tau} \left(\frac{f m_{\pi^+}^2 m_\tau G_F}{\sqrt{2} M_A^2 \cos^2\beta} \right)^2 (\tan\beta(\Delta_d - 2\Delta_s)$$

$$+ \quad \cot\beta\Delta_u)^2 \{\frac{1+\delta_{l_X}^2 - \delta_\eta^2}{2}(|r_{2X\tau}|^2 + |r_{2\tau X}|^2 \delta_{l_X}^2) - 2\delta_{l_X}^2 |r_{2\tau X} r_{2X\tau}|)\}$$

Predictions on charged current process

Hadron invariant mass $\sqrt{s}$ distribution for $\tau \to K^- \pi^0$.

$$\sum_{X=e,\mu,\tau} \frac{d\mathrm{Br}(\tau \to \nu_X K^- \pi^0)}{d\sqrt{s}} = \frac{1}{\Gamma} \frac{G_F^2 |V_{us}|^2}{2^5 \pi^3} \frac{(m_\tau^2 - s)^2}{m_\tau^3} p_K$$

$$\Bigg((\frac{2m_\tau^2}{3s} + \frac{4}{3}) {p_K}^2 |F|^2 + \frac{m_\tau^2}{2} |1 - \frac{s}{M_H^2} \tan^2\beta (1 - \frac{r_{2\tau\tau}}{\sin\beta})|^2 |F_s|^2$$

$$+ \frac{m_\tau^2}{2} (\frac{s \tan^2\beta}{M_H^2 \sin\beta})^2 (|r_{2e\tau}|^2 + |r_{2\mu\tau}|^2) |F_s|^2 \Bigg).$$

F vector form factor, F_s scalar form factor.
We will estimate both flavor conserving contribution $X = \tau$ and flavor changing contribution $X = \mu, e$.

Form Factors :Chiral Lagrangian with vector resonance

$$F = -\frac{1}{\sqrt{2}}\left(f_{+}^{\mathrm{CHPT}} + \frac{1}{2g^2f^2}\frac{(\delta A_K^*)^2}{M_V^2+\delta A_K^*}\right)$$

$$F_s = -\frac{\Delta_{K\pi}}{\sqrt{2}Q^2}\left(f_0^{\mathrm{CHPT}} + \frac{(\delta A_K^* + Q^2\delta B_K^*)^2}{2g^2f^2(M_V^2+\delta A_K^*+Q^2\delta B_K^*)}\right)$$

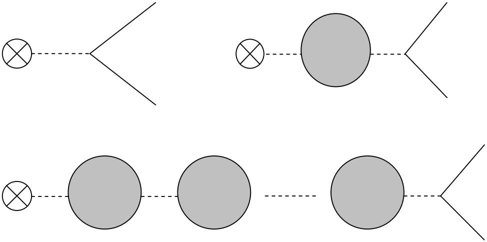
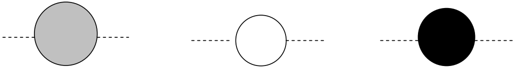


Figure: The form factor contribution from the self-energy of K^*. The self-energy corrections due to K, π, η mesons loop are summed as the dressed propagator.

Form factor calculation: continued



M_V : vector meson mass in chiral limit. δA and δB are chiral corrections to vector meson self energy including the finite counter terms of the Lagarangian (z_V, c_1, c_2).

$$[(M_V^2 + \delta A) g^{\mu\nu} + \delta B Q^\mu Q^\nu)] D_{\nu\rho} = \delta^\mu_\rho$$

$$\mathcal{L} = \mathcal{L}^{CHPT(0)} + M_V^2 \mathrm{Tr}(V_\mu - \frac{\alpha_\mu}{g})^2 + \mathcal{L}_c, \quad \alpha_\mu \sim \frac{1}{f^2}[\pi, \partial_\mu \pi]$$

$$\mathcal{L}_c = \mathcal{L}^{CHPT(2)} - \frac{Z_V}{2} \mathrm{Tr} F_{\mu\nu} F^{\mu\nu} + C_1 \mathrm{Tr}\left(\frac{\xi\chi\xi + \xi^\dagger \chi^\dagger \xi^\dagger}{2}\right)(V_\mu - \frac{\alpha_\mu}{g})^2 + C_2 \mathrm{Tr}\left(\frac{\xi\chi\xi + \xi^\dagger \chi^\dagger \xi^\dagger}{2}\right) \mathrm{Tr}(V_\mu - \frac{\alpha_\mu}{g})^2 .., \chi = \mathrm{diag.}(m_\pi^2, m_\pi^2, 2m_K^2 - m_\pi^2).$$

Predictions for Form factors

- Two on-shell conditions for ρ and K^* are imposed.
  $\rightarrow$ two relations among (M_V, z_v, c_1, c_2)
- The other parameter g is determined from Γ_{K^*} (or Γ_ρ).
- The counterterms $l_{9\mathrm{eff}}$ and l_5 in $\mathcal{L}^{CHPT(2)}$ are also determined from the slope parameter of K_{e3} decay and $\frac{F_K}{F_\pi}$.
- As a result, our form factors contain two undetermined parameters (M_V, z_v).

Comparison with the Belle Data

The prediction on hadron invariant mass spectrum using our form factors are compared with the data of $\tau \to K_s \pi^- \nu$ from Belle: Epifanov et.al.PLB,654,65(2007).

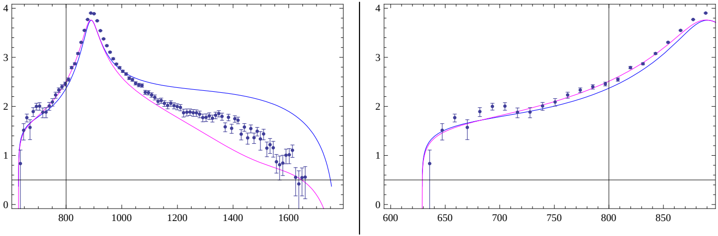
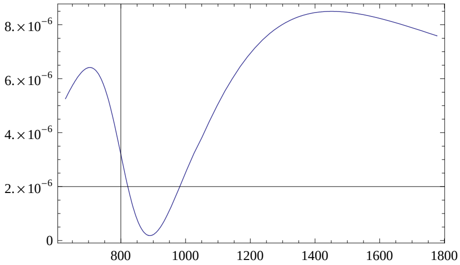


Figure: Hadronic Invariant mass spectrum for $\tau \to \nu K_s \pi^-$ decay. Vertical axis corresponds to Log_{10} N/11.5(MeV). Left:whole region. Right: $\sqrt{s} \leq M_{K^*}$. The parameters are chosen as $(M_V, z_v) = (700, 0.8)(Blue), (800, 0.7)(Purple)$

Effect of $|r_{X\tau}|$ $(X = e, \mu)$.

The ratio of flavor changing/flavor conserving$|_{\rm SM}$ is shown and it is tiny, i.e., O$(10^{-5}) \sim O(10^{-6})$ for the charged Higgs mass $M_H = 215(GeV)$, and flavor changing couplings, $r_{e\tau} = 0.9, r_{\mu\tau} = 1$, and $\tan\beta = 14.1$.

$$\frac{\sum_{X=e,\mu} \frac{dB_r(\tau \to K^- \pi^0 \nu_X)}{d\sqrt{s}}}{\frac{dB_r(\tau \to K^- \pi^0 \nu_\tau)}{d\sqrt{s}}}$$



Summary

- In type III, two Higgs doublet model, there is a relation between FCNC ($\tau \to \mu A$) for neutral Higgs and FCCC ($\tau \to \nu_\mu H^-$) for charged Higgs.
- We constrain the charged lepton sector flavor changing couplings $r_{x\tau}$ ($X = e, \mu$) using the experimental upper limits from $\tau \to l_X \eta(\pi^0)$. The most stringent limit is obtained from $\tau \to \mu(e)\eta$ and they constrain the couplings at the order of $1(\frac{M_A}{200(\mathrm{GeV})})^2$.
- Using the constraints, we estimate the flavor changing contribution to charged currents. $\tau \to \nu_X(X = e, \mu)H^-$. The ratio of the flavor changing part and conserving part is shown to be at most $O(10^{-5})$ and can be completely ignored.
- For the analysis of $\tau \to \nu_X K\pi$ decay, the new form factor is developped and it gives good description on the hadronic invariant mass spectrum. We compared it with the spectrum from Belle. ($\sqrt{s} \le M_K^*$).