Flavor changing amplitudes in the littlest Higgs model with T-parity

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Ref: T.Goto, Y.O. and Y.Yamamoto, “Ultraviolet divergences of flavor changing amplitudes in the little Higgs model with T-parity”
Phys. Lett. B 670 (2009) 378, arXiv:0809.4753 [hep-ph]

Flavor and Electroweak symmetry breaking

- There should be something new at the TeV scale which is related to physics of the electroweak symmetry breaking.
- How flavor observables are sensitive to new physics depends on scenarios.

  Tree vs. Loop

  Mass scale of new physics

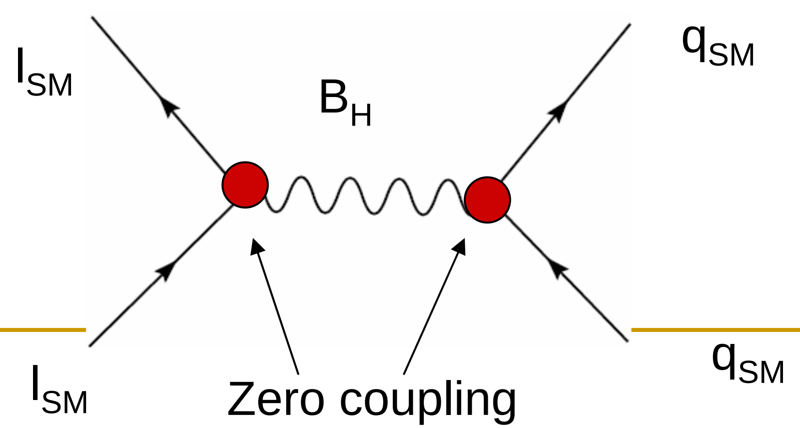
  New source of flavor mixing vs. MFV
- SM has special features on the flavor mixing through CKM (and PMNS) matrices.

Little Higgs Models with T parity

- The Higgs doublet field is a part of pseudo-NG bosons associated with a symmetry breaking dynamics at about 10 TeV.
- The quadratic divergence of the Higgs mass term is cancelled by extra-gauge bosons and a heavy top quark partner at the one loop level. (A solution to the “little hierarchy problem”)

N.Arkani-Hamed,A.G.Cohen, E.Katz, A.E.Nelson, T.Gregorie and J.G.Wacker,2002
N.Arkani-Hamed,A.G.Cohen, E.Katz,and A.E.Nelson,2002

- Electroweak precision measurements still put a strong constraints mostly due to tree-level exchange of extra-gauge bosons.
- The original model is extended to possess T-parity, so that no dangerous diagrams exist in terms of electroweak constraints. Masses of new particles can be below 1 TeV. C.H.Cheng and I.Low,2003



- We have reevaluated FCNC amplitudes in the Littlest Higgs Model with T-parity (LHT). We have found that the left-over logarithmic divergence is cancelled by new contributions due to an extra term in the Z-u_{HR} vertex.

- Content of this talk
  - Structure of LHT
  - FCNC amplitudes in LHT
  - Examples of numerical results of $B(K\text{->}\pi\nu\nu)$

The littlest Higgs Model with T-parity (LHT)

Electrorweak symmetry breaking

SU(5)/SO(5) non linear sigma model . Global SU(5) is broken to SO(5) by VEV of symmetric tensor Σ.

$$\Sigma = \xi \Sigma_0 \xi^T$$

$$\langle \Sigma \rangle = \Sigma_0 = \left(\begin{array}{cc|c|cc} 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ \hline 0 & 0 & 1 & 0 & 0 \\ \hline 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{array} \right)$$

f~O(1)TeV

24-10=14 Nambu-Goldstone bosons are expressed by

$$\xi = \exp(i\Pi/f)$$

SM Higgs doublet, H_{SM}

$$2\Pi = \left(\begin{array}{cc|c|cc} -\omega^0 - \frac{\eta}{\sqrt{5}} & -\sqrt{2}\omega^+ & -i\sqrt{2}\pi^+ & -i2\phi^{++} & -i\sqrt{2}\phi^+ \\ -\sqrt{2}\omega^- & \omega^0 - \frac{\eta}{\sqrt{5}} & h + i\pi^0 & -i\sqrt{2}\phi^+ & \sqrt{2}(\phi^P - i\phi^0) \\ \hline i\sqrt{2}\pi^- & h - i\pi^0 & \frac{4}{\sqrt{5}}\eta & -i\sqrt{2}\pi^+ & h + i\pi^0 \\ \hline i2\phi^{--} & i\sqrt{2}\phi^- & i\sqrt{2}\pi^- & -\omega^0 - \frac{\eta}{\sqrt{5}} & -\sqrt{2}\omega^- \\ i\sqrt{2}\phi^- & \sqrt{2}(\phi^P + i\phi^0) & h - i\pi^0 & -\sqrt{2}\omega^+ & \omega^0 - \frac{\eta}{\sqrt{5}} \end{array} \right)$$

T parity: $\Pi \rightarrow -\Omega\Pi\Omega : \Omega = diag(1, 1, -1, 1)$

Only H_{SM} is T-even.

Gauge symmetries

$$\text{global:} \quad SU(5) \overset{f}{\Rightarrow} SO(5)$$

$$\cup \qquad\qquad \cup$$

$$\text{gauged:} \quad [SU(2)\times U(1)]_1 \times [SU(2)\times U(1)]_2 \overset{f}{\Rightarrow} SU(2)\times U(1)$$

SM electroweak

SU(5) translation $\Sigma \to V \Sigma V^T$

Generators of gauge symmetries.

$$Q_1^a = \begin{pmatrix} \sigma^a/2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$Y_1 = \frac{1}{10}\begin{pmatrix} 3 & & & & \\ & 3 & & & \\ & & -2 & & \\ & & & -2 & \\ & & & & -2 \end{pmatrix}$$

$$Q_2^a = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\sigma^a * /2 \end{pmatrix}$$

$$Y_2 = \frac{1}{10}\begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix}$$

SM gauge symmetry : Q_1+Q_2, Y_1+Y_2

T parity: $g_1 = g_2, g'_1 = g'_2$

$$W_1, B_1 \leftrightarrow W_2, B_2$$

T-odd gauge bosons (W_H, Z_H,A_H) ~mass 0(f)
T-even gauge bosons = SM gauge bosons

Gauge-NG Lagrangian

$$\mathcal{L}_{\mathrm{NG}} = \frac{f^2}{8} \mathrm{tr}\left[(\mathcal{D}^\mu \Sigma^\dagger)(\mathcal{D}_\mu \Sigma)\right].$$

$$\mathcal{D}_\mu \Sigma = \partial_\mu \Sigma - i\left[g(\widehat{W}_\mu \Sigma + \Sigma \widehat{W}_\mu^T) + g'(\hat{B}_\mu \Sigma + \Sigma \hat{B}_\mu^T)\right]$$

Fermion sectors

In addition to the heavy top partner for the little Higgs mechanism, mirror fermions for SU(2) doublets have to be introduced to assign the T-parity.

$$q_1 = \begin{pmatrix} u_1 \\ d_1 \end{pmatrix}_L \qquad q_2 = \begin{pmatrix} u_2 \\ d_2 \end{pmatrix}_L$$

T-parity: $q_1 \leftrightarrow -q_2$

T-even $q_{SM} = \frac{1}{\sqrt{2}}(q_1 - q_2)$

T-odd $q_{HL} = \frac{1}{\sqrt{2}}(q_1 + q_2)$

Right –handed heavy doublet

In order to provide gauge-invariant mass terms for mirror quarks/leptons right-handed doublet fermions have to be introduced.

SU(5) embedding

$$\psi_1 = \begin{pmatrix} -i\sigma^2 q_1 \\ 0 \\ 0 \end{pmatrix}$$

$$\psi_2 = \begin{pmatrix} 0 \\ 0 \\ -i\sigma^2 q_2 \end{pmatrix}$$

$$\psi_R = \begin{pmatrix} * \\ * \\ -i\sigma^2 q_{HR} \end{pmatrix}$$

ψ_R 5 of SO(5) and non-linear rep.of SU(5)

$$\psi_R \to U\psi_R$$

$$\xi\psi_R \to V\xi U^\dagger U\psi_R = V\xi\psi_R$$

$$V \in SU(5), U(\Pi, V) \in SO(5)$$

Mirror fermion mass terms

T conjugate

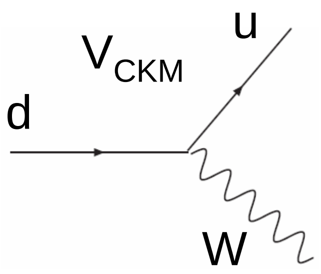
$$L_\kappa = -\kappa^{ij} f(\bar{\psi}_2{}^i \xi + \bar{\psi}_1{}^i \Sigma_0 \Omega \xi^\dagger \Omega)\psi_R^j + H.c.$$

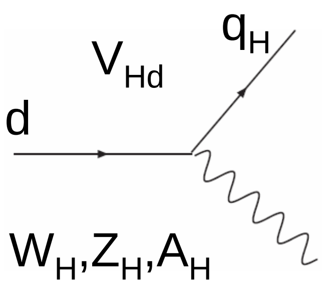
This terms gives 0(f) mass terms for mirror quark doublets.

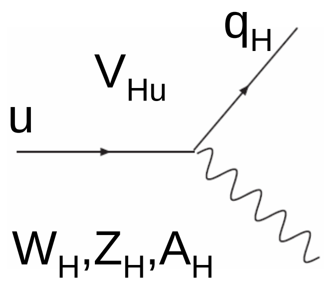
κ^{ij} is a new source of flavor mixing.

J.Hubisz,S.J.Lee,G.Paz, 2005

After diagonalization of the fermion mass matrices, flavor changing are induced in the gauge boson-fermion vertexes.







$$V_{Hu}^\dagger V_{Hd} = V_{CKM}$$

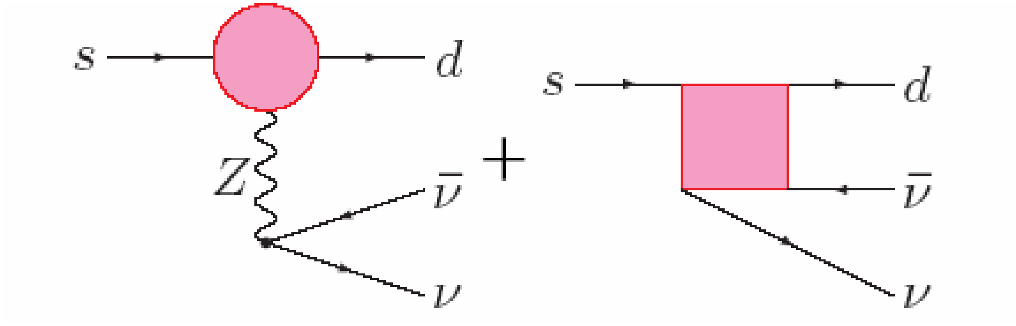
Out of three mixing matrices, two are independent.

Flavor changing amplitude at one loop

We have recalculated one loop Z penguin and box contributions in the 'tHooft-Feymman gauge.

Ref. M.Blanke et.al. 2006-2008

K-> π νν process



T-even contributions

SM + T even heavy top loop. Proportional to the SM CKM factor.

(MFV-type contribution)

$$\lambda_k = (V^*_{\rm CKM})_{ki}(V_{\rm CKM})_{kj}$$

T-odd contributions

Vanish at f-> infinity. Mirror fermion contributions should decouple in this limit.

$O(v^2/f^2)$ contributions can be sizable because they depend on a new mixing factor.

$$\xi_k = (V^*_{Hd})_{ki}(V_{Hd})_{kj}.$$

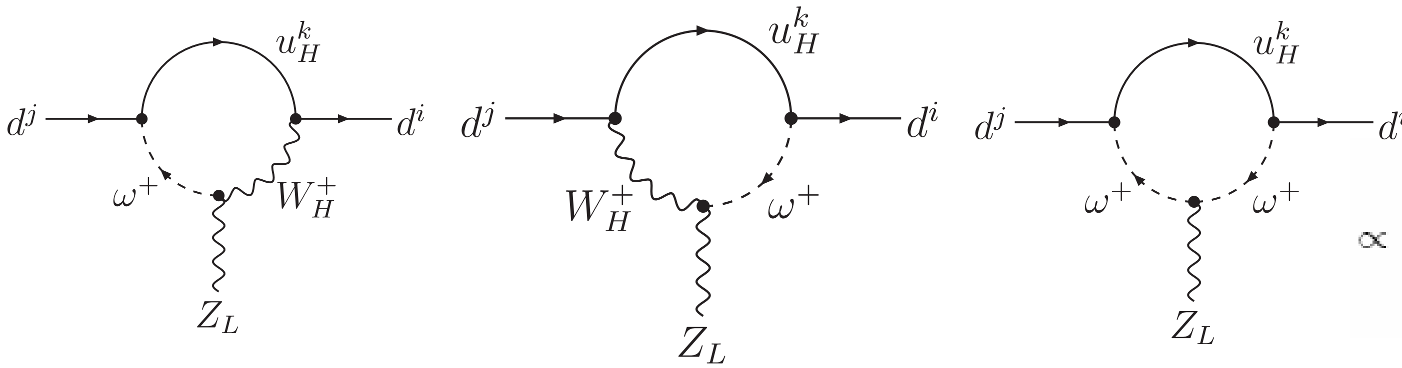
O(v^2/f^2) contributions come from expansion of $\xi = \exp(i\Pi/f)$ around the vacuum.

$$\frac{f^2}{8}\,\mathrm{tr}\left[(\mathcal{D}^\mu\Sigma^\dagger)(\mathcal{D}_\mu\Sigma)\right]$$

- Box diagrams: finite

- Z-penguin diagrams

$$\Sigma = \xi\Sigma_0\xi^T$$

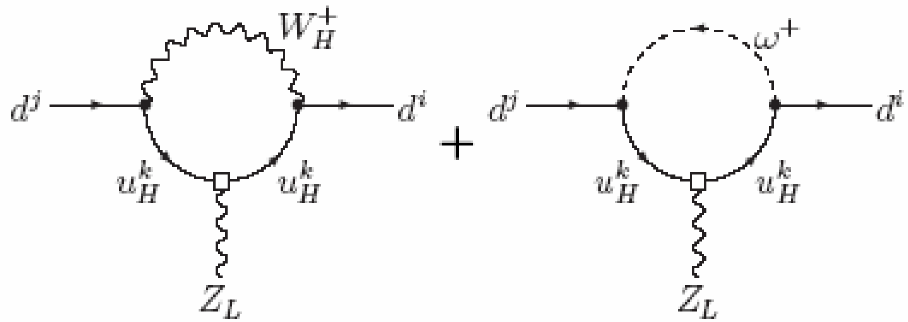


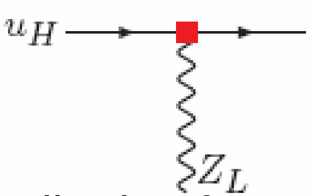
$$\propto \left(\cos^2\theta_W - \frac{v^2}{8f^2}\right)$$

The right diagram gives a logarithmic divergent contribution from the v^2/f^2 term .

M.Blanke, A.J.Buras, A.Poschenrieder, S.Recksiegel, C.Tarantino, S.Uhlig, and A.Weiler, 2007

A new $O(v^2/f^2)$ contribution from the Z-u_{HR} vertex.





$$\propto \gamma^\mu \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W - \frac{v^2}{8f^2}\frac{1+\gamma_5}{2} \right)$$

Extra contribution from the right diagram cancel the divergence.
Extra terms arise because u_{HR} is a part of non-linear representation of SU(5).

$$\psi'_R = \xi\psi_R$$

$$\begin{aligned}\mathcal{L}_{\text{kin}}(q_{HR}) &= \frac{1}{2}\overline{\Psi}'_R i\not{D}\Psi'_R + (\text{T-parity conjugate}) \\ &= \frac{1}{2}\overline{\Psi}_R\left[i\not{\partial} + \xi^\dagger(g\not{\widehat{W}} + g'\not{\widehat{B}}^{\Psi_R})\xi + (i\xi^\dagger\not{\partial}\xi)\right]\Psi_R + \text{T. c..}\end{aligned}$$

$d_j \to d_i\, \nu_l\, \nu_m$ amplitude

$$\mathcal{L}^{\rm eff}_{[d\nu]} = C^{ijlm}_{[d\nu]LL}(\bar{d}^i\gamma^\mu \mathbf{L} d^j)(\bar{\nu}^l\gamma_\mu \mathbf{L}\nu^m)$$

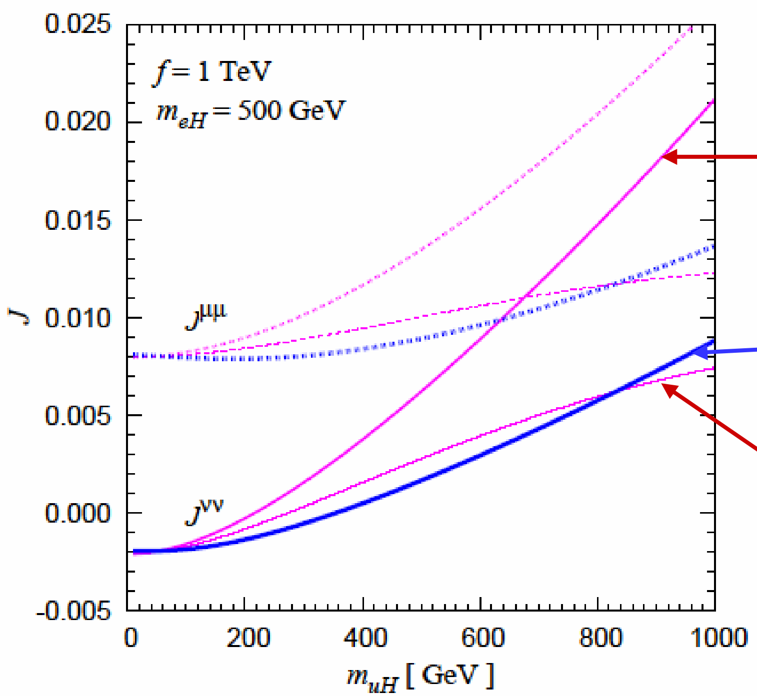
SM — T-even heavy top — T-odd

$$C^{ijlm}_{[d\nu]LL} = -\frac{g^4}{(4\pi)^2 m^2_{W_L}}\left[\delta_{lm}\left(\sum_k \lambda_k X_{\rm SM}(x_k) + \lambda_t \bar{X}_{\rm even}\right) + \sum_{k,n}\lambda^{H\nu}_n \xi_k J^{\nu\bar{\nu}}(z_k, y_n)\right]$$

$$x_k = m^2_{u^k}/m^2_{W_L},\ z_k = m^2_{u^k_H}/m^2_{W_H},\ y_n = m^2_{e^n_H}/m^2_{W_H}$$

$$\lambda_k = (V^*_{\rm CKM})_{ki}(V_{\rm CKM})_{kj} \qquad \xi_k = (V^*_{Hd})_{ki}(V_{Hd})_{kj}.$$

$$\lambda^{H\nu}_n = (V^*_{H\nu})_{nl}(V_{H\nu})_{nm}$$



Without the new contribution ($\Lambda=4\pi f$)

Full contribution

Drop the divergent term by hand

Example of numerical results.

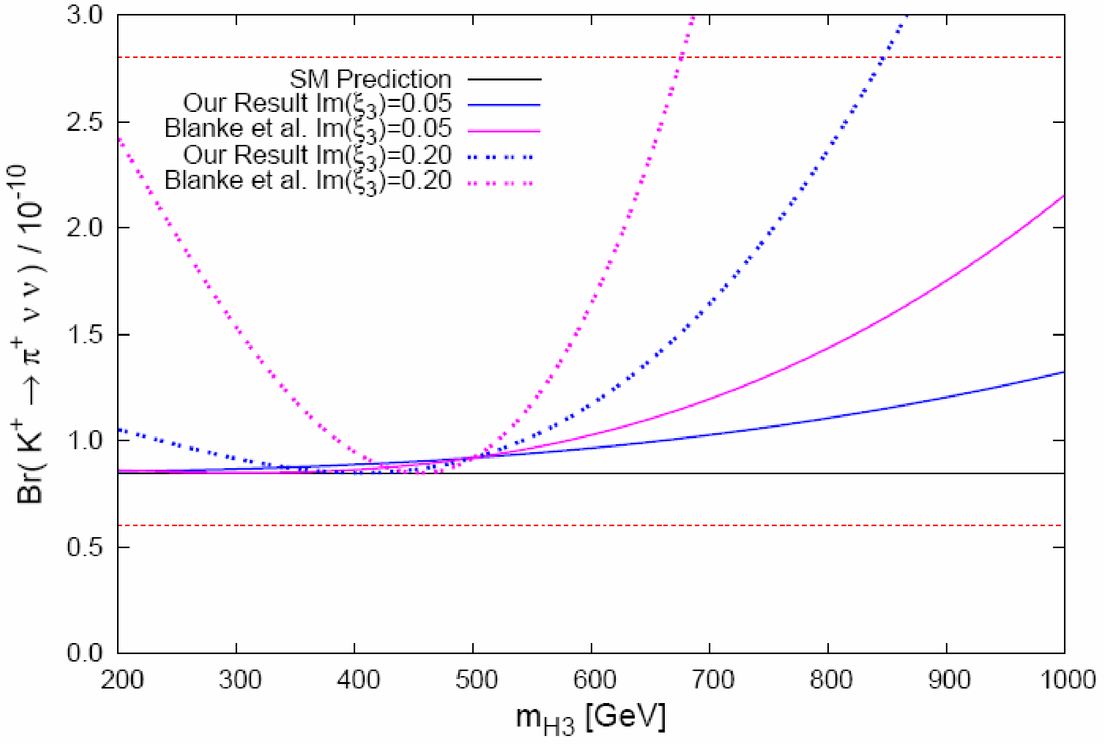
$f = 1\text{TeV},\ m_{T_+} = 1.34\text{TeV}$ $\quad m_{u_H^{1,2}} = m_{e_H^{1,2,3}} = 500\text{GeV}$

$\text{Re}[(V_{Hd})^*_{31}(V_{Hd})_{32}] = 0$

$\text{Br}(K^+ \to \pi^+ \nu \bar{\nu})$

Blue: full calculation

Red: without the new contribution

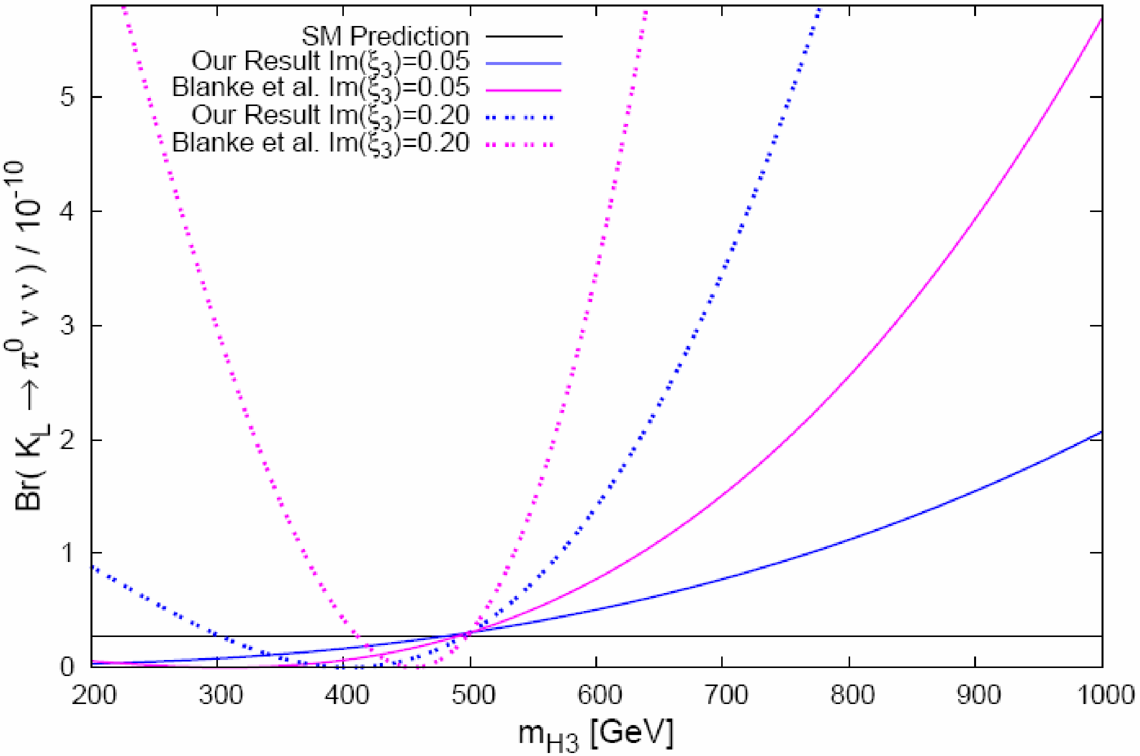


$\xi_3 = (V_{Hd})_{31}(V_{Hd})^*_{32},\ \text{Br(exp)} = (1.5^{+1.3}_{-0.9}) \times 10^{-10}.$

$\mathrm{Br}(K_L \to \pi^0 \nu \bar{\nu})$

Blue: full calculation

Red: without the new contribution



$\xi_3 = (V_{Hd})_{31}(V_{Hd})^*_{32}$, $\mathrm{Br(exp)} < 2.1 \times 10^{-7}$.

The deviation form the SM can be still large after canceling the divergence. More importantly, the FCNC process is predictable within the effective Lagrangian without reference to physics at the cutoff scale.

Summary

- We have reevaluated FCNC amplitudes in the Littlest Higgs model with T-parity, and found that there is no UV-cutoff dependence.
- The branching ratios of K->$\pi\nu\nu$ processes can be significantly different from the SM predictions in this model.

The absence of the divergence is confirmed by a recent paper on LFV in LHT .

F. del Aguila, J.I.Illana, and M.D. Jenkins, JHEP01 (2009) 080
arXiv:0811.2891[hep-ph]