Flavor Physics in the Littlest Higgs with T-Parity

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"Particle Physics at the Energy Frontier of New Phenomena"

SuperB Physics Workshop
University of Warwick
April 15th 2009

Outline

Literature

Flavor violation in the quark sector

- Hubisz, Lee, Paz, hep-ph/0512169
- Blanke, Buras, Poschenrieder, Tarantino, Uhlig, Weiler, hep-ph/0605214
- Blanke, Buras, Poschenrieder, Recksiegel, Tarantino, Uhlig, Weiler, hep-ph/0609284, hep-ph/0610298
- Blanke, Buras, Recksiegel, Tarantino, Uhlig, hep-ph/0703254, 0704.3329
- Blanke, Buras, Recksiegel, Tarantino, 0805.4393
- Goto, Okada, Yamamoto, 0809.4753
- Blanke, Buras, BD, Recksiegel, Tarantino, 0904.soon

Lepton flavor violation

- Choudhury, Cornell, Deandrea, Gaur, Goyal, hep-ph/0612327
- Blanke, Buras, BD, Poschenrieder, Tarantino,hep-ph/0702136
- del Aguila, Illana, Jenkins, 0811.2891
- Blanke, Buras, BD, Recksiegel, Tarantino, 0904.soon

The Littlest Higgs Model with T-Parity

Arkani-Hamed, Cohen, Georgi, hep-th/0104005, hep-ph/0105239
Arkani-Hamed, Cohen, Katz, Nelson, hep-ph/0206021
Cheng, Low, hep-ph/0308199, hep-ph/0405243

Little Higgs Idea

Higgs boson as a **pseudo-Goldstone boson**

- **collective symmetry breaking** explains smallness of its mass

- **global $SU(5)$** broken spontaneously to $SO(5)$ at scale $f \sim 1\,\mathrm{TeV}$
- gauged subgroup $[SU(2) \times U(1)]^2 \longrightarrow SU(2)_L \times U(1)_Y$
- new heavy gauge bosons $W_H^\pm, Z_H, A_H$ and heavy scalar triplet Φ
- top quadratic divergence cancelled by new heavy quark **T**

T-parity

Discrete symmetry, under which new particles are odd

- analogous to R-parity in SUSY
- **no tree level contributions** to EW precision observables
- lightest T-odd particle (A_H) stable: **dark matter candidate** (?)

Fermion Content of the LHT Model

- **T-even quark sector**:

$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \end{pmatrix}_L \quad \begin{pmatrix} t \\ b \end{pmatrix}_L \quad \begin{matrix} u_R \\ d_R \end{matrix} \quad \begin{matrix} c_R \\ s_R \end{matrix} \quad \begin{matrix} t_R \\ b_R \end{matrix} \quad T_+$$

  - **standard CKM mixing** + mixing of T_+ with t

- **T-odd mirror quark sector**: Low, hep-ph/0409025

$$\begin{pmatrix} u_H \\ d_H \end{pmatrix} \quad \begin{pmatrix} c_H \\ s_H \end{pmatrix} \quad \begin{pmatrix} t_H \\ b_H \end{pmatrix} \quad T_-$$

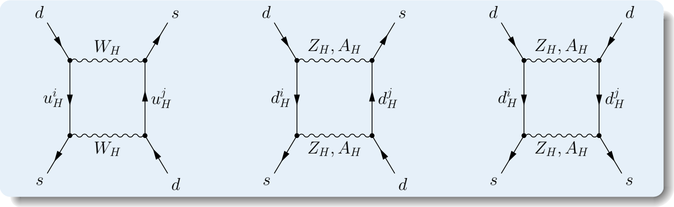
  - **new CKM-like mixing matrices V_{Hu}, V_{Hd}** parameterizing mirror quark interactions with SM quarks

- **Lepton sector**:
  SM leptons + mirror leptons, analogous to quark sector

Flavor Violation in the LHT Model

Hubisz, Lee, Paz, hep-ph/0512169; BBPTUW, hep-ph/0605214
BBPRTUW, hep-ph/0609284

- **T-even sector:** contributions of T_+ (CMFV)
  - **small effects** ($\lesssim$ 20%)
- **T-odd sector:** heavy gauge bosons & mirror fermions



  - contribution at the **loop level** (T-parity forbids tree level effects)
  - **new sources of flavor and CP-violation** (V_{Hd})
  - potentially **large effects**
  - but **no new operators** (only LH couplings)

Basic Structure of LHT Decay Amplitudes

$$\mathcal{A}_{\text{LHT}} = \sum_i B_i^{\text{SM}} \eta_i^{\text{QCD}} \Big[\overbrace{\underbrace{\lambda^i_{\text{CKM}} F_i(m_i, m_{T_+}, \ldots)}}^{\text{T-even sector}} + \overbrace{\xi^i_{V_{Hd}} \underbrace{G_i(m^i_H, M_{W_H})}}^{\text{T-odd sector}} \Big]$$

real & flavor universal loop functions

- **T-even sector**: CMFV
- **T-odd sector**:
  - **new sources of flavor & CP-violation** ($\xi^i_{V_{Hd}}$)
  - but **only SM operators** (pure V-A couplings)

$\Rightarrow$ **specific pattern of flavor violation**

Very different from **RS models** ($\longrightarrow$ talk by K. Gemmler) that have

- new sources of flavor violation
- new operators
- tree-level FCNCs

Naive Expectations for K and B Physics

BBPRTUW, hep-ph/0610298

relative size of LHT effects: $\propto \frac{1}{\lambda^i_{\text{CKM}}} \xi^i_{V_{Hd}}$

$$\frac{1}{\lambda_t^{(K)}} \simeq 2500 \quad \gg \quad \frac{1}{\lambda_t^{(d)}} \simeq 100 \quad > \quad \frac{1}{\lambda_t^{(s)}} \simeq 25$$

- **largest effects in K** physics observables
- **moderate effects in $B_{d,s}$** physics observables
- but pattern may be reversed by specific hierarchies in $\xi^i_{V_{Hd}}$

The Issue of Divergences

LH without T-parity

Buras, Poschenrieder, Uhlig, Bardeen, hep-ph/0607189

Z penguin contains left-over singularity

$\Rightarrow$ reflects **sensitivity to the UV completion**

Similar effect also encountered in LHT BBPRTUW, hep-ph/0610298

However: Goto, Okada, Yamamoto, 0809.4753
del Aguila, Illana, Jenkins, 0811.2891

- additional contribution to Z penguin
- singularity exactly cancelled
- **FCNC amplitudes in LHT fully calculable!**

modified predictions for decays mediated by Z penguins
(e. g. $K \to \pi\nu\bar{\nu}$, $\mu \to eee$) ($\to$ **numerical update**) BBDRT, 0904.soon
but **no impact** on $P - \bar{P}$ mixing, $\mu \to e\gamma, \ldots$!

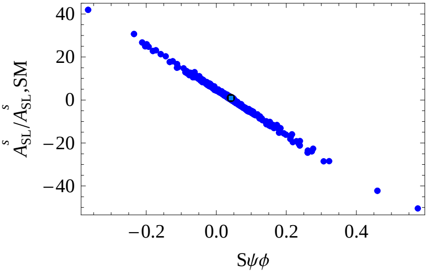
CP-Violation in $B_s - \bar{B}_s$ Mixing

BBPTUW, hep-ph/0605214; BBRT, 0805.4393; BBDRT, 0904.soon

Generally: LHT effects in B physics expected to be small

but: CP-violation in B_s extremely suppressed in the SM due to $\beta_s \simeq -1^\circ$

$\Rightarrow$ **large LHT effects** in B_s still possible!

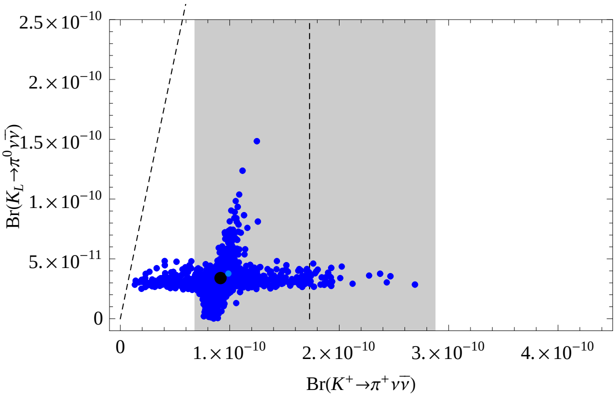


- $S_{\psi\phi} \sim 0.5$ possible
- naturally, $S_{\psi\phi} \lesssim 0.2$
- strong correlation with A^s_{SL}

Ligeti et al., hep-ph/0604112

The $K \to \pi\nu\bar{\nu}$ System

BBDRT, 0904.soon

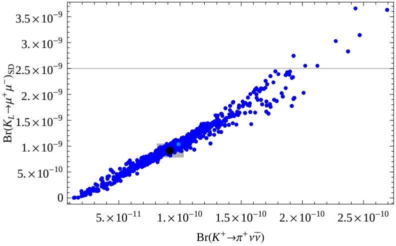


- **factor 2–3 enhancements** of $K \to \pi\nu\bar{\nu}$ possible
- **strict correlation** (two branches of possible points)

Correlations between Rare K Decays

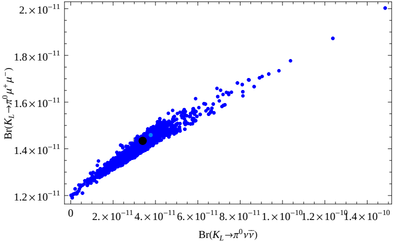
$K_L \to \mu^+\mu^-$ vs $K^+ \to \pi^+\nu\bar{\nu}$

(CP conserving)



$K_L \to \pi^0\mu^+\mu^-$ vs $K_L \to \pi^0\nu\bar{\nu}$

(CP violating)



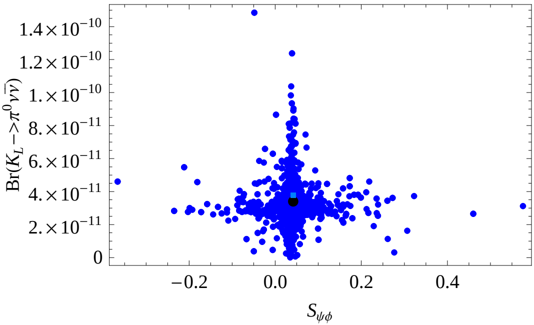
Strong linear correlation in both cases

BBDRT, 0904.soon

- **V-A structure** of flavor violating coupling ($K_L \to \mu^+\mu^-$ vs. $K^+ \to \pi^+\nu\bar{\nu}$)
- **universality of CP-phases** ($K_L \to \pi^0\mu^+\mu^-$ vs. $K_L \to \pi^0\nu\bar{\nu}$)

K Physics vs B Physics

BBDRT, 0904.soon



simultaneous large effects in $S_{\psi\phi}$ and rare K decays **unlikely**, but not impossible

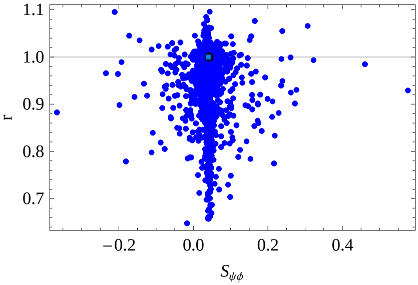
Violation of the Golden CMFV Relation

$$\frac{Br(B_s \to \mu^+\mu^-)}{Br(B_d \to \mu^+\mu^-)} = \frac{\hat{B}_{B_d}}{\hat{B}_{B_s}} \frac{\tau_{B_s}}{\tau_{B_d}} \frac{\Delta M_s}{\Delta M_d} \, r$$

Buras, hep-ph/0303060

r $\neq$ **1** signals

- **new sources of flavor violation** or
- new operators



BBDRT, 0904.soon

LHT Pattern of Flavor Violation

...and a comparison to the RS model with custodial symmetry

LHT	**RS-Custodial**
large effects in rare **K** decays	✓
moderate effects in **B** physics	∼
exception: $S_{\psi\phi} \lesssim 0.4$	∼
but **not simultaneously** with large K effects	✓
$K \longrightarrow \pi\nu\bar{\nu}$ system: strict correlation	×
$K_L \longrightarrow \mu^+\mu^-$ & $K^+ \to \pi^+\nu\bar{\nu}$: linear correlation	×

$\Rightarrow$ **Both K and B physics allow for a distinction!**

LFV Mediated by Mirror Leptons

- **SM (plus right-handed Dirac neutrinos)**:
  LFV strongly suppressed due to smallness of m_ν

$$Br(\mu \to e\gamma)_{\text{SM}} \lesssim 10^{-54}$$

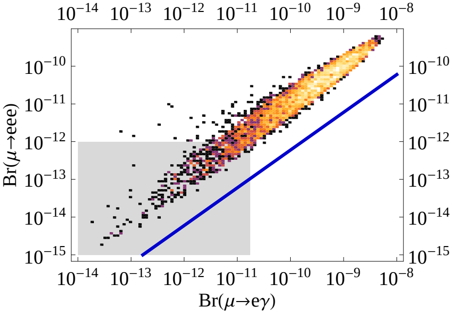
- **LHT**: LFV mediated by mirror leptons, $m_H^\ell \sim 500\,\text{GeV}$
  large effects can be expected
- **experimental bound:** (MEGA collaboration)

$$Br(\mu \to e\gamma)_{\text{exp}} < 1.2 \cdot 10^{-11} \qquad (90\%\ \text{C.L.})$$

  will be improved to $\sim \mathbf{10^{-13}}$ by MEG soon
- experimental prospects also for τ decays (SuperB, LHCb)

$\mu \to e\gamma$ and $\mu \to eee$

BBDRT, 0904.soon



Red/yellow points: **LHT**

Blue line: **MSSM**

- most points exceed experimental bounds

del Aguila, Illana, Jenkins, 0811.2891

$\Rightarrow \sim$ **10% fine-tuning** in mirror lepton parameters required

- **strong correlation** between $\mu \to e\gamma$ and $\mu^- \to e^- e^+ e^-$
- **dipole contribution** fully negligible unlike in the **MSSM**

LHT Upper Bounds on LFV Branching Ratios

...after imposing all available constraints

BBDRT, 0904.soon

	$f = 1\,\mathrm{TeV}$	$f = 0.5\,\mathrm{TeV}$	SuperB
$\tau \to \ell\gamma$	$8 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
$\tau \to \ell\ell\ell$	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
$\tau \to \ell\pi$	$4 \cdot 10^{-10}$	$2 \cdot 10^{-8}$	?
$\tau \to \ell\eta$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-10}$
$\tau \to \ell\eta'$	$1 \cdot 10^{-10}$	$1 \cdot 10^{-8}$	?
$\dots$	$\dots$	$\dots$	$\dots$

For $f \lesssim 1\,\mathrm{TeV}$:

LHT effects may be observable at future facilities!

Correlations and Comparison with Supersymmetry

MSSM: dipole operator **dominates** in decays $\ell_i \to \ell_k \ell_k \ell_k$, $\ell_i \to \ell_j \ell_k \ell_k$

Ellis, Hisano, Raidal, Shimizu, hep-ph/0206110
Brignole, Rossi, hep-ph/0404211
Arganda, Herrero, hep-ph/0510405
Paradisi, hep-ph/0508054, hep-ph/0601100

$$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu \to e\gamma)} \simeq \frac{\alpha}{3\pi}\left(\log\frac{m_\mu^2}{m_e^2} - 2.7\right)$$

$$\frac{Br(\tau^- \to \ell^- e^+ e^-)}{Br(\tau \to \ell\gamma)} \simeq \frac{\alpha}{3\pi}\left(\log\frac{m_\tau^2}{m_e^2} - 2.7\right)$$

$$\frac{Br(\tau^- \to \ell^- \mu^+ \mu^-)}{Br(\tau \to \ell\gamma)} \simeq \frac{\alpha}{3\pi}\left(\log\frac{m_\tau^2}{m_\mu^2} - 2.7\right)$$

LHT: dipole operator **irrelevant**, decays dominated by Z^0-penguin and box diagrams

BBDPT, hep-ph/0702136

$\Rightarrow$ **Very different pattern!**

Ratios of LFV Branching Ratios

BBDRT, 0904.soon

	LHT	MSSM
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$ $\star$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$ $\star$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$

$\star$ can be significantly enhanced by Higgs contributions

Paradisi, hep-ph/0508054, hep-ph/0601100

Summary

LHT in K and B physics

- **large effects** possible in B_s **CP-violation** and **rare K decays**
- **moderate effects** in most **B physics** observables
- specific **correlations** allow for **distinction from other NP frameworks** (CMFV, RS-Custodial, ...)

LHT and lepton flavor violation

- **large effects** expected in **LFV μ and τ decays**
- **ratios** of branching ratios very **different from SUSY**

- Flavor physics **complementary** to collider physics in unravelling the nature of new physics
- SuperB facility can significantly contribute to that aim