Flavour in the Littlest Higgs with T-Parity

Confronting other New Physics Scenarios

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Outline

1. **Little Higgs Basics**
2. **FCNC Processes in the Littlest Higgs with T-Parity**
   - Flavour Structure
   - K and B Physics Observables
   - Comparison with the RS-Custodial Results
3. **Lepton Flavour Violation**
   - Little Higgs Results
   - Comparison with Supersymmetry
4. **Conclusions**

Some Literature

Flavour violation in the quark sector

- Hubisz, Lee, Paz, hep-ph/0512169
- MB, Buras, Poschenrieder, Tarantino, Uhlig, Weiler, hep-ph/0605214
- MB, Buras, Poschenrieder, Recksiegel, Tarantino, Uhlig, Weiler, hep-ph/0609284, hep-ph/0610298
- MB, Buras, Recksiegel, Tarantino, Uhlig, hep-ph/0703254, 0704.3329
- MB, Buras, Recksiegel, Tarantino, 0805.4393
- Goto, Okada, Yamamoto, 0809.4753
- MB, Buras, Duling, Recksiegel, Tarantino, 0903.xxxx

Lepton flavour violation

- Choudhury, Cornell, Deandrea, Gaur, Goyal, hep-ph/0612327
- MB, Buras, Duling, Poschenrieder, Tarantino,hep-ph/0702136
- del Aguila, Illana, Jenkins, 0811.2891
- MB, Buras, Duling, Recksiegel, Tarantino, 0903.xxxx

The Littlest Higgs Model with T-Parity

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 $f \sim 1\,\text{TeV}$
- gauged subgroup $\mathbf{[SU(2) \times U(1)]^2 \longrightarrow SU(2)_L \times U(1)_Y}$
- new heavy gauge bosons $\mathbf{W_H^\pm}$, $\mathbf{Z_H}$, $\mathbf{A_H}$ and heavy scalar triplet $\mathbf{\Phi}$
- 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** (?)

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

Fermions in 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

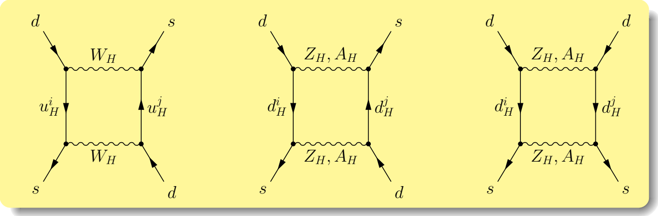
$$\begin{pmatrix} u_H \\ d_H \end{pmatrix} \quad \begin{pmatrix} c_H \\ s_H \end{pmatrix} \quad \begin{pmatrix} t_H \\ b_H \end{pmatrix} \quad T_-$$

  ➢ **new CKM-like mixing matrices $\mathbf{V_{Hu}}$, $\mathbf{V_{Hd}}$** parameterising mirror quark interactions with SM quarks

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

LHT Flavour Violation

- **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)
  - ➢ **new sources of flavour and CP-violation** (V_{Hd})
  - ➢ but **no new operators** (only LH couplings)
  - ➢ potentially **large effects**

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

Basic Structure of LHT Decay Amplitudes

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

real & flavour universal loop functions

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

↓

specific pattern of flavour violation

recall: RS-Custodial → SEE AJB'S TALK

- new sources of flavour & CP-violation
- new operators
- tree level FCNCs

Naïve Expectations for K and B Physics

BBPRTUW, HEP-PH/0610298

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

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

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

Logarithmically Enhanced Cutoff-Dependence?

LH without T-parity: Z penguin contains left-over singularity

- reflects **sensitivity to the UV completion**

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

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 identified
- singularity exactly cancelled
- **FCNC amplitudes in LHT fully calculable!**

→ see talk by Y. Okada

modified predictions for decays mediated by Z penguins
(e. g. $K \to \pi\nu\bar{\nu}$, $\mu \to eee$) ➢ **numerical update**   BBDRT, 0903.xxxx
but no impact on $P - \bar{P}$ mixing, $\mu \to e\gamma, \ldots$!

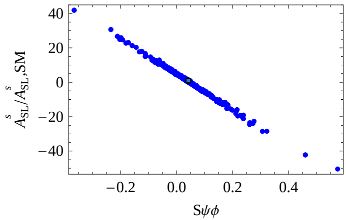
CP-Violation in $B_s - \bar{B}_s$ Mixing

BBPTUW, hep-ph/0605214; BBRT, 0805.4393; BBDRT, 0903.xxxx

generally: LHT effects in B physics expected to be small

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

➢ **large LHT effects** possible

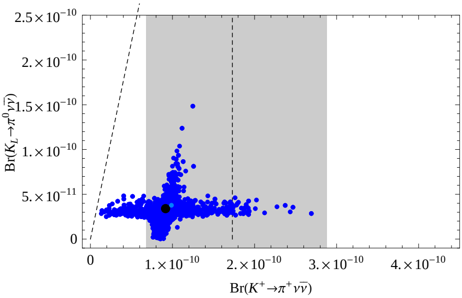


- $S_{\psi\phi} \sim 0.5$ possible
- naturally $S_{\psi\phi} \lesssim 0.2$
- strong correlation with A^s_{SL}

Ligeti et al., hep-ph/0604112

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

BBDRT, 0903.xxxx

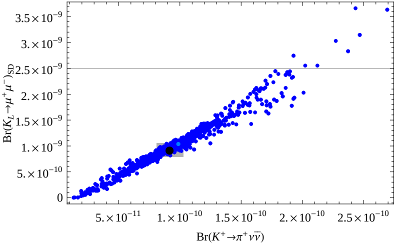


- **factor 2–3 enhancements** of $K \to \pi\nu\bar{\nu}$ possible
- **strict correlation** (two branches of possible points)
  - ➢ **equal CP-phases** in $K^0 - \bar{K}^0$ and $K \to \pi\nu\bar{\nu}$

Correlations between Various Rare K Decays

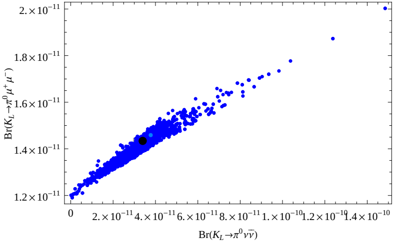
$K_L \to \mu^+\mu^-$ vs. $K^+ \to \pi^+\nu\bar{\nu}$

(CP-conserving)



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

(CP-violating)

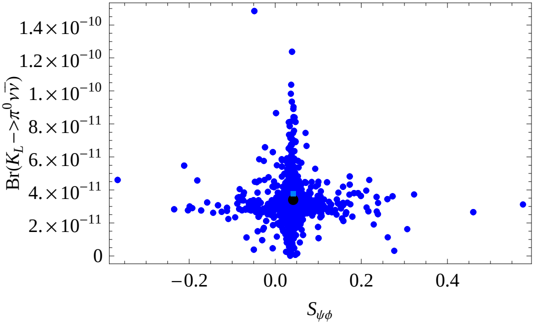


strong linear correlation in both cases BBDRT, 0903.xxxx

- **V-A structure** of flavour 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 versus B Physics

BBDRT, 0903.xxxx



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

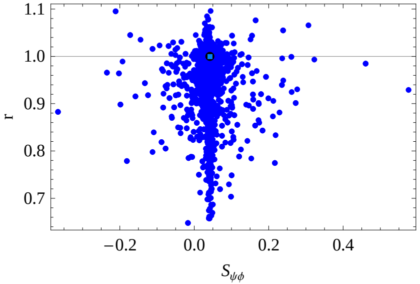
Violation of a "Golden" CMFV Relation

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

Buras, hep-ph/0303060

r $\neq$ **1** signals

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



BBDRT, 0903.xxxx

LHT Pattern of Flavour Violation

LHT	RS-Custodial
large effects in rare **K** decays	$=$
moderate effects in **B** physics	$\simeq$
exception: $\mathbf{S}_{\psi\phi} \lesssim \mathbf{0.4}$	$\neq$
but **not simultaneously** with large K effects	$=$
$\mathbf{K} \longrightarrow \pi\nu\bar{\nu}$ system: strict correlation	$\neq$
$\mathbf{K_L} \longrightarrow \mu^+\mu^-$ **&** $\mathbf{K}^+ \longrightarrow \pi^+\nu\bar{\nu}$: linear correlation	$\neq$

➢ **both K and B physics offer powerful tools to distinguish between these two models!**

LFV Mediated by Mirror Leptons

- **SM (+right-handed Dirac neutrinos):**
  LFV very much 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)

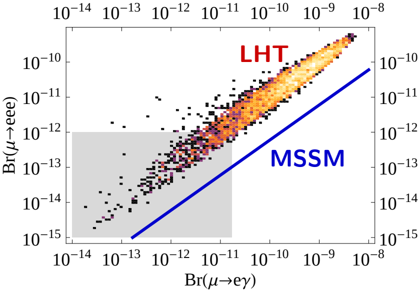
$$Br(\mu \to e\gamma)_{\text{exp}} < 1.2 \cdot 10^{-11} \qquad (90\%\ \text{C. L.})$$

  will be improved to $\sim \mathbf{10^{-13}}$ by MEG soon

- experimental prospects also for τ decays (LHCb, SuperB)

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

BBDRT, 0903.xxxx



- most points exceed experimental bounds :
  $\sim$ **10% fine-tuning** in mirror lepton parameters required

  del Aguila, Illana, Jenkins, 0811.2891
- **strong correlation** between $\mu \to e\gamma$ and $\mu^- \to e^- e^+ e^-$
- **dipole contribution** fully negligible $\neq$ **MSSM**

LHT Upper Bounds on LFV Branching Ratios

after imposing all available constraints: BBDRT, 0903.xxxx

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

for $f \lesssim 1$ TeV: **LHT effects may be observable at future facilities**

Correlations and Comparison with Supersymmetry

MSSM: dipole operator **dominates** 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

➢ **very different pattern!**

Ratios of LFV Branching Ratios

BBDRT, 0903.xxxx

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

❇ can be significantly enhanced by Higgs contributions

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

Summary – Grand Picture of LHT Flavour Violation

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 flavour violation

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

➢ **Flavour physics complementary to collider physics for disentangling the nature of NP**