Lepton Flavour Violation in the Littlest Higgs Model with T-Parity (LHT)

1. <u>Some Notions about Little Higgs Models</u>

2. <u>Lepton Flavour Violating Decays in LHT</u>

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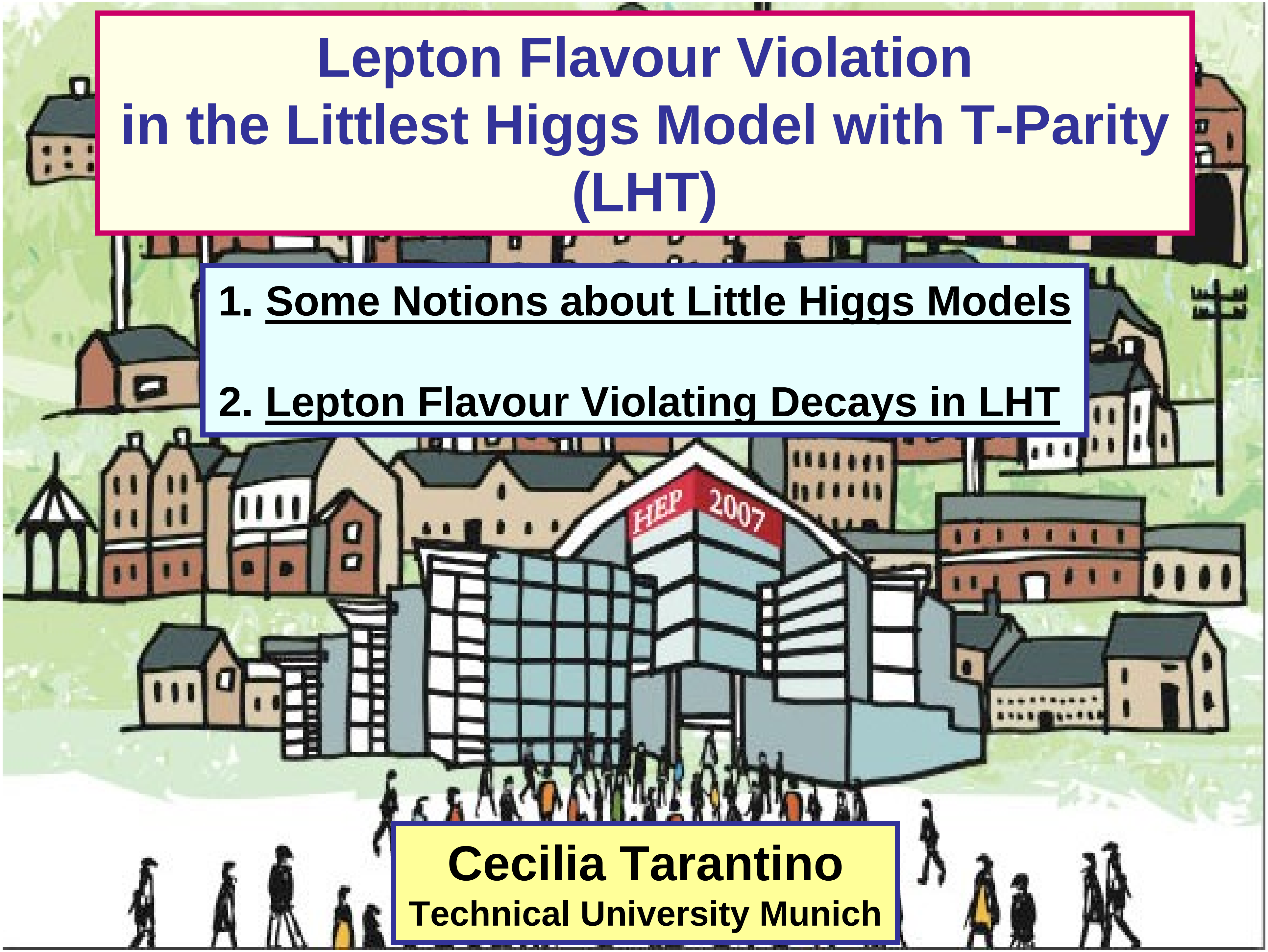


A brief theoretical introduction…

The Little Hierarchy Problem

``New Physics (NP) at 1 TeV is expected but its effects are not observed´´

From the instability of the Higgs mass

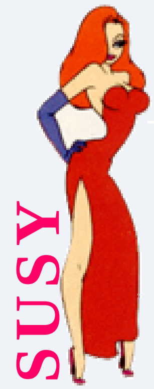
Parameterizing NP by higher-dimensional operators suppressed by the NP scale Λ:

$(h^\dagger D_\mu h)^2/\Lambda^2$, $(D^2 h^\dagger D^2 h)/\Lambda^2$,…

Ew precision tests yield $\Lambda \geq$5-10TeV

Little Higgs Models can stabilize the Higgs mass without violating this bound!

SUSY vs Little Higgs



Problematic quadratic divergences in m_H^2

	SUSY	Little Higgs
Quadratic divergences canceled by:	(different statistics) super-partners	(same statistics) heavy partners
Coupling relationships due to:	boson-fermion symmetry	global symmetry

More formally, in Little Higgs Models:
[N. Arkani-Hamed, A.G. Cohen, H. Georgi (2001)]

1. The Higgs is light as it is the Goldstone boson of a spontaneously broken global symmetry (G)

2. Gauge and Yukawa couplings of the Higgs are introduced by gauging a subgroup of G

3. ``Dangerous´´ quadratic corrections are avoided at one-loop through Collective Symmetry Breaking
   (the Higgs becomes massive only when two couplings are non-vanishing)

The most economical in matter content: Littlest Higgs (LH)

[N. Arkani-Hamed, A.G. Cohen, E. Katz, A.E. Nelson (2002)]

Global Spontaneous SB: $SU(5) \xrightarrow[f \approx O(1TeV)]{} SO(5)$

Gauging: $[SU(2) \otimes U(1)]_1 \otimes [SU(2) \otimes U(1)]_2 \xrightarrow[f]{} SU(2)_L \otimes U(1)_Y$

(g_1) (g'_1) (g_2) (g'_2)

Collective SB: $\delta m_H^2 \propto g_1^{(\prime)2} g_2^{(\prime)2}$

UV-cutoff $\Lambda = (4\pi f)$

New Heavy Particles (with O(f) masses)

Gauge Bosons: $W^{\pm}_H$, Z^0_H, A^0_H

Fermions: T

Scalars: Φ(triplet)

Electroweak (ew) precision tests

Tree-level heavy gauge boson contributions and the triplet Φ vev make ew precision tests highly constraining

[Han, Logan, McElrath, Wang (2003)]

[Csaki, Hubisz, Kribs, Meade, Terning (2003)]

⇒ $f \geq 2\text{-}3$ TeV

The little hierarchy problem is back!

The solution comes from a discrete symmetry:

T-Parity [H.C. Cheng, I. Low (2003)]

Symmetry under $[SU(2) \otimes U(1)]_1 \leftrightarrow [SU(2) \otimes U(1)]_2$

⇔ $g_1 = g_2$ $g'_1 = g'_2$

T-parity forbids the unwanted contributions:

- SM particles are T-even,
- new particles are T-odd

(similarly to R-parity in SUSY)

smaller f allowed by ew tests

[Hubisz,Meade,Noble,Perelstein (2005)]

⇓

$f \geq 500$ GeV

The Littlest Higgs Model with T-Parity (LHT)

Dark Matter candidate

T-even Sector:

SM Particles + T_+

T-odd Sector:

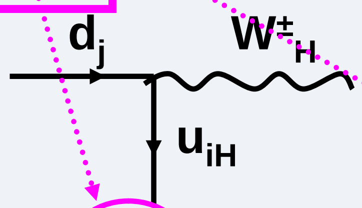
Gauge Bosons: $W^{\pm}_H$, Z^0_H, A^0_H

Fermions: T_-, Mirror Fermions (f_H)

Scalars: Φ

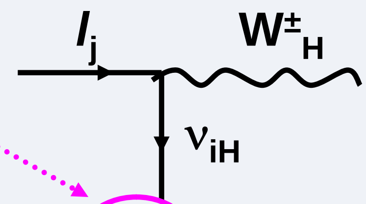
with NEW flavour interactions

New mixing matrices in addition to V_{CKM} and V_{PMNS}



$\sim (V_{Hd})_{ij}\,\gamma_\mu\,(1-\gamma_5)$

Quark Sector



$\sim (V_{Hl})_{ij}\,\gamma_\mu\,(1-\gamma_5)$

Lepton Sector

New parameters of the LHT model:

Global symmetry breaking scale: f ~ 1TeV

1 parameter describing the T_+: x_L

V_{Hd} and V_{Hl}: 3 angles and 3 phases each

3 generations of mirror quarks and leptons (6 masses)

LHT goes beyond Minimal Flavour Violation (MFV)

``visible effects in flavour physics are possible´´

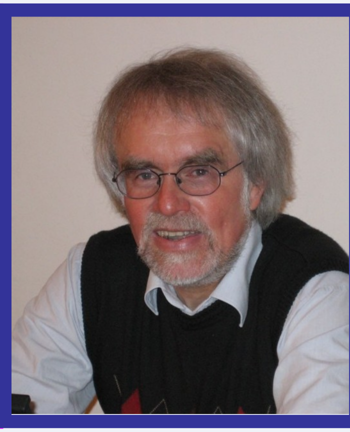
Flavour Physics Analyses in LHT

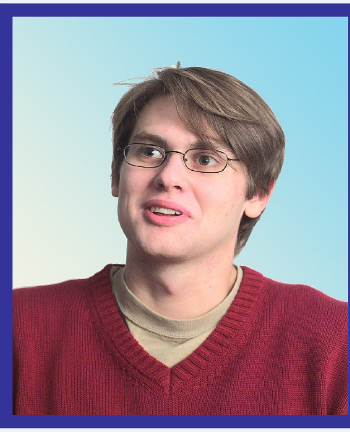
J.Hubisz et al., hep-ph/0512169 ← Quark sector

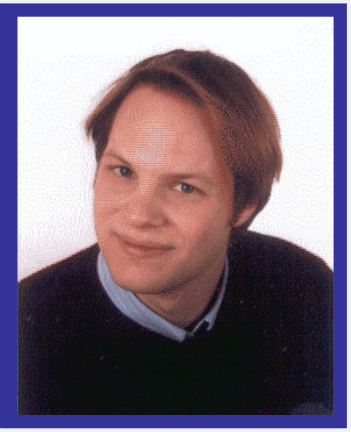
A.Goyal, hep-ph/0609095 ← Lepton sector
S.R. Choudhury et al., hep-ph/0612327 ← Lepton sector

LHT Team at the Technical University Munich


M.Blanke


A.J Buras


B.Duling


A.Poschenrieder


S.Recksiegel


CT


S.Uhlig

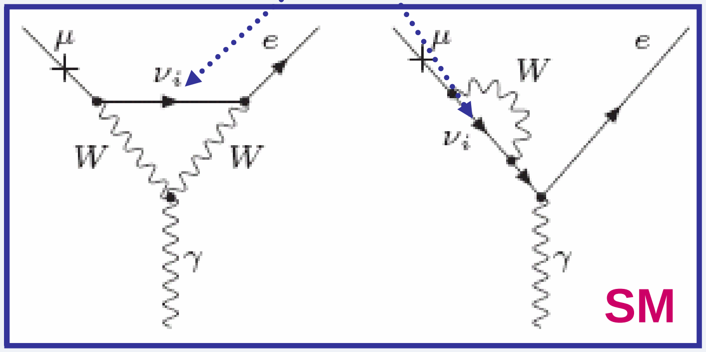

A.Weiler

Quark sector
hep-ph/0605214
hep-ph/0609284
hep-ph/0610298
hep-ph/0703254
0704.3329[hep-ph]

Lepton sector
hep-ph/0702136

Lepton Flavour Violating (LFV) decays

LFV decays are strongly suppressed in the SM, due to tiny neutrino masses



E.g.

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

^
^

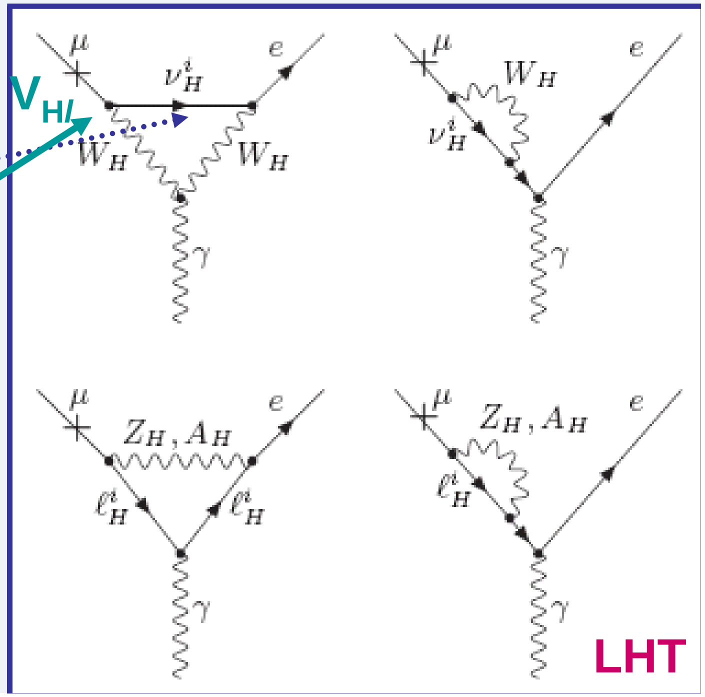
10^{-11} – 10^{-13}

present (MEGA) – near future (MEG)

experimental upper bounds

In the LHT model:

- **Mirror leptons have masses of O(1 TeV)**
- **New flavour violating interactions appear**



Spectacular departures from the SM are possible
(e.g. of 45 orders of magnitude in $\mu \to e\,\gamma$)

In hep-ph/0702136, we have calculated in LHT the LFV decays:

$\mu \to e\gamma$
$\tau \to \mu\gamma$
$\tau \to e\gamma$

$\mu^- \to e^- e^+ e^-$
$\tau^- \to \mu^- \mu^+ \mu^-$
$\tau^- \to e^- e^+ e^-$

$K_{L,S} \to \mu e$
$B_{d,s} \to \mu e$
$B_{d,s} \to \tau e$
$B_{d,s} \to \tau \mu$

$\Delta L=1$
$\Delta S=1$
($\Delta B=1$)

$K_{L,S} \to \pi^0 \mu e$

$\tau \to \mu\pi$
$\tau \to e\pi$
$\tau \to \mu\eta$
$\tau \to e\eta$
$\tau \to \mu\eta'$
$\tau \to e\eta'$

$\Delta L=2$

$\tau^- \to e^- \mu^+ e^-$
$\tau^- \to \mu^- e^+ \mu^-$

($\Delta L=1$, $\Delta L=2$)

$\tau^- \to \mu^- e^+ e^-$
$\tau^- \to e^- \mu^+ \mu^-$

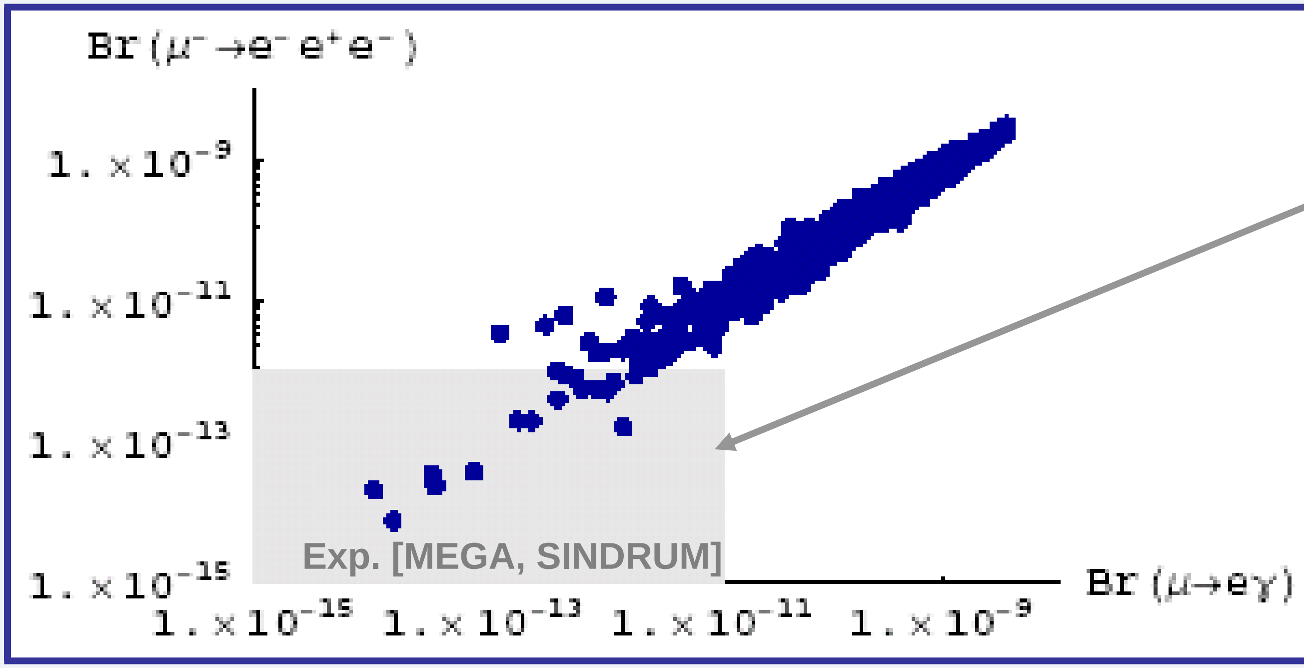
$\mu\,\mathrm{Ti} \to e\,\mathrm{Ti}$

AND $(g-2)_\mu$

(LHT effects are found to be a factor 5 below the experimental uncertainty)

$\mu^- \to e^- e^+ e^-$ vs. $\mu \to e\,\gamma$

- f = 1 TeV (or 500 GeV)
- 300 GeV ≤ m^{l}_{Hi} ≤ 1.5 TeV
- general scan over V_{Hl}



The exp. constraints rule out a large region of parameter space

We impose them in the rest of the analysis

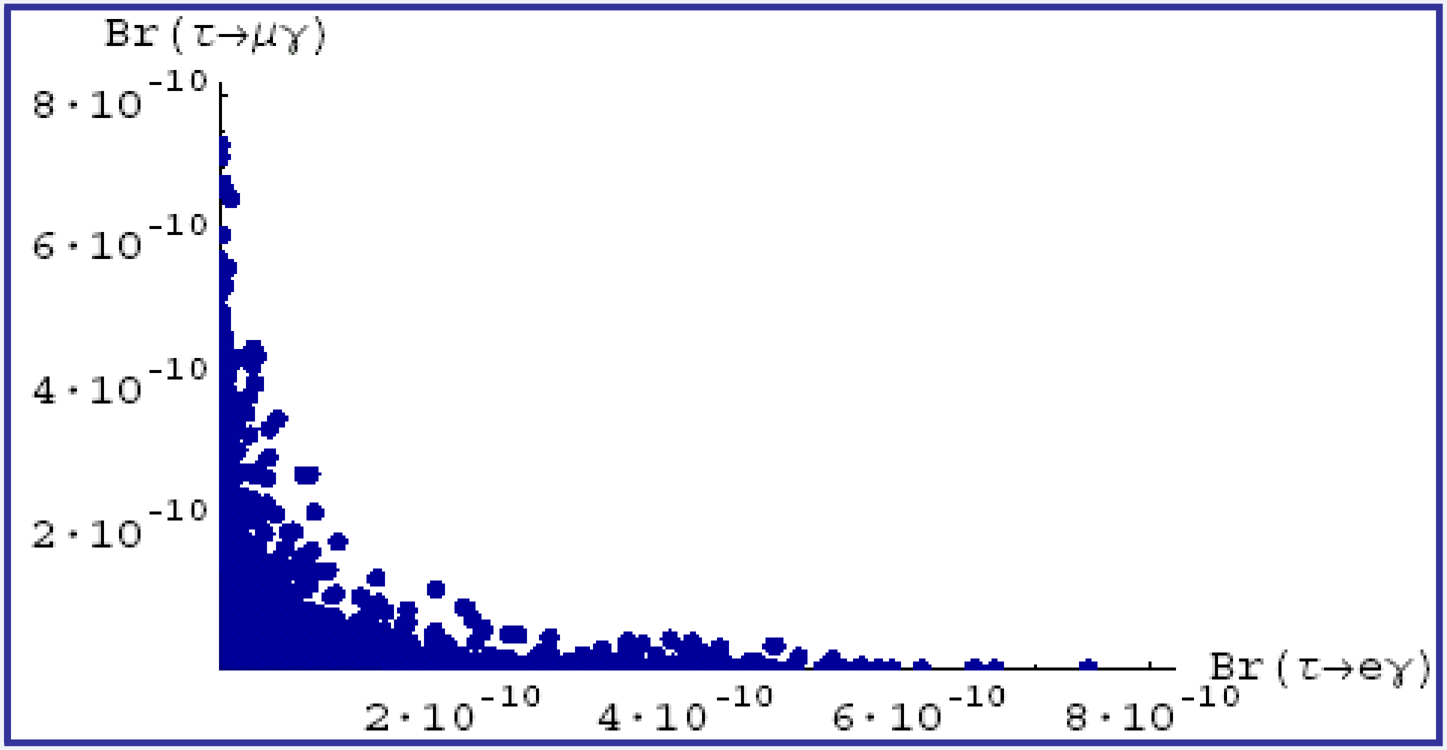
To satisfy the experimental constraints:

- V_{Hl} must have a strong hierarchy (different from $V^{\dagger}_{PMNS}$ and V_{CKM})

or

- Mirror leptons have to be quasi-degenerate

$\tau \to \mu\gamma$ vs. $\tau \to e\gamma$



- $\tau \to \mu\gamma$ **and** $\tau \to e\gamma$ **can be individually as high as 8 •10^{-10}** **(close to the planned sensitivity at a Super Flavour Factory)**

- **Larger values of** $\tau \to \mu\gamma$ **correspond to smaller values of** $\tau \to e\gamma$ **(from the** V_{Hl} **structure)**

A similar pattern is found in $\tau \to \mu\,\pi(\eta)$ **vs.** $\tau \to e\,\pi(\eta)$, **that can be individually as high as 2• 10^{-9} (6• 10^{-10})** **[one (two) order of magnitude below present exp. bounds: Belle+BaBar]**

S. Banerjee, hep-ex/0702017

LHT vs. Exp. upper bounds

	decay	$f = 1000$ GeV	$f = 500$ GeV	exp. upper bound
☺	$\mu \to e\gamma$	$1.2 \cdot 10^{-11}$ $(1 \cdot 10^{-11})$	$1.2 \cdot 10^{-11}$ $(1 \cdot 10^{-11})$	$1.2 \cdot 10^{-11}$ [17]
☺	$\mu^- \to e^- e^+ e^-$	$1.0 \cdot 10^{-12}$ $(1 \cdot 10^{-12})$	$1.0 \cdot 10^{-12}$ $(1 \cdot 10^{-12})$	$1.0 \cdot 10^{-12}$ [42]
☺	$\mu\mathrm{Ti} \to e\mathrm{Ti}$	$2 \cdot 10^{-10}$ $(5 \cdot 10^{-12})$	$4 \cdot 10^{-11}$ $(5 \cdot 10^{-12})$	$4.3 \cdot 10^{-12}$ [29]
☺	$\tau \to e\gamma$	$8 \cdot 10^{-10}$ $(7 \cdot 10^{-10})$	$1 \cdot 10^{-8}$ $(1 \cdot 10^{-8})$	$9.4 \cdot 10^{-8}$ [33]
☺	$\tau \to \mu\gamma$	$8 \cdot 10^{-10}$ $(8 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(1 \cdot 10^{-8})$	$1.6 \cdot 10^{-8}$ [33]
	$\tau^- \to e^- e^+ e^-$	$7 \cdot 10^{-10}$ $(6 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$2.0 \cdot 10^{-7}$ [71]
	$\tau^- \to \mu^- \mu^+ \mu^-$	$7 \cdot 10^{-10}$ $(6 \cdot 10^{-10})$	$3 \cdot 10^{-8}$ $(3 \cdot 10^{-8})$	$1.9 \cdot 10^{-7}$ [71]
	$\tau^- \to e^- \mu^+ \mu^-$	$5 \cdot 10^{-10}$ $(5 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$2.0 \cdot 10^{-7}$ [72]
	$\tau^- \to \mu^- e^+ e^-$	$5 \cdot 10^{-10}$ $(5 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$1.9 \cdot 10^{-7}$ [72]
	$\tau^- \to \mu^- e^+ \mu^-$	$5 \cdot 10^{-14}$ $(3 \cdot 10^{-14})$	$2 \cdot 10^{-14}$ $(2 \cdot 10^{-14})$	$1.3 \cdot 10^{-7}$ [71]
	$\tau^- \to e^- \mu^+ e^-$	$5 \cdot 10^{-14}$ $(3 \cdot 10^{-14})$	$2 \cdot 10^{-14}$ $(2 \cdot 10^{-14})$	$1.1 \cdot 10^{-7}$ [71]
☺	$\tau \to \mu\pi$	$2 \cdot 10^{-9}$ $(2 \cdot 10^{-9})$	$5.8 \cdot 10^{-8}$ $(5.8 \cdot 10^{-8})$	$5.8 \cdot 10^{-8}$ [33]
☺	$\tau \to e\pi$	$2 \cdot 10^{-9}$ $(2 \cdot 10^{-9})$	$4.4 \cdot 10^{-8}$ $(4.4 \cdot 10^{-8})$	$4.4 \cdot 10^{-8}$ [33]
	$\tau \to \mu\eta$	$6 \cdot 10^{-10}$ $(6 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$5.1 \cdot 10^{-8}$ [33]
	$\tau \to e\eta$	$6 \cdot 10^{-10}$ $(6 \cdot 10^{-10})$	$2 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$4.5 \cdot 10^{-8}$ [33]
	$\tau \to \mu\eta'$	$7 \cdot 10^{-10}$ $(7 \cdot 10^{-10})$	$3 \cdot 10^{-8}$ $(3 \cdot 10^{-8})$	$5.3 \cdot 10^{-8}$ [33]
	$\tau \to e\eta'$	$7 \cdot 10^{-10}$ $(7 \cdot 10^{-10})$	$3 \cdot 10^{-8}$ $(3 \cdot 10^{-8})$	$9.0 \cdot 10^{-8}$ [33]
☺	$K_L \to \mu e$	$4 \cdot 10^{-13}$ $(2 \cdot 10^{-13})$	$3 \cdot 10^{-14}$ $(3 \cdot 10^{-14})$	$4.7 \cdot 10^{-12}$ [50]
	$K_L \to \pi^0 \mu e$	$4 \cdot 10^{-15}$ $(2 \cdot 10^{-15})$	$5 \cdot 10^{-16}$ $(5 \cdot 10^{-16})$	$6.2 \cdot 10^{-9}$ [73]
	$B_d \to \mu e$	$5 \cdot 10^{-16}$ $(2 \cdot 10^{-16})$	$9 \cdot 10^{-17}$ $(9 \cdot 10^{-17})$	$1.7 \cdot 10^{-7}$ [74]
	$B_s \to \mu e$	$5 \cdot 10^{-15}$ $(2 \cdot 10^{-15})$	$9 \cdot 10^{-16}$ $(9 \cdot 10^{-16})$	$6.1 \cdot 10^{-6}$ [75]
	$B_d \to \tau e$	$3 \cdot 10^{-11}$ $(2 \cdot 10^{-11})$	$2 \cdot 10^{-10}$ $(2 \cdot 10^{-10})$	$1.1 \cdot 10^{-4}$ [76]
	$B_s \to \tau e$	$2 \cdot 10^{-10}$ $(2 \cdot 10^{-10})$	$2 \cdot 10^{-9}$ $(2 \cdot 10^{-9})$	—
	$B_d \to \tau\mu$	$3 \cdot 10^{-11}$ $(3 \cdot 10^{-11})$	$3 \cdot 10^{-10}$ $(3 \cdot 10^{-10})$	$3.8 \cdot 10^{-5}$ [76]
	$B_s \to \tau\mu$	$2 \cdot 10^{-10}$ $(2 \cdot 10^{-10})$	$3 \cdot 10^{-9}$ $(3 \cdot 10^{-9})$	—

☺ = LHT effects could be seen in the near future

Distinction between LHT and MSSM from LFV correlations

☺ = LHT and MSSM can be clearly distinguished

Correlations between BR´s
- are less parameter-dependent
- can provide a clear model signal

J.R. Ellis et al., hep-ph/0206110
A. Brignole and A. Rossi, hep-ph/0404211
E. Arganda and M.J. Herrero, hep-ph/0510405
P. Paradisi, hep-ph/0505046,0508054,0601110

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$ ☺	$0.4\ldots2.5$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$ ☺	$0.4\ldots2.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$ ☺	$0.4\ldots2.3$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$ ☺	$0.3\ldots1.6$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$ ☺	$0.3\ldots1.6$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$1.3\ldots1.7$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$1.2\ldots1.6$	~ 0.2	$5\ldots10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-2}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$

⇒ The MSSM is dominated by the dipole operator, while the LHT by box- and Z-penguin diagrams

☺ & the double ratios ($\mu\leftrightarrow e$):

$$R_1=\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to \mu^-\mu^+\mu^-)}\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)},$$

$$R_2=\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to \mu^-\mu^+\mu^-)}\frac{Br(\tau\to \mu\gamma)}{Br(\tau\to e\gamma)},$$

$$R_3=\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}\frac{Br(\tau\to \mu\gamma)}{Br(\tau\to e\gamma)}.$$

$0.8 \le R_{1,2,3} \le 1.3$ [LHT]

$R_1 \approx 20$, $R_2 \approx 5$, $R_3 \approx 0.2$ [MSSM]

Conclusions

The Littlest Higgs Model with T-parity

- **solves the little hierarchy problem**
- **is compatible with ew precision tests**
- **introduces new flavour violating interactions**
- **can yield large effects in Flavour Physics**
- **in particular in Lepton Flavour Violating decays**
  (strongly suppressed within the SM by tiny ν masses)

- **Many LHT upper bounds for LFV decays are close to present and near future exp. upper bounds !!**

- **Correlations of Br´s could provide a clear distinction between LHT and MSSM !!**

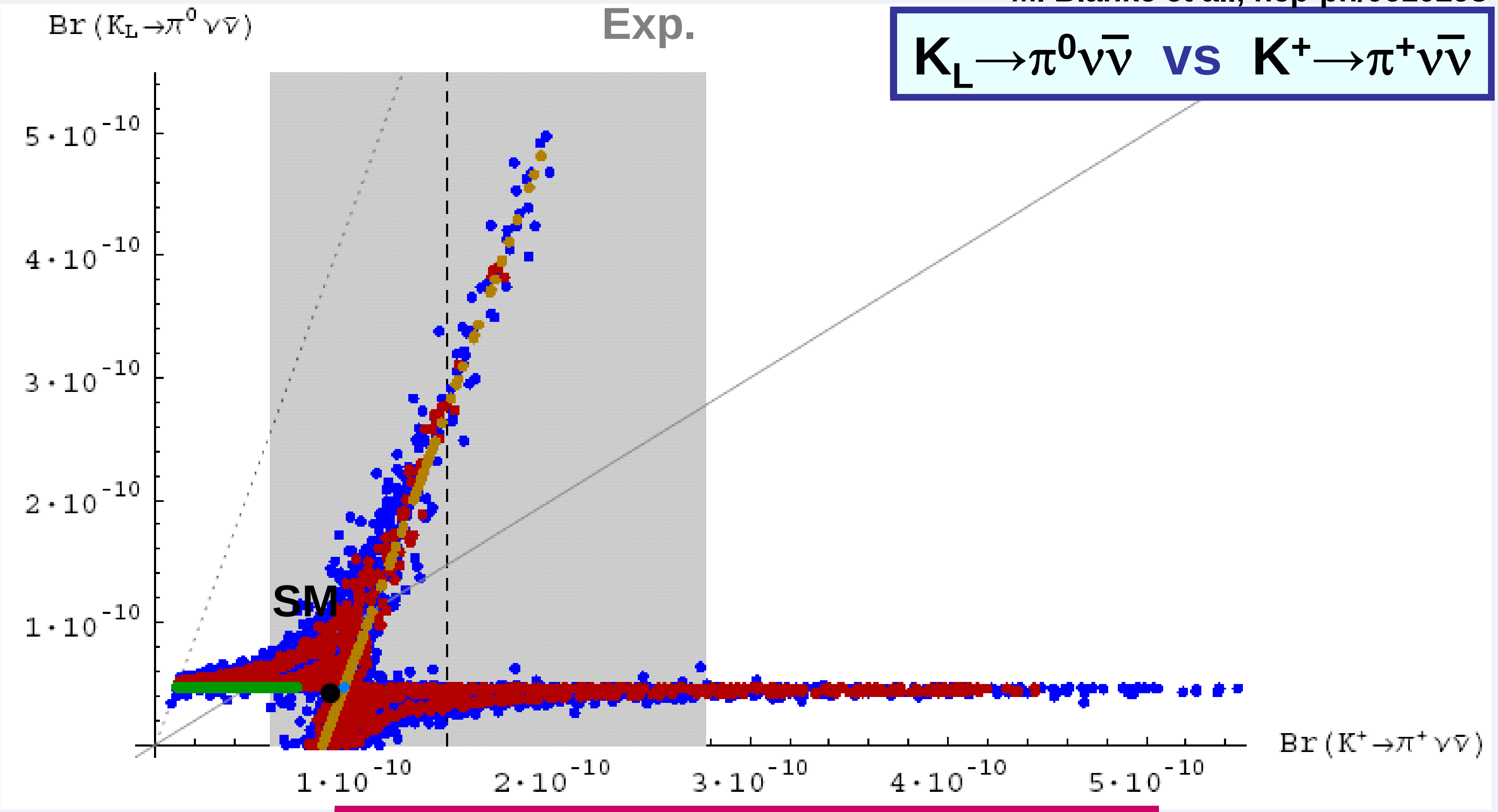
BACKUP

LHT effects in the quark sector in 1 slide

The largest effects are found in rare K decays, where the SM contribution is CKM suppressed by $(V_{ts}^* V_{td})$

M. Blanke et al., hep-ph/0610298

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



Two distinguished branches appear!

~10 times enhancement in $K_L \to \pi^0 \nu\bar{\nu}$

~5 times enhancement in $K^+ \to \pi^+ \nu\bar{\nu}$