Lepton Flavour Violating Decays in the Littlest Higgs Model with T-Parity

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Abstract. We present the results of an extensive analysis of lepton flavour violating decays in the Littlest Higgs model with T-parity (LHT). As lepton flavour violation is highly suppressed in the Standard Model by small neutrino masses, the LHT effects turn out to be naturally huge and could be seen in the near future experiments.

1. The LHT Model

The *little hierarchy problem*, i.e. the problem of hierarchy between a low ($\approx 10^2$ GeV) Higgs mass and a quite high (> 10 TeV) Standard Model (SM) cutoff scale indicated by electroweak (ew) precision measurements, has been one of the main motivations to elaborate models of New Physics (NP). While Supersymmetry is at present the leading candidate, different proposals have been formulated more recently. Among them, Little Higgs models play an important role, being perturbatively computable up to about 10 TeV and with a rather small number of parameters.

In Little Higgs models[1] the Higgs is naturally light as it is identified with a Nambu-Goldstone boson of a spontaneously broken global symmetry, whose gauge and Yukawa interactions are incorporated without generating quadratic one-loop mass corrections, through the so-called *collective symmetry breaking* (CSB). Indeed, the CSB has the peculiarity of generating the Higgs mass only when two or more couplings in the Lagrangian are non-vanishing, thus avoiding one-loop quadratic divergences. Diagrammatically, the CSB is realized through the contributions of new particles with masses around 1 TeV, that cancel the SM quadratic divergences.

The most economical, in matter content, Little Higgs model is the Littlest Higgs (LH)[2], where the global group $SU(5)$ is spontaneously broken into $SO(5)$ at the scale $f \approx \mathcal{O}(1\,\text{TeV})$ and the SM ew sector is embedded in an $SU(5)/SO(5)$ non-linear sigma model. Gauge and Yukawa Higgs interactions are introduced by gauging the subgroup of $SU(5)$: $[SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2$. In the LH model, the new particles appearing at the TeV scales are the heavy gauge bosons $(W_H^{\pm}, Z_H, A_H)$, the heavy top (T) and the scalar triplet Φ.

In the LH model, however, ew precision tests are satisfied only for quite large values of the NP scale, $f \geq 2 - 3\,\text{TeV}$[3, 4], due to tree-level heavy gauge boson contributions and the triplet vacuum expectation value (vev). The LH model can be reconciled with ew precision tests by introducing a discrete symmetry called T-parity[5], which acts as an automorphism that exchanges the $[SU(2) \times U(1)]_1$ and $[SU(2) \times U(1)]_2$ gauge factors. As T-parity explicitly forbids the tree-level contributions of heavy gauge bosons and the interactions that induced the triplet vev, the compatibility with ew precision data can be obtained already for smaller values of the

NP scale, $f \geq 500\,\mathrm{GeV}$[6]. Another important consequence is that particle fields are T-even or T-odd under T-parity. The SM particles and the heavy top T_+ are T-even, while the heavy gauge bosons $W_H^\pm, Z_H, A_H$ and the scalar triplet Φ are T-odd. Additional T-odd particles are required by T-parity: the odd heavy top T_- and the so-called mirror fermions, i.e., fermions corresponding to the SM ones but with opposite T-parity and $\mathcal{O}(1\,\mathrm{TeV})$ mass. Mirror fermions are characterized by new flavour interactions with SM fermions and heavy gauge bosons, which involve two new unitary mixing matrices in the quark sector, V_{Hd} and V_{Hu} satisfying $V_{Hu}^\dagger V_{Hd} = V_{CKM}$, and two in the lepton sector, $V_{H\ell}$ and $V_{H\nu}$ satisfying $V_{H\nu}^\dagger V_{H\ell} = V_{PMNS}^\dagger$[7, 8].

Because of these new mixing matrices, the Littlest Higgs model with T-parity (LHT) does not belong to the Minimal Flavour Violation (MFV) class of models[9, 10] and significant effects in flavour observables are possible. Other LHT peculiarities are the rather small number of new particles and parameters (the SB scale f, the parameter x_L describing T_+ mass and interactions, the mirror fermion masses and V_{Hd} and $V_{H\ell}$ parameters) and the absence of new operators in addition to the SM ones. On the other hand, one has to recall that Little Higgs models are low energy non-linear sigma models, whose unknown UV-completion introduces a theoretical uncertainty reflected by a left-over logarithmic cut-off dependence[11, 12] in $\Delta F = 1$ processes.

2. Lepton Flavour Violation in the LHT Model

Several studies of flavour physics have been performed in the LHT model in the last three years, for both quark[7, 12, 13] and lepton sectors[14, 15]. They show that the LHT mirror fermion interactions can yield large NP effects in the quark sector, mainly in K and B rare and CP-violating decays[12], and that even larger NP effects are possible in the lepton sector[14, 15]. The smallness of ordinary neutrino masses, in fact, assures that the mirror fermion contributions to lepton flavour violating (LFV) decays represent by far the dominant effects.

In[15] we have studied the most interesting LFV processes: $\ell_i \to \ell_j\gamma$, $\tau \to \ell P$ (with $P = \pi, \eta, \eta'$), $\mu^- \to e^-e^+e^-$, the six three-body decays $\tau^- \to l_i^- l_j^+ l_k^-$ and the rate for $\mu - e$ conversion in nuclei. We have also calculated the rates for $K_{L,S} \to \mu e$, $K_{L,S} \to \pi^0\mu e$, $B_{d,s} \to \mu e$, $B_{d,s} \to \tau e$ and $B_{d,s} \to \tau\mu$.

The number of significant experimental constraints on flavour violating decays is rather limited in the lepton sector . Basically only the upper bounds on $Br(\mu \to e\gamma)$[16], $Br(\mu^- \to e^-e^+e^-)$[17], $Br(K_L \to \mu e)$[18] and $R(\mu Ti \to eTi)$[19] can be used in our analysis. The situation may change significantly in the coming years thanks to near future experiments[19, 20, 21, 22]. Meanwhile, we have estimated the LHT effects, imposing the experimental bounds mentioned above and scanning over mirror lepton masses in the range $[300\,\mathrm{GeV}, 1500\,\mathrm{GeV}]$ and over the parameters of the $V_{H\ell}$ mixing matrix, with the symmetry breaking scale f fixed to $f = 1\,\mathrm{TeV}$ or $f = 500\,\mathrm{GeV}$ in accordance with ew precision tests[6]. We note that for $f = 500\,\mathrm{GeV}$ also the very recent experimental upper bounds on $\tau \to \mu\pi, e\pi$ given in [23], where Belle[24, 25] and BaBar[26, 27] results have been combined, become effective.

We have found that essentially all the rates considered can reach or approach present experimental upper bounds[15]. In particular, in order to suppress the $\mu \to e\gamma$ and $\mu^- \to e^-e^+e^-$ decay rates below the experimental upper bounds, the $V_{H\ell}$ mixing matrix has to be rather hierarchical, unless mirror leptons are quasi-degenerate.

Moreover, following the strategy proposed in[28, 29, 30] in the supersymmetric framework, we have identified certain correlations between branching ratios that are less parameter dependent than the individual branching ratios and could provide a clear signature of the model. In particular, we find that the ratios $Br(\ell_i \to \ell_j\ell_j\ell_j)/Br(\ell_i \to \ell_j\gamma)$, $Br(\ell_i \to \ell_j\ell_j\ell_j)/Br(\ell_i \to \ell_j\ell_k\ell_k)$ and $Br(\ell_i \to \ell_j\ell_k\ell_k)/Br(\ell_i \to \ell_j\gamma)$ could allow for a transparent distinction between the LHT model and the MSSM (see Table 1).

Finally, we have studied the muon anomalous magnetic moment finding that, even for values of the NP scale f as low as $500\,\mathrm{GeV}$, $a_\mu^{LHT} < 1.2 \cdot 10^{-10}$. This value is roughly a factor 5 below

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.4\ldots 2.5$	$\sim 6\cdot 10^{-3}$	$\sim 6\cdot 10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.4\ldots 2.3$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to\mu^-\mu^+\mu^-)}{Br(\tau\to\mu\gamma)}$	$0.4\ldots 2.3$	$\sim 2\cdot 10^{-3}$	$0.06\ldots 0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.3\ldots 1.6$	$\sim 2\cdot 10^{-3}$	$0.02\ldots 0.04$
$\frac{Br(\tau^-\to\mu^-e^+e^-)}{Br(\tau\to\mu\gamma)}$	$0.3\ldots 1.6$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$1.3\ldots 1.7$	~ 5	$0.3\ldots 0.5$
$\frac{Br(\tau^-\to\mu^-\mu^+\mu^-)}{Br(\tau^-\to\mu^-e^+e^-)}$	$1.2\ldots 1.6$	~ 0.2	$5\ldots 10$
$\frac{R(\mu Ti\to eTi)}{Br(\mu\to e\gamma)}$	$10^{-2}\ldots 10^{2}$	$\sim 5\cdot 10^{-3}$	$0.08\ldots 0.15$

Table 1. *Comparison of various ratios of branching ratios in the LHT model and in the MSSM without and with significant Higgs contributions.*

the current experimental uncertainty[31], implying that the possible discrepancy between the SM prediction and the data cannot be solved in the LHT model.

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