

# *K* and *B* Physics in the Littlest Higgs Model with T-Parity

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## 1. Introduction

One of the most attractive solutions to the so-called *little hierarchy problem* that affects the Standard Model (SM) is provided by Little Higgs models. They are perturbatively computable up to  $\sim 10$  TeV and have a rather small number of parameters, although their predictivity can be weakened by a certain sensitivity to the unknown ultraviolet (UV) completion of the theory. In these models, in contrast to supersymmetry, the problematic quadratic divergences to the Higgs mass are cancelled by loop contributions of new particles with the same spin-statistics of the SM ones and with masses around 1 TeV.

The basic idea of Little Higgs models is that the Higgs is naturally light as it is identified with a Nambu-Goldstone boson (NGB) of a spontaneously broken global symmetry.

The most economical, in matter content, Little Higgs model is the Littlest Higgs (LH) model [1], where the global group  $SU(5)$  is spontaneously broken into  $SO(5)$  at the scale  $f \approx \mathcal{O}(1 \text{ TeV})$  and the electroweak (ew) sector of the SM 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 scale are the heavy gauge bosons ( $W_H^\pm, Z_H, A_H$ ), the heavy top ( $T$ ) and the scalar triplet  $\Phi$ .

In the LH model, significant corrections to ew observables come from tree-level heavy gauge boson contributions and the triplet vacuum expectation value (vev) which breaks the custodial  $SU(2)$  symmetry. Consequently, ew precision tests are satisfied only for quite large values of the New Physics (NP) scale  $f \geq 2 - 3 \text{ TeV}$ , unable to solve the little hierarchy problem. Motivated by reconciling the LH model with ew precision tests, Cheng and Low [2] proposed to enlarge the symmetry structure of the theory by introducing a discrete symmetry called T-parity. T-parity forbids the tree-level contributions of heavy gauge bosons and the interactions that induced the triplet vev. The custodial  $SU(2)$  symmetry is restored and the compatibility with ew precision data is obtained already for smaller values of the NP scale,  $f \geq 500 \text{ GeV}$ . 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  $\Phi$  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  $\mathcal{O}(1 \text{ TeV})$  masses. Mirror fermions are characterized by new flavour interactions with SM fermions and heavy gauge bosons, which involve in the quark sector two new unitary mixing matrices analogous to the CKM matrix. They are  $V_{Hd}$  and  $V_{Hu}$ , respectively involved when the SM quark is of down- or up-type, and satisfying  $V_{Hu}^\dagger V_{Hd} = V_{\text{CKM}}$  [3].

$V_{Hd}$  contains 3 angles, like  $V_{\text{CKM}}$ , but 3 phases [4], i.e. two additional phases relative to the SM matrices, that cannot be rotated away in this case.

Because of these new mixing matrices, the LHT model does not belong to the Minimal Flavour Violation (MFV) class of models and significant effects in flavour observables are possible, without adding new operators to the SM ones.

Several studies of flavour physics in the LH model without T-parity have been performed in the last four years. Without T-parity, mirror fermions and new sources of flavour and CP-violation are absent, the LH model is a MFV model and NP contributions result to be very small.

More recently, an extensive flavour physics analysis has also been performed in the LHT model [5,6]. In this model, new mirror fermion interactions can yield large NP effects, mainly in *K* and *B* rare and CP-violating decays.

## 2. $K^0 - \bar{K}^0$ and $B_{d,s}^0 - \bar{B}_{d,s}^0$ Mixing [5]

The short distance structure of  $\Delta F = 2$  processes in the LHT model is fully encoded in three perturbatively calculable functions

$$S_K \equiv |S_K| e^{i2\varphi_K}, S_{B_d} \equiv |S_{B_d}| e^{i2\varphi_{B_d}}, S_{B_s} \equiv |S_{B_s}| e^{i2\varphi_{B_s}}, \quad (1)$$

relevant for  $K^0 - \bar{K}^0$ ,  $B_d^0 - \bar{B}_d^0$  and  $B_s^0 - \bar{B}_s^0$  mixings, respectively.

In the SM they all reduce to a real single function  $S_{\text{SM}} = S_0(x_t)$  that is dominated by box diagrams with top quark exchanges. In the LHT model, where the new mixing matrix  $V_{Hd}$  is present, the inclusion of box diagrams with internal mirror quarks and heavy gauge bosons ( $W_H^\pm, Z_H, A_H$ ) makes the one-loop functions in (1) complex quantities. Moreover, the universality between  $K^0$ ,  $B_d$  and  $B_s$  systems, valid in the SM is broken so that the magnitudes  $|S_i|$  and the phases  $\varphi_i$  depend on  $i = K, B_d, B_s$ . We recall that in constrained MFV models the short distance functions are as in the SM real and universal, although different from  $S_{\text{SM}}$ .

The size of  $\varphi_i$  depends on the structure of the matrix  $V_{Hd}$ , which is so far only weakly constrained by the existing data on  $\Delta M_K$ ,  $\Delta M_d$ ,  $\Delta M_s$ ,  $\sin 2\beta$  and  $\varepsilon_K$ , mainly due to significant hadronic uncertainties in  $\Delta M_{d,s}$  and  $\varepsilon_K$ . This allows to obtain interesting departures from the SM, in particular in the  $B_s^0 - \bar{B}_s^0$  system but also in connection with the slight discrepancy, existing within the SM, between the values of  $|V_{ub}|$  obtained from tree level decays and the value of  $\sin 2\beta$  measured from the CP-asymmetry  $S_{\psi K_S}$ .

The main messages from [5] are as follows:

- The presence of a non-vanishing phase  $\varphi_{B_d}$  implies that  $S_{\psi K_S} = \sin(2\beta + 2\varphi_{B_d})$ , so that with  $\varphi_{B_d} \simeq -5^\circ$  the possible discrepancy between  $|V_{ub}|$  and  $S_{\psi K_S}$  can be cured.
- The presence of a non-vanishing phase  $\varphi_{B_s}$  allows to

enhance the CP-asymmetry  $S_{\psi\phi}$  from the SM prediction 0.04 to 0.30 with an analogous enhancement of the semileptonic asymmetry  $A_{SL}^s$  and a smaller but sizable enhancement of  $A_{SL}^d$ .

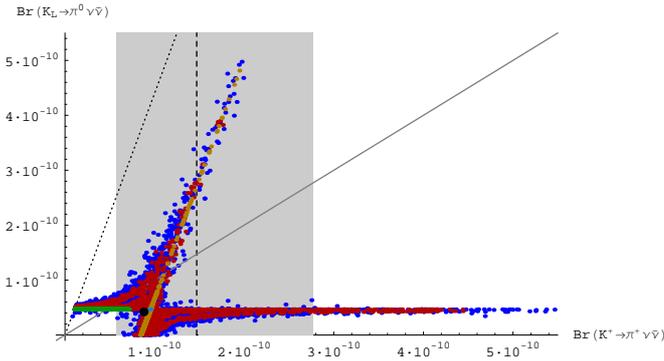
### 3. Rare $K$ and $B$ Decays [6]

The short distance structure of the LHT model, that is relevant for rare  $K$  and  $B$  decays, is fully encoded in nine perturbatively calculable functions ( $i = K, d, s$ )

$$X_i = |X_i|e^{i\theta_X^i}, \quad Y_i = |Y_i|e^{i\theta_Y^i}, \quad Z_i = |Z_i|e^{i\theta_Z^i}, \quad (2)$$

that result from the SM box and penguin diagrams and analogous diagrams with new particle exchanges. In the SM and in models with constrained MFV all these functions are real and independent of  $i$ , with consequent strong correlations between various observables in  $K$ ,  $B_d$  and  $B_s$  systems.

In the LHT model, the non-vanishing  $\theta$ 's originate from the new phases of the  $V_{Hd}$  matrix. The additional dependence on  $i$  in (2) and the possibility of large  $\theta_{X,Y,Z}^K$  imply a pattern of FCNC processes that differs significantly from the SM and the constrained MFV one.

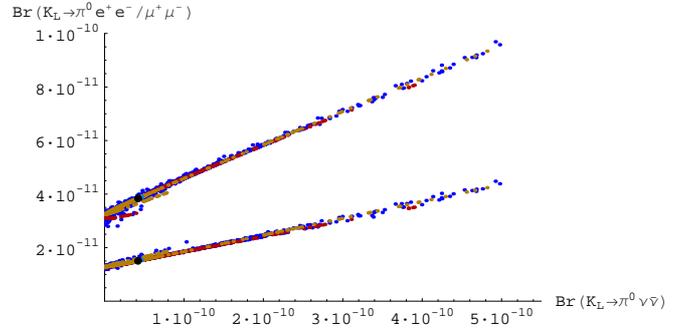


**Fig. 1:**  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$  vs.  $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ . The shaded area represents the experimental  $1\sigma$ -range for  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$ . The model-independent Grossman-Nir bound is displayed by the dotted line, while the solid line separates the two areas where  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$  is larger or smaller than  $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ .

The main messages from [6] are as follows:

- The most evident departures from the SM predictions are found in  $K \rightarrow \pi \nu \bar{\nu}$  decays (Fig. 1).  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$  can be enhanced even by an order of magnitude and  $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$  by a factor 5. Moreover,  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$  can be larger than  $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ , which is not possible in MFV models.

- $Br(K_L \rightarrow \pi^0 e^+ e^-)$  and  $Br(K_L \rightarrow \pi^0 \mu^+ \mu^-)$  can be both enhanced by a factor 2 – 3 and are strongly correlated.
- A strong correlation between  $Br(K_L \rightarrow \pi^0 \ell^+ \ell^-)$  and  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$  exists, as shown in Fig. 2.



**Fig. 2:**  $Br(K_L \rightarrow \pi^0 e^+ e^-)$  (upper curve) and  $Br(K_L \rightarrow \pi^0 \mu^+ \mu^-)$  (lower curve) as functions of  $Br(K_L \rightarrow \pi^0 \nu \bar{\nu})$ . The corresponding SM predictions are represented by dark points.

- The universality of new physics effects, characteristic for MFV models, can be largely broken, in particular between  $K$  and  $B_{s,d}$  systems. NP effects, in fact, are typically larger in  $K$  system where the SM contribution is CKM-suppressed. In particular, sizable departures from MFV relations between  $\Delta M_{s,d}$  and  $Br(B_{s,d} \rightarrow \mu^+ \mu^-)$  and between  $S_{\psi K_S}$  and the  $K \rightarrow \pi \nu \bar{\nu}$  decay rates are possible.

Our analysis of FCNC processes in the LHT model revealed very interesting and peculiar patterns that not only differ from those found in the SM and MFV models. We are looking forward to the forthcoming data from Tevatron, LHC,  $B$ - and  $K$ - dedicated experiments that will tell us whether the LHT model represents a good description of nature.

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