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Nuclear Physics B Proceedings Supplement 00 (2014) 1–3

Nuclear Physics
B Proceedings
Supplement

www.elsevier.com/locate/procedia

14 th International Workshop on Tau Lepton Physics, Aachen-Germany,
15-19th September 2014

Lepton Flavor Violation in the Simplest Little Higgs Model ☆

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Abstract

We study the possibility of Lepton Flavour Violation (LFV) in the hadronic decays of the τ lepton beyond the Standard Model (SM). We use the Composite Higgs models frame where in general the Higgs is a composite particle and a Goldstone boson of the spontaneous breaking of a higher symmetry. In particular, we consider the case of the Simplest Little Higgs Model (SLH), where the initial group of symmetry is SU(3)$_L$×U(1)$_X$, and LFV only happens through perturbative processes at one-loop with the assumption of the existence of a multiplet of heavy neutrinos. We study the decays $\tau \longrightarrow \mu$ (P, PP), where P stands for a pseudoscalar meson. We use the unitary gauge.

Keywords: Lepton flavor violation, Tau decay, Little Higgs models, Simplest Little Higgs model.

1. Why LFV?

Flavor symmetries provide a natural approach to explain the peculiar mass hierarchies and mixing patterns of the Standard Model fermions. Sources of Lepton Flavor Violation are generally present in new physics beyond the SM. The flavor puzzle is one of the main unresolved problems of particle physics. Experimentally many of the properties are already well known, such as the strong hierarchy of quark masses, whereas the mixing between quarks is found to be weak, with the small Kobayashi-Maskawa mixing angles.

One of the main goals of physics Beyond the Standard Model (BSM) is to solve this flavor puzzle. Despite the big amount of experimental data on the structure and couplings of the fermion sector, more information is required to unravel the different predictions of the various models. A highly important field of phenomenology in this regard are charged LFV processes, as they provide crucial information on the flavor structure of the leptonic sector in many theories BSM physics. Unfortunately, in the SM with light left-handed neutrinos, LFV is naturally suppressed via the GIM mechanism due to the small neutrino masses. The observation of charged LFV would be a clear signal of new physics, and the fact that it is not observed already provides strong bounds on BSM physics. Searching for transitions $\tau \longrightarrow e$ and $\tau \longrightarrow \mu$ is experimentally much more difficult due to the lower fluxes in τ production wich are available so far. The current best limits on τ decays are obtained

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☆Supported by grant FPA2007-60323 and PROMETEOII/2013/007

Email address: `andrea.lami@ific.uv.es` (Andrea Lami) by the B-factories BABAR and Belle. Generally most relevant for phenomenology are the decays to $l\gamma$ with the 90% C.L. limits (charge averaged) [1]:

$$Br(\tau \longrightarrow e\gamma) < 3.3 \times 10^{-8}, \qquad (1)$$

$$Br(\tau \longrightarrow \mu\gamma) < 4.4 \times 10^{-8}. \qquad (2)$$

In the future, the Super B-factory projects like Belle II could achieve sensitivities on LFV τ decays of the order 10^{-9}. Examples of new physics frameworks are those that incorporate a Seesaw mechanism to generate the light neutrino masses, either with or without supersymmetry and with right-handed neutrinos close to the GUT scale or the electroweak scale. There are also many others BSM frameworks in which lepton flavor symmetries can be embedded, like Extra-dimensional models or the Composite Higgs models [2], and of particular interest are the Little Higgs Models (LH).

2. Which model?

In the SM, the Higgs mass receives quadratically divergent radiative corrections dependent on the cutoff scale of the model. Since the measure the Higgs mass is M_H ≈125 GeV, naturalness arguments [3] demand this cut-off scale be near the TeV to avoid fine tuning the model parameters (hierarchy problem). Hence, new physics effects are expected before or at the TeV scale. Many beyond SM scenarios have been proposed to solve this hierarchy problem, such as supersymmetry, technicolor and extra-dimensions among others. However, the same electroweak precise data (EWPD) and flavor physics in general disfavor new particles at scales somewhat below E∼ 10 TeV, giving rise to the so called *little (flavor) hierarchy problem.* Little Higgs models are also an attempt to solve the hierarchy problem, bridging the gap to ∼ 10 TeV. This is done making the Higgs a pseudo-Goldstone boson of a new approximate global symmetry broken at a scale $f\sim$ 1 TeV. There are two categories of LH models: those that have the SM gauge group emerging from the diagonal breaking of the product of several groups (for instance $(SU(2)\times U(1))^N$) and those where it emerges from the breaking of larger simple group (for example SU(N)×U(1)). At any rate, LH models introduce new particles with masses of order f. However EWPD generally requires $f\gtrsim4$ TeV, reintroducing the little hierarchy problem. In product group models, these constrains can be alleviated by introducing an additional discrete symmetry, T-parity. Flavor violating processes depend on the new heavy scale as well as on the misalignment of SM and heavy flavors. Hence, the corresponding limits can be satisfied sending f to a high enough value or aligning both sectors with a high enough precision. For instance, in the Littlest Higgs model with T-parity (LHT) present bounds on lepton flavor violating processes require $f\sim$ 10 TeV or a misalignment of at most 1% between the SM and the heavy fermion mass matrices. Once f is of the order of several TeV, it is of the order of the scale implied by the EWPD bounds on simple group models. This means that simple group models and the LHT would be on similar footing as long as flavor constraints on the former models are not more stringent than in the LHT case. The LFV limits on the Simplest Little Higgs model [4] are comparable to those on the LHT. This is so since in this simple group case the matter content of the model guarantees the absence of tree-level charged lepton FCNC, and the corresponding LFV processes are then one-loop suppressed. In the SLH model the new global symmetry is $(SU(3)\times U(1))^2$, where only the diagonal subgroup SU(3)×U(1) is gauged. This gauge symmetry is broken at the scale f into the SM gauge group $SU(2)_L\times U(1)_Y$. Left-handed (right-handed) matter fields transform as SU(3) triplets (singlets), implying only the addition of heavy quasi-Dirac neutrinos to complete the lepton multiplets. The quark sector in the SLH is more involved. There are two ways of embedding the SM quark doublets into the new SU(3) triplets. In any case, the quark Yukawa Lagrangians allow for mixing between heavy and light quarks of all three families.

3. The Simplest Little Higgs model

The only new source of LFV in the SLH model is the misalignment of the SM down-type lepton mass matrix with the new heavy neutrino mass matrix [5]. Since we also neglect SM neutrino masses and mixing effects, this is in fact the only source of LFV. This means that mixing matrices only appear in vertices that couple SM leptons to the new heavy neutrinos and, since our external particles are charged, only charged currents can contribute to the flavor change [6] . The SLH model is an $SU(3)_L\times U(1)_X$ gauge theory. This gauge symmetry is a diagonal subgroup of a global $(SU(3)\times U(1))_1\times(SU(3)\times U(1))_2$

group. The global symmetry is spontaneously broken to (SU(2)×U(1))$_1$×(SU(2)×U(1))$_2$ and the gauge symmetry reduces to the SM gauge group SU(2)$_L$×U(1)$_Y$. There are two scalar multiplets $\phi_{1,2}$ transforming as **(3, 1)** and **(1, 3)]** under SU(3)$_1$×SU(3)$_2$. They can be expressed as follows:

$$\phi_1 = exp\left(\frac{i\theta'}{f}\right) exp\left(\frac{i\tan\beta\,\theta}{f}\right)\left(\begin{array}{c} 0 \\ 0 \\ f\cos\beta \end{array}\right), \quad (3)$$

$$\phi_2 = exp\left(\frac{i\theta'}{f}\right) exp\left(\frac{-i\cot\beta\,\theta}{f}\right)\left(\begin{array}{c} 0 \\ 0 \\ f\sin\beta \end{array}\right), \quad (4)$$

where we have developped our calculations in the unitarity gauge, such that:

$$\theta = \left(\begin{array}{ccc} 0 & 0 & h^0 \\ 0 & 0 & h^- \\ h^{0\dagger} & h^+ & 0 \end{array}\right), \quad (5)$$

$$\theta' = 0. \quad (6)$$

In the sector of the gauge bosons we have the standard foton, the neutral Z boson and the bosons W$^\pm$ but also a new neutral vector Z' and new charged vectors X$^\pm$ (as always in this type of models the new particles have $M_{X,Z'} \propto f$).
Each lepton family consists of an SU(3) left-handed triplet **(3)** and 2 right-handed singlets **(1)**. There is no right-handed light neutrino:

$$L_m = \left(\begin{array}{c} \nu_L \\ l_L \\ i\,N_L \end{array}\right)_m, \; l_{Rm},\; N_{Rm}\;. \quad (7)$$

The structure of the quark fields depends on the embedding we select. One can construct a quark sector that is directly anomaly-free with no additional degrees of freedom. This requires that the first two families contain SU(3) left-handed conjugate triplet representations **(3)** and three right-handed singlets. The third family is analogous to the lepton sector:

4. Calculations & Results

We are calculating the tau decay in a muon plus pseudoscalars. In the case of SLH this process takes place through various penguin diagrams $\tau \to \mu\gamma$, $\tau \to \mu$Z, $\tau \to \mu$Z'. Since we are in the unitarity gauge, also the contribution coming from the boxes is necessary to account for the divergences. The final hadrons will be two pseudoscalar mesons like $\pi^+ \pi^-$, K$^+$ K$^-$. we are implementing hadronization with resonance chiral theory:

$$\bar{q}\gamma_\mu \frac{\lambda^j}{2} q \to \frac{i}{2}\langle \lambda^j(\partial_\mu\phi\phi - \phi\partial_\mu\phi)\rangle - \frac{F_V}{\sqrt{2}}\langle \lambda^j \partial^\nu V_{\nu\mu}\rangle. \quad (8)$$

Bounds on branching ratios from B-factories will provide information on the cut-off scale of the SLH model. Assumptions on the masses of heavy neutrinos will also be discussed.

$$A_{LFV} \propto \sum_i V_l^{i\tau} V_l^{i\mu} F[Q^2; M^2_{N_i}; \frac{v}{f}]. \quad (9)$$

We foresee on SLH cut-off, in order to provide a reasonable framework for TeV discovery at LHC or precision physics at the B-factories.

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