Referee report on doctoral thesis

Aspects of baryon and lepton number non-conservation in the Standard model of particle interactions and beyond

by

Matěj Hudec

The subject of the Matěj Hudec work is baryon and lepton number violation in theories beyond the Standard Model (SM). The first chapter introduces several scenarios beyond the SM (BSM) with respect to the lepton and baryon number violation. Key aspect is the discussion of relations between accidental and imposed symmetries. An interesting finding is relation between presence or absence of color Levi-Civita tensors in the Largrangian and baryon number violation or conservation.

The second chapter is focusing on quark-lepton unification theories with extended gauge symmetry $SU(4)_C \times SU(2)_L \times U(1)_R$, identifying the most general scalar potential in Minimal Quark Lepton Symmetry Model (MQLSM) and its extension with inverse seesaw mechanism, so called Filiviez Pérez and Wise model (FPW). The chapter contains overview of the gauge boson and scalar sectors, including relations for the BSM scalar masses, followed by an extensive discussion on the number of physics phases in quark-lepton mixing matrices. According to the author, this is for the first time when these phases are discussed in the literature.

Chapter 3 introduced fundamentals necessary for the phenomenological studies presented further. In particular, it contains a discussion of flavor symmetries, B-meson anomalies and leptoquarks. Thanks to careful approach and independent calculations of branching ratios, the author discovered errors in the code `flavio` (a package for flavor phenomenology in the SM and beyond) for branching ratios of $K^0_{L,S} \to e\mu$.

The most important parts of the thesis are, to my view, chapters 4 and 5. They contain phenomenological analysis of MQLSM and FPW models (chapter 4) and scenario with gauge lepto-quarks in similar $SU(4)_C$ models with additional lepton generations (chapter 5). In the case of MQLSM and FPW models, the author finds that it is difficult to accommodate in these models the observed experimental anomalies R_K and R_{K^*} in B-meson decays together with the experimental limit on tau decay $\tau^- \to e^- \pi^+ \pi^-$. This work has been published by M. Hudec and his collaborators in PLB 787 (2018) 159 and PRD 101 (2020) 095024. Both papers are added to the thesis as an attachment. Matěj Hudec made significant contributions to these findings, as is specified in the introductory part of chapter 4

Gauge lepto-quark scenario with additional lepton generations is studied extensively in chapter 5. More than 20 observables, mostly various meson rare decays plus $\mu \to e$ conversion on nuclei, were analyzed together with the goal to identify the best candidates for BSM experimental signatures. To be able to carry such extensive analysis, author and his collaborators set up a dedicated computational framework based on tools `wilson` (package for running and matching Wilson coefficients in effective field theories above and below EW scale), already mentioned package `flavio`, and `smelli` (package for finding global likelihood for precision constrains and flavor anomalies). Two new interesting observables were added to `smelli`, $BR(B^0_{d,s} \to e^+e^-)$ and $\mu \to e$ conversion. The most sensitive observables are listed in table 5.1. Not only this, table 5.2 lists processes that does not constrain the model parameters together with current experimental limits and with indication what precision is needed in order to start to constrain the model. I find these tables invaluable for guiding the future experimental searches of new physics in meson rare decays. The publication of these results is in preparation (Ref. [31], H. Gedeonová and M. Hudec).

Concerning the thesis, I have just few questions

1) You mentioned several times that lack of measurement of branching ratio of $K^0_S \to e\mu$ and that such measurement would be very interesting from theory point of view. Do you know why it was not measured so far and can you elaborate more on future prospects of such measurement?
2) I don't understand the statement about global leptoquark mass limit of 86 TeV which was obtained using simplified Smirnov's approach. You wrote on page 76 that current limit on $\mu \to e$ conversion violates this limit by 3 orders of magnitude. Yet, at the end you find in your approach the mass limit comparable with 86 TeV. Can you explain it a little more?
3) The list of most sensitive observables in table 5.1 is still quite long. Can you rank them further to see which one is the most sensitive? What are current experimental prospects to improve their measurement? Are there any hot candidates for which we can expect interesting experimental improvements in near future?
4) What brings new 2021 measurement of R_K from LHCb from the point of view of discussions in chapter 4 and 5? Is FPW model ruled out now as well?
5) What is the relation of discussed leptoquark models to anomalous magnetic moment of muon? Can these models accommodate the observed tension between theory and measurements?

From the formal point of view, the thesis is well structured. It is written in clear and readable English with a minimum of typos. Also in terms of graphics, it reaches an excellent level. I appreciated the electronic version with working hyperlinks, not only for the bibliography but also for other references, like formulae, etc.

Matěj Hudec thesis presents very well his findings concerning the baryon and lepton number violation in several BSM scenarios. The obtained results are in particular very interesting for the phenomenology of rare meson decays and the violation of lepton flavor universality observed in several B-meson decays. As such, they can drive future searches for BSM physics. The work of Matěj Hudec during his PhD study was broader than the presented study of baryon and lepton number violation. The third paper attached to the thesis, *Hierarchy and decoupling*, by Matěj Hudec and his supervisor Michal Malnský, published J. Phys. G: Nucl. Part. Phys. 47 (2020) 015004, was devoted to the discussion of hierarchy problem and its relation to the decoupling theorem.

In summary, I conclude that the Ph.D. thesis of Matěj Hudec contains original physics results, very relevant for the future development of searches for new phenomena beyond Standard Model. With this, I have no hesitation to recommend the thesis to be accepted and I recommend after successful defense to award Matěj Hudec the Ph.D. degree.

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