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Report on Dr. Michal Malinsky habilitation thesis

It gives me great pleasure to write a report on the habilitation thesis "Radiative effects in gauge extensions of the Standard Model of particle interactions" by Dr. Michal Malinsky. It is very impressive presentation of many aspects of the Standard Model (SM) gauge extensions. The Standard Model is a very successful theory of elementary interactions and is extremely well tested. The habilitation thesis of Dr. Malinsky is devoted to the gauge extensions of SM, guided by the SM lack to approach neutrino masses. Namely, observed neutrino flavour oscillations point towards the necessity to extend the SM and create a new theory which can generate neutrino masses. Dr. Malinsky's expertise is in the area the SM extensions, which contain a Majorana neutrino, baryon and lepton number violations within unified gauge model, constructions of unified gauge models.

The habilitation thesis "Radiative effects in gauge extensions of the Standard Model of particle interactions" contains five chapters. In the first chapter, Introduction, the author presents the motivation for his research, pointing out a quest to understand the origin of neutrino masses. Masses of neutrinos are very light with masses in sub-eV mass scale. The simplest and widely accepted mechanism to explain such a smallness is a see-saw mechanism. Majorana neutrinos violate lepton number and smallness of neutrino masses is attributed to the see-saw scale of $10^{12\text{-}14}$ GeV. Lepton number conservation was one of empirical symmetries of the low-energy physics. Even more, the SM is not able to account for the baryon- to-photon number density ratio in the early Universe. The SM baryon currents have the same properties as leptonic ones and therefore one might think that there is a same origin of their violation. The violation of baryon and lepton number can be nicely accommodated within the idea of grand unification of the strong and electroweak interactions. Dr. Malinsky is a world expert in the construction of grand unification models as SU(5), SO(10) and recently Pati-Salam like models. His motivation is well supported by the experimental data coming from NUSEX, FREJUS, SOUDAN, Kamiokande, Super-Kamiokande, IMB, DUNE, Hyper-K.

In the second chapter "Perturbative baryon and lepton number violation in gauge extensions of the Standard Model" Dr. Malinsky first considers right-handed singlet fermions. He notices that simple Dirac mass terms for neutrinos does not copy the SM behavior. Namely, by requiring the cancelation of anomalies one obtains quantization of hyper(charge). In the model with the three right-handed neutrinos there is no constraint on the hypercharge. Neutrino masses can be generated by so-called Type I seesaw mechanism. Such approach causes a perturbative lepton number violation and leptonic CP violation. Also, most intriguing is a possibility for neutrino-less double beta decay. In addition, author considers baryogensis. Majorana neutrinos may have been preceded by an epoch of spontaneous leptogenesis in which a net lepton number was created in the C and CP-asymmetric out-of-equilibrium decays of the heavy Majorana neutrinos. In this chapter he also considers low-energy effective theories which are based on a matching procedure by first integrating out heavy degrees of freedom from the complete theory in its path-integral formulation. The dimension 5 Weinberg operator is considered within existing three types of seesaw mechanism. The baryon number violation is considered then by using the dimension 6 operators. Related to this issue, the author then considers proton decay and reviews the experimental results. After that the author considers tree-level renormalizable operators leading to baryon-lepton number violation. He also nicely points out that although the energy scale is 12-13 orders of magnitude above currently accessible energies, but still low-energy experiments can test this very high energy phenomena. Luckily, such a large scale can be probed in the structure of the model itself. It is related to the evolution of its

running couplings which, indeed, exhibit a nice convergence feature at about $10^{15\text{-}16}$ GeV. Dr. Malinsky presents the evolution of running non-abelian gauge couplings in the Standard Model assuming no new dynamics appearing throughout the evolution up to scale of 10^{16} GeV. The right-handed neutrinos, being singlets of nonabelian gauge theories does not modify running of the couplings. Regarding the topological defects, the main difference between the unified and the electroweak symmetry breaking is the topological structure of the corresponding co-set spaces which, in the SM case, yields no stable topological defects. This, however, does not necessarily happen for the breaking of new gauge group, especially if this gauge group is simple. Dr. Malinsky reviews features of the basic Georgi-Glashow SU(5) model and its phenomenological implications. However, this model cannot (in its minimal form) account for non-zero neutrino masses and the weak mixing angle (evolved from M_G to M_Z) turns out to be wrong. The supersymmetric version of this model has following nice features: can correct the value of the weak mixing angle, can provide cold dark matter candidate, can cure so-called "hierarchy problem" (the apparent need for order-by-order fine-tuning among the bare and the high- scale (cut-off) contributions in the formula for the electroweak vacuum-expectation values). This proposal cannot get the proton lifetime anywhere near the desired (non-supersymmetric) limit of 10^{34} years.

The third chapter "Radiative effects in potentially realistic unified gauge models" Dr. Malinsky considers Left-Right symmetric models, Pati-Salam, SO(10) grand unifying group. First, he discusses the minimal supersymmetric SO(10) GUT and only later concentrates on the non-SUSY version. However, the minimal SUSY SO(10) cannot explain type-I seesaw contribution to the light neutrino masses, since it requires the B- L breaking scale well below the GUT scale.

The model is being criticized by the community and it is no longer considered as a viable route towards a complete theory of perturbative baryon number violation. Non-supersymmetric SO(10) Higgs model seems to be more successful than supersymmetric one. The scalar sector can be accommodated within representations 45 and 126. In such a scenario one often encounters a situation in which an intermediate-scale effective gauge theory features two Abelian factors. Then author presents the renormalization of one Abelian gauge theories and then when two Abelian gauge group are present. He also considers one-loop matching in schemes with the two U(1) mixing. Part of this chapter is devoted to renormalizable flipped SU(5).Dr. Malinsky offers an interesting scenario of renormalizable theory of perturbative B violation.

The 4th chapter contains conclusions and outlook. Dr. Malinsky points out that clear experimental signals of physics beyond the SM these are the neutrino flavour oscillations which necessarily indicate that neutrinos are not massless and second, that there is no clue on what is behind the peculiar matter generation pattern, why there is so little CP violation. Also, on the experimental side, the SM does not explain matter-like but invisible gravitating component of the Universe's energy density budget -dark matter. In addition, currently there is no understanding of the number of baryons left behind the initial annihilation.

In the last chapter dr. Malinski incudes the copies of his seven research papers on the above-mentioned problem. They are published in most important journals for high energy physics and they have attracted a lot of attention within our community. It is very impressive ability of Dr. Malinsky to attack such deep theoretical questions of the current theory, exhibiting not only understanding of current affairs in theoretical high energy physics, but also presenting his contributions to solving them in a very creative way.

If degrees will be used for the evaluation of habilitation theses I would grade it with highest possible degree. It was very educational to read it and I hope that wider audience would have opportunity to read it. There are many very honest and critical description of the existing theoretical results, that it makes it very useful for a reader. Also, he explains his own findings clearly, keeping critical distance towards all the results. In this light I expect that he will be able to carry out his research idea with same sharpness, offering many new insight in the current theory.

The plagiarism audit (Turnitin report) shows that the thesis of Dr. Malinsky is an original work with minimum overlap with the existing literature.

I do not have any hesitation in recommending Faculty of Mathematics and Physics at Charles University to accept the habilitation thesis "Radiative effects in gauge extensions of the Standard Model of particle interactions" by Dr. Michal Malinsky.