Posudek práce

předložené na Matematicko-fyzikální fakultě
Univerzity Karlovy

☐ posudek vedoucího ☑ posudek oponentky
☐ bakalářské práce ☑ diplomové práce

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Odborná úroveň práce:
☑ vynikající ☐ velmi dobrá ☐ průměrná ☐ podprůměrná ☐ nevyhovující

Věcné chyby:
☑ téměř žádné ☐ vzhledem k rozsahu přiměřený počet ☐ méně podstatné četné ☐ závažné

Výsledky:
☑ originální ☐ původní i převzaté ☐ netriviální kompilace ☐ citované z literatury ☐ opsané

Rozsah práce:
☐ veliký ☑ standardní ☐ dostatečný ☐ nedostatečný

Grafická, jazyková a formální úroveň:
☑ vynikající ☐ velmi dobrá ☐ průměrná ☐ podprůměrná ☐ nevyhovující

Tiskové chyby:
☑ téměř žádné ☐ vzhledem k rozsahu a tématu přiměřený počet ☐ četné

Celková úroveň práce:
☑ vynikající ☐ velmi dobrá ☐ průměrná ☐ podprůměrná ☐ nevyhovující

Slovní vyjádření, komentáře a připomínky oponentky:

The thesis addresses two of the most pressing problems of today's particle physics: the non-zero, but tiny neutrino masses and the baryon asymmetry observed in our Universe. The seesaw mechanisms and the leptogenesis provide standard solutions to these puzzles, however, the thesis relates these phenomena in a compelling way by assuming a unification of the gauge interactions at high scales provided by the so-called Grand Unified Theories.

The thesis comprehensibly introduces all the above mentioned notions and summarizes the relevant existing literature. On top of that, original results are provided by finding the fits to Yukawa sector of certain SO(10) theories that reproduce all the low-energy data and surprisingly, also the baryon asymmetry, although this parameter was not directly fitted. These are very interesting and valuable results that provide additional insights into the structure of the SO(10) theories.

In practice, the student had to learn how to use different numerical packages and implement the given model there, moreover, he also successfully designed his own algorithm for finding good Yukawa fits. The thesis is well structured, the explanations are clear and the language level is high. I must admit that the background theory presented in the thesis is limited to the amount strictly necessary for deriving the results (it is, e.g., not very clear where the different structures in the density matrix equations above (2.21) come from or there are not too many details about the structure of the $SO(10)$ theories). On the other hand, in all such places, suitable references are provided and perhaps going to all these details would lead to doubling the length of the thesis which is unnecessary.

In summary, I highly appreciate this work that can indisputably be recognized as a Master thesis. Below, I present several questions that are related rather to the curiosity of the referee than to flaws in the thesis.

Případné otázky při obhajobě a náměty do diskuze:

- Let me first inquire about the role of the scalar triplet Δ_L whose presence could in principle lead to generation of further lepton asymmetry and that also provides a contribution to light neutrino masses through type-II seesaw mechanism. The thesis argues that neither the REAP package for solving the renormalization-group equations nor the ULYSSES code for calculation of the lepton asymmetry are suited for inclusion of Δ_L,[1] consequently, the explored parameter space is restricted to the region satisfying condition (2.18) and the effect of the type-II seesaw is only mimicked by a GUT-scale contribution (A.6). On the other hand, it would be interesting to see if the validity of condition (2.18) was checked a posteriori for the good flavour fits, in particular, what is the typical value of M_Δ in the relevant parameter range? As for the type-II seesaw contribution, certain information can be obtained from Fig. 5.6, however, it is still not clear to me which of the contributions to neutrino masses (type I vs type II) dominates. In this respect, also the last sentence before section 5.1 confused me. ("The situation is worse in case of the combined seesaw, where we are unable to reproduce reasonable χ^2.")

[1] Although the webpage reapmpt.hepforge.org mentions the implementation of the type-II seesaw model in the code, perhaps it is not in combination with type-I as needed in the SO(10) context?

- Let me also ask about the numerical solution of the Boltzmann equations for the lepton asymmetry. Fig. 5.9 shows the evolution of the $B-L$ asymmetries obtained based on the density matrix equations (see above (2.21)) starting at the point where $z = M_1/T = 0.1$. Given the fact that $M_2, M_3 \gg M_1$, I expect that the heavier right-handed neutrinos are already out of equilibrium at $z = 0.1$ and this is probably confirmed by the fact that the asymmetries "jump" to non-zero values immediately. How does one, however, choose the initial conditions for $N_{N_R^{2,3}}$ if they start already with non-equilibrium values? Or is the numerical solution in fact started already earlier and only part of the evolution is depicted in Fig. 5.9? Further, it would be interesting to understand, what is the reason for the "dips" in $N_{\tau\tau}$ and N_{ee} at certain temperatures.
- In section 5.2, the fit of the three-Yukawa model is considered where the number of free parameters is increased from 23 to 35, hence, as mentioned in the thesis, "fits with practically zero χ^2" are possible. I expect that multiple of such very good fits might be obtained, how can one than define the "best" fit given in formula (5.2)? Also it is not clear to me, why the actual χ^2 for the best fit is three orders of magnitude smaller than the one explicitly given in Table 5.3 (if the pulls are defined as p_i in formula (4.1)). Finally, the baryon asymmetry turned out to be smaller than the experimental value for the "best" fit. I understand that optimization of η_B would be computationally expensive, however, is it expected that a larger value of the asymmetry can be obtained for certain parameter range? Could there be perhaps a disconnected region of parameter space where good fits are also obtained, but that is "further" from the small $\tilde{Y}$ regime explored here?
- Finally, let me ask a naive question related to the spectrum of the SO(10) theories. The so-called extended survival hypothesis is mentioned above eq. (3.14) which suggests that some of the scalars could survive to energies below the GUT scale. On the other hand, the RGE evolution takes into account only the thresholds related to the right-handed neutrinos masses. Are indeed all the scalars except for the SM Higgs expected to have masses at the GUT scale in this simplified scenario?

Práci:

☑ doporučuji

☐ nedoporučuji

uznat jako diplomovou.

Navrhuji hodnocení stupněm:

☑ výborně ☐ velmi dobře ☐ dobře ☐ neprospěl

Místo, datum a podpis oponentky:

Stavanger, 27. srpna 2024

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