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New advances in the minimal potentially realistic $SO(10)$

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We present new advances in the minimal $SO(10)$ Higgs model where the $45 \oplus 126$ scalars drive spontaneous symmetry breaking down to the Standard model. A comprehensive analysis of all theoretical aspects of the model was performed extending previous results. Computational tools, including full one-loop mass corrections and one-loop scalar beta functions, were developed and allowed us to construct thorough viability constraints. Only two potentially realistic scenarios were identified, one of them seems to be preferred.

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1. Introduction

The minimal realistic renormalizable SO(10) Higgs model, where $45 \oplus 126$ drives spontaneous symmetry breaking, is studied as a basis of a promising grand unified extension of the Standard model. The theory used to be discarded due to the tachyonic instabilities in the scalar spectrum [1] which have to be remedied by one-loop analysis [2]. Remarkably, the model is robust with respect to the theoretical uncertainties afflicting proton decay calculations in GUT scenarios [3]. As such it can support "high quality" proton lifetime estimates.

2. Analysis

As the first step towards proton decay estimate we perform thorough analysis of the model parameter space. It accounts for theoretical consistency aspects, ignoring further phenomenological limitations for now. We identify and implement the following constraints.

2.1 Unification

The Higgs model under consideration is to be implemented as a part of the physical theory with the Standard model emerging at low energies. As such, the underlying $SO(10)$ gauge group has to break down to the $SU(3)_c \times SU(2)_L \times U(1)_Y$ in at least two stages.[1] As we shall see in the Section 2.3, there are only two viable breaking chains. Let us note that our results are in alignment with previous studies of gauge unification based solely on the minimal survival hypothesis [4]. This is due to the fact that the unification pattern is mostly influenced by gauge boson masses which are not much affected by the new perturbativity constraints.

2.2 Tachyonicity

One of the most important and best motivated consistency constraints is non-tachyonicity of the scalar masses[2]. The whole numerical calculation of full one-loop effective scalar masses was accomplished to solve the notorious tree-level tachyonic instabilities in the scalar spectrum. It extended previous calculations which involved only pseudo-Goldstone masses in specific limits [5, 6]. Moreover, this was accompanied by the procedure of "taming of the logs" which resolved an issue of non-physical IR diverging logarithms present in one-loop effective mass corrections. We showed that non-tachyonicity of such effective masses implies non-tachyonicity of physical masses as long as one remains in the perturbative regime.

2.3 Perturbativity

All calculations are performed in the perturbative regime. This aspect was almost ignored in previous studies of the parameter space, e.g. [7, 8]. Therefore novel perturbativity constraints are defined and imposed. These are very powerful in identifying viable part of the parameter space.

1. *Global mass perturbativity test* - the relative size of the full one-loop effective scalar mass corrections to the tree-level masses, parametrized by quantity $\bar{\Delta}$, is constrained.

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[1] The SM gauge couplings would not unify in case of the single-stage spontaneous symmetry breaking.

[2] Gauge masses are always non-tachyonic.

2. *Stability under the RG running* - the one-loop effective scalar masses possess residual renormalization scale dependence as they were calculated in the unphysical $\overline{\text{MS}}$ scheme. The whole set of the one-loop beta functions was derived to control stability under the RG running, which is parametrized by quantity $\bar{t}$.[3]

Furthermore, it turns out that the VEV structure of the one-loop scalar corrections is such that it allows only two viable scenarios that will not lead to potentially large contributions to the one-loop effective scalar masses. These are identified with two distinguished breaking chains with $SU(4)_C \times SU(2)_L \times U(1)_R$ or $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ intermediate symmetries.

As thresholds in the perturbativity criteria are chosen, to some degree, arbitrarily, we studied the effect of their strictness on the viable parameter space, see Figs. 1-2. One can observe preference for the $SU(4)_C \times SU(2)_L \times U(1)_R$ scenario which is more stable with respect to the perturbativity.

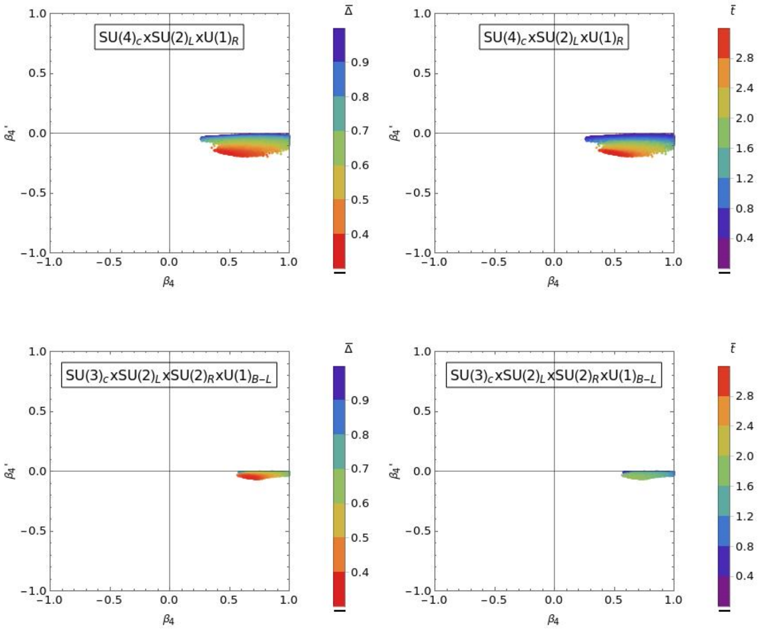

Figure 1: Scatter plots of viable points projected onto two scalar parameters (β_4, β_4') that shape the scalar mass spectrum. Colour encodes stability under the RG running ($\bar{t}$, the bigger the better) or magnitude of one-loop scalar mass corrections relative to tree-level values ($\bar{\Delta}$, the smaller the better).

3. Conclusions

The minimal realistic $SO(10)$ Higgs model under consideration is one of the models that allows for a proton lifetime analysis that is robust with respect to theoretical uncertainties. We performed a thorough parameter space investigation that involved theoretical consistency constraints as a first step towards a detailed proton decay study. Namely, we required Standard model gauge couplings to unify, mass spectrum to be non-tachyonic and all the calculations to conform perturbativity.

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[3] Roughly speaking, $\bar{t}$ quantifies how many orders of magnitude in renormalization scale one can run scalar couplings up and down before encountering Landau-pole type singularity.

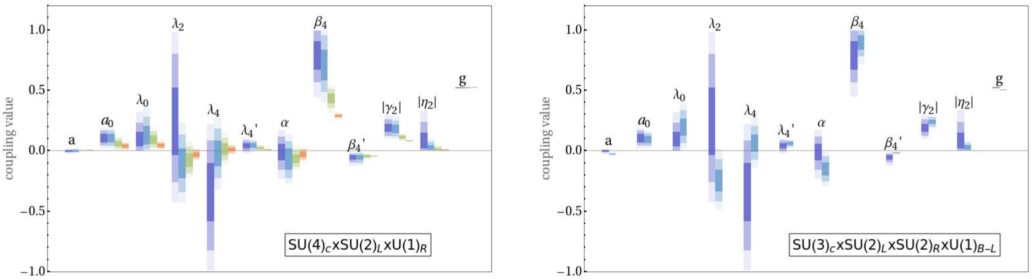

Figure 2: 1-σ, 2-σ and 3-σ highest density intervals (with decreasing opacity) of scalar parameters. Dark blue, light blue, green and orange colour encodes increasing strictness of the perturbativity measure controlling RG running stability.

For that the one-loop effective scalar masses were numerically calculated and one-loop scalar beta functions were derived.

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References

[1] M. Yasue, Phys. Rev. D **24** (1981), 1005 doi:10.1103/PhysRevD.24.1005

[2] S. Bertolini, L. Di Luzio and M. Malinsky, Phys. Rev. D **81** (2010), 035015 doi:10.1103/PhysRevD.81.035015 [arXiv:0912.1796 [hep-ph]].

[3] H. Kolešová and M. Malinský, Phys. Rev. D **99** (2019) no.3, 035005 doi:10.1103/PhysRevD.99.035005 [arXiv:1612.09178 [hep-ph]].

[4] S. Bertolini, L. Di Luzio and M. Malinsky, Phys. Rev. D **80** (2009), 015013 doi:10.1103/PhysRevD.80.015013 [arXiv:0903.4049 [hep-ph]].

[5] L. Gráf, M. Malinský, T. Mede and V. Susič, Phys. Rev. D **95** (2017) no.7, 075007 doi:10.1103/PhysRevD.95.075007 [arXiv:1611.01021 [hep-ph]].

[6] K. Jarkovská, Pseudo-Goldstone bosons in grand unified theories, Master thesis, 2018, available in the Thesis repository of the Charles University: http://hdl.handle.net/20.500.11956/99155.

[7] S. Bertolini, L. Di Luzio and M. Malinsky, Phys. Rev. D **87** (2013) no.8, 085020 doi:10.1103/PhysRevD.87.085020 [arXiv:1302.3401 [hep-ph]].

[8] H. Kolešová and M. Malinský, Phys. Rev. D **90** (2014) no.11, 115001 doi:10.1103/PhysRevD.90.115001 [arXiv:1409.4961 [hep-ph]].