Grimus-Neufeld modelio neutrino sektoriaus pernormavimas

Renormalization of the neutrino sector of Grimus-Neufeld model

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One of the challenges of contemporary particle physics is to explain the origin of the non-zero neutrino masses. Despite the fact that the first clear evidence of non-vanishing neutrino masses has been seen almost 20 years ago [1], there is still no final explanation for it. Numerous models have been proposed to accommodate this missing piece in the puzzle. For a review of some most popular ones, see [2]. One of the most straightforward ways to make a model that includes massive neutrinos is to take the Standard Model and extend it by the so called seesaw mechanism [3, 4]. In the seesaw mechanism, one postulates additional heavy neutral fermions that interact with the neutrinos of the Standard Model via the Higgs boson. After the electroweak symmetry breaking, the neutrinos acquire masses that are inversely proportional to the masses of the postulated additional fermions. So the seesaw mechanism not only explains the existence of the masses of neutrinos, but also the smallness of them, which is a highly desired feature for a model.

In the seesaw mechanism, the neutrinos couple to scalars of the theory. Hence, in the case of the Standard Model's scalar sector, they couple only to a single scalar particle - the Higgs boson. However, there is no evidence, that the scalar sector consists of only one Higgs boson. In fact, there are many theoretical motivations for an extended Higgs sector, such as grand unified theories or supersymmetric theories. The generic two Higgs doublet model is the extension in which there are two Higgs doublets instead of one. This model, paired with the seesaw mechanism, allows for yet another way of generating neutrino mass: via loop corrections. This means that the neutrino, which is massless at the zero order approximation, can acquire a mass radiatively, through the loops of the additional scalar particles. This set up, where both, the seesaw and radiative masses of neutrinos, are possible, is called Grimus-Neufeld model [5]. The minimal realization of this model is with one heavy fermion. This leads to one mass term for one light neutrino already at zero order approximation and a mass term for the second light neutrino only after the loop corrections are taken into account. One of the neutrinos still stays massless. However, the two non-zero masses are enough to explain experimentally observed neutrino oscillations, where only the mass differences enter.

Mass parameters of the neutrinos are defined in the renormalization procedure. The most commonly used scheme is the on-shell (OS) scheme, where the physical mass of the particle is defined as the real part of the pole of the propagator. However, it is shown that this scheme does not lead to a gauge invariant definition of the mass for unstable particles [6]. The solution to this problem is allowing the mass parameter to be complex and to coincide with the exact pole of the propagator. This definition of mass is proven to be gauge invariant at all orders [6]. The renormalization scheme using this definition of mass is called the complex mass scheme (CMS) [7, 8]. The propagators and the counterterms, however, can still stay gauge dependent.

We renormalize masses of the neutrinos of the Grimus-Neufeld model [5] at one loop level. We discuss the choices of OS and CMS renormalization schemes. By rearranging the loop corrections as proposed in [9], we define the mass counterterms to be gauge invariant and study the gauge invariance of the neutrino propagators.

Keywords: seesaw neutrinos, loop corrections, two Higgs doublet model, renormalization, gauge invariance

References

[1] Y. Fukuda *et al.*, "Evidence for oscillation of atmospheric neutrinos," *Phys. Rev. Lett.*, vol. 81, pp. 1562–1567, 1998.

[2] G. Senjanovic, "Neutrino mass: From LHC to grand unification," *Riv. Nuovo Cim.*, vol. 34, pp. 1–68, 2011.

[3] P. Minkowski, "$\mu \to e\gamma$ at a Rate of One Out of 10^9 Muon Decays?," *Phys. Lett.*, vol. B67, pp. 421–428, 1977.

[4] R. N. Mohapatra and G. Senjanovic, "Neutrino Mass and Spontaneous Parity Violation," *Phys. Rev. Lett.*, vol. 44, p. 912, 1980.

[5] W. Grimus and H. Neufeld, "Radiative Neutrino Masses in an SU(2) X U(1) Model," *Nucl. Phys.*, vol. B325, pp. 18–32, 1989.

[6] P. Gambino and P. A. Grassi, "The Nielsen identities of the SM and the definition of mass," *Phys. Rev.*, vol. D62, p. 076002, 2000.

[7] A. Denner and S. Dittmaier, "The Complex-mass scheme for perturbative calculations with unstable particles," *Nucl. Phys. Proc. Suppl.*, vol. 160, pp. 22–26, 2006. [,22(2006)].

[8] B. A. Kniehl and A. Sirlin, "Pole Mass, Width, and Propagators of Unstable Fermions," *Phys. Rev.*, vol. D77, p. 116012, 2008.

[9] S. Liebler and W. Porod, "Electroweak corrections to Neutralino and Chargino decays into a W-boson in the (N)MSSM," *Nucl. Phys.*, vol. B849, pp. 213–249, 2011. [Erratum: Nucl. Phys.B856,125(2012)].