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RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

RADIATIVE CORRECTIONS TO NEUTRINO MASS IN TYPE-3/2 SEESAW MECHANISM*

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ABSTRACT

Recently proposed Type-3/2 seesaw mechanism is an alternative model to the Type-I seesaw. In this novel mechanism the light neutrino masses are induced via a vector-spinor, which keeps the Higgs mass stabilized at one loop. Here, in this letter, radiative corrections to the light neutrino masses via this vector spinor are studied. It is shown that the active neutrinos get trivial correction from the vector spinor loop as long as the mass of vector spinor is at the order of 2.8×10^{12} *GeV or higher. This is in agreement with the minimum mass value required for inducing active neutrino masses (*$M_\psi \approx 10^{14}$ *GeV) and naturalness criteria of Higgs field (*$M_\psi \approx 10^{16}$ *GeV) in Type-3/2 seesaw mechanism.*

Keywords: *Neutrino Mass, Type-3/2 Seesaw Mechanism, Radiative Corrections.*

TİP-3/2 TAHTAREVALLİ MEKANİZMASINDA NÖTRİNO KÜTLESİNE GELEN IŞINIMSAL DÜZELTMELER

ÖZ

Yakın zamanda önerilen Tip-3/2 tahterevalli mekanizması, Tip-I tahterevalliye alternatif bir modeldir. Bu yeni mekanizmada, hafif nötrino kütleleri, Higgs kütlesini bir döngüde sabit tutan bir vektör-spinör aracılığıyla indüklenir. Burada, bu makalede, bu vektör spinör aracılığıyla hafif nötrino kütlelerine yapılan ışınımsal düzeltmeler incelenmiştir. Vektör spinör kütlesi $2.8 \times 10^{12}\ GeV$ *veya daha yüksek olduğu sürece, aktif nötrinoların vektör spinör döngüsünden önemsiz düzeltmeler aldığı gösterilmiştir. Bu, Tip-3/2 tahterevalli mekanizmasında aktif nötrino kütlelerini indüklemek için gereken minimum kütle değeri (*$M_{\psi} \approx 10^{14}\ GeV$*) ve Higgs alanının doğallık kriteri (*$M_{\psi} \approx 10^{16}\ GeV$*) ile uyumludur.*

Anahtar Kelimeler: *Nötrino Kütlesi, Tip-3/2 Tahtarevalli Mekanizması, Işınımsal Düzeltmeler.*

1. INTRODUCTION

One of the outstanding shortcomings of the Standard Model (SM) is small but nonzero neutrino masses. SM predicts that neutrinos have no mass, which is in contradiction with results from experiments detecting neutrinos from the Sun (Simirnov, 2003) as well as atmospheric neutrinos produced by cosmic rays (Y. Fukuda et al. [Super-Kamiokande], 1998). This conflict between the theory and experiments shows that SM needs to be extended with at least a new physics (NP) field.

Neutrino physics has come of age in the past two decades (Balantekin and Kayser, 2018). However, the nature of neutrino mass is still an open question. Neutrinos may be Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$) particles. Although, there are many Dirac mass models in which lepton number conservation is imposed without a satisfactory reason (Demir et al., 2008; Bonilla and Valle, 2016; Wang and Han, 2017; Yao and Ding., 2018; Calle et al., 2019; Saad, 2019; Jana et al., 2019), due to the fact that the constructions are more simpler and economical, Majorana-type neutrinos which violate lepton number seem to be the more promising case. In literature, there is a vast number of attempts to explain light neutrino masses via new physics beyond the SM. The first and foremost among them is the seesaw mechanism (Gell-Mann et al., 1979) introducing the Majorana-type particles as right handed neutrinos of heavy masses at GUT scale, which generate the light neutrino masses at tree-level from a dimension-5 operator: the Weinberg operator. In this mechanism, the mediator of Weinberg operator is a singlet fermion and this is the first attempt (Type-I seesaw mechanism) to obtain the suppressed neutrino masses via a new physics scale with a factor v_H/Λ_{NP}. There are also Type-II seesaw (Cheng and Li, 1980; Schechter and Valle, 1980) (Mediator: A triplet scalar) and Type-III seesaw (Foot et al., 1989) (Mediator: A triplet fermion) mechanisms in literature. Apart from the seesaw mechanisms at tree level, there are also radiative neutrino mass models (Hou and Wong, 1994; Nomura et al., 2021; Ma and Suematsu, 2009; Babu and Julio, 2012; Hehn and Ibarra, 2013; Nomura et al., 2017; Ahriche et al., 2018), which produce neutrino masses at loop levels (for the most recent reviews see (Cai et al., 2017; Klein et al., 2019)). Despite numerous neutrino mass models (Herrero-García and Schmidt, 2019), the non-observation of right handed neutrinos, Higgs triplets of $SU(2)_l$ and the glitches associated with the non-renormalizable terms, which are part of some of these models show the necessity to continue the studies on BSM.

Recently, a completely new approach to the neutrino mass problem has been put forward and dubbed the Type-3/2 seesaw mechanism, in which the SM is extended with vector-spinor fields (Demir et al., 2021). The novelty of this new approach lies in the fact that while the quantum corrections due to the huge mass of the right handed neutrinos involved in the Type-I seesaw worsen the big hierarchy problem, the corrections from the Spin-3/2 field solve the same problem at a certain value of mass which happens to fall in the neutrino mass generation range. This advantage makes the Type-3/2 seesaw mechanism a very promising model. In this brief letter, with the investigation of radiative corrections to light neutrino masses via vector spinors we have shown that Type-3/2 seesaw mechanism is a stronger model inducing light neutrino masses, solving naturalness problem and also keeping the light neutrino masses stabilized.

The paper is organized as follows: In Sec.2 we give the basics of vector spinor fields, the constraints on them and introduce the interaction between the Higgs sector and vector spinor field. In Sec.3 we explain the Type-3/2 seesaw mechanism and give the radiative correction to neutrino masses via vector-spinor. Finally, Sec.4 is devoted to the comments and discussion.

2. MODEL

Vector spinor fields ψ_α , introduced by Rarita and Schwinger (Rarita and Schwinger, 1941) have the propagator

$$S^{\mu\nu}(p) = \frac{i}{p-M} \Pi^{\mu\nu}(p) \qquad (\mathbf{1})$$

Carrying one Spin-3/2 proper and two auxiliary Spin-1/2 components through the projector

$$\Pi^{\mu\nu} = -\eta^{\mu\nu} + \frac{\gamma^\mu \gamma^\gamma}{3} + \frac{(\gamma^\mu p^\nu - \gamma^\nu p^\mu)}{3M} + \frac{2p^\mu p^\nu}{3M^2} \qquad (\mathbf{2})$$

These fields exhibit both spinor and vector characteristics and it is necessary to impose the two constraints (Pascalutsa, 2001; Pilling, 2005)

$$p^{\alpha}\psi_{\alpha}(p)|_{p^2=M^2} = 0 \tag{3}$$

and

$$\gamma^{\alpha}\psi_{\alpha}(p)|_{p^2=M^2} = 0 \tag{4}$$

to eliminate the two auxiliary Spin-1/2 components and make ψ_{α} satisfy the Dirac equation that is expected of an on-shell fermion.

The important implication that constraints (3) and (4) convey is that $p^{\alpha}\psi_{\alpha}(p)$ and $\gamma^{\alpha}\psi_{\alpha}(p)$ both vanishes on the physical shell (Demir et al., 2017).

As a singlet fermion, ψ_{α}, at the renormalizable level, makes contact with the SM through the neutrino portal

$$L_{int}^{H-L-\psi} = C_{3/2}^{ik}\overline{L^i}H\gamma^{\alpha}\psi_{\alpha}^{k} + h.c. \tag{5}$$

in which L^i is the lepton doublet ($i = 1,2,3$), H is the Higgs doublet with vacuum expectation value $v_H \approx 246\ GeV$ and ψ_{α} is the vector spinor with Lorentz index ($\alpha = 0,1,2,3$) and generation index ($k = 1,2,3$).

3. RADIATIVE CORRECTION TO LIGHT NEUTRINO MASSES VIA VECTOR SPINOR

In the recently proposed Type-3/2 seesaw mechanism (Demir et al., 2021) the light neutrino masses are induced in the same way as the Type-I seesaw mechanism via the diagram given in Figure 1.

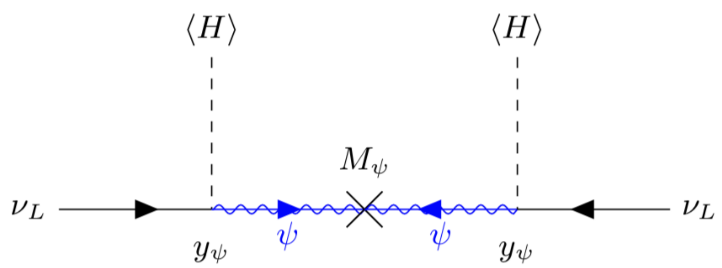

Figure 1. Diagrammatic representation of the Type-3/2 seesaw mechanism.

Type-3/2 seesaw mechanism induces the light neutrino masses as below

$$m_\psi = \frac{2C_\psi^2 \langle H \rangle^2}{9M_\psi} \qquad \textbf{(6)}$$

in which only one kind of vector spinor is considered for convenience. It is obvious that, to be able to induce light neutrino masses compatible with the observations, the mass of vector spinor must be at least around $10^{14}\ GeV$ for a coupling constant $C_\psi \ \approx \ \mathcal{O}(1)$.

Considering the interaction (5) along with the constraint (4), it is easy to see that the natural habitat for the vector spinor ψ_α is loop diagrams. One such important loop diagram through which the effects of ψ_α manifest itself is the Higgs self-energy correction induced by the $\nu - \boldsymbol{\psi}$ loop (Sargın, 2020).

Another equally important loop diagram is the neutrino mass correction induced by $H^0 - \boldsymbol{\psi}$ loop and will be the subject of this section.

The interaction given in (5) leads to one loop correction to neutrino mass via the diagram given in Figure 2.

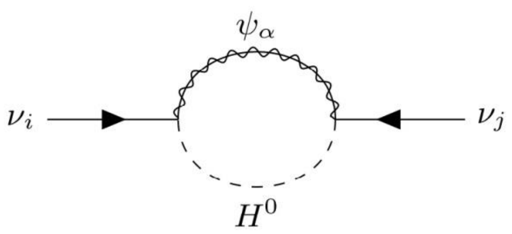

Figure 2. Higgs-vector spinor loop that contributes to the active neutrino masses in Type-3/2 seesaw mechanism.

The correction to active neutrino mass from $H^0 - \psi$ loop is given by

$$(\delta m_\nu)_\psi = -\frac{C_\psi^2}{24\pi^2}\frac{M_H^2}{M_\psi} ln \frac{\mu^2}{M_H^2} \qquad \textbf{(7)}$$

Here, C_ψ's are pure numerical constants at the order of $\mathcal{O}(1)$ and the parameter $M_H = 125.6$ GeV. The value of μ does not change the value of the correction significantly. Thus, μ is fixed the value 1 TeV which is at the order of electroweak scale. Then, the only relevant parameter one is left with in determining the radiative corrections to neutrino masses is M_ψ.

In that regard, from the analysis depicted in Figure 3, it is seen that to stabilize the neutrino mass against the radiative correction by $H^0 - \psi$ loop, the mass of vector-spinor should be 2.8×10^{12} GeV or higher. When we consider this correction in Type-3/2 seesaw mechanism, the vector-spinor field with the mass at the order of 10^{14} GeV is more than capable of keeping the neutrino mass stable against radiative correction by $H^0 - \psi$ loop.

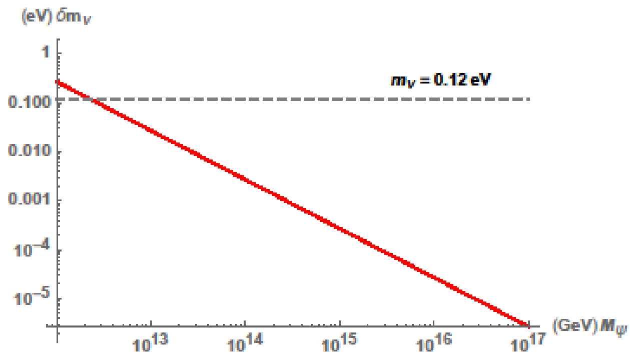

Figure 3. The radiative correctons to active neutrino masses vs the mass of Spin-3/2 field.

4. CONCLUSION

In this paper, we show that in novel Type-3/2 seesaw mechanism the light neutrino masses remain stabilized at loop level via vector spinors, which appear only in loops at renormalizable level. The mass of vector-spinor field required by inducing the active neutrino masses in Type-3/2 seesaw mechanism leads to trivial radiative corrections to the masses of light neutrinos. $M_\psi \approx 10^{14}\, GeV$ leads to $\delta m_\nu \approx 0.002\, eV$ corrections, which is in agreement with the upper bound on the lightest neutrino mass scale.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

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