Type-II Seesaw Triplet Scalar Effects on Neutrino Trident Scattering

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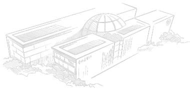

Content

Neutrino trident scattering

Neutrino Trident Scattering (NTS) is a weak process:

A neutrino, scattering off a heavy nucleus, generates a pair of charged leptons.

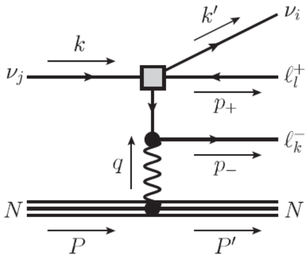

Figure 1: Diagrams for the $\nu_j \to \nu_i \ell_k^- \ell_l^+$.

Neutrino trident scattering

1964 Trident scattering to examine the V-A theory.
(Czyz, Sheppey, and Walecka)

1971 Momentum and angular distribution of the NTS.
(Lovseth and Radomiski, Koike et al, Fujikawa)

1972 Trident scattering to examine the W-S theory.
(Brown, Hobbs, Smith and Stanko)

Measurements of $\nu_\mu \to \nu_\mu \mu^+ \mu^-$.

1990 $\frac{\sigma_{\text{exp}}}{\sigma_{\text{SM}}} = 1.58^{+0.64}_{-0.64}$ CHARM-II. (Geiregat et al., 1990.)

1991 $\frac{\sigma_{\text{exp}}}{\sigma_{\text{SM}}} = 0.82^{+0.28}_{-0.28}$ CCFR. (S. R. Mishra et al., 1991.)

1999 $\frac{\sigma_{\text{exp}}}{\sigma_{\text{SM}}} = 0.72^{+1.73}_{-0.72}$ NuTeV. (T. Adams et al., 2000)

The average value $\frac{\sigma_{\text{exp}}}{\sigma_{\text{SM}}} = 0.95^{+0.25}_{-0.25}$

Revival

2014 Trident scattering to constrain new physics.
(Altmannshofer, Gori, Pospelov, and Yavin)

Neutrino trident scattering

In SM, the interaction terms between μ and ν_μ are

$$
\begin{aligned}
\mathcal{L}_W =& \frac{g}{2\sqrt{2}} \left(\bar{\nu}_\mu \gamma^\alpha \left(1-\gamma^5\right) \mu W_\alpha^+ + \bar{\mu}\gamma^\alpha \left(1-\gamma^5\right) \nu_\mu W_\alpha^-\right) \\
\mathcal{L}_Z =& \frac{g}{4\cos\theta_W} \left(\bar{\nu}_\mu \gamma^\alpha \left(1-\gamma^5\right) \nu_\mu + \bar{\mu}\gamma^\alpha \left(-1+\gamma^5+4\sin^2\theta_W\right) \mu\right) Z_\alpha
\end{aligned}
\tag{1.1}
$$

So in SM, a $\mu^+\mu^-$ pair can be generated by W and Z exchange from the operator

$$
\begin{aligned}
& \frac{g^2}{8m_W^2} \bar{\nu}_\mu \gamma^\alpha \left(1-\gamma^5\right) \nu_\mu \bar{\mu}\gamma_\alpha \left(1-\gamma^5\right) \mu \\
& \frac{g^2}{16m_W^2} \bar{\nu}_\mu \gamma^\alpha \left(1-\gamma^5\right) \nu_\mu \bar{\mu}\gamma_\alpha \left(-1+\gamma^5+4\sin^2\theta_W\right) \mu
\end{aligned}
\tag{1.2}
$$

where the momentum transfer is much smaller than m_W.

Neutrino trident scattering

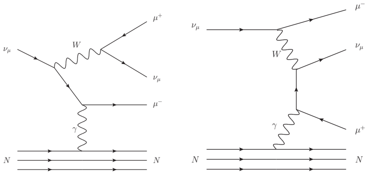

Figure 2: W contribution.

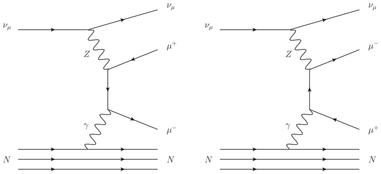

Figure 3: Z contribution.

In SM, the weak interaction contribution would be

$$\frac{g^2}{16m_W^2}\bar{\nu}_\mu\gamma^\alpha\left(1-\gamma^5\right)\nu_\mu\bar{\mu}\gamma_\alpha\left(1-\gamma^5+4\sin^2\theta_W\right)\mu \qquad (1.3)$$

Type-II Seesaw

In Type-II Seesaw, one heavy Higgs triplet Δ is added[1], which contributes to reduce the cross section of NTS.

Table 1: Quantum number of the particles concerned with type-II seesaw. $Q = I_3 + Y$.

		$SU(2)_L$	$U(1)_Y$
L_{L_i}	$\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$	2	$-\frac{1}{2}$
Φ	$\begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$	2	$\frac{1}{2}$
Δ	$\begin{pmatrix} \Delta^+/\sqrt{2} & \Delta^{++} \\ \Delta^0 & -\Delta^+/\sqrt{2} \end{pmatrix}$	3	1

[1] Konetschny and Kummer, 1977; Magg and Wetterich,1980; Schechter and Valle, 1980; Cheng and Li, 1980; Lazarides et al., 1981; Mohapatra and Senjanovic, 1981.

Type-II Seesaw

The extra Yukawa coupling term

$$-\mathcal{L}_{M_\nu} = f_{ij} L_{L_i}^T C i\sigma^2 \Delta L_{L_j} + \text{h.c.} \tag{1.4}$$

1. lepton number violated by 2.
2. generate Majorana mass matrix of neutrino after SSB.

Type-II Seesaw

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1. lepton number violated by 2.
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Covariant derivative,

$$\begin{aligned} D_\mu \Phi =& \partial_\mu \Phi - i\frac{g}{2} W_\mu^a \sigma^a \Phi - i\frac{g'}{2} B_\mu \Phi \\ D_\mu \Delta =& \partial_\mu \Delta - i\frac{g}{2}\left[W_\mu^a \sigma^a, \Delta\right] - ig' B_\mu \Delta. \end{aligned} \tag{1.5}$$

Type-II Seesaw

The Higgs sector is also extended

$$\mathcal{L}_{\text{Higgs}} = \left(D^{\mu}\Phi\right)^{\dagger}\left(D_{\mu}\Phi\right) + \text{Tr}\left[\left(D^{\mu}\Delta\right)^{\dagger}\left(D_{\mu}\Delta\right)\right] - V(\Phi,\Delta). \quad (1.6)$$

where

$$\begin{aligned} V(\Phi,\Delta) = &- m_{\Phi}^{2}\Phi^{\dagger}\Phi + M^{2}\,\text{Tr}\,\Delta^{\dagger}\Delta + \left(\mu\Phi^{T}i\sigma^{2}\Delta^{\dagger}\Phi + \text{ h.c. }\right) \\ &+ \frac{\lambda}{4}\left(\Phi^{\dagger}\Phi\right)^{2} + \lambda_{1}\Phi^{\dagger}\Phi\,\text{Tr}\,\Delta^{\dagger}\Delta + \lambda_{2}\left(\text{Tr}\,\Delta^{\dagger}\Delta\right)^{2} \\ &+ \lambda_{3}\,\text{Tr}\left(\Delta^{\dagger}\Delta\right)^{2} + \lambda_{4}\Phi^{\dagger}\Delta\Delta^{\dagger}\Phi. \end{aligned} \quad (1.7)$$

Type-II Seesaw

After SSB,

$$\langle\Phi\rangle \overset{SSB}{\Longrightarrow} \begin{pmatrix} 0 \\ v_d/\sqrt{2} \end{pmatrix} \qquad \langle\Delta\rangle \overset{SSB}{\Longrightarrow} \begin{pmatrix} 0 & 0 \\ v_\Delta/\sqrt{2} & 0 \end{pmatrix}.$$

$$m_\Phi^2 = \frac{\lambda}{4}v_d^2 + \frac{\lambda_1+\lambda_4}{2}v_\Delta^2 - \sqrt{2}\mu v_\Delta$$

$$M^2 = -\frac{\lambda_1+\lambda_4}{2}v_d^2 - (\lambda_2+\lambda_3)\,v_\Delta^2 + \frac{\mu v_d^2}{\sqrt{2}v_\Delta} \sim m_\Delta^2 \equiv \frac{\mu v_d^2}{\sqrt{2}v_\Delta}. \tag{1.8}$$

we can generate the mass of gauge bosons and Higgs bosons

$$m_W^2 = \frac{g^2(v_d^2+2v_\Delta^2)}{4} \qquad m_Z^2 = \frac{(g^2+g'^2)(v_d^2+4v_\Delta^2)}{4}. \tag{1.9}$$

Type-II Seesaw

To show the mass of Higgs bosons, we write Φ and Δ in more explicit form

$$\Phi = \begin{pmatrix} \phi^+ \\ (v_d + h_d + iz_d)/\sqrt{2} \end{pmatrix}, \quad \Delta = \begin{pmatrix} \Delta^+/\sqrt{2} & \Delta^{++} \\ (v_\Delta + h_t + iz_t)/\sqrt{2} & -\Delta^+/\sqrt{2} \end{pmatrix} \tag{1.10}$$

Then from $\mathcal{L}_{\text{Higgs}}$, we can get the mass of Δ^{++} easily

$$m^2_{\Delta^{++}} = \frac{\mu v_d^2}{\sqrt{2} v_\Delta} - \frac{\lambda_4}{2} v_d^2 - \lambda_3 v_\Delta^2 \approx \frac{\mu v_d^2}{\sqrt{2} v_\Delta} = m^2_\Delta. \tag{1.11}$$

Type-II Seesaw

While Δ^+ would mix with ϕ^+, ie.

$$\mathcal{L}_{\text{Higgs}} \supset \begin{pmatrix} \phi^+ & \Delta^+ \end{pmatrix} M_{\text{charged}} \begin{pmatrix} \phi^+ \\ \Delta^+ \end{pmatrix}, \\ M_{\text{charged}} = \begin{pmatrix} \sqrt{2}\mu v_\Delta - \frac{\lambda_4 v_\Delta^2}{2} & -\mu v_d + \frac{\sqrt{2}}{4}\lambda_4 v_\Delta v_d \\ -\mu v_d + \frac{\sqrt{2}}{4}\lambda_4 v_\Delta v_d & \frac{\mu v_d^2}{\sqrt{2} v_\Delta} - \lambda_4 v_d^2 \end{pmatrix} \tag{1.12}$$

where $\det(M_{\text{charged}})=0$ and $\text{Tr}(M_{\text{charged}}) \neq 0$.

Type-II Seesaw

So there's a Goldstone boson

$$G^{\pm} \equiv \cos\beta\phi^{\pm} + \sin\beta\Delta^{\pm}, \tag{1.13}$$

where $\tan\beta = \frac{\sqrt{2}v_\Delta}{v_d}$. It would be eaten up by $W^{\pm}_{\mu}$ boson.

And a massive physical field $H^{\pm}$ is left,

$$H^{\pm} \equiv -\sin\beta\phi^{\pm} + \cos\beta\Delta^{\pm}, \quad m^2_{H^+} = \frac{\left(2\sqrt{2}\mu - \lambda_4 v_\Delta\right)}{4v_\Delta}\left(v_d^2 + 2v_\Delta^2\right). \tag{1.14}$$

Because of the small mixing angle β, we can always treat H^+ as Δ^+ approximatively, eg.

$$m^2_{\Delta^+} = m^2_{H^+} \approx \frac{\mu v_d^2}{\sqrt{2}v_\Delta} = m^2_\Delta. \tag{1.15}$$

Type-II Seesaw

Acquire the neutrino mass matrix from the added Yukawa coupling terms $\mathcal{L}_{M_\nu}$,

$$\begin{aligned} -\mathcal{L}_{M_\nu} =& f_{ij} L^T_{L_i} C i\sigma^2 \Delta L_{L_j} + \text{h.c.} \\ =& - f_{ij}\bar{\ell^c_i} P_L \ell_j \Delta^{++} - \sqrt{2} f_{ij} \bar{\nu^c_i} P_L \ell_j \Delta^{+} + f_{ij} \bar{\nu^c_i} P_L \nu_j \Delta^{0} + \text{h.c.} \ , \end{aligned} \tag{1.16}$$

the last term would induce a Majorana-type mass matrix, ie.

$$m_{ij} = (M_\nu)_{ij} = \sqrt{2} f_{ij} \nu_\Delta = \frac{\mu v_d^2}{m_\Delta^2} f_{ij}, \tag{1.17}$$

so the neutrino masses are suppressed by the mass of added Higgs boson m_Δ.

Content

Type-II Seesaw contribution to NTS

$$-\mathcal{L}_{M_\nu} = -f_{ij}\overline{\ell_i^c}P_L\ell_j\Delta^{++} - \sqrt{2}f_{ij}\overline{\nu_i^c}P_L\ell_j\Delta^{+} + f_{ij}\overline{\nu_i^c}P_L\nu_j\Delta^0 + \text{h.c.} \ .$$

In type-II seesaw model, a $\mu^+\mu^-$ pair can be generated by Δ^+,

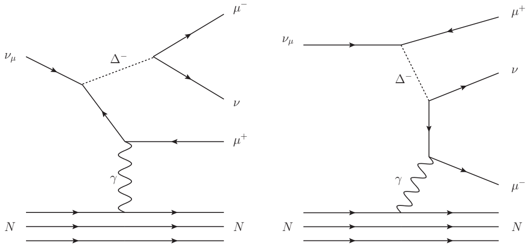

Figure 4: Type-II Seesaw contribution to NTS.

Type-II Seesaw contribution to NTS

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The effective operator would be

$$\frac{2f_{ij}f^*_{kl}}{m^2_\Delta}\bar{\nu^c_i}P_L\ell_j\bar{\ell}_lP_L\nu^c_k = \frac{m_{ij}m^*_{kl}}{2m^2_\Delta v^2_\Delta}\bar{\nu}_k\gamma^\mu P_L\nu_i\bar{\ell}_l\gamma_\mu P_L\ell_j \tag{2.1}$$

Notice that we should sum over all flavor neutrinos in final states. Then we get the final modification

$$\frac{\sigma}{\sigma_{SM}} = \frac{1}{(1+4s^2_w)^2+1}\left(\left(1+4s^2_w-\frac{2m^2_W}{g^2}\frac{|m_{\mu\mu}|^2}{m^2_\Delta v^2_\Delta}\right)^2+\left(1-\frac{2m^2_W}{g^2}\frac{|m_{\mu\mu}|^2}{m^2_\Delta v^2_\Delta}\right)^2 + 2\left(\frac{2m^2_W\,|m_{\mu\mu}|^2}{g^2m^2_\Delta v^2_\Delta}\right)^2\left(\frac{|m_{e\mu}|^2+|m_{\tau\mu}|^2}{|m_{\mu\mu}|^2}\right)\right), \tag{2.2}$$

where $\frac{m^2_W}{g^2}$ could be replaced by the electroweak vev v because

$$\frac{4m^2_W}{g^2} = v^2_d + 2v^2_\Delta = v^2 = \frac{1}{\sqrt{2}G_F} = (246\text{GeV})^2 \tag{2.3}$$

Type-II Seesaw contribution to NTS

Treat the ratio as a quadratic function of $\frac{1}{m_\Delta^2 v_\Delta^2}$

$$\frac{\sigma}{\sigma_{\text{SM}}} = a\left(\frac{1}{m_\Delta^2 v_\Delta^2}\right)^2 + b\left(\frac{1}{m_\Delta^2 v_\Delta^2}\right) + 1, \tag{2.4}$$

where

$$a = \frac{\left(v^2\left|m_{\mu\mu}\right|^2\right)^2\left(1 + \frac{\left|m_{e\mu}\right|^2 + \left|m_{\tau\mu}\right|^2}{\left|m_{\mu\mu}\right|^2}\right)}{2\left(\left(1+4s_w^2\right)^2 + 1\right)}$$
$$b = -\frac{v^2\left|m_{\mu\mu}\right|^2\left(2+4s_w^2\right)}{\left(1+4s_w^2\right)^2+1} \tag{2.5}$$

When degenerating to SM, we can see that

$$m_\Delta^2 v_\Delta^2 \to \infty, \qquad \frac{\sigma}{\sigma_{SM}} \to 1,$$

which means that the type-II contribution to trident scattering is negligible if $m_\Delta^2 v_\Delta^2$ is very large.

Type-II Seesaw contribution to NTS

With the property of quadratic function, we can draw the figure,

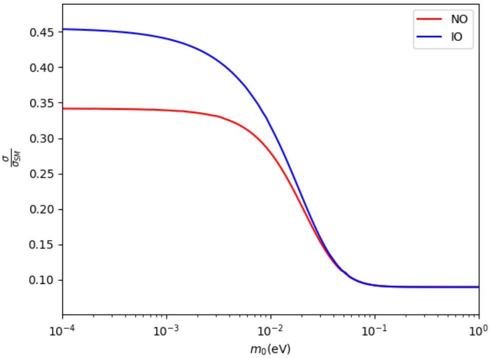
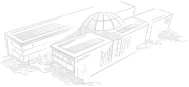


Figure 5: The rough lower bound of the ratio $\frac{\sigma}{\sigma_{\rm SM}}$.

Constrains on type-II seesaw

Use upper bound of $\dfrac{1}{m_\Delta^2 v_\Delta^2}$ to constrain $\dfrac{\sigma}{\sigma_{SM}}$ better.

1. $\ell_i^- \to \ell_j^+ \ell_k^- \ell_l^-$
2. $\ell_i^- \to \ell_j^- \gamma$



Constrains on type-II seesaw

$$-\mathcal{L}_{M_\nu} = -f_{ij}\bar{\ell_i^c}\ell_j\Delta^{++} - \sqrt{2}f_{ij}\bar{\nu_i^c}\ell_j\Delta^{+} + f_{ij}\bar{\nu_i^c}\nu_j\Delta^{0} + \text{h.c.}\ .$$

$\ell_i^- \to \ell_j^+\ell_k^-\ell_l^-$ arises at tree level and is mediated by Δ^{++}.

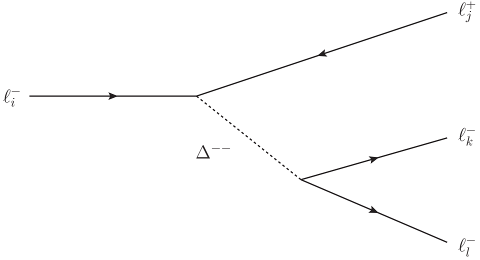


Figure 6: The diagram of $\ell_i^- \to \ell_j^+\ell_k^-\ell_l^-$.

Constrains on type-II seesaw

Its rate is found to be

$$\Gamma\left(\ell_i^- \rightarrow \ell_j^+ \ell_k^- \ell_l^-\right) = \frac{1}{2\left(1+\delta_{kl}\right)} \frac{m_{\ell_i}^5}{192\pi^3} \left| \frac{f_{ij} f_{kl}}{m_\Delta^2} \right|^2 . \qquad (2.6)$$

With the upper bound of branching ratio, we can give the lower bound of $m_\Delta^2 v_\Delta^2$.

Process	Branching[2]	Constraint
$\mu^- \rightarrow e^+ e^- e^-$	1.0×10^{-12}	$m_\Delta v_\Delta > \left| (M_\nu)_{\mu e} (M_\nu)_{ee} \right|^{1/2} \times 145\text{TeV}$
$\tau^- \rightarrow \mu^+ e^- e^-$	1.5×10^{-8}	$m_\Delta v_\Delta > \left| (M_\nu)_{\tau\mu} (M_\nu)_{ee} \right|^{1/2} \times 8.6\text{TeV}$
$\tau^- \rightarrow \mu^+ \mu^- e^-$	2.7×10^{-8}	$m_\Delta v_\Delta > \left| (M_\nu)_{\tau\mu} (M_\nu)_{\mu e} \right|^{1/2} \times 8.8\text{TeV}$
$\tau^- \rightarrow \mu^+ \mu^- \mu^-$	2.1×10^{-8}	$m_\Delta v_\Delta > \left| (M_\nu)_{\tau\mu} (M_\nu)_{\mu\mu} \right|^{1/2} \times 7.9\text{TeV}$

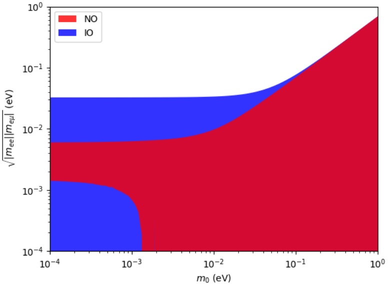
[2] R. Primulando, J. Julio and P. Uttayarat, 2019.

Constrains on type-II seesaw

These constrains are weak. eg, for $\mu^- \to e^+ e^- e^-$,

Figure 7: The range of $|m_{\mu e} m_{ee}|^{1/2}$.

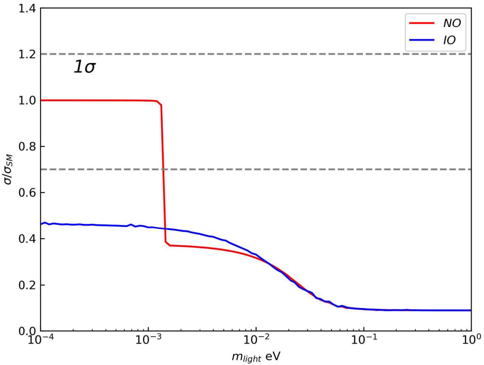
The lower bound of $m_\Delta^2 v_\Delta^2$ is significant only when lightest neutrino mass m_0 is smaller that 10^{-3}.



Constrains on type-II seesaw

So the range of ratio is still very large.

Figure 8: The lower bound of the ratio $\frac{\sigma}{\sigma_{\text{SM}}}$ with the constrain from $\mu^- \to e^+e^-e^-$.



Constrains on type-II seesaw

$$-\mathcal{L}_{M_\nu} = -f_{ij}\overline{\ell^c_i}\ell_j\Delta^{++} - \sqrt{2}f_{ij}\overline{\nu^c_i}\ell_j\Delta^{+} + f_{ij}\overline{\nu^c_i}\nu_j\Delta^{0} + \text{h.c.}\ .$$

$\ell_i^- \to \ell_j^-\gamma$ occurs through one-loop penguin diagrams, mediated either by Δ^+ or Δ^{++},

Constrains on type-II seesaw

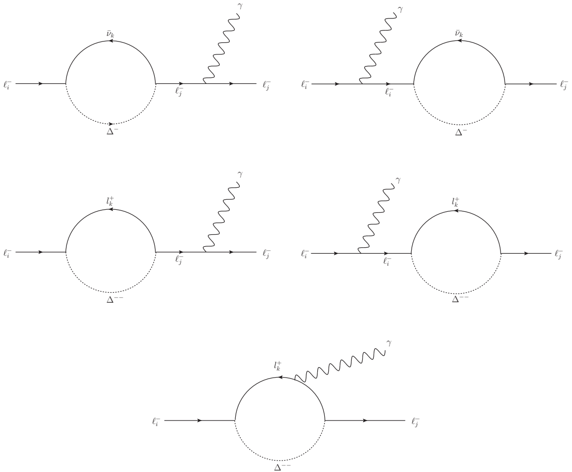


Figure 9: The diagram of $\ell_i^- \to \ell_j^- \gamma$.

Constrains on type-II seesaw

Neglected all internal lepton masses, we can get decay rate,

$$\Gamma\left(\ell_i^- \to \ell_j^- \gamma\right) = \frac{m_{\ell_i}^5 \alpha_{em}}{(192\pi^2)^2} \left|f^\dagger f\right|_{ij}^2 \left(\frac{1}{m_{\Delta^+}^2} + \frac{8}{m_{\Delta^{++}}^2}\right)^2 = \frac{m_{\ell_i}^5 \alpha_{em}}{(192\pi^2)^2} \left(\frac{9\left|f^\dagger f\right|_{ij}}{m_\Delta^2}\right)^2 . \tag{2.7}$$

Lower bound of $m_\Delta^2 v_\Delta^2$ could be

Process	Branching[3]	Constraint
$\mu^- \to e^-\gamma$	4.2×10^{-13}	$m_\Delta v_\Delta > \sqrt{9\left\|M_\nu^\dagger M_\nu\right\|_{\mu e}} \times 15.3\text{TeV}$
$\tau^- \to e^-\gamma$	3.3×10^{-8}	$m_\Delta v_\Delta > \sqrt{9\left\|M_\nu^\dagger M_\nu\right\|_{\mu e}} \times 0.6\text{TeV}$
$\tau^- \to \mu^-\gamma$	4.4×10^{-8}	$m_\Delta v_\Delta > \sqrt{9\left\|M_\nu^\dagger M_\nu\right\|_{\mu e}} \times 0.56\text{TeV}$

[3] R. Primulando, J. Julio and P. Uttayarat, 2019.

Constrains on type-II seesaw

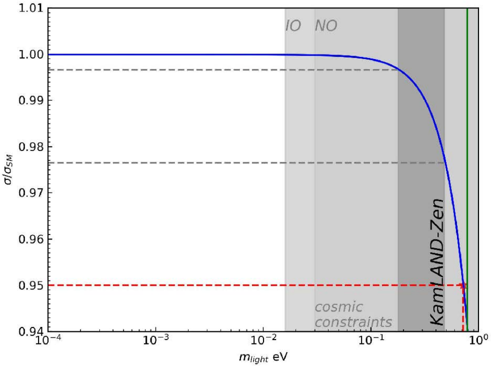
These constrains are much stronger, eg,

$$0.041\text{eV} < 3\sqrt{\left|M_\nu^\dagger M_\nu\right|_{\mu e}} < 0.054\text{eV}. \tag{2.8}$$

Constrains on type-II seesaw

So the range of ratio is very small.

Figure 10: The lower bound of the ratio $\frac{\sigma}{\sigma_{\mathrm{SM}}}$ with the constrain from $\mu^- \to e^-\gamma$.

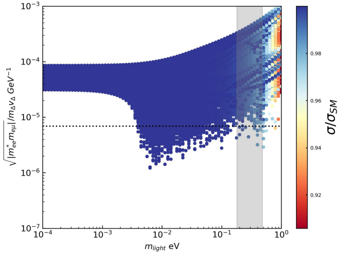


Constrains on type-II seesaw

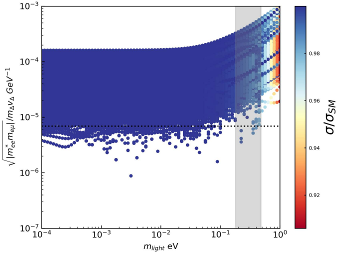
To combine the constrains from $\mu^- \to e^+e^-e^-$ and $\mu^- \to e^-\gamma$,

1. v_Δ in $(6.3 \sim 20)\mathrm{eV}\left(\frac{100\mathrm{GeV}}{m_\Delta}\right) \Rightarrow \Gamma(\mu \to e\gamma)$ is satisfied.
2. scanning the parameter in 3σ region.
3. calculate the $\Gamma(\mu \to e^+e^-e^-)$ and $\frac{\sigma}{\sigma_{SM}}$.

Figure 11: Combine two constrains.



(a) NO



(b) IO

Content

Recent Experimental data

The recent new measurement W mass by CDF,

$$m_W^{\text{CDF}} = 80,433.5 \pm 9.4\text{MeV},$$

7σ level above the SM prediction,

$$m_W^{\text{SM}} = 80,357 \pm 6\text{MeV}.$$

Keeping other SM parameters unchanged as before,

$$\rho \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = 1.0019.$$

Type-II seesaw modification on W mass

In type-II seesaw model, the mass of W and Z are changed as

$$m_W^2 = \frac{g^2(v_d^2 + 2v_\Delta^2)}{4} \qquad m_Z^2 = \frac{(g^2 + g'^2)(v_d^2 + 4v_\Delta^2)}{4},$$

so we can easily acquire

$$\rho = 1 + \Delta\rho = 1 - \frac{2v_\Delta^2}{v_d^2 + 4v_\Delta^2}. \tag{3.1}$$

It's evidently smaller than 1, which is contradict to what we discussed before.

Type-II seesaw modification on W mass

Considering

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2}, \tag{3.2}$$

we get that $v_d^2 + 2v_\Delta^2 = v^2 = (246\text{GeV})^2$. Meanwhile ,

$$\rho = 1 - \frac{2v_\Delta^2}{v_d^2 + 4v_\Delta^2} = 1 - \frac{2v_\Delta^2}{v^2 + 2v_\Delta^2} = \frac{1}{1 + 2\left(\frac{v_\Delta}{v}\right)^2} \tag{3.3}$$

Signiffcant effect on ρ needs v_Δ to be of order a GeV or so.

As the modification is in the wrong direction, so we want v_Δ to be little small

Type-II seesaw modification on W mass

Notice the constrains we discussed before,

$$\begin{aligned} m_\Delta v_\Delta &> \sqrt{9\left|M_\nu^\dagger M_\nu\right|_{\mu e}} \times 15.3\text{TeV} \\ \Rightarrow v_\Delta &> (6.25 - 8.39)\text{eV}\left(\frac{100\text{GeV}}{m_\Delta}\right), \end{aligned} \tag{3.4}$$

which is compatible with experimental lower limit[4] of a few hundred GeV of m_Δ.

So v_Δ could be very small.

[4] Particle Data Group Collaboration, P. A. Zyla et al., 2020.

Prospects

To make the model in right direction, we can inrtoduce some new scalar Higgs bosons, the mass of W and Z are changed as

$$m_W = g^2 \sum_i \frac{v_i^2}{2}(I_i(I_i+1) - Y_i^2), \quad m_Z = (g^2 + g'^2) \sum_i (Y_i^2 v_i^2) \tag{3.5}$$

so that

$$\rho = \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = \frac{\sum_i v_i^2(I_i(I_i+1) - Y_i^2)}{2\sum_i (Y_i^2 v_i^2)}. \tag{3.6}$$

If their hypercharge Y is 0, they would give a positive contribution to ρ.

Prospects

For example[5], we can introduce a triplet ξ whose $Y = 0$, then

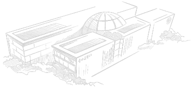
$$\rho = \frac{\frac{v_d^2}{2} + v_\Delta^2 + 2v_\xi^2}{2(\frac{v_d^2}{4} + v_\Delta^2)} = 1 - \frac{2v_\Delta^2}{v_d^2 + 4v_\Delta^2} + \frac{4v_\xi^2}{v_d^2 + 4v_\Delta^2}. \quad (3.7)$$

If the contribution of v_Δ is small enough to neglect, with $\Delta\rho = 0.0019$ we can estimate that

$$v_\xi \approx 5.36\text{GeV}. \quad (3.8)$$

[5] J.-Y. Cen, J.-H. Chen, X.-G. He, and J.-Y. Su, 2018.

Content



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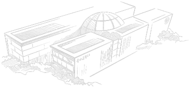
A challenge to experimental test.

W mass

1. A non-zero v_Δ make $\Delta\rho < 0$ which is in the wrong direction.



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   Their vevs should reach of order a GeV.

Thanks

李政道研究所 Tsung-Dao Lee Institute

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Question

Questions?