Type-II Seesaw Triplet Scalar Effects on Neutrino Trident Scattering

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1. Type-II Seesaw model

In addition to the SM Higgs field, the type-II seesaw model contains an additional triplet Higgs field,

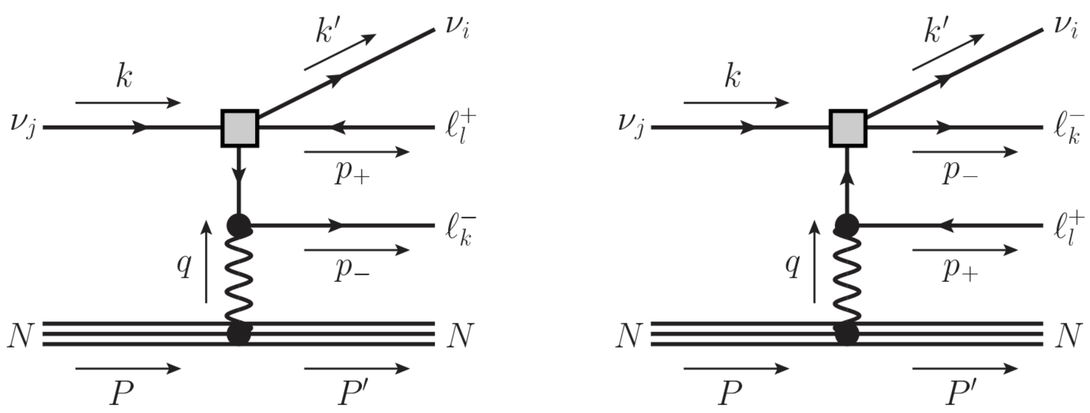
$$\Delta = \begin{pmatrix} \Delta^+/\sqrt{2} & \Delta^{++} \\ \Delta^0 & -\Delta^+/\sqrt{2} \end{pmatrix}$$

From the Yukawa coupling term,

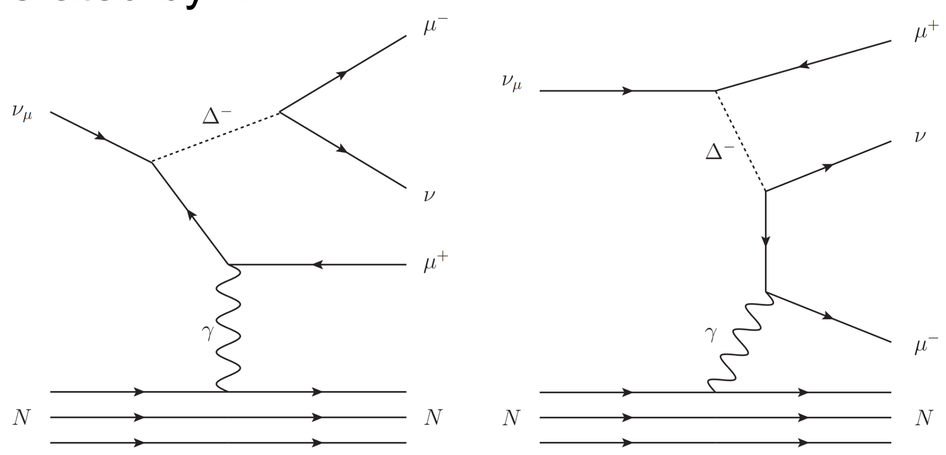
$$-\mathcal{L}_{M_\nu} = Y_{ij} L_{L_i}^T C i\sigma^2 \Delta L_{L_j} + \text{h.c.}$$

$$\left(M_\nu\right)_{ij} = \sqrt{2} v_\Delta Y_{ij} \rightarrow M_\nu = \frac{\mu v_d^2}{m_\Delta^2} Y$$

2. Neutrino Trident Scattering



Neutrino trident scattering(NTS)[1]: a weak process by which a neutrino, scattering off a heavy nucleus, generates a pair of charged leptons.
In type-II seesaw model, a $\mu^+\mu^-$ pair can be generated by Δ^+,



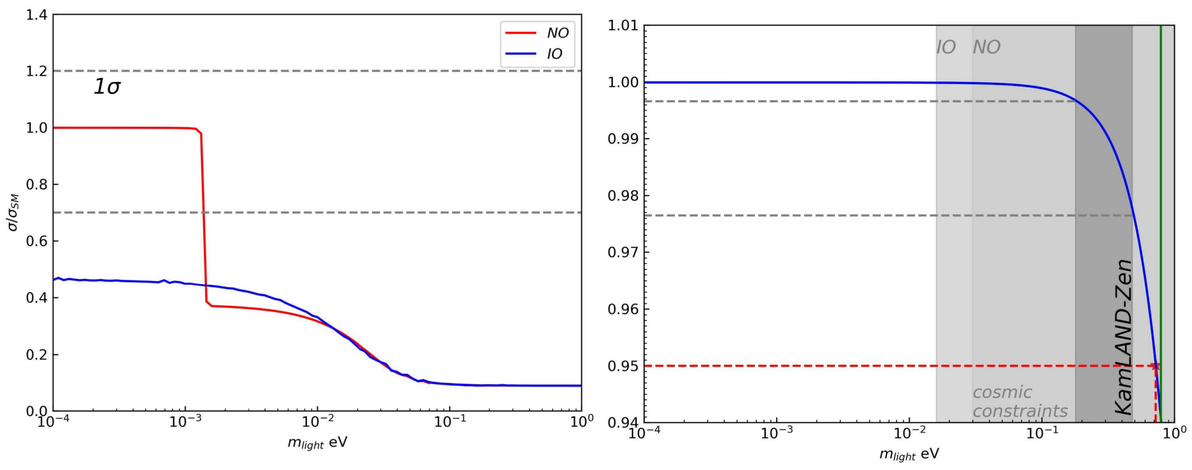
The final modification would be

$$\frac{\sigma}{\sigma_{SM}} = \frac{\left(1+4s_w^2 - \frac{2m_w^2}{g^2}\frac{|m_{\mu\mu}|^2}{m_\Delta^2 v_\Delta^2}\right)^2 + \left(1-\frac{2m_w^2}{g^2}\frac{|m_{\mu\mu}|^2}{m_\Delta^2 v_\Delta^2}\right)^2 + 2\left(\frac{2m_w^2|m_{\mu\mu}|^2}{g^2 m_\Delta^2 v_\Delta^2}\right)^2 \left(\frac{|m_{e\mu}|^2 + |m_{\tau\mu}|^2}{|m_{\mu\mu}|^2}\right)}{\left(1+4s_w^2\right)^2 + 1}$$

3. Constrains on Trident

Type-II seesaw also induce new processes not exist in the SM, such as $l_i^- \rightarrow l_j^+ l_k^- l_l^-$ and $l_i^- \rightarrow l_j^- \gamma$ which provide severe constraints to the model parameters.

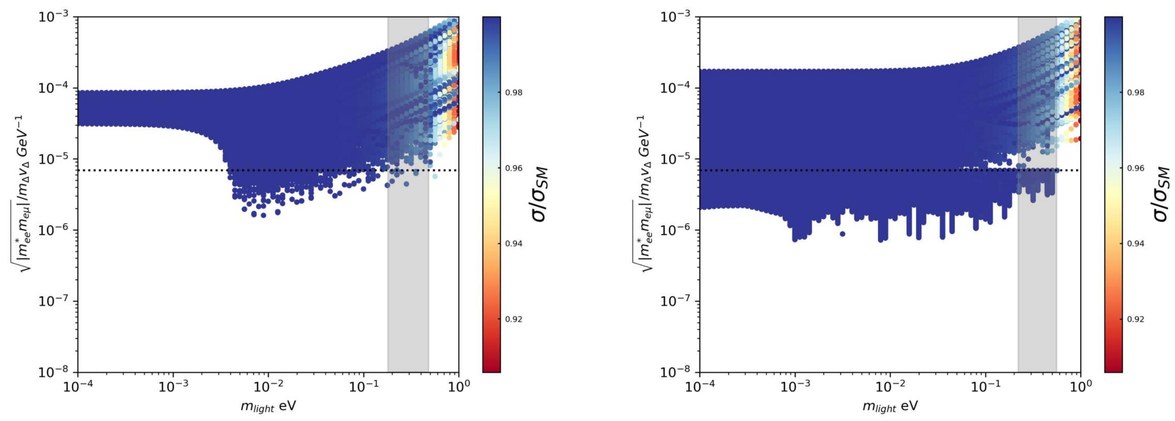
Process	Branching	Constraint
$\mu^- \rightarrow e^+e^-e^-$	1.0×10^{-12}	$m_\Delta v_\Delta > \left\|(M_\nu)_{\mu e}(M_\nu)_{ee}\right\|^{1/2} \times 145\text{TeV}$
$\mu^- \rightarrow e^-\gamma$	4.2×10^{-13}	$m_\Delta v_\Delta > \sqrt{9\left\|M_\nu^\dagger M_\nu\right\|_{\mu e}} \times 15.3\text{TeV}$



· By taking into account these constraints, σ/σ_{SM} can at most reach 0.98 (shown as dashed gray line in the figure) at 3σ level.

4. Combine the Constrains

Combine these two constrains,



The dashed line corresponds to the upper limit from $\mu^- \rightarrow e^+e^-e^-$. Points above the dashed line are ruled out. (a) for NO case, and (b) for IO case.

·The deviation of σ/σ_{SM} from 1 is constrained to less than about 2% at 3σ level.

5. Conclusion

· From cosmological considerations, the effect of Δ on σ/σ_{SM} is limited to be less than 0.1%. This is a challenge to experimental test.
· If a deviation is more than 2% will be found, the Type-II seesaw is unlikely to be able to explain the data.

[1] Altmannshofer, W. , Gori, S. , Justo Martín-Albo, Sousa, A. , & Wallbank, M. . (2019). Neutrino tridents at dune.