Type-II seesaw triplet scalar effects on neutrino trident scattering

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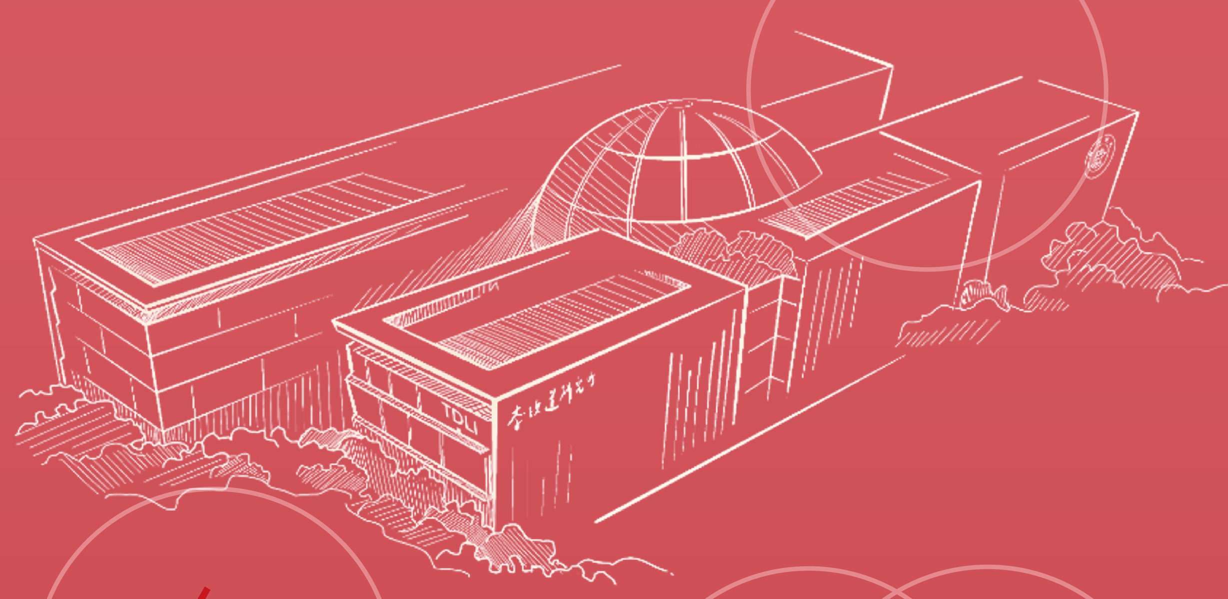
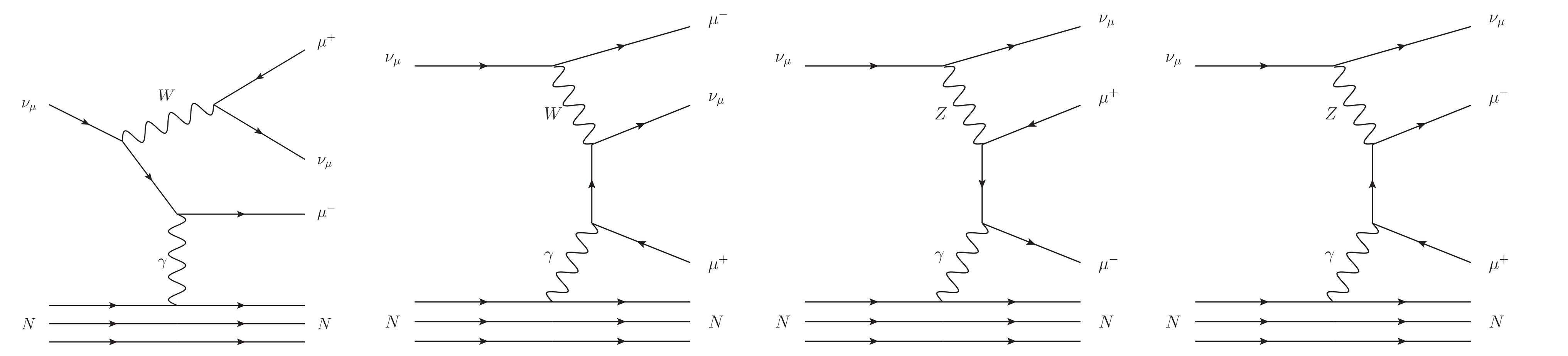


1. Neutrino Trident Scattering in SM

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



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

2. Type-II Seesaw model

Type-II Seesaw model introduce one heavy Higgs triplet Δ,

$$\mathcal{L}_{\text{Higgs}}=\left(D^\mu\Phi\right)^\dagger\left(D_\mu\Phi\right)+\operatorname{Tr}\left[\left(D^\mu\Delta\right)^\dagger\left(D_\mu\Delta\right)\right]-V(\Phi,\Delta). \qquad (2)$$

where

$$\begin{aligned}V(\Phi,\Delta)=&-m_\Phi^2\Phi^\dagger\Phi+M^2\operatorname{Tr}\Delta^\dagger\Delta+\left(\mu\Phi^Ti\sigma^2\Delta^\dagger\Phi+\text{ h.c. }\right)+\frac{\lambda}{4}\left(\Phi^\dagger\Phi\right)^2\\&+\lambda_1\Phi^\dagger\Phi\operatorname{Tr}\Delta^\dagger\Delta+\lambda_2\left(\operatorname{Tr}\Delta^\dagger\Delta\right)^2+\lambda_3\operatorname{Tr}\left(\Delta^\dagger\Delta\right)^2+\lambda_4\Phi^\dagger\Delta\Delta^\dagger\Phi.\end{aligned} \Rightarrow m_\Delta^2\approx\frac{\mu v_d^2}{\sqrt{2}v_\Delta}. \qquad (3)$$

From the Yukawa coupling term introduced by Type-II model,

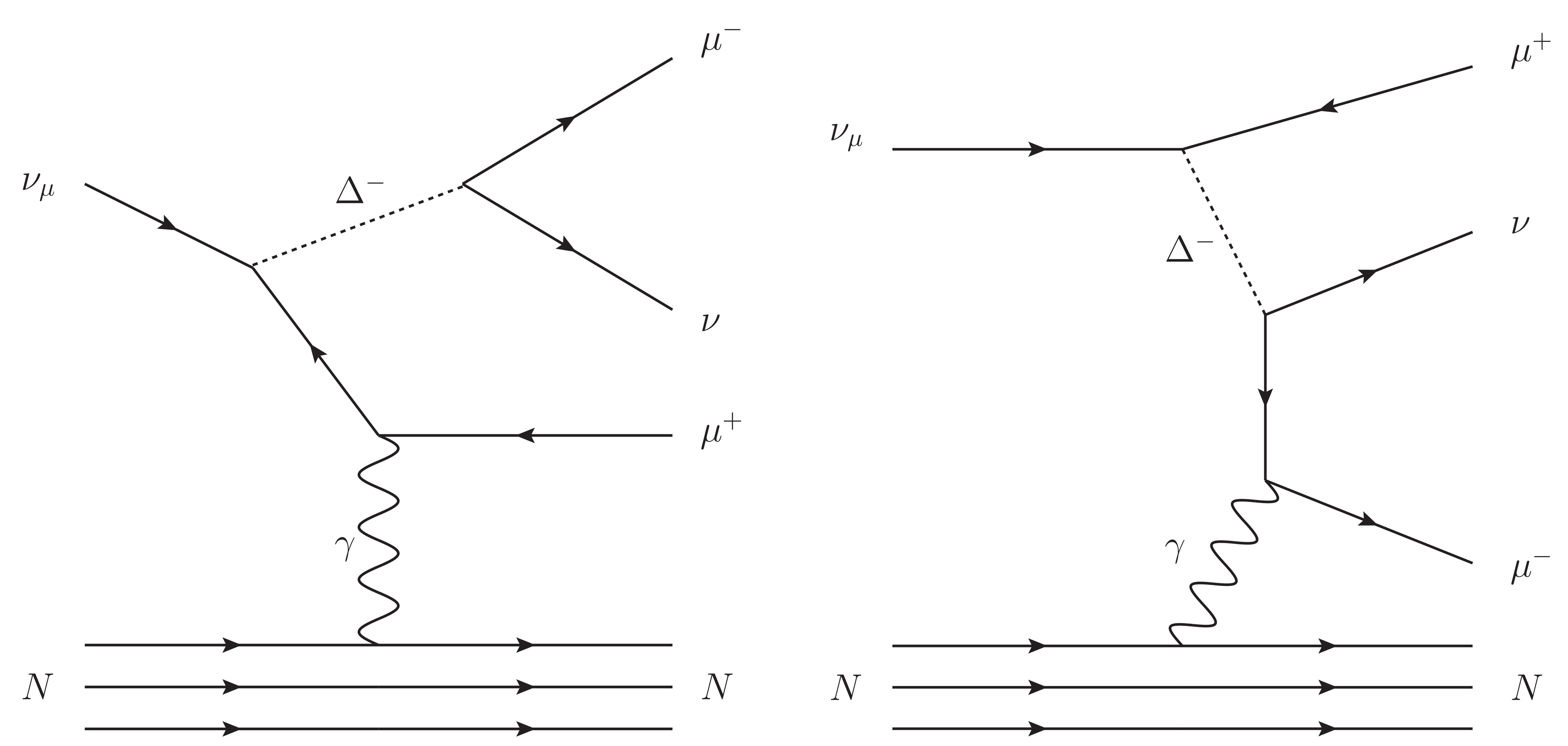
$$-\mathcal{L}_{M_\nu}=f_{ij}L_{L_i}^TCi\sigma^2\Delta L_{L_j}+\text{h.c.}\ , \qquad (4)$$

we can derive the tiny Majorana neutrino mass

$$m_{ij}=\left(M_\nu\right)_{ij}=\sqrt{2}f_{ij}\nu_\Delta=\frac{\mu v_d^2}{m_\Delta^2}f_{ij}, \qquad (5)$$

3. Neutrino Trident Scattering in Type-II Seesaw model

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



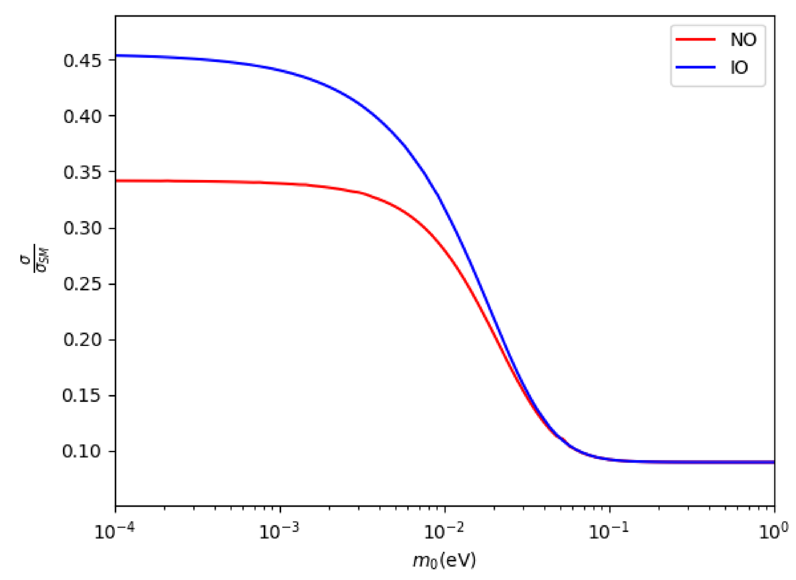
$$\frac{m_{ij}m_{kl}^*}{2m_\Delta^2v_\Delta^2}\bar{\nu}_k\gamma^\mu P_L\nu_i\bar{\ell}_l\gamma_\mu P_L\ell_j. \qquad (6)$$

The final modification would be

$$\begin{aligned}\frac{\sigma}{\sigma_{SM}}=\frac{1}{\left(1+4s_w^2\right)^2+1}\Bigg(&\left(1+4s_w^2-\frac{2m_W^2}{g^2}\frac{|m_{\mu\mu}|^2}{m_\Delta^2v_\Delta^2}\right)^2+\left(1-\frac{2m_W^2}{g^2}\frac{|m_{\mu\mu}|^2}{m_\Delta^2v_\Delta^2}\right)^2\\&+2\left(\frac{2m_W^2}{g^2m_\Delta^2v_\Delta^2}\frac{|m_{\mu\mu}|^2}{}\right)^2\left(\frac{|m_{e\mu}|^2+|m_{\tau\mu}|^2}{|m_{\mu\mu}|^2}\right)\Bigg),\end{aligned} \qquad (7)$$

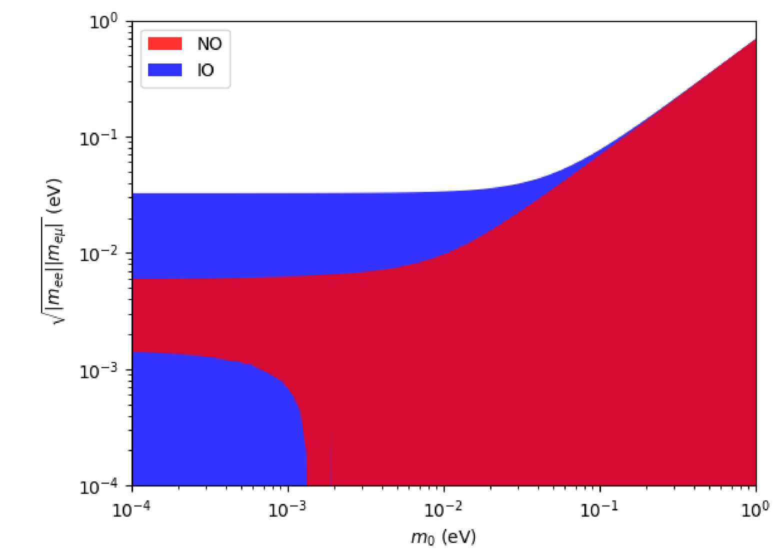
5. The rough lower bound of the ratio.

Treat the ratio $\frac{\sigma}{\sigma_{\rm SM}}$ as a quadratic function of $\frac{1}{m_\Delta^2 v_\Delta^2}$, we can draw its rough lower bound,

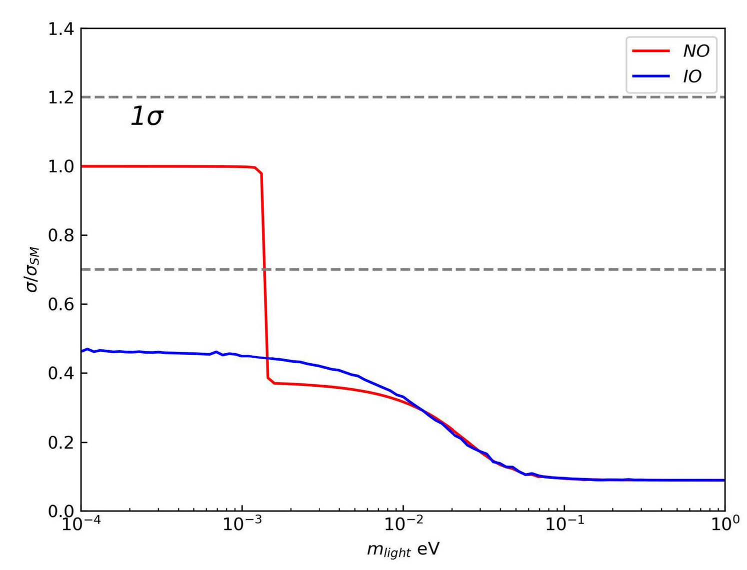


6. Constrains from CLFV

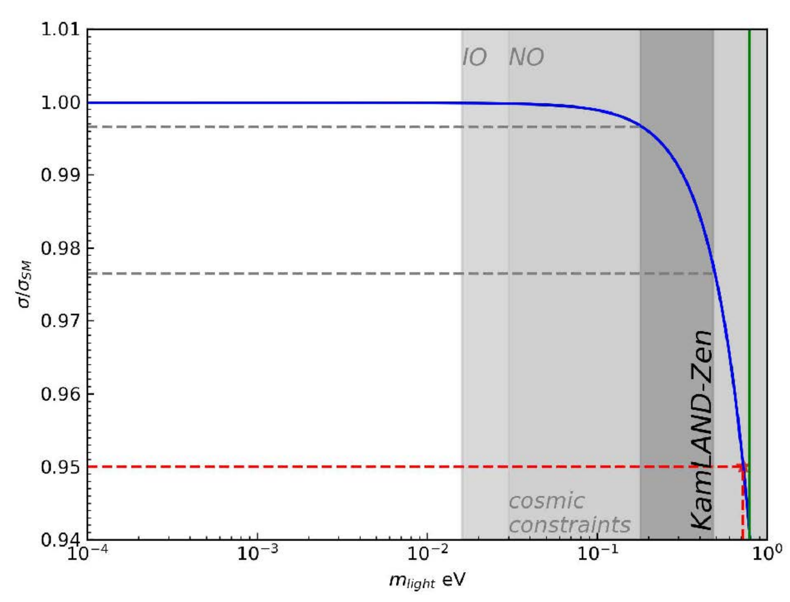
From $\mu^-\to e^+e^-e^-$, we can derive $m_\Delta v_\Delta > |m_{\mu e}m_{ee}|^{1/2}\times 145$TeV, where the $|m_{\mu e}m_{ee}|^{1/2}$ range is determined by m_0



Then the range of ratio is still very large,

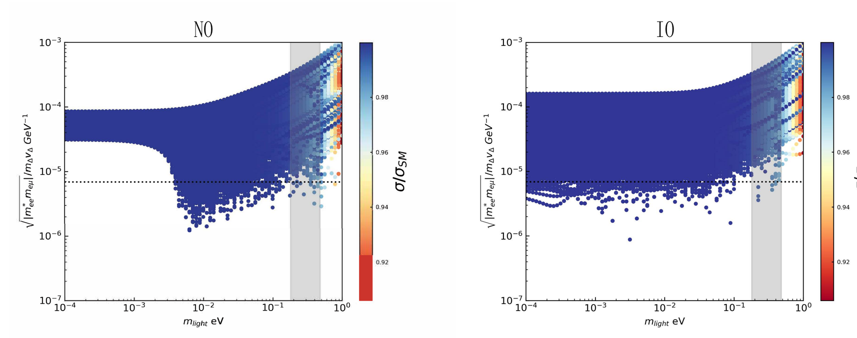


From $\mu^-\to e^-\gamma$, we can constrain $m_\Delta v_\Delta > 3\left|M_\nu^\dagger M_\nu\right|_{\mu e}^{\frac{1}{2}}\times 15.3$TeV, where $0.041\text{eV} < 3\left|M_\nu^\dagger M_\nu\right|_{\mu e}^{\frac{1}{2}} < 0.054\text{eV}$. Then the range of ratio would be very small,



7. Combine the constrains from $\mu^-\to e^+e^-e^-$ and $\mu^-\to e^-\gamma$

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



8. Conclusion

- Combining constraints from $0\nu\beta\beta$, $\frac{\sigma}{\sigma_{\rm SM}}>0.977$. Close to the current experimental central value.
- From cosmological considerations, the effect of Δ on $\frac{\sigma}{\sigma_{\rm SM}}$ is limited to be less than 0.1%. A challenge to experimental test.

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