Lepton Number Violating Non-standard Neutrino Interactions and Neutrino Oscillations

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Outline

- Motivation
- Model
- Constraints
- Effects in Neutrino Oscillations
- Conclusion

Motivation

Why non-standard interactions?

- From neutrino oscillation data, it has been known that neutrinos are mixed and therefore can oscillate.
- These are the evidence of physics beyond the standard model.
- There might be new interactions involving neutrinos and other particles.

Why lepton-number violating?
$\rightarrow$ There is no interference with standard interactions, so it would be less constrained. However, we need to watch out for induced neutrino masses.

Models of Operator

- There are several operators that generate lepton number violating interactions such as $LLHH$, $LLLe^cH$, $LLQd^cH$, $LLQu^cH$, $L\overline{e^c}d^c\overline{u^c}H$, and the other higher dimensional operators.
- Here only $LLLe^cH$ and $L\overline{e^c}d^c\overline{u^c}H$ will be considered.
- The new interactions of neutrino from these operators are

$$
\begin{aligned}
\mathcal{O}_1 &= \frac{G_F}{\sqrt{2}}\epsilon^{\rho\sigma}_{\alpha\beta}\left(\nu^T_{\alpha L}C^{-1}\nu_{\beta L}\right)\left(\overline{l_{\rho R}}l_{\sigma L}\right), \\
\mathcal{O}_2 &= \frac{G_F}{\sqrt{2}}\epsilon'^{\rho\sigma}_{\alpha\beta}\left(\overline{d_{\rho R}}\nu_{\alpha L}\right)\left(l^T_{\beta R}C^{-1}u_{\sigma R}\right),
\end{aligned}
$$

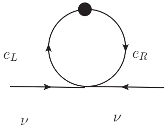
  ϵ and $\epsilon'$are the new parameters.

- The first operator has been well studied (Zee, 1980; Babu & Pakvasa, 2002). But, here another version will be given.

Constraints from Neutrino Mass

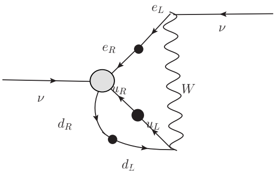
These two operators can generate neutrino mass at one- or two-loop level.

- $LLLe^cH$



  This may induce large neutrino masses (in order of charged lepton masses), so, extra symmetry will be introduced to avoid that.

- $L\overline{e^c}d^c\overline{u^c}H$



  This will induce neutrino mass of order of 1 eV with heaviest fermions in the loop.

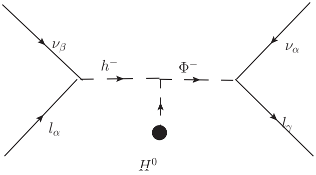
Renormalizable Lagrangian

- The $LLLe^cH$ operator can be built by the following Lagrangian

$$\mathcal{L} = f_{\alpha\beta}\ L_\alpha^T L_\beta h^+ + Y_{\alpha\gamma}\ \overline{l_{\gamma R}}\Phi^\dagger L_\alpha + \kappa\Phi^T H h^-,$$

where $\alpha \neq \beta \neq \gamma$. Here, Φ and h are extra Higgs doublet and singly charged Higgs respectively.

- The unbroken lepton numbers are $L_\beta + L_\gamma$ and $L_\alpha - L_\beta + L_\gamma$, so it is not possible to generate neutrino mass.
- Also there is no constraint from rare lepton decay such as $l_\alpha \to l_\beta\gamma$.



- The new parameter is defined as

$$\frac{\epsilon_{\alpha\beta}^{\gamma\alpha}}{\sqrt{2}} = \frac{1}{16}\frac{f_{\alpha\beta}Y_{\alpha\gamma}\kappa v}{m_\Phi^2 m_h^2 G_F},$$

where v is the SM VEV.

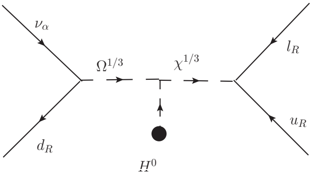
Renormalizable Lagrangian

- The $L\overline{e^c}d^c\overline{u^c}H$ operator can be built by

$$\mathcal{L} = f_{\alpha\sigma}\ \overline{d_{\sigma R}}\Omega^\dagger L_\alpha + Y_{\beta\rho} u^T_{\rho R} C^{-1} l_{\beta R}\chi^{1/3} + \kappa\Omega^T H\chi^{-1/3},$$

here Ω and χ are leptoquark doublet and singlet respectively.

- The corresponding Feynman diagram is



- The new parameter is defined as

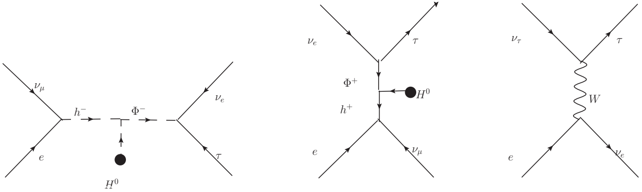
$$\frac{\epsilon'^{\rho\sigma}_{\alpha\beta}}{\sqrt{2}} = \frac{1}{16}\frac{f_{\alpha\sigma} Y_{\beta\rho}\kappa v}{m^2_\Omega m^2_\chi G_F}.$$

Consequences

- Suppose $LLLe^cH$ Lagrangian is in the form of

$$\mathcal{L} = f_{e\mu}\ L_e^T L_\mu h^+ + Y_{e\tau}\ \overline{l_{\tau R}}\Phi^\dagger L_e + \lambda \Phi^T H h^- .$$

- If neutrino production is through standard pion decay, this lagrangian may lead to detection of wrong type of neutrino at the detector.



- Since there is no interference, no CP violation will be observed from this operator.

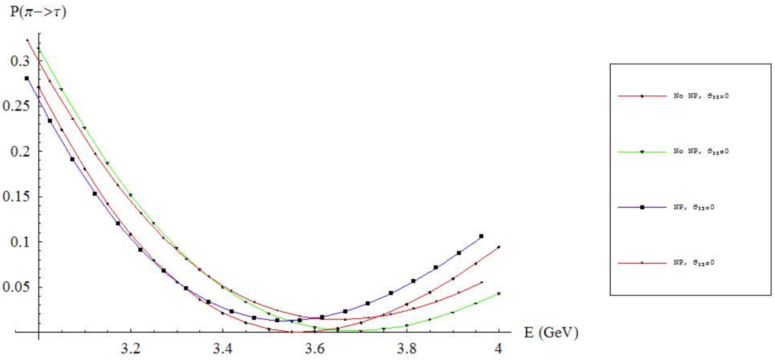


Figure: The probability of tau detection with new physics, $|\epsilon^{\tau e}_{e\mu}|^2 \sim 0.05$. $\theta_{12} = 34^o$, $\theta_{23} = 45^o$, $|\Delta m^2_{32}| = 3 \times 10^{-3}\mathrm{eV}^2$.

Consequences

- Suppose $L\overline{e^c}d^c\overline{u^c}H$ Lagrangian is

$$\mathcal{L} = f_{\alpha d}\ \overline{d_R}\Omega^\dagger L_\alpha + Y_{\mu u} u_R^T C^{-1} l_{\mu R}\chi^{1/3} + \lambda\Omega^T H\chi^{-1/3},$$

  $\alpha = e,\ \mu,\ \tau.$

- This will affect pion decay, $\pi^+ \to \mu^+\overline{\nu_\alpha}$, so positron may be detected in addition to electron from the standard process.
- The branching ratio for $\pi \to \mu e$ is 2×10^{-3} so $|\epsilon'^{ud}_{e\mu}|^2 \sim 10^{-3}$, and no constraints for $\epsilon'^{ud}_{\mu\mu}$ and $\epsilon'^{ud}_{\tau\mu}$.
- Since there is no interference, no CP violation will be observed from this operator too.

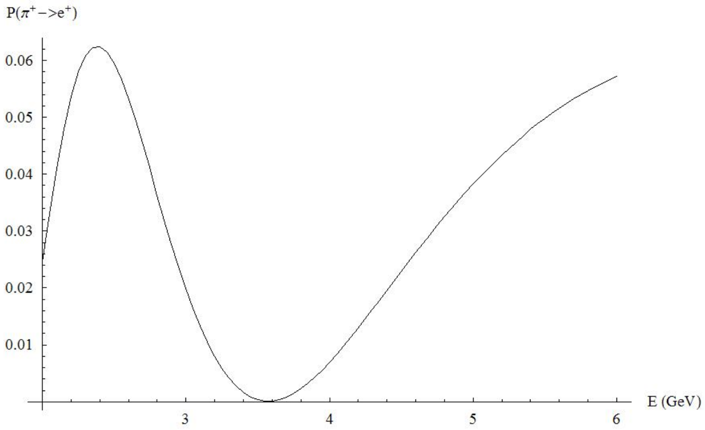


Figure: The probability of positron detection with new physics, $\epsilon'^{ud}_{\mu\mu} \sim \epsilon^{ud}_{\tau\mu} \sim 0.25$. $\theta_{12} = 34^o$, $\theta_{23} = 45^o$, $|\Delta m^2_{32}| = 3 \times 10^{-3}\mathrm{eV}^2$.

Conclusion

- Lepton number violating new interactions of neutrino arising from operators $LLLe^cH$ and $L\overline{e^c}d^c\overline{u^c}H$ may have large effect.
- In our models, these operators are not constrained from neutrino mass and rare lepton decay.
- These effects may be observed in future neutrino oscillation experiments.