Lepton EDM's from Heavy Right-Handed Majorana Neutrinos

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Tatsu Takeuchi

with

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Electric Dipole Moment (EDM)

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Under CPT:

$$\begin{array}{ccccccc}
\vec{\sigma} & \xrightarrow{P} & \vec{\sigma} & \xrightarrow{C} & -\vec{\sigma} & \xrightarrow{T} & +\vec{\sigma} \\
\vec{B} & \xrightarrow{P} & \vec{B} & \xrightarrow{C} & -\vec{B} & \xrightarrow{T} & +\vec{B} \\
\vec{E} & \xrightarrow{P} & -\vec{E} & \xrightarrow{C} & +\vec{E} & \xrightarrow{T} & +\vec{E}
\end{array}$$

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\end{array}$$

Non-zero d violates P, CP, and T.

EDM's as measures of CP violation

- CP violation in the quark sector

- CP violation in the lepton sector

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- CP violation in the lepton sector
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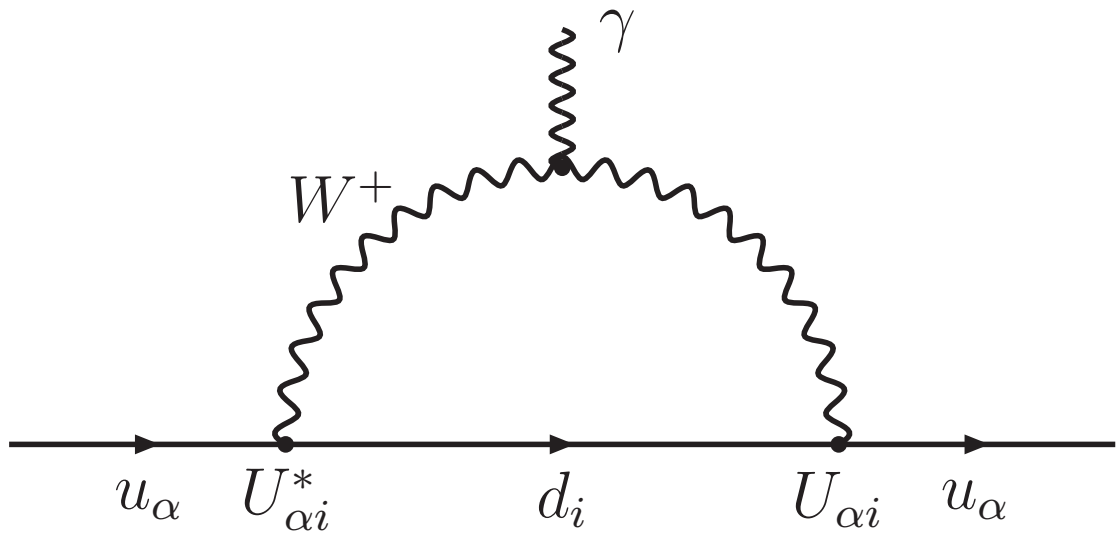
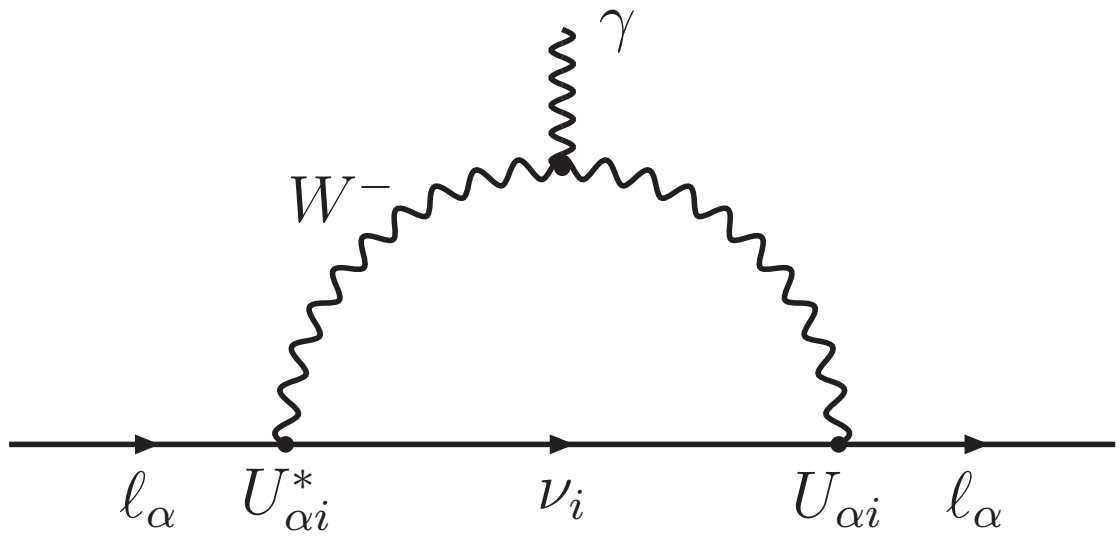
  - Could be a source of leptogenesis
  - Lepton EDM's generated at the 2-loop level

1-loop diagram



$$\propto |U_{\alpha i}|^2$$

1-loop diagram



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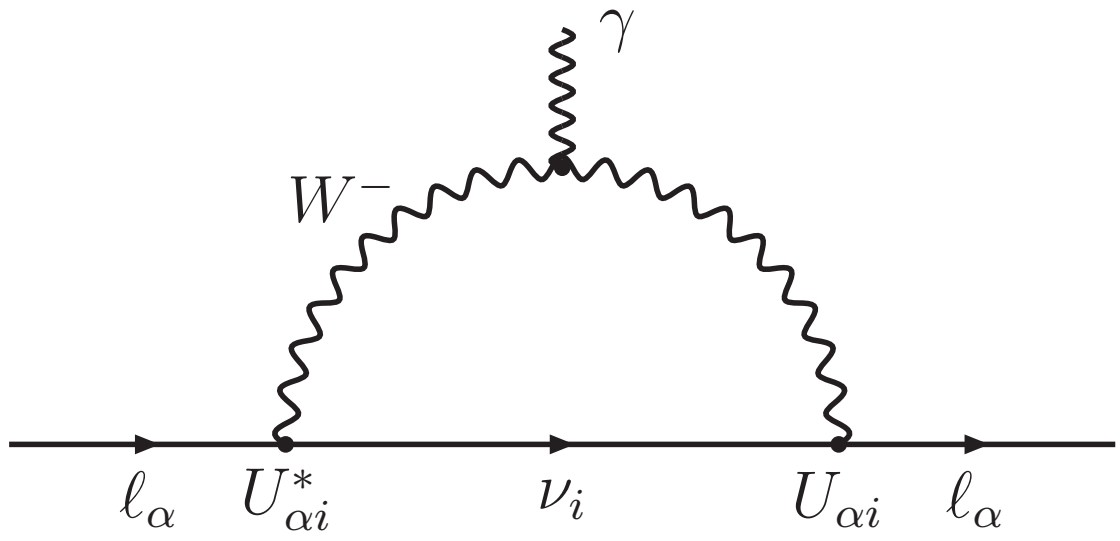
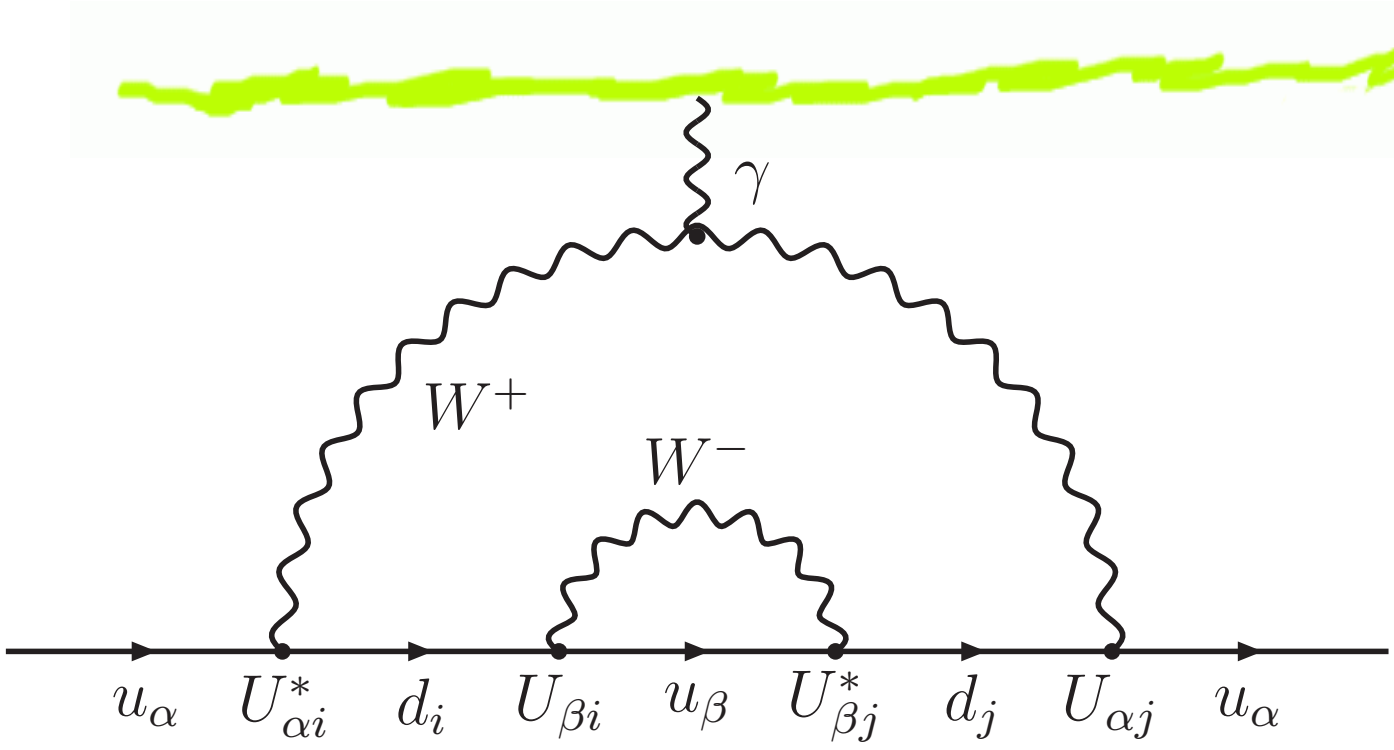


$$\propto |U_{\alpha i}|^2$$

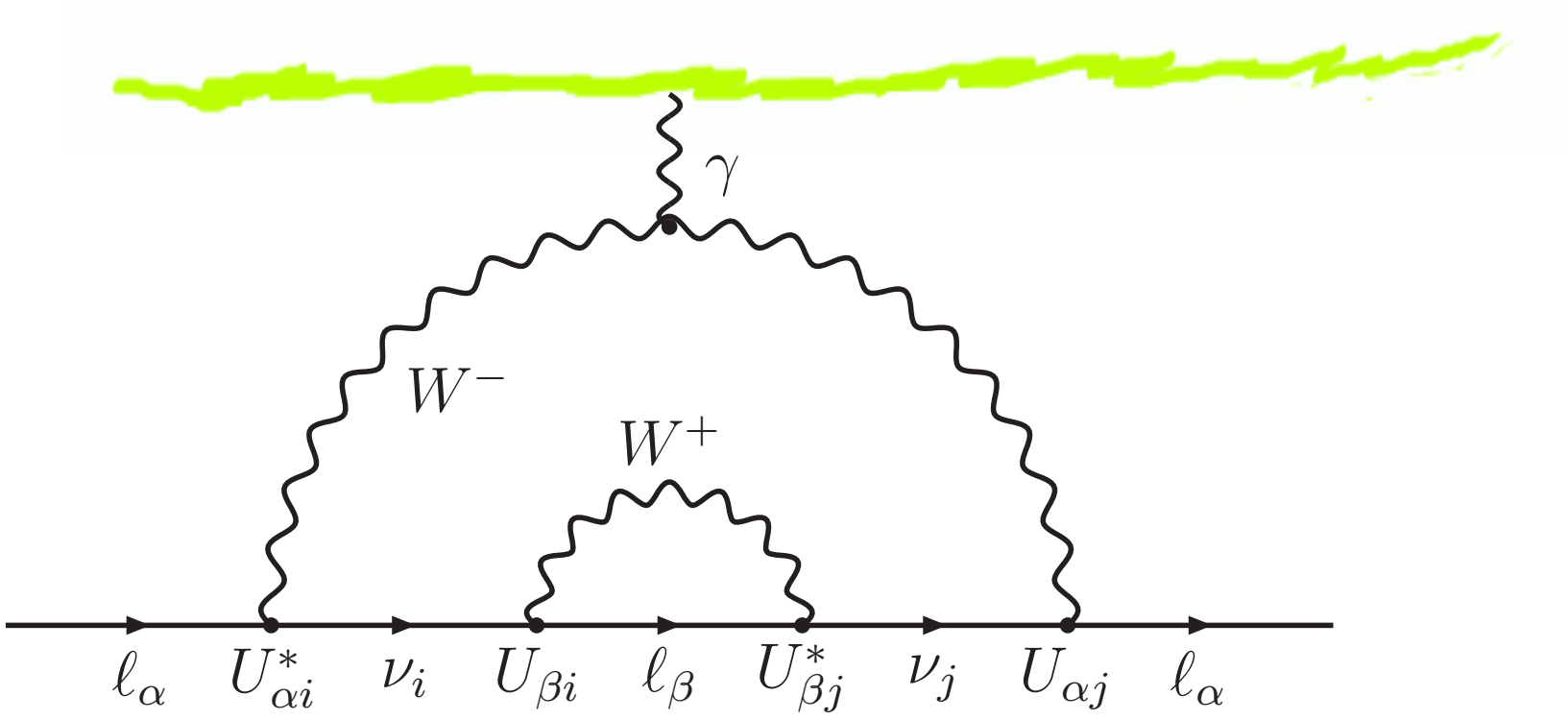
Insensitive to complex phases

2-loop diagram



$$\propto (U^*_{\alpha i} U_{\beta i})(U_{\alpha j} U^*_{\beta j})$$

2-loop diagram



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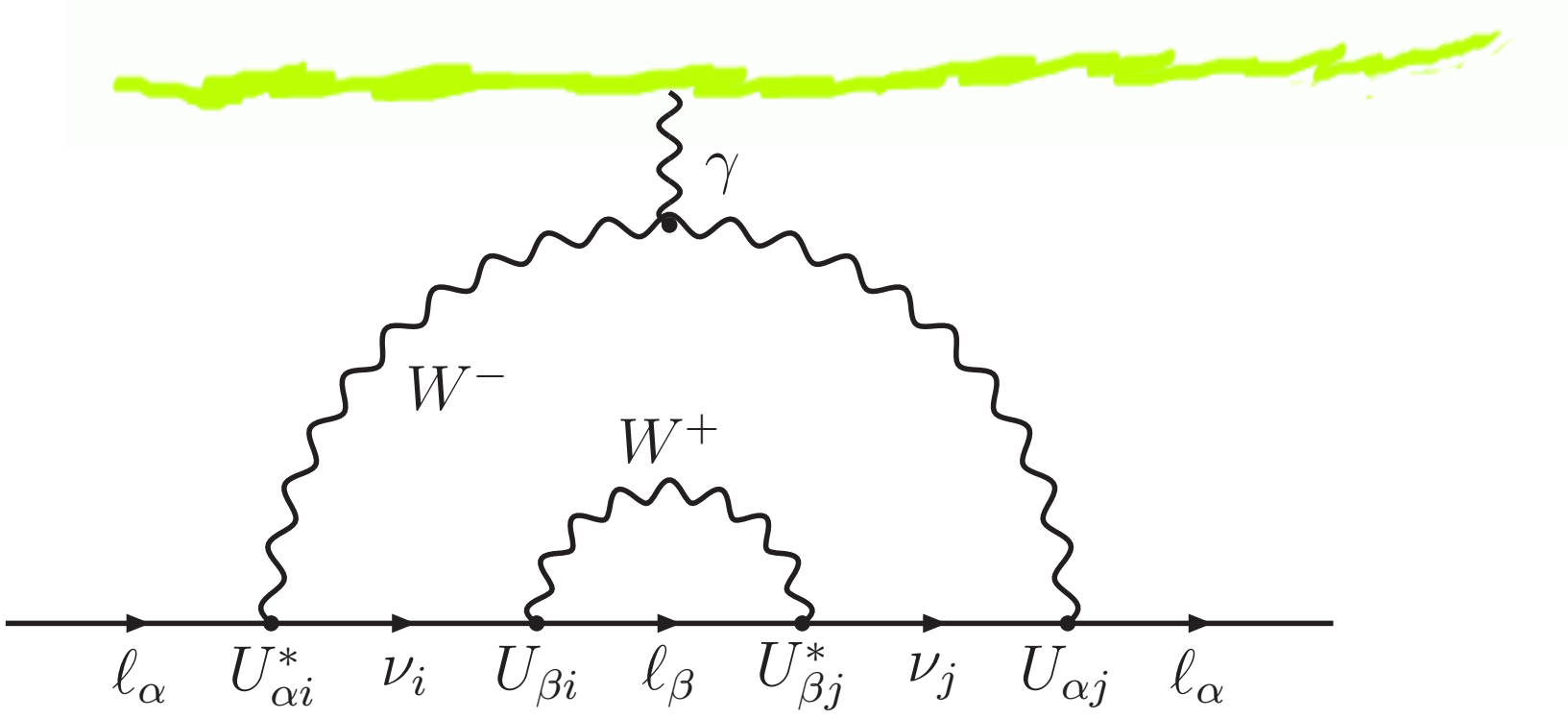

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Diagram is symmetric under the interchange $i \leftrightarrow j$

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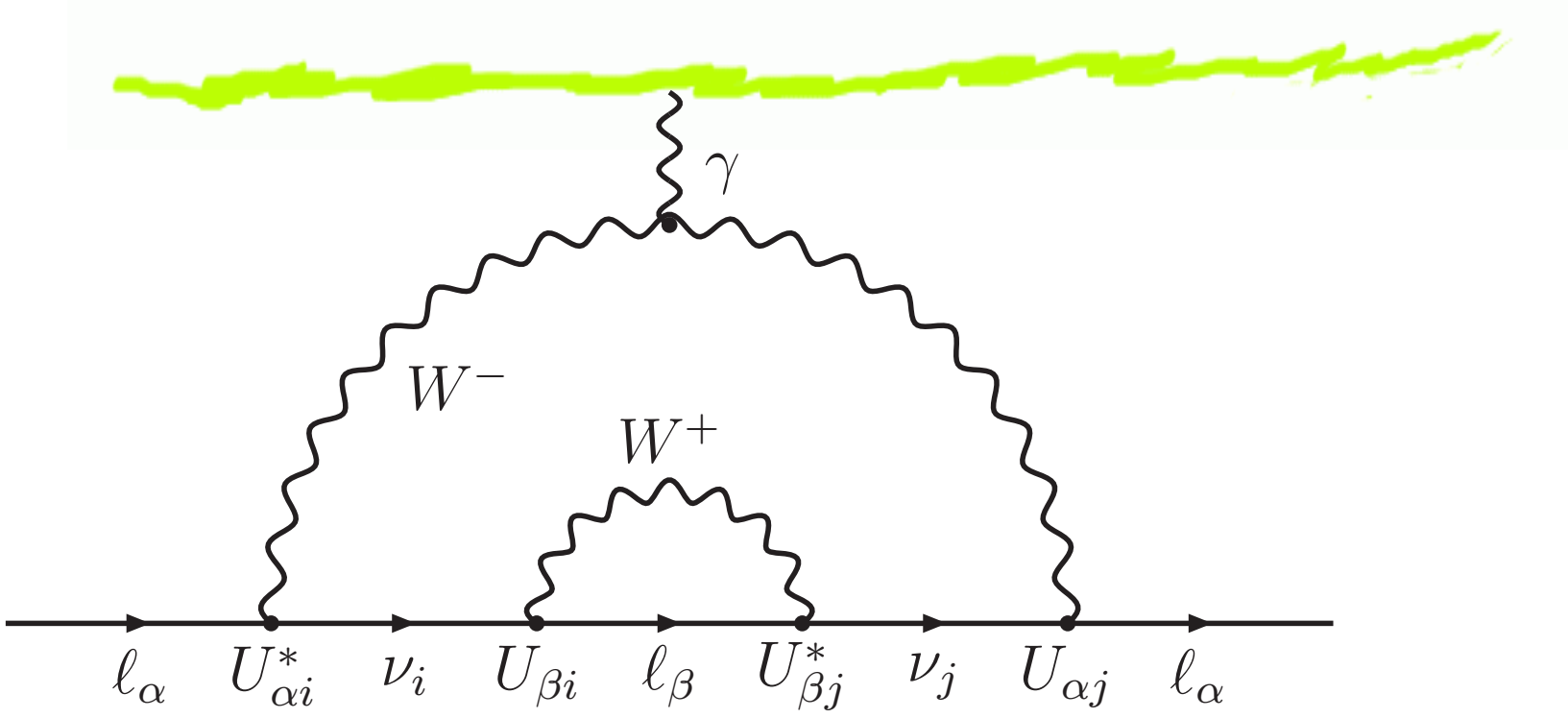


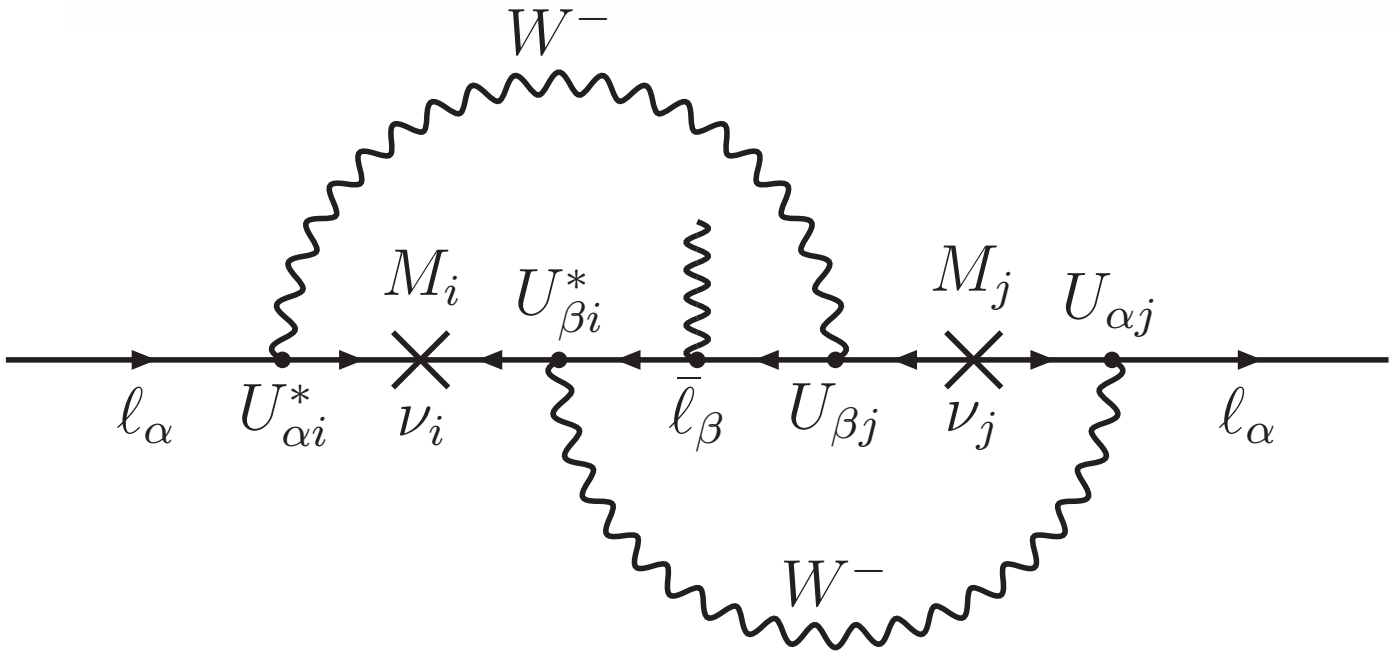
$$\propto (U^*_{\alpha i} U_{\beta i})(U_{\alpha j} U^*_{\beta j})$$

Diagram is symmetric under the interchange $i \leftrightarrow j$

$\Longrightarrow$ Imaginary parts of $(U^*_{\alpha i} U_{\beta i})(U_{\alpha j} U^*_{\beta j})$ cancel

Shabalin, Sov. J. Nucl. Phys. 28 (1978) 75

2-loop diagram unique to leptons



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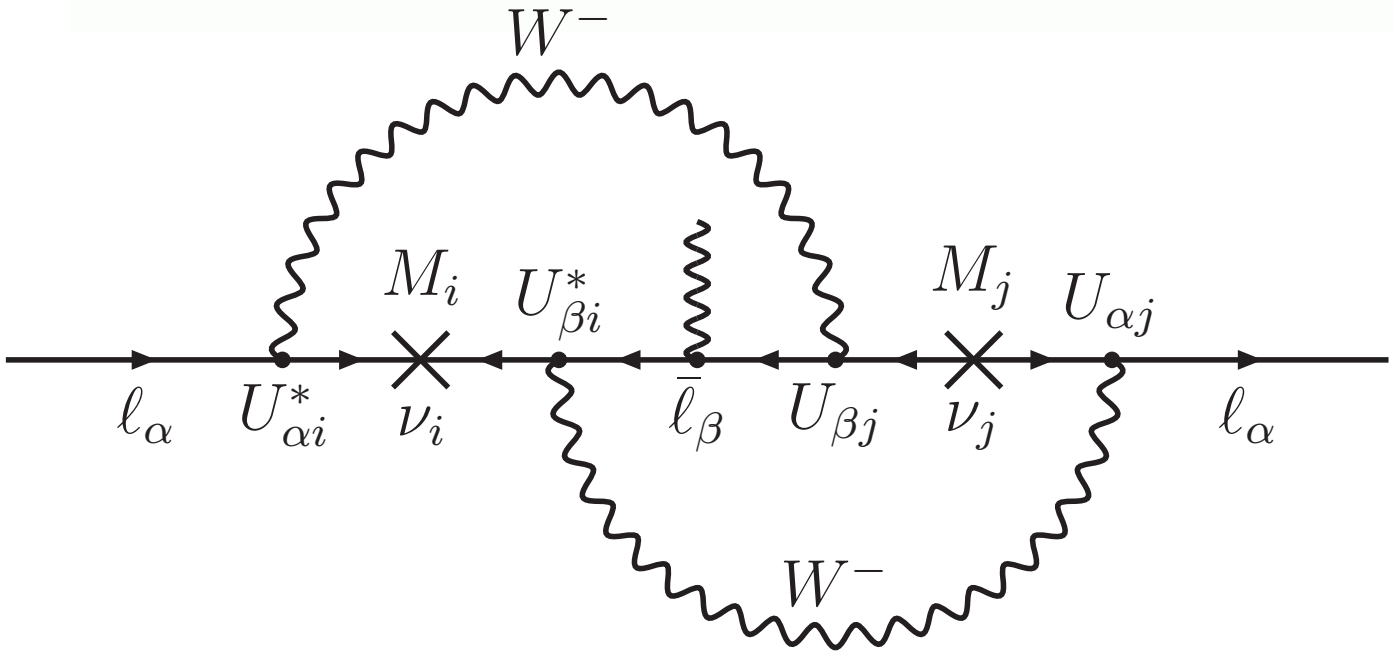

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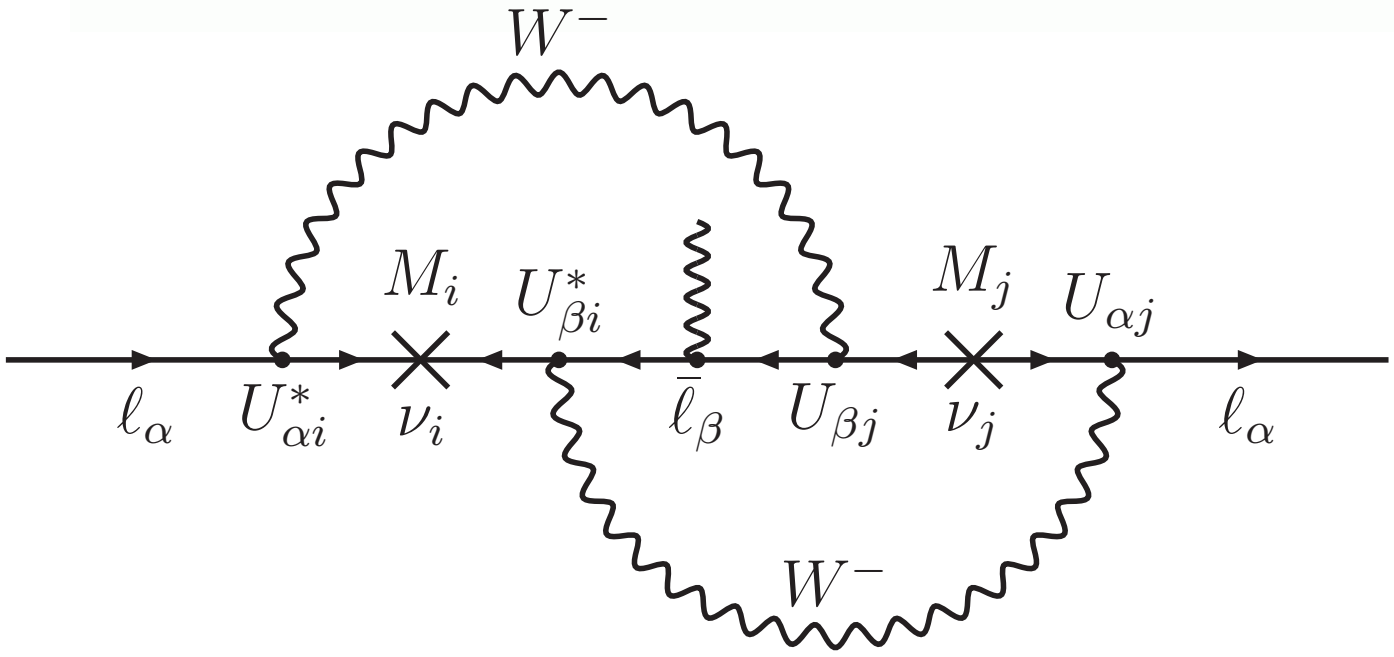

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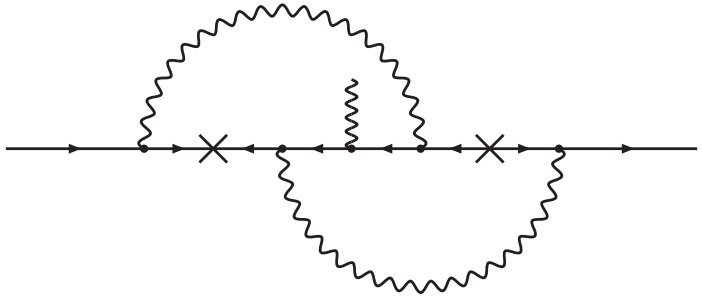
Is it significant?



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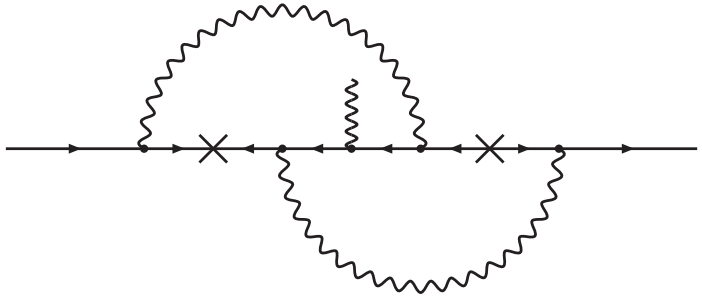

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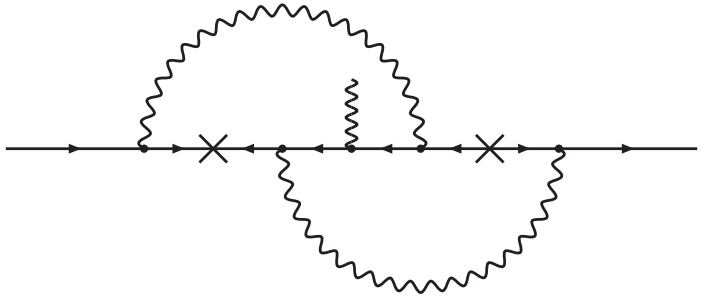

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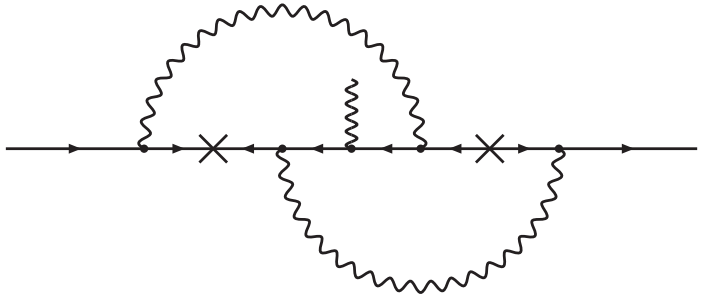

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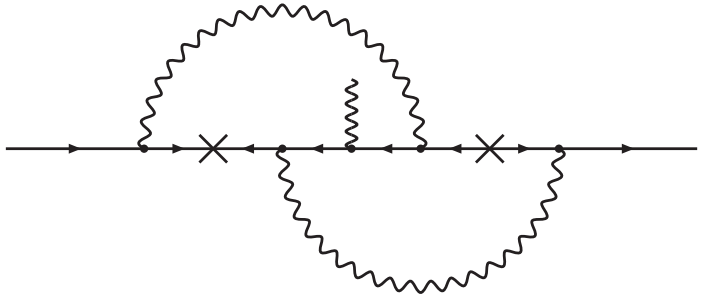

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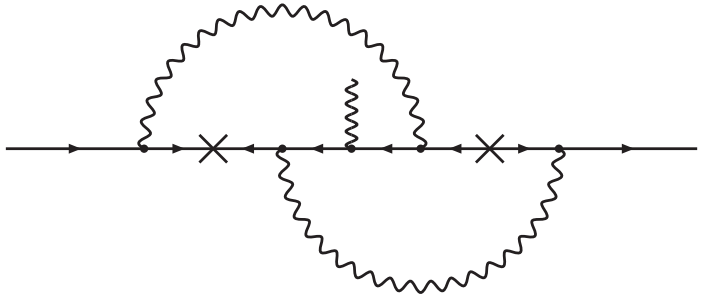

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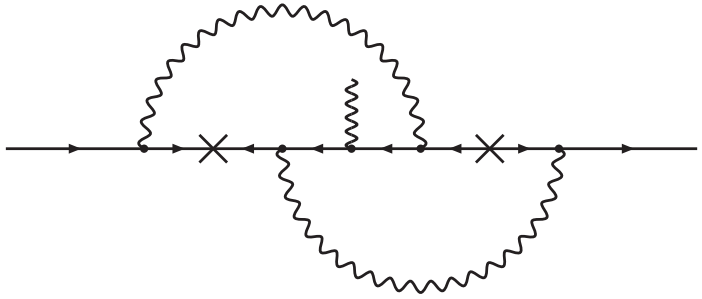

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  $\rightarrow$ same order as the light neutrino contribution.

TeV-Scale Seesaw Models

Example: Okamura Texture PRD 68, 073001 (2003)

$$\begin{bmatrix} 0 & 0 & 0 & \alpha D & \beta D & \gamma D \\ 0 & 0 & 0 & \alpha D & \beta D & \gamma D \\ 0 & 0 & 0 & \alpha D & \beta D & \gamma D \\ \alpha D & \alpha D & \alpha D & \alpha M & 0 & 0 \\ \beta D & \beta D & \beta D & 0 & \beta M & 0 \\ \gamma D & \gamma D & \gamma D & 0 & 0 & \gamma M \end{bmatrix}$$

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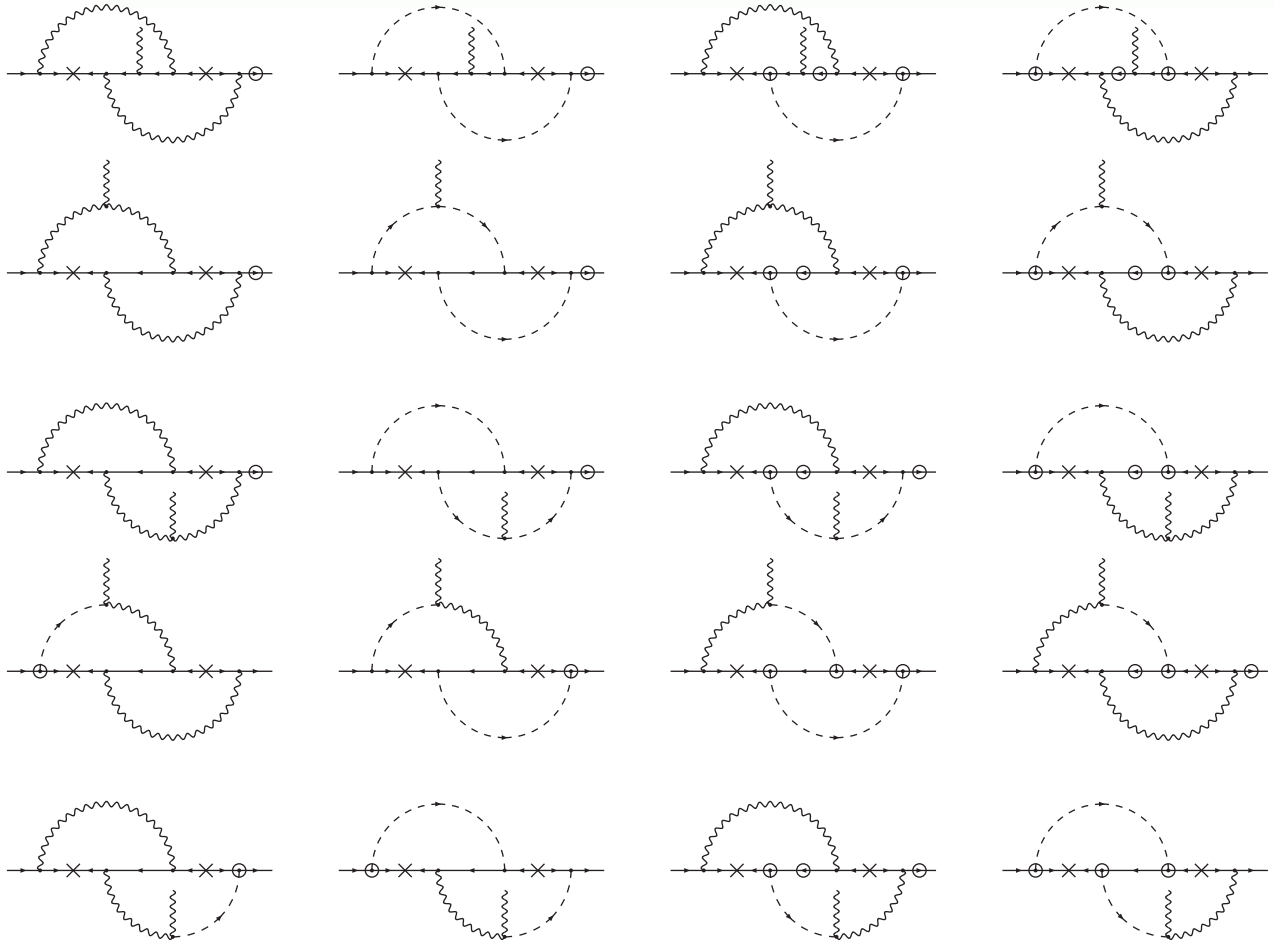
  $\rightarrow$ light masses automatically zero.
  $\rightarrow$ mixings and masses are independent.
  $\rightarrow$ lepton EDM's can be large!?

20 Diagrams



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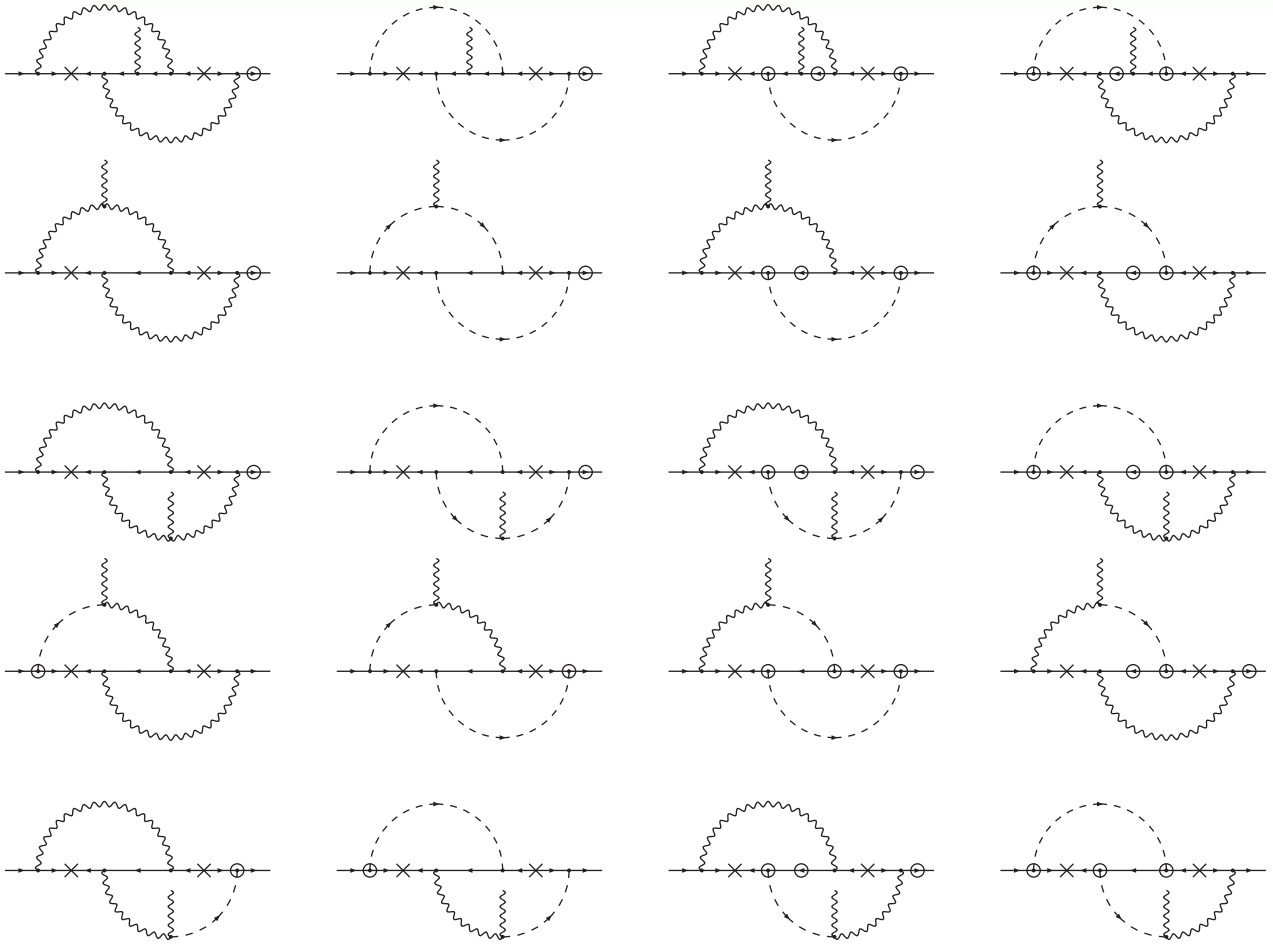

Give to graduate student!

Results by Saifuddin Rayyan 1

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- Use:

  M_W, neutrino Dirac mass $\gg$ charged lepton masses

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- 10 of the 20 diagrams can be neglected.
- Leading order contribution in the changed lepton mass can be calculated exactly.
- Final result:

  $d =$ see next page

Results by Saifuddin Rayyan 2

$$\frac{eg^4}{2}\, m \sum_\beta \sum_{i>j} M_i M_j\, \Im\left(\tilde{V}_{\alpha i}\tilde{V}_{\beta i}\tilde{V}^*_{\beta j}\tilde{V}^*_{\alpha j}\right) R_1(M_i, M_j)$$

$$+2e\, m \sum_\beta \sum_{i>j} M_i M_j\, \Im\left(\tilde{\Lambda}_{\alpha i}\tilde{\Lambda}_{\beta i}\tilde{\Lambda}^*_{\beta j}\tilde{\Lambda}^*_{\alpha j}\right) R_2(M_i, M_j)$$

$$+\frac{eg^3}{\sqrt{2}} M_W \sum_\beta \sum_{i>j} M_i M_j\, \Im\left(\tilde{\lambda}_{\alpha i}\tilde{V}_{\beta i}\tilde{V}^*_{\beta j}\tilde{V}^*_{\alpha j}\right) R_3(M_i, M_j)$$

$$+\sqrt{2}\, eg\, M_W \sum_\beta \sum_{i>j} M_i M_j\, \Im\left(\tilde{\Lambda}_{\alpha i}\tilde{\Lambda}_{\beta i}\tilde{V}^*_{\beta j}\tilde{\lambda}^*_{\alpha j}\right) R_4(M_i, M_j)$$

Results by Saifuddin Rayyan 2

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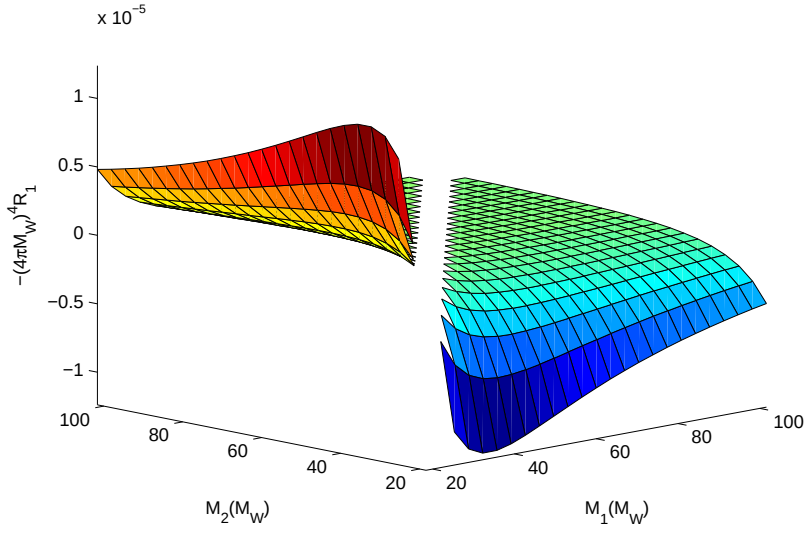
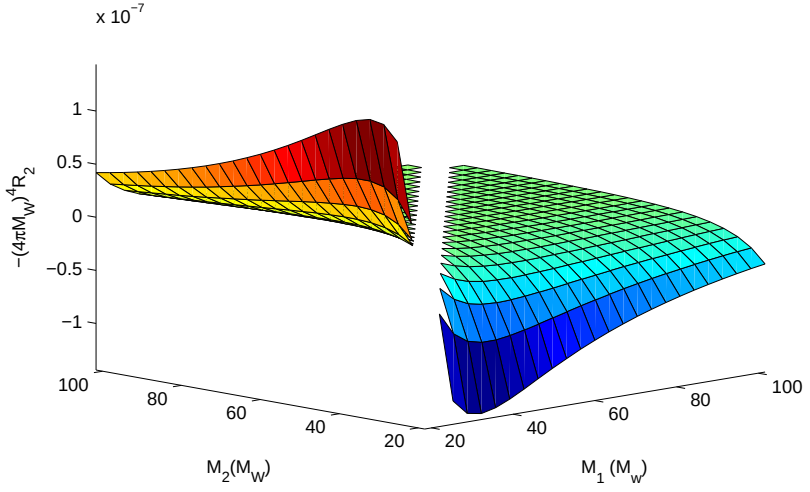
Expressions for the R-functions fill many pages.

Results by Saifuddin Rayyan 3





Dependence of R_1 and R_2 on the two Majorana masses.

Numerical Results

Current Experimental Limits:

$$\begin{aligned} d_e &= (6.9 \pm 7.4) \times 10^{-28}\,\mathrm{e}\cdot\mathrm{cm} \\ d_\mu &= (3.7 \pm 3.4) \times 10^{-19}\,\mathrm{e}\cdot\mathrm{cm} \end{aligned}$$

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Preliminary Result for Okamura Model:

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Preliminary Result for Okamura Model:

d_e can be as larger as or larger than $O(10^{-28})\,\mathrm{e}\cdot\mathrm{cm}$

(Actual number depends on choice of parameters.)

Conclusions

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- TeV-scale see-saw models can lead to a sizable lepton EDM if there is a large mass splitting among the heavy right-handed neutrinos.

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- TeV-scale see-saw models can lead to a sizable lepton EDM if there is a large mass splitting among the heavy right-handed neutrinos.
- Next generation of experiments could either discover lepton EDM or place strong constraints on TeV-scale seesaw models.