Appearance of Majorana phase in two flavor neutrino oscillations with neutrino decay

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Based on : *Phys.Rev.D* 107 (2023) 1, 013002

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Invisibles23 Workshop, Göttingen, Germany

31st August 2023

Indian Institute of Technology Bombay

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

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Asymmetry Essential Asymmetries of Nature

Motivation

- Oscillation probabilities depend on Majorana phases for **neutrino decoherence**, with an off-diagonal term in decoherence matrix.

F. Benatti et al. Phys.Rev.D 64(2001),085015
A. capolupo et al. Phys. Lett. B 7929(2019) 298-303

- Towards distinguishing Dirac from Majorana with **Gravitational waves**.

Stephen S. King et al. 2306.05389

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Our Proposal

- The decay-Hamiltonian $\mathcal{H} = M - i\Gamma/2,$

$$\mathcal{M} = \begin{pmatrix} a_1 & 0 \\ 0 & a_2 \end{pmatrix}, \quad \Gamma/2 = \begin{pmatrix} b_1 & \frac{1}{2}\eta e^{i\xi} \\ \frac{1}{2}\eta e^{-i\xi} & b_2 \end{pmatrix}$$

$$a_1 = m_1^2/2E \text{ and } a_2 = m_2^2/2E$$

- The time evolution operator for neutrinos in the mass eigenbasis is $\mathcal{U} = e^{-i\mathcal{H}t}$

$$n_\mu = Tr[(-i\mathcal{H}t).\sigma_\mu]/2 \qquad \mathcal{U} = e^{n_0}\left[\cosh n\ \sigma_0 + \frac{\vec{n}.\vec{\sigma}}{n}\sinh n\right]$$

- In flavor basis

$$\mathcal{U}_f = U\mathcal{U}U^{-1} \qquad P_{\alpha\beta} = |(\mathcal{U}_f)_{\alpha\beta}|^2$$

Nielsen, M., Chuang, I. (2010). Quantum Computation and Quantum Information

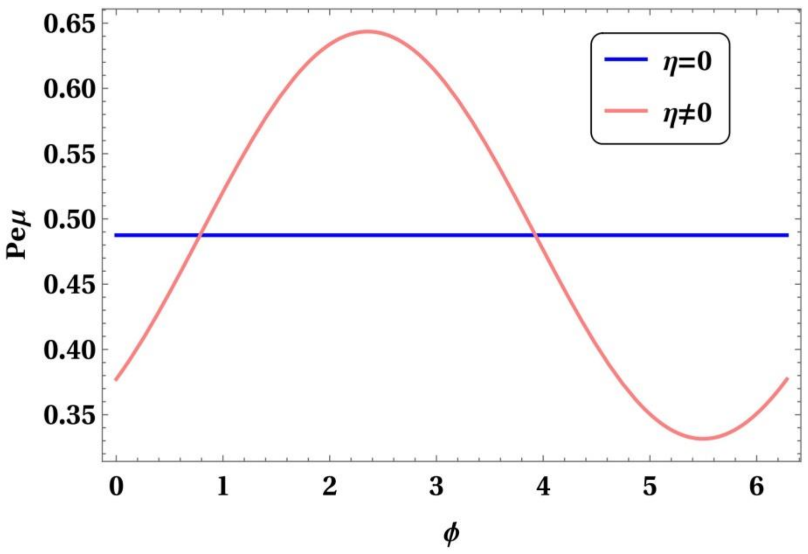
Outcomes

In the limit

$$b_1 = b = b_2 \text{ and } \eta \ll |a_2 - a_1|$$

$$P_{e\mu} = e^{-2bt}\left(P_{e\mu}^{\rm vac} + 2\eta \sin(\xi - \phi)\mathcal{B}\right)$$

$$\mathcal{B} = \frac{\sin(2\theta)\sin^2\left[\frac{1}{2}t(a_2 - a_1)\right]}{(a_2 - a_1)}$$



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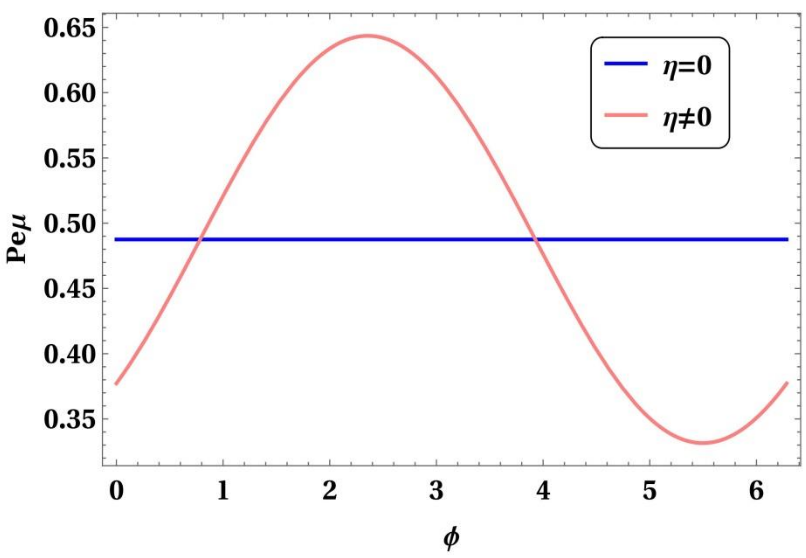

CPT Conservation $\bar{M} = M$ and $\bar{\Gamma} = \Gamma^*$

$$\phi \to -\phi \quad \xi \to -\xi$$

$$P_{\bar{e}\bar{\mu}} = e^{-2bt}\left(P_{\bar{e}\bar{\mu}}^{\text{vac}} - 2\eta\sin(\xi-\phi)\mathcal{B}\right)$$

CP Violation $P_{\bar{e}\bar{\mu}} \neq P_{e\mu}$

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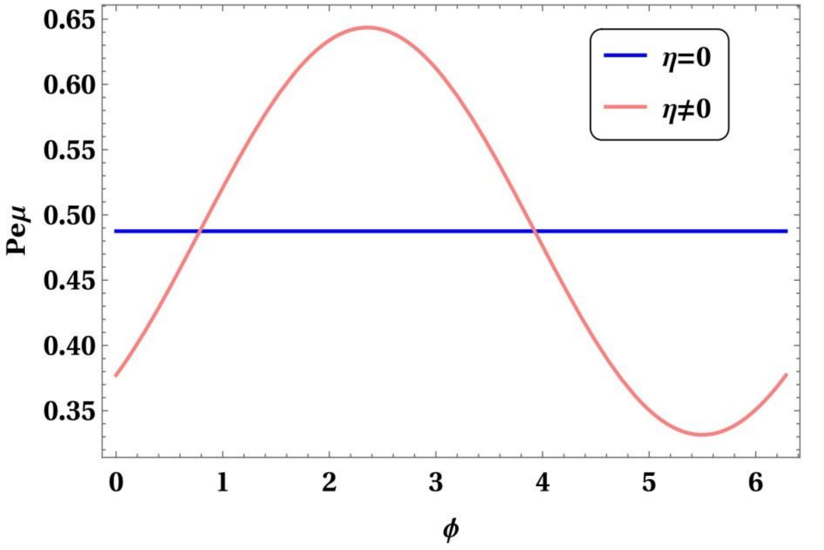
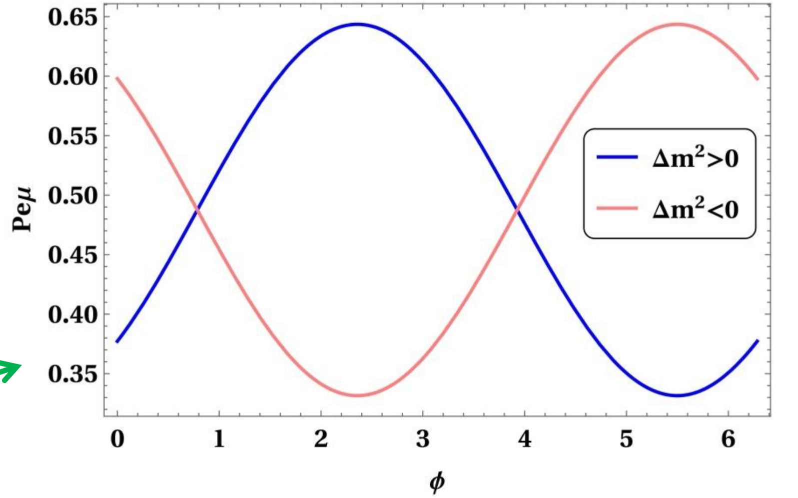
Sensitive to Mass Hierarchy





Do we ever observe this effect ??

- Supernova 1987A, $\tau_\nu \geq 5.7 \times 10^5 \text{ s } (m_\nu/\text{eV})$

  $\Gamma_\nu \equiv b \approx 10^{-21}$ for m_ν =1eV.

J.A.Frieman et al. Phys.Lett.B 200(1988) 115-121

The new effects considered in this work are of order

$$\eta/(a_2 - a_1) = \eta E/\Delta m^2$$

- Effects are of **order 10%** for $\Delta m^2 \approx 10^{-4}\,\text{eV}^2$ if **E=10^7 GeV**

★ **Ultra high energy neutrinos** from astrophysical sources provide a platform to study the effect.

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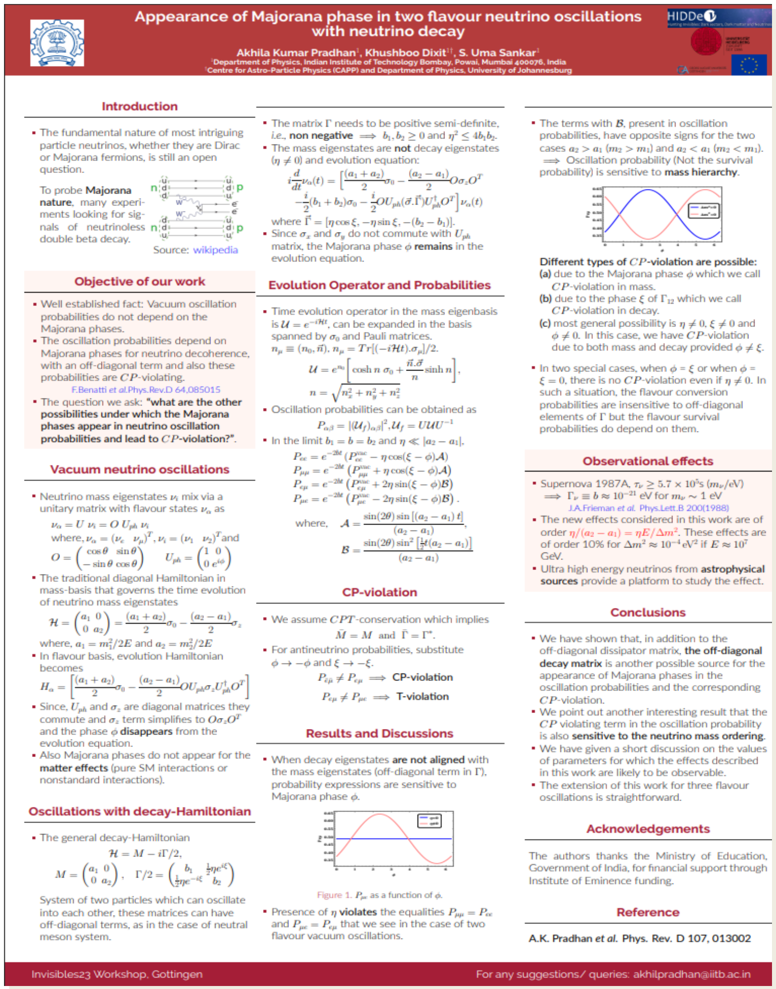
Thank you for your attention



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