Probing Leptonic CP Structure through Neutrinoless Double Beta

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Abstract

We study CP violation in the leptonic sector in the context of Neutrinoless Double Beta Decay. We determine the allowed region for the effective Majorana mass by considering random values of the Majorana phases and incorporating the current experimental constraints on neutrino oscillation parameters. We further discuss the implications of existing limits from KamLAND-Zen and cosmological bounds on, as well as the projected sensitivity of next-generation experiments to probe and constrain the CP structure of the lepton sector.

Introduction

- Neutrino oscillation experiments have firmly established that neutrinos are massive particles and undergo flavor mixing.
- The fundamental nature of neutrinos, namely whether they are Dirac or Majorana fermions, remains one of the central open questions in particle physics.
- Neutrinoless double beta decay ($0\nu\beta\beta$) provides the most sensitive probe of lepton number violation and Majorana neutrino masses.
- The decay amplitude depends on the effective Majorana mass parameter $m_{\beta\beta}$, which is sensitive to the CP-violating Majorana phases of the PMNS matrix.

Effective Majorana mass

The leptonic mixing matrix can be written as $U_{\rm PMNS} = V(\theta_{12}, \theta_{13}, \theta_{23}, \delta)\ {\rm diag}\left(1, e^{i\alpha_{21}/2}, e^{i\alpha_{31}/2}\right)$, where δ denotes the Dirac CP phase and α_{21}, α_{31} are the Majorana CP phases.
The effective Majorana mass governing the standard light-neutrino exchange mechanism is

$$m_{\beta\beta} = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|.$$

The corresponding half-life is
$\left[T_{1/2}^{0\nu}\right]^{-1} = G^{0\nu}|M^{0\nu}|^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$, where $G^{0\nu}$ is the phase-space factor and $M^{0\nu}$ denotes the nuclear matrix element.

PMNS Parametrizations and CP structure

PDG Parametrization. In the standard PDG convention the effective Majorana mass can therefore be written as

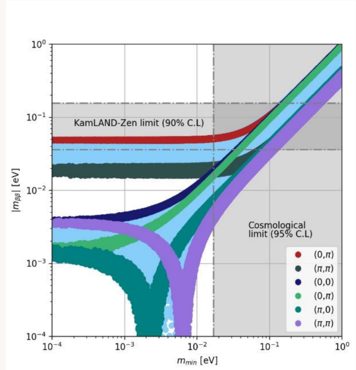
$$m_{\beta\beta} = \left|m_1 c_{12}^2 c_{13}^2 e^{2i\alpha_1} + m_2 s_{12}^2 c_{13}^2 e^{2i\alpha_2} + m_3 s_{13}^2 e^{2i\delta}\right|.$$

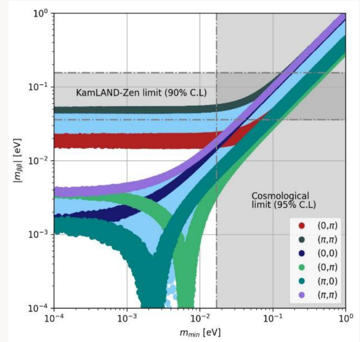
Symmetric Parametrization. In the symmetric parametrization of Schechter and Valle the effective Majorana mass is

$$m_{\beta\beta} = \left|m_1 c_{12}^2 c_{13}^2 + m_2 s_{12}^2 c_{13}^2 e^{2i\phi_{12}} + m_3 s_{13}^2 e^{2i\phi_{13}}\right|.$$

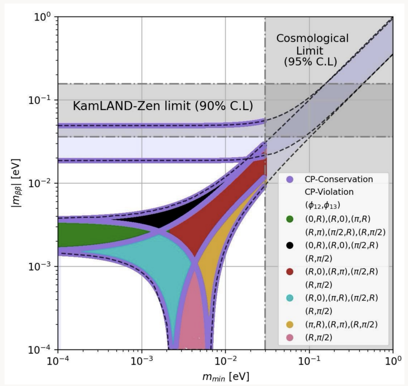
Numerical results

Comparison of the parameterizations for representative values of the Majorana phases. Left: PDG parameterization. Left: PDG (α_1, α_2), Right: Symmetric (ϕ_{12}, ϕ_{13}).





For PDG parametrization and R is random value,



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Work supported by Sistema Nacional de Investigadoras e Investigadores, PAPIIT IN-112825 and PICI CI-2688

NEUTRINO '26
International Conference on Neutrino Physics and Astrophysics
June 22nd - 26th, 2026
UCI Department of Physics & Astronomy