Revisiting the quantum decoherence scenario as an explanation for the LSND anomaly

Pouya Bakhti

IPM, Iran

pouya_bakhti@ipm.ir

June 24, 2015

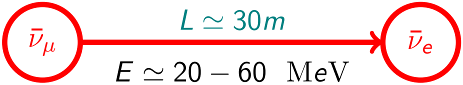
Reference

- P. B., Y. Farzan and T. Schwetz, JHEP **1505** (2015) 007 [arXiv:1503.05374 [hep-ph]].

Overview

1. LSND anomaly
2. Quantum Decoherence
3. Analysis of short baseline and reactor neutrino data
4. Predictions for future experiments and possible experimental tests
5. Summary

LSND anomaly



$\frac{\Delta m_{23}^2 L}{E} \ll 1$

no flavor change expected

sterile neutrino

$\Delta m^2 \sim 1eV^2$

appearnce-disapearance tension

Cosmology

LSND anomaly

Quantum Decoherence has been proposed as an alternative explanation to LSND anomaly

- G. Barenboim and N. E. Mavromatos, JHEP **0501** (2005) 034 [hep-ph/0404014].
- G. Barenboim, N. E. Mavromatos, S. Sarkar and A. Waldron-Lauda, Nucl. Phys. B **758** (2006) 90 [hep-ph/0603028].
- Y. Farzan, T. Schwetz and A. Y. Smirnov, JHEP **0807** (2008) 067 [arXiv:0805.2098 [hep-ph]].

Quantum Decoherence

H is Hamiltonian, $\mathcal{D}[\rho]$ is QD effect

$$\frac{d\rho}{dt} = -i[H, \rho] - \mathcal{D}[\rho]$$

Maintaining complete positivity leads to the Lindblad form

$$\mathcal{D}[\rho] = \sum_m \left[\{\rho, D_m D_m^\dagger\} - 2 D_m \rho D_m^\dagger \right]$$

With consideration of unitarity and conservation of energy, D_m and H can be simultaneously diagonalized

$$H = \mathrm{Diag}[h_1, h_2, h_3]\,, \qquad D_m = \mathrm{Diag}[d_{m,1}, d_{m,2}, d_{m,3}]$$

Quantum Decoherence

Solving evolution equation

$$\rho(t) = \begin{bmatrix} \rho_{11}(0) & \rho_{12}(0)e^{-(\gamma_{12}-i\Delta_{12})t} & \rho_{13}(0)e^{-(\gamma_{13}-i\Delta_{13})t} \\ \rho_{21}(0)e^{-(\gamma_{21}-i\Delta_{21})t} & \rho_{22}(0) & \rho_{23}(0)e^{-(\gamma_{23}-i\Delta_{23})t} \\ \rho_{31}(0)e^{-(\gamma_{31}-i\Delta_{31})t} & \rho_{32}(0)e^{-(\gamma_{32}-i\Delta_{32})t} & \rho_{33}(0) \end{bmatrix}$$

$U_{\alpha i}$ is PMNS matrix

$$\gamma_{ij} \equiv \sum_m (d_{m,i} - d_{m,j})^2$$

$$\Delta_{ji} \equiv h_j - h_i \approx \frac{\Delta m_{ji}^2}{2E_\nu}$$

$$\rho_{ij}(0) = \rho_{ij}^{(\alpha)}(0) = U_{\alpha i} U_{\alpha j}^*$$

Quantum Decoherence

The flavor conversion probability is

$$P_{\alpha\beta} = \langle \nu_\beta | \rho^{(\alpha)}(t) | \nu_\beta \rangle = \sum_{ij} U^*_{\beta i} U_{\beta j}\, \rho^{(\alpha)}_{ij}(t)$$

we conjecture an exponential dependence on energy for d_i

$$d_i = \sqrt{\gamma_0}\ \exp\left[- \left(\frac{E}{E_i} \right)^n \right] ,$$

Previous explanation proposed a power law dependence ($\gamma \propto 1/E^n$) that is excluded now by Daya Bay and RENO because they predicted no oscillation between near and far detectors (Y. Farzan, T. Schwetz and A. Y. Smirnov, JHEP **0807** (2008) 067 [arXiv:0805.2098 [hep-ph]])

Quantum Decoherence

Based on KamLAND

$$\gamma_{12} \simeq 0 \quad \text{and} \quad \gamma \equiv \gamma_{13} \simeq \gamma_{32}$$

For $\Delta_{21} L \ll 1$

$$P_{\bar{\mu}\bar{e}}(\gamma, L) = P_{\mu e}(\gamma, L) \simeq 2|U_{\mu 3}|^2 |U_{e3}|^2 \left[1 - e^{-\gamma L} \cos(\Delta_{31} L)\right]$$

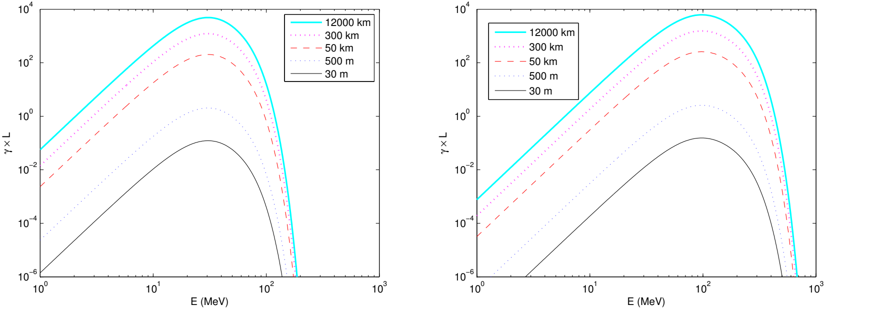
$$P_{\bar{e}\bar{e}}(\gamma, L) = P_{ee}(\gamma, L) \simeq 1 - 2|U_{e3}|^2 (1 - |U_{e3}|^2) \left[1 - e^{-\gamma L} \cos(\Delta_{31} L)\right]$$

$$P_{\bar{\mu}\bar{\mu}}(\gamma, L) = P_{\mu\mu}(\gamma, L) \simeq 1 - 2|U_{\mu 3}|^2 (1 - |U_{\mu 3}|^2) \left[1 - e^{-\gamma L} \cos(\Delta_{31} L)\right]$$

For LSND and KARMEN, $\Delta_{31} L \ll 1$

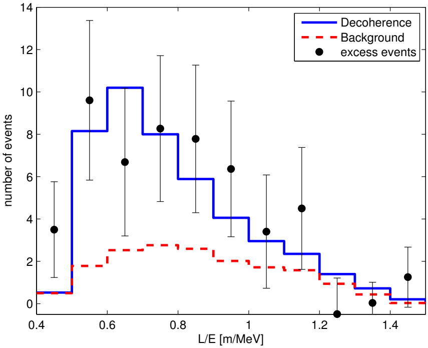
$$P_{\bar{\mu}\bar{e}}(\gamma, L) = P_{\mu e}(\gamma, L) = 2|U_{\mu 3}|^2 |U_{e3}|^2 \left(1 - e^{-\gamma L}\right) \approx |U_{e3}|^2 \left(1 - e^{-\gamma L}\right)$$

Analysis of short baseline and reactor neutrino data



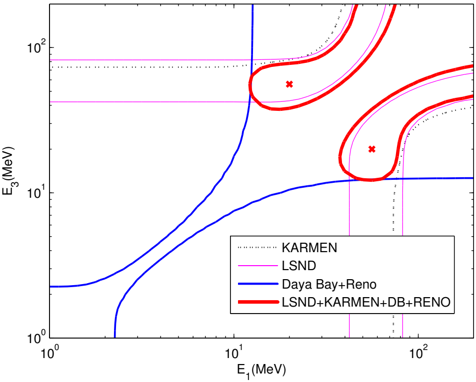
- $n = 2$, $\gamma_0 = 0.01\ \mathrm{m}^{-1}$ for both panels, and $E_1 = E_2 = 20$ MeV, $E_3 = 55$ MeV ($E_1 = E_2 = 60$ MeV, $E_3 = 200$ MeV) for the left (right) panel

Analysis of short baseline and reactor neutrino data



- Decoherence prediction for LSND for $\gamma_0 = 0.01$ m^{-1}, $E_1 = E_2 = 18$ MeV and $E_3 = 63$ MeV compared with data

Analysis of short baseline and reactor neutrino data



- Constrains on the parameters $E_{1,3}$ from short baseline and reactor experiments at 90% C.L. taking $n = 2$ and $\gamma_0 = 0.01\ \text{m}^{-1}$.

Analysis of short baseline and reactor neutrino data

Data	$\chi^2_{\rm min}$/DOF	GOF	$\chi^2_{\rm PG}$/DOF	PG
LSND	4.8/8	77%		
KARMEN	7.0/7	43%		
Daya Bay and RENO	78/98	93%		
LSND+KARMEN	14/17	66%	2.3/2	32%
LSND+KARMEN+Reactor	93/118	96%	3.2/4	52%

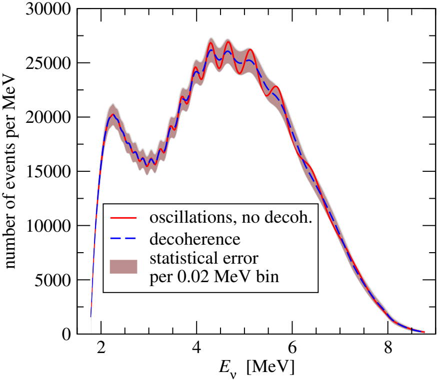
- $\chi^2_{\rm min}$/DOF and goodness of fit (GOF)
- Consistency of different experiments, $\chi^2_{\rm PG} = \chi^2_{\rm tot,min} - \sum_i \chi^2_{i,\rm min}$
- $E_1 = E_2$ and E_3 are taken as free parameters to fit the data and the rest are fixed to $\gamma_0 = 0.01\ {\rm m}^{-1}$, $n = 2$ and $\sin^2 2\theta_{13} = 0.085$

Predictions for future experiments and possible experimental tests

- JUNO and RENO-50 experiments
    - reactor experiments
    - 50 km baseline
    - They will be ready for data taking from 2020 for 5 years
    - In China and South Korea respectively

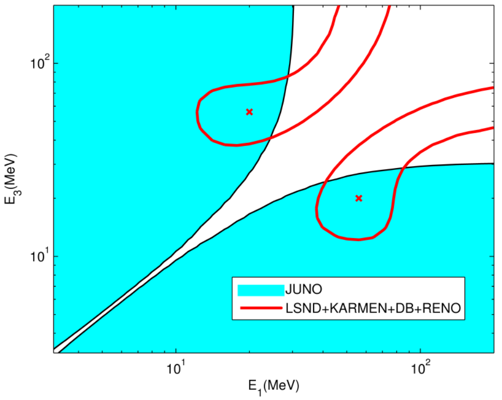
$$P_{\bar{e}\bar{e}} = 1 - \sin^2 2\theta_{12} \sin^2 \frac{\Delta_{21} L}{2} - \frac{1}{2} \sin^2 2\theta_{13} + \frac{1}{2} \sin^2 2\theta_{13}\, e^{-\gamma L} \left[\cos^2 \theta_{12} \cos(\Delta_{31} L) + \sin^2 \theta_{12} \cos(\Delta_{32} L)\right]$$

Predictions for future experiments and possible experimental tests



- Event spectrum at JUNO for an exposure of 4320 kt GW yr.

Predictions for future experiments and possible experimental tests



- In the shaded regions, JUNO can distinguish the decoherence scenario from standard oscillations at more than 3σ $(\Delta\chi^2 = 9)$.

Summary

- Review LSND anomaly
- Review quantum decoherence
- Quantum decoherence explains LSND anomaly
- QD will be tested by future reactor experiments JUNO and RENO-50

Thank you for your attention.