Damped neutrino oscillations

Erroneous measurements of neutrino oscillation parameters?

Based on `hep-ph/0502147`

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Outline

- Standard neutrino oscillations
- Sub-leading effects and damping factors
- Implications for experimental measurements
- Outlook
- Summary and conclusions

Neutrino oscillations

- Prime candidate for neutrino flavor conversion
- Pure quantum mechanical effect
- Requires neutrinos to be massive and mix
- Physics beyond the SM?

Standard oscillation formulas

The probability of an α flavor neutrino to convert to a β flavor neutrino is given by

$$P_{\alpha\beta} = \sum_{i,j=1}^{3} J_{\alpha\beta}^{ij} \exp(-\mathrm{i}2\Delta_{ij}),$$

where $\Delta_{ij} = \Delta m_{ij}^2 L/(4E)$,

$$J_{\alpha\beta}^{ij} = U_{\beta i} U_{\alpha i}^* U_{\beta j}^* U_{\alpha j},$$

and U is the leptonic mixing matrix.

The leptonic mixing matrix

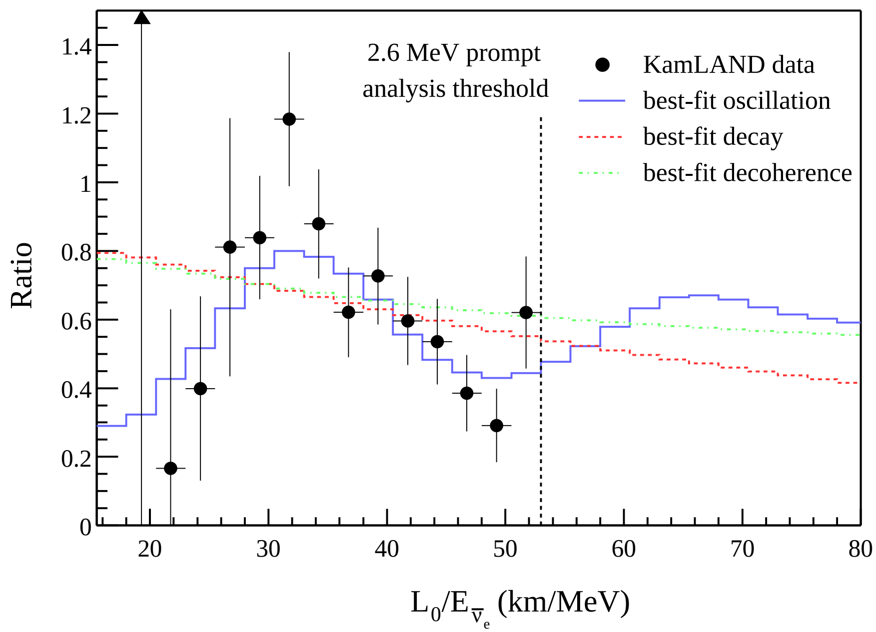
The standard way of parameterizing the leptonic mixing matrix in the case of three neutrino flavors is:

$$U =$$

$$\begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-\mathrm{i}\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{\mathrm{i}\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{\mathrm{i}\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{\mathrm{i}\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{\mathrm{i}\delta} & c_{23}c_{13} \end{pmatrix}$$

$$s_{ij} = \sin(\theta_{ij}), \; c_{ij} = \cos(\theta_{ij})$$

Oscillations vs. other effects



KamLAND Collaboration, Phys. Rev. Lett. **94**, 081801 (2005)

Possible other effects:

- Neutrino decay
- Neutrino quantum decoherence
- Neutrino wave-packet decoherence
- etc ...

Damping factors

- Even if not leading, other effects may still contribute
- Introduce “damping factors” into the neutrino oscillation formulas:

$$P_{\alpha\beta} = \sum_{i,j=1}^{3} D_{ij} J_{\alpha\beta}^{ij} \exp(-\mathrm{i}2\Delta_{ij}),$$

where

$$D_{ij} = \exp\left(-\alpha_{ij} \frac{|\Delta m_{ij}^2|^\xi L^\beta}{E^\gamma}\right)$$

Damping factors (2)

- The parameters α_{ij}, ξ, β, and γ are characteristic for the type of effect
- The number of free parameters can often be reduced to one or two for specific effects
- Examples:

Damping type	β	γ	ξ
Wave packet decoherence	2	4	2
Decay	1	1	0
Oscillations to ν_s	2	2	0
Absorption	1	-1	0
Quantum decoherence I	1	-2	0
Quantum decoherence II	1 or 2	2	2

Two classes of damping

- Most types of damping falls into one of two categories
- Decoherence-like damping – damps only the interference terms:

$$D_{ii} = 1 \Leftrightarrow \alpha_{ii} = 0 \Rightarrow \sum_\beta P_{\alpha\beta} = 1$$

  Includes: Neutrino wave-packet decoherence, neutrino quantum decoherence

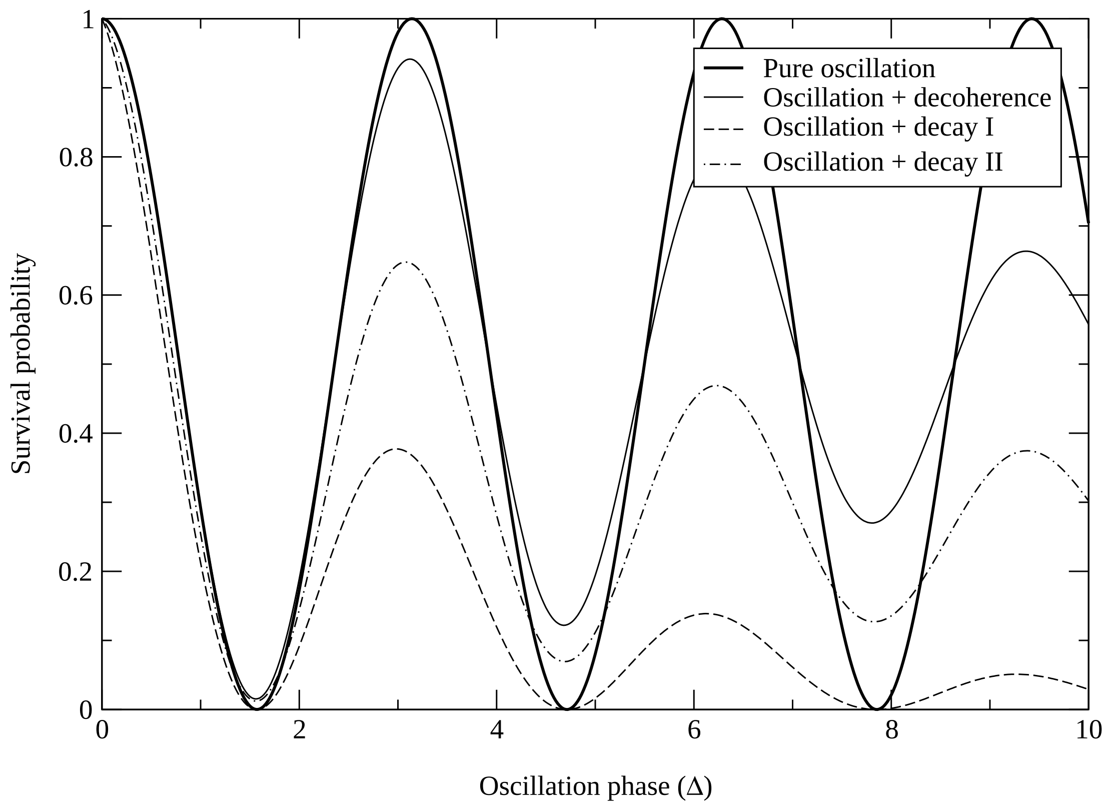
- Decay-like damping – acts independently on the mass eigenstates:

$$D_{ij} = A_i A_j \Leftrightarrow \alpha_{ij} = \alpha_i + \alpha_j \Rightarrow \sum_\beta P_{\alpha\beta} < 1$$

  Includes: Neutrino decay, neutrino absorption

Damped probabilities (2f)

The effect of damping on the neutrino survival probability $P_{\alpha\alpha}$:



Implications for experiments

- Damping effects modify the neutrino oscillation probabilities
- Will give erroneous measurements of the oscillation parameters if not taken into account
- Higher dimension of the parameter space

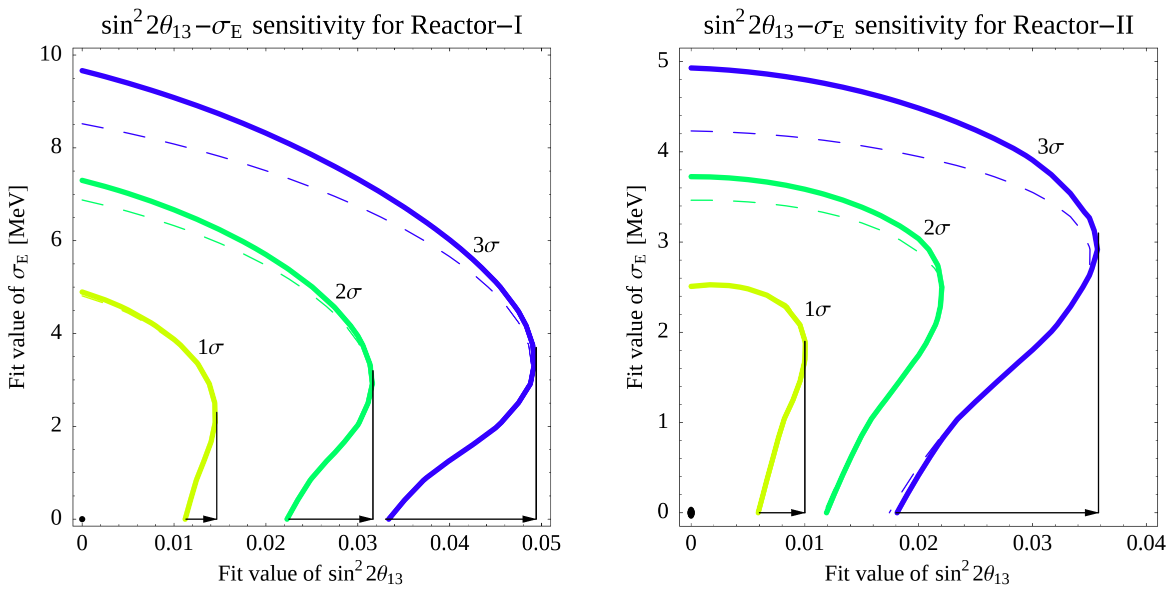
Example: θ_{13} at CHOOZ

- For neutrino wave packet decoherence at a reactor experiment:

$$
\begin{aligned}
P_{\bar{e}\bar{e}} \quad = \quad & c_{13}^4 \left\{1 - \frac{1}{2}\sin^2(2\theta_{12})[1 - D_{21}\cos(2\Delta_{21})]\right\} \\
& + \frac{1}{2}\sin^2(2\theta_{13})[D_{31}c_{12}^2\cos(2\Delta_{31}) \\
& + D_{32}s_{12}^2\cos(2\Delta_{32})] + s_{13}^4.
\end{aligned}
$$

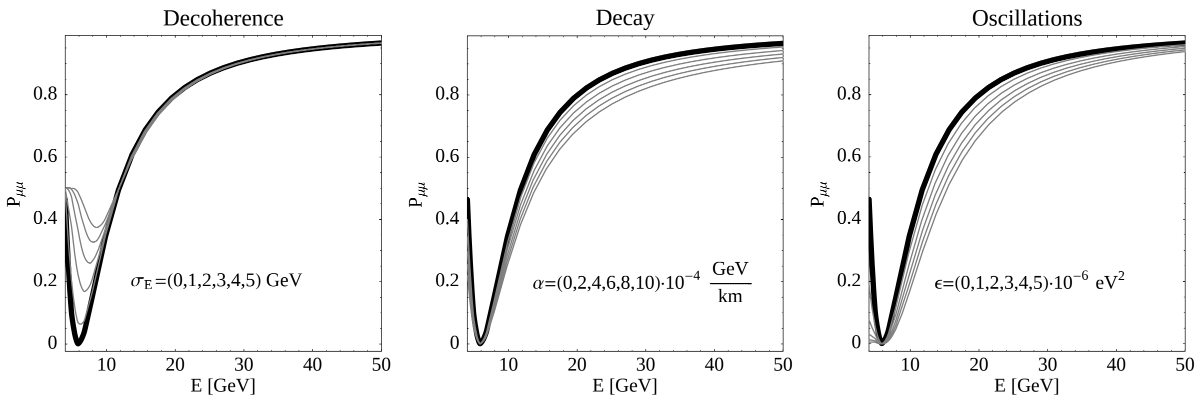
- The effect of the damping terms could counter a θ_{13} effect
- If the damping parameters are allowed to vary, the bound on θ_{13} may become weaker

Example: θ_{13} at CHOOZ (2)



Which type of damping?

- How to identify the specific effect?
- Baseline length fixed – no information on β
- Energy dependence is a better candidate:



Outlook

- Effects that may not be described by damping factors
- Hamiltonian level effects (e.g., matter effects)
- Alters the effective neutrino oscillation parameters directly
- Work in progress

Summary and conclusions

- Sub-leading mechanism treated in a common framework
- May alter the precision determination of neutrino oscillation parameters
- Distinguishing different types of effects

Damped formulas (2f)

- Decoherence-like damping:

$$P_{\alpha\beta} = \delta_{\alpha\beta} + \frac{1}{2}(1 - 2\delta_{\alpha\beta}) \sin^2(2\theta)[1 - D\cos(2\Delta)]$$

- Decay-like damping (only one decaying mass eigenstate):

$$\begin{aligned} P_{\alpha\alpha} &= \left[(c^2 + As^2)^2 - A\sin^2(2\theta)\sin^2(\Delta)\right], \\ P_{\beta\beta} &= \left[(Ac^2 + s^2)^2 - A\sin^2(2\theta)\sin^2(\Delta)\right], \\ P_{\alpha\beta} &= \frac{1}{4}\sin^2(2\theta)[1 + A^2 - 2A\cos(2\Delta)], \end{aligned}$$