Neutrino quantum decoherence at reactor experiments

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March 9th 2021

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SEZIONE DI TORINO

Introduction

Neutrino oscillations provide the first laboratory evidence for New physics

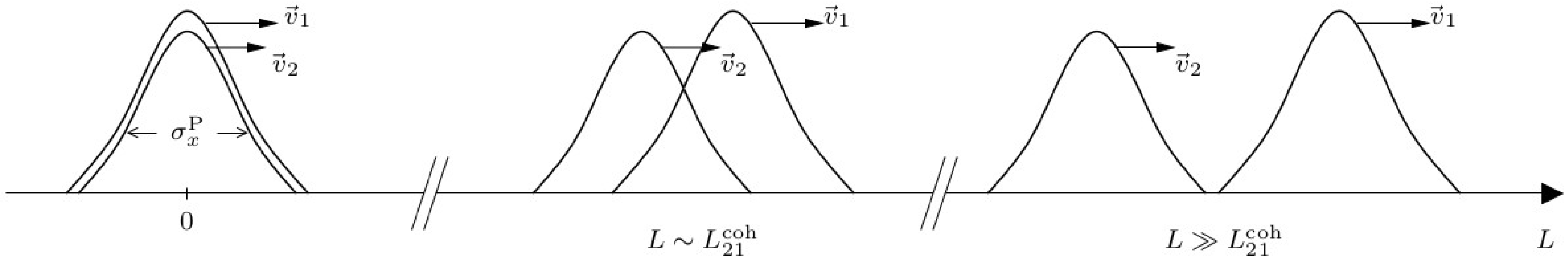
They arise as a consequence of neutrino mixing

Neutrinos produced at some source are in a superposition of different momentum states. The neutrino wave function must be treated as a **wave packet**

Coherence is essential for neutrino oscillations!

Introduction

Neutrinos evolve as wave packets, not plane waves!



Physics that leads to decoherence: the wave packets corresponding to different neutrino mass eigenstates propagate with different speeds and, given enough time, the wave-packets ultimately separate.

Nuclear reactors are excellent laboratories to study neutrino coherence!

Giunti, Kim, Fundamentals of neutrino physics

Neutrino oscillations with decoherence

When treating neutrinos as wave packets, there is a correction due to the wave packet size

$$P^{\text{dec}}(\overline{\nu}_e \to \overline{\nu}_e) = \sum_{j,k} |U_{ej}|^2 |U_{ek}|^2 \, \exp[-i\Delta_{jk} - \xi_{jk}]$$

where the decoherence term depends on the size of the wavepacket width

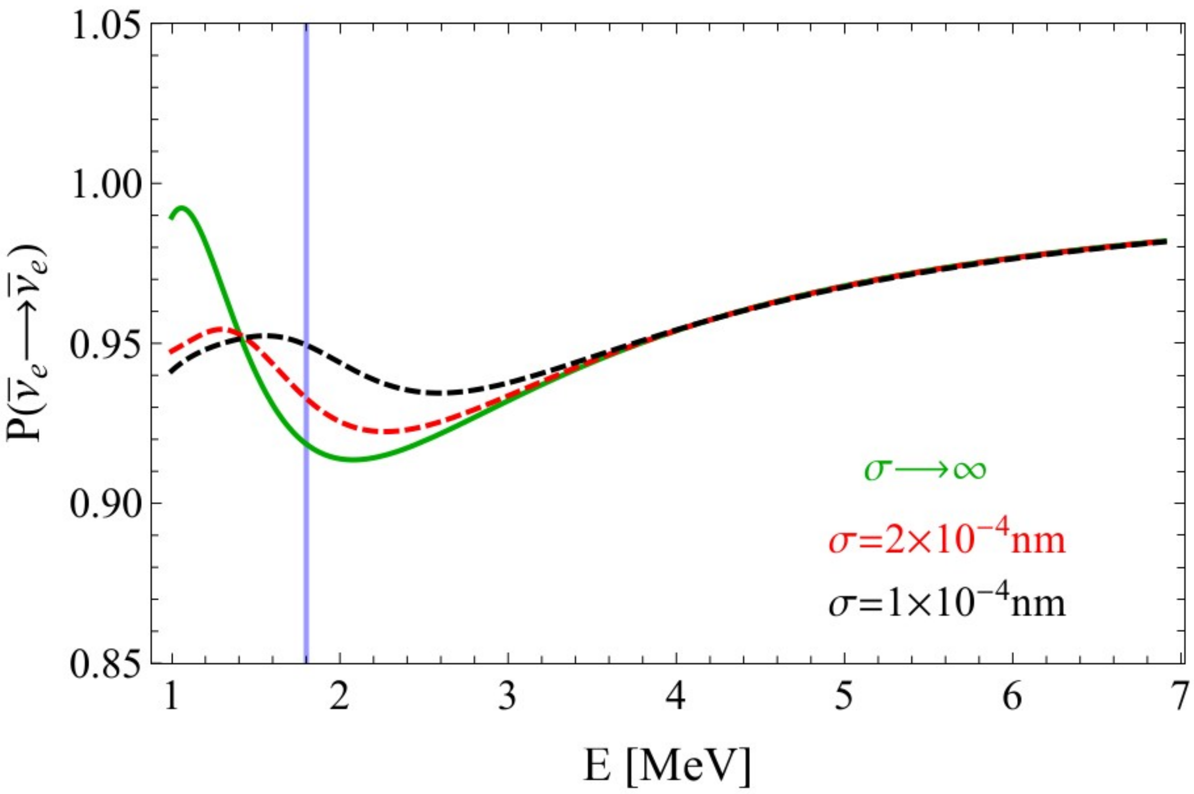
$$\Delta_{jk} \equiv 2\pi \frac{L}{L^{\text{osc}}_{jk}} \equiv \frac{\Delta m^2_{jk} L}{2E} \qquad \xi_{jk}(L,E) = \left(\frac{L}{L^{\text{coh}}_{jk}}\right)^2 \quad L^{\text{coh}}_{jk} = \frac{4\sqrt{2}E^2}{|\Delta m^2_{jk}|}\sigma$$

Giunti, Kim, Lee, PLB274 (1992), M. Beuthe, PRD66 (2002)
Kayser, Kopp, arXiv:1005.4081

Neutrino oscillations with decoherence

Oscillation probability for baselines relevant at reactor experiments

Finite width induces a damping of the oscillation probability



Bounds from current experiments

RENO

6 power plants

2 identical detectors

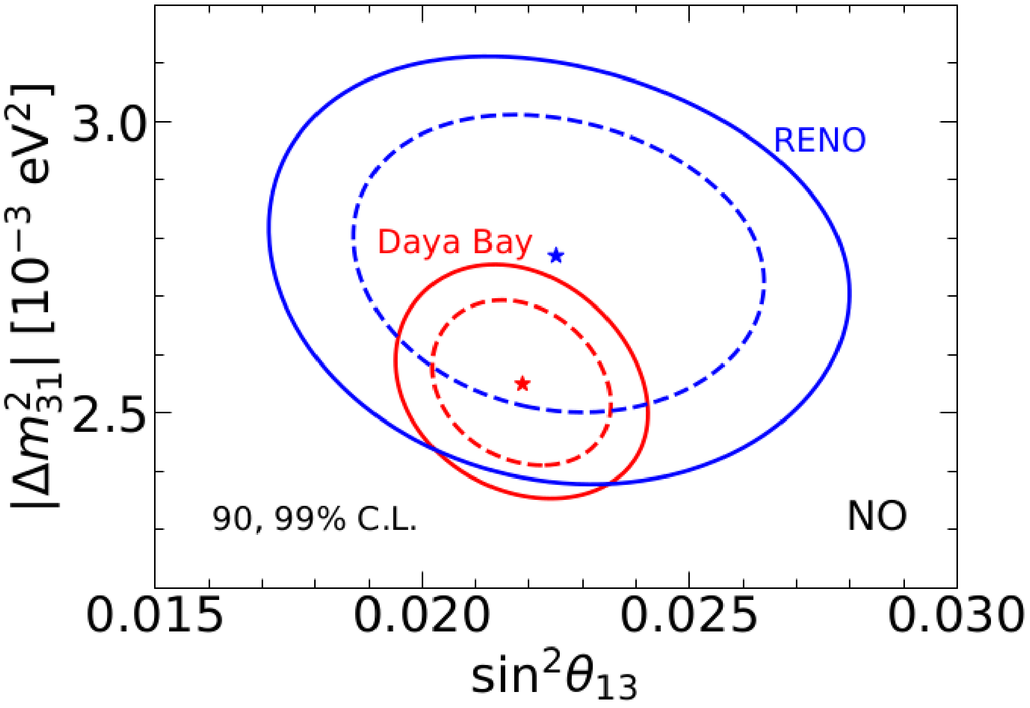
We include 2900 days of data

Daya Bay

6 power plants

8 identical detectors at 3 experimental halls, 2 function as near detectors, 1 as far detector

We include 1958 days of data

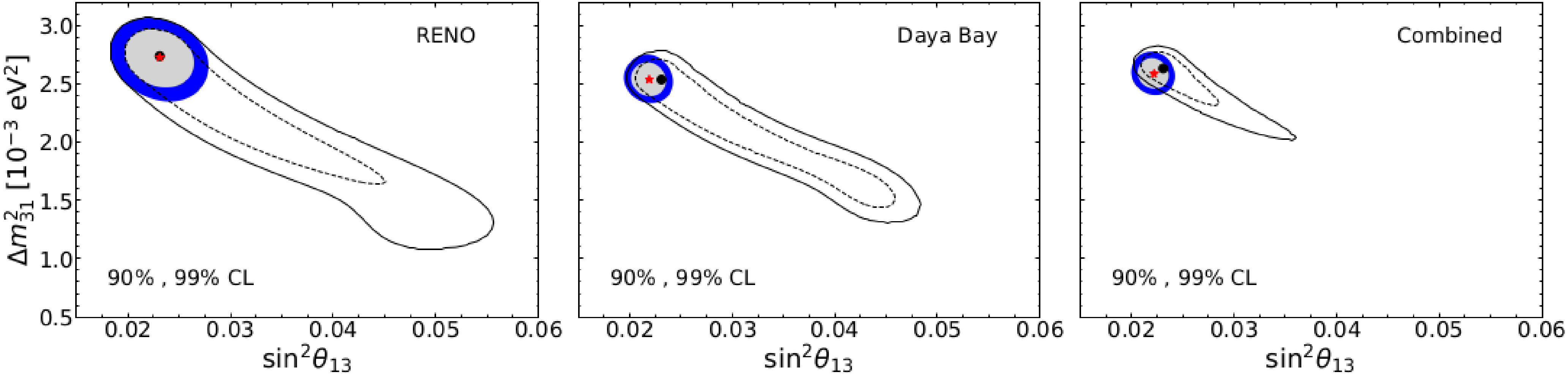


RENO, data from Neutrino2020
Daya Bay, PRL, 1809.02261

Bounds from current experiments

Sensitivity is reduced when including the wave packet width in the analysis

The role of RENO is more important here than in the standard analysis

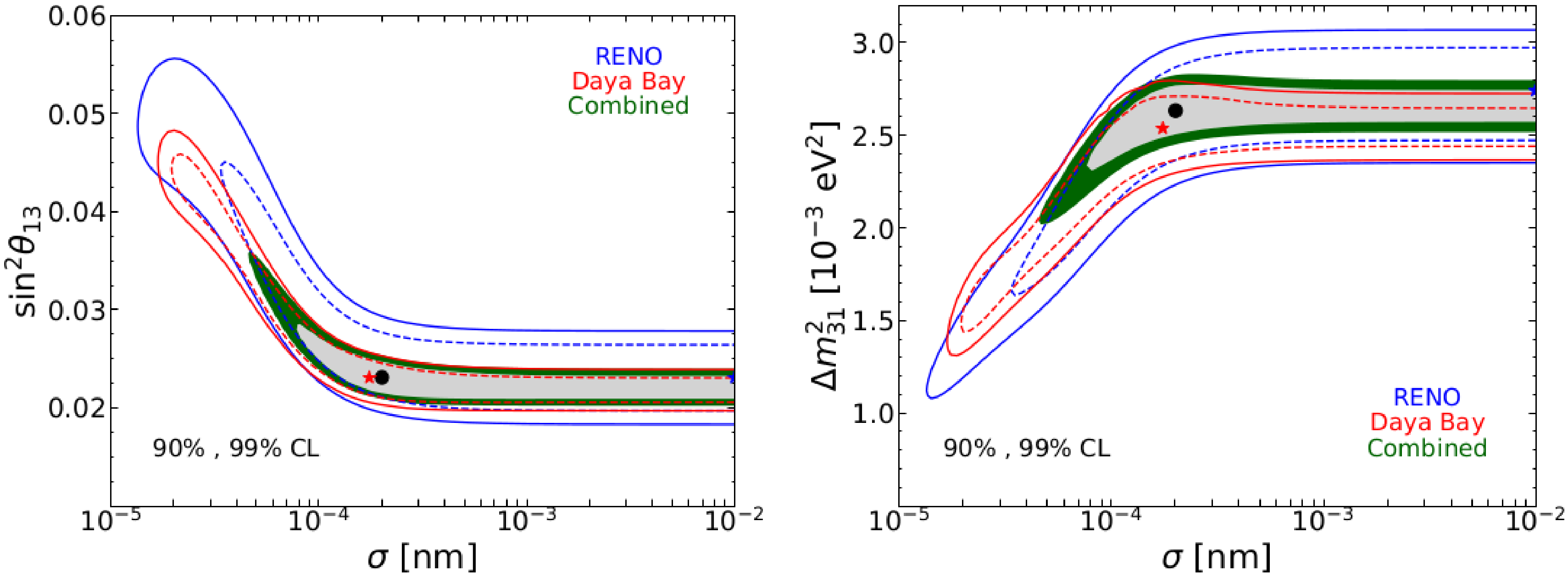


de Gouvêa, De Romeri, Ternes, 2005.03022, JHEP2020

Bounds from current experiments

The reduction of sensitivity is due to a new correlation between the standard parameters and the wave packet width

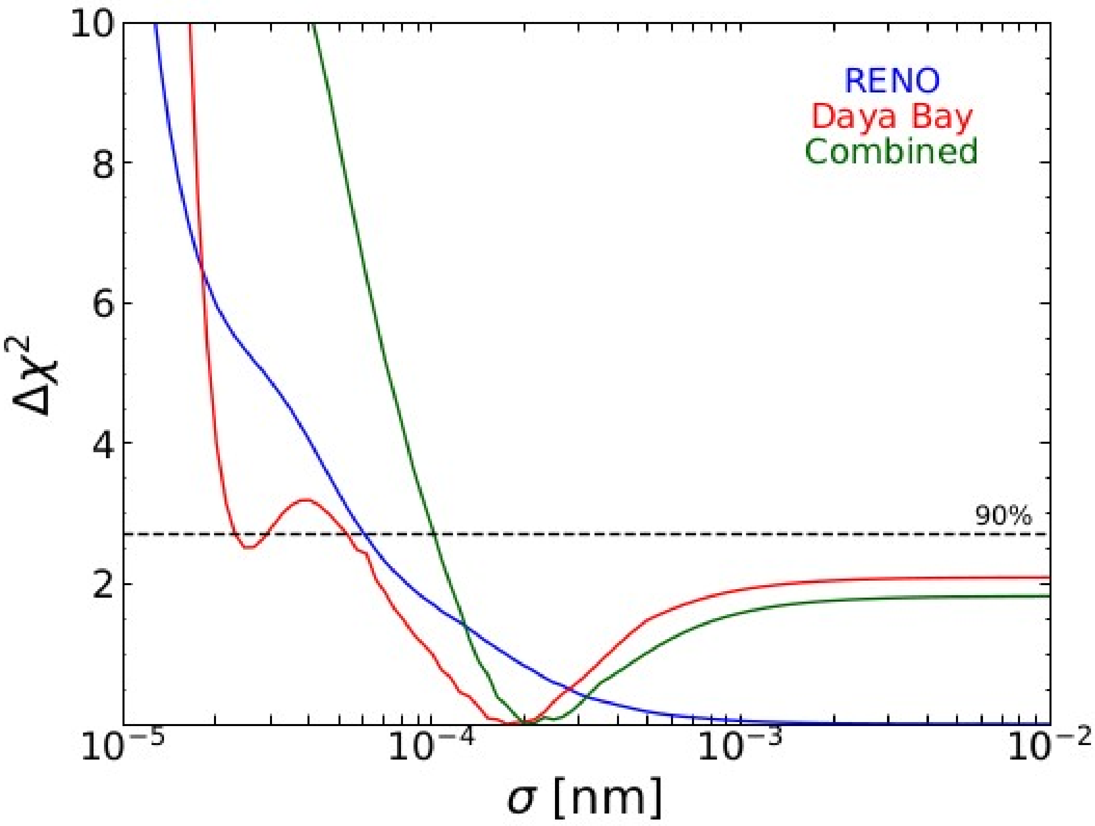
Small values of sigma a correlated with large (small) values of the mixing angle (mass splitting) de Gouvêa, De Romeri, Ternes, 2005.03022, JHEP2020



Bounds from current experiments

From RENO+DB we obtain a lower bound: σ > 10^{-4} nm at 90%

For larger values of sigma the effect in the oscillation probability disappears. The lines extend to infinity.



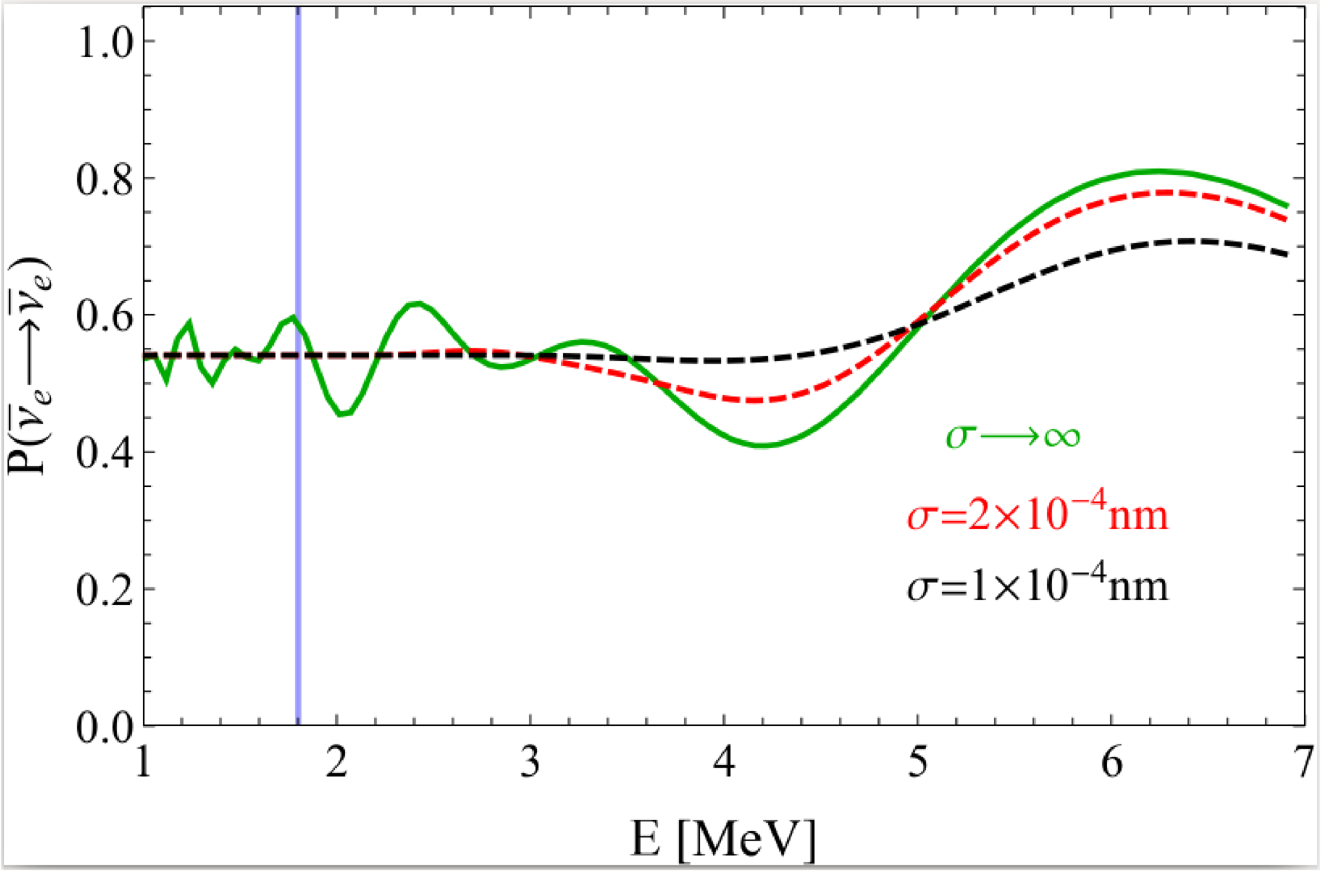
de Gouvêa, De Romeri, Ternes, 2005.03022, JHEP2020

Bounds from current experiments

KamLAND

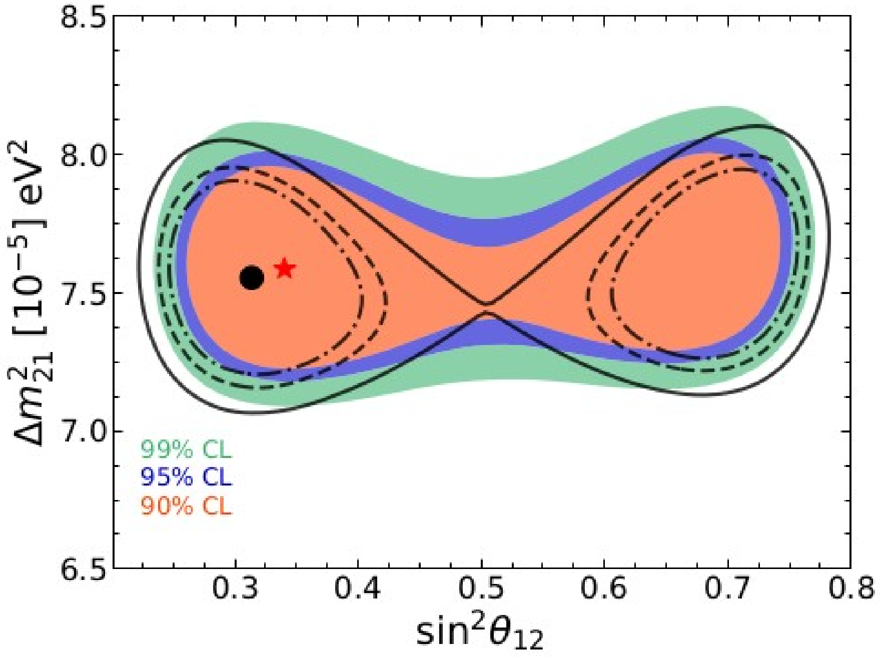
many reactors with baselines ranging from ~150 to ~1000 km baselines

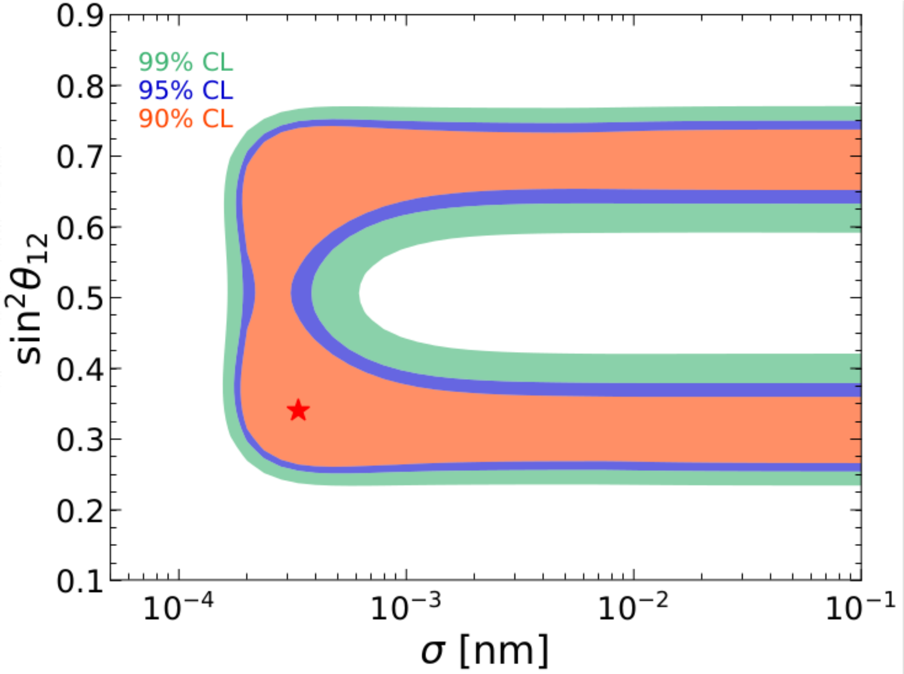
Observes oscillation minimum and maximum



Bounds from current experiments

Correlation between standard parameters and σ appears only for solar angle

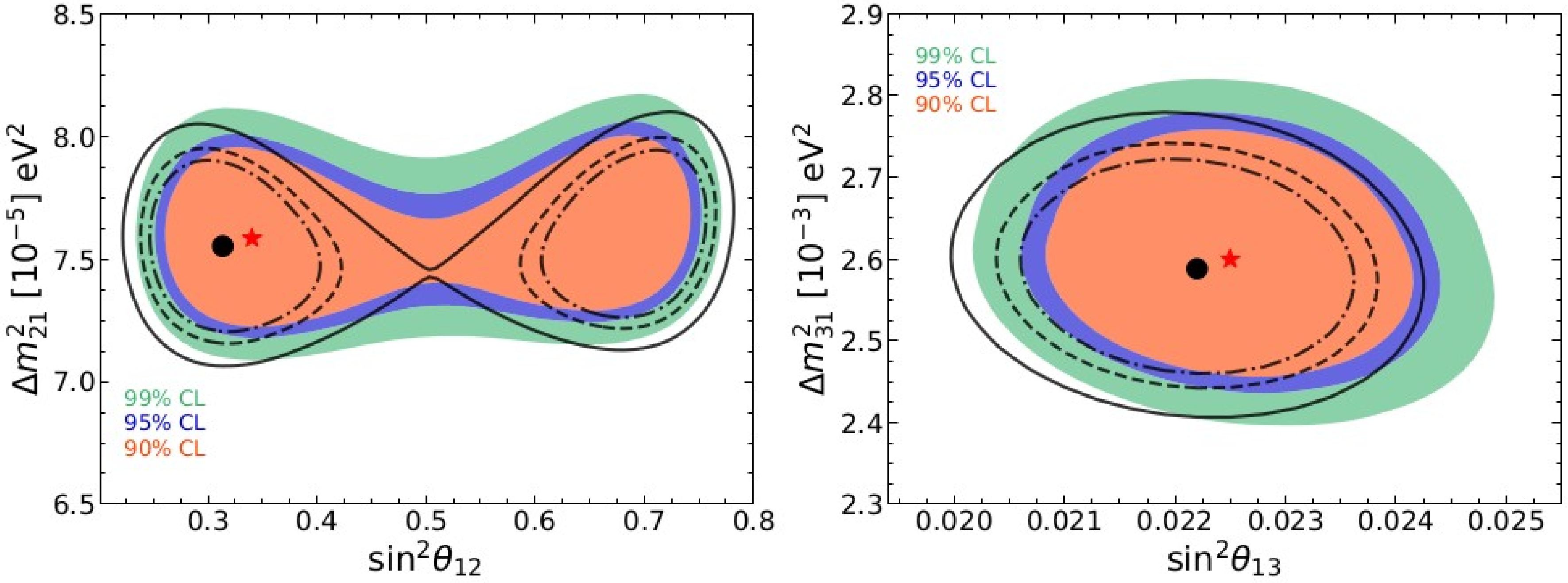




de Gouvêa, De Romeri, Ternes, Preliminary

Bounds from current experiments

Combining all data restores the sensitivity to the oscillation parameters

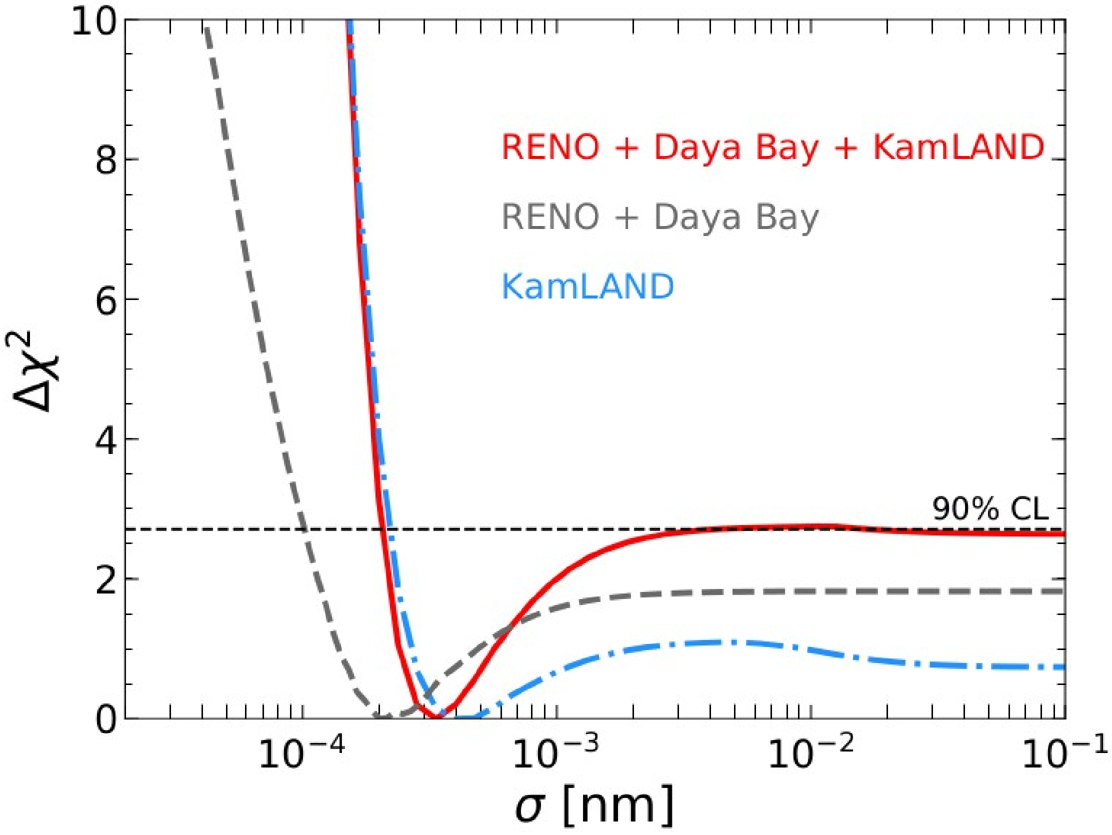


de Gouvêa, De Romeri, Ternes, Preliminary

Bounds from current experiments

From the combined analysis we obtain a lower bound (driven by KL):
$\sigma > 2 \times 10^{-4}$ nm at 90% CL

Coherence scenario is disfavored at 90% CL



de Gouvêa, De Romeri, Ternes, Preliminary

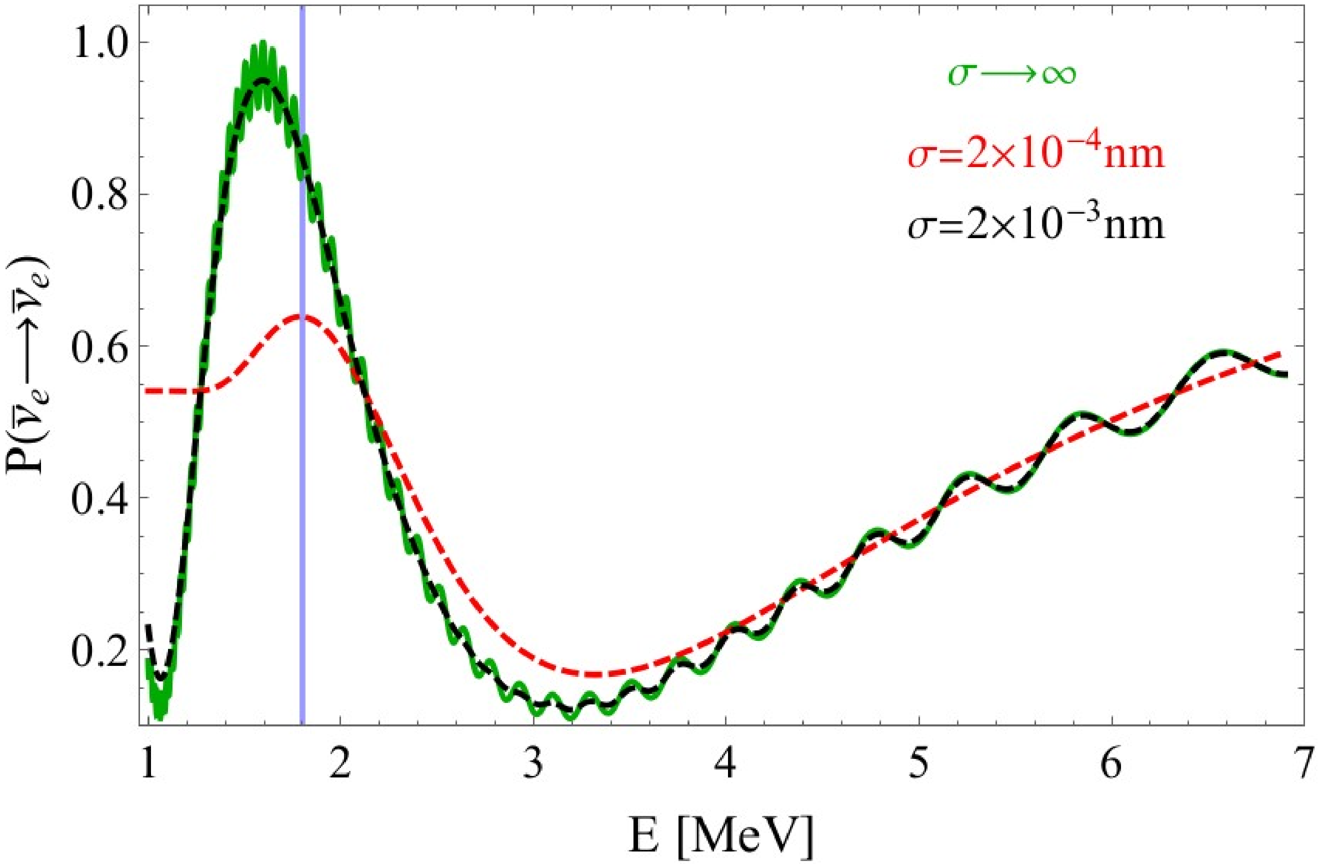
Sensitivity at JUNO

JUNO
10 reactors

2 detectors

JUNO will measure the oscillation parameters at below 1%

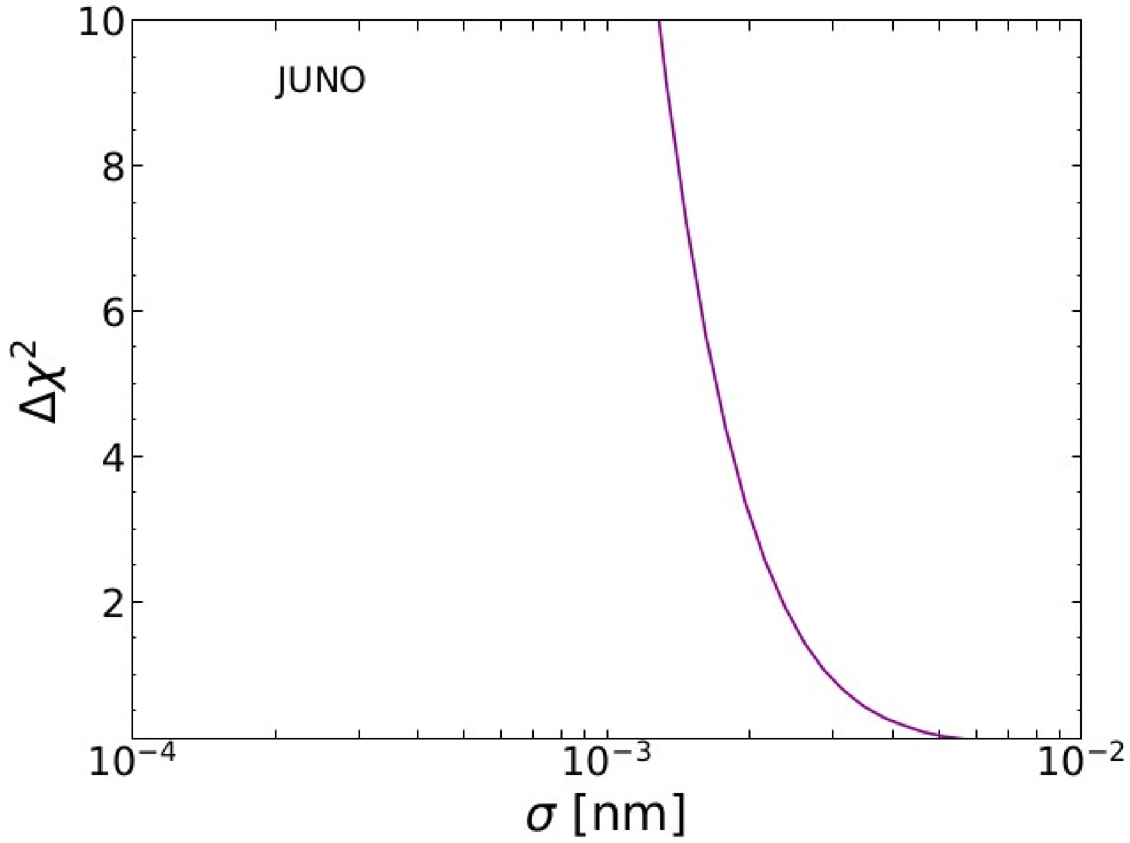
Sensitivity to several oscillation lengths



de Gouvêa, De Romeri, Ternes, 2005.03022, JHEP2020

Sensitivity at JUNO

A bound a factor ~10 stronger than the current one can be obtained after 6 years of data taking



de Gouvêa, De Romeri, Ternes, 2005.03022, JHEP2020

Conclusions

We analyzed data from RENO, Daya Bay and KamLAND to obtain lower bounds on the neutrino wave packet width

We find that $\sigma > 2\text{x}10^{-4}$ nm at 90% CL

Assuming 6 years of running time for JUNO this bound could be improved by a factor of 10

If the best fit value for σ lies within the sensitivity of JUNO, a clear measurement would be possible