Neutrino quantum decoherence at current and future reactor experiments

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Introduction

Neutrino oscillations provide the first laboratory evidence for New physics

They arise as a consequence of neutrino mixing

The QM uncertainty principle implies that when neutrinos are produced at some source they must be in a superposition of different momentum states. The neutrino wave function must be a **wave packet**

Coherence is essential for neutrino oscillations!

Introduction

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.

Eventually, the wave packets of the j-th and k-th mass eigenstate will have no significant overlap any more and their coherence will be lost, leading to a suppression of neutrino oscillations

Nuclear reactors are excellent laboratories to study neutrino coherence!

Neutrino oscillations with decoherence

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

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

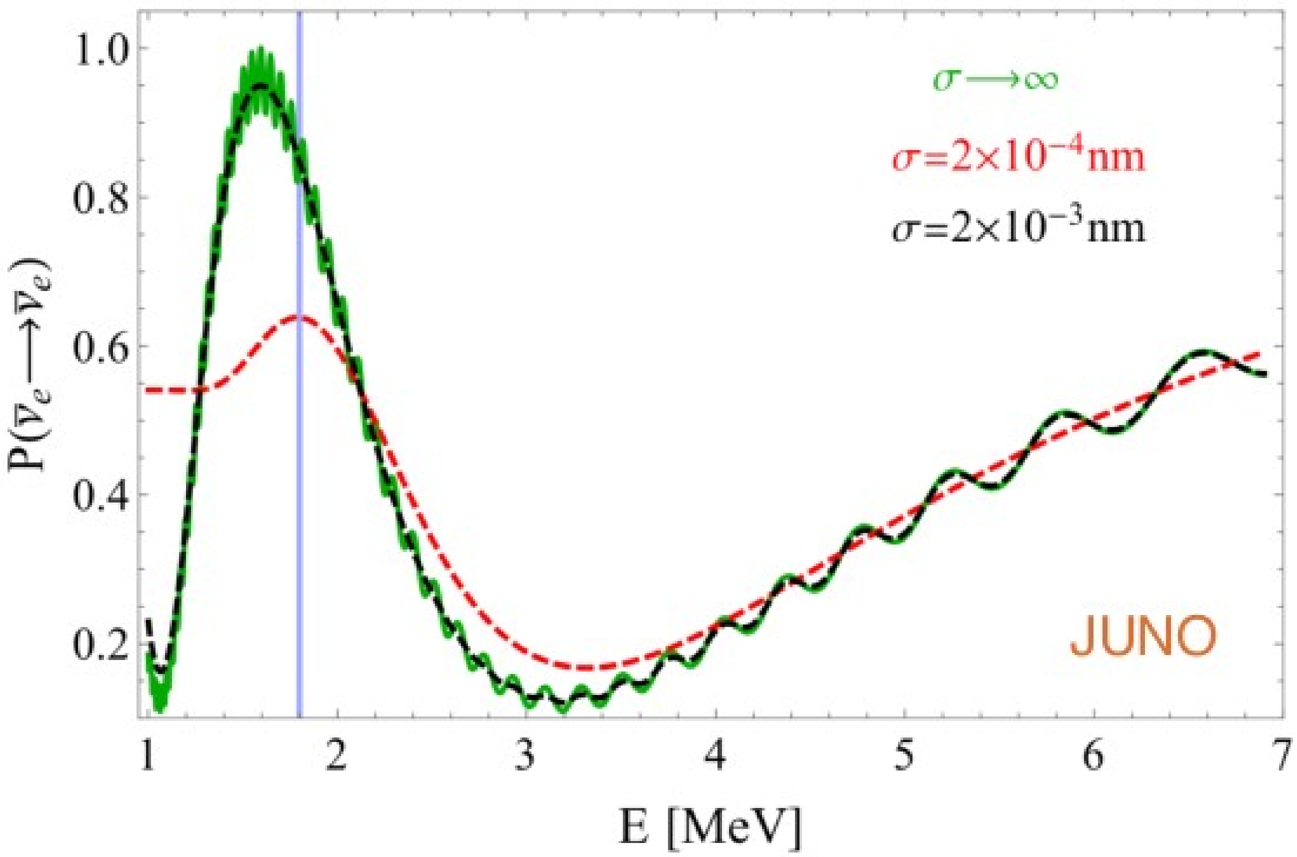
where

$$\xi_{jk}(L, E) = \left(\frac{L}{L^{\rm coh}_{jk}}\right)^2, \qquad L^{\rm coh}_{jk} = \frac{4\sqrt{2}E^2}{|\Delta m^2_{jk}|}\sigma$$

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

Neutrino oscillations with decoherence

The decoherence flattens out the neutrino oscillations



arXiv:2005.03022, de Gouvêa, De Romeri, Ternes

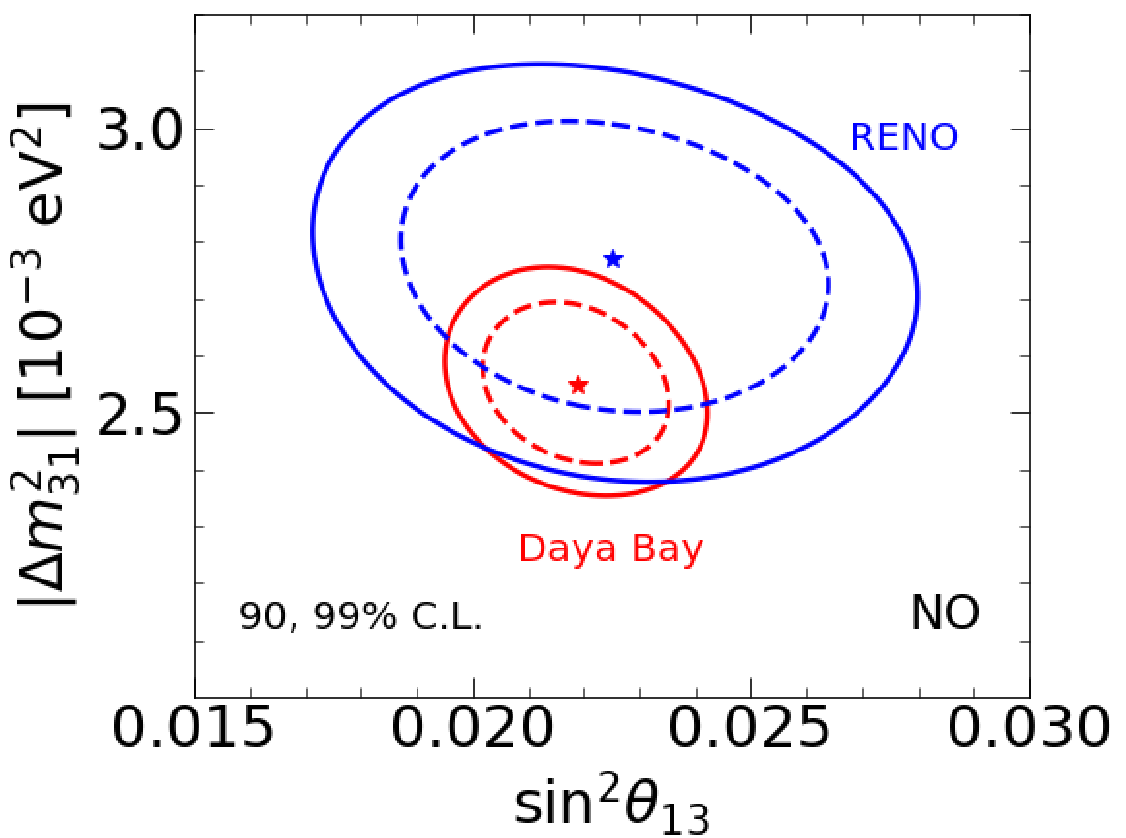
Bounds from current experiments

RENO

6 power plants

2 identical detectors

We include 2900 days of data
RENO, private communication



Daya Bay

6 power plants

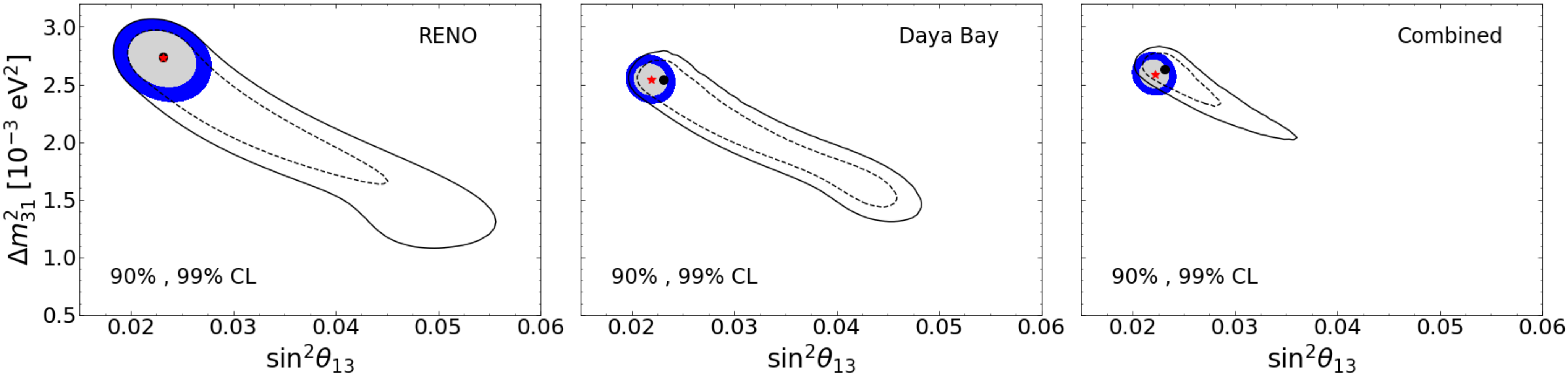
8 identical detectors at 3 experimental halls, 2 function as near detectors, 1 as far detector

We include 1958 days of data
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

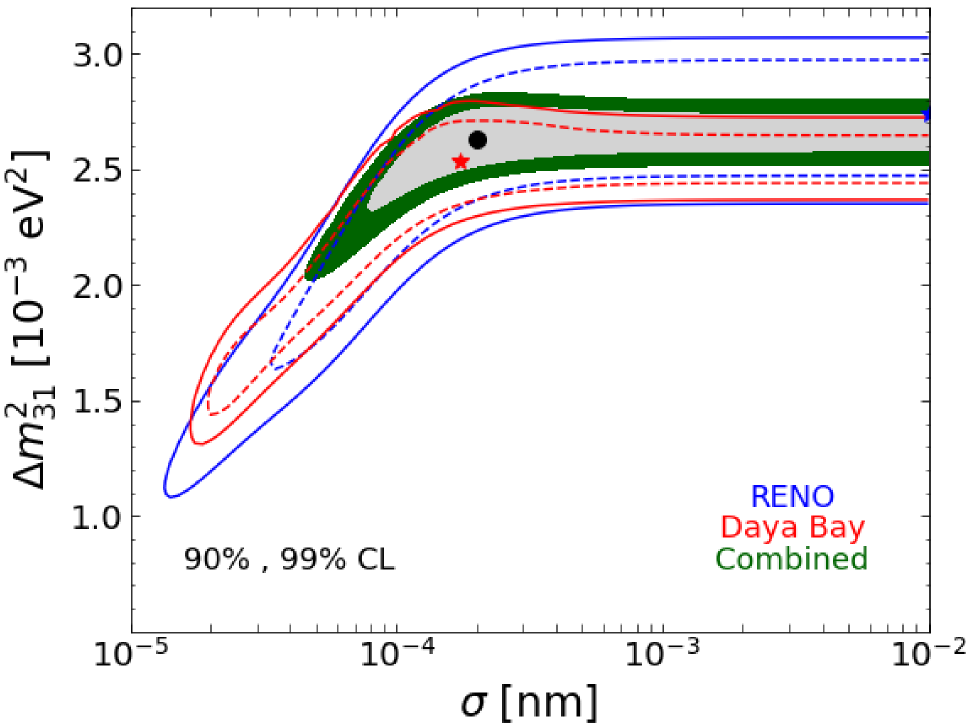


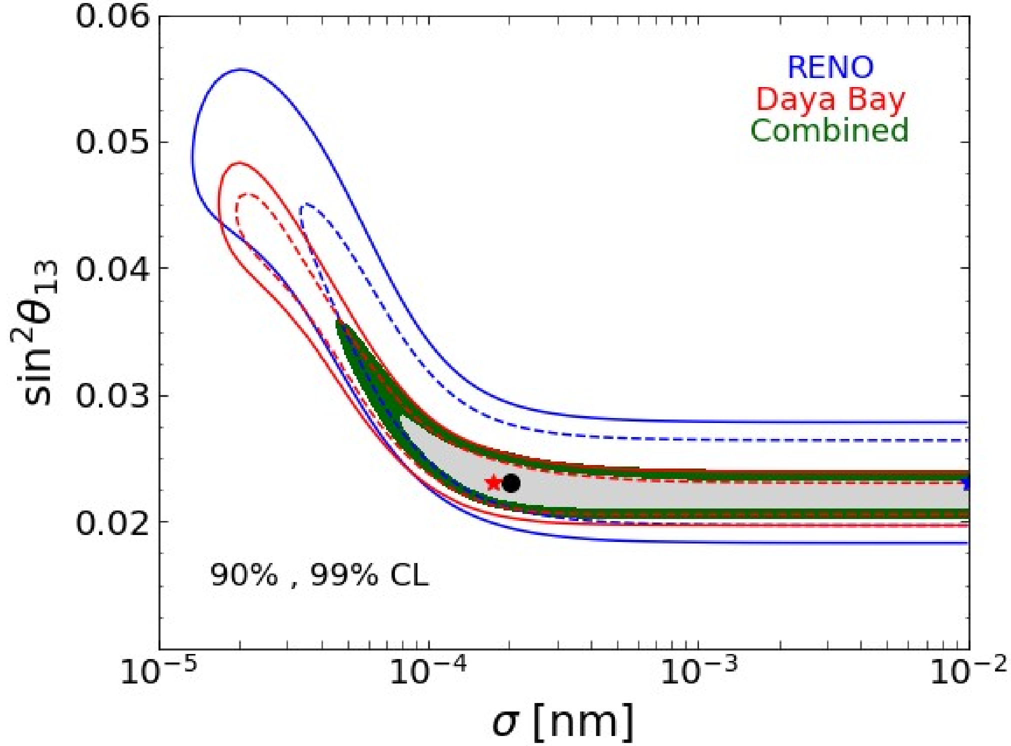
arXiv:2005.03022, de Gouvêa, De Romeri, Ternes

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)





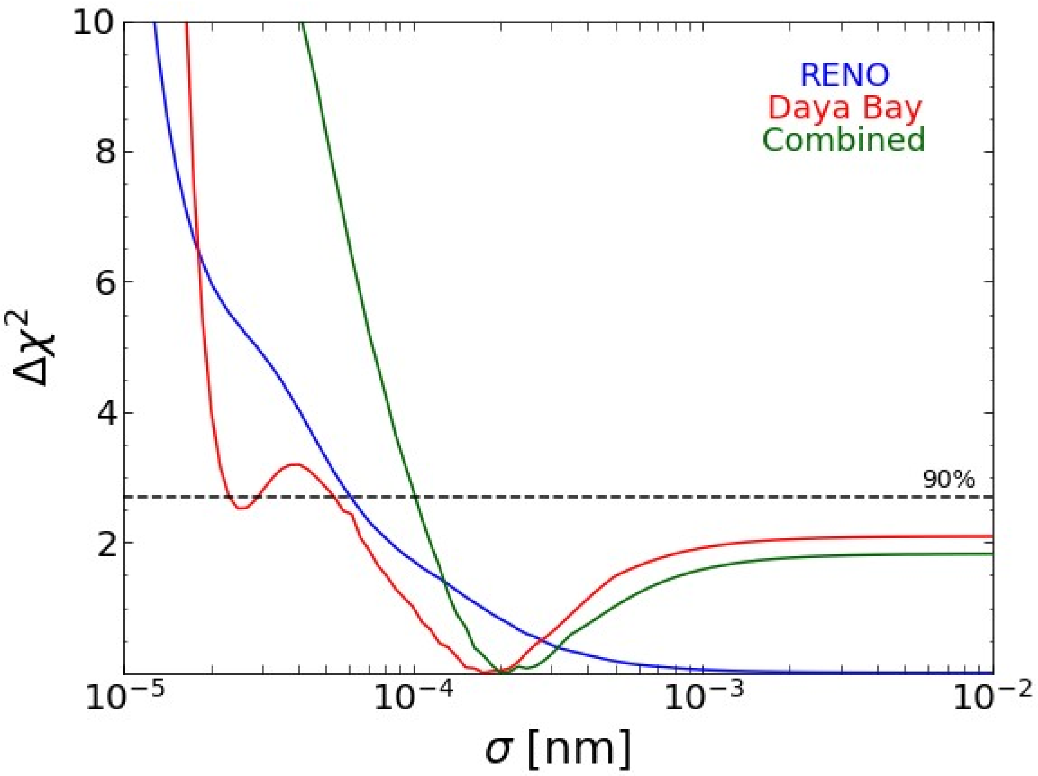
arXiv:2005.03022, de Gouvêa, De Romeri, Ternes

Bounds from current experiments

From the combined analysis we obtain a lower bound:

σ > 1.0e-4 nm at 90% CL

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



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Sensitivity at JUNO

JUNO:

12 reactors

1 far detector (+ 1 near detector under consideration)

JUNO will measure the solar parameters and the atmospheric mass splitting at below 1%

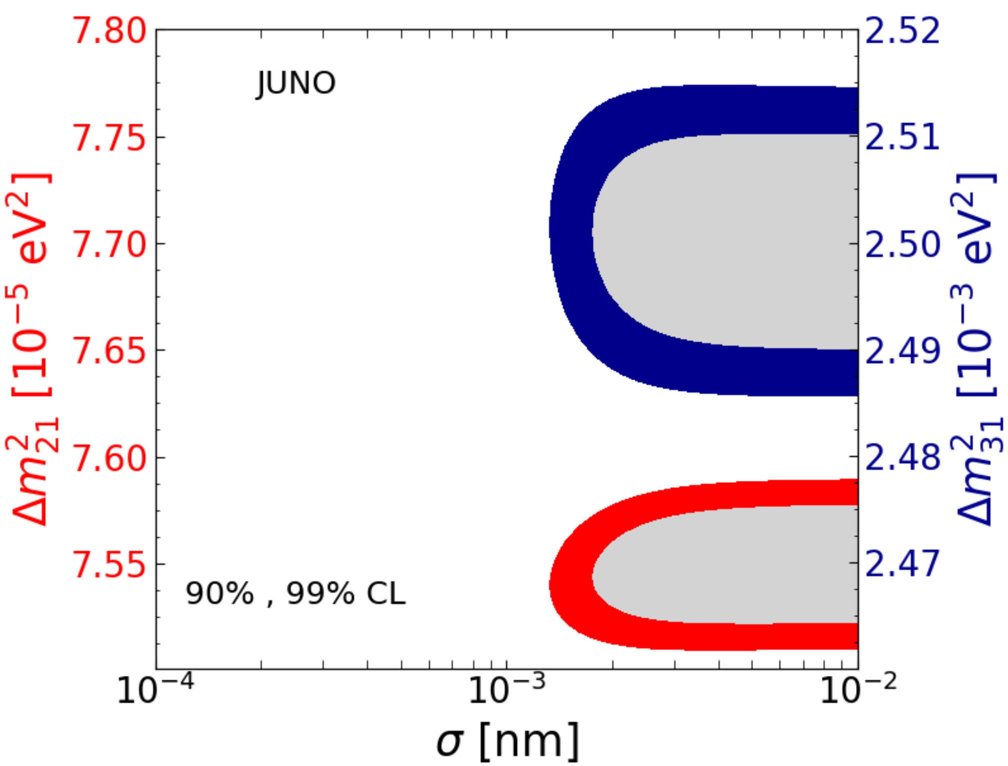
Sensitivity to both oscillation lengths should break the degeneracy observed in current experiments

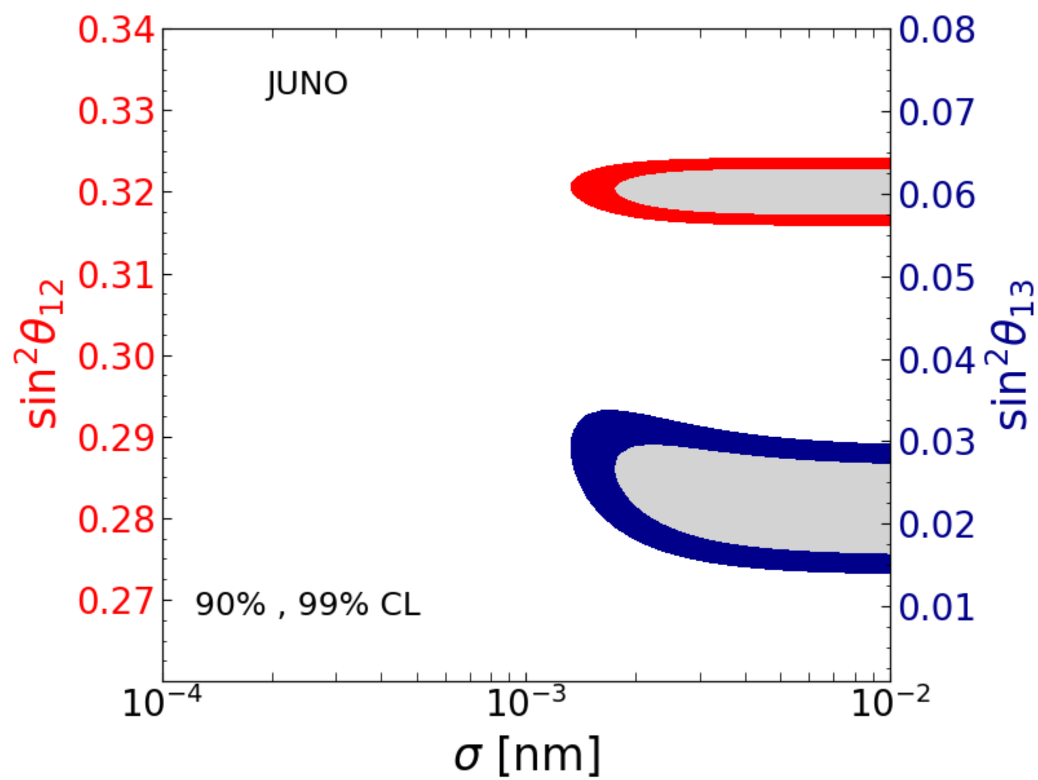
JUNO, J.Phys. G, 1507.05613

JUNO+IceCube, PRD, 1911.06745

Excluding decoherence

The measurement of the standard neutrino oscillation parameters remains mostly unaffected





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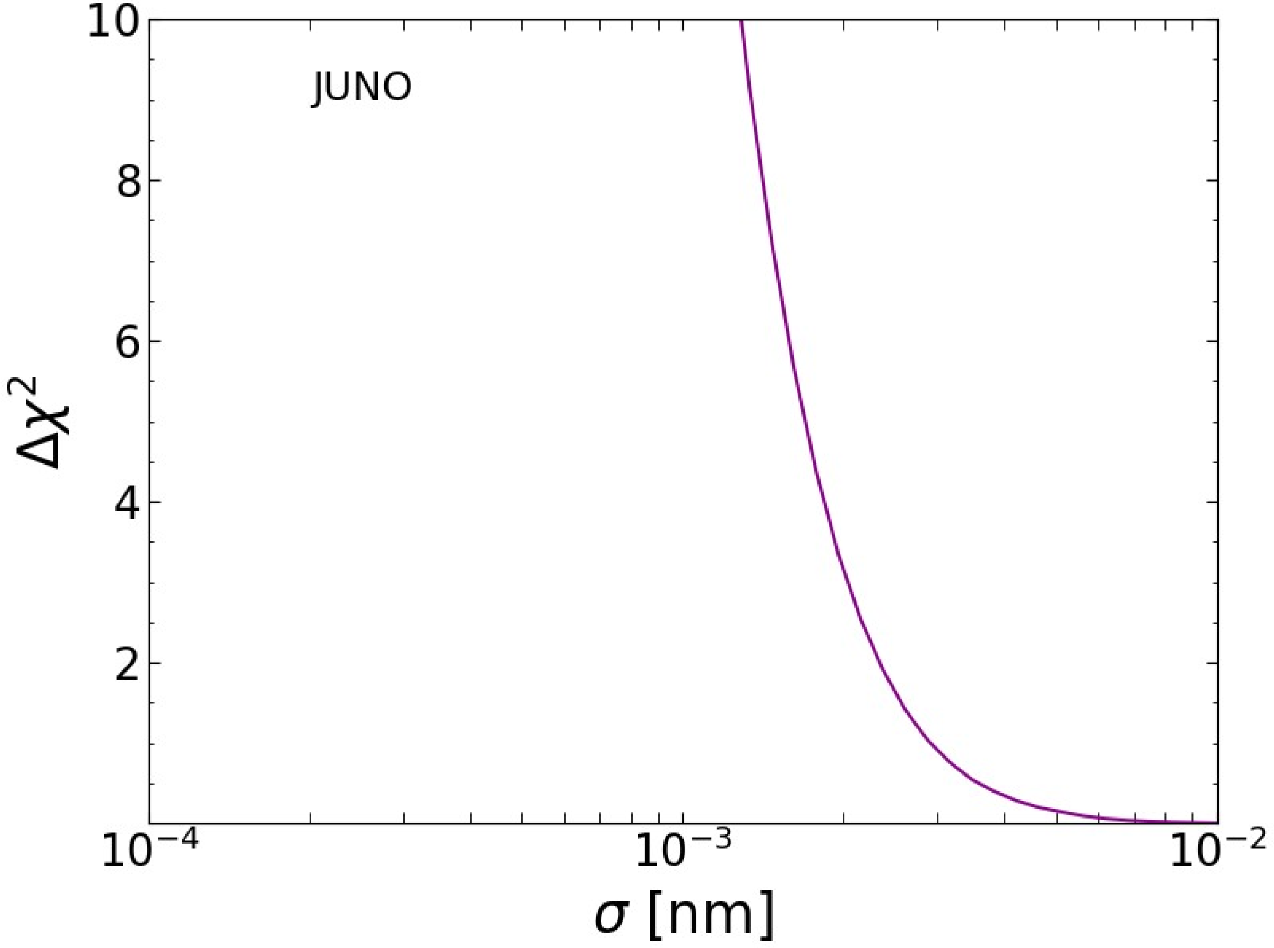
Excluding decoherence

A bound more than a factor 20 stronger than the current one can be obtained after 6 years of data taking



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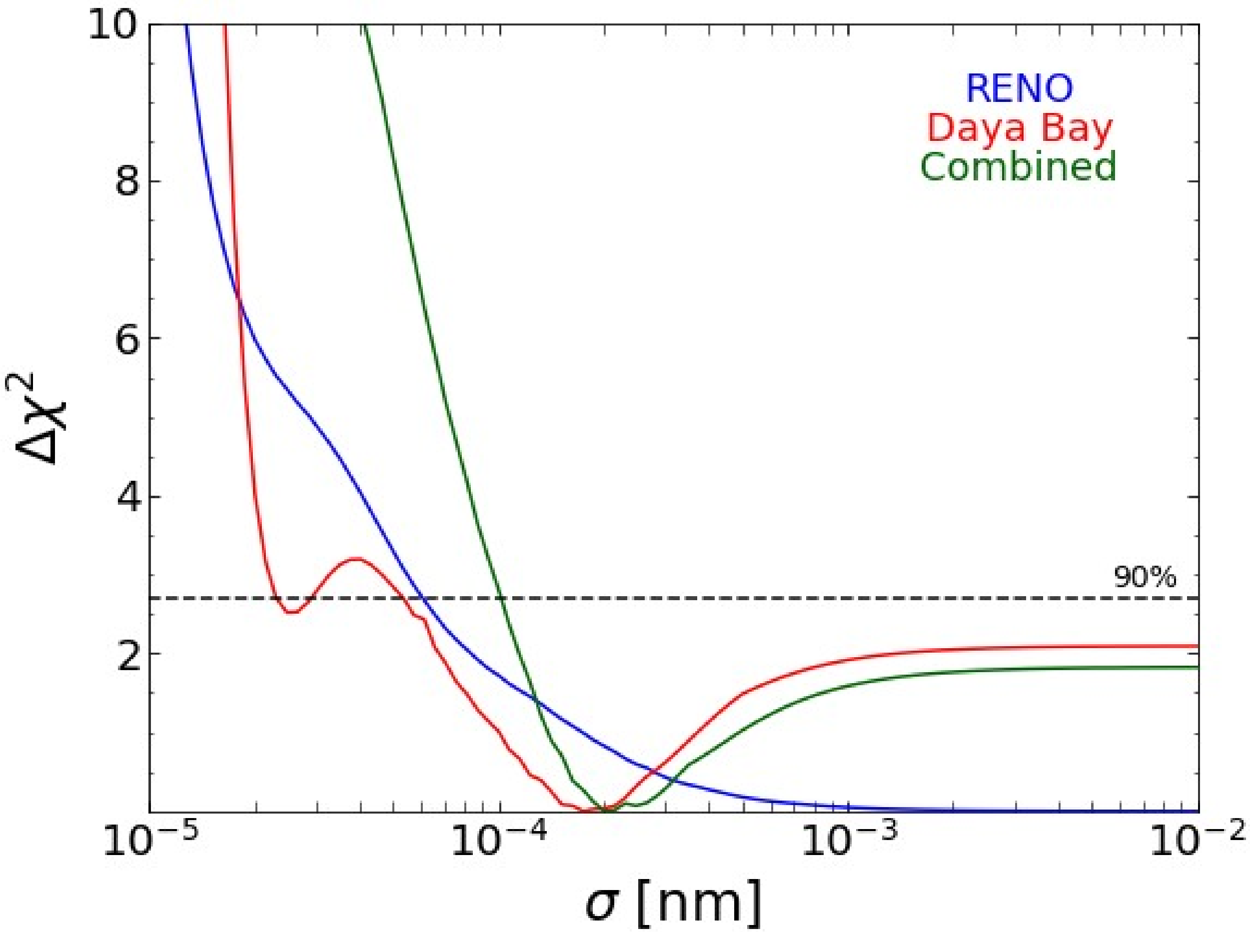
Measuring decoherence

We create the fake data with the best fit value obtained in the analysis of current data



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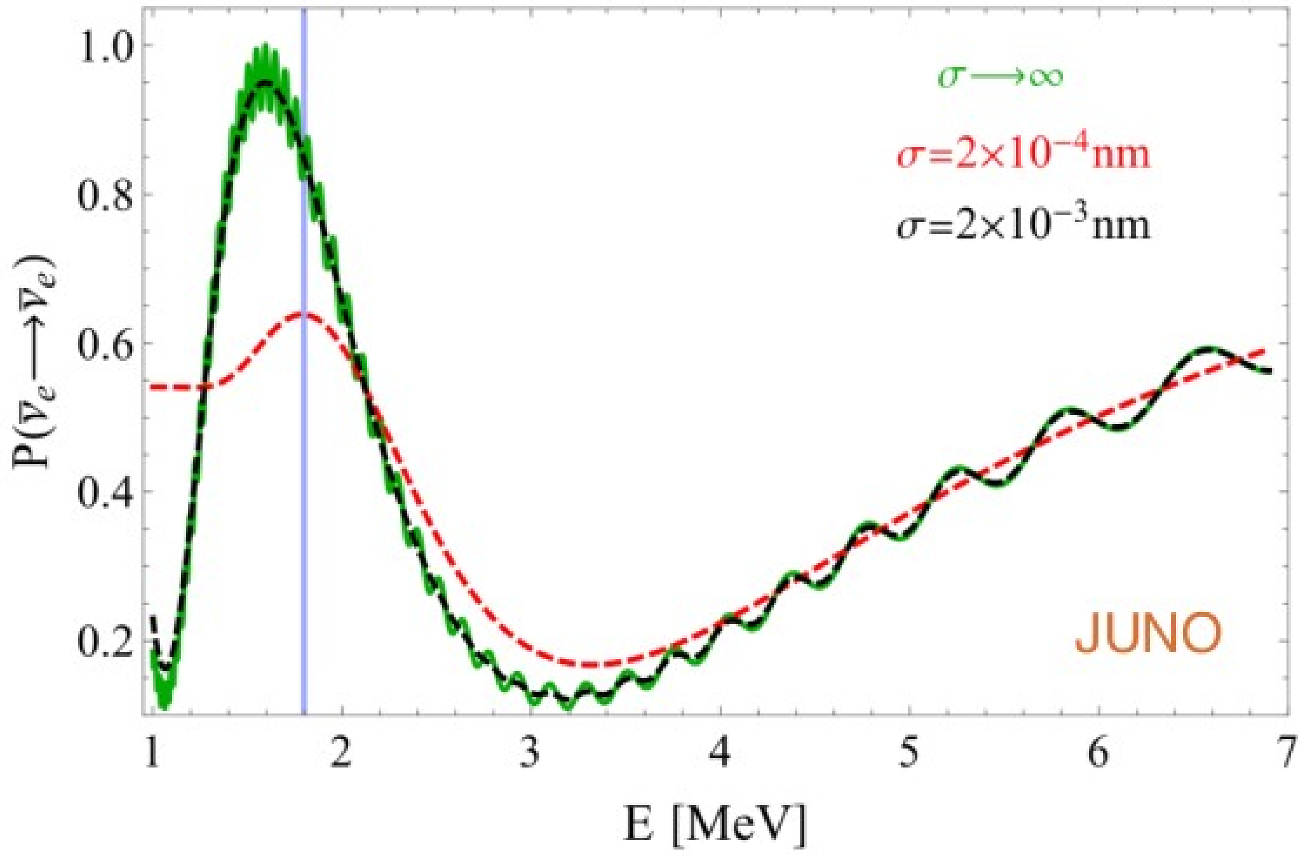

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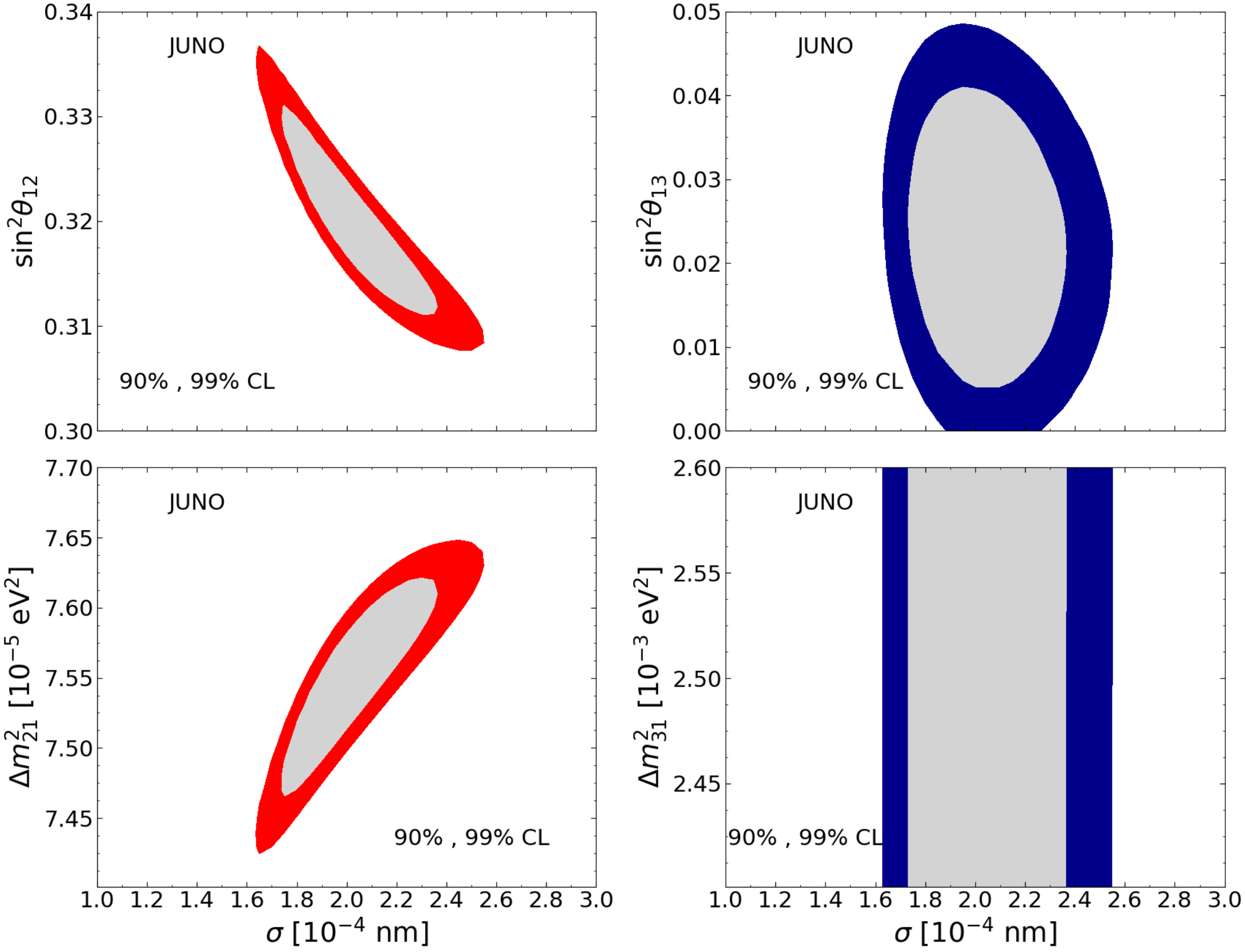
Measuring decoherence

The correlations re-appear because now a measurement of the atmospheric angle is not possible anymore



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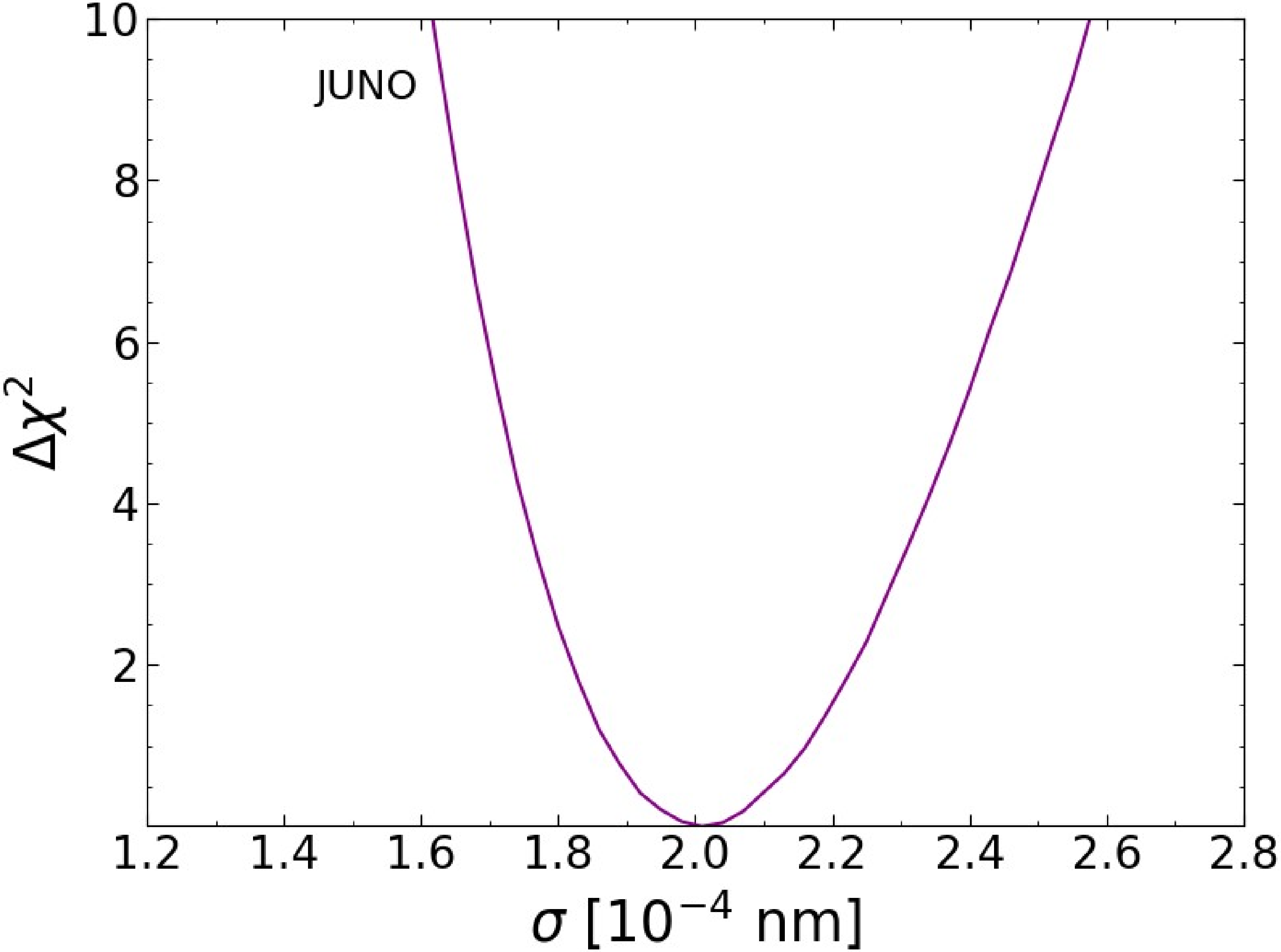
Measuring decoherence

The coherence scenario would be excluded at more than 10 sigma



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Conclusions

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

We find that $\sigma > 1.0e\text{-}4$ nm at 90% CL

Assuming 6 years of running time for JUNO this bound could be improved by a factor of 20

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