Search for sterile neutrino with Daya Bay and TAO detectors

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Introduction

Reactor neutrino experiments have played a significant role in the confirmation of neutrino mixing phenomena.

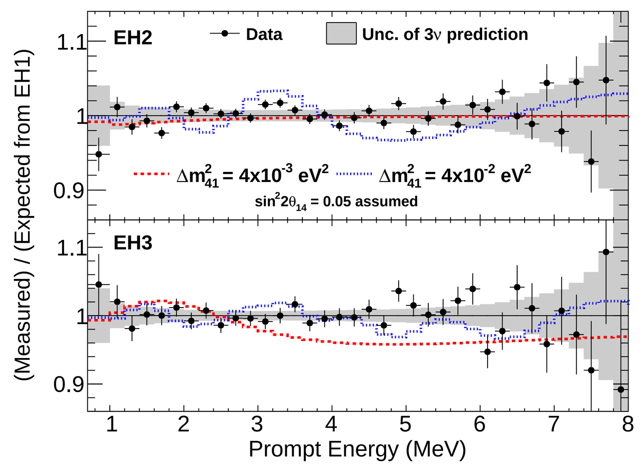
At the same time, experiments observed a defficit of antineutrino flux on a distance < 100 m (2.48σ deviation from unity 0.943 ± 0.023 measured/expected ratio [1]). This deficit could be explained via a wrong calculation of flux, or an additional neutrino state that change oscillation probability on a short distance. Additional state is called sterile.

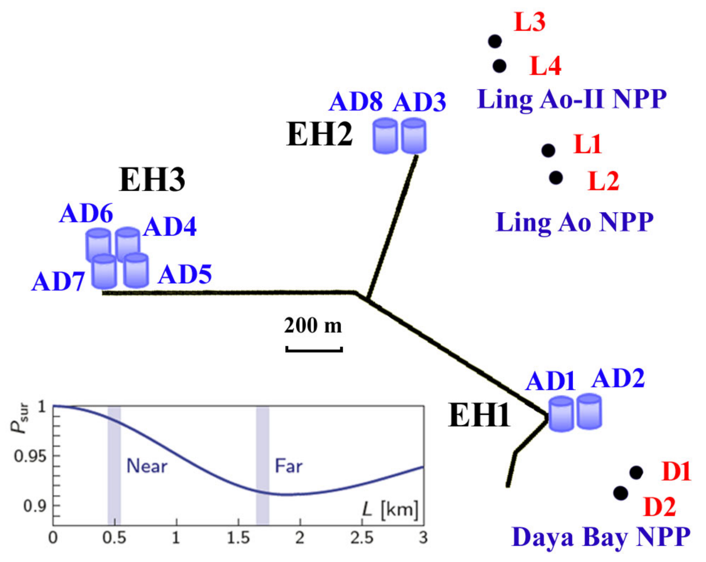
Modern experiments possible to measure sterile neutrino parameters in region $\Delta m^2_{41} < 1$ eV^2. The next generation experiments JUNO and TAO will improve this limit to $\Delta m^2_{41} \sim 10$ eV^2, where reactor antineutrino anomaly is observed [2].

The Daya Bay Experiment

A reactor antineutrino experiment [3]

- Measures $\overline{\nu}_e$ disappearance from six reactors at multiple baselines from ~ 0.4 km (near halls) to ~ 1.7 km (far hall) baselines.



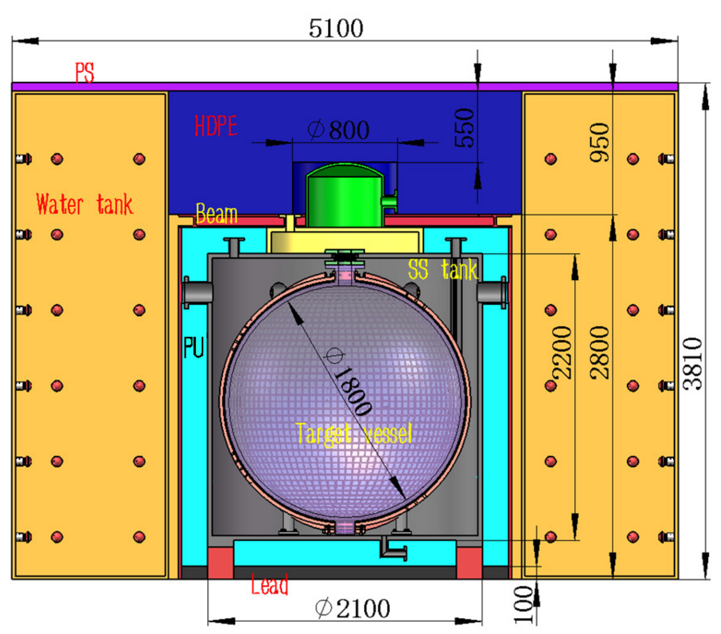


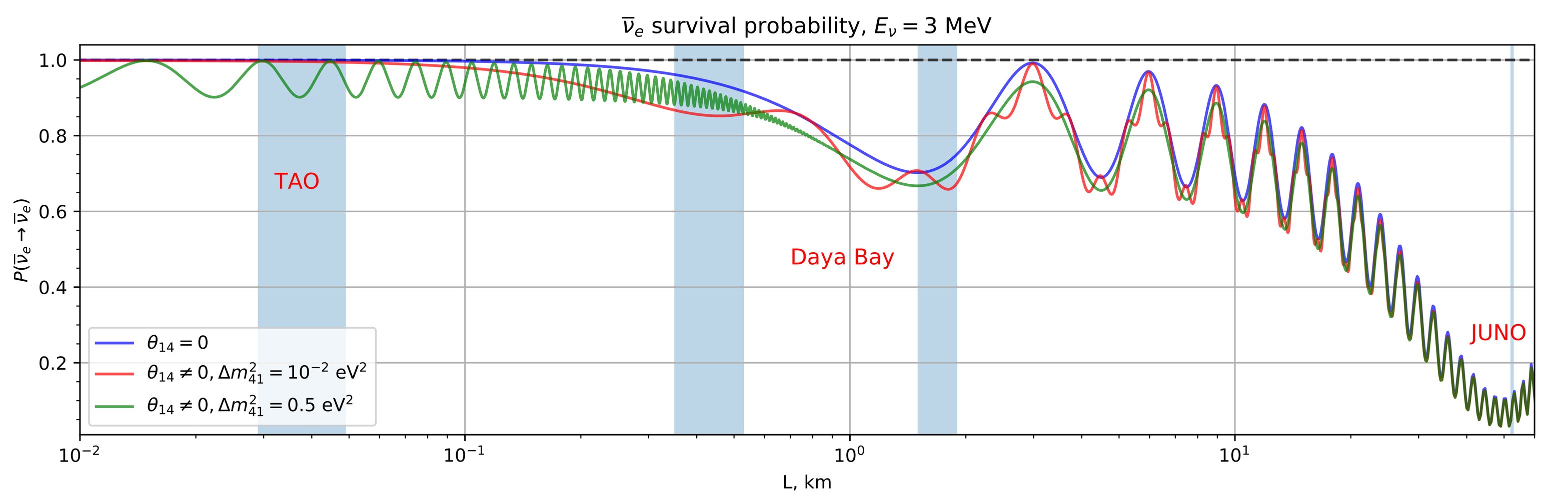
- Large statistics (more than $2.5 \cdot 10^6$ events).

TAO Experiment

A satellite experiment of JUNO [TAO::overview]

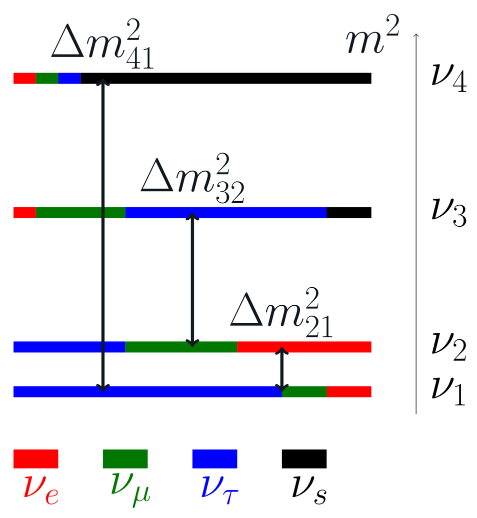
- Precise measurement of $\overline{\nu}_e$ flux from Taishan NPP.
- Reactor-detector distance – 30 m.
- Nearly $4.5 \cdot 10^6$ $\overline{\nu}_e$ events after 6 years of data taking.
- Low sensitivity to three-neutrino mixing.
- Energy resolution is $1.5\%/\sqrt{\mathrm{E[MeV]}}$.





Neutrino oscillations

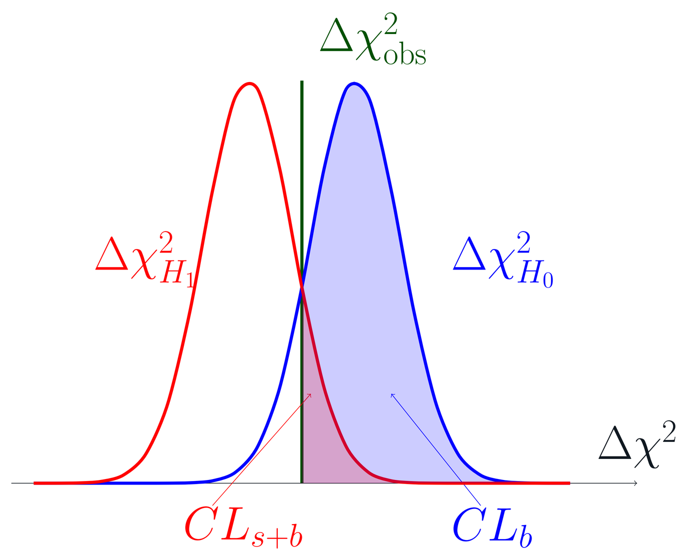
- Neutrino flavor eigenstates are a superposition of mass eigenstates.
- Neutrino mixing can be parameterized by the Pontecorvo-Maki-Nakagawa-Sakata matrix.
- Commonly, neutrino oscillation is parameterized by three-neutrino mixing.
- An additional state (sterile) that does not interact through the weak interaction, but it could mix with active states.
- A sterile state possible exploration of reactor antineutrino.



Analysis Method

CL_s method [4] was used to produce exclusion region:

- $H_0 : \sin^2 2\theta_{14} = 0$ three neutrino mixing
- $H_1 : \sin^2 2\theta_{14} \neq 0$ four neutrino mixing
- $\Delta\chi^2 = \chi^2_{H_1} - \chi^2_{H_0}$
- $CL_s = \frac{CL_{s+b}}{CL_b}$
- Exclusion rule: $CL_s < \alpha$
- $\Delta\chi^2$ has Gaussian approximation [5]

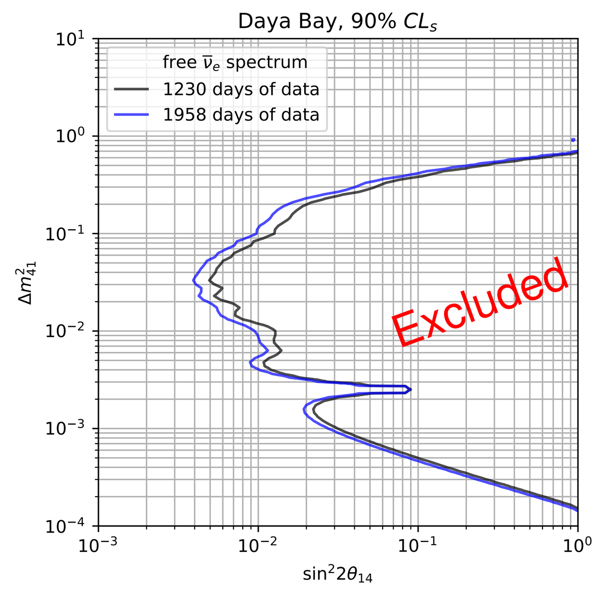


Daya Bay analysis of sensitivity

$$P(\overline{\nu}_e \to \overline{\nu}_e) \approx 1 - \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right) - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)$$

- Using Huber-Mueller model of $\overline{\nu}_e$ energy spectrum [6], [7] with possibility of variation it.
- The Daya Bay sensitivity contour region based on 1230 and 1956 days of data taking.
- The experiment is sensitive to $\sin^2 2\theta_{14}$ in the region

$$2 \cdot 10^{-4}\ \mathrm{eV}^2 < \Delta m^2_{41} < 3\ \mathrm{eV}^2.$$



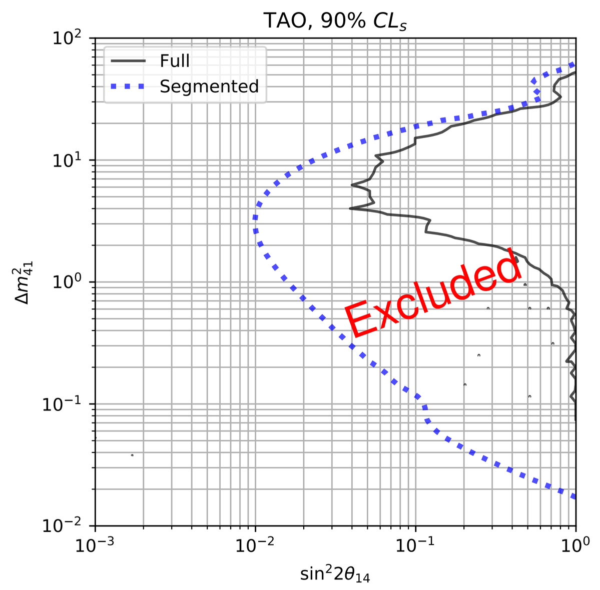
TAO analysis of sensitivity

$$P(\overline{\nu}_e \to \overline{\nu}_e) \approx 1 - \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

- Antineutrino spectrum model of Huber-Mueller [6], [7] with possibility of variation it.
- Splitting detector into subdetectors allows to increase sensitivity.
- The experiment is sensitive to $\sin^2\theta_{14}$ in the region

$$10^{-2}\ \mathrm{eV}^2 < \Delta m^2_{41} < 12\ \mathrm{eV}^2.$$

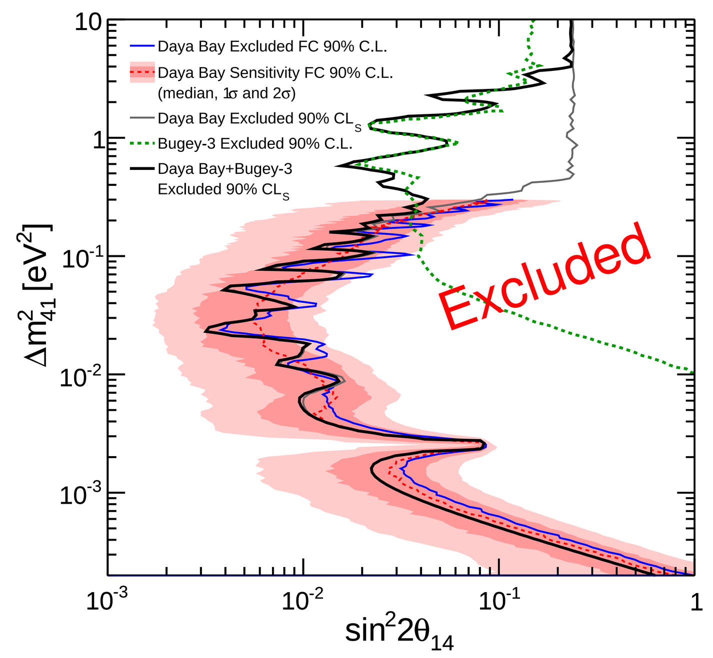
- Combined analysis with JUNO is expected to improve sensitivity to sterile neutrinos.



Future improvement

- Use observed data to calculate excluded are in the Daya Bay.
- Improve method of accounting detector spatial extent of TAO.
- Analyze data of TAO detector in combination with JUNO.
- Update systematics of TAO connected with fiducial volume.

Conclusion



- No evidence of light sterile neutrino is found (for the Daya Bay).
- Stringent limits are obtained on the $\sin^2 2\theta_{14}$ in the region:
  - for the Daya Bay – $2 \cdot 10^{-4}$ eV$^2 < \Delta m^2_{41} < 0.3$ eV^2;
  - for TAO – $2 \cdot 10^{-2}$ eV$^2 < \Delta m^2_{41} < 20$ eV^2.
- Analyses of the Daya Bay and TAO experiments with using Asimov data were produced.

References

1. Mention, G. *et al.* Reactor antineutrino anomaly. *Physical Review D* **83.** ISSN: 1550-2368. http://dx.doi.org/10.1103/PhysRevD.83.073006 (Apr. 2011).
2. Serebrov, A. P. *et al.* Search for sterile neutrinos with the Neutrino-4 experiment and measurement results. *Physical Review D* **104.** ISSN: 2470-0029. http://dx.doi.org/10.1103/PhysRevD.104.032003 (Aug. 2021).
3. Cao, J. & Luk, K.-B. An overview of the Daya Bay reactor neutrino experiment. *Nuclear Physics B* **908.** Neutrino Oscillations: Celebrating the Nobel Prize in Physics 2015, 62–73. ISSN: 0550-3213 (2016).
4. Read, A. L. Presentation of search results: The CL(s) technique. *J. Phys. G* **28** (eds Whalley, M. R. & Lyons, L.) 2693–2704 (2002).
5. Qian, X., Tan, A., Ling, J., Nakajima, Y. & Zhang, C. The Gaussian CL method for searches of new physics. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **827,** 63–78. ISSN: 0168-9002 (Aug. 2016).
6. Huber, P. Determination of antineutrino spectra from nuclear reactors. *Phys. Rev. C* **84,** 024617 (2 Aug. 2011).
7. Mueller, T. A. *et al.* Improved predictions of reactor antineutrino spectra. *Phys. Rev. C* **83,** 054615 (5 May 2011).