Sterile Neutrino Search from Daya Bay

Olivia Dalager, University of California, Irvine ❖ odalager@uci.edu
(on behalf of the Daya Bay collaboration)

1. Daya Bay Reactor Neutrino Experiment

Daya Bay Reactor Neutrino Experiment was designed to precisely measure the neutrino mixing angle θ_{13}.

- Nuclear reactors produce a pure sample of electron antineutrinos
  - Six 2.9 GW_{th} reactors in 3 nuclear power plants (NPP)
  - $\sim 2 \times 10^{20}\ \overline{\nu}_e/\mathrm{second}/\mathrm{GW}_{th}$
- 3 underground experimental halls (EHs) which house eight functionally identical antineutrino detectors (ADs)
  - 2 near halls (EH1 and EH2)
  - 1 far hall (EH3)

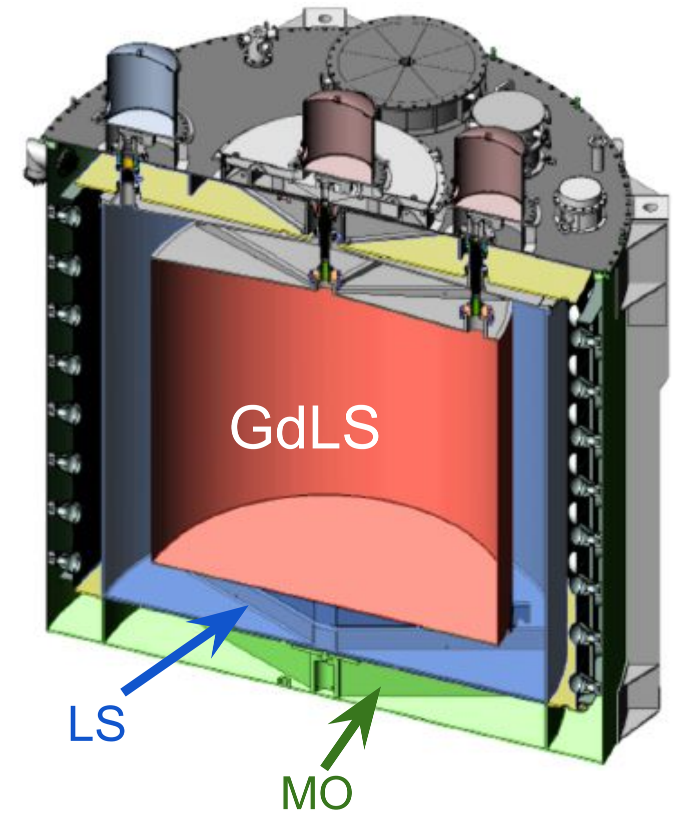
Locations of the three EHs and the nuclear reactors.

2. Antineutrino Detection

Each near hall has two ADs, while the far hall has four.

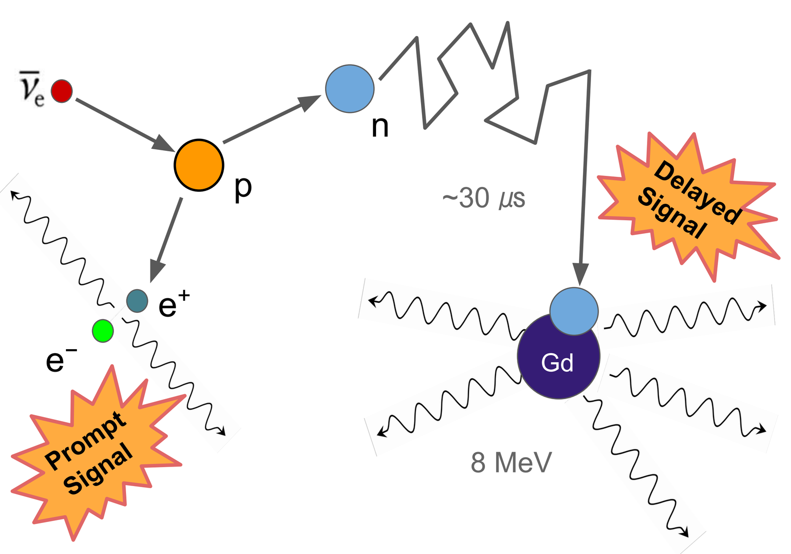
- Each AD has 3 zones:
  - **Gadolinium doped liquid scintillator (GdLS)** - 20 tons
    - Primary neutrino target volume
  - **Liquid scintillator (LS)** - 22 tons
    - γ catcher and target volume
  - **Mineral oil (MO)** - 40 tons
    - Additional bugger
- 192 8-inch photomultiplier tubes (PMTs)
  - Located in MO region
- The ADs are submerged in a water pool that shields the ADs and allows to tag cosmic-ray muons

Cross-section of AD.



Antineutrino interactions are detected in the ADs via inverse beta decay (IBD) process:

$$\overline{\nu}_e + p \rightarrow e^+ + n$$



Schematic of IBD interaction with neutron capture on Gadolinium.

- The double coincidence signature of IBDs allows to extract signal with very little (< 2%) background
  - Positron annihilation and loss of kinetic energy
  - Neutron capture on gadolinium: nGd
- Prompt energy directly related to antineutrino energy
  - $E_{\overline{\nu}_e} \approx E_p + 0.78\ \mathrm{MeV}$

3. Sterile Neutrinos

Sterile neutrinos have been theorized as an additional state, which does not participate in weak interactions.

- Experiments usually search for these particles using the 3 active + 1 sterile neutrino framework
- In Daya Bay, the existence of a sterile neutrino would appear as an additional spectral distortion

LSND and MiniBooNE observed $\overset{(-)}{\nu}_e$ excess in $\overset{(-)}{\nu}_\mu$ beam could be explained by active-to-sterile neutrino oscillations with an effective mixing angle $\theta_{\mu e}$:

$$P^{SBL}_{\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e} = \sin^2(2\theta_{\mu e}) \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

where: $\sin^2 2\theta_{\mu e} \equiv \sin^2 2\theta_{14} \sin^2 \theta_{24}$

Constrained by $\overline{\nu}_e$ disappearance experiments (Daya Bay and Bugey-3)

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

Constrained by $\overset{(-)}{\nu}_\mu$ disappearance experiments (MINOS/MINOS+)

$$P_{\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_\mu} \approx 1 - \sin^2(2\theta_{23}) \cos(2\theta_{24}) \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \sin^2(2\theta_{24}) \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

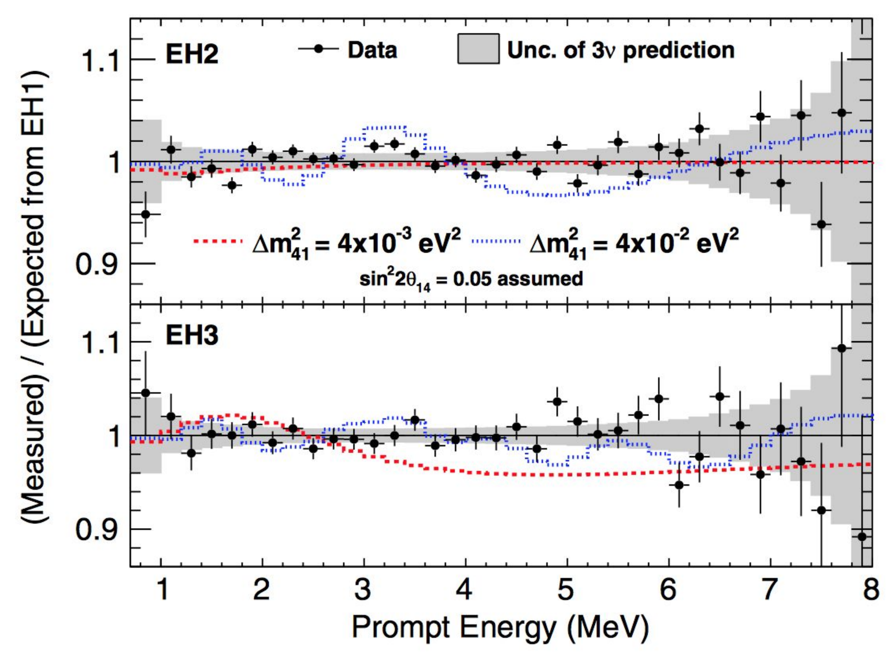
4. Daya Bay-only Search

Daya Bay searched for sterile neutrinos by comparing the relative antineutrino rates and spectra observed at different experimental halls.

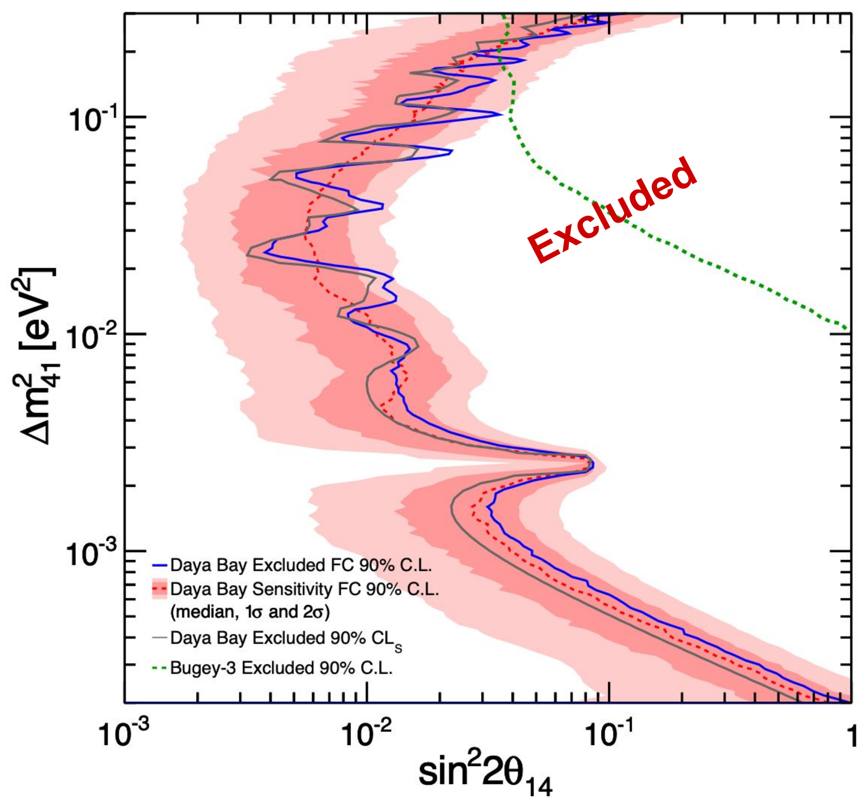
- 1230 days of data
- Relative near-far measurement
- Assumes 3+1 neutrino model

Two complementary statistical methods give consistent results:

- Feldman-Cousins
- Gaussian CL_s



Above: Data vs prediction of neutrino oscillations of 3+1 neutrino model. Additional oscillatory behavior beyond 3-ν model not observed



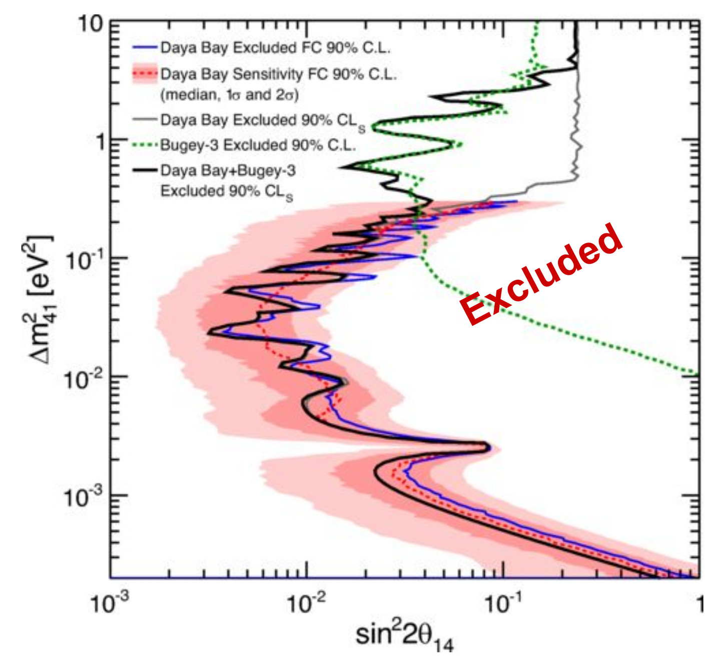
Left: Daya Bay-only results for the exclusion of Δm_{41}^2 - $\sin^2 2\theta_{14}$ parameter space for sterile neutrinos at 90% CL.

World's best $\sin^2 2\theta_{14}$ limits for $|\Delta m^2_{41}| \leq 0.2\ \mathrm{eV}^2$

5. Combined Results

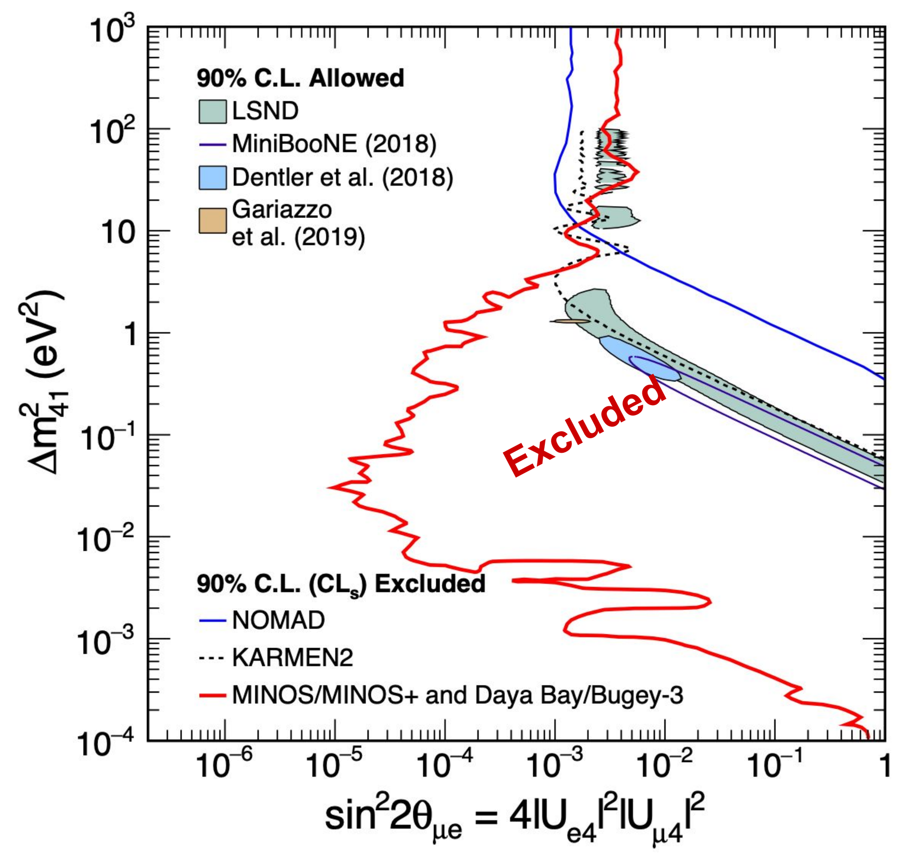
Daya Bay, Bugey-3, and MINOS/MINOS+ combined efforts in order to explore into the LSND and MiniBooNE allowed regions of parameter space.

- Bugey-3
  - Short baseline reactor experiment in France in the 1990s
  - Looked for $\overline{\nu}_e$ disappearance
  - Combining with Bugey-3 extended the Δm_{41}^2 range of the search



Daya Bay, Bugey-3, and combined exclusion regions at 90% CL_s.

- MINOS/MINOS+
  - Long baseline accelerator experiment in Fermilab and Soudan mine
  - Looks for $\overset{(-)}{\nu}_\mu$ disappearance
  - Combining with MINOS/MINOS+ allows to explore the Δm_{41}^2 - $\sin^2 2\theta_{\mu e}$ parameter space



MINOS/MINOS+ beamline from Fermilab in IL to Soudan mine in MN

Left: Combined Daya Bay, Bugey-3, and MINOS/MINOS+ results for the exclusion of Δm_{41}^2 - $\theta_{\mu e}$ parameter space for sterile neutrinos at 90% CL.

Daya Bay, Bugey-3, and MINOS/MINOS+ combined results exclude the LSND and MiniBooNE allowed regions for $\Delta m_{41}^2 < 5\ \mathrm{eV}^2$ at 90% CL_s

- The remaining LSND and MiniBooNE allowed regions are excluded at 90% CL_s by NOMAD
- **Previous global fits now completely excluded**

References

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