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Reactor short baseline neutrino experiments

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The theoretical prediction of the reactor neutrino flux is challenged by the most recent experimental results. Numbers of experiments are being conducted to measure electron antineutrino spectrum from reactors at distances less than tens of meters. The experiments are to verify the possible existence of an eV-scale sterile neutrino and to figure out the source of reactor antineutrino anomaly.

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The discrepancy between the measured flux of the reactor electron antineutrino ($\bar{\nu}_e$) and the flux model (referred as H-M model in below, [1, 2]) was compiled as the Reactor Antineutrino Anomaly (RAA) [3]. And combined with other anomalous short-baseline (SBL) result [4–6], it is suggested that there can be another neutrino mass state around 1 eV and a corresponding active-to-sterile neutrino oscillation [7]. More recently, the three mid-baseline reactor experiment, Daya Bay [8], RENO [9], and Double Chooz [10], have found out that not only the numbers of $\bar{\nu}_e$, but also the spectral shape do not agree with the H-M model. Interestingly, all the three experiments and a more recent SBL experiment, NEOS [11], observed so called "5 MeV bump" in their prompt energy spectrum which was not shown in the Bugey-3 data [12]. Daya Bay and RENO analyzed the evolution of their measured fluxes along with the fuel component changes during the reactor burnup cycles and claimed that the $\bar{\nu}_e$ flux from ^{235}U is overestimated in the Huber model [1] by about 8% with significance larger than 2σ [13, 14]. But the measured fluxes from other fissile isotopes still have large uncertainties to rule out the eV sterile neutrino theory. On the other hand, there are theoretical efforts to figure out the source of the mismatch between theory and measurement and to improve the reactor-ν flux prediction [15–17], but none of them still successfully reproduce the measured spectral shape within a reasonable uncertainty level.

To test the RAA and to search for an active-to-sterile neutrino oscillation with $\Delta m^2_{41} \sim 1$ eV^2, numbers of reactor short baseline experiments are being conducted worldwide currently. Neutrino-

Table 1: Experimental setup for the reactor ν-SBL experiments. (H/LEU: high-/low- enriched uranium fuel, Φ, H: diameter and height of the cylindrical reactor core; PS=plastic scintillator, LS=liquid scintillator, PSD=pulse shape discrimination)

Experiment	Reactor, fuel, thermal capacity, active core size	Baseline distance	Detector specifications
DANSS	Kalinin-4, LEU, 3.1 GW, $\Phi 3.1 \times$ H3.6 (m)	10.7-12.7 m	· 1 m^3 volume, highly segmented, · extruded PS coated with Gd sheet, · movable detector platform
NEOS	Hanbit-5, LEU, 2.8 GW, $\Phi 3.1 \times$ H3.8 (m)	24 m	· 1008 L, homogeneous, · 0.5% Gd-loaded LS, PSD · no distance resolution
Neutrino-4	SM-3 HEU, 100 MW, $\Phi 42 \times$ H35 (cm)	6-12 m	· 1.42 m^3, segmented · 0.1% Gd-loaded LS, · movable detector platform
PROSPECT	HFIR, HEU, 85 MW, $\Phi 40 \times$ H50 (cm)	6.7-9.2 m	· 3000 L, segmented, · ^{6}Li-loaded LS, PSD, · distance resolution using segmentation
STEREO	ILL, HEU, 58.3 MW, $\Phi 40 \times$ H80 (cm)	9-11 m	· 1800 L, segmented, · 0.2% Gd-loaded LS, PSD, γ-catcher, · distance resolution using segmentation

4 [18], PROSPECT [19], Solid [20], and STEREO [21] use research reactors of which the most of the fissions are from ^{235}U isotope, and the sizes of the active core is relatively small compared to the commercial reactors so that they can have better sensitivities using baseline resolution. DANSS [22] and NEOS [11] use commercial reactor cores of which the cylindrical shape have about 3 m in diameter, and 4 m in height, so that they don't have a good sensitivity for Δm^2_{41} higher than several eV^2. Each of the experiment uses its unique techniques to enhance the sensitivity, such as segmentation, moving of the detector and use of ^{6}Li or Gd, for background reduction, baseline resolution and efficient inverse-beta-decay (IBD) n-capture. The key features of several active experiments are summarized in Table. 1.

Currently, there are IBD prompt energy spectra from NEOS [11], PROSPECT [23], DANSS [24] and Neutrino-4 [25]. The DANSS spectrum has the great statistical precision but does not show a clear 5 MeV bump due to its large energy resolution. The energy resolution of the Neutrino-4 is insufficient to see the small distortions in the spectrum, but its prompt energy spectrum show a large disagreement with the expected one. The PROSPECT spectrum has the best energy resolution (4.5% RMS at 1 MeV) among the experiments, but it needs to improve the statistical precision to tell the spectral distortions in the ^{235}U-only spectrum.

Results on the active-to-sterile neutrino mixing parameters from the current active experiments are shown in Fig. 1, together with the RAA allowed region [3] and the original Bugey-3 result [12]. The RAA best fit point ($\Delta m^2_{41} = 2.3$ eV^2, $\sin^2 2\theta_{14} = 0.14$) is excluded by all the current experiments with confidence levels greater than 95%. Only Neutrino-4 [25] claims that there is a strong positive signal at $\Delta m^2_{41} \sim 7$ eV^2, $\sin^2 2\theta_{14} \sim$ 0.4, all the other experiments observed no strong evidence.

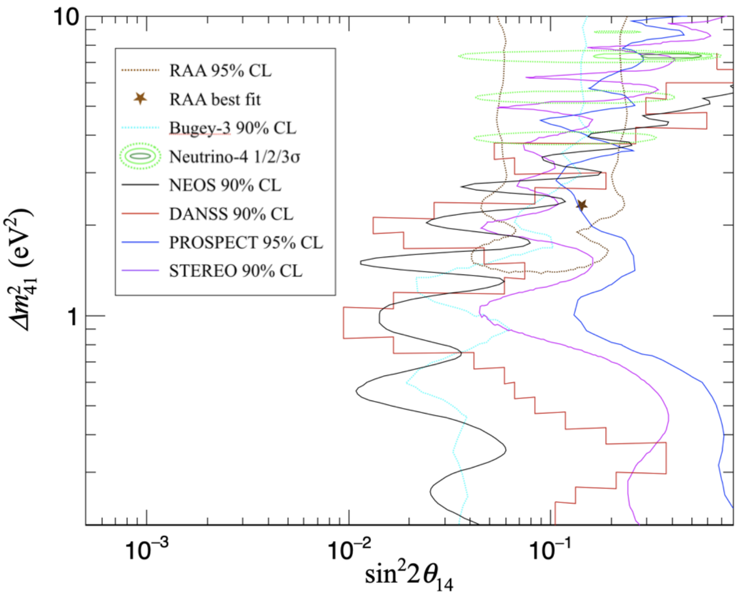

Figure 1: Allowed 3+1ν oscillation parameter space [3, 11, 12, 23–26].

One thing to note is that the exclusion curves from all the recent data, except for Neutrino-4, shares similar "bays and capes" at Δm^2_{41} around 1-2 eV^2. DANSS, PROSPECT and STEREO have their χ^2 local minima here at 1 eV$^2 < \Delta m^2_{41} <$ 2 eV^2. NEOS has another exclusion bay in the others' cape, due to its reactor-to-detector distance is about twice larger than the others, but it also has its two best fit points at $\Delta m^2_{41} = 1.3$ eV^2 and 1.7 eV^2. Considering that there is little correlation between the experiments, it is intriguing that they have common local best fit points around the same mass-squared split, and the value of which is very close to existing global analysis result [7].

The precisions of the prompt energy spectra of the experiments described will be improved as more data are being accumulated in each experiment. The dedicated $\bar{\nu}_e$ spectrum from ^{235}U will be updated from research reactor experiments, and spectrum evolution for the fuel component change will also get more precisions by experiments each of which uses a single commercial reactor core. It is also worth to wait and see how the constraints on 3+1ν oscillation parameter space will evolve by the updated results from the reactor SBL measurements.

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