Search for Oscillations of Reactor Antineutrinos at Very Short Baselines

Anomalous results from a variety of neutrino experiments, astrophysical observations, and cosmology suggest the possible existence of sterile neutrinos. Most recently, a re-analysis of short-baseline reactor neutrino experiments has revealed a discrepancy between observations and the predicted antineutrino flux. While the spectral shape and uncertainties obtained in this work are comparable to previous predictions, the predicted reactor $\overline{\nu}_e$ flux has increased by about 3.5% [1–3]. When combined with experimental data at baselines between 10-100 m these recent calculations suggest a ∼6% difference between the measured and predicted reactor antineutrino flux.

This "*reactor anomaly*" can be interpreted as either a sign of new physics or due to unknown physics in the reactor $\overline{\nu}_e$ flux predictions. It has been suggested that such a deficit may be the signature of additional sterile neutrino states with mass splittings of the order of $\sim 1\mathrm{eV}^2$ and oscillation lengths of $\mathcal{O}(3\,\mathrm{m})$ [4]. Current km-scale reactor experiments, while highly precise, cannot easily probe oscillation lengths of this order[5–7]. At these baselines the oscillation effect from potential sterile states averages to yield an effective rate deficit. Most existing experiments are limited by the contributions from multiple reactor cores and an inability to take background data without the presence of any reactor $\overline{\nu}_e$.

A new experiment at very short baselines in a controlled research environment is needed to fully disentangle reactor flux and spectrum uncertainties from possible sterile neutrino oscillations and other effects.

One experimental approach [8, 9] is to measure the reactor $\overline{\nu}_e$ flux and spectrum from reactors at distances comparable to the expected sterile neutrino oscillation length of $\mathcal{O}(3\,\mathrm{m})$. A measurement of both the $\overline{\nu}_e$ rate and energy spectrum as a function of distance can be used to perform a definitive search for oscillations in the region suggested by global fits (Fig. 1). However, at these short baselines, a detector's position resolution, energy resolution, and the finite dimensions of the reactor core become important. This motivates the use of segmented detectors [10] near reactors with compact cores (dimensions of <1 m). The use of highly-enriched uranium (HEU) fuel in US research reactors offers a unique, very nearly static, core composition that minimizes spectral variations during oscillation measurements and will help test our understanding of reactor $\overline{\nu}_e$ calculations. A benchmark measurement of a static core will also provide the opportunity to better understand the time variation of $\overline{\nu}_e$ spectra at conventional reactors with low-enriched uranium (LEU) fuel. The duty cycle of research reactors provides an opportunity for extensive background measurements during the duration of the experiment. Fuel handling at research reactor facilities may enable dedicated studies of spent nuclear fuel that are not possible at commercial power plants.

Experimental challenges including the background rejection in detectors operated near a reactor and without significant overburden, the precision energy calibration, and control of detector systematics are tractable with existing technologies and the recent experience from multi-detector $\overline{\nu}_e$ experiments [6, 7]. Careful detector and shielding designs will be required and can be validated in R&D at the reactor sites. Multiple, segmented detectors with position resolution will allow a relative measurement of the $\overline{\nu}_e$ flux and spectrum at different distances.

The National Institute of Standards and Technology (NIST) [11], Oak Ridge National Laboratory (ORNL) [12], and Idaho National Laboratory (INL) [13] operate powerful, highly compact research reactors and have identified potential sites for the deployment of one or multiple compact $\overline{\nu}_e$ detectors at distances between 4-20 m from the reactor cores [17]. Fig 1 illustrates the experimental concept and sensitivity to short-baseline oscillations.

US reactor facilities offer a unique opportunity for a search of $\overline{\nu}_e$ oscillations at very short baselines. A 5σ discovery is possible with 3 years of data taking. This experiment will resolve one of the outstanding anomalies in neutrino physics, make a precision study of the $\overline{\nu}_e$ flux and spectrum, and develop the use of advanced scintillators and detectors without overburden for applications in reactor monitoring and safeguards.

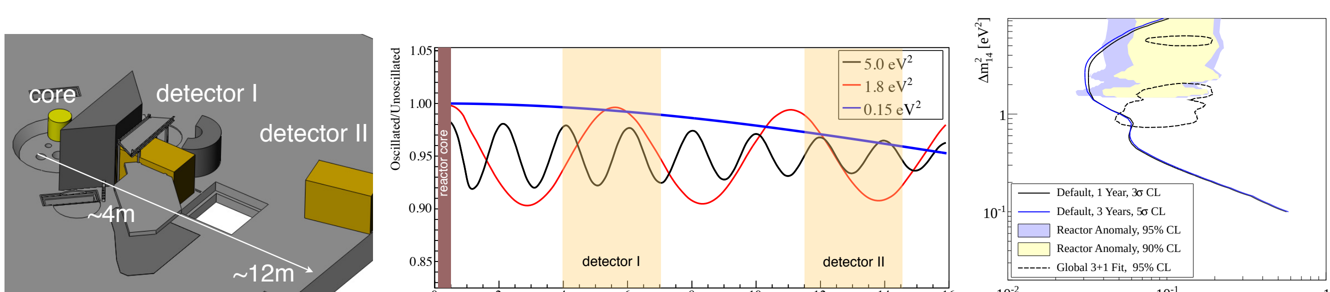

FIG. 1: Left: Engineering concept of ton-scale $\overline{\nu}_e$ detectors at distances of 4-20 m from a reactor core. The NIST facility is shown as an example. Middle: Concept of probing short-baseline oscillation of unknown t Δm^2 with 2 or more radially extended detectors. Oscillations are detected either within one detector or between two detectors. Right: Sensitivity and discovery potential of a nominal short-baseline reactor experiment with 1 and 3 years of data. Figures from [10].

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