Search for Sterile Neutrinos with a Radioactive Source at Daya Bay

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Data from a variety of short-baseline experiments as well as astrophysical observations and cosmology favor the existence of additional neutrino mass states beyond the 3 active species in the Standard Model. Most recently, a re-analysis of short-baseline reactor neutrino experiments found a 3% deficit between the predicted antineutrino flux and observations [1]. This has been interpreted as indication for the existence of at least one sterile neutrino. with a mass splitting of $\sim 1\text{eV}^2$ [2]. The possible implications of additional sterile neutrino states would be profound and change the paradigm of the Standard Model of Particle Physics. As a result, great interest has developed in testing the hypothesis of sterile neutrinos and providing a definitive resolution to the question if sterile neutrinos exist [3, 4].

We propose to use the far site detector complex of the Daya Bay reactor experiment together with a compact PBq $\overline{\nu}_e$ source as a location to search for sterile neutrinos with $\geq$ eV mass [5]. The Daya Bay reactor experiment is a next-generation reactor experiment under construction at the Daya Bay Nuclear Power Plant near Shenzhen, China and designed to make a high-precision measurement of the neutrino mixing angle θ_{13} using antineutrinos from the Day Bay reactor complex [6]. The experiment has three underground sites, two at short distances from the reactors ($\sim$300 m) with two $\overline{\nu}_e$ detectors each, and one at a further baseline ($\sim$1.8 km) with four $\overline{\nu}_e$ detectors. The far site detector complex of the Daya Bay reactor experiment houses four 20-ton antineutrino detectors with a separation of 6 m.

When combined with a compact radioactive $\overline{\nu}_e$ source the Daya Bay far detectors provide a unique setup for the study of neutrino oscillation with multiple detectors over baselines ranging from 1.5-8 m. The geometric arrangement of the four identical Daya Bay detectors and the flexibility to place the $\overline{\nu}_e$ source at multiple locations outside the antineutrino detectors and inside the water pool allows for additional control of experimental systematics. Daya Bay's unique feature of being able to use multiple detectors and multiple possible source positions will allow us to cross-check any results. In addition, the water pool surrounding the four far-site Daya Bay detectors provides natural shielding and source cooling minimizing technical complications resulting from a hot, radioactive source. As a source we propose to use a heavily shielded, 18.5 PBq ^{144}Ce source approximately 16 cm in diameter ($\Delta Q = 2.996$ MeV).

This experimental setup can probe sterile neutrino oscillations most powerfully by measuring spectral distortions of the energy and baseline spectrum. If the source's $\overline{\nu}_e$ rate normalization is well-measured, further information can be provided by measuring total rate deficits. The dominant background of this experiment, reactor $\overline{\nu}_e$, will be measured to less than 1% in rate and spectra by the near-site detectors. In addition, the detector systematics of all detectors will be well-understood after 3 years of dedicated θ_{13} running, minimizing expected detector-related systematics.

The proposed Daya Bay sterile neutrino experiment can probe the 0.3-10 eV^2 mass splitting range to a sensitivity of as low as $\sin^2 2\theta_{new} < 0.04$ at 95% CL. The experiment will be sensitive at 95% CL to most of the 95% CL allowed sterile neutrino parameter space suggested by the reactor neutrino anomaly, MiniBooNE, LSND, and the Gallium experiments. In one year, the 3+1 sterile neutrino hypothesis can be tested at essentially the full suggested range of the parameters Δm^2_{new} and $\sin^2 2\theta_{\text{new}}$ (90% C.L.).

In order to realize such an experiment, R&D towards the development of a PBq $\overline{\nu}_e$ source must be conducted. The process of selectively harvesting fission products from spent nuclear fuel has been developed in the nuclear reprocessing industry, and will need to be tailored to remove ^{144}Ce with high efficiency and purity from a small number of spent fuel assemblies. The necessary R&D and development work can be conducted in the years ahead during the θ_{13} measurement at Daya Bay.

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