Update on the IsoDAR Program For P5

The DAEδALUS Collaboration, October 31, 2013

The Snowmass process sparked larger interest in the DAEδALUS program, of which IsoDAR is a sub-project. The purpose of this memo is to update P5 on developments in summer and fall, 2013. These were not highlighted at Snowmass because they were incomplete at the time. Our program aims to develop a new, powerful isotope-decay-at-rest source for applications across many sites. Our new results are on IsoDAR@WATCHMAN (preliminary) and IsoDAR@JUNO (published). We also list new studies we have initiated since Snowmass.

Context

P5 has access to the DAEδALUS whitepaper [1] submitted to the Snowmass study; nevertheless, a brief discussion of context for the new results may be useful. We are presenting a program to develop new resources for neutrino physics and other fields in particle physics based on cyclotron technology. The applications are world-wide, including in the US. The designs are modular, so that there is cost savings in producing multiple machines. The overall development program is called DAEδALUS and an important subproject is called IsoDAR.

DAEδALUS (Decay-At-rest Experiment for δ_{CP} studies At a Laboratory for Underground Science) is a phased R&D program leading to a high-sensitivity search for CP-violation [2, 3] as well as other physics. The CP parameter study is a unique, cyclotron-driven $\bar{\nu}_\mu \to \bar{\nu}_e$ search that uses tracing of the oscillation wave to measure δ_{CP}. DAEδALUS, when combined with Hyper K (with the JPARC beam running neutrinos-only), can achieve an uncertainty of 4 to 12 degrees on δ_{CP}, depending on the actual value of the parameter. The accelerator system consists of a two-cyclotron design featuring an injector and a superconducting ring cyclotron that is very similar to the RIKEN machine.

The smaller injector cyclotron, which will be developed first, also can be used as a driver to provide a very pure $\bar{\nu}_e$ flux. IsoDAR is a novel isotope decay-at-rest source of $\bar{\nu}_e$ for Beyond Standard Model searches. The source [4] consists of an accelerator producing 60 MeV protons [5] that impinge on a ^{9}Be target, producing neutrons. IsoDAR can use the same design as the injector cyclotron for the two-cyclotron DAEδALUS system. The neutrons enter a surrounding 99.99% isotopically pure ^{7}Li sleeve, where neutron capture results in ^{8}Li; this isotope undergoes β decay at rest to produce an isotropic $\bar{\nu}_e$ flux with an average energy of $\sim$6.5 MeV and an endpoint of $\sim$13 MeV. The $\bar{\nu}_e$ interact with hydrogen via inverse beta decay (IBD), $\bar{\nu}_e + p \to e^+ + n$, which is easily tagged through a prompt-light, neutron-capture coincidence. The $\bar{\nu}_e$ also interact with electrons, allowing a very precise measurement of a purely leptonic interaction. The Standard Model now fully predicts this process and so new physics can be probed.

IsoDAR@WATCHMAN

A new opportunity that arose during summer, 2013 was to pair IsoDAR with the US-based WATCHMAN detector. WATCHMAN was originally planned as a 1 kton Gd-doped water-based detector. However, new studies have led the WATCHMAN group to consider the addition of a light-doping and full-doping water-based liquid scintillator (LS). The details of this detector will be presented by the WATCHMAN group. We have studied the physics case based on detector parameters which

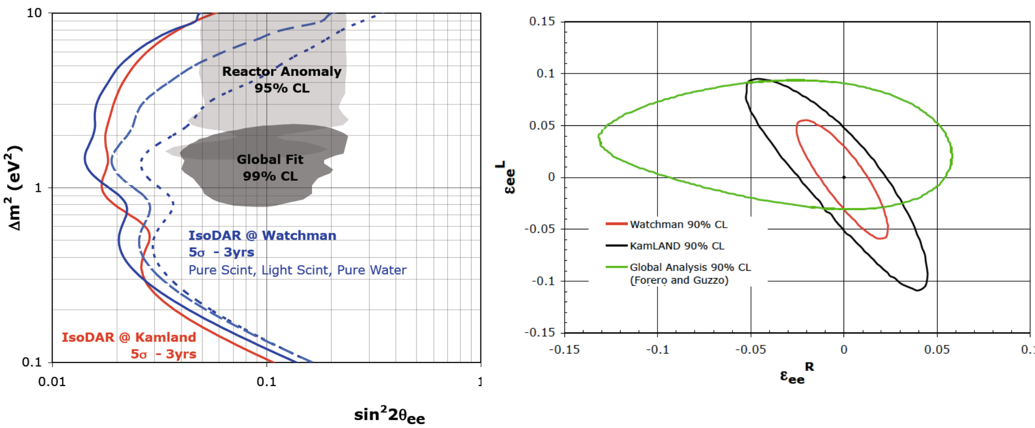

Figure 1: IsoDAR@WATCHMAN sensitivity to new physics. Left: Sensitivity to a sterile neutrino after three years of running is shown in blue. Three WATCHMAN scenarios are presented, all of which have Gd-doping: “Pure Water,” which has no scintillator; “Light Scint,” which has 1% liquid scintillator doping, similar to LSND; “Pure Scint,” which is equivalent to KamLAND. The IsoDAR@KamLAND sensitivity is shown in red. Shown by the light (dark) gray areas are the 99% allowed regions for the Reactor Anomaly [6] (Global Oscillation Fit [7]). Right: Sensitivity to a new non-standard interaction expressed as a correction to the left- and right-handed couplings. Red shows the sensitivity for WATCHMAN with light scintillator. Black is the sensitivity for KamLAND which shows the pure scintillator capability [8]. Green is the present global fit to the world’s data [9].

have been provided by the WATCHMAN group. The studies presented here consider placement of the detector 6.5 m above or below a cylindrical fiducial volume. We indicate the results are preliminary as WATCHMAN continues to refine its detector capabilities; however, the results are nearing publication.

Fig. 1 (left) shows the WATCHMAN 5σ sensitivity to a $\bar{\nu}_e$ disappearance search for 3 years of running. This analysis relies on tracing the L/E dependence of the disappearance wave, which is the key signature for oscillations. The fully LS version is very similar to the KamLAND expectation, up to variations that occur because of the difference in detector shapes. As expected, the highest sensitivity arises from the highest level of doping, which has the best energy resolution. All of the scenarios make a definitive statement concerning the reactor neutrino anomaly [6, 7], indicated in gray, in three years of running.

The physics of $\bar{\nu}_e$-e scattering favors the lightly-doped LS version. The sensitivity to the new non-standard interaction physics is expressed as corrections to the left- and right-handed couplings in Fig. 1 (right). The expectation with WATCHMAN for the lightly doped scintillator (red) is substantially better than the fully-doped LS (shown for KamLAND in black) [8] because directional reconstruction allows a factor of three reduction in the backgrounds. Both are orthogonal to, and significantly more precise than the existing limits on new physics from previous measurements of these couplings (green) [9].

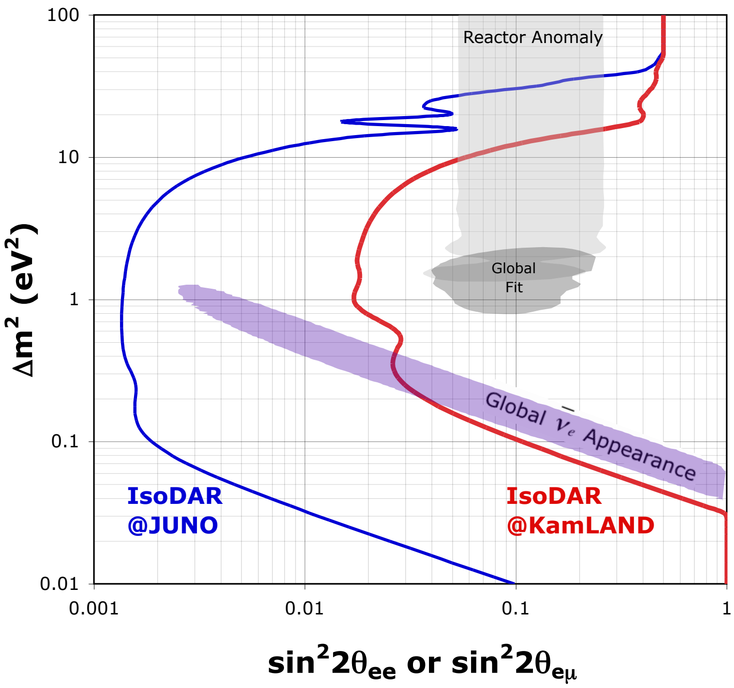

Figure 2: Red and blue solid curves indicate Δm^2 vs. $\sin^2 2\theta_{ee}$ boundaries where the null oscillation hypothesis can be excluded at 5σ with IsoDAR@KamLAND and IsoDAR@JUNO experiments, respectively, for three-year data runs. Also, shown by the light (dark) gray areas are the 99% allowed regions for the Reactor Anomaly[6] (Global Oscillation Fit[7]). Finally, the purple region corresponds to the Δm^2 vs. $\sin^2 2\theta_{e\mu}$ allowed region at 99% CL from a combined fit to all $\bar{\nu}_e$ appearance data[11].

IsoDAR@JUNO

Since summer, we have also been working to understand the capability of JUNO with an IsoDAR source. These results have been published recently on the arXiv and submitted to Physical Review D [10]. In this case, the sensitivity entirely covers the high Δm^2 appearance and disappearance anomalies at 5σ as shown in Fig. 2.

IsoDAR is a $\bar{\nu}_e$ disappearance search. If no disappearance is observed, then the equivalent appearance signal can be ruled out in any model which is CPT-conserving. From the following chain of reasoning:

1. CPT invariance requires that $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations and $\nu_e \to \nu_\mu$ oscillations must be identical.

2. The probability for ν_e disappearance must be larger than for $\nu_e \to \nu_\mu$ oscillations.

3. CPT invariance requires that the probability of $\bar{\nu}_e$ disappearance be the same as the probability for ν_e disappearance.

As with all IsoDAR analyses, this result relies on reconstructing the L/E dependence of the oscillation wave. The primary improvement over KamLAND comes from the $\times 20$ increase in statistics which extends the L/E range. Resolution is dominated by the 40 cm uncertainty on the L that is inherent in the source, and so the improved energy resolution of JUNO represents only a small contribution to the sensitivity.

Other New Pairings for IsoDAR

Since Snowmass, we have initiated some new studies which we envision will produce results in the winter and spring. There are:

- **IsoDAR@LAr** – Because of the 7.48 MeV $\bar{\nu}_e$ CC scattering threshold in argon, which suppresses electron-like events from nuclear scattering, these studies are primarily focussing on $\bar{\nu}_e$-e scatters.
- **IsoDAR@LENA** – This configuration is a straightforward extension of the JUNO study, and is now underway. The differences are that LENA is 50 kt rather than 20 kt, is cylindrically-shaped and has energy resolution comparable to KamLAND rather than JUNO.

References

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