IsoDAR and DAEδALUS

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The DAEδALUS collaboration seeks to construct a number of high-intensity cyclotrons for use throughout neutrino physics, including searching for a sterile neutrino, sensitivity to non-standard neutrino interactions, measurements of coherent neutrino-nucleus scattering and ultimately, a determination of CP violation in neutrinos. This proceedings focusses on the physics goals of the DAEδALUS project.

1 Introduction

We don't know if neutrinos obey Charge-Parity (CP) symmetry and we don't know how many neutrinos there are. Answers to these questions are vital for understanding the neutrino's place amongst the fundamental particles as well as its role in the evolution of the universe. The DAEδALUS collaboration has set out to produce cyclotron-based neutrino sources for, among other things, answering these questions. The experimental concept calls for two classes of cyclotrons in producing isotope and pion/muon decay-at-rest sources of neutrinos, an injector cyclotron and a Superconducting Ring Cyclotron (SRC). The injector cyclotron can be combined with a liquid scintillator based neutrino detector for trying to answer the question of how many neutrinos there are [1], and a set of SRC devices, located at various distances from an ultra-large free-proton-based detector, can be used to measure CP violation in neutrinos [2]. While there are a number of technological challenges associated with constructing these devices (e.g., see Ref. [3]), the focus of this work is on the physics capabilities of these unique experiments.

2 IsoDAR

The Isotope Decay-at-Rest experiment (IsoDAR), doubling as the injector cyclotron design for the DAEδALUS neutrino CP violation project, will use a 600 kW resistive cyclotron to accelerate 5 mA of 60 MeV/amu H_2^+. For IsoDAR, a dedicated experiment that will utilize this source, the ions will be directed onto a ^{9}Be target to produce a large flux of neutrons emanating from the target. These MeV-scale neutrons, produced at the level of $\sim$0.1 neutron per incoming proton [4], will slow down and eventually capture inside of a surrounding ^{7}Li ($\geq$99.99% isotopically pure) sleeve. The product of this capture, ^{8}Li, beta decays with a half-life of 840 ms to produce an electron antineutrino with energy in the 3-14 MeV range. There are about 15 $\overline{\nu}_e$ per 1000 protons on target expected. The cyclotron-target configuration can be placed within $\sim$10 m of a planned or existing liquid scintillator based detector, such as KamLAND [5], for

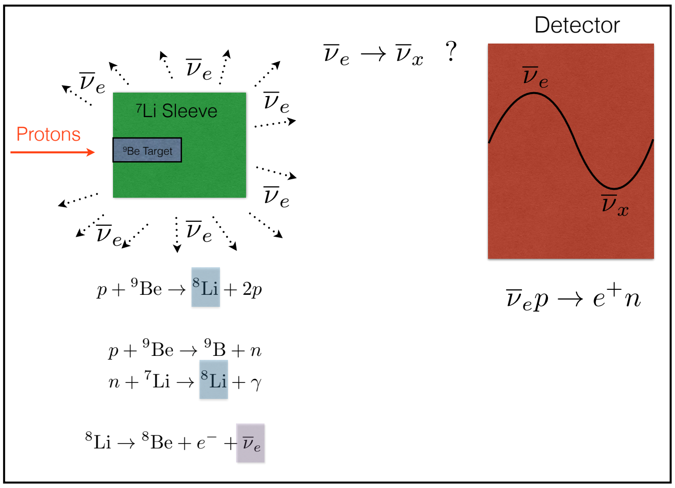

Figure 1: The IsoDAR idea for an intense source of electron antineutrinos source near a planned or existing liquid scintillator detector.

collecting electron antineutrino induced inverse beta decay (IBD) interactions ($\overline{\nu}_e p \rightarrow e^+ n$) and $\overline{\nu}_e$-electron elastic scatters ($\overline{\nu}_e e^- \rightarrow \overline{\nu}_e e^-$). The collected electron antineutrino IBD events can provide sensitivity to high-Δm^2 neutrino oscillations, a signal which would be indicative of the existence of at least one light sterile neutrino. The approximately 800,000 IBD events expected in 5 years running IsoDAR 16 m away from the 897 ton fiducial mass KamLAND detector would allow a sensitivity of $>10\sigma$ to electron antineutrino disappearance at $\Delta m^2 \sim 1$ eV^2. Such a large sample would even provide the ability to distinguish between the existence of one or two sterile neutrinos in many mixing scenarios [6]. Further, the $\approx$2500 $\overline{\nu}_e$-electron elastic events expected would provide a unique test of non-standard neutrino interactions and physics beyond the Standard Model in general [7]. The IsoDAR idea, with a focus on the oscillation concept, is shown in Figure 1.

3 DAEδALUS

The neutrino CP violating parameter δ_{CP} can be measured by studying $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations at medium baseline (tens of km for neutrino energies in the 20-50 MeV range). For DAEδALUS, the muon antineutrino flux is produced with 800 MeV protons striking a carbon target to create charged pions. The pions quickly come to rest in the target and decay to a muon and a muon neutrino ($\pi^+ \rightarrow \mu^+ \nu_\mu$). The positively charged muon subsequently comes to rest as well and decays to a positron and two neutrinos ($\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$) with energies from 0-52.8 MeV. Electron antineutrino appearance from the muon antineutrino component of this source can be studied, via the IBD interaction at medium baseline, to provide a measurement of δ_{CP}. A set of cyclotrons, at distances of 1 km, 8 km, and 20 km away from a single ultra-large detector are envisioned by DAEδALUS for this purpose. In general, the near cyclotron will be used to constrain the initial flux via ν_e-electron scattering, the middle-distance cyclotron will constrain the rise probability, and the far cyclotron(s) will be used to power the fit for electron antineutrino appearance. Neutrinos from the different sources are differentiated at the single detector with pulse timing. DAEδALUS requires the power of the cyclotrons at each site to be 0.8, 1.6 and 4.8 MW, from near to far. These tentative requirements are set such that DAEδALUS can match the sensitivity of the Long Baseline Neutrino Experiment (LBNE) 2011 baseline design [8]. Notably, the contamination of intrinsic $\overline{\nu}_e$, from the source rather than from appearance, is at the $\sim 4\times10^{-4}$ level because almost all of the (grand)parent π^- capture on nuclei before they have a chance to decay. The DAEδALUS experimental concept, in consideration of the CP violation measurement, is shown in Figure 2.

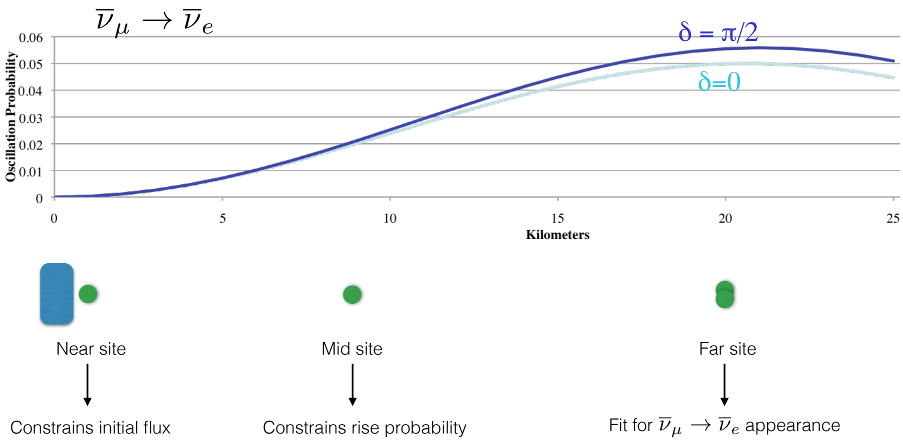

Figure 2: The DAEδALUS experimental concept, depicting the various accelerator locations and their general purposes, with respect to an ultra-large detector. A set of example oscillation probabilities, for two different values of $\delta_{\rm CP}$, is also shown.

Along with contributing information about the initial composition of the un-oscillated source, the first "near" cyclotron can be used for a set of of short-baseline measurements, especially when considered in combination with smaller detectors located near the accelerator. Specifically, a coherent neutrino-nucleus scattering experiment with a dark-matter-style detector sensitive to nuclear recoils at the keV-scale is possible [9]. Such a detector could be located tens of meters from the source in order to search for the well-predicted, but as-yet-unseen, coherent interaction of a neutrino with an entire nucleus. In case the accelerator is located at a deep underground lab, a dedicated dark matter experiment nearby could also make the discovery. Further, a multi-detector configuration could provide a unique neutral current based sterile neutrino oscillation search using the coherent events [10]. Such a neutral current based disappearance search would be uniquely sensitive to the sterile flavor component of the fourth neutrino mass eigenstate, a measurement which is not directly accessible using charged current based searches.

The near cyclotron can also be used to look for high-Δm^2 oscillations, $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ appearance as well as the disappearance of ν_e, in combination with the envisioned nearby ultra-large detector [11]. Both of these measurements can be considered complimentary to IsoDAR's low(er) energy electron antineutrino disappearance probe. In the case that a new oscillatory frequency consistent with a sterile neutrino is confirmed, we will want to measure its properties, including precise determinations of its characteristic mass splitting and mixing angles. Such measurements are best accomplished, of course, using multiple flavors in both appearance and disappearance modes and with both neutrinos and antineutrinos. It is also worth noting that the envisioned short baseline electron antineutrino appearance search with DAEδALUS can be considered a direct test of the LSND and MiniBooNE antineutrino anomalies [12, 13, 14].

4 Status and conclusion

DAEδALUS is working within a four-phase program for surmounting the technological obstacles associated with building and operating these megawatt-class cyclotrons and establishing their cost-effectiveness and ability. The currently underway Phase 1 aims to deploy and test an intense H_2^+ ion source; Phase 2 will demonstrate a full-scale version of the low energy beam transport and injector cyclotron systems, and use this system to definitively address the sterile neutrino; Phase 3 will continue with the production of an actual full superconducting ring cyclotron accelerator module at a near location from an ultra-large water or scintillator based detector for sterile neutrino and coherent neutrino-nucleus scattering physics; and Phase 4 involves the deployment of the complete DAEδALUS experiment featuring cyclotrons at three distances for a measurement of δ_{CP}. This program of research and development and measurements relevant for accelerator science, producing medical isotopes for industry [15], and neutrino physics is ongoing. Among other physics goals, this program will help to answer two of the most profound and important questions in physics today: 1) How many neutrinos are there? and 2) Do neutrinos and antineutrinos behave the same?

Acknowledgments

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