Snowmass2021 - Letter of Interest

NuLat: A Compact Anti-Neutrino Detector

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Topical Group(s):

☐ (NF1) Neutrino oscillations

☐ (NF2) Sterile neutrinos

☐ (NF3) Beyond the Standard Model

☐ (NF4) Neutrinos from natural sources

☐ (NF5) Neutrino properties

☐ (NF6) Neutrino cross sections

☐ (NF7) Applications

☐ (TF11) Theory of neutrino physics

☐ (NF9) Artificial neutrino sources

(NF10) Neutrino detectors

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Abstract:

We present a new segmented neutrino lattice detector, NuLat, which is based on the Raghaven Optical Lattice design originally employed in Low-Energy solar Neutrino Spectroscopy (LENS) detector and fast-timing electronics developed for MiniTimeCube. With its wall-free 3D segmentation, high light-yield, fast timing, pulse-shape discrimination, 6 Li doped plastic scintillator cubes for distinctive neutron tagging, and complete event topology (dE,t,x,y,z), NuLat offers unparalleled background rejection. Once completed, NuLat will be tasked with reactor monitoring for the purposes of searching for sterile neutrinos, contributing towards the study of absolute neutrino flux, and nuclear nonproliferation.

1 Motivation

A right-handed sterile neutrino is involved in some models of neutrino mass. Some experimental results cannot be accommodated within the standard three-neutrino framework but could be explained by a sterile neutrino with mass around 1 eV. A definitive discovery of a sterile neutrino would point to the scale of physics responsible for neutrino mass, provide clues to the actual mechanism and contribute to hot dark matter. Explicit observation of the spectral distortion expected for oscillations involving the sterile neutrino is required for a definitive discovery. We believe a later, larger version of our prototype detector will be capable of such measurements and be able to constrain the limits of finding low-energy (1 eV scale) sterile neutrinos.

Nuclear nonproliferation is also a goal of this detector through anti-neutrino reactor monitoring. While there are already various other methods of reactor monitoring, there are many benefits to using neutrinos, the greatest being the fact that neutrinos cannot be shielded, hidden, or falsified.
As reactors run, U-238 is converted into Plutonium. Plutonium can be harvested while it is still weapons grade or spent up in the reactor for fuel, depending on how soon the rods are removed. As the neutrino spectrum differs between isotopes, collecting enough particles allows us to differentiate which dominant isotope is currently undergoing fission in the reactor, and with high enough statistics, the current ratio of isotopes can be uncovered. Information pertaining to power output and frequency of fuel changes will also be detectable. With the capability of high background rejection allowing the detector to work above ground and good mobility due to its small size, the NuLat detector is optimal for reactor monitoring tasks, even potentially performing outside a reactor facility and causing no interference to power production activities.

2 Detection Methodology

Neutrinos are detected through the Inverse-Beta Decay (IBD) method where an incoming neutrino interacts with a proton in the detector producing a positron carrying energy and a neutron carrying momentum. In our detector the fast positron quickly scintillates, on the scale of nanoseconds, allowing us to record a start signal and information on the neutrino's energy. The slower neutron is captured on Lithium-6 in our scintillator, producing an approximately 7us delay which we use as a stop signal.

Light from the scintillation is then channeled to aligned PMTs through the Raghaven Optical Lattice. In our prototype detector the lattice consists of a 5 x 5 x 5 array of 2.5” scintillating cubes with a 0.01” air gap between them. This lets us take advantage of total internal reflection due to the scintillating cubes having a higher index of refraction than the air. Through total internal reflection, the majority of light is channeled to the edges of the lattice along the principle axes of the interaction where it reaches PMTs.

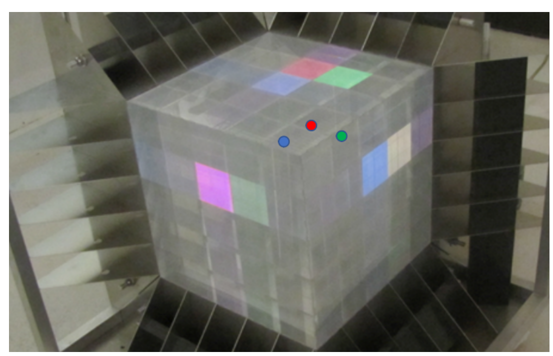

Figure 1 (above): Opened up prototype showing the Raghaven Optical Lattice. Light sources demonstrate its ability to simultaneously detect multiple sources. In this example, multiple colored sources can be located by observing color combinations on 3 sides of the detector.

Once digitized, we use our electronics featuring a very sophisticated, programmable fast trigger to reject background on the fly (as opposed to offline). The first method used is timing coincidence and energy cutoffs as the positron produces a signal comparable to the original neutrinos whereas the interaction between Lithium-6 and the proton gives a 400 keV signal with a 7us delay. Due to the 3D segmentation of the Raghaven Optical Lattice, we are also able to tell which cube each interaction takes place in and can use a geometric trigger. Our simulations show that 25% of neutron/positron events occur within the same cube and 60% occur within a cube and its neighbor allowing rejection or simultaneous measurement of many further off events as not being related. Another tool at our disposal is the use of pulse shape discrimination to verify neutron and positron signals. From all this we are left with a good signal to background ratio and complete event topology (dE, x, y, z, t) of our neutrino events.

3 Previous Work

While the NuLat Detector has the potential for great work, detector development is still in an early phase. Simulations and physical tests have been conducted showing the cube array's ability to properly channel a high percentage of the light to the PMT collecting the light for that row and column. Upon near-completion of our prototype detector, we accurately detected directed LED light along one measurement axis, testing PMT cross-talk, and diffuse scintillation light along 3 axes giving us location of an event. Monte Carlo simulations have also shown effectiveness of the detector design. Upcoming experiments will involve running radon through the apparatus to test our triggering on multi-particle events, eventually full testing at a reactor, and the potential use of a liquid scintillator alternative to our current plastic-based version.

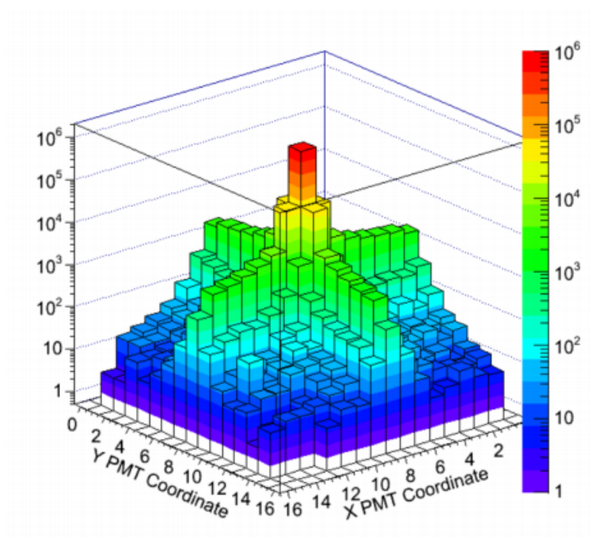

Figure 2 (left): Log plot of light output on the (X-Y) face of a mirrored NuLat design via deposition of 2 MeV in the central cell of the detector. Demonstrates light guiding efficiency of the detector