NuLat : a novel detector to measure $\bar{\nu}_e$ flux

Christina Nelson on behalf of the NuLat Collaboration
Department of Physics & Astronomy, University of Hawaii Manoa

Abstract

- We introduce NuLat, which is a novel detector to measure inverse beta decay of neutrinos in close proximity to a nuclear reactor. The motivation is to search for anomalous neutrino oscillations and study electron anti-neutrinos which may provide insight into the "Reactor Antineutrino Anomaly". NuLat consists of loaded plastic scintillator which form a Raghavan optical lattice; air gaps result in total internal reflection which guides light to photomultipliers. This design provides the spatial and energy resolution necessary to discern signal from backgrounds. We share the University of Hawaii's (UH) involvement in the NuLat collaboration and testing of light guides.

Inverse beta decay (IBD) & the RAA Anomaly

- Large $\bar{\nu}_e$ flux is produced from the β-decay of radioisotopes in nuclear reactors.
- IBD is detected by the process: $\bar{\nu}_e + p \rightarrow e^+ + n$
- Phase difference between mass eigenstates produce oscillations in the time-dependent wave function [2]

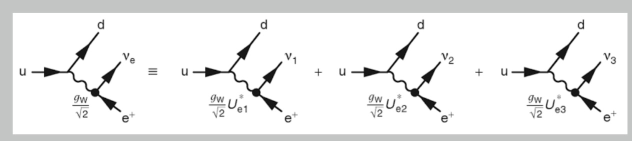

Figure : Components of different mass eigenstates from β^+ -decay [2]

- The survival probability of $\bar{\nu}_e$ in close proximity to a nuclear reactor is

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - sin^2(2\theta_{13}) sin^2\Big(\frac{\Delta m^2_{32} L}{4E_{\bar{\nu}}}\Big)$$

- $\bar{\nu}_e$ flux in a nuclear reactor shows about a 6% lower yield than calculation [3]; this is the so-called Reactor anti-neutrino anomaly.
- Is this due to $\bar{\nu}_e$ oscillating into a new sterile neutrino mass state within meters from the reactor?

Motivation for short baseline $\bar{\nu}_e$ search

- The RAA observed by various short baseline experiments
- Red line represents 3 active neutrino mixing solution
- Blue line shows a solution with a new neutrino mass state [4]
- NuLat will measure in a region not yet investigated

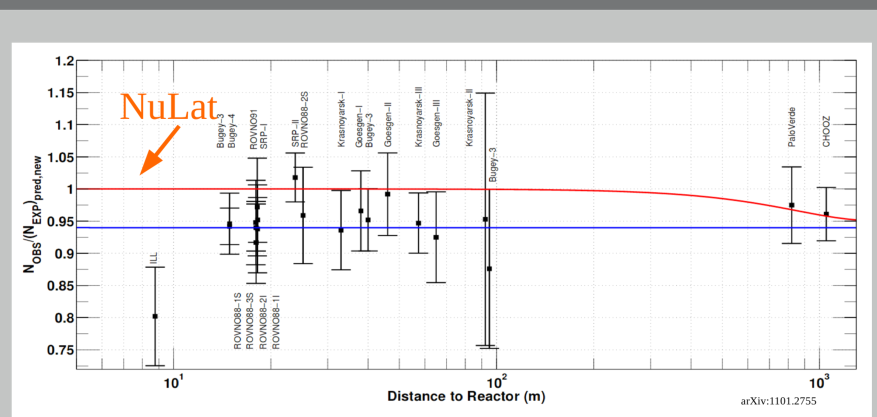

Figure : Experimental results from short baseline experiments [4]. NuLat will make important measurements from a distance to a reactor not yet done by previous experiments.

The Detector

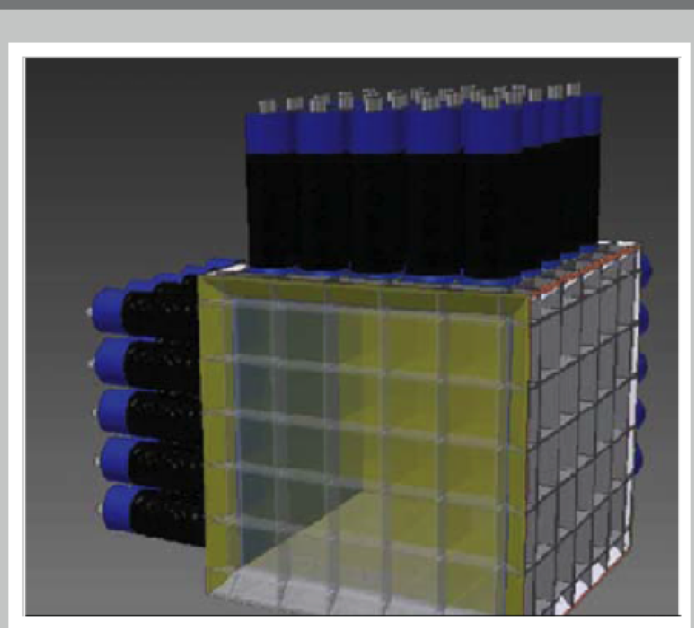

Figure : CAD drawing of NuLat with array of PMTs (partially removed for visualization). [1]

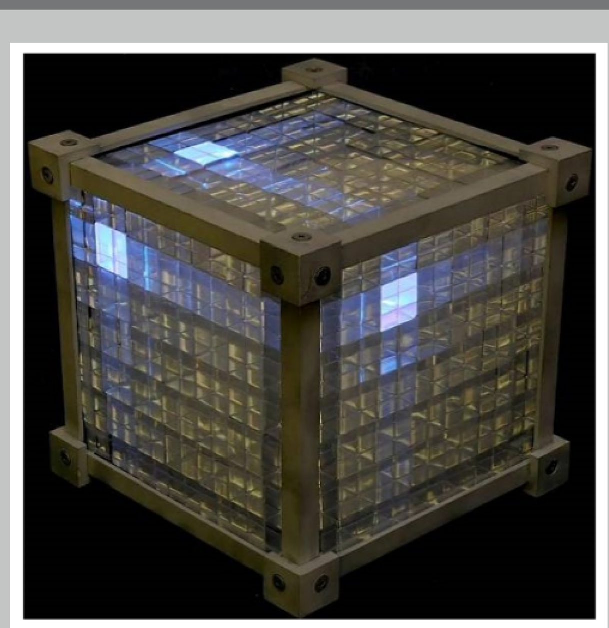

Figure : Photo of ROL demonstrator, note that the light source position is clearly visible. [1]

- Design based on the Raghavan optical lattice (ROL) developed by the Low-Energy Neutrino Spectroscopy (LENS) Collaboration
- An array of ^{6}Li doped scintillator cells, referred to as light guides (LG) will channel the light via total internal reflection to an array of photomultipliers
  - Inverse beta decay produces a positron and a neutron
  - The incoming neutrino energy is transferred to the positron through inelastic scattering
  - Momentum is imparted to the neutron
  - Thus, measurement of e^+ kinetic energy provides good measure of ν kinetic energy
- Optical 3D segmentation of ROL and precise time-of-flight methods allows localization of events in the detector [1]

Light Guide Testing

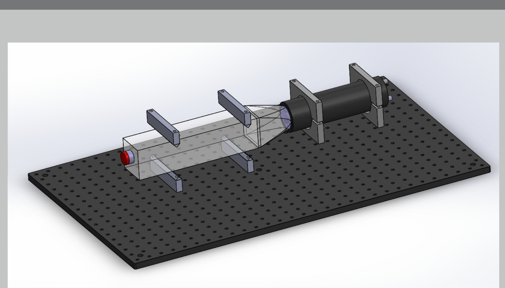

Figure : CAD drawing of setup in dark box for measurements with Po^{210} source; long block mimics detector.

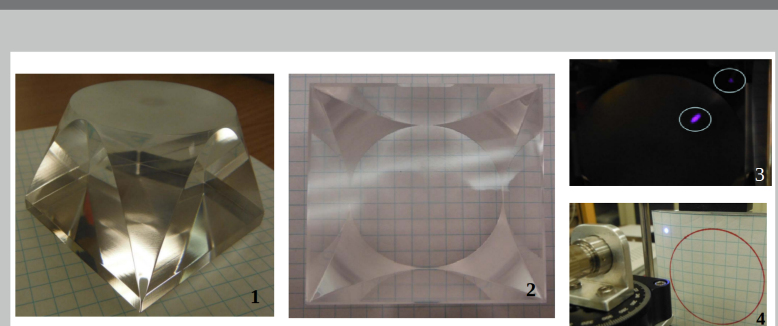

Figure : (1),(2) Side view & top view of LG respectively, (3) Laser incident on square face corner shows light guided out circular end via TIR, (4) Nd:YAG laser normal incidence to square of LG.

- Effectively guiding light from cubes to circular PMT face requires a light guide (LG)
- UH is evaluating different LG geometries to measure the light collection increase
- Complimentary measurements are made using Po^{210} and a Nd:YAG laser with a diffusion bulb
- 2 LG designs are considered here
  - short LG (sLG) measuring (5.7×5.7×4.0) cm, (2.2×2.2×1.6) in.
  - long LG (lLG) with dimensions (6.3×6.3×7.5) cm, and (2.5×2.5×3.0) in.

Results: Figure

- Histogram shows data taken with Po^{210}, dark box LG setup shown in figure (5)
- Plot with red crosses: background distribution
- Blue filled plot: measurements with ^{210}Po
- Green area: weighted backgrounds subtracted for the same counting duration
- Good background rejection is obtained from LG measurements with ^{210}Po

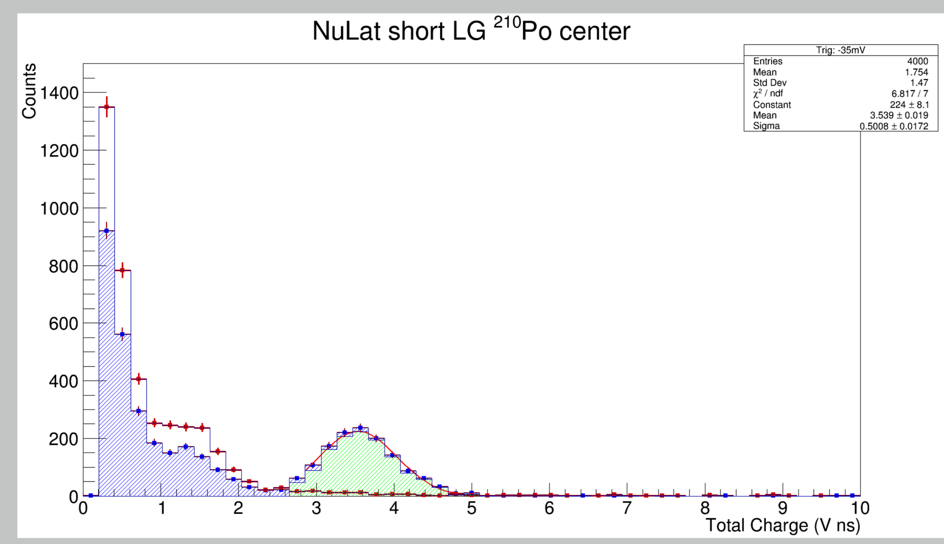

Figure : Charge distribution of measurements taken with experimental setup shown in figure (5). ^{210}Po is centered on the square end of the LG.

- Laser measurements compliment LG study because Po^{210} is not monoenergetic
- Nd:YAG laser with a diffusion bulb centered normal to square face of LG
  - primarily at the 2nd harmonic, 532 nm
- Trigger is made on a reference diode to ensure that the PMT is sensitive to the laser signal

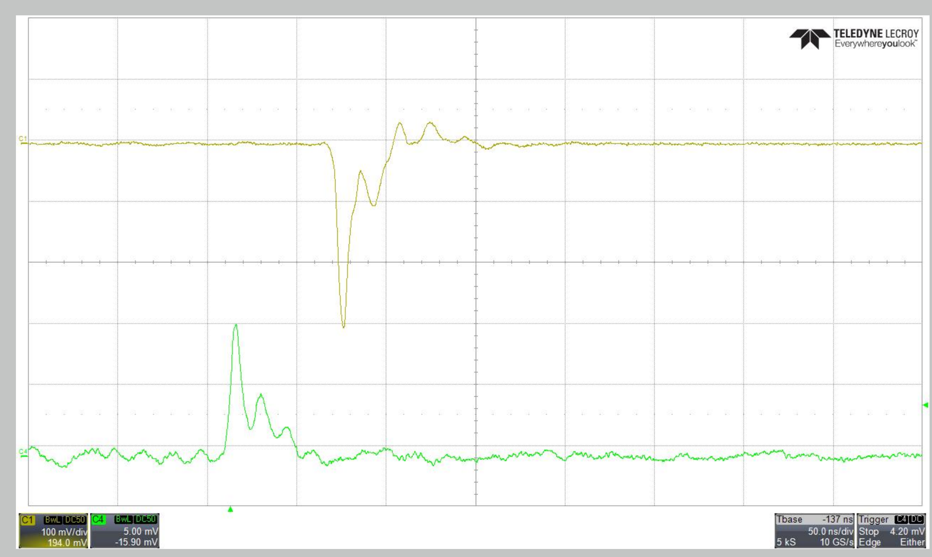

Figure : Oscilloscope reading from PMT signal (yellow) triggered by Nd:YAG laser pulse (green), note the different scales for each waveform.

Results: Table

- Assessing photo-electron (PE) yield from PMTs with mean value of integrated charge distribution in several instances: bare PMT, sLG, and lLG
- LOE denotes Nd:YAG laser output energy obtained from manufacturer test results
- Distance from laser diffusion bulb to PMT or LG face is constant, 20.3 cm (8 in)

LOE [mJ]	bare PMT [Vns]	sLG & PMT [Vns]	lLG & PMT [Vns]
20	1.355 ± 0.004	1.539 ± 0.004	1.958 ± 0.012
40	2.797 ± 0.006	2.895 ± 0.006	4.413 ± 0.008
60	3.447 ± 0.007	3.576 ± 0.006	5.560 ± 0.010

Table : Mean integrated charge value at various Nd:YAG laser power settings

- Measurements with the sLG yield on average an increase of $\lessapprox$ 13% PE
- lLG gives an increase of $\gtrapprox$ 50% PE
- From these results production of lLG for NuLat is chosen

Conclusion

- The NuLat detector is unique to short baseline neutrino experiments, in design and measurement region wrt distance from reactor
- ^{210}Po source measurements with the LG show good signal to background discrimination
- Laser data is used to probe light collection efficiency with two LG designs
- Nd:YAG laser with diffusion bulb incident to square face of LG results in a PE increase of $\lessapprox$ 13 % and $\gtrapprox$ 50 % with the sLG and lLG respectively
- The results are sufficient to proceed with lLG production
- Although detecting missing reactor $\bar{\nu}_e$ is difficult, NuLat has excellent spatial and energy resolution and can be deployed at short baselines
- Measurements made by NuLat are important to fill in our understanding of the RAA and the deficit of $\bar{\nu}_e$ flux observed by many experiments

Reference

1. arXiv:1501.06935v1 [physics.ins-det] NuLat: A new type of Neutrino Detector for Sterile Neutrino Search at Nuclear Reactors and Nuclear Nonproliferation Applications. January 29, 2015.
2. Mark Thomson. Modern Particle Physics. Cambridge University Press, 2013. Pg.342-343.
3. M.Cribier. Reactors antineutrino anomalies and searches for sterile neutrinos. IOP Publishing, Journal of Physics:593.
4. G.Mention et al. The Reactor Antineutrino Anomaly. arXiv:1101.2755v4[hep-ex] 23 Mar 2011.

Acknowledgments

- We would like to acknowledge the Virginia Tech group and the other Universities in the NuLat collaboration; also the Department of Energy for the funding for this experiment.

Contact Information

- Web: christinanelson.github.io
- Email: canelson@hawaii.edu
- Phone: +1 (808) 956 7087