Directional Measurement of Anti-Neutrinos with KamLAND

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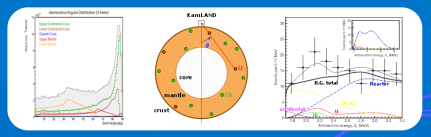
Development of Liquid-Scintillator, Optics and Photo-Sensor will enable KamLAND to detect anti-neutrinos direction through the inverse beta decay.

Physics Motivation

1. Geo anti-neutrino
   — Measurement of radiogenic heat source distribution inside the Earth.
   — Separation from reactor neutrino.



2. Reactor anti-neutrino
   — Improvement of oscillation sensitivity.
   — Reactor monitor.

3. Supernova anti-neutrino
   — Early warning and locating of SN.

Furthermore, directional measurement can provide an additional tool to reduce B.G. and to distinguish various sources of anti-neutrinos. And thus, it holds good in all KamLAND-like experiments.

Directional Measurement Principle

In KamLAND, electron anti-neutrinos are detected through the inverse beta decay:

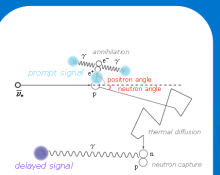
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

This reaction gives two signals: a prompt positron and a delayed neutron capture. This coincidence allows almost B.G.-free measurement. In addition, it has the potential of the anti-neutrino directional measurement. *Because the positional information of those two signals holds the directional information of the incident anti-neutrino.*

A prompt positron deposits the energy and cause ionization, then releases two gammas by the annihilation with an electron. This prompt signal process is raised immediately after the inverse beta decay. So prompt signal holds an anti-neutrino vertex position.

And the delayed neutron scattering angle is known as the right figure.

Therefore, the direction of the incident anti-neutrino can be estimated if the neutron direction is measured.



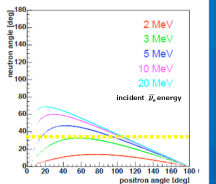
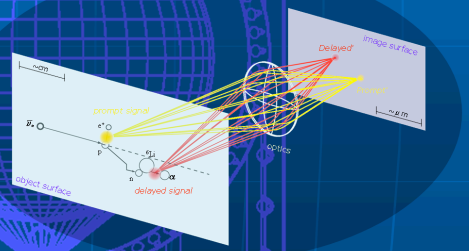


Figure. n direction as a function of e^+ direction for incident $\bar{\nu}_e$ energy.

3 Developments for New Detector

1. Liquid-Scintillator
   - Large neutron-capture cross section to minimize the thermal diffusion.
   - (n, α) reaction constituent to hold the n-capture position information.
   — The strongest candidate is ^{6}Li-loaded LS.
2. Optics
   - Large depth of field.
   - High light correction efficiency.
   - Small aberration.
3. Photo-Sensor
   - Position sensitivity to detect a reaction as an image.
   - High quantum efficiency to get the position information from few photons.
   - Continuous read-out.

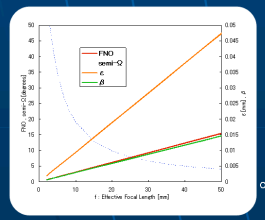


Optics

Requirement
- Object range : 2,500~15,500 mm
- Angle of View : ~90˚
- Resolution : ~10 mm
- Coverage : ~10 %
- Few number of lenses
- Low cost material

Depth of Field is incompatible with Optical Diameter.

→ **Large number of Pan-focus Optics with small optical diameter. Photo-sensor for each Optics ("Optics-Sensor unit")**



Optical Parameter
- f : Effective Focal Length
- FNO : F-number
- ε : Allowable image blur
- β : Magnification at the best focused surface
- Ω : Angle of view

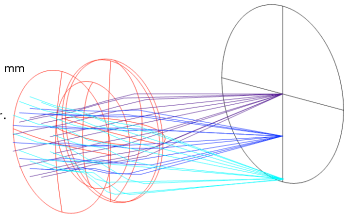
Hyper Focal Distance

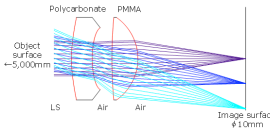
$$S_h = \frac{f^2}{\varepsilon \, FNO}$$

On the supposition of photo-sensor
- active area size : ϕ10mm
- resolution : ~10 ²mm

Rough sample
- f=10.4mm
- F=3.1
- β =-0.00231
- Ω =50˚
- DOF:2,500~∞ mm

(Blur stays in 0.01mm at center. But this optics is imperfect anastigmatic.)





Problem

Giving first priority to Depth of Field, detector needs too large number (~10⁸) of optics-sensor unit.

To solve this problem,
- Finite Optics and limit to the measurement area.
- other optical tools, like reflex mirrors.

We need more R&D for Optics.