Geo-Neutrino Measurement with KamLAND

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KamLAND Experiment

KamLAND Experiment

Electron anti-neutrino detection via inverse beta decay process

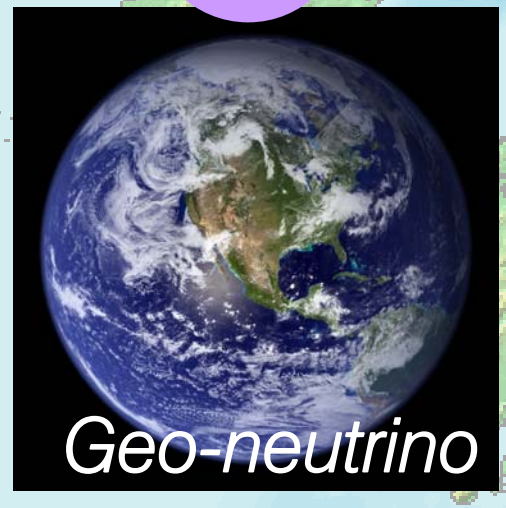
$\bar{\nu}e + p \rightarrow e^+ + n$

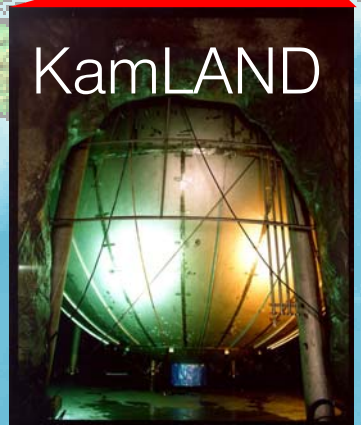
Electron neutrino detection via electron scattering process

$\nu e + e \rightarrow \nu e + e$

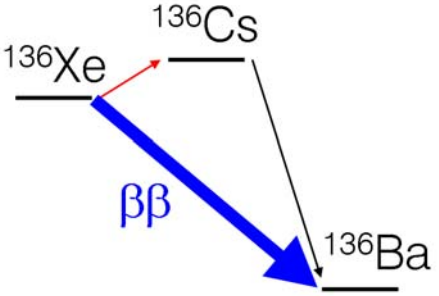
$\bar{\nu}_e$

ν_e



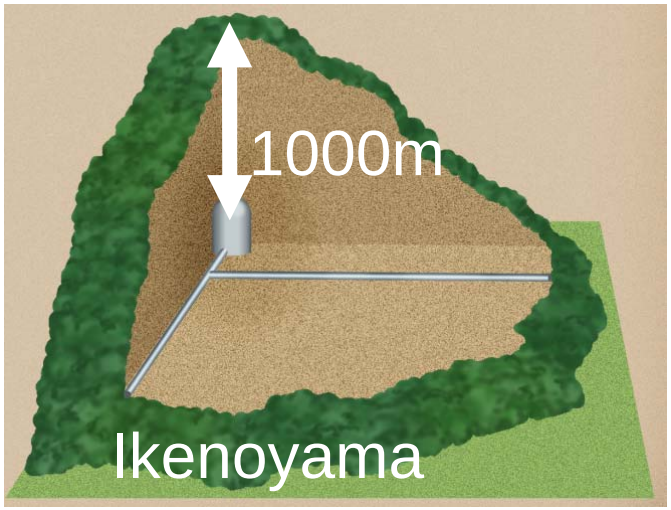


2011 start



Double beta decay (KamLAND-Zen)

KamLAND Detector



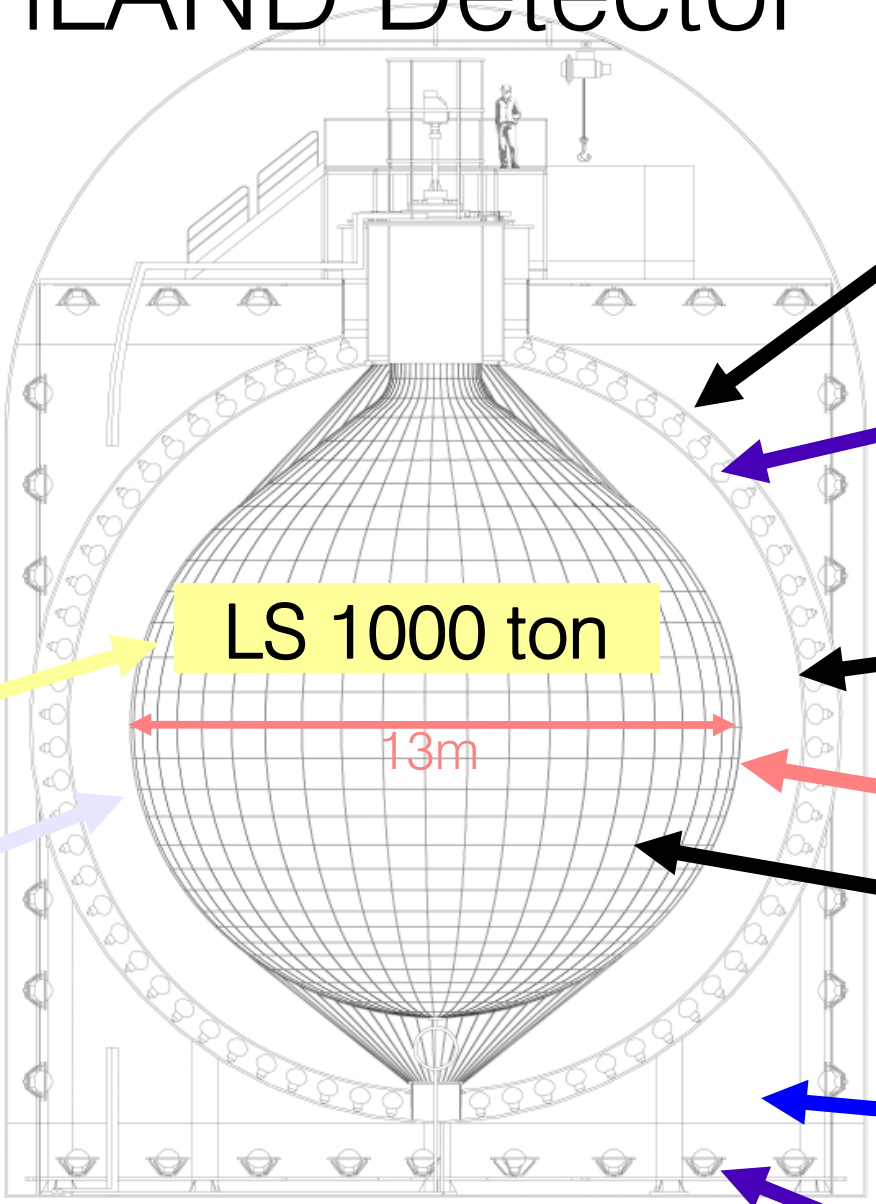
Liquid Scintillator(LS)

Dodecane	80%
Trimethel Benzene	20%
PPO 1.36 g/l	

Buffer Oil

Dodecane	50%
Isoparaffin	50%

Density : 0.78 g/cm^3



Stainless tank
(ϕ = 18 m)

ID PMT
17inch 1325
20inch 554

Acrylic board
(ϕ =16.5 m)

Balloon

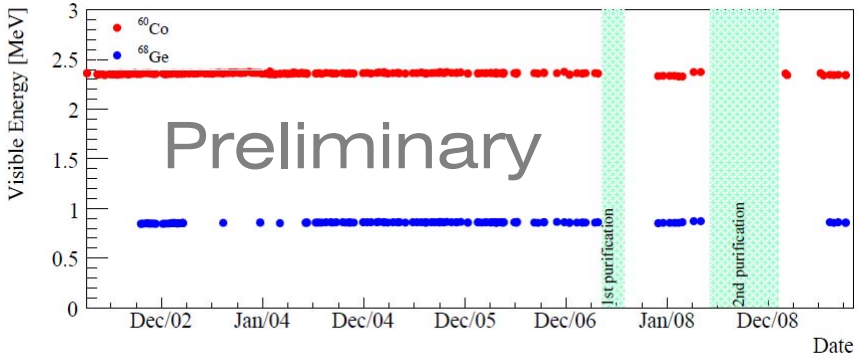
Kevlar rope

Pure water

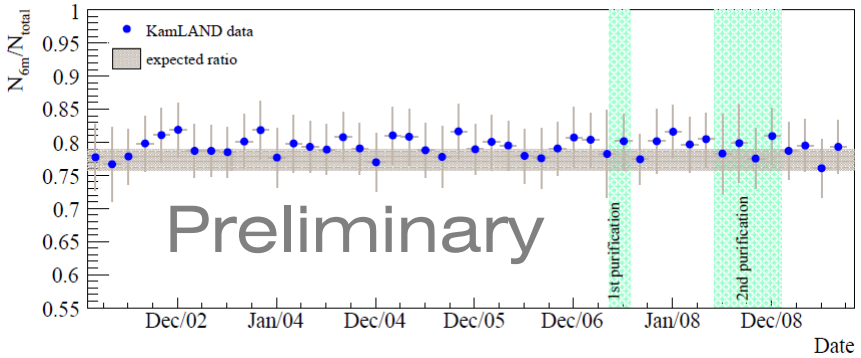
OD PMT
20inch 225

Detector Performance

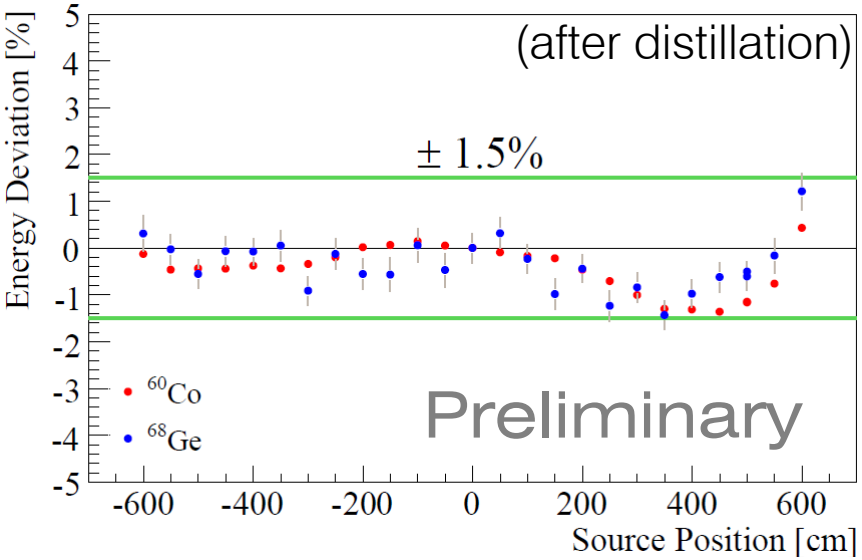
^{68}Ge/^{60}Co Energy time variation



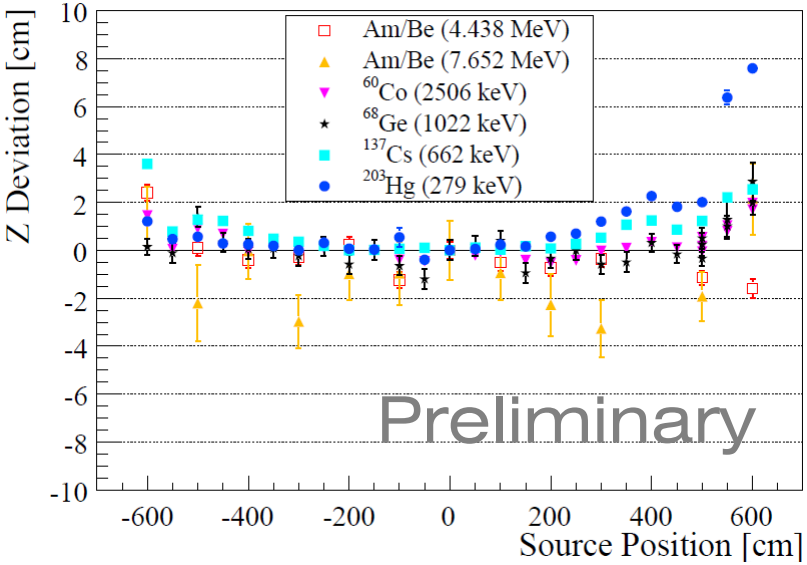
^{12}B N_{6m}/N_{all} time variation



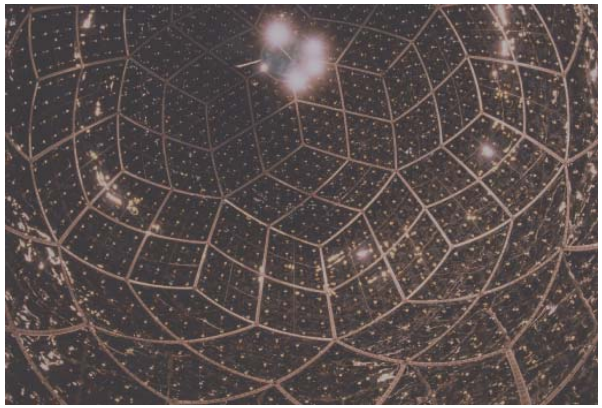
^{68}Ge/^{60}Co Energy Z-position variation



Source Z-position deviation

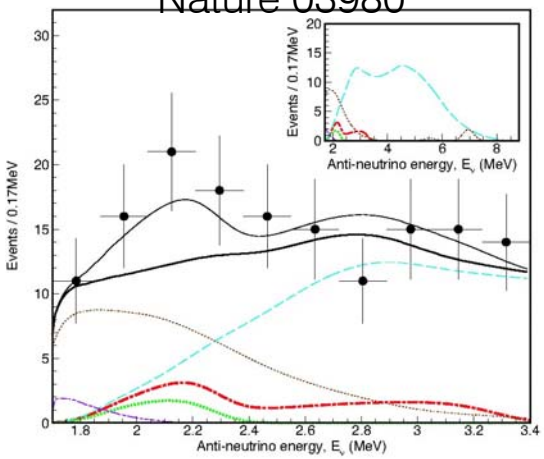


History of KamLAND

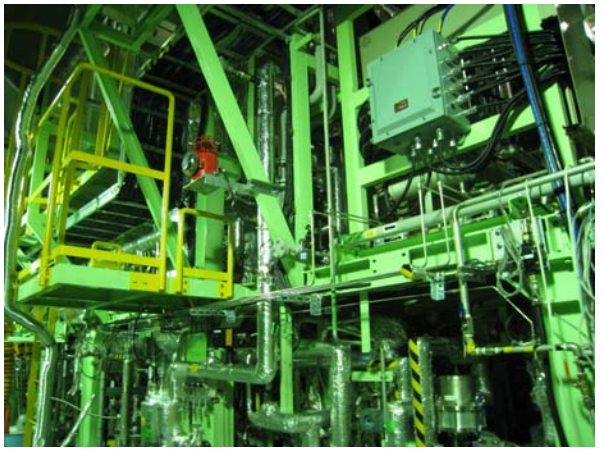


Construction

Nature 03980



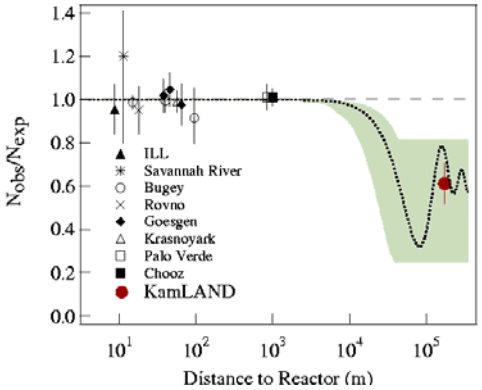
Geo-Neutrino



Distillation

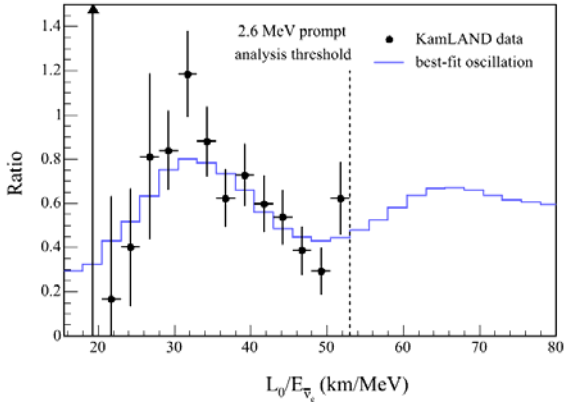
2000 2002 2005 2008

Disappearance



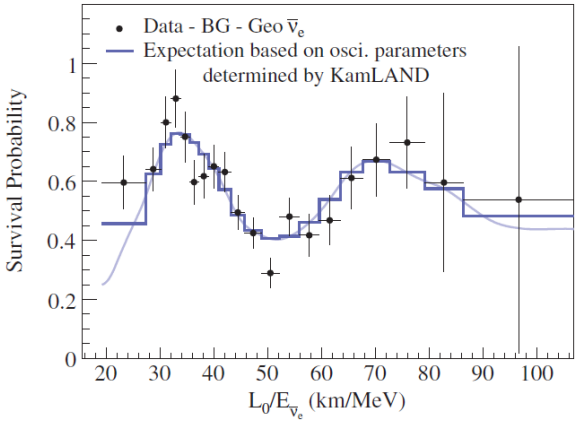
PRL90 021802

Spectral Distortion



PRL94 081801

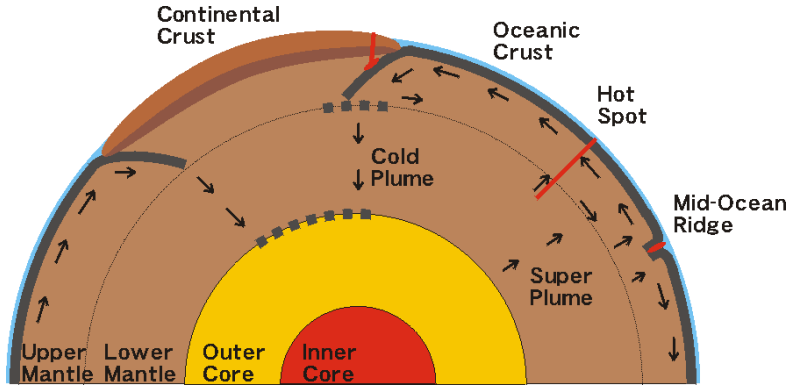
Precise Measurement



PRL100 221803

Geo-neutrino Observation in KamLAND

Geo-Neutrino



Energy Budget of the Earth,
Heat flow measurement : 44 TW
Heat generation:
radiogenic ~ 20 TW
other sources (cooling of core, solidification of outer core…)

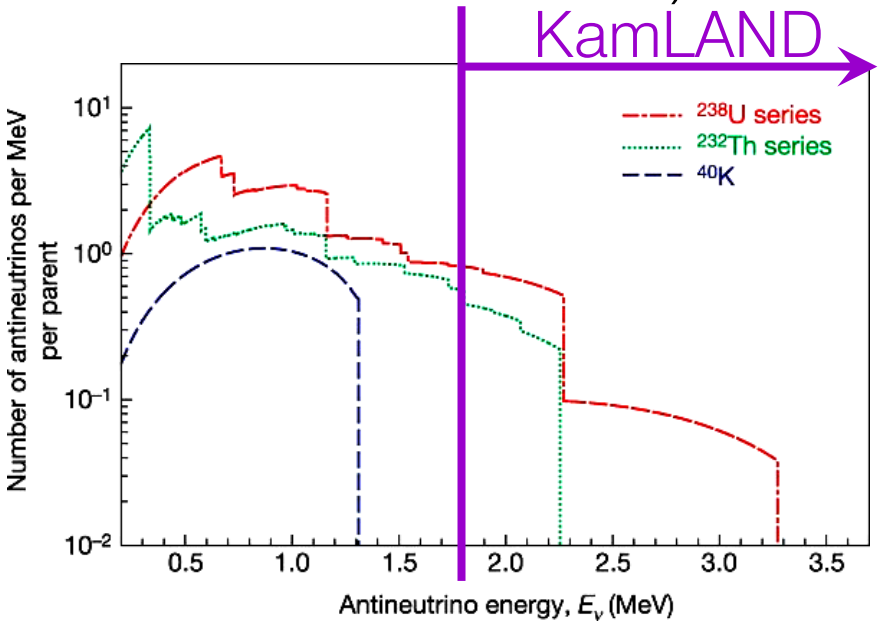
$$^{238}\mathrm{U} \rightarrow ^{206}\mathrm{Pb} + 8\alpha + 6\mathrm{e}^- + 6\bar{\nu}_\mathrm{e} + 51.7\,\mathrm{MeV}$$

$$^{232}\mathrm{Th} \rightarrow ^{208}\mathrm{Pb} + 6\alpha + 4\mathrm{e}^- + 4\bar{\nu}_\mathrm{e} + 42.7\,\mathrm{MeV}$$

$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} + 1.311\,\mathrm{MeV}\ (89.28\%)$$

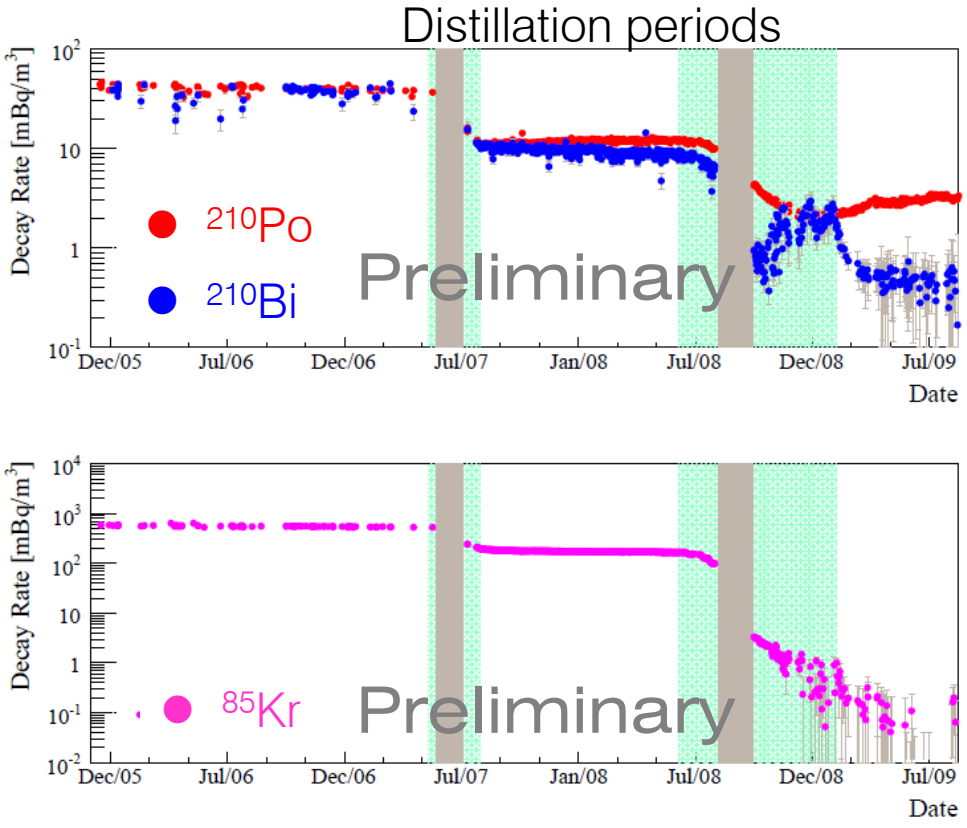
$$^{40}\mathrm{K} + \mathrm{e}^- \rightarrow ^{40}\mathrm{Ar} + \nu_\mathrm{e} + 1.505\,\mathrm{MeV}\ (10.72\%)$$

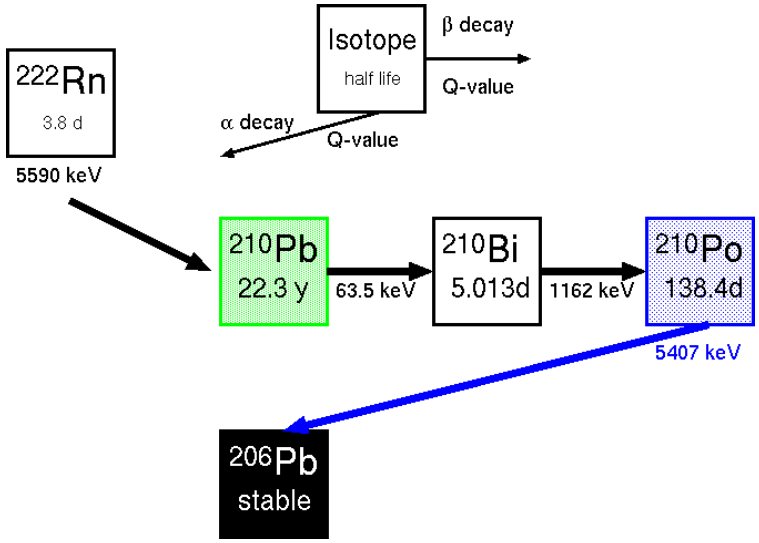
Radiogenic heat source :
U(8TW), Th(8TW), and K(4TW).
[Bulk Silicate Earth (BSE) model]



Direct exploration of the Earth's interior using neutrinos

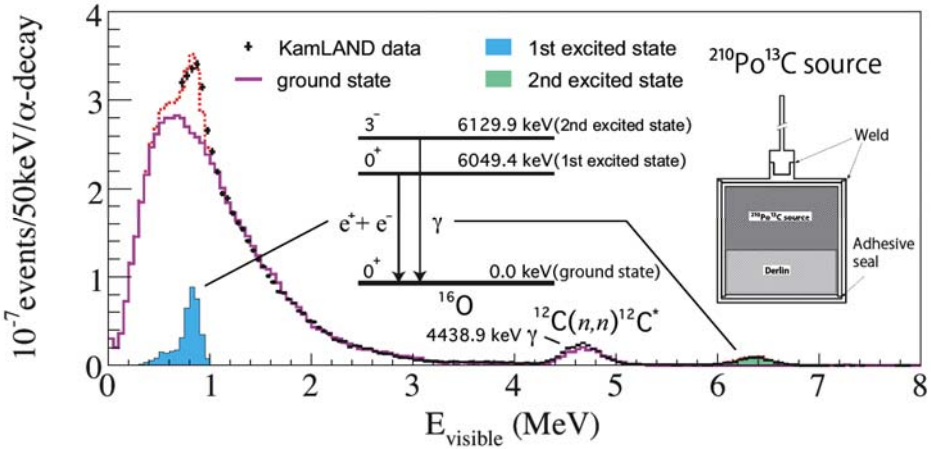
Upgrade from Nature paper



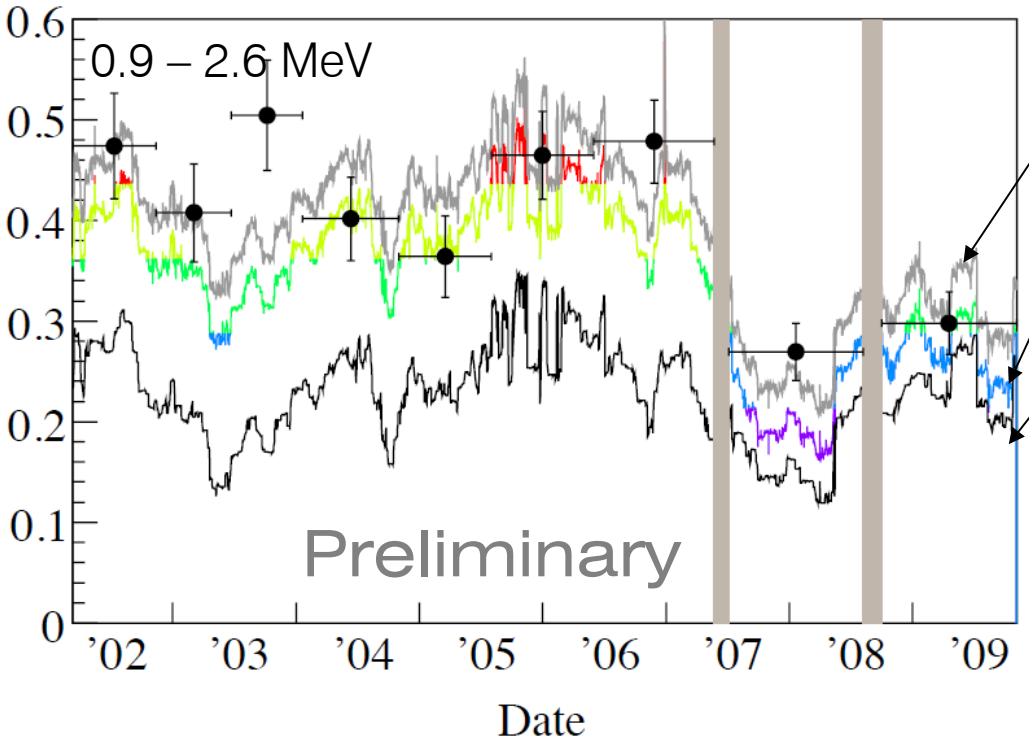


LS purification by 2 times distillation removed radioactive impurities, main α source of ^{210}Po. ^{13}C(α,n)^{16}O background has been reduced.

^{210}Po^{13}C source calibration



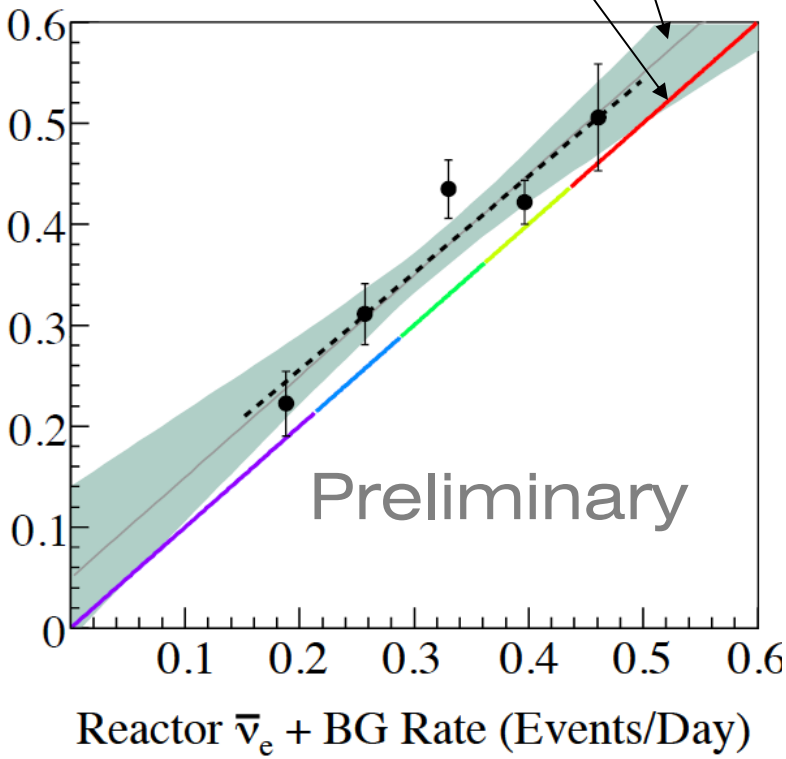
Reactors and Backgrounds



Reactor + non ν BG + geo ν model

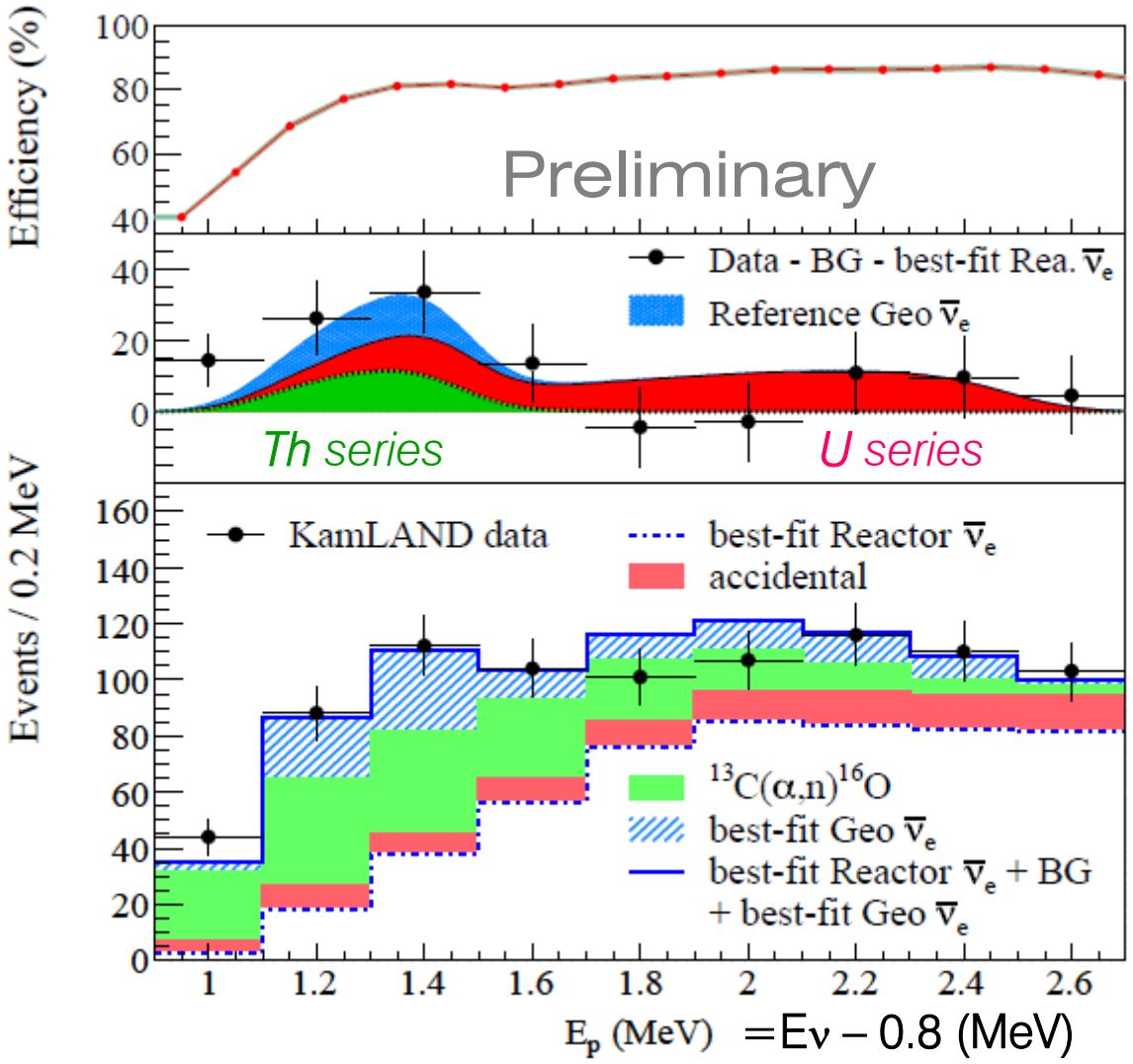
Reactor + non ν BG

Reactor expected



Time information is effective to improve geo-neutrino discrimination.

Observed Geo-neutrino



Analysis period
9/Mar. 2002 – 4/Nov. 2009
3.49×10^{32} target-proton-years

Observed events: 841

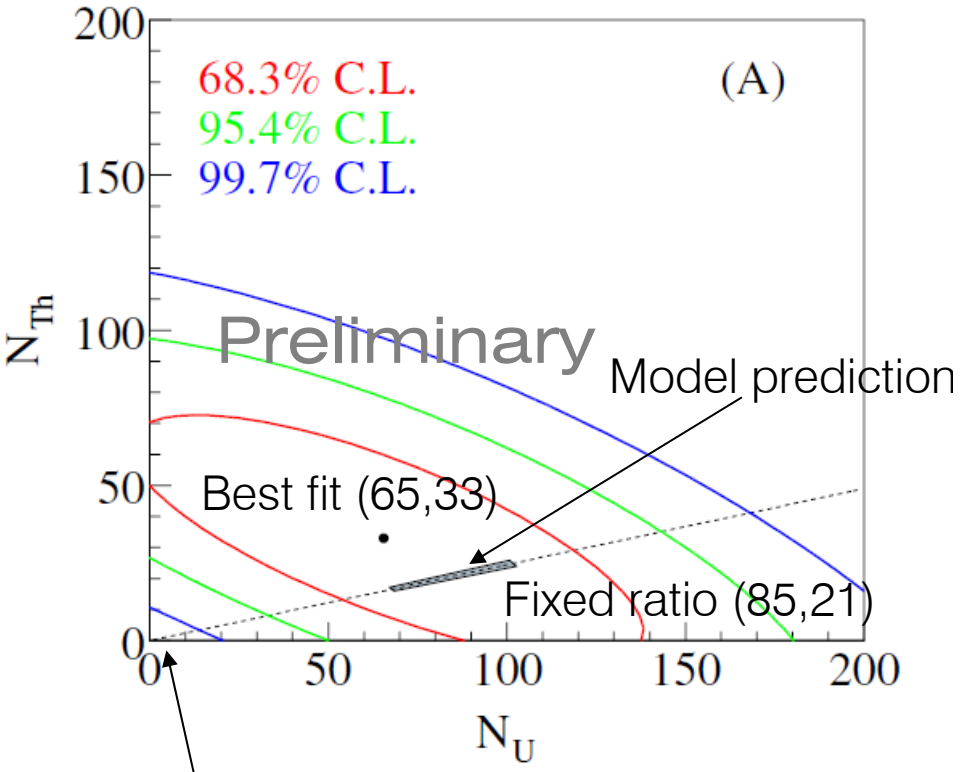
Backgrounds: 729.4 ± 32.3

reactor neutrino	484.7 ± 26.5
$^{13}C(\alpha,n)^{16}O$	165.3 ± 18.2
accidental	77.4 ± 0.1
μ induced ^{9}Li	2.0 ± 0.1
fast n + atm.ν	<2.8

Rate-only analysis,
Geo-neutrino candidates
111^{+45}_{-43} events

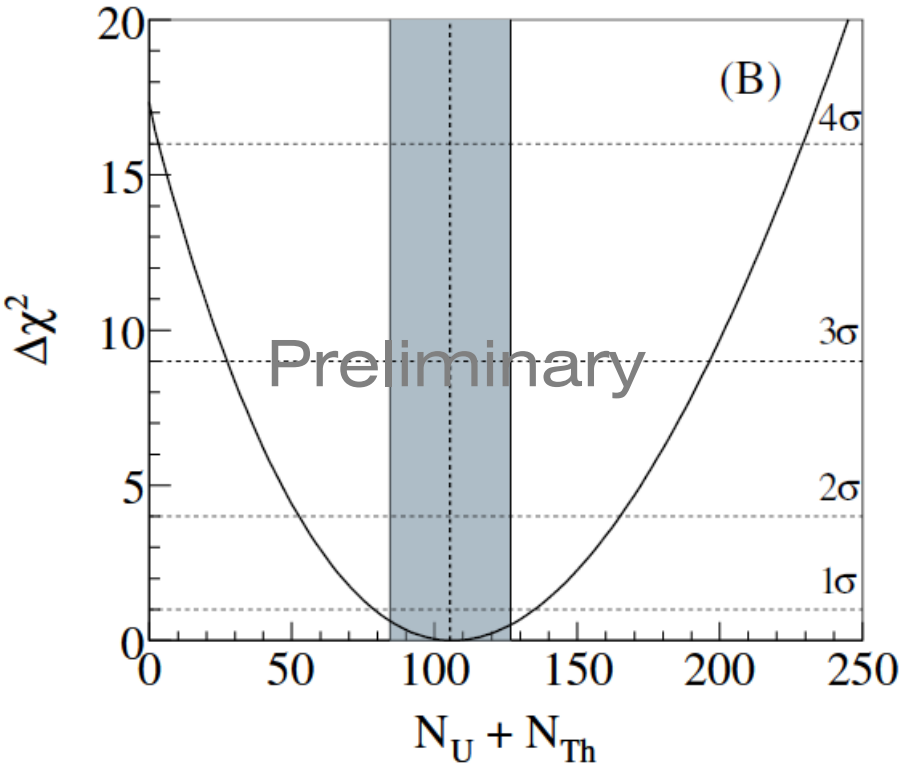
Number of U and Th Events

Rate + Shape + Time $\Delta\chi^2$



0 signal excluded 99.997% C.L.

Mass ratio fixed U/Th=3.9

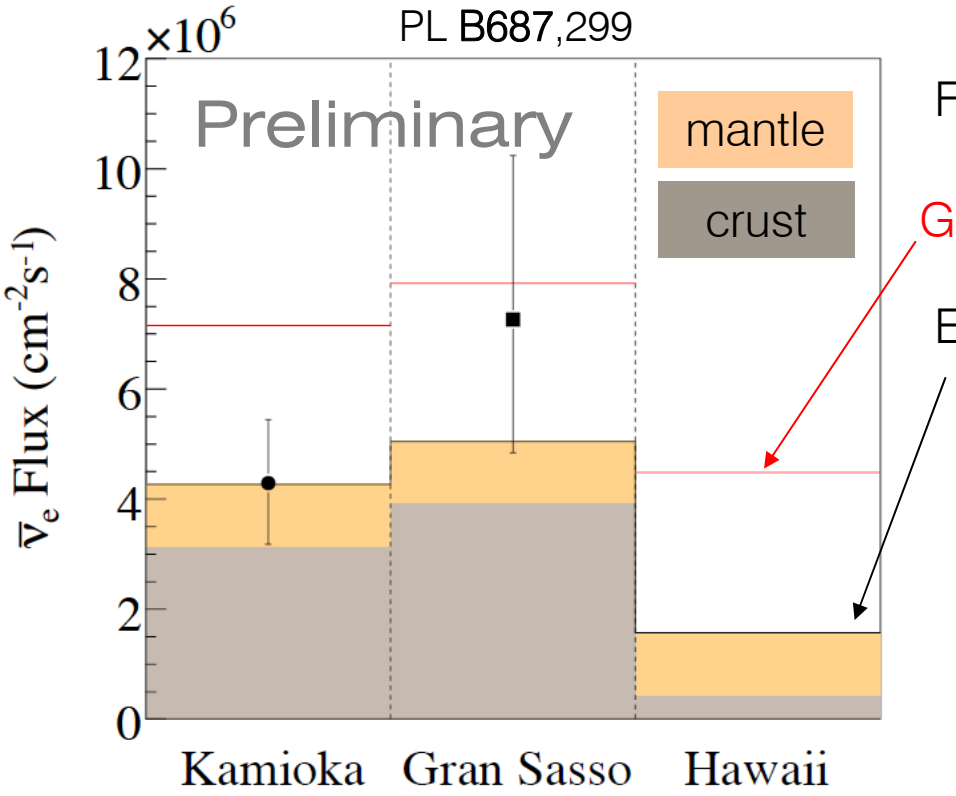


Geo-neutrino events $106\ ^{+29}_{-28}$

(Flux $4.3\ ^{+1.2}_{-1.1}$ x 10^6 /cm^2/sec)

Heat flow ~ 16 TW (U and Th)

Impact on Geology



Full radiogenic models are disfavored

Geo-neutrino flux of full radiogenic case

Earth model prediction

KamLAND observation of geo-neutrino is consistent with the Earth model prediction.

For next stage, more statistics, other sites observation are important. Separation of geo-neutrino source (upper, lower mantle or crust) starts new era of geology. Directional measurement is useful.

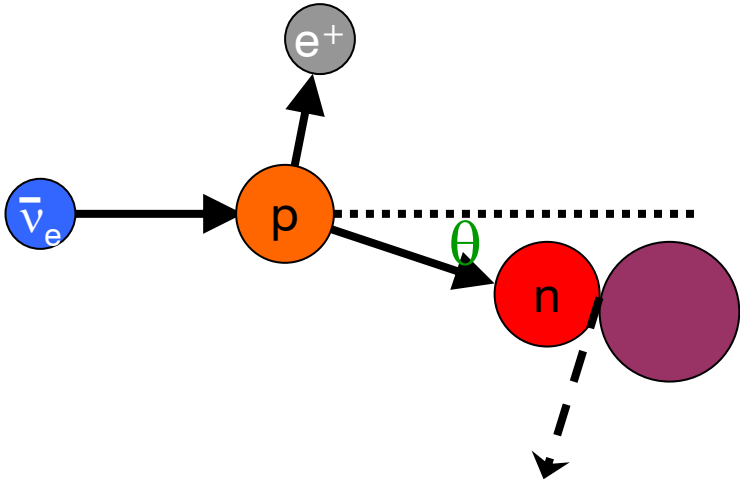
Directional Measurement of Anti-neutrino Detection

How to

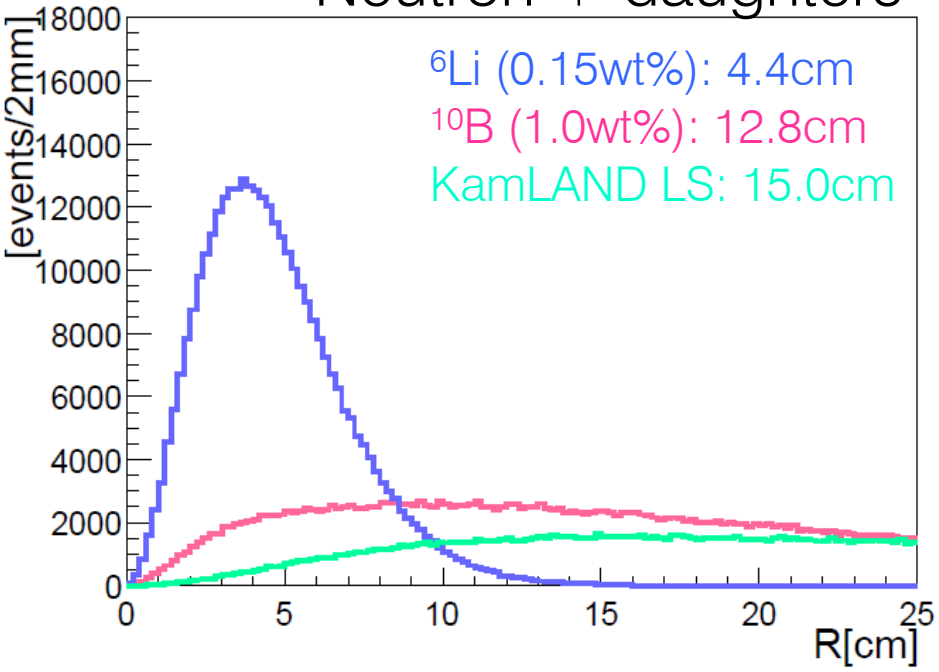
- Liquid scintillator upgrade.
  Neutron generated by inverse beta decay process has directional information of initial anti-neutrino. Capture it before diffusion.
  ➡ ^{6}Li loaded liquid scintillator
- Vertex resolution of the detector.
  Imaging detector can detect a signal with high resolution ($<$ 1cm).
  ➡ Imaging Intensifier and CCD

Advantage of ^{6}Li

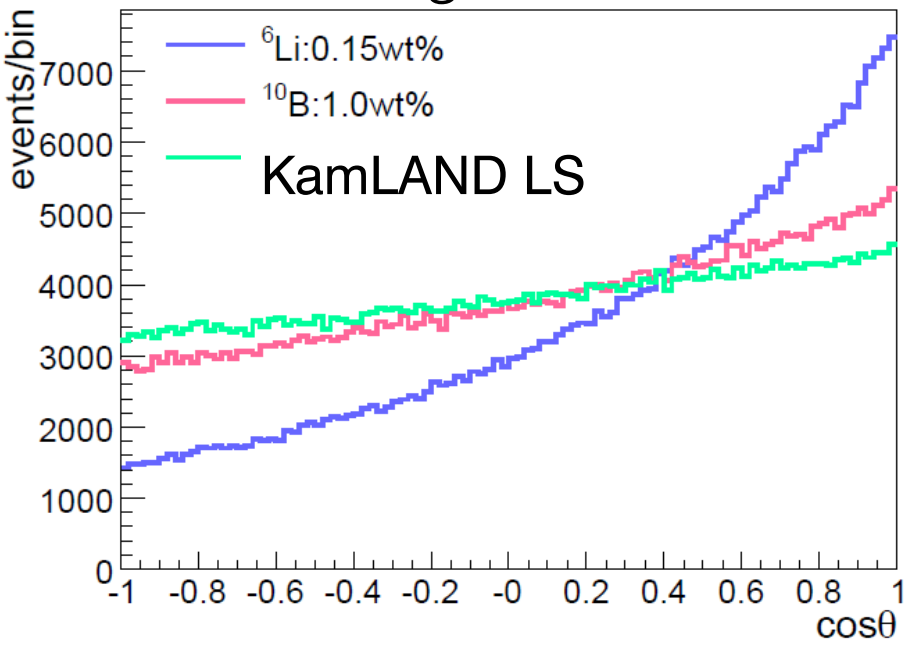
- ^{6}Li (940 barn) c.f. ^{1}H(0.3 barn)
  $n + {}^{6}Li \rightarrow \alpha + {}^{3}H$ (Q=4.8 MeV)
- ^{10}B(3835 barn)
  $n + {}^{10}B \rightarrow {}^{7}Li^{*} + \alpha$ (94%)
  $\hookrightarrow {}^{7}Li + \gamma$ (0.48 MeV)
  $n + {}^{10}B \rightarrow {}^{7}Li + \alpha$ (6%,Q=2.8 MeV)



Neutron + daughters



Angular distribution



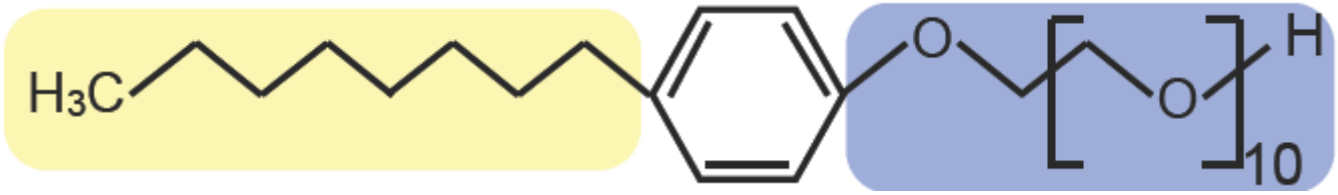
Dissolve Li in LS

Li compound is insolvable in oil, solvable in water.

1. mix Pseudecumen + PPO + surfactant
2. mix Li compounds + pure water
3. mix 1 + 2

Surfactant : clear, colorless liquid at room temperature

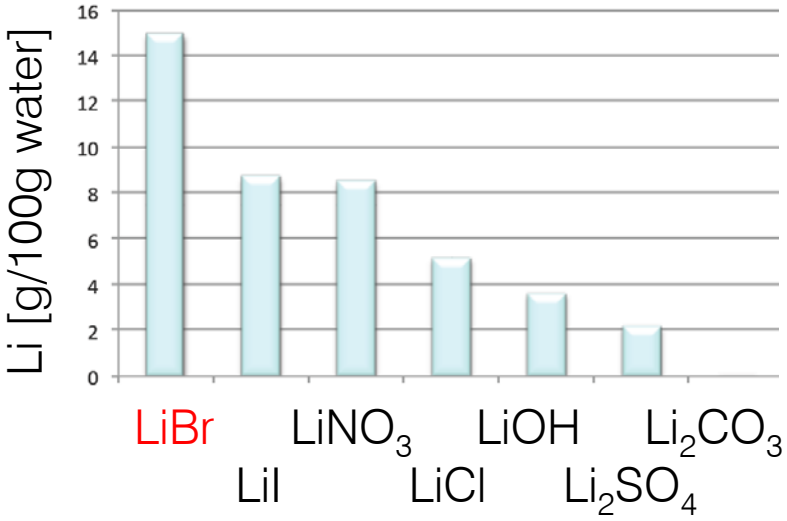
Polyoxyethylen(10)Nonylephenyl Ether (POE)



Li compound: LiBr

186.8 [g/100g water]

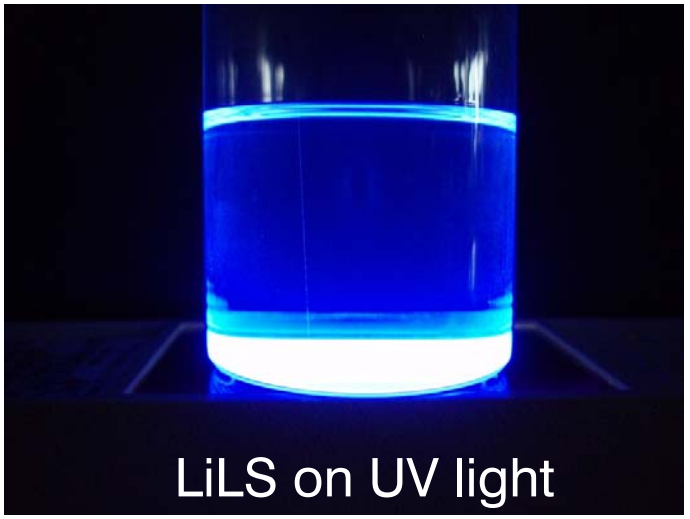
Thermal neutron capture cross section of Br is small. (6.9 barn)



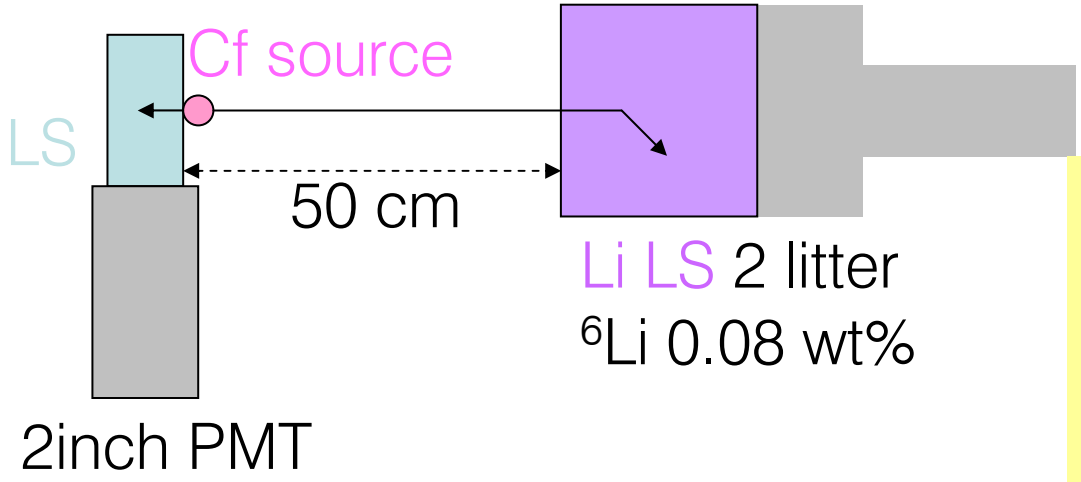
Li Loaded LS

	Mixture ratio [%]		^{nat}Li[wt %] ^{6}Li[wt %]	Tranceparency @400nm [cm]	light yield KamLAND[%]
	PC	POE			
Target			2.0 0.15	＞70	＞100
Natural	50	50	1.04 0.078	64.6	46.1±0.4
Enrich	80	20	- 0.15	135	122±0.8

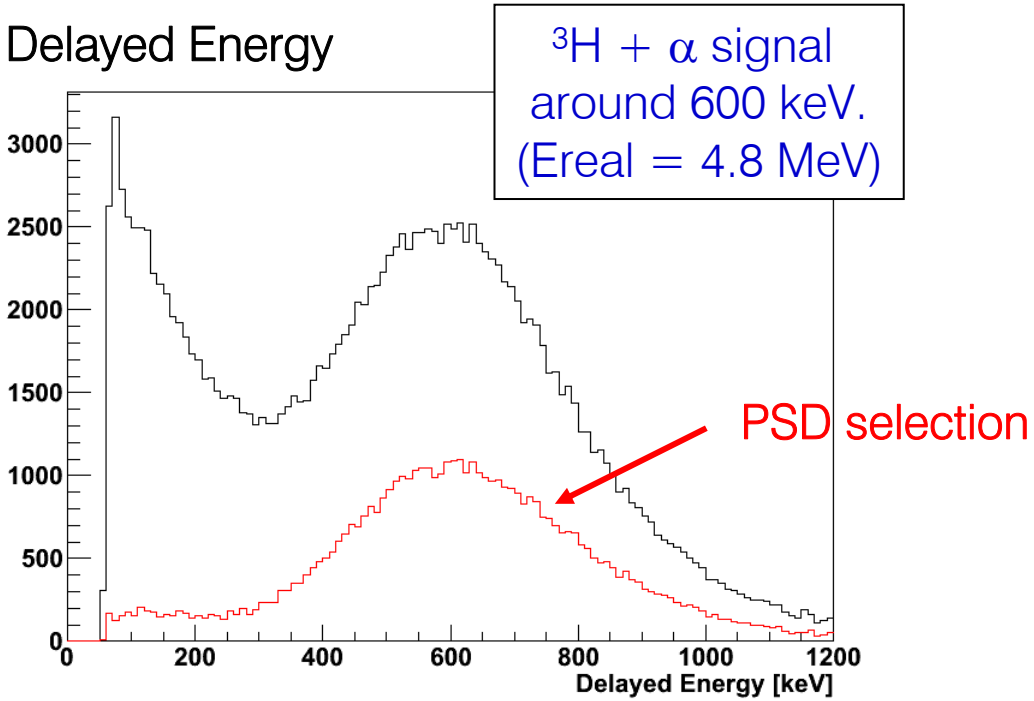
From accelerated test, we confirm more than 2 years stability in enriched case components,
＜ 4months for natural case components.

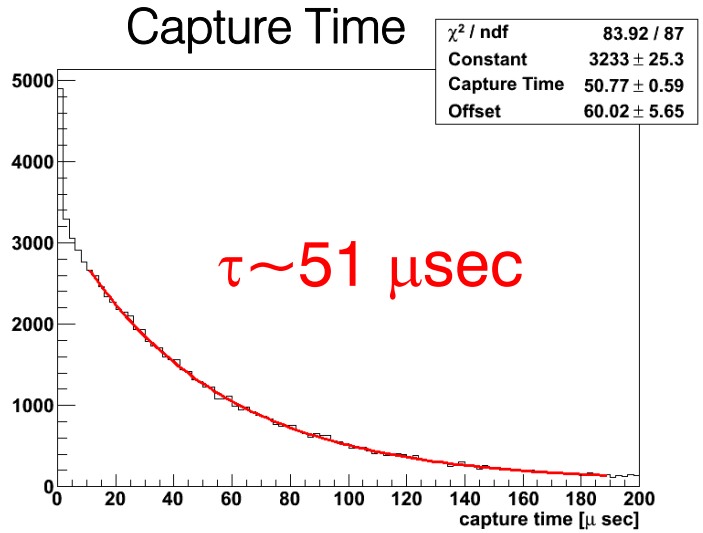


Neutron Capture of Cf Source



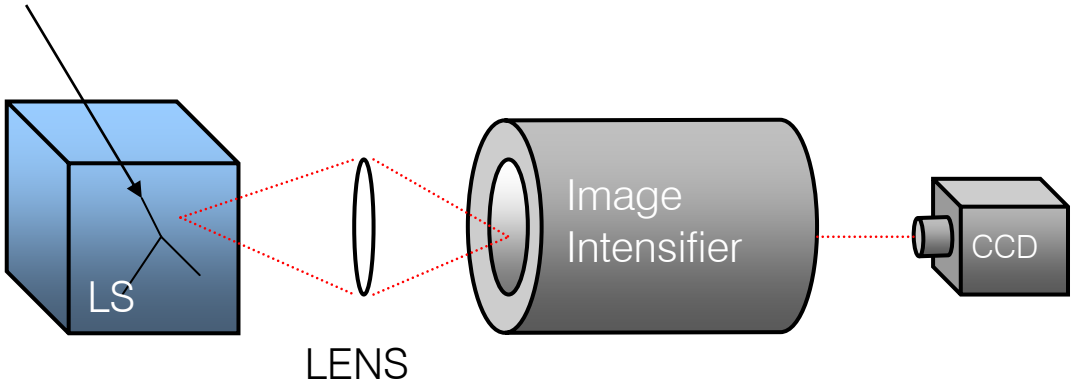
Detection method
1. Fission γ using normal LS
2. γ or proton from neutron recoil in Li LS (prompt signal)
3. ^{6}Li capture signal in Li LS. (delayed signal)





Imaging System

- Get event position with high resolution from images.
- Detection of weak scintillation light needs amplifier system and proper optics.
  Use Image Intensifier (I.I.) and CCD camera.
- Optics has incompatible parameters of Depth Of Field (DOF) and light collection power.



Cosmic ray muon

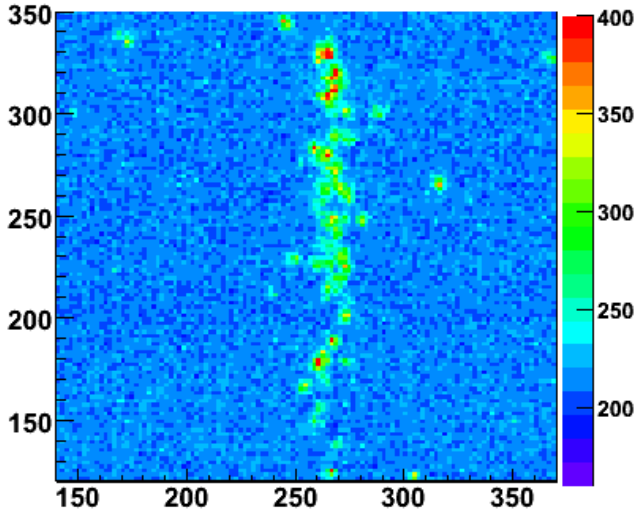


Image Intensifier

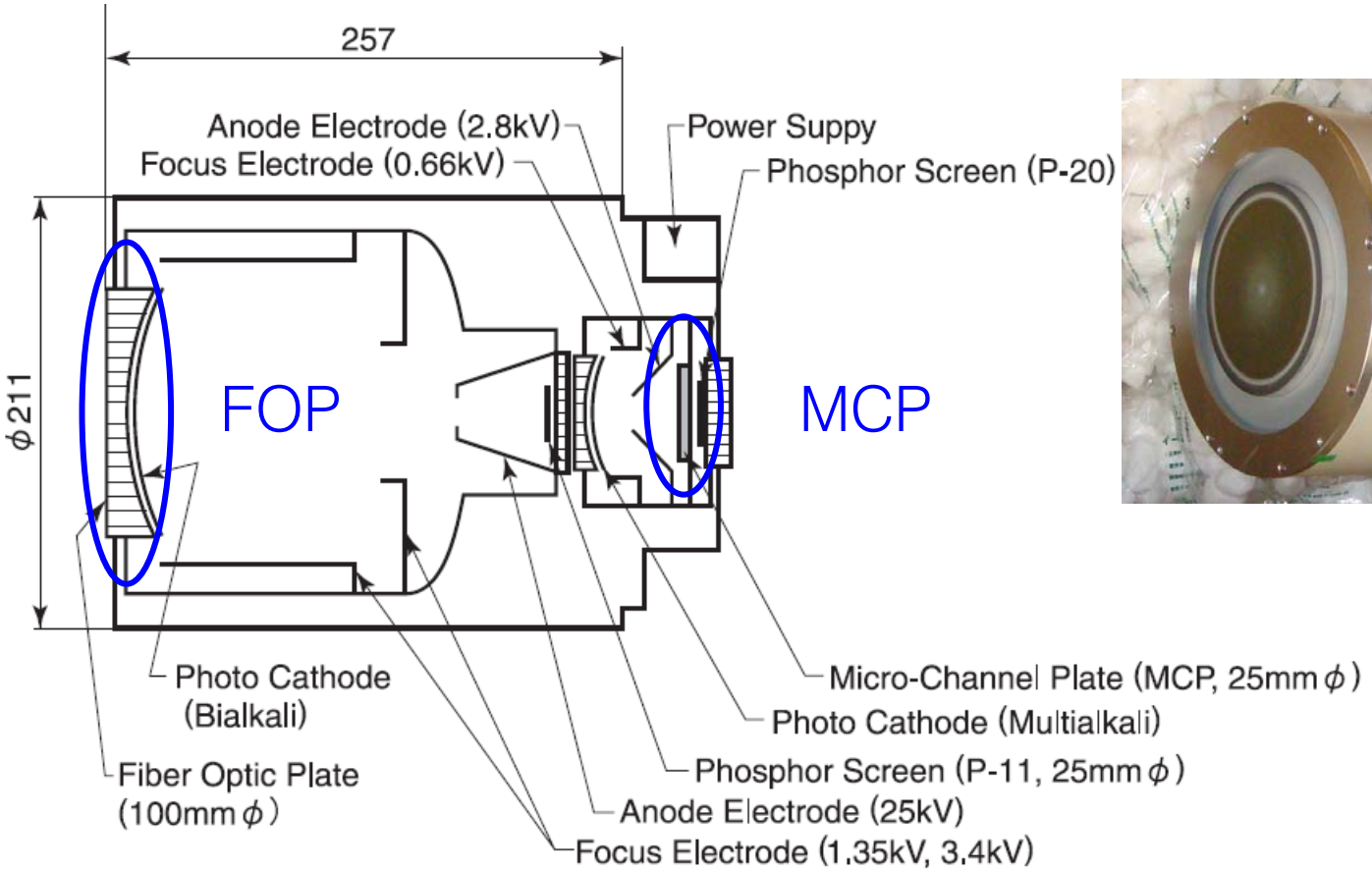


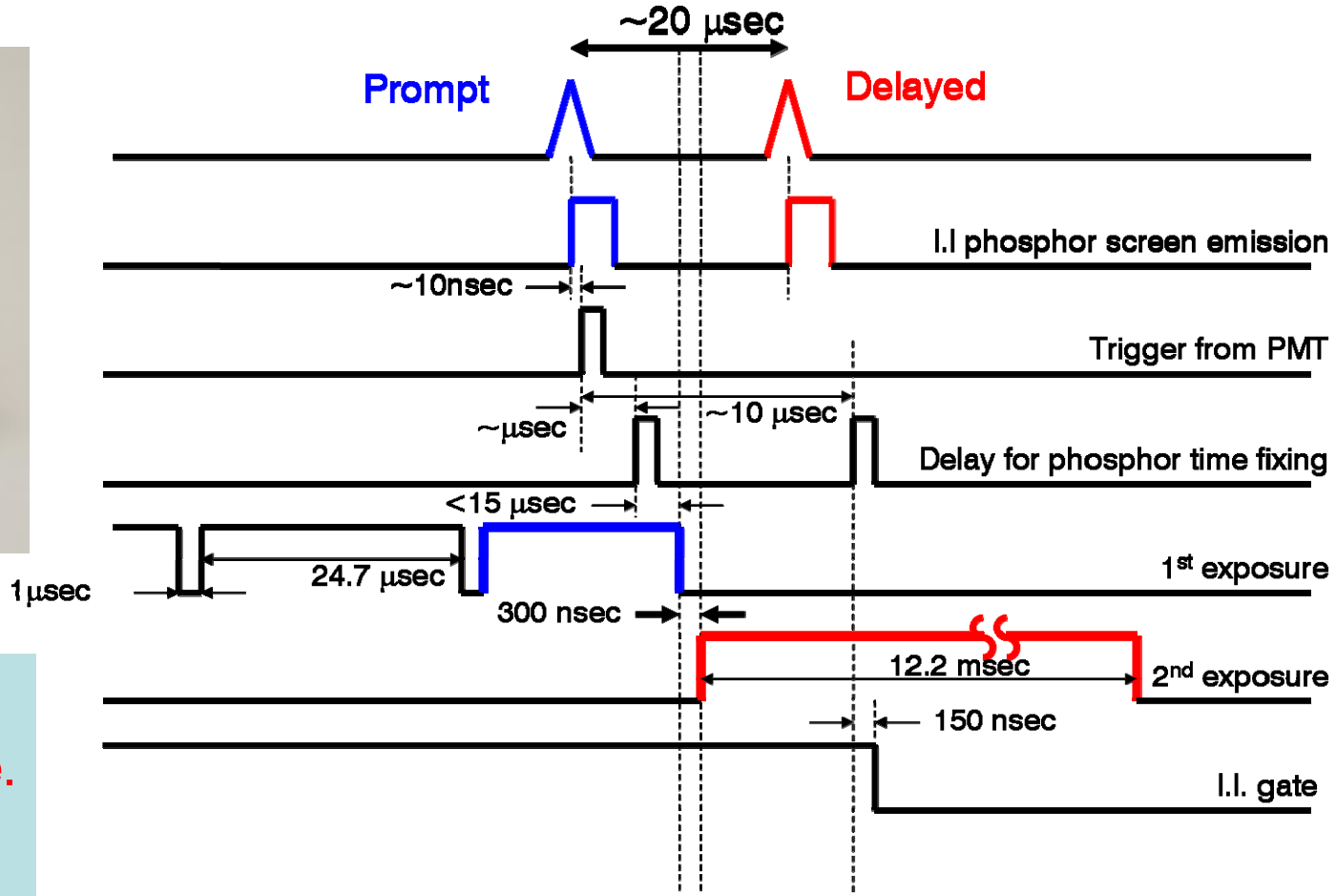
Photo cathode is bialkali (Q.E. 22% @ 420nm)

FOP transparency is 40% @ 420nm

MCP gain $10^3 \sim 10^5$

Camera and Data Taking

CCD camera



Special Order Item

2 images recordable.

flushing time

< 1μsec

exposure time

> 33μsec

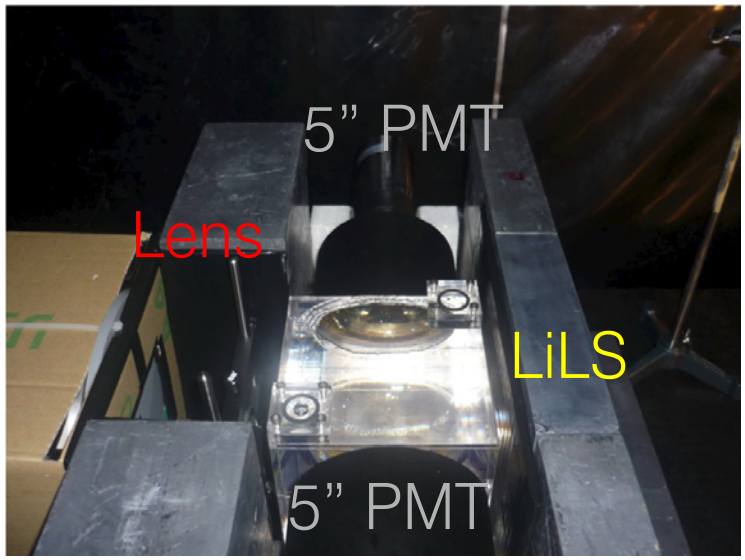
pixel 640(W)x480(H)

CCD needs trigger signal to release the shutter,

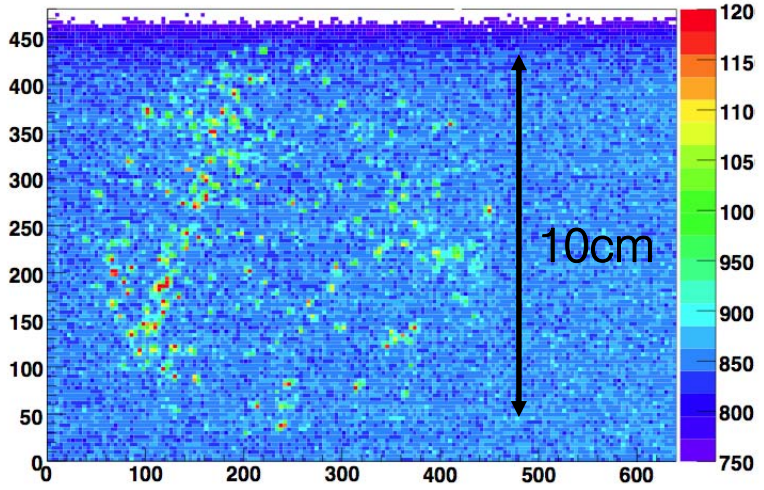
Use PMT signal

Image from LiLS

I.I. + CCD
(inside box)



Cosmic ray muon



Catch comic ray muon images successfully.
But can not find clear image of neutron capture signal.
(5” PMT has a clear peak of neutron capture signal.)

We will prepare new I.I. and take images.

Summary

- KamLAND observed geo-neutrino with lower systematic uncertainty.
- Geo neutrino measurement at other sites and directional detector will help to understand inside the Earth.
- ^{6}Li liquid scintillator and Imaging detector has a power to measure anti-neutrino direction.