KamLAND: Examination of the LMA Solution with Reactor Neutrinos

KamLAND Collaboration

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First Event

KamLAND Experiment

1,000 ton liquid scintillator neutrino detector located at the former site of Kamiokande

1st phase experiment

(E_{th} = 1.8 MeV)

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

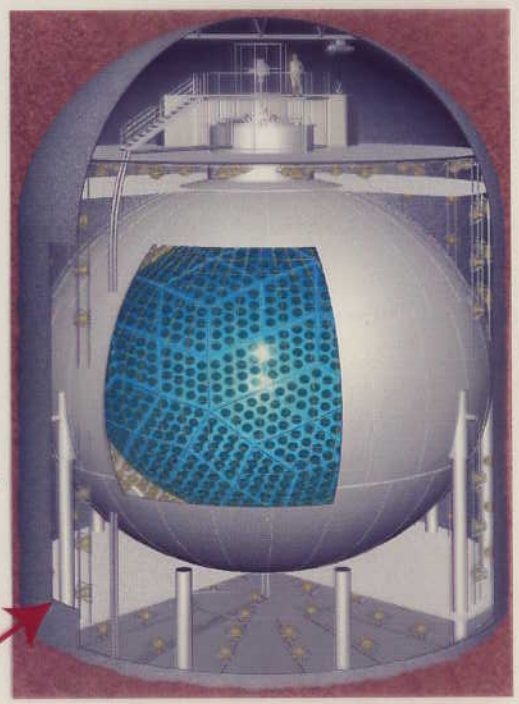
- Neutrino Oscillation Search by Reactor Anti-neutrinos

175 km

$\bar{\nu}_e$

- Terrestrial Anti-neutrino Detection

$\bar{\nu}_e$



2nd phase experiment

(E_{th} = 200 keV)

$\nu_e + e^- \rightarrow \nu_e + e^-$

- Solar neutrino Detection

^{7}Be Neutrino

ν_e

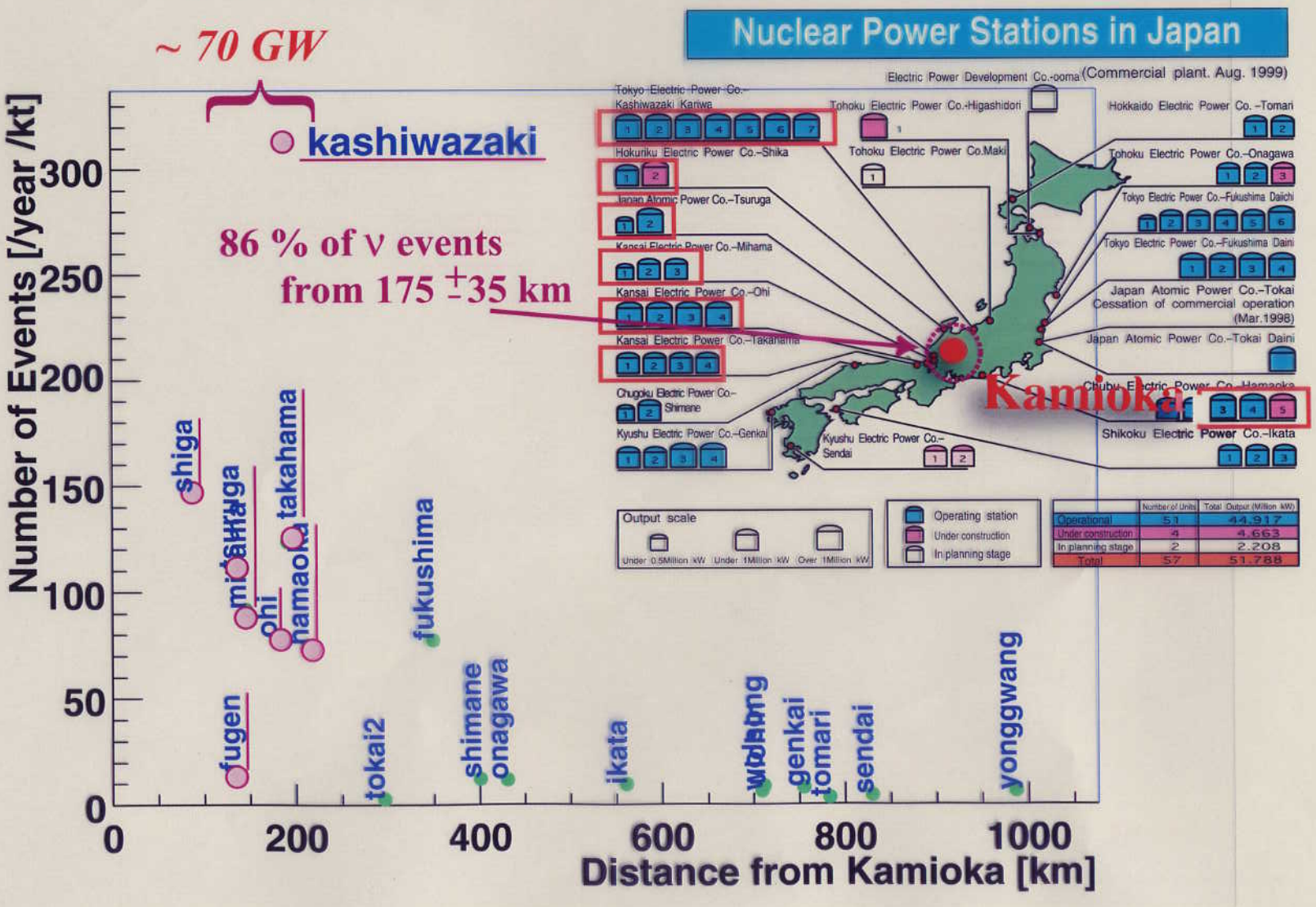
supernova-burst ν, relic supernova ν, atmospheric ν, Proton Decays, · · ·

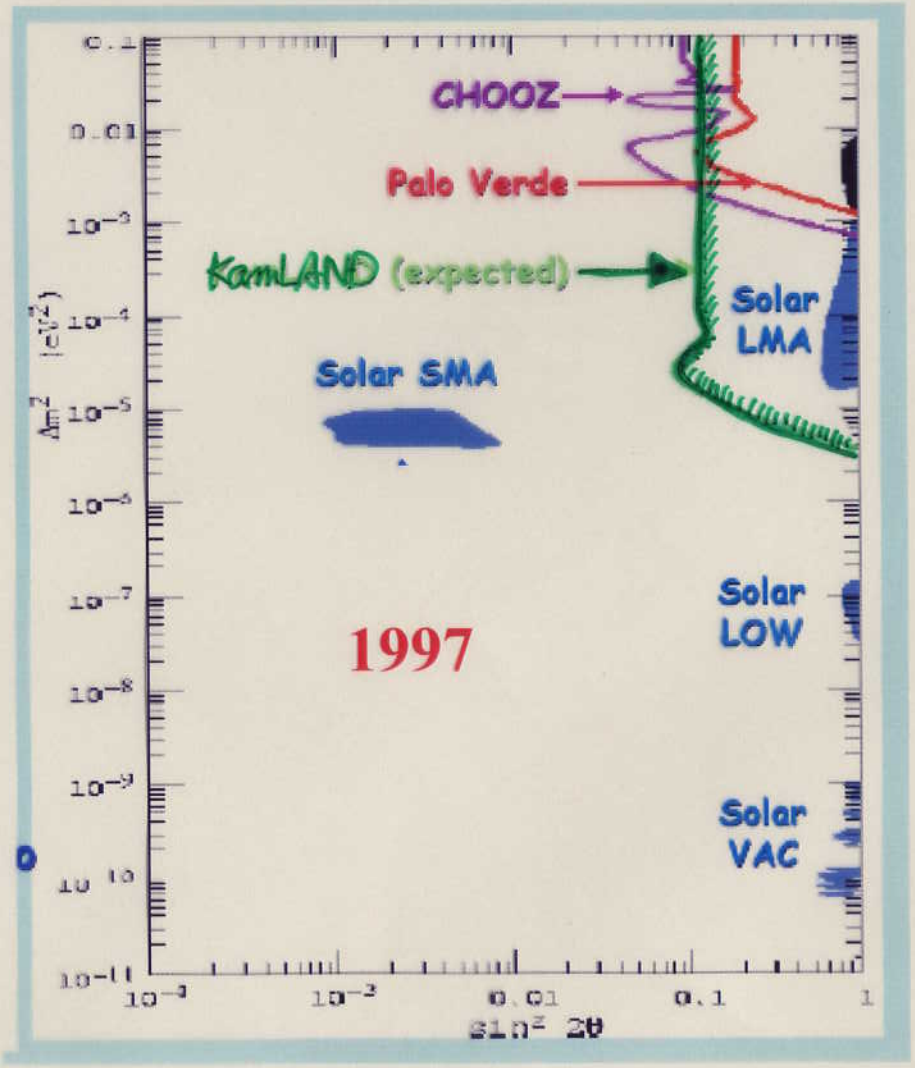
Reactor Neutrinos

Power Plant Reactors and Event Rate

20 % of world nuclear power

~ 70 GW




CHOOZ
Palo Verde
KamLAND (expected)
Solar LMA
Solar SMA
Solar LOW
Solar VAC
1997
Δm^2 (eV^2)
$\sin^2 2\theta$
0.1
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-3}
10^{-2}
0.01
0.1
1

Investigate Solar Neutrino Anomaly under Laboratory Conditions

KamLAND :

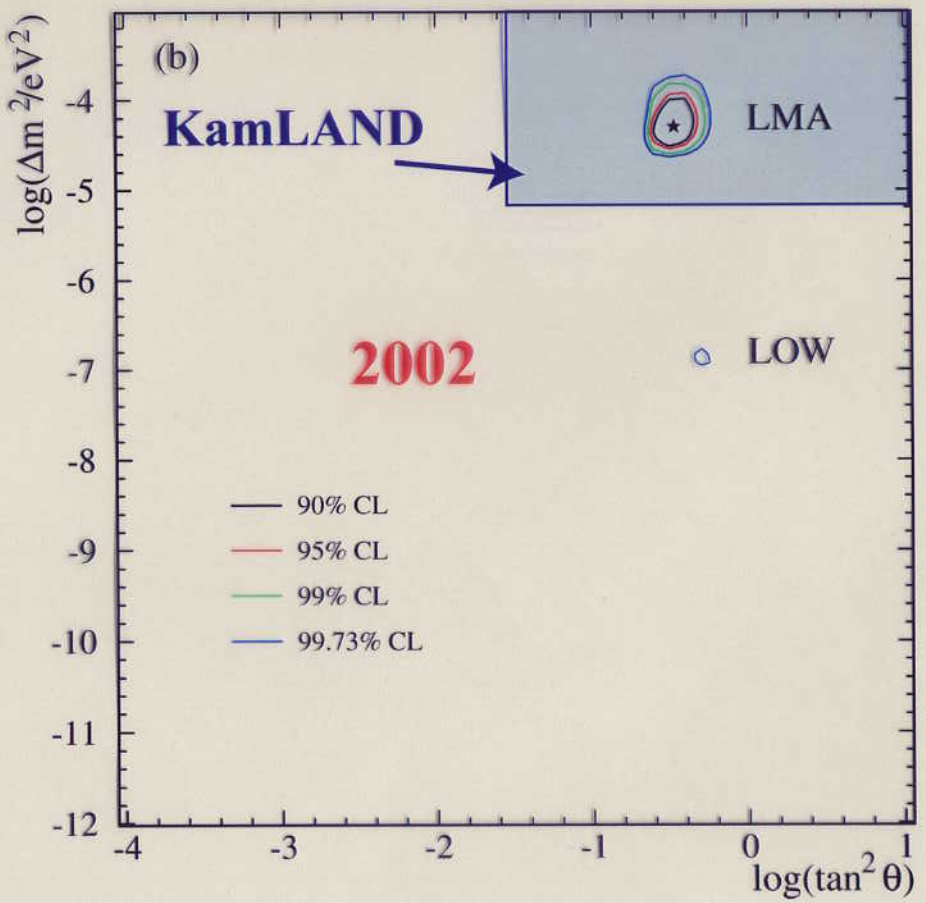
thermal power ~ 70 GW

<E> ~ 3 MeV

< baseline> ~ 180 km

$\Delta m^2 \sim 10^{-5}\ eV^2$

SNO in Phys Rev. Lett. 89, 011302 (2002).



$\bar{\nu}_e$ Production : Fission Rate

- **Main Fuel Component :**

  4 main isotopes

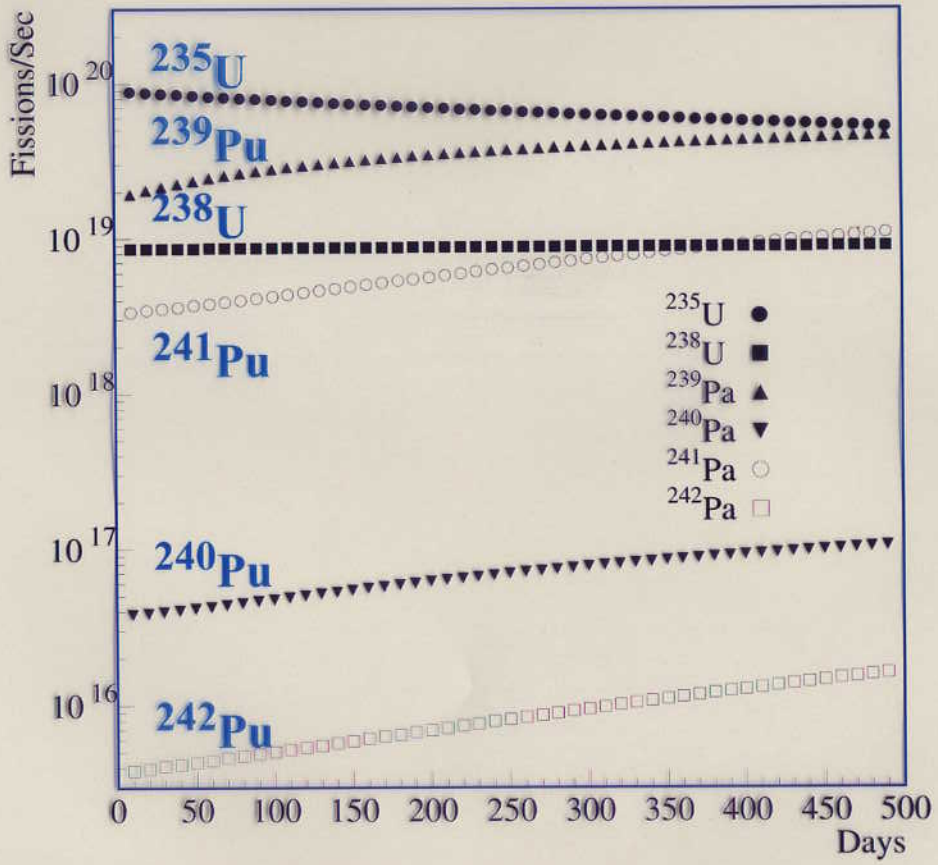
  ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu (99.9%)

  others (^{240}Pu, ^{242}Pu, ,) (< 0.1%)

- **Time evolution of fission rate :**

  Reactor thermal power

  calculation in one of the Palo Verde reactor core

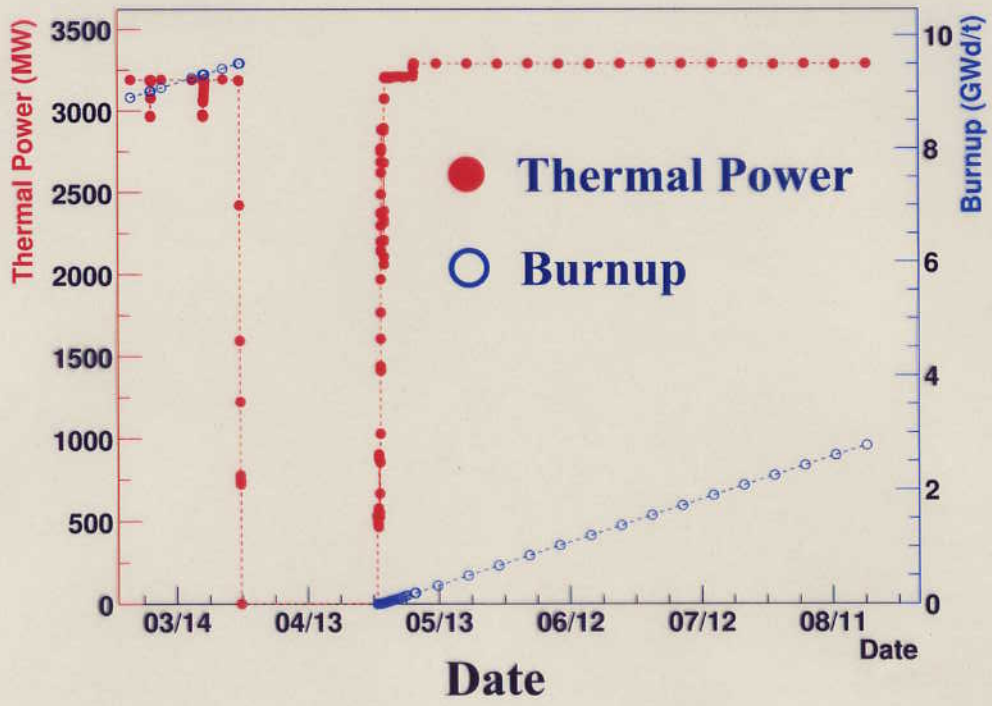


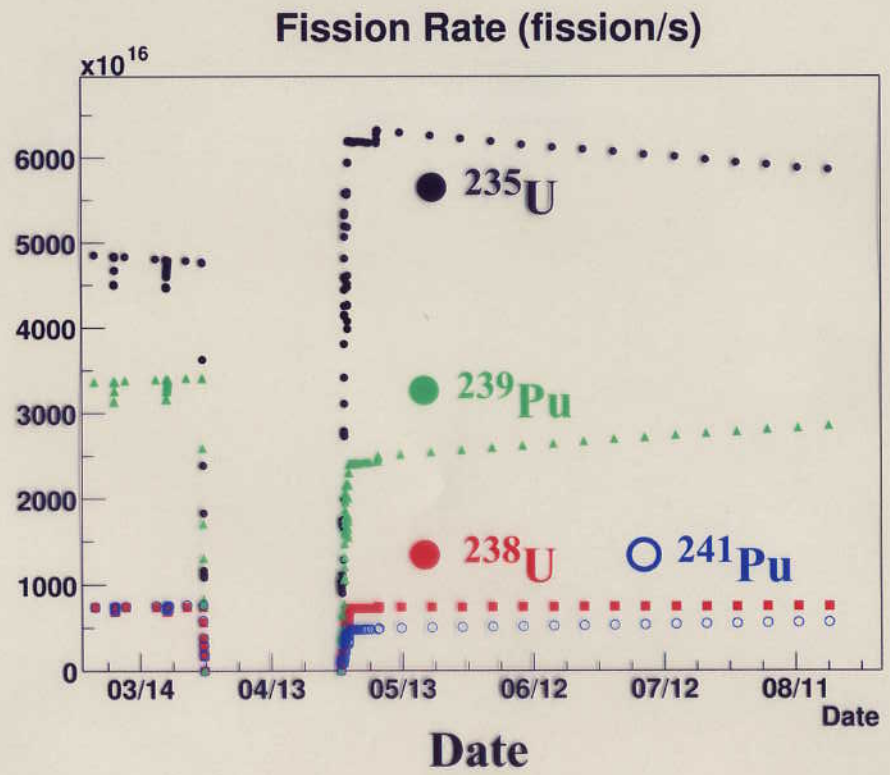
Uncertainty < 1% (neutrino yield)
: fuel-sampling & analyzing for isotopic components

→ **No need for near detector**

Example of Fission Rate Calculation

One of Japanese Reactors





Reactor $\bar{\nu}_e$ Energy Spectrum

- $\bar{\nu}_e$ associated with ^{235}U, ^{239}Pu and ^{241}Pu

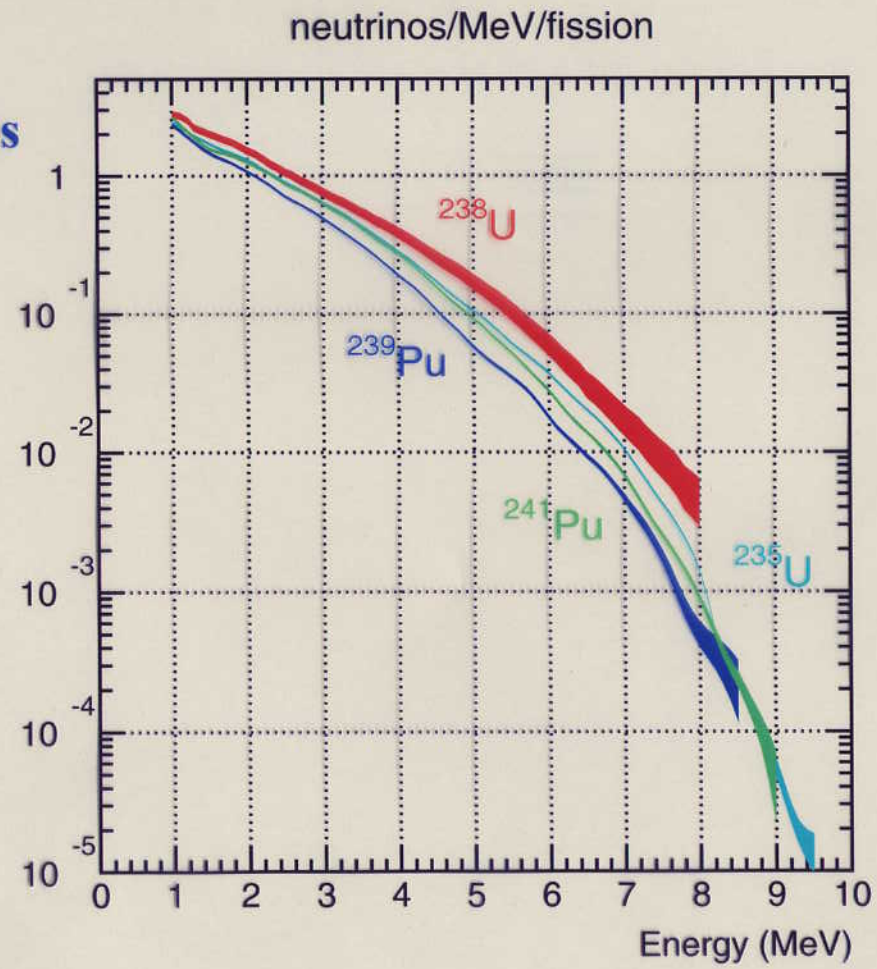
  measured β – spectra
  from thermal neutron fissions

  superposition of 30 hypothetical
  β-decay branches

  conversion $E_e \longrightarrow E_\nu$

- $\bar{\nu}_e$ associated with ^{238}U

  calculation based on
  744 unstable fission products

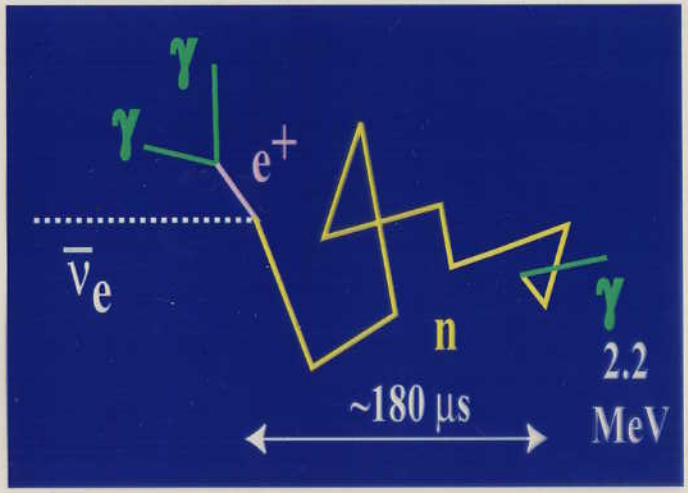


Reactor $\bar{\nu}_e$ Detection in Liquid Scintillator

reaction process : inverse- β decay ($\bar{\nu}_e + p \longrightarrow e^+ + n$)

$+ p \longrightarrow d + \gamma$

distinctive two-step signature



$$E_{th} = \frac{(M_n + m_e)^2 - M_p^2}{2M_p} = 1.806\ MeV$$

- **prompt part :** e^+

  $\bar{\nu}_e$ energy measurement

  $$E_\nu \sim (E_e + \Delta)[1 + \frac{E_e}{M_p}] + \frac{\Delta^2 - m_e^2}{M_p}$$

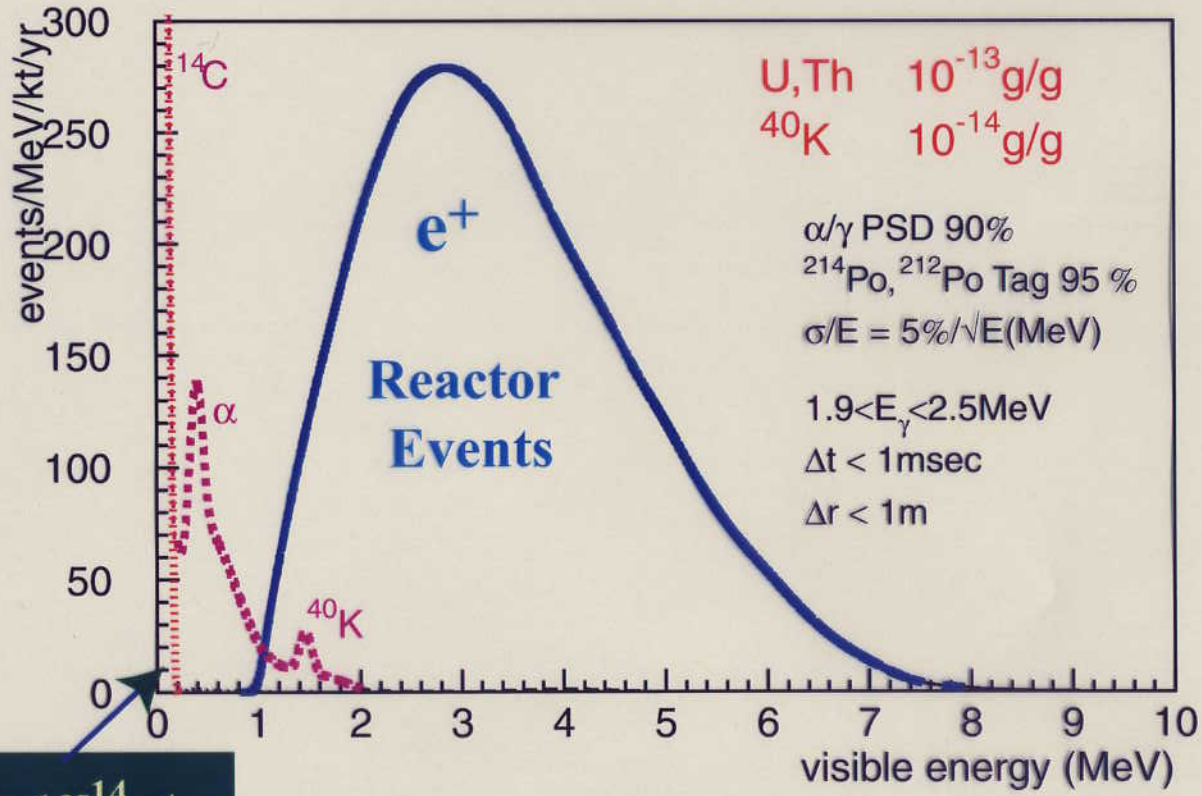
  $$\Delta = M_n - M_p$$

- **delayed part :** γ **(2.2 MeV)**

- **tagging : correlation of time, position and energy between prompt and delayed signal**

KamLAND e^+ Visible Energy Spectrum

$$\bar{\nu}_e + p \longrightarrow e^+ + n$$
$$n \longrightarrow + p \longrightarrow d + \gamma$$



U, Th : 10^{-14} g/g
^{40}K : 10^{-15} g/g

Need radioactively ultra pure detector

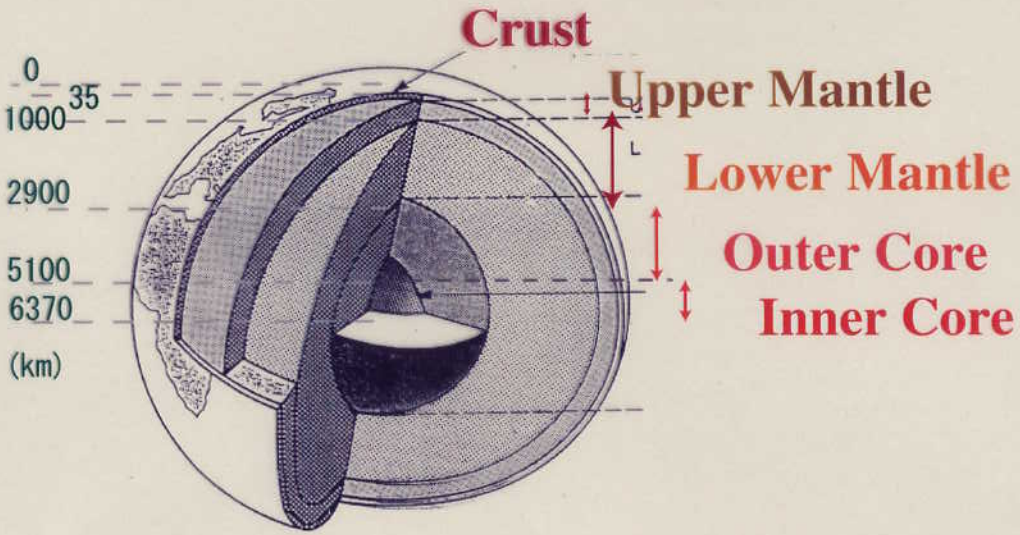
GEONEUTRINOS

:

Earth is Antineutrino Star

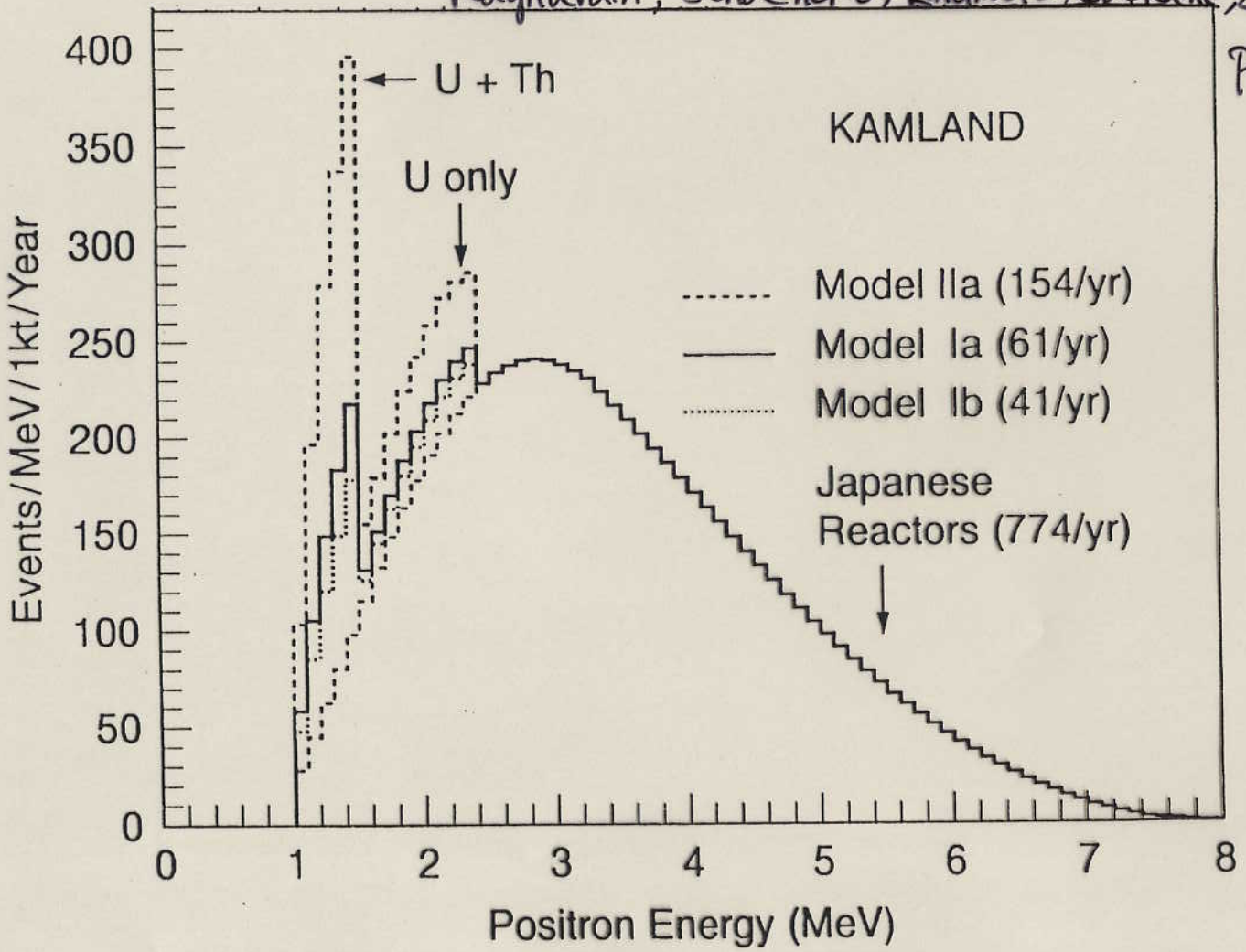
◎ Radiogenic Heat (40 - 60% of 40 TW) from U / Th (Crust, Mantle) Decays

◎ Basic Factor in Interior Dynamics and History of the Present Earth



Raghavan, Schoenert, Enomoto, Suekane, Shirai, A.S

PRL 80 (1998)



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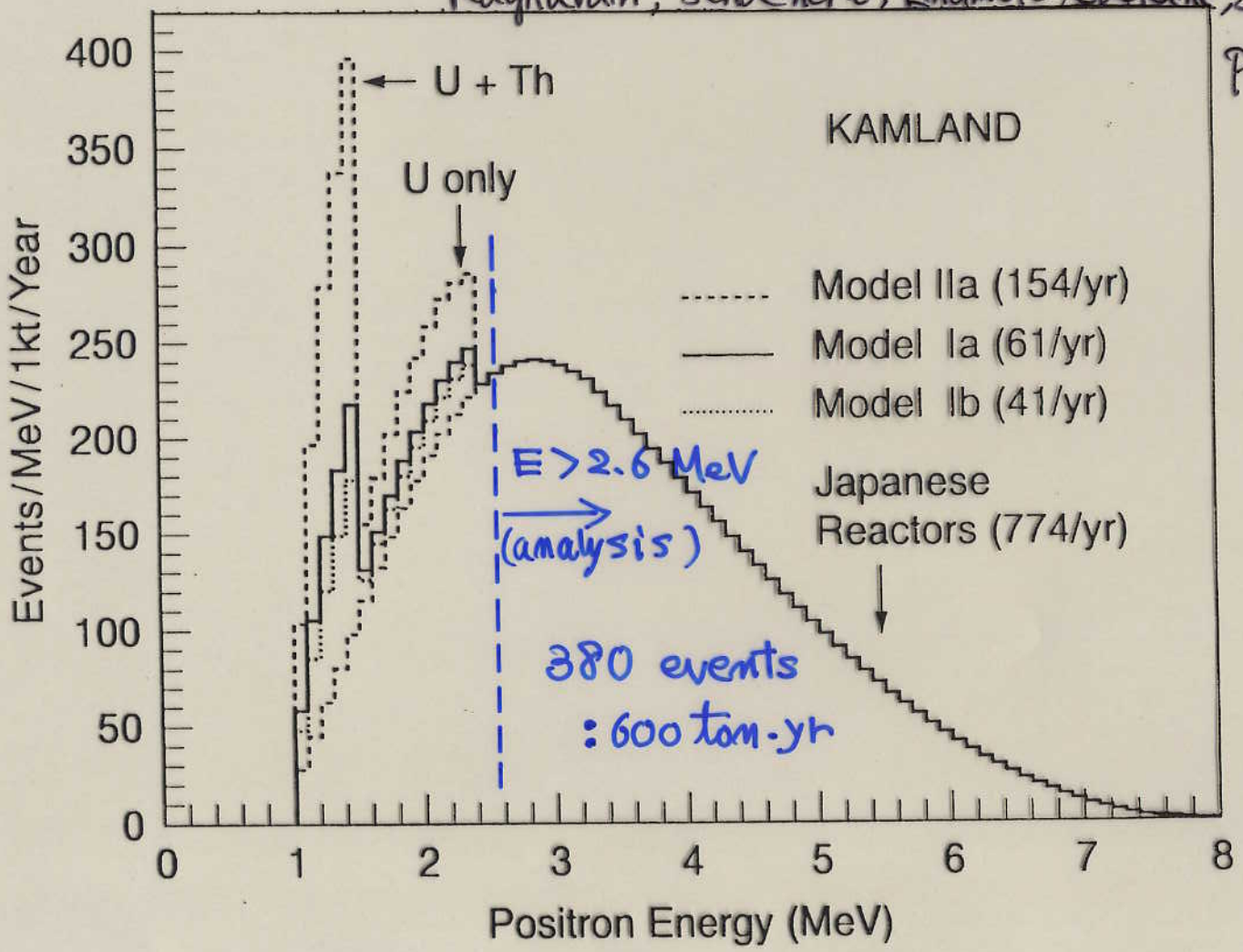
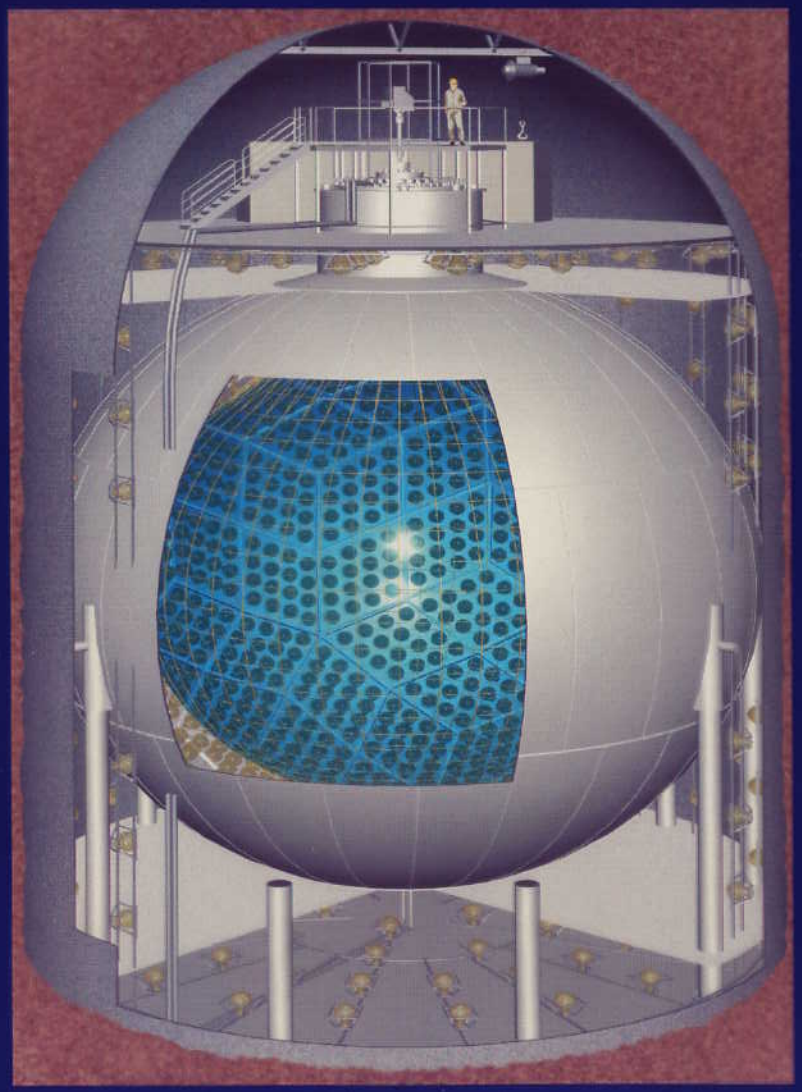
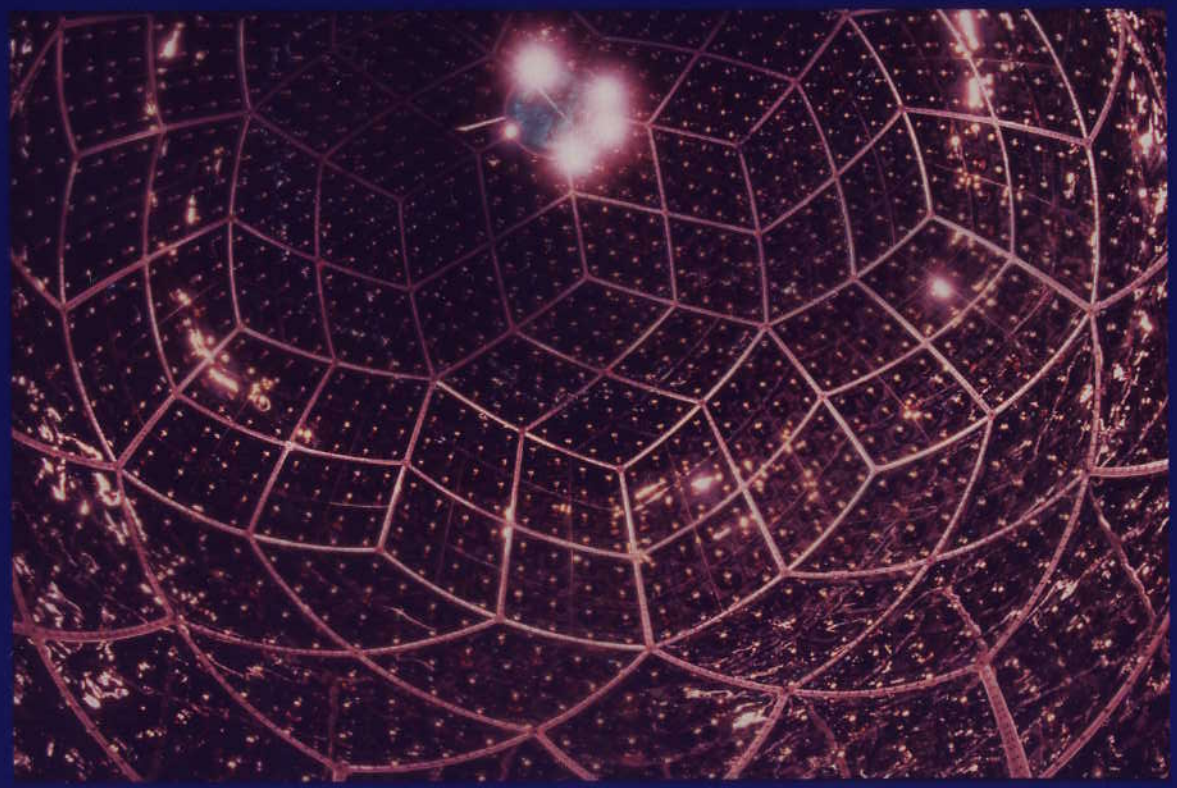


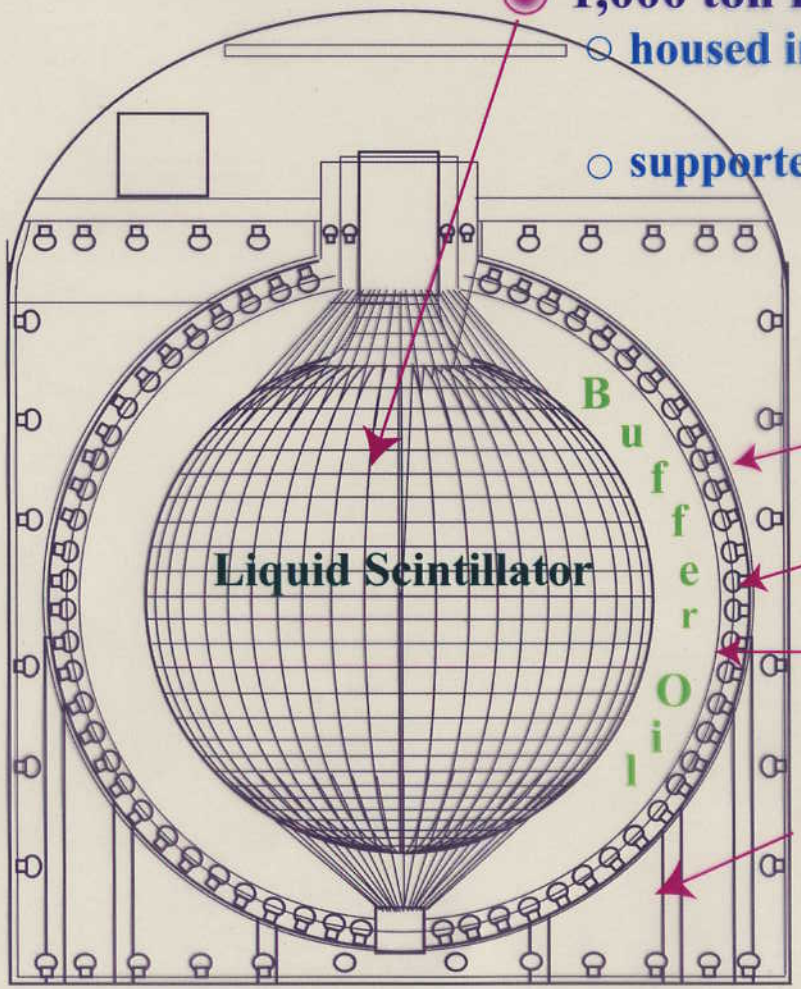
KamLAND Detector



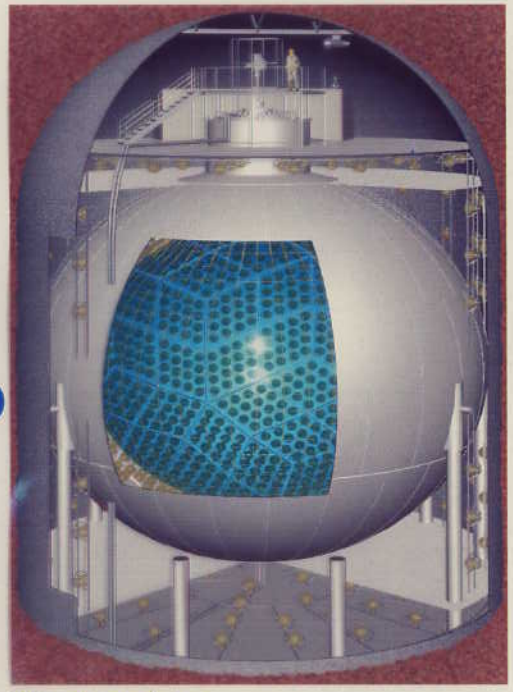


KamLAND Detector

- Detector site : Old Kamiokande site (2700 m.w.e.)

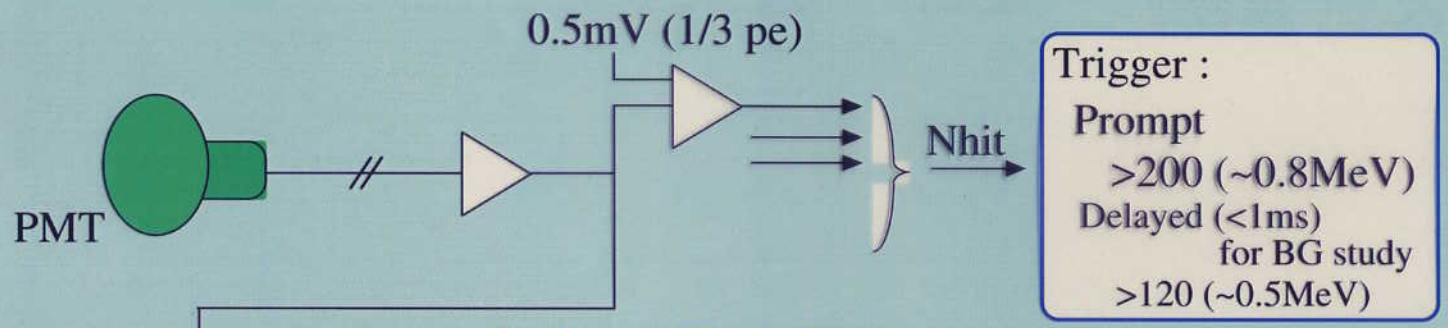


- 1,000 ton Liquid Scintillator ($\rho = 0.78$)
  - housed in spherical balloon (13m diameter) of plastic film (185 μm)
  - supported by cargo net structure



- 3,000 m^3 Scintillation Light Detector
  - 18m diameter stainless steel tank filled with paraffin oil ($\rho = 0.76$)
  - 1,325 17-inch+554 20-inch PMT's photosensitive coverage ~ 32 %
  - acrylic wall (120 plates) : Rn barrier
- Water Cherenkov Outer Detector
  - 225 Kamiokande 20-inch PMT's

Data Taking Electronics

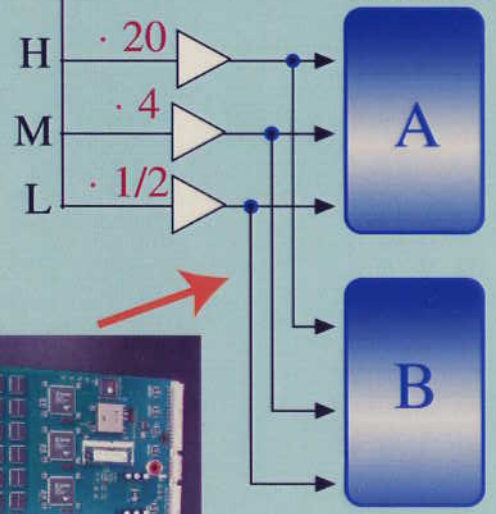


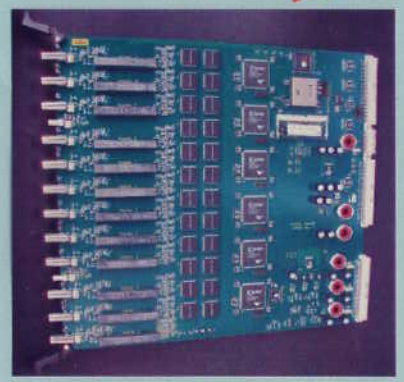
Trigger :
Prompt
>200 (~0.8MeV)
Delayed (<1ms)
for BG study
>120 (~0.5MeV)

Trigger rate ~25Hz
Data size
~150GB/d (on-line)
~10GB/d (waveform analysis)

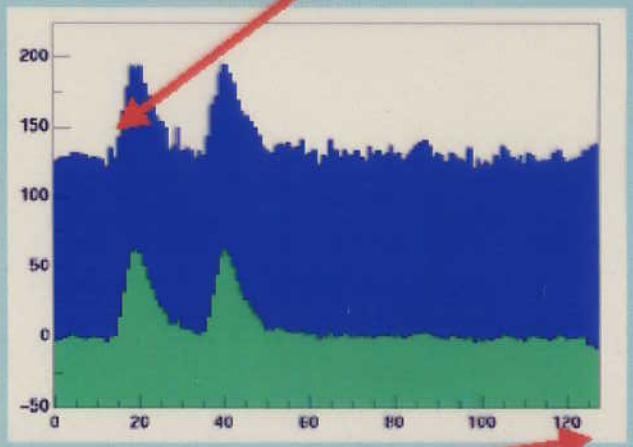
Analogue Transient Waveform Digitizers (ATWDs)

dynamic range
~ 1mV - 1 V





- The ATWDs are self launching with a threshold ~1/3 p e.

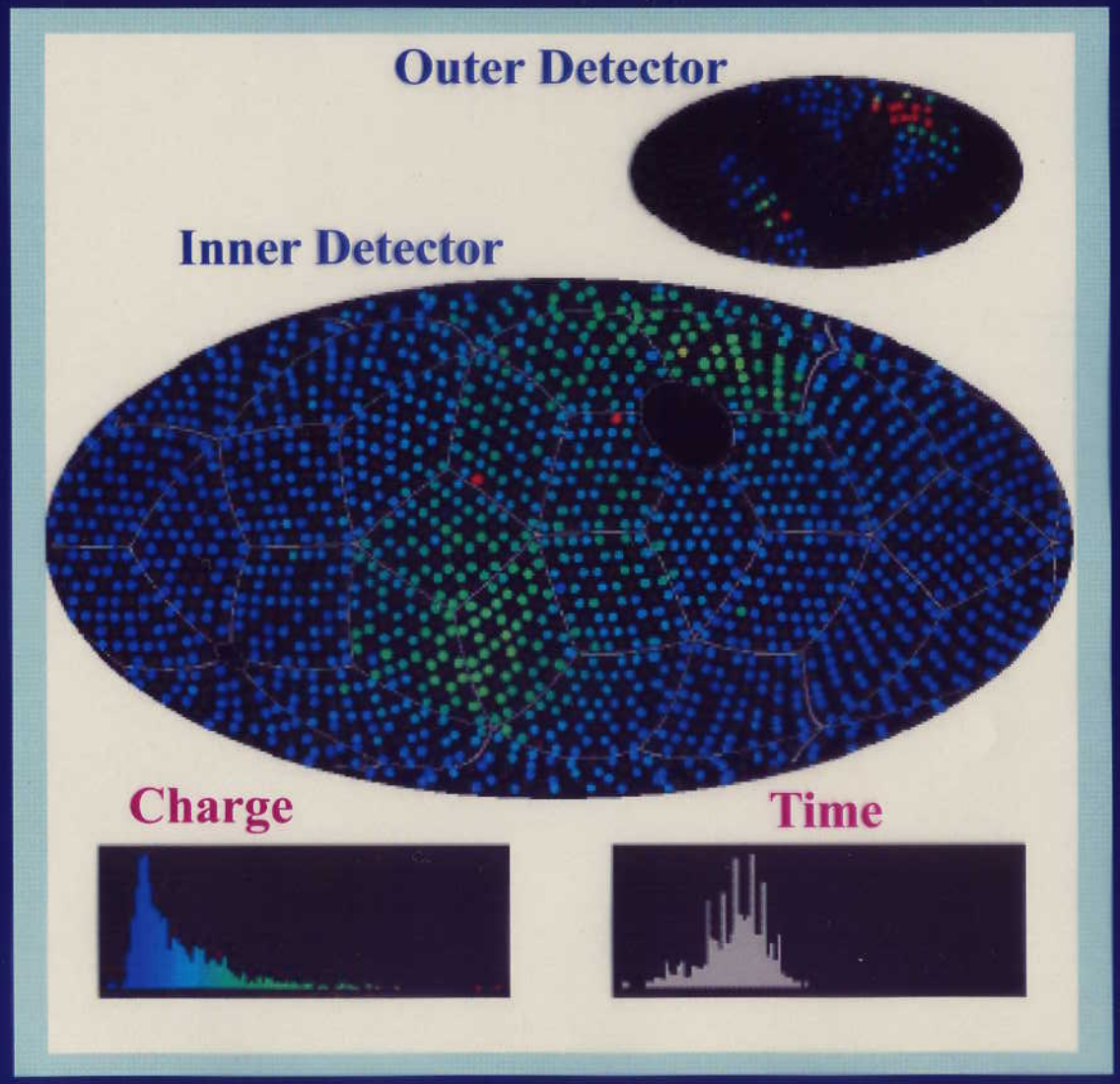


- There are 128 samples per waveform with a sample time of 1.5ns

KamLAND - Launch

January 22, 2002

Detector Performance

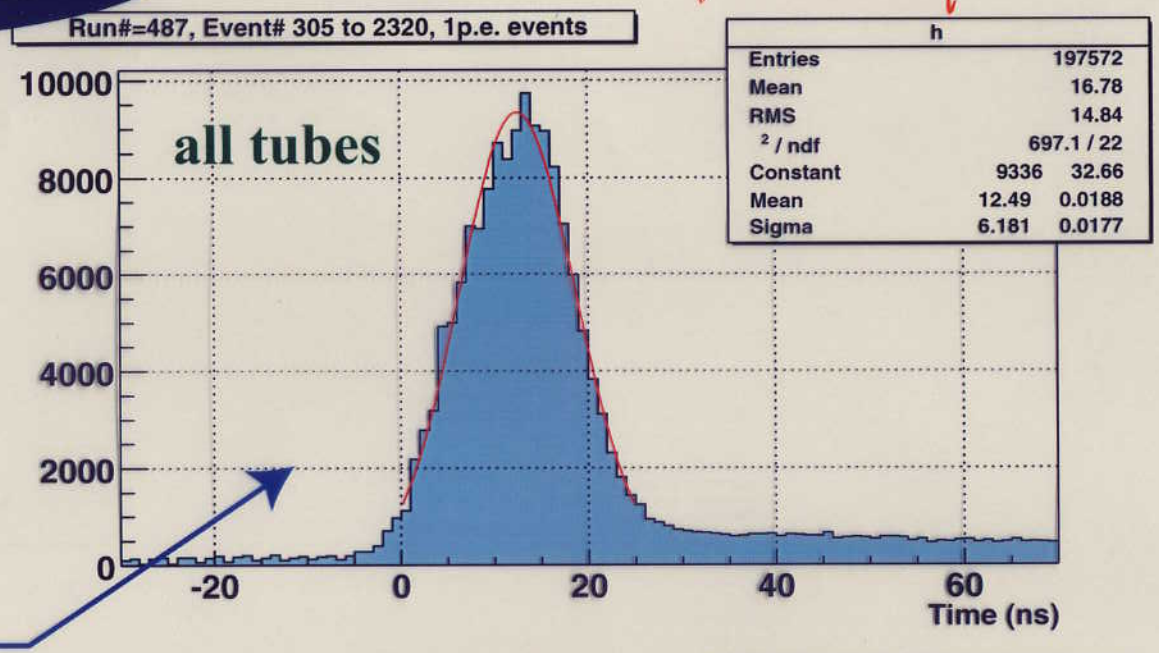


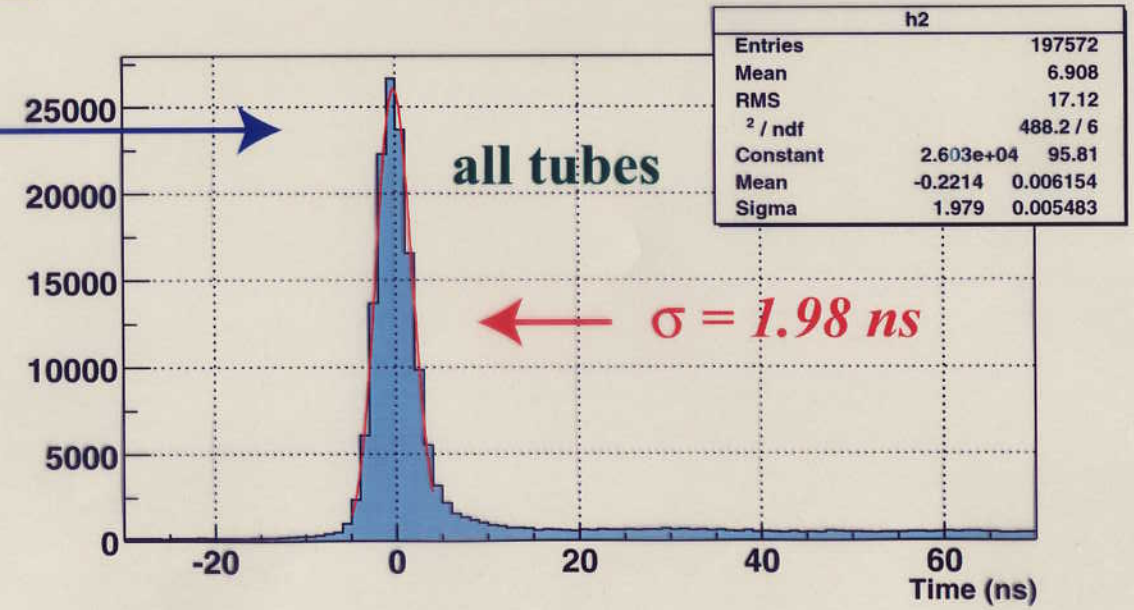
Timing Calibration

Preliminary

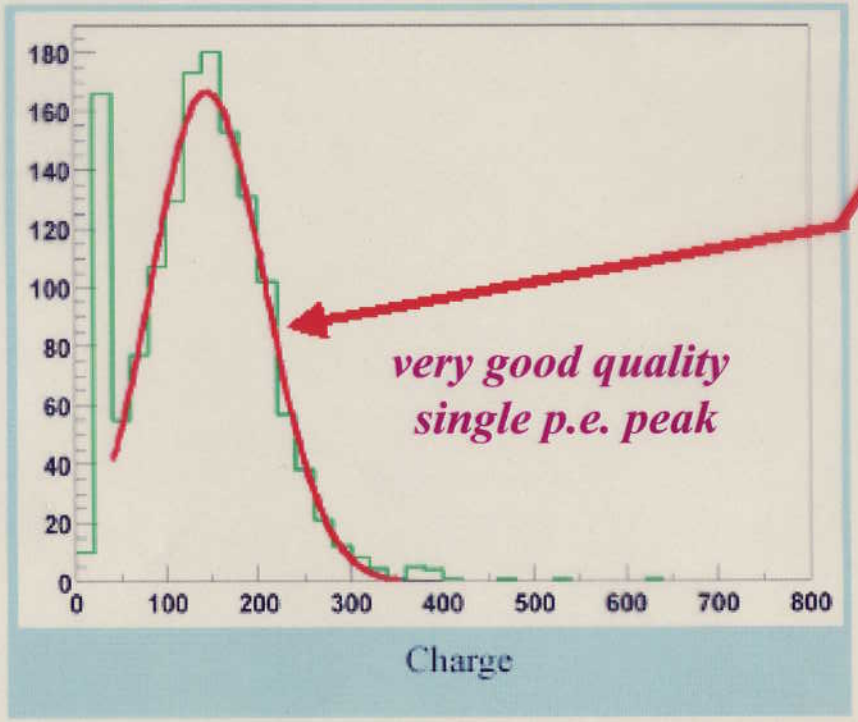
Timing calibration was done using a dye laser (λ= 500 nm)

single p.e. events before and after correction

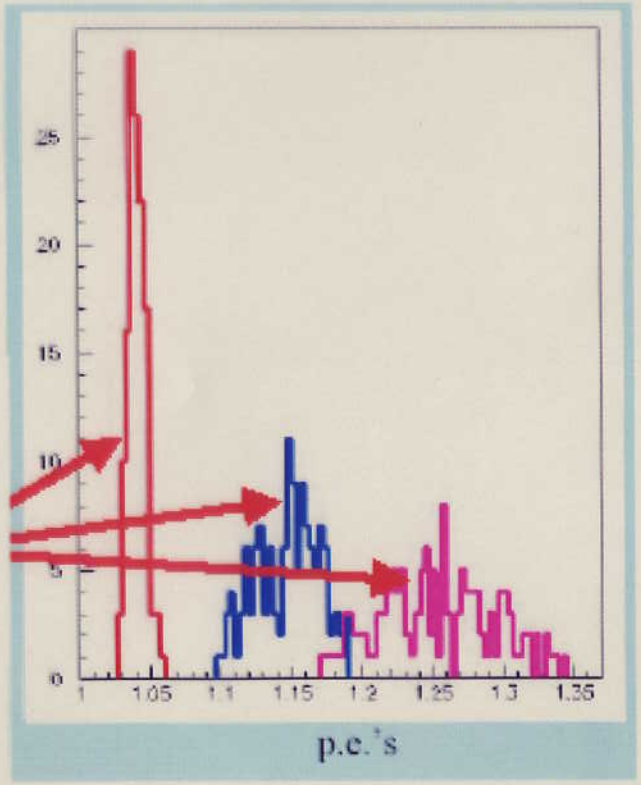




Gain Calibration



gain calibration :
single photoelectron peak
for each PMT

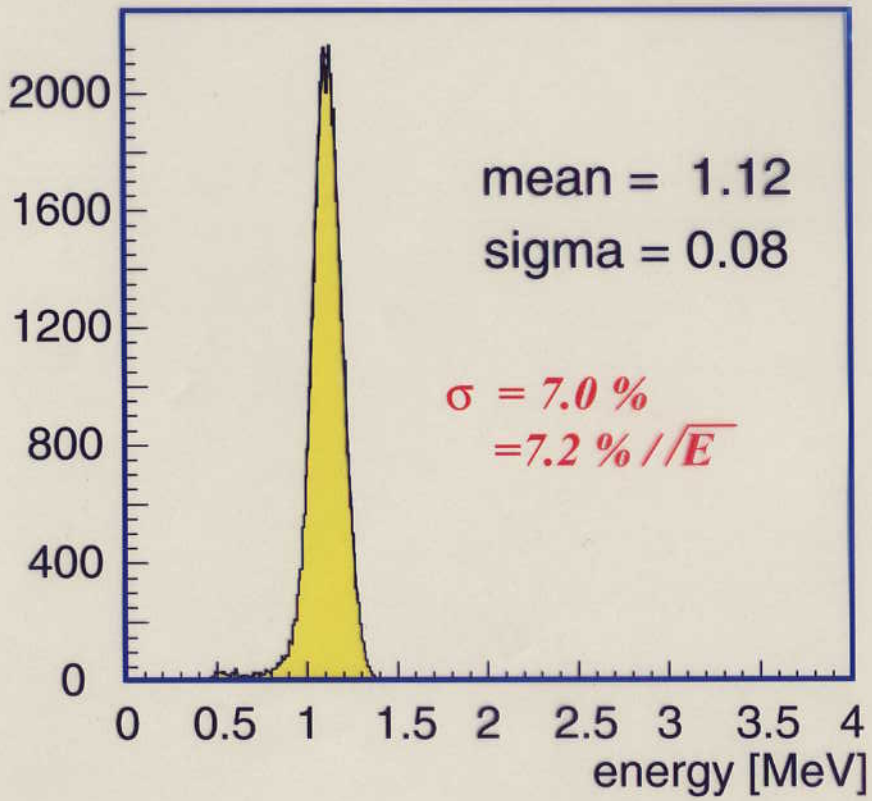


gain calibration at higher p.e.'s
: nitrogen laser
15 % intensity change with different filters

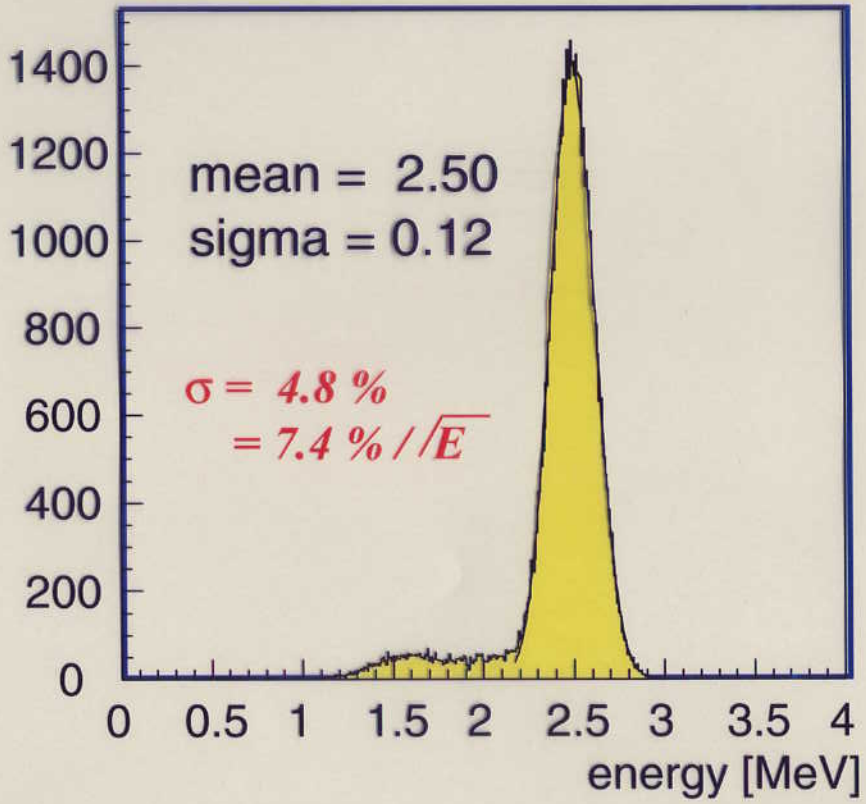
Energy Calibration

Preliminary

^{65}Zn : 1.115 MeV (γ)

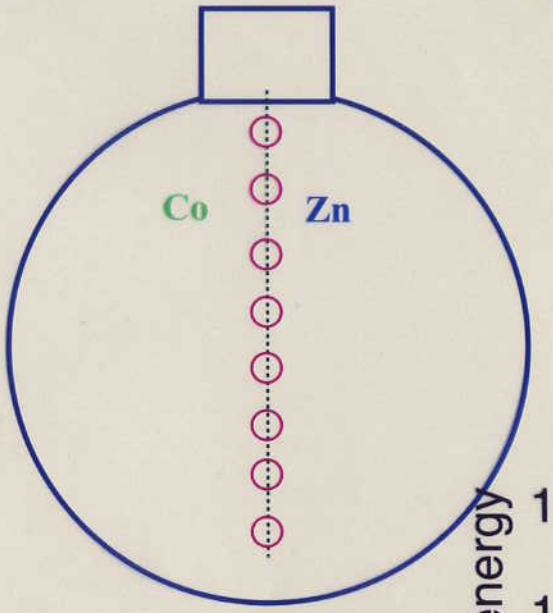


^{60}Co : 2.506 MeV ($\gamma + \gamma$)



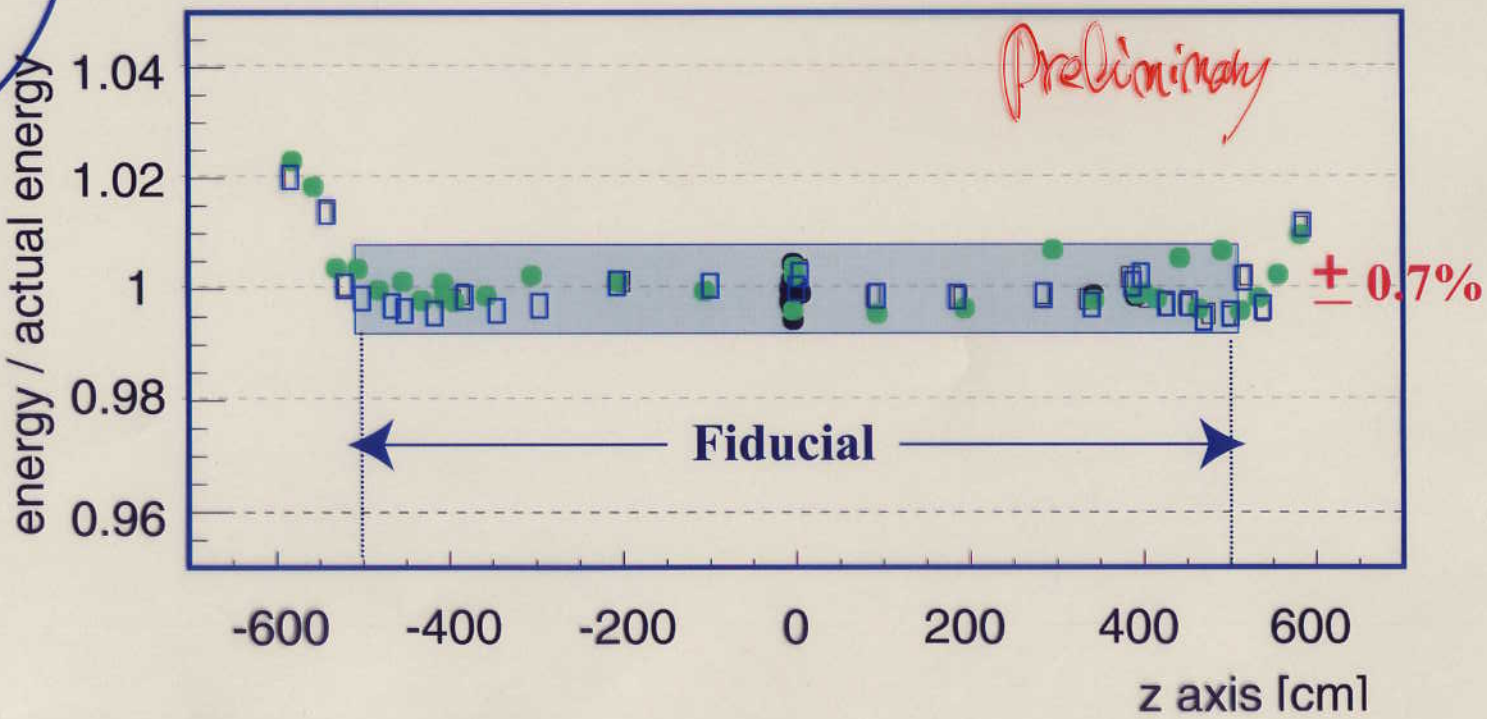
The light yield : 260 pe / MeV

Position Dependence : Energy



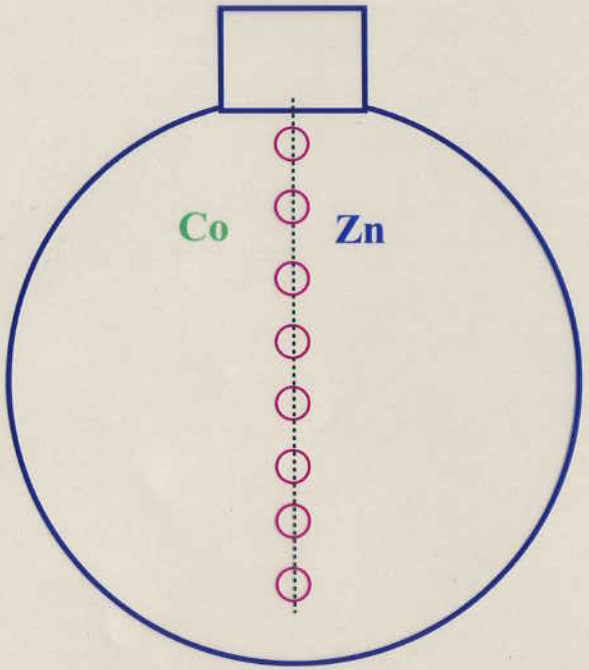
^{65}Zn : 1.116 MeV (γ)

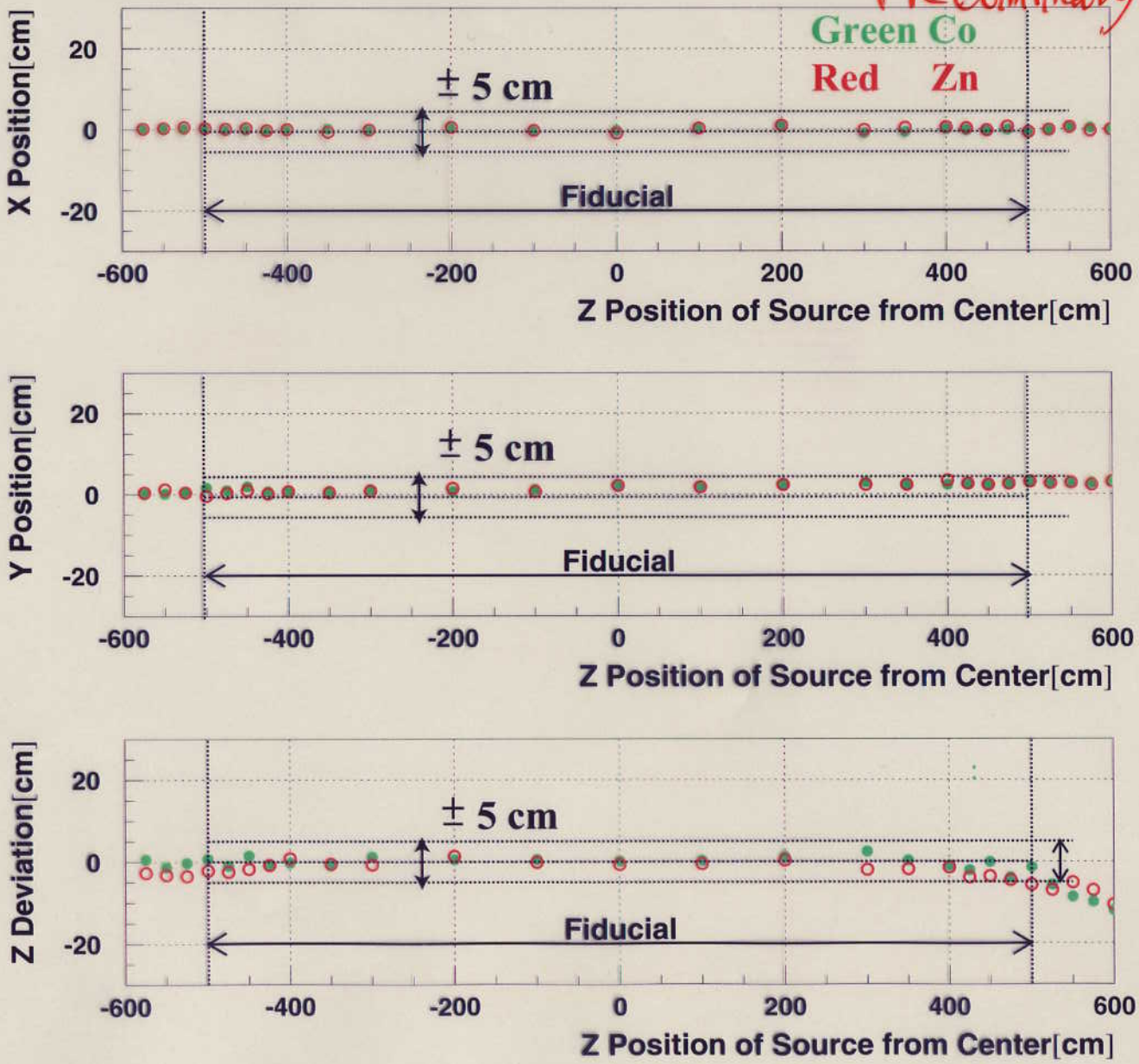
^{60}Co : 2.506 MeV ($\gamma + \gamma$)



Vertex Reconstruction Uncertainty

Preliminary





Trigger Efficiency

KamLAND trigger scheme

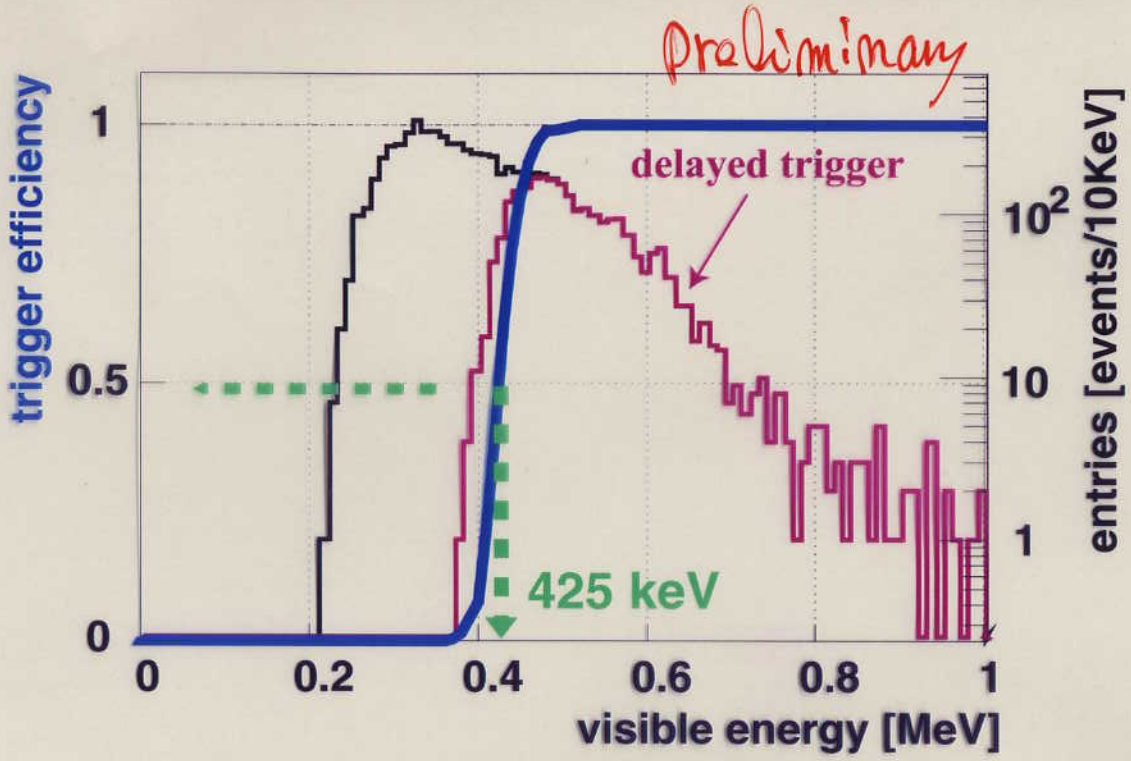
:

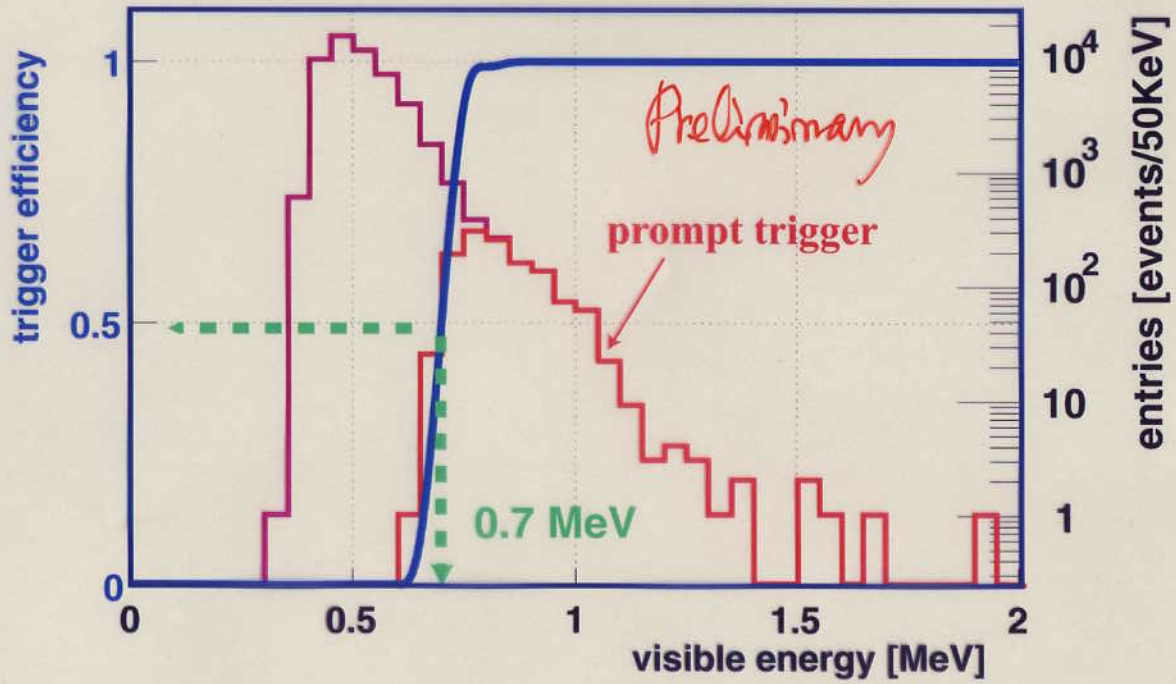
* prompt trigger

* delayed trigger

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

$$+ p \longrightarrow d + \gamma$$





Radioactivity in Liquid Scintillator : ^{238}U

$$^{238}U : {}^{214}Bi \xrightarrow[\beta+\gamma]{} {}^{214}Po \xrightarrow[\alpha]{} {}^{210}Pb$$

$\beta+\gamma$: $E = 3.27$ MeV, $\tau = 28.7$ min.

α: $E = 7.69$ MeV, $\tau = 237\ \mu s$

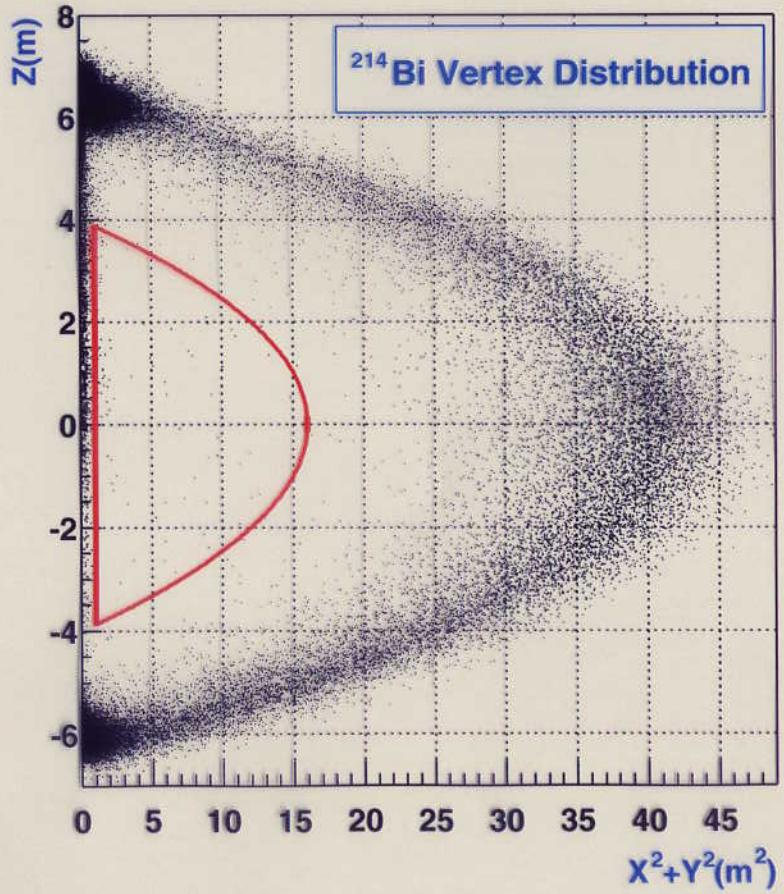
event selection

$\Delta R < 100$ cm

$5\ \mu s < \Delta t < 1000\ \mu s$

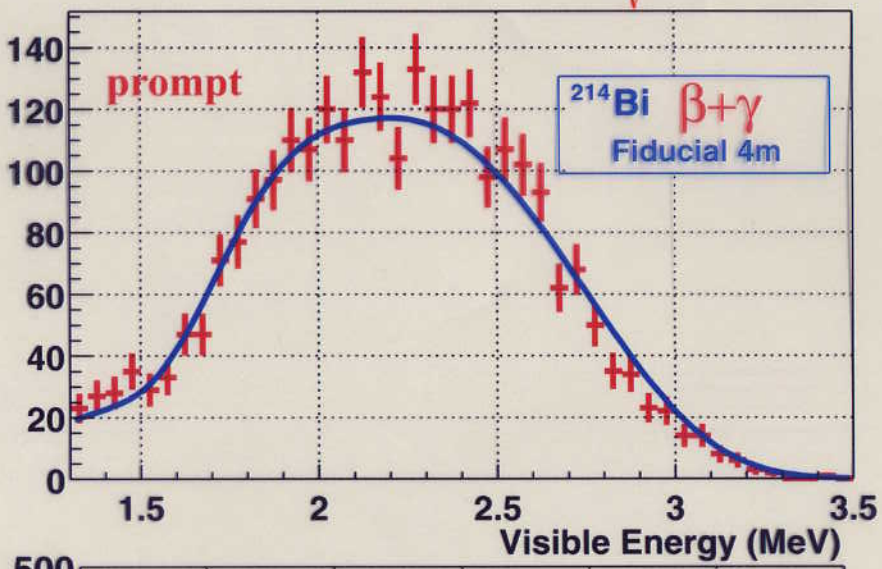
$E_{prompt} > 1.3$ MeV

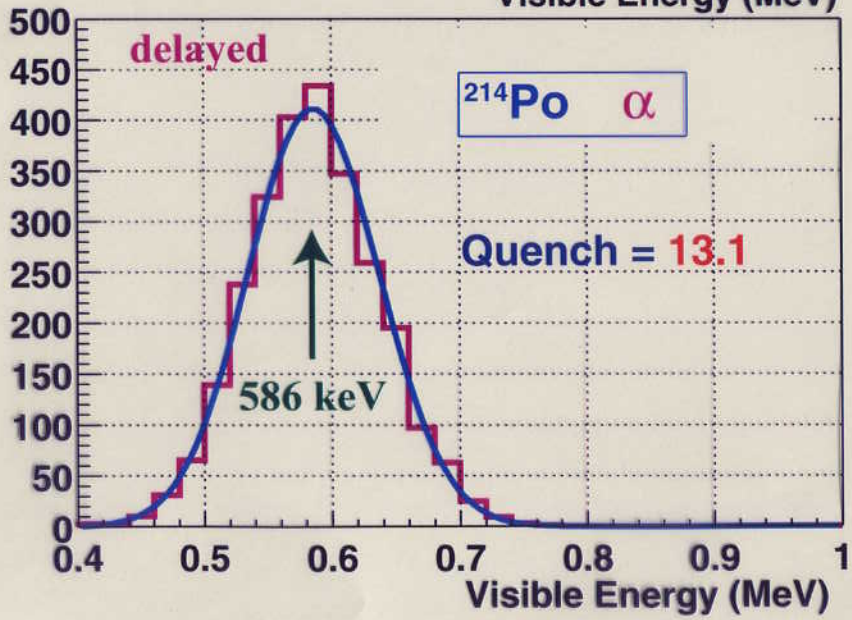
$0.3 < E_{delayed} < 1$ MeV



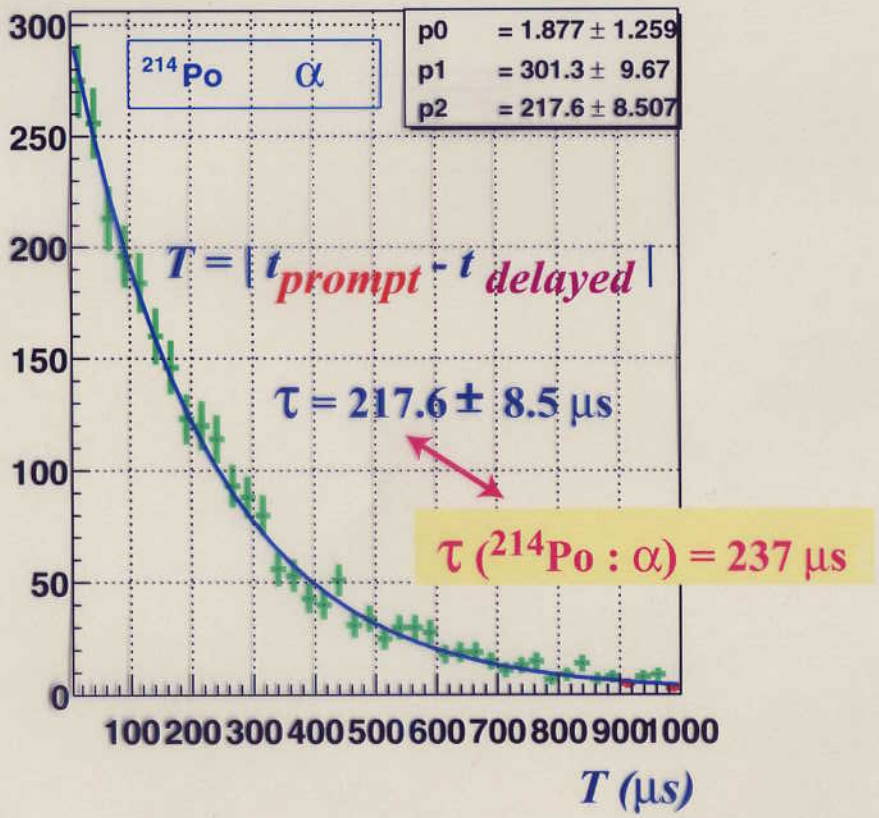
^{214}Bi - ^{214}Po - ^{210}Pb Signal

Preliminary





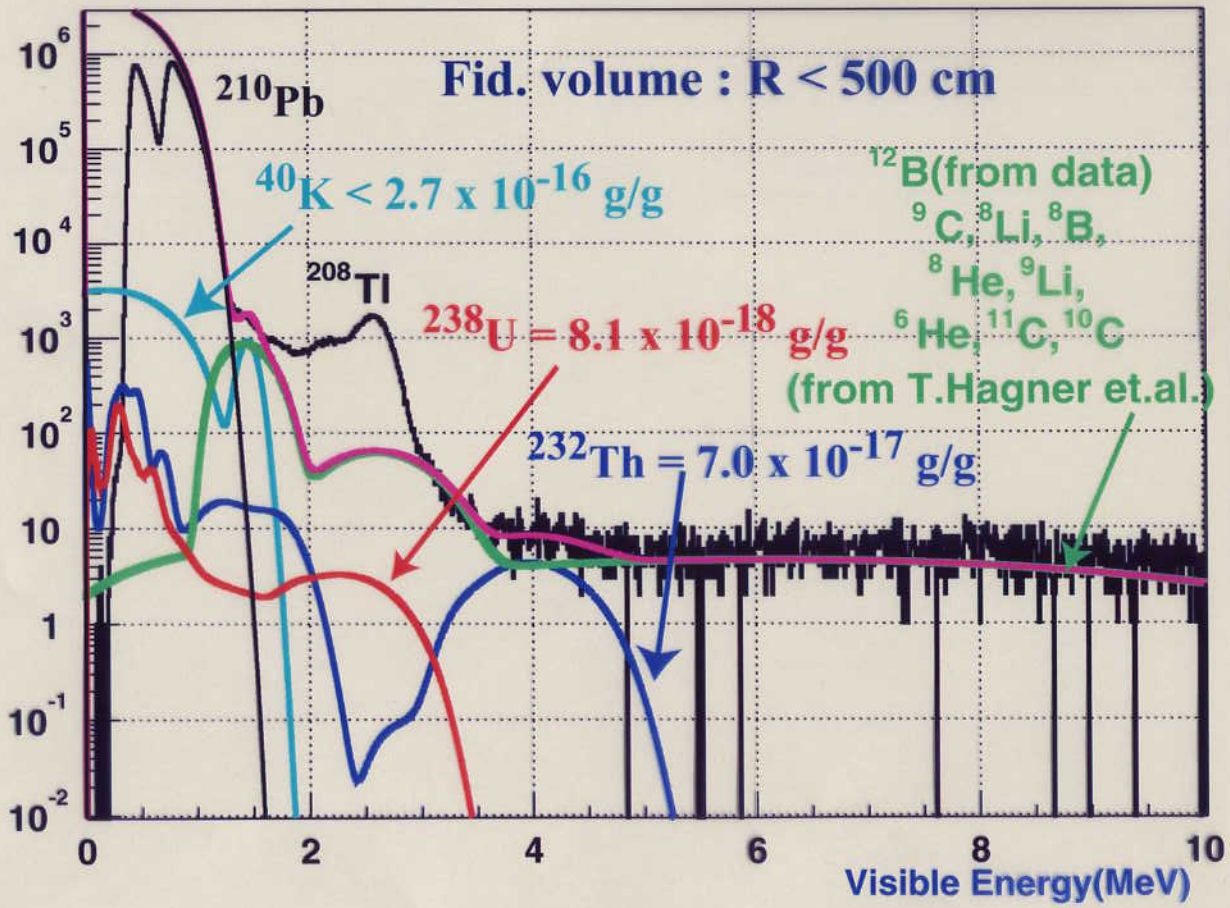
$^{238}U = 8.1 \times 10^{-18}$ g/g



Radioactivity inside Liquid Scintillator

^{40}K, ^{232}Th

Preliminary



	requirement (g/g)	
	reactor	solar ^{7}Be
U	$< 10^{-14}$	$< 10^{-16}$
Th	$< 10^{-14}$	$< 10^{-16}$
K	$< 10^{-15}$	$< 10^{-18}$

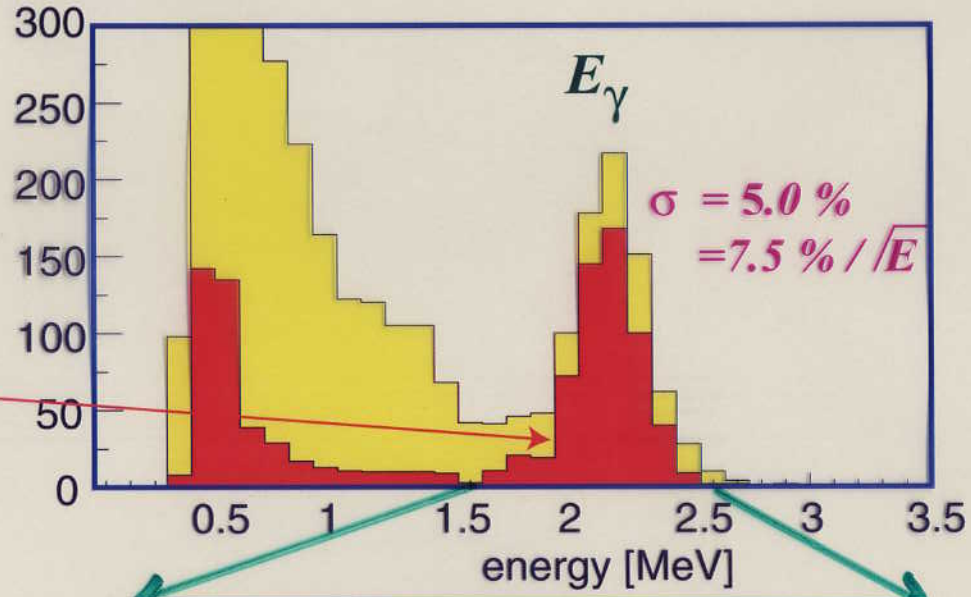
μ - Induced Neutrons

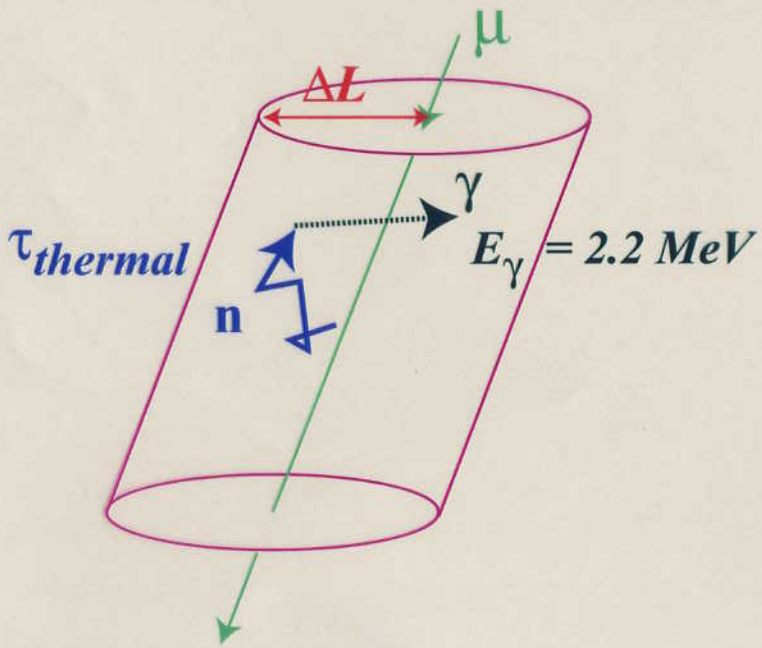
event selection

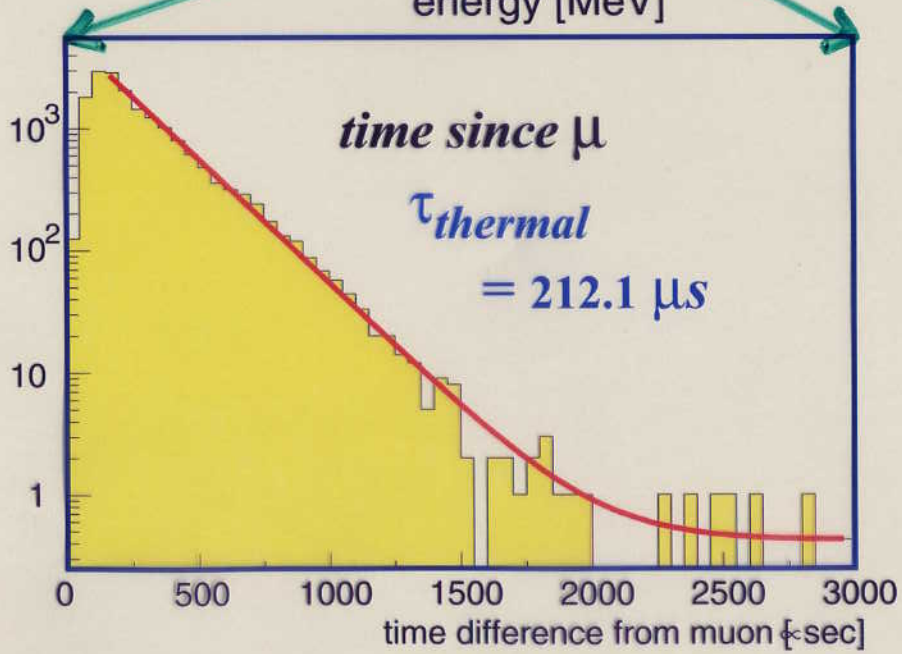
$R < 550$ cm

$\Delta t = |t_\mu - t_\gamma| < 2$ ms

$\Delta L < 200$ cm







μ - Induced Spallation: ^{12}B

Preliminary

event selection

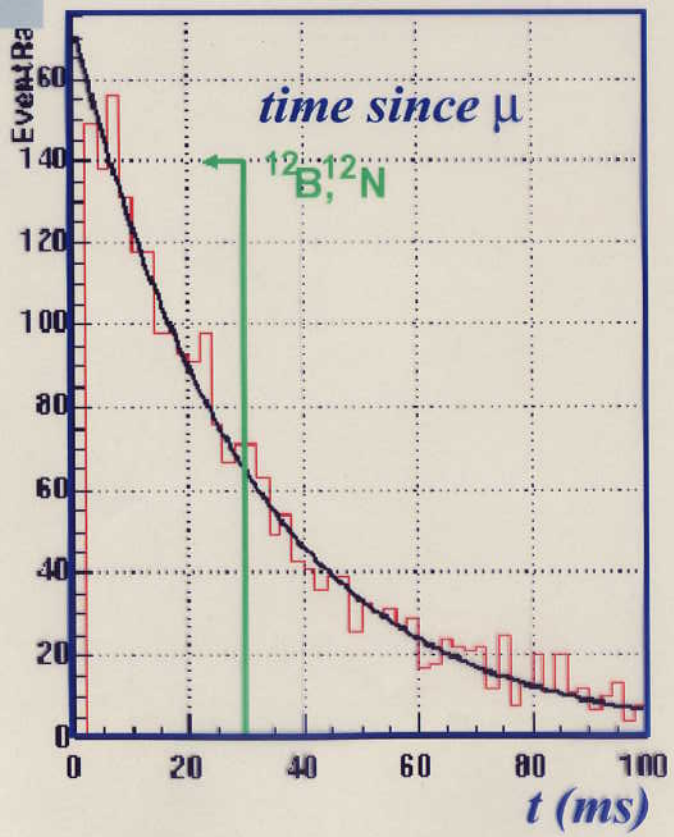
$Q_\mu > 1000000$ *p.e.*

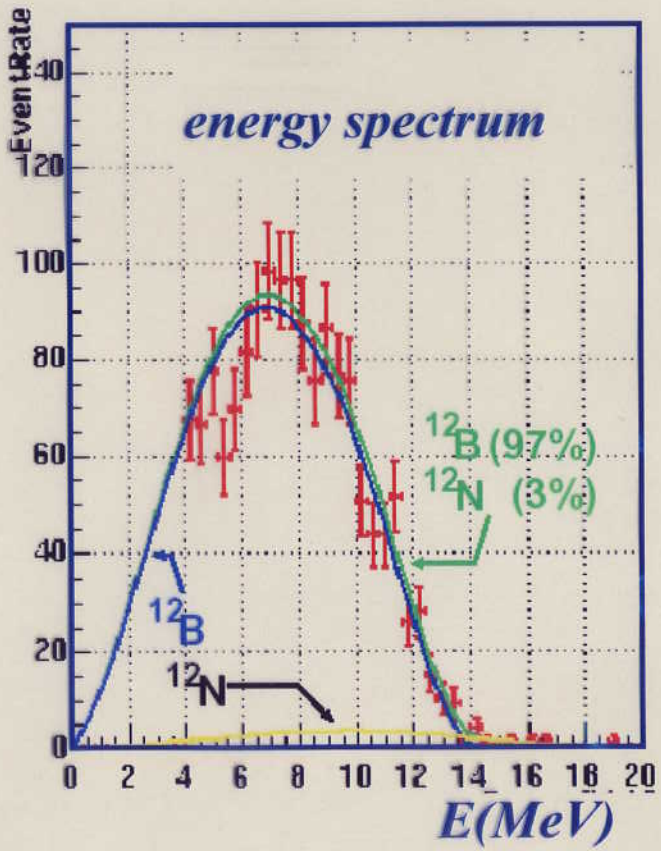
$2 < \Delta t < 30$ *ms*

$E > 4$ *MeV*

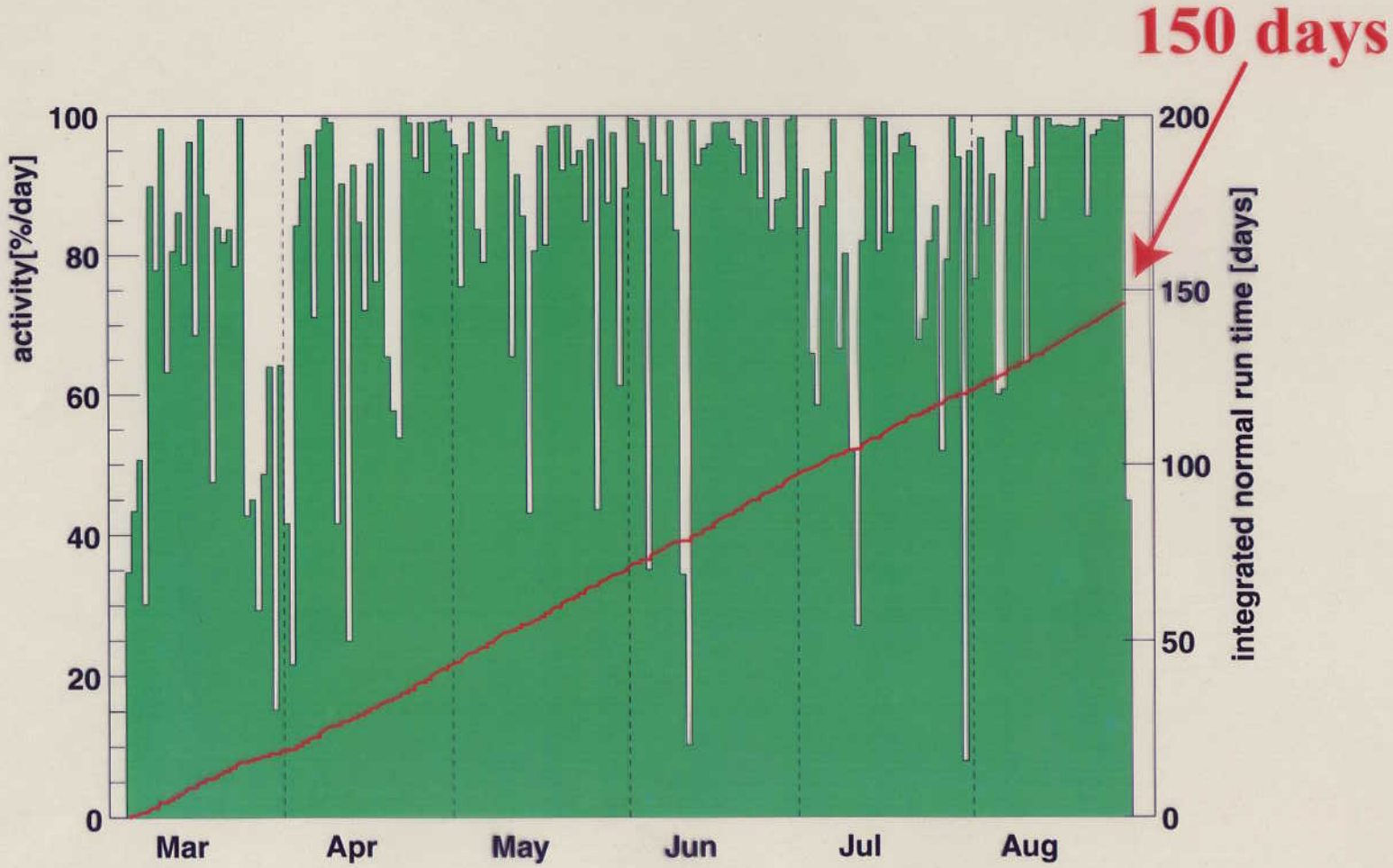
$$\mu^- + {}^{12}C \longrightarrow {}^{12}B + \nu_\mu$$

$$\hookrightarrow \beta^- \; (E_{max} = 13.4 \text{ MeV}, \; \tau = 20.0 \text{ ms})$$



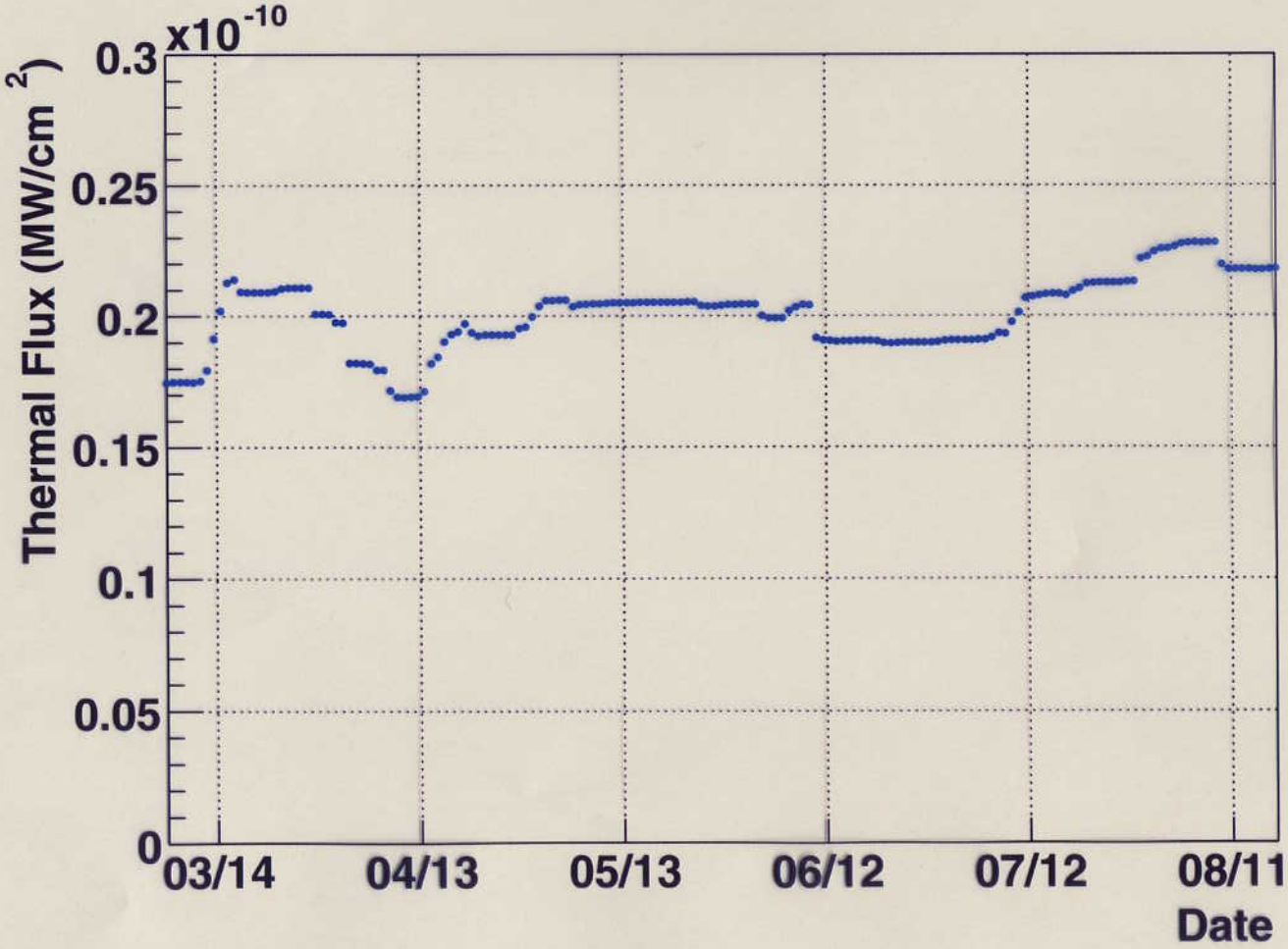


KamLAND Run Time



Thermal Flux History

Thermal fluxes at KamLAND from Japanese and Korean reactors

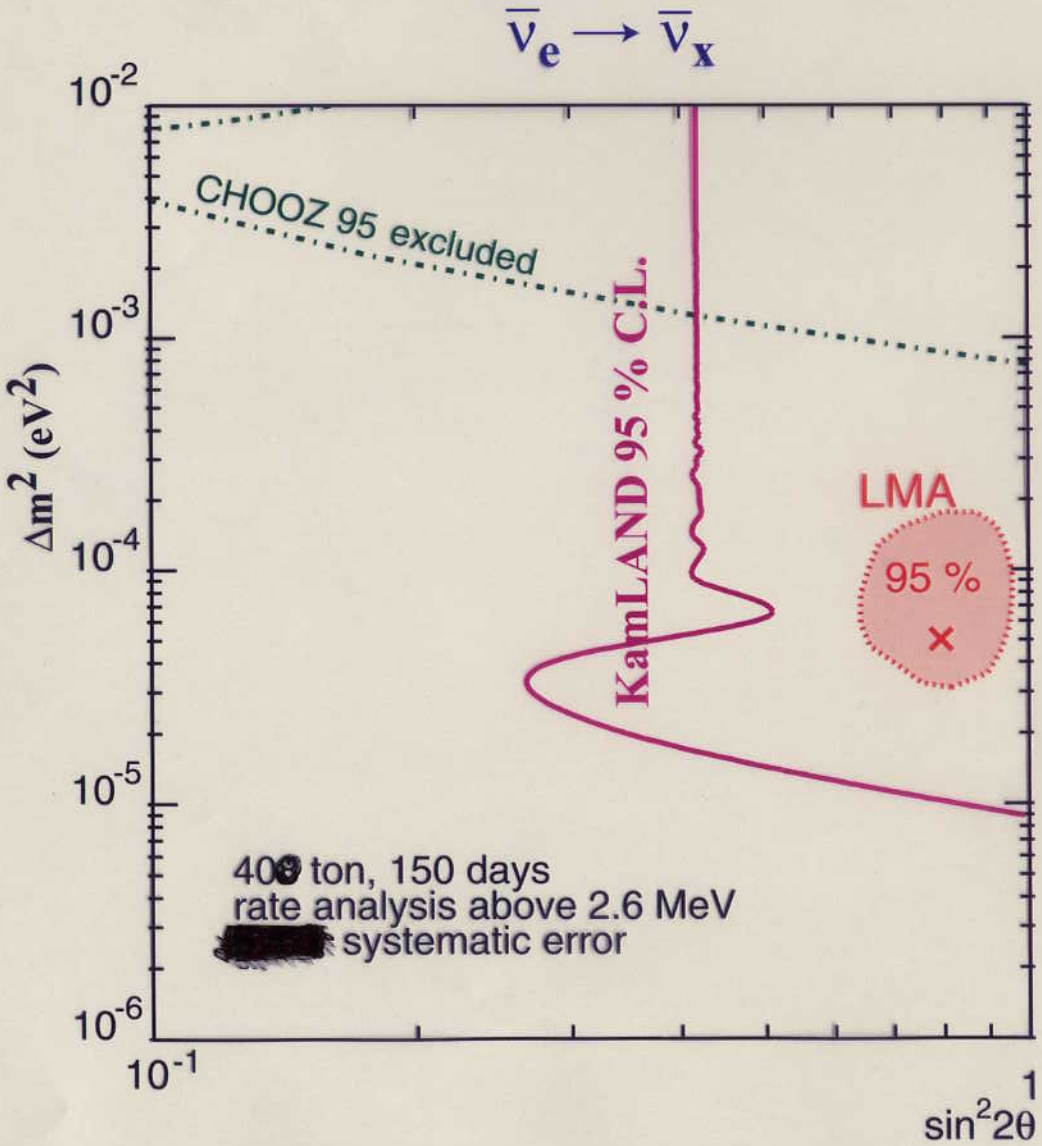


Expected Sensitivity to Δm^2 & $\sin^2 2\theta$

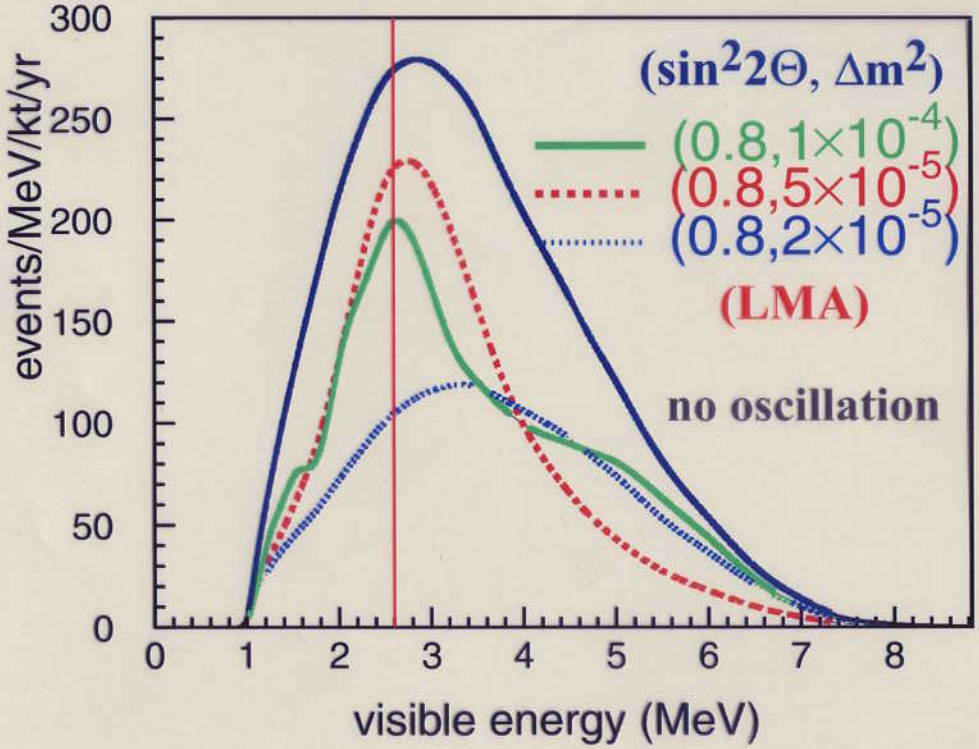
for 150 days data

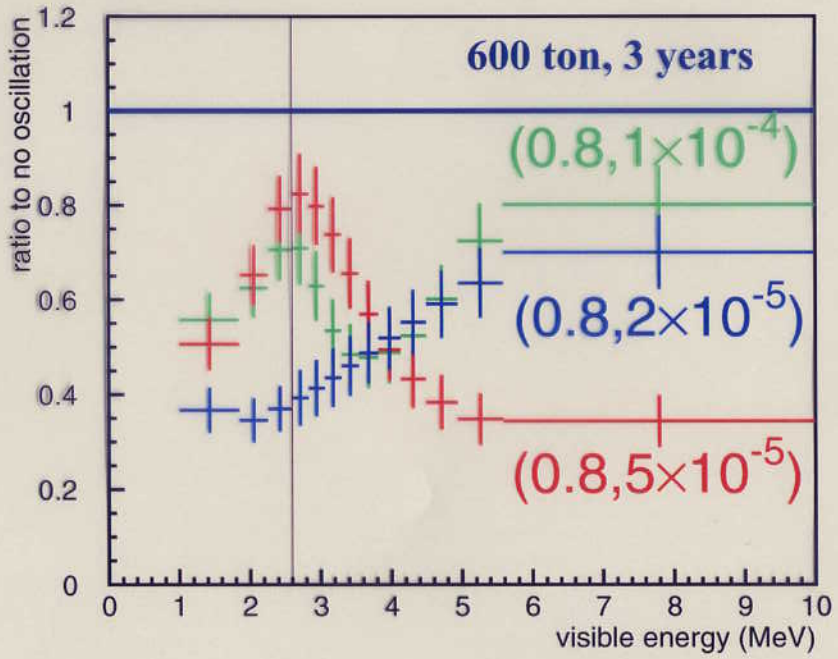
Systematic Error for [redacted] m , E > 2.6 MeV

Null Oscillation Case : 150 Days



Visible Energy Spectra with and without Oscillations

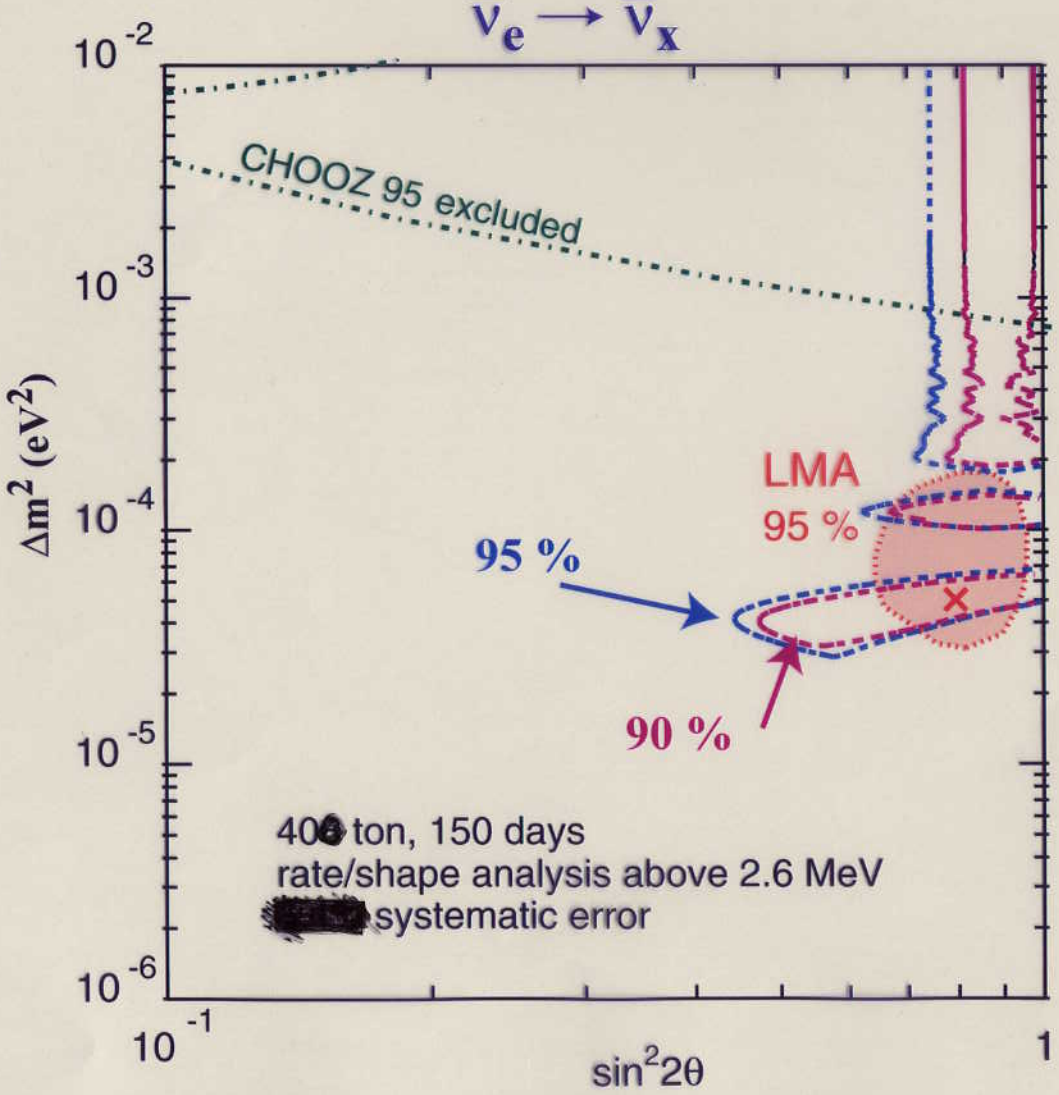


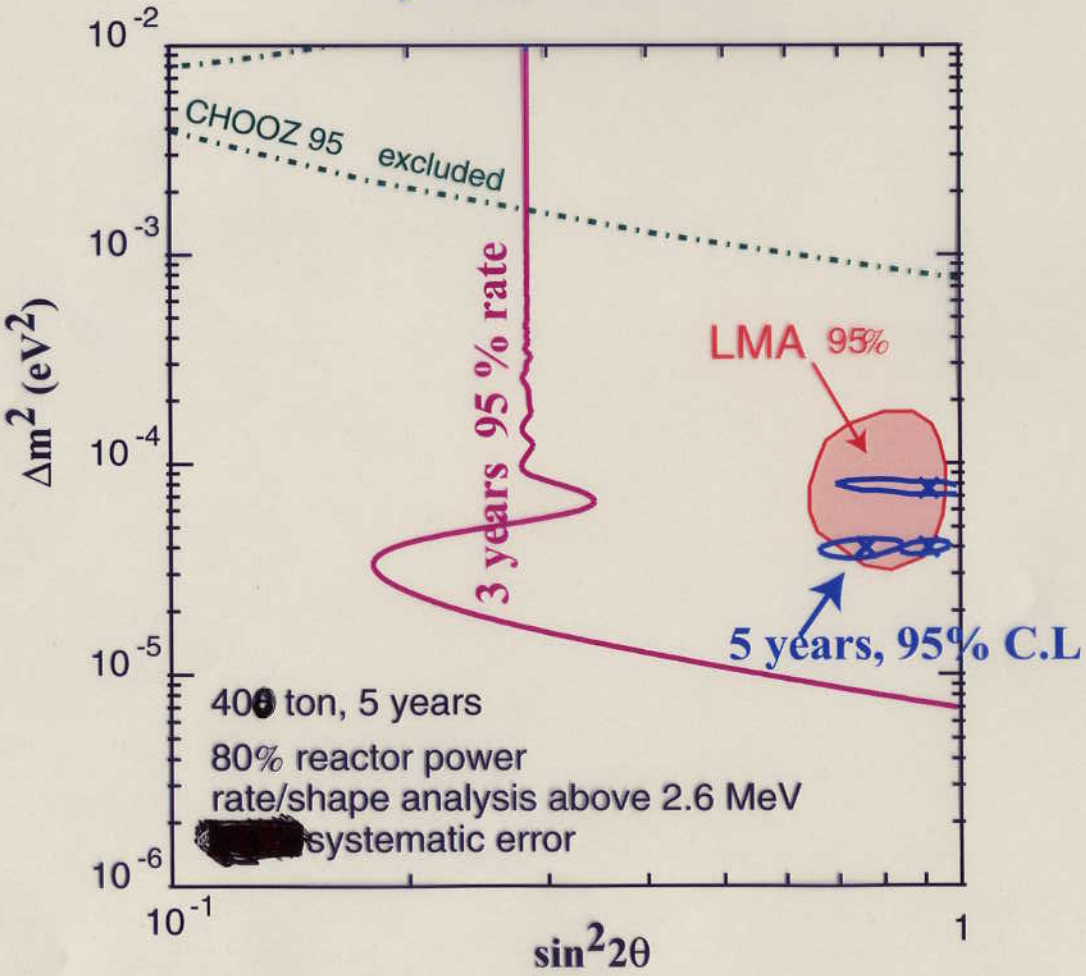


Oscillation Case : 150 Days

Rate & Shape Analysis

$\bar{\nu}_e \rightarrow \bar{\nu}_x$



Pinpoint Parameter-Space

Rate & Shape Analysis
5 years, 95% C.L