

Start of KamLAND

Kamioka Liquid Scintillator Anti-Neutrino Detector

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- 1.KamLAND Overview
- 2.Reactor $\bar{\nu}$ experiment by KamLAND
- 3.Detector Performance
Energy, Vertex, Background
- 4.Summary

KamLAND Collaboration Institutes

Tohoku University
KEK

University of Alabama
Lawrence Berkeley National Laboratory
University of California, Berkeley,
California Institute of Technology
Drexel University

University of New Mexico
TUNL

University of Hawaii

Louisiana State University

Stanford University

IHEP, Beijing

University of Tennessee

14 Institutes,
96 collaborators



$\nu_\mu \rightarrow \nu_\tau$ (atmospheric ν , SK)

$\nu_e \rightarrow \nu_x$ (^8B solar ν , SK+SNO)



ν_e : Determine mass (Δm^2) and mixing angles of ν

Challenging mysteries of ν

Beyond the SM
Fundamental mechanisms
for ν -mass, mixing in very
high energy scale

Reactor $\bar{\nu}_e$

LMA

^7Be Solar ν_e

SMA LOW VAC

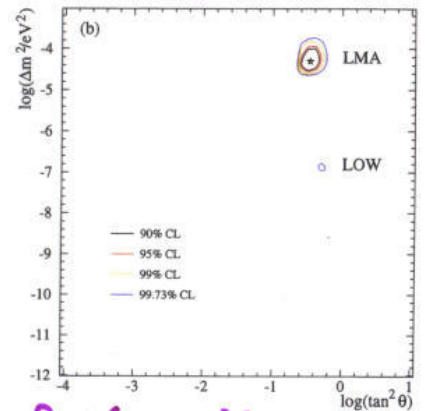
KamLAND

Geo $\bar{\nu}_e$

Supernova
 $\nu, \bar{\nu}$

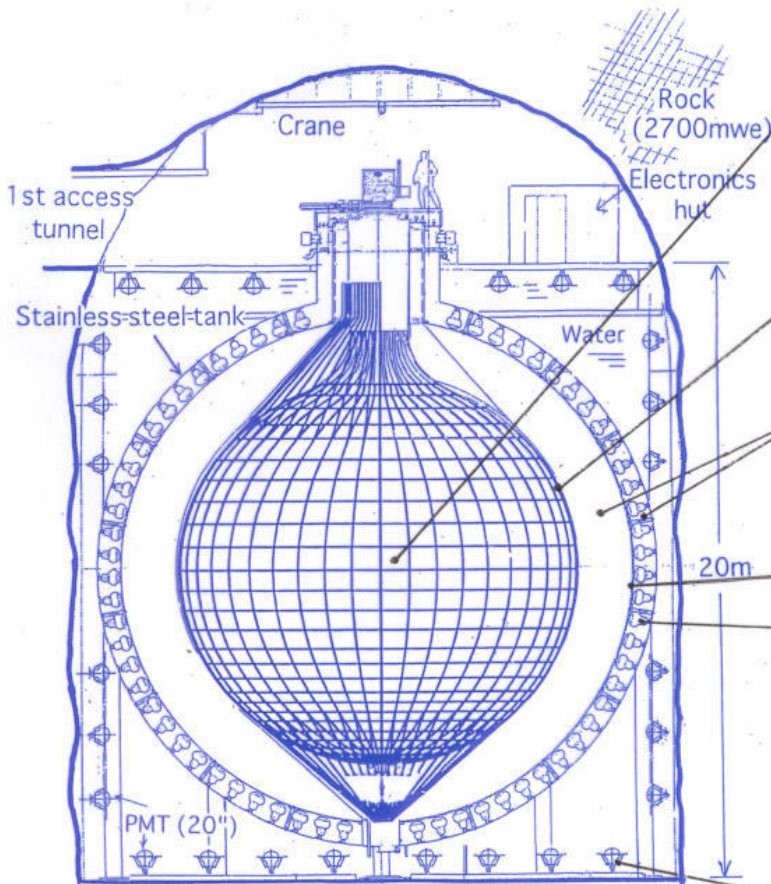
1000ton liquid scintillator
detector,
Highly sensitive to ν with
E ~MeV or below.

LMA: the most promising!
SNO+(K+Ga+SK(D/N))+SSM



Best fit $\left\{ \begin{array}{l} \tan^2 \theta = 0.34 \\ \Delta m^2 = 5 \times 10^{-5} eV^2 \end{array} \right.$

KamLAND Detector



Liquid scintillator (1000ton)

Dodecane(80%)
+Pseudocumene(20%)+PPO(1.5g/l)

Balloon+Kevlar ropes

13m ϕ , EVOH/3Ny/EVOH, 135 μ m

Buffer Oil (inner+outer)

Dodecane(50%)+Isoparaffin (50%)

$$\rho_{LS}/\rho_{BO}=1.003$$

Acrylic plate (3mmt)

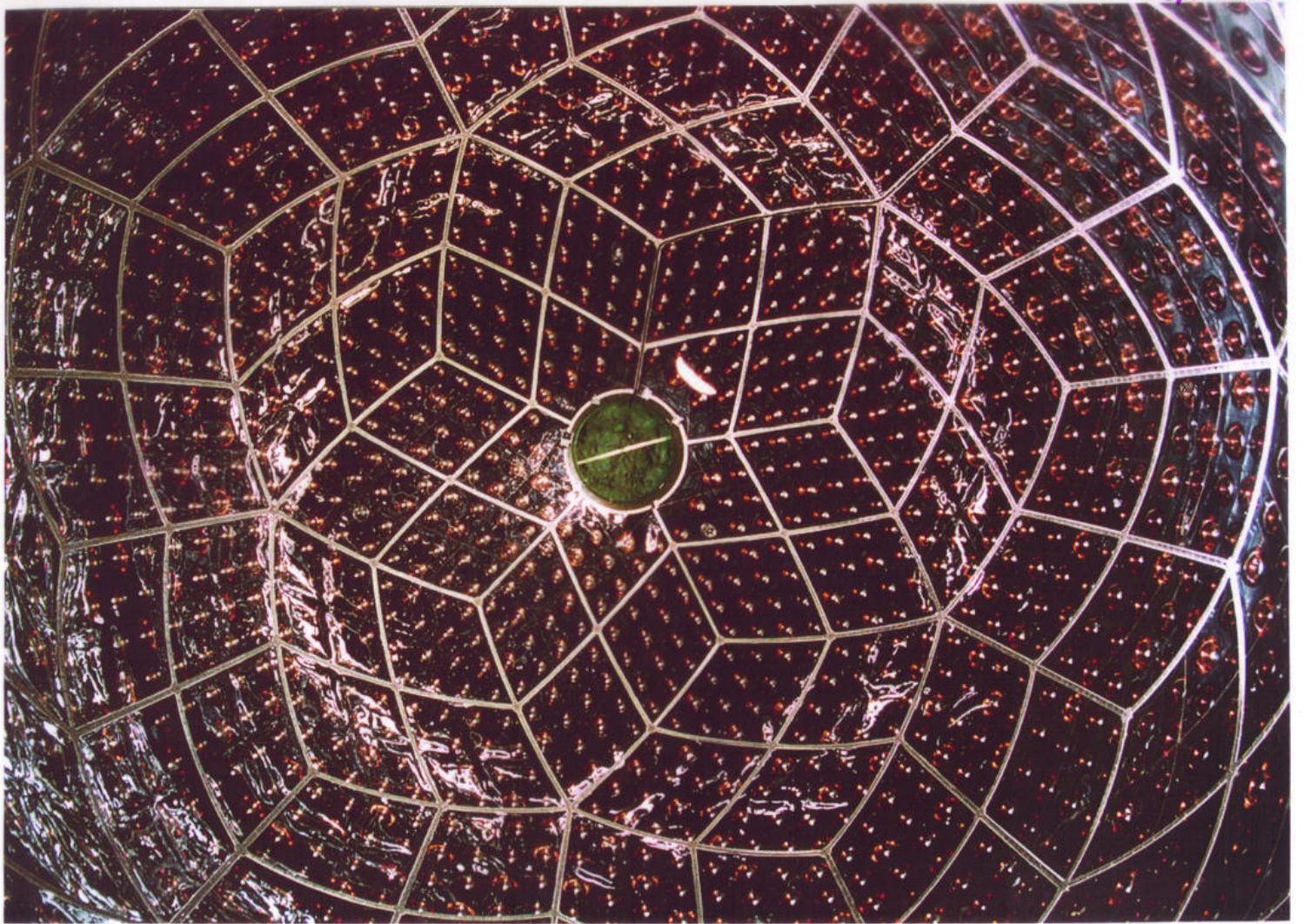
PMT 17"($\sigma\sim 1$ ns) \times 1325+ 20"($\sigma\sim 5$ ns) \times 554
 $\Omega=35\%$ of 4π
 440pe/MeV, $\sigma/E=5\%/\sqrt{E}$,
 $\sigma_{vtx}\sim 10$ cm (@1MeV)

Outer Detector *Water \checkmark*

PMT 20" \times 225 in purified water

13m
18m

Sep. 2000



Reactor $\bar{\nu}_e$ experiment

- Pure $\bar{\nu}_e$ flux
 - Flux is well known ($\sim 1\%$)
 - Low energy ($< \text{several MeV}$)
- \rightarrow Front detector is not necessary.
 \rightarrow Disappearance exp., Large L/E

$$N_{\text{ev}} = \sum_i^{\text{reactors}} \frac{1}{4\pi L_i^2} \phi_i (1 - \sin^2 2\theta \sin^2 \frac{\Delta M^2 L_i}{4E_\nu}) \sigma(\bar{\nu}_p \rightarrow e^+ n) N_p$$

KamLAND

Powerful (70GW) reactors @ L $\sim 175 \pm 35 \text{ km}$

$\rightarrow 1.3 \times 10^6 \bar{\nu}_e / \text{s/cm}^2$ (21.8 MeV)

$\rightarrow \Delta M^2 = \sim 6 \times 10^{-6} \text{ eV}^2$ (@ $\sin^2 \theta \sim 1$)

1000ton LS (CH_2)

$\rightarrow 10^{32}$ free protons

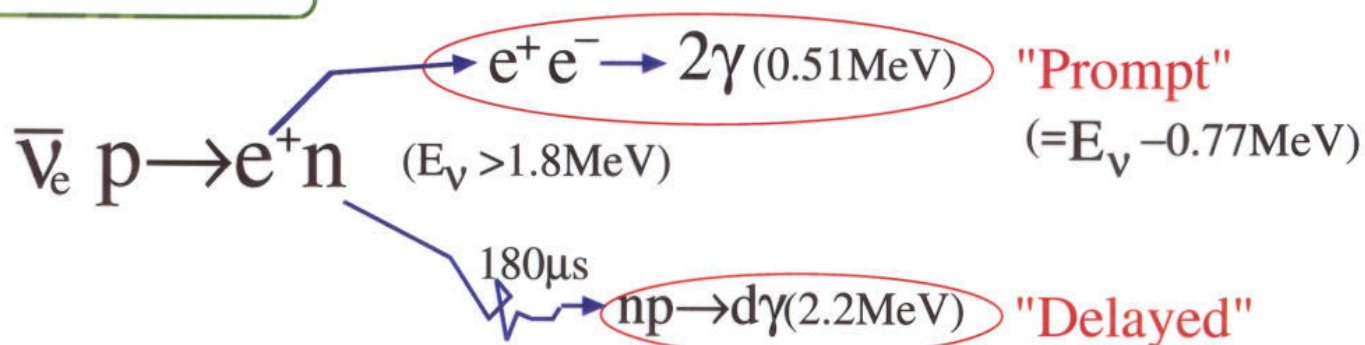
$\rightarrow 550 / \text{yr}$ (No oscill., Fid. vol. 600 ton, Reactor eff. 80%)

Covers LMA !!

Reactor Neutrino Experiment

at KamLAND

$\bar{\nu}_e$ Detection

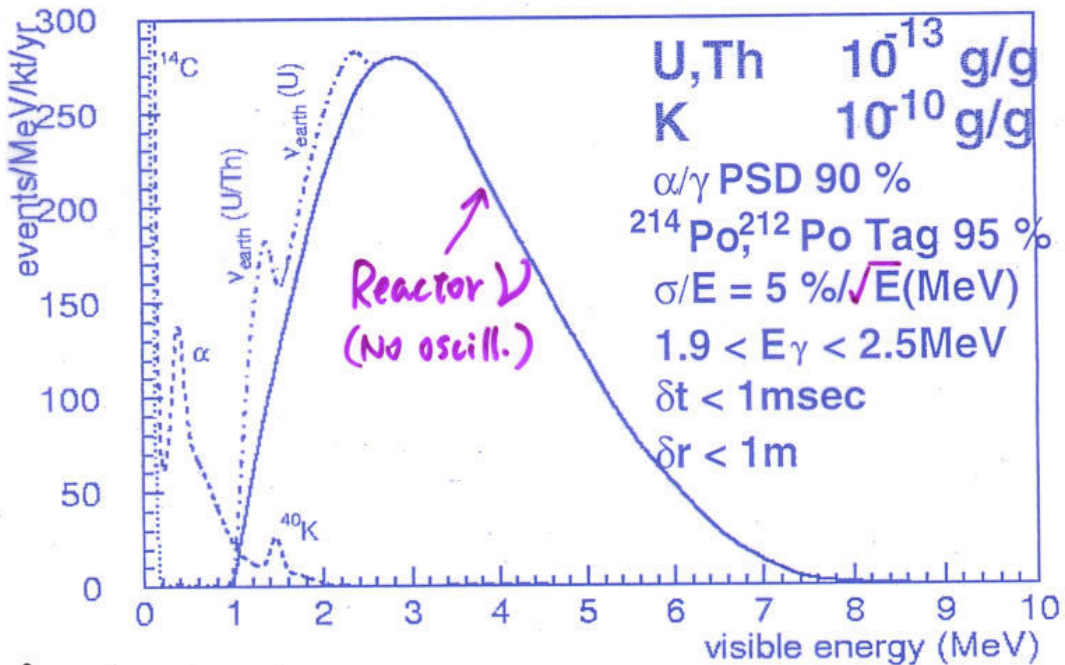


- $\bar{\nu}_e$ only (CC)
- Reject BG (delayed signal ← timing, distance, energy)
- σ is large ($\sim 100\sigma(\nu e \rightarrow \nu e)$) and well known.
- E_ν is measured by prompt energy.

● KamLAND Liquid Scintillator

Large light yield, High purity, Pulse shape discrimination (n/ γ , α / γ)
 Fast response, cheap, safe

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



Fiducial volume = 600 ton
 Reactor off. = 80 %

No oscill. \rightarrow 550 ev/yr (Reactor), ~ 400 ev/yr (Geo.), ^{214}Po 390 ev/yr ($\geq 2.6 \text{ MeV}$, above Geo. ν)

Reactor v experiment

Systematic Uncertainties (Initial)

Q_{thermal} 2%

Fiducial Volume 3% $\longleftrightarrow \Delta(\text{Vertex-shift}) \sim 5\text{cm}$

Flux error from E_V 3% $\longleftrightarrow \Delta(\text{E-scale}) < 2\%$
(SuperK $\sim 0.3\%$)

$$\frac{\Delta V}{V} = 3 \frac{\Delta R}{R} \lesssim 0.03$$

($R = 5\text{m}$)

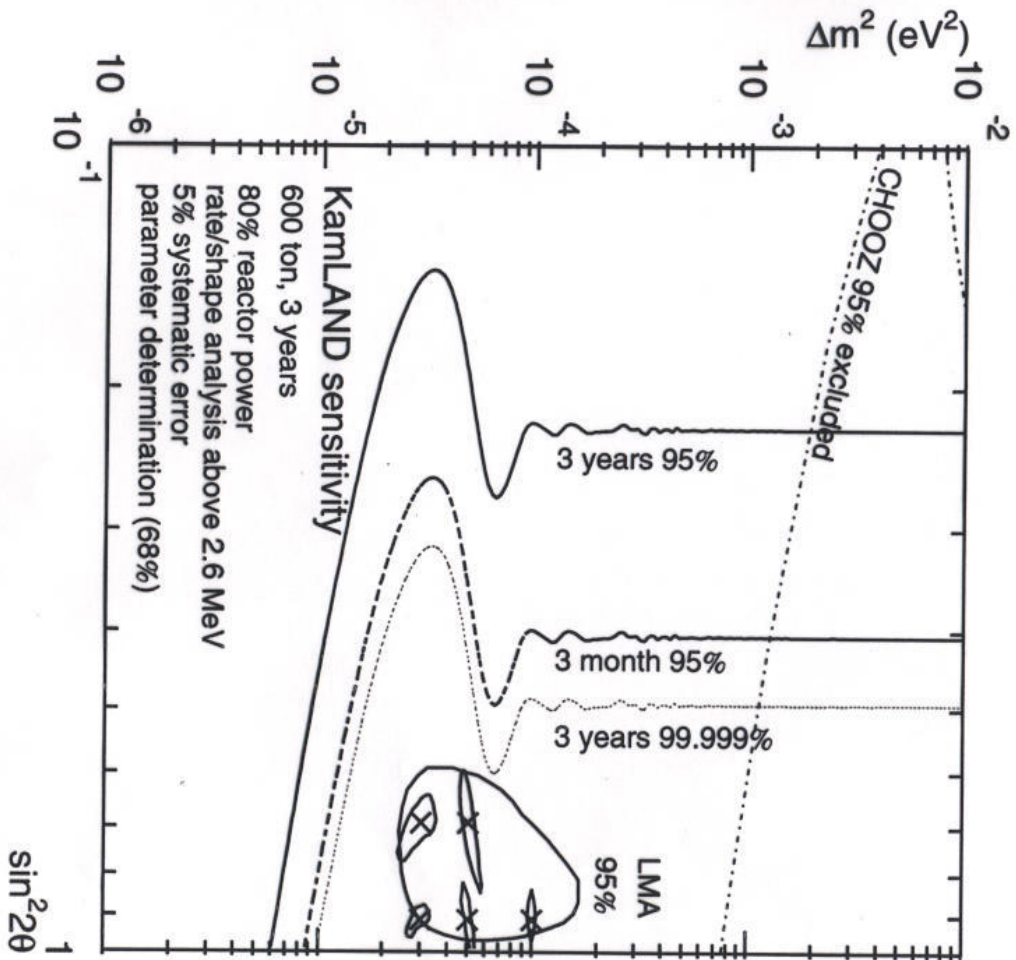
Cross Section 1%

Others $\sim 1\%$

Total $\sim 5\%$



Gain & Timing checks

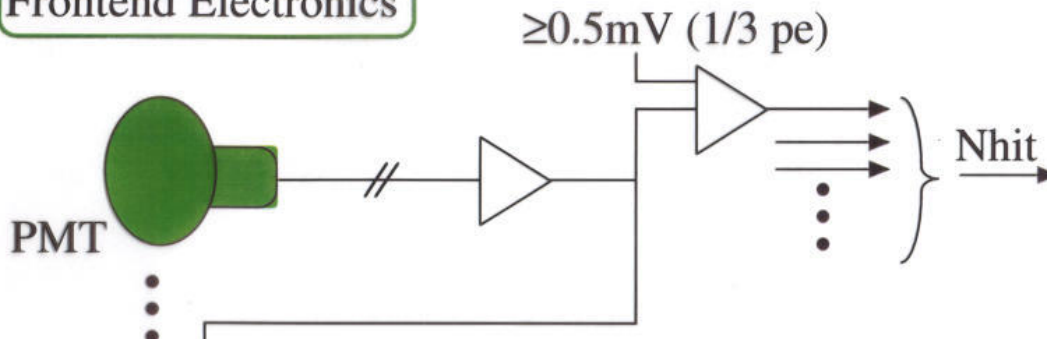


A purple gradient oval with a dark blue outline, centered on a white background. The text inside is in a black serif font.

KamLAND:

Detector Performance

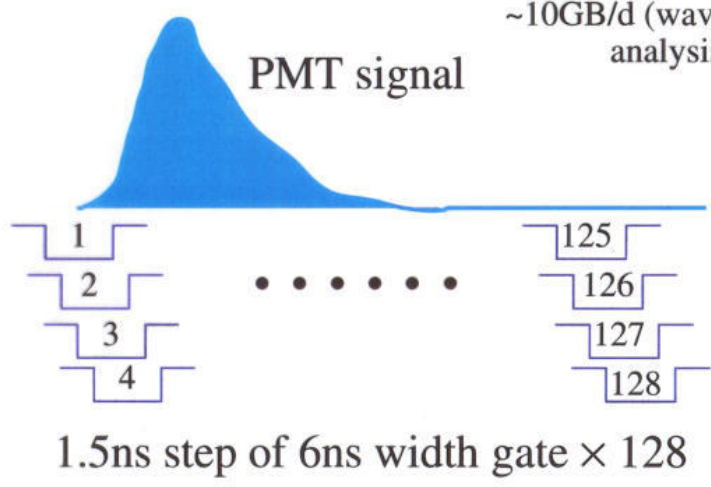
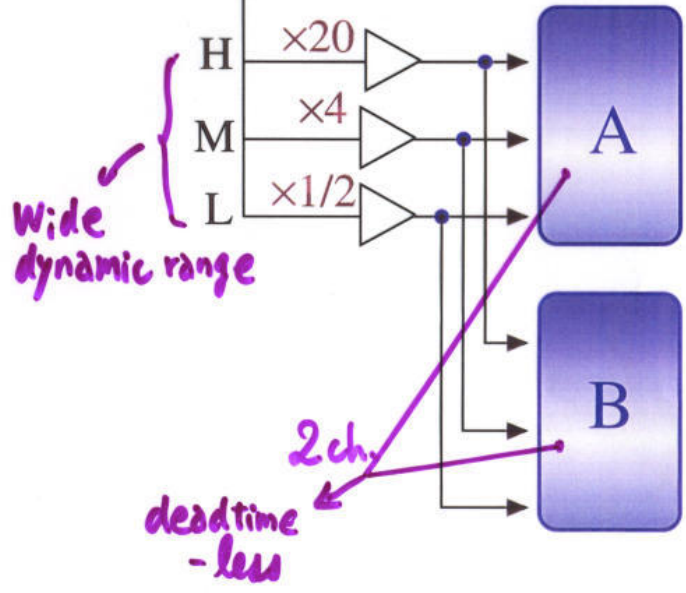
Frontend Electronics



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

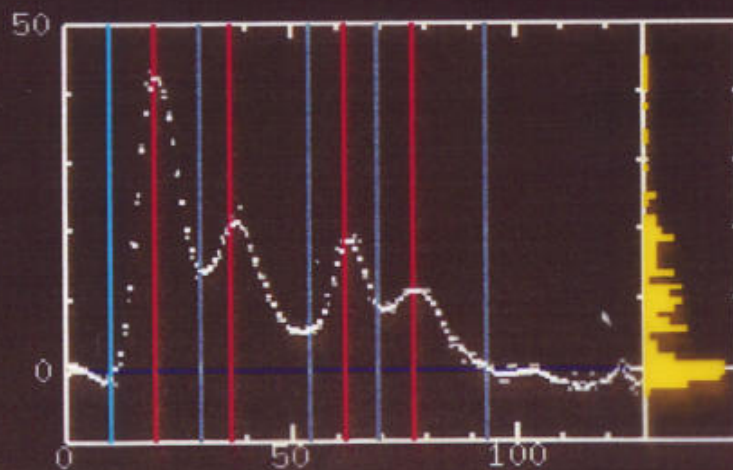
Trigger rate ~25Hz
Data size
~150GB/d (on-line)
~10GB/d (waveform analysis)

Analogue Transient Waveform Digitizer



Multi Photon Analysis

```
KamLAND Waveform Display  
Run/Subrun/Event : 113/0/304  
UT: Sun Feb 24 15:49:05 2002  
TimeStamp : 2578169707  
TriggerType : 0x3a10 / 0x2  
Time Difference 64.5 sec  
NumHit : 1124  
Channel : 3 BH(11)
```

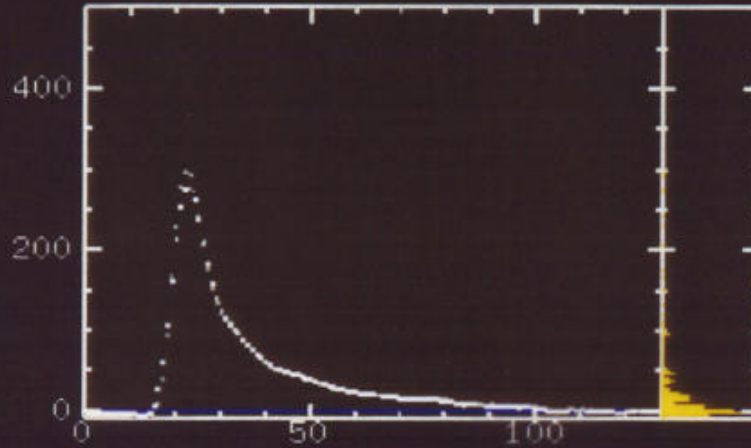


↑ leading edges ↑ found pulses

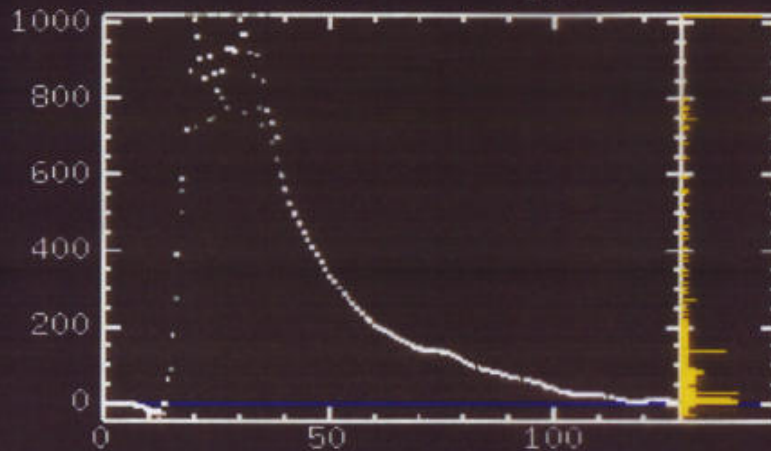
KamLAND Waveform Display

KamLAND Waveform Display
Run/Subrun/Event : 113/0/1499
UT: Sun Feb 24 15:49:19 2002
TimeStamp : 3146704014
TriggerType : 0xffffea21 / 0xffff0002
Time Difference 16.7 msec
NumHit : 1155
Channel : 1110 AH(13) AM(13) AL(13)

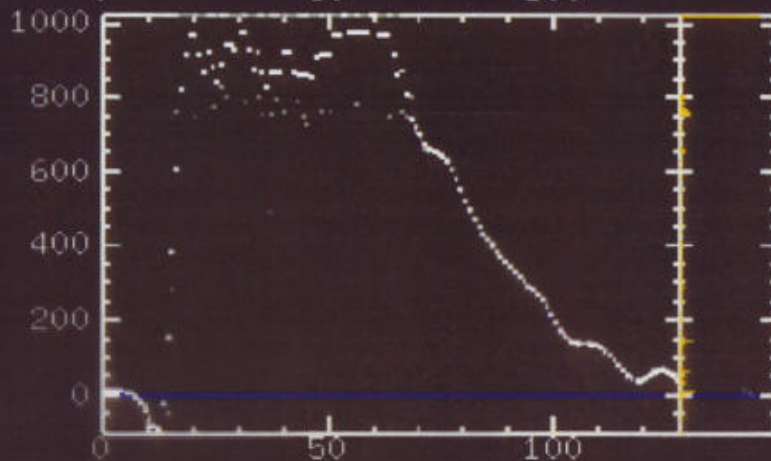
Low gain



Middle gain



High gain



Gain calibration for E-scale

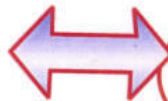
LED: 30 pieces are installed at peripheral positions in the detector,
PMT check @ 1pe level.

$$\longrightarrow 4.7 \times 10^6 \pm 6\%$$

N₂ dye laser & fiber flasher: larger light

Vertex check

Timing cal.: 500nm dye laser with a
diffuser ball for T-Q



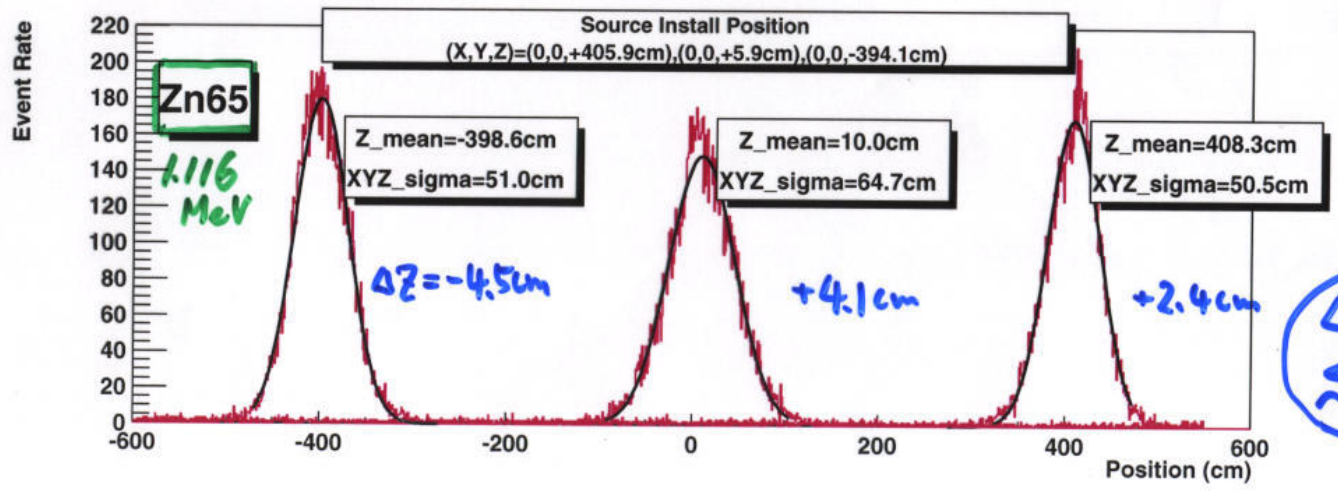
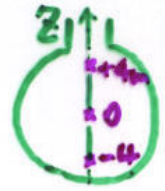
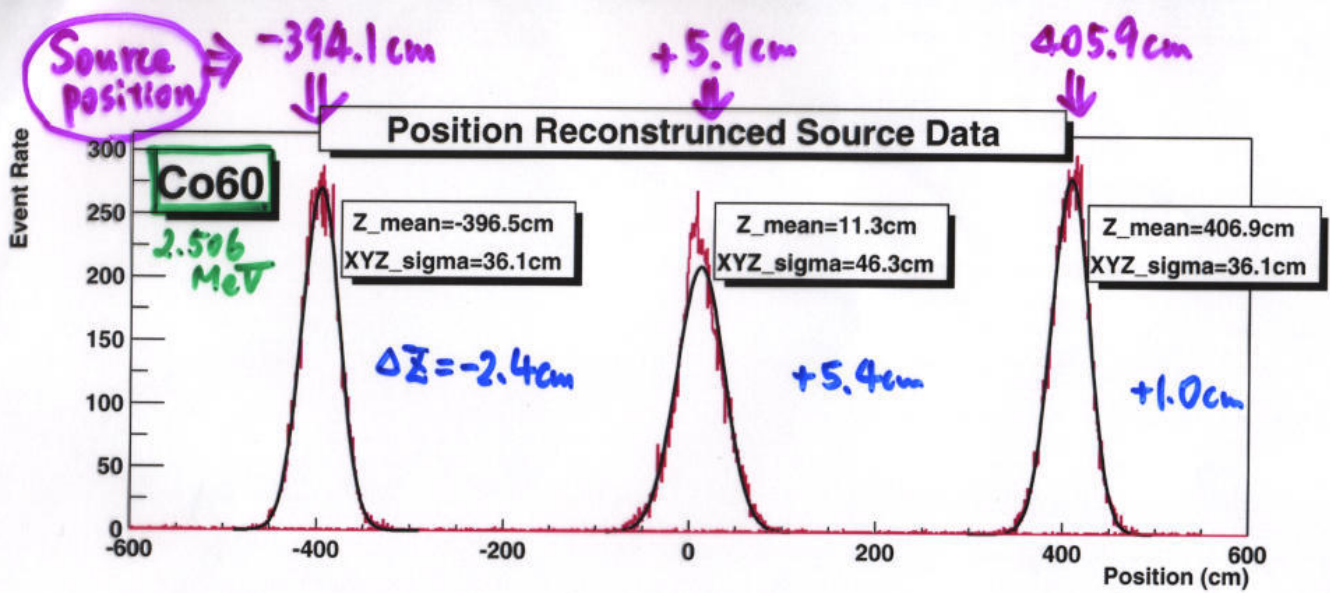
Source placed at different positions

⁶⁰Co: γ (1.173+1.333)

⁶⁵Zn: γ (1.116)

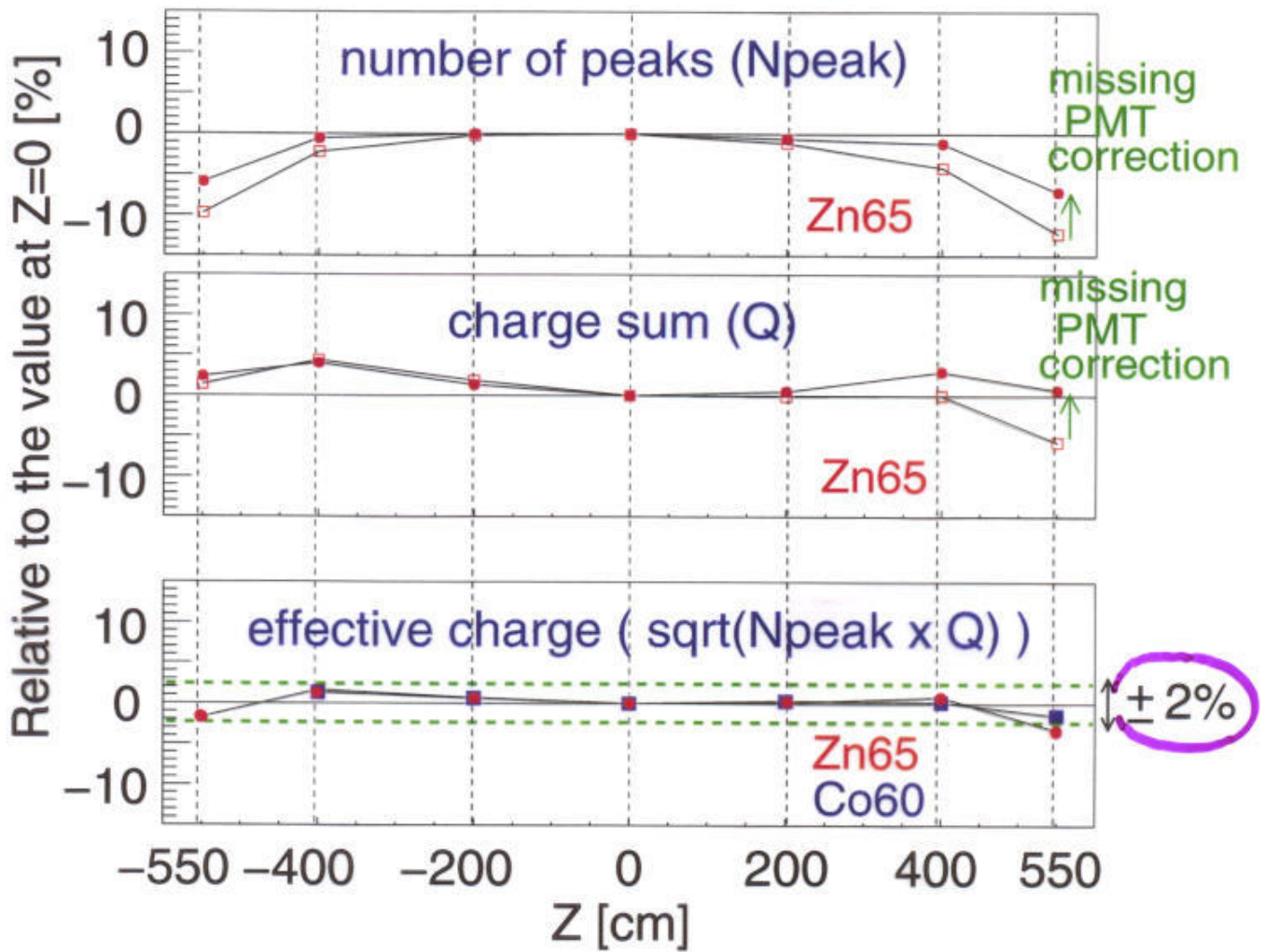
Background studies

Rn+U/Th/K, n from μ -ons, ...
and hit distributions

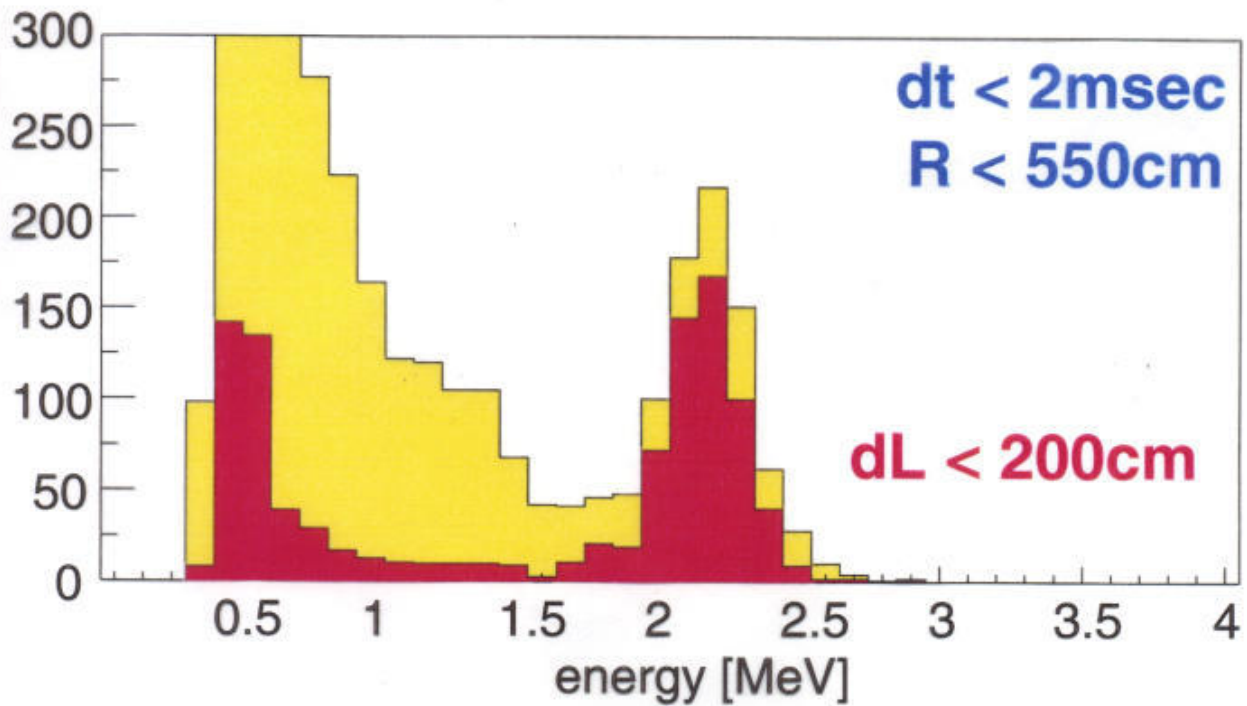
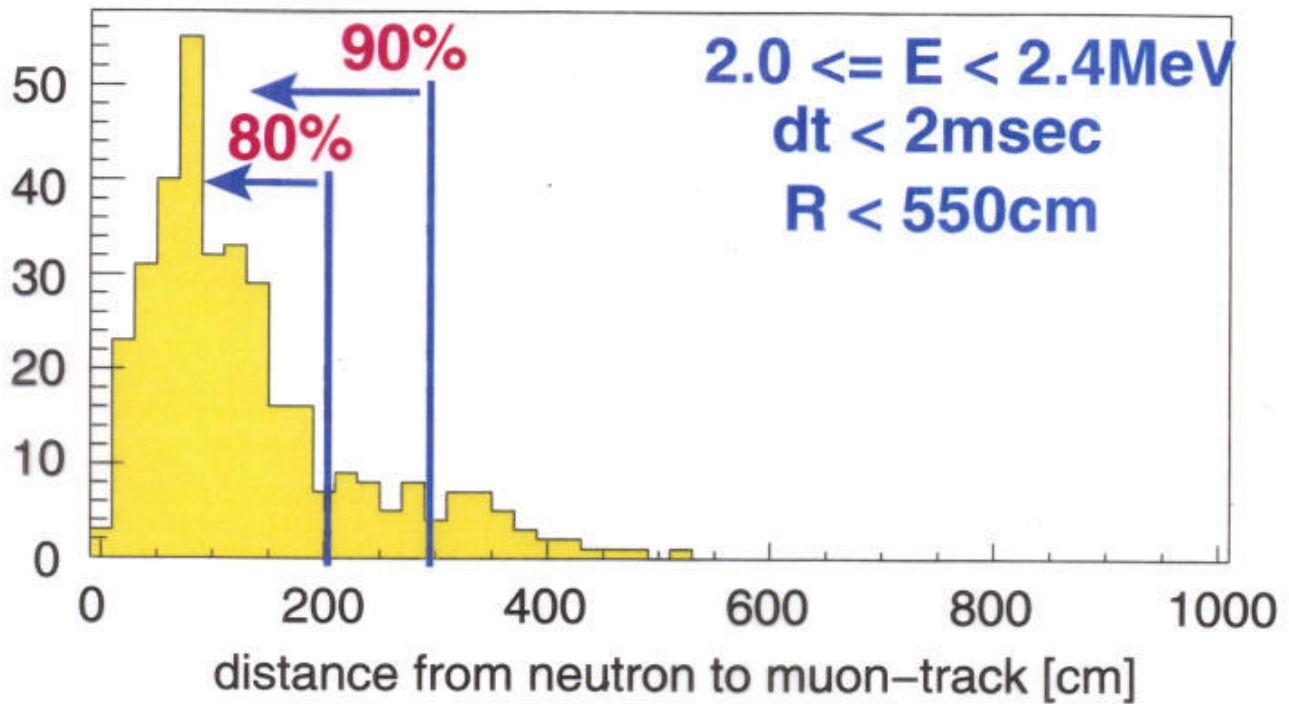


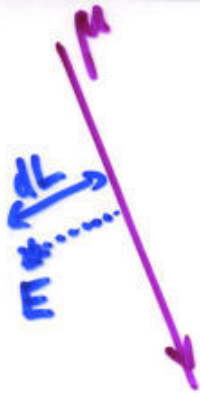
ΔZ -shift $\lesssim 5\text{ cm}$

Z-dependence at Source calibration

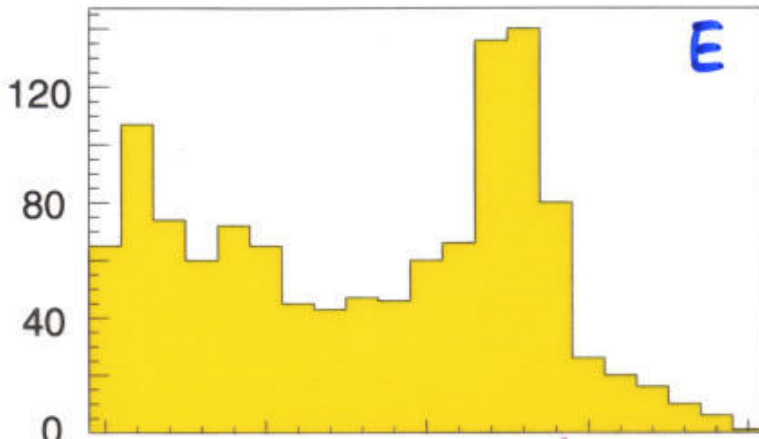


Neutrons from μ spallation of ^{12}C

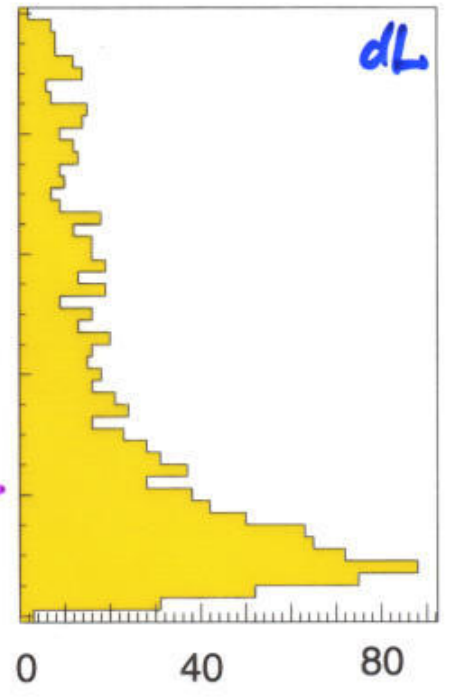
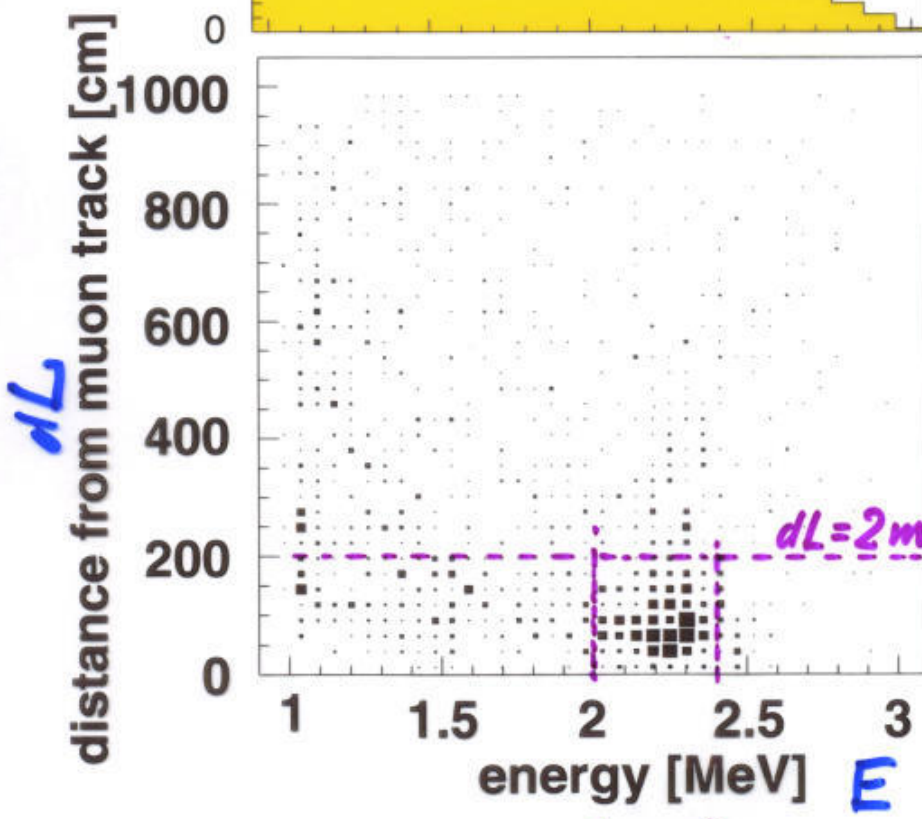




Neutrons from
 μ spallation of ^{12}C

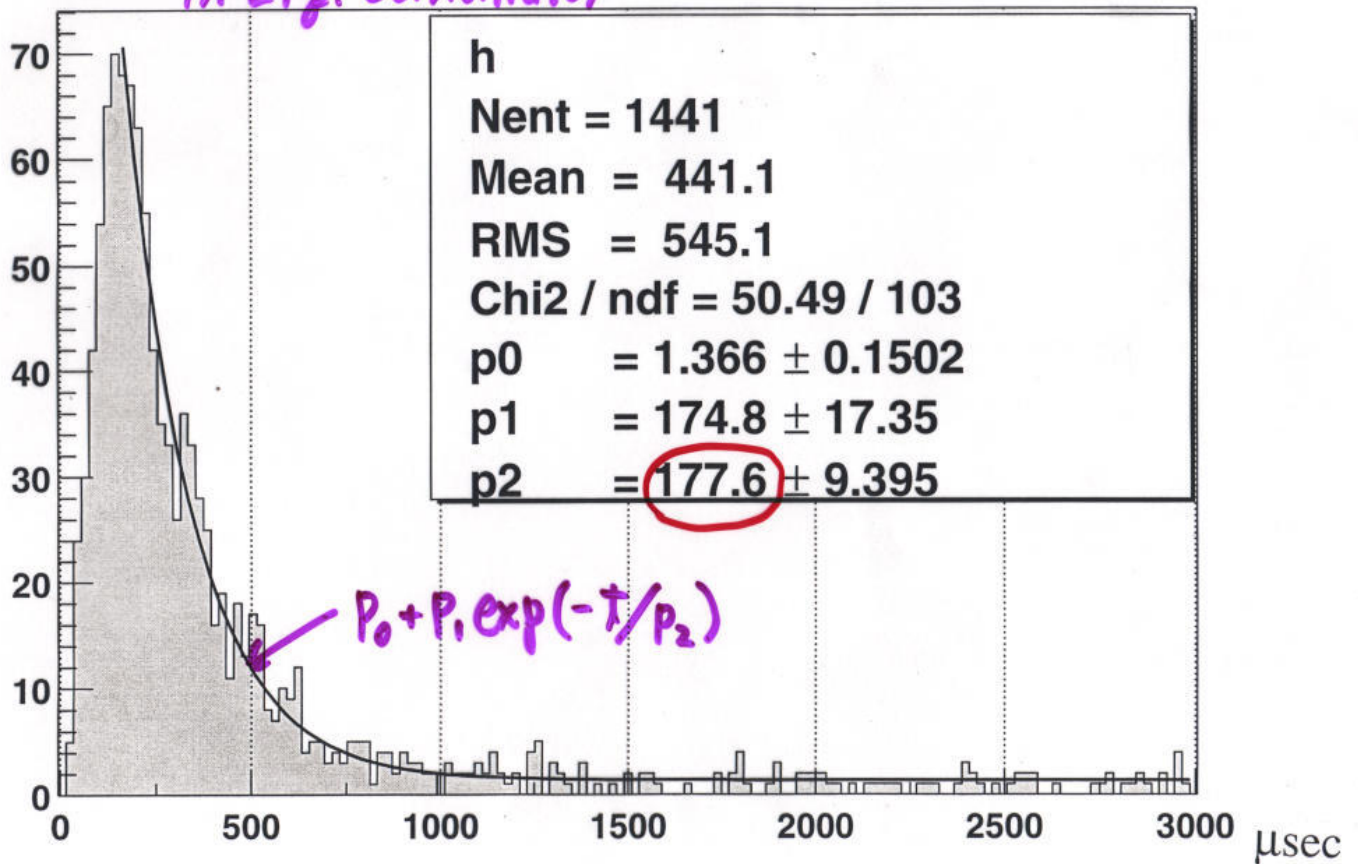


$dt < 2\text{msec}$
 $R < 550\text{cm}$



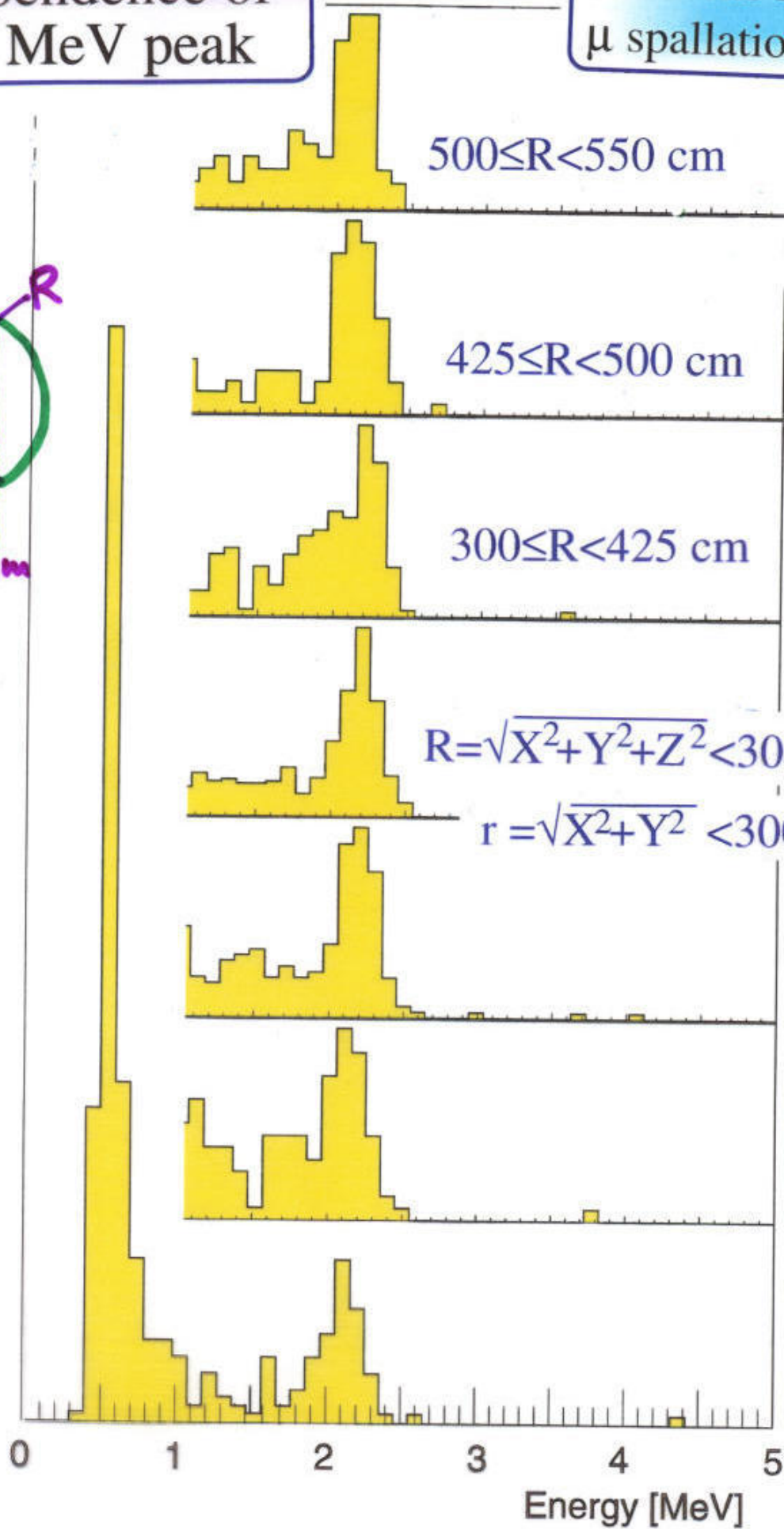
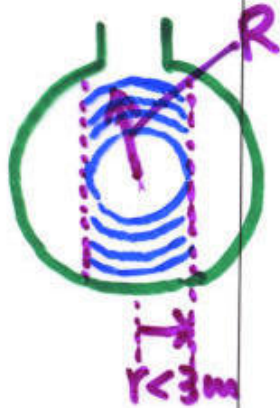
$2 \leq E < 2.4\text{MeV}$

"Neutron life" $\sim 180 \mu\text{sec}$
in Liq. Scintillator



Z-dependence of
2.2 MeV peak

Neutrons from
 μ spallation of ^{12}C



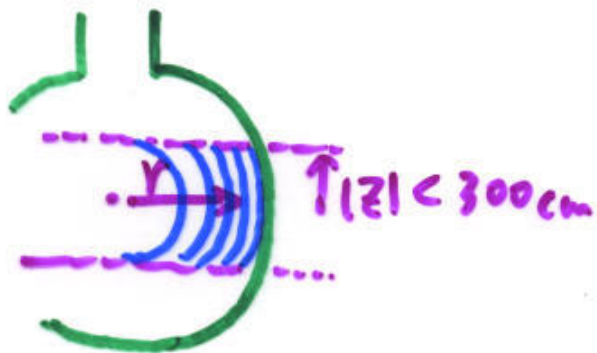
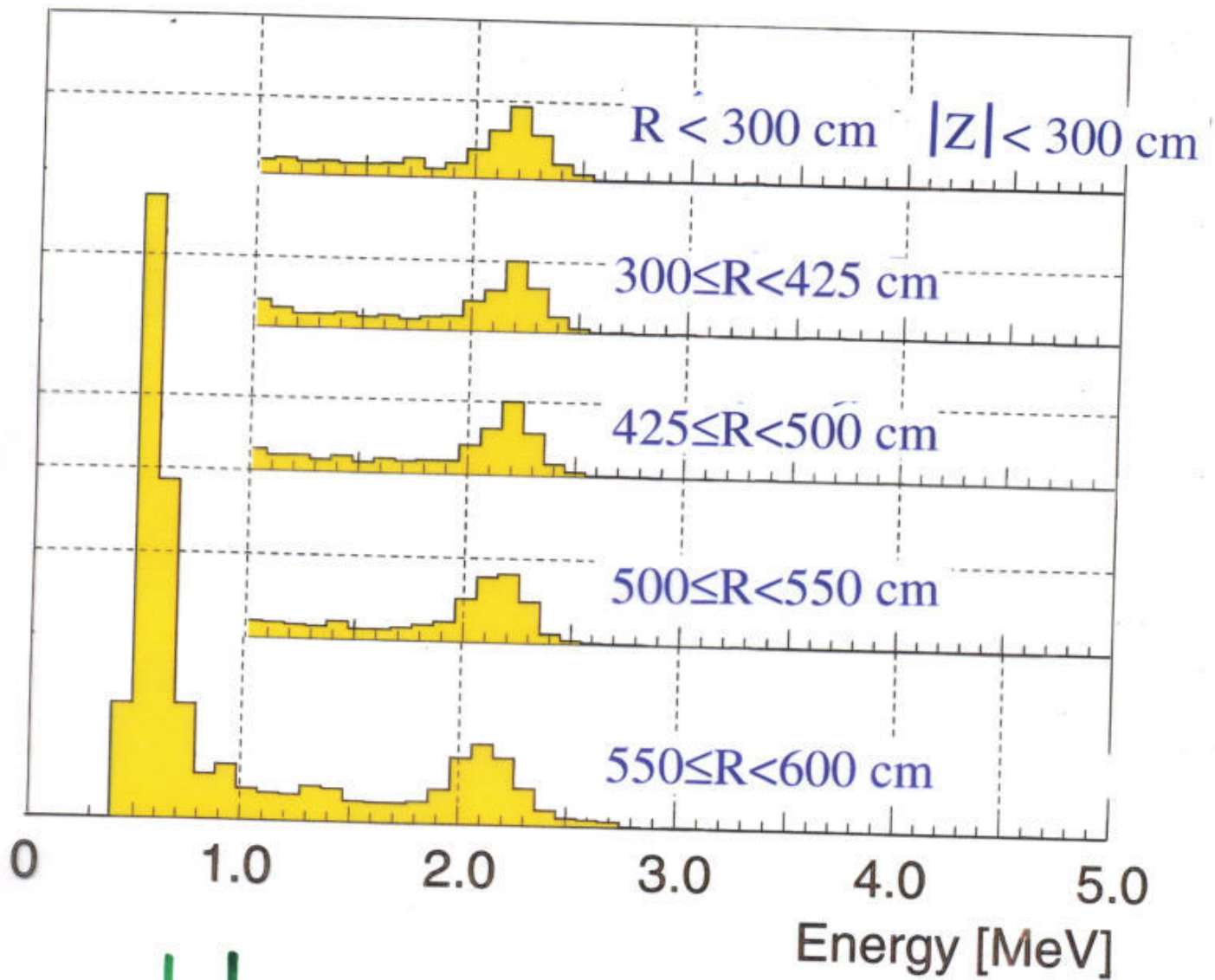
top
↑

↓
bottom

Energy [MeV]

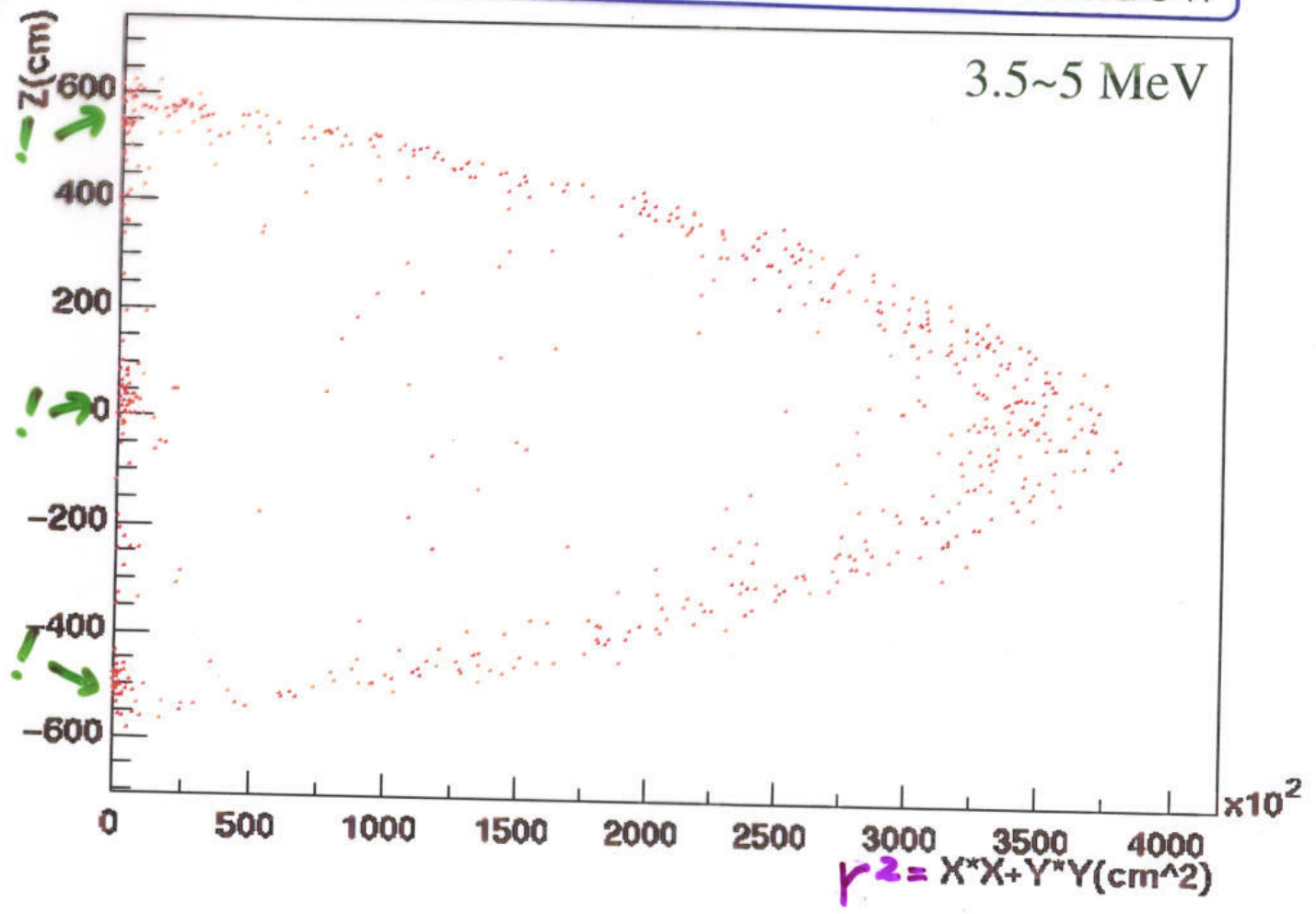
Neutrons from spallation of ^{12}C

r-dependence of
2.2 MeV peak

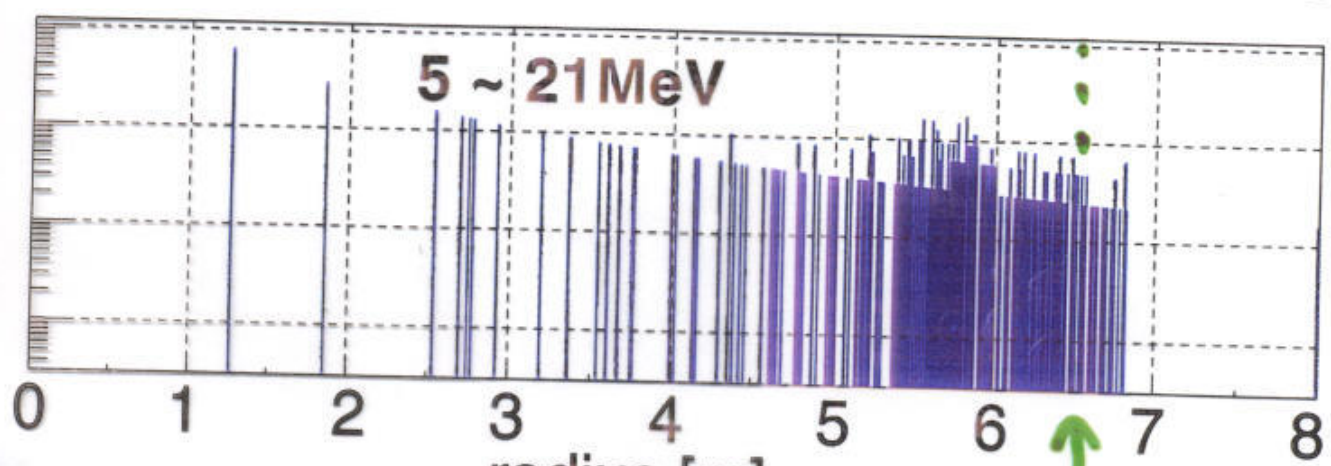
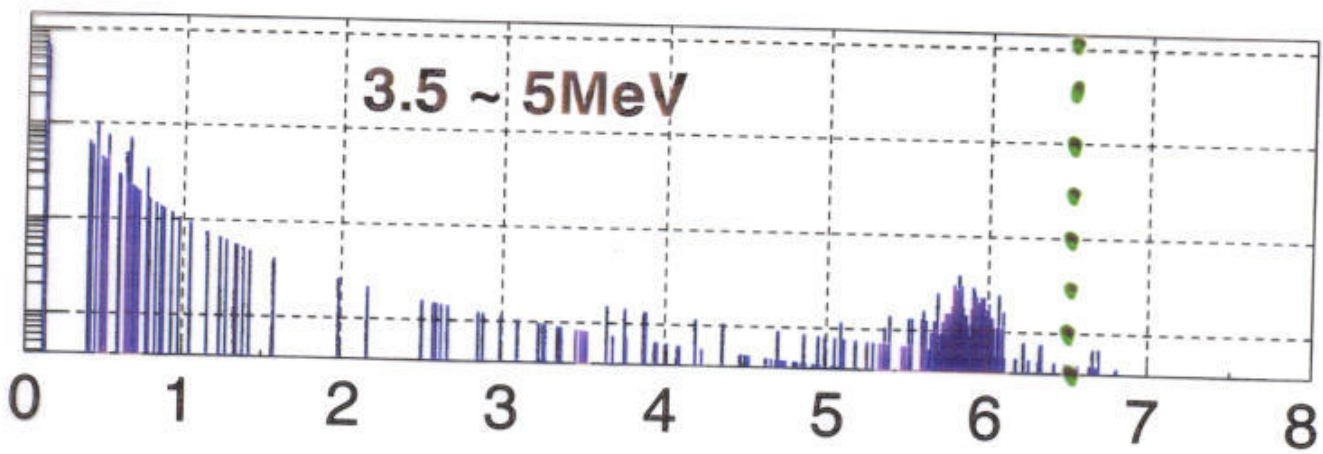
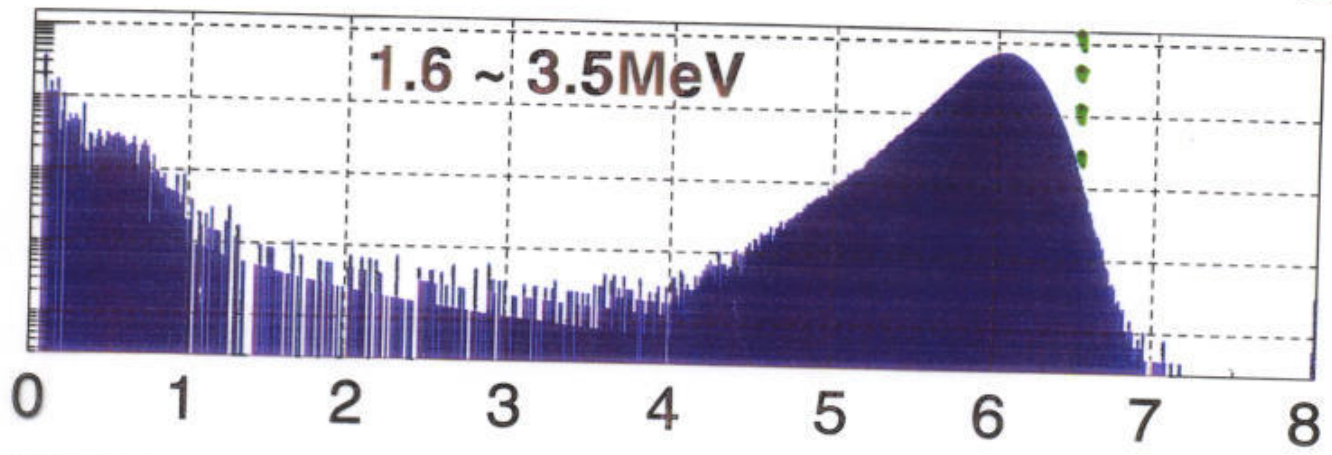
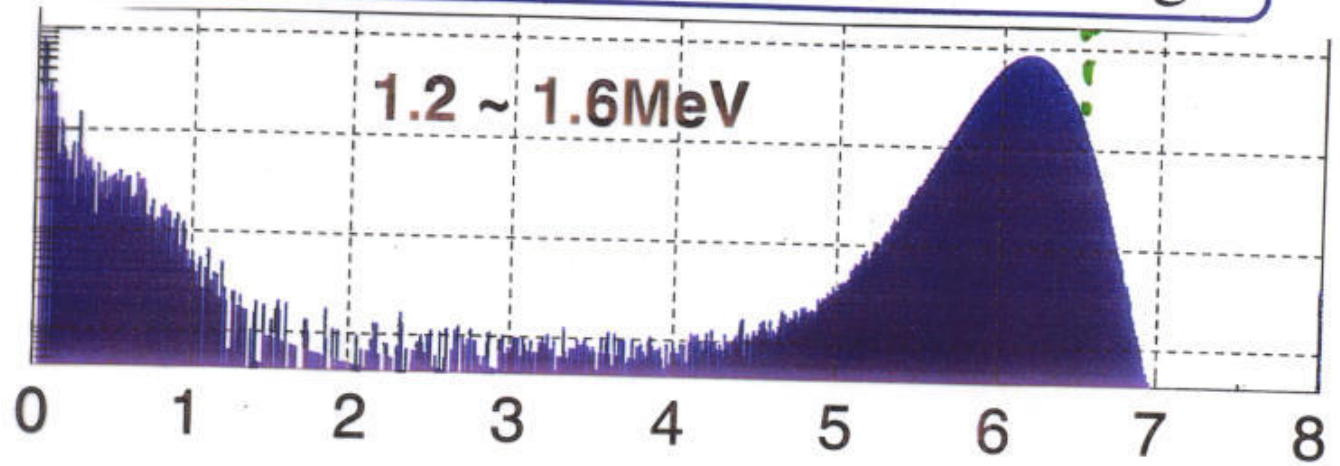


Graph

Vertex distribution for ^{208}Tl window



Vertex R distribution with $1/R^2$ weight

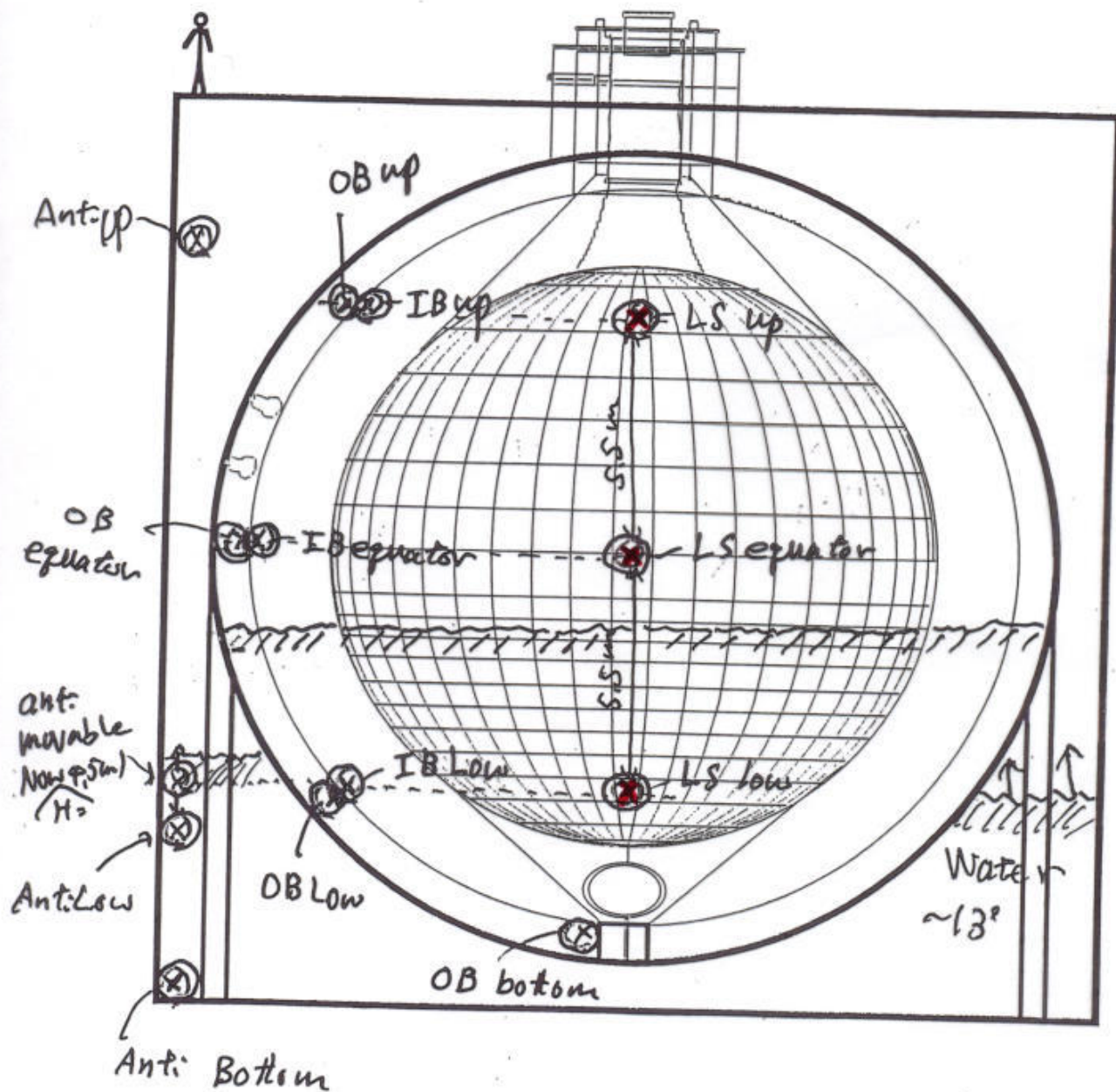


radius [m]



Balloon

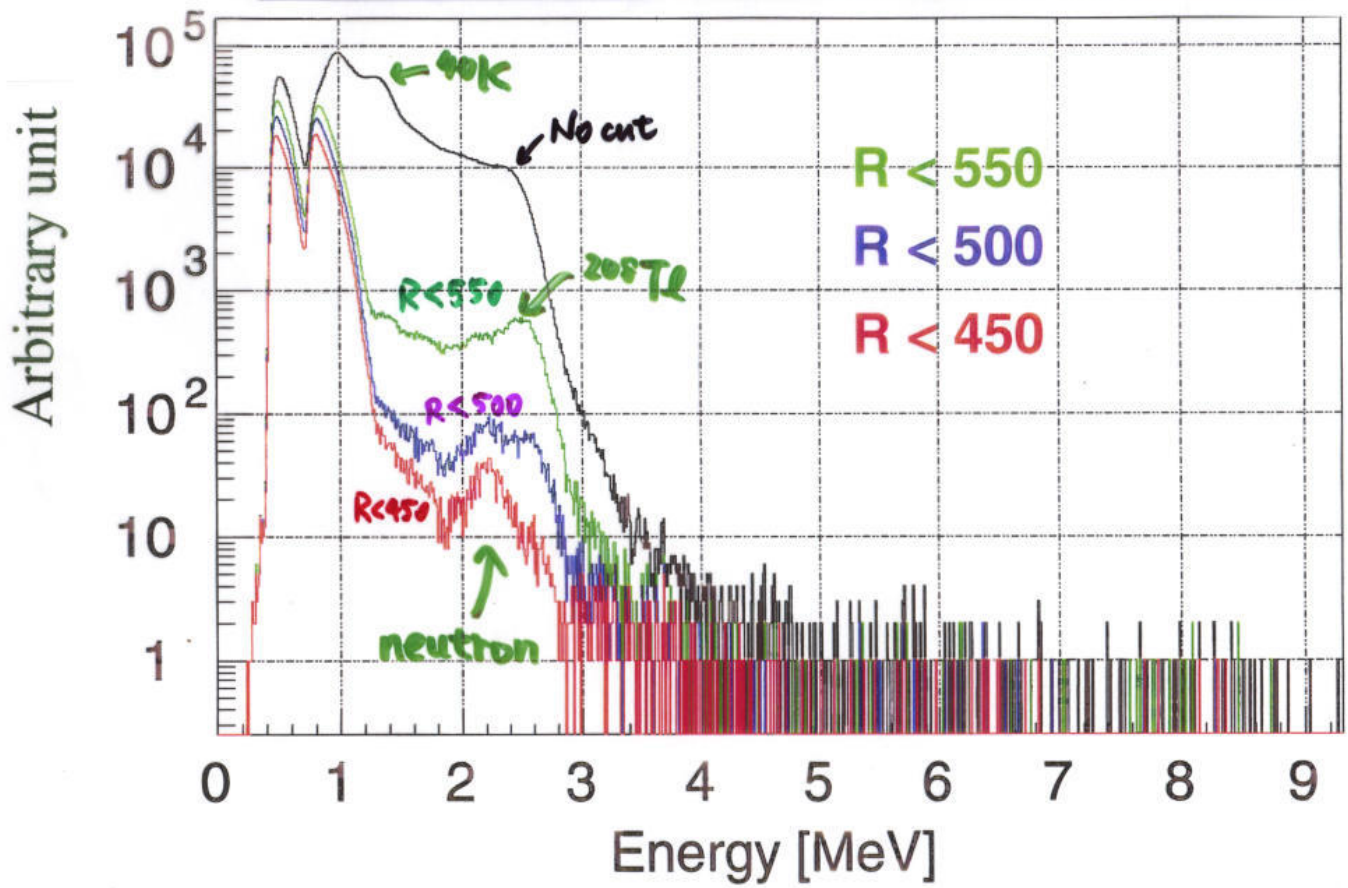
Positions of Pt thermo tips (14 thermo tips)

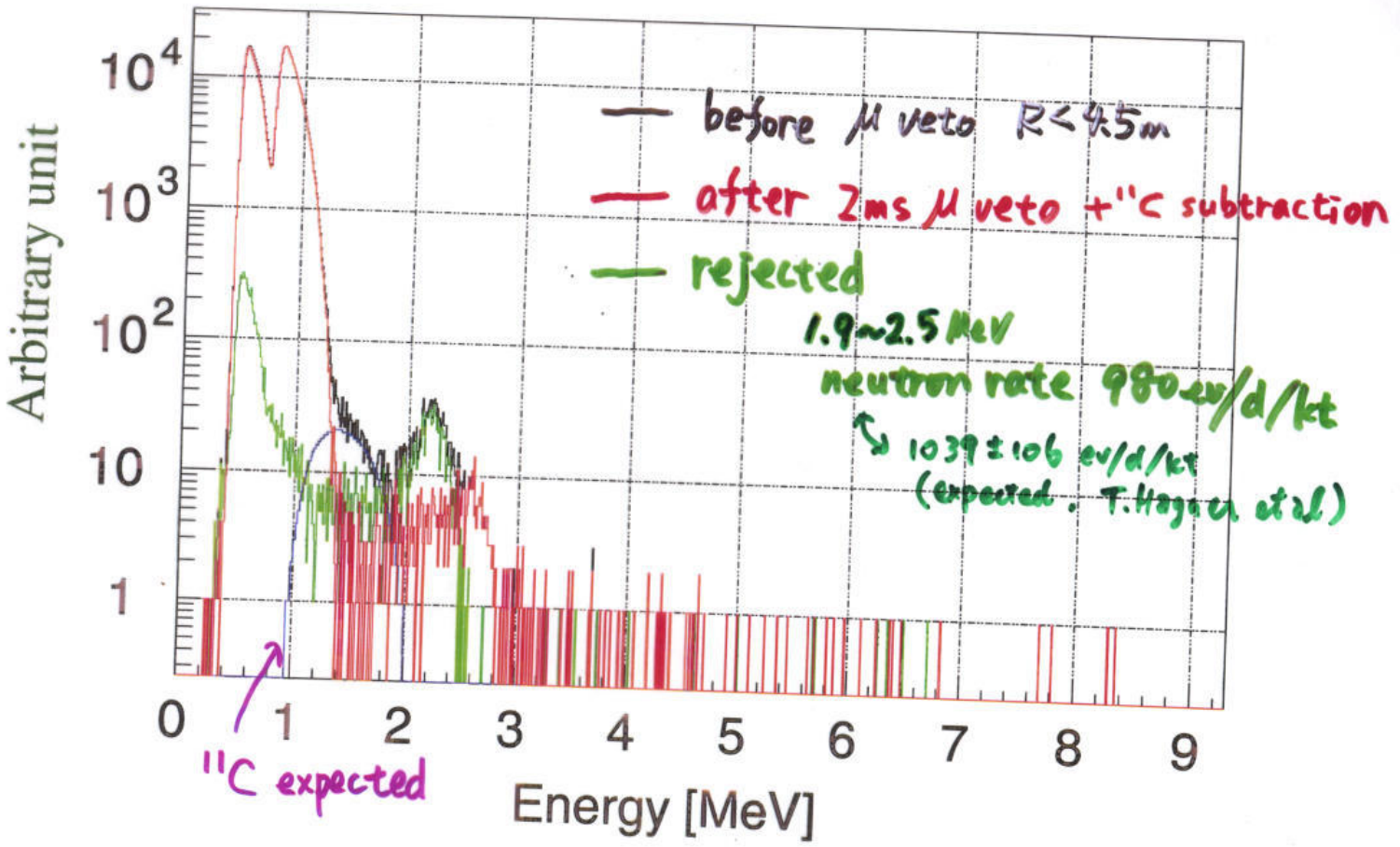


Pt thermometers are suspended at
 $Z = 5.5, 0, -5.5\text{m}$.

(Pt w/ stainless capsule)

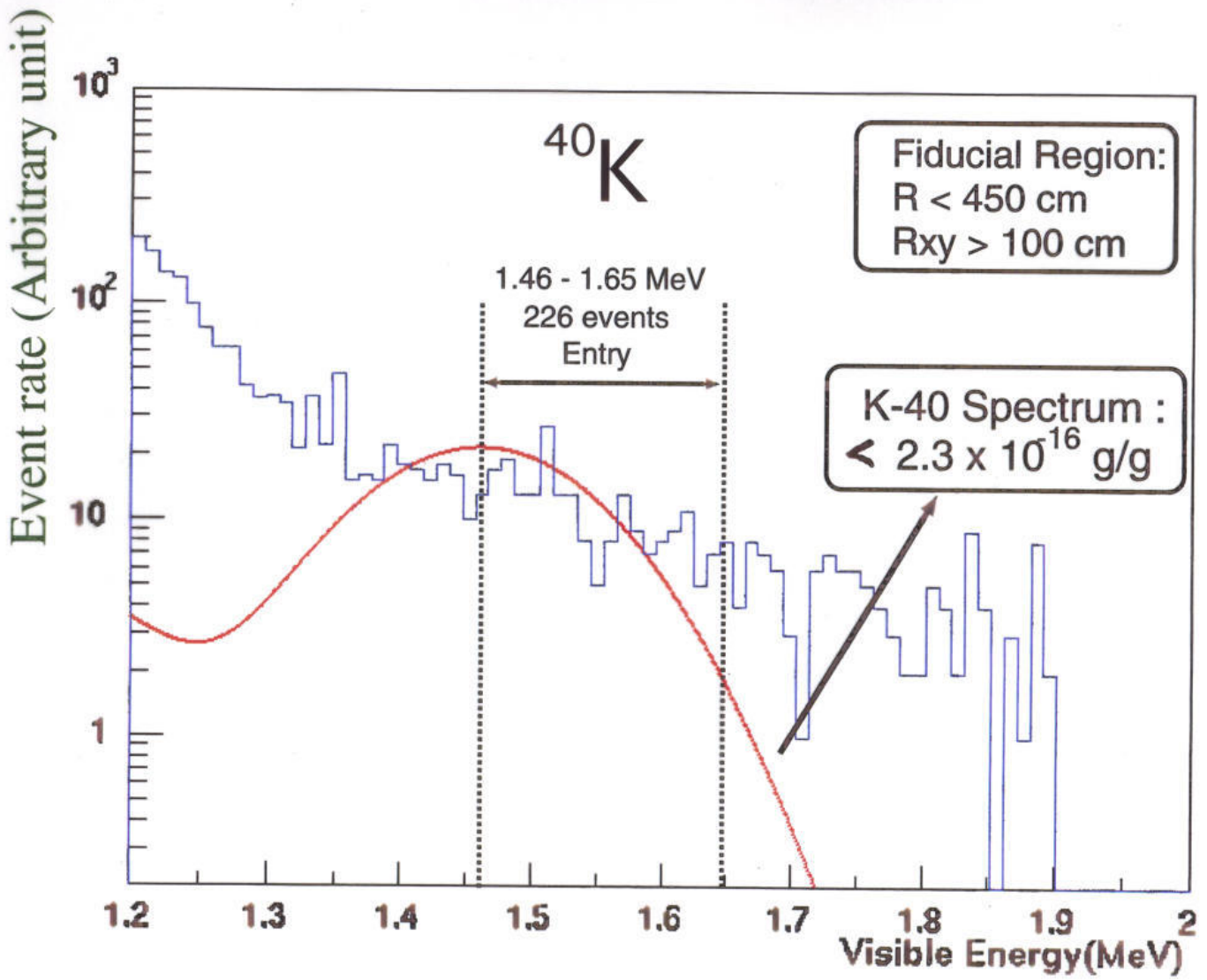
Energy spectra with various fiducial volume

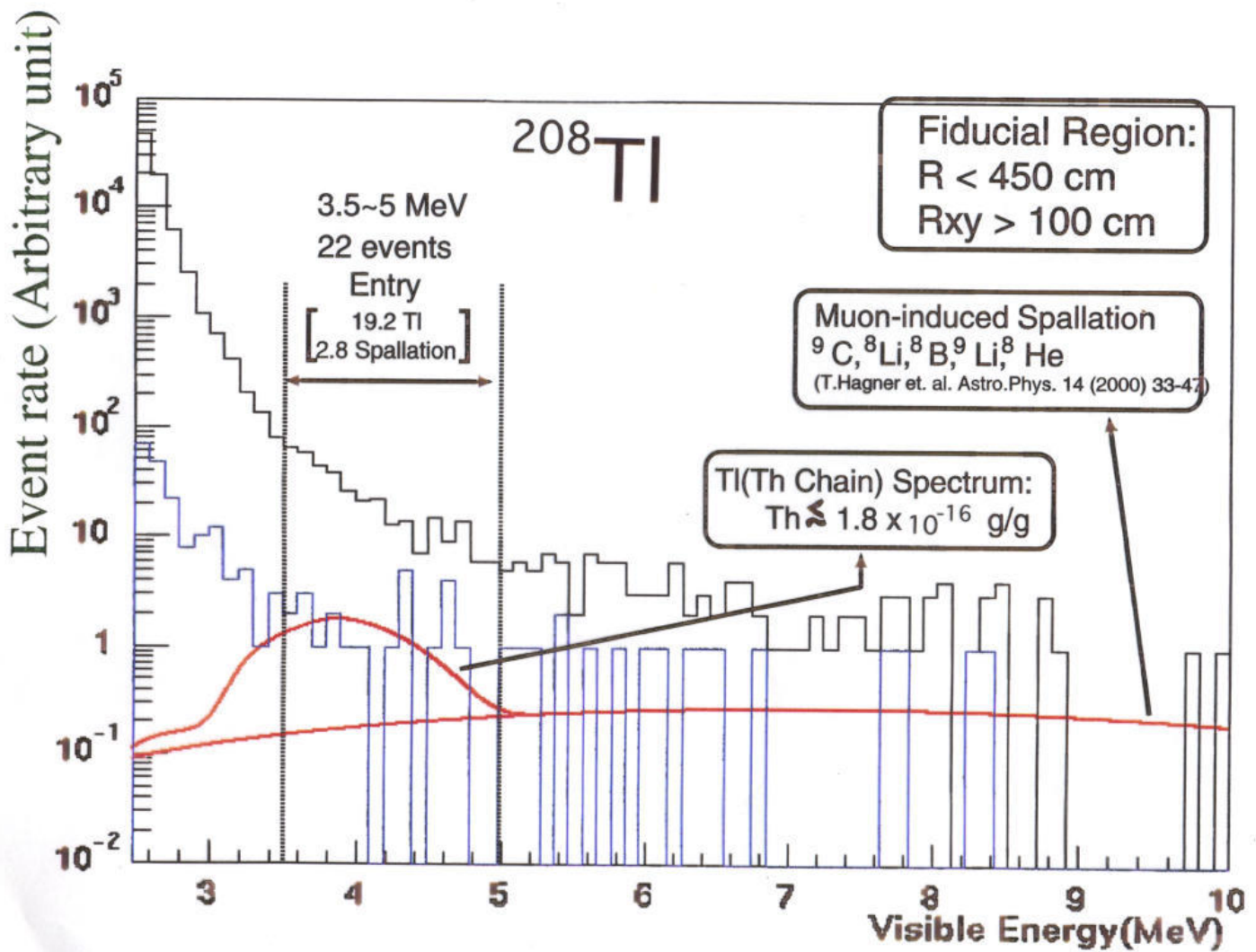




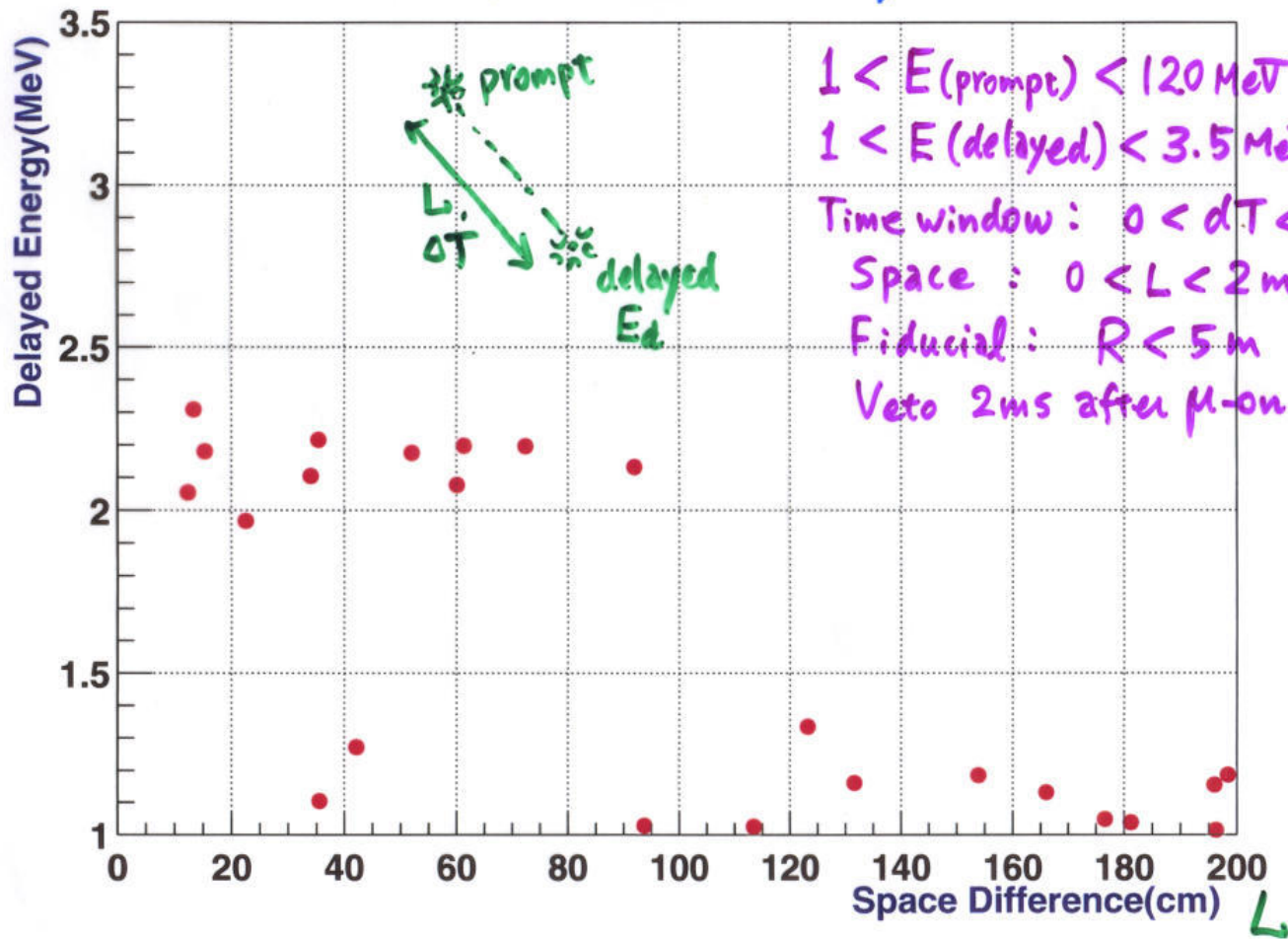
^{10}C is not subtracted yet.

$^{222}Rn \lesssim 4 \mu Bq / m^3$

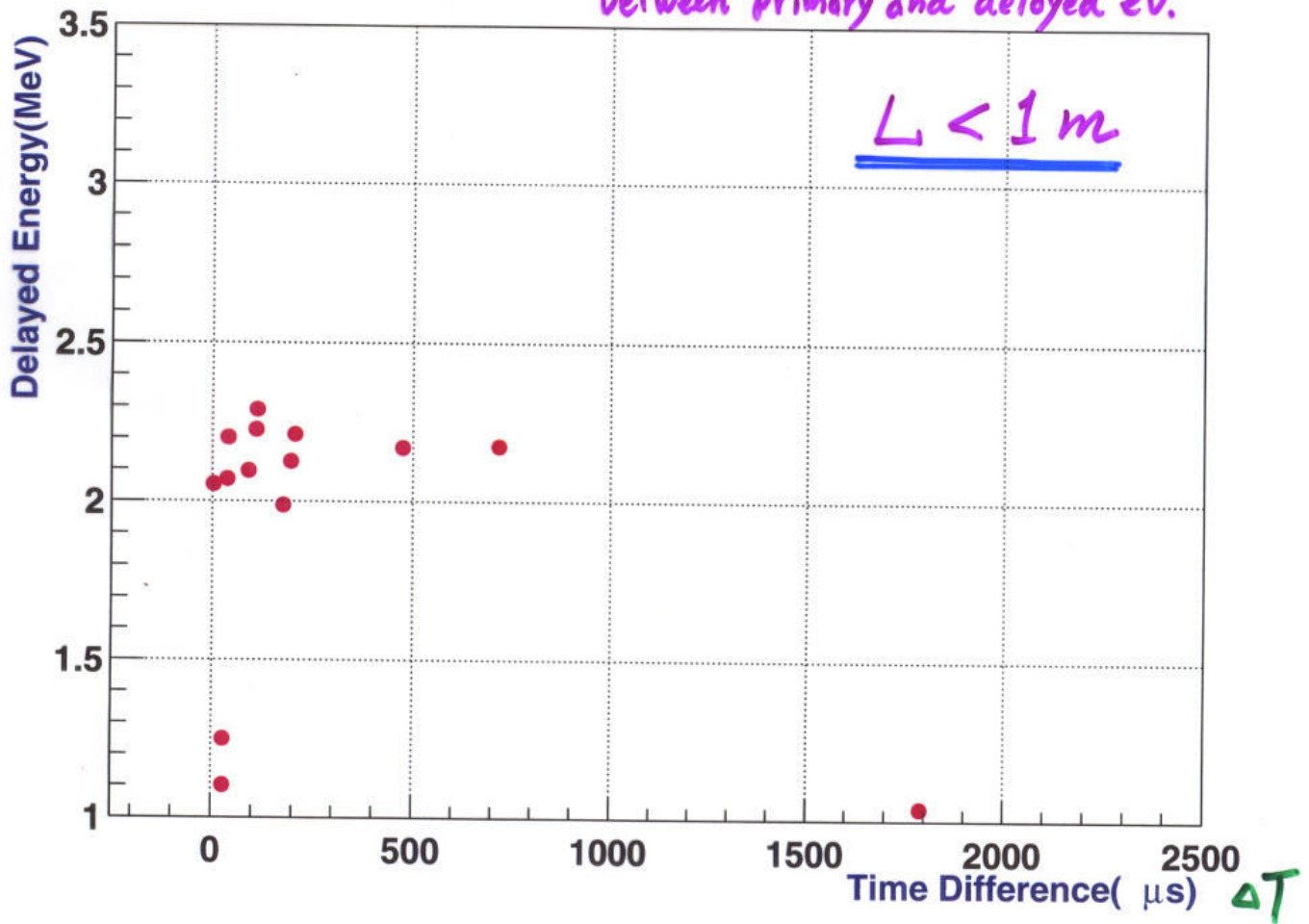




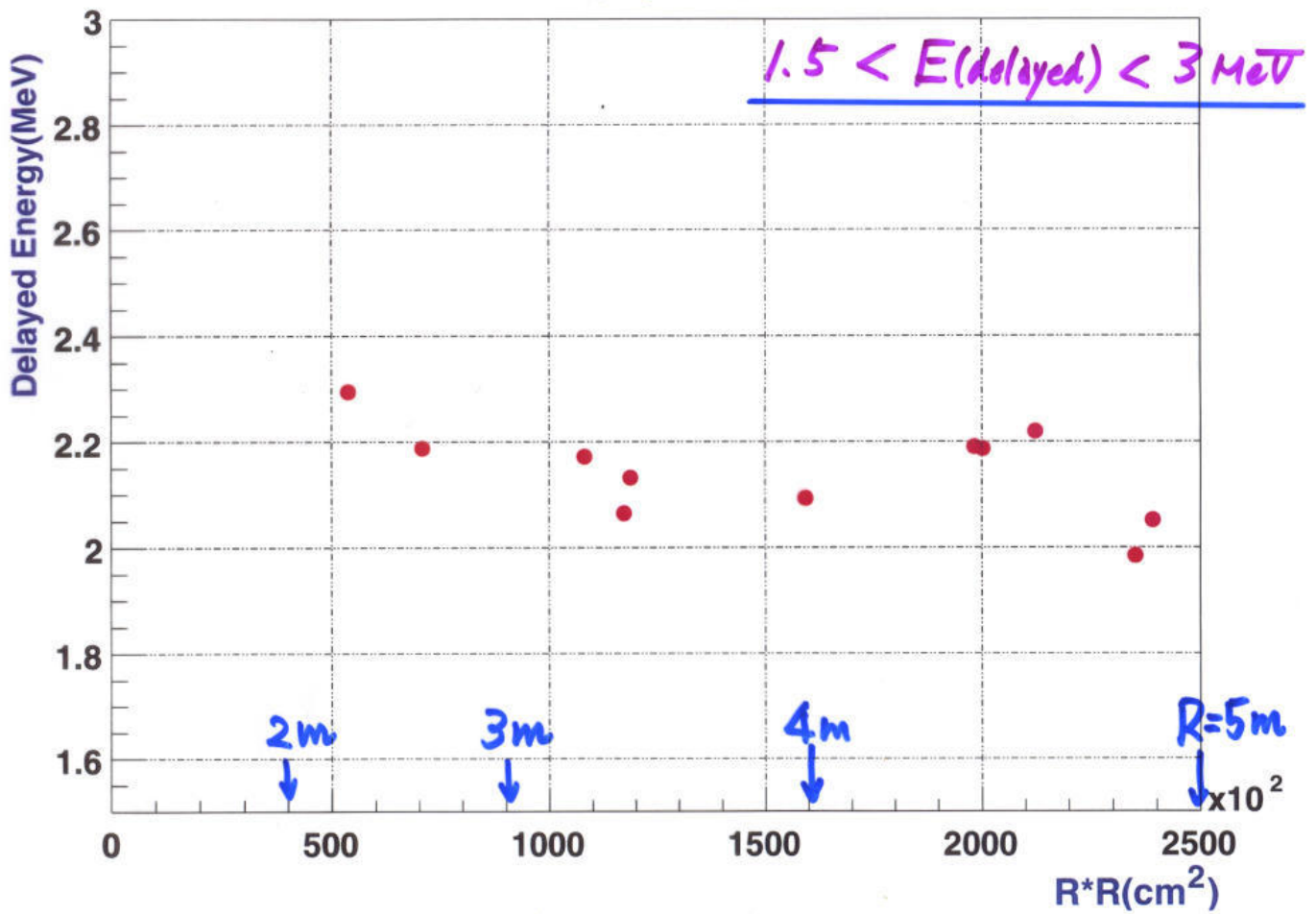
E (delayed) VS Space difference
 (Distance betw. primary & delayed ev.)



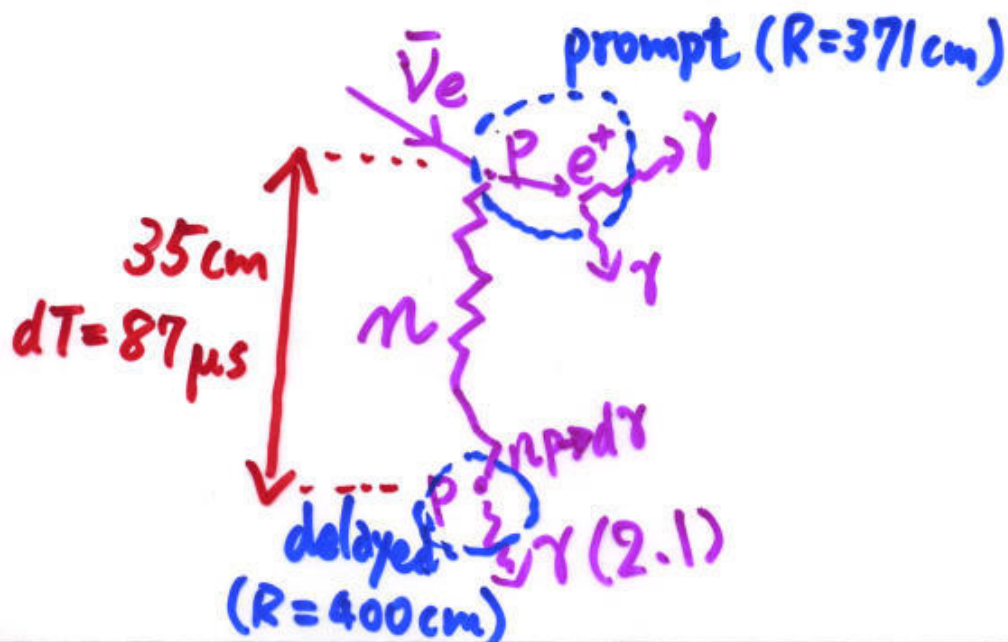
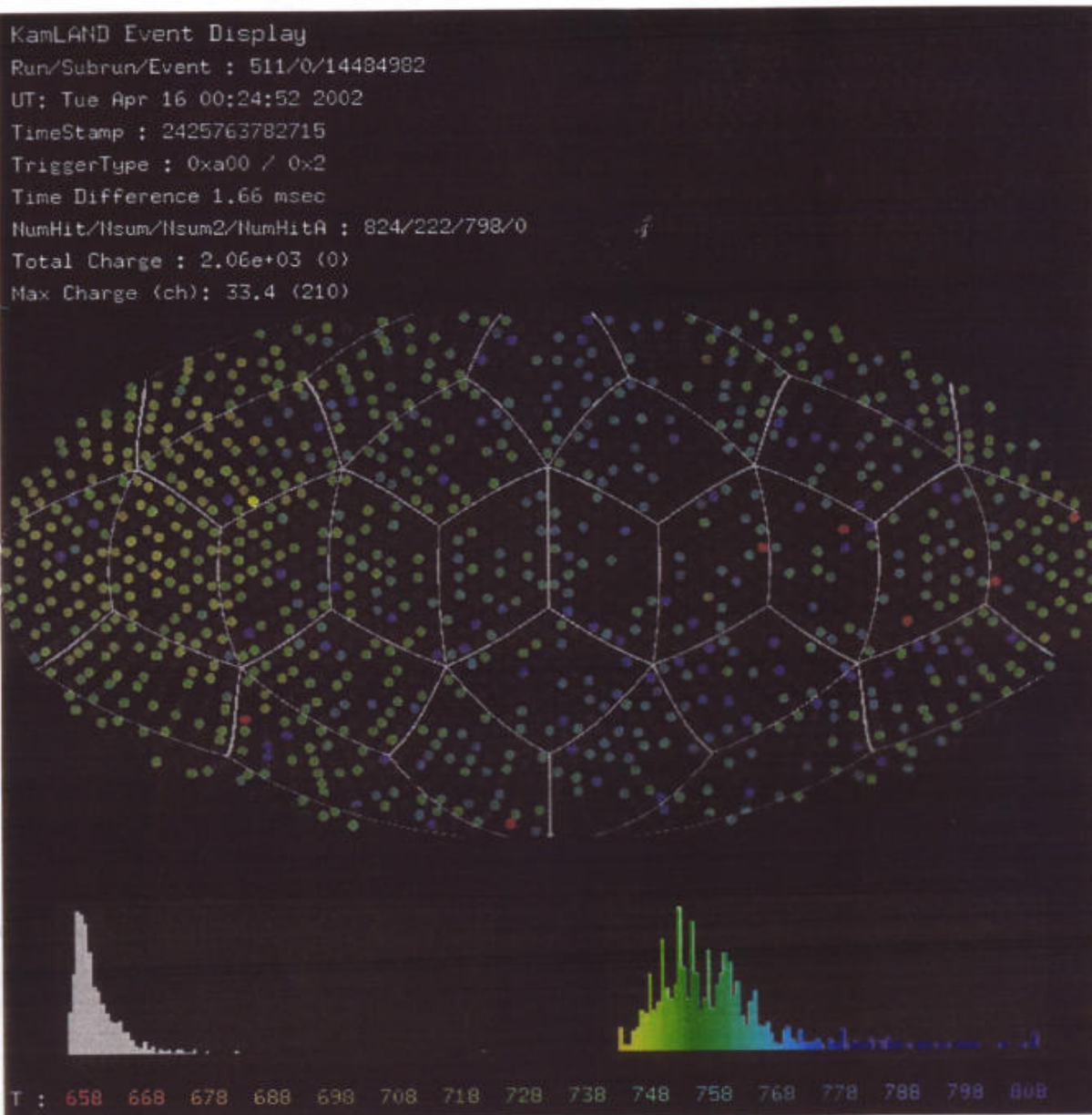
*E(delayed) vs Time difference
between primary and delayed ev.*



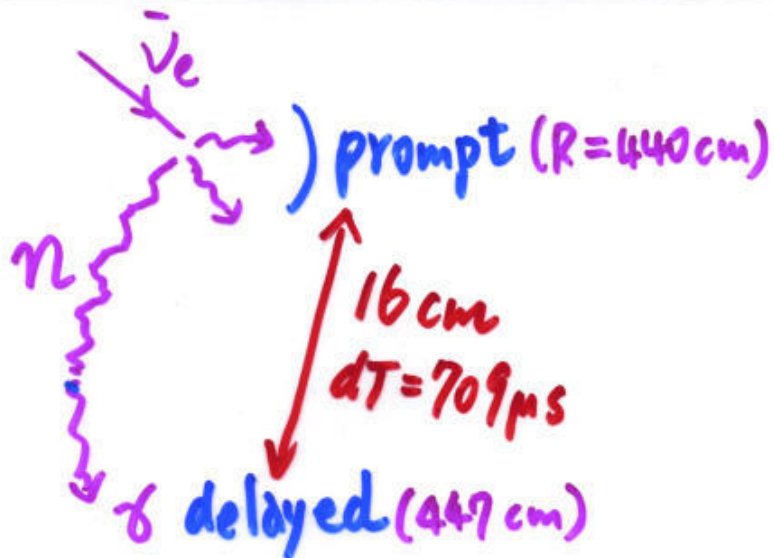
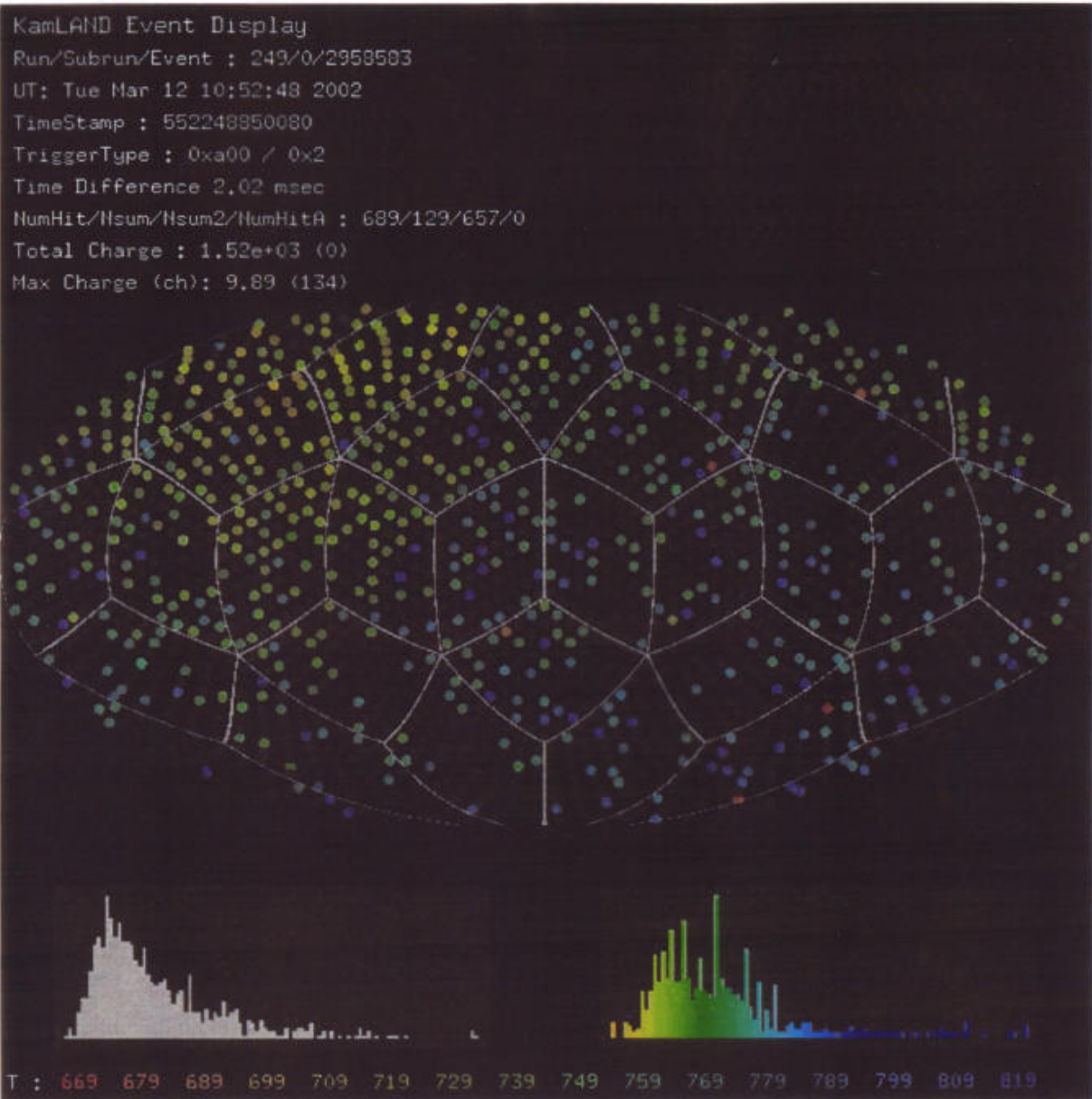
$E(\text{delayed})$ vs. Event position for $\bar{\nu}_e$ candidates
($R \neq 2$)



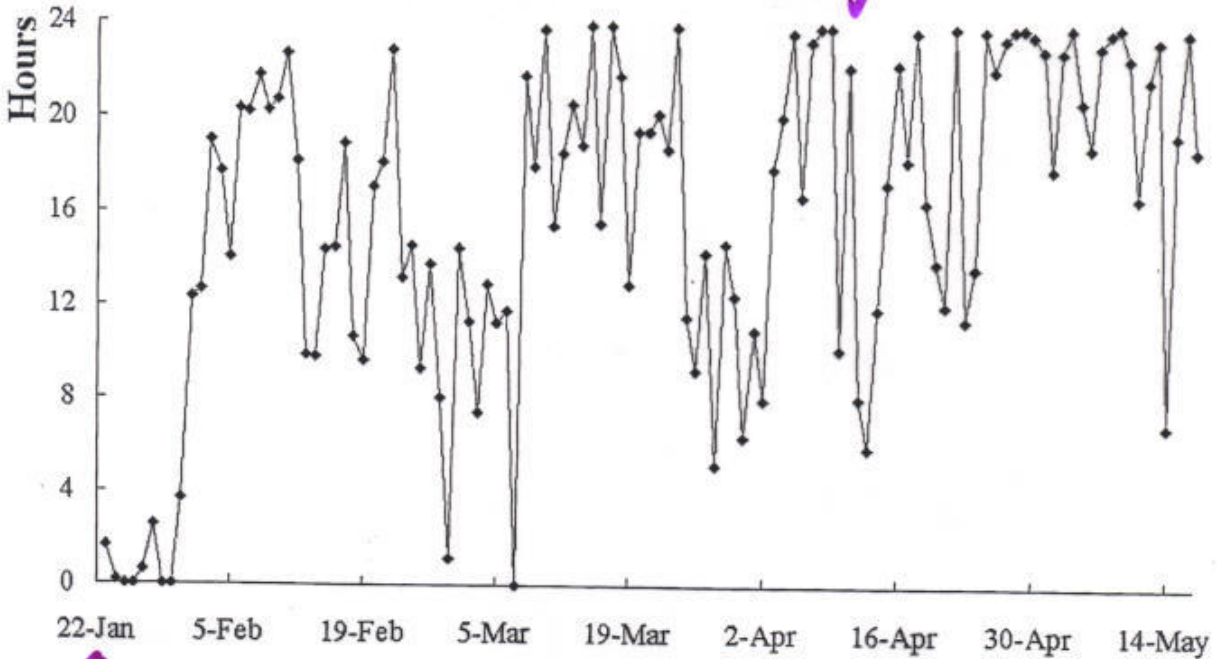
$\bar{\nu}_e$ candidate (prompt)



$\bar{\nu}_e$ candidate (prompt)

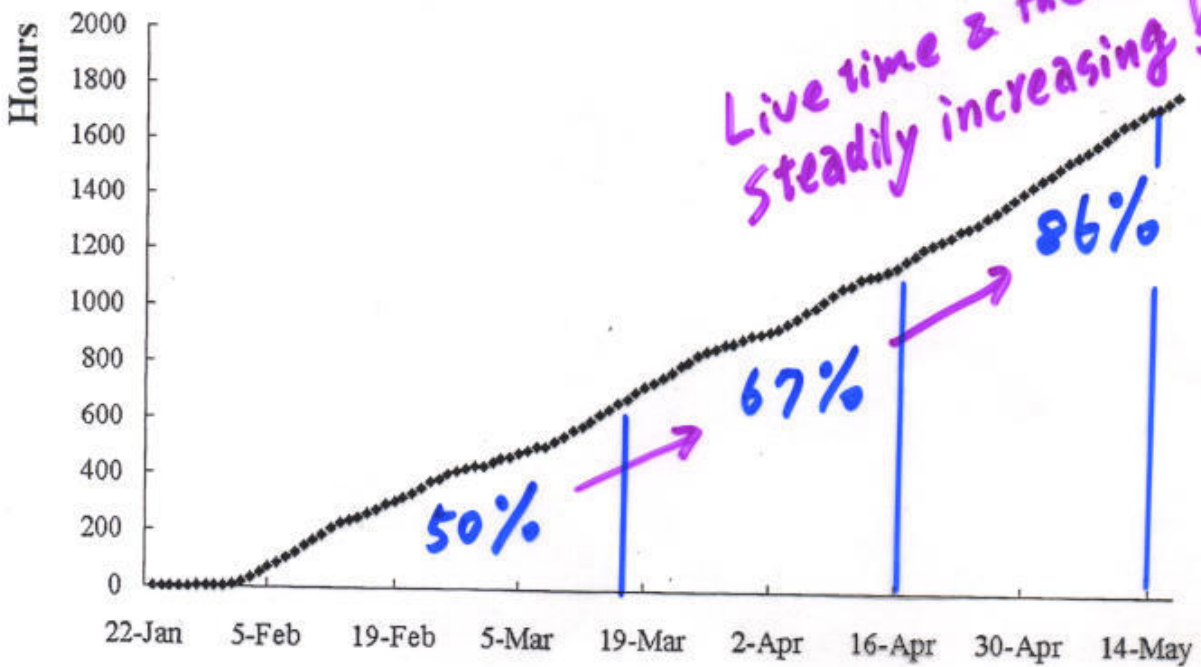


Physics Live Time /day



↑
KamLAND started!

Total Live Time



Live time & the eff. steadily increasing!

50%

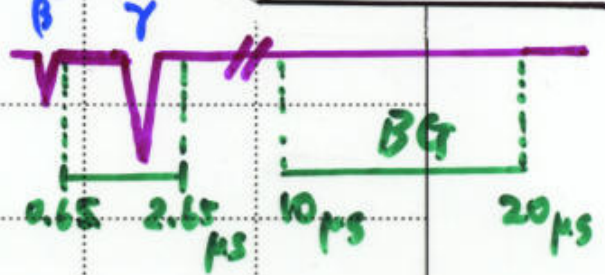
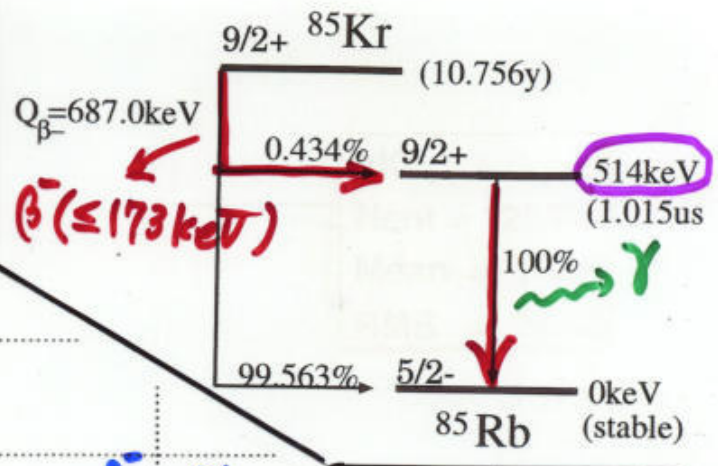
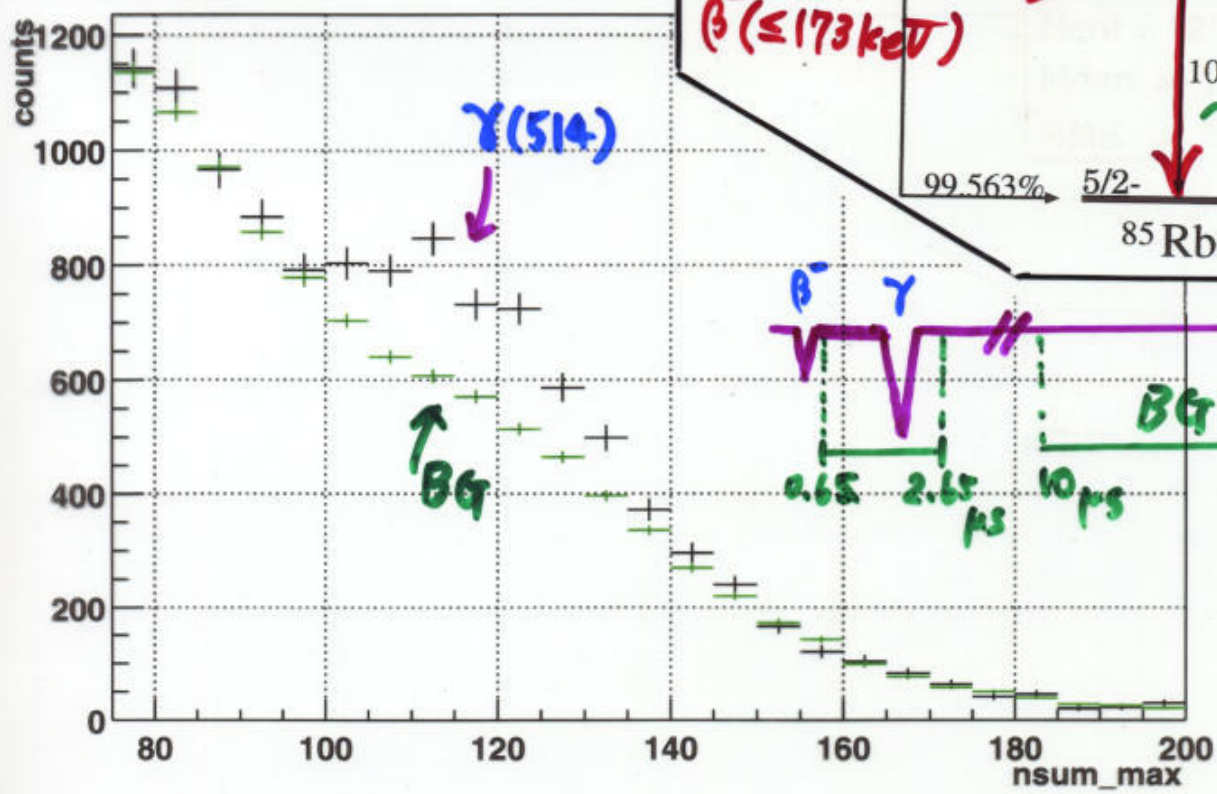
67%

86%

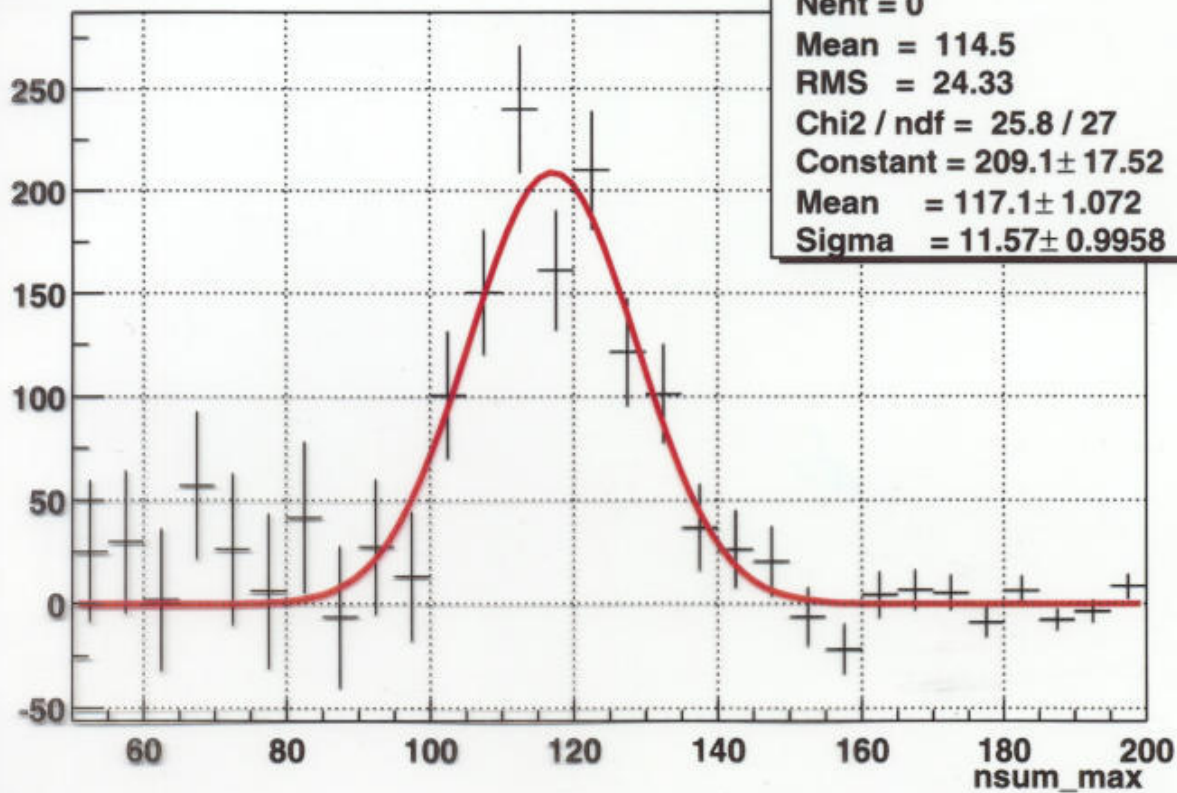
Summary

- After 4 years' construction and oil filling periods, KamLAND has started data taking on Jan.22,2002.
- Detector has shown excellent performance with small systematics and very low backgrounds required for reactor neutrino experiment.
- Further studies on background reduction are ongoing for ${}^7\text{Be}$ solar neutrino detection.
- **Exciting results will come soon !!**

Kr85 gamma



Kr85 gamma



h
 Nent = 0
 Mean = 114.5
 RMS = 24.33
 Chi2 / ndf = 25.8 / 27
 Constant = 209.1 ± 17.52
 Mean = 117.1 ± 1.072
 Sigma = 11.57 ± 0.9958