KamLAND experiment

Tadao Mitsui

Research Center for Neutrino Science, Tohoku Univ.

- Introduction
- data analysis
- summary

KamLAND Collaboration Institutes

14 Institutes,
96 collaborators

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

KamLAND
Kamioka Liquid scintillator Anti-Neutrino Detector

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

$\nu_e \rightarrow \nu_x$ (^{8}B 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 $\overline{\nu}_e$ (LMA)

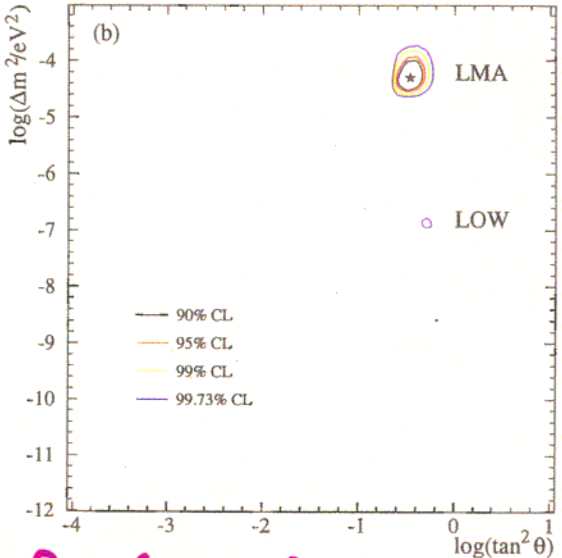
7Be Solar ν_e (SMA LOW VAC)

KamLAND → Geo $\overline{\nu}_e$

KamLAND → Supernova $\nu, \overline{\nu}$

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

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



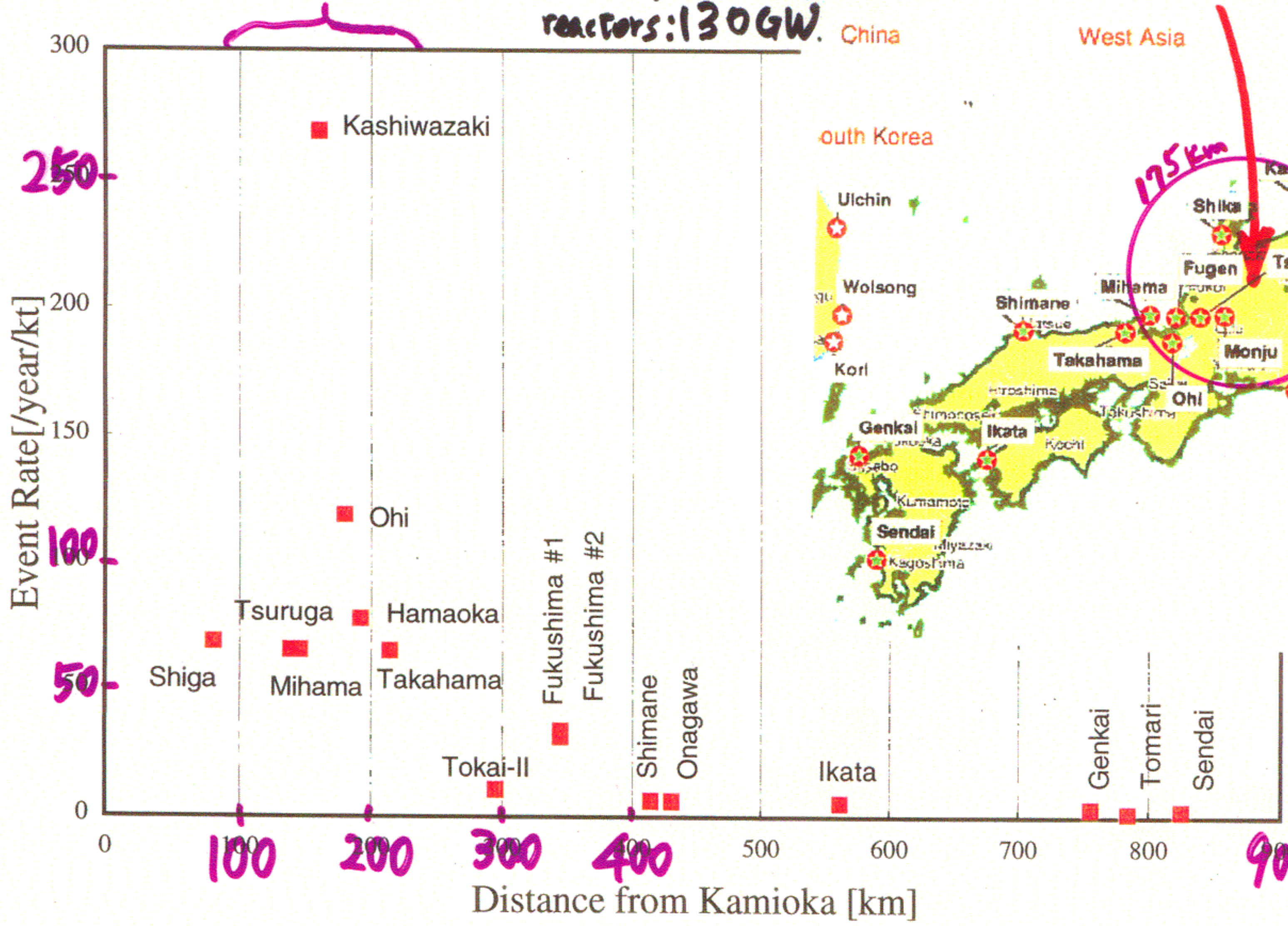
Best fit { $\tan^2\theta = 0.34$, $\Delta m^2 = 5\times10^{-5}$ eV^2 }

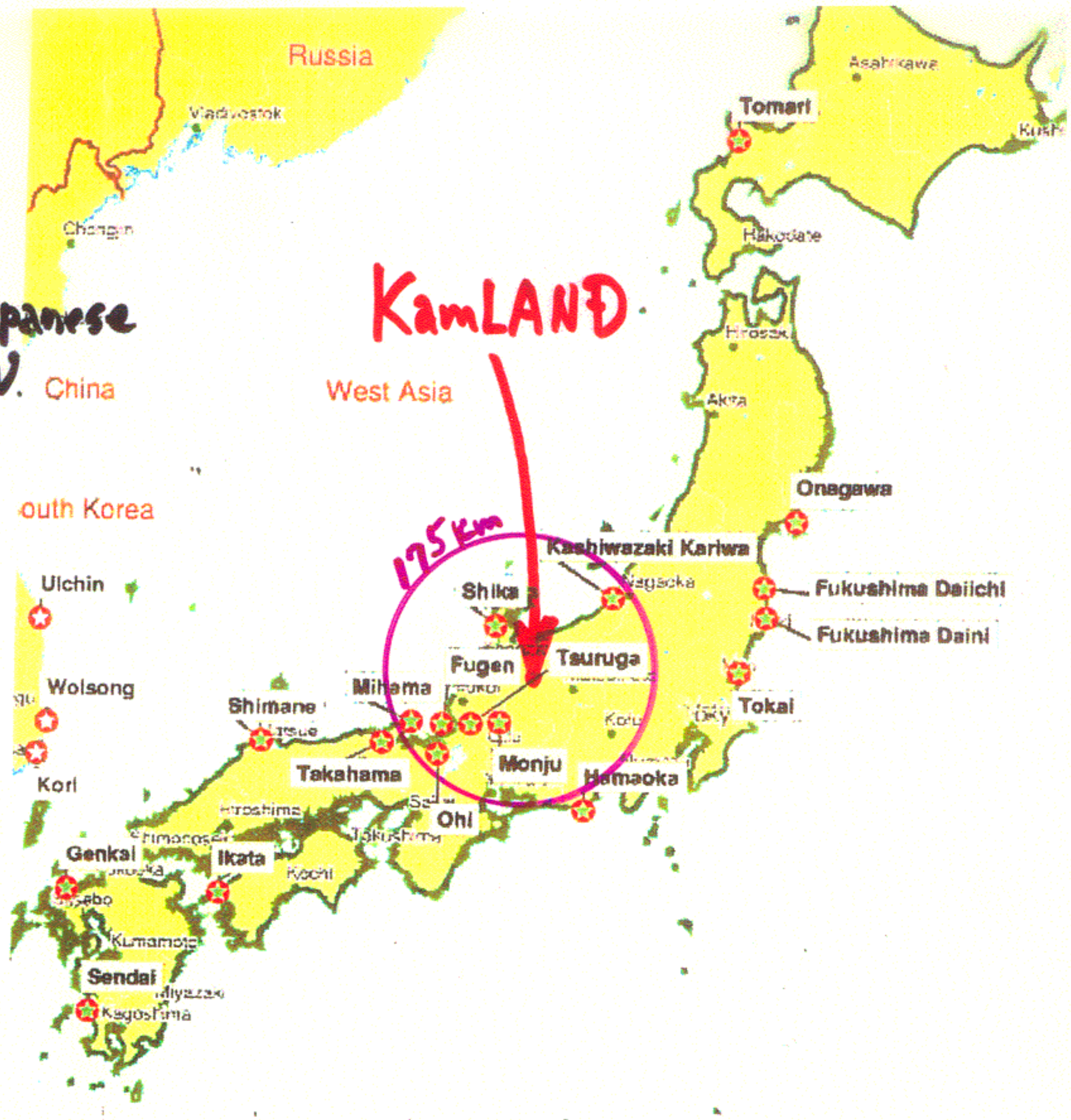
Kamioka:

80% of Φ_ν from reactors (70 GWth)

$\leq 175 \pm 35$ km

↑ total Japanese reactors: 130 GW.





$\bar{\nu}_e$ Detection

$$\bar{\nu}_e\, p \rightarrow e^+ n \quad (E_\nu > 1.8\text{MeV})$$

- $e^+ e^- \rightarrow 2\gamma$ (0.51MeV) "Prompt" $(= E_\nu - 0.77\text{MeV})$
- 180μs: $np \rightarrow d\gamma$(2.2MeV) "Delayed"

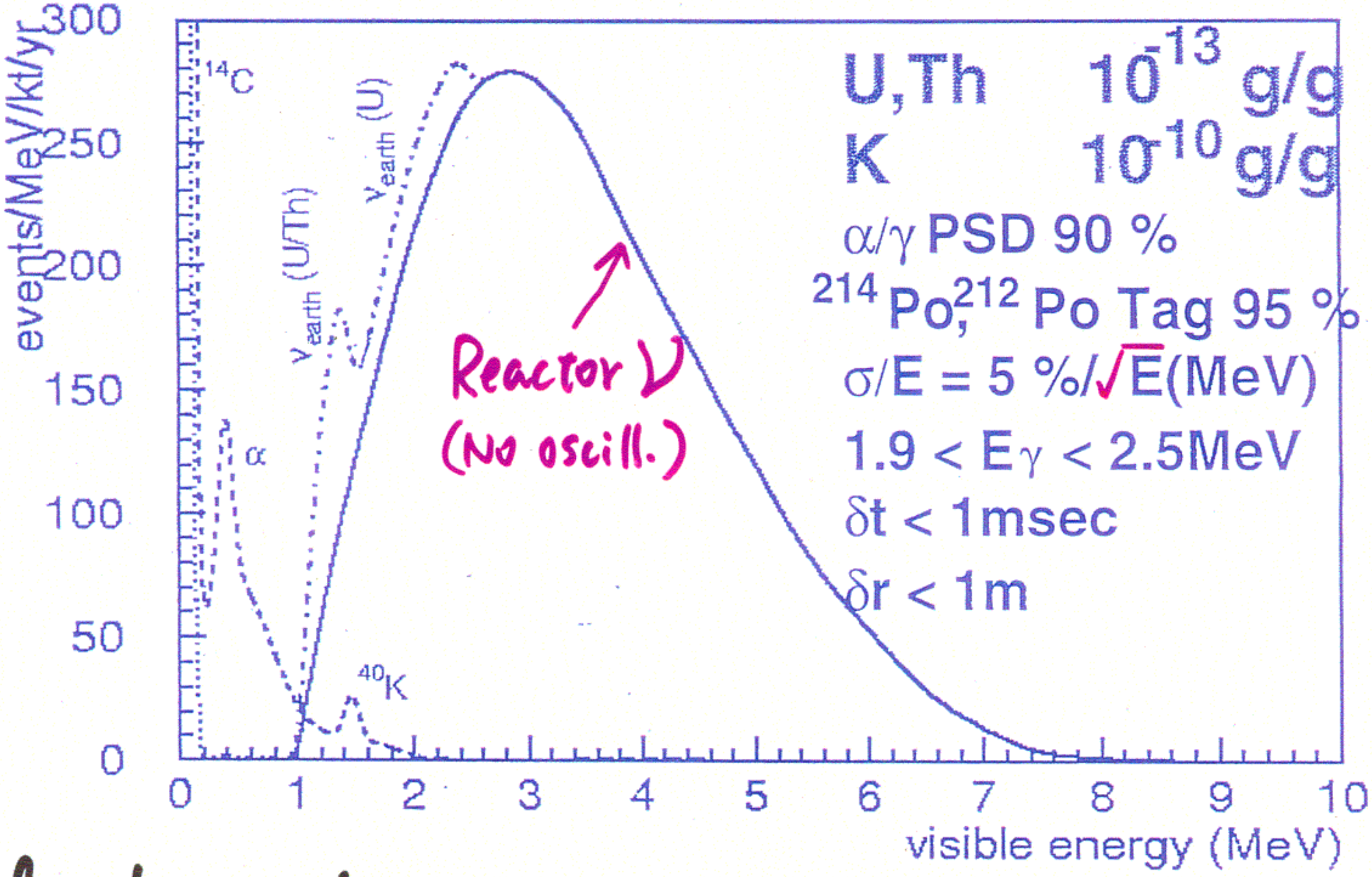
- $\bar{\nu}_e$ only (CC)
- Reject BG (delayed signal← timing, distance, energy)
- σ is large ($\sim 100\sigma(\nu e \rightarrow \nu e)$) and well known.
- E_ν is measured by prompt energy.

- KamLAND Liquid Scintillator

  Large light yield, High purity, Pulse shape discrimination (n/γ, α/γ)

  Fast response, cheap, safe

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



Fiducial volume = 600 ton

Reactor eff. = 80 %

No oscill. → 550 ev/yr (Reactor), ~40 ev/yr (Geo-), Reactor 390 ev/yr (≥ 2.6 MeV, above Geo-ν)

Reactor ν experiment

Systematicn Uncetainties (Initial)

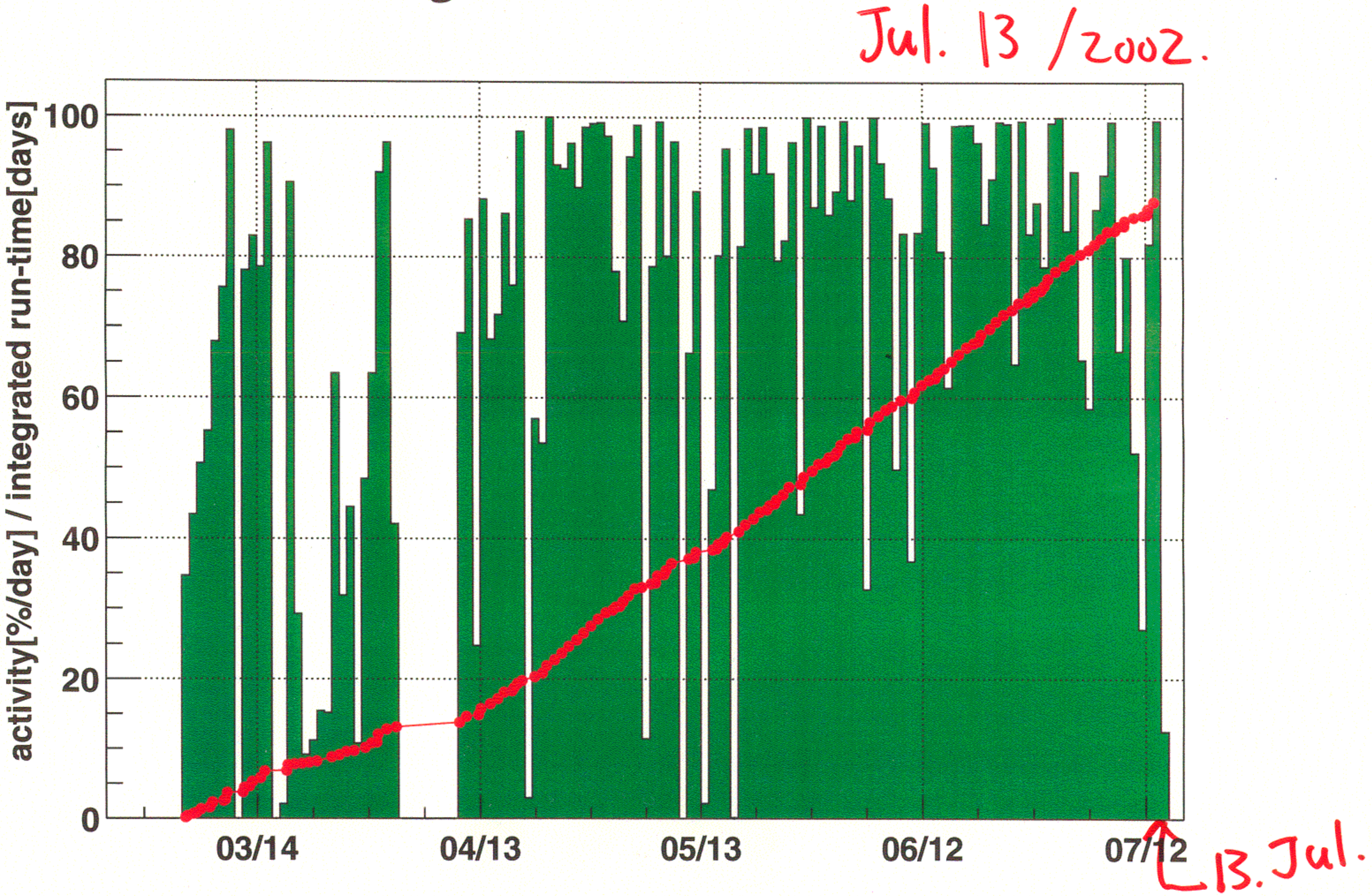
$Q_{thermal}$	2%	
Fiducial Volume	3%	⟷ Δ(Vertex-shift) ~ 5cm
		$\frac{\Delta V}{V} = 3\frac{\Delta R}{R} \lesssim 0.03$ $(R=5m)$
Flux error from Eν	3%	⟷ Δ(E-scale) <2% (SuperK ~ 0.3%)
Cross Section	1%	
Others	~1%	
Total	~ 5%	

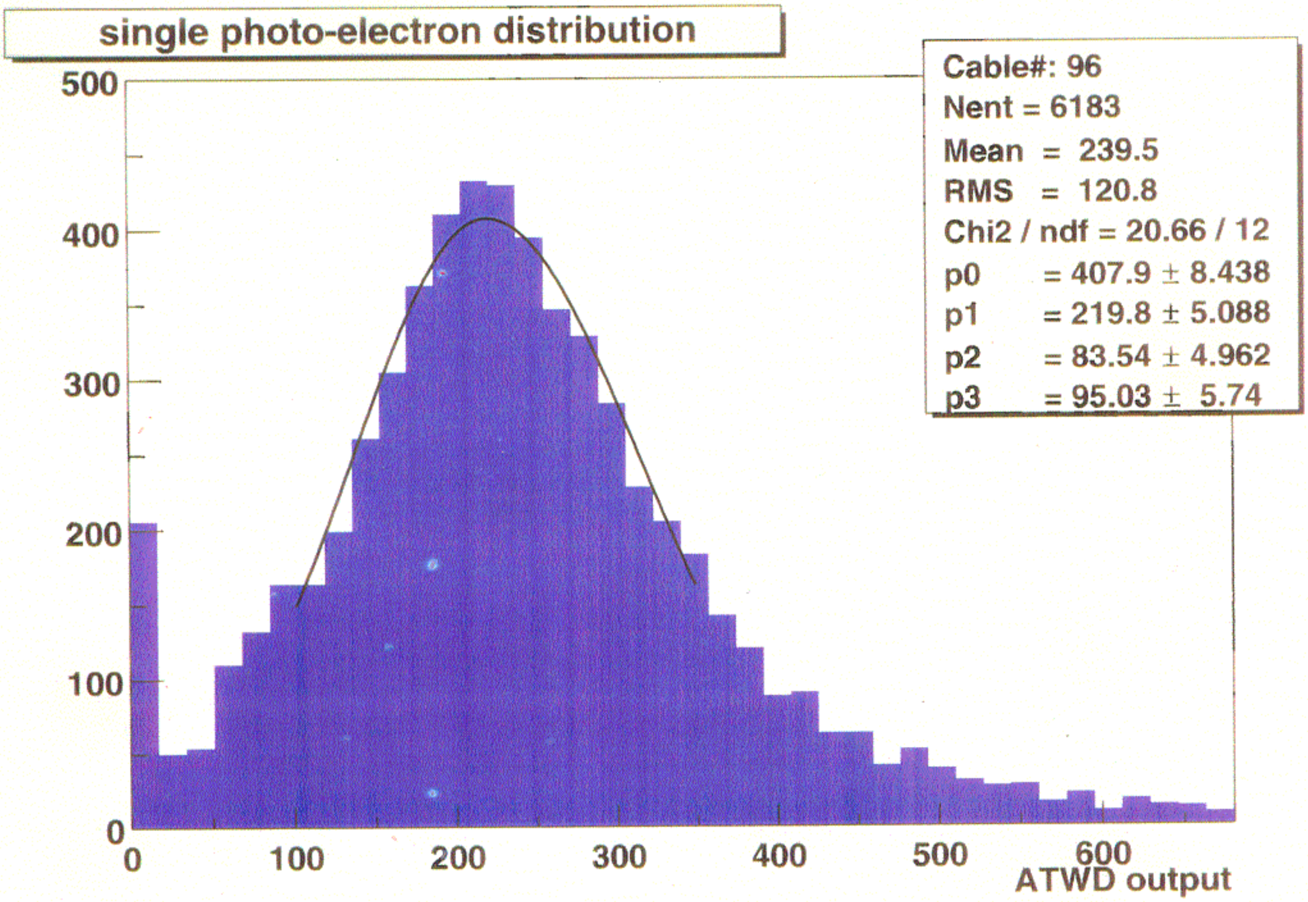
↓

Gain & Timing checks

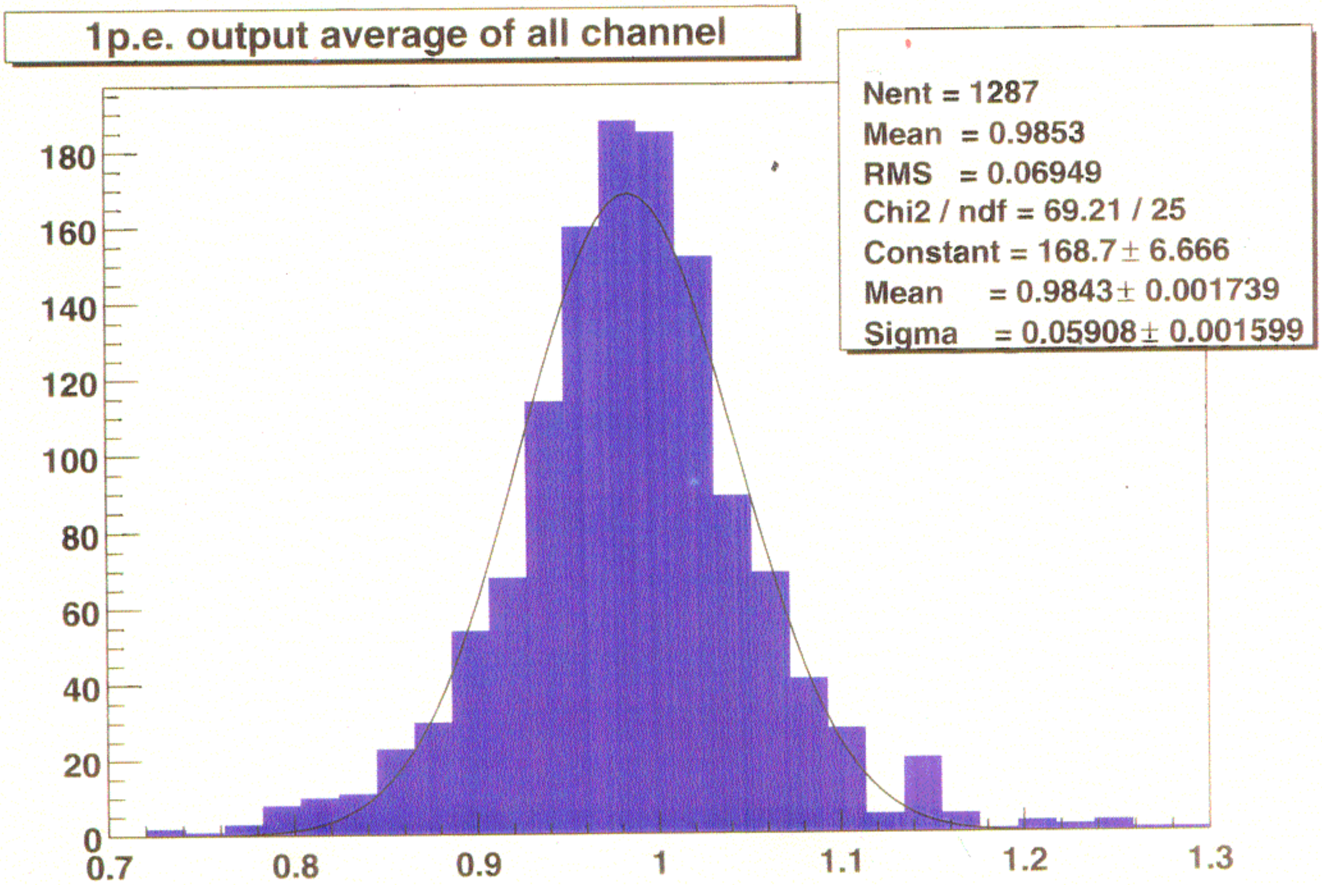
6

Now taking data





single photo-electron distribution
Cable#: 96
Nent = 6183
Mean = 239.5
RMS = 120.8
Chi2 / ndf = 20.66 / 12
p0 = 407.9 ± 8.438
p1 = 219.8 ± 5.088
p2 = 83.54 ± 4.962
p3 = 95.03 ± 5.74
0
100
200
300
400
500
0
100
200
300
400
500
600
ATWD output



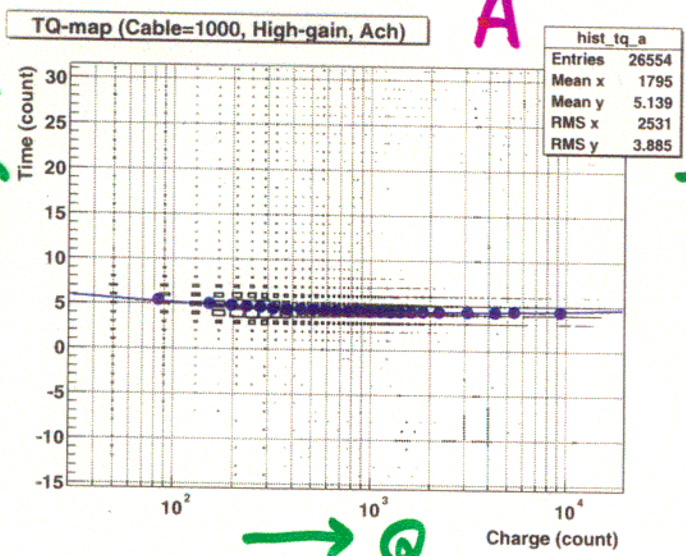
1p.e. output average of all channel
Nent = 1287
Mean = 0.9853
RMS = 0.06949
Chi2 / ndf = 69.21 / 25
Constant = 168.7 ± 6.666
Mean = 0.9843 ± 0.001739
Sigma = 0.05908 ± 0.001599
0
20
40
60
80
100
120
140
160
180
0.7
0.8
0.9
1
1.1
1.2
1.3

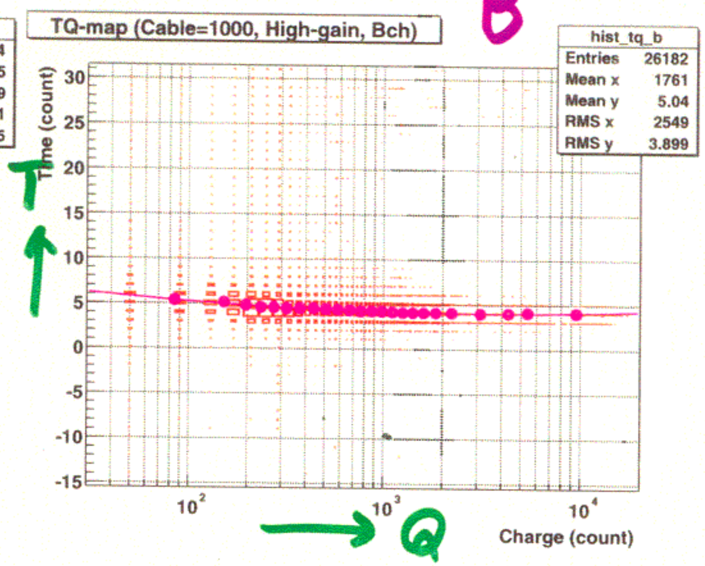
11

(81)

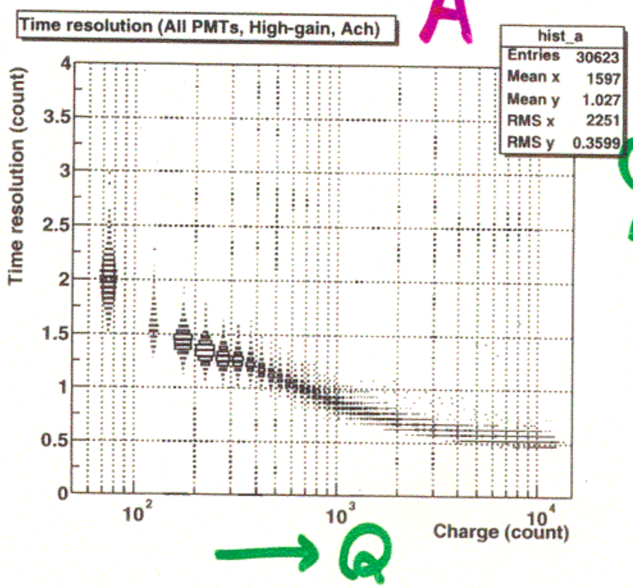
Timing Calibration

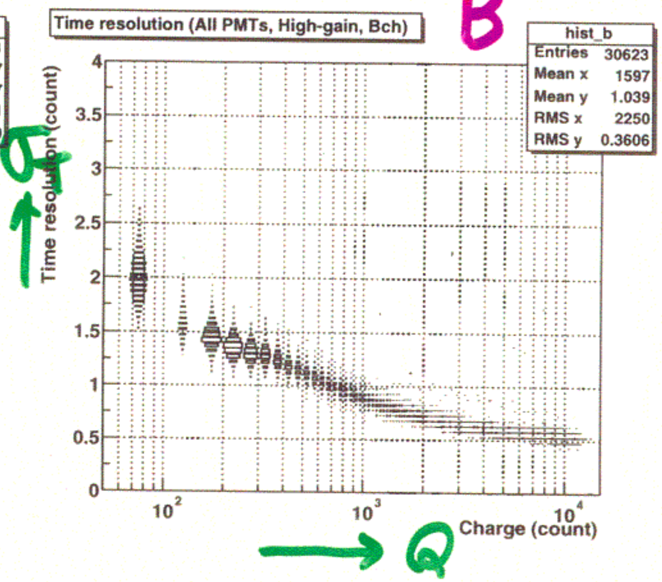
T-Q map

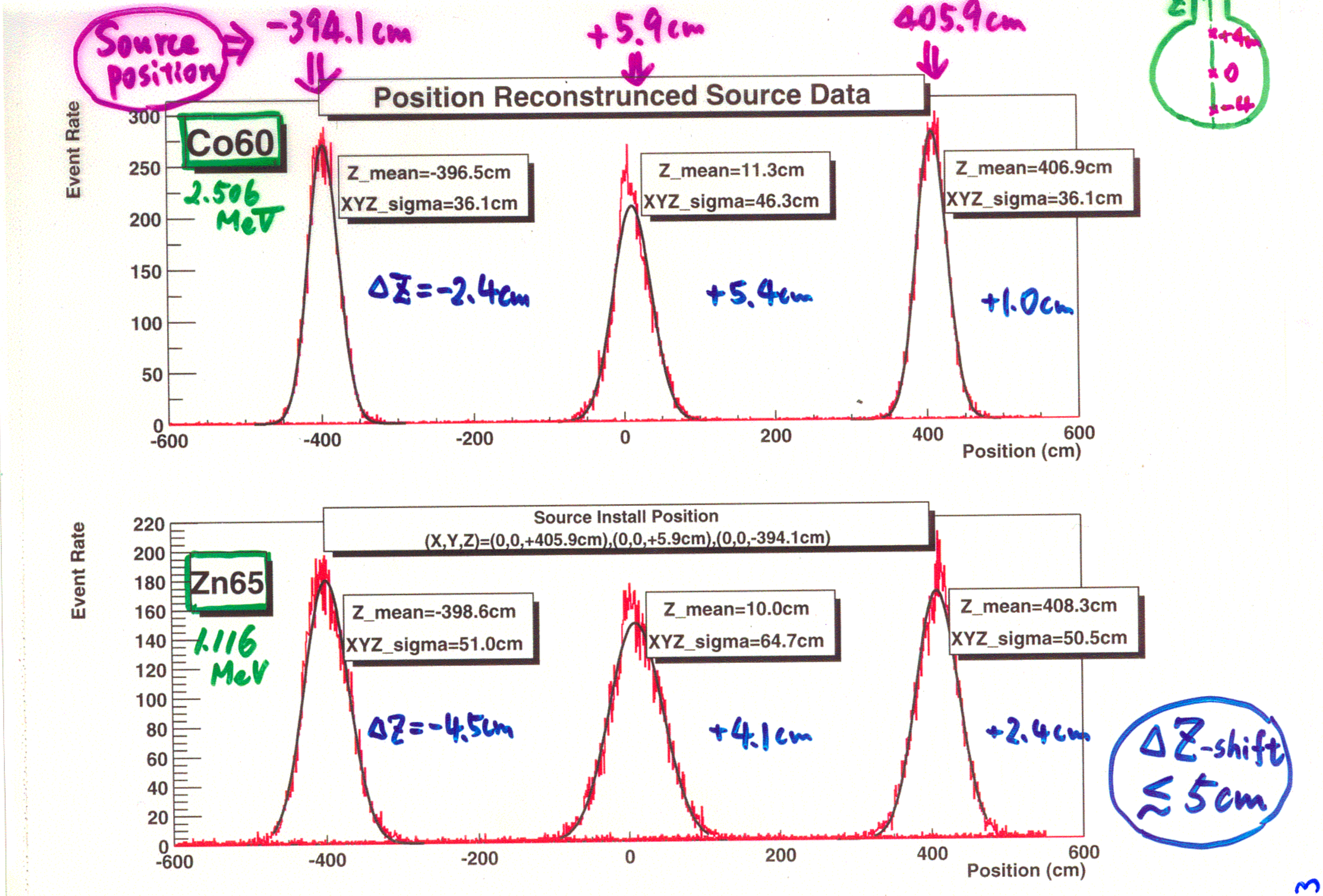




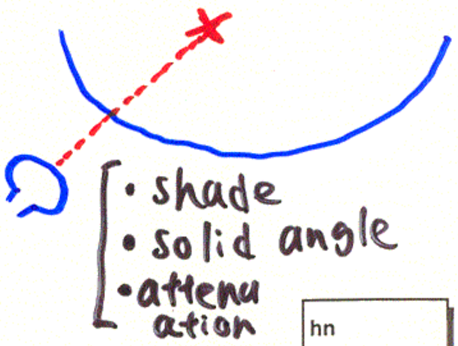
Time resolution

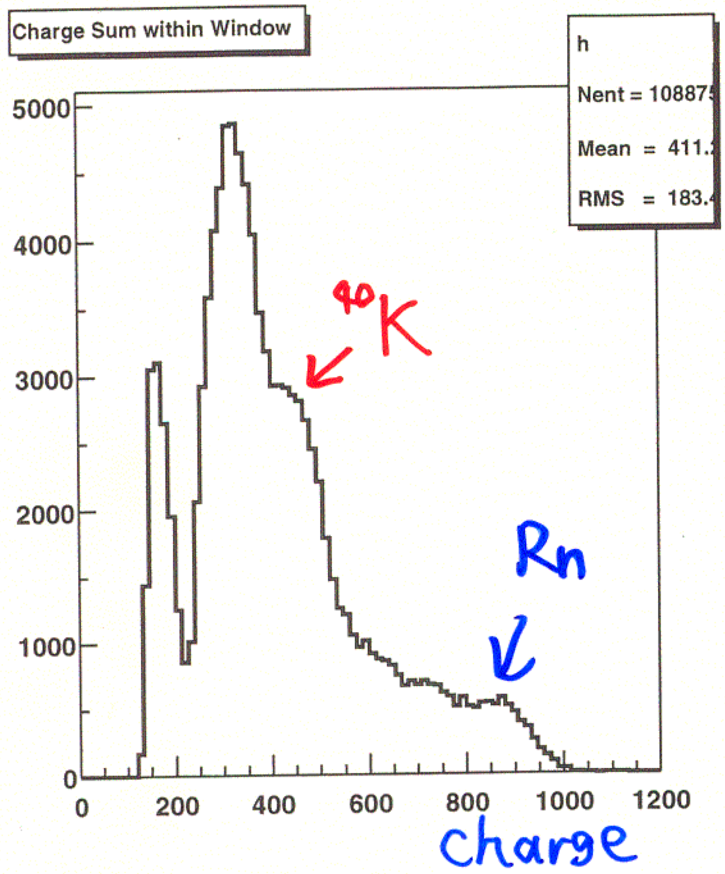


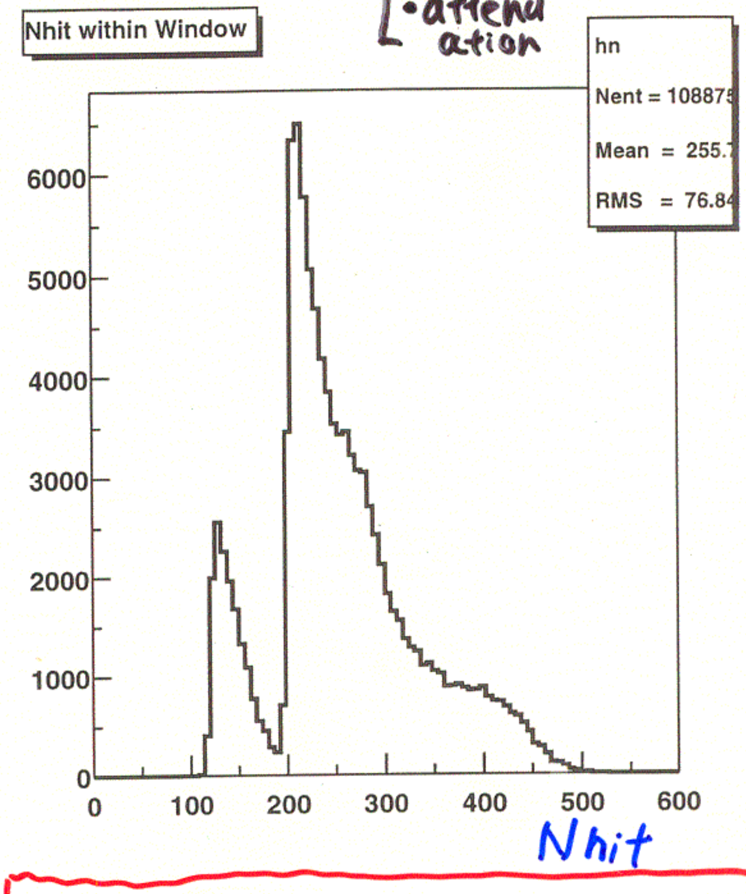


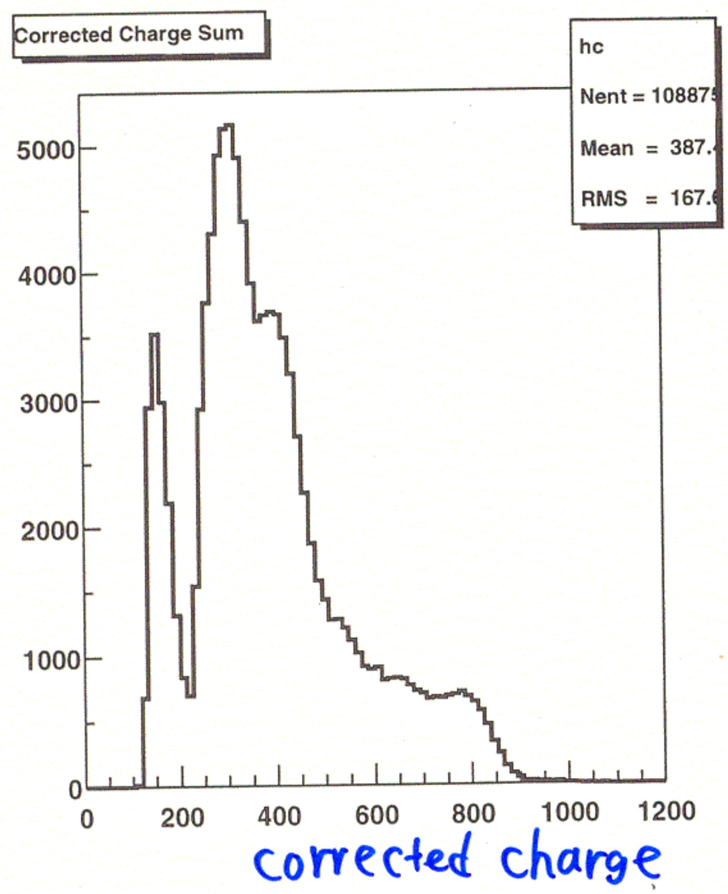

Source position
-394.1cm
+5.9cm
405.9cm
Position Reconstrunced Source Data
Event Rate
Co60
2.506 MeV
Z_mean=-396.5cm
XYZ_sigma=36.1cm
Z_mean=11.3cm
XYZ_sigma=46.3cm
Z_mean=406.9cm
XYZ_sigma=36.1cm
ΔZ=-2.4cm
+5.4cm
+1.0cm
Position (cm)
Source Install Position
(X,Y,Z)=(0,0,+405.9cm),(0,0,+5.9cm),(0,0,-394.1cm)
Zn65
1.116 MeV
Z_mean=-398.6cm
XYZ_sigma=51.0cm
Z_mean=10.0cm
XYZ_sigma=64.7cm
Z_mean=408.3cm
XYZ_sigma=50.5cm
ΔZ=-4.5cm
+4.1cm
+2.4cm
ΔZ-shift ≲ 5cm

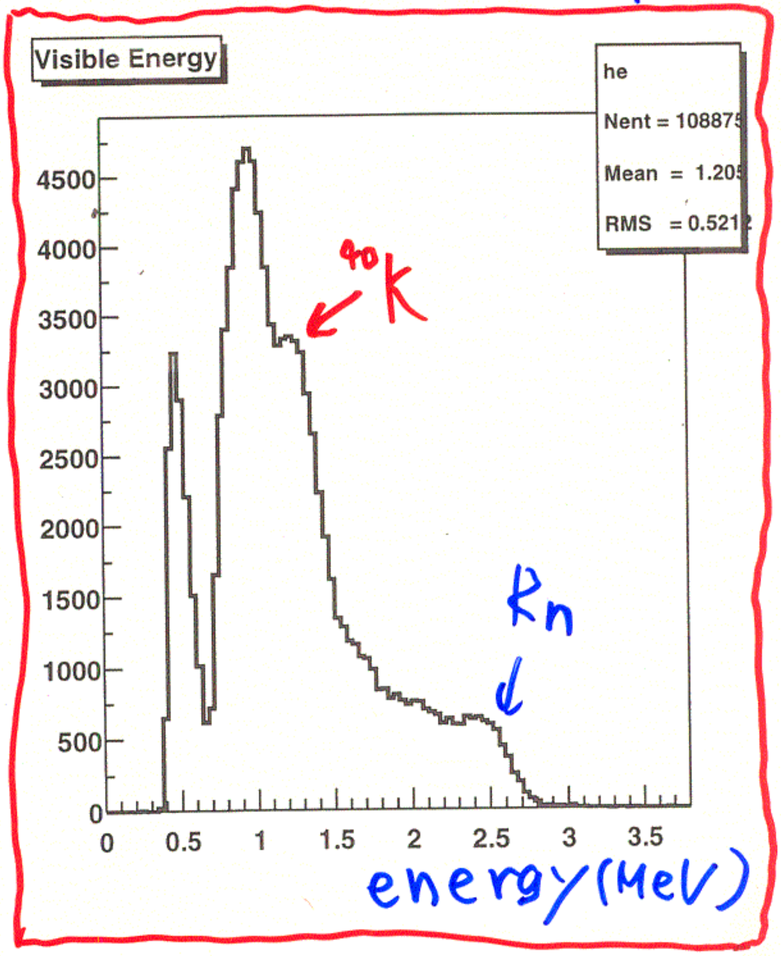
Energy estimater
(in off-line analysis)











Back grounds.

(1) radio impurity

^{40}K ...... $< 2.3 \times 10^{-16}$ g/g

U ..... $< 3 \times 10^{-16}$ g/g

Th ..... $< 1.8 \times 10^{-16}$ g/g

(2) spallation products

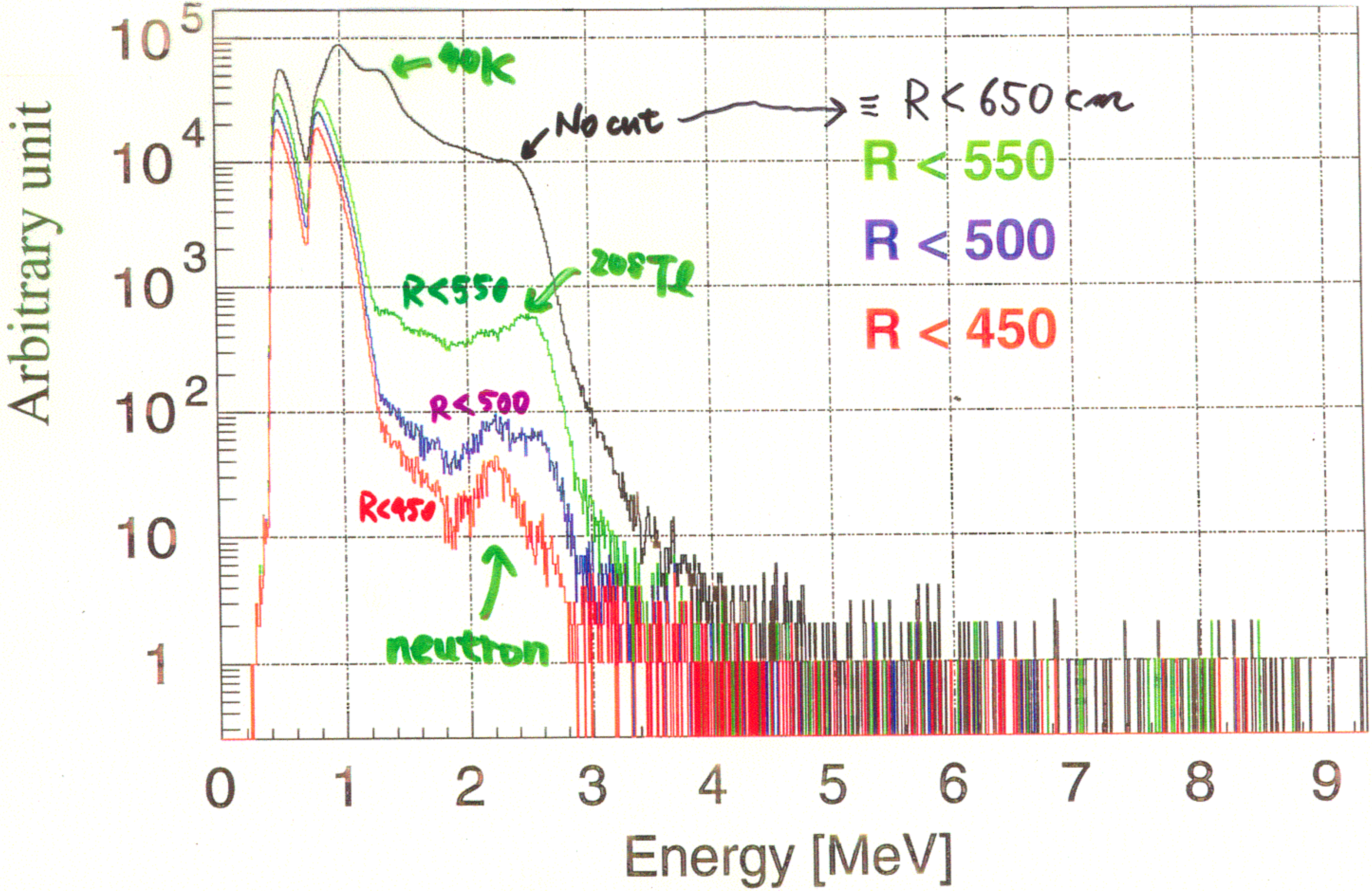
n, ^{11}C, ^{10}C

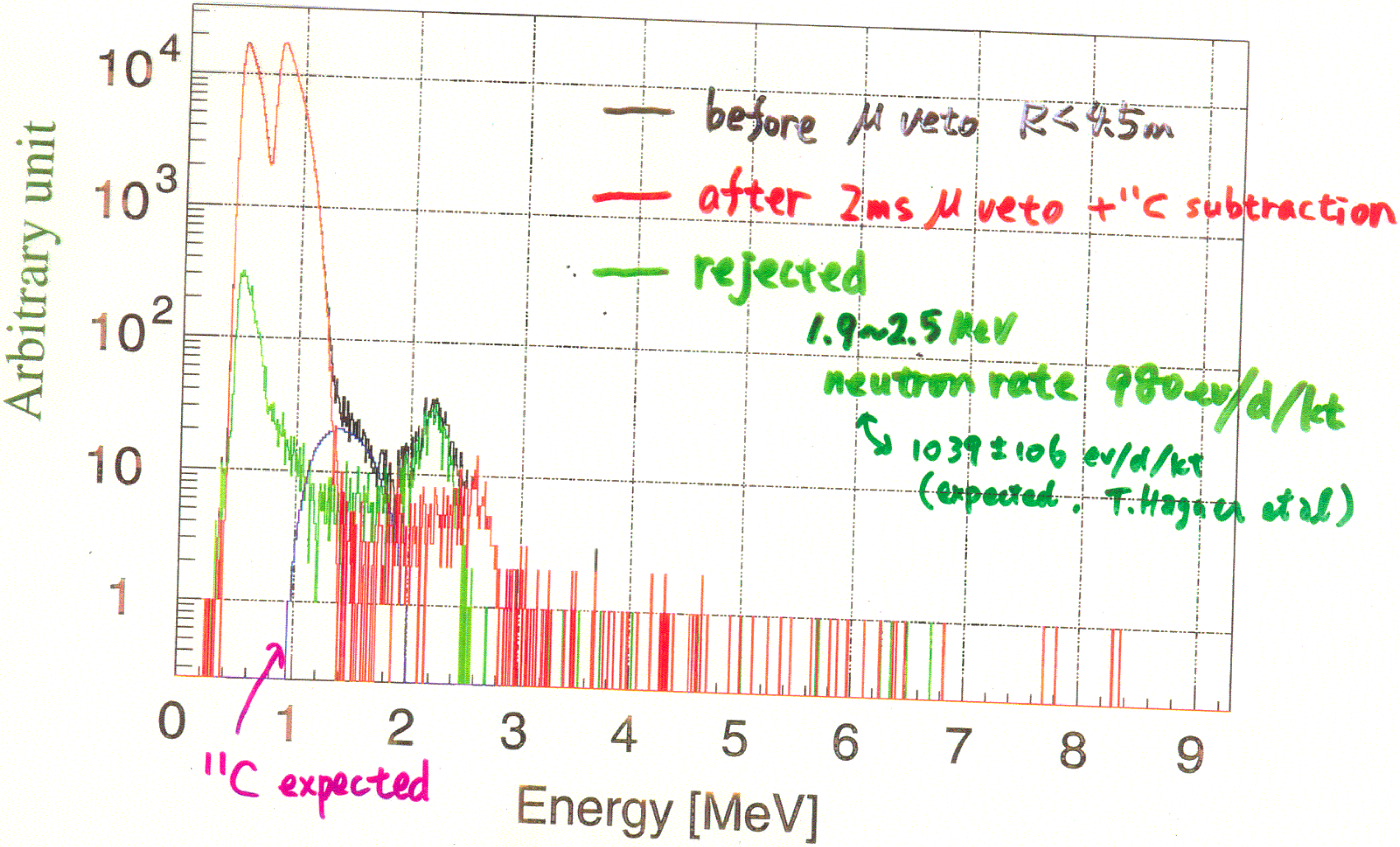
^{9}Li, ^{8}He

⇒ μ veto (1~2 s ? with spatial cut ?)

now ~~is~~ being studied.

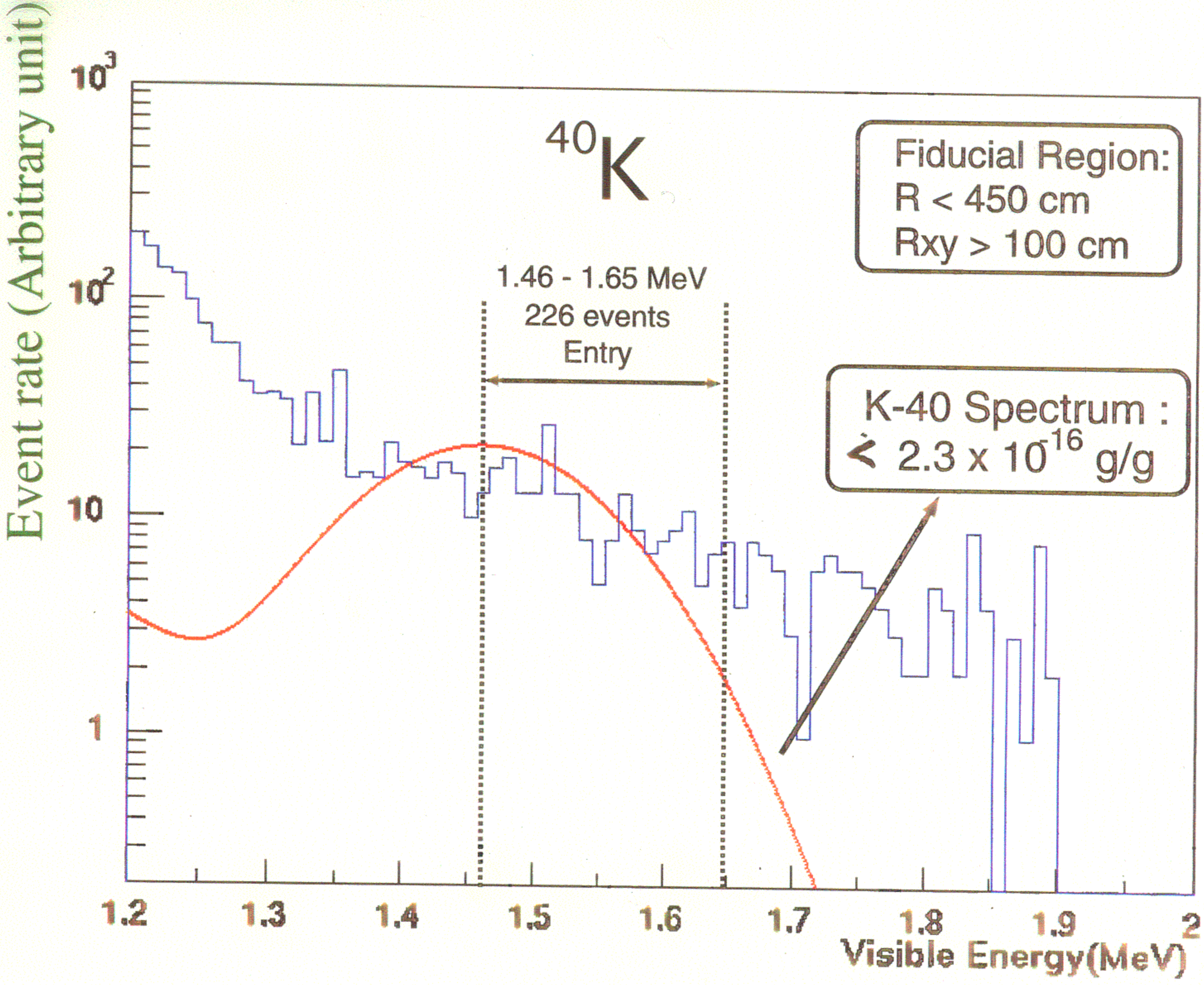
Energy spectra with various fiducial volume



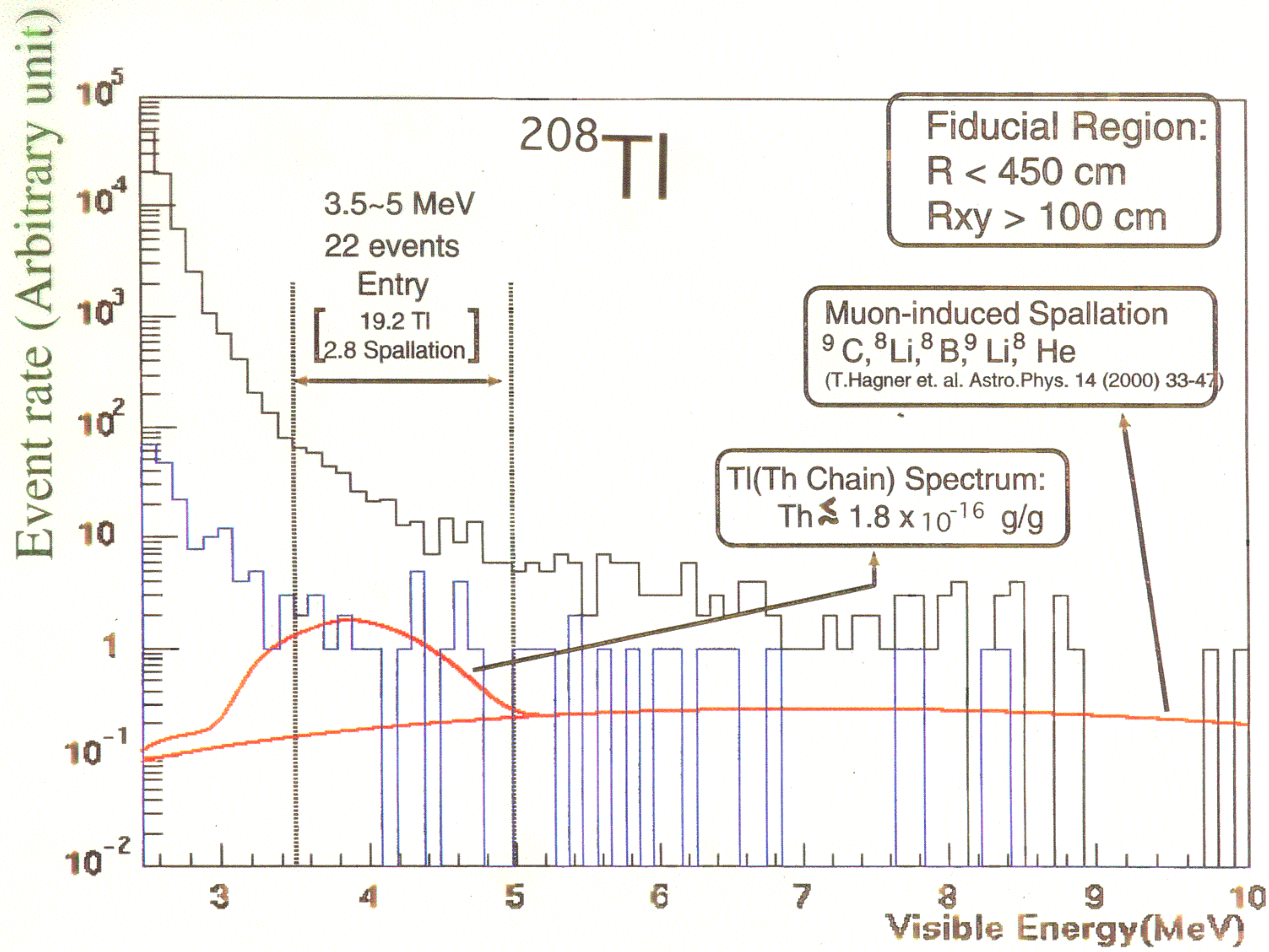


^{10}C is not subtracted yet.

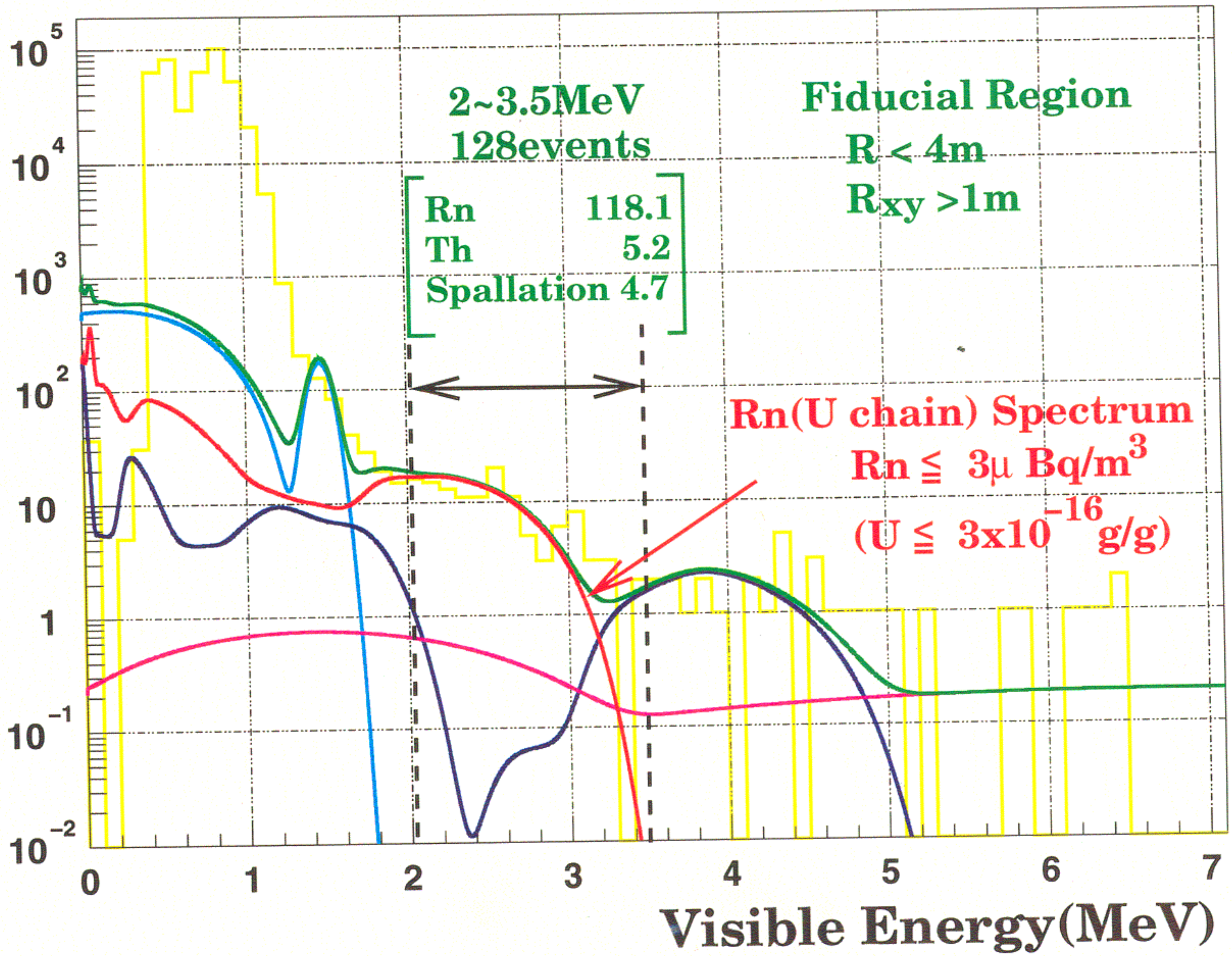
$^{222}Rn \lesssim 4\ \mu Bq/m^3$



Event rate (Arbitrary unit)
10^3
10^2
10
1
40K
Fiducial Region:
R < 450 cm
Rxy > 100 cm
1.46 - 1.65 MeV
226 events
Entry
K-40 Spectrum :
< 2.3 x 10^-16 g/g
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Visible Energy(MeV)



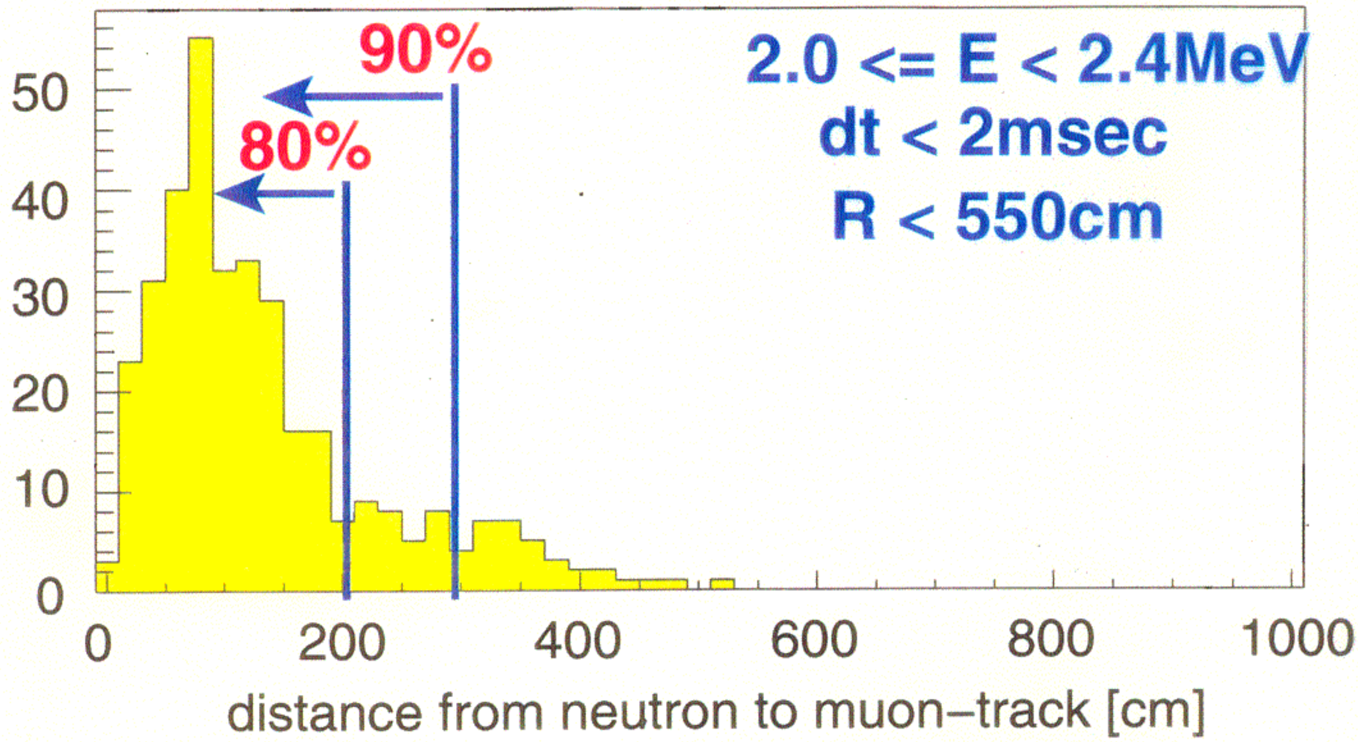
Event rate (Arbitrary unit)
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
208 Tl
3.5~5 MeV
22 events
Entry
[19.2 Tl
2.8 Spallation]
Fiducial Region:
R < 450 cm
Rxy > 100 cm
Muon-induced Spallation
9C, 8Li, 8B, 9Li, 8He
(T.Hagner et. al. Astro.Phys. 14 (2000) 33-47)
Tl(Th Chain) Spectrum:
Th ≲ 1.8 x 10^-16 g/g
3
4
5
6
7
8
9
10
Visible Energy(MeV)

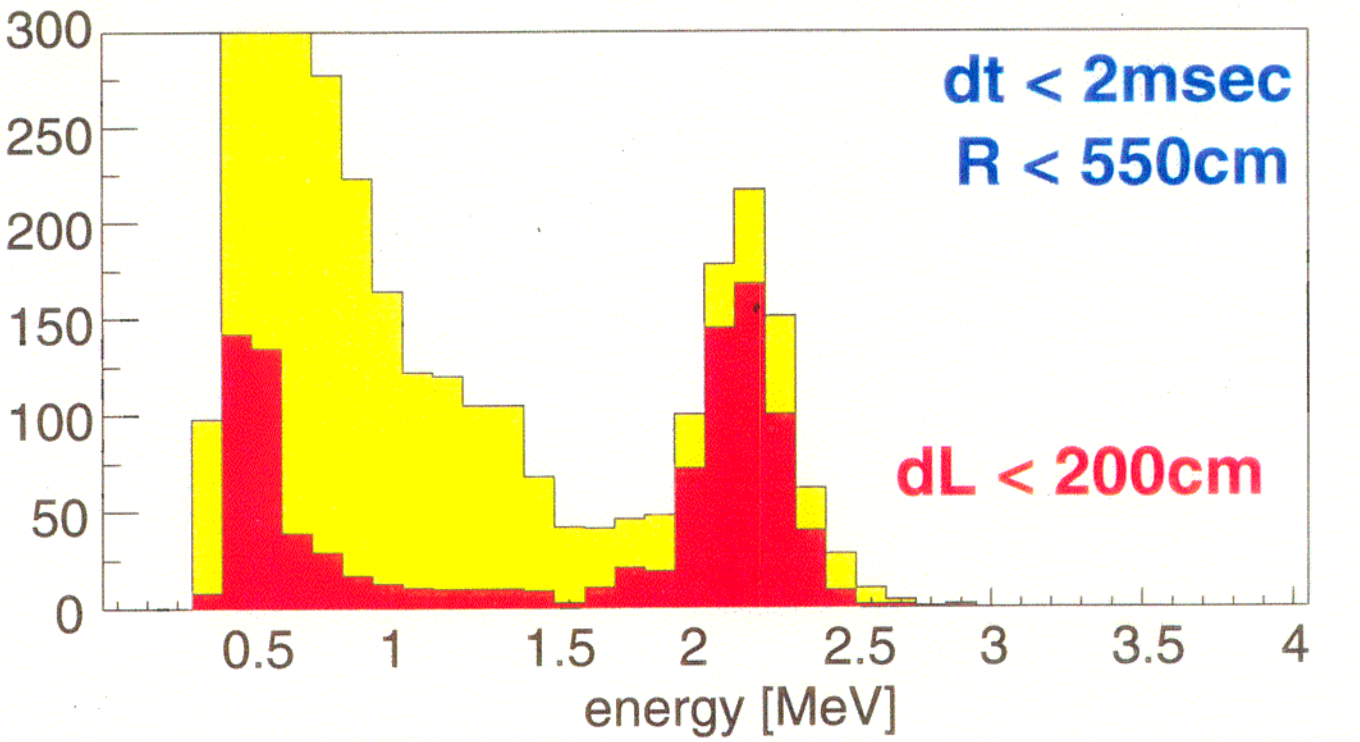


10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
0
1
2
3
4
5
6
7
Visible Energy(MeV)
2~3.5MeV
128events
Rn 118.1
Th 5.2
Spallation 4.7
Fiducial Region
R < 4m
Rxy >1m
Rn(U chain) Spectrum
Rn ≦ 3μ Bq/m^3
(U ≦ 3x10^-16 g/g)

20

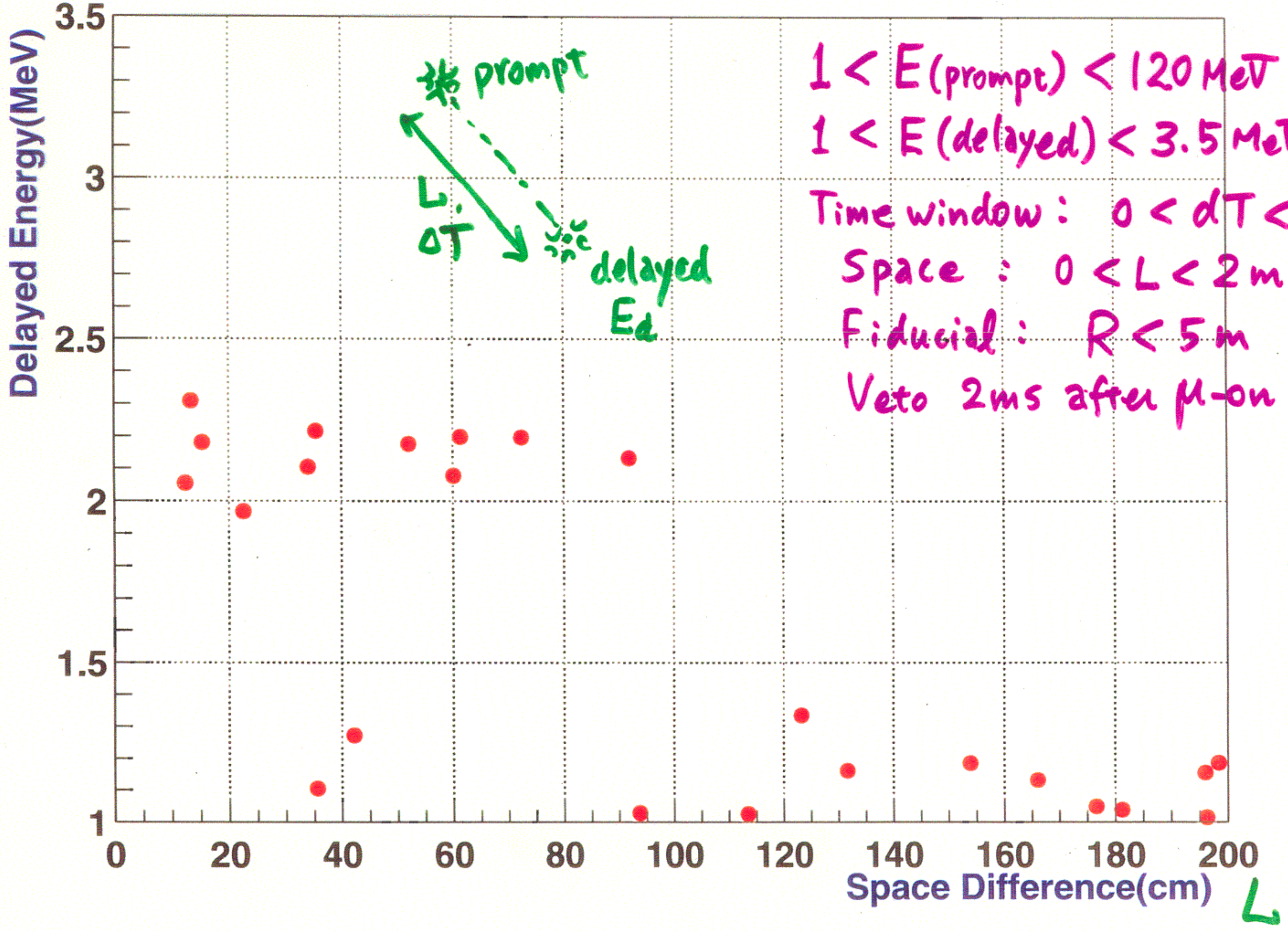
Neutrons from μ spallation of ^{12}C

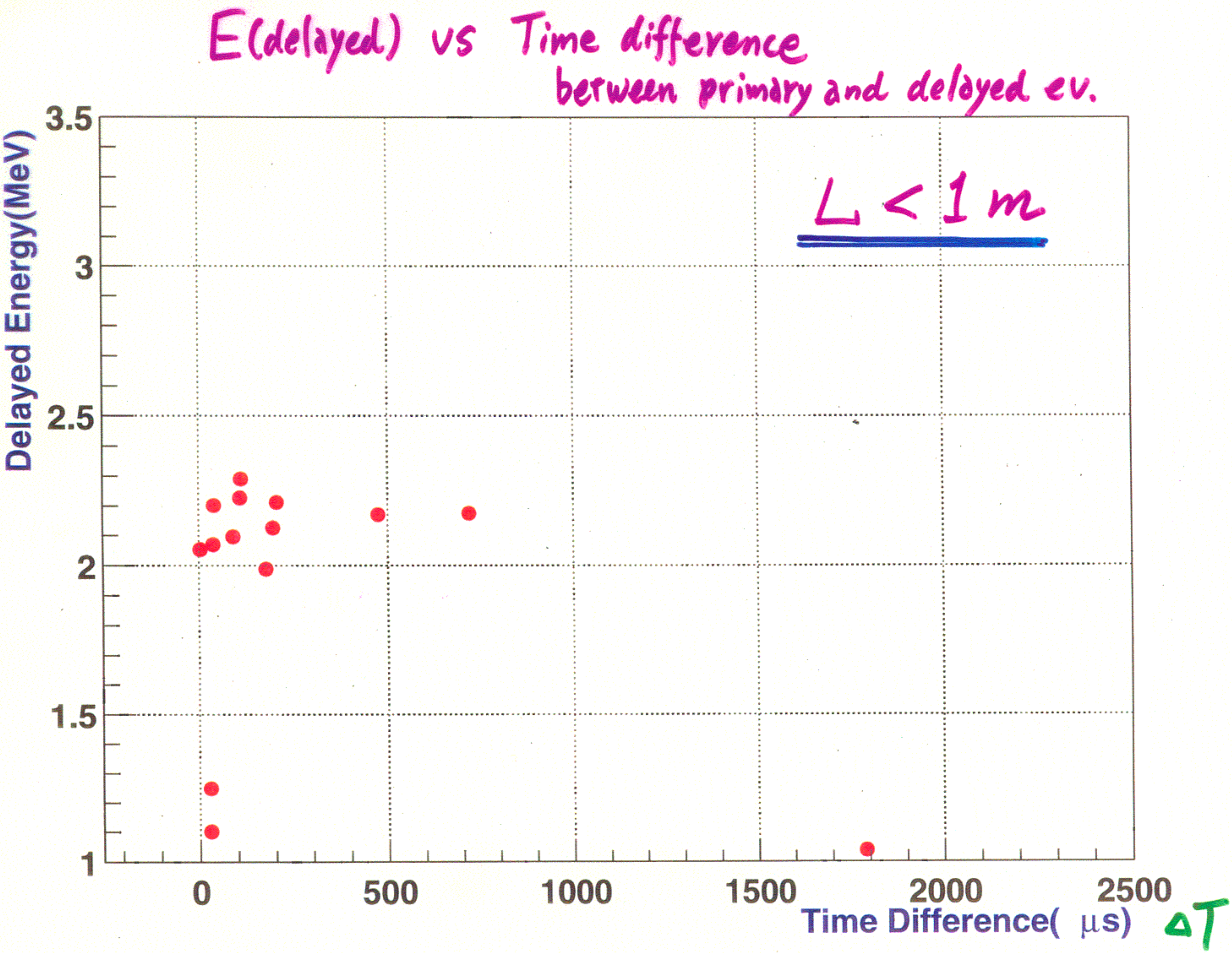




E (delayed) VS Space difference

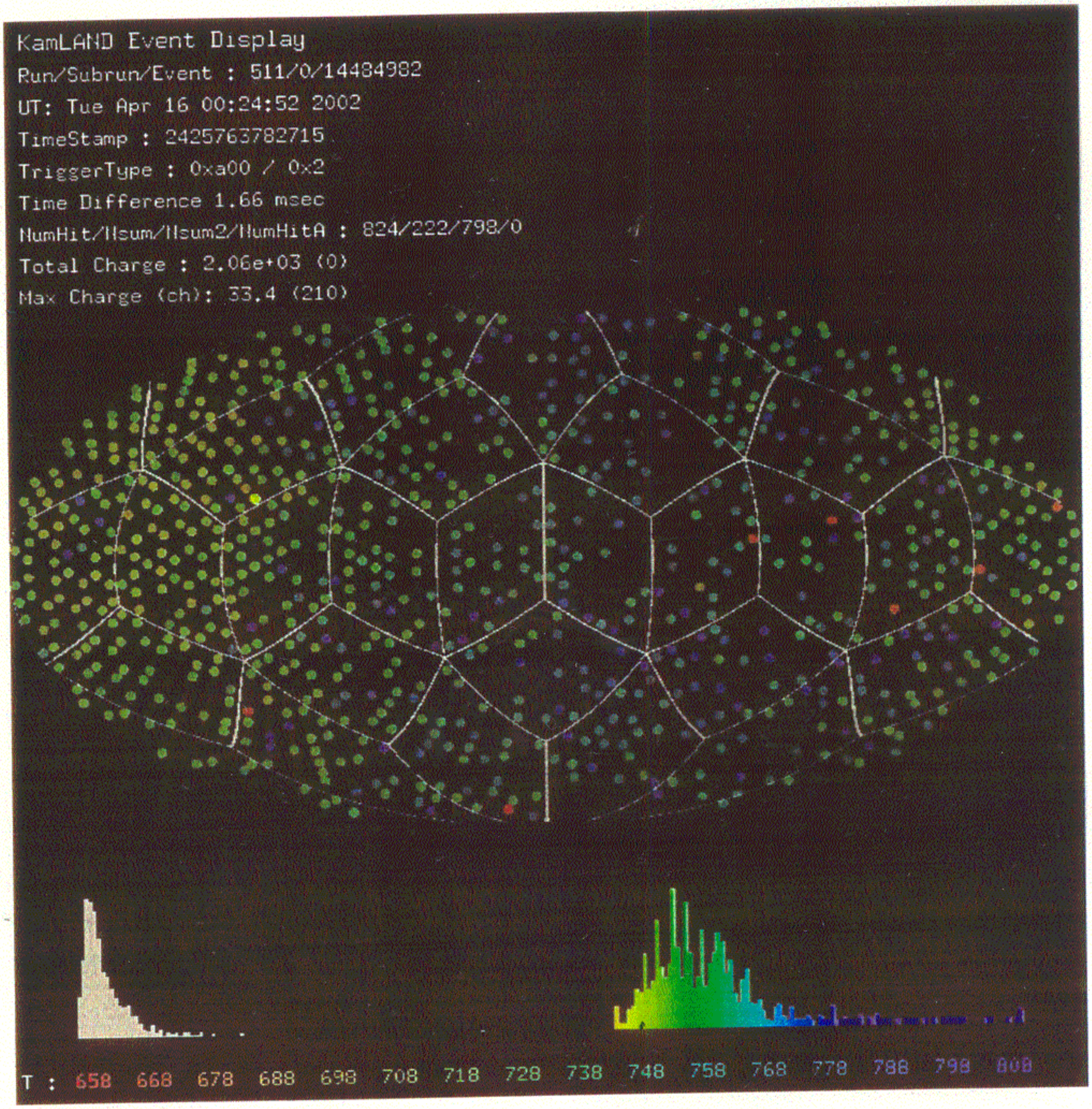
(Distance betw. primary & delayed ev.)

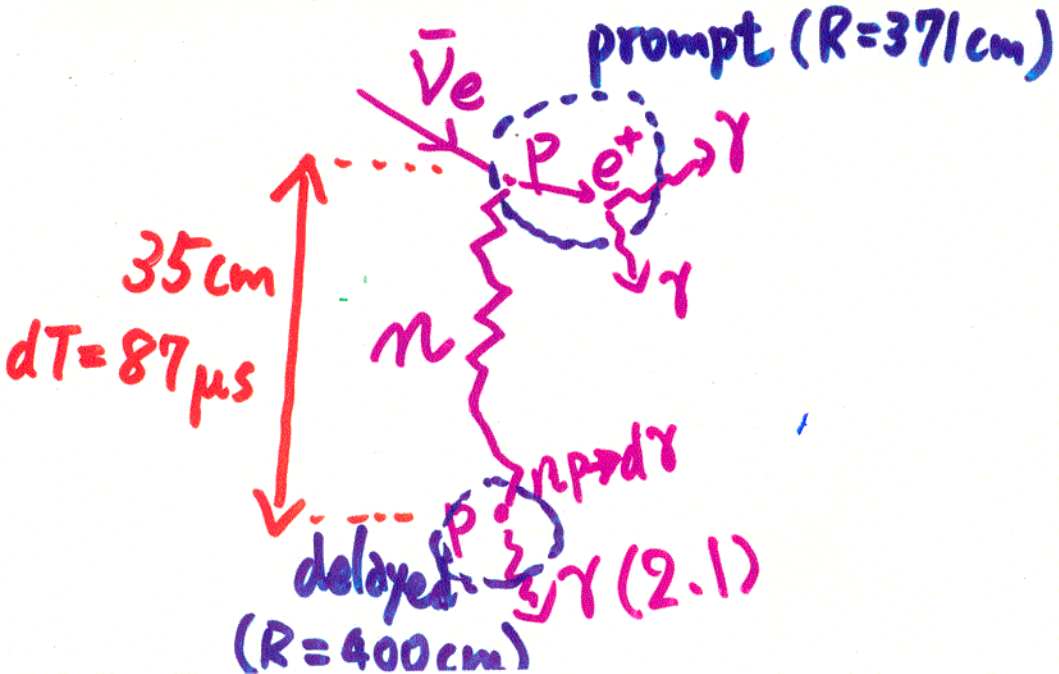



E(delayed) vs Time difference
between primary and delayed ev.
L < 1 m
Delayed Energy(MeV)
3.5
3
2.5
2
1.5
1
0
500
1000
1500
2000
2500
Time Difference(μs)
ΔT

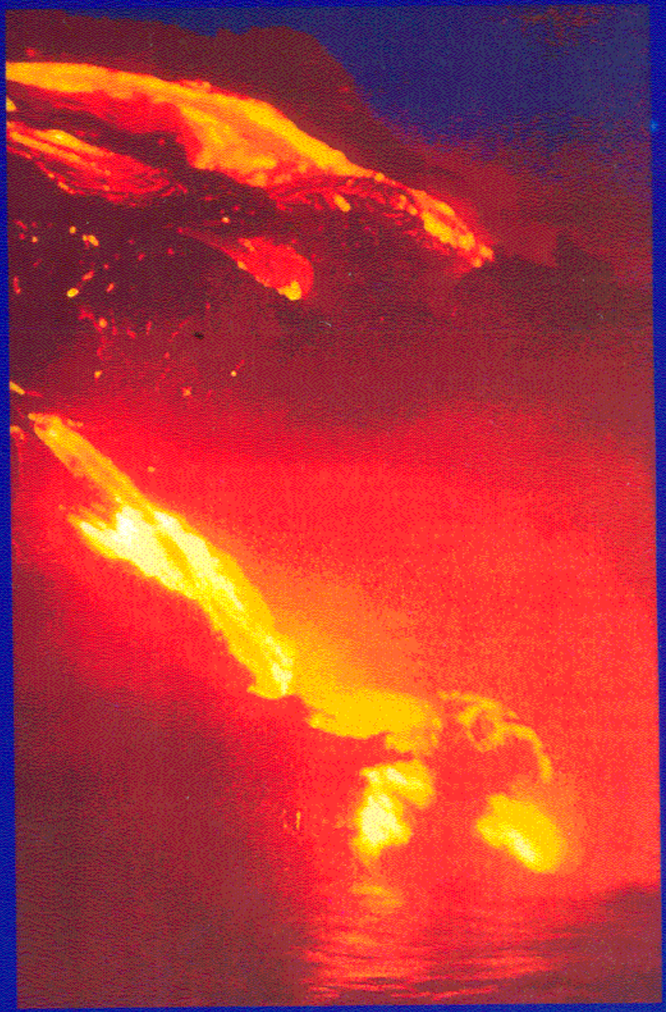
23

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





Geoneutrino Physics



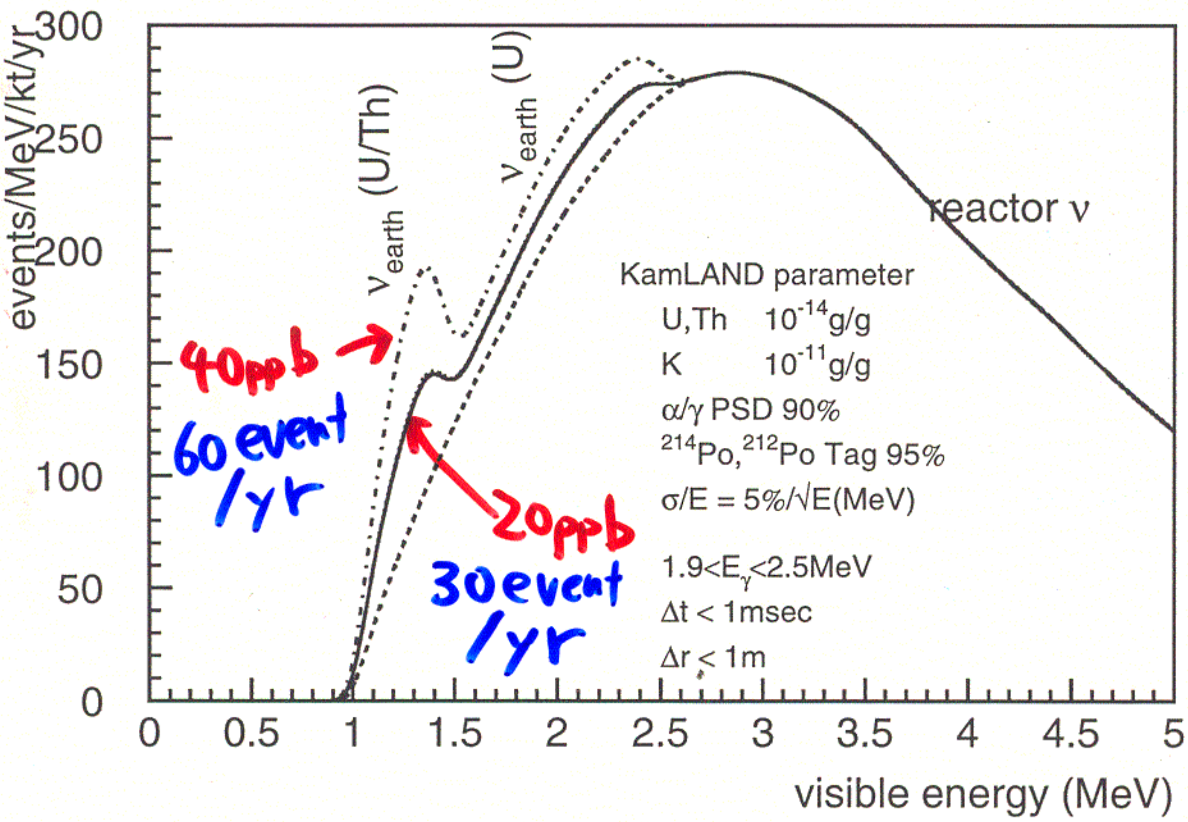
Dependence on U(Th) in the primitive mantle

|||

present-day mantle + crust

&

present-day radigenic heat source



20ppb : standard estimation
16TW (40% of total heat flow)

40ppb : same as moon or mercury
32TW (80% of total heat flow)

25.5

Mantle/Crust models

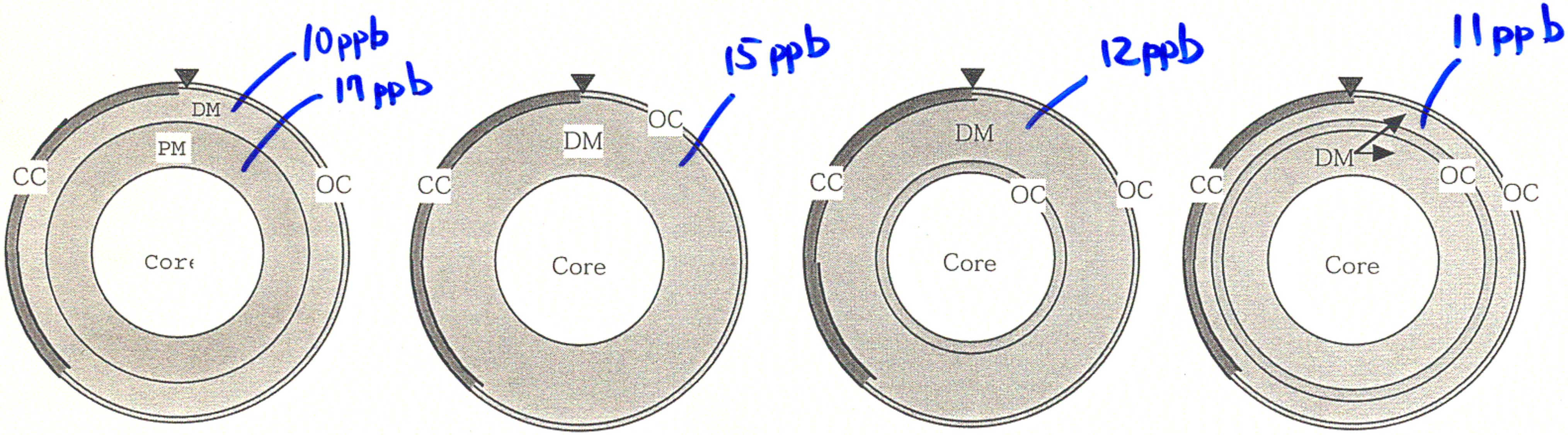
E. Ohtani

Density profile : PREM

Important reservoirs in the Earth's interior

PM. Bulk silicate Earth= Primitive mantle U= 20ppb Th/U=3.92 (M
CC. Contineta1 crust U=1.4ppm Th/U=4 (Rudnick and Fountain, 19
OC. Oceanic crust U=100ppb Th/U=2.2 (Taylor and McLennen, 1985
DM. Depleted mantle U=13ppb Th/U=2.6 (Sun and McDonough, 1989)

Thicness of kayers in m
CC thickness 30 km 40% area
OC thickness 10 km 60%
UM., 10(30)~660 km
LM, 660~2900 km
OC in TZ, 550~660 km
OC in CMB, 2700~2900 km



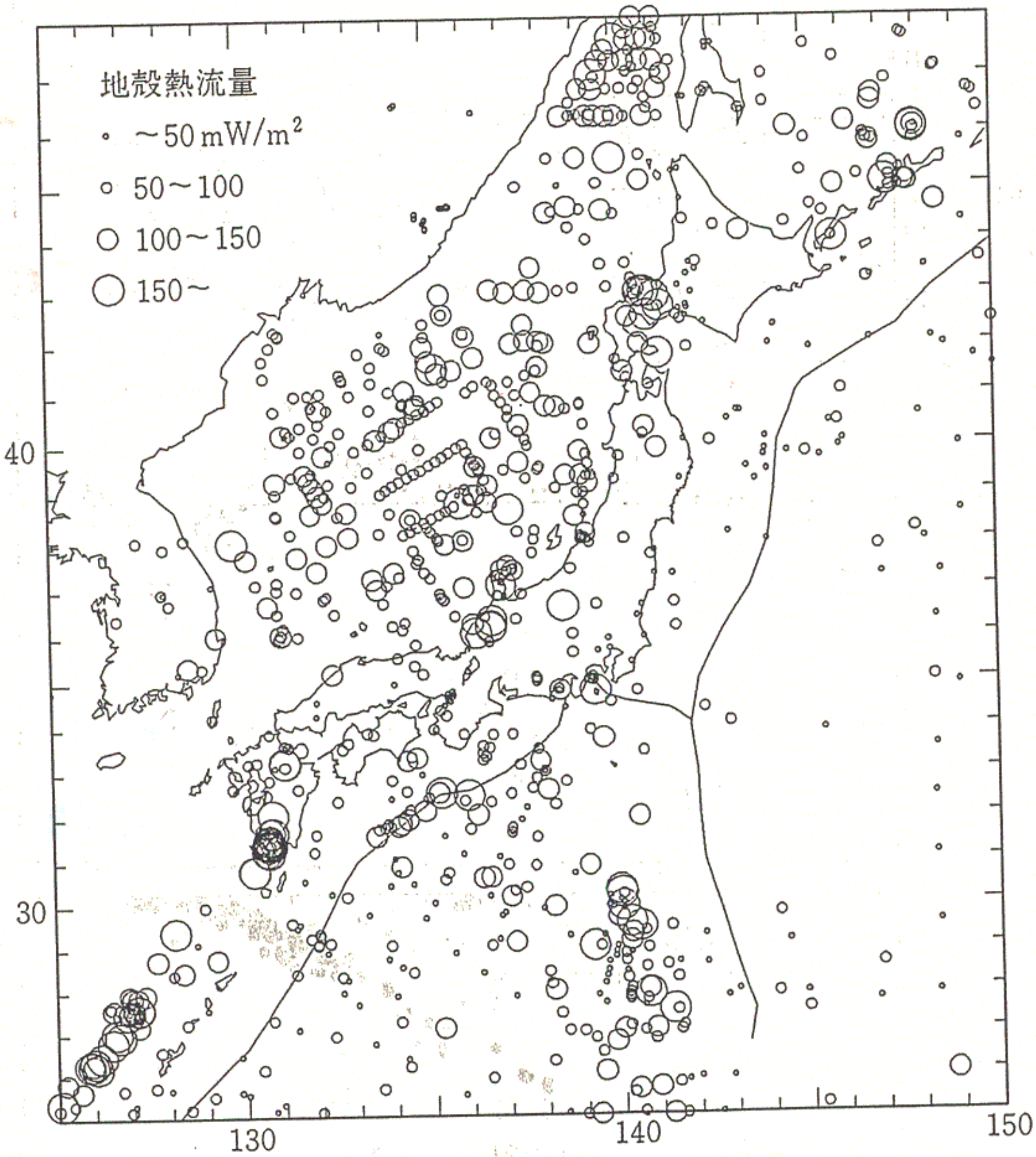
Model 1
Standard (static) model
27.8 event/yr

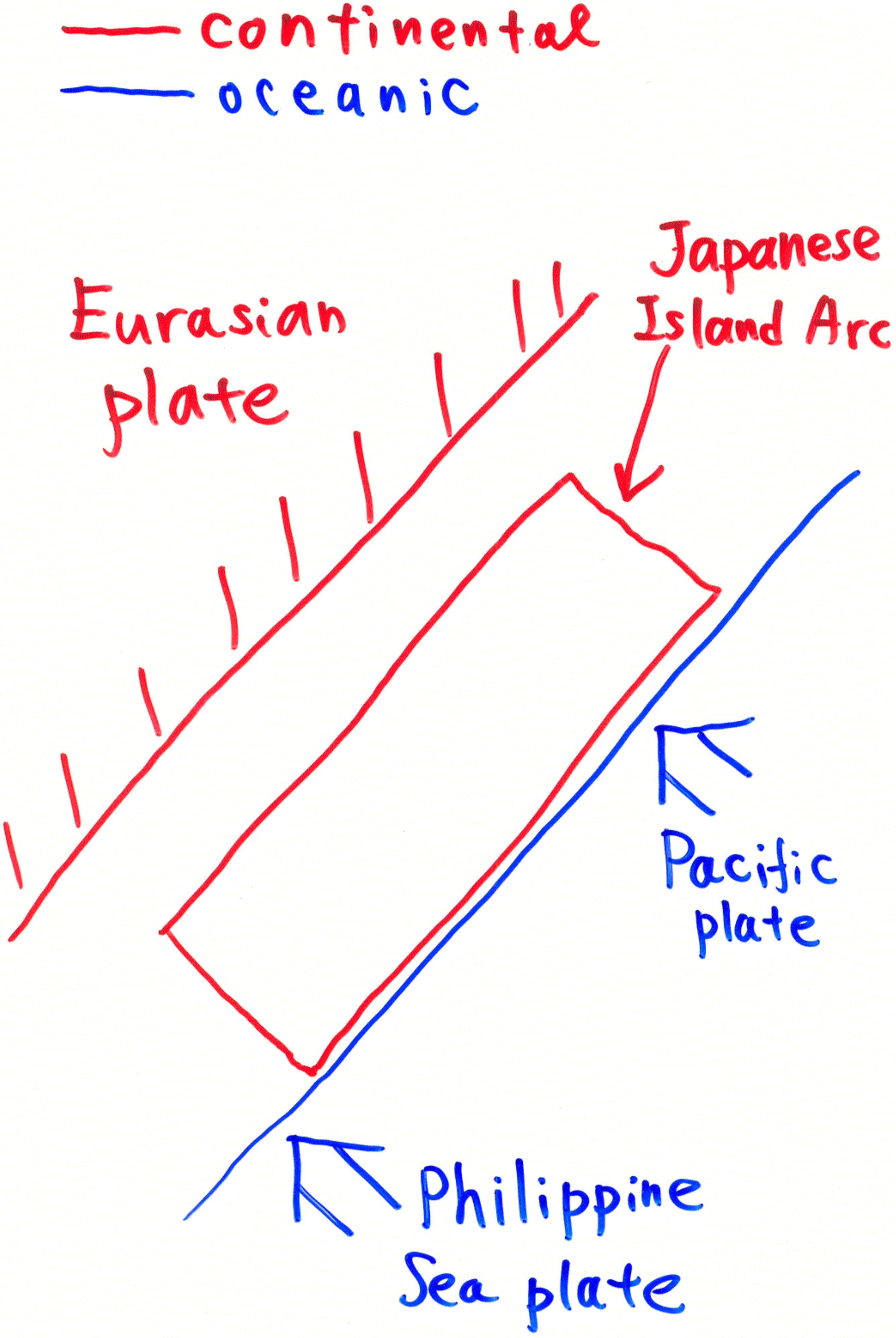
Model 2
Mixing mode
28.6 event/yr

Model 3
Heterogeneous model 1
27.8 event/yr

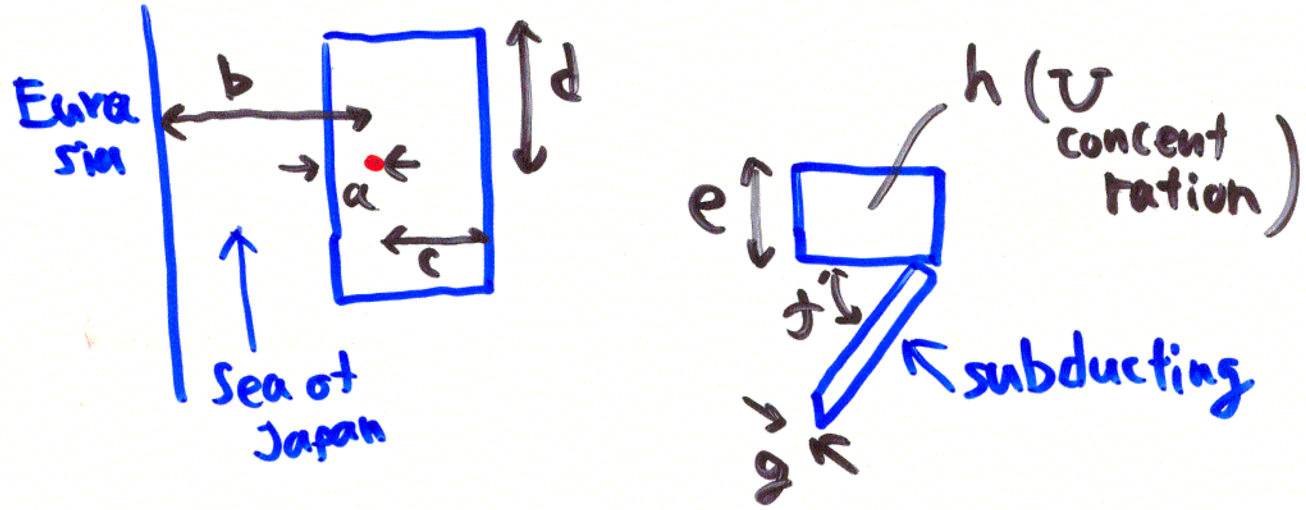
Model 4
Heterogeneous model 2
28.9 event/yr

⑨


地殻熱流量
〜50 mW/m²
50〜100
100〜150
150〜
40
30
130
140
150


continental
oceanic
Eurasian plate
Japanese Island Arc
Pacific plate
Philippine Sea plate

Dependence on the local structure around Kamioka



	Standard	max		min	
a	150 km	200	+0.5	100	−0.7
b	600 km	400	+0.7	800	−0.5
c	300 km	400	+0.5	200	−0.7
d	1500 km	2000	+0.0	1000	−0.1
e	30 km	35	+1.5	25	−1.7
f	45°	30	+0.0	60	−0.0
g	10 km	20	+0.01	5	−0.01
h	1.4 ppm	2.0	+5.8	1.0	−3.9

20% of total geo-ν flux

changes of geo-ν event/yr

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}Be solar neutrino detection.
- Exciting results will come soon !!