Solar neutrino results, KamLAND & prospects

- **Solar Neutrino History**
- **KamLAND**
- **Prospects**

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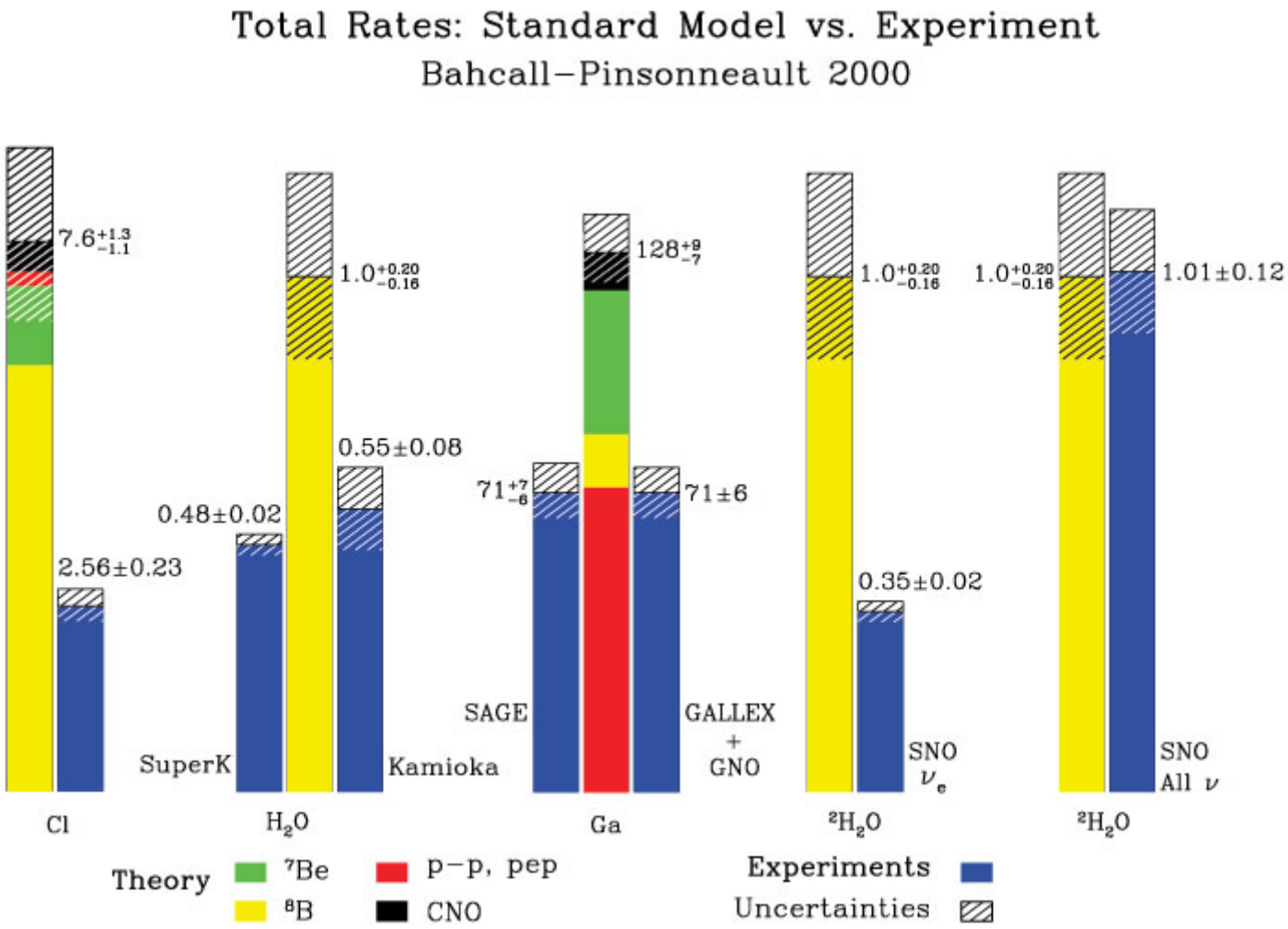
Duke/TUNL

www.awa.tohoku.ac.jp/~kengo/NuFact03.pdf

Solar Neutrino Problem



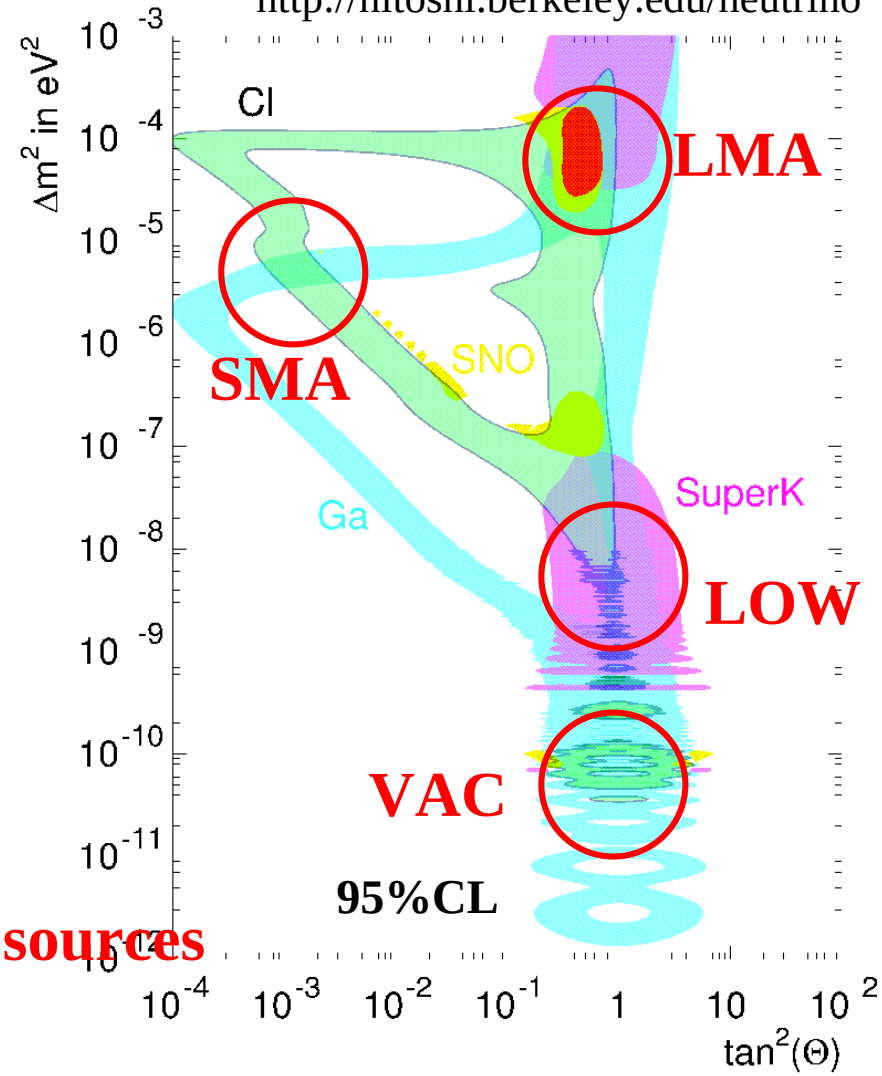
Neutrino Oscillation

✓Cl, Kamiokande,Ga
→ LMA,SMA,LOW,VAC
✓SuperK day night, SuperK energy spectrum
→ LMA+LOW

SNO NC; $\nu_e+\nu_\mu+\nu_\tau$
✓Flavor transition
✓SNO day/night
→LMA

KamLAND; Man made neutrino sources

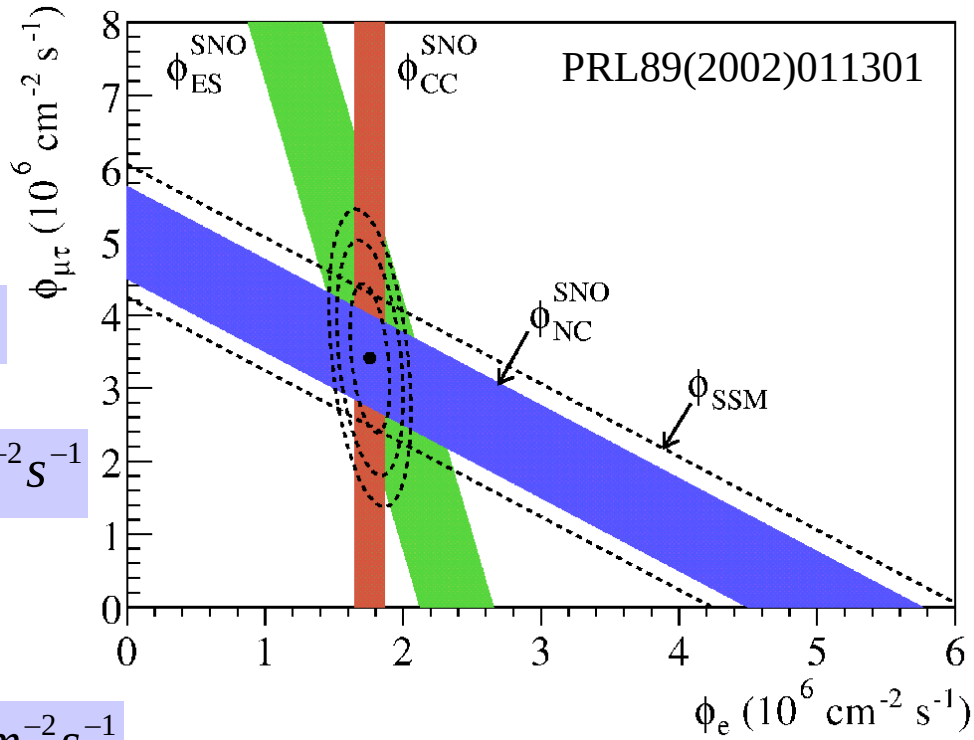
http://hitoshi.berkeley.edu/neutrino



SNO result

$$\phi_e = 1.76^{+0.05}_{-0.05}(stat)^{+0.09}_{-0.09}(syst)\times 10^6 cm^{-2}s^{-1}$$

$$\phi_{\mu\tau} = 3.41^{+0.45}_{-0.45}(stat)^{+0.48}_{-0.45}(syst)\times 10^6 cm^{-2}s^{-1}$$



Without the constraint on energy

$$\phi^{SNO}_{NC} = 6.42^{+1.57}_{-1.57}(stat)^{+0.55}_{-0.58}(syst)\times 10^6 cm^{-2}s^{-1}$$

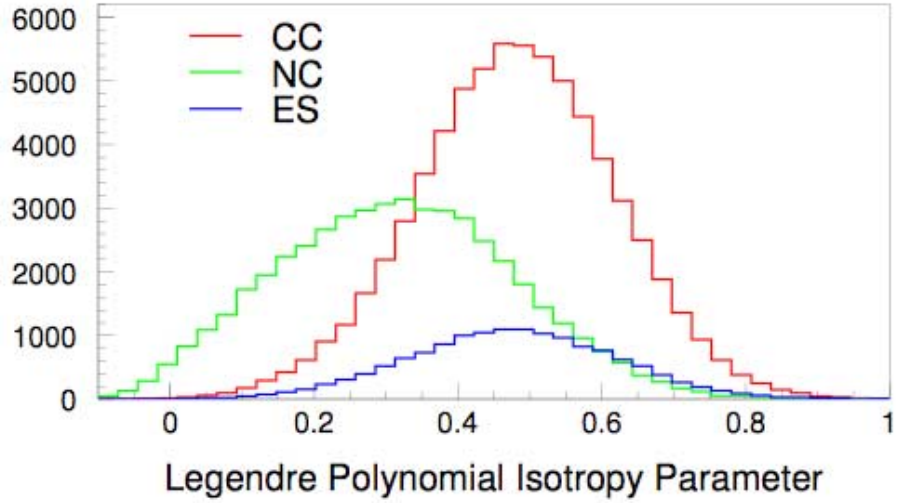
$$\phi_{SSM} = 5.05^{+1.01}_{-0.81}\times 10^6 cm^{-2}s^{-1}$$ ← **(SSM)**

- **First direct measurement of active ^{8}B ν.**
- **Strong evidence for neutrino flavor transition.**
- **Total ^{8}B ν agrees with SSM.**
- **SNO Day/night + All solar → LMA.**

SNO Status

- **Neutron capture on Cl**
  - **Large σ of neutron capture on Cl**
  - **8.6MeV multiple γs**
  - **Good light isotropy**
  - **Better NC extraction**
  - **Result is expected in a few months?**

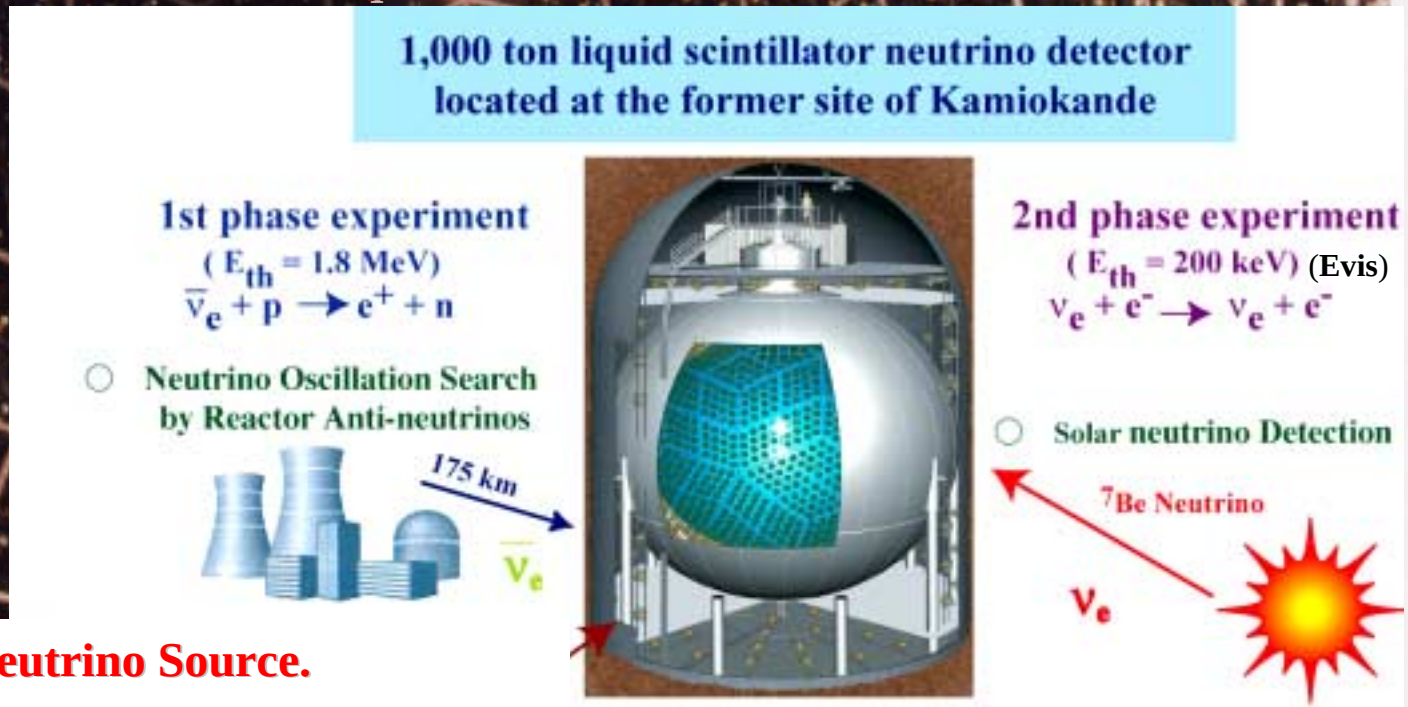
A.Poon I.O.P. HEPP Particle Physics 2003, Durham



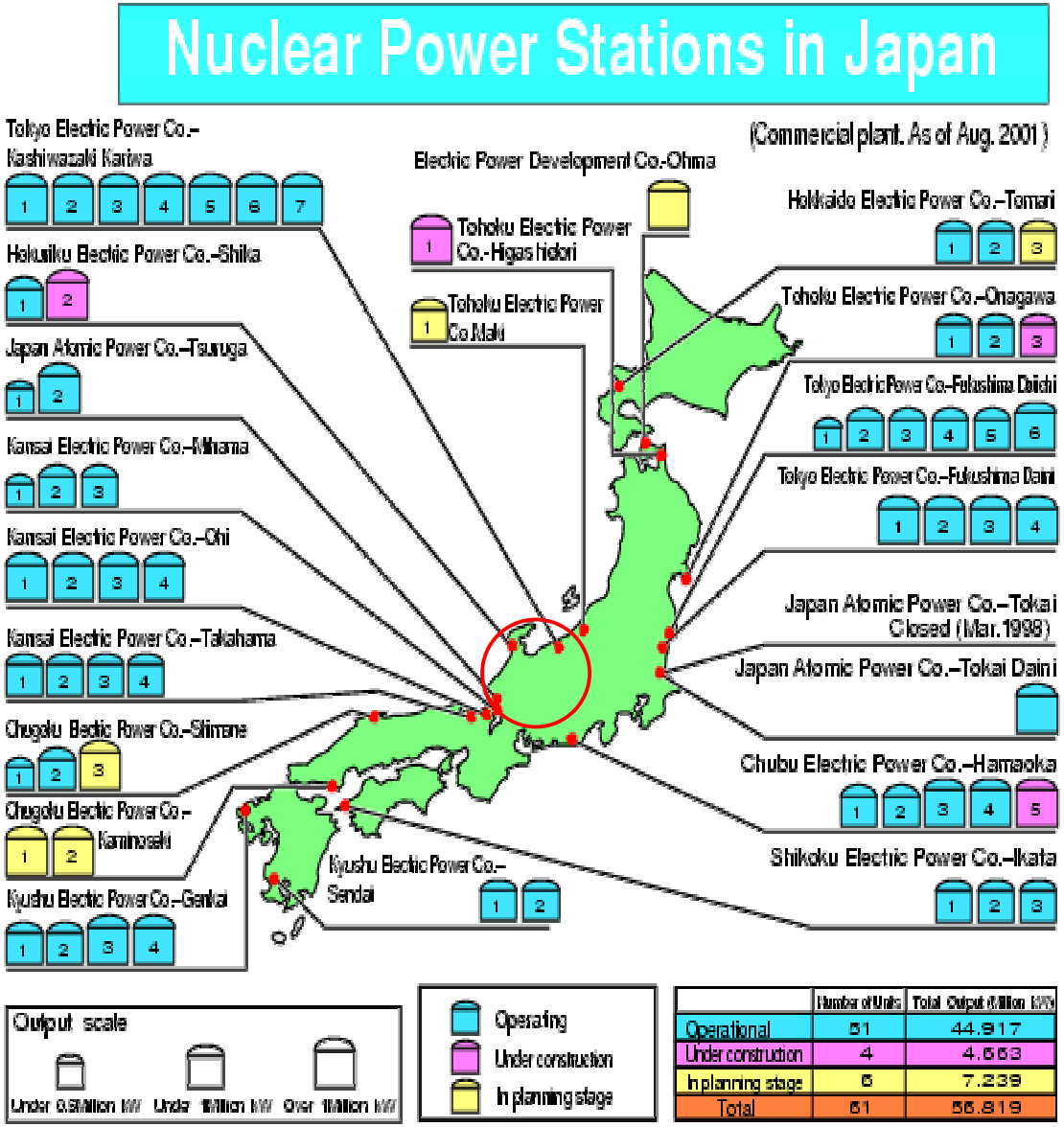
- **Installation of Neutral Current Detector Array**
  - **$n+^3He \rightarrow p+t$**
  - **Independent NC measurement(syst.+9.1/-8.5→+/- 4.5 %)**
  - **Sept. 03 → ?**

KamLAND

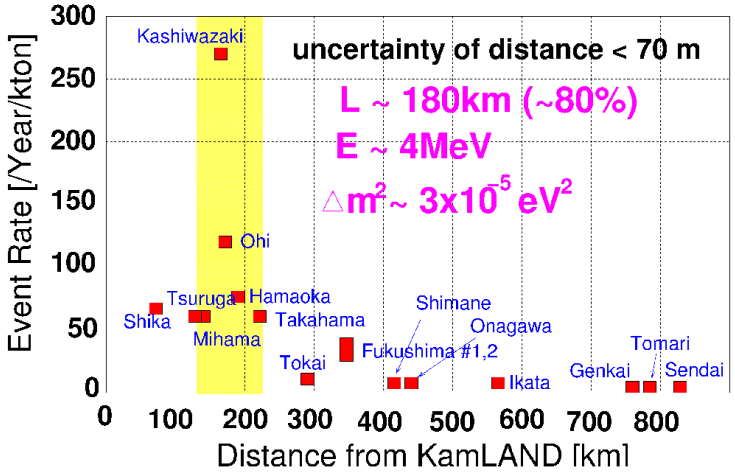
Kamioka Liquid scintillator Anti Neutrino Detector



- **Reactor Anti Neutrino Source.**
- **Energy distortion? under Lab. condition.**
- **LMA?**
- **CPT invariance.**
- **^{7}Be neutrinos.**

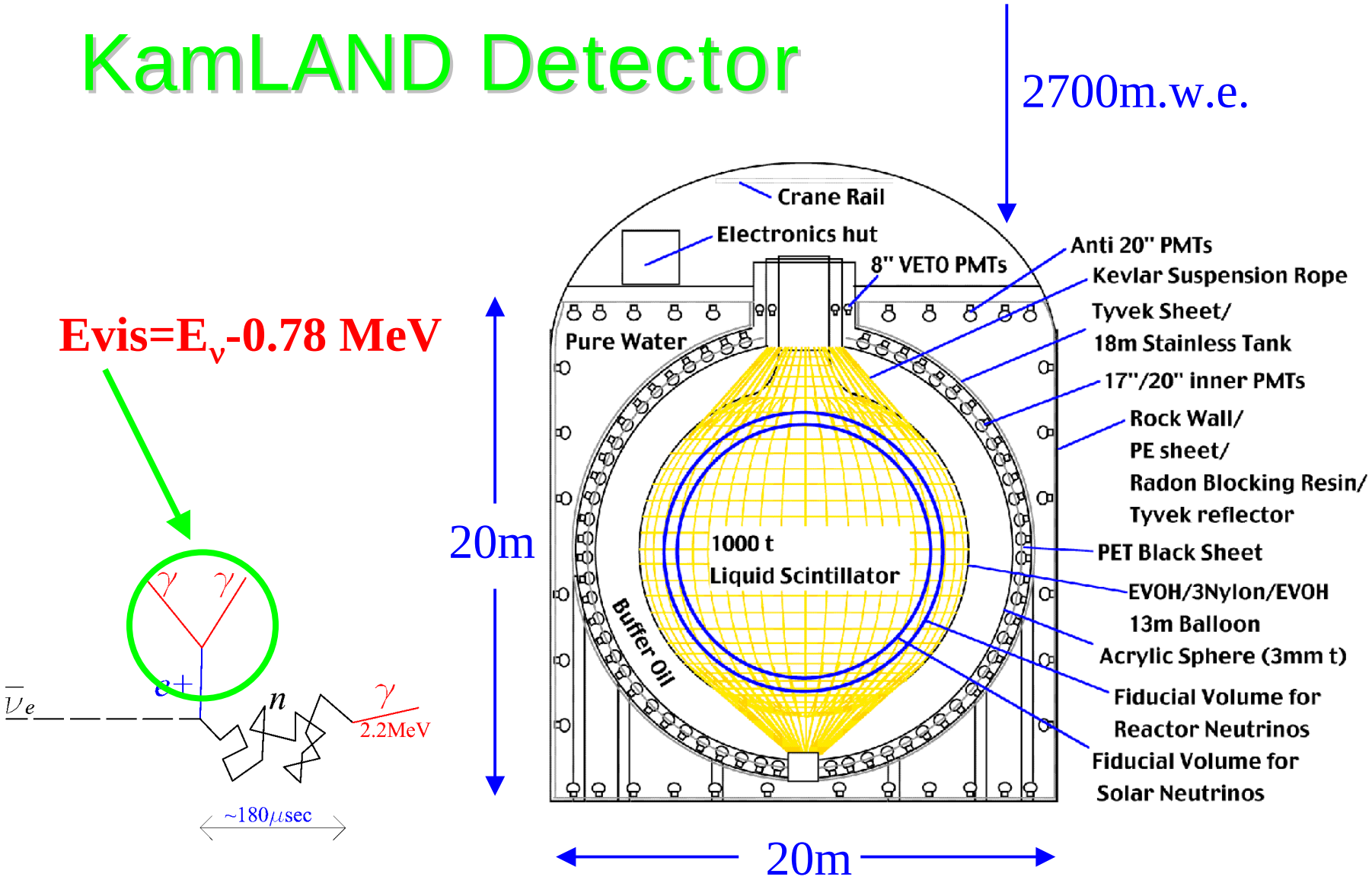


a few /day in KamLAND



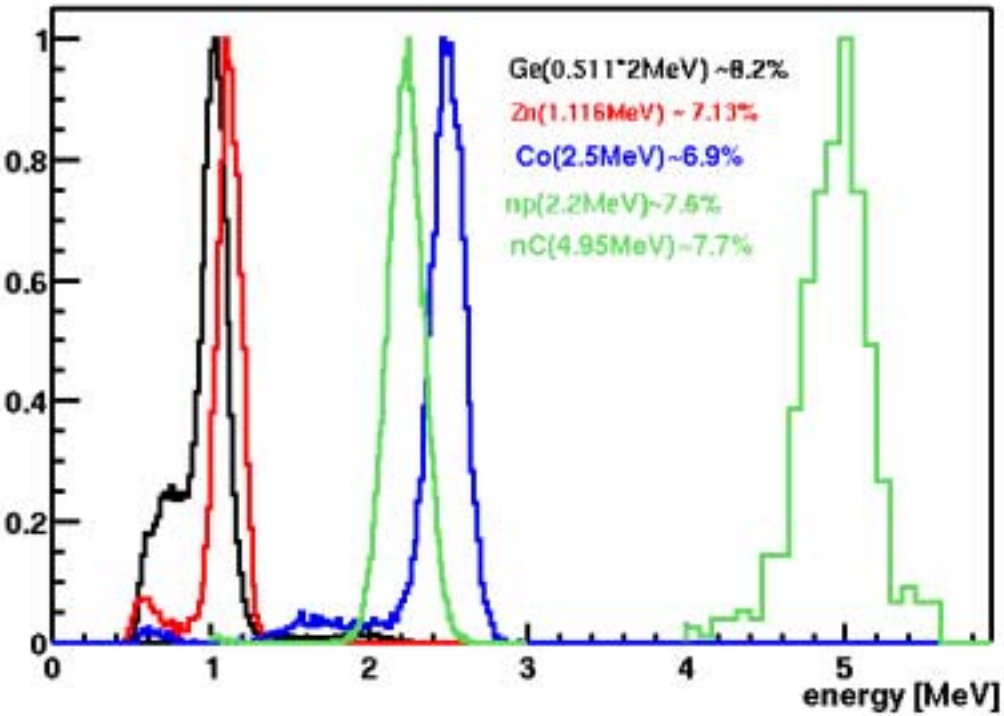
- **Thermal power, Burn-up, Fuel change record data, Simple model of reactor core.**
  - → **fission rate**
  - → **energy spectrum @KamLAND**
- **Korea(2.3+- 0.2% @N(ν))**

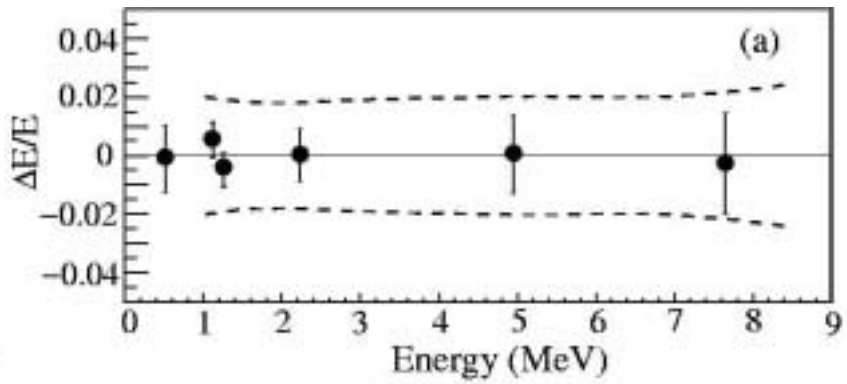
KamLAND Detector



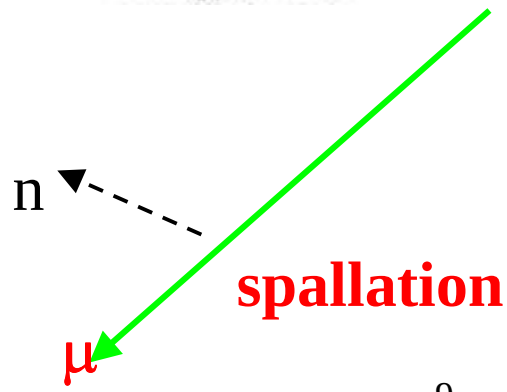
Energy resolution

^{68}Ge ($\gamma + \gamma$) : 1.012 MeV
^{65}Zn (γ) : 1.116 MeV
^{60}Co ($\gamma + \gamma$) : 2.506 MeV
AmBe (γ,n) : 2.20, 4.40, 7.6 MeV
n+p→d+γ : 2.2 MeV
n+^{12}C→^{13}C+γ : 4.9MeV





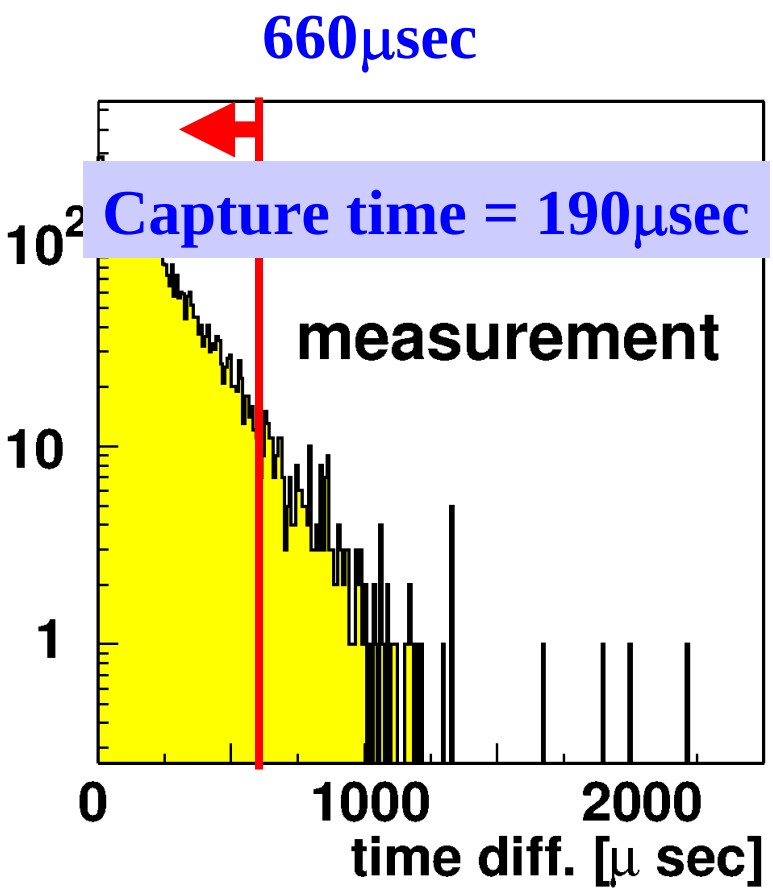
- $\Delta E/E \sim 7.5\% / \sqrt{E}$ [MeV]
- ΔE_{syst}=1.9% at 2.6MeV
  → 2.1% for anti ν_e

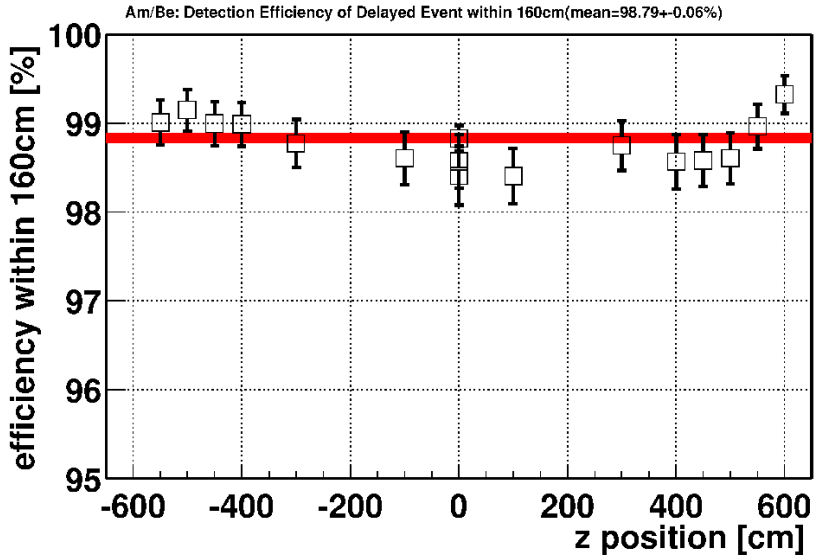


AmBe Neutrons

$$^{241}Am \rightarrow {}^{238}Np + \alpha$$

$$\alpha + Be \rightarrow {}^{12}C^{*} + \boxed{n}$$



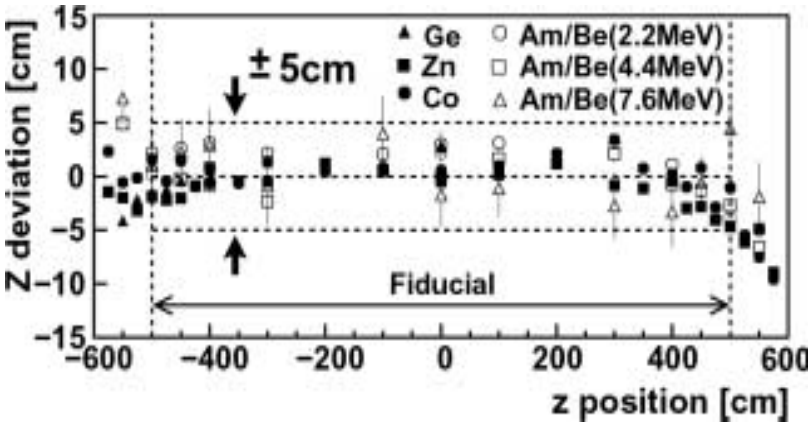


Delayed coincidence effi = 95.3 %

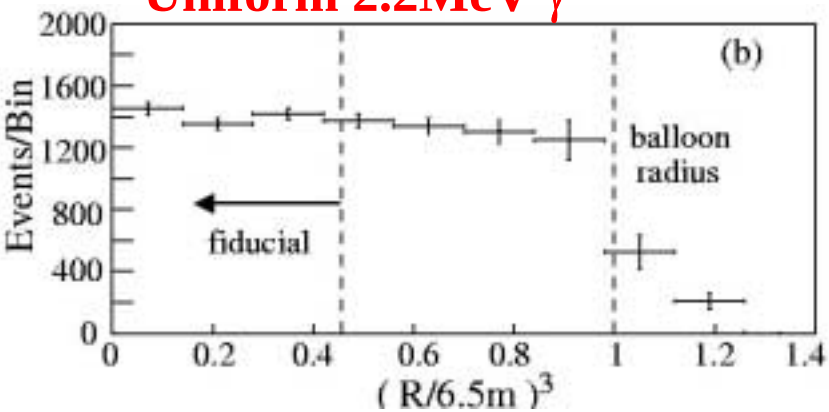
Detection effi= 98.8%

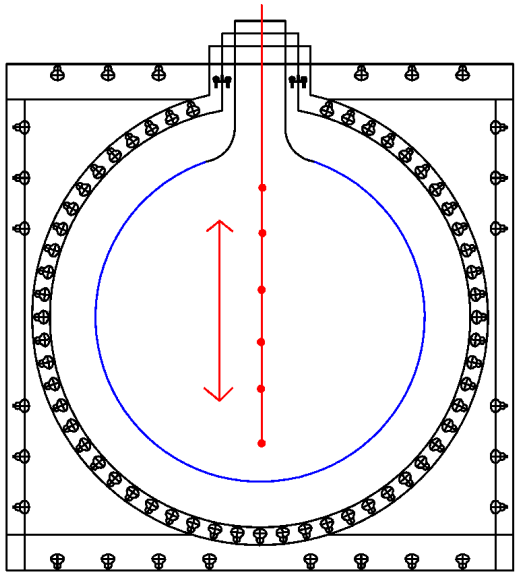
Vertex reconstruction

5cm resolution



Uniform 2.2MeV γ





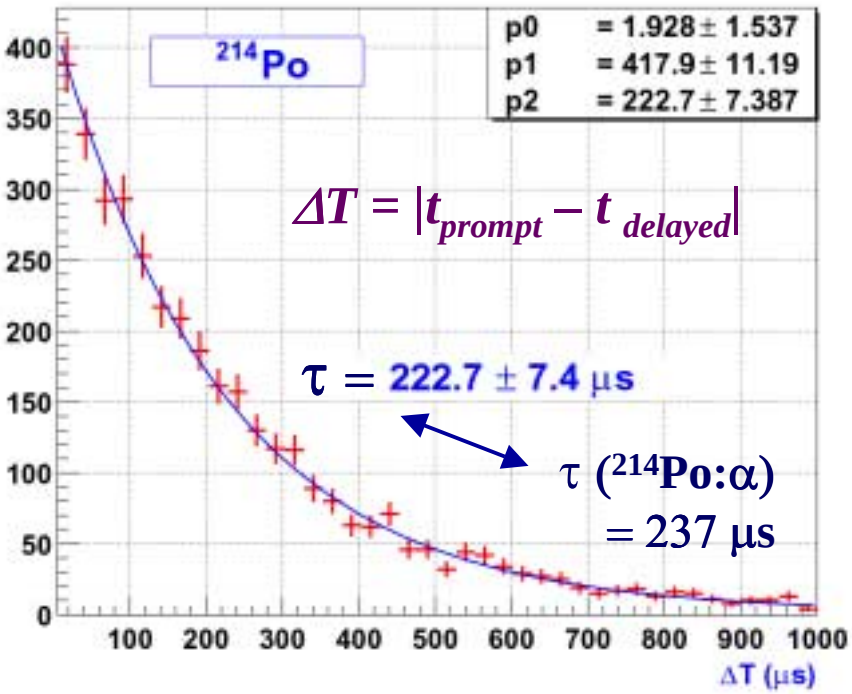
4.1% uncertainty on number of neutrinos coming from fiducial mass ratio

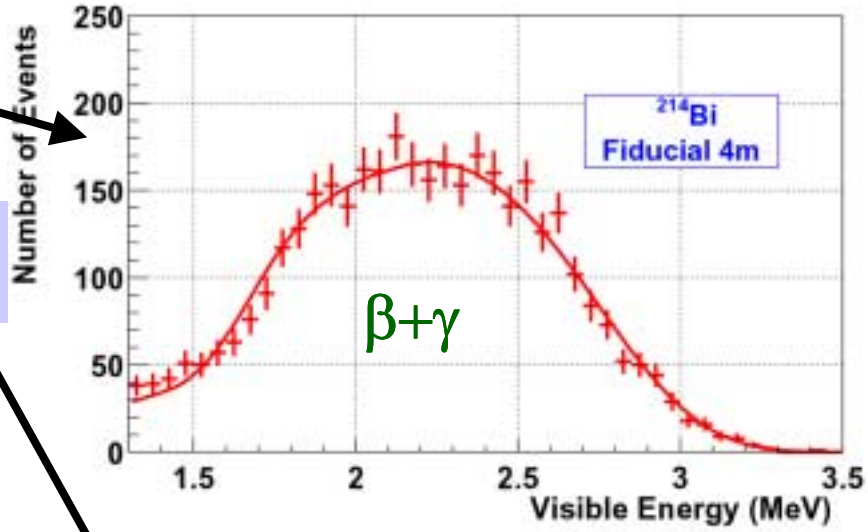
^{214}Bi – ^{214}Po – ^{210}Pb Signal

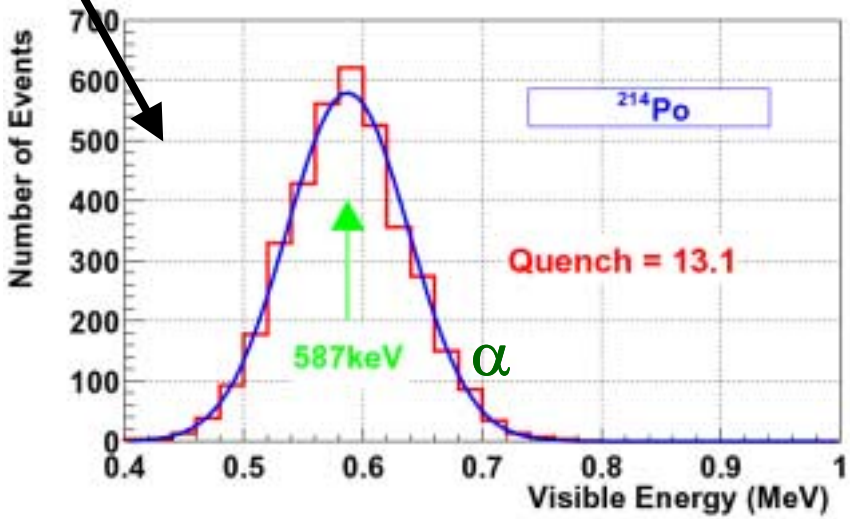
prompt

delayed

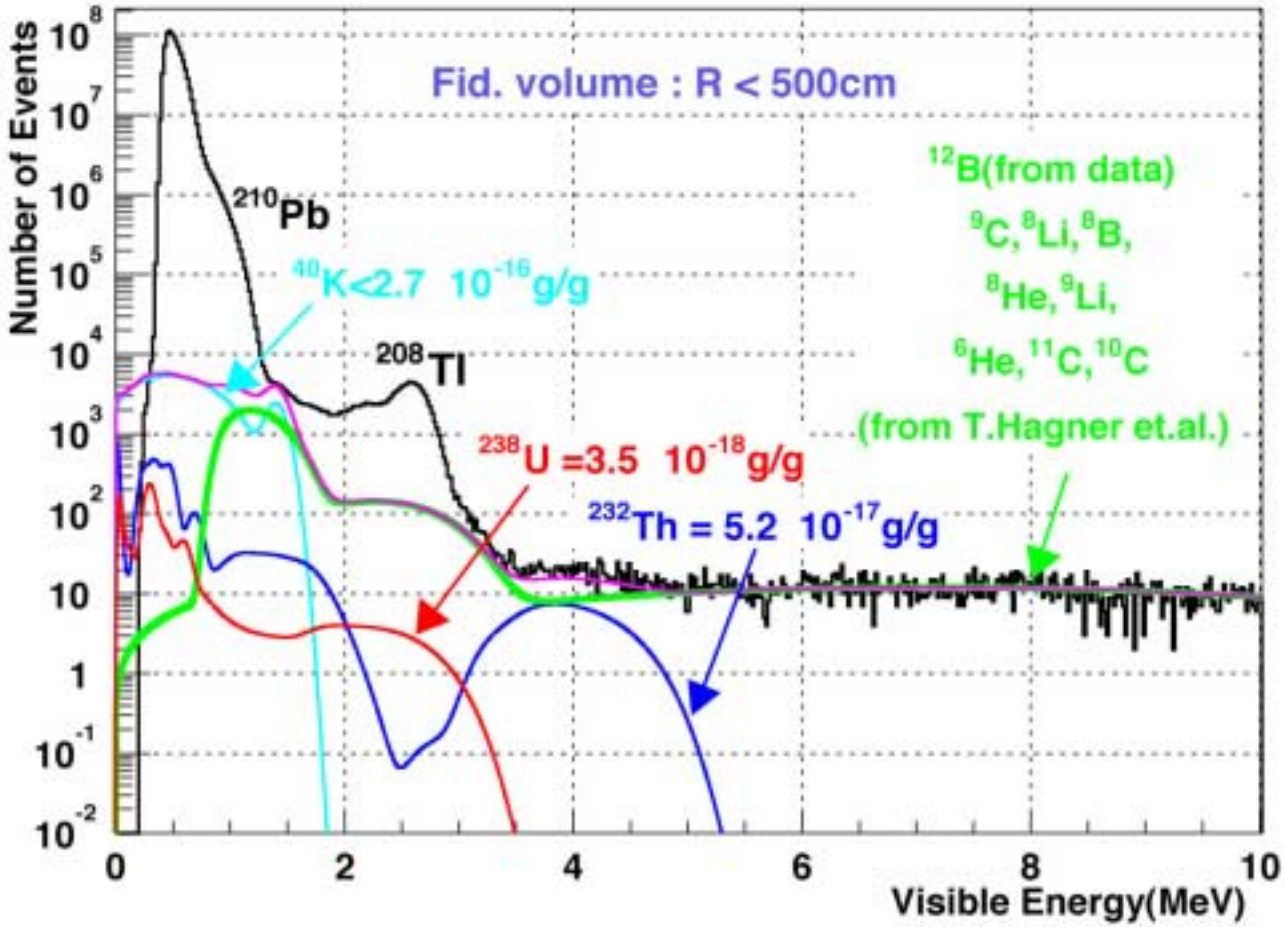
^{238}U = (3.5±0.5)x10^{-18} g/g







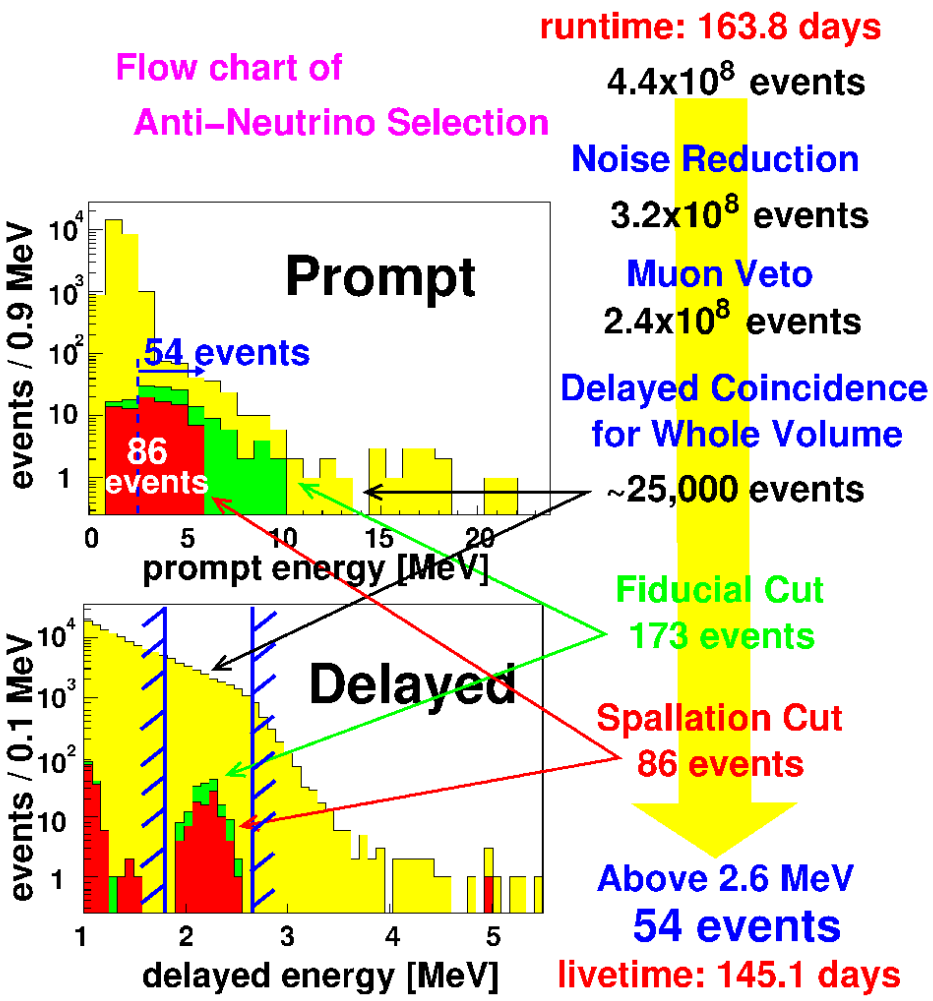
Radioactive Background in LS



Source	BG in data sample
Accidental	0.0086±0.0005
$^{9}Li/^{8}He$	0.94±0.85
Fast Neutrons	<0.5
U	Negligible
Th	Negligible
	0.95±0.86

Source	Systematic E(%)
Total LS mass	2.13
Fiducial Mass ratio	4.06
Energy threshold	2.13
Cut efficiency	2.06
Live time	0.07
Reactor Power	2.05
Fuel composition	1.00
Time lag	0.28
ν spectra	2.48
Cross section	0.2
	6.42

Neutrino Event selection



Details

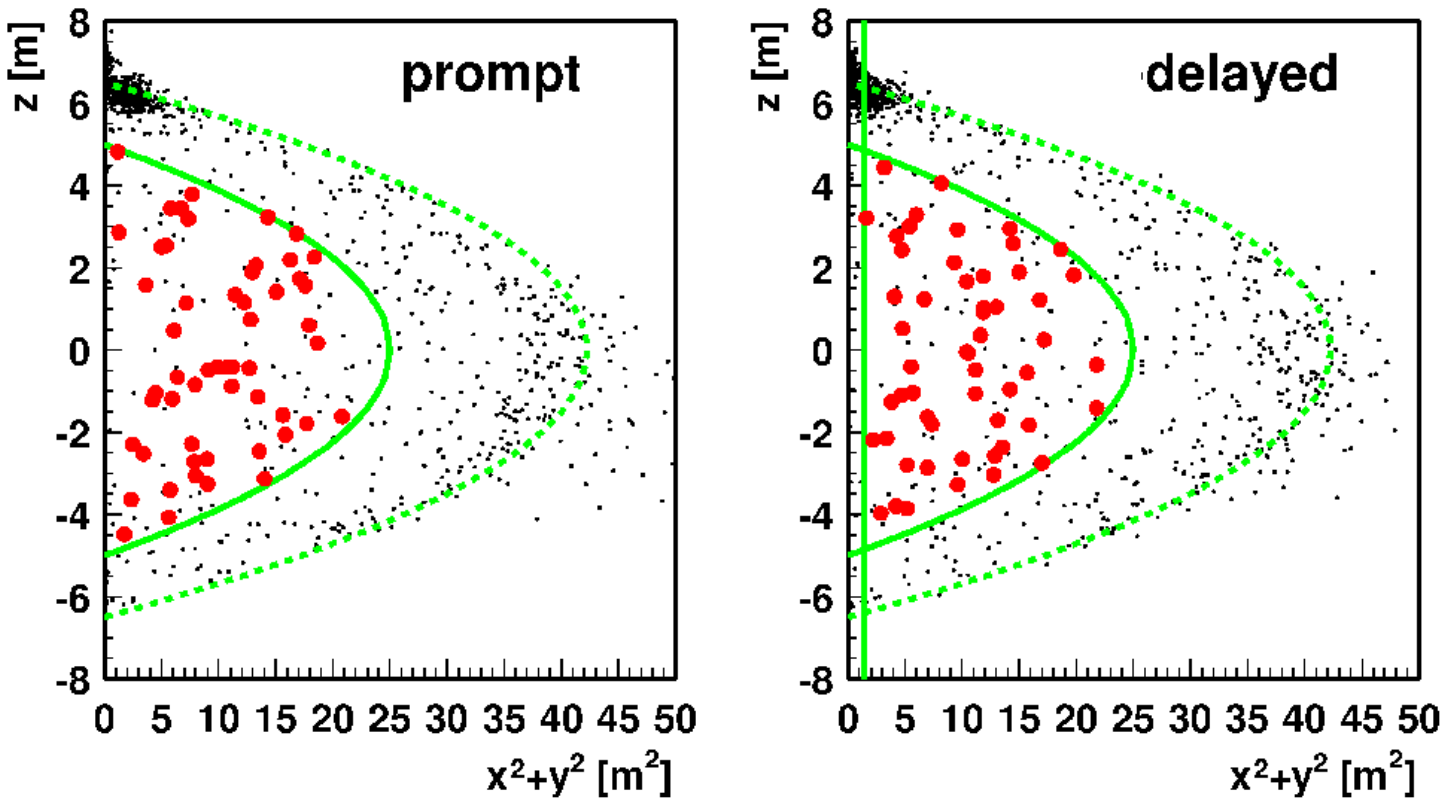
- Timing correlation in PMTs
- no μ veto signals
- $0.5 < \Delta T < 660$ μsec
- $1.8 < E_{delayed} < 2.6$ MeV

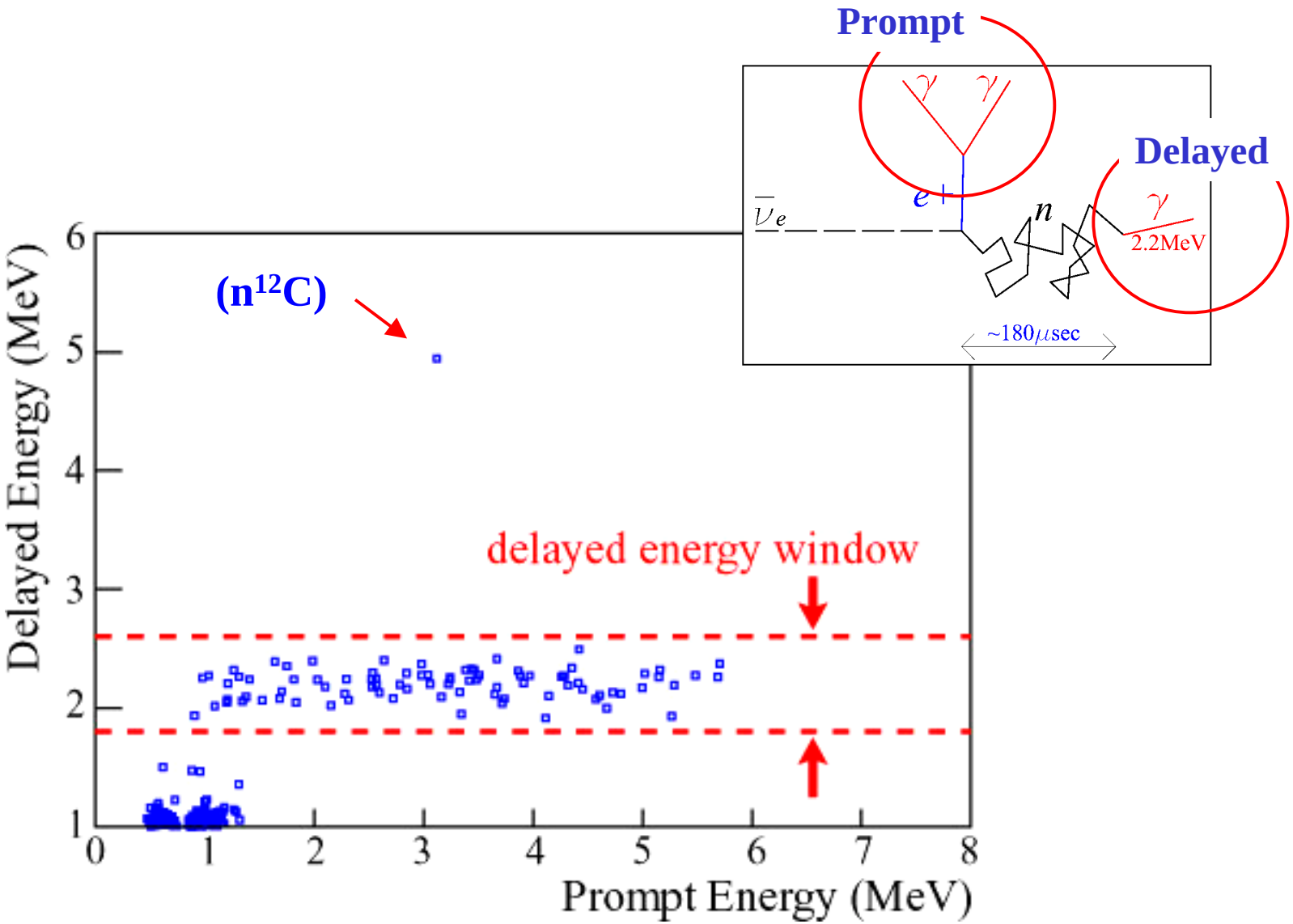
- $R < 5$ m : 409 ton, 3.46×10^{31} free protons
- $\Delta R < 1.6$ m, $R_d > 1.2$ m

- Veto for 2msec. after muons.
- Veto for 2sec. after muons ($E > 10^6$ p.e.) (0.02Hz)
- Cylindrical (R=3m) 2sec veto around muons ($E < 10^6$ p.e.)

⇒ tagging efficiency 78.3%

Vertex position after delayed coincidence




Prompt
Delayed
γ
γ
e^+
$\bar{\nu}_e$
n
γ
2.2MeV
~180μsec
(n^{12}C)
delayed energy window
Delayed Energy (MeV)
Prompt Energy (MeV)
0
1
2
3
4
5
6
7
8

KamLAND result

Mar. 4 – Oct. 6, 2002
162 ton•yr (145.1 days)

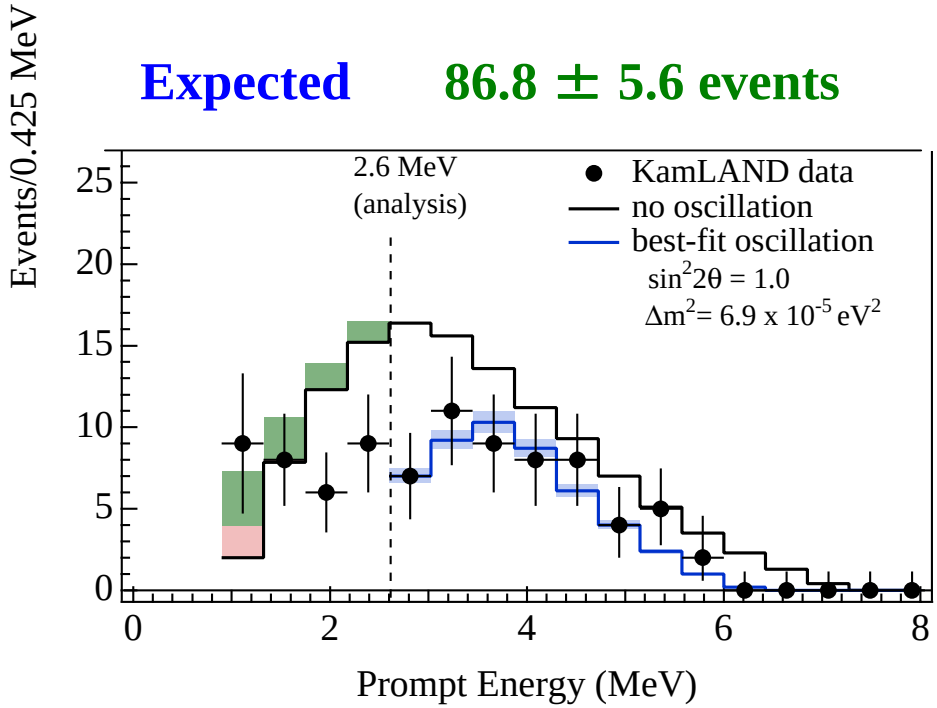
Observed **54 events (E>2.6MeV)**

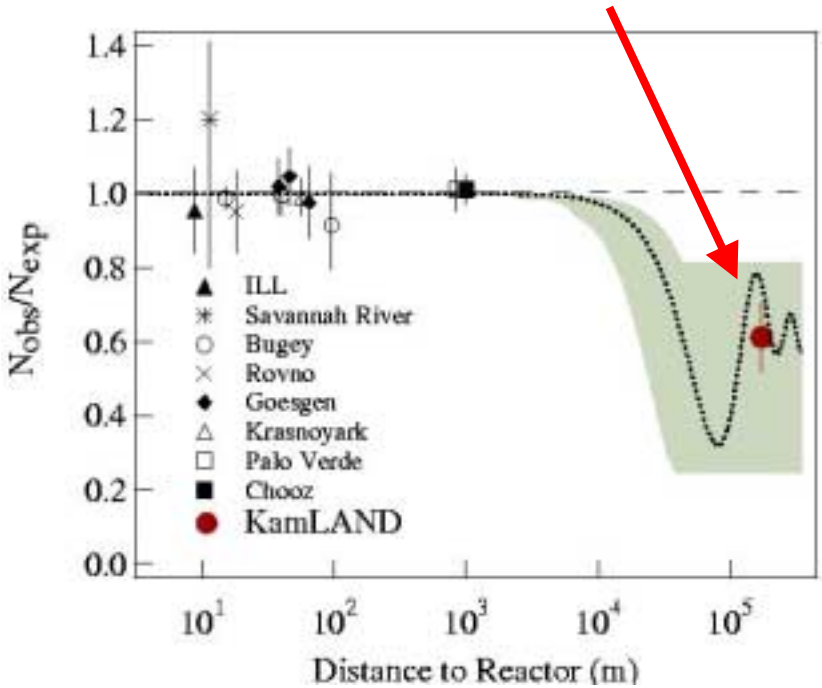
Background **1 ± 1 events**

Expected **86.8 ± 5.6 events**

$$\frac{N_{obs} - N_{bg}}{N_{expected}} = 0.611 \pm 0.085(stat)$$

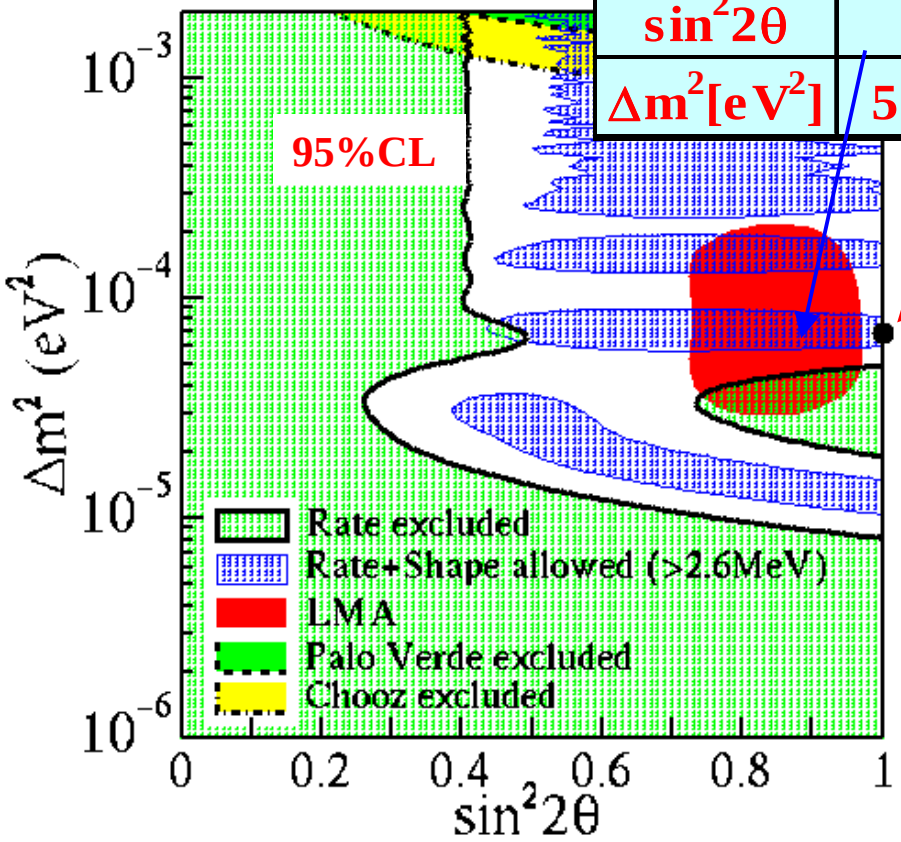
$$\pm 0.041(sys)$$



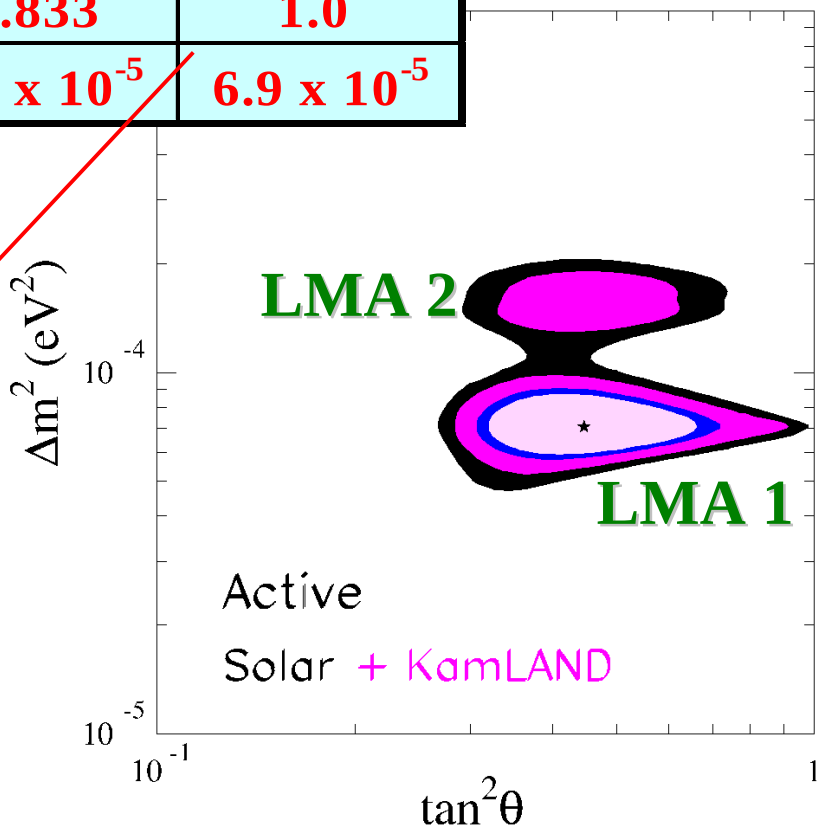


KamLAND impacts

Best fit	LMA	KamLAND
$\sin^2 2\theta$	0.833	1.0
$\Delta m^2 [eV^2]$	5.5×10^{-5}	6.9×10^{-5}



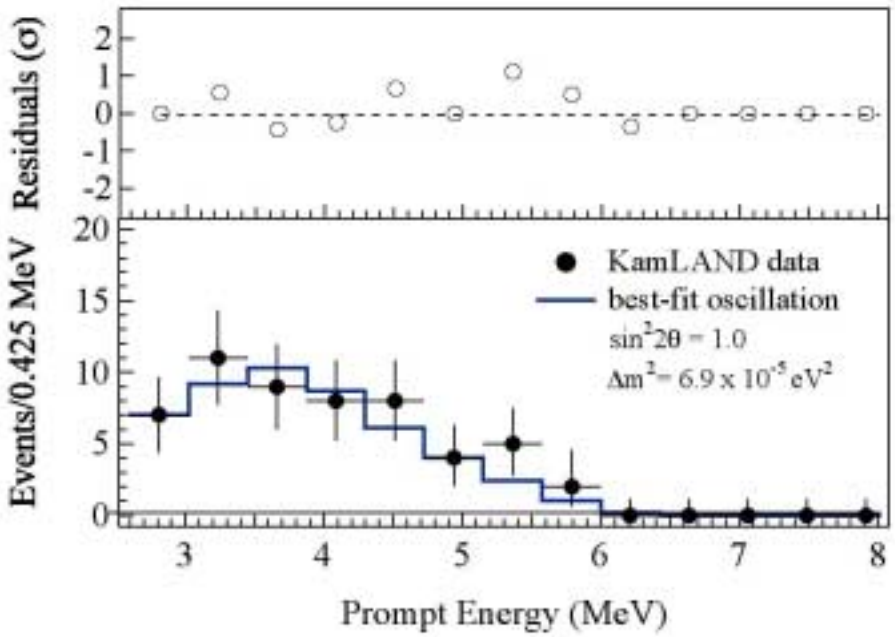
KamLAND



All combined

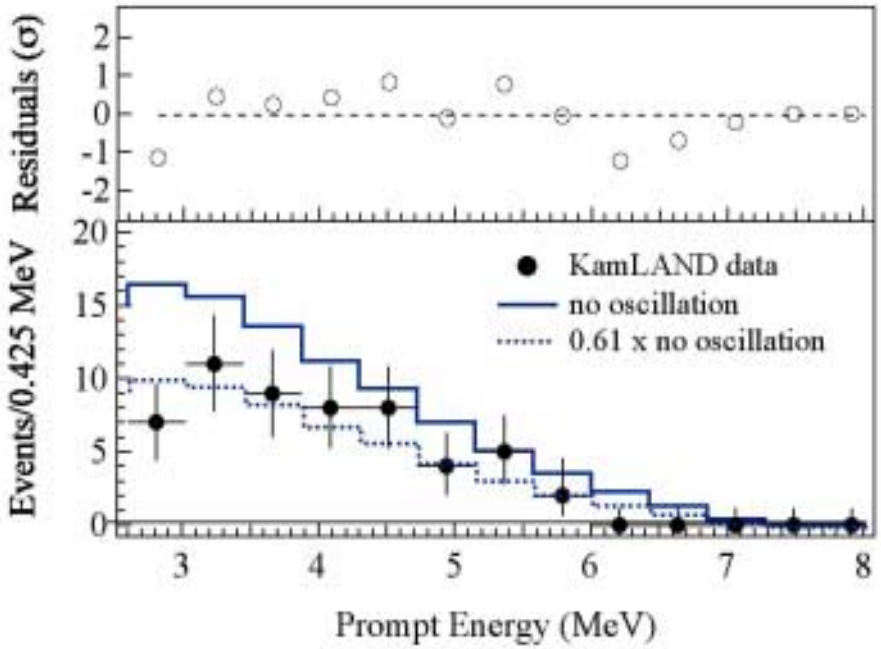
Spectral Distortion?

2-ν oscillation: best-fit



Data and best oscillation fit consistent at 93% C.L.

No oscillation, flux suppression



Data and scaled no-oscillation shape consistent at 53% C.L

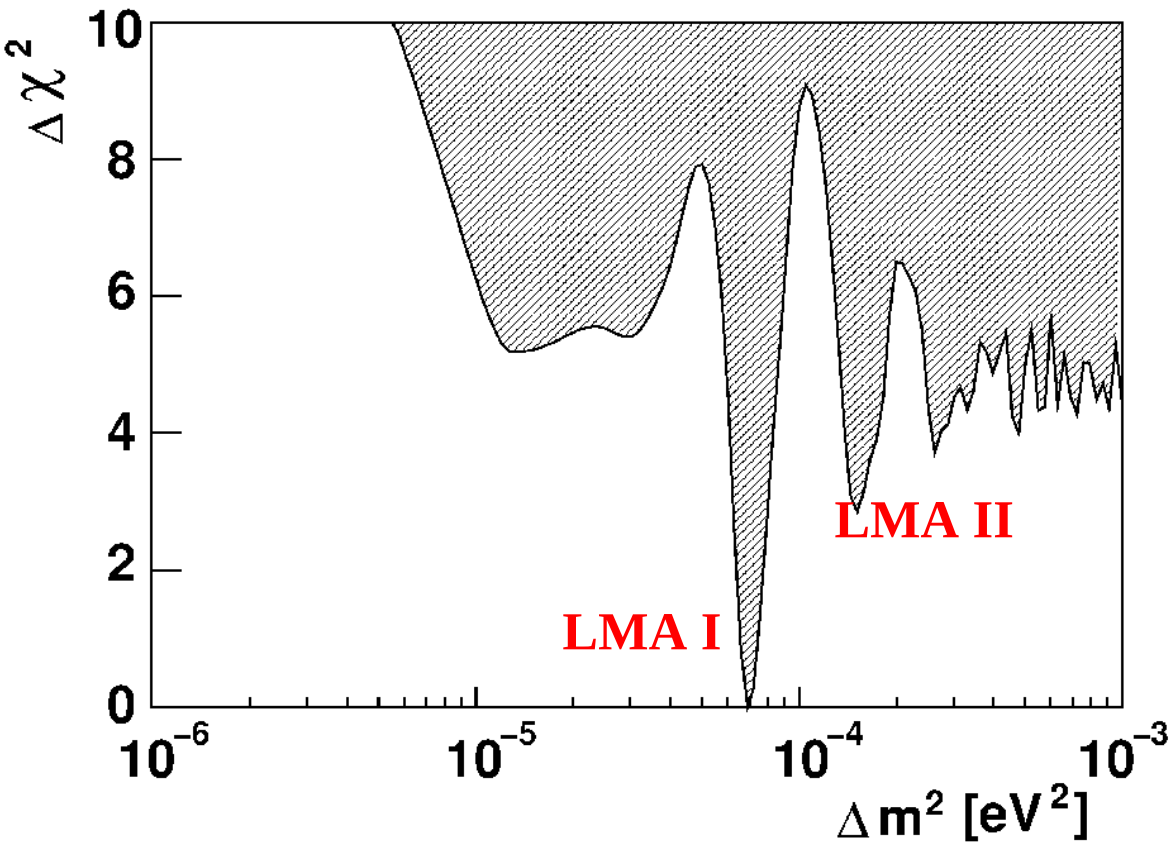
Need more reactor neutrino and calibration data

KamLAND Prospects

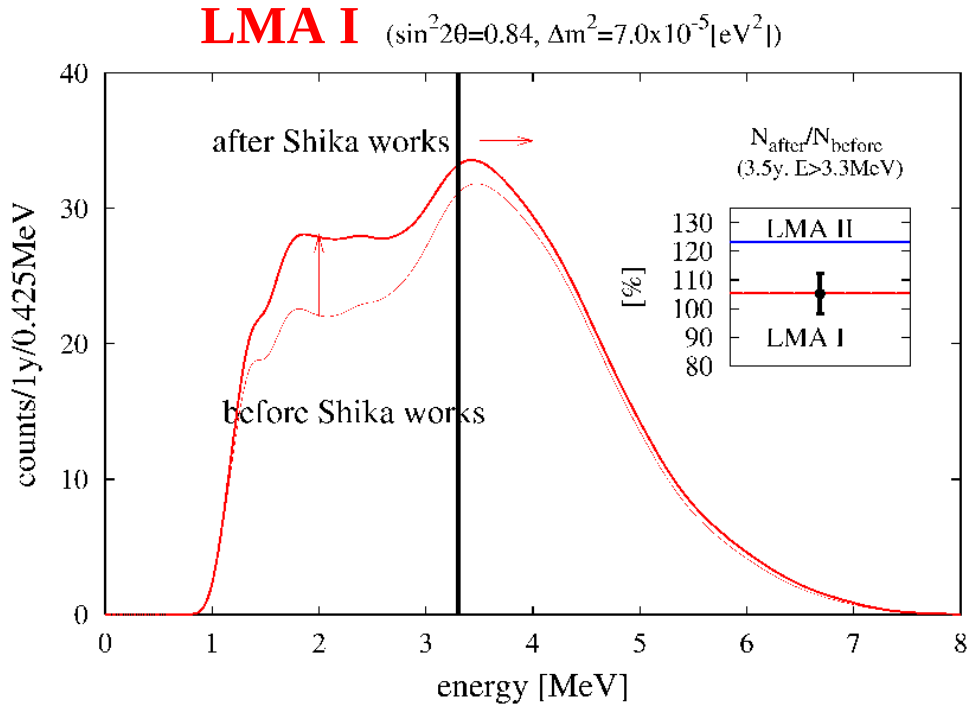
- **Neutrino Oscillation? Precision measurements**
  - **Energy Spectrum distortion?**
  - **Current reactor power in Japan ~50%.**
  - **A new reactor is coming.**
  - **LMA 1 or LMA2**

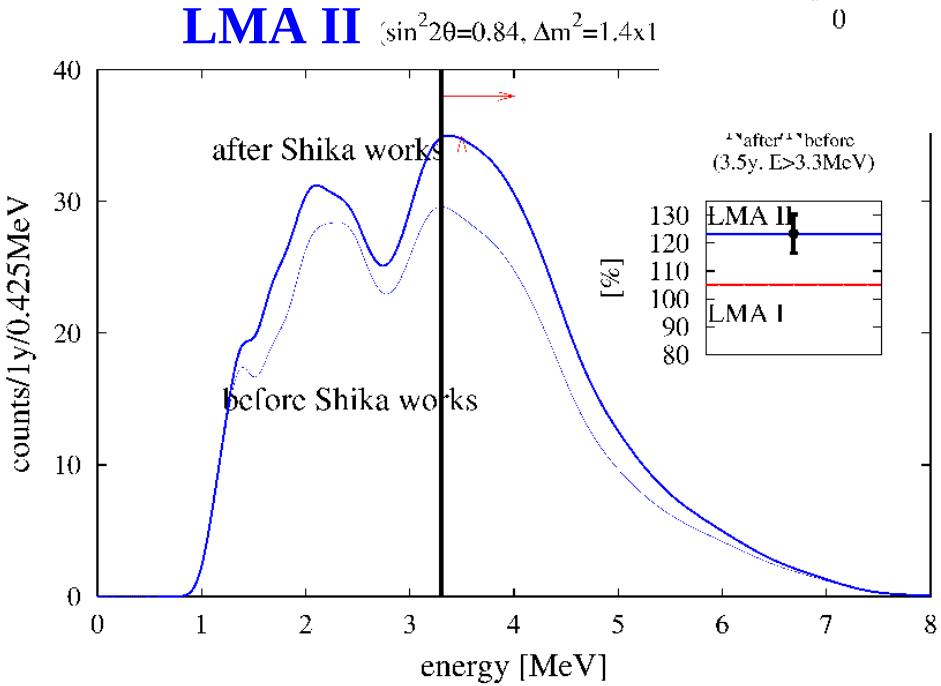
- **7Be**
  - **Purification system improvement**

χ^2 projection



Before and After Shika





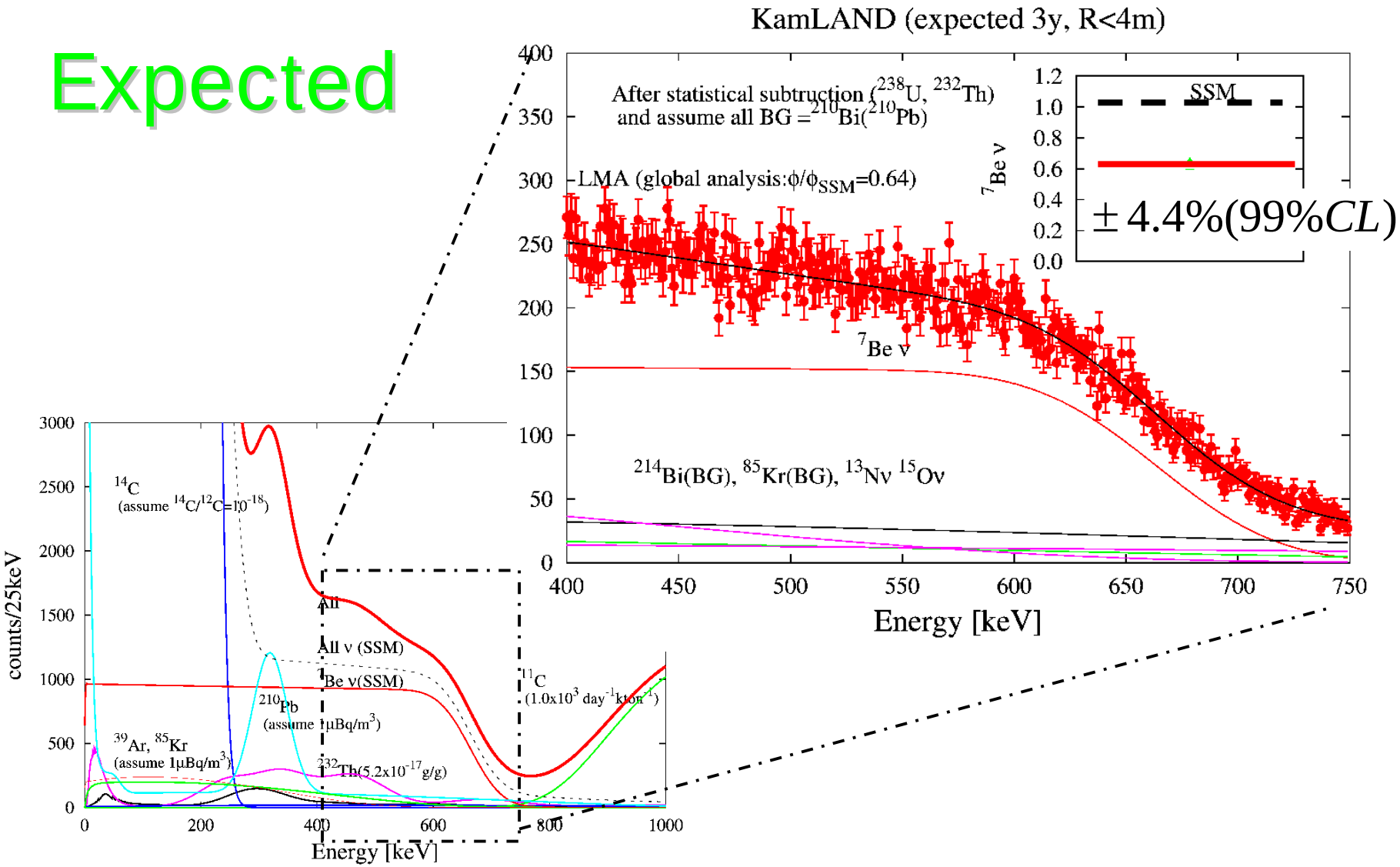
Solar ν @ KamLAND

- **No direct observation of ^{7}Be ν.**

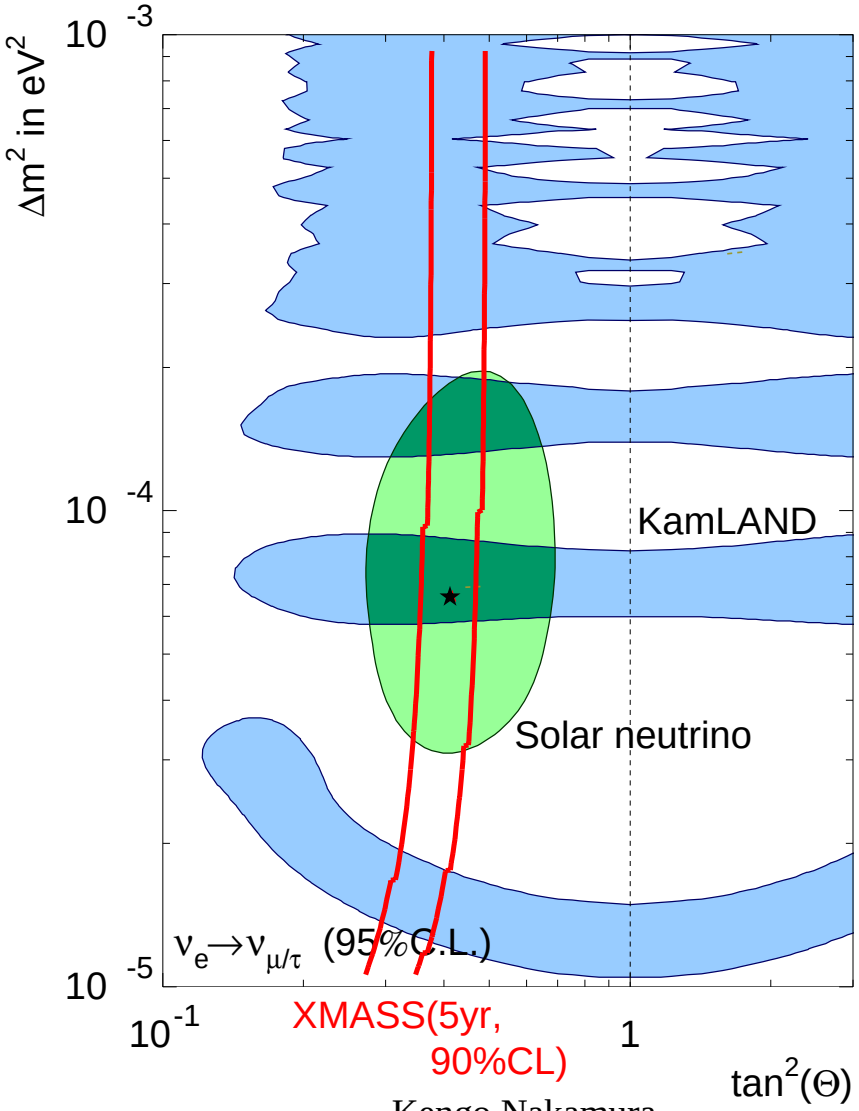
- **Improve KamLAND purification system.**
- **^{210}Pb; 10^{-20} g/g → 10^{-25} g/g (Water extraction)**

- **Air tight valve housings.**
- **Testing the water extraction.**

Expected


KamLAND (expected 3y, R<4m)
After statistical subtruction (^{238}U, ^{232}Th)
and assume all BG = ^{210}Bi(^{210}Pb)
LMA (global analysis:ϕ/ϕ_{SSM}=0.64)
^{7}Be ν
^{214}Bi(BG), ^{85}Kr(BG), ^{13}Nν ^{15}Oν
SSM
^{7}Be ν
±4.4%(99%CL)
Energy [keV]
^{14}C
(assume ^{14}C/^{12}C=10^{-18})
All
All ν (SSM)
Be ν(SSM)
^{210}Pb
(assume 1μBq/m^{3})
^{39}Ar, ^{85}Kr
(assume 1μBq/m^{3})
^{232}Th(5.2x10^{-17}g/g)
^{11}C
(1.0x10^{3} day^{-1}kton^{-1})
counts/25keV
Energy [keV]

XMASS

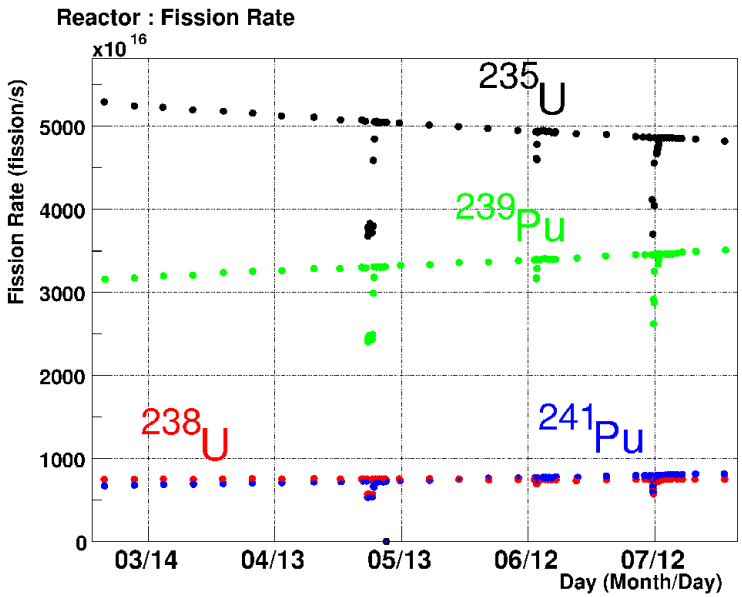

Δm^2 in eV^2
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
$\tan^2(\Theta)$
KamLAND
Solar neutrino
$\nu_e \rightarrow \nu_{\mu/\tau}$ (95%C.L.)
XMASS(5yr, 90%CL)

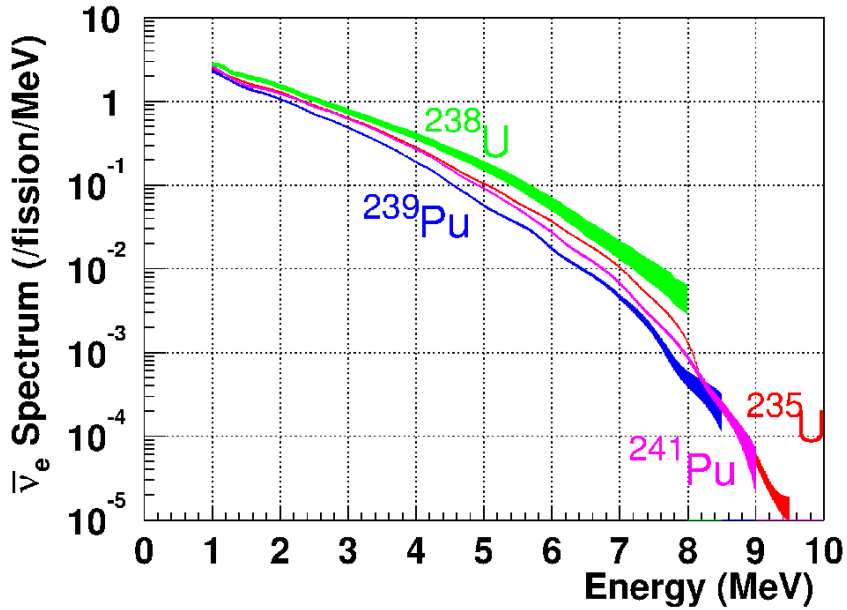
Summary

- **Last year**
  - **^{8}B neutrino measurement and strong evidence of neutrino flavor transition by SNO.**
  - **KamLAND observed a clear deficit in reactor neutrinos.**
- **Current Status related to KamLAND and SNO**
  - **SNO cl results coming soon and new NC detector installation.**
  - **KamLAND stable n data taking during reactor shutdown.**
- **Future**
  - **KamLAND update results.**
  - **KamLAND purification system will be improved for ^{7}Be Solar neutrino detection.**

Backup slides

How to calculate neutrino flux from reactors

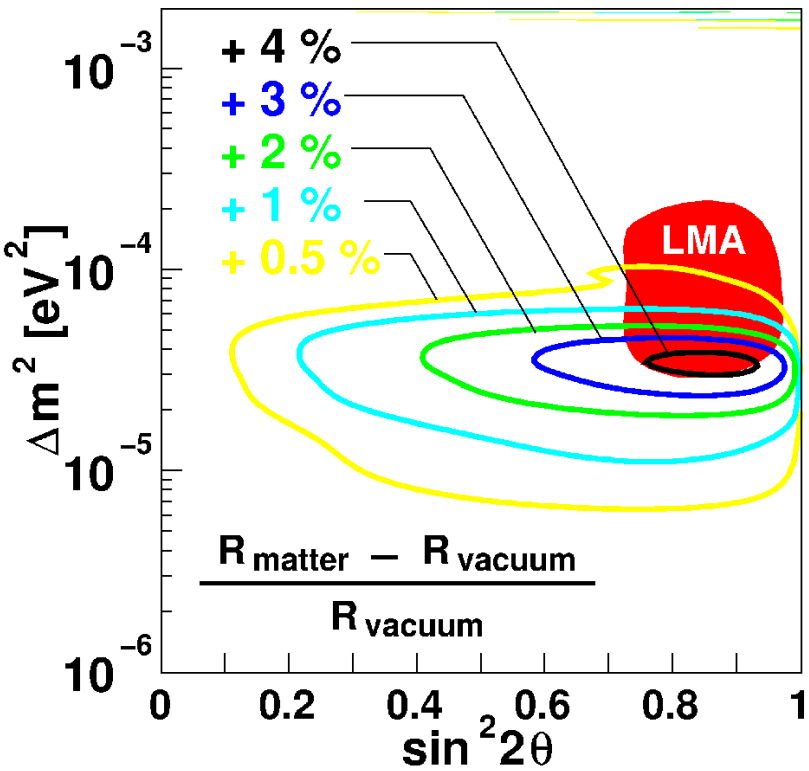


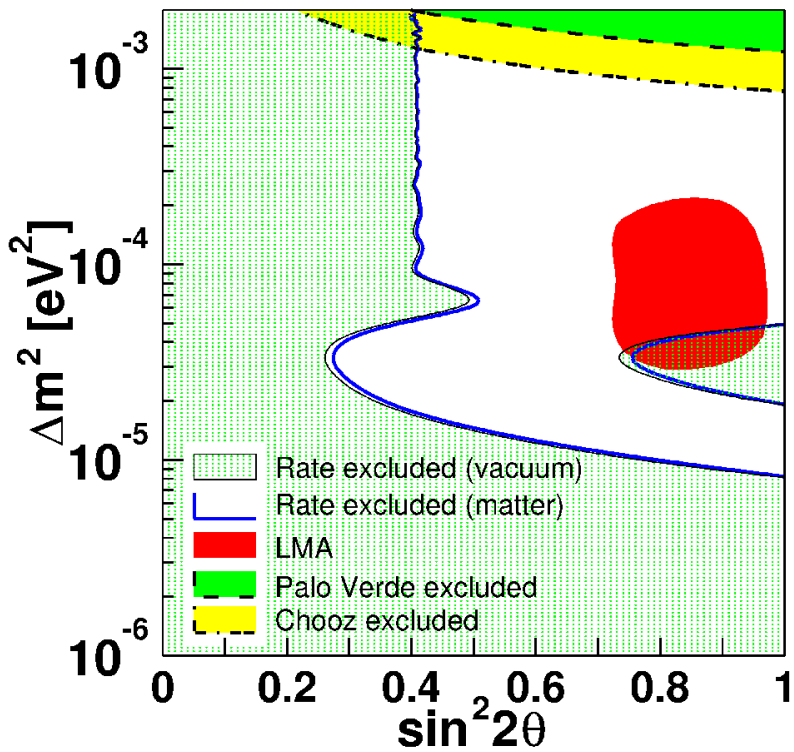


Solar Neutrino at KamLAND

Background	Current	Goal	Method
^{238}U	3.5×10^{-18} g/g	OK	
^{232}Th	5.2×10^{-17} g/g	OK	
^{222}Rn	3.3×10^{-8} Bq/m^{-3}	OK	
^{40}K	$<2.7 \times 10^{-16}$ g/g	$<10^{-18}$ g/g	Water Extraction
^{210}Pb	$\sim 10^{-20}$ g/g	5×10^{-25} g/g	Water Extraction
^{85}Kr	0.7Bq/m^{-3}	10^{-6} Bq/m^{-3}	N_2 purge
^{222}Rn leak			N_2 purge/ air tight valves

Matter effect





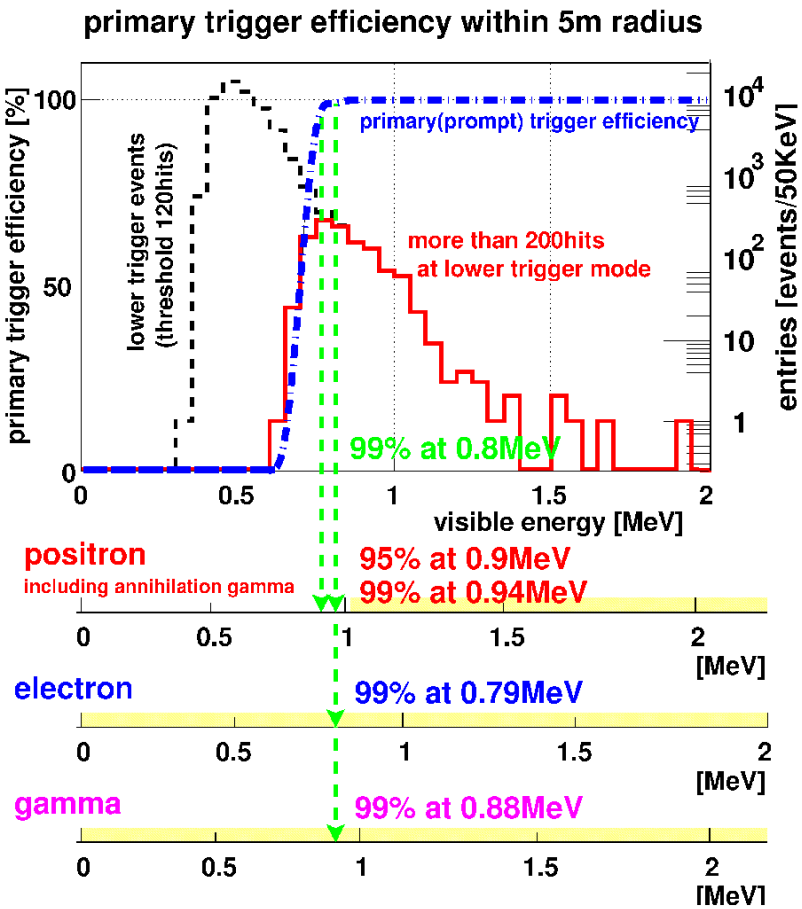
θ_{13}

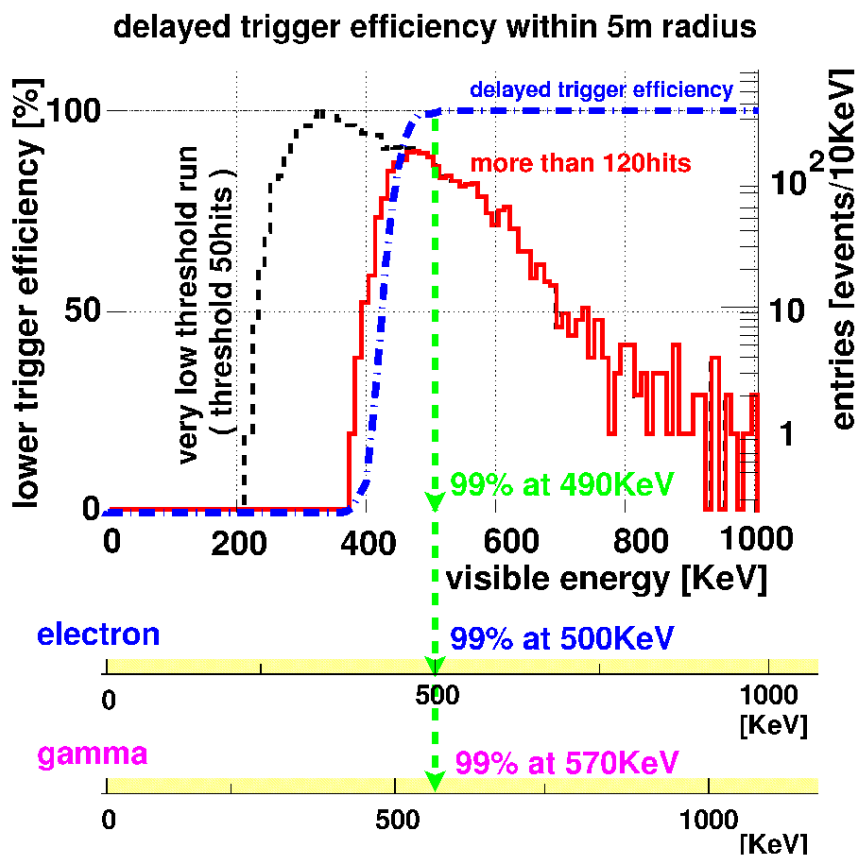
The KamLAND is actually measuring;

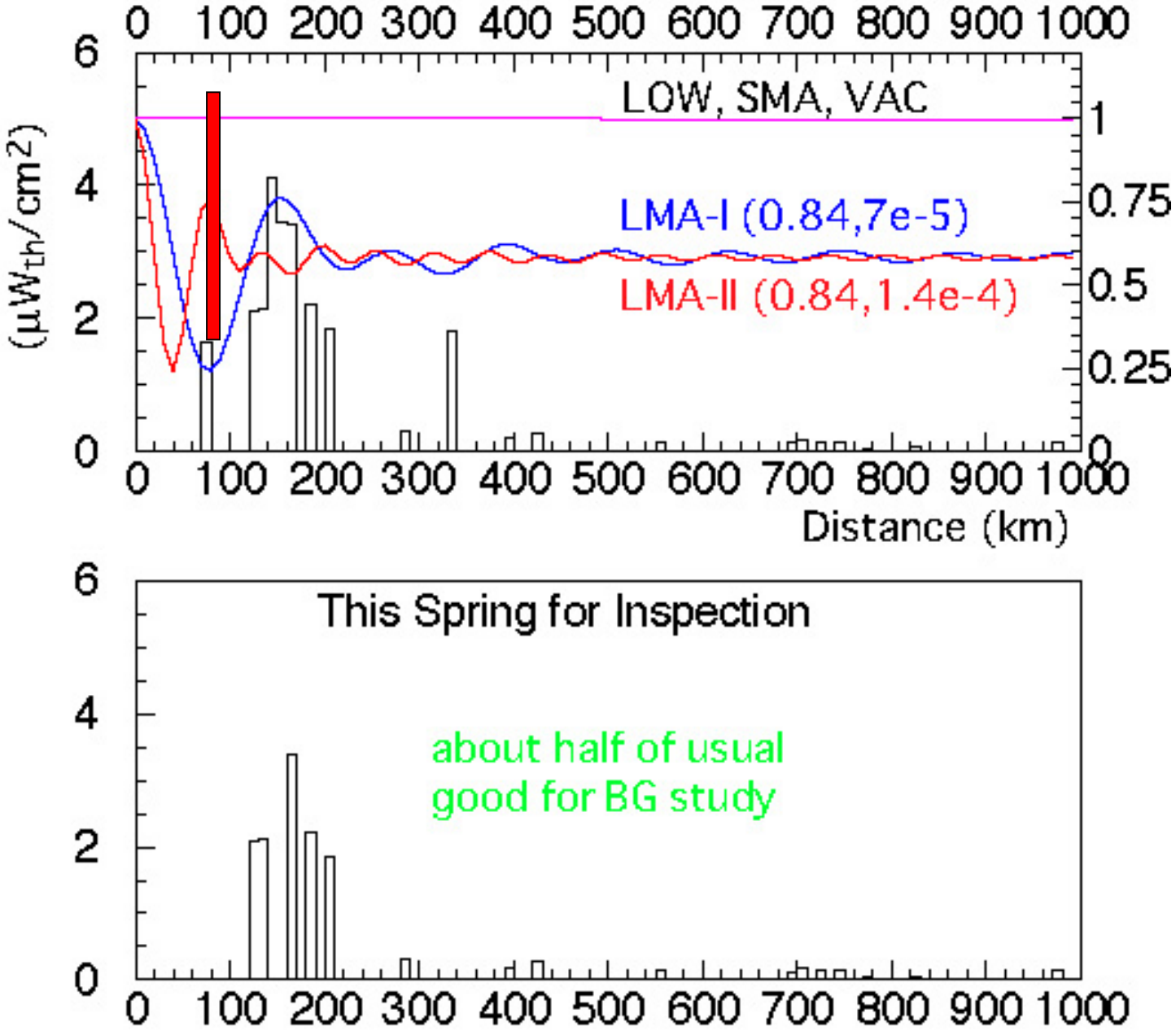
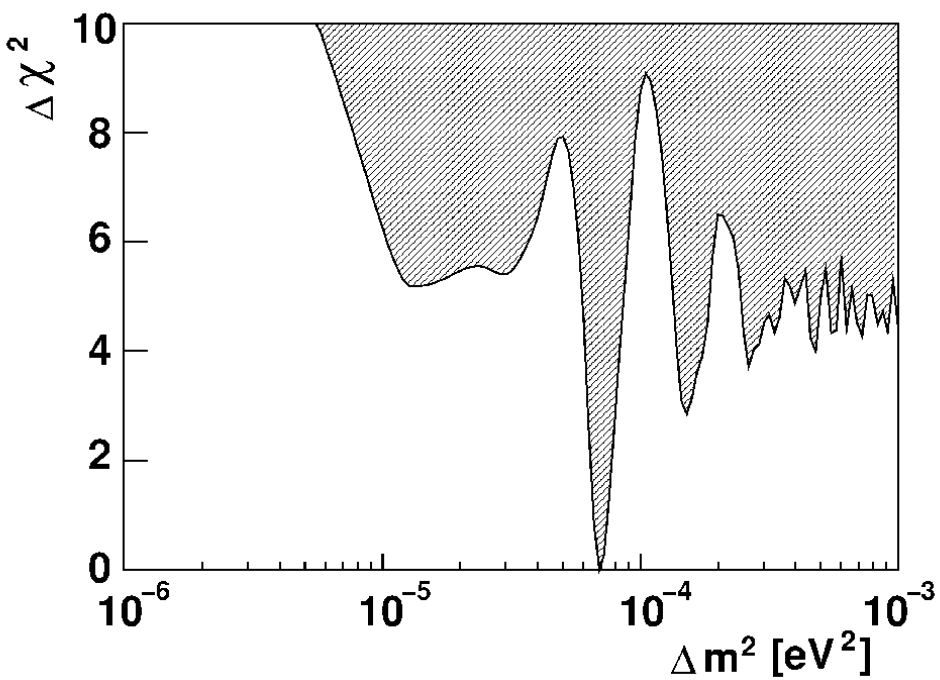
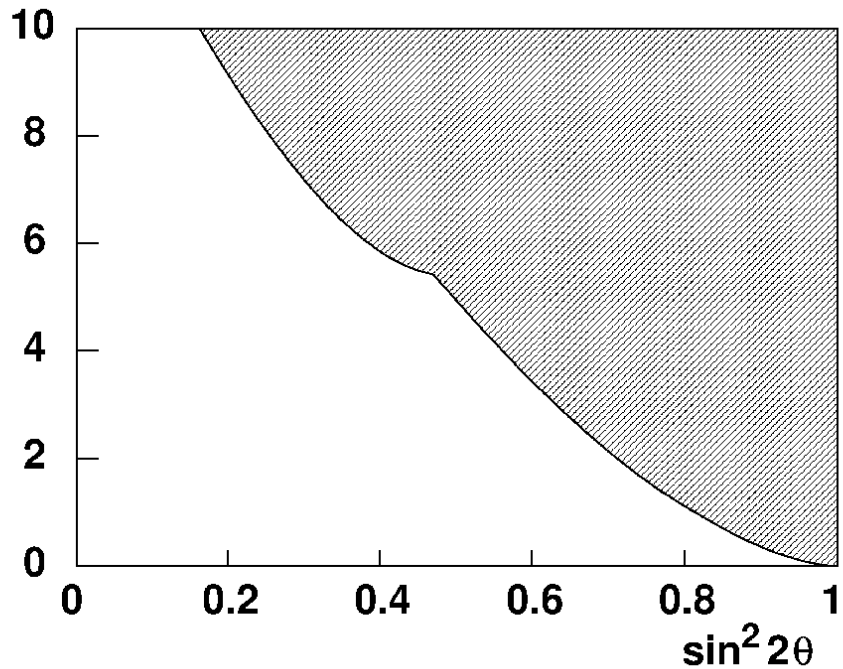
$$P(\bar{\nu}_e \to \bar{\nu}_e) \approx \cos^4\theta_{13}\left(1-\sin^2 2\theta_{12}\sin^2\frac{\Delta m_{12}^2 L}{4E}\right)$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}\begin{pmatrix} \cos\theta_{13} & 0 & e^{i\delta}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix}\begin{pmatrix} \cos\theta_{23} & \sin\theta_{23} & 0 \\ -\sin\theta_{23} & \cos\theta_{23} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Trigger efficiency






LOW, SMA, VAC
LMA-I (0.84,7e-5)
LMA-II (0.84,1.4e-4)
(μW_th/cm²)
Distance (km)
This Spring for Inspection
about half of usual
good for BG study

χ^2 projection