KamLAND Results and Future

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for the KamLAND Collaboration

The XXII International Conference on
Neutrino Physics and Astrophysics
June 13-19, 2006, Santa Fe

KamLAND collaboration

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@Laforet Zao Resort & Spa (Oct. 8, 2005)

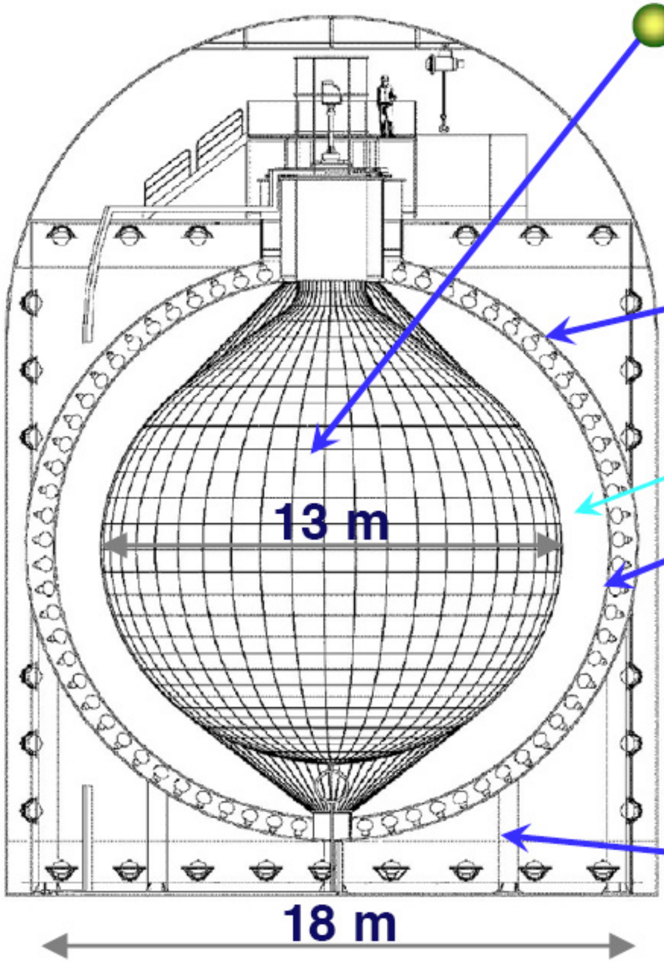
KamLAND results and future

- Reactor results and future
- Geoneutrino results and future
- Solar neutrino future
  - ^{7}Be
  - pep, CNO, low-energy ^{8}B
- Other physics
  - Solar $\overline{\nu_e}$, supernova, and other high energy $\overline{\nu_e}$
  - Invisible decay of neutron

KamLAND Detector

- detector location: old Kamiokande site

  : 2700 m.w.e.



- 1000 ton liquid scintillator

  : 80% (dodecane) + 20% (pseudocumene)
  + 1.52 *g/l* PPO
  : housed in spherical plastic balloon

- 3000 m^3 stainless steel vessel

  : filled with a mixture of paraffin oil
  and dodecane ($\Delta\rho$ = 0.04%)

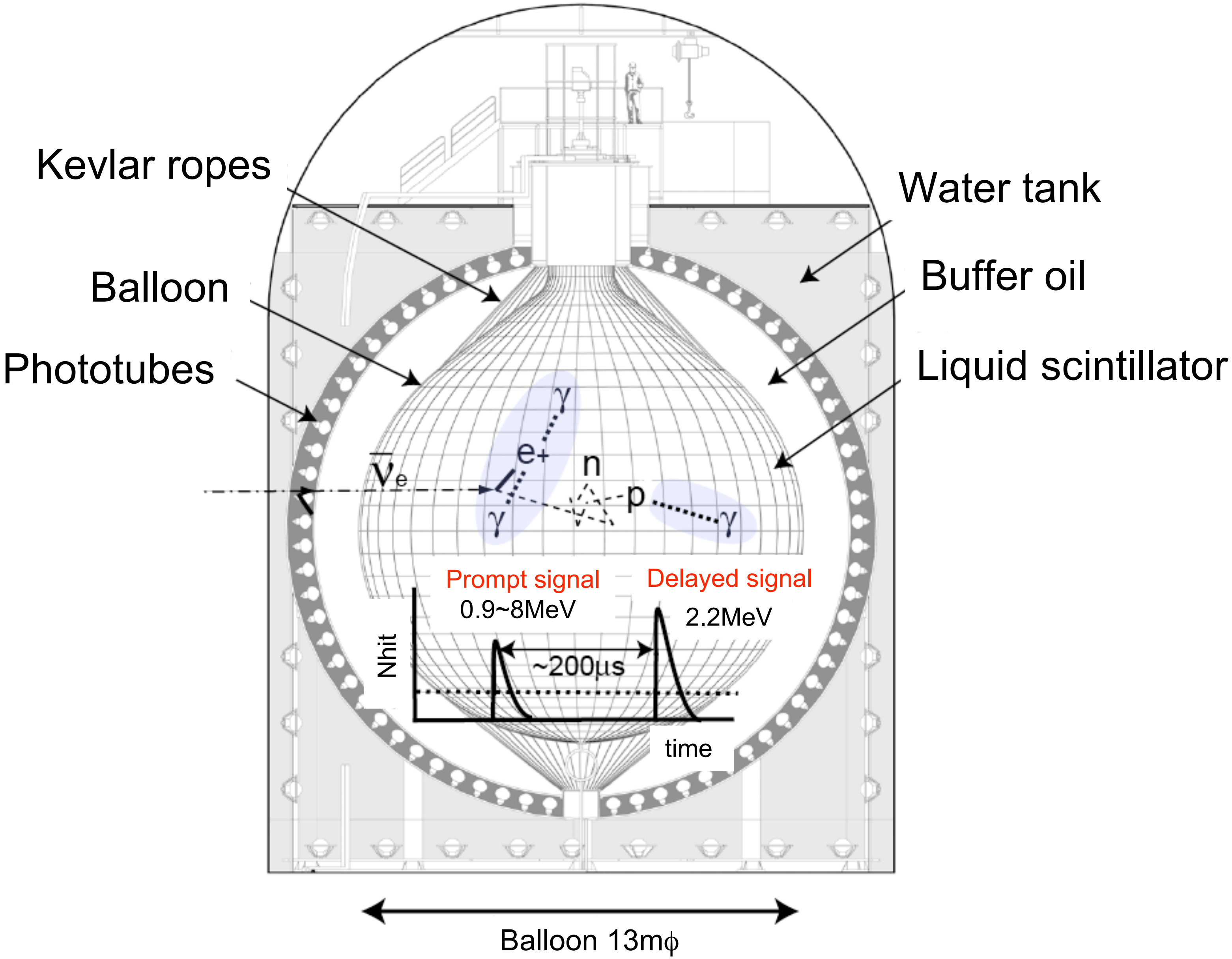
- 1325 17-inch + 554 20-inch PMT's

commissioned in February, 2003

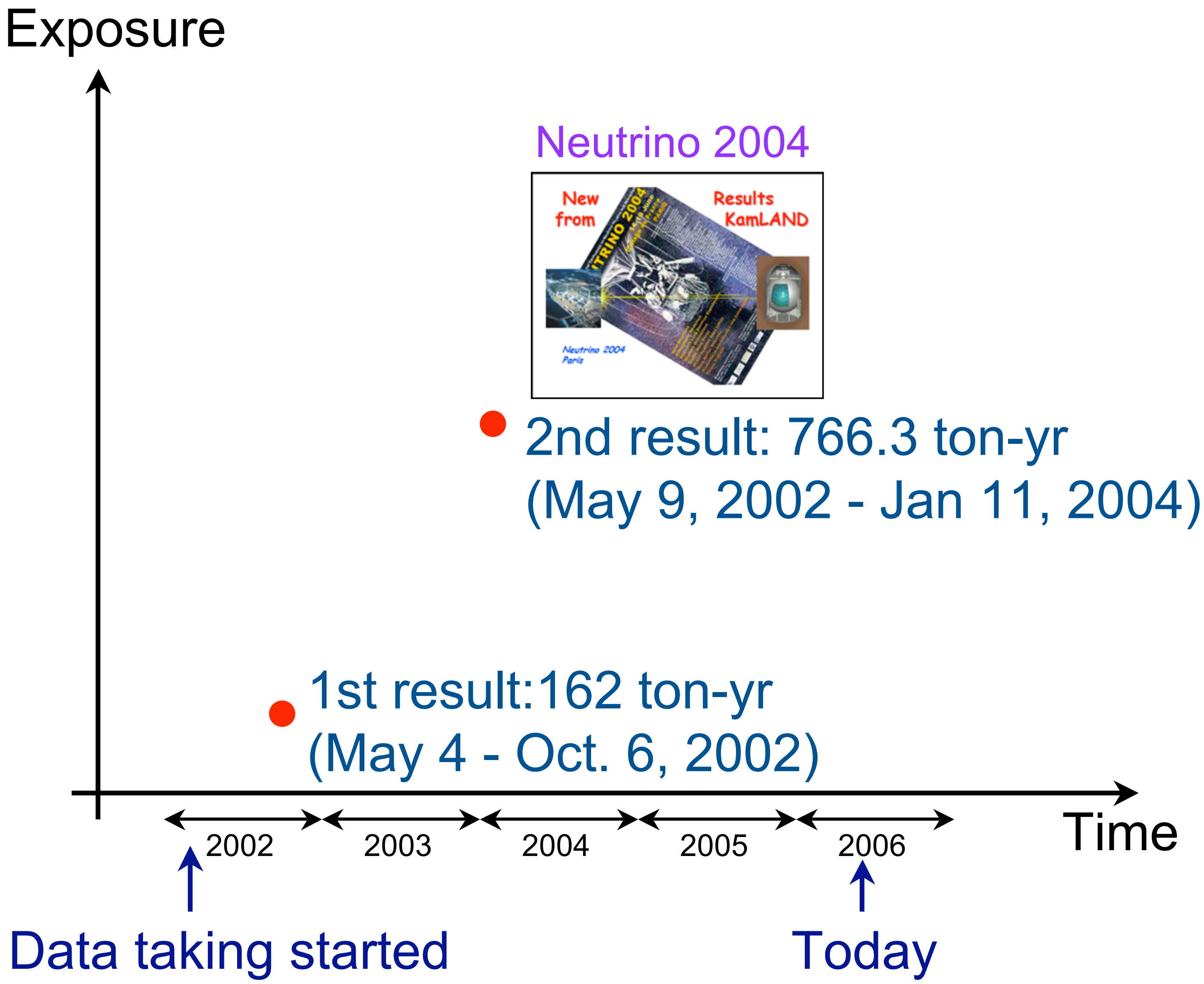
photocathode coverage : 22% → 34%
energy resolution at 1 MeV : 7.3% → 6.3%

- water Cerenkov outer detector

Kamioka Liquid *Antineutrino* Detector

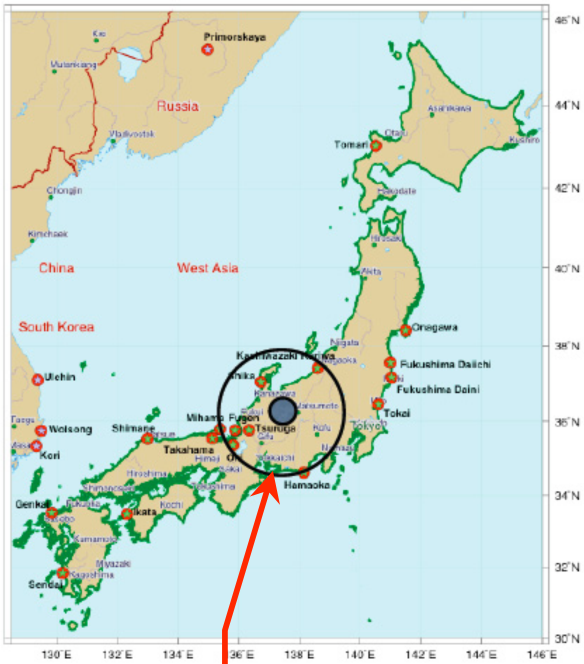


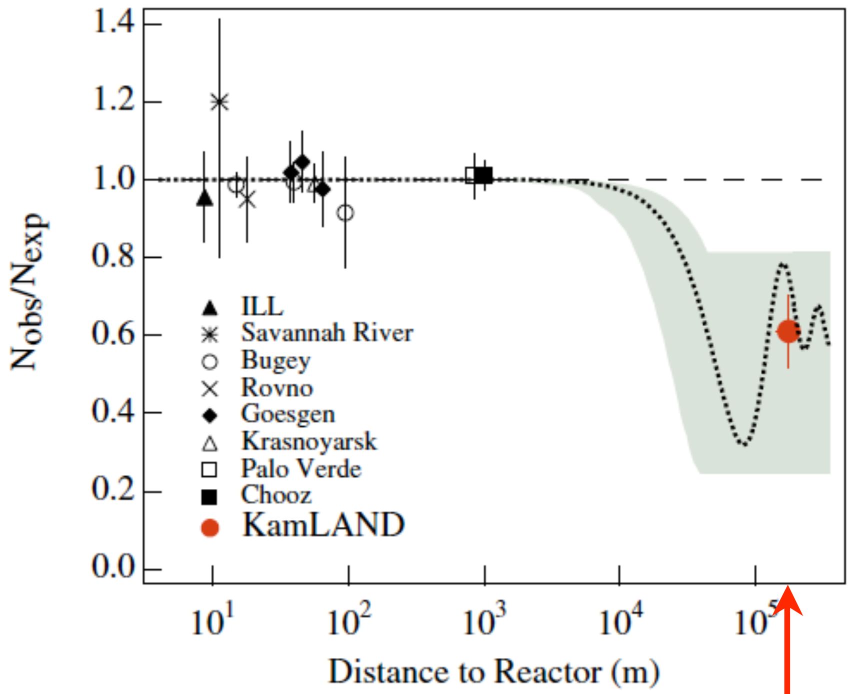
Reactor results



First result: reactor neutrino disappearance

Phys. Rev. Lett. 90 (2003) 021802





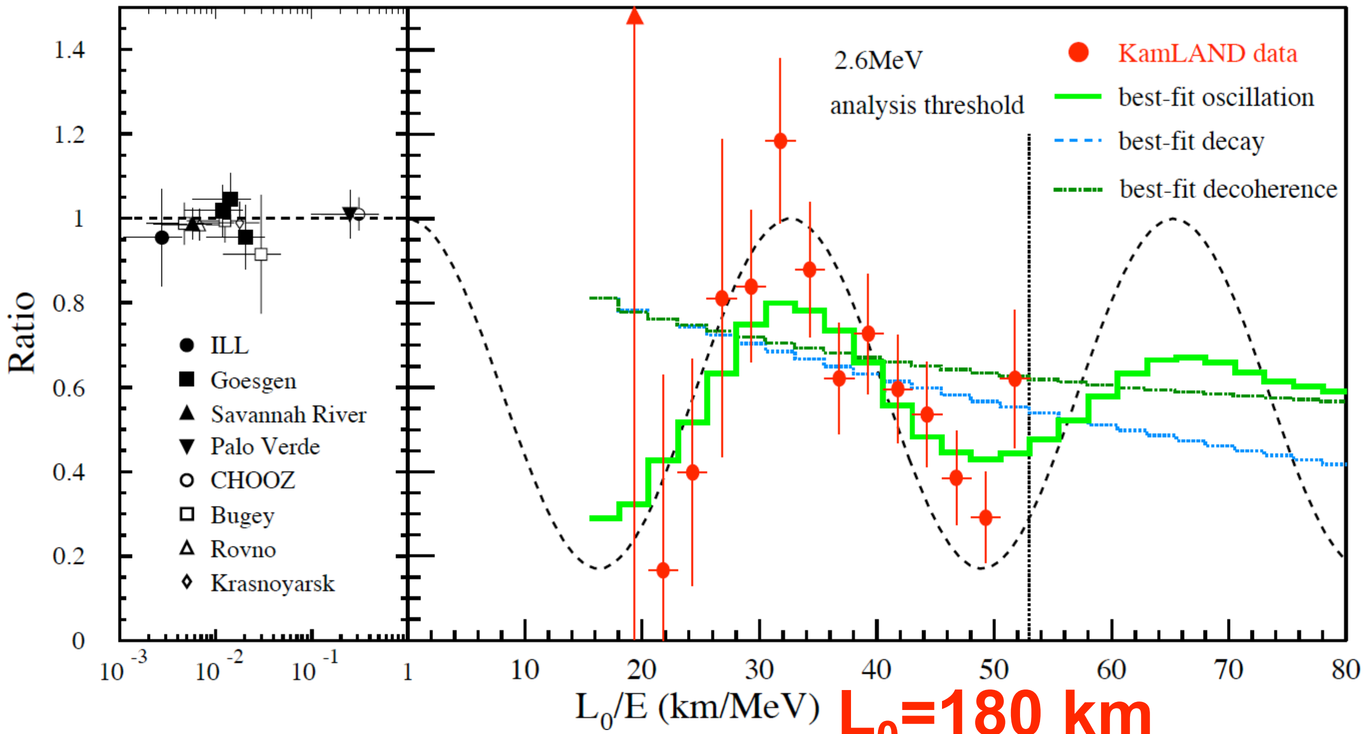
180 km

180 km

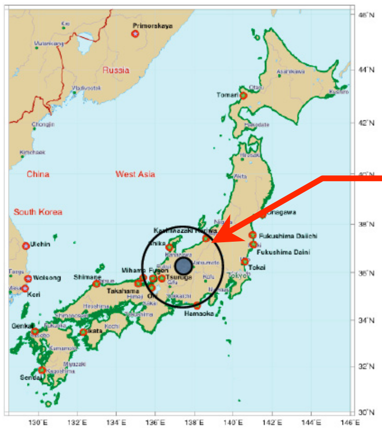
Disappearance: 99.95%C.L.

2nd result: spectral distortion

Phys. Rev. Lett. 94 (2005) 081801

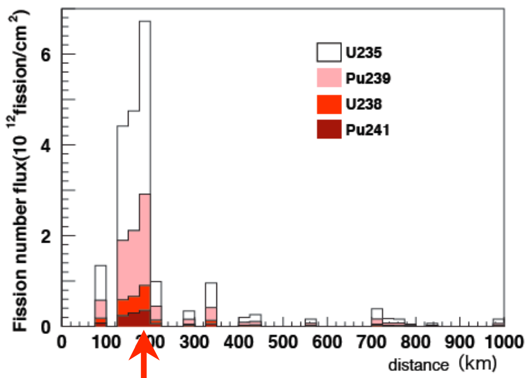


L_0=180 km



L_0

L_0



Determination of solar neutrino solution
Precise measurement of Δm_{12}^2

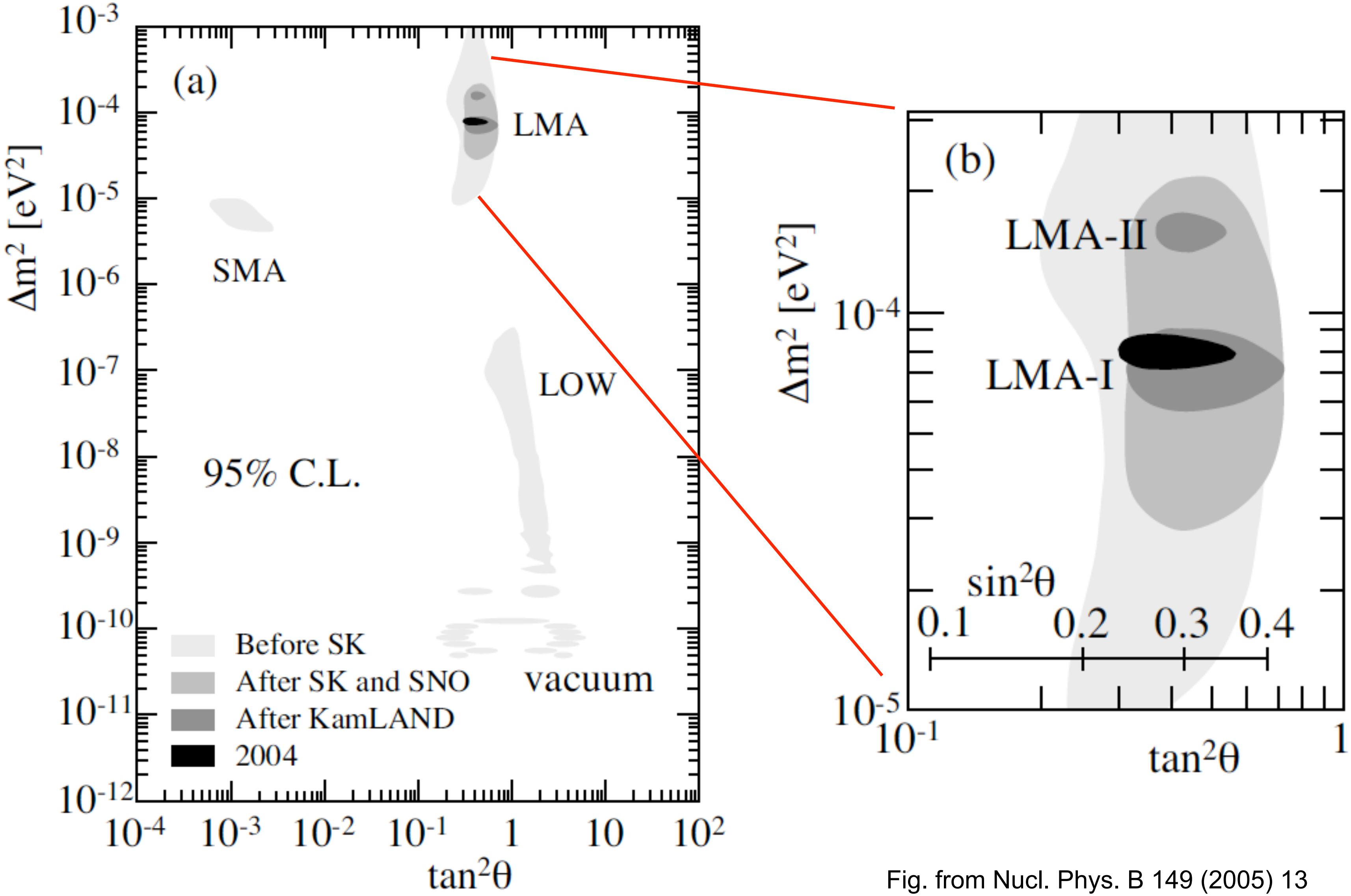


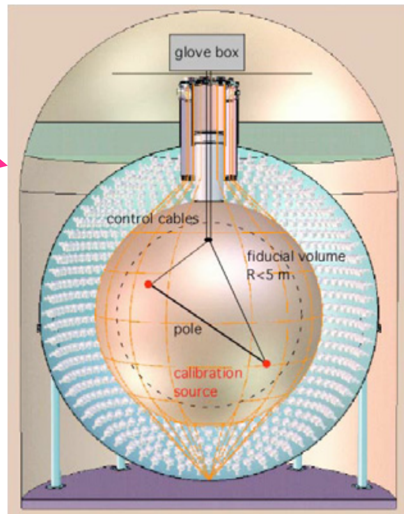
Fig. from Nucl. Phys. B 149 (2005) 13

Reactor future

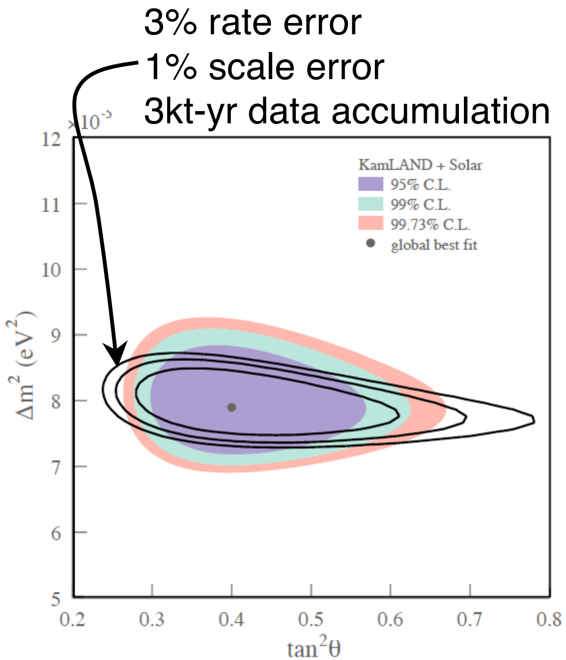
- Keep taking data: (statistical error) $\propto$ (time)$^{-1/2}$
- Reduction of the systematic error to keep (total error) $\sim\propto$ (time)$^{-1/2}$
  - All volume calibration instead of only along the vertical axis: from July 2006, the “4π system”
  - Better understanding of the detector, improving analysis tools
- See also posters
  - #56 T. Classen for energy scale
  - #57 D. Dwyer for oscillation analysis
  - #60 L. Hsu for Monte Carlo

Systematic	%
Fiducial volume	4.7
Energy threshold	2.3
Efficiency of cuts	1.6
Livetime	0.06
Reactor power	2.1
Fuel composition	1.0
$\bar{\nu}_e$ spectra	2.5
Cross section	0.2
Total	6.5

improve



“4π system”



"Geoneutrinos"

- Electron antineutrinos produced in the Earth's interior (crust and mantle) by decays of ^{238}U, ^{232}Th, and ^{40}K
- Decays of ^{238}U, ^{232}Th, and ^{40}K :

  ~40% of Earth's power
- Earth's power: $\rightarrow$ plate tectonics, earthquakes, volcanoes, geomagnetism, …
- Origin and history of the Earth
- Pointed out since ν discovered

  (1950's, G. Gamow, …)

Heat balance of the Earth

heat

geo-ν

Heat flow measurement:

44 TW? (Pollack H.N. et al, Rev. Geophys 31, 267)

31 TW? (Hofmeister, A.M et al. Tectonophysics 395)

= (?)

Radiogenic:

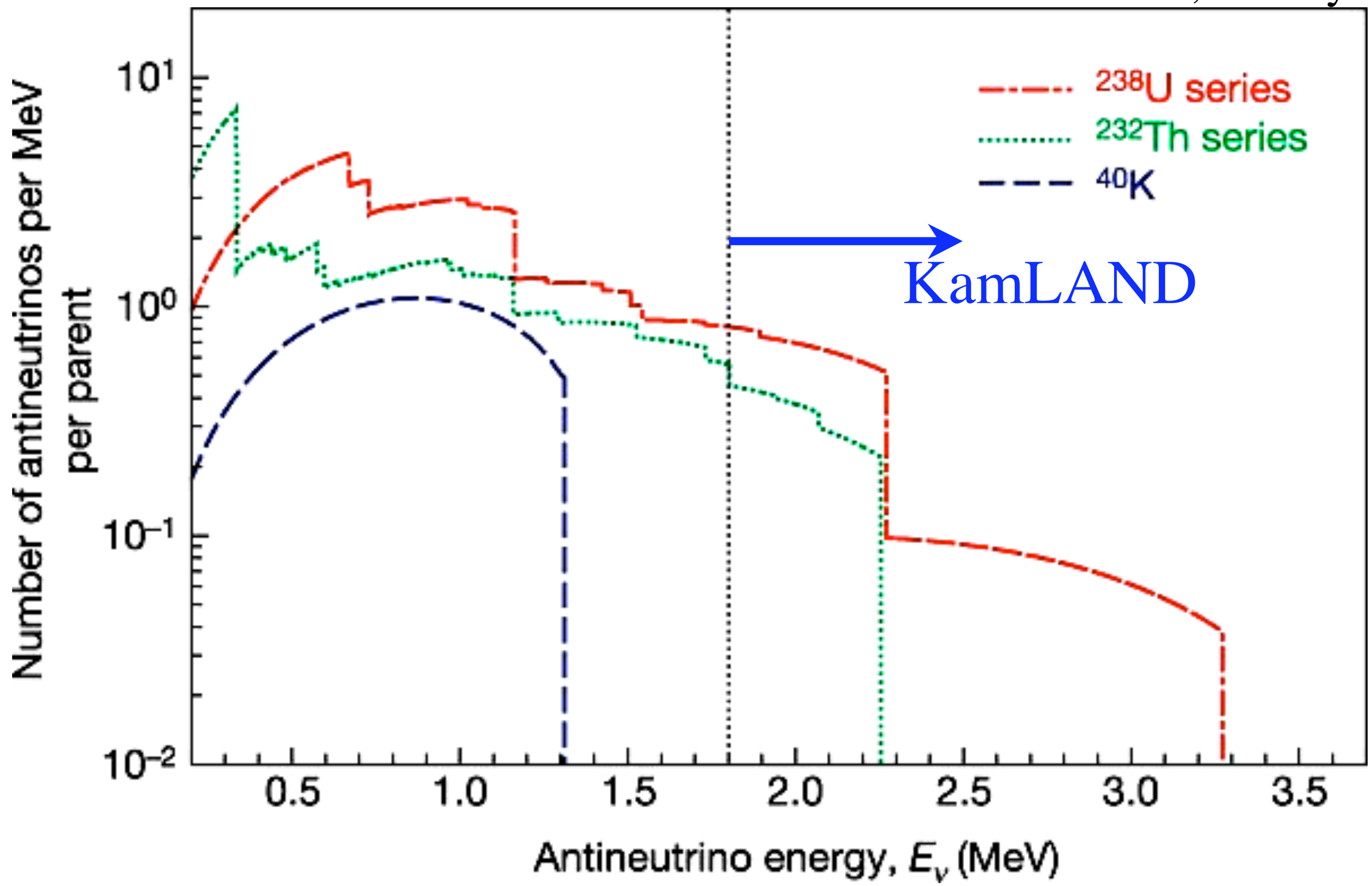
19 TW(McDonough et a. Chem. Geol. 120, 223)

+

Cooling of core, solidification of outer core, … (originates from initial gravitational energy)

Energy spectra of geoneutrinos

Nature 436, 28 July 2005

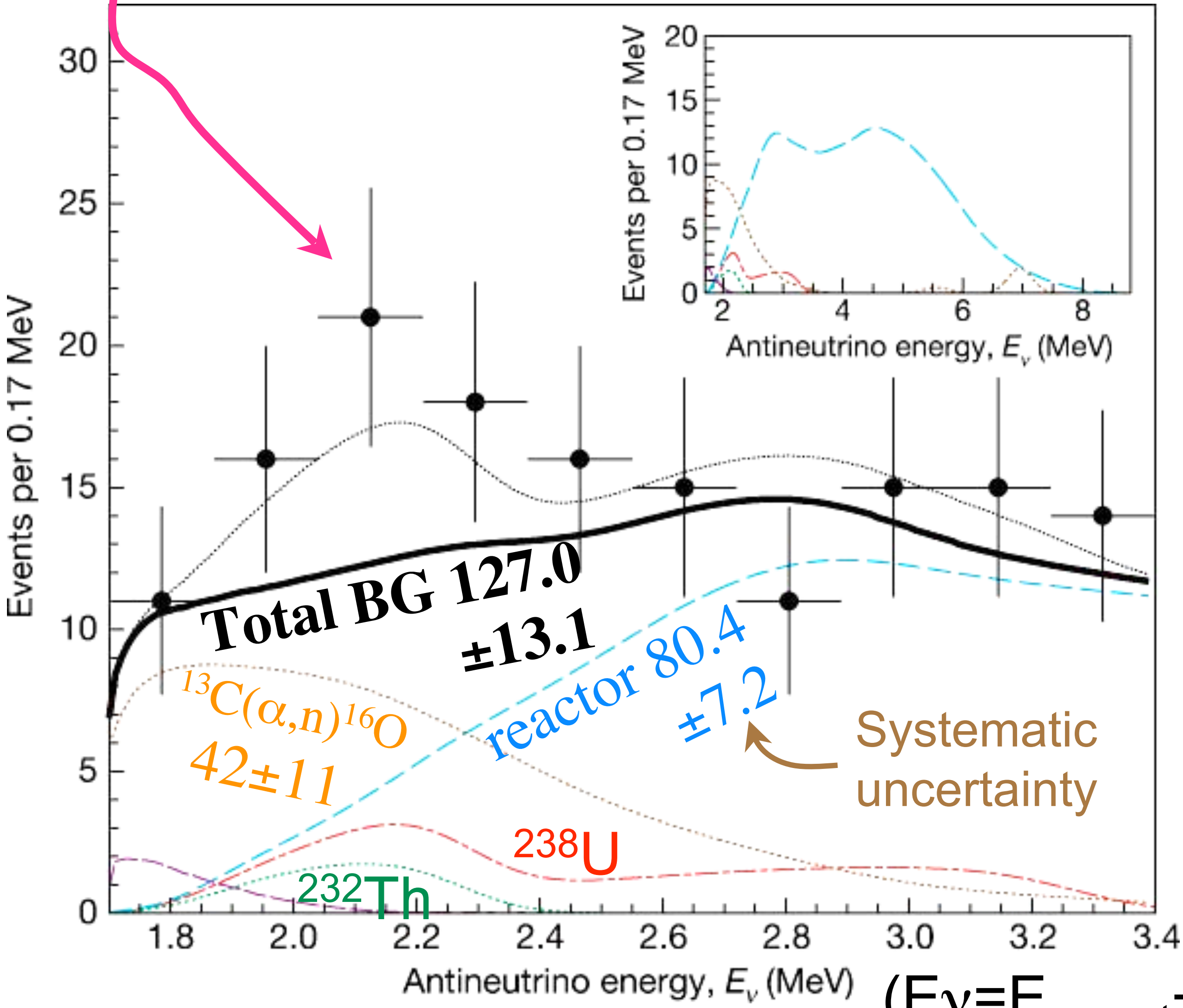


The expected ^{238}U, ^{232}Th, and ^{40}K decay chain electron anti-neutino energy distribution. KamLAND can only detect electron antineutrinos to the right of the vertical dotted black line; hence it is insensitive to ^{40}K electron antineutrinos.

Geoneutrino results

152 events observed
"signal" 25 $^{+19}_{-18}$

Nature 436, 28 July 2005



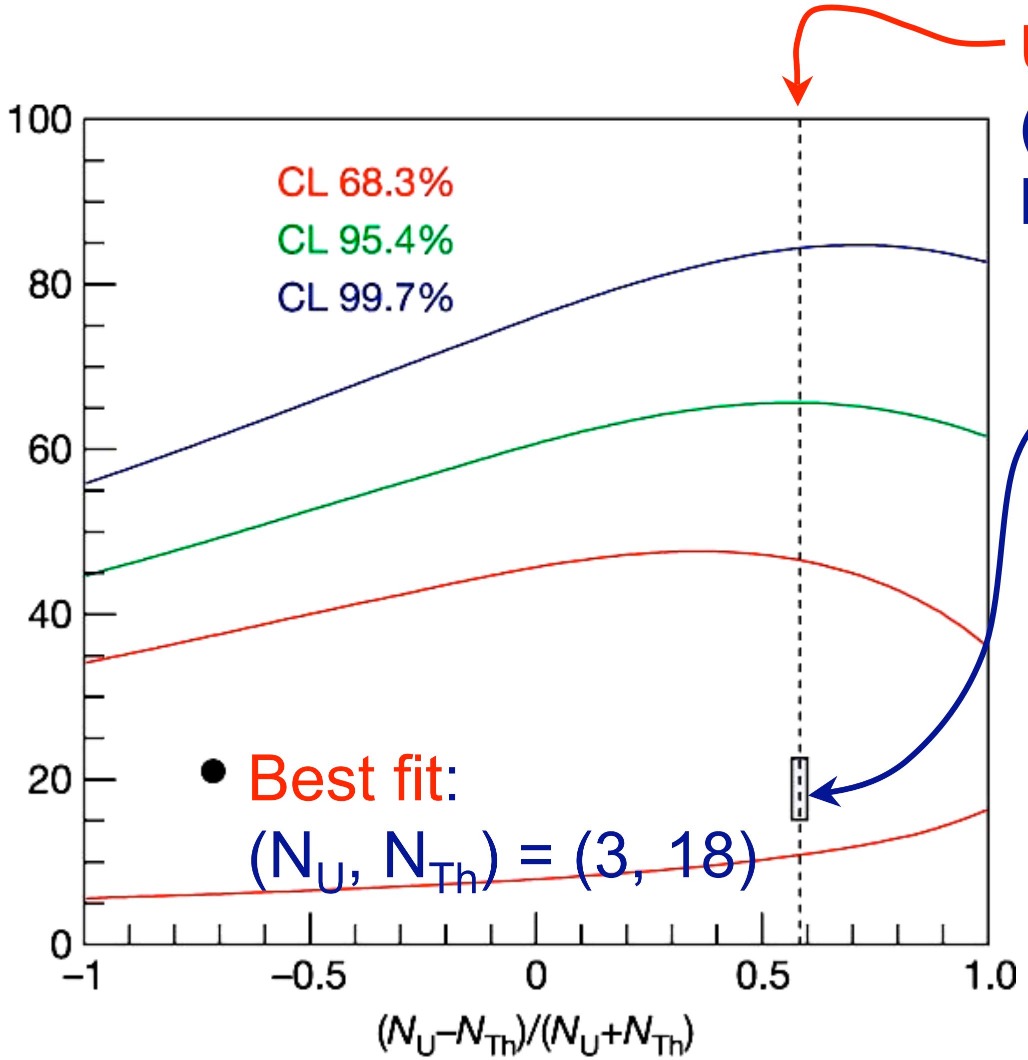
Data-set:
749.1 days
(Mar. 9, 2002 -Oct. 30, 2004)

Fiducial:
5 m radius

($E\nu = E_{prompt} + 0.8MeV$)

Rate + shape analysis

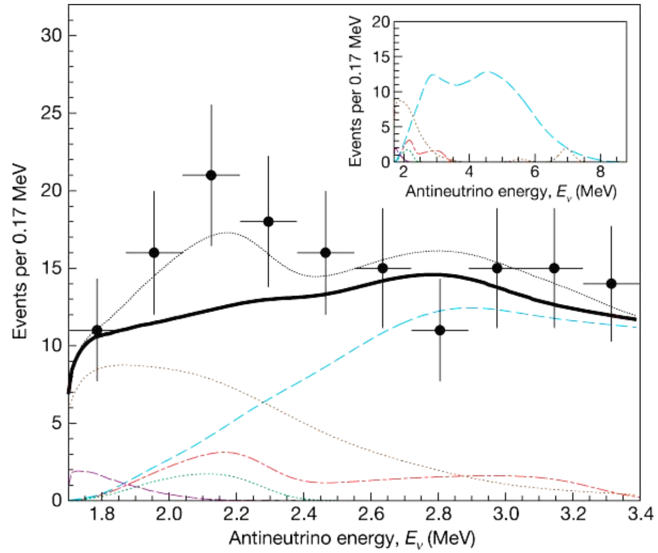
Total number of geo-ν in dataset N_U+N_{Th}



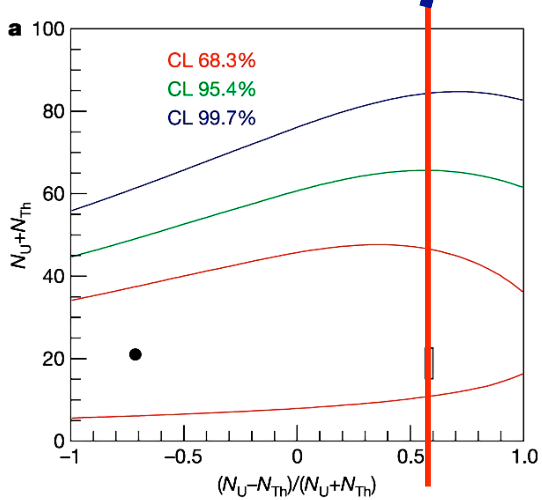
Relative intensity (U and Th)

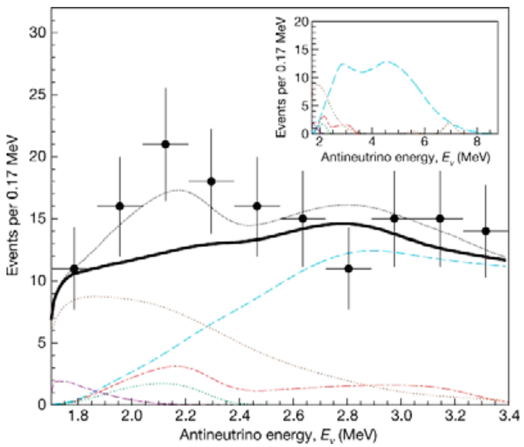
U/Th=3.9 (in mass ratio)
(“definitely” expected in
BSE model (“chondritic”))

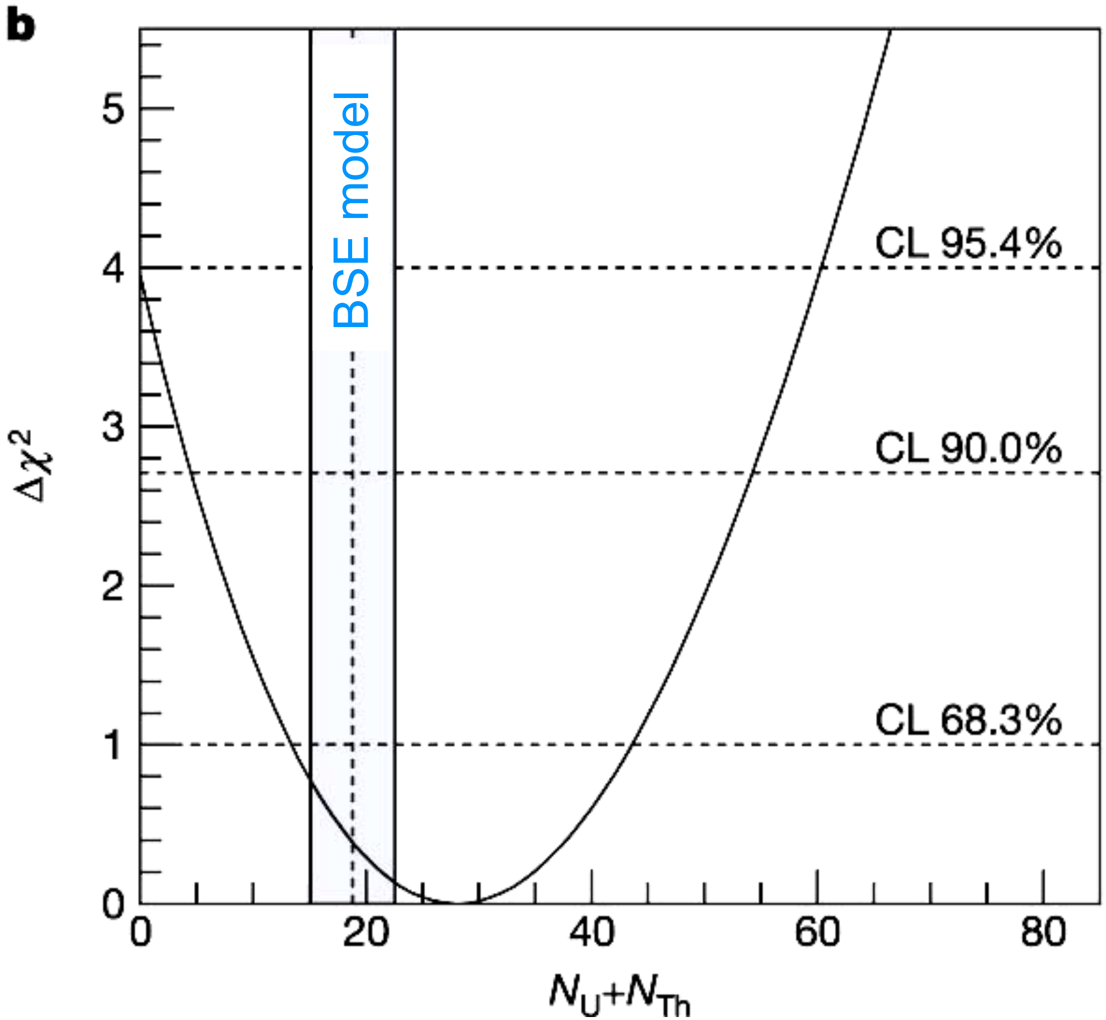
BSE model



U/Th ratio is fixed







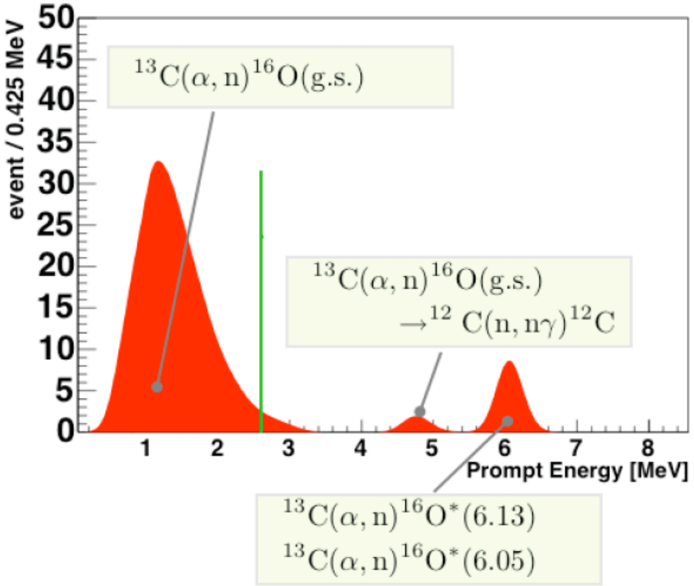
Geoneutrino future: $^{13}C(\alpha,n)^{16}O$ reduction

$T_{1/2} = 22.3y$ 5.013d 138.4d

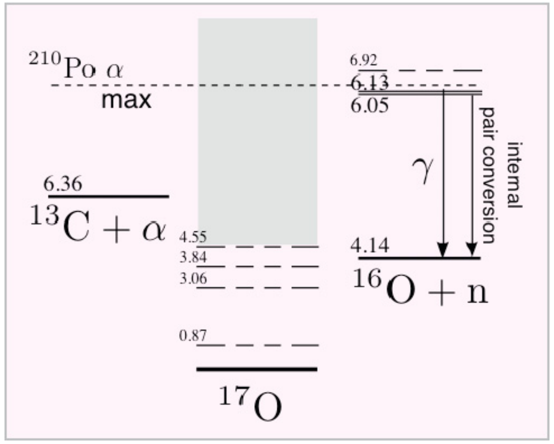
$^{210}Pb \rightarrow {}^{210}Bi \rightarrow {}^{210}Po \rightarrow {}^{206}Pb$

α

5.3 MeV



$^{13}C\ (\alpha,\ n)\ ^{16}O$



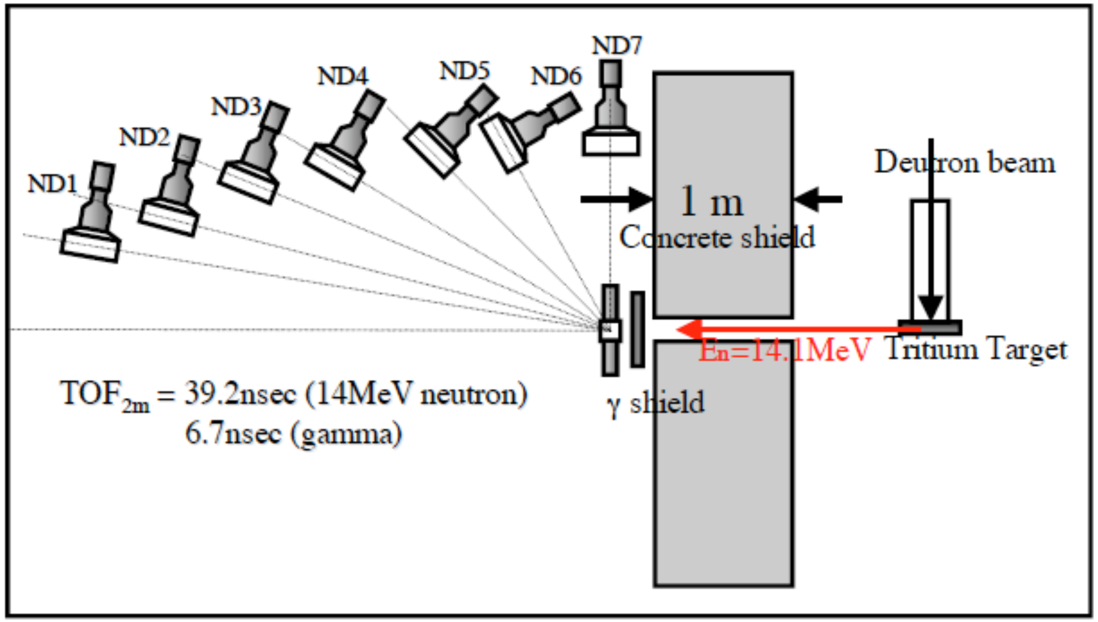
- Reduction of systematic error: currently going on
- Reduction of ^{210}Pb: near future (see "solar neutrino future" next)

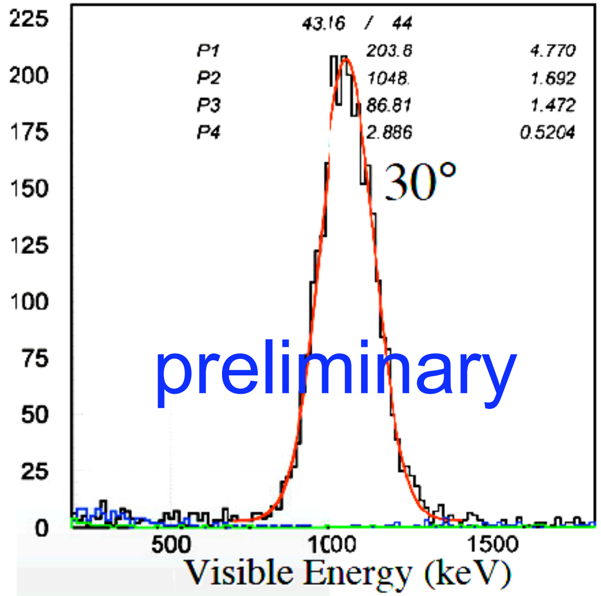
Geoneutrino future – reduction of systematic uncertainty of $^{13}C(\alpha,n)^{16}O$

- Use new data of cross section of $^{13}C(\alpha,n)^{16}O$:
  (Harissopulos et al. (2005), systematic error 20% $\rightarrow$ 4%)
- Measurement of events below 0.9 MeV:
  (almost pure sample of $^{13}C(\alpha,n)^{16}O$, currently consistent with the estimated rate, $\rightarrow$ measurement ongoing for more statistics)
- Measurement of the visible energy of neutron events:
  - quenching effect of the scintillator
  - (visible energy) / (real energy) ~ 1/4 for protons recoiled by neutrons from $^{13}C(\alpha,n)^{16}O$ (calculation from α quenching)
  - no direct measurement exists, so conservative uncertainties assumed
  - $\rightarrow$ direct measurement (next slide)

Energy scale of neutron events

– measurement using monochromatic neutrons

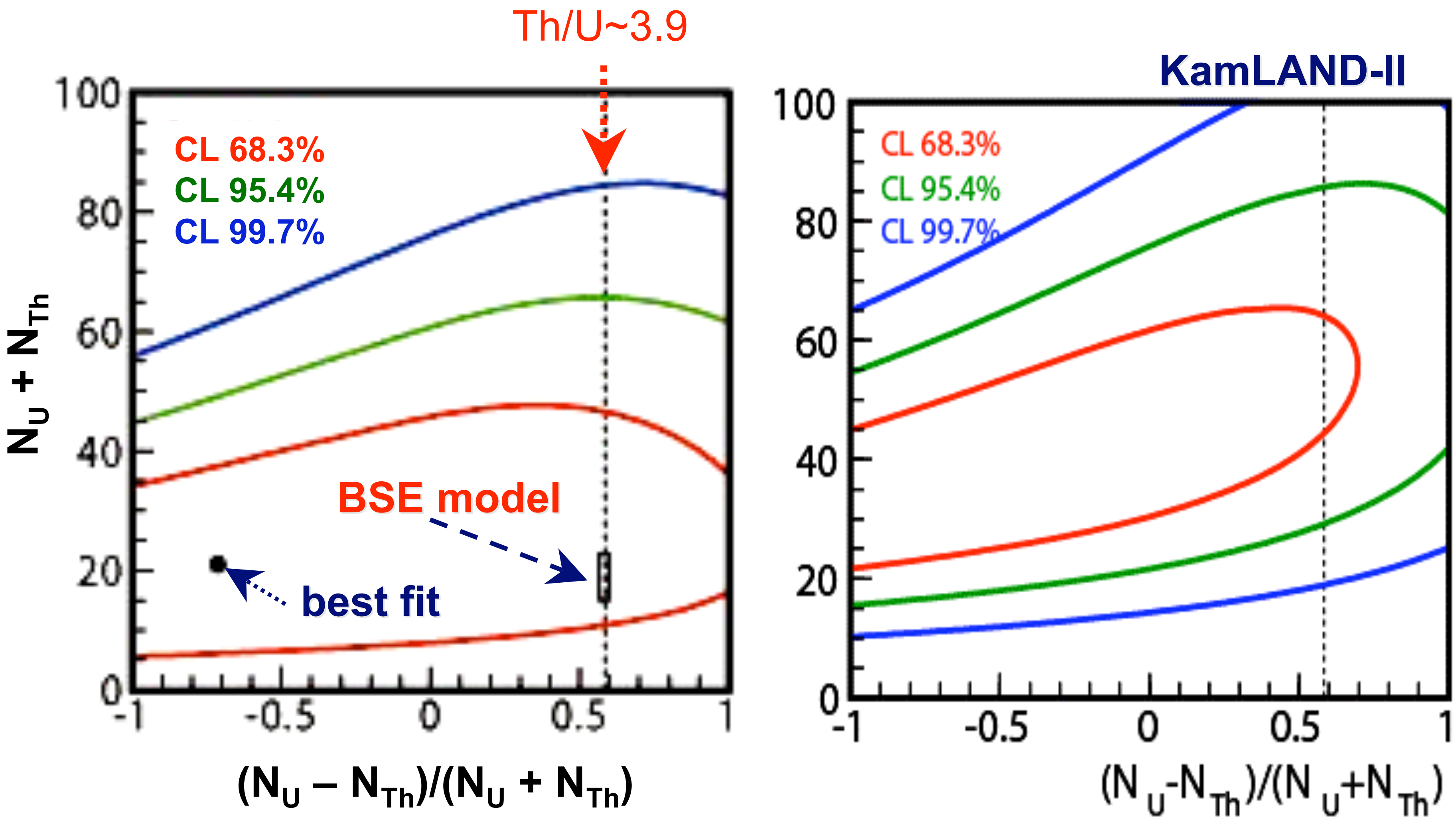




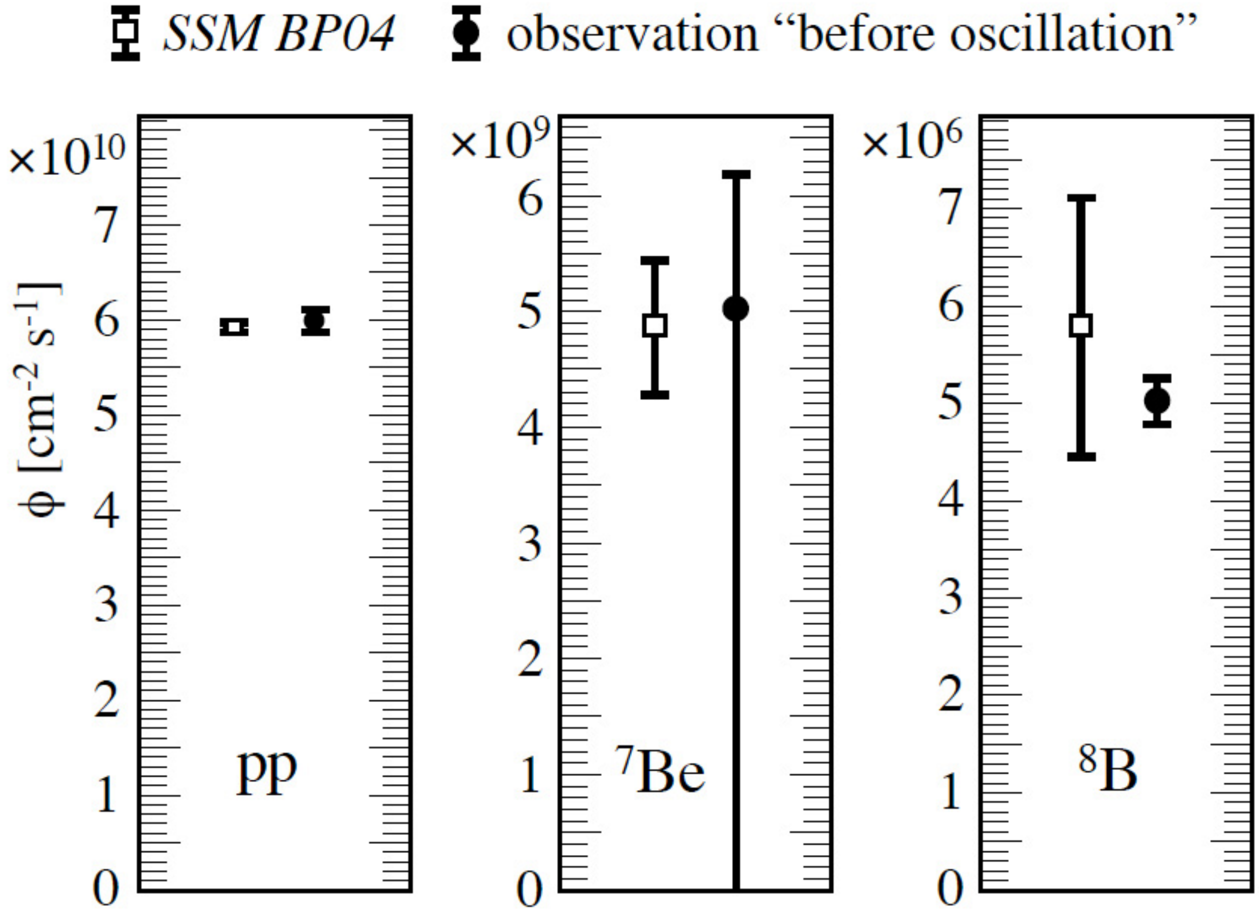
OKTAVIAN @ Osaka Univ.

14.1-MeV monochromatic neutron beam

Geoneutrino future



Solar neutrino future



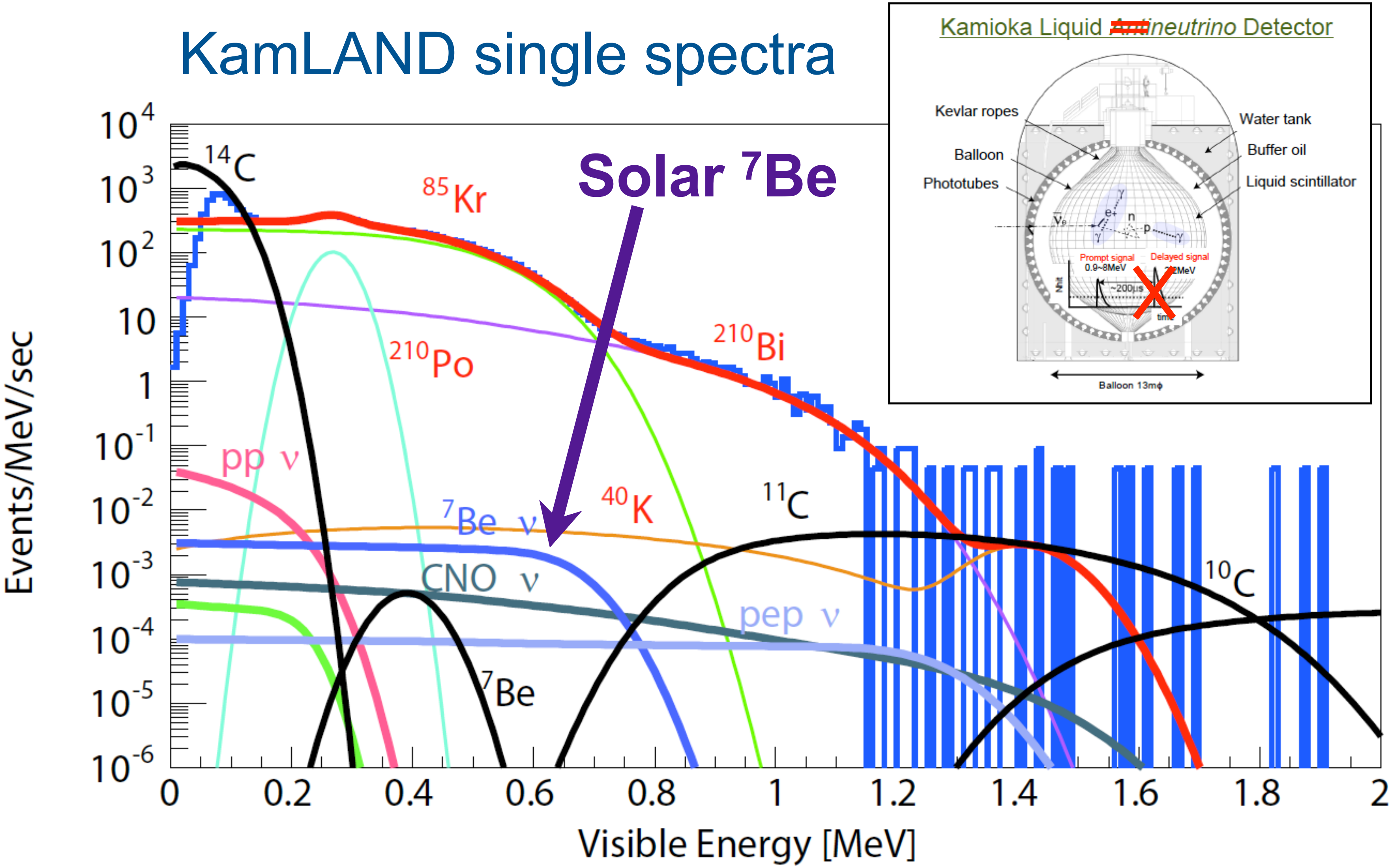
All flux free
Luminosity
constraint

J.N. Bahcall, M.C. Gonzalez-Garcia, and C. Pena-Garay, J. High Energy Phys. 0408 (2004) 016,hep-ph/0406294.

Fig. from Nucl. Phys. B 149 (2005) 13

- ^{8}B: precisely measured
- pp: constrained by luminosity
- ^{7}Be: key to understand total pp-chain

Solar neutrino future



Reduction of ^{210}Pb, ^{85}Kr by 10^{-5}

→ KamLAND "solar ν phase"

$T_{1/2} = 22.3\,\text{y}$ 5.013d   138.4d

$$^{210}\text{Pb} \rightarrow {}^{210}\text{Bi} \xrightarrow[\text{1.2 MeV}]{\beta^-} {}^{210}\text{Po} \xrightarrow[\text{5.3 MeV}]{\alpha} {}^{206}\text{Pb}$$

$$^{13}\text{C}\,(\alpha, n)\,^{16}\text{O}$$

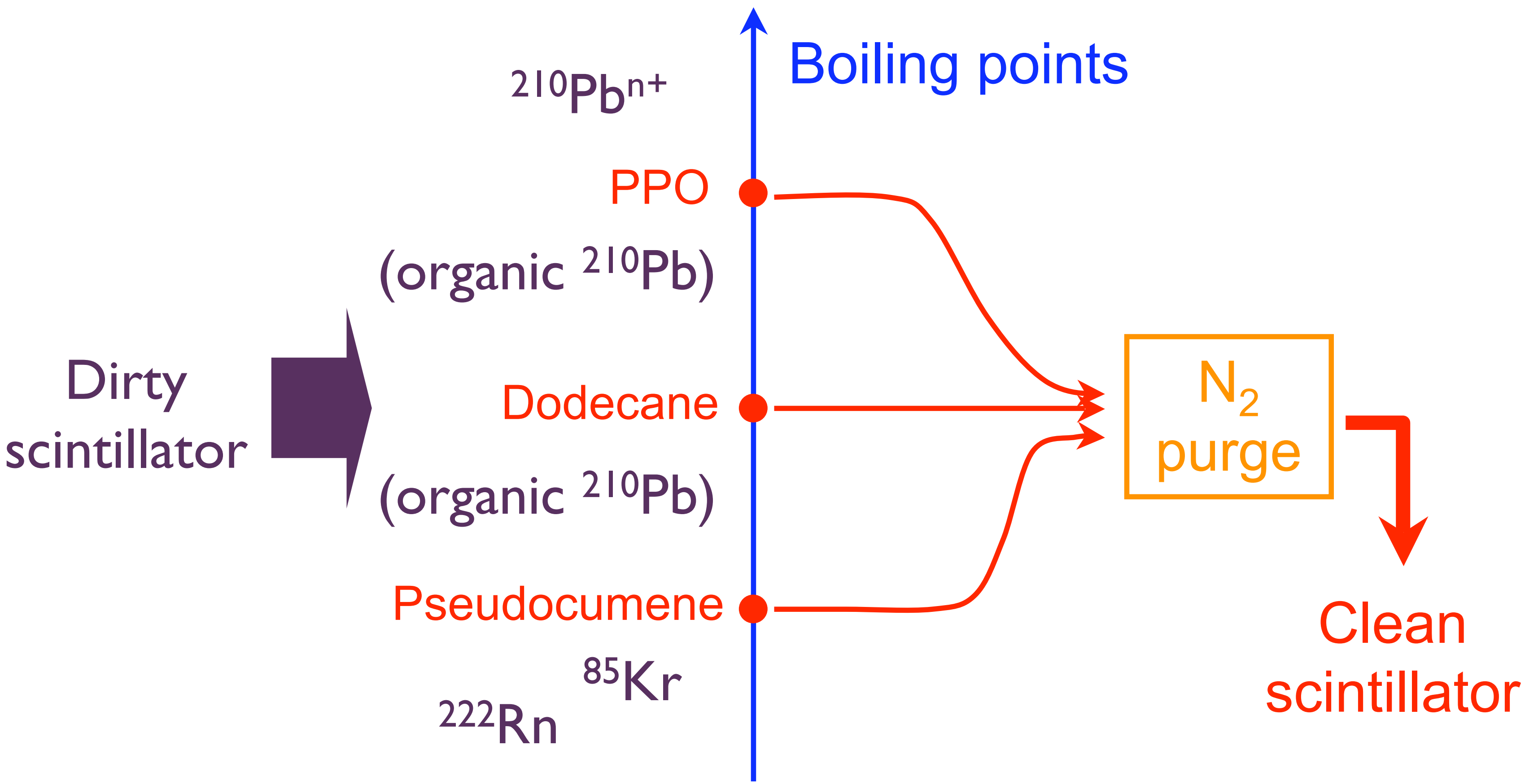
$T_{1/2} = 10.8\,\text{y}$

$$^{85}\text{Kr} \xrightarrow[\text{0.69 MeV}]{\beta^-} {}^{85}\text{Rb}$$

- Obstacles for solar ^{7}Be (^{210}Bi, ^{85}Kr, ^{210}Po), and antineutrino (reactor and geoneutrino) physics (^{210}Po)

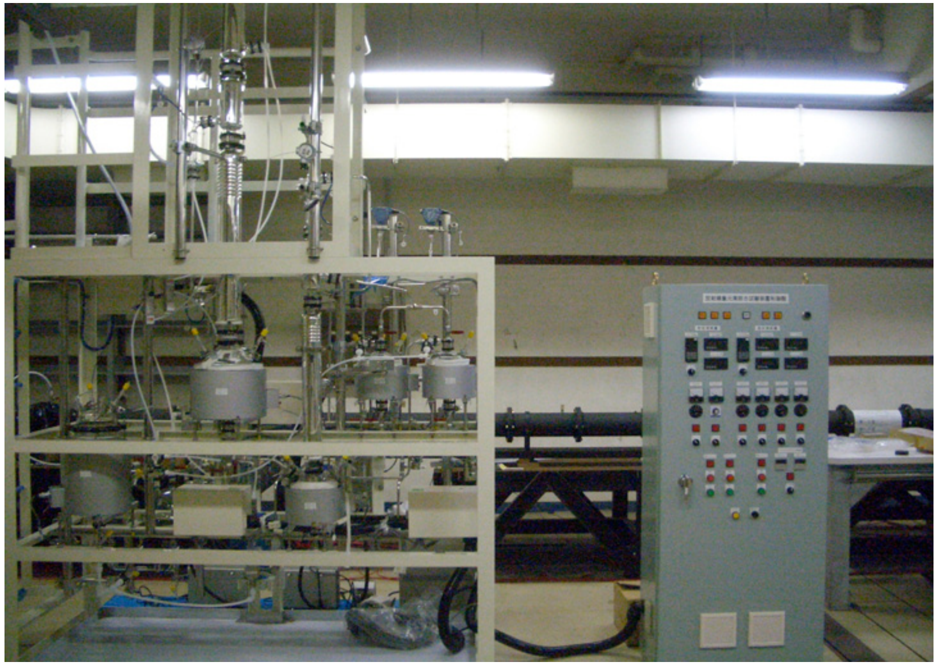
Distillation + N_2 purge

- KamLAND scintillator:
  - 80% dodecane ($C_{12}H_{26}$)
  - 20% pseudocumene (1,2,4-$(CH_3)_3$-C_6H_3),
  - 1.5-g/l PPO (2,5-Diphenyloxazole, 2,5-$(C_6H_5)_2$-C_3HNO)



Distillation−R&D since 2004

~ milli-liter system



~ liter system

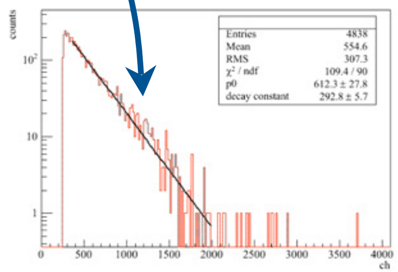
Real system:

~ 1.5 kilo-liter / hr (design flow rate)

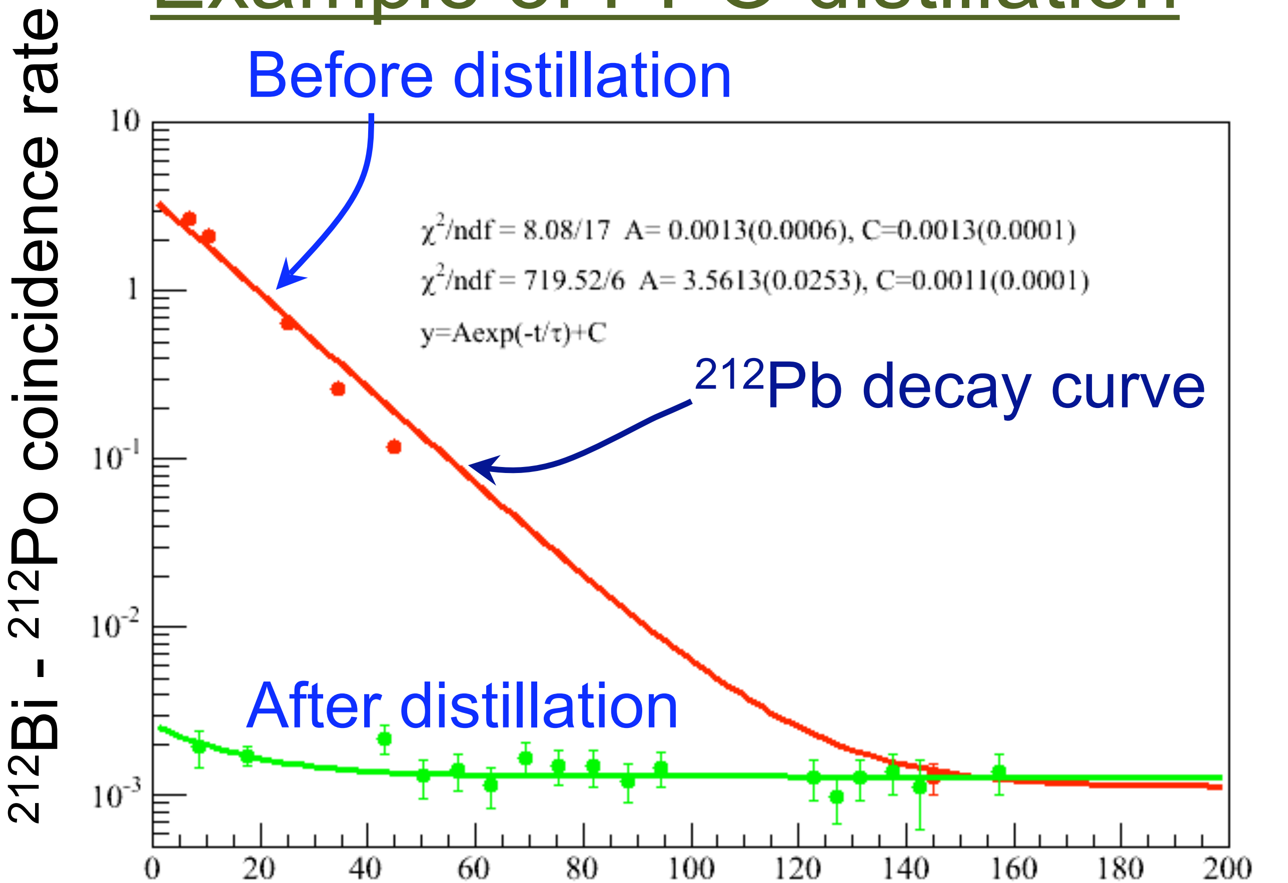
Construction starting August, 2006

R&D using ^{212}Pb instead of real ^{210}Pb

- *In KamLAND*: $^{222}\mathrm{Rn} \rightarrow {}^{218}\mathrm{Po} \rightarrow {}^{214}\mathrm{Pb} \rightarrow {}^{214}\mathrm{Bi}$
  $\rightarrow {}^{214}\mathrm{Po} \rightarrow {}^{210}\mathrm{Pb} \rightarrow {}^{210}\mathrm{Bi} \rightarrow {}^{210}\mathrm{Po} \rightarrow {}^{206}\mathrm{Pb}$
- *Pb removal R&D*: $^{220}\mathrm{Rn} \rightarrow {}^{216}\mathrm{Po} \rightarrow {}^{212}\mathrm{Pb}$
  $\rightarrow {}^{212}\mathrm{Bi} \rightarrow {}^{212}\mathrm{Po} \rightarrow {}^{208}\mathrm{Pb}$
- ^{212}Pb is tagged by ^{212}Bi-^{212}Po ($T_{1/2}$ = 299 ns)
- ^{212}Pb decay curve ($T_{1/2}$ = 10.6 hr)
- Both ^{212}Pb and ^{210}Pb are Po daughter:
  → molecular forms in the scintillator
  are expected to be similar



Example of PPO distillation



~ 4×10^{-4} reduction achieved

~10^{-4} ~10^{-5} reduction has been achieved also for dodecane, and pseudocumene distillation

* See also poster #28 G. Keefer

Toward “solar ν phase”

- Excavation of a new mine tunnel for the distillation system
  (completed: Fall, 2005)
- New computer system for data acquisition and storage of larger data
  (installed: Winter, 2005)
- New electric power ~ 1MW for the distillation system
  (power line construction going on: June, 2006)
- Design of the distillation system
  (almost done: June, 2006)
- Construction of the N_2 generator and purge system
  (partly done, will complete in September 2006)
- Construction of distillation system
  (August - September, 2006)
- Construction of “miniLAND” (1-ton detector to measure ^{222}Rn level after purification, down to ~1 mBq/m^3 ($\approx$ μBq/m3 for ^{210}Pb))
- Construction of Kr detector (see also poster #30 C. Mauger)

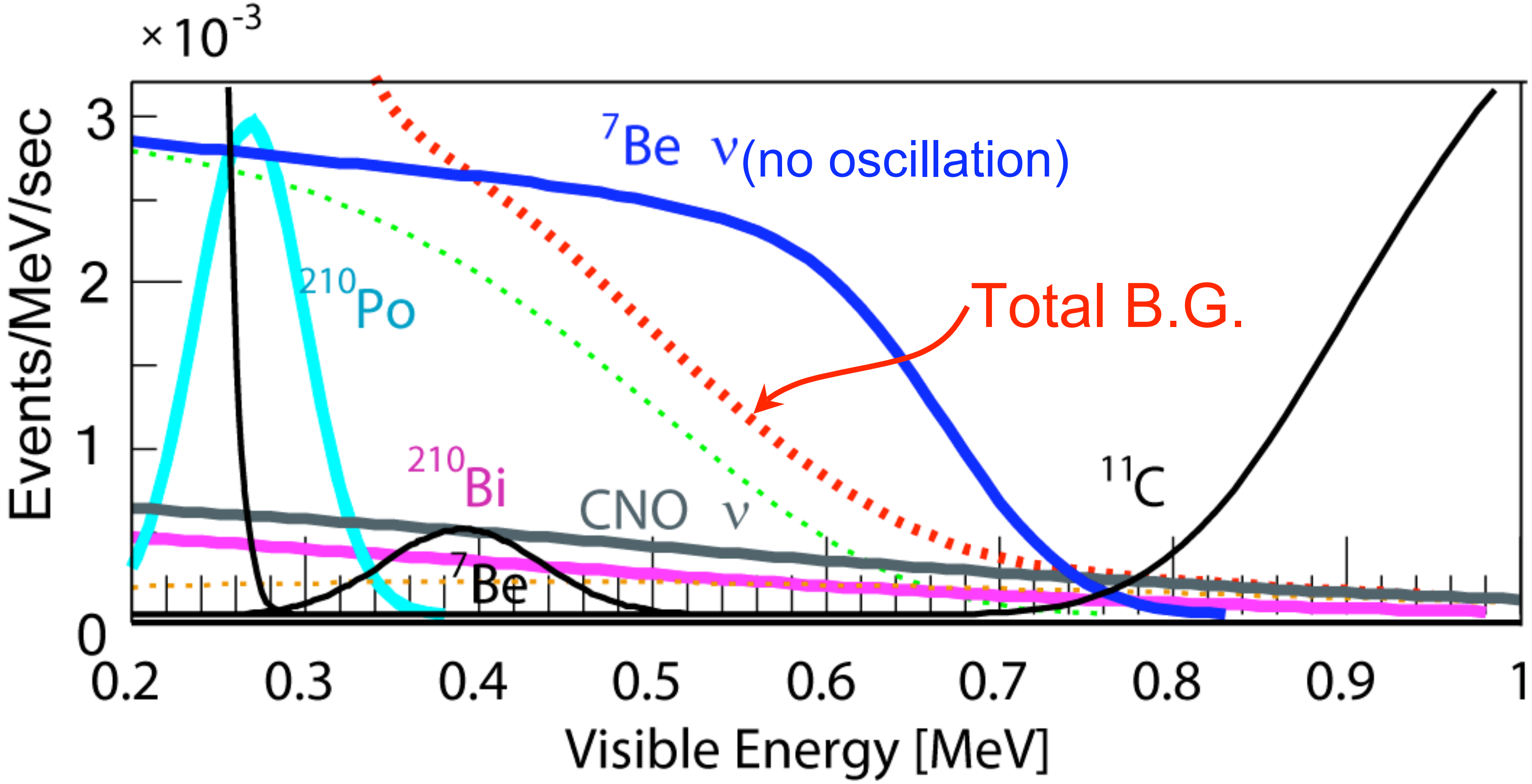
Toward “solar ν phase” (continued)

- Engineering run of the distillation system
- Real purification of the KamLAND scintillator
  (this will take a few months …)
- Observation of the solar ^{7}Be neutrinos

Control room for the distillation system in the newly excavated mine tunnel

Solar neutrino future

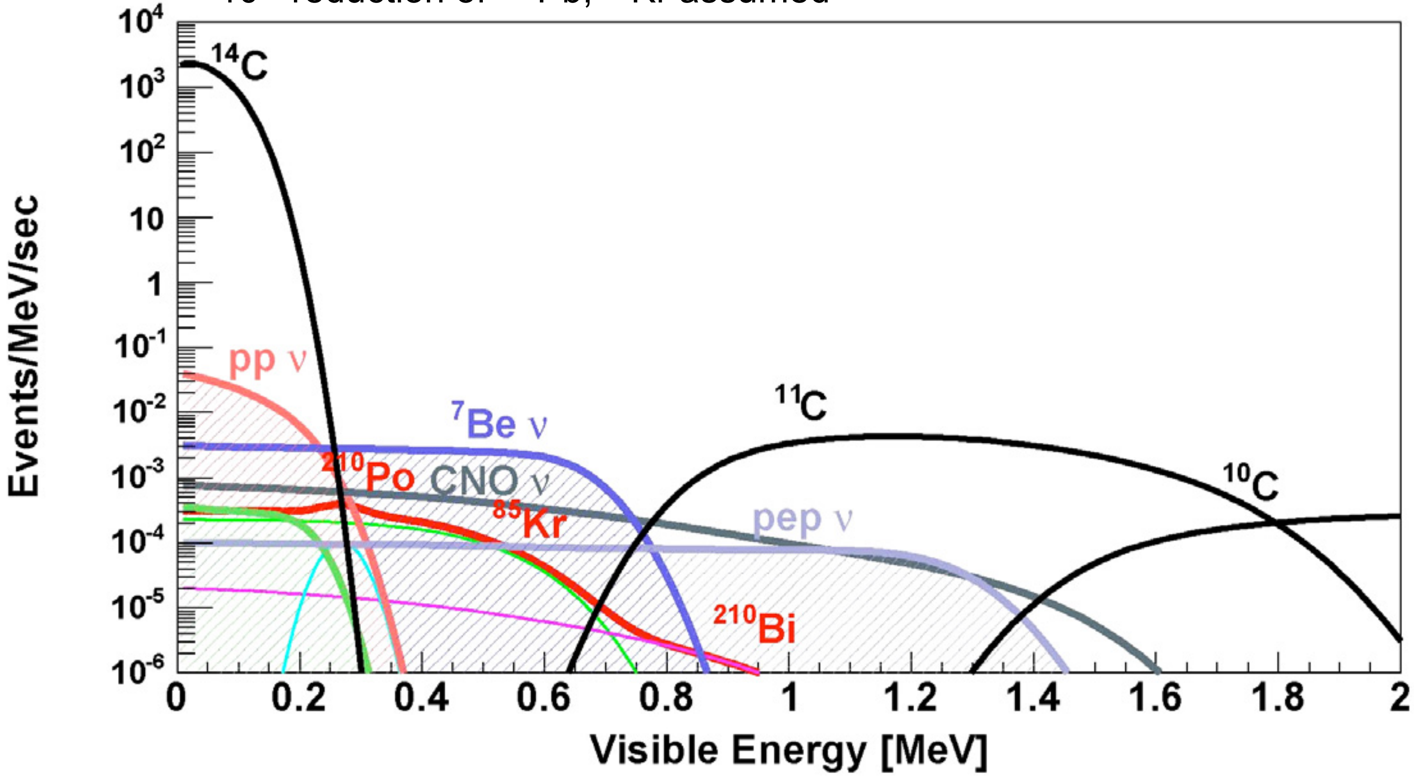
- After ~3×10^{-5} reduction of ^{210}Pb and ^{85}Kr



pep and CNO neutrinos

- Even after successful ^{210}Pb, ^{85}Kr reduction, at KamLAND depth 2,700 m.w.e., spallation $^{11}C(T_{1/2}$ = 20.4 min.) is a serious background …

10^{-6} reduction of ^{210}Pb, ^{85}Kr assumed



^{11}C off-line rejection

muon + neutron tagging (Galbiati et al., hep-ph/0411002)

Most of ^{11}C are created by

$$\boxed{{}^{12}\mathrm{C} + \mathrm{X} \rightarrow {}^{11}\mathrm{C} + n + \mathrm{Y} + \cdots}$$

$$\mathrm{X} = \gamma, n, p, \pi^-, \pi^+, e, \mu$$

~ 95% of ^{11}C reaction produce neutrons

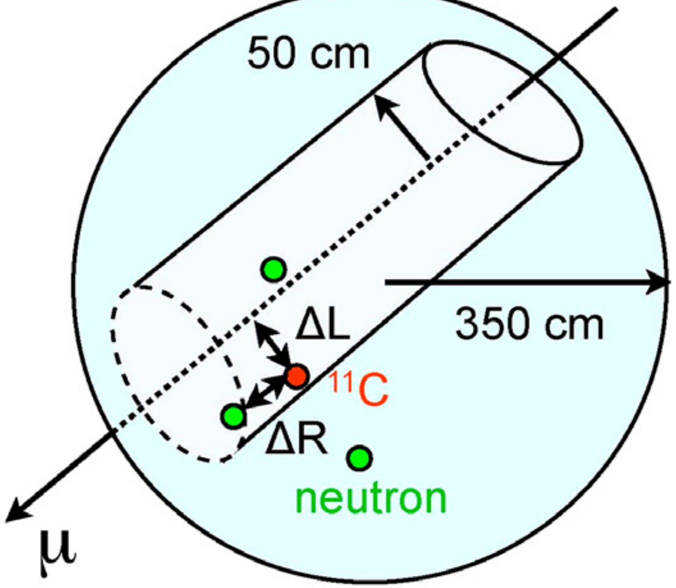
3-fold coincidence

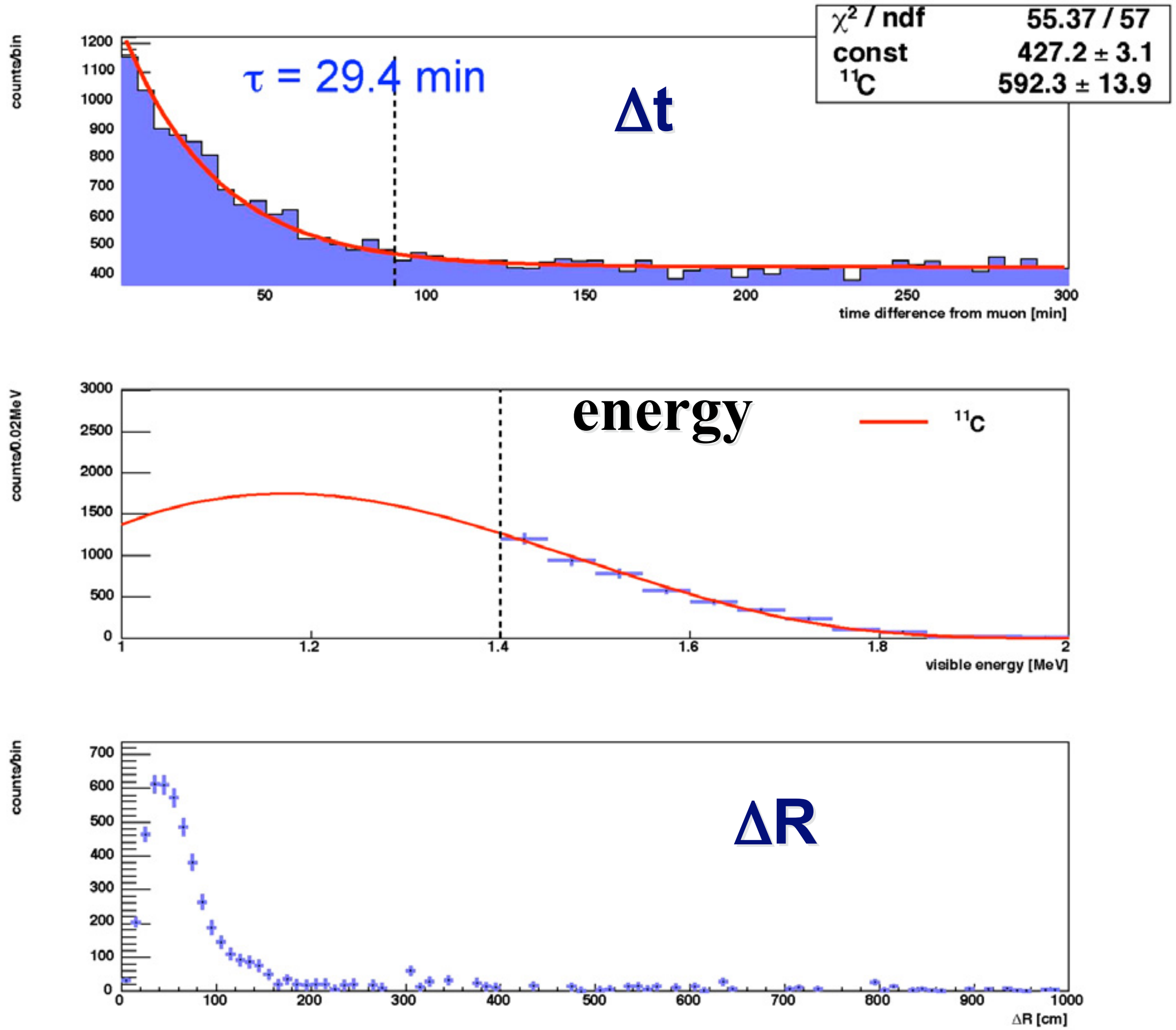
(1) muon - (2) neutron (capture time ~ 210 μsec)

- (3) ^{11}C (lifetime = 29.4 min)

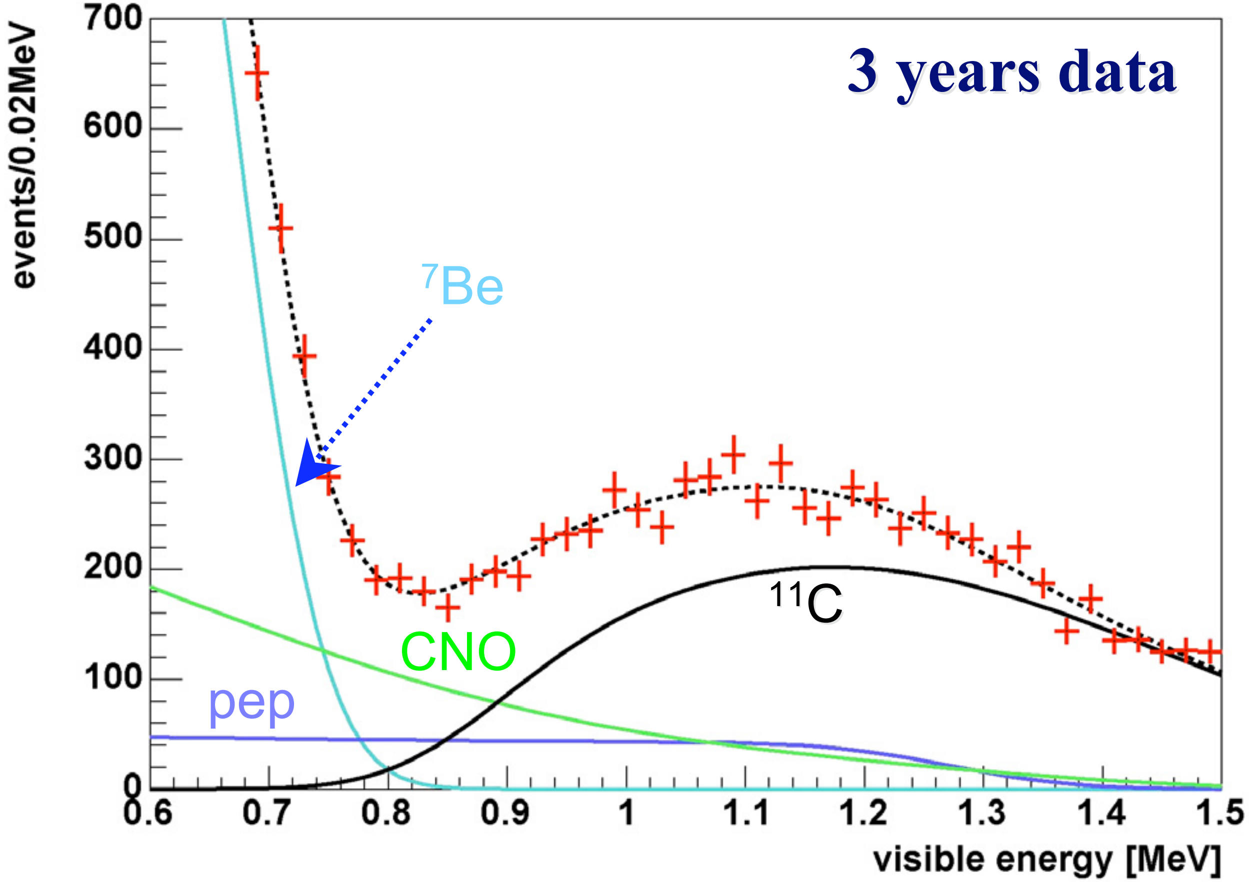
μ–n–^{11}C events in KamLAND data

(ΔL < 50 cm, #$n_{detected}$ > 0)





pep CNO future

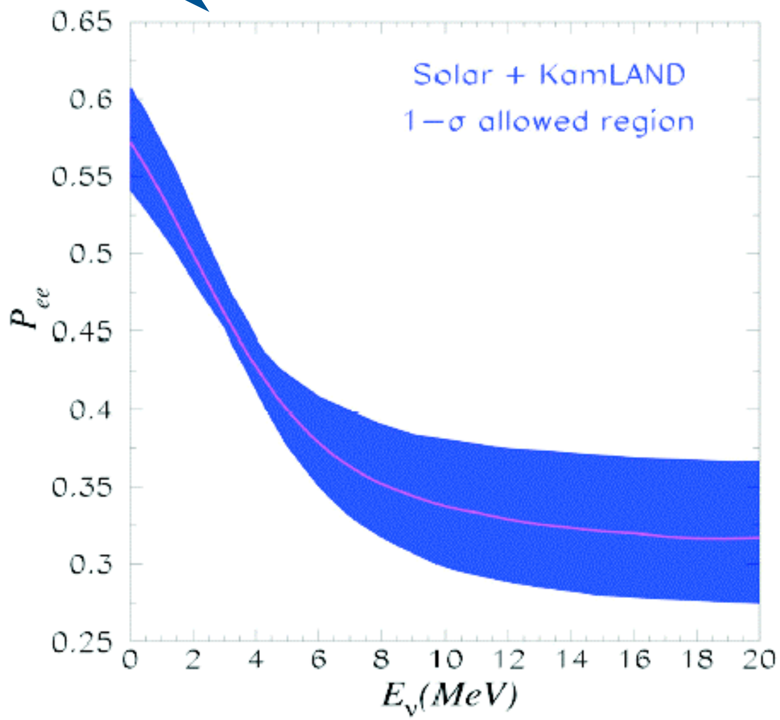


- Problem: electronics dead time after large μ signal → missing neutrons
- ^{11}C without neutrons (5%)
- Veto by μ only? → better μ fitter with better understanding of μ events
- See also poster: #55 L. Winslow for muon tracker

Low-energy ^{8}B neutrino–MSW distortion

- If ^{208}Tl ($\beta + \gamma$, Q = 5 MeV) reduced enough
- $\rightarrow$ ^{232}Th reduction needed (distillation works?)

KamLAND: low-energy frontier



from Pena-Garay

Solar $\overline{\nu}_e$, other high energy $\overline{\nu}_e$

PRL 92 (2004) 071301
see also talk by A. Friedland (this morning)

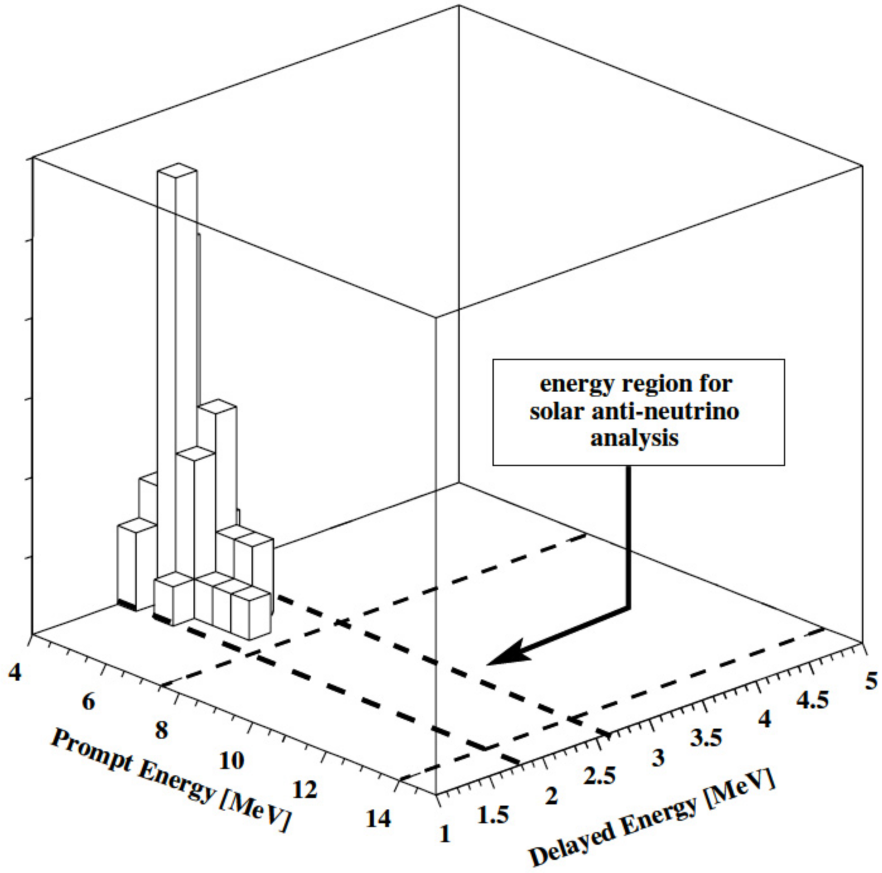


FIG. 2. Energy distribution of the final event candidates. The tail from reactor $\bar{\nu}_e$ events is visible below 8 MeV.

- ν_e / SSM-^{8}B $< 2.8 \times 10^{-4}$ (90 % C.L.)
- Supernova search: almost no B.G.
- See also poster #111 K. Ishii for supernova search

Invisible nucleon decay

$n \to inv.$, $nn \to inv.$ PRL 96 (2006) 101802

- For example, $n \to 3\nu$, $nn \to 2\nu$ (GUT or other new phys. beyond SM)

  (R. N. Mohapatra and A. Perez-Lorenzana, Phys. Rev. D 67, 075015 (2003))
- s-shell neutron disappearance from $^{12}C \to$ highly excited $^{11}C^*$, $^{10}C^*$

  (Y. Kamyshkov and E. Kolbe, Phys. Rev. D 67, 076007 (2003))
- After single neutron disappearance from ^{12}C (*s* shell)
  1. $^{11}C^* \to {}^{10}C_{g.s.} + n$
  2. $^{11}C^* \to {}^{10}C^* + n \to {}^{10}C_{g.s.} + n + \gamma$ (3.35 MeV)
- After two neutron disappearance from ^{12}C (*s* shell)
  1. $^{10}C^* \to {}^{9}C_{g.s.} + n$
  2. $^{10}C^* \to {}^{9}C^* + n \to {}^{8}B_{g.s.} + p + n$
- All 4 modes should appear as triple coincidence events.

  $\to$ very low background search
- $\tau(n \to inv.) > 5.8 \times 10^{29}$ yr (90% C.L.) (factor ~3 improvement)
- $\tau(nn \to inv.) > 1.4 \times 10^{30}$ yr (90% C.L.) (factor $>10^4$ improvement)
- See also poster: #110 T. Miletic

Summary

- Reactor neutrino:
  - Data taking is going well and will continue
  - All volume calibration is starting soon
- Geoneutrino:
  - Efforts to reduce systematic error of B.G.
- Solar neutrino:
  - Toward "solar ν phase" (^{210}Pb, ^{85}Kr reduction by 10^{-5})
  - Distillation will start in September 2006
- Thank you very much and please keep encouraging KamLAND