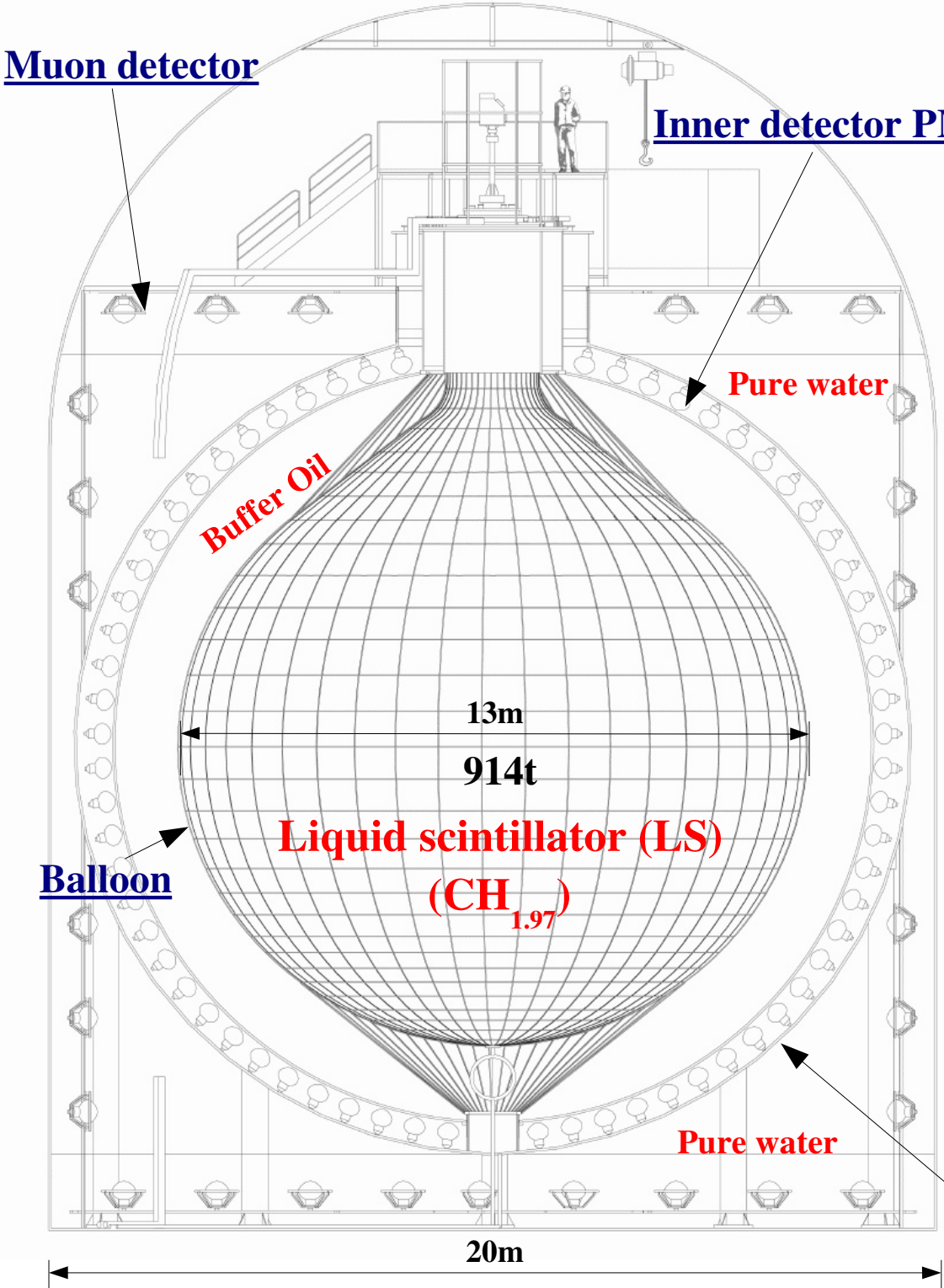
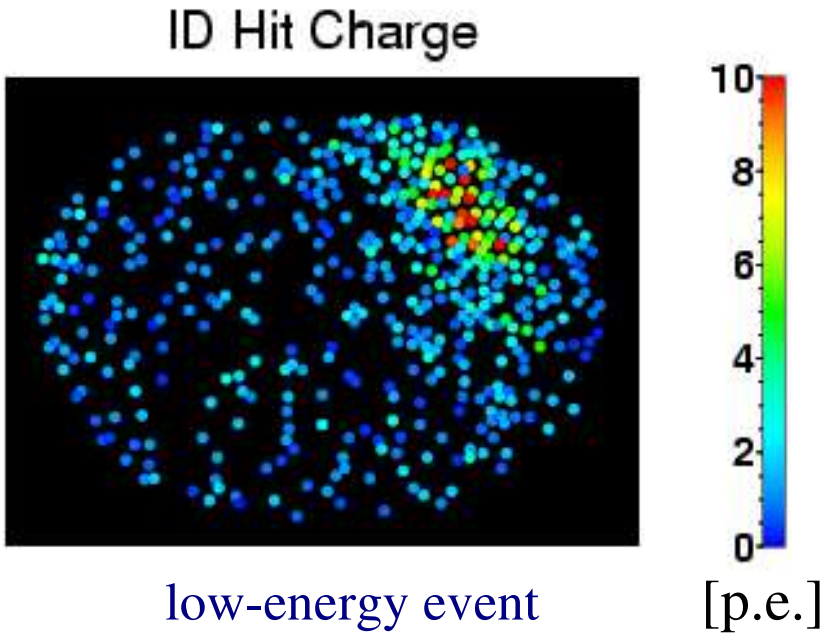
KamLAND current status & future prospects

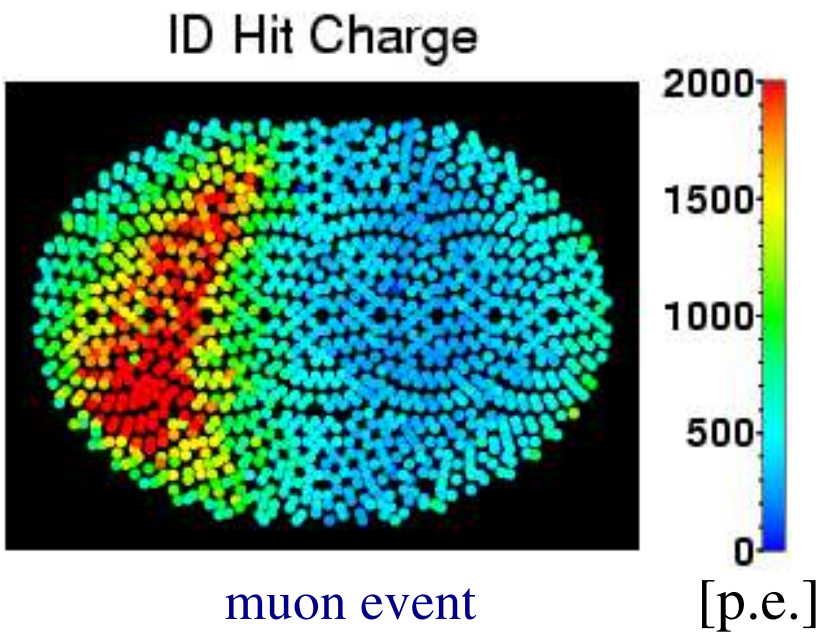
Alexandre Kozlov
Research Center for Neutrino Science
Tohoku University
(The KamLAND Collaboration)

Workshop on Next Generation Nucleon Decay and Neutrino Detectors
October 2-5, 2007, Hamamatsu, JAPAN



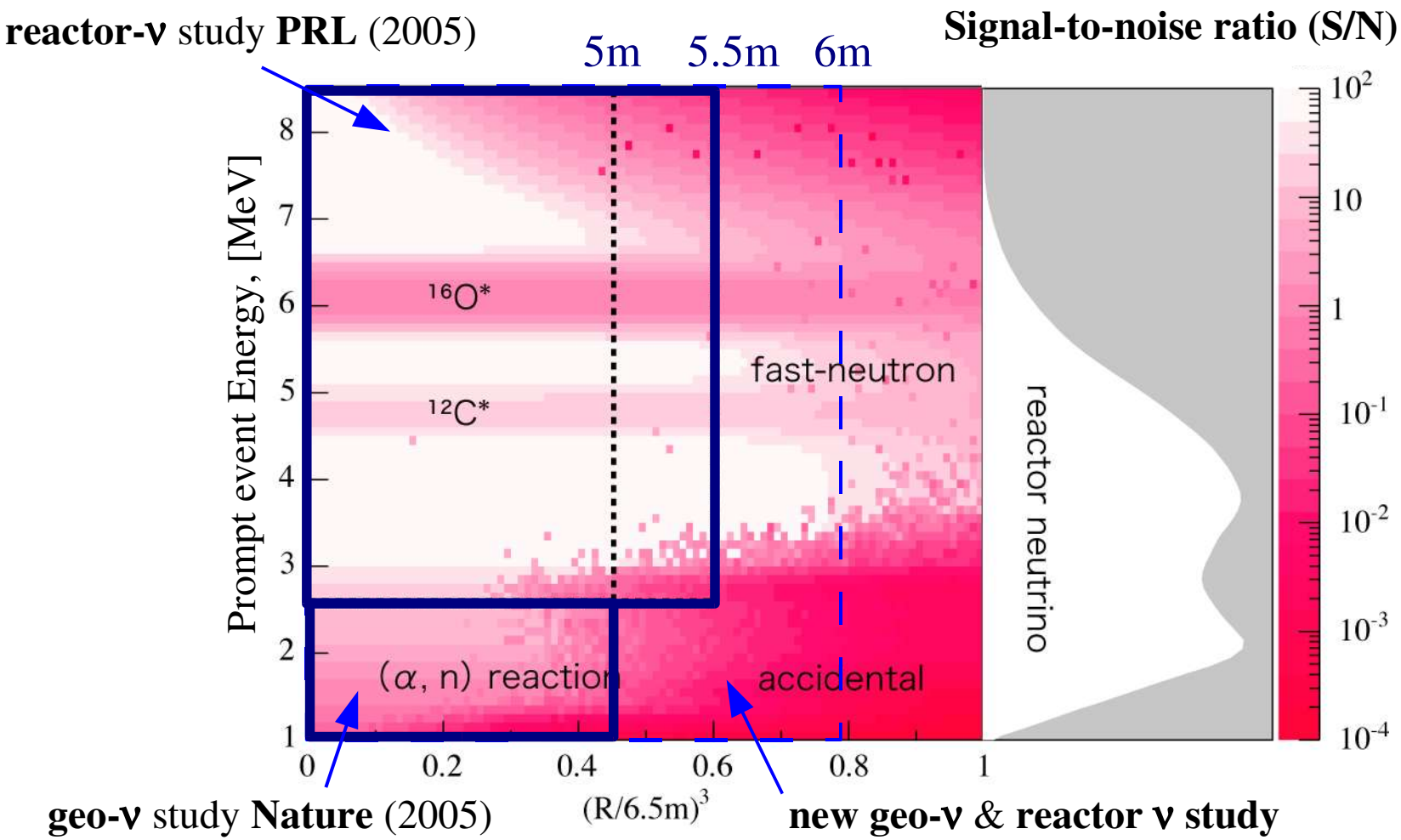


low-energy event



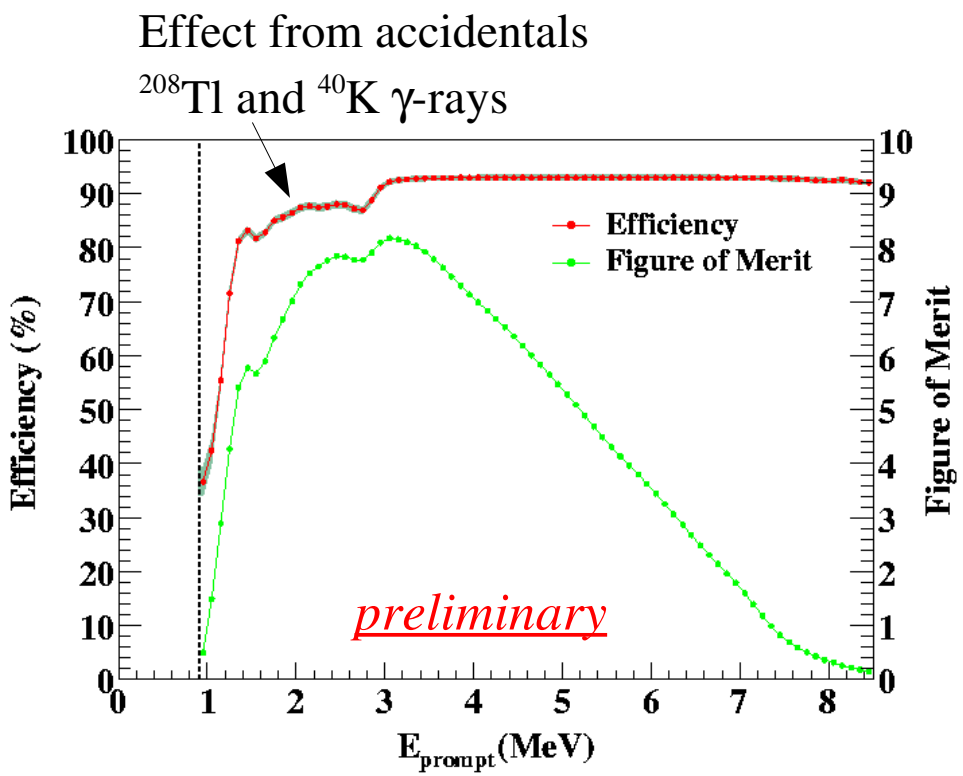
muon event

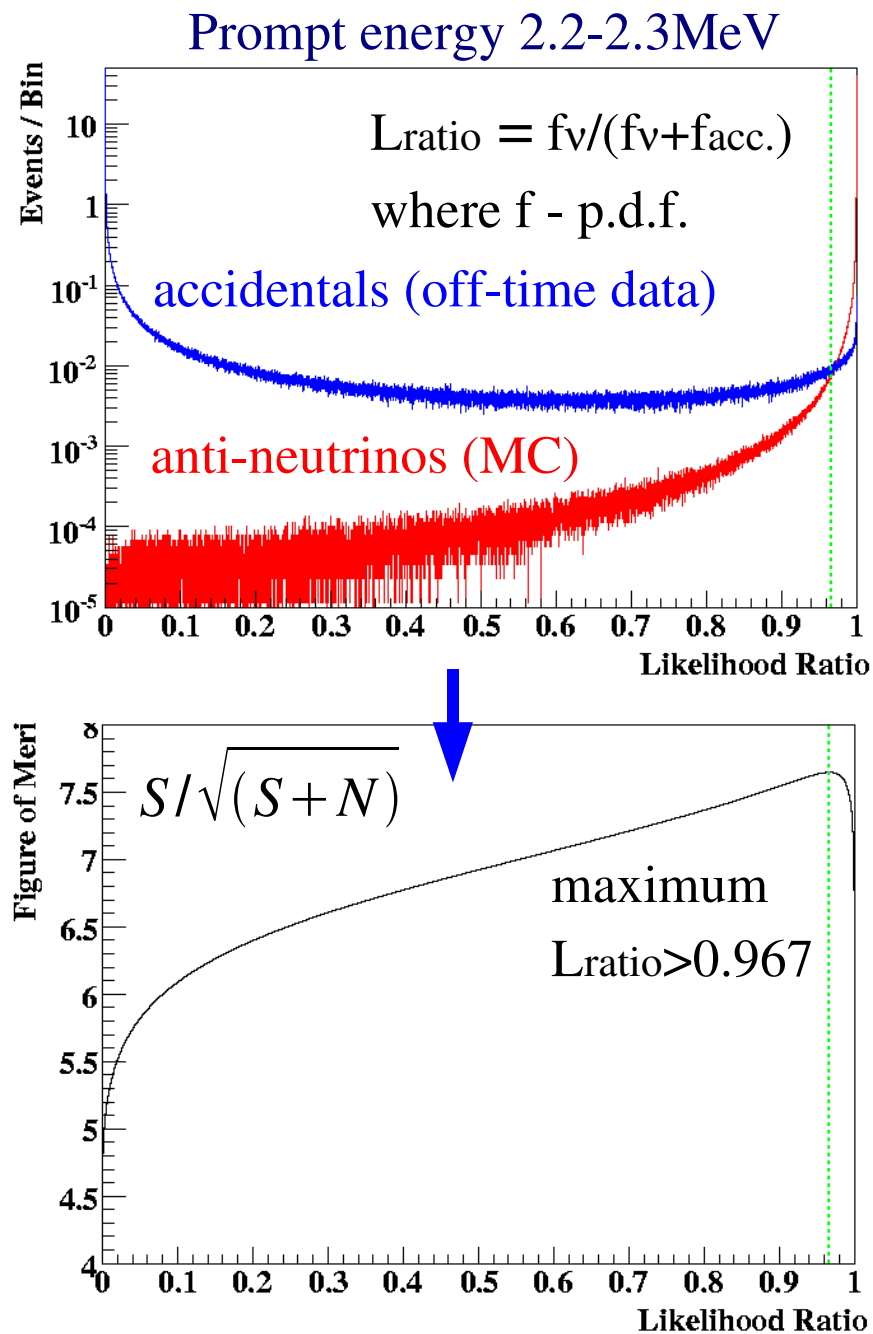
New improved anti-neutrino data analysis



This plot is for Prompt-Delayed pairs separated by ΔT<1ms, and ΔR<2m. In new analysis variable selection criteria allowed to suppress accidentals effectively and to perform combined analysis using a 0.9-8.5MeV energy range and a 6m fiducial volume.

Selection of anti-neutrino events

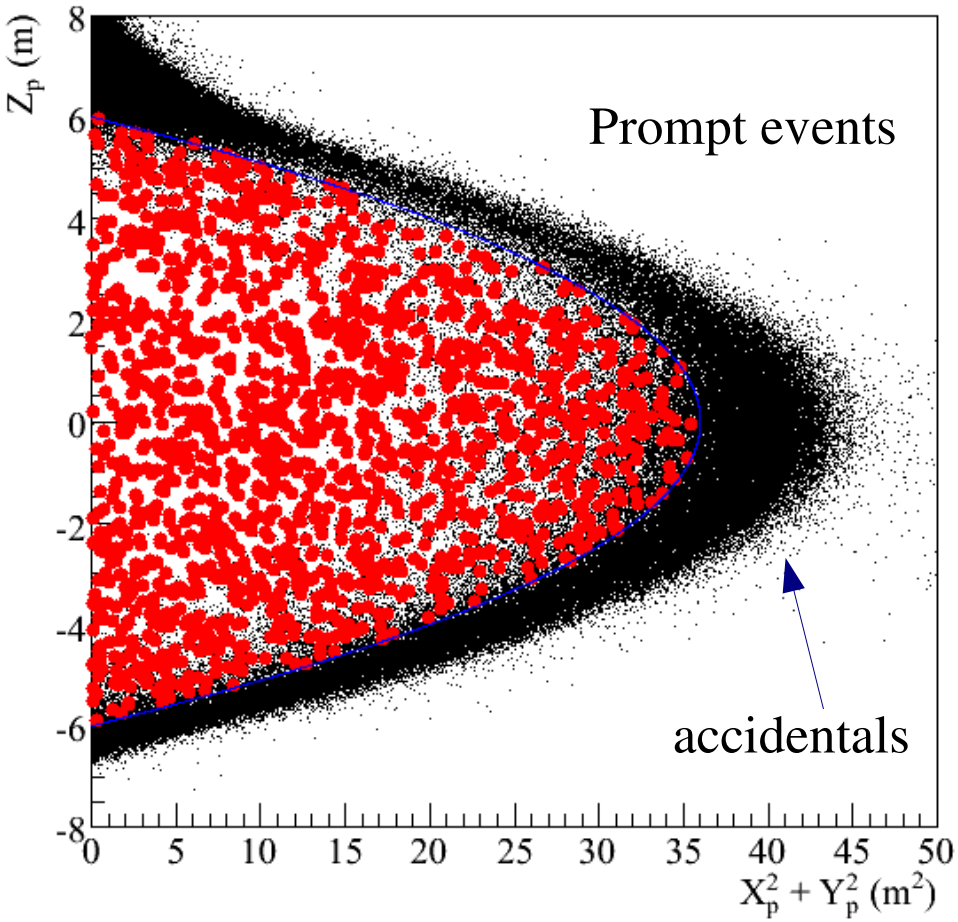


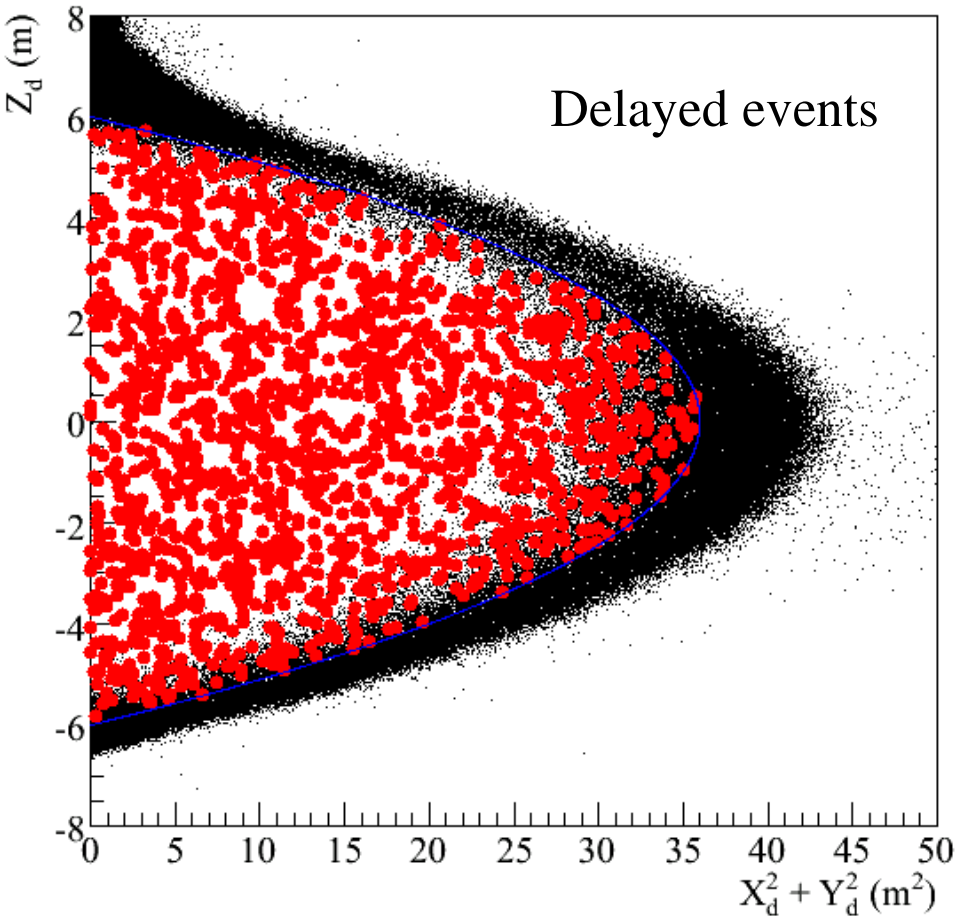


For each bin in Eprompt there are R_p, R_d, E_d, ΔT, ΔR parameters.

muon cuts include full volume 2s veto after a showering muon, 3m cylinder cut along track of a non-showering muon for 2s to suppress the ^{9}Li correlated background

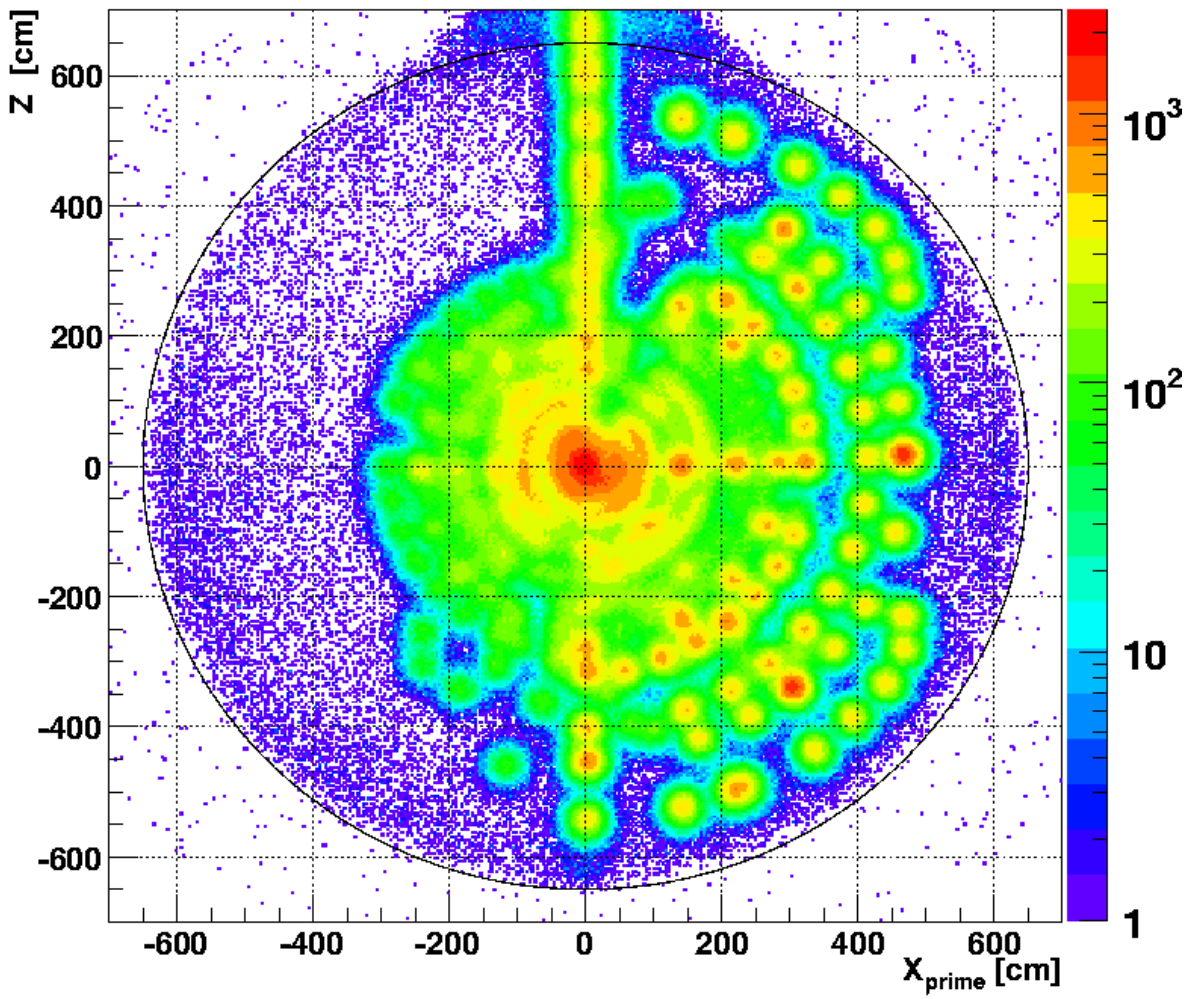
Distribution of anti-neutrino events in KamLAND





The **red** **(black)** points show vertex location of correlated events with and without the selection cut. Left figure shows Prompt, and right figure Delayed events. Anti-neutrino events are distributed uniformly, while accidentals located near the balloon edge.

Estimation of the fiducial volume uncertainty



off-axis calibration system was used to deploy ^{241}Am^{9}Be, ^{210}Po^{13}C, ^{60}C, ^{68}Ge, and ^{203}Hg sources outside of the detector central axis to study vertex reconstruction biases at distances up to 5.75m away from the detector center. This confirmed that the new Tohoku vertex fitter, in addition to improved vertex resolution (21cm→12cm at 1MeV), reconstructs event's position with a bias < 3cm.

The fiducial volume (FV) uncertainty, 1.8%, was determined by using the off-axis calibration system and uniformly distributed μ-induced β-emitter ^{12}B events. For comparison, the 4.7% FV uncertainty was used for the 2nd KamLAND result.

Calculation of the expected (α,n) background

^{210}Po 5.3MeV α-particle interaction on ^{13}C:

(g.s.) $\alpha + {}^{13}C \rightarrow {}^{16}O + n$ (3-7MeV)

$n + {}^{12}C \rightarrow {}^{12}C + n + \gamma$ (4.44MeV)

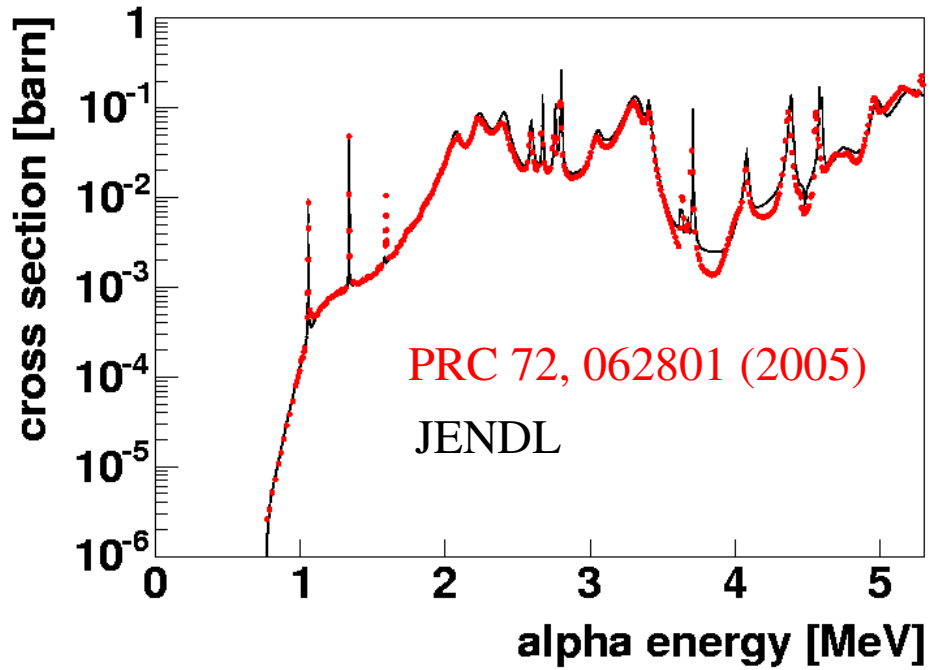
(1st) $\alpha + {}^{13}C \rightarrow {}^{16}O^* (6.05MeV) + n$ (0-0.5MeV)

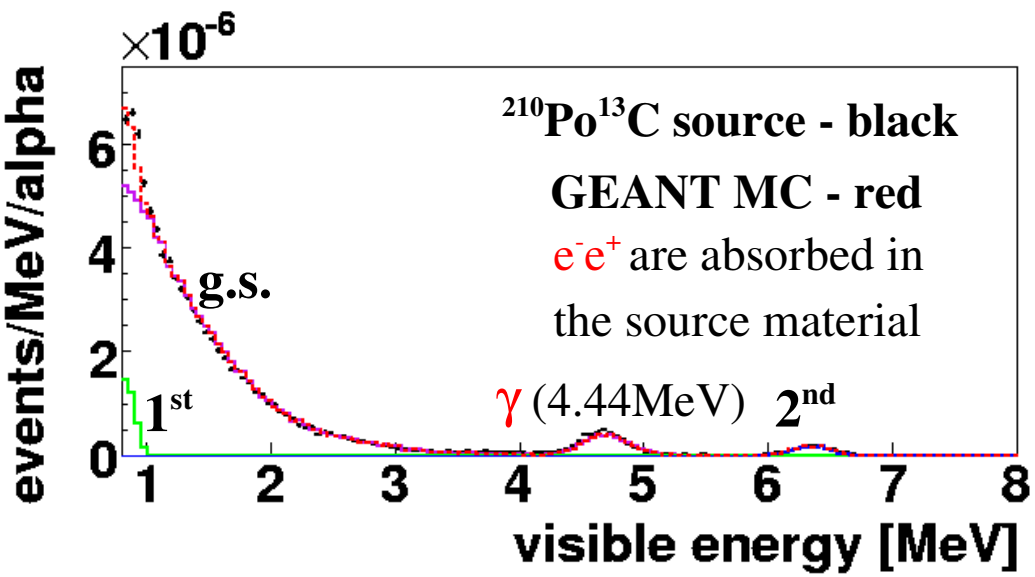
(2nd) $\alpha + {}^{13}C \rightarrow {}^{16}O^* (6.13MeV) + n$ (0-0.5MeV)

1st (2nd) excited states of ^{16}O decay to e^-e^+ (γ-ray)

all these reactions produce correlated events

not distinguishable from anti-neutrino signals





Expected number of events:

ground state 163.3 ± 18.0

excited states 18.7 ± 3.7

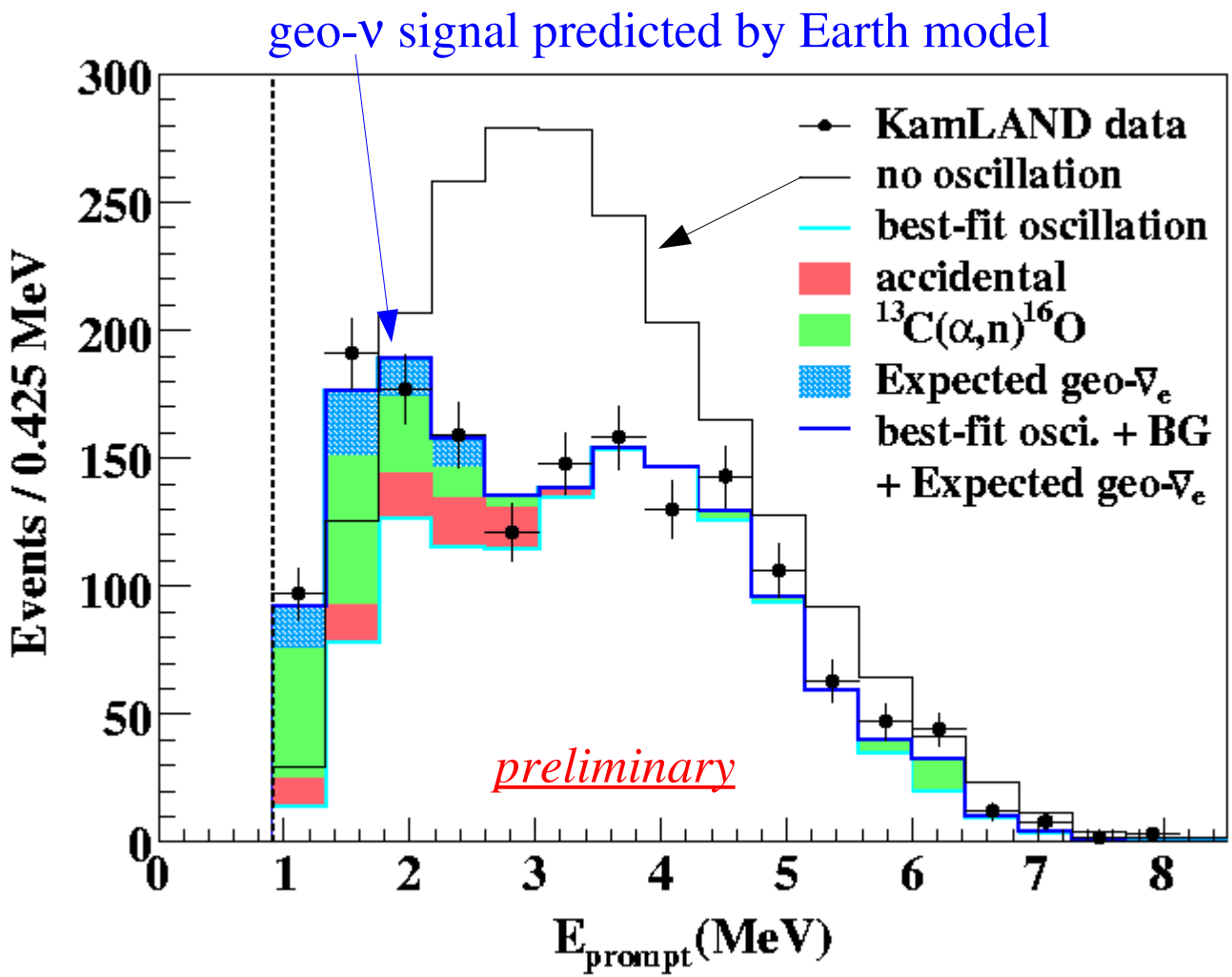
Compared to the 2nd KamLAND result:

Error for g.s. reduced: 32%→11%

Error for exc. st. reduced: 100%→20%

10% energy scale error was removed

The anti-neutrino energy spectrum



Plot shows the Prompt event energy (e^+ kinetic energy + $2m_e$) which can be converted to $E_\nu \approx E_{prompt} + 0.8\text{MeV}$

Best fit values:

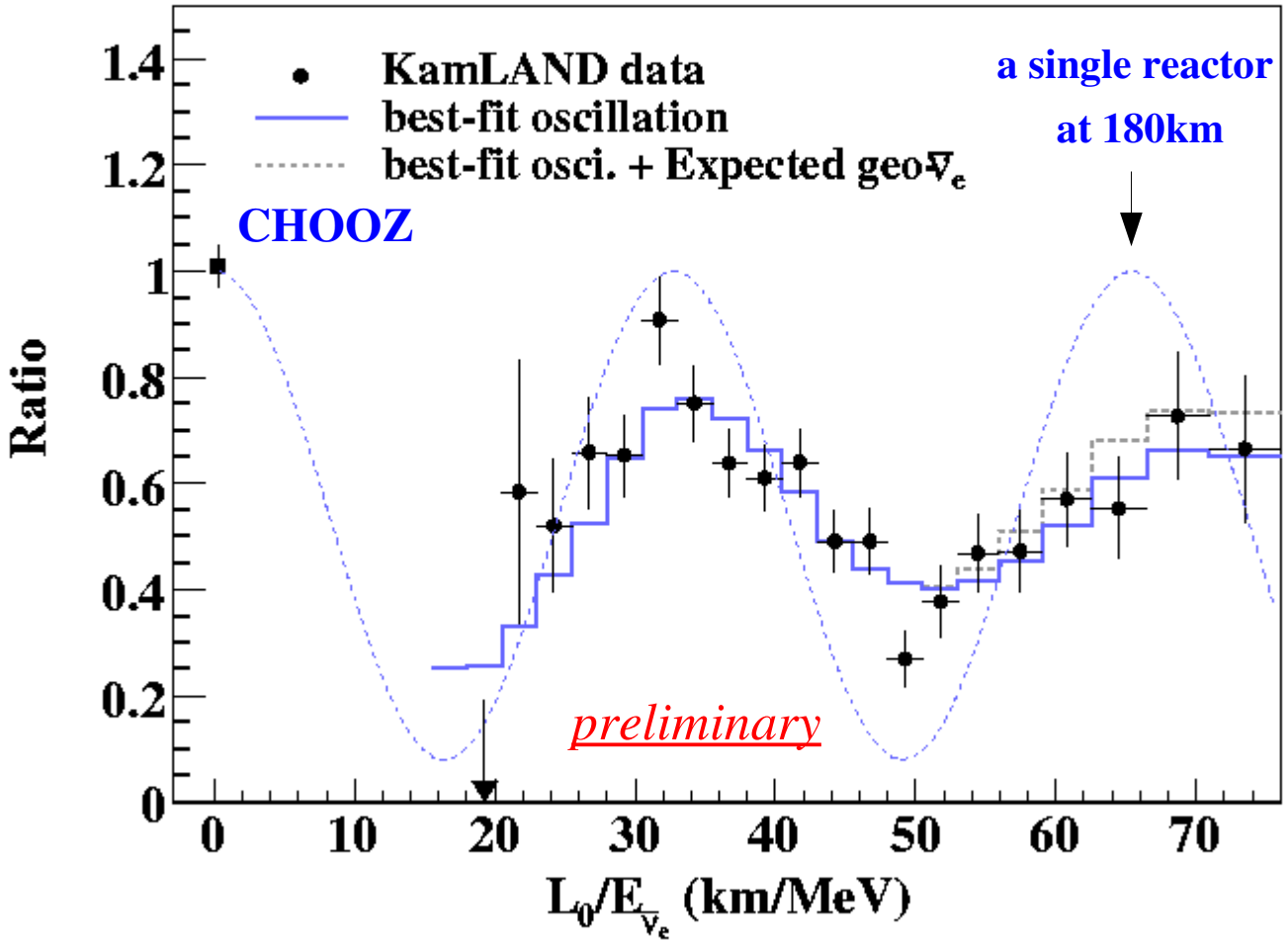
$\Delta m^2 = 7.58\times10^{-5}\text{eV}^2$

$\tan^2\theta = 0.56$

χ^2 / NDF = 21.0/16 (18% C.L.)

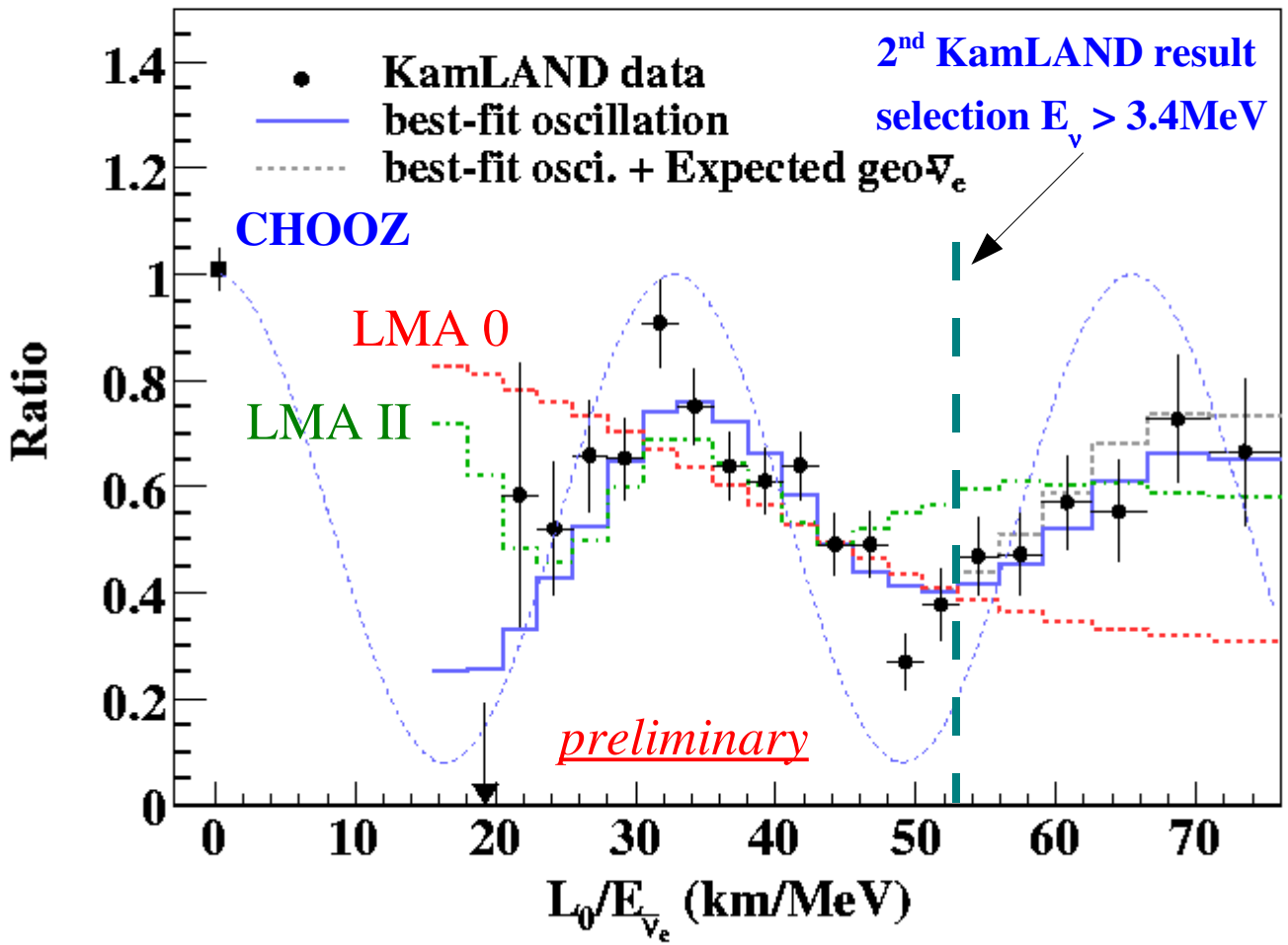
Data taken between March 9, 2002 and May12, 2007, the 2881 ton-year exposure is used. This is KamLAND only result (no SNO data included) with U/Th geo-ν contributions being free parameters. Scaled spectrum with no oscillations included is excluded at a 5.2σ level, χ^2 / NDF = 63.9/17, (while 5σ is a formal requirement for discovery of a phenomenon).

The L_0/E_ν oscillation plot (L_0=180km)



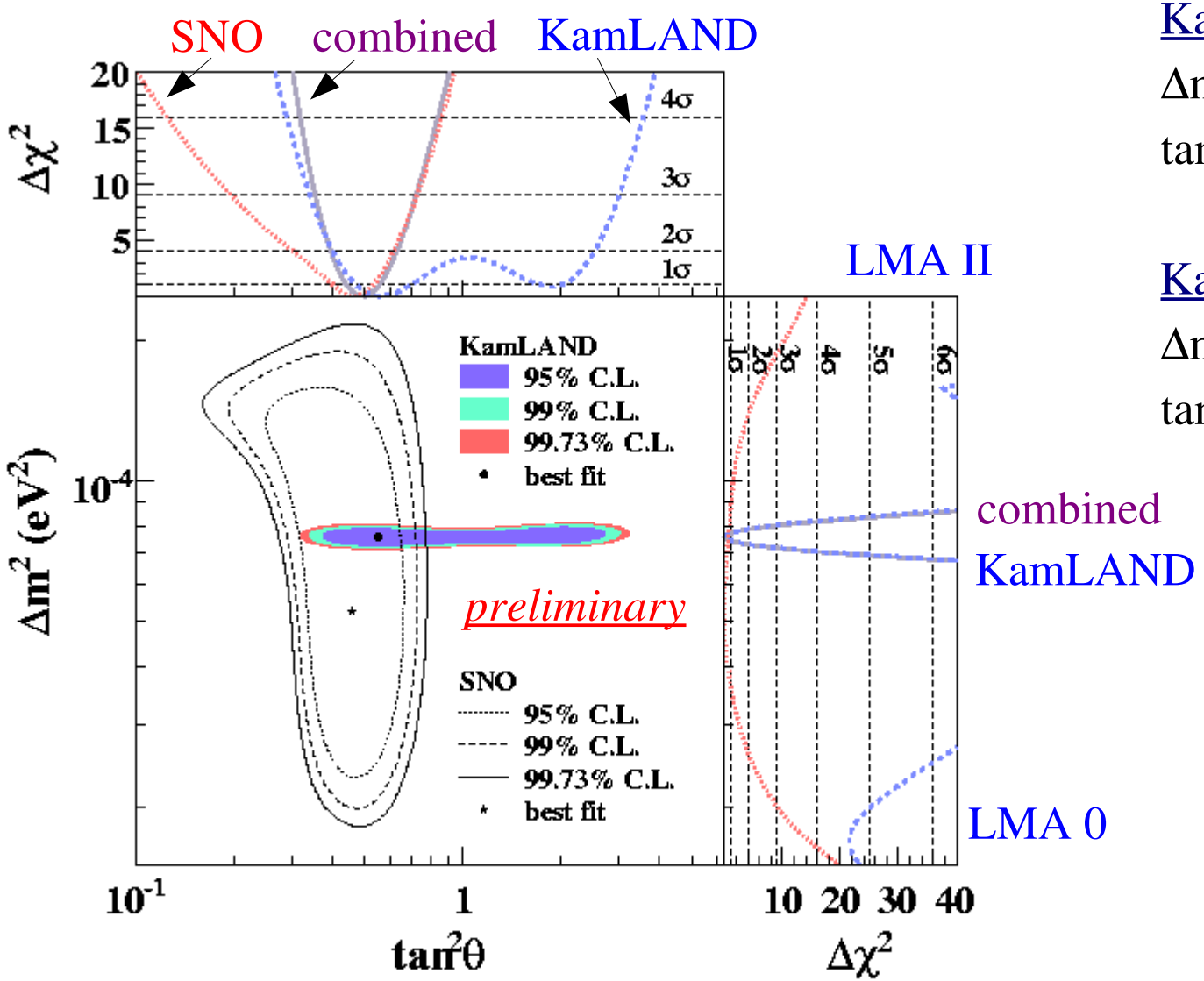
The KamLAND and CHOOZ data plotted as **Ratio = (Nobs - Nbg)/(Nexp)** , where **Nobs** is number of observed events, **Nexp** is number of expected in no oscillation case, **Nbg** is number of expected ^{9}Li, (α, n), and accidental background events.

The L_0/E_ν oscillation plot: LMA 0, I, II vs data



The 2nd KamLAND result was obtained for the E_ν >3.4MeV to avoid the geo-ν background, while data below 3.4MeV has a power to distinguish between different LMA regions. New analysis excluded alternative solutions (LMA 0, LMA II) by more than 4σ.

New result for oscillation parameters



KamLAND+SNO:

$\Delta m^2 = 7.59^{+0.20}_{-0.21} \times 10^{-5} eV^2$

$\tan^2\theta = 0.49^{+0.07}_{-0.05}$

KamLAND only:

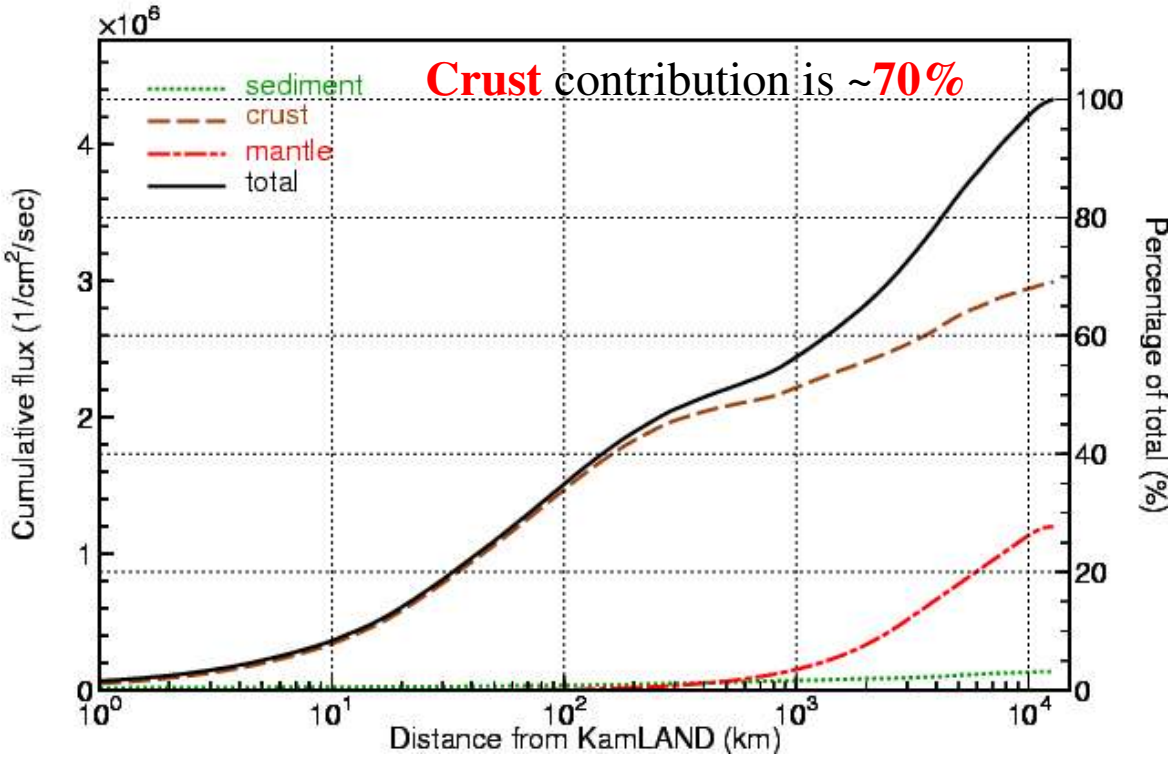
$\Delta m^2 = 7.58^{+0.21}_{-0.20} \times 10^{-5} eV^2$

$\tan^2\theta = 0.56^{+0.14}_{-0.09}$

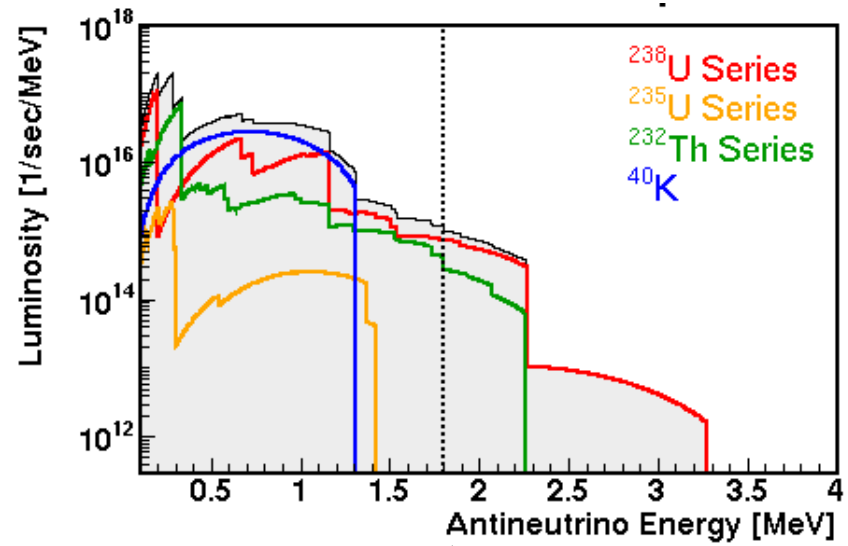
New feature of this analysis: KamLAND substantially improves mixing angle measurement.

Solar data has no effect on the Δm^2 measurement.

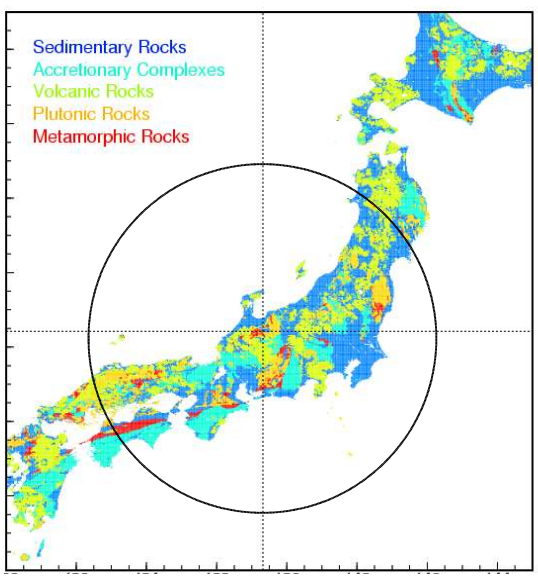
Expected geo-neutrino signal at KamLAND



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



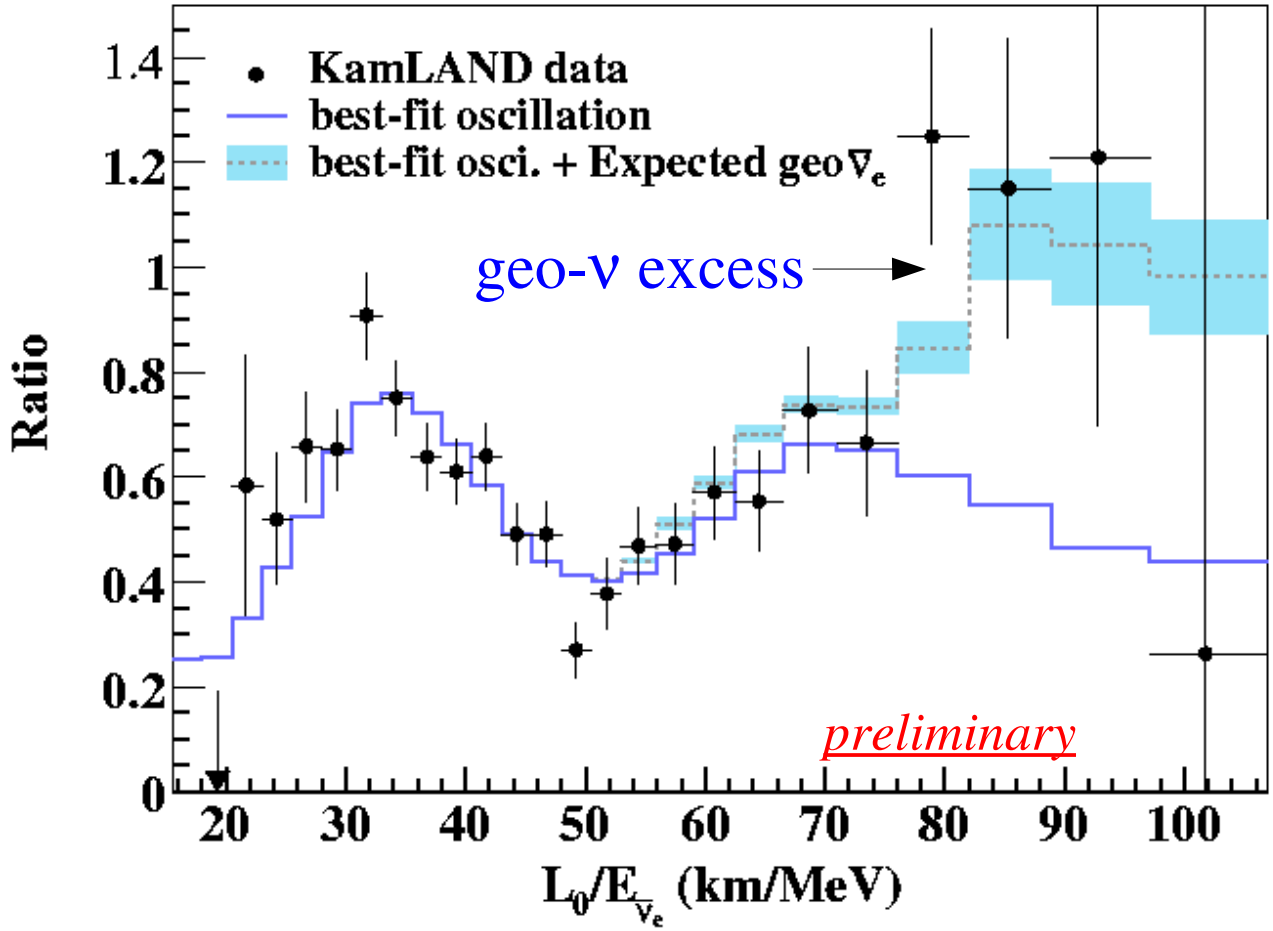
Threshold:1.8MeV

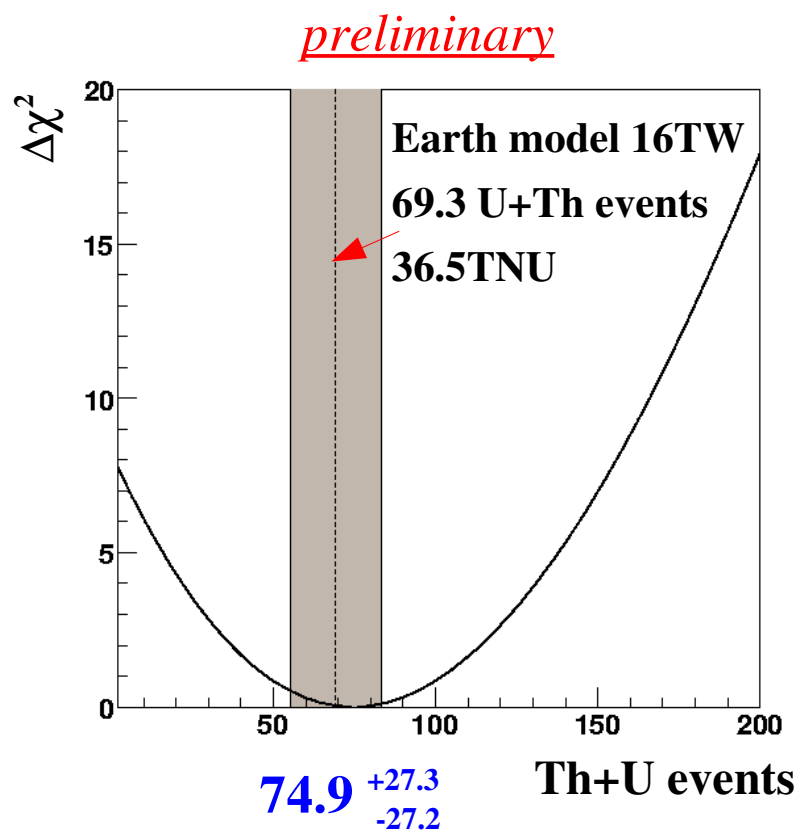


Area within 500km gives ½ of the total expected geo ν flux at the KamLAND location.

Geo-neutrinos carry information about the absolute amount and distribution of the U/Th/K in the crust, mantle and core. This information may help to understand mechanisms of Earth formation, and its dynamics.

The second geo-neutrino result



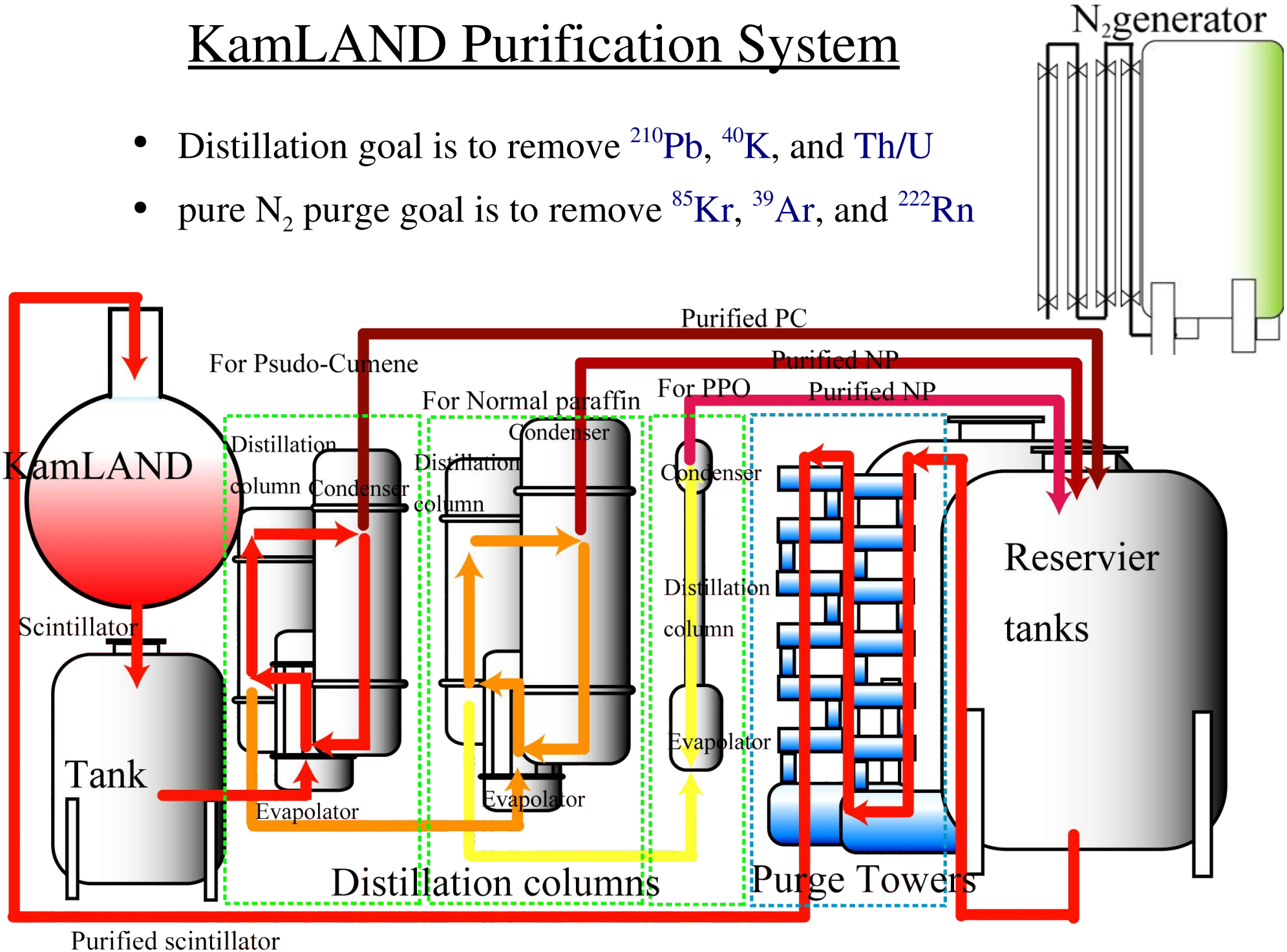


The Rate+Shape+Time data analysis were performed with the SNO result included to improve precision on the mixing angle. The Th/U mass ratio was fixed at 3.9.

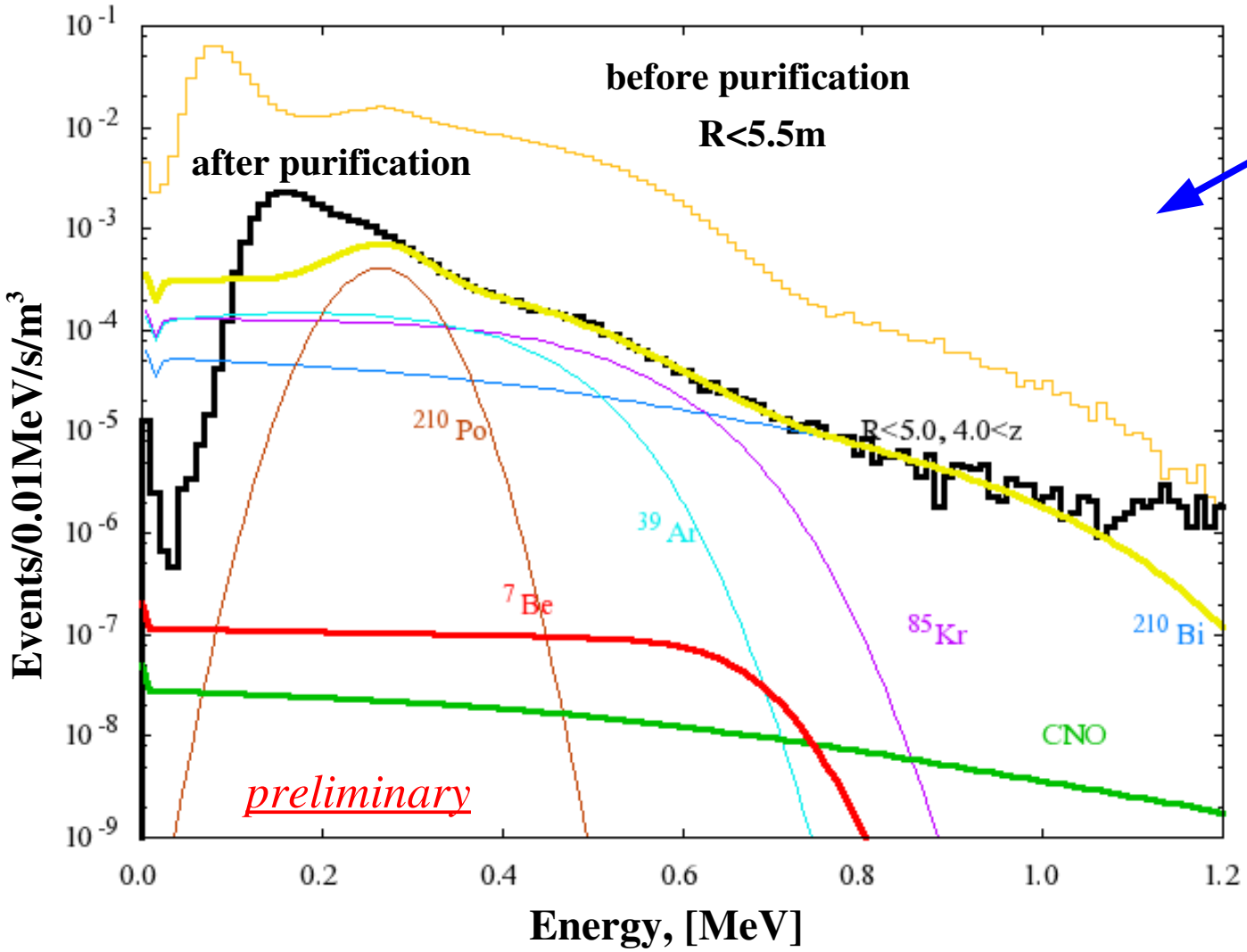
Result: **39.4** $^{+14.4}_{-14.3}$ TNU while previous result published in Nature was **57.4** $^{+32.0}_{-30.0}$ TNU (TNU = event / 10^{32} target-proton per year)

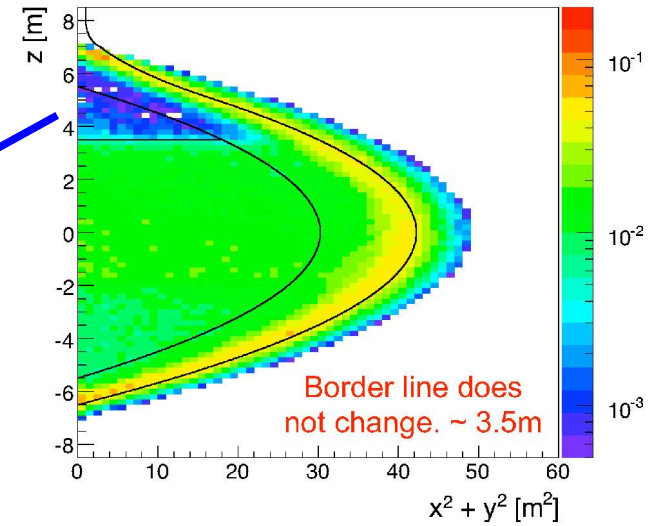
KamLAND Purification System

- Distillation goal is to remove ^{210}Pb, ^{40}K, and Th/U
- pure N_2 purge goal is to remove ^{85}Kr, ^{39}Ar, and ^{222}Rn



Background reduction after the 1st stage of purification

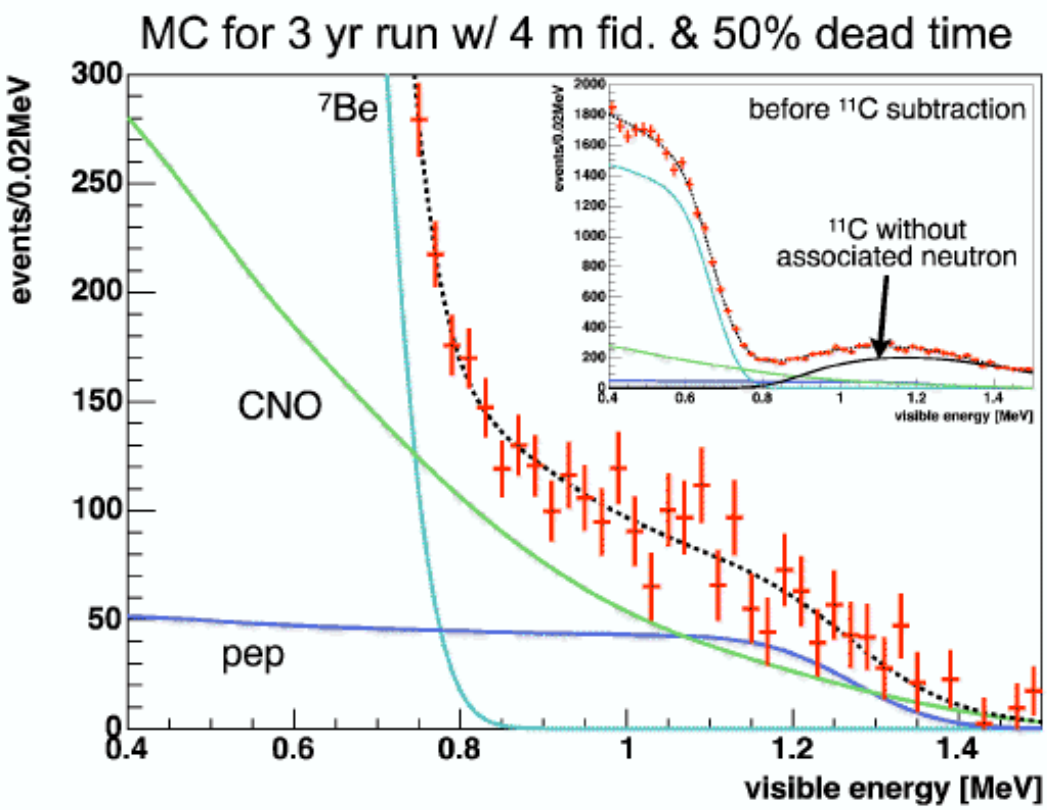


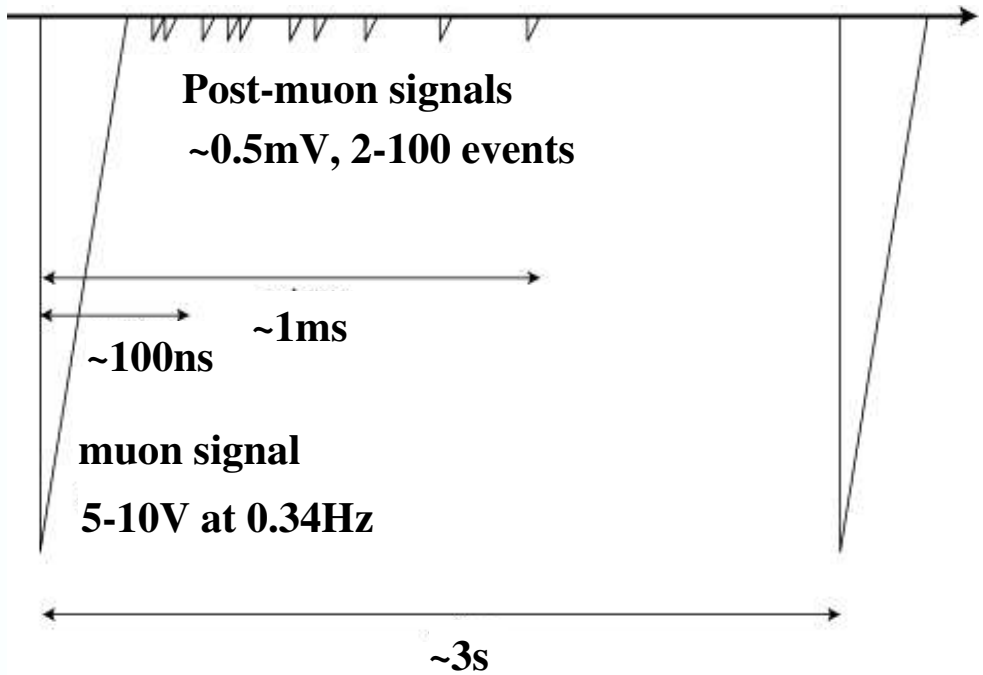


The distribution of events with energy 0.45-0.7MeV (mostly ^{85}Kr β-decays)

About 1700m^3 of the KamLAND scintillator were purified. Due to mixing between purified and non-purified scintillator purification effect is smaller than needed for the ^{7}Be observation. The upper part of the detector is filled with scintillator after a 2nd pass through the system.

Detector upgrade towards the solar neutrino detection

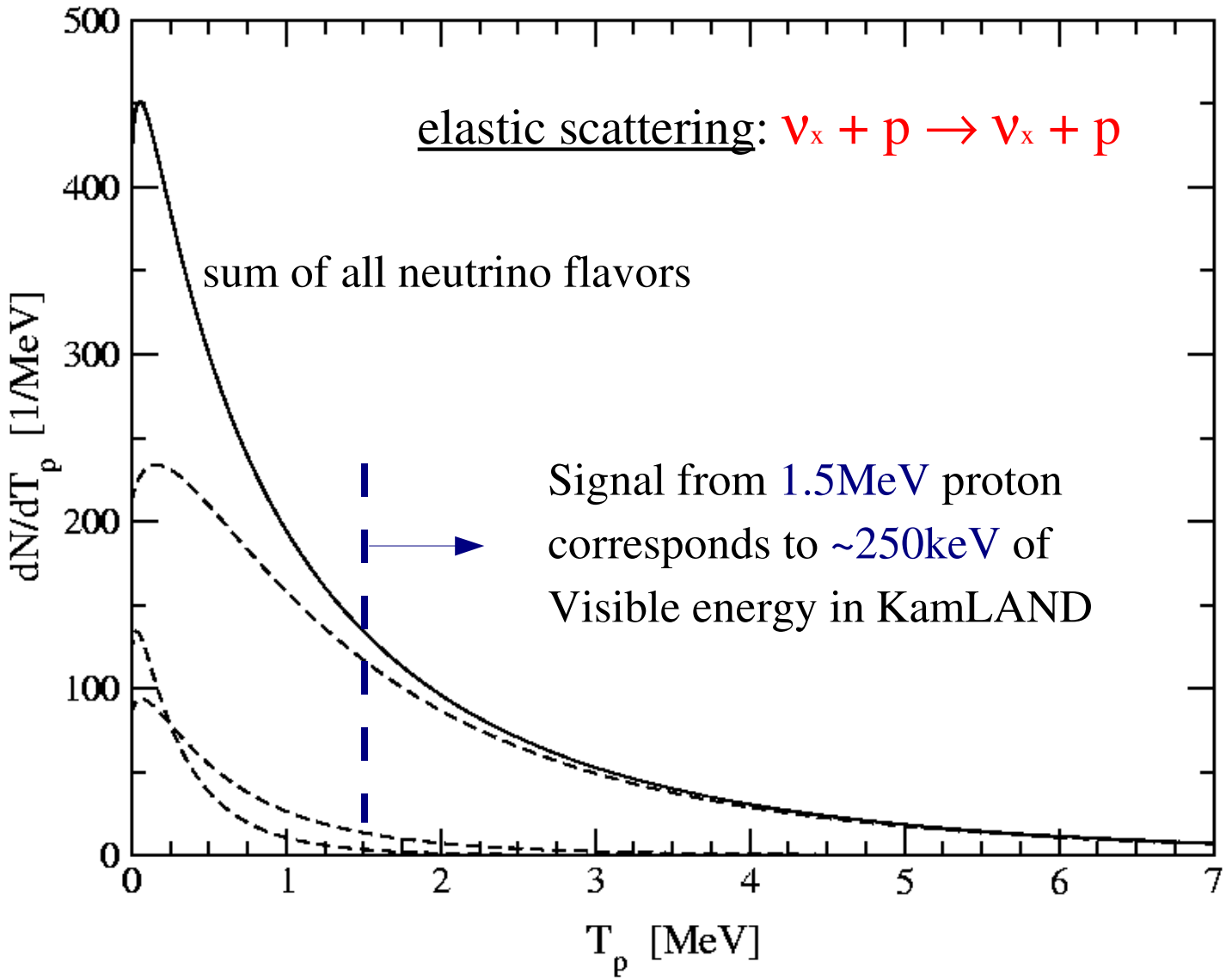




95% of the ^{11}C nuclei are produced in $^{12}C+\mu \rightarrow {}^{11}C+n$ reaction. Detection of the neutron after muon should allow to veto a small part of the detector volume until ^{11}C decays and reduce background for measurement of the pep and CNO solar neutrinos. Technique was successfully tested in KamLAND but new electronics is needed to improve veto efficiency.

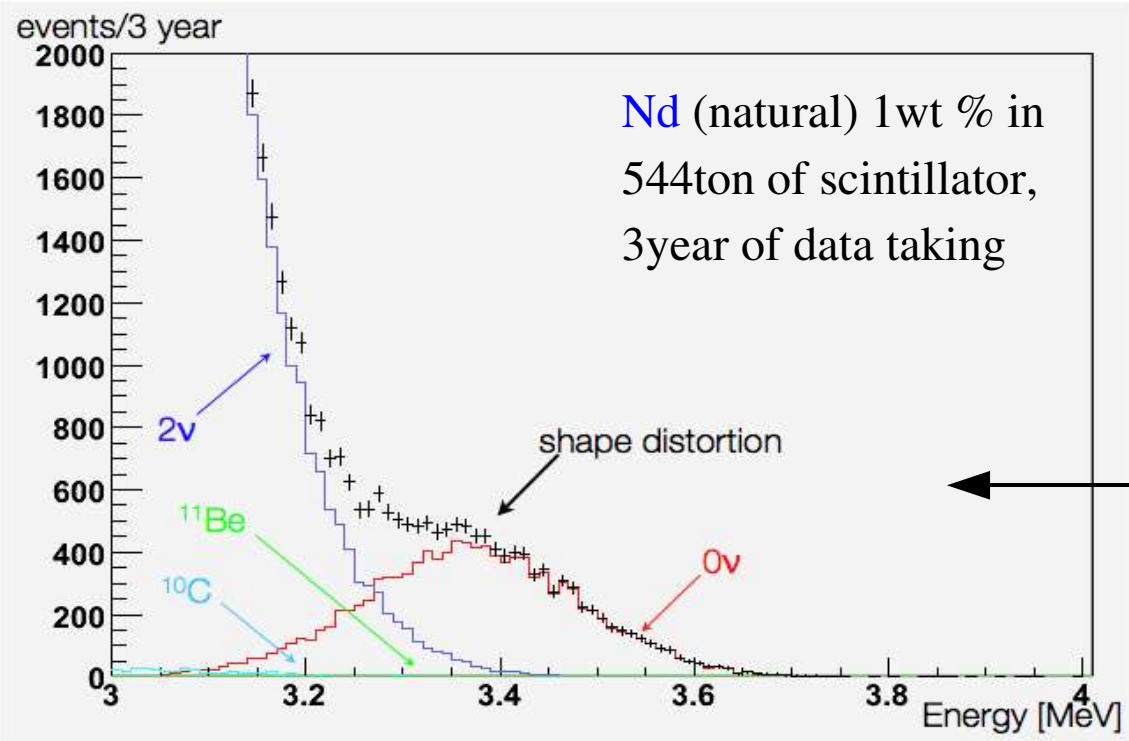
A new deadtime-free data acquisition electronics was developed for the solar pep/CNO neutrino observation with KamLAND. It aims to detect all neutrons produced by muons. The number of neutrons after a muon can reach 60~100, and therefore capability of collecting multiple signals is crucial.

Sensitivity to the SN neutrinos after purification



The proton-recoil energy spectrum in KamLAND from SN (3×10^{53}ergs) at 10kpc from PRD **66**, 033001 (2002). Background reduction at the low energy region, a large detector mass, and high H/C ratio makes KamLAND a unique tool for the SN neutrino detection.

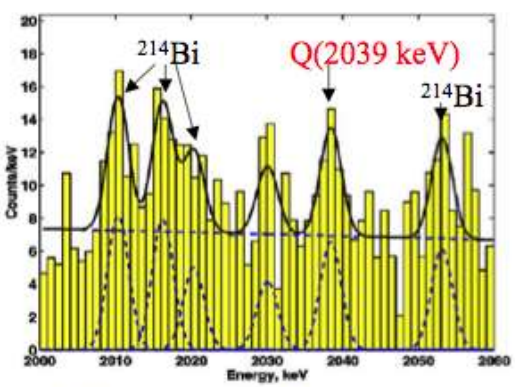
Search for neutrino-less double β-decay in KamLAND



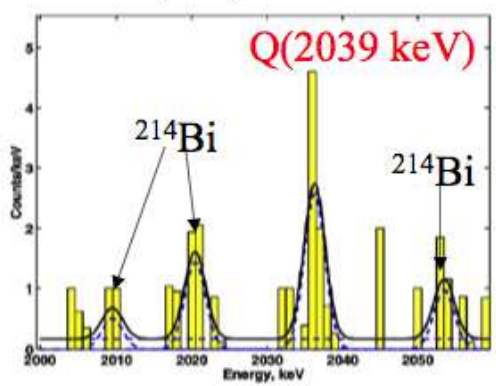
One of the possible scenario of the more distant future of KamLAND is a search for neutrino-less double β-decay (e.g. ^{150}Nd, Q=3.367MeV).

Simulations show how KamLAND data would look like if KKDC claim about the neutrino mass is true.

Klapdor,K,D,C, Phys. Lett. B 586 (2004) 198



Sum energy of 2 electrons



Pulse shape analysis

To do:

develop a new liquid scintillator with a high light yield, understand energy resolution well, study background (^{208}Tl internal + external), etc

Conclusion

- The "reactor" phase is over with 4.1 years of the detector livetime
- KamLAND measured $\Delta m^2 = 7.59\times10^{-5} eV^2$ with a 2.8% uncertainty
- KamLAND improved measurement of $\theta_{12} \approx 35$ degrees
- Purification of the scintillator has been started. More work is needed.
- Main goals after the purification: ^{7}Be, CNO, pep solar neutrinos, geo-ν, a new window for the SN neutrinos detection (via proton recoil)
- More distant goals: search for neutrino-less double β-decay, direction sensitive detection of the geo-and-reactor neutrinos with a ^{6}Li loaded scintillator