INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

KamLAND after the reactor phase

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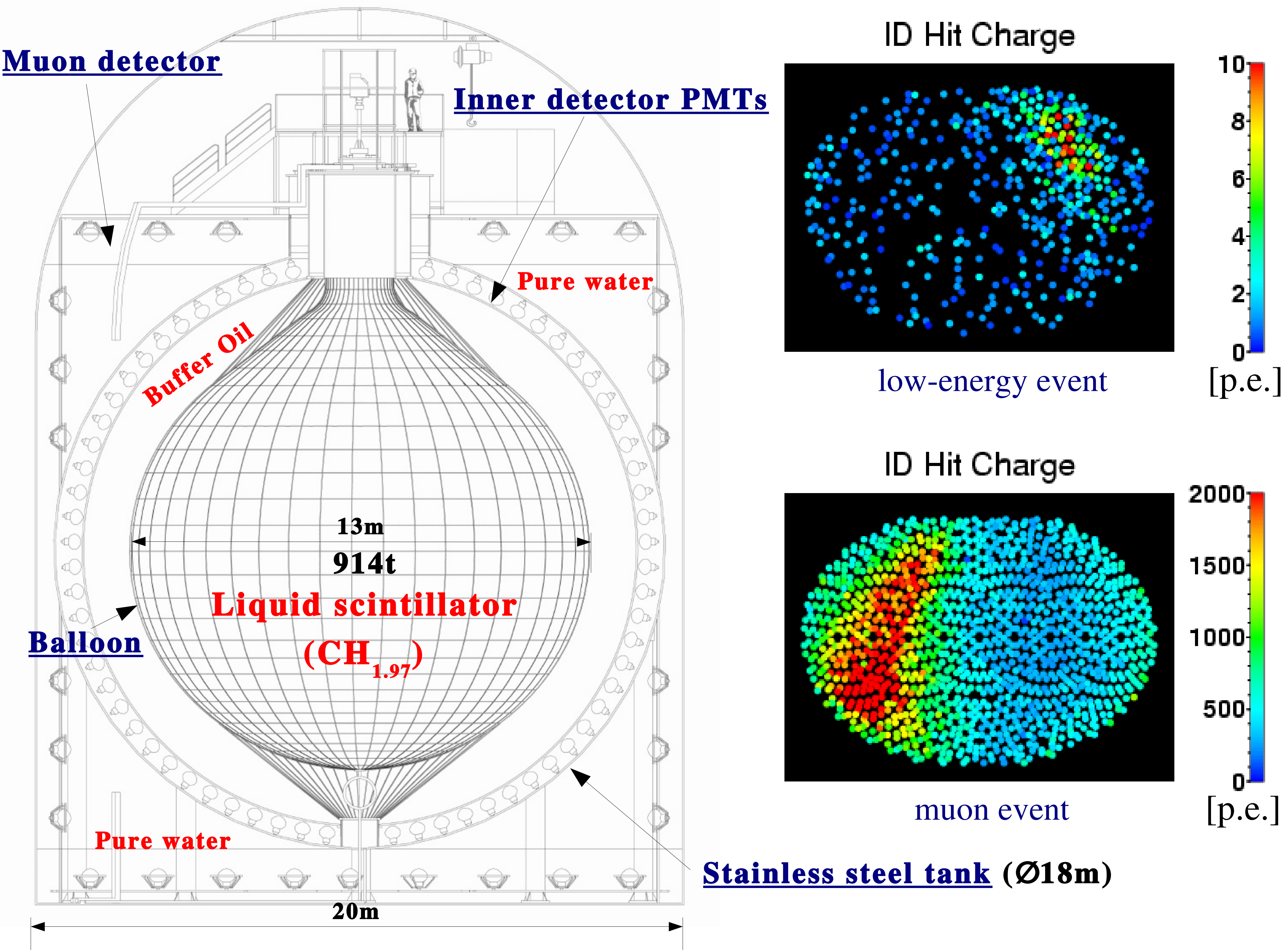
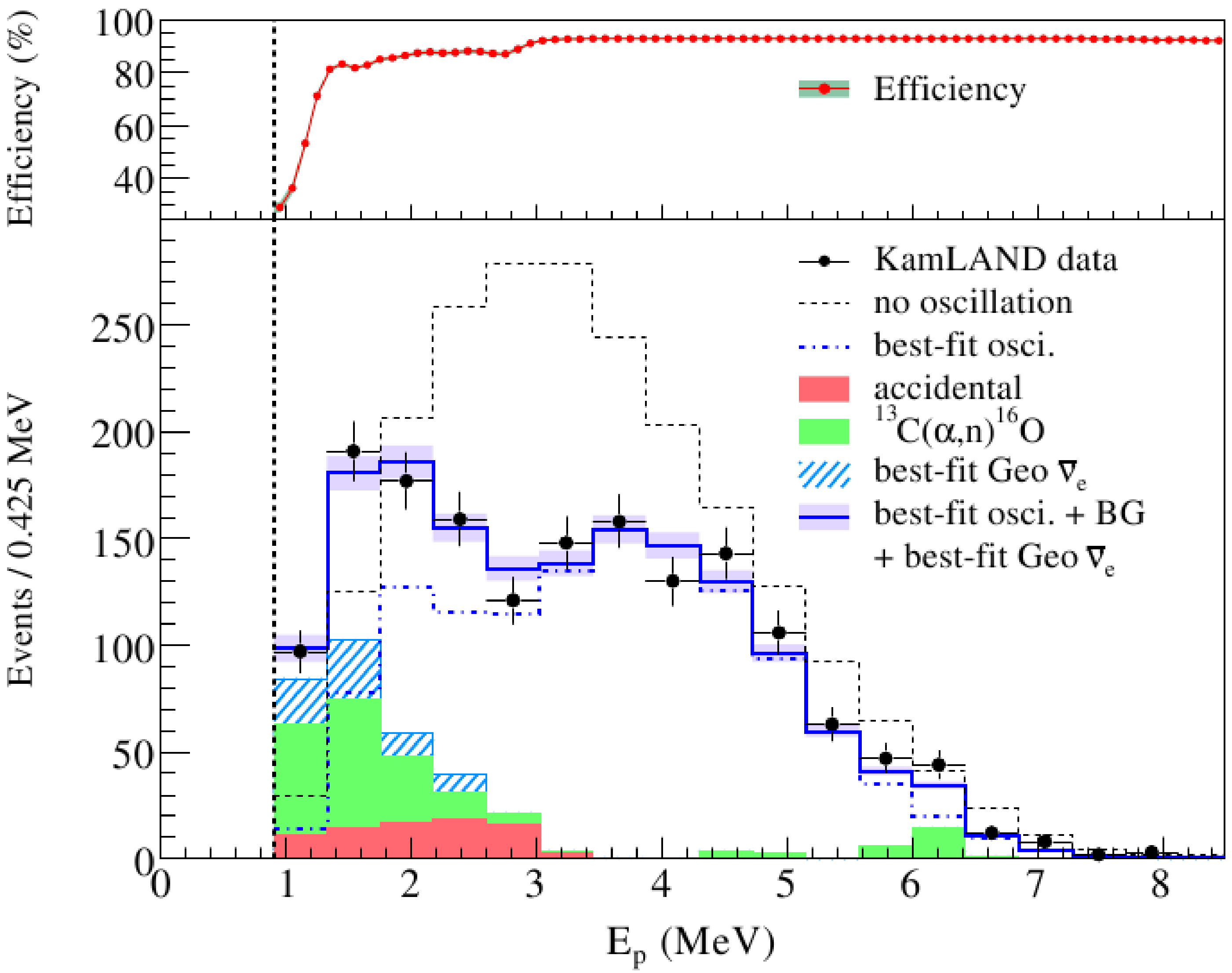

Muon detector
Inner detector PMTs
Pure water
Buffer Oil
13m
914t
Liquid scintillator
($CH_{1.97}$)
Balloon
Pure water
Stainless steel tank (Ø18m)
20m
ID Hit Charge
10
8
6
4
2
0
low-energy event
[p.e.]
ID Hit Charge
2000
1500
1000
500
0
muon event
[p.e.]

The full anti-neutrino energy spectrum



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

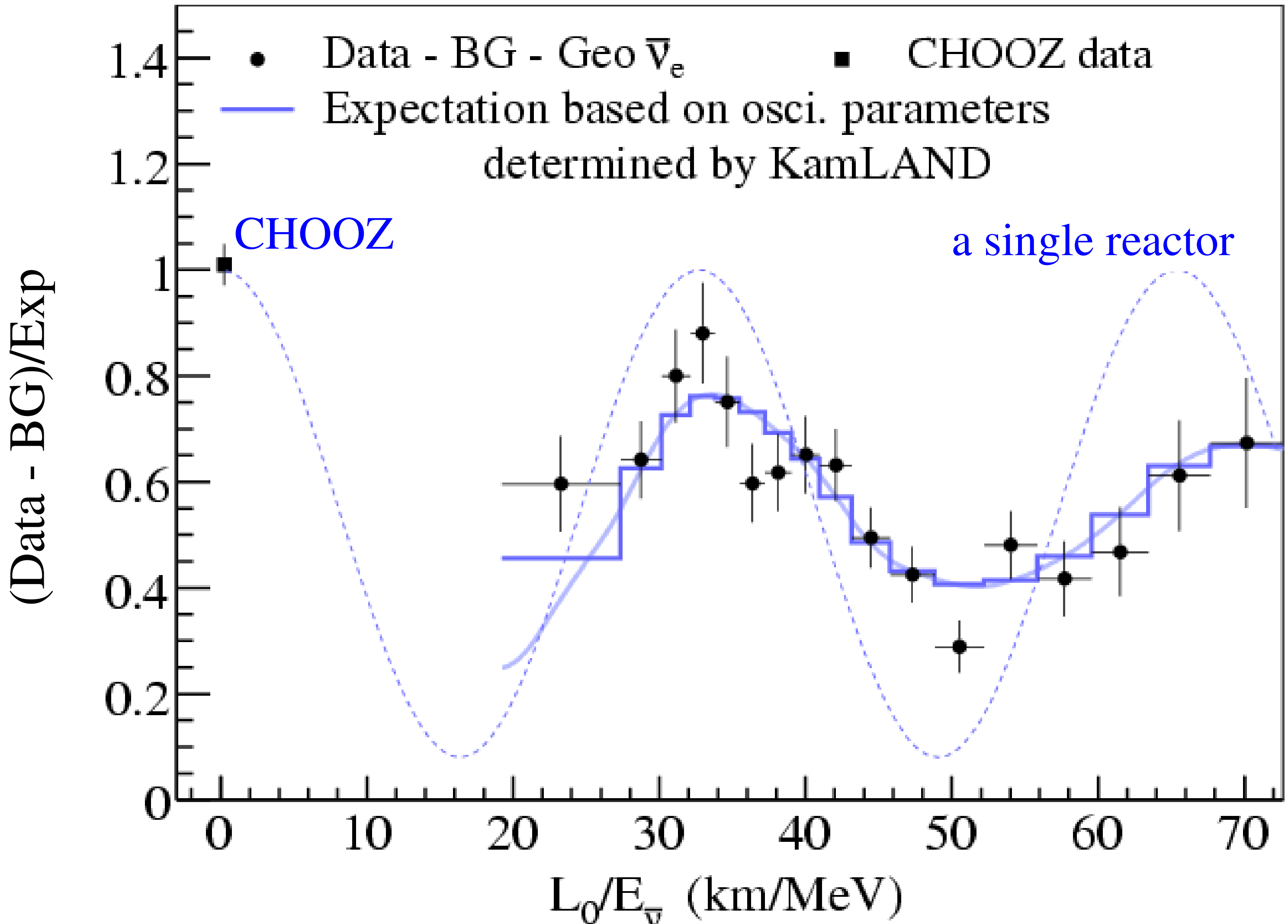
The best fit values:

$\Delta m_{21}^2 = 7.58 \times 10^{-5}(eV^2)$

$\tan^2\theta_{12} = 0.56$

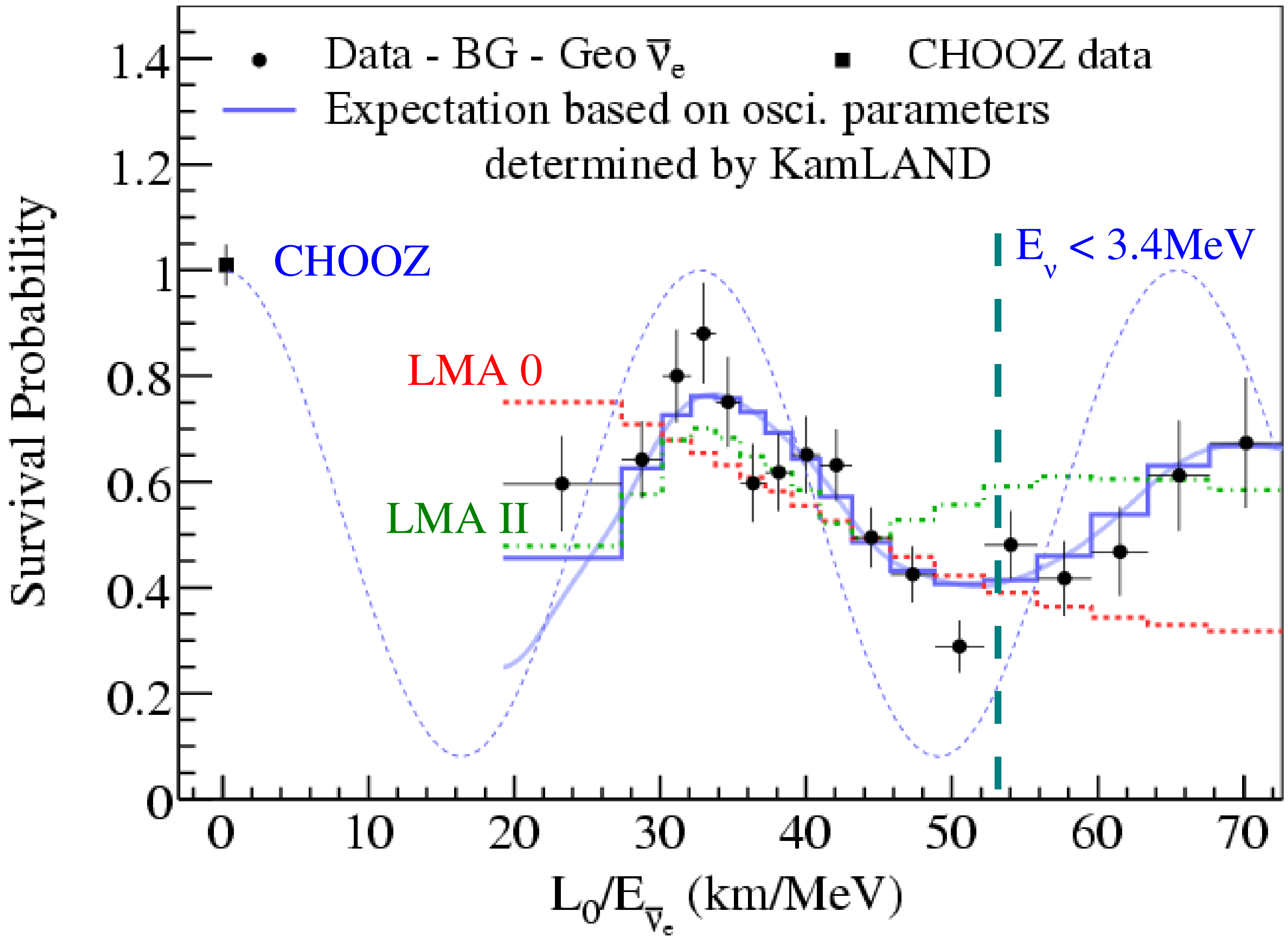
Data taken between March 9, 2002 and May12, 2007, the 2.44×10^{32} proton-year exposure was used. This is the KamLAND only result (using $\theta_{13} = 0$ and taking into account reactor flux time variation). Scaled reactor spectrum (no oscillations included) was excluded at the 5.1σ level.

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



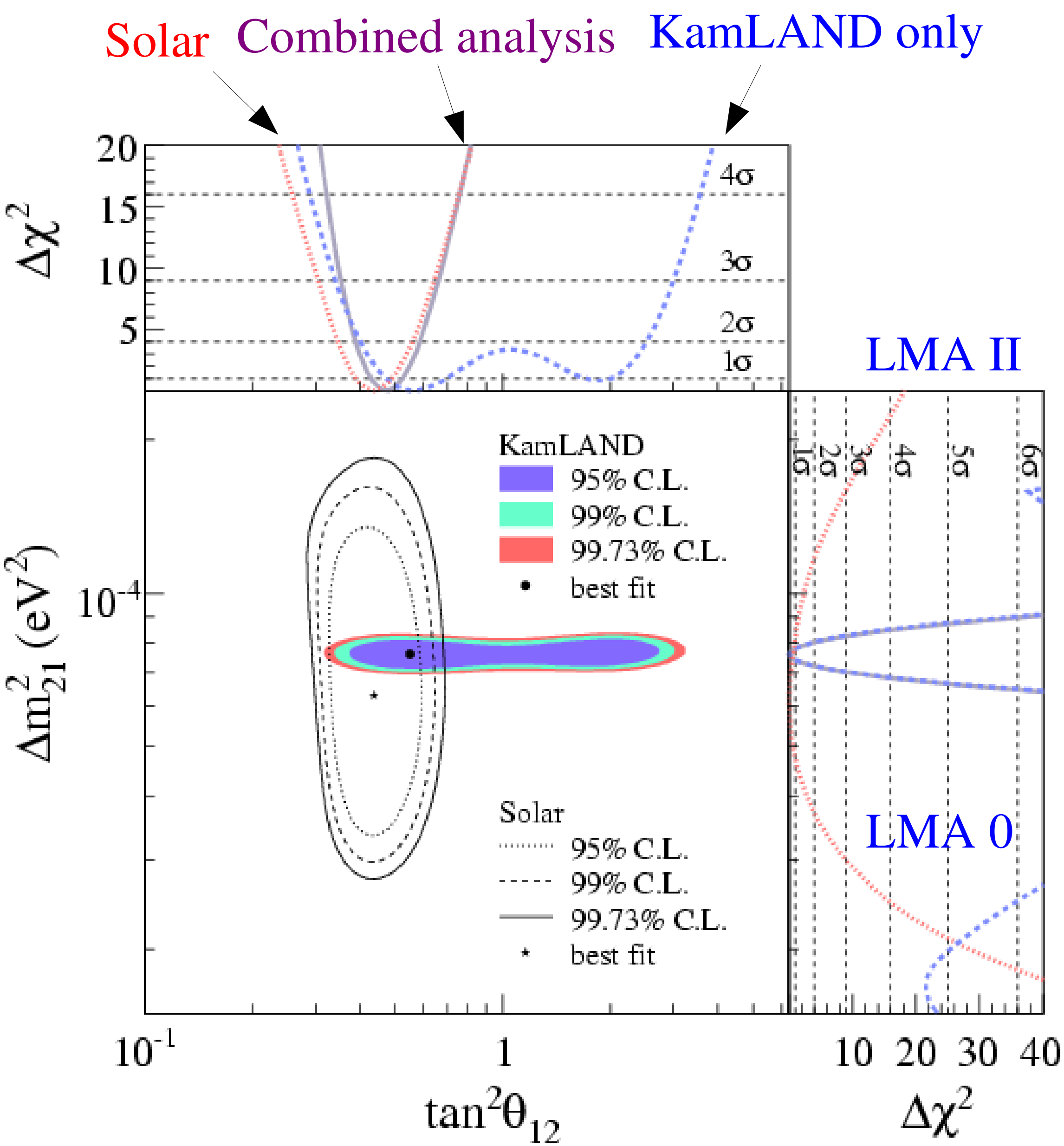
The KamLAND and CHOOZ data plotted as (Data - BG)/Exp, where Data is number of observed events, Exp is number of expected events in no oscillation case, BG is number of expected background events including geo-neutrinos. L_0 is flux weighted average distance to reactors.

The L_0/E_ν oscillation plot: LMA vs data



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

KamLAND + Solar oscillation analysis



KamLAND only:

$\Delta m^2 = 7.58^{+0.14}_{-0.13}(st) \pm 0.15(syst) \times 10^{-5}\ (eV^2)$

$\tan^2\theta = 0.56^{+0.10}_{-0.07}(st)^{+0.1}_{-0.06}(syst)$

KamLAND+solar:

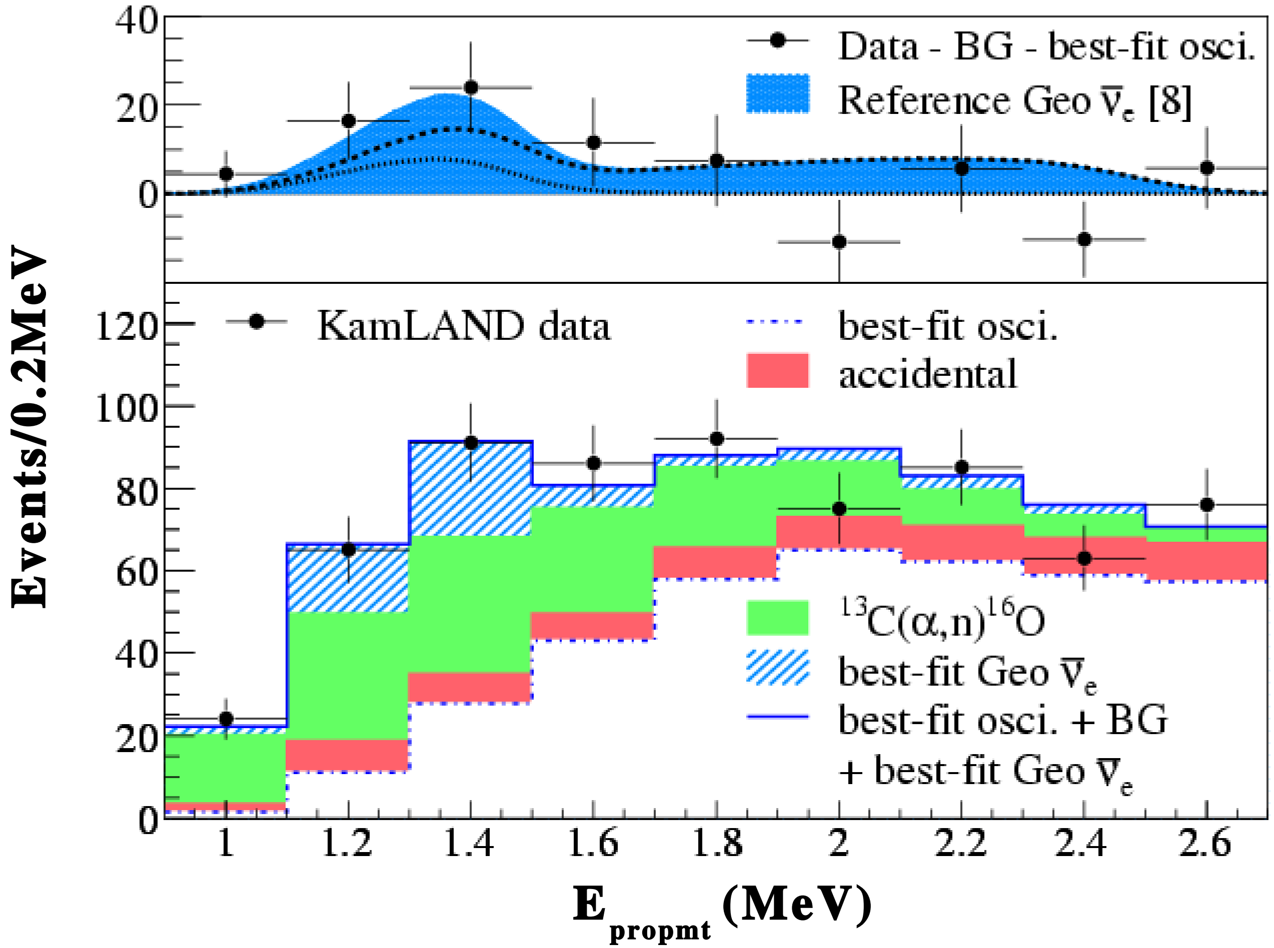
$\Delta m^2 = 7.59 \pm 0.21 \times 10^{-5} (eV^2)$

$\tan^2\theta = 0.47^{+0.06}_{-0.05}$

Only the LMA I solution remains

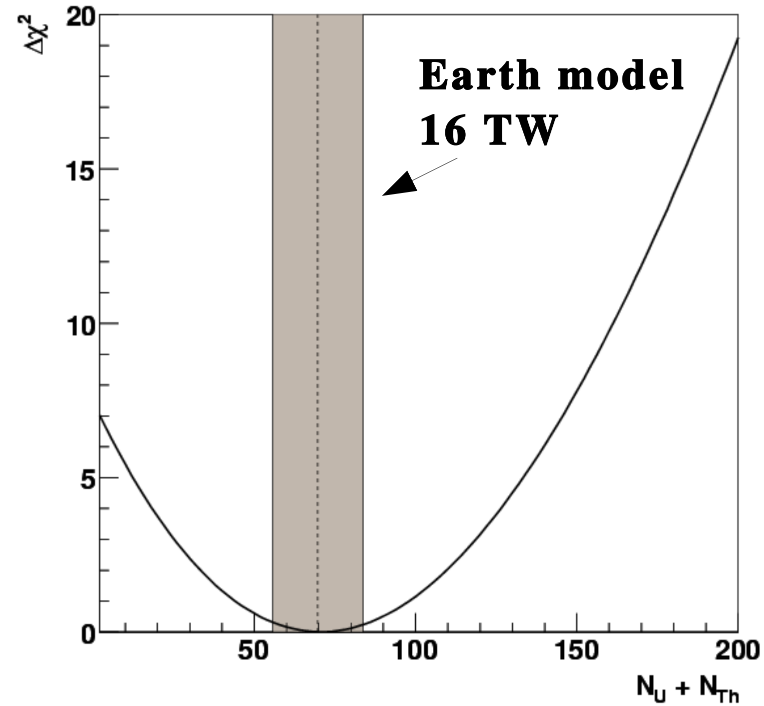
KamLAND improved result for mixing angle and Δm^2. Solar data have no effect on the Δm^2 measurement.

The second geo-neutrino result



Rate + Shape + Time analysis results

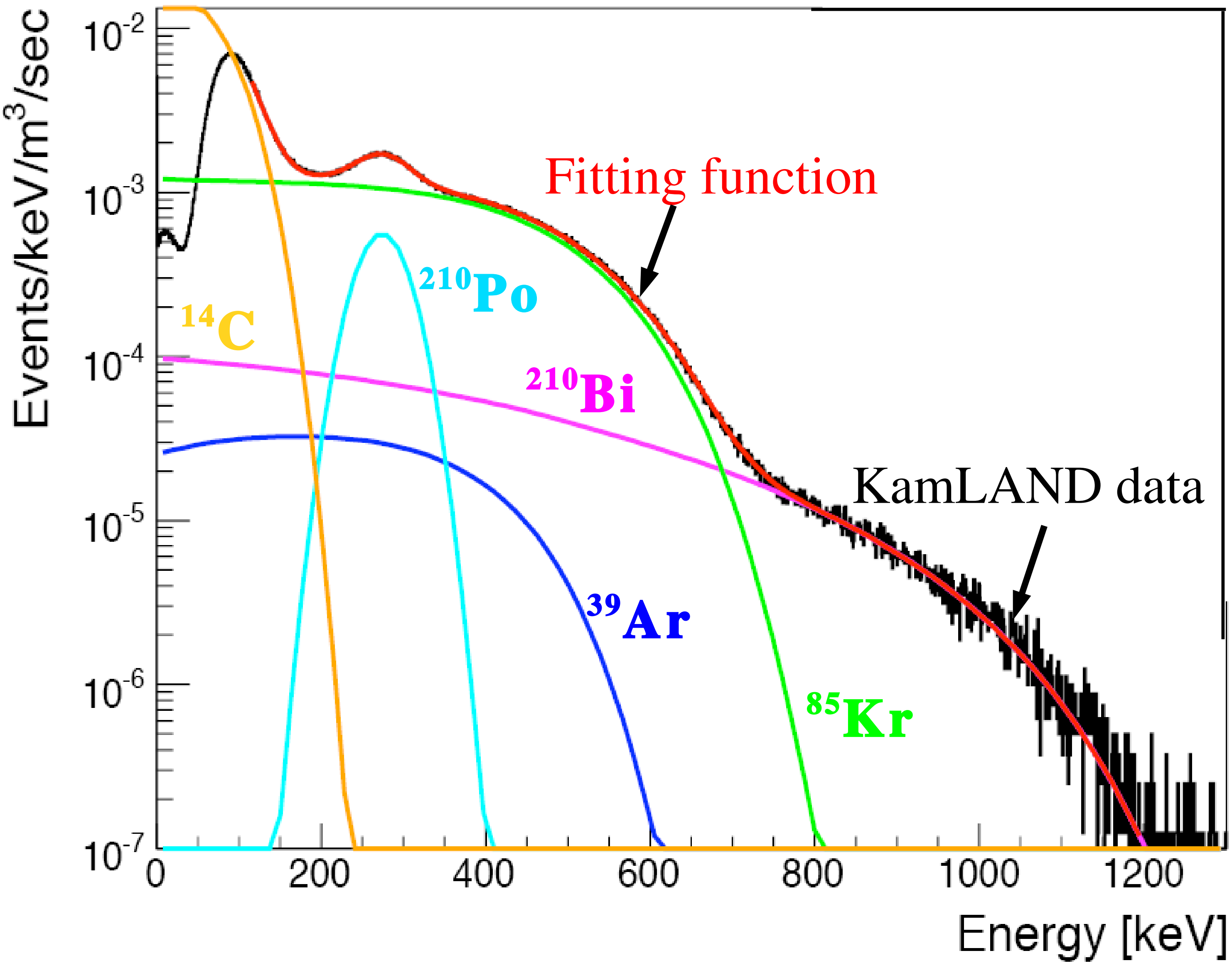
with SNO oscillation constraint



The Th/U mass ratio was fixed at 3.9. Number of geo-neutrinos, **73 ± 27**, corresponds to flux (4.4 ±1.6) x 10^6 (cm^{-2} s^{-1}). This result is consistent with the reference Earth model which predicts flux 2.24 x 10^6 (cm^{-2} s^{-1}) for **U** (56.6 events) and 1.9 x 10^6 (cm^{-2} s^{-1}) for **Th** (13.1 events) assuming **16 TW** for a radiogenic heat production.

Reference Earth model: S. Enomoto *et al*, Earth Planet Sci Lett. **258**,147 (2007)

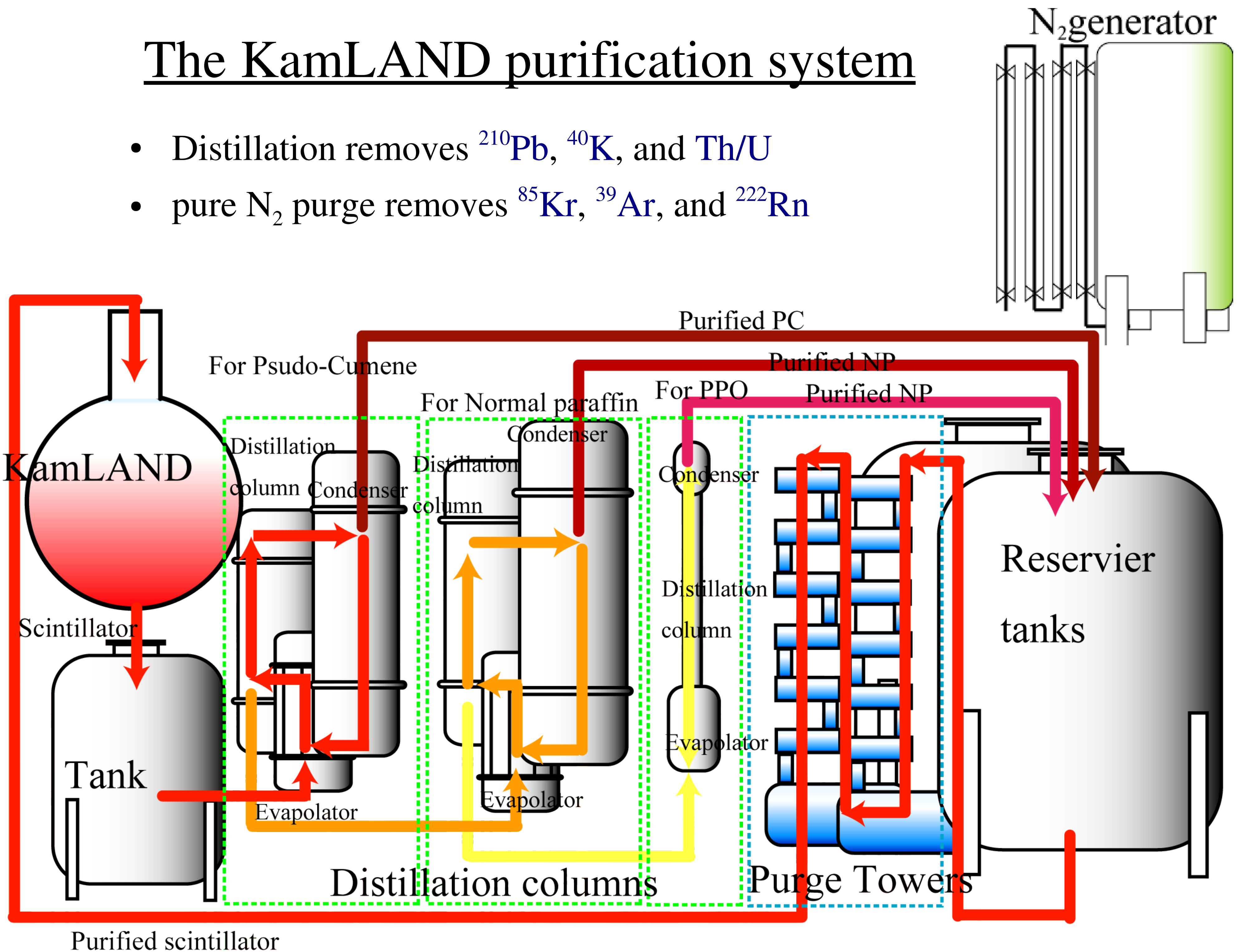
Solar neutrino background before start of distillation



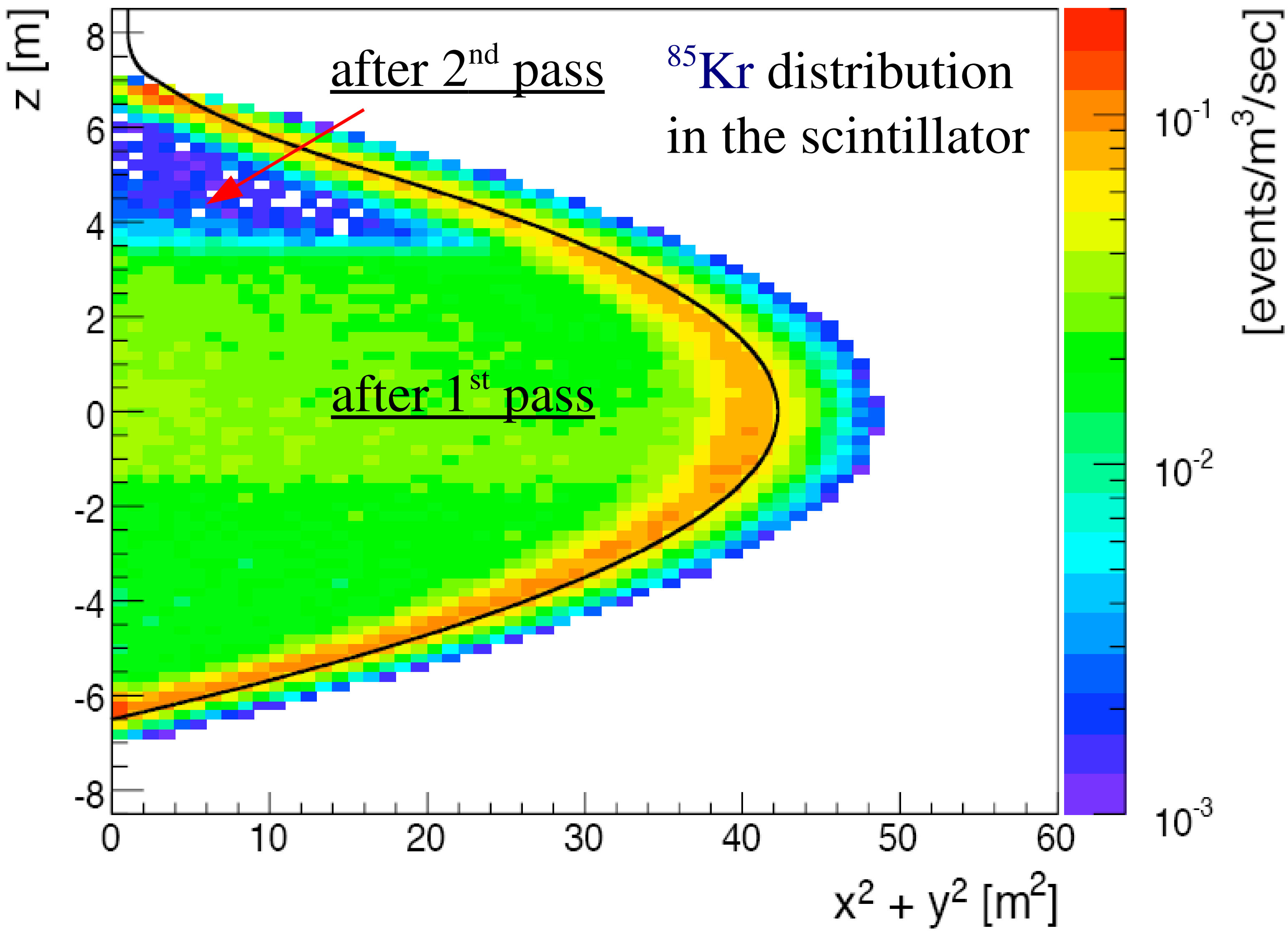
Observation of low energy solar neutrinos required removal of ^{85}Kr and ^{222}Rn decay products: ^{210}Pb → ^{210}Bi → ^{210}Po

The KamLAND purification system

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

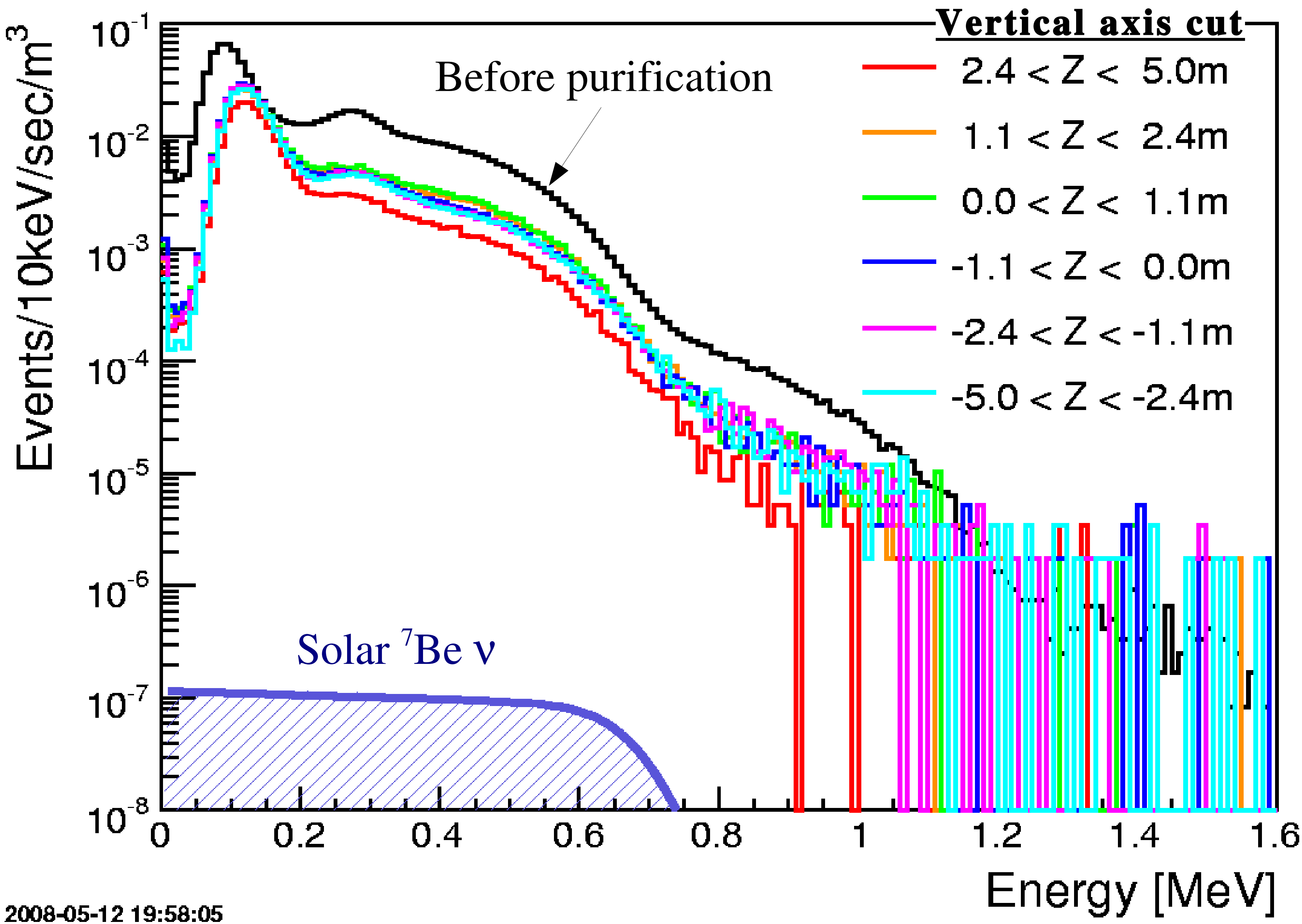


KamLAND after 1st purification campaign in 2007

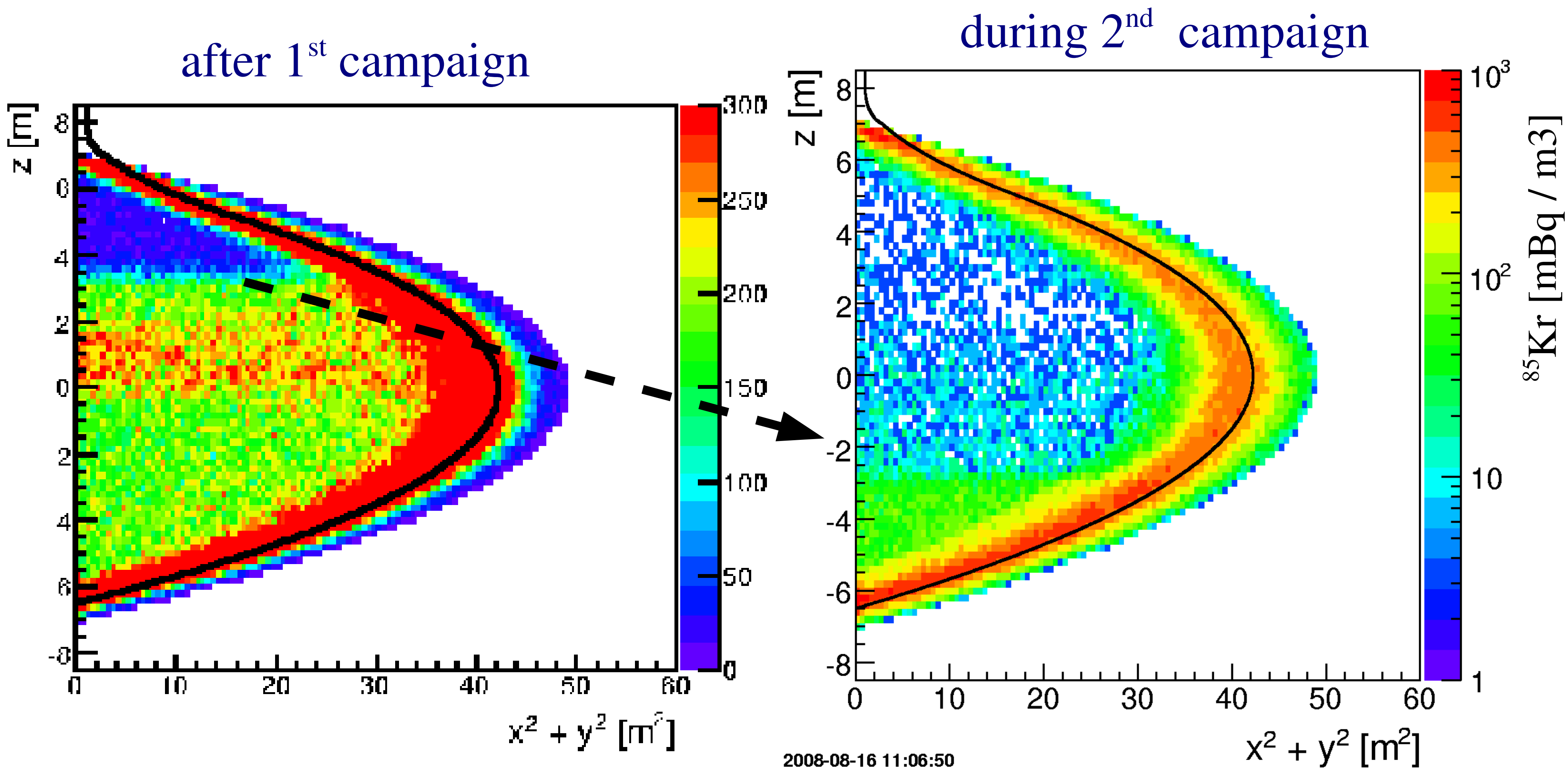


About 1700m^3 of the KamLAND scintillator were purified in 2007. Due to mixing between purified and non-purified scintillator purity level needed for the ^{7}Be ν observation was not reached.

The low energy event spectrum after 1st campaign

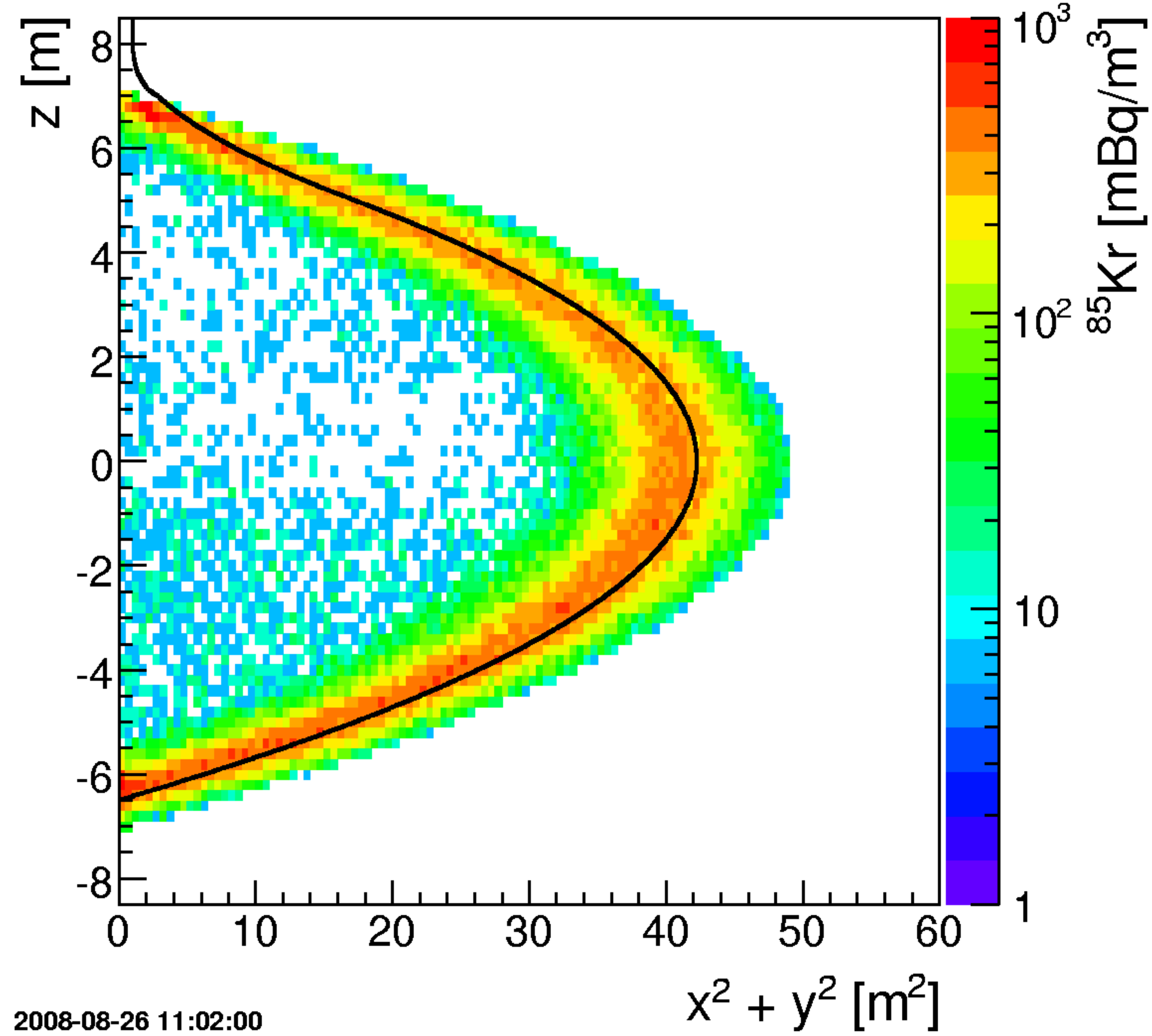


New purification campaign started in May 2008



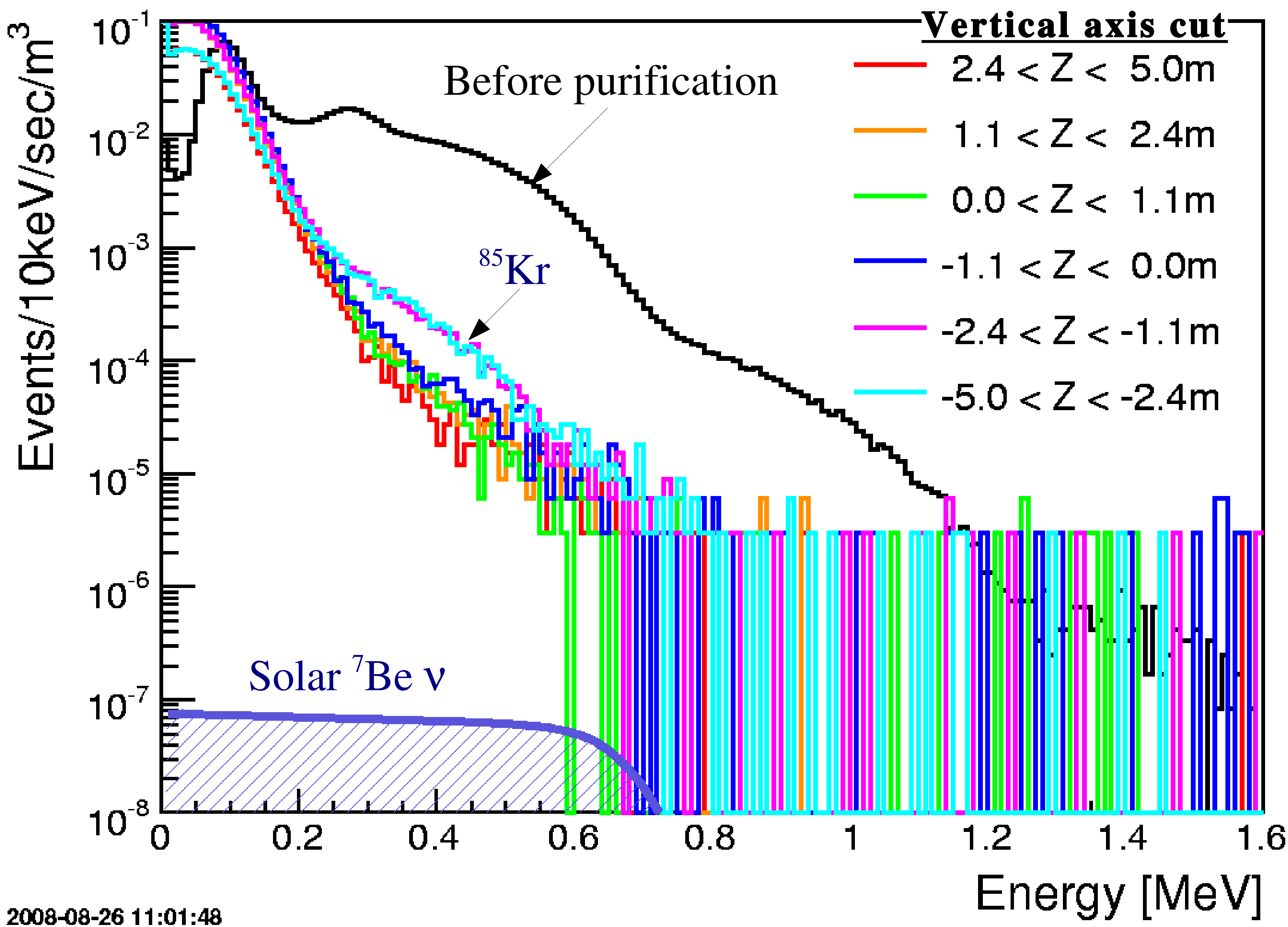
The boundary between the more purified and less purified scintillator which remained since August of 2007 was gradually pushed down by newly purified scintillator which was filled from the top while less purified scintillator was taken from the bottom of KamLAND. Purified scintillator quality control includes: light yield, transparency, density, PPO concentration, ^{85}Kr and ^{222}Rn level measurements.

Distribution of ^{85}Kr events in scintillator (Aug 2008)

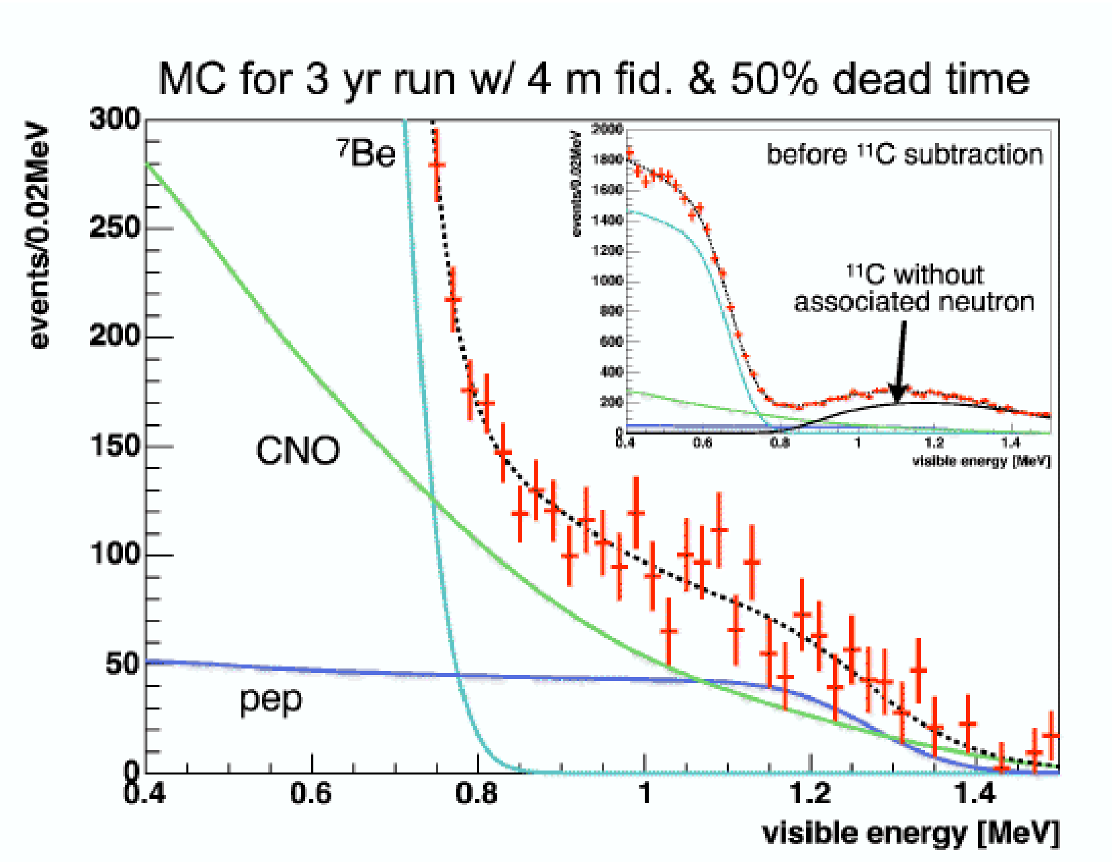


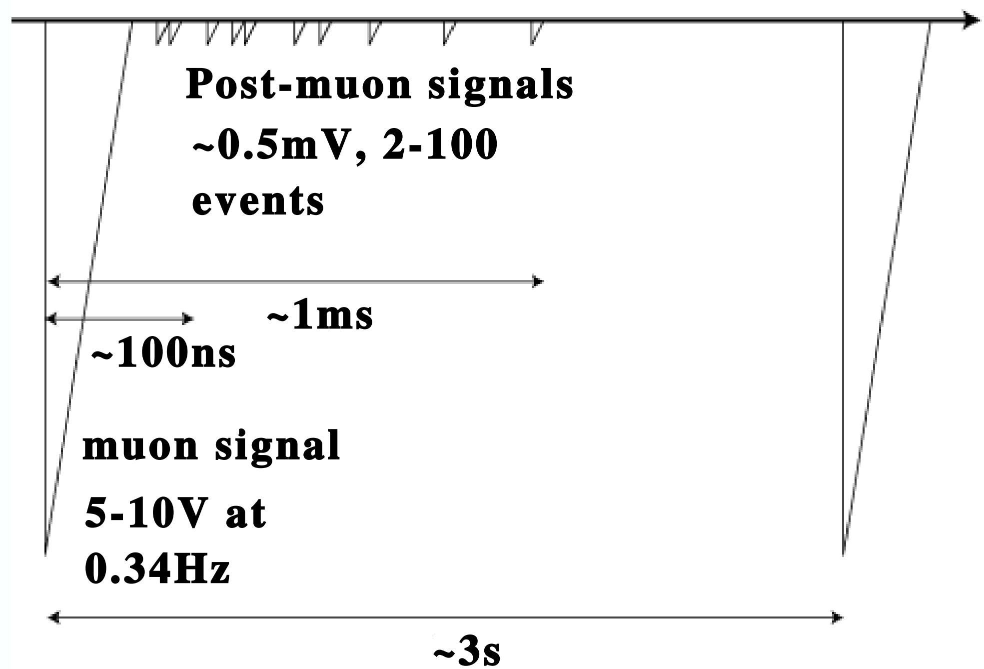
More than a full detector volume (~1300m^3) was circulated already this year. Typical scintillator flow is ~0.88 ton/hour.

The low energy event spectrum (Aug 2008)



The pep and CNO solar neutrino detection

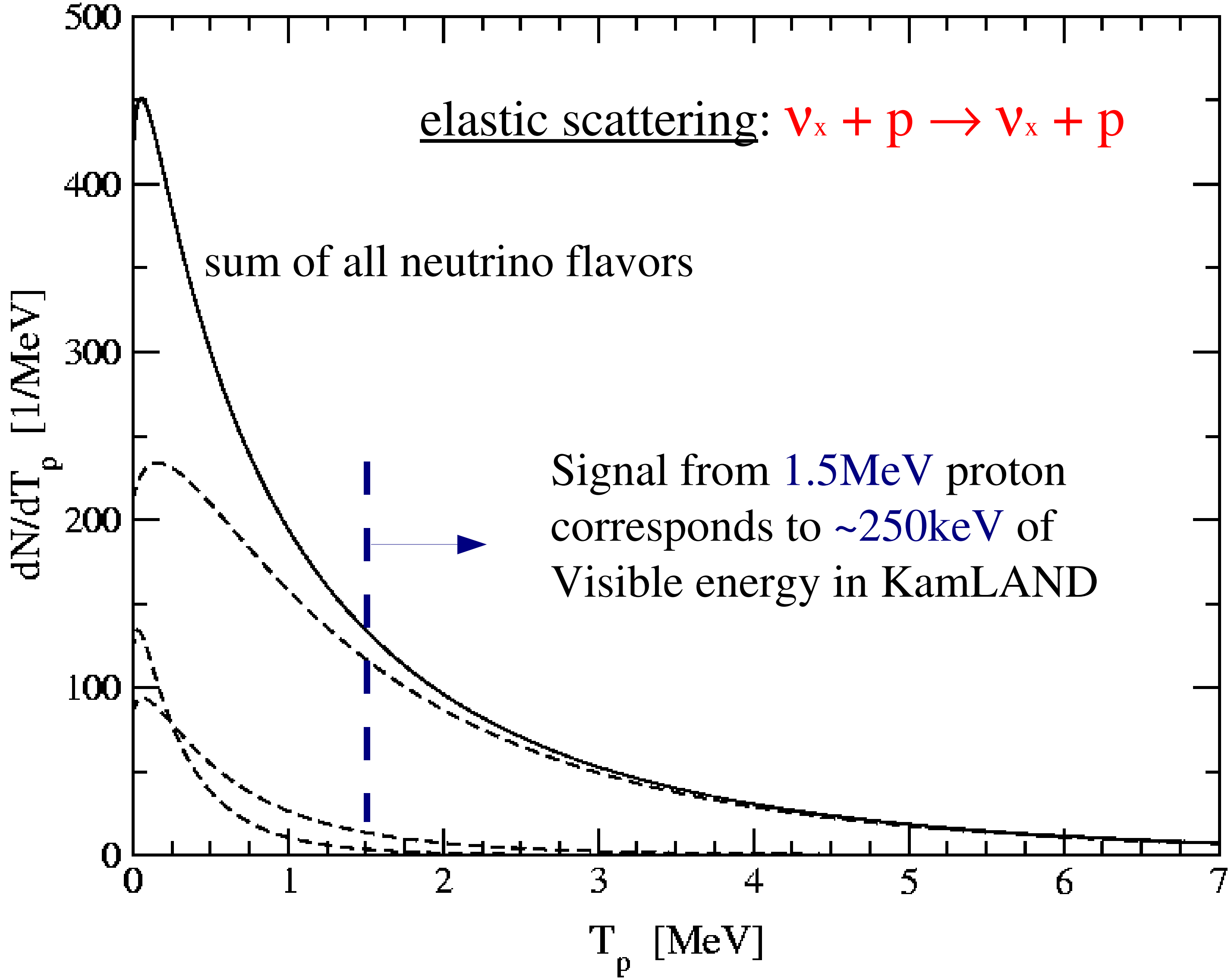




95% of the ^{11}C nuclei are produced in $^{12}C+\mu\rightarrow{}^{11}C+n$ reaction. Detection of the neutron after muon should allow to veto a small part of the detector volume until ^{11}C decays and reduce background for measurement of the pep and CNO solar neutrinos. Technique was successfully tested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

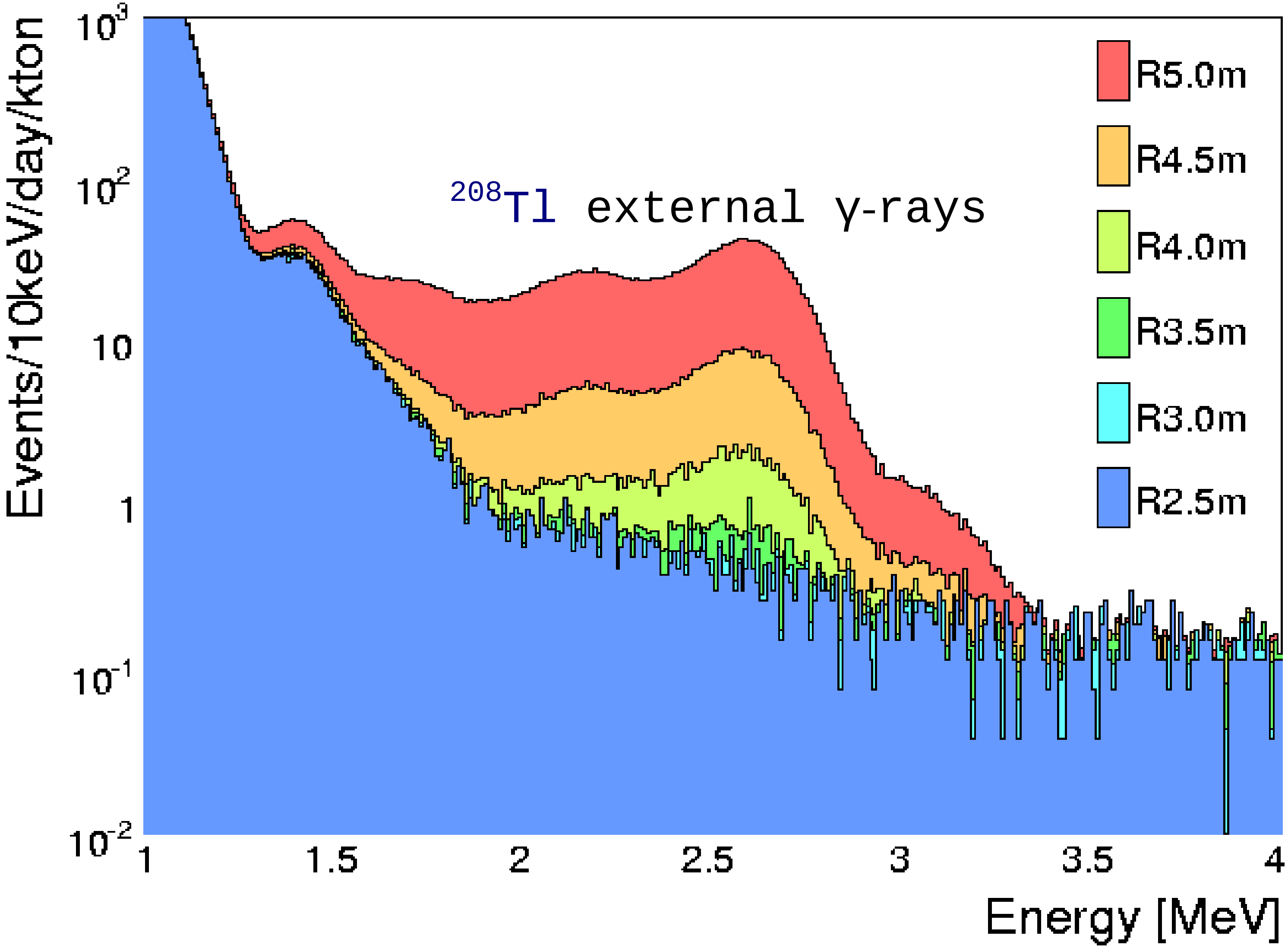
A new deadtime-free data acquisition electronics was developed for the solar pep/CNO neutrino observation with KamLAND. It aims to detect all neutrons produced by muons. The number of neutrons after a muon can reach 60~100, and therefore capability of collecting multiple signals is crucial.

New channel for the SN neutrino detection



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.

KamLAND as 0νββ detector



The central region of KamLAND provides a very clean environment free from the external γ-ray background. It can be used to accommodate a large scale ^{136}Xe 0ββν experiment which we think will become the next step in the KamLAND development. At first, we plan to load 200kg of ^{136}Xe right after the solar neutrino phase completion.

Summary

- The "reactor-ν" phase was successfully completed with 4.1 years of the detector livetime. The new PRL paper was published.
- KamLAND measured $\Delta m^2 = 7.59 \pm 0.21\times10^{-5}(eV^2)$, and improved precision of the measurement of θ_{12}
- The 2nd purification campaign was started in May. More than $1300m^3$ of scintillator were already purified this year. Distillation will continue most likely with reversed scintillator flux when a cold and more dense scintillator is filled from the bottom.
- New physics opportunities after the end of purification: ^{7}Be, CNO+*pep* solar neutrinos, geo-ν measurement without the (α, n) background, the SN neutrinos detection via the proton recoil.
- After the solar neutrino phase search for the neutrinoless double β-decay using ^{136}Xe will be started in stages.