Neutron disappearance in KamLAND

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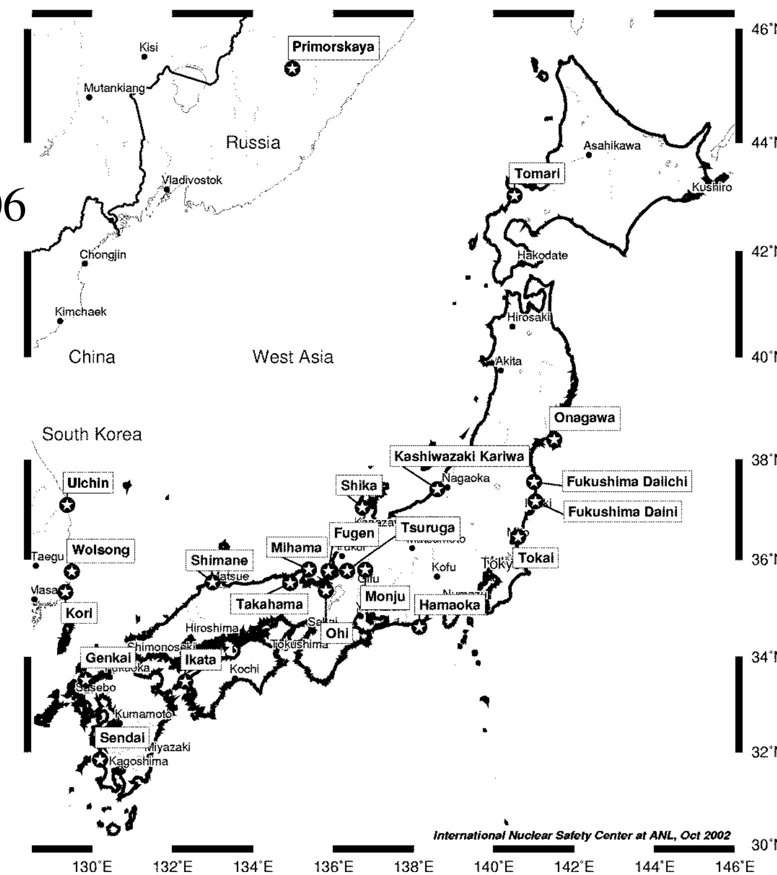


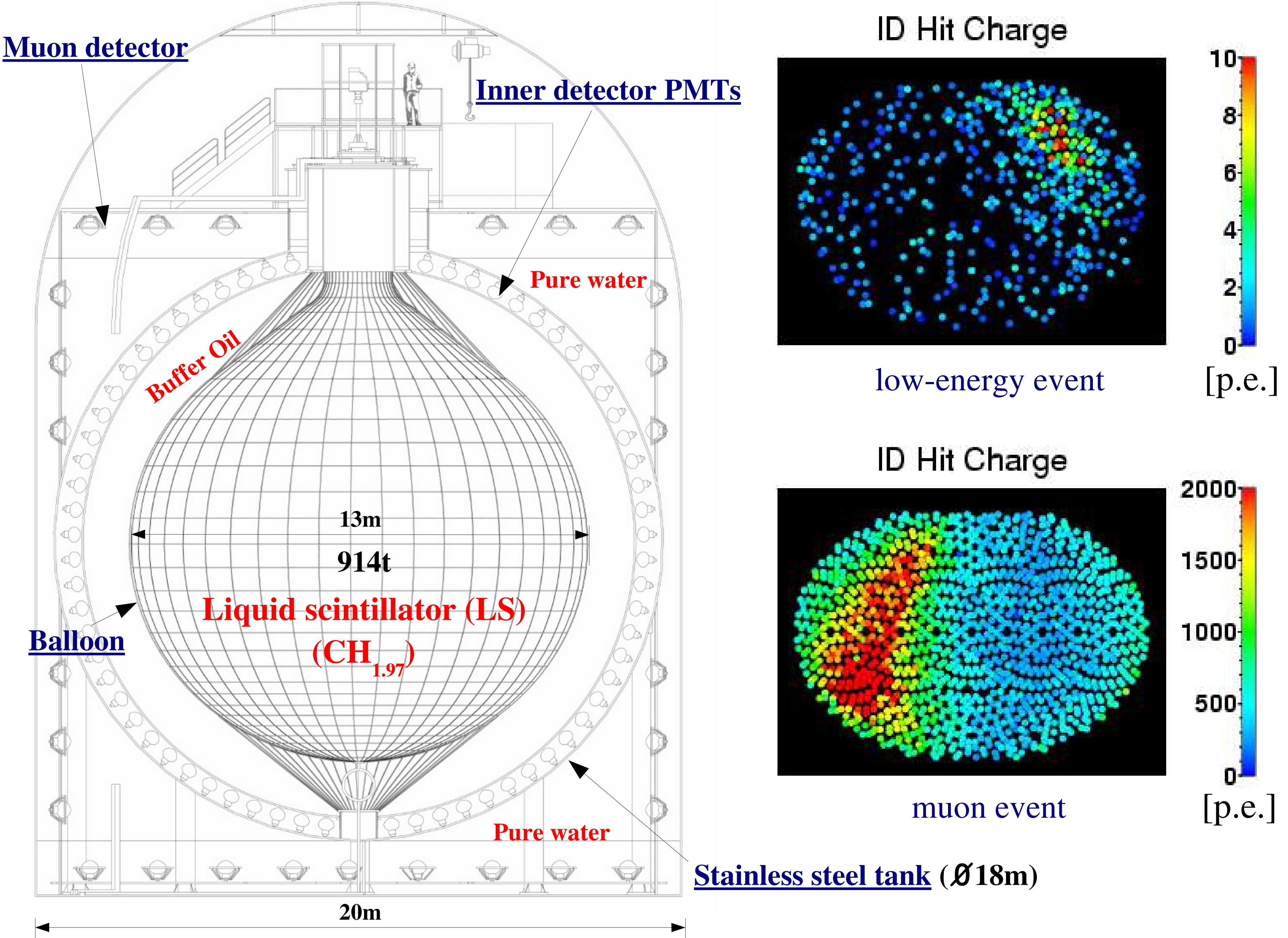
$\tau(n \to inv) > 5.8 \times 10^{29}$ years

$\tau(nn \to inv) > 1.4 \times 10^{30}$ years

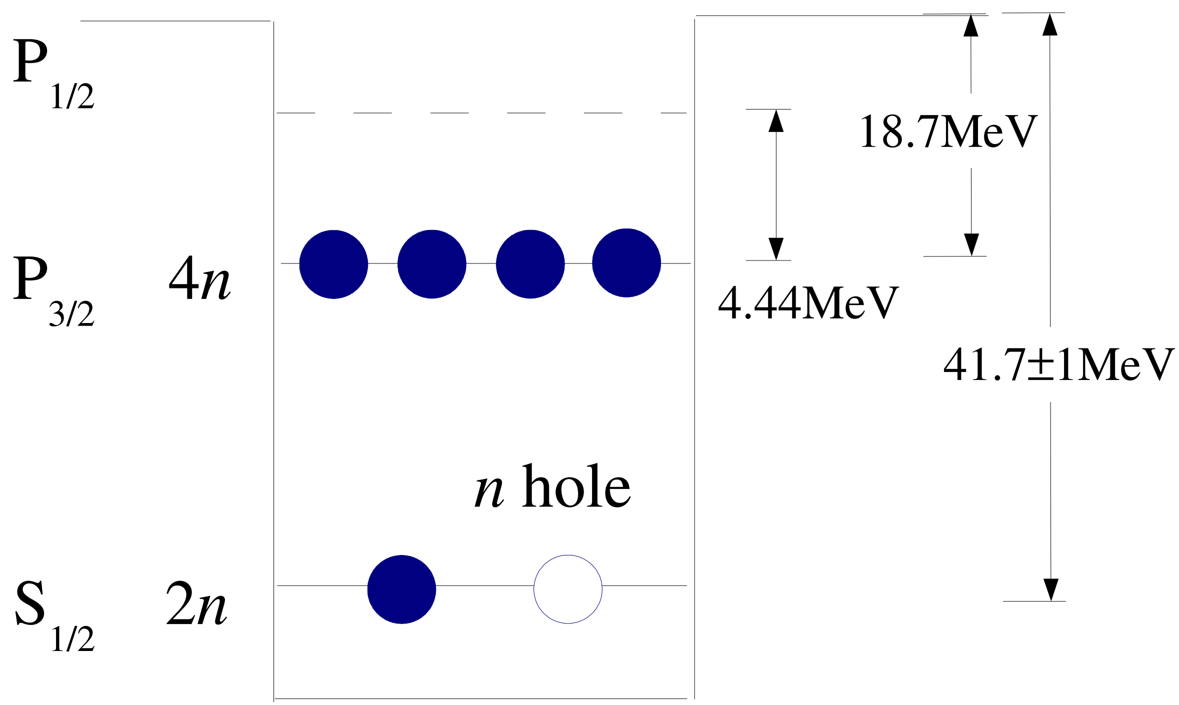
(90% C.L.)

Search for Baryon and Lepton Number Violations, International Workshop

September 20-22, 2007 at LBL, Berkley


Muon detector
Inner detector PMTs
Pure water
Buffer Oil
13m
914t
Liquid scintillator (LS)
(CH1.97)
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.]

Neutron disappearance/decay in the ^{12}C nuclei



A bound neutron disappearance (e.g. decay into `invisible' products such as ν's) from the inner s-shell of the ^{12}C nucleus leaves the daughter nuclear system in a highly excited state. In the process of de-excitation of the daughter energetic particles (n, p, α, γ) are emitted. Some de-excitation modes can be observed in KamLAND with a very little background.

Signatures of nucleon disappearance in large underground detectors
Phys. Rev. D **67**, 076007 (2003) by Yuri Kamyshkov, Edwin Kolbe

The daughter ($^{11}C^*$ or $^{10}C^*$) de-excitation modes

Decay products	Residual radioactive nucleus	De-excitation branching ratio per s-shell n, %	# of correlated events
n	^{10}C (β^+; $T_{1/2}$ = 19.3s)	3.0	3
n + γ	^{10}C (β^+; $T_{1/2}$ = 19.3s)	2.8	3
n	^{9}C (β^+; $T_{1/2}$ = 127ms)	6.2	3
n + p	^{8}B (β^+; $T_{1/2}$ = 770ms)	6.0	3

De-excitation of $^{11}C^*$ or $^{10}C^*$ formed as the result of a single (two) neutron disappearance in ^{12}C may produce a sequence of three space-and-time correlated events in KamLAND:

example:
($n \rightarrow inv$)

1st event + 2nd event + 3rd event

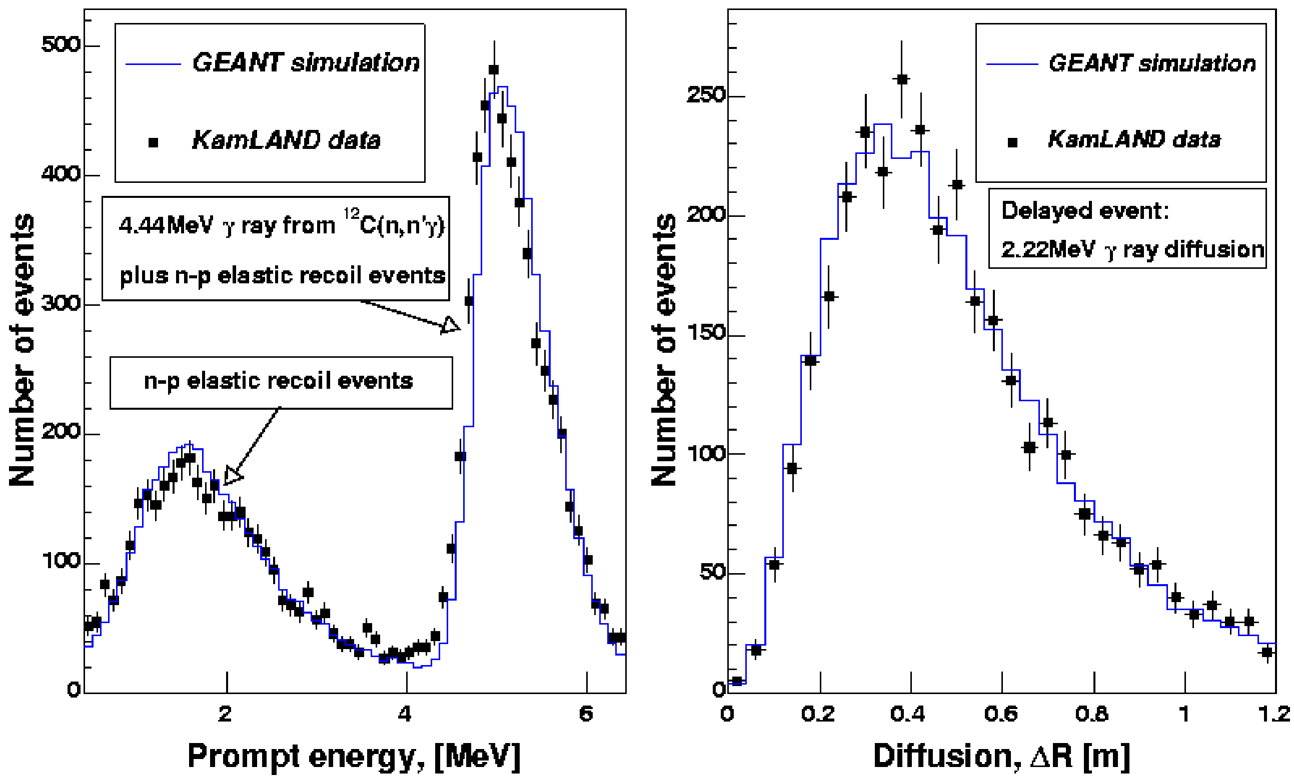
~100ns | **0.5-1000μs** | **3ms-70s**

emitted neutron scatters elastically on protons

neutron capture on p
$n + p \rightarrow d + \gamma$ (2.2MeV)

$^{10}C \rightarrow \beta^+ + {}^{10}B + \gamma$

A neutron signal in the KamLAND scintillator

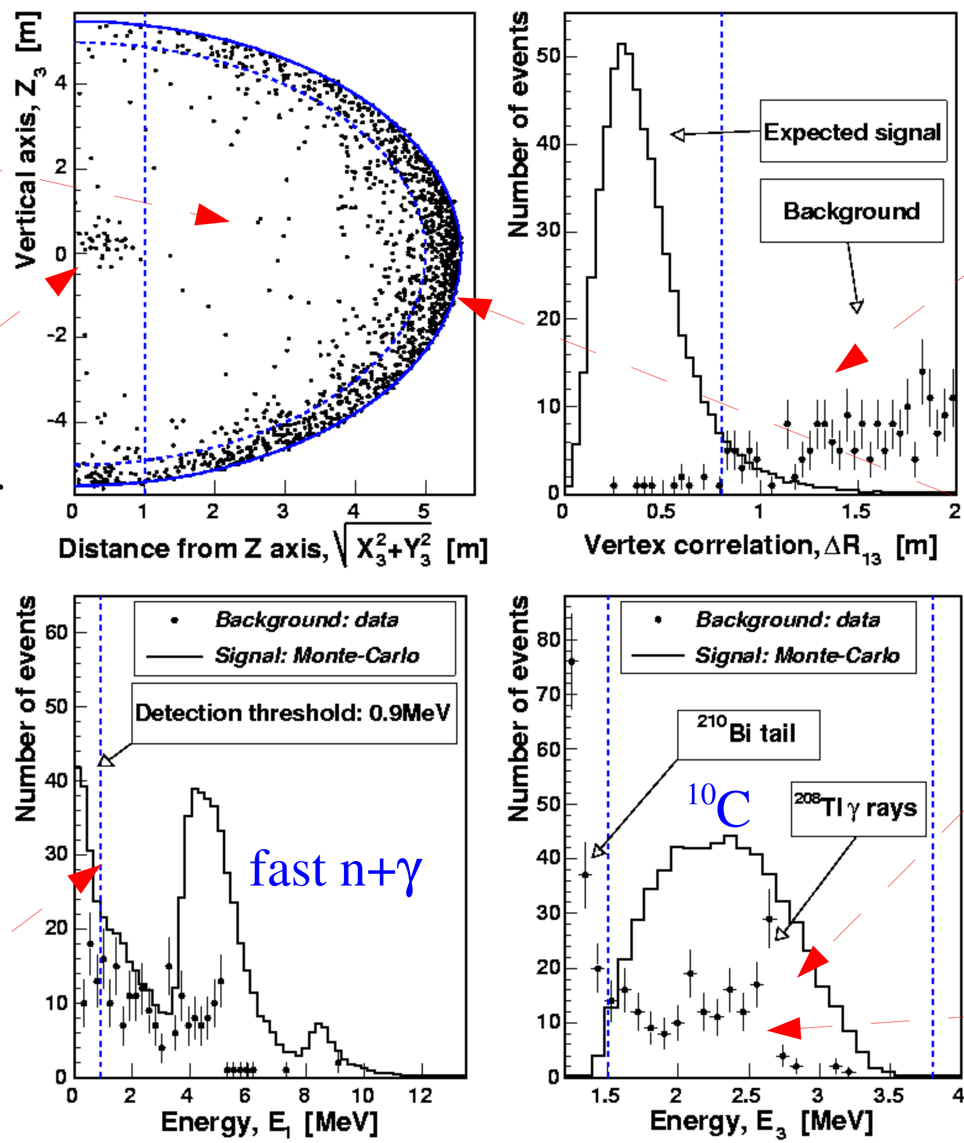


Although response of the KamLAND LS to γ-rays was well understood, energy scale for neutrons was not yet calibrated. Instead, we used the ^{241}Am-^{9}Be neutron source data for optimization of Birks coefficients used in GEANT simulations. Then the GEANT Monte-Carlo program tuned to the Am-Be and other calibration data was used to calculate the detection efficiency of three correlated events for certain selection criteria.

Signal and background for the n disappearance in KamLAND

the 5m radius fiducial volume

background events from a thermometer



A tight space correlation between **1**st and **3**rd events allows to reduce the accidental background.

The 2.6MeV ^{208}Tl γ-rays from surrounding rocks and the PMTs glass is the major background.

blue dashed lines show software cuts

KamLAND events are shown for a relaxed cut: $\Delta R_{13} < 2$m

Background : correlated pairs from the $\bar{\nu}_e + p \rightarrow e^+ + n$ *plus* **accidentals** as the **3**rd event

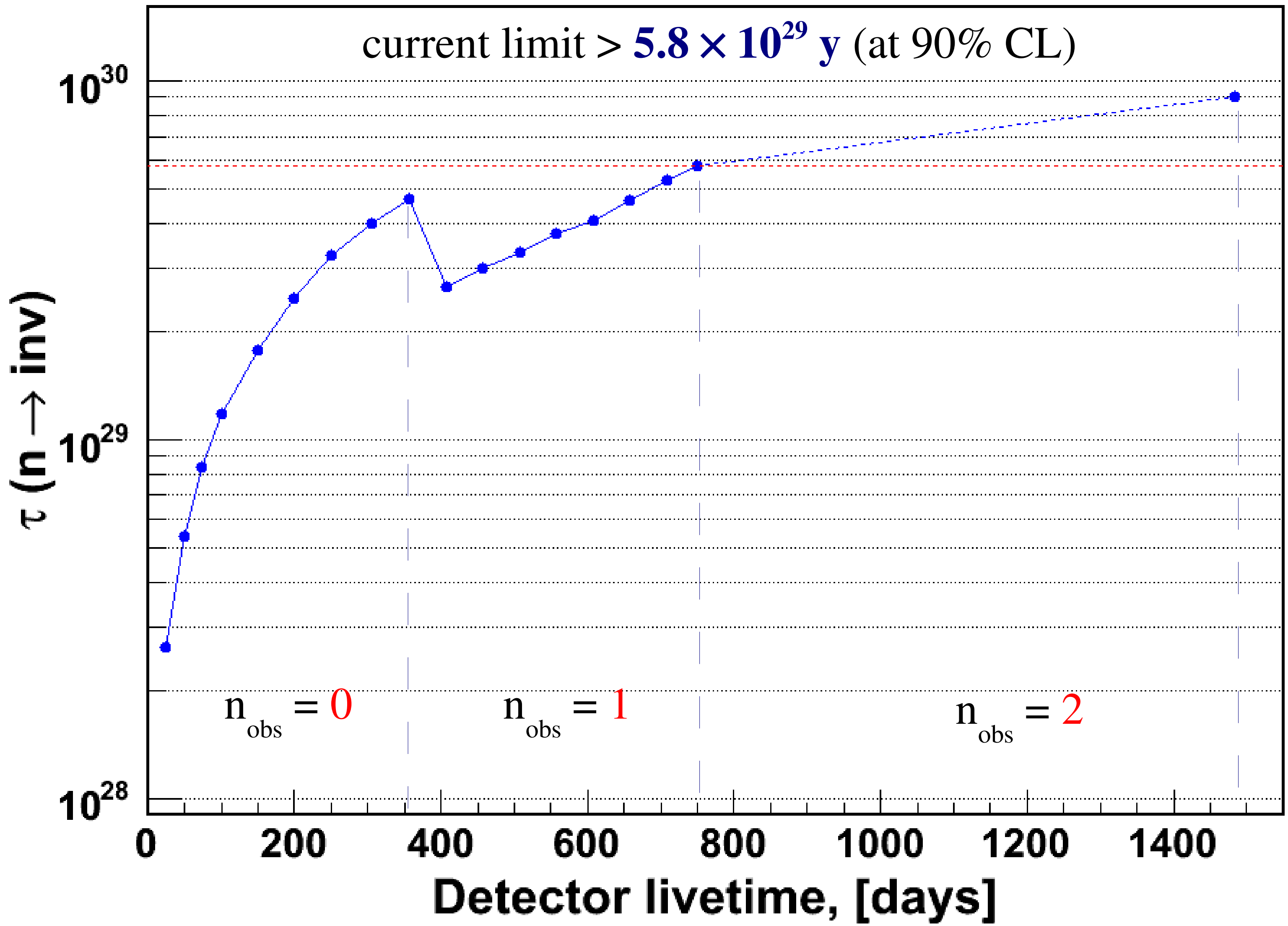
Results of the search for n→inv events in KamLAND

The KamLAND data analyzed, (ton · years):	838
The detector **live-time**, T (days):	749.8
Number of **observed candidate** events:	1
Number of **expected background** events:	0.82 ± 0.26
Number of **s-shell neutrons in ^{12}C nuclei**, N_0:	3.48×10^{31}
The largest number of events compatible with observation at 90% CL using Feldman-Cousins procedure, x_{lim}:	3.53
After taking into account uncertainties, x_{lim}:	3.82
Branching, Br / **efficiency**, ε:	0.03 / 0.430; 0.028 / 0.651

$$\tau\,(n \to inv) > (N_0 \cdot T) / x_{lim} \cdot \sum \varepsilon \cdot Br = 5.8 \times 10^{29} \text{ years}$$

The effect of the uncertainty in the theoretical branching ratio (**30%**) and uncertainty of the number of expected background events is calculated using the program POLE: J. Conrad *et al.* , Phys. Rev. D **67**, 012002 (2003)

The $\tau(n \rightarrow inv)$ limit vs the observation time

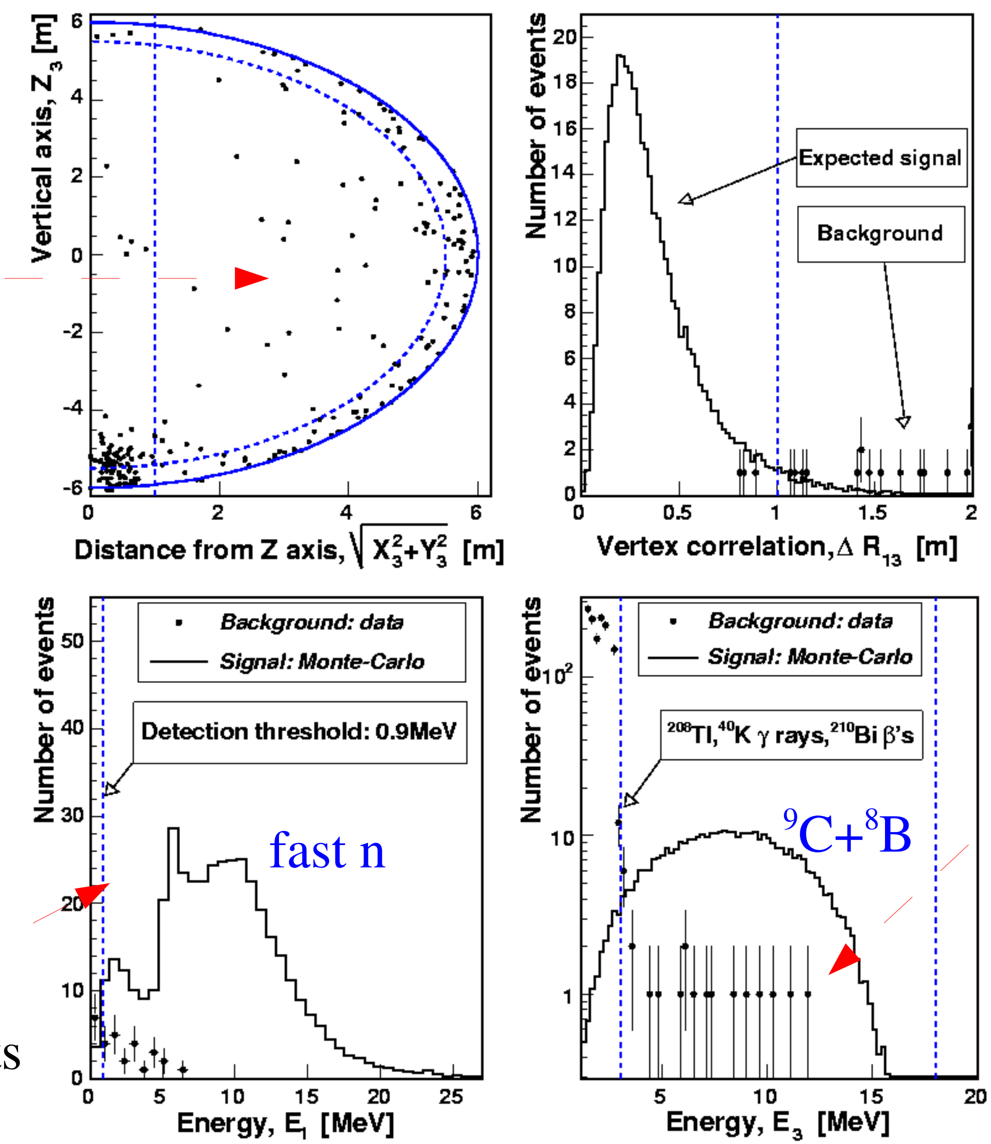


The reactor phase live-time is ~1500 days. If the number of observed events (n_{obs}) will be 2 (instead of 1 in the published data set), expected $\tau(n \rightarrow inv) > \mathbf{9 \times 10^{29}}$ **y** (at 90% CL)

Signal and background for the nn disappearance in KamLAND

the 5.5m radius fiducial volume

blue dashed lines show software cuts



The **3rd** event energy cut excludes 2.6MeV γ's from ^{208}Tl decays. This drastically reduces the number of accidentals.

Remaining events are mainly due to radioactive nuclei produced in $\mu + ^{12}C$ interaction, and higher energy external γ-rays.

KamLAND events are shown for a relaxed cut: $\Delta R_{13} < 2$m

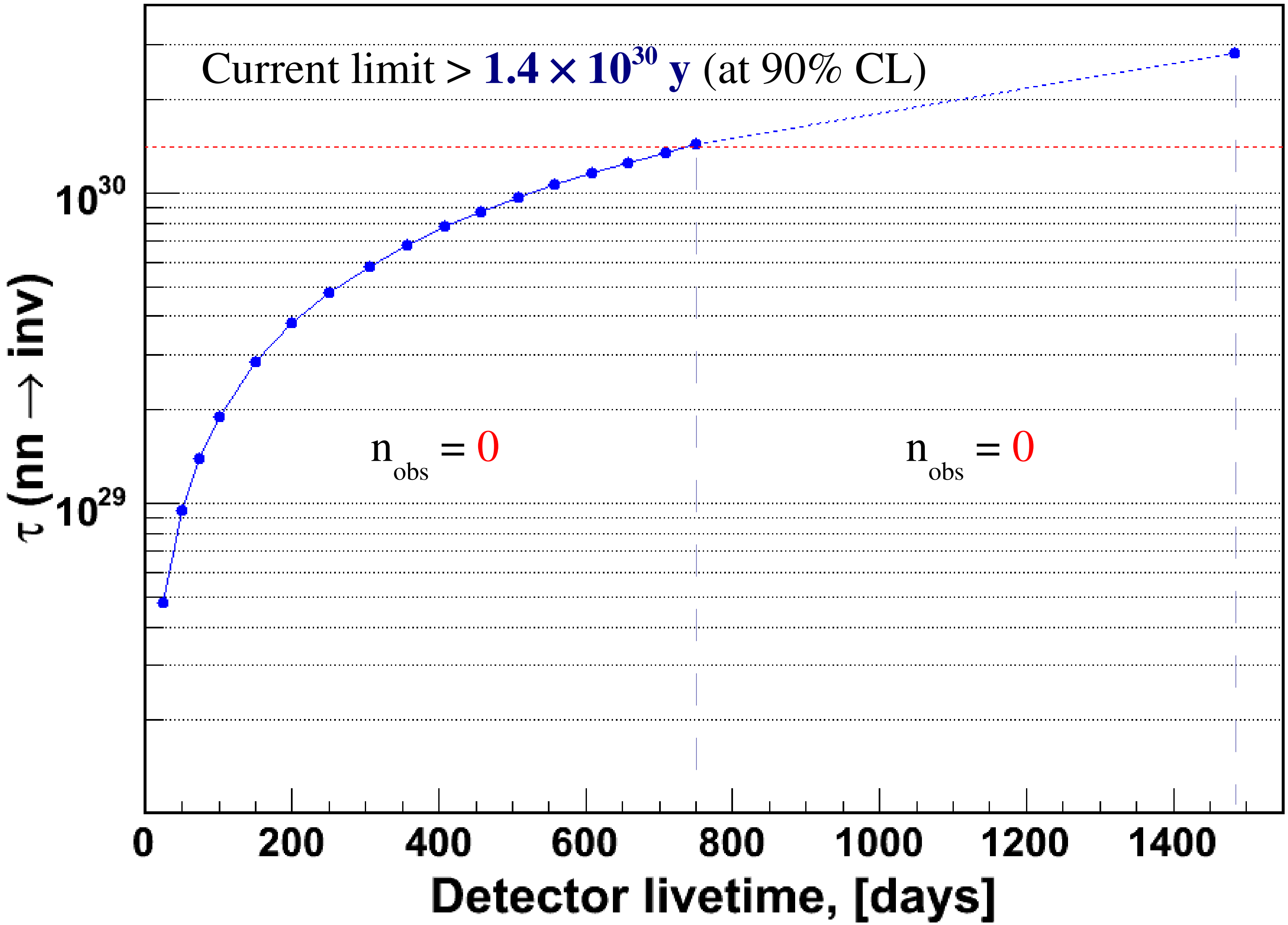
Results of the search for nn→inv events in KamLAND

The KamLAND data analyzed, (ton · years):	1119
The detector **live-time**, T (days):	751.4
Number of **observed candidate** events:	0
Number of **expected background** events:	0.018 ± 0.010
Number of **s-shell neutrons in ^{12}C nuclei**, N_0:	4.63×10^{31}
The largest number of events compatible with observation at 90% CL using Feldman-Cousins procedure, x_{lim}:	2.41
After taking into account uncertainties, x_{lim}:	2.75
Branching, Br / **efficiency**, ε:	0.062 / 0.680; 0.060 / 0.678

$$\tau\,(nn \rightarrow inv) > (N_0 \cdot T) / x_{lim} \cdot \sum \varepsilon \cdot Br = 1.4 \times 10^{30} \text{ years}$$

The effect of the uncertainty in the branching ratio (**30%**) and uncertainty for the number of expected background events is calculated using the program POLE: J. Conrad *et al.* , Phys. Rev. D **67**, 012002 (2003)

The $\tau(nn \to inv)$ limit vs the observation time



A very low background should allow to improve the published limit to $\mathbf{2.8 \times 10^{30}}$ **y** with the final data set from the KamLAND reactor phase (~1500 days).

Summary

- The result of SNO search for de-excitation γ-rays following the neutron disappearance in ^{16}O: $\tau(n \to inv) > 1.9 \times 10^{29}$ y was improved by the KamLAND measurement to $\tau > 5.8 \times 10^{29}$ y (90% C.L.)

- The best previous limit for $\tau(nn \to inv) > 4.9 \times 10^{25}$ y set by the Borexino collaboration (with CTF) was improved to $\tau > 1.4 \times 10^{30}$ y (90% C.L.)

- The current KamLAND result can be improved using already available data by a factor 1.5–2.

- Purification of the KamLAND LS cannot substantially improve conditions for the $n \to inv$ observation since the majority of background events originate from the external γ-rays from the ^{208}Tl β-decay.