KamLAND-Zen

estino double beta of

Zero

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Q=2.458MeV, Natural Abundance=8.9% $T^{2v}_{1/2} = 2.2 \times 10^{21}$ yr (EXO, KL)

Rare Gas:



KamLAND-Zen

Zero neutrino double beta decay search experiment



Water + 225 PMTs

Minor modification of KL => Low cost, Quick start

Mini-balloon (MIB, ~3mφ) Xe (320~380kg, 91%¹³⁶Xe)+ LS (Decane+PC+PPO), 13ton

1000ton Ultra-pure LS PMTs (1325 17"+ 554 20")

- Quick start relatively small cost.
- Detector is well understood.
- Easy Scale up the Xe amount.
- Xe ON-OFF run can be done.
- Other physics done in parallel by KamLAND (Geov, SuperNovae,...).

Zen(禅)=Spiritual practice of Buddhism of deep quiet meditation to find an enlightenment !



KamLAND-Zen Collaboration



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KamLAND-Zen Mini-Balloon (MIB)

Material		Nylo	n film, 25µm	-		
Cleanliness		U,Th 40K	n: O(10 ⁻¹²)g/g, (: O(10 ⁻¹¹)g/g	00	200	
Mechanical strength		~	>10N/cm	1	_ ゴア接続森	/// <u>/</u>
LS compatibility			\bigcirc	-		H.H.
Xe tightness			\bigcirc	1394	R 3718	K A
Light trai	nsparency	> 95	5%@400nm	_		
Xe tightness te	st Tension measurement	Weldi is t	ng method he key !	6.05m	<u>報祖 (N=12)</u>	
Light transmission	Go	Hea F re film	et - Additional film 	1580	<u> 横組 (N = 1)</u> 南韓60度よりも南極に近い位置	
Optimization and control of the temperature and time for the impulse welding 3.0						



R&D of MIB 2009~2011

EVOH, Dec.2009





PE, Feb.2010

Structure, Handling, Deployment, Liquid handling

Inflation







Test in a water pool

25µm Nylon test balloon



Final rehearsal Jan.2011







Construction of MIB

June-july, 2011

Super-Clean room (Class1) in Tohoku University

Rinsing Ny film by purified water using an ultrasonic machine



Welding by hand



leak check with helium & repair



Mini-Balloon in the detector



Phase I started Oct.2011

Deployment (top of the detector)



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Phase-I results



89.5kg 136Xe exposure

Event selection : FV (R<1.35m), μ -on cut (<2ms), Delayed coincidence cut (²¹⁴Bi-Po, reactor v).

A peak in the ROI (2.3-2.7MeV)

^{110m}Ag dominant (β⁻, Q=3.01MeV, τ =360d) ! : Peak position and shape are well reproduced and the decreasing rate is consistent with the half life of ^{110m}Ag. ⁶⁰Co, ²⁰⁸Bi, ⁸⁸Y : not well fitted.



Fukushima-1 reactor accident in 2011 : ¹³⁴Cs/¹³⁷Cs, ^{110m}Ag found in the soil around in our lab. in Tohoku.



Other backgrounds were identified : ²¹⁴Bi, ¹⁰C, ¹³⁶Xe 2v Strong limits are provided ;

- T^{0v}_{1/2} >1.9×10²⁵ yr (90%C.L.)
 - > 3.4×10²⁵ yr (90%C.L.) (KLZ+EXO-200)

 $(m_{\beta\beta}) < (120-250) meV (90\% C.L.)$

"K.K. claim" in ⁷⁶Ge was disfavored (97.5%C.L.).

We conducted Xe-LS purification !



Phase-II analysis



²¹⁴Bi dominates on the balloon with strong z-dependence !

Simultaneous fit of the energy spectrum for 20 concentric spherical shells of equal-volume for upper and lower hemispheres each.

¹³⁶Xe, 504 kg yr (Dec.2013~Oct.2015)

Event selection :

R<2m, µ-on cut (<2ms), Delayed coincidence cut (²¹⁴Bi-²¹⁴Po (<τ=237μs), ²¹²Bi-²¹²Po (<τ=0.4μs), Reactor v), Poorly reconstructed event cut.





over the background.

number of events: Observed and Best-fit (+estimated) R<1m, 2.3<E<2.7 MeV, Period-1 Period-2 (270.7days) (263.8days) **Observed** 22 11 ¹³⁶Xe 2vββ 5.48 5.29 214Bi 0.25 0.03 208TI 0.001 0.001 110mAg 8.5 0.0 214Bi 2.45 2.56 208TI 0.02 0.03 110mAg 0.003 0.002 3.3 (2.7±0.7) **10C** 2.8 (2.6±0.7) 6He $0.08(.07\pm.18)$ 0.08 (.07±.18) $0.16(.15\pm.04)$ $0.15(.14\pm.04)$ 12B 137Xe 0.5 (0.5±0.2) $0.4 (0.5 \pm 0.2)$

Summary of the

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Xe-LS is purified, $^{110m}\mbox{Ag}$ has gone ! $^{136}\mbox{Xe}\ 2\nu\beta\beta$

²¹⁴Bi from the MIB.

¹⁰C from spallation events



Limits on T^{0v}_{1/2} (90%C.L.) Phase-I: >1.9×10²⁵ yr Phase-II : $> 9.2 \times 10^{25}$ yr **Combined:** $T^{0v}_{1/2} > 1.07 \times 10^{26} \text{ yr}$ $\langle m_{\beta\beta} \rangle < (61~165) \text{ meV}$ m_{lightest} < (180~480)meV (90%C.L.) What's Next? ^{110m}Ag has gone ! ¹³⁶Xe 2v => Improve ΔE (Challenge in the Future) ²¹⁴Bi => Replace the MIB $^{10}C => \mu - n^{-10}C$ coincidence, +New analysis method.

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KamLAND-Zen 800 ~750kg Xe to ¹⁶ explore IH region !

A new MIB of twice the volume was constructed in much improved cleanliness control than Zen400 MIB !



The new MIB was deployed into the name the last summer.

The new MIB deployment (Aug.'16)

After inflated with dummy LS, we found a leak (~40ℓ/day) by several phenomena. MIB was collected (Nov.) and checked.

We found small holes on the welding lines. Film didn't break, but welding lines break. Welding done as the same way for the first (Zen400) MIB didn't break.

We didn't lose any Xenon. The data show the MIB film is much cleaner than the previous one ; U,Th is 2.5 and ~10 times cleaner than Zen400-I and II, respectively

- UniporV	(Unit=10 ⁻¹² g/g)			
Preiminary	238U	232Th		
After washed	2	6		
Zen800	5.3±0.8	31±7		
Zen400-I	14±1	79±3		
Zen400-II	46±4	336±2		

New MIB in the detector viewed 17 by a fixed-point camera



Welding line MIB shape (Camera, data analysis) and total weight. Analysis of the MIB-LS sample (decane-based) showed the outer LS (dodecane-based) component.



We decided to start a new MIB construction. "'`--" The new MIB will be installed in KamLAND this autumn.

KamLAND2-Zen

>1000kg Xe to fully cover IH region !





Accelerator/Atmospheric v experiments (NMH?) CMB : $\Sigma m_v \sim O(100)$ meV

 $\langle m_{\beta\beta} \rangle$ can be in "IMH-region".

Improved sensitivity can make a "SURPRISE" at any time !

Summary

• KamLAND-Zen is a unique $0\nu\beta\beta$ search experiment using a Xe+LS with MIB in the ultra-low background facility, KamLAND.

In the first stage, KamLAND-Zen400, phase-I (320kg Xe) and phase-II (380kg Xe) after the Xe+LS purification were performed, whose data corresponds to ¹³⁶Xe exposure of 593.5kg*yr.

• The analysis has provided the limit on the half life $T^{0v}_{1/2} > 1.07 \times 10^{26}$ yr (90%C.L.) and constrains $\langle m_{\beta\beta} \rangle <$ (61-165) meV (90%C.L.), which is the most stringent limit and approaching to the IMH region.

• A new phase KamLAND-Zen800 with ~750kg Xe is under preparation for making much cleaner MIB to explore the IMH region. After a trial in the last summer the new phase will start this autumn.

 Our future plan is the KamLAND2-Zen using >1ton Xe. Many R&Ds are under way aiming to full coverage of the IMH region.



Thank you !

