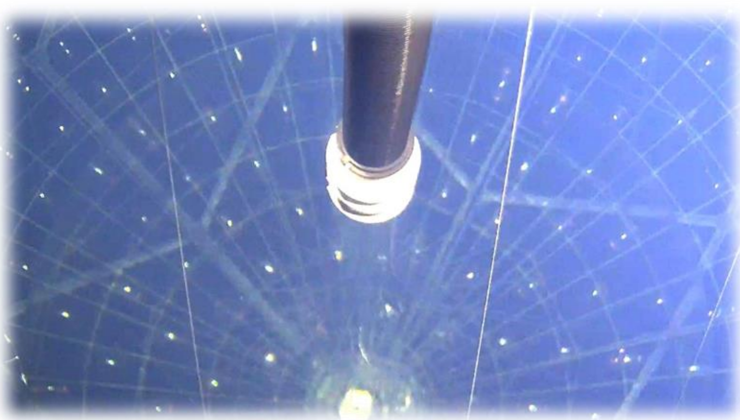



Search for neutrinoless double beta decay with the KamLAND-Zen experiment

Dmitry CHERNYAK

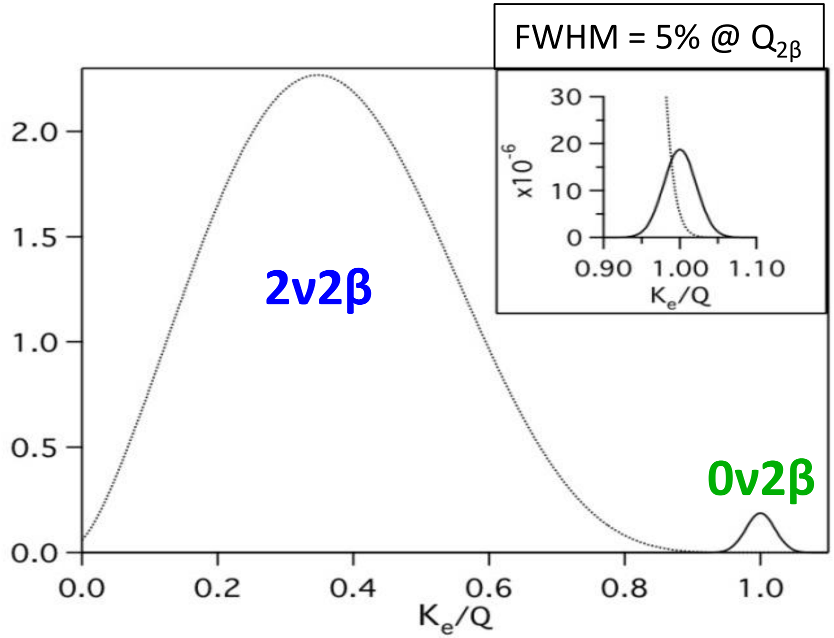
On Behalf of the KamLAND-Zen Collaboration

Kavli Institute for the Physics and Mathematics of the Universe,
The University of Tokyo, Kashiwa, Japan

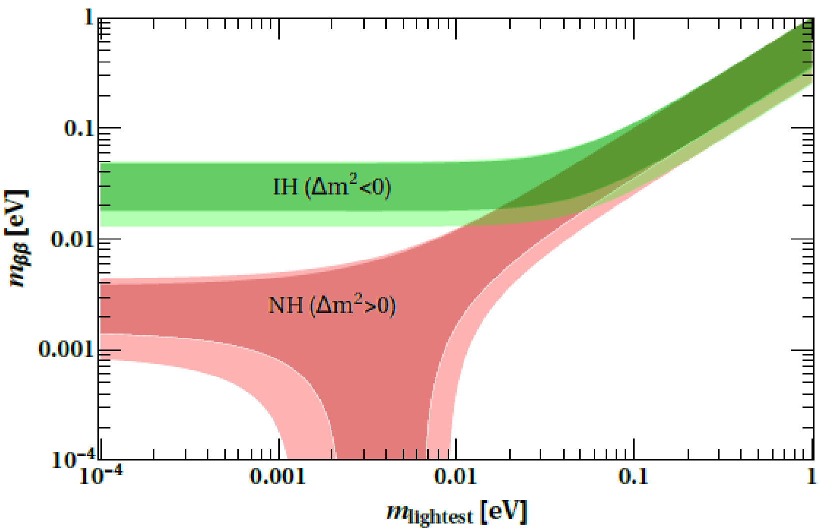




IV International Conference on Particle Physics and Astrophysics, Moscow, 22-26 October 2018

Double beta decay



S.R.Elliot and P.Vogel, Ann.Rev.Nucl.Part.Sci. 52 (2002) 115



S.Dell'Oro et al., Adv. in High En. Phys. (2016) 2162659

Two-neutrino double beta decay ($2\nu2\beta$)

$2\beta^-$: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ ΔL=0

Allowed by the Standard Model,
was observed for 11 isotopes

Neutrinoless double beta decay ($0\nu2\beta$)

$2\beta^-$: $(A,Z) \rightarrow (A,Z+2) + 2e^-$ ΔL=2

Process without emission of neutrino or antineutrino

Forbidden by the Standard Model,
is not observed

Observation of $0\nu2\beta$:

- prove the lepton number violation
- establish the Majorana nature of the neutrino
- help to determine neutrino mass hierarchy and estimate the effective Majorana mass of neutrino
- help to test leptogenesis

KamLAND-Zen Collaboration

~ 50 collaborators, 12 institutes, 3 countries

Collaboration Meeting at Toyama, March 2018

Tohoku University
S. Abe, A. Gando, Y. Gando, T. Hachiya, S. Hayashida, K. Hosokawa, S. Ieki, H. Ikeda, K. Inoue, K. Ishidoshiro, Y. Kamei, N. Kawada, T. Kinoshita, M. Koga, T. Mitsui, H. Miyake, K. Nakamura, S. Obara, A. Ohno, N. Ohta, S. Ohtsuka, H. Ozaki, T. Sato, I. Shimizu, Y. Shirahata, J. Shirai, A. Suzuki, A. Takeuchi, K. Tamae, K. Ueshima, Y. Wada, H. Watanabe

Kavli IPMU
A. Kozlov, D. Chernyak

Osaka University
Y. Takemoto, S. Umehara, S. Yoshida

Tokushima University
K. Fushimi, S. Hirata, K. Hata

UC Berkeley & LBNL
B. Berger, B. Fujikawa

TUNL
H. Karwowski, D. Markoff, W. Tornow

Nikhef
P. Decowski

MIT
L. Winslow, J. Ouellet, S. Fraker

University of Washington
J. Detwiler, S. Enomoto

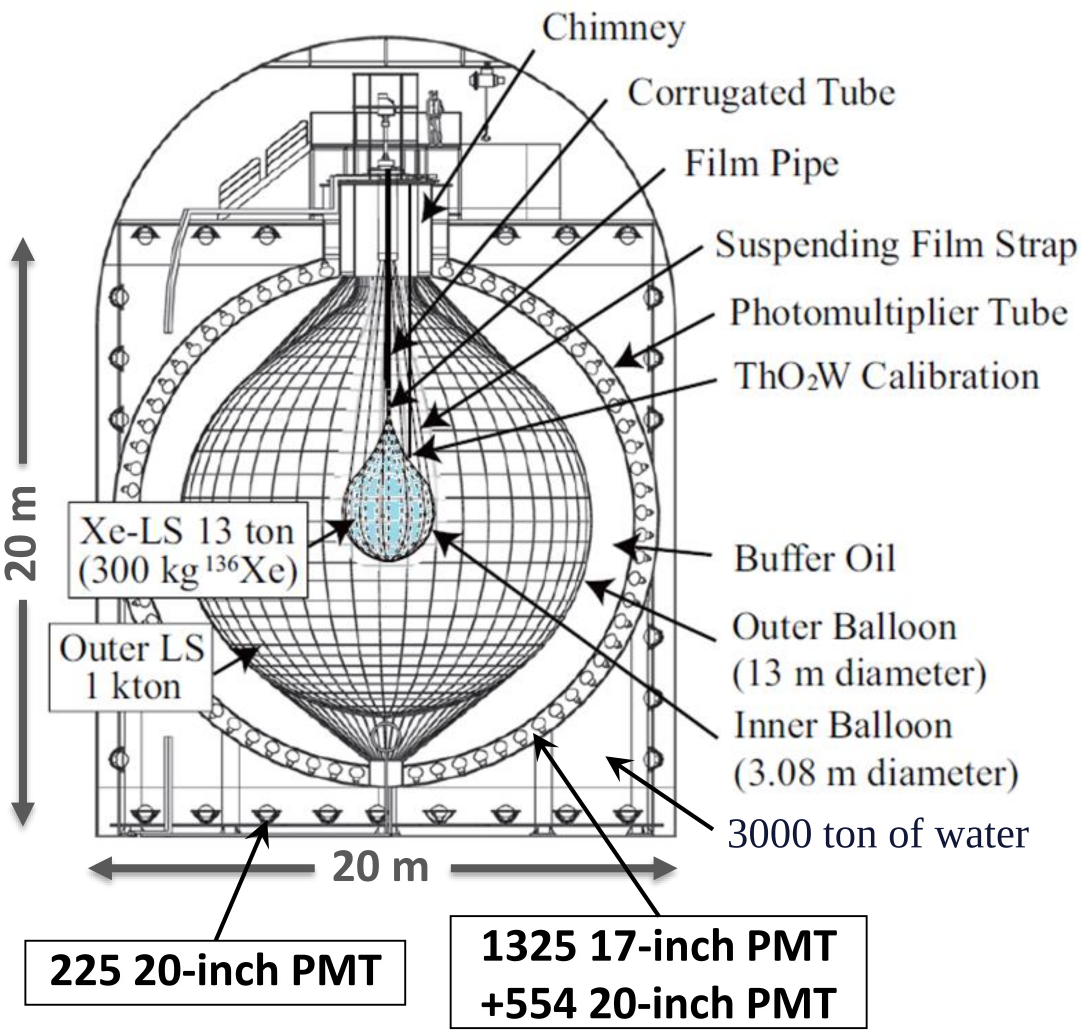
Virginia Tech
T. O'Donnell

University of Tennessee
Yu. Efremenko

University of Hawaii
J. Maricic, K. Choi

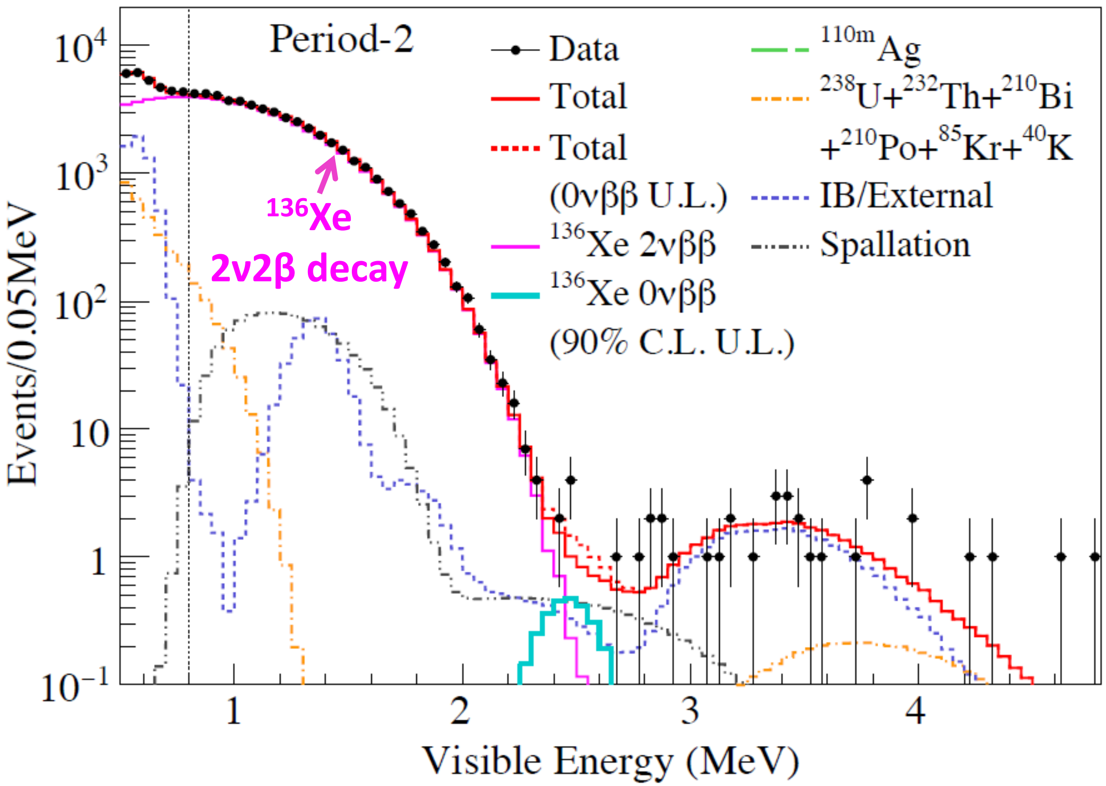
KamLAND-Zen 400 detector

Detector is located in **Kamioka underground laboratory** at the **depth** of **2700 m.w.e.**, and exploits the KamLAND **radio-purity**, **light sensors (PMTs)** and **data acquisition system**.



- **Enriched Xe** (≈91% of ^{136}Xe):
  - **Phase I (2011–2012)**: **320kg**
  - **Phase II (2013–2015)**: **383kg**
- **Nylon mini-balloon**:
  25μm-thick, R=1.54m, V=16.5m^3,
  ^{238}U, ^{232}Th ~ a few × 10^{-11} g/g
- **Liquid scintillator**:
  $C_{10}H_{22}$(81.8%) + PC(18%) +
  PPO(2.7g/l) + Xe(≈2.5wt%)
- **FWHM @ $Q_{2\beta}$**:
  - **Phase I**: **≈9.9%**
  - **Phase II**: **≈11%**
- **Target $\langle m_{2\beta} \rangle$: 60 meV/2 years**

KamLAND-Zen 400: 2ν2β result



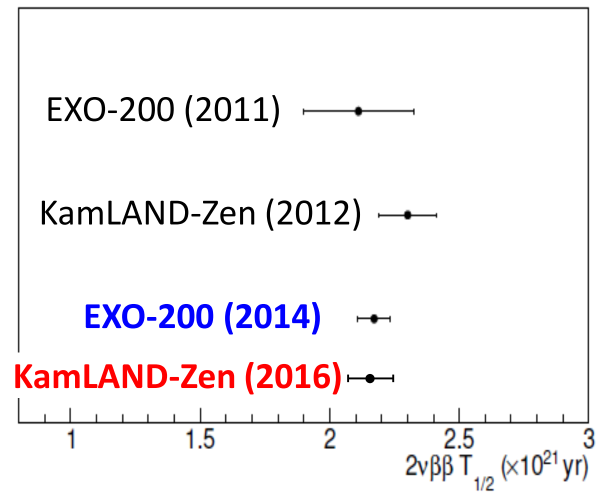
Systematic uncertainties (%)	
Fiducial volume	3.0
Xenon mass	0.8
Detector energy scale	0.3
Efficiency	0.2
^{136}Xe enrichment	0.09
Total	3.1

EXO-200 (2014):

$T^{2\nu}_{1/2}$ = (2.165 ± 0.016(stat) ± 0.059(syst)) × 10^{21} yr [1]

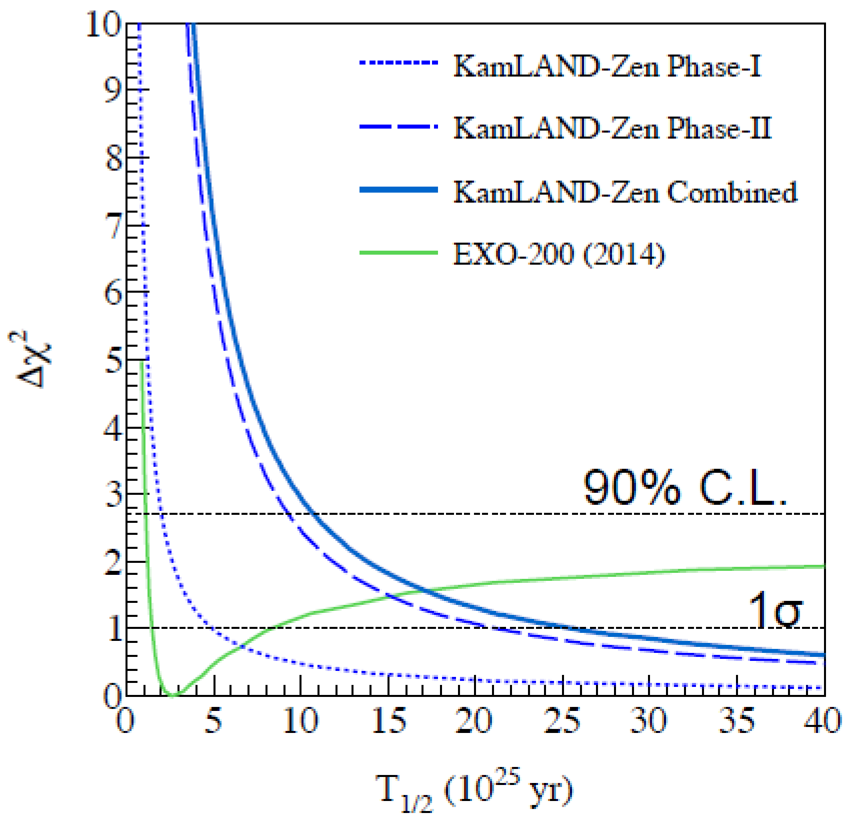
KamLAND-Zen (2016):

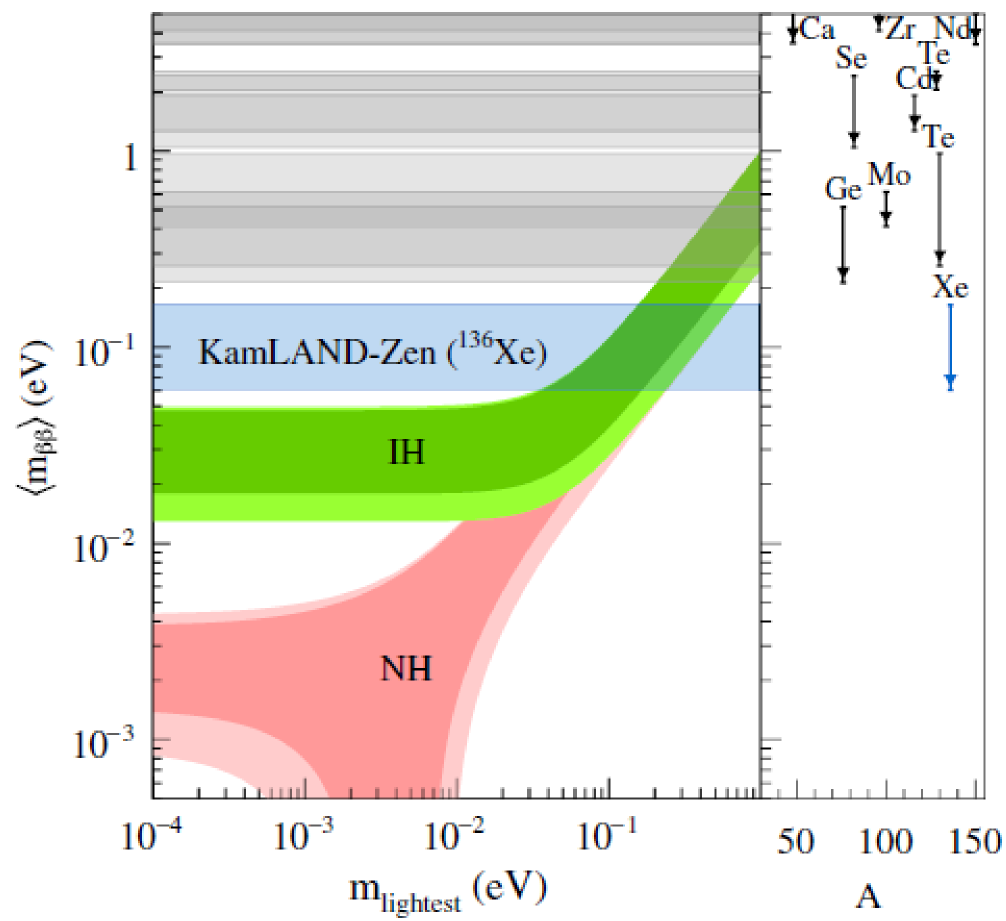
$T^{2\nu}_{1/2}$ = (2.21 ± 0.02(stat) ± 0.07(syst)) × 10^{21} yr [2]



[1] J. B. Albert et al. (EXO Collaboration), Phys. Rev. C 89, 015502(2014)
[2] A. Gando et al., Phys. Rev. Lett. 117 (2016) 082503

KamLAND-Zen 400: 0ν2β search





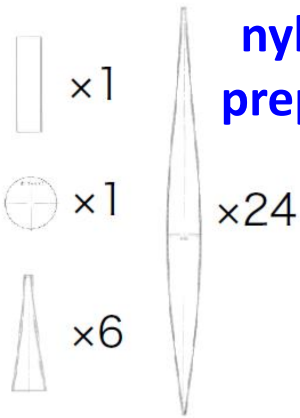
Phase I: 2011/10/12–2012/06/14
Phase II: 2013/12/11–2015/10/27
213.4 + 534.5 days of data

GERDA (2018): $\langle m_\nu \rangle$ < (110–260) meV

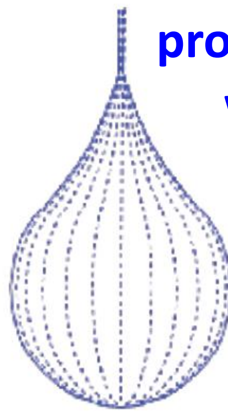
$T^{0\nu}_{1/2}$ > 1.07 × 10^{26} yr at 90% C.L. ← **Best limit** → $\langle m_\nu \rangle$ < (61–165) meV

A. Gando et al., Phys. Rev. Lett. 117 (2016) 082503

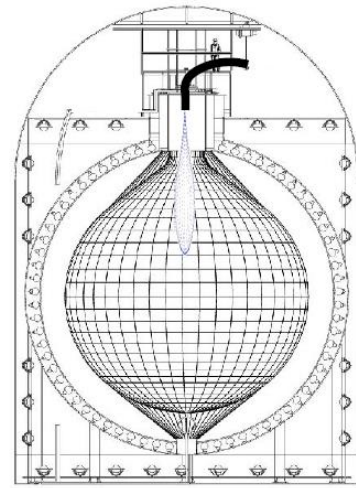
Preparation of KamLAND-Zen 800



25μm-thick nylon film preparation

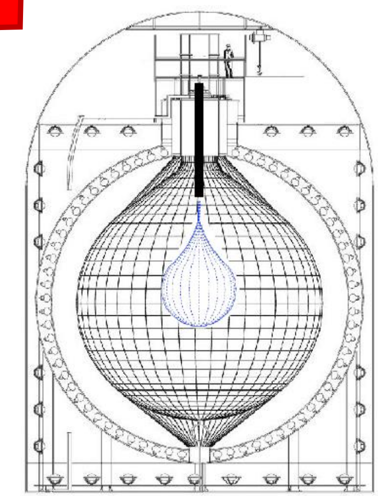


Mini-balloon production by welding

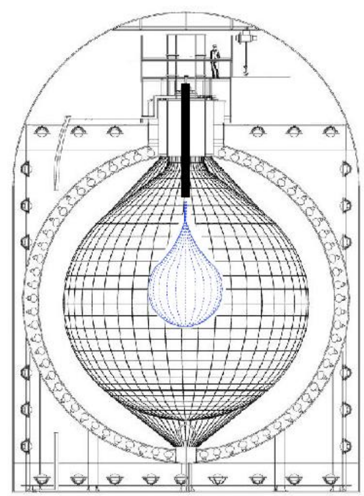


Mini-balloon installation in KamLAND

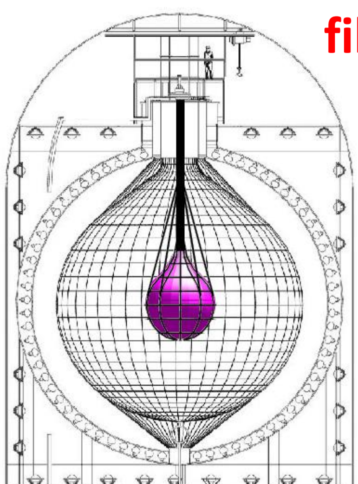
Mini-balloon filling with Dummy LS



LS purification



Xe-loaded-LS filling



Physics run start

Enriched ^{136}Xe: ~ 750kg
Target sensitivity: ~ 40meV

Toward cleaner mini-balloon

Clean wear control

Regular room

Inner suits

Class 1000 clean room

1st clean suit

Class 1 super clean rooms

Preparation room

Clean suit change

Mini-balloon production room

Laundry twice per day

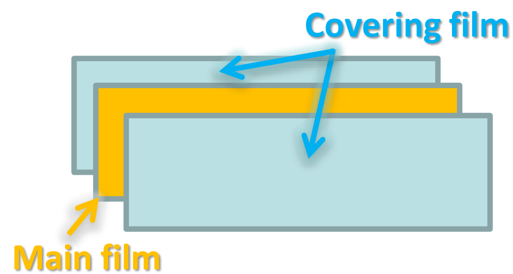
Static-electricity control

65% humidity prevent static-electricity

Mist generation system

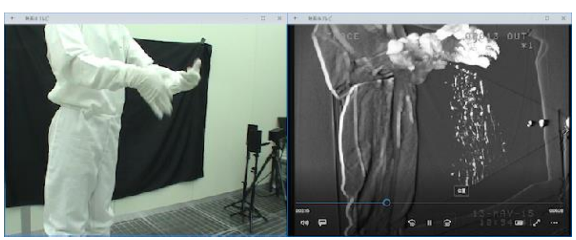
Ion-generation system

Film cover setting



Mini-balloon film was sandwiched between two clean nylon films

Particle flow check



- Check particle generation by our hands, suits, etc.
- Particle flow on/near desks

Semi-automatic welding machine

Zen 400

Zen 800

Zen 400: Hand-welding by a professional from a company

Zen 800: Semi-automatic welding by scientists with speed up & less particle drop

Mini-balloon production

Washing nylon film

Cutting

Welding

Packing

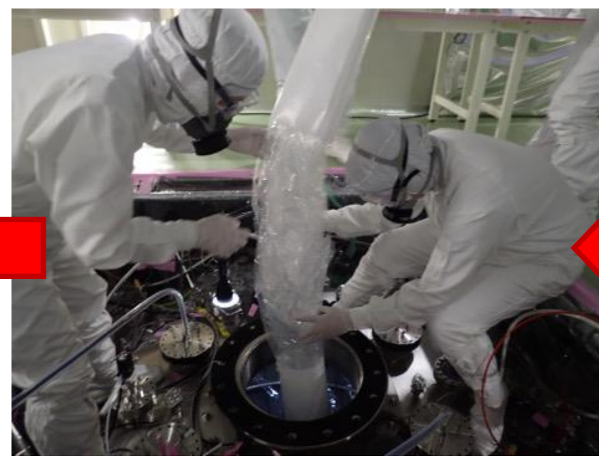
Folding

He leak check & repairing

Mini-balloon installation

Delivery to Kamioka

Mini-balloon parts assembling

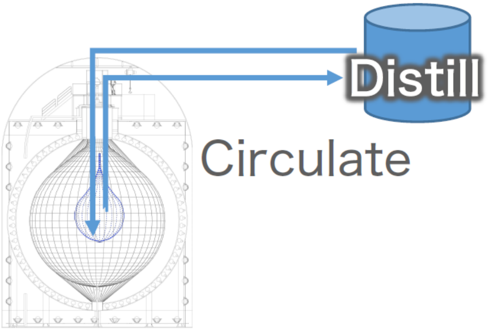


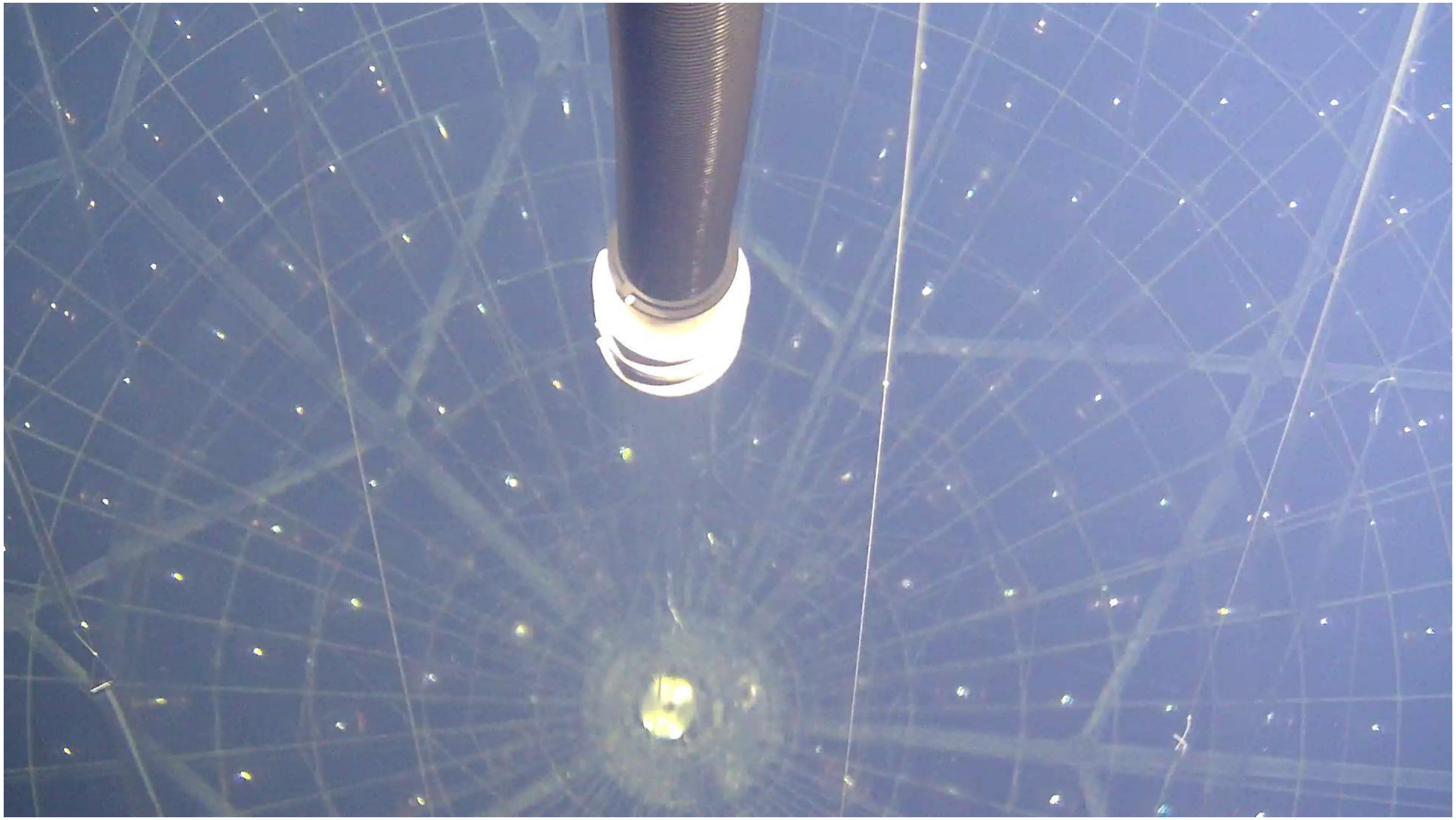
Mini-balloon installation into KamLAND

← Inner view of KamLAND detector

Current status of KamLAND-Zen 800

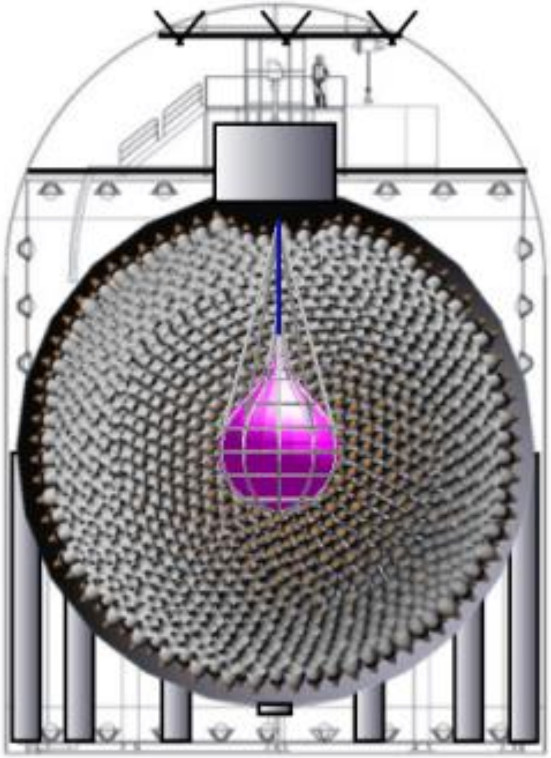
- Mini-balloon was successfully installed this May
- Filled with Dummy LS
- LS purification is currently in progress
- We will start the preparation of Xe-LS in November
- **KamLAND-Zen 800 will start this winter**





KamLAND2-Zen: Future prospects

Enriched xenon mass ≥ 1000kg



KamLAND-Zen weak point: Energy resolution

We need to detect **more light** to improve energy resolution → reduce the **2ν2β tail background**

Target sensitivity: $\langle m_\nu \rangle \sim 20$ meV

Gain in number of detected photons

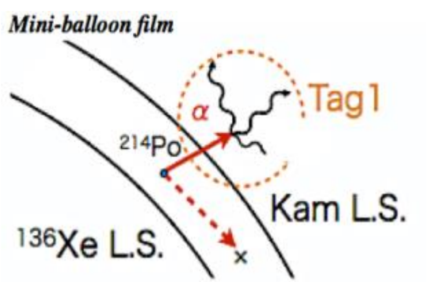
(after upgrade to KamLAND2-Zen)

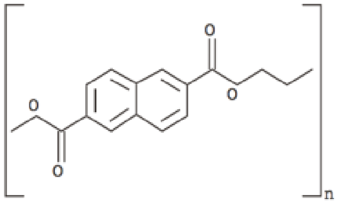
Lab scintillator: **1.4** times

High QE PMTs: **1.9** times

Light collecting cones: **1.8** times

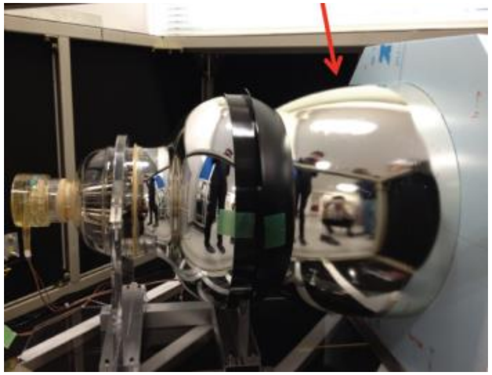
Dead layer free scintillation film balloon





Polyethylene naphthalate

Winston cone



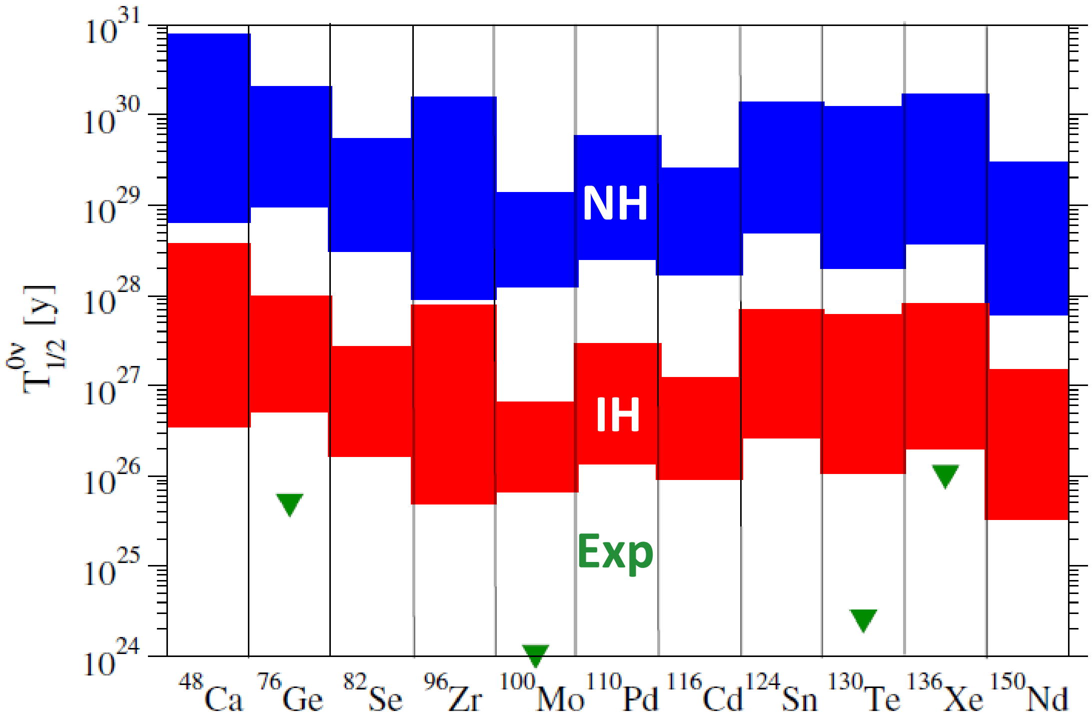
Conclusions

- **KamLAND-Zen 400** was successfully completed. We obtained the **world's best limit** for **0ν2β decay** of ^{136}Xe: $T^{0\nu}_{1/2} > 1.07 \times 10^{26}$ **yr** at 90% C.L. which corresponds to $\langle m_\nu \rangle <$ **(61–165) meV** depending on NME. We also measured **2ν2β decay** of ^{136}Xe: $T^{2\nu}_{1/2} = (2.21 \pm 0.02(\mathrm{stat}) \pm 0.07(\mathrm{syst})) \times 10^{21}$ **yr** which is in accordance with EXO-200 results

- **KamLAND-Zen 800** is **expected to enter the IH mass region** with the sensitivity of $\langle m_\nu \rangle \sim$ **40 meV**. New mini-balloon (twice larger in volume) was successfully installed this spring. LS purification is almost finished and preparation of the Xe-LS will start in few weeks. **KamLAND-Zen 800 will start this winter**

- **KamLAND2-Zen** is a next-generation project to **cover most of the IH mass region**. Several R&D are in progress to reach the sensitivity of $\langle m_\nu \rangle \sim$ **20 meV**

Choice of 2β decay isotope



J.D.Vergados, H.Ejiri, F.Simkovic, IJMPE Vol. 25, No. 11 (2016) 1630007

Isotope	$Q_{2\beta}$ (MeV)	Natural abund. (%)	Enrichable by centrifugation
^{48}Ca	4.272	0.187	No
^{76}Ge	2.039	7.8	Yes
^{82}Se	2.995	9.2	Yes
^{96}Zr	3.350	2.8	No
^{100}Mo	3.034	9.6	Yes
^{116}Cd	2.814	7.5	Yes
^{130}Te	2.527	33.8	Yes
^{136}Xe	**2.458**	**8.9**	**Yes**
^{150}Nd	3.371	5.6	No (?)

^{136}Xe was chosen for KamLAND-Zen thanks to:

- Large $Q_{2\beta}$ > 2 MeV
- Slow 2ν2β decay
- Isotopic enrichment and commercial availability
- Solubility in liquid scintillator, established purification, easy extraction