Latest results and current status of KamLAND-Zen

Kavli Institute for the Physics and Mathematics of the Universe

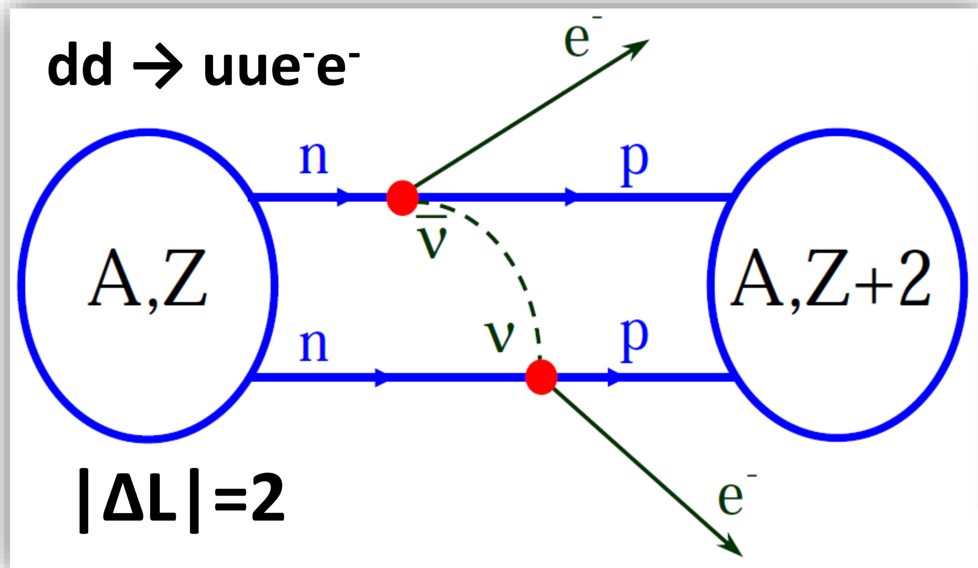
Alexandre KOZLOV

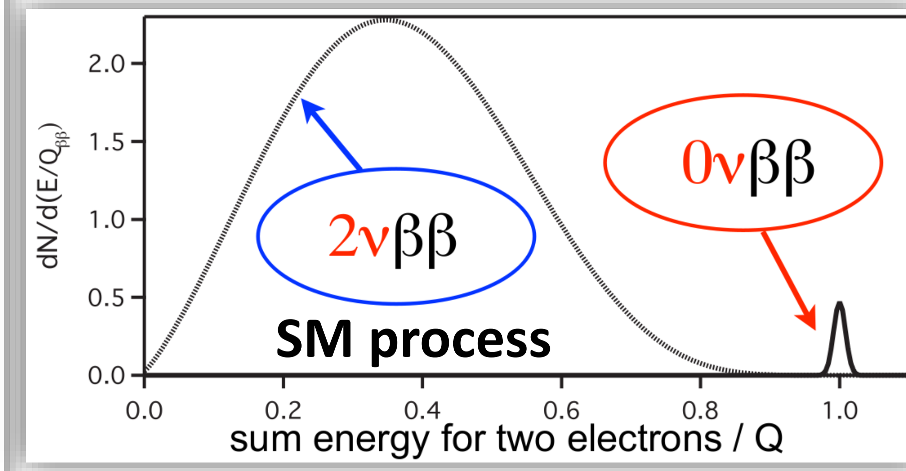
TeV Particle Astrophysics 2016, CERN (September 13, 2016)

The KamLAND-Zen history in brief

- Transition from the **KamLAND** neutrino to **KamLAND-Zen** neutrinoless double beta decay experiment began 8 years ago after discovery of the **LMA** solution for the **Solar neutrino problem** and precise measurement of Δm_{21}^2.
- In March 2008 we decided to begin search for neutrinoless double beta decay of **^{136}Xe (Q=2.458MeV)**. The KamLAND-Zen collaboration was formally separated from the KamLAND collaboration.
- The KamLAND-Zen construction coincided in time with the **Fukushima nuclear accident** in 2011 which became source of the unexpected **^{110m}Ag** (Q=3.01MeV; τ = 1yr) background.
- **KamLAND-Zen 400 Phase I**: Oct 12, 2011 – June 14, 2012
- In between: purification campaign to remove **^{110m}Ag**.
- **KamLAND-Zen 400 Phase II**: Dec 11, 2013 – Oct 27, 2015.
- **KamLAND-Zen 800** is being prepared now.

The 0νββ test of seesaw mechanism by Yanagida





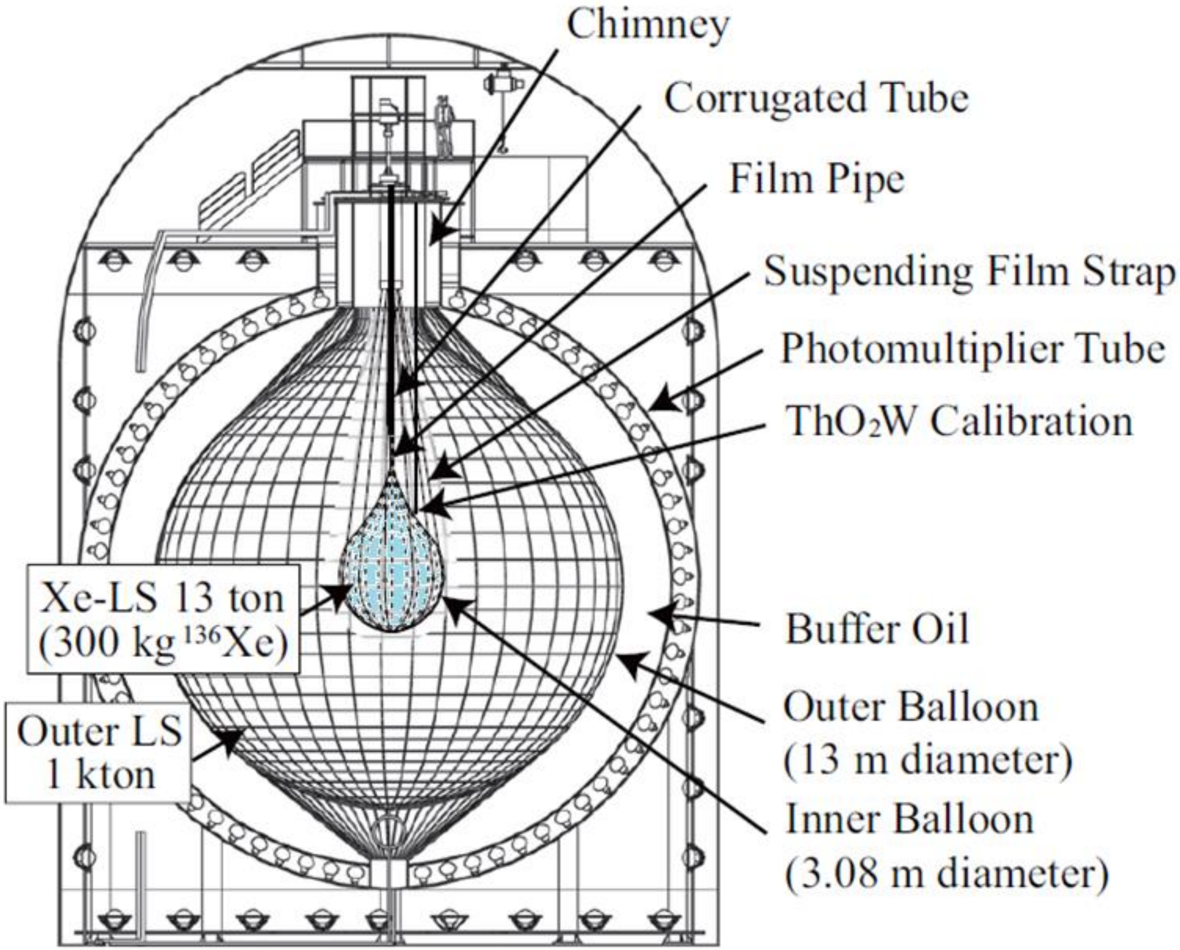
Test of the **Leptogenesis** (Fukugita & Yanagida) as explanation for **baryon asymmetry of the Universe**

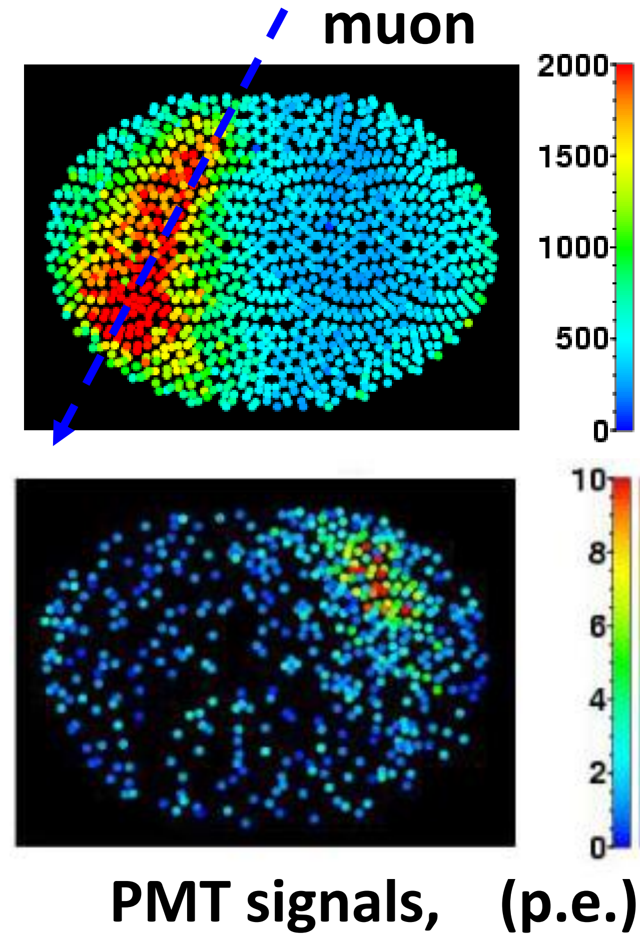
In calorimeters, as KamLAND, **sum of kinetic energies** of two electrons is measured

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q_{\beta\beta},Z)\cdot|M^{0\nu}|^2 \cdot m_{\beta\beta}^2$$

- $G^{0\nu}(Q_{\beta\beta},Z)$ – phase space factor
- $|M^{0\nu}|$ – nuclear matrix elements
- $m_{\beta\beta}$ – effective mass of neutrino

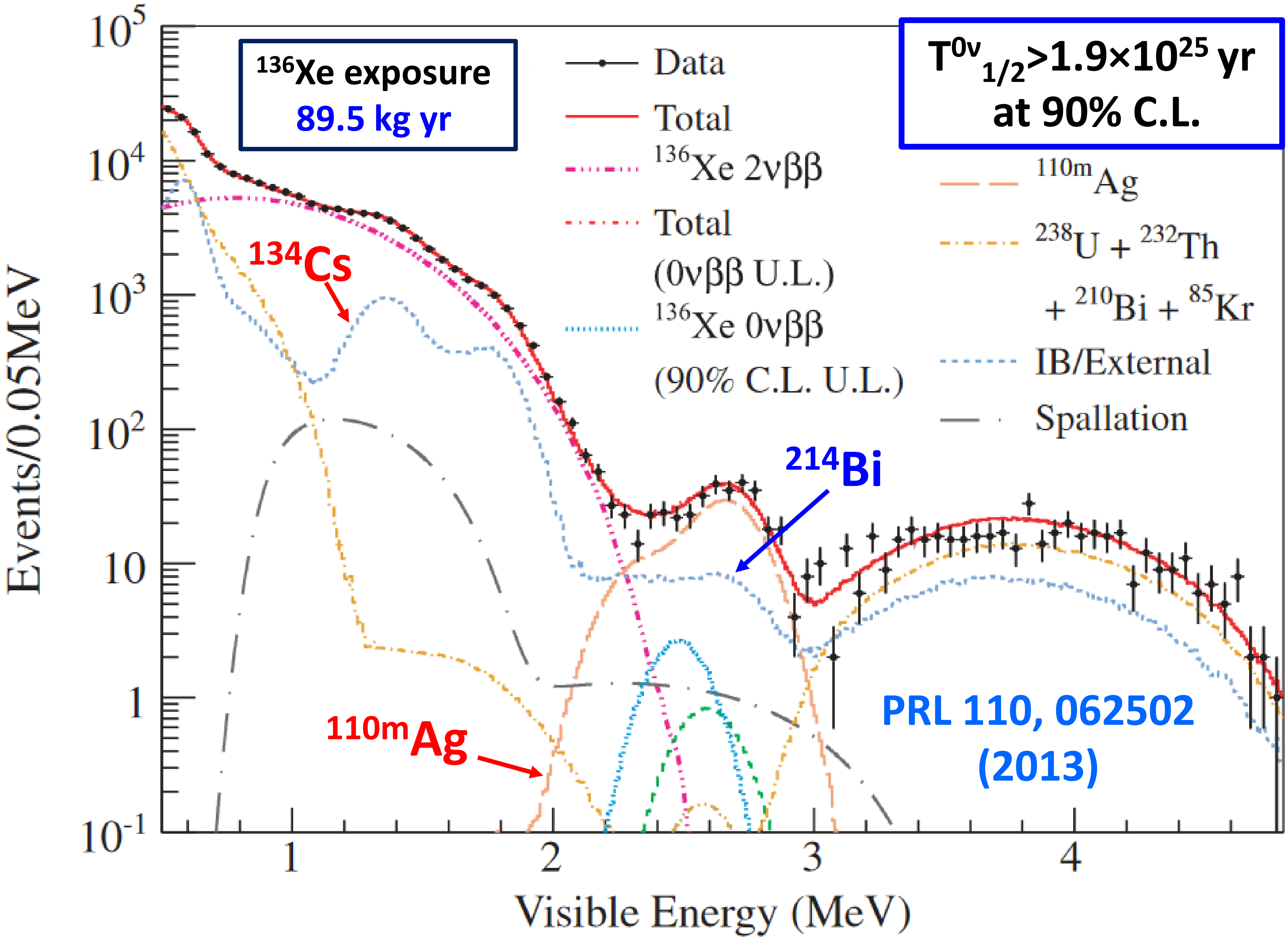
Structure of the KamLAND-Zen 400



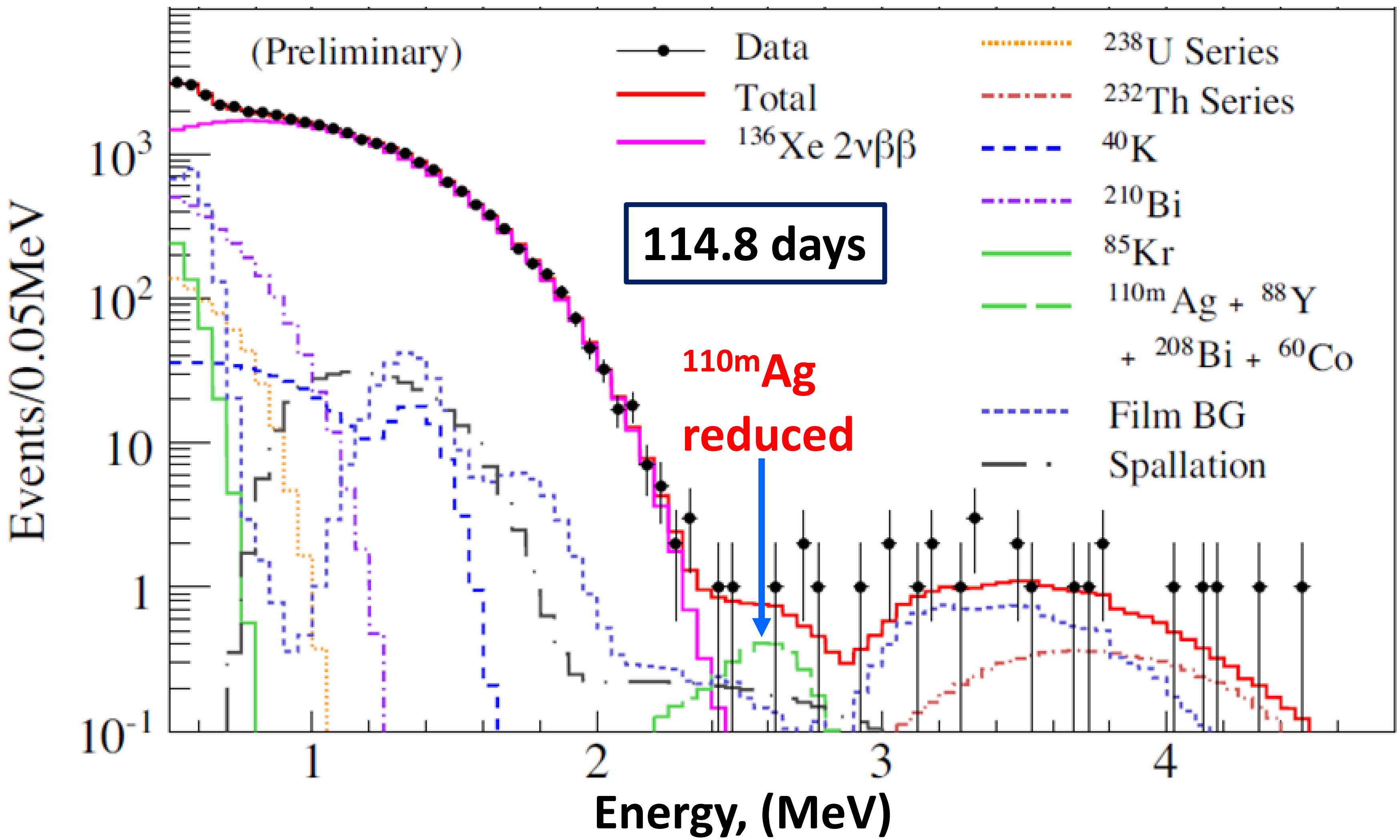


- **Liquid scintillator** loaded with xenon **(2.5-3wt%)** enriched to **90.8%** ^{136}**Xe** in a **ø3.08m** mini-balloon made of a **25μm**-thick Nylon film.
- Exploits the KamLAND detector **radio-purity, 1879 PMTs** 17&20-inch, and **data acquisition system** (currently 2 parallel running systems).

Phase I result affected by Fukushima fallout



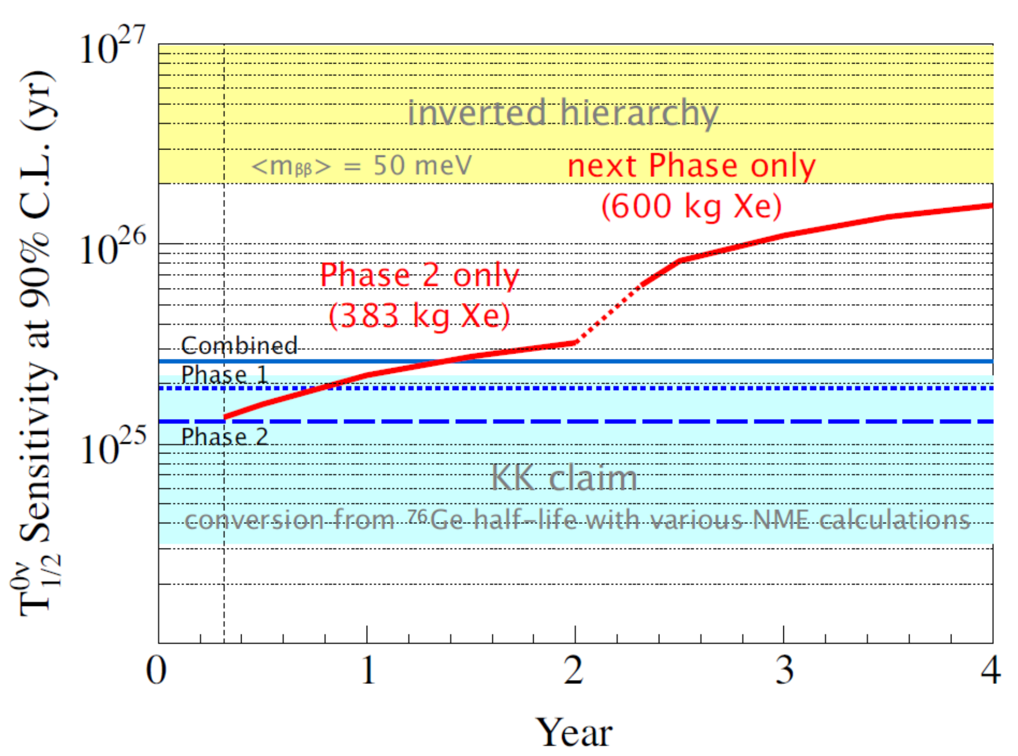
Intermediate result at the beginning of Phase II

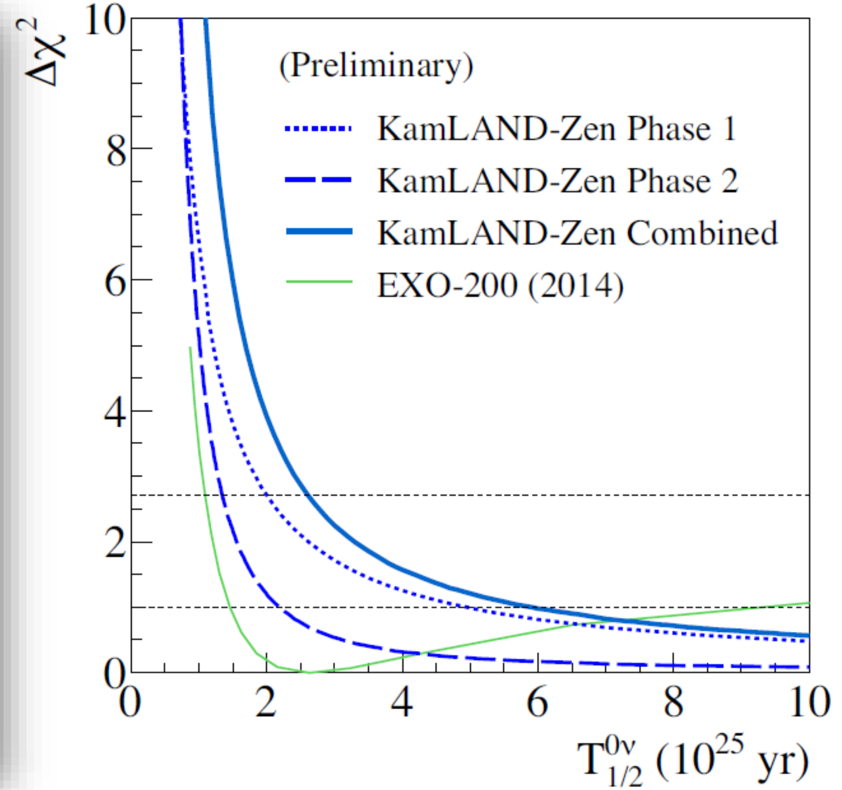


During **Phase II** the same mini-balloon was used but amount of enriched xenon was increased from **320kg** to **383kg**.

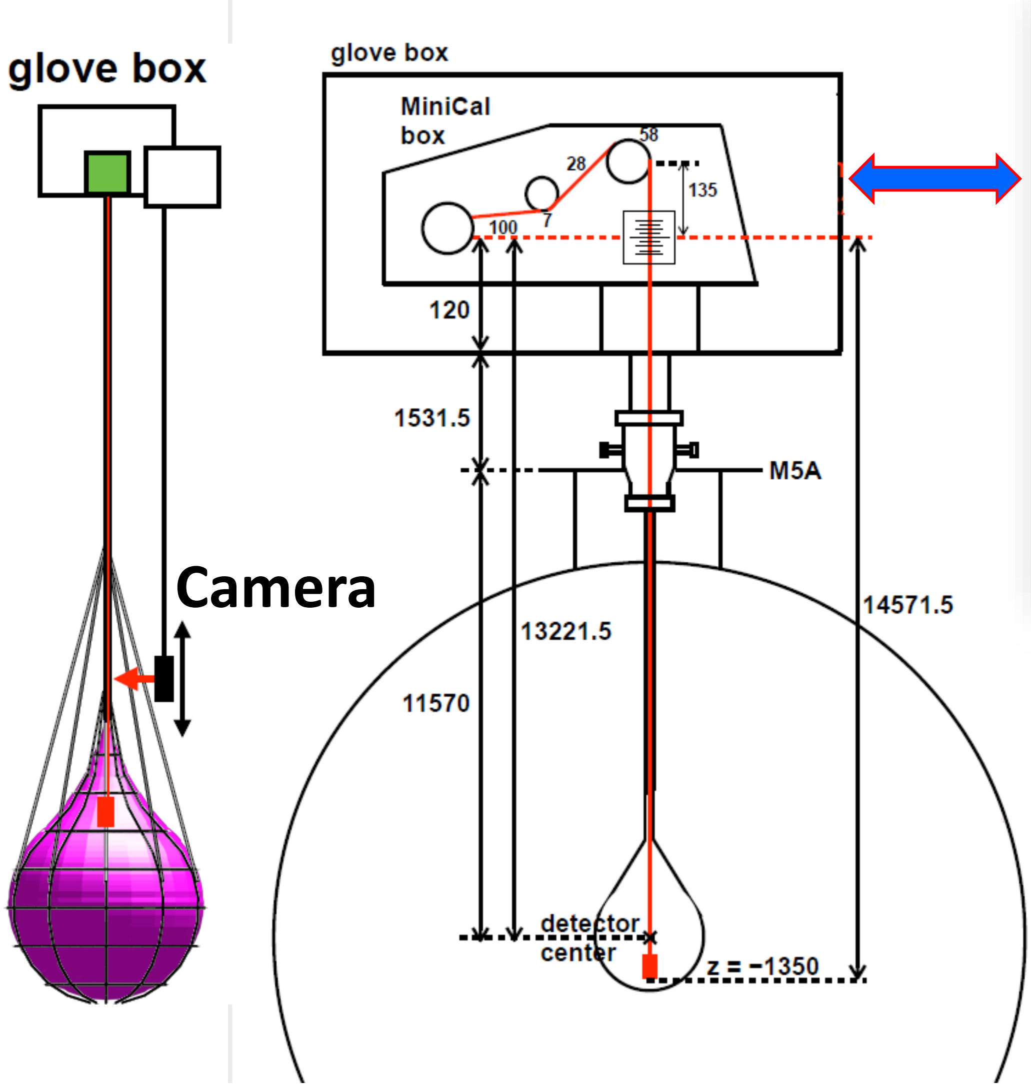
Intermediate result at the beginning of Phase II

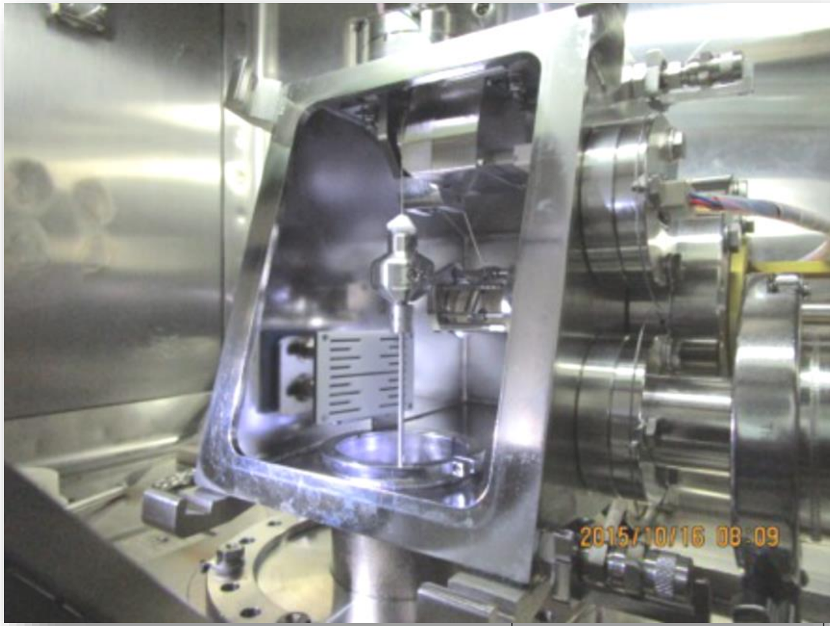
$T^{0\nu}_{1/2} > 2.6\times10^{25}$ yr at 90% C.L. → $m_{\beta\beta} <$ (140-280) meV

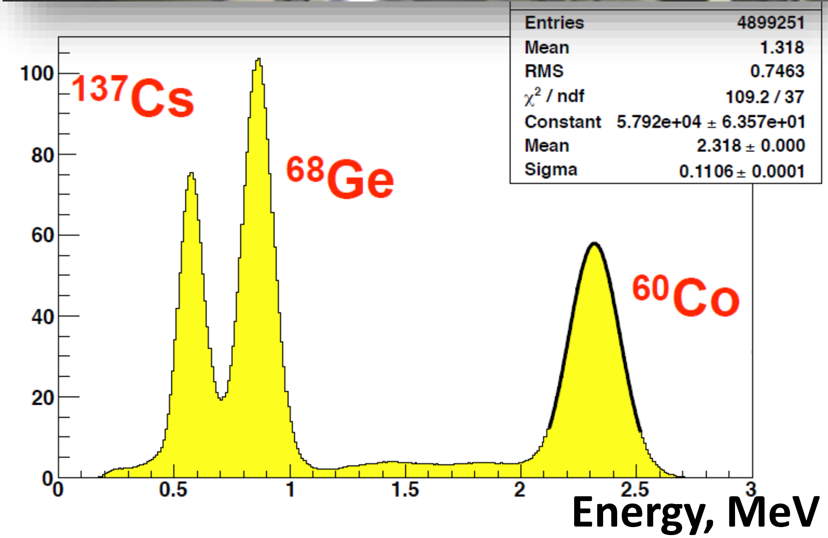




The **KamLAND-Zen result alone** excluded neutrinoless double beta decay observation ("KK") claim: Mod. Phys. Lett. A **21**, 1547 (2006).



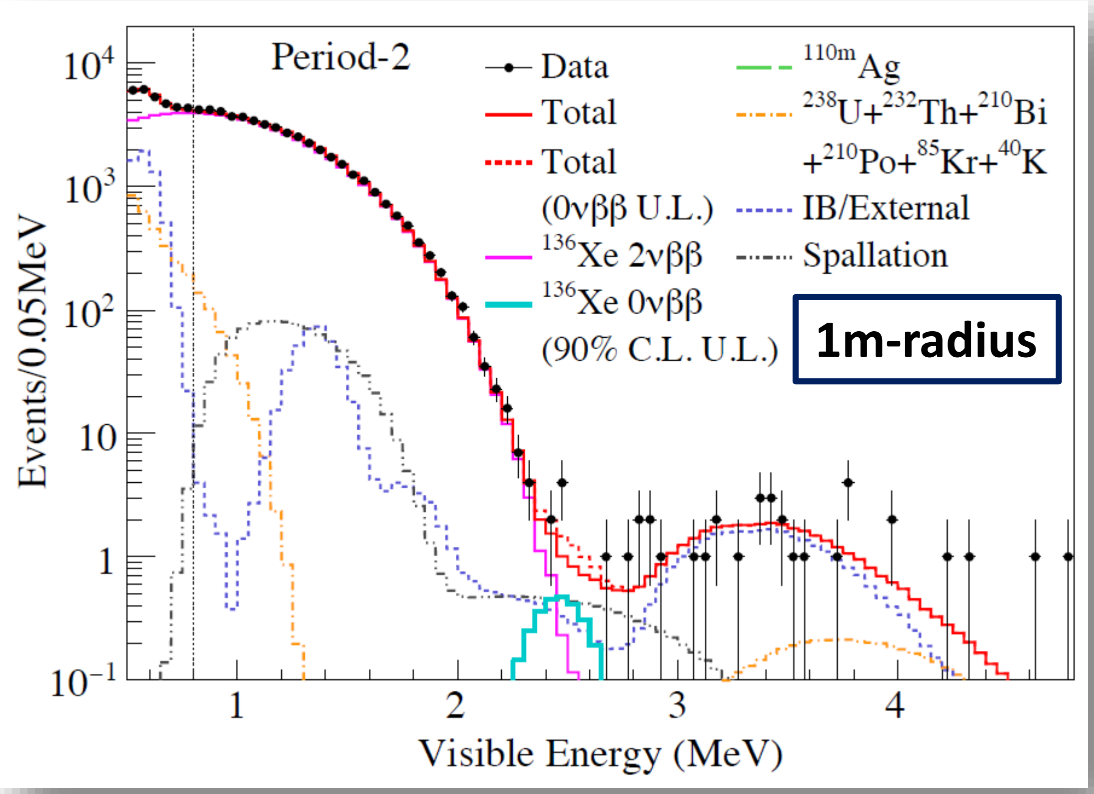


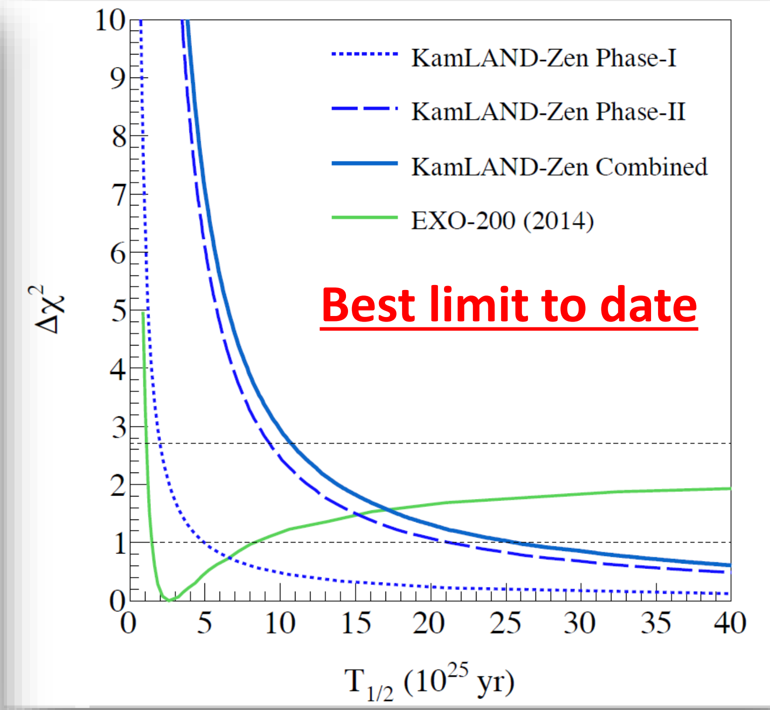


At the end of Phase II **calibration sources** were deployed directly to the **Xenon loaded liquid scintillator**. Position dependence of events reconstructed **Energy** and **Vertex** information was measured.

Final result from KamLAND-ZEN 400

$T^{0\nu}_{1/2} > 1.07\times10^{26}$ yr at 90% C.L.

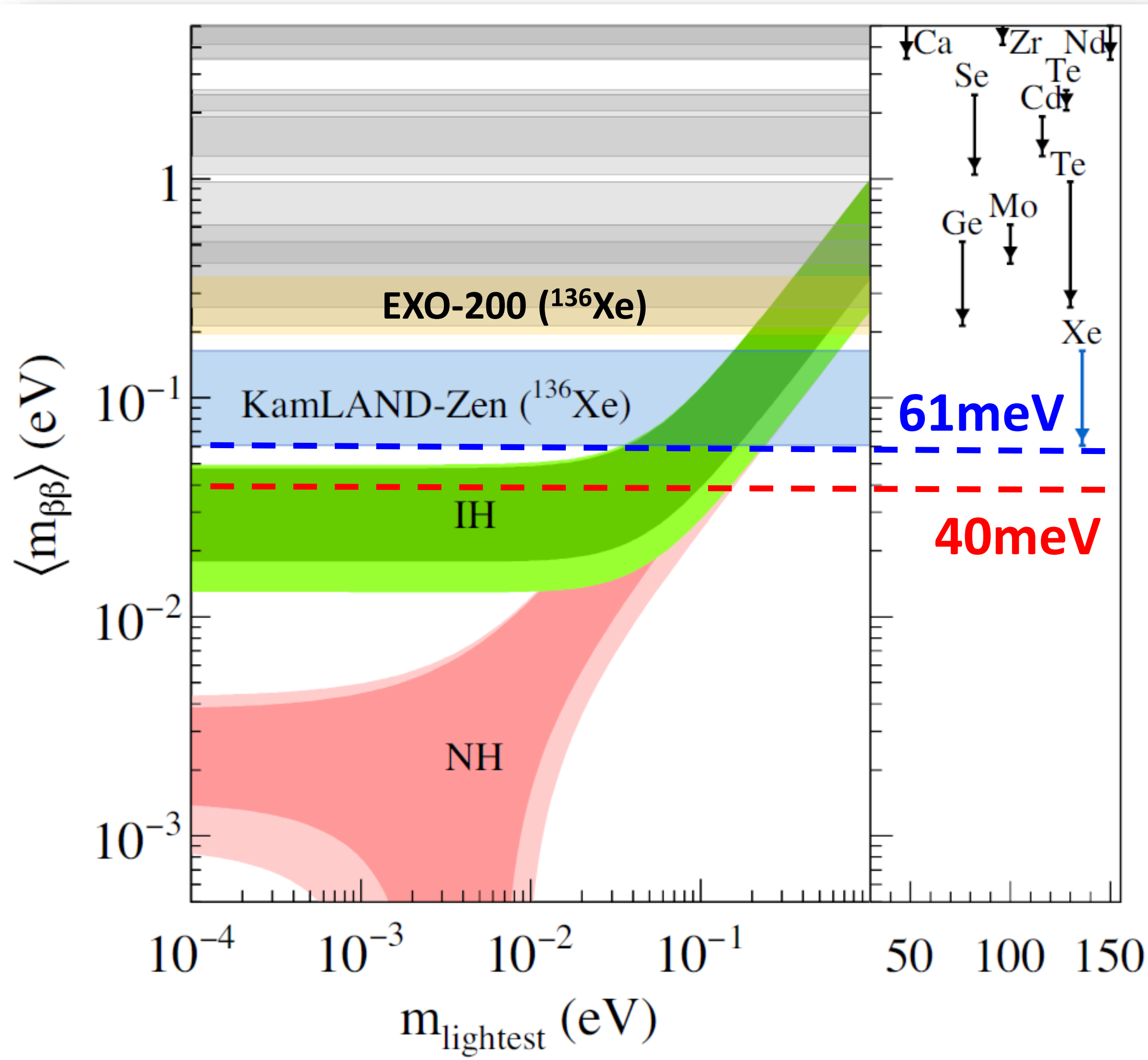




PRL 117, 082503 (2016)

Phase I (89.5kg yr): October 12, 2011 – June 14, 2012
Phase II (504kg yr): December 11, 2013 – October 27, 2015

First test of the IH mass region with KL-ZEN 800



CP violation in the neutrino sector

↕

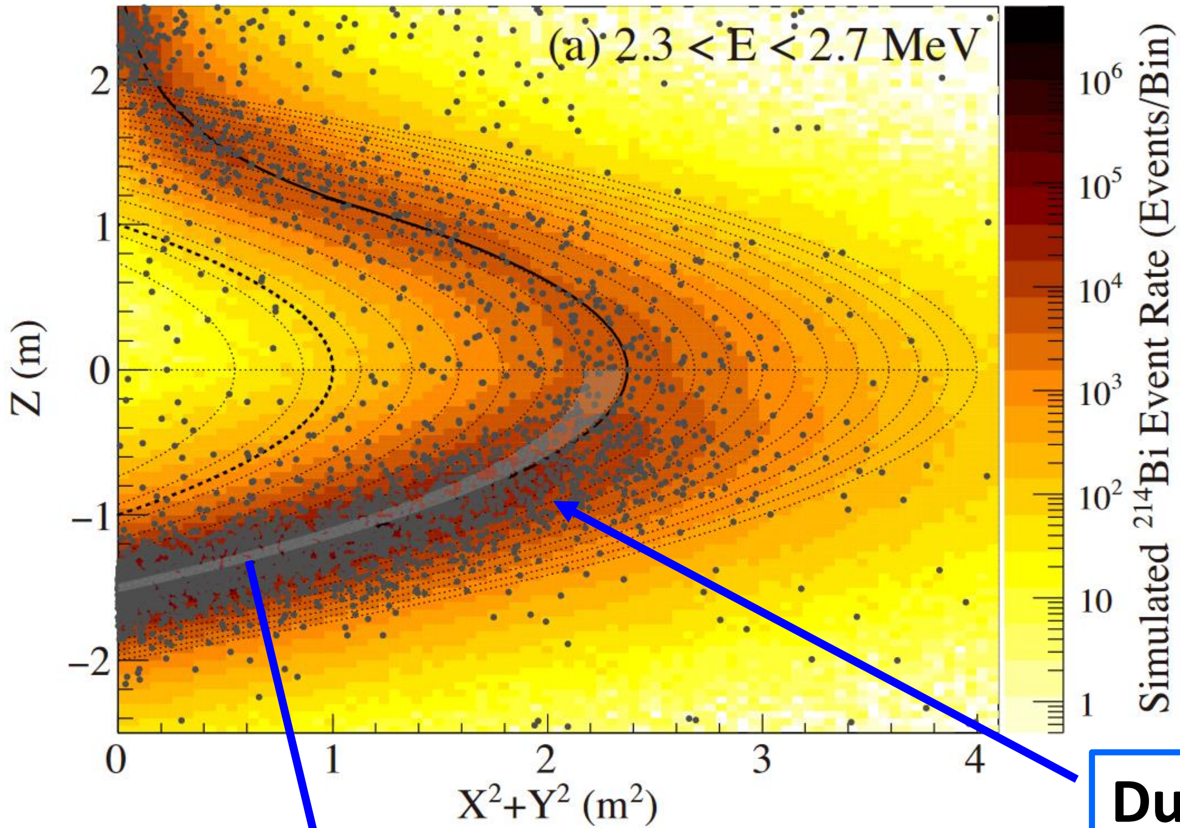
baryon asymmetry of the Universe

KL-ZEN 400
(better than expected)

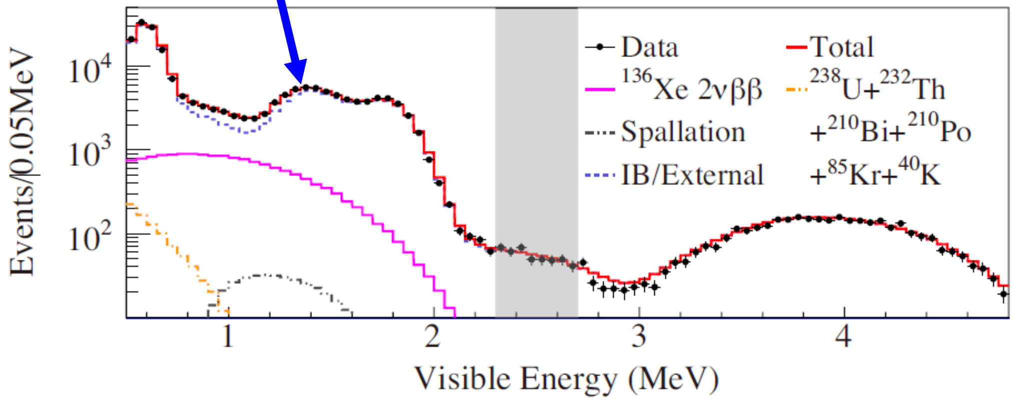
KL-ZEN 800 (expected)
40meV

$m_{\beta\beta}$ = 47 ± 1 meV
K. Harigaya, M. Ibe, and T. Yanagida
"Seesaw mechanism with Occam's razor"
PRD 86, 013002 (2012)

^{214}Bi events on the first mini-balloon surface

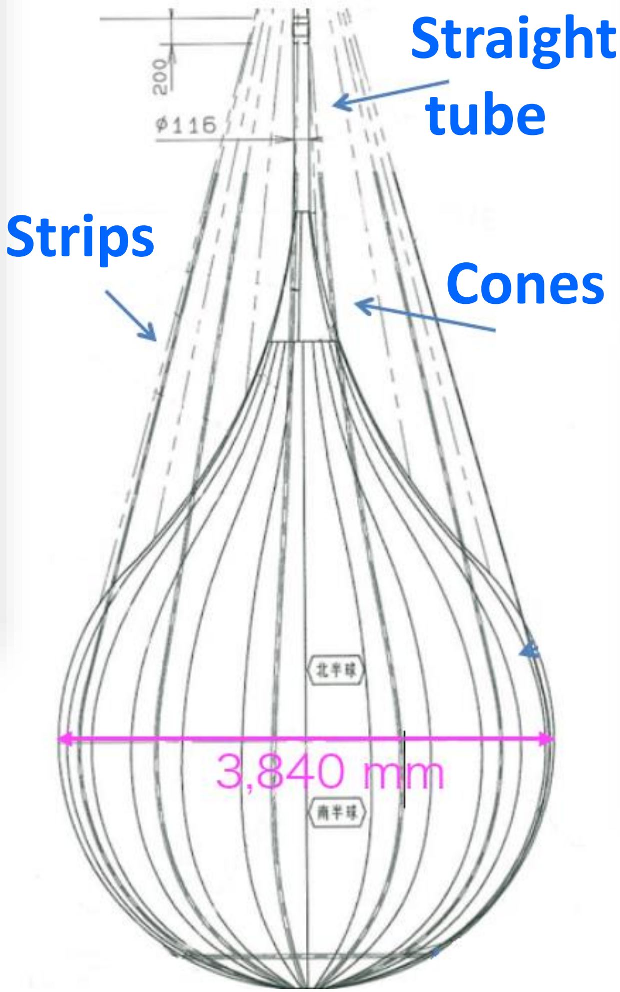


The **^{214}Bi** activity on the mini-balloon`s surface corresponds to **0.16ppb** of **^{238}U** assuming equilibrium while film itself has a **2ppt** of **^{238}U** (measured by ICP-MS).



Dust particles that contain **^{238}U** originate from the mini-balloon construction and failure of diaphragm pump which was a part of the purification system.

New mini-balloon

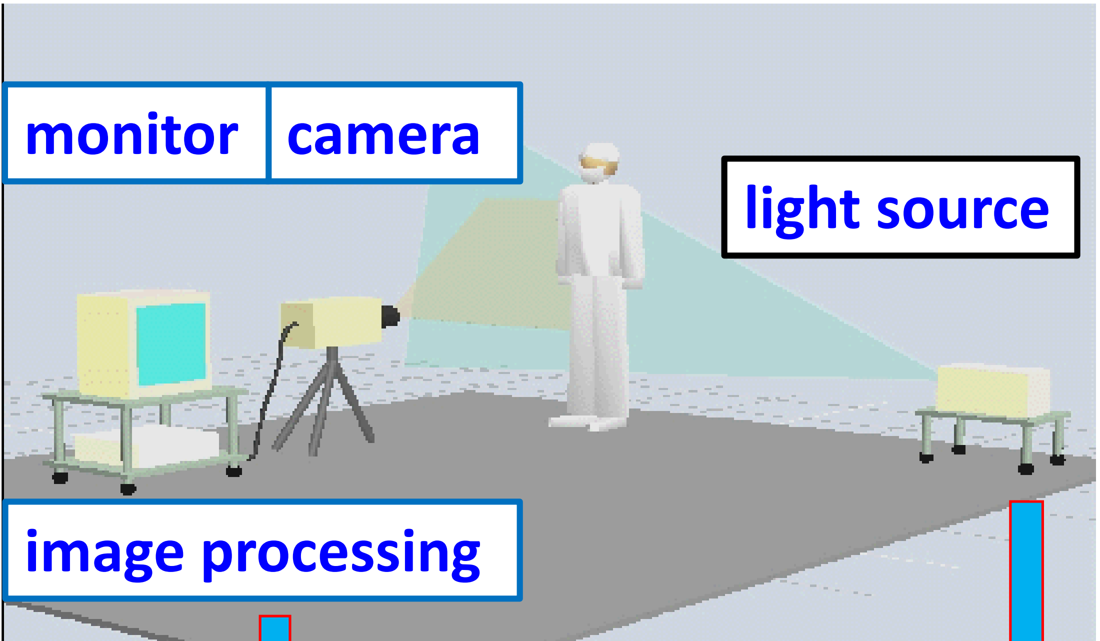


Volume: **31.4m^3**
Diameter: **3.84m**
Material: **Nylon**
Thickness: **25μm**

Work was done during **high humidity season.**

Tohoku U. **class 1 clean room** was used for construction. The clean room and all instruments were carefully cleaned . Dust samples were scanned for **^{137}Cs** at the underground **HPGe** detector at Kamioka.

Laser visualization system for control of airborne particles

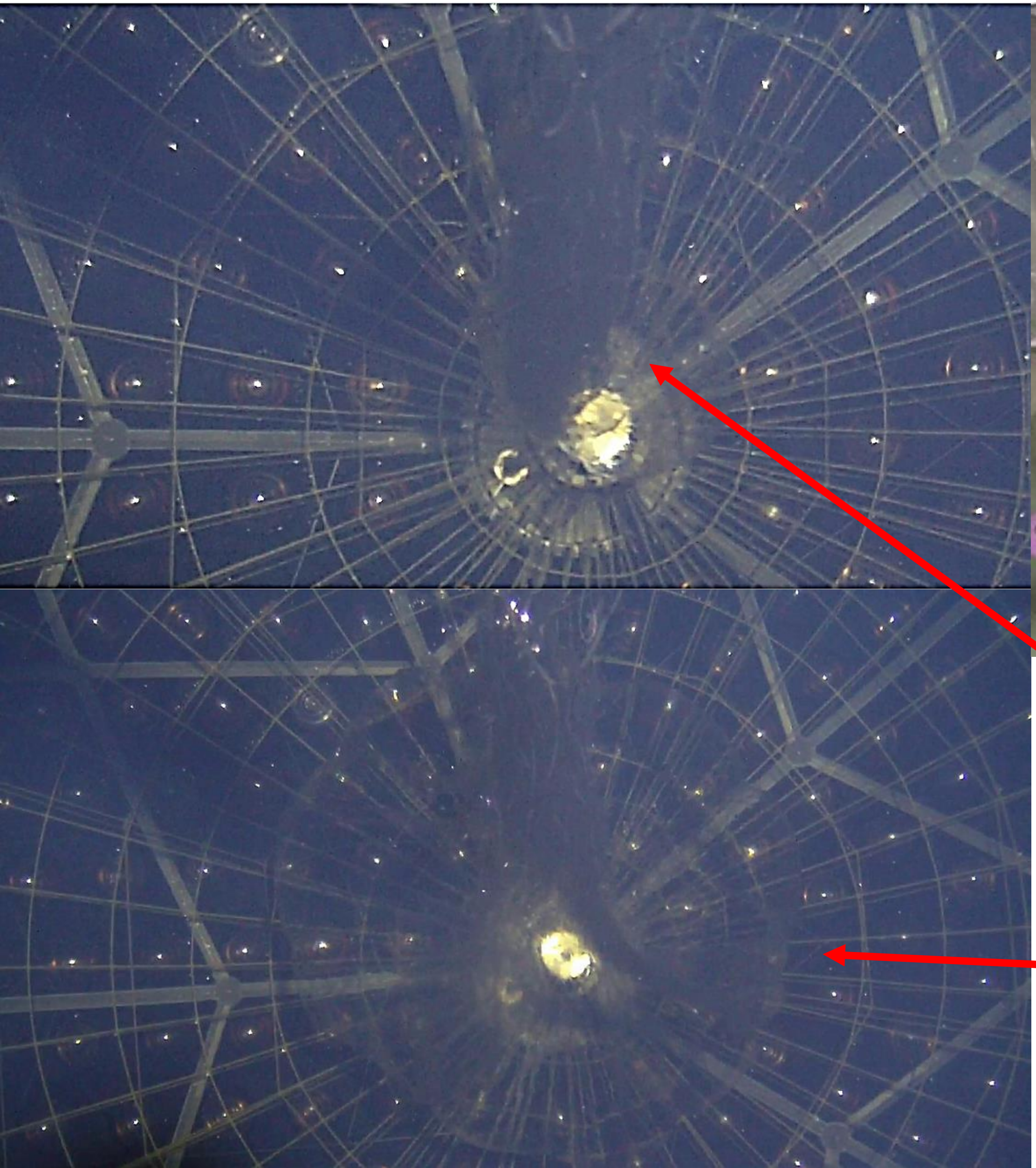


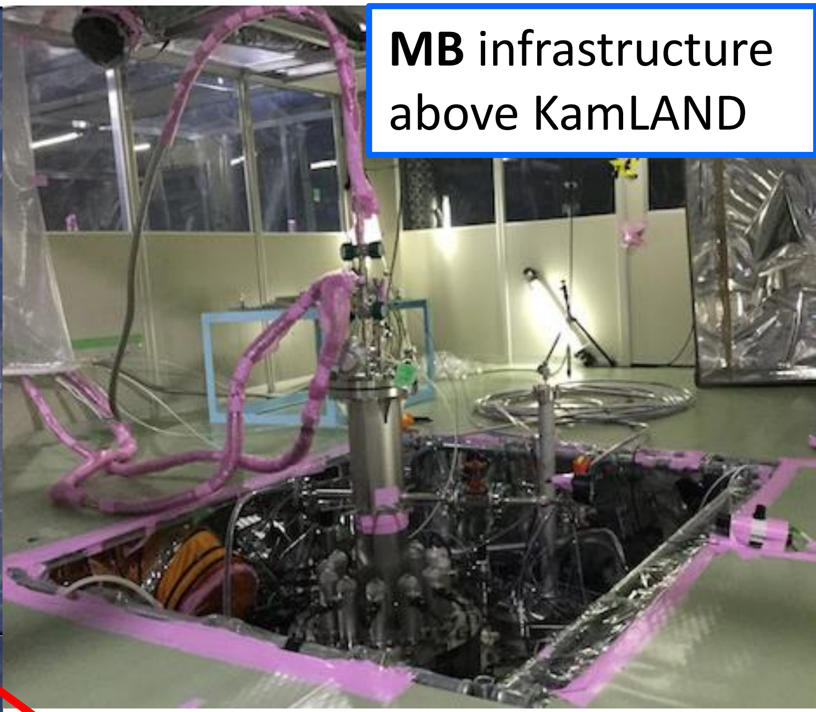
Helps to select

- ❑ clean-room consumables: gloves, clean suits, wiping materials.
- ❑ working procedures such as human's motions that minimize number of dust particles in the air.

New mini-balloon production (summer-autumn 2015)

The new mini-balloon (MB) at KamLAND (Aug 2016)



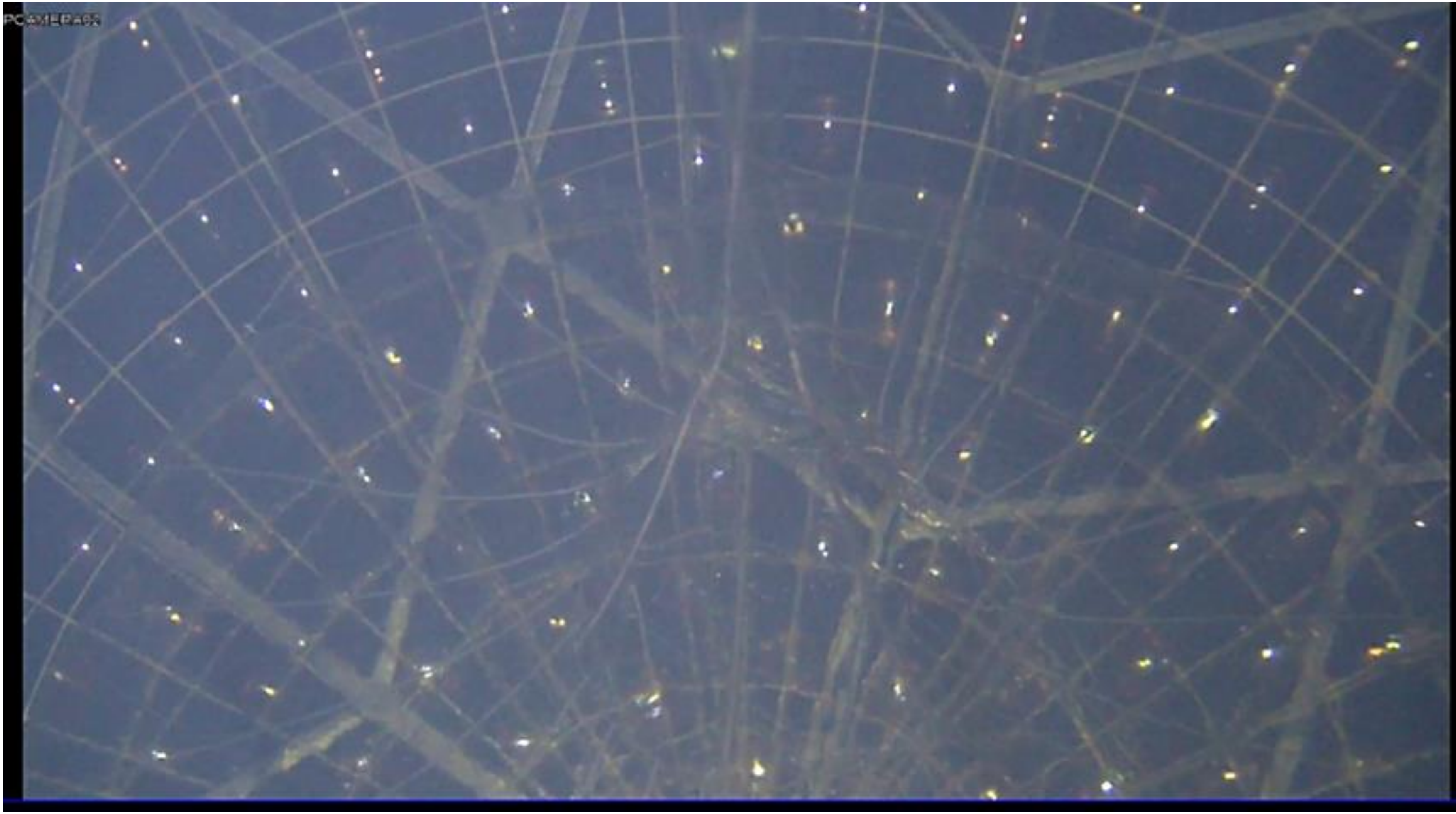


MB infrastructure above KamLAND

MB after deployment to the KamLAND (Top view)

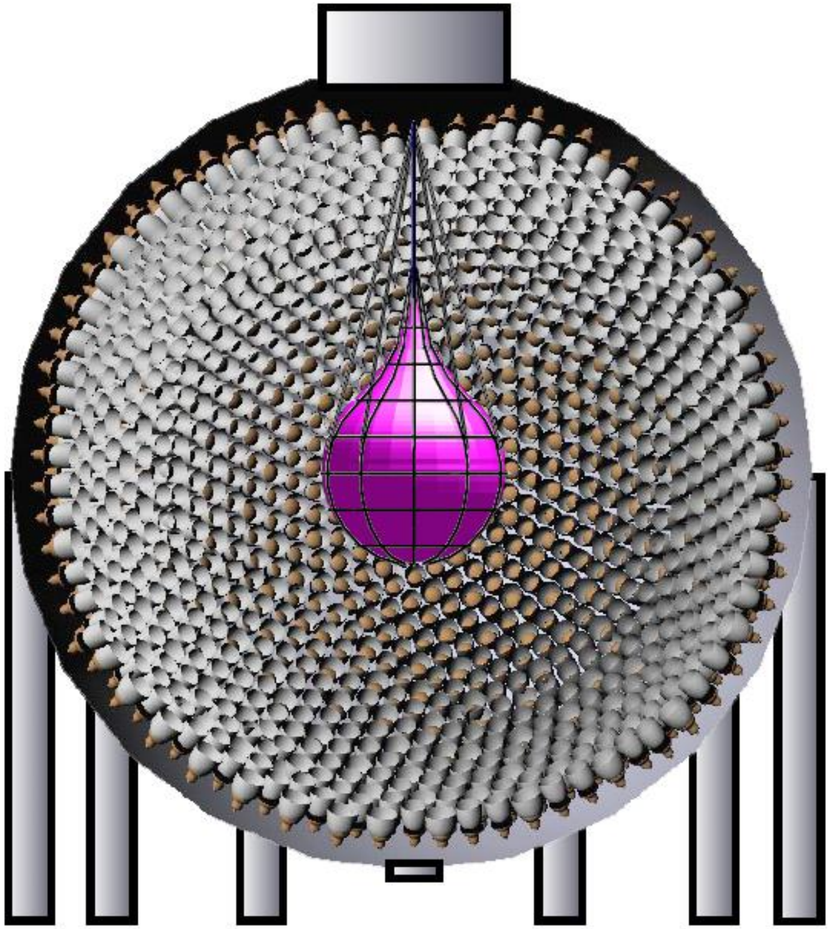
MB partially filled with a "dummy" liquid scintillator

The new MB at KamLAND (August 2016)



The mini-balloon was inflated using **30m^3** of **liquid scintil**lator. It will be replaced by the **Xenon loaded liquid scintillator** in **October-November**.

KamLAND2-Zen to cover the IH mass region



Enriched xenon mass > 1000kg

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

Sensitivity target: $m_{\beta\beta}$ ~ 20meV

Gain in number of detected photons

(after upgrade to KamLAND2)

Lab scintillator: **1.4** times

High QE PMTs: **1.9** times

Light collecting cones: **1.8** times

Summary

- **The KamLAND-Zen 400kg** experiment was completed in Oct 2015. We successfully extracted enriched xenon from liquid scintillator, purified it by distillation, and returned it back to storage facility.
- We published **world's best limit**: $T^{0\nu}_{1/2} > 1.07\times10^{26}$ **yr at 90% C.L.** which corresponds to $m_{\beta\beta}$ **= 61-165meV** depending on choice of NME.
- A **new** (2x larger) **mini-balloon** was deployed to KamLAND on Aug 8th and was inflated using $30.2m^3$ of liquid scintillator.
- Currently **condition** and **background** from the new mini-balloon are being studied.
- **The Xenon-loaded liquid scintillator** will replace current liquid scintillator in **October-November** of this year.
- During the next **800kg** phase we may test **Prof. Yanagida's prediction** for $m_{\beta\beta}$ **= 47±1meV.**
- We work on future **KamLAND2-Zen** project to cover most of the **IH** mass region.