Status of KamLAND2-Zen construction

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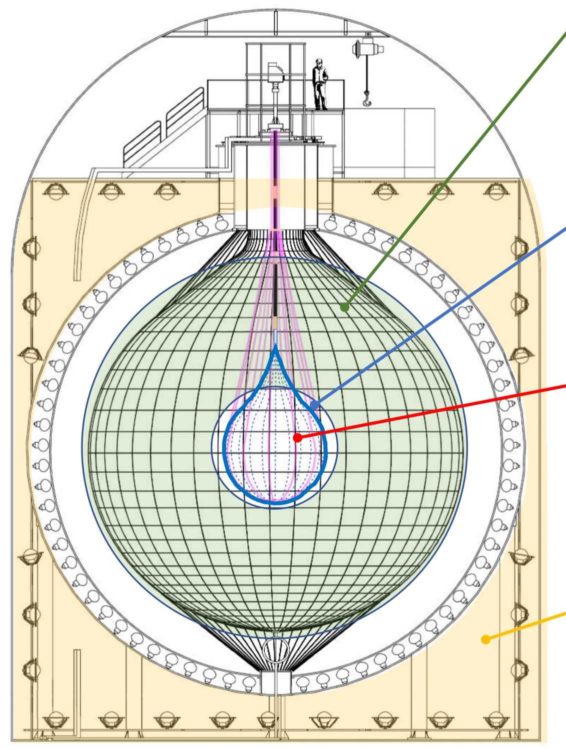
KamLAND-Zen experiment

Zero-neutrino double-beta decay search with KamLAND detector

KamLAND-Zen detector setup



1000-ton purified liquid scntillator

- Low radioactivity : U, Th ≤ 10^{-17} g/g
- Reactor, geo, solar neutrino observation

Inner balloon

- Xenon container
- Clean nylon

Xe-loaded liquid scintillator

- 91% enriched Xe dissolved at ~3 wt%
- Double-beta decay search

Outer water-Cherenkov detector

- Purified water
- Muon veto

Advantage of the KamLAND detector

- Ultra-low radioactivity by LS distillation
- Large size : no external γ-ray background
- Scalability : larger mini balloon, more xenon

→ Ideal enviromnet for extremely rare decay search

KamLAND-Zen 400 (2011 – 2015)

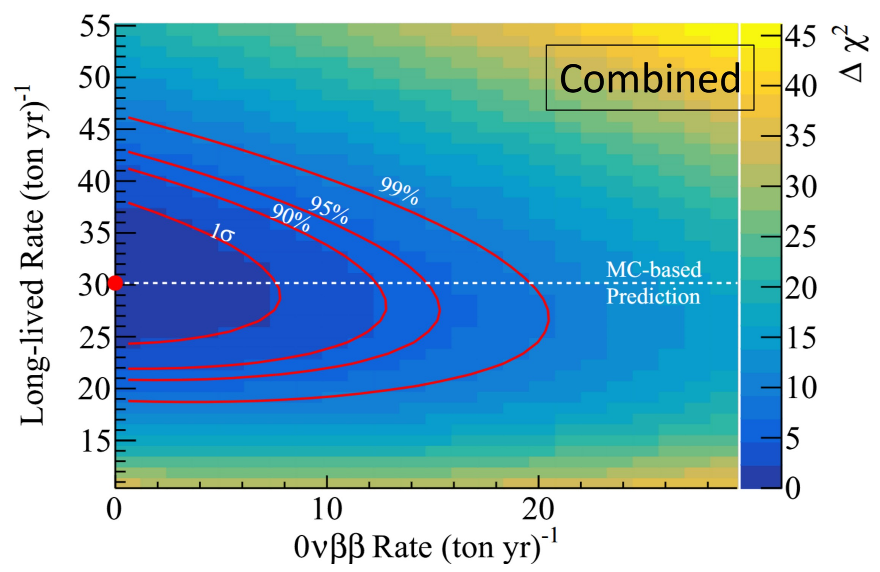
- Mini-balloon radius = 1.54 m
- 320–380 kg of enriched xenon

KamLAND-Zen 800 (2019 – 2024)

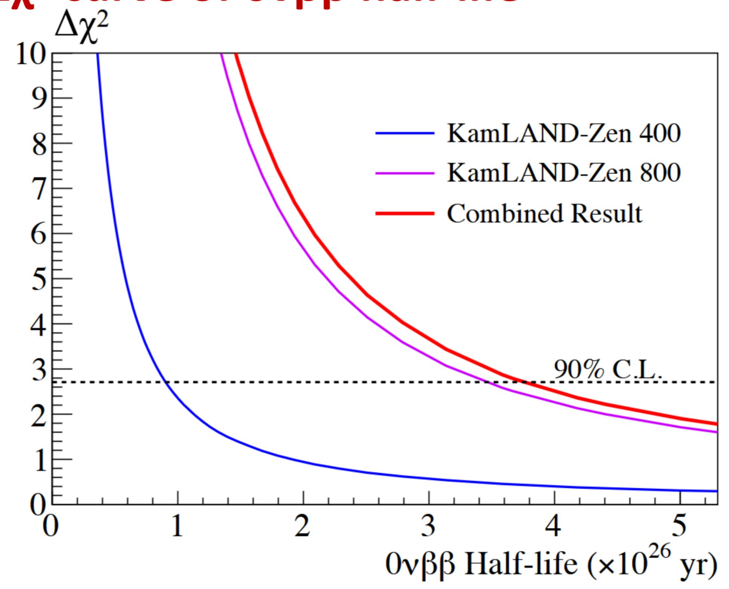
- Mini-balloon radius = 1.90 m
- 745±3 kg of enriched xenon

Results from KamLAND-Zen

$\Delta\chi^2$ map of 0νββ rate and L.L. rate in ROI



$\Delta\chi^2$ curve of 0νββ half-life



0νββ rate best fit : 0 event, 90% C.L. upper limit : < 9.7 events

Lower limit on 0νββ half-life : $T_{1/2} > 3.8 \times 10^{26}$ year (combined result)

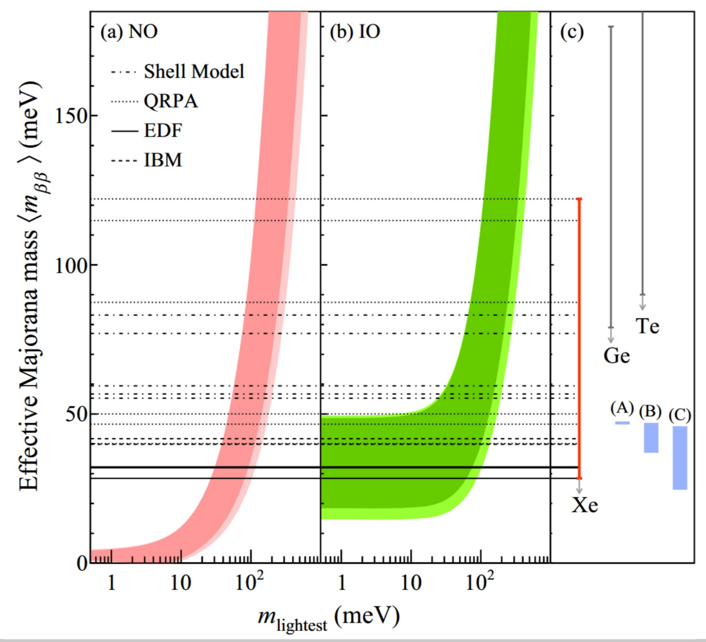
Limit on effective Majorana mass

Using $(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(g_{A,\mathrm{eff}}/g_A)^4|M^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$,

The lower limit on 0νββ half-life is translated to

$$\langle m_{\beta\beta}\rangle < 28 - 122 \text{ meV}$$

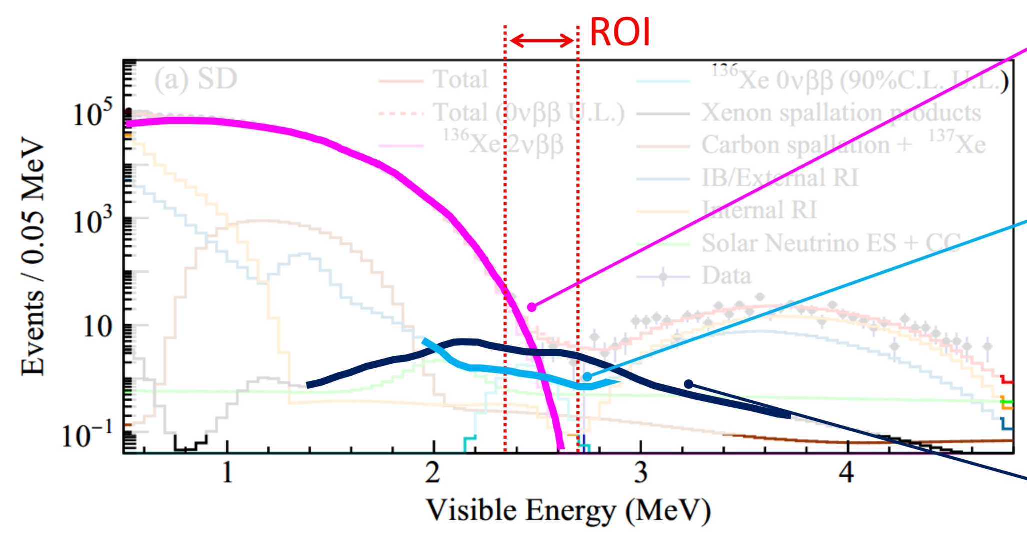
Ref) Phys. Rev. Lett. 135, 262501 (2025)



No positive signal
Most stringent limit on the effective Majorana

Toward further sensitivity

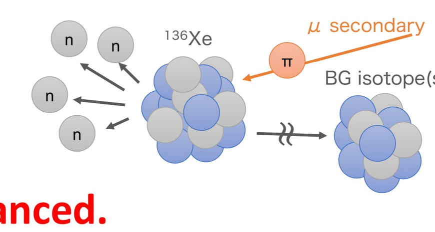
Background summary of KamLAND-Zen



Background	Estimated	Best-fit
^{136}Xe $2\nu\beta\beta$	27.6 ± 0.2^a	27.68
Residual radioactivity in Xe-LS		
^{238}U series	0.08 ± 0.01	0.08
^{232}Th series	···	1.35
External (Radioactivity in IB)		
^{238}U series	···	6.61
^{232}Th series	···	0.04
Neutrino interactions		
^{8}B solar νe^- ES	3.57 ± 0.09	3.58
Spallation products		
Long-lived	17.82 ± 1.30^a	20.27
^{10}C	0.00 ± 0.05	0.00
^{6}He	0.54 ± 0.27	0.56
^{137}Xe	0.72 ± 0.60	0.71

Ref) Phys. Rev. Lett. 135, 262501 (2025)

Background reduction strategy



^{136}Xe $2\nu\beta\beta$: Energy-based discrimination necessary
→ **Detector energy resolution needs to be enhanced.**

Long-lived spallation products : Tagged with μ-n's-spallation triple coincidence
→ **Neutron detection efficiency should be improved**

Radioactivity in IB : ^{214}Bi in the mini-balloon nylon film
Tagged with ^{214}Bi—^{214}Po delayed coincidence
→ **Higher detection efficiency of ^{214}Po in mini-balloon is required.**

KamLAND2-Zen experiment

Detector upgrade highlights

- **Light yield increase** by
  - ➢High transparency liquid scintillator (x1.4)
  - ➢Light-correction mirrors on PMT (x1.8)
  - ➢High quantum efficiency PMT (x1.9)

  ✓**x5 increased effective light yield**
  ✓**Twice better energy resolution@Q-value**
  ✓**2νββ background reduction by order of 2.**

- New mini-balloon of **scintillating material**

  ✓**Film-^{214}Bi rejection by α-tagging**
  ✓**Expanding effective volume**

- State-of-the-art read-out electronics: **MoGURA2**
  - ➢RFSoC powered data acquisition

  ✓**~100% spallation neutron detection**
  ✓**Improved L.L. tagging : 44% → 60%**

Target sensitivity

- $\langle m_{\beta\beta}\rangle = 20$ meV with 5 years
- **KamLAND2-Zen aims to cover the IO region.**

Detector decommissioning and new detector construction timeline

KamLAND-Zen decommission	KamLAND2 construction	KamLAND2-Zen construction

2024 – 2025 – 2026 – 2027 – 2028 – 2029

Xe extraction → **DAQ stop** → OD dismantling → LS&BO extraction → PMT removal → OD reconstruction → **Now** → HQE PMT + light-collection mirror installation → LS&BO installation → New DAQ system install → **KamLAND2 start** → Mini-balloon installation → Xe loading → **KamLAND2-Zen start**