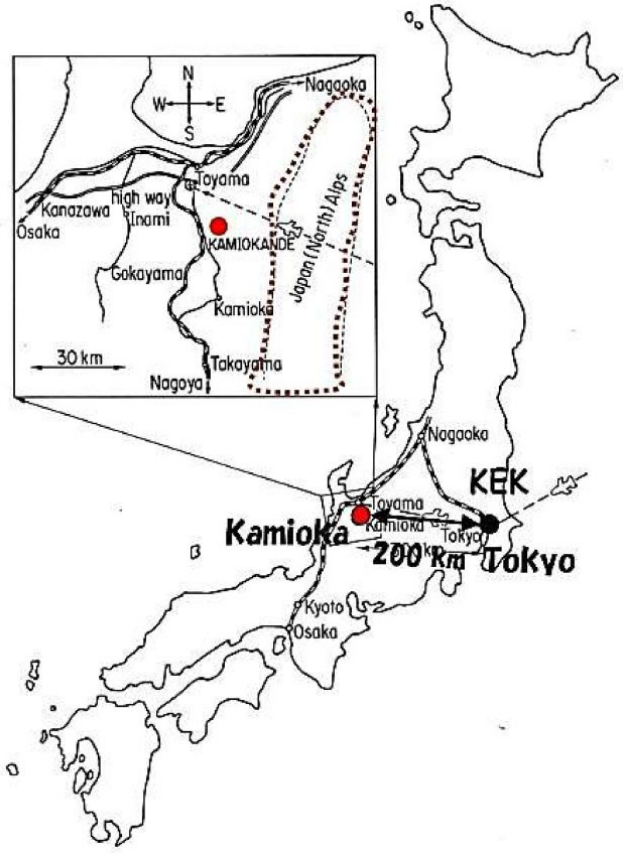
Recent results of the KamLAND-Zen experiment

National Research Nuclear University

НИЯУ МИФИ

Alexandre Kozlov



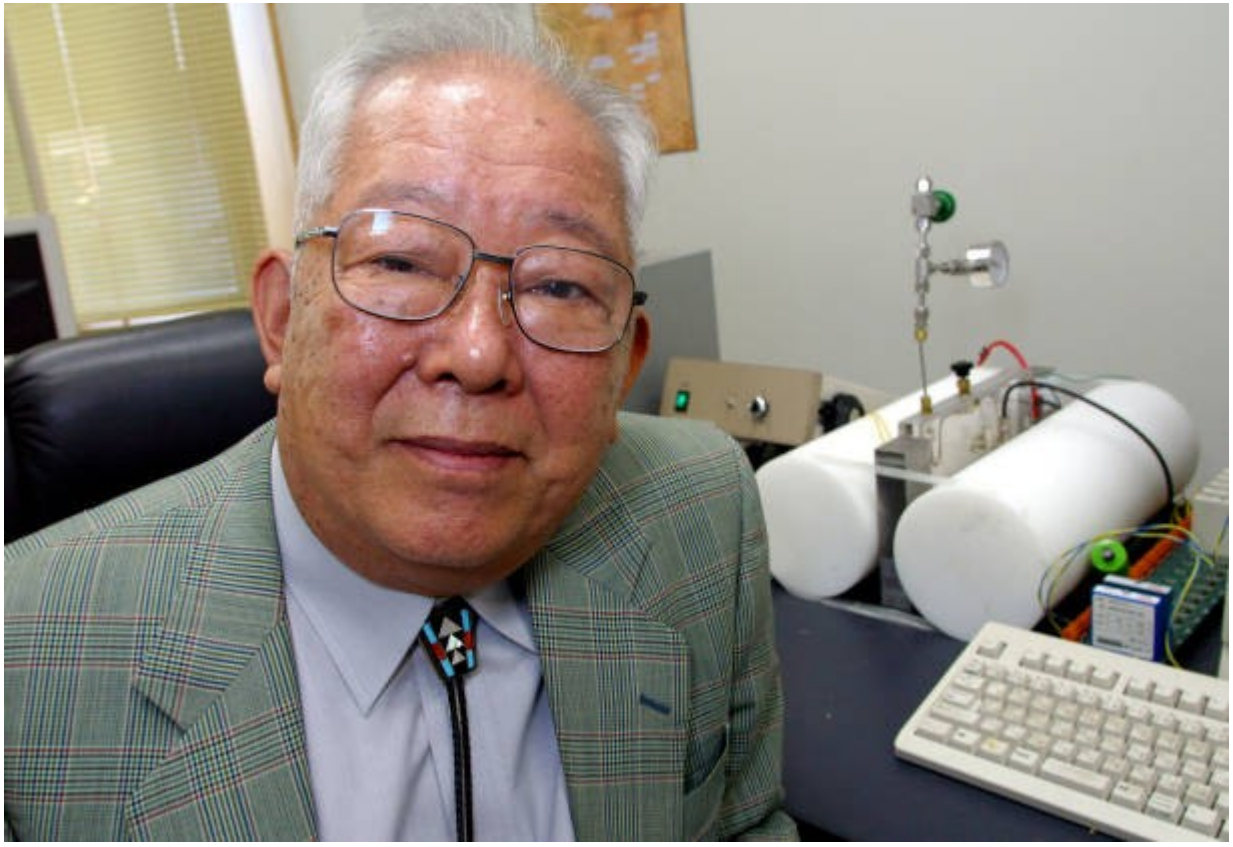
Nucleus-2022, Moscow

Search for physics beyond the SM at Kamioka

(good timing, industry support and luck)

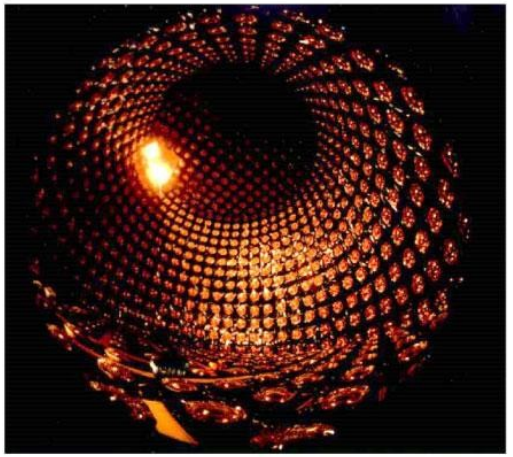
Atsuto Suzuki

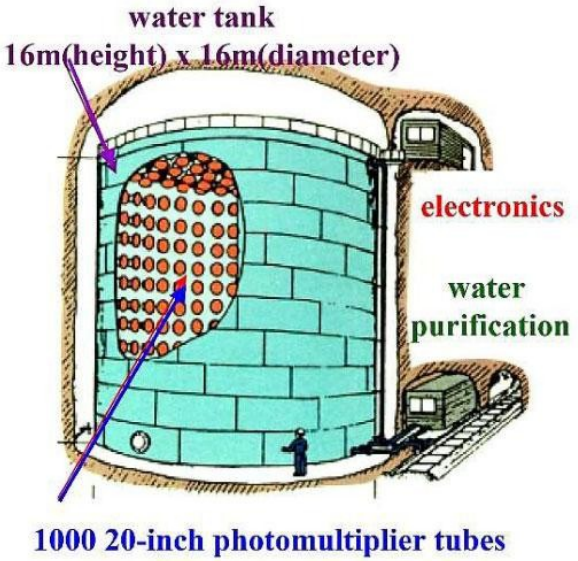
鈴木 厚人



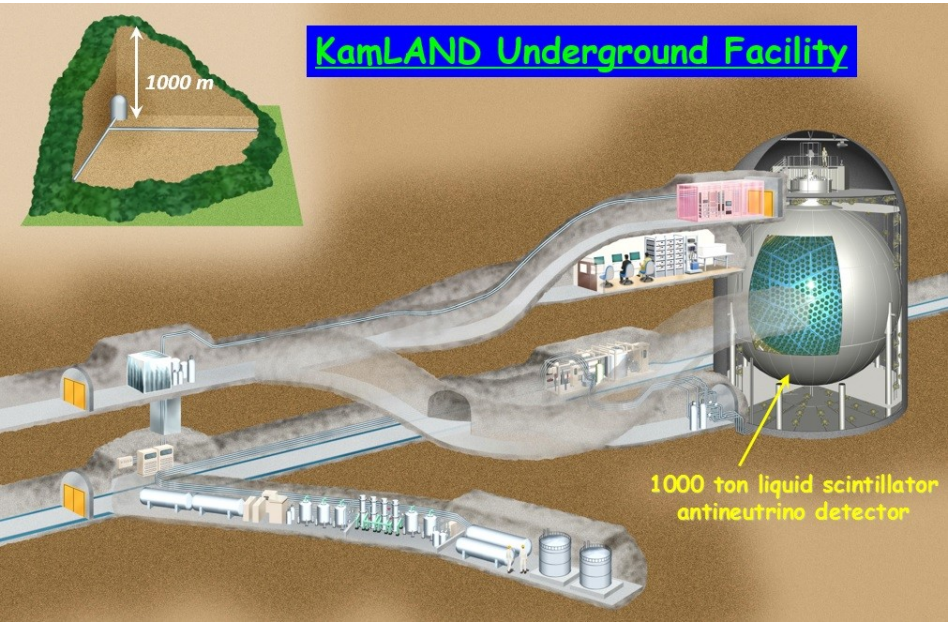
Masatoshi Koshiba

小柴 昌俊

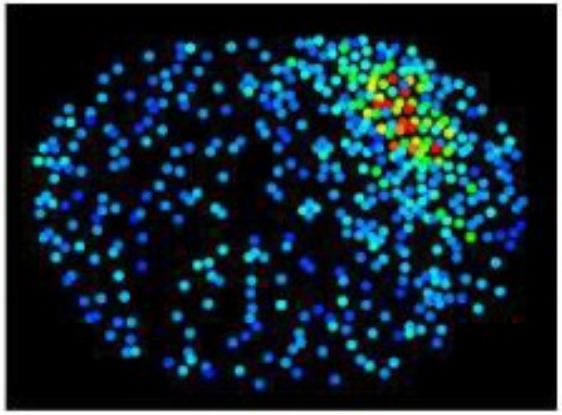




Kamiokande: search of **p decay**
(3kt *water Cherenkov* detector,
6 July 1983; detected SN1987A)



OD upgrade (2016)



Point-like event

KamLAND: search of **ν oscillation** (1kt *liquid scintillator* detector,
17 Jan 2002; confirmed LMA for Solar neutrino problem in 2003)

Why do we need mines?

Intensity ($cm^{-2} s^{-1} sr^{-1}$)

10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, 10^{-10}, 10^{-11}, 10^{-12}, 10^{-13}

- Crouch World Survey, 1987
- Crookes and Rastin, 1973
- Bergamasco et al., 1971
- Stockel, 1969
- Castagnoli et al., 1965
- Avan and Avan, 1955
- Randall and Hazen, 1951
- Bollinger, 1950
- Clay and Van Gemert, 1939
- Wilson, 1938

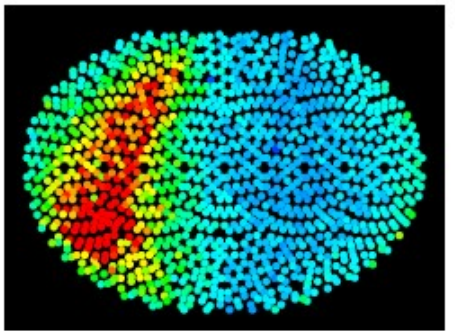
Kamioka

1km of rock

0 2 4 6 8 10 12 14 16 18

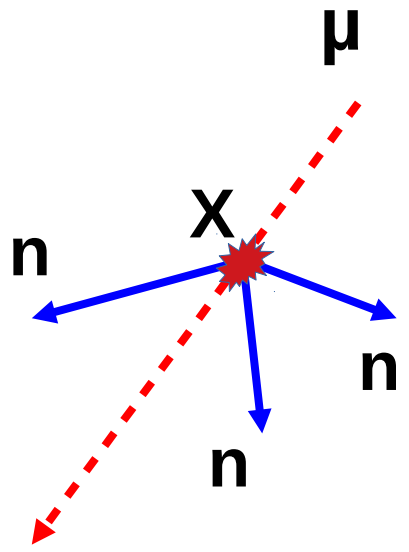
Depth (10^3 m.w.e.)

〈 Eμ 〉 ~ 260GeV



KamLAND

The cosmic-ray muon flux vs depth (in m.w.e.)



X (^{10}C, ^{11}C, ...)

The 0νββ experiment using ^{136}Xe

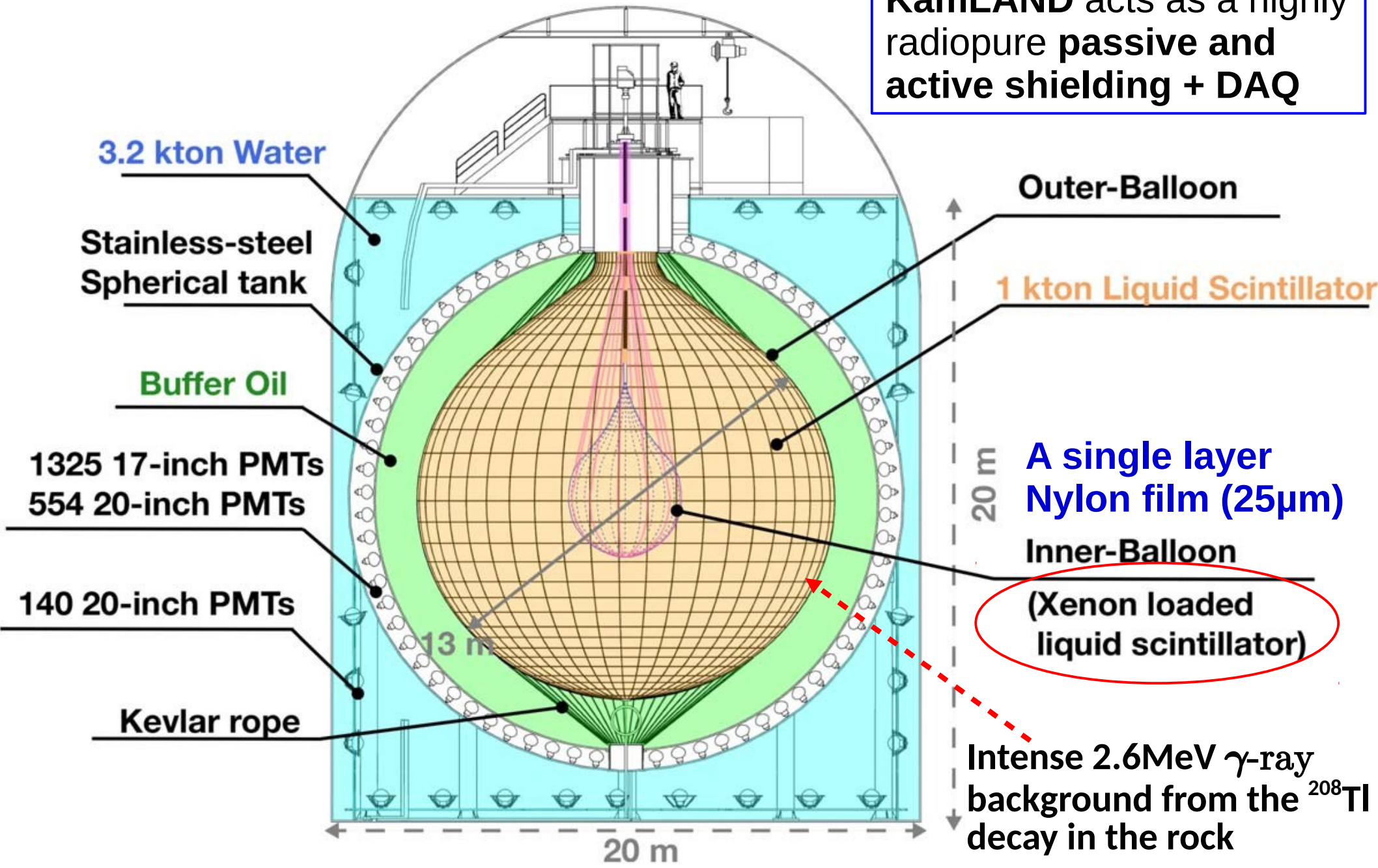
►**The KamLAND-Zen collaboration** was formed at Caltech KamLAND meeting, March 16-19 2008

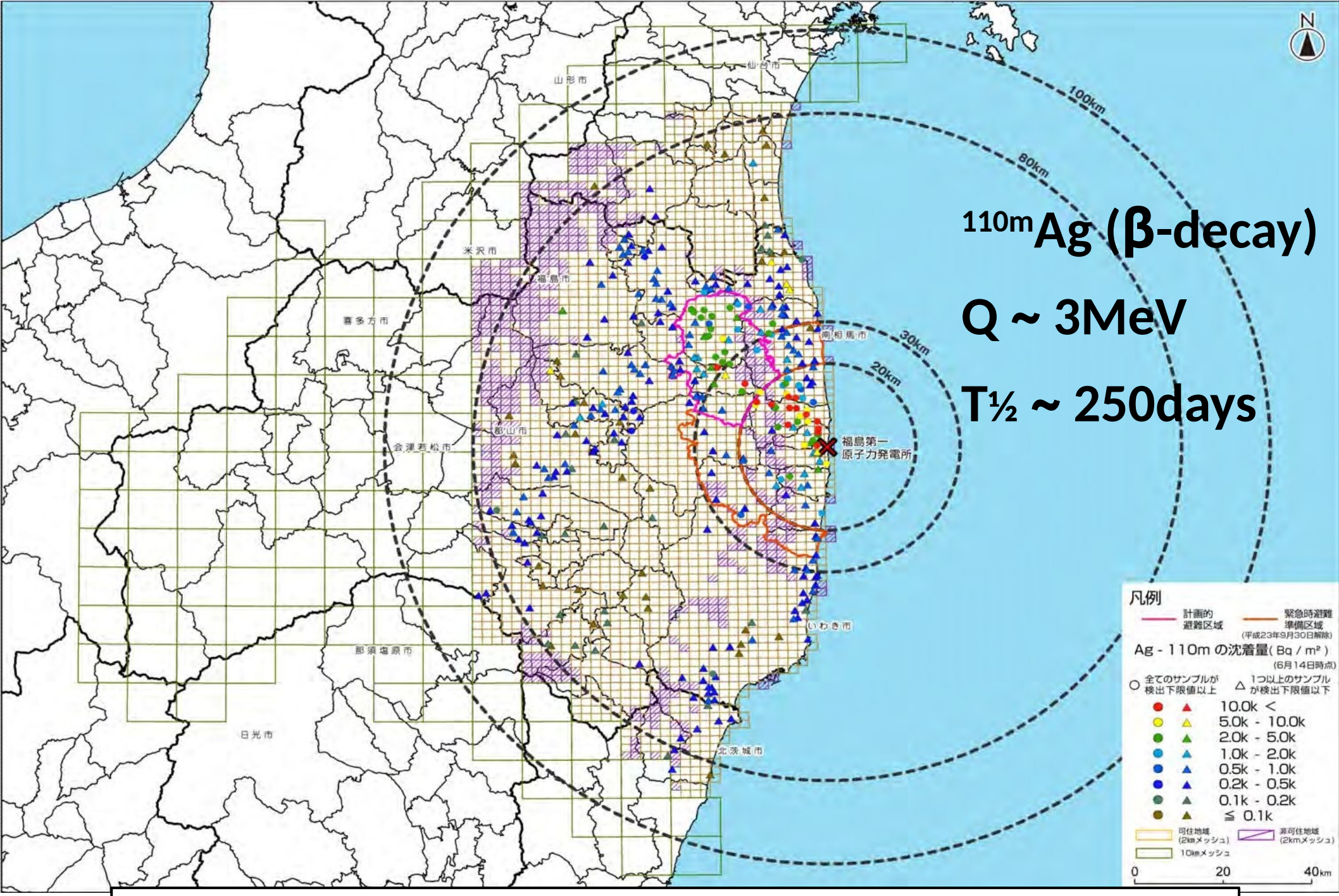
►**KamLAND-Zen 400** (ø3.2m mini-balloon)
– Phase-I 320kg of enriched xenon (2011-2012)
– Purification
– Phase-II 380kg of enriched xenon (2013-2015)
– Upgrade
►**KamLAND-Zen 800** (ø3.8m mini-balloon)
745kg of enriched xenon (2019-until now)

Xenon gas, ~91% enriched in ^{136}Xe, was delivered from Russia

KamLAND-Zen: search of **0νββ decay in the ^{136}Xe detector**, began in October 2011

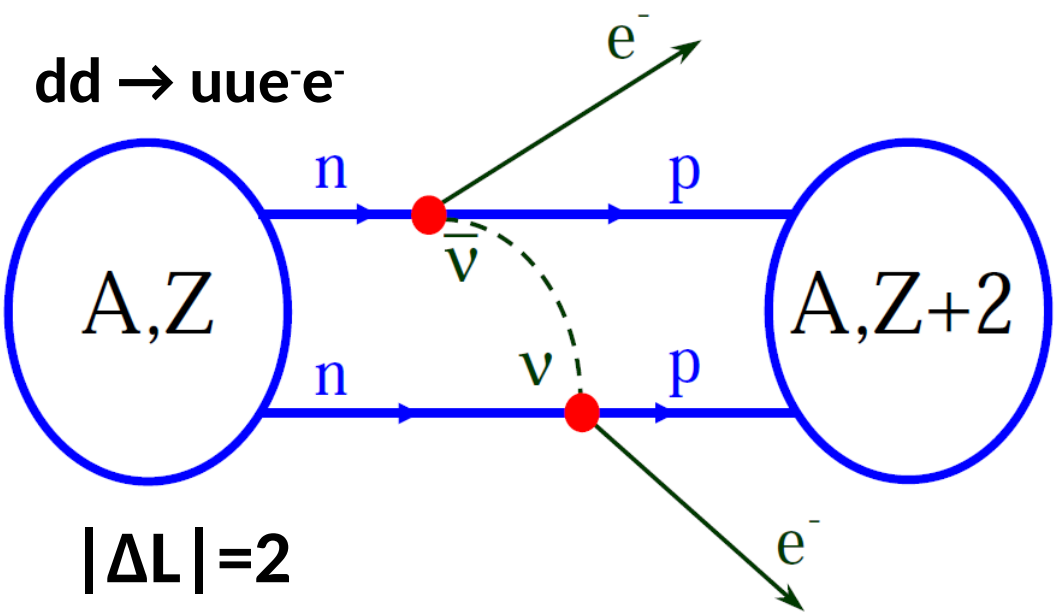
KamLAND acts as a highly radiopure **passive and active shielding + DAQ**



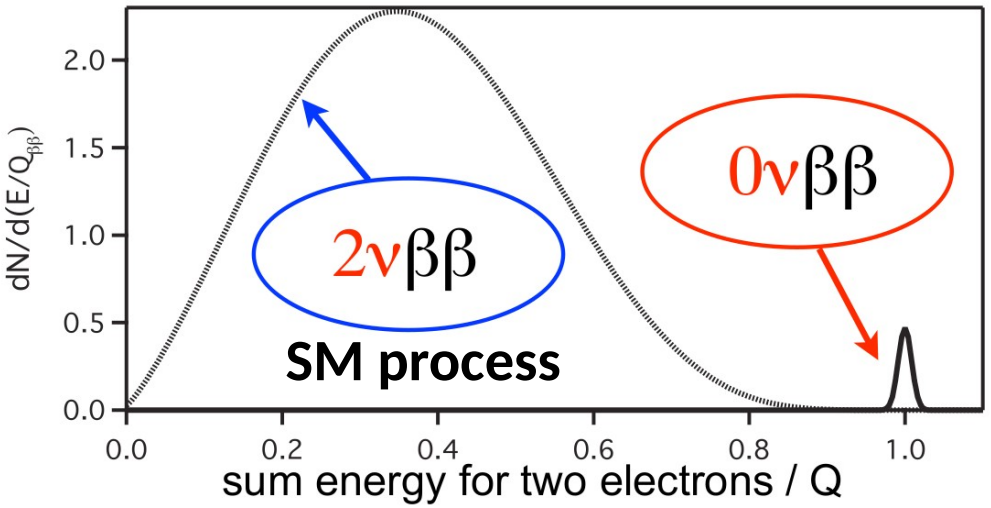


^{110m}Ag fallout from the **Fukushima-I nuclear incident** in 2011 had a long lasting negative impact on the KamLAND-Zen 400 experiment

The 0νββ test of seesaw mechanism



$T_{½} \sim 10^{19}$-10^{21}y , $Q_{ββ} \sim$ 2-3MeV



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

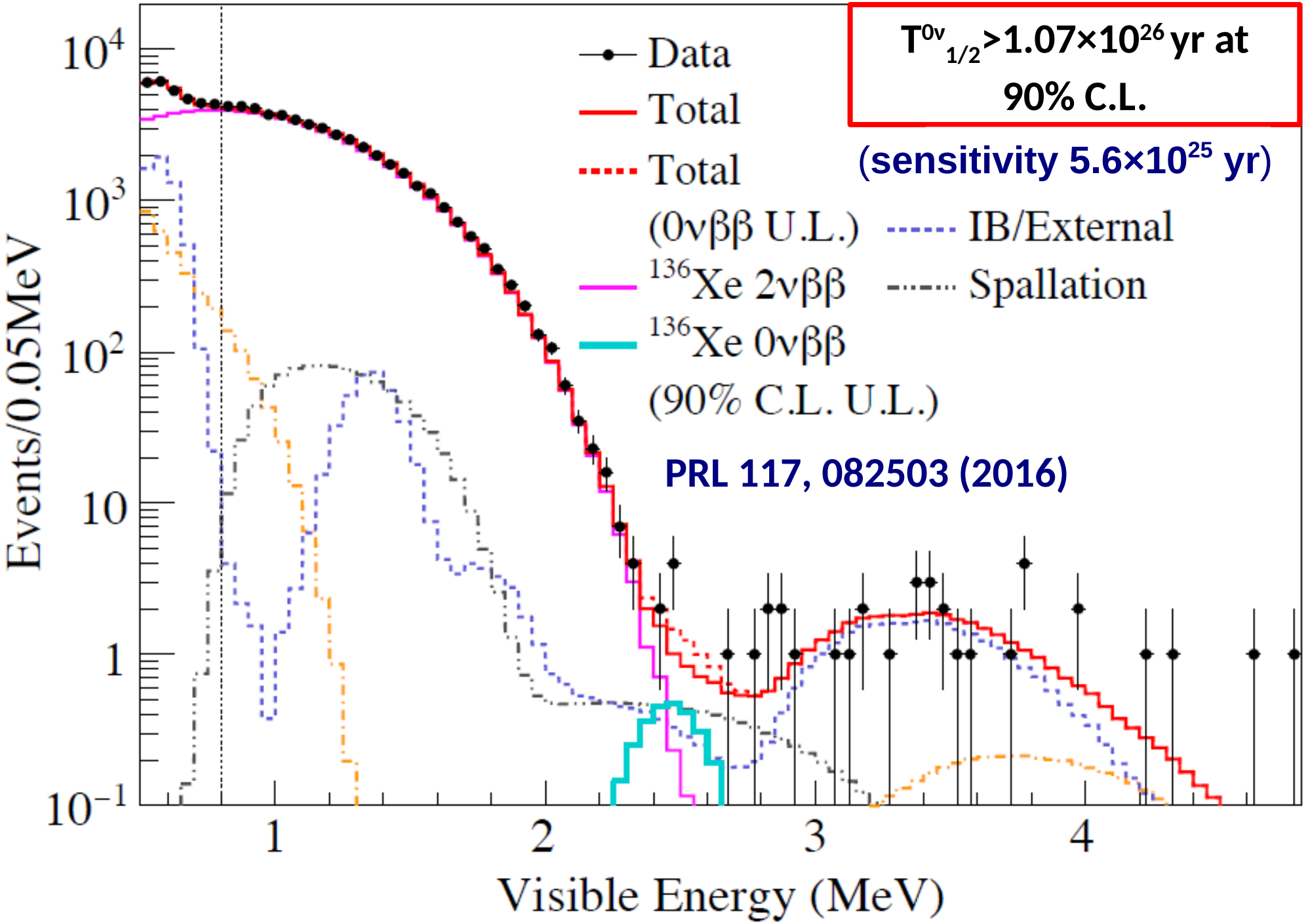
In calorimeters, such as KamLAND, **sum of kinetic energies of two electrons** is measured

$$(T^{0\nu}_{½})^{-1} = G^{0\nu}(Q_{ββ},Z)\cdot|M^{0\nu}|^2\cdot m_{ββ}^2$$

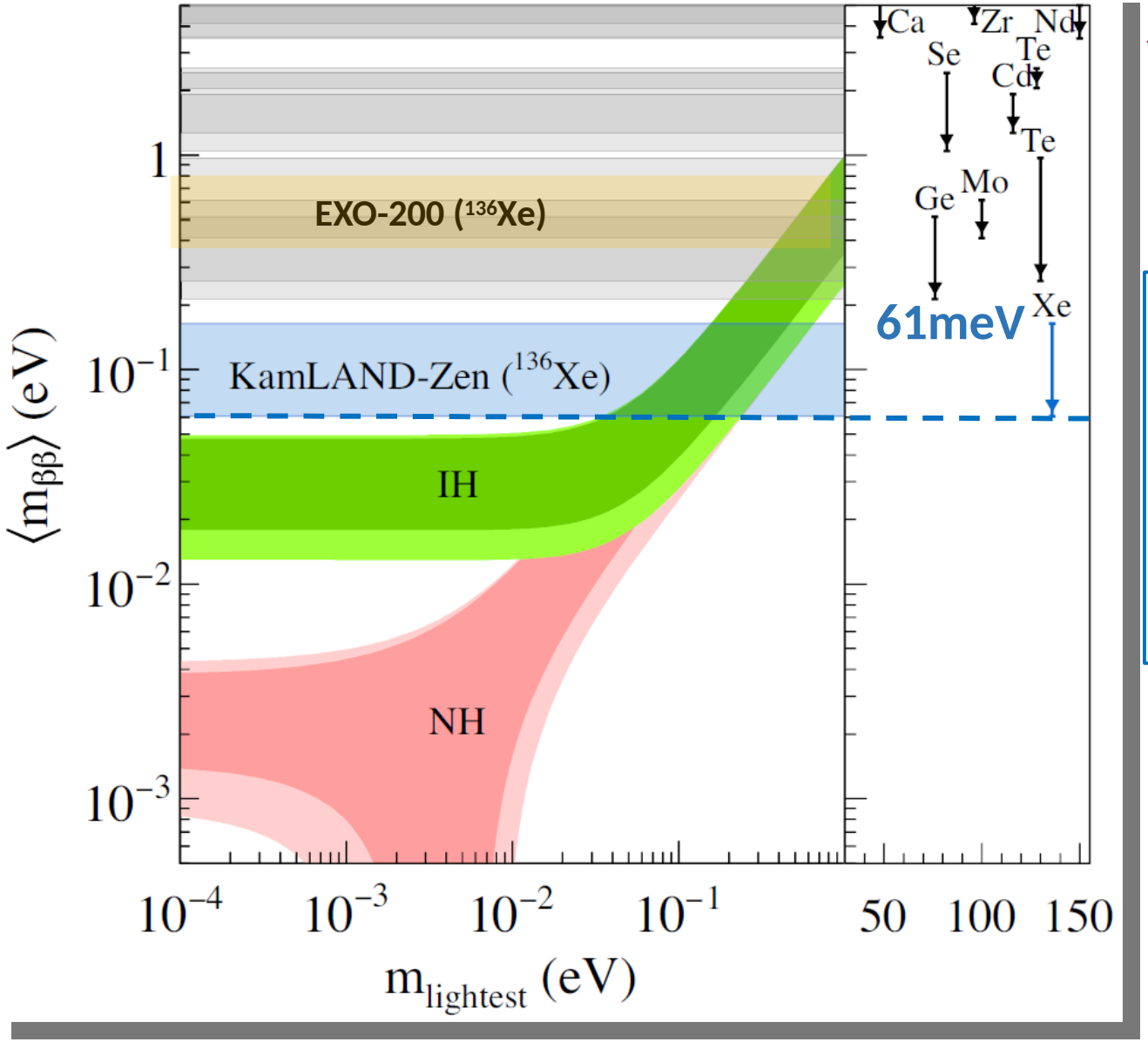
- $G^{0\nu}(Q_{ββ},Z)$ – phase space factor
- $|M^{0\nu}|$ – nuclear matrix elements
- $m_{ββ}$ – effective mass of neutrino

- The **only** method to measure **the absolute neutrino mass** below quasi-degenerate region.
- **Neutrino sector** is the **place** where **physics beyond Standard Model** was observed.

The KamLAND-Zen 400: final result (year 2016)



The final result of the KamLAND-Zen 400 (2016)

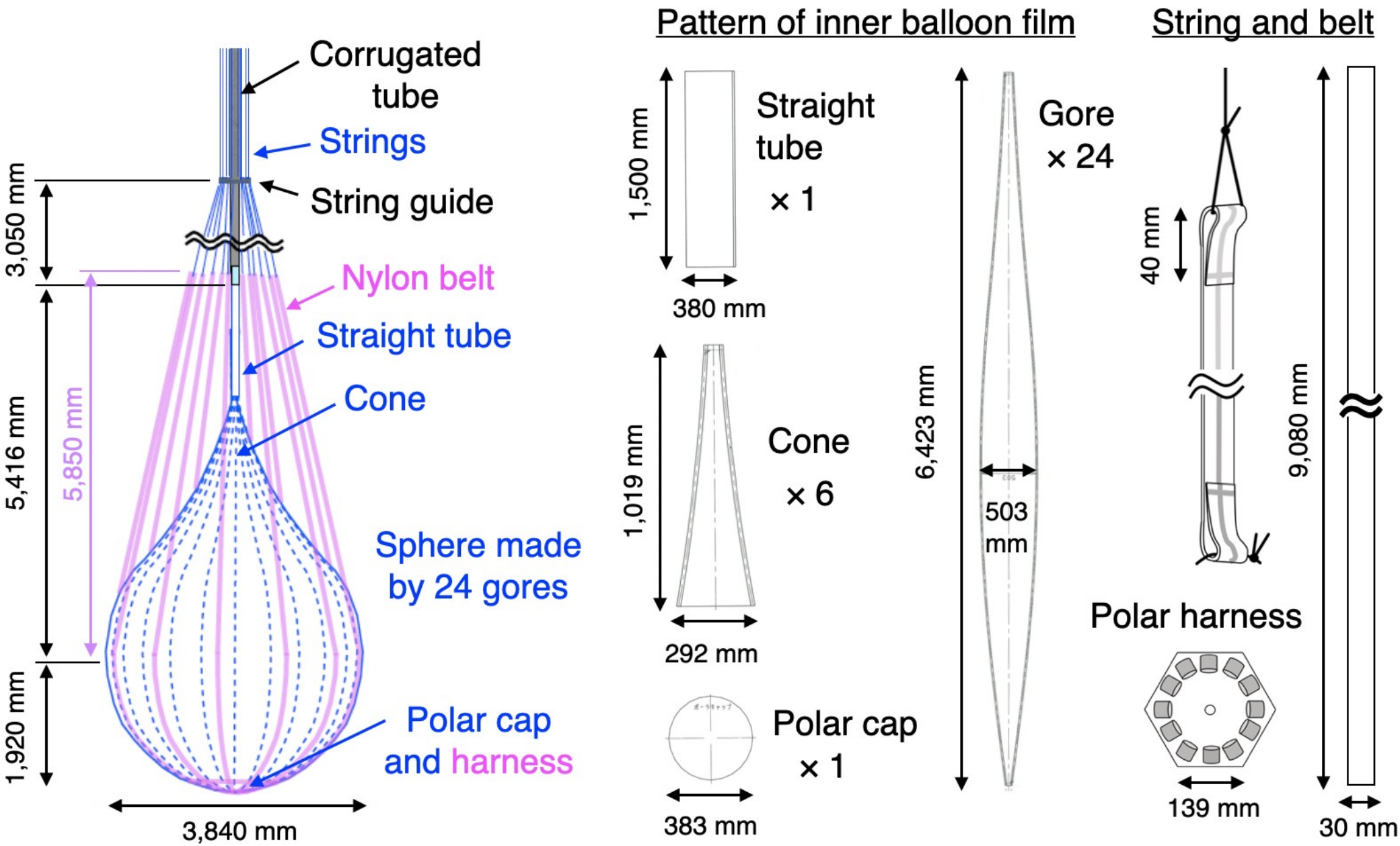


$\langle m_{\beta\beta} \rangle$ < (61-165)meV

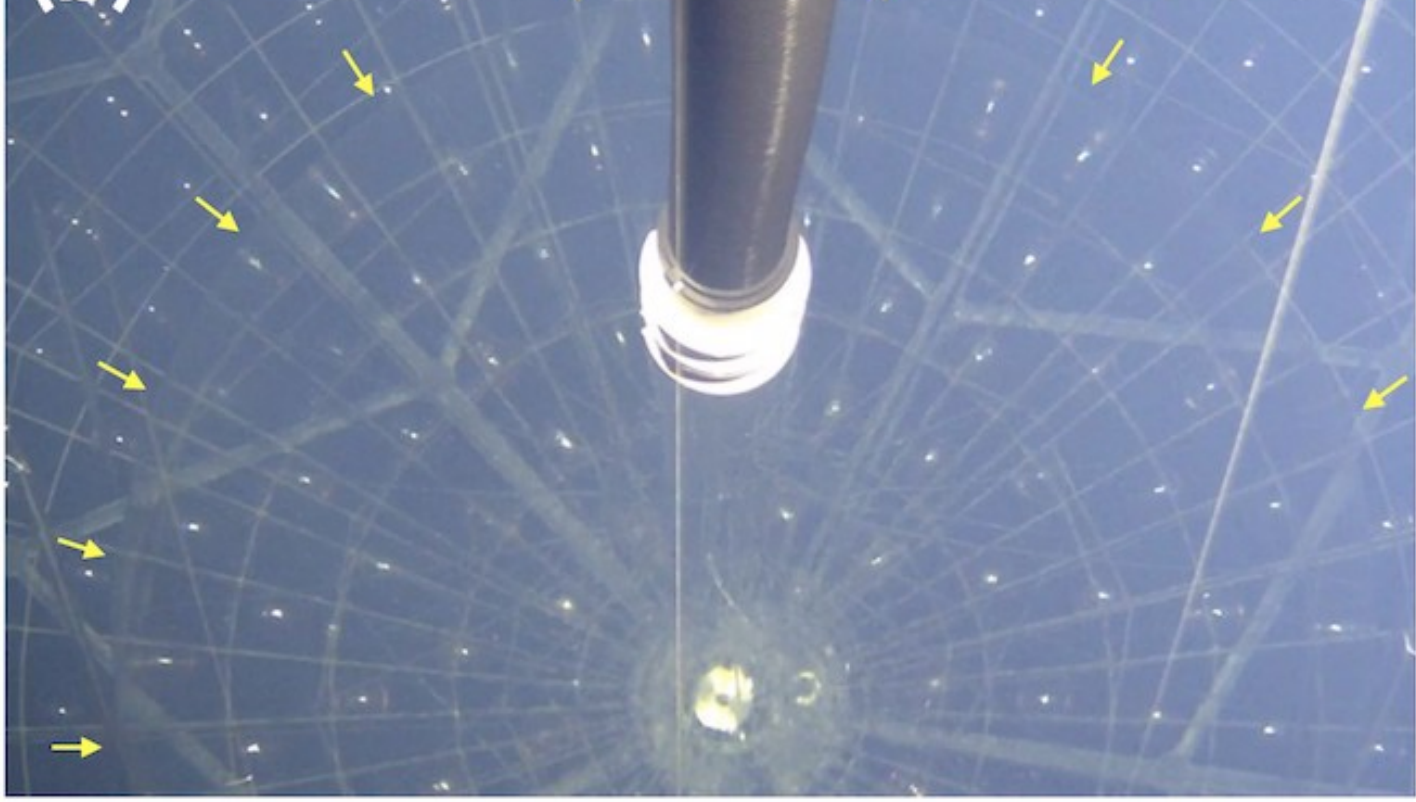
UL: $m_{lightest}$ 180-480 meV

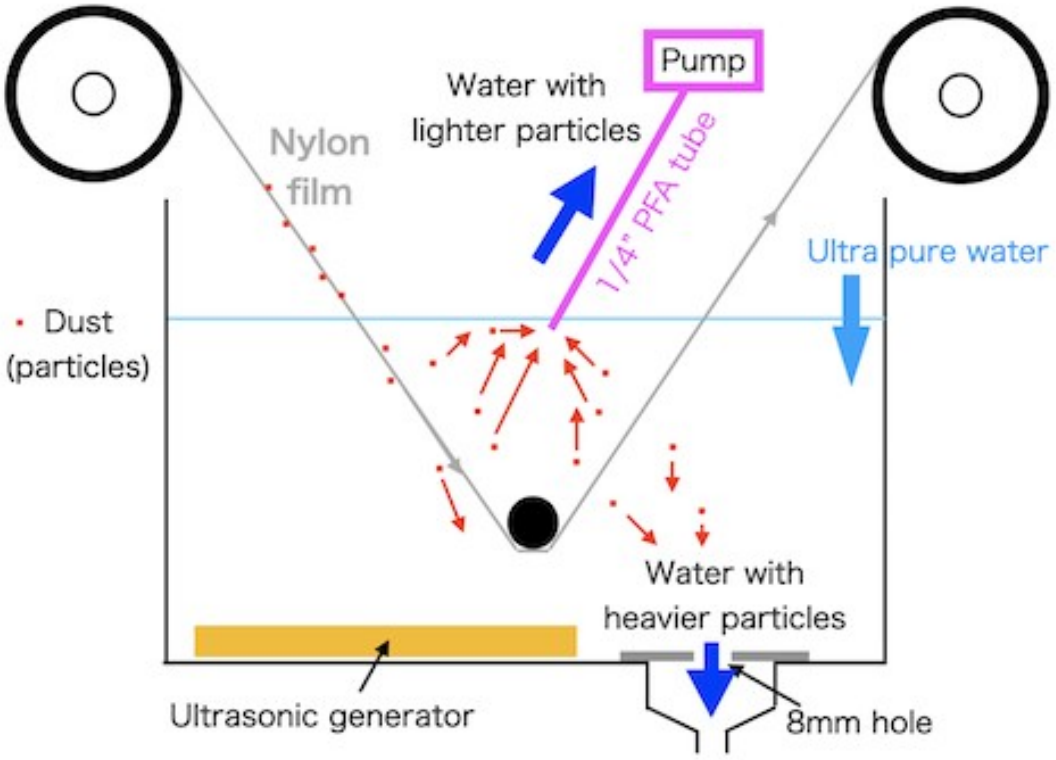
Prediction for the
$m_{\beta\beta}$ = 47±1 meV:
K. Harigaya, M. Ibe, and T. Yanagida "Seesaw mechanism with Occam's razor"
PRD 86, 013002 (2012)

The new mini-balloon for KamLAND-Zen 800

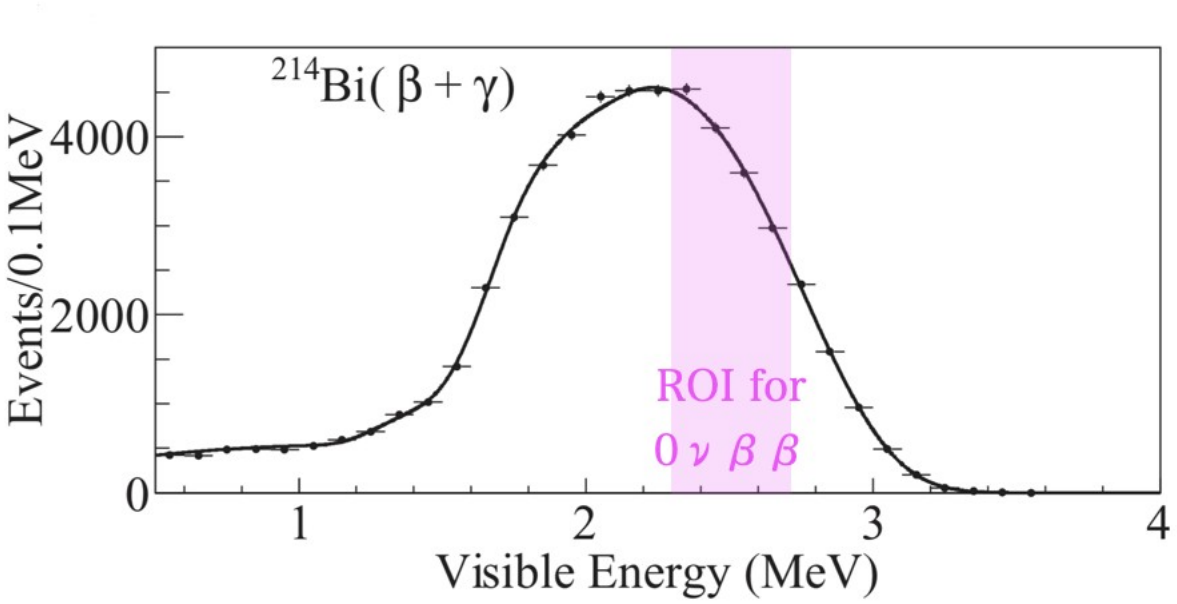


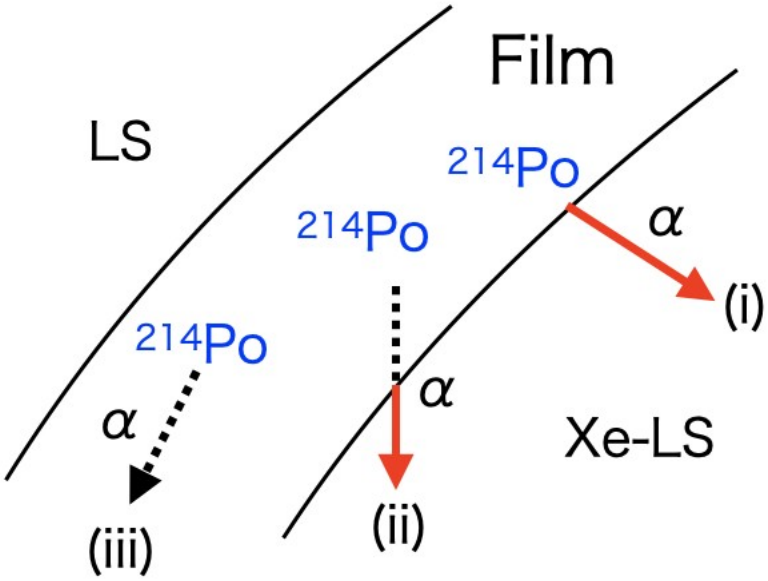
JINST 16 P08023 (2021)



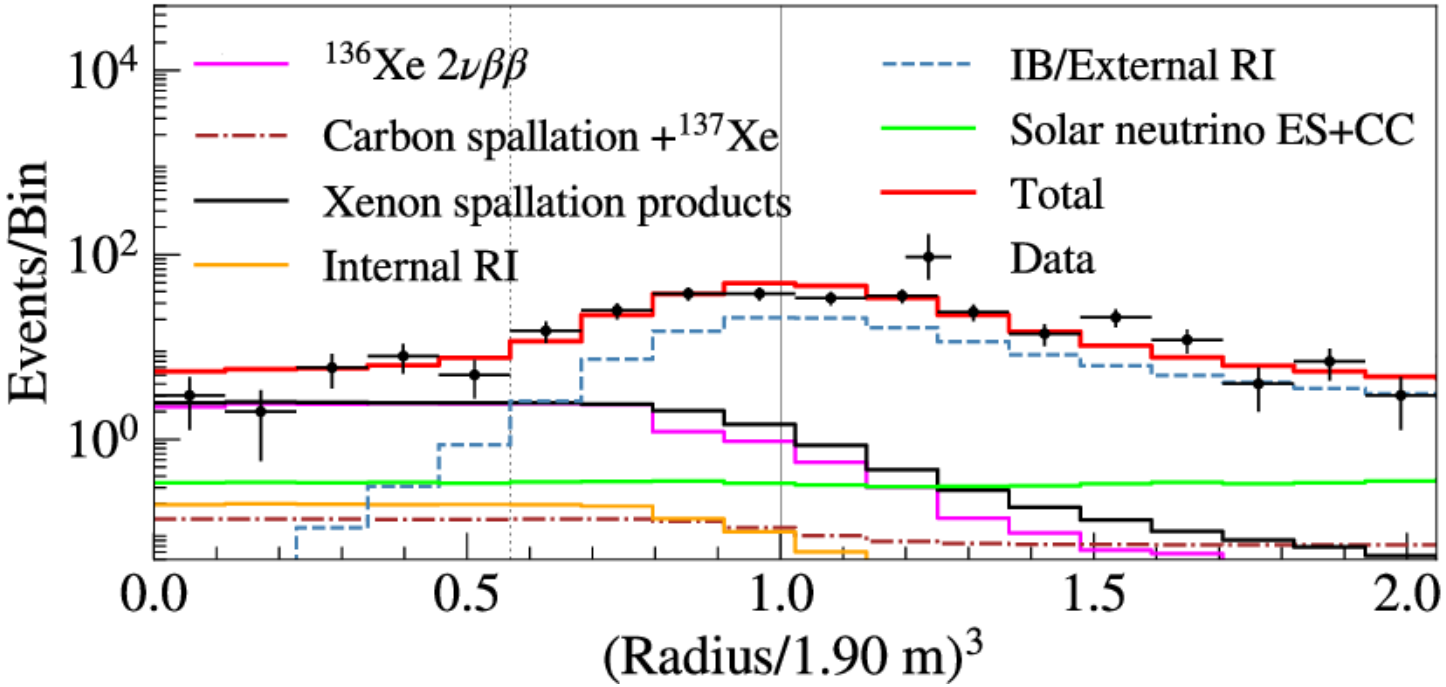

Pump
Water with
lighter particles
Nylon
film
1/4" PFA tube
Ultra pure water
Dust
(particles)
Water with
heavier particles
Ultrasonic generator
8mm hole

Uranium and Thorium impurities in the new mini-balloon film





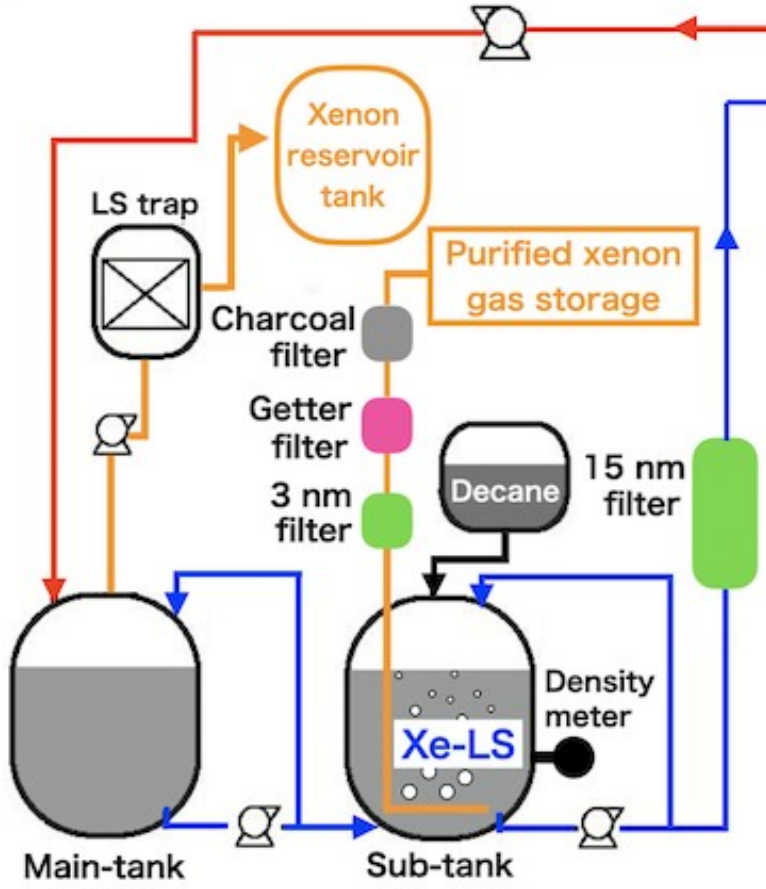
vertex distribution of events in the 0νββ window

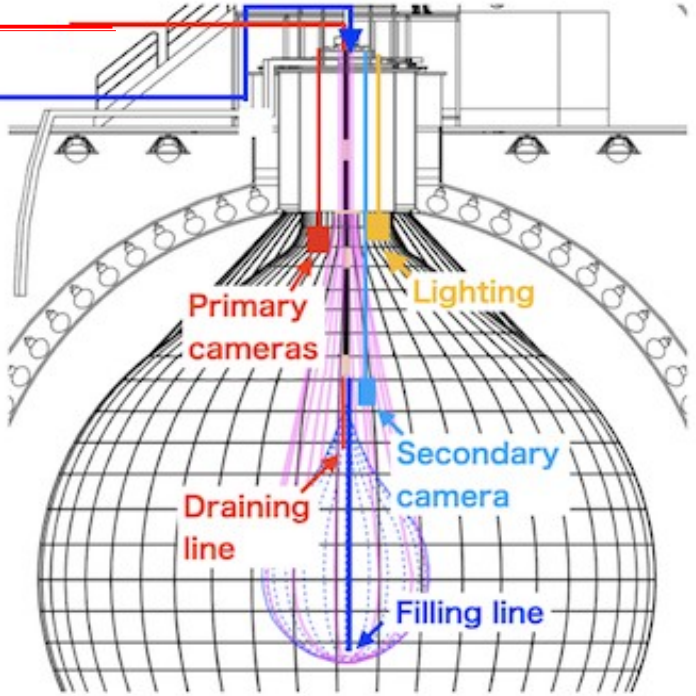


^{238}U ~3 × 10^{-12} g/g$_{film}$

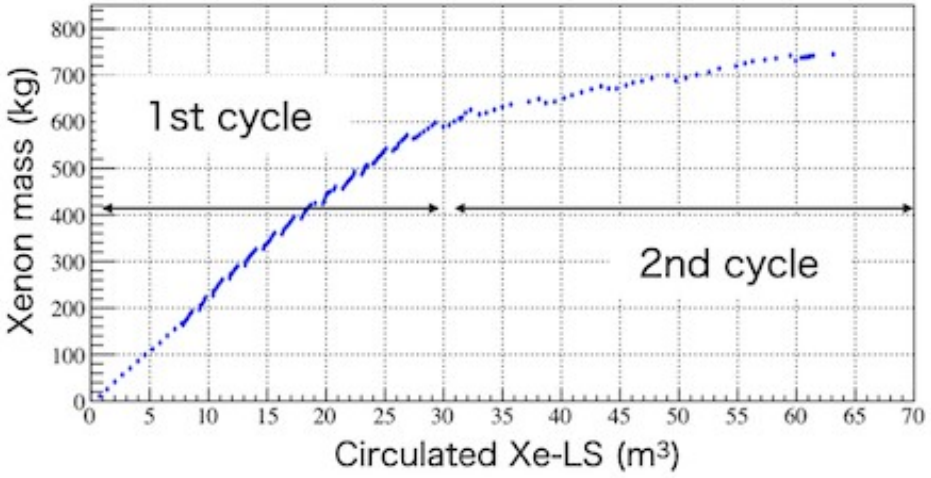
^{232}Th ~4 × 10^{-11} g/g$_{film}$

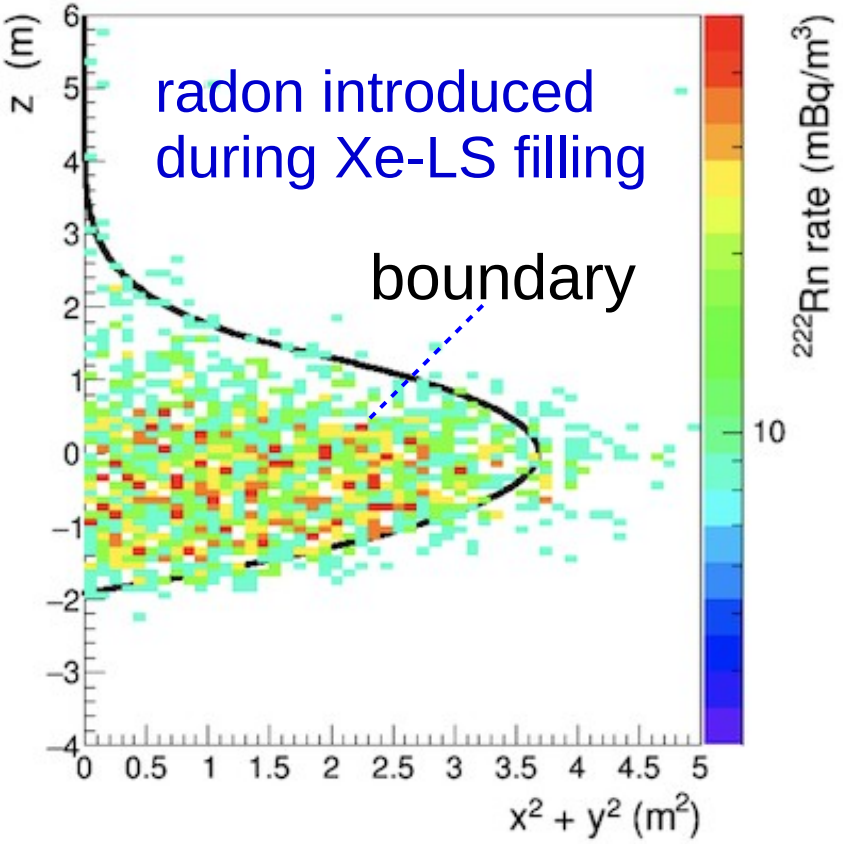
×10 reduction





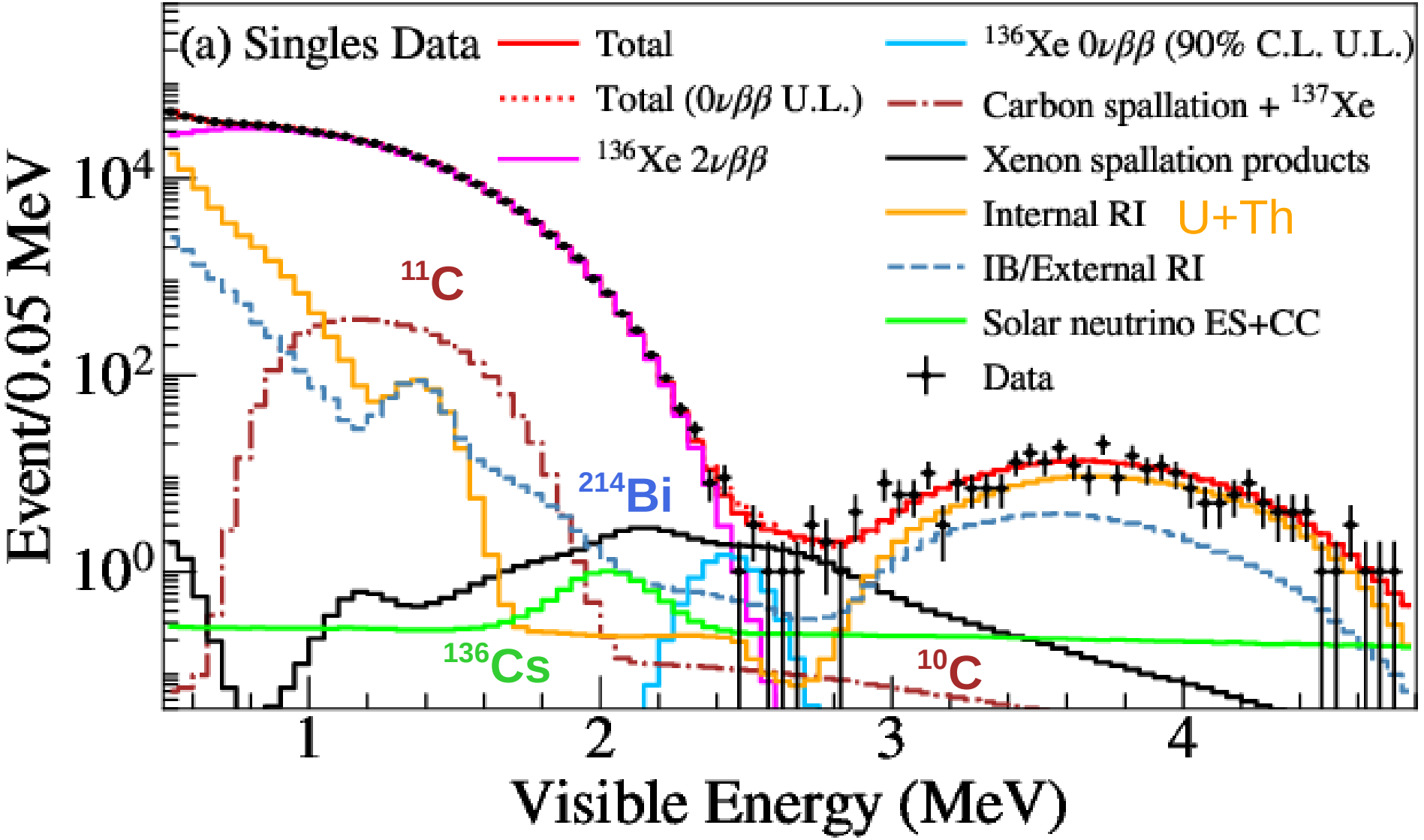
KL-Zen 800: Xenon loading



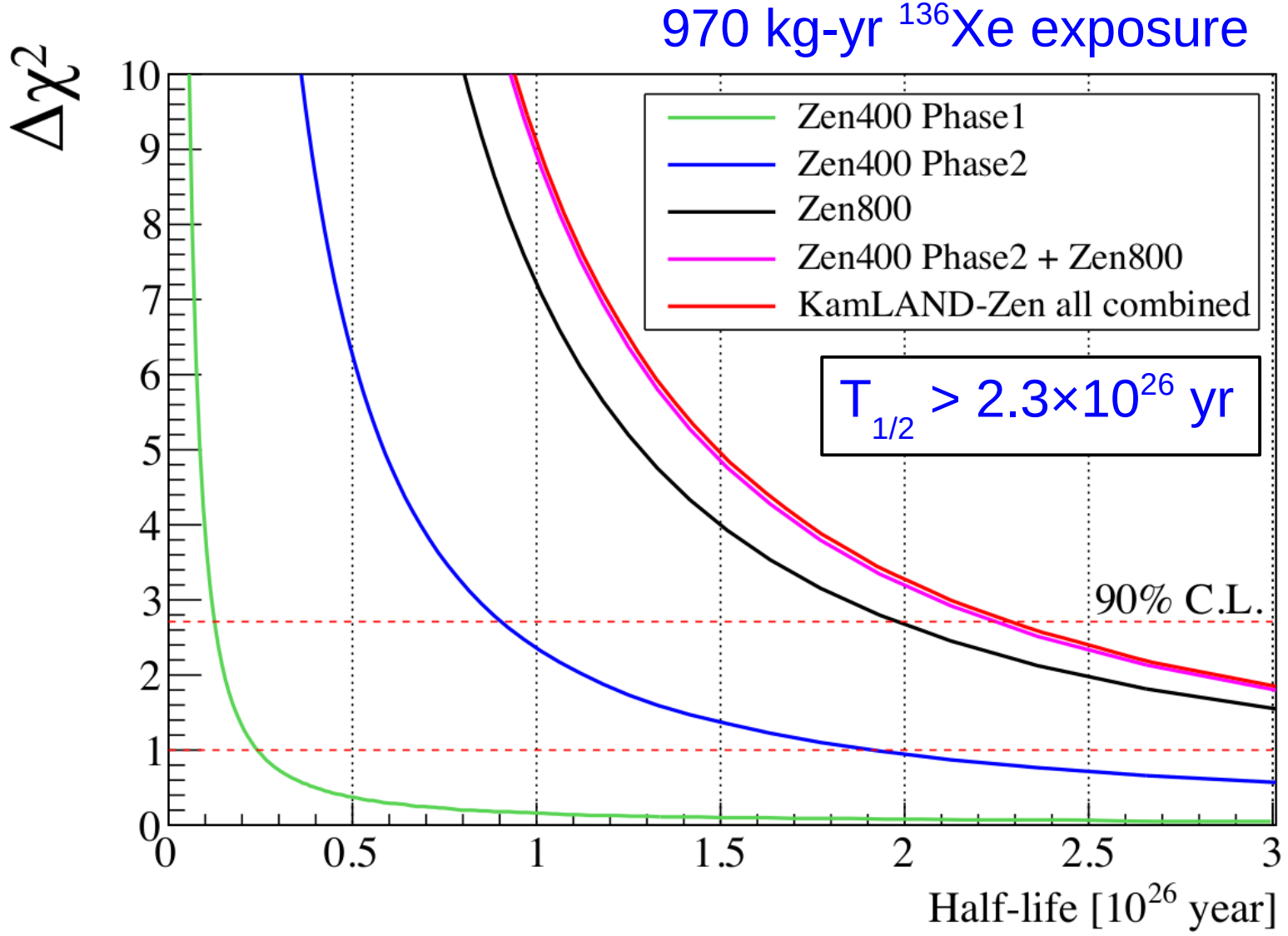


The new 0νββ result from KamLAND-Zen 800

Best fit for 0νββ : 0



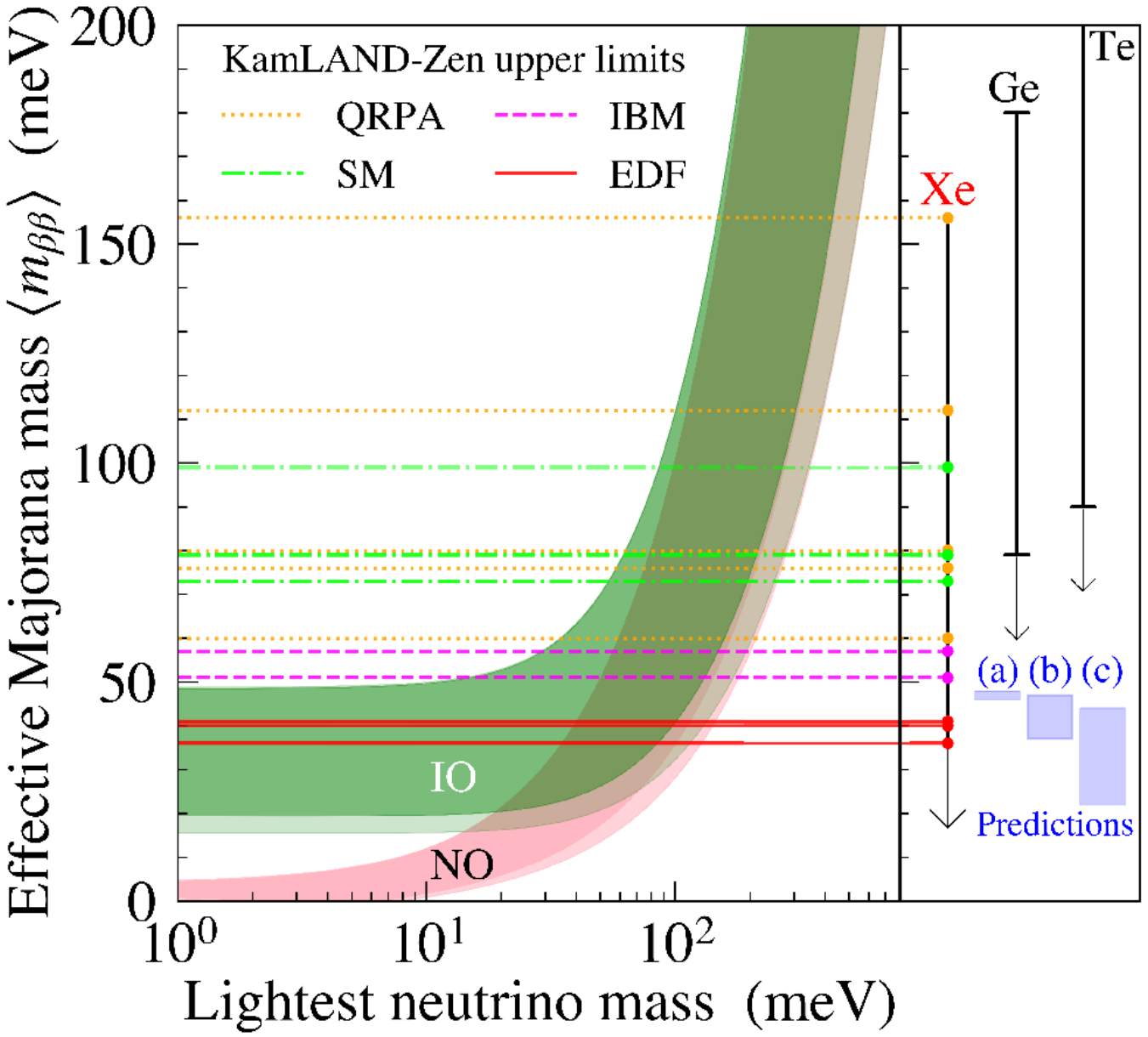
^{136}Xe Half-life limit (KamLAND-Zen 400 + 800)



^{76}Ge (GERDA): $T_{1/2} > 1.8\times10^{26}$ yr [PRL 125, 252502 (2020)]

^{130}Te (CUORE): $T_{1/2} > 2.2\times10^{25}$ yr [Nature 604, 53 (2022)]

The best to date limit on the effective neutrino mass



$\langle m_{\beta\beta} \rangle$ < 36-156 meV

CUORE < 90-305meV
GERDA < 79-180meV

Theoretical predictions:
(a) Phys. Rev. D 86, 013002
(b) Phys. Lett. B 811, 135956
(c) Euro. Phys. J. C 80, 76

Summary

- The KamLAND-Zen 800 was the first 0νββ experiment to explore the IH region.

- Data taking is going to continue for two more years.

970 kg-yr ^{136}Xe exposure $T_{1/2} > 2.3\times10^{26}$ yr at 90% CL

$\langle m_{\beta\beta} \rangle < 36\text{-}156$ meV

(depends on choice of NME)

Article in Physical Review Letters is going to be published soon

Thank you!

Neutrino masses