



Neutrinoless double beta decay search with KamLAND-Zen

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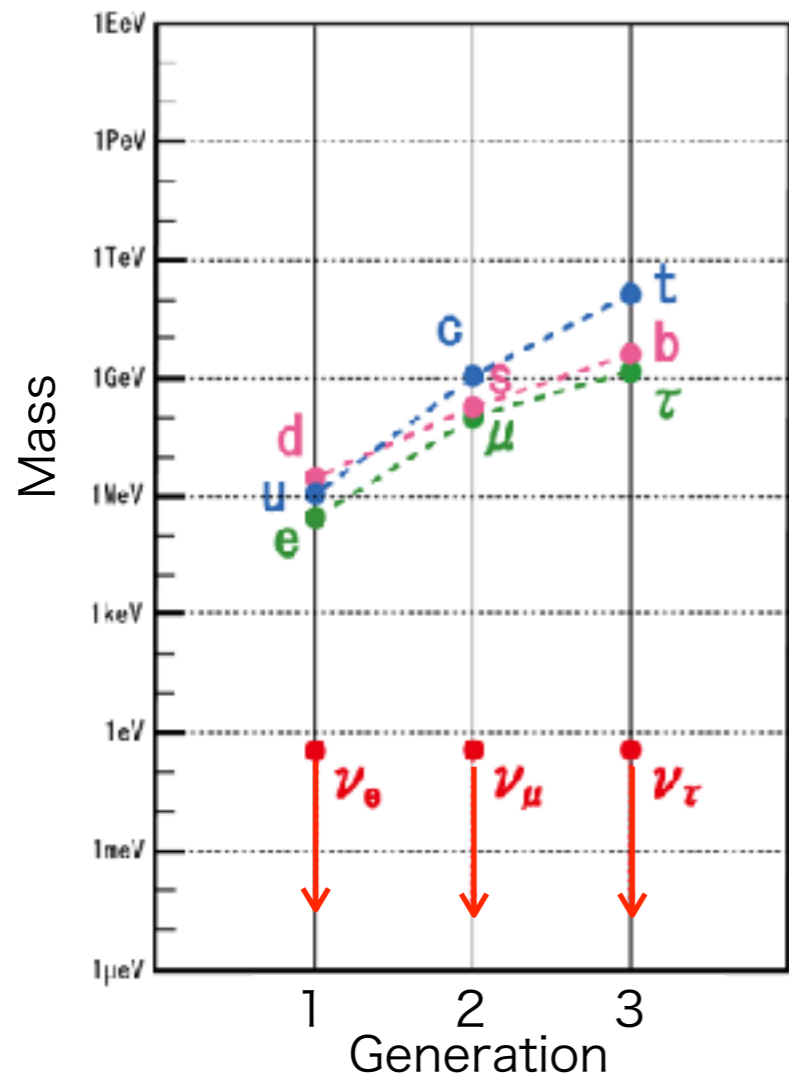
on behalf of the KamLAND-Zen collaboration

Research Center for Neutrino Science, Tohoku University

Neutrino is Majorana?

Neutrino oscillation : $m_\nu \neq 0$

- Absolute mass scale ?
- Hierarchy of ν_1, ν_2, ν_3 ?



Neutrino mass is much lighter than other particles.
It looks un-natural !

Neutrino mass



Dirac

$$\nu \neq \bar{\nu}$$

$$m_{\nu R} = m_{\nu L}$$

Majorana case

$$m_R \gg m_L, m_D$$

Assuming the heavy right-handed neutrino



Small mass is explained by See-saw mechanism

Majorana

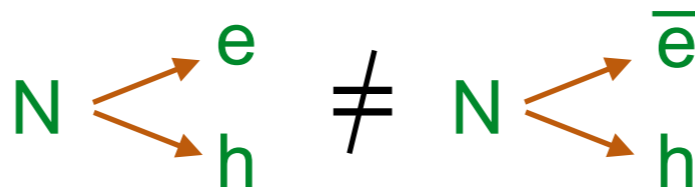
$$\nu = \bar{\nu}$$

$$m_{\nu R} \neq m_{\nu L}$$

$$m_\nu \sim \frac{m_D^2}{m_R}$$



Early Universe



N : Heavy right-handed ν
 h : Higgs
 e : Electron

Heavy right-handed ν makes lepton number asymmetry (ΔL)



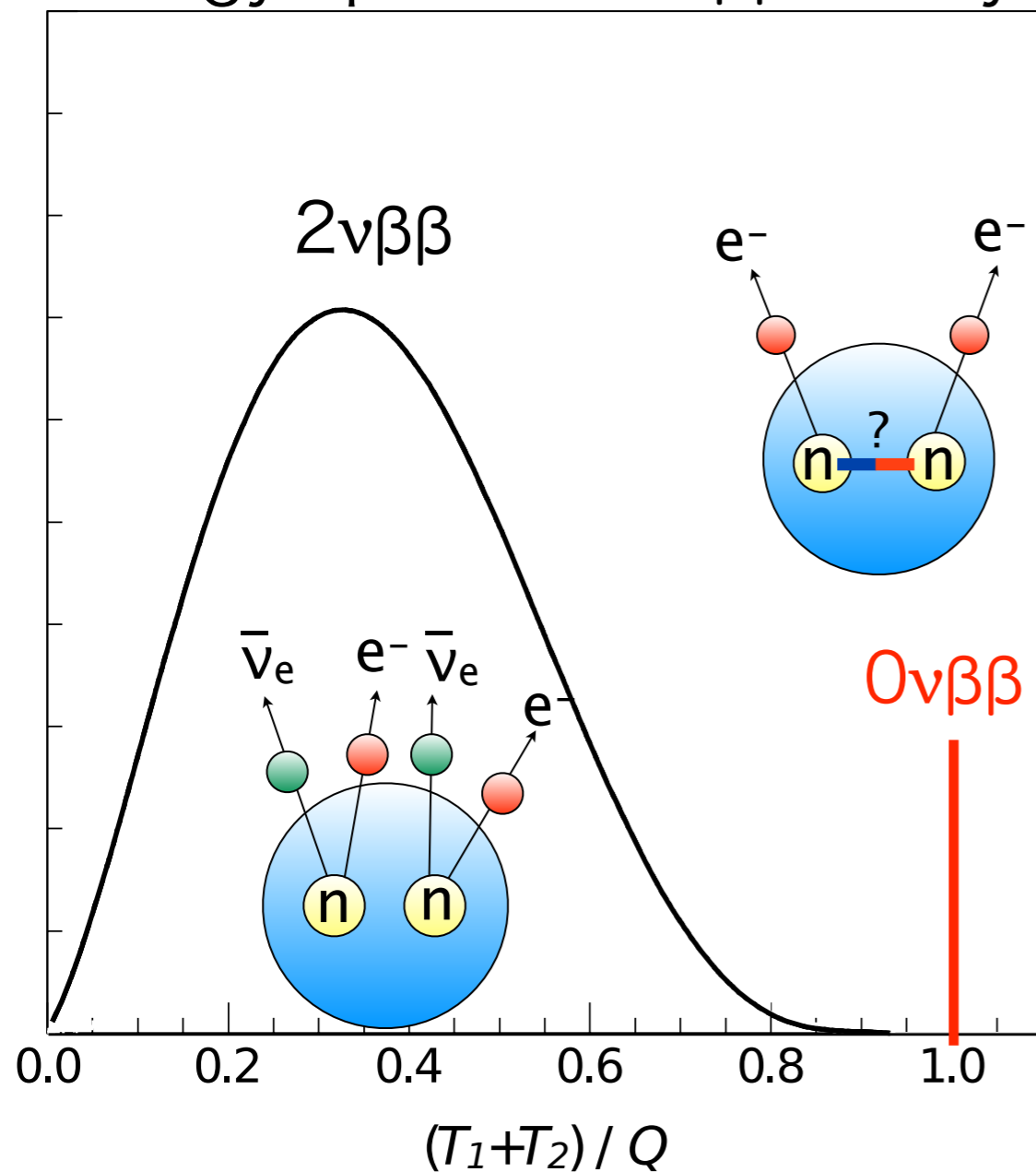
ΔL makes Baryon number asymmetry (ΔB)

Matter dominant universe can be explained (not anti-matter dominant, not equilibrium matter)

$0\nu\beta\beta$ decay event search

Only one realistic experiments for Majorana neutrino test

Energy spectra for $\beta\beta$ decay



$0\nu\beta\beta$ decay

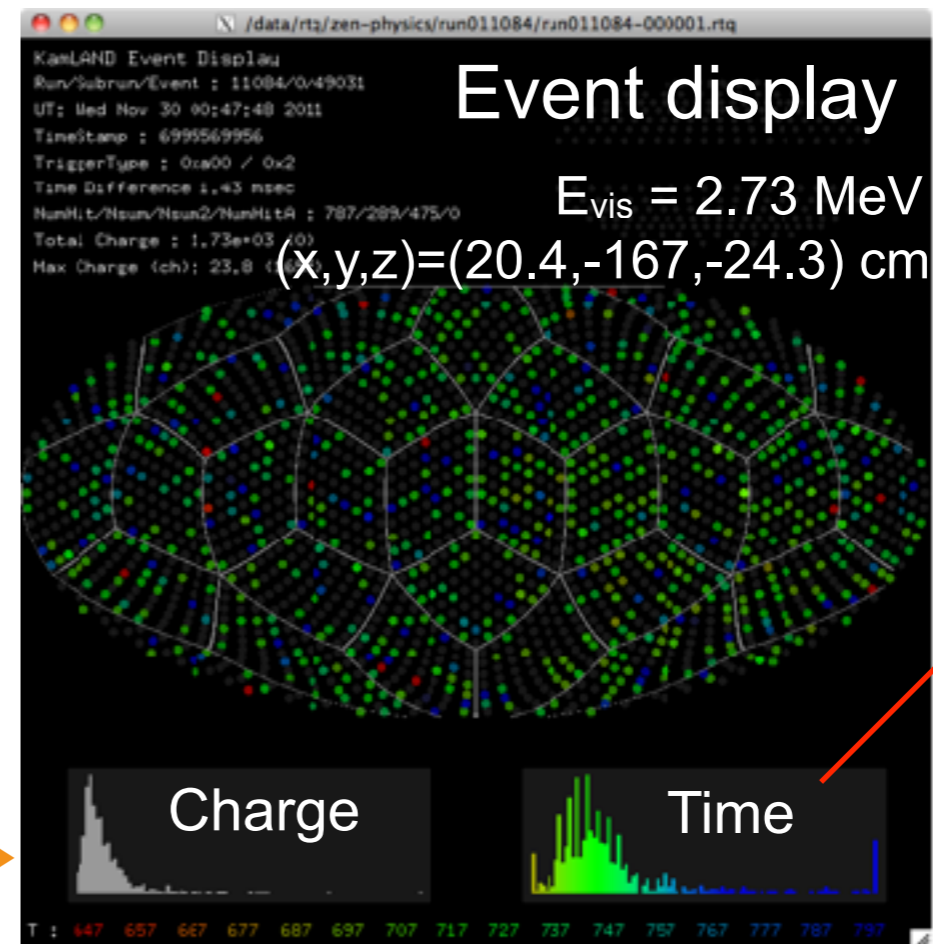
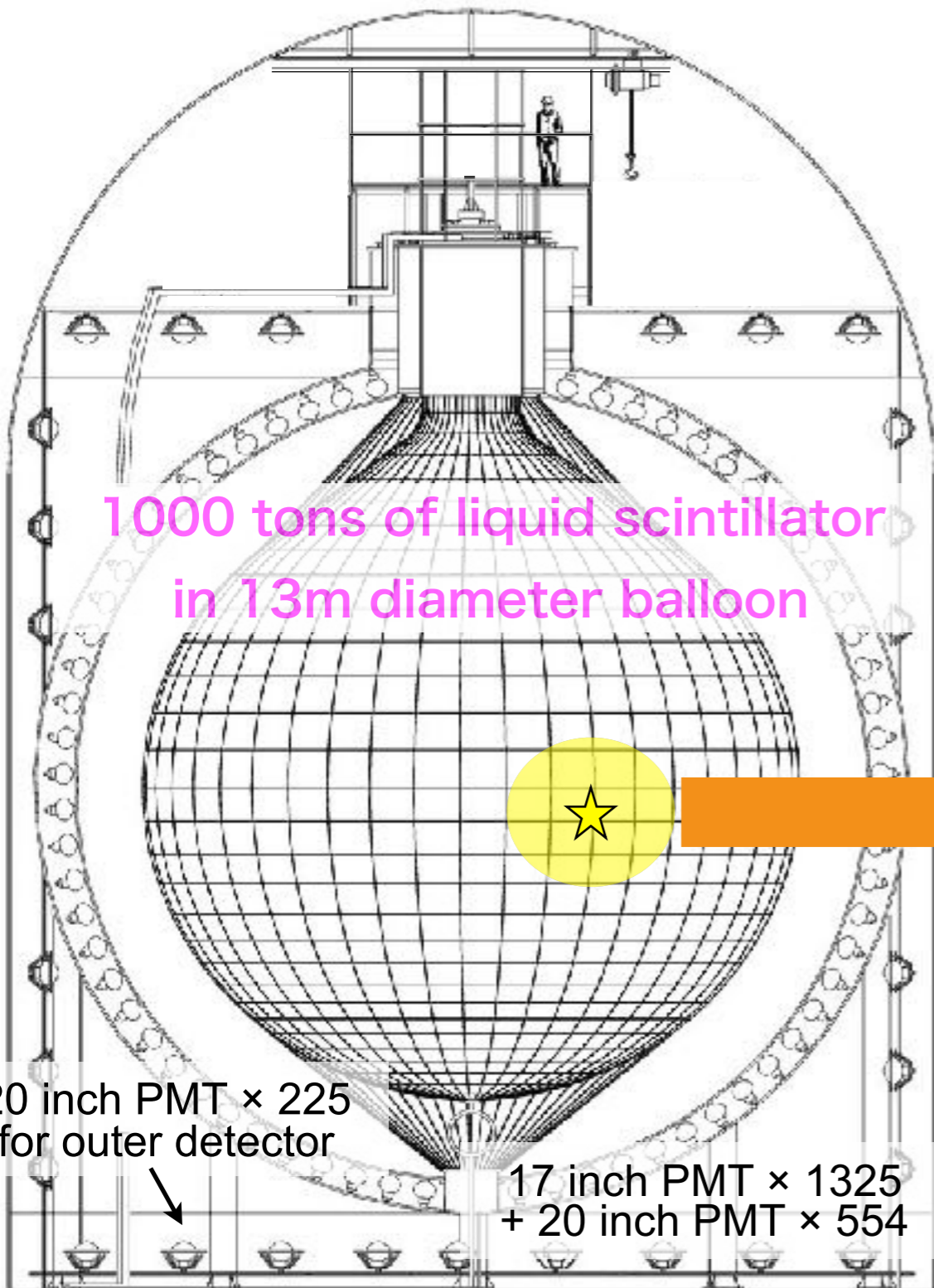
- $(A,Z) \rightarrow (A,Z+2) + 2e^-$
- Monochromatic peak at Q value
- 2β generation
- Backgrounds
 - ✓ Environmental γ -rays
 - Energy region of Q values is few MeV
 - ✓ Cosmogenic neutron
 - ✓ Cosmogenic radioactivity isotopes
 - ✓ Radioactivity in container, etc.
 - ✓ Tail of $2\nu\beta\beta$ (depend on E_{res})

KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector

In Kamioka mine, Japan

- 2700 m.w.e. : 10^{-5} muon from ground level
- Photo coverage 34%
- 17 inch PMT 1325 + 20 inch PMT 554



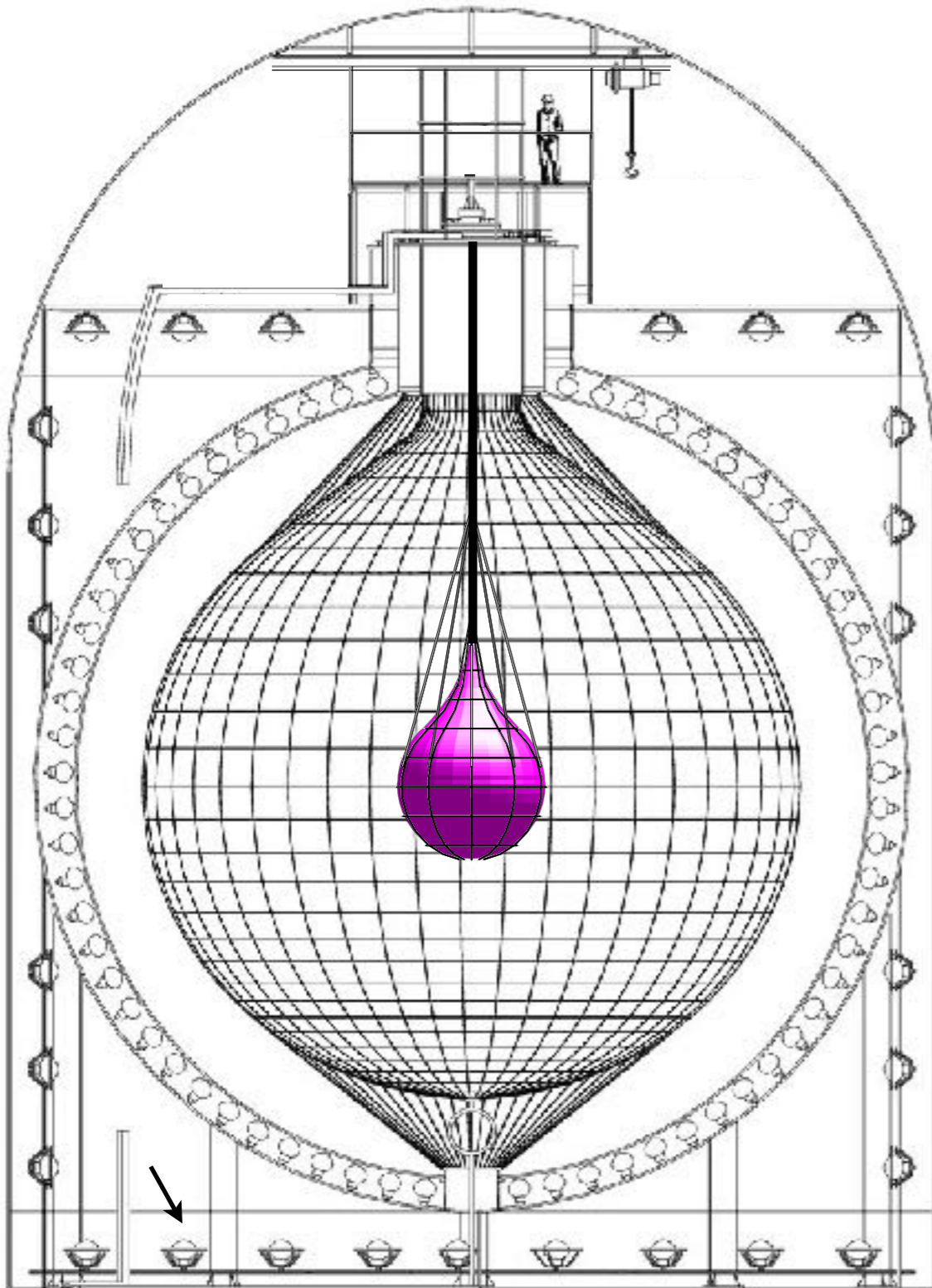
Charge + Time + transparency \rightarrow Energy

- Energy resolution : $\sim 6.4\% / \sqrt{E(\text{MeV})}$ (sigma)
- Vertex resolution : $\sim 12\text{cm} / \sqrt{E(\text{MeV})}$ (sigma)
- U, Th level of LS in balloon : $10^{-17} \sim 10^{-18} \text{ g/g level}$

KamLAND-Zen

KamLAND

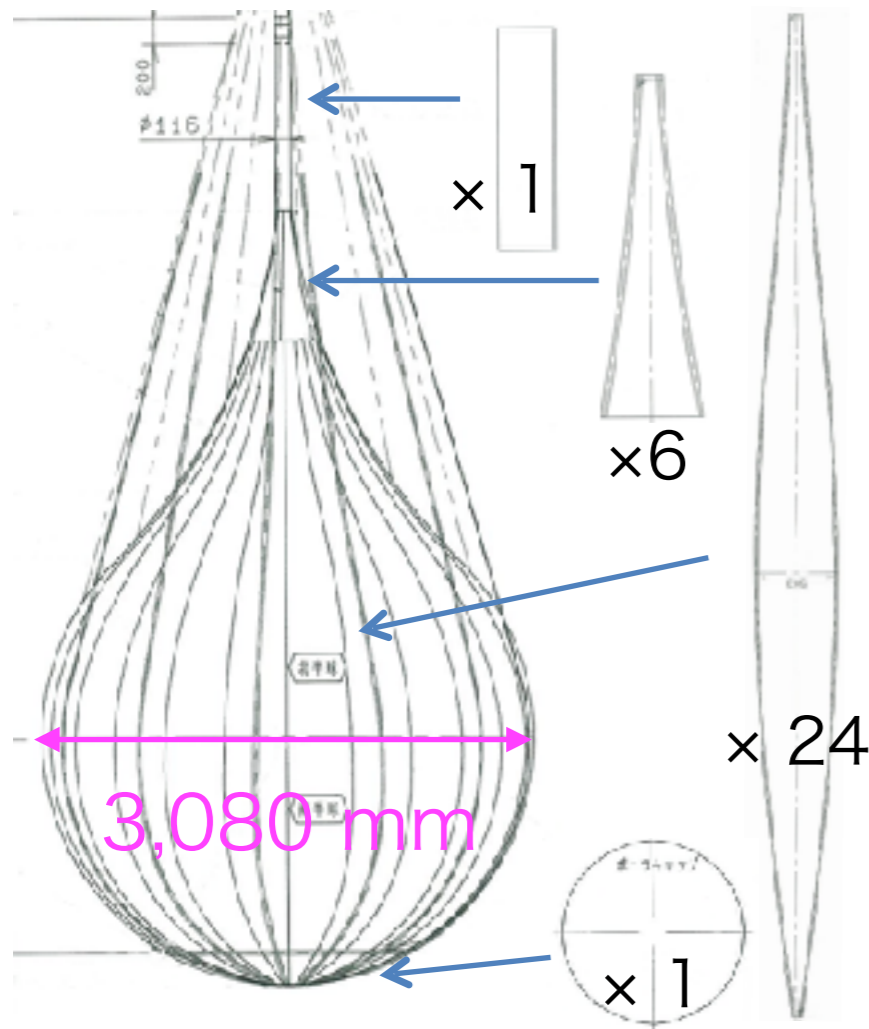
Zero neutrino double beta decay search



KamLAND-Zen

- ^{136}Xe loaded LS in inner mini-balloon
- 90.6% enriched ^{136}Xe
- Q value : 2.458MeV
- Xenon gas soluble 3.2 wt% in LS,
- Xenon can be removed from LS by vacuum and gas bubbling methods
- Only detect scintillation light with no particle ID methods (between 2 beta and gamma, single beta, alpha, proton)
- Energy resolution : $6.6 \sim 7.3\% \sqrt{E(\text{MeV})}$ (sigma)
- Low radio-activity environment
Ultra-low background LS is shielding for gamma-ray from outside.
- Scalability in 13m diameter balloon

Inner balloon for KamLAND-Zen

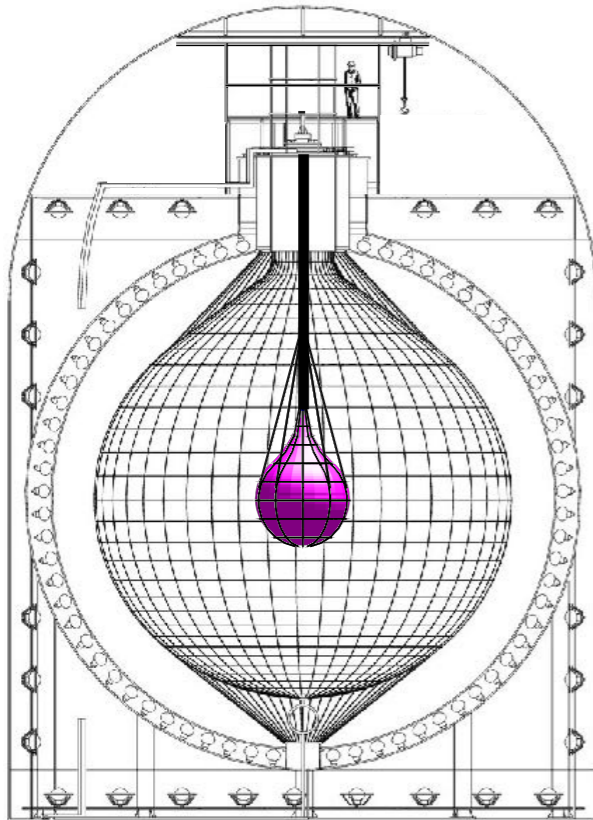


Inner mini-balloon

- Polymer materials have much lower ^{238}U , ^{232}Th contamination than metals
- Low mass container to reduce ^{238}U , ^{232}Th
- Made by welded 25 μm thickness nylon film
- The film is transparent
- Made in class 1 super clean room
(to avoid surface contaminations)

Zen 400 production





KamLAND-Zen 400

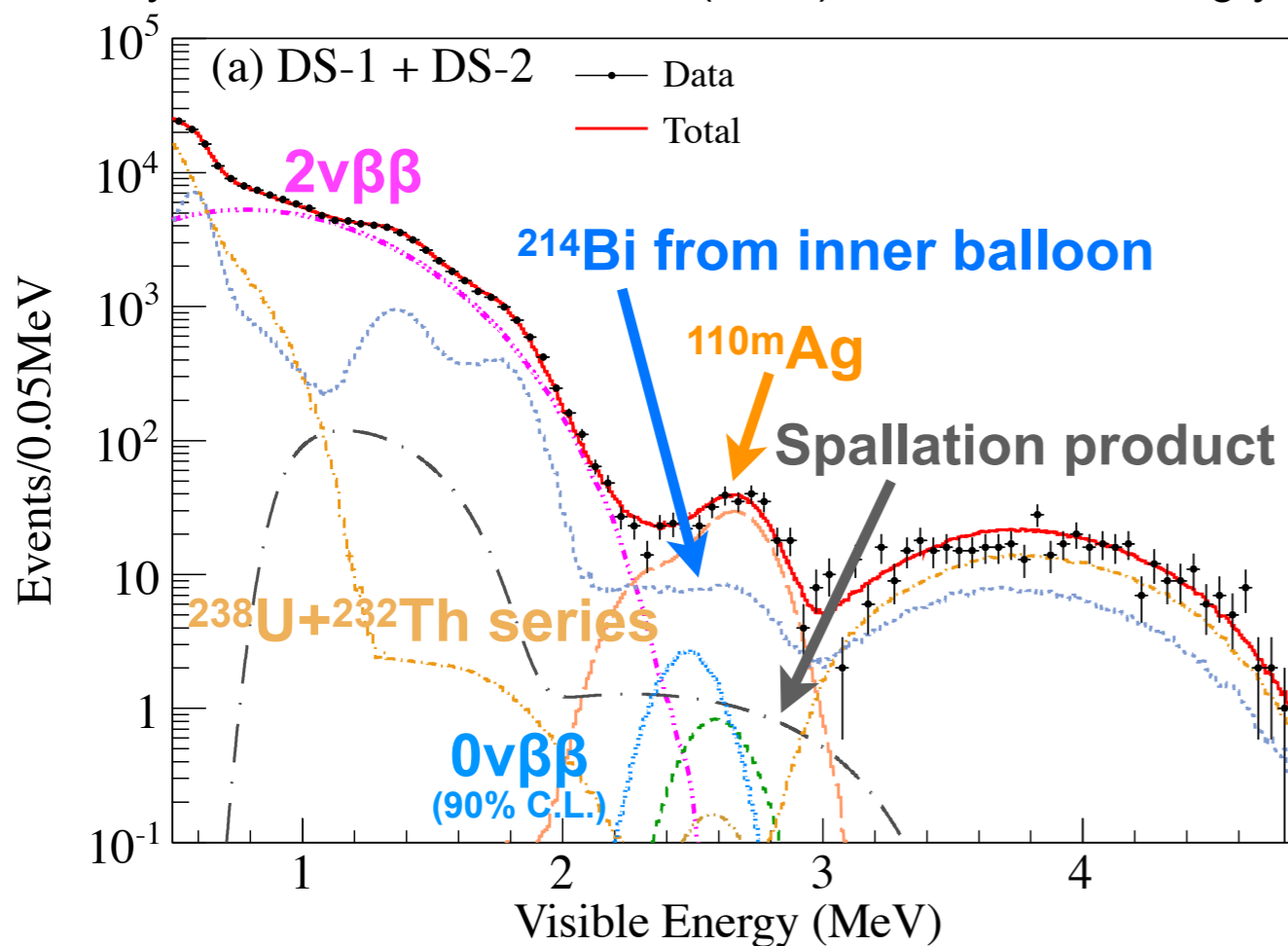
- ✓ R = 1.54m mini-balloon
- ✓ Xenon 320 kg : 2011 ~ 2012 Phase I
- ✓ 383 kg : 2013 ~ 2015 Phase II

KamLAND-Zen 400 Phase I



Phys. Rev. Lett. 110, 062502 (2013)

^{136}Xe 89.5 kg-yr



Lower limit for $0\nu\beta\beta$ in phase I
 $T^{1/2} > 1.9 \times 10^{25}$ yr (90% C.L.)

^{110m}Ag

- It looks Ag came from Fukushima reactor accident (Because ^{137}Cs is also observed)
- Ag existing in LS and surface of balloon



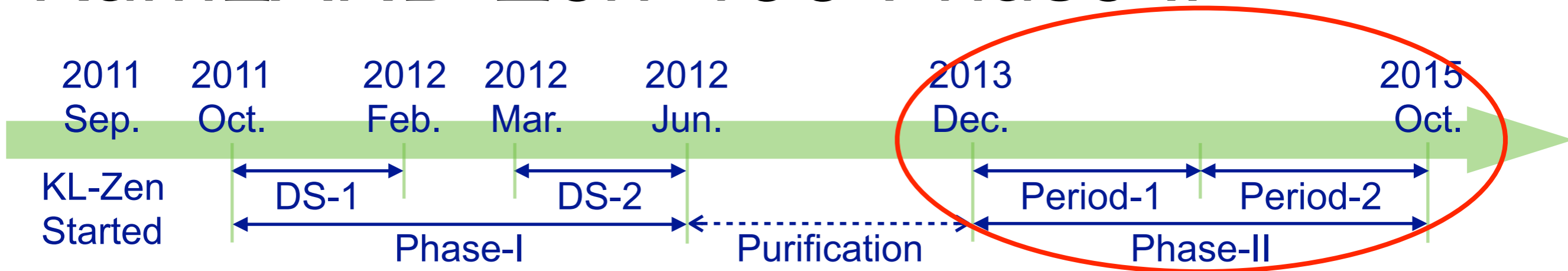
Purification

LS : purified by distillation

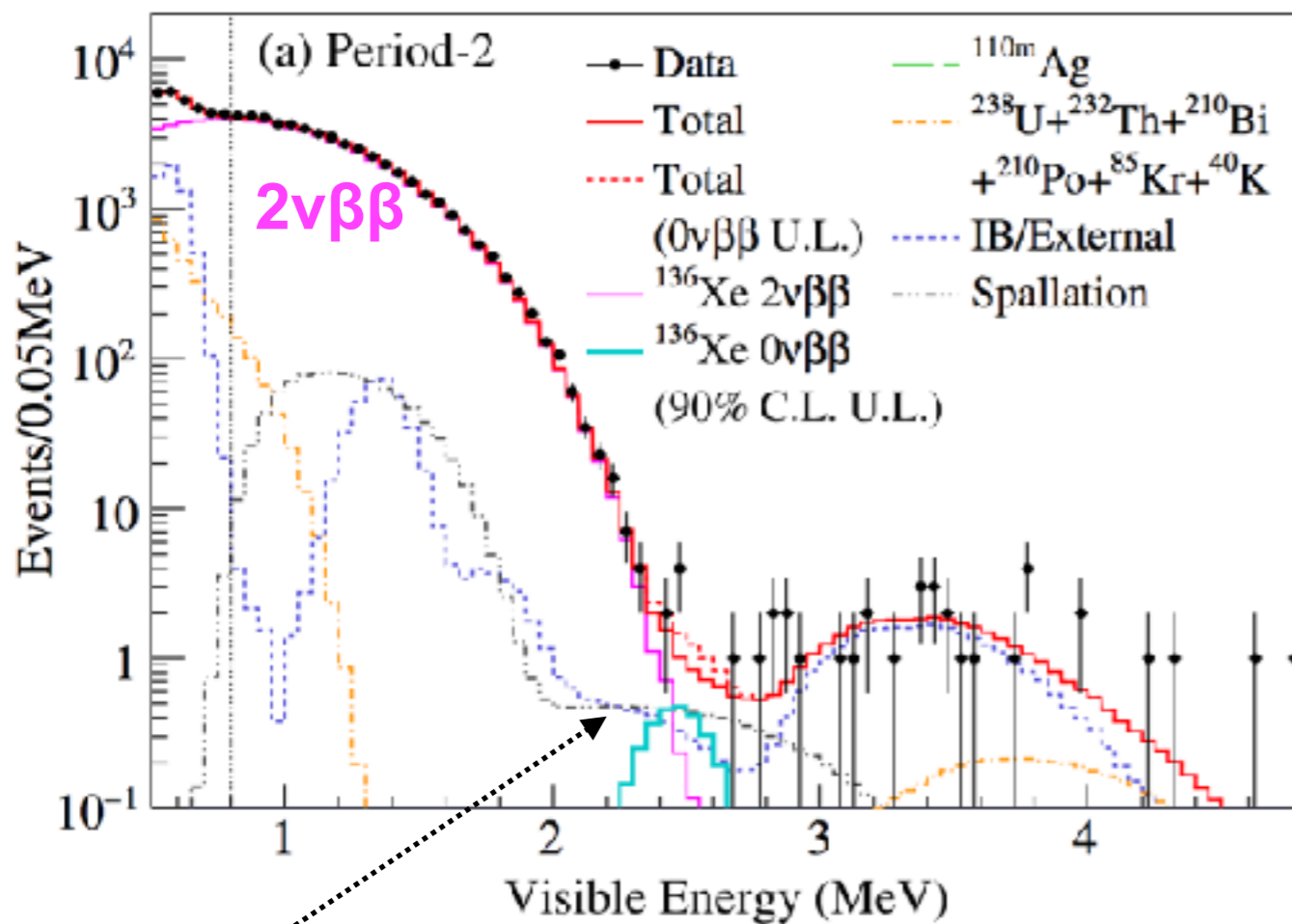
Xe : Extracted from LS,

Xenon gas was purified by distillation and getter filter

KamLAND-Zen 400 Phase II



Energy spectrum ($R < 1\text{ m}$)



2νββ result

$$T^{1/2} = 2.21 \pm 0.02(\text{stat.}) \pm 0.07(\text{syst.}) \times 10^{21} \text{ yr}$$

- Consistent with EXO-200 result

0νββ result (only Phase II)

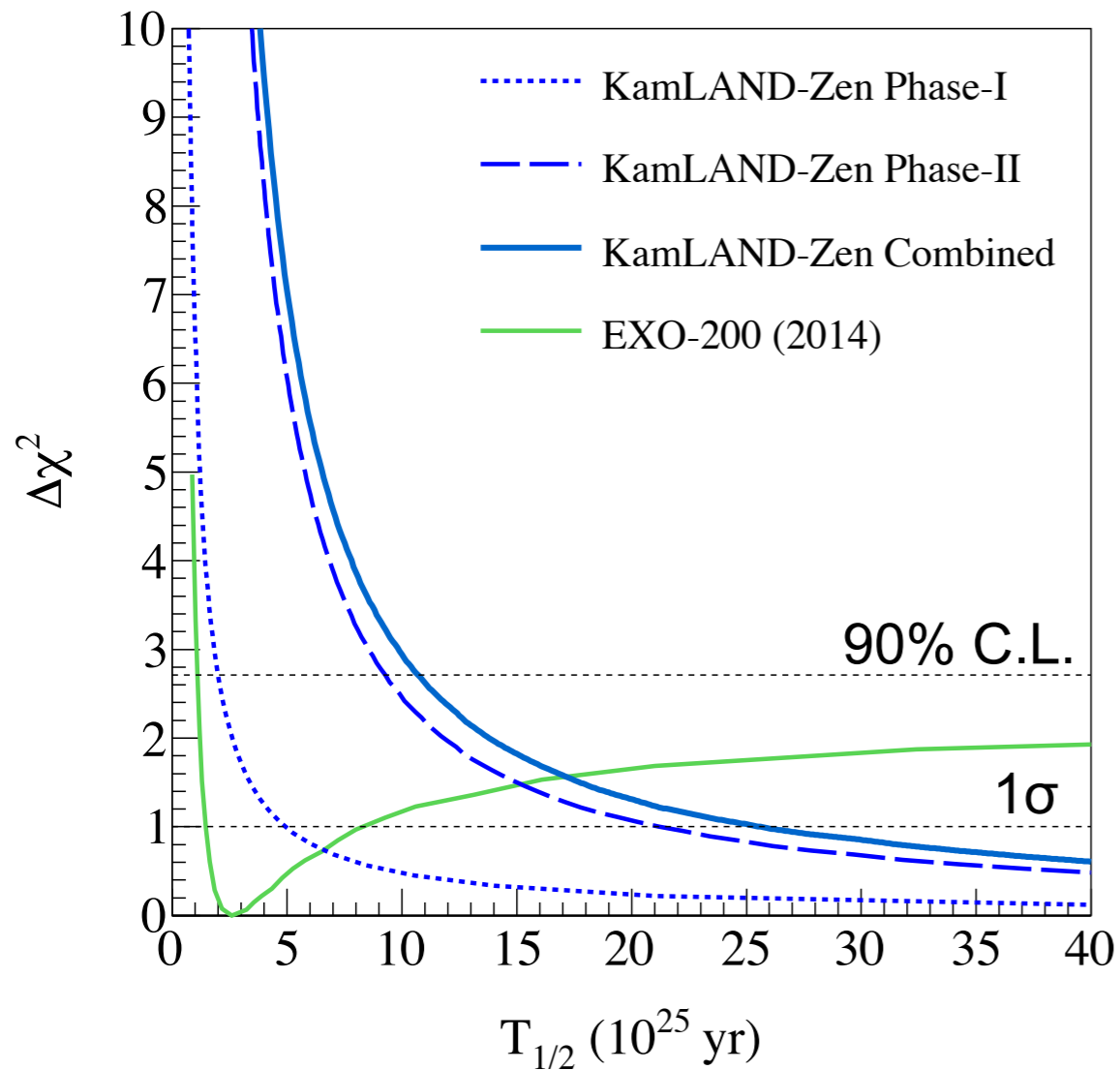
$$T^{1/2} > 9.2 \times 10^{25} \text{ yr}$$

Film BG (^{214}Bi)

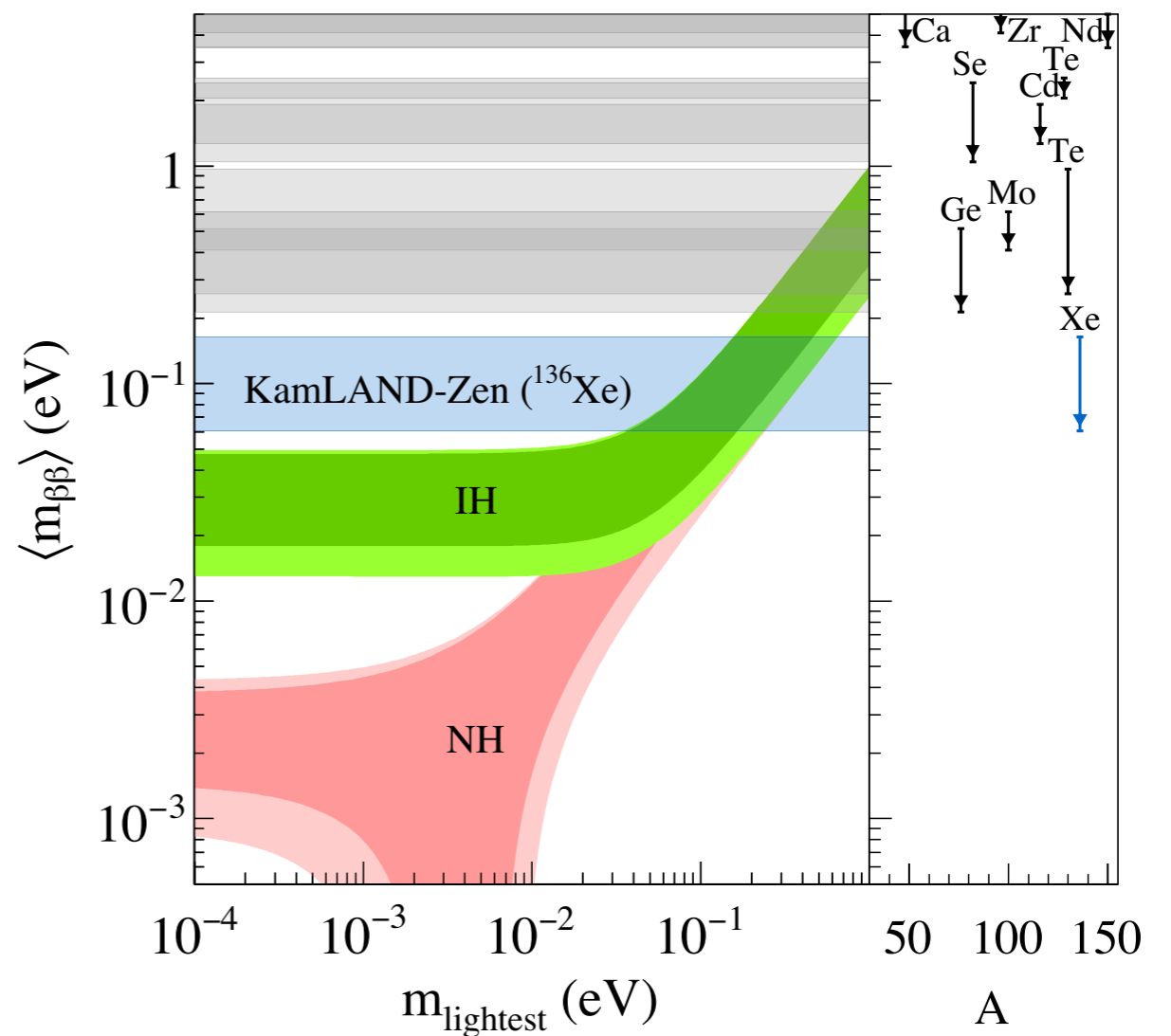
Inner surface of mini-balloon was contaminated by pump failure at purification, then fiducial volume was 43% at phase II

Results for KamLAND-Zen 400

Limit on the ^{136}Xe half-life



Limit on the Majorana mass



Phase I & II combined analysis

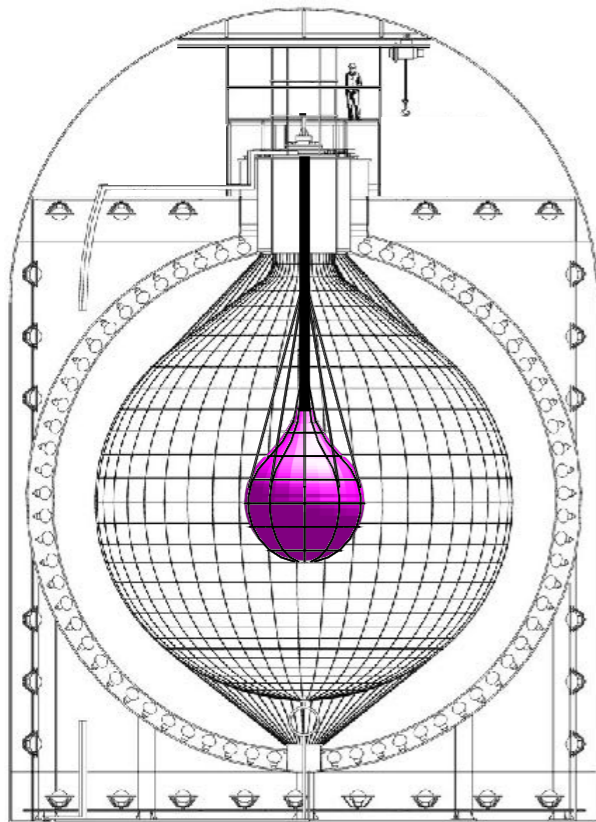
$T^{1/2} > 1.07 \times 10^{26}$ yr (90% C.L.)

Phase-1: $T^{1/2} > 1.9 \times 10^{25}$ yr

Phase-2: $T^{1/2} > 9.2 \times 10^{25}$ yr

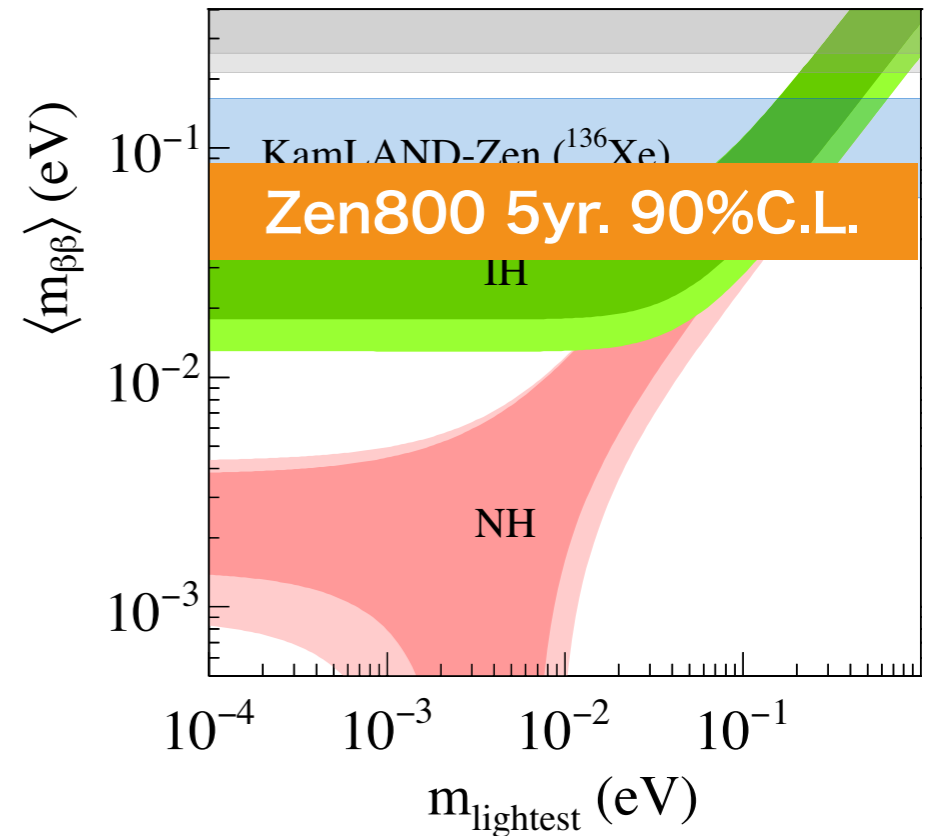
$\langle m_{\beta\beta} \rangle < 61-165$ meV

We reached $\langle M_{\beta\beta} \rangle < 100$ meV

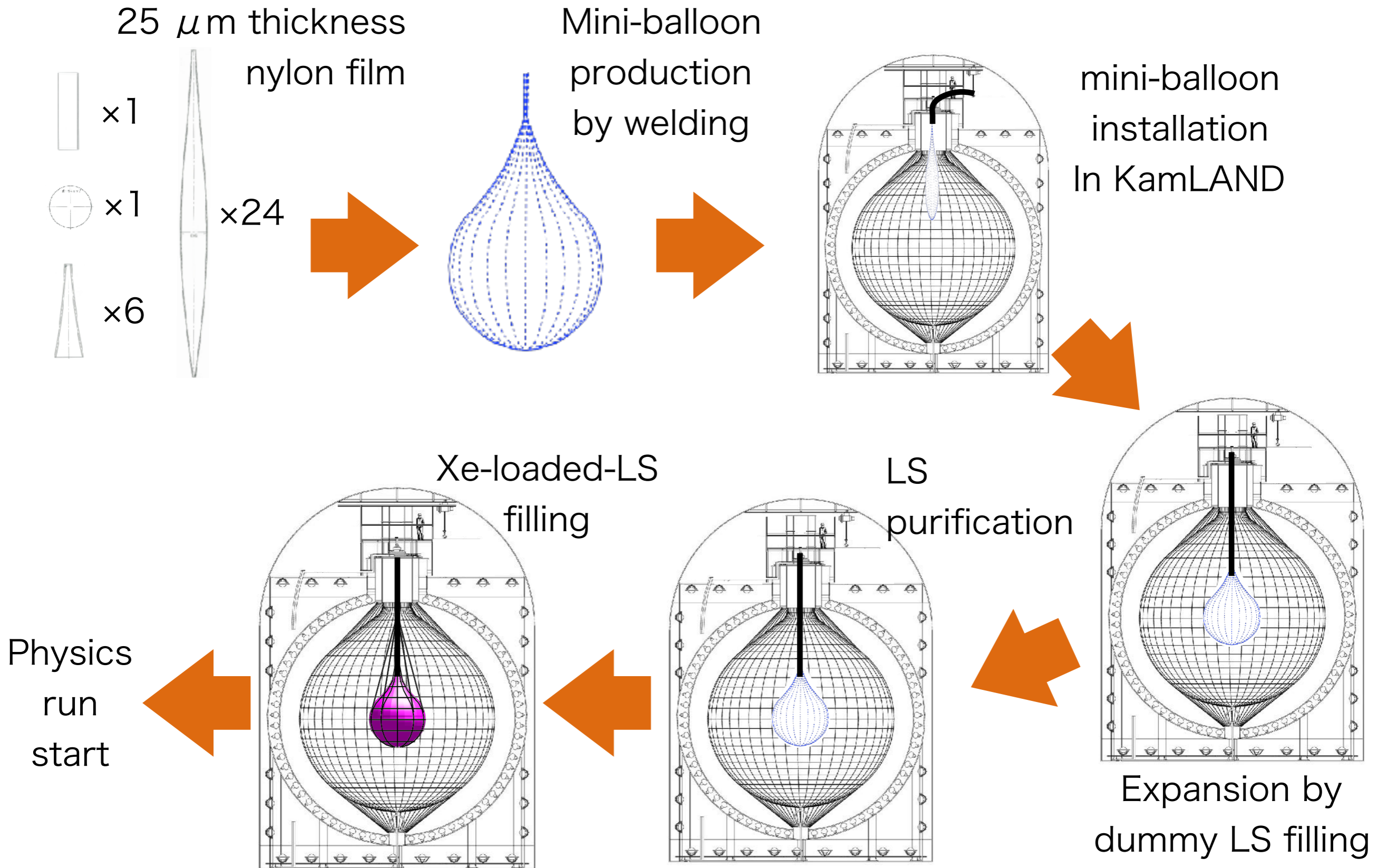


KamLAND-Zen 800

- ✓ R = 1.92m mini-balloon
- ✓ ~750 kg of xenon gas
- ✓ This phase will begin this winter



KamLAND-Zen 800



Mini-balloon production

Toward ultra low background vessel

The cause of contamination is dust from outside

- Clean wear control
- Static-electricity control
- Particle flow check
- Film cover setting
- Semi-automatic welding machine

mini-balloon production

Toward ultra low background vessel

The cause of contamination is dust from outside

→ Clean wear control

Outside of clean room



Clean inners

Class 1000 clean room



1st clean suit

Class 1 super clean room
(changing/preparation room)



clean suit change

Class 1
mini-balloon
production
Room

Once we wear,
Suits go to laundry



laundry
twice a day

mini-balloon production

Toward ultra low background vessel

The cause of contamination is dust from outside

→ Static-electricity control

65% humidity prevent static-electricity

→ Particle flow check

Check what cause of particle generation

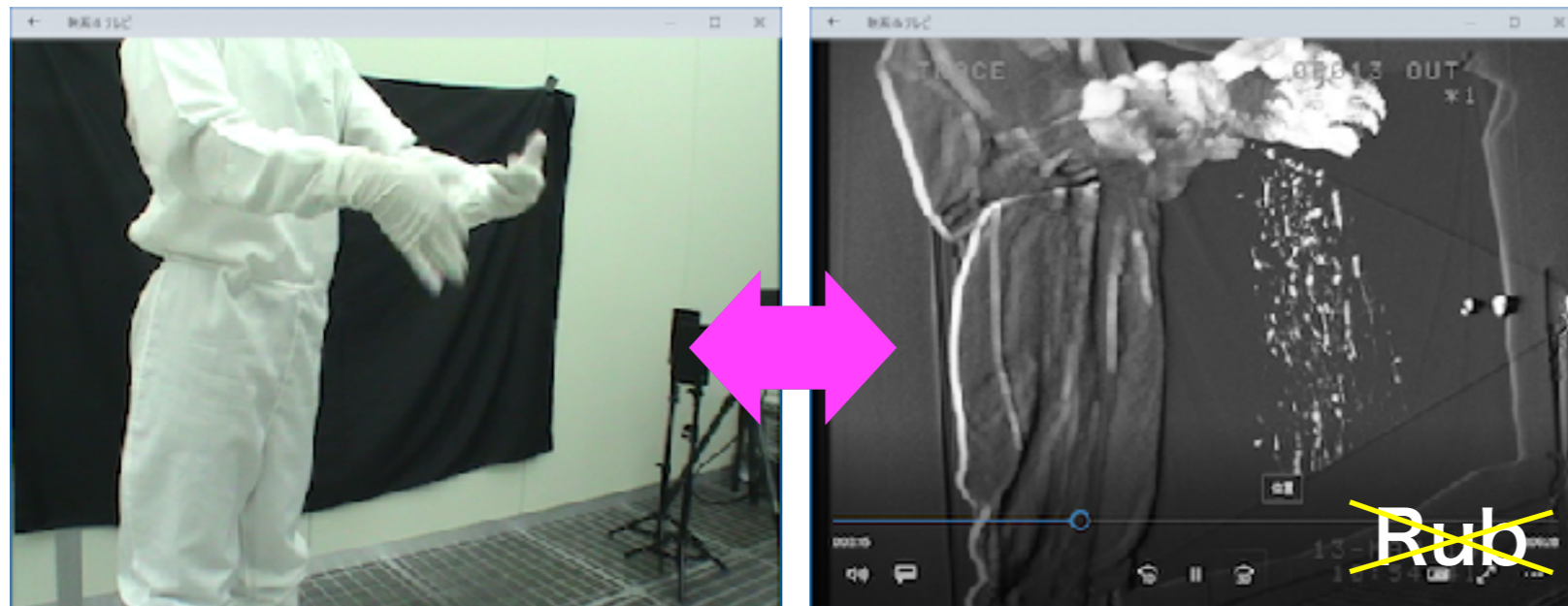


Mist generation system just before ULPA (HEPA) filter

+



Ion generation system



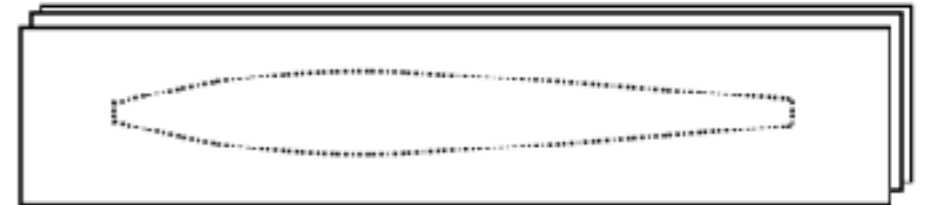
- Check particle generation by our hands, suits, etc.
- Particle flow on/near desks
- Wash hands just before touching mini-balloon film

mini-balloon production

Toward ultra low background vessel

The cause of contamination is dust from outside

- Film cover setting
- Semi-automatic welding machine



mini-balloon film was sandwiched between 2 clean nylon (strip edge when welding)

Zen 400



Hand welding by company person

Zen 800

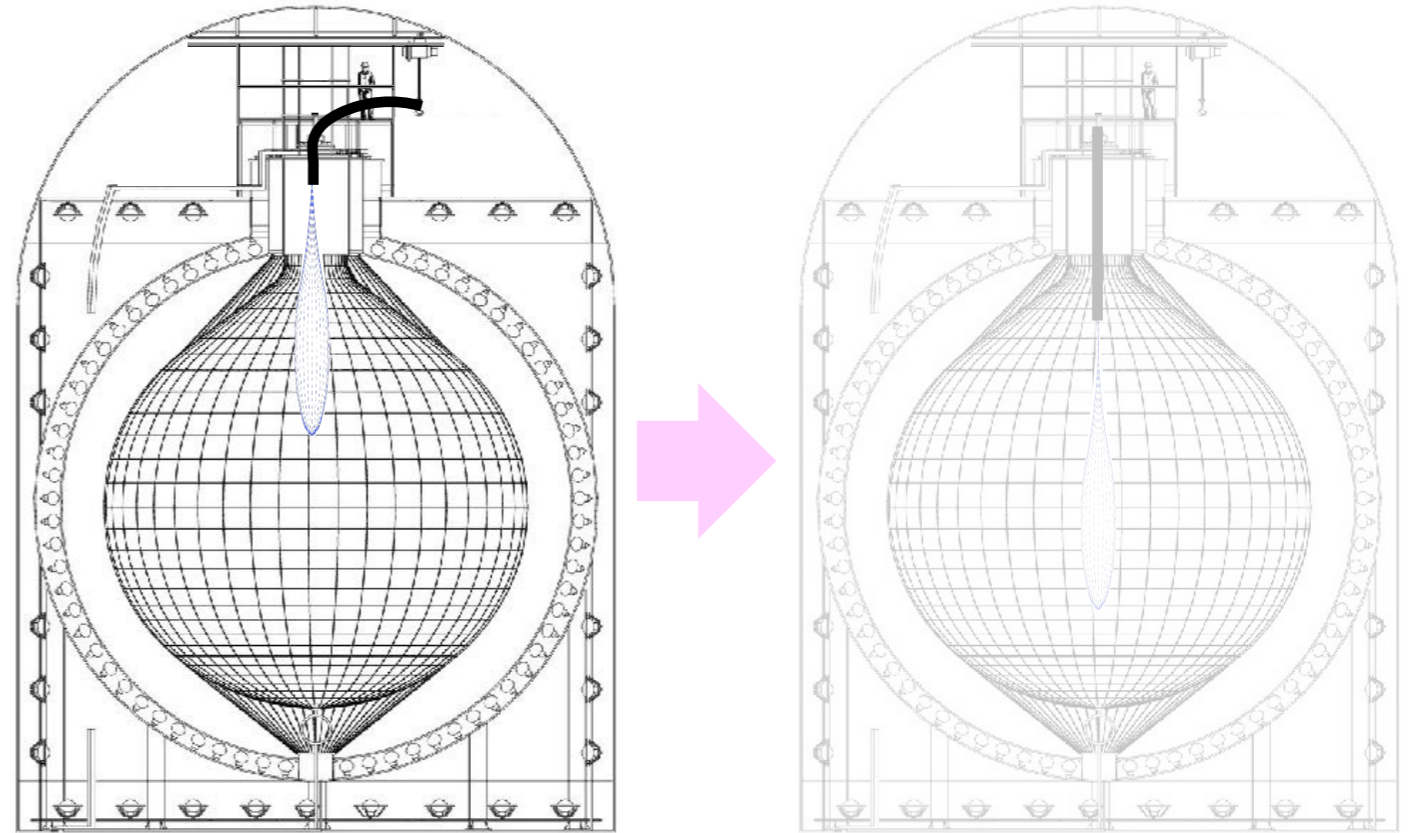


Semi-automatic welding by scientists
- Particle drop control from human
- Speed up

mini-balloon production 2017 ~ 2018



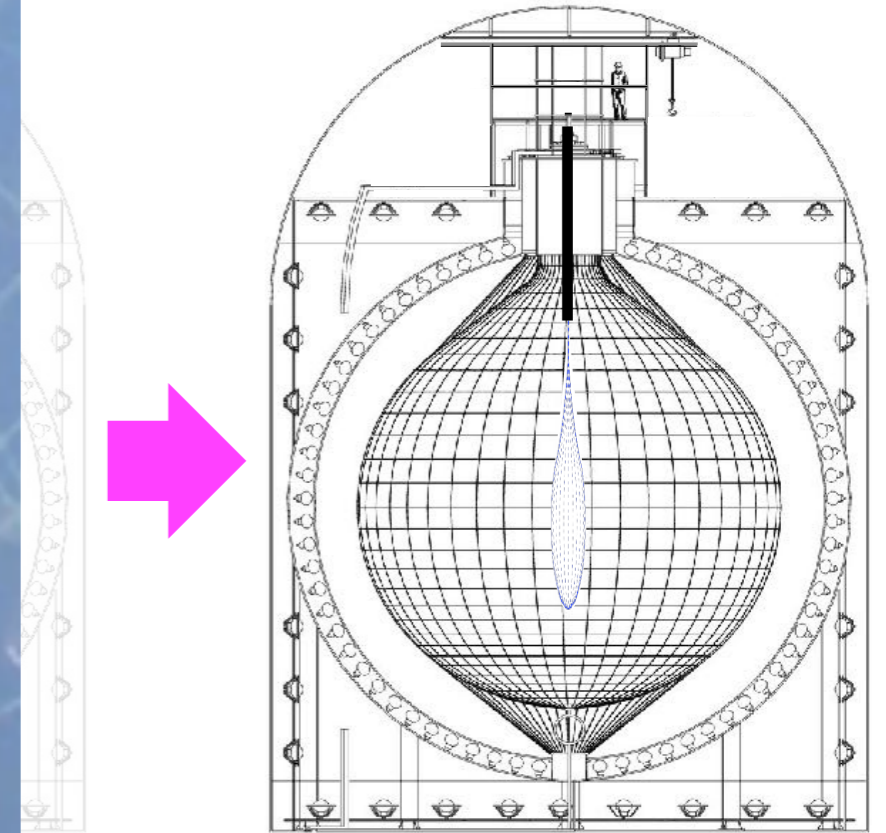
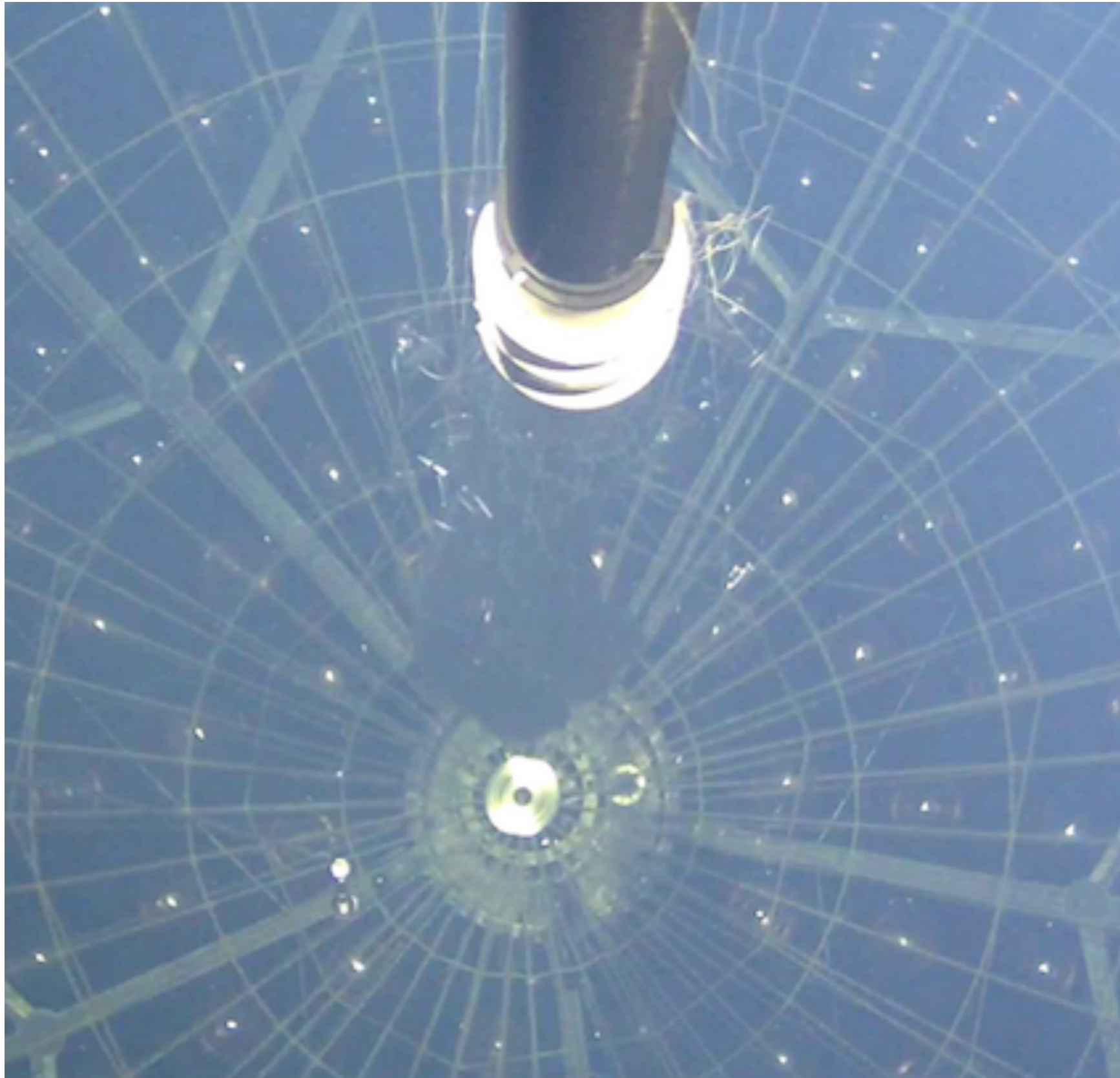
mini-balloon installation May 10, 2018



↔
50cm width for detector access

mini-balloon installation

May 10, 2018



mini-balloon installation
with + 0.4% weight liquid
scintillator to KamLAND LS

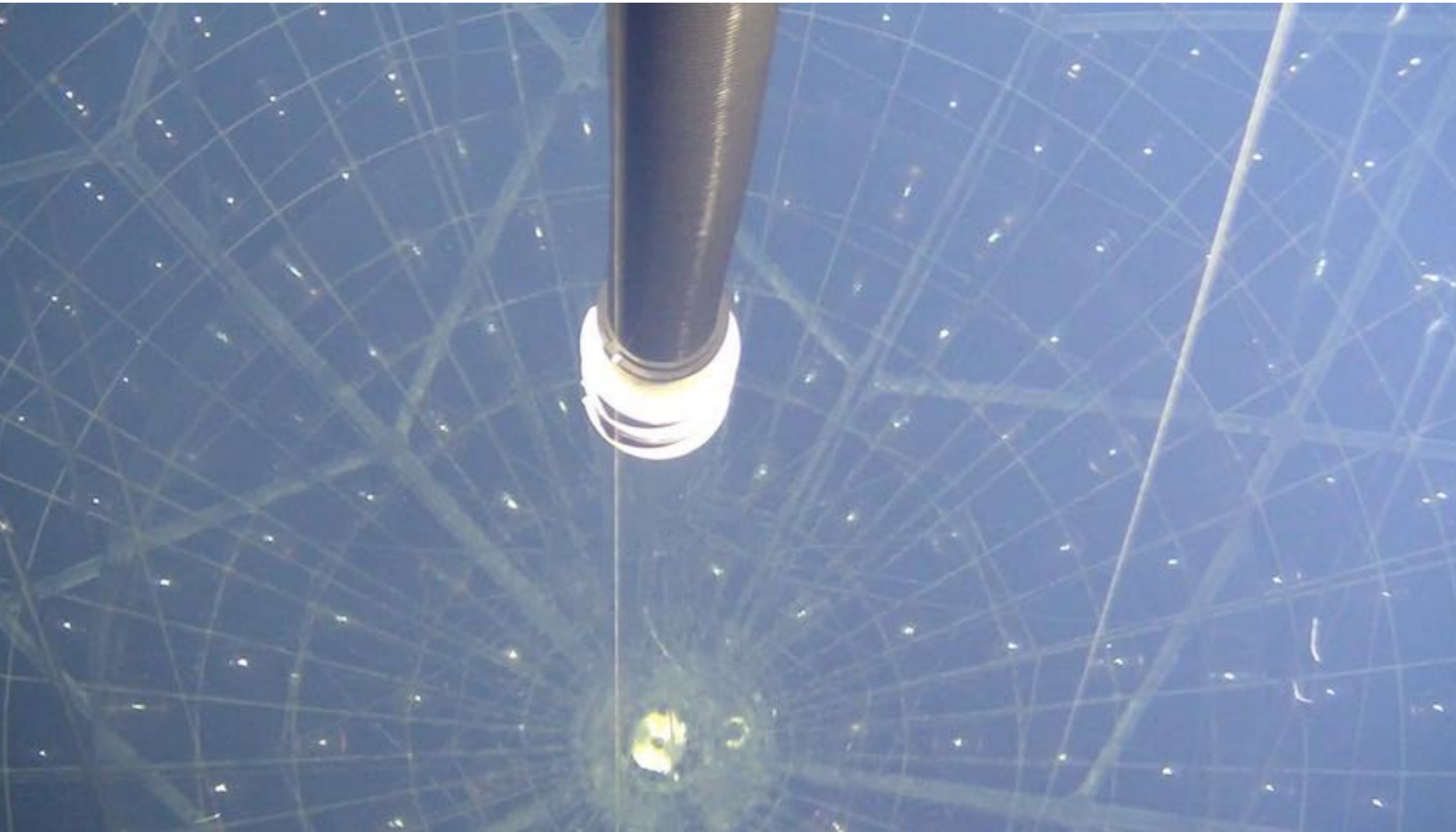
May 10 24:35



After the installation & piping connections 20

Dummy LS filling

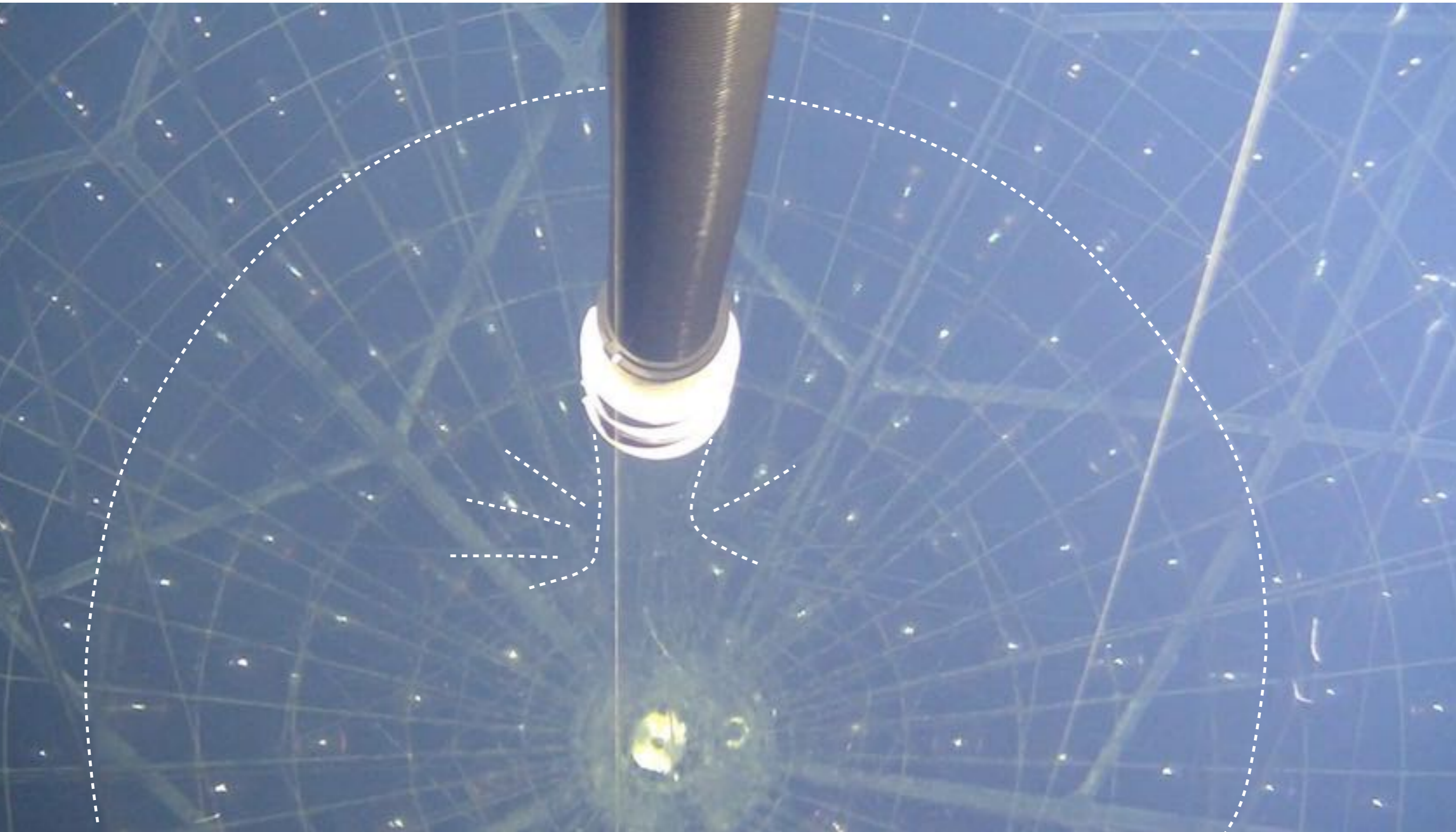
Dummy LS = non Xe loaded LS



After 30.5 m³ LS filling, we started DAQ to investigate background status of LS and mini-balloon

Dummy LS filling

Dummy LS = non Xe loaded LS



After 30.5 m³ LS filling, we started DAQ to investigate background status of LS and mini-balloon

Dummy LS filling

Dummy LS = non Xe loaded LS



No indication of leakage observed

Camera,

Weight,

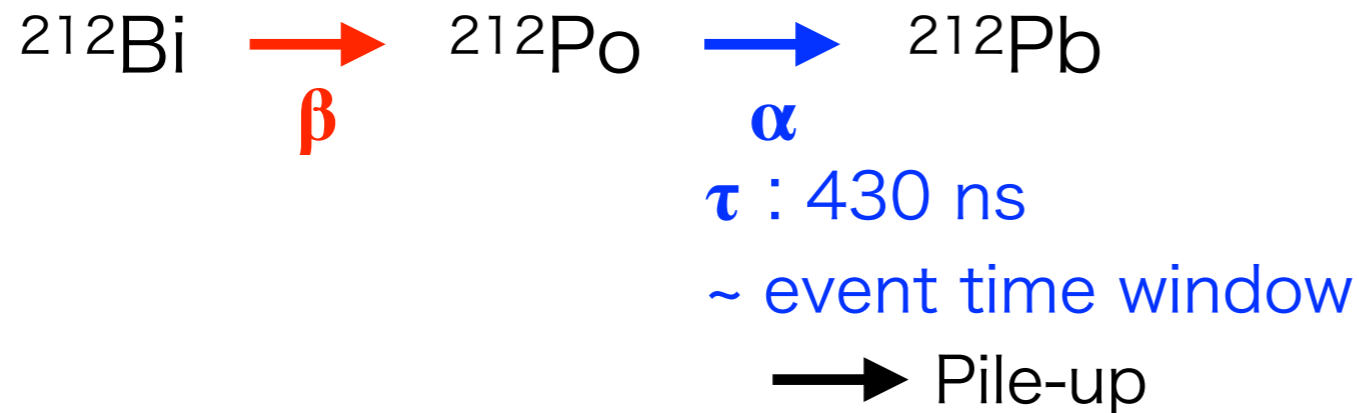
Natural RI events

LS composition measurement by GC-analysis

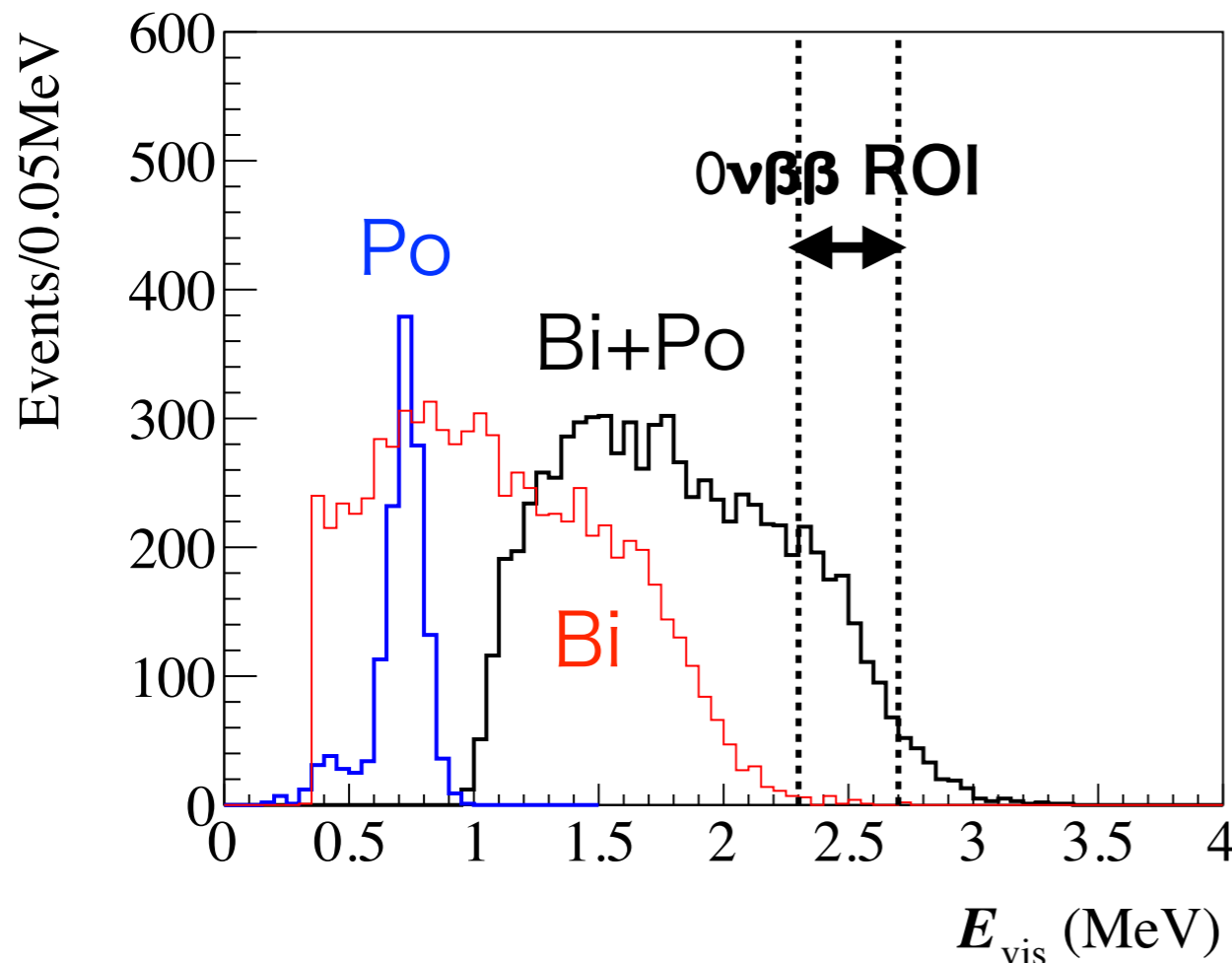
After 30.5 m³ LS filling, we started DAQ to investigate background status of LS and mini-balloon

Backgrounds and purification

^{232}Th daughters



Energy spectra of tagged Bi-Po from Zen400 data



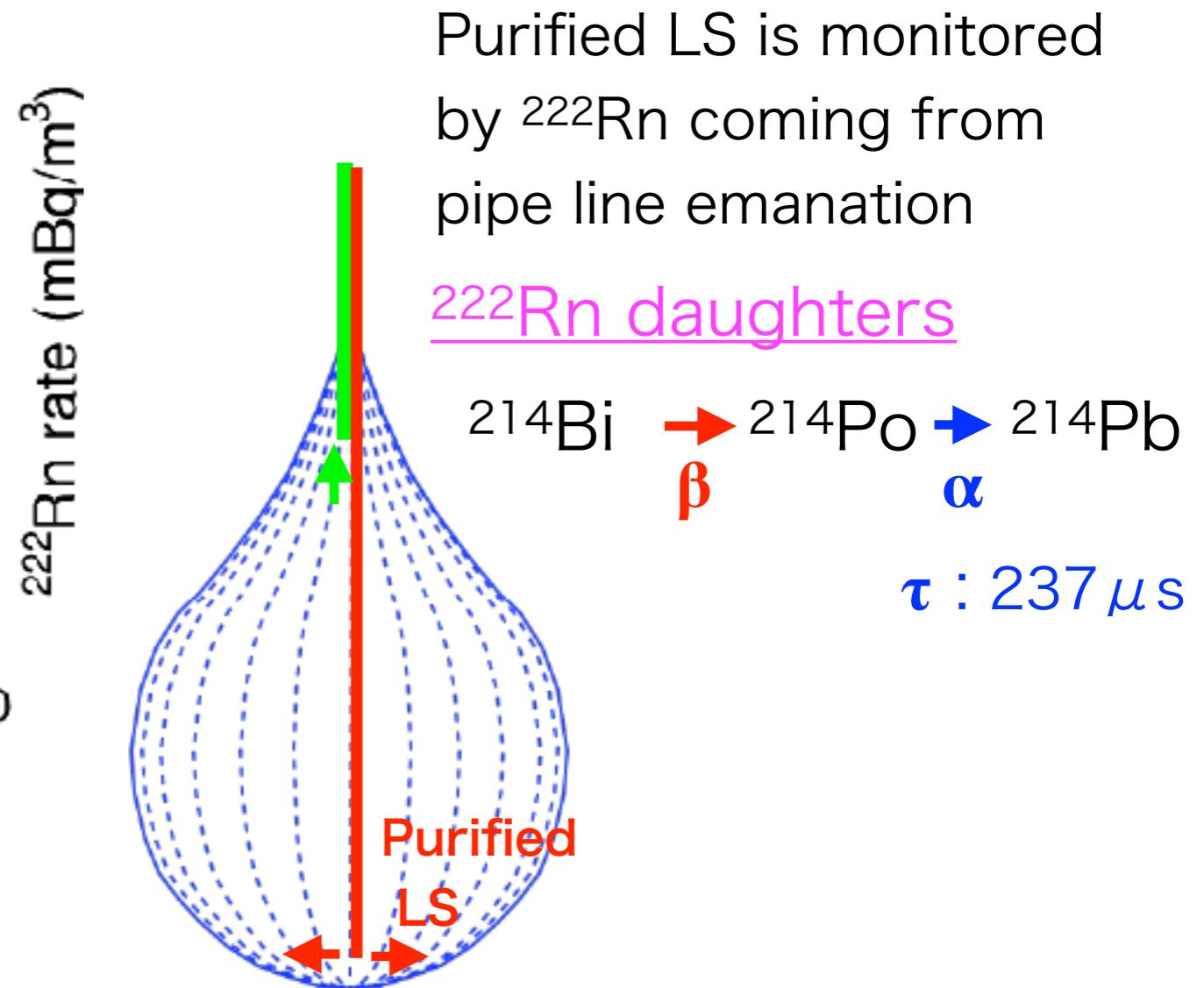
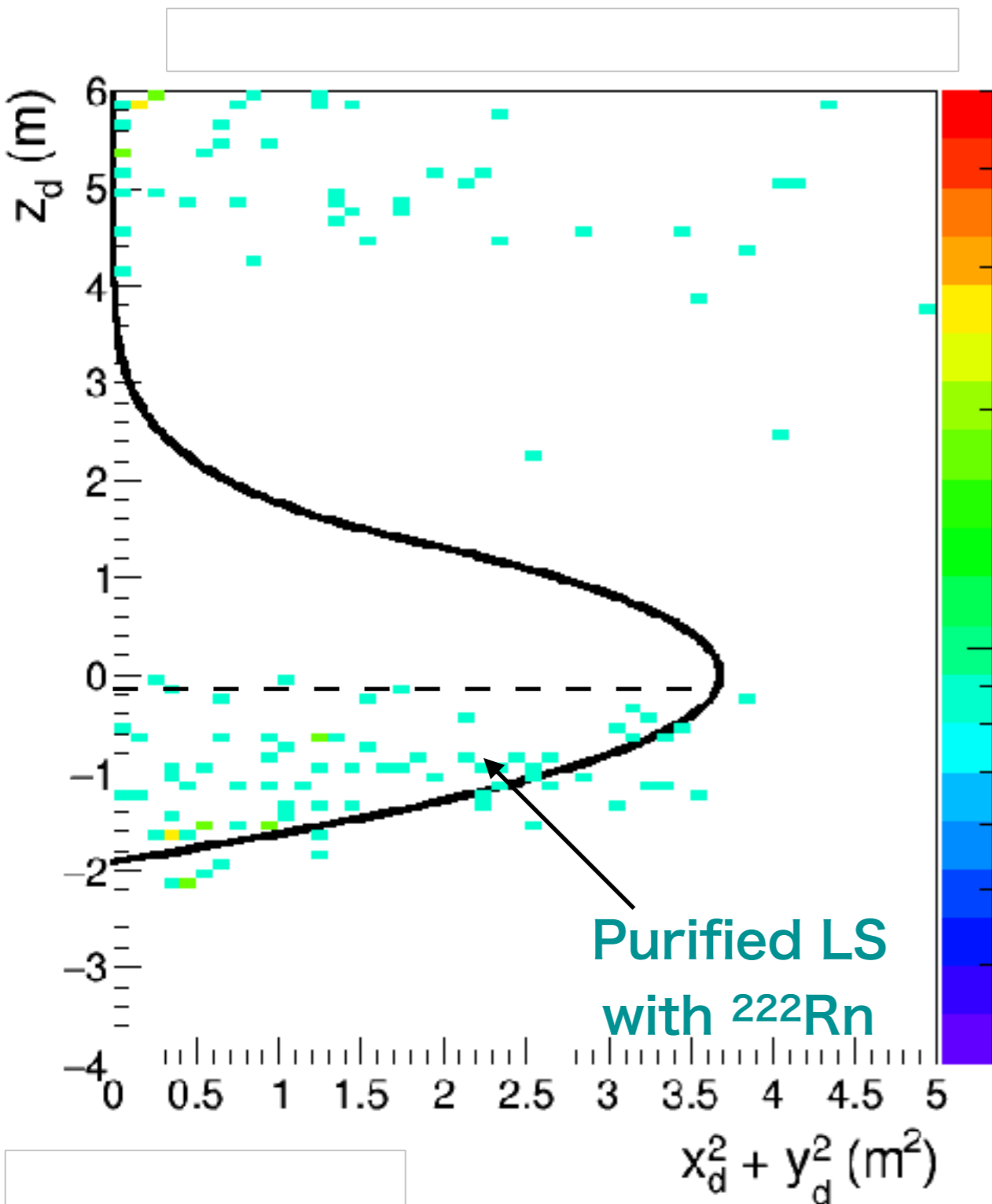
^{232}Th in LS

- Zen 400 : $5.9 \times 10^{-17} \text{ g/g}$
 - Target : $< O(10^{-16}) \text{ g/g}$
 - After LS filling : $O(10^{-15}) \text{ g/g}$
- Sensitivity is not so bad by this condition



LS Purification by distillation
(to achieve best performance)

Purification



After the purification

- Xenon is dissolved in LS
- Physics run will start this winter

Summary

- KamLAND-Zen searches for neutrino-less double beta decay with ^{136}Xe loaded liquid scintillator
- KamLAND-Zen 400 reached $\langle m_{\beta\beta} \rangle$ below 100 meV
- KamLAND-Zen 800
 - Inner mini-balloon has been produced using various low-background techniques
 - Inner mini-balloon was successfully installed
 - liquid scintillator is currently purified
 - KamLAND-Zen 800 DAQ will commence this winter

KamLAND-Zen collaboration

~50 people, 11 institutes, 3 countries

Collaboration meeting at Toyama, Mar. 2018

RCNS, Tohoku University

S. Abe, A. Gando, Y. Gando,
T. Hachiya, S. Hayashida, K. Hosokawa,
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

TUNL

H.J. Karwowski, D.M. Markoff,
W. Tornow*

Virginia Tech

T. O'Donnell

Kavli-IPMU (*)

A. Kozlov, D. Chernyak

Osaka University

Y. Takemoto, S. Umehara, S. Yoshida

Tokushima University

K. Fushimi, S. Hirata

Kyoto University

A. Ichikawa, S. Obara

UC Berkeley & LBNL

B.E. Berger*, B.K. Fujikawa*

MIT

L.A. Winslow, J. Ouellet, E. Krupczak

University of Tennessee

Y. Efremenko*

University of Washington

J.A. Detwiler*, S. Enomoto*

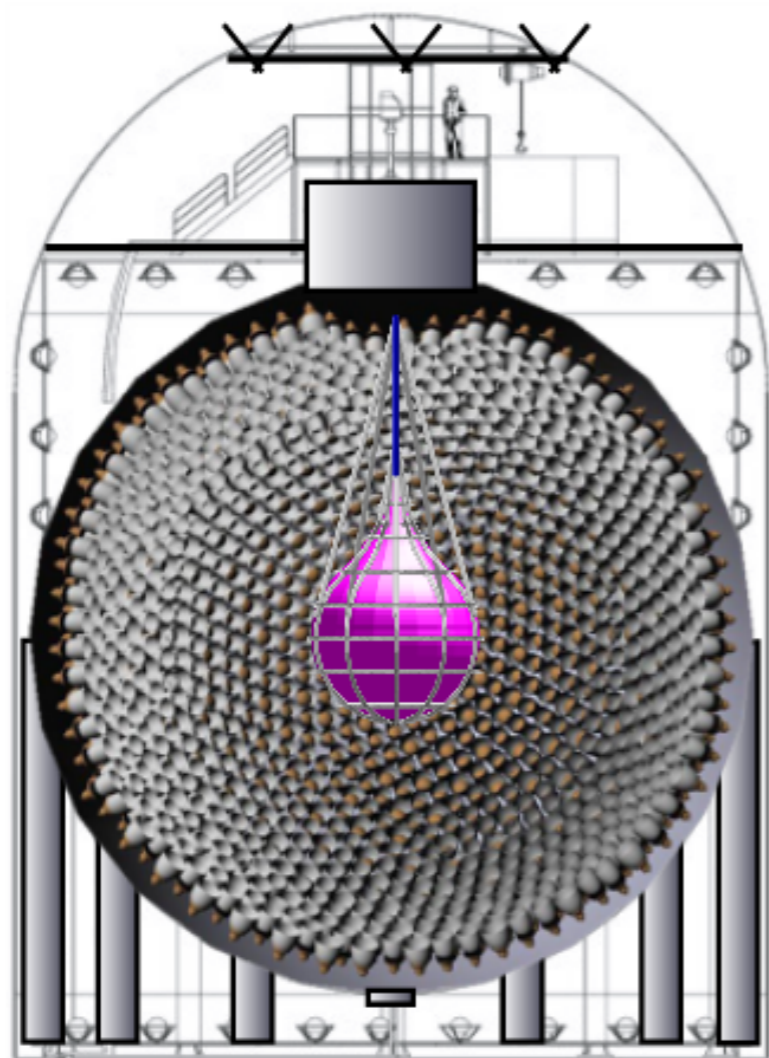
Boston University

C. Grant, A. Li*

Nikhef

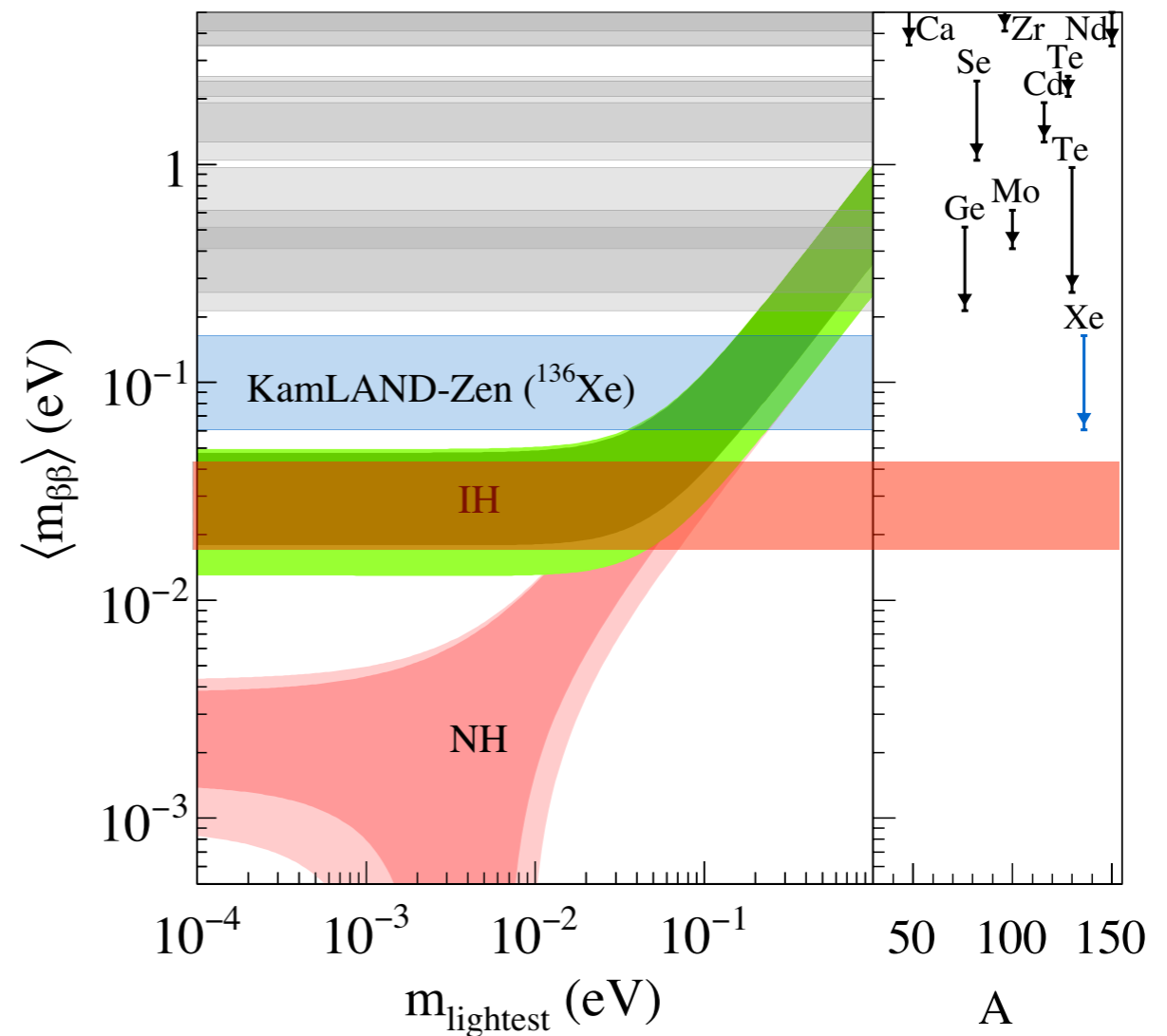
M.P. Decowski*

KamLAND2-Zen



Energy resolution \rightarrow 1.8%

- High light yield LS
- Light collection mirror
- High Q.E. PMTs



- Scintillation container for ^{214}Bi rejection
- Particle ID by imaging devices
- high xenon concentration LS by pressurized to reduce ^{10}C