Current status and future prospects of KamLAND-Zen

23 October 2018

DBD18 @ Hilton Waikoloa Village

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Research Center for Neutrino Science, Tohoku University

KamLAND(-Zen) collaboration

Japan
Tohoku University, RCNS
University of Tokyo, Kavli IPMU
Osaka University
Tokushima University
Kyoto University **new**

US
University of California Berkeley
University of Tennessee
Triangle University Nuclear Laboratory
University of Washington
Massachusetts Institute of Technology
Virginia Polytechnic Institute and State University
University of Hawaii
Boston University **new**

Netherland
Nikhef, University of Amsterdam

※ Second affiliation is not listed.

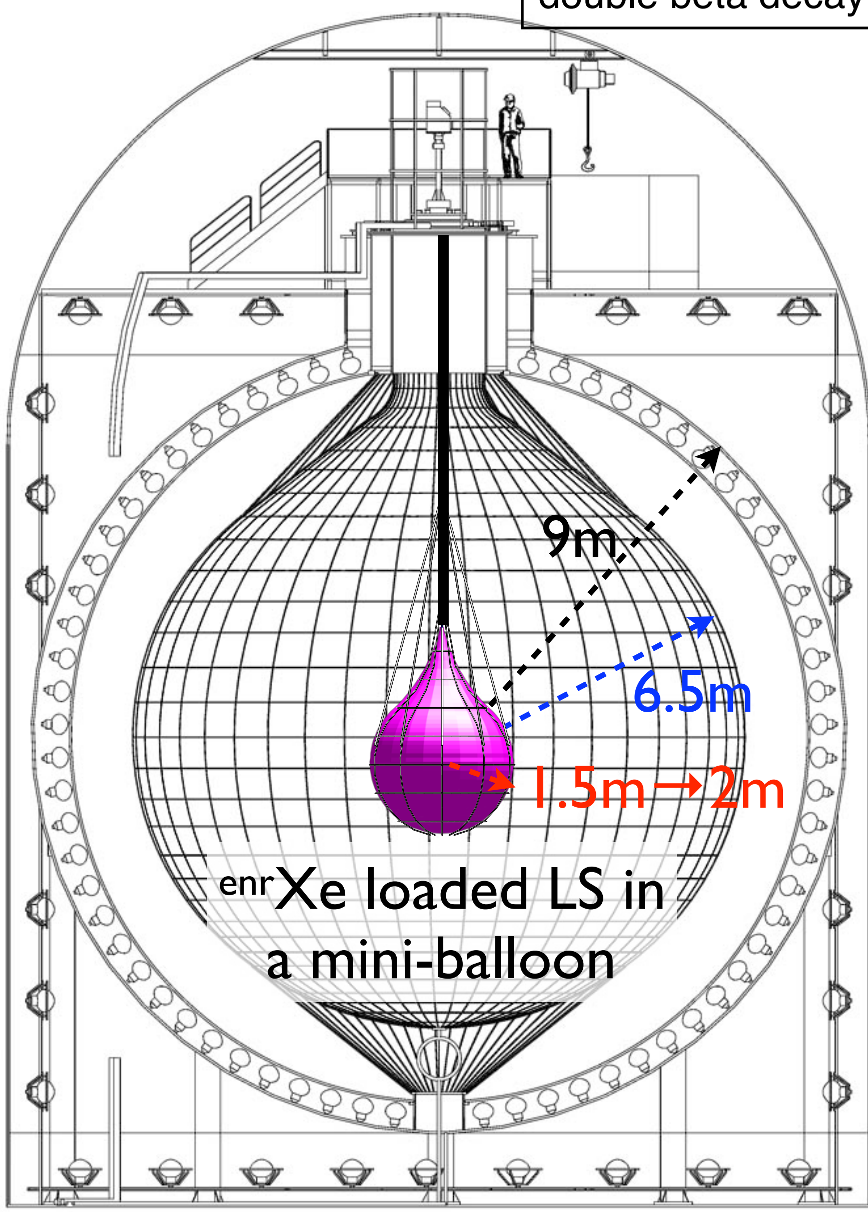
Collaboration meeting @MIT

~50 physicists

We chose ^{136}Xe as it can be loaded in LS up to ~3 wt%.

KamLAND-Zen

Zero Neutrino double beta decay search



90% enriched ^{136}Xe
320kg for phase-I
380kg for phase-II
750kg for Zen 800 (to start in months)

largest amount so far

^{136}Xe

Noble gas

Centrifugal enrichment possible

$Q_{\beta\beta}$=2459 keV

(below ^{208}Tl 3198-5001 keV)

Advantages of using KamLAND

⓪ low cost and quick start (running detector)

① BG can be identified (full active thick shielding)

② In-situ purification possible (liquid media)

③ On/Off measurements possible (xenon is removable)

④ multi-purpose (geo-neutrino)

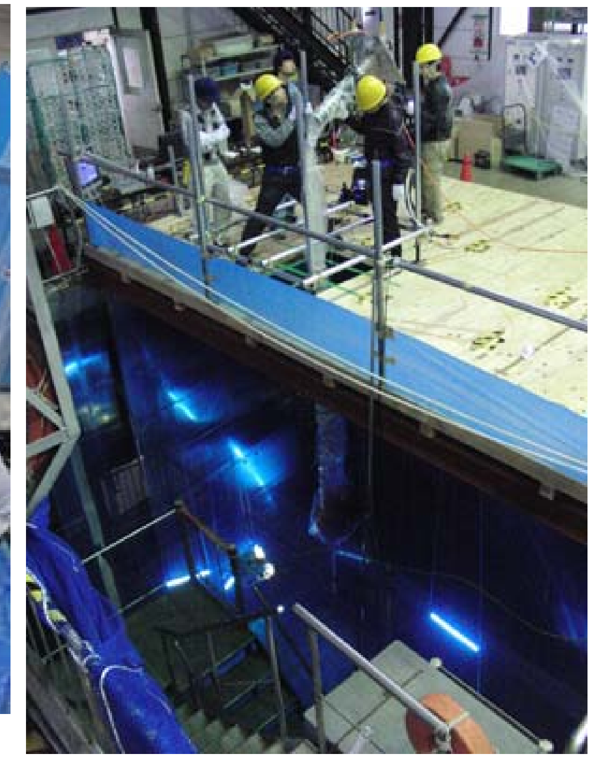
⑤ easily scalable (mini-balloon)

Test fabrication and rehearsal of installation (since 2009)

80μm-T PE prototype

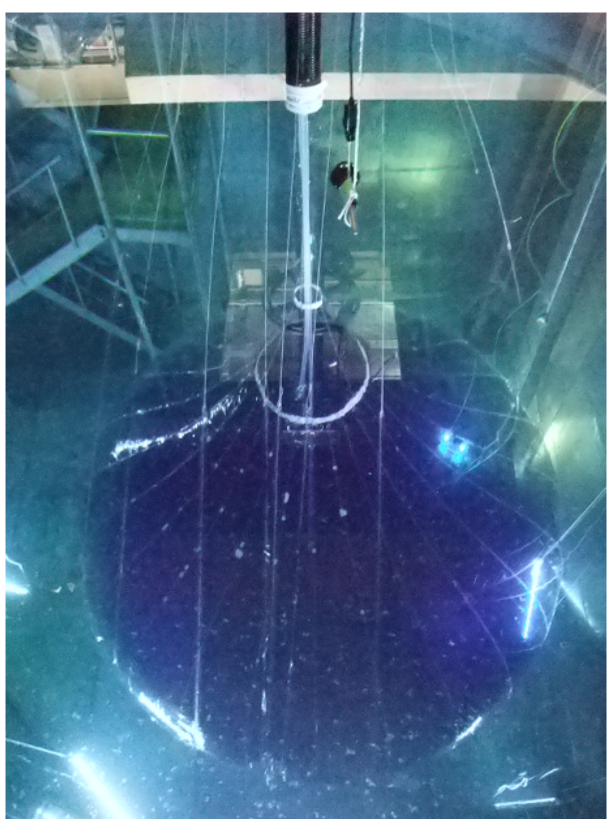
25μm-T Nylon-6 prototype

10m length when folded



Rehearsal with 8 m depth pool

Suspension mechanism



Established stratified replacement

Xenon handling system

Xenon mixing, density control

etc.

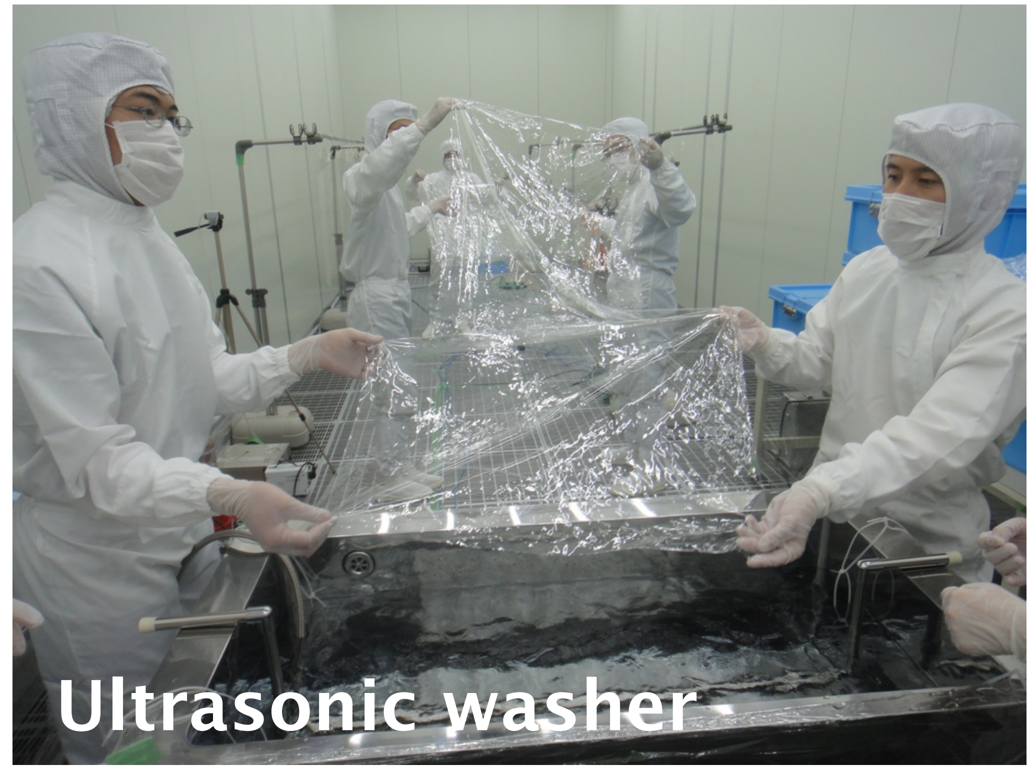
Clean tent in the dome

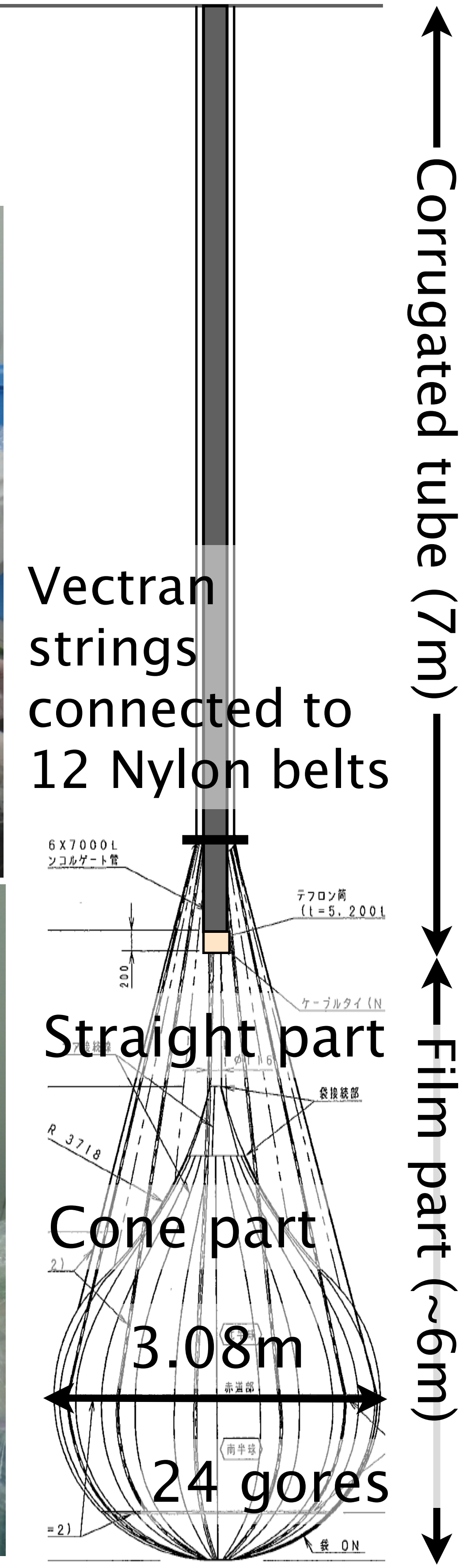
New cavity, buffer tanks

Mini-balloon fabrication for Zen 400

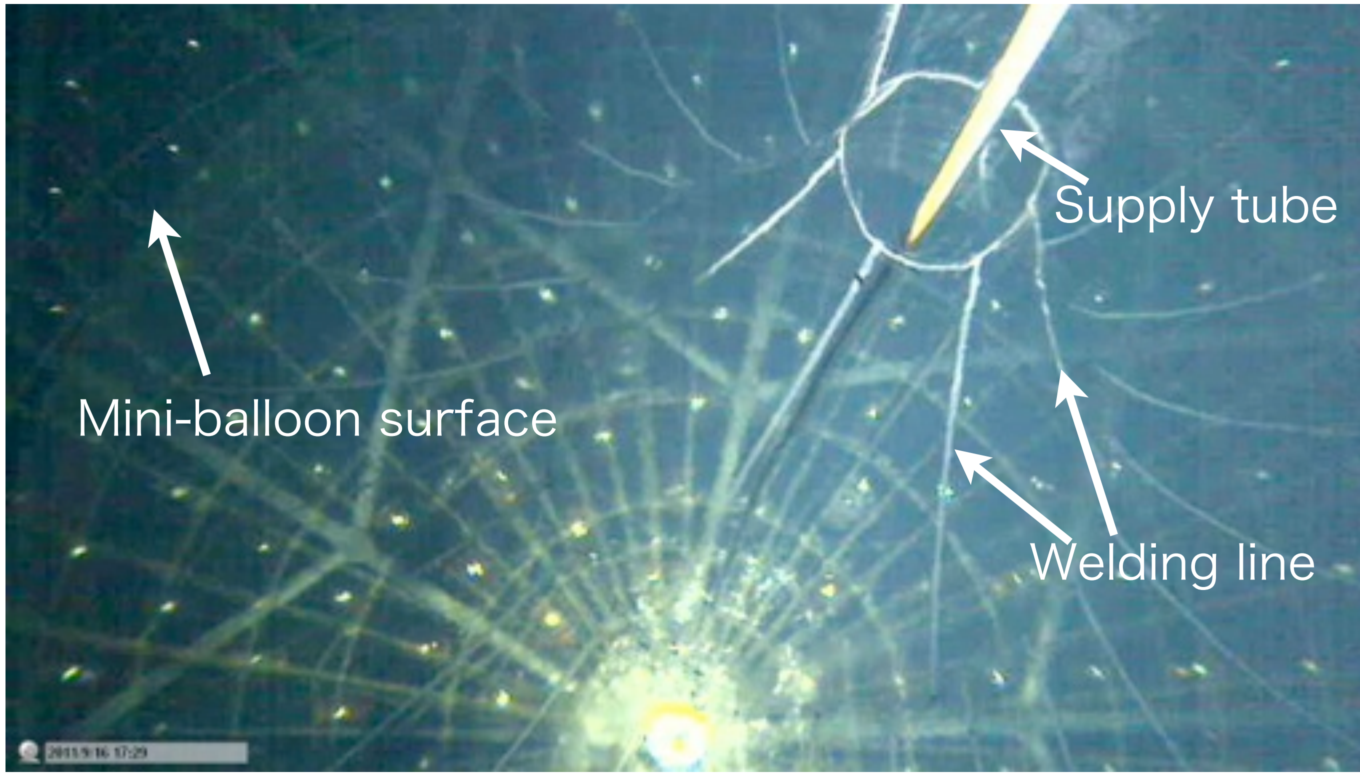
- Work in class-1 super-clean-room
  (class 1 : # of 0.5 μm particles in 1 cubic feet < 1

Less material → 25μm Nylon-6
  Transparency 99.4% @400nm
  Strength 19.4 N/cm
  Xe permeability < 220 g/year
Low radio impurity
  → film w/o filler
  U : 150 → 2×10^{-12} g/g
  Th : 59 → 3×10^{-12} g/g
  ^{40}K : 140 → 2×10^{-12} g/g

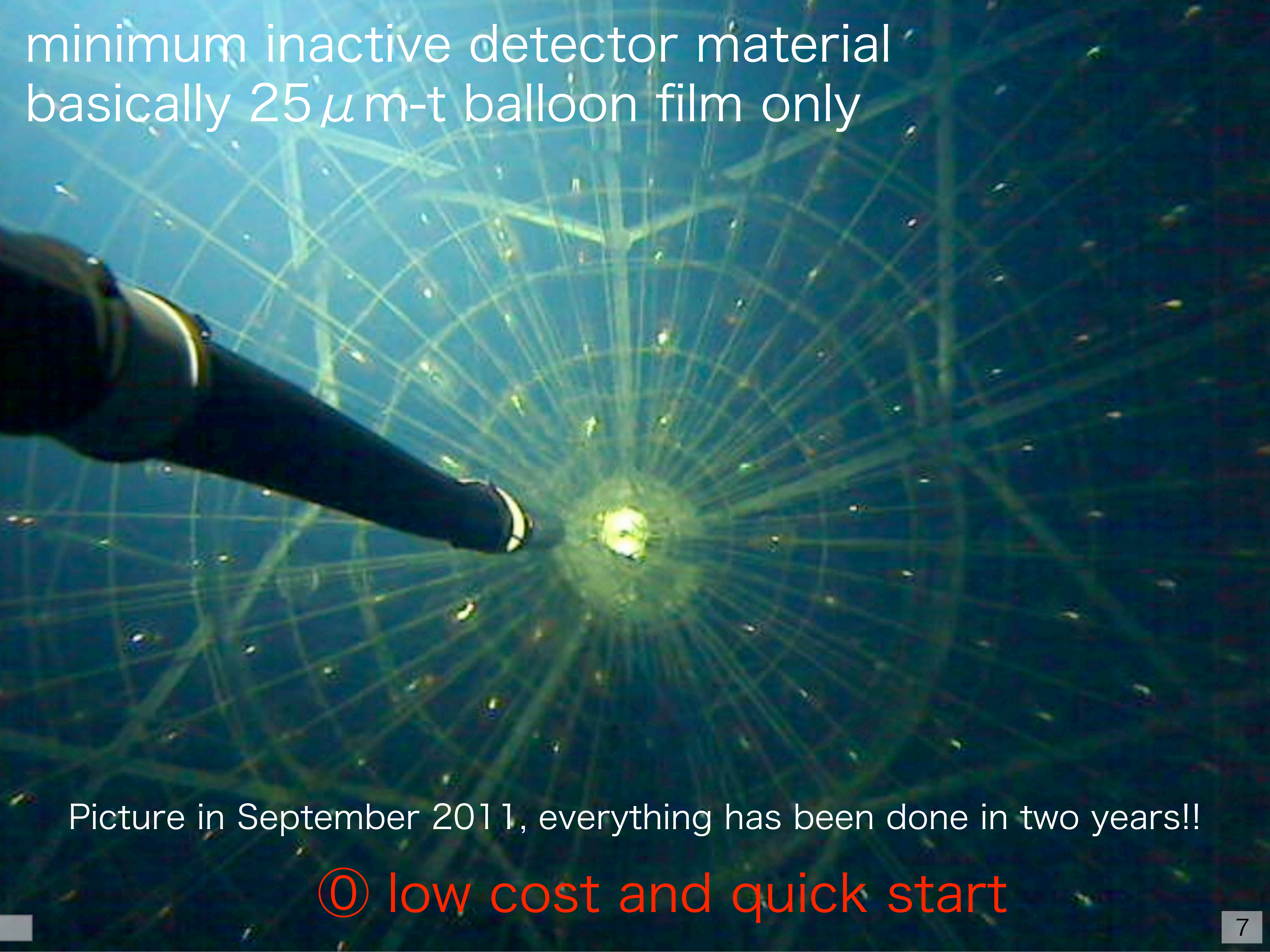




- all tools and parts are cleaned in this room



Inflated with dummy LS and replaced with xenon-loaded LS,
Retracted the tube after density adjustment



minimum inactive detector material
basically 25 μm-t balloon film only

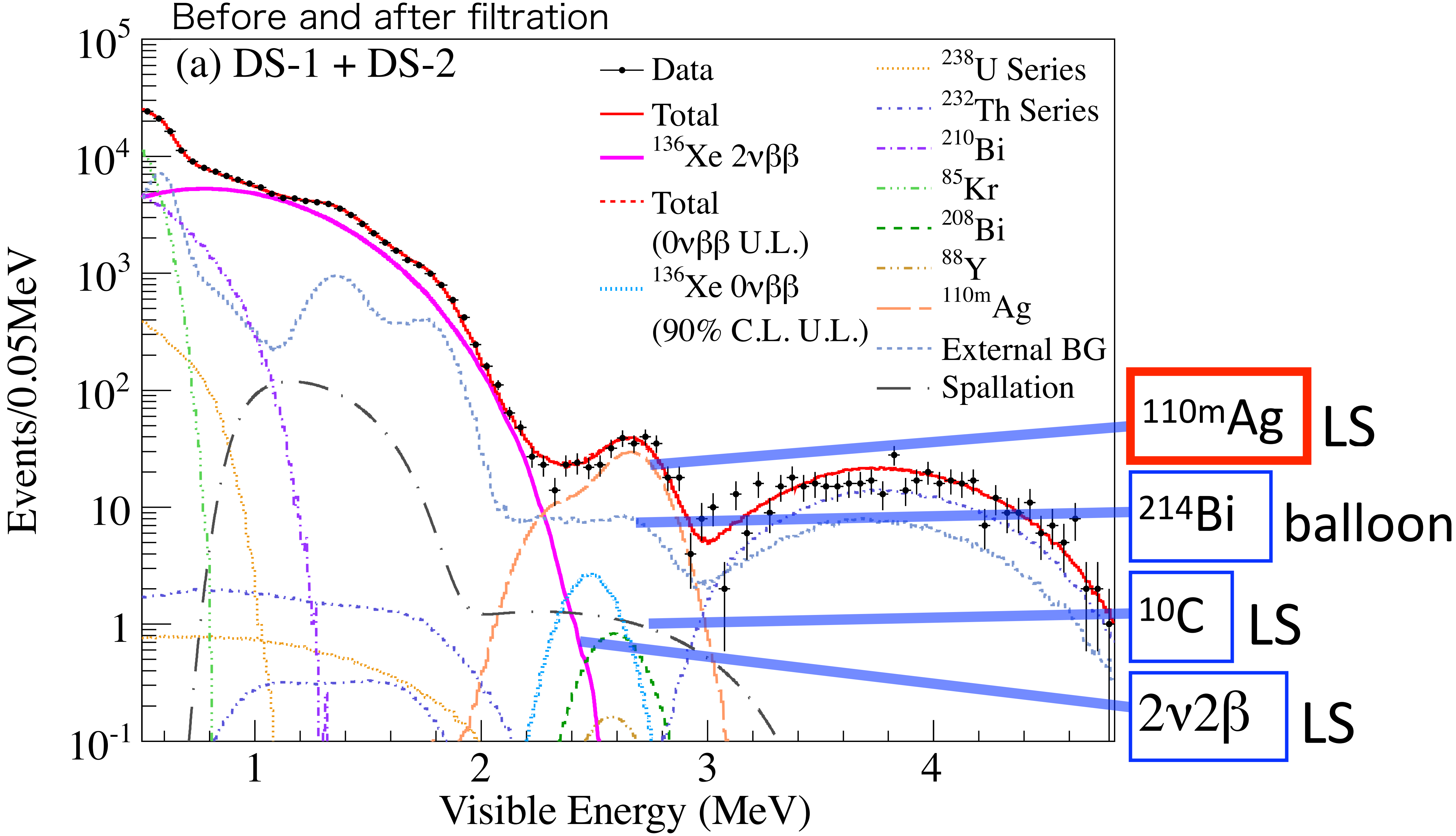
Picture in September 2011, everything has been done in two years!!

◎ low cost and quick start

KamLAND-Zen 400 phase I

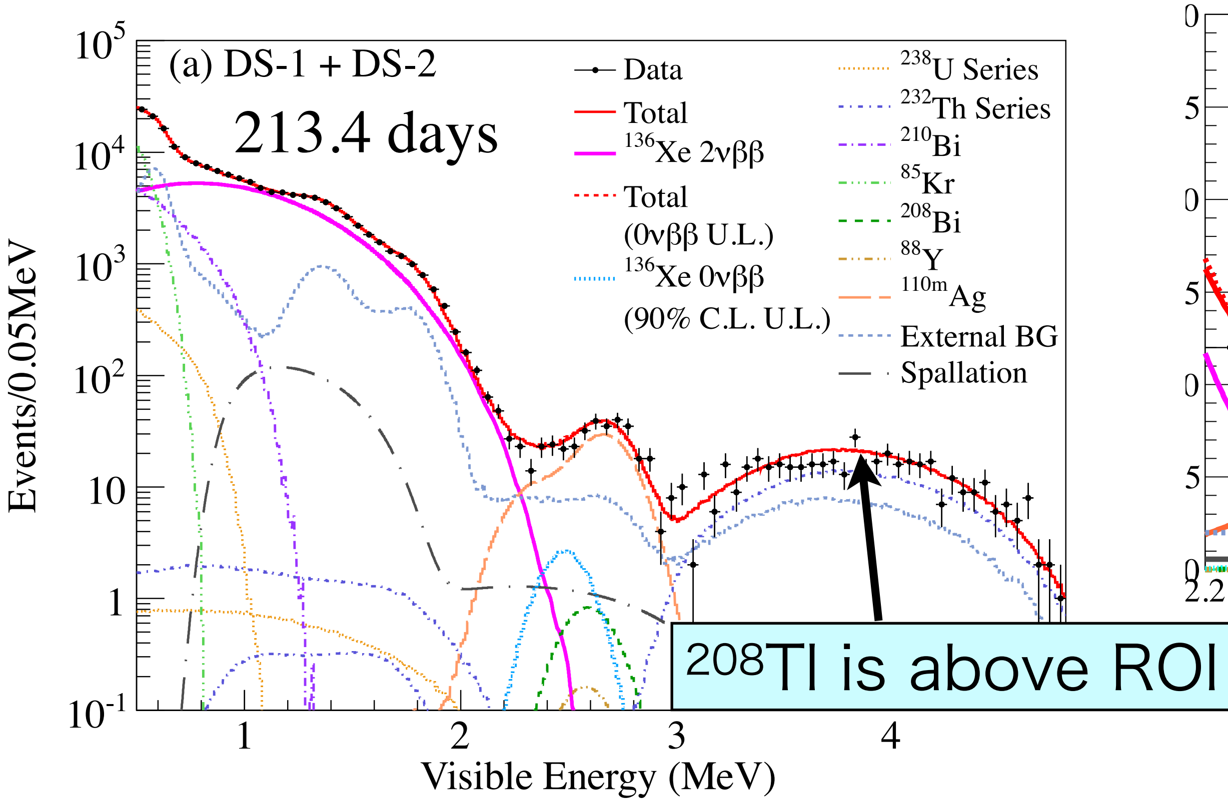
(320kg xenon loading)

Before and after filtration

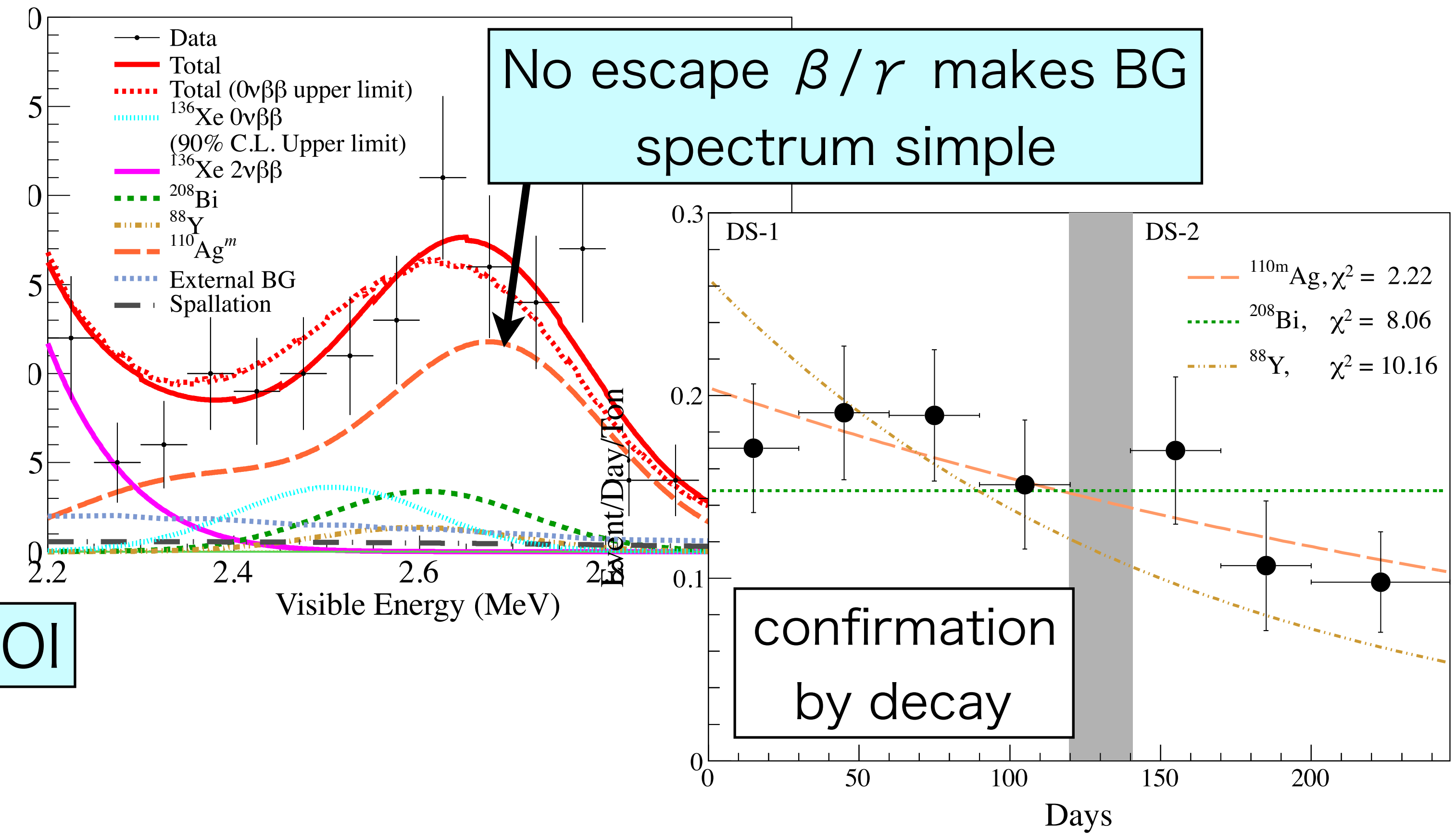


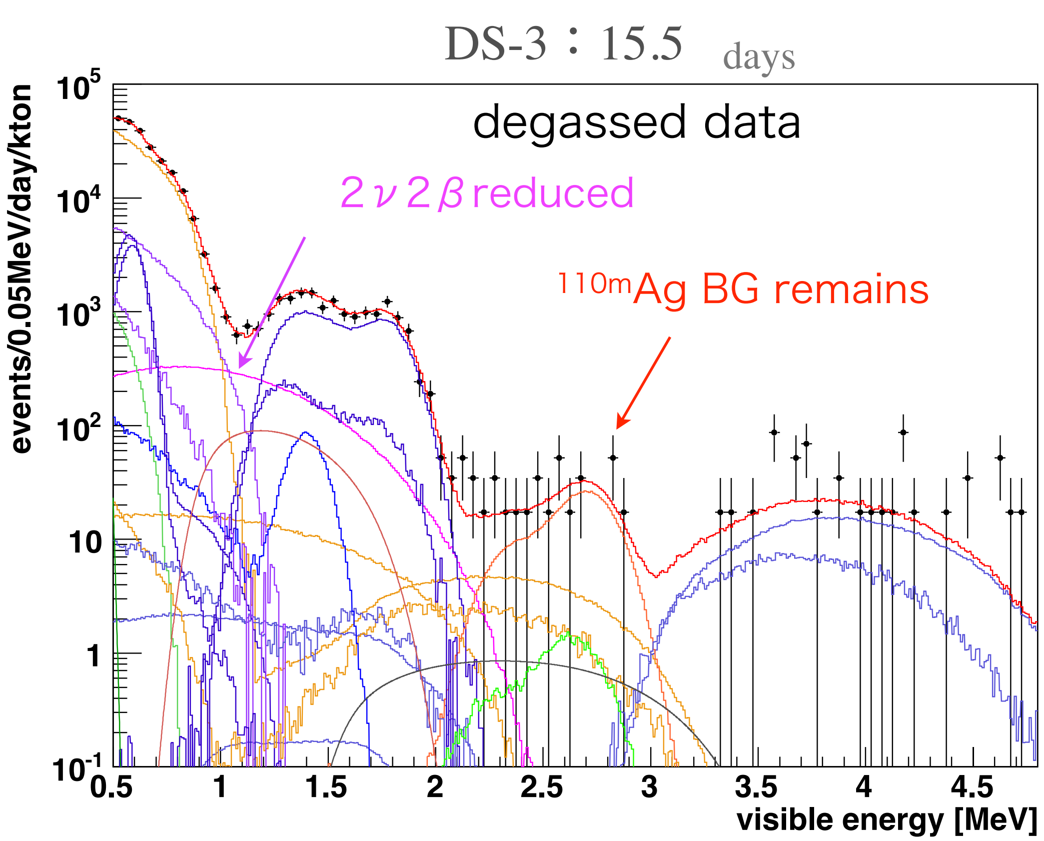
Unexpected BG has found

Thanks to full active apparatus,



Dominant ①BG identified as ^{110m}Ag

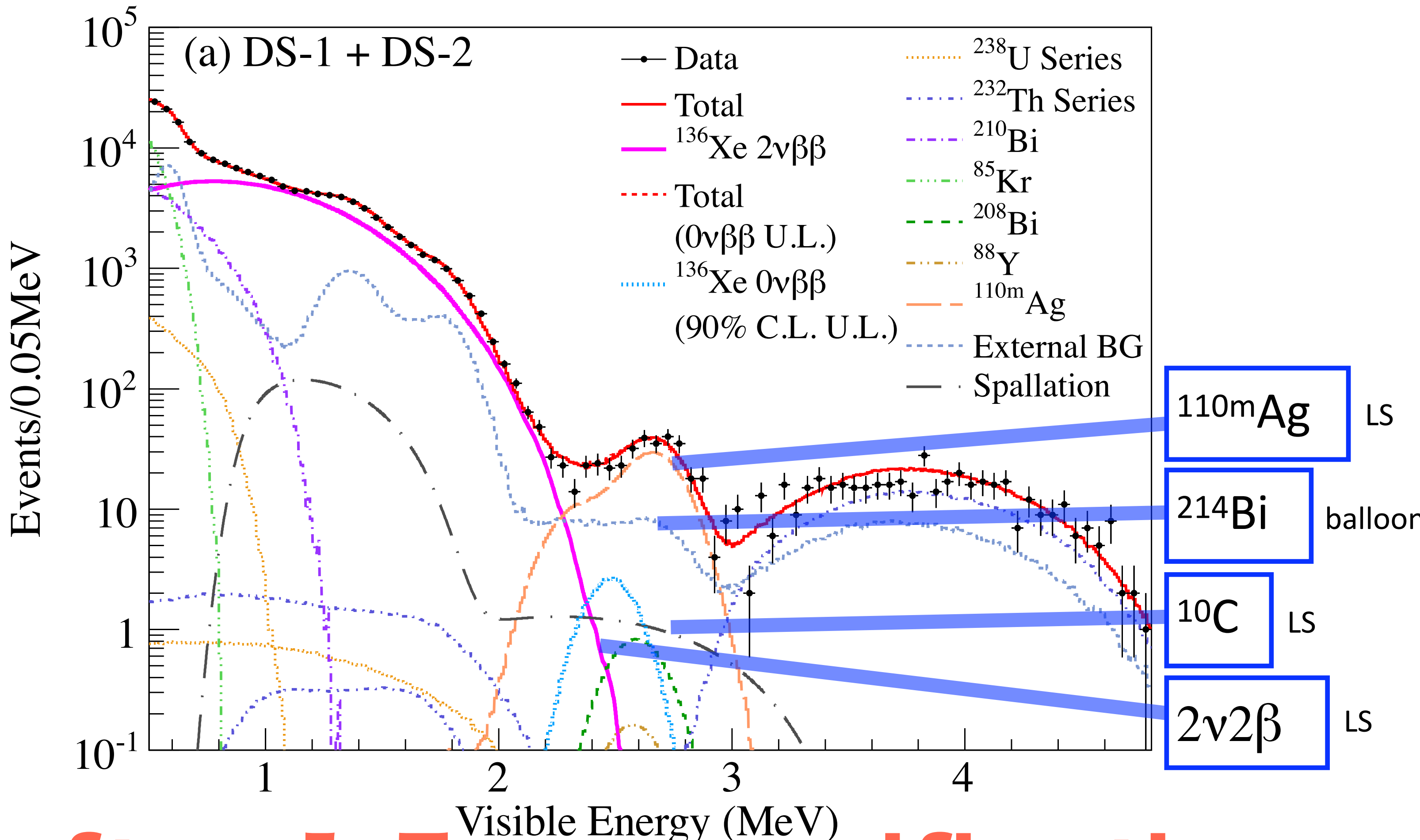




Xenon can be degassed from Xe-LS.
And ^{136}Xe ③on/off measurement has been demonstrated.
(useful for signal confirmation)

Phase-1 320kg

before purification



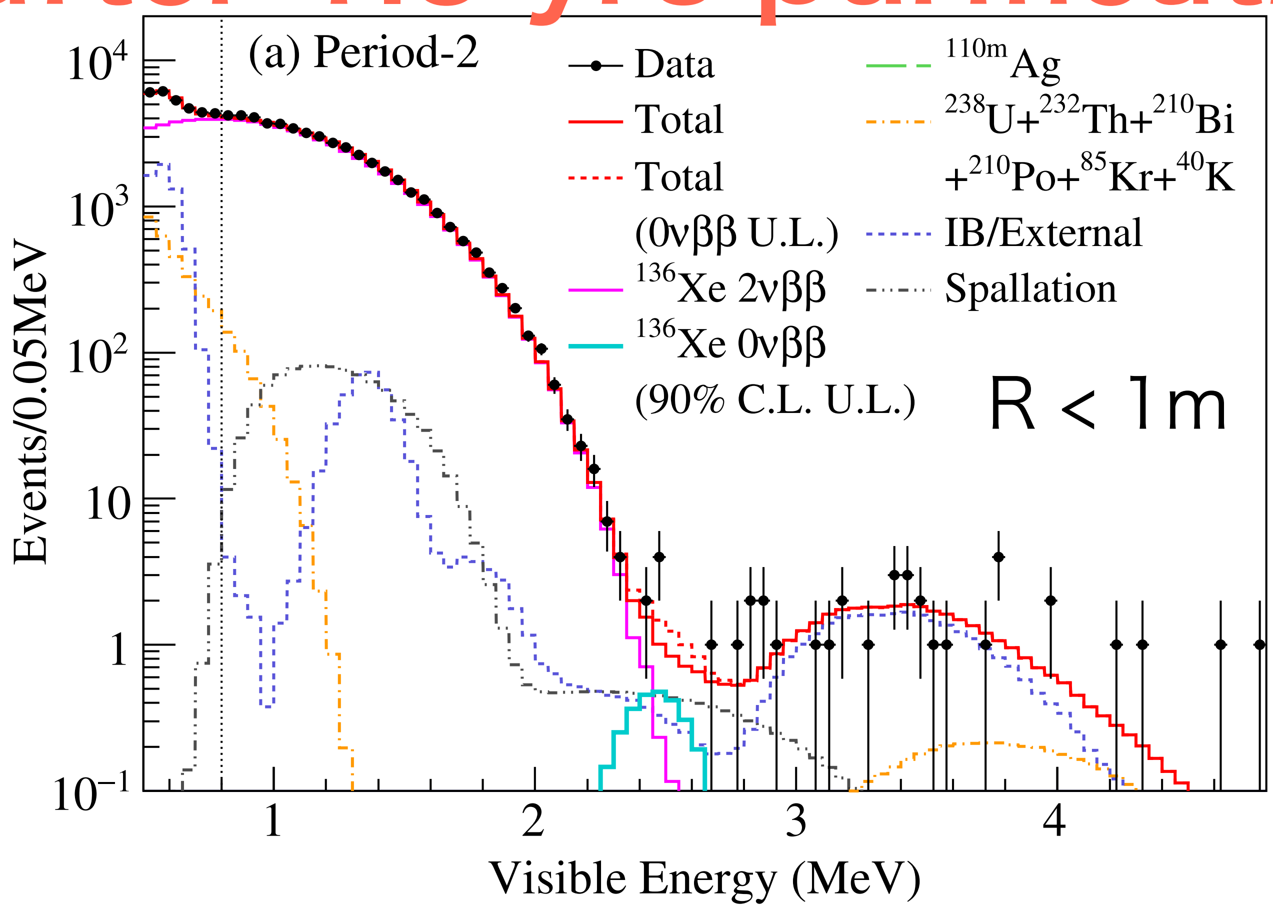
$>1.9 \times 10^{25}$y

after 1.5 yrs purification

Phase-2 380kg

after purification

^{110m}Ag reduction 1/20



2013/12/11 - 2014/10/27

534.5 days (504 kg-yr)

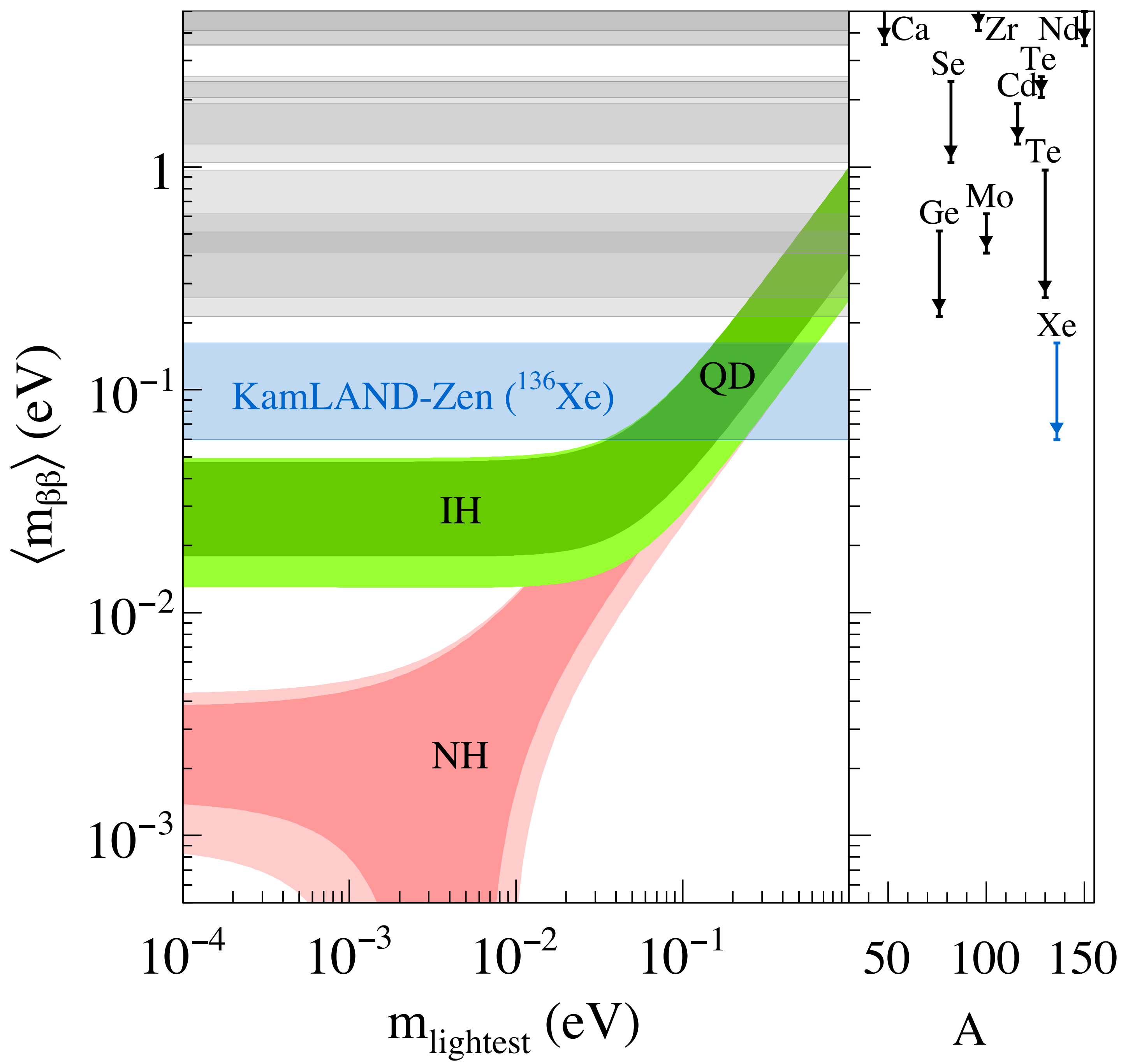
(cf. $T_{1/2}$(^{110m}Ag)=250 days)

②in-situ purification possible!!

KamLAND-Zen 400 Phase 1+2 combined

$$T_{1/2}^{0\nu} > 1.07 \times 10^{26}\ \mathrm{yr}$$

(sensitivity 5.6×10^{25} yr)



It also provides upper limit of $m_{lightest}$ at 180-480 meV.

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

PRL117, 082503 (2016)

Big leap toward IH region !

“Advantages of using KamLAND”

have been all demonstrated;

⓪ low cost and quick start (running detector) ✅

① BG can be identified (full active thick shielding) ✅

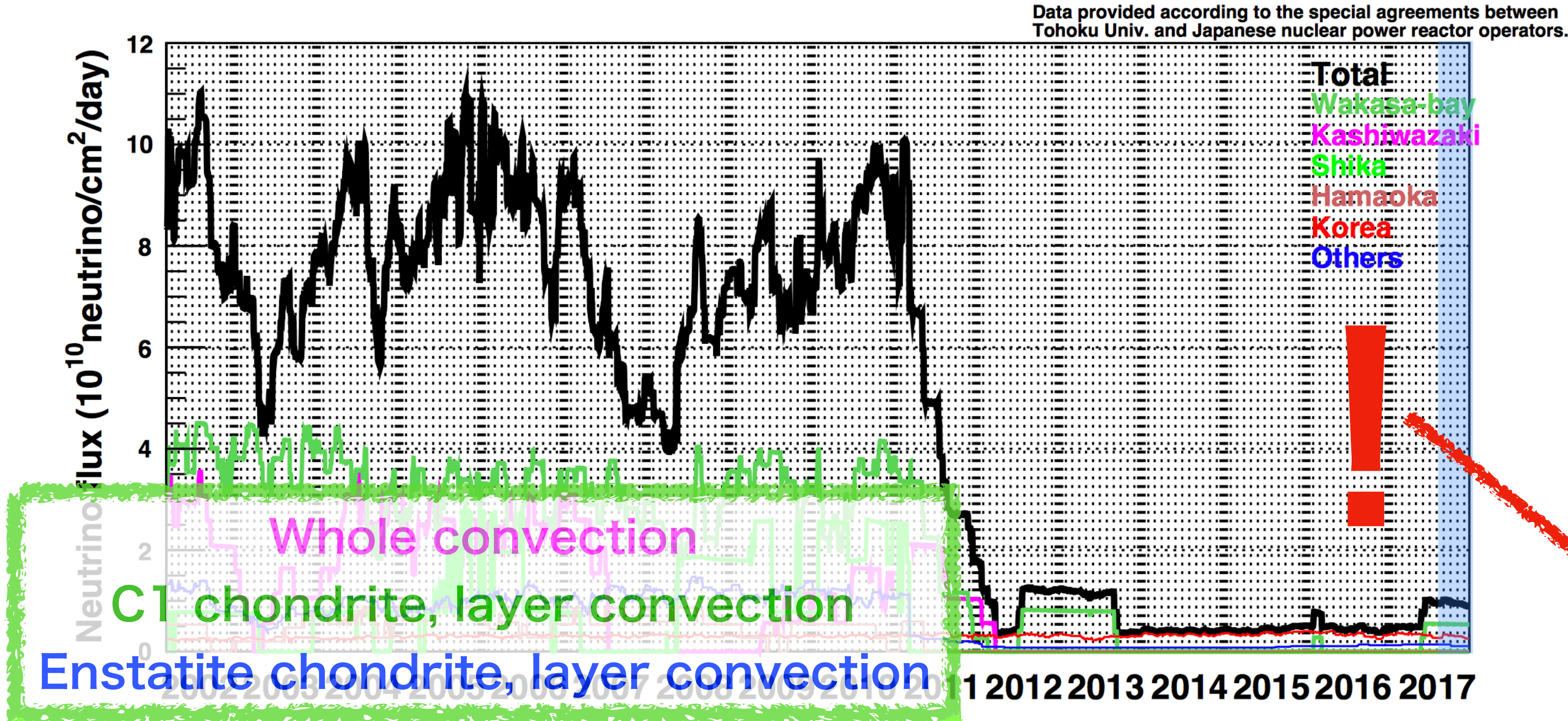
② In-situ purification possible (liquid media) ✅

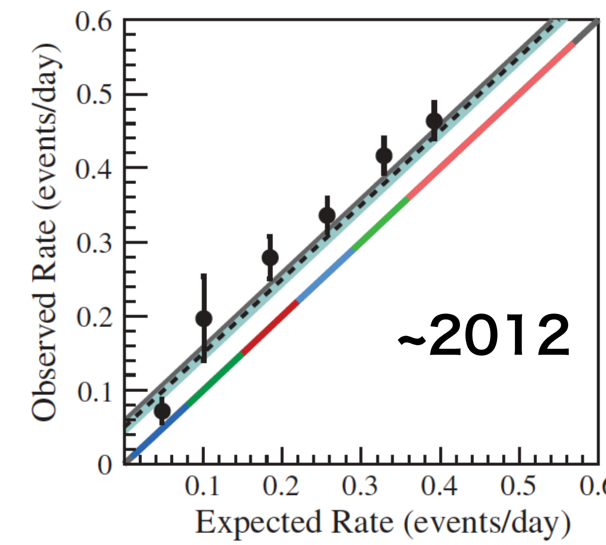
③ On/Off measurements possible (xenon is removable) ✅

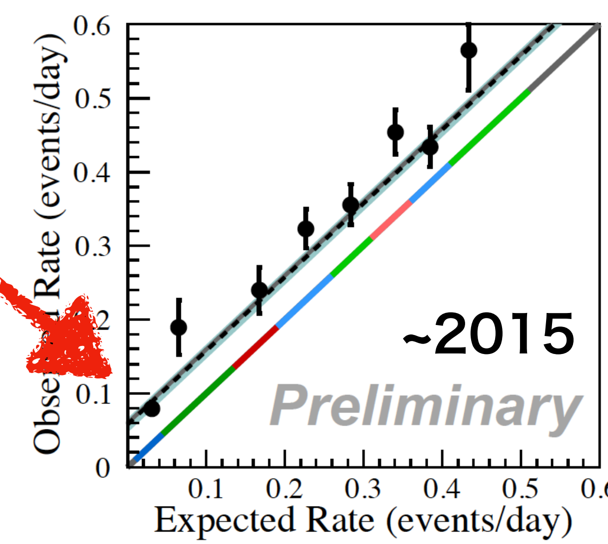
④ multi-purpose (ex. geo-neutrino) ✅

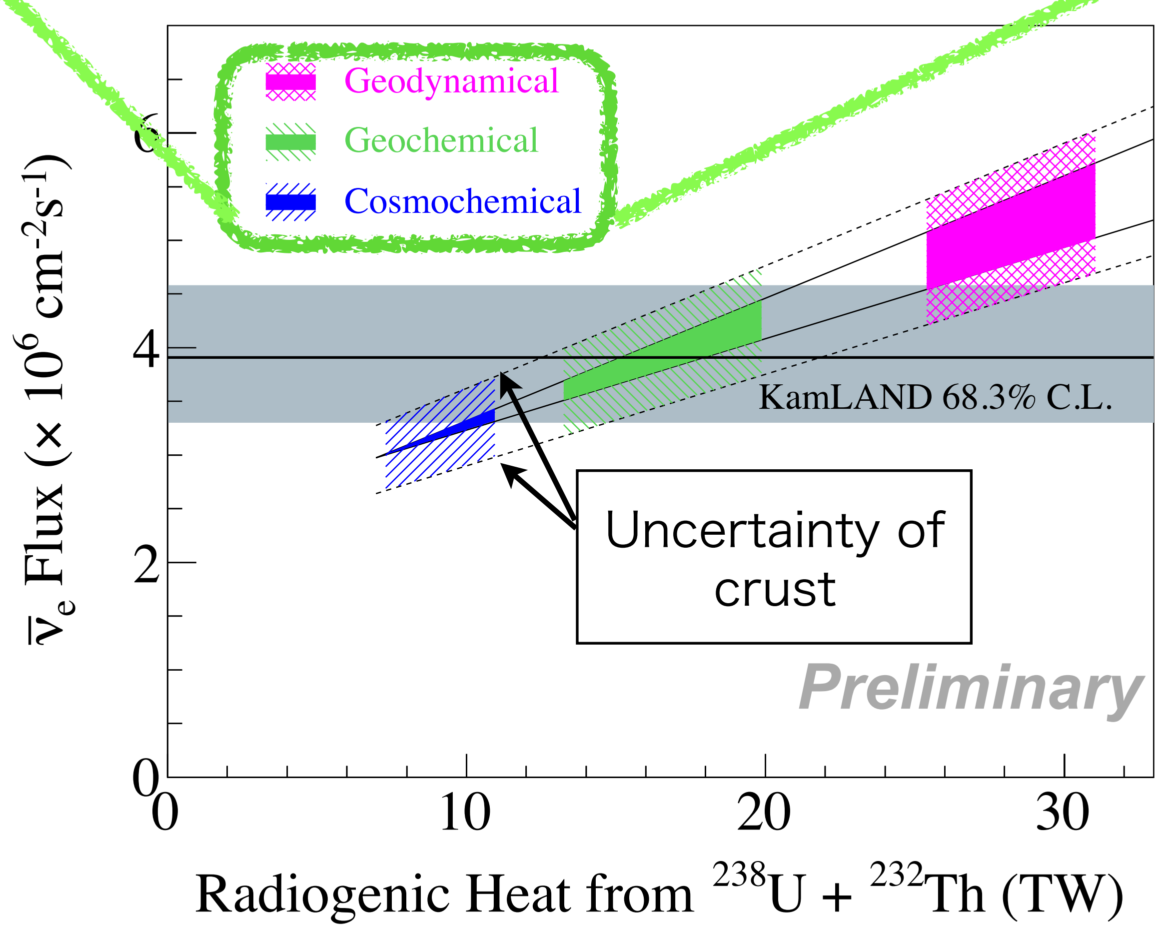
⑤ easily scalable (mini-balloon) **ongoing**

④ multi-purpose









Geo-neutrino observation may conclude primordial meteorite of the earth, and dynamics of the mantle !!

And more …

〇Pre-supernova alarm using Silicon-burning neutrinos

〇Simultaneous measurement of supernova temperature and luminosity with coherent scattering on hydrogen

〇Very long baseline (Korean) reactor oscillation (if Japanese ones are suspended)

〇Verification of CPT in comparison with neutrino and anti-neutrino oscillation (when Japanese reactors come up)

〇MSW upturn of solar ^{8}B neutrinos above 2 MeV

〇CNO cycle neutrinos (maybe with new electronics)

〇Physics with J-PARC neutrino beam

〇Search for charged dark matter with small mass difference to LSP

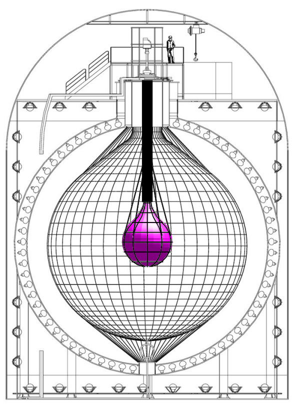
〇Sterile neutrino search with cyclotron (IsoDAR)

〇Verification of DAMA/LIBRA with NaI deployment

Yes, KamLAND-Zen has diverse physics targets

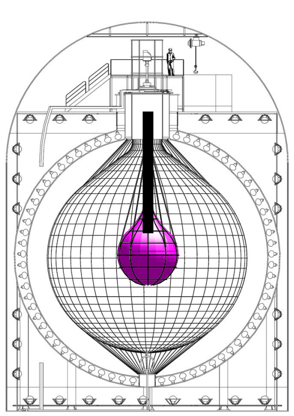
Timeline of KamLAND-Zen

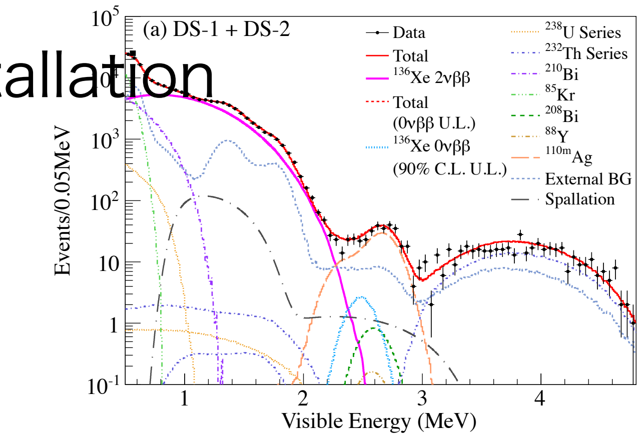
KamLAND-Zen 400

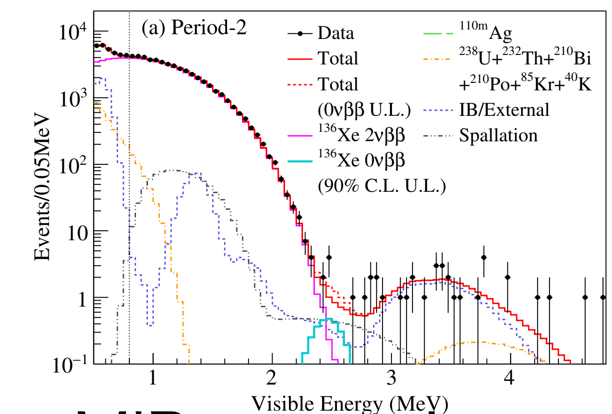


2011	MIB production	MIB installation, xenon installation
	400 phase1 — 320kg	Filtration
2012		Xenon extraction
	LS purification	
	Recovery from fire	Fire
2013	LS purification	
		Xenon installation
2014	400 phase2 — 380kg	
2015	MIB production	
		Calibration, xenon extraction, MIB extraction
2016	OD refurbishment	
	MIB production	MIB installation, characterization
		Leak
		MIB extraction, hole inspection
2017	Welding improvement	
	MIB production	
2018		MIB installation, characterization
	LS purification	
	Xenon installation	**We are here, just before xenon installation.**
2019	Zen 800 — 750kg	

KamLAND-Zen 800







2nd mini-balloon fabrication

cleaning, cleaning and

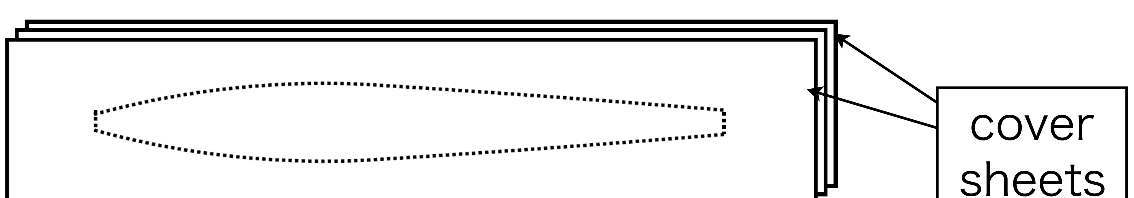
cleaning as usual

Example of improvements

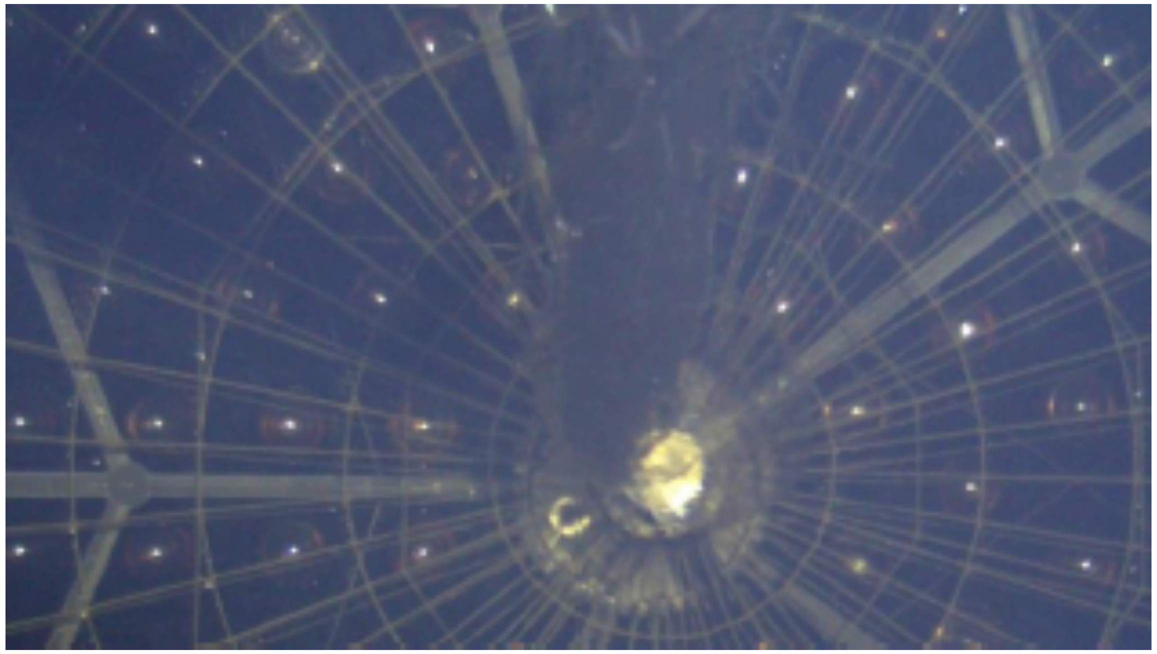
before

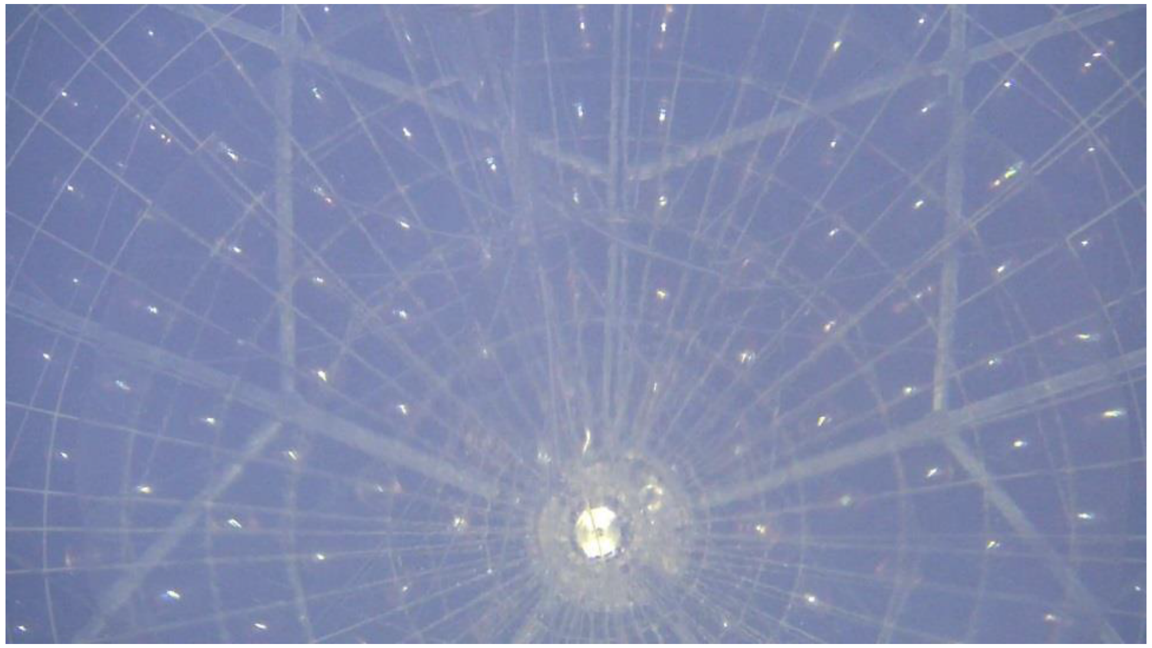
after

keep staying away
goggle
welding machine
cover sheet
glove on glove
laundry twice a day
clean underwear
changing room in a clean room
dust visualization
more neutralizer
・・・



after Leak check and repair





New mini-balloon has been deployed and inflated with "dummy" LS in August 2016

spent 1+α yrs in total

through characterization of mini-balloon

We confirmed that the mini-balloon is cleaner !!

Measures we took worked!

preliminary

x1E-12 g/g_{film}	^{232}Th	^{238}U
intrinsic	6	2 Target
This time*	31+-7	5.3+-0.8
Zen 400 1st	79+-3	14+-1
Zen 400 2nd	336+-2	46.1+-4

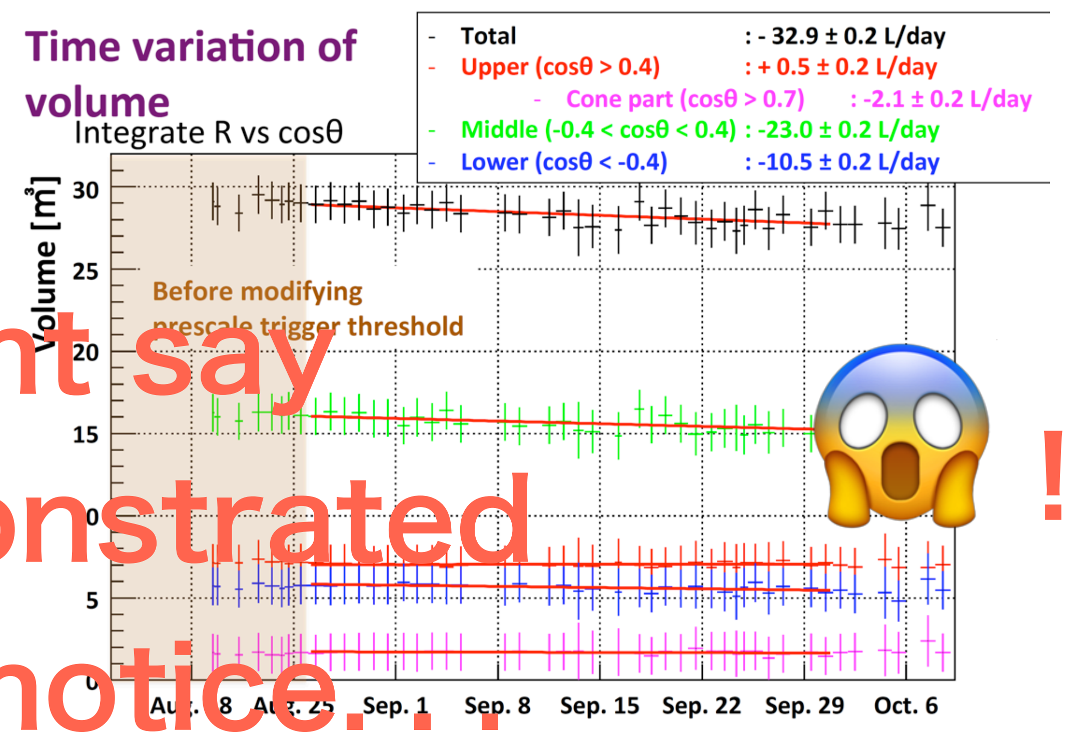
~1/10

Yes, cleaner!

At the same time, we noticed;

Indications of leak;

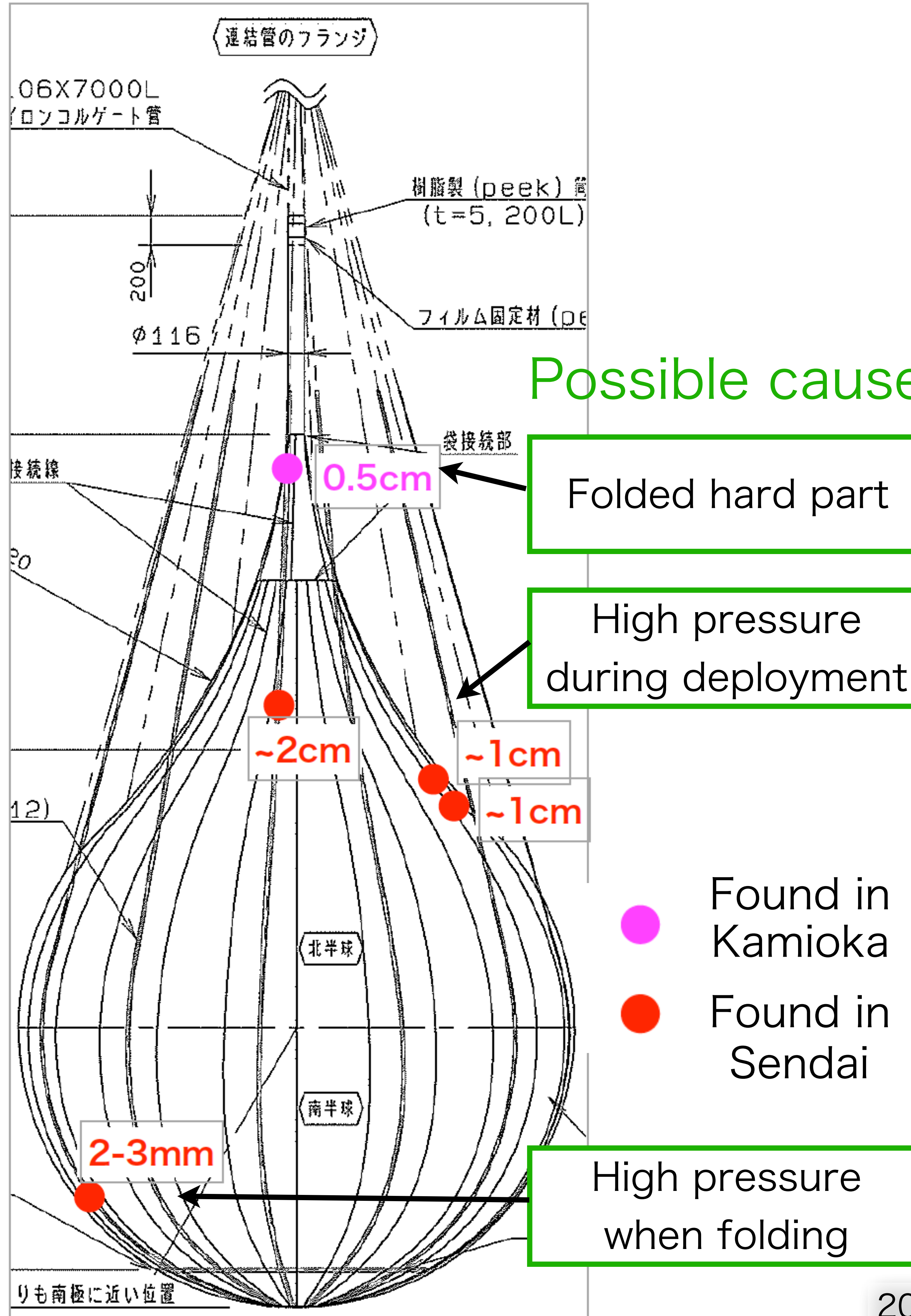
- camera image
- load cell
- balloon shape reconstruction with ^{210}Po events
- ^{222}Rn decay rate
- mixture of KL-LS and dummy-LS by gas-chromatography



I might say we demonstrated we can notice. . .

! !

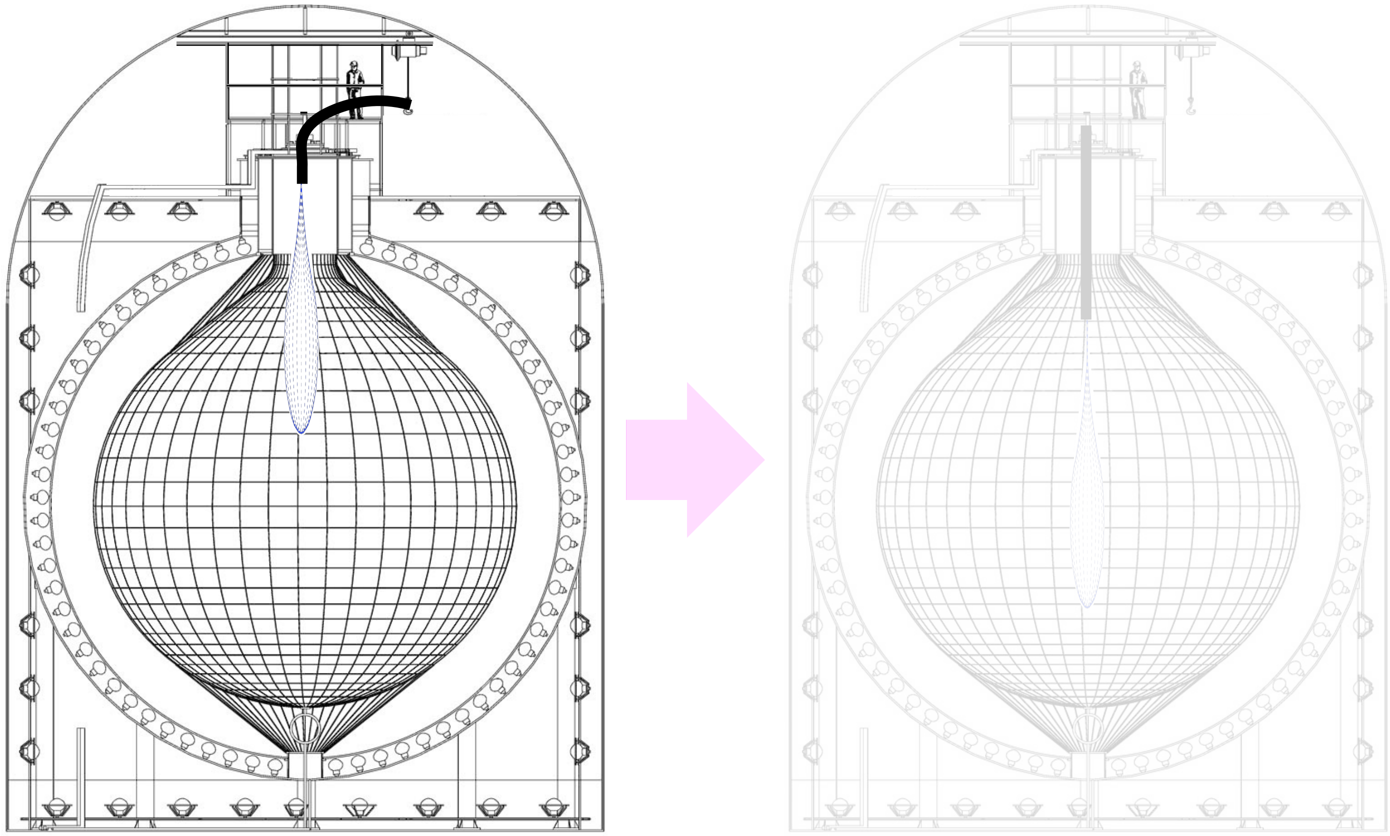
Inspection of holes with a He leak detector



after 1.5 yrs of effort Including improvement of welding

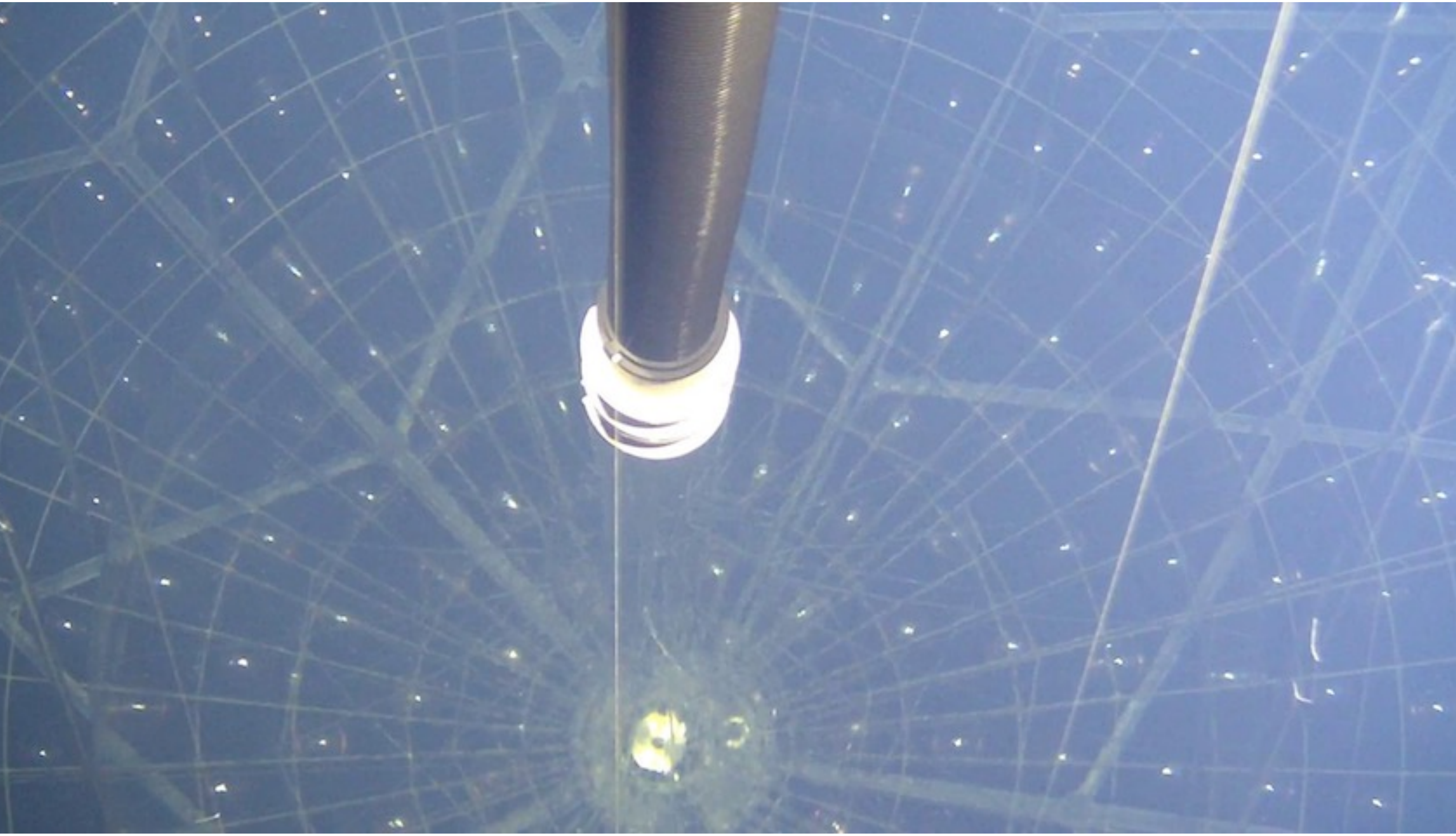
mini-balloon installation May 10, 2018

50cm width for detector access



Dummy LS filling

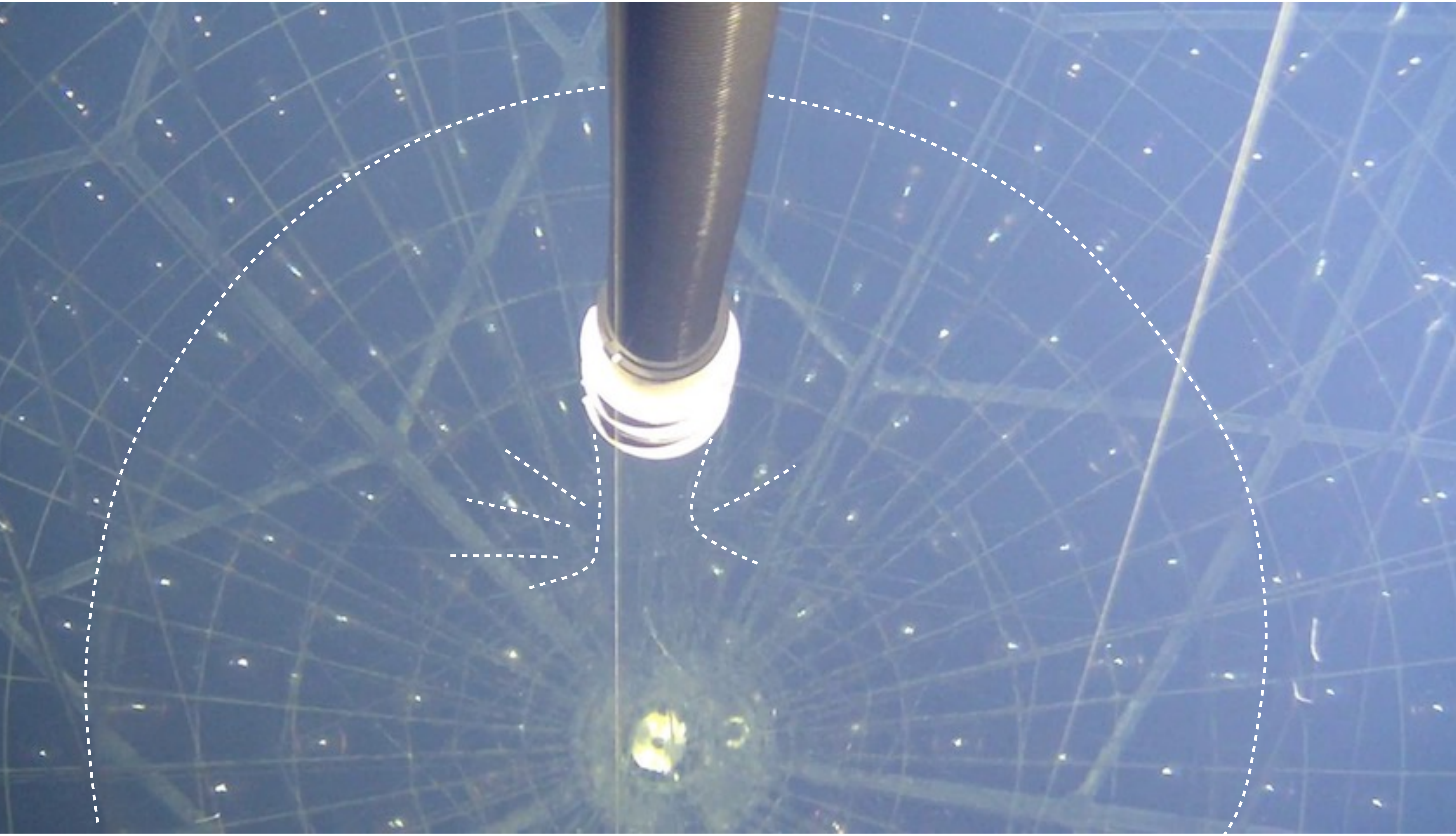
Dummy LS = non Xe loaded LS



After 30.5 m^3 LS filling, we started DAQ to investigate background status of LS and mini-balloon

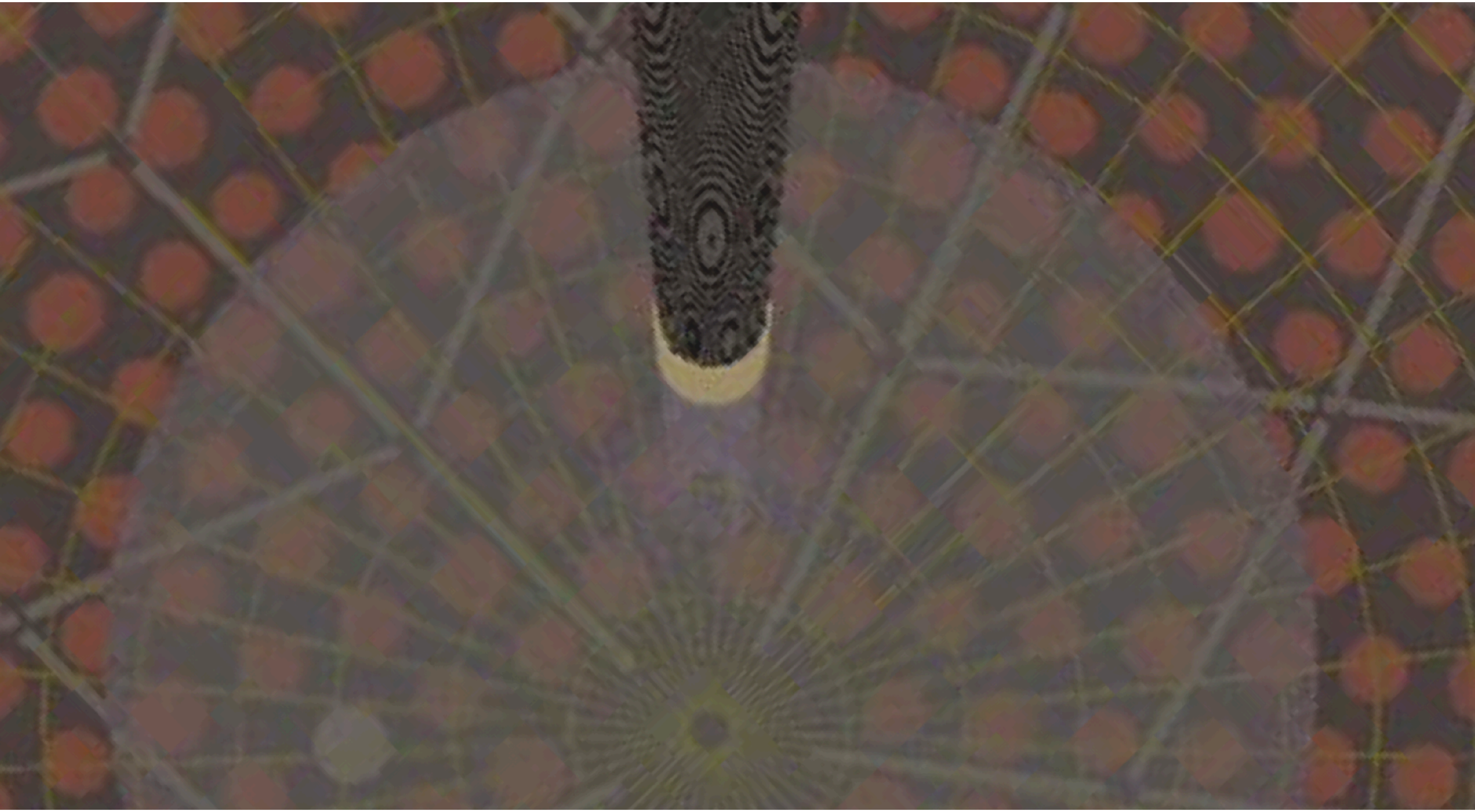
Dummy LS filling

Dummy LS = non Xe loaded LS

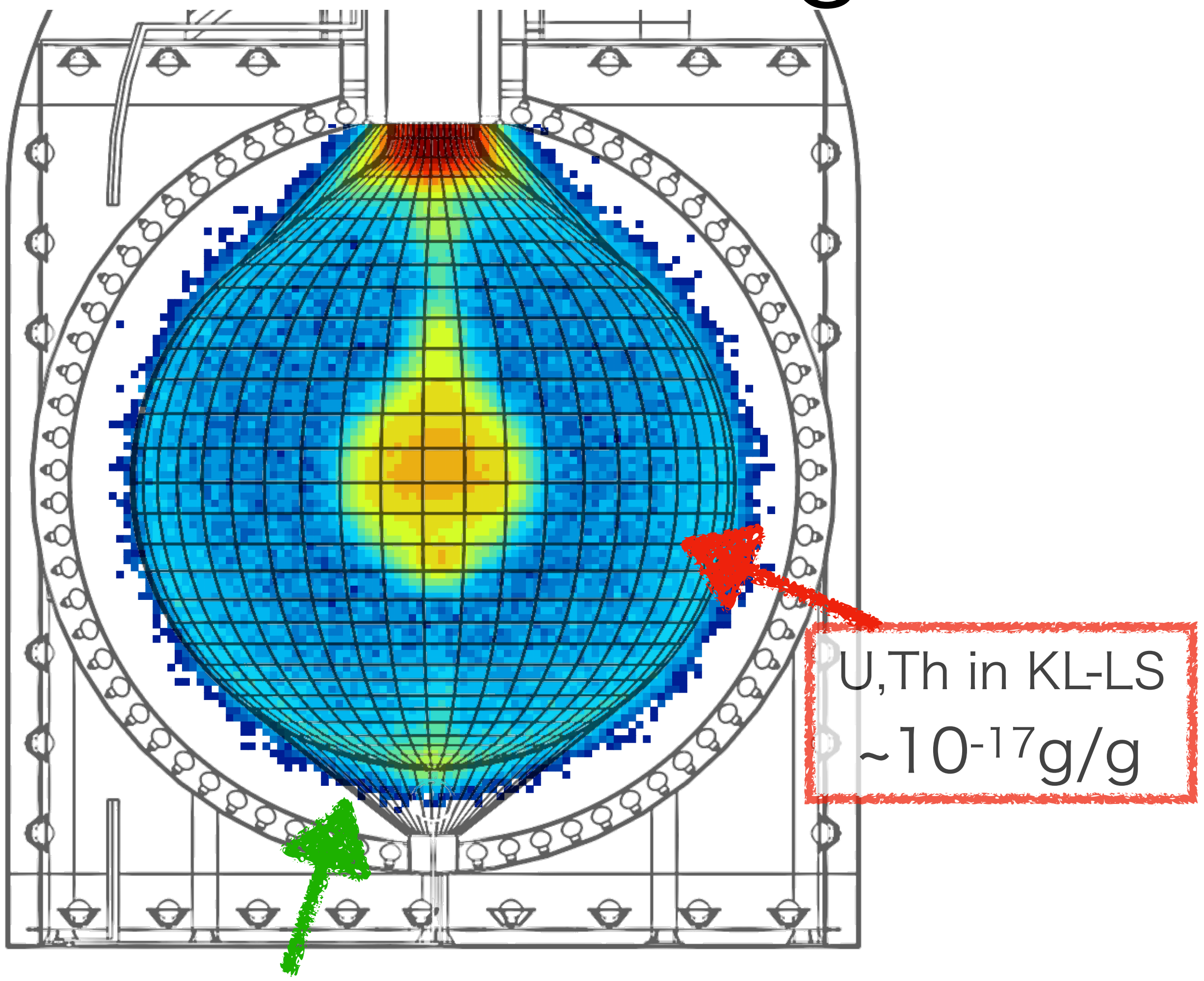


After 30.5 m^3 LS filling, we started DAQ to investigate background status of LS and mini-balloon

Simulation, mini-balloon stays as expected



Characterization of mini-balloon, again



^{214}Bi-Po Delayed coincidence

Basic investigation before xenon.

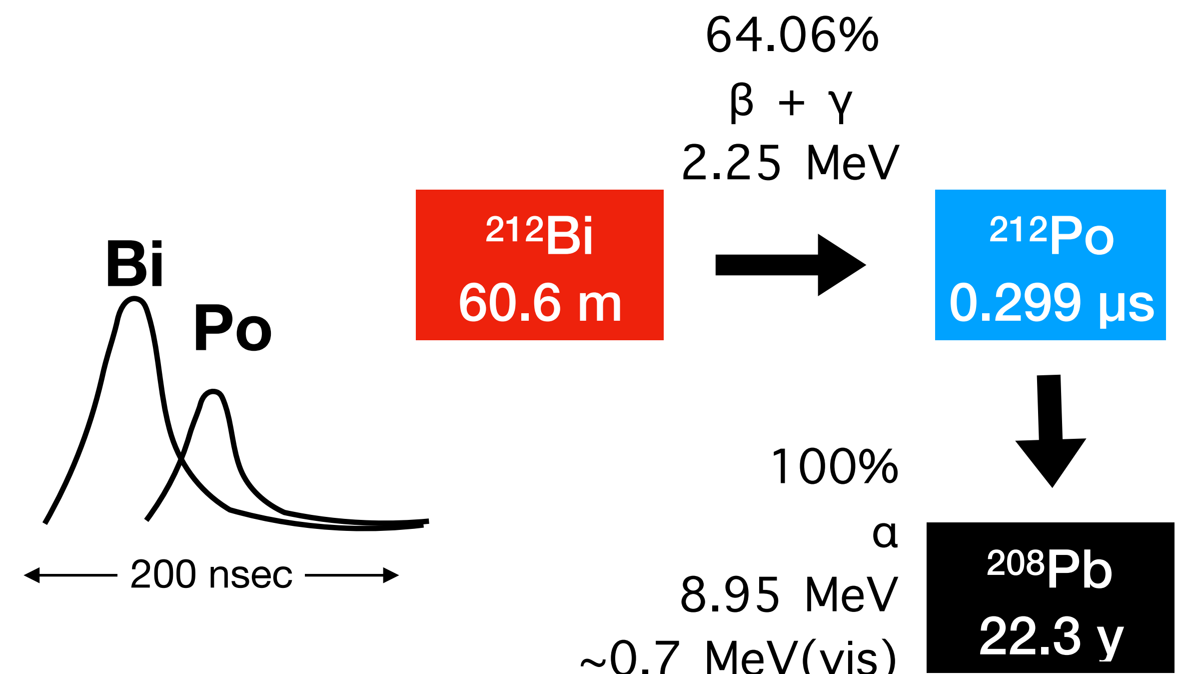
✅ mini-balloon is clean

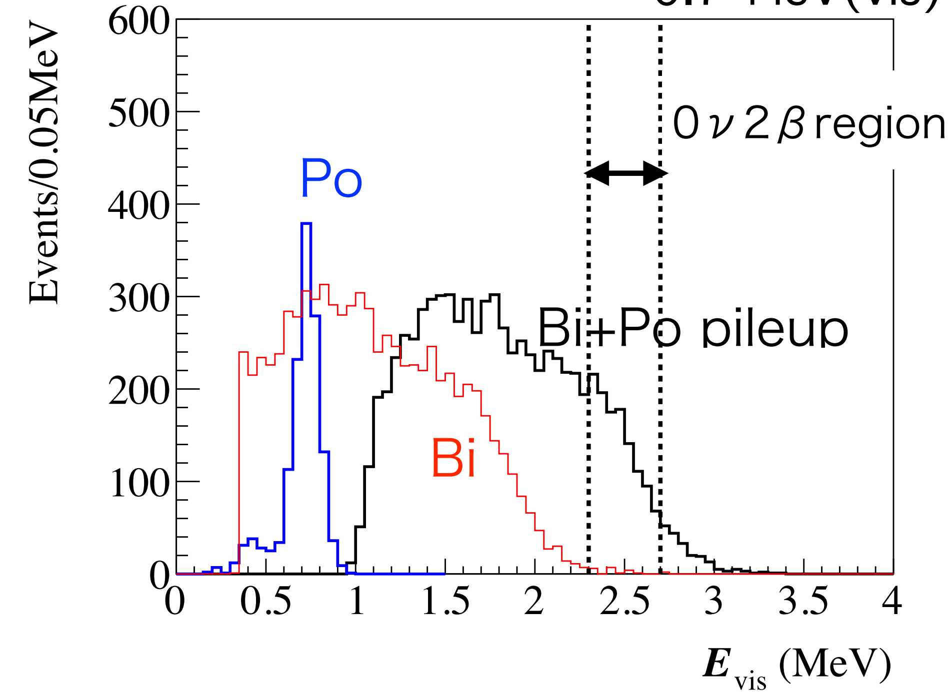
✅ no evidence of leakage

✅ ^{238}U is low enough

⁉️ ^{232}Th(~10^{-15}g/g)

^{212}Bi-Po in 232Th series is a possible BG.





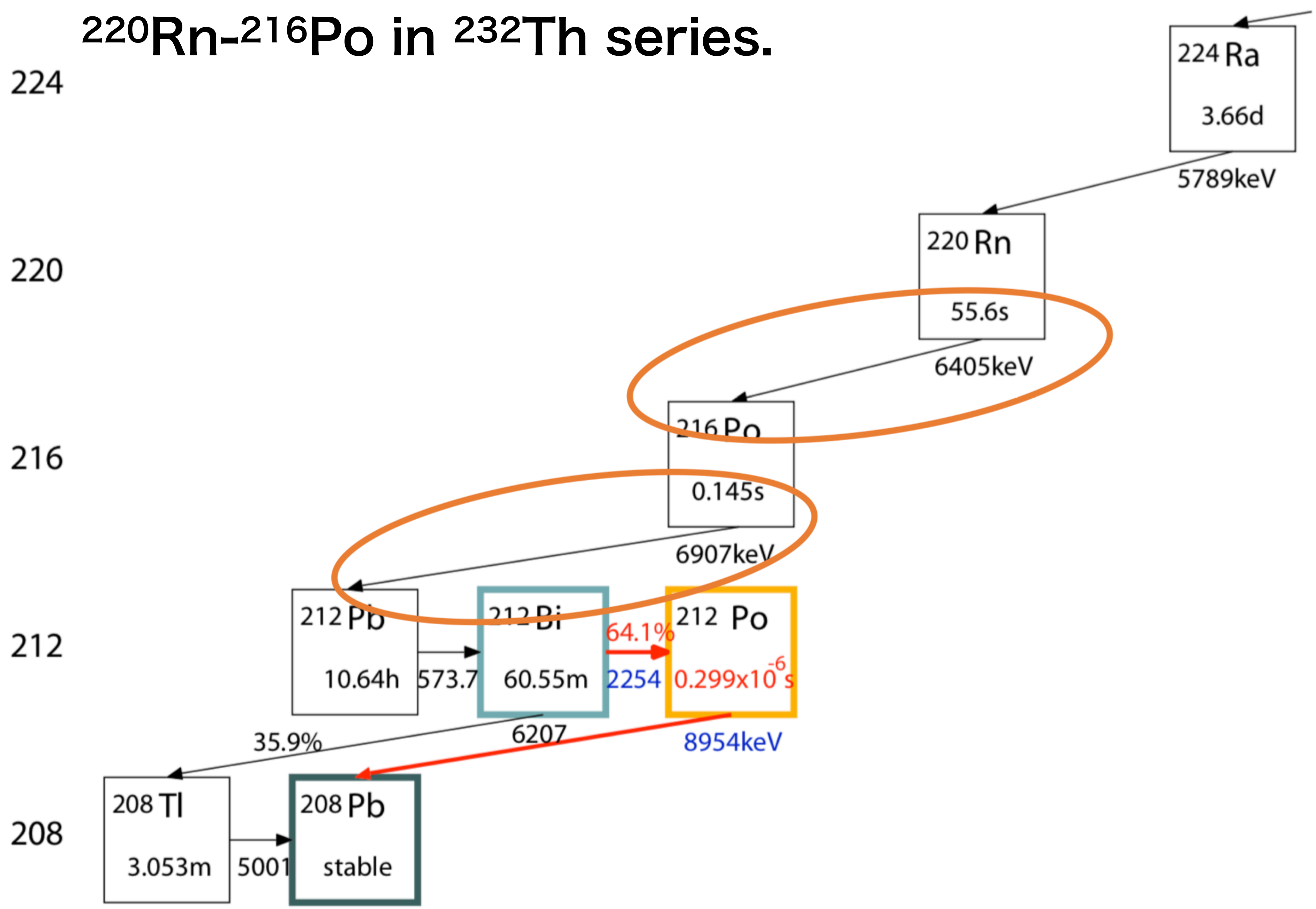
Pileup BG is as large as current ^{10}C BG and tolerable.

But ^{10}C rejection is improving, and we chose purification!

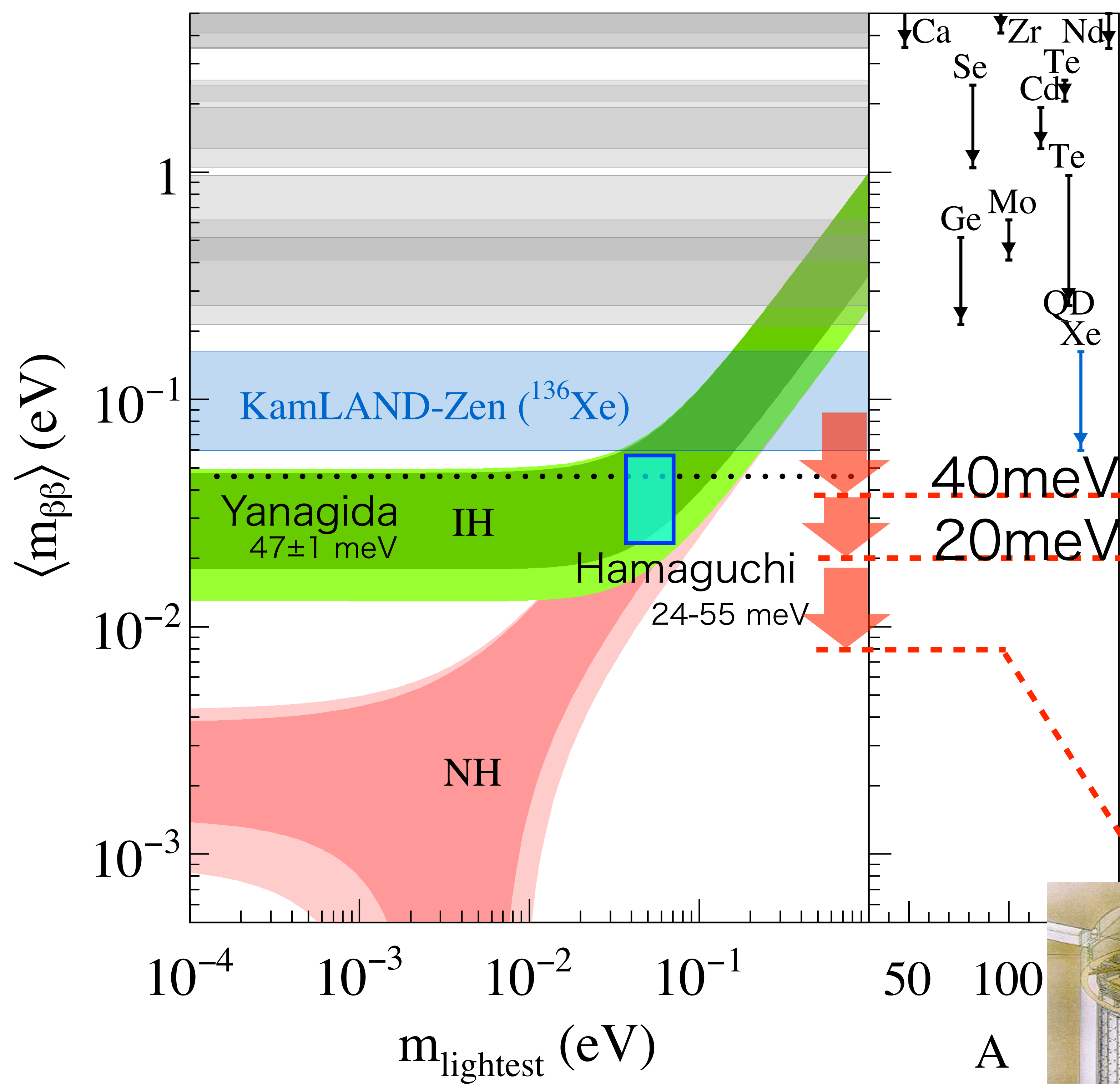
One more way to reduce ^{212}Bi-Po pileup

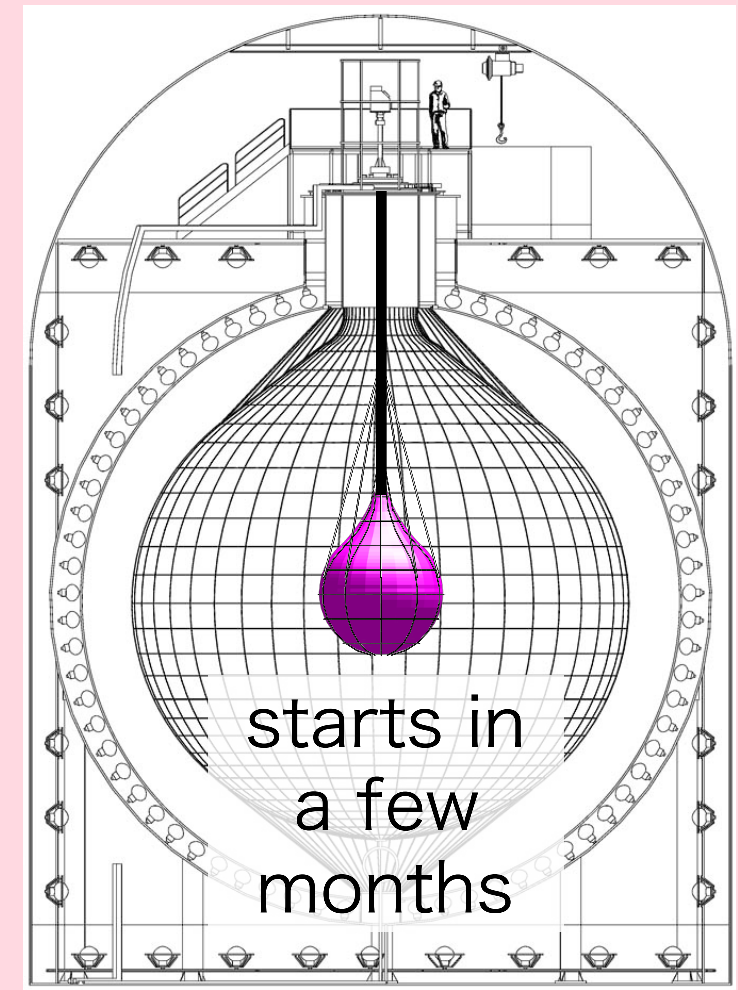
^{232}Th series

KamLAND can tag sequential decay of ^{220}Rn-^{216}Po in ^{232}Th series.



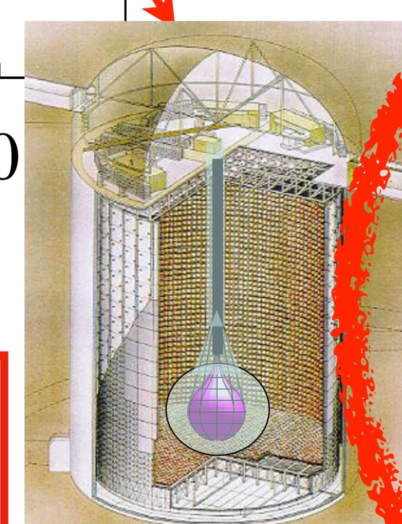
Both ^{208}Tl, ^{212}Bi-^{212}Po can be suppressed with 2 days veto after the tag.
Useful for $0\nu 2\beta$ search and low threshold ^{8}B neutrino observation

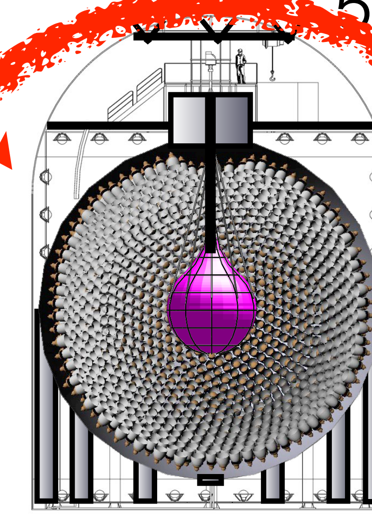




low BG film, 750 kg xenon
KamLAND-Zen 800

5×10^{26}y (5y)





~30M$

better resolution
scintillating film
KamLAND2-Zen

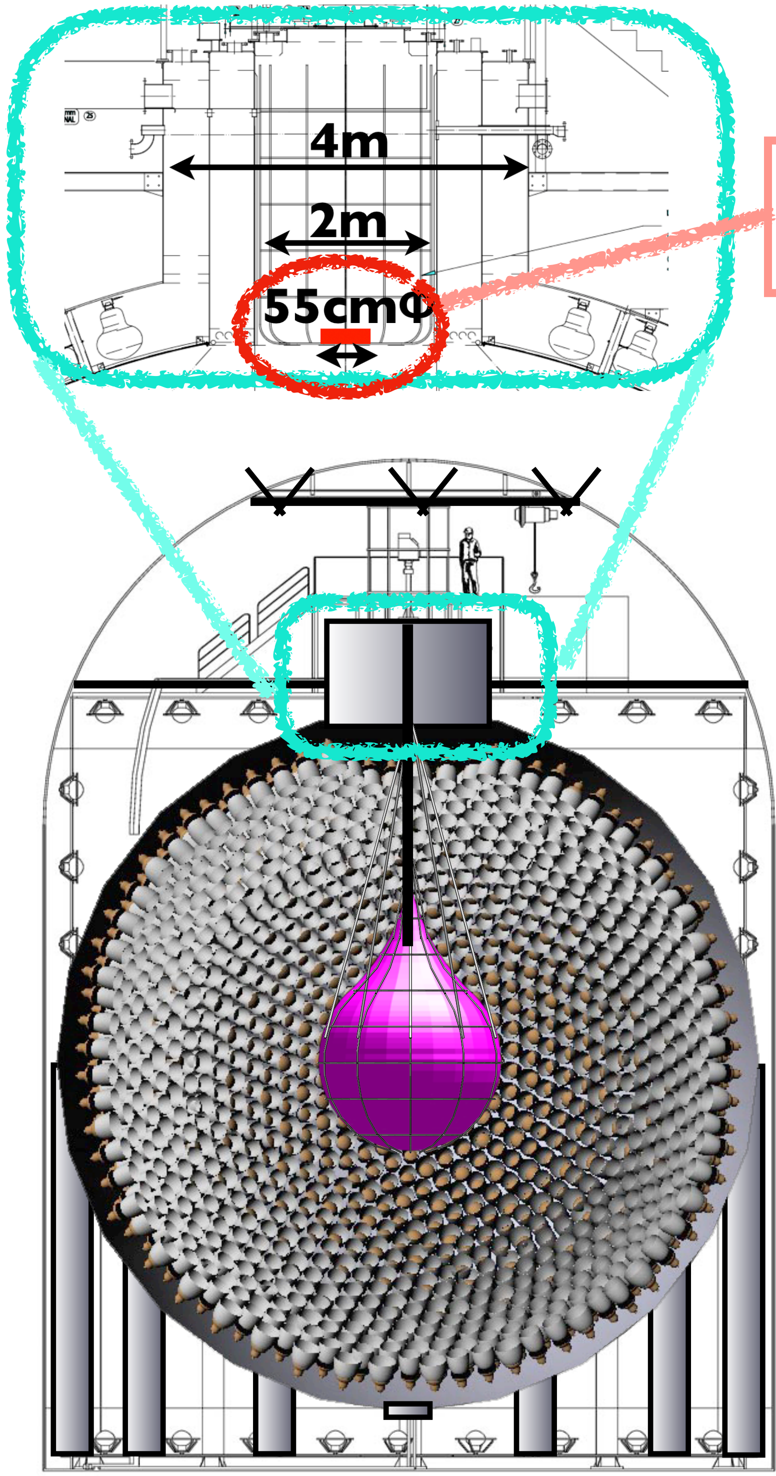
2×10^{27}y (5y)

The discovery may be just around the corner.

KamLAND-Zen is closest !!!

And more future plans!

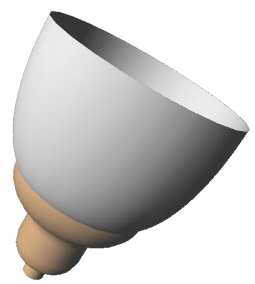
Higher energy resolution for reducing 2ν BG



Expansion of entrance

1000+ kg xenon

⇨ KamLAND2-Zen



Winston cone light collection ×1.8

high q.e. PMT light collection ×1.9

17"ϕ→20"ϕ ε=22→30+%

New LAB LS light collection ×1.4

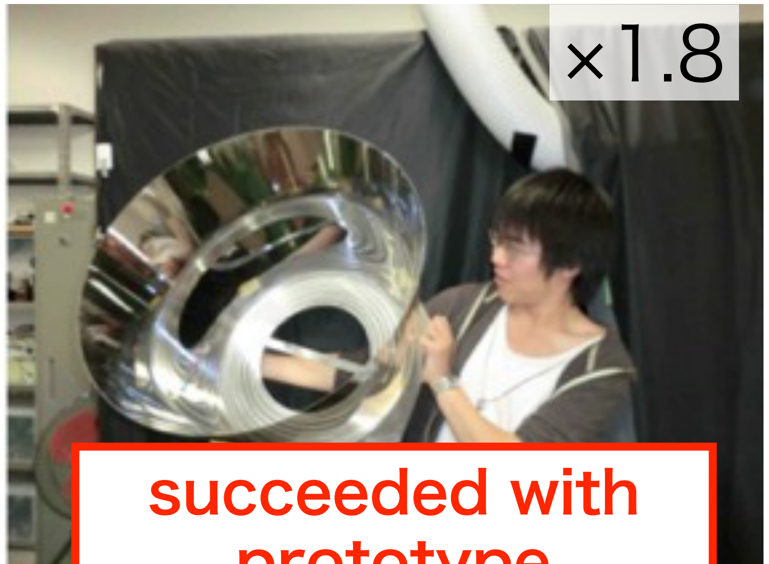
(better transparency)

expected σ(2.6MeV)= 4% → ~2%

target sensitivity 20 meV

R&D for KamLAND2-Zen and future

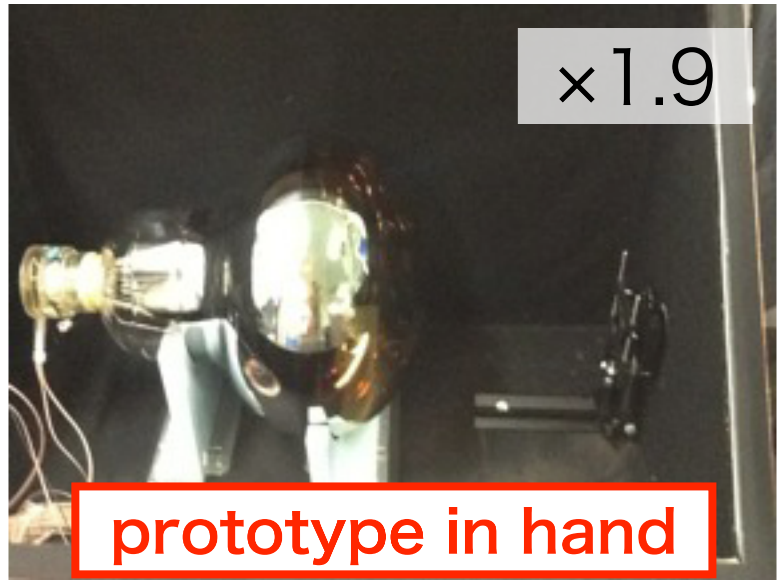
○ winston cone



×1.8

succeeded with prototype

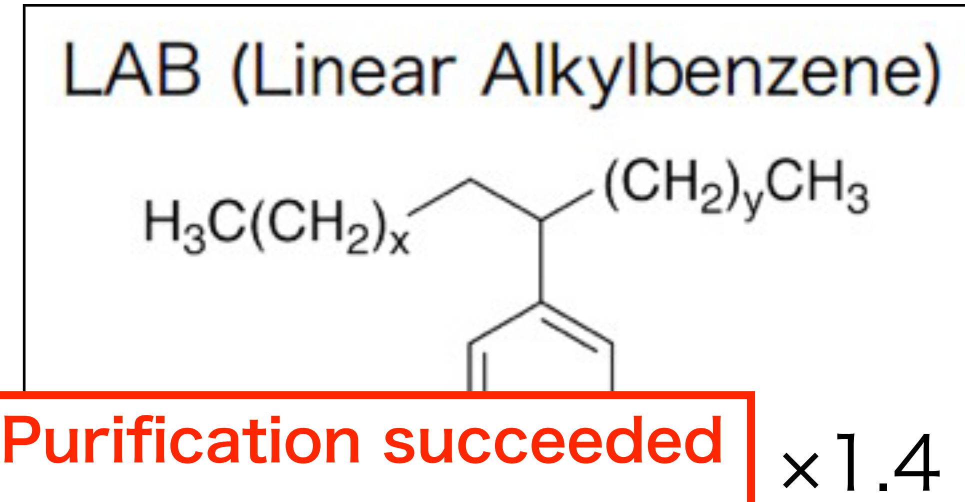
○ HQE-PMT



×1.9

prototype in hand

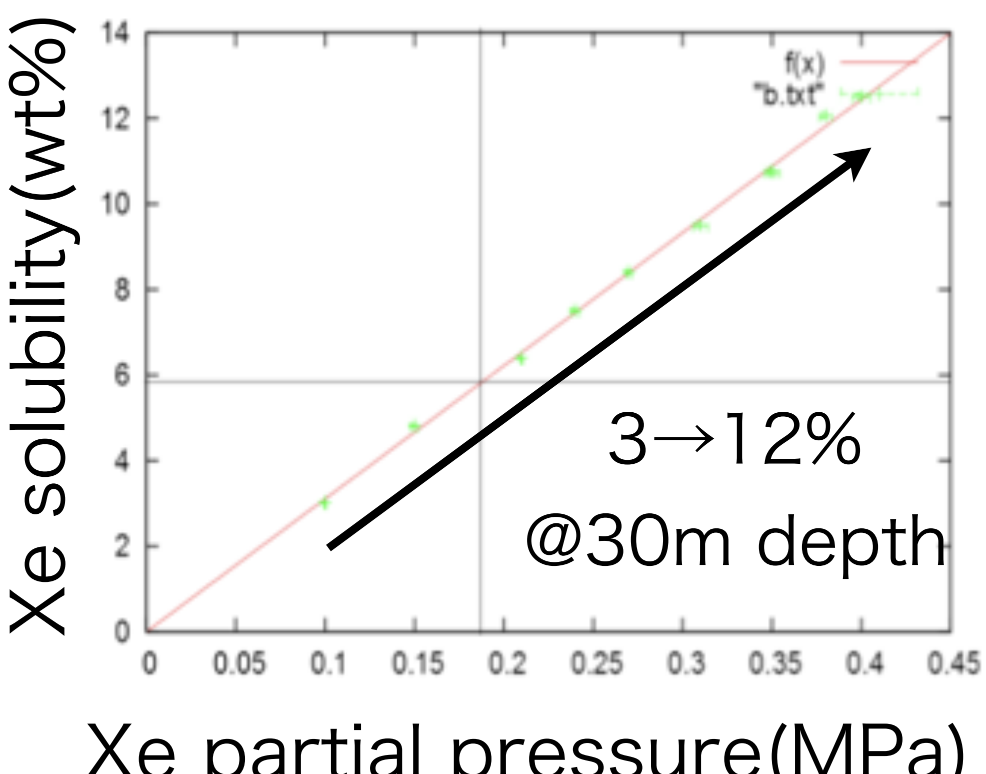
○ New LAB-LS



Purification succeeded with charcoal

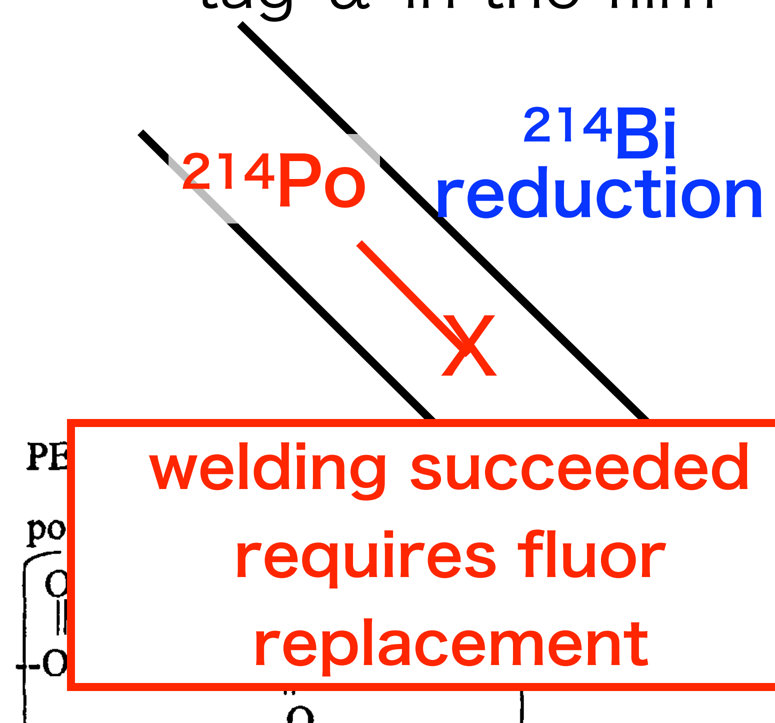
×1.4

○ denser xenon



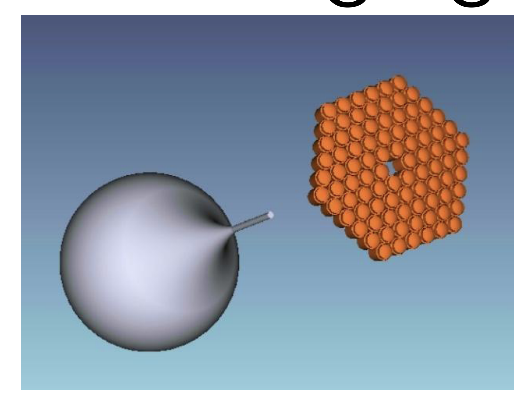
principle confirmed

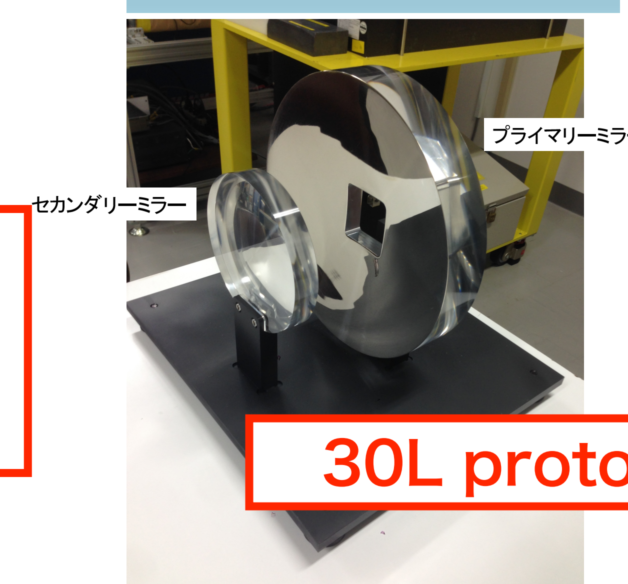
○ scintillator film



welding succeeded requires fluor replacement

○ imaging

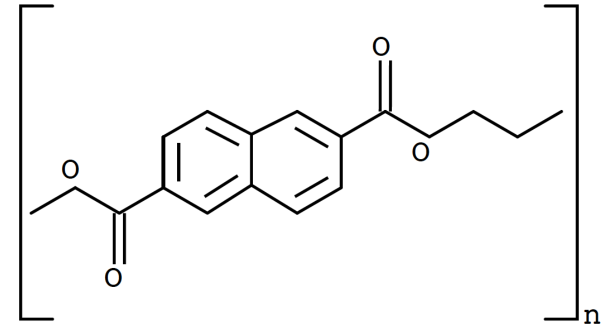




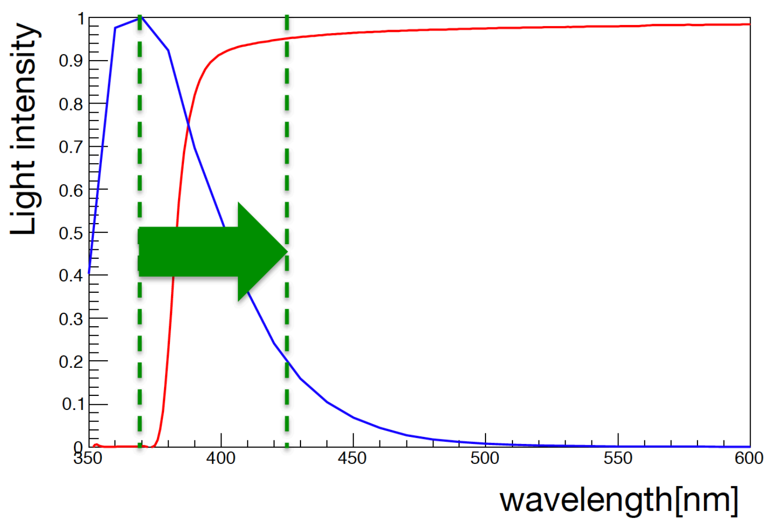
β / γ id.

30L prototype

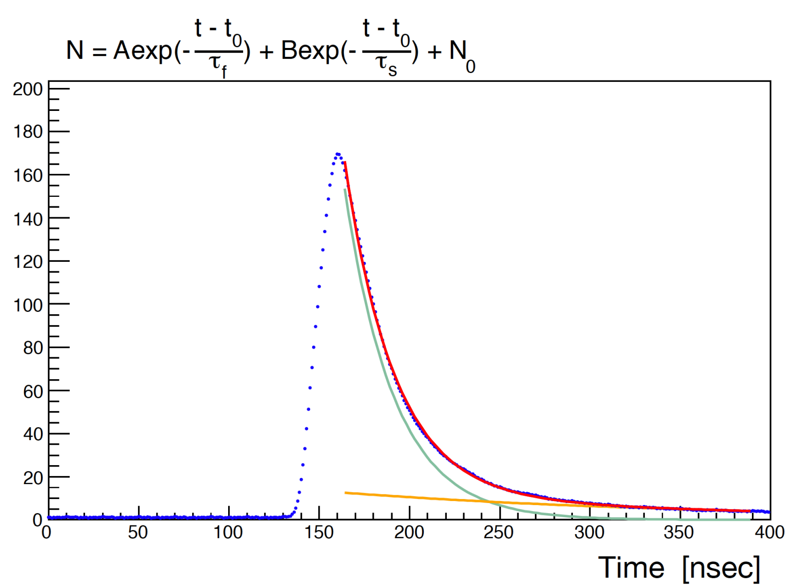
PolyEthylene Naphthalate (PEN)



η =10,500ph/MeV
λ_{PEN}=425nm
U,Th < 3 ppt



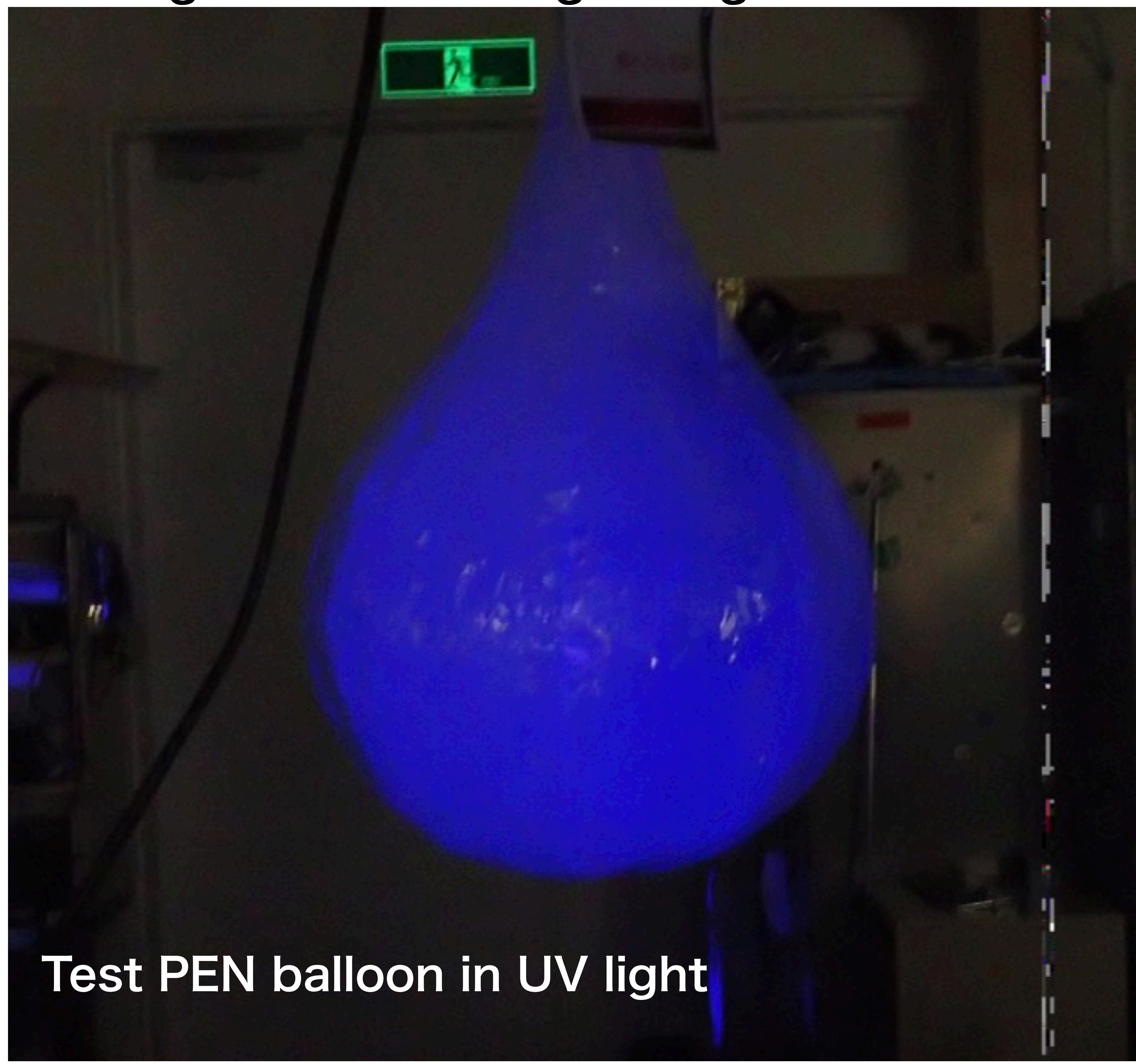
requires Bis-MSB in LS



τ~27 nsec, much slower than Kam-LS 4 nsec

PSD possible

welding easier & strong enough



Possible BG from natural radioactivity

^{214}Bi - ^{214}Po (missed)

LS 99.975% rejection (double pulse)

Nylon6 ~50% rejection ← Obstacle to enlarge FV

PEN 99.95% rejection (double pulse)

^{212}Bi - ^{212}Po (pileup)

95% rejection (double pulse)

95% rejection (^{220}Rn-^{216}Po tagging)

LS 99.75% rejection in total ← Requires only 10^{-15}g/g

Nylon6 97.5% rejection (no α or double pulse)

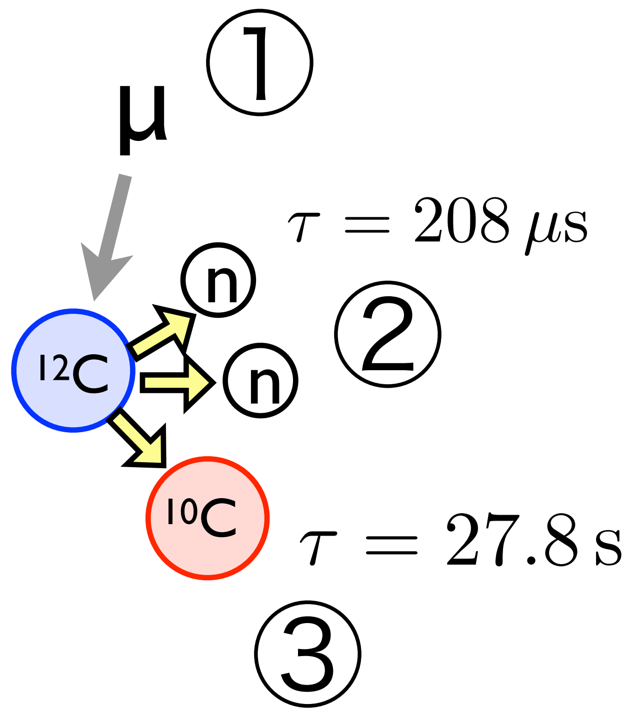
PEN ~99.95% rejection (double pulse, ^{220}Rn-^{216}Po, PSD)

Any one of three α

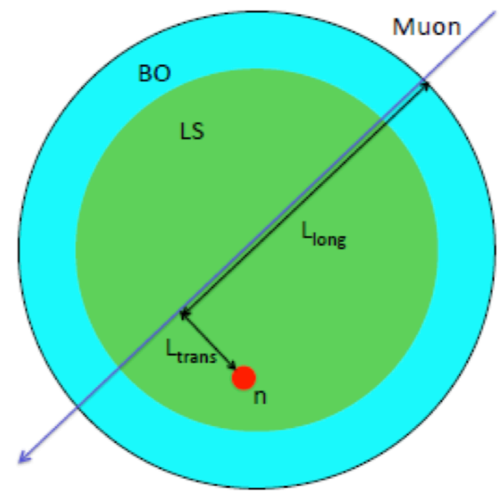
PEN enables thicker (easier to handle) film and/or larger FV.

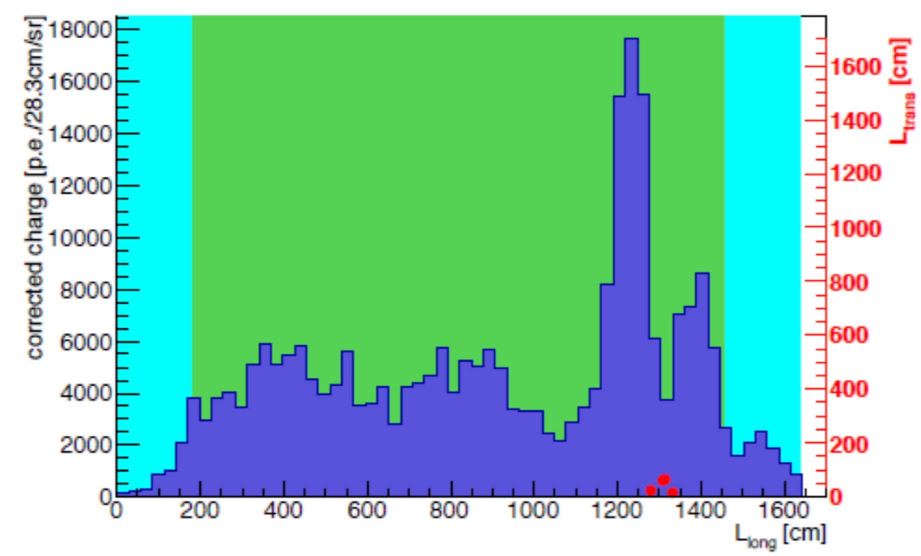
Further ^{10}C reduction, analysis & electronics

1. Triple fold coincidence

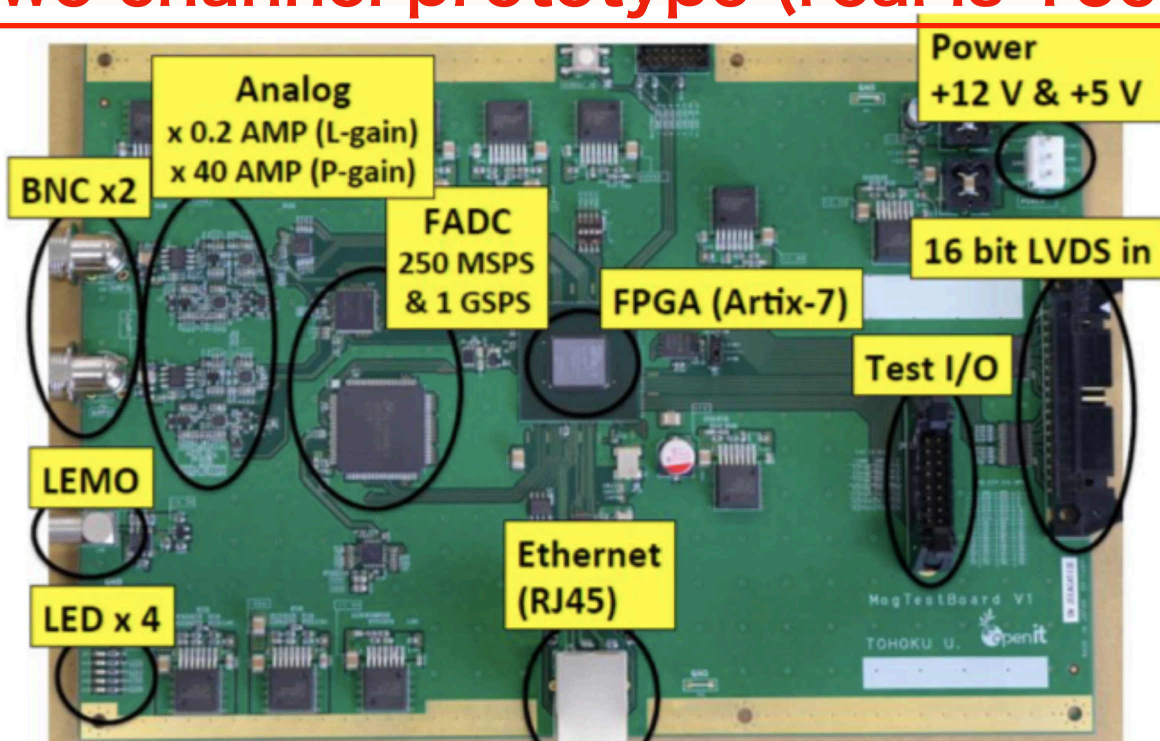


2. Energy loss along μ track





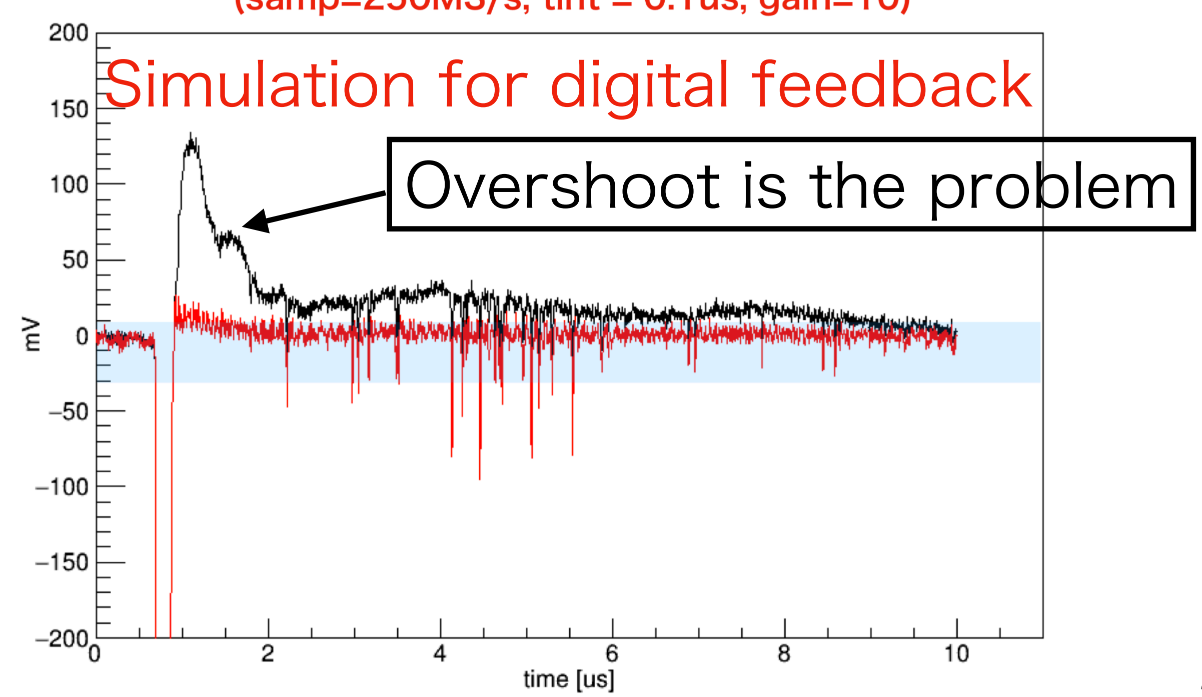
Two channel prototype (real is 16ch)



Wide range, low noise, fast FADC, ethernet data transfer

Baseline restoration with digital feedback or feedforward

Input & digital BLR with high spec DAC
(samp=250MS/s, tint = 0.1us, gain=10)

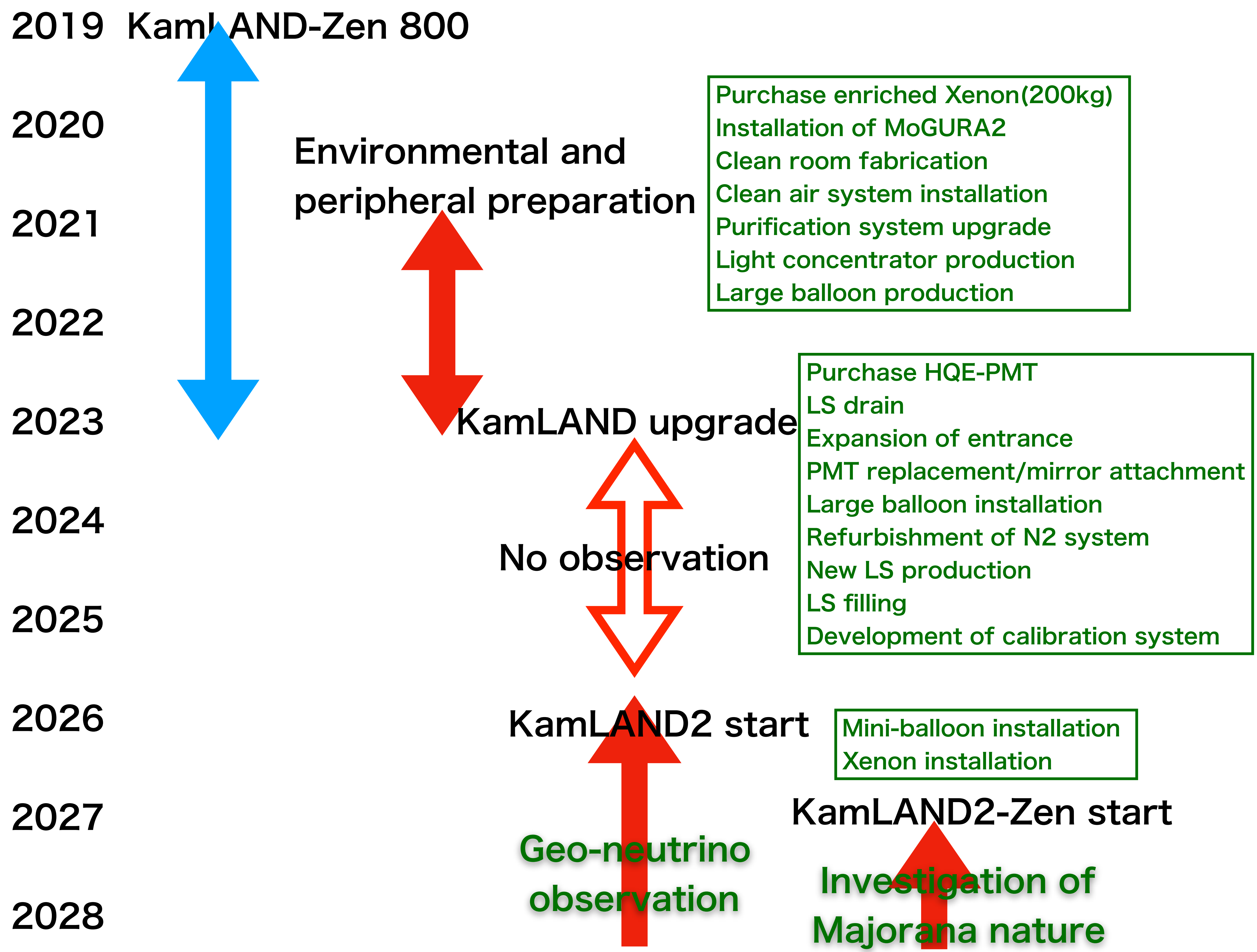


Conceptual design

Rough extrapolation of BG estimation & sensitivity

	KamLAND-Zen 400	KamLAND-Zen 800	KamLAND2-Zen 2.38-2.58 MeV	KamLAND2-Zen High P
$2\nu 2\beta$ [/100kgXe/y]	7.4	7.4	$\xrightarrow[\sigma E]{}$ <0.15	<0.15
^{10}C [/100kgXe/y]	1.3	$\xrightarrow[\text{analysis}]{}$ 0.18	$\xrightarrow[\sigma E]{}$ 0.09	$\xrightarrow[\text{1.8 atm}]{}$ 0.05
$^{8}B\nu$ [/100kgXe/y]	0.33	0.33	$\xrightarrow[\sigma E]{}$ 0.16	$\xrightarrow[\text{1.8 atm}]{}$ 0.09
FV (loading) [kgXe]	100 (380)	300 (750)	$\xrightarrow[\text{PEN}]{}$ 1000 (1000)	1000 (1000)
(Expected) reach	61-165 meV 1.07×10^{26}yr	40 meV 5×10^{26}yr	20 meV 2×10^{27}yr	<20meV $>2\times10^{27}$yr

Schedule


2019 KamLAND-Zen 800
2020
2021
2022
2023
2024
2025
2026
2027
2028
Environmental and peripheral preparation
Purchase enriched Xenon(200kg)
Installation of MoGURA2
Clean room fabrication
Clean air system installation
Purification system upgrade
Light concentrator production
Large balloon production
KamLAND upgrade
Purchase HQE-PMT
LS drain
Expansion of entrance
PMT replacement/mirror attachment
Large balloon installation
Refurbishment of N2 system
New LS production
LS filling
Development of calibration system
No observation
KamLAND2 start
Mini-balloon installation
Xenon installation
KamLAND2-Zen start
Geo-neutrino observation
Investigation of Majorana nature

Summary

・KamLAND-Zen 400 has the current world best record on effective Majorana mass of neutrinos.

$$T^{0\nu}_{1/2} > 1.07 \times 10^{26}\,\mathrm{yr}$$

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

・It also validated "advantages of using KamLAND", and the last item of scalability is on-going.

・KamLAND-Zen 800 will start in a few month with a target sensitivity of 40 meV.

・KamLAND2-Zen aims at sensitivity below 20 meV, adopting HQE-PMT, Winston Cone, LAB-LS, new electronics with BLR, PEN-MIB, and maybe high pressure xenon loading.

・R&D for KL2-Zen to launch around 2027 is going well.

Thank you!