KamLAND-Zen

7 March 2019

Aoba Science Hall, Tohoku University

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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
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
Netherland
Nikhef, University of Amsterdam

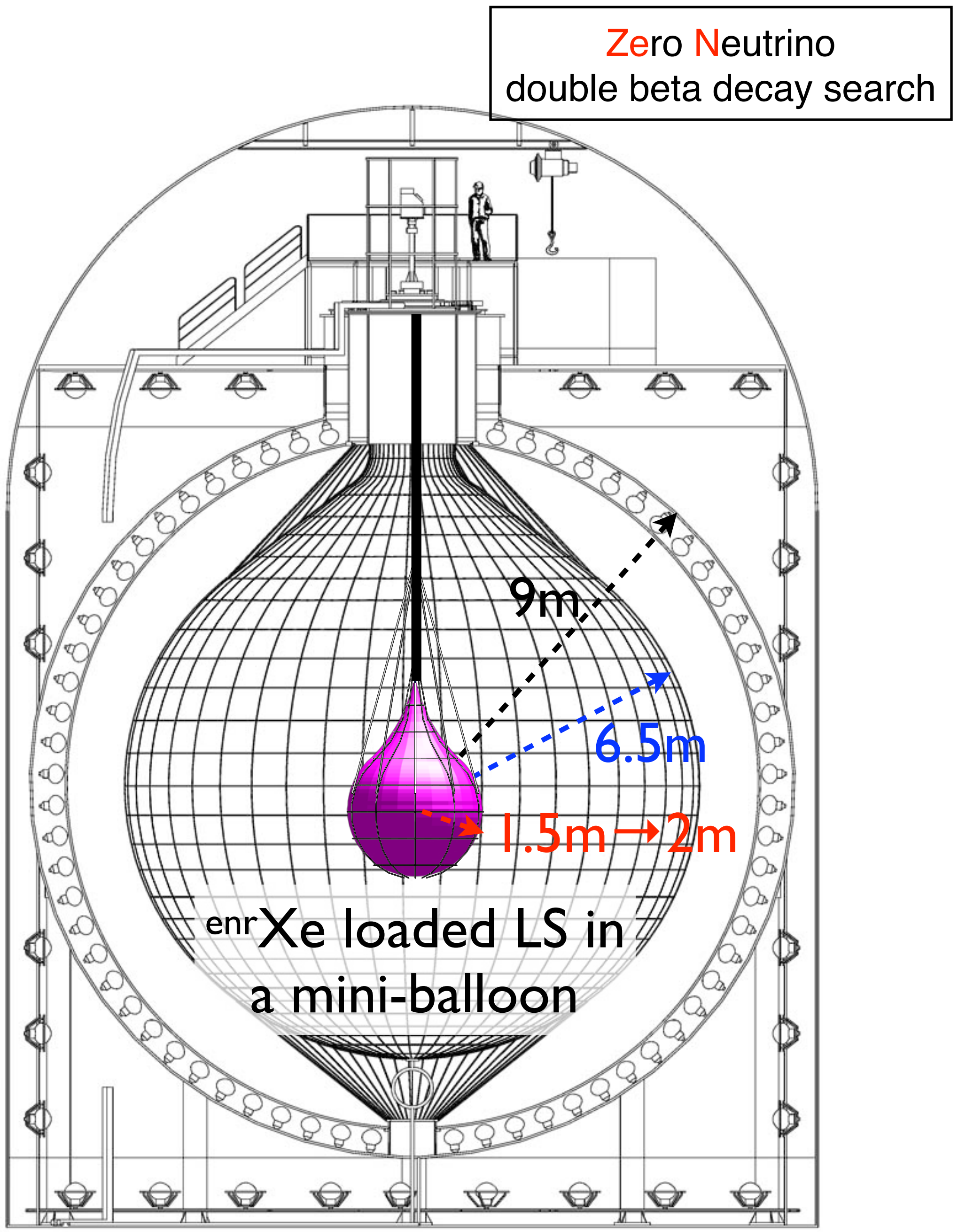
※ Second affiliation is not listed.

Collaboration meeting @MIT

~50 physicists

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

KamLAND-Zen



90% enriched ^{136}Xe
320kg for phase-I
380kg for phase-II
745kg for Zen 800 (started in January)

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)

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

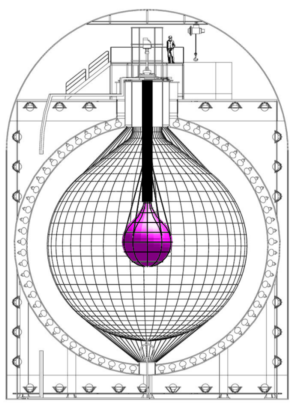
Initial funding in 2009 and picture in September 2011

Everything has been done in two years!!

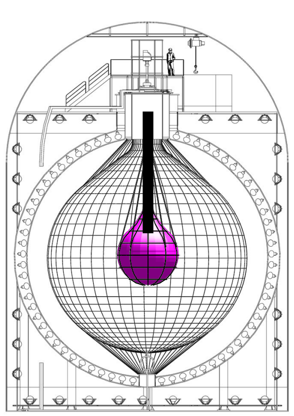
◎ low cost and quick start

Timeline of KamLAND-Zen

KamLAND-Zen 400



KamLAND-Zen 800



2011
2012
2013
2014
2015
2016
2017
2018
2019

MIB production ← MIB installation, xenon installation

400 phase1
320kg ← Filtration

← Xenon extraction

LS purification
Recovery from fire ← Fire

LS purification

← Xenon installation

400 phase2
380kg

MIB production

← Calibration, xenon extraction, MIB extraction

OD refurbishment

MIB production

← MIB installation, characterization ← Leak

← MIB extraction, hole inspection

Welding improvement

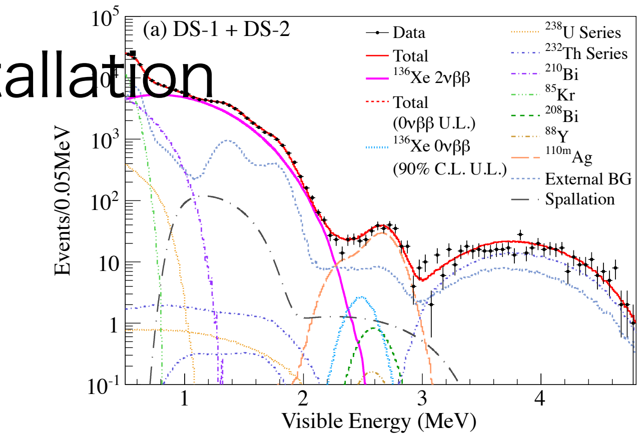
MIB production

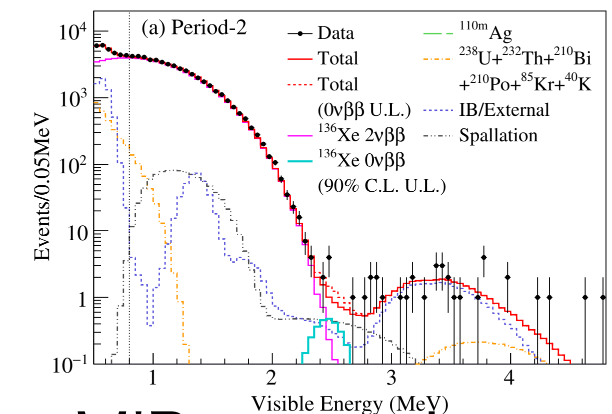
← MIB installation, characterization

LS purification

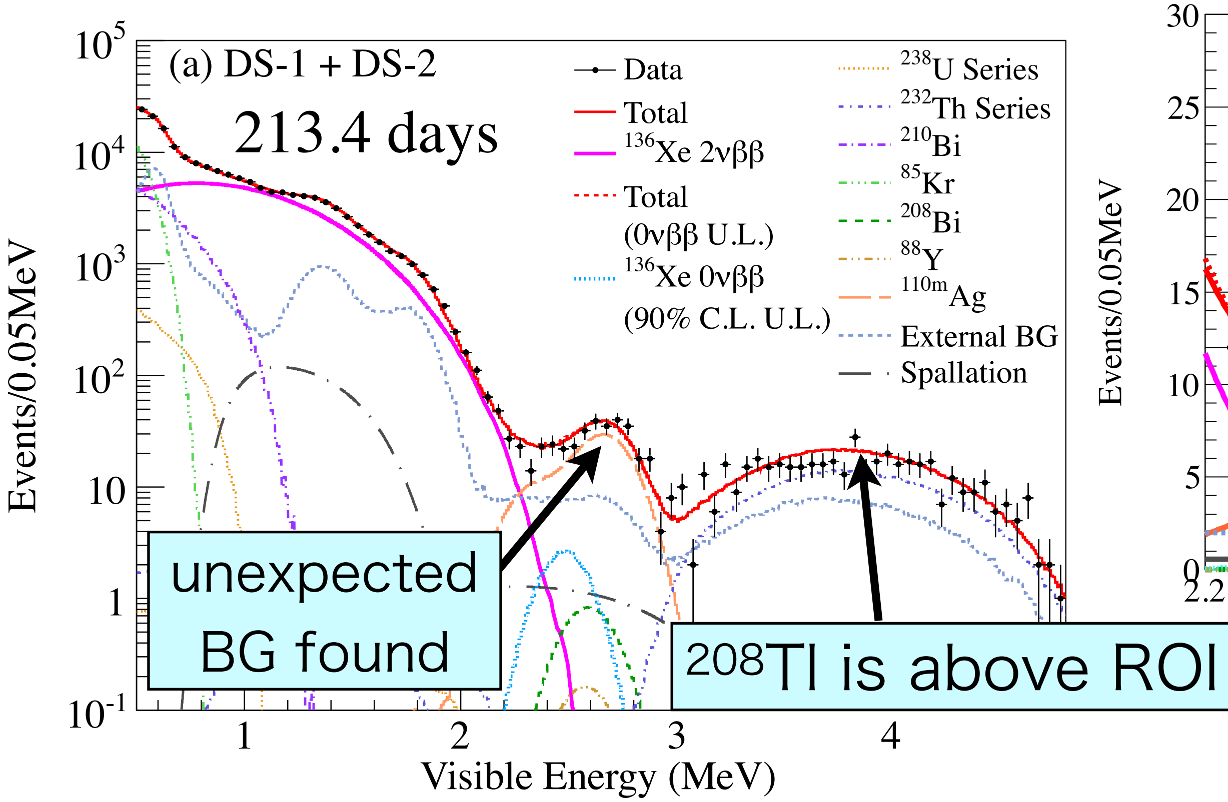
Xenon installation

Zen 800
745kg ← **We are here**
accumulated about 1 month data

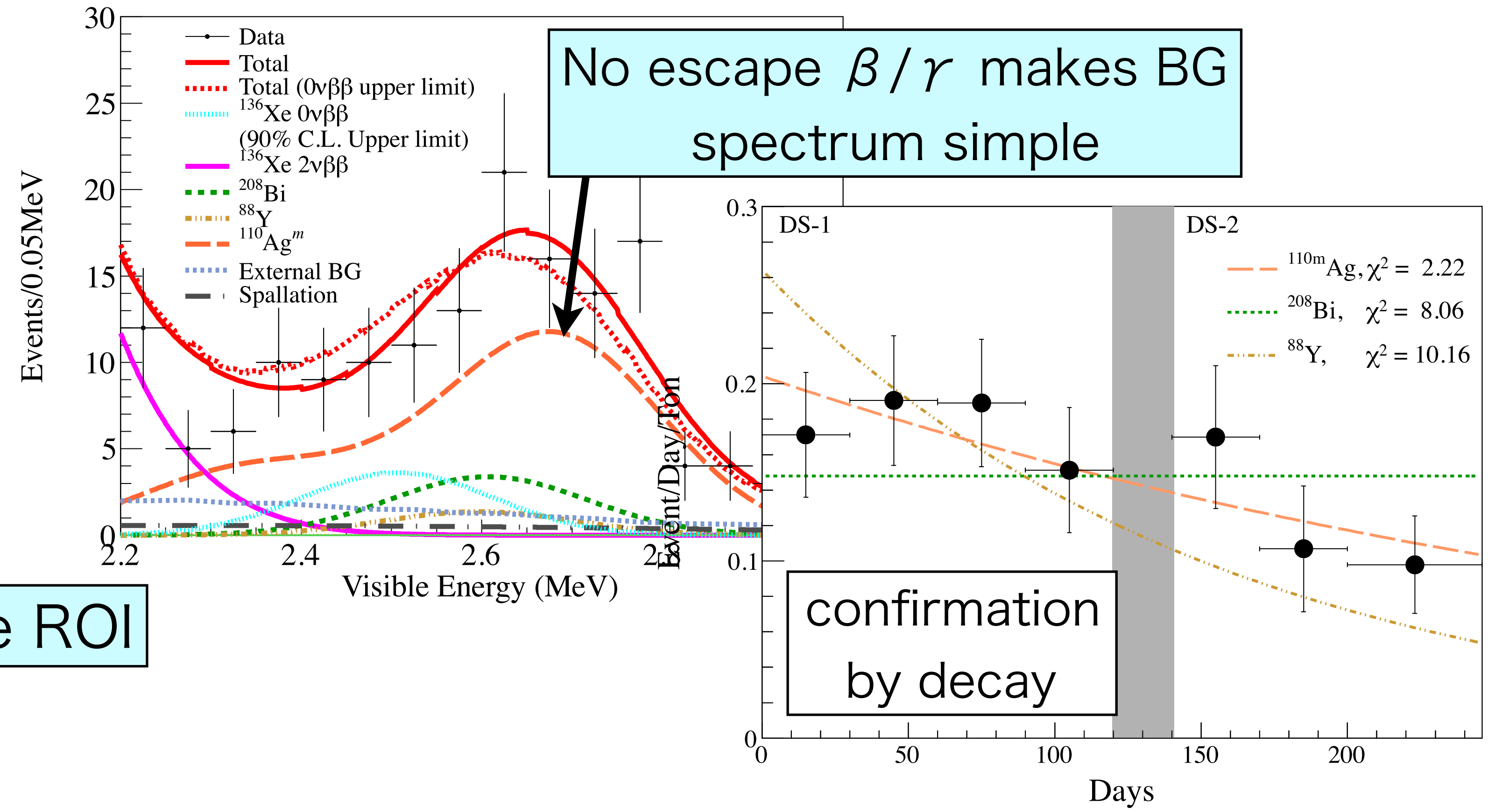


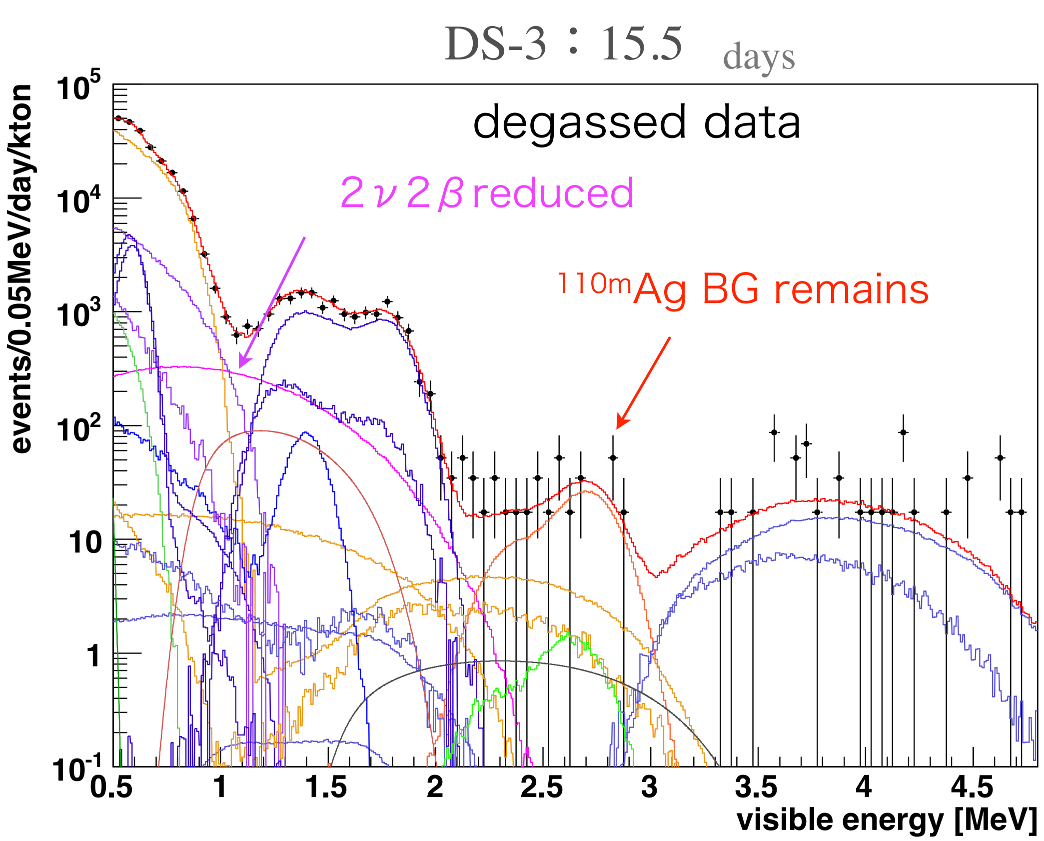


Thanks to full active apparatus,



Dominant ①BG identified as ^{110m}Ag

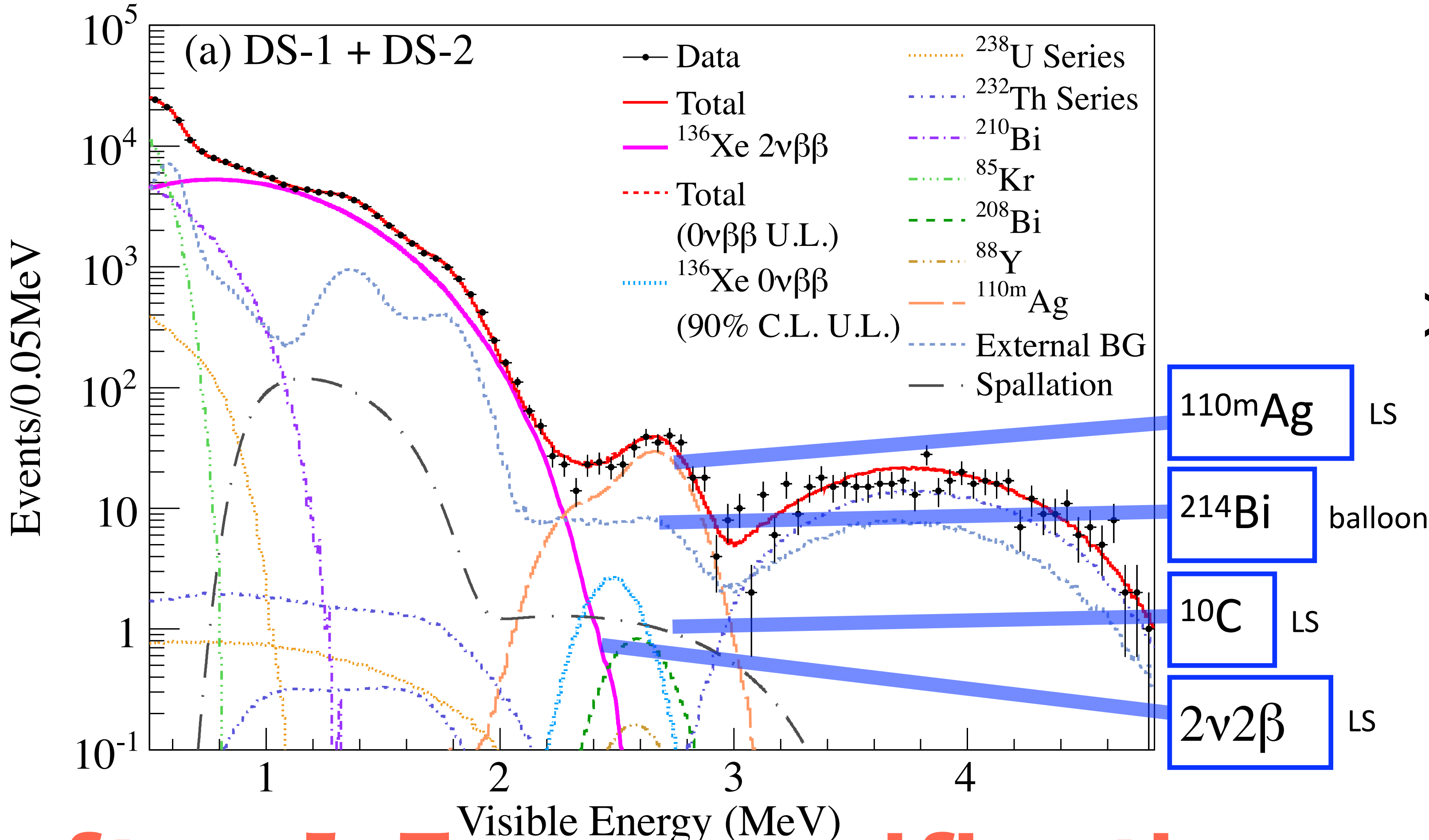




Xenon can be degassed from Xe-LS.
And ^{136}Xe ③on/off measurement has been demonstrated.
(useful for signal confirmation)

Phase-1 320kg

before purification



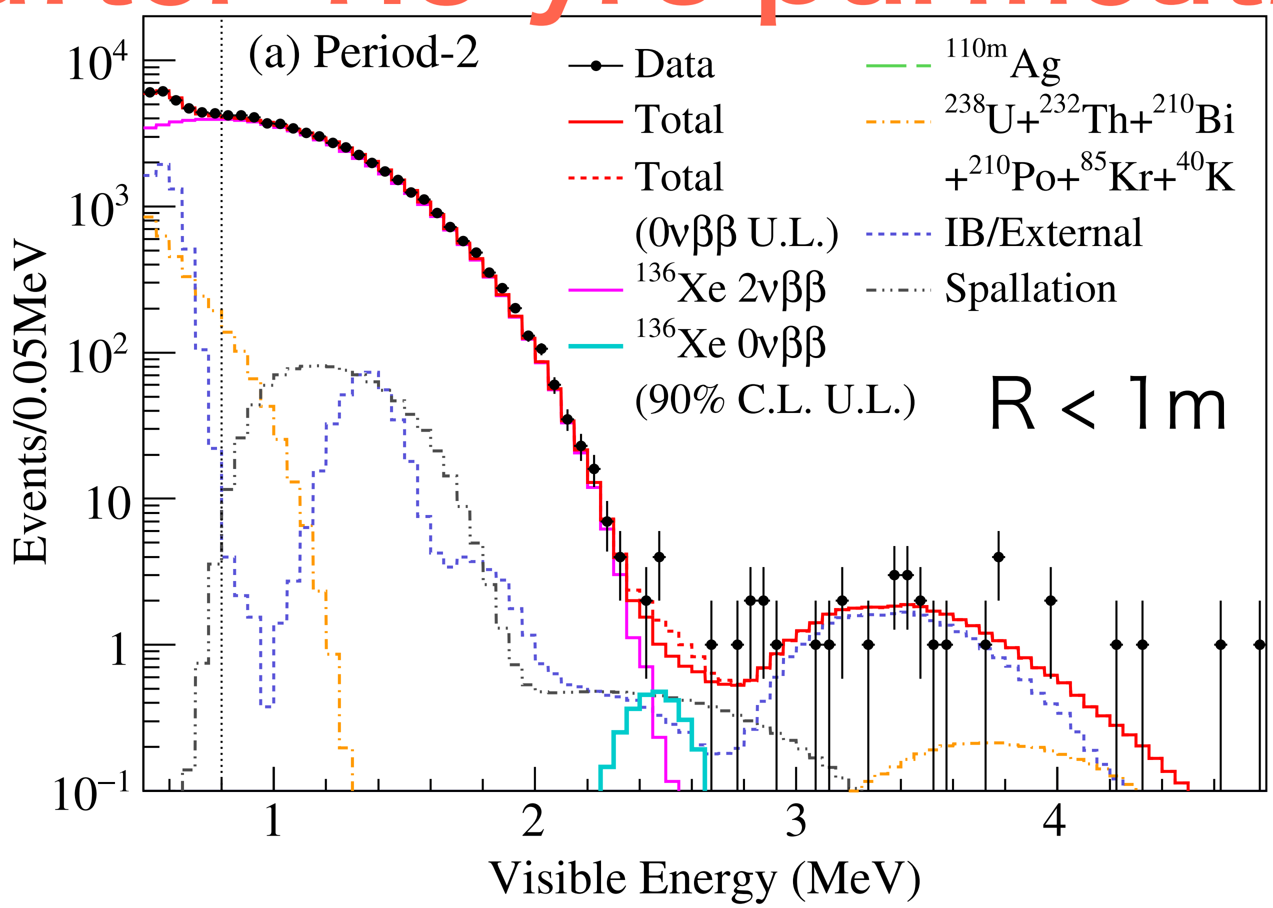
$>1.9\times10^{25}$y

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)

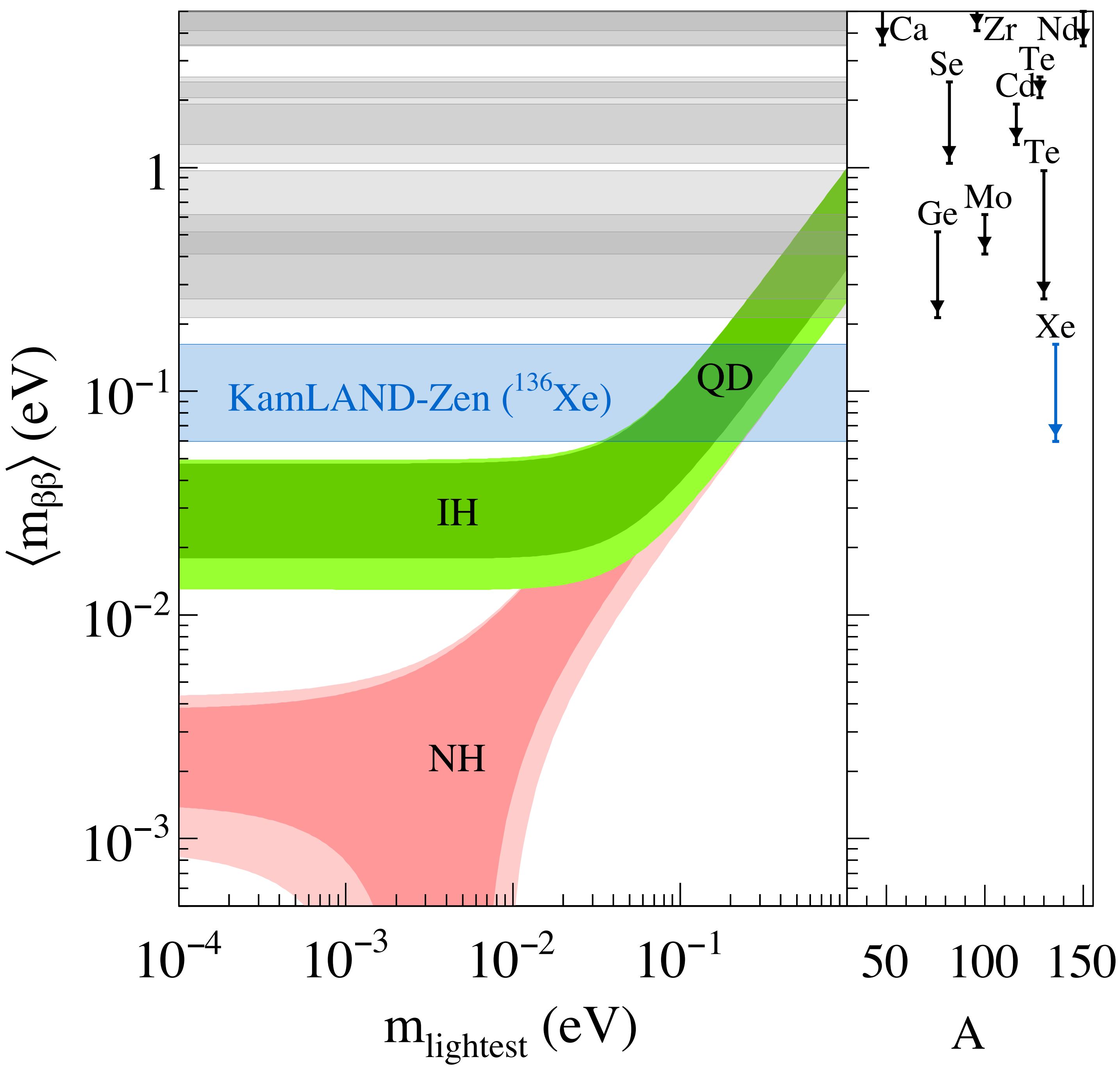
(cf. $T_{1/2}$(^{110m}Ag)=250 days)

②in-situ purification possible!!

KamLAND-Zen 400 Phase 1+2 combined

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

(sensitivity 5.6×10^{25} yr)



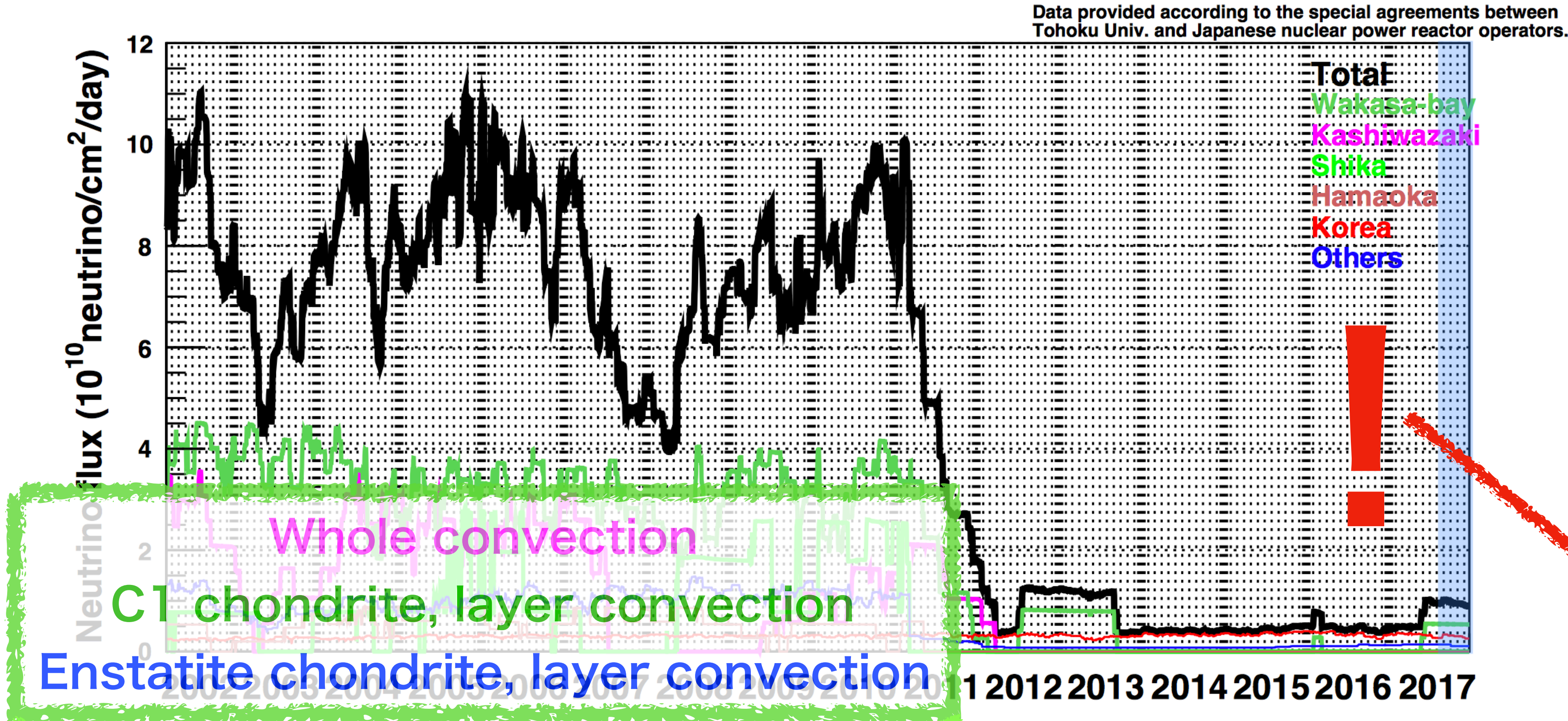
It also provides upper limit of $m_{lightest}$ at 180-480 meV.

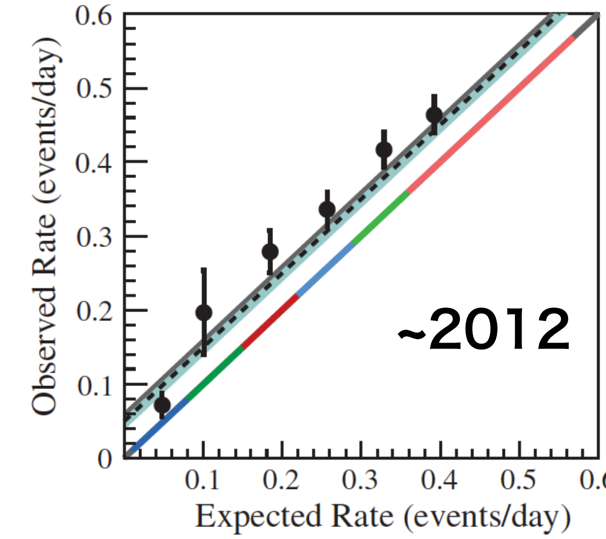
$$\langle m_{\beta\beta} \rangle < (61 - 165)\ \mathrm{meV}$$

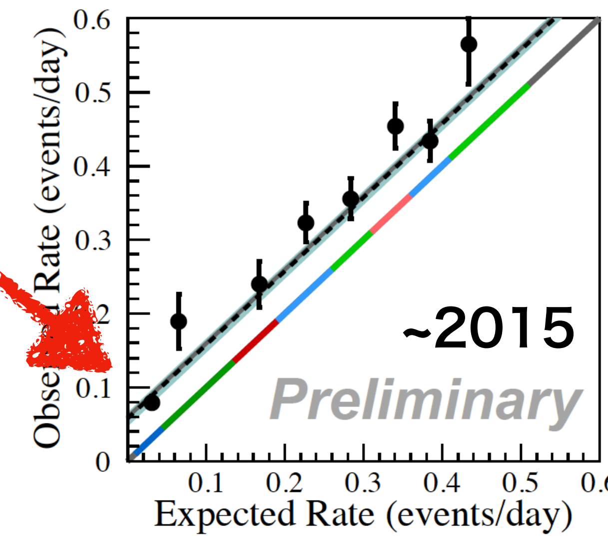
PRL117, 082503 (2016)

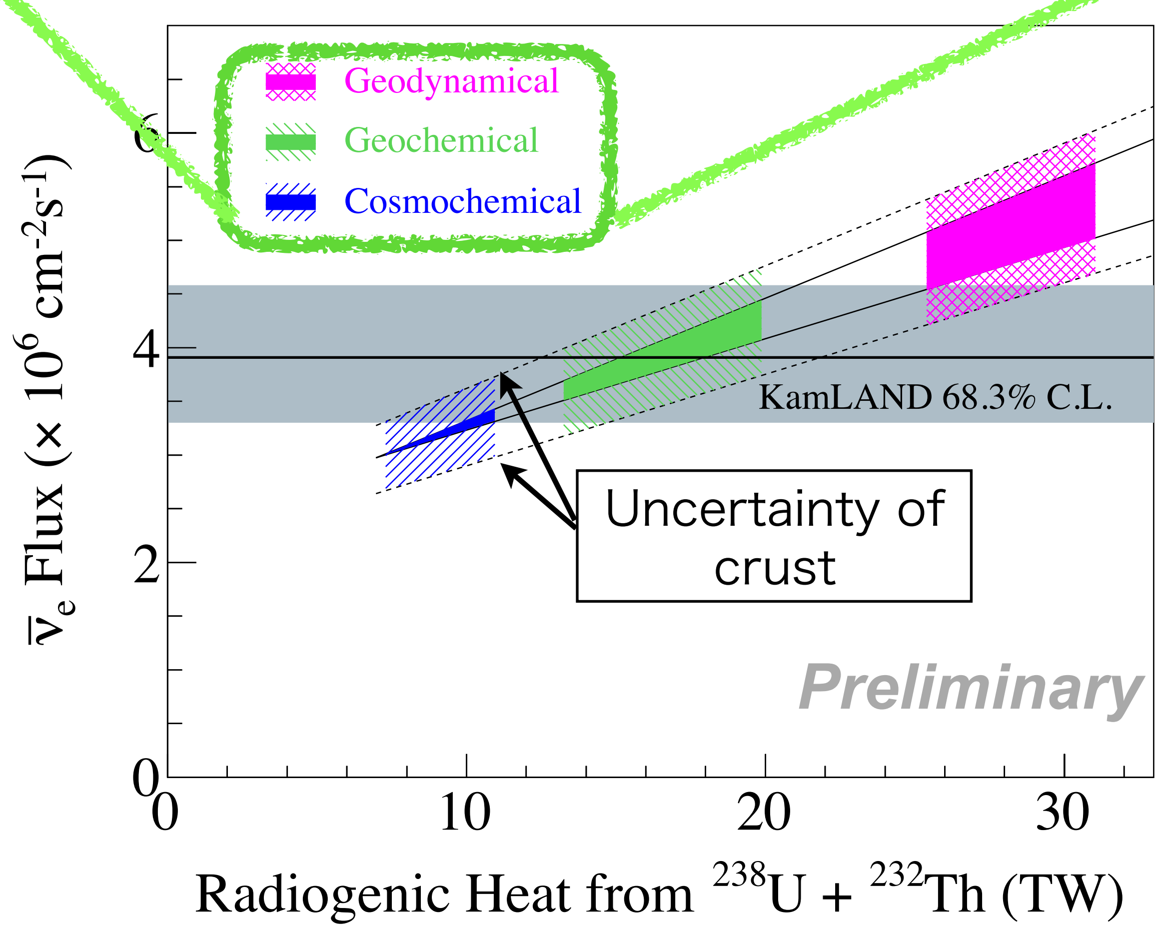
Big leap toward IH region !

④ multi-purpose









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

And more …

○Pre-supernova alarm using Silicon-burning neutrinos

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

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

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

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

○CNO cycle neutrinos (maybe with new electronics)

○Physics with J-PARC neutrino beam

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

○Sterile neutrino search with cyclotron (IsoDAR)

○Verification of DAMA/LIBRA with NaI deployment

Yes, KamLAND-Zen has diverse physics targets

“Advantages of using KamLAND”

have been almost demonstrated;

⓪ low cost and quick start (running detector) — ✅ ran in 2 years

① BG can be identified (full active thick shielding) — ✅ ^{110m}Ag identified

② In-situ purification possible (liquid media) — ✅ ^{110m}Ag removed

③ On/Off measurements possible (xenon is removable) — ✅ BG confirmed by degassing

④ multi-purpose (ex. geo-neutrino) — ✅ leading geo-ν

⑤ easily scalable (mini-balloon)

⑤ easily scalable

double size mini-balloon fabrication

cleaning, cleaning and

cleaning as usual

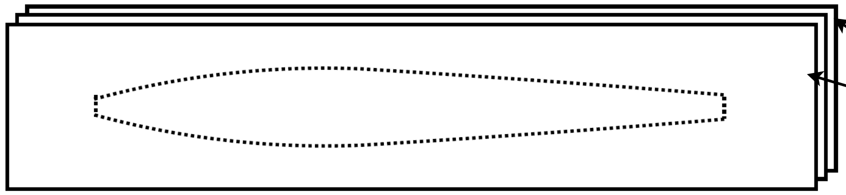
Example of improvements

before

after

clean underwear

changing room in a clean room



cover sheets

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
・・・

laundry twice a day

New mini-balloon has been installed in August 2016

spent 1+α yrs for fabrication

Characterization 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

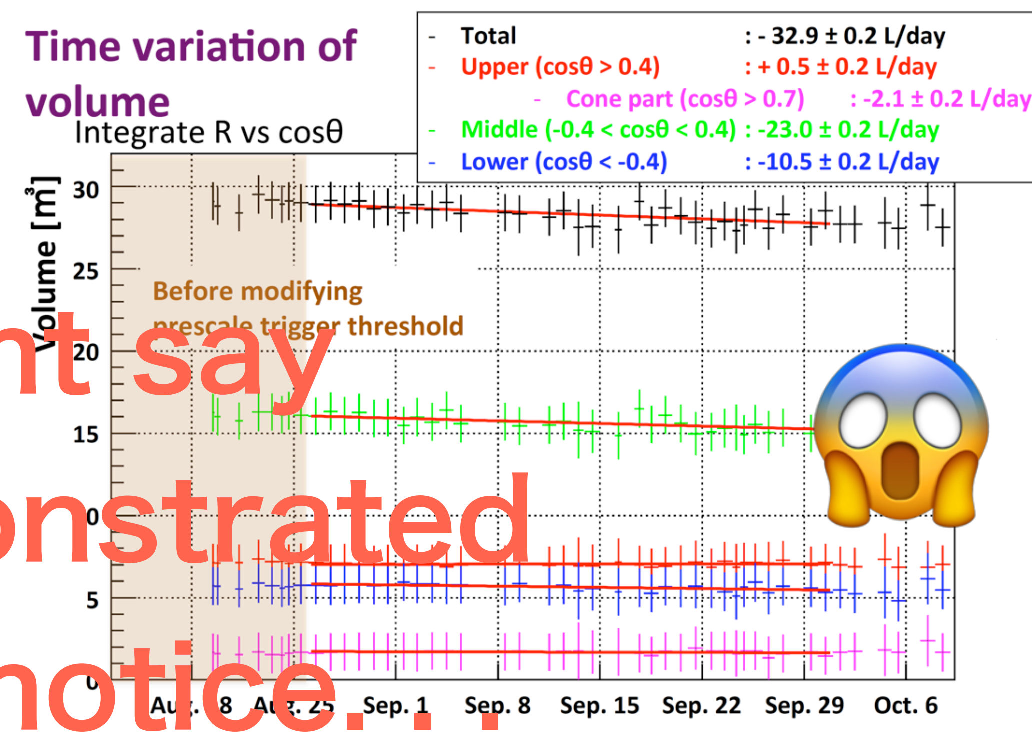
~1/10

Yes, cleaner!

At the same time, we noticed;

Indications of leak;

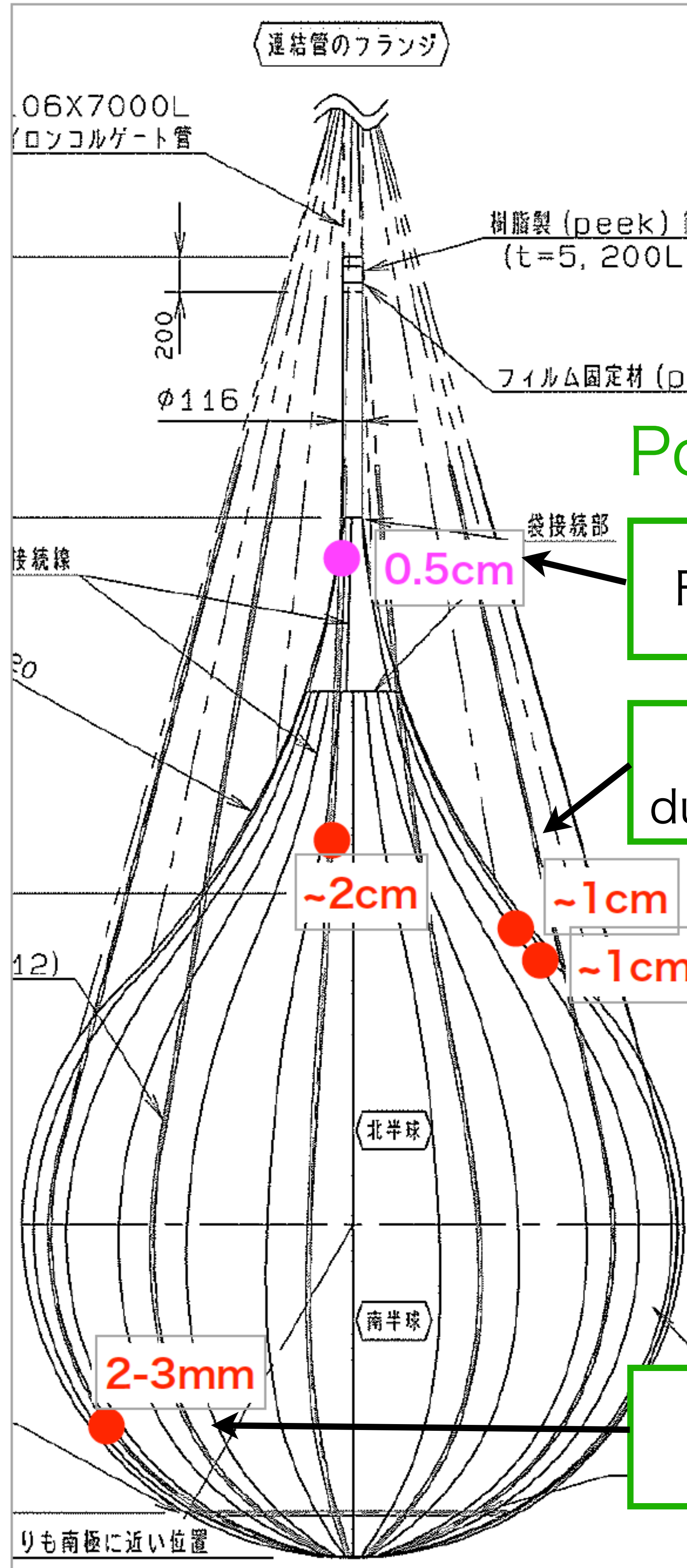
- camera image
- load cell
- balloon shape reconstruction
  with ^{210}Po events
- ^{222}Rn decay rate
- mixture of KL-LS and dummy-LS
  by gas-chromatography



I might say we demonstrated we can notice. . .

！！

Inspection of holes with a He leak detector



Possible cause

Folded hard part

High pressure during deployment

High pressure when folding

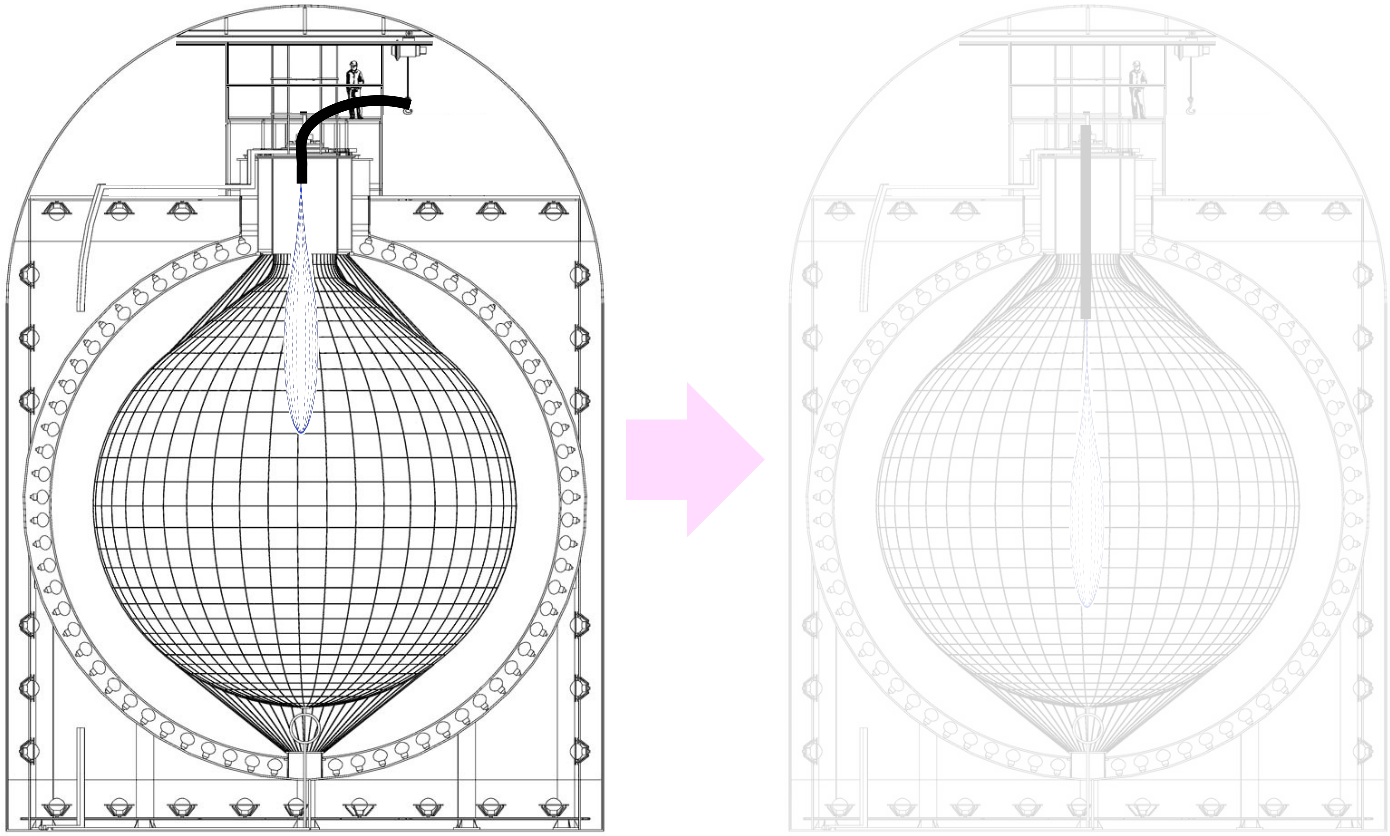
● Found in Kamioka

● Found in Sendai

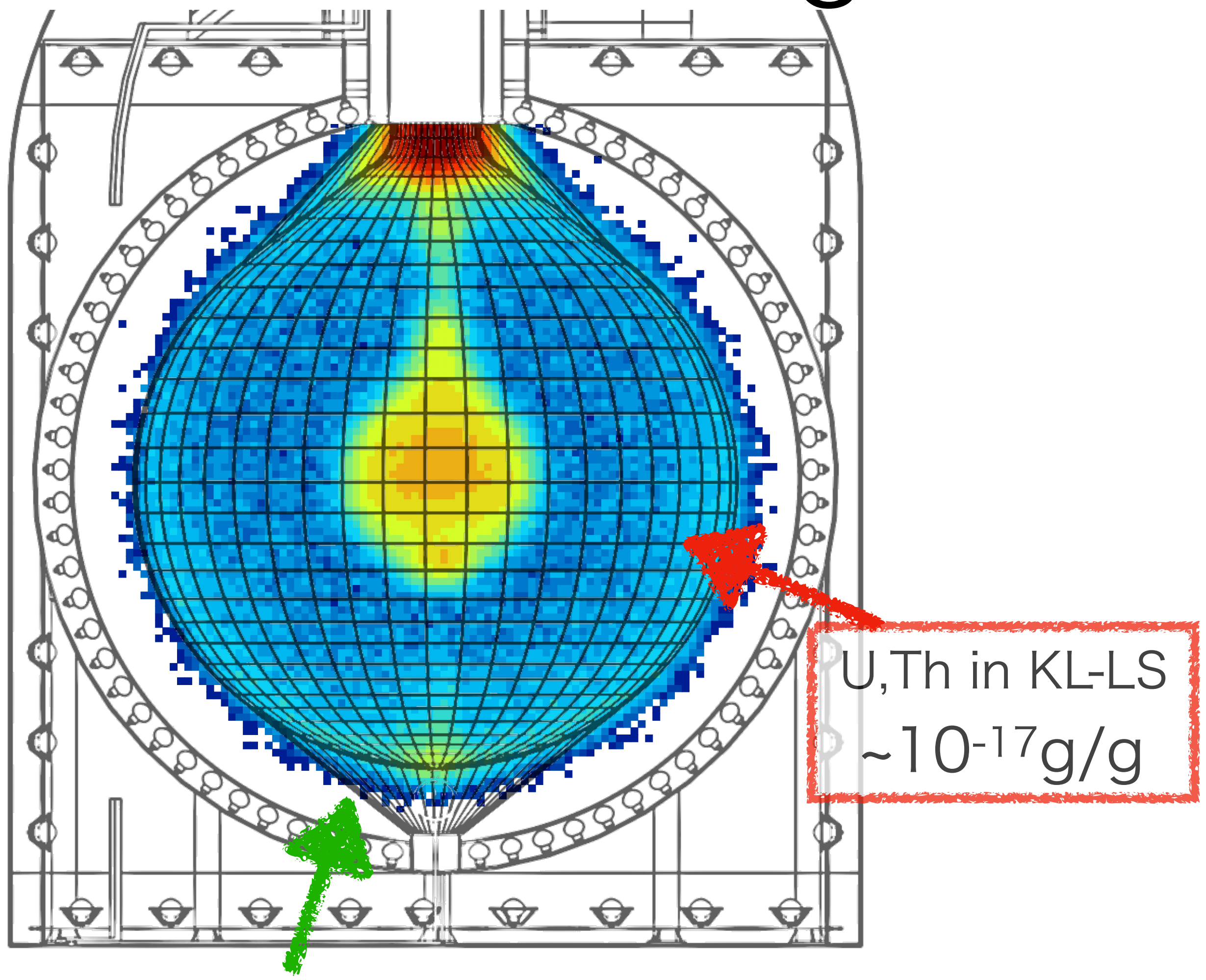
after 1.5 yrs of effort Including improvement of welding

mini-balloon installation again May 10, 2018

50cm width for detector access



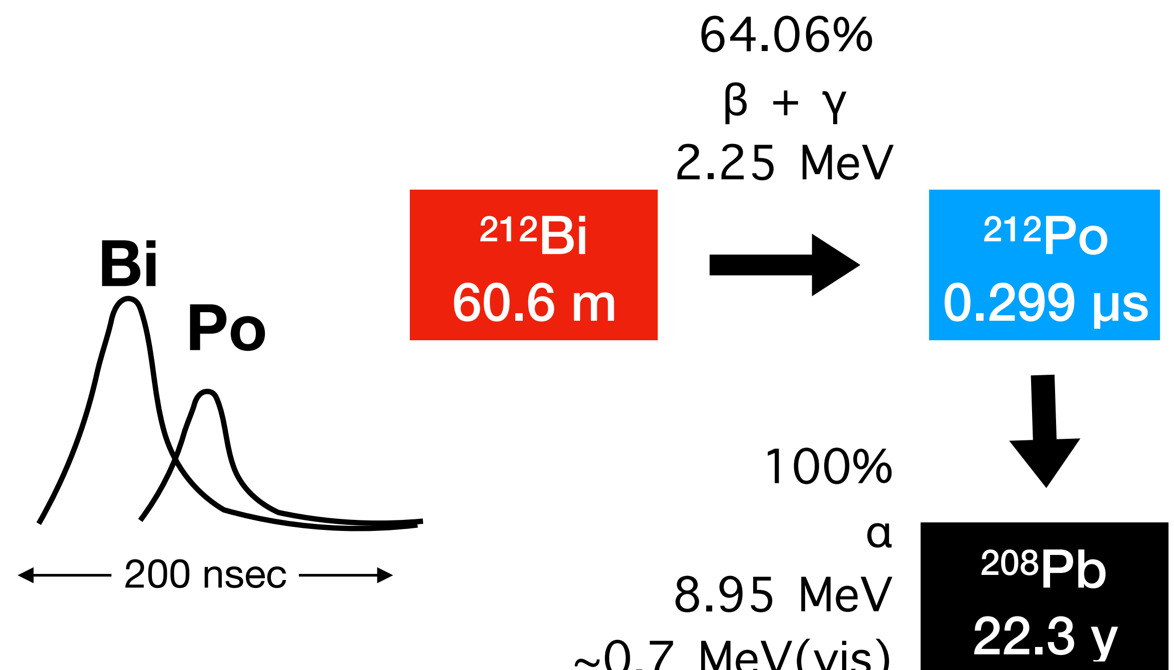
Characterization of mini-balloon, again

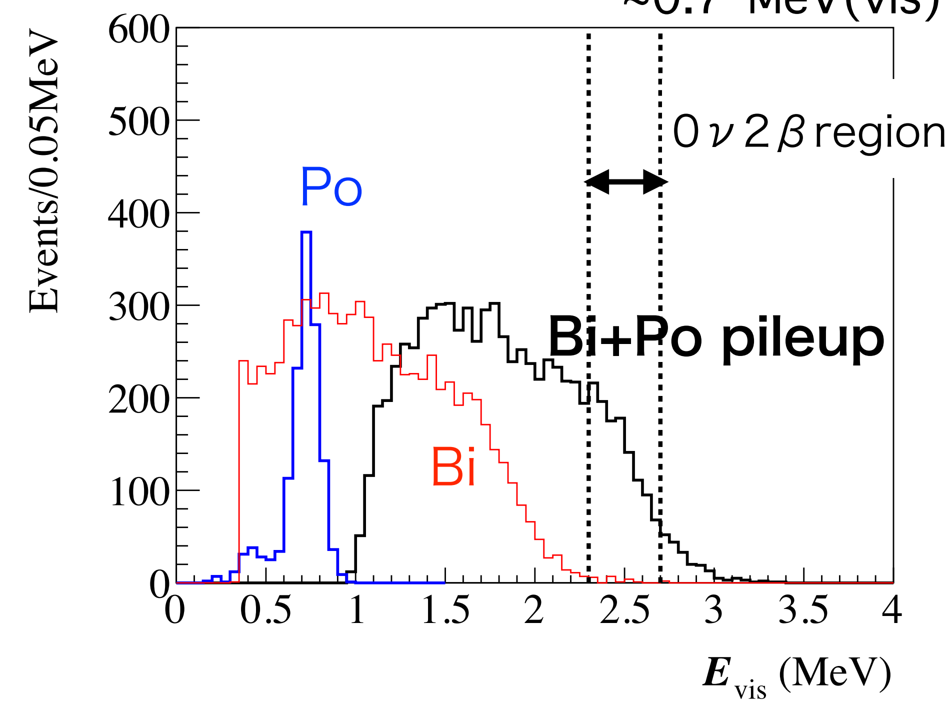


Basic investigations before xenon.

- ✅ mini-balloon is clean
- ✅ no evidence of leakage
- ✅ ^{238}U is low enough
- ⁉️ ^{232}Th(~10^{-15}g/g)

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

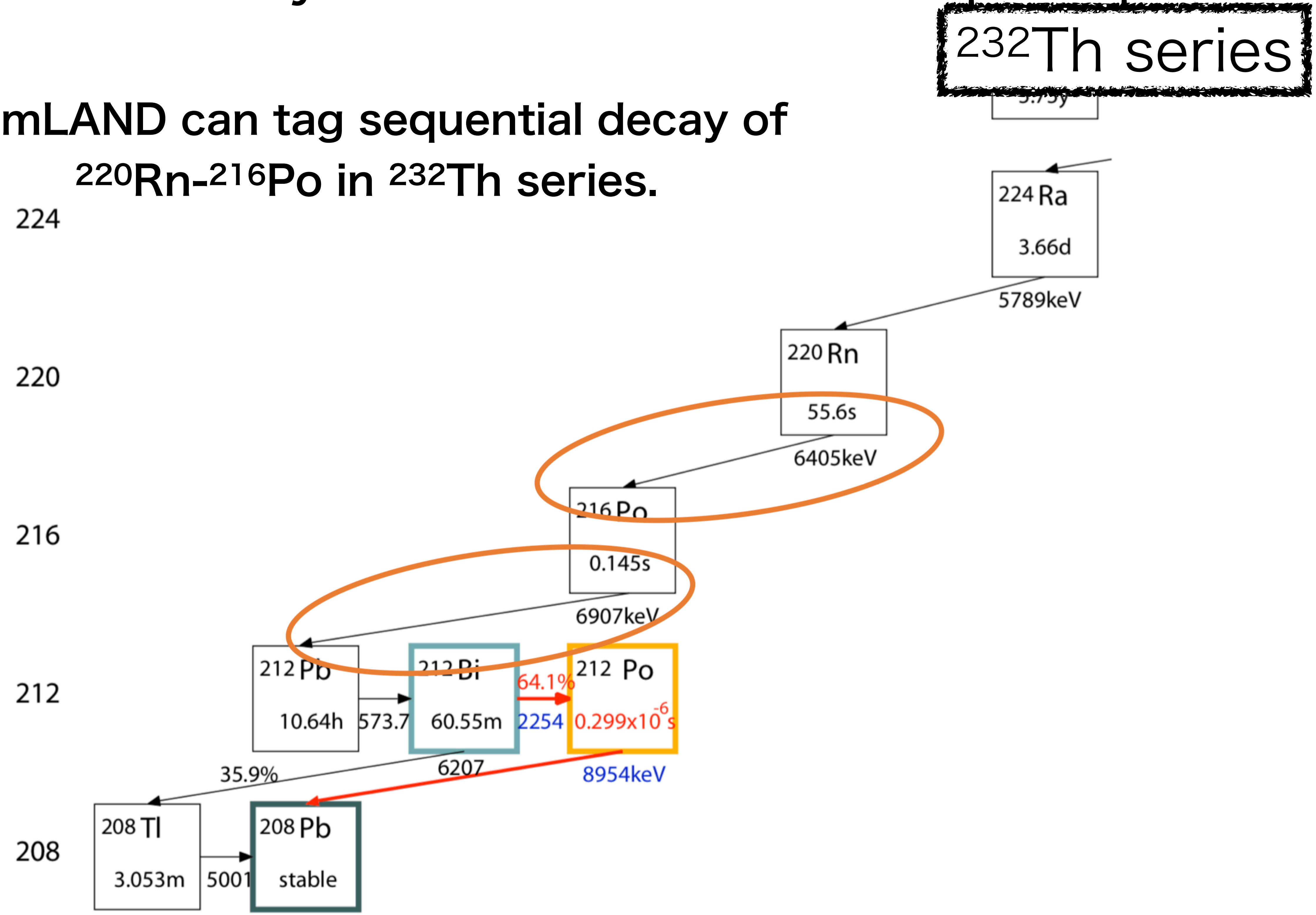




Pileup BG is as large as current ^{10}C BG and tolerable.
But ^{10}C rejection is improving, and we chose **purification**!

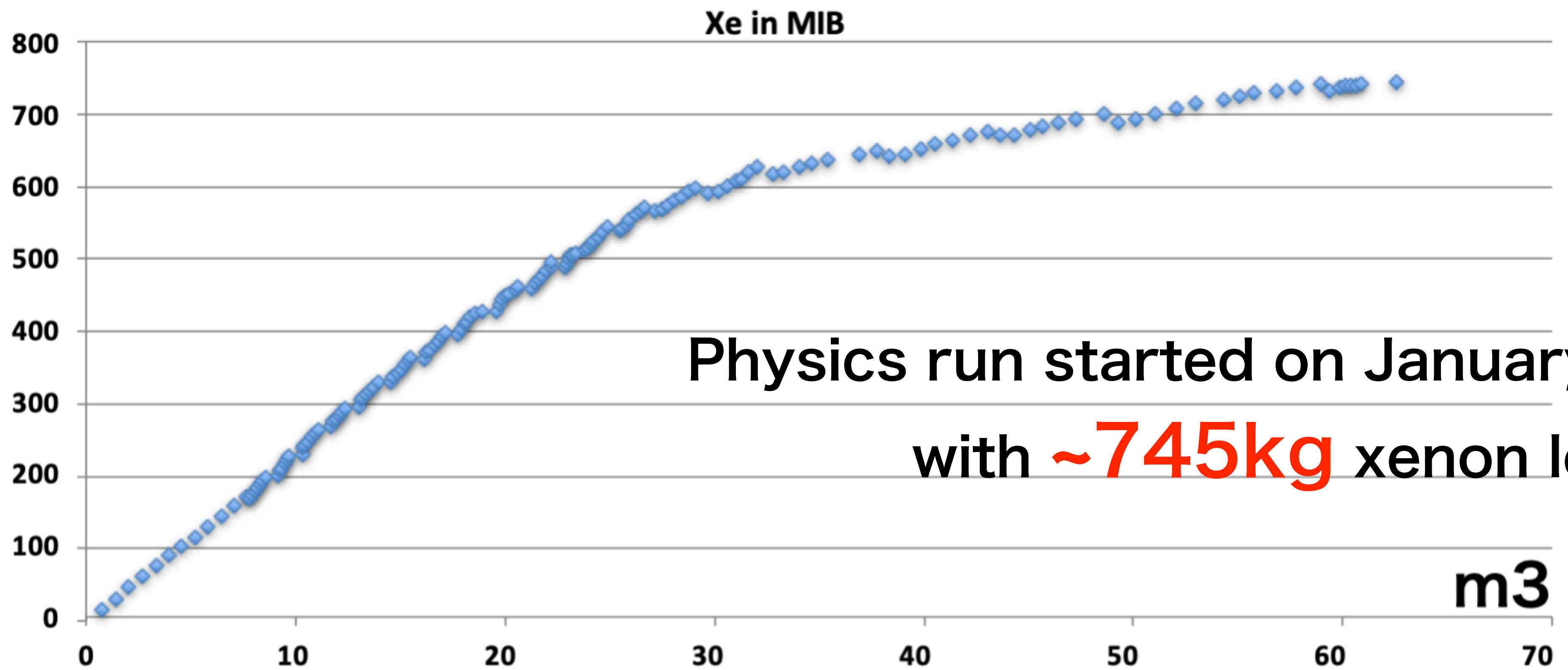
One more way to reduce ^{212}Bi-Po pileup

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



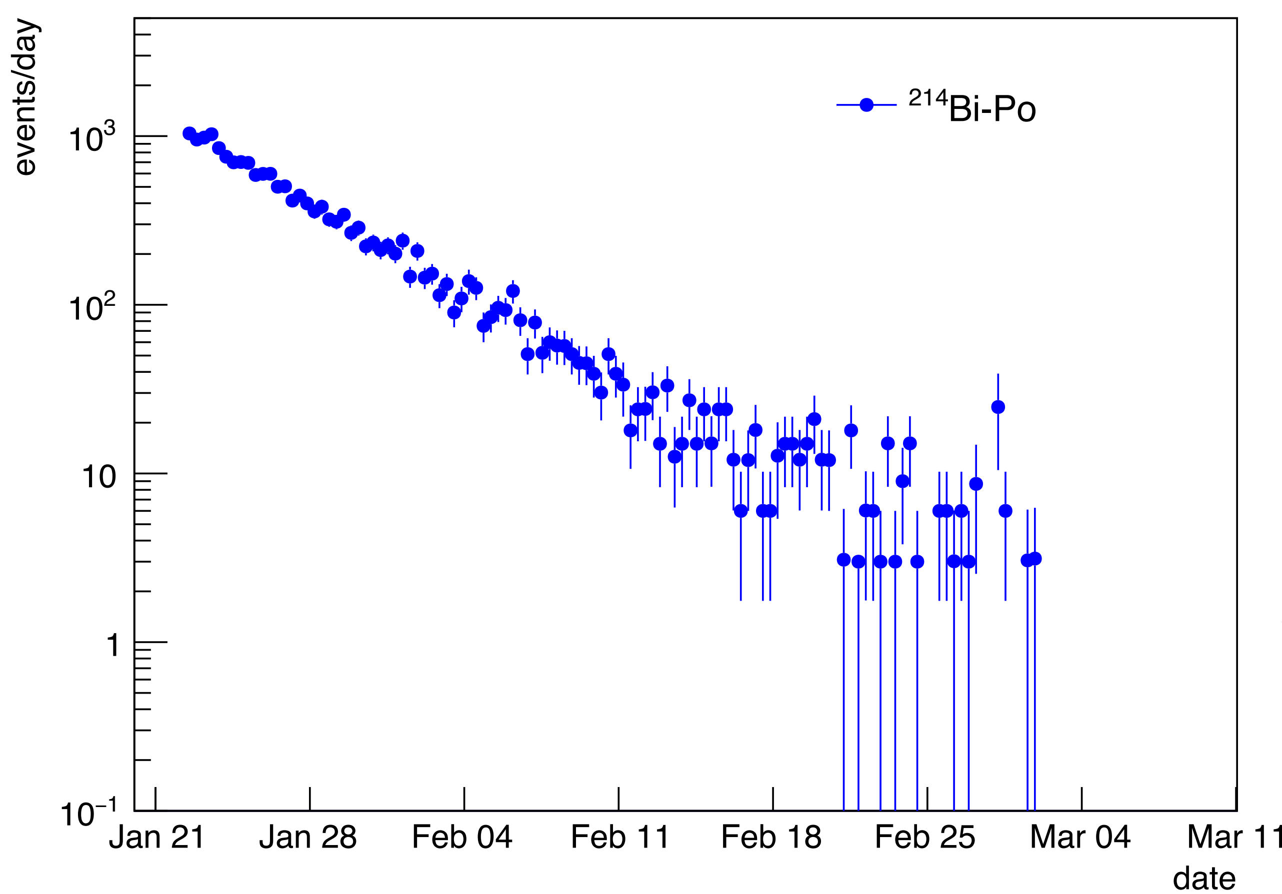
Both ^{208}Tl, ^{212}Bi-^{212}Po can be suppressed with 2 days veto after the tag.
Useful for $0\nu2\beta$ search and low threshold ^{8}B neutrino observation

Xenon loading started in November 2018 after the purification



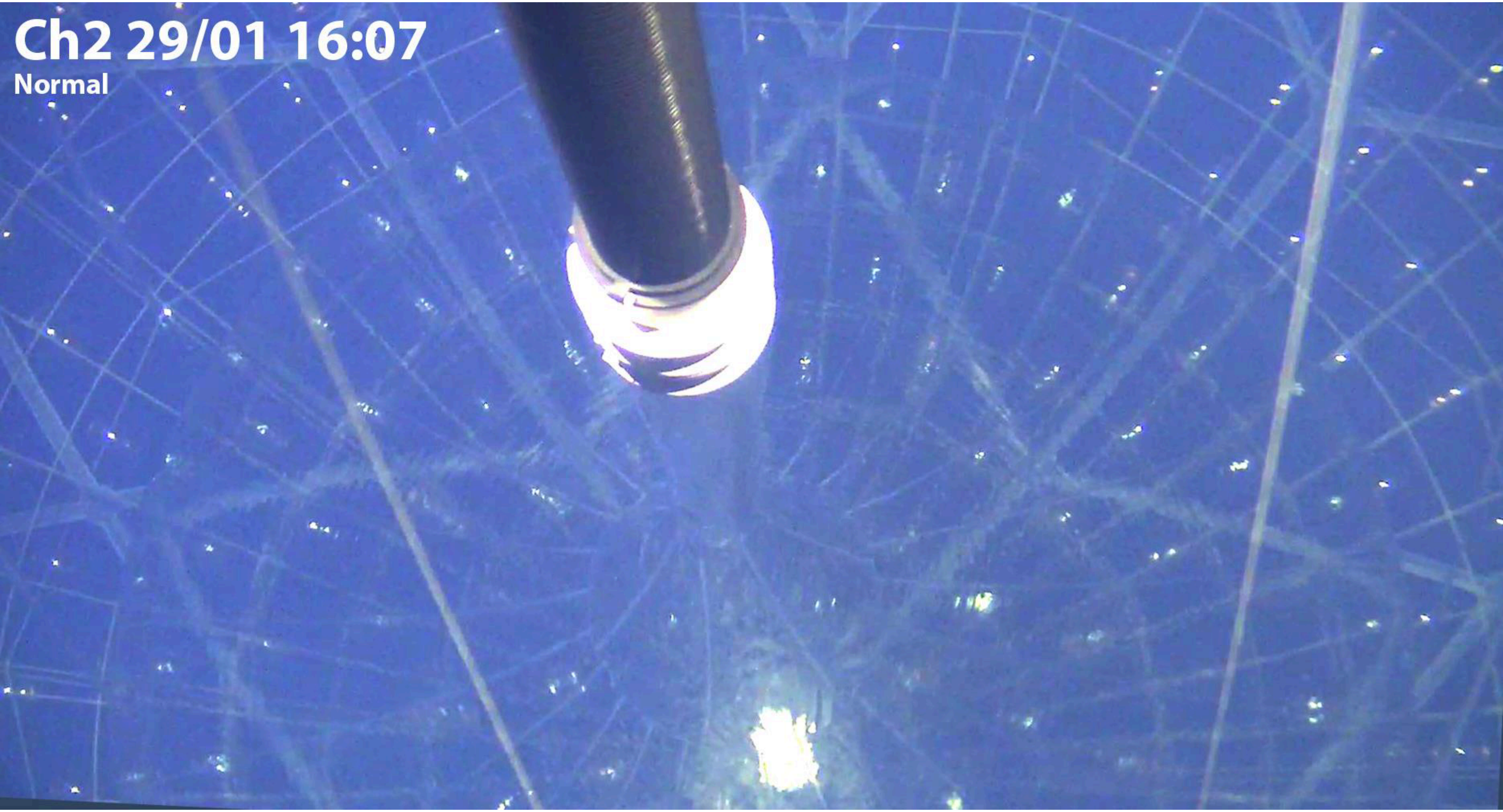
Physics run started on January 22, 2019

with ~745kg xenon loading



^{222}Rn is still decaying

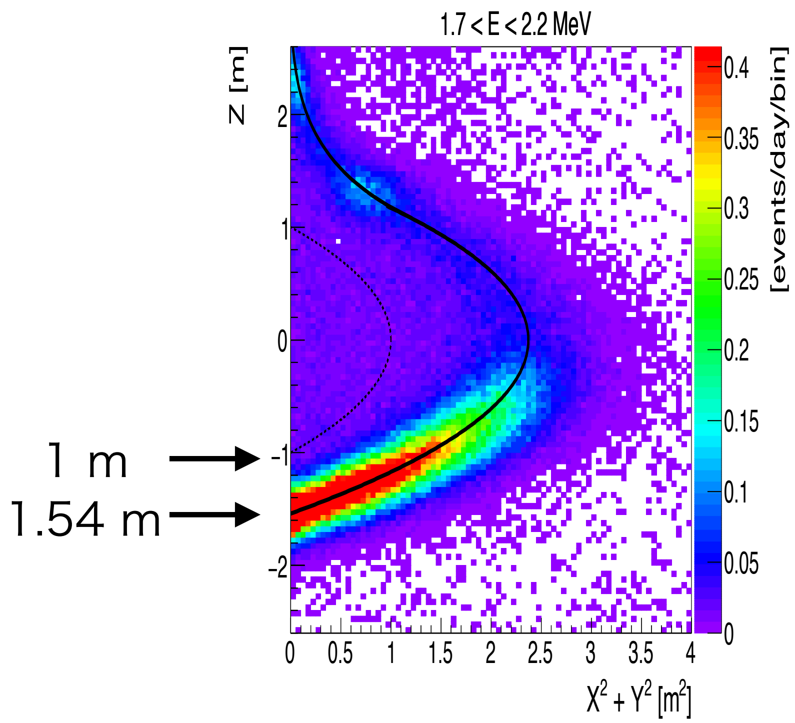
Picture taken on 29 January 2019



mini balloon with 745 kg of enriched xenon

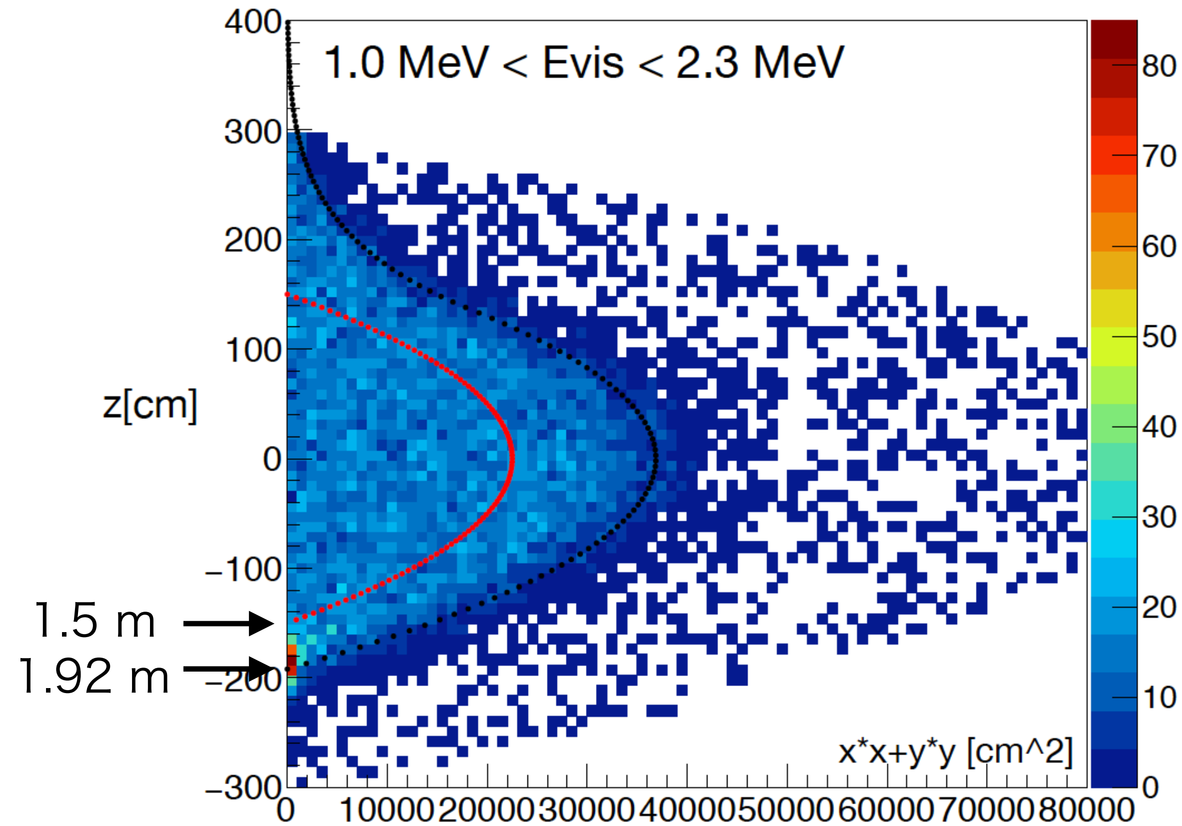
2ν region Z vs ρ^2

Zen 400 phase 2



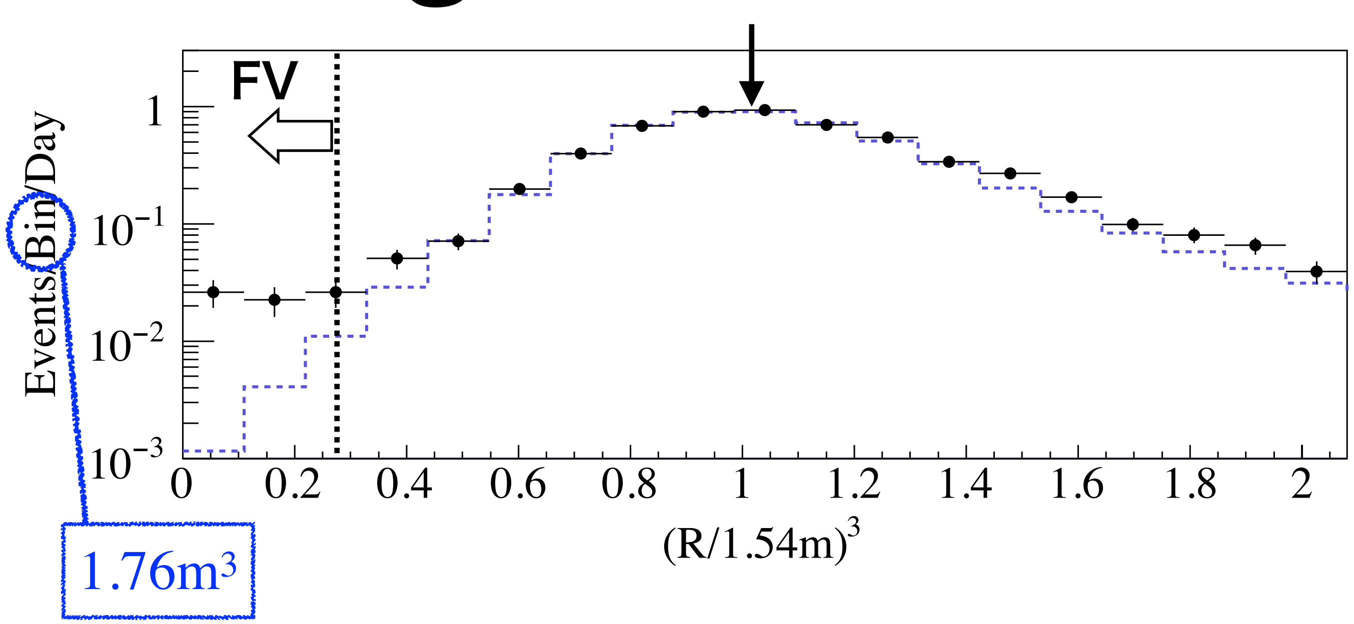
contaminated with ^{134}Cs,
dust sank

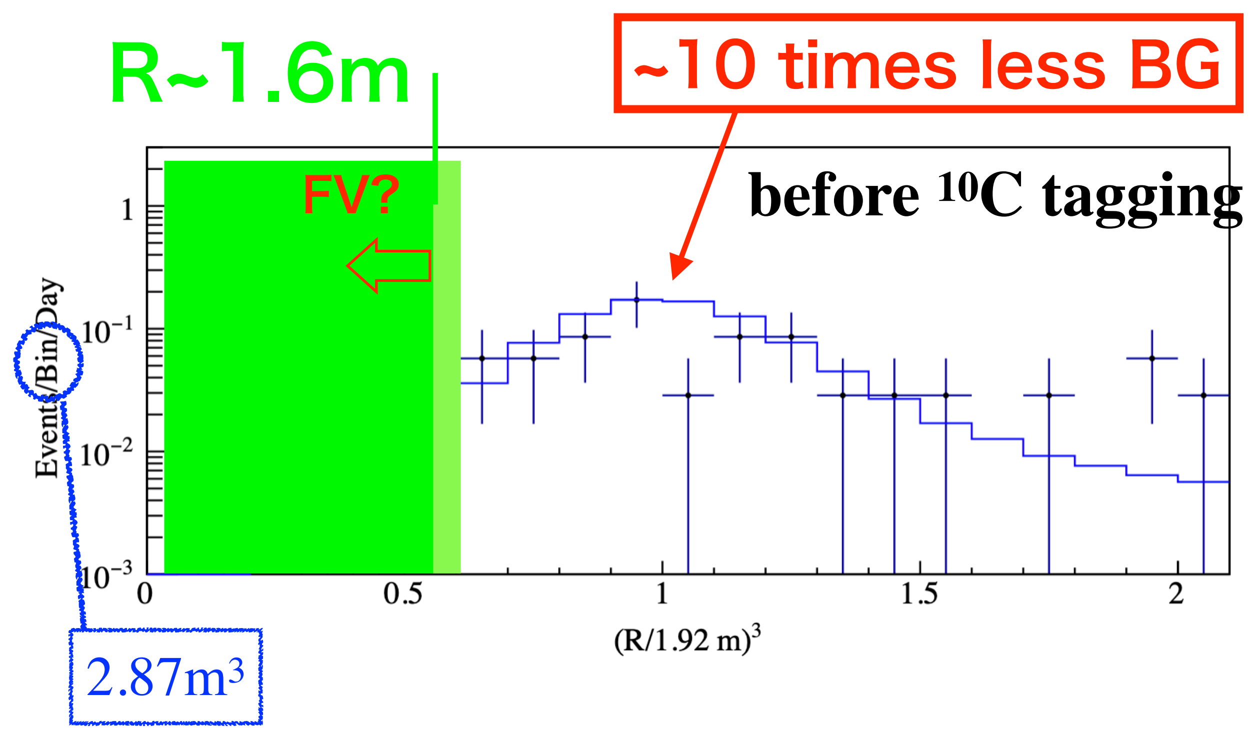
Zen 800



$2\nu 2\beta$ dominates in all volume

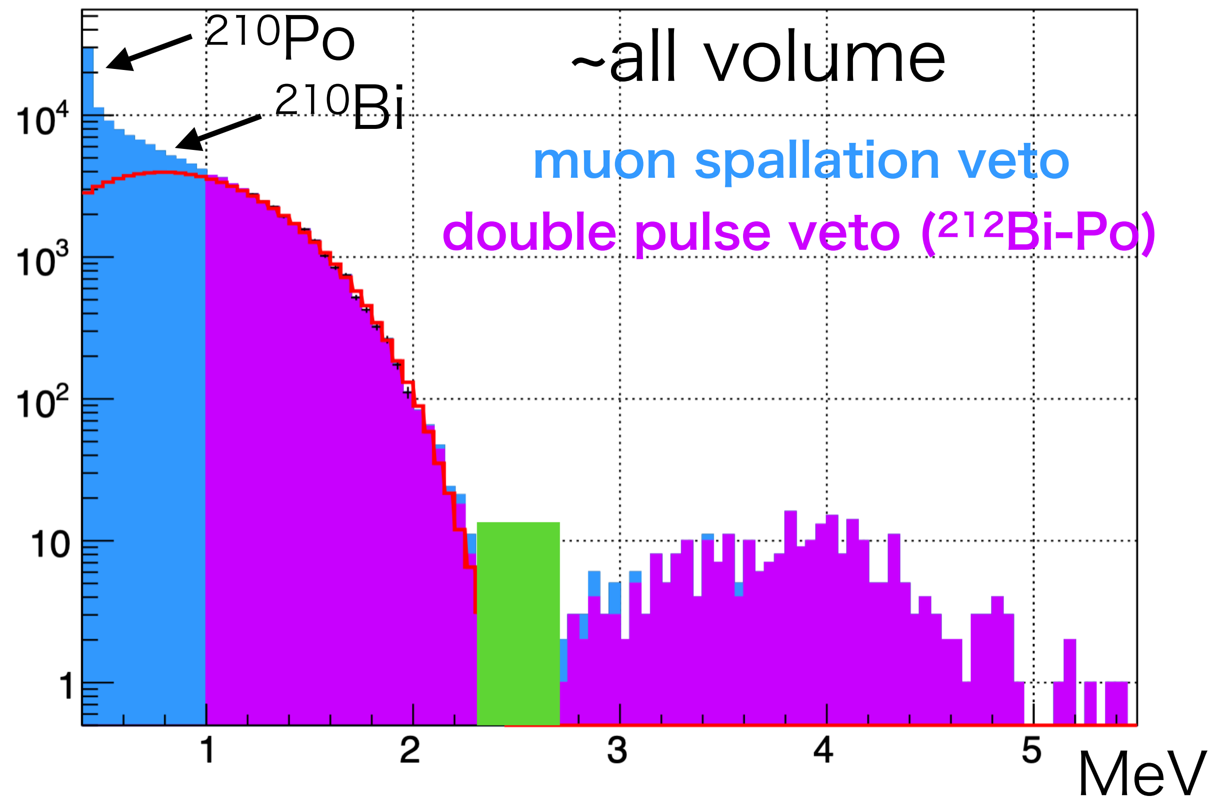
0ν region (2.3-2.7 MeV) r^3



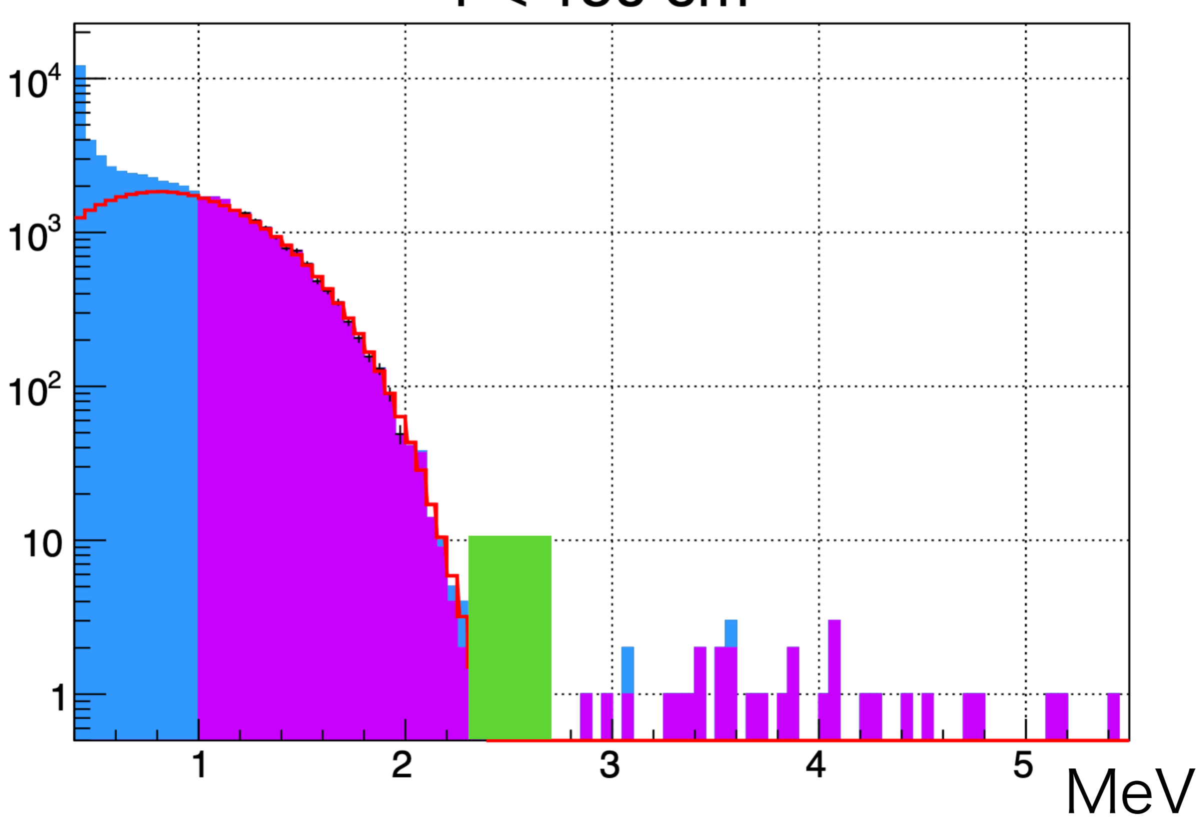


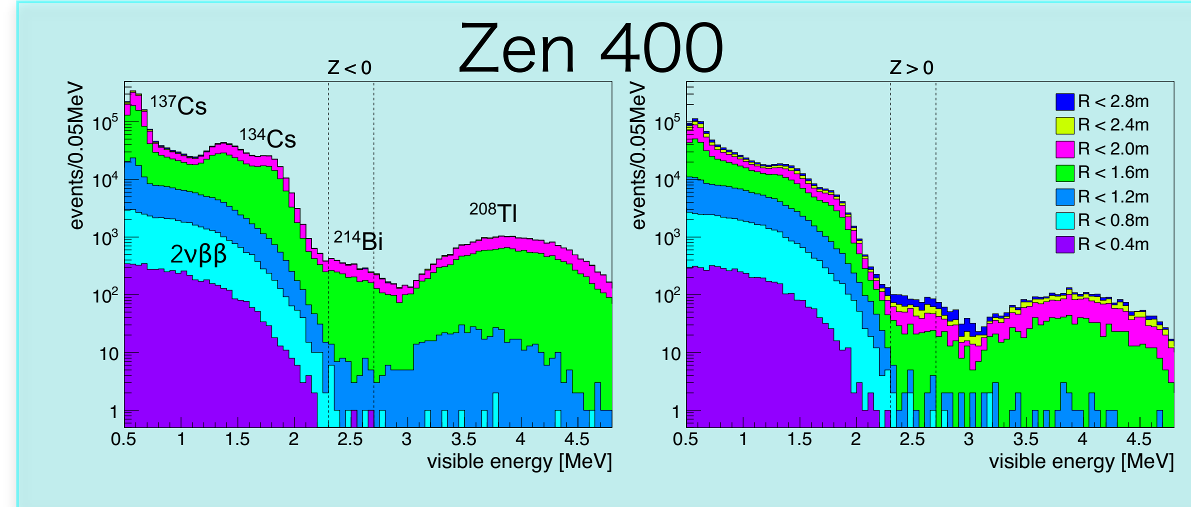
after ^{214}Bi-Po cut

r < 220 cm (r$_{balloon}$ =1.92m)



r < 150 cm





No strange BG is seen in $2\nu2\beta$ region even in all volume.

^{208}Tl and probably ^{214}Bi are seen in higher energies.

^{214}Bi rejection efficiency on the mini-balloon is ~50%.

Radius cut reduces ^{208}Tl and ^{214}Bi (potential BG) very well. FV can be 3~4 times larger and equivalent with all volume of Zen 400.

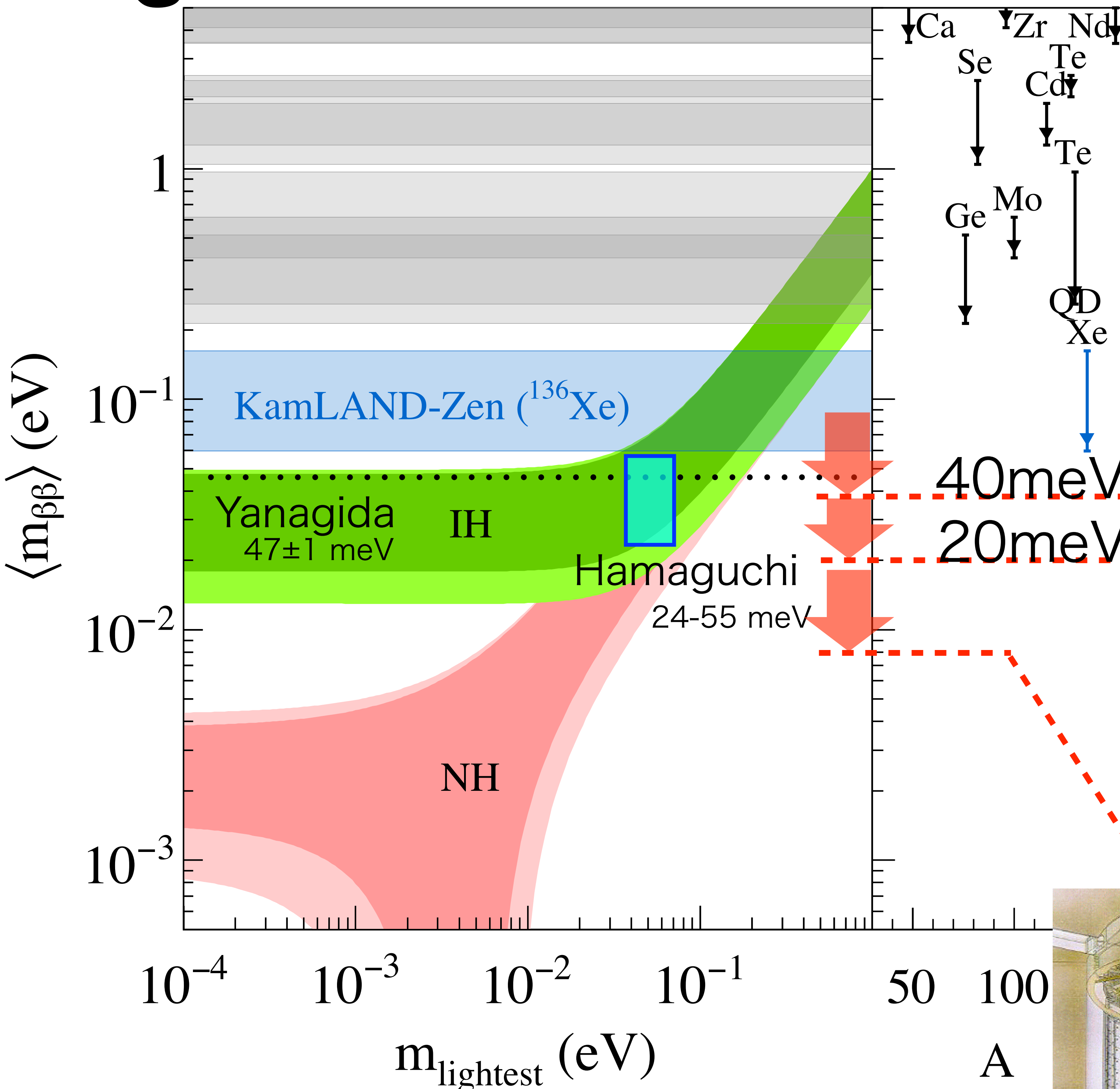
Finally,

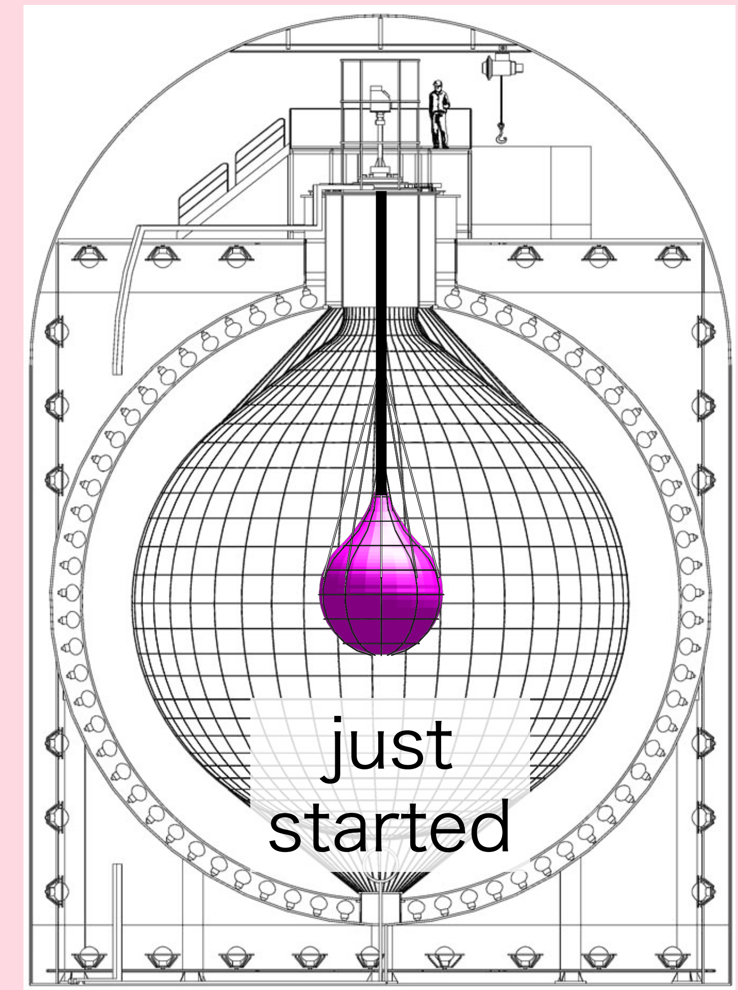
"Advantages of using KamLAND"

have been all demonstrated;

⓪ low cost and quick start (running detector)	✅	ran in 2 years
① BG can be identified (full active thick shielding)	✅	^{110m}Ag identified
② In-situ purification possible (liquid media)	✅	^{110m}Ag removed
③ On/Off measurements possible (xenon is removable)	✅	BG confirmed by degassing
④ multi-purpose (ex. geo-neutrino)	✅	leading geo-ν
⑤ easily**?** scalable (mini-balloon)	✅	mass doubled

Target sensitivities

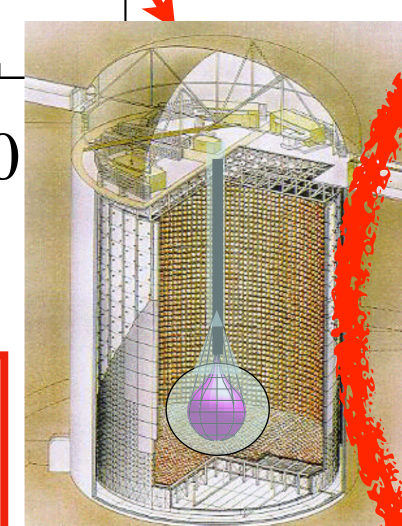


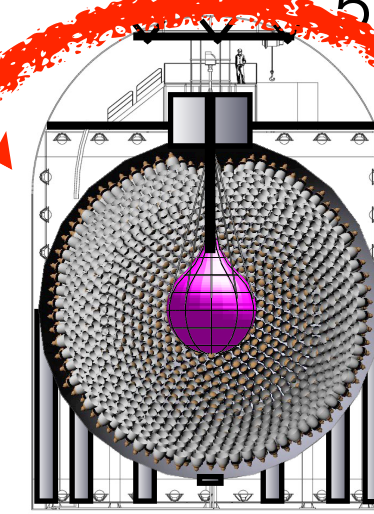


low BG film, 750 kg xenon

KamLAND-Zen 800

5x10^{26}y (5y)





~30M$

better resolution

scintillating film

KamLAND2-Zen

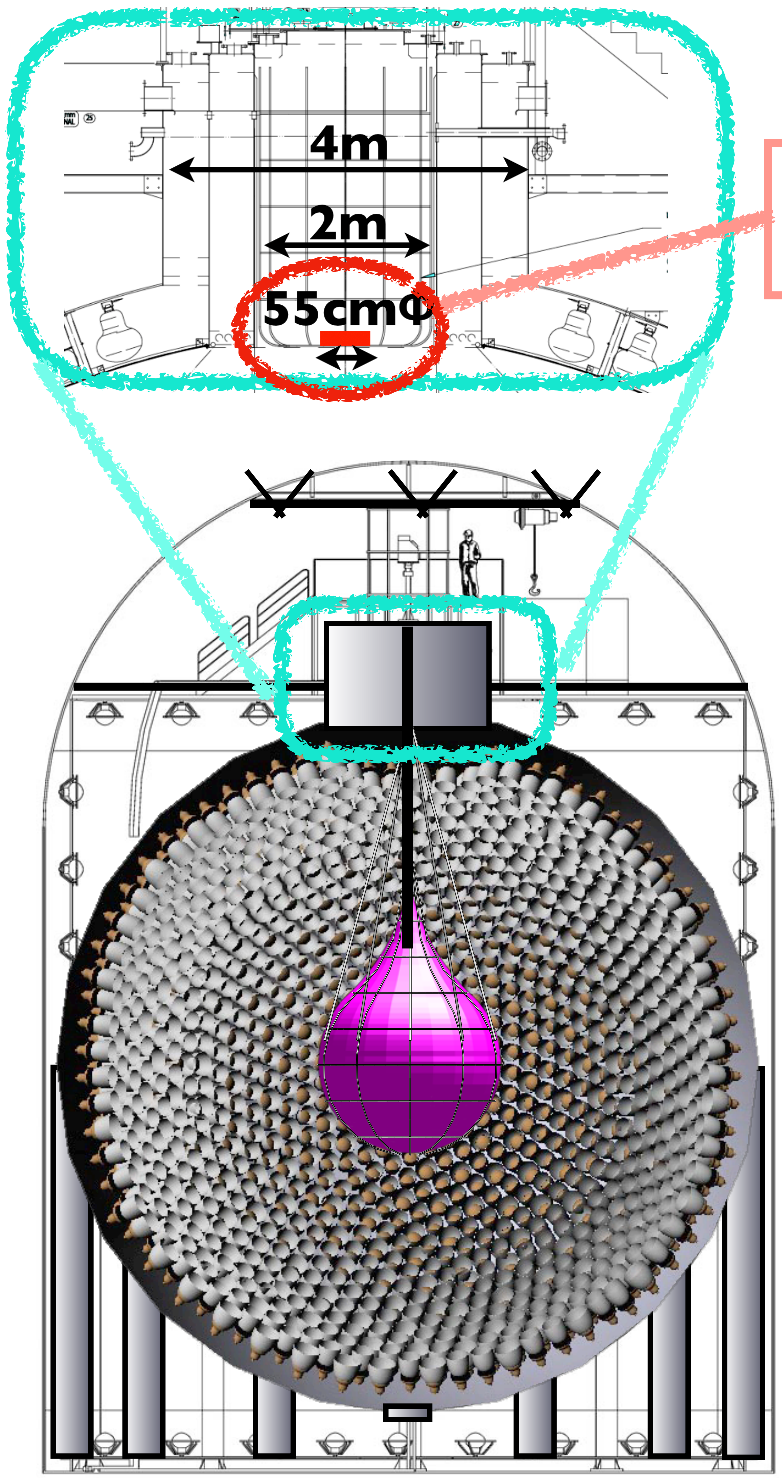
2x10^{27}y (5y)

The discovery may be just around the corner.

KamLAND-Zen is closest !!!

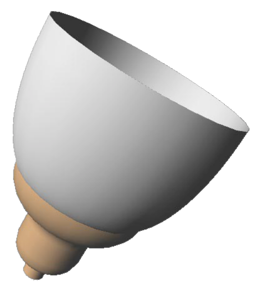
And more future plans!

Higher energy resolution for reducing 2ν BG



1000+ kg xenon

→ KamLAND2-Zen



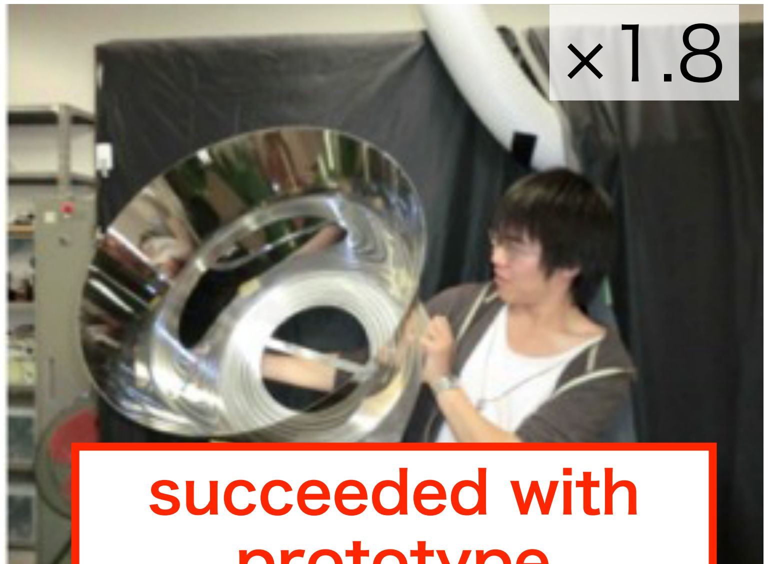
Winston cone	light collection ×1.8
high q.e. PMT 17"ϕ→20"ϕ ε=22→30+%	light collection ×1.9
New LAB LS (better transparency)	light collection ×1.4

expected σ(2.6MeV)= 4% → ~2%

target sensitivity 20 meV

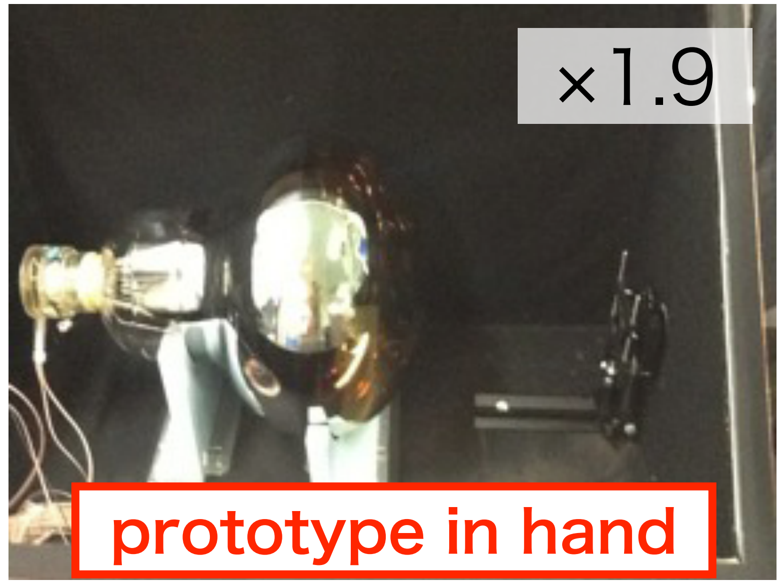
R&D for KamLAND2-Zen and future

○ winston cone



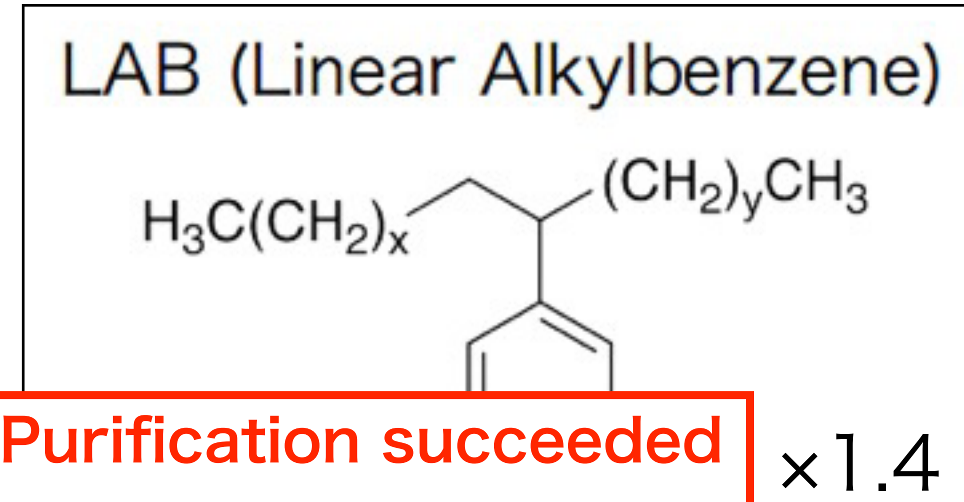
succeeded with prototype

○ HQE-PMT



prototype in hand

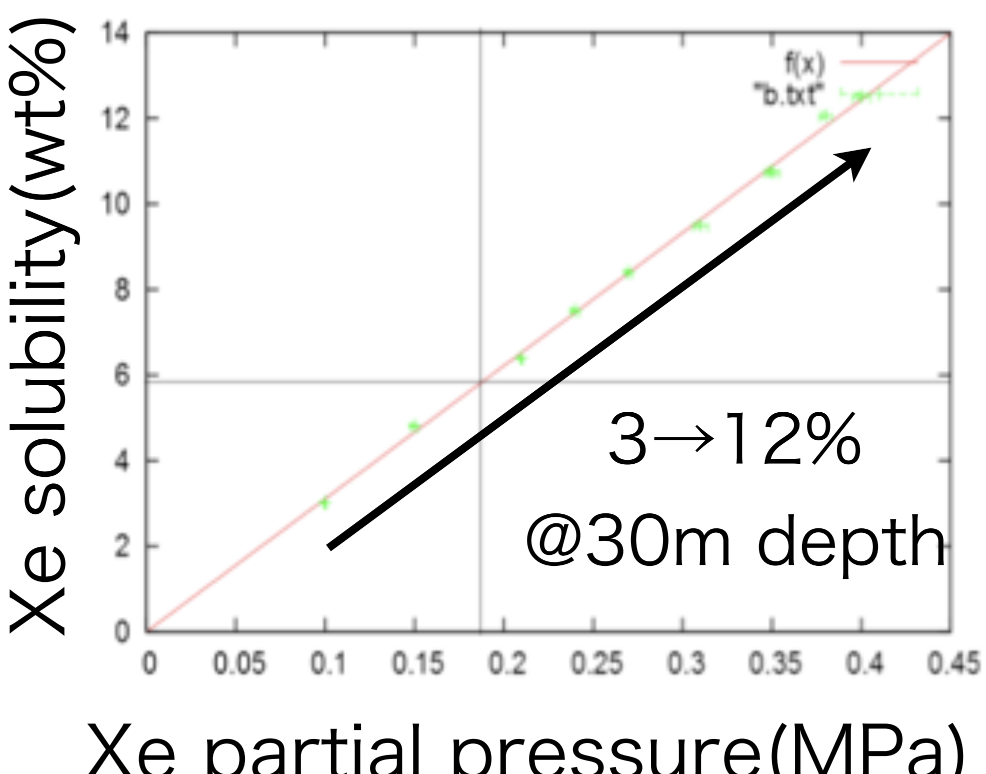
○ New LAB-LS



Purification succeeded with charcoal

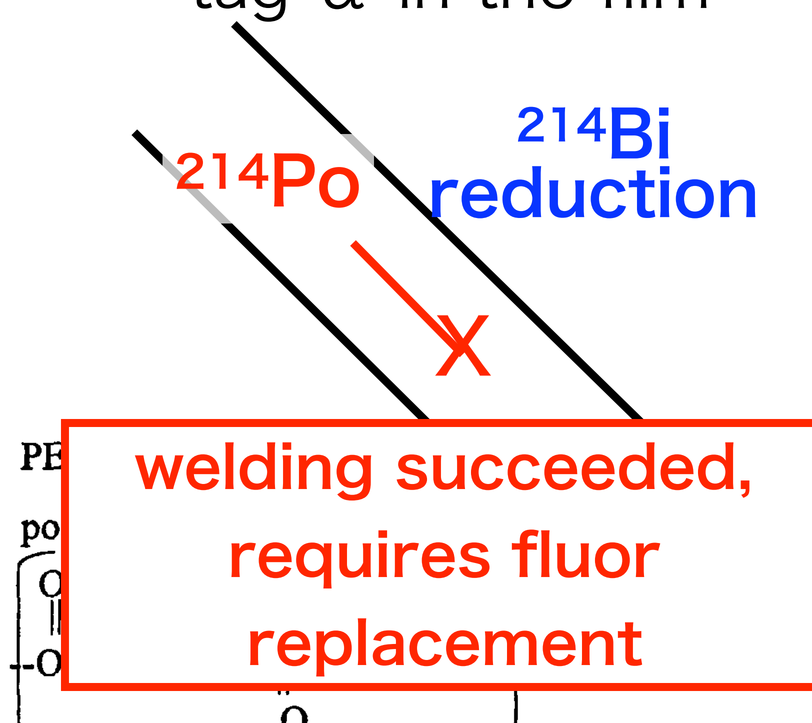
×1.4

○ denser xenon



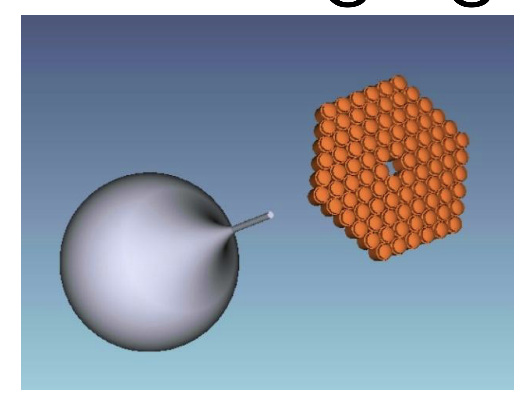
principle confirmed

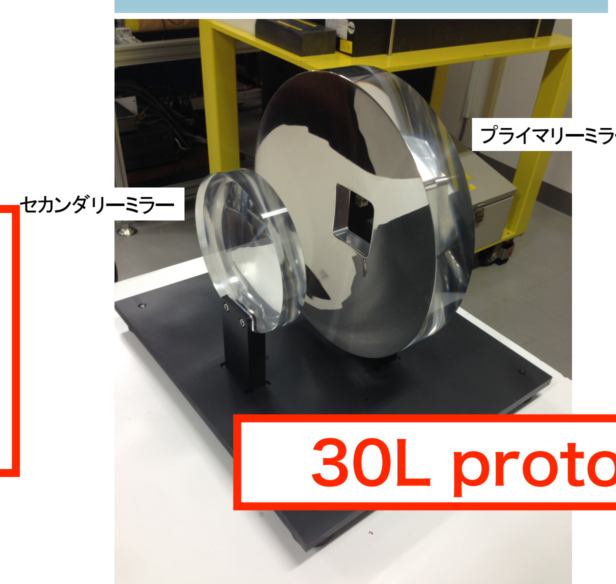
○ scintillator film



welding succeeded, requires fluor replacement

○ imaging

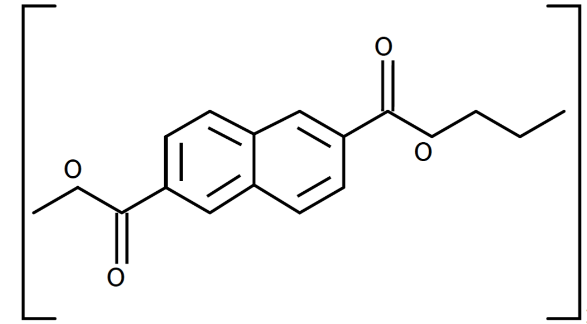




β / γ id.

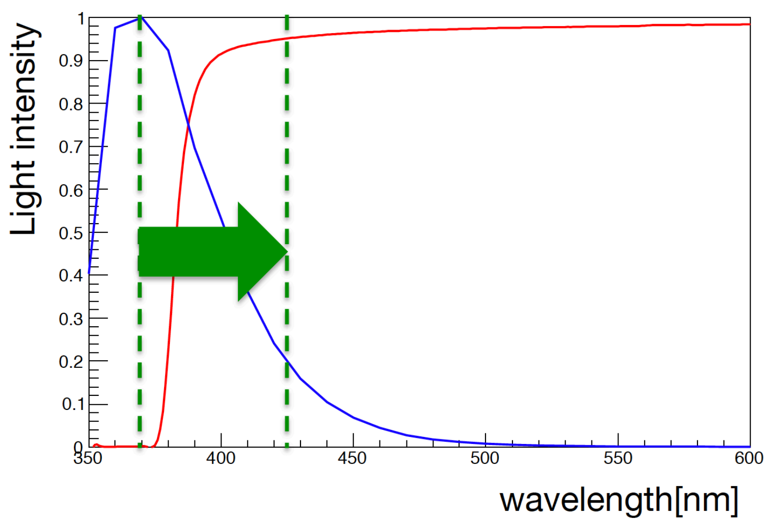
30L prototype

PolyEthylene Naphthalate (PEN)

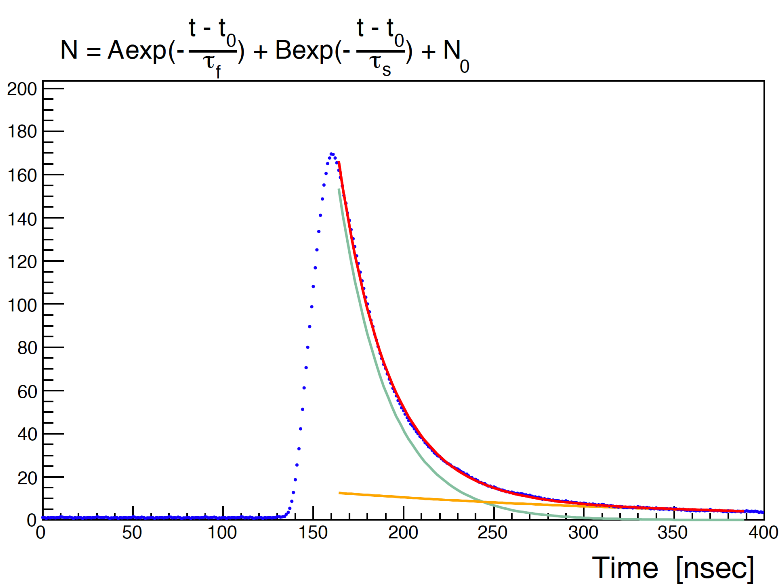


η =10,500ph/MeV
λ_{PEN}=425nm
U,Th < 3 ppt

welding easier & strong enough

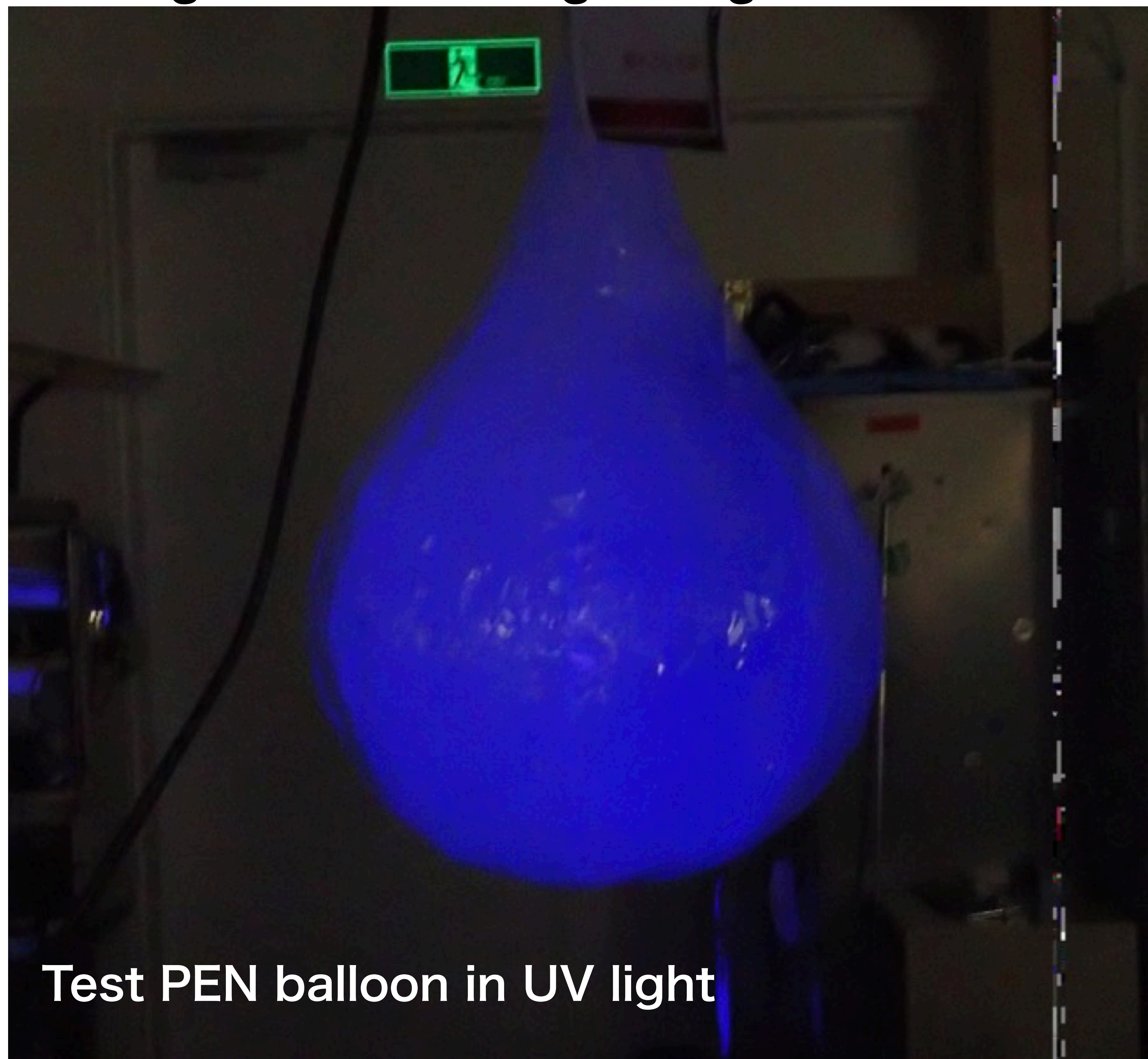


requires Bis-MSB in LS



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

PSD possible



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)

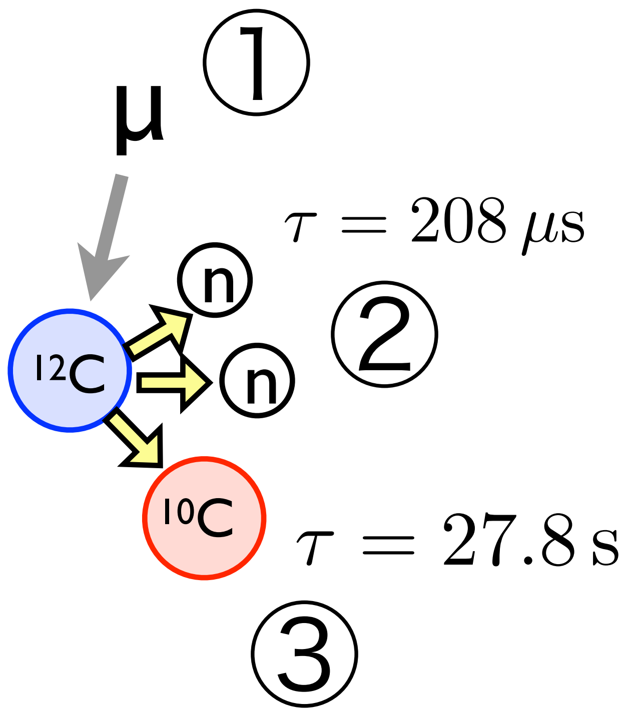
PEN ~99.95% rejection (double pulse, ^{220}Rn-^{216}Po, PSD)

Any of three α identification tells it's a surface BG.

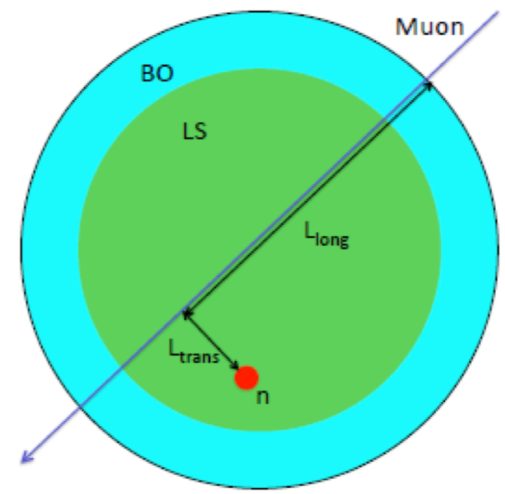
PEN reduces surface BG very efficiently,
thus enables thicker (easier to handle) film and/or larger FV.

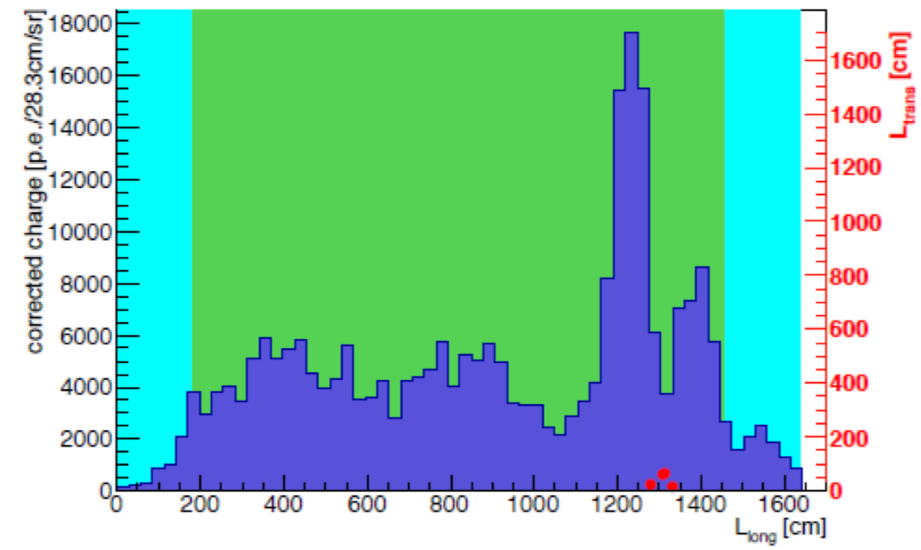
Further ^{10}C reduction, analysis & electronics

1. Triple fold coincidence

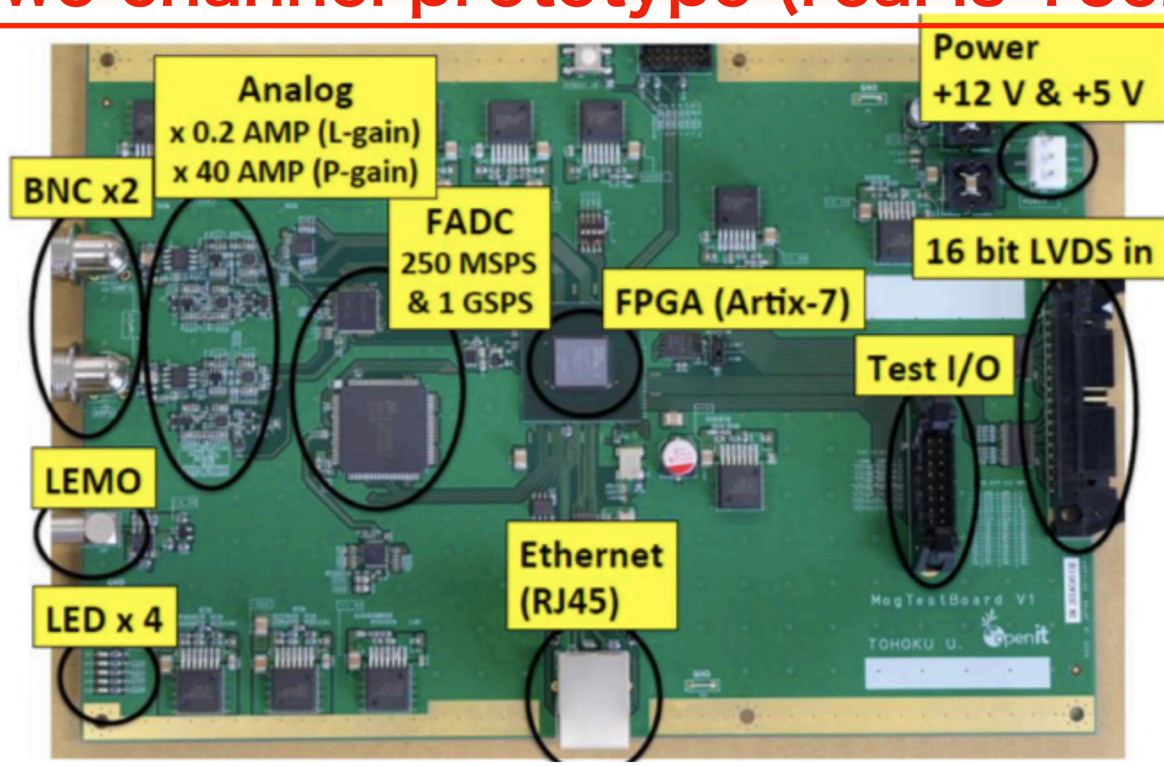


2. Energy loss along μ track





Two channel prototype (real is 16ch)



Wide range, low noise, fast FADC, ethernet data transfer (real adds digital BLR)

3. Wider timing distribution for spread vertices

~50% reduction possible

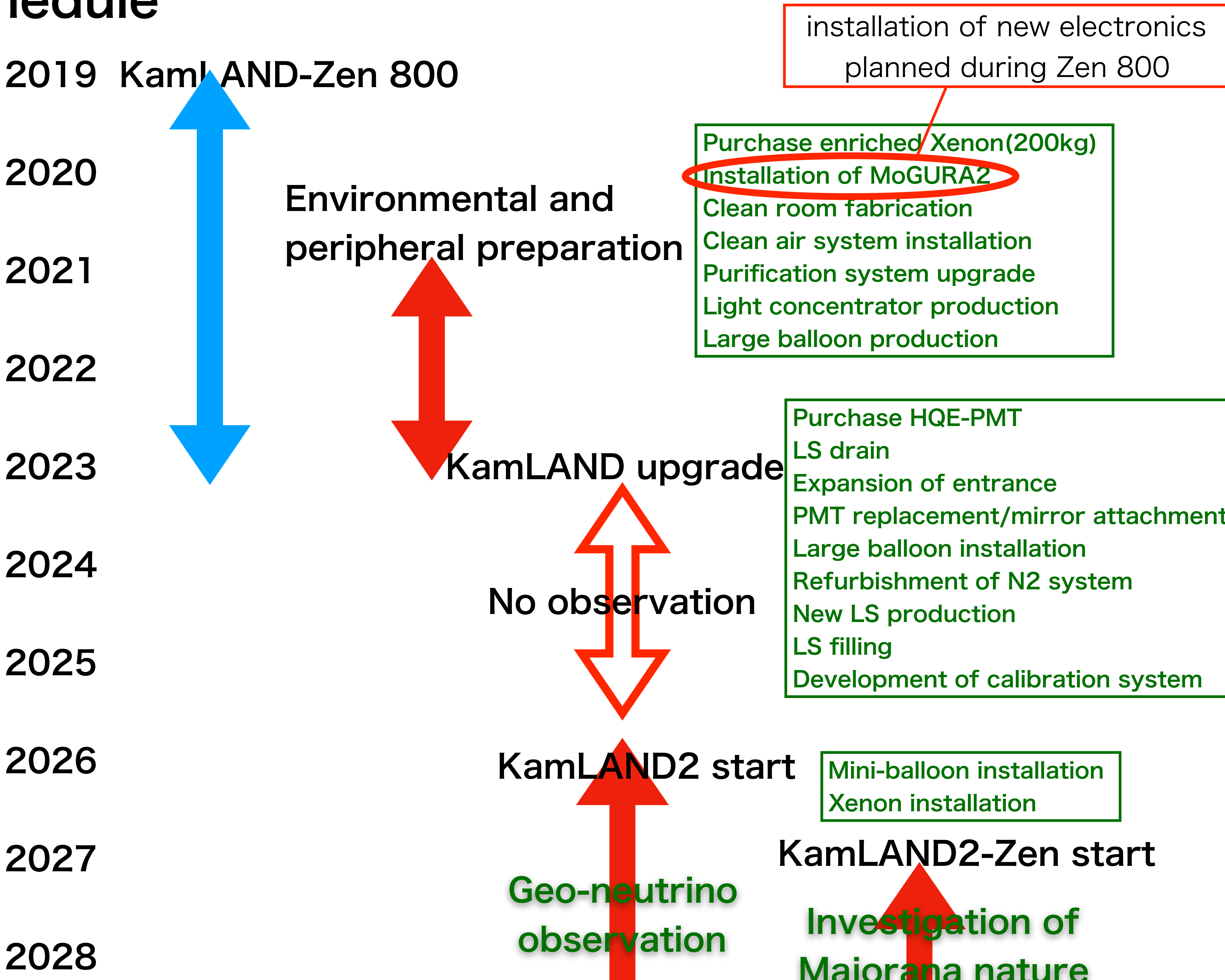
New electronics will improve ^{10}C reduction from 64% to ~99%.
Zen 800 is going to introduce them.

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
$2\nu2\beta$ [/100kgXe/y]	7.4	7.4	→ (σE) <0.15	<0.15
^{10}C [/100kgXe/y]	1.3	→ (analysis) 0.18	→ (σE) 0.09	→ (1.8 atm) 0.05
$^{8}B\nu$ [/100kgXe/y]	0.33	0.33	→ (σE) 0.16	→ (1.8 atm) 0.09
FV (loading) [kgXe]	100 (380)	300+ (745)	→ (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


installation of new electronics planned during Zen 800
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."

・KamLAND-Zen 800 successfully launched in January 2019 with a target sensitivity of 40 meV.

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

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

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Thank you!