KamLAND-Zen experiment

禅

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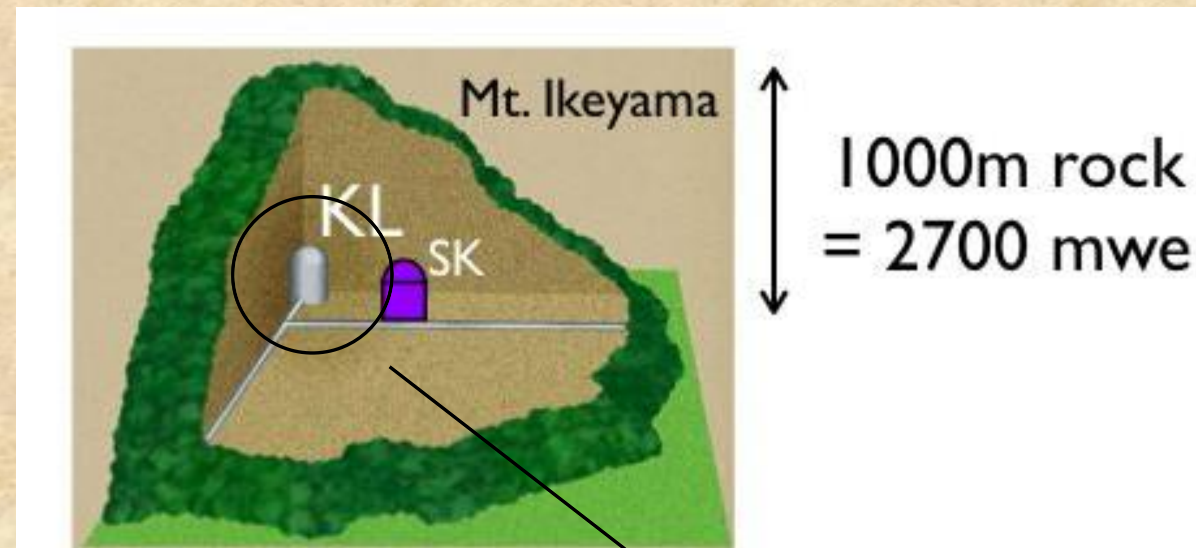
MEDEX’17

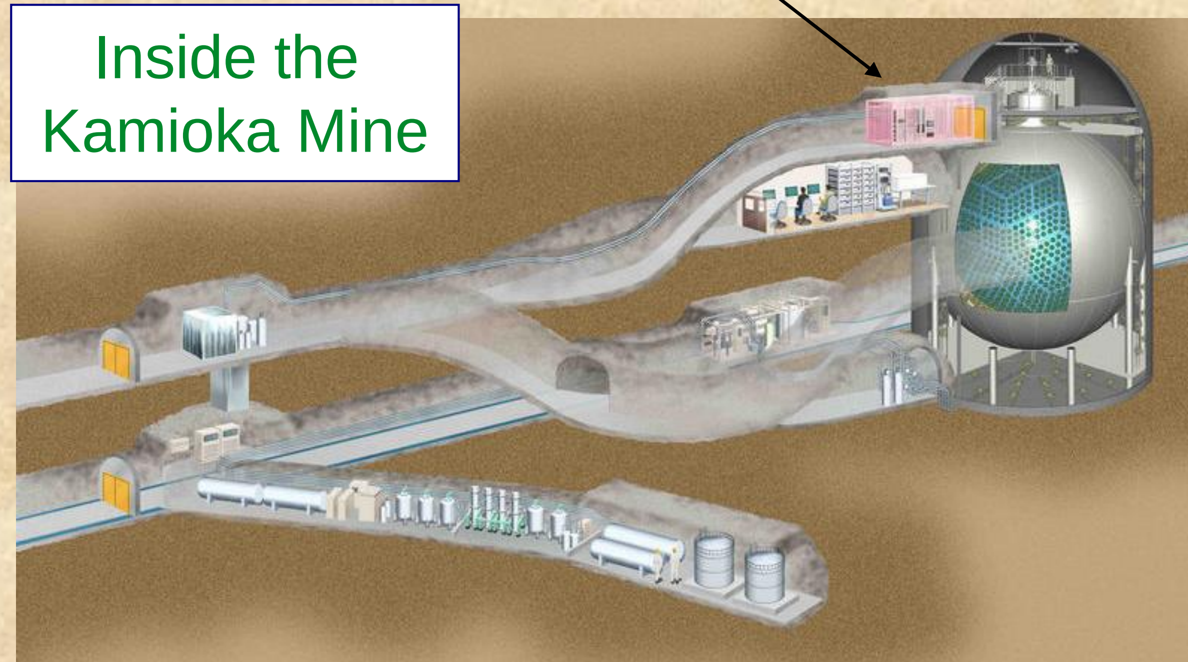
On Behalf of the KamLAND-Zen collaboration

KamLAND -Kamioka Liquid-scintillator Anti-Neutrino Detector

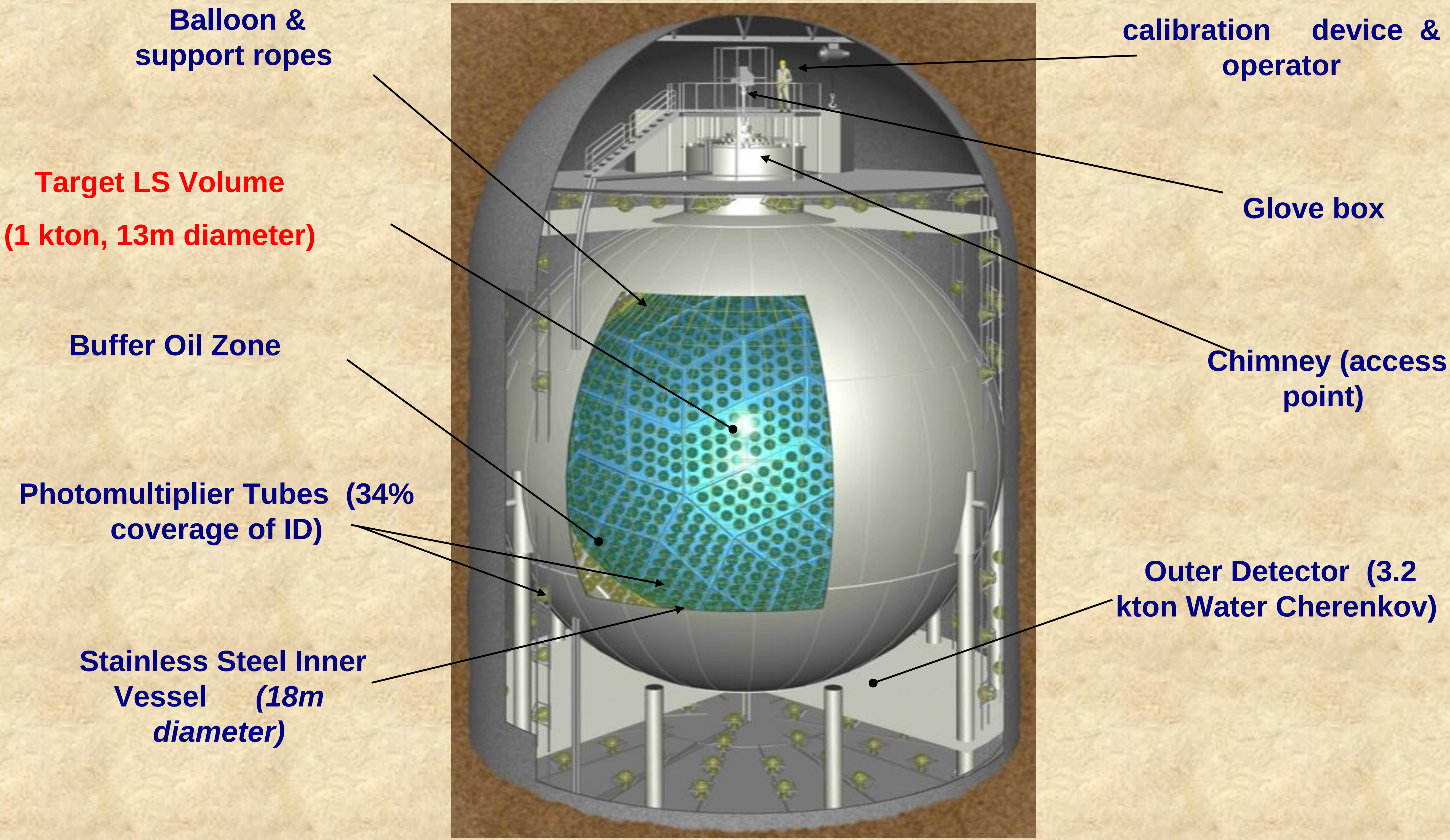
Surrounded by 55 Japanese Reactor Units



Inside the Kamioka Mine

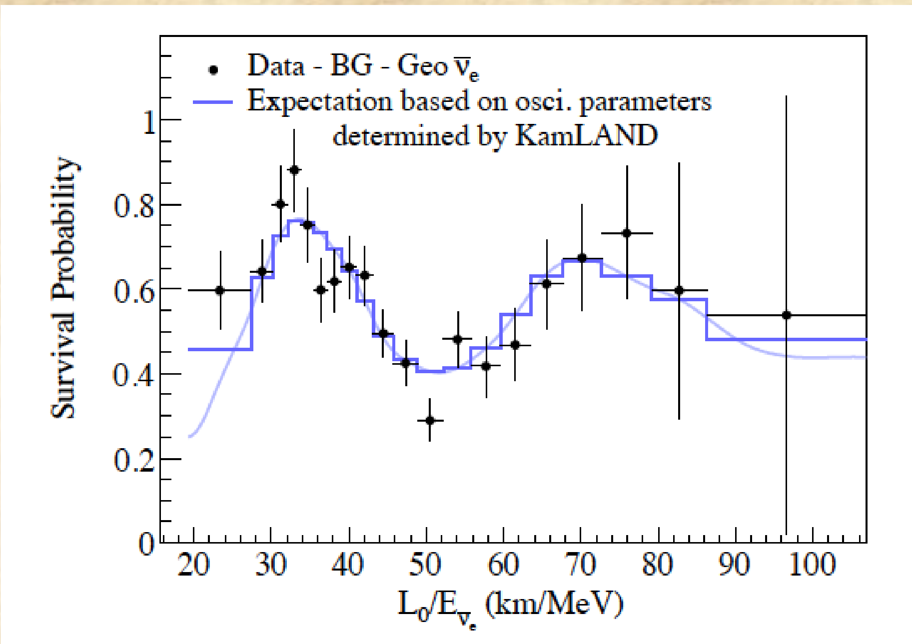


The KamLAND Detector

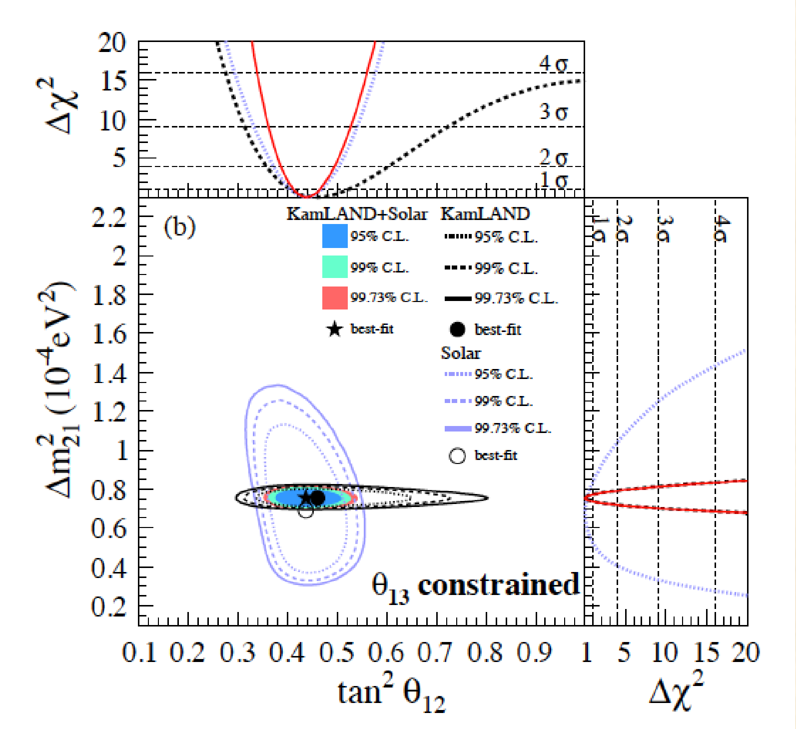


The KamLAND Results during the last decade

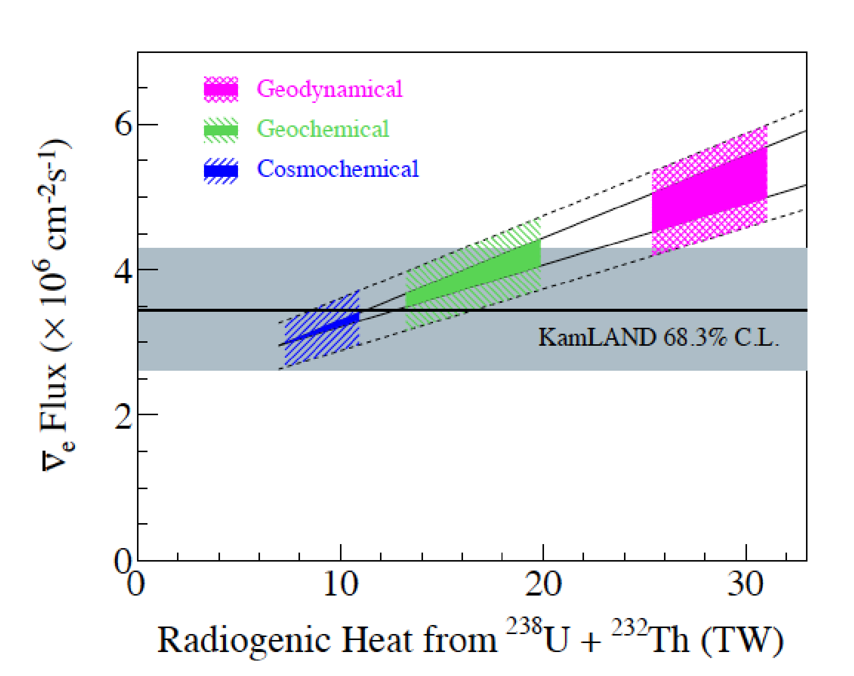
First measurement of neutrino oscillations



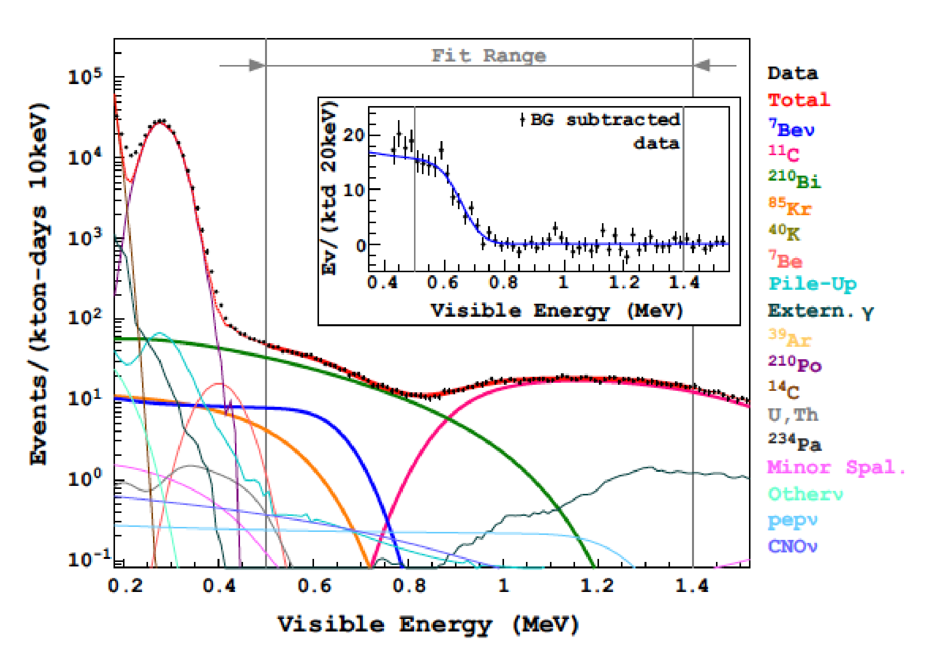
Precision measurement Of mixing parameters



First detection of geo neutrinos and measurement of the Earth radiogenic heat

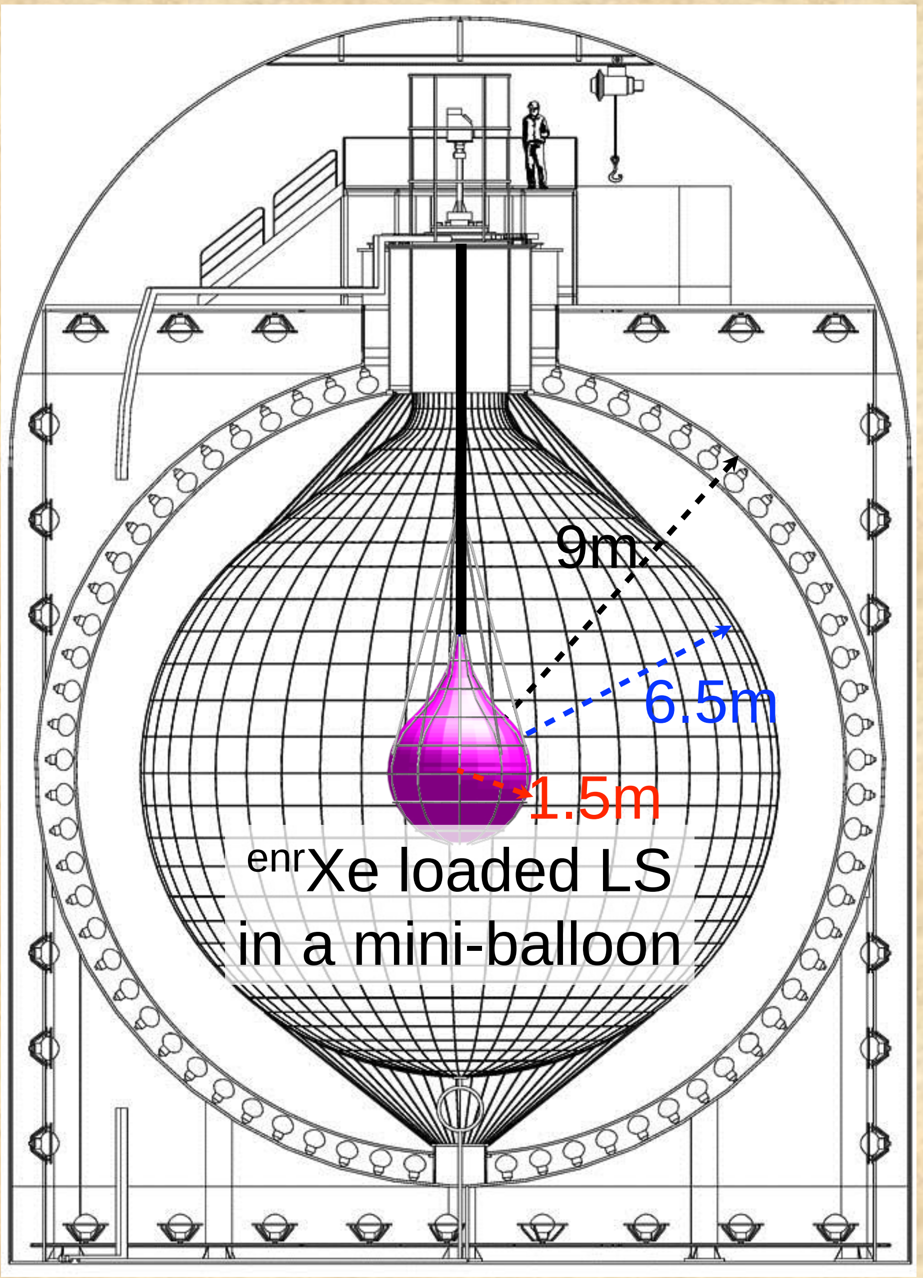


^{7}Be solar ν measured, BG well-understood



From the KamLAND to KamLAND-Zen

Zero Neutrino
double beta decay search



~~320kg 90% enriched ^{136}Xe installed for phase-1~~
~~and 380kg for phase-II~~

Advantages of using KamLAND as a double beta decey experiment

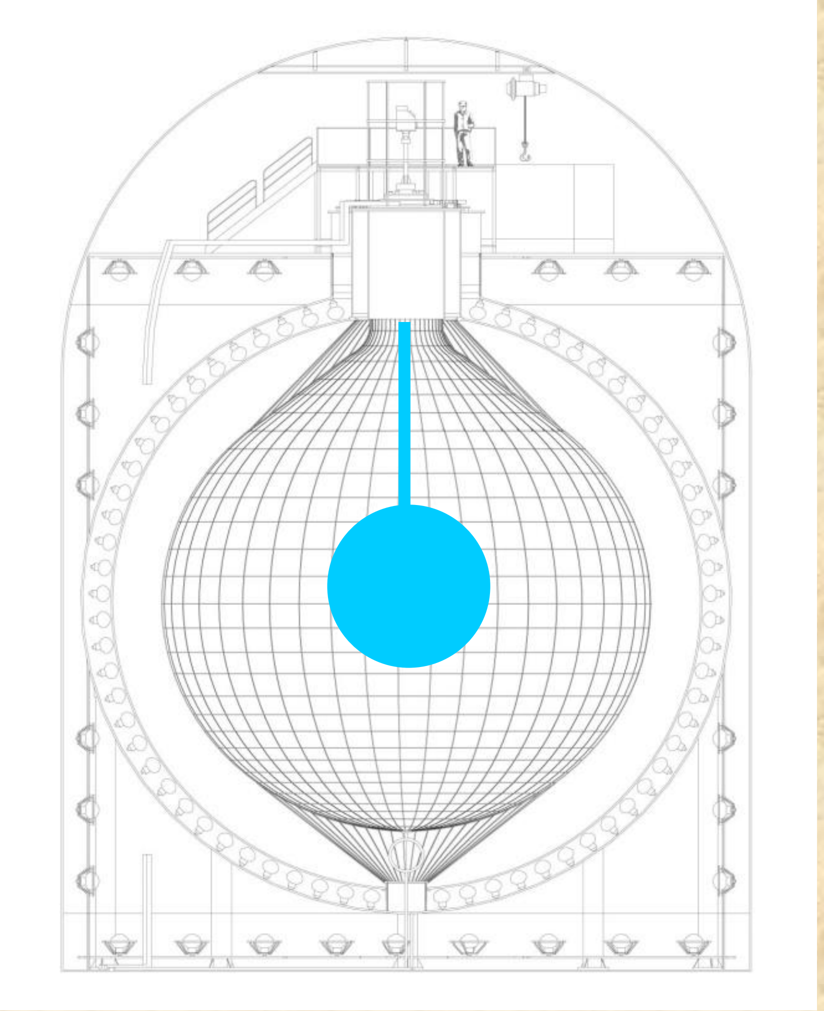
- running detector
  → relatively low cost and quick start
- huge and clean (1200m^3, U: 3.5x10^{-18} g/g, Th: 5.2x10^{-17})
  → negligible external gamma
  (Xe and mini-balloon need to be clean)
- Xe-LS can be purified, mini-balloon replaceable
  if necessary, with relatively low cost
  → highly scalable (up to several tons of Xe)
- No escape or invisible energy from β, γ
  → BG identification relatively easy
- **anti-neutrino physics continues**
  → geo-neutrino w/o Japanese reactors, waiting for SN

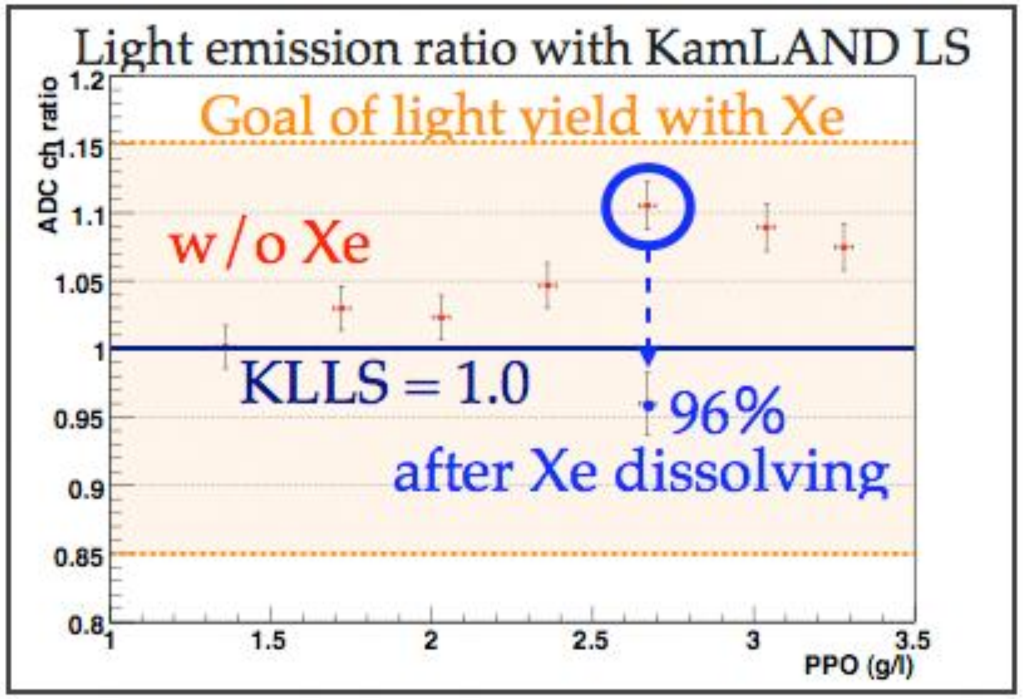
To incorporate new capabilities a few modifications/developments are necessary

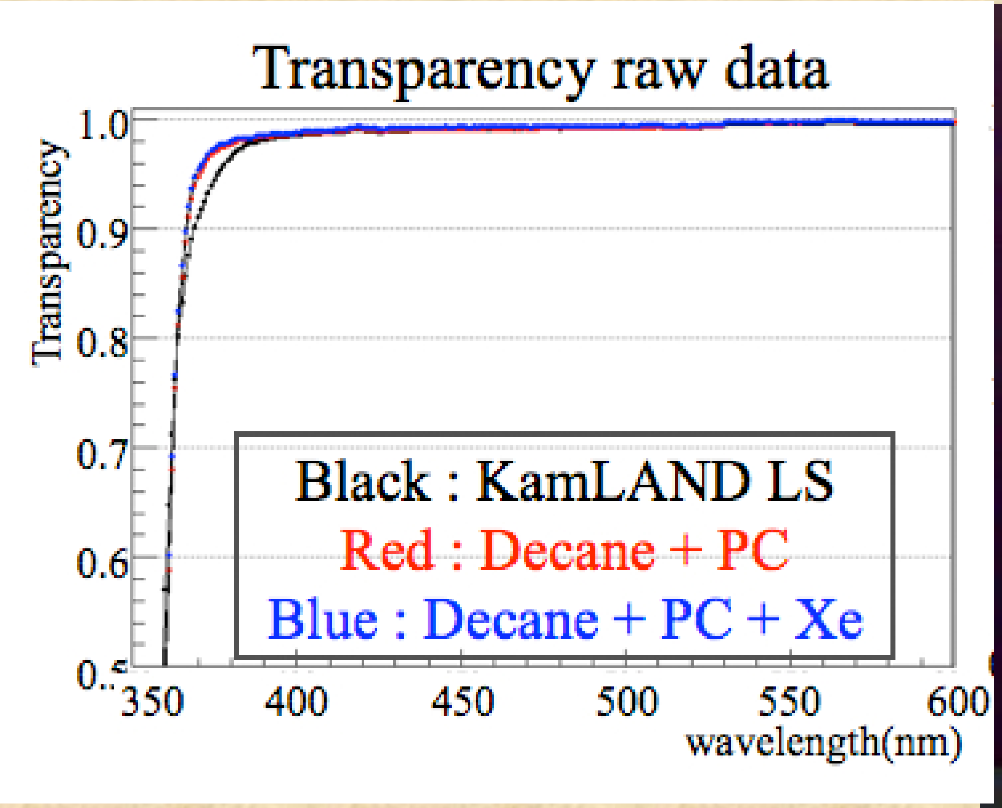
Development of Xe loaded scintillator

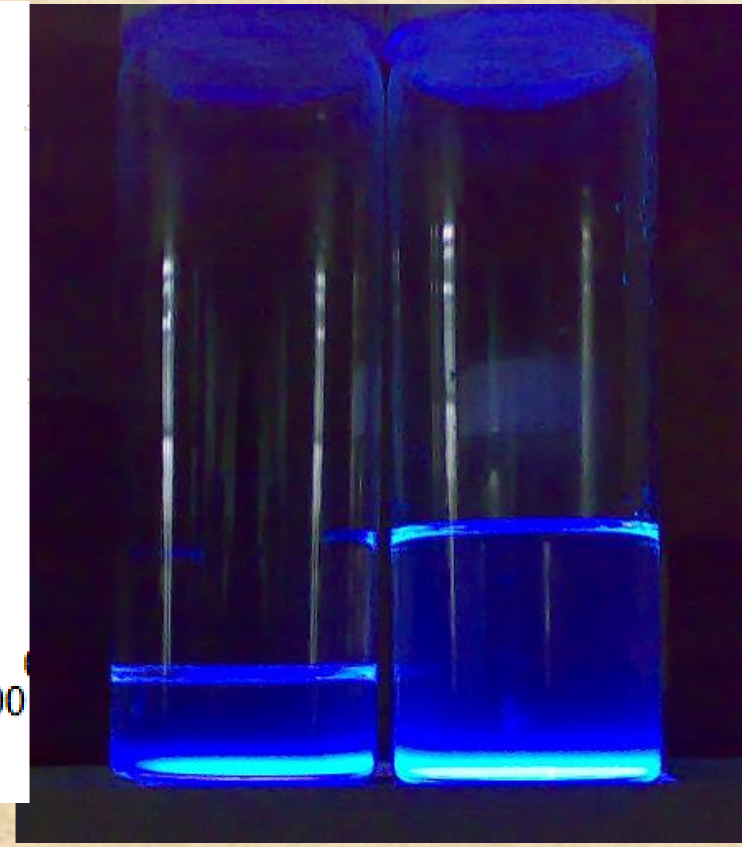
Mini Balloon is very thin so Xe loaded scintillator should have the same density as the KamLAND scintillator

Xe loaded LS		KamLAND LS
PC 17.7%	=	PC 20%
Decane 82.3%		Dodecane 80%
PPO(~2.7g/l)		PPO(1.36g/l)
Xe 3.0wt%		

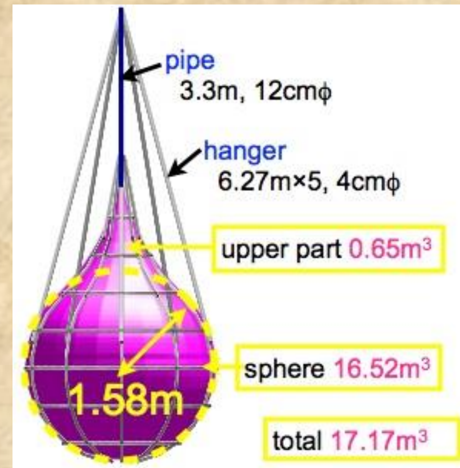




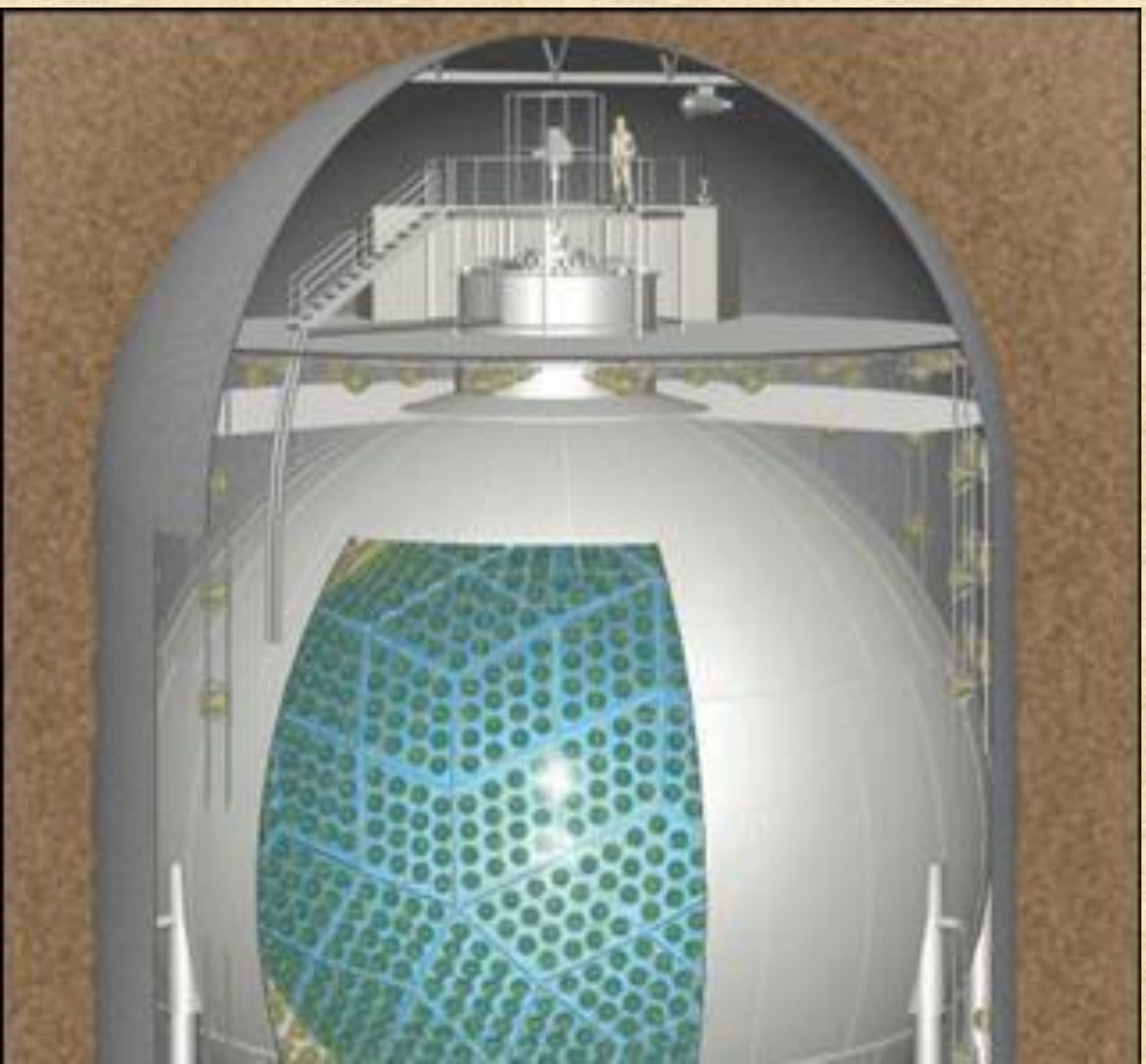




KamLAND Deck Modifications

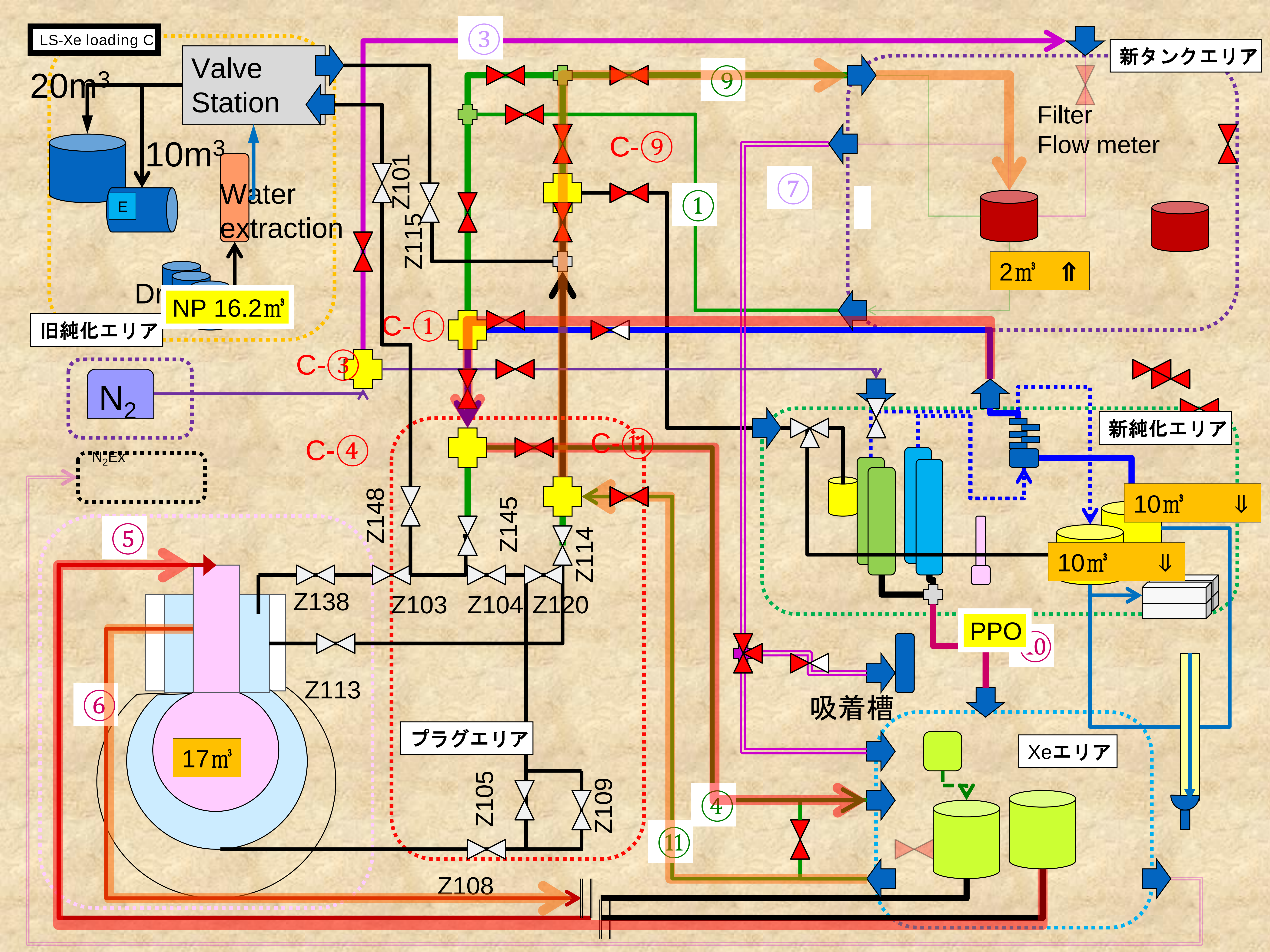


Need sy balloon



Have to build new capabilities to:

- Load scintillator with Xe.
- Push scintillator inside mini balloon
- Replace scintillator inside mini balloon with Xe loaded scintillator
- Remove and store excess of KamLAND scintillator from the outside of mini balloon
- Remove Xe loaded scintillator out of mini balloon
- Remove Xe from scintillator



LS-Xe loading C
20m3
Valve Station
10m3
E
Water extraction
Dr
NP 16.2㎥
旧純化エリア
N2
N2Ex
③
⑨
C-⑨
①
⑦
新タンクエリア
Filter
Flow meter
2㎥ ⇑
C-①
C-③
C-④
C-⑪
Z101
Z115
Z148
Z145
Z114
新純化エリア
10㎥ ⇓
10㎥ ⇓
PPO
⑤
Z138
Z103
Z104
Z120
Z113
⑥
17㎥
プラグエリア
吸着槽
Xeエリア
Z105
Z109
④
⑪
Z108

Scintillator Handling Infrastructure
new addition to the KamLAND

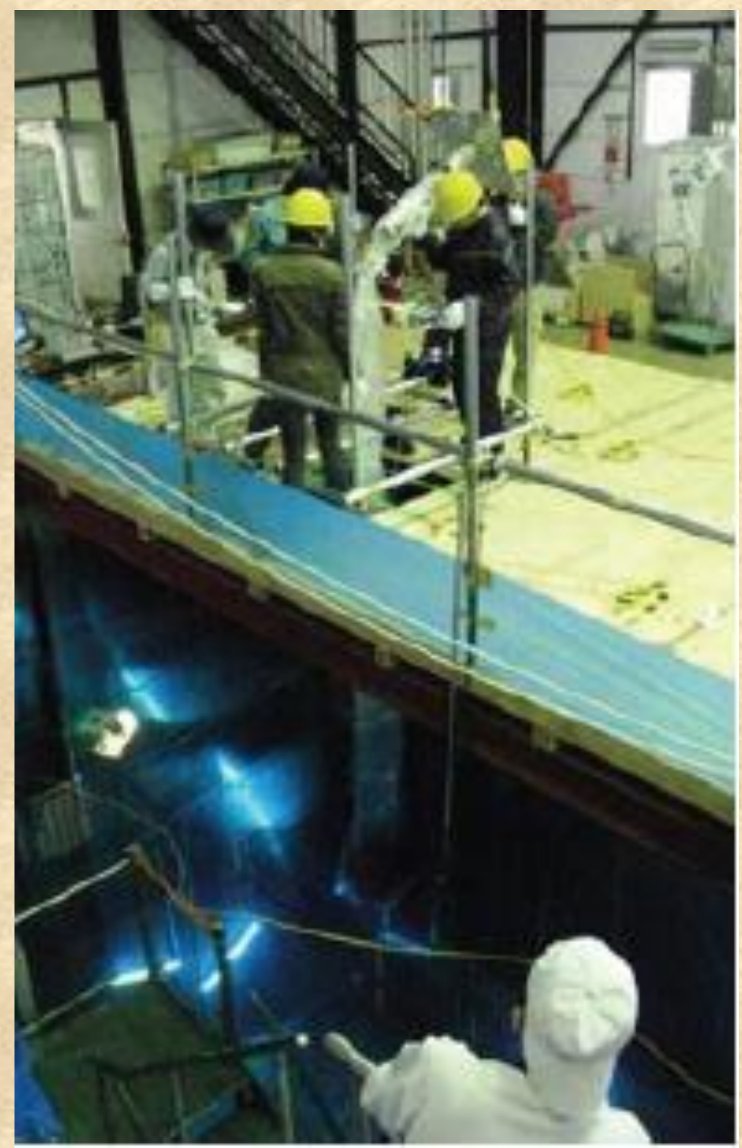
Mini Balloon. *Thickness - 25 μm*

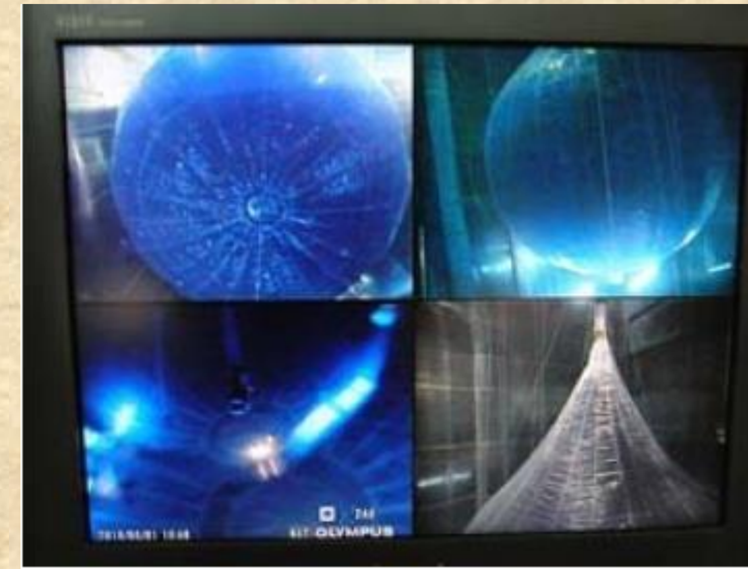
Assembly/Deployment

- Weld Balloon together, test it for a leaks.
- Fold it and wrap inside protective layer (Cocoon)
- Move to the detector site.
- Remove transportation protective layer in a clean environment
- Lower its bottom while it is folded via chimney.
- Filled it with small amount (~100 l.) of scintillator with density higher than that of KamLAND scintillator.
- Deploy it all the way, remove protective layer and straps.
- Expand it using regular liquid scintillator
- Replace regular scintillator with Xe loaded scintillator

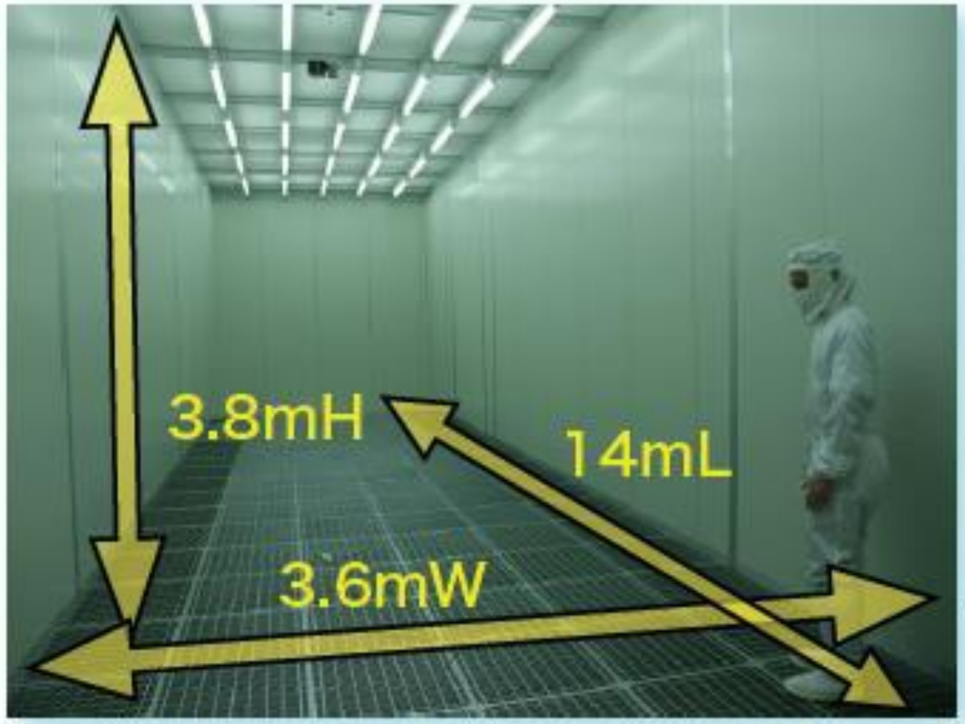
Test deployment of Mini Balloon Prototype





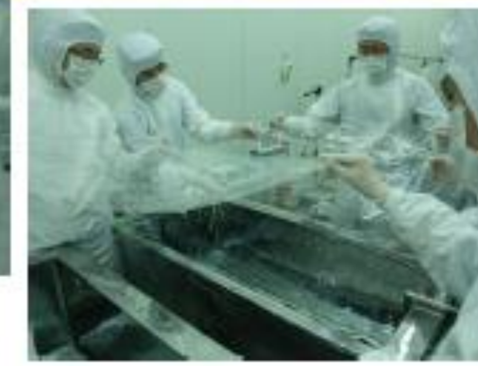


Mini-balloon fabrication in super clean room (2011.May~July)



A super-clean room in the Nishizawa center, Tohoku Univ.

Class 1 (=1 particle(>0.1μm) /feet³)



Film rinsing with ultra-pure water using an ultrasonic machine

Carefully checking films.

Welding gores by an impulse welding machine

Helium leak check

Repairing works

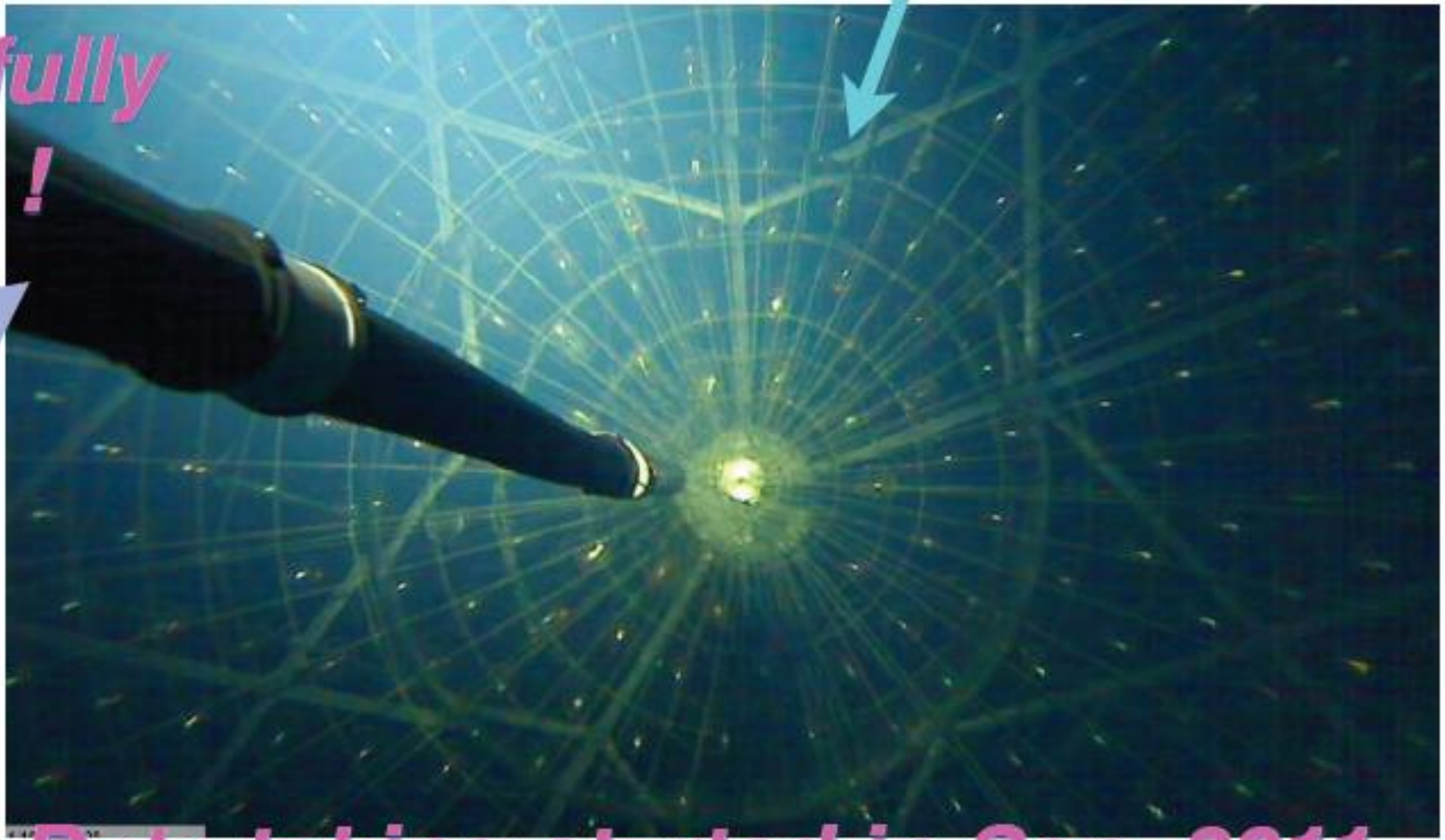
July 2011


Putting the nylon belts
Packing
Shipping to Kamioka
Kamioka in the mine
A clean tent at the KamLAND dome area
Mini-balloon into the tent
Preparation for the deployment
Monitoring camera
Camera installation
Connecting the corrugated tube

Install the mini-balloon into KamLAND (Aug.2011)

View by a monitor camera from the detector top.
The mini-balloon edge can be seen by the deformed shape of the beam in the tank.

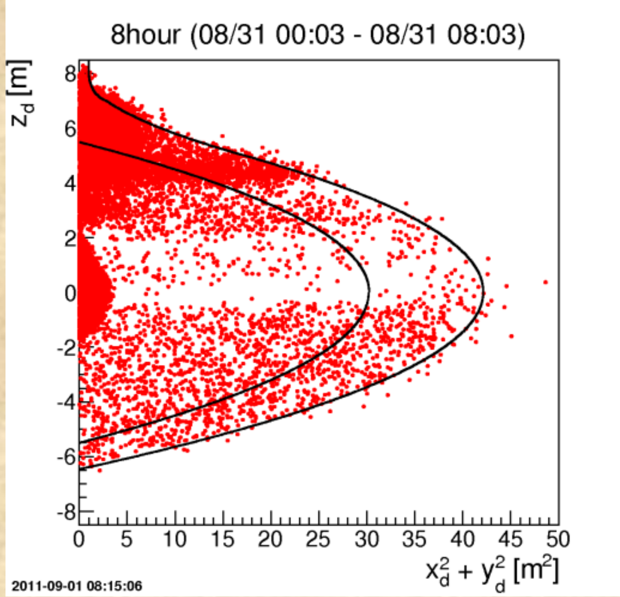
Succesfully done !

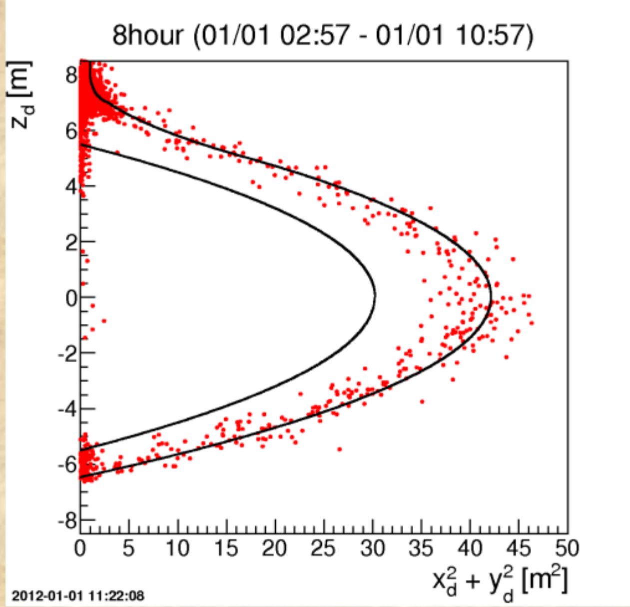


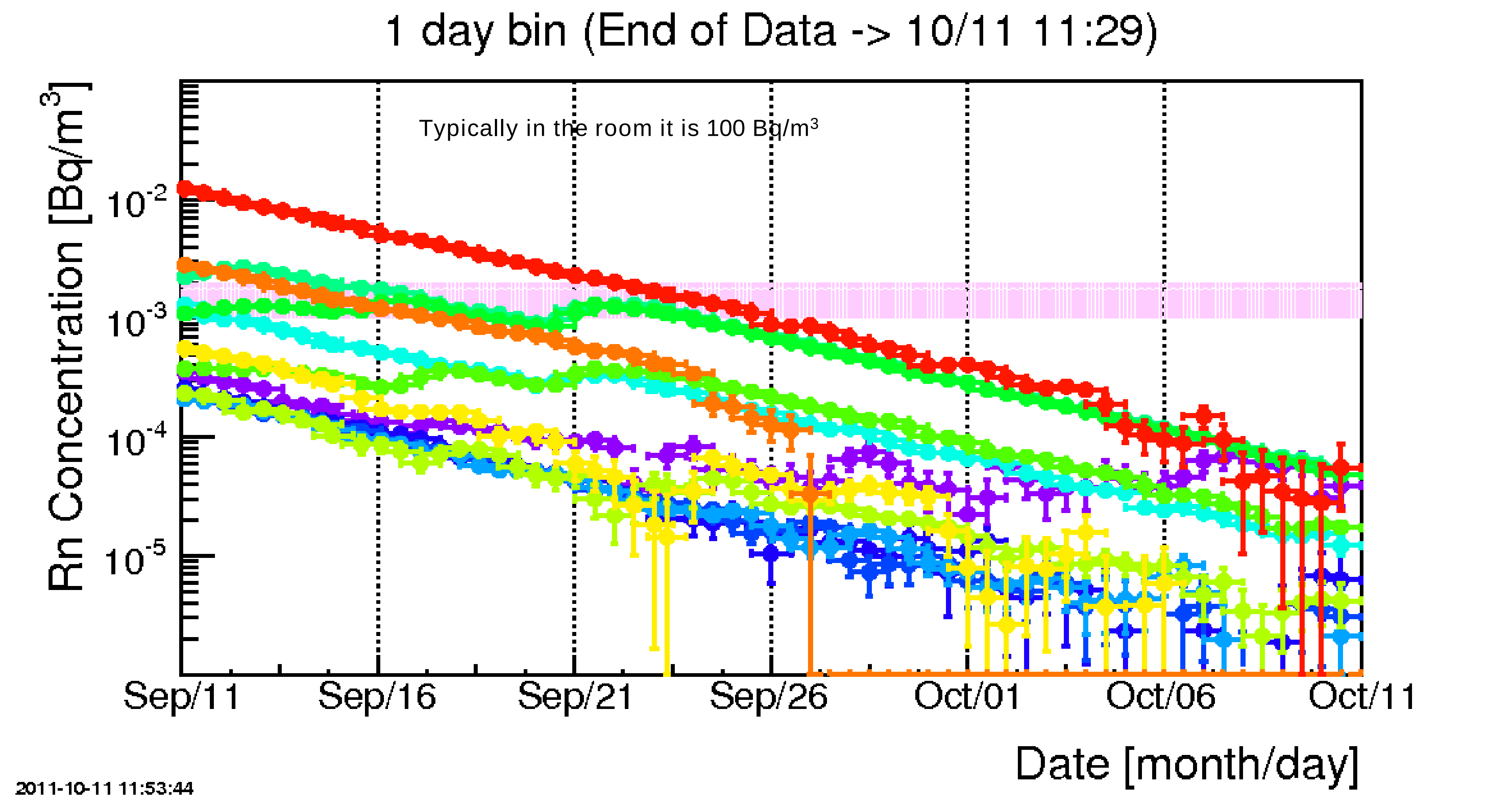
Connection pipe

Data taking started in Sep. 2011

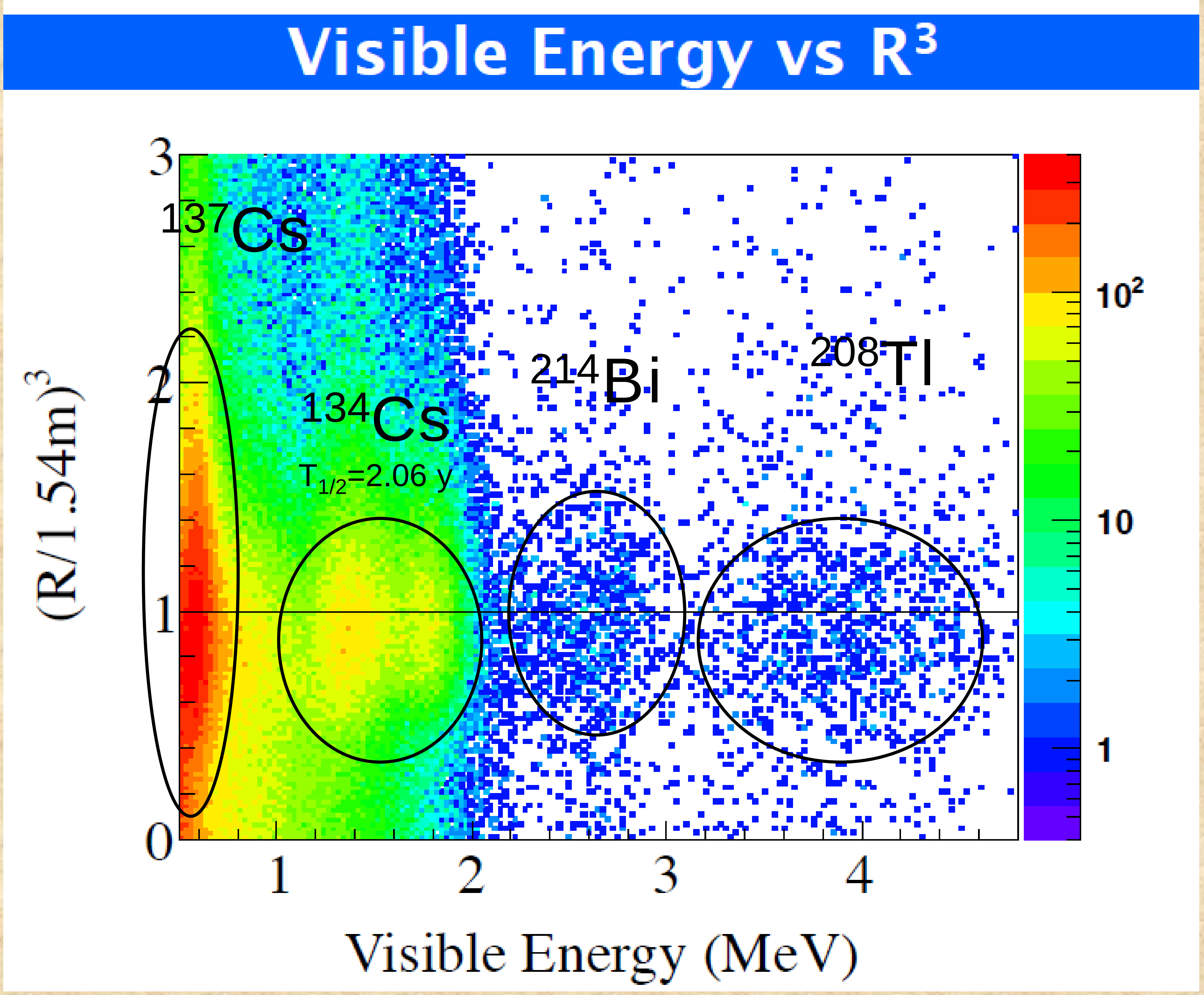
We have to wait for Radon to decay for a while







After calibration of energy and vertex reconstructions we can look into Physics



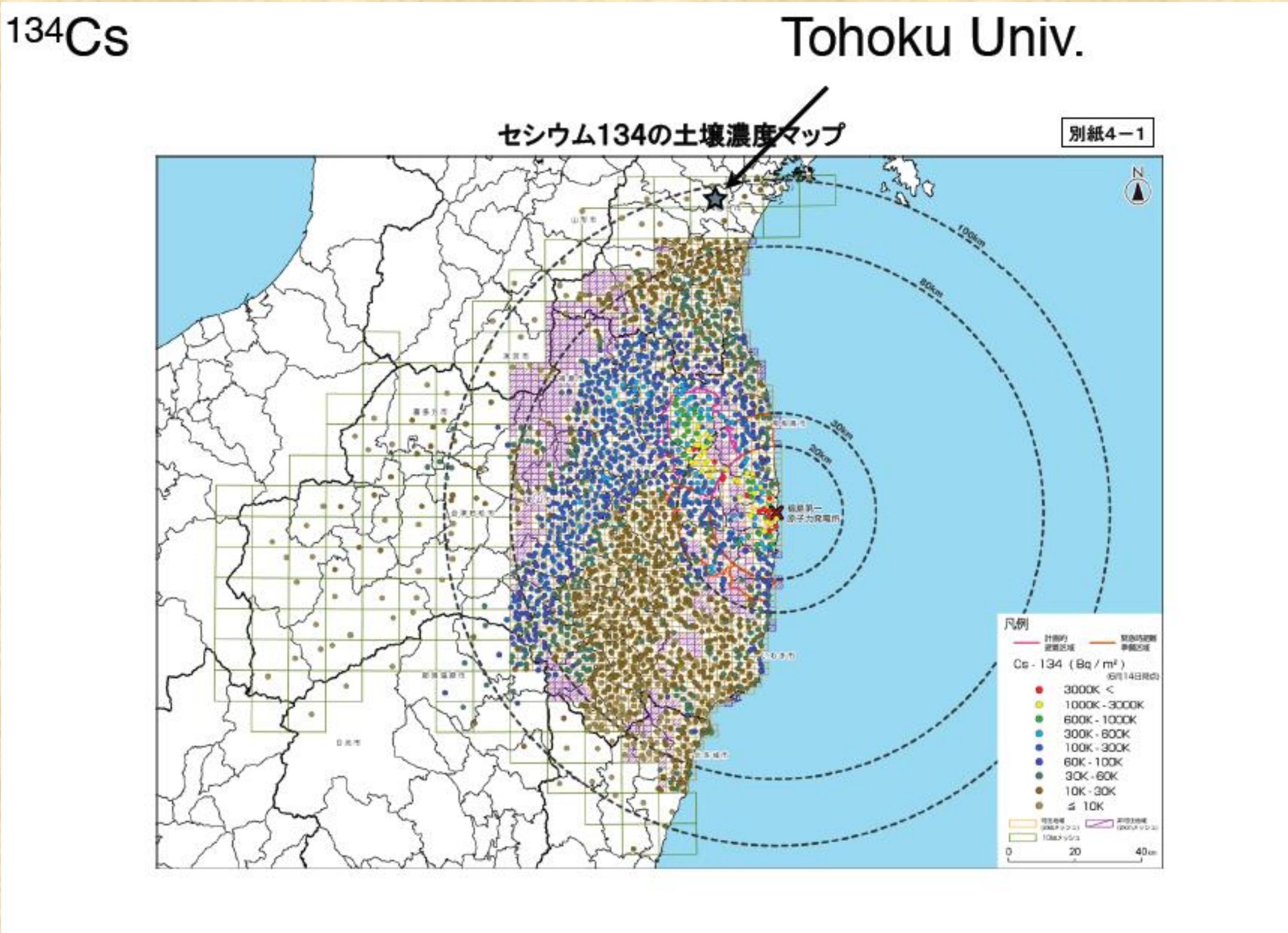
Very Unfortunate Timing

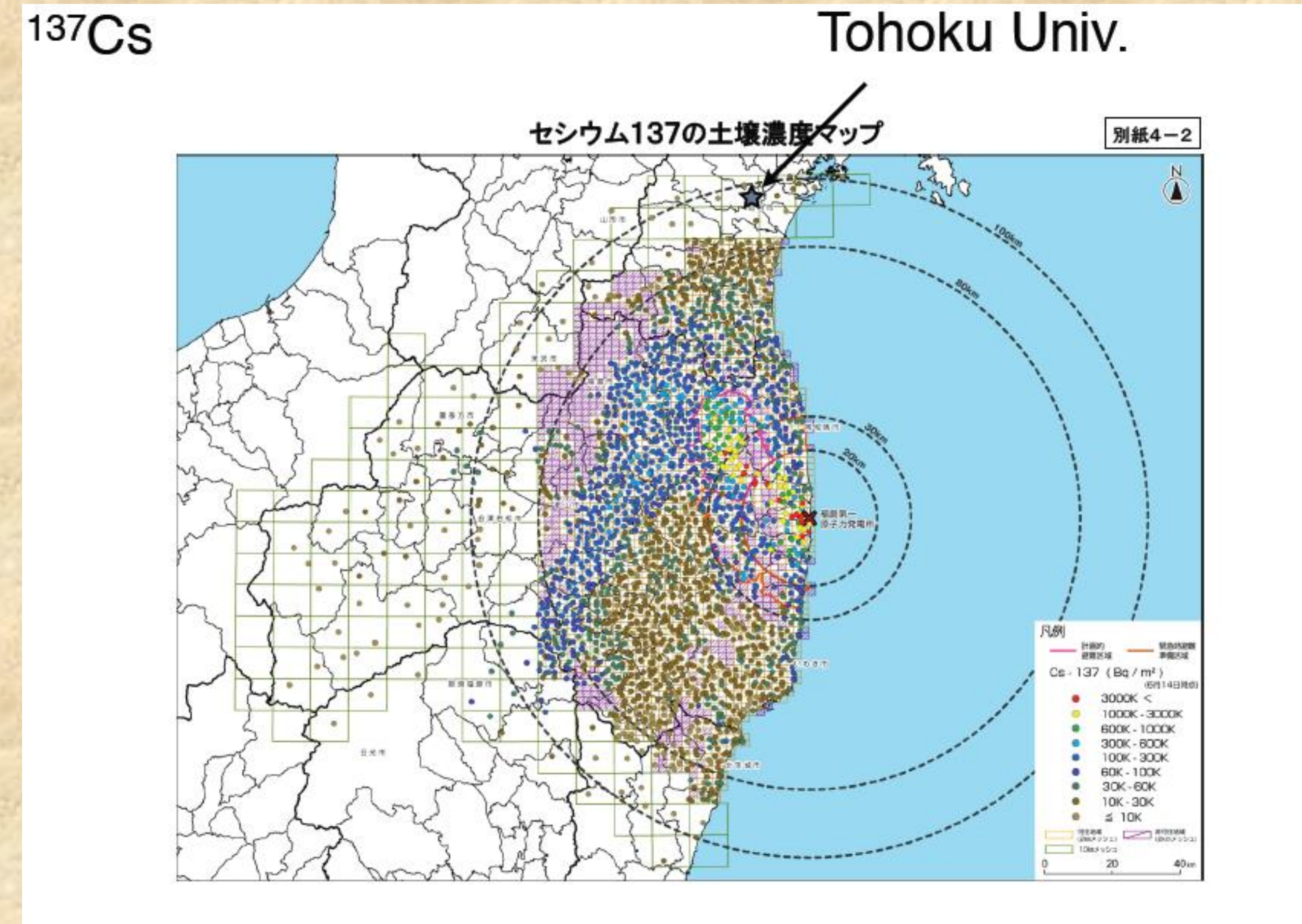
April 2011 – all materials were ready and stored at Sendai class 10 clean room to build mini balloon

May- July 2011 Balloon was build

August 2011 balloon was transported to Kamioka and deployed in the KamLAND

Cesium from Fukushima



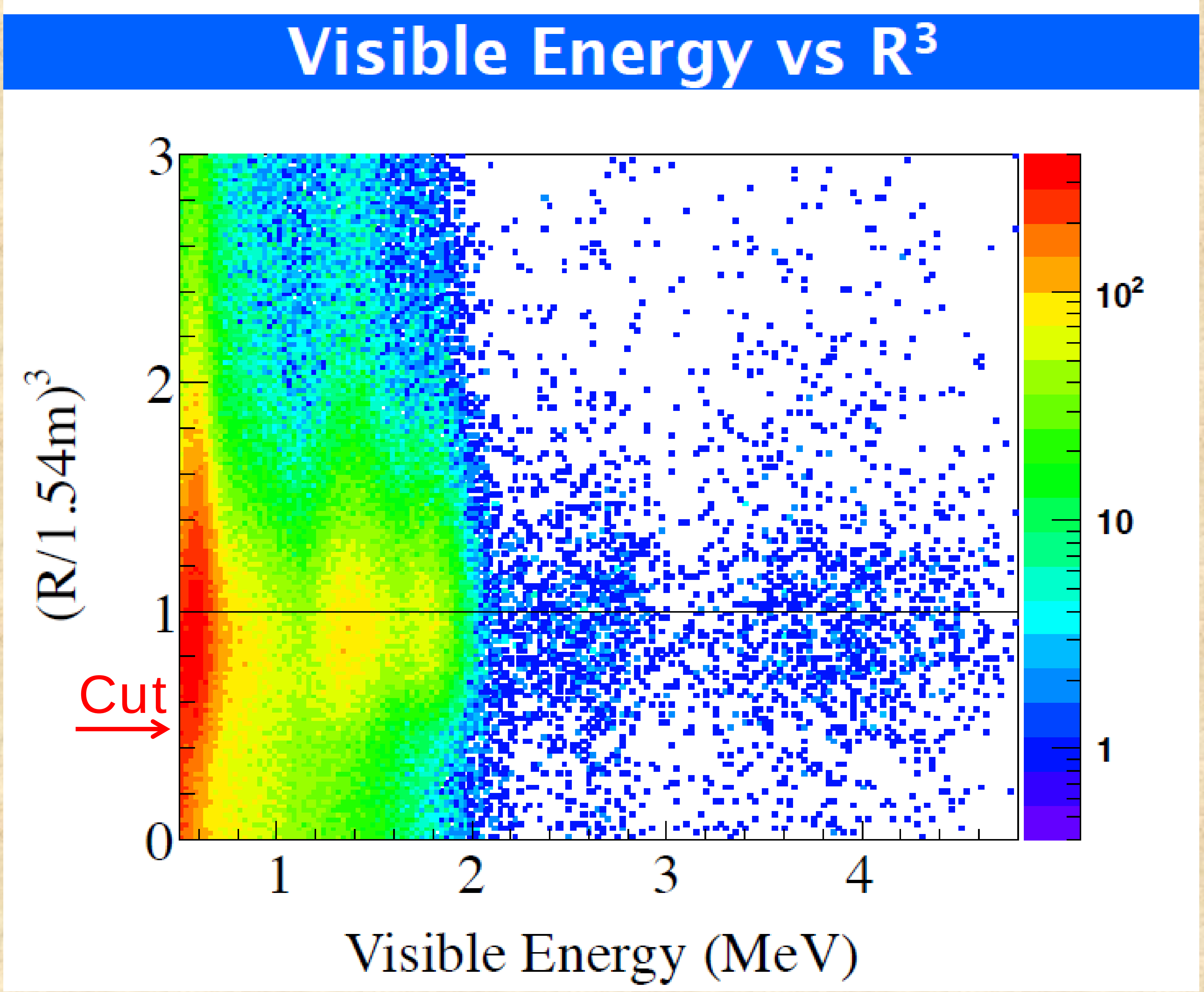


^{134}Cs $t_{1/2}$=2.07 y ^{137}Cs $t_{1/2}$=30.06 y

Ratio of two Cs isotopes in soil samples at Sendai is the same as on the mini-balloon!

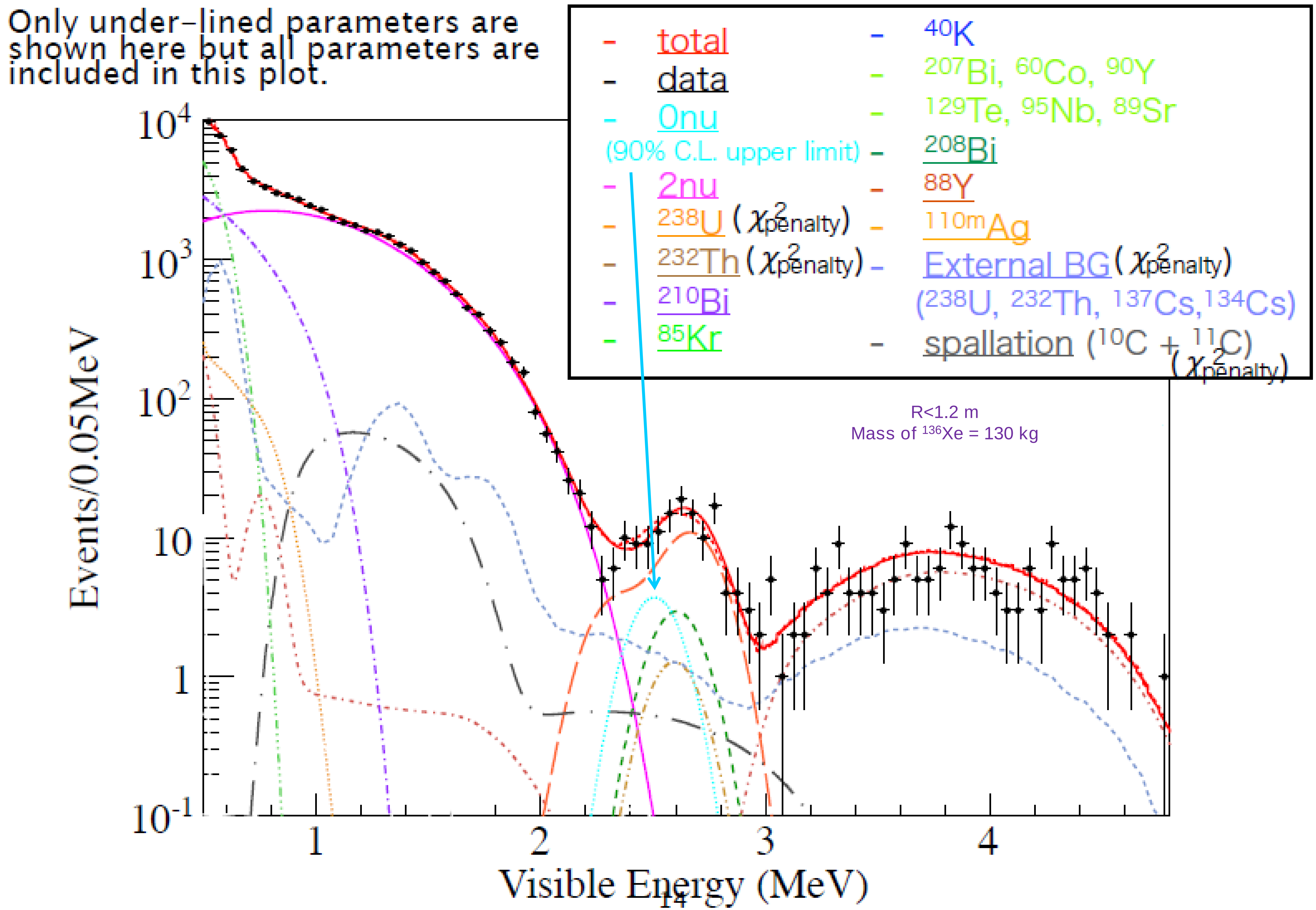
However all contamination on the balloon we can cut away by sacrificing fiducial mass

Radial Cut



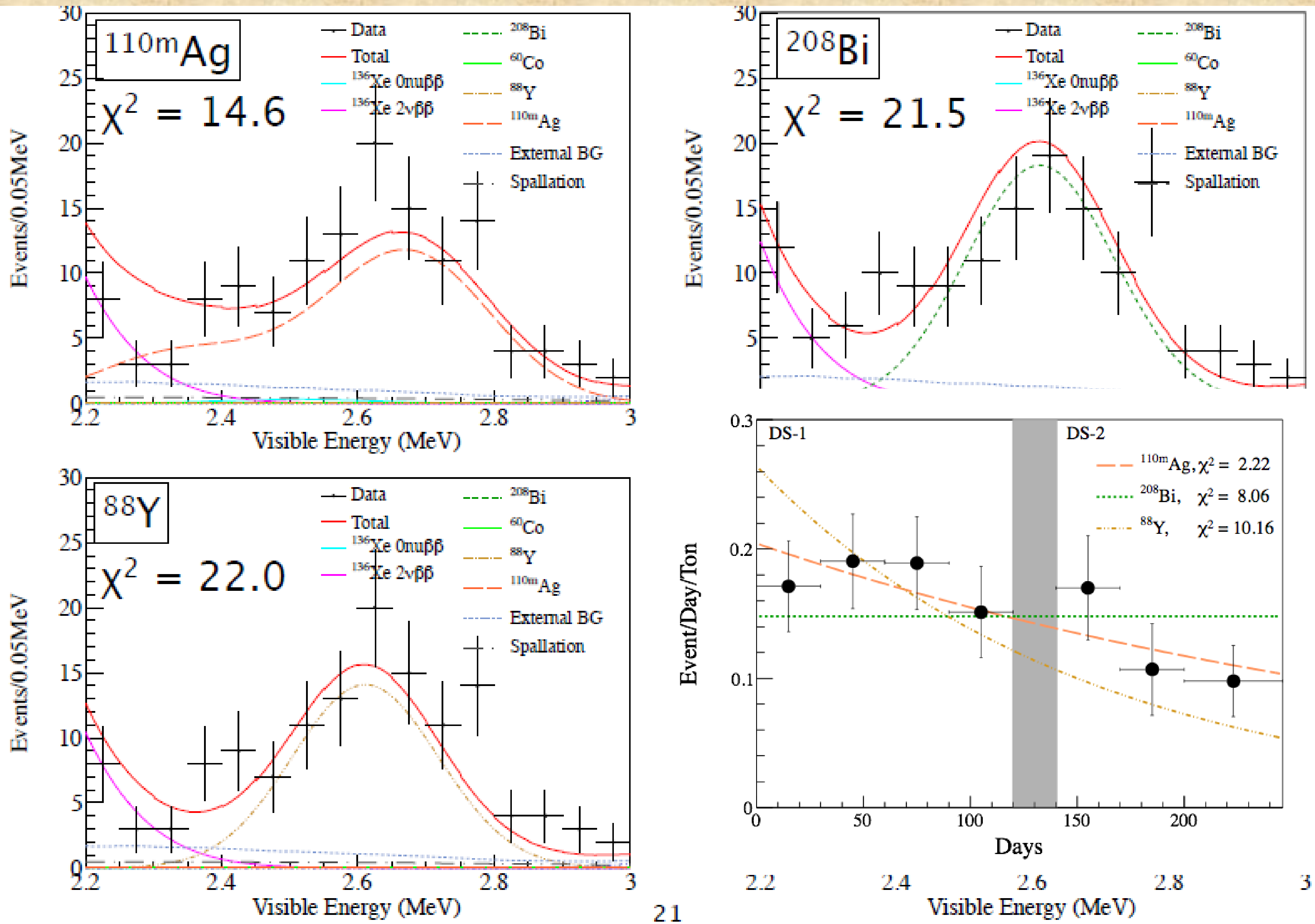
Cs contamination helps us to define mini balloon position!!!

Energy Spectrum



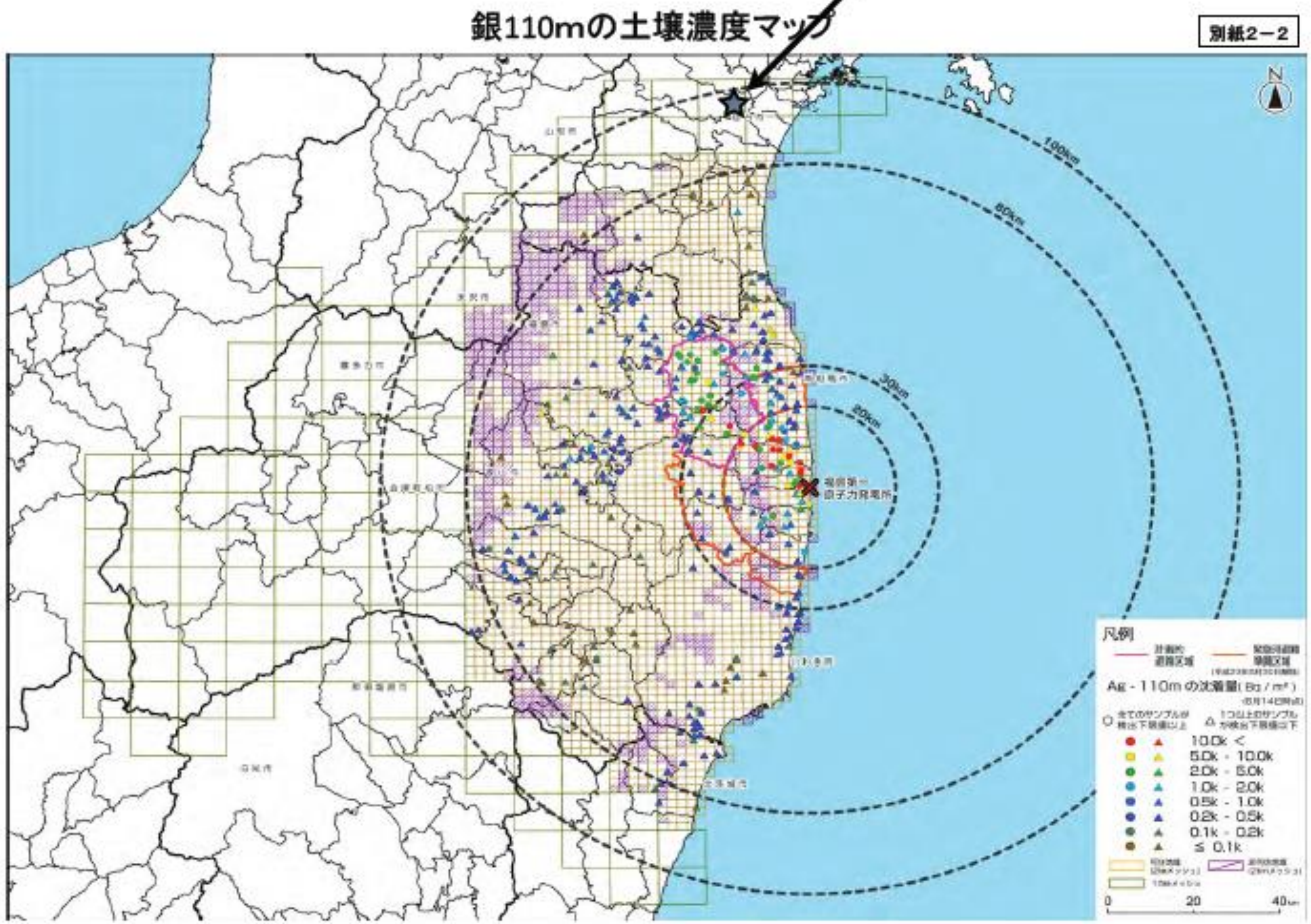
Investigating background near 2.6 MeV

KamLAND-Zen is a full energy absorption experiment. Only limited number of candidates for BG need to be checked



^{110m}Ag

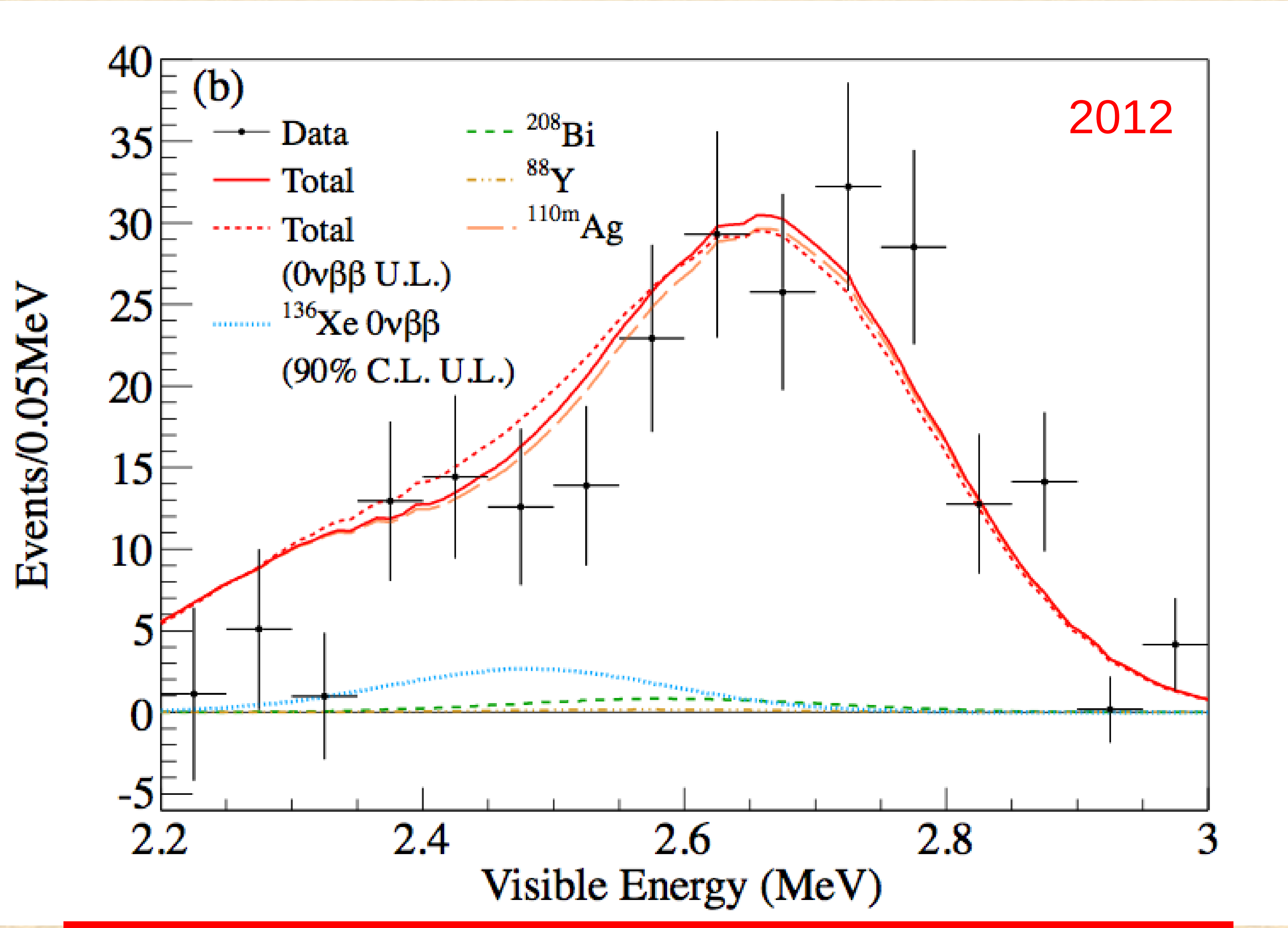
Tohoku Univ.



Total we got a few thousands atoms of ^{110m}Ag in the scintillator

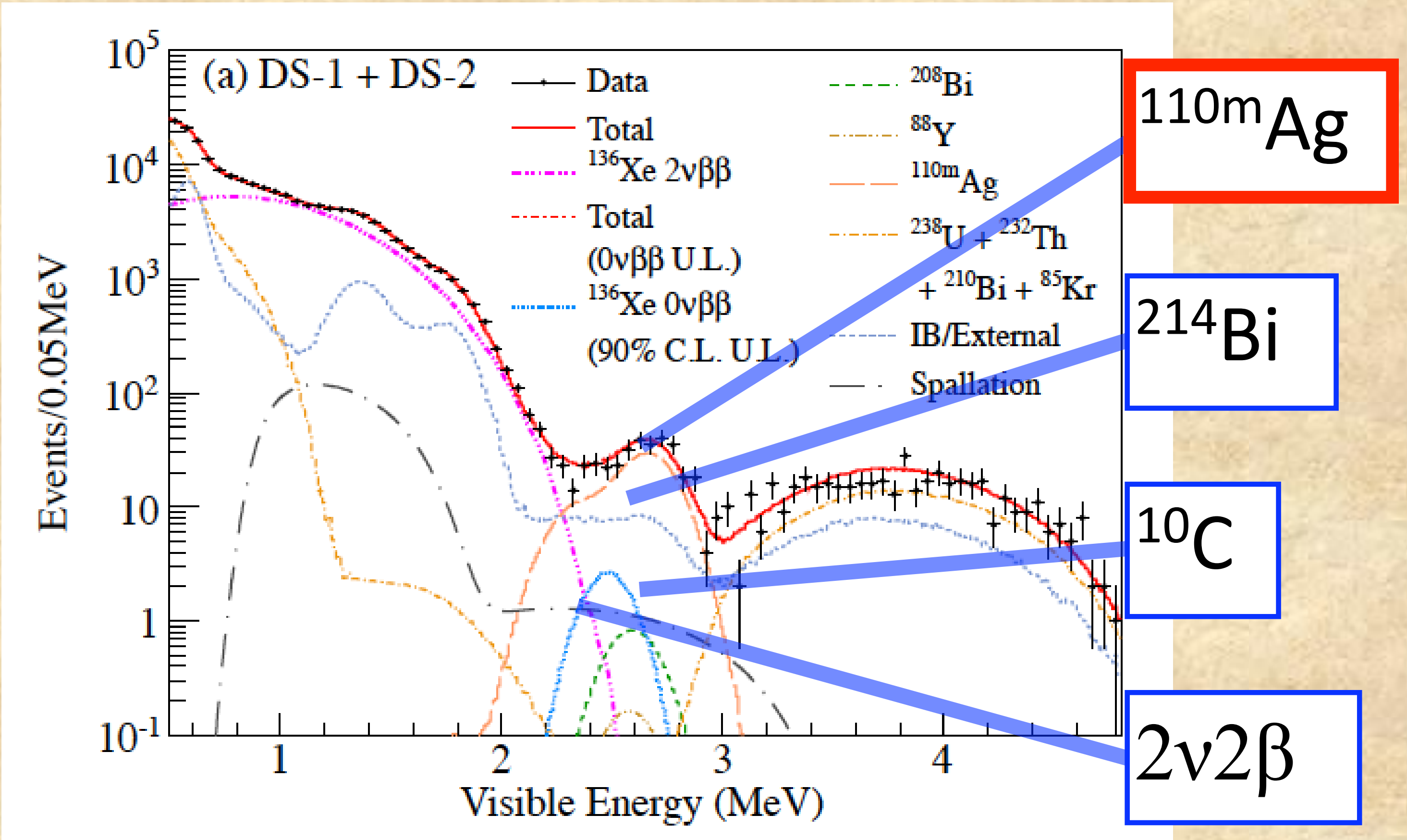
First results from KamLAND-Zen

Two years after the beginning of detector modification



$$T^{0\nu}_{1/2} > 1.9 \times 10^{25}\ \mathrm{yr} \quad (90\%\ \mathrm{C.L})$$

Path forward



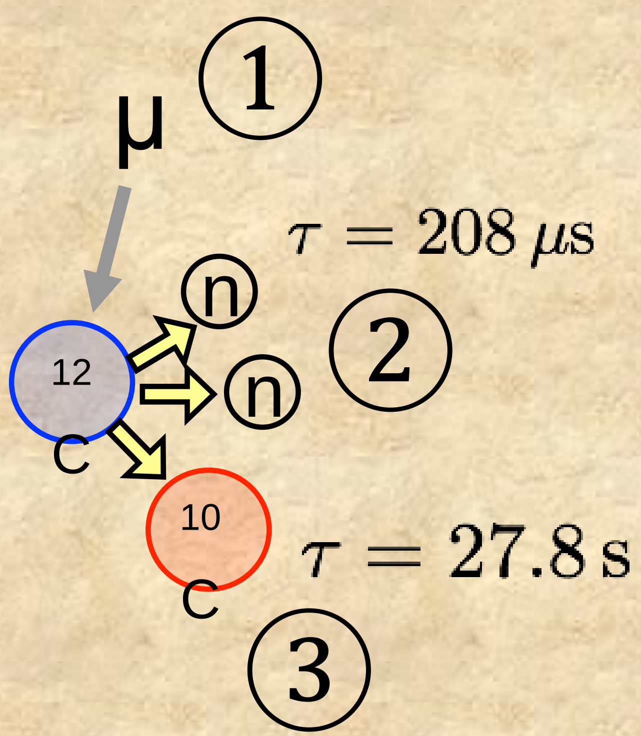
purification !!

fine binning of volume

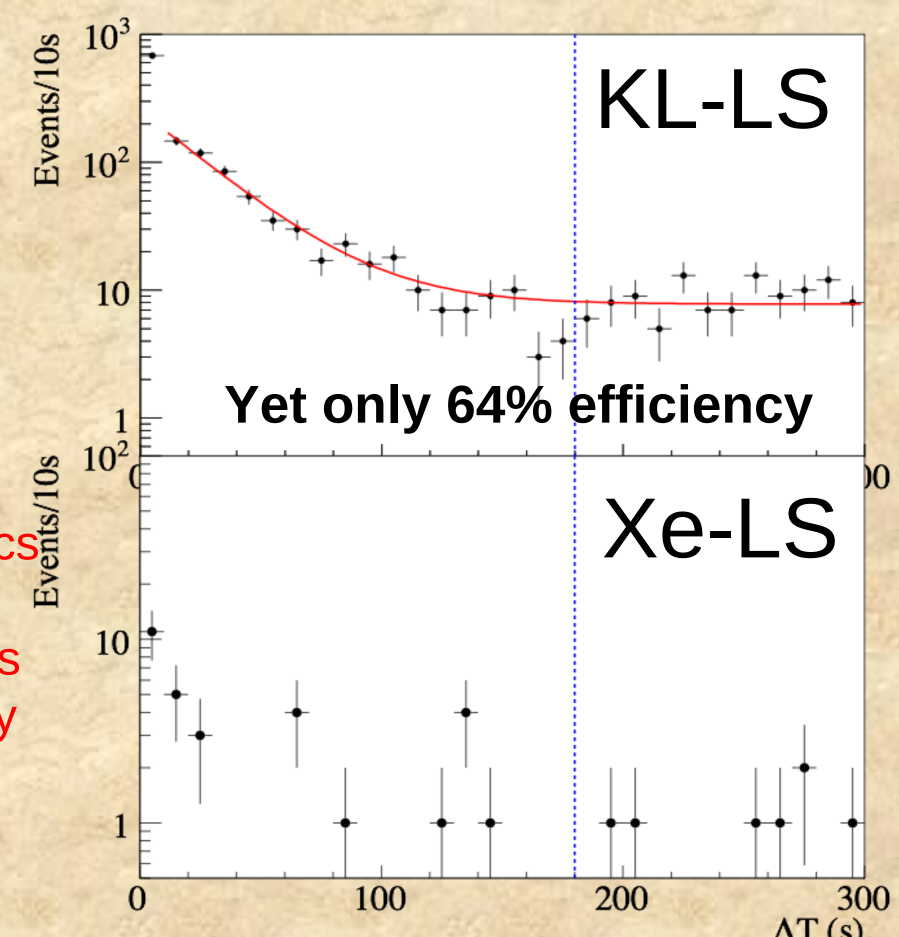
triple fold coincidence

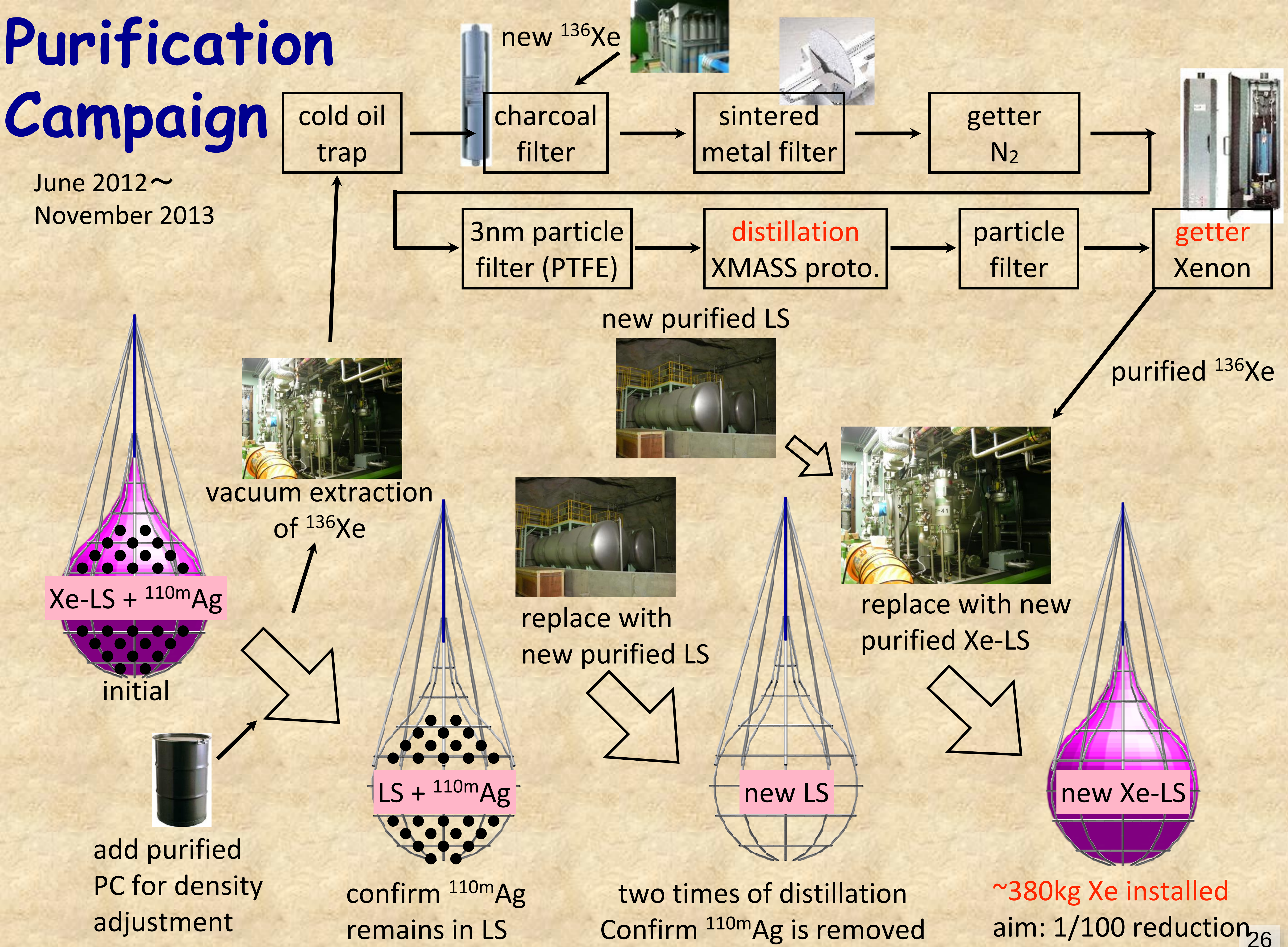
future task

tripe fold coincidence for ^{10}C rejection



dead time free electronics
MoGURA
(original electronics was
designed in last century

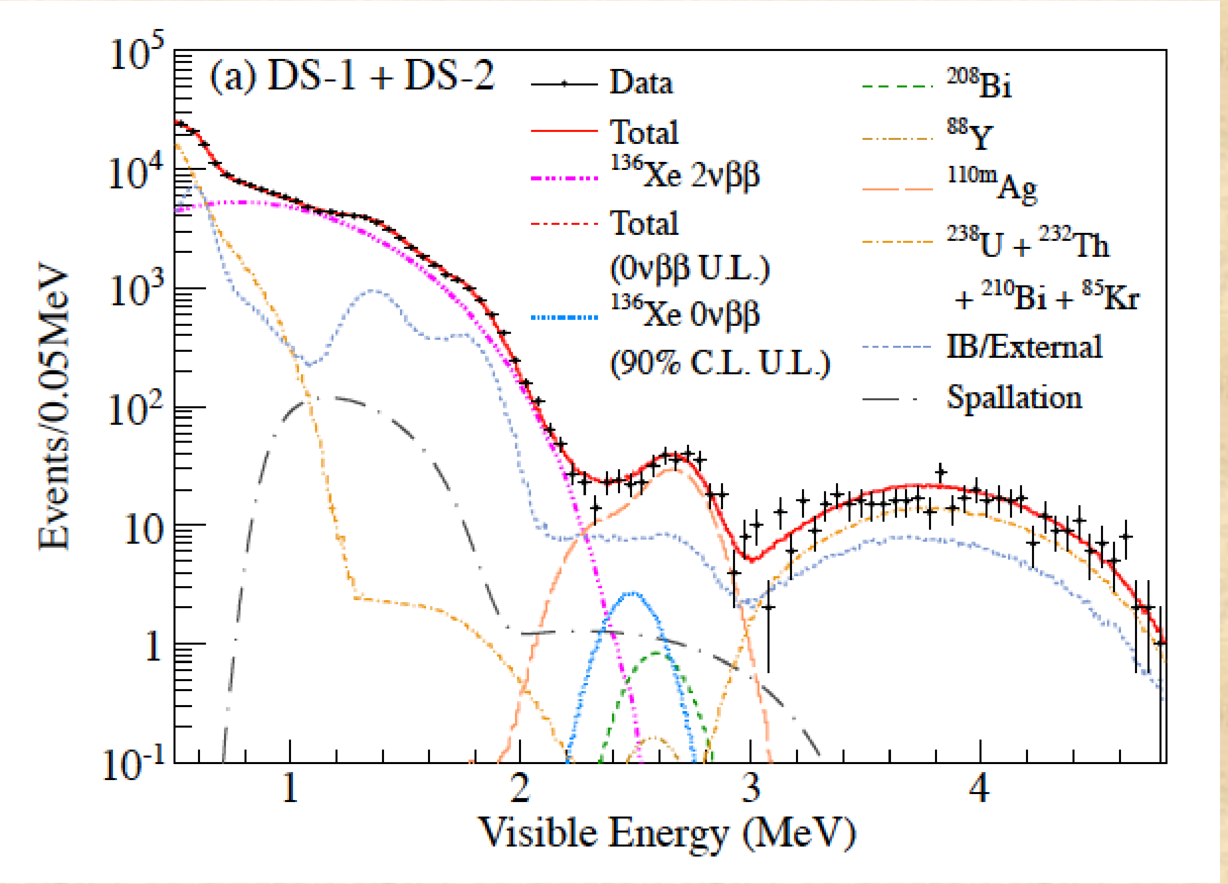



Purification Campaign
June 2012～
November 2013
new ¹³⁶Xe
cold oil trap
charcoal filter
sintered metal filter
getter N₂
3nm particle filter (PTFE)
distillation XMASS proto.
particle filter
getter Xenon
new purified LS
purified ¹³⁶Xe
vacuum extraction of ¹³⁶Xe
Xe-LS + 110mAg
initial
add purified PC for density adjustment
LS + 110mAg
confirm 110mAg remains in LS
replace with new purified LS
new LS
two times of distillation
Confirm 110mAg is removed
replace with new purified Xe-LS
new Xe-LS
~380kg Xe installed
aim: 1/100 reduction

B.G. improvements after purification

Phase-1 320kg

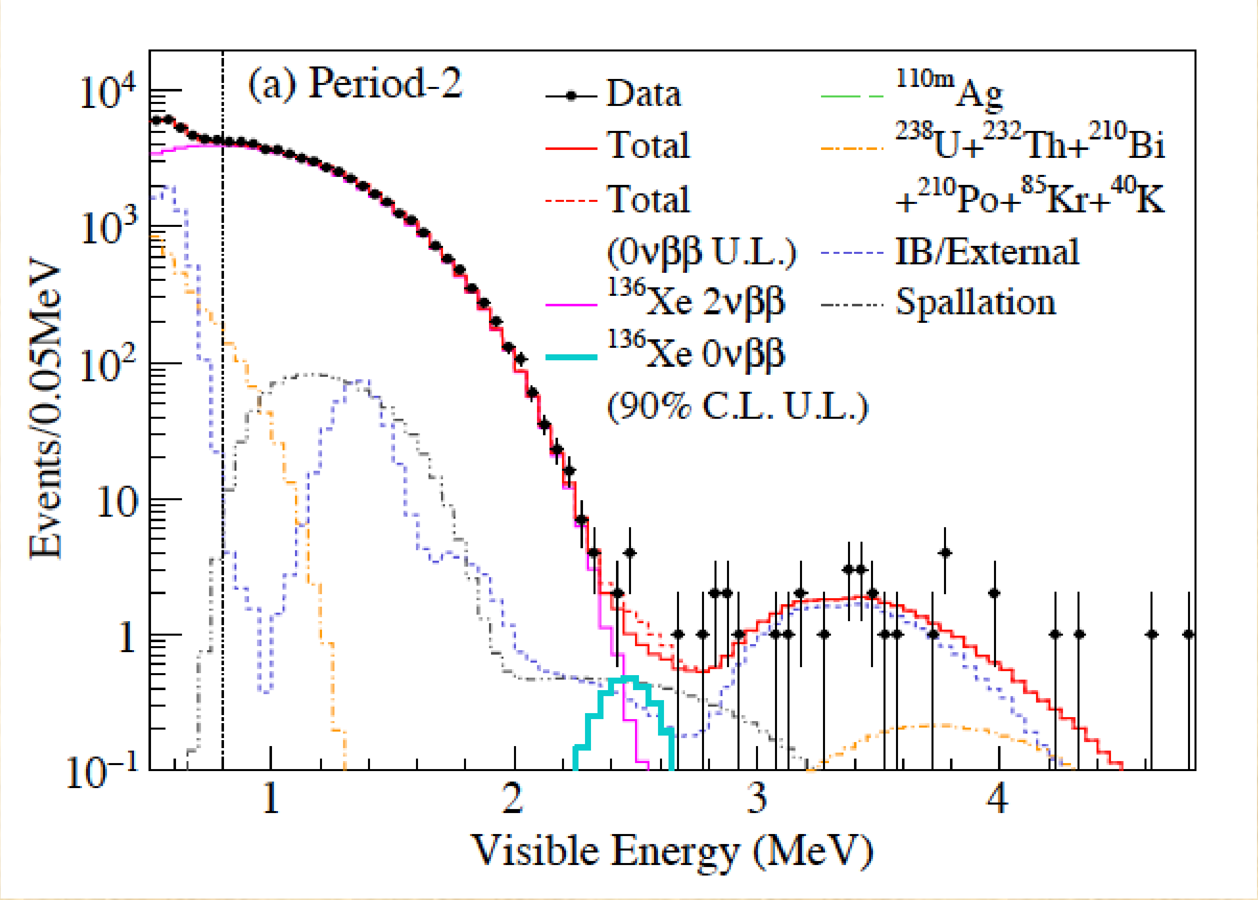
before purification



in-situ purification possible!!

Phase-2 380kg

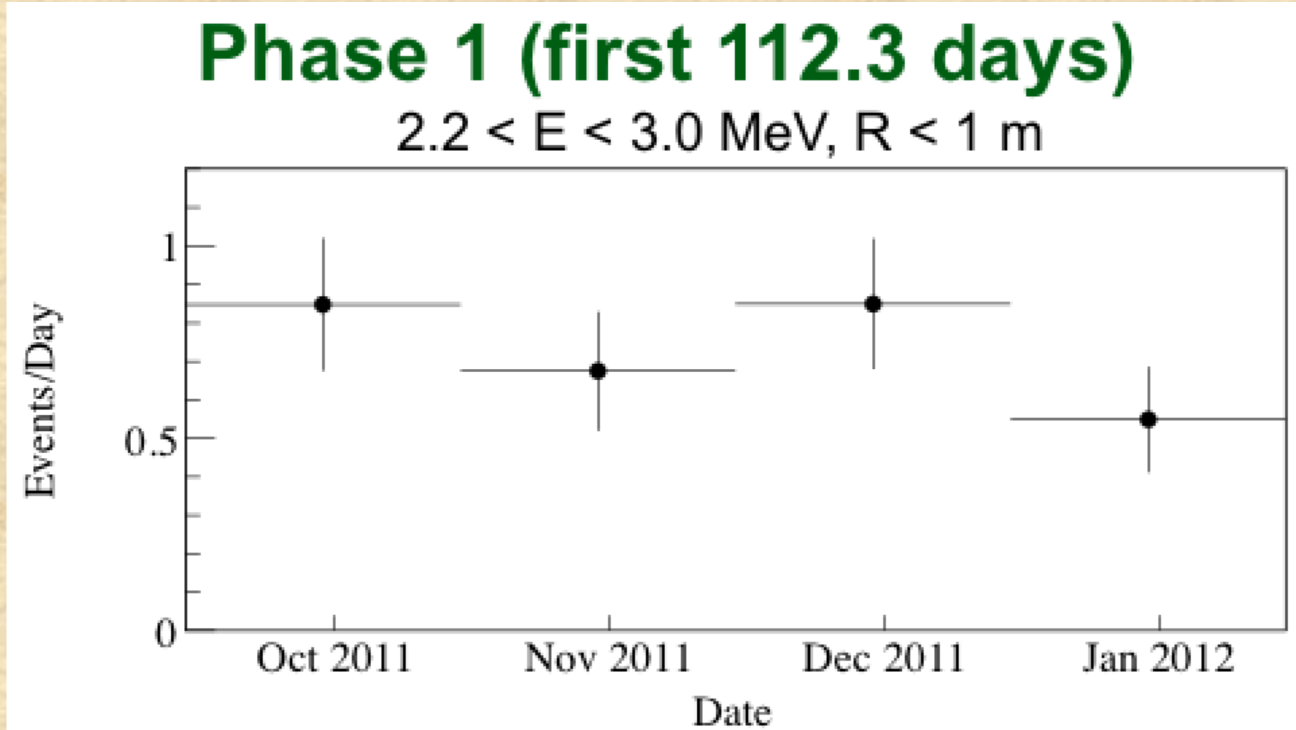
after purification



2013/12/11 - 2014/10/27
534.5 days (504 kg-yr)

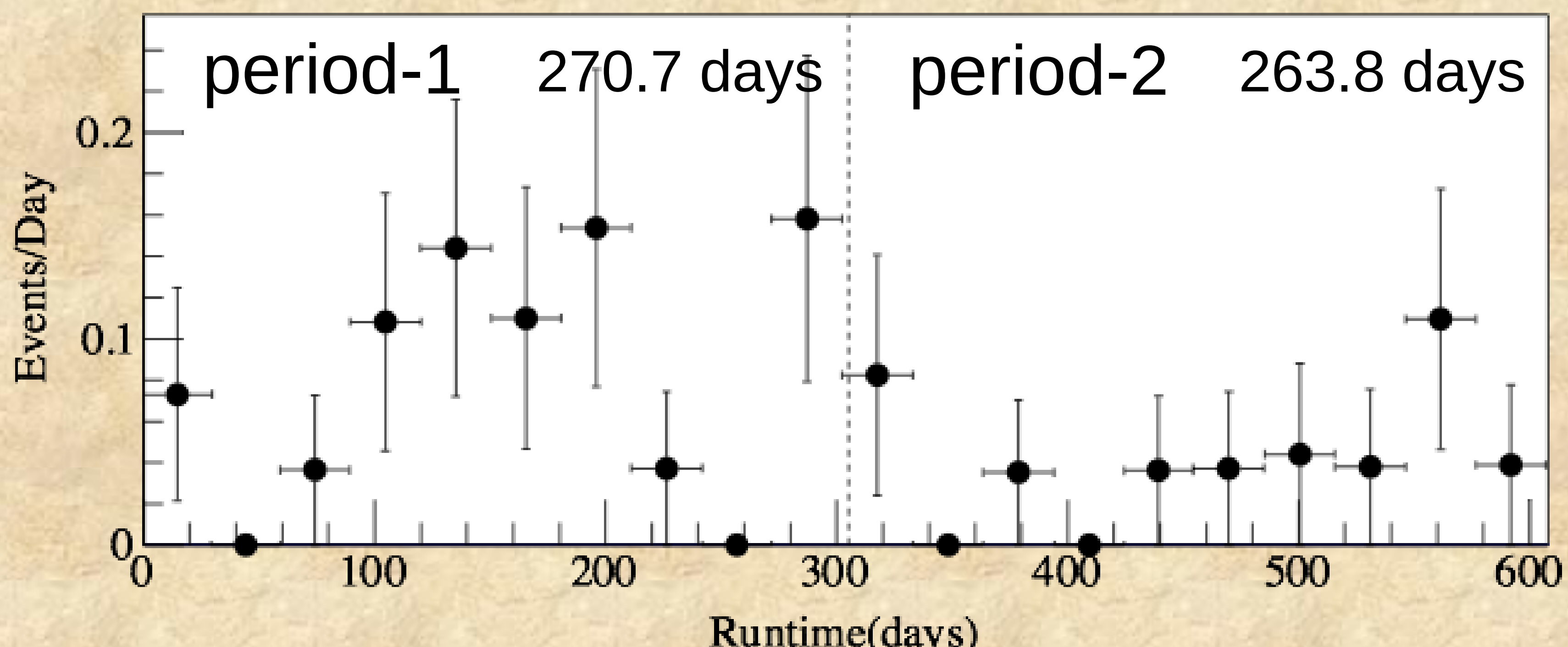
(cf. $T_{1/2}(^{110m}Ag)$=250 days)

Event rates at R.O.I.



Phase 2 534.5 days

2.3 < E < 2.7 MeV, R < 1 m



22 events **11 events**

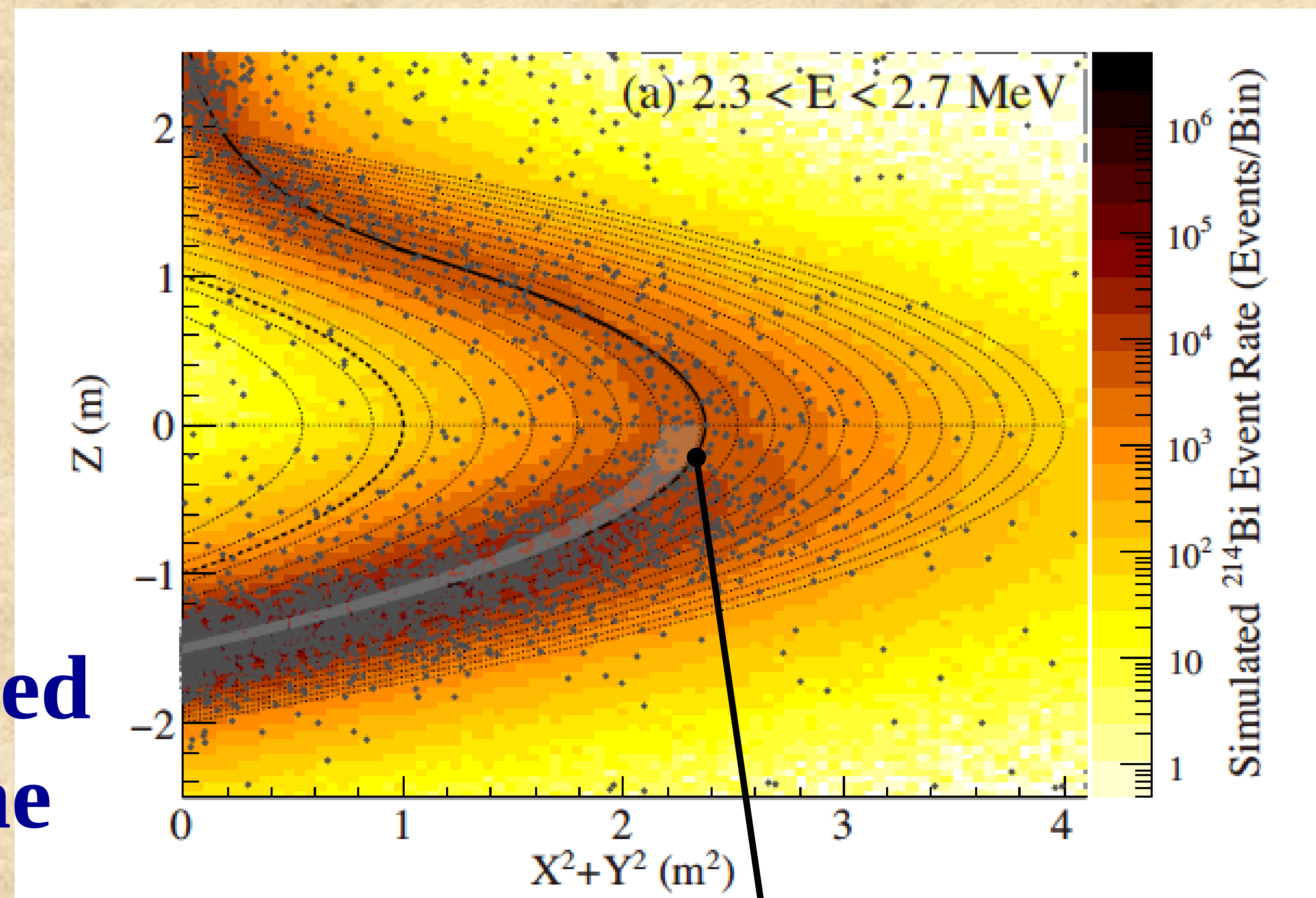
A hypothesis: "Dust" sank !?

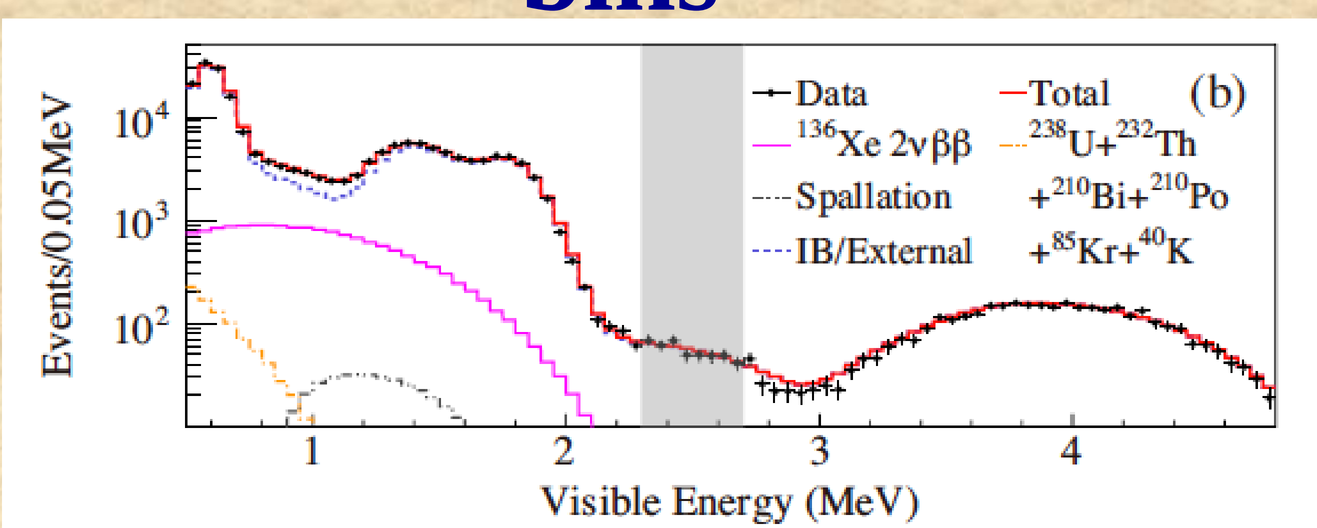
Yet only ~2σ discrepancy from the simple decay

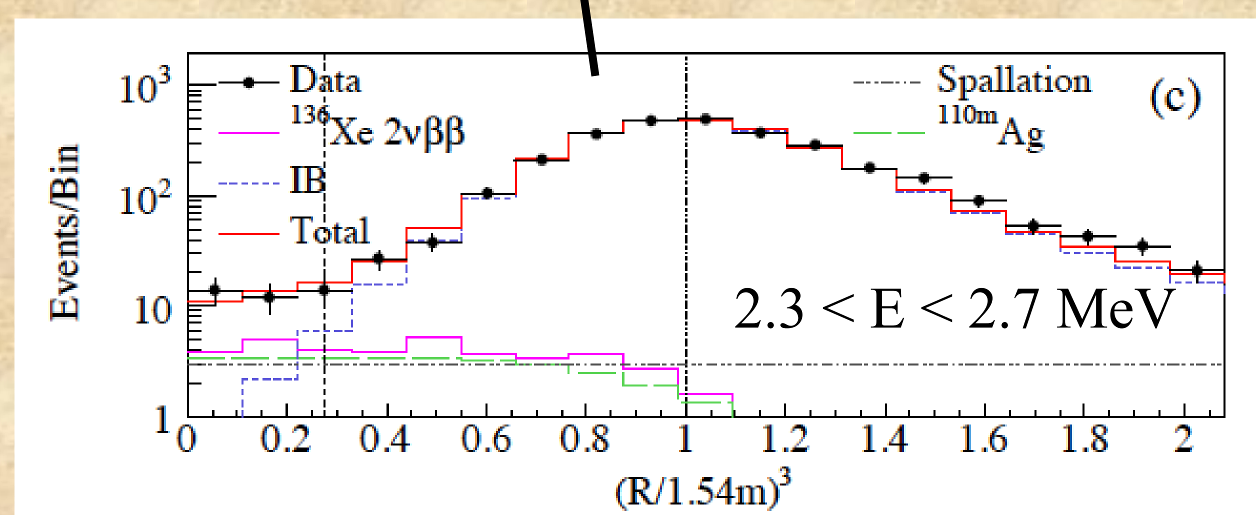
New data set analysis

In order to improve the sensitivity, we have performed all volume and time-binned analysis.

Xe volume was divided into 40 equal-volume bins







Energy and radial distributions are well-reproduced by known BGs.

Some details about individual contributions

	Period-1 (270.7 days)		Period-2 (263.8 days)	
Observed events	22		11	
Background	Estimated	Best-fit	Estimated	Best-fit
^{136}Xe $2\nu\beta\beta$	...	5.48	...	5.29
Residual radioactivity in Xe-LS				
^{214}Bi (^{238}U series)	0.23 ± 0.04	0.25	0.028 ± 0.005	0.03
^{208}Tl (^{232}Th series)	...	0.001	...	0.001
^{110m}Ag	...	8.5	...	0.0
External (Radioactivity in IB)				
^{214}Bi (^{238}U series)	...	2.56	...	2.45
^{208}Tl (^{232}Th series)	...	0.02	...	0.03
^{110m}Ag	...	0.003	...	0.002
Spallation products				
^{10}C	2.7 ± 0.7	3.3	2.6 ± 0.7	2.8
^{6}He	0.07 ± 0.18	0.08	0.07 ± 0.18	0.08
^{12}B	0.15 ± 0.04	0.16	0.14 ± 0.04	0.15
^{137}Xe	0.5 ± 0.2	0.5	0.5 ± 0.2	0.4

Summary for $2.3 < E < 2.7$ MeV, $R < 1$ m

Results on 0ν2β from the second phase

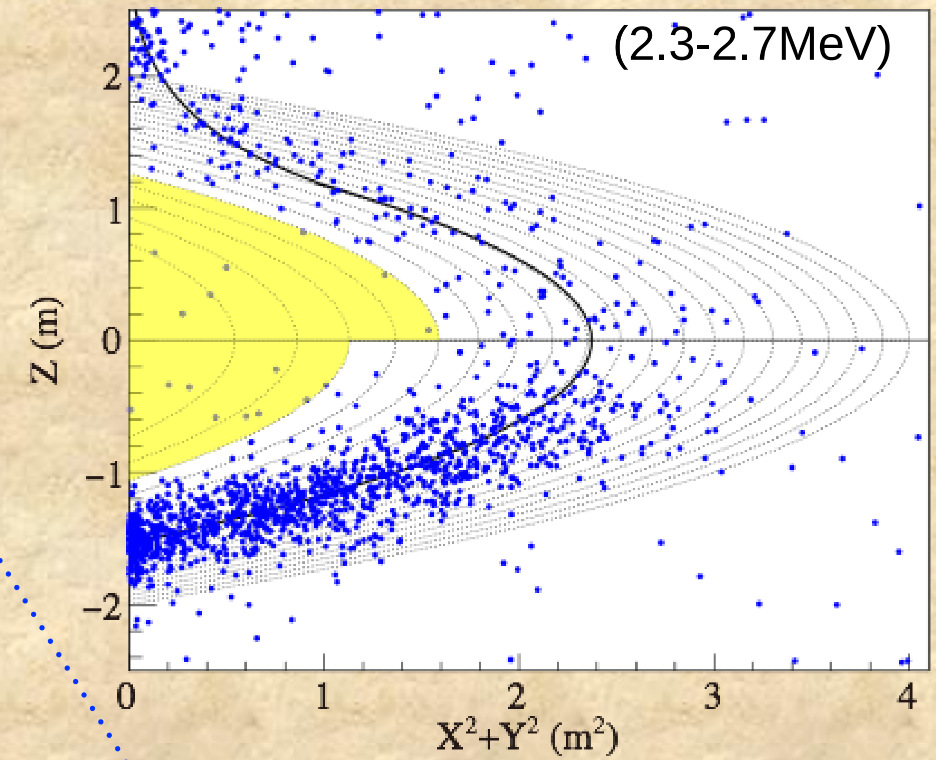
	period-1	period-2
livetime	270.7 days	263.8 days
^{136}Xe 0ν2β decay rate	< 5.5 /kton/day	< 3.4 /kton/day

combined < 2.4 /kton/day (90%C.L.)

^{136}Xe 0ν2β half-life > 9.2×10^{25} yr (90%C.L.)

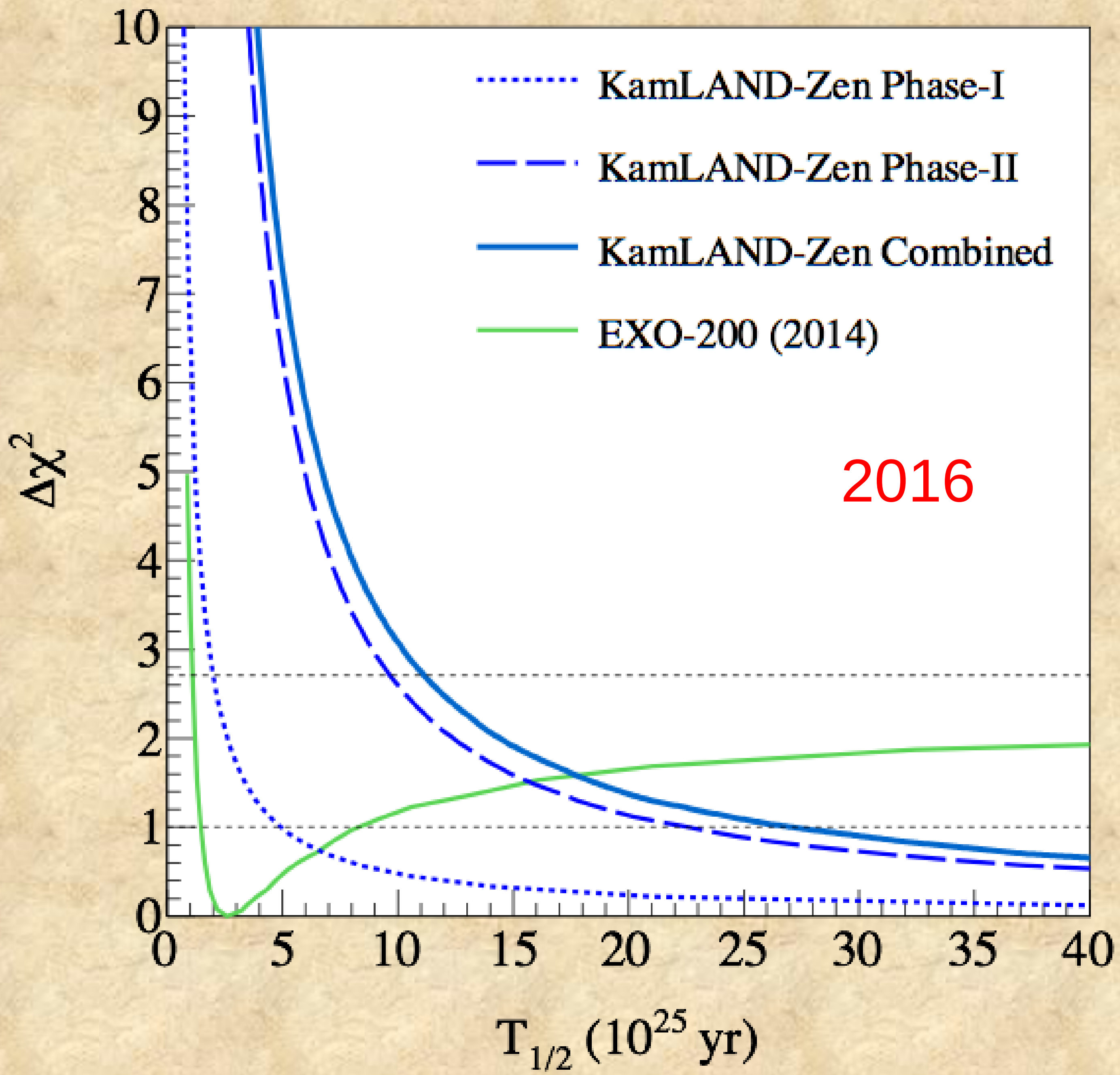
Lucky region
R >1m, Z>0 region

use FV for period-2 data
upper hemisphere R<1.26 m (5 bins)
lower hemisphere R<1.06 m (3 bins)



provides better limit of
< 3.25 /day/kton

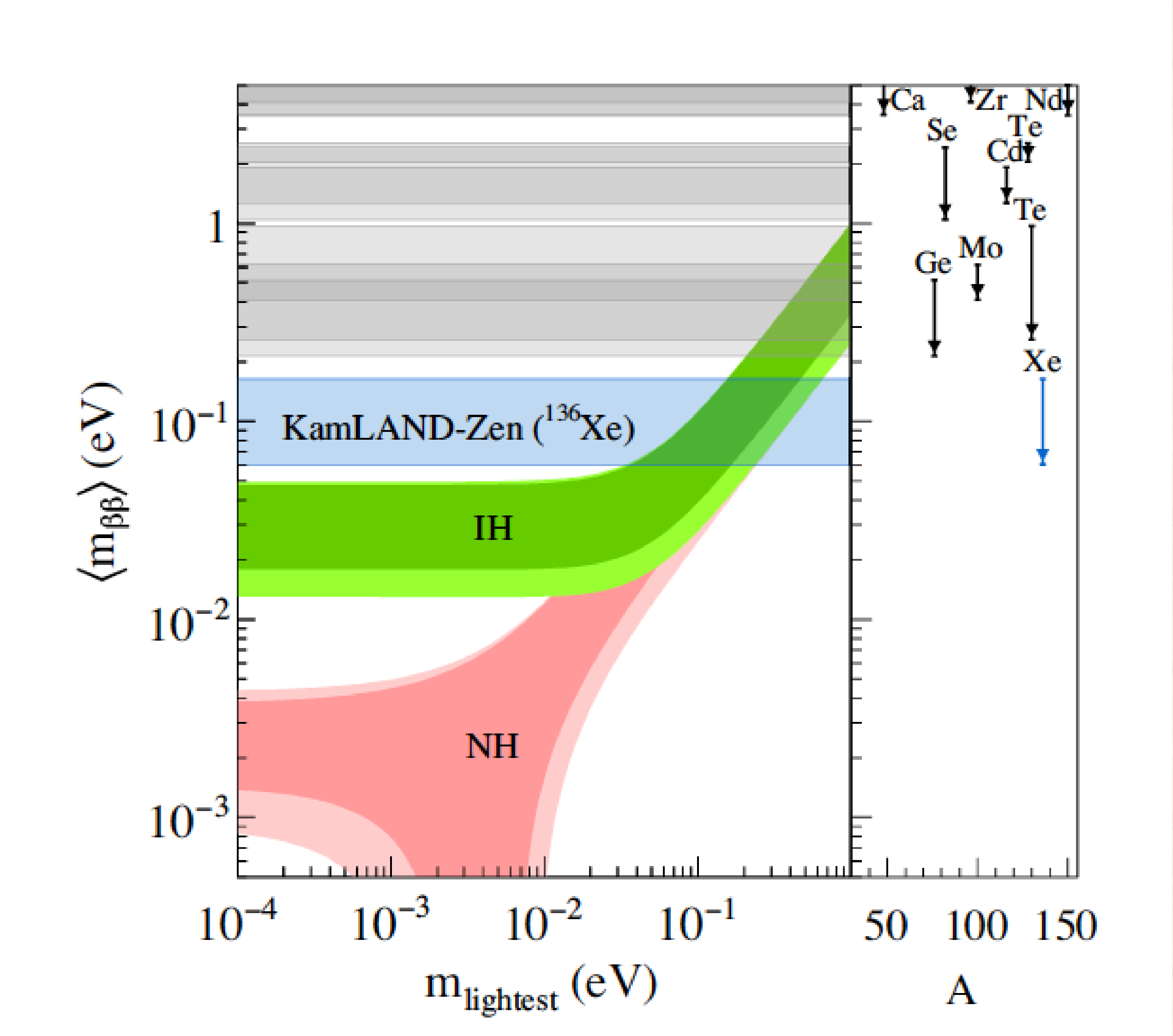
Phase-1 & 2 combined limit



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

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

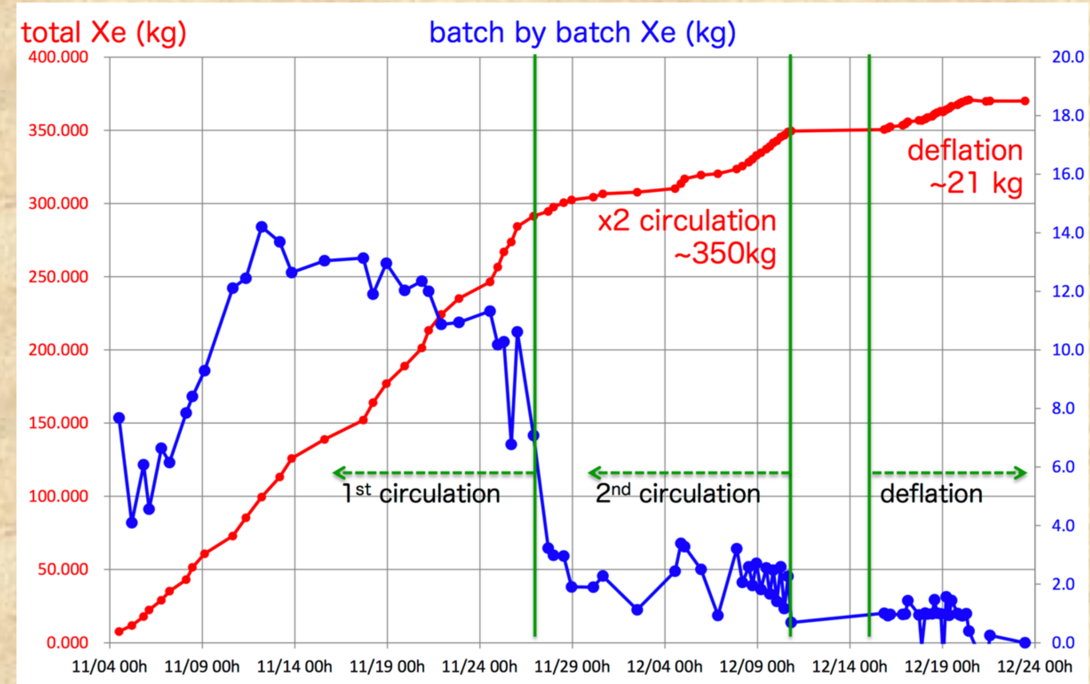
$$\langle m_{\beta\beta} \rangle < (61 - 165)\,\mathrm{meV}$$



Big leap toward IH !!

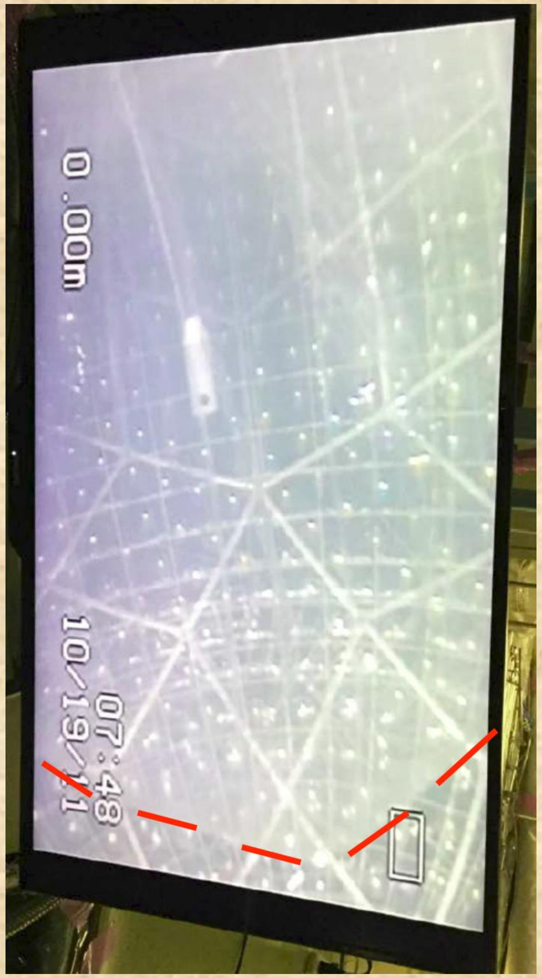
Path forward → bigger and cleaner mini-balloon.
more mass of Xenon isotope (~800 kg)

Mini-balloon has been extracted. (Dec. 2015)



for tank investigation required by law

Xenon has been recovered during recirculation and deflation of the mini-balloon.



deflation

2nd mini-balloon fabrication during the summer of 2016

cleaning, cleaning, and cleaning

New bigger mini-balloon was deployed in August 2016

after Leak check and repair

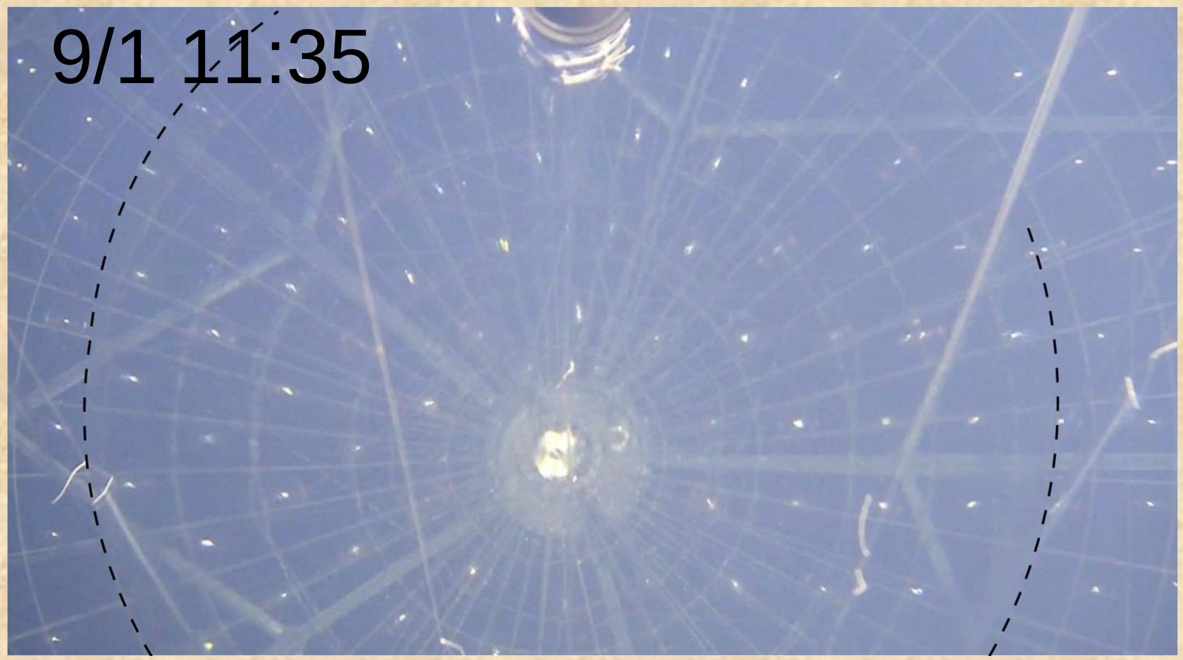
New mini-balloon has been deployed and inflated with LS without Xe

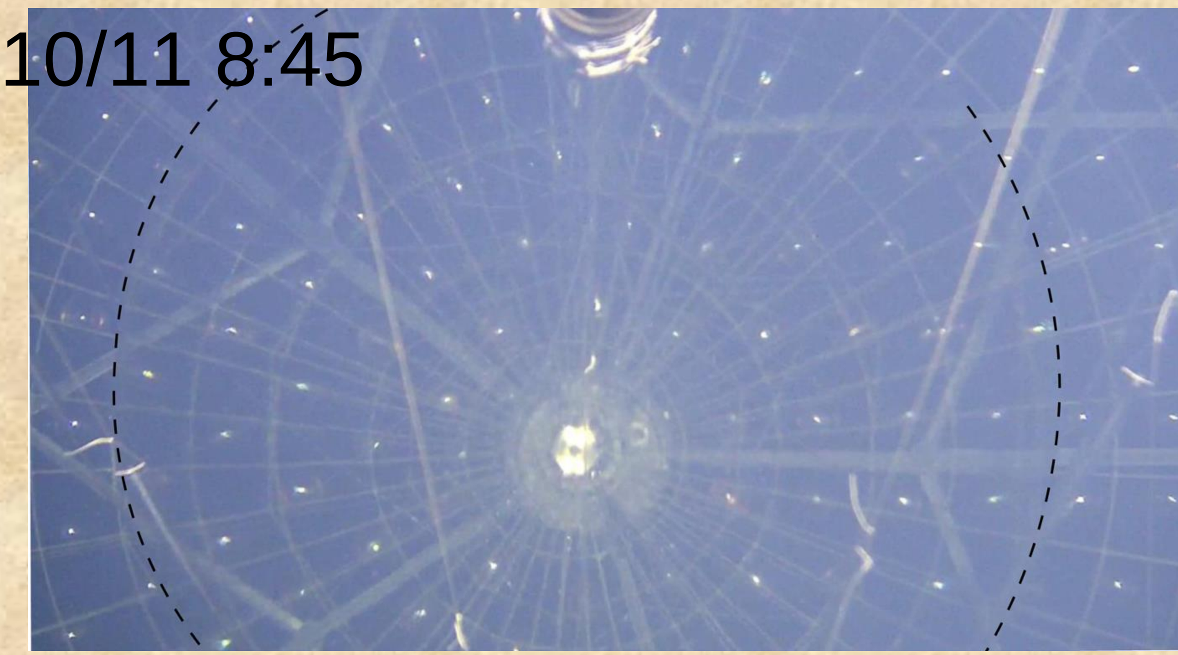
New mini-balloon troubles

After deployment we confirmed that the mini-balloon is cleaner !!

Measures we took worked!

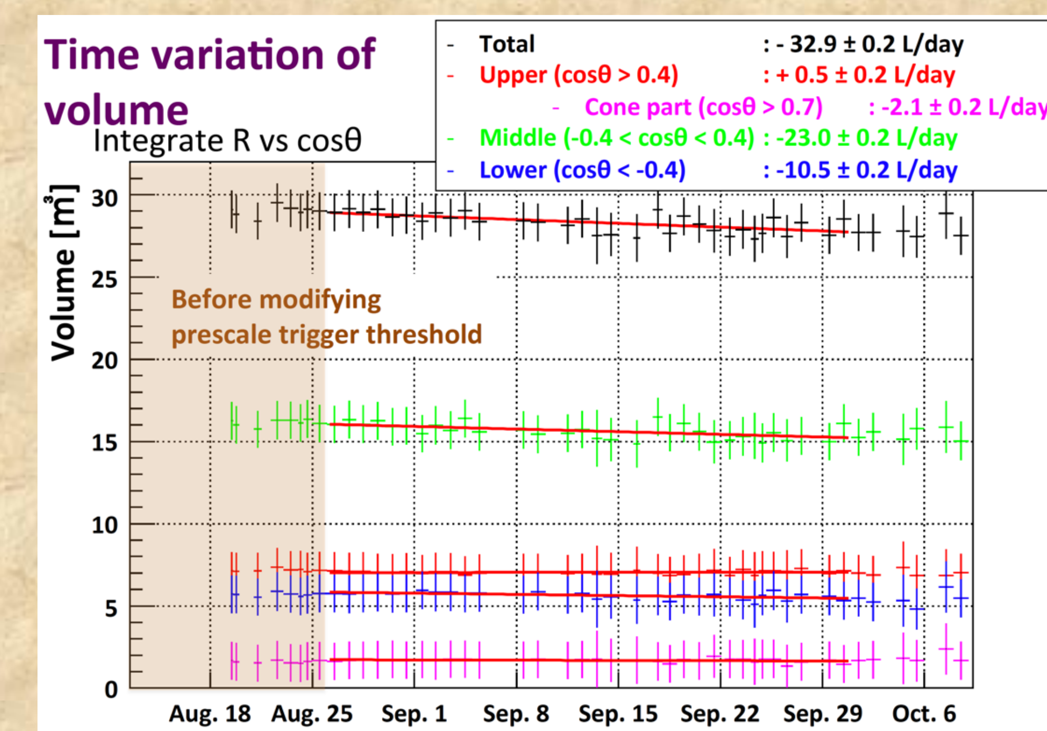
At the same time, we noticed;





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



Need to start over

Bad news:
we lost one year of statistics

Good news:
no any amount of Xe was lost.
we manage to evaluate radio purity of the new mini balloon
we do not see any traces of Cs or ^{110}Ag
Th and U contamination is 3 times lower than before

Present Status:

Extensive R&D were conducted to prevent for welding failure

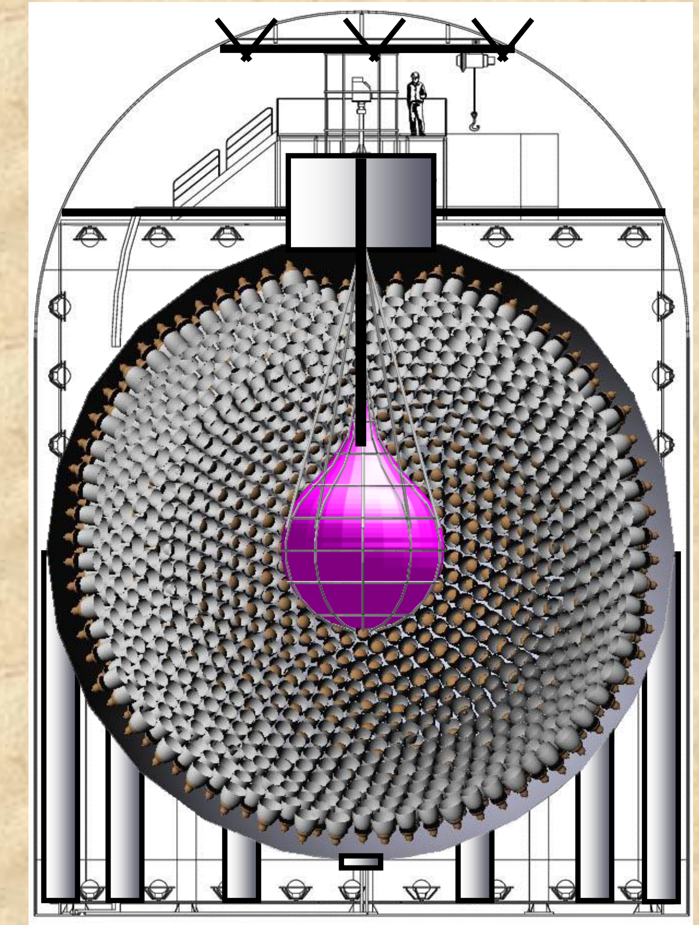
Even more rigorous program for cleanness during film preparation and welding

Final preparations are on the way to build a new mini-balloon during this summer

Target is to deploy 800 kg experiment in the fall of 2017

Some long range plans!

Higher energy resolution for reducing 2ν BG



1000+ kg xenon

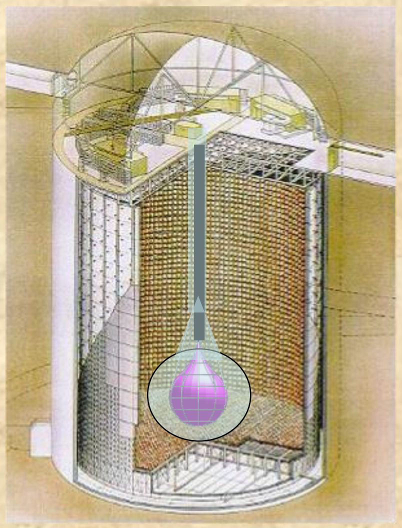
KamLAND2-Zen

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

And more?



Super-KamLAND-Zen

in connection with Hyper-Kamiokande

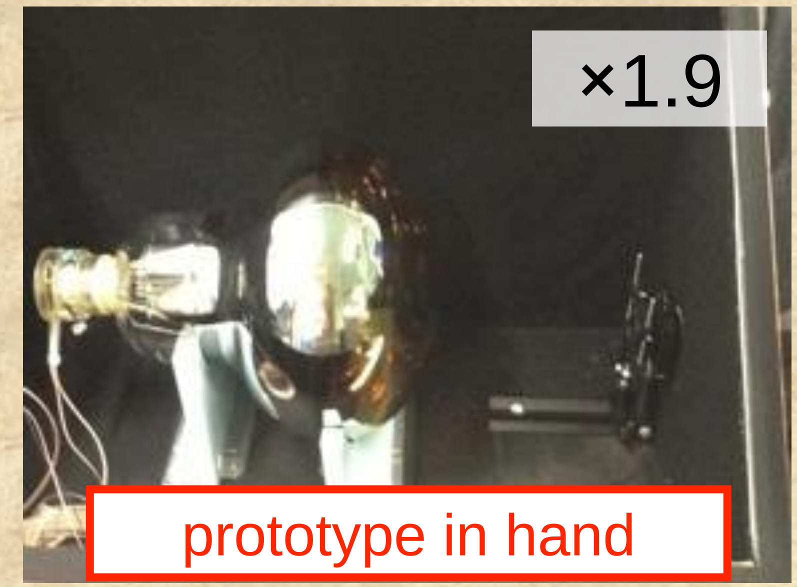
target sensitivity 8 meV

R&D for KamLAND2-Zen and future

○ winston cone

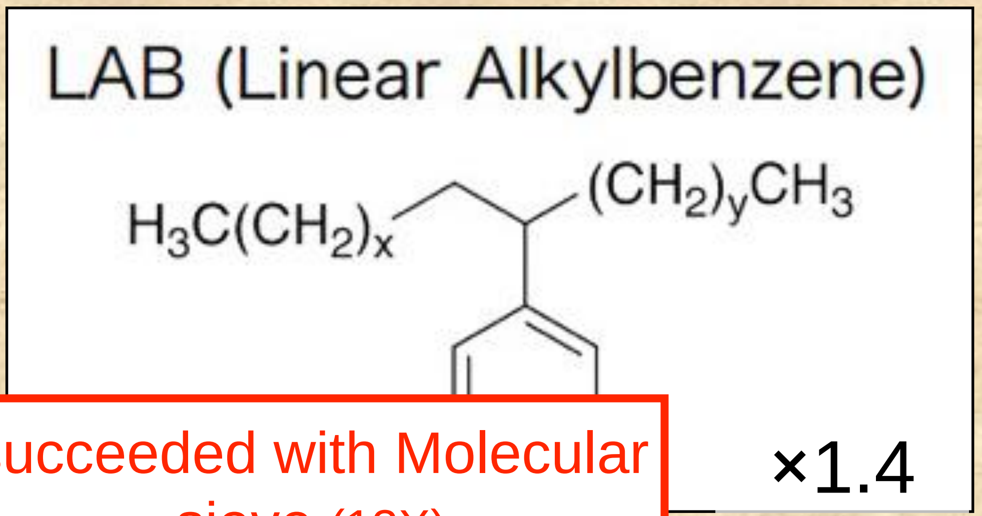
succeeded with prototype

○ HQE-PMT



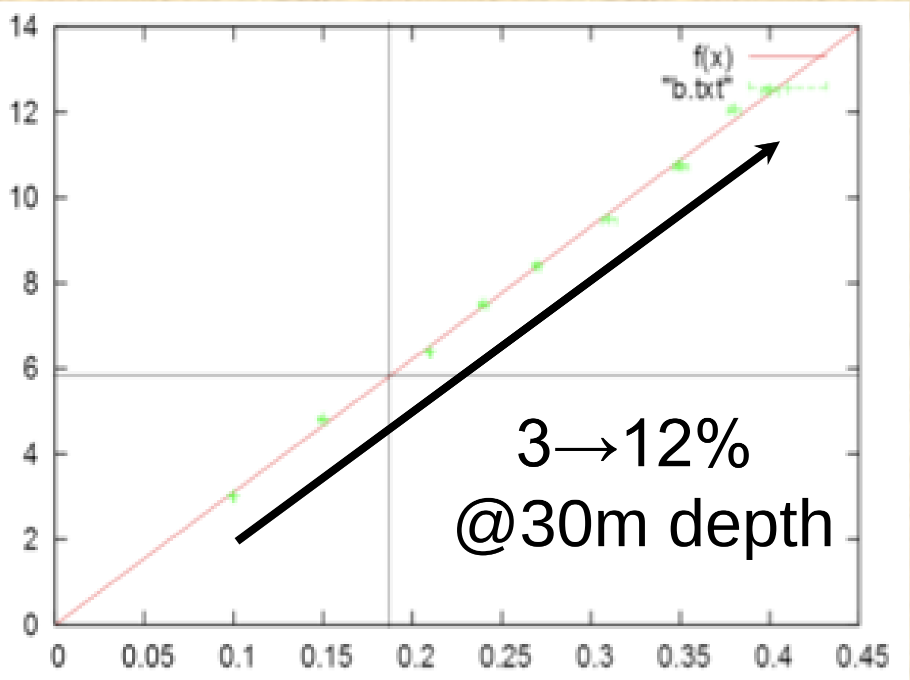
prototype in hand

○ New LAB-LS



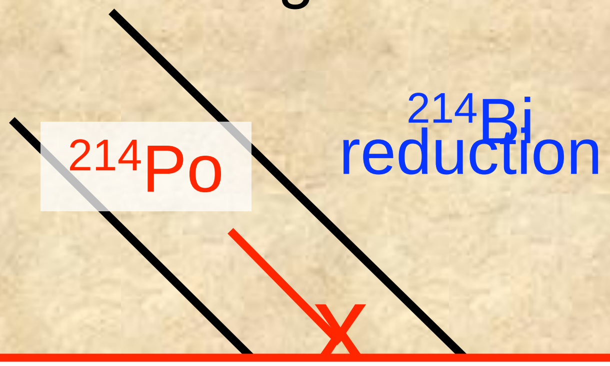
succeeded with Molecular sieve (13X)

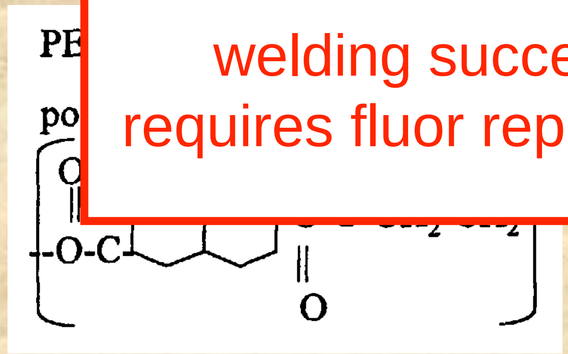
○ denser xenon



principle confirmed

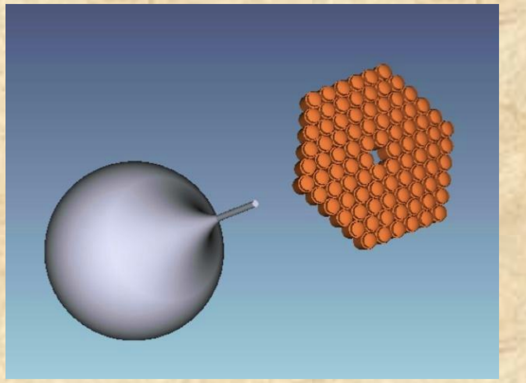
○ scintillator film

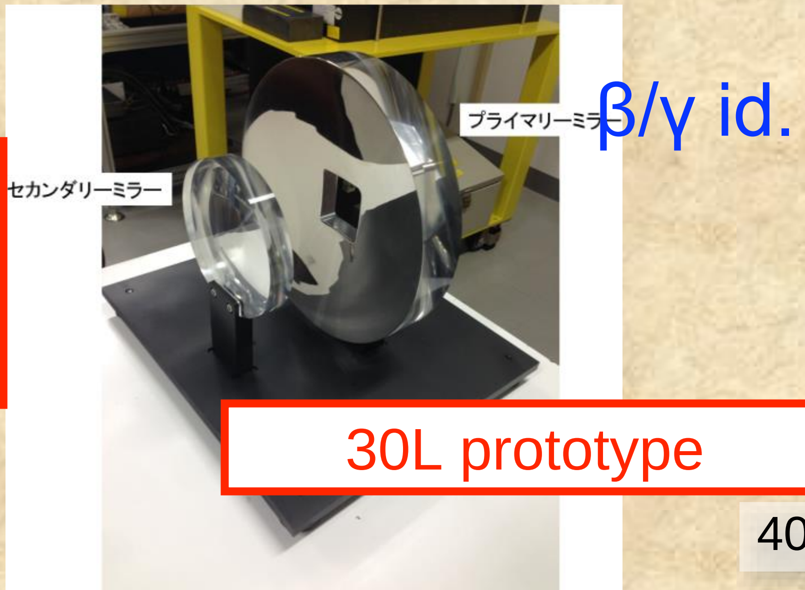




welding succeeded
requires fluor replacement

○ imaging





30L prototype

Summary

- **Phase-1 & 2 combined result for 0ν2β of ^{136}Xe**

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

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

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- **KamLAND-Zen 800** **(20 kg of izotope per collaboratior)** **is on the way**
  Mini-balloon for 750kg once installed, but there was a leak
  Balloon film was cleaner than previous installation
  deployment is planning to be in the fall 2017.

- **R&D for KamLAND2-Zen is going well.**
  Target sensitivity below 20 meV.

Thank you!

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
. . .