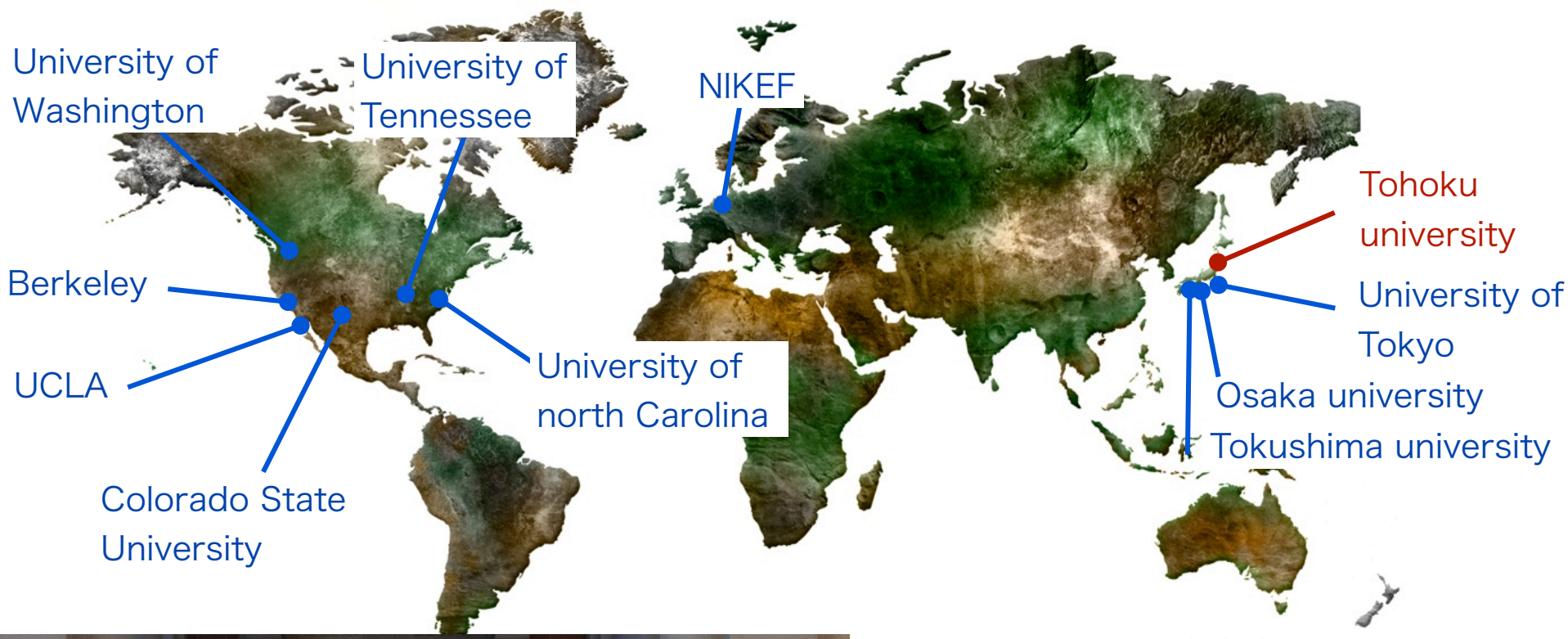
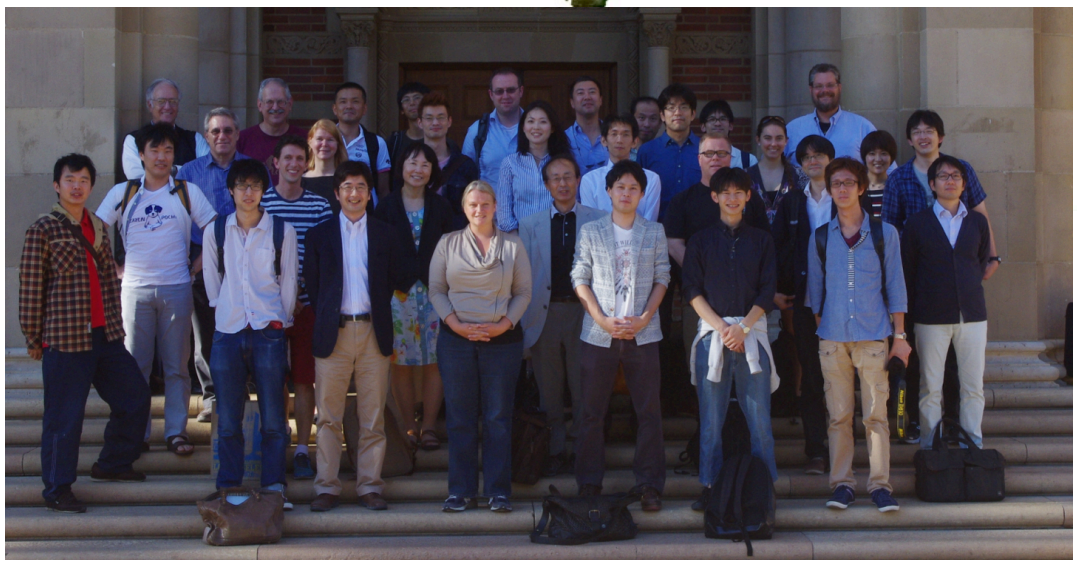
KamLAND-Zen

Koji Ishidoshiro (Tohoku Univ.)

Double Beta Decay and Underground Science, 7th October, 2014

KamLAND-Zen collaboration





11 institutes,
48 scientists

Collaboration meeting @UCLA, 2014

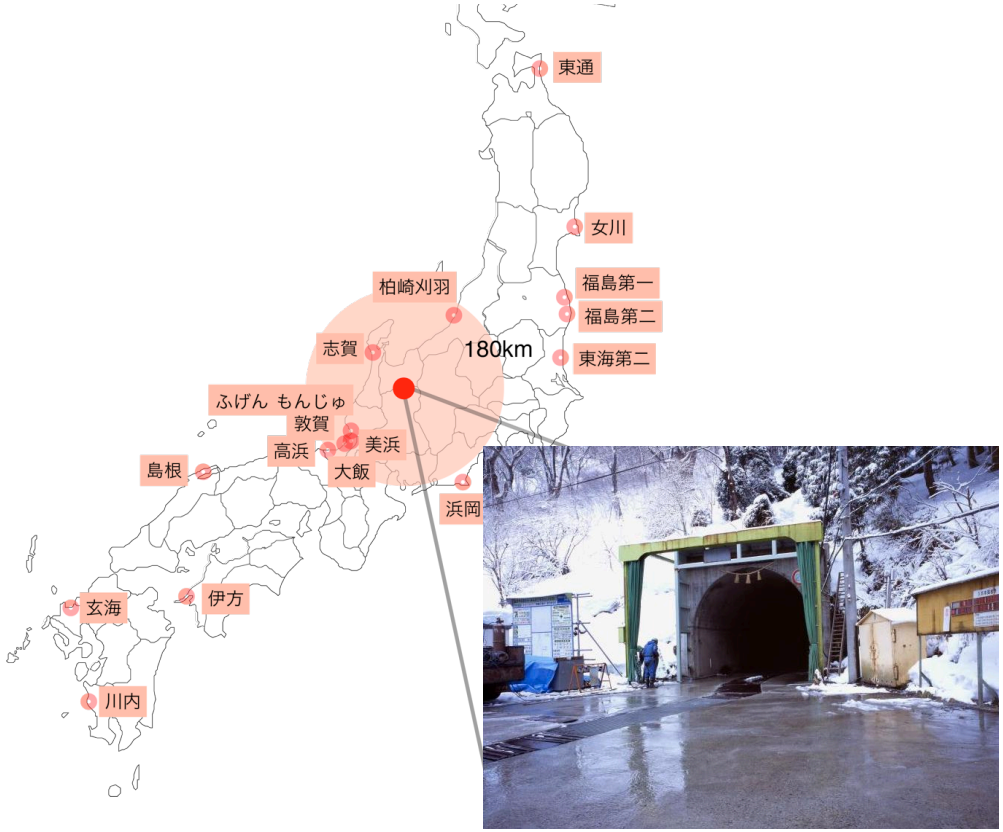
KamLAND detector

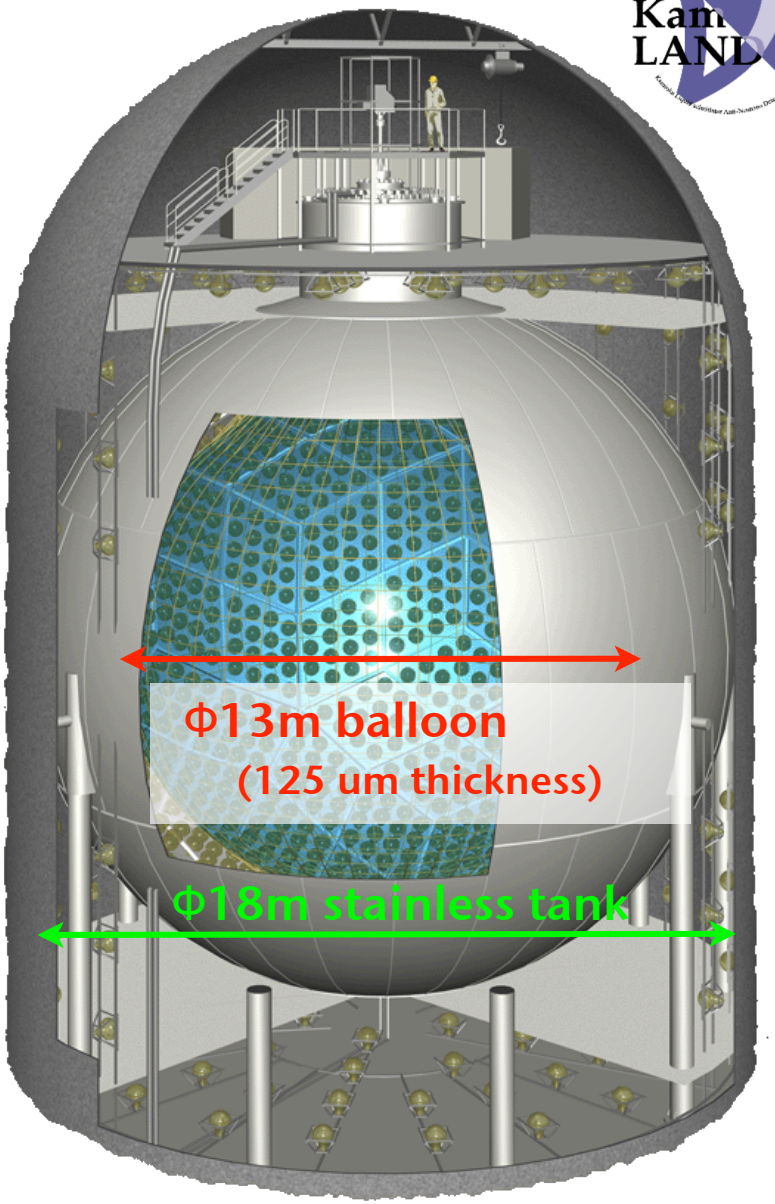
Kamioka Liquid scintillator
Anti-Neutrino Detector (since 2002)

- 1,000 m depth (Kamioka mine)
- 1,000 t liquid scintillator

  Dodecane (80%), Psedocumene (20%), PPO (1.36g/l)

- 1,325 17inch + 554 20inch PMTs



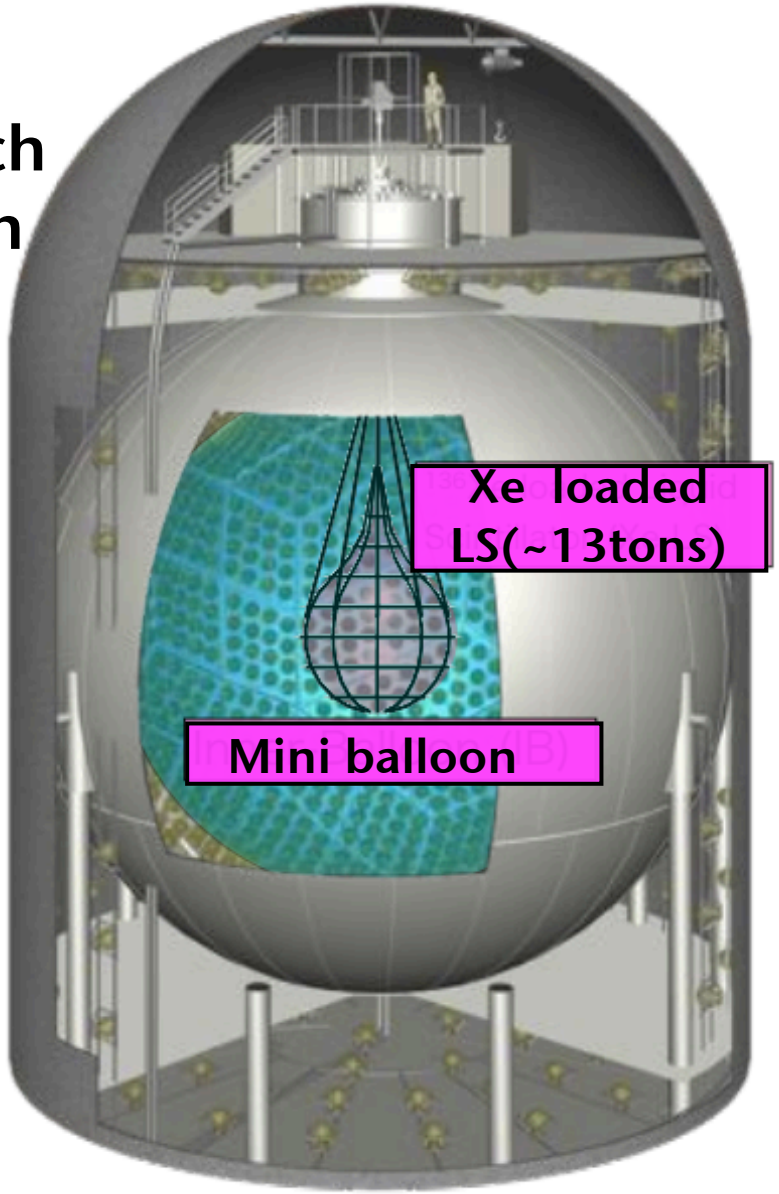


Outer detector (for muon veto)
- 3.2kton water cherenkov detector
- ~100 20inch PMTs

KamLAND-Zen

Neutrino-less Double-beta decay search using ^{136}Xe loaded LS in a mini balloon

decane 80.2%, pseudocumene 19.8%,
PPO 2.7g/l, Xe 2.4wt%



Advantages of KamLAND-Zen

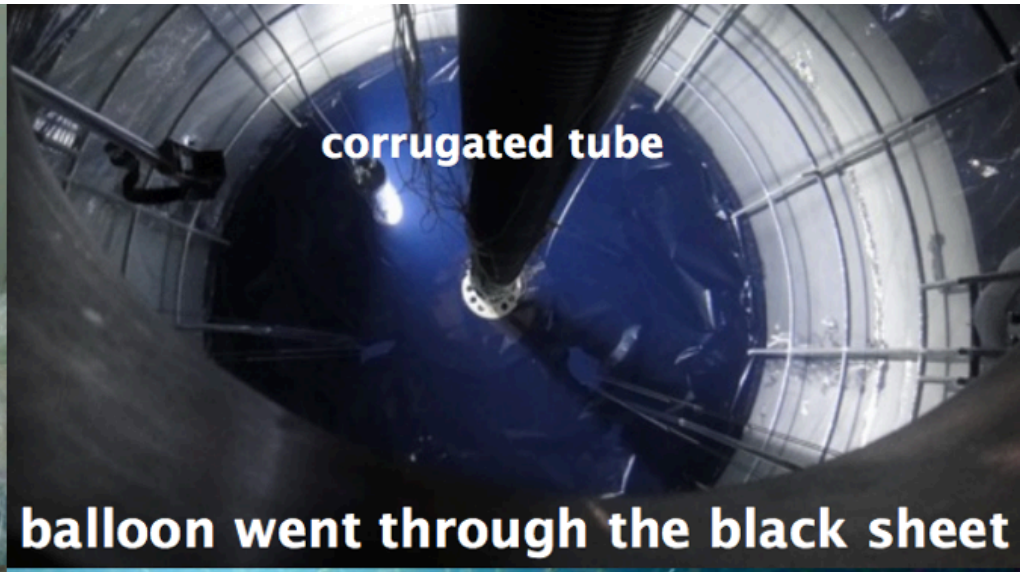
- running detector: start quickly
- pure LS & 9m radius active shield
  U < 3.5 x10^{-18} g/g, Th < 5.2x10^{-17} g/g
- high scalability
  replacement of a mini ballon
  off-measurement

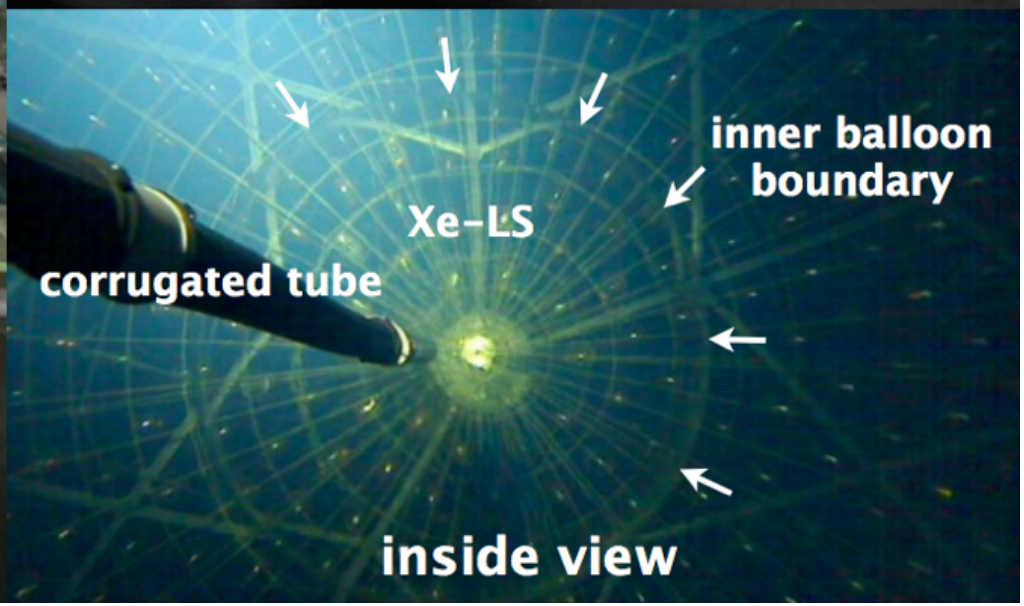
Why ^{136}Xe

- Good solubility to LS (3wt%)
- Chemically stable (easy to handle)
- Establishment of enrichment method
- Q-value is 2.46MeV -> Low BG region in KamLAND

Balloon fabrication & installation

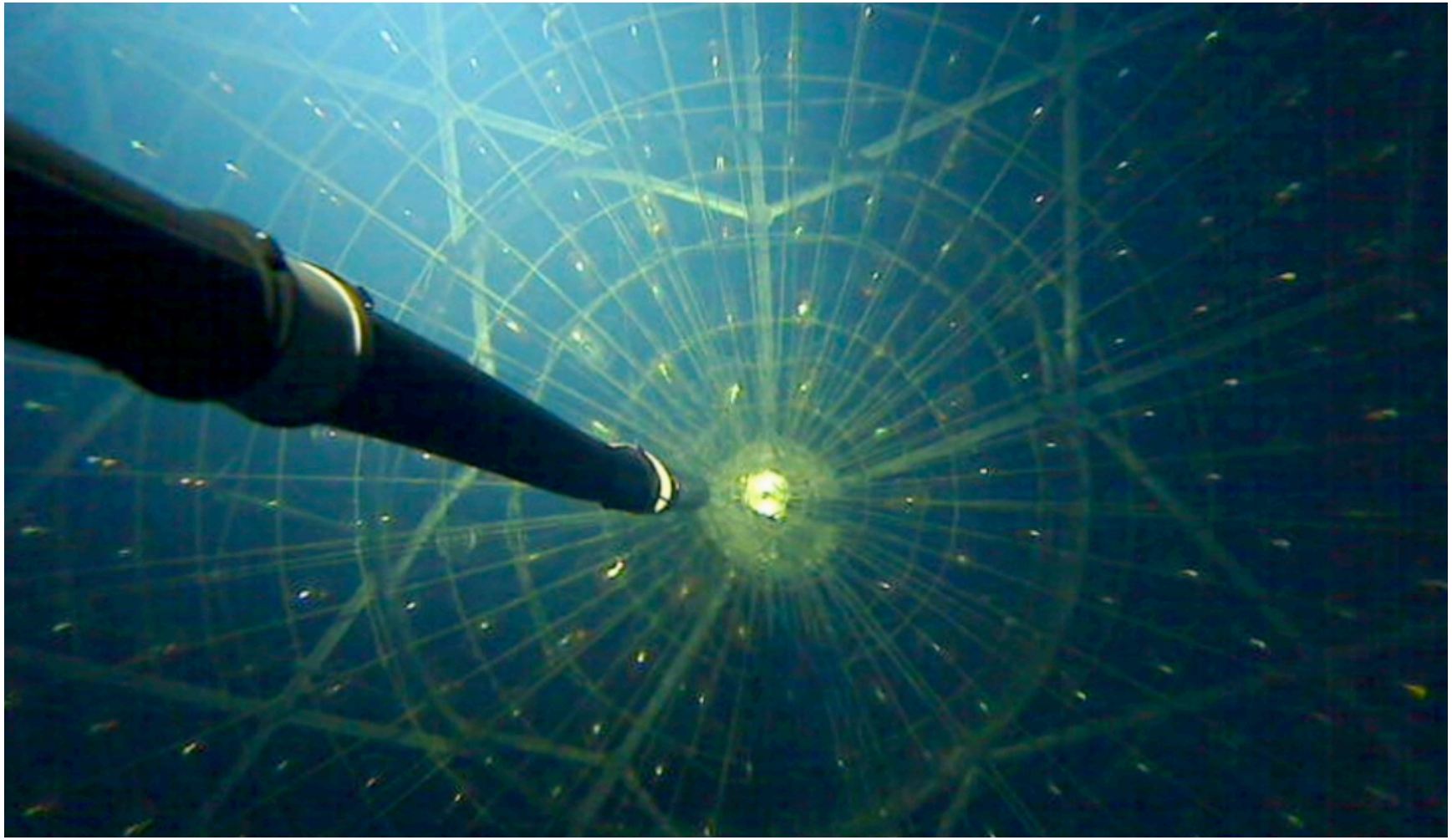
2011 Summer





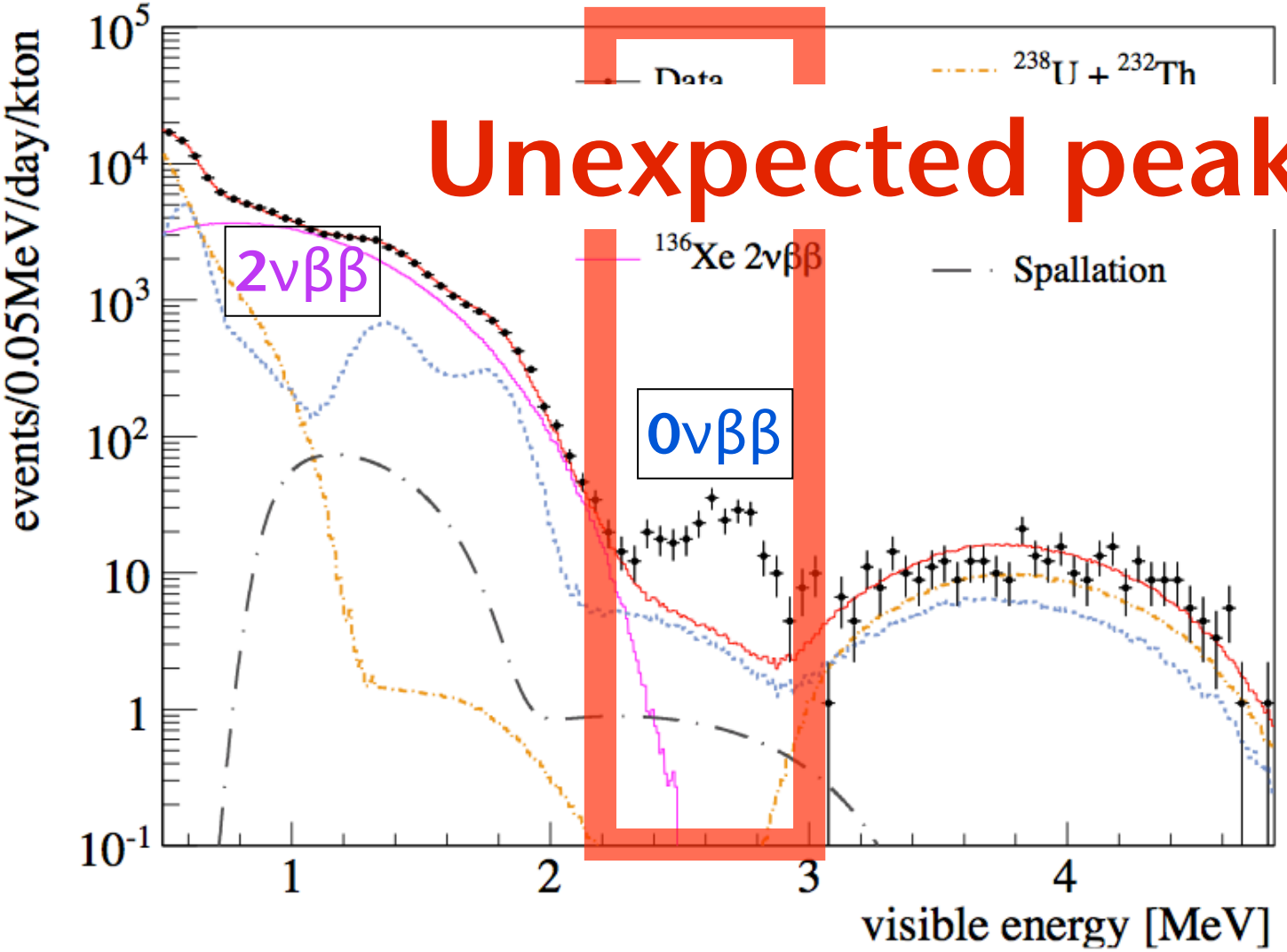
1st Data taking

Start September, 2011 (DS1)
90.6% enriched xenon gas 320 kg(^{136}Xe 290kg)



Energy spectrum

Used data: October 12, 2011 - January 2, 2012 (DS1)

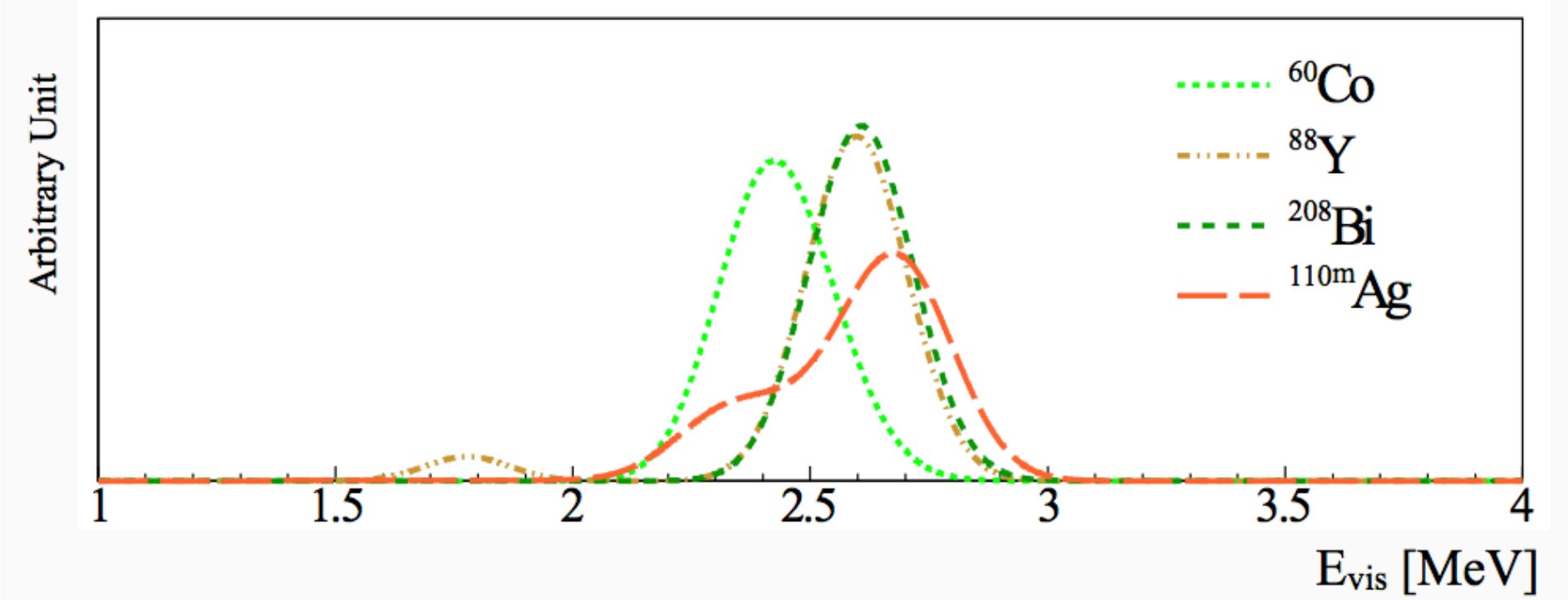


$T^{2\nu} = 2.38 \pm 0.2 \pm 0.014 \times 10^{21}$ yr

BG candidates

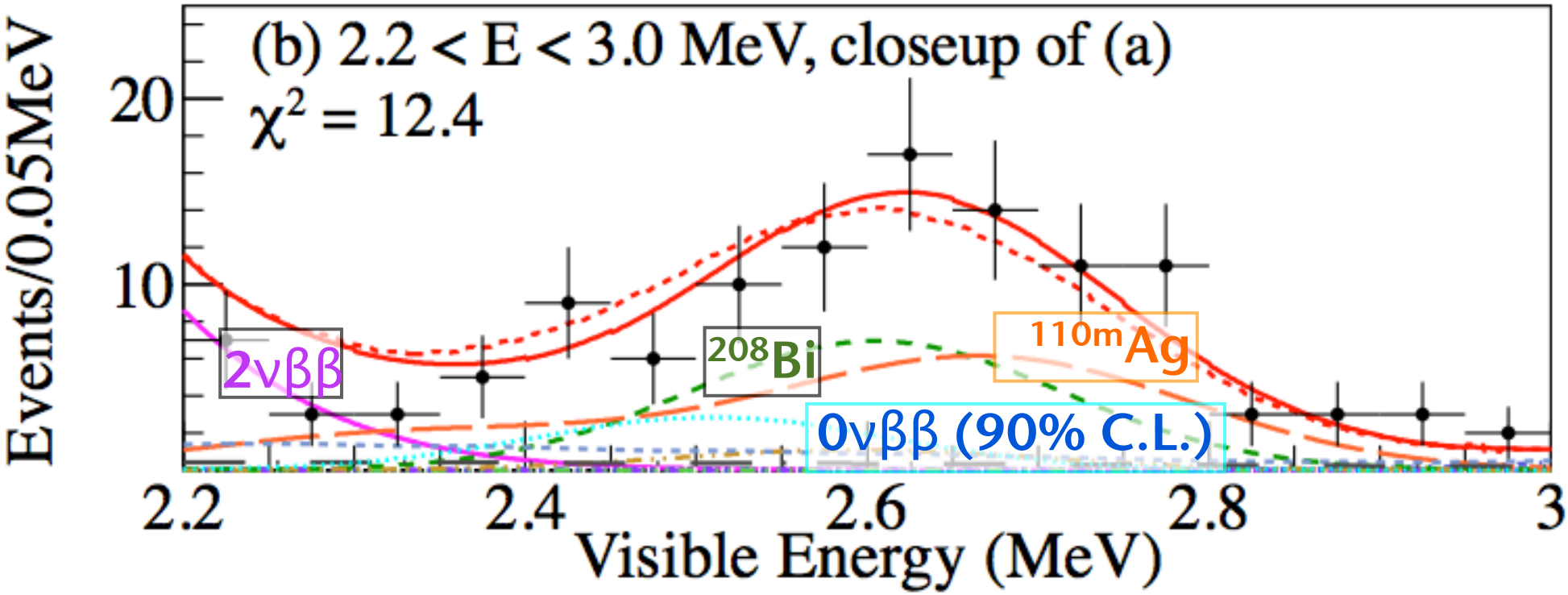
Search all isotopes and all decays in the ENSDF database

	decay	τ	Q-value[MeV]
^{110m}Ag	$\beta^- + \gamma$	360 days	3.01
^{88}Y	EC + γ	154 days	3.62
^{208}Bi	EC + γ	5.31×10^5 yr	2.88
^{60}Co	$\beta^- + \gamma$	7.61 yr	2.82



First result

Likelihood fit to the binned energy spectrum

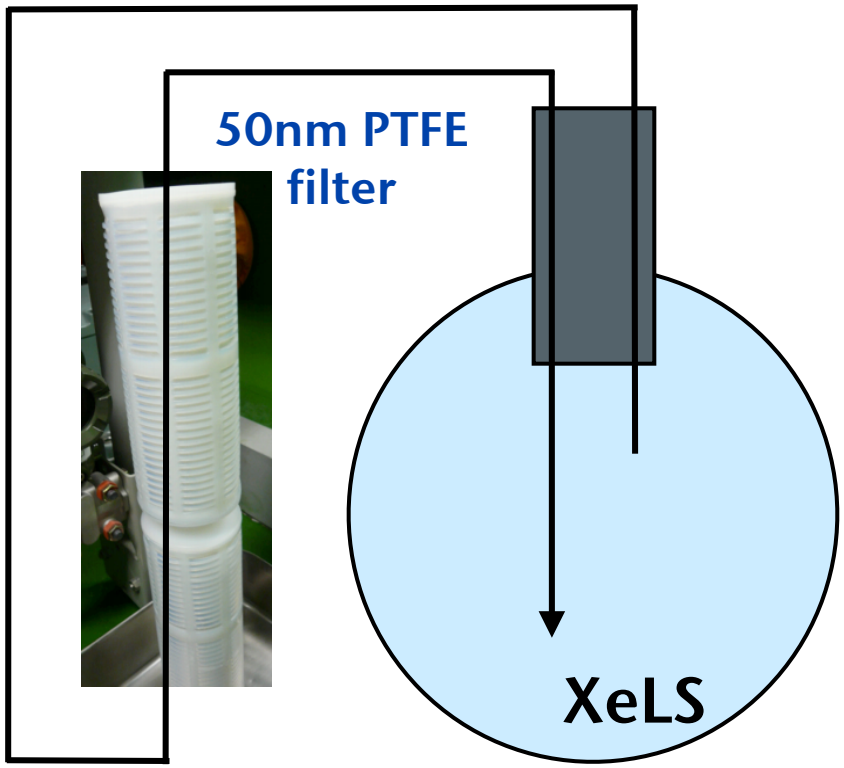


$T^{0\nu} > 5.7 \times 10^{24}$ yr (90% C.L.)

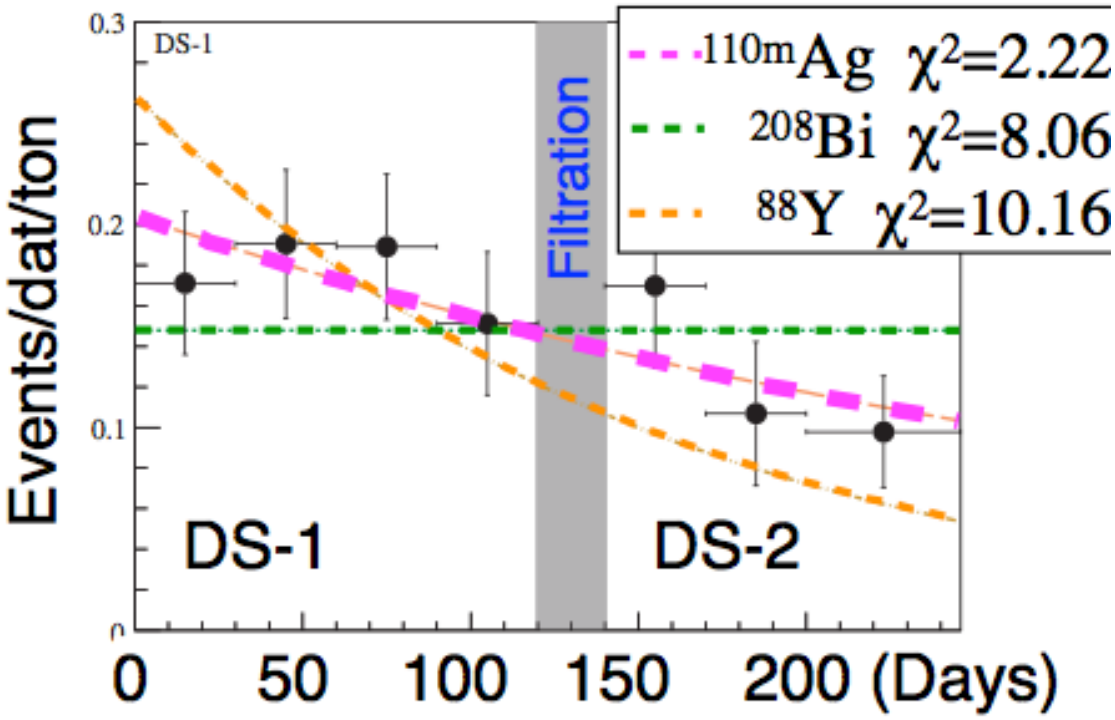
$\Rightarrow$ $m_{\beta\beta} < 0.3\text{-}0.6$ eV

Reduction of BG

2012	2013
DS1 DS2 ↔ Filtration	



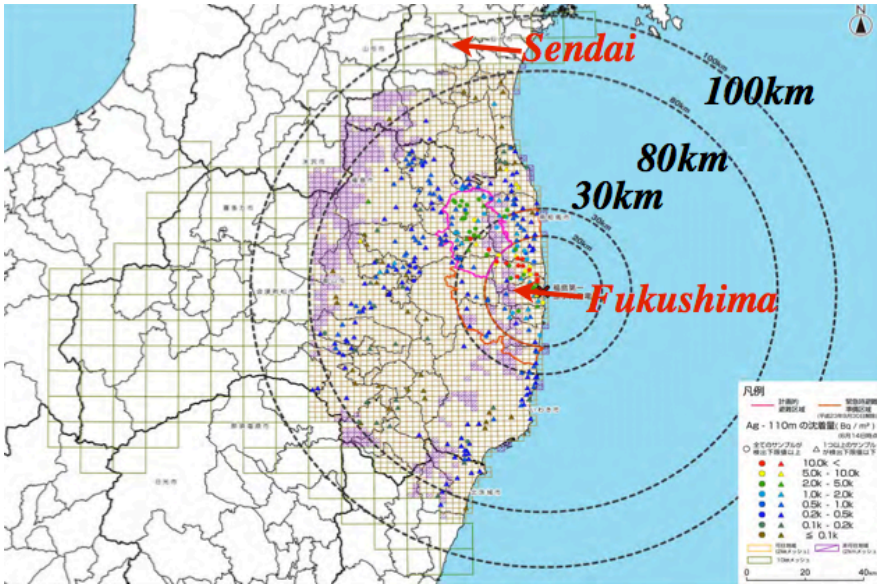
2.3 volume

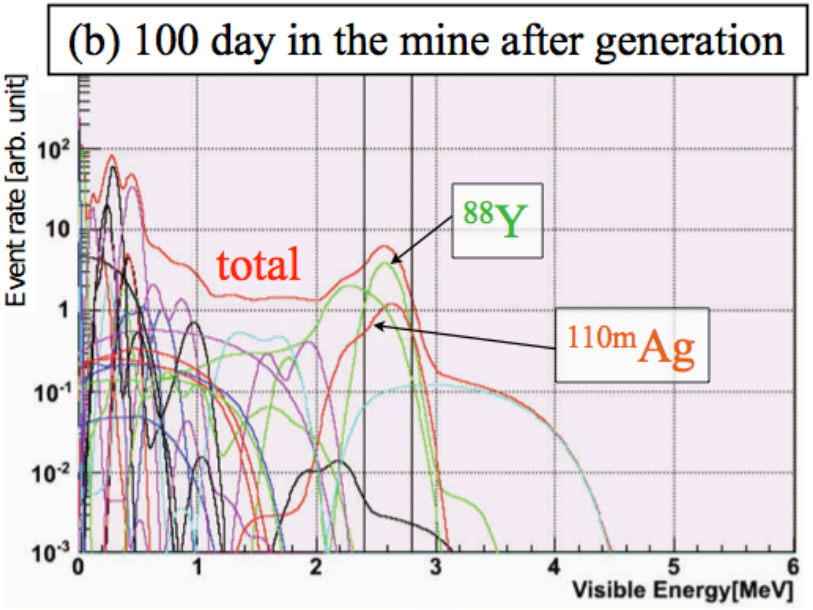


BG is identified as ^{110m}Ag.

Possible origin of ^{110m}Ag

Fallout from Fukushima





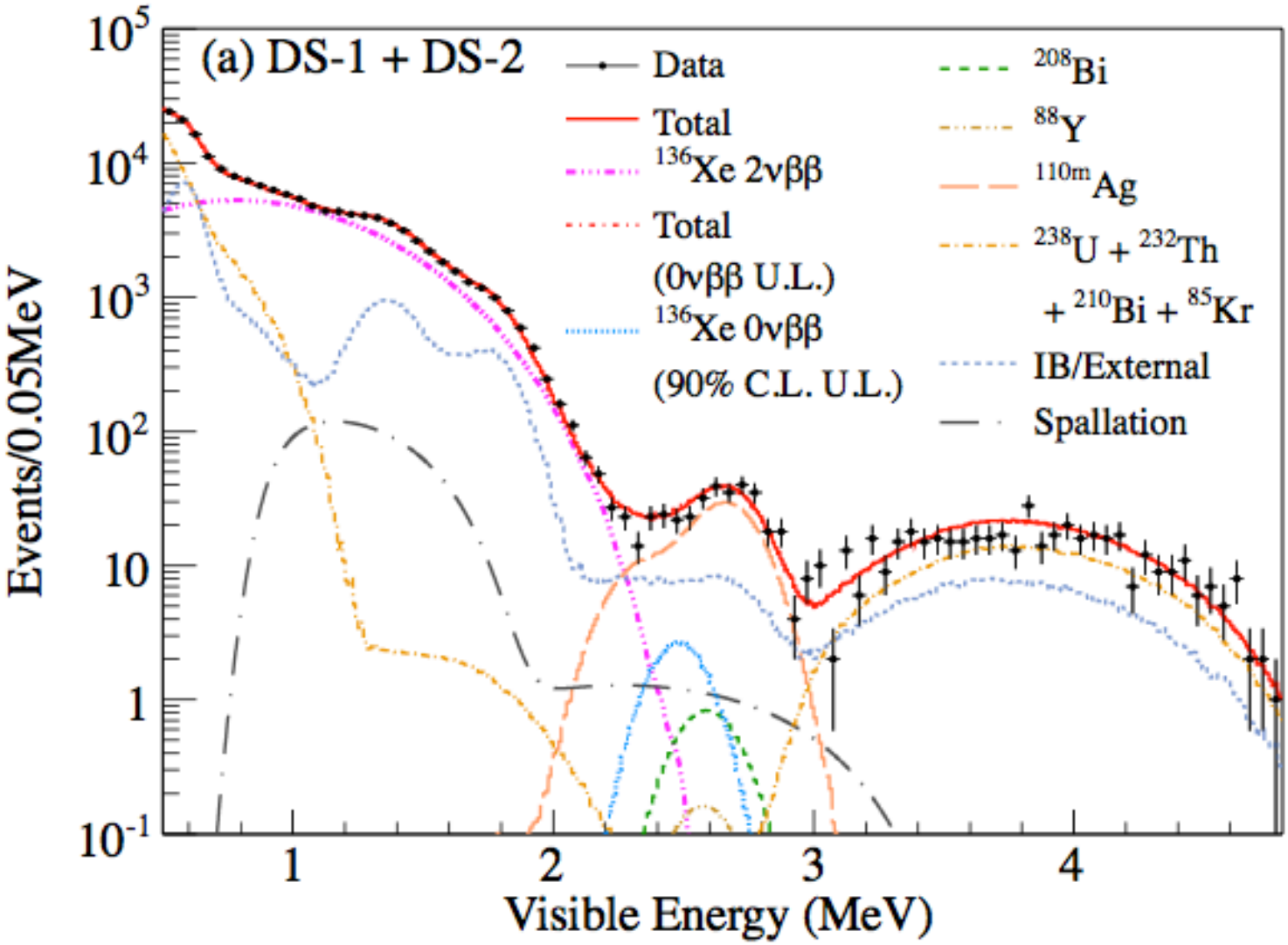
Spallation products from ^{136}Xe

We do not have conclusion for ^{110m}Ag origin.

Result of the 1st phase (DS1+DS2)

DS1+DS2: October 12, 2011 - June 2, 2012

Total live time: 213.4 days, Total Exposure: 89.5 kg yr



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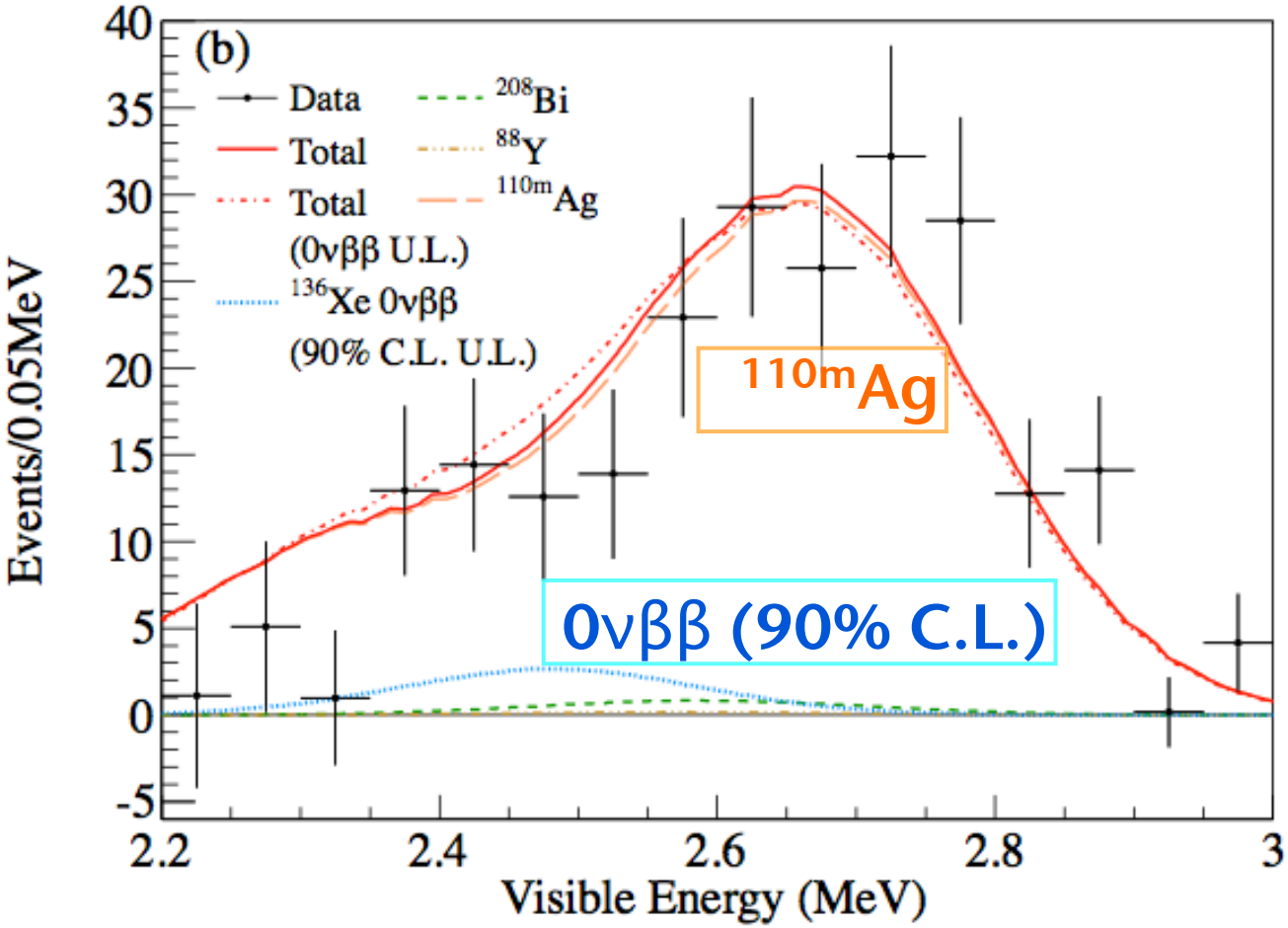
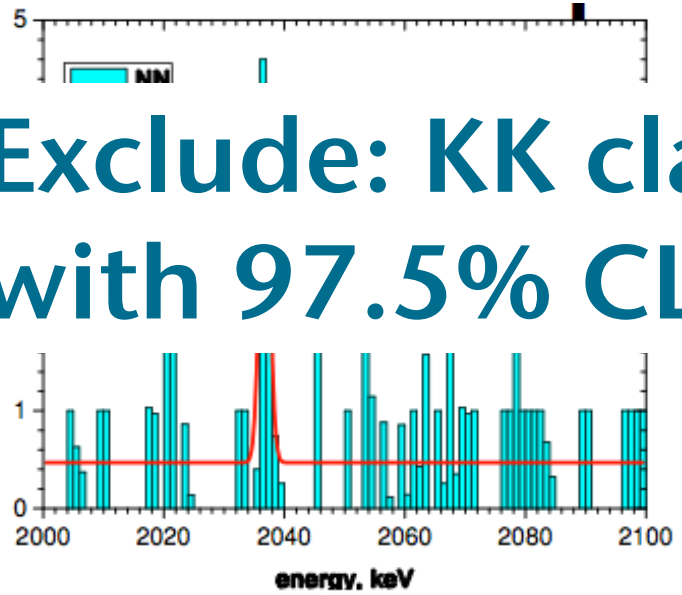


Lower limit
- $T^{0\nu} > 1.9 \times 10^{25}$ yr (90% C.L.)

- $T^{0\nu} > 3.4 \times 10^{25}$ yr (Combined with EXO-200)

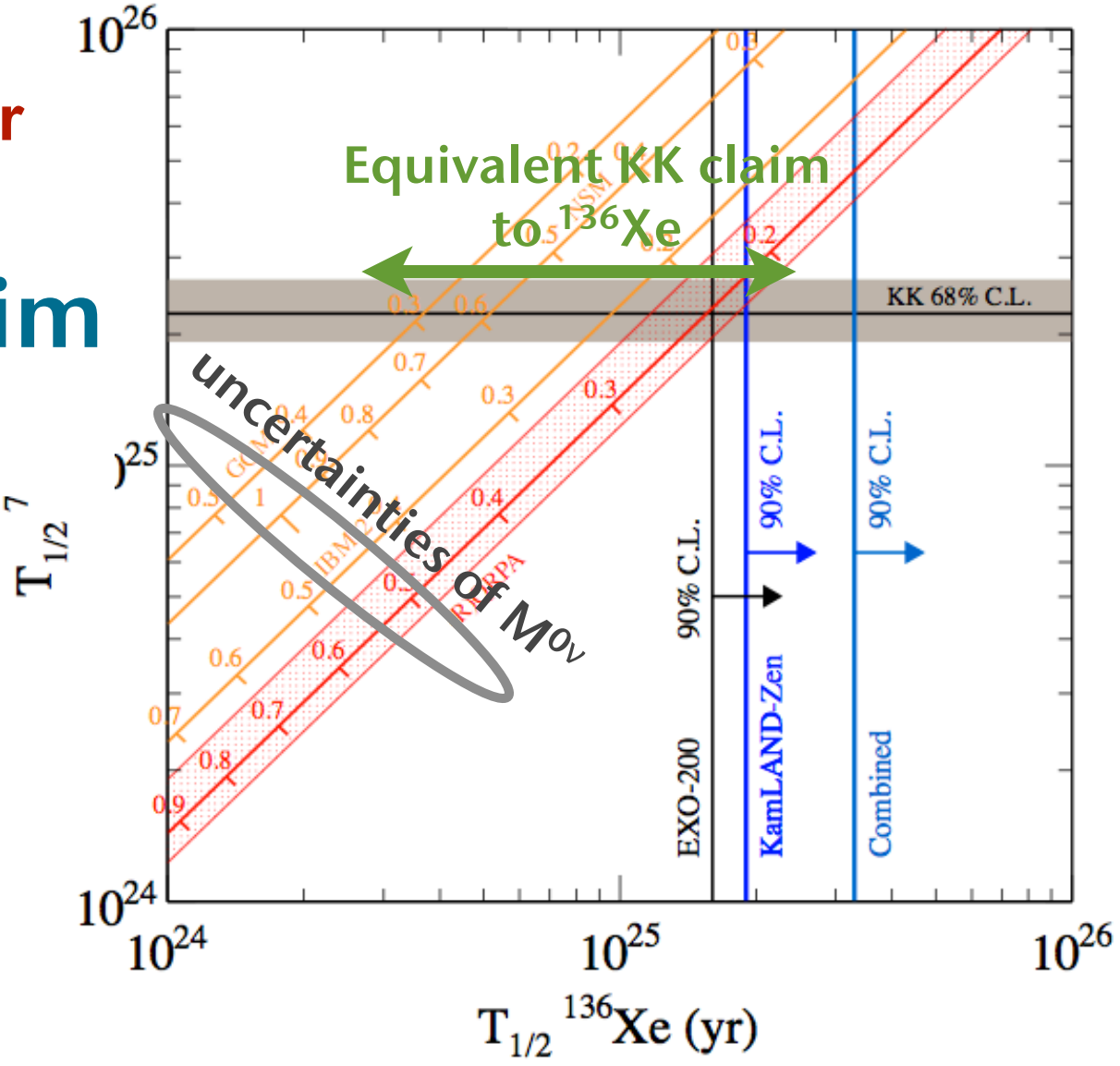
Test of KK claim

KK claim
$T^{0\nu}$ (^{76}Ge)
= $2.23^{+0.44}_{-0.31} \times 10^{25}$ yr



Exclude: KK claim with 97.5% CL

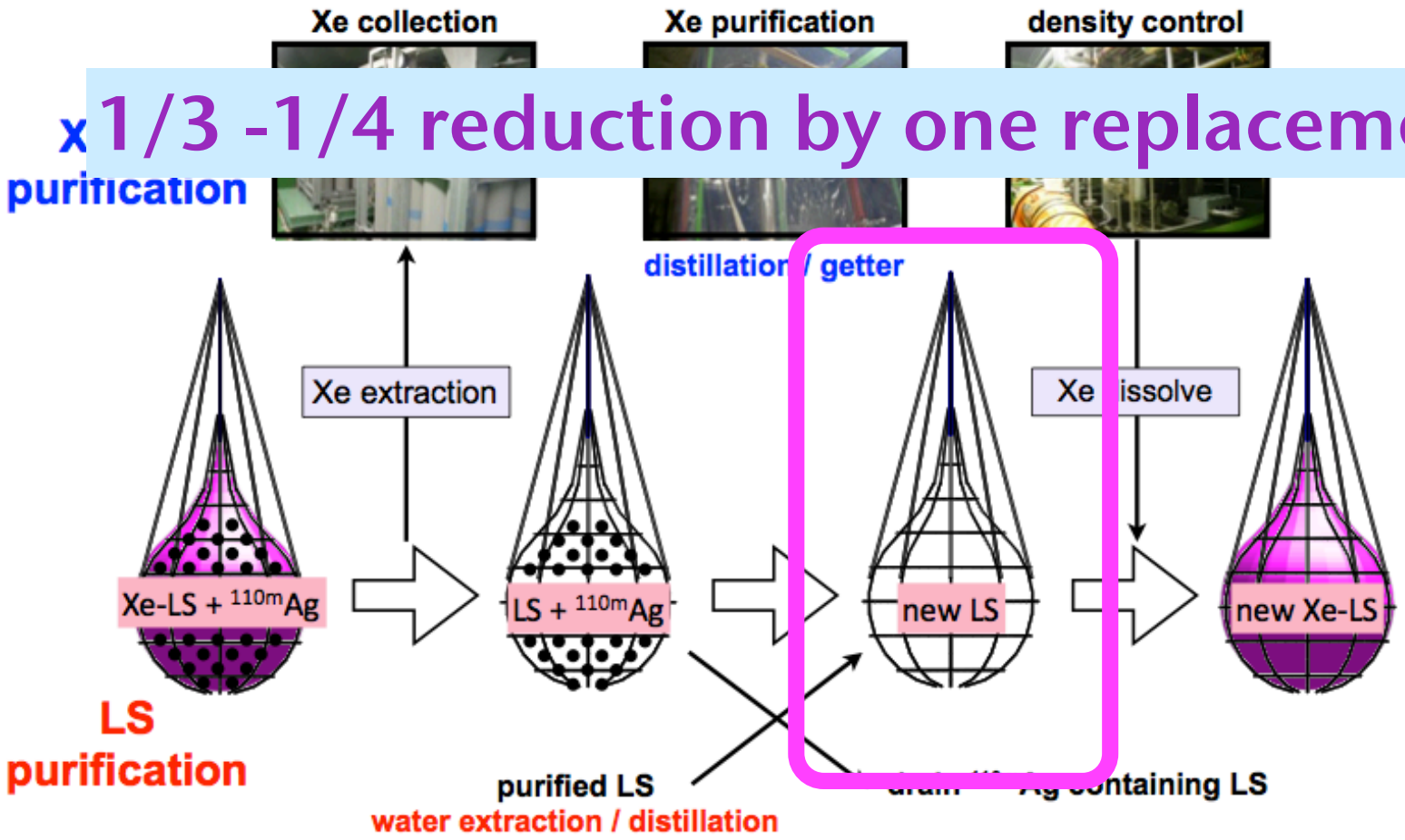
Correlation between $T^{0\nu}$ ^{136}Xe and ^{76}Ge



$$(T^{0\nu})^{-1} = G^{0\nu} |M^{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$

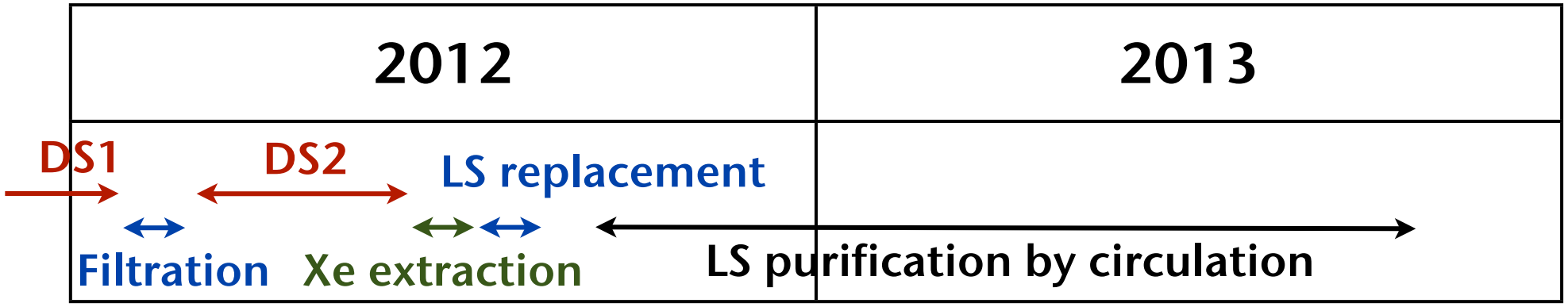
Reduction of BG

2012	2013
DS1 DS2 LS replacement Filtration Xe extraction	



1/3 -1/4 reduction by one replacement

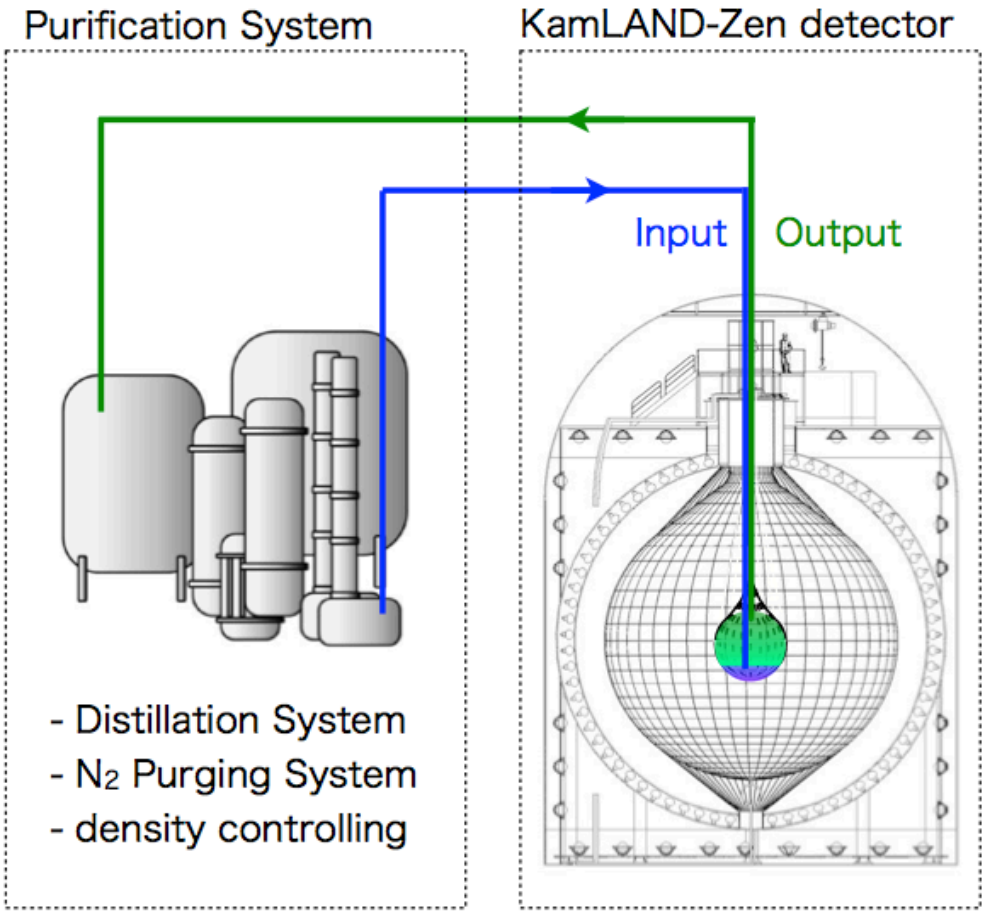
Reduction of BG



BG reduction: not enough

LS purification
by circulation mode.

Start: Nov, 2012
3 volume circulation



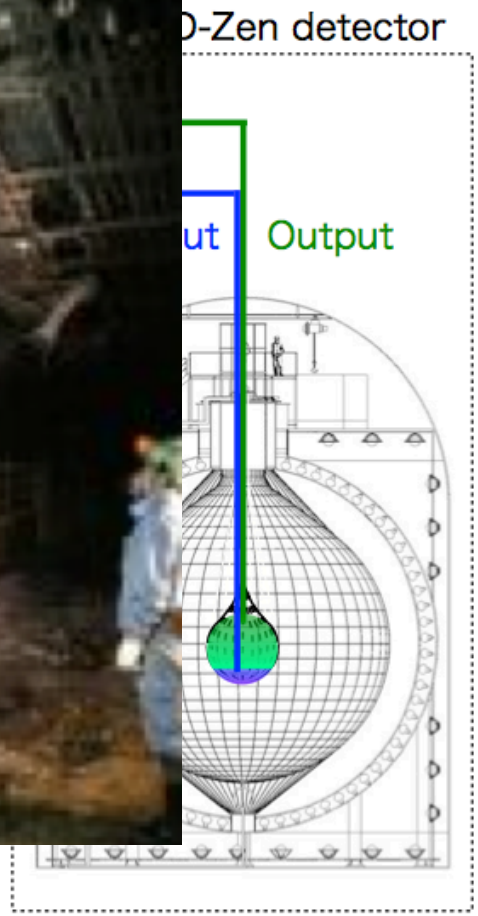
Reduction of BG

2012	2013
DS1 → ; DS2 ↔ ; LS replacement ★ ; Filtration ↔ ; Xe extraction ↔↔	LS purification by circulation →

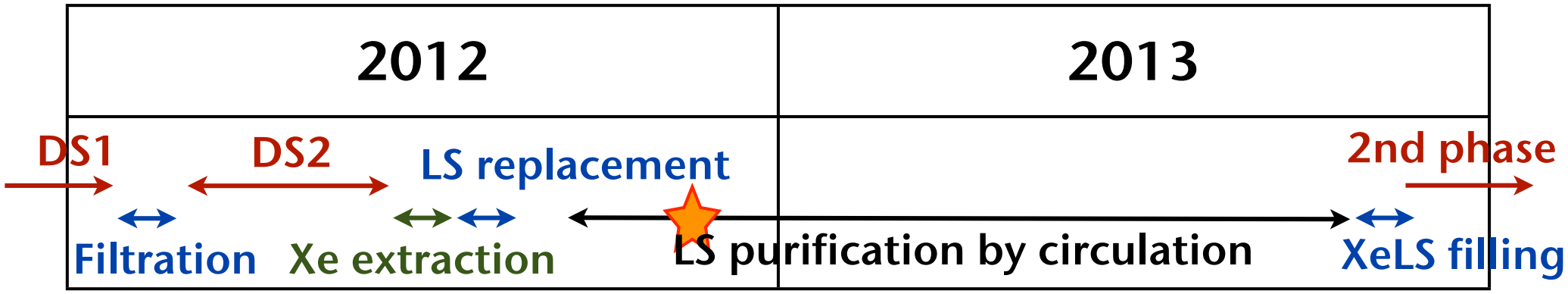
BG reductio

LS purificati
by circula

Start: Nov, 2
3 volume ci



2nd phase KamLAND-Zen

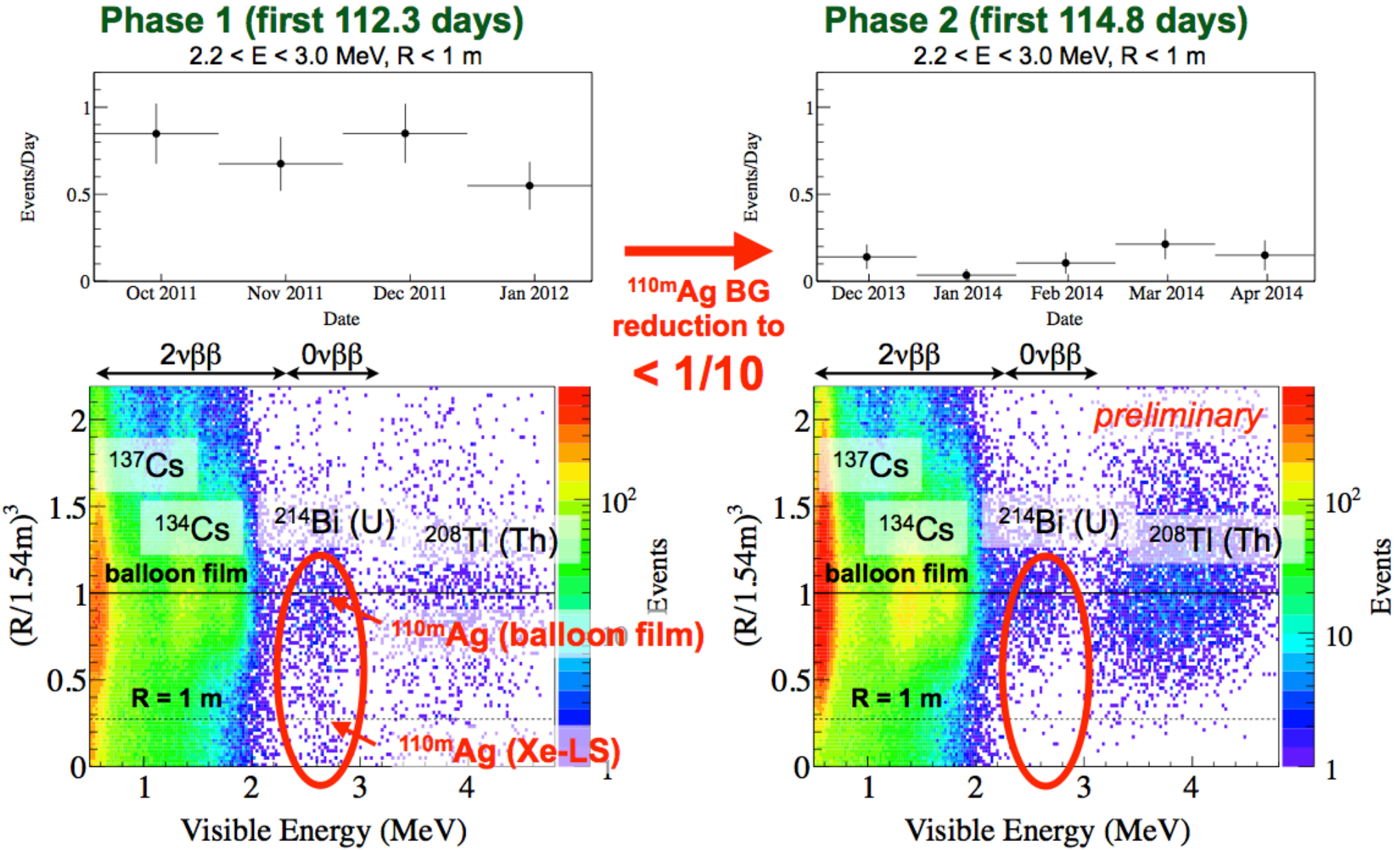


Dec. 2013: start 2nd-phase data taking

Improvements from the 1st phase

1. Remove radioactive impurities by Xe-LS purification
   BG (^{110m}Ag) can be removed.
2. Increase amount of Xenon
   Xe concentration (2.44 ± 0.01) wt% -> (2.96 ± 0.01) wt%
3. Optimization of volume selection
   Rejection for ^{214}Bi on the surface of balloon film
4. Spallation cut after muon
   μ-n-^{10}C triple coincidence cut for ^{10}C rejection

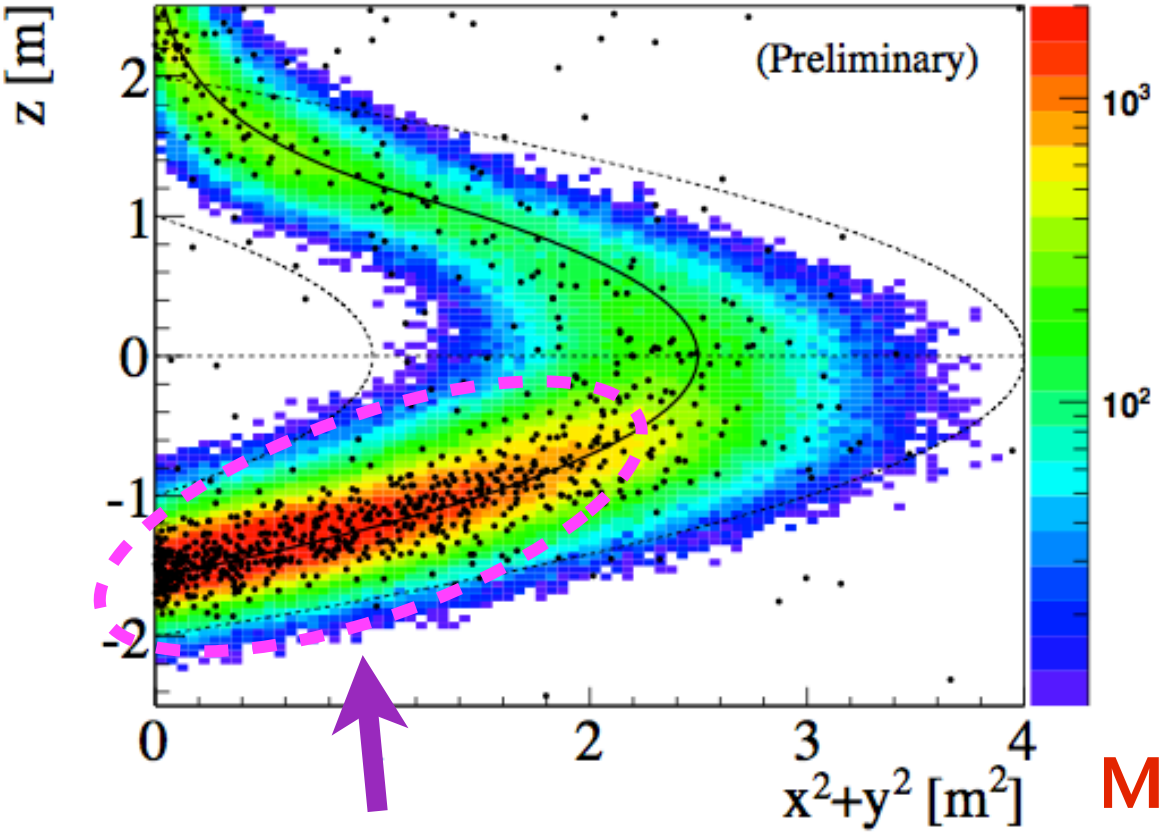
Removal radioactive impurities



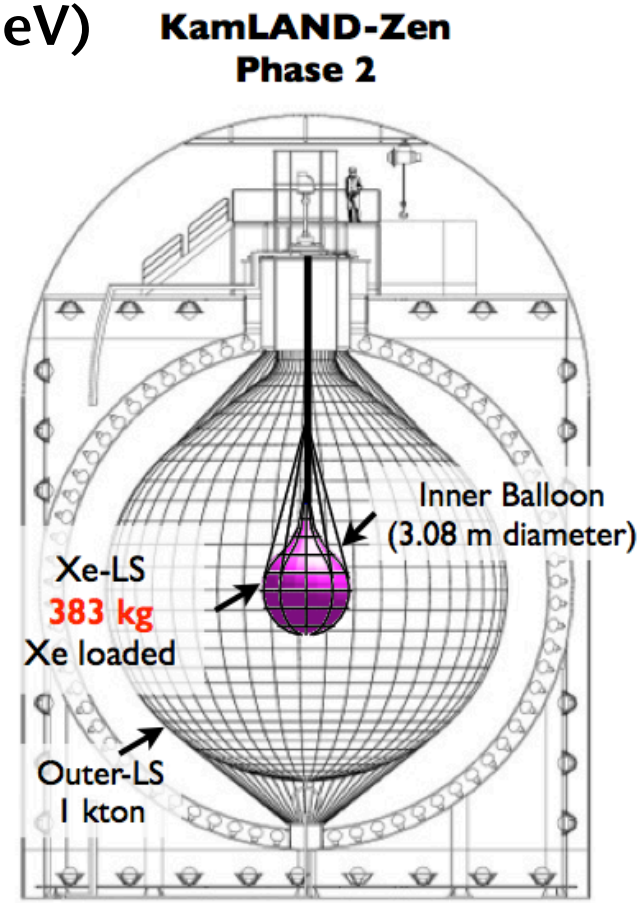
Optimization of volume selection

Vertex distribution

- Event candidate: black points (2.3 < E < 2.7 MeV)
- ^{214}Bi MC simulation: color histogram



Large ^{214}Bi BG due to leakage in diaphragm pump



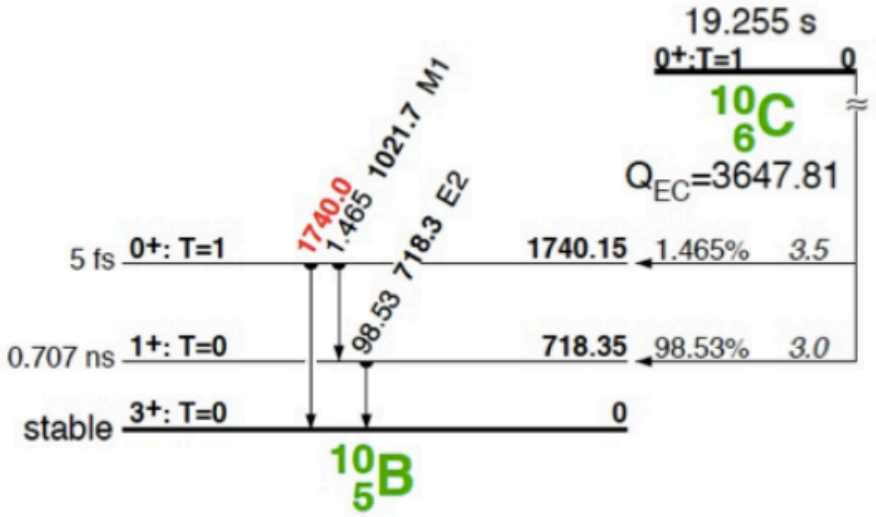
Multi-volume selection

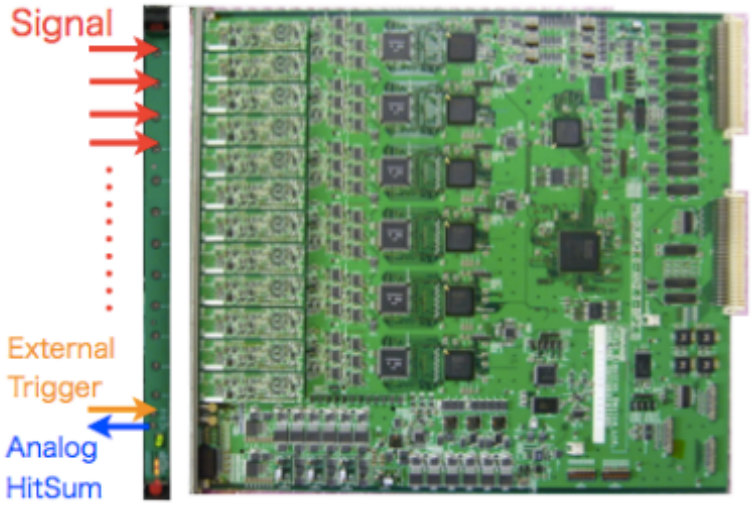
40 equal volume bins

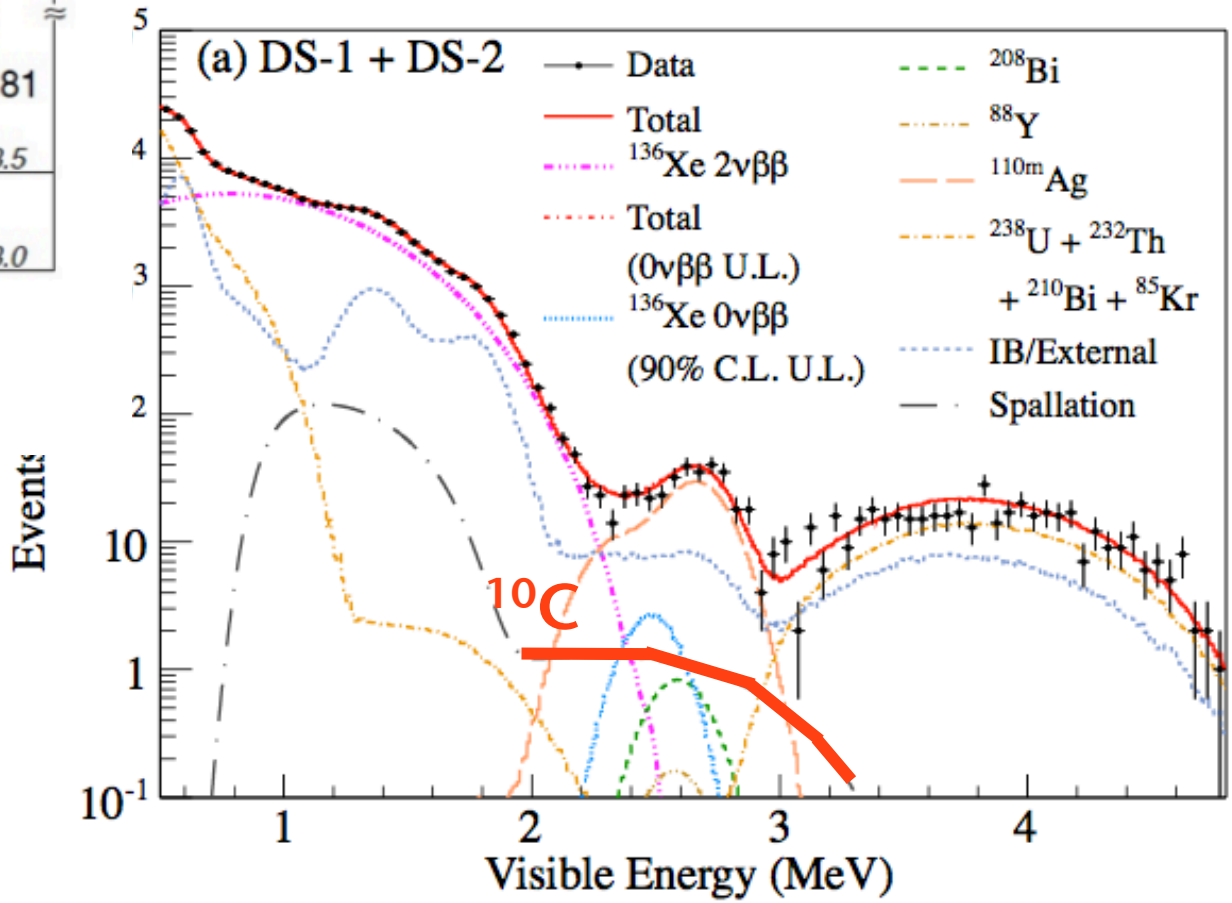
(20+20 bins in upper and lower hemisphere (r<2m))

Spallation cut after muon

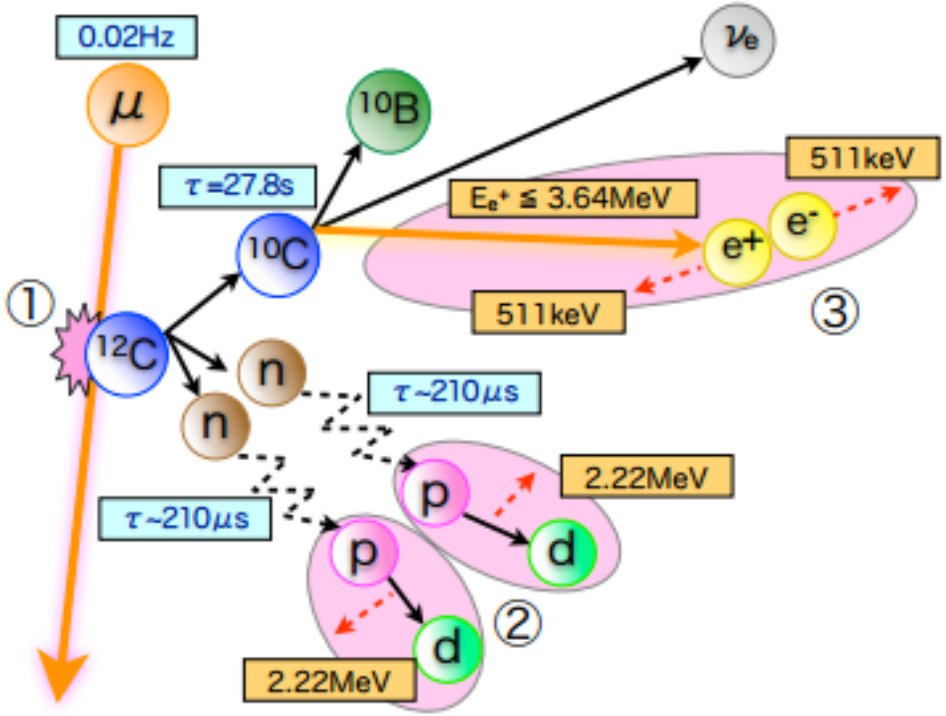
After ^{110m}Ag reduction, ^{10}C BGs are not negligible.

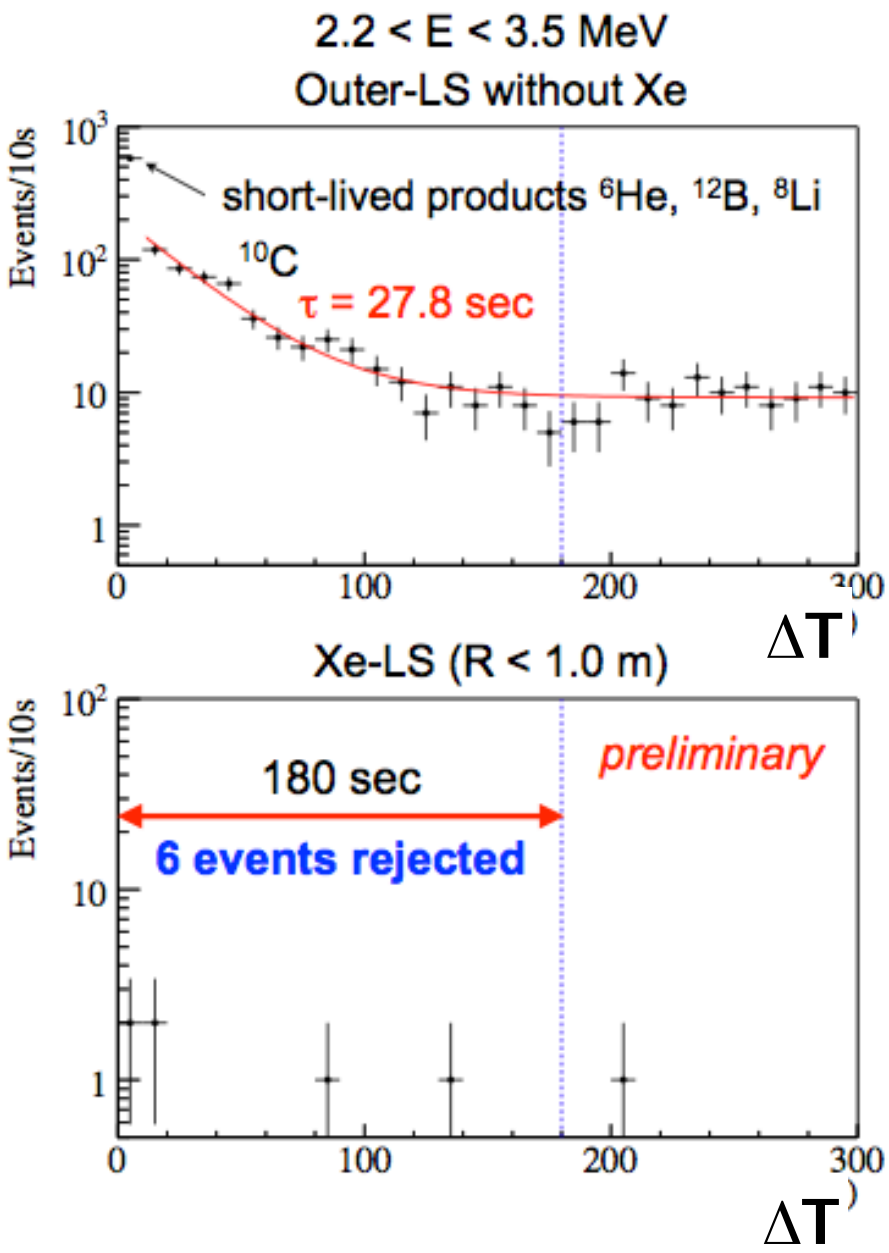






Spallation cut after muon





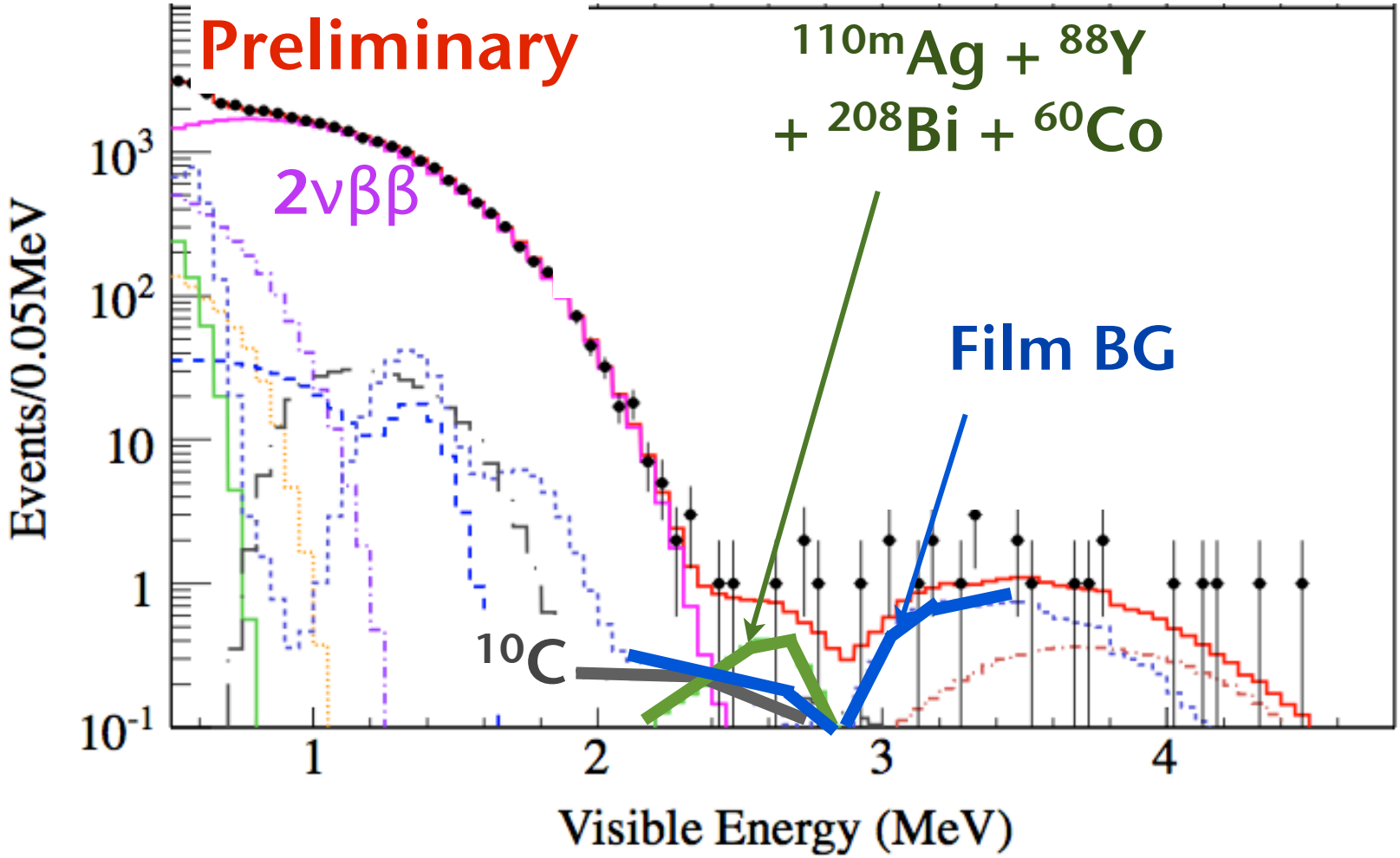
10C rejection efficiency: 72±5%

signal inefficiency: 7%

Energy spectrum (Phase-2)

Used data: Dec. 11, 2013 - May 1, 2014 (114.8days)

r < 1.0m

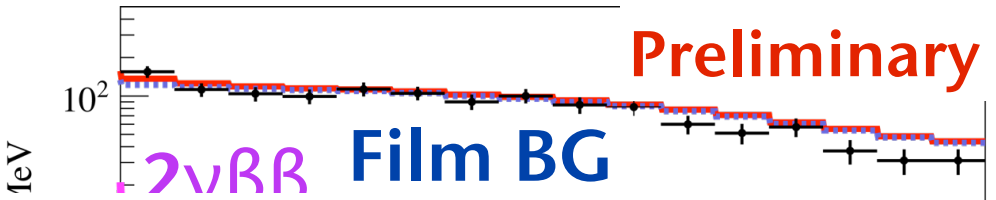


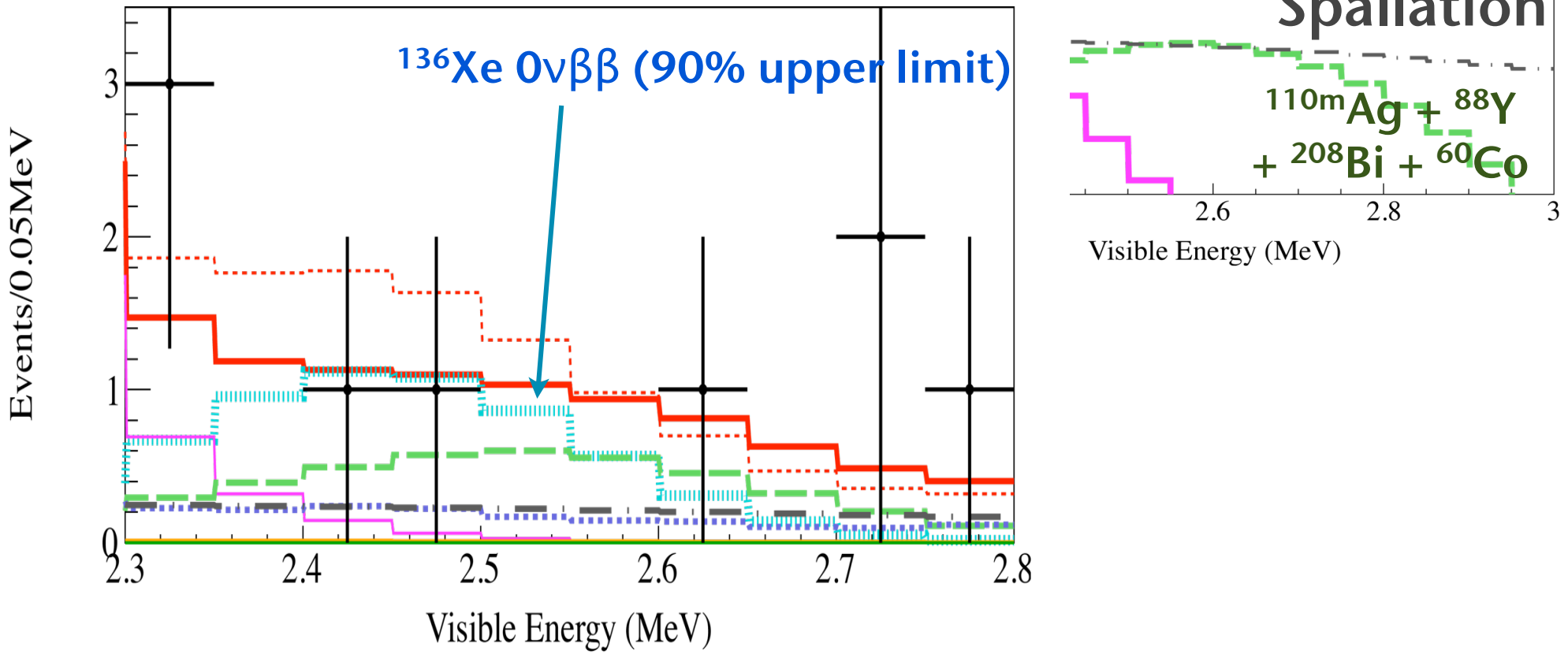
$T^{2\nu} = 2.32 \pm 0.05(stat) \pm 0.08(syst) \times 10^{21}$ yr

Fit results

R < 1m

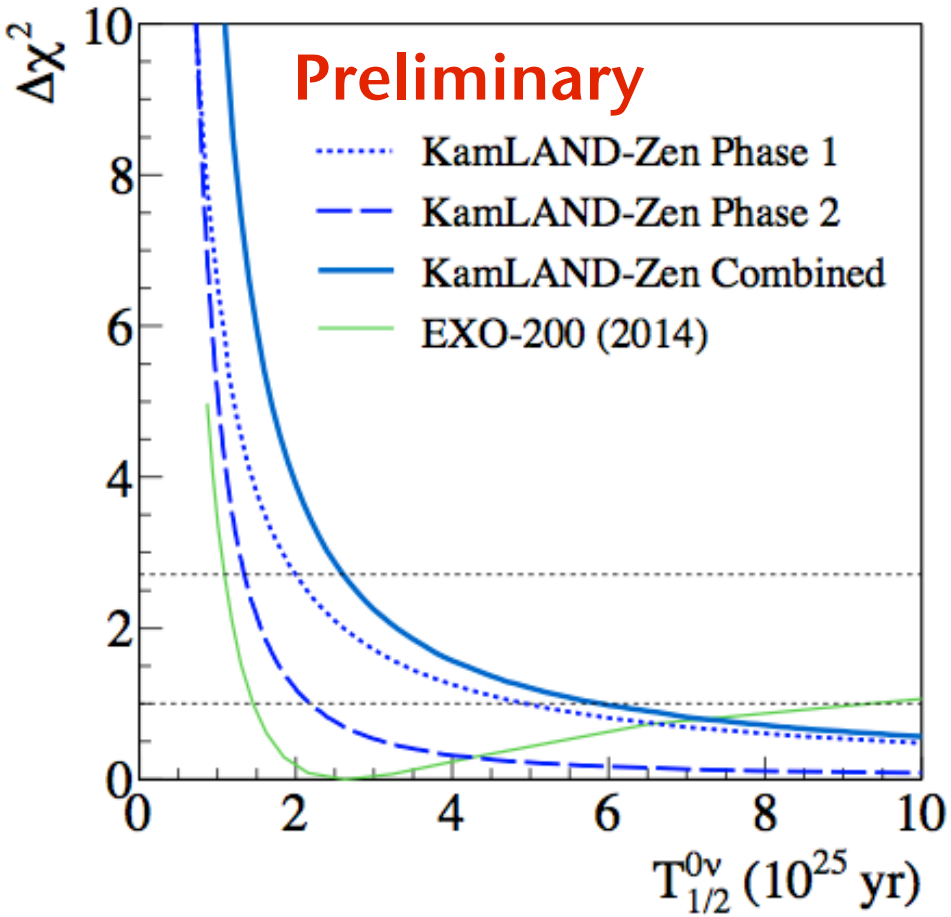
1m < R < 2m





Phase-2 result: $T^{0\nu} > 1.3 \times 10^{25}$ yr (90% C.L.)

Result of Phase-2



Phase-2 result: $T^{0\nu}$ >1.3 x 10^{25} yr (90% CL)

Phase-1 result: $T^{0\nu}$ >1.9 x 10^{25} yr (90% CL)

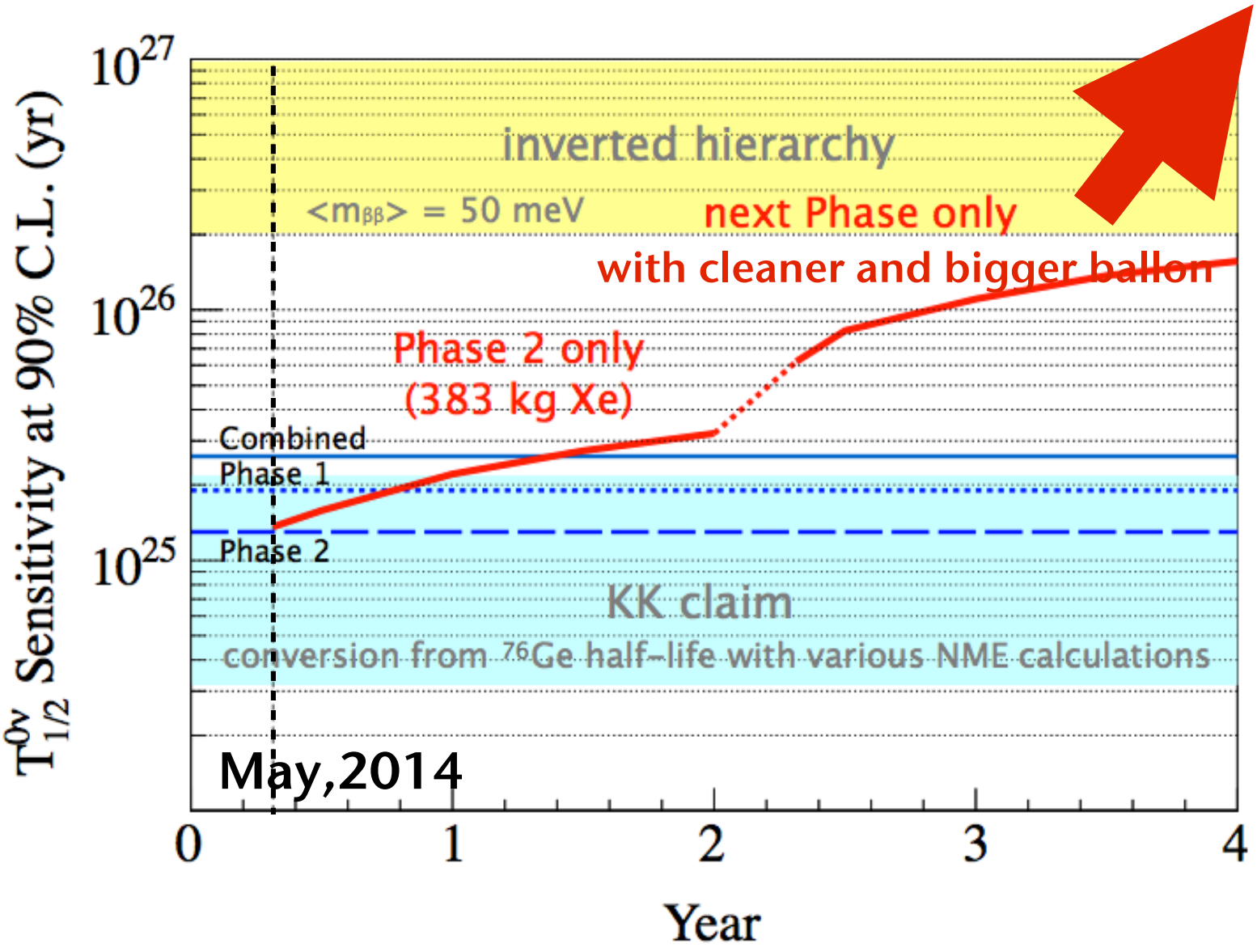
Combined result: $T^{0\nu}$ >2.6 x 10^{25} yr (90% CL)

$m_{\beta\beta}$ < 140-280 meV based on (R)QRPA models

J. of Phys. G 39, 124006 (2012)

Prospects

KamLAND2-Zen

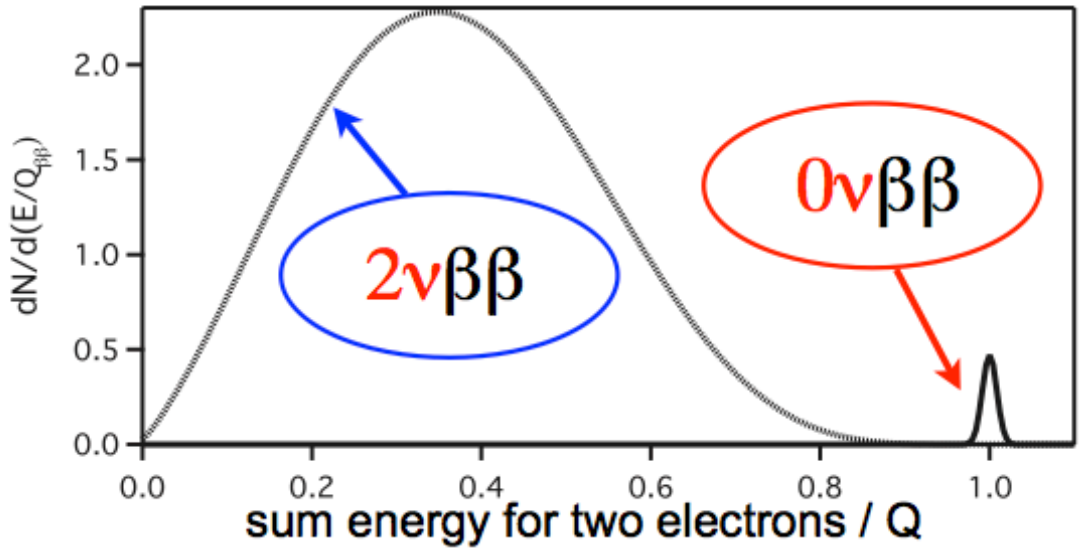


R&D for KamLAND2-Zen

1. **Improvements of energy resolution**
   -> **Reduction of 2νββ events**

$2\nu\beta\beta$ $(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\bar{\nu}_e$

$0\nu\beta\beta$ $(Z, A) \rightarrow (Z+2, A) + 2e^-$



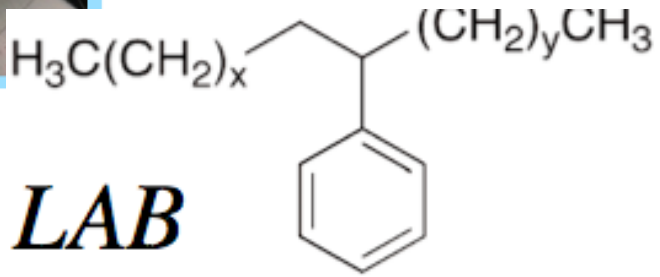
More photons

Winston cone

Higher light collection efficiency

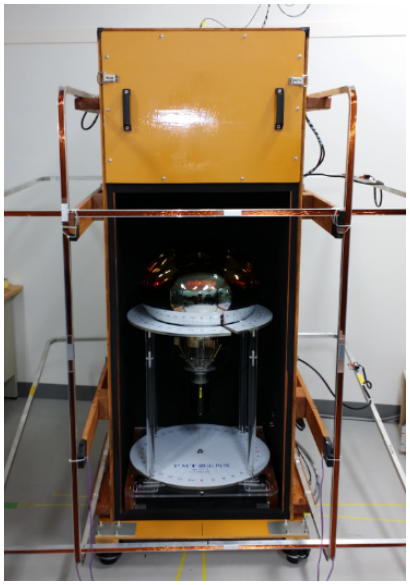
Brighter LS

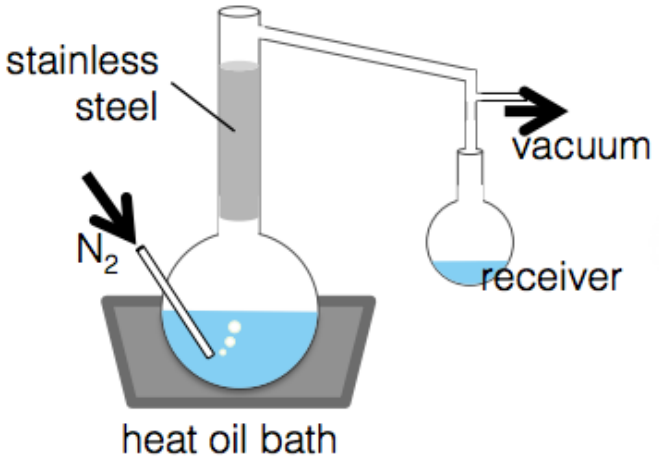
Light yield will be increased ~40%



HighQE PMT

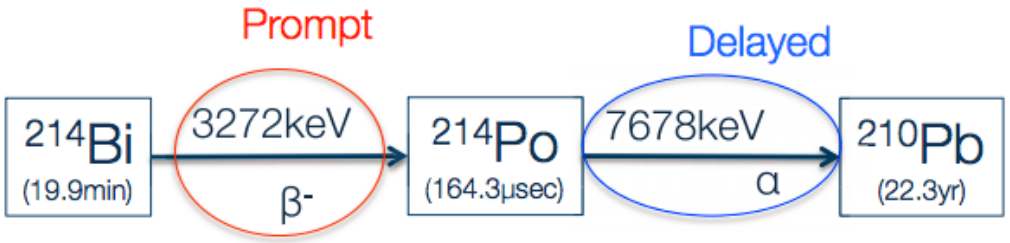
QE 21% -> 31%

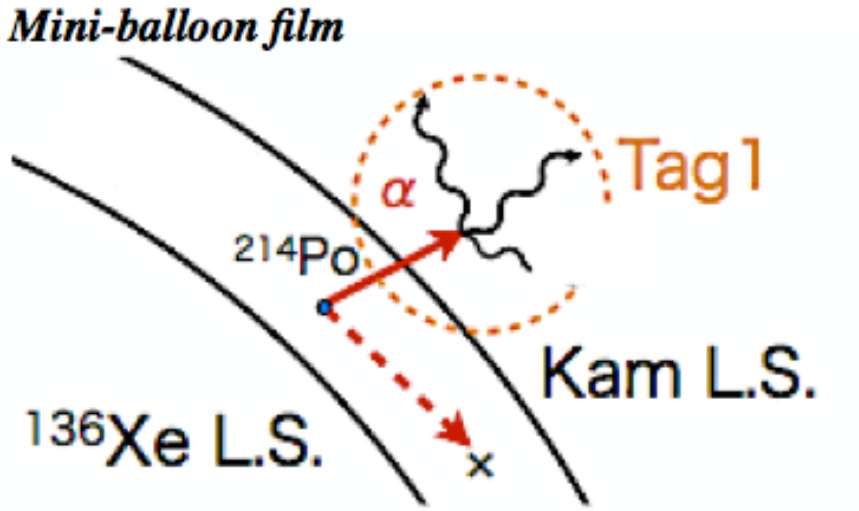




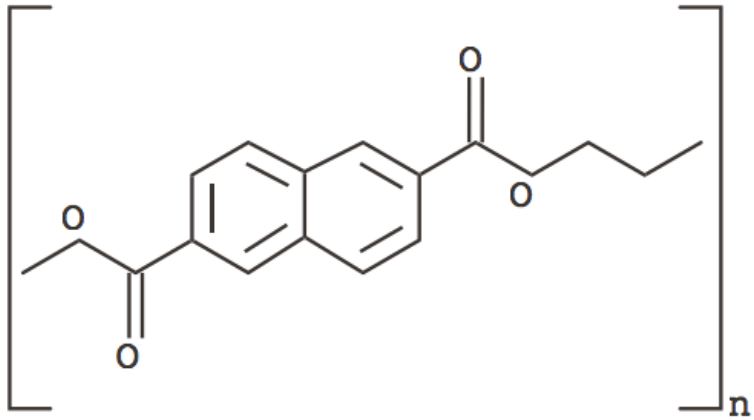
R&D for KamLAND2-Zen

2. Innovative approach
- Dead-layer free scintillation ballon





Polyethylene naphtalate

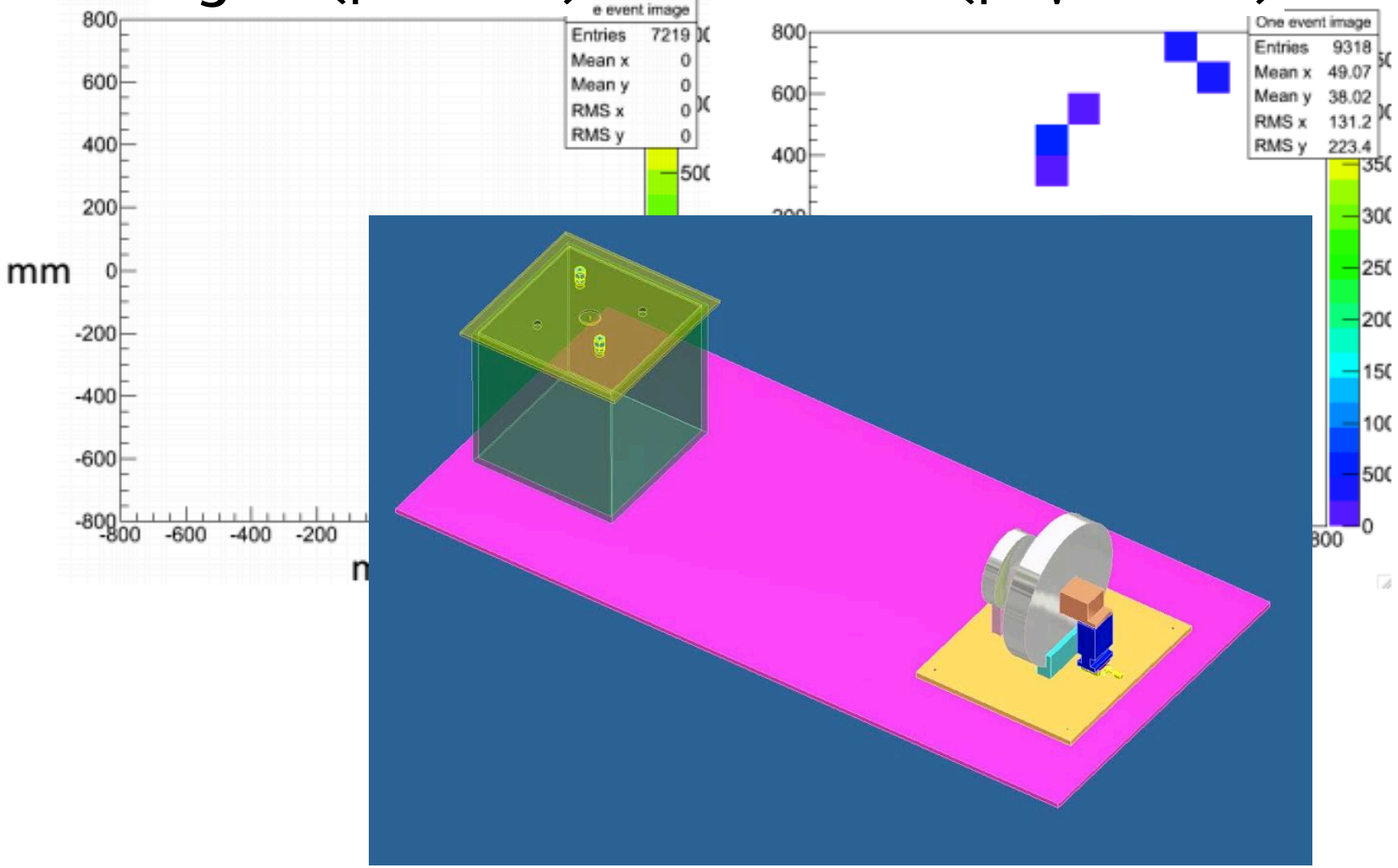


R&D for KamLAND2-Zen

2. Innovative approach
- Imaging camera

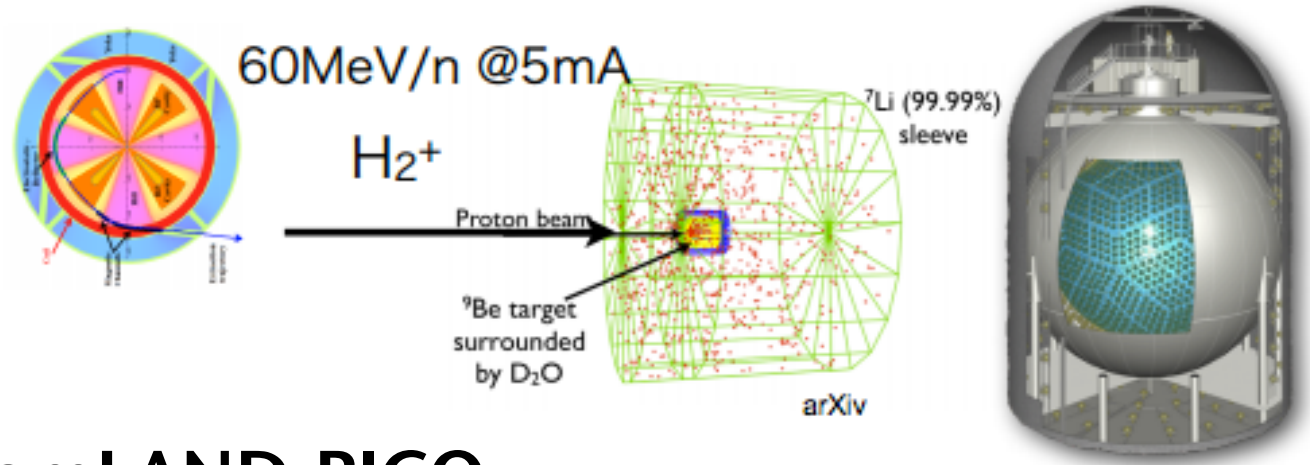
signal (β events)

BG (β+γ events)

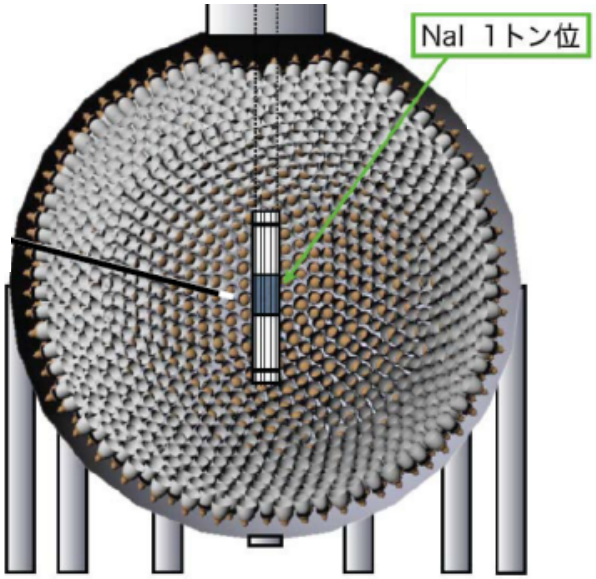


Other possibilities

IsoDAR



KamLAND-PICO



Summary

KamLAND-Zen: double-beta decay experiment

Preliminary new results were released.

Phase-1 result: $T^{0\nu} > 1.9 \times 10^{25}$ yr

Phase-2 result: $T^{0\nu} > 1.3 \times 10^{25}$ yr

Combined result: $T^{0\nu} > 2.6 \times 10^{25}$ yr

$m_{\beta\beta} < 140$-280 meV
with various (R)QRPA models

- Phase 2 will continue for about one year
- 600-700kg phase was already funded
- Several R&D for KamLAND2-Zen is ongoing
to search for $0\nu\beta\beta$ decay in the inverted mass hierarchy
- future possibilities (IsoDAR, KamLAND-PICO)