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on Directional Dark Matter Detection
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KamLAND-Zen Experiment
for Zero Neutrino Double Beta Decay Search

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KamLAND-Zen Collaboration

KamLAND: **Kam**ioka **L**iquid scintillator **A**nti-**N**eutrino **D**etector
Zen: **Ze**ro **n**eutrino double beta decay search

- **Research Center for Neutrino Science, Tohoku University**
  A. Gando, Y. Gando, H. Hanakago, H. Ikeda, K. Inoue, K. Ishidoshiro, R. Kato, M. Koga, S. Matsuda, T. Mitsui, D. Motoki, T. Nakada, K. Nakamura, A. Obata, A. Oki, Y. Ono, M. Otani, I. Shimizu, J. Shirai, A. Suzuki, Y. Takemoto, K. Tamae, K. Ueshima, H. Watanabe, B.D. Xu, S. Yamada, H. Yoshida
- **Kavli IPMU, University of Tokyo** A. Kozlov
- **Osaka University** S. Yoshida
- **University of California Berkeley and LBNL**
  T.I. Banks, S.J. Freedman, B.K. Fujikawa, K. Han, T. O'Donnell
- **Colorado State University** B.E. Berger
- **University of Tennessee** Y. Efremenco
- **TUNL** H.J. Karwowski, D.M. Markoff, W. Tornow
- **University of Washington** J.A. Detwiler, S. Enomoto
- **NIKHEF and University of Amsterdam** M.P. Decowski

A total of 42 members

(as at 7 February 2013)

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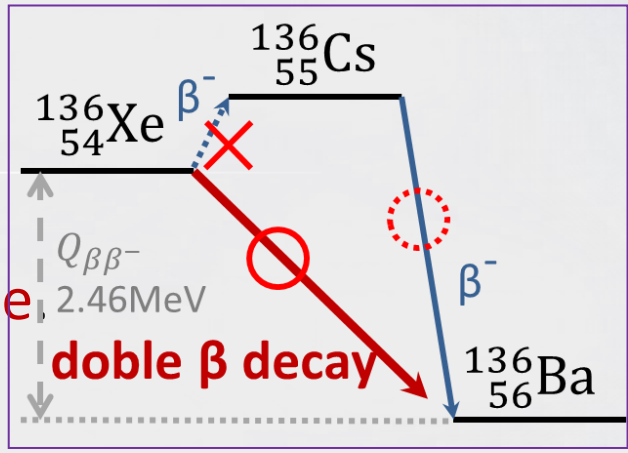
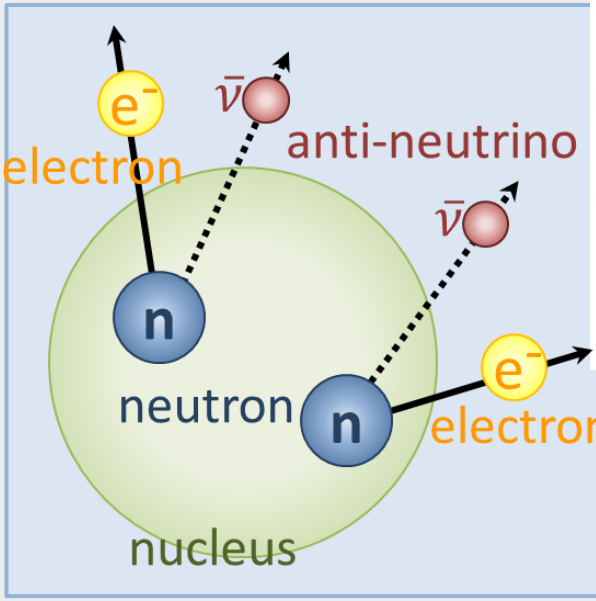
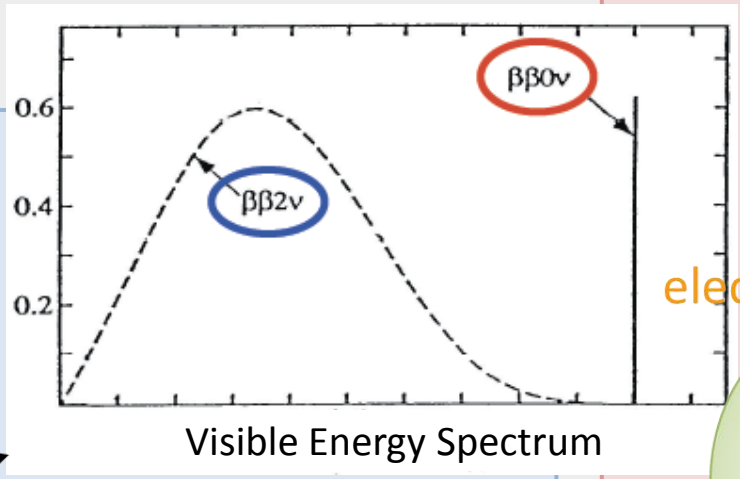
Double Beta Decay



- One beta decay is energetically prohibited.
  Only two simultaneous beta decays are possible.
- A number of double beta nuclei exists.
  ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{136}Xe, ^{150}Nd etc…
- Two different modes can be possible.

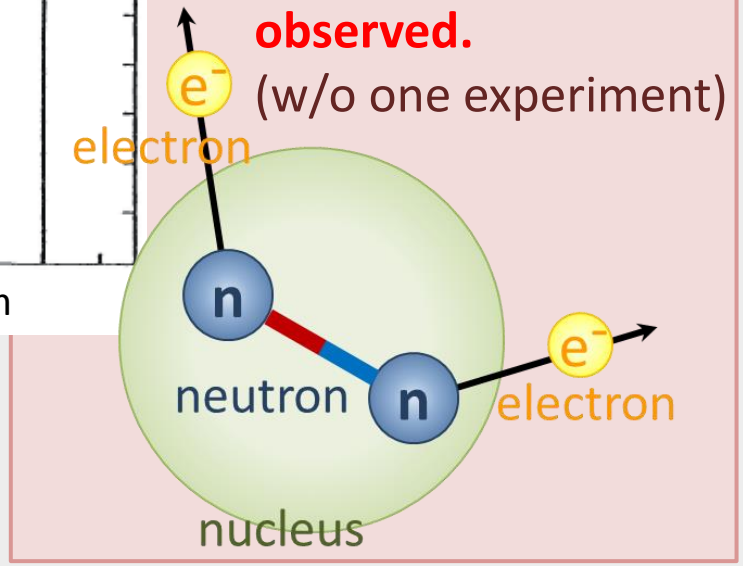




Visible Energy Spectrum

2νββ
Previously observed for several nuclei.

0νββ
Still has not been observed.
(w/o one experiment)



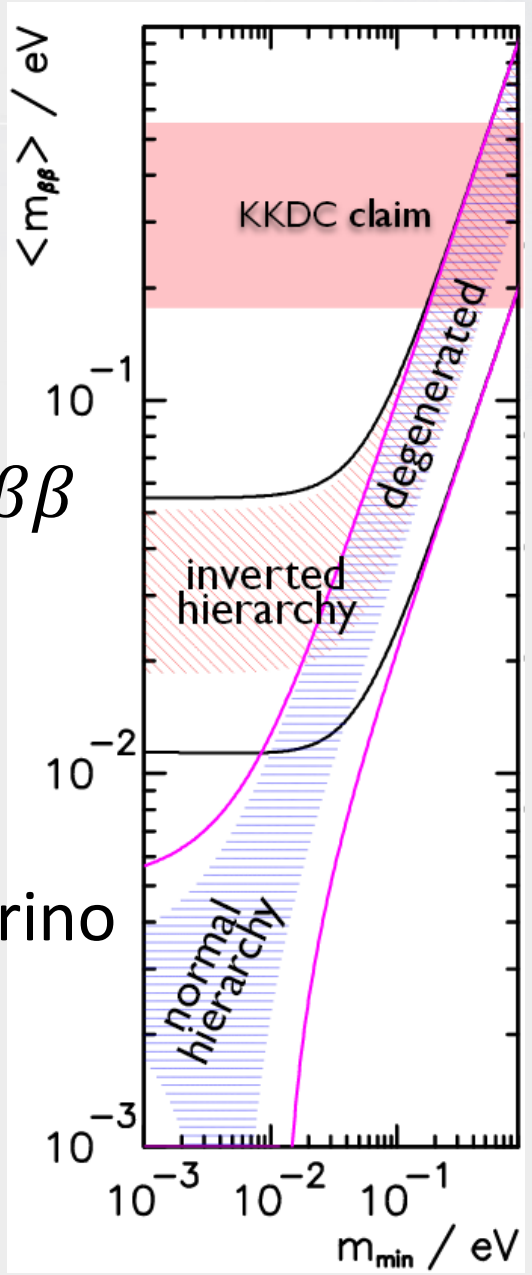
Motivations of 0νββ Search

- Lepton number violation
  - ⇨ Forbidden in the Standard Model
- Only *Majorana neutrinos* can decay by $0\nu\beta\beta$ $(\nu = \bar{\nu})$
  - ⇨ Hint for See-Saw Mechanism
    Leptogenesis of universe
- Effective mass and Mass hierarchy of neutrino

Decay rate Nuclear matrix element

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

Phase factor Effective neutrino mass



Current Situation in the World

Experiment	Nucleus	Exposure [kg-yr]	$T^{0\nu}_{1/2}$ [yr] 90% C.L.	$\langle m_{\beta\beta} \rangle$ [eV]
KamLAND-Zen	$^{136}Xe \rightarrow {}^{136}Ba$	89.5	$>1.9 \times 10^{25}$	<0.12-0.25*
EXO-200	$^{136}Xe \rightarrow {}^{136}Ba$	32.5	$>1.6 \times 10^{25}$	<0.14-0.38
CUORICINO	$^{130}Te \rightarrow {}^{130}Xa$	19.75	$>2.8 \times 10^{24}$	<0.30-0.71
Heidelberg-Moscow	$^{76}Ge \rightarrow {}^{76}Se$	35.5	$>1.9 \times 10^{25}$	<0.35
NEMO-3	$^{82}Se \rightarrow {}^{82}Kr$	6.3	$>1.5 \times 10^{22}$	<1.5-3.1
	$^{96}Zr \rightarrow {}^{96}Mo$	0.031	$>9.2 \times 10^{21}$	<7.2-19.5
	$^{100}Mo \rightarrow {}^{100}Rn$	6.3	$>2.7 \times 10^{22}$	<0.8-1.2
	$^{150}Nd \rightarrow {}^{150}Sm$	0.093	$>1.8 \times 10^{22}$	<4.0-6.3

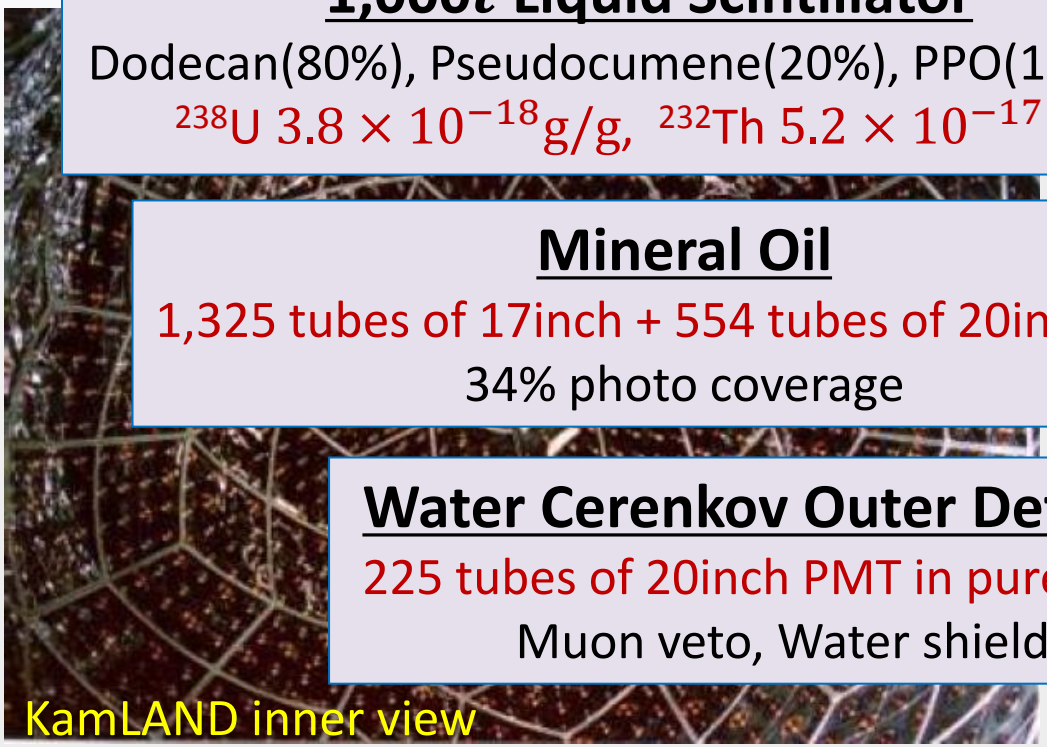
* Combined with EXO-200

Part of the Heidelberg-Moscow group claimed signal (KKDC claim)

$T^{0\nu}_{1/2} = 2.33^{+0.44}_{-0.31} \times 10^{25}$yr, $\langle m_{\beta\beta} \rangle$ = 0.18-0.43 eV (2σ C.L.)

Some experiments are running near the claim.
->GERDA(^{76}Ge), CUORE(^{130}Te), EXO and KamLAND-Zen (^{136}Xe)

KamLAND Experiment



1,000t Liquid Scintillator

Dodecan(80%), Pseudocumene(20%), PPO(1.36g/ℓ)

^{238}U 3.8×10^{-18}g/g, ^{232}Th 5.2×10^{-17}g/g

Mineral Oil

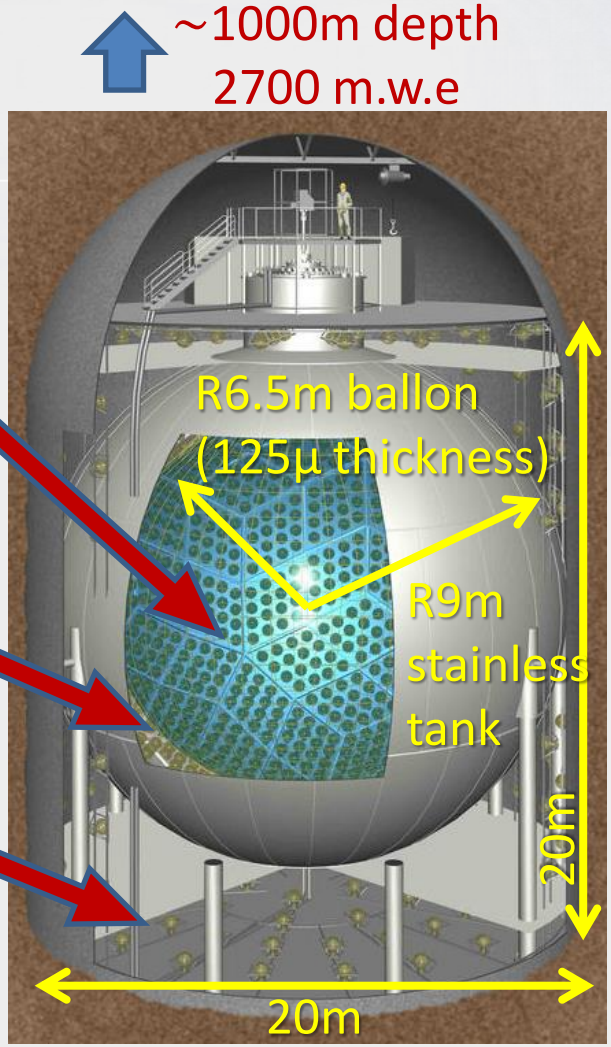
1,325 tubes of 17inch + 554 tubes of 20inch PMT

34% photo coverage

Water Cerenkov Outer Detector

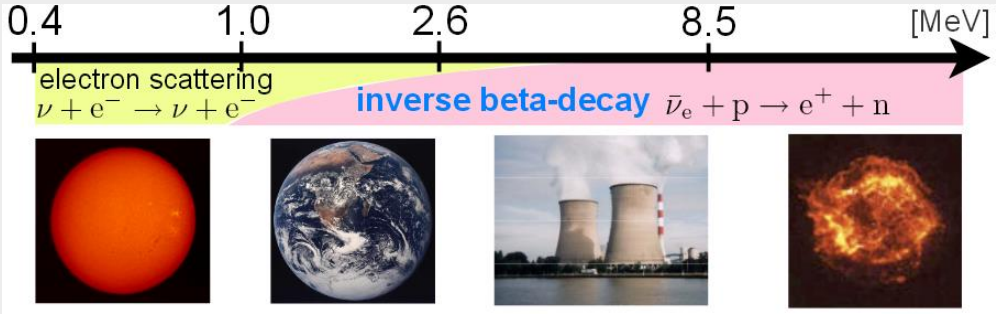
225 tubes of 20inch PMT in pure water

Muon veto, Water shield

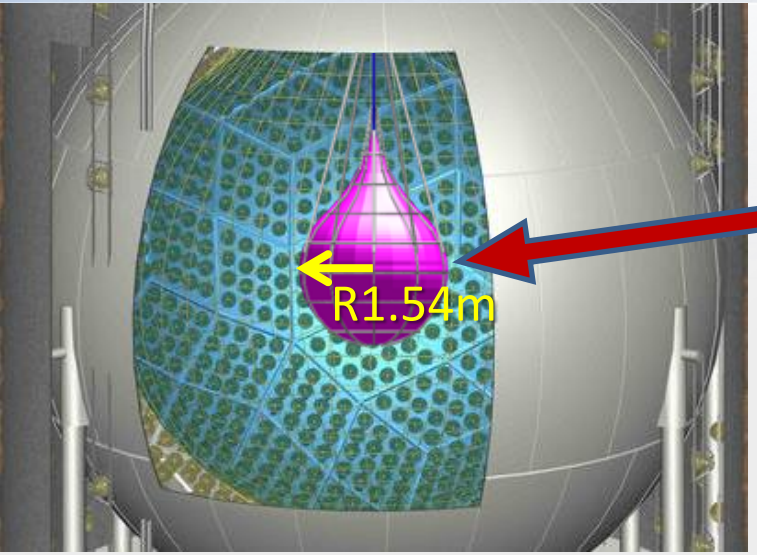


- **Wide energy range, ultra-low BG**
- **Many physics results**

solar neutrinos, *geo neutrinos*,
reactor neutrinos, *supernova neutrinos*
etc…



KamLAND-Zen Experiment



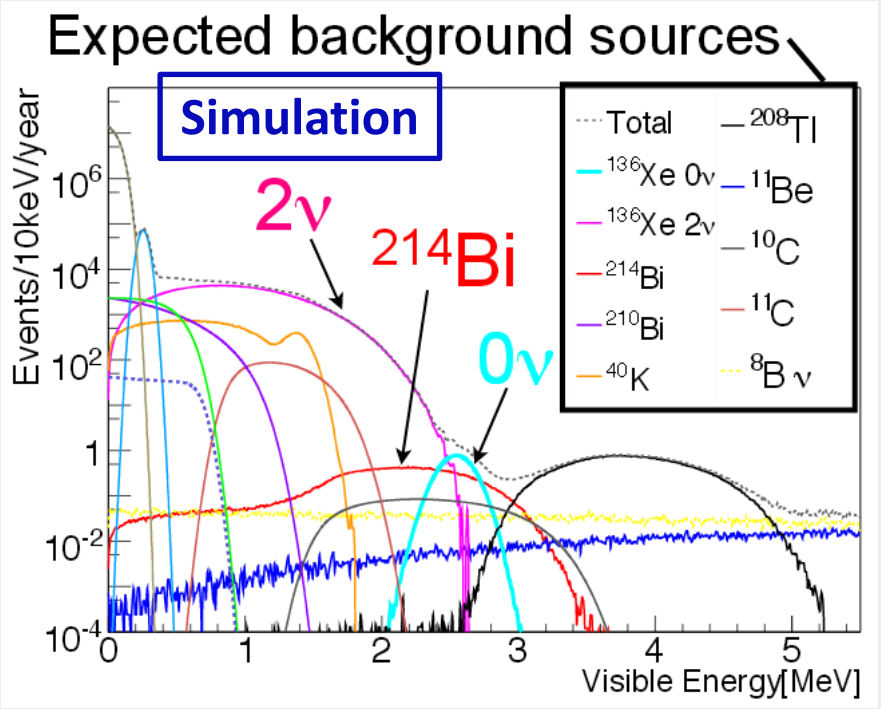
Mini-Balloon

25μm thickness nylon film, 17m^3 volume

Xe loaded LS

PC(18%,) Decan(82%), PPO(2.7g/ℓ)

+ Xe gas(2.44wt%) 136Xe 91% enriched



Xe advantage

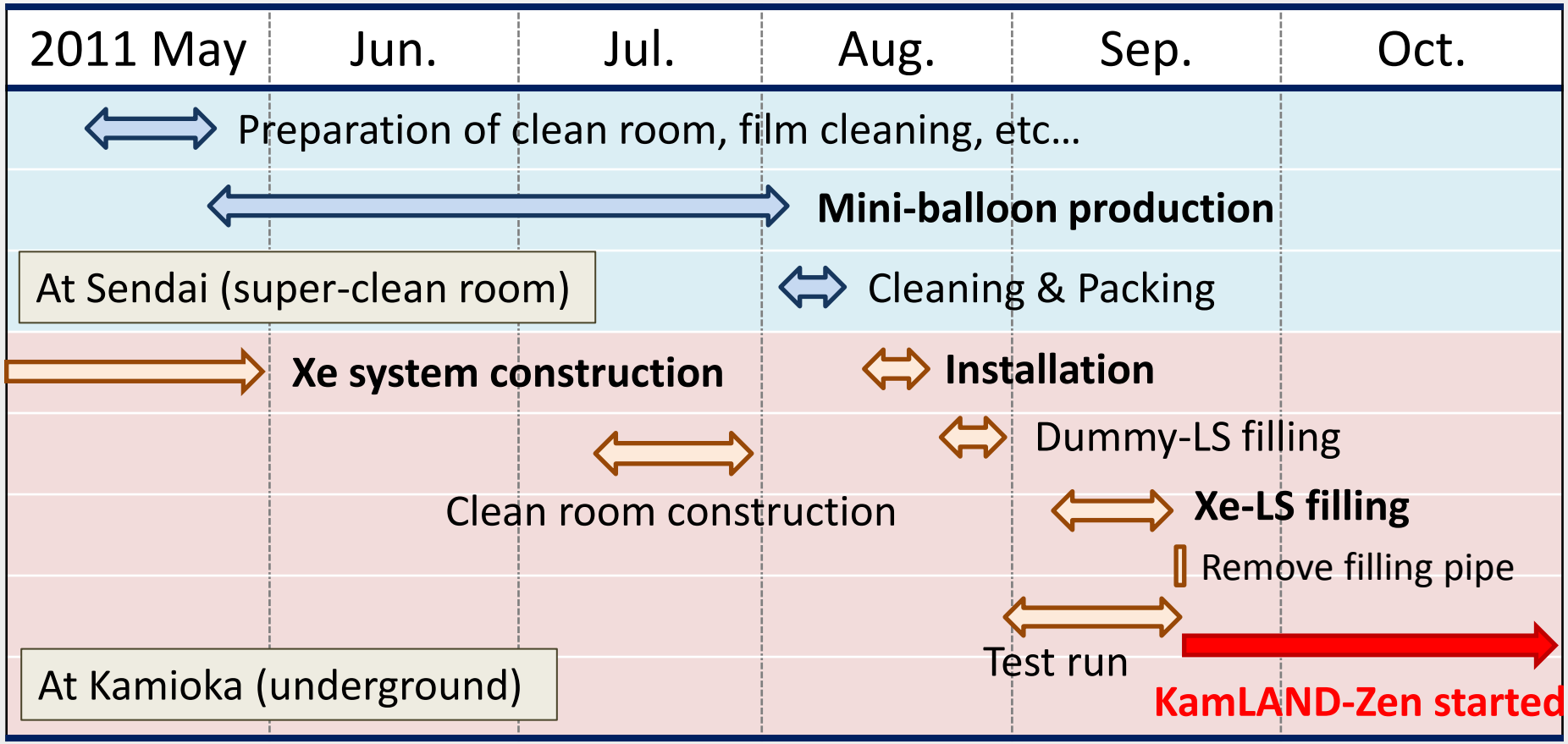
1. Isotopic enrichment is available
2. Purification method is established
3. Solubility to LS >3 wt%
4. Slow 2ν rate so good separation with 0ν

+ Large scale and Low BG of KamLAND

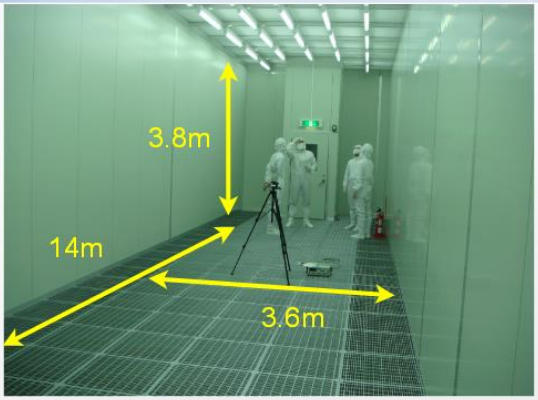
$\langle m_\nu \rangle = 150$meV, Xe:400kg

Detector Construction

- Quick and smooth construction and installation.
- KamLAND-Zen 1st phase started since Sep. 24, 2011



Mini-Balloon Production



Class 1 clean room at Sendai, Tohoku University's facility

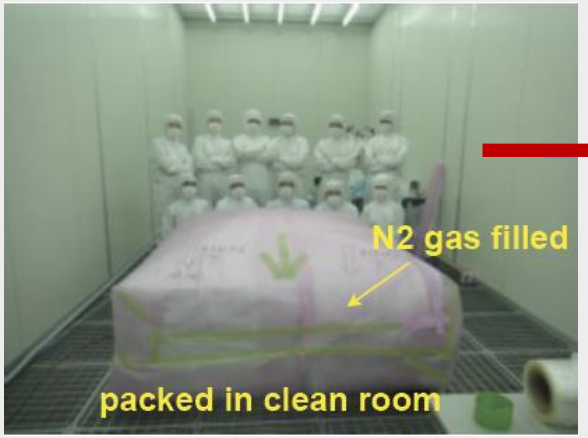
Ultra-sonic cleaning using ultra-pure water

A roll for bringing

Heat welding

Material Characters

Transparency at 400nm		99.1%
Breaking strength		>20 [N/cm]
Xe leakage		<0.26 [kg/year]
Radioactive Impurities	^{238}U	1.9×10^{-12}g/g
	^{232}Th	4.9×10^{-12}g/g
	^{40}K	5.6×10^{-12}g/g

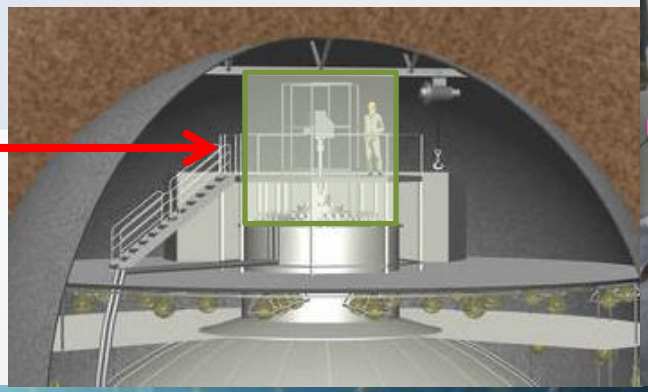


To Kamioka Underground

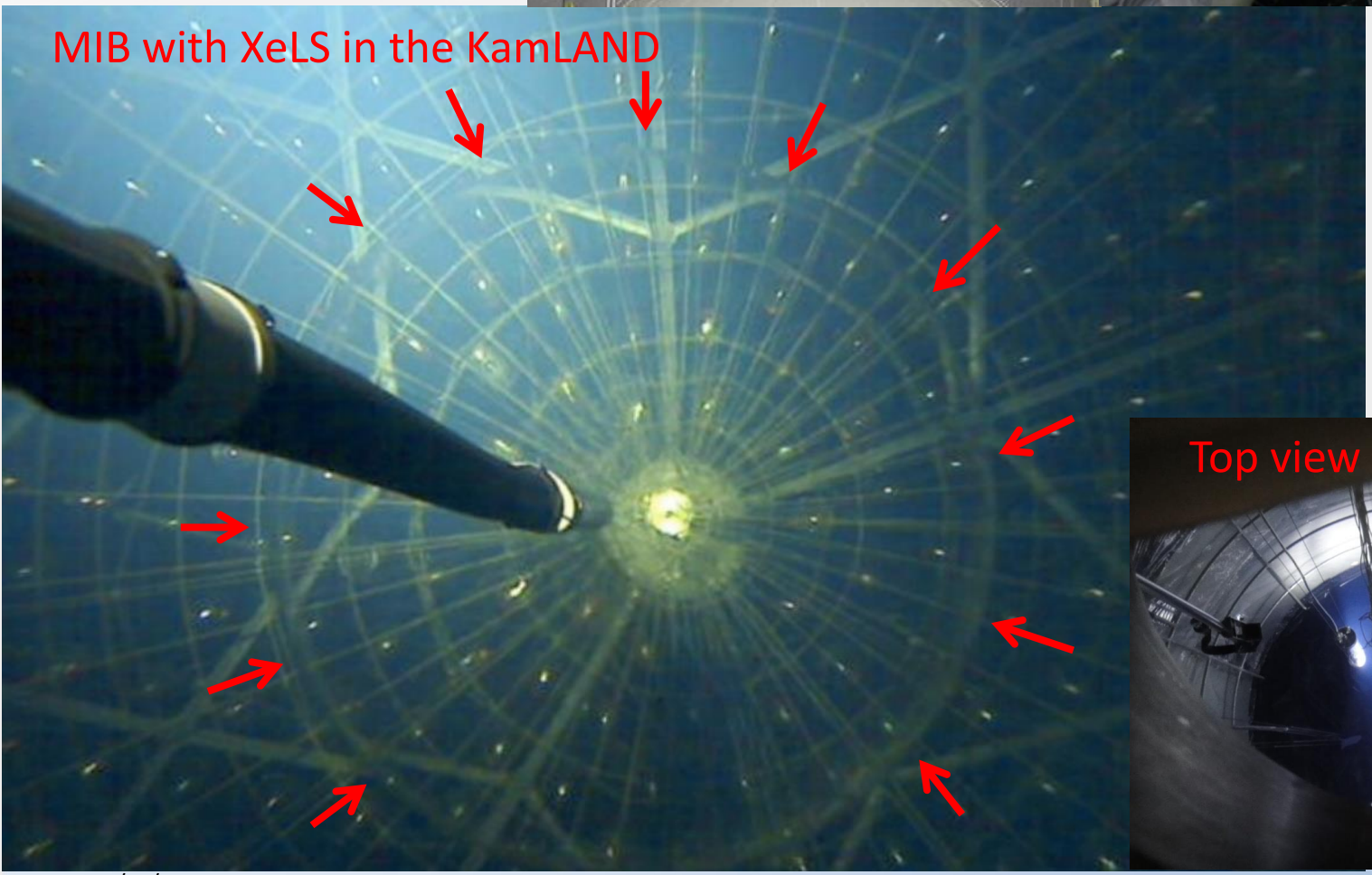
Preparetion of Xe Loaded LS

Installation

Class 10
Clean room

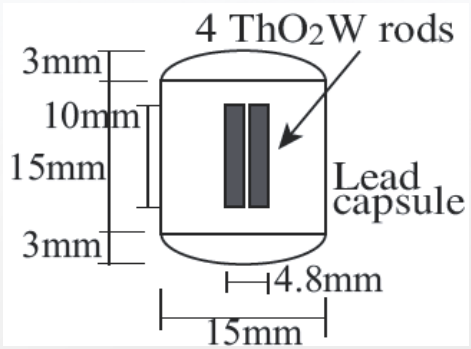


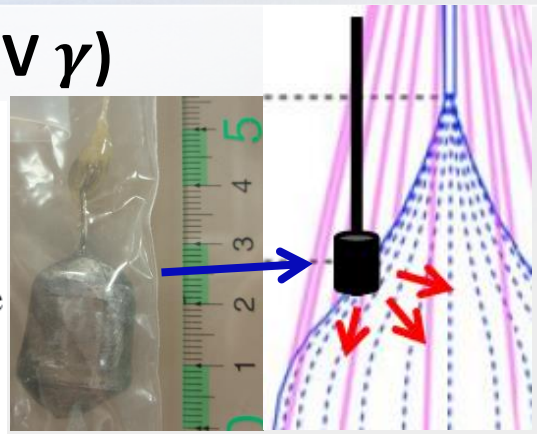
MIB with XeLS in the KamLAND

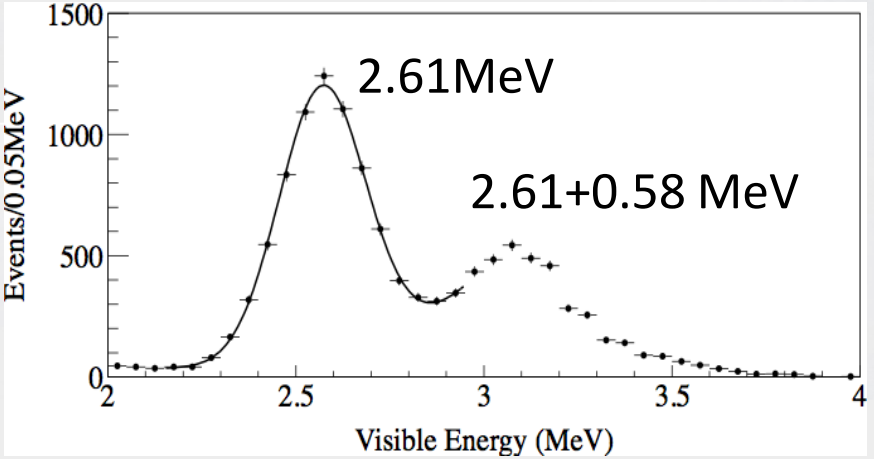


Calibration

- **208Tl (2.61MeV γ)**







$$\sigma = (6.6 \pm 0.3)\%/\sqrt{E[\mathrm{MeV}]}$$

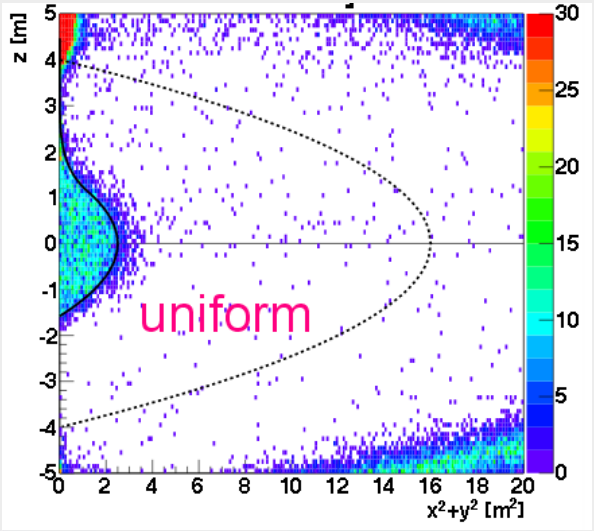
- **214Bi ($\beta + \gamma$)**

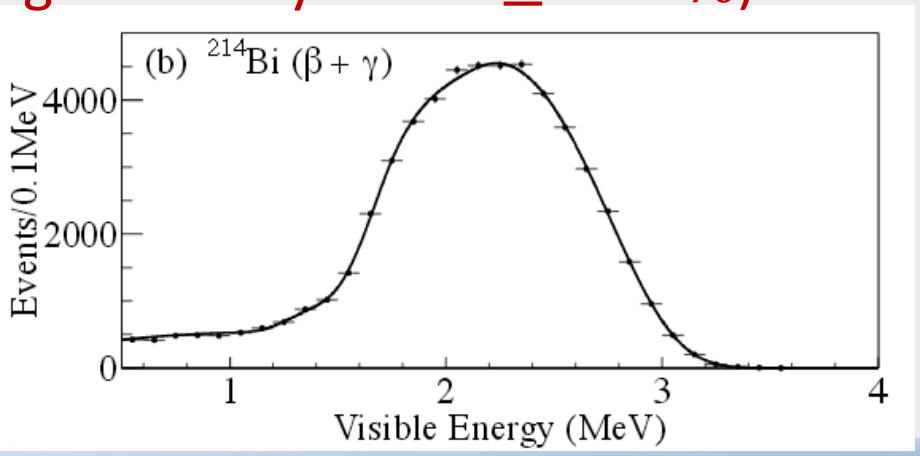
Sequential decay of ^{214}Bi-^{214}Po

Identifiable by delayed coincidence

(Tagging efficiency $99.97 \pm 0.01\%$)

Vertex Distribution





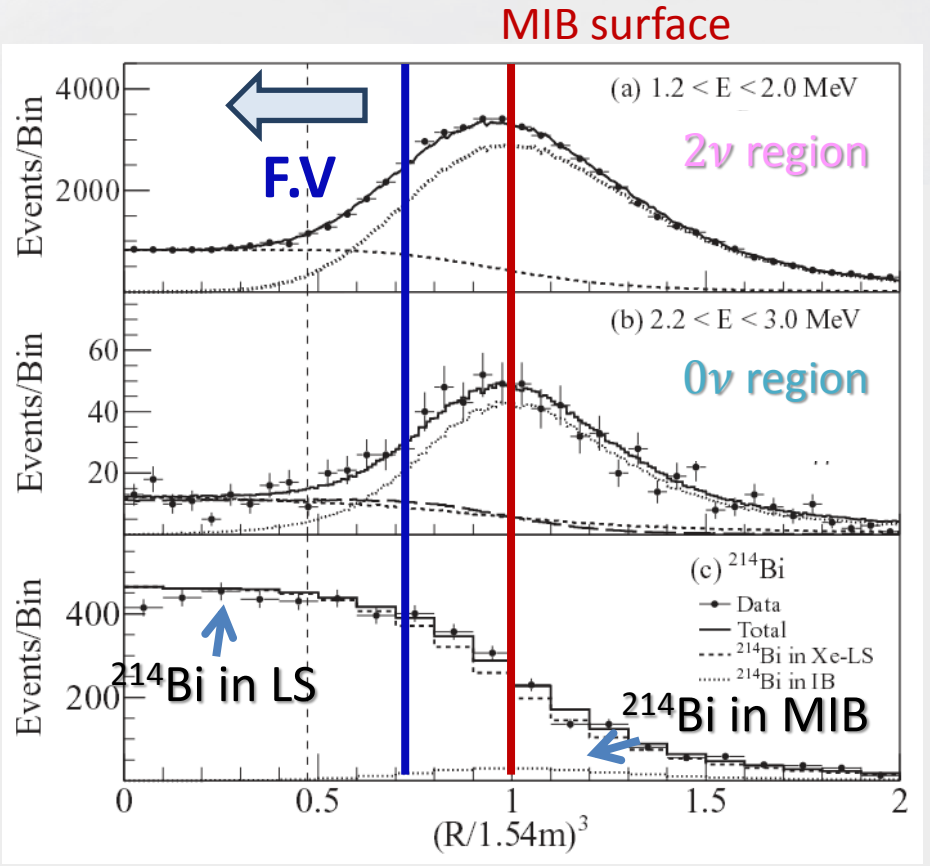
Fiducial Volume

DS2 has inlet pipe in MIB for several activities.

	DS1	DS2
Live time [day]	112.3	101.1
Fiducial Xe-LS mass [ton]	8.04	5.55
Xe concentration [wt%]	2.44	2.48
^{136}Xe mass [kg]	179	125
^{136}Xe exposure [kg-yr]	54.9	34.6

- Systematic Uncertainties

Fiducial Volume	4.0 %
Enrichment of ^{136}Xe	0.05 %
Xe amount	0.36 %
Energy scale	0.3 %
Detection efficiency	0.2%
Total	3.9%

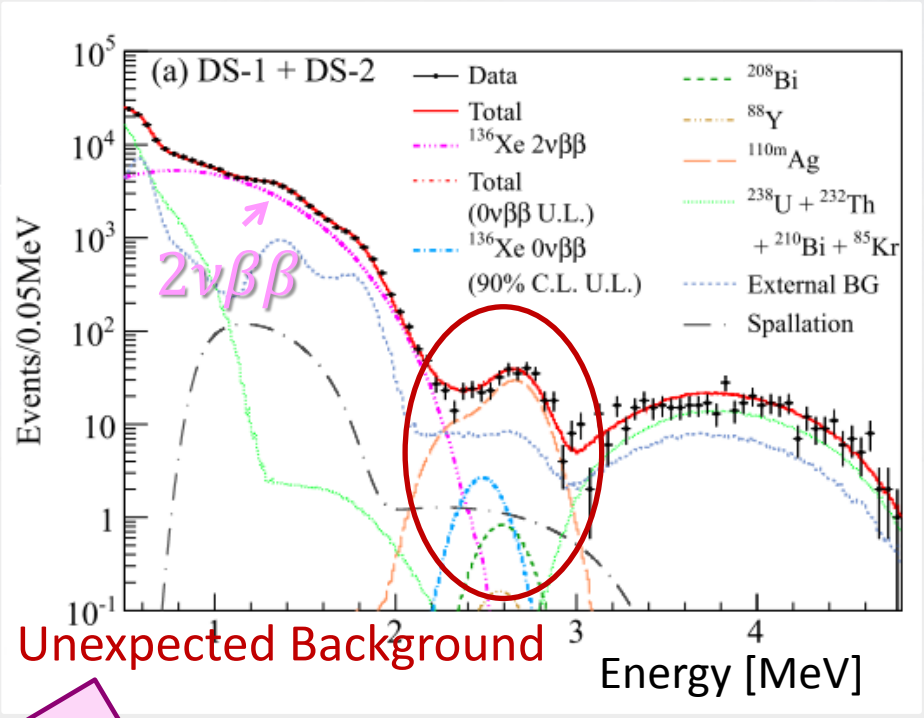


Fiducial Volume is estimated with ^{214}Bi rate of inside balloon.
Systematic Error of F.V. is dominant.

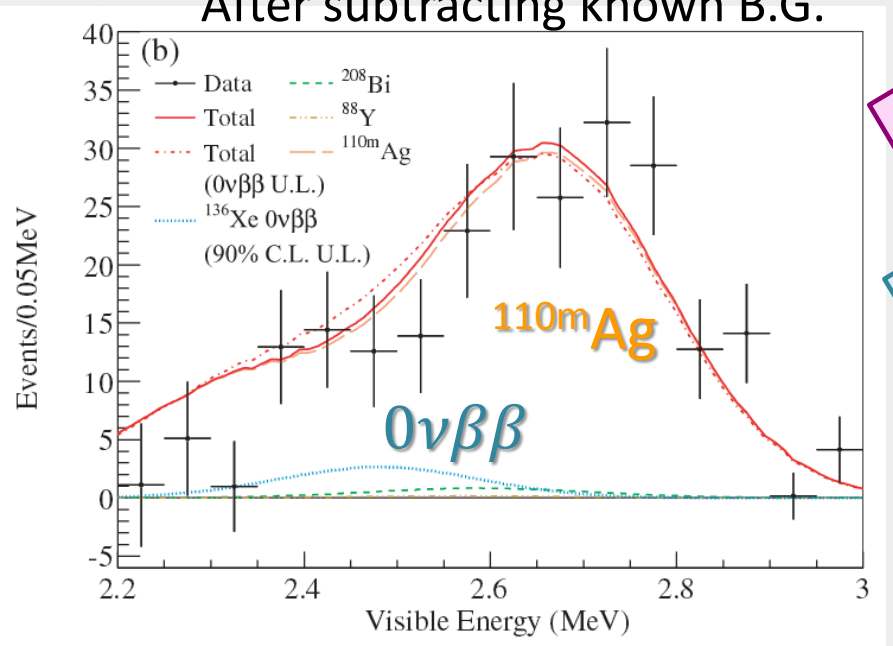
Recent Results

- Event Selection

1. Fiducial Cut
2. 2ms veto after muon
3. Remove Bi-Po events
4. Anti-nu CC reaction cut
5. Vertex-time-charge test to cut noise



After subtracting known B.G.



2νββ

$$T_{1/2}^{2\nu} = 2.30 \times 10^{21}\text{year}$$
$$\pm 0.02(stat.) \pm 0.14(sys.)$$

0νββ

$$T_{1/2}^{0\nu} > 1.9 \times 10^{25}\text{yr} \quad 90\%\ \text{C.L.}$$

Background

Half-life & energy spectrum fitting

⇒ Identified as ^{110m}Ag

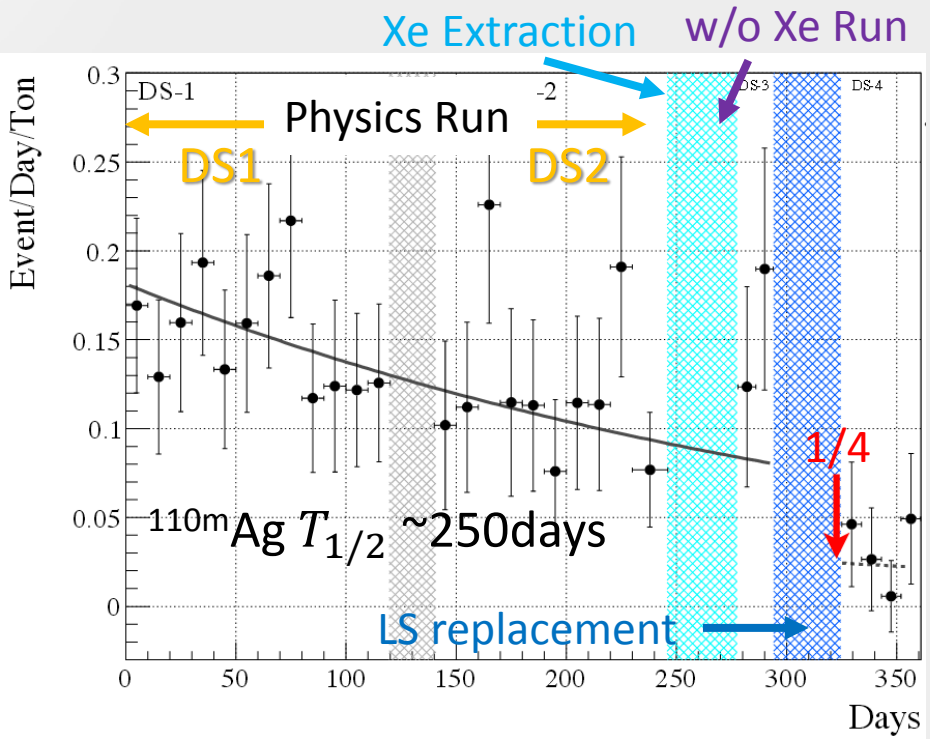
After Xe Extraction

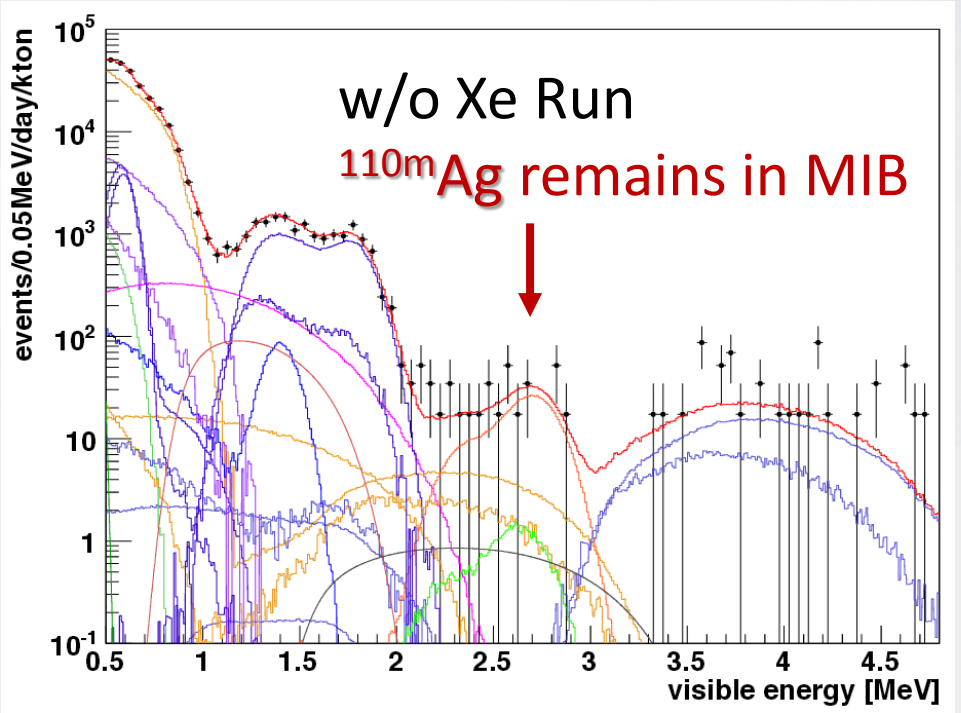
Extraction Xe from MIB

- Check $2\nu\beta\beta$ disappear
- B.G. remains in MIB
- Confirm not 0ν

Extracted Xe was collected into botlle

➡ Will be purified by distillation





Replacement with new LS

- To remove ^{110m}Ag from MIB

Reduction factor was 1/4.

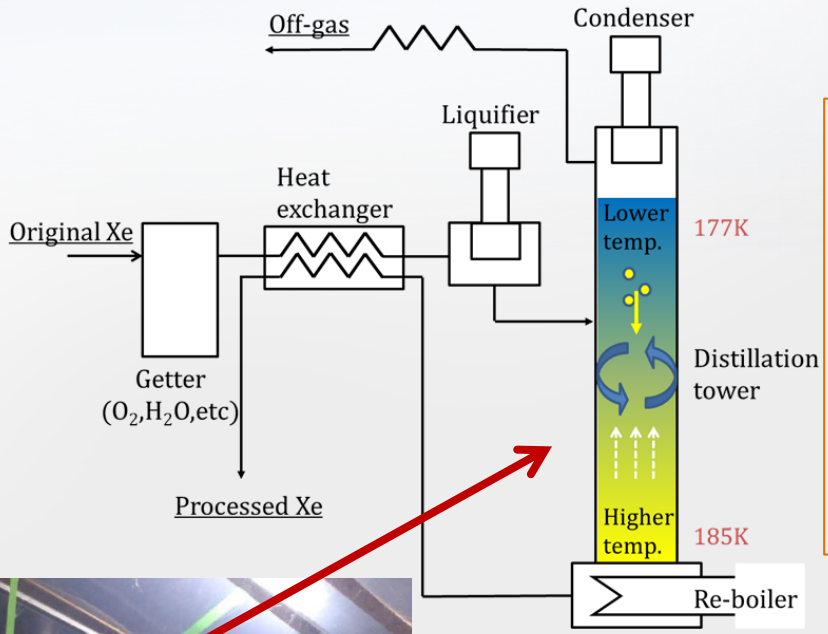
^{110m}Ag on balloon surface remains and diffused into LS

Need to more reduction

Target->1/100

Purification for Xe

New item for KamLAND-Zen
The System is provided by XMASS group
K.Abe *et. al*, Astropart. Phys. 31,290-296(2009)

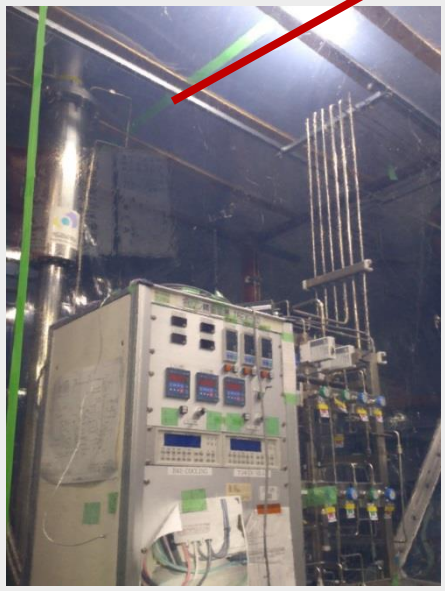


Developed for Kr removal from Xe.

Number of theoretical column: 6

Process speed: 0.6 kg Xe/h

Higher boiling point materials than Xe can be removed.



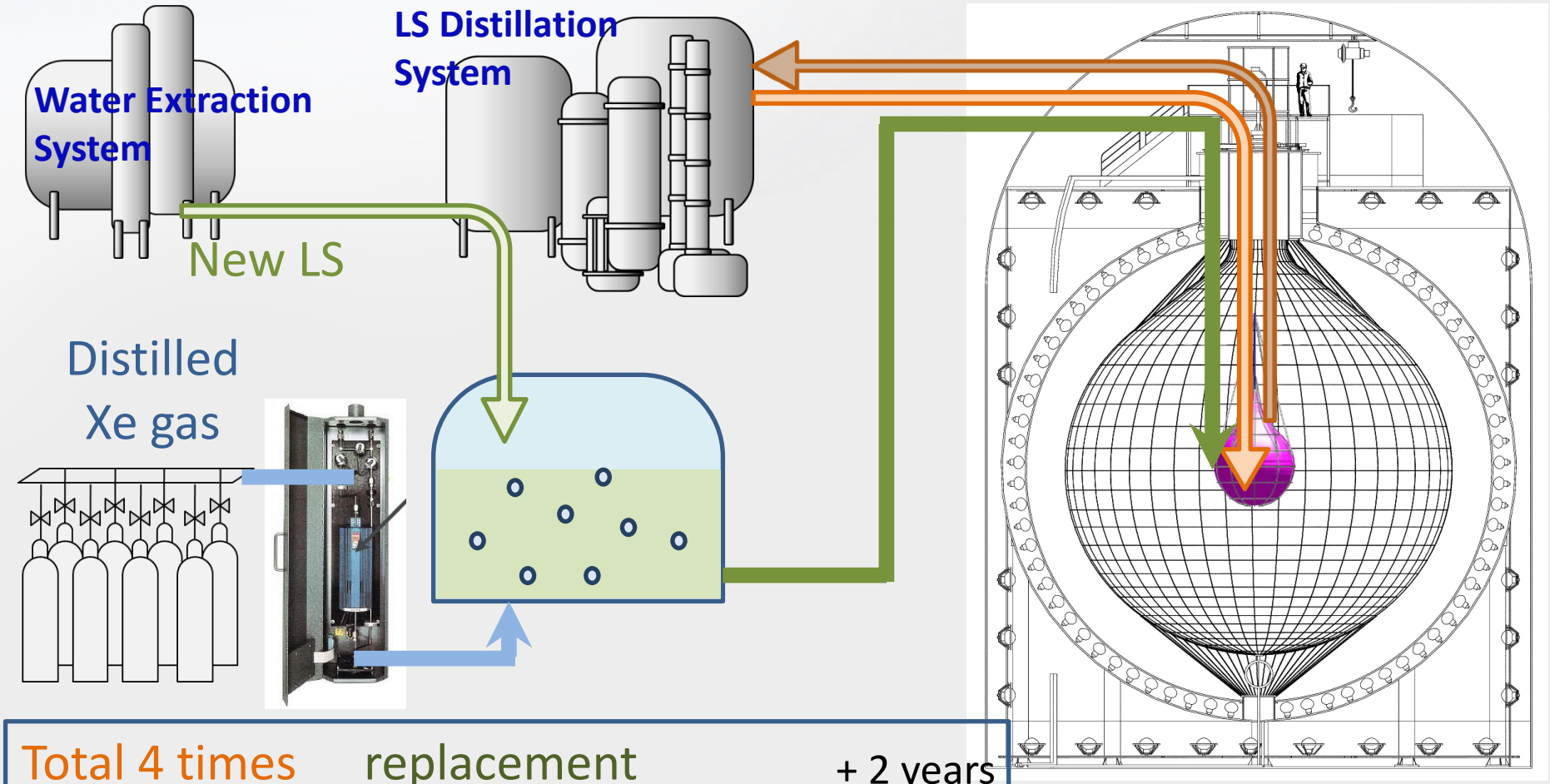
- 411.5kg distilled Xe was already prepared for next Xe-LS.
- Distilled Xe gas will be passed into Getter before filling.

Zr alloy

H_2O, N_2, O_2, CH_4, CO, CO_2, and Metallic atoms are adsorbed.

Circular Purification

Repeat LS distillation and replacement for MIB LS containing ^{110m}Ag

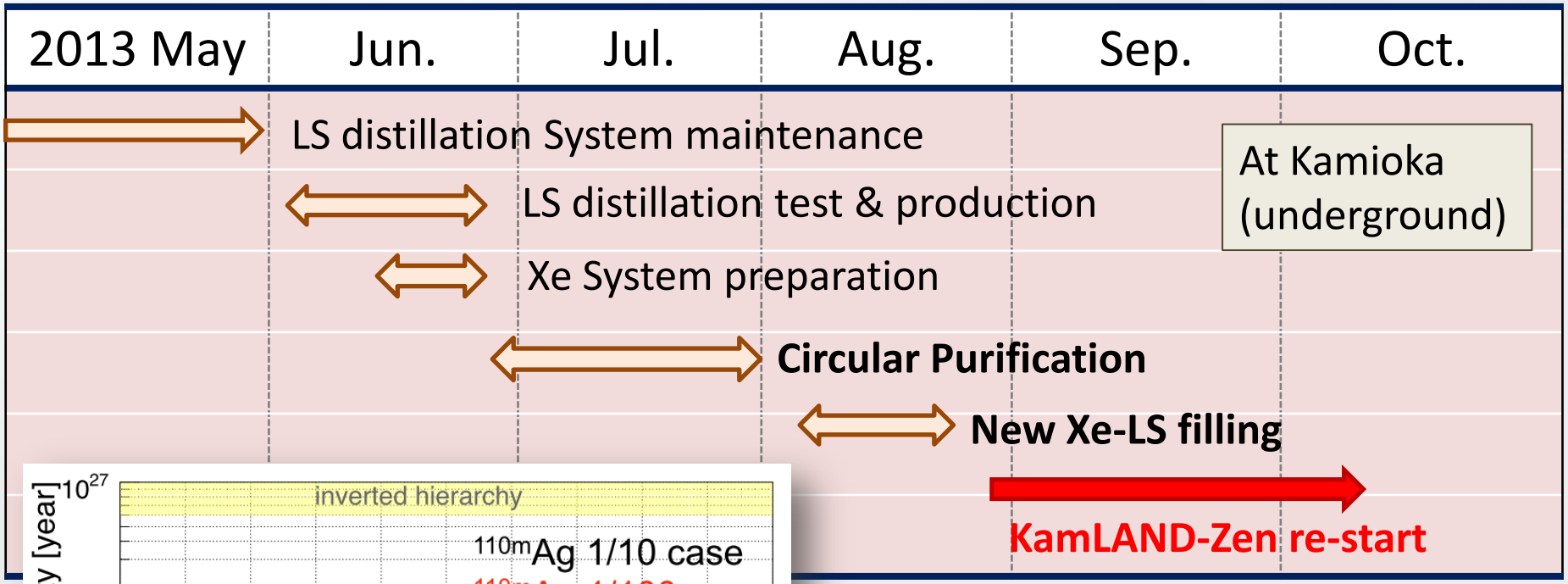


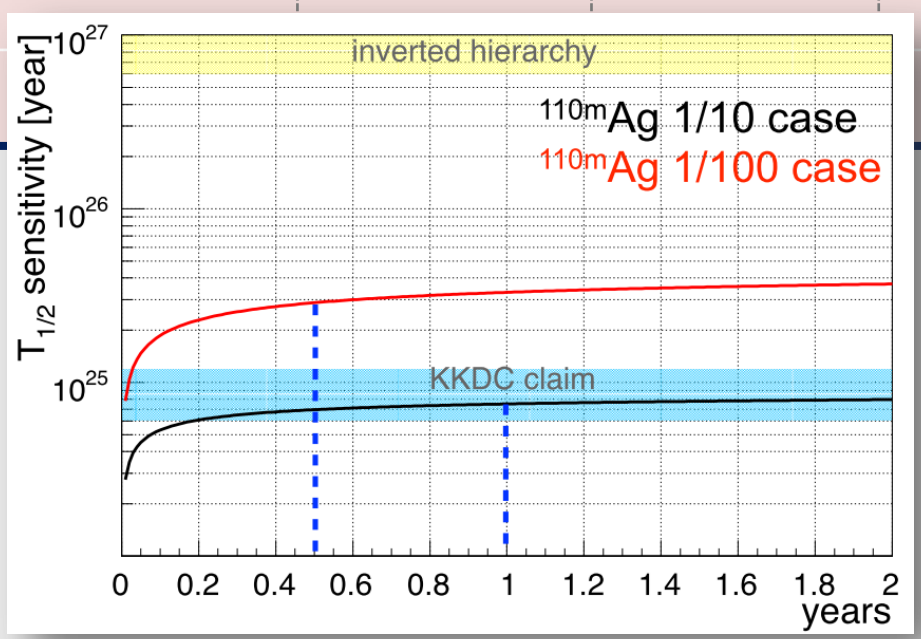
Total 4 times replacement + replacement with new LS(with Xe) + 2 years (decay)

$$\left(\frac{1}{4}\right)^4 \times \frac{1}{4} \times \frac{1}{4} = \frac{1}{4096}$$ reduction! (ideal…)

Restart measurement

Schedule & Expected Sensitivity





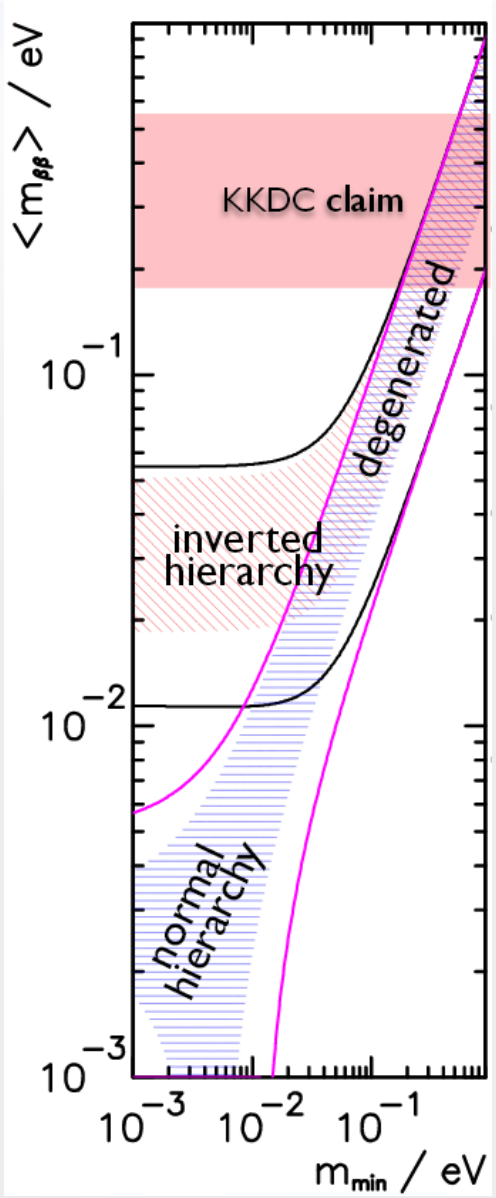
In ^{100m}Ag 1/100 case,
We can achieve

$$T^{0\nu}_{1/2} > 3.0 \times 10^{25}\text{yr}$$

$$\langle m_{\beta\beta} \rangle \sim 80\text{meV}$$

for 6 month run time.

Future Plans



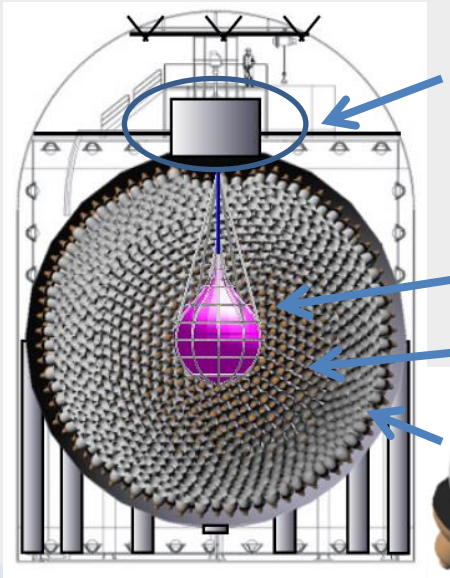
Exclude KKDC claim (97.5% C.L.)

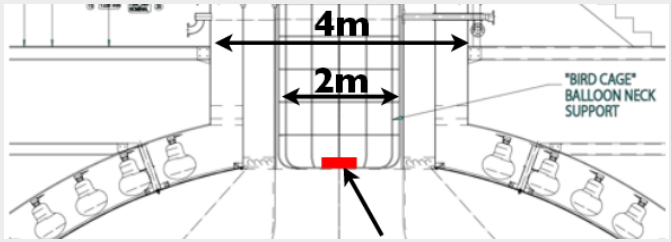
Current
(KamLAND-Zen + EXO-200 conbined)

After purification (~ March, 2014)

New mini-balloon (600kg~ ^{136}Xe)
start preparation in this year

KamLAND2-Zen

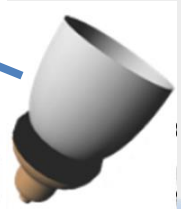




Expansion of opening section

~1000kg ^{136}Xe balloon

New brighter LS



Light collection cone to improve energy resolution.

Summary

- KamLAND-Zen recent results
  - $T_{1/2}^{2\nu} = 2.30 \pm 0.02(stat.) \pm 0.14(sys.) \times 10^{21}$ yr
  - $T_{1/2}^{0\nu} > 1.9 \times 10^{25}$yr 90% C.L
  - Exporsure 89.5 kg-yr
- Combined with EXO-200
  - $\langle m_{\beta\beta} \rangle$: <120-250 meV
- Current activities of KamLAND-Zen
  - LS purification for reducing ^{110m}Ag B.G.
  - After purification run will start from Sep. 2013.
  - KamLAND-Zen will achieve <80meV effective mass limit by the early of next year.
- KamLAND-Zen next phase is funded from this year.
- KamLAND2-Zen has great potential to search below inverted hierarchy.

World's best

World's best

World's best

Exclude KKDC claim (97.5% C.L.)