Liquid Scintillator Based 0νββ Detector

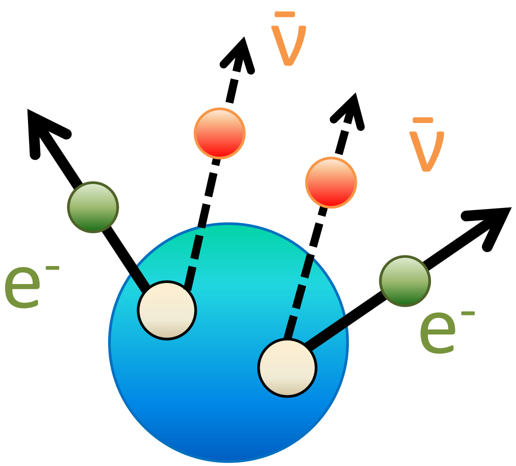
NNN16 @ 北京

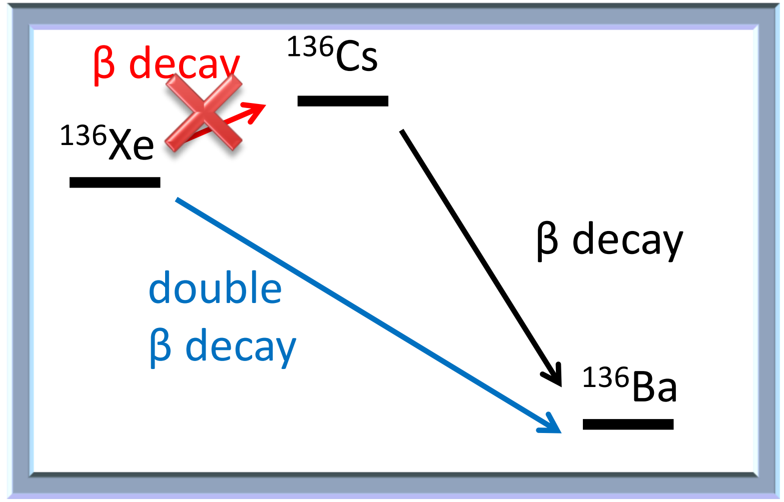
2016/11/3

Research Center for Neutrino Science
Tohoku University
H. Ikeda

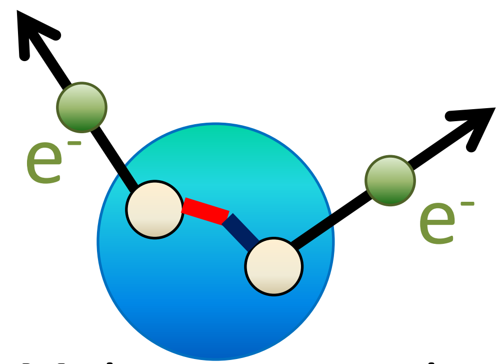
Neutrinoless double β decay

2νββ





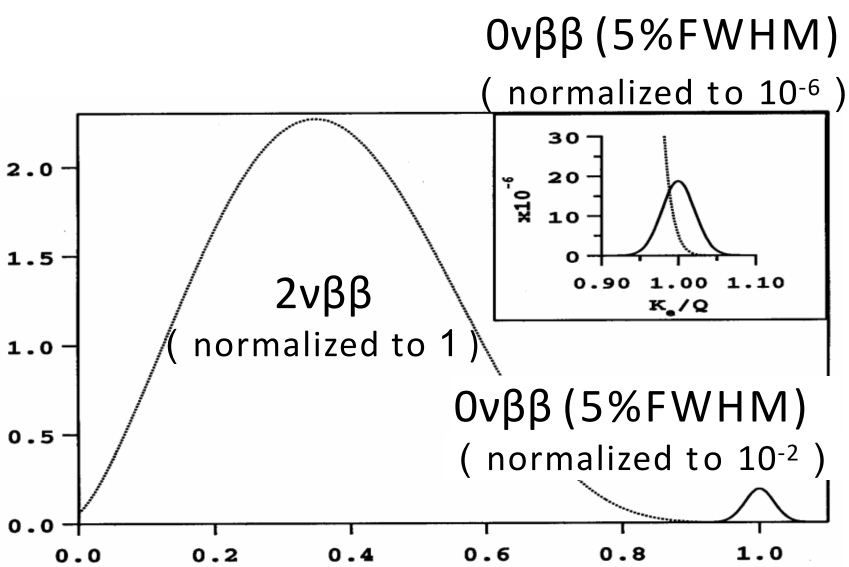
0νββ



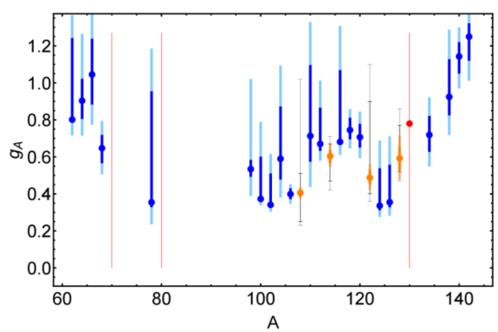
Majorana neutrino

$$\langle m_{\beta\beta}\rangle = \left|\Sigma_i U_{ei}^2 m_{\nu_i}\right|$$

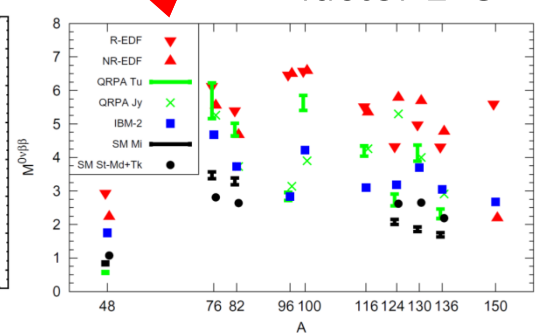
$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} g_A^4 |M^{0\nu}|^2 \langle m_{\beta\beta}\rangle^2$$



Uncertainties



factor 2~3

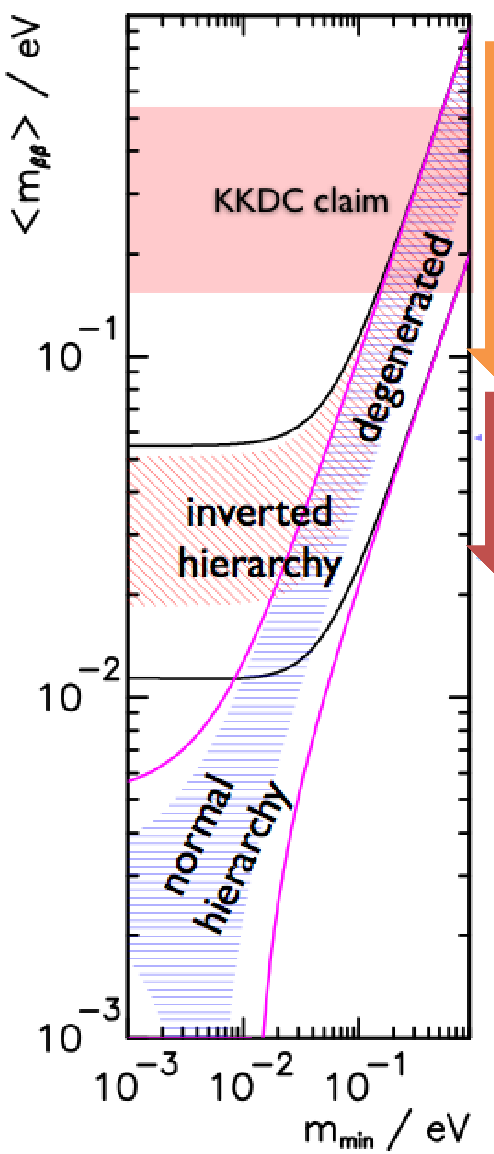


arXiv:1606.02908

arXiv:1605.05059

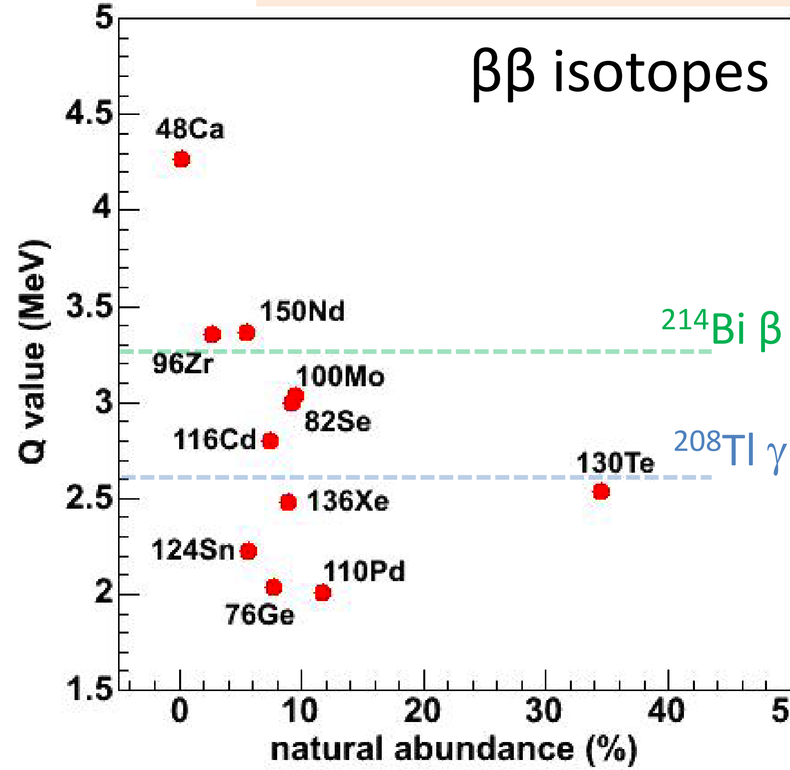
0νββ Targets

High Q value : BG free
High N. A. : No enrichment



~60meV
10^2~10^3 kg targets
$T_{1/2}$: 10^{26} ~ 10^{27} y

~20meV
10^3~10^4 kg targets
$T_{1/2}$: 10^{27} ~ 10^{28} y



- **Large number of 0νββ targets.**
- **Background free detector.**
- **High vertex/energy resolution.**

0νββ experiments

Current experiments and R&D Programs

Alex Wright, Neutrino2016

Experiment	Isotope	Technique	Location
Majorana Demonstrator	^{76}Ge	Point contact Ge	Sanford
GERDA II	^{76}Ge	Semicoax/BE Ge + veto	LNGS
CDEX	^{76}Ge	Point contact Ge	CJPL
NG-Ge76	^{76}Ge	Point contact Ge	
COBRA	^{116}Cd, etc	CdZnTe	LNGS
CANDLES	^{48}Ca	CaF_2 scintillator + veto	Kamioka
AMoRE	^{100}Mo	Low-T MMC	Y2L
DCBA/MTD	^{100}Mo	Foils + tracker	KEK
MOON	^{100}Mo	Foils + scintillator	
EXO200	^{136}Xe	LXe TPC	WIPP
nEXO	^{136}Xe	LXe TPC	SNOLAB
NEXT	^{136}Xe	High-P TPC	LSC
PandaX III	^{136}Xe	High-P TPC	CJPL
KamLAND-Zen	^{136}Xe	Liquid scintillator	Kamioka
SuperNEMO	^{82}Se	Foils + tracker	
CUPID	^{130}Te, ^{82}Se, ^{100}Mo, ^{116}Cd	Hybrid bolometers	
CUORE/CUORE-0	^{130}Te	TeO_2 bolometers	LNGS
SNO+	^{130}Te	Liquid scintillator	SNOLAB

LS based 0νββ detector

Merit

- Ultra **low background environment** by LS purification for neutrino detectors.
  (U,Th ~10^{-18} g/g by water extraction, distillation, adsorption…)
- Active shield itself.
- Large size detector can store **much 0νββ source**.
  (ton size)
- On-off observation is possible for ^{136}Xe.

Demerit

- Can **not see 2 electron tracks**.
  (10cm/√E[MeV] order vertex resolution)
- 2νββ signals BG case.
  (worth energy resolution, short live time of 2νββ)
- Not easy for dissolving metal 0νββ sources into LS.
- LS rerated backgrounds.
  (long lived spallation productions)
- Large photons by cosmic ray muon. (PMT ringing, after pulse)

SNO+

Slides by Mark Chen

SNO+ Status and Schedule

- Now filling with water (~77% complete)
- November 2016: first delivery of LAB for commissioning scintillator purification plant
- Scintillator filling in 2017
- Late 2017: purification of tellurium, adding tellurium to the liquid scintillator
- Early 2018: start double beta decay search

SNO+ Water Fill Movie

SNO+ Scintillator Plant before insulation

Natural Tellurium in Liquid Scintillator

SNO+ approach to neutrinoless double beta decay

- 0.5% Te loading has 1,330 kg of ^{130}Te ***isotope***
  - photo shows LAB with 19% Te, by weight!

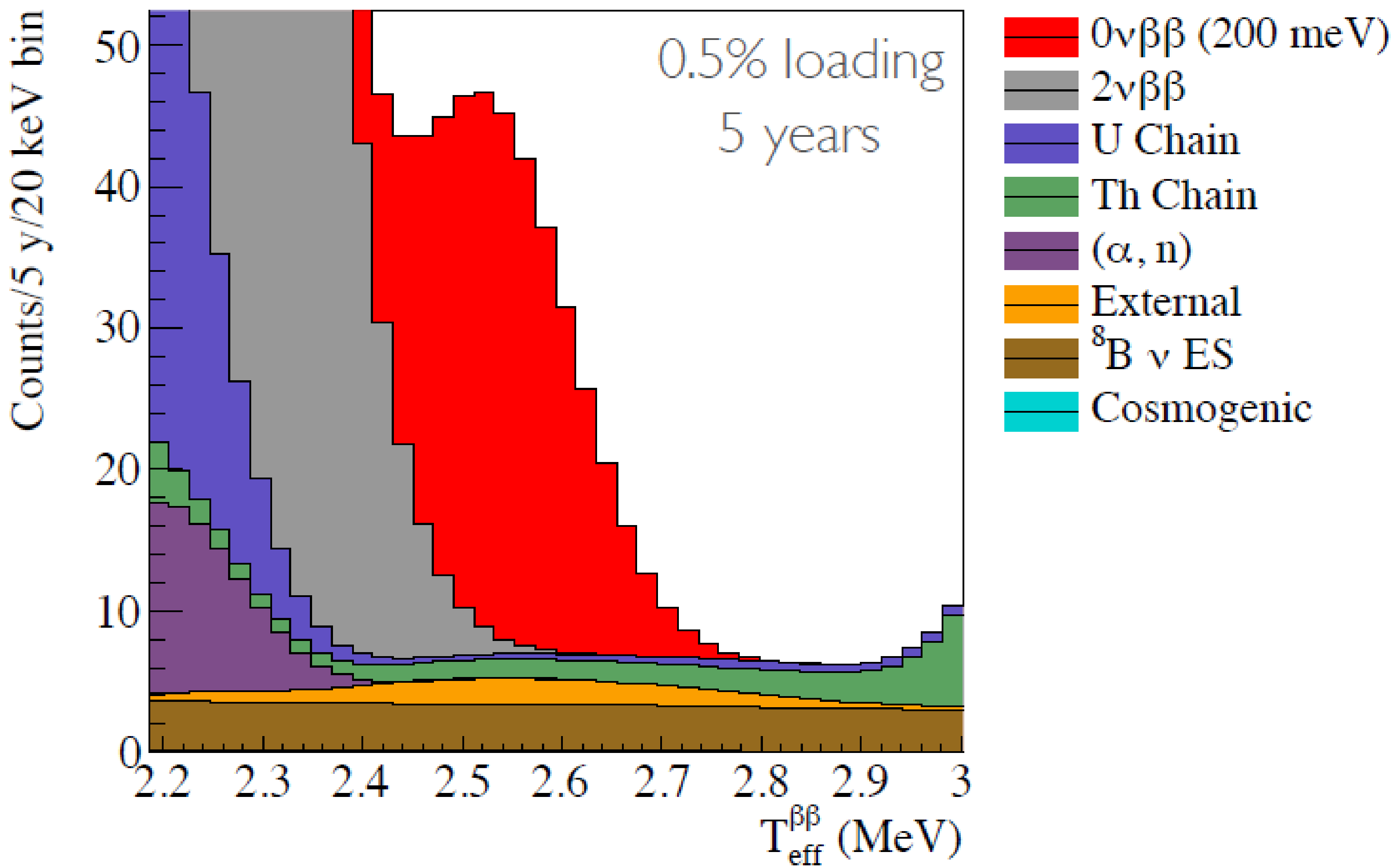
must purify all components of scintillator cocktail
to achieve ultra-low backgrounds for NLDBD

- LAB + PPO
- telluric acid
- 1,2-butanediol (new loading technique)
- ultra-pure water used in synthesis

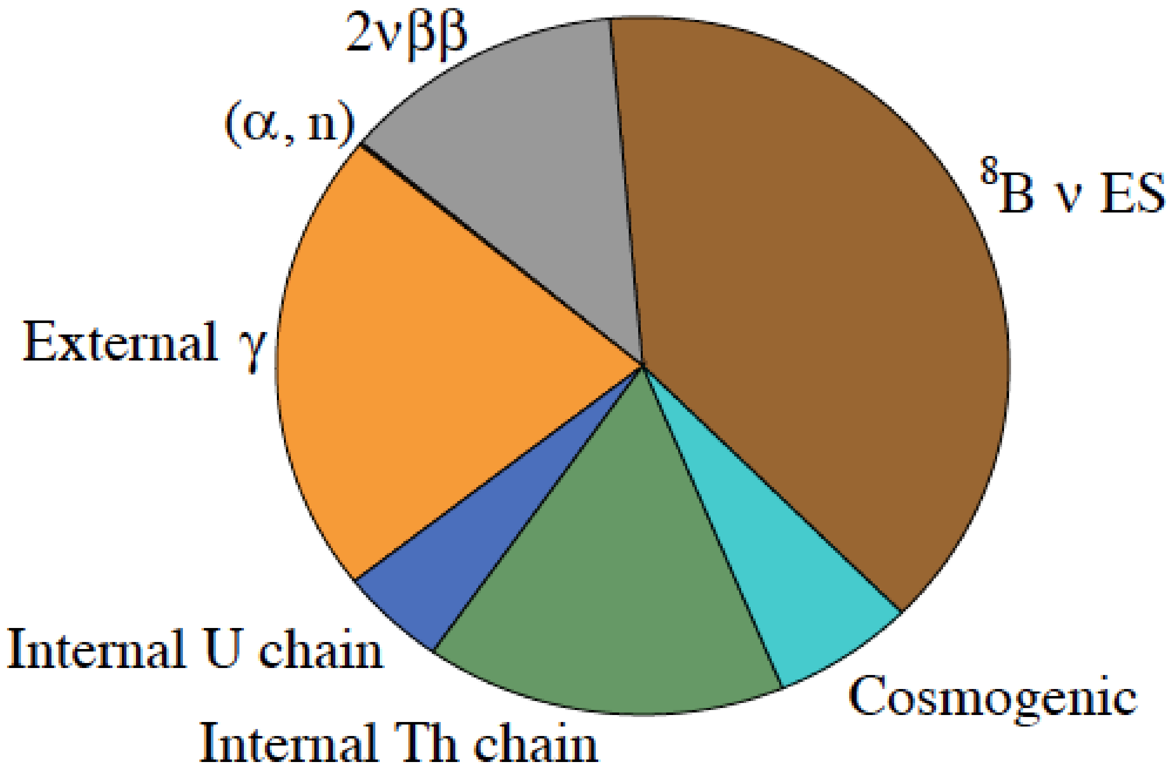
tested the purification of all components

- purification reduction factors of ~10^3-10^5 per pass, in our tests

SNO+ Simulated Energy Spectrum

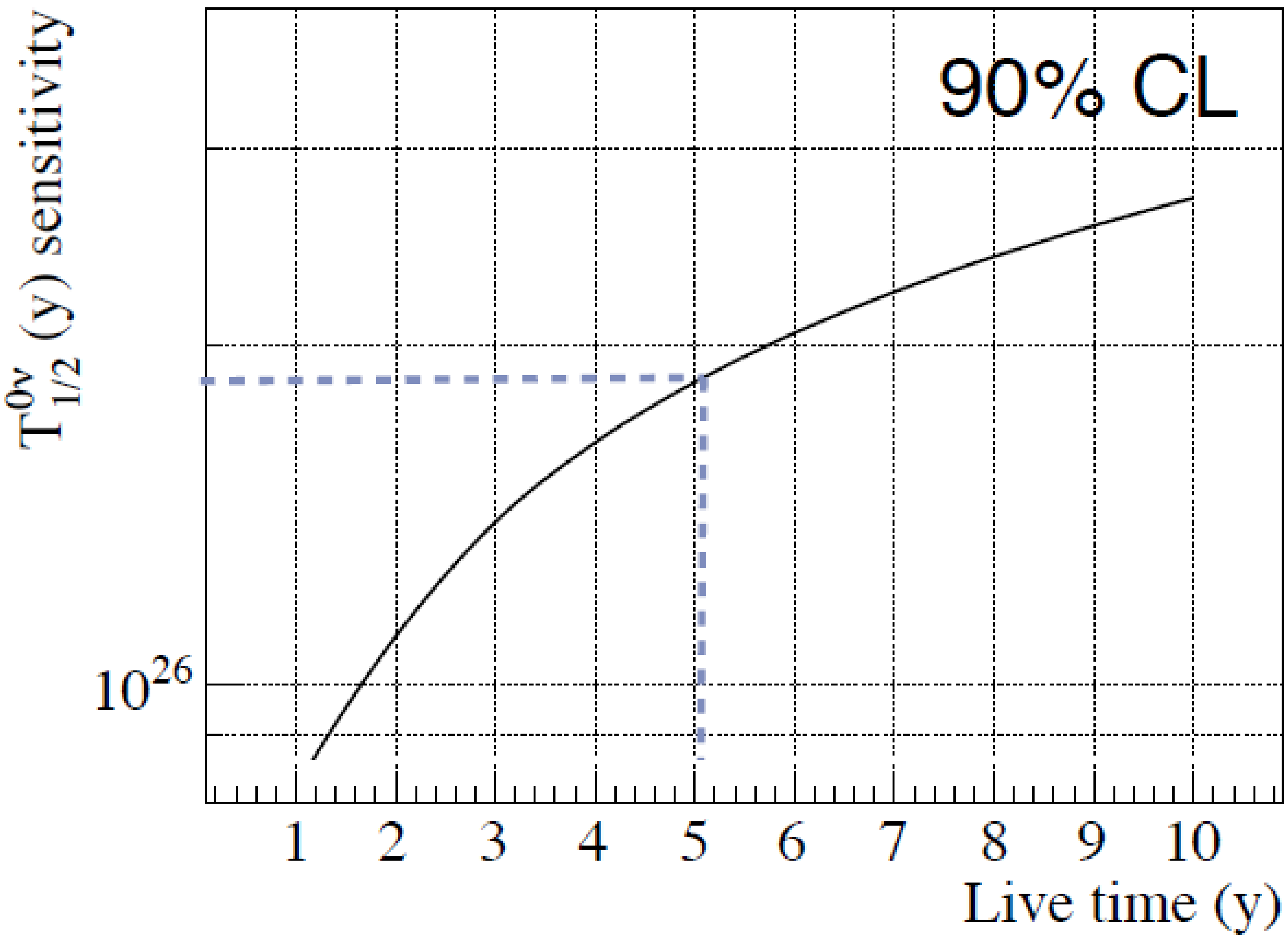


SNO+ Background Budget



Total: 14 counts/year in ROI (Year 1)

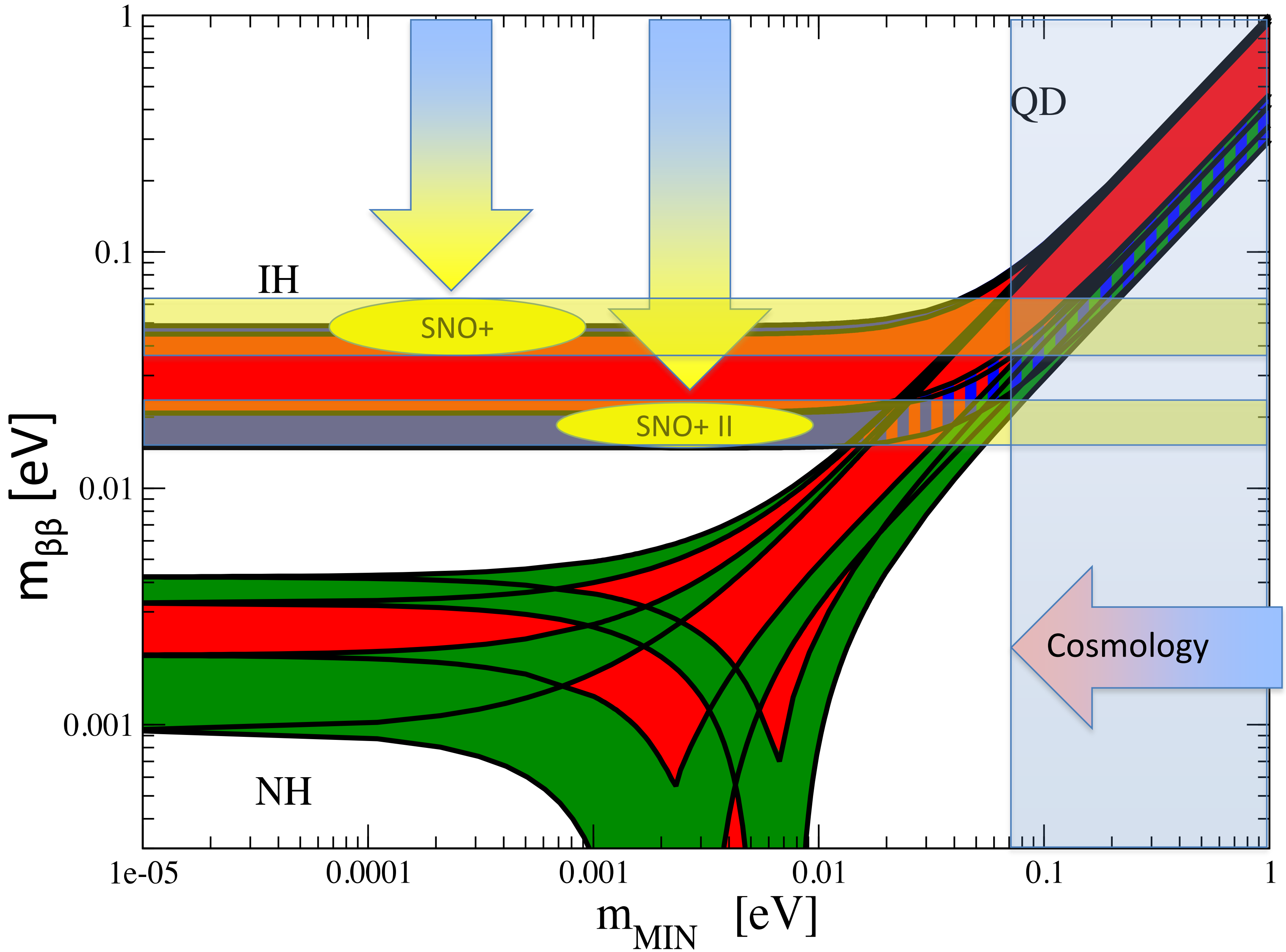
Double Beta Sensitivity



$T_{1/2} > 1.96 \times 10^{26}$ yr (90% CL)

$m_{\beta\beta} < 36\text{-}90$ meV

Neutrino Mass: Cosmology and Double Beta Decay



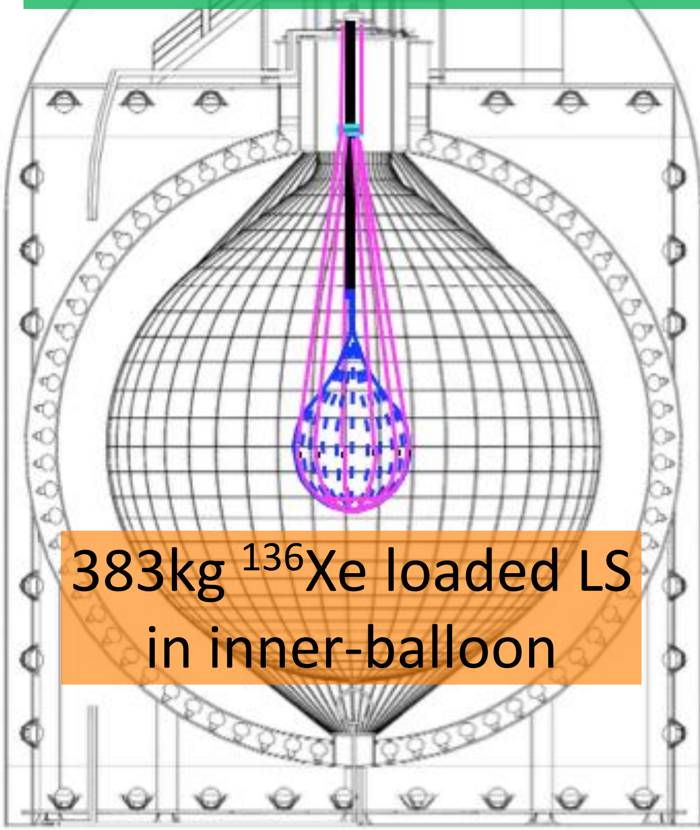
KamLAND-Zen

KamLAND-Zen 400

Kamioka Liquid-scintillator Anti-Neutrino Detector Zero neutrino double beta decay search

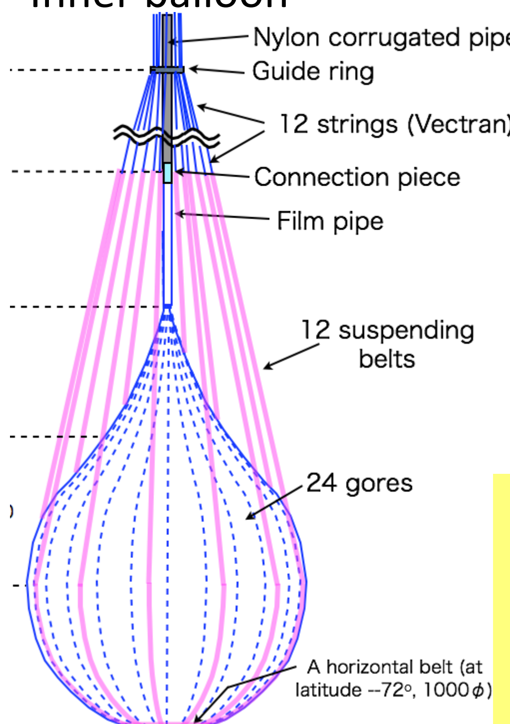
KamLAND
- ✓ Quick start with relatively low cost
- ✓ Flexible operation
- ✓ Easy to scale up
- ✓ Other physics in parallel (geo-neutrino, SN, …)

^{136}Xe
- ✓ Noble gas
- ✓ Enrichment (91% ^{136}Xe)
- ✓ Dissolving into LS (> 3 wt%)
- ✓ Long lived 2νββ

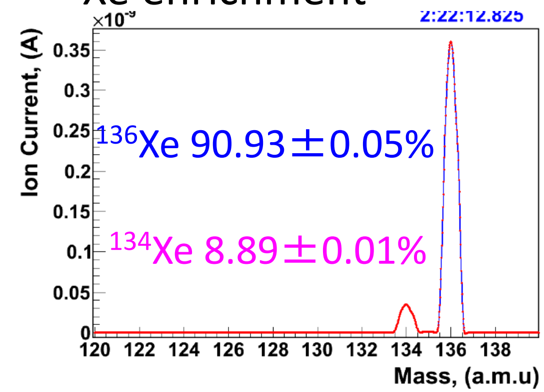


383kg ^{136}Xe loaded LS in inner-balloon

Inner balloon



^{136}Xe enrichment

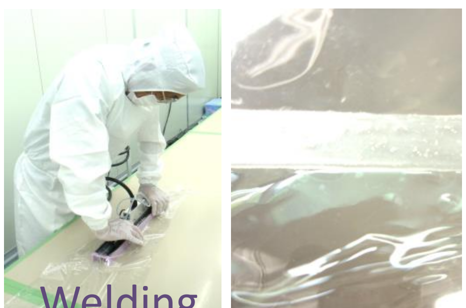


- Nylon film: 25μ-thick
- U,Th~10^{-12}, ^{40}K~10^{-11}g/g
- Xe tightness
- >95% transparent @400nm

KamLAND-Zen 400 Construction

2011 2012 2013 2014 2015 2016
5 9

Construction

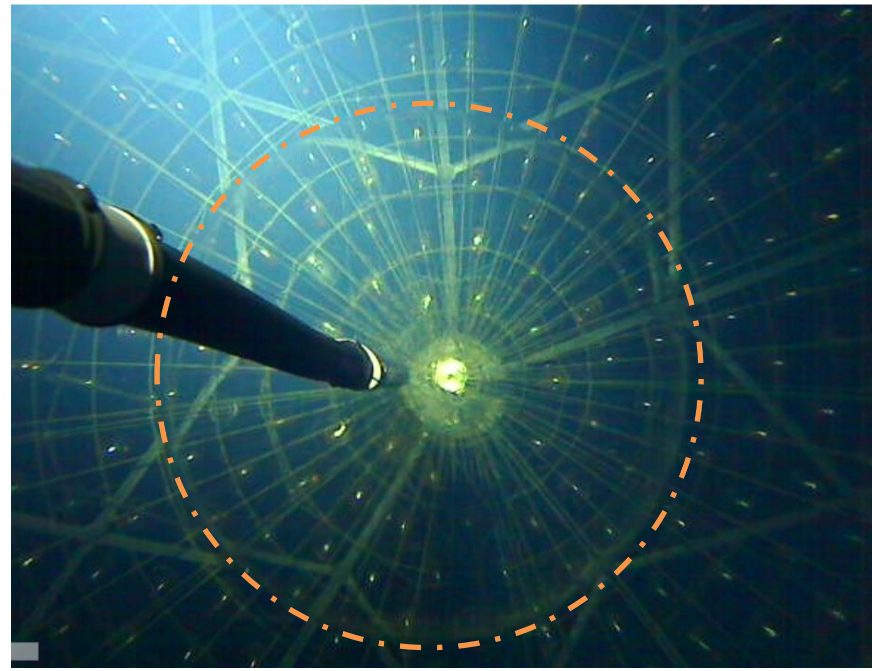


Installation

Xe dissolving system

Class 1 super clean room @ Junichi Nishizawa Memorial Center, Tohoku University

Xe loaded LS filling



LS Decane(82%) + PC(18%) + PPO(2.7g/l)
LS purified by water extraction & distillation
320 kg enriched Xe in LS

KamLAND-Zen 400 phase 1

2011 | 2012 | 2013 | 2014 | 2015 | 2016

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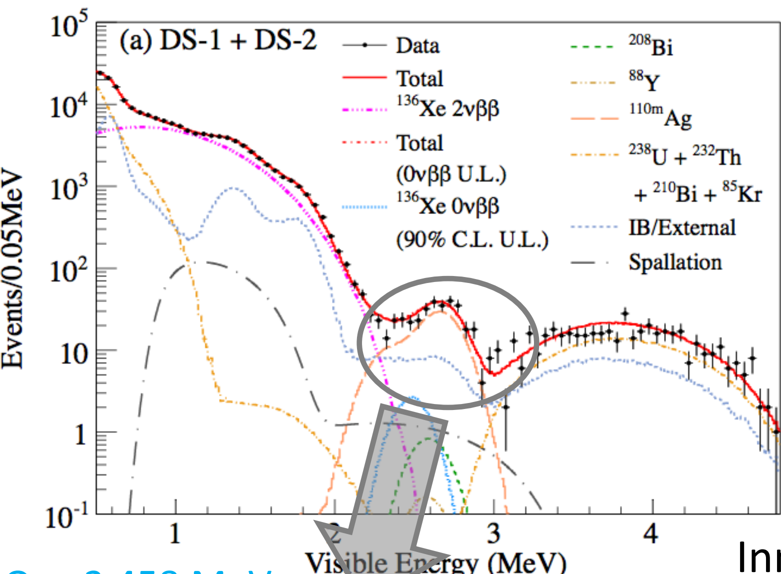
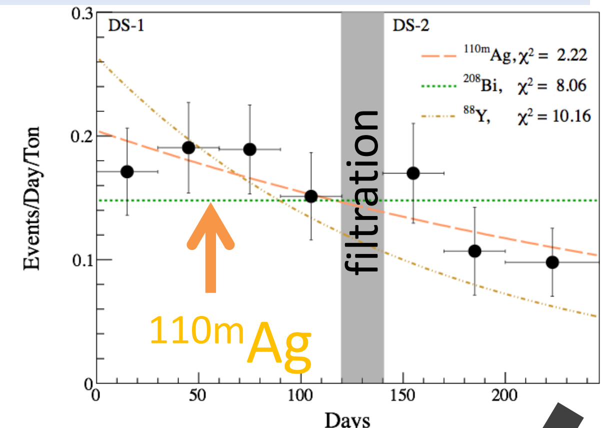
89.5kg-year ^{136}Xe measurement: $T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ year (90%C.L.)



From ENSDF database candidates are ^{110m}Ag, ^{88}Y, ^{208}Bi, ^{60}Co

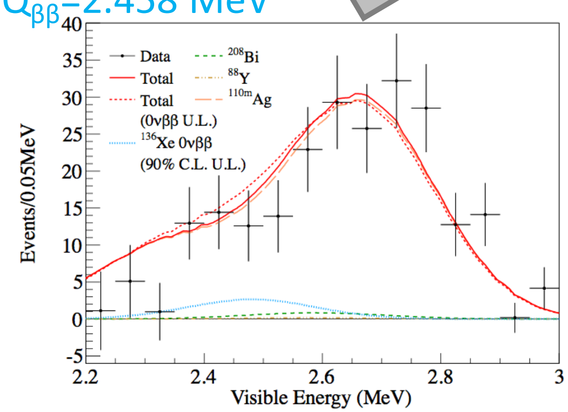
Where comes from?

- ^{136}Xe Spallation
- Fukishima-I reactor

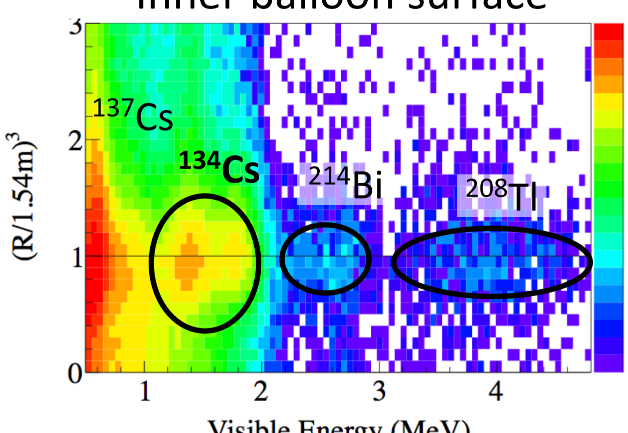


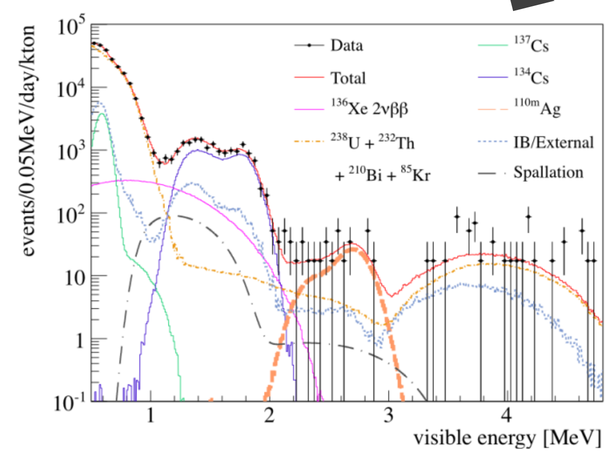
After Xe extraction

$Q_{\beta\beta}$=2.458 MeV



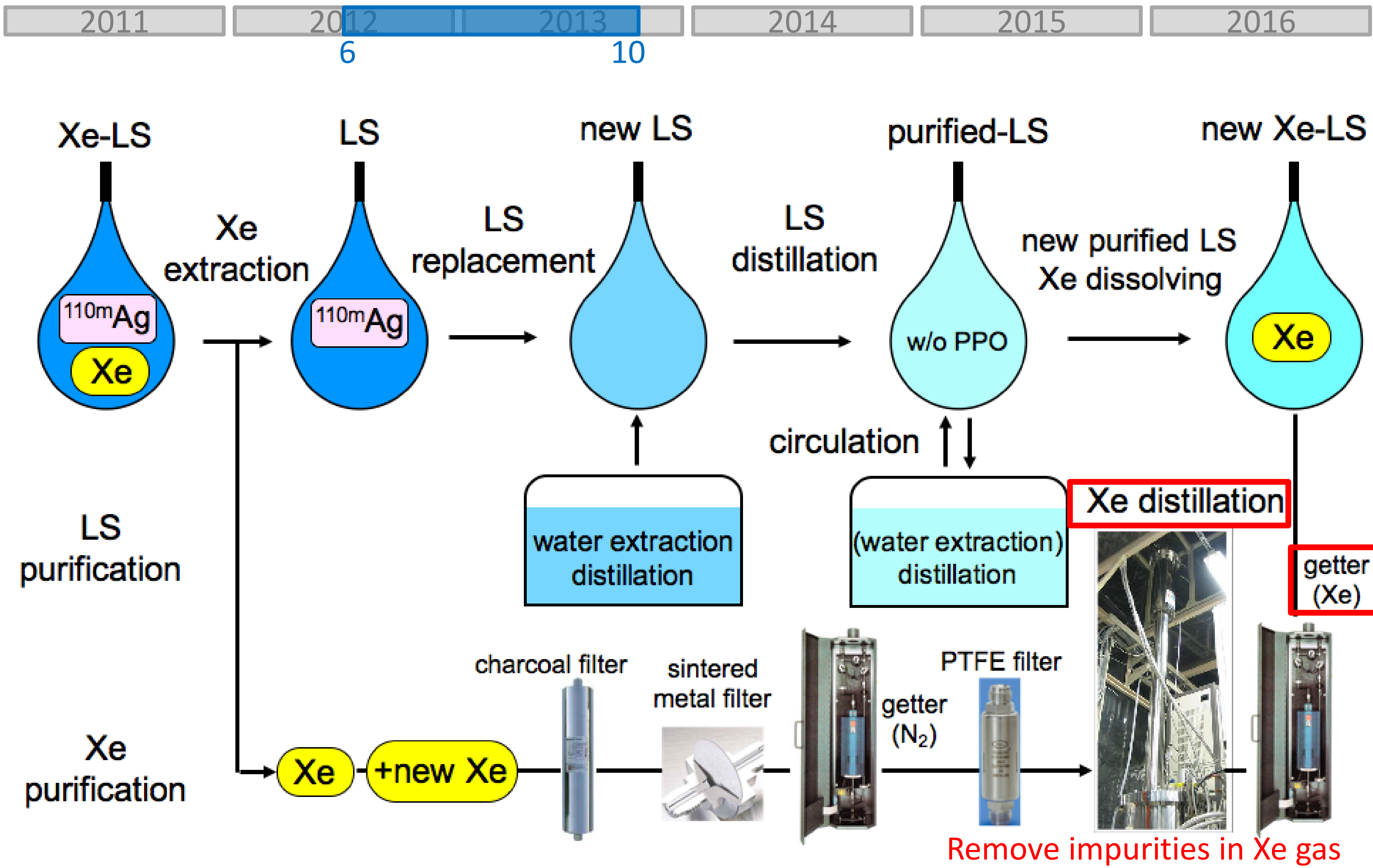
Inner balloon surface





^{110m}Ag rate did not change

KamLAND-Zen 400 Purification

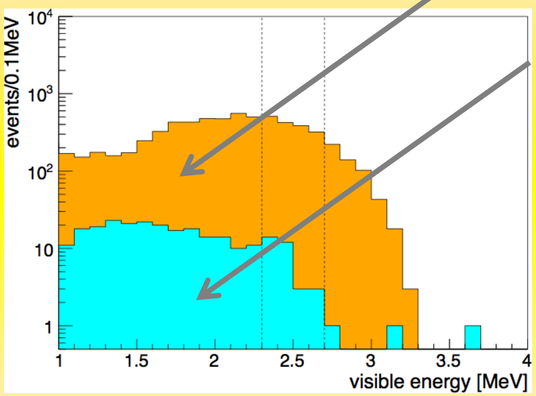


KamLAND-Zen 400 phase 2 BG

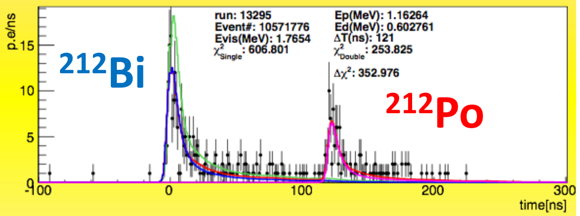
2011 | 2012 | 2013 | 2014 | 2015 | 2016

12 | 10

$^{214}Bi/^{212}Bi$ Tagging



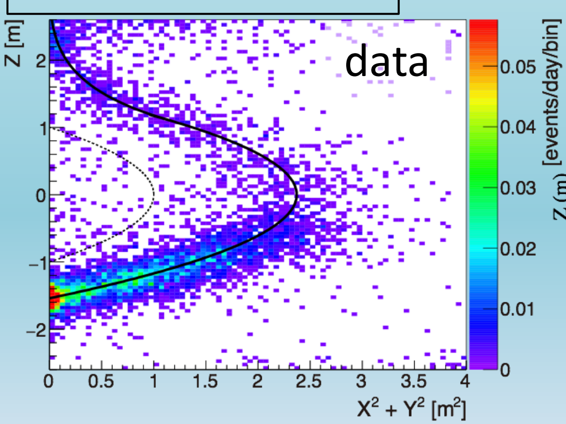
- delayed coincidence
  ^{214}Bi-^{214}Po
- pileup event search

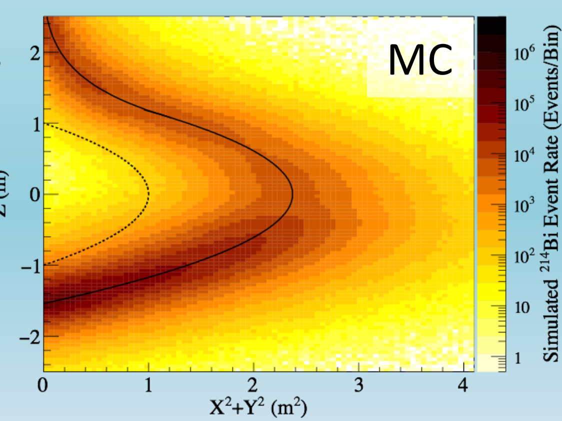


LS purification cycle did not remove Bi on surface

(Some Po signal extinction by film)

^{214}Bi on IB surface

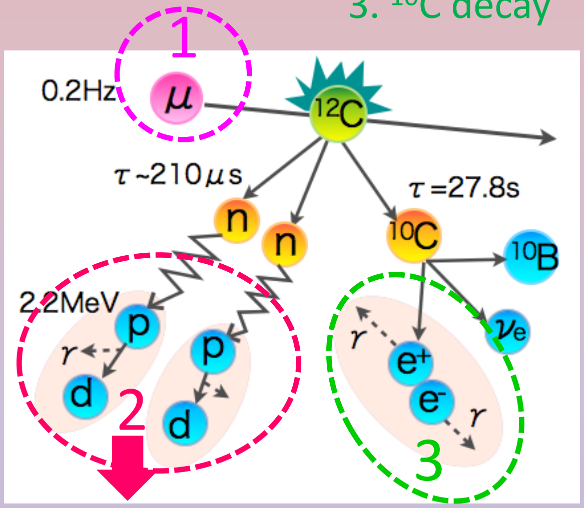


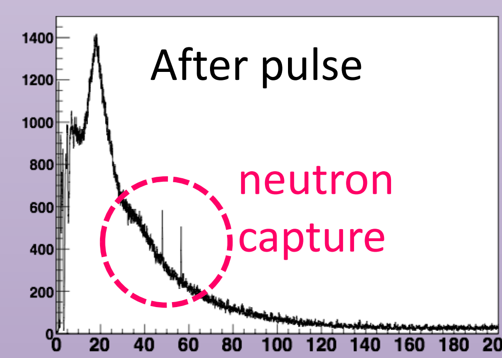


Reconstruction of non-uniform ^{214}Bi distribution

^{10}C tagging

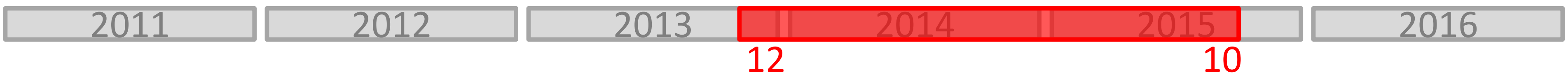
Triple coincidence
1. muon
2. neutron capture
3. ^{10}C decay





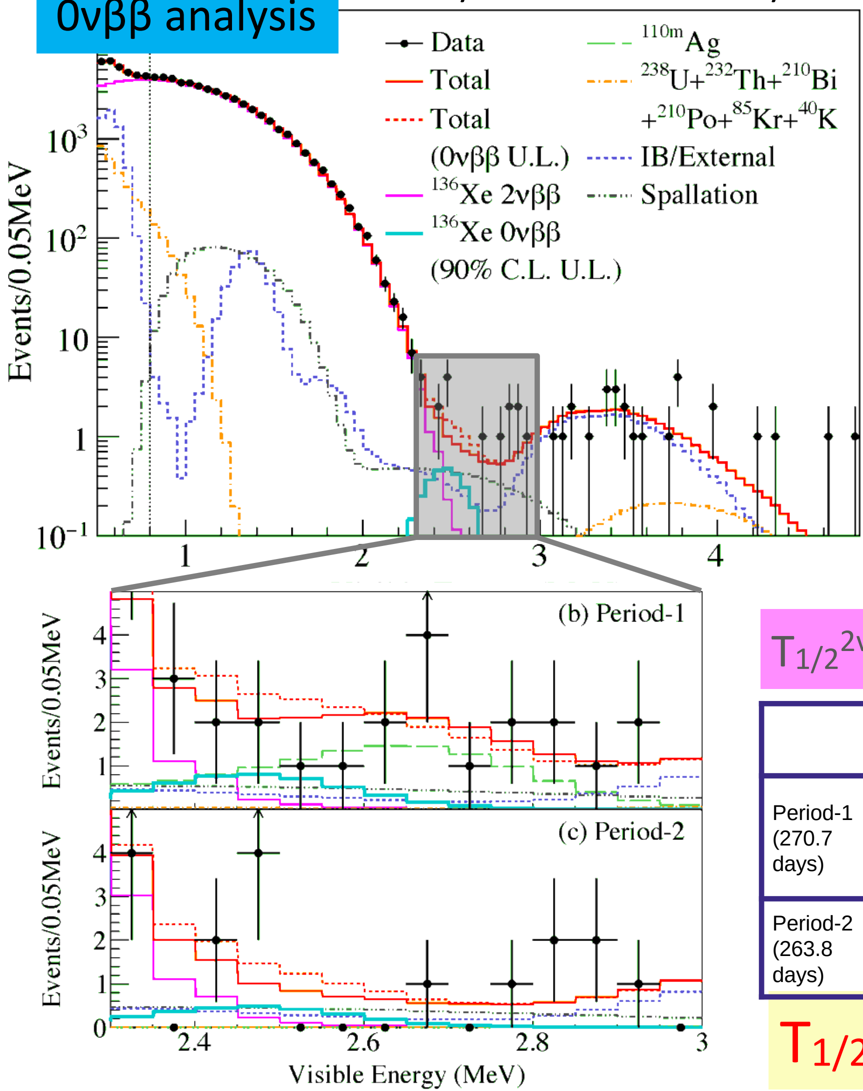
^{10}C detection efficiency: 64±4 %

KamLAND-Zen 400 phase 2



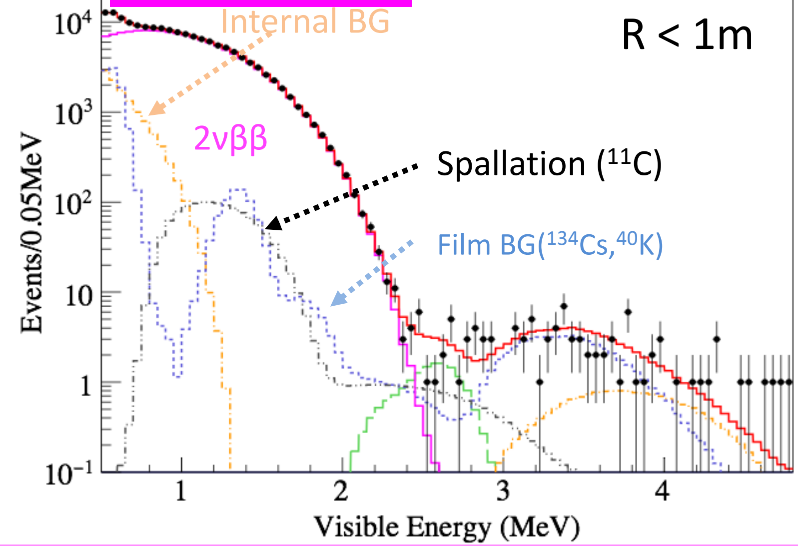
0νββ analysis

systematic uncertainty 3.1 %



2νββ analysis

Small Film BG area

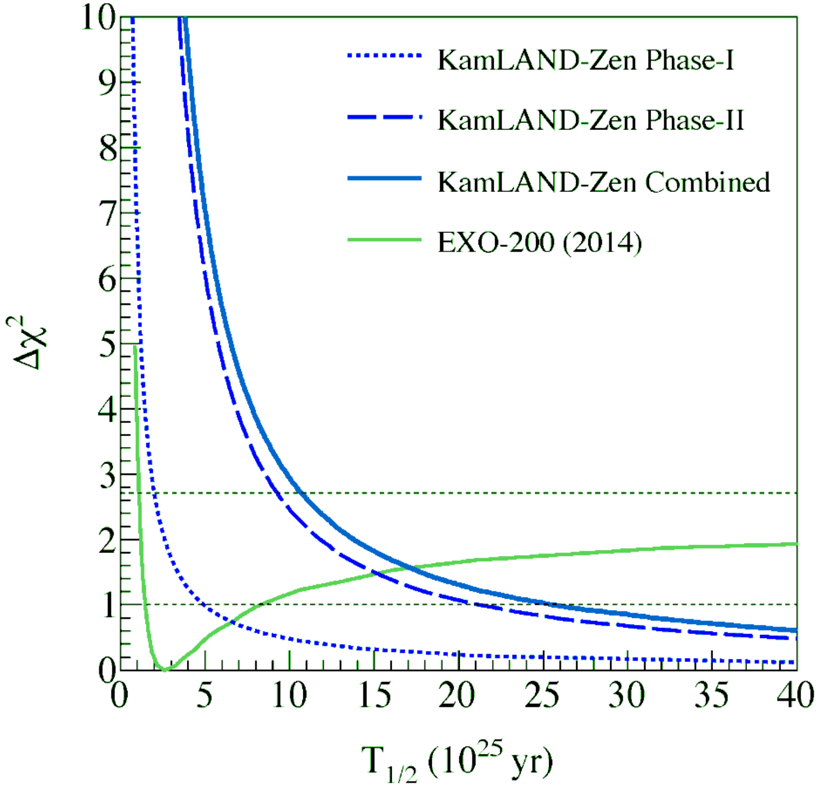


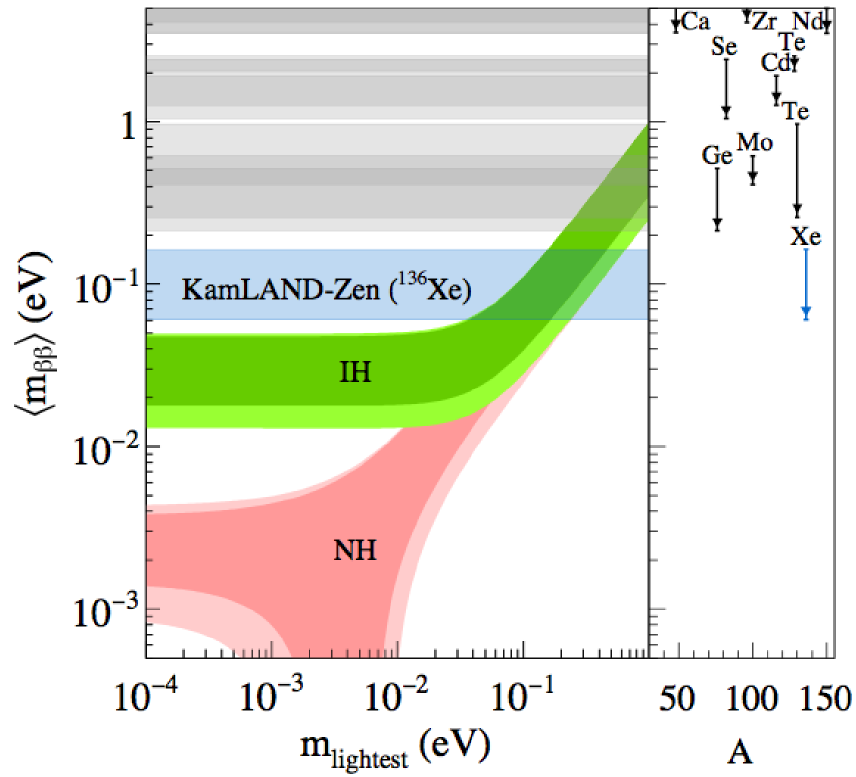
$T_{1/2}^{2\nu} = 2.21 \pm 0.02(\text{stat}) \pm 0.07(\text{syst}) \times 10^{21}$ year (90% C.L.)

		0νββ	2νββ	^{214}Bi LS	^{110m}Ag	^{214}Bi film	spallation	Total BG	Observed
Period-1 (270.7 days)	Estimated	-	-	0.23 ± 0.04	-	-	3.4 ± 0.8	-	22
	Best-fit	0	5.48	0.25	8.5	2.56	4.04	20.8	
Period-2 (263.8 days)	Estimated	-	-	0.03 ± 0.01	-	-	3.3 ± 0.8	-	11
	Best-fit	0	5.29	0.03	0.0	2.45	3.43	11.3	

$T_{1/2}^{0\nu} > 9.2 \times 10^{25}$ year (90% C.L.)

KamLAND-Zen 400 phase 1+2





Upper limit of ^{136}Xe 0νββ half life (90%C.L.)

Phase 1 : $T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ year

Phase 2 : $\mathbf{T_{1/2}^{0\nu} > 9.2 \times 10^{25}}$ **year**

Phase 1+2 : $\mathbf{T_{1/2}^{0\nu} > 1.07 \times 10^{26}}$ **year**

Effective Majorana mass

$\langle m_{\beta\beta} \rangle$ < 61 ~ 165 meV

$m_{lightest}$ < 180 ~ 480 meV

KamLAND-Zen 400 removal

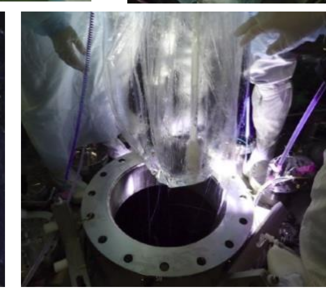
2011 | 2012 | 2013 | 2014 | 2015 | 2016

10 12

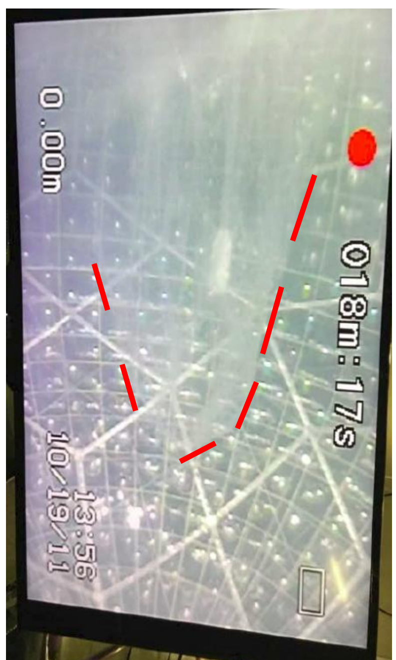
Smooth work !!





1. Xe extraction from LS
2. LS draining from inner balloon
3. Inner balloon removal
4. Close top flange

KamLAND-Zen 800

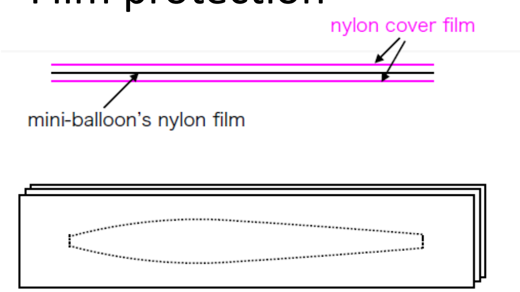
2011 | 2012 | 2013 | 2014 | **2015** | 2016

Laser Visualization

Some updated method

- Cleanup duper cleanroom by ourselves.
  (Covering HEPA filter edge)
- Wash everything by detergent, pure water, ethanol and IPA.
- Wear clean room inner cloth. (washing every time)
- Two stage clean cloth. Final cloth (working inner balloon construction) is washed every time.
- Doubled-over glove, goggle.
- More electrostatic eliminators.
- Covering inner balloon film.
- and more …

Film protection



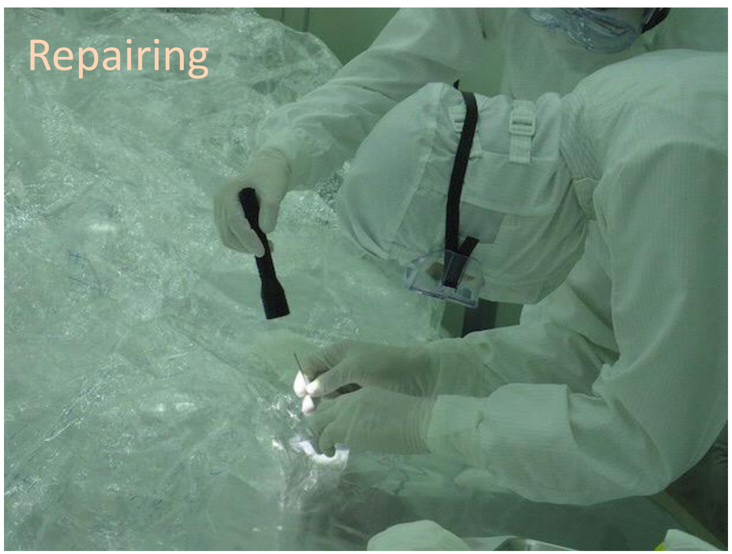
Welding machine

Working on only high humidity season.
(Static electricity catches dust.)

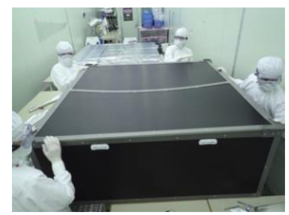
KamLAND-Zen 800

2011 | 2012 | 2013 | 2014 | 2015 | 2016

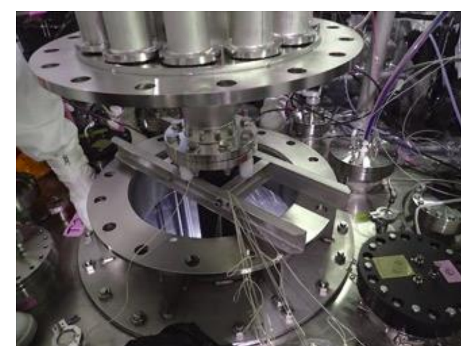
He leak check



Shrinking

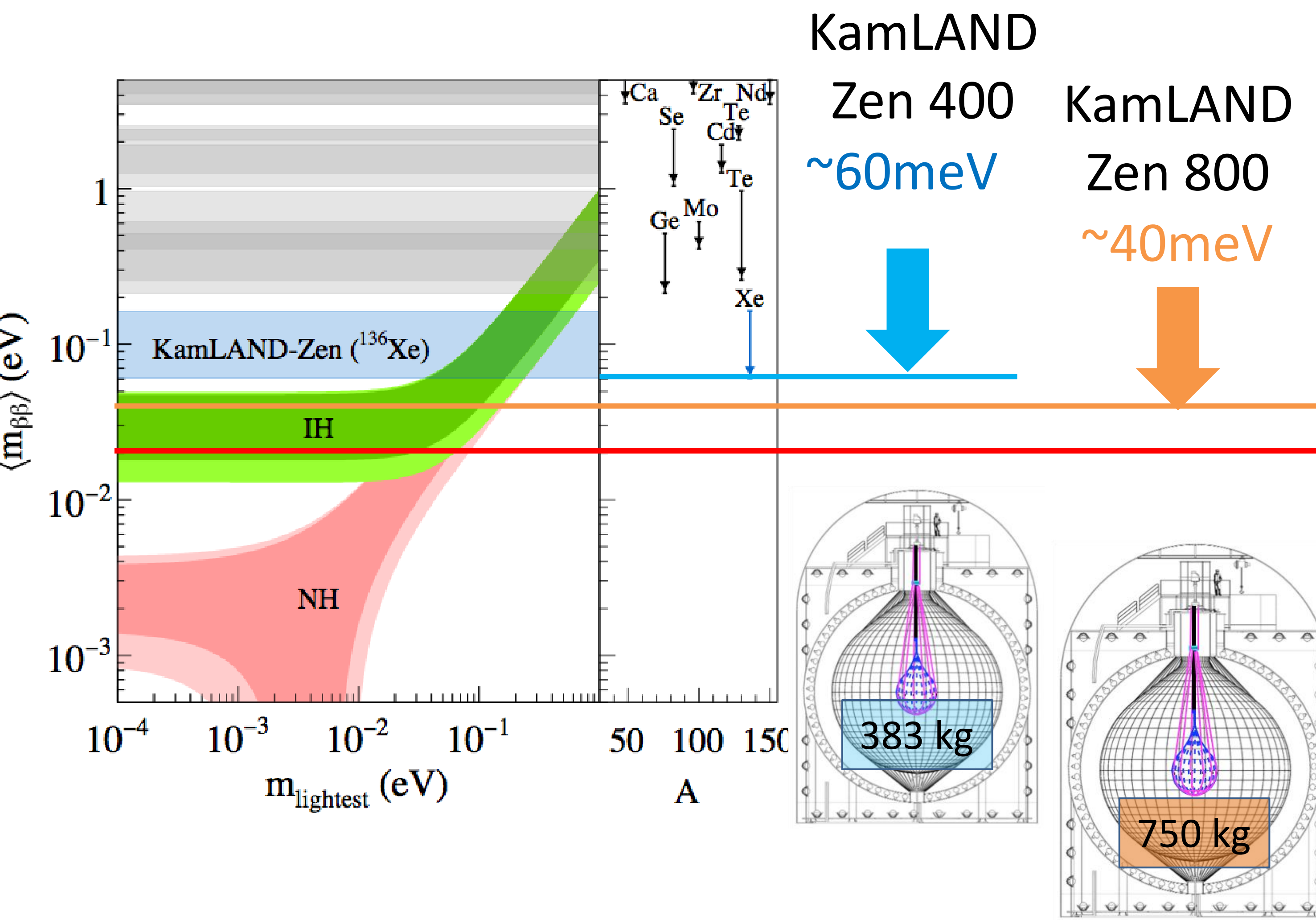


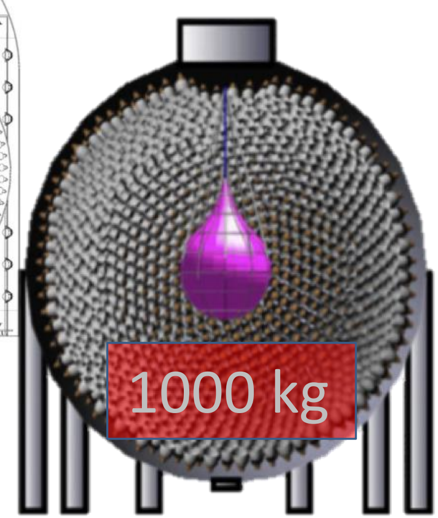
Installation



30 m^3 LS w/o Xe has been installed into inner balloon. Now measuring background.

KamLAND-Zen Sensitivity





KamLAND2 : HighQE PMT w/ Cones

Summary

- LS based detector can storage massive ββ isotopes.
- LS detector has scalability and flexibility.
- LS detector can purify after commissioning. Surface contamination can not remove.
- Backgrounds from surface contamination are serious. We must take care of all processes from detector construction.