KamLAND-Zen double beta decay experiment

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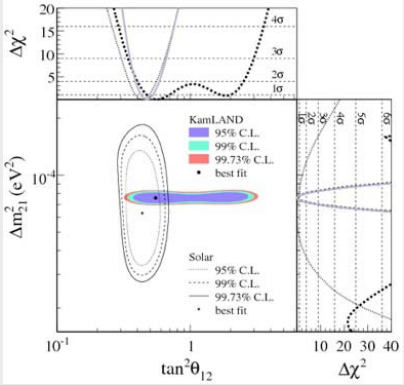
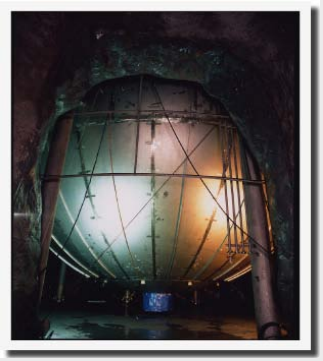
NPB2012 @Shenzhen

Summary of KamLAND





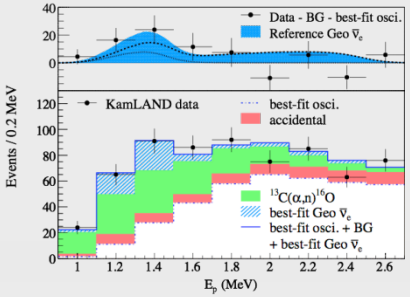
2009 - 2011
^{7}Be solar ν_e measurement

2007 LS distillation system construction

2005 precision measurement of reactor $\overline{\nu}_e$

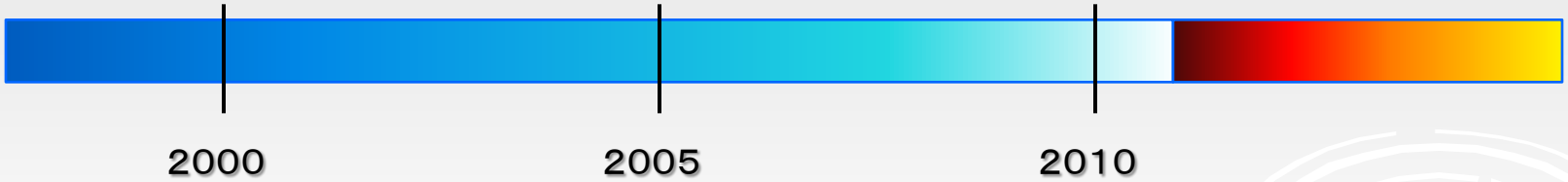
2004 observed Geo-$\overline{\nu}_e$

2003 reactor $\overline{\nu}_e$ distortion



2002 start data-taking

1998 – 2001 construction



2011- KamLAND-Zen start

Motivation of KamLAND-Zen for ββ

- KamLAND

  Large volume: 1,200m^3 Liquid Scintillator

  Ultra low radioactivity: U:<3.5x10-18g/g, Th<5.2x10-17g/g

  Distillation technique

  Experience of balloon development

  New electronics

  Detector is running. => quick start by low cost.

  mach advantage for 0νββexperiment !

- Disadvantage

  KamLAND Energy Resolution:

$$\Delta E = \frac{6.2\%}{\sqrt{\mathbf{E(MeV)}}}$$ (34% photo coverage)

Merits of ^{136}Xe on KamLAND

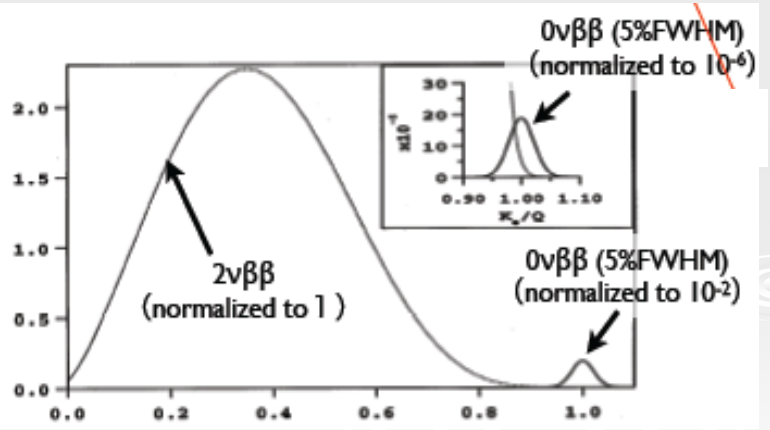
Before EXO-200 and KamLAND-Zen start

Nucleus	$T^{0\nu}_{1/2}$(50 meV)	$T^{2\nu}_{1/2}$ measured (year)	Nat.Abundane (%)	Q-value (keV)
$^{136}Xe \rightarrow ^{136}Ba$	4.55×10^{26}	$>10^{22}$	8.9	2476

Rodin et al., Nucl. Phys. A793 (2007)213-215

Merits on KamLAND

- Isotopic enrichment
- purification established
- solubility to LS > 3%, easy extracted
- slow 2νββ ($T^{2\nu}_{1/2}$ $>10^{22}$ years)
  small $T^{0\nu}$/ $T^{2\nu}$ ratio



KamLAND-Zen collaboration

Tohoku University

Kavli IPMU Tokyo University

Osaka University

University of California Berkeley and LBNL

Colorado State University

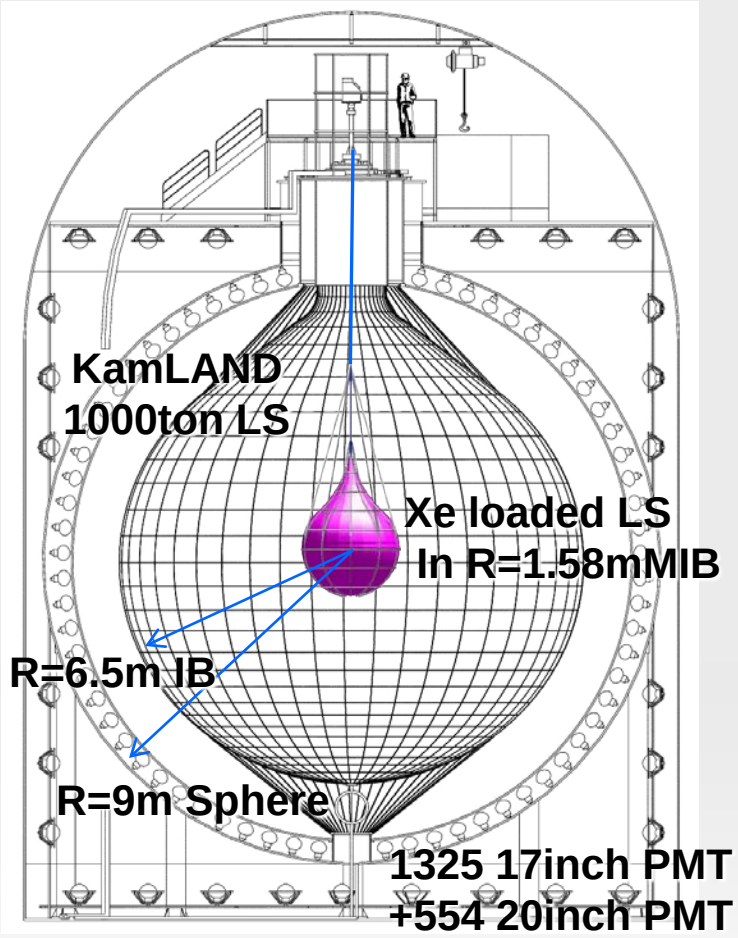
University of Tennessee

TUNL

University of Washington

NIKHEF and University of Amsterdam

KamLAND-Zen project



1st phase

^{136}Xe ~320kg (91% enriched)

R=1.58m balloon

V=16.5m^3

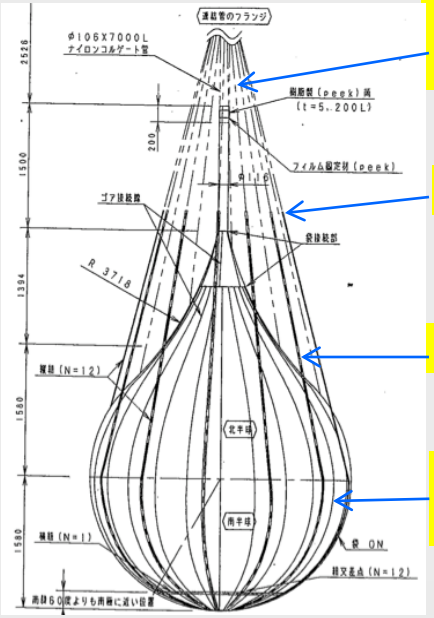
LS : C10H22(81.8%)+PC(18%)

+PPO+Xe(~3wt%)

ρLS : 0.78kg／ℓ

target : ~60meV / 2years for 0νββ

KamLAND-Zen MIB



nylon black corrugate tube

12 nylon strings

12 Nylon belts

MIB film (24 gores)

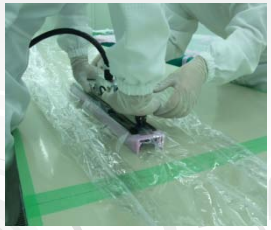
Sphere diameter	3.16m
volume	17m^3
Film thickness	25μm
Film strength	3kg/cm
Connection part strength	2kg/cm
Xe leakage	<1.3kg/5years
Transparency (@400nm)	99%
U contamination	2E-12g/g
Th contamination	3E-12g/g
40K contamination	2E-12g/g

filling test by water

Real balloon construction in the ultra clean room (crass 1)

Ultra-sonic cleaning using pure water

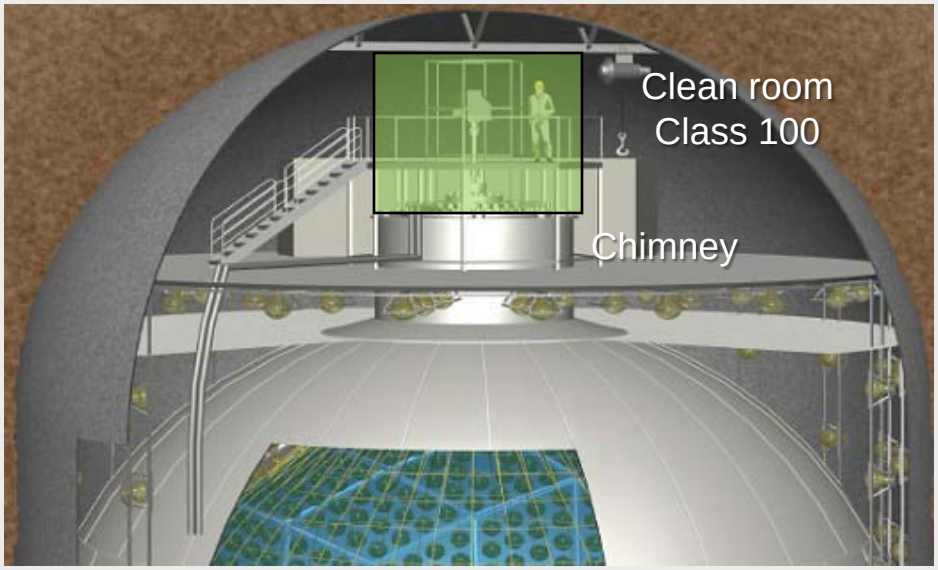
heat welding



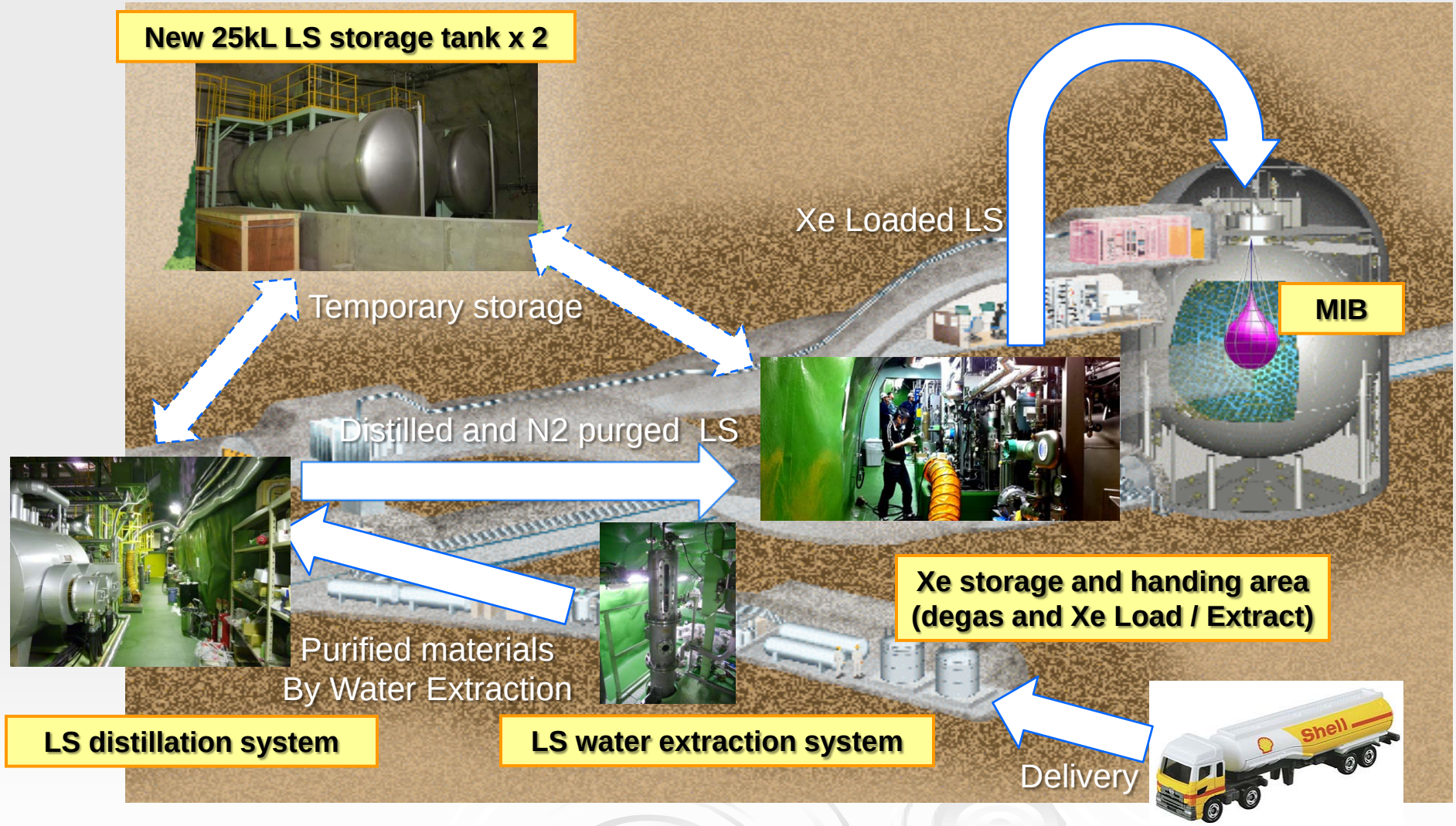
He leak test & Repair work

Before shipping

Installation of KamLAND-Zen mini balloon



Making Xe loaded LS

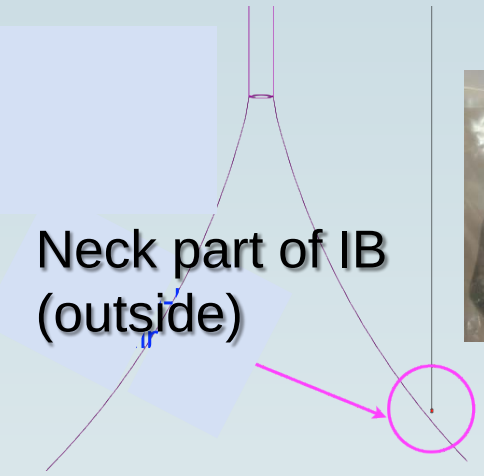


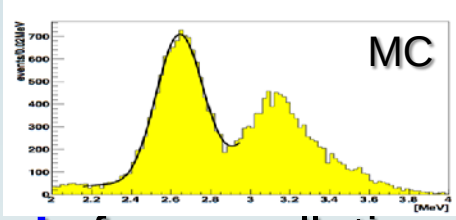
Normal data taking has been started on 24 September 2011

Energy Calibration

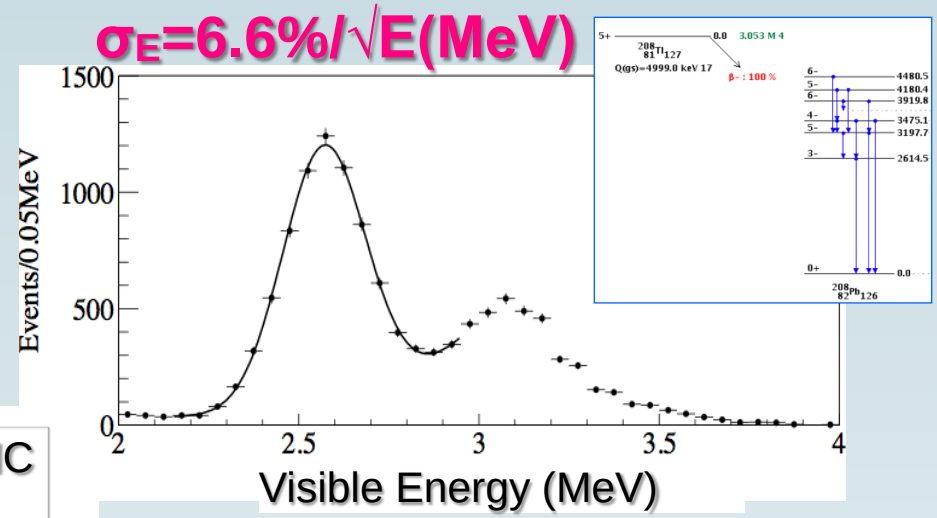
1. Calibration source

^{208}Tl(2.6 MeV γ, source)





$\sigma_E = 6.6\%/\sqrt{E(MeV)}$



2. **2.225 MeV gamma's** from spallation neutrons capture on protons.

3. Radioactivity in Xe-LS

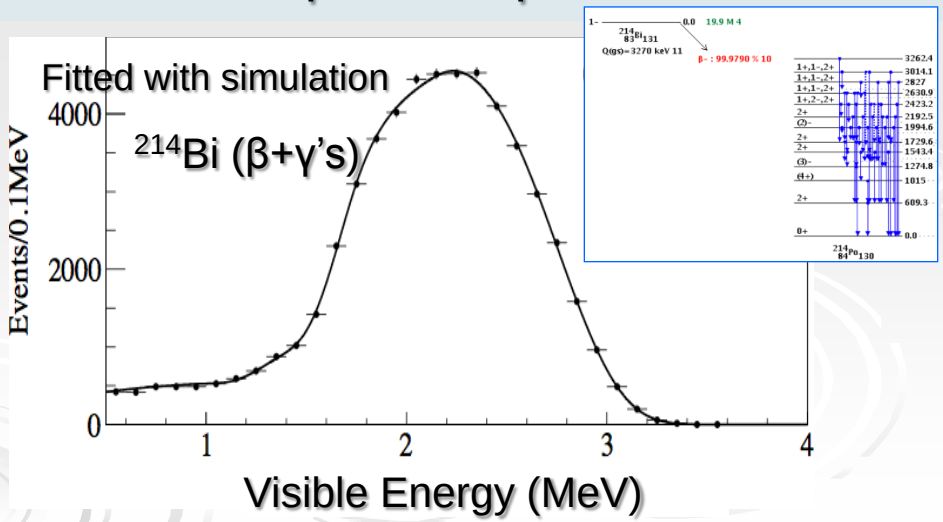
from initial contamination

Prompt delayed

^{222}Rn 3.824 day → ^{214}Bi 19.9 m → ^{214}Po 164.3 μs → ^{210}Pb 22.3 yr

Q_β = 3.272 MeV

Q_α = 7.687 MeV



Fiducial Volume

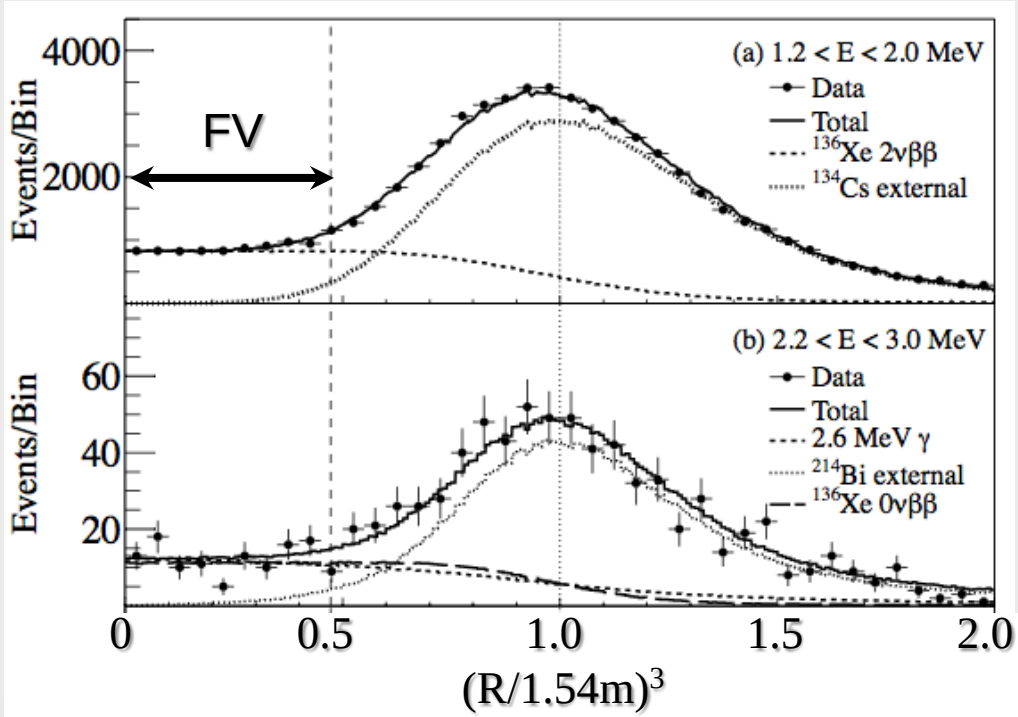
R<1.2 m, LS = 7.24 m^3
→ 125 kg ^{136}Xe in the FV
(^{136}Xe 90.93% enrichment,
2.44% by weight)

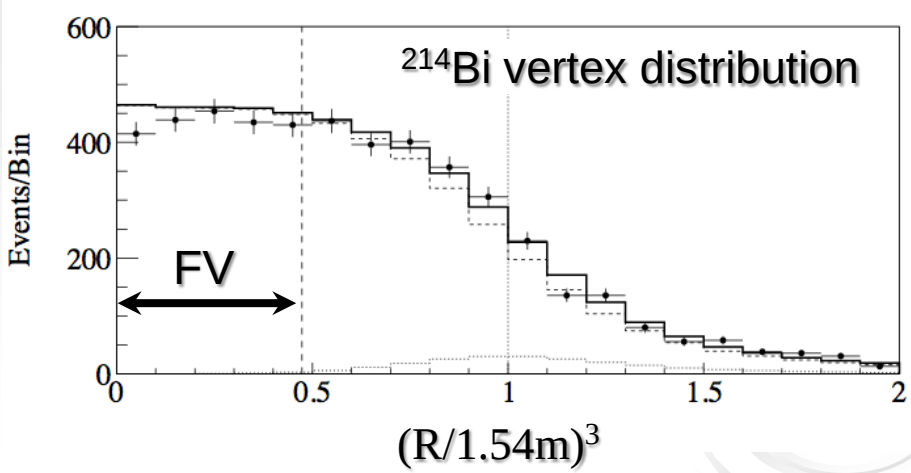
Volume ratio=0.438 ± 0.005
((R<1.2m)/Total 16.51 ± 0.17 m^3)

Total fiducial volume error 5.2%

^{214}Bi rate (from vertex distribution)
ratio = 0.423 ± 0.007(stat.) ± 0.004(syst.)
(R<1.2 / Total ^{214}Bi events)

Vertex resolution σ=~15cm/√E

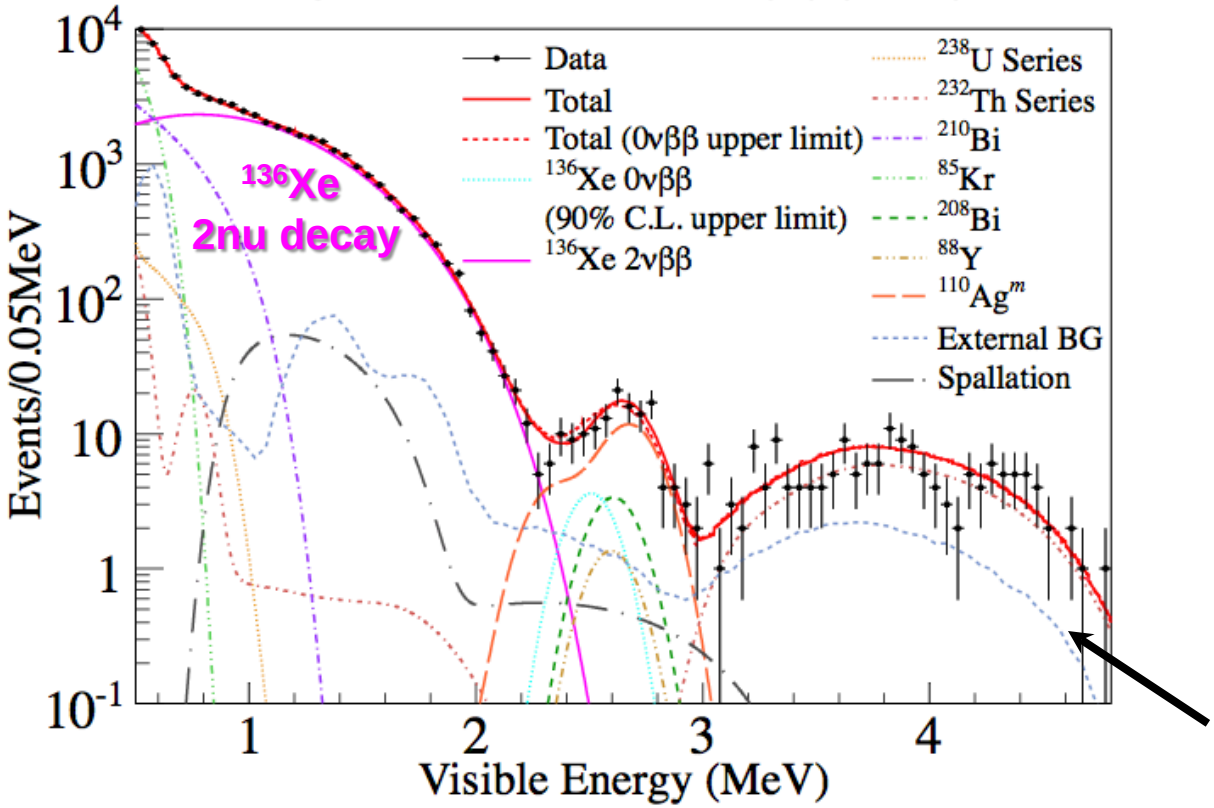




systematic uncertainty	error
fiducial volume	5.2%
enrichment of Xe	0.05%
Xe amount 2.44±0.01wt%	0.34%
energy scale	0.3%
Xe-LS edge effect	0.06%
total	5.2%

result of ^{136}Xe 2νββ half life

Phys. Rev. C 86, 021601(R) (2012)



- Livetime 112.3 days.
- ^{136}Xe 125 kg.

Event selection:
1. 1.2-m-radius FV.
2. 2msec veto after muon.
3. Sequential Bi-Po decay tagged.
4. Anti-neutrino (from reactor) tagged.
5. Vertex-time-charge test.

^{208}Tl distributed here.

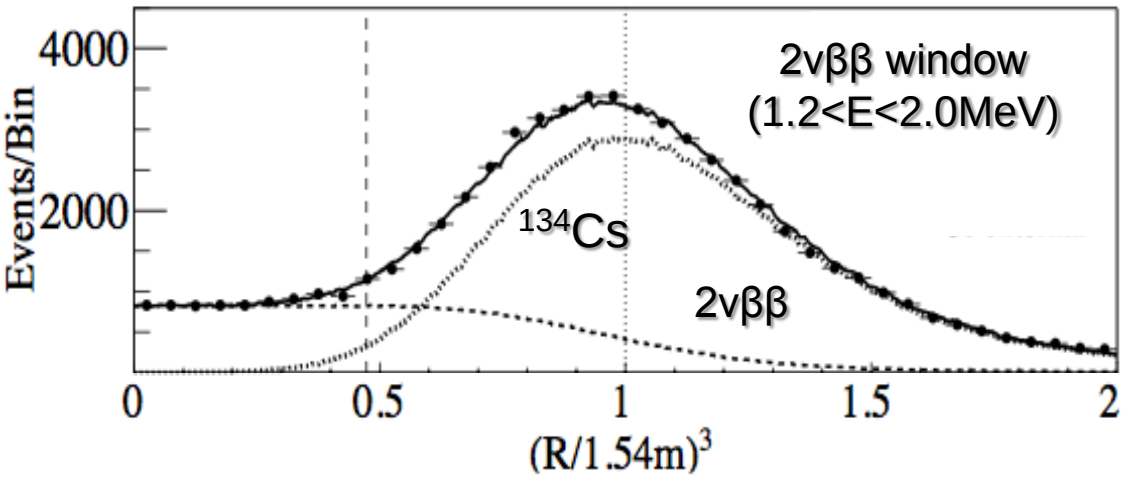
$T^{2\nu}_{1/2}$=2.30±0.02(stat)±0.12(syst) ×10^{21} years

$T^{2\nu}_{1/2}$=2.38±0.02(stat)±0.14(syst) ×10^{21} years (1st result)

- high precision measurement.
- consistent with EXO results.

Unexpected background for ^{136}Xe 0νββ

^{134}Cs distribute on the MIB. Origin → Fallout of Fukushima reactor accident

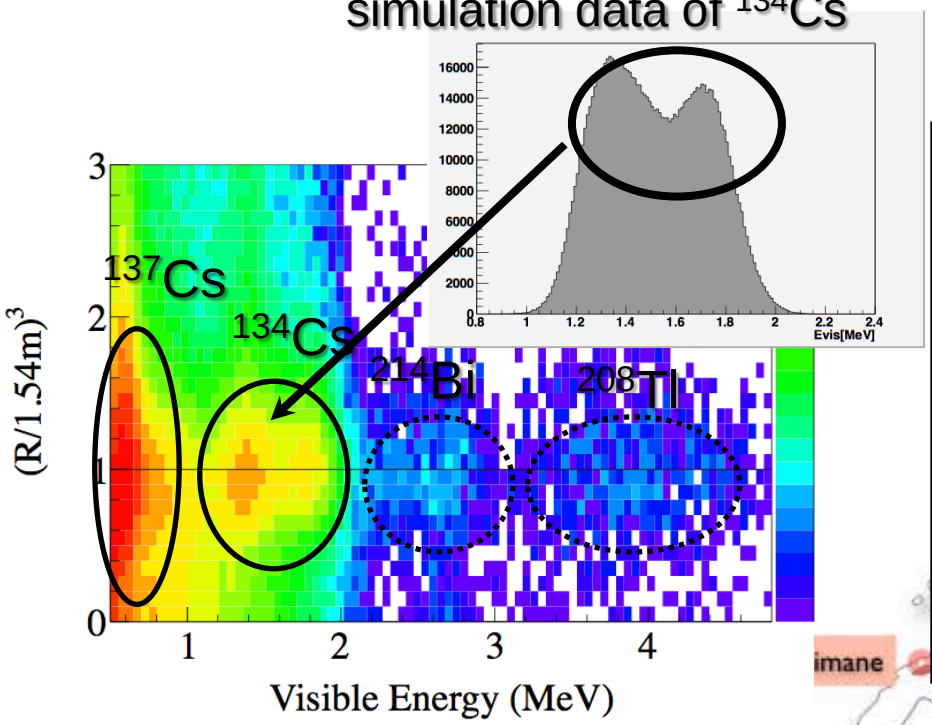


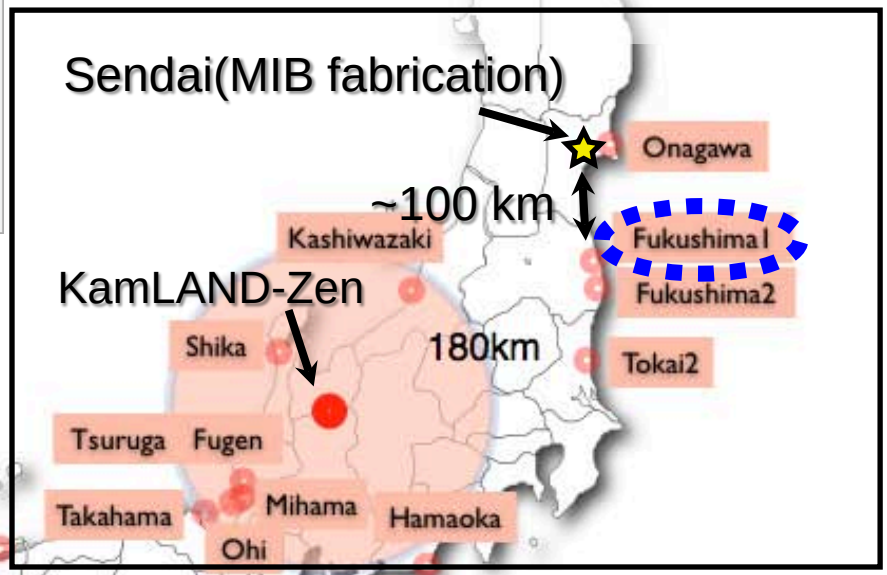
Why Fukushima?
- Cs doesn't exist in nature.
- Ratio of ^{134}Cs/^{137}Cs data (~0.8)& soil sample almost consistent.

Possibility Spallation of ^{136}Xe?
- Amount of ^{137}Cs can't explain.

Why on MIB?
- MIB made in Sendai (Cs detected in soil sample by Ge detector).
- Fit well with data.
- Cs don't dissolve to LS.

simulation data of ^{134}Cs

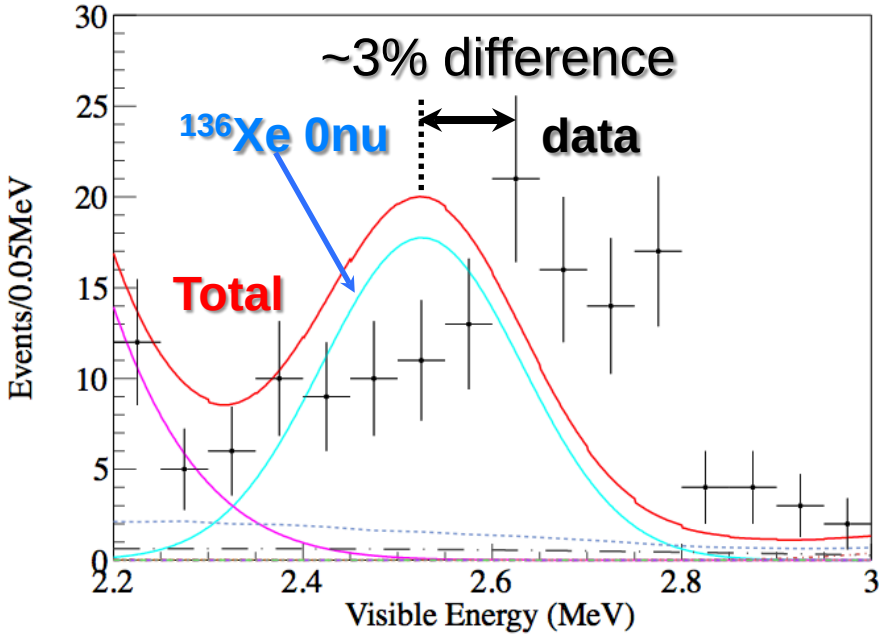




Unexpected background for ^{136}Xe 0νββ

Fit the peak with 0nu spectrum

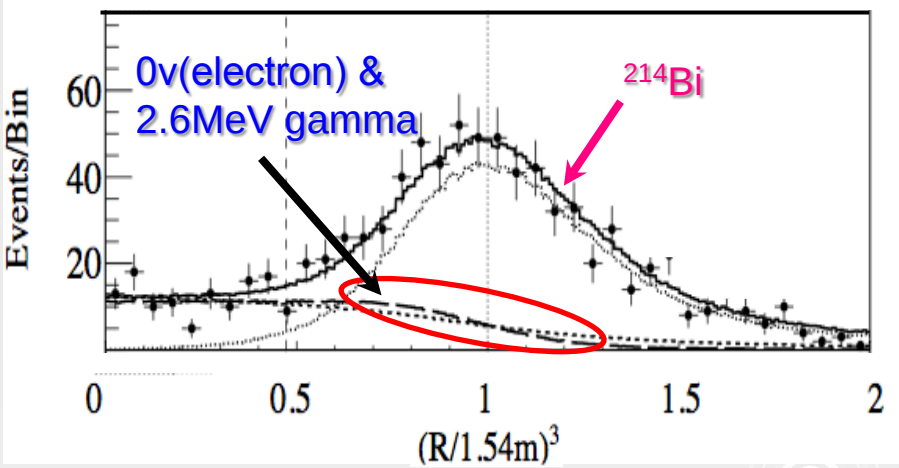
※close-up picture (fitting range is 0.5-4.8 MeV)



No background hypothesis excluded more than 5 sigmas.

Features of peak

- Rate is stable.
- Uniformly distributed in Xe-LS.
- No signal in KamLAND-LS
- beta or gamma : difficult to distinguish



What is this background?

Long-lived radioactive impurities ?

Cosmogenic spallation nuclei ?

- ex-situ measurement didn't determine BG.
Amount of BG is too small to measure.

Search all nuclei and decay path in the ENSDF

database of nuclei

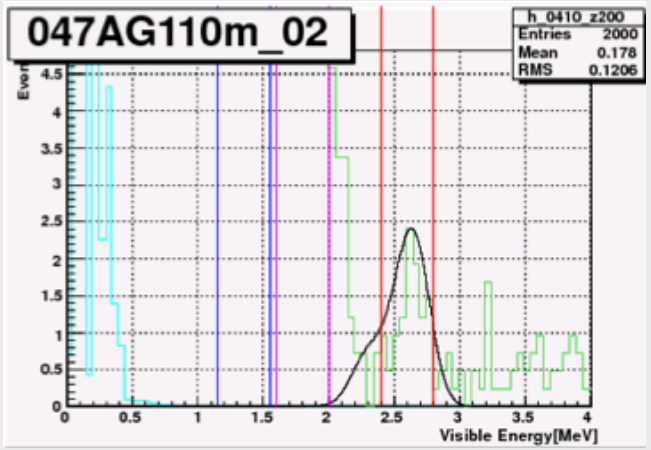
ENSDF search

We search all of isotopes, all of decays in ENSDF

- Procedure

- Follow every ENSDF cascade info and check lifetime, Q-value and so on.
- Make energy spectrum of $\beta^-(+\gamma)$, β^+ $(+\gamma)$ and EC$(+\gamma)$ decays expected in KamLAND (considered alpha quenching, energy resolution, the time structure of the chain and pile-up in DAQ etc.)
- Check its peak and shape (it is in 2.4-2.8 MeV?).
- Check long lived parent (> 30days) for each candidates.

example of spectrum



4 nuclei remains.

	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

※ ^{110m}Ag is one of reactor fallout, too.

- Nuclei w/ 100sec~30days are rejected from the study of energy spectrum w/ close A,Z nuclei.
→ negligible

- Study on time-correlation event with muon w/ <100 sec lifetime is estimated to be $<6.7 \times 10^{-3}$ /ton·day (90% CL).
→ small

Cosmogenic spallation at aboveground?

Possibility of cosmogenic spallation in Xe?

- Xe enriched in Russia and sent to mine by airplane (high cosmic ray flux).

^{136}Xe + p(1 GeV) cross section

P.Napolitiani et. al.
Phys. Rev. C **76,** 064609 (2007)

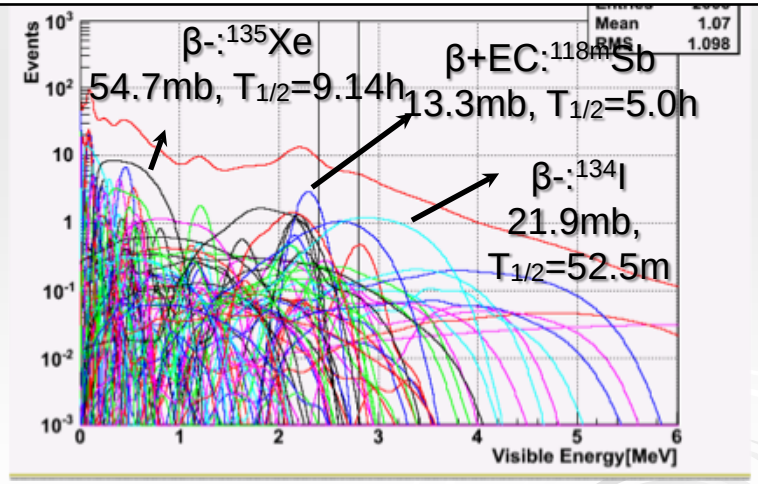
quantitative background estimation is difficult due to transportation loss in the gas system.

^{136}Xe → surface → mine → Radioactivities after X + Y days → energy spectrum

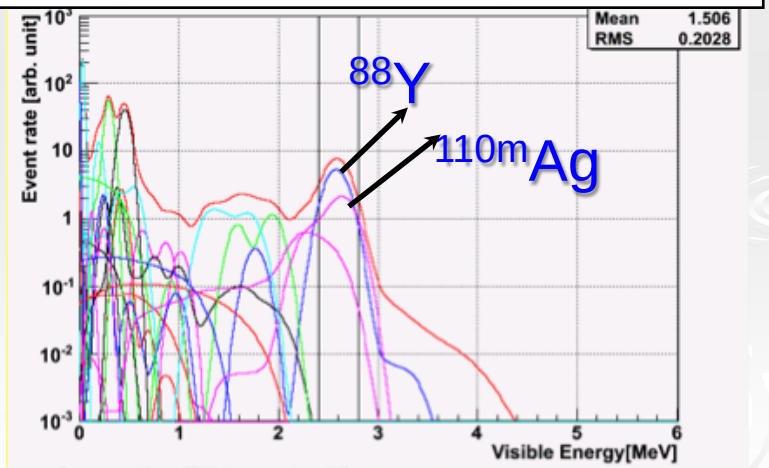
surface: X = 100 days

mine: Y = 0, 100, 300, 600days

100 days on surface, 0 days in the mine



100 days on surface, 300 days in the mine

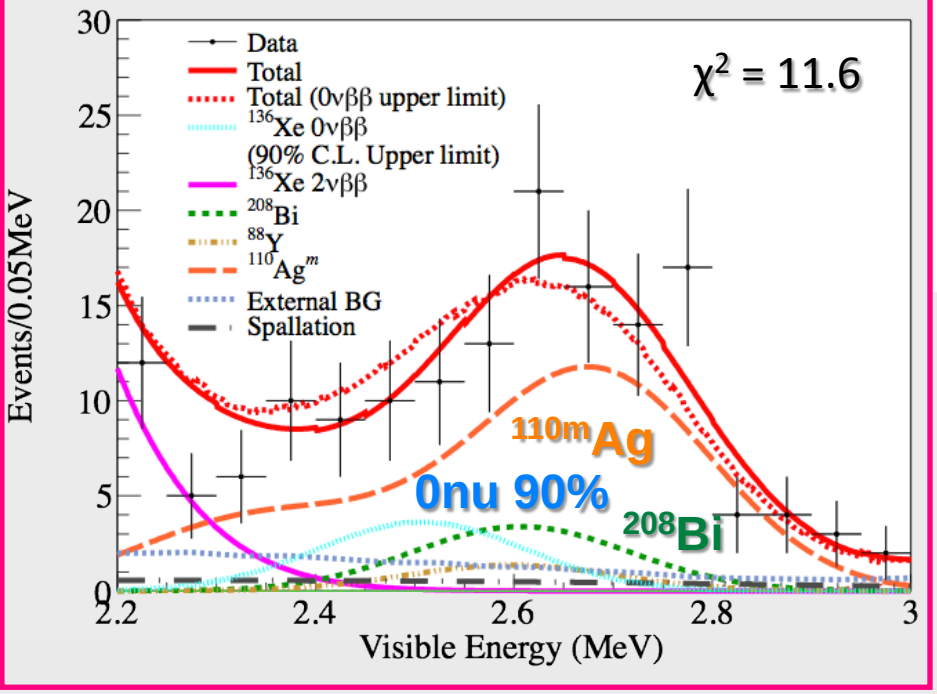


→ ^{110m}Ag and ^{88}Y remains.

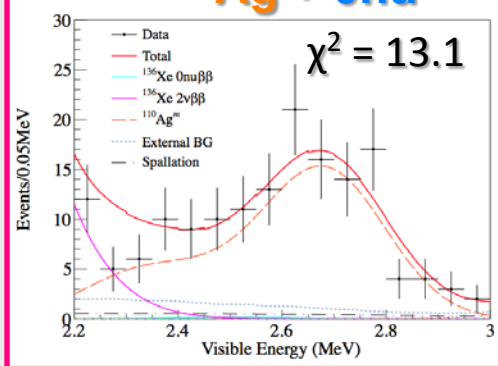
Limit on ^{136}Xe 0νββ decay

Simultaneous fit

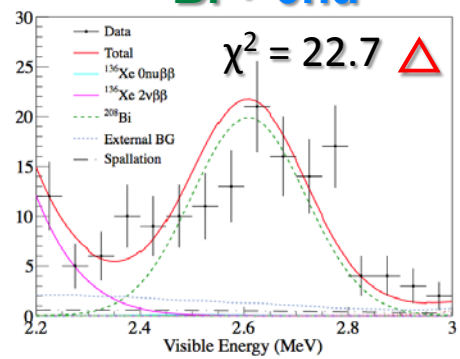
and 90% CL upper limit for 0νββ



^{110m}Ag + 0nu



^{208}Bi + 0nu



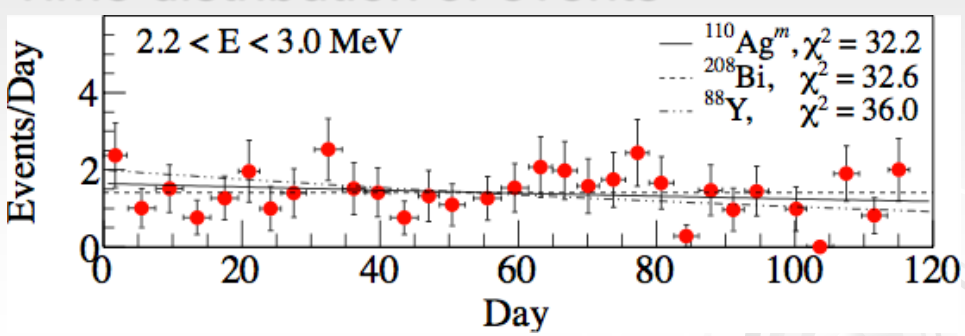
^{88}Y + 0nu → χ^2 = 22.2 △

^{60}Co + 0nu → χ^2 = 82.9 ✕

0nu only → χ^2 = 85.0 ✕

BG is likely to be ^{110m}Ag.

Time distribution of events



Stable. No strong discrimination.

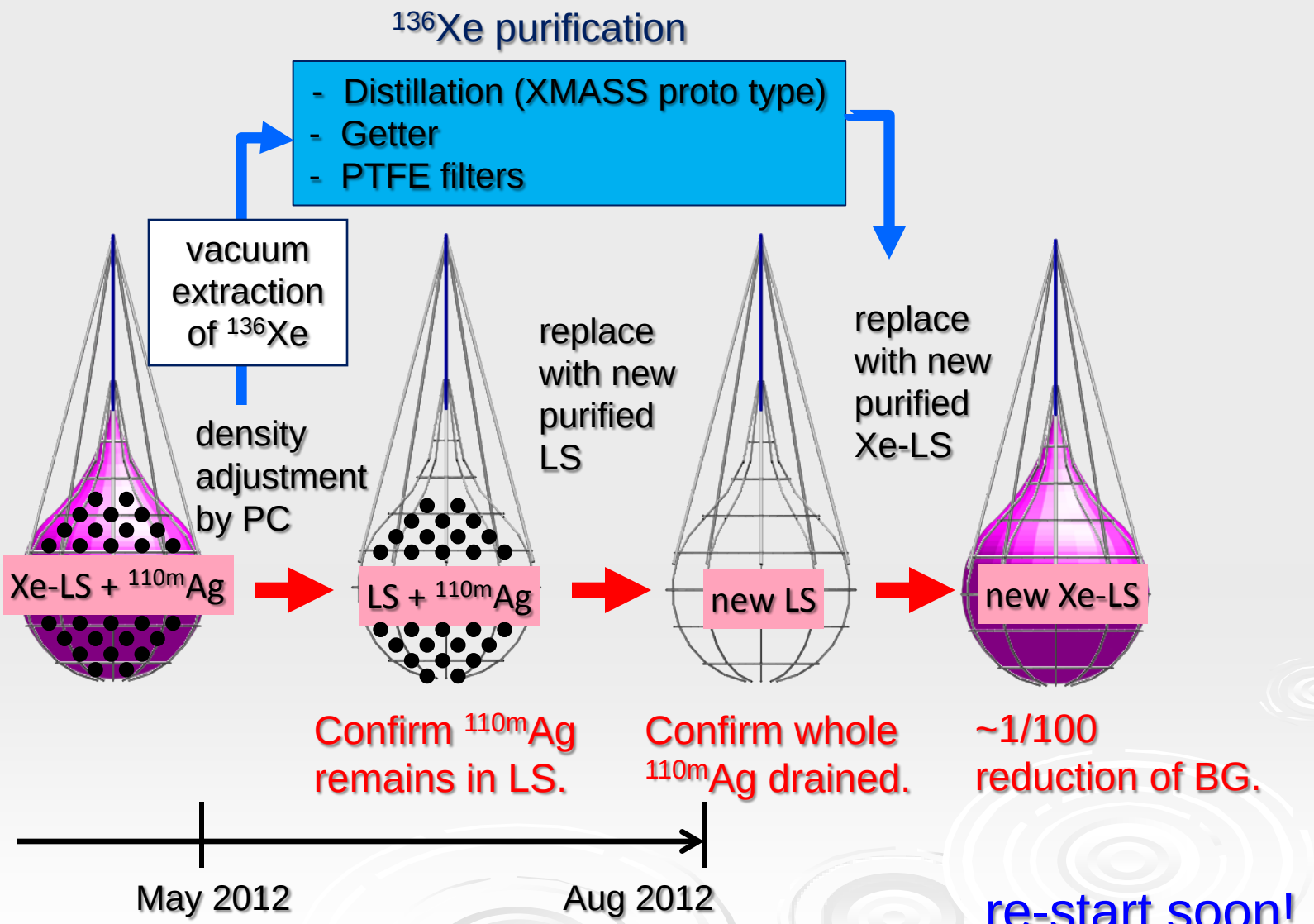
$T^{0\nu}_{1/2} > 6.2 \times 10^{24}$ yr

⇩

(R)QRPA (CCM SRC)
Phys.Rev.C79,055501(2009)

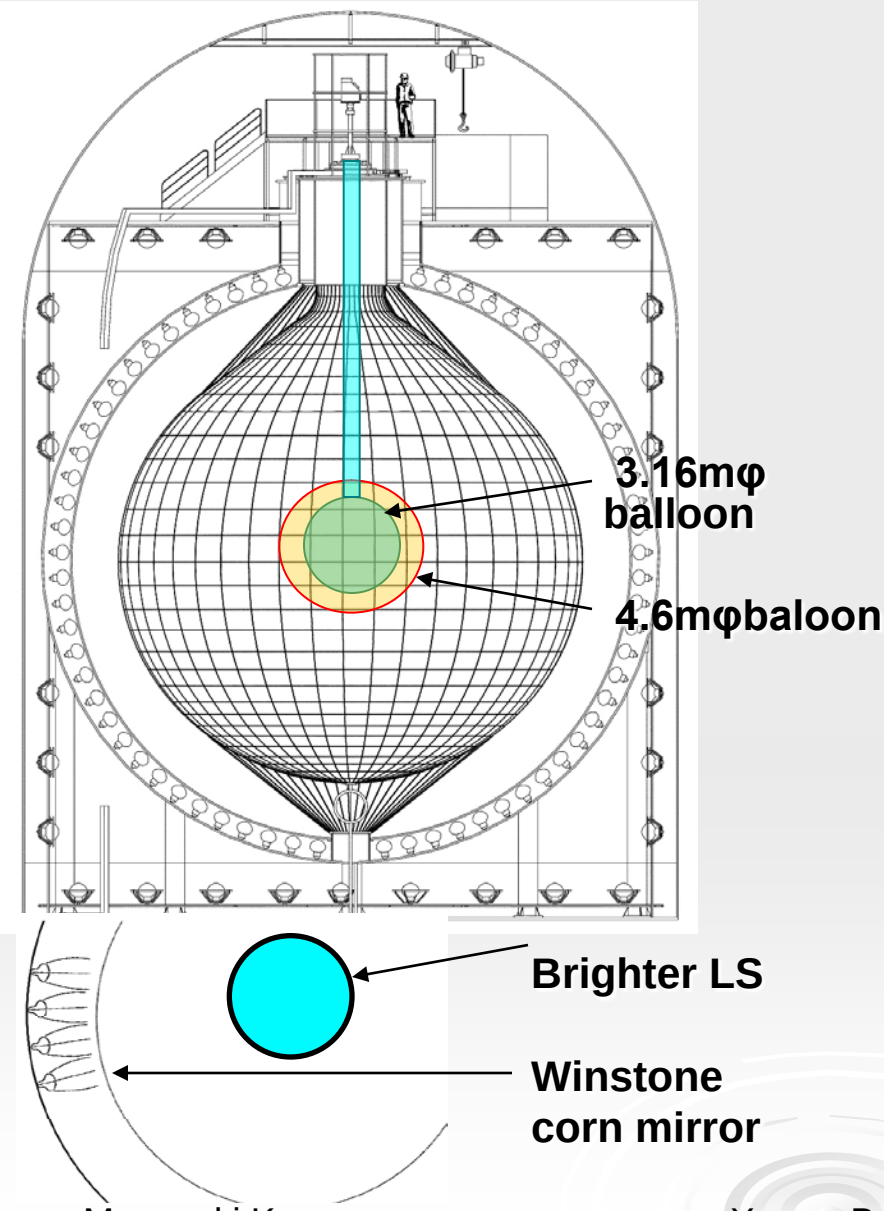
$\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54$ eV
(90% C.L.)

How to reduce the BG ?



re-start soon!

Future Plan



Current phase

re-start (from Dec. 2012?)

KamLAND-Zen'

- **we will purchase 700~800kg enrich ^{136}Xe to the end of 2013**
- **make bigger balloon**
- **same component XeLS (~3wt%)**
- **main tank inspection & OD repair (beginning of 2014?)**

tank opening (2016?)

KamLAND-Zen2 ^{136}Xe 1000kg

- **R=2.3m balloon**
  V=51.3m^3,S=66.7m^2
- **improvement of energy resolution**
  (brighter LS, higher light concentrator)
  ~25meV with 5 years

summary

- KamLAND-Zen started from September 2011

- 112 days result
  - ○ 2νββ decay

    $T^{2\nu}_{1/2}$=2.30±0.02(stat)±0.12(syst) ×10^{21} yr

  - ○ 0νββ decay

    $T^{0\nu}_{1/2}$ > 6.2×10^{24} yr at 90% C.L.

    corresponding to $\langle m_{\beta\beta} \rangle$< 0.26-0.54 eV.

- Under the reduction of BG from LS.
  We will restart soon (end of 2012~)

- Considering to upgrade (-Zen' and -Zen2)