Results from KamLAND-Zen

Neutrino 2014

XXVI Conference on Neutrino Physics and Astrophysics

Jun. 6, 2014

Itaru Shimizu (Tohoku Univ.)

KamLAND-Zen Collaboration

K. Asakura,[1] A. Gando,[1] Y. Gando,[1] T. Hachiya,[1] S. Hayashida,[1] H. Ikeda,[1] K. Inoue,[1, 2] K. Ishidoshiro,[1] T. Ishikawa,[1] S. Ishio,[1] M. Koga,[1, 2] R. Matsuda,[1] S. Matsuda,[1] T. Mitsui,[1] D. Motoki,[1] K. Nakamura,[1, 2] S. Obara,[1] Y. Oki,[1] M. Otani,[1] T. Oura,[1] I. Shimizu,[1] Y. Shirahata,[1] J. Shirai,[1] A. Suzuki,[1] H. Tachibana,[1] K. Tamae,[1] K. Ueshima,[1] H. Watanabe,[1] B.D. Xu,[1] Y. Yamauchi,[1] H. Yoshida,[1] A. Kozlov,[2] Y. Takemoto,[2] S. Yoshida,[3] K. Fushimi,[4] T.I. Banks,[5] S.J. Freedman,[2, 5†] B.K. Fujikawa,[2, 5] T. O'Donnell,[5] L.A. Winslow,[6] B.E. Berger,[7] Y. Efremenko,[2, 8] H.J. Karwowski,[9] D.M. Markoff,[9] W. Tornow,[2, 9] J.A. Detwiler,[10] S. Enomoto,[2, 10] and M.P. Decowski[2, 11]

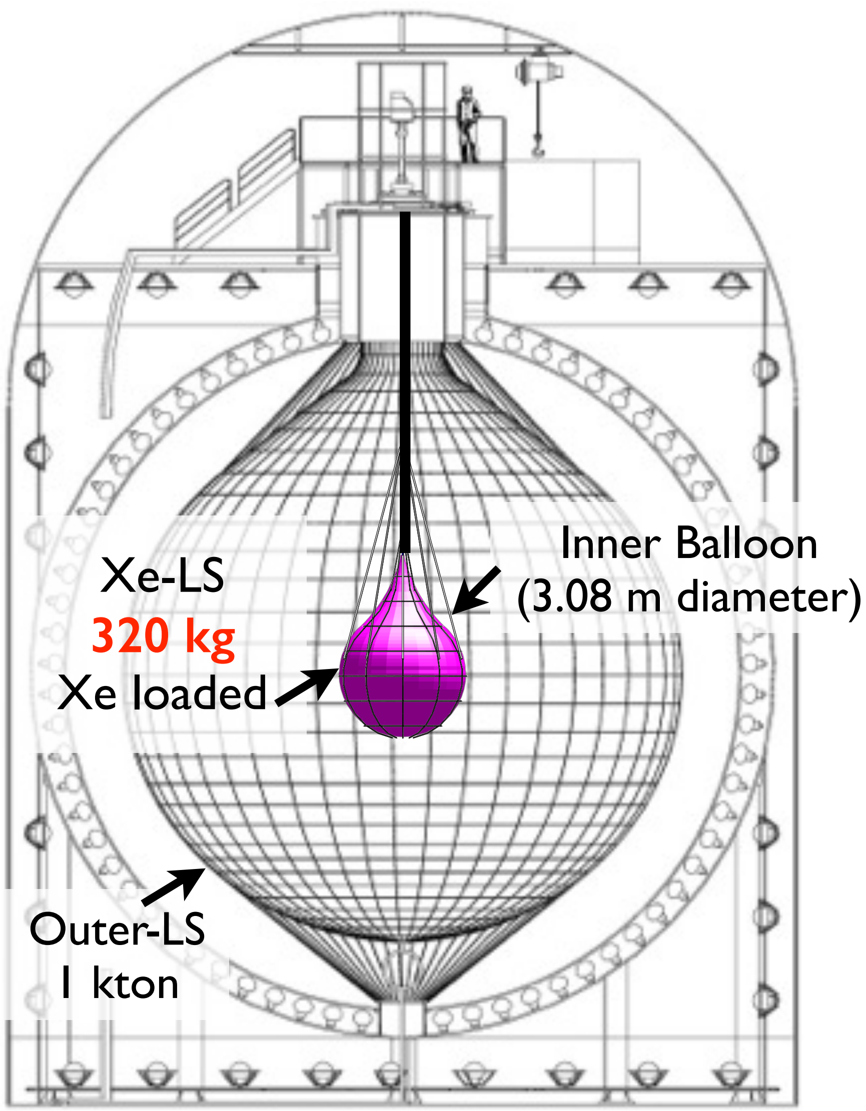
1Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan
2Kavli Institute for the Physics and Mathematics of the Universe (WPI), University of Tokyo, Kashiwa, 277-8583, Japan
3Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan
4Faculty of Integrated Arts and Science, University of Tokushima, Tokushima, 770-8502, Japan
5Physics Department, University of California, Berkeley, and Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
6Department of Physics and Astronomy, University of California, Los Angels, Los Angels, California 90095, USA
7Department of Physics, Colorado State University, Fort Collins, Colorado 80523, USA
8Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA
9Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA; Physics Departments at Duke University, Durham, North Carolina 27705, USA; North Carolina Central University, Durham, North Carolina 27701, USA and the University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA
10Center for Experimental Nuclear Physics and Astrophysics, University of Washington, Seattle, Washington 98195, USA
11Nikhef and the University of Amsterdam, Science Park, Amsterdam, the Netherlands

Photo in the KamLAND collaboration meeting (Mar. 2014)

KamLAND-Zen

Kamioka Liquid Scintillator Anti-Neutrino Detector
Zero Neutrino Double Beta

KamLAND-Zen Phase I



Xenon loaded LS (Xe-LS)

decane	82%
pseudo-cumene	18%
PPO	2.7 g/liter
xenon	2.44 wt%

$\sigma_E(2.5\text{MeV}) = 4\%$

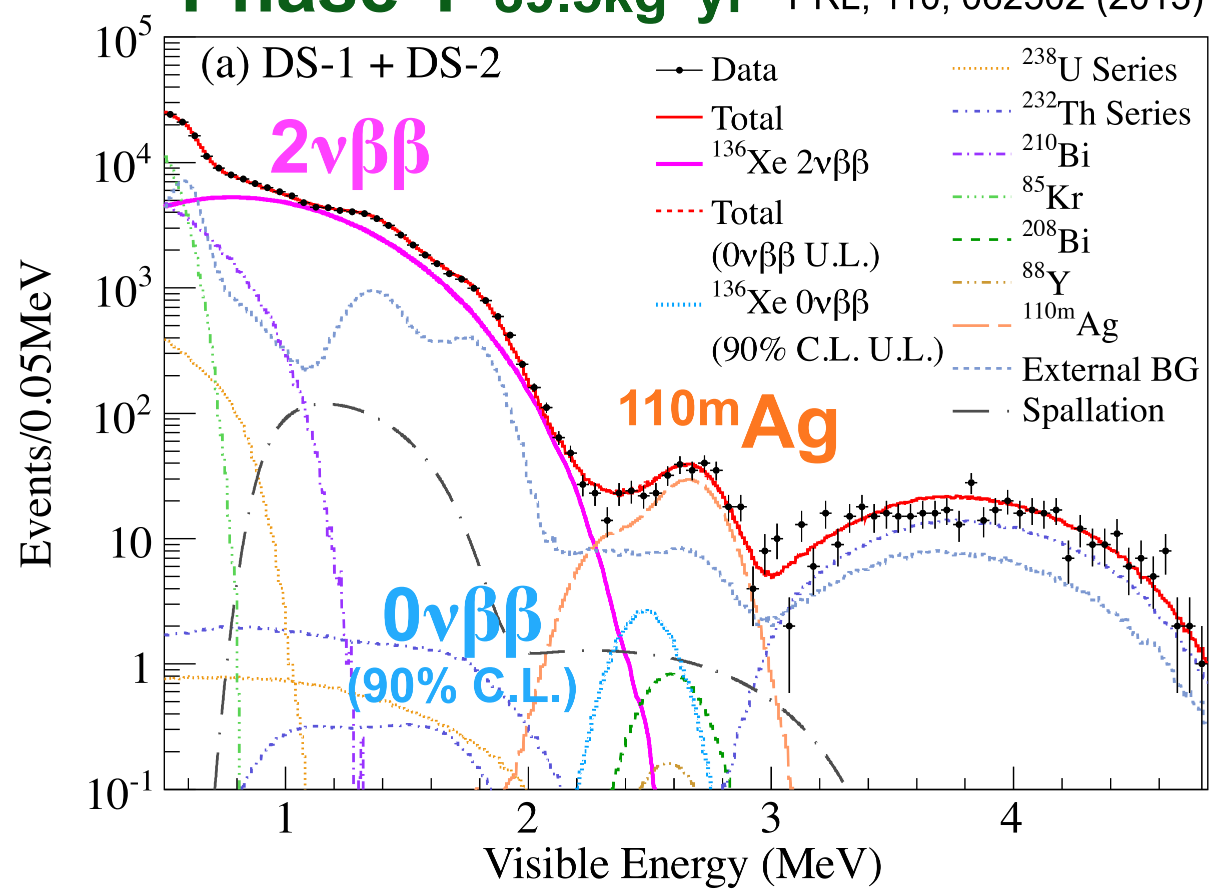
Advantage of KamLAND

- running detector : start quickly with relatively low cost
- big and pure : no BG from external gamma-rays
- purification of LS, replacement of mini-balloon are possible

→ **high scalability** (a few ton of Xe)

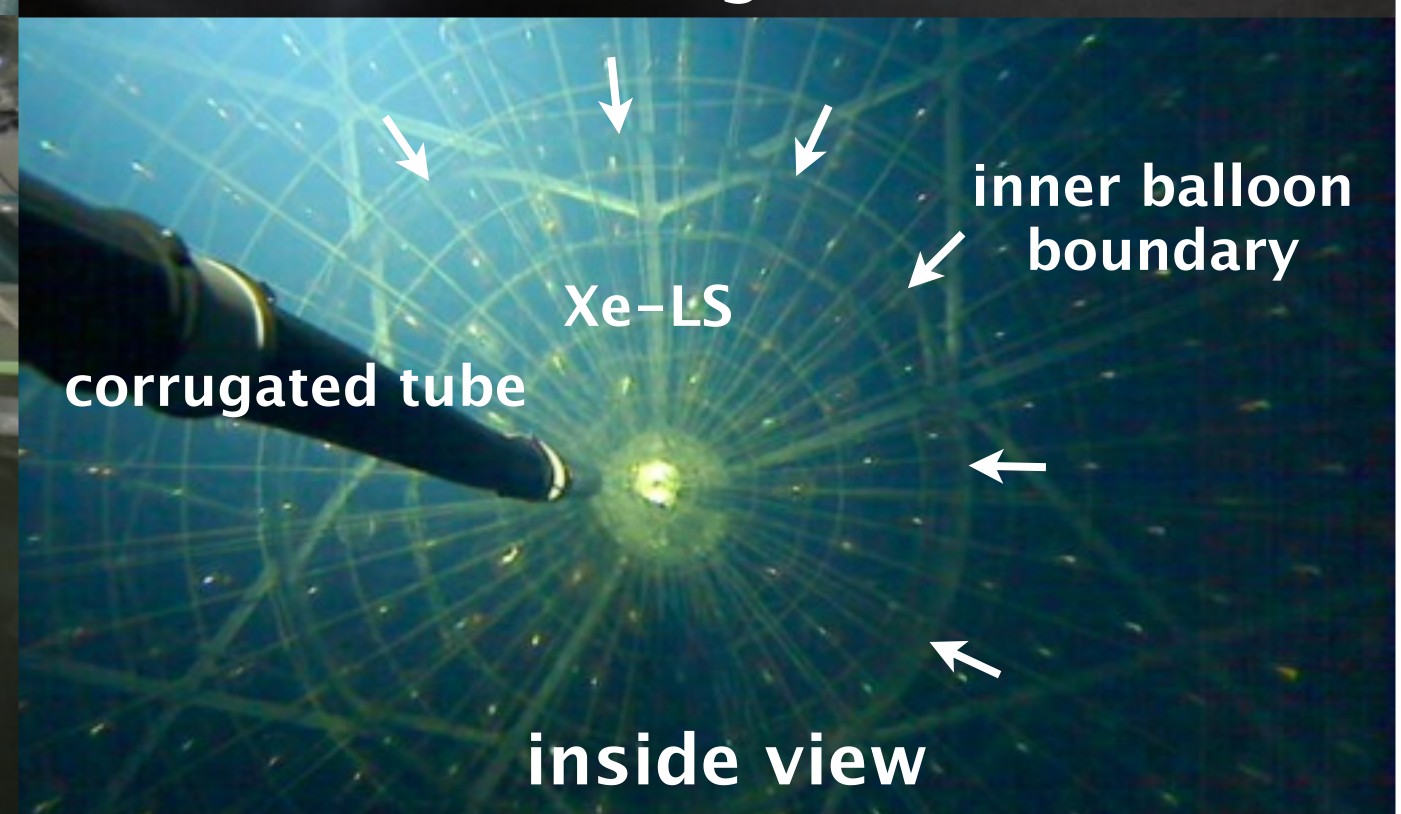
realize double beta-decay search with **low background**

Phase 1 89.5kg•yr PRL, 110, 062502 (2013)



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

Construction in 2011



Improvement Efforts after Phase 1

1. Remove radioactive impurities by Xe-LS purification

candidates of ~2.6 MeV peak

⟶ only 4 nuclei ^{110m}Ag (250 d), ^{208}Bi (3.68×10^5 yr), ^{88}Y (107 d), ^{60}Co (5.27 yr)

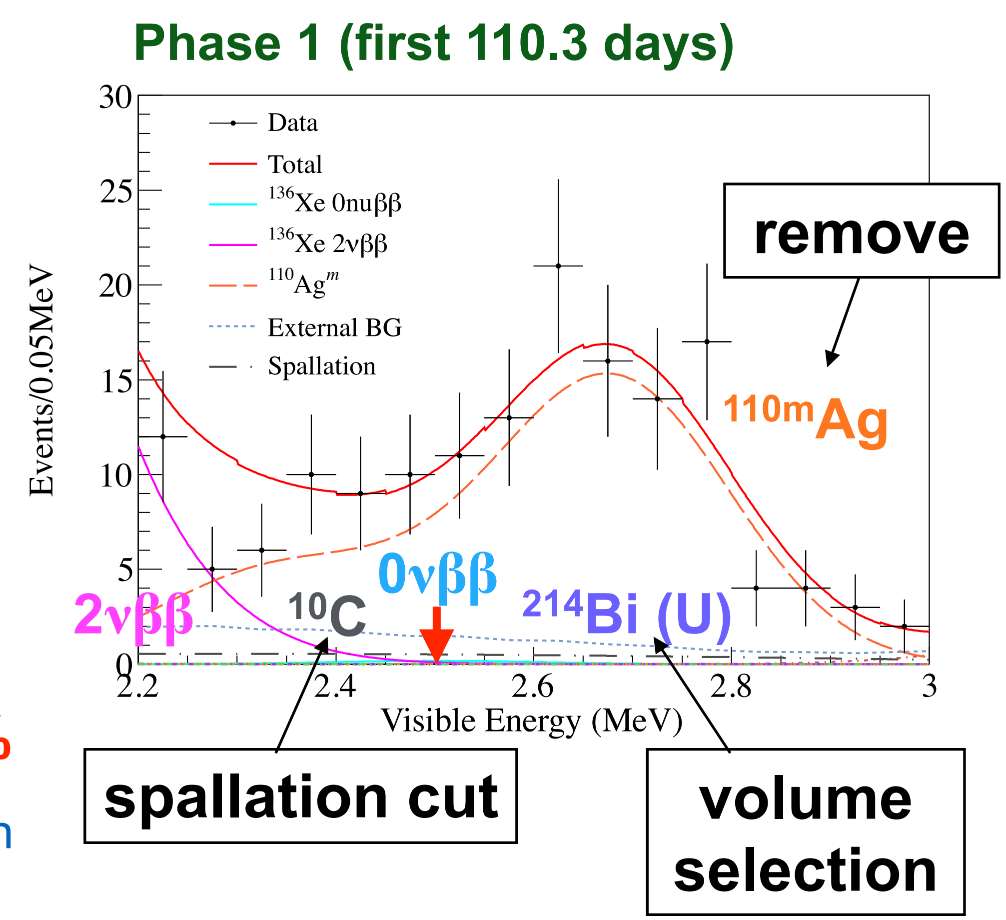
lifetime longer than 30 days ↖ detected in Fukushima fallout

Two possible sources:

(1) contamination by Fukushima-I reactor fallout

(2) cosmogenic Xe spallation while above ground

"primary" background source (^{110m}Ag) can be removed by Xe-LS purification



2. Increase amount of Xenon

	phase 1		phase 2
Xe concentration	(2.44 ± 0.01) wt%	⟶	(2.96 ± 0.01) wt%

increase of S/N ~ 1.2 Xe-pressurized phase is a future option

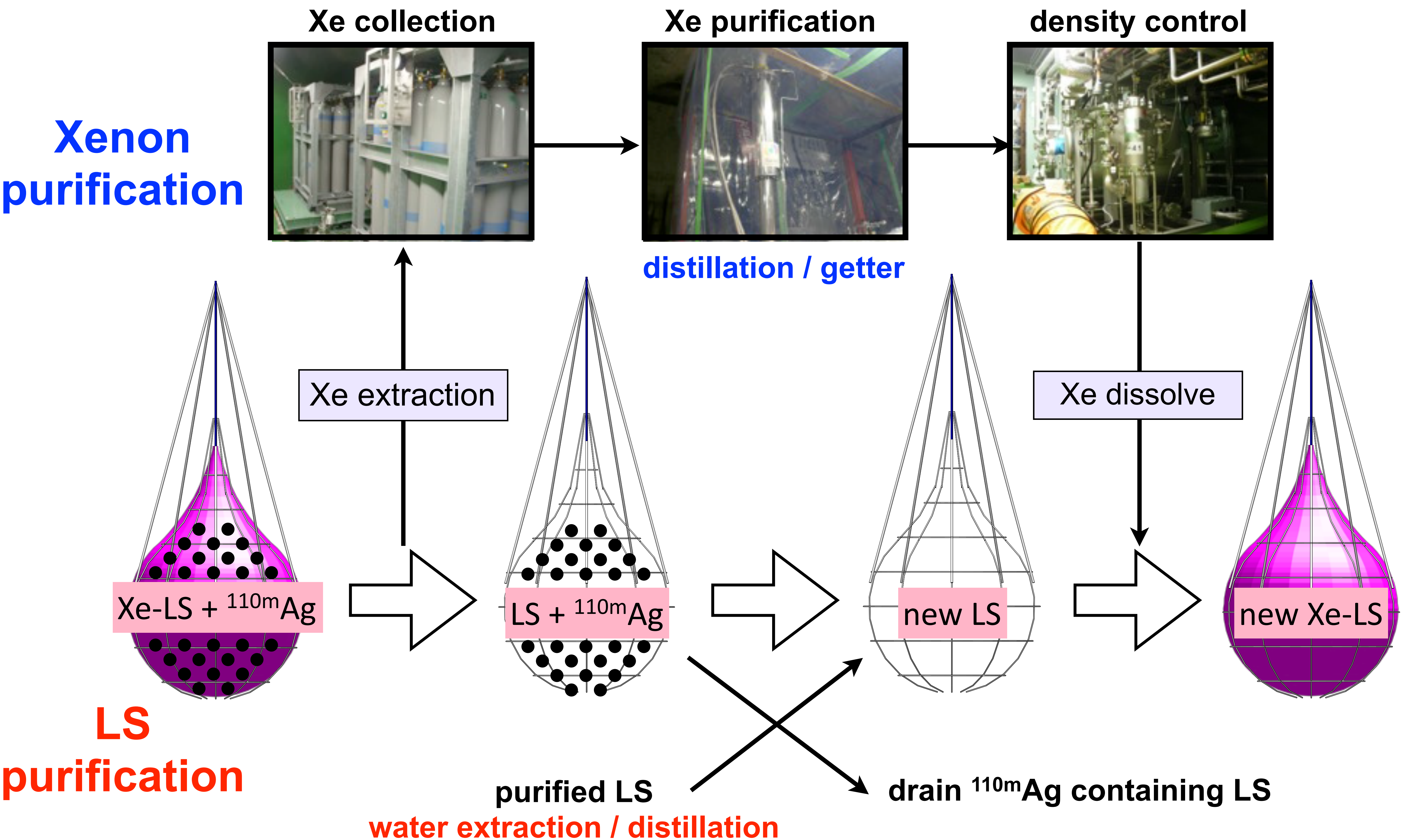
3. Spallation cut after muon

muon-neutron-^{10}C (τ = 27.8 s) triple coincidence ⟶ ^{10}C background rejection

4. Optimization of volume selection

fiducial volume limitation by ^{214}Bi (U) on the balloon film ⟶ multi-volume selection

Purification Strategy



Xenon and LS purification to reduce radioactive impurities

Circulation of LS

Purification activity for 1.5 years

Jun. 2012 Xe extraction from Xe-LS
leakage trouble in diaphragm pump → increase of balloon film BG
→ confirm ^{110m}Ag remains in Xe-depleted LS

Jul. 2012 Xe purification by distillation and getter

Aug. 2012 Replacement by **new purified LS**
→ confirm ^{110m}Ag reduction to
1/3 - 1/4 **not enough …**

Nov. 2012 LS distillation in circulation mode (×**1**)
fire accident in the purified air system

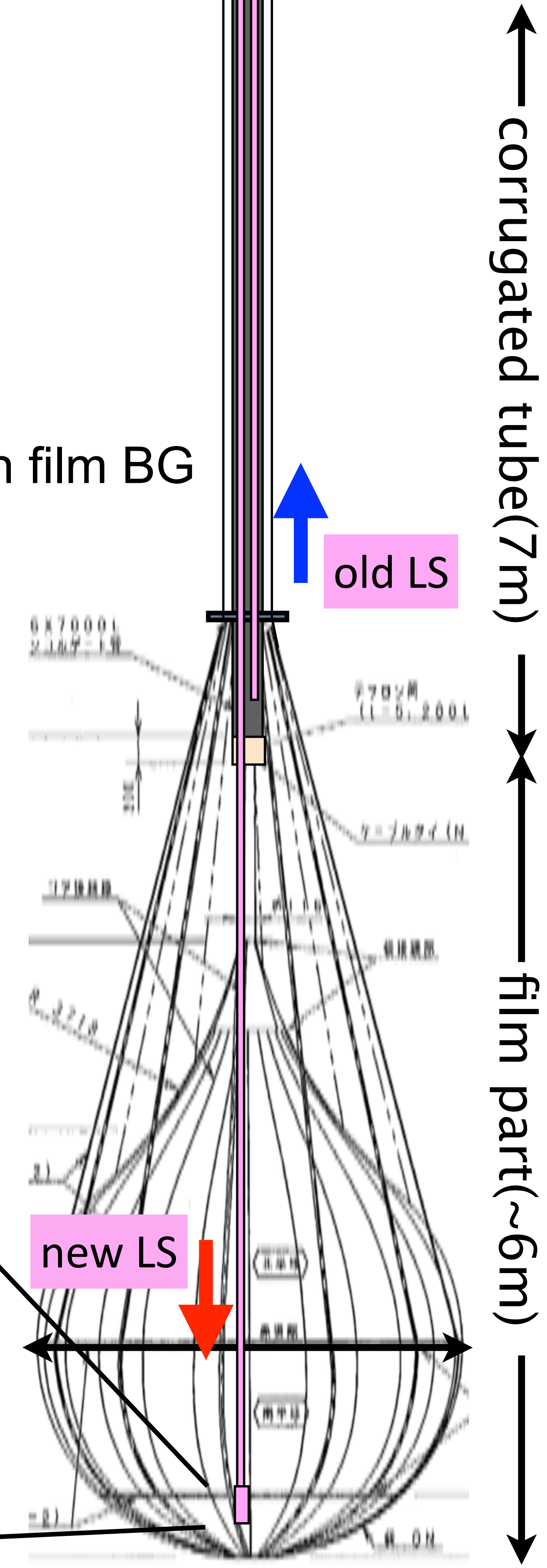
Jul. 2013 LS distillation in circulation mode (×**2**)

Oct. 2013 Replacement by **new purified LS**

Nov. 2013 Dissolving **purified Xe** into LS

Dec. 2013 Start phase 2 data-taking
→ confirm ^{110m}Ag reduction to
< 1/10 **including the decay**

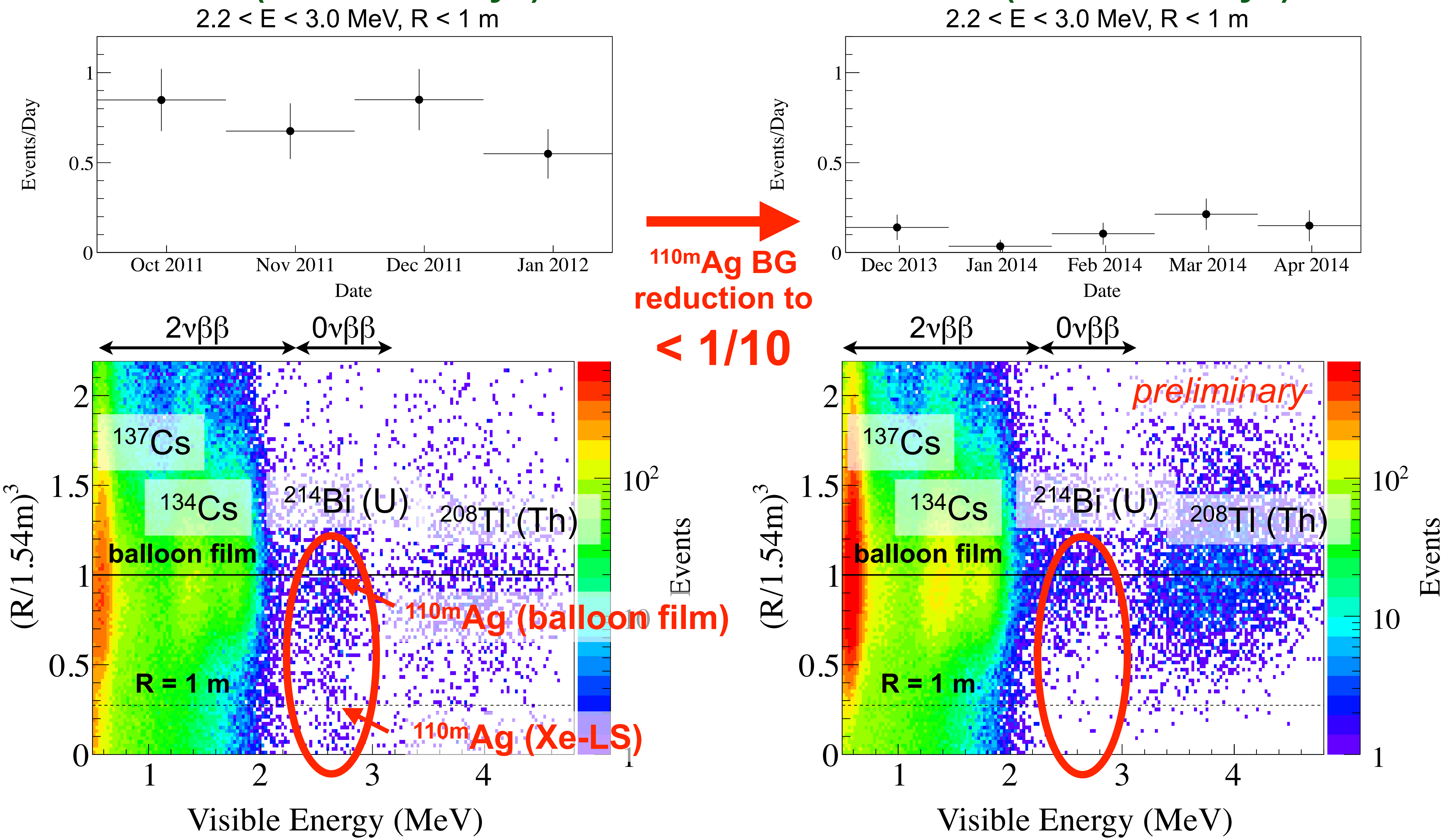
LS outlet



Phase 2 (low BG) data-taking started on Dec. 11, 2013

^{110m}Ag Background Reduction

Phase 1 (first 112.3 days) | **Phase 2 (first 114.8 days)**

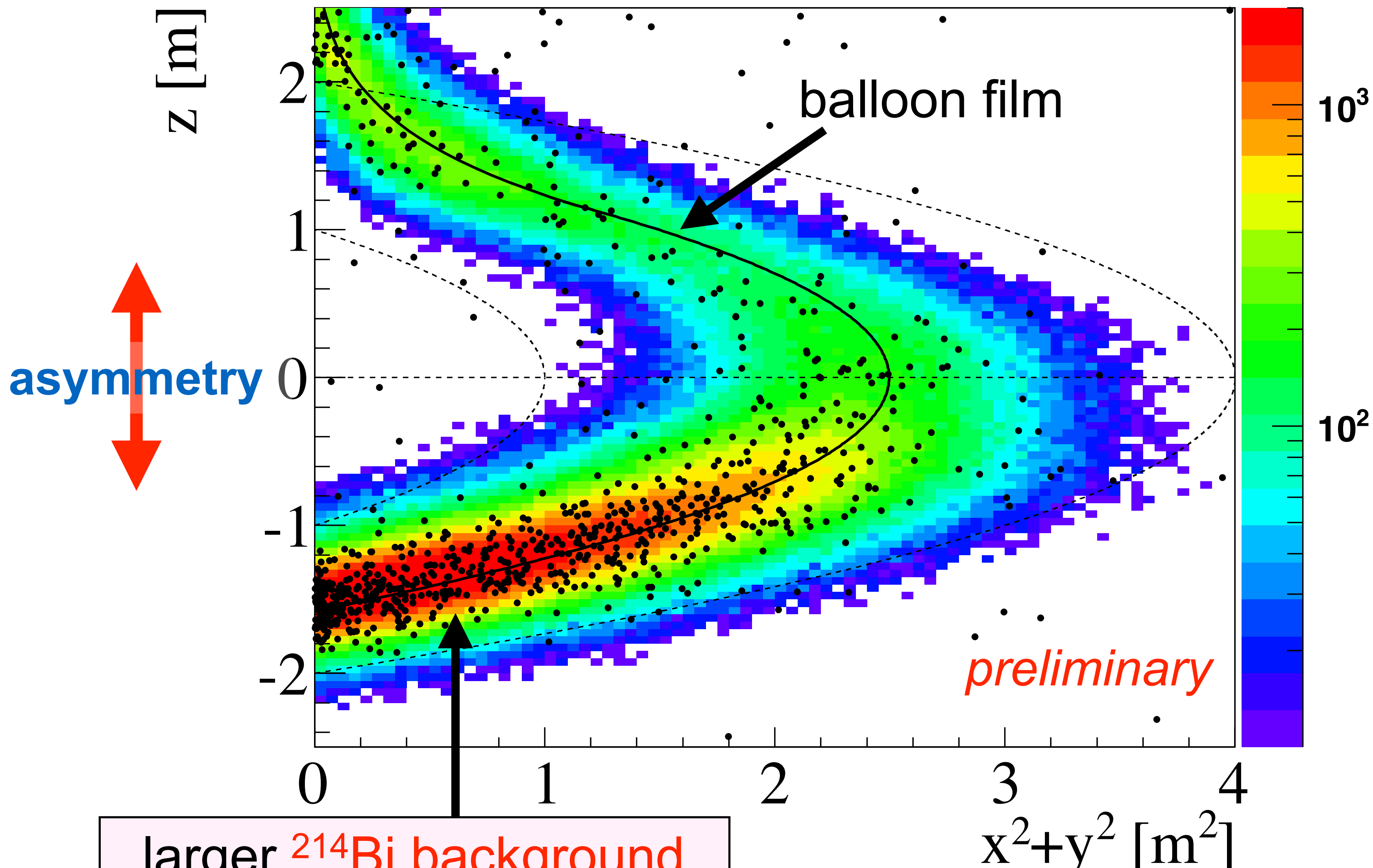


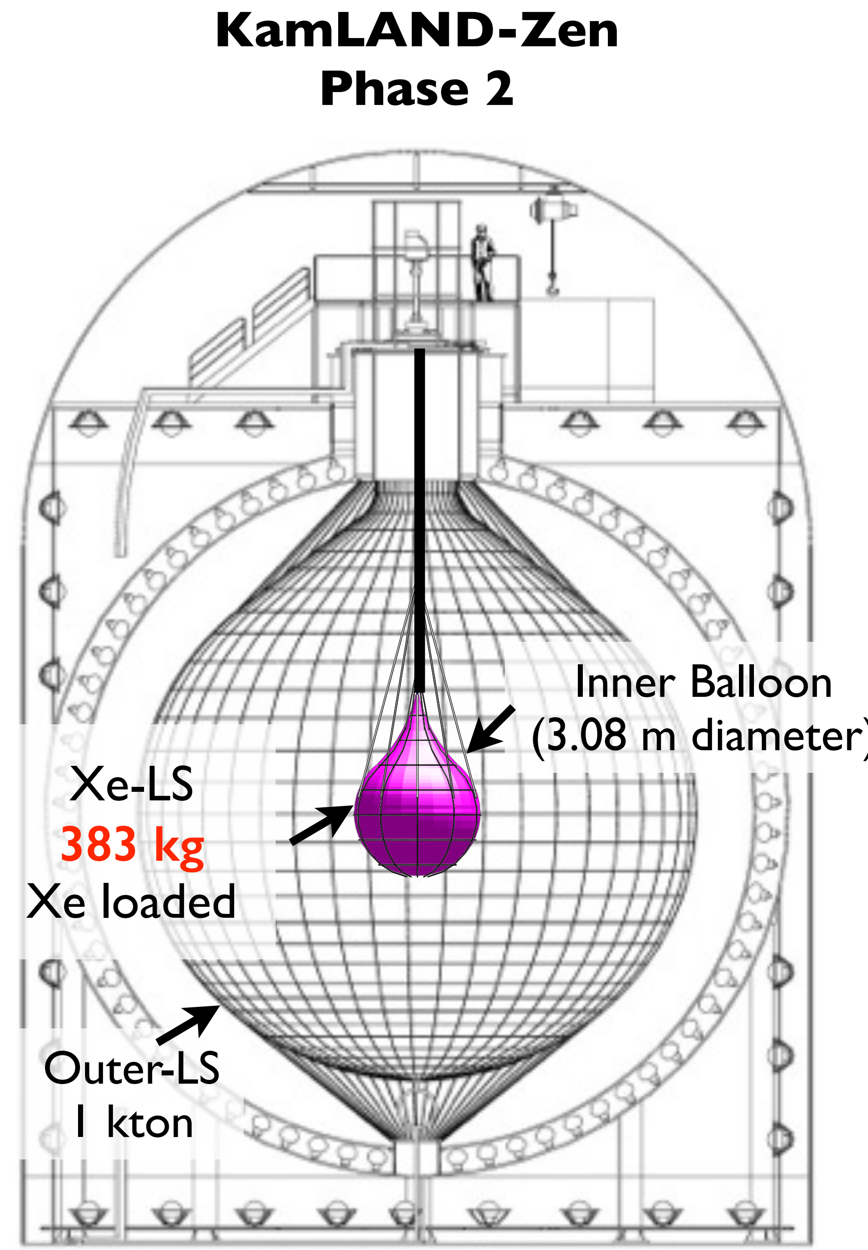
Primary BG : ^{214}Bi (U) at balloon / spallation ^{10}C / remaining ^{110m}Ag?

Optimization of Volume Selection

ROI : 2.3 < E < 2.7 MeV

candidate events (black points)
^{214}Bi MC simulation (color histogram)





larger ^{214}Bi background
at balloon bottom
(due to leakage in diaphragm pump)

multi-volume selection for analysis optimization

↓

target volume for spectral fit : R < 2.0 m

40 equal volume bins

(20 bins + 20 bins in upper / lower hemisphere)

Verification of ^{214}Bi Vertex Distribution

vertex is reconstructed from each PMT hit timing

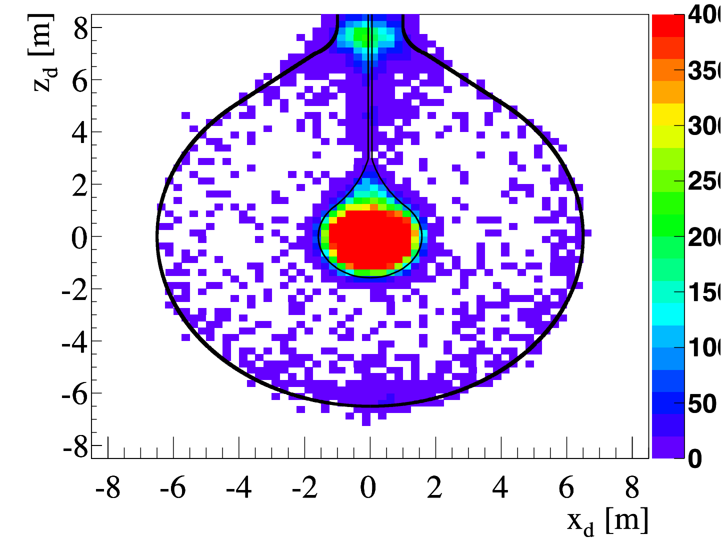
dispersion by gamma-ray diffusion and finite timing resolution

↓

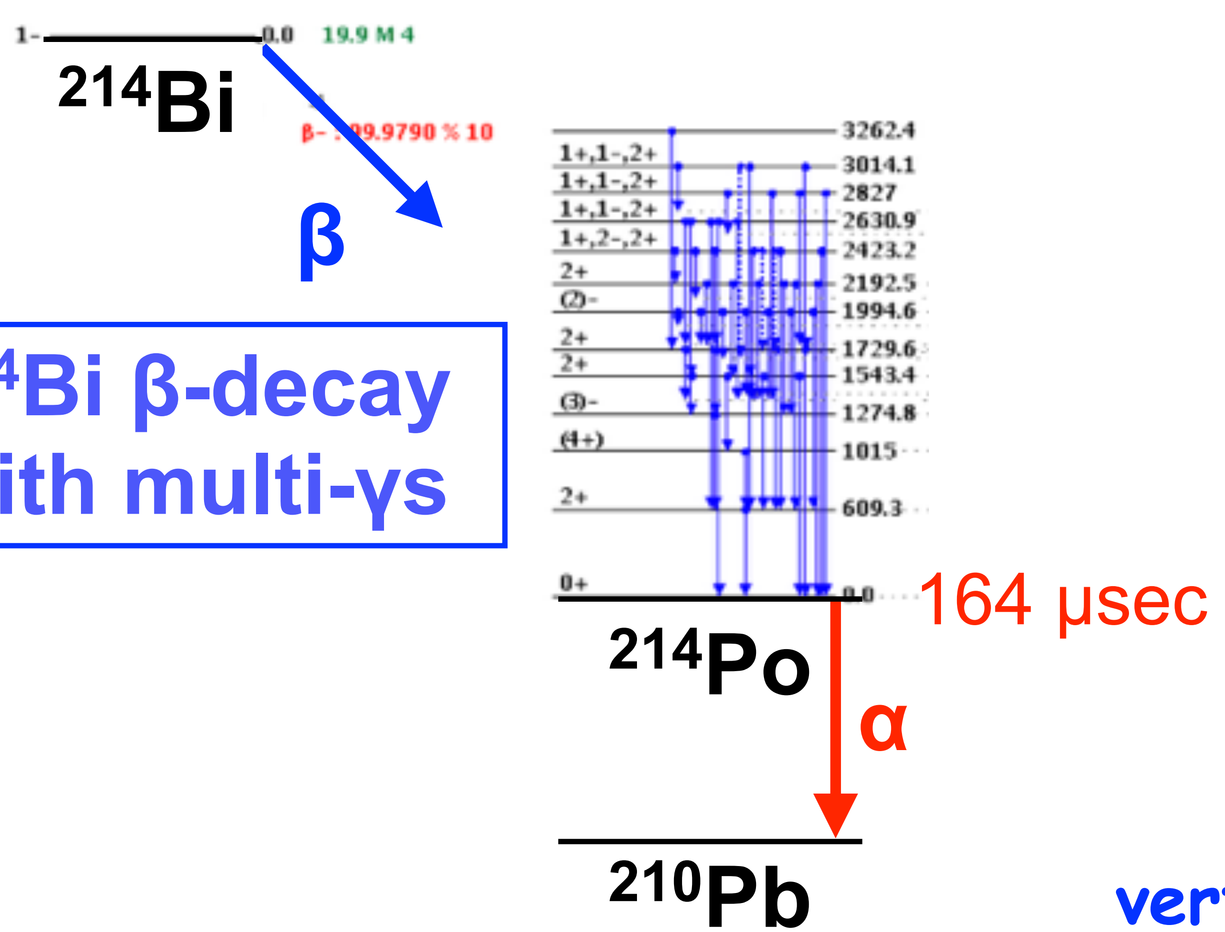
evaluated by detector full MC simulation

(Geant4 detector simulation tuned for KamLAND)

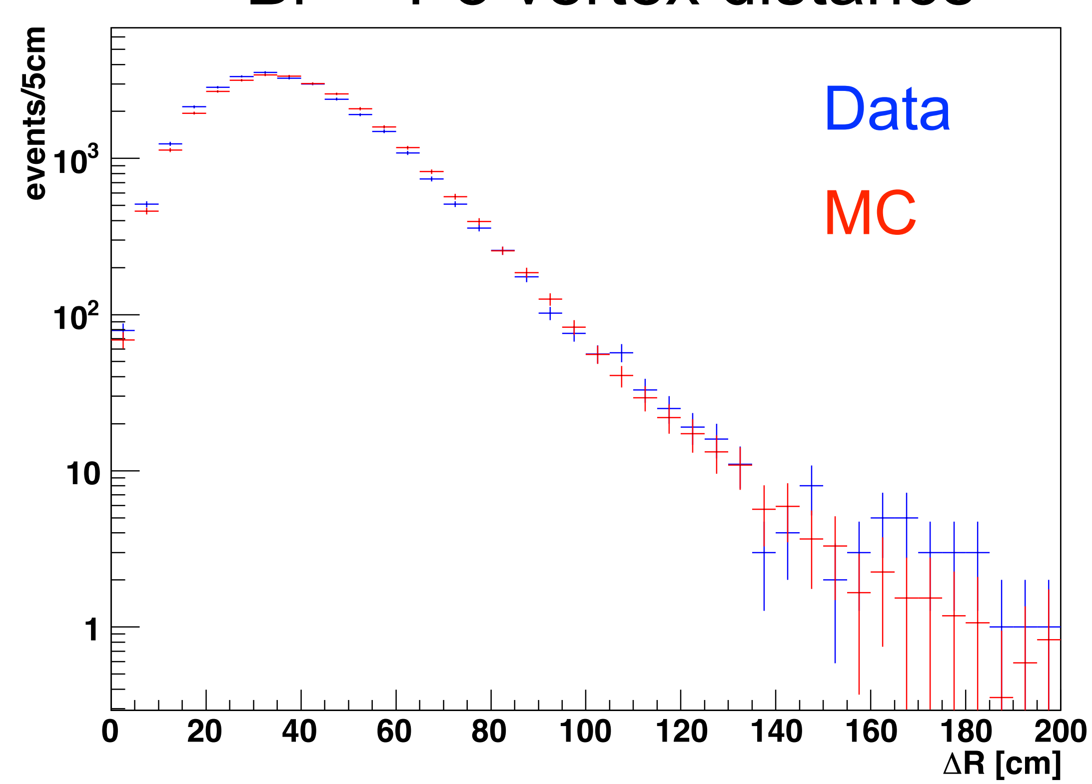
pure ^{214}Bi-^{214}Po samples from initial ^{222}Rn



^{214}Bi β-decay with multi-γs



^{214}Bi-^{214}Po vertex distance

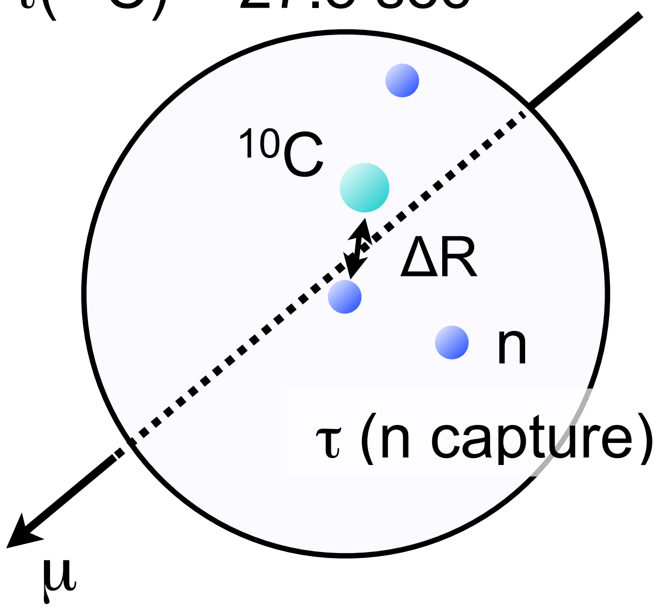


vertex distribution is well reproduced

Spallation Cut after Cosmic-ray Muon

^{10}C rejection by neutron tagging

$\tau(^{10}C)$ = 27.8 sec



space and time correlation cut

- ΔT < 180 s
- ΔR < 1.6 m

preliminary

Baseline restorer and signal splitter

1GHz FADC + 3 range 200 MHz FADC for each channel

Trigger module

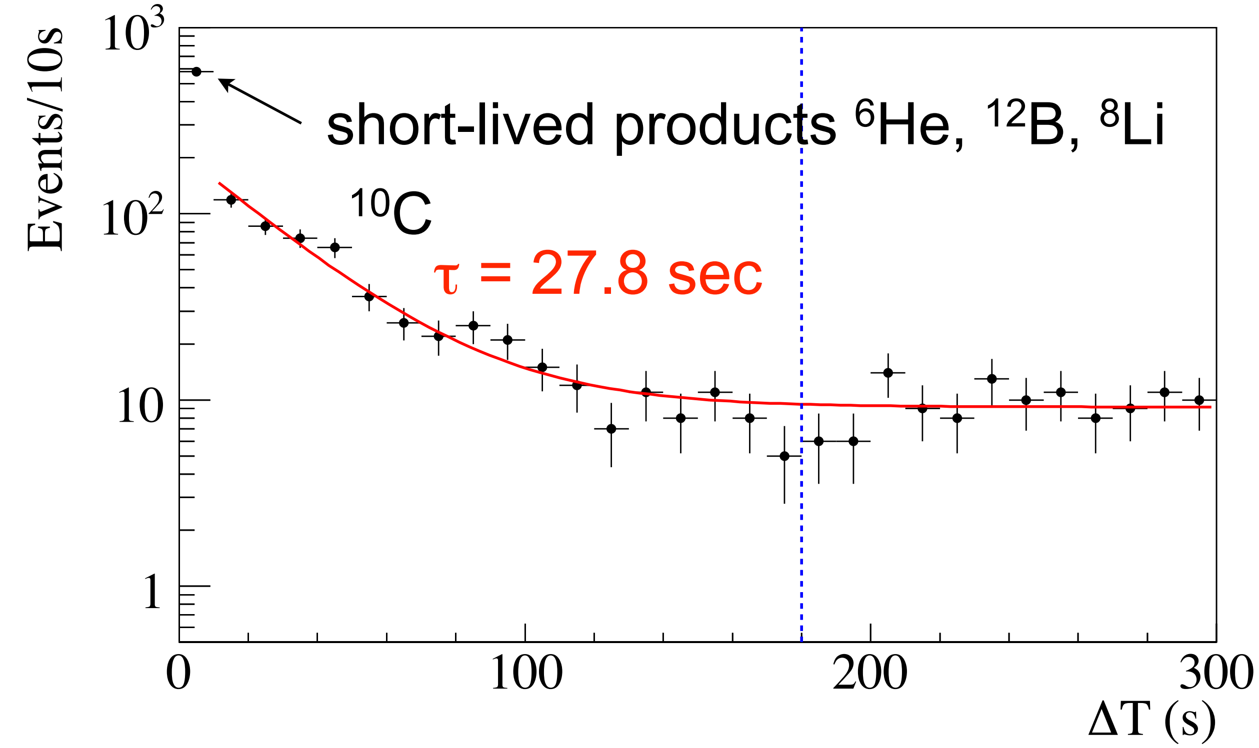
preliminary

BG rejection efficiency (^{10}C)	72 ± 5%
signal inefficiency	7%

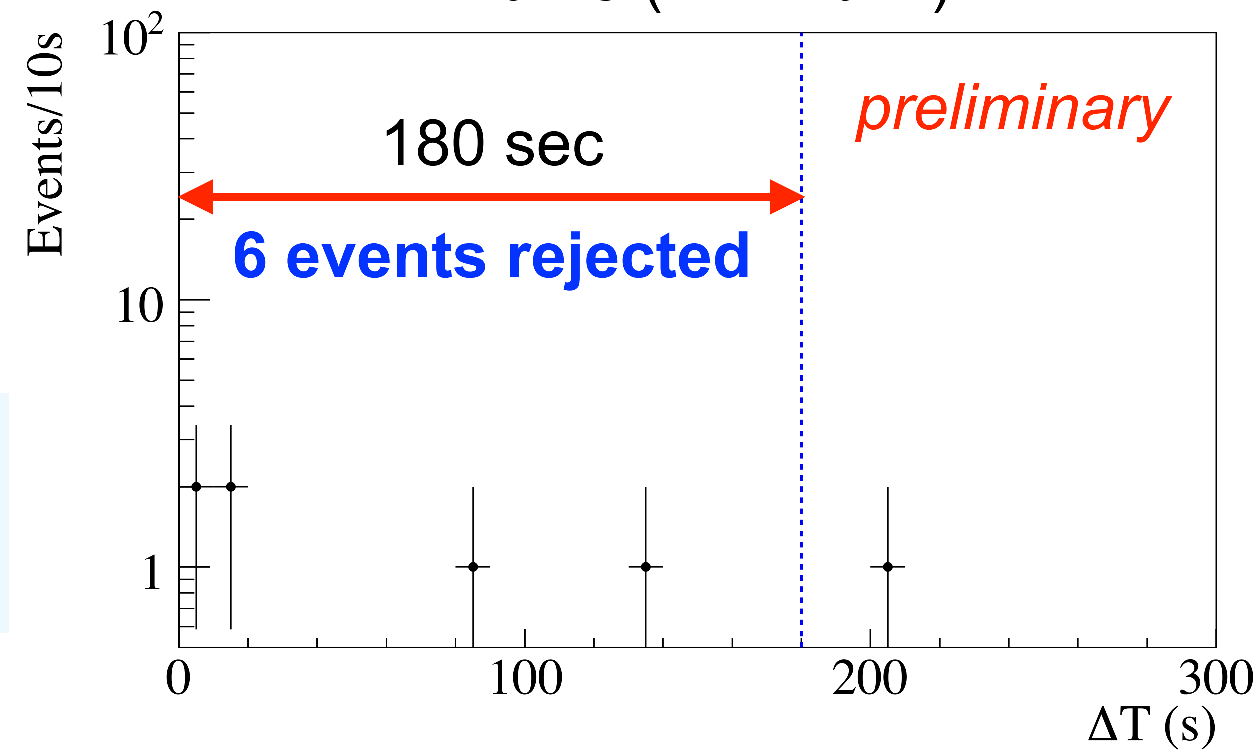
Efficient background rejection

2.2 < E < 3.5 MeV

Outer-LS without Xe



Xe-LS (R < 1.0 m)

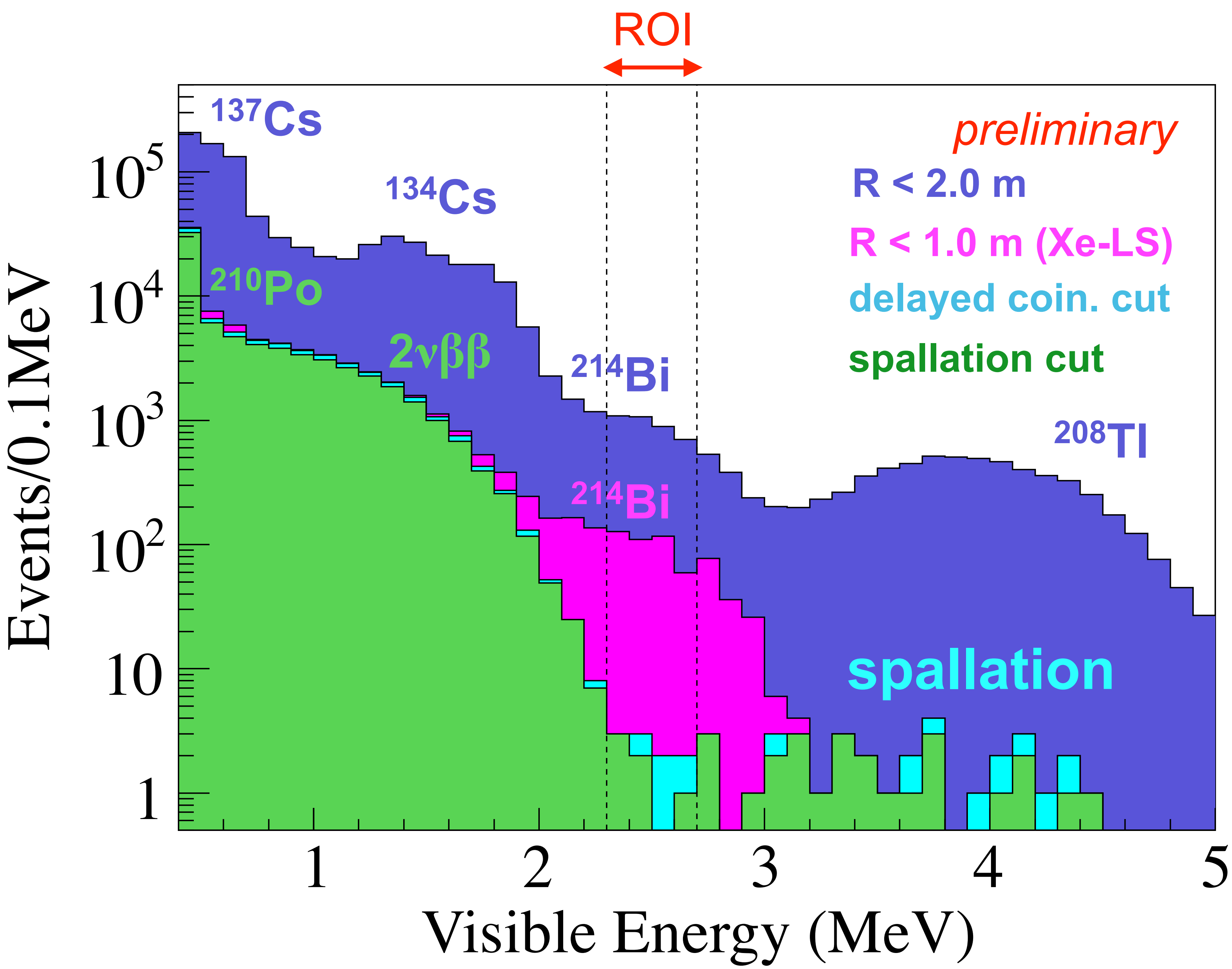


Event Reduction

Phase 2 **114.8 days**

ββ isotope ^{136}Xe **90.77% enriched** $Q_{\beta\beta}$ = 2458 keV

348 kg ^{136}Xe in all volume Dec. 11, 2013 - May 1, 2014



number of event in ROI (2.3 < E < 2.7 MeV)

Dec. 11, 2013 - May. 1, 2014
around mini-balloon
(R < 2.0 m)
&
muon veto

3756 events

volume cut
R < 1.0 m
(V = 4.2 m^3)

413 events

delayed coincidence cut
(^{214}Bi-Po, ^{212}Bi-Po, anti-ν)

10 events

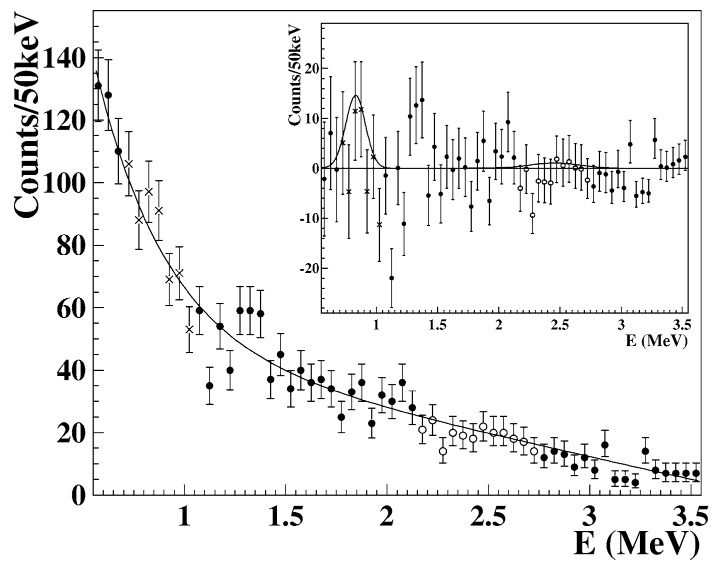
Spallation cut

6 events
(Livetime 114.8 days)

Volume selection and spallation cut distinguish backgrounds

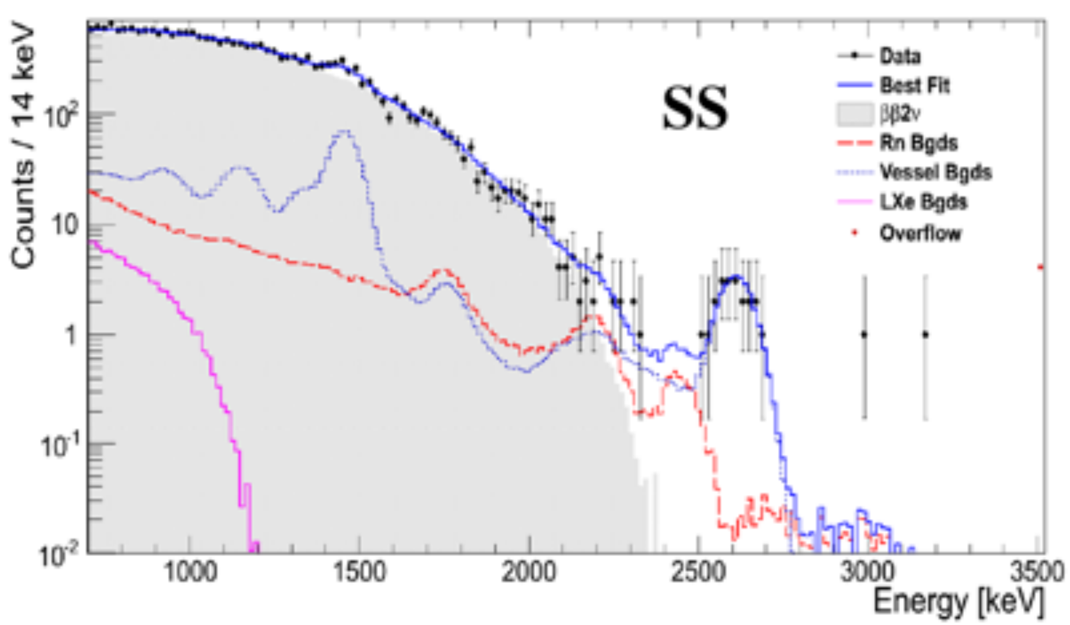
Fit to Energy Spectrum for 2νββ

DAMA (2002) Liquid Xe scintillator



$T^{2\nu}_{1/2} > 1.0 \times 10^{22}$ yr at 90% C.L.

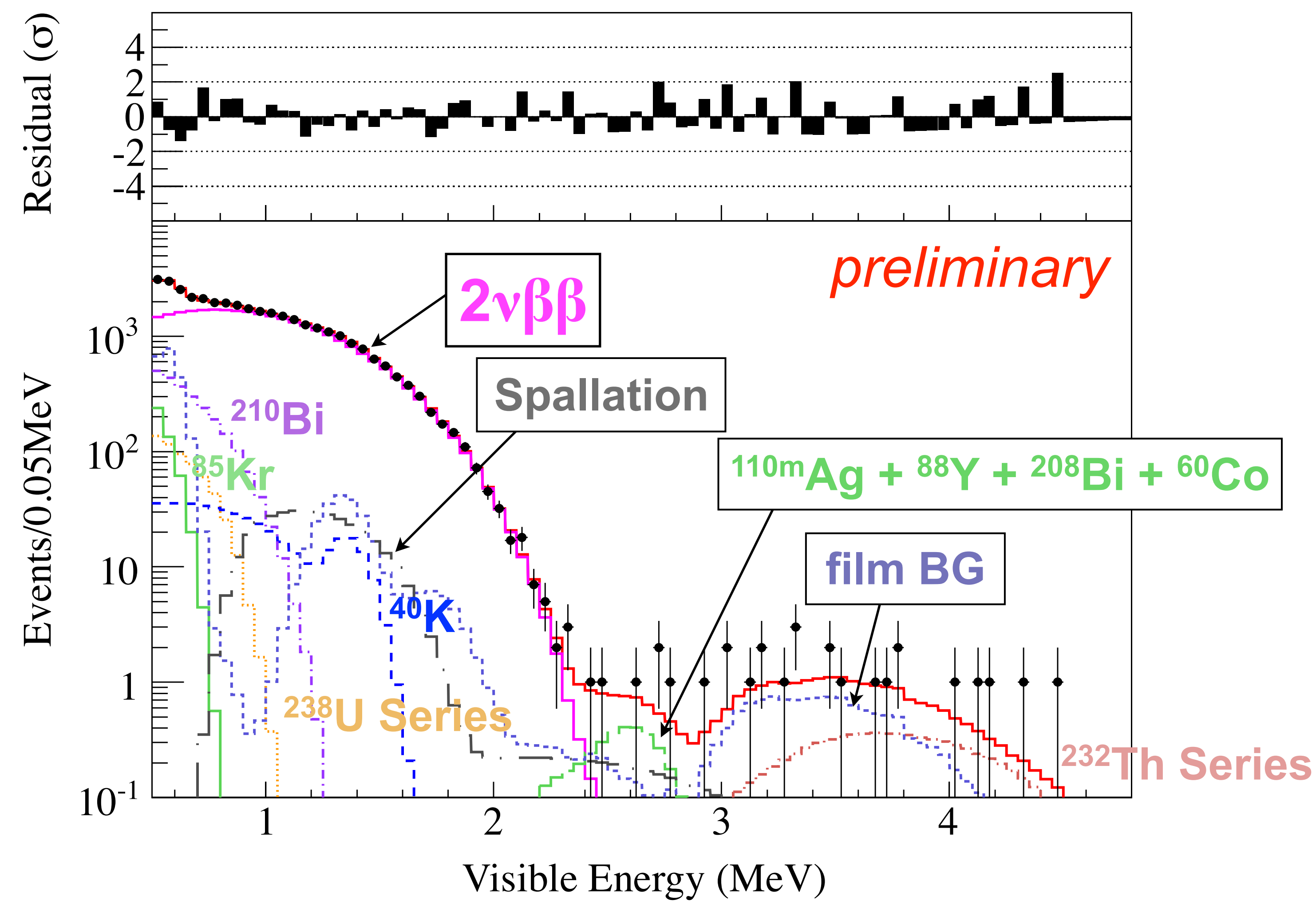
EXO-200 (2013) Liquid Xe TPC + scintillator



$T^{2\nu}_{1/2} = 2.165 \pm 0.016(\text{stat}) \pm 0.059(\text{syst}) \times 10^{21}$ yr ← consistent with EXO-200

KamLAND-Zen (2014) Xe loaded liquid scintillator

Phase 2 Internal (R < 1.0 m)



$T^{2\nu}_{1/2} = 2.32 \pm 0.05(\text{stat}) \pm 0.08(\text{syst}) \times 10^{21}$ yr

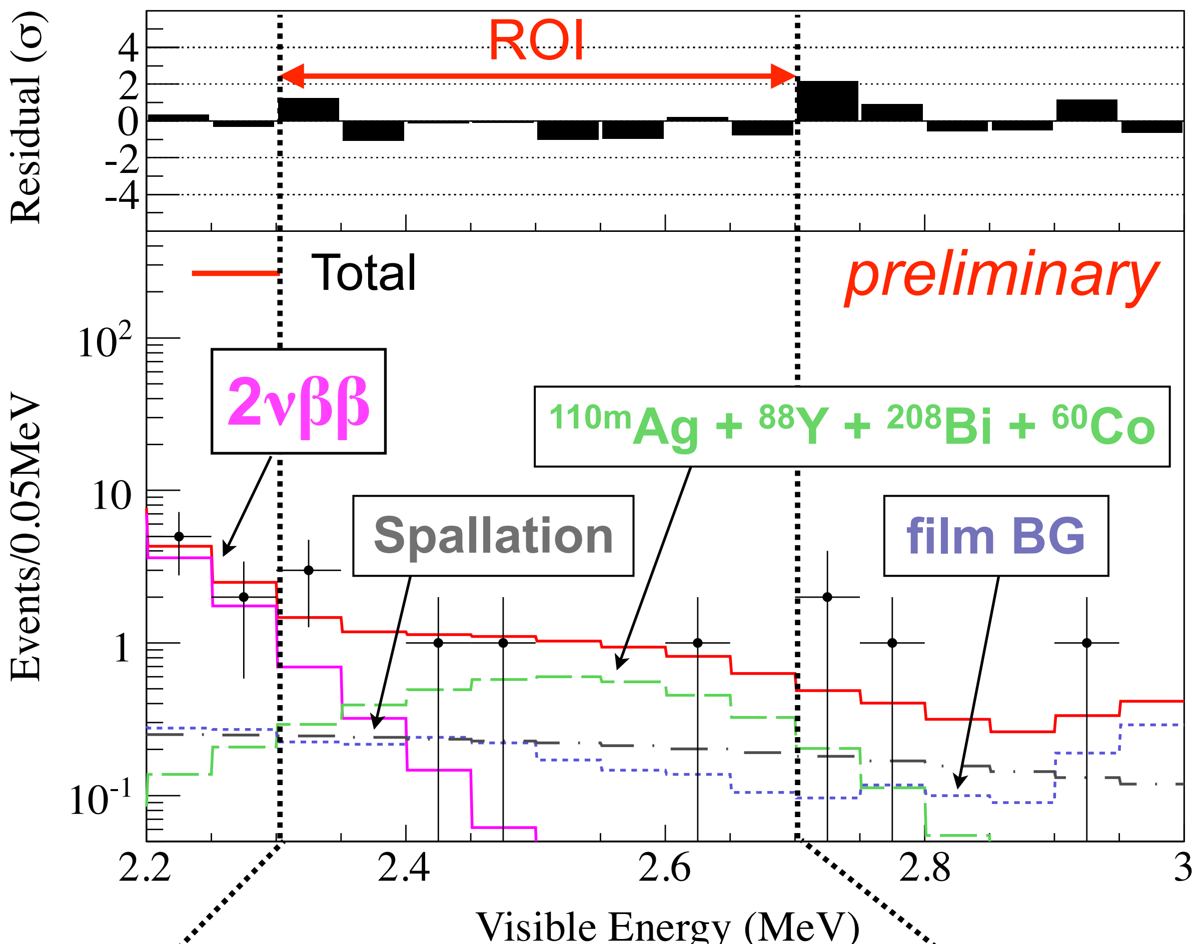
consistent with KamLAND-Zen Phase 1

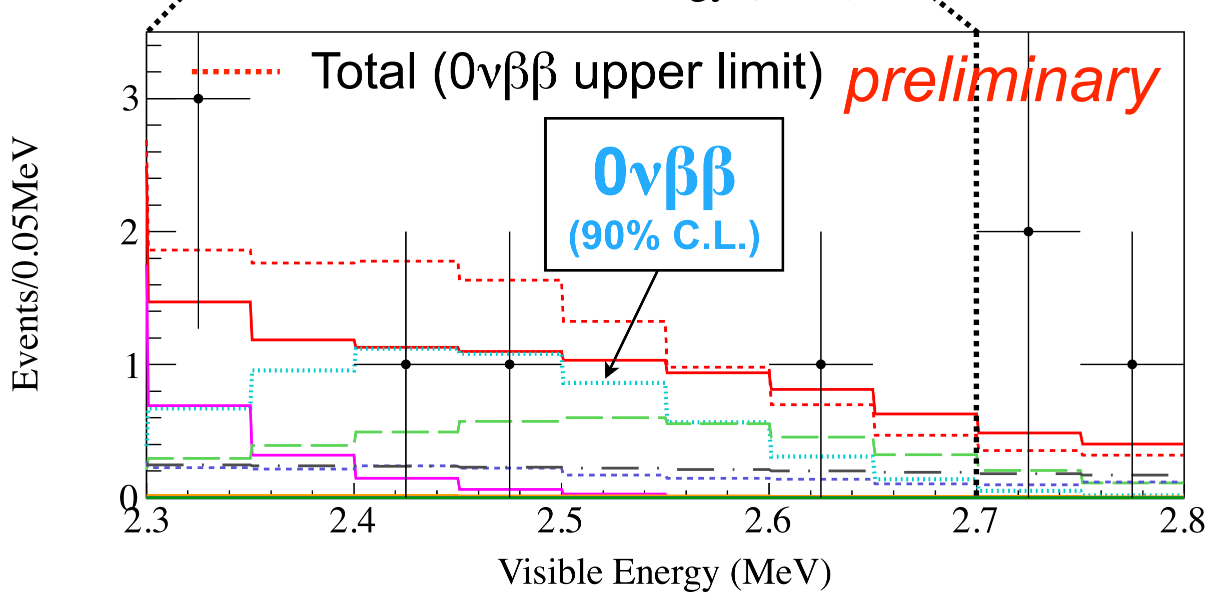
↓

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

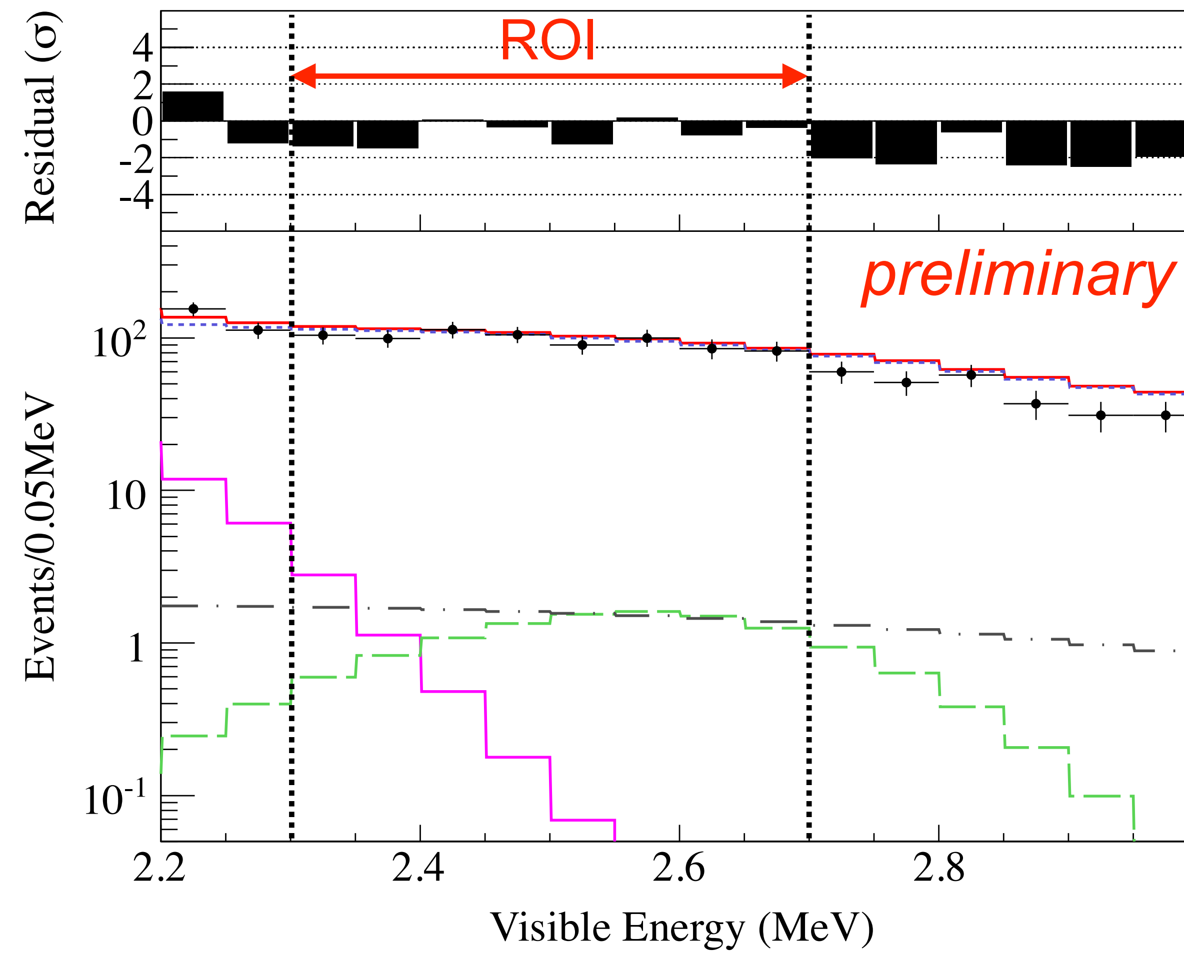
Fit to Energy Spectra for 0νββ

Internal (R < 1.0 m)





External (1.0 < R < 2.0 m)



Fit to Energy-Volume 2D spectra

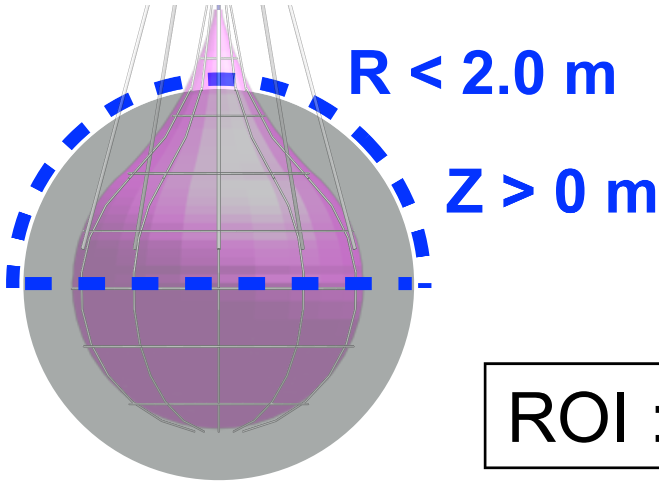
Limits on 0νββ at 90% C.L.

< 17.0 events/day/kton-LS

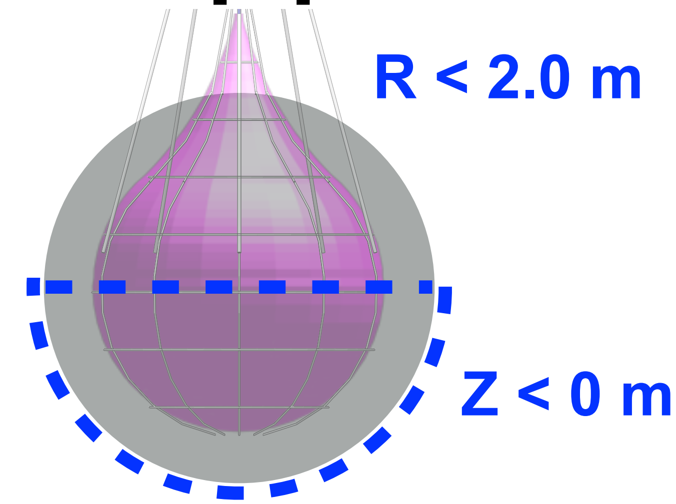
↓

$T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr

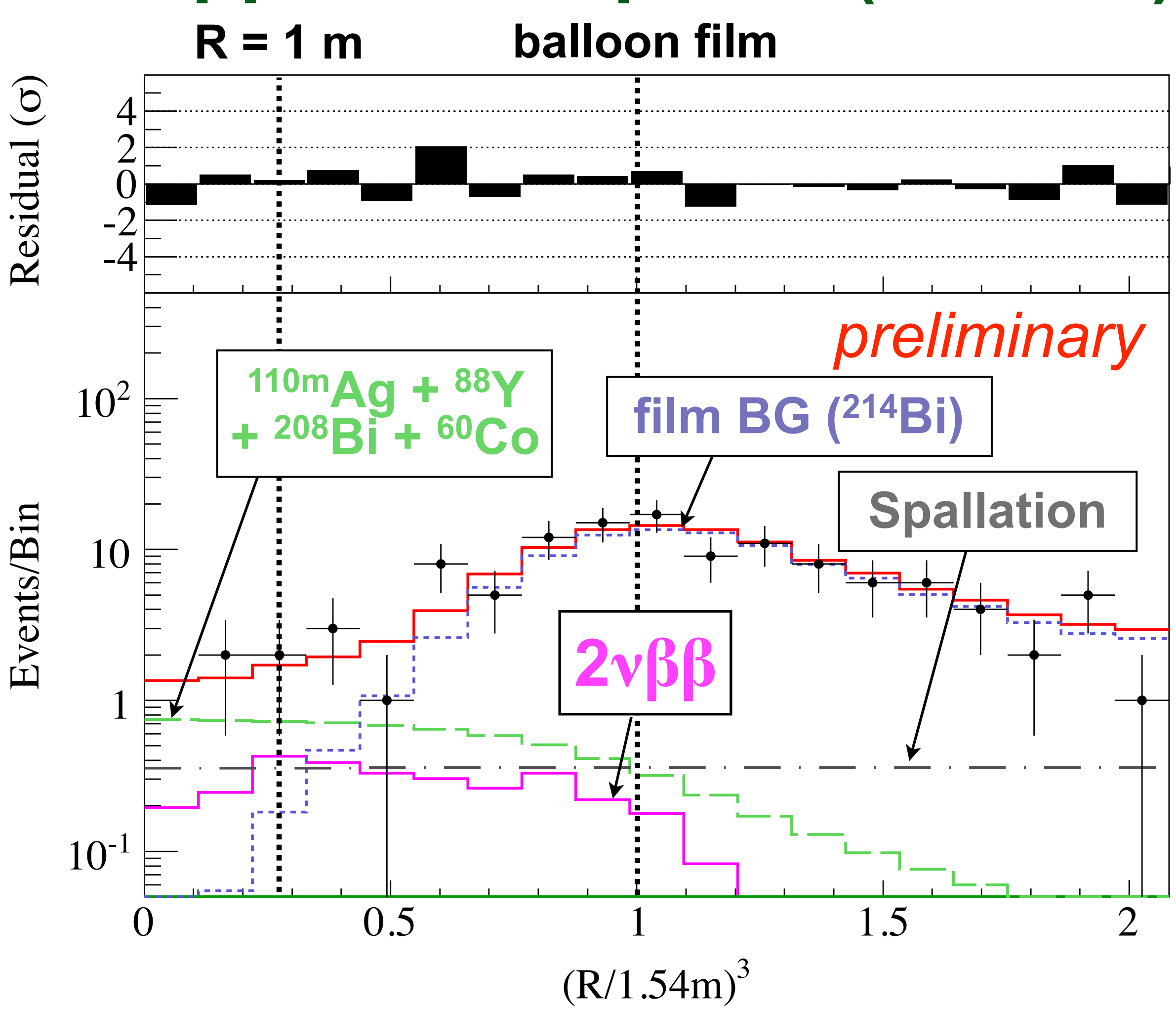
Fit to R^3 Spectra for $0\nu\beta\beta$



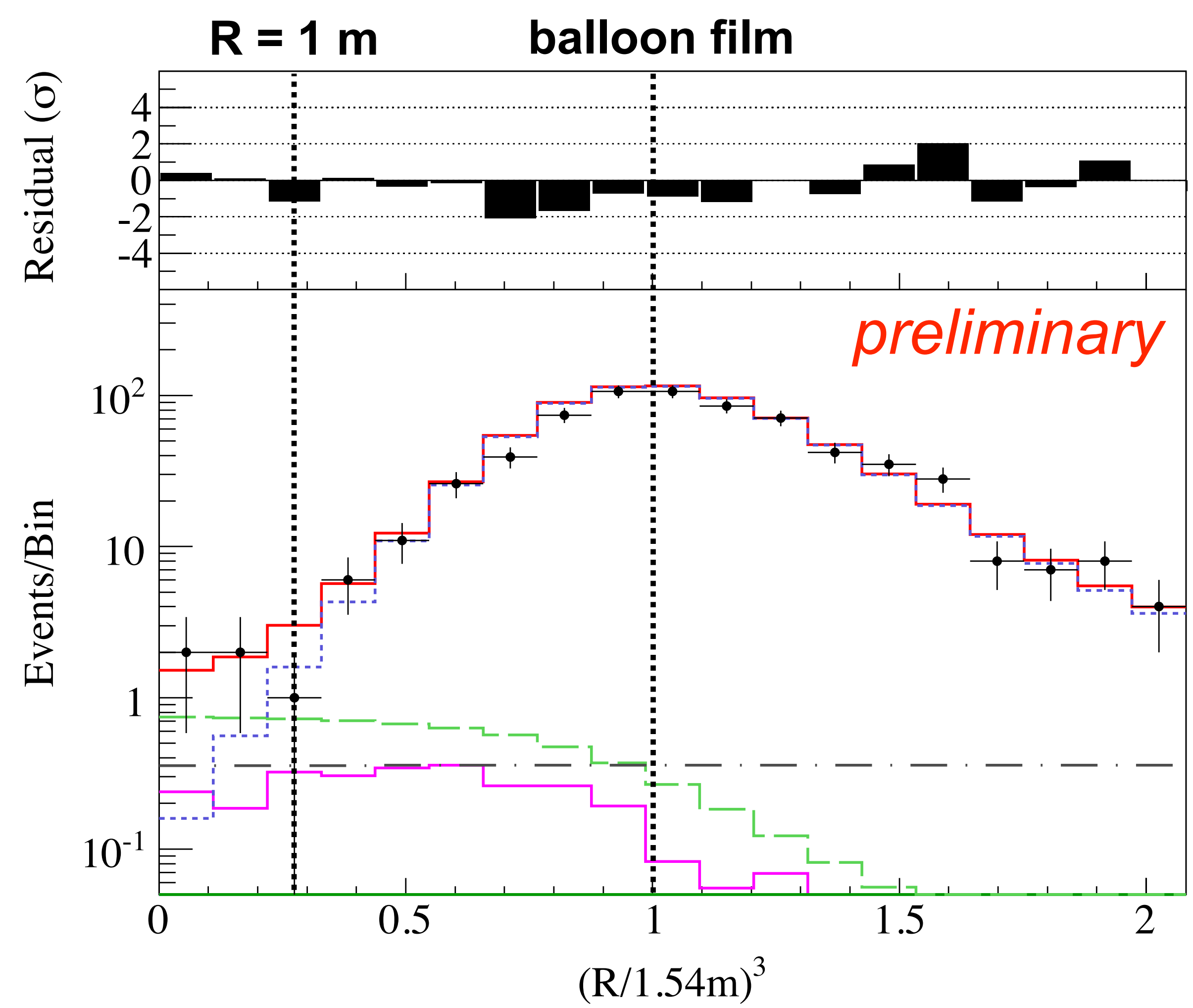
ROI : 2.3 < E < 2.7 MeV



Upper hemisphere (Z > 0 m)

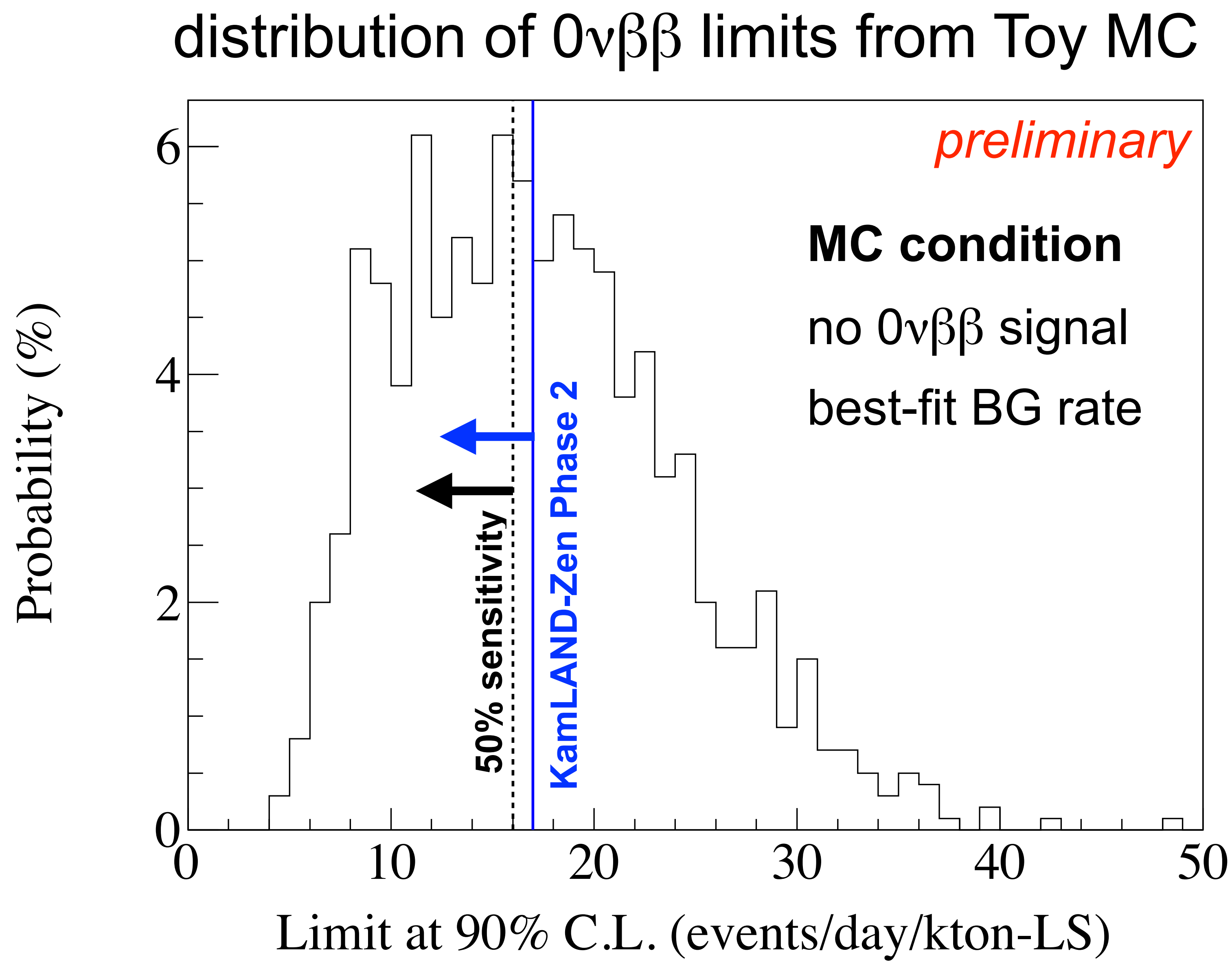


Lower hemisphere (Z < 0 m)



^{214}Bi vertex dispersion is consistent with data

Upper Limits from Toy MC



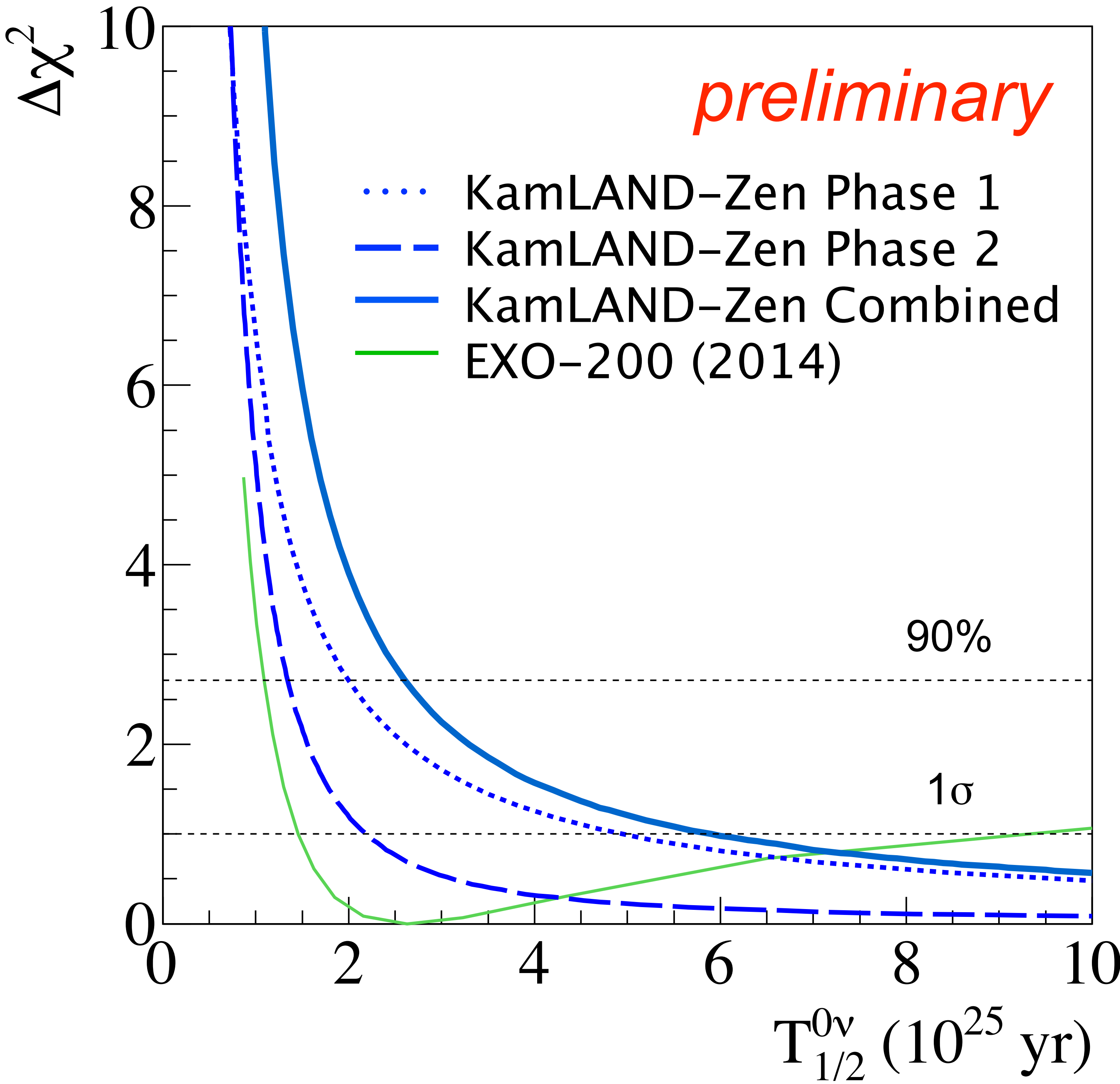
< 17 events/day/kton-LS 52% of the time

< 16 events/day/kton-LS 50% of the time

Sensitivity is checked by MC assuming best-fit BG rate

^{136}Xe 0νββ Decay Half-life

combined result (Phase 1 + 2)



<u>Half-life limit at 90% C.L.</u>

KamLAND-Zen

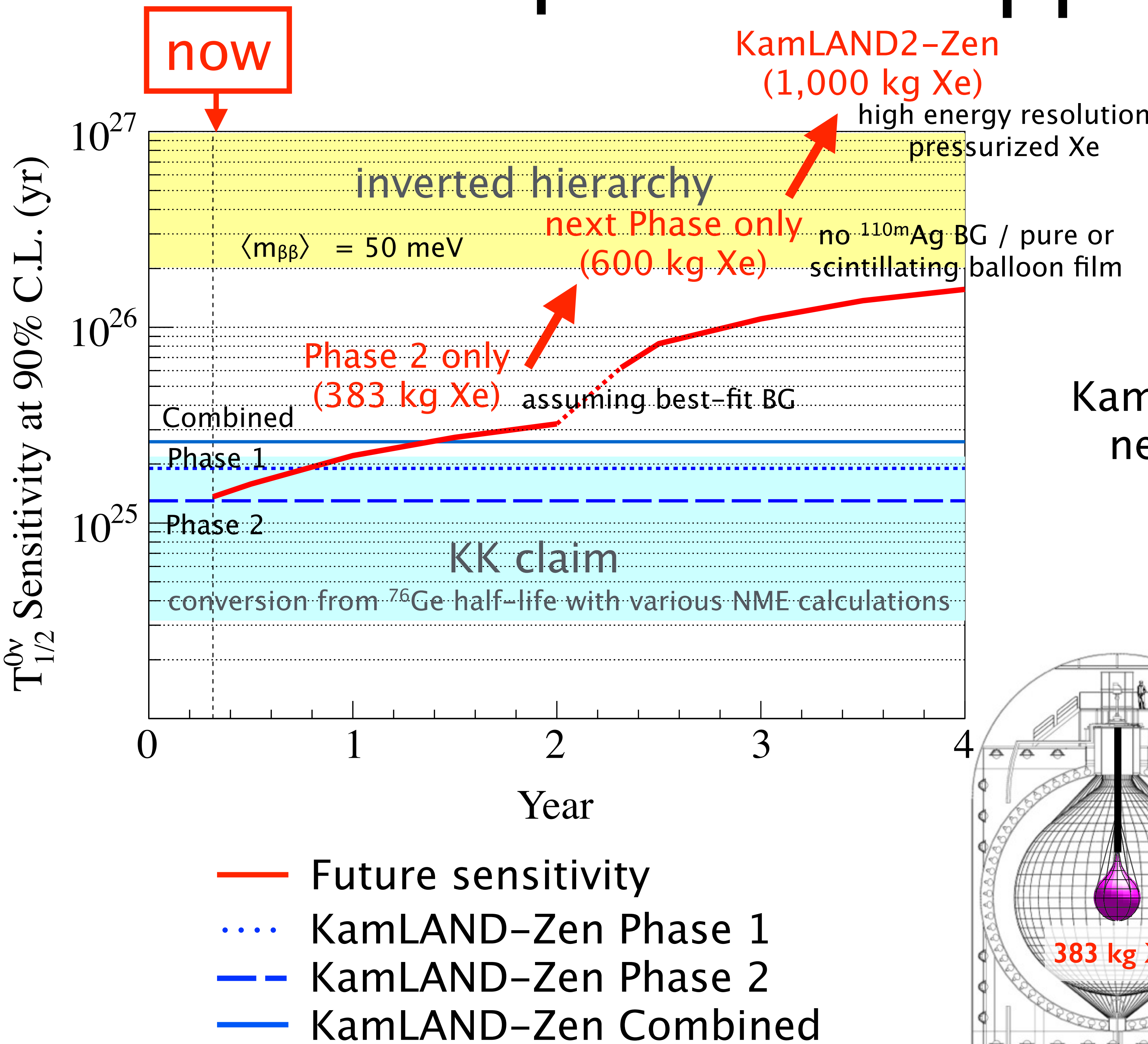
Phase 1	$T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr
Phase 2	$T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr
Combined	$T^{0\nu}_{1/2} > 2.6 \times 10^{25}$ yr

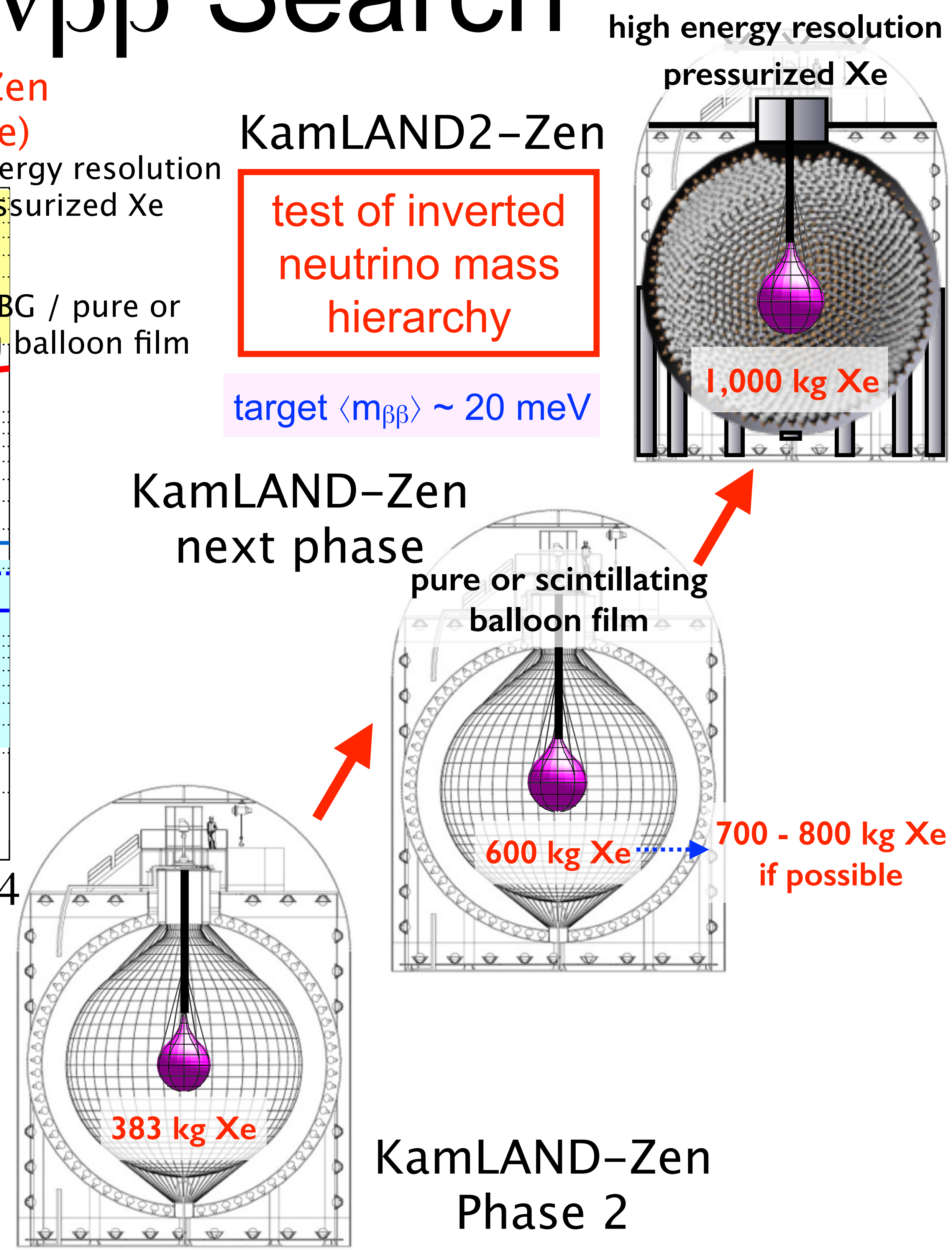
QRPA NME model
J. Phys. G 39 124006 (2012)

$\langle m_{\beta\beta} \rangle$ < 0.14-0.28 eV

Limits on ^{136}Xe half-life and effective neutrino mass are improved

Prospect for 0νββ Search





Detector improvements are planned in the near future

Summary

- We demonstrated the Xe-LS purification by circulating the liquid scintillator.
- The overall reduction factor for the ^{110m}Ag background including the decay is more than 10.
- New results from KamLAND-Zen are presented.

KamLAND-Zen limits on 0νββ at 90% C.L.

preliminary

Phase 1 (213 days)	$T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr
Phase 2 (115 days)	$T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr
Combined	**$T^{0\nu}_{1/2} > 2.6 \times 10^{25}$ yr**

↓

$\langle m_{\beta\beta} \rangle$ < 0.14-0.28 eV (QRPA)

- Several detector improvements are planned aiming at a test of inverted neutrino mass hierarchy.

Backup

KamLAND-Zen Result (2012)

$T_{1/2}(^{136}Xe) \rightarrow \langle m_{\beta\beta} \rangle \rightarrow T_{1/2}(^{76}Ge)$

use same NME (parameter)

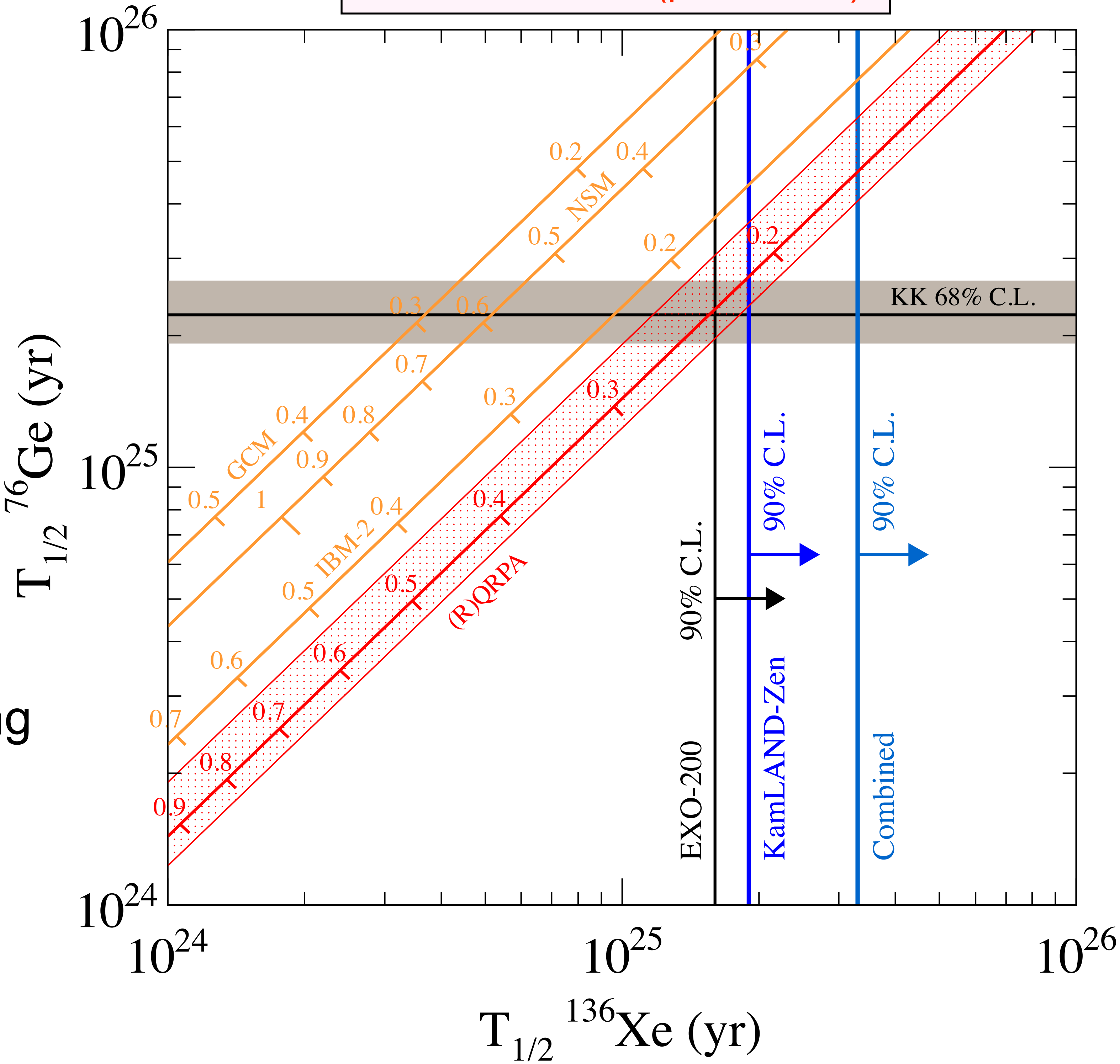
$T_{1/2} > 1.9\times10^{25}$ yr (KL-Zen)

↓ + EXO-200

$T_{1/2} > 3.4\times10^{25}$ yr (combined)

↓ uncertainty from NME

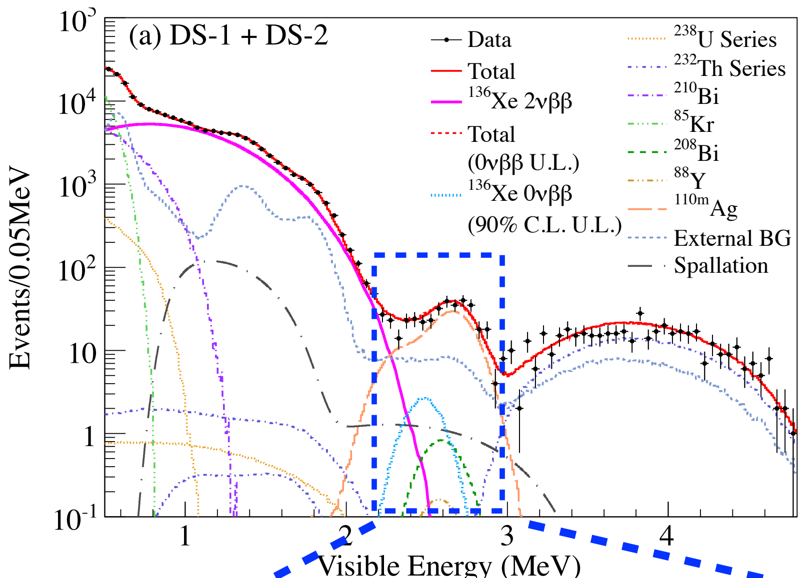
$\langle m_{\beta\beta} \rangle < 120 - 250$ meV (90% C.L.)



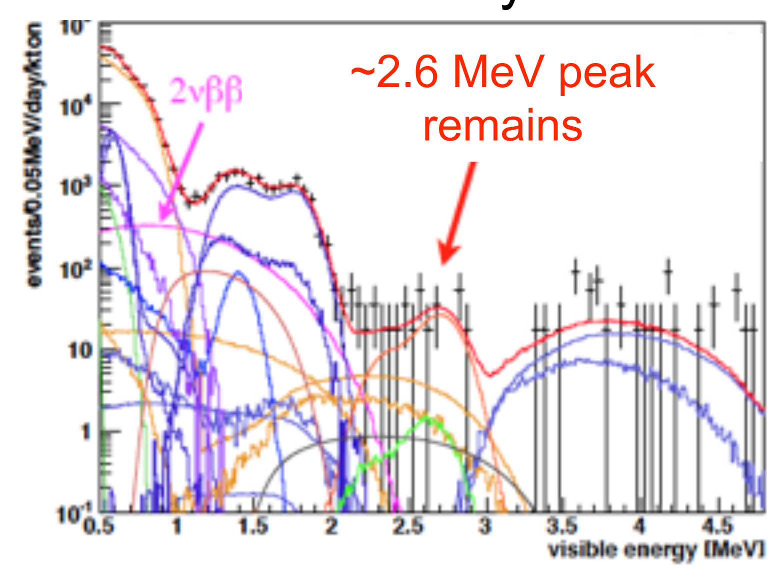
It is **inconsistent with KK claim** at more than 97.5% C.L. assuming light Majorana neutrino and available nuclear models

Limit on half-life of ^{136}Xe 0νββ

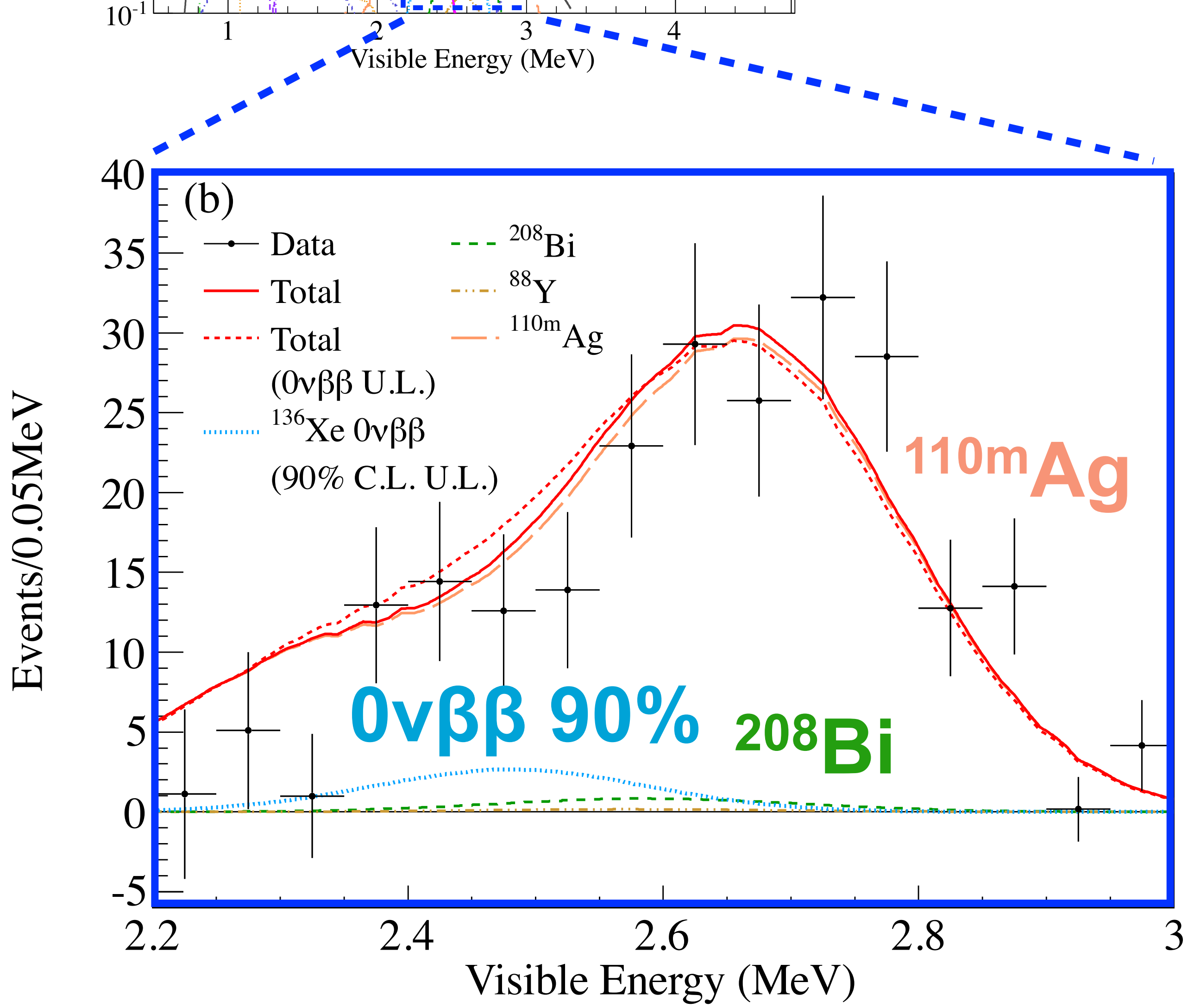
213 days



15.5 days



Xe extraction →



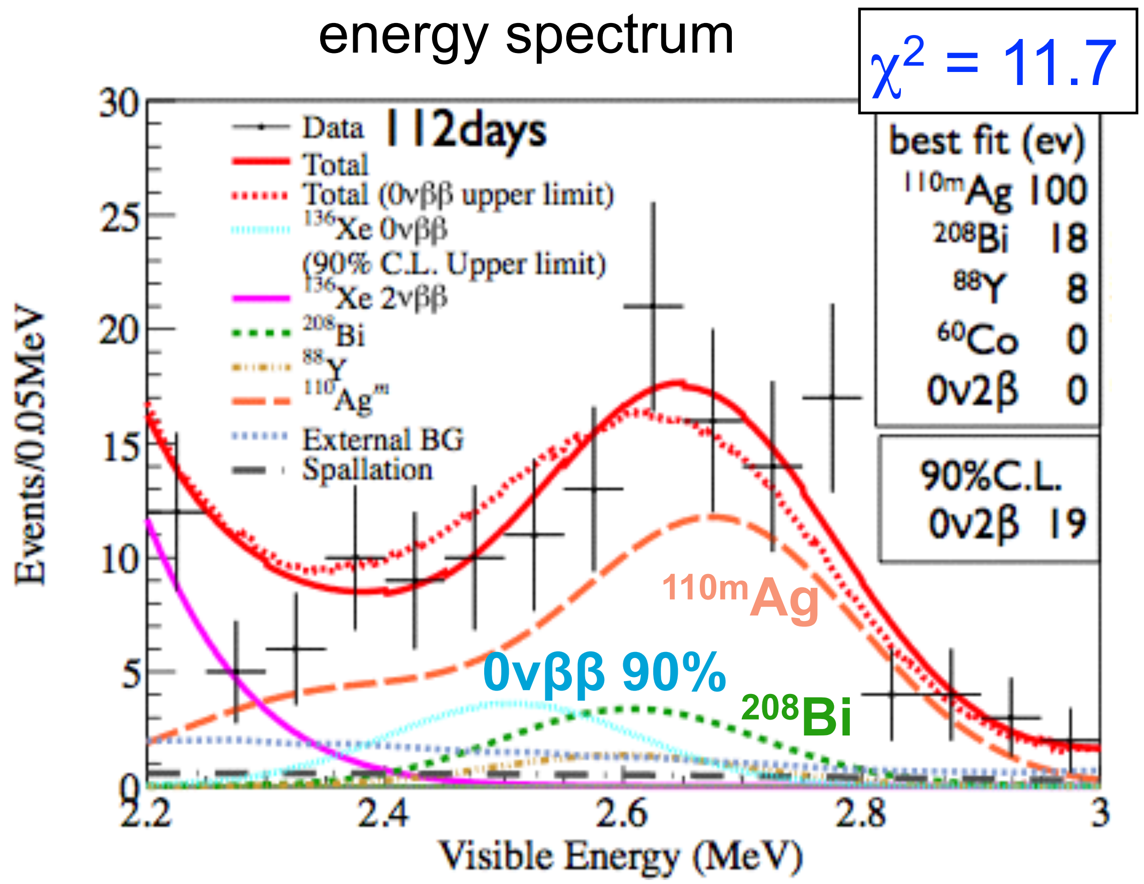
89.5kg·yr

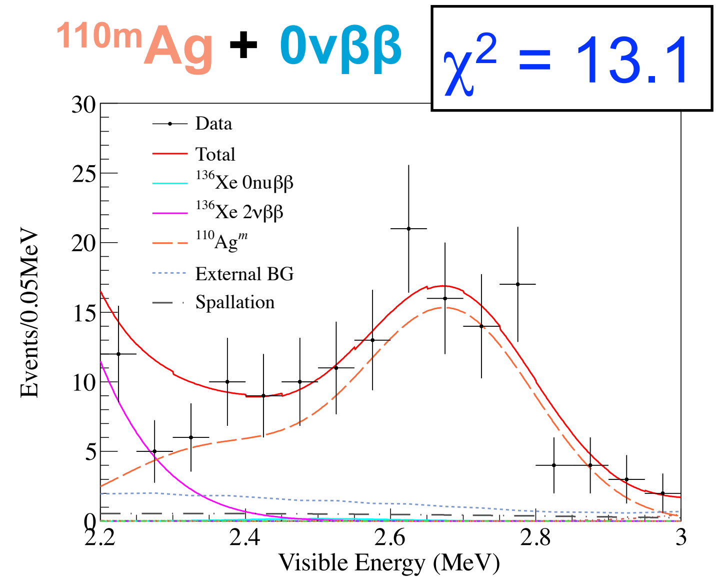
$T^{0\nu}_{1/2} > 1.9\times10^{25}$ yr (90% C.L.)

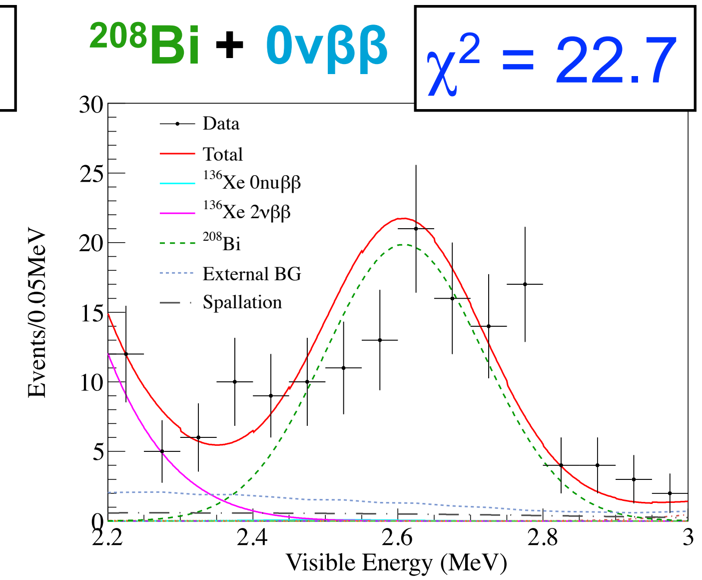
Background near 2.6 MeV

112.3 day livetime

energy spectrum

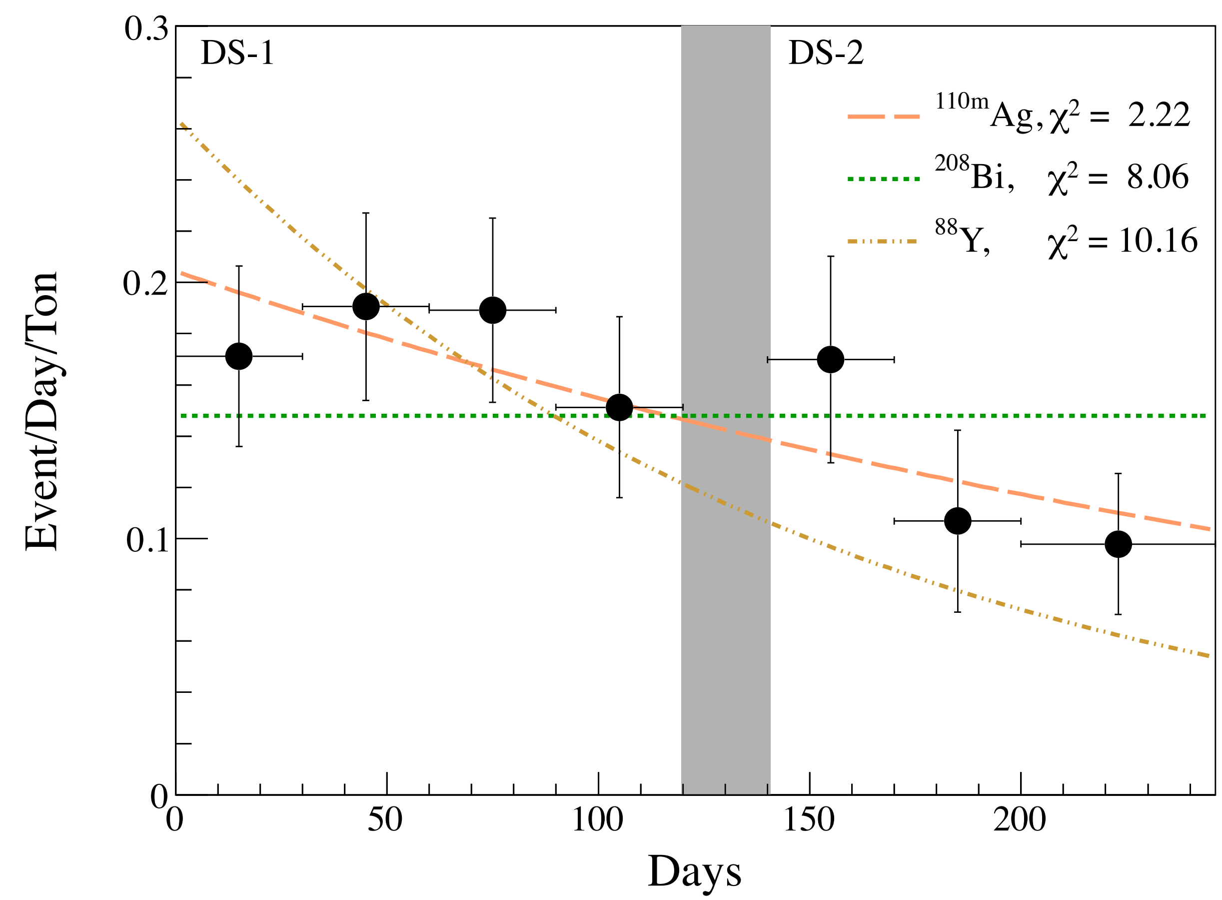






	χ^2	χ^2
simul. fit	12.4	11.6
0ν+	16.5	13.1
0ν+	15.8	22.7 △
0ν+	16.7	22.2 △
0ν+	65	82.9 ✕
0ν only	64.5	85 ✕

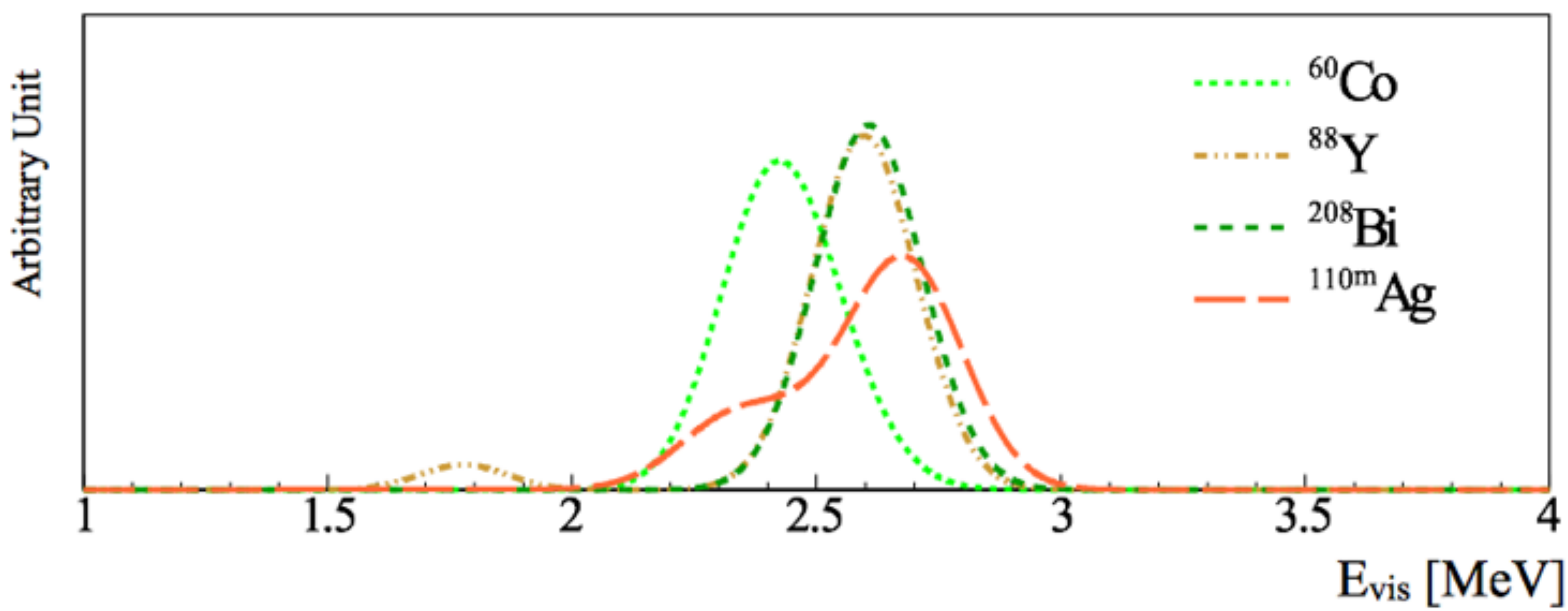
event rate variation （2.2 < E < 3.0 MeV）



consistent with ^{110m}Ag decay (250 days)

Background Candidates

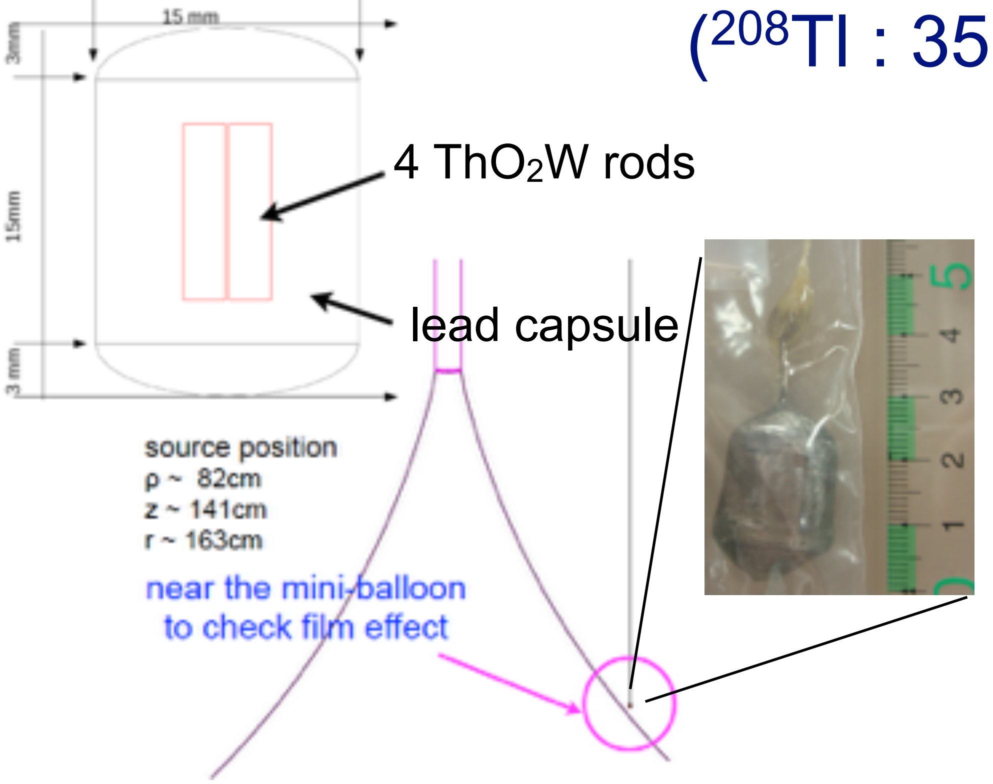
	Decay Mode	Q-Value [MeV]	Half-Life
^{110m}Ag	β^-	3.01	249.79 day
^{208}Bi	EC	2.88	3.68×10^5 year
^{88}Y	EC	3.62	106.65 day
^{60}Co	β^-	2.82	5.2714 year



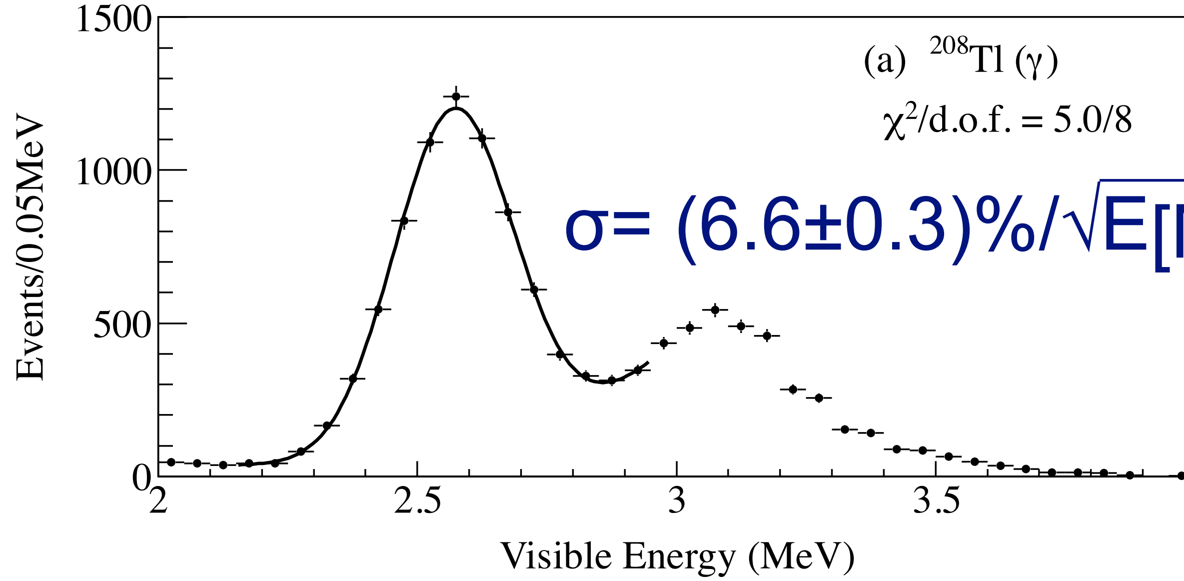
Energy Calibration

ThO_2W electrode w/ ^{232}Th 2~4 wt%

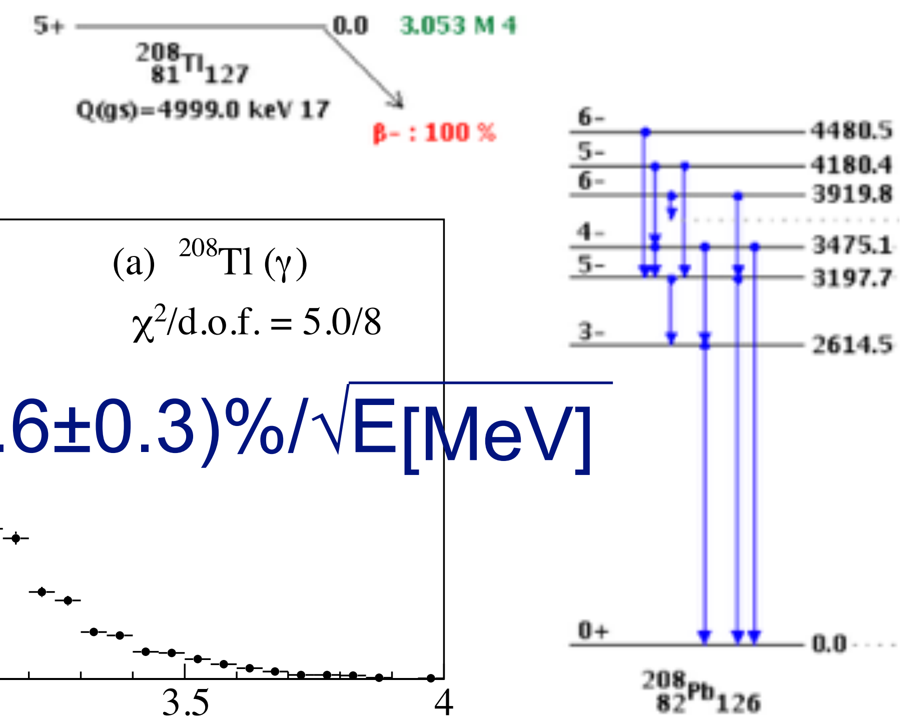
(^{208}Tl : 35.9%)



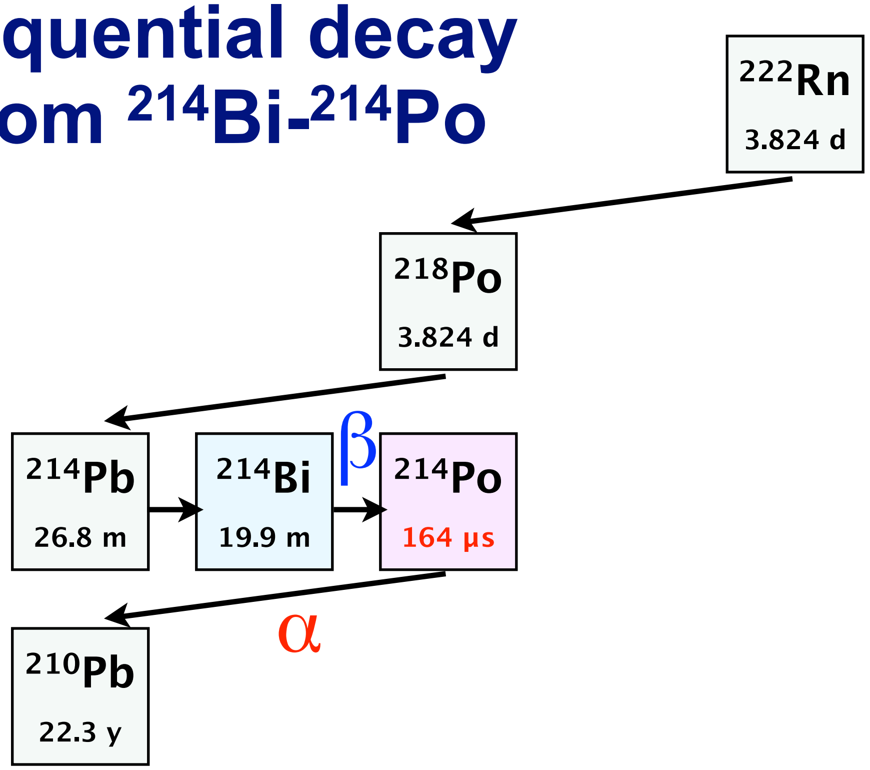
^{208}Tl decay
(2.6 MeV γ)



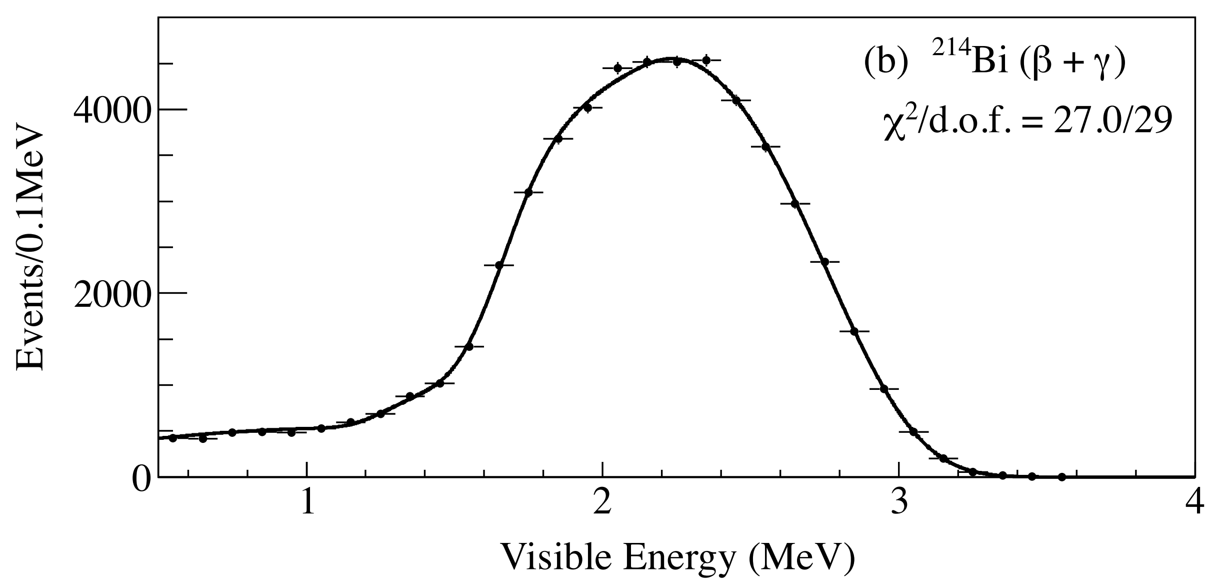
$\sigma = (6.6 \pm 0.3)\% / \sqrt{E[MeV]}$

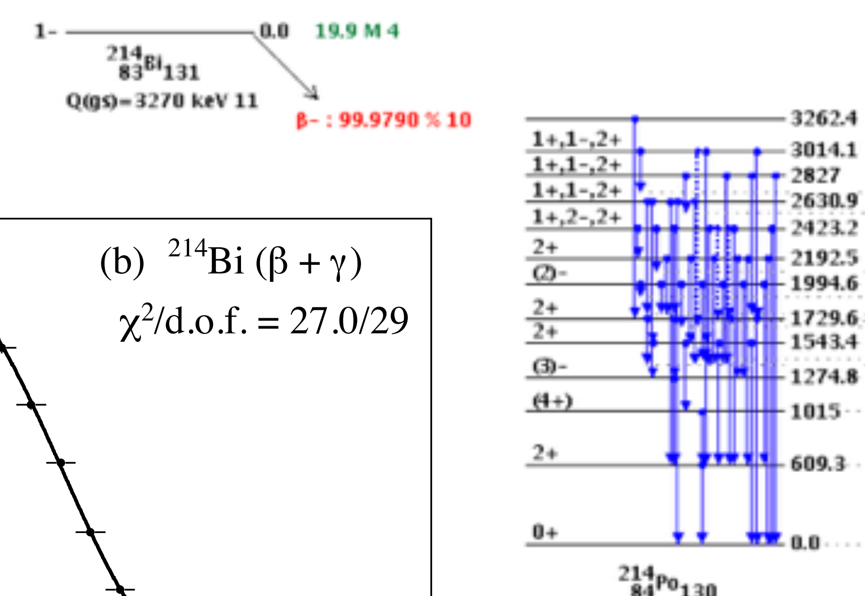


Sequential decay from ^{214}Bi-^{214}Po

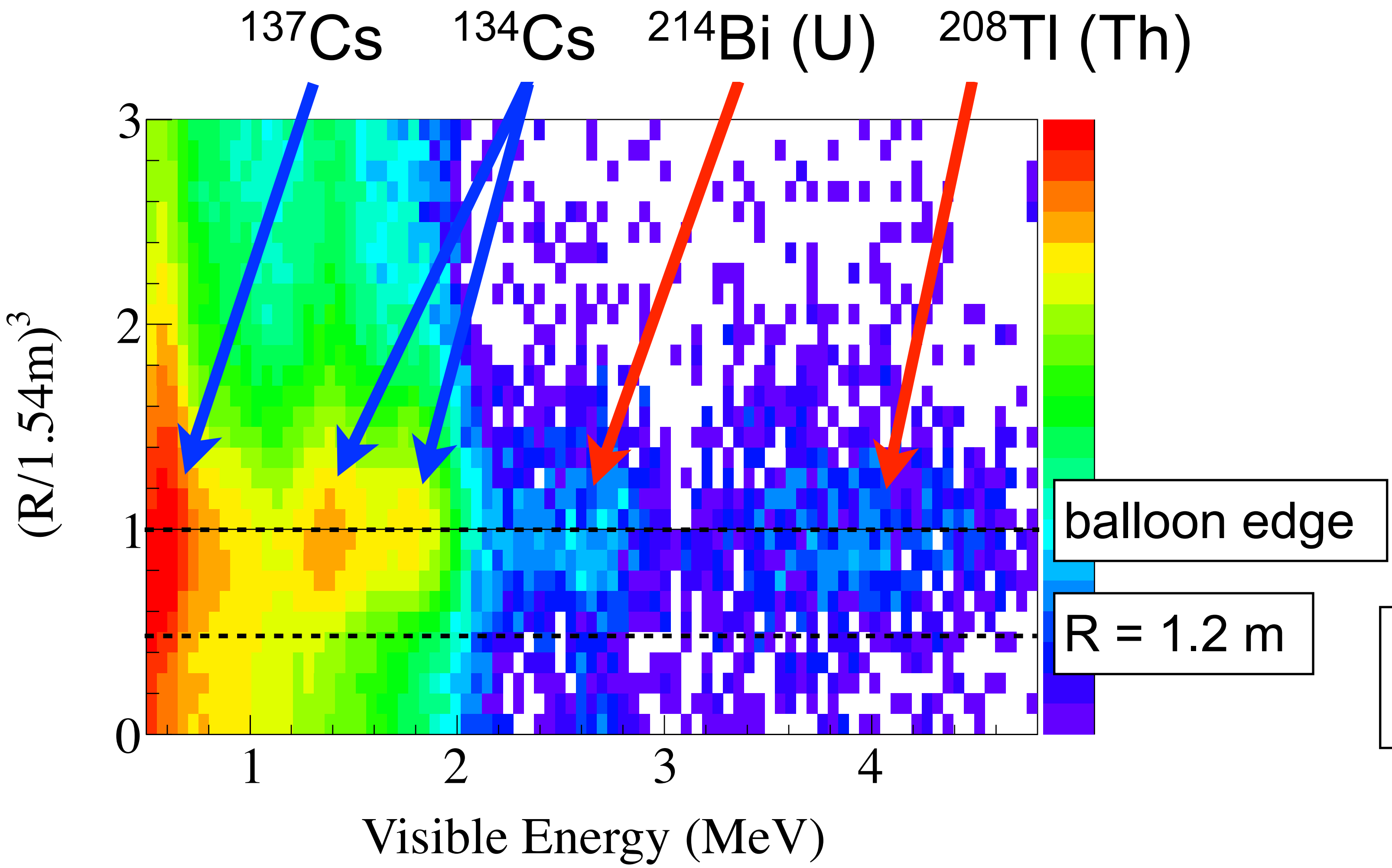


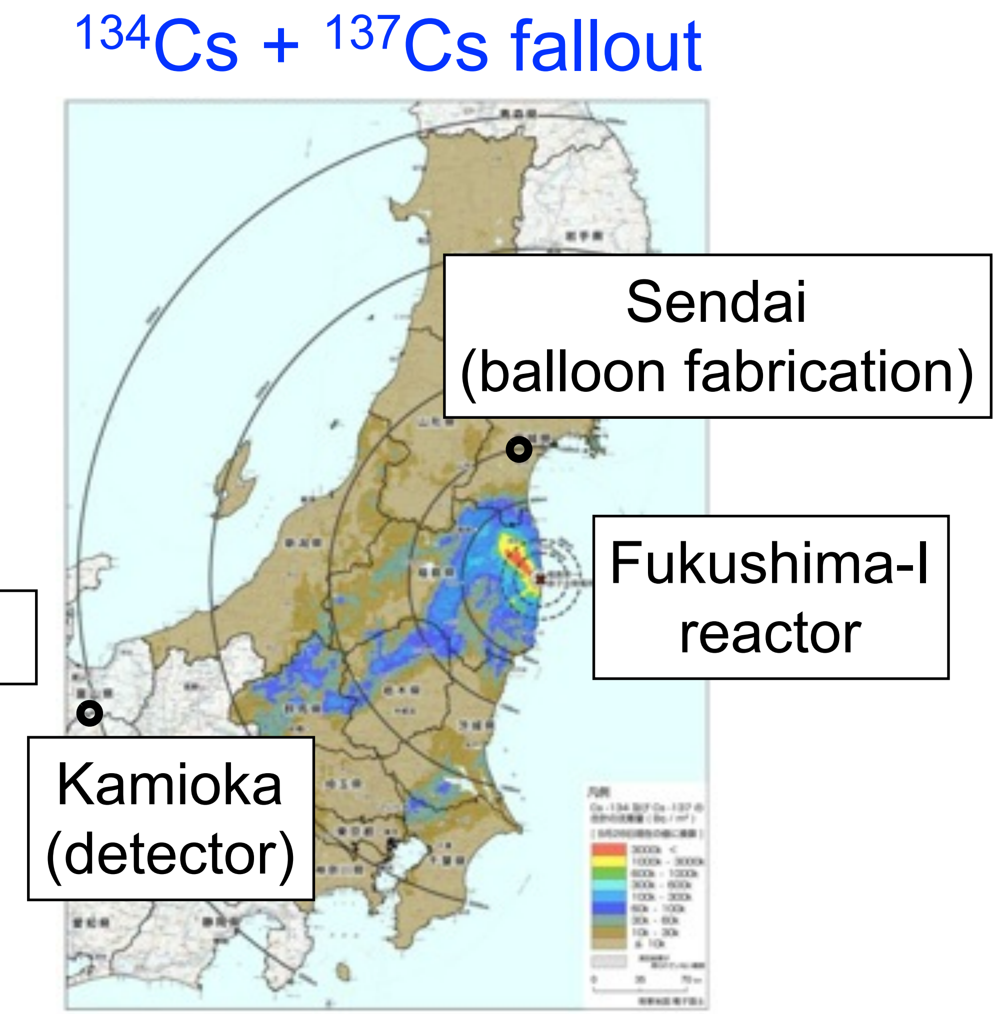
^{214}Bi decay
(β + γ)





Radioactive Impurities





Observed ratio of $^{134}Cs/^{137}Cs$ (~0.8) is consistent with Fukushima-I reactor fallout

Radioactive impurities

- Found unexpected fallout BG in $2\nu\beta\beta$ energy region, but it concentrates on the balloon possible contamination during balloon fabrication?

- U and Th impurities are higher than expected (factor ~10 in balloon)

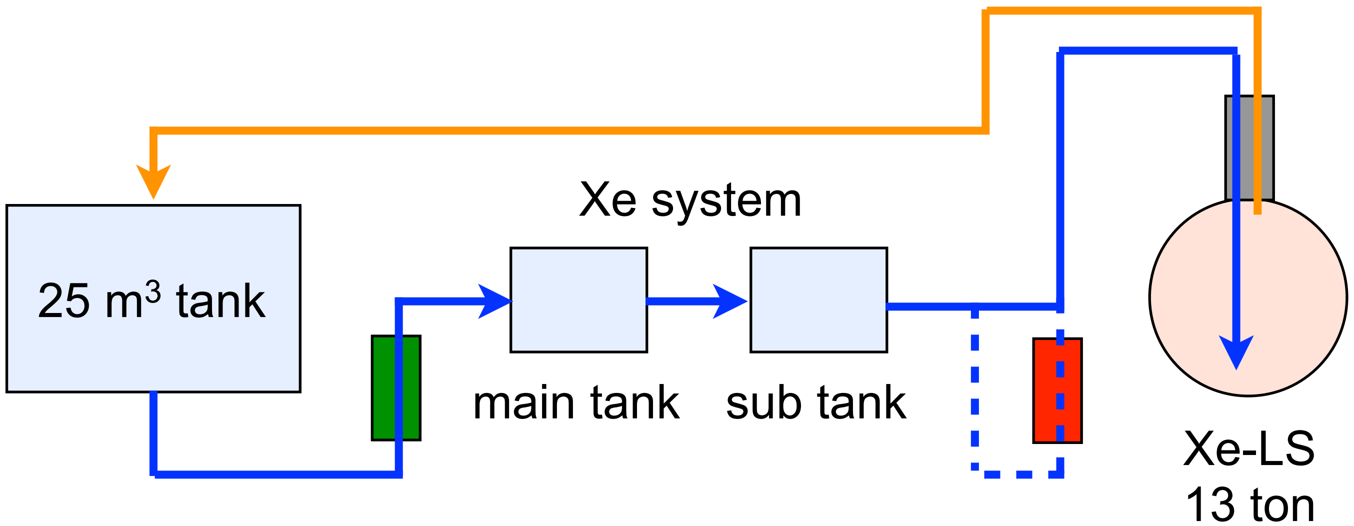
^{238}U: 3.5×10^{-16} g/g (LS), 2.2×10^{-11} g/g (balloon) → fiducial volume limitation in $0\nu\beta\beta$ analysis

^{232}Th: 2.2×10^{-15} g/g (LS), 1.4×10^{-10} g/g (balloon)

KamLAND-Zen Construction

mini balloon fabrication & installation → dummy LS filling → Xe-LS filling
(inflation) (replace)

24 gores from film

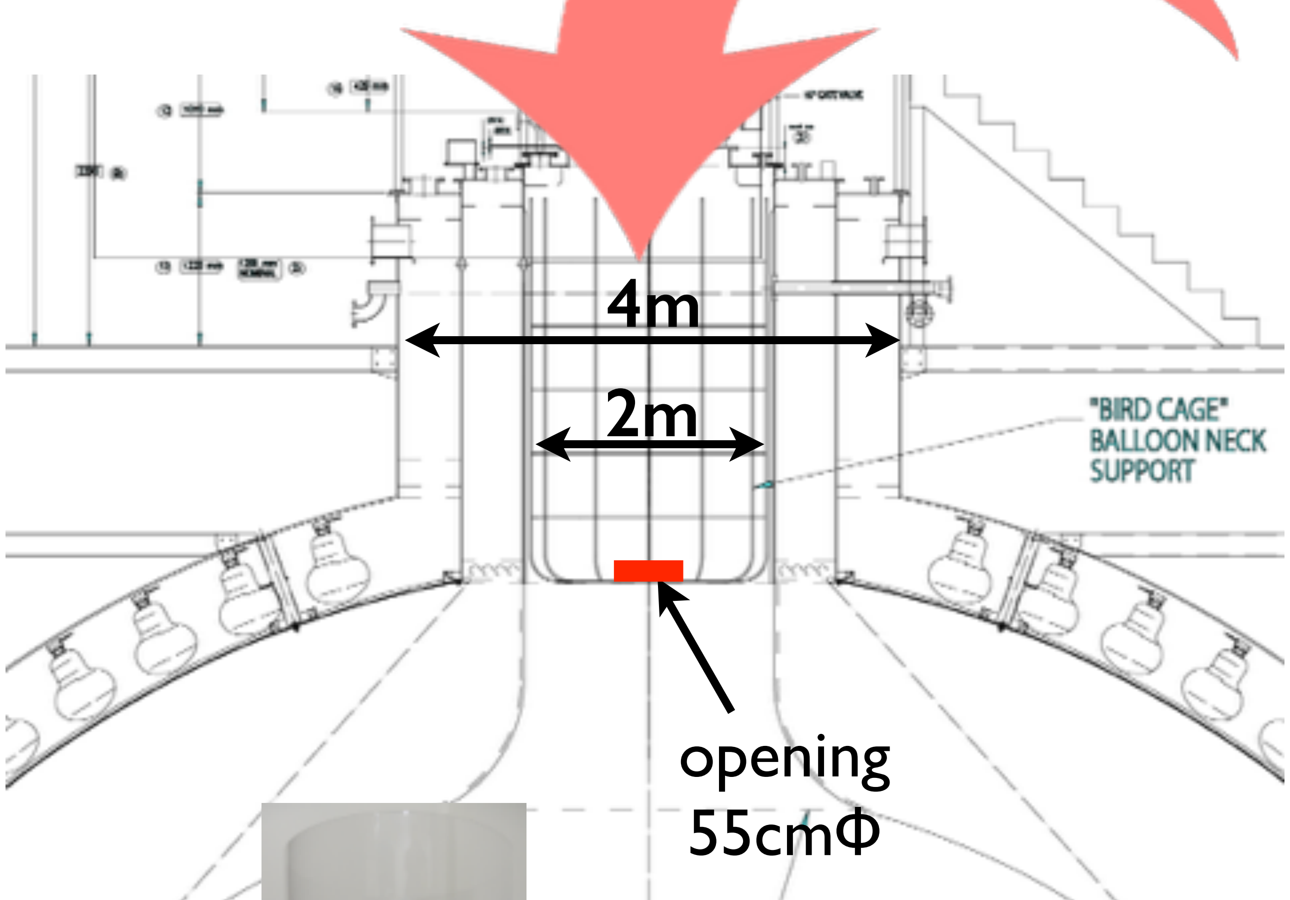


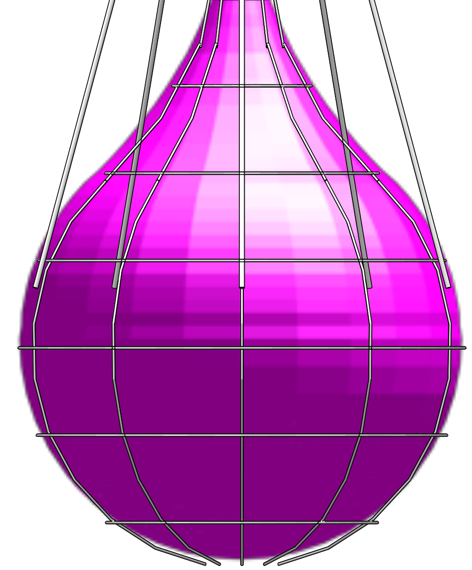
heat welding

LS storage (25 m^3 x 2)

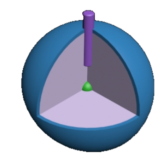
Xe loading in LS

KamLAND2 Prospect

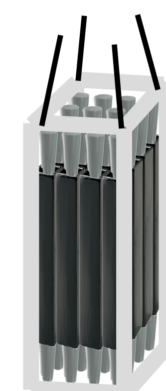




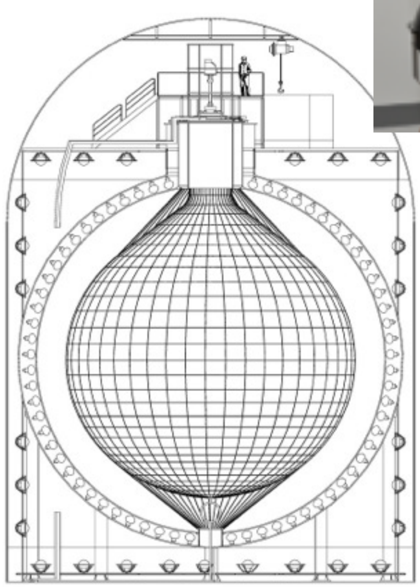
large balloon
Xe >1000 kg



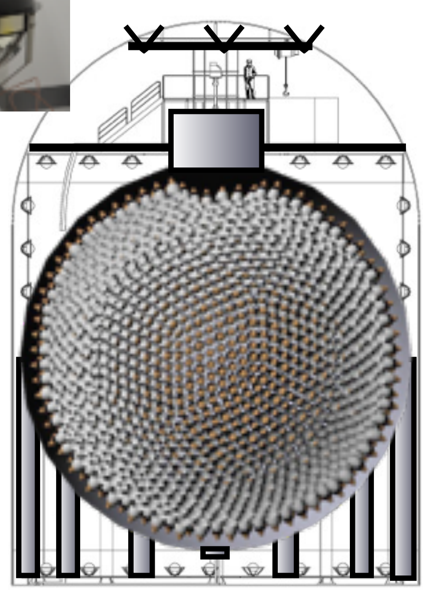
75kCi ^{144}Ce
sterile neutrino search



NaI 1 ton
dark matter search



KamLAND



KamLAND2

general-purpose

larger crane
strengthen floor
enlarge opening

high performance

high light yield LS
light collecting mirror
hight Q.E. PMT
(imaging device)

physics target in KamLAND2

double-beta : ^{136}Xe (inverted hierarchy)
other nuclei : $CdWO_4$, CaF_2, Nd-LS
sterile neutrino search : 75kCi ^{144}Ce
dark matter search : high-purity NaI
solar CNO neutrino (ν astrophysics)
geo neutrino (ν geo-science)
sterile neutrino precise search : cyclotron

All Decay Search from ENSDF

thousands of　　millions of

all nuclei and decay path in the ENSDF data-base have been surveyed

ENSDF (Evaluated Nuclear Structure Data File) http://ie.lbl.gov/databases/ensdfserve.html

Published material: Nuclear Wallet Cards, Nuclear Data Sheets, Table of Isotopes

Service site: NuDat (IAEA,BNL), Isotope Explorer (LBNL, Lund)

basic data file related to nuclear structure and decays

↓

calculate visible energy spectrum of backgrounds

(including LS quenching effect and energy resolution)

eg. decay path of ^{110m}Ag → ^{110}Cd constructed from ENSDF

decay

```
===DECAY===
File   :all_ensdf2.txt
Levels :110Cd   *ADOPTED LEVELS, GAMMAS                    00NDS    200003
Parent :110AG  P 117.59    5 6+              249.76 D  4          2892.2    16
Product:110Cd   *110AG B- DECAY (249.76 D)                        00NDS    200003
Normal :       N 0.957     3        0.9856   6 1.01
Level Gamma Transi. Energy(keV) Halflife(s)    beta-(%)    beta+       EC      alpha
---                               (keV, upper:endpoint, lower: average)
nlevel=23

nlevel=23
 1                   0.00  1.00000E+30    0.0000     0.0000     0.0000    0.0000
                                 0.00              0.00      0.00
                                 0.00              0.00      0.00
   ngamma=0  (original: 0)
 2                 657.76  5.39000E-12    0.0000     0.0000     0.0000    0.0000
                                 0.00              0.00      0.00
                                 0.00              0.00      0.00
   ngamma=1  (original: 1)
    1    2 ->    1     657.76              100.0000
 3                1475.79  6.80000E-13    0.0000     0.0000     0.0000    0.0000
                                 0.00              0.00      0.00
                                 0.00              0.00      0.00
   ngamma=2  (original: 2)
```

Name of a Decay

Branching ratio for states of daughter nuclei

γ-cascade

```
===CASCADE===
3
   620.3553   0.0000E+00
   884.6781   7.3000E-13
   657.7600   5.3900E-12
 11.752492
path: 7->4->2->1
3
   687.0091   0.0000E+00
   818.0244   6.8000E-13
   657.7600   5.3900E-12
 18.087727
path: 7->3->2->1
2
   687.0091   0.0000E+00
  1475.7792   6.8000E-13
 10.276061
path: 7->3->1
2
  1505.0280   0.0000E+00
   657.7600   5.3900E-12
 59.883721
path: 7->2->1
-1
```

Energy of each gamma ray

Lifetime for each state

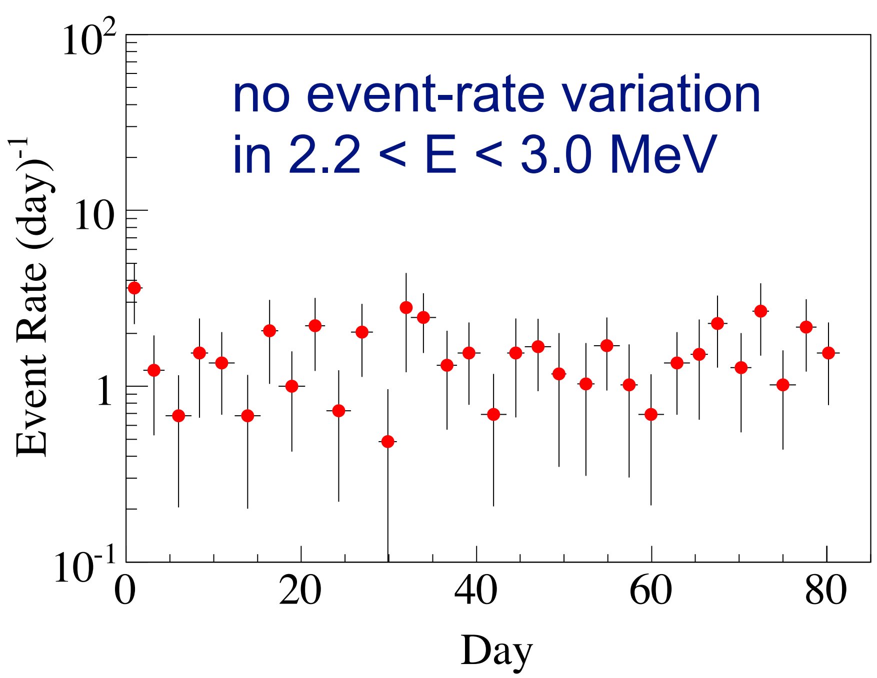
Cascade path

Identified Background Candidates

background candidates with peak around $0\nu\beta\beta$ ($2.4 < E < 2.8$ MeV)

β^- decay + IT decay

A	element	Z	parent state	sum of half life(s)
60	Co	27		1.66E+08
68	Co	27		0.331
83	Se	34		16.6
82	Br	35		1.27E+05
106	Rh	45	meta	1.56E+08
110	Ag	47	meta	2.16E+07
116	In	49	meta	1.48E+04



lifetimes longer than 30 days

β^+ decay, EC + IT decay

A		Z	parent state	sum of halflife (s)
52	MN	25		5.13E+05
57	NI	28		1.28E+05
82	RB	37	meta	2.21E+06
86	Y	39	meta	6.23E+04
88	Y	39		1.64E+07
93	MO	42	meta	4.94E+04
92	TC	43		4.77E+02
93	TC	43	meta	2.67E+03
100	RH	45		3.89E+05
106	Ag	47	meta	7.15E+05
108	In	49		4.11E+03
110	In	49		3.25E+04
115	Te	52	meta	4.98E+02
149	Ho	67	meta	5.60E+01
156	Ho	67	meta	4.68E+02
160	Ho	67		1.81E+04
176	Ta	73		2.91E+04
203	Bi	83		4.23E+04
208	Bi	83		1.16E+13
210	At	85		2.92E+04
212	FR	87		1.20E+03

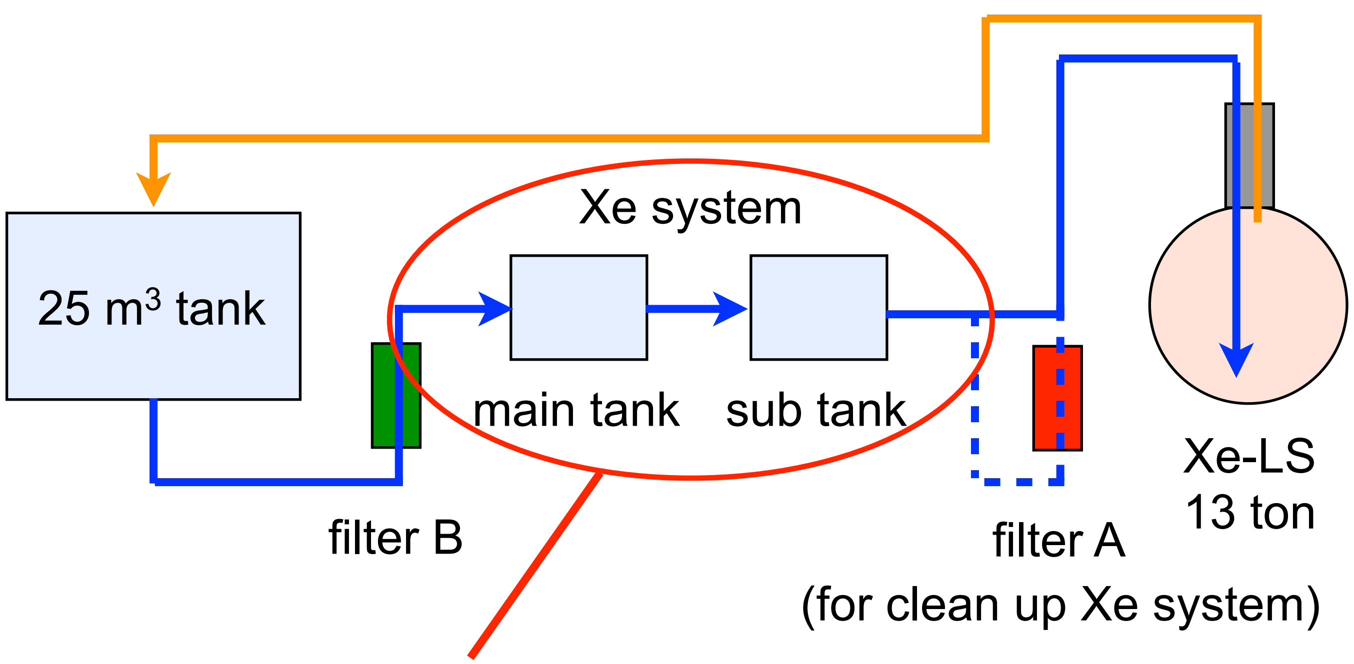
→ only 4 nuclei **^{110m}Ag (250 d), ^{208}Bi (3.68×10^5 yr), ^{88}Y (107 d), ^{60}Co (5.27 yr)**

Material Impurity Analysis

ICP-MS measurement

impurity analysis with mass spectroscopic analysis

material samples: filter A, filter B, Xe bottle, Xe-LS, Dummy-LS



measurement of ^{209}Bi, ^{107}Ag, ^{89}Y

	Bi209	Ag107	Y89
FilterA *	48ng	2300ng	
FilterB *	22ng	<50ng	870ng
Xe bottle *	40ng	<100ng	<100ng
XeLS	<10ppt		
XeLS (circuration)	<10ppt	<40ppt	<10ppt
Dummy LS		<40ppt	<2ppt
Amount in LS (13ton)	<0.1mg	<0.4mg	<0.1mg

Ag, Bi are contained in solder (Xe system)

^{208}Bi environmental activity of ^{208}Bi is ~0.18 mBq/gBi A.Shinohara et.al, Appl.Radiot.Isot.Vol.37,No10,p1025, (1986)

To explain the BG level at 2.6 MeV, ~1 ppb ^{209}Bi in Xe-LS is required,

but the obtained limit is < 10 ppt ⟶ environmental ^{208}Bi was excluded

^{110m}Ag environmental activity of ^{110m}Ag in solder is checked by Ge detector

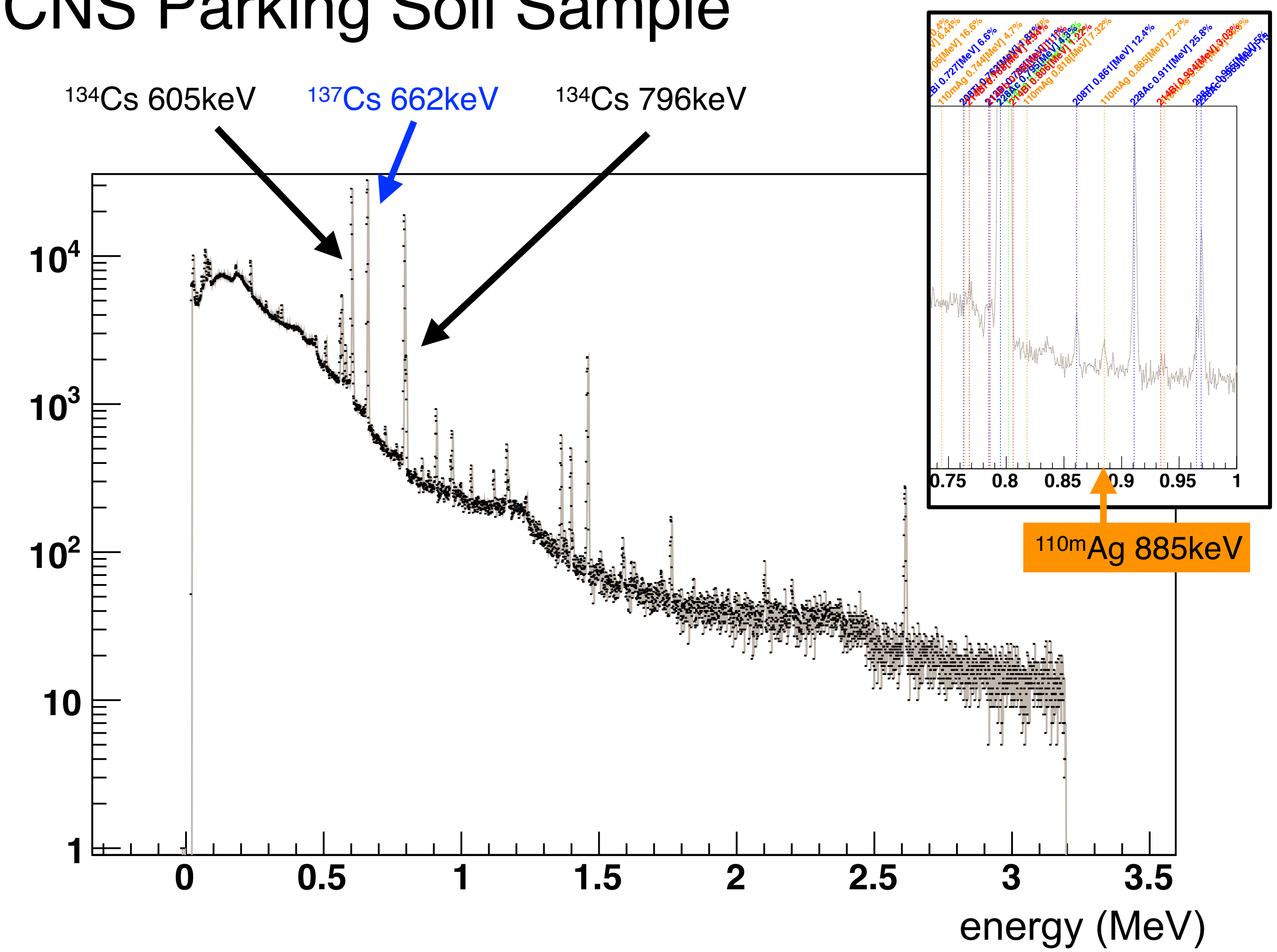
⟶ environmental ^{110m}Ag was excluded

Possible Impurity Source

Fukushima-I reactor fallout

soil sample taken near the balloon production facility
→ ^{110m}Ag (250 d) is identified by Ge detector

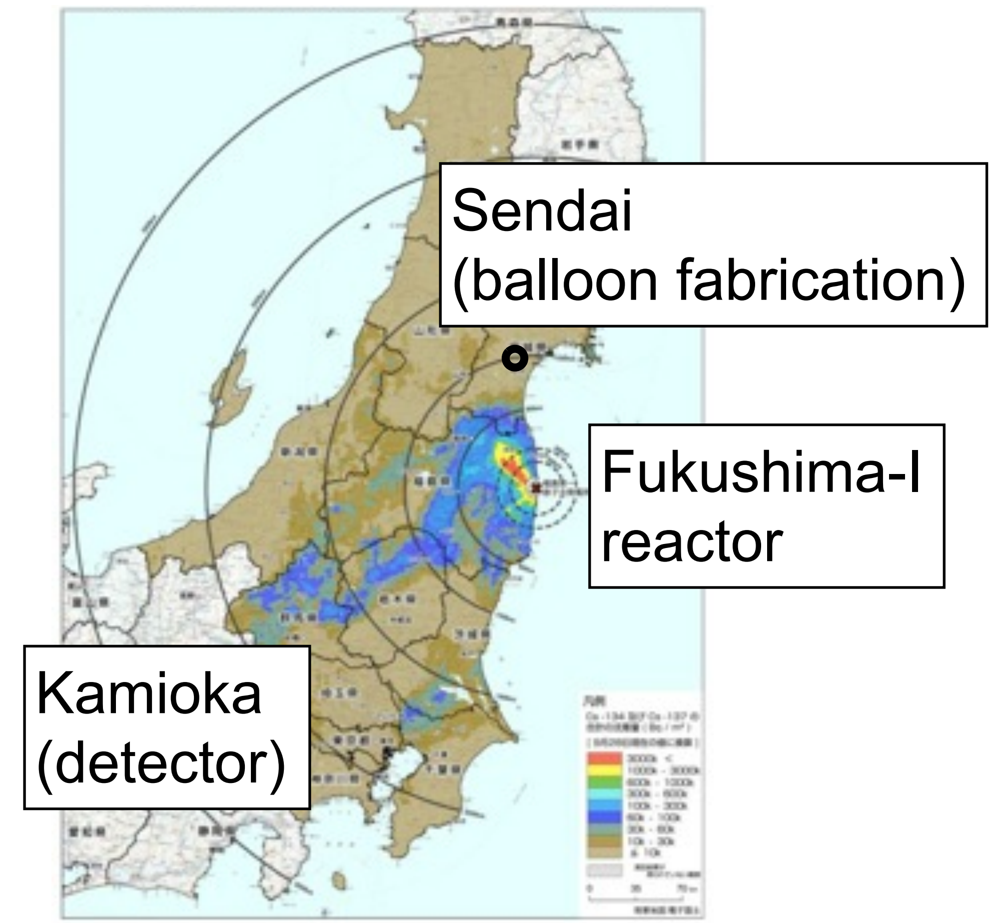
RCNS Parking Soil Sample



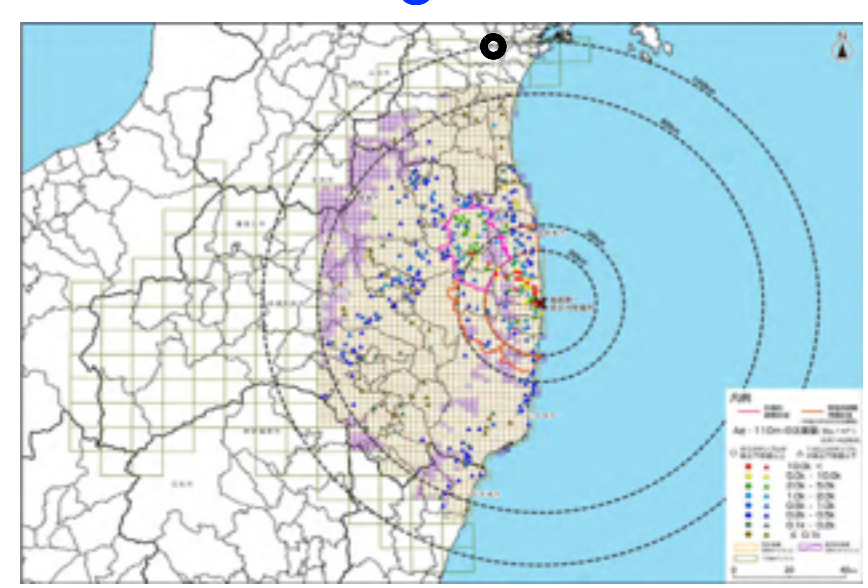
activity ratio of ^{110m}Ag/^{137}Cs ~ 0.004

^{208}Bi (3.68×10^5 yr), ^{88}Y (107 d), and ^{60}Co (5.27 yr) are not detected near Fukushima and our soil samples

^{134}Cs + ^{137}Cs fallout



^{110m}Ag fallout



Cosmogenic Spallation at Underground

cosmic-ray muon spallation in Xe-LS

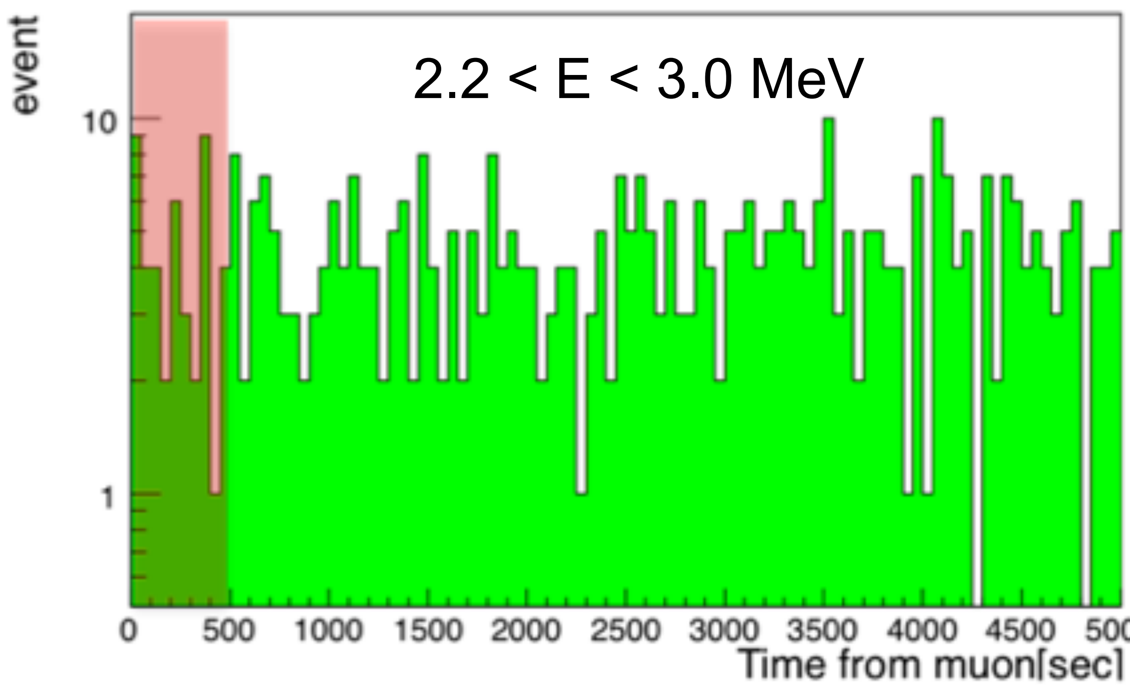
carbon (^{12}C) target	previously studied in KamLAND LS
xenon (^{136}Xe, ^{134}Xe) target	need reevaluation !!

underground products

- short-lived nuclei ($T_{1/2}$ < 100 s)
  study of time correlation with muons
  < 0.02 /ton·day (90% CL) ⟶ small

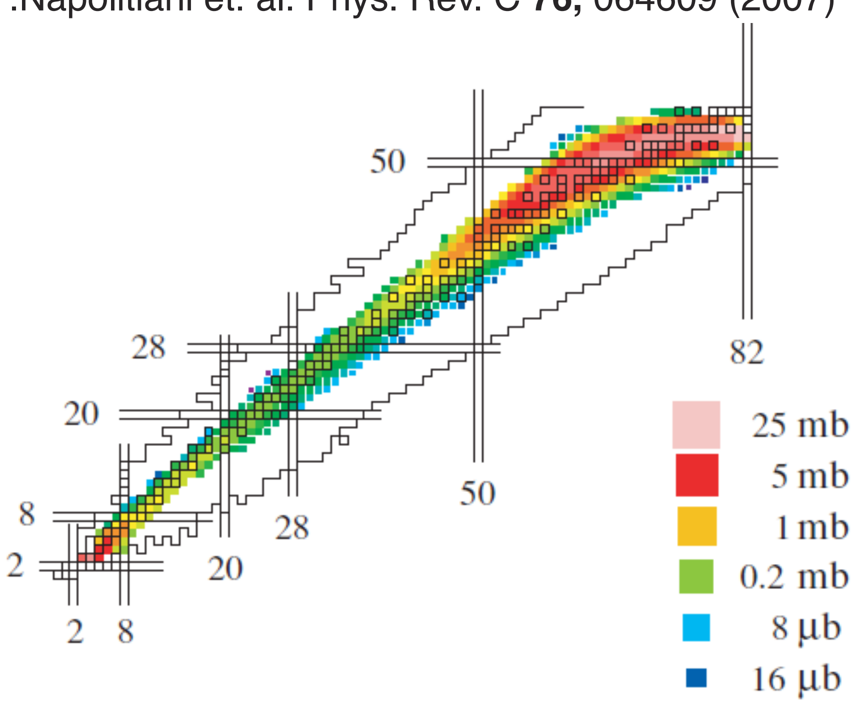
- long-lived nuclei (100 s < $T_{1/2}$ < 30 d)
  study of E spectrum
  w/ close A, Z nuclei ⟶ negligible

time correlation from muons



cross section data of proton-^{136}Xe

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



Underground spallation products are not serious backgrounds

Cosmogenic Spallation at Aboveground

cosmogenic spallation in Xe

Xe (^{136}Xe) gas enriched in Russia
→ gas bottle was transported by airplane

cosmic-ray proton/neutron is dominant source

flux is ~100 times higher than sea-level

how to estimate

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

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

^{136}Xe → surface (X = 100 days) → mine (Y = **0**, 100, 300, 600 days) → radioactivities after X+Y days → energy spectrum

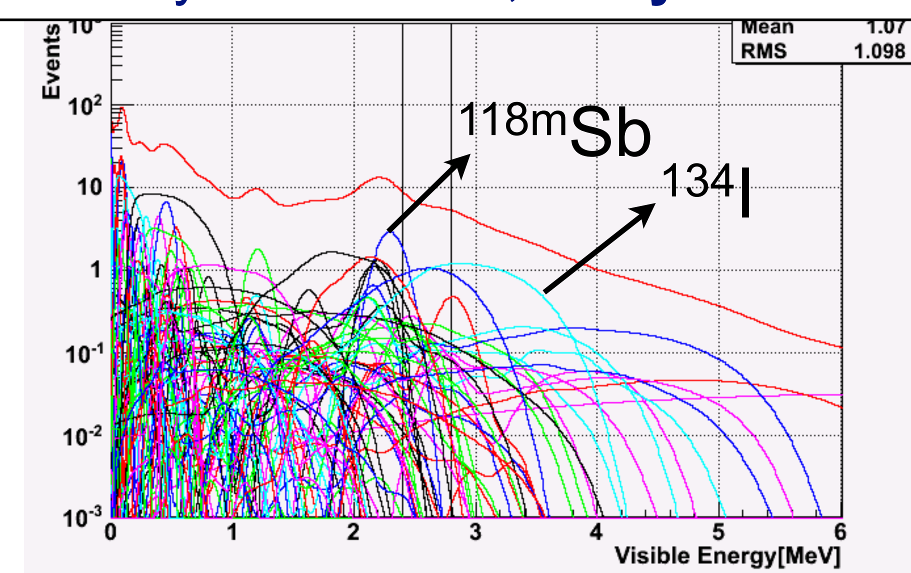
aboveground products

cross-section of ^{136}Xe + 1 GeV proton
P.Napolitiani et. al. Phys. Rev. C **76,** 064609 (2007)

production by surface proton/neutron is dominant

→ ^{110m}Ag and ^{88}Y are candidate BG

100 days on surface, **0 days** in mine



For reference, aboveground spallation in other experiments

enriched ^{76}Ge	^{57}Co, ^{54}Mn, ^{68}Ge, ^{65}Zn, ^{60}Co	PRC 82, 054610 (2010)
enriched ^{116}Cd	^{110m}Ag, ^{106}Ru	arXiv:1108.2771

Cosmogenic Spallation at Aboveground

cosmogenic spallation in Xe

Xe (^{136}Xe) gas enriched in Russia

→ gas bottle was transported by airplane

cosmic-ray proton/neutron is dominant source

flux is ~100 times higher than sea-level

how to estimate

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

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

^{136}Xe → surface X = 100 days → mine Y = 0, **100**, 300, 600 days → radioactivities after X+Y days → energy spectrum

aboveground products

cross-section of ^{136}Xe + 1 GeV proton

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

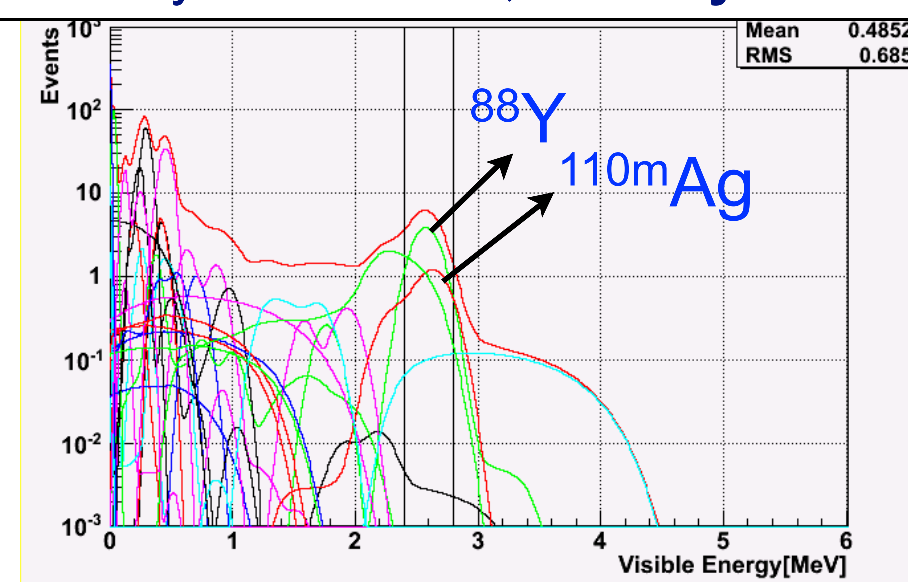
production by surface proton/neutron is dominant

→ ^{110m}Ag and ^{88}Y are candidate BG

For reference, aboveground spallation in other experiments

enriched ^{76}Ge	^{57}Co, ^{54}Mn, ^{68}Ge, ^{65}Zn, ^{60}Co	PRC 82, 054610 (2010)
enriched ^{116}Cd	^{110m}Ag, ^{106}Ru	arXiv:1108.2771

100 days on surface, **100 days** in mine



Cosmogenic Spallation at Aboveground

cosmogenic spallation in Xe

Xe (^{136}Xe) gas enriched in Russia
→ gas bottle was transported by airplane

cosmic-ray proton/neutron is dominant source
flux is ~100 times higher than sea-level

how to estimate

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

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

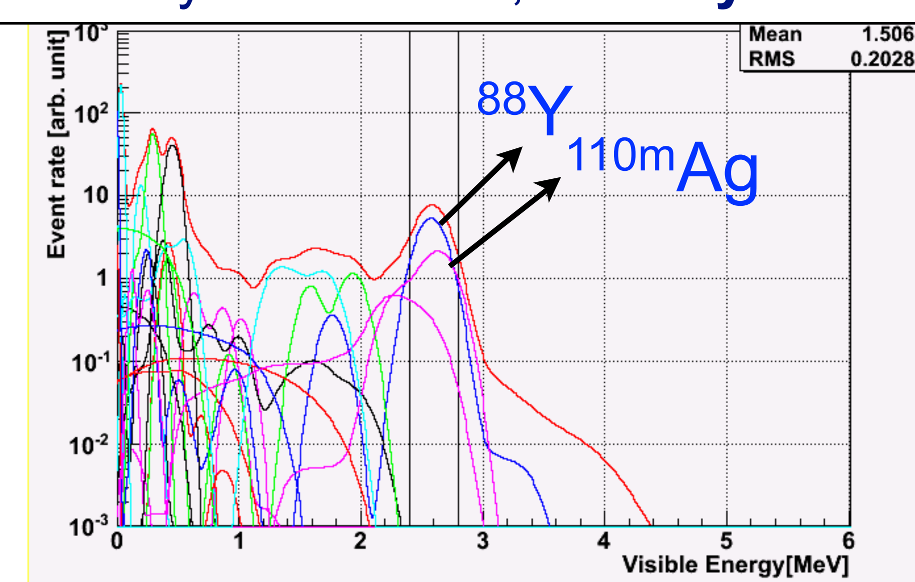
^{136}Xe → surface X = 100 days → mine Y = 0, 100, **300**, 600 days → radioactivities after X+Y days → energy spectrum

aboveground products

cross-section of ^{136}Xe + 1 GeV proton
P.Napolitiani et. al. Phys. Rev. C **76,** 064609 (2007)

production by surface proton/neutron is dominant
→ ^{110m}Ag and ^{88}Y are candidate BG

100 days on surface, **300 days** in mine



For reference, aboveground spallation in other experiments

enriched ^{76}Ge	^{57}Co, ^{54}Mn, ^{68}Ge, ^{65}Zn, ^{60}Co	PRC 82, 054610 (2010)
enriched ^{116}Cd	^{110m}Ag, ^{106}Ru	arXiv:1108.2771

Cosmogenic Spallation at Aboveground

cosmogenic spallation in Xe

Xe (^{136}Xe) gas enriched in Russia
→ gas bottle was transported by airplane

cosmic-ray proton/neutron is dominant source
flux is ~100 times higher than sea-level

how to estimate

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

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

^{136}Xe → surface X = 100 days → mine Y = 0, 100, 300, **600** days → radioactivities after X+Y days → energy spectrum

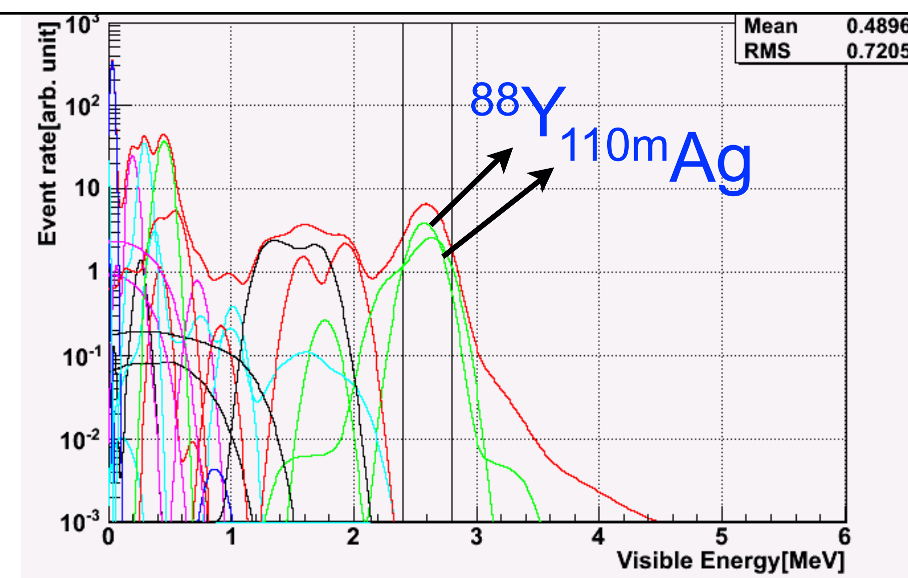
aboveground products

cross-section of ^{136}Xe + 1 GeV proton
P.Napolitiani et. al. Phys. Rev. C **76,** 064609 (2007)

production by surface proton/neutron is dominant

→ ^{110m}Ag and ^{88}Y are candidate BG

100 days on surface, **600 days** in mine



For reference, aboveground spallation in other experiments

enriched ^{76}Ge	^{57}Co, ^{54}Mn, ^{68}Ge, ^{65}Zn, ^{60}Co	PRC 82, 054610 (2010)
enriched ^{116}Cd	^{110m}Ag, ^{106}Ru	arXiv:1108.2771