“New” result of KamLAND-Zen

Kunio Inoue
for the KamLAND-Zen collaboration

Revealing the history of the universe with underground particle and nuclear research 2016, Koshiba Hall, 11 May 2016

“New”

Search for Majorana Neutrinos near the Inverted Mass Hierarchy region with KamLAND-Zen

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(KamLAND-Zen Collaboration)

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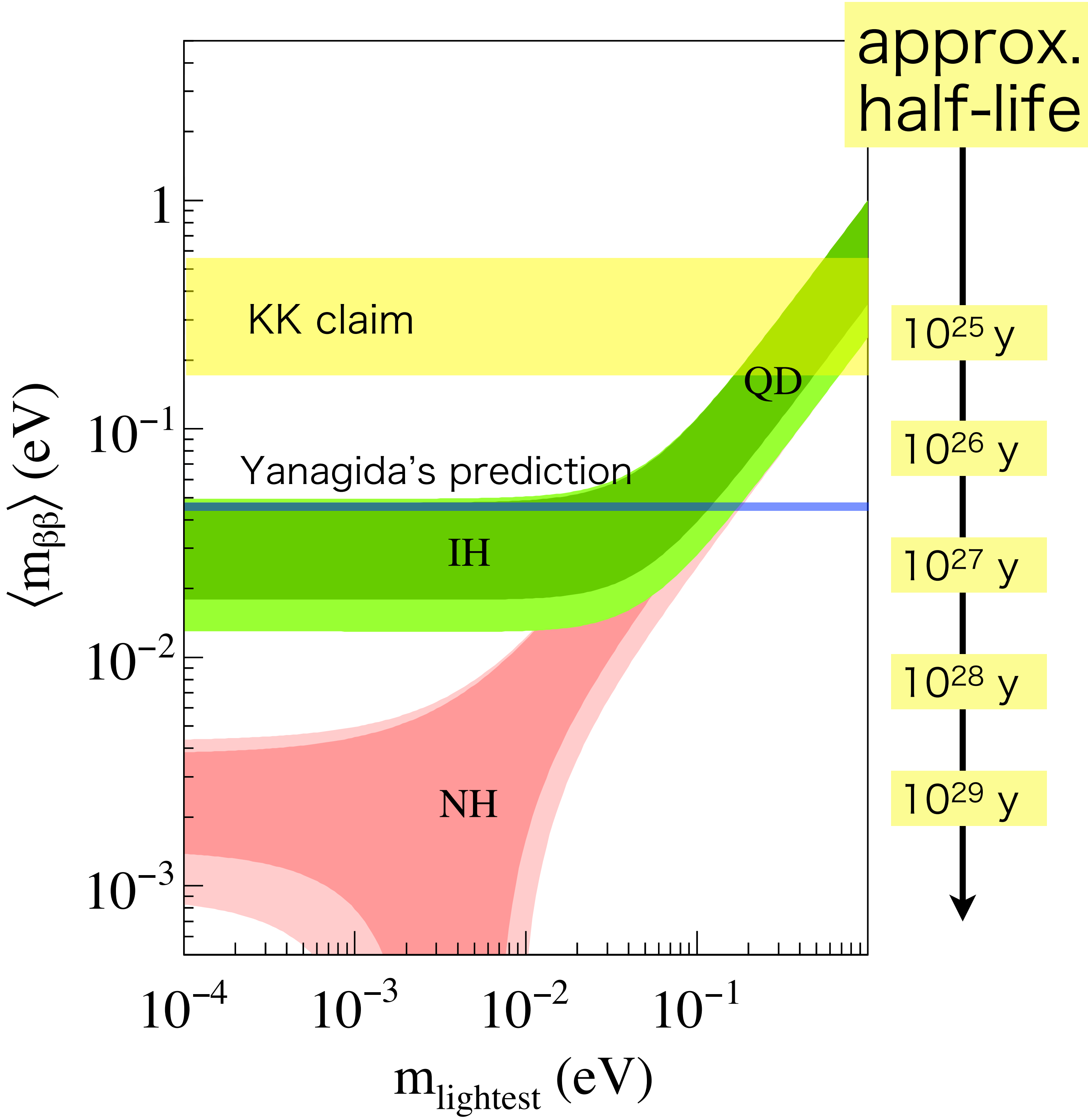
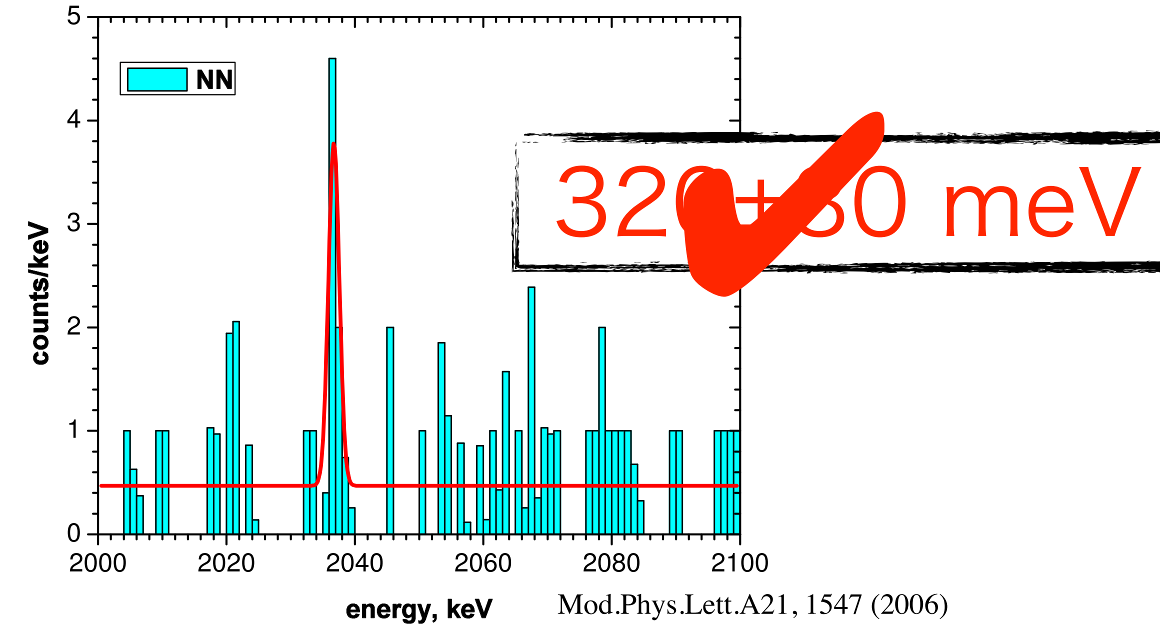
(Dated: May 11, 2016)

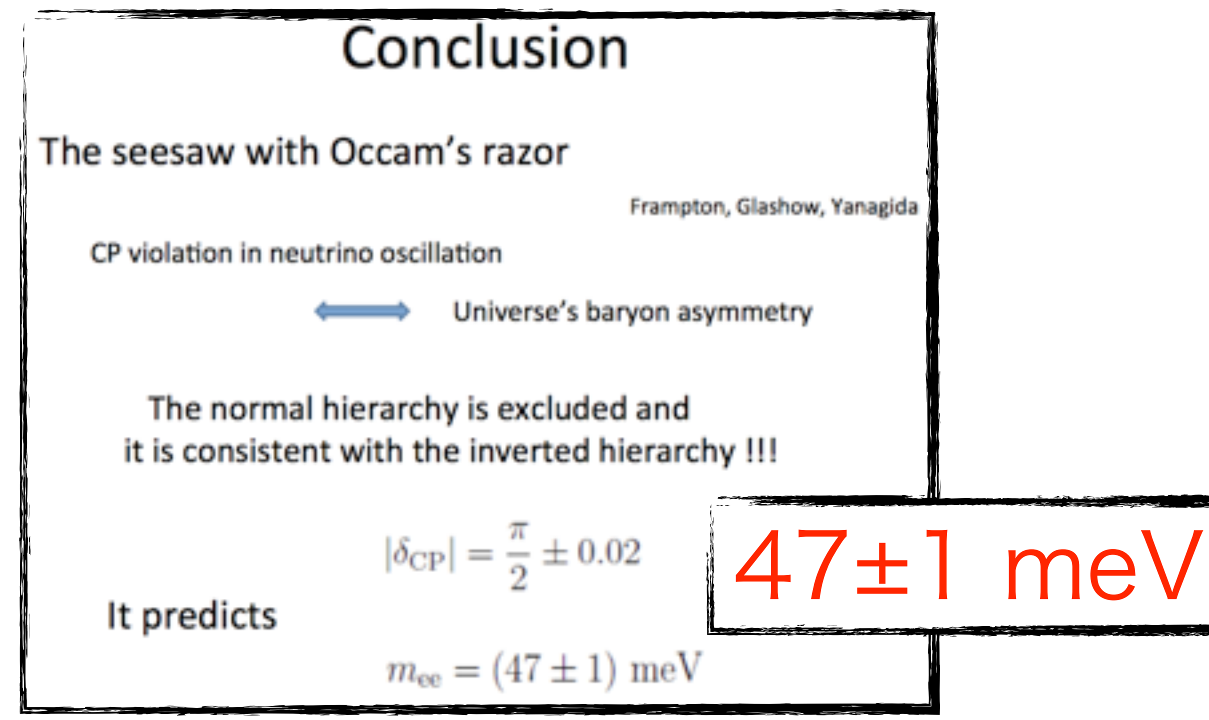
The latest paper has been submitted to PRL and posted on arXiv, yesterday.

Milestone





Mod.Phys.Lett.A21, 1547 (2006)



Conclusion

The seesaw with Occam's razor

Frampton, Glashow, Yanagida

CP violation in neutrino oscillation

↔ Universe's baryon asymmetry

The normal hierarchy is excluded and
it is consistent with the inverted hierarchy !!!

$|\delta_{CP}| = \frac{\pi}{2} \pm 0.02$

It predicts

$m_{ee} = (47 \pm 1)$ meV

Phys.Rev.D86, 013002 (2012)

full coverage of Quasi Degenerate → next milestone

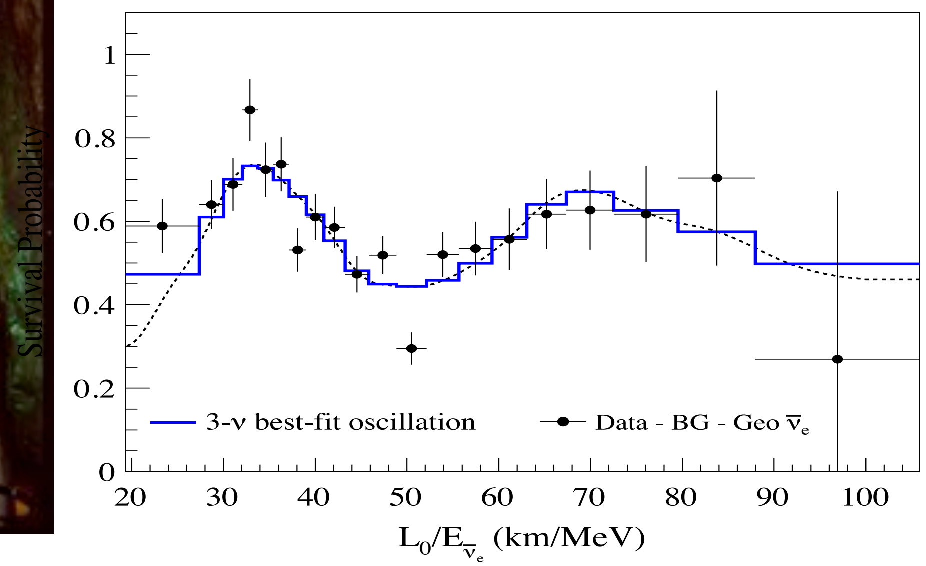
full coverage of Inverted Hierarchy → next gen. exp.

full coverage of $m_{lightest}$~0 → very difficult

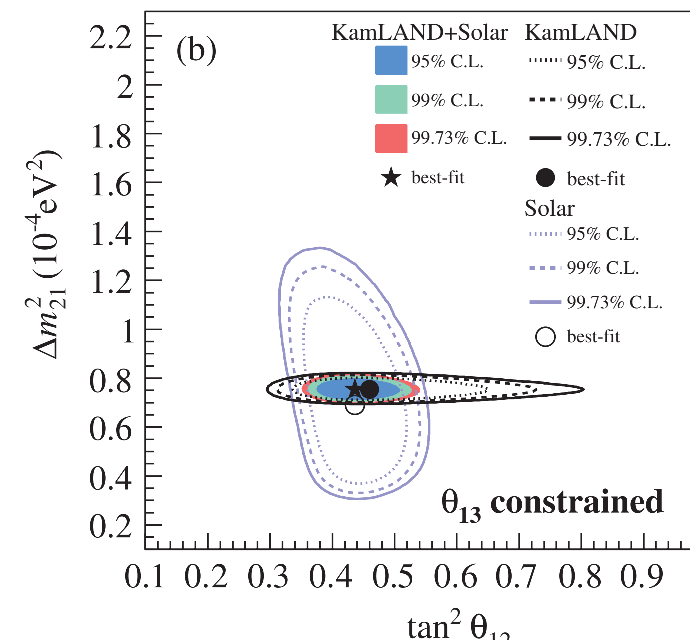
Ultra-low BG underground (& huge) experiment is necessary

It is KamLAND !!

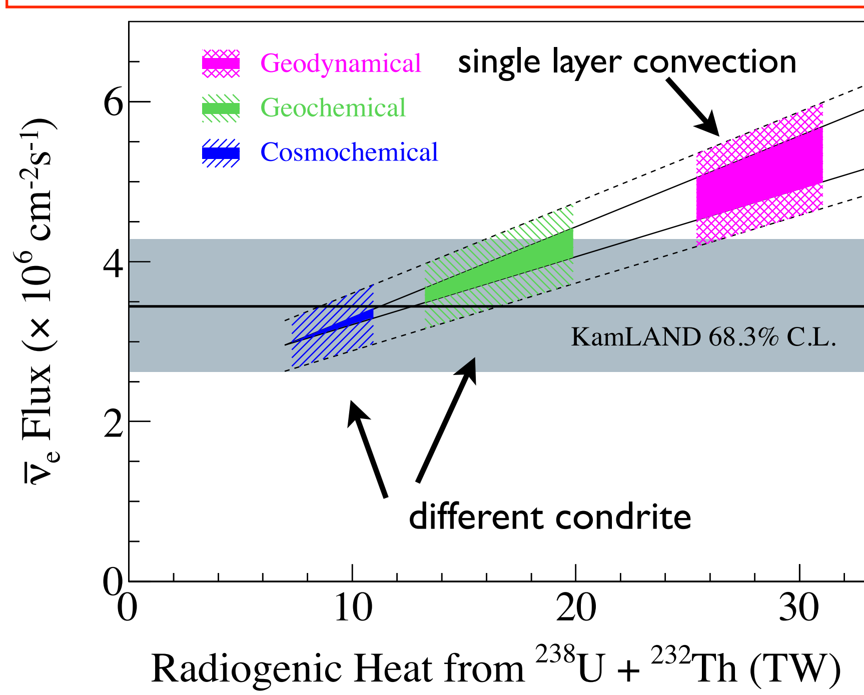
2 cycles of oscillations



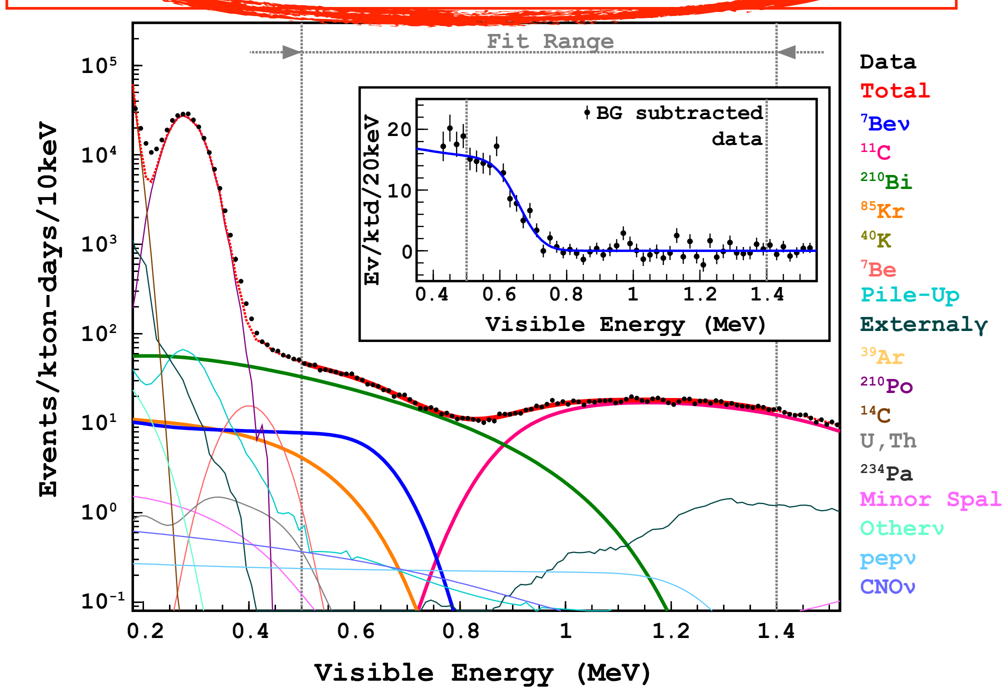
Precision measurement



Radiogenic heat measured,
Model discrimination started

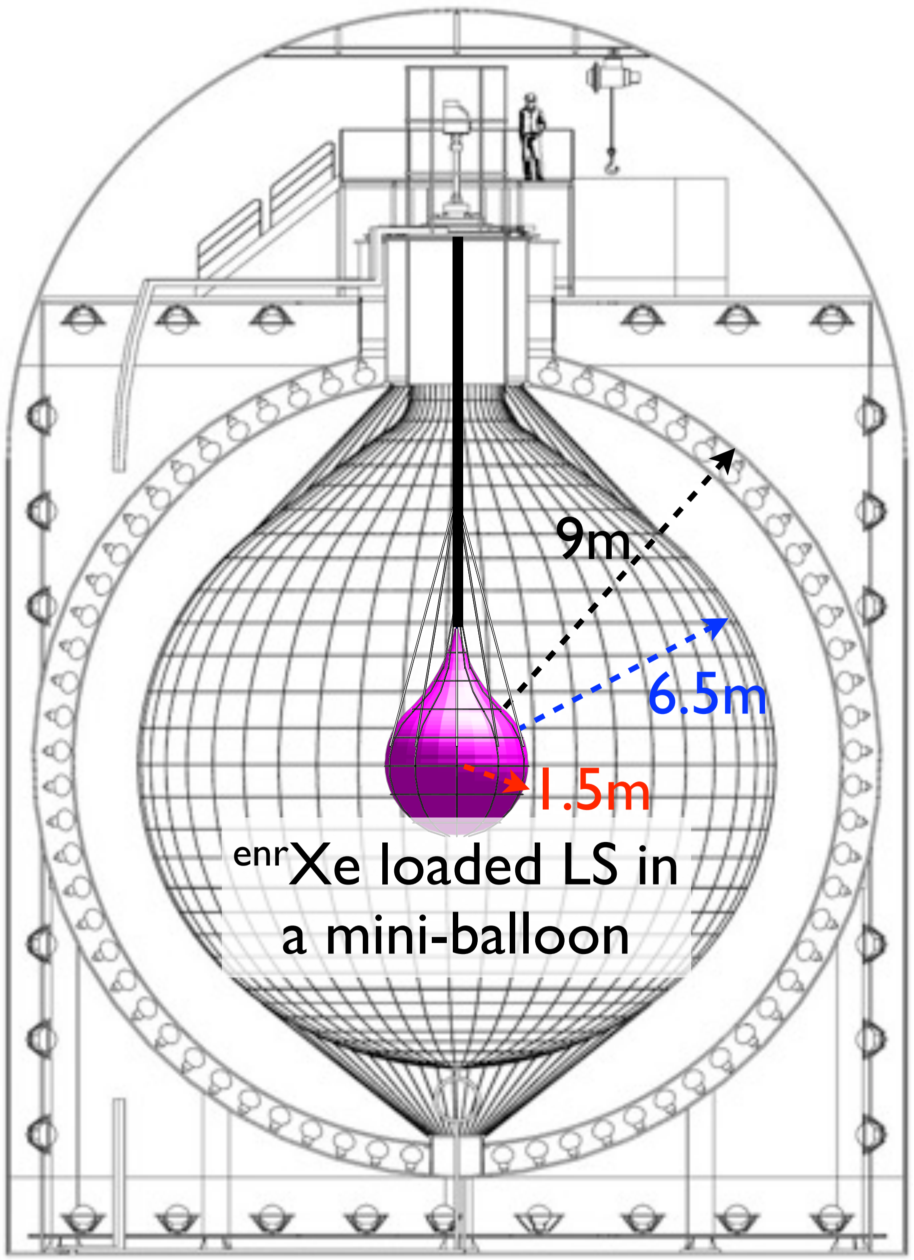


^{7}Be solar ν measured,
BG well-understood



KamLAND-Zen

Zero Neutrino
double beta decay search



320kg 90% enriched ^{136}Xe installed for phase-1
and 380kg for phase-2

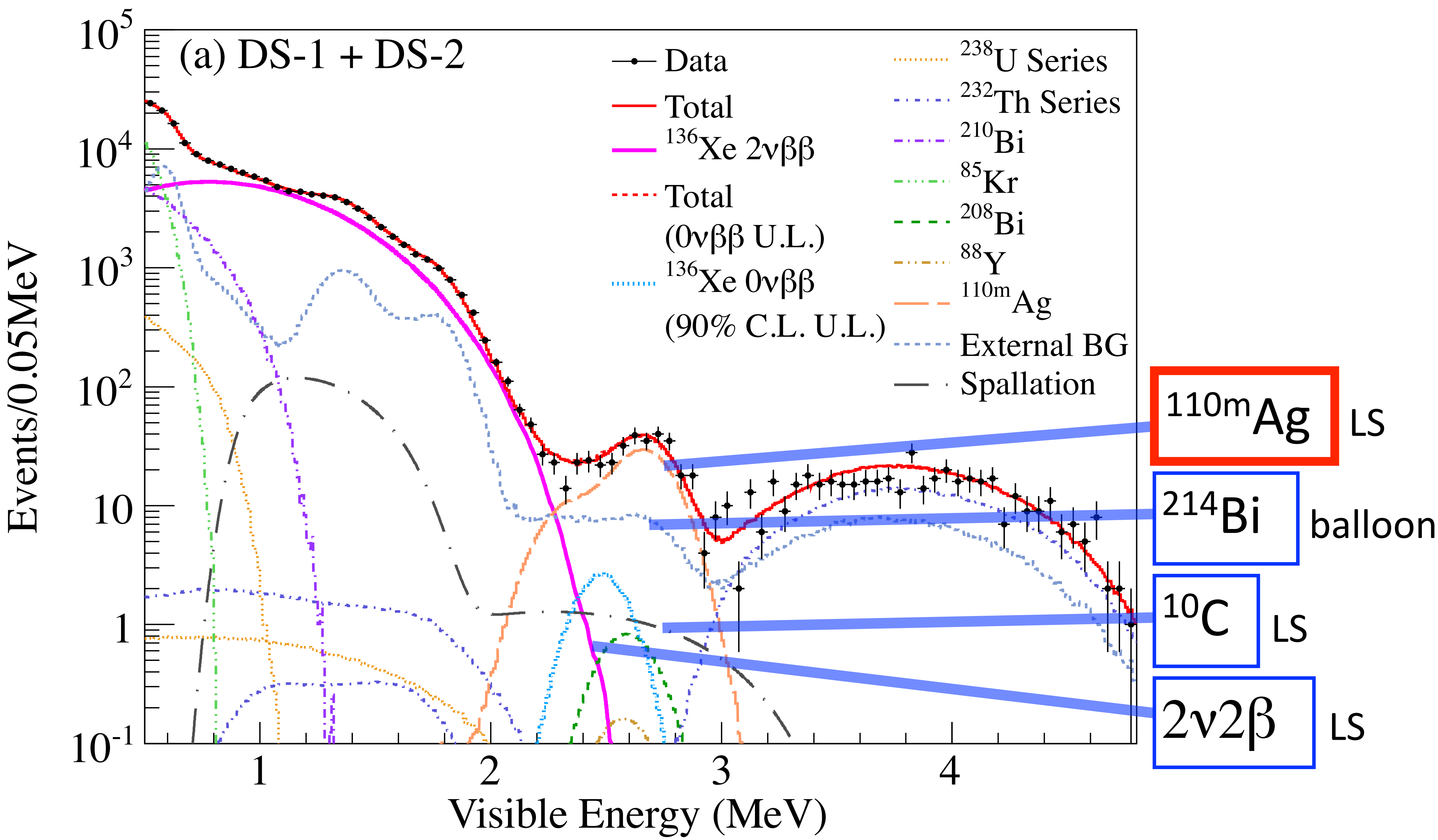
Advantages of using KamLAND

- running detector
  → relatively low cost and quick start
- huge and clean ($1200m^3$, U: 3.5×10^{-18} g/g, Th: 5.2×10^{-17})
  → negligible external gamma

  (Xe and mini-balloon need to be clean)
- Xe-LS can be purified, mini-balloon replaceable if necessary, with relatively low cost
  → highly scalable (up to several tons of Xe)
- No escape or invisible energy from β, γ
  → BG identification relatively easy
- **anti-neutrino observation continues**
  → geo-neutrino w/o Japanese reactors

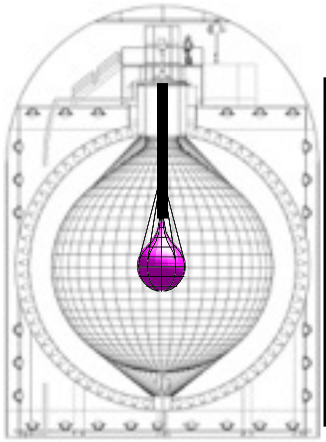
KamLAND-Zen started in 2011

only 2 years from initial funding

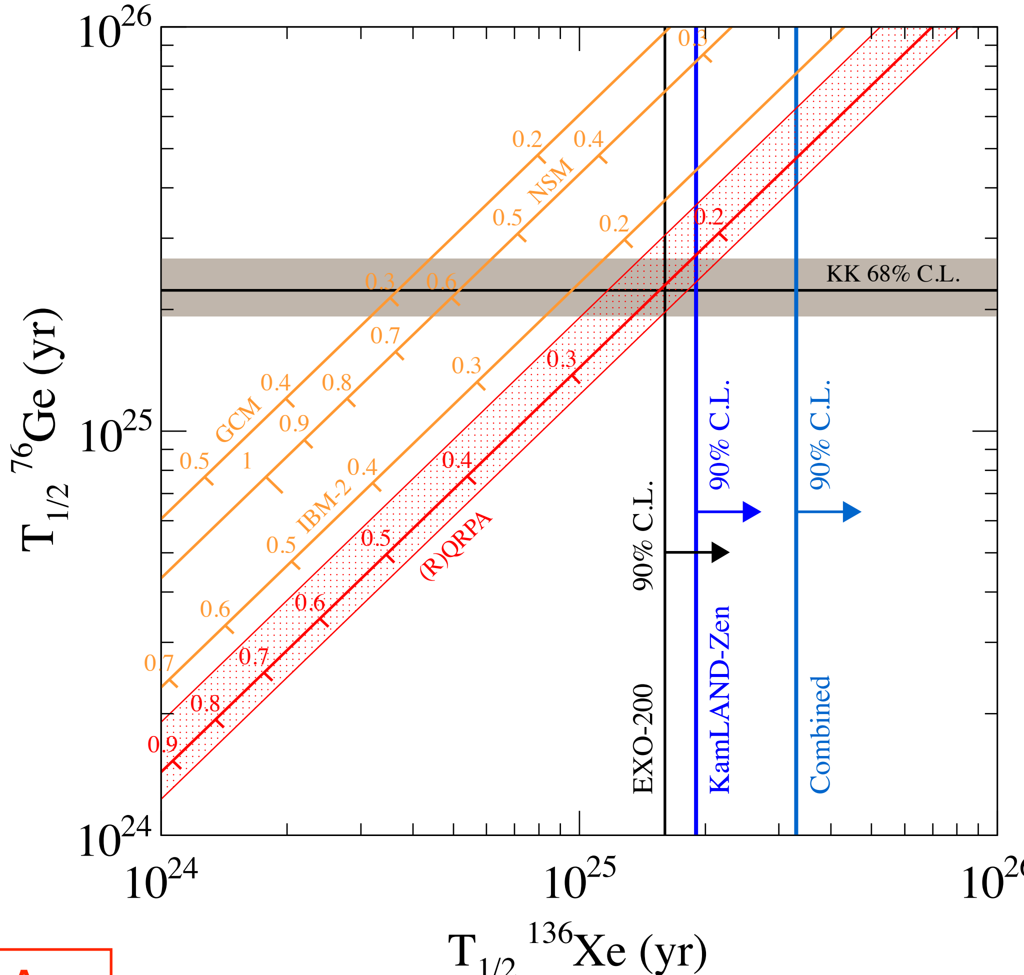


Unexpected BG has found

published result w/ high silver rate (phase-1)



~320kg 90% enriched ^{136}Xe installed initially



Phys.Rev.Lett, 110, 062502 (2013)

so far the world best limit

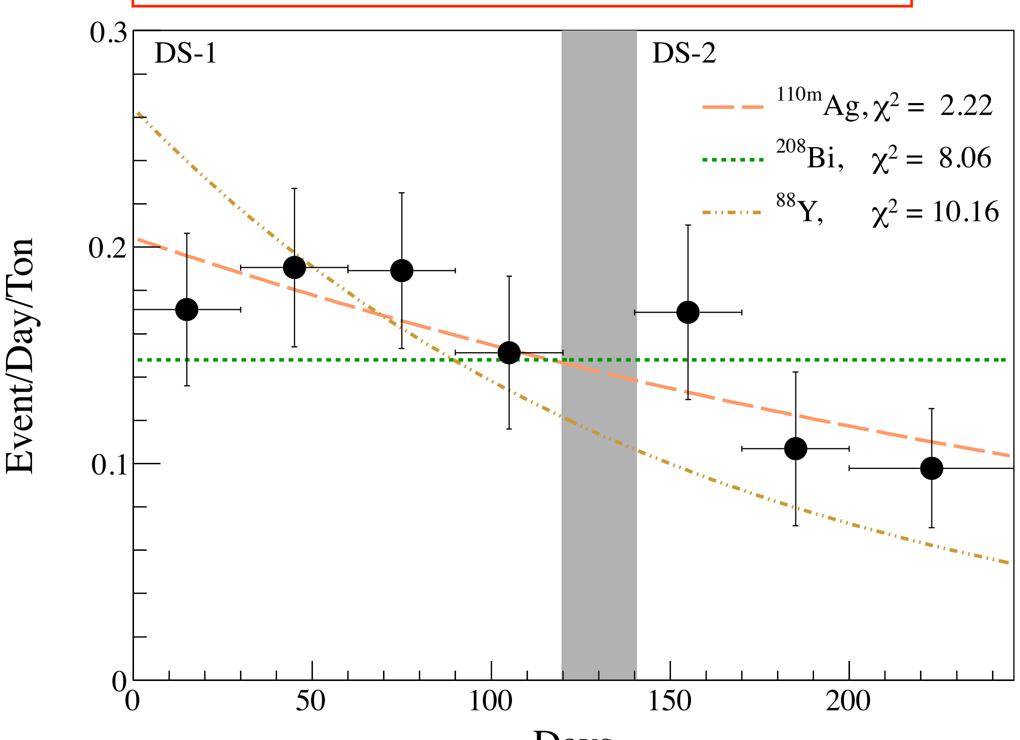
$T_{1/2} > 1.9\times10^{25}$ yrs (KL-Zen)

$> 3.4\times10^{25}$ yrs (combined)

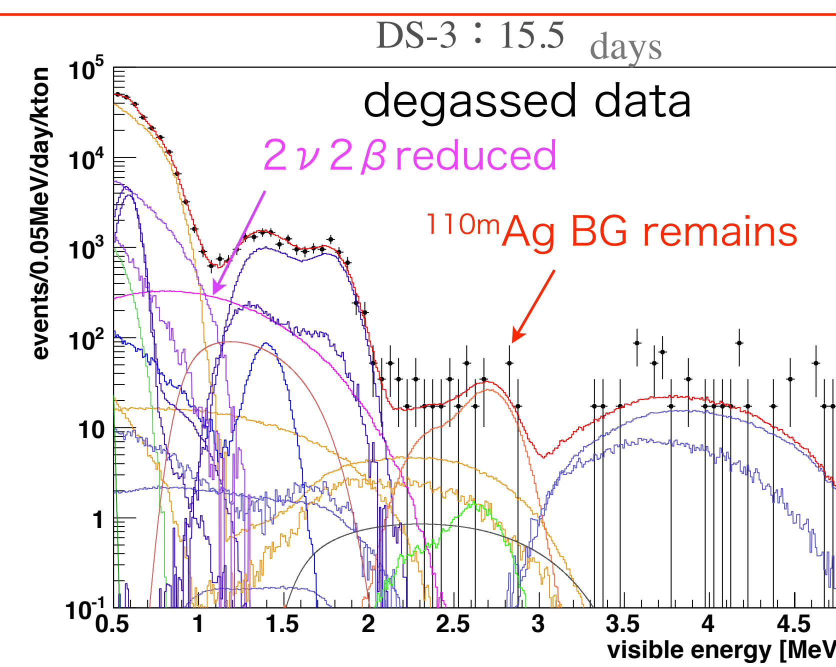
$\langle m_{\beta\beta}\rangle < 120 \sim 250\,\mathrm{meV}$

KK-claim refuted at 97.5% CL

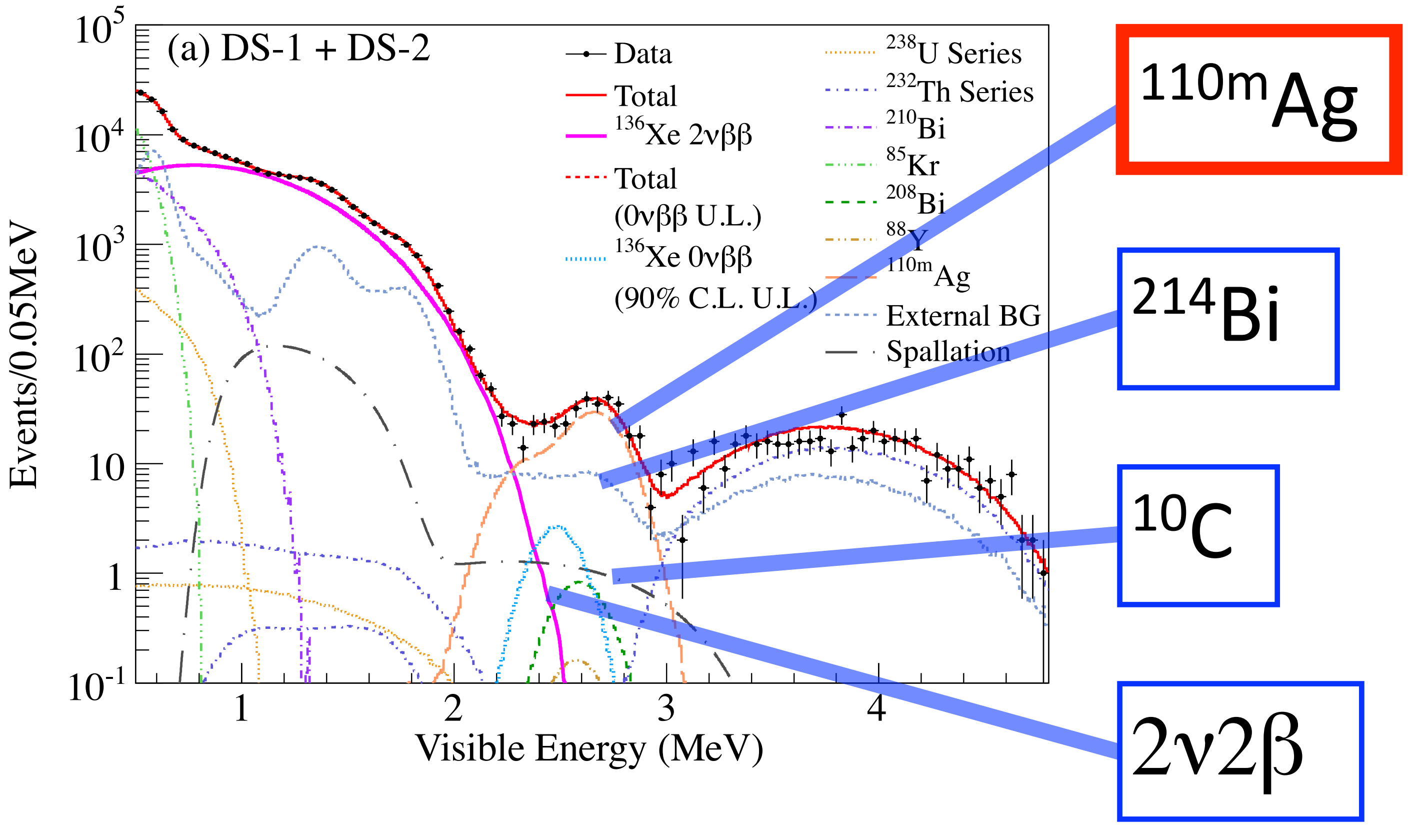
BG identified as ^{110m}Ag



Xe on-off measurement demonstrated



What can we do?



purification !!

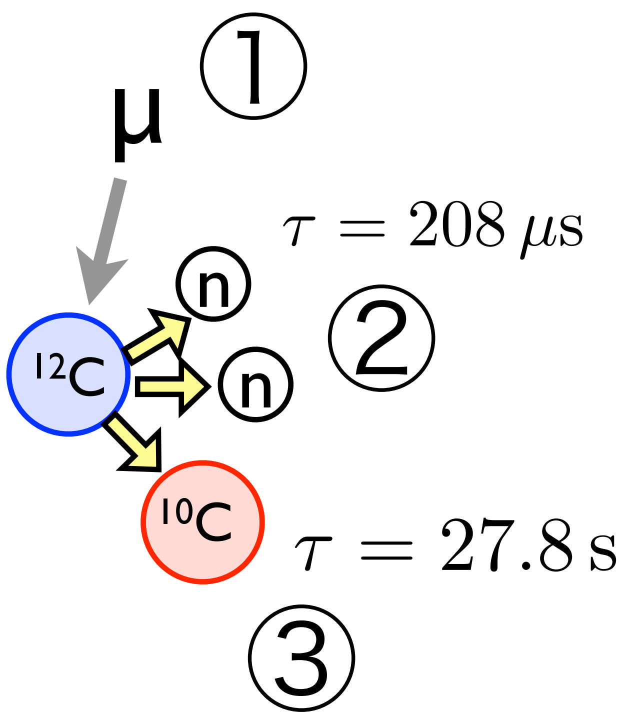
fine binning of volume

triple fold coincidence

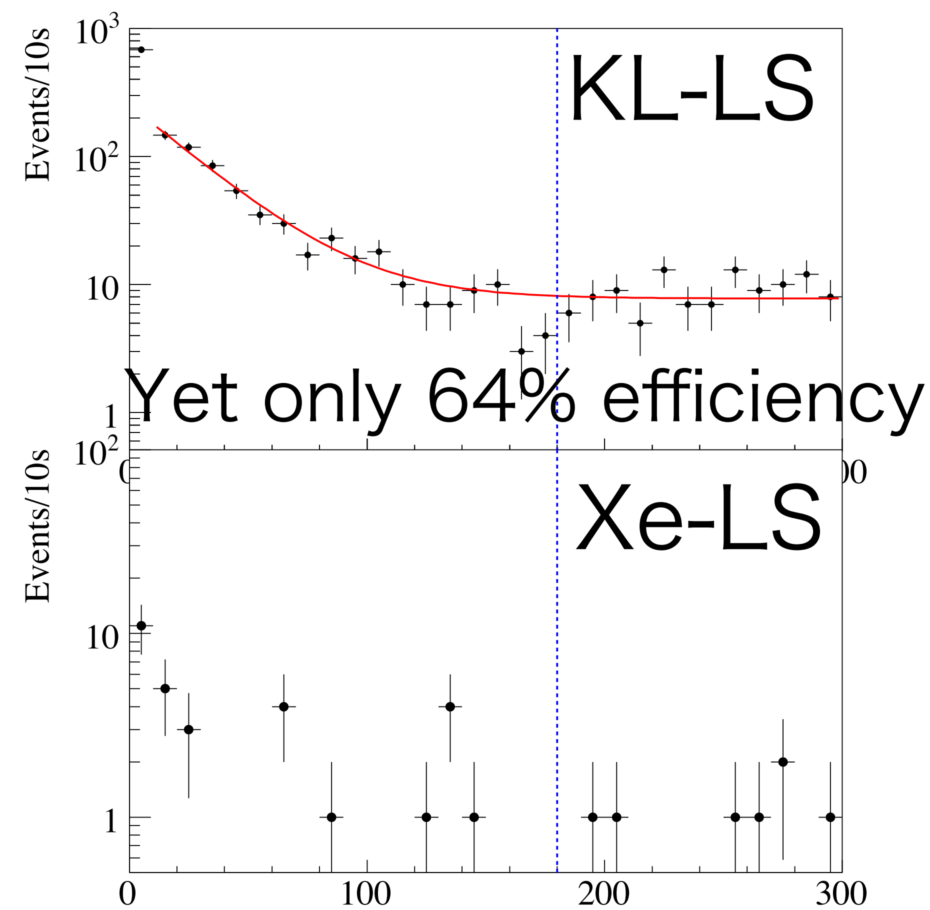
future task

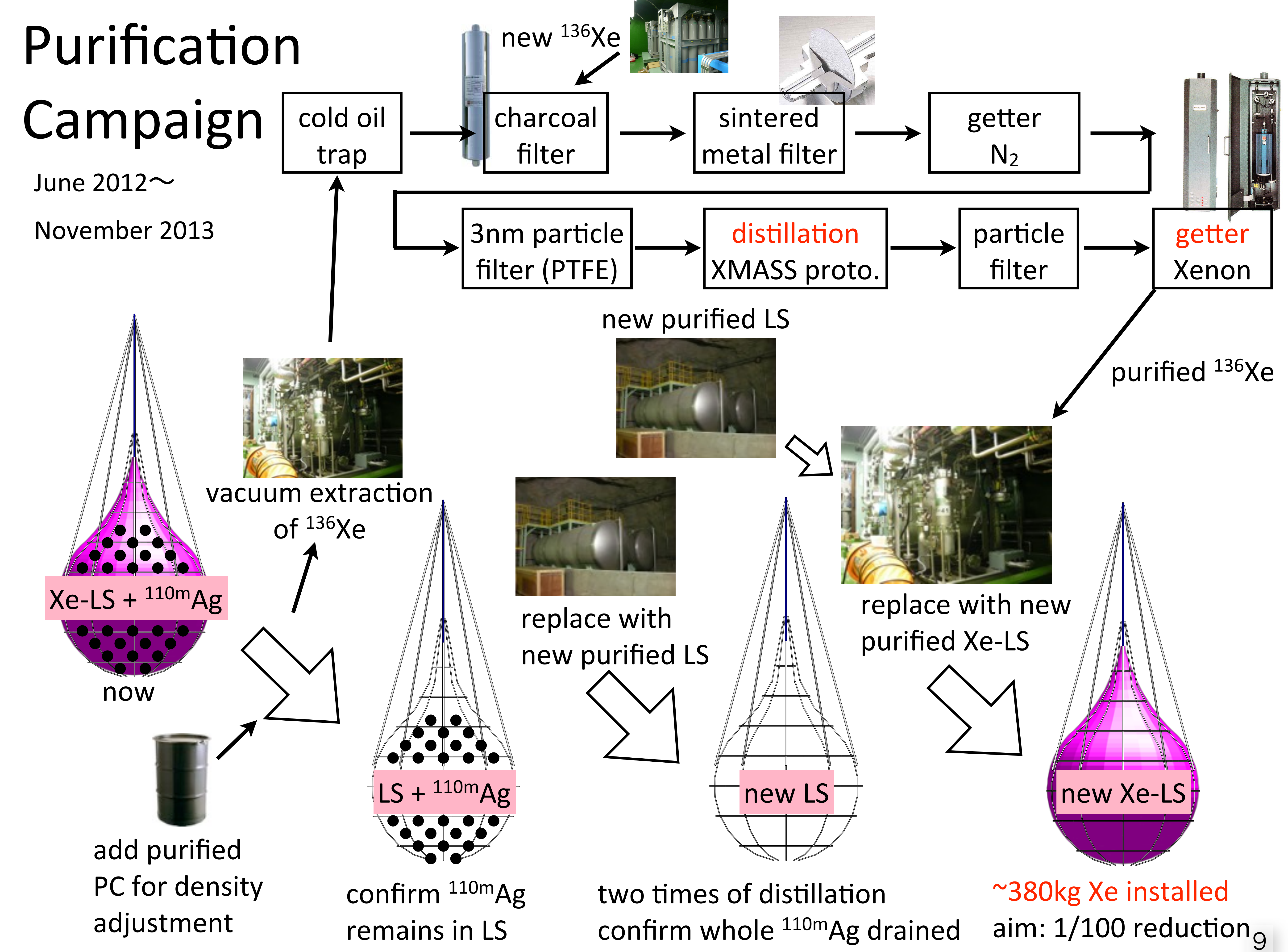
tripe fold coincidence

for ^{10}C rejection



dead time free electronics MoGURA

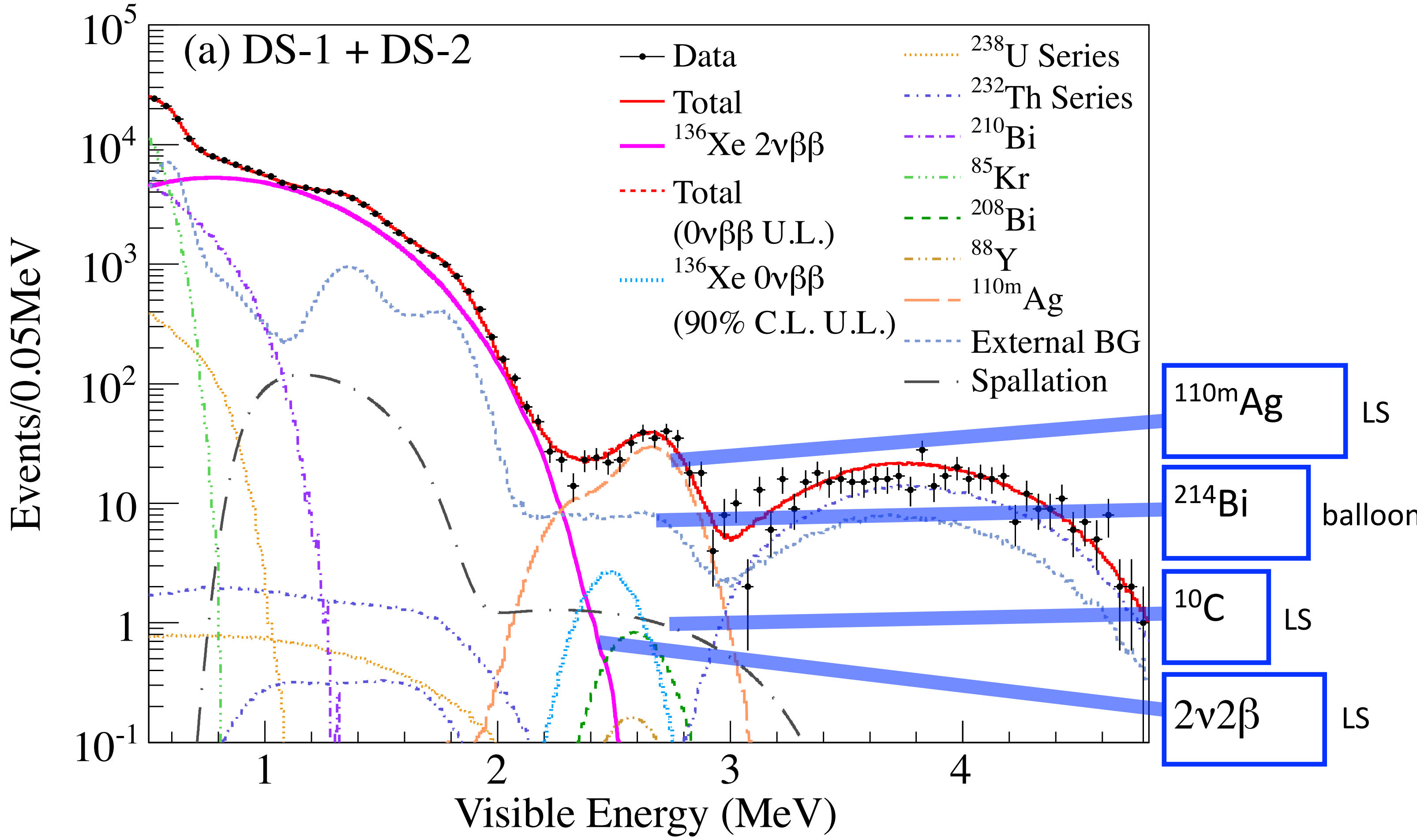



Purification Campaign
June 2012～
November 2013
new ^{136}Xe
cold oil trap
charcoal filter
sintered metal filter
getter N_2
3nm particle filter (PTFE)
distillation XMASS proto.
particle filter
getter Xenon
new purified LS
purified ^{136}Xe
vacuum extraction of ^{136}Xe
Xe-LS + ^{110m}Ag
now
add purified PC for density adjustment
LS + ^{110m}Ag
confirm ^{110m}Ag remains in LS
replace with new purified LS
new LS
two times of distillation
confirm whole ^{110m}Ag drained
replace with new purified Xe-LS
new Xe-LS
~380kg Xe installed
aim: 1/100 reduction

@Neutrino 2014

Phase-1 320kg

before purification

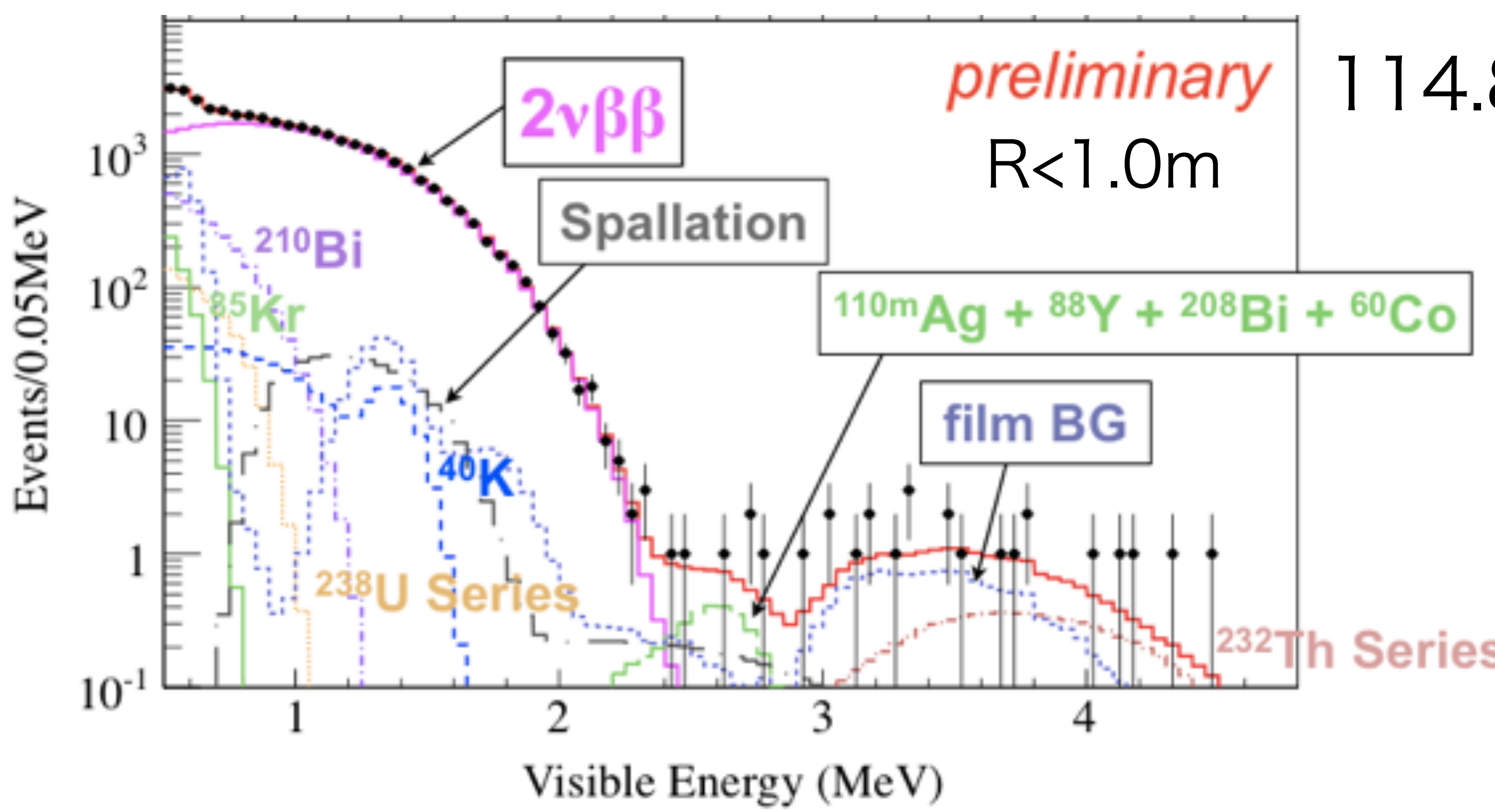


>1.9x10^{25}y

Phase-2 380kg

after purification

^{110m}Ag reduction <1/10



114.8 days

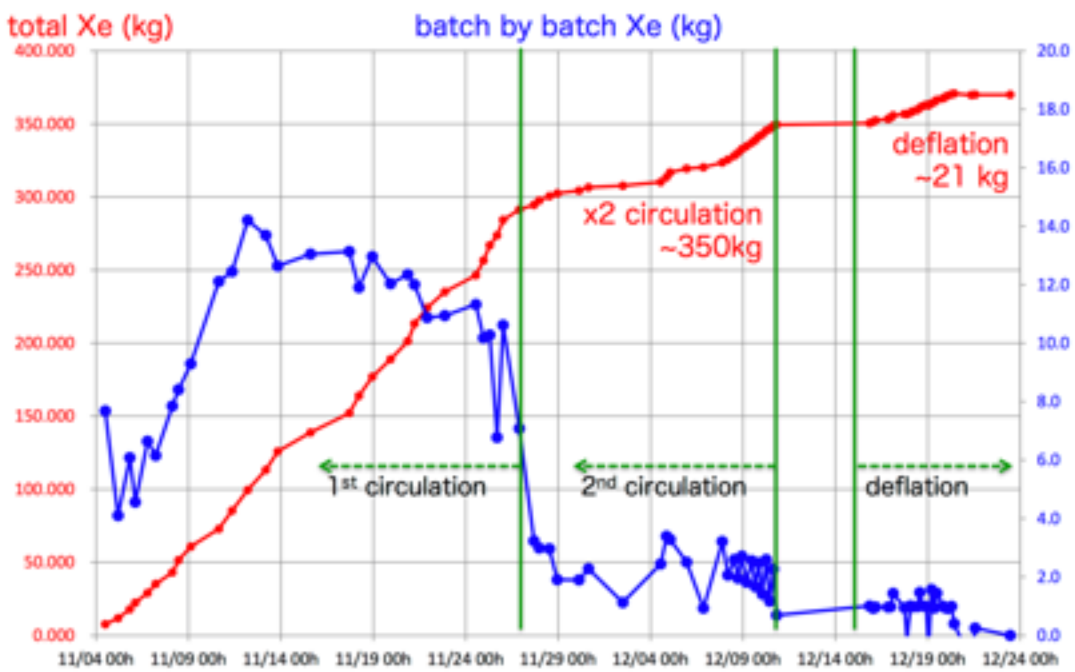
>1.3x10^{25}y

combined

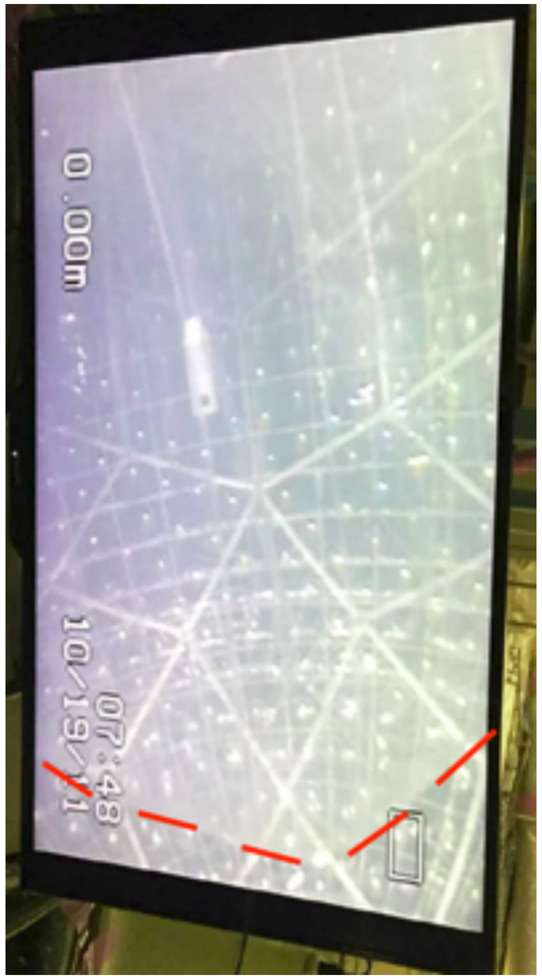
>2.6x10^{25}y

Now, the mini-balloon is extracted. (Dec. 2015)

for tank investigation required by law



Xenon has been recovered during recirculation and deflation of the mini-balloon.



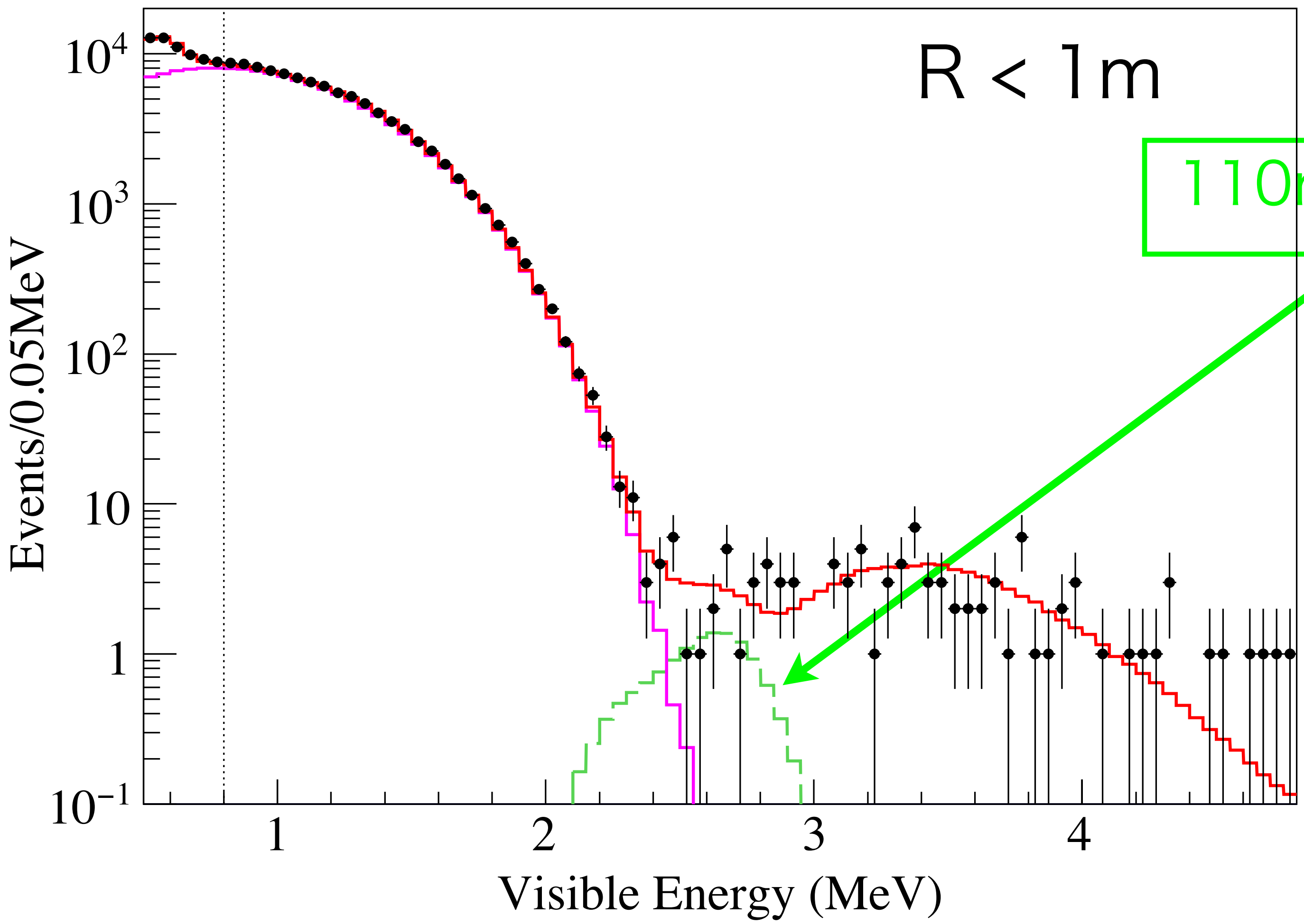
deflation →

We have acquired phase-2 data (after purification)

from December 11 2013 to October 27, 2015;

total livetime of 534.5 days (cf. $T_{1/2}(^{110m}Ag)$=250 days)

and exposure of 504 kg-yr.



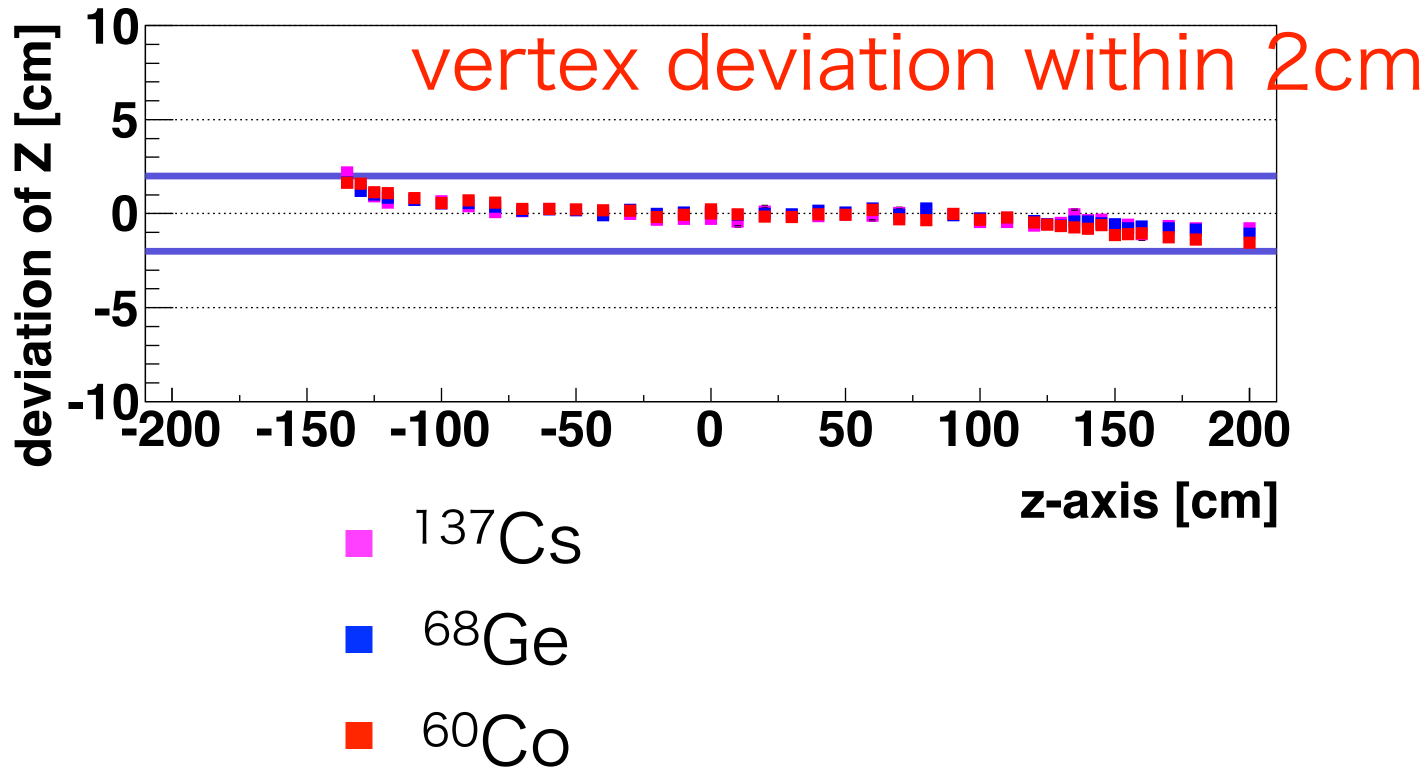
^{110m}Ag still exists?

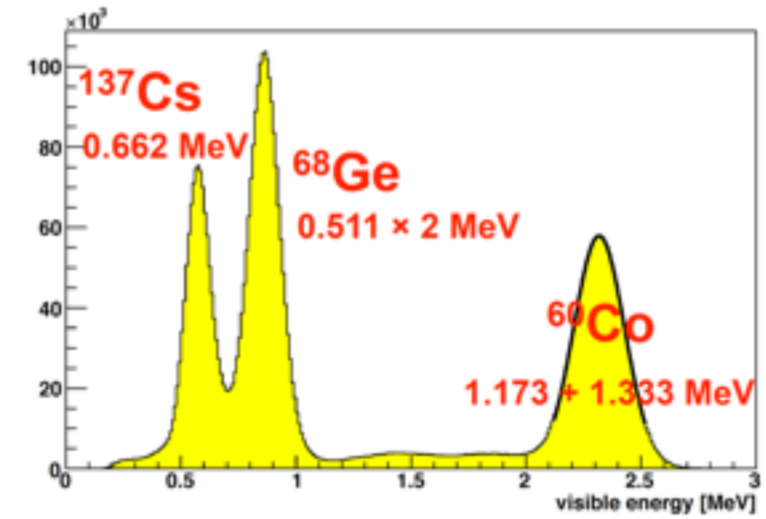
We might have scrubbed and dropped “dust” during extraction of the LS supply tube.

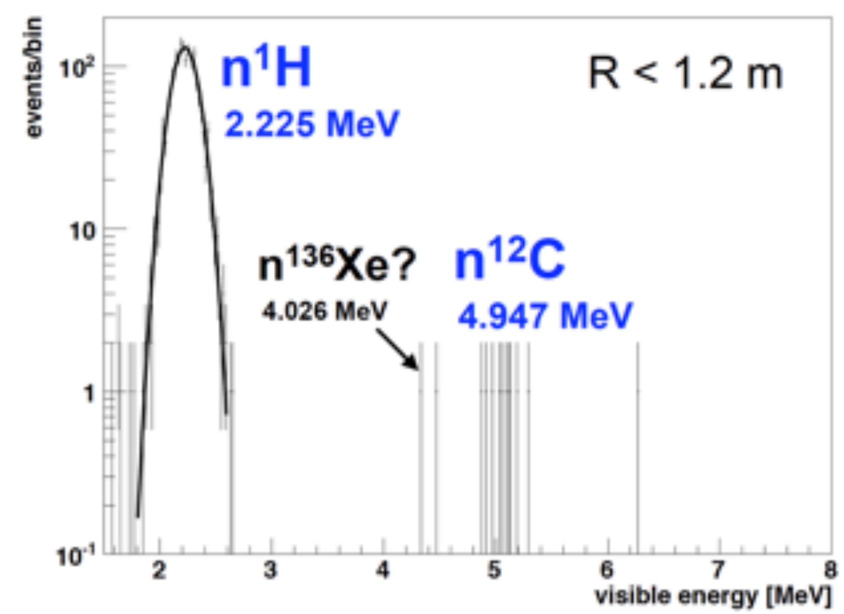
In order to improve the sensitivity, we have performed all volume and time-binned analysis.

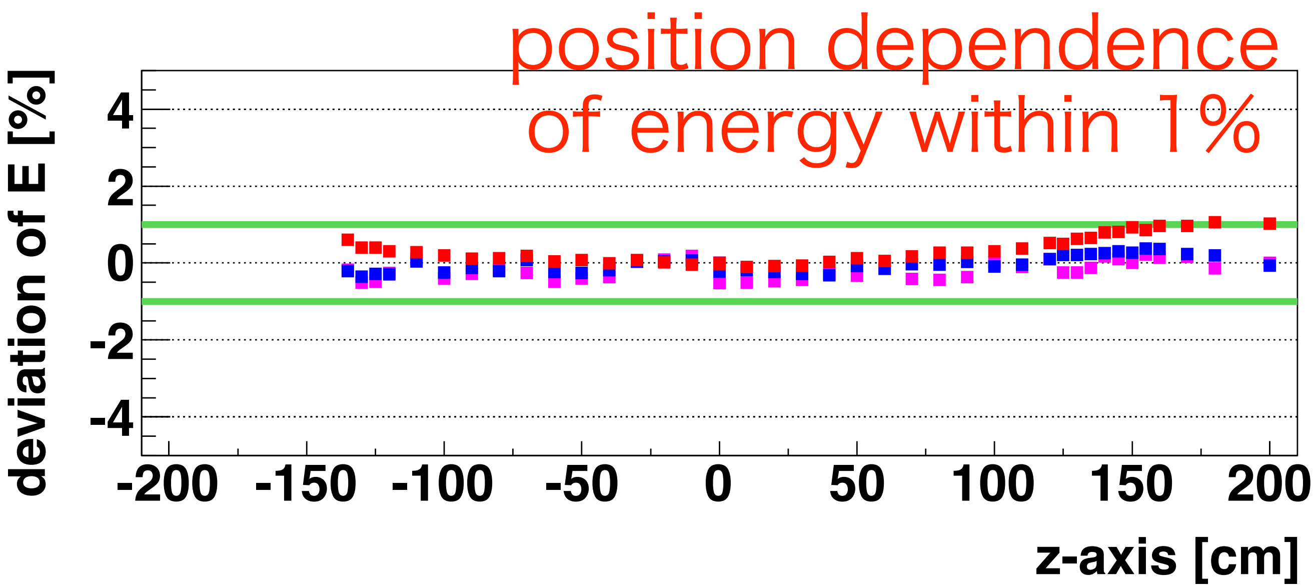
Source calibration

(Oct. 2015)





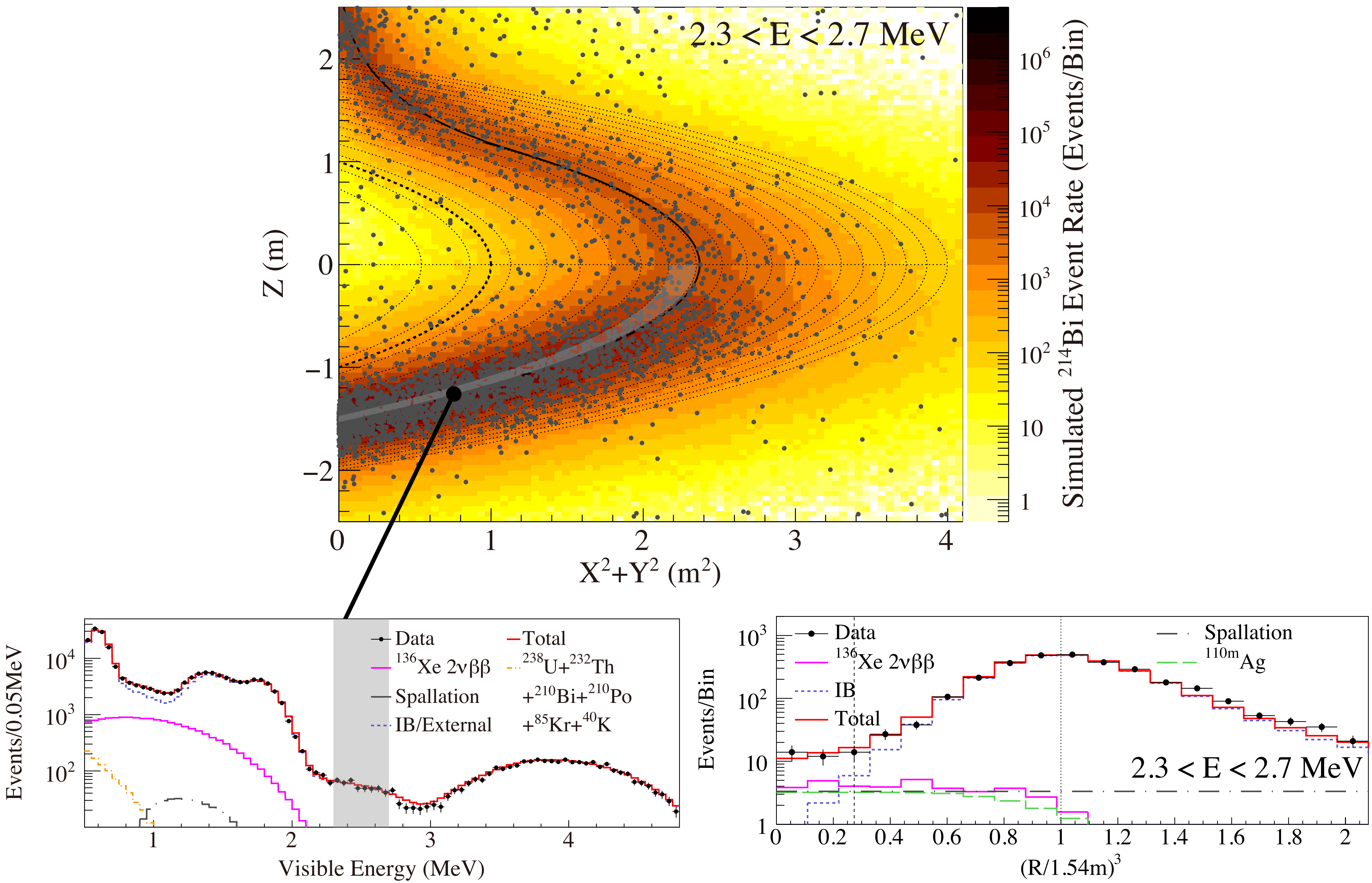




also in-situ calibration with n-capture on ^{1}H/^{12}C and ^{214}Bi

Energy resolution in phase-2: ~7.3%/$\sqrt{E}$

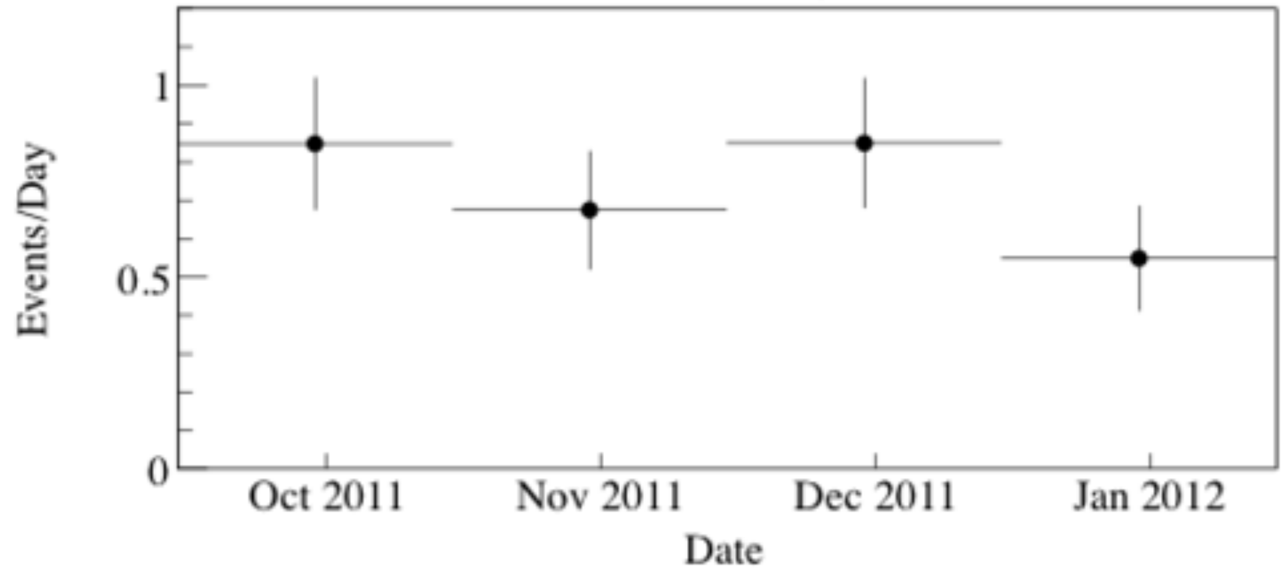
40 equal-volume bins



Energy and radial distributions are well-reproduced by known BGs.

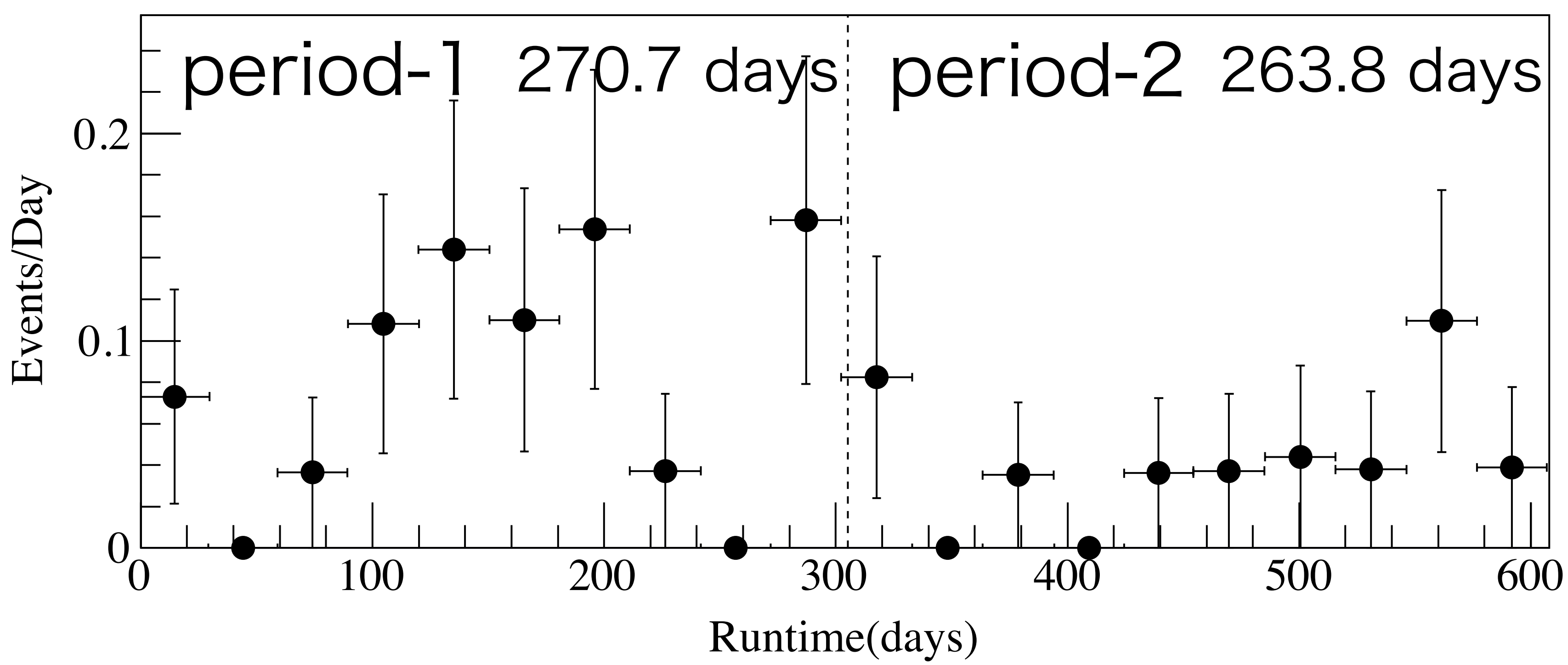
Phase 1 (first 112.3 days)

2.2 < E < 3.0 MeV, R < 1 m



Phase 2 534.5 days

2.3 < E < 2.7 MeV, R < 1 m

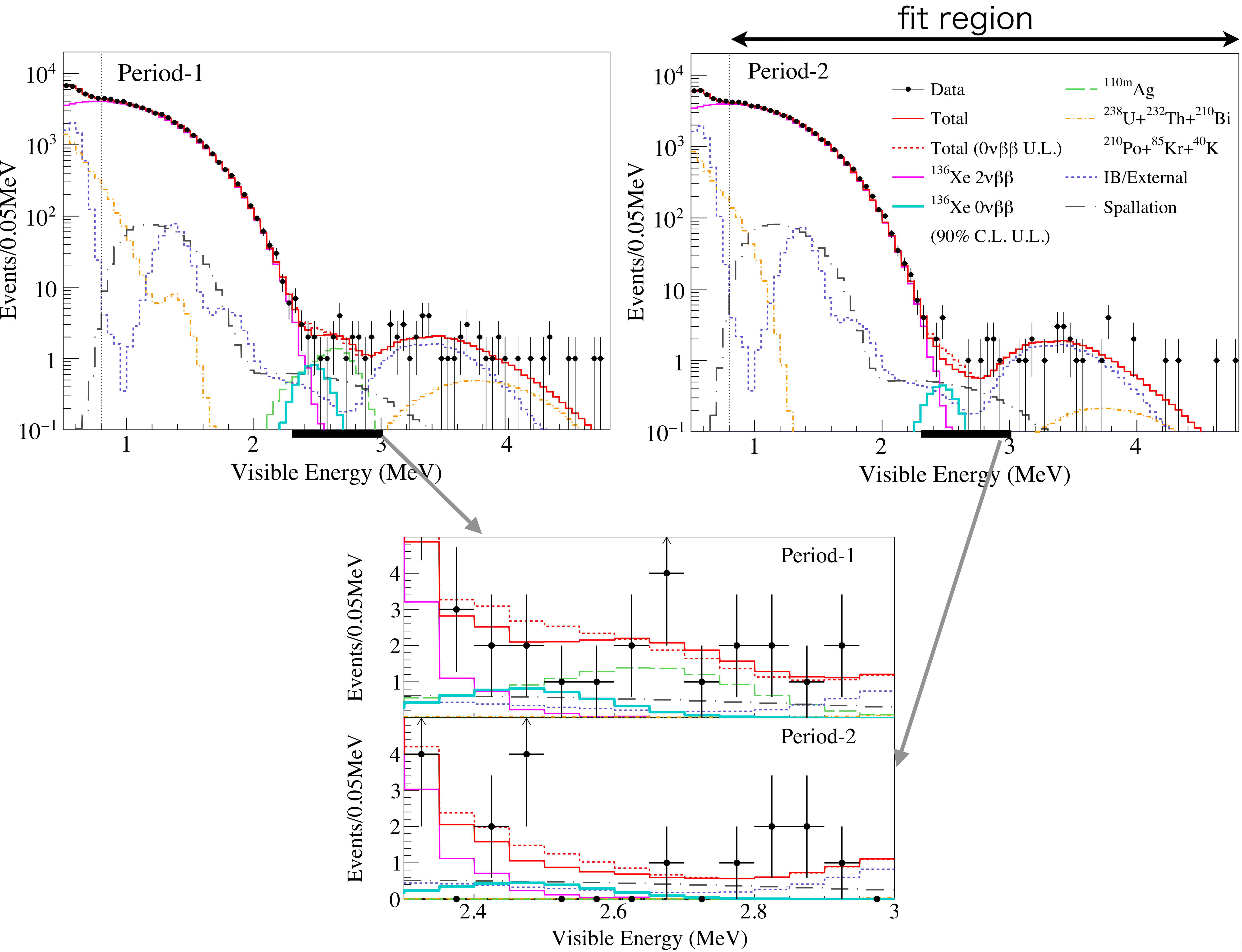


22 events 11 events

known BG other than ^{110m}Ag ~11 events

A hypothesis:
“Dust” sank !?

Yet only ~2σ discrepancy from the simple decay


fit region
Period-1
Period-2
Data
Total
Total (0νββ U.L.)
136Xe 2νββ
136Xe 0νββ
(90% C.L. U.L.)
110mAg
238U+232Th+210Bi
210Po+85Kr+40K
IB/External
Spallation
Events/0.05MeV
Visible Energy (MeV)

Event summary $2.3 < E < 2.7$ MeV, $R < 1$ m

	Period-1 (270.7 days)		Period-2 (263.8 days)	
Observed events	22		11	
Background	Estimated	Best-fit	Estimated	Best-fit
^{136}Xe $2\nu\beta\beta$	-	5.48	-	5.29
Residual radioactivity in Xe-LS				
^{214}Bi (^{238}U series)	0.23 ± 0.04	0.25	0.028 ± 0.005	0.03
^{208}Tl (^{232}Th series)	-	0.001	-	0.001
^{110m}Ag	-	8.0	-	0.002
External (Radioactivity in IB)				
^{214}Bi (^{238}U series)	-	2.55	-	2.45
^{208}Tl (^{232}Th series)	-	0.02	-	0.03
^{110m}Ag	-	0.002	-	0.001
Spallation products				
^{10}C	2.7 ± 0.7	3.2	2.6 ± 0.7	2.7
^{6}He	0.07 ± 0.18	0.08	0.07 ± 0.18	0.08
^{12}B	0.15 ± 0.04	0.16	0.14 ± 0.04	0.15
^{137}Xe	0.9 ± 0.5	1.1	0.9 ± 0.5	0.8

Results on $0\nu 2\beta$

	period-1	period-2
livetime	270.7 days	263.8 days
^{136}Xe $0\nu 2\beta$ decay rate	$<$ 5.6 /kton/day	$<$ 3.2 /kton/day

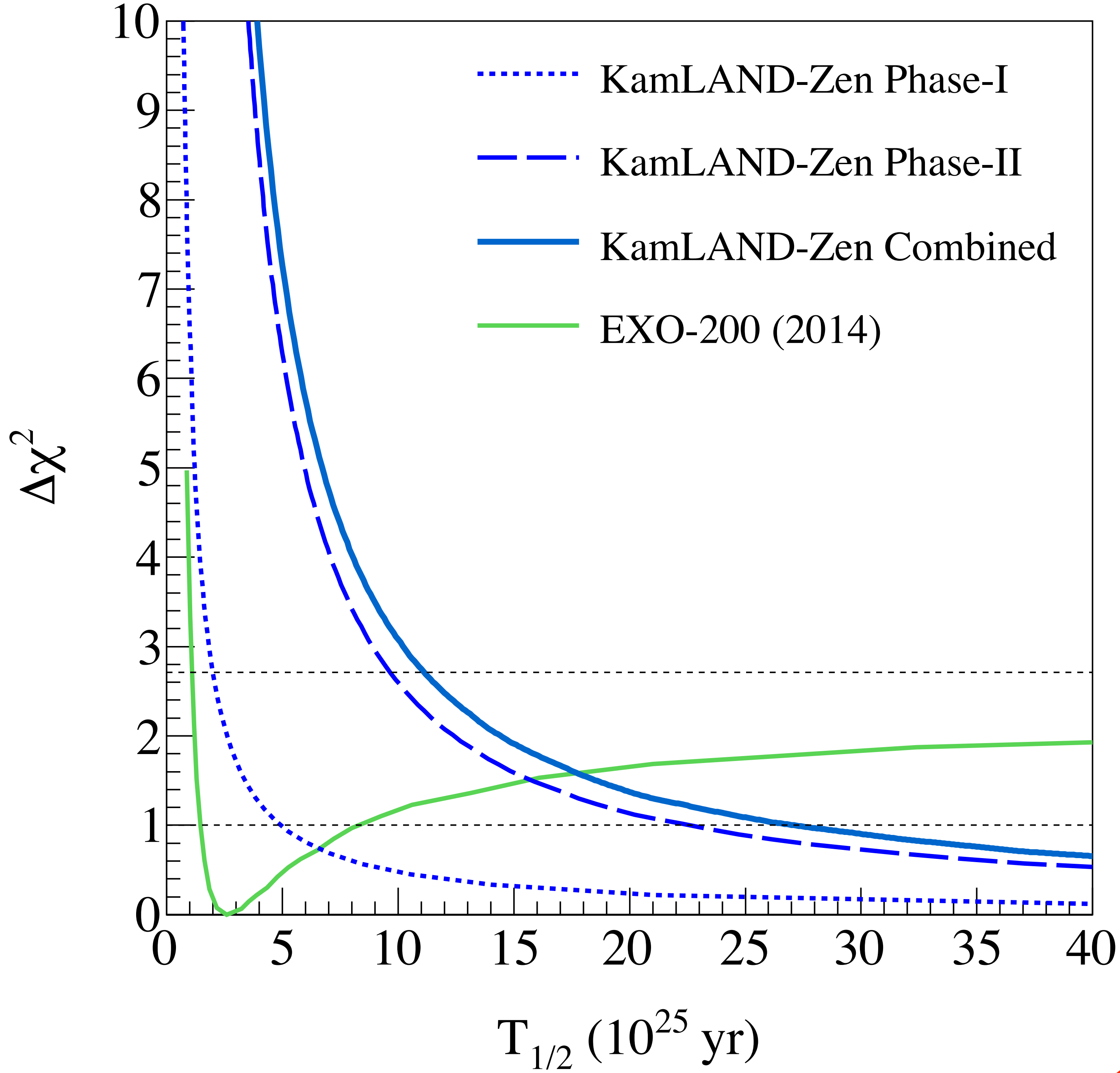
combined $<$ 2.4 /kton/day (90%C.L.)

^{136}Xe $0\nu 2\beta$ half-life $>$ 9.6×10^{25} yr (90%C.L.)

sensitivity $>$ 4.9×10^{25} yr

(11% probability)

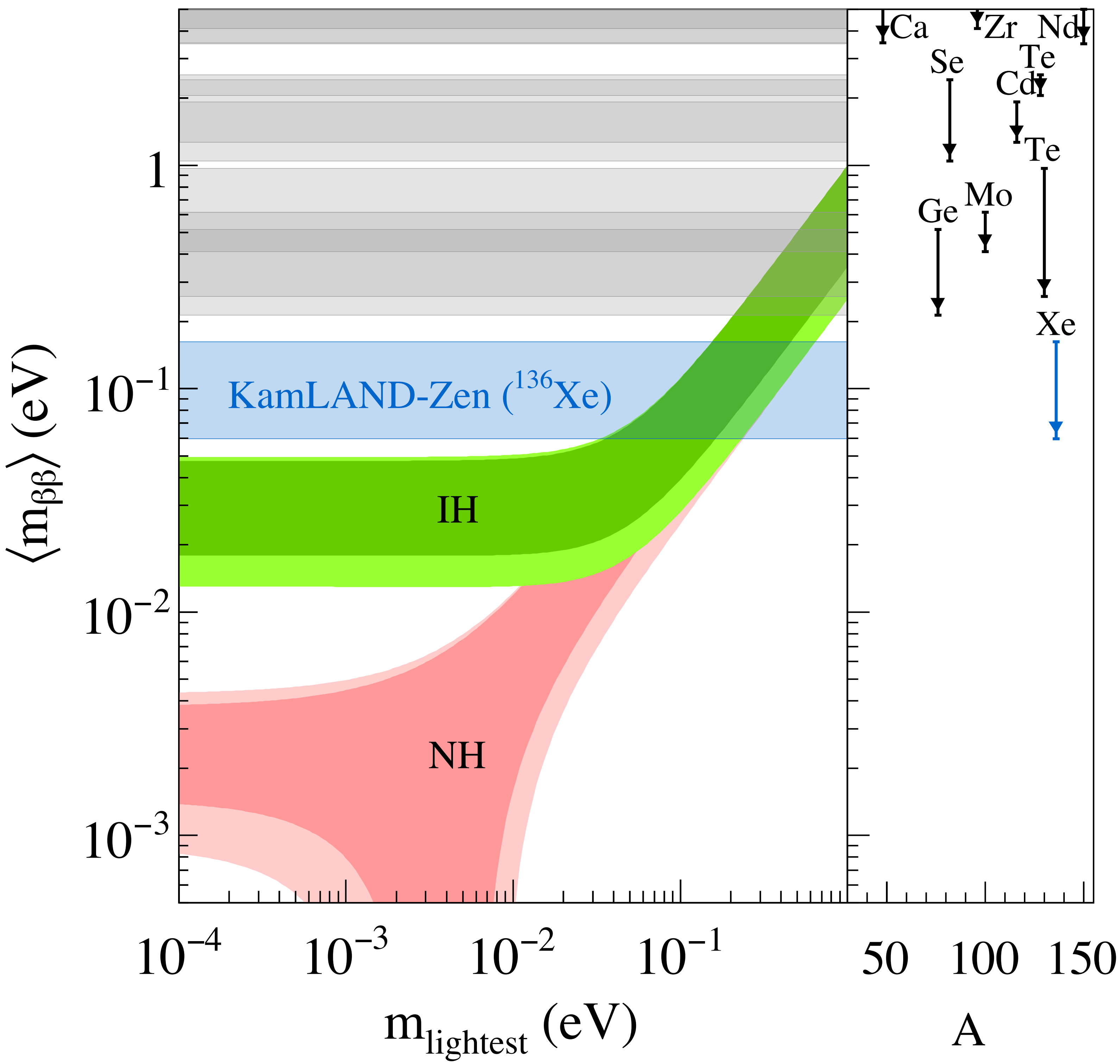
Phase-1 & 2 combined limit



!!!

$$T^{0\nu}_{1/2} > 1.1 \times 10^{26}\ \mathrm{yr}$$

$$\langle m_{\beta\beta} \rangle < (60 - 161)\ \mathrm{meV}$$



Big leap toward IH !!

Our challenge continues!

Three dominant BGs; 2ν, "^{214}Bi on the film" and ^{10}C.

next target

further optimization of triple-fold coincidence

We have purchased 800 kg of enriched xenon in total.

We have fabricated a larger mini-balloon with better measures against dusts.

We will resume the search with 750 kg of xenon in this fall. To be called as "KamLAND-Zen 800".

(Expected sensitivity is below 50 meV hoping to cover Yanagida's prediction.)

Mini-balloon fabrication

cleaning, cleaning and cleaning as usual

Example of improvements

before

after

keep staying away
goggle
welding machine
cover sheet .
glove on glove
laundry twice a day .
clean underwear .
changing room in a clean room .
dust visualization
more neutralizer
. . .

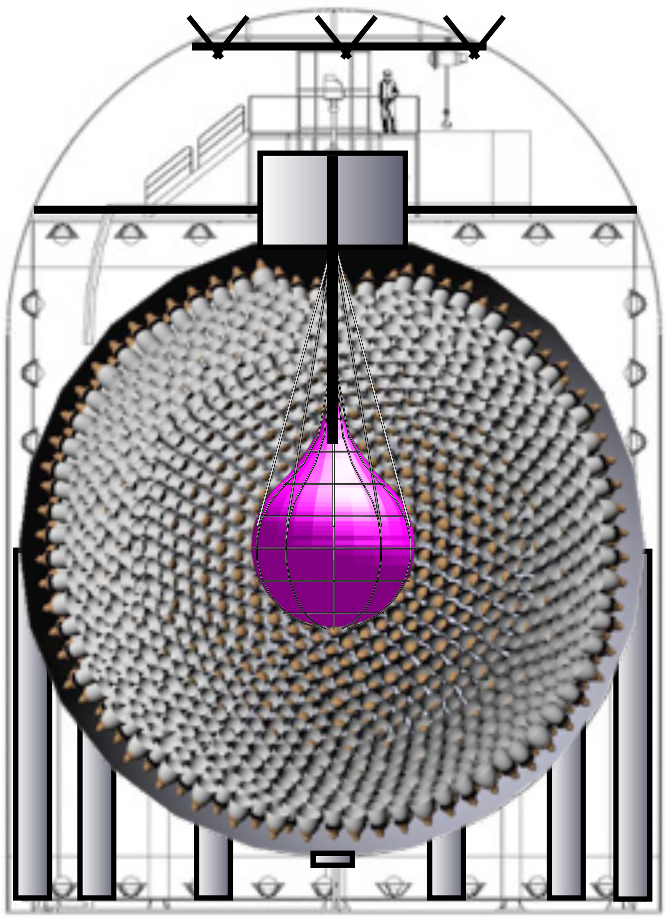
Well done!

Leak check and repair in high humidity
will start soon.

And more future plans!

Higher energy resolution for reducing 2ν BG

⇨ KamLAND2-Zen



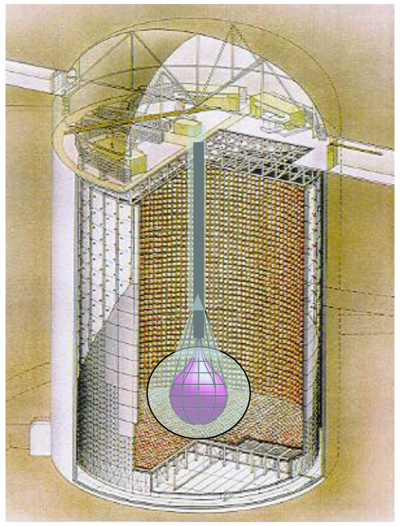
1000+ kg xenon

Winston cone	light collection ×1.8
high q.e. PMT 17"ϕ→20"ϕ ε=22→30+%	light collection ×1.9
New LAB LS (better transparency)	light collection ×1.4

expected σ(2.6MeV)= 4% → ~2%

target sensitivity 20 meV

And more?



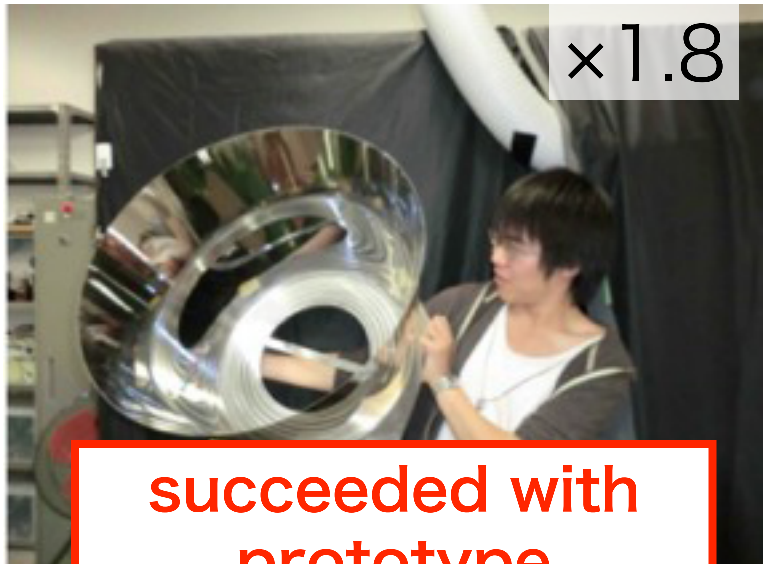
Super-KamLAND-Zen

in connection with Hyper-Kamiokande

target sensitivity 8 meV

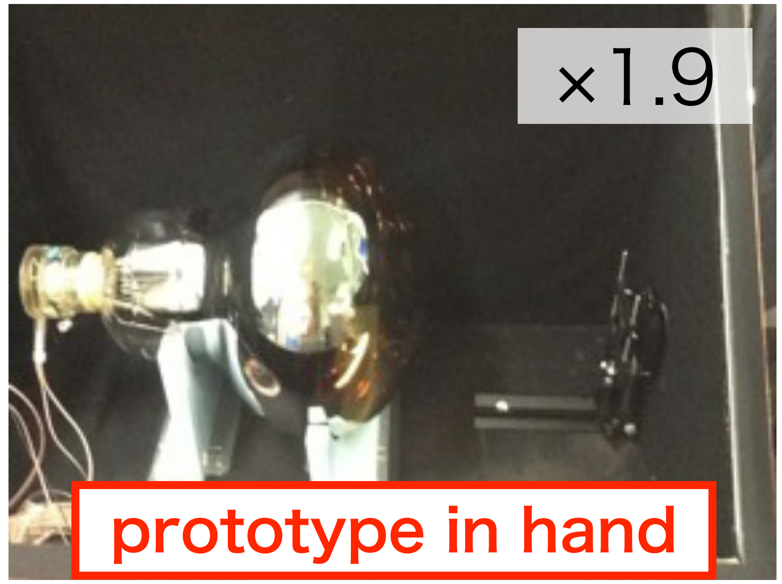
R&D for KamLAND2-Zen and future

○ winston cone



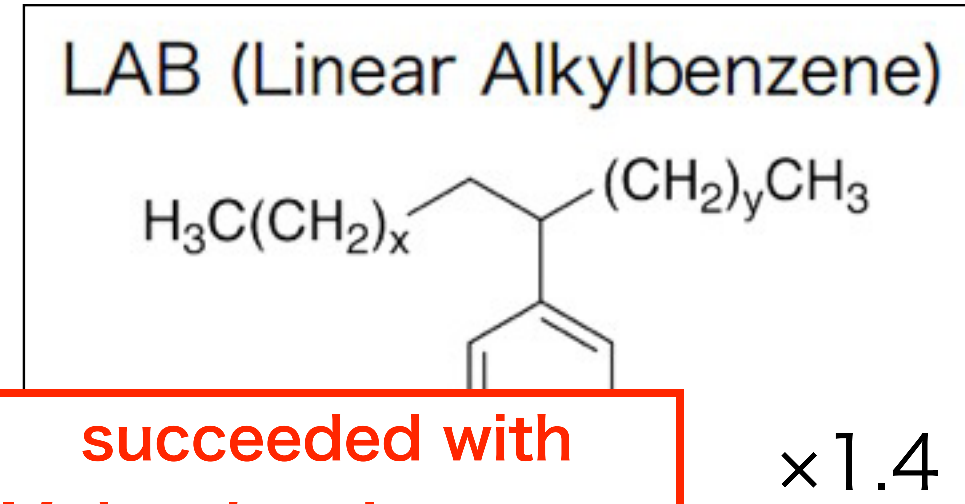
succeeded with prototype

○ HQE-PMT



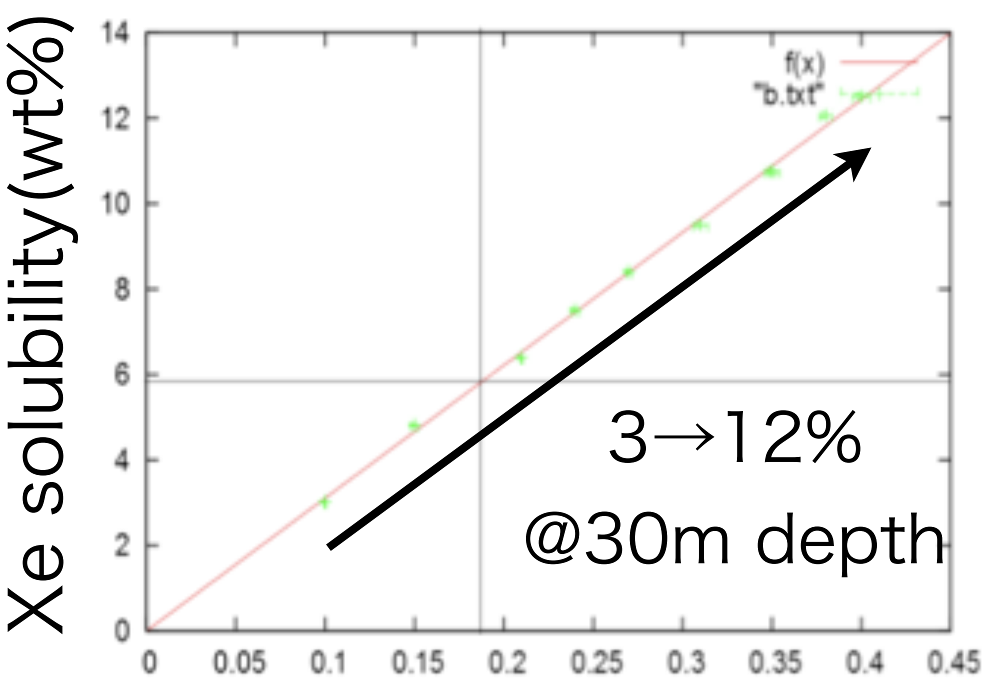
prototype in hand

○ New LAB-LS



succeeded with Molecular sieve (13X)

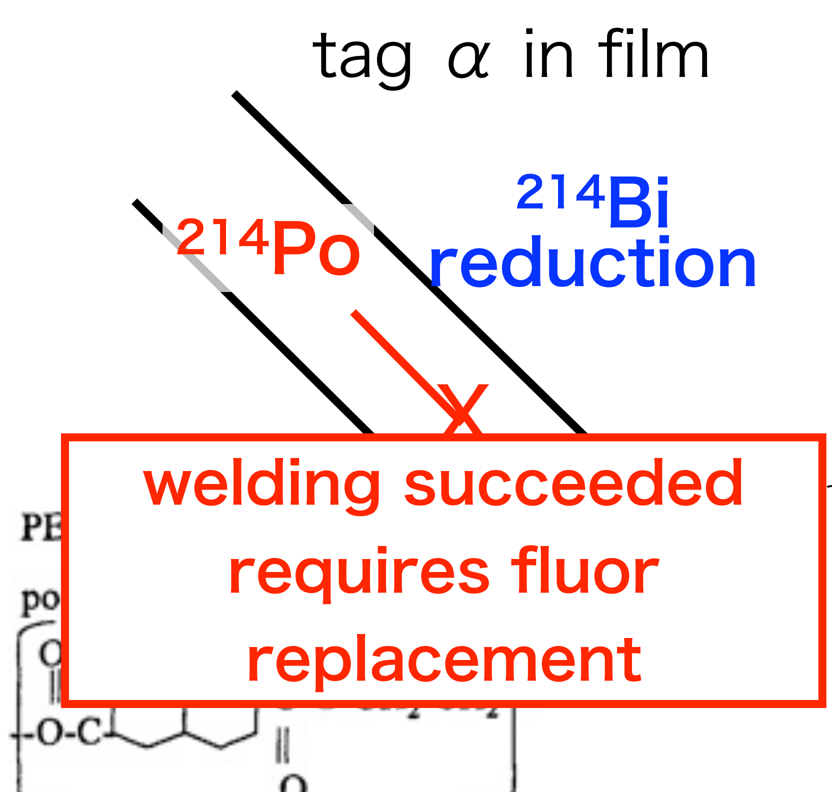
○ denser xenon



Xe partial pressure(MPa)

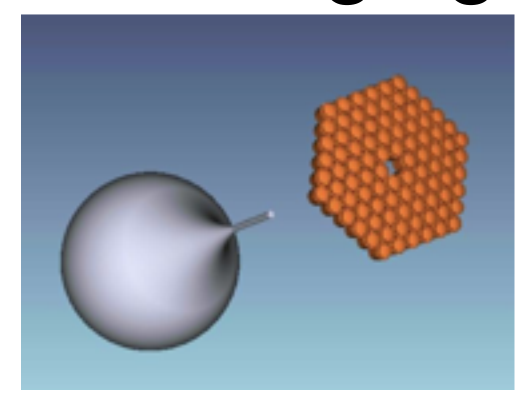
principle confirmed

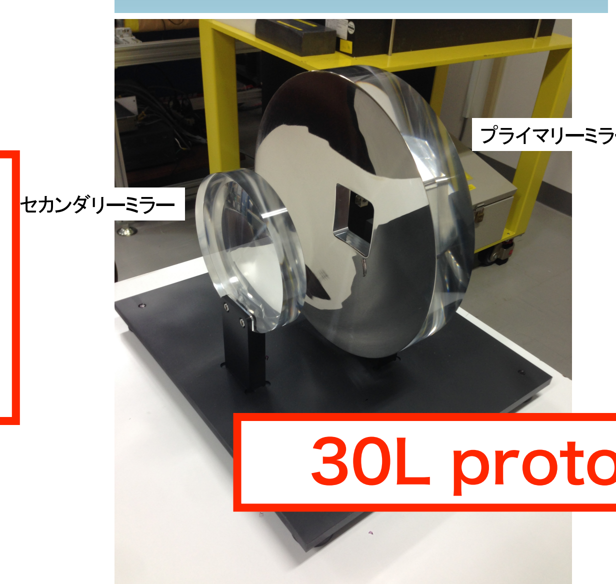
○ scintillator film



welding succeeded requires fluor replacement

○ imaging





β/γ id.

30L prototype

Summary

- New results from Phase-2 (534.5 days, 380 kg) presented

  ^{110m}Ag has been successfully reduced.

  improved analysis: 40 equal bins for volume, 2 time bins

- Phase-1 & 2 combined result for $0\nu 2\beta$ of ^{136}Xe

$$T_{1/2}^{0\nu} > 1.1 \times 10^{26}\,\mathrm{yr}$$

$$\langle m_{\beta\beta} \rangle < (60 - 161)\,\mathrm{meV}$$

- KamLAND-Zen 800 planned to start in this fall.

  750kg of enriched xenon will be installed.

  Target sensitivity is below 50 meV.

- R&D for KamLAND2-Zen is going well.

  Target sensitivity is below 20 meV.

Thank you!