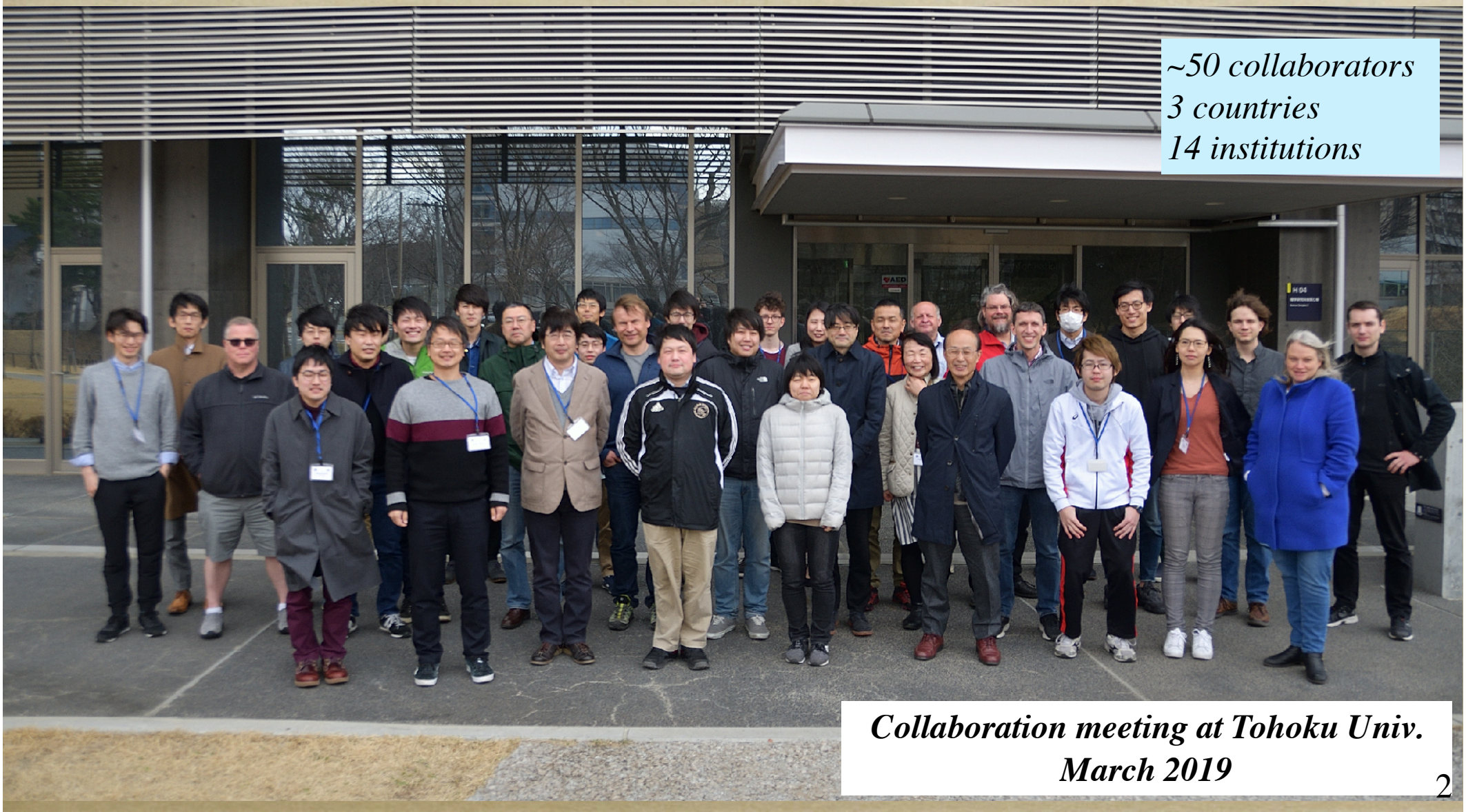
KamLAND-Zen

New Trends in High-Energy Physics

May 14 2019

Kota Ueshima
Tohoku University RCNS
for the KamLAND-Zen collaboration

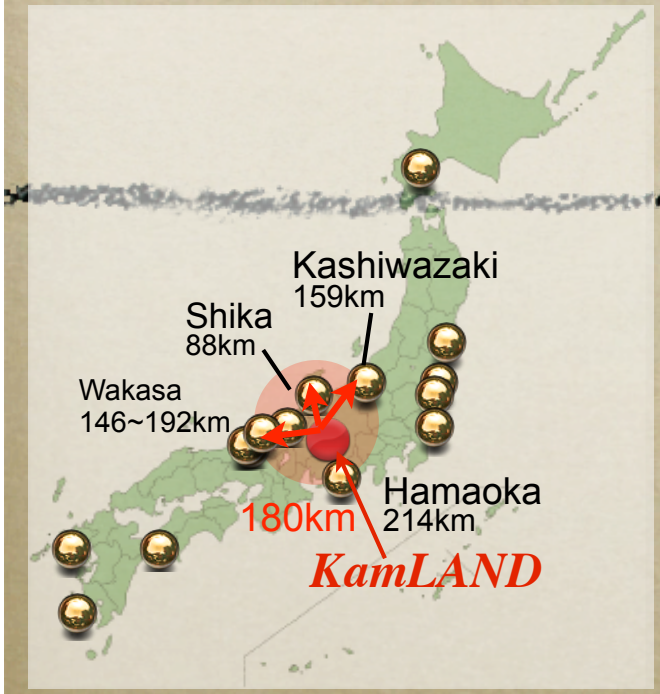
KamLAND-Zen Collaboration



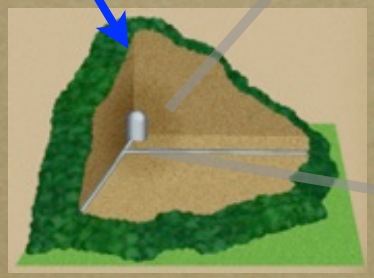
~50 collaborators
3 countries
14 institutions

Collaboration meeting at Tohoku Univ.
March 2019

KamLAND



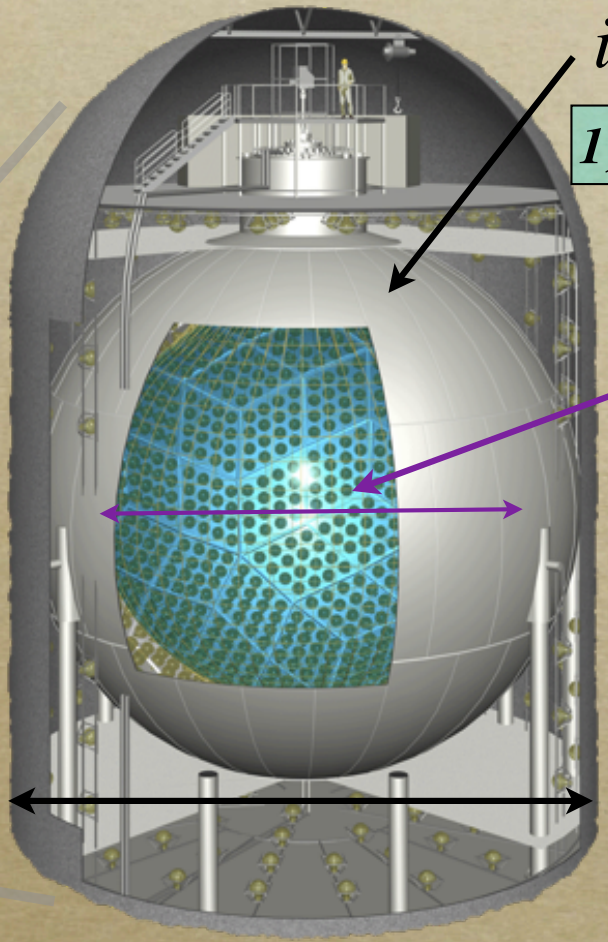
cosmic ray



1000m
depth

KamLAND

***Kam**ioka **L**iquid Scintillator **A**nti-**N**eutrino **D**etector*



inner detector

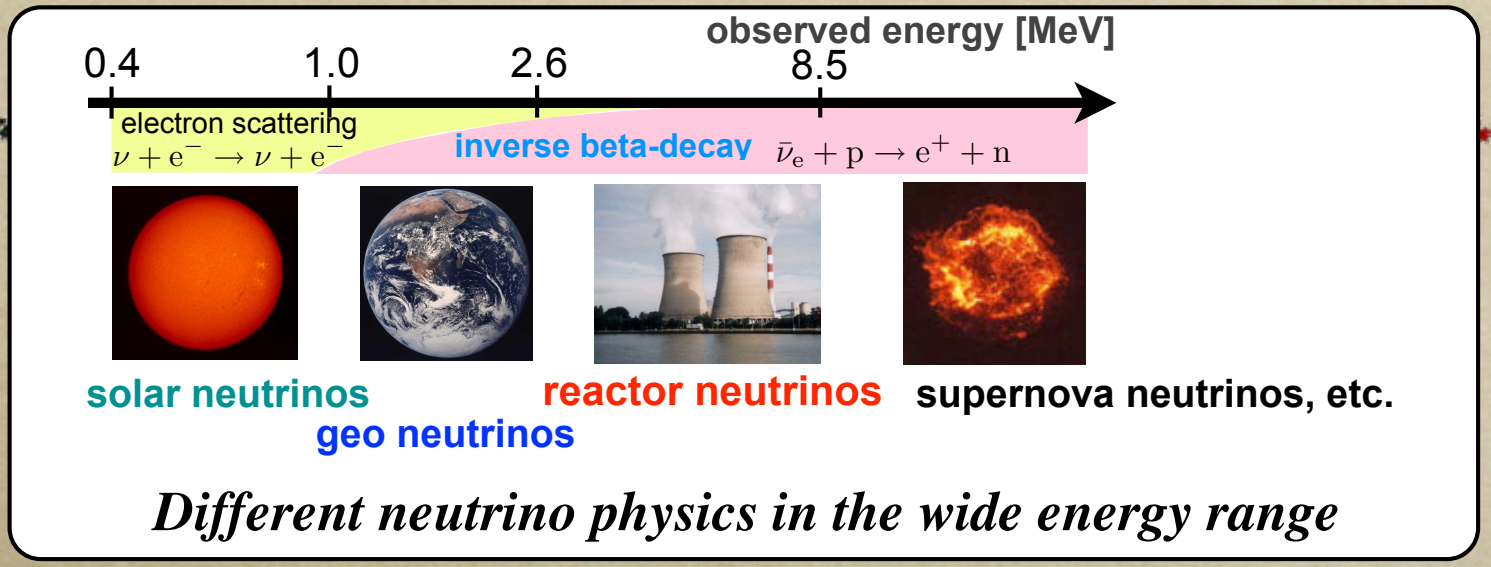
1,325 17inch + 554 20inch PMTs

**** Photo coverage 34%***

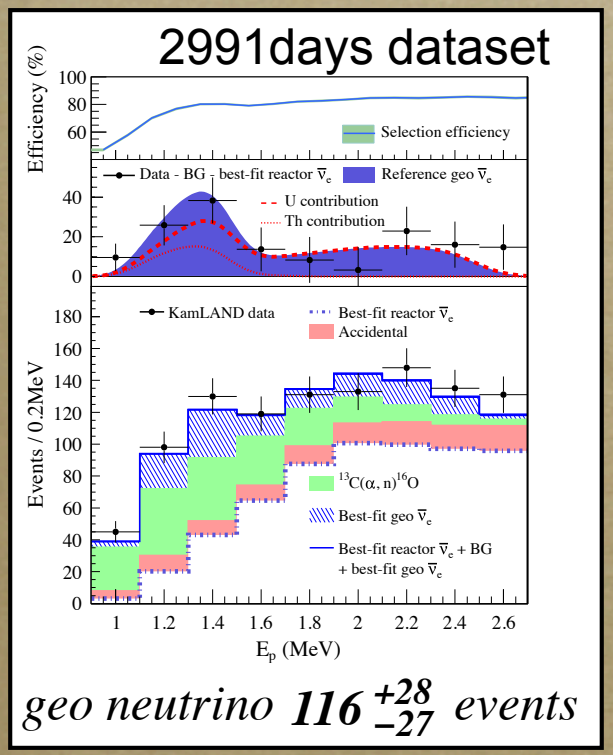
balloon
ϕ13m,135μm thick.
1 kton LS

Water Cherenkov outer detector
ϕ18m, 3.2 kton pure water
Refurbished in 2016
140 20inch PMTs
**** Muon veto***

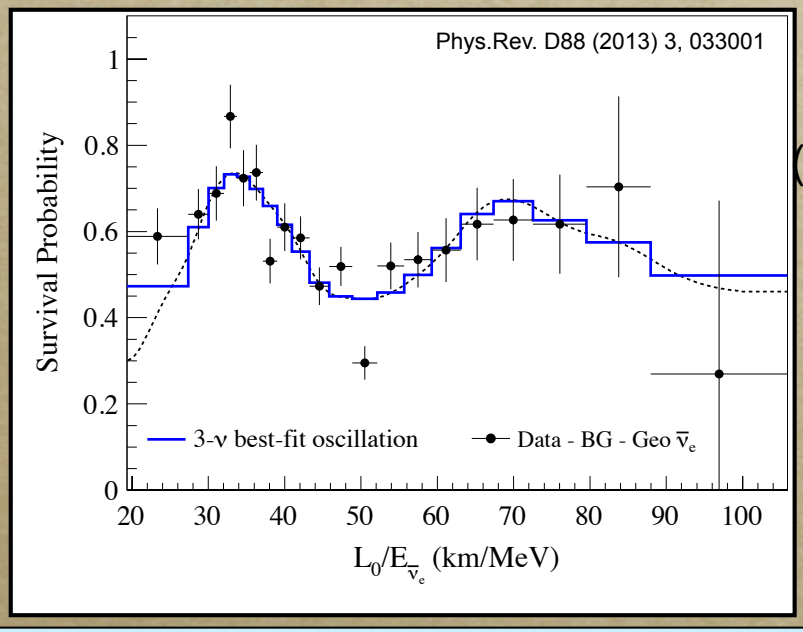
Physics



Different neutrino physics in the wide energy range



geo neutrino $\mathbf{116}^{+28}_{-27}$ *events*



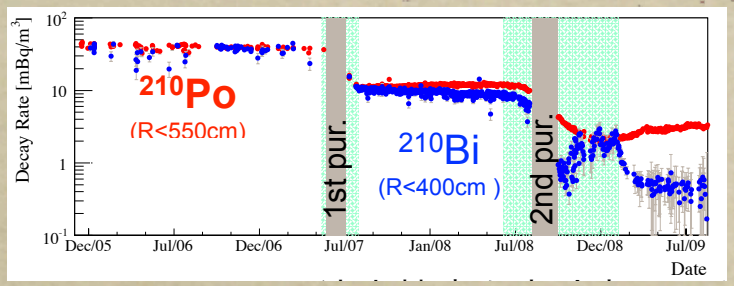
※L_0=180km fixed
(flux-weighted average)

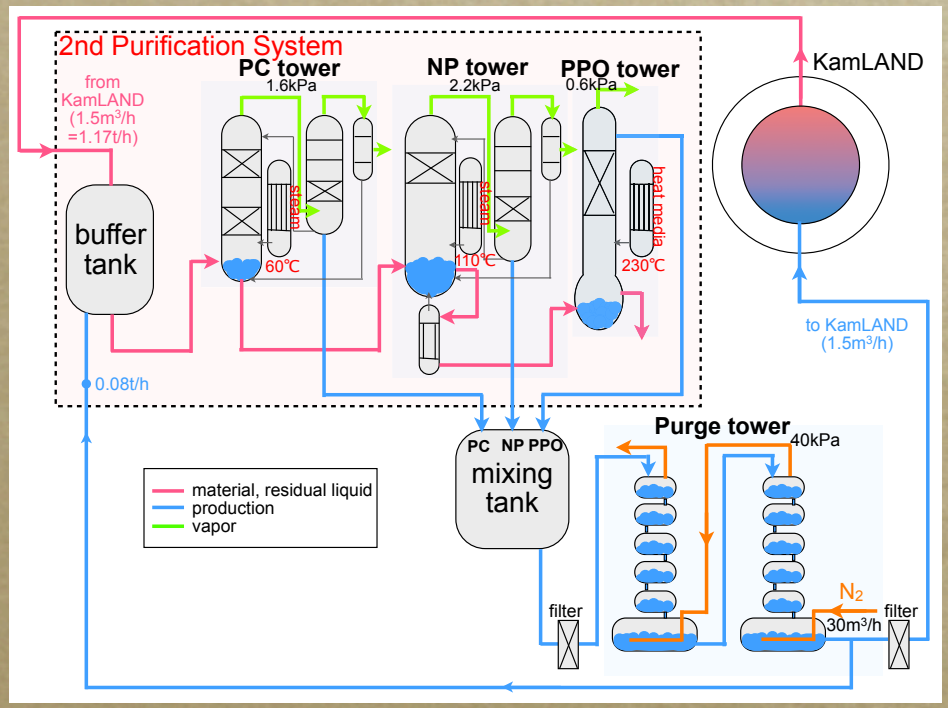
best-fit parameters
(KamLAND only)

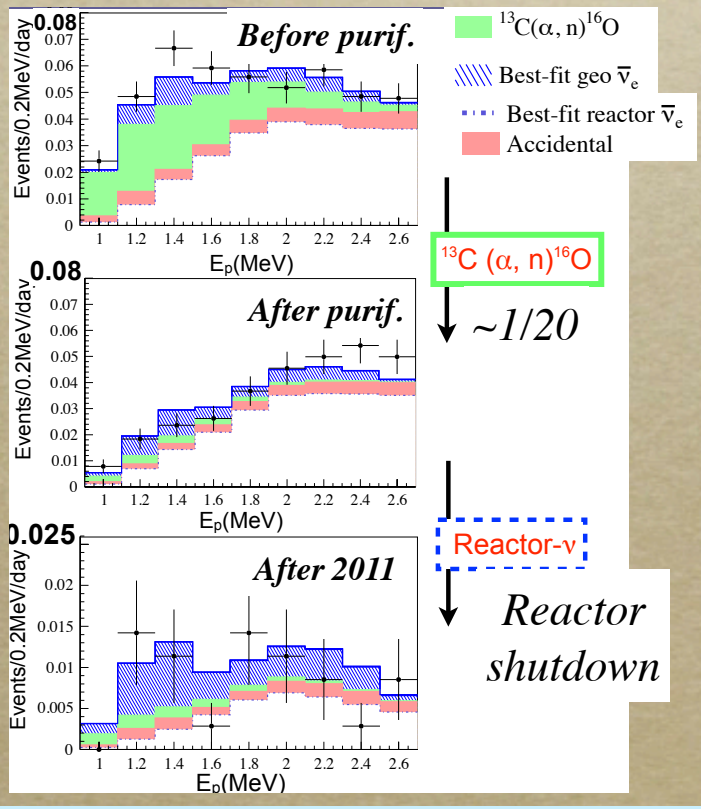
$$\Delta m^2_{21} = 7.54^{+0.19}_{-0.18} \times 10^{-5}\mathrm{eV}^2$$
$$\tan^2\theta_{12} = 0.481^{+0.092}_{-0.080}$$
$$\sin^2\theta_{13} = 0.010^{+0.033}_{-0.034}$$

2 cycles of oscillation were measured precisely

1k ton LS purification system

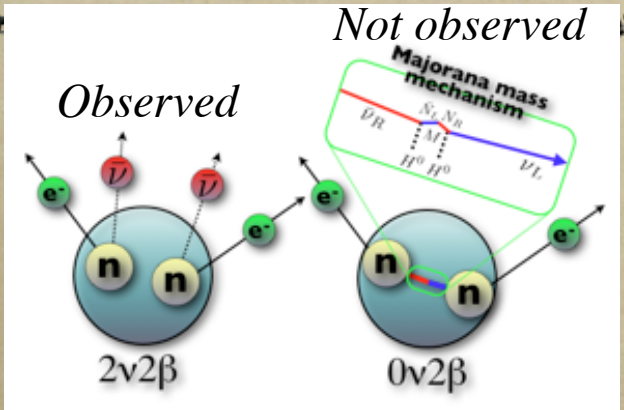






Achieved ultra low impurity (^{238}U:3.5×10^{-18}g/g, ^{232}Th:5.2×10^{-17}g/g)

Neutrinoless double beta decay



If neutrinos are Majorana particle, 0ν2β may occur.

- *effective neutrino mass
- *mass hierarchy
- * lepton number violation
- * evidence of Majorana particle

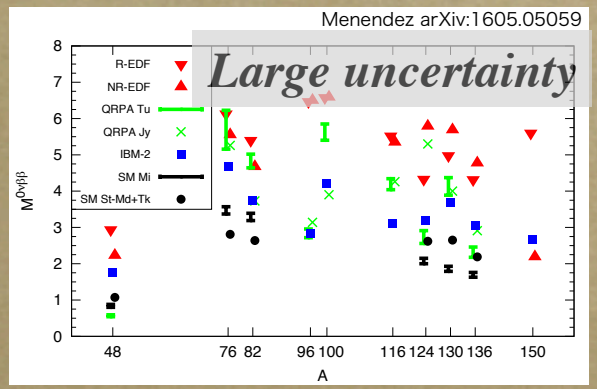
Big impact on particle physics!!

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}|M^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

G: phase space factor

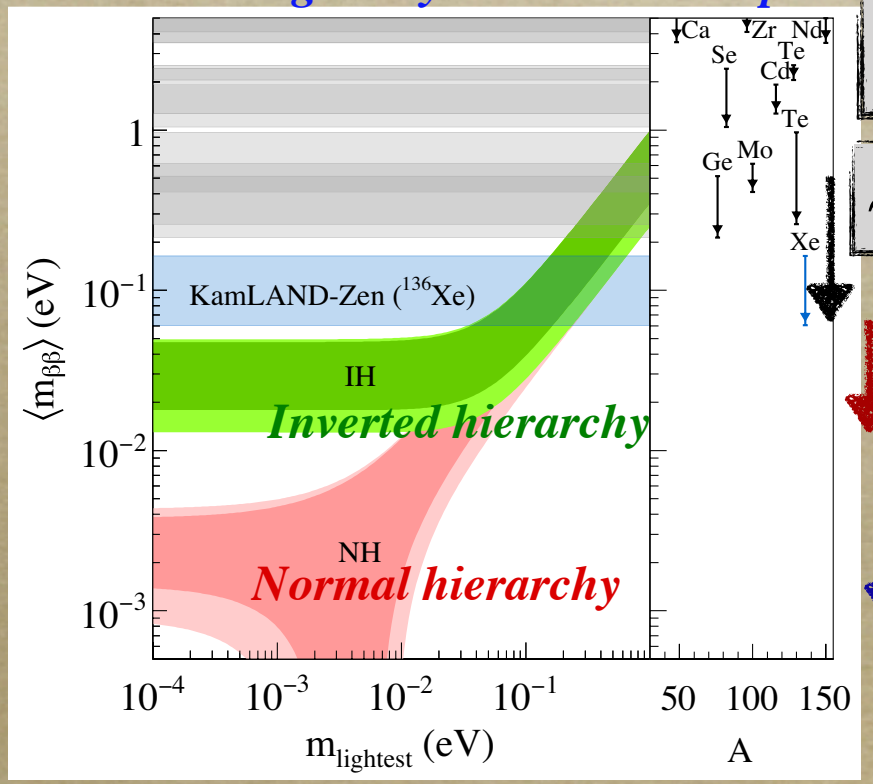
$$\langle m_{\beta\beta}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

Nuclear matrix element



Large uncertainty

Allowed region by ν oscillation exp.



Amount of target nucleus

~100kg

~1ton

~100ton

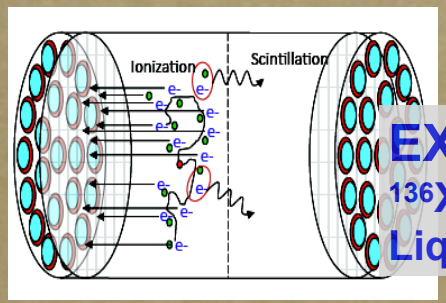
0ν2β search experiment

Isotopes for double beta decay

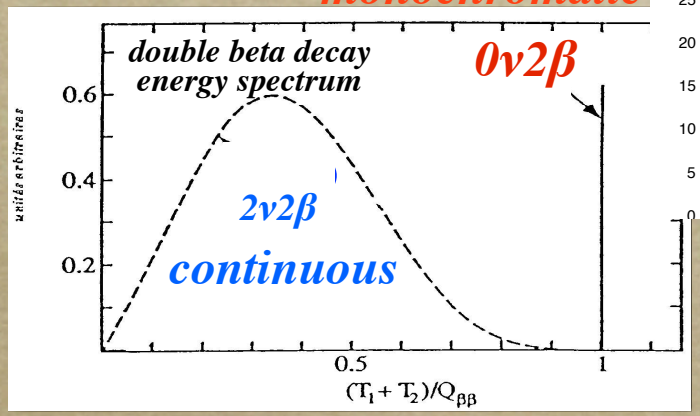
Isotopes	Q-value (keV)	N.A. (%)	$T^{2\nu}_{1/2}$ (year) measurement PDG2015, no error included	$T^{0\nu}_{1/2}(50\,\mathrm{meV})$ calculation PRC 79, 055501 (2009), (R)QRPA (CCM SRC)	Pros & Cons
^{48}Ca	4273.6 ± 4	0.19	4.4 × 10^{19}	-	Q-value **highest**, N.A. **small**, enrichment **difficult**
^{76}Ge	2039.006 ± 0.050	7.6	1.84 × 10^{21}	(2.99-7.95)×10^{26}	2ν **long**, enrichment **~90%**
^{82}Se	2995.50 ± 1.87	8.7	9.6 × 10^{19}	(0.85-2.38)×10^{26}	enrichment **>90%**
^{96}Zr	3347.7 ± 2.2	2.8	2.35 × 10^{19}	(3.16-6.94)×10^{26}	
^{100}Mo	3034.40 ± 0.17	9.4	7.11 × 10^{18}	(0.59-2.15)×10^{26}	2ν**short**, enrichment **>90%**
^{110}Pd	2017.85 ± 0.64	7.5	-	-	
^{116}Cd	2813.50 ± 0.13	7.5	2.8 × 10^{19}	(0.98-3.17)×10^{26}	enrichment **80~90%**
^{124}Sn	2287.80 ± 1.52	5.8	-	-	
^{130}Te	2527.01 ± 0.32	34.1	7.0 × 10^{20}	(7.42-2.21)×10^{26}	N.A. **high**
^{136}Xe	2457.83 ± 0.37	8.9	2.165 × 10^{21}	(1.68-7.17)×10^{26}	2ν **long**, enrichment **~90%**
^{150}Nd	3317.38 ± 0.20	5.7	9.11 × 10^{18}	-	2ν **short**, enrichment **difficult**

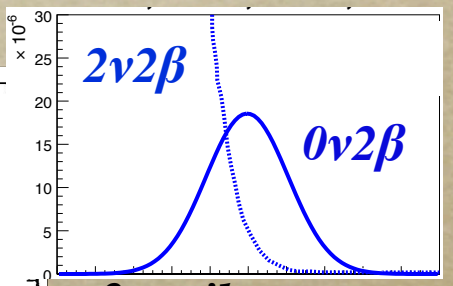
No perfect isotope

Various experimental technique



monochromatic





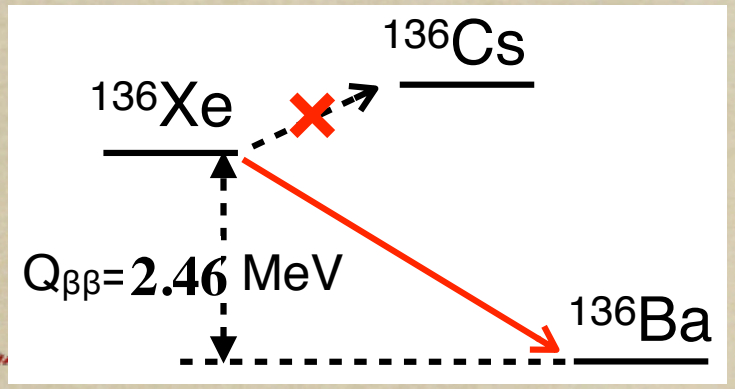
2ν tail events

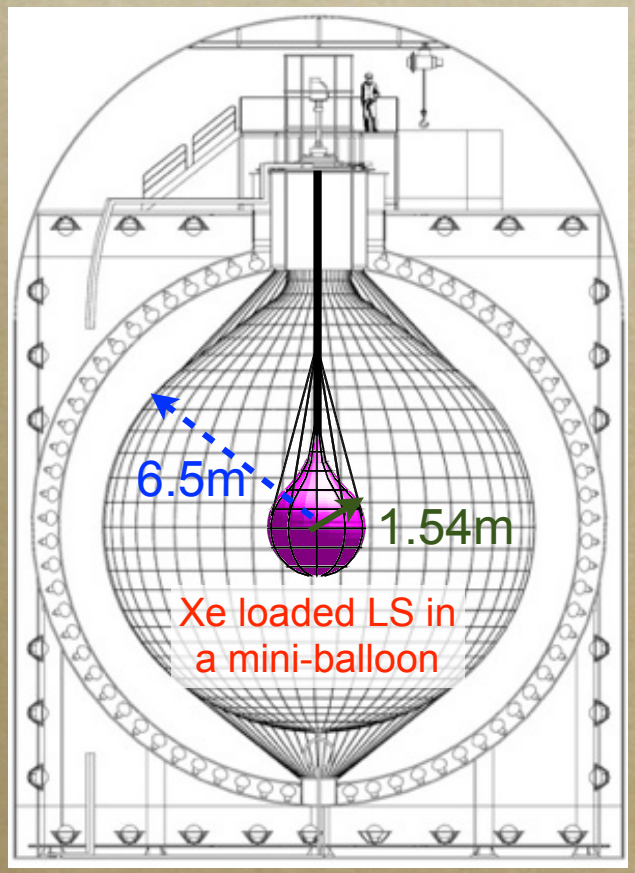
0ν2β is very rare event.

Required ultra low BG detector with high energy resolution

KamLAND-Zen

Zero **N**eutrino Double Beta Decay Search





Detector features

Mini-balloon was installed at center of KamLAND (ultra clean)

Xe loaded LS was installed in Sep. 2011.

↳ ***320kg 91% enriched ^{136}Xe***

DAQ was started in Oct. 2011.
(The project was started in 2009)

^{136}Xe merit

*enrichment is available ~**91%***

***High solubility**:Xe is dissolved in LS **3wt%** at 1 atm.*

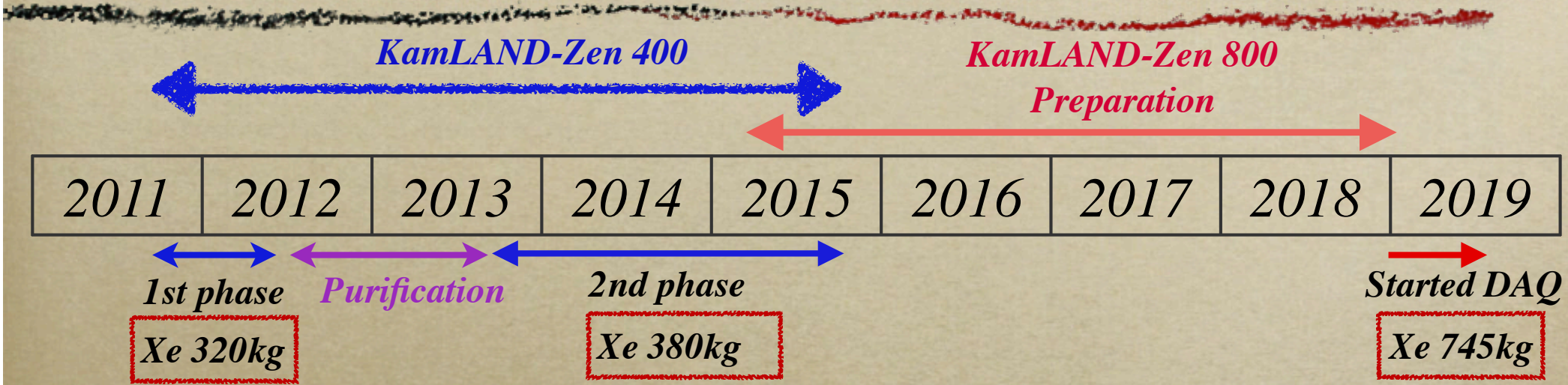
*collect Xe from Xe loaded LS by degassing **easily**.*

purification method is established (LS, Xe)

***High scalability**: replace with big balloon*
and dissolve ton scale ^{136}Xe.

If 0ν2β signal was observed, it can be verified using same detector with ^{136}Xe removed.

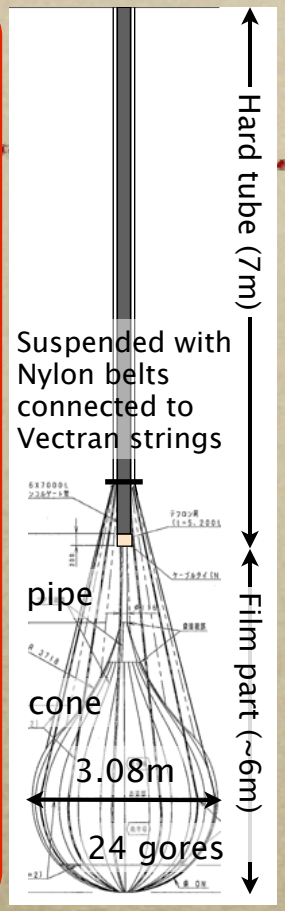
History



- *1st phase (Oct.2011- Jun.2012)* ***PRL 110, 062502(2013)***
- *Purification (Jun.2012-Nov.2013) Xe extraction, Xe purification, LS purification.*
- *2nd phase (Dec.2013- Oct.2015)*
  Latest 0ν2β result was released in 2016. ***PRL 117, 082503(2016)***
- *Preparation for KamLAND-Zen 800 phase was started in 2015*
  (Zen 400 mini-balloon extraction, new mini-balloon production, extracted xenon & new xenon purification)
- *KamLAND-Zen 800 phase was started. Jan.2019 -*

Mini-balloon production and installation

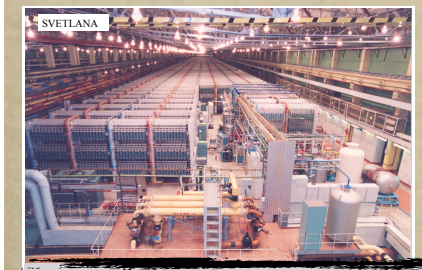
at Sendai in June 2011



Mini-balloon was made in Sendai.
Deflated Mini-balloon was delivered to Kamioka.
After the Mini-balloon was installed in KamLAND, the Mini-balloon was inflated using normal LS.
Finally the normal LS was replaced with the Xe loaded LS.

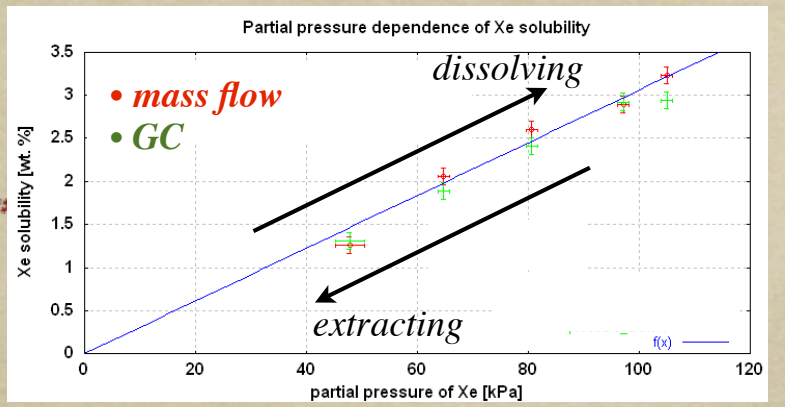
at Kamioka mine in Aug 2011

Xe handling system



^{136}Xe made in Russia

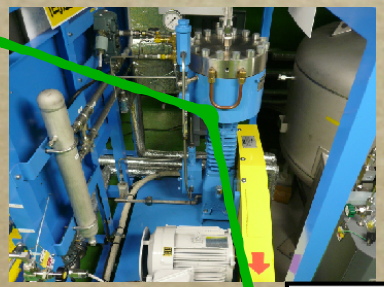
Kamioka mine



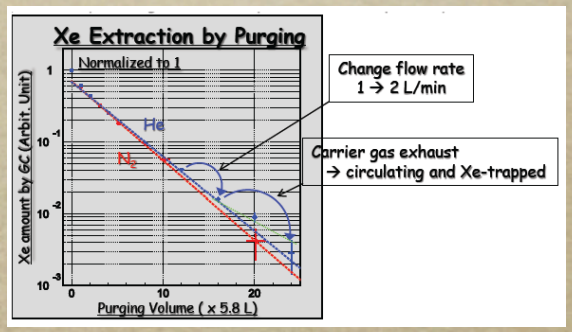
Xe solubility follows Henry's law.

Dissolving: increase partial pressure of Xe

Extracting: degassing + nitrogen purge passing through Xe cold trap



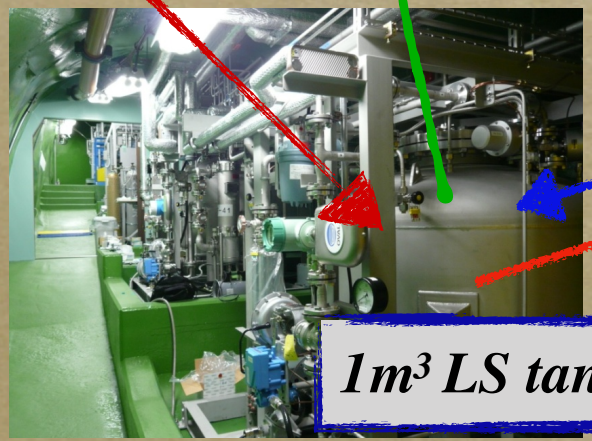
Compresser ~6MPa



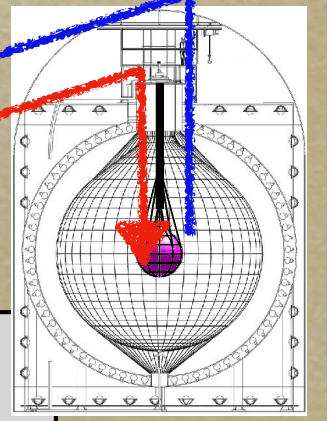
Xe dissolving

Xe extraction

Xe-LS extraction



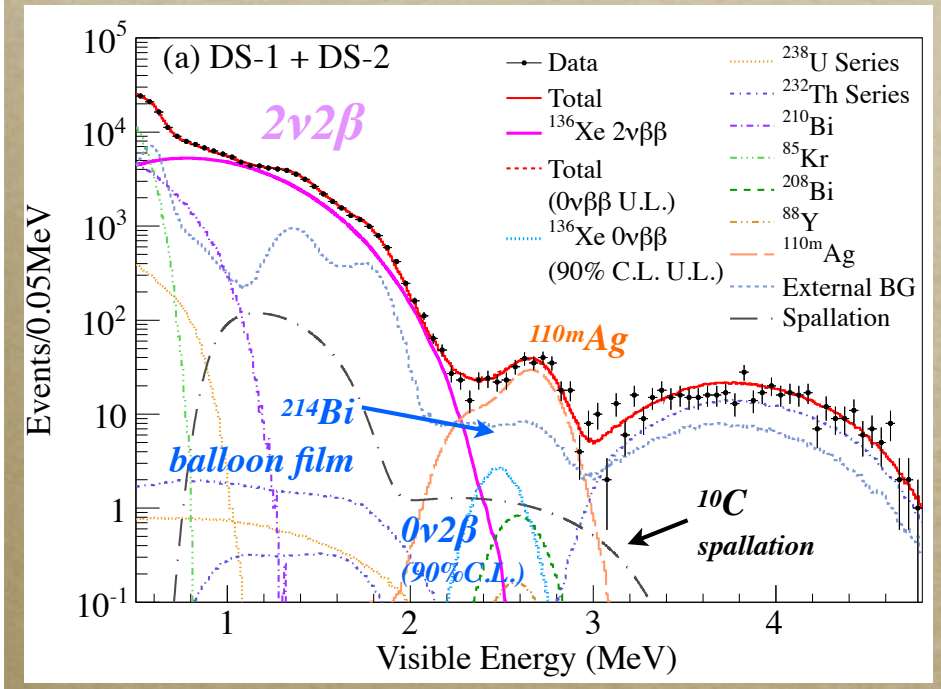
1m^3 LS tank



Filling Xe-LS
Density ~ ±0.01%
Temperature < ±0.3°C

1st Phase result

PRL **110**, 062502 (2013)



Unexpected ^{110m}Ag is dominant BG.

Fallout product from Fukushima reactor accident

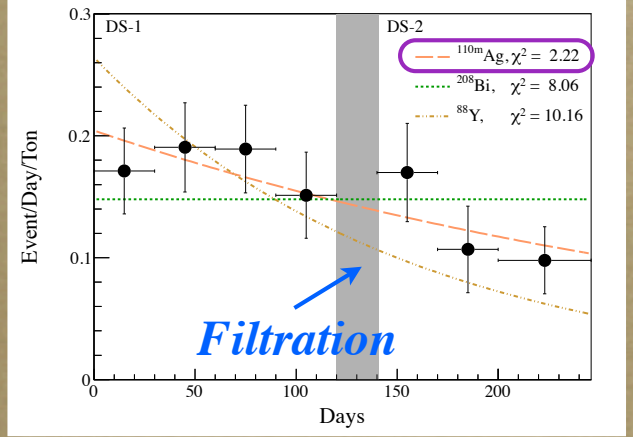
FV is optimized to 1.35m radius for 0ν2β analysis.
livetime 213.4 days
exposure: 89.5 kg*yr

0ν2β result

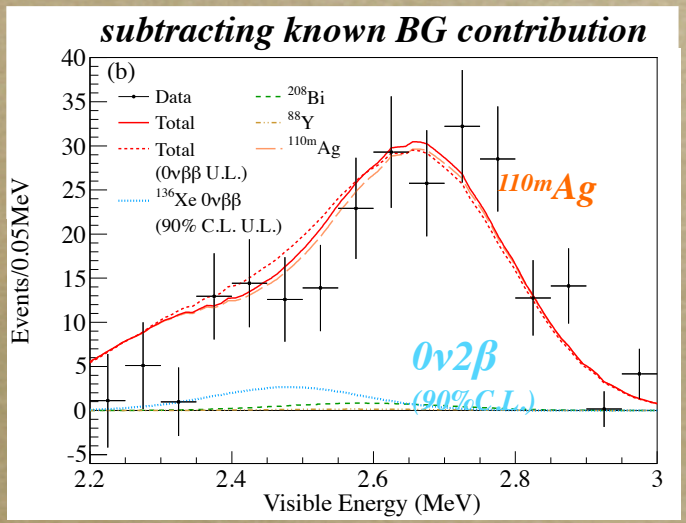
$$T^{0\nu2\beta}_{1/2} > 1.9\times10^{25}\,\mathrm{yr}\ (90\%\ \mathrm{C.L.})$$

$$\langle m_{\beta\beta}\rangle < 0.16 - 0.33\ \mathrm{eV}\ (90\%\ \mathrm{C.L.})$$

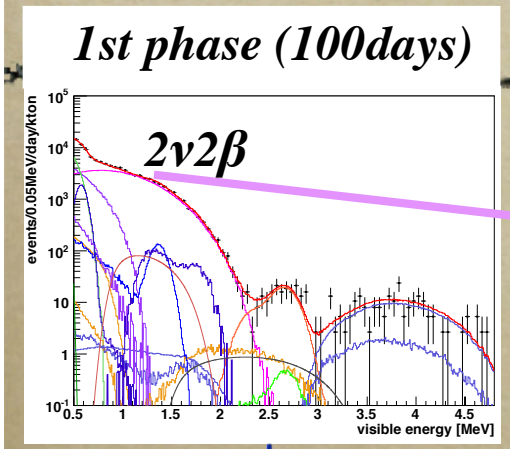
Time variation at 0ν region

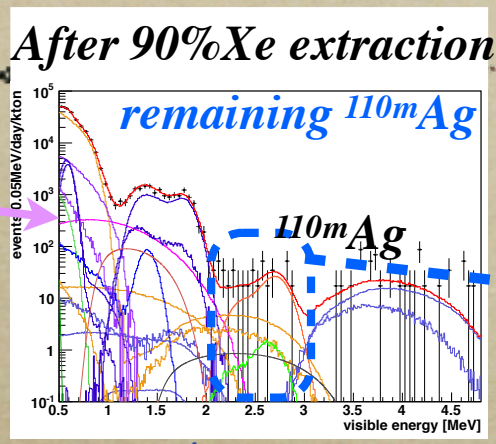


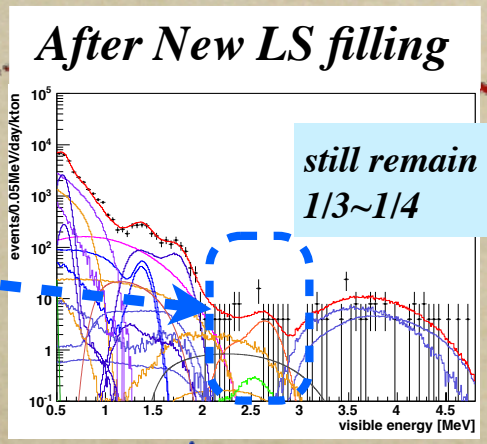
subtracting known BG contribution



Purification methods







not 0ν signal

Xe

Xe-LS + ^{110m}Ag

LS + ^{110m}Ag

new LS

1st phase

new LS

water extraction, distillation

drain

LS + ^{110m}Ag

380kg

purified Xe

2nd phase

new Xe-LS

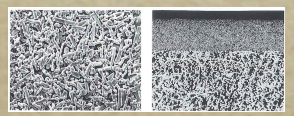
Further LS purification
using distillation system
~ 3 cycles

Xe purification system

Xe was collected passing through LS cold trap.

charcoal filter
LS vapor < 1ppb

adsorption type filter



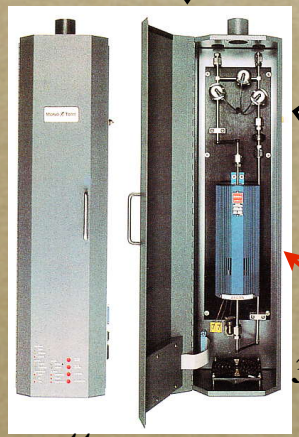
sintered metal filter (SUS)

SAES

Media 404

	Impinger 1	Impinger 2	
Metal	Metal Generation (ppmw)	Metal after SST (ppmw)	Trap Efficiency
Fe	1.3	0.03	98%
	1.2	0.02	98%
	1.3	0.01	99%
	1.4	0.03	98%
	3.1	0.03	99%
	3.3	0.02	99%
Cr	1.2	0.03	98%
	6.54	0.03	100%
Cu	0.08	0.005	94%
	0.03	0.003	91%
	0.05	0.005	91%
Ni	0.18	0.018	91%
	0.5	0.01	98%

Metal also trapped in charcoal.

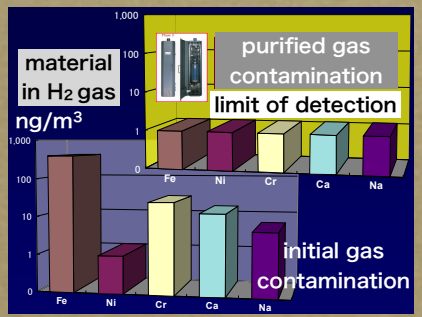


getter
$H_2O, N_2, O_2, CH_4, CO, CO_2$ <1ppb

Zr alloy
350~400°C

PTFE filter
pore size 3nm

SAES

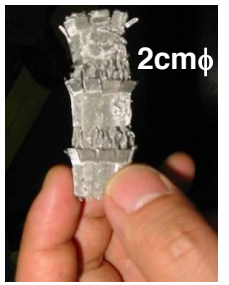


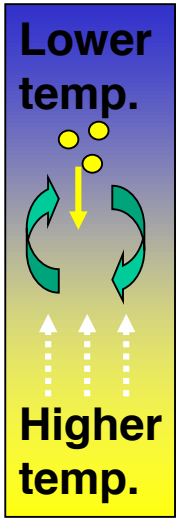
Xe distillation system

borrowed from XMASS

design goal: reducing Kr by more than 3orders of magnitude. (achieved)

column



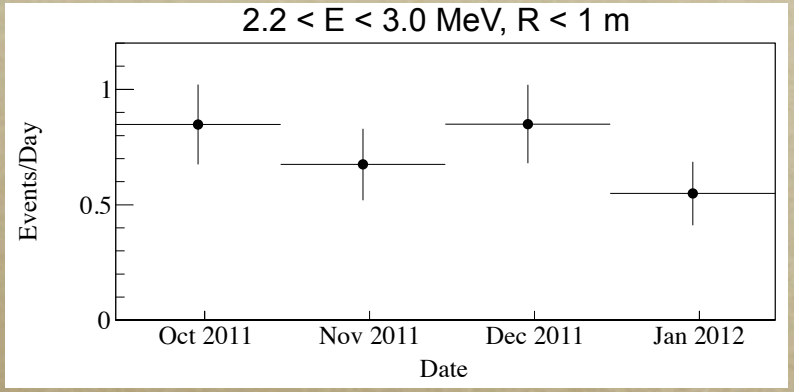


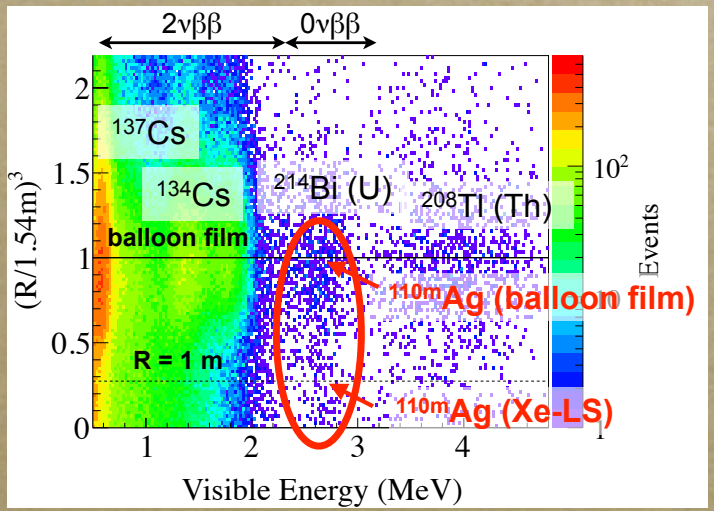
Nitrogen concentration in Xe was reduced from 2% to less than 100ppm. Metal might be removed.

~410kg Xe was purified.

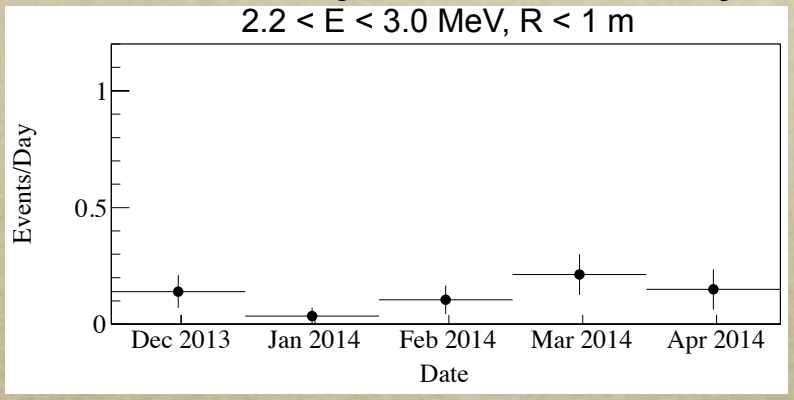
Ag BG reduction results

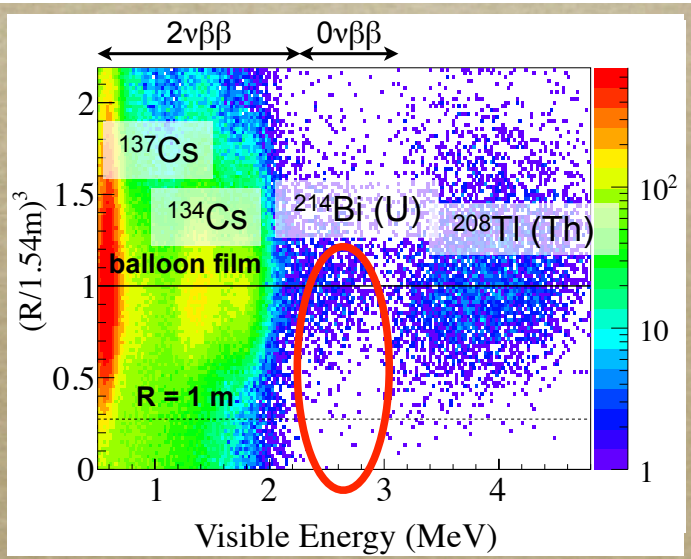
1st Phase (first 112.3 days)





2nd Phase (first 114.8days)





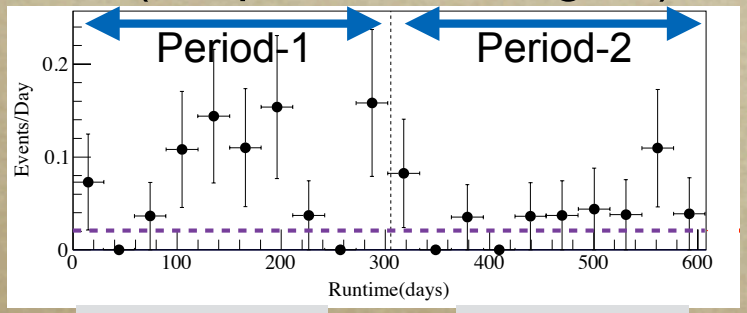
^{110m}Ag BG was reduced by a factor of more than 10.

KamLAND-Zen 400 result

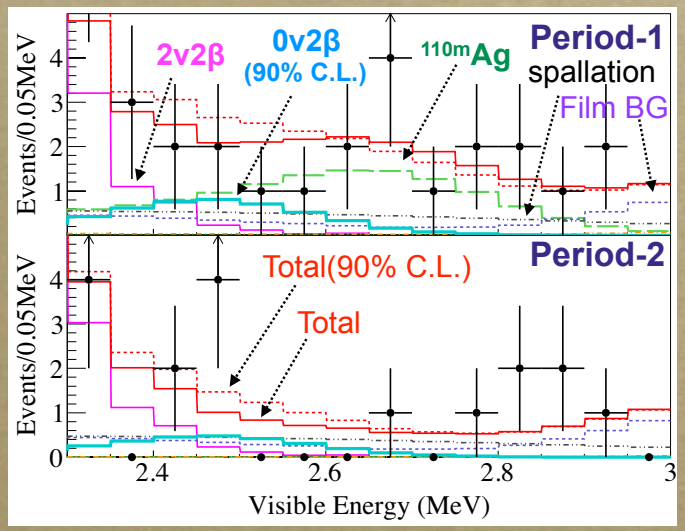
PRL 117, 082503(2016)

2nd Phase Result

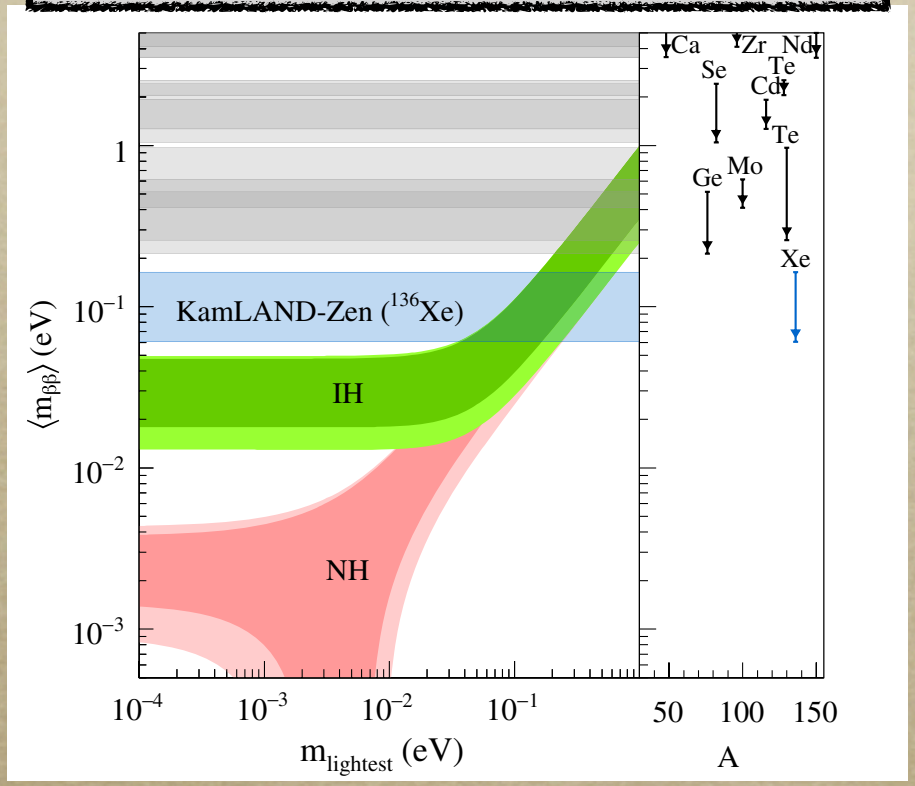
R<1.0m 2.3<E<2.7 MeV
(0ν2β sensitive region)



22 events 11events



Combined Result (1st & 2nd Phase)



$T^{0\nu2\beta}_{1/2} > 1.07\times10^{26}\,yr$ (90% C.L.)

best upper limit

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

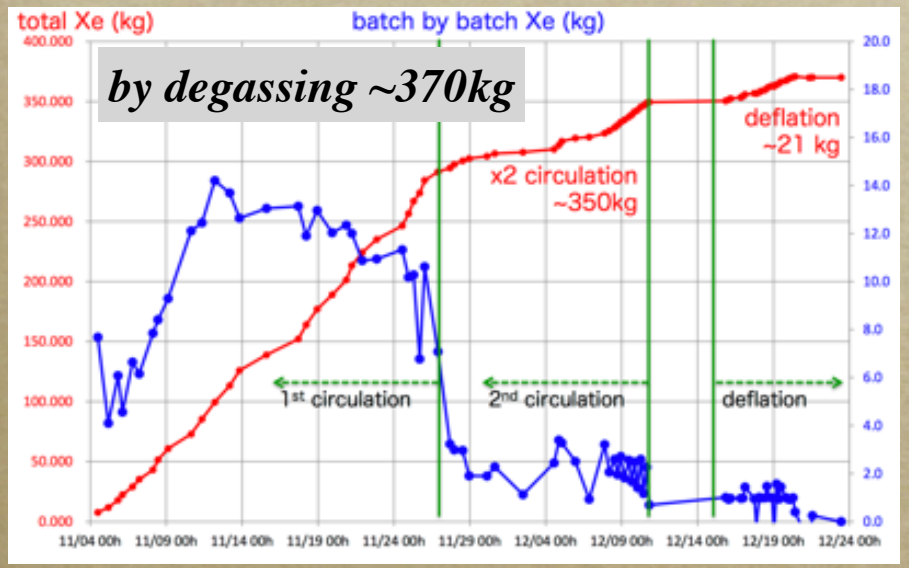
$\langle m_{\beta\beta}\rangle$ limit reached near IH region below 100meV

Toward KamLAND-Zen 800 phase

increase ^{136}Xe & ultra clean mini-balloon production

Zen-400 mini-balloon extraction

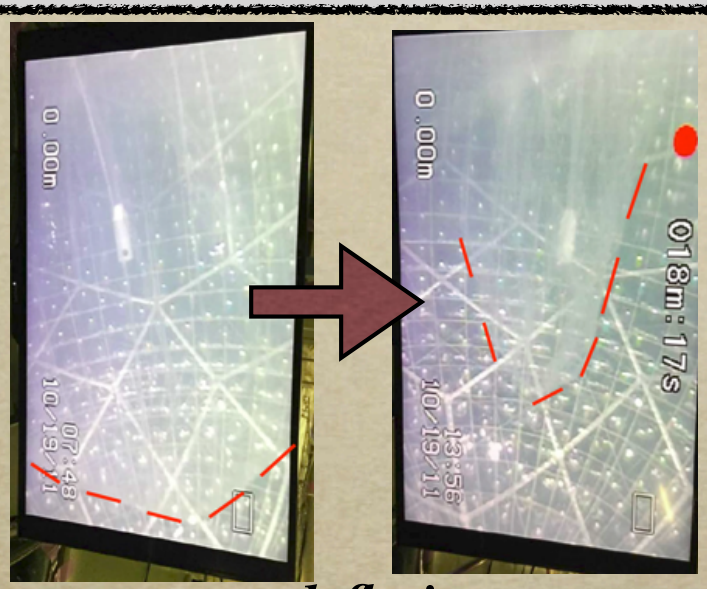
Xe collection from mini-balloon



remaining Xe in LS was collected by N2 purge ~10kg

Purified collected Xe and new Xe using distillation system.

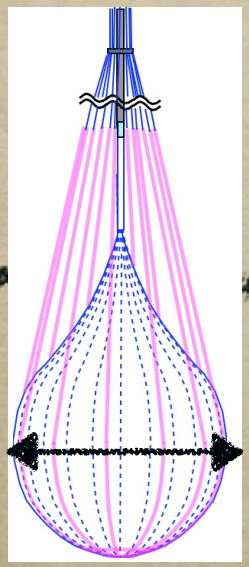
770kg Xe was purified for KamLAND-Zen 800 phase.



deflation

Zen 800 mini-balloon production

Toward ultra clean mini-balloon production



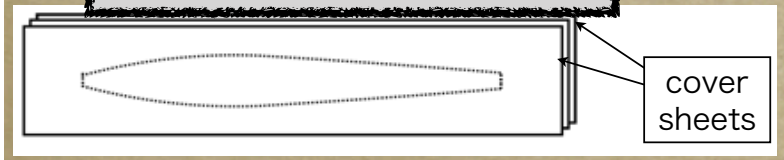
ϕ3.84m
(Zen400 ϕ3.08m)

Clean underwear

goggle
Double gloves

Change clean suits in the clean room

Balloon film protection



2 class 1 clean rooms

~$6000/month

Room1:mini-balloon production
Room2: changing clean suits cleaning all equipments

Static-electricity control

Mistgeneration system

Humidity control

+

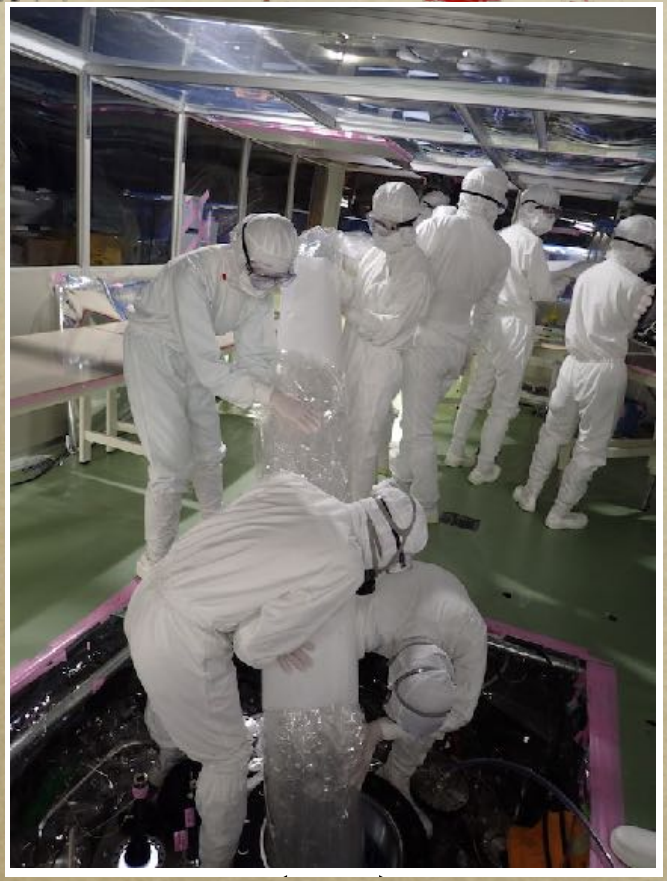
Ion generation system

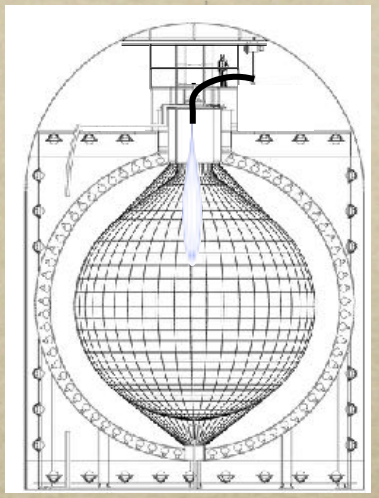
Semi-automatic welding machine

Zen 400

Zen 800

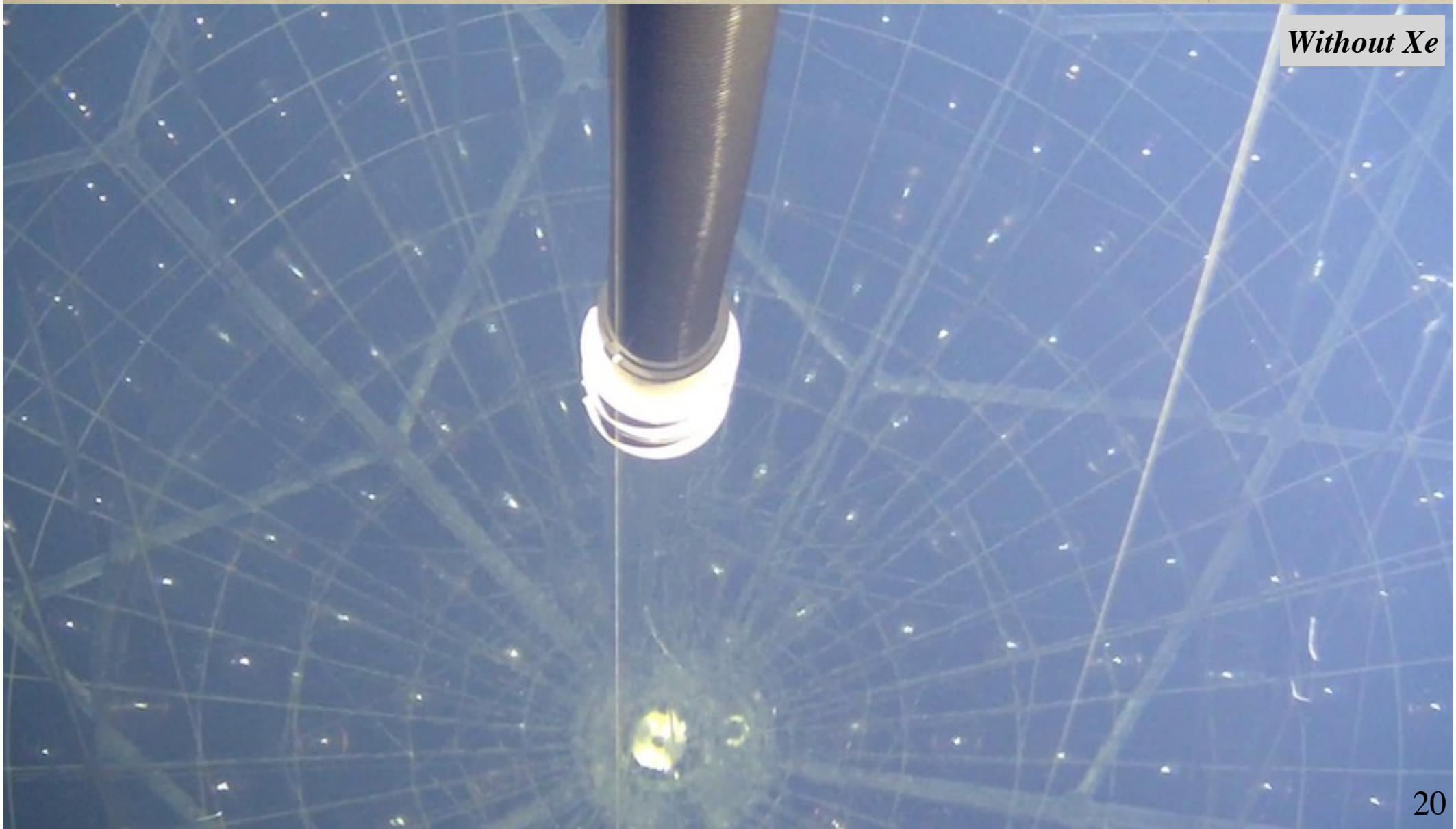
Zen 800 mini-balloon installation



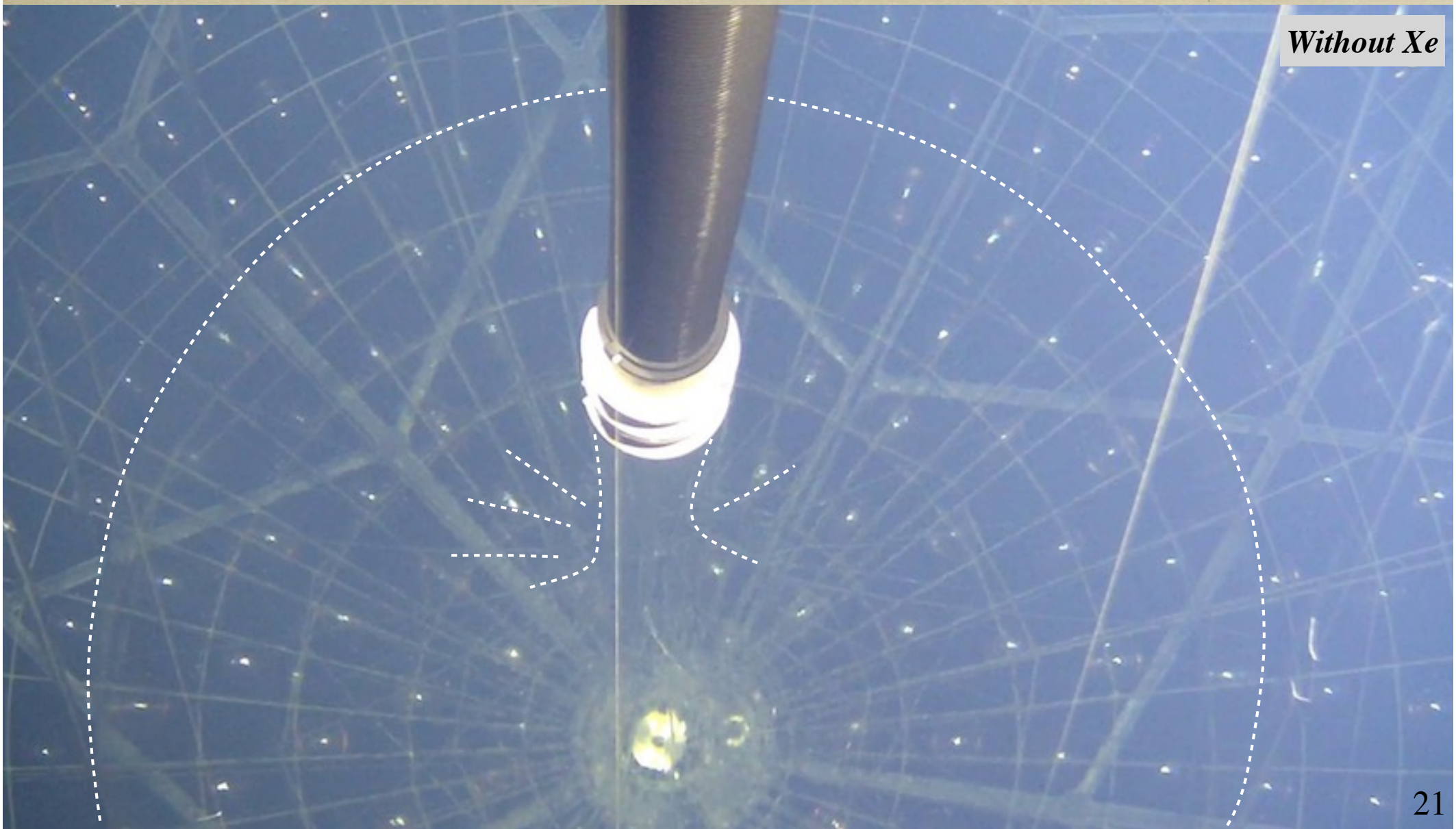


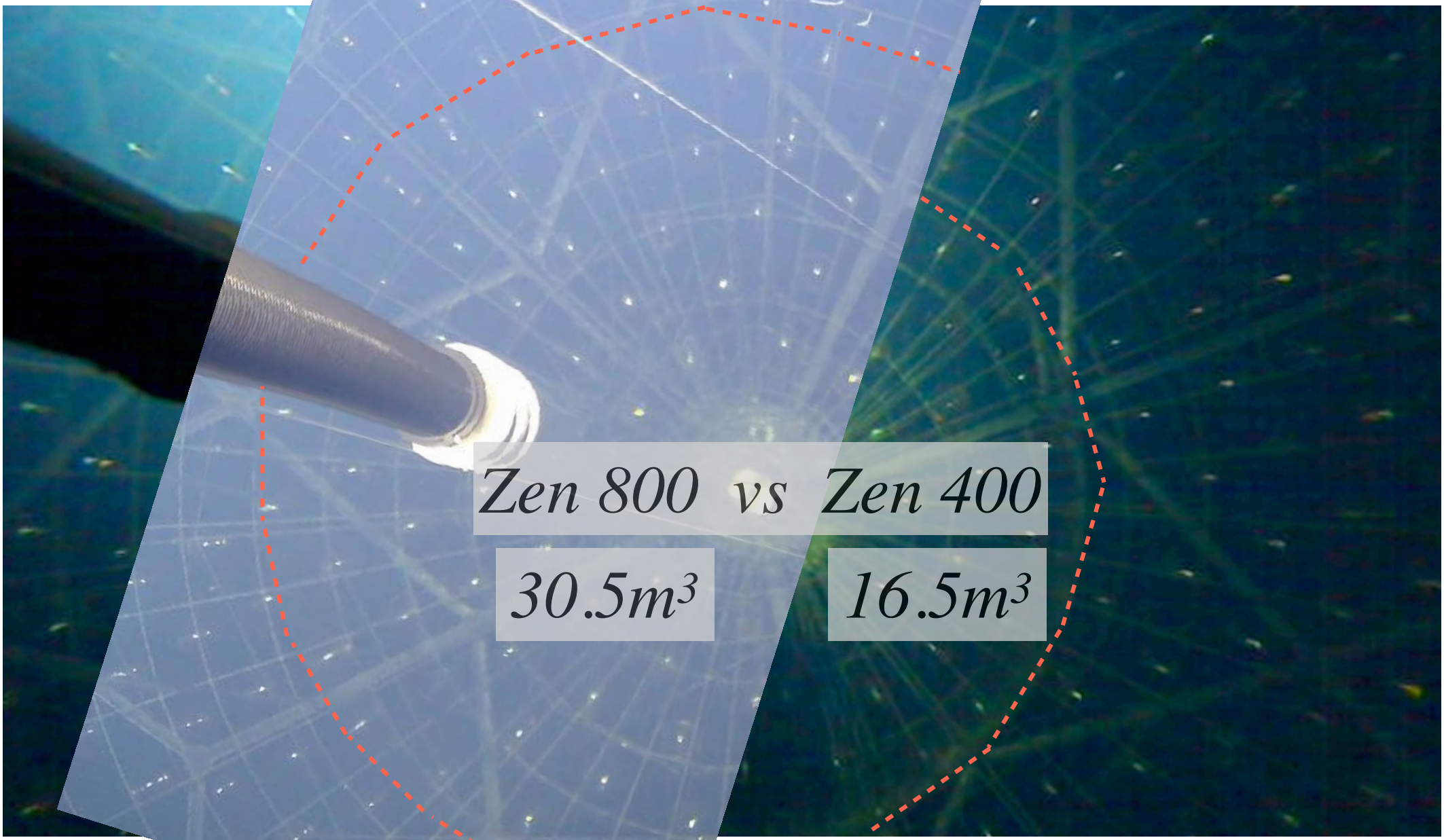
Zen 800 mini-balloon was installed in May 2018

30.5m³ normal LS filling



30.5m³ normal LS filling

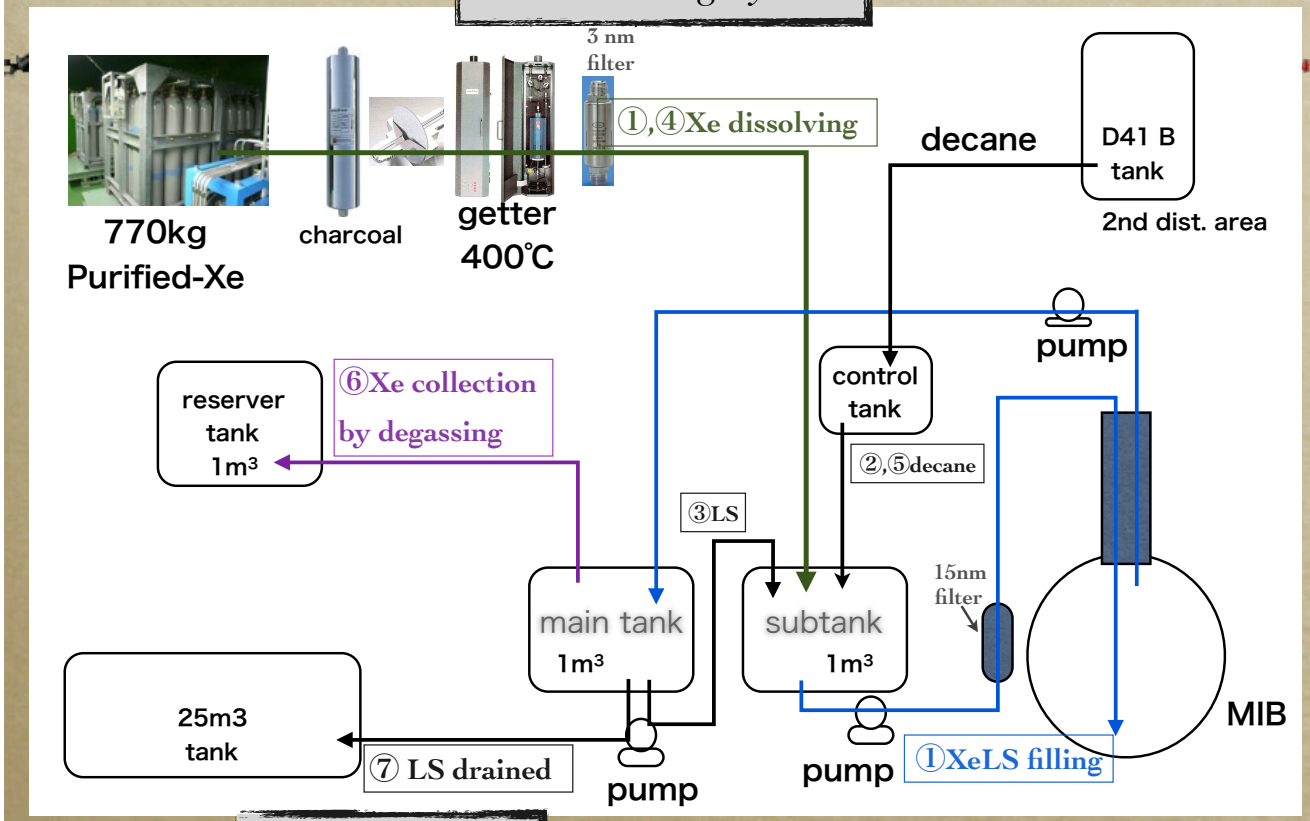



Zen 800 vs Zen 400
30.5m³
16.5m³

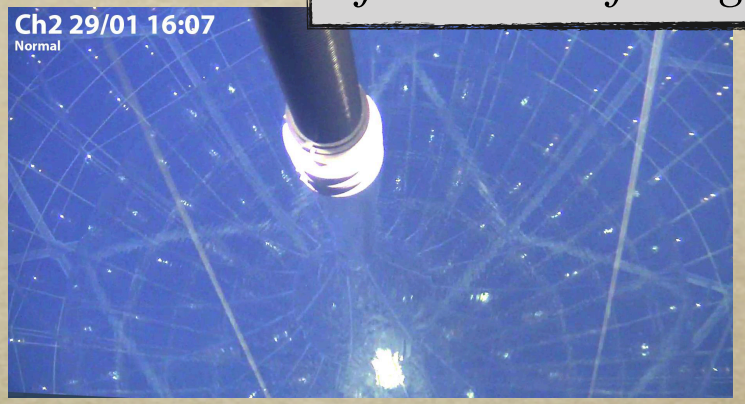
Xe dissolving

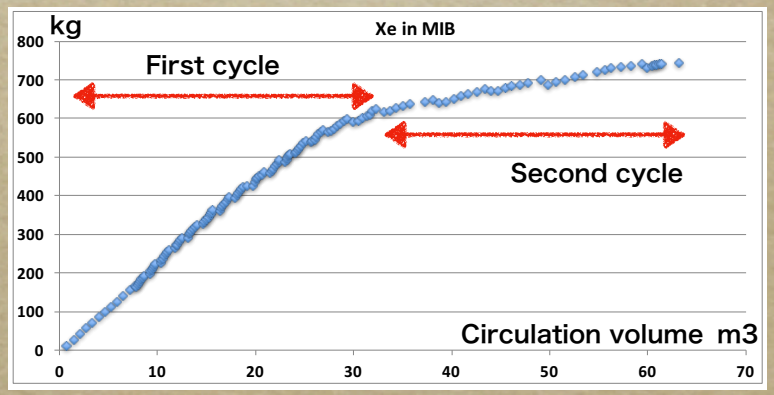
Nov. 2018~ Jan. 2019

Xe dissolving system

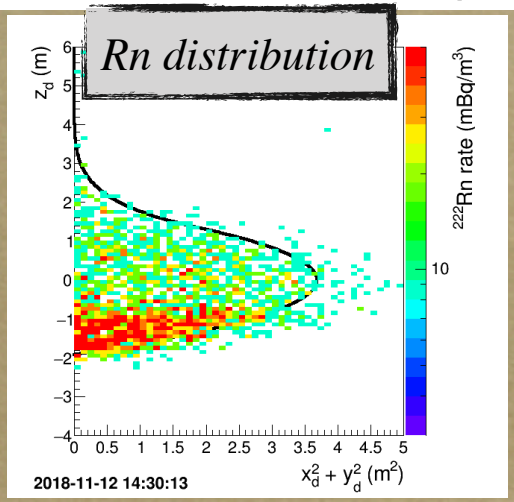


After Xe-LS filling





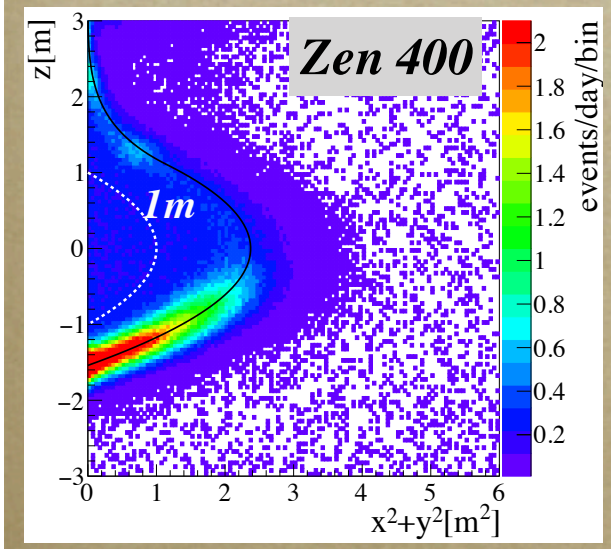
Rn distribution

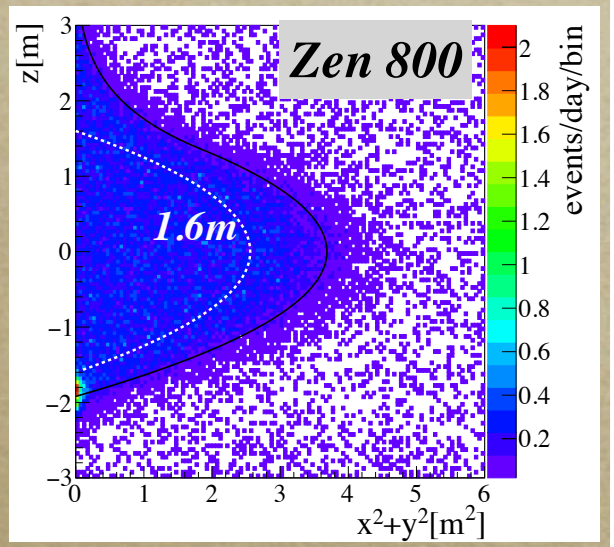


745kg Xe was installed.
Physics run was started in Jan. 2019.

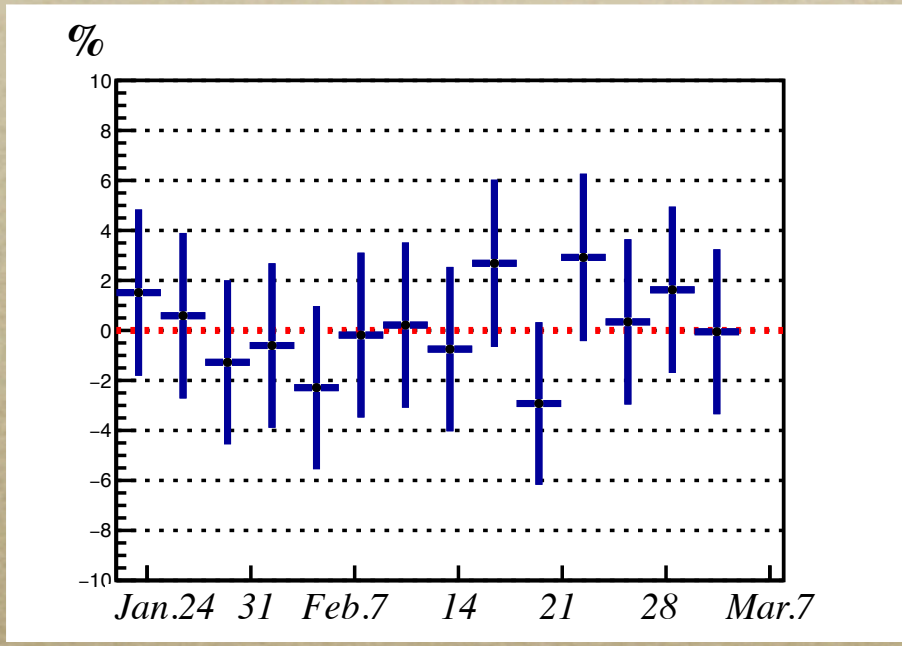
2ν2β event distribution

2ν2β events distribution (1.0<Evis<2.3)





2ν2β event rate time variation r<220 cm

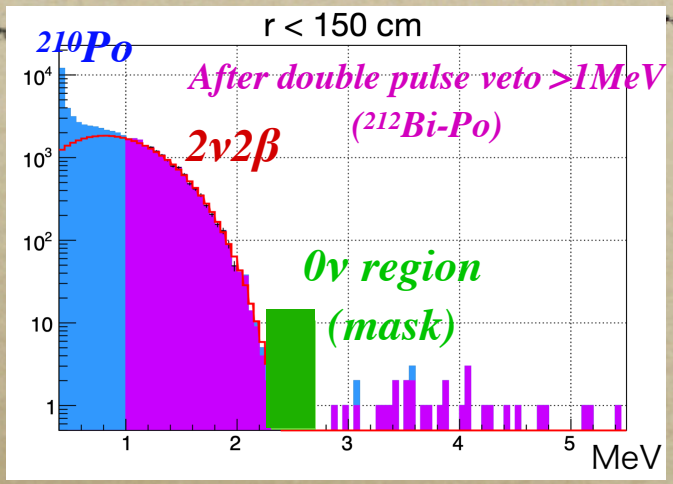


2ν2β events dominant for all volume!!

Stable 2ν2β event rate!!

0ν2β search status

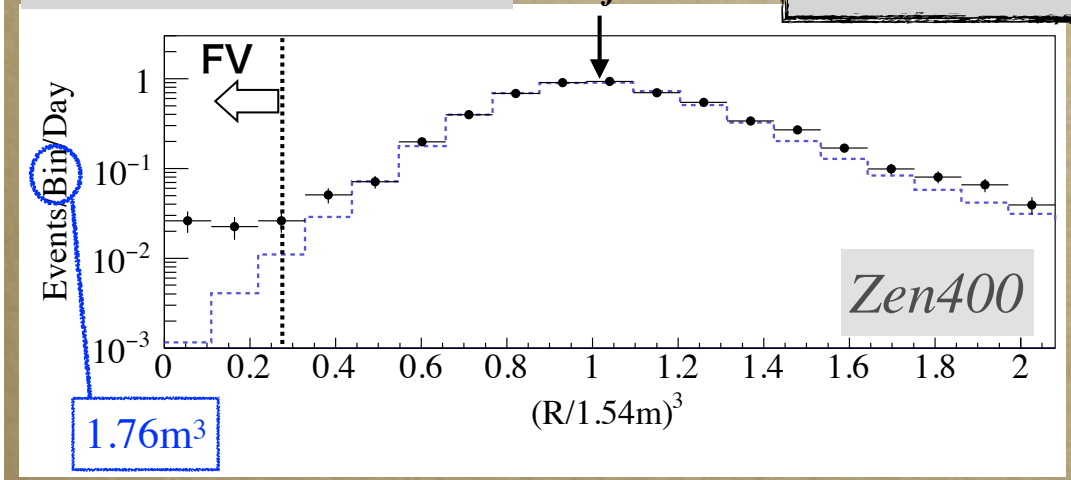
Energy spectrum after ^{214}Bi-Po veto



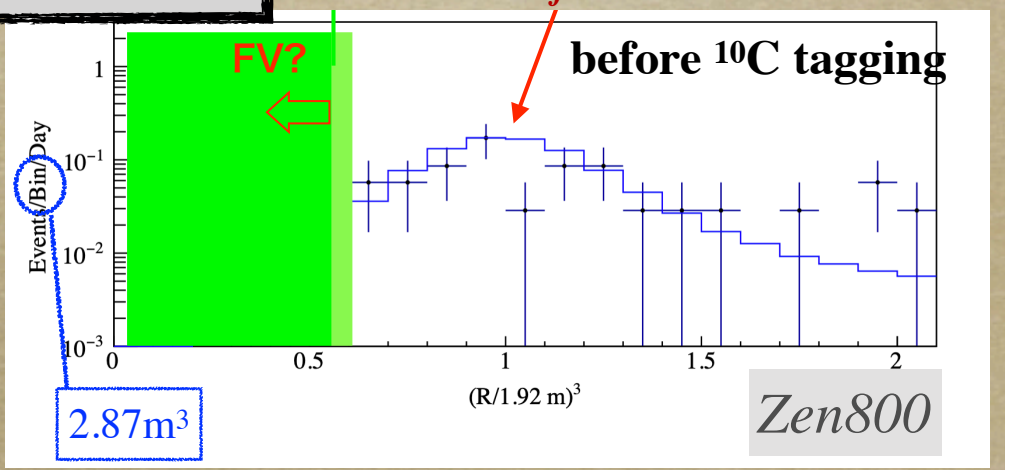
No strange BG!!

Mini-balloon was clean!! ~1/10 low BG
FV will be increased to 3~4 times of Zen400.

r^3 event distribution



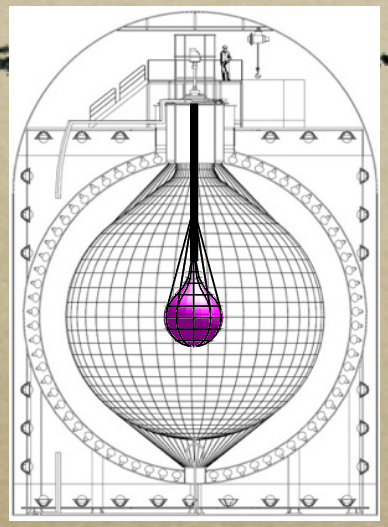
0ν region (2.3~2.7MeV)



*Target Sensitivity : $\langle m_{\beta\beta} \rangle \sim$ **40meV** (5yr data taking)*

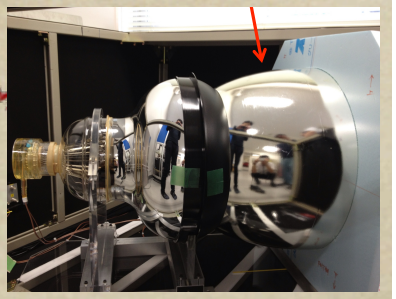
Future prospects

Reduce 2ν2β



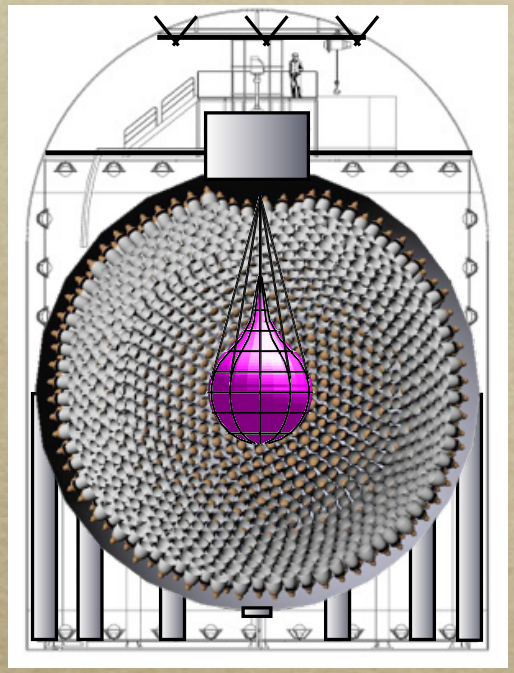
Improve σ_E

Winston cone



KamLAND2-Zen

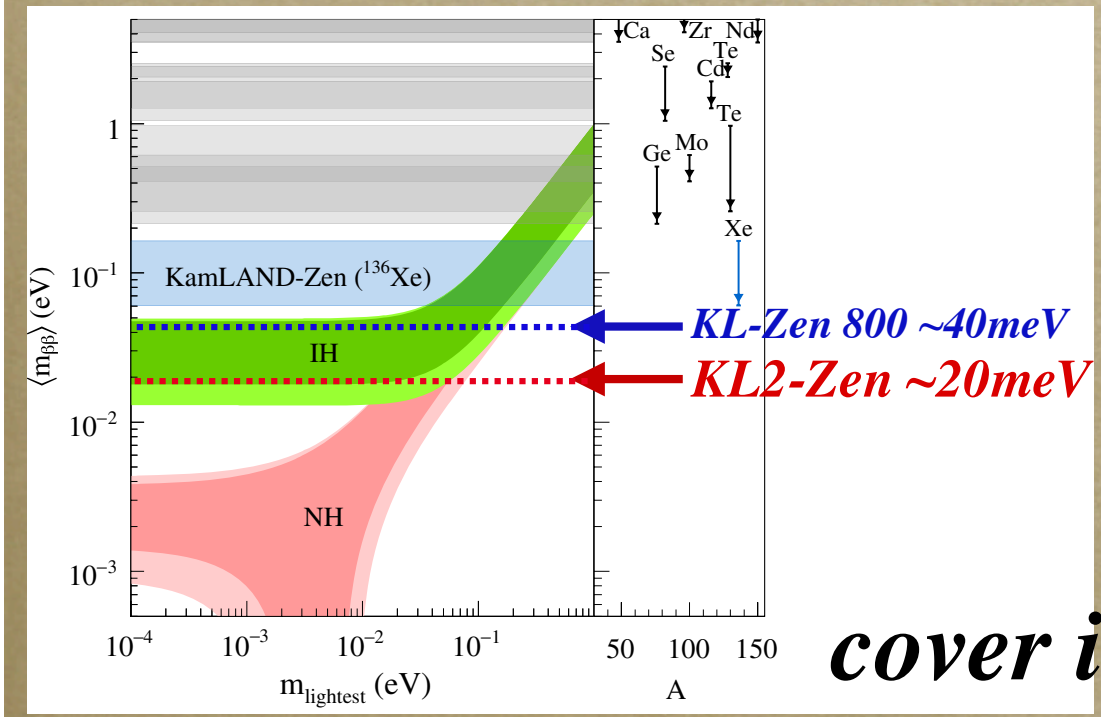
>1000kg ^{136}Xe



1. Winston cone
light yield ×1.8

2. High Q.E. 20"PMT
QE~22% → >30%
light yield ×1.9

3. High light yield LS
KL LS 8000ph/MeV
Standard 12000ph/MeV
→ light yield ×1.4



KL-Zen 800 ~40meV

KL2-Zen ~20meV

E resolution at 2.6MeV 4% → < 2.5%
(simple calculation < 2%)

sensitivity ~20meV / 5 yr

cover inverted hierarchy region

Summary

- ***The ^{110m}Ag BG was reduced by a factor of more than 10.***
- ***KamLAND-Zen latest result:***
  the 0ν2β half life limited to more than 1.07×10^{26} yr (90% C.L.)

  $\langle m_{\beta\beta}\rangle$ ***< 61 - 165 meV*** *(90%C.L.)* ***Near IH region***
- ***The installed new mini-balloon was cleaner than Zen400 balloon.***
- ***745kg Xe was installed. KamLAN-Zen 800 DAQ was started in January 2019.*** $\langle m_{\beta\beta}\rangle \sim 40meV$ *(5yr data taking)*