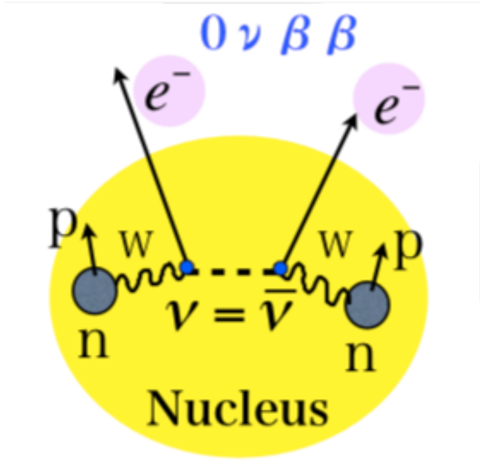
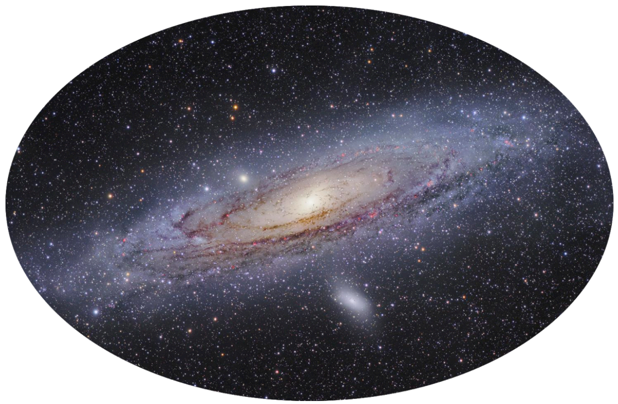
KamLAND-Zen
Challenging the Mysteries of Neutrinos and the Universe





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Research Center for Neutrino Science
Tohoku University

NuSTEC School @Okayama University, Nov.14, 2015

Contents

- Matter dominance of the world and the relation to Neutrinos
- Importance to determine the nature of neutrinos ; Majorana ($\nu = \overline{\nu}$) or Dirac ($\nu \neq \overline{\nu}$)
- Double beta decay to answer the question
- KamLAND-Zen experiment
- Summary

13.7billion years ago !

E.Hubble

Hubble's Law: v=HD (1929)

H=67.15±1.2km/s/Mpc

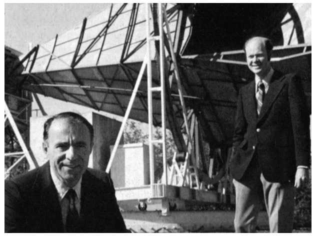
G.Gamow

Nucleosynthesis (1946)

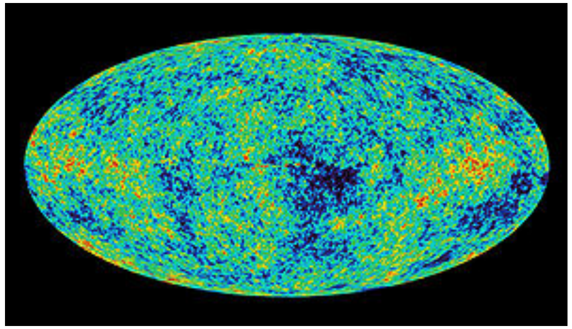
H, ^{4}He, D, ^{3}He, ^{7}Li,

Discovery of CMB (1965)

Cosmic Microwave Background)



A.Penzias & R.Wilson



CMB images by WMAP

Matter-dominance world !

Why matter dominance ?

A.Sakharov

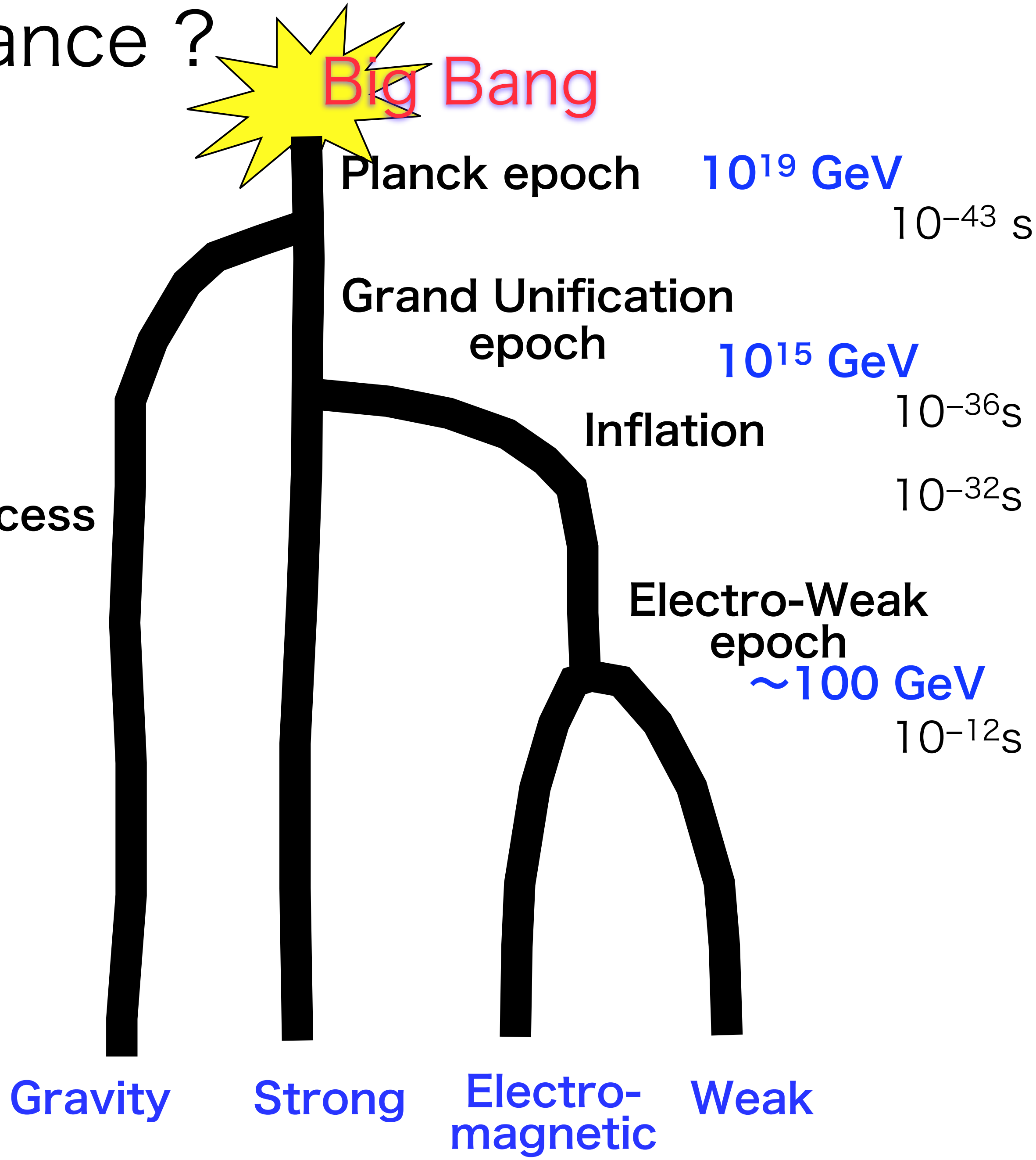
3 conditions are necessary

1) Baryon number violating process
2) C and CP violation
3) Interactions in thermal non-equilibrium

$$\frac{n_B - n_{\bar{B}}}{n_B} = 6\times10^{-10}$$

Baryogenesis

Neutrinos might take a role!



Fundamental problem of Neutrinos

T.Kajita

A.McDonald

$M_\nu \neq 0$

$\ll M_q, M_{\ell^\pm}$

Atmospheric ν,
Solar ν, Reactor ν,
Accelerator ν

Oscillation

ΔM^2_{13} θ_{13} θ_{12}

ΔM^2_{23} θ_{23}

ΔM^2_{21}

?

$M_1 \simeq M_2 \gtrless M_3$

δ_{CP}

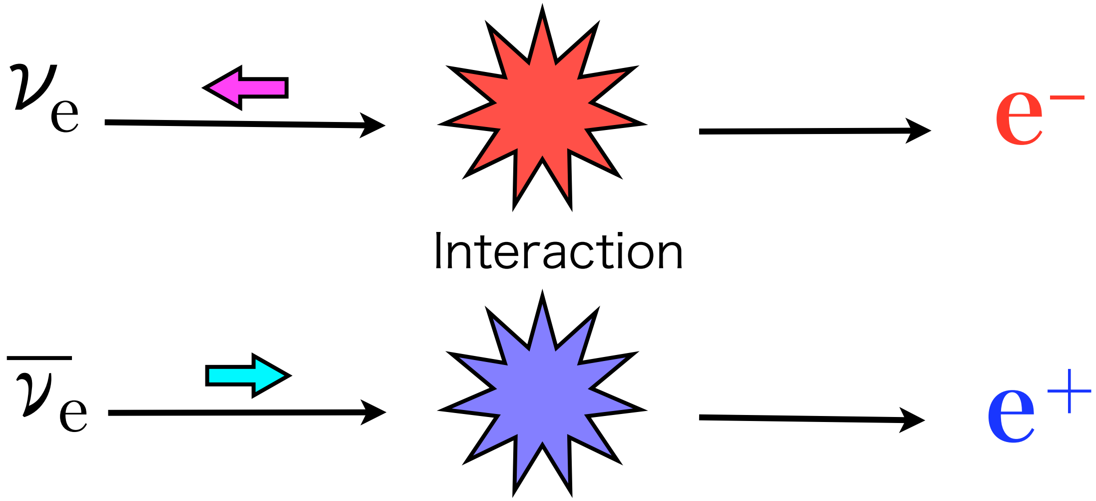
Q=0

$\nu = \overline{\nu}$ Majorana

$\nu \neq \overline{\nu}$?

Dirac

Actually ν and $\overline{\nu}$ are discriminated clearly



ν is found as only left-handed.

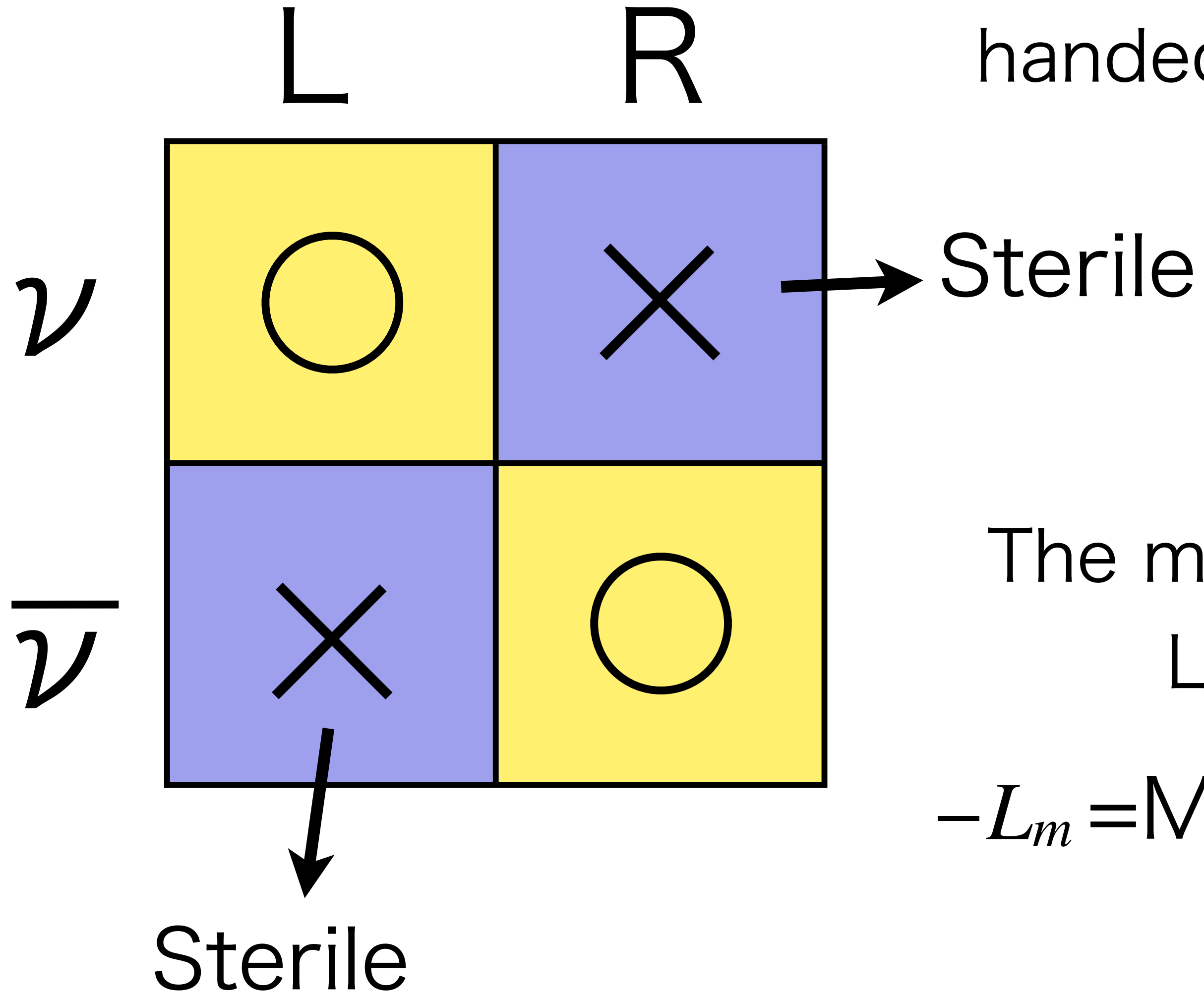
No right-handed ν is found.

$\overline{\nu}$ is found as only right-handed.

No left-handed anti-ν is found.

If $\nu \neq \overline{\nu}$ (Dirac particle)

Standard model is constructed on the Left handed interaction.



The mass term in the Lagrangian

$$-L_m = M_D(\overline{\psi}_R \psi_L + \text{h.c.})$$

Dirac Mass term

In general neutral fermions can have another mass terms in the Lagrangian.

$$-L_m = (\text{Dirac term}) + (1/2) M_L [\overline{(\psi^c)_R} \psi_L + \text{h.c.}] + (1/2) M_R [\overline{(\psi^c)_L} \psi_R + \text{h.c.}].$$

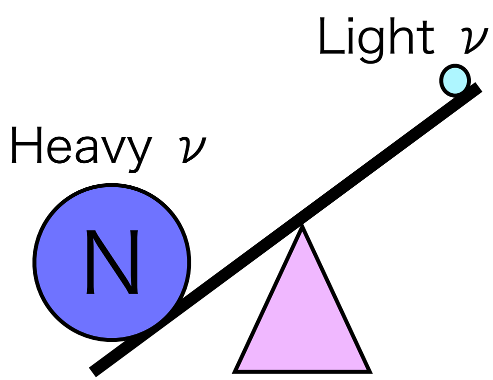
$$f = \left(\psi_L + (\psi_L)^c\right)/\sqrt{2}, \quad F = \left(\psi_R + (\psi_R)^c\right)/\sqrt{2}$$

2 independent mass eigenvalues by diagonalizing the Mass matrix.

See-saw mechanism

$$M_\nu = M_{q,l^\pm}{}^2 / M_N$$

$$\Rightarrow M_N >> M_{q,l^\pm}$$

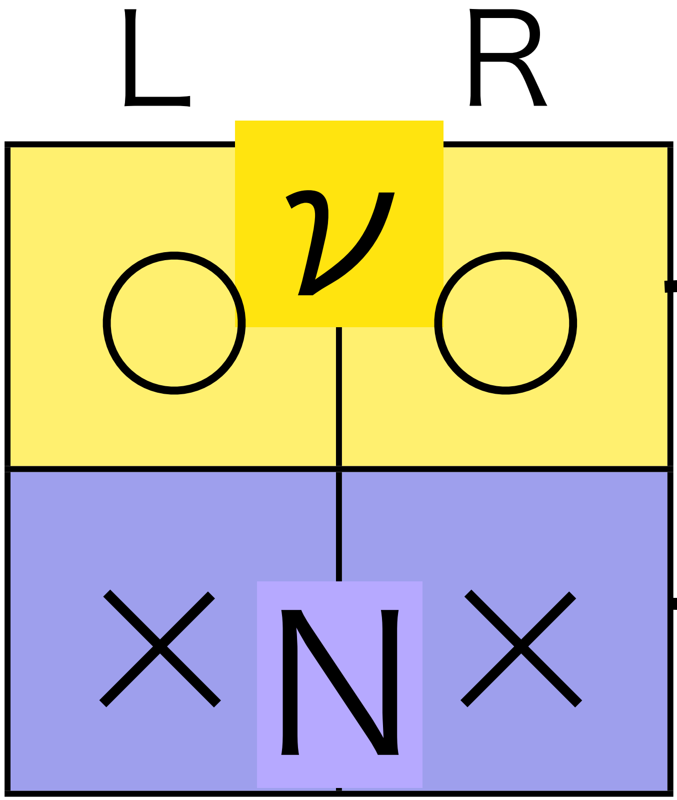


Extremely small ν mass

Extremely huge mass of N => $M_N \sim 10^{14}$GeV !

～GUT scale

$\nu = \overline{\nu}$?



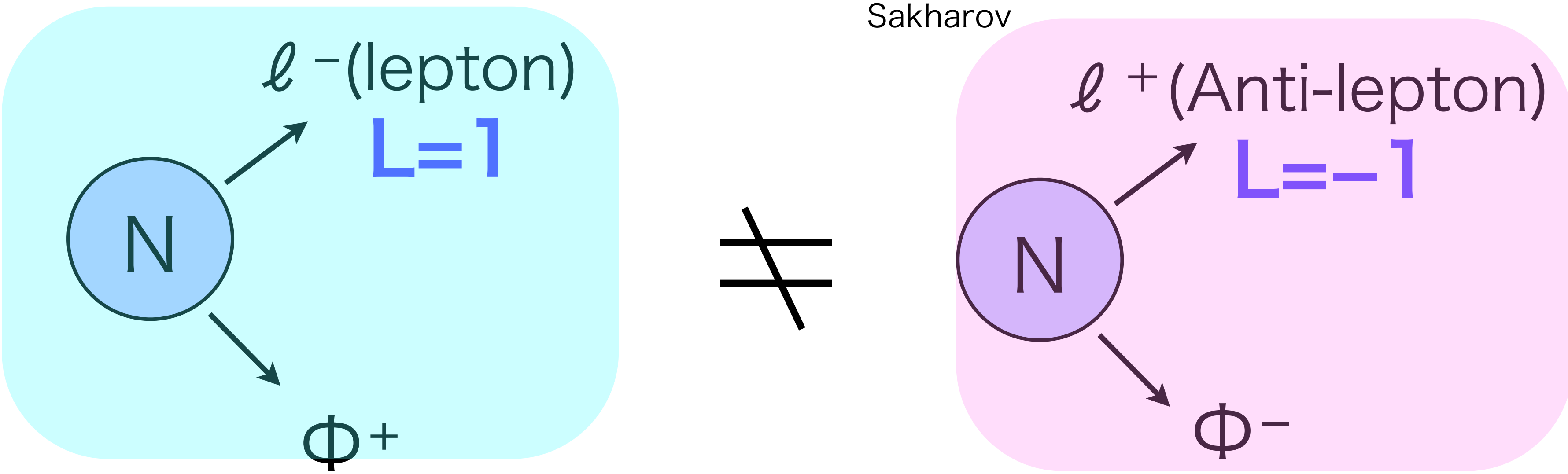
Existing light ν does different interactions for L and R states.

The mass is too heavy to be experimentally studied directly.

$M_N \gg M_q, M_{\ell^\pm}$

The heavy Majorana neutrinos could generate lepton numbers by CP violation.

Sakharov



(B−L) conserved (in GUT)

Net lepton numbers are generated. → Baryon number generation → Matter-dominance

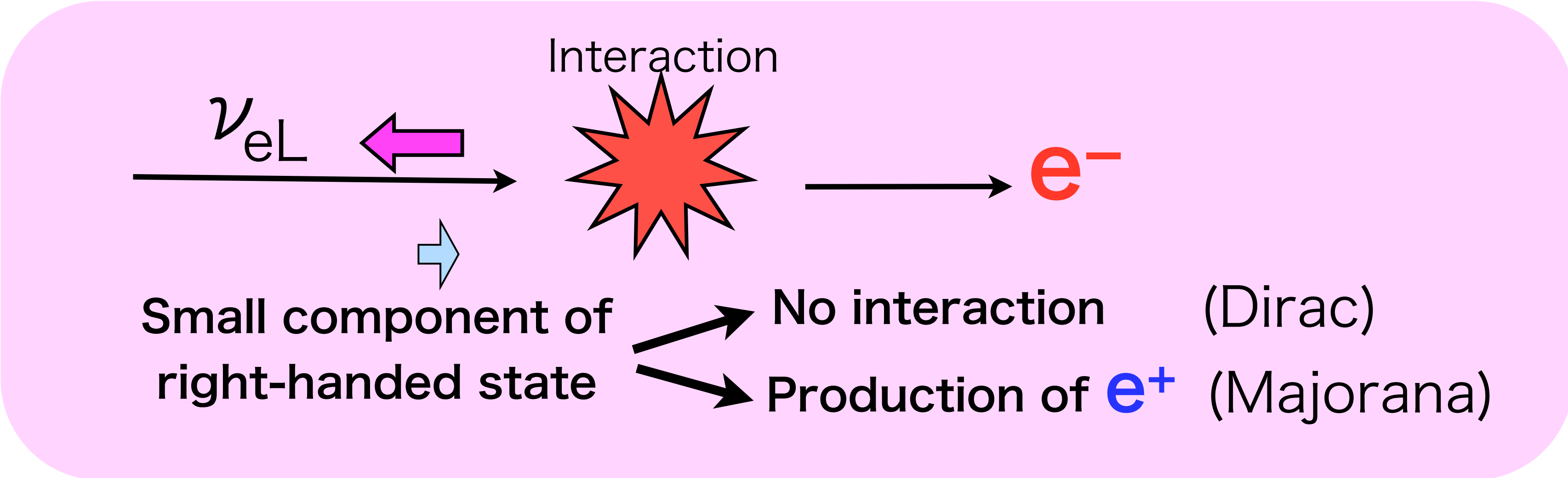
If νs are Majorana, matter dominance of the Universe might be explained !

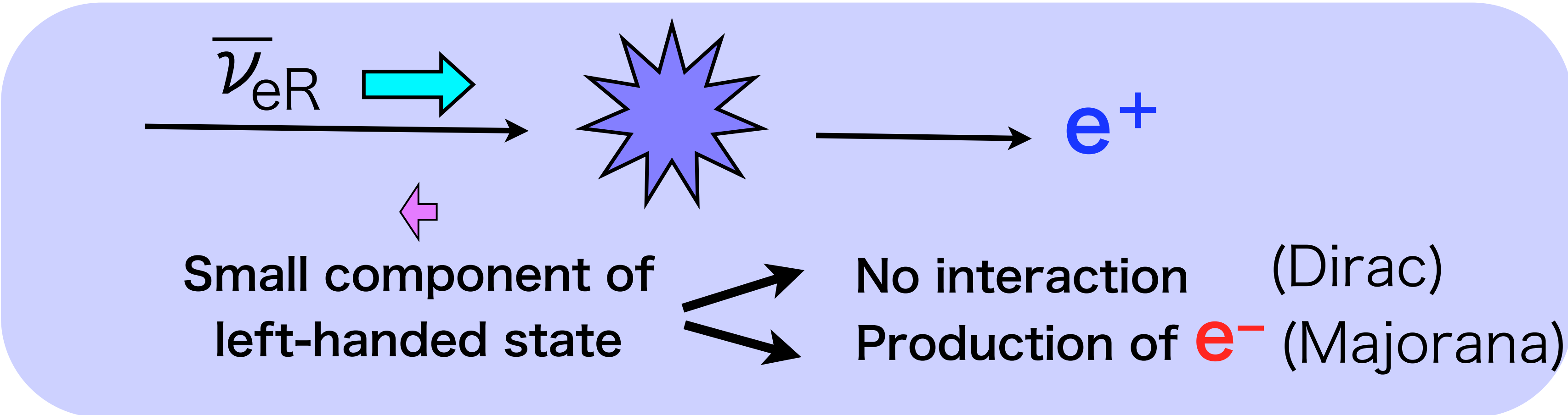
Is it possible to check whether $\nu = \overline{\nu}$ or not ?

Majorana Dirac

$$M_\nu \neq 0 \Rightarrow \beta_\nu < 1.$$

⇒ Helicity is not the strict quantum number.



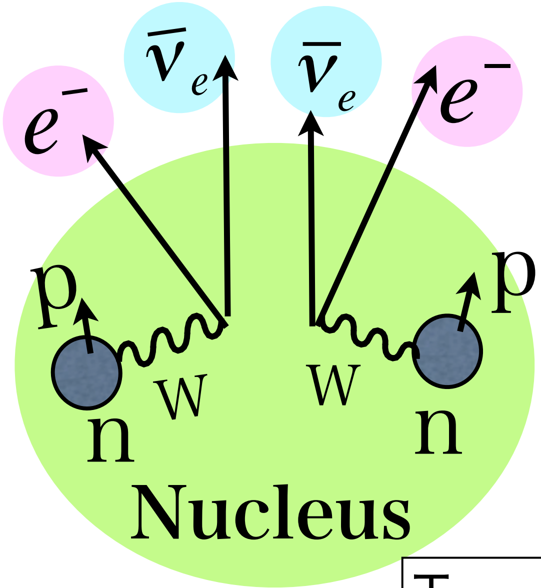


Rate difference for E_ν(∼MeV) : $\sim 1/\gamma^2 \sim 1/10^{14}$ ⇒ Hopeless!

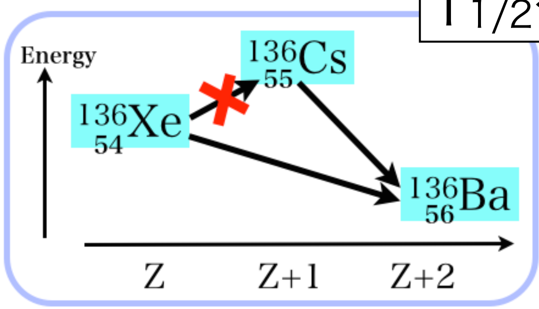
Nuclear double beta decay ($\beta\beta$)
without neutrino emission
($0\nu\beta\beta$)
has a key to the problem !

Double beta decay : 2ν and 0ν

$2\nu\beta\beta$



$T_{1/2} \sim 10^{21}$ yrs

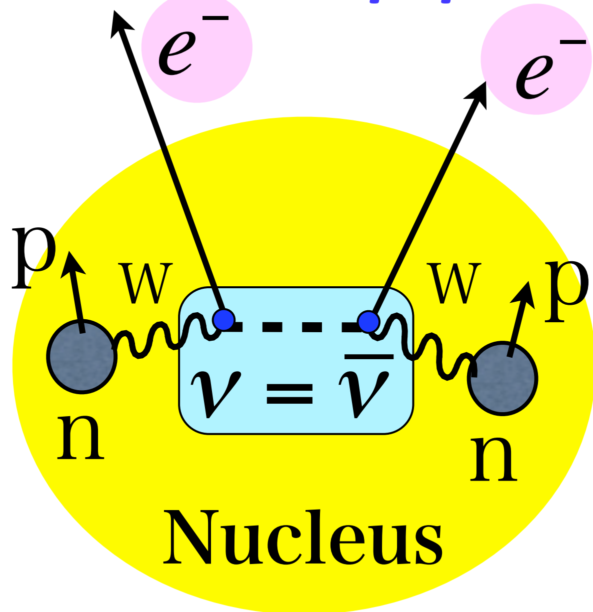


2nd-order weak process.
Observed in many nucleus;
^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}T, ^{136}Xe, ^{150}Nd

if ν's are Majorana $0\nu\beta\beta$ occurs irrespective of the actual processes.

Phys.Rev.D, 25, 2951 (1982)

$0\nu\beta\beta$



$\Delta L=2$ process : Beyond the SM.
Light ν exchange is the dominant.

Not observed yet.

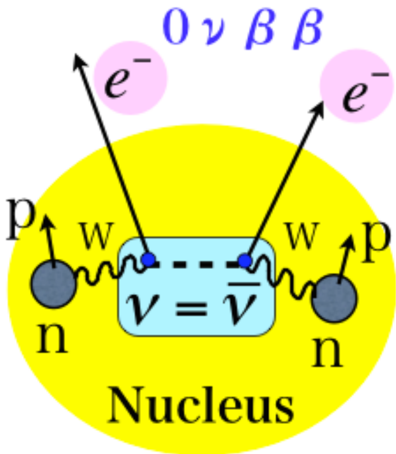
$0\nu\beta\beta$ half life ($T_{1/2}^{0\nu}$) for the light ν exchange

Phase space factor (reliably estimated)

Nuclear matrix element (by theoretical calculation and Model dependent)

Results of different $\beta\beta$ nuclei can be related.

$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}\left|M^{0\nu}\right|^2 \left\langle m_{\beta\beta}\right\rangle^2$$



Effective Majorana ν mass

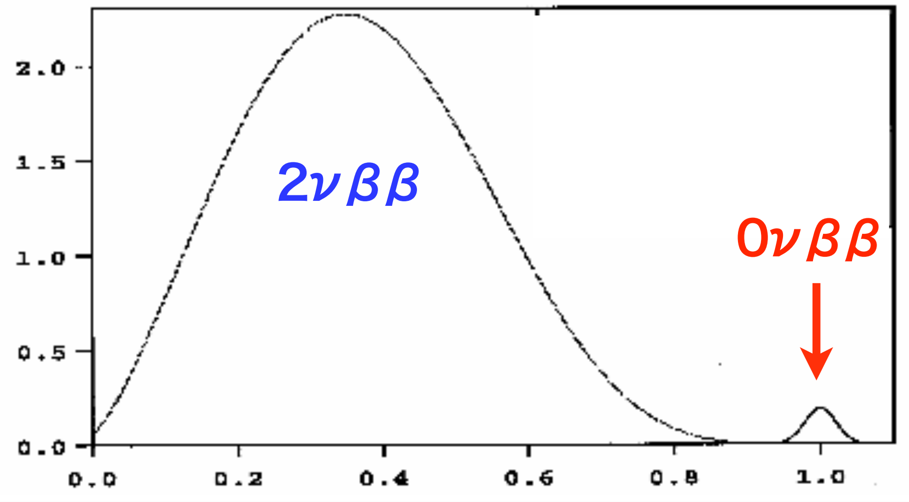
All of the particle physics information!

$$\left\langle m_{\beta\beta}\right\rangle = \left|\sum_i U_{ei}^2 m_{\nu_i}\right| = \left|c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i\alpha_{21}} m_2 + s_{13}^2 e^{i(\alpha_{31}-2\delta)} m_3\right|$$

$(c_{ij} = \cos\theta_{ij},\ s_{ij} = \sin\theta_{ij},\ \alpha_{21},\ \alpha_{31},\ \delta : \text{CP-phase})$

The absolute ν mass scale, the mass ordering and CP violation angles.

Signal of $0\nu\beta\beta$ decays



Energy/Q-value (at most ～a few MeV)

$$N_{\beta\beta}^{0\nu} = \frac{\ln 2}{T_{1/2}^{0\nu}} \times \varepsilon \times \frac{Ma}{W} N_A \times t$$

ε =detection eff., M=mass of target, a=Natural abundance, W=Atomic mass, t=Running time

Sensitivity to $\langle m_{\beta\beta} \rangle$

If no B.G. $\propto 1/\sqrt{Mat}$

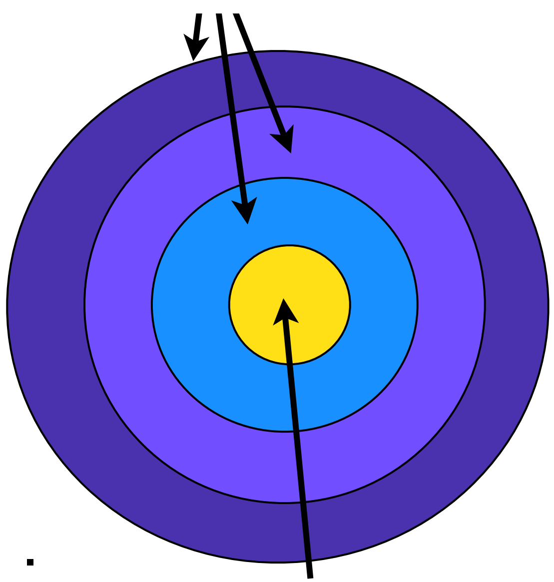
If $\mathrm{B.G.} = cM \times t \times \Delta E$, $\propto (\Delta E/Mat)^{1/4}$

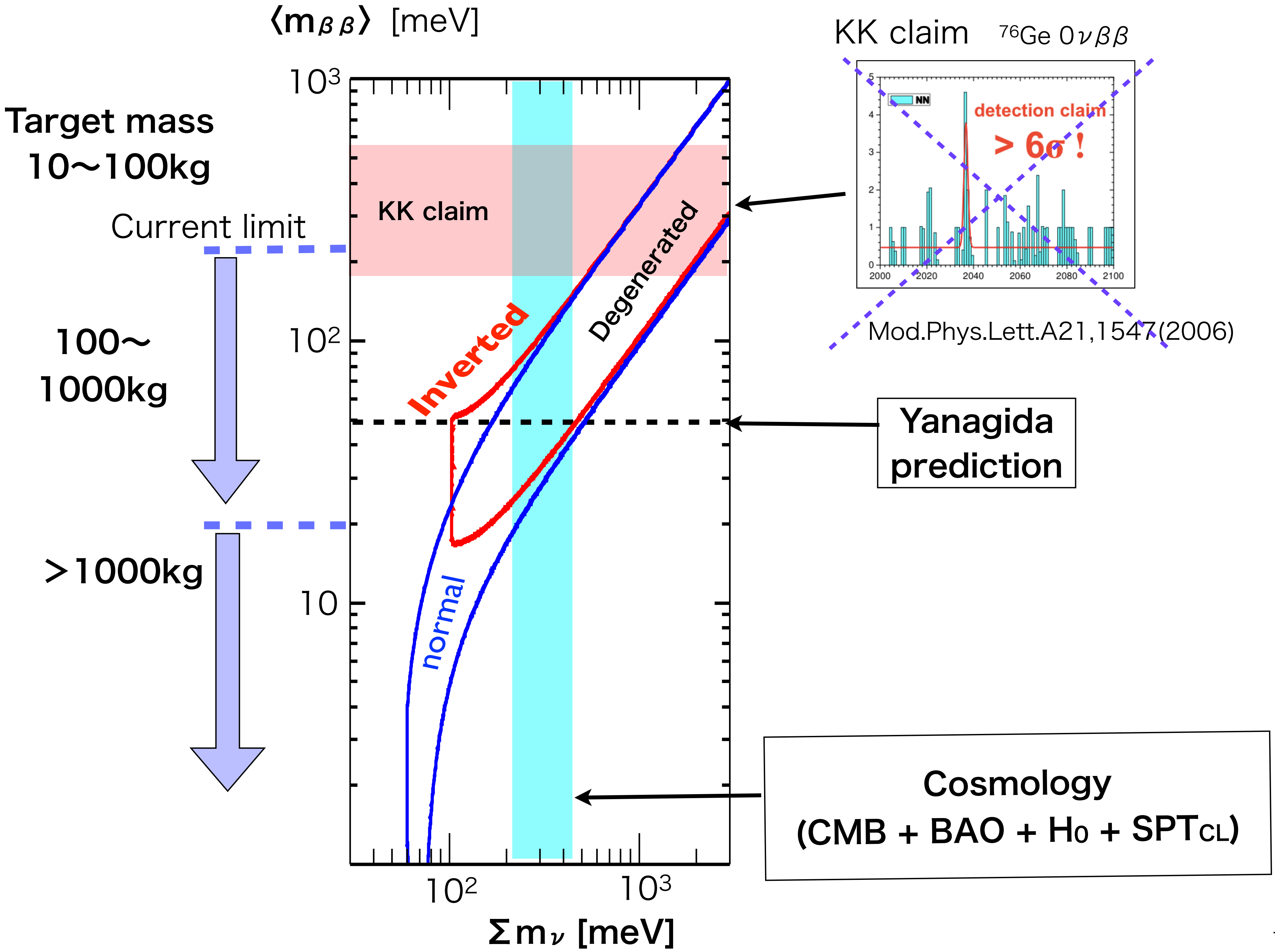
Large mass, Extremely low B.G.

Heavy shield, high purity,

Techniques ; E-resolution, tracking, timing, . . .

＊Cost





⟨mββ⟩ [meV]
10^3
10^2
10
Target mass
10〜100kg
Current limit
100〜
1000kg
>1000kg
KK claim
Inverted
Degenerated
normal
10^2
10^3
Σmν [meV]
KK claim 76Ge 0νββ
NN
detection claim
> 6σ !
2000
2020
2040
2060
2080
2100
Mod.Phys.Lett.A21,1547(2006)
Yanagida prediction
Cosmology
(CMB + BAO + H0 + SPTCL)

Current status of $0\nu\beta\beta$ searches

Nucleus	Experiment	$T^{0\nu}_{1/2}$ limit (yr) @ 90% C.L.	$\langle m_{\beta\beta}\rangle$ (eV)
$^{48}Ca \rightarrow {}^{48}Ti$	ELEGANT VI	$> 5.8 \times 10^{22}$	< 3.5-22
$^{76}Ge \rightarrow {}^{76}Se$	GERDA	$> 2.1 \times 10^{25}$	< 0.19-0.30*
$^{82}Se \rightarrow {}^{82}Kr$	NEMO-3	$> 3.2 \times 10^{23}$	< 0.8-1.4
$^{96}Zr \rightarrow {}^{96}Mo$	NEMO-3	$> 9.2 \times 10^{21}$	< 9.3-13.7
$^{100}Mo \rightarrow {}^{100}Ru$	NEMO-3	$> 1.0 \times 10^{24}$	< 0.4-0.7
$^{116}Cd \rightarrow {}^{116}Sn$	Solotvina	$> 1.7 \times 10^{23}$	< 1.2-2.2
$^{128}Te \rightarrow {}^{128}Xe$	(Geo chemical)	$> 7.7 \times 10^{24}$	< 0.7-1.2
$^{130}Te \rightarrow {}^{130}Xe$	CUORICINO	$> 2.8 \times 10^{24}$	< 0.44-0.81
$^{136}Xe \rightarrow {}^{136}Ba$	KamLAND-Zen	$> 2.6 \times 10^{25}$	< 0.14-0.28
	EXO-200	$> 1.1 \times 10^{25}$	<0.21-0.43
$^{150}Nd \rightarrow {}^{150}Sm$	NEMO-3	$> 1.8 \times 10^{22}$	< 4.0-6.3

SuperNEMO, SNO+, Majorana, CUORE etc.
a flood of new experiments are in preparation !

KamLAND-Zen runs with the highest sensitivity !

^{136}Xe

Excellent for 0ν search!

High Q-value: 2.458MeV
Longest $2\nu\beta\beta$ half life : 2.4×10^{21} yr
High nat.abundance: 8.9%

Rare gas

Established techniques for **isotope enrichment** and **purification**

High chemical stability
High safety, nontoxic,
Easy handling

Repeatable in experiments
Easy to scale up !

High solubility to LS
3.5 weight %
(4 times volume of Xe gas dissolves into LS !)

1 weak point : Expensive!

Xe+ LS combination is an excellent strategy !

Use KamLAND !

We make use of

KamLAND detector

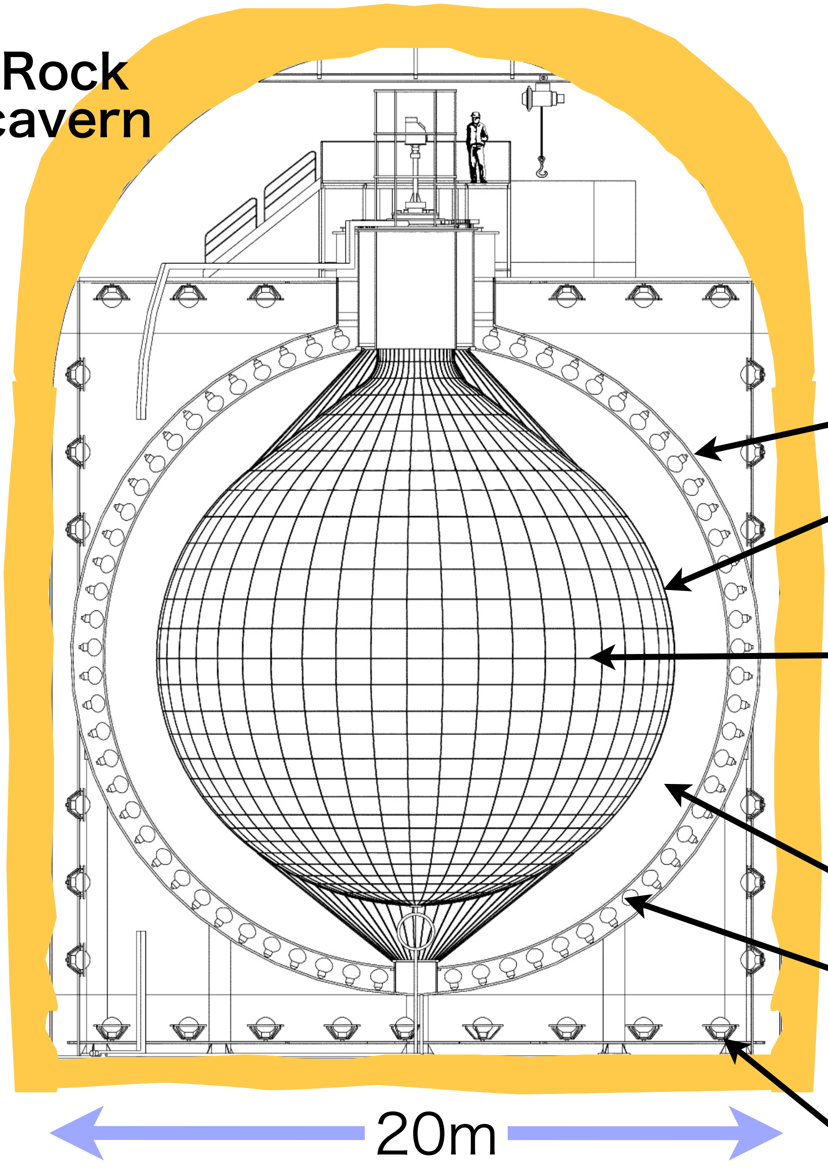
Kamioka Liquid-scintillator Anti-Neutrino Detector

KamLAND

Kamioka Liquid-scintillator Anti-Neutrino Detector

World's largest LS detector
Successfully operated since 2002.

1000m rock overburden (= 2,700m w.e.)
Cosmic ray flux : 1/100,000 of the ground level.



Spherical stainless steel tank (18mϕ)

Balloon (13mϕ):
135μm thick film (Nylon+ EVOH)

1,000ton Ultra-pure LS

Dodecane(80%)+Pseudocumene(20%)+PPO(1.4g/l)

U~10^{-18}g/g, Th~10^{-17}g/g, ^{40}K<10^{-16}g/g

Buffer oil

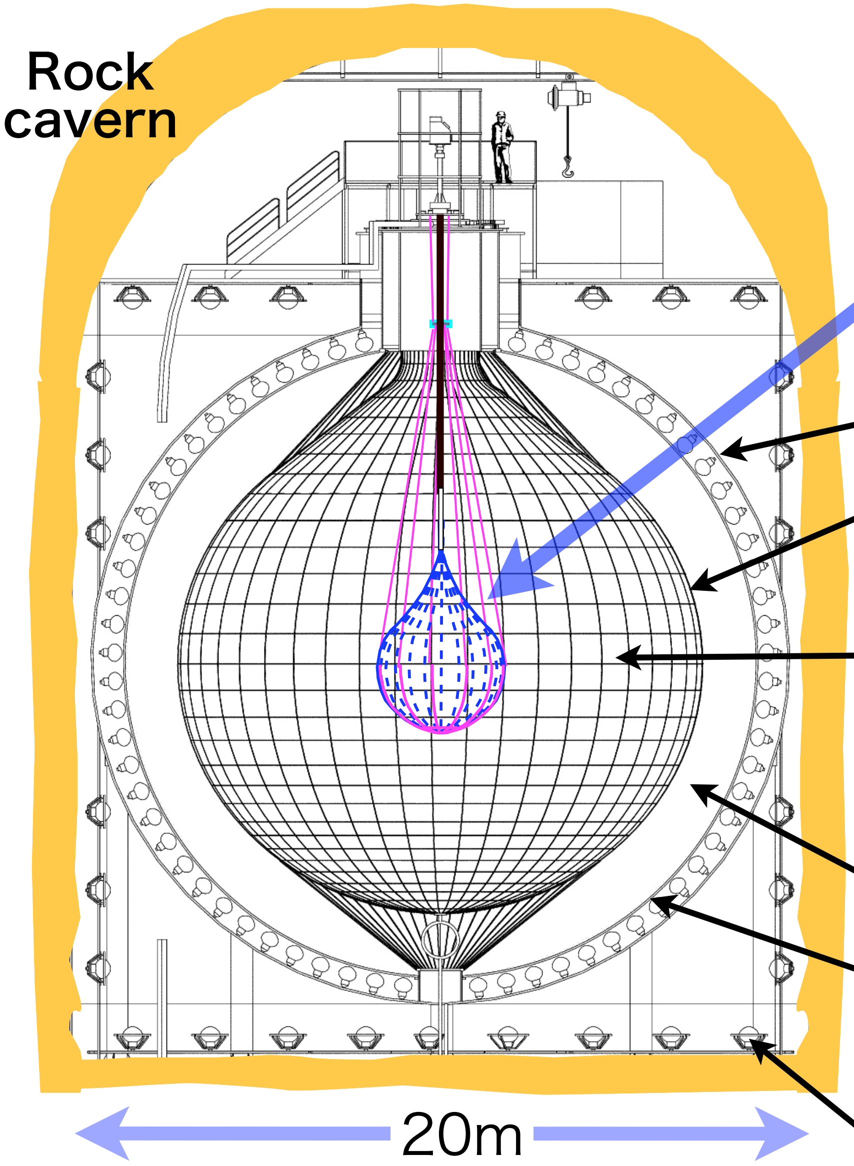
(1325 17"+554 20") PMTs

34% of 4π, $\sigma_E/E=6.5\%/\sqrt{E_{[MeV]}}$

Outer detector: 3200 ton purified water +225 20"PMT

KamLAND-Zen

Zero-Neutrino double-beta decay experiment



Mini-balloon

LS+380kg enriched with ^{136}Xe

Spherical stainless steel tank (18mϕ)

Balloon (13mϕ):

135μm thick film (Nylon+ EVOH)

1,000ton Ultra-pure LS

Dodecane(80%)+Pseudocumene(20%)+PPO(1.4g/l)

U~10^{-18}g/g, Th~10^{-17}g/g, ^{40}K<10^{-16}g/g

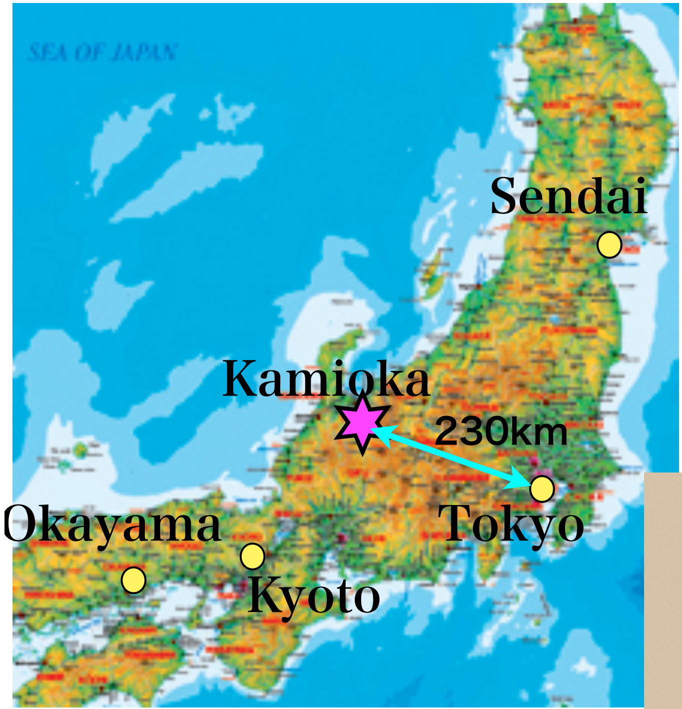
Buffer oil

(1325 17"+554 20") PMTs

34% of 4π, $\sigma_E/E=6.5\%/\sqrt{E_{[MeV]}}$

Outer detector: 3200 ton purified water +225 20"PMT

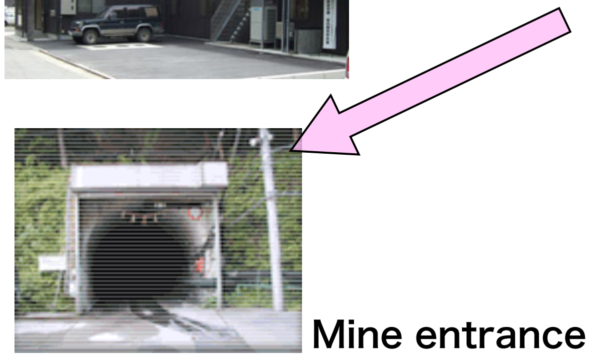
Location of KamLAND



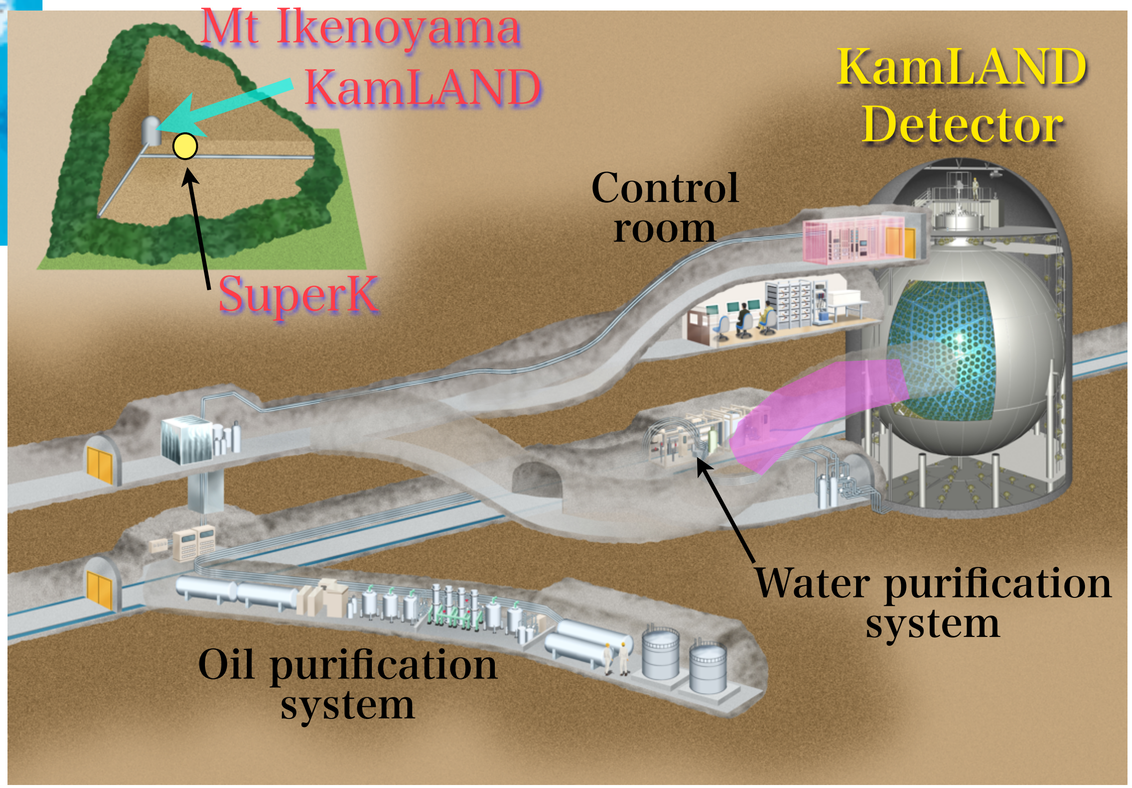
1000m underground of Kamioka mine, in Gifu prefecture. Former Kamiokande site.
Cosmic ray flux : 1/100,000 of the above ground

Mozumi area

Kamioka lab.

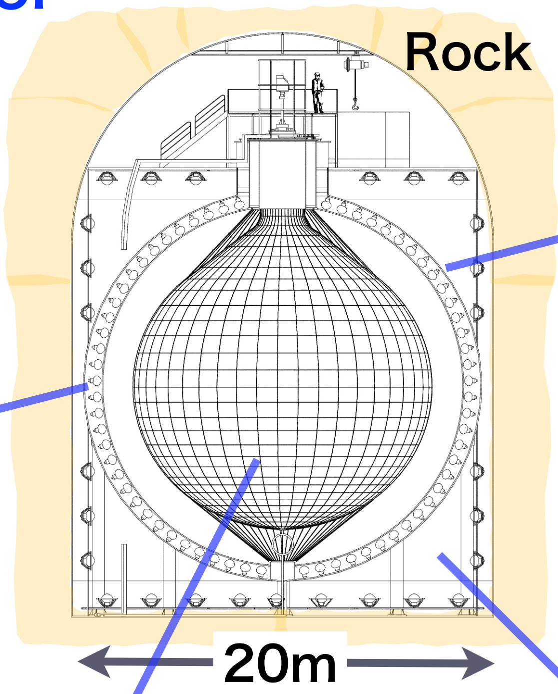


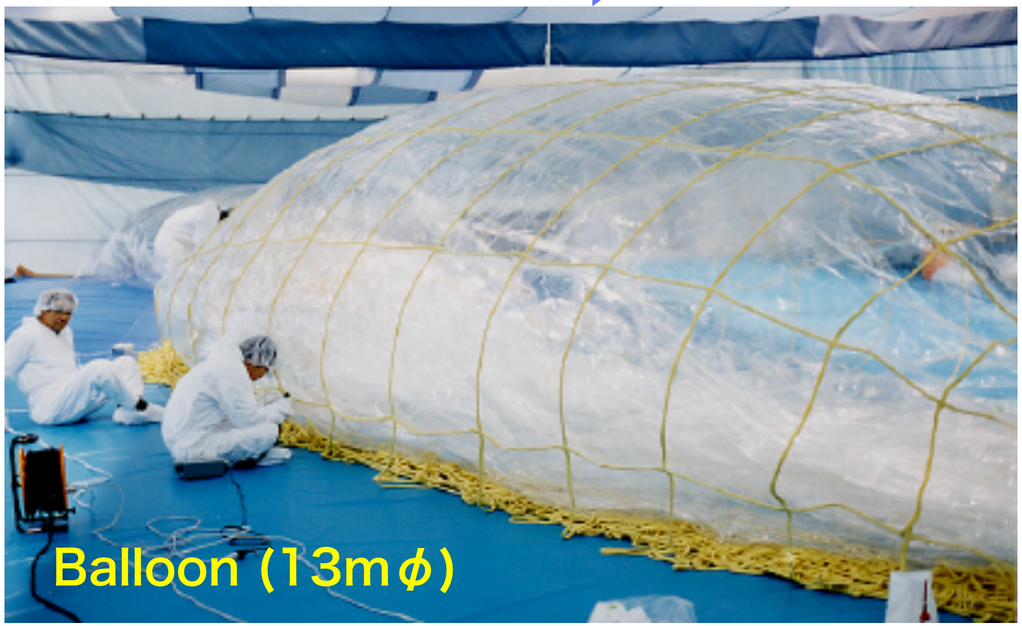
Mine entrance



KamLAND detector

Start data taking since Jan.2002



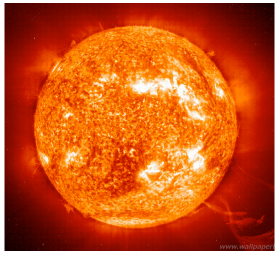


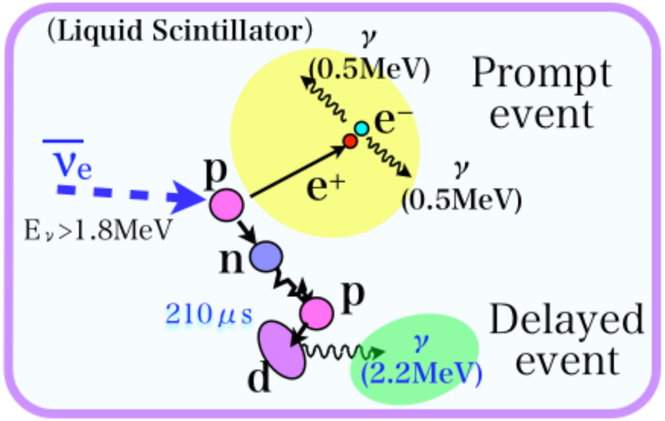
135μm (3 Nylon layers+EVOH 2 layers)

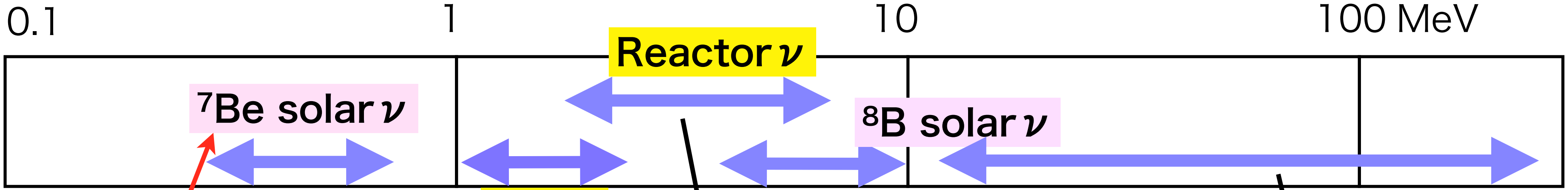
3200-ton pure water tank
+225 Kamikande 20”PMT

KamLAND results

$\overline{\nu}_e$ detection by inverse beta decay reaction

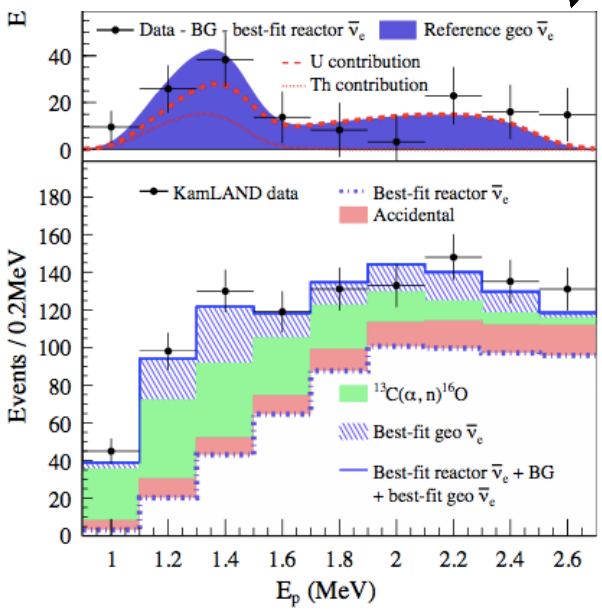




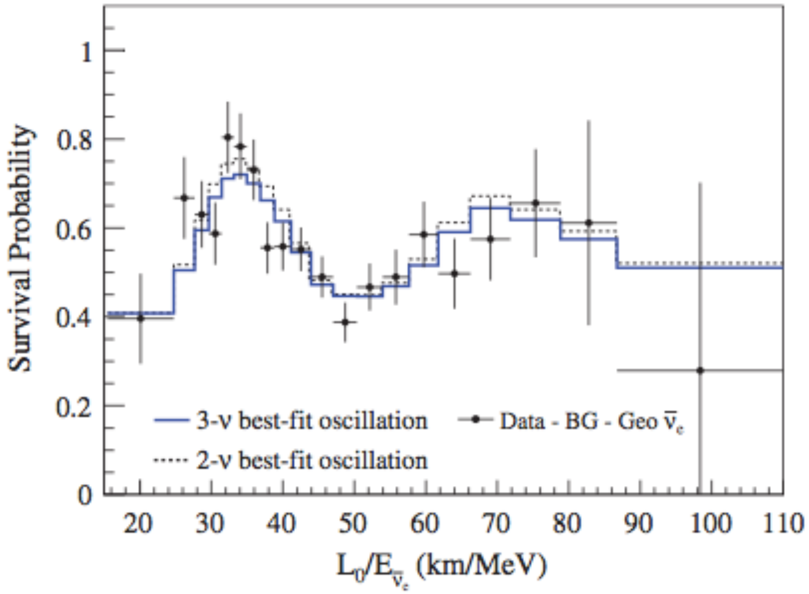


*Purification (2 times)
(in 2007 and 2008)

Phys.Rev.D88, 033001(2013)



Phys.Rev.D83, 052002(2011)

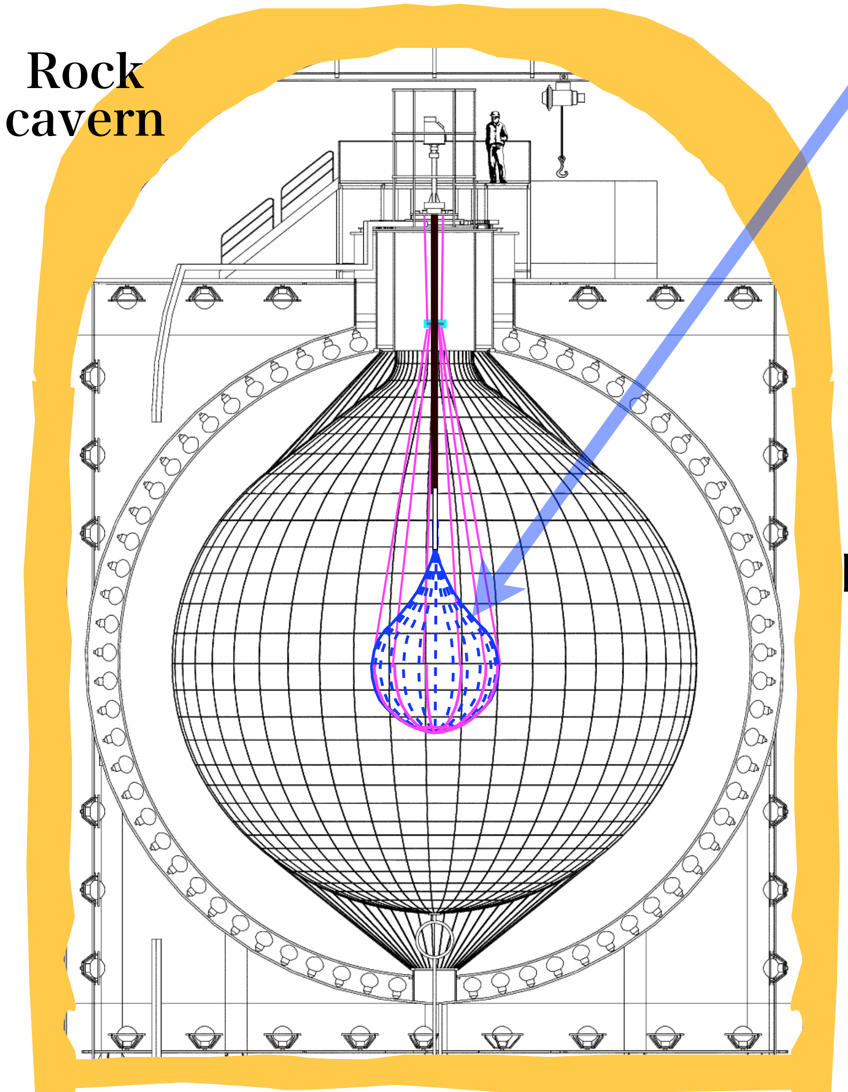


Atmospheric ν
Supernova ν
GRB, AGN
Nucleon decay
•
•
•
•

KamLAND-Zen experiment

Zero-Neutrino double-beta decay experiment

KamLAND-Zen



Mini-balloon (3.08mϕ)
filled with Xe+LS

Xe 91% enriched with ^{136}Xe,
320kg => 380kg

World's largest ^{136}Xe amount.

LS Decane(82%)+Pseudocumene(18%)
+PPO(2.7g/ℓ)+Xe (2.44wt%)

Film Clean nylon of 25μm thick U= 2×10^{-12}, Th:3×10^{-12}, ^{40}K: 2×10^{-12}(g/g)

Minimum detector modification (low cost and short construction period).

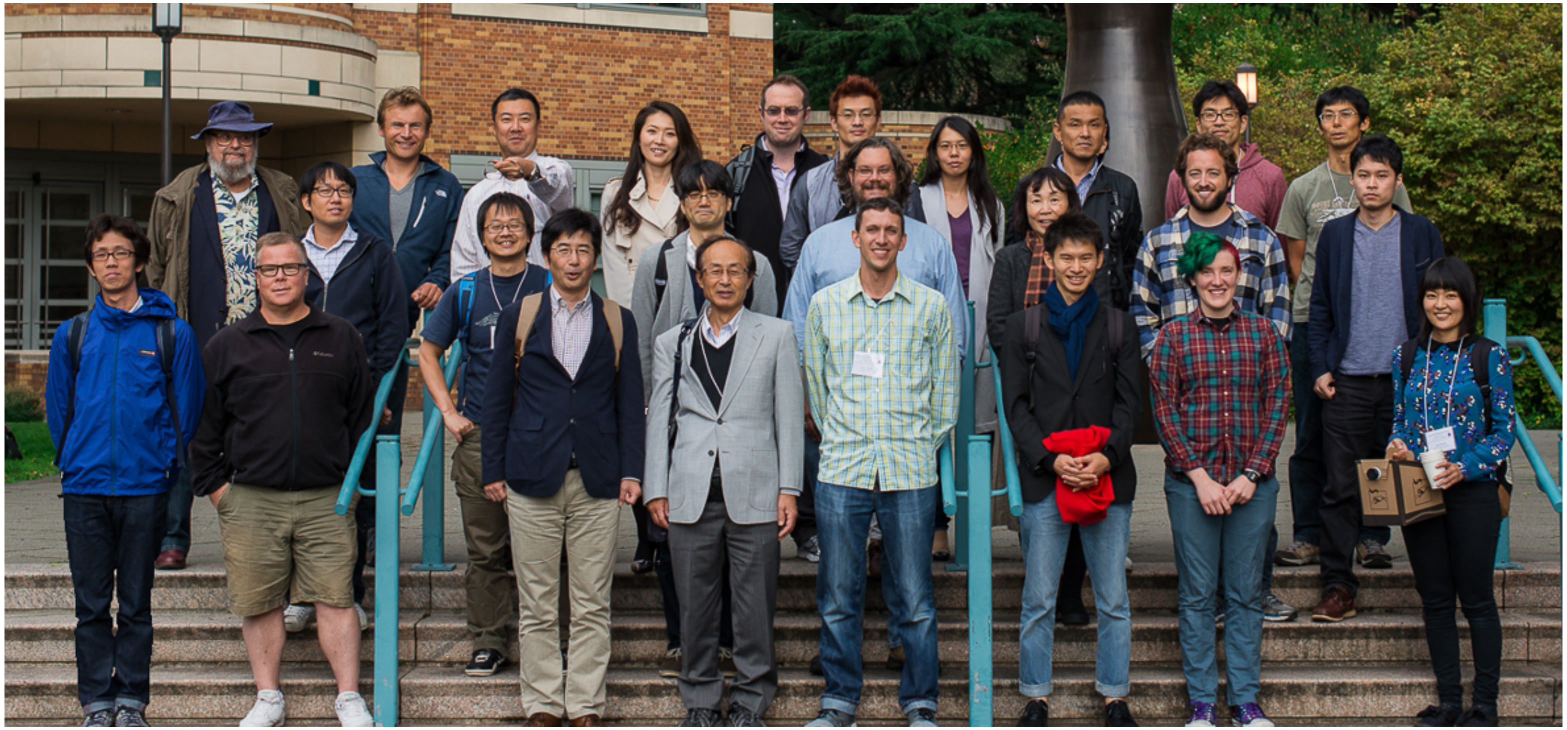
Detector performance is well understood.

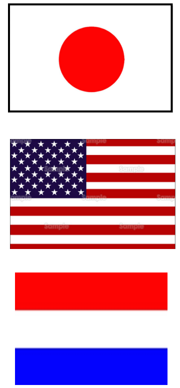
High scalability, repeated Xe purification, blank run is possible.

Other physics can be done in parallel.
(Geoν, Atmosphericν, SuperNova ν, etc.)

KamLAND-Zen Collaboration

～ 40 physicists from 11 institutes,





Sep.16, 2015
@Univ. of Washington,

Tohoku Univ : *A.Gando, Y.Gando, H.Ikeda, K.Imoue, K.Ishidoshiro, M.Koga, S.Matsuda, T.Mitsui, K.Nakamura, I.Shimizu, J.Shirai, A.Suzuki, K.Tamae, K.Ueshima, H.Watanabe, S.Obara, S.Hayashida, T.Oura, Y.Shirahata, T.Hachiya, H.Ozaki, Y.Karino, T.Takai, Y.Teraoka, A.Hayashi, Y.Shibukawa, Y.Honda, K.Soma*

Tokyo Univ. IPMU : *A.Kozlov, Y.Takemoto, B.E.Berger* **Oska Univ :** *S.Yoshida*

Tokushima Univ : *K.Fushimi* **Berkeley National Lab :** *T.I.Banks, B.K.Fujikawa, T.O'Donnell,*

Massachusetts Institute of Technology : *.LA.Winslow, J.Ohellet, E.Krupczak*

Univ. of Tennessee : *Y.Efremenko* **North Carolina Univ :** *H.J.Karwowski*

Duke Univ : *D.M.Markoff, W.Tornow* **Univ. of Washington :** *J. Detwiler, S.Enomoto*

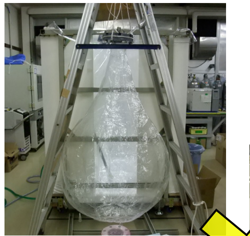
Univ. of Amsterdam : *M.P.Decowski*

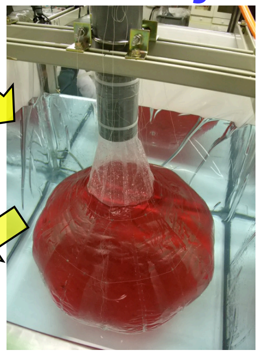
Development of mini-balloon (2009~2010)

Film characteristics and sealing technique

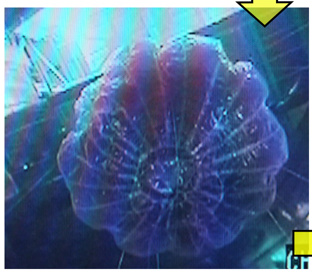
Film material	Nylon, 25 μm thick
Mechanical strength	>10N/cm
Xe tightness (leak)	<1kg/5yr
Light transparency	>95% (400nm)
LS compatibility	Long term stability
Radio-purity (g/g)	U,Th~10^{-12}, ^{40}K ~10^{-11}
Sealing technique	Impulse welding*

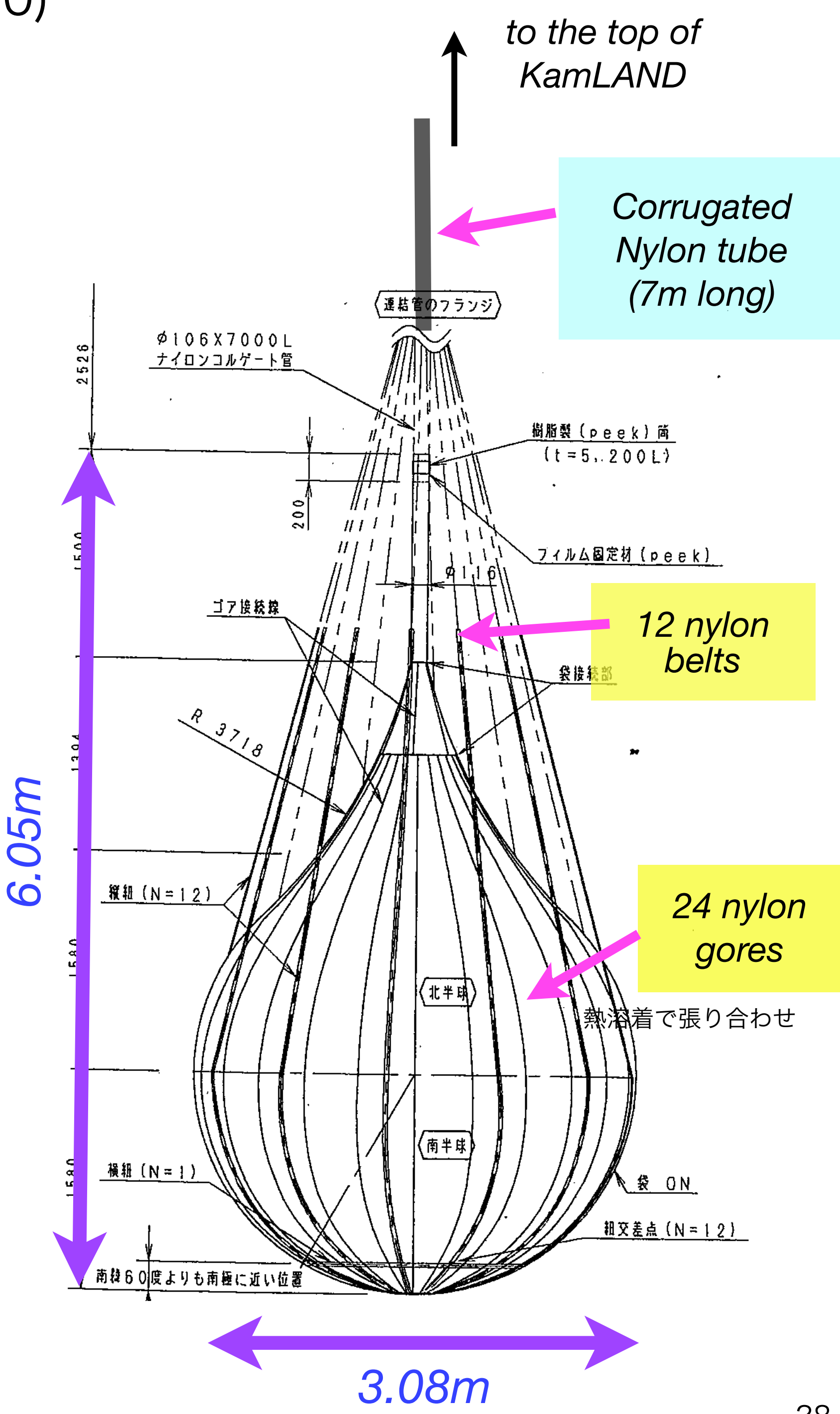
*Direct heating with well-controlled temp. & time.





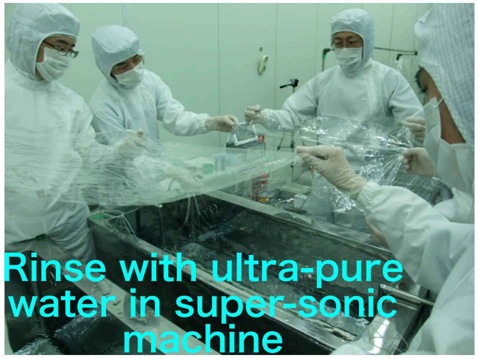
Many trials balloons





Construction in a class1 super clean room in Tohoku University. *(=1 particle(>0.1μm) /feet³)*

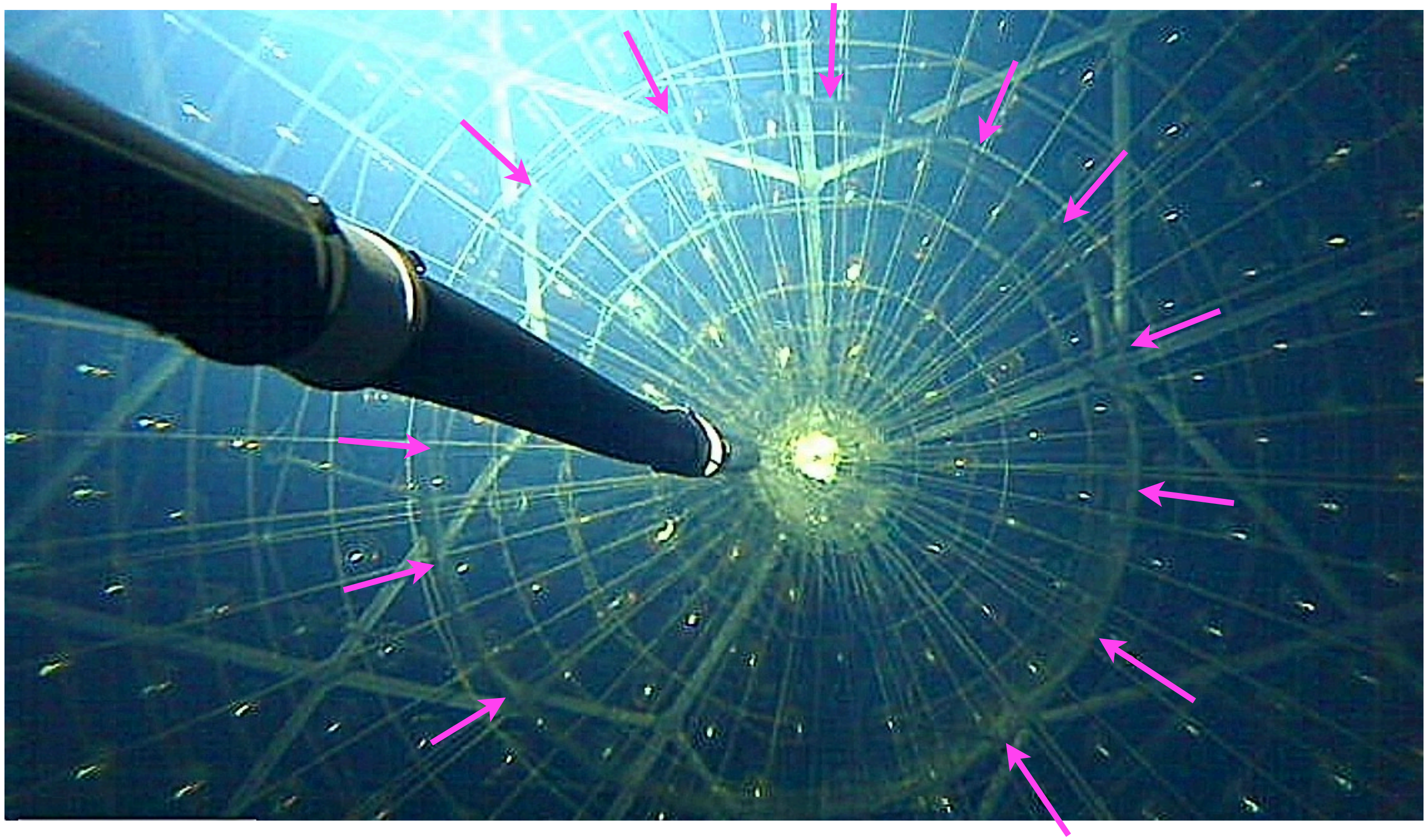
(May-July, 2011)



to KamLAND

Installation to the detector

Successfully Installed in the KamLAND, *(Aug.23,2011)*



KamLAND-Zen activity

2011	2012	2013	2014	2015	2016

Start KL-Zen

Restart

Construction of Mini-balloon after 2 years R&D

Phase1

Xe-LS Purification

Phase2

Now

New phase

Now: Stop phase2 and doing analysis for post-purification data. Preparation for New phase.

$0\nu\beta\beta$ $T^{0\nu}_{1/2}$

1st: Phys.Rev.C 85, 045504 (2012)

> 5.7×10^{24} yr (90%C.L.) (27.4kg*yr)

2nd: Phys.Rev.C 86, 021601(R) (2012)

> 6.2×10^{24} yr (90%C.L.) (38.6kg*yr)

3rd: Phys.Rev.Letters 110, 062502 (2013)

> 1.9×10^{25} yr (90%C.L.) (89.5kg*yr)

> 3.4×10^{25} yr (KL-Zen +EXO-200 90%C.L.)

$\langle m_{\beta\beta}\rangle$ < (120~250) meV

$2\nu\beta\beta$ $T^{2\nu}_{1/2}$

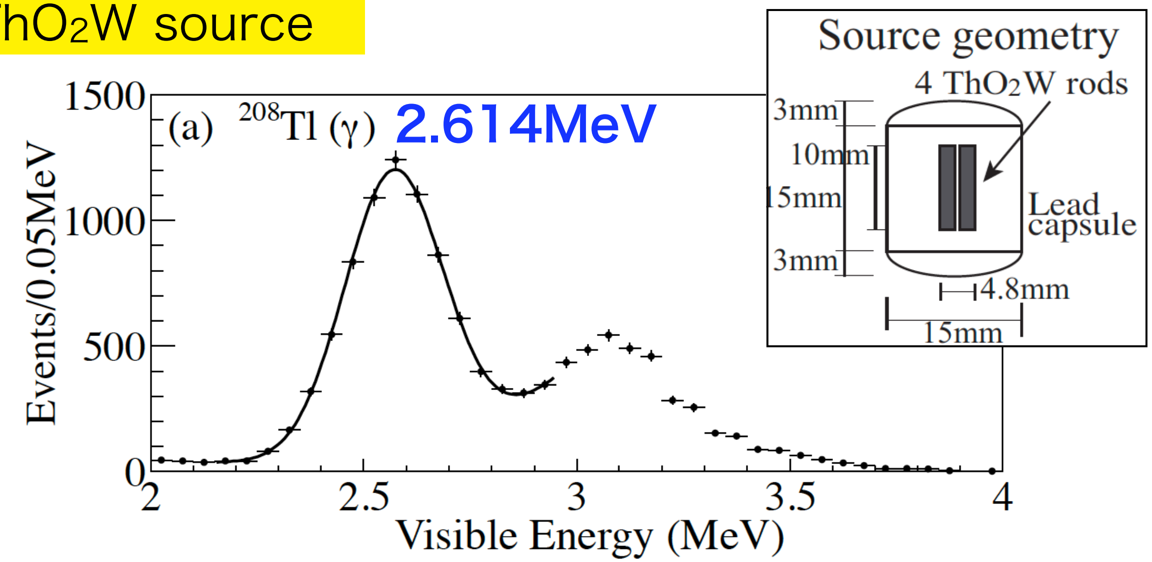
$2.38 \pm 0.02(st) \pm 0.14(sys) \times 10^{21}$ yr

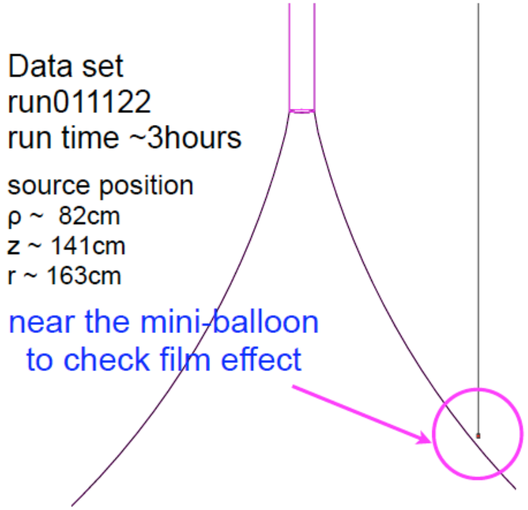
$2.30 \pm 0.02(stat) \pm 0.12(sys) \times 10^{21}$ yr

Consistent with EXO-200 (136Xe)

Energy calibration

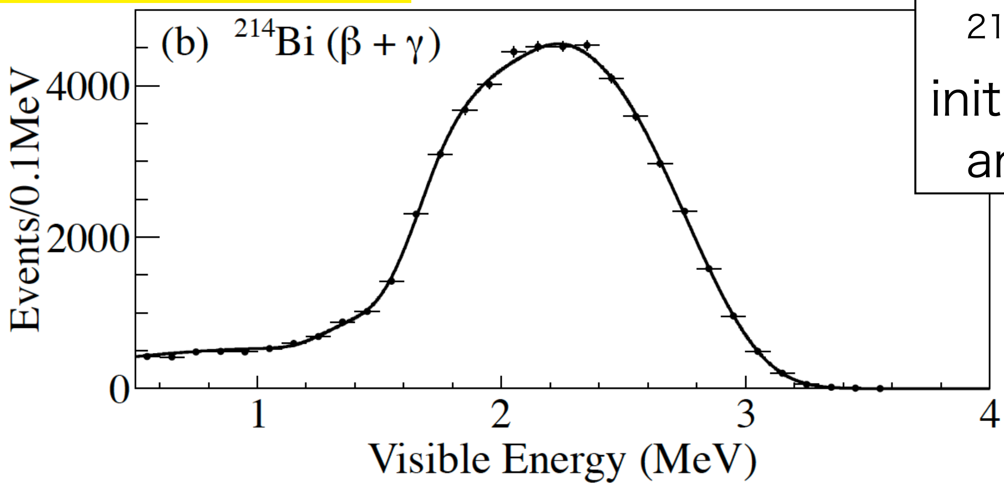
ThO2W source



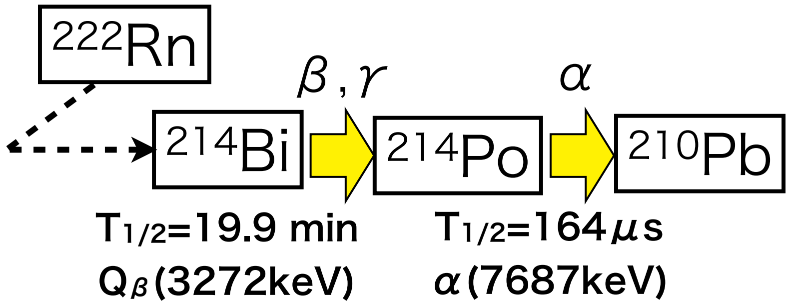


$\Delta E/E = (6.6 \pm 0.3)\% / \sqrt{E_{[MeV]}}$ (@2.614MeV)

^{214}Bi→ ^{214}Po events



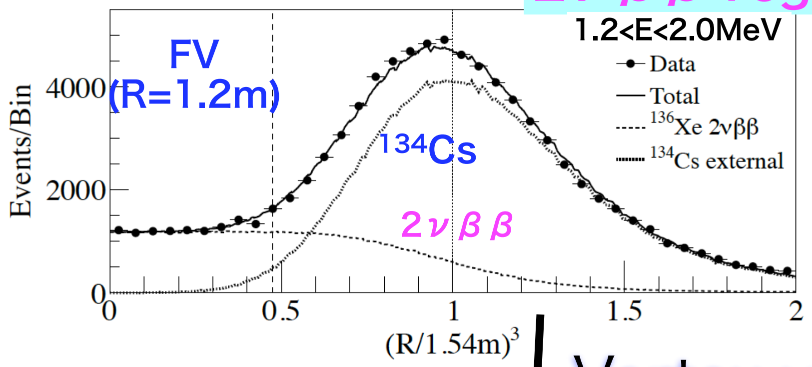
Using delayed coincidence of ^{214}Bi⇒^{214}Po from residual ^{222}Rn in the initial stage, the energy scale parameters are tuned to reproduce the spectrum.

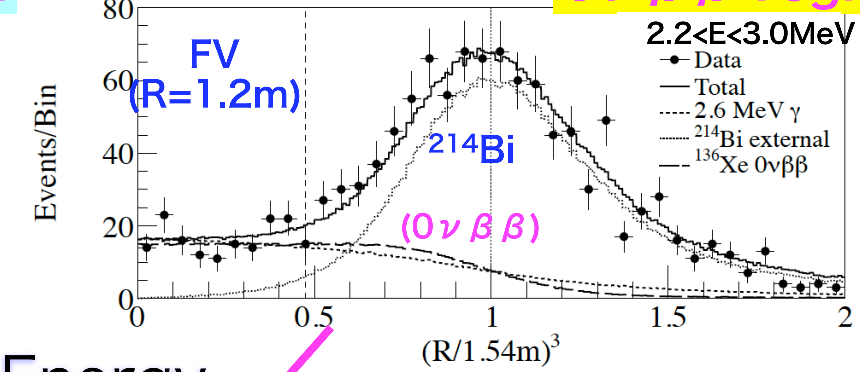


2.225MeV γ's from spallation neutrons; n+p→d+γ

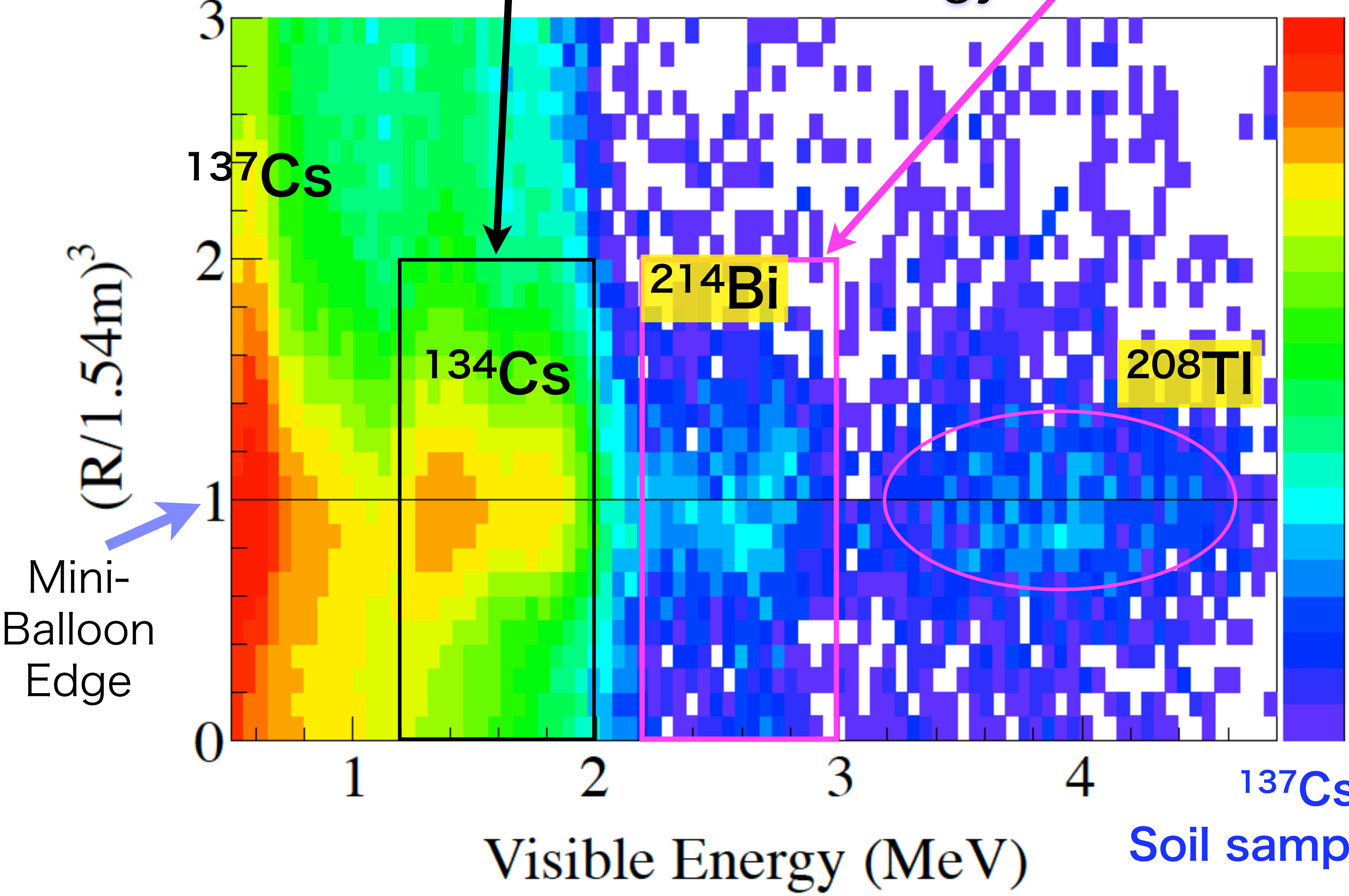
(Systematic variation of the reconstructed energies over the Xe-LS volume <1.0%)

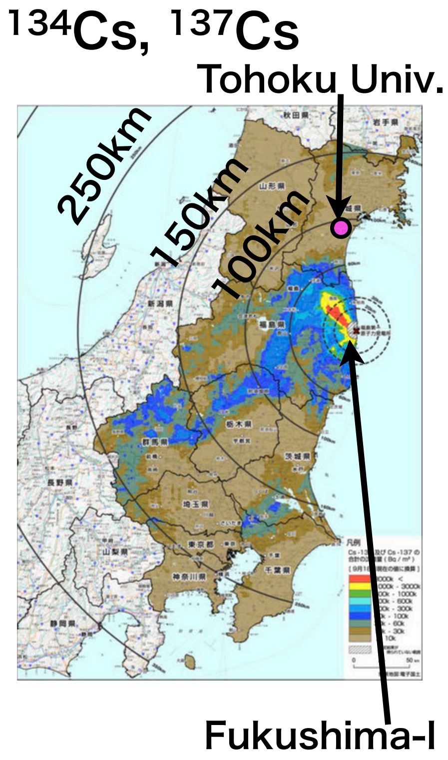
Vertex distribution





Vertex vs. Energy





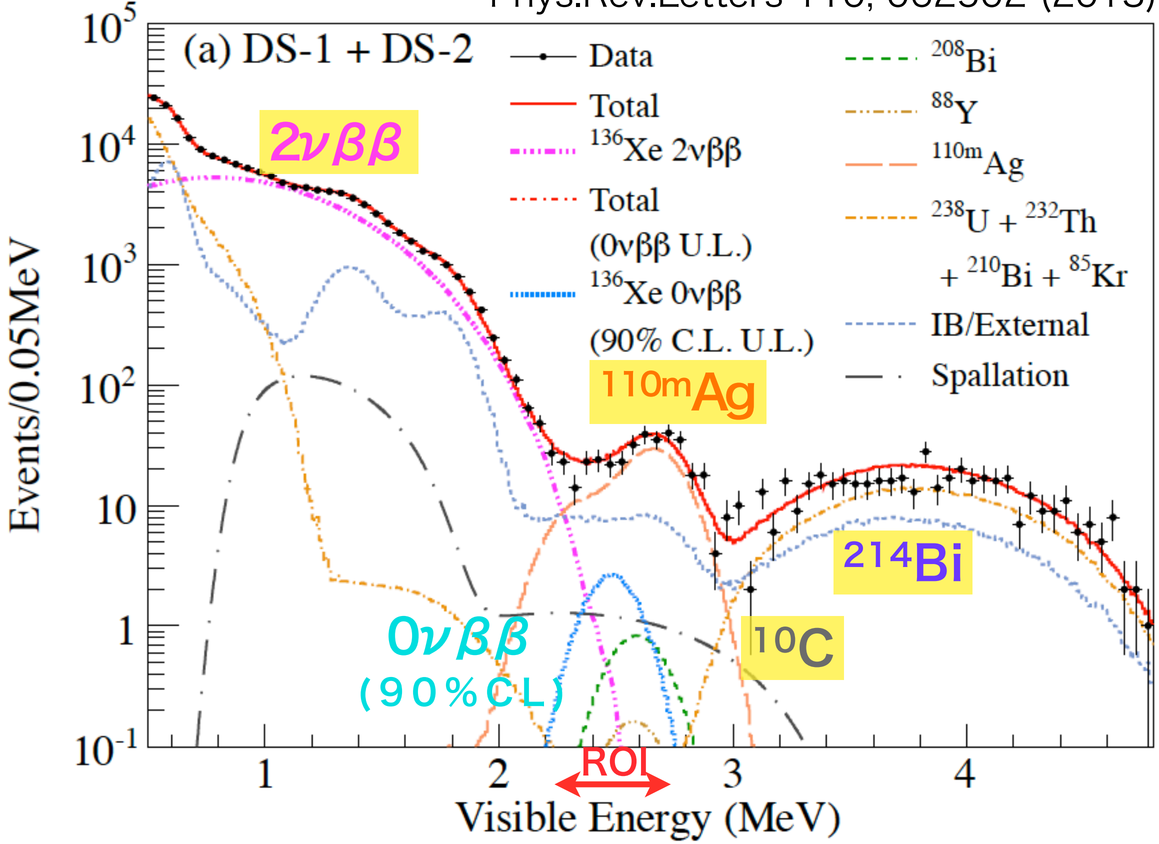
$^{137}Cs/^{134}Cs \sim 0.8$

Soil samples around RCNS.

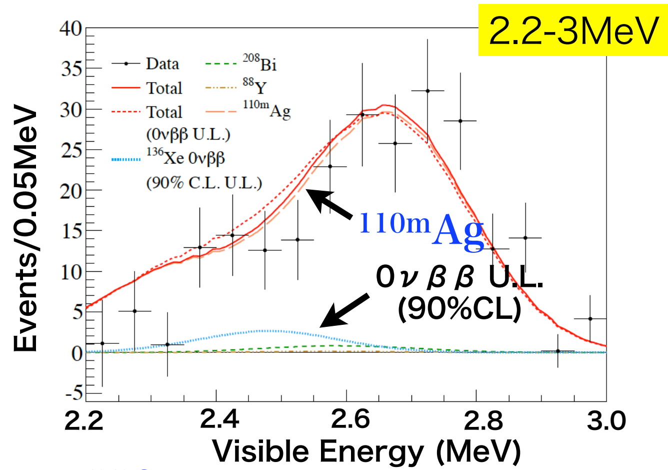
Phase1 results (Oct.'11～Jun.'12)

^{136}Xe 89.5kg*yr (Live time =213.4days)

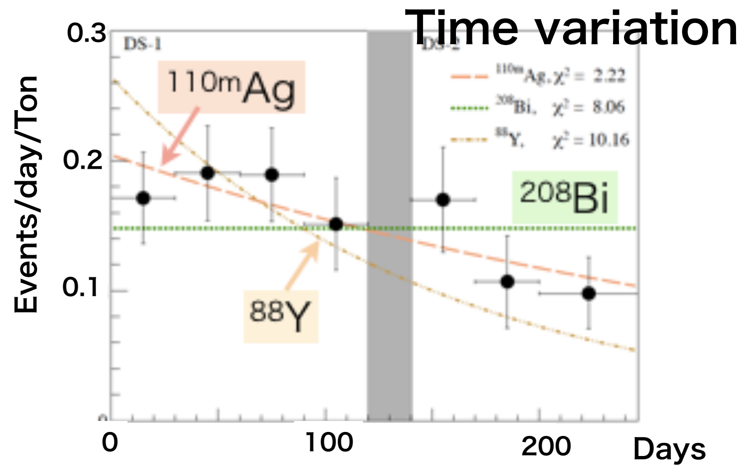
Phys.Rev.Letters 110, 062502 (2013)



(Q=2.458MeV)



^{110m}Ag is dominant !



Consistent with ^{110m}Ag decay ($T_{1/2}$=250d).

$T^{0\nu}_{1/2} > 1.9\times10^{25}$ yrs (95%CL)

Backgrounds

^{110m}Ag (Xe-LS): Largest !
=> Xe-LS purification.
^{214}Bi (mini-balloon film, U-daughter)
^{10}C (Xe-LS, μ-on spallation)
$2\nu\beta\beta$(Xe-LS)

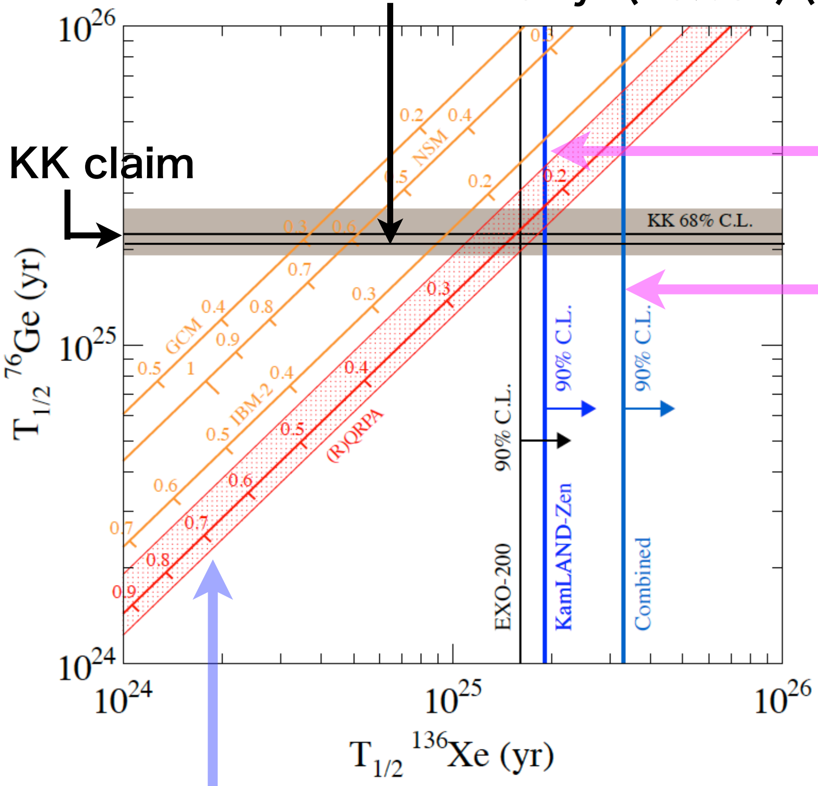
KamLAND-Zen (phase1) results and other high sensitivity experiments (GERDA, EXO-200)

^{76}Ge ^{136}Xe

GERDA

> 2.1×10^{25}yr (90%CL) (2013)

KK claim



Predictions from NME calculations

$$T_{1/2}^{0\nu} > 1.9 \times 10^{25} \text{yr} \ (90\%\text{CL})$$ KamLAND-Zen Phae1

$$T_{1/2}^{0\nu} > 3.4 \times 10^{25} \text{yr} \ (90\%\text{CL})$$ KamLAND-Zen Phase1 +EXO-200

$\langle m_{\beta\beta} \rangle < (120 \sim 250)$ meV

Comparison with ^{76}Ge experiment by using Nuclear matrix element

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

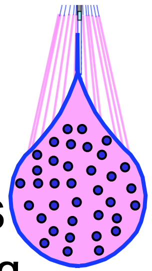
$$T_{1/2}^{0\nu} = 2.23^{+0.44}_{-0.31} \times 10^{25} \text{yr (90\% CL)}$$ KK claim

- **Exclude the KK claim in ^{76}Ge $0\nu\beta\beta$ (> 97.5%CL).**
- **Constrain $0\nu\beta\beta$ more strictly than a next-generation search (GERDA) for ^{76}Ge.**

KamLAND-Zen activity ~Purification~

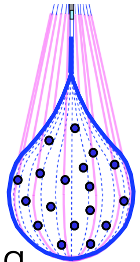
2011	2012	2013	2014	2015	2016

Start KL-Zen — Phase1
Purification
Restart — Phase2 — Now



Xe+LS
$+^{110m}Ag$

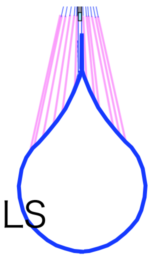
Jun 2012 : Stop Phase1 data taking.
Xe extraction by replacing Xe-LS with dummy LS.
Leakage trouble in a pump
increased bkg in the balloon film.
^{110m}Ag remained in Xe-depleted LS.



LS
$+^{110m}Ag$

Xe purification (distillation & getter).

Aug 2012: Replace LS with new purified LS.
^{110m}Ag reduced 1/3〜1/4.

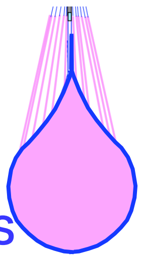


New LS

Nov 2012: LS distillation in circulation mode (×1)

Fire accident

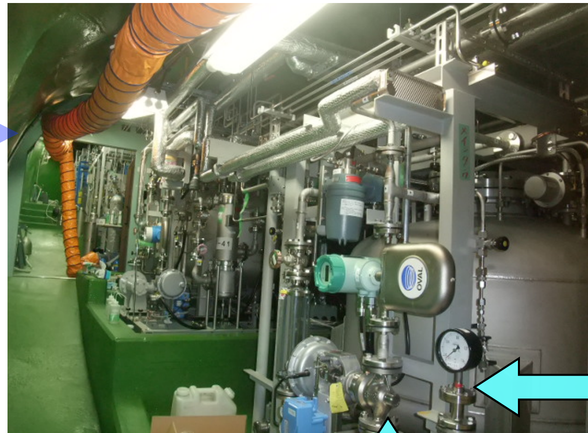
Jul 2013: LS distillation in circulation mode (×2)



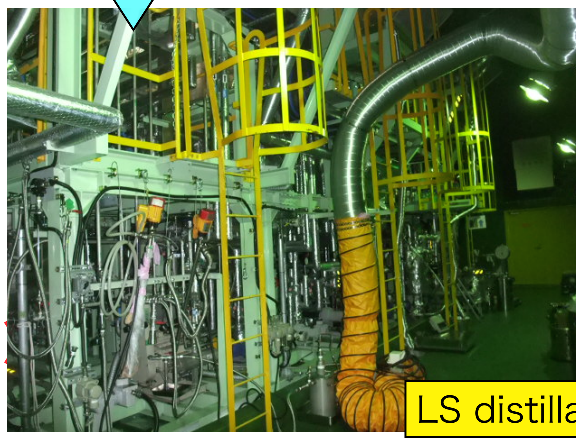
New
Xe+LS

Oct 2013: Replace LS with new purified LS.
Nov 2013: Dissolve Xe to LS. (Xe: 320⇒380kg)
Dec 2013: Start Phase2 data taking.

Xe Collection / Density control

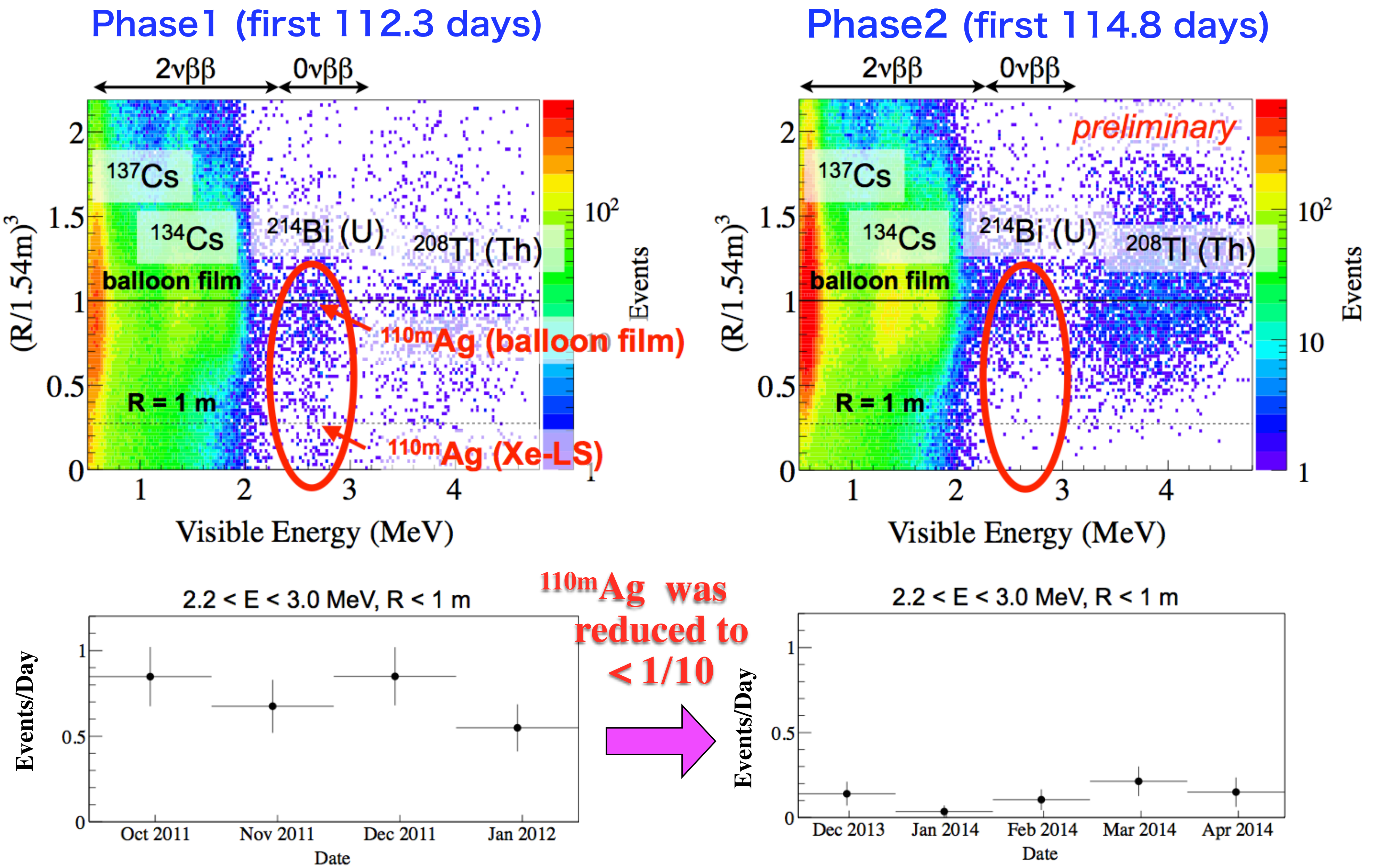


Xe purification distillation /Getter



LS distillation

^{110m}Ag reduction by purification

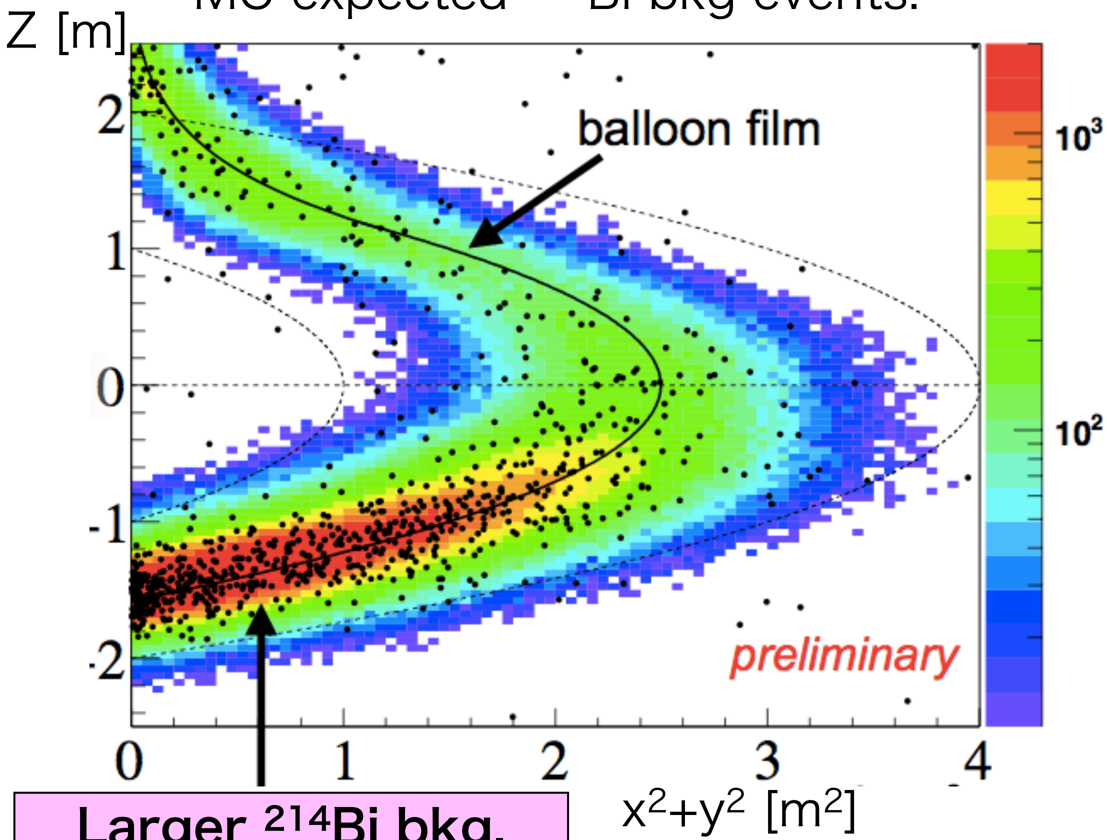


Primary bkg ; ^{214}Bi (U, balloon film), ^{10}C(spallation), remaining ^{110m}Ag ?

Optimization of Fiducial volume

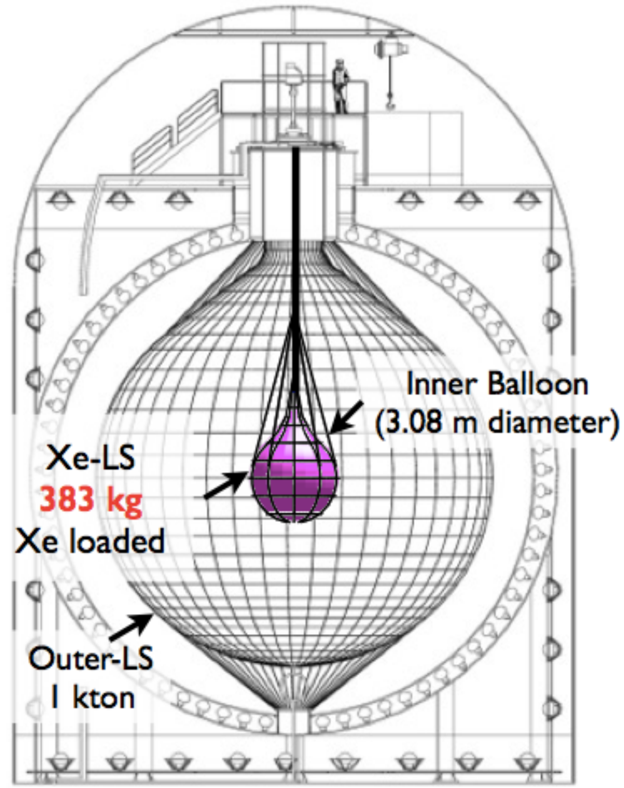
ROI: 2.3 <E< 2.7MeV

Vertex distribution of
Candidate $\beta\beta$ events (black dots) and
MC-expected ^{214}Bi bkg events.



Larger ^{214}Bi bkg. (due to a leakage of diaphragm pump during Xe extraction after phase1)

KamLAND-Zen
Phase2

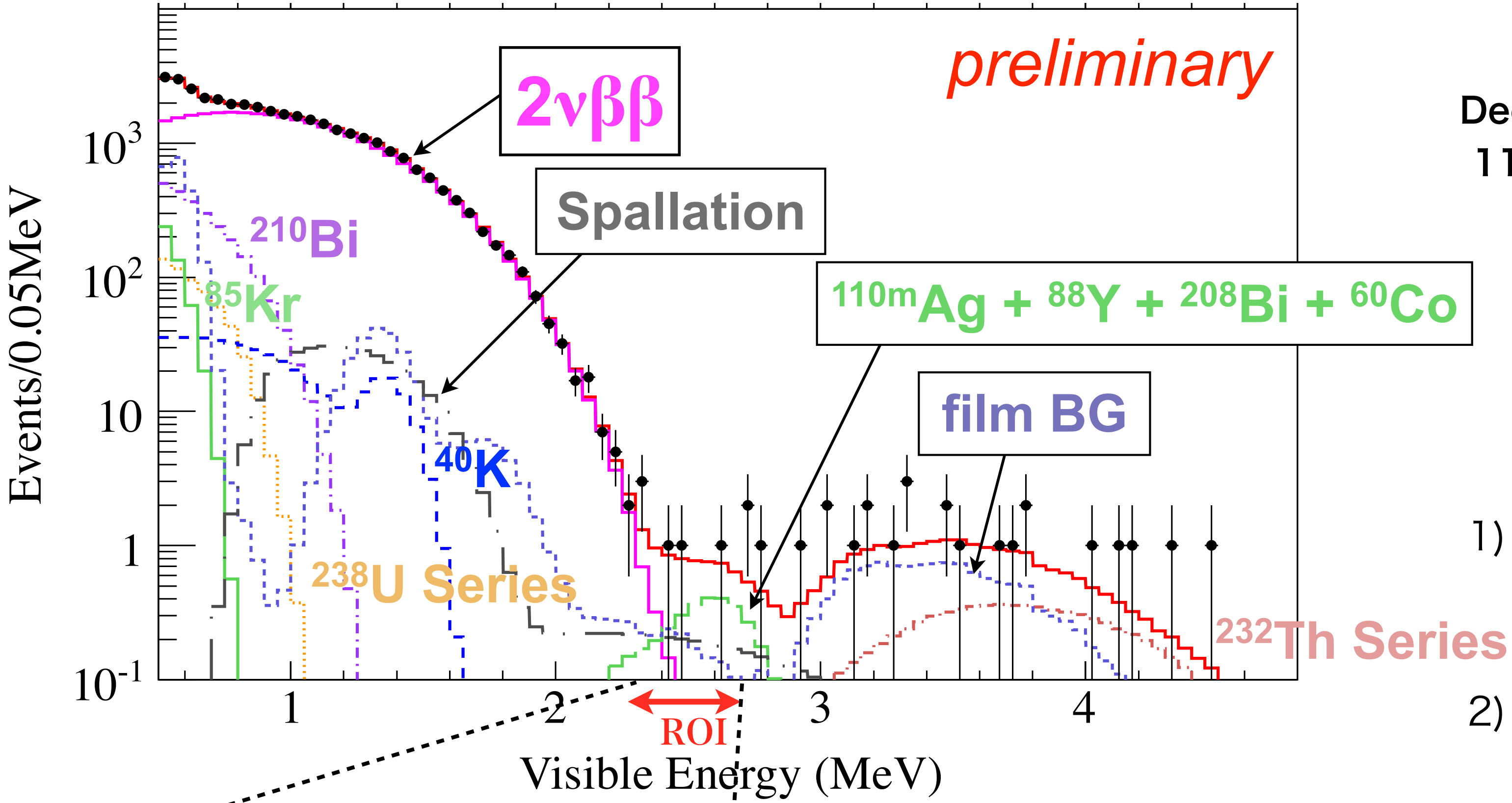


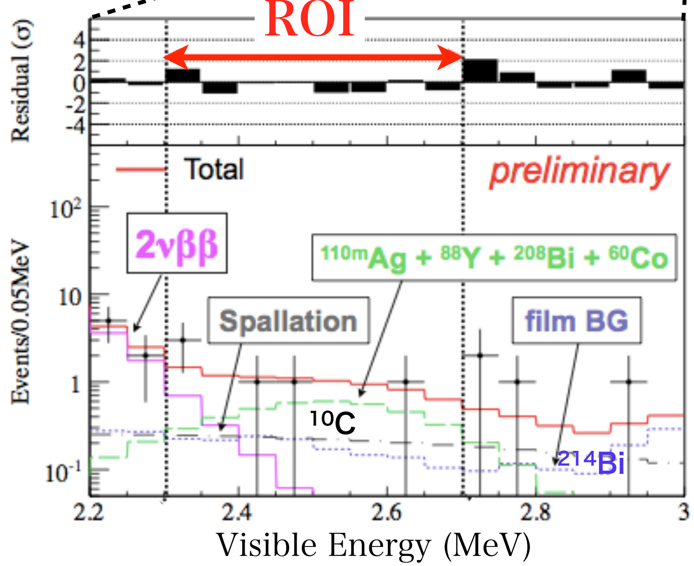
Multi-volume analysis

Spectral fit for target volume : R<2.0m

40 bins of equal volume in R and θ:
20 bins (upper)+20 bins (lower) hemisphere.

Phase2 spectrum (R<1m)





Phase2

Dec.11,2013-May1,2014,
114.8days, 348kg ^{136}Xe

Event selection and Number of events in ROI (ROI: 2.3-2.7MeV)

1) Around mini-balloon; R<2m & μ-on Veto
   3756 events
2) Volume cut ; R<1m
   413 events
3) Delayed coincidence cut ^{214}Bi→Po, ^{212}Bi→Po and Anti-ν
   10 events
4) Spallation cut
   6 events

Fit to energy-volume 2D spectra.

No excess over the bkg expectation.

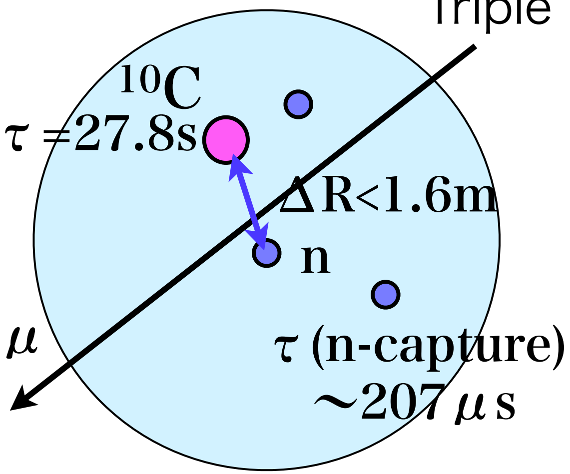
Limits on $0\nu\beta\beta$ rate
＜17.0 events/day/kton-LS (90%CL)

$T^{0\nu}_{1/2} > 1.3\times10^{25}$ yr (90%CL)

^{10}C rejection

^{10}C : produced by μ-on spallation of ^{12}C in LS,
$Q(\beta^+)$=3.648MeV, τ=27.8s,

Triple coincidence ; μ-n-^{10}C



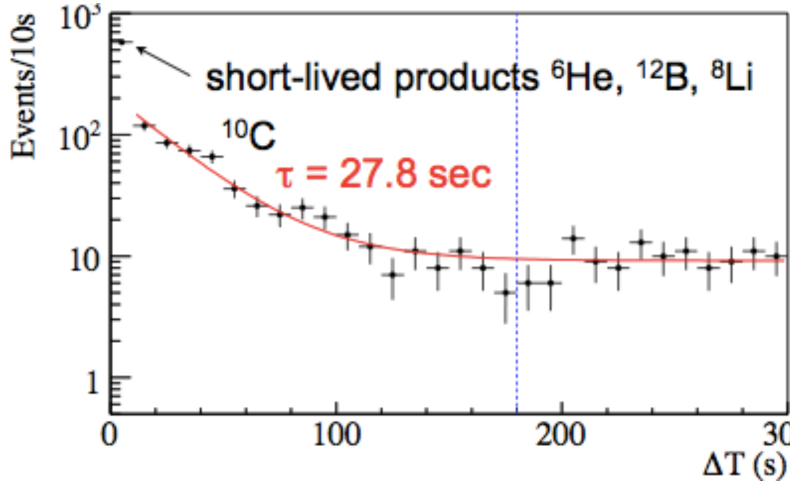
Space-time correlation cut

ΔT < 180s

ΔR < 1.6m

Preliminary

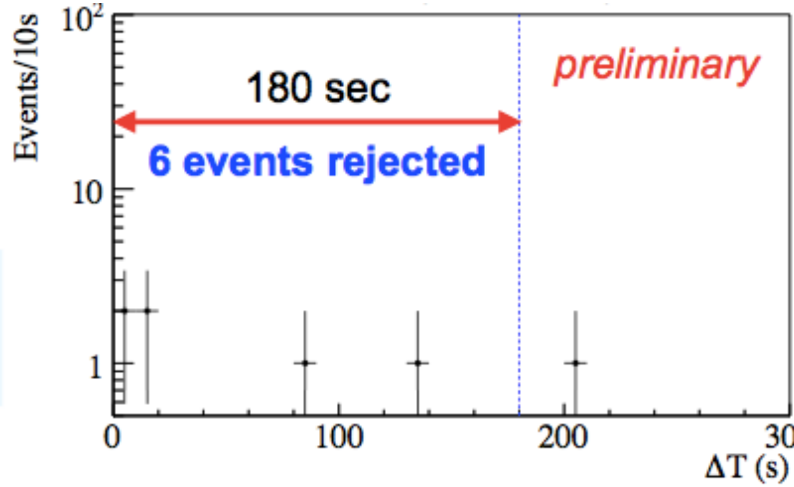
2.2<E<3.5MeV
Outer LS region (without Xe)



Neutron detection using MoGRA electronics system

Baseline restorer | **4 FADCs for each channel : 1GHz+3×200MHz** | **Trigger module**

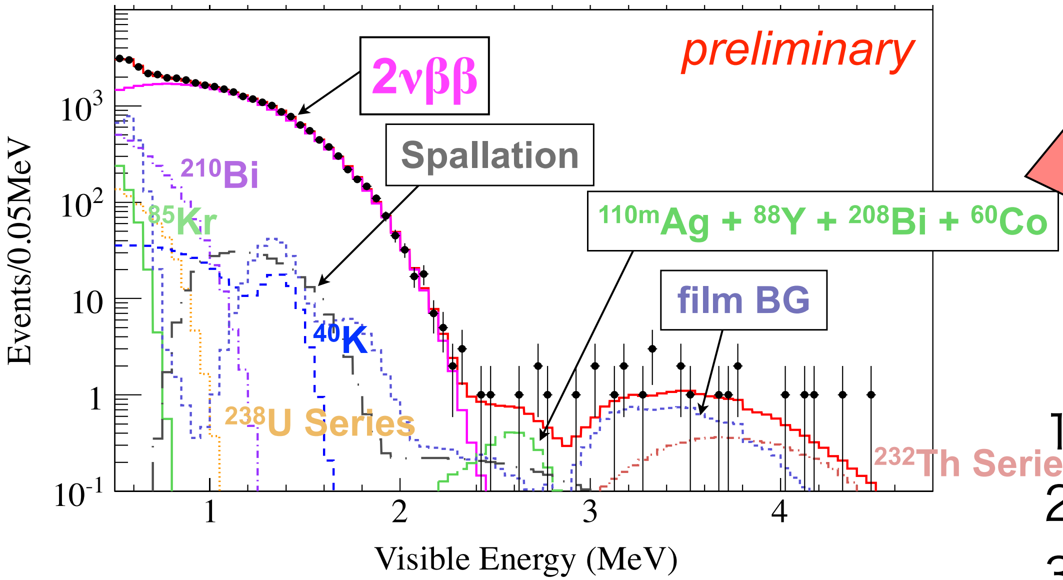
Xe- LS region (R<1.0m)



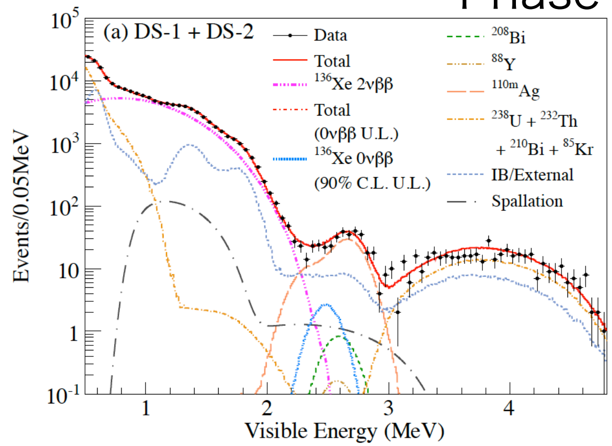
^{10}C Rejection efficiency = 72±5 %
Inefficiency for signal = 7 %

Efficient ^{10}C rejection can be made.

Phase2 (after purification)

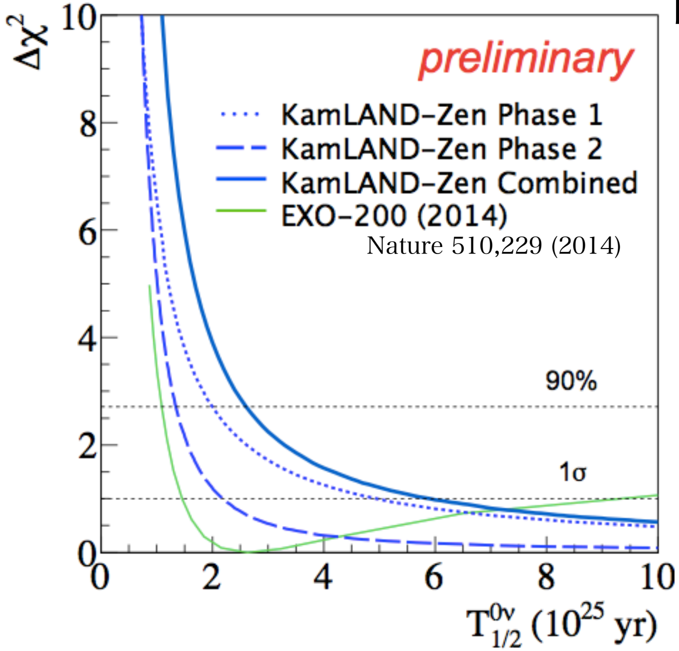


Phase1



1. ^{110m}Ag =>1/10 by Xe-LS purification !
2. ^{214}Bi (film): Fid.vol. optimization
3. ^{10}C (spallation) : μ-n-^{10}C triple coin.

Limits on half life $T^{0\nu}_{1/2}$(90%C.L.)



$T^{0\nu}_{1/2} > 1.9\times10^{25}$ yr (phase1) 213days

$> 1.3\times10^{25}$ yr (phase2) 115days

$> 2.6\times10^{25}$ yr

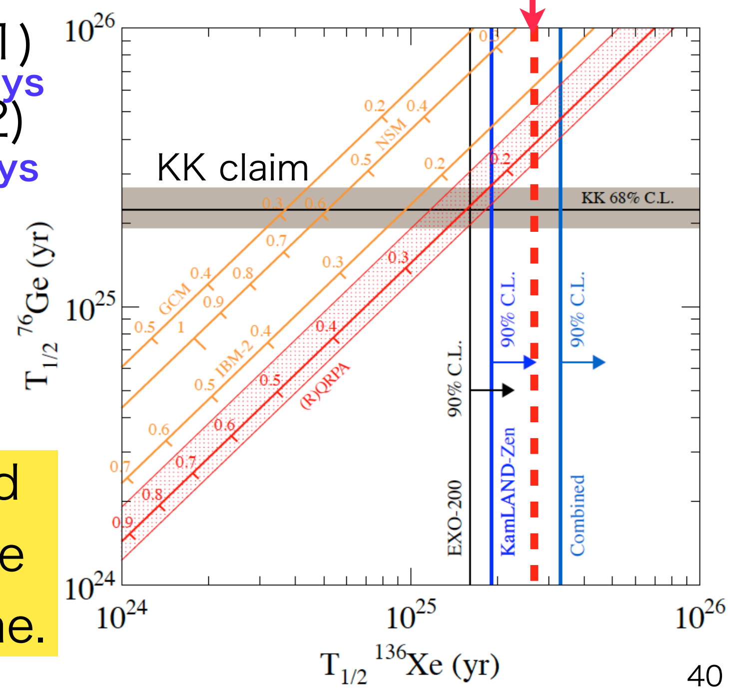
(Phase1+phase2)

⟨$m_{\beta\beta}$⟩ < 140~280meV

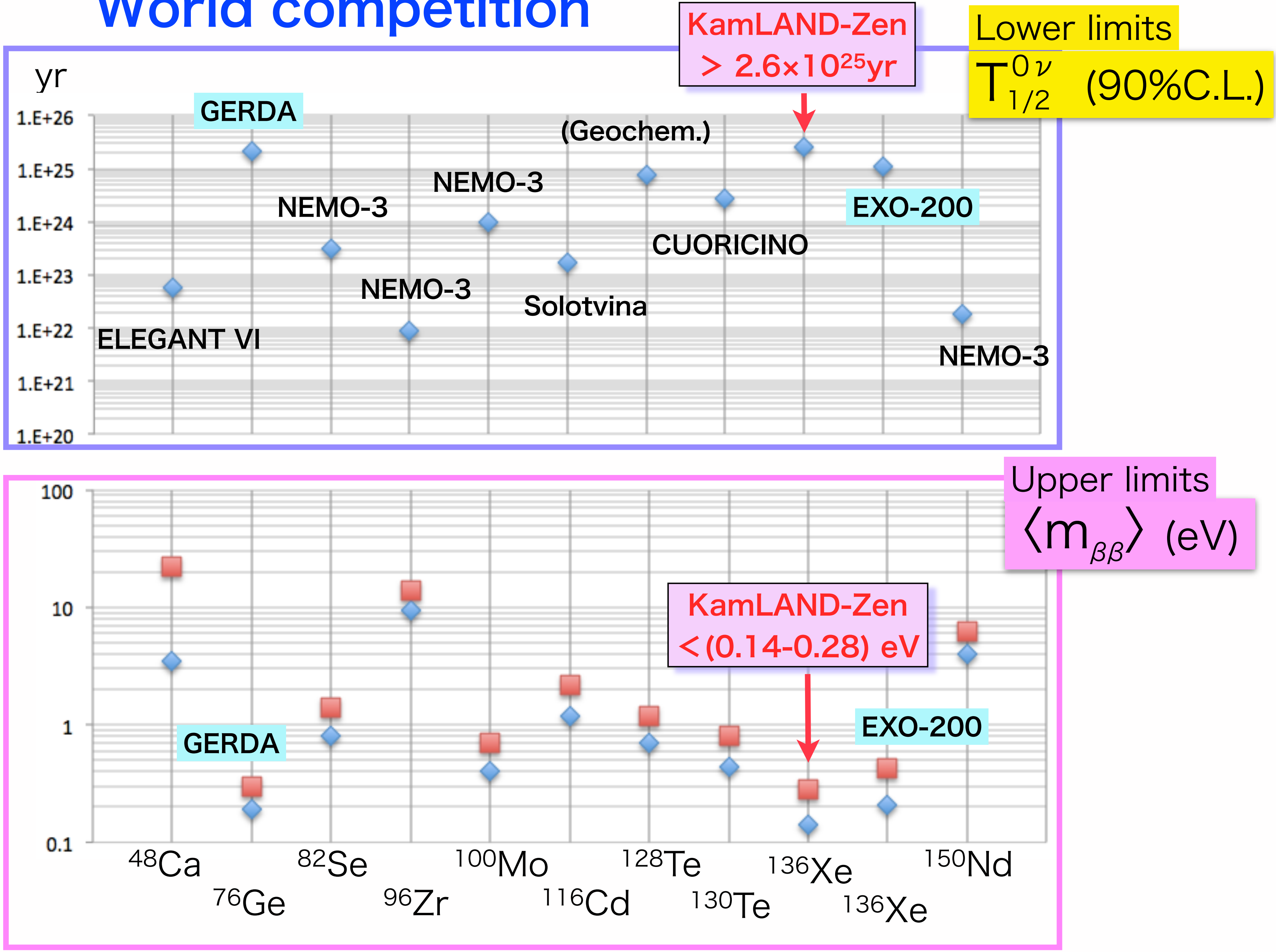
Most stringent limit and refute KK claim for ^{76}Ge with KamLAND-Zen alone.

Phase1+phase2

> 2.6×10^{25} yr



World competition



KamLAND-Zen provides most stringent limits on $0\nu\beta\beta$ decay!

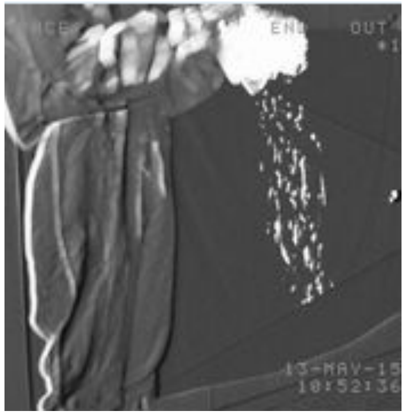
Toward the next Phase, KamLAND-Zen 800!

Remove ^{214}Bi

Construct a new larger mini-balloon (>700kg Xe) with much more care about the cleanliness.

Film $U= 2\times10^{-12}$, $Th: 6\times10^{-12}$, $^{40}K: <1.2\times10^{-11}$ (g/g) (The same level as the present one.)

Study dusts by visualization



New clean suites and goggles

Film lamination against dusts

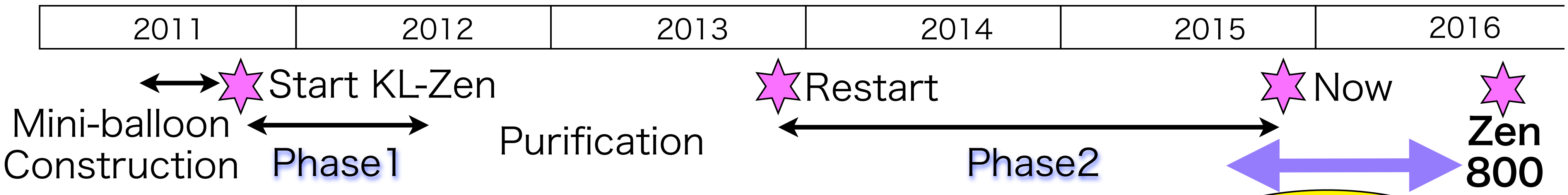
Clean storage bag

And... Study the film surface with a microscope.
Introduce two types of clean wears,
change them every time in the work and wash them.
Reinforce static electricity eliminators.

Every efforts to protect film against dusts !

Mini-balloon construction was finished in October !
It will be deployed in the next year.

KamLAND-Zen activity



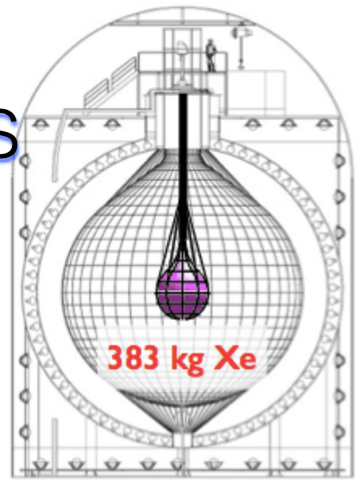
Timeline for the “KamLAND-Zen 800”

2015

- Oct.26 : Stop data taking (Phase2)
- Oct -Dec : Calibration, Xe collection, Mini-balloon removal **Now !**

2016

- Jan ~Apr : Outer detector refurbishment (replace PMTs, add reflection sheet), Detector tank inspection, Purification of Xe and LS
- May -Jul : New mini-balloon deployment, Introduce Xe ~800kg.
- Aug : Start data taking !



Future plan : Remove $2\nu\beta\beta$ and others.

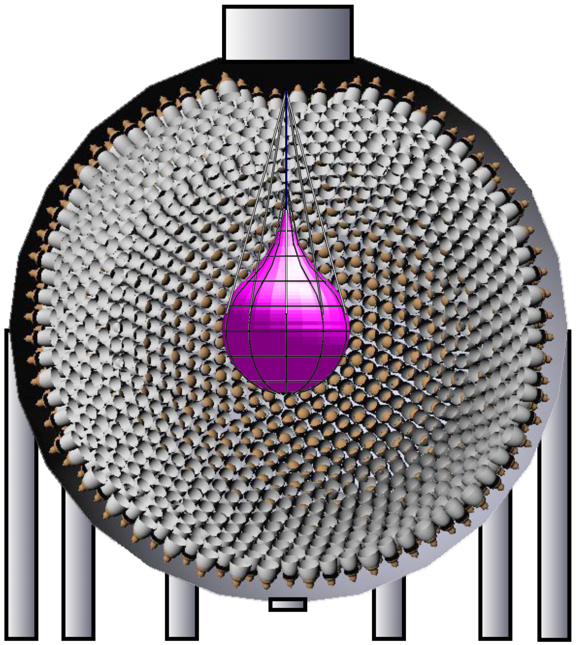
KamLAND2-Zen ; 1ton enriched Xe

$\langle m_{\beta\beta} \rangle \Rightarrow$ 20meV/5yr, Full coverage of the inverted mass hierarchy !

R&Ds for improving σ_E and Bkg rejection

Reject $2\nu\beta\beta$

KamLAND2-Zen



More photons for better σ_E

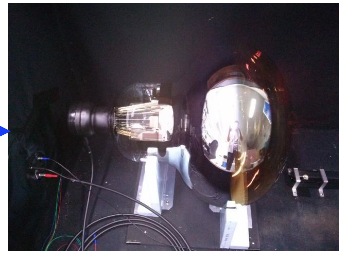
New LS (L.Y.×1.4),

High QE PMT(17”⇒20”, Q.E.×1.9),

Light collector of PMT(×1.8)

$\Rightarrow \sigma_E/E$= 4% ⇒ ∼2% (@2.6MeV)

High QE PMT



Winstone Cone

Scintillating balloon

Efficient α-tag to reject ^{214}Bi decay occurred in the balloon film.

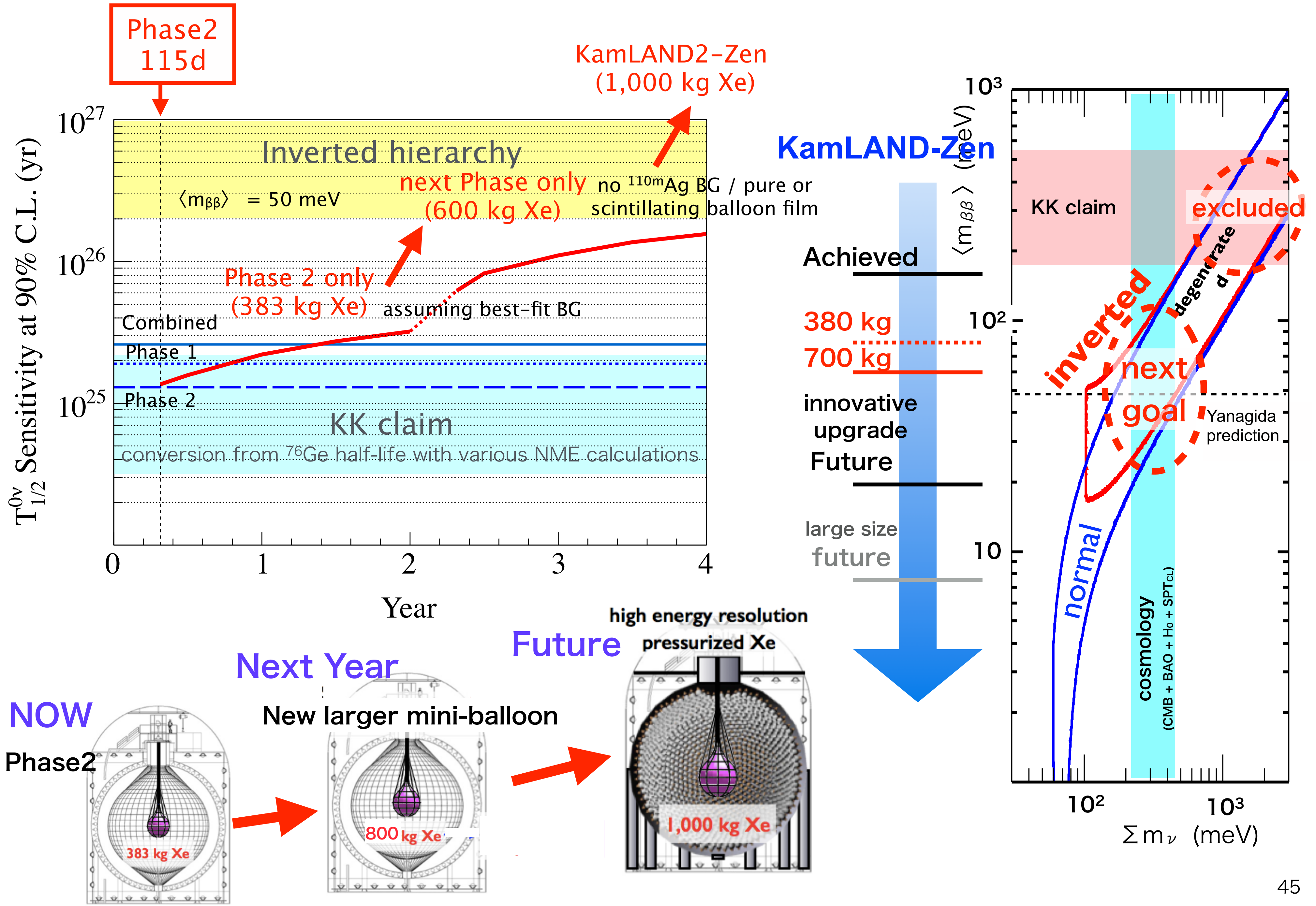
Event pattern recognition

Imaging sensor for β/γ discrimination

Remove radioactive elements in LS

Metal scavenger for LS

Prospect of KamLAND-Zen



Summary

- The question of Majorana nature of neutrinos is very important and related to the neutrino mass problem.
- If neutrinos are found Majorana particles, it would open a new physics window to the extremely high energy world of the early Universe !
- Neutrino-less double beta decay ($0\nu\beta\beta$) is the unique process to check the Majorana nature of neutrinos.
- Many challenges have been made worldwide for the $0\nu\beta\beta$.
- KamLAND-Zen is a leading experiment for $0\nu\beta\beta$ using a large amount of ^{136}Xe in ultra-low radioactivity environment of the KamLAND detector.
- The current backgrounds are reduced to ~1/10 and preparation for the new phase of KamLAND-Zen 800 are going on.
- Various R&Ds are being done for future KamLAND2-Zen to fully cover the inverted mass hierarchy region.

Thank you !