Recent results of KamLAND-Zen

11-July-2012

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[Paper]

Measurement of the double-β decay half-life of ^{136}Xe
with the KamLAND-Zen experiment (published 19 April 2012)
http://prc.aps.org/pdf/PRC/v85/i4/e045504

Limits on Majoron-Emitting Double-Beta Decays of ^{136}Xe
in KamLAND-Zen (Dated May 30, 2012)
http://arxiv.org/pdf/1205.6372.pdf

reference

- http://www.awa.tohoku.ac.jp/rcns/wp-content/uploads/2012/06/Results-from-KamLAND-Zen.pdf
- http://www.icepp.s.u-tokyo.ac.jp/info/sympo/18/torape/Hakuba2012-Matsuda.pdf
- http://www.jahep.org/hepnews/2011/11CKamLAND-Zen-04final.pdf

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- **Physics motivation**
- **Detector and Selection**
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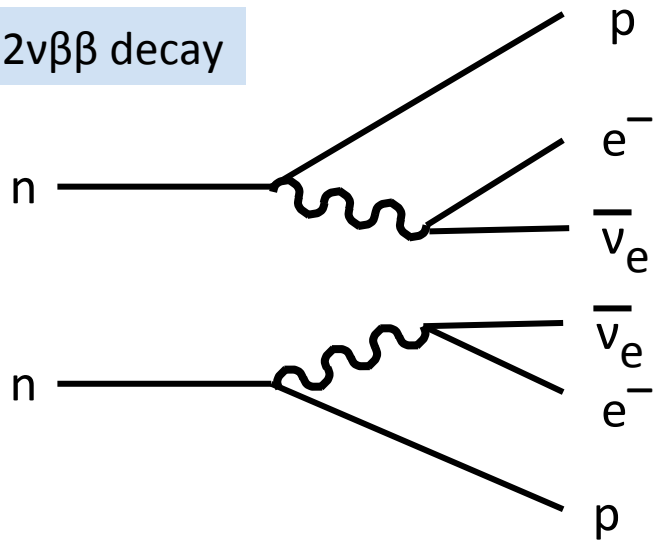
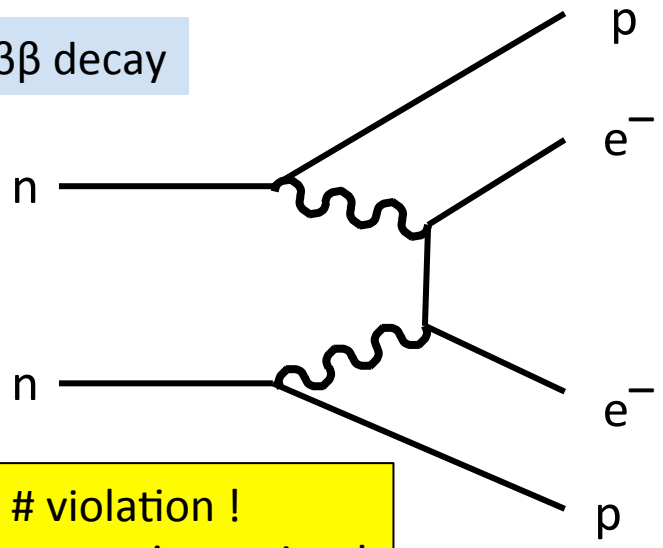
Physics motivation

2νββ decay

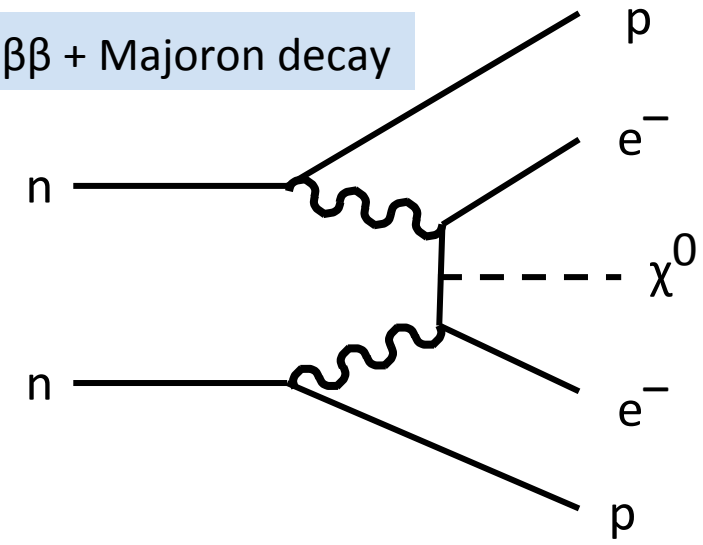


0νββ decay



lepton # violation !
neutrino = anti neutrino !

0νββ + Majoron decay



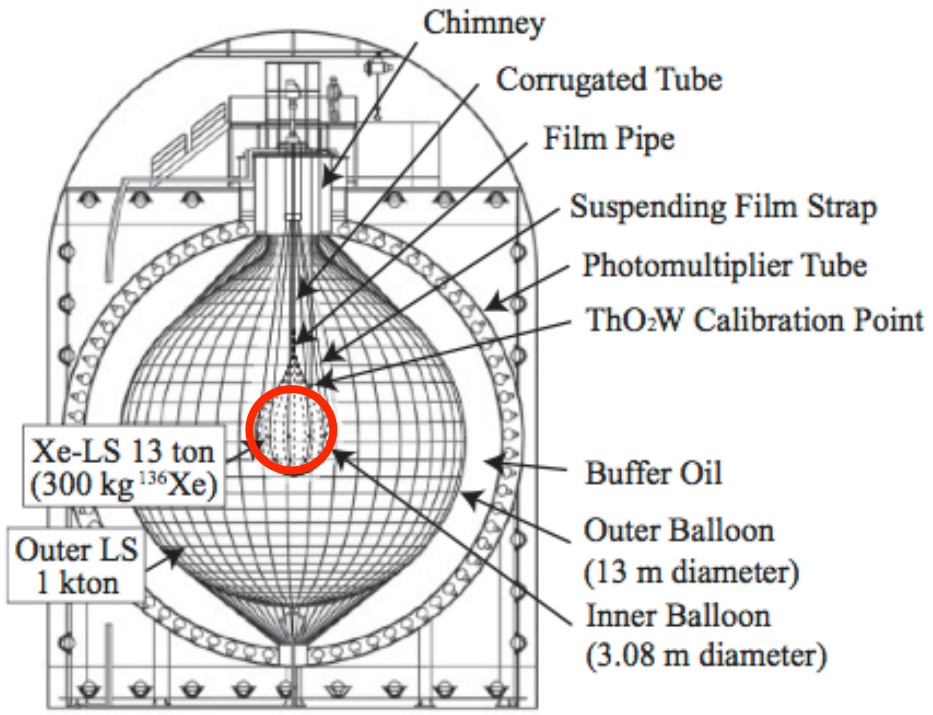
0νββ search is the only way for check whether neutrino is Majorana or Dirac.

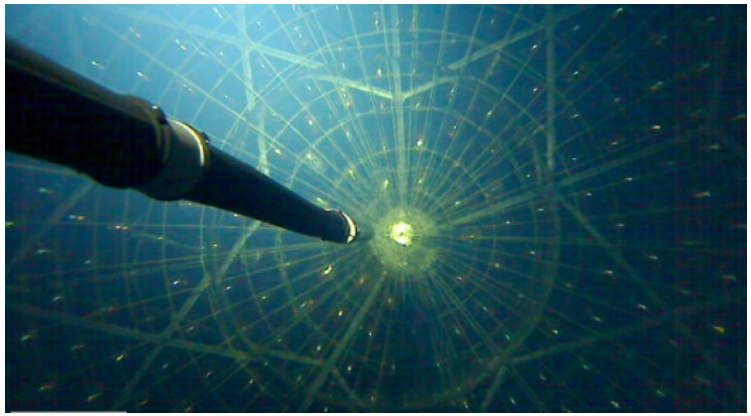
0νββ rate has relation to neutrino mass.

There are other mechanisms.
(0νββ + Majoron)

Detector [1/4]

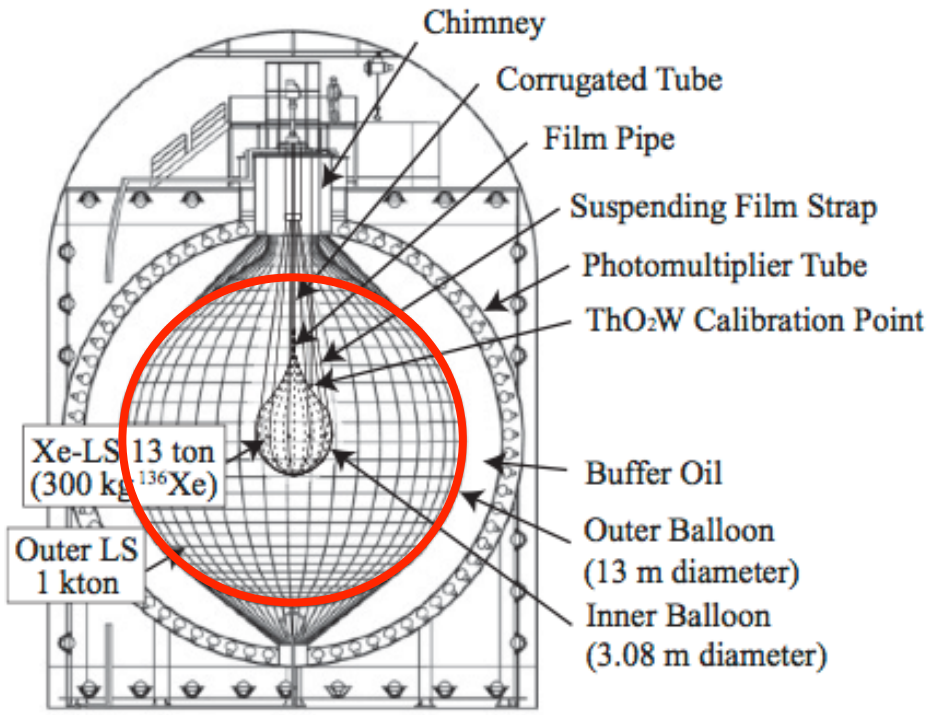
- Inner Balloon (IB)
  - radius : 1.54 [m]
  - film thickness : 25 [μm]
  - Liquid Scintillator (LS) : 13 [ton]
  - ^{136}Xe :
    - 300 [kg]
    - 2.44 ± 0.01 % by weight
  - role :
    - 2 beta decay source
    - Detector





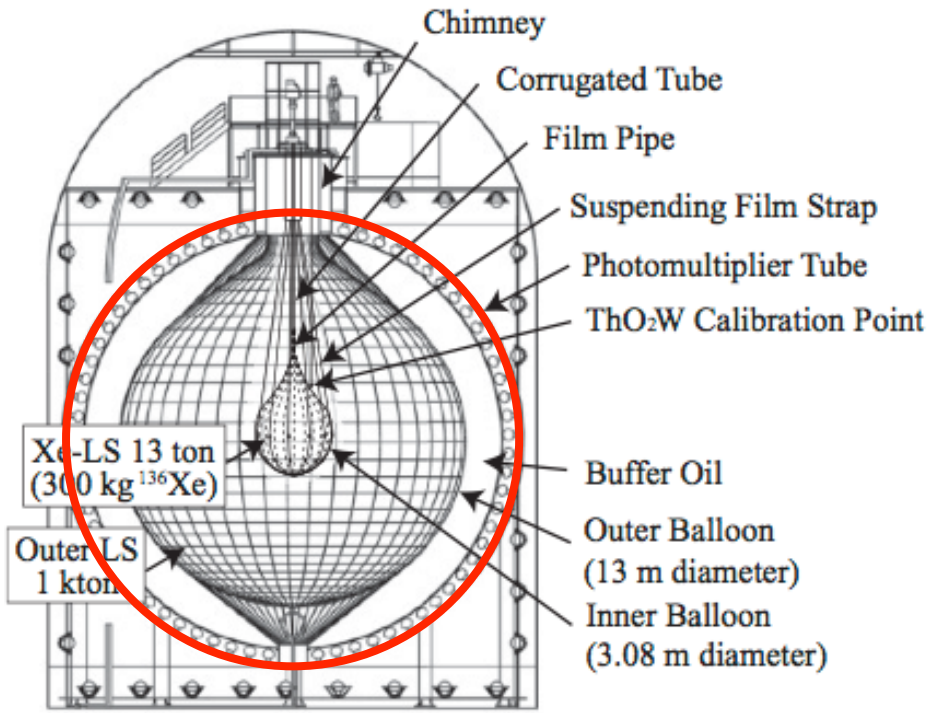
Detector [2/4]

- Outer Balloon (OB)
  - radius : 6.5 [m]
  - film thickness : 135 [μm]
  - Liquid Scintillator (LS) : 1000 [ton]
  - role :
    - Detector
    - Shield for Inner Balloon



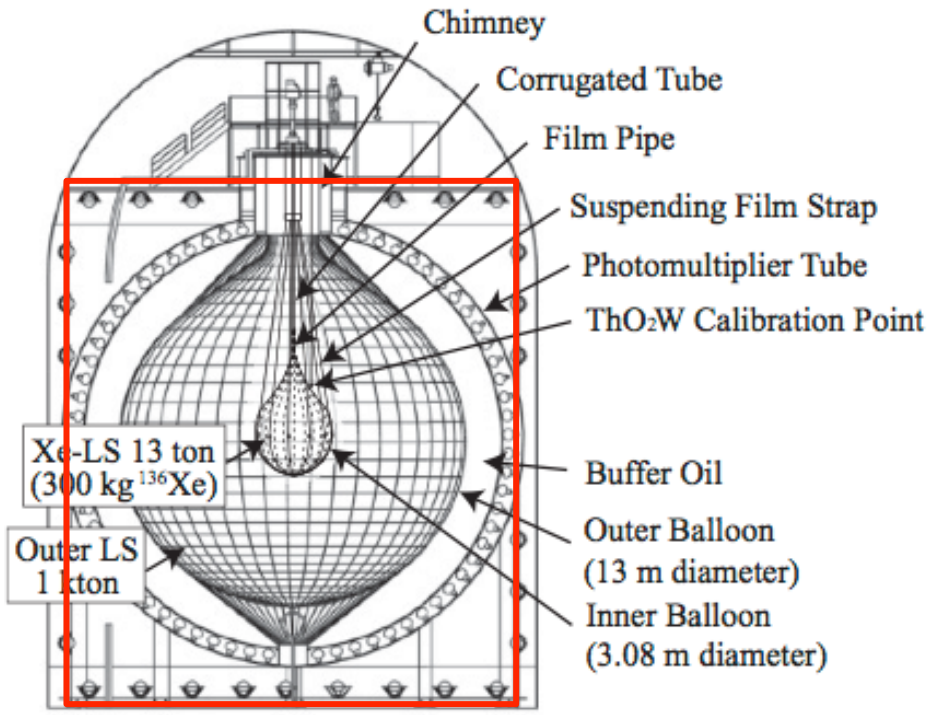
Detector [3/4]

- Buffer Oil (BO)
  - radius : 9 [m]
  - role :
    - shield
- Spherical Stainless-steel containment Tank (SST)
  - radius : 9 [m]
  - role :
    - shield for Liquid Scintillator
  - PMT :
    - 17 inch : 1325
    - 20 inch : 554
    - coverage : 34 [%]



Detector [4/4]

- Outer Detector (OD)
  - Water : 3200 [ton]

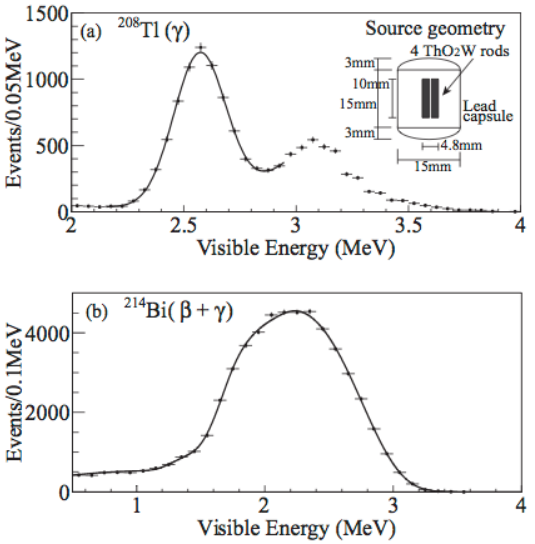


☺ Huge LS & low BG
→ KamLAND is good for 0νββ decay search

DAQ system

- Trigger
  - 70 or more 17-inch PMT hit (~0.4 [MeV])
  - 1 [ms] lower energy threshold (~0.25 [MeV]) after trigger
- Accuracy
  - vertex resolution : 15 [cm] / sqrt(E [MeV])
  - energy resolution : (6.6 ± 0.3) [%] / sqrt(E [MeV])
  - Concerning about
    - PMT gain variation
    - solid angle
    - shadowing
    - transparency of materials
  - Calibration
    - γ from ^{208}Tl decay
    - β + γ form ^{214}Bi decay
    - 2.225 [MeV] gamma from neutron capture by proton

Some BG occurs sequentially. Lower energy threshold cannot be set always.

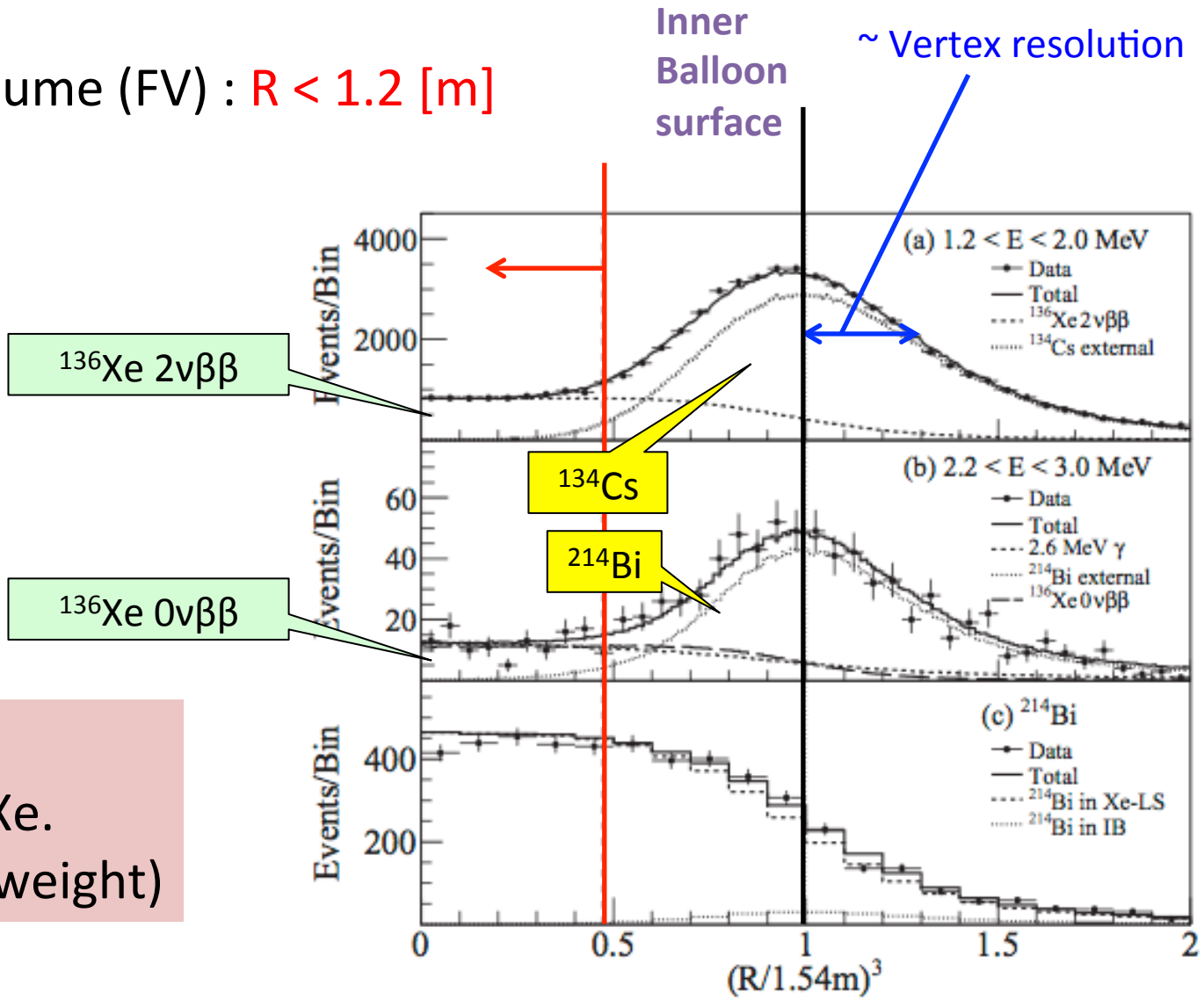


Candidate eventselection [1/2]

- i) Fiducial Volume (FV) : R < 1.2 [m]

Ratio of 134Cs to 137Cs is consistent with contamination by fallout.

FV cut is performed to mitigate BG from **IB**.



FV contains
125 ± 7 [kg] of ^{136}Xe.
(2.44 ± 0.01 % by weight)

Candidate eventselection [2/2]

- ii) Muon event veto
  - Muon : 10,000 p.e. event or more than 5 OD hits
  - Events occurring within 2 [ms] after muon are also vetoed

Muon causes noisy or low efficiency sequential events.
From physical and electronic side.

- iii) Coincidence cut
  - 99.97 ± 0.01 % of ^{214}Bi – ^{212}Po BG is removed

- iv) Reactor neutrino veto
  - KamLAND knows its feature well
- v) VTQ test

Total live time after cut : 77.6 [days] for paper in April.
112.3 [days] for paper in May.

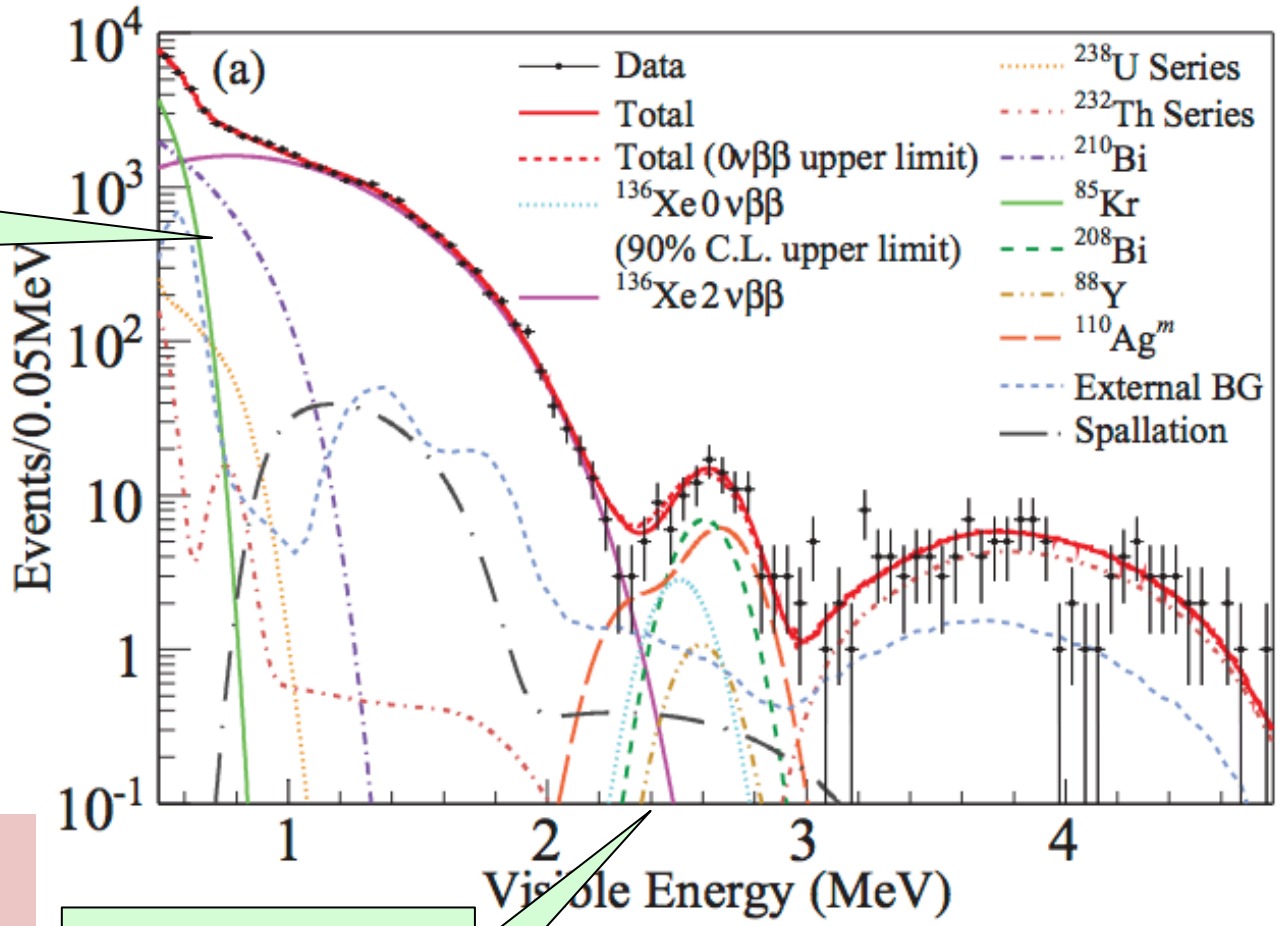
Result (paper in April)

^{136}Xe 2νββ
is dominant in
Low-energy region

half-life of ^{136}Xe 2νββ is
$2.38 \pm 0.02 \pm 0.14 \times 10^{21}$ [yr]

lower limit of
half-life of ^{136}Xe 0νββ is
5.7×10^{24} [yr] (90% C.L.).

Corresponding effective mass is
$\langle m_{\beta\beta} \rangle < (0.3 - 0.6)$ [eV]



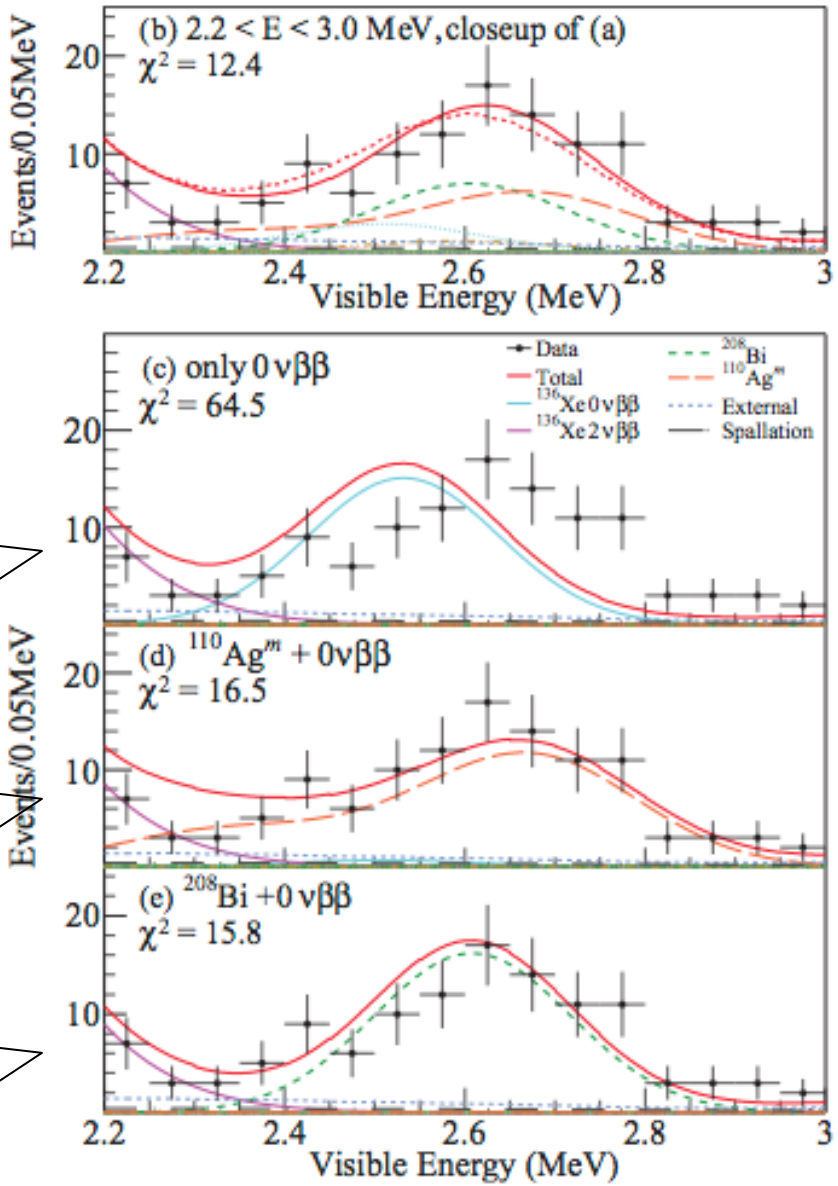
number of
^{136}Xe 0νββ
is < 15 according
to the fit

- Spectrum for fit to 0νββ region
  - ^{100}Ag
  - ^{88}Y
  - ^{208}Bi
  - ^{60}Co
  - ^{136}Xe 0νββ
- All isotopes in the ENSDF database were searched

Fit with ^{136}Xe 0νββ only

Fit with ^{110}Ag + ^{136}Xe 0νββ only

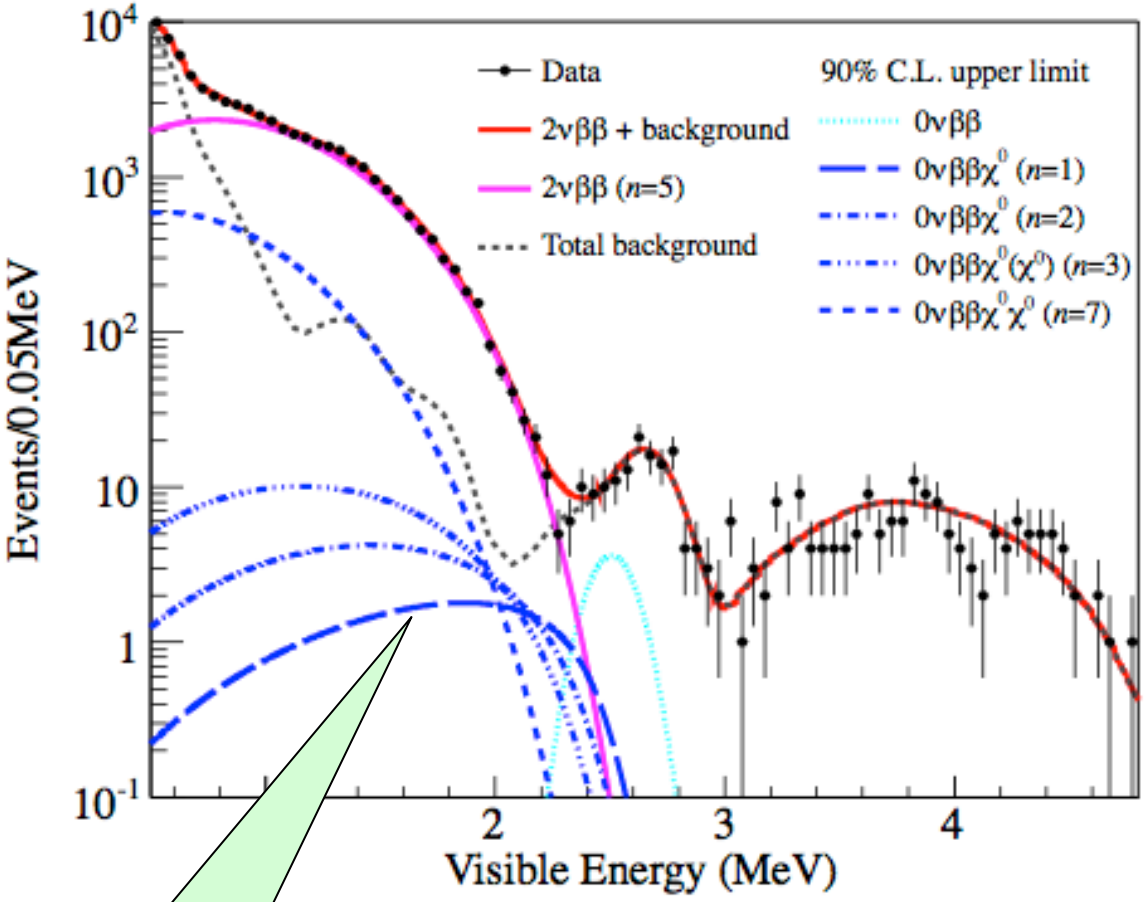
Fit with ^{208}Bi + ^{136}Xe 0νββ only



Result (paper in May)

Contribution from
Majoron-emitting mode to zero

half-life of ^{136}Xe 2νββ is
$2.30 \pm 0.02 \pm 0.12 \times 10^{21}$ [yr]



lower limit of
half-life of ^{136}Xe 0νββ is
6.2×10^{24} [yr] (90% C.L.).

Corresponding effective mass is
$\langle m_{\beta\beta} \rangle < (0.26 - 0.54)$ [eV]

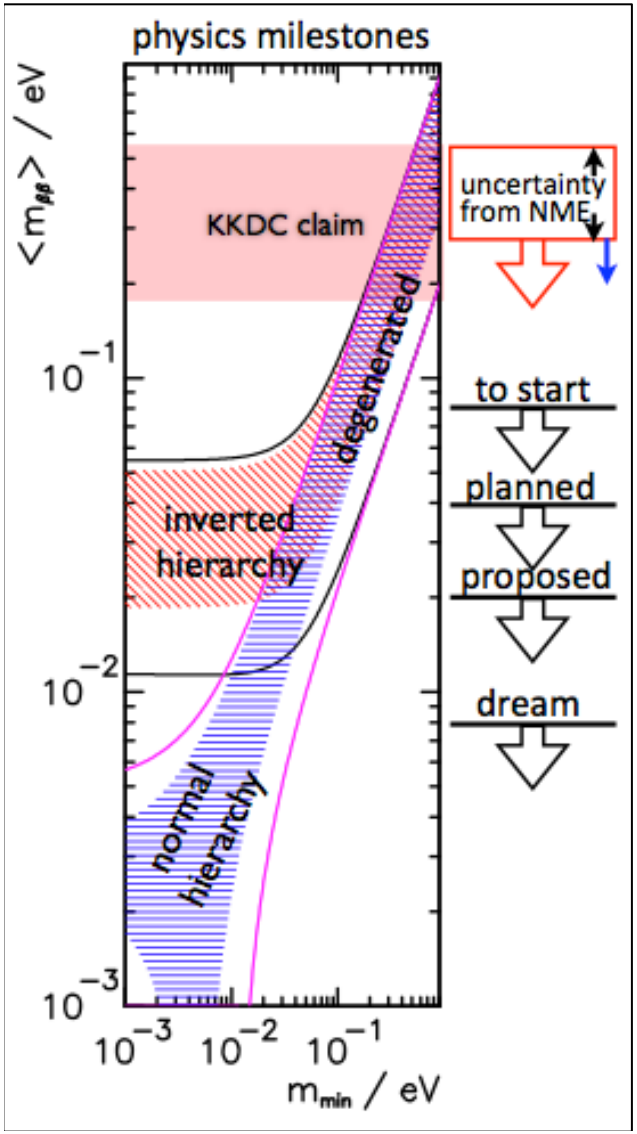
n = 1
ordinary mode

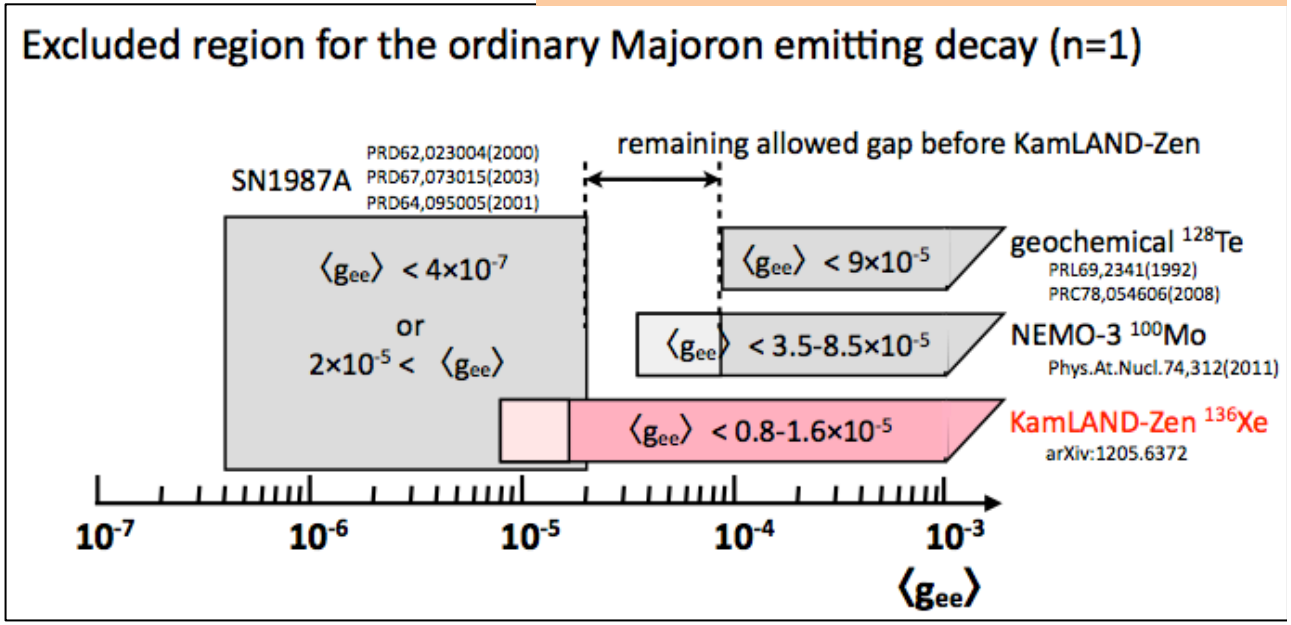
lower limit of half-life of ^{136}Xe
Majoron-emitting mode (n=1) is
2.6×10^{24} [yr]

- 2νββ spectrum and one of a 0νββ (+Majoron) spectrum are fitted simultaneously.

Model	Decay Mode	NG boson	L	n	Matrix Element	Results from this measurement	
						$T_{1/2}$ (yr)	$\langle g_{ee} \rangle$
IB	$0\nu\beta\beta\chi^0$	no	0	1	$M_F - M_{GT}$ [12, 13]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
IC	$0\nu\beta\beta\chi^0$	yes	0	1	$M_F - M_{GT}$ [12, 13]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
ID	$0\nu\beta\beta\chi^0\chi^0$	no	0	3	$M_{F\omega^2} - M_{GT\omega^2}$ [8]	$> 4.5 \times 10^{23}$	< 0.68
IE	$0\nu\beta\beta\chi^0\chi^0$	yes	0	3	$M_{F\omega^2} - M_{GT\omega^2}$ [8]	$> 4.5 \times 10^{23}$	< 0.68
IIB	$0\nu\beta\beta\chi^0$	no	-2	1	$M_F - M_{GT}$ [12, 13]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
IIC	$0\nu\beta\beta\chi^0$	yes	-2	3	M_{CR} [8]	$> 4.5 \times 10^{23}$	< 0.013
IID	$0\nu\beta\beta\chi^0\chi^0$	no	-1	3	$M_{F\omega^2} - M_{GT\omega^2}$ [8]	$> 4.5 \times 10^{23}$	< 0.68
IIE	$0\nu\beta\beta\chi^0\chi^0$	yes	-1	7	$M_{F\omega^2} - M_{GT\omega^2}$ [8]	$> 1.1 \times 10^{22}$	< 1.2
IIF	$0\nu\beta\beta\chi^0$	gauge boson	-2	3	M_{CR} [8]	$> 4.5 \times 10^{23}$	< 0.013
"bulk"	$0\nu\beta\beta\chi^0$	bulk field	0	2	–	$> 1.0 \times 10^{24}$	–

from slide of Neutrino2012, 6th June



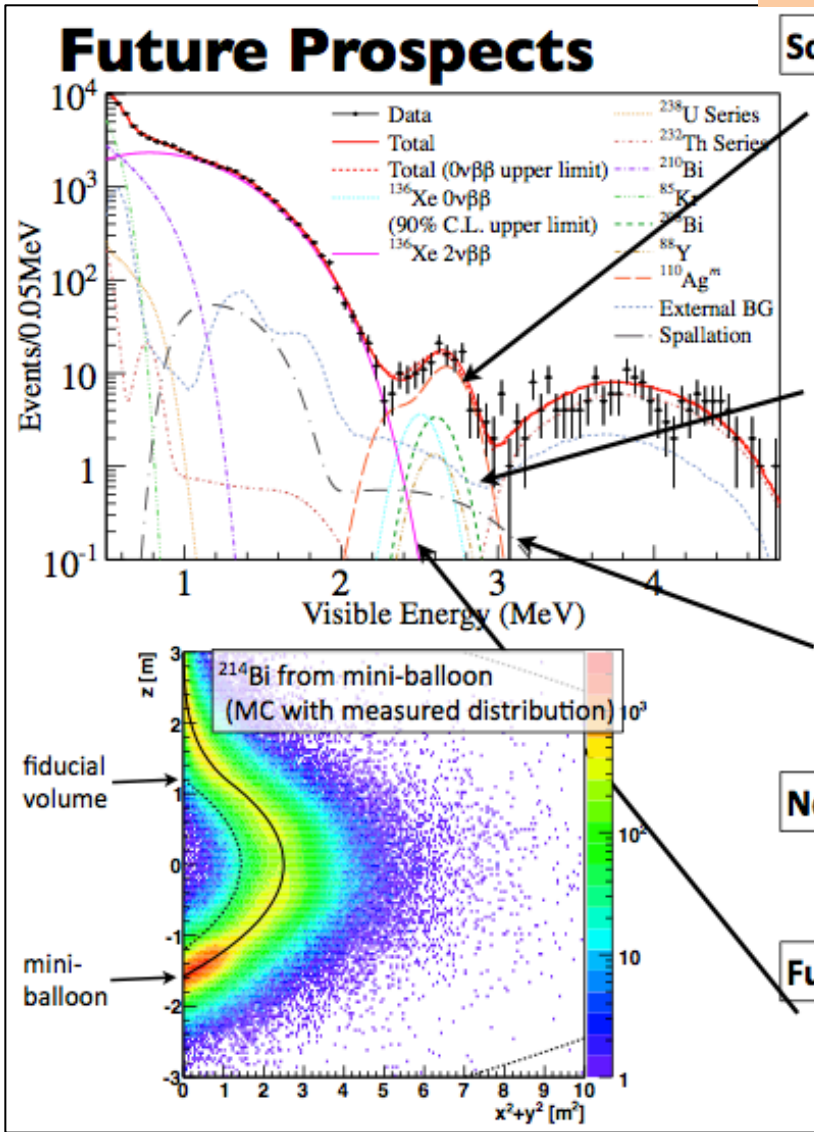


Systematics

paper in April		→	paper in May
FV error	5.2 %		
enrichment of 136Xe	0.05 %		
Xe concentration	2.8 %	→	supplemental xenon concentration measurement
detector energy scale	0.3 %		
Xe-LS edge effect	0.06 %		
detection efficiency	0.2 %		
Total	5.9 %	→	5.2 %

Future Prospects

from slide of Neutrino2012, 6th June



Soon TARGET sensitivity : ~80meV

^{110m}Ag and maybe ^{208}Bi, ^{88}Y in the Xe-LS are expected to be removed by purification of Xenon extraction/distillation/adsorption to be applied from next week. (~100days more data)
LS is replaced with new purified one.
TARGET: more than factor 100 reduction (ref poster 169-1)

For ^{214}Bi on the balloon, drastic improvement requires reproduction of mini-balloon (to be done with increased amount of Xenon), but optimization of fiducial volume cut is also effective.

For ^{10}C from spallation, (ref posters 48-3) 80+% reduction w/o significant efficiency drop is achieved so far (not applied here yet).

Near Future TARGET sensitivity : ~40meV

increased Xenon amount and cleaner balloon
maybe pressurize for higher concentration (ref posters 50-2)

Future TARGET sensitivity : ~20meV

For 2ν2β reduction,
LS replacement, light collector attachment are planned. ---> KamLAND2-Zen