Double Beta Decay of ^{136}Xe with KamLAND

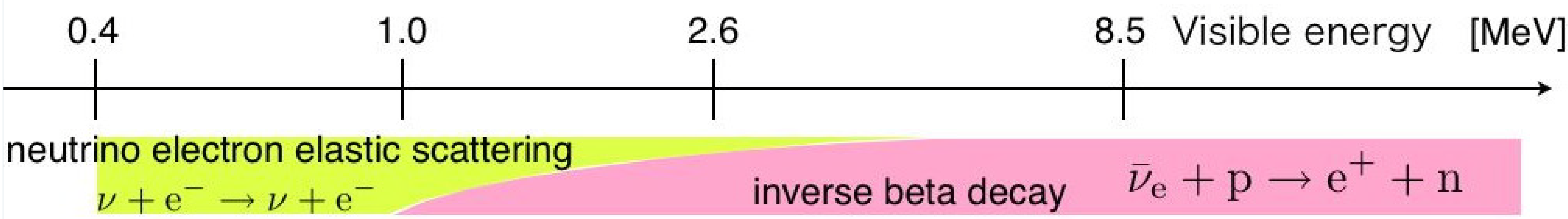
Sei Yoshida
Research center for Neutrino Science, Tohoku University
for the KamLAND collaboration

KamLAND Collaboration

S.Abe[1], T.Ebihara[1], S.Enomoto[1], K.Furuno[1], Y.Gando[1], H.Ikeda[1], K.Inoue[1], Y.Kibe[1], Y.Kishimoto[1], M.Koga[1], Y.Minekawa[1], T.Mitsui[1], K.Nakajima[1], K-H.Nakajima[1], K.Nakamura[1], M.Nakamura[1], K.Owada[1], I.Shimizu[1], Y.Shimizu[1], J.Shirai[1], F.Suekane[1], A.Suzuki[1],Y.Takemoto[1], K.Tamae[1], A.Terashima[1], H.Watanabe[1], E.Yonezawa[1], S.Yoshida[1], A.Kozlov[2], J.Busenitz[3], T.Classen[3], C.Grant[3], G.Keefer[3], D.Leonard[3], D.MaKee[3], A.Piepke[3], M.P.Decowski[4], J.A.Detwiler[4], S.J.Freedman[4], B.K.Fujikawa[4], F.Gray[4],E.Guardincerri[4], L.Hsu[4], K.Ichimura[4], R.Kadel[4], K.-B.Luk[4], H.Murayama[4], T.O'Donnell[4], H.M.Steiner[4], L.A.Winslow[4], D.A.Dwyer[5], C.Jillings[5], C.Mauger[5], R.D.McKeown[5], C.Zhang[5], B.E.Berger[6], C.E.Lane[7], J.Maricic[7], T.Miletic[7], M.Batygov[8], J.G.Learned[8], S.Matsuno[8], S.Pakvasa[8], J.Foster[9], G.A.Horton-Smith[9], A.Tang[9], S.Dazeley[10], K.Downum[11], G.Gratta[11], K.Tolich[11], W.Bugg[12], Y.Efremenko[12], Y.Kamyshkov[12], O.Perevozchikov[12], H.J.Karwowski[13], D.M.Markoff[13], W.Turnow[13],K.M.Heeger[14],F.Piquemal[15], and J.-S.Ricol[15]

1. Research Center of Neutrino Science, Tohoku University
2. IPMU, The University of Tokyo
3. Department of Physics and Astronomy, University of Alabama
4. Physics Department, University of California Birkeley/ Lawrence Berkeley National Laboratory
5. W.K.Kellogg Radiation Laboratory, California Institute of Technology
6. Department of Physics, Colorado State University
7. Physics Department, Drexel University
8. Department of Physics and Astronomy, University of Hawaii at Manoa
9. Department of Physics, Kansas State University
10. Department of Physics and Astronomy, Louisiana State University
11. Physics Department, Stanford University
12. University of Tennessee
13. Triangle Universities of Nuclear Laboratory/Physics Department, Duke University
14. Department of Physics, University of Wisconsin
15. CEN Bordeaux-Gradignan, IN2P3-CNRS and University Bordeaux I

Physics in KamLAND



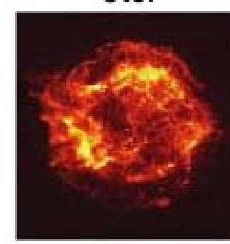
Solar neutrino

Current target

Geological anti-neutrinos
Nature 436, 499 (2005)

Reactor anti-neutrinos
PRL 100, 221805 (2008)
PRL 94, 081801 (2005)
PRL 90, 021802 (2003)

supernova relic neutrino
etc.

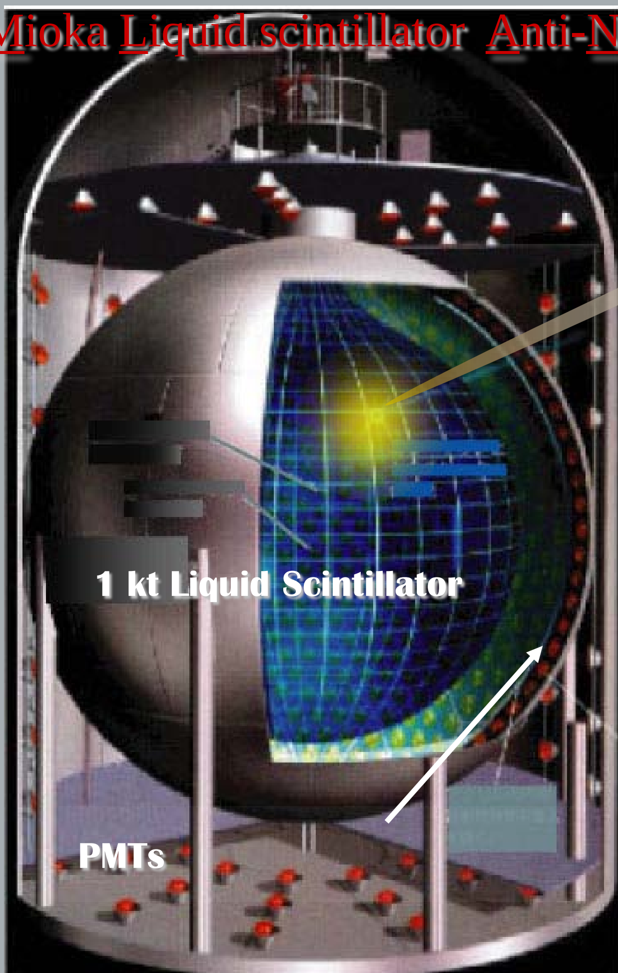


n-Disappearance, anti-neutrino from the Sun and other sources
PRL 96, 101802 (2006)
PRL 92, 071301 (2004)

Next physics target :
Neutrinoless double beta decay

KamLAND Detector

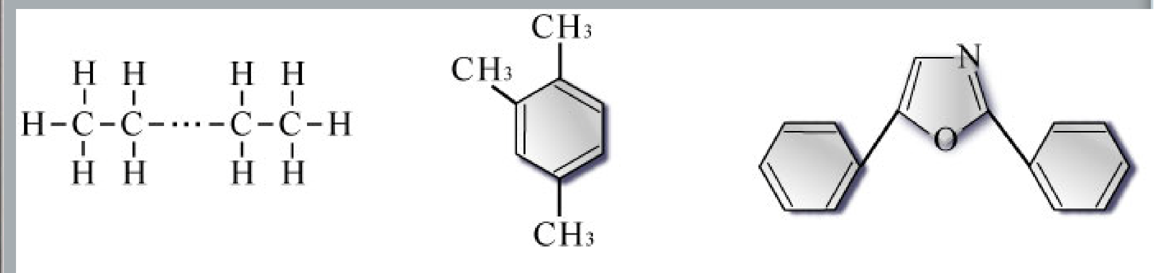
KAMioka Liquid scintillator Anti-Neutrino Detector



KamLAND Detector

- Kamioka mine overburden : 2700m.w.e.
  Muon rate : 0.33Hz

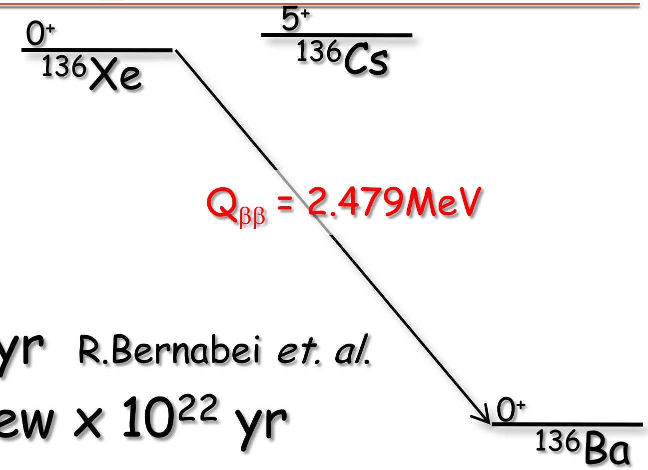
- 1000 tons of Liquid Scintillator



Dodecane ($C_{12}H_{26}$) : 80% | Pseudocumene : 20% (1,2,4-Trimethyl Benzene) | PPO 1.36 g/l (2,5-Diphenyloxazole)

- Mineral Oil : Buffer against external BG
- 1979 PMTs(17” 1325 + 20” 554)
- Photocathod coverage : 34%
- Outer water Cherenkov detector for muon veto

^{136}Xe as ββ Isotope



- 2νββ half-life ; Not yet observed
  - Best experimental limit ; > 1.0 x 10^{22} yr R.Bernabei *et. al.*
  - Theoretical expectation ; ~ 10^{21} - a few x 10^{22} yr
- Advantages of ^{136}Xe
  - Q-value ; valley of natural RI background
  - Gaseous isotope can be purified during the experiment
  - No long lived unstable Xe isotopes
  - Easy to enrich

$0\nu\beta\beta$ in KamLAND

$0\nu\beta\beta$ in KamLAND

- Low-background condition
- Large volume detector → high scalability
- Well-understood (measured) background model
- Liquid detector allows for additional in-situ purification.
- No further modification to the detector
  ← dissolve/load $\beta\beta$ isotope in LS
- Anti-neutrino measurements ; simultaneously

^{136}Xe in KamLAND

- Easy to dissolve ; more than 3 wt%
- Easy to extract
- $T_{1/2}^{2\nu\beta\beta} > 10^{22}$ yr ➔ require modest energy resolution

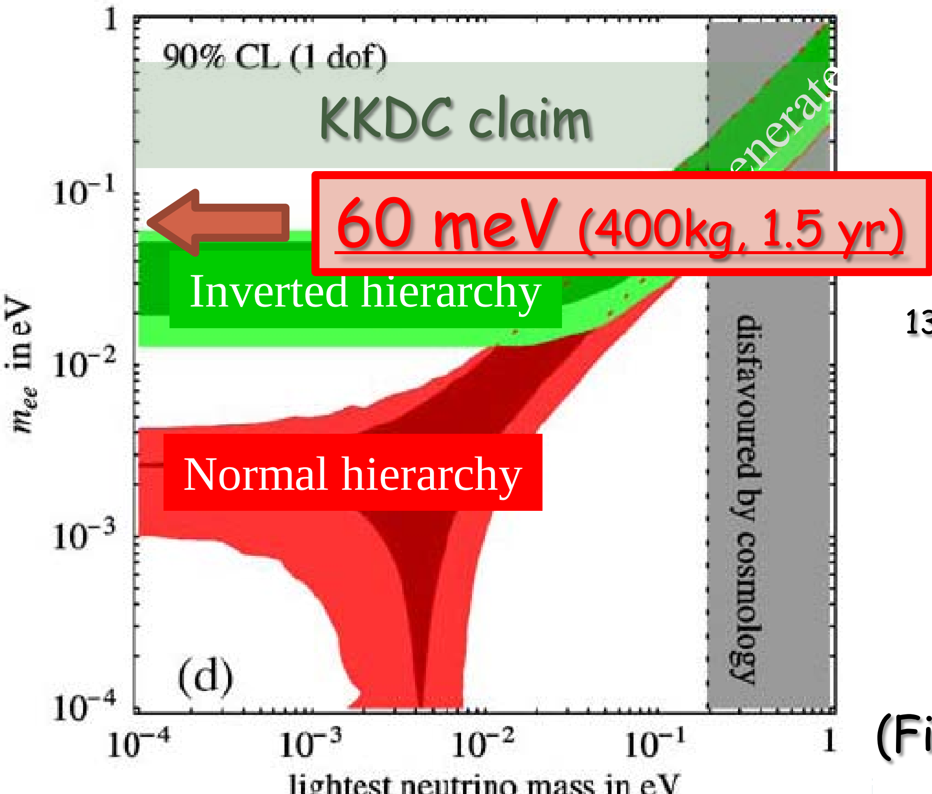
High sensitivity with low cost

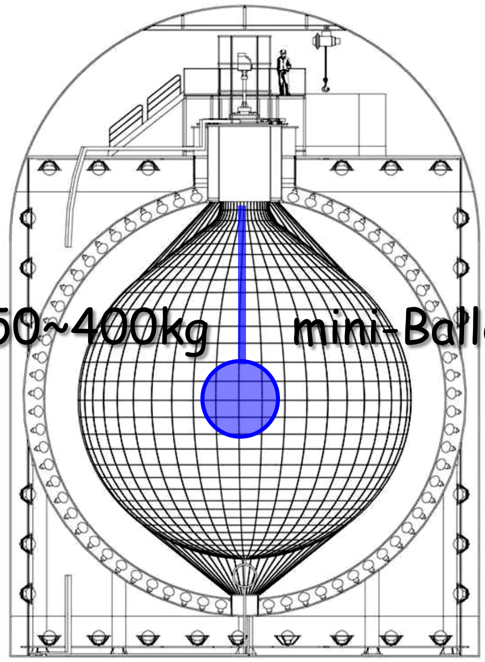
Milestone in KamLAND ββ decay(1)

1st Phase

This talk

- Install mini-balloon into KamLAND.
- 250 ~ 400 kg of enriched ^{136}Xe loaded liquid scintillator
- Explore KKDC claimed region ; down to 60meV
- Keyword=Quickness ; Start data taking 2011/Spring



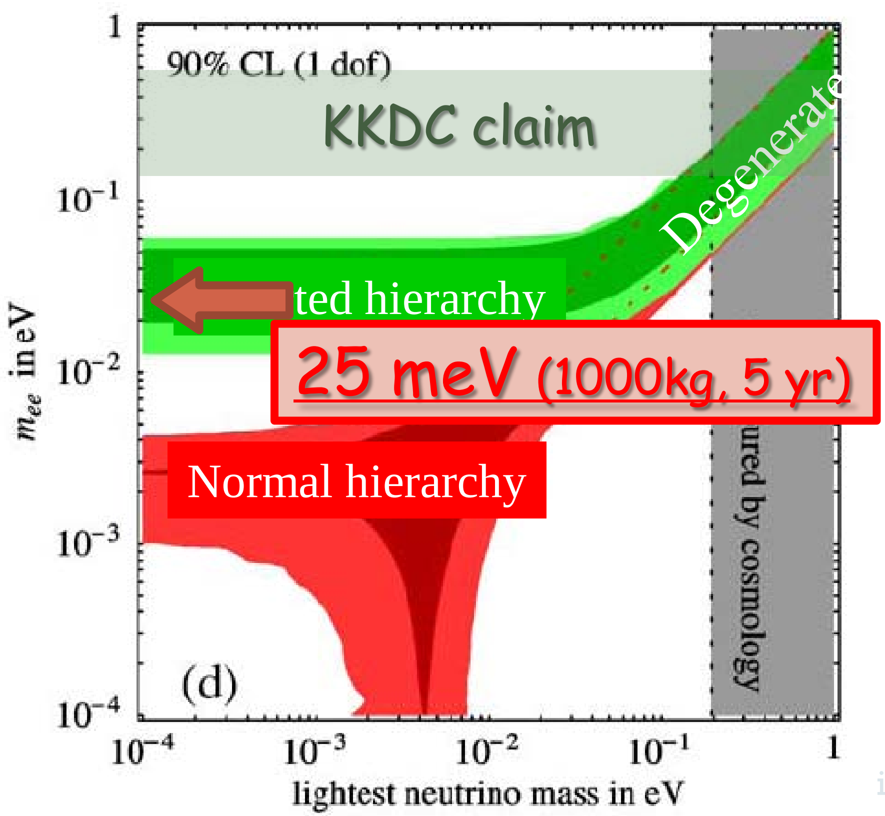


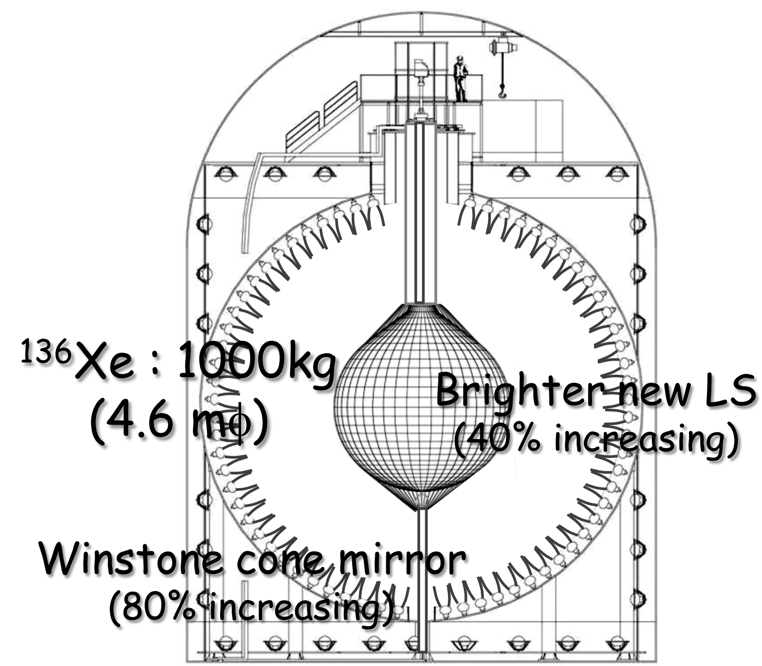
(Final Xe volume depends on the budget.)

Milestone in KamLAND ββ decay(2)

2nd Phase

- 1000 kg of enriched ^{136}Xe loaded liquid scintillator
- Brighter LS development (target; ~40% increase L.Y.)
- Light concentrator (target; ~80%)
- Explore the inverted hierarchy region ; down to 25meV





R&D for 1st Phase

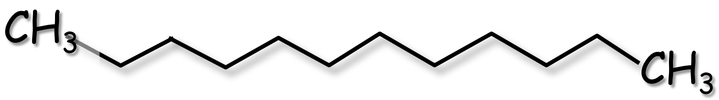
- Development of Xe loaded liquid scintillator

- Development of mini-balloon
- Construction of Xe gas handling system
- Minor modification of chimney region to install mini-balloon

- Software development
  - Simulation for the background study
  - Data taking for new electronics

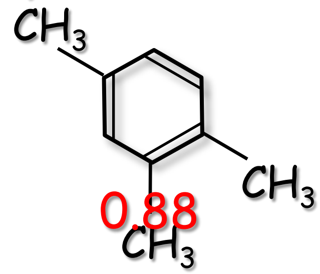
Xe loaded LS for ββ decay (1)

- Density control ;
  - Density of KamLAND LS = 777.2 kg/m^3 @15 ℃
  - KamLAND LS components ;



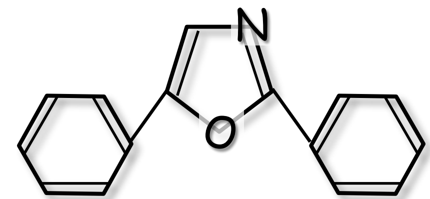
Density ; 0.75

Dodecane ($C_{12}H_{26}$) : 80 wt%



0.88

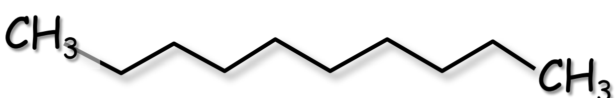
Pseudocumene : 20 wt%
1,2,4-Trimethylbenzene



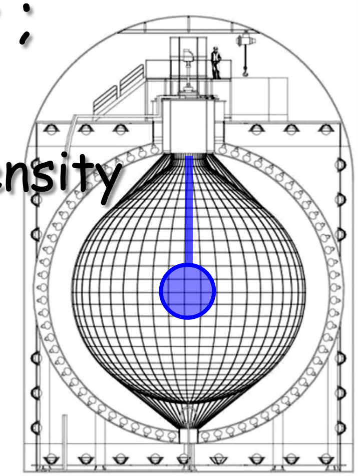
PPO ($C_{15}H_{11}NO$) : 1.36 g/l
2,5-Diphenyloxazole

- To dissolve Xe into LS → Lighten LS density ;
  - Decrease PC amount → decrease light output
  - Similar chemical & optical property with lighter density

    Dodecane ($C_{12}H_{26}$) → <u>Decane ($C_{10}H_{22}$)</u>

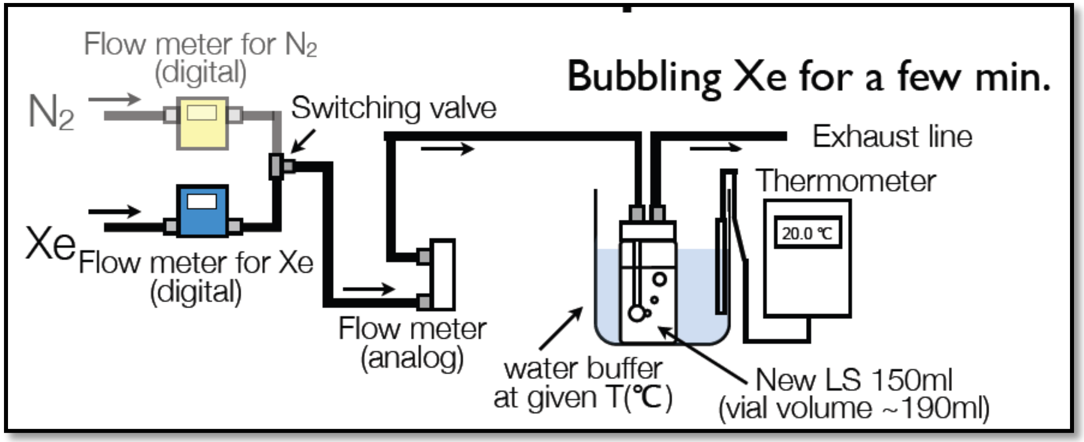


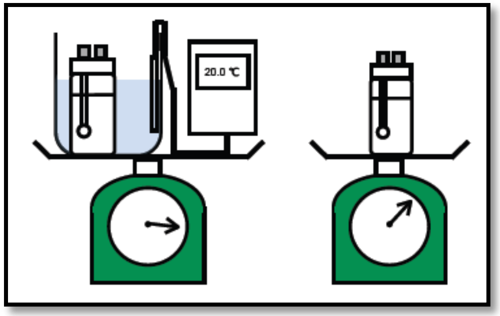
Density ; 0.735



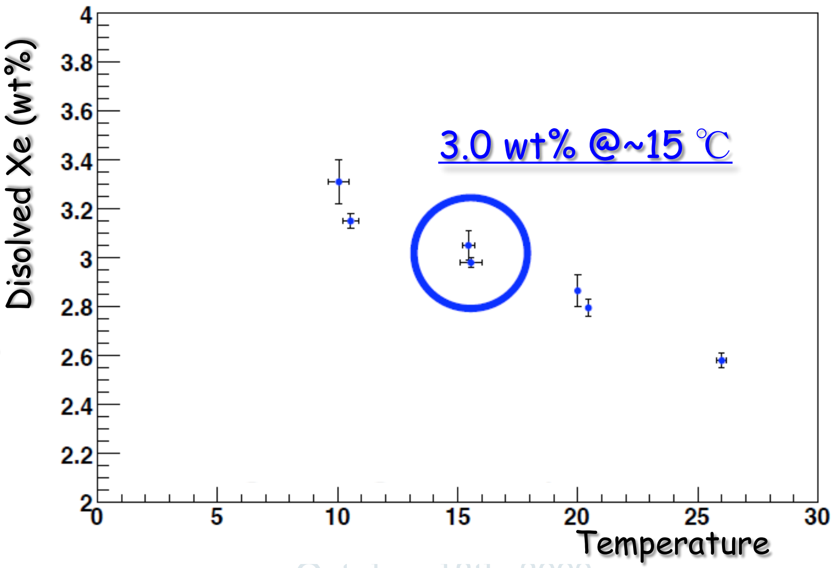
Xe loaded LS for ββ decay (2)

- Xe solubility measurement
  - Controlling LS temperature (Solubility depends on temp.)





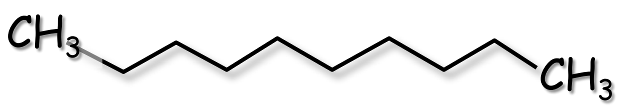
- <u>Set point = 2.5 wt%</u>
  - T @ center of KamLAND
    10 ~ 13℃
  - There is enough margin if temp. would be fluctuated.



Xe loaded LS for ββ decay ; Summary

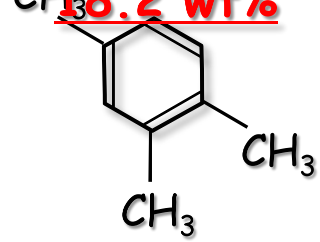
- LS candidate composition
  - Density control
  - Solubility
  - Light yield → increase PPO

81.8 wt%



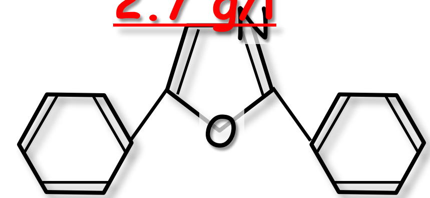
Decane ($C_{12}H_{26}$)

18.2 wt%



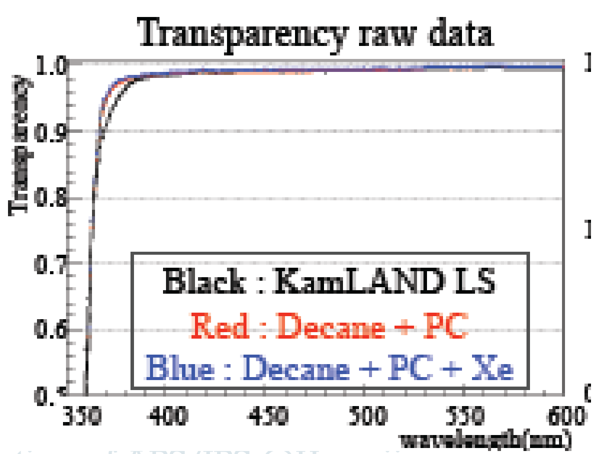
Pseudocumene
1,2,4-Trimethylbenzene

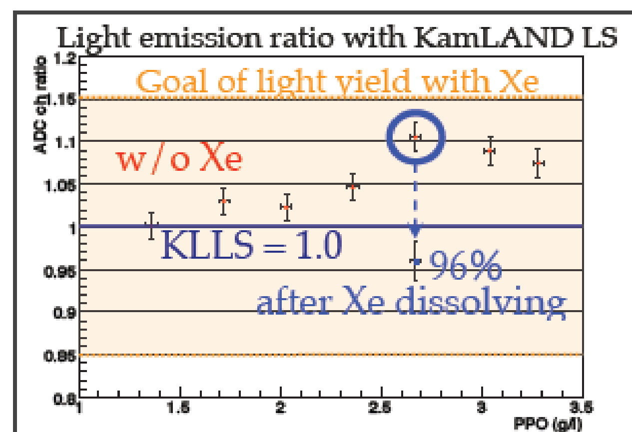
2.7 g/l



PPO ($C_{15}H_{11}NO$)
2,5-Diphenyloxazole

- Xe
  - 2.5 wt%





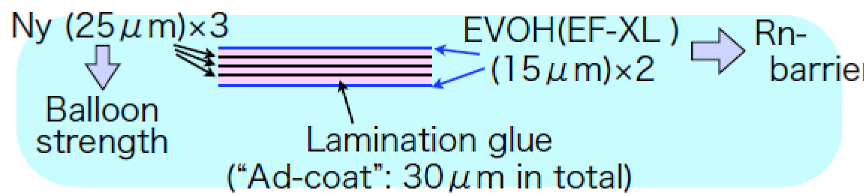
Development of mini-Balloon

- Experience of 13mϕ KamLAND Balloon

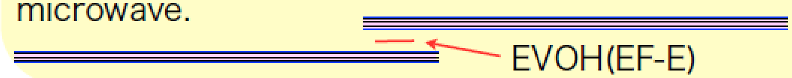
Image of mini-Balloon
(2.7 ~ 4 mϕ)

- KamLAND balloon structure

KamLAND balloon film (135μm)



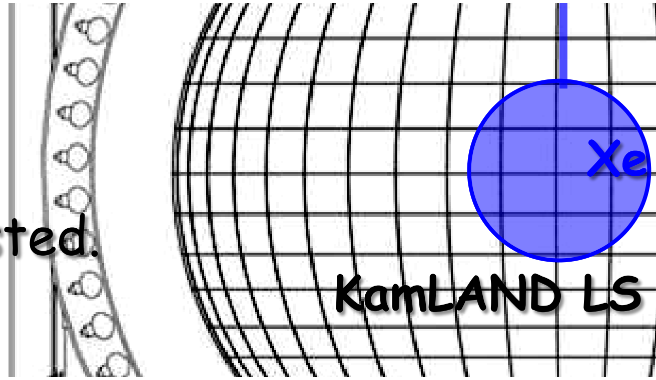
Film connection is made by sandwiching an EVOH film (no-extended type) and heat welding with microwave.



- To reduce background from mini-balloon materials
  - Without using lamination glue
    → only use heat connection
  - Using much thinner films

Development of mini-Balloon

- Requirements for Materials
  - Low background
    - Radio-purity ; 10^{-13} g/g for U/Th
    - Less volume → thin film (~ 25 μm)
  - Transparency to PPO emission wavelength (350 nm ~ 450 nm)
  - Non-permeability for Xe gas
  - Chemical compatibilities ; against PC, Decane and Dodecane
  - Mechanical strength
  - Without aging effect



- Candidate Film
  - Several kinds/thickness of films are tested.
    - EVOH (extended, non-extended)
    - Nylon
    - Multi-layer
  - Good Candidates ; EVOH with heat connection
    → 1st test mini-balloon will be made in October !

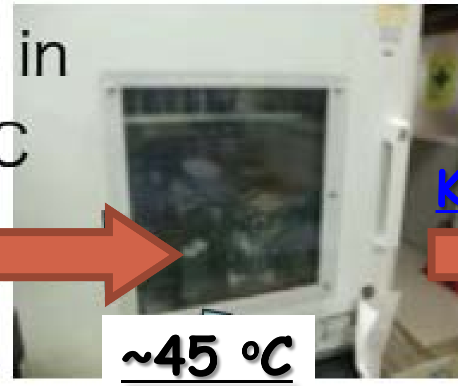
R&D of Balloon Films(1)

- Xe gas permeability measurement
  - Enriched Xe gas is so expensive. → to avoid loosing gas

LS+Xe

KamLAND LS

Film sample



~45 ℃

KamLAND LS

Xe concentration with Gaschromatgraph analyzer

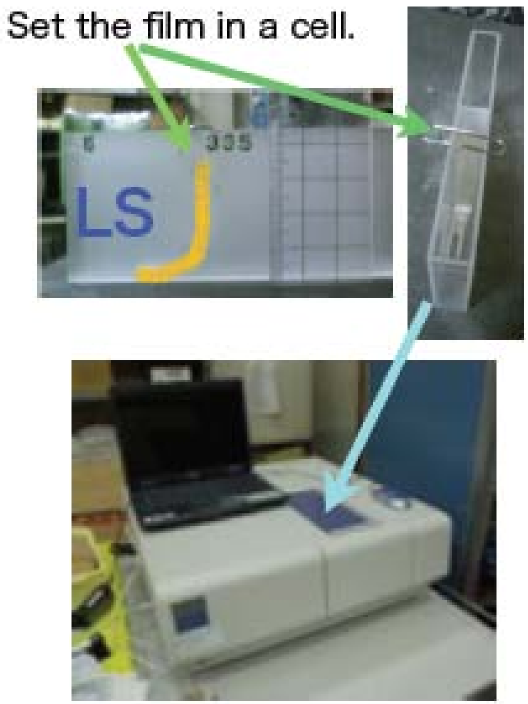
Film & Liquid sample

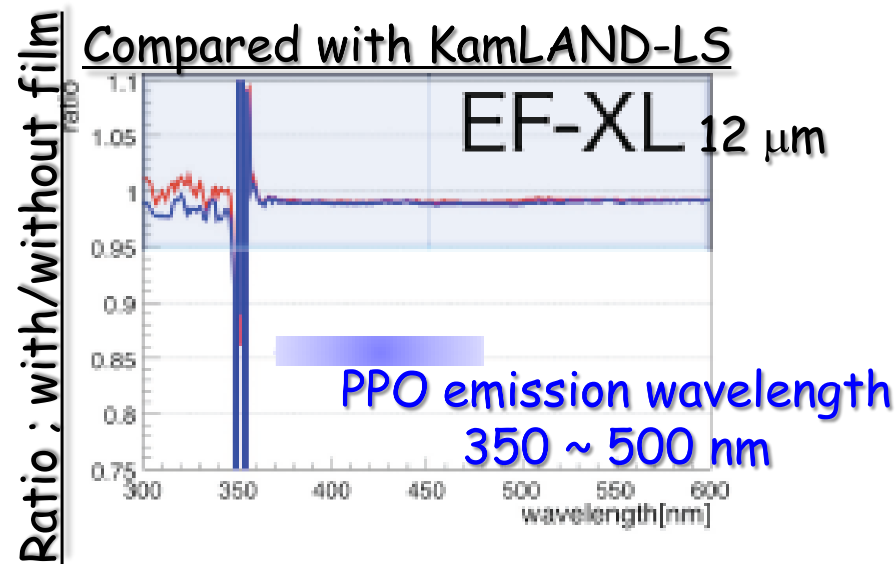
Xe gas leakage through films ;
less than a few kg/5 yr
for every film samples

- Chemical compatibility/ Aging effect
  - Checking color, weight, chemical components in soaked liquid,………

R&D of Balloon Films(2)

- Optical transparency measurement
  - Using spectro-photometer





Almost no absorption of scintillation light !

- Aging effect was also investigated by acceleration method with conditions of 45 deg.C , 40 days.

  → OK (Transparency, Mechanical strength, Weight)

R&D of Balloon Films(3)

- Mechanical strength test
  - Before/after soaking test in LS

Film sample
(20mm x 40mm)

- Radioactive impurity measurement
  - Detection limit of ICP-MS ; ~ a few x 10^{-11} g/g for U/Th
  - Requirement ; ~ 10^{-13} g/g
  - Not achieved the required level.

→ planning the Neutron Activation Analysis

Xenon Gas Handling System

- Requirements for Xe gas system
  - Repetition to dissolve/extract Xe gas into/from LS
    for ex., if BG of mini-balloon is above the required level,
  - Radio-pure system ← against ^{222}Rn emanation

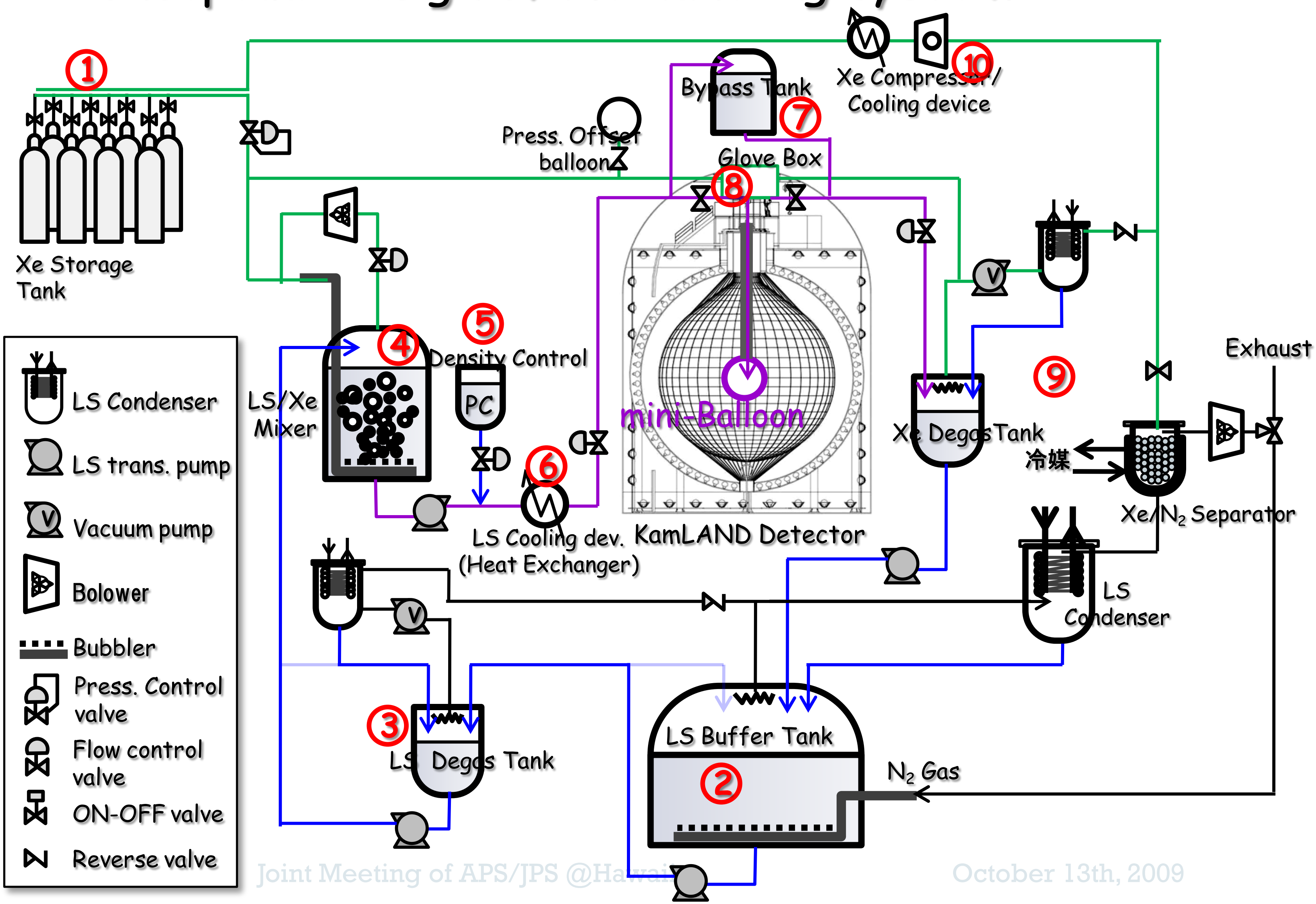
Enriched ^{136}Xe (~92 %) is expensive,
  - Small dead volume of Xe gas
  - Large extraction efficiency → loss-less extraction system
  - Without leakage ; < 10^{-5} Pa.m^3/sec for whole system

  - Quality Control
    - Dissolved Xe concentration
    - Temperature control of Xe-LS, Transparency, Density control, Chemical composition of LS, etc……
    - Impurity measurement (O_2 contents, RI's)

We have experience in the construction and operation of the distillation system.

Xenon Gas Handling System

- Conceptual design of Xe handling system



Xenon Gas Handling System

- We have much experience in
  - LS/Xe dissolve system → purge tower system
  - Gas handling → pure Nitrogen generator

Background Studies for ββ decay

- Background Candidates in 1st Phase
  - KamLAND ; Current background around $Q_{\beta\beta}$ is well-understood.
    1. Cosmic-muon induced background ; ^{10}C, ^{11}Be

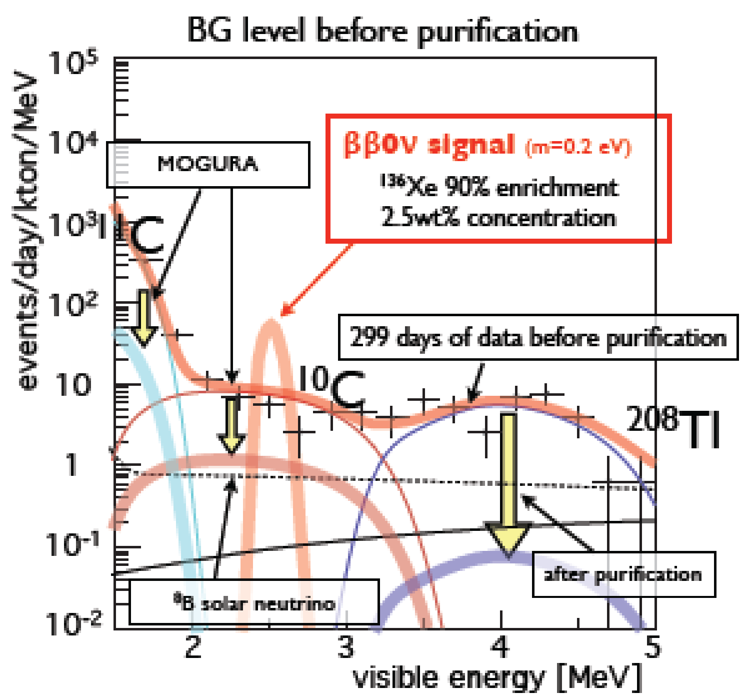
       → tagging with new electronics
    2. ^{8}B solar neutrino → unavoidable in KamLAND

  - After installing mini-balloon & Xe loaded LS
    3. $2\nu\beta\beta$ decay of ^{136}Xe

       E-resolution ; 7.8%/√E
    4. ^{214}Bi, ^{208}Tl in mini-balloon

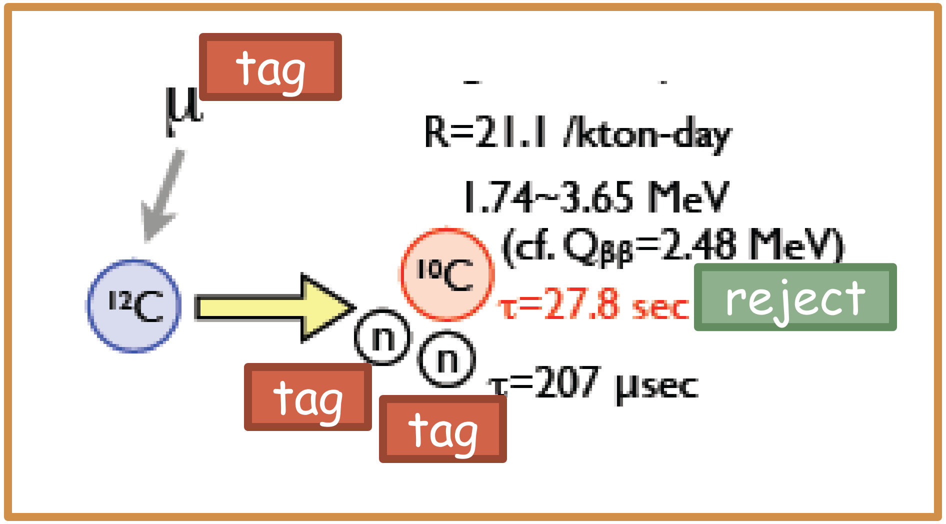
       → by delayed coincidence
    5. ^{208}Tl in KamLAND-LS & Xe-LS

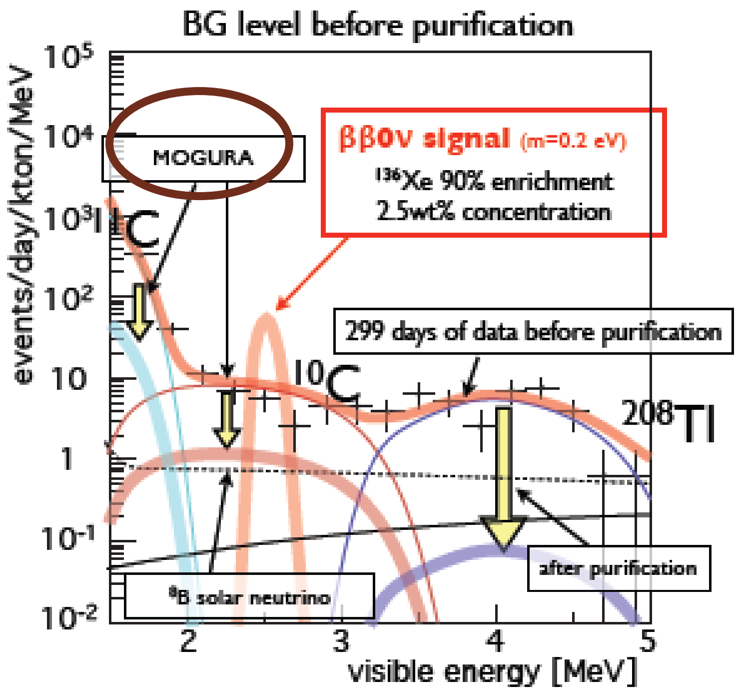
       → tagging by delayed coin.



Background Studies (1)

- Spallation background ; ^{10}C
  - New dead time free electronics for tagging neutron after muon
  - New electronics is being installed.

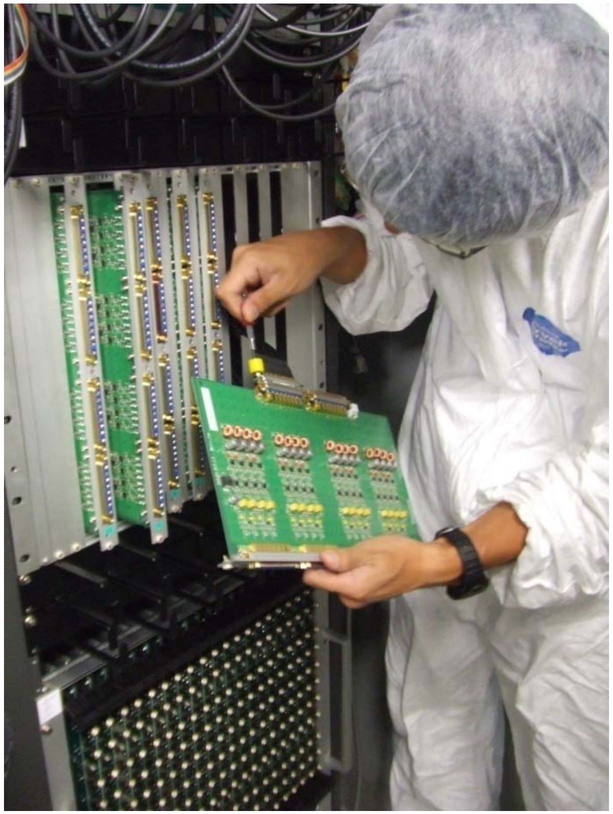




- **Factor ~20 reduction by tagging neutrons**

Background Studies (2)

- Toward spallation background rejection
  - New electronics MOGURA installation



- Ready to start data taking at ~ the end of this year.

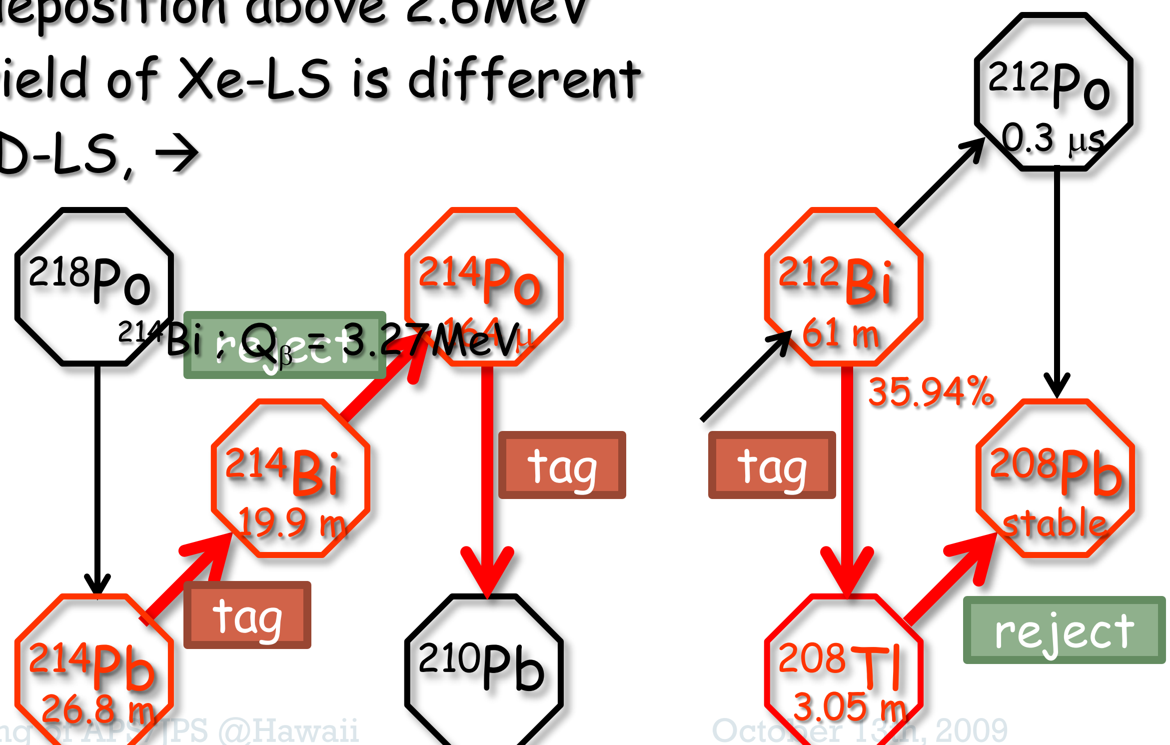
Background Studies (3)

- ^{214}Bi, ^{208}Tl in mini-balloon
  - Rejection by delayed coincidence
  - Range of α-particle in materials ~ short ; rejection efficiency is expected to be small, relatively (~ 70%).

    → also use ^{214}Pb - ^{214}Bi coincidence

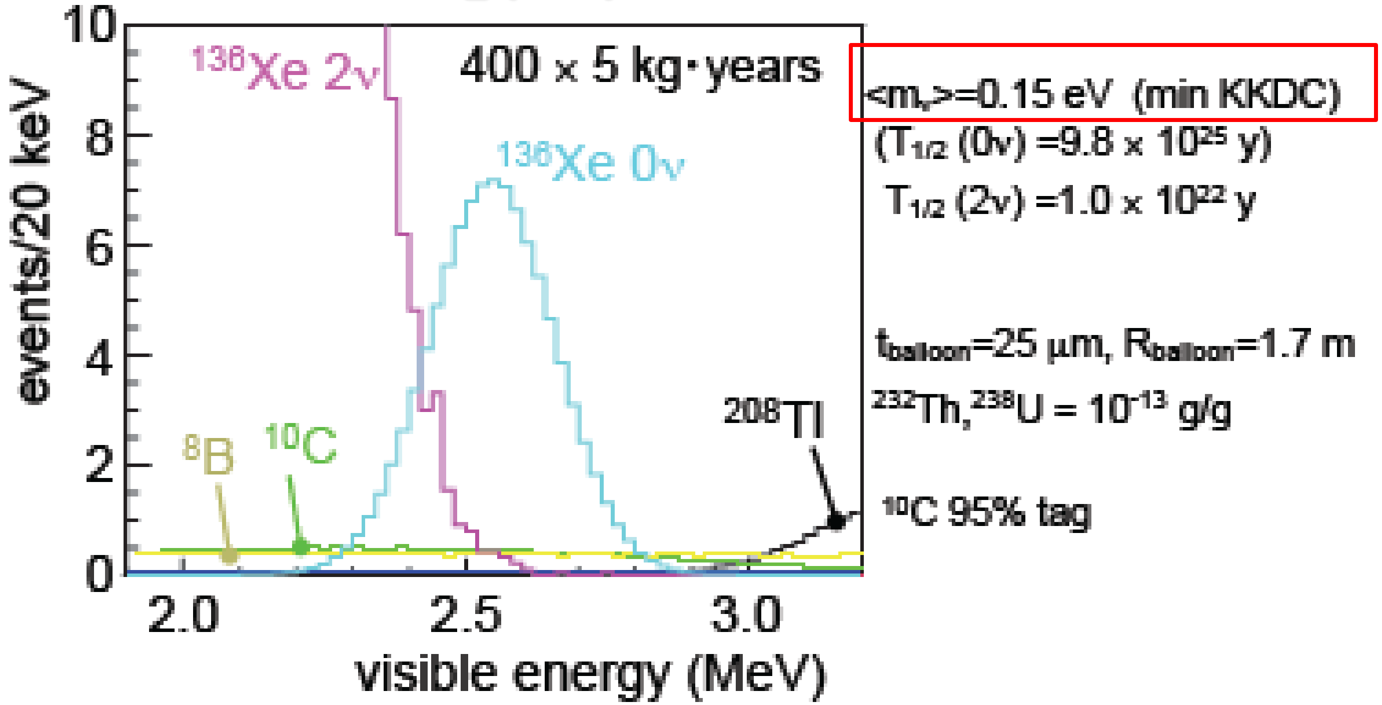
  - ^{208}Tl ; energy deposition above 2.6MeV

    but if light yield of Xe-LS is different with KamLAND-LS, →



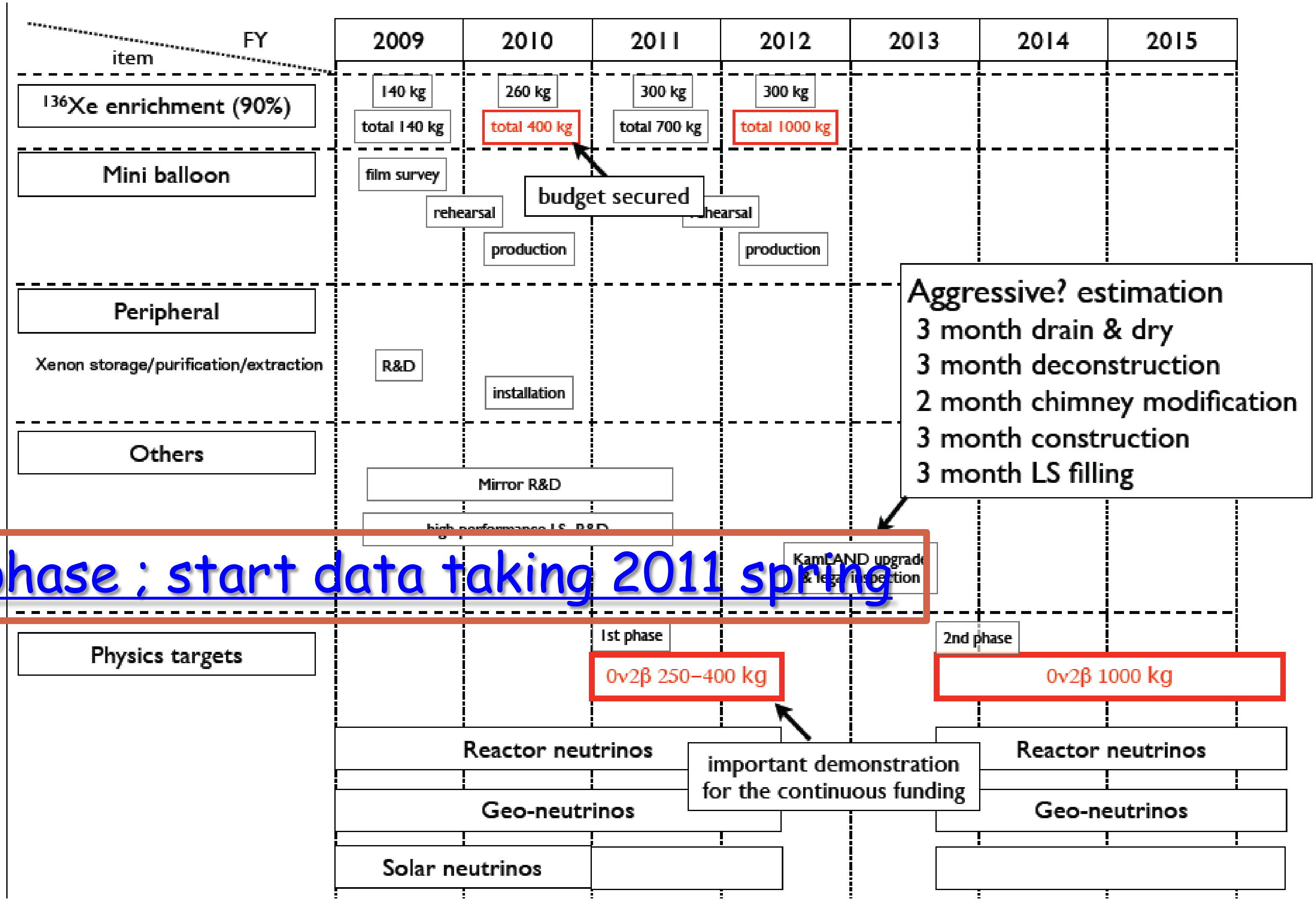
Expectation in 1st Phase ββ

- Simulated energy spectrum



- Backgrounds are expected far below the ^{136}Xe 0νββ peak.
- Sensitivity of 1st phase ; below KKDC claim

Time Table of the ββ Project



- 1st phase ; start data taking 2011 spring

Summary

- Next physics target of KamLAND ; $0\nu\beta\beta$ decay
- Enriched ^{136}Xe dissolved liquid scintillator

- Milestone
  - 1st phase ; 250 ~ 400 kg of Xe → 60 meV (KKDC claim, degenarate)
  - 2nd phase ; 1000 kg of Xe with increasing L.Y. → 25 meV (inverted hierarchy)
- R&D items for 1st phase
  - Xe-LS development ; already finished
  - Development of mini-balloon ; making 1st text balloon
  - Xe gas handling system & quality control system ; designing & development
  - Background study ; simulation studies are finished, New electronics is being installed.
- 1st Phase ; start data taking on 2011/spring