TAUP 2013, September XX, 2013

Status of the KamLAND-Zen Experiment

Patrick Decowski
for the KamLAND-Zen Collaboration

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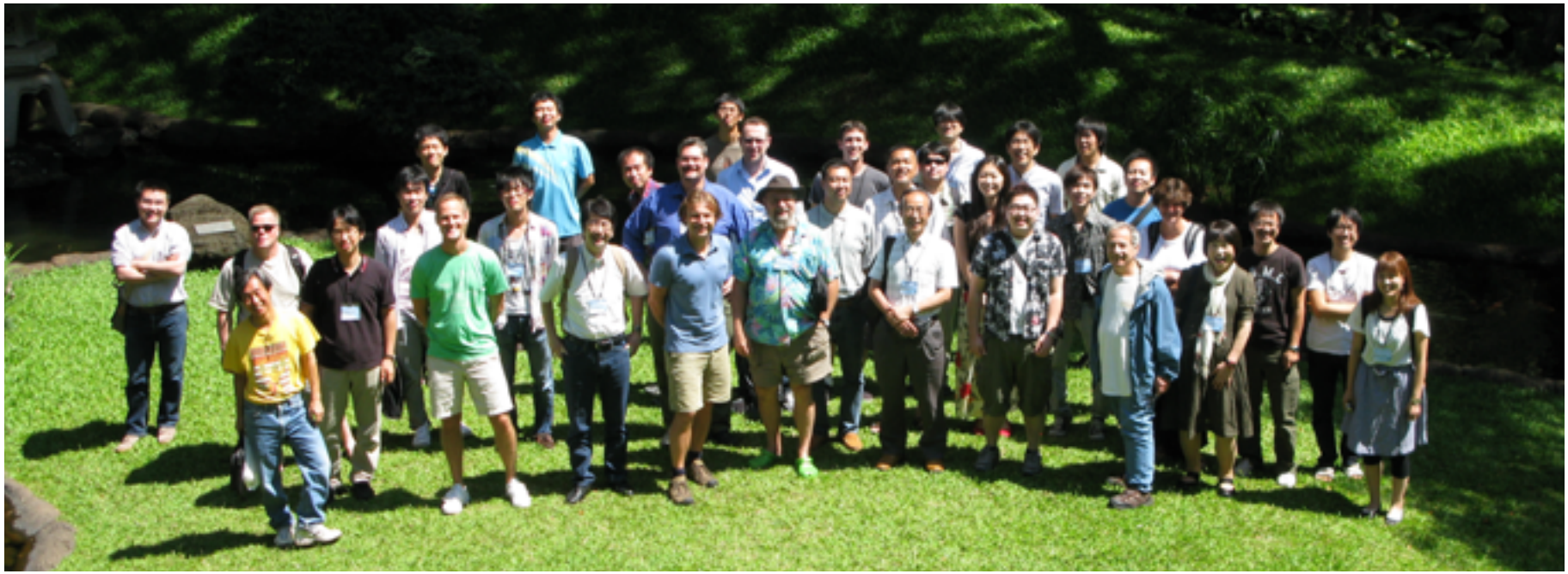
KamLAND-Zen Collaboration



A. Gando,[1] Y. Gando,[1] H. Hanakago,[1] H. Ikeda,[1] K. Inoue,[1,2] K. Ishidoshiro,[1] R. Kato,[1] M. Koga,[1,2] S. Matsuda,[1] T. Mitsui,[1] D. Motoki,[1] T. Nakada,[1] K. Nakamura,[1,2] A. Obata,[1] A. Oki,[1] Y. Ono,[1] M. Otani,[1] I. Shimizu,[1] J. Shirai,[1] A. Suzuki,[1] Y. Takemoto,[1] K. Tamae,[1] K. Ueshima,[1] H. Watanabe,[1] B.D. Xu,[1] S. Yamada,[1] H. Yoshida,[1] A. Kozlov,[2] S. Yoshida,[3] T.I. Banks,[4] S.J. Freedman,[2,4] B.K. Fujikawa,[2,4] K. Han,[4] T. O'Donnell,[4] B.E. Berger,[5] Y. Efremenko,[2,6] H.J. Karwowski,[7] D.M. Markoff,[7] W. Tornow,[7] J.A. Detwiler,[8] S. Enomoto,[2,8] and M.P. Decowski[2,9]

(The KamLAND-Zen Collaboration)

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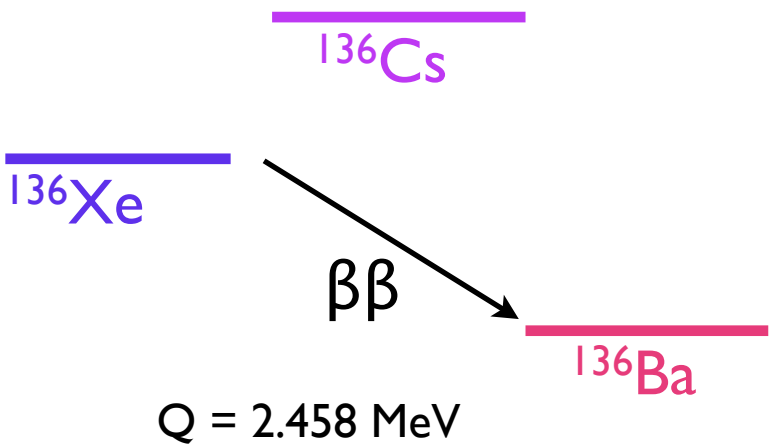
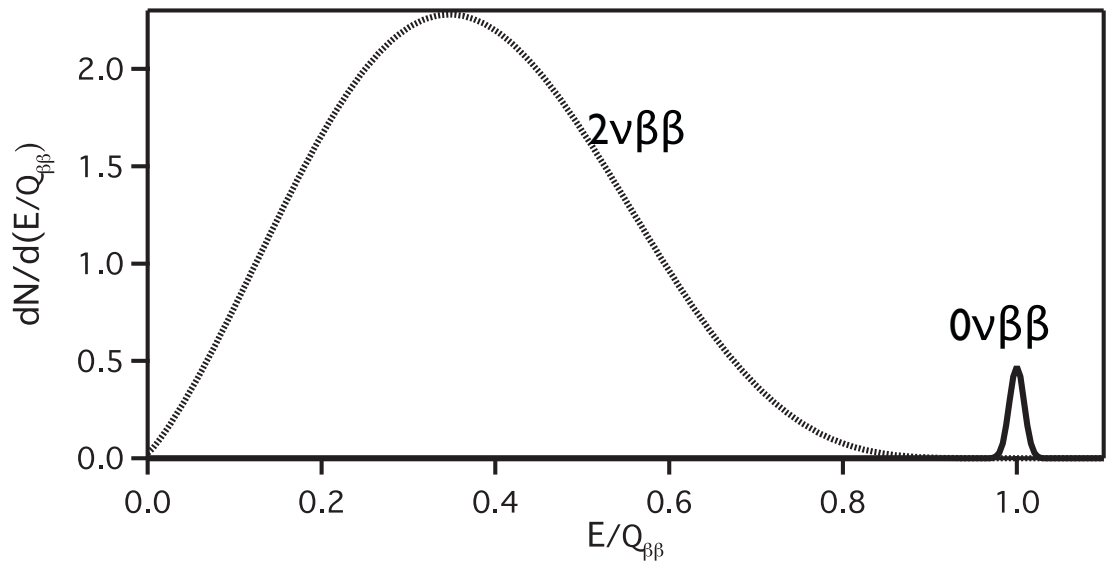
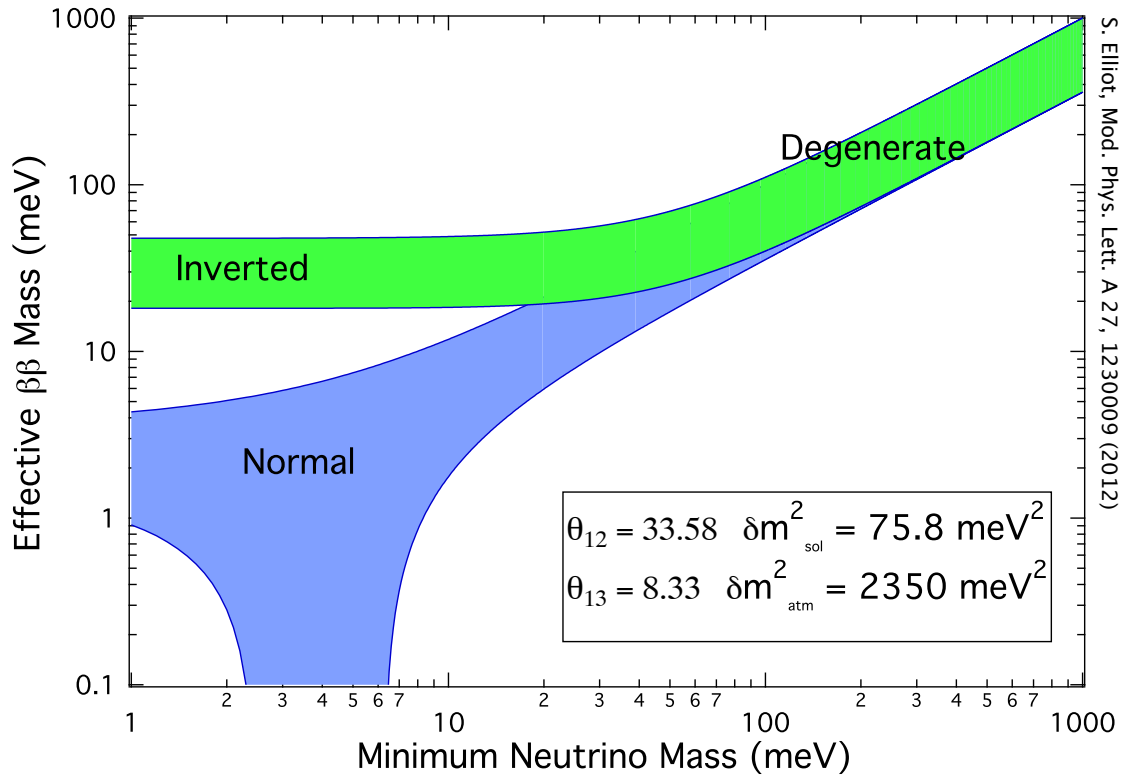
Raison d'Etre





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

Interesting physics

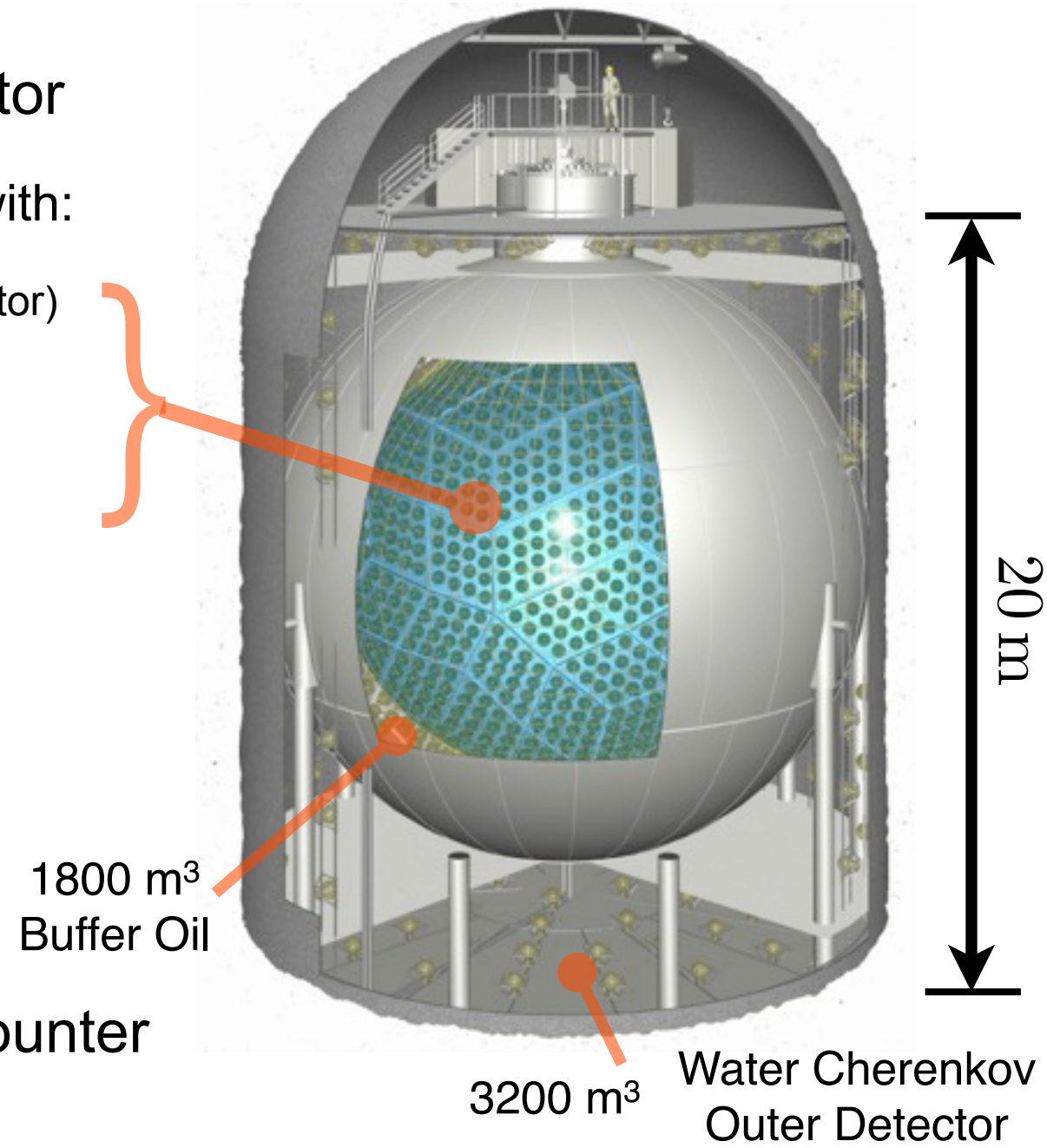


S. Elliot, Mod. Phys. Lett. A 27, 1230009 (2012)

Patrick Decowski/Nikhef

KamLAND(-Zen) detector

- 1 kton Scintillation Detector
  - 6.5m radius balloon filled with:
    - 20% Pseudocumene (scintillator)
    - 80% Dodecane (oil)
    - PPO
- 34% PMT coverage
  - ~1300 17” fast PMTs
  - ~550 20” large PMTs
- Multi-hit electronics
- Water Cherenkov veto counter



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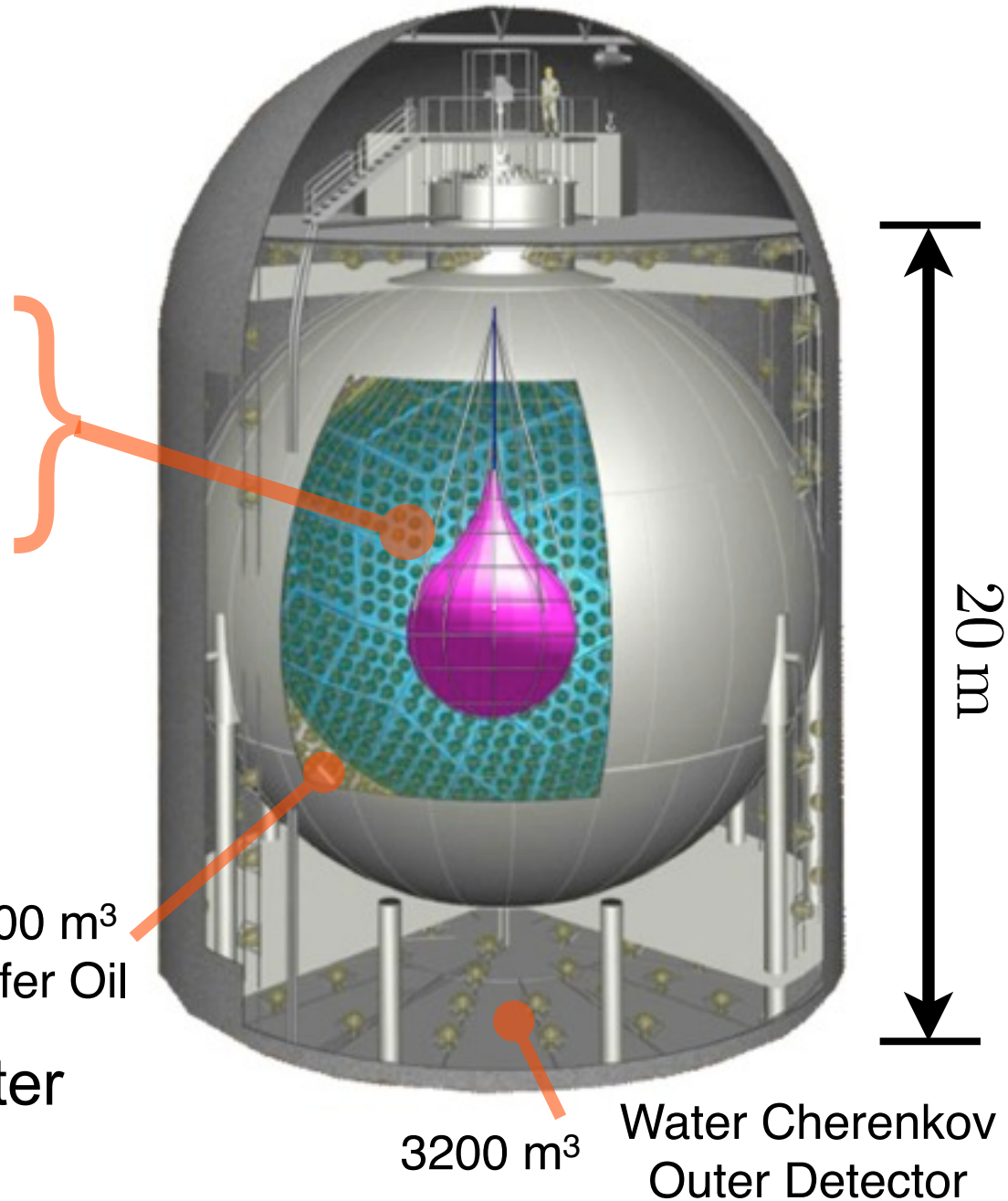
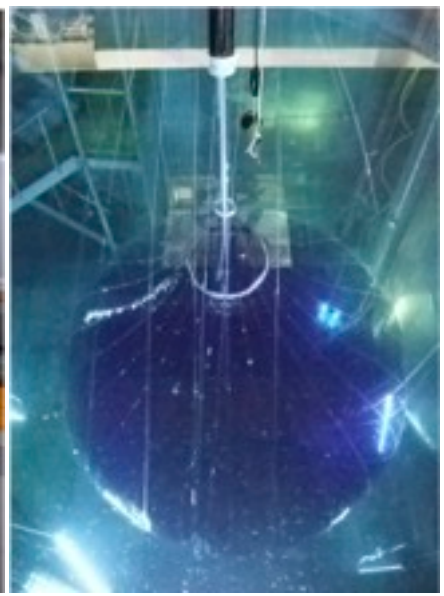
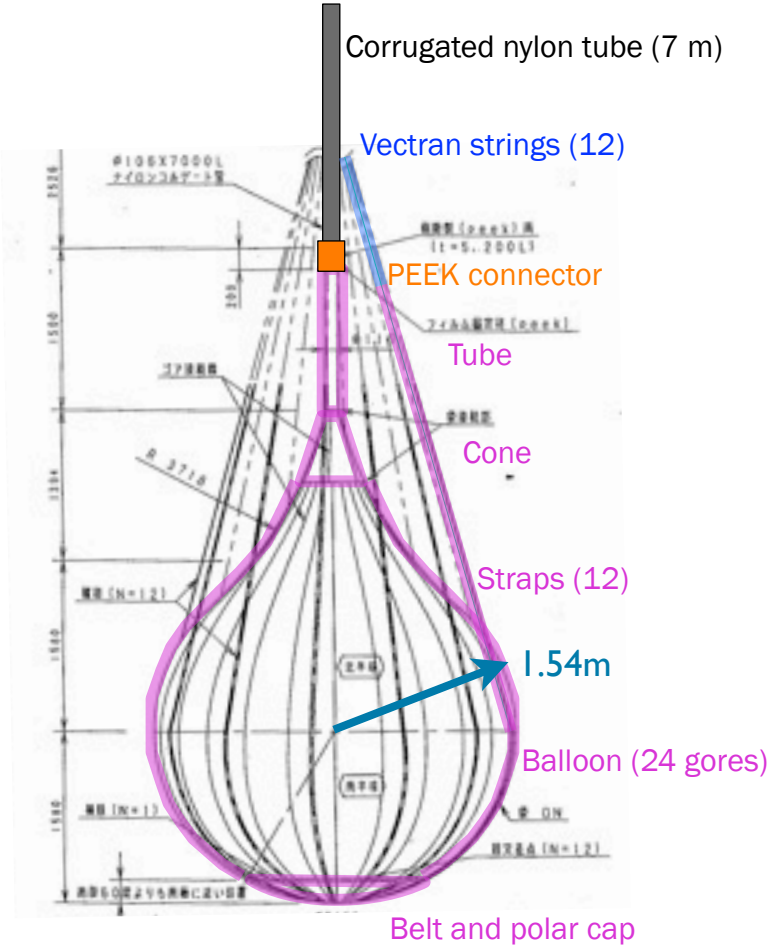


Mini-Balloon

- Requirements
  - Chemical compatibility with LS
  - Mechanically strong, low radioactivity
  - Barrier against Xe:
    - loss < 220g/yr
  - Transmission of scintillation light
    - 99.4% at 400nm

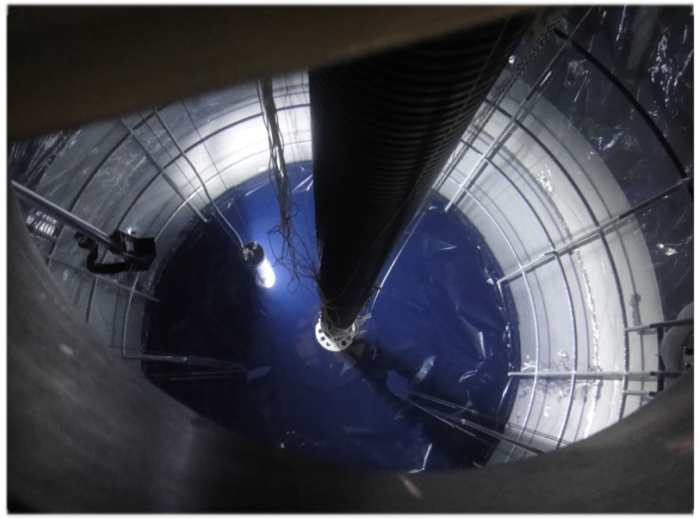


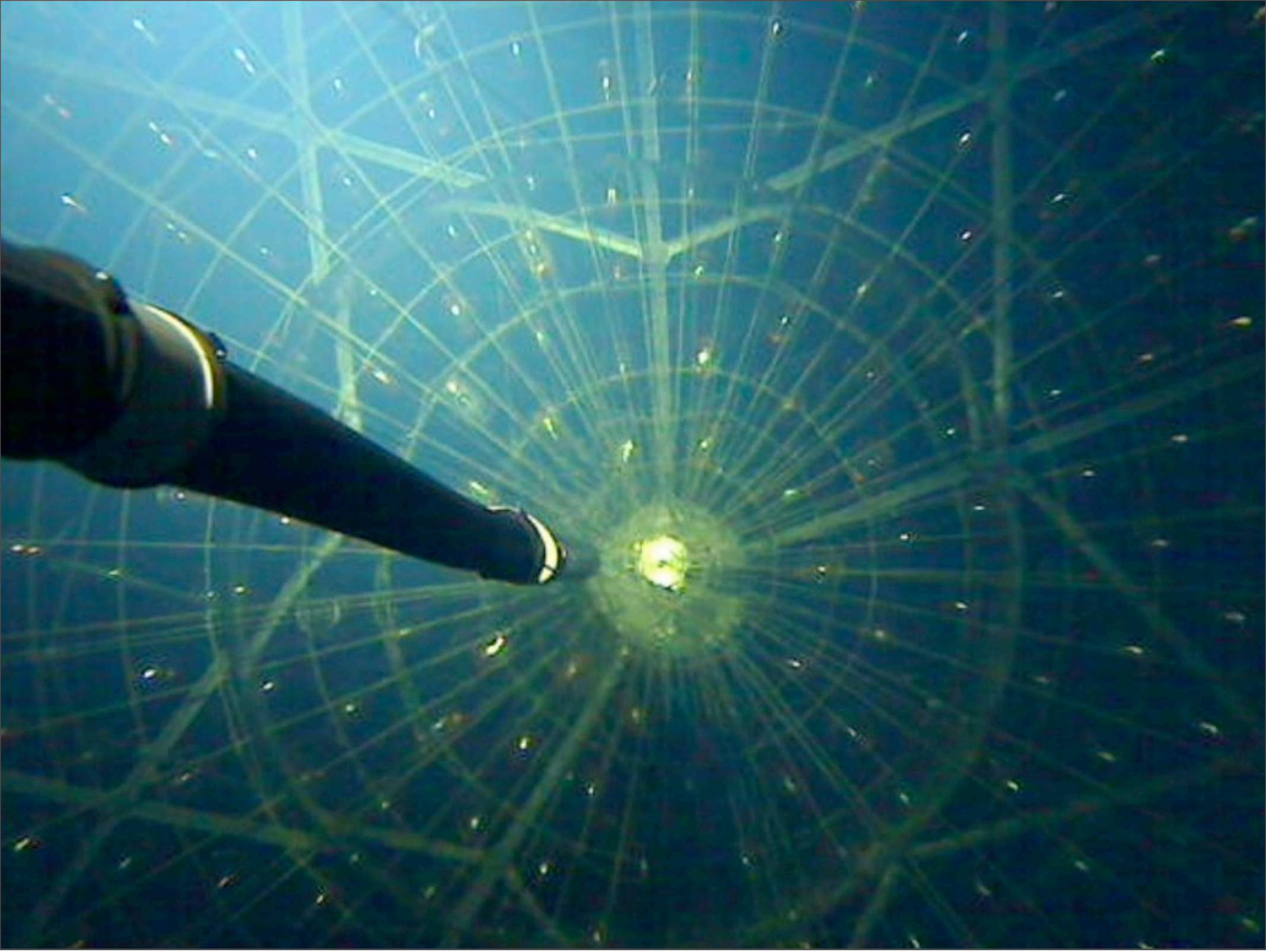


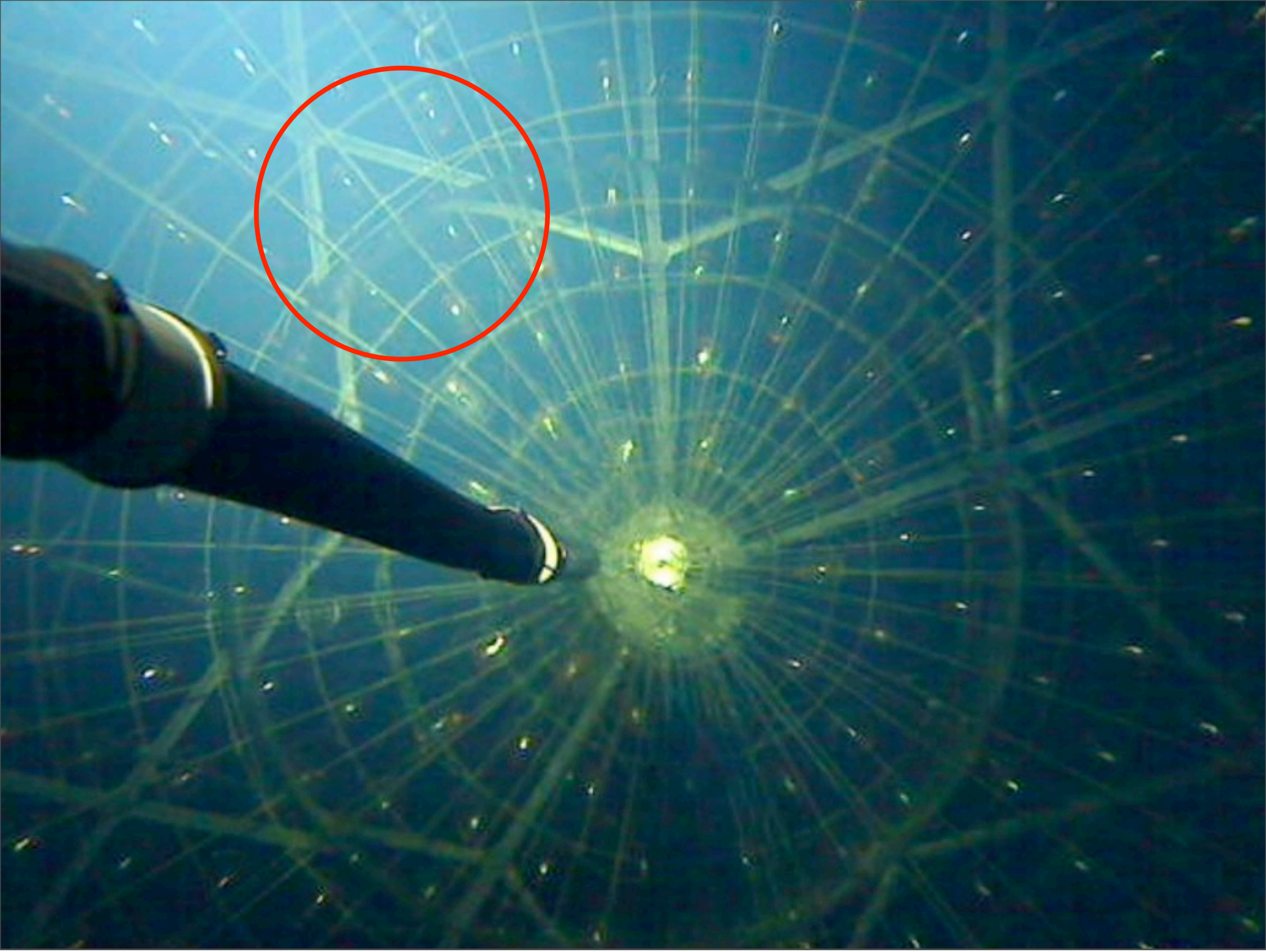
- Material: 25 μm thick ultra-pure nylon
  - U/Th/K ≲ 10^{-12} g/g
- 1/4 & full scale tests in air and water

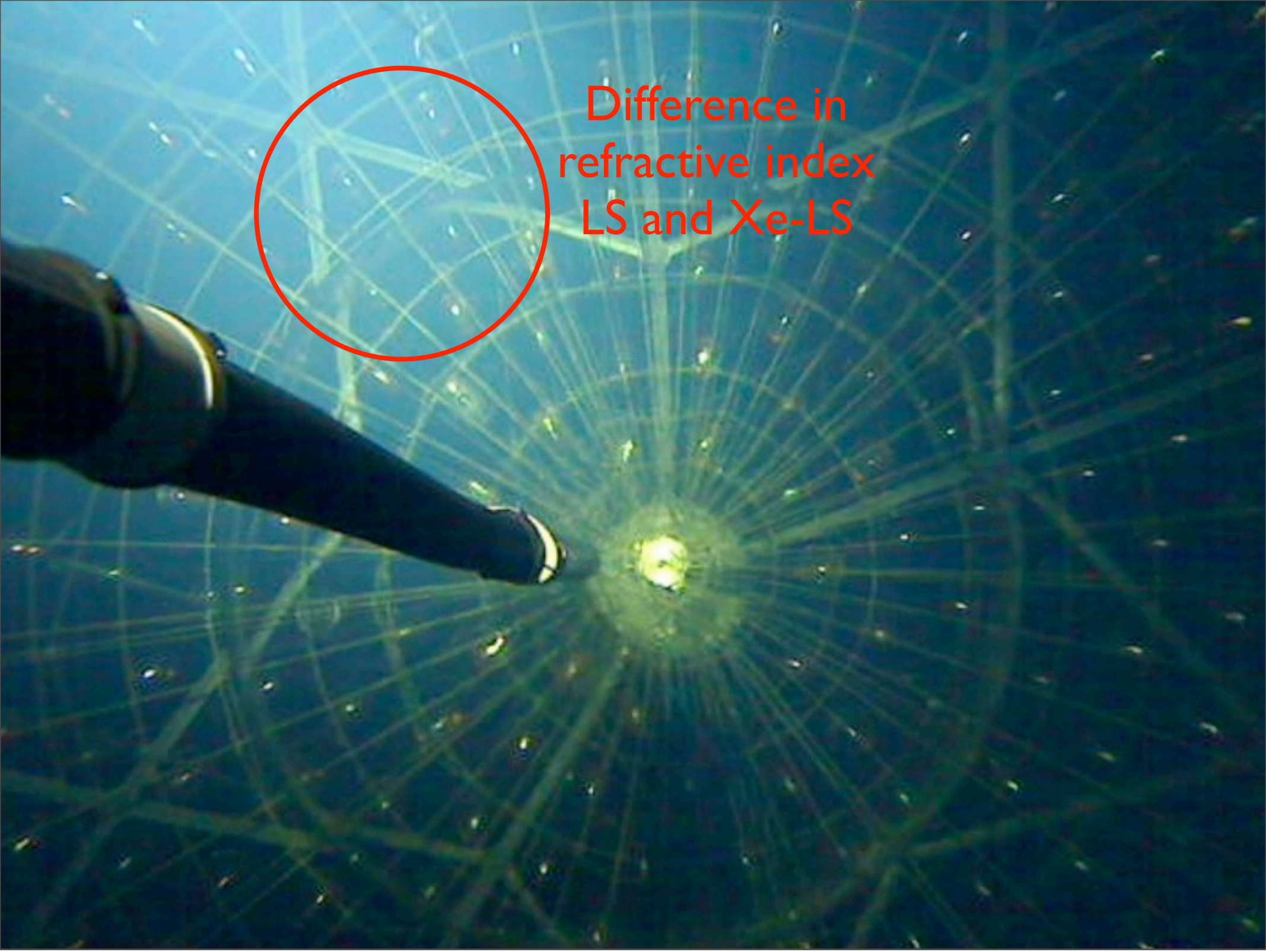
Mini-Balloon Construction: May-Aug 2011

Near Sendai



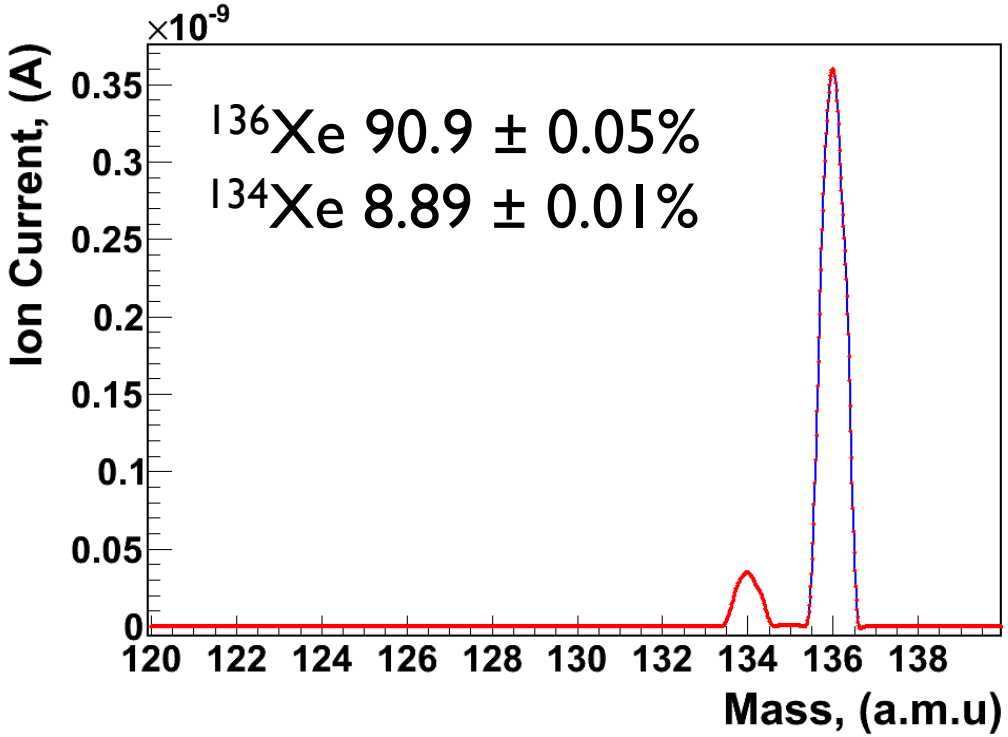





Difference in
refractive index
LS and Xe-LS

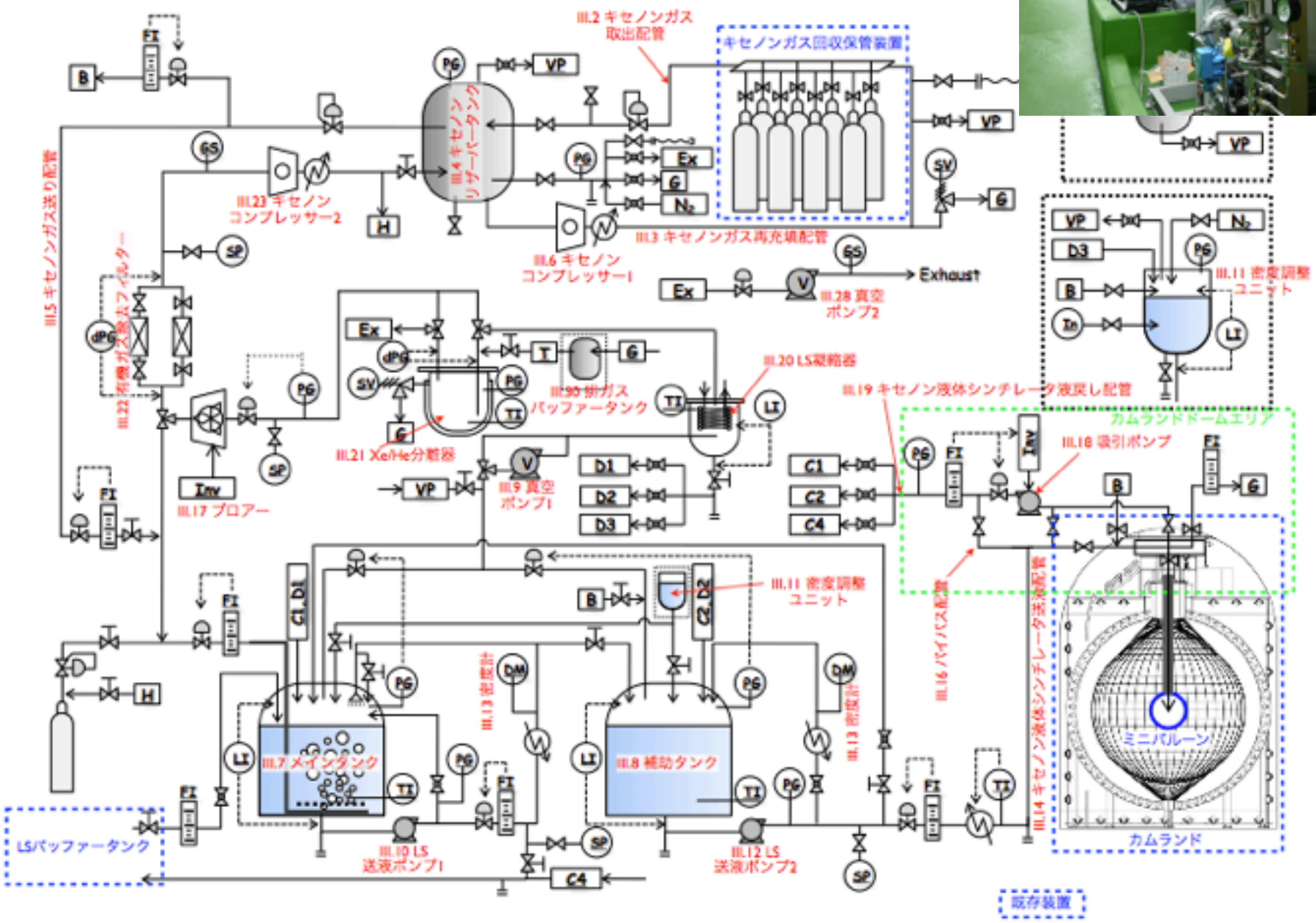
Xe loaded Liquid Scintillator

- Enrichment by gas centrifuge in Russia
- ~320kg of enriched Xe
- Xe-LS
  - 82% Decane
  - 18% Pseudocumene
  - 2.7 g/l PPO
  - 2.4%wt Xe
- Backgrounds
  - ^{238}U: $(1.3 \pm 0.2)\times10^{-16}$ g/g
  - ^{232}Th: $(1.8 \pm 0.1)\times10^{-15}$ g/g



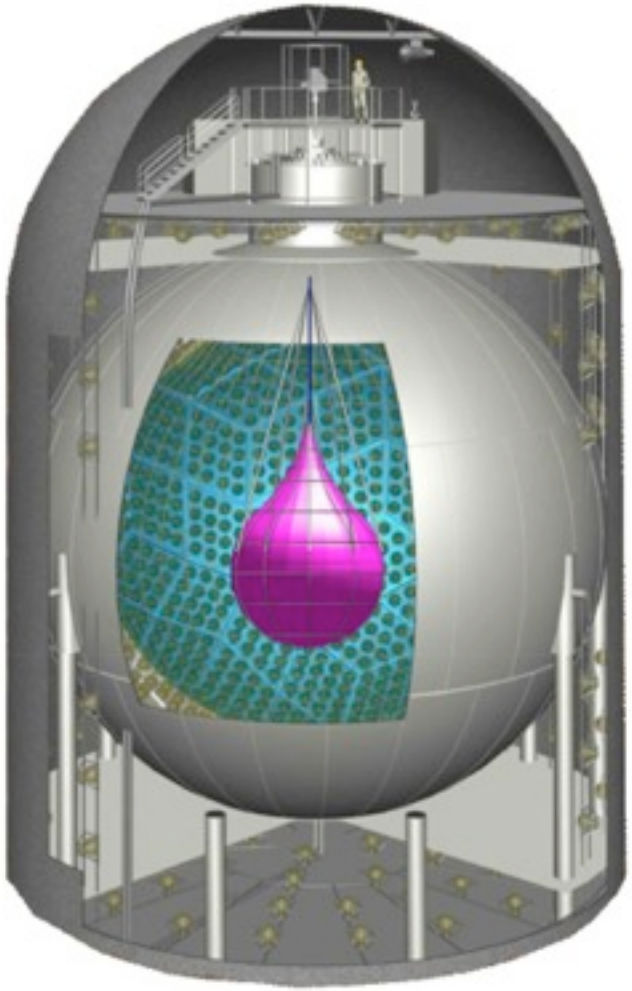
Xe-LS Handling System

図1 装置全体のフロー概念図



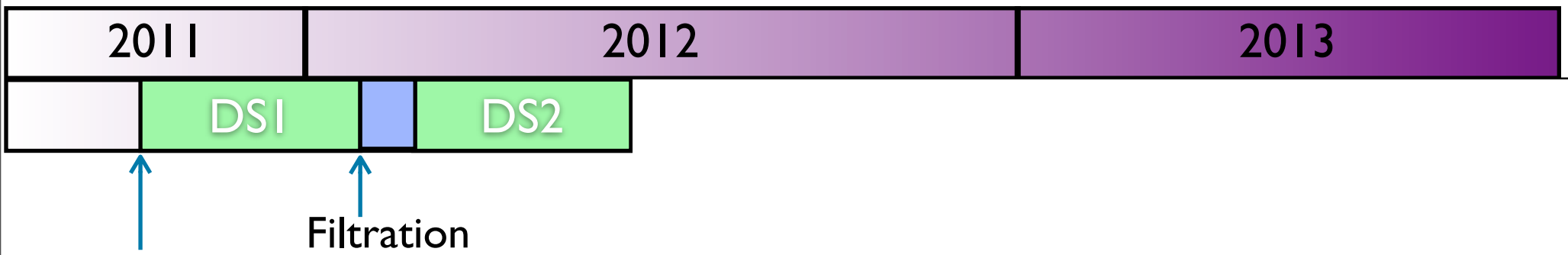
KamLAND-Zen advantages & disadvantages

- +Well-understood detector
- +Highly pure, self-shielding environment
- +Large ββ source mass, scalable
- -Relatively poor energy resolution
- -No particle identification



Neutrino oscillation & geoneutrino measurements are continuing

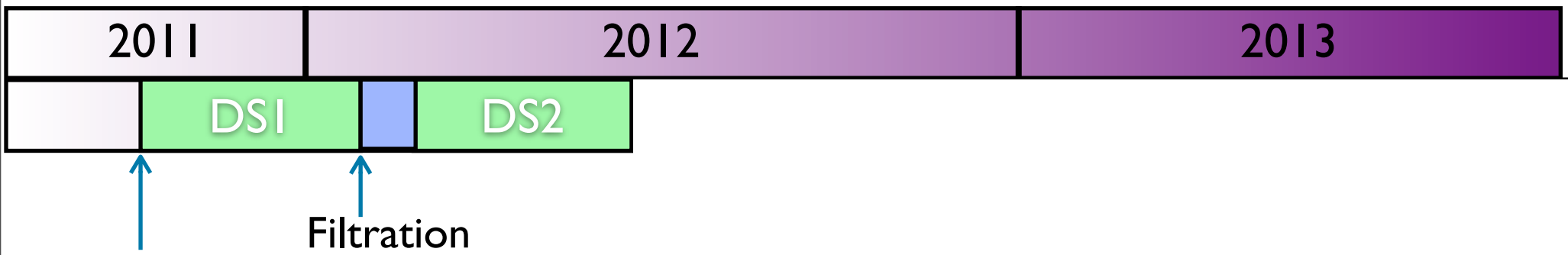
KamLAND-Zen Timeline



Sept '11:Start of KamLAND-Zen

	DS-1	DS-2	Total
live time (days)	112.3	101.1	213.4
fiducial Xe-LS mass (ton)	8.04	5.55	-
Xe concentration (wt%)	2.44	2.48	-
^{136}Xe mass (kg)	179	125	-
^{136}Xe exposure (kg yr)	54.9	34.6	89.5

KamLAND-Zen Timeline



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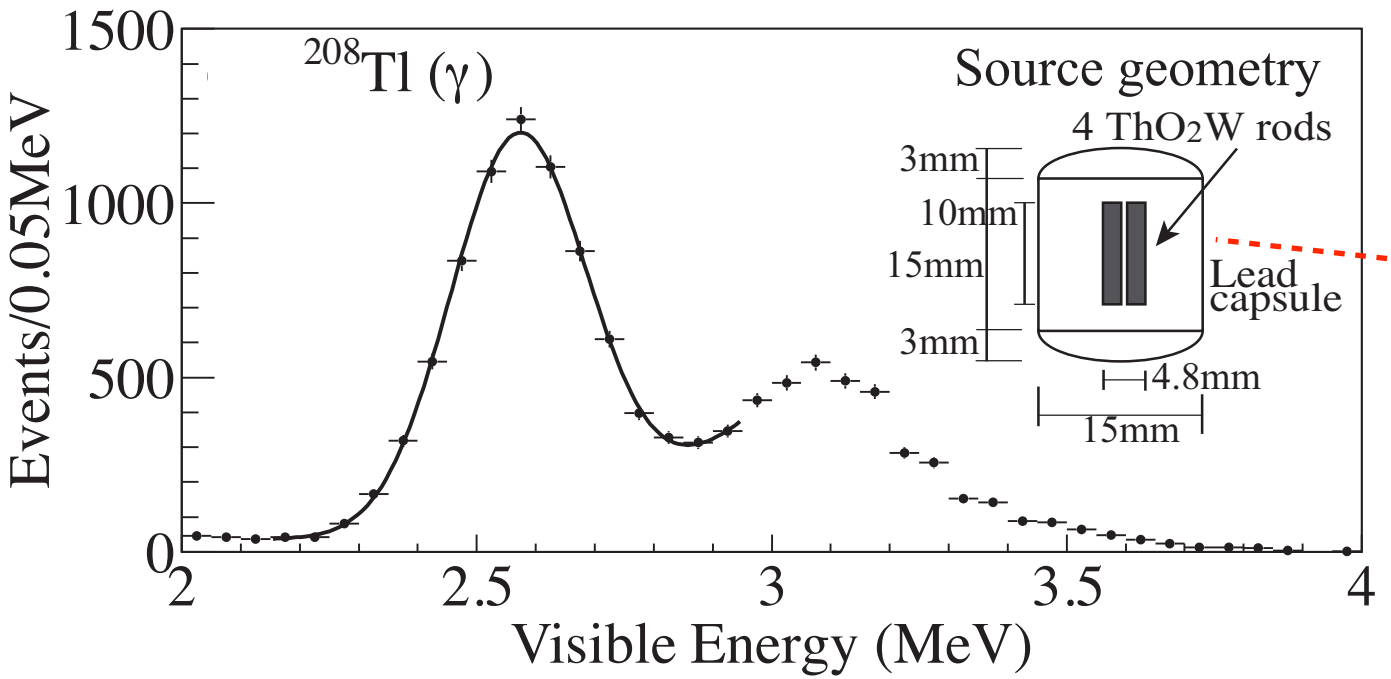
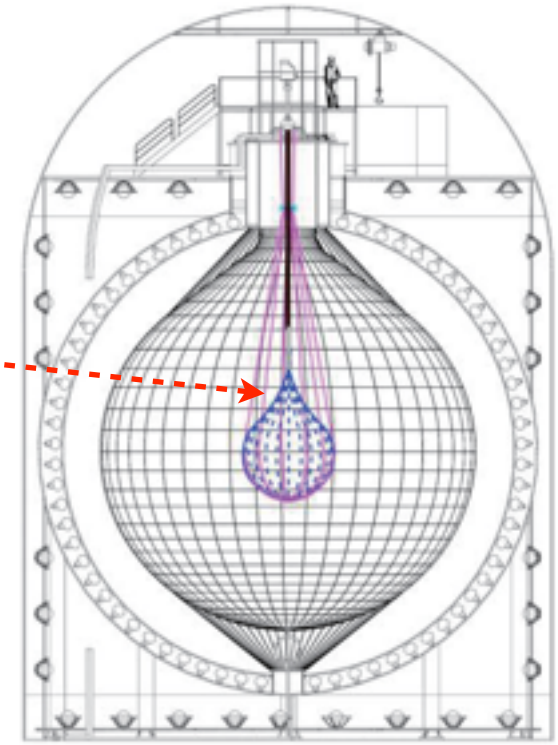
Calibration

KamLAND is well-understood. Previous reconstruction algorithms can be easily adapted

External energy calibration





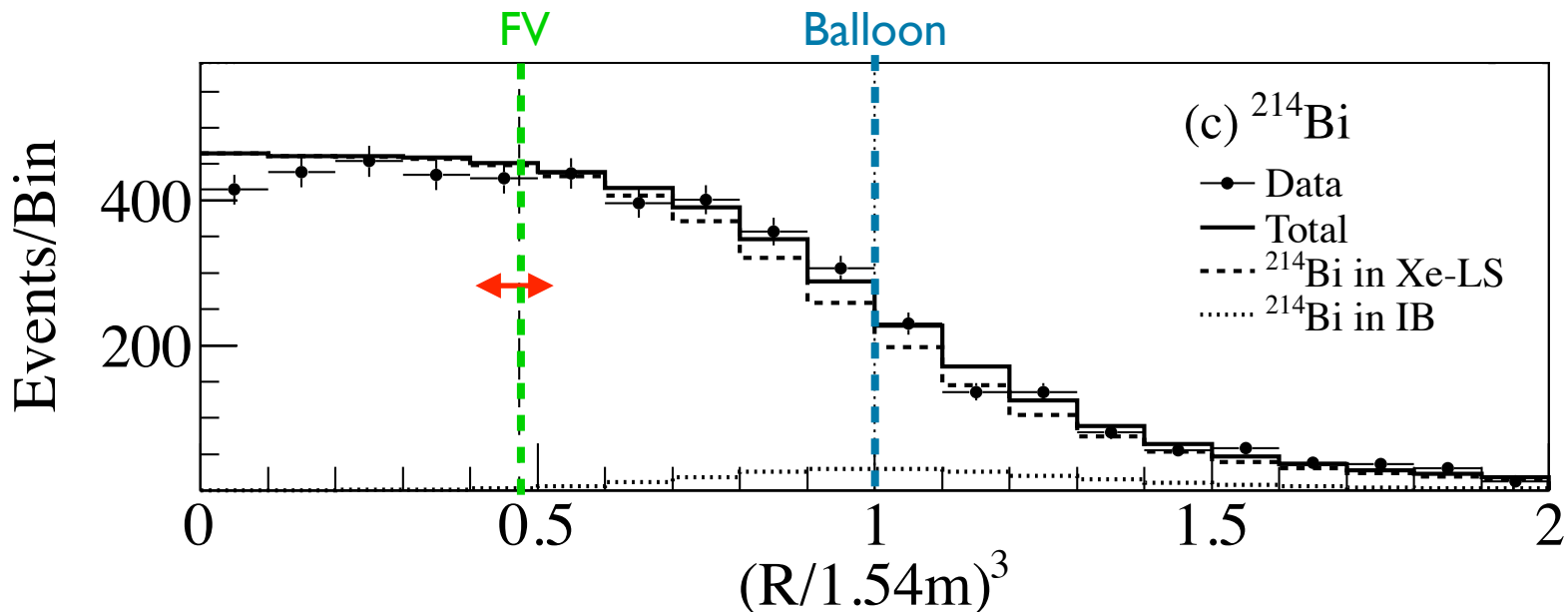
Internal calibration sources: tagged ^{214}BiPo, ^{222}Rn during filling, 2.225 MeV neutron capture γ

σ_P = 15cm / $\sqrt{E(MeV)}$

σ_E = (6.6 ± 0.3)% / $\sqrt{E(MeV)}$

Systematic Uncertainties

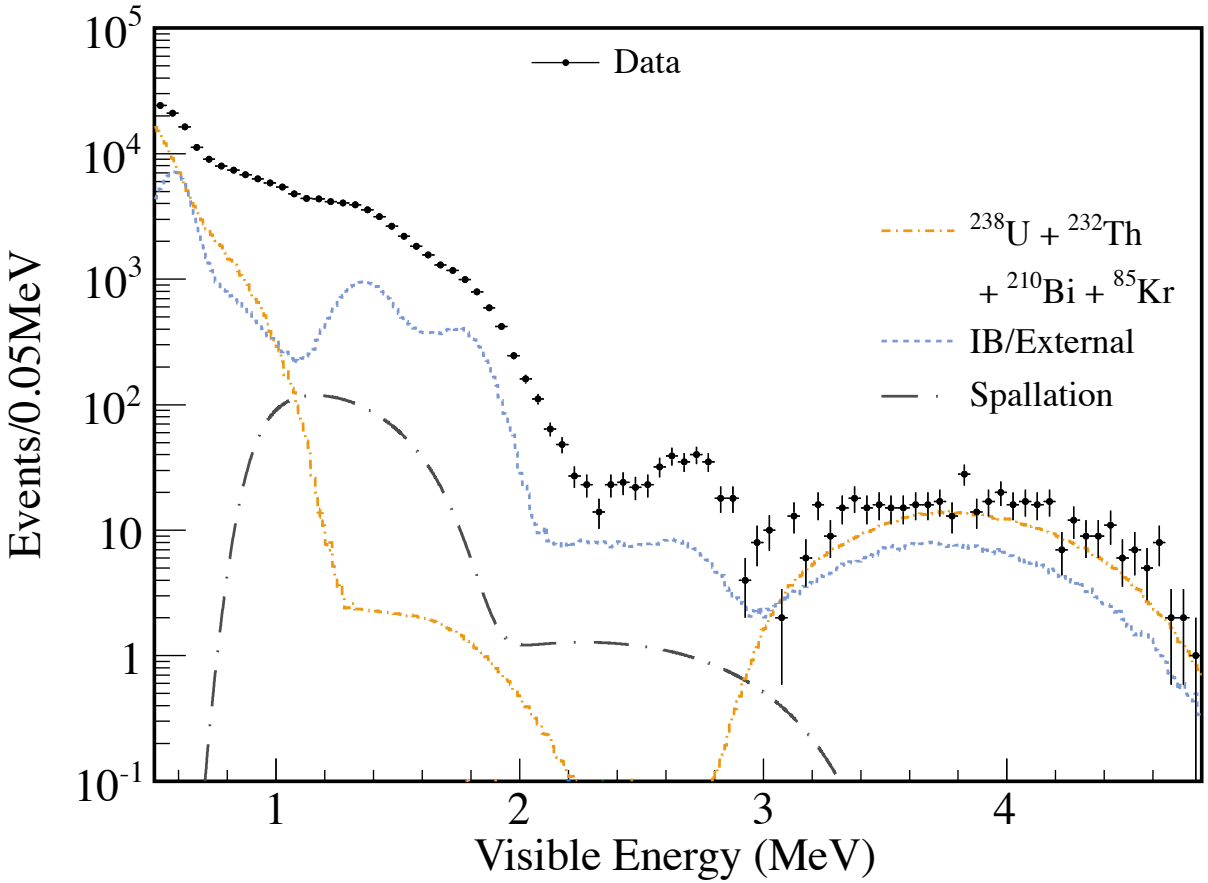
- Fiducial Volume: R^3 of ^{214}Bi in early data uniform to within 3.9%/4.1%



- Xe concentration within 0.3%
- Enrichment, E-scale, efficiency, livetime, Xe-LS edge effect: all <0.3%

Combined systematic uncertainty: 3.9%/4.1% for DS-1/DS-2

Latest 0ν2β results



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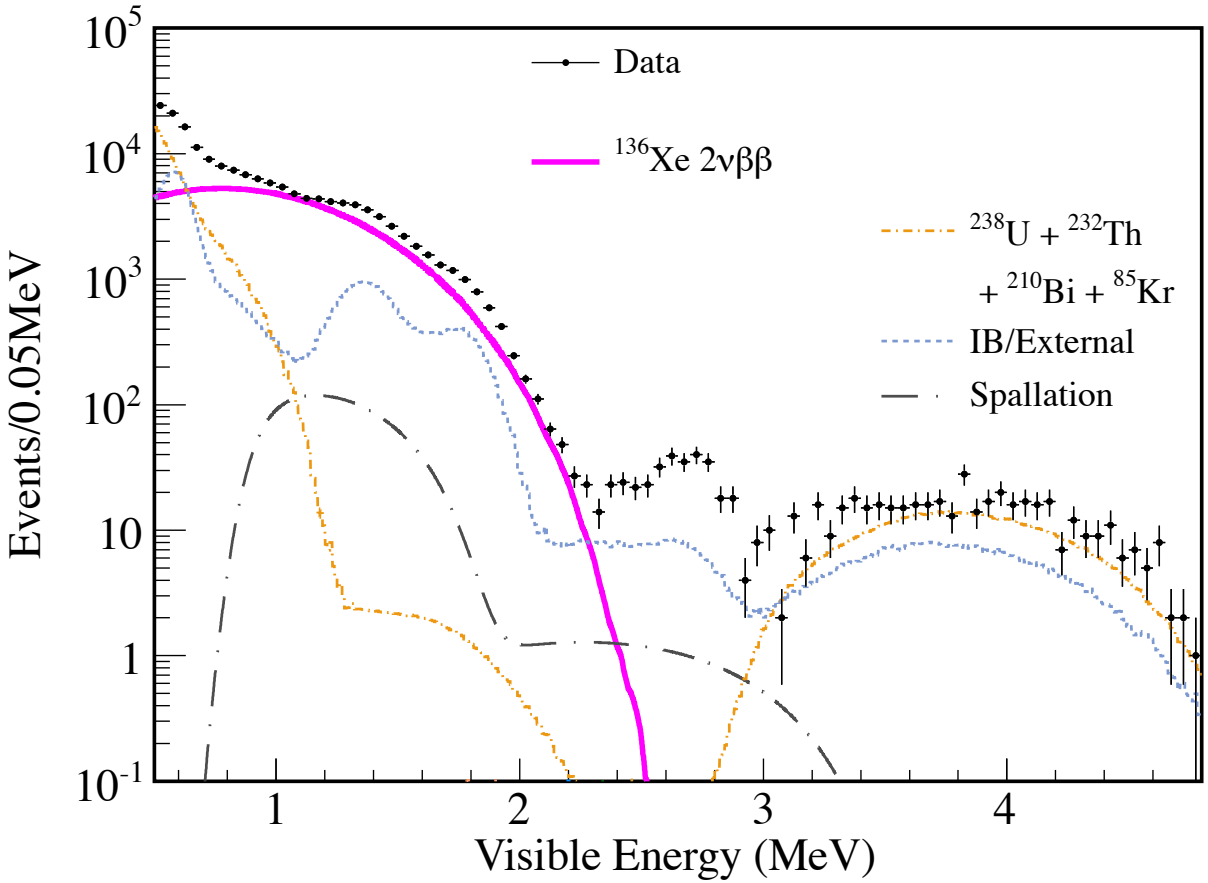

$$T^{2\nu}_{1/2} = 2.30 \pm 0.02\,(\mathrm{stat}) \pm 0.12\,(\mathrm{sys}) \times 10^{21}\ \mathrm{yr}$$

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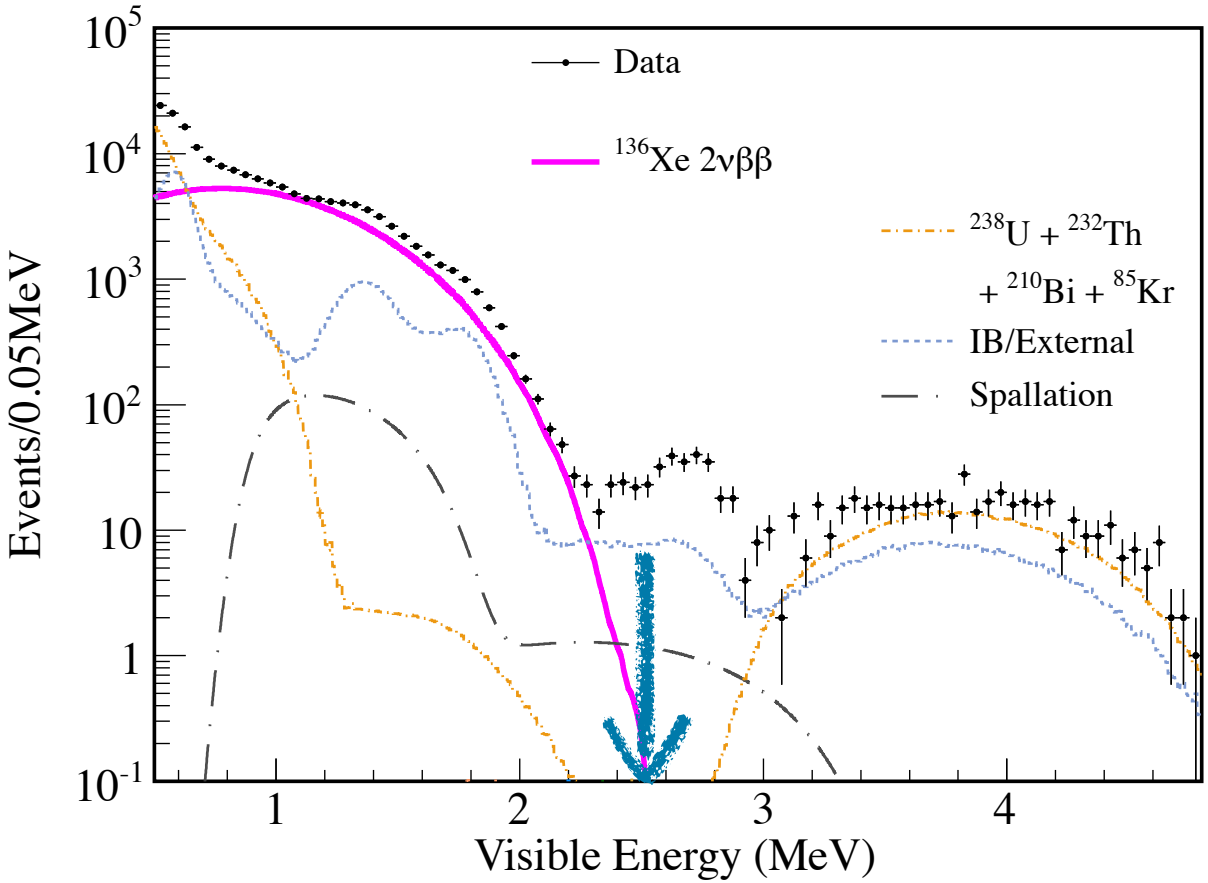

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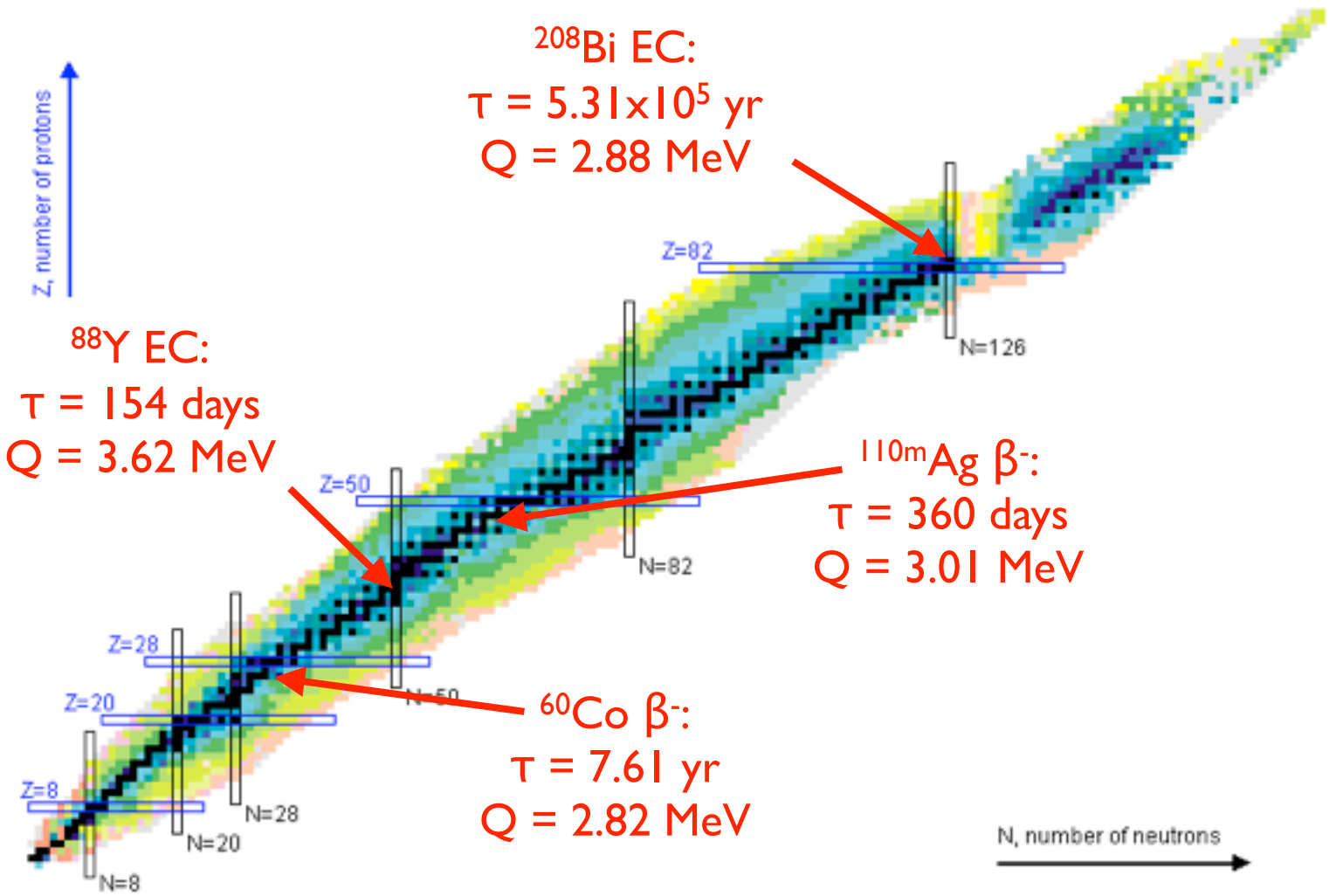
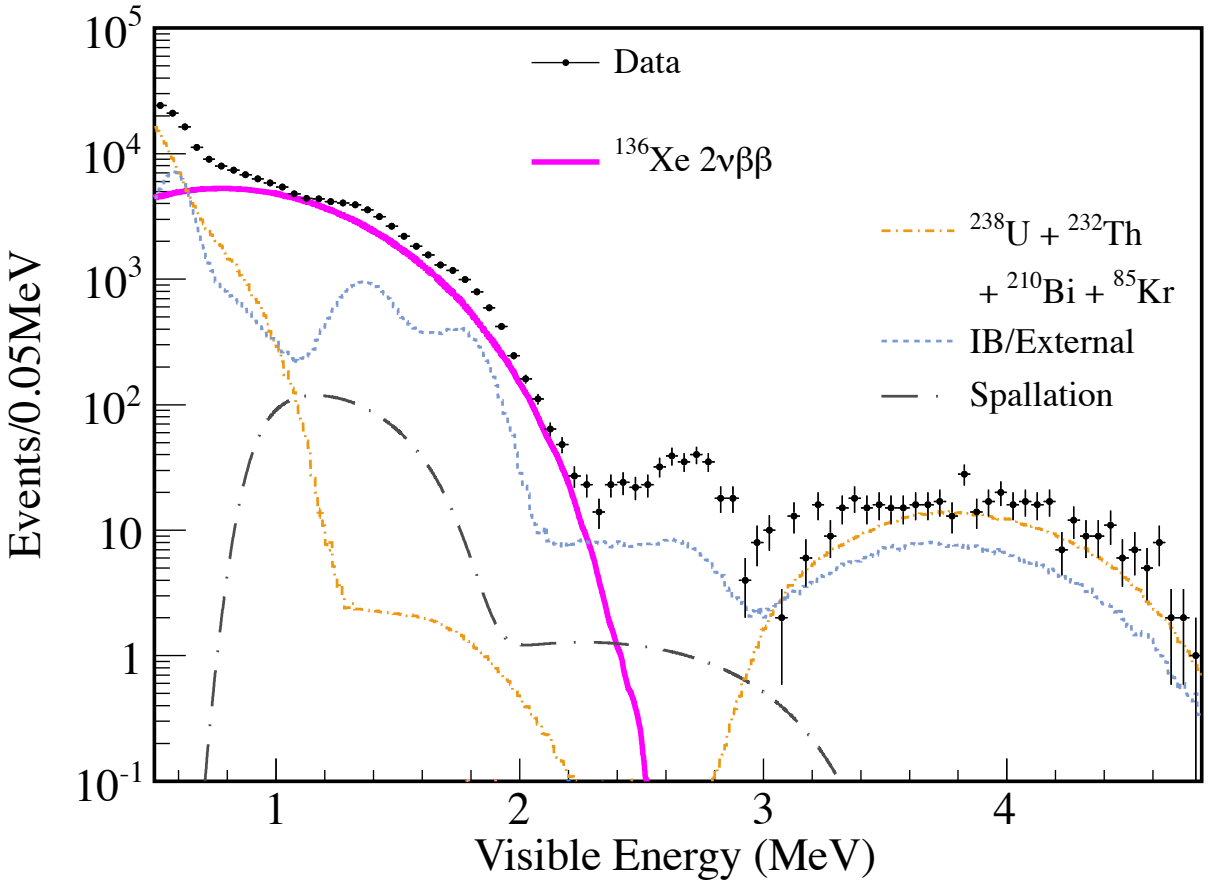
Results from the ENSDF search

- Search through *thousands* of isotopes in ENSDF and *millions* of decay paths that can give a peak between 2.4 MeV and 2.8 MeV
  - Account for all particle-dependent energy non-linearities
  - Require τ > 30 days, or 100s < τ < 30 days if production cross section is fairly large



NuDat 2.6

Latest 0ν2β results



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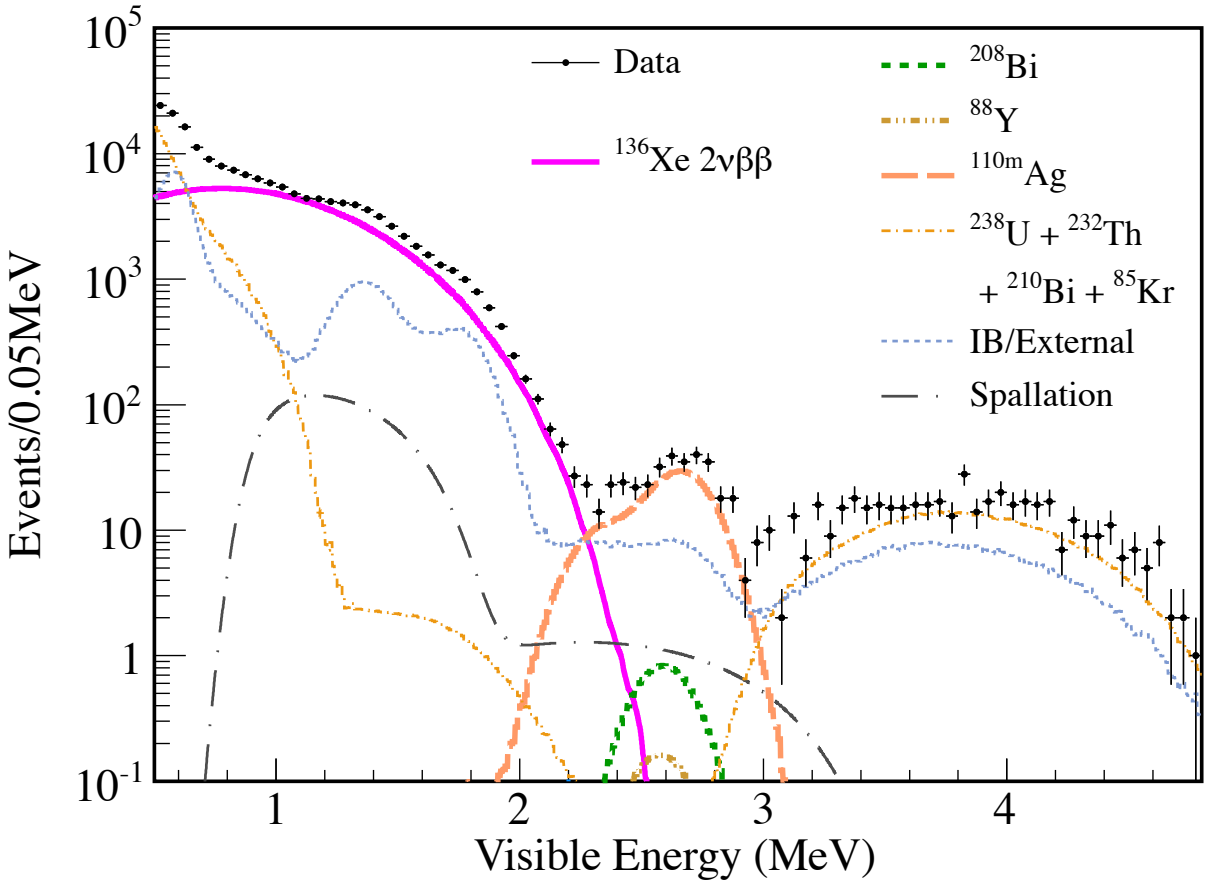

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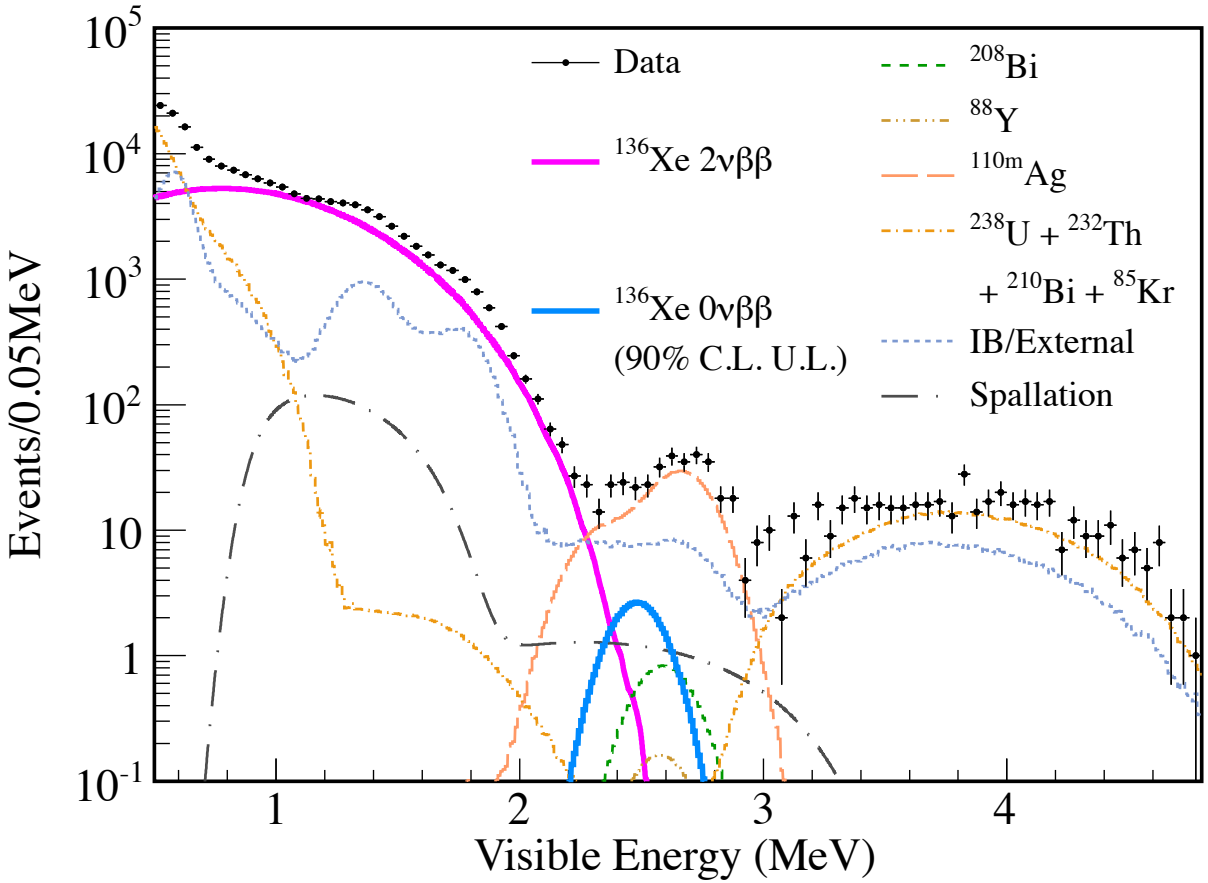
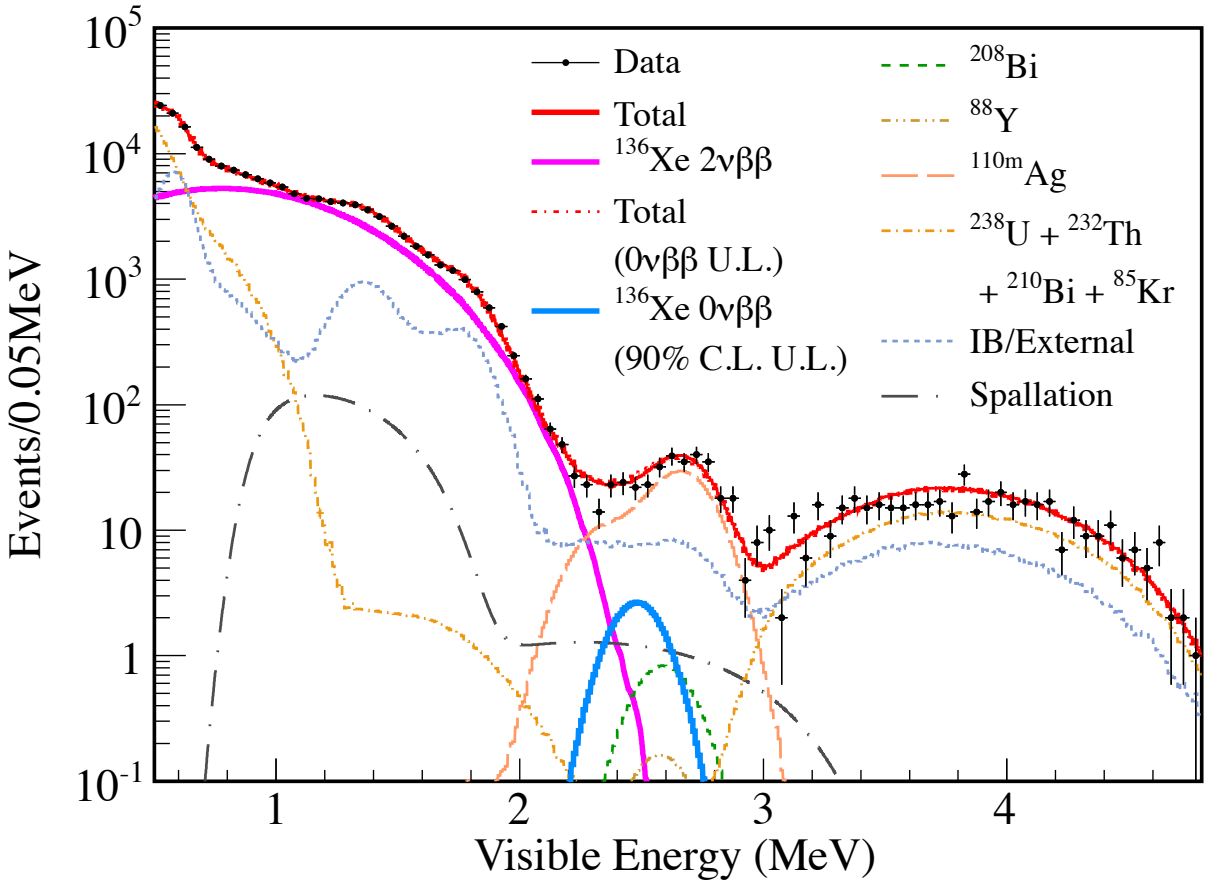


$T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr (90% CL)

(sensitivity $T^{0\nu}_{1/2} > 1.0 \times 10^{25}$ yr)

Latest 0ν2β results



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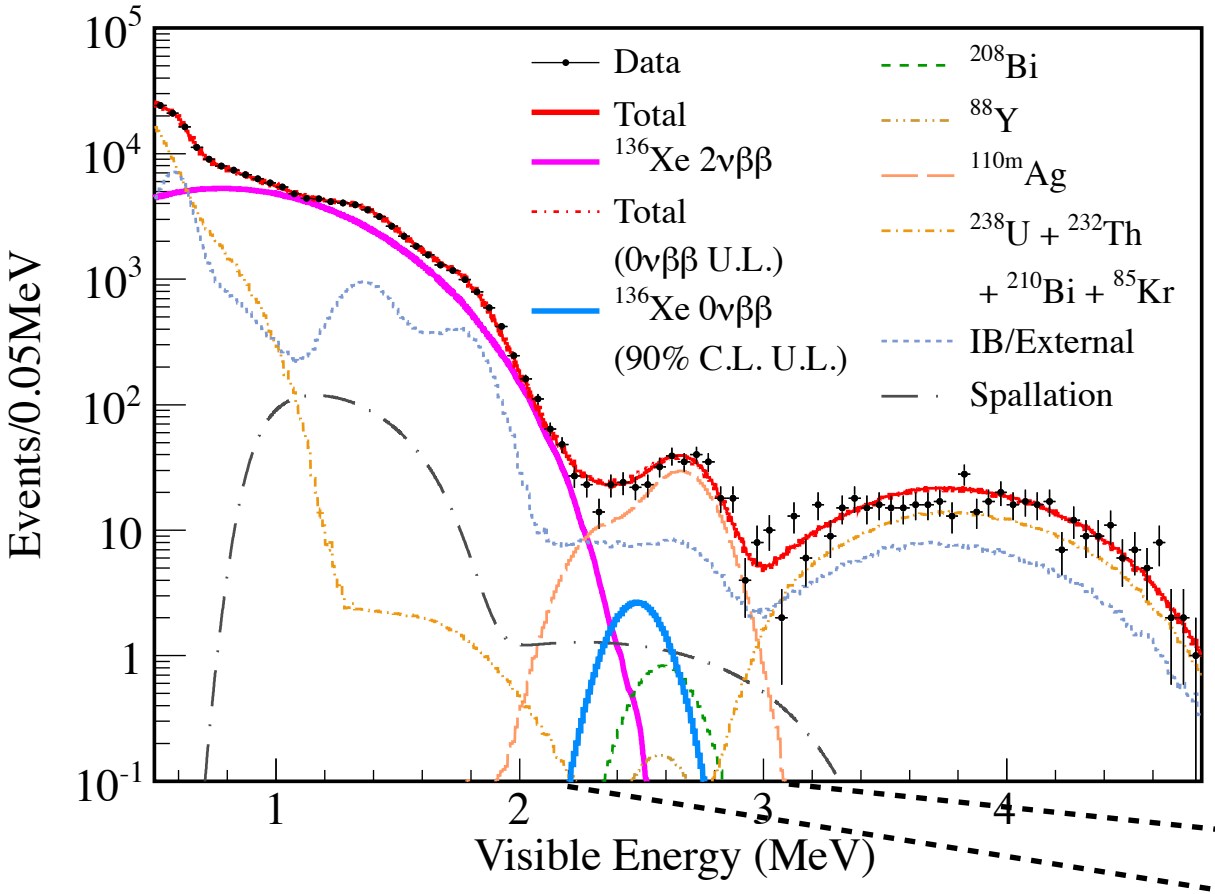

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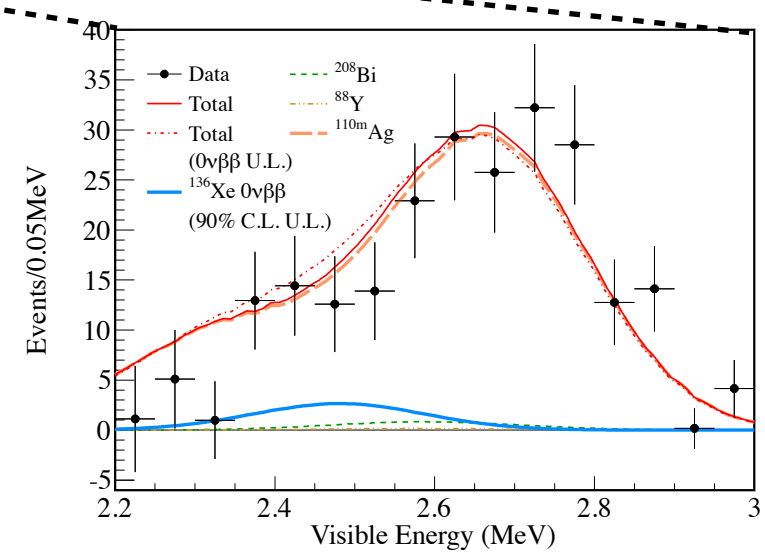

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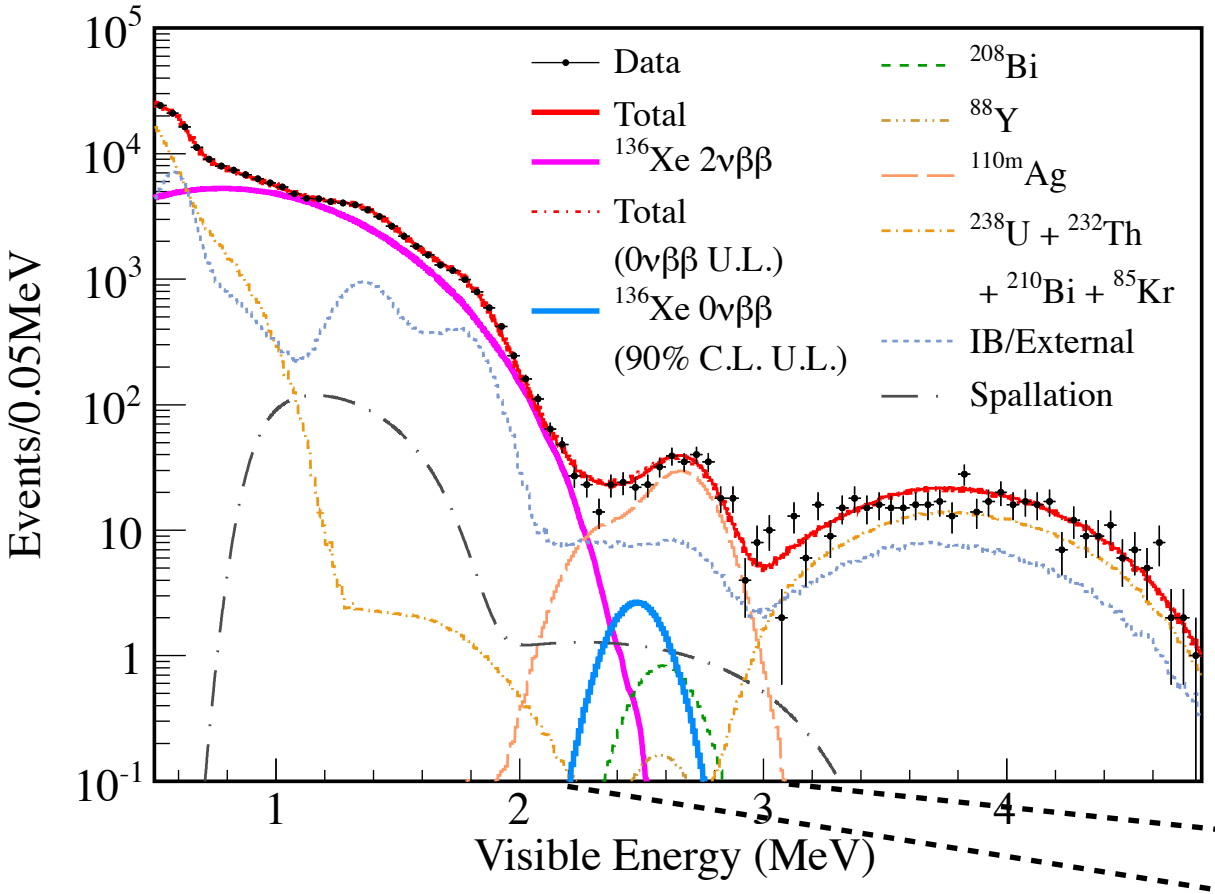

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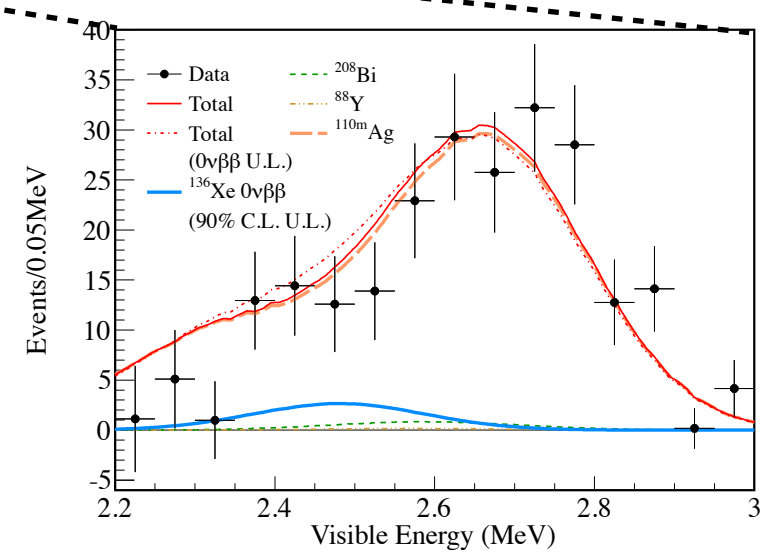
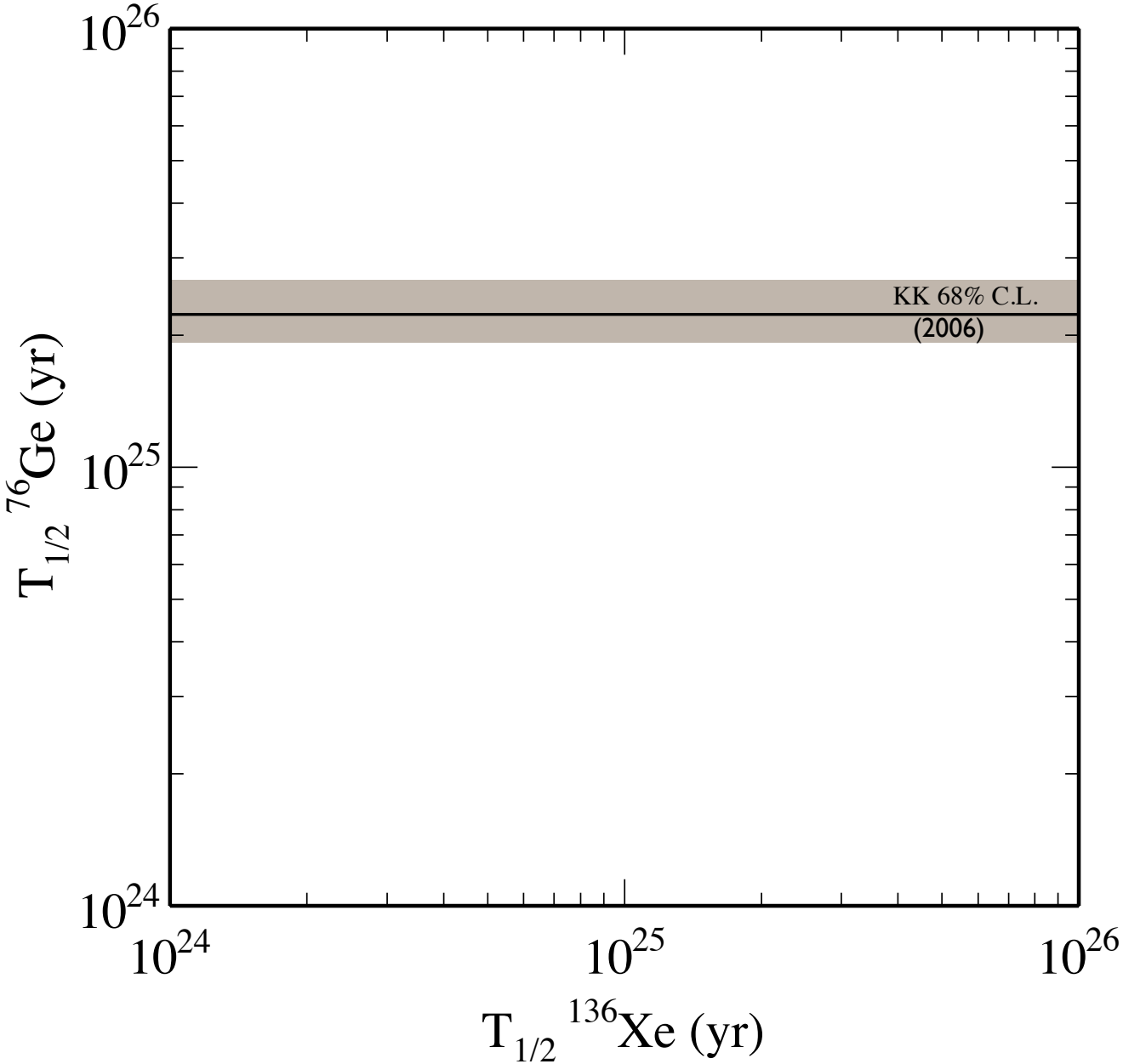
(sensitivity $T^{0\nu}_{1/2} > 1.0 \times 10^{25}$ yr)

No inclusion of ^{60}Co, ^{88}Y, ^{208}Bi increases the limit slightly to $T^{0\nu}_{1/2} > 2.0 \times 10^{25}$ yr



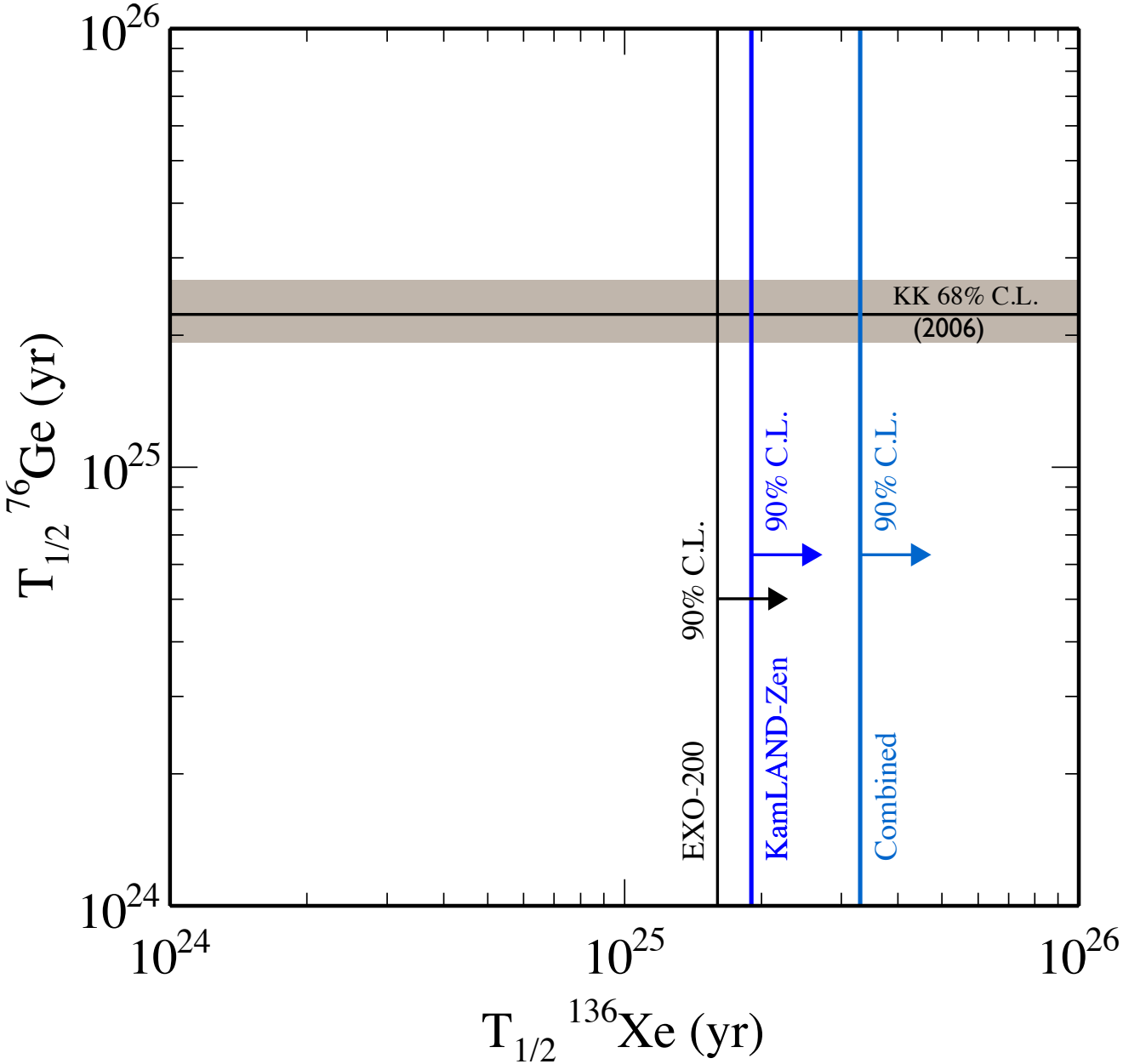
Patrick Decowski/University of Amsterdam

The positive claim in ^{76}Ge…



KamLAND-Zen Collaboration, Phys.Rev.Lett. 110 (2013) 062502

The positive claim in ^{76}Ge…



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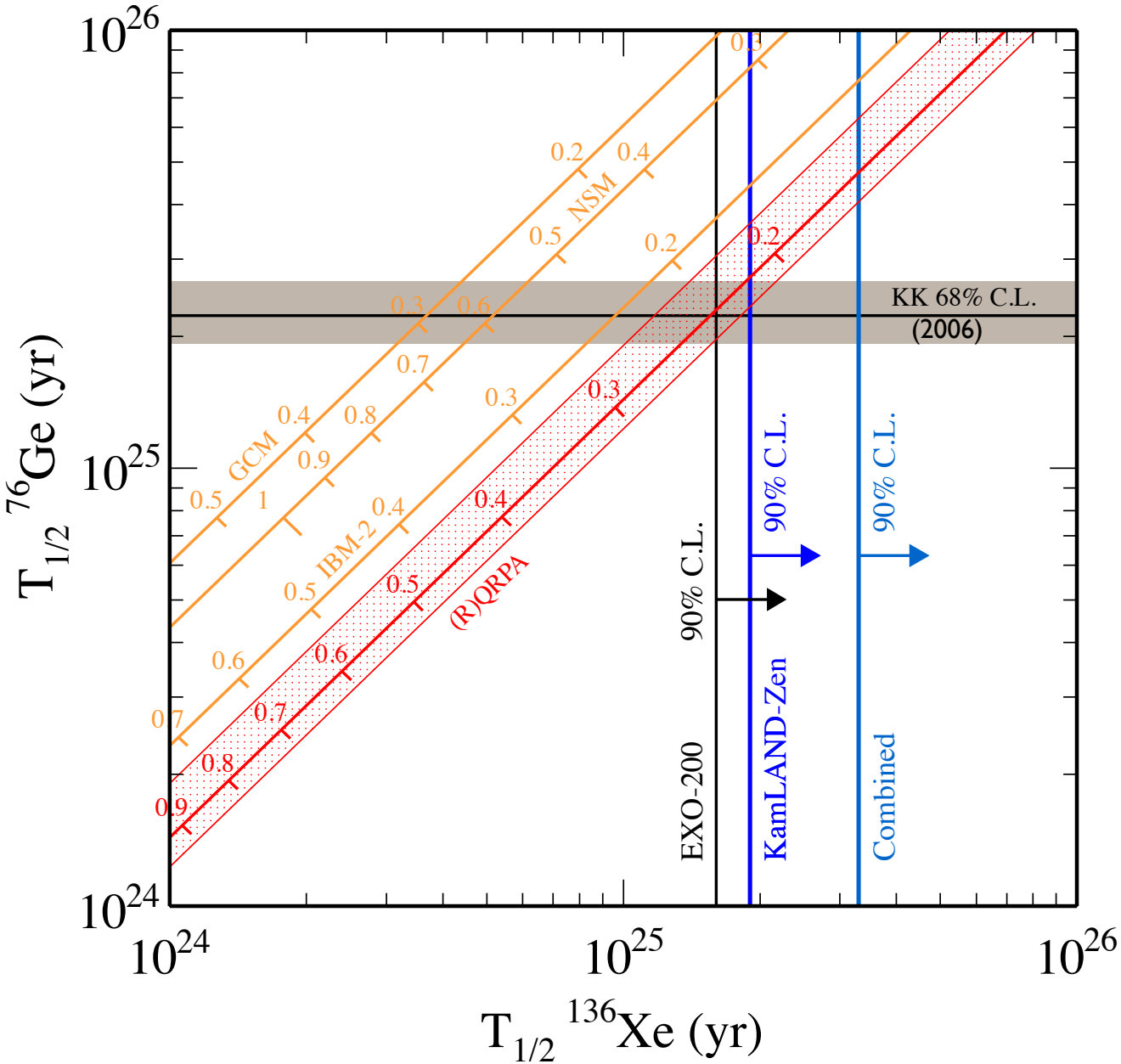

$\langle m_{\beta\beta} \rangle$ < 120 - 250 meV

Combined limit from EXO-200 + KLZ: $T^{0\nu}_{1/2} > 3.4 \times 10^{25}$ yr

KKDC claim is excluded at >97.5% C.L.

KamLAND-Zen Collaboration, Phys.Rev.Lett. 110 (2013) 062502

Patrick Decowski/Nikhef

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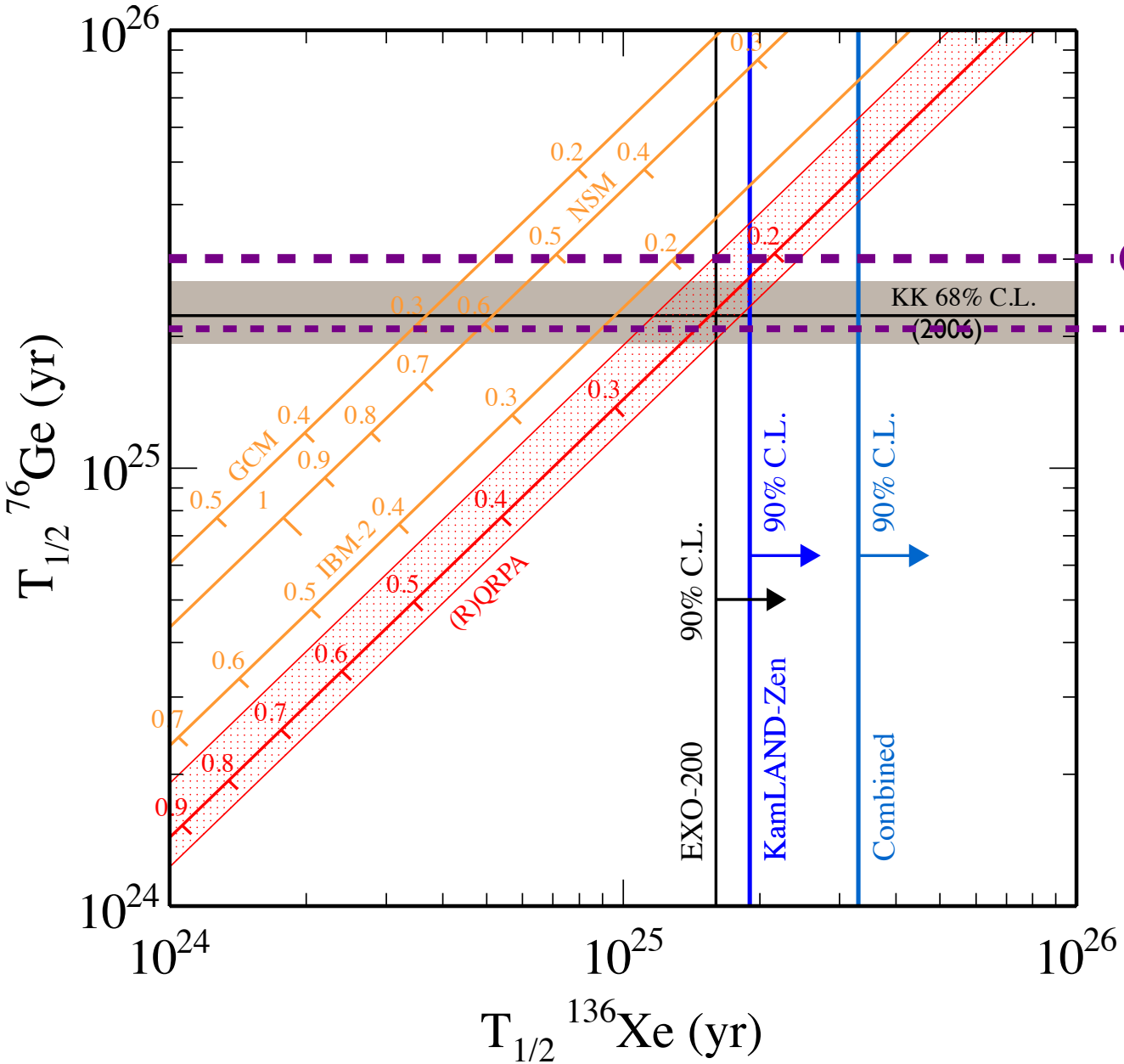

Ge combined

GERDA Phase I

arXiv:1307.4720

KamLAND-Zen Collaboration, Phys.Rev.Lett. 110 (2013) 062502

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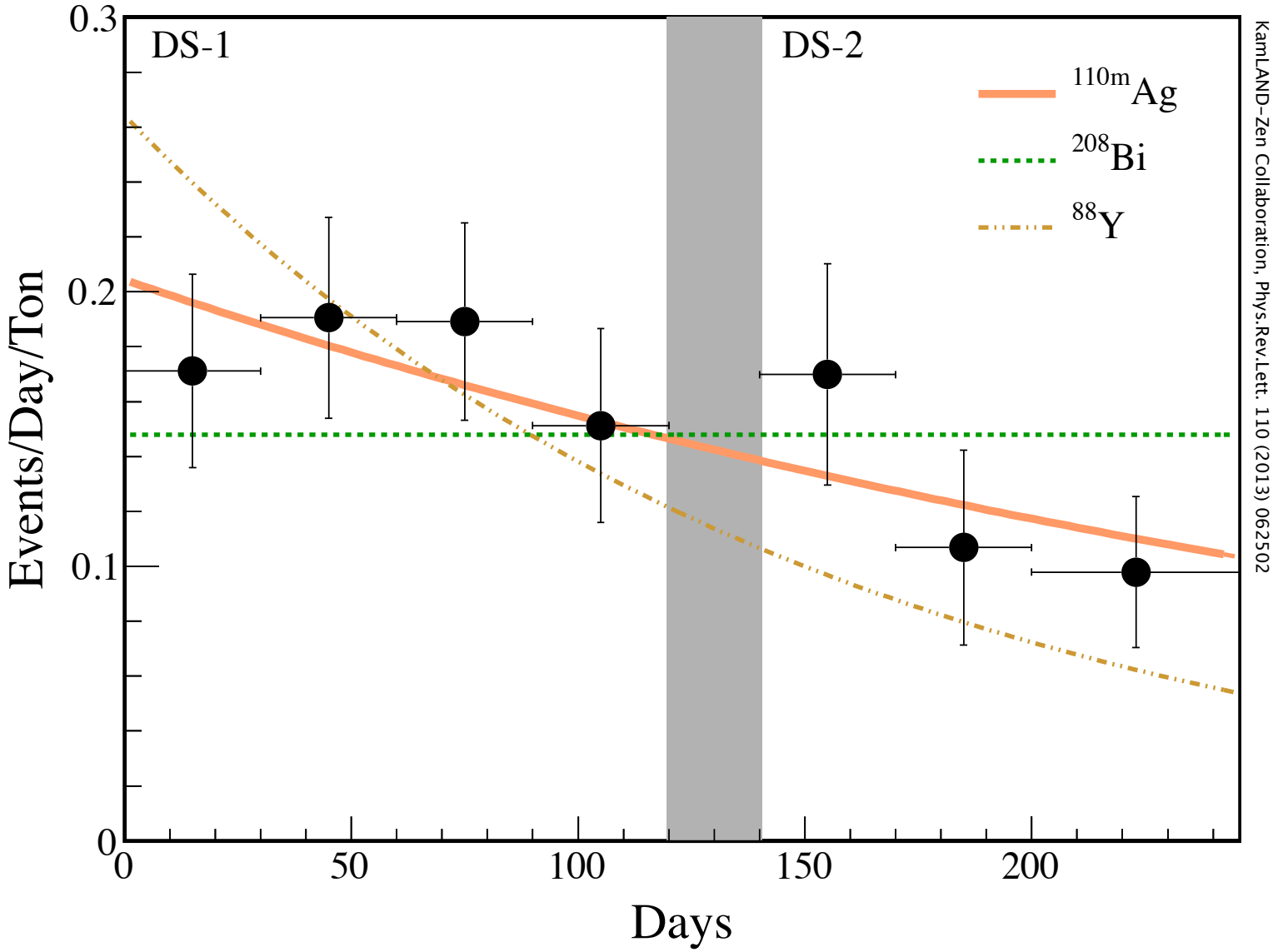
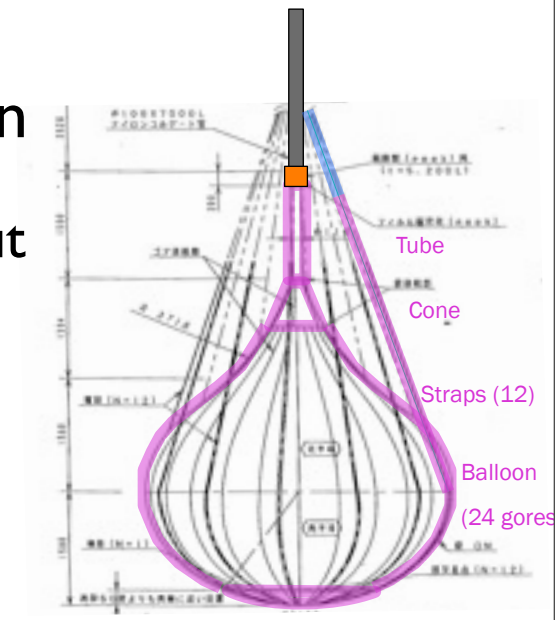
Patrick Decowski/Nikhef

Decay consistent with ^{110m}Ag



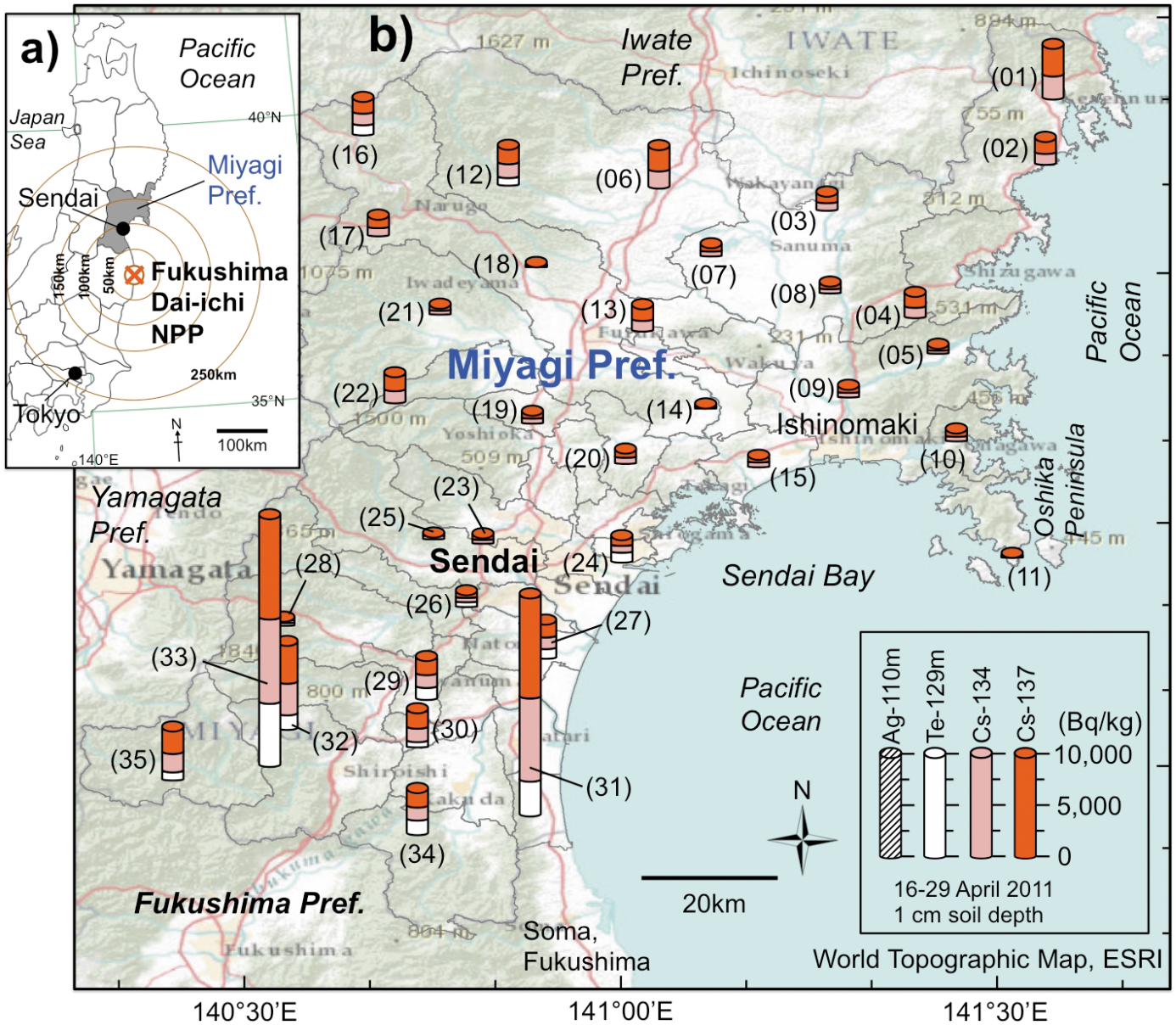
Is the background from Fukushima?

- Great Tohoku Earthquake & Fukushima in March'11
- Both ^{134}Cs and ^{137}Cs reconstructed on mini-balloon
  - Ratio ^{134}Cs / ^{137}Cs ~ 0.8, consistent with Fukushima fallout
  - Activity of Cs proportional to area of mini-balloon welds
  - → Introduced during manufacture in June 2011
- ^{110m}Ag was found in soil samples around Sendai
  - Plausible that ^{110m}Ag was also introduced during manufacture
  - Rates low. For DS-1/DS-2 (3.3 ± 0.4) day^{-1}/ (2.2 ± 0.4) day^{-1}



[However, we cannot exclude cosmic activation of Xe → little known]

Independent Fallout Measurement



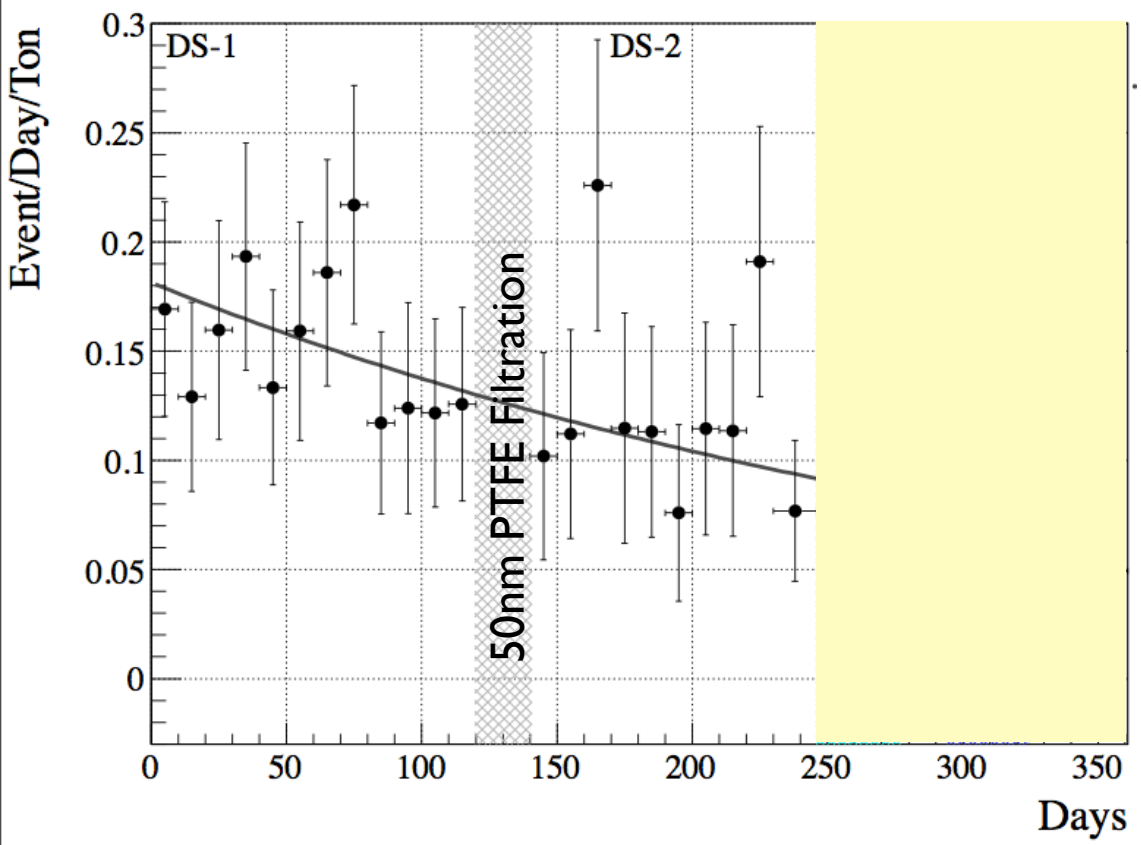
Geochemical Journal, Vol. 46, pp. 279 to 285, 2012

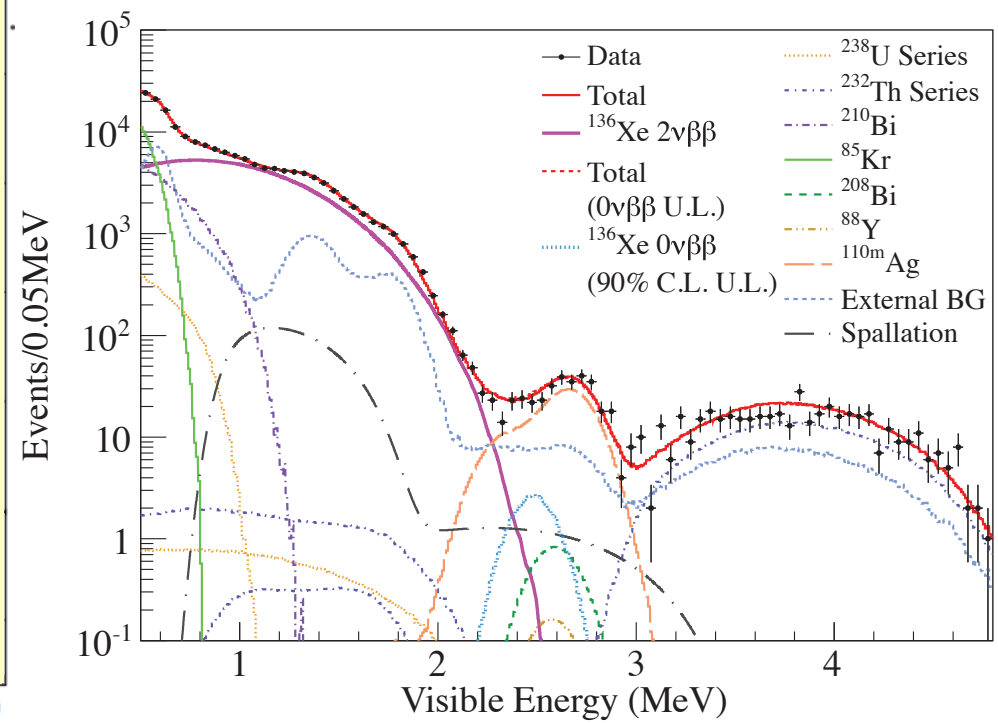
^{134}Cs / ^{137}Cs ~1

Patrick Decowski/University of Amsterdam

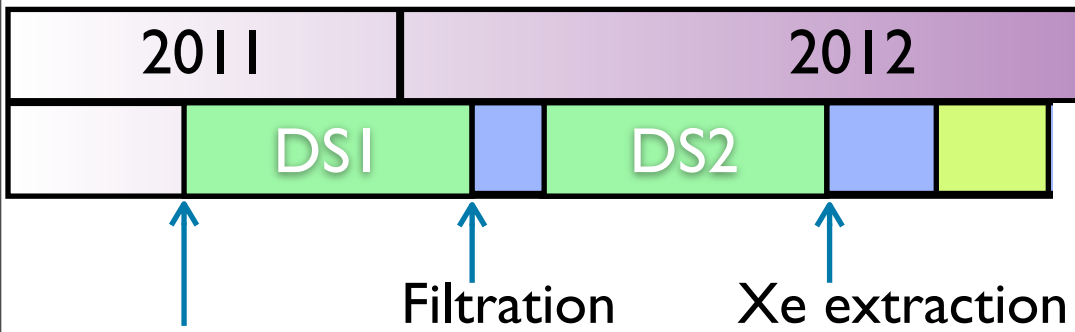
KamLAND-Zen Timeline

Sept '11:Start of KamLAND-Zen

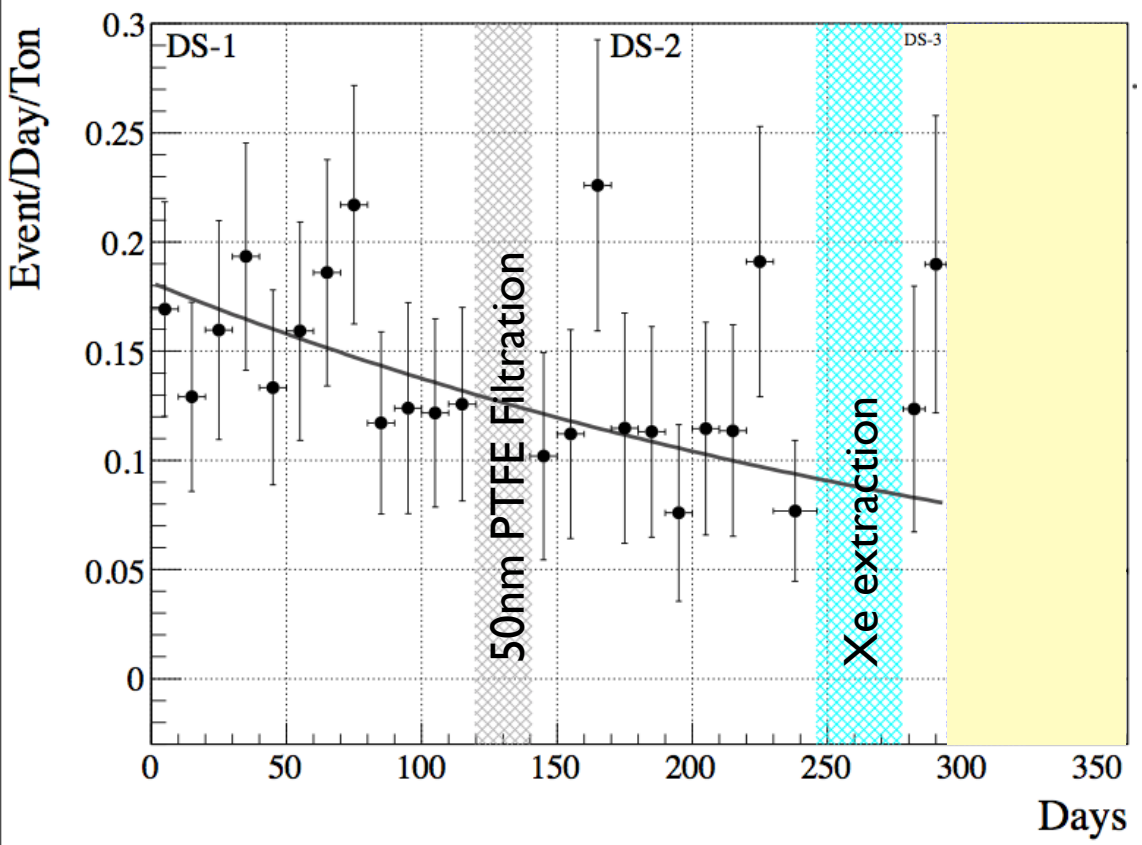


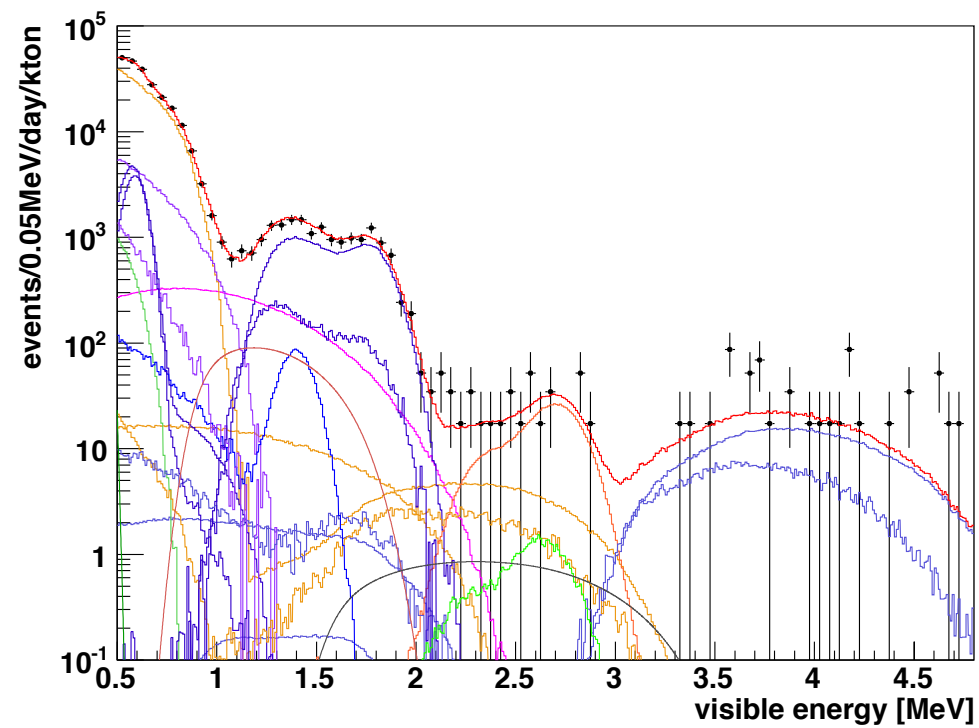


KamLAND-Zen Timeline

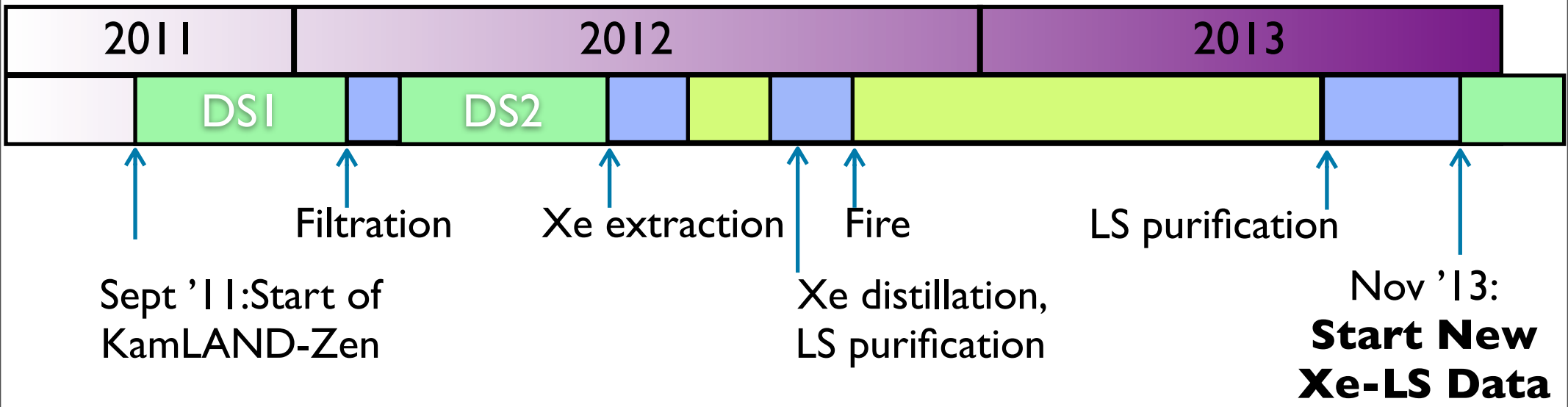


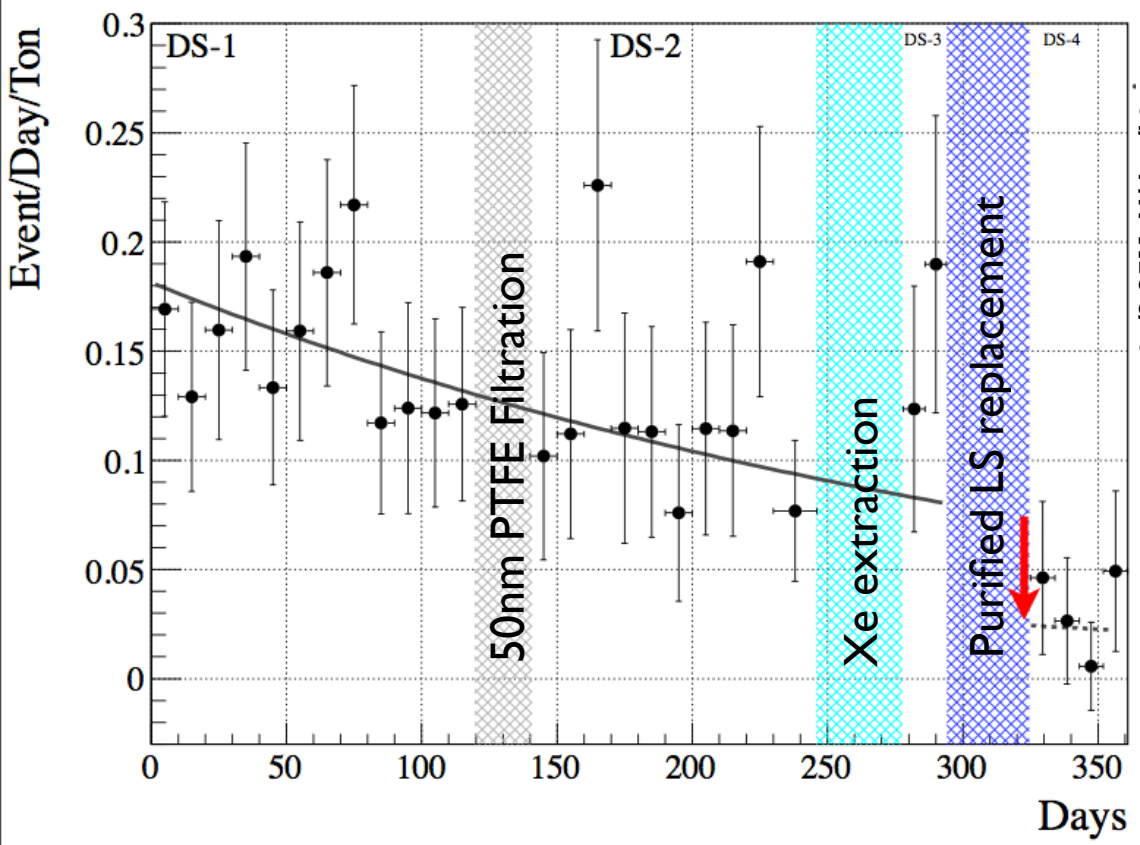
Sept '11:Start of KamLAND-Zen

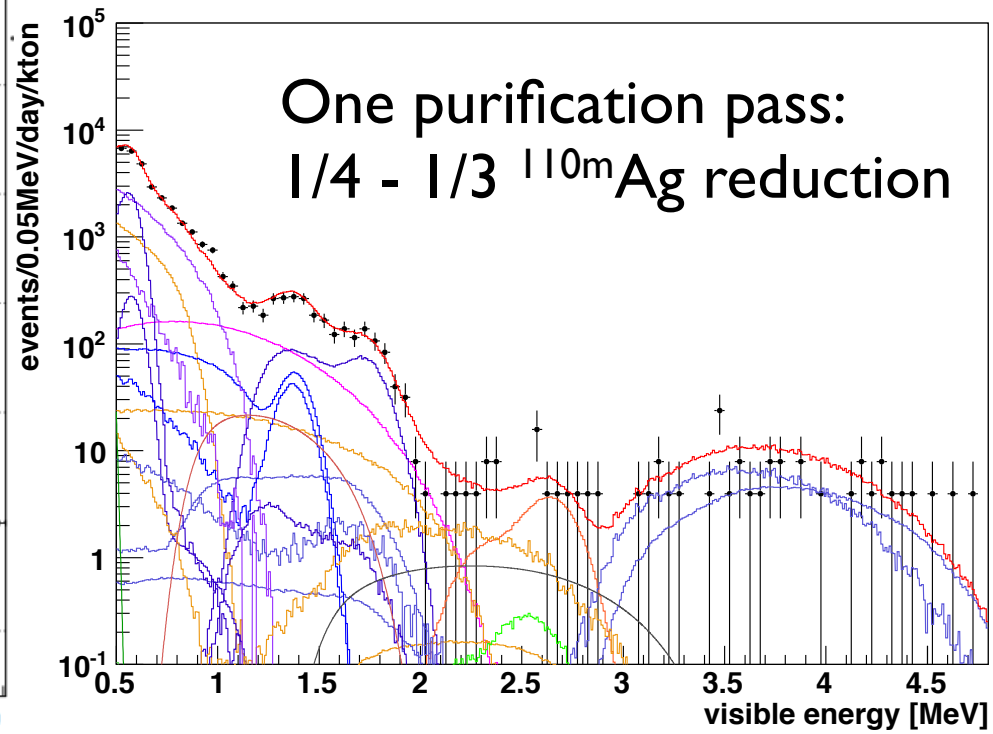




KamLAND-Zen Timeline





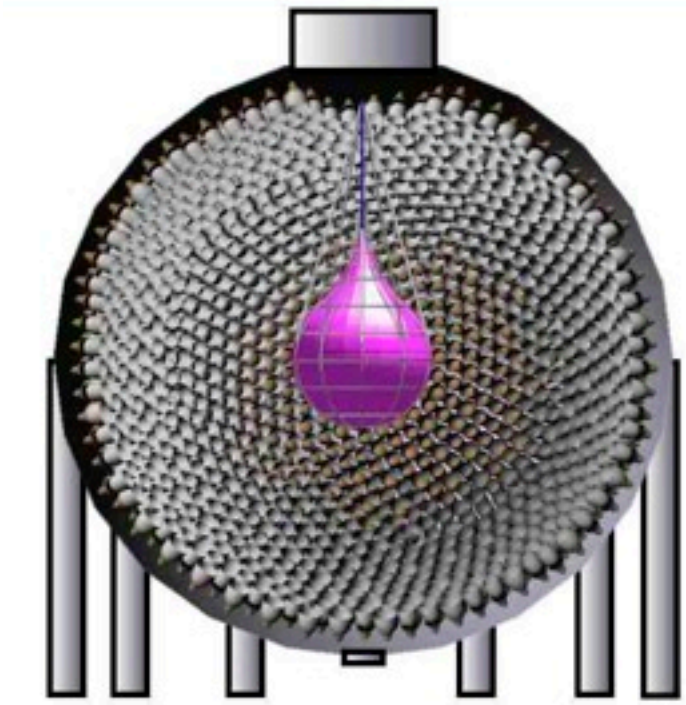


Plans

- Complete LS purification
  - 3 volume exchanges
  - Decay of ^{110m}Ag ($t_{1/2}$ = 250 days)
  - → Should reduce ^{110m}Ag to 1/100
- Restart data taking in Nov 2013
- Few months of data taking to monitor achieved BG
- Option to install new mini-balloon if ^{110m}Ag still too high
  - Load with 600kg of ^{136}Xe (already in hand)
- Detector vessel has to be inspected before May 2016

Longer Term Future: KamLAND2-Zen

- 2nd Phase of KamLAND-Zen (~2016)
  - 1 ton of ^{136}Xe
  - Enhanced Xe-LS with more light yield
  - Winston cone reflectors to increase PMT coverage from 24% → ~70%
- May be able to cover inverted hierarchy

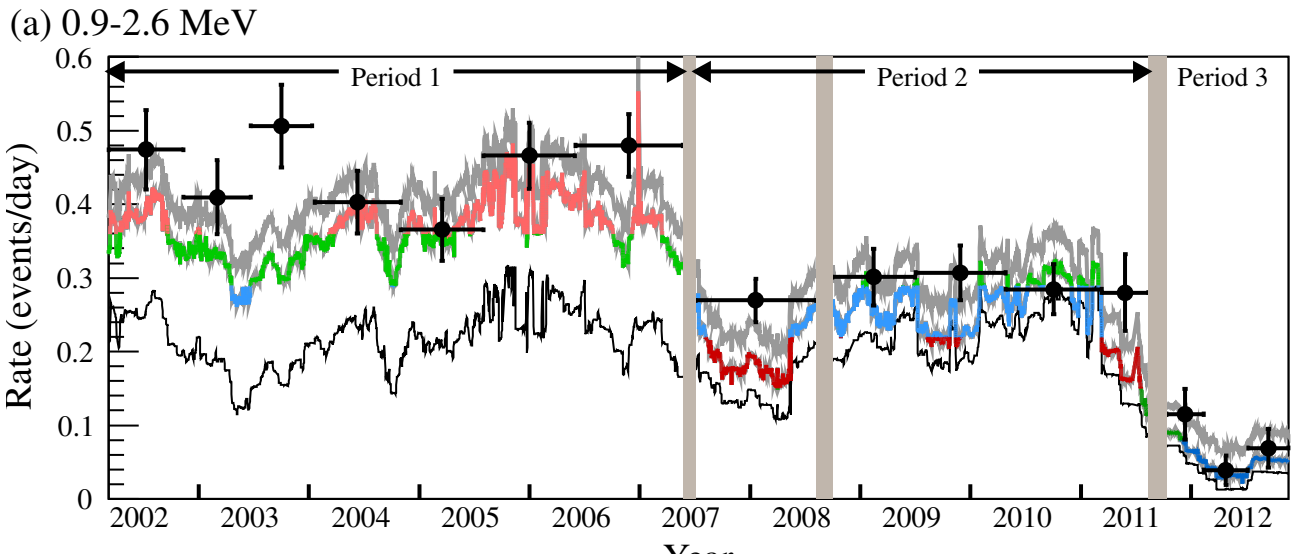


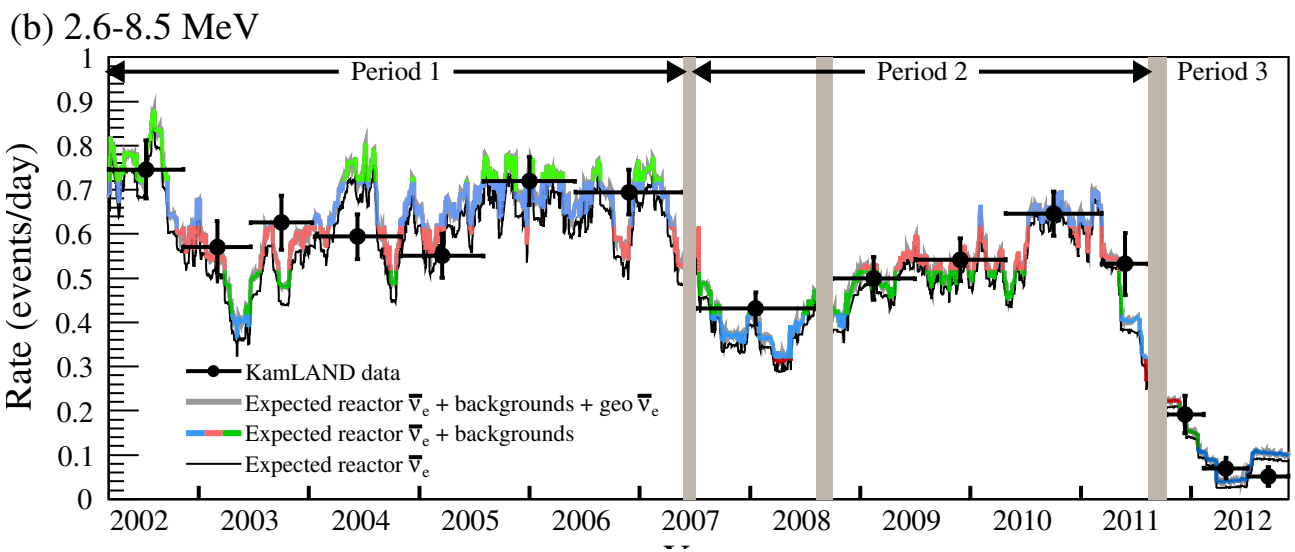
For 17"PMT For 20"PMT

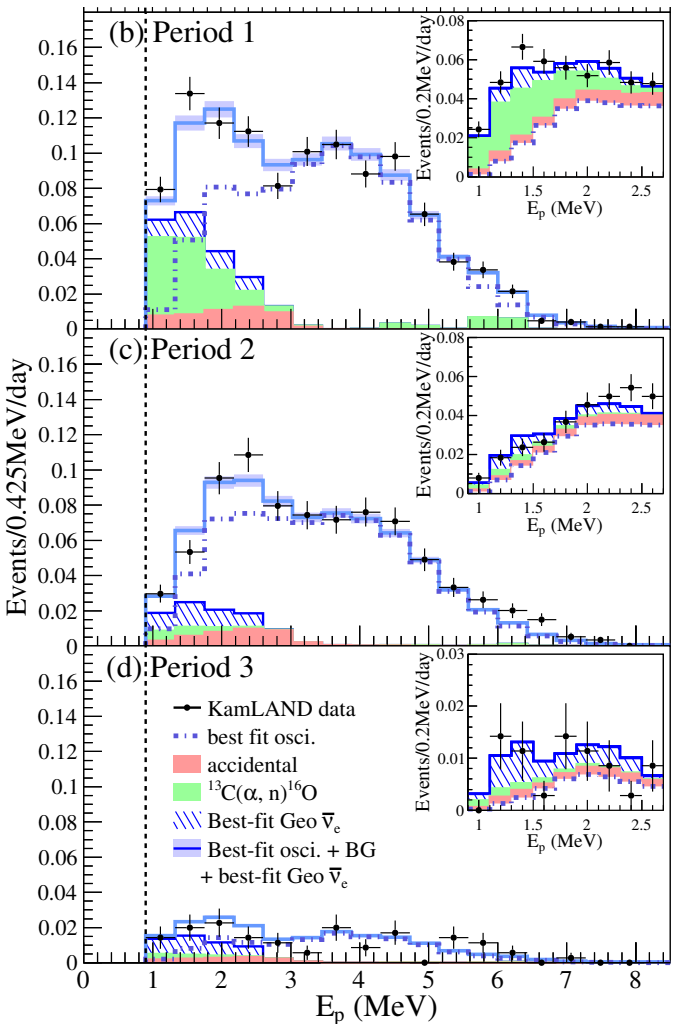
Summary

- KamLAND-Zen data based on 89.5 kg-yr exposure:
  - $T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ yr (90% C.L.)
  - Combined with EXO-200: $T_{1/2}^{0\nu} > 3.4 \times 10^{25}$ yr (90% C.L.)
  - Combined limit excludes KKDC at 97.5% C.L.
- Purification campaign to remove ^{110m}Ag almost completed, new run about to start
- Plans to upgrade the detector for more light collection and 1 ton ^{136}Xe.
- Reactor and geo-neutrino measurements ongoing…

Post Fukushima

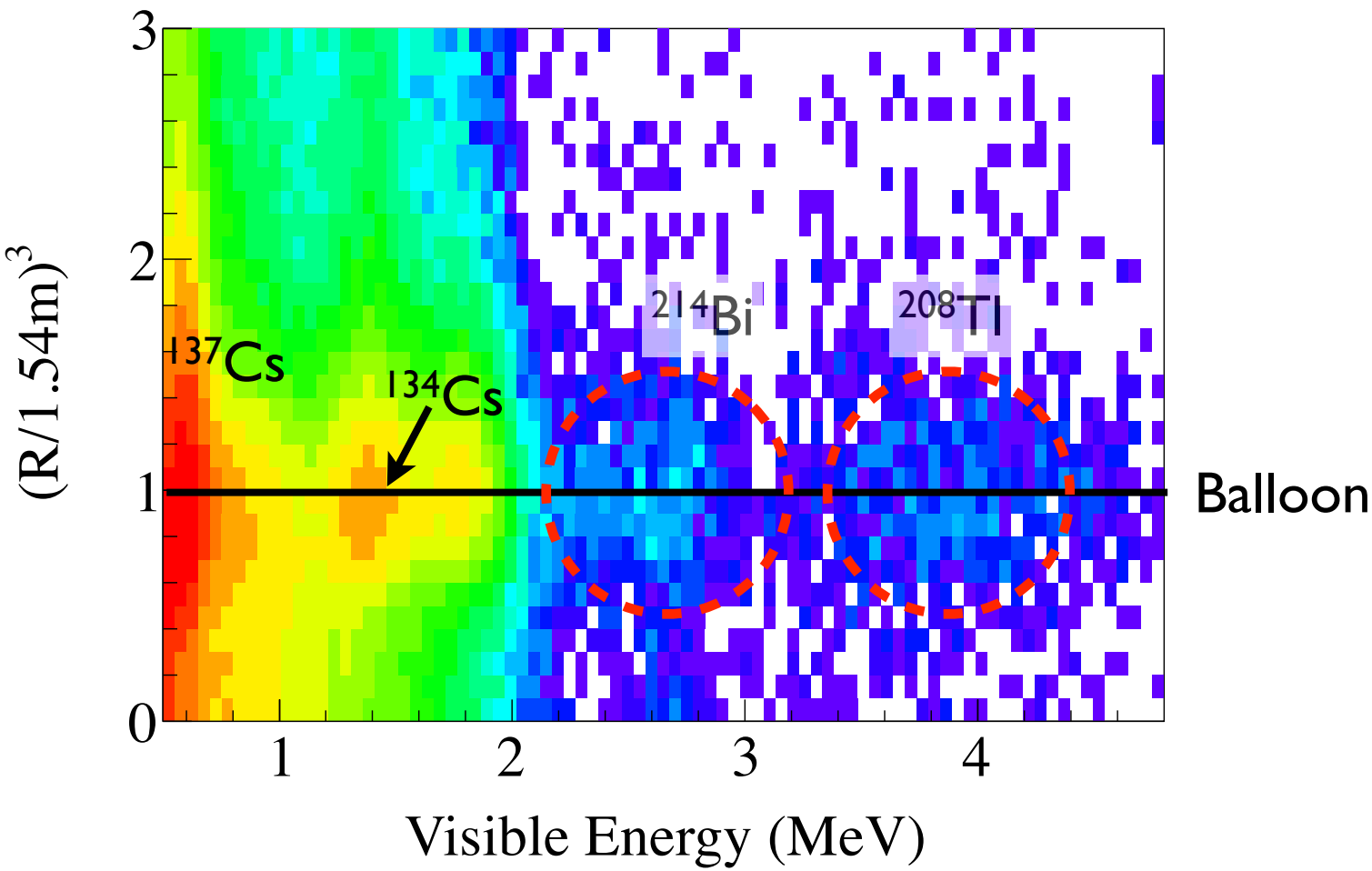






A. Gando et al. (KamLAND Collaboration), Phys. Rev. D **88**, 033001 (2013)

Post Fukushima

Spatial dependence of Backgrounds

$^{137}Cs/^{134}Cs$ are Fukushima fallout products, ^{214}Bi from U-chain