From KamLAND to KamLAND-Zen

20 Years of History

禅

Yuri Efremenko
University of Tennessee

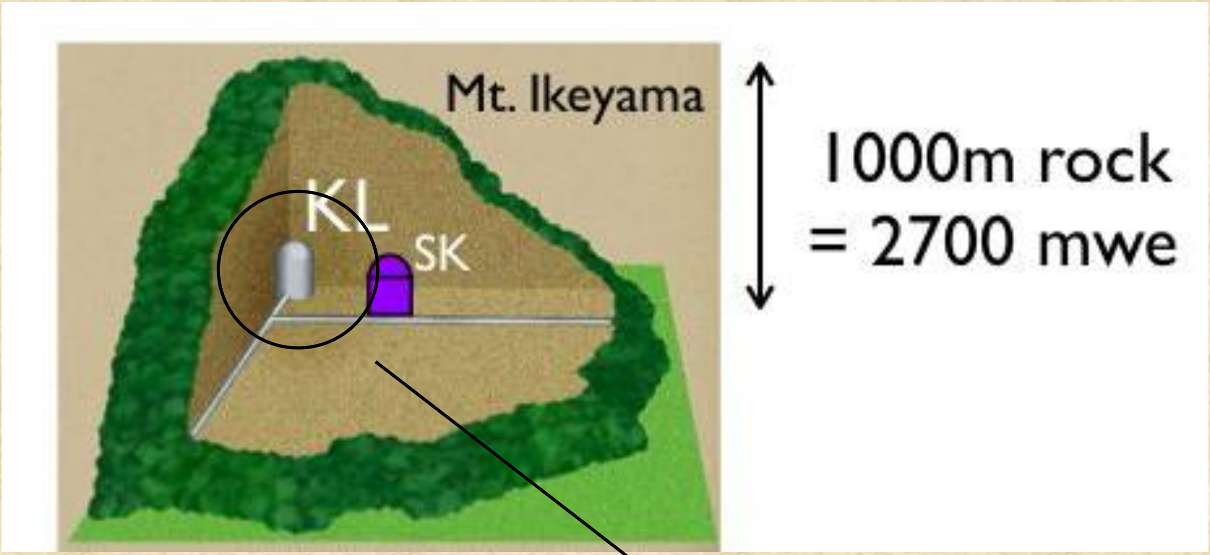
50 years of Baksan Neutrino Laboratory

On Behalf of the KamLAND-Zen collaboration

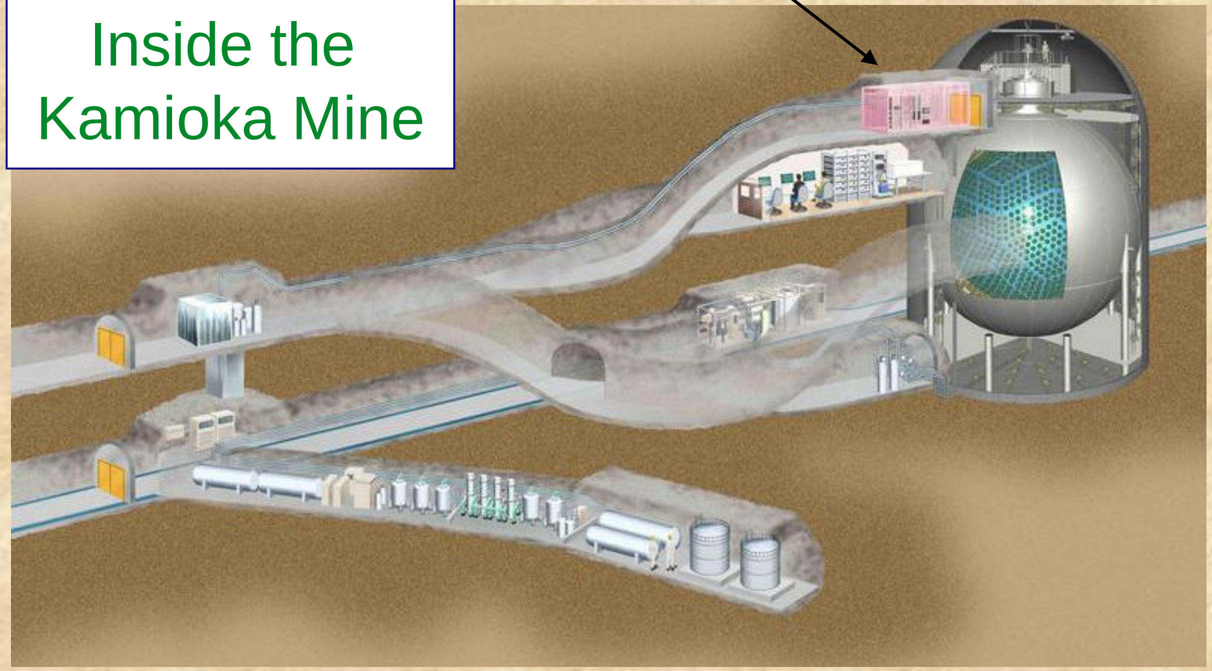
KamLAND -Kamioka Liquid-scintillator Anti-Neutrino Detector

Surrounded by 55 Japanese Reactor Units

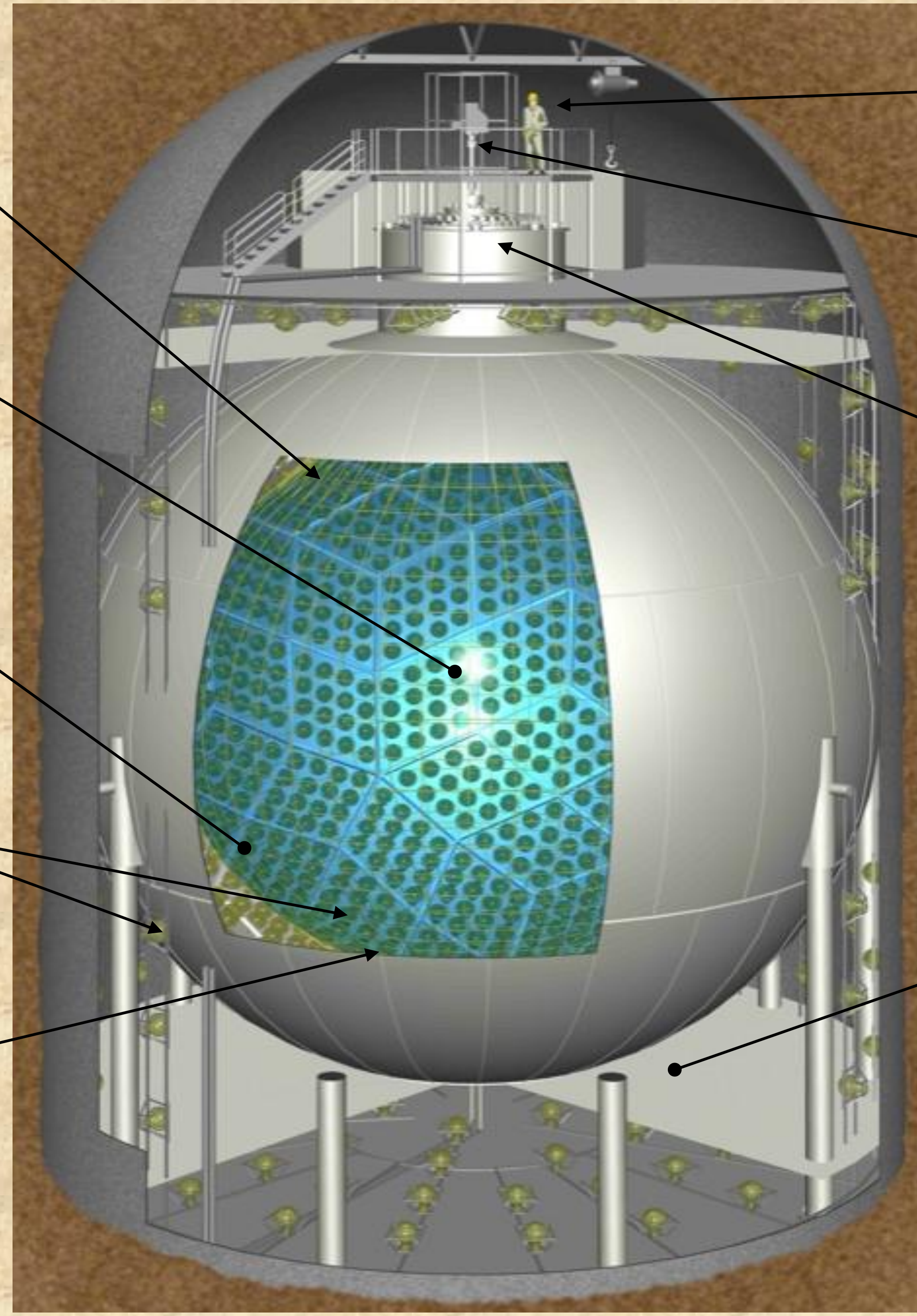
Detecting reactor $\bar{\nu}_e$ 1km beneath Mt. Ikeyama



Inside the Kamioka Mine



The KamLAND Detector



Balloon & support ropes

Target LS Volume

(1 kton, 13m diameter)

Buffer Oil Zone

Photomultiplier Tubes (34% coverage of ID)

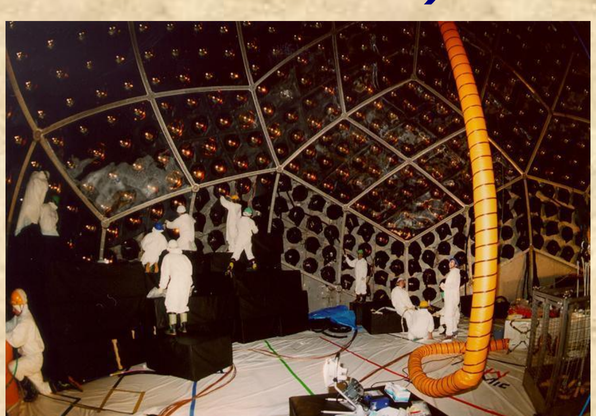
Stainless Steel Inner Vessel *(18m diameter)*

calibration device & operator

Glove box

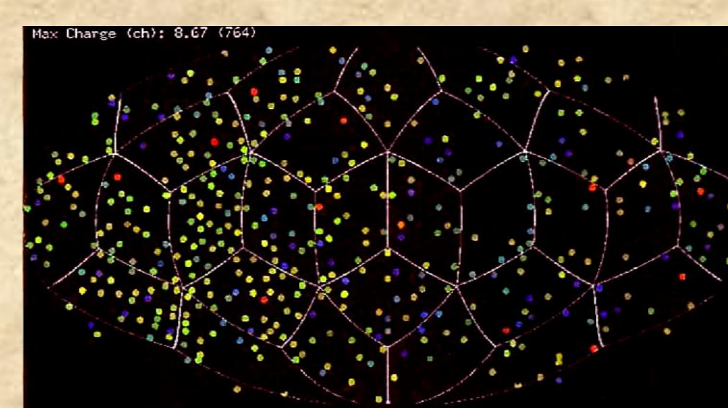
Chimney (access point)

Outer Detector (3.2 kton Water Cherenkov)



Construction started in 1998

First Neutrinos 2001

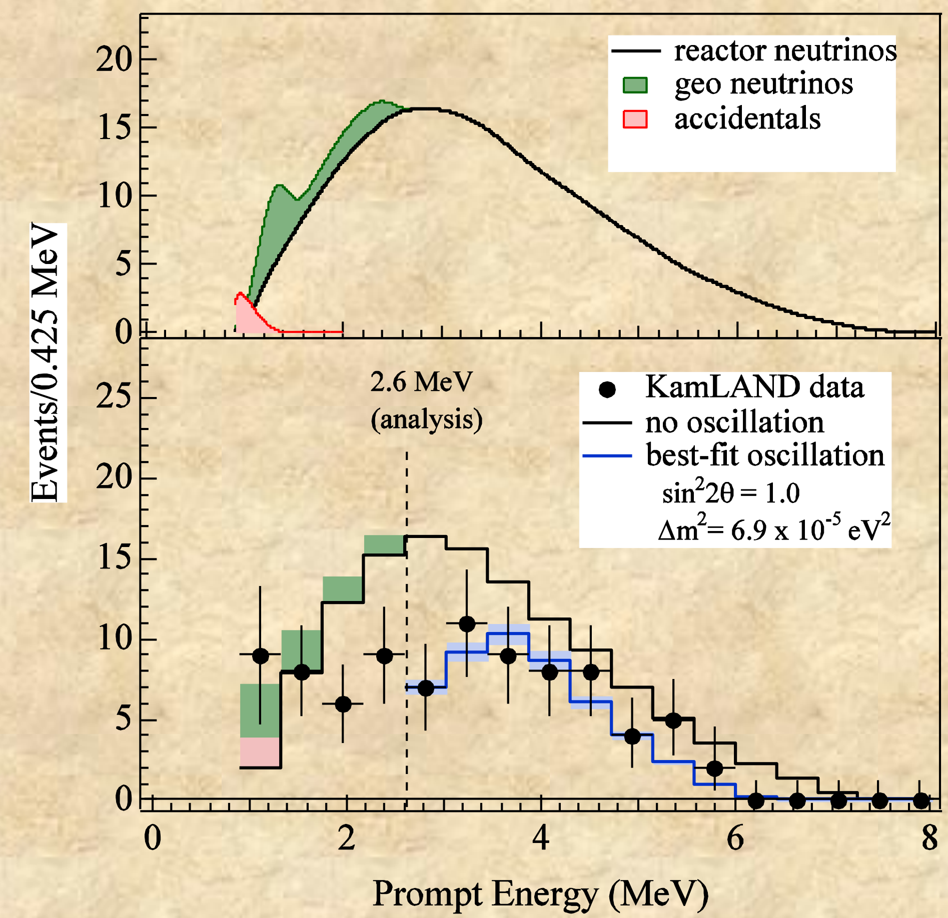


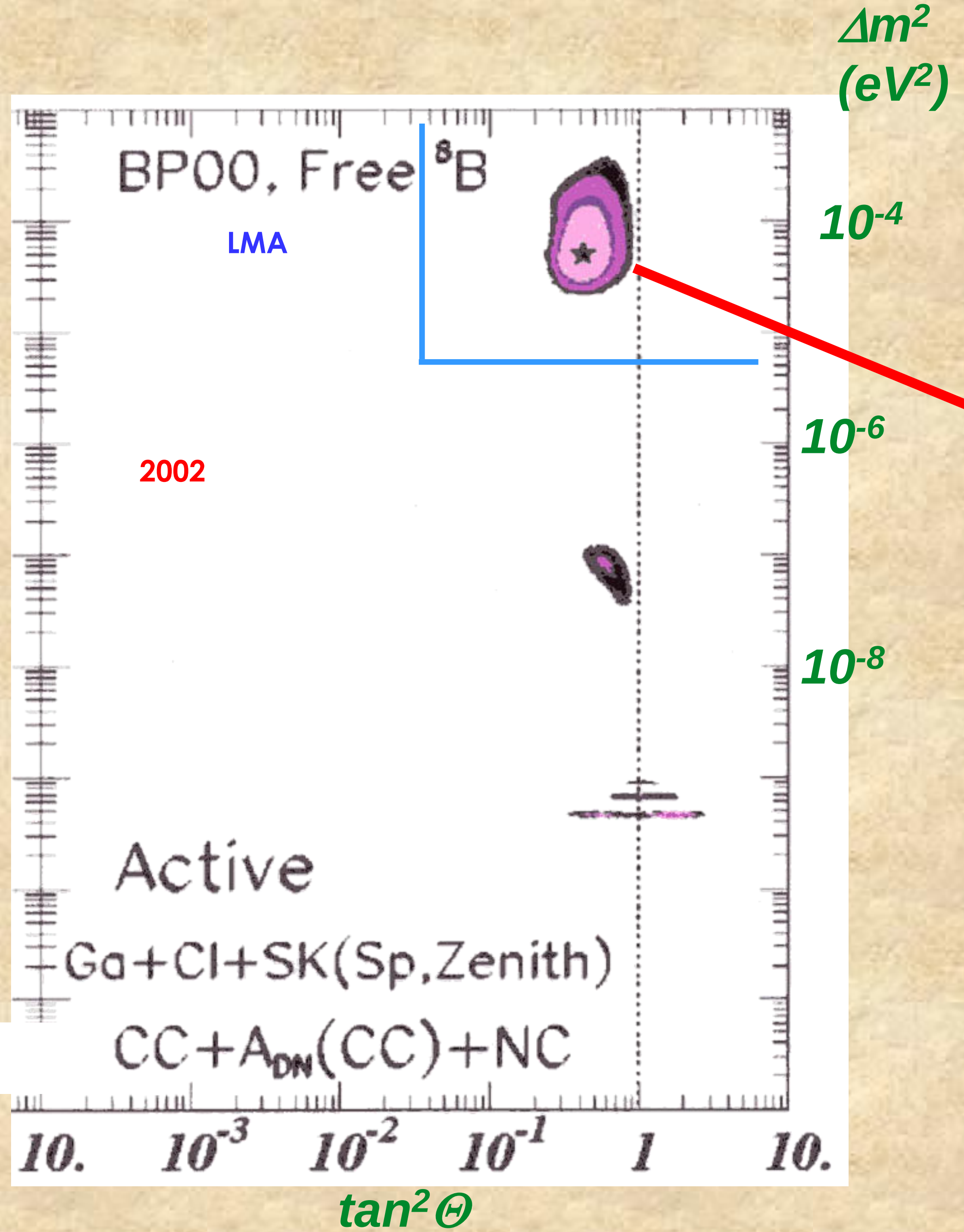
2003

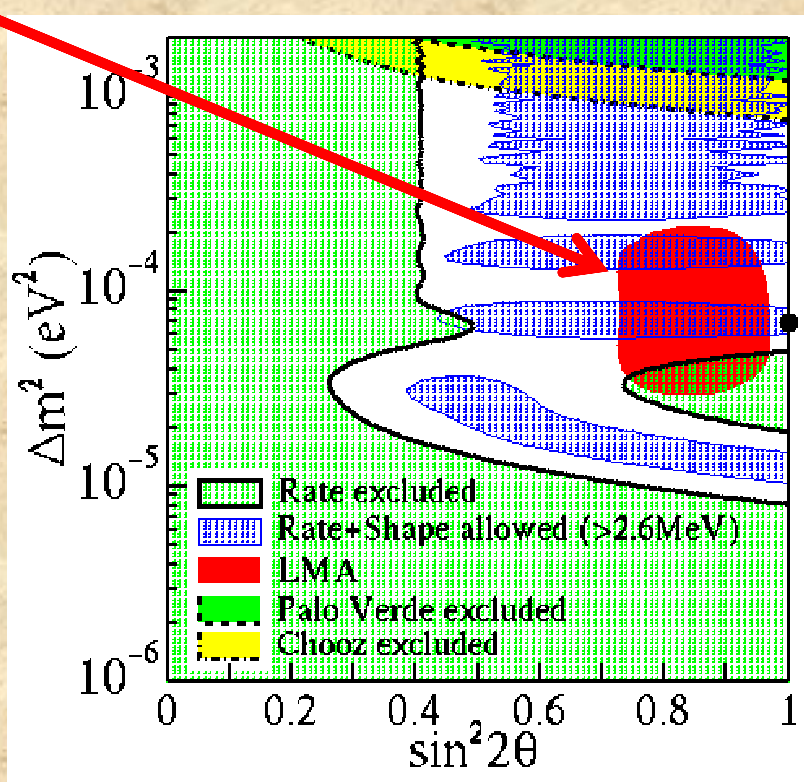
First Scientific result:

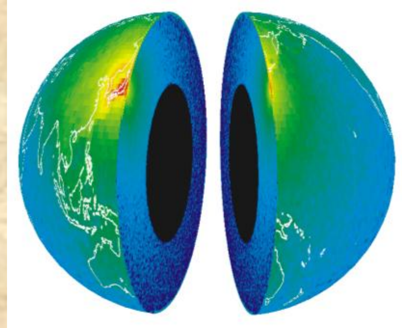
“First results from KamLAND: Evidence for reactor anti-neutrino disappearance”

Phys.Rev.Lett. 90 (2003) 021802.









2005

Discovery of Geo Neutrinos

Experimental investigation of geologically produced antineutrinos with KamLAND   Nature 436 (2005) 499-503.

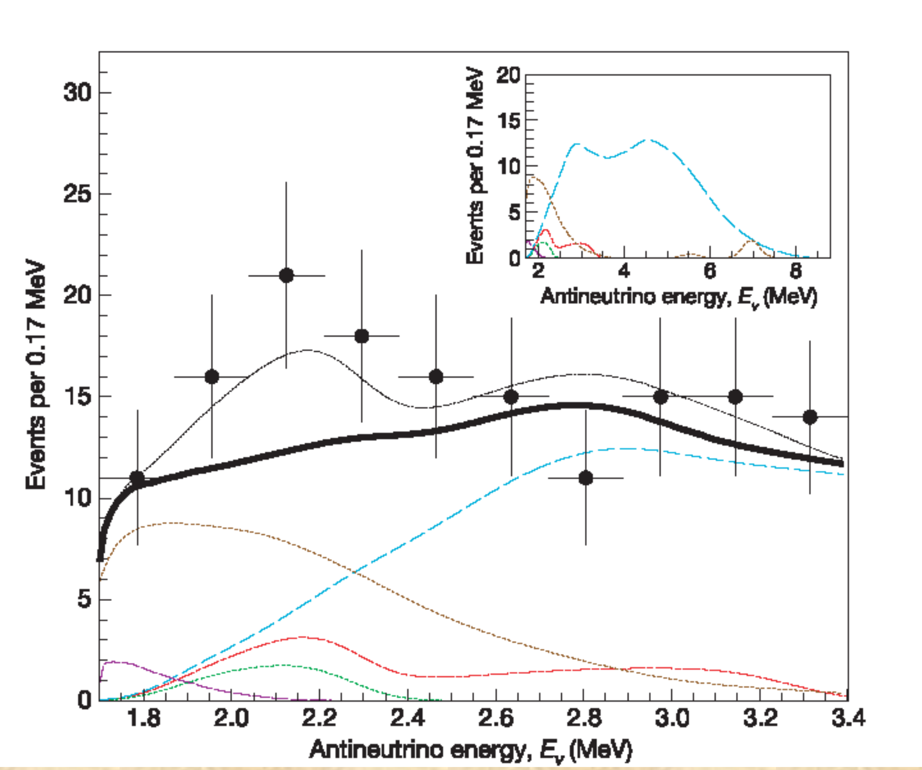
$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He + 6e^{-} + 6\bar{\nu}_{e} + 52$ [MeV]

$^{235}U \rightarrow {}^{207}Pb + 6\,{}^{4}He + 4e^{-} + 4\bar{\nu}_{e} + 47$ [MeV]

$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^{4}He + 4e^{-} + 4\nu_{e} + 43$ [MeV]

$^{40}K \rightarrow {}^{40}Ca + e^{-} + \nu_{e} + 1.31$ [MeV]   (89.3%)

$^{40}K + e^{-} \rightarrow {}^{40}Ar + \nu_{e} + 1.505$ [MeV]   (10.7%)



It was beginning of the new branch of science Neutrino Geo Physics

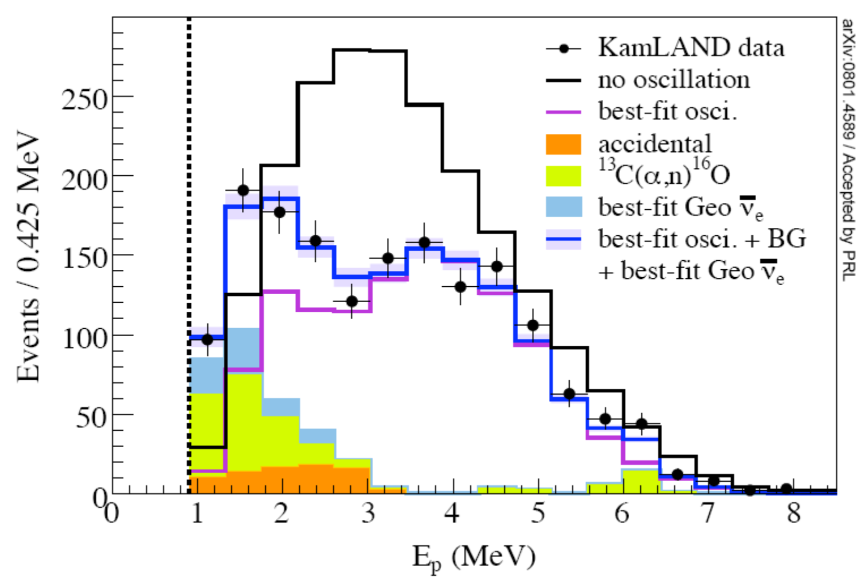
2008

Discovery of Neutrino oscillations

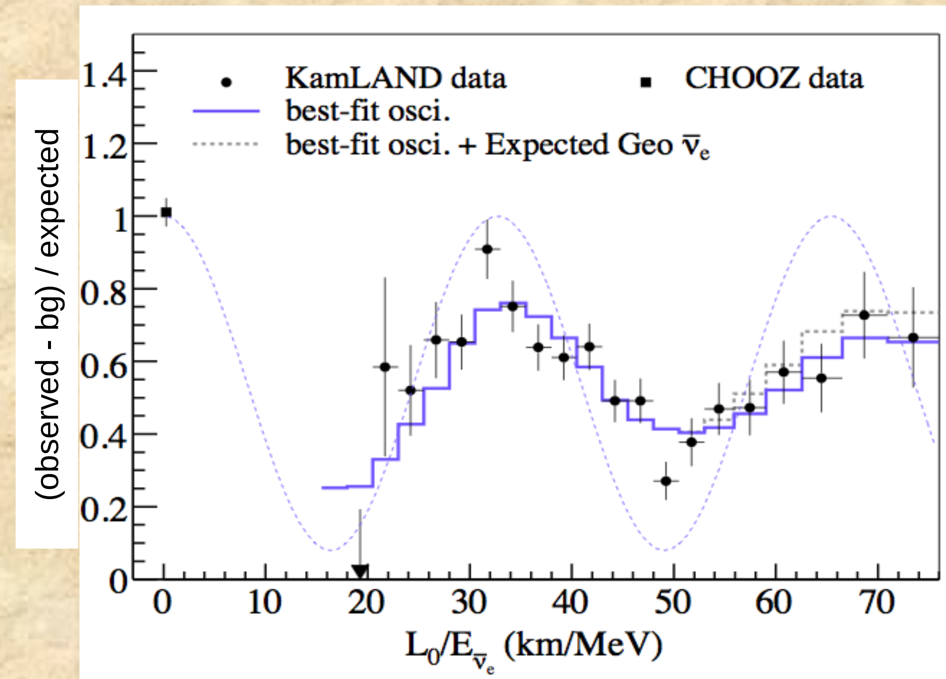
Precision Measurement of Neutrino Oscillation Parameters with KamLAND

Phys.Rev.Lett. 100 (2008) 221803.

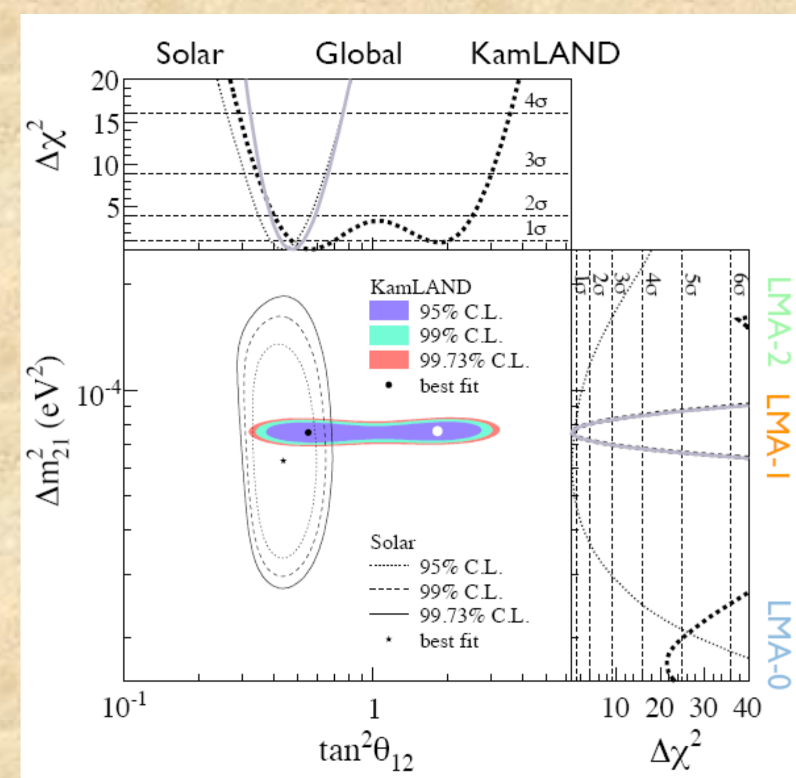
From Mar 9, 2002 to May 12, 2007
1491 live days, 2881 ton-year exposure (3.8x KL2004)



Fit to scaled no-oscillation spectrum excluded at 5.1σ



L_0 = 180km flux-weighted average reactor distance



Two importan results in one publication.

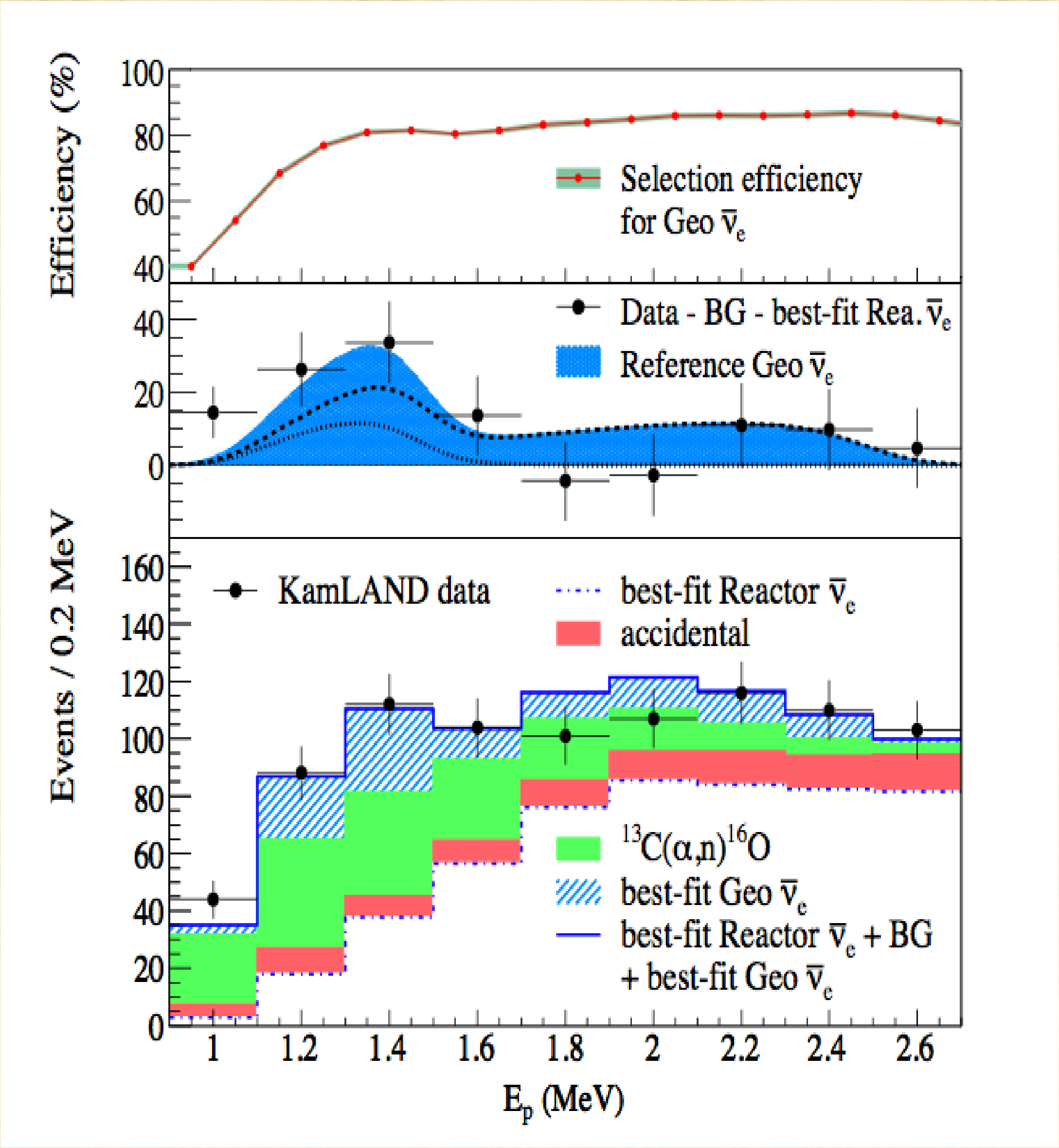
Observation of clear patter of oscilaltions
Presice measurement of deltaM 12

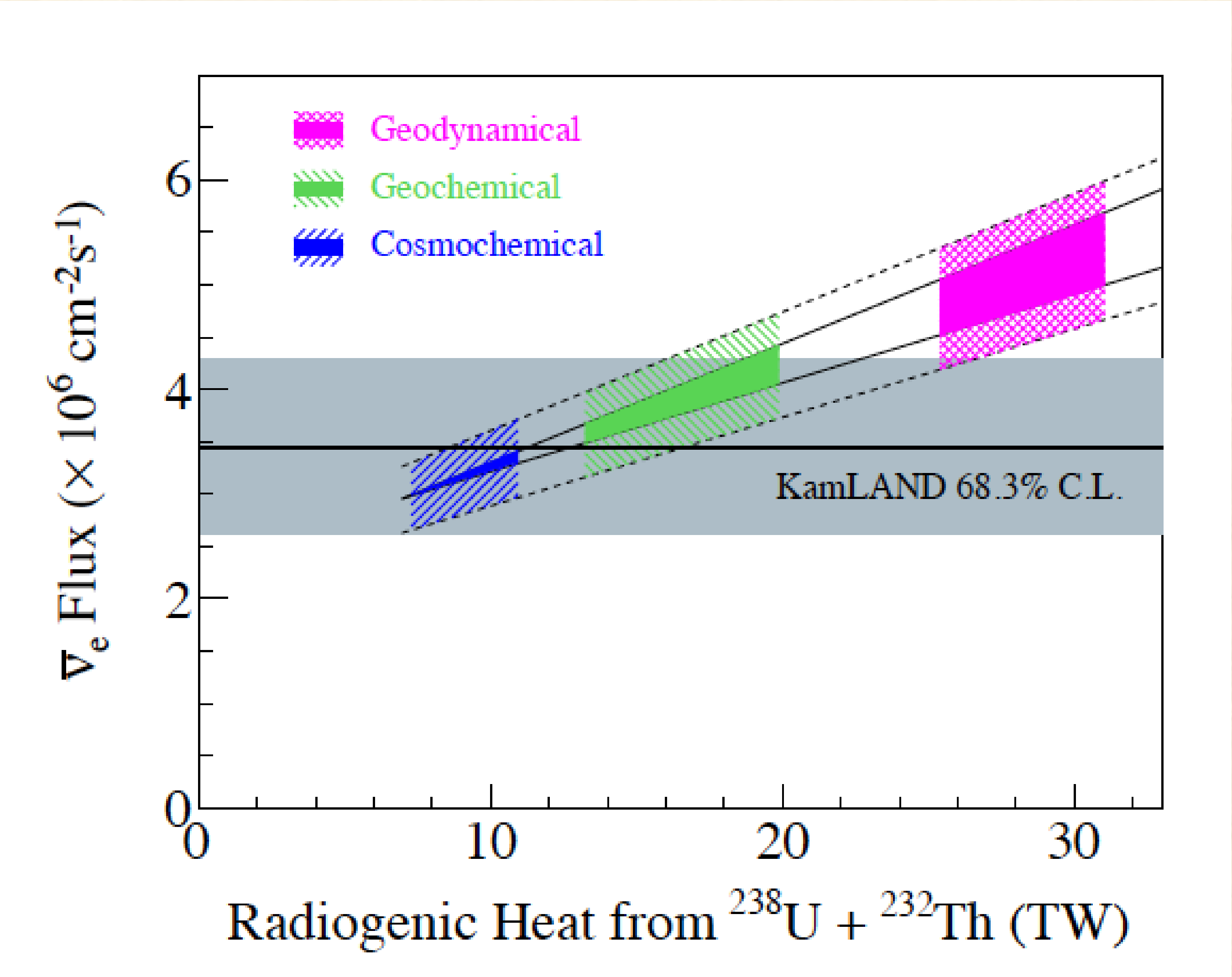
2011

First constrain on the Earth Geological models

Partial radiogenic heat model for Earth revealed by geoneutrino measurements

Nature Geo. 4 (2011) 647-651



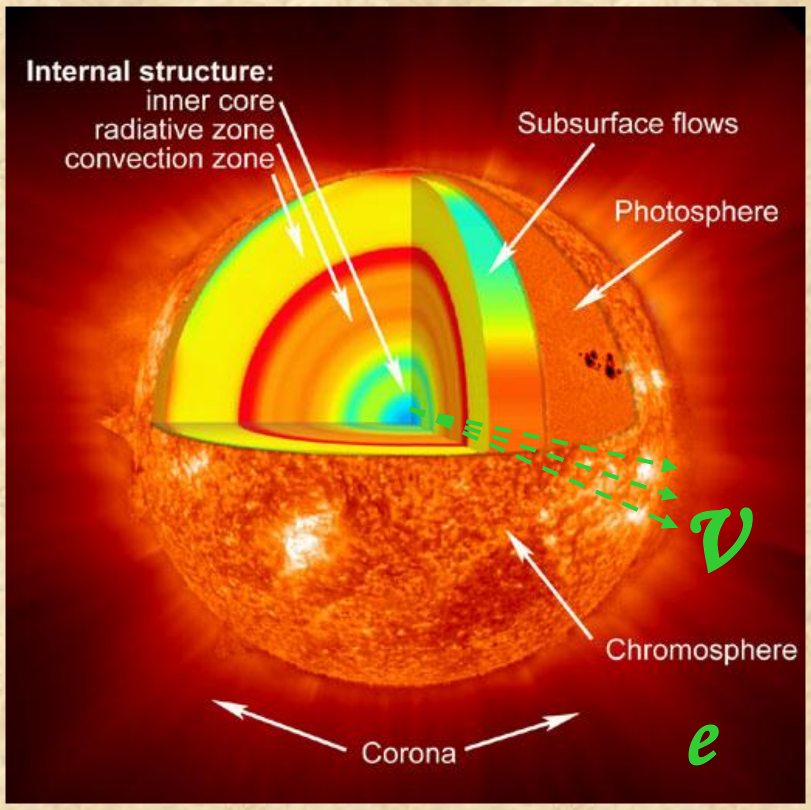


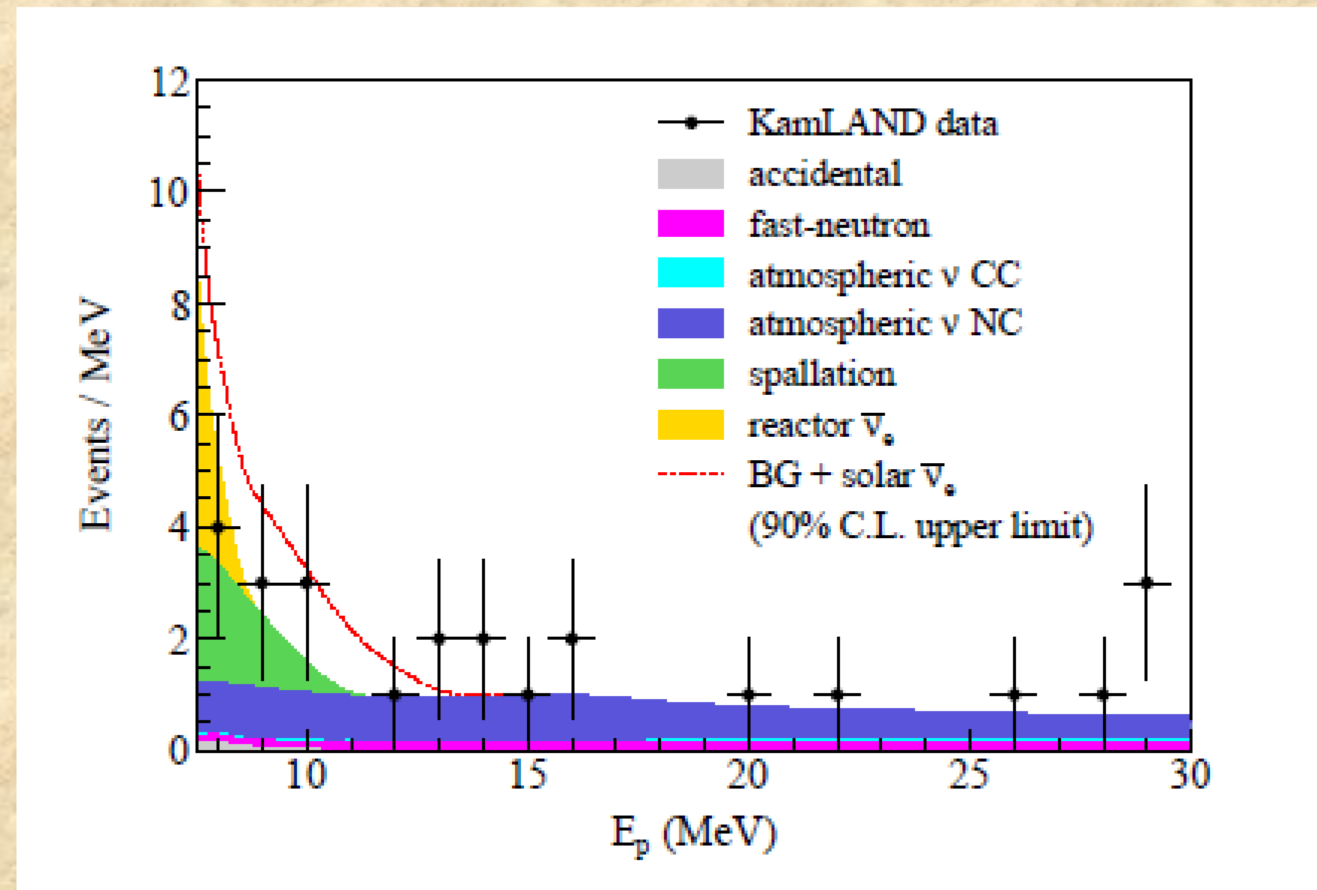
2012

Study of anti neutrinos coming from the sun

A study of extraterrestrial antineutrino sources with the KamLAND detector

By KamLAND Collaboration Astrophys.J. 745 (2012) 193.





$$\nu_{eL} \xrightarrow{\text{SFP}} \bar{\nu}_{\mu R} \xrightarrow{\text{osc.}} \bar{\nu}_{eR}$$

$$\Phi_{\bar{\nu}_e} < 93.4\, cm^{-2} s^{-1} \ for$$

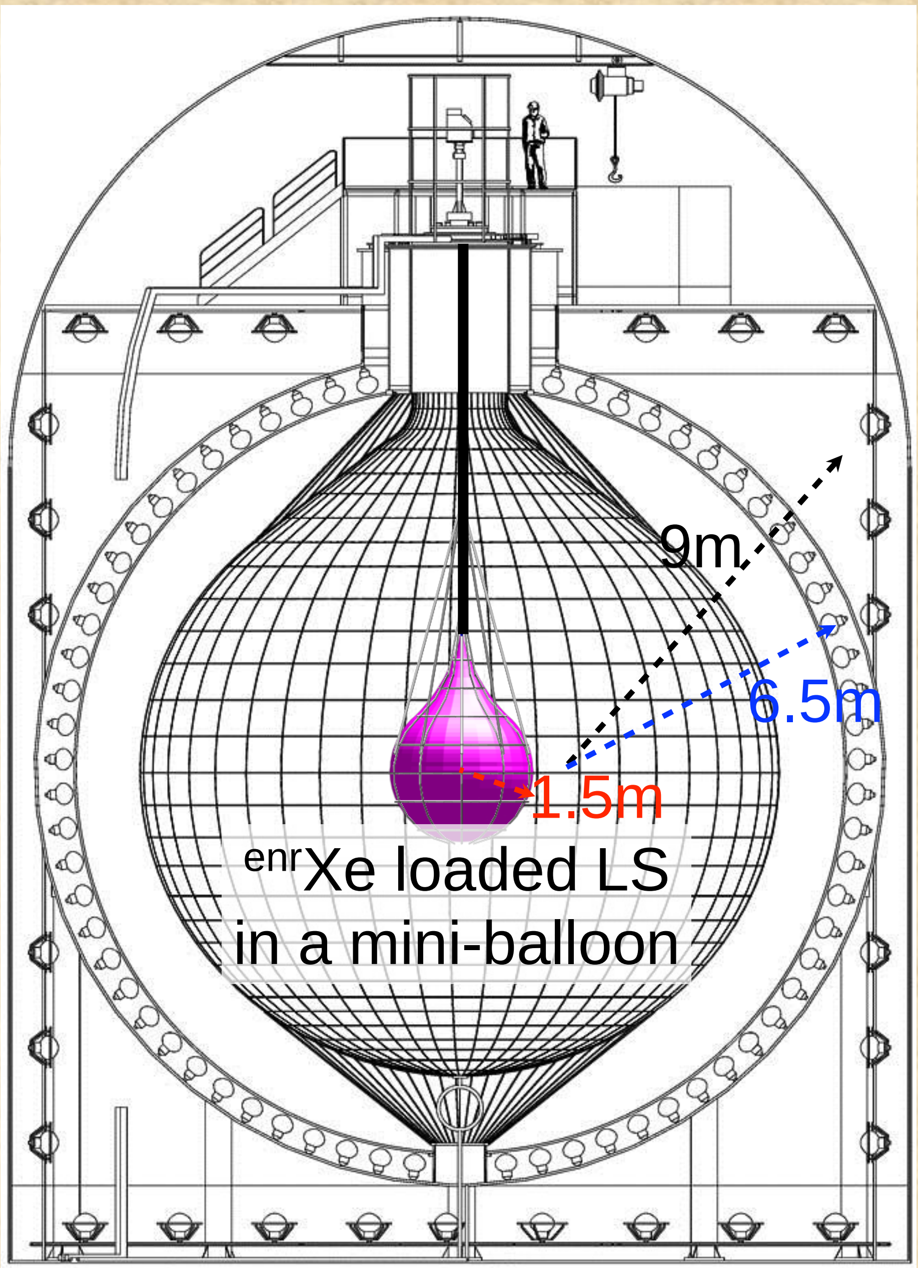
Neutrino conversion probability:
P<5.3×10^{-5}

$$\frac{\mu}{10^{-12}\mu_B}\frac{B_T(0.05R_S)}{10kG} < 5.9\times 10^2$$

L.B. Okun, M.B. Voloshin, M.I. Vysotsky
1986. 26 pp. ITEP-86-82. Sov.Phys. JETP 64 (1986) 446-452

2011
From KamLAND to KamLAND-Zen

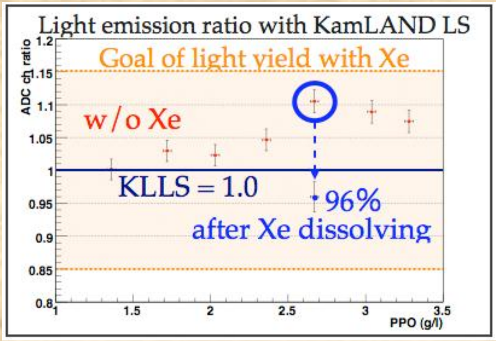
This transition is an upgrade of the KamLAND detector to add the capability to search for neutrinoless double beta decay with isotopically enriched ^{136}Xe.



All original physics of KamLAND has been preserved

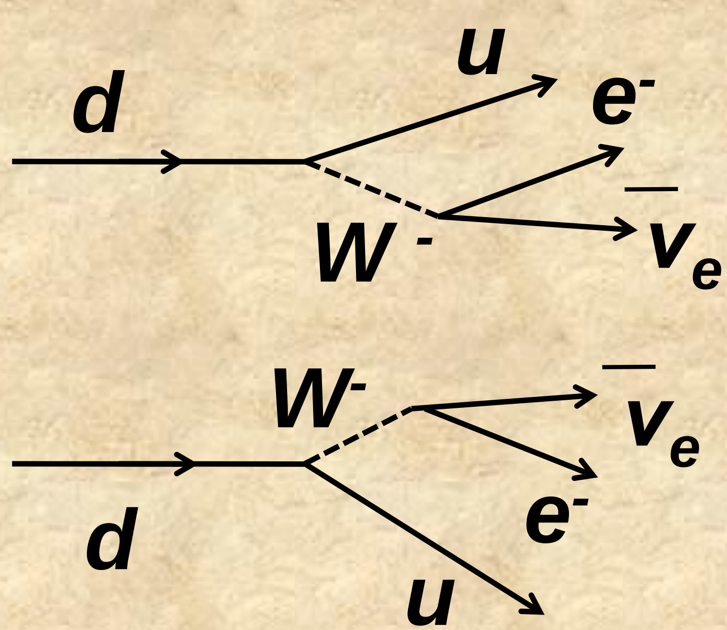
Necessary steps to proceed:

- **Acquire ^{136}Xe isotope**
- **Development of Xe-loaded scintillator with the same density as the KamLAND scintillator**
- **Detector chimney modification**
- **Construction of Xe-loaded scintillator handling infrastructure**
- **Construction of a new mini balloon**
- **Deployment of mini balloon and loading with Xe scintillator**

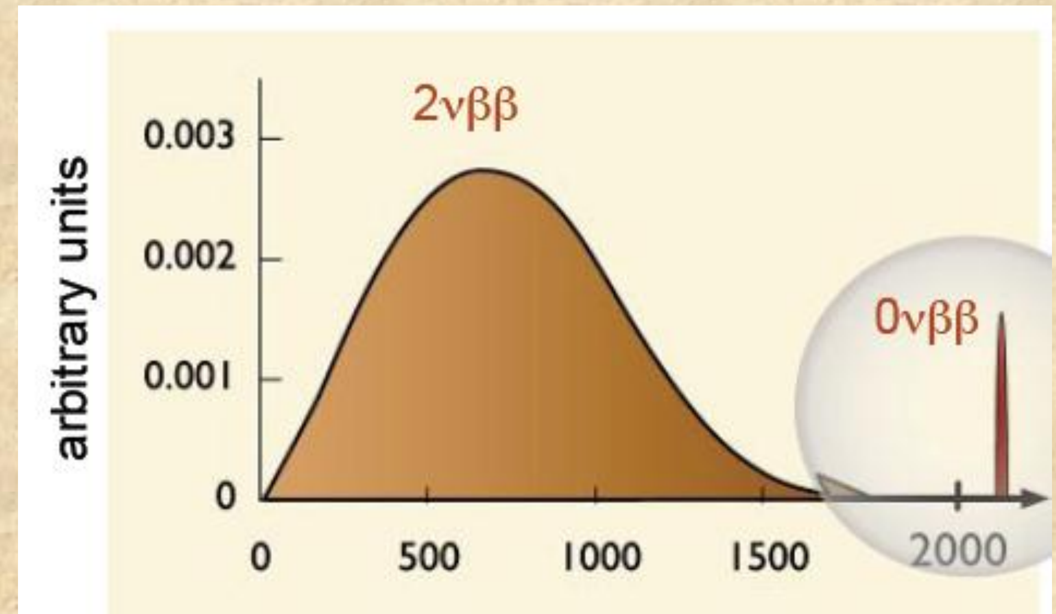


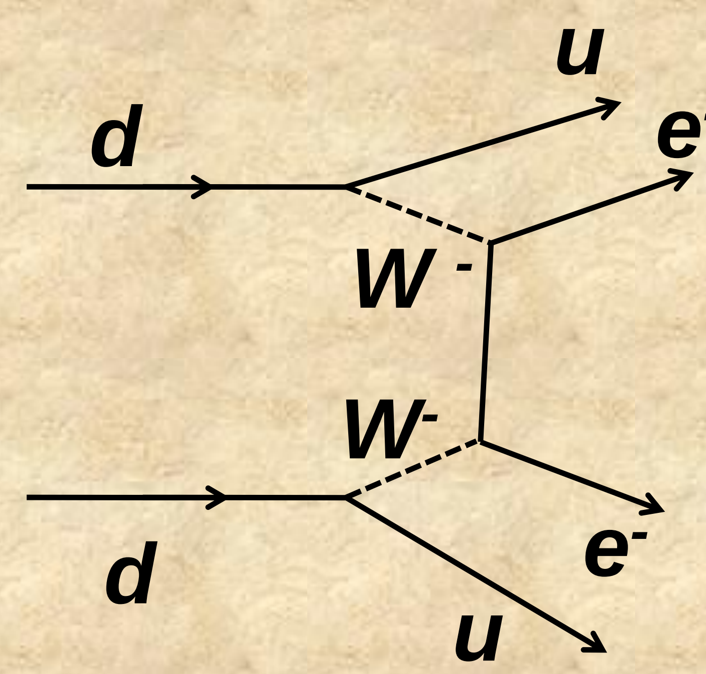
Phase I: 320kg 90% enriched ^{136}Xe

Two neutrino Double beta decay



$$ {}^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-} + 2\bar{\nu}_e $$





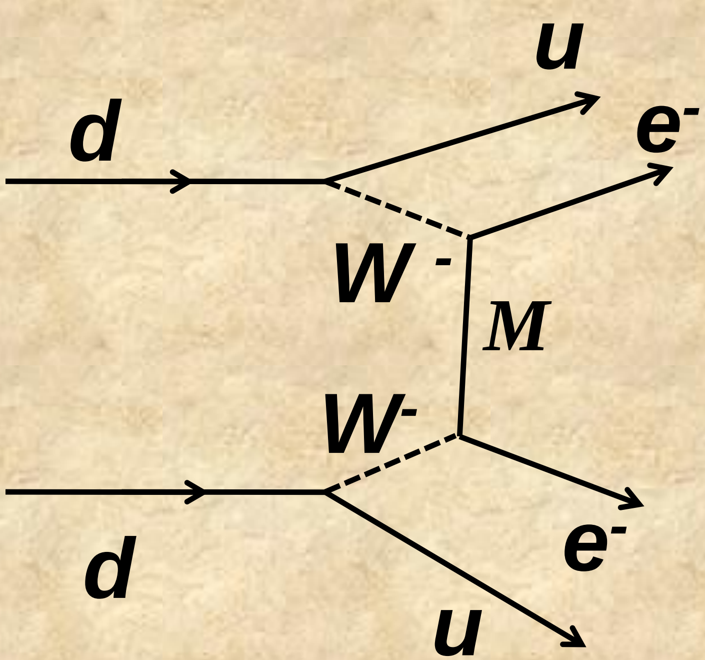
$$ \left(T_{1/2}^{0\nu}\right)^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\,|M^{0\nu}|^2 < m_\nu >^2 $$

$$ \langle m_\nu \rangle = \left| \sum_{i=1}^{3} U_{ei}^2 \cdot m_i \right| \approx \left| (0.87)^2 \cdot m_1 + (0.5)^2 \cdot \sqrt{m_1^2 + \Delta m_{21}^2} \cdot e^{2i\beta} + s_{13}^2 \cdot m_3 \cdot e^{-2i(\gamma-\delta)} \right| $$

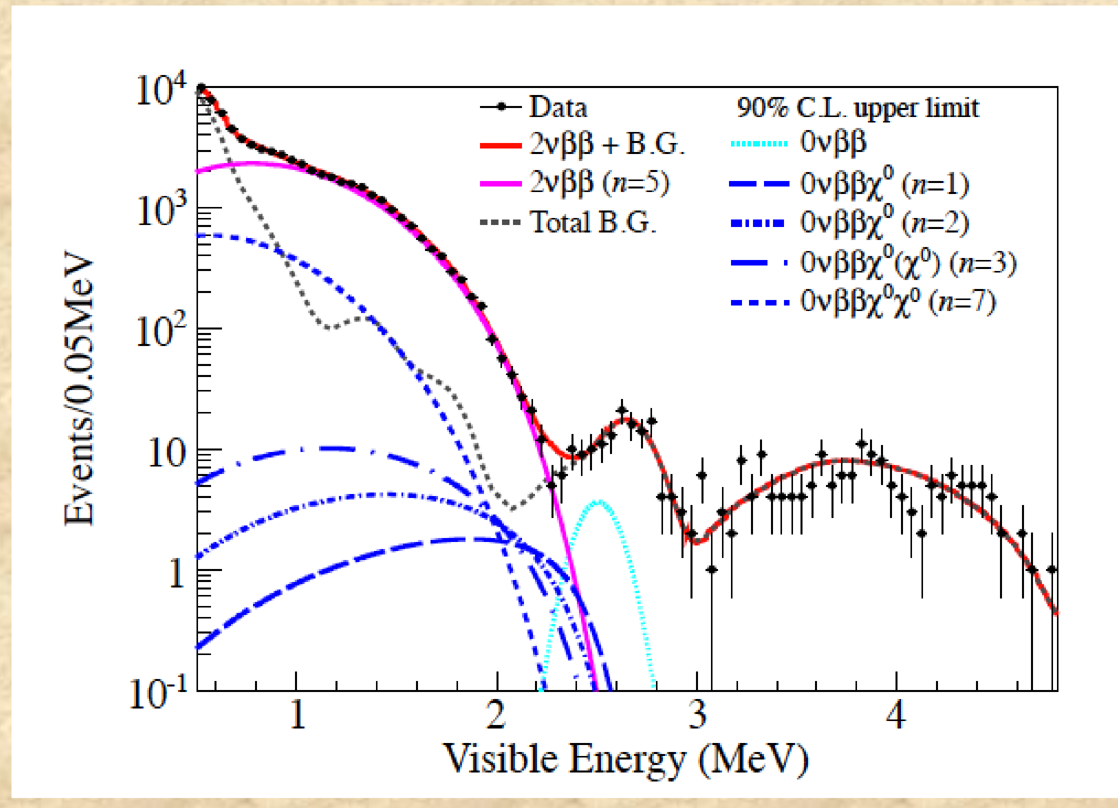
2012

First Result for the KamLAND-Zen

- Measurement of the double-beta decay half-life of ^{136}Xe with the KamLAND-Zen experiment: Phys.Rev. C85 (2012) 045504
- Limits on Majoron-emitting double-beta decays of ^{136}Xe in the KamLAND-Zen experiment: Phys.Rev. C86 (2012) 021601



$T_{1/2}(2\nu) = (2.38 \pm 0.02 \pm 0.14)*10^{21}$ years

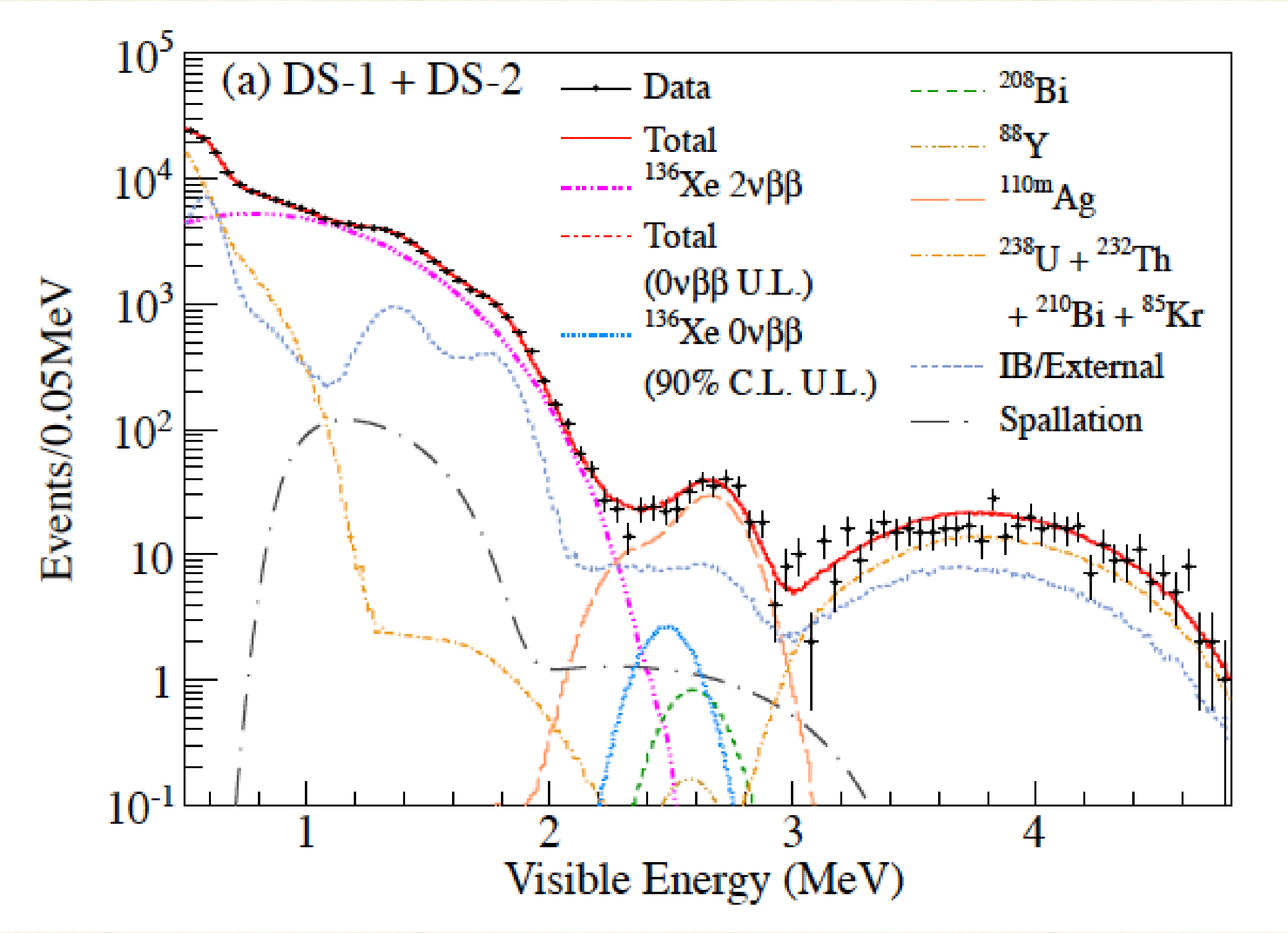


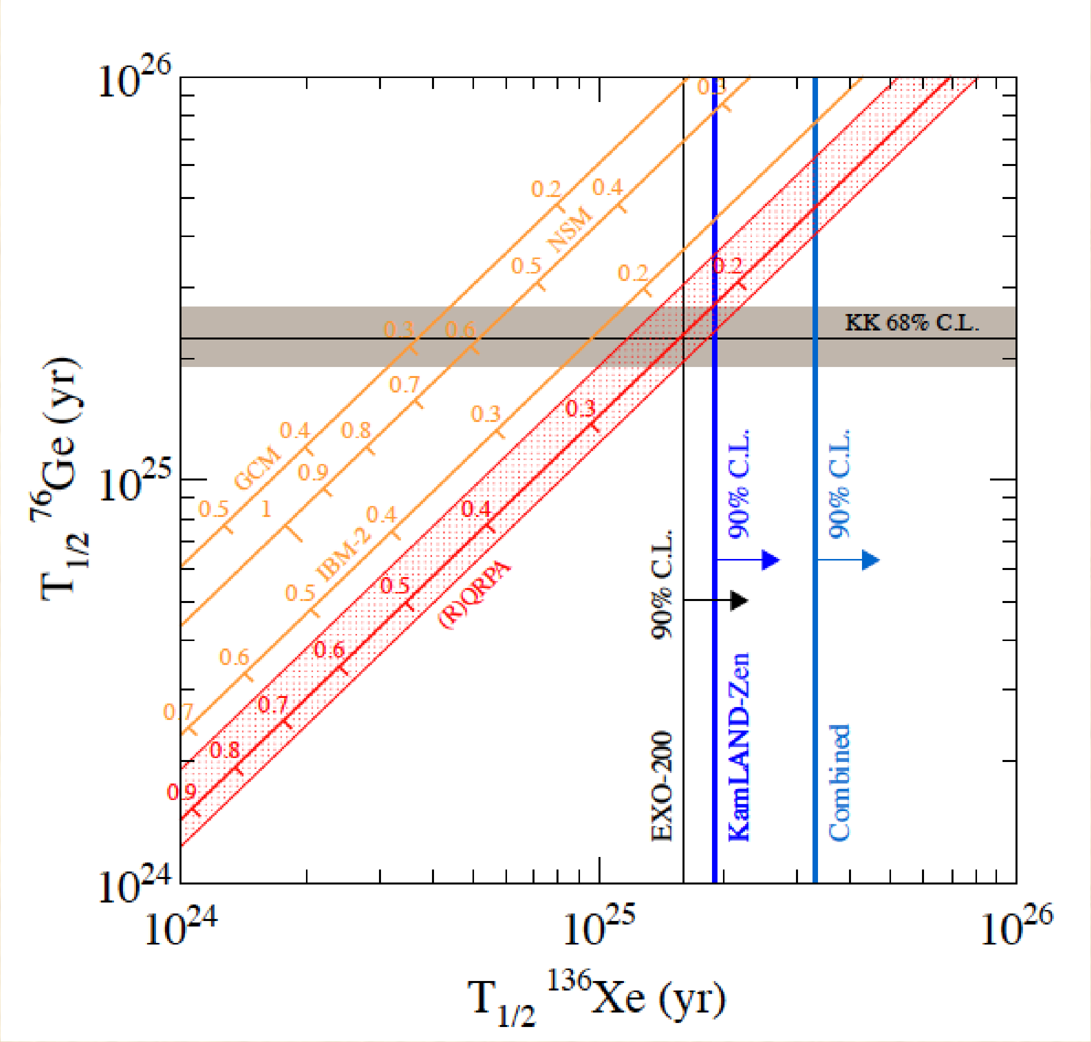
Model	Decay mode	NG boson	L	n	Matrix element	Results from this measurement $T_{1/2}$ (yr)	$\langle g_{ee} \rangle$
IB	$0\nu\beta\beta\chi^0$	No	0	1	$M_F - M_{GT}$ [13,14]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
IC	$0\nu\beta\beta\chi^0$	Yes	0	1	$M_F - M_{GT}$ [13,14]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
ID	$0\nu\beta\beta\chi^0\chi^0$	No	0	3	$M_{F\omega^2} - M_{GT\omega^2}$ [9]	$> 4.5 \times 10^{23}$	< 0.68
IE	$0\nu\beta\beta\chi^0\chi^0$	Yes	0	3	$M_{F\omega^2} - M_{GT\omega^2}$ [9]	$> 4.5 \times 10^{23}$	< 0.68
IIB	$0\nu\beta\beta\chi^0$	No	−2	1	$M_F - M_{GT}$ [13,14]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
IIC	$0\nu\beta\beta\chi^0$	Yes	−2	3	M_{CR} [9]	$> 4.5 \times 10^{23}$	< 0.013
IID	$0\nu\beta\beta\chi^0\chi^0$	No	−1	3	$M_{F\omega^2} - M_{GT\omega^2}$ [9]	$> 4.5 \times 10^{23}$	< 0.68
IIE	$0\nu\beta\beta\chi^0\chi^0$	Yes	−1	7	$M_{F\omega^2} - M_{GT\omega^2}$ [9]	$> 1.1 \times 10^{22}$	< 1.2
IIF	$0\nu\beta\beta\chi^0$	Gauge boson	−2	3	M_{CR} [9]	$> 4.5 \times 10^{23}$	< 0.013
"bulk"	$0\nu\beta\beta\chi^0$	Bulk field	0	2	–	$> 1.0 \times 10^{24}$	–

2013

Would best sensitivity to the neutrino less double beta decay

Limit on neutrino less double-beta decay of ^{136}Xe from the first phase of KamLAND-Zen and Comparison with the positive claim in ^{76}Ge: Phys.Rev.Lett 110(2013) no 6, 0625





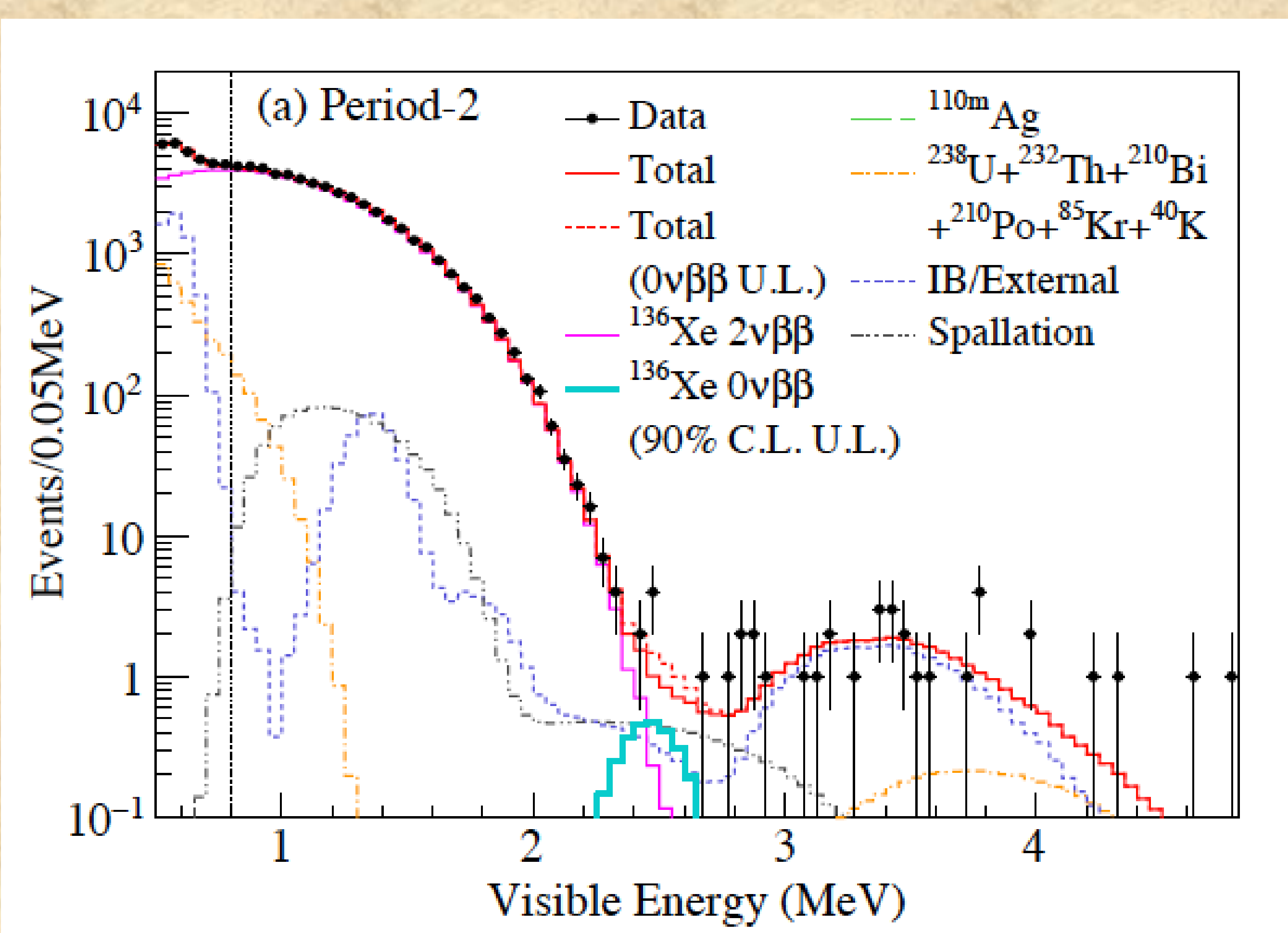
$T_{1/2}(0\nu) > 3.4\ 10^{25}$ years

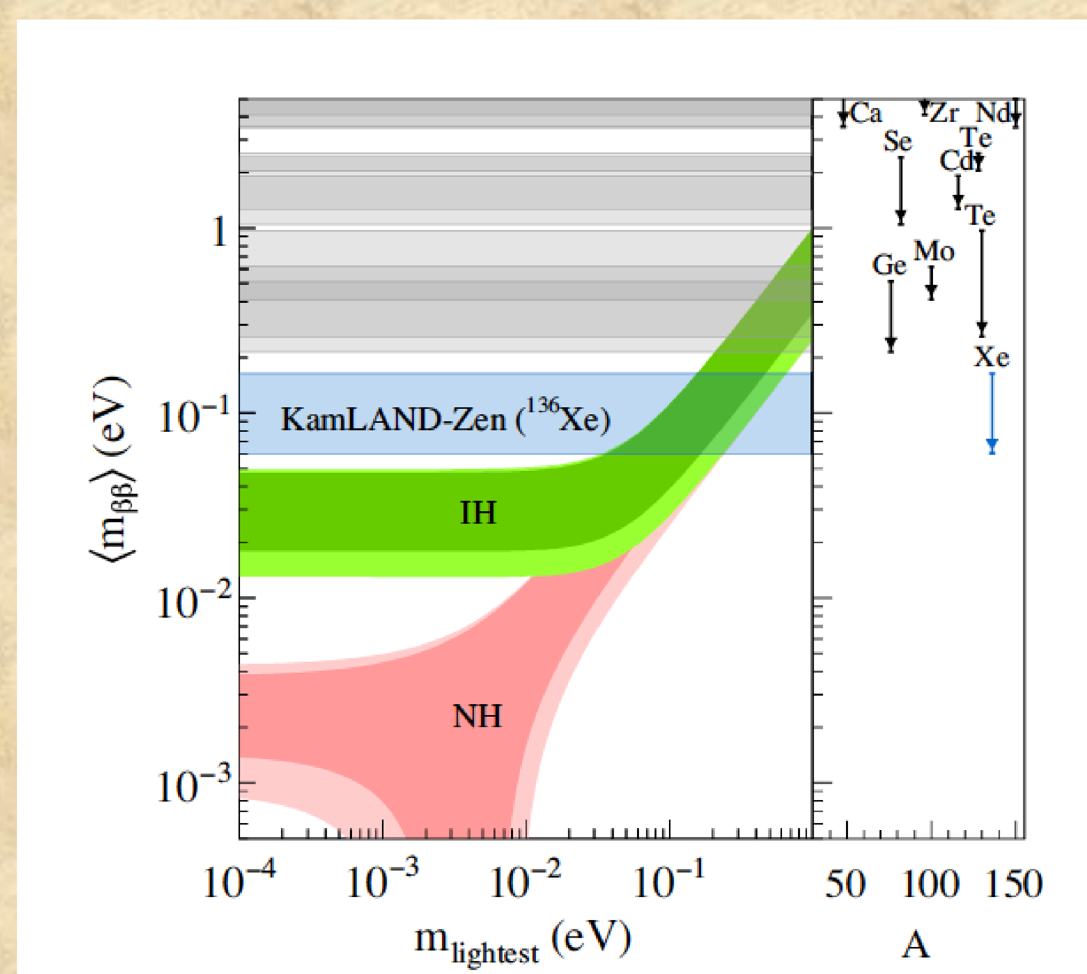
2016

Two large improvements in neutrino less double beta decays:

Search for Majorana Neutrinos near the Inverted Mass Hierarchy Region with KamLAND-Zen Phys.Rev.Lett. 117 (2016) no.8, 082503

Search for double-beta decay of ^{136}Xe to excited states ^{136}Ba with the KamLAND-Zen experiment   Nucl.Phys. A946 (2016) 171-181.





$T_{1/2}(0\nu) > 1.07\ 10^{26}$ years

$$\langle m_{\beta\beta} \rangle < (61 - 165)\,\mathrm{meV}$$

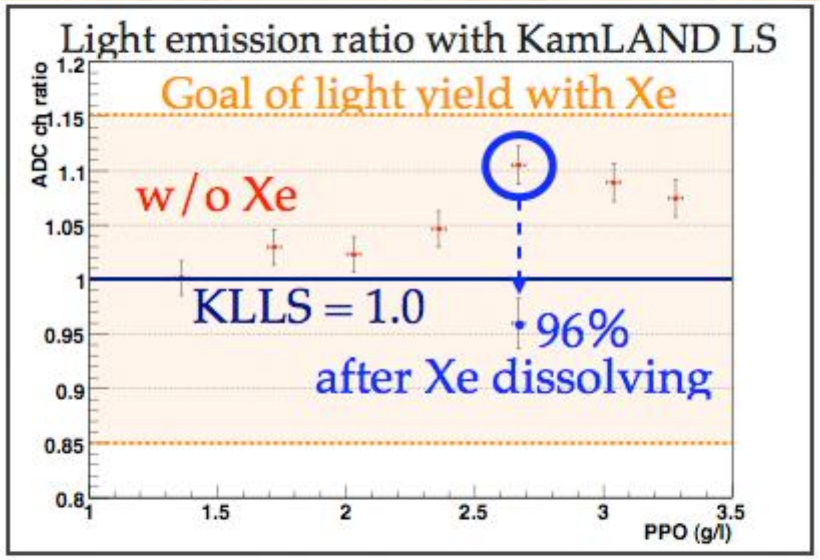
2017

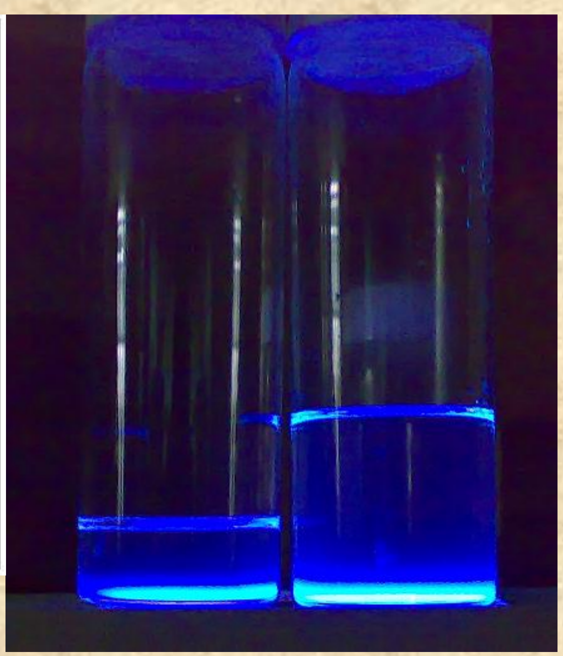
Moving forward with the next step to increase ^{136}Xe isotope mass up to 750 kg

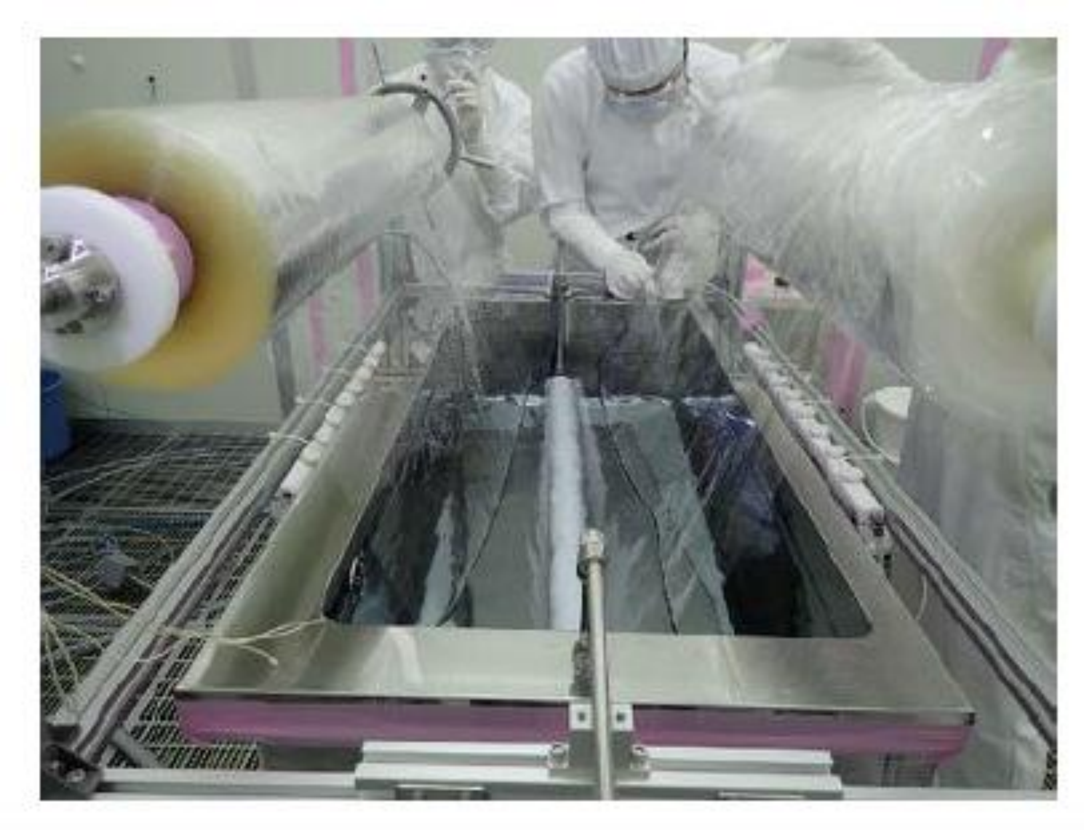
We are in process of construction new bigger mini balloon,

Deployment in the fall of 2017

Expected that new mini balloon with be more radio pure as well.



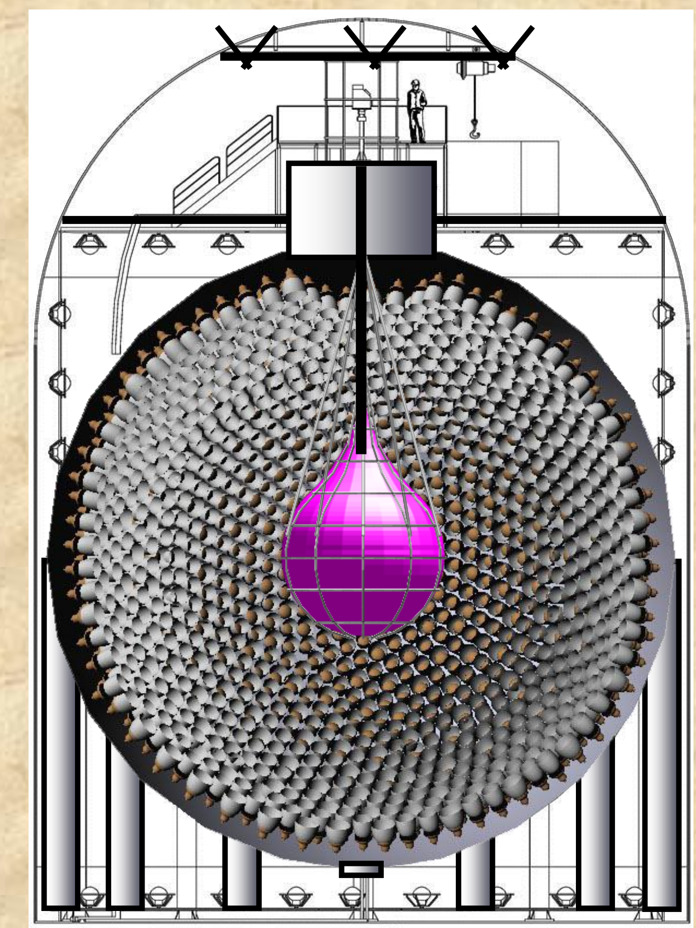




Some long range plans!

Higher energy resolution for reducing 2ν BG

→ KamLAND2-Zen



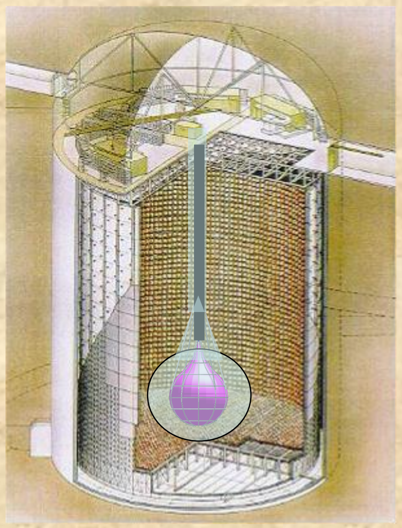
1000+ kg xenon

Winston cone	light collection ×1.8
high q.e. PMT 17"φ→20"φ ε=22→30+%	light collection ×1.9
New LAB LS (better transparency)	light collection ×1.4

expected σ(2.6MeV)= 4% → ~2%

target sensitivity 20 meV

And more?



Super-KamLAND-Zen

in connection with Hyper-Kamiokande

target sensitivity 8 meV

Summary

- **During the last 20 years KamLAND delivered large amounf of impressive and diverse results in neutrino phsyics**

- **During that period 25 high impart papers were published in referred journals with an average of 262 citations per paper**

- **KamLAND is moving forward with even more ambisious goals and have robast long range program**

Thank you!