

Enlightenment is
found in nothing.

Status of KamLAND-Zen

Kunio Inoue
RCNS, Tohoku University
(KamLAND-Zen collaboration)

NDM12, 11 June 2012, Nara



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Truth is found in
 $0\nu 2\beta$.

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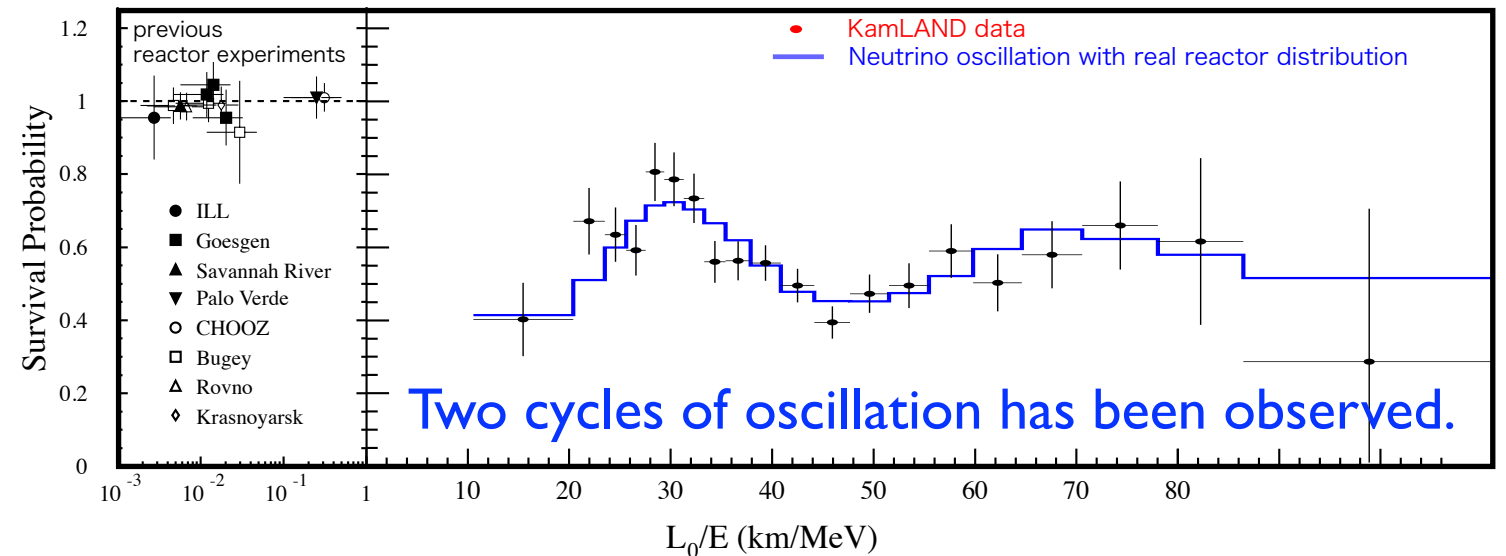
Contents

- KamLAND → KamLAND-Zen
- Measurement of the $2\nu 2\beta$ half life of ^{136}Xe
- Background situation
- Limit on the $0\nu 2\beta$ half life of ^{136}Xe
- Limits on Majoron-emitting Double-Beta decays
- Future Prospects

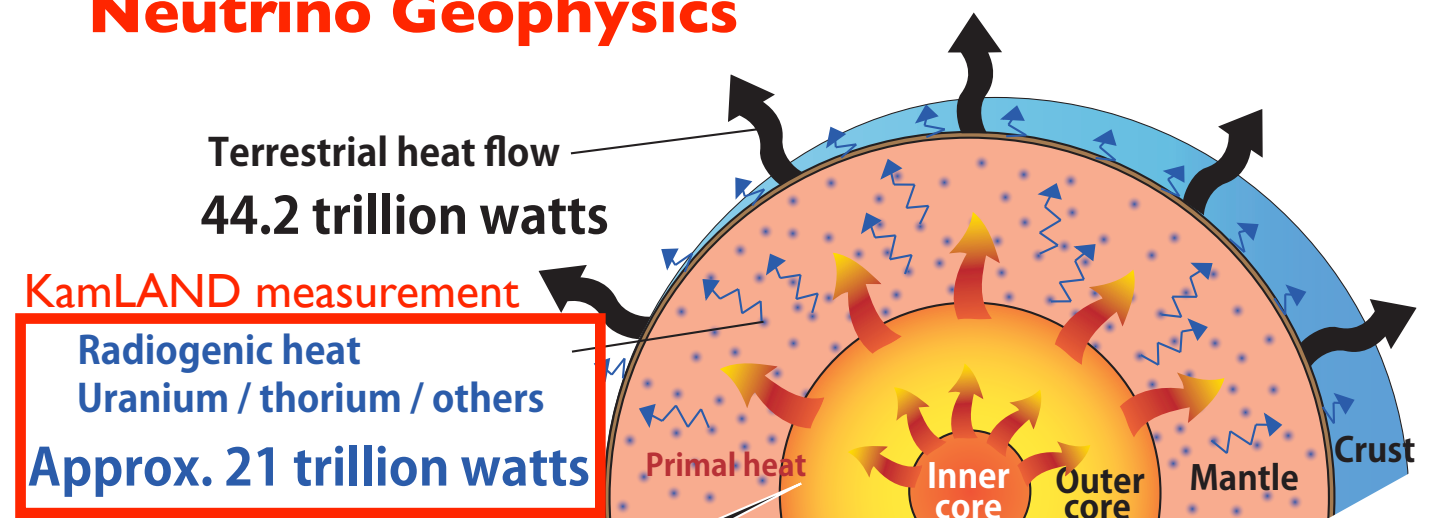
based on
Phys.Rev.C85, 045504(2012)
and update arXiv:1205.6372

KamLAND Kamioka Liquid-scintillator Anti-Neutrino Detector

Evidence of neutrino oscillation



Neutrino Geophysics

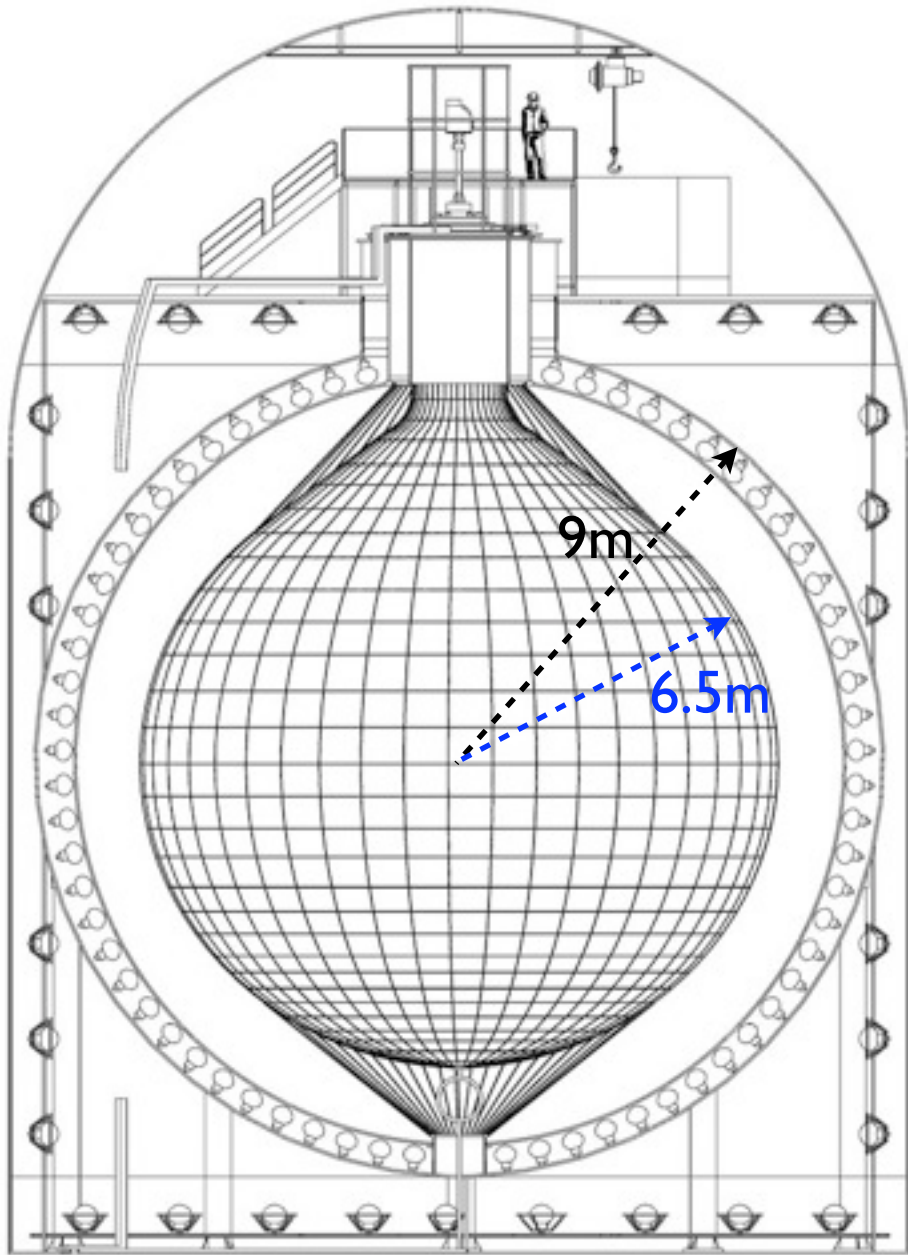


Heat from the time of the Earth's formation still exists

It is the world largest liquid scintillator detector.

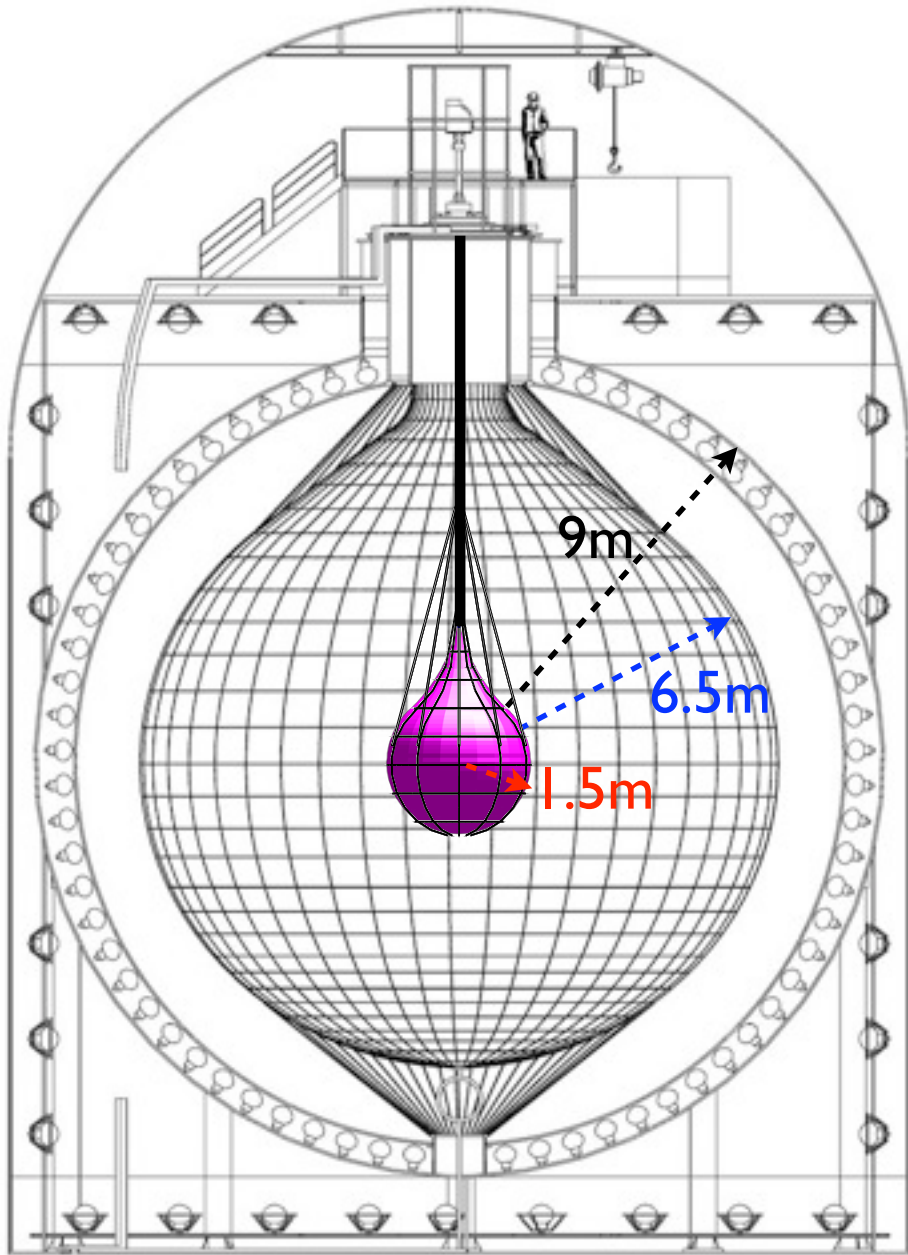
Huge (1200m^3) & Clean (U: 3.5×10^{-18} g/g, Th: 5.2×10^{-17}) !

KamLAND



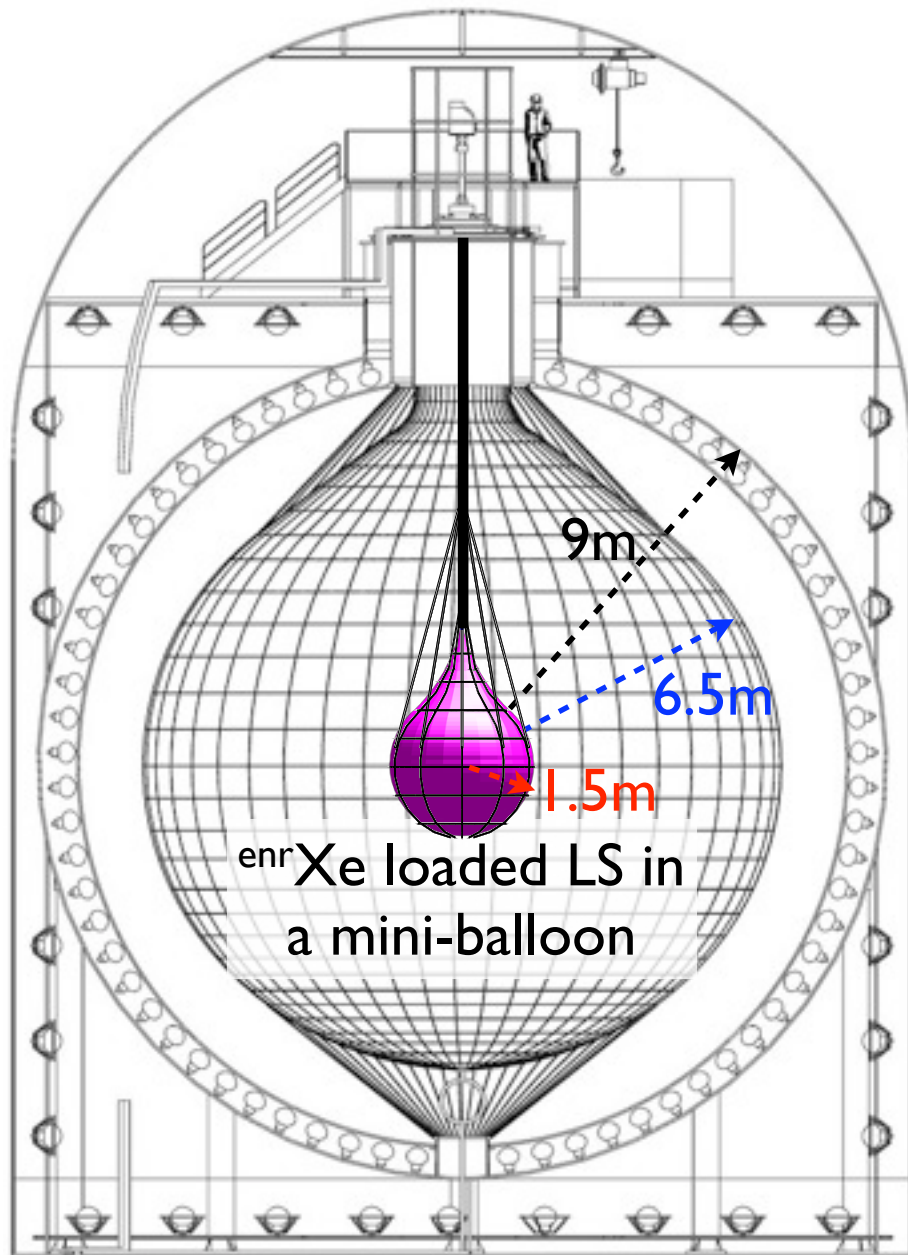
idea to load Xe into LS is from Raju PRL72,1411(1994)

KamLAND



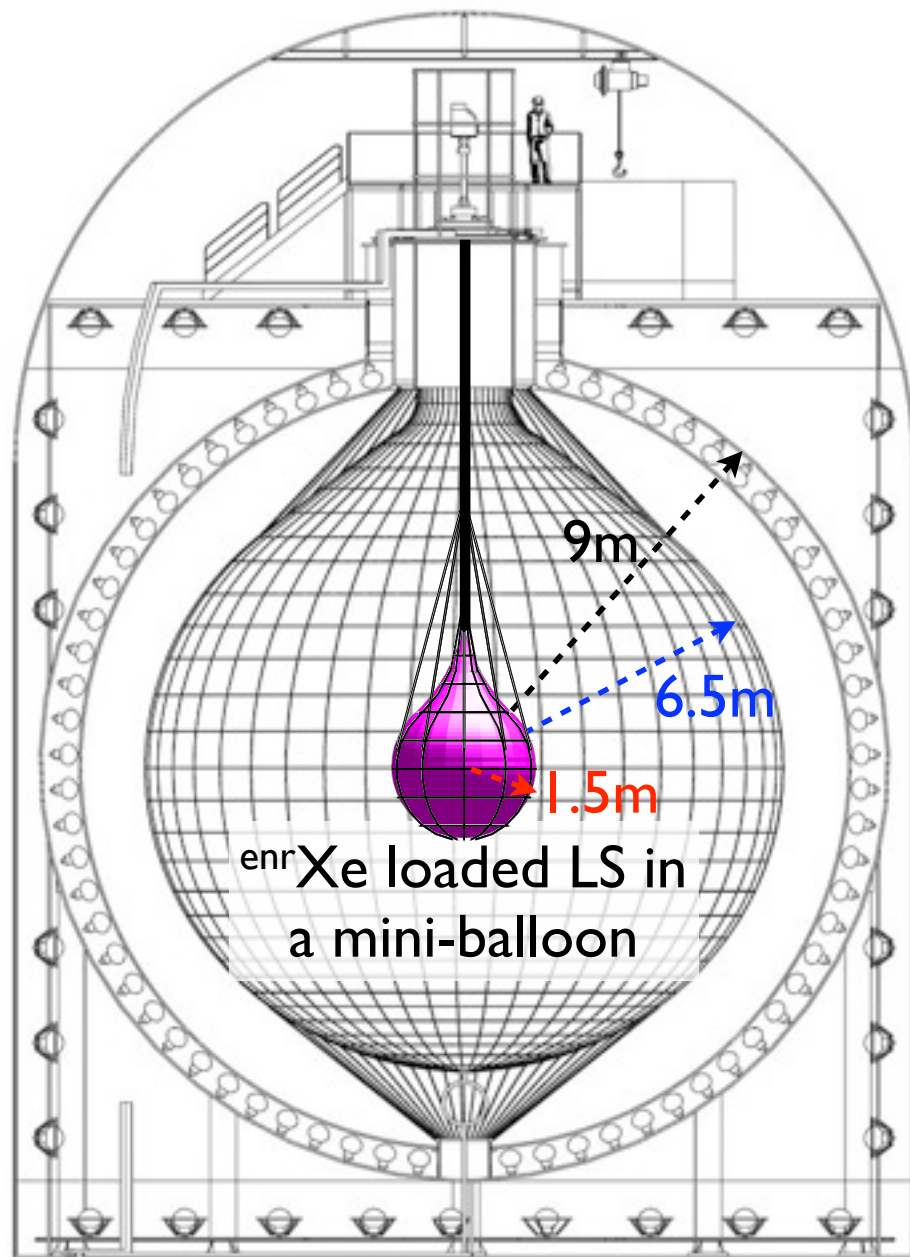
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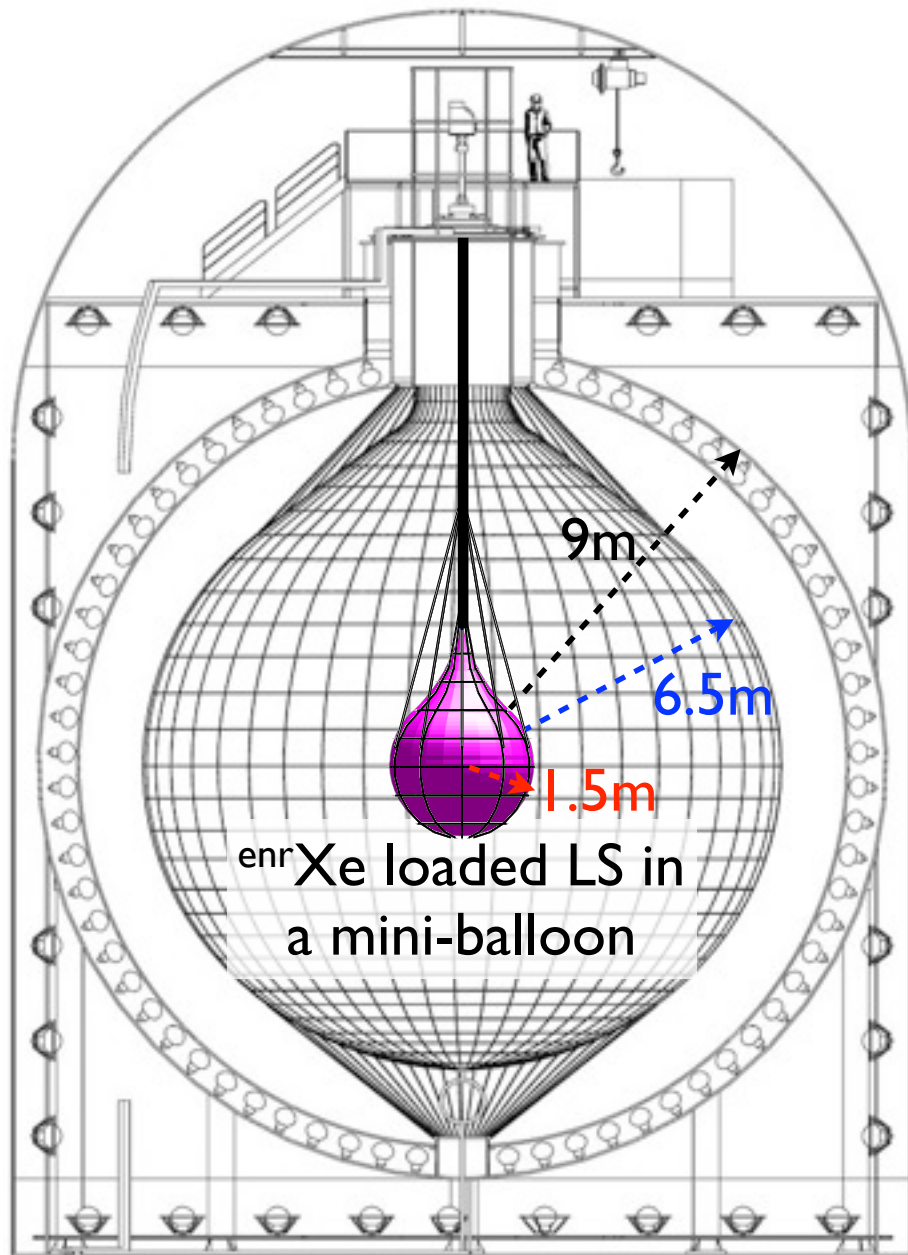
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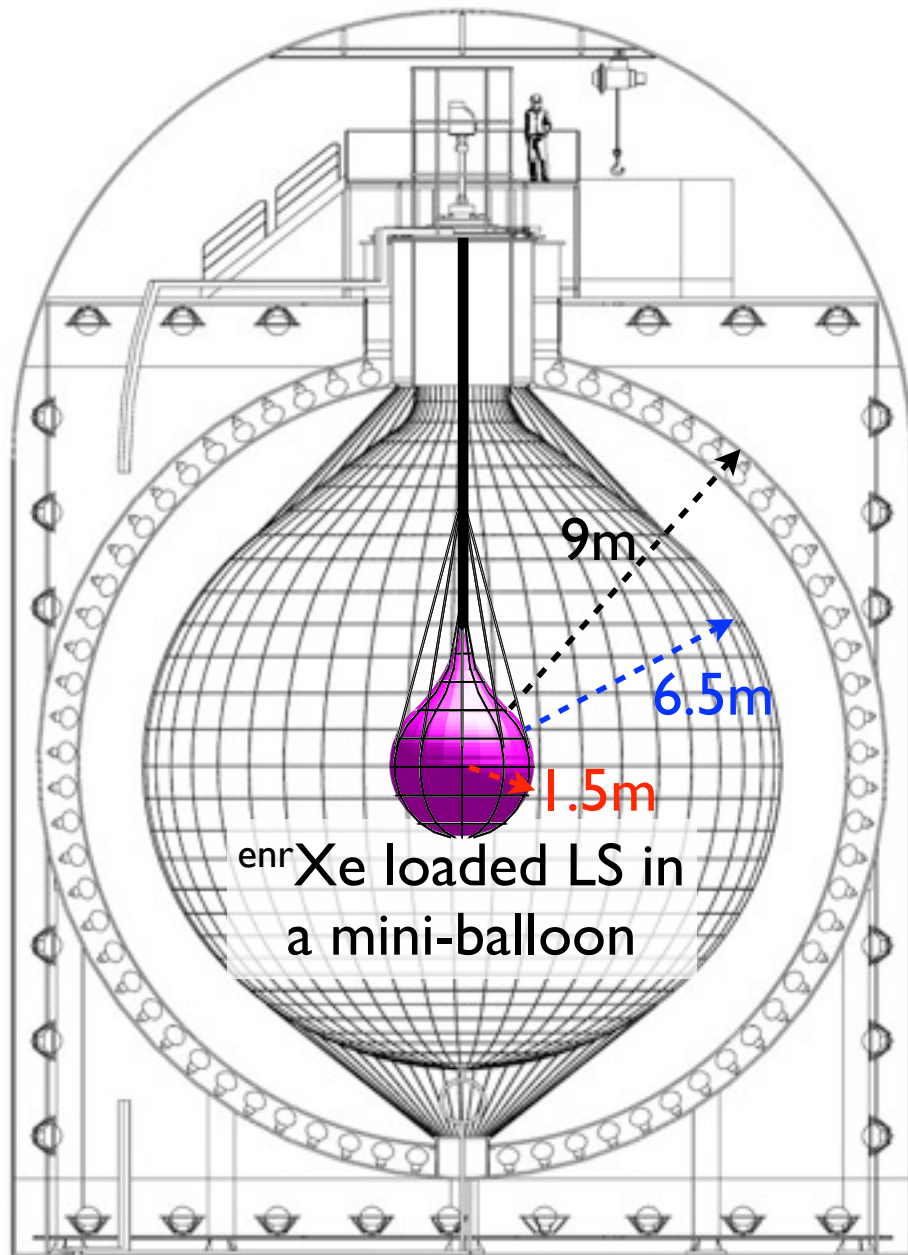
Zero Neutrino
double beta decay search



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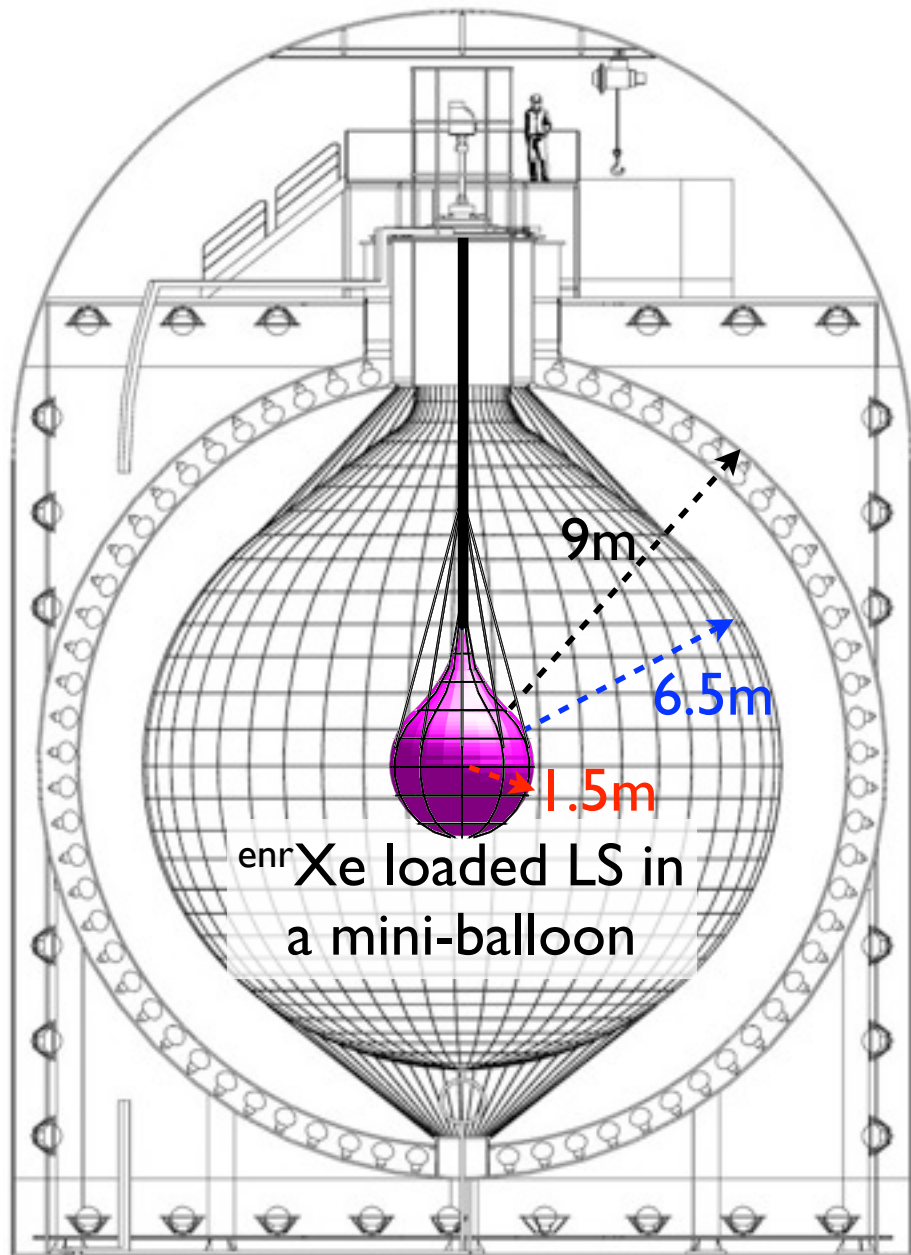


idea to load Xe into LS is from Raju PRL72,1411(1994)

~320kg 90% enriched ^{136}Xe installed so far
total 600+ kg in the mine
production reaches 700kg in this year

KamLAND-Zen

Zero Neutrino
double beta decay search



Good features of using KamLAND

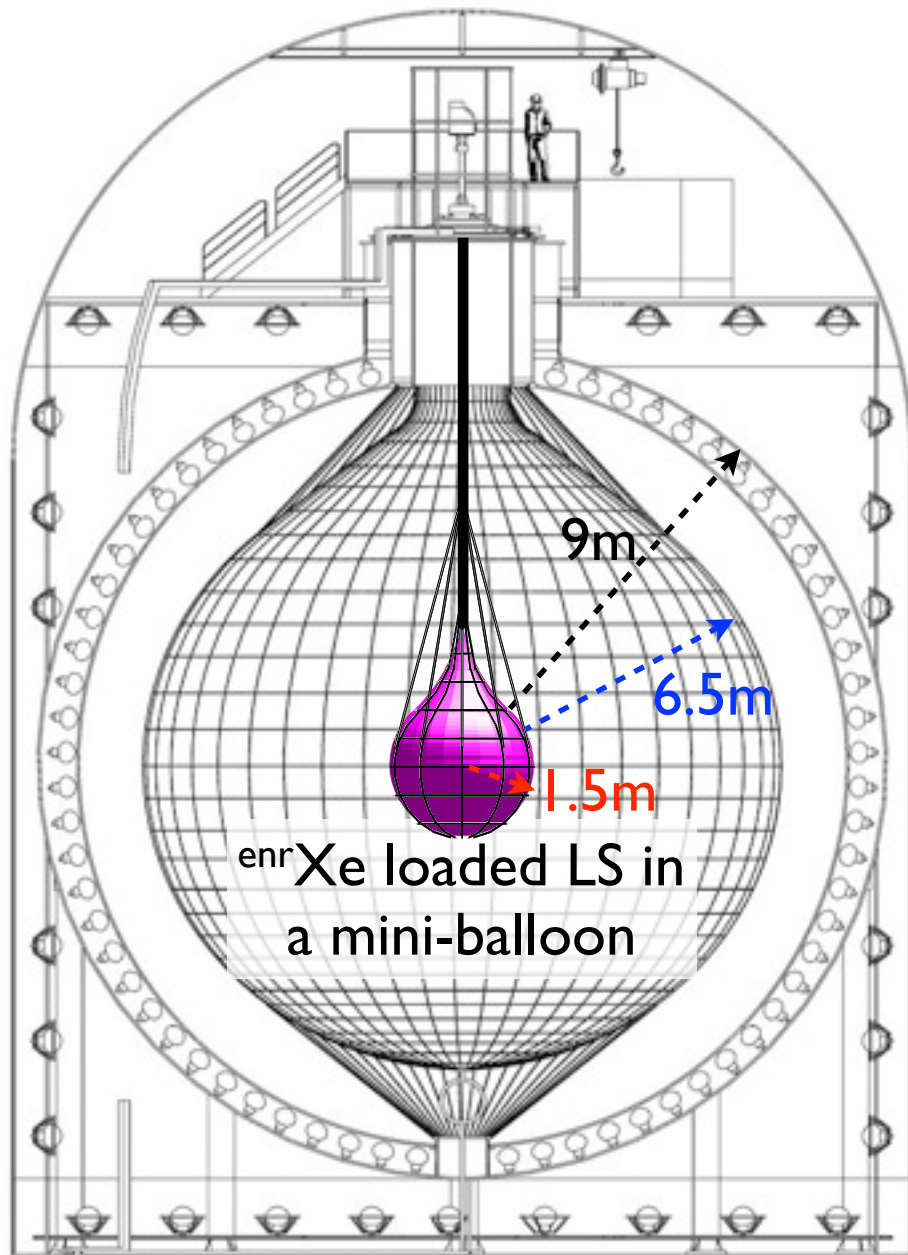
- running detector
 - relatively low cost and quick start
- huge and clean (1200m^3 , U: $3.5 \times 10^{-18}\text{g/g}$, Th: 5.2×10^{-17})
 - negligible external gamma
 - (Xe and mini-balloon need to be clean)
- Xe-LS can be purified, mini-balloon replaceable if necessary, with relatively low cost
 - highly scalable (up to several tons of Xe)
- No escape or invisible energy from β , γ
 - BG identification relatively easy
- anti-neutrino observation continues
 - geo-neutrino w/o japanese reactors

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Disadvantages toward an ultimate sensitivity

- × relatively poor energy resolution
 - tolerable thanks to slow $2\nu 2\beta$ and low BG
- × no β/γ discrimination so far
- × delicate balloon film
- × limited LS composition (for density matching)

mini balloon fabrication

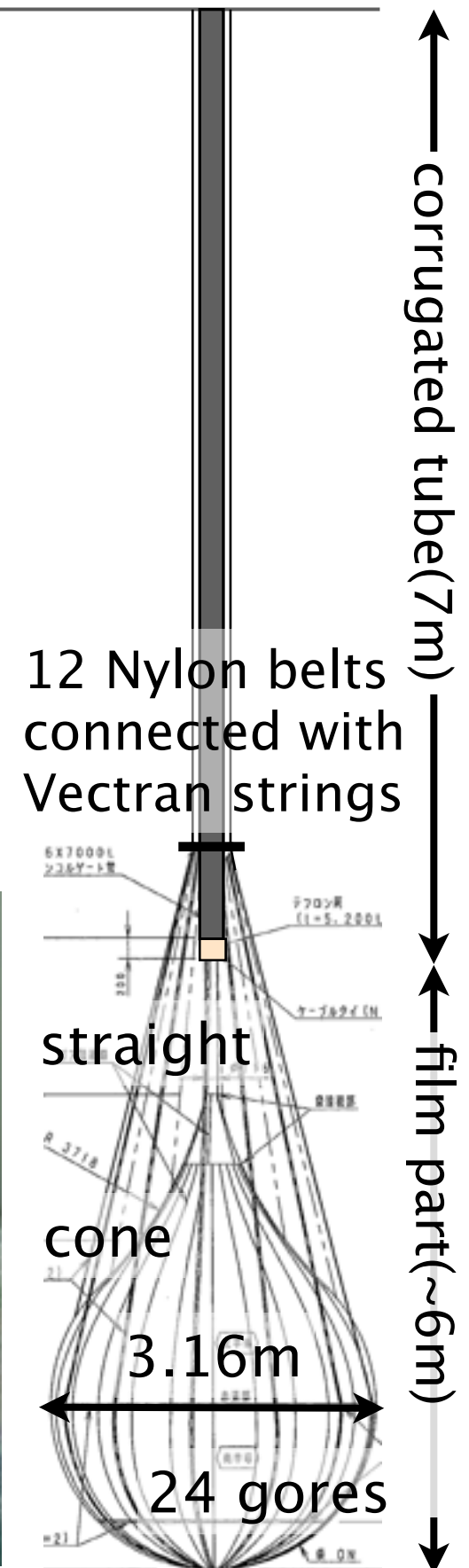
- produced in a class 1 super-clean-room
(class 1 = less than 1 0.5-micron-particle in cubic feet)

less material → **25 μm Nylon6**
 transparency 99.4% @400nm
 strength 19.4 N/cm
 Xe barrier < 220 g/year

low radioactivity

→ specially made no filler film

U : 150 → $2 \times 10^{-12} \text{g/g}$
 Th : 59 → $3 \times 10^{-12} \text{g/g}$
 ^{40}K : 140 → $2 \times 10^{-12} \text{g/g}$



- All tools and parts to be used for the installation have been cleaned here.

Installation in a class 10~100 clean room
built at the top of KamLAND



balloon and corrugated tube deployment

Installation in a class 10~100 clean room
built at the top of KamLAND



balloon and corrugated tube deployment



balloon went through the black sheet

Installation in a class 10~100 clean room
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installation completed

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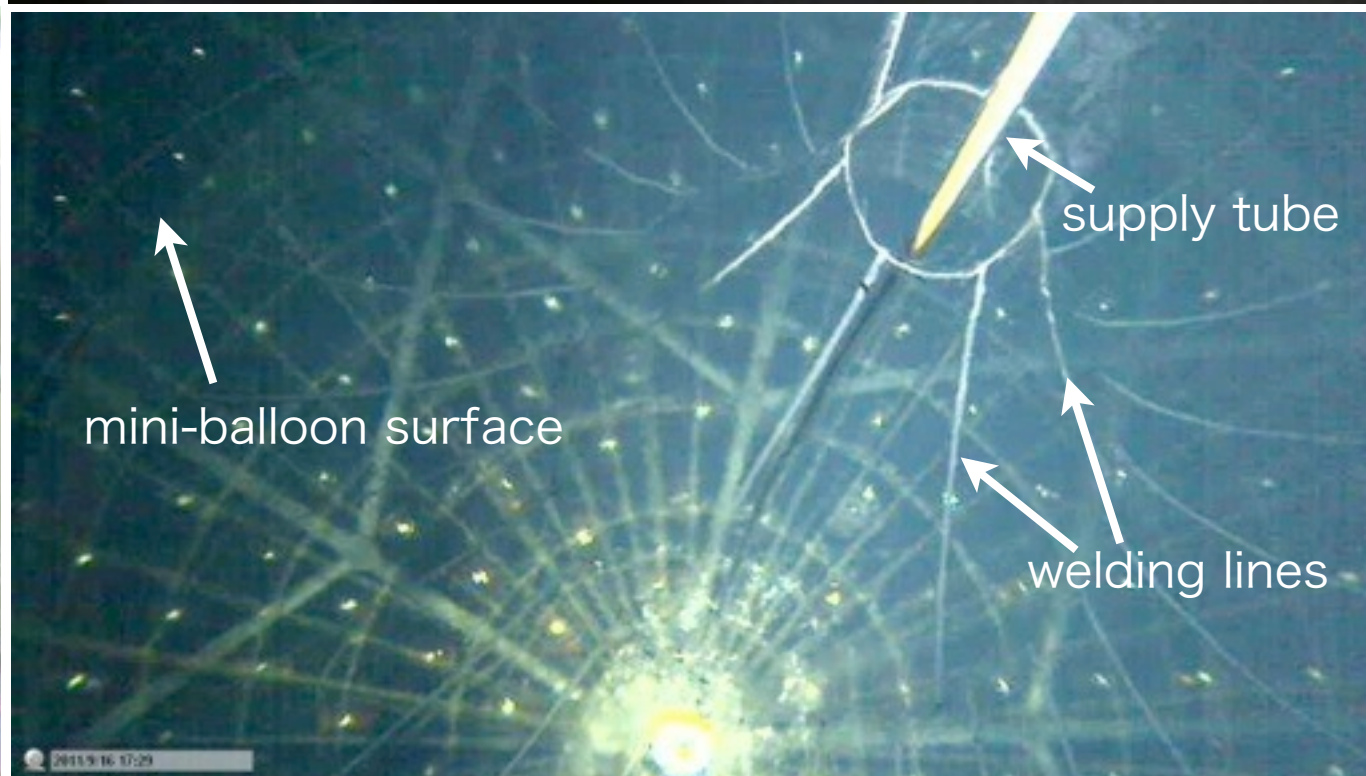


balloon went through the black sheet

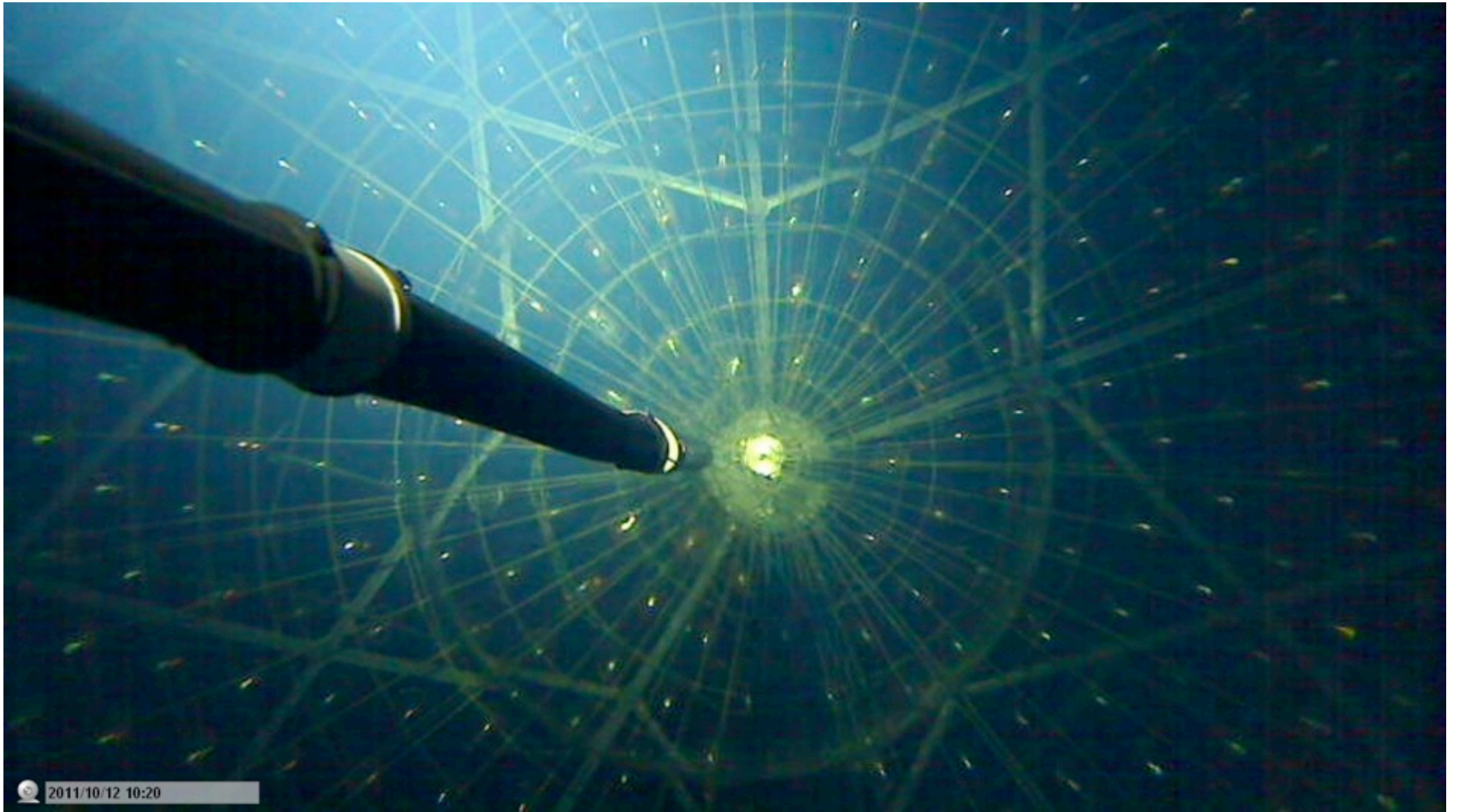


installation completed





mini-balloon inflated with dummy LS and then
replaced with Xe-loaded LS
density tuning finished and tubes to be extracted

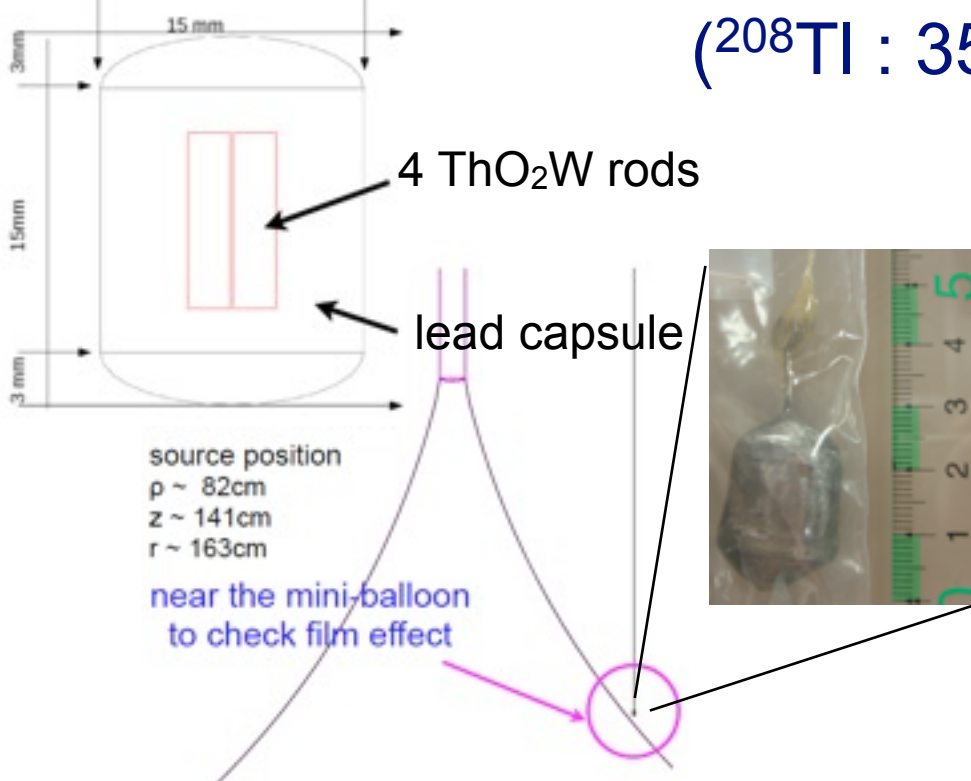


Normal data taking has been started on September 24th, 2011.

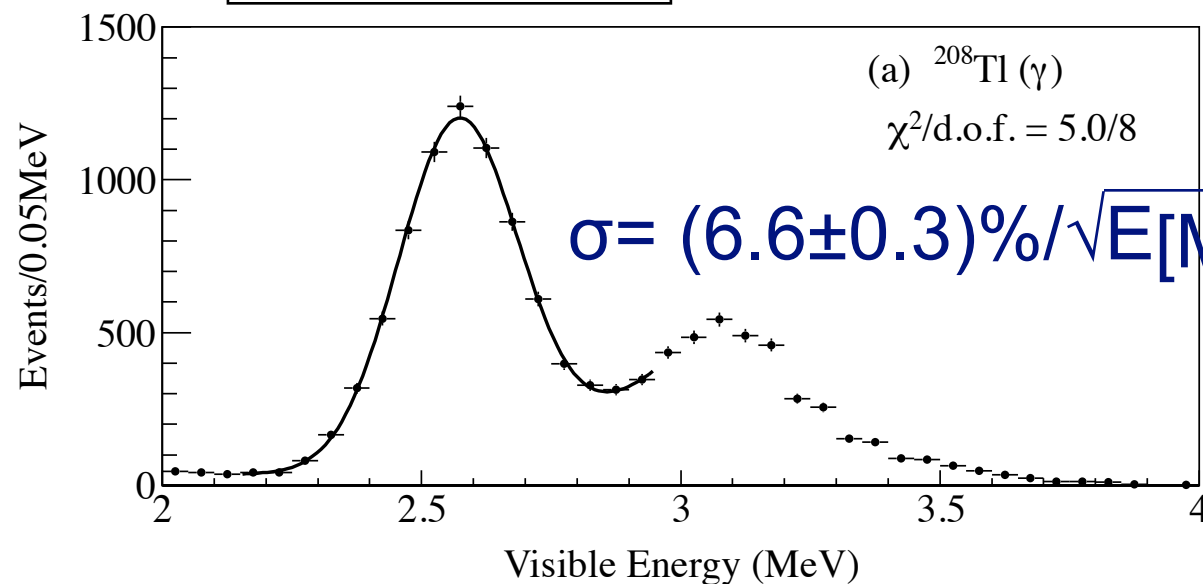
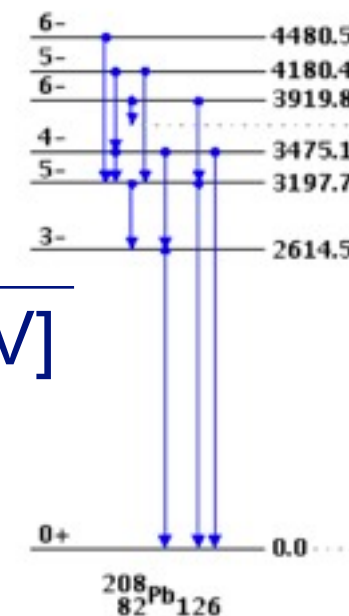
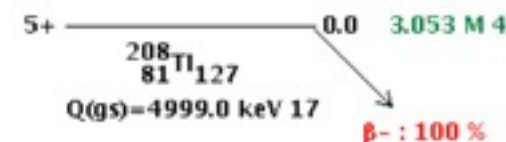
only two years from the first budgets in FY2009

Energy Calibration

**ThO₂W electrode w/ ²³²Th 2~4 wt%
(²⁰⁸Tl : 35.9%)**

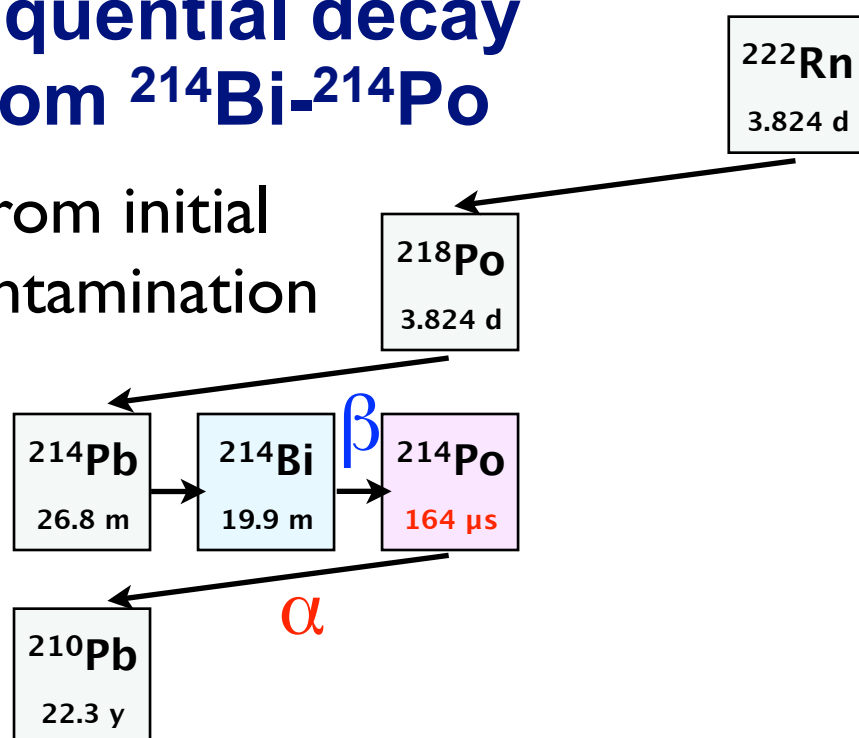


**²⁰⁸Tl decay
(2.6 MeV γ)**

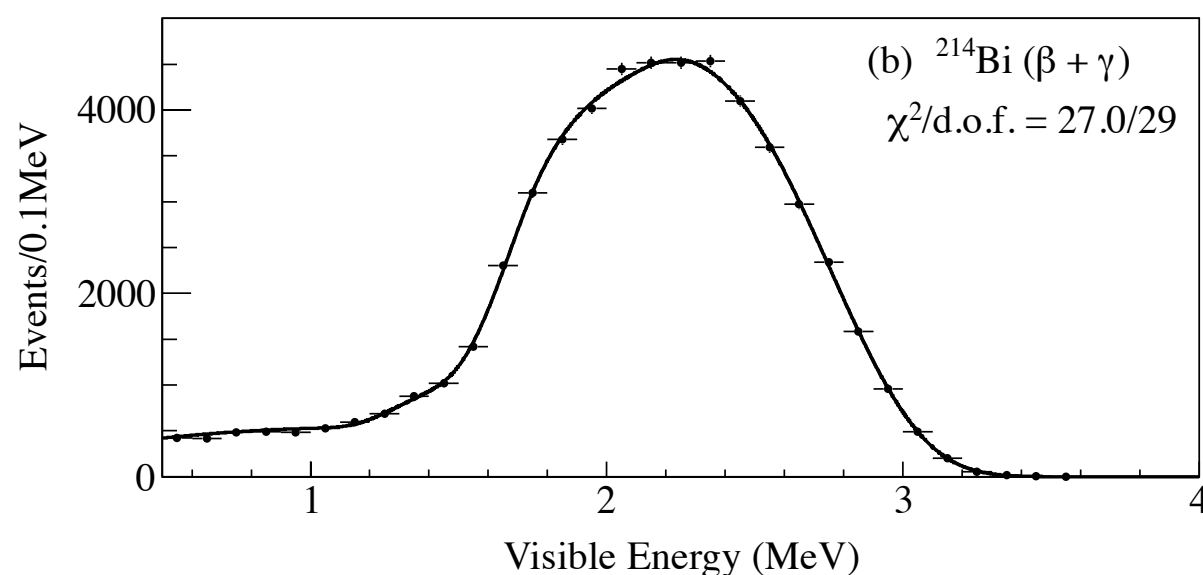
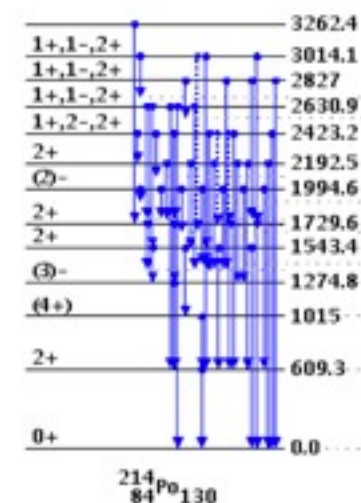
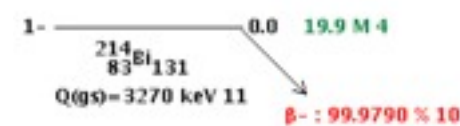


**Sequential decay
from ²¹⁴Bi-²¹⁴Po**

from initial
contamination



**²¹⁴Bi decay
($\beta + \gamma$)**



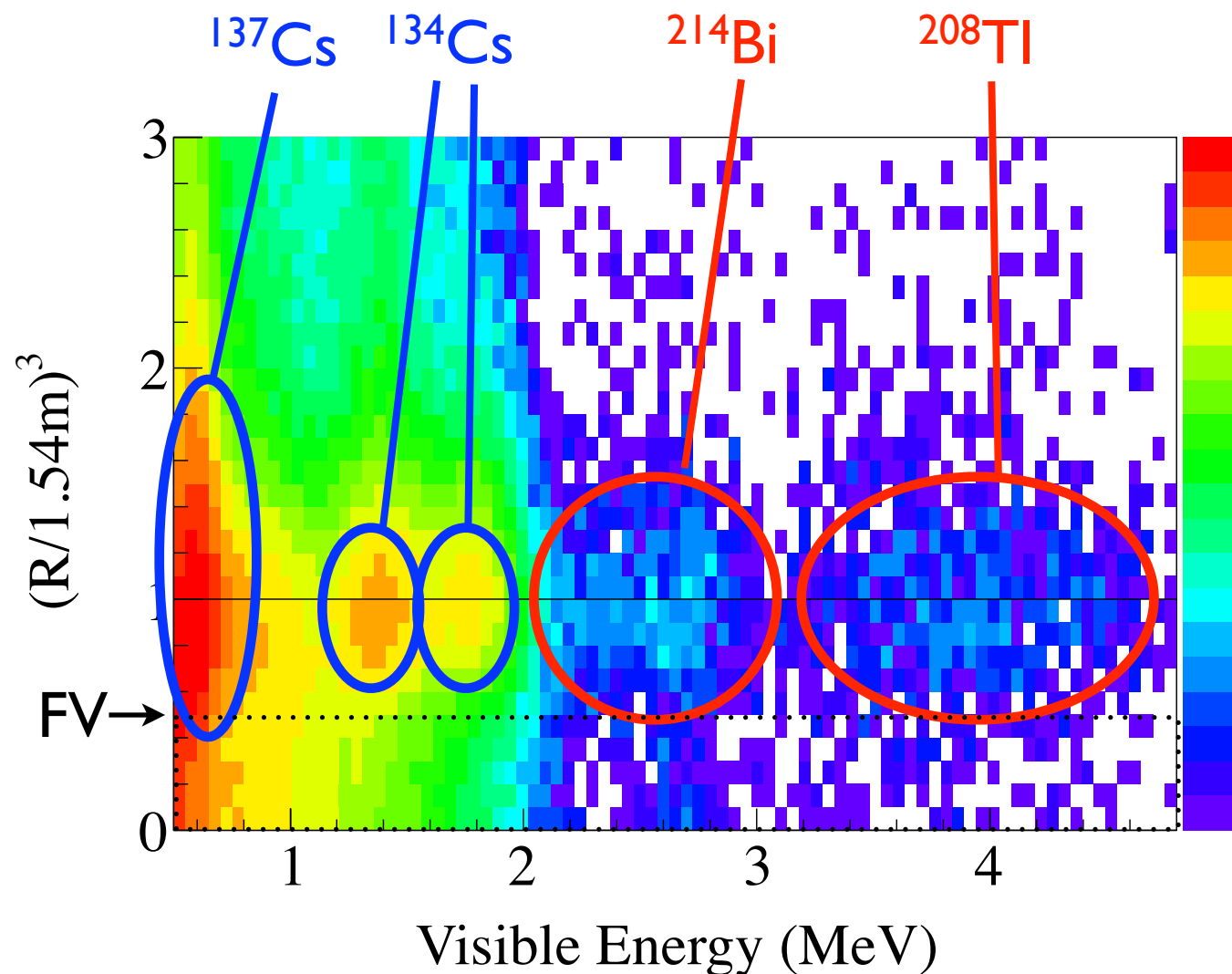
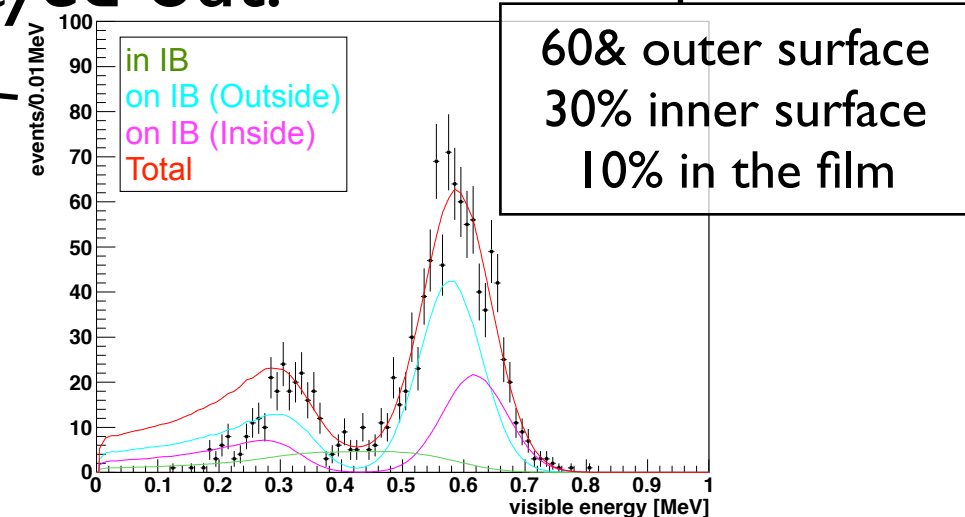
After a while, excess Radon in the balloon decayed out.

^{238}U : $3.5 \times 10^{-16} \text{g/g}$ (LS), $2.2 \times 10^{-11} \text{g/g}$ (balloon)

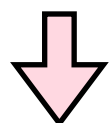
^{232}Th : $2.2 \times 10^{-15} \text{g/g}$ (LS), $1.4 \times 10^{-10} \text{g/g}$ (balloon)

• Vertex, fiducial volume calibration

^{214}Po spectral fit

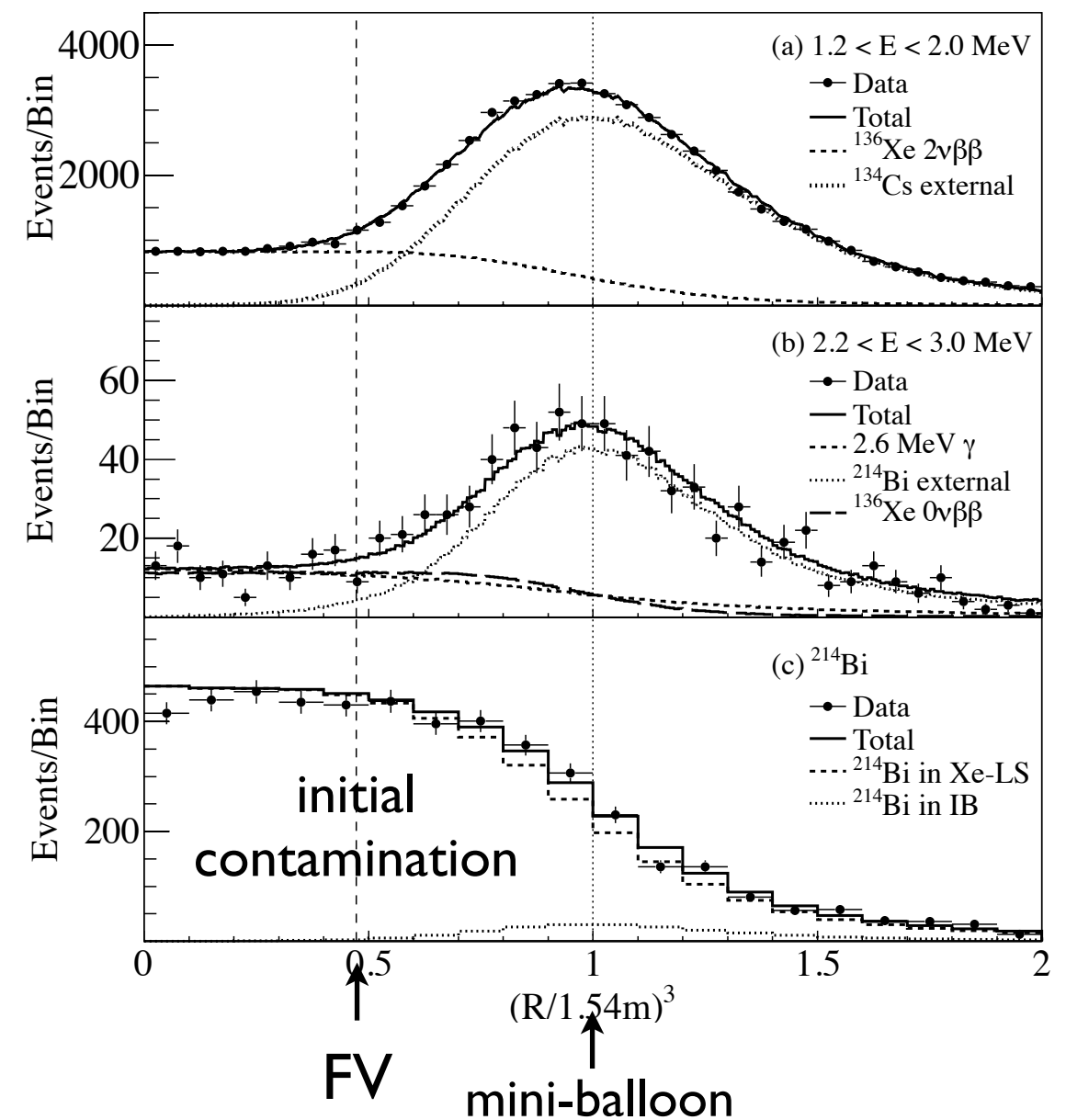


Fabrication in the super-clean room was not clean enough.



Subject for the next fabrication

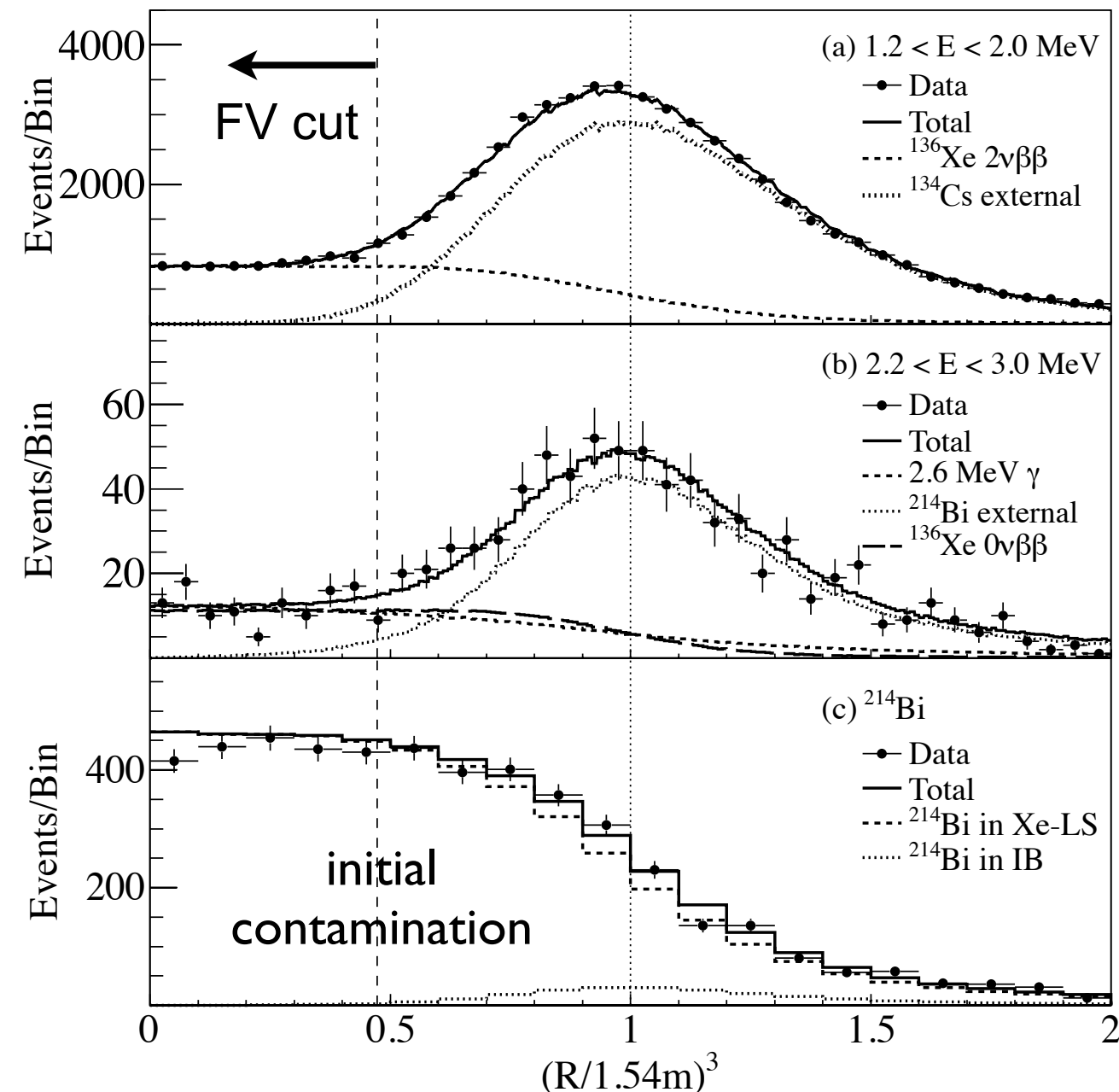
vertex resolution from balloon events
 $\sim 15\text{cm}/\sqrt{E}$



Fiducial Volume

R^3 vertex distribution

$R = 1.2 \text{ m}$ $R = 1.54 \text{ m}$

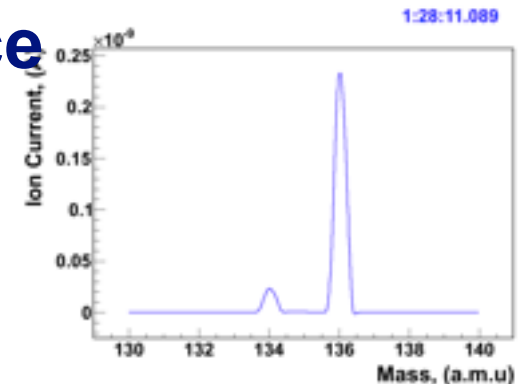


Fiducial volume of Xe-LS

$$R < 1.2 \text{ m} \quad V = 7.24 \text{ m}^3$$

Xe isotopic abundance

^{136}Xe : 90.93%,
 ^{134}Xe : 8.89%



Xe amount by weight measurement
 (supplied)-(returned)

- Xe concentration = $(2.44 \pm 0.01) \text{ wt\%}$

consistent direct gas chromatography analysis

- Xe concentration = $(2.52 \pm 0.07) \text{ wt\%}$

Uncertainty of the fiducial volume

^{214}Bi vertex uniformity check

$$V_{1.2\text{m}} / V_{\text{total}} = 0.438 \pm 0.005$$

$$N_{1.2\text{m}} / N_{\text{total}} = 0.423 \pm 0.007(\text{stat}) \pm 0.004(\text{syst})$$

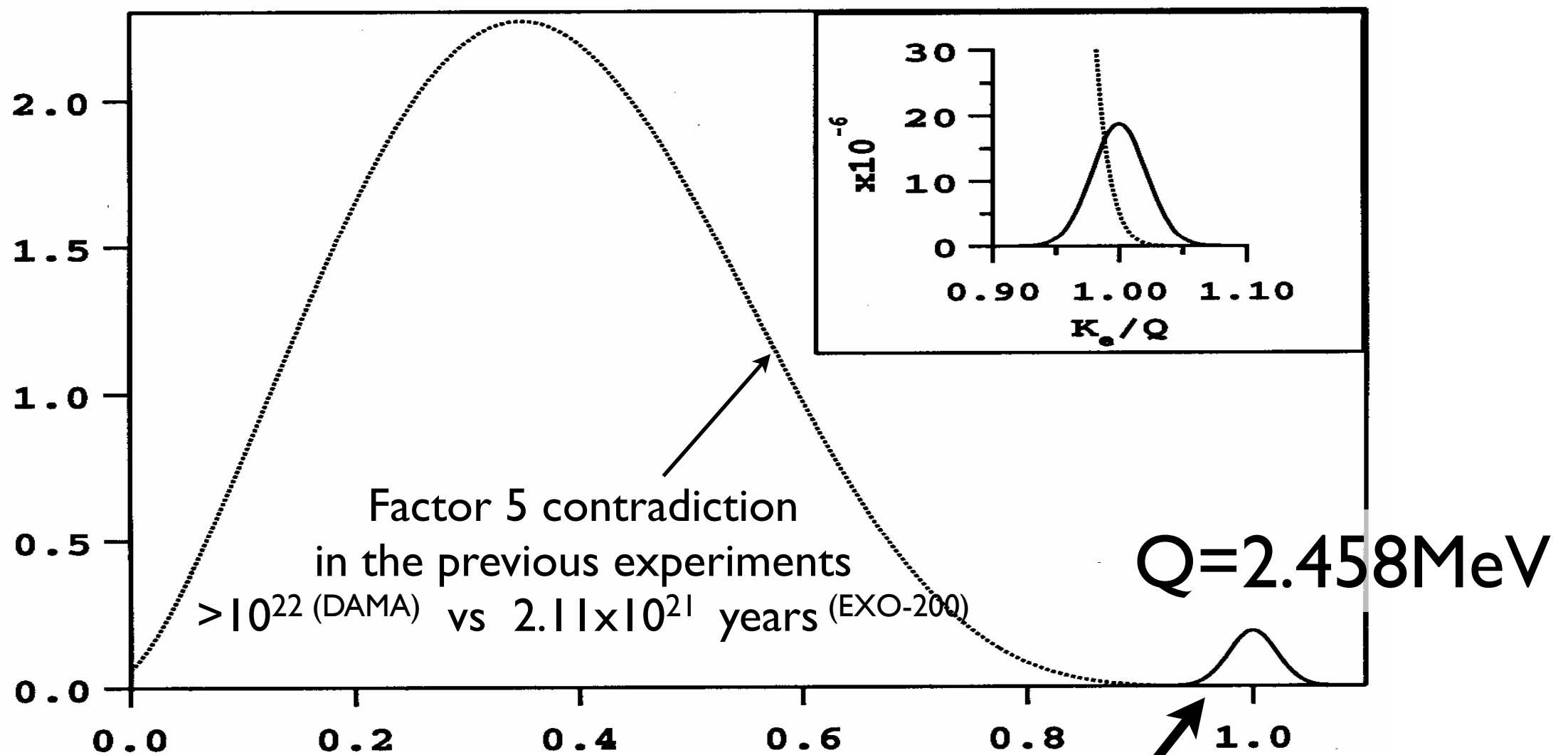
FV uncertainty $\rightarrow$ **5.2%** dominant error

Xe amount in the fiducial volume

$125 \pm 7 \text{ kg}$ of ^{136}Xe in the FV

Well, let's see the initial result.

note that

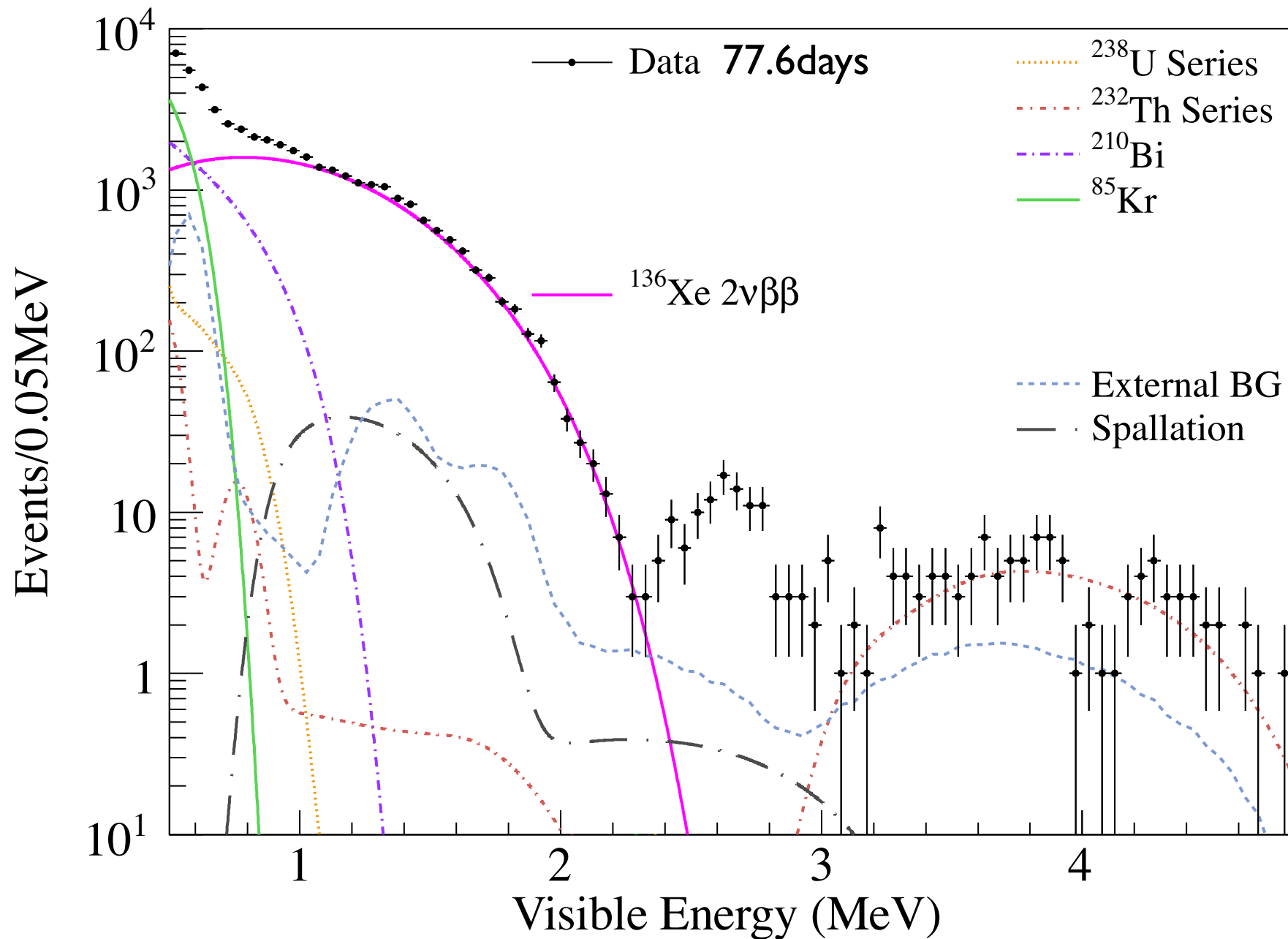


This peak, if found, is a big discovery.

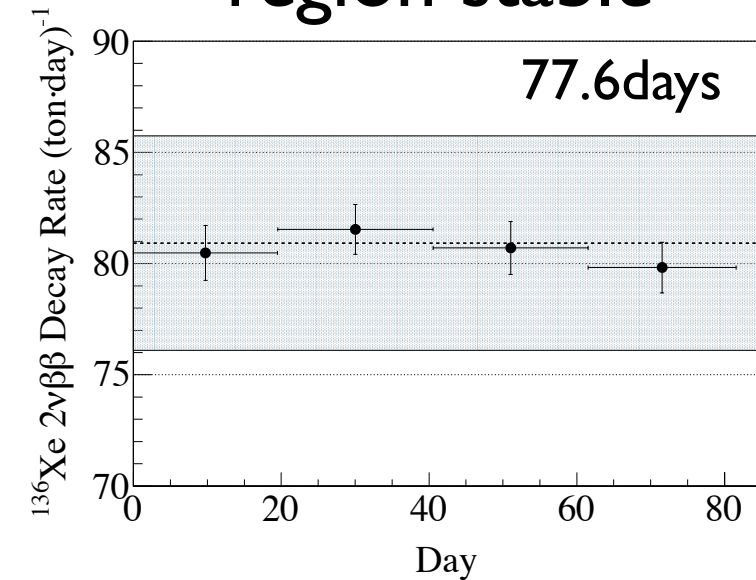
Data from the initial 3month

2011 10/12~2012 1/2 total livetime 77.6 days 27.4kg-yr exposure of ^{136}Xe

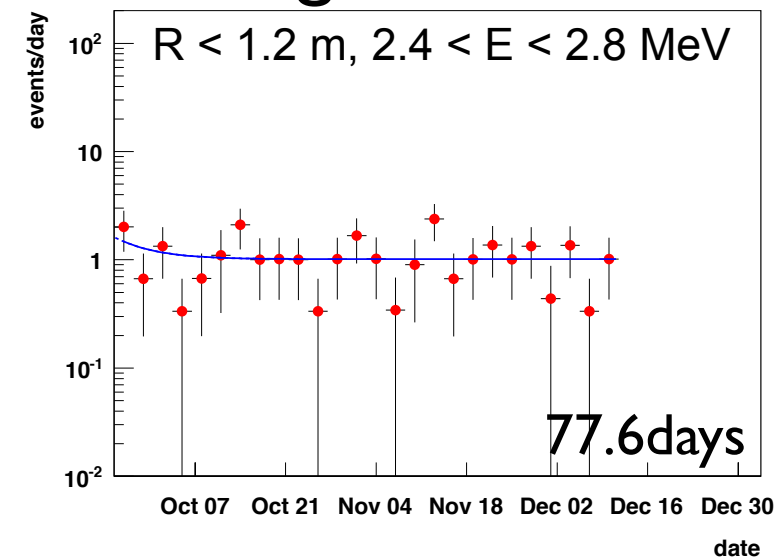
update 2011 10/12~2012 2/9 112.3 days 38.6kg-yr



rate at 2ν
region stable



rate at 0ν
region stable

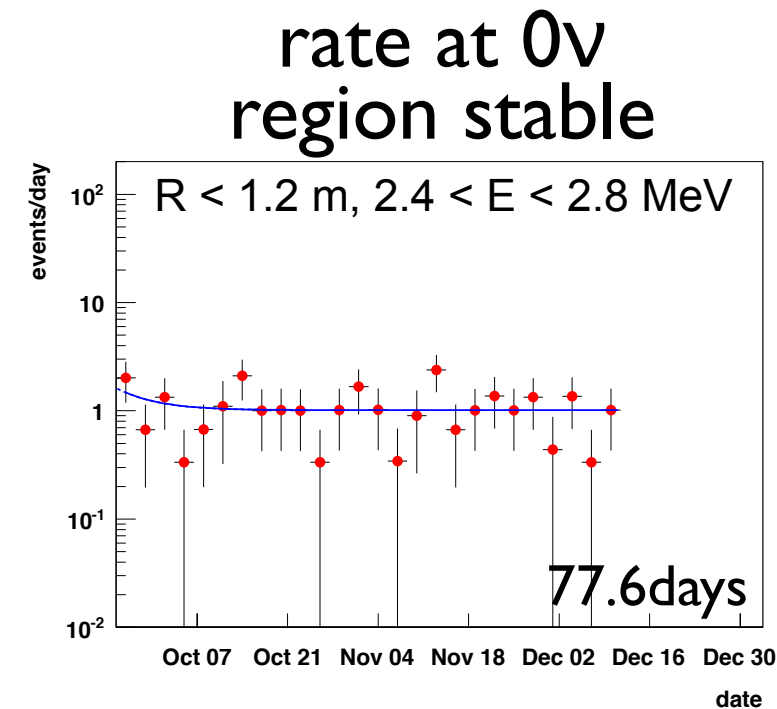
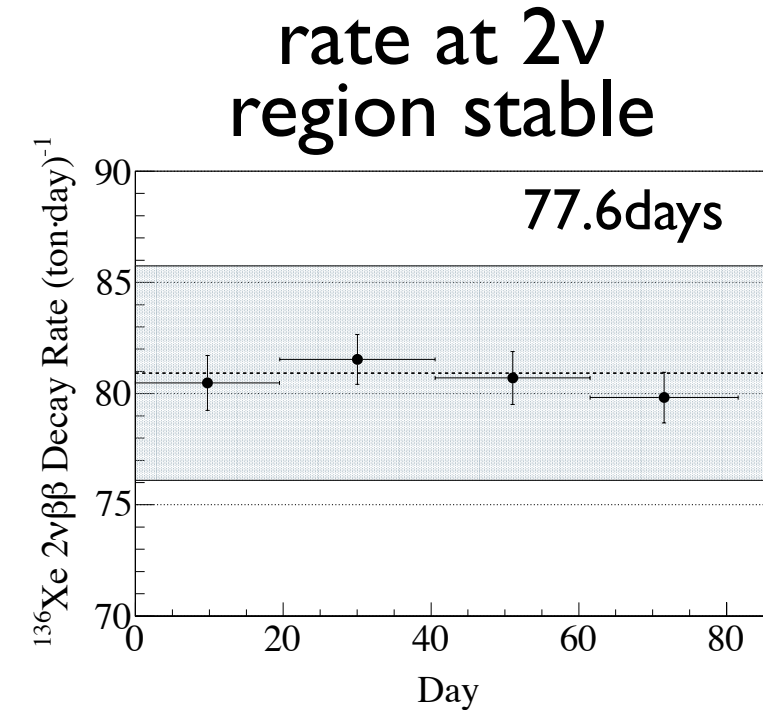
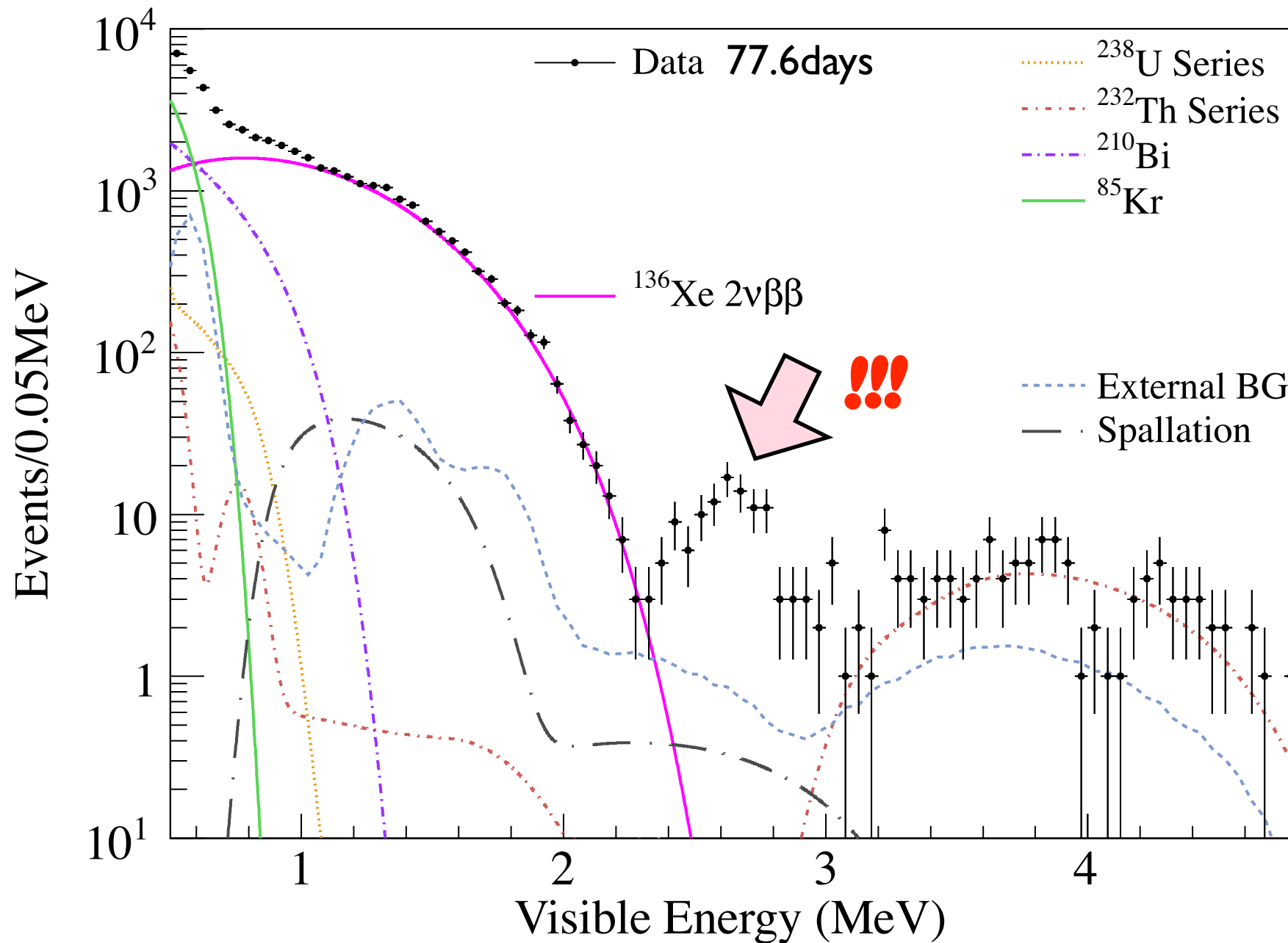


2ν measurement with the largest mass

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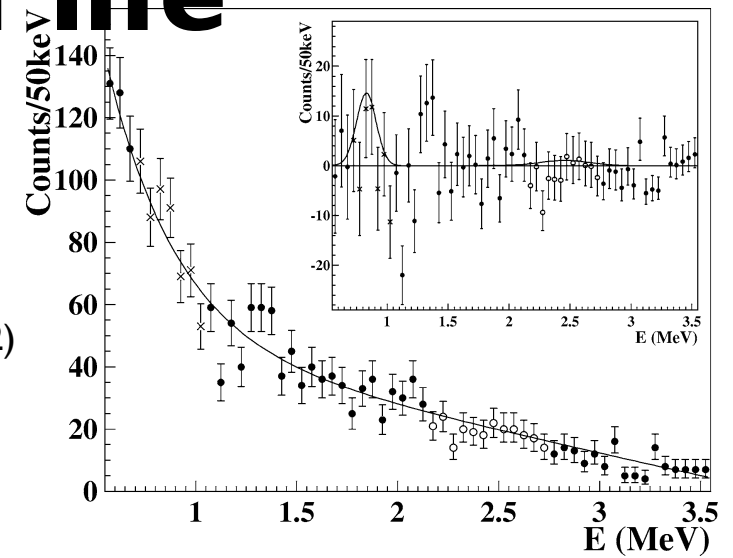
2v measurement with the largest mass
peak at $0\nu 2\beta$ ($Q=2.458\text{MeV}$) !!!?

Measurement of the $2\nu 2\beta$ half life

DAMA (2002)

Liquid Xe scintillator

$$T^{2\nu}_{1/2} > 1.0 \times 10^{22} \text{ years at 90\% CL} \quad \text{Phys.Lett.B546,23(2002)}$$



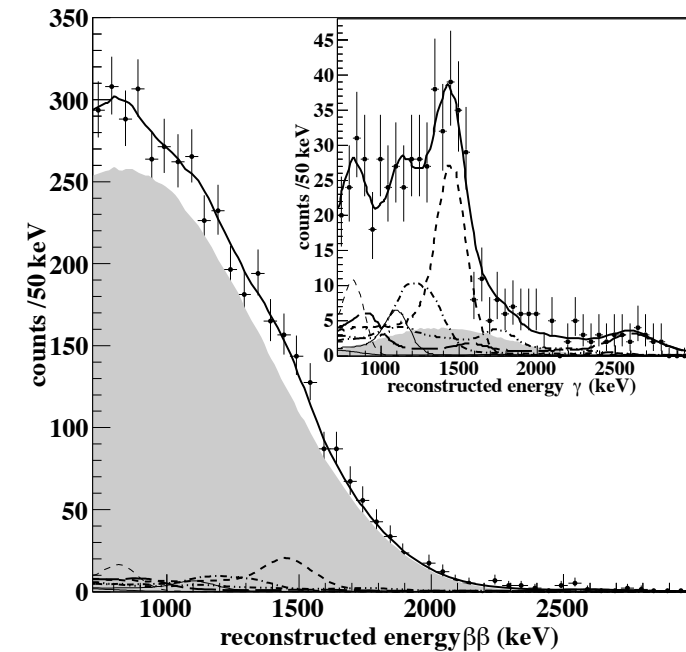
factor 5 contradiction

EXO-200 (2011)

Liquid Xe TPC + scintillator

$$T^{2\nu}_{1/2} = 2.11 \pm 0.04(\text{stat}) \pm 0.21(\text{syst}) \times 10^{21} \text{ years}$$

Phys.Rev.Lett.107,212501(2011)

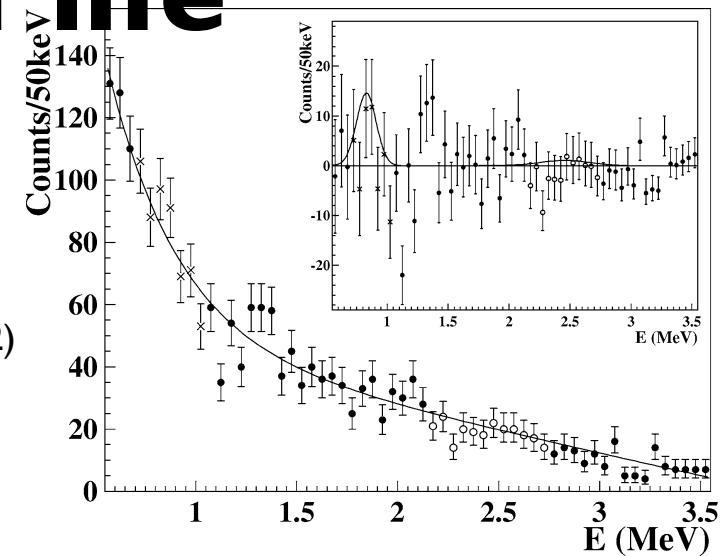


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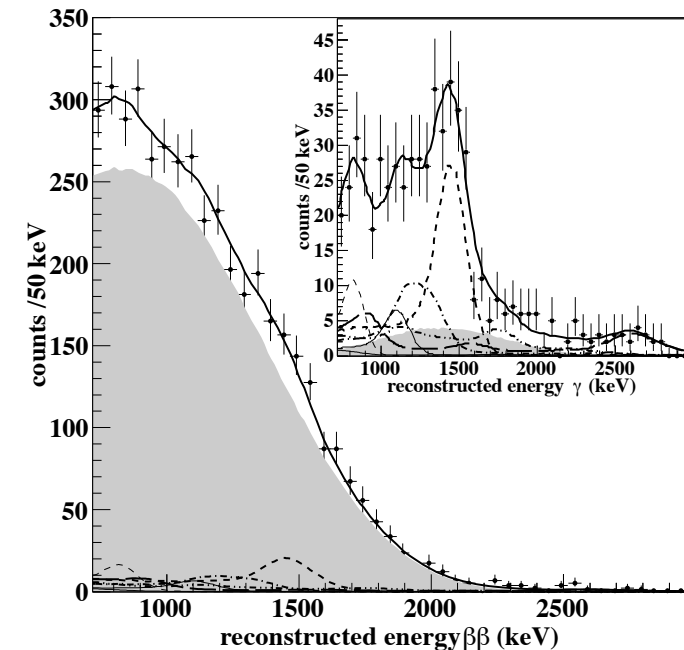
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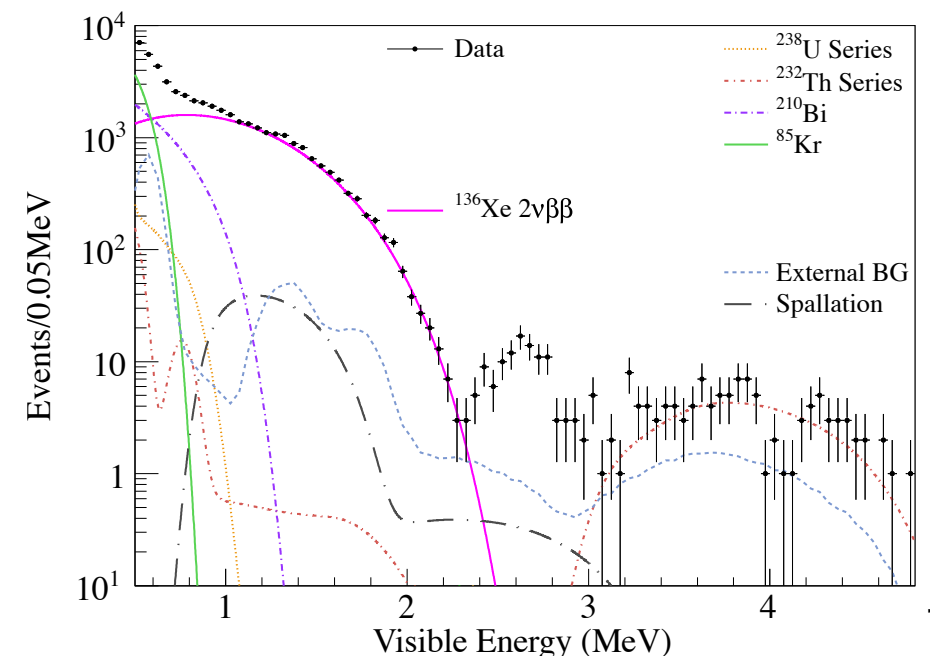


KamLAND-Zen (2012)

Xe loaded liquid scintillator

$$T^{2\nu}_{1/2} = 2.38 \pm 0.02(\text{stat}) \pm 0.14(\text{syst}) \times 10^{21} \text{ years}$$

Phys.Rev.C85,045504(2012)



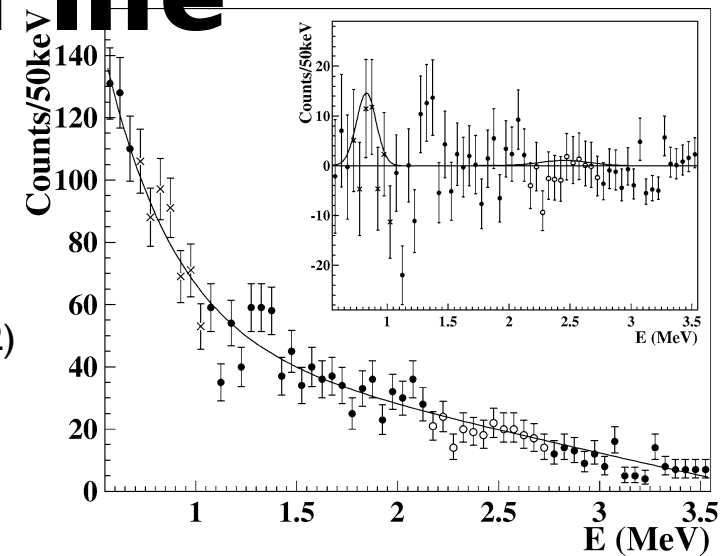
KamLAND-Zen agrees with EXO-200.

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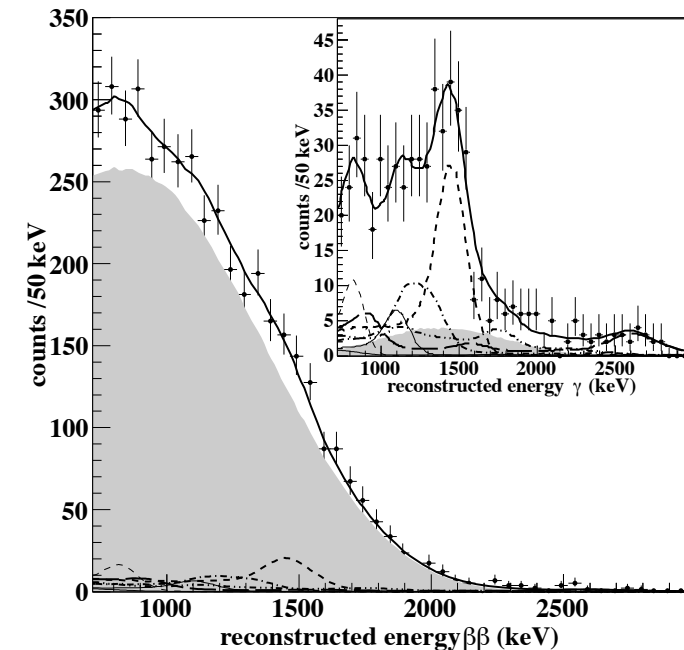
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update $T^{2\nu}_{1/2} = 2.23 \pm 0.017(\text{stat}) \pm 0.22(\text{syst}) \times 10^{21} \text{ years}$

arXiv:1205.5608

KamLAND-Zen (2012)

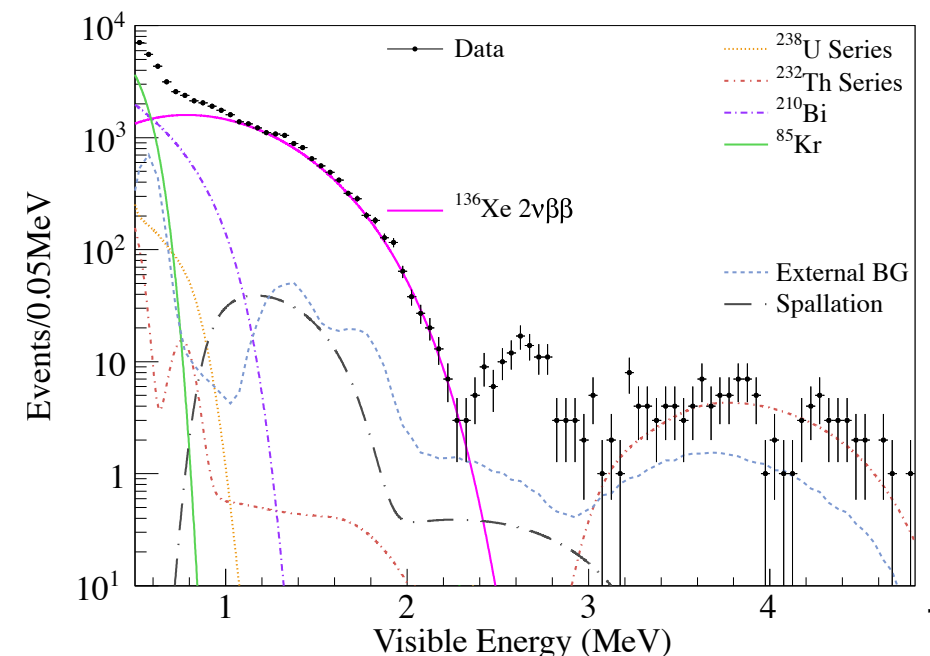
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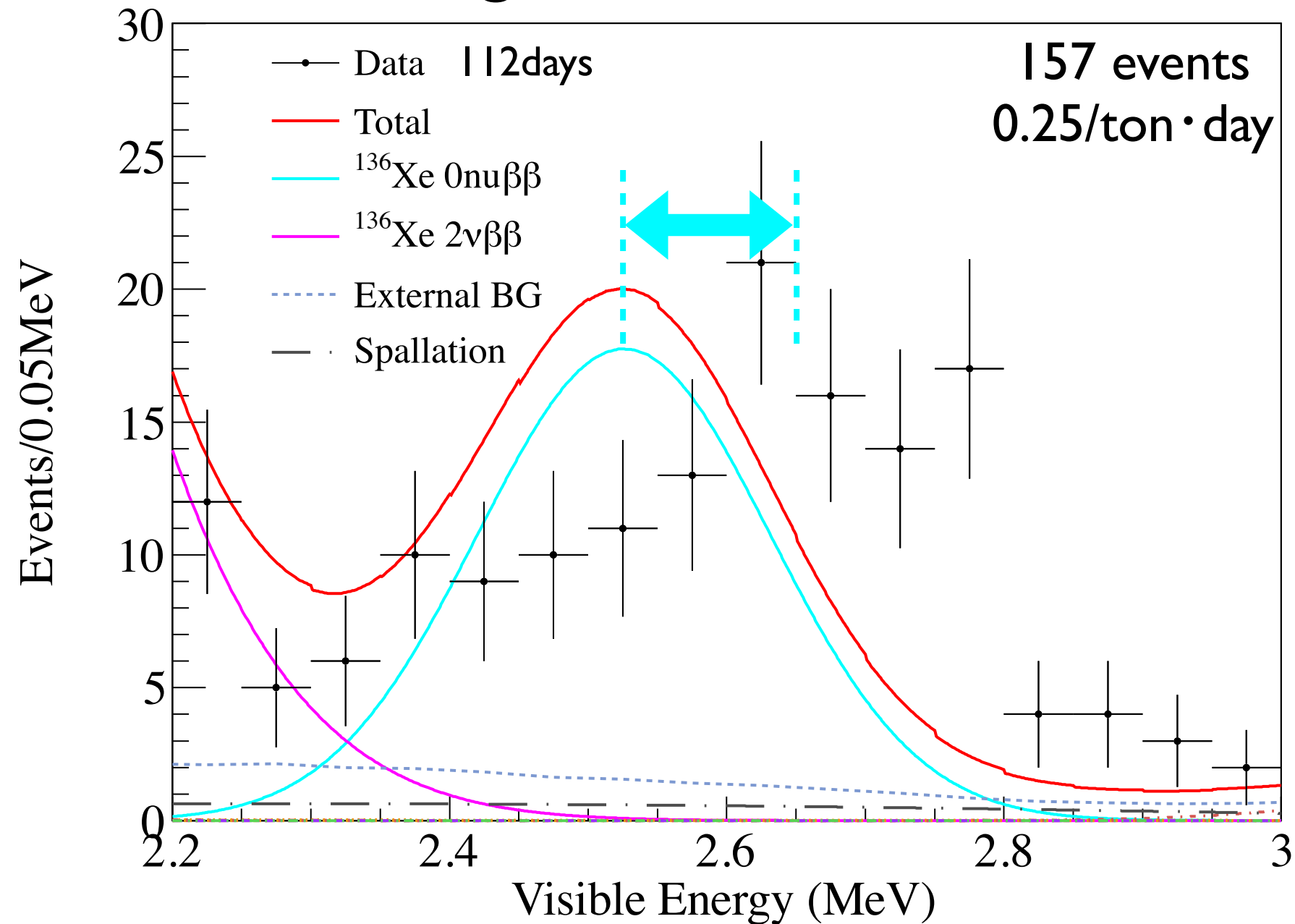
update $T^{2\nu}_{1/2} = 2.30 \pm 0.02(\text{stat}) \pm 0.12(\text{syst}) \times 10^{21} \text{ years}$

arXiv:1205.6372



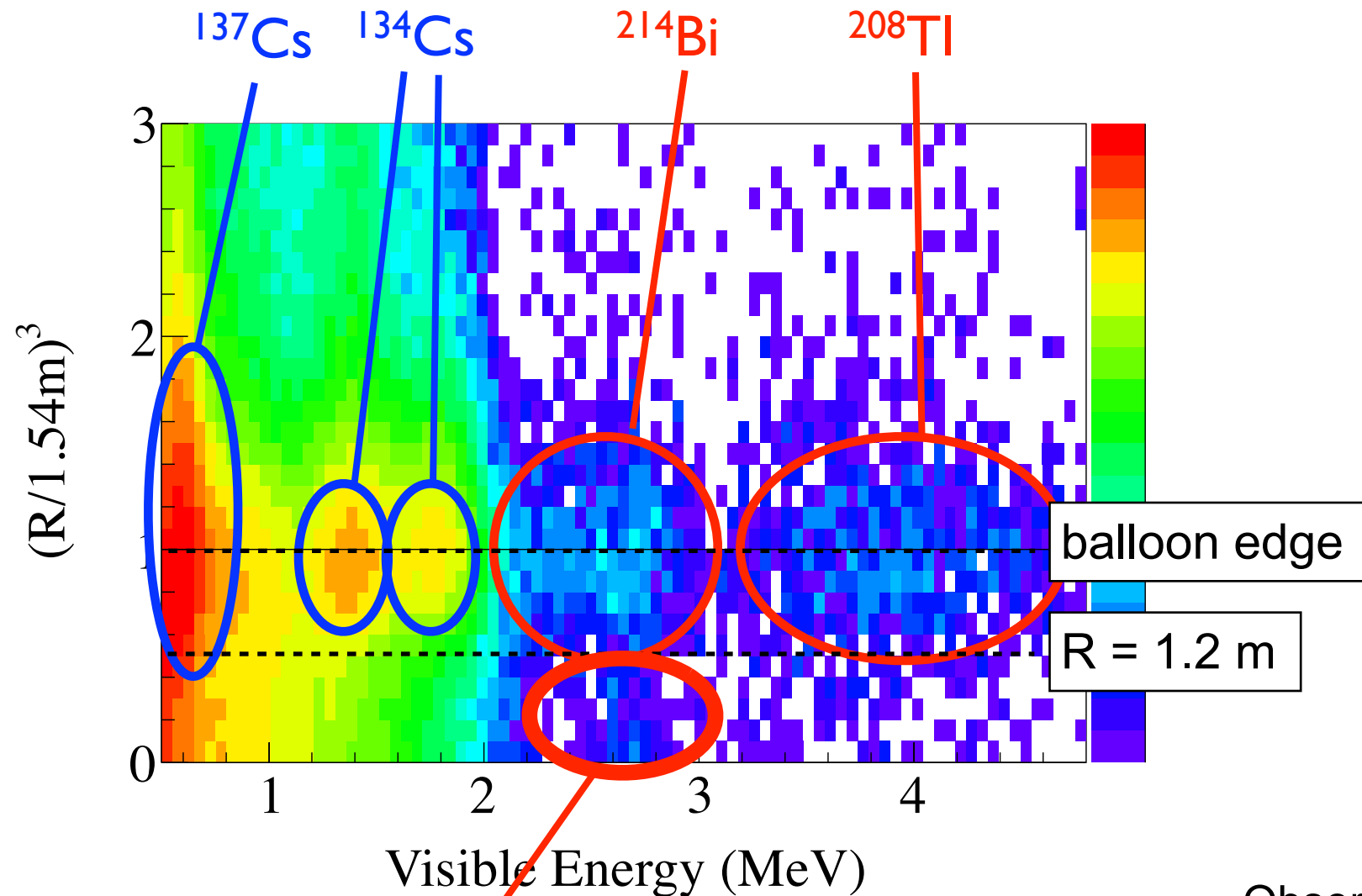
Background situation

Peak fit with 0v signal

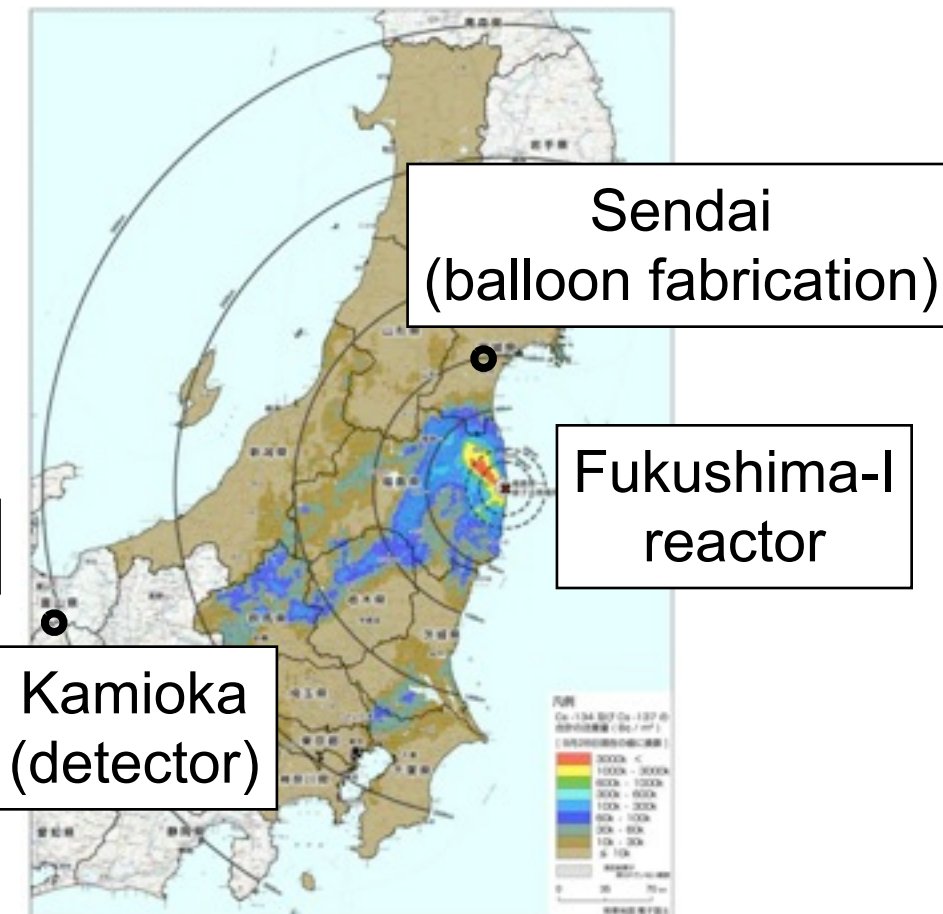


Peak position is different from that of expected 0v.
0v only is rejected at more than 8σ level.

Radioactive Impurities



$^{134}\text{Cs} + ^{137}\text{Cs}$ fallout



Observed ratio of $^{134}\text{Cs}/^{137}\text{Cs}$ (~ 0.8) is consistent with Fukushima-I reactor fallout

- Cesium is from Fukushima-I reactor fallout. It is not very serious for $0\nu 2\beta$ search. It doesn't leach out, fortunately.
- ^{214}Bi on the mini-balloon is limiting the fiducial volume.
- ^{208}Tl is not serious. It appears far above $0\nu 2\beta$ peak.

What is the peak around 2.6MeV?

Two possibilities:

- Radioactive impurities should be long-lived.
- Cosmogenic spallation nuclei at the underground should have time-correlation with muons.

thousands of millions of
All nuclei and decay path in the **ENSDF** have been surveyed.
<http://ie.lbl.gov/databases/ensdfserve.html>

Study on time-correlation limits nuclei w/ <100 sec lifetime
should be <0.007 /ton·day (90% CL). → small

Nuclei w/ 100sec~30days are rejected from the study of
energy spectrum w/ close A,Z nuclei. → negligible

Nuclear reactions (α , γ), (α , $\alpha\gamma$), (n, γ) have small cross sections
→ negligible

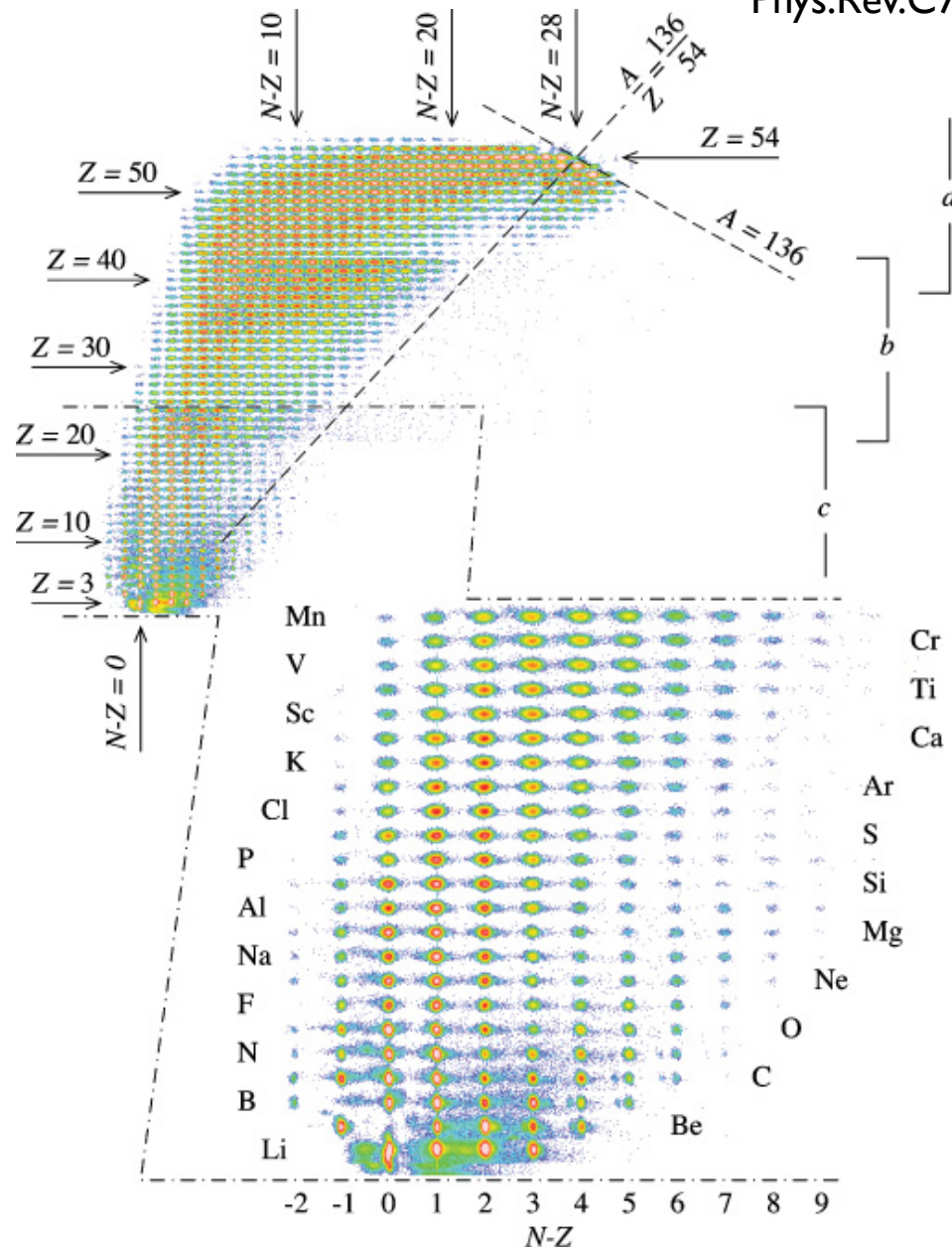
Only 4 nuclei w/ more than 30 days and peak around 0V remained.

$^{110\text{m}}\text{Ag}$ ($T_{1/2}=250\text{d}$), ^{208}Bi ($3.68\times 10^5\text{y}$), ^{88}Y (107d), ^{60}Co (5.27y)

BG from spallation

Spallation products from ^{136}Xe measured with 1 GeV proton equivalent beam

Phys.Rev.C76,064609(2007)



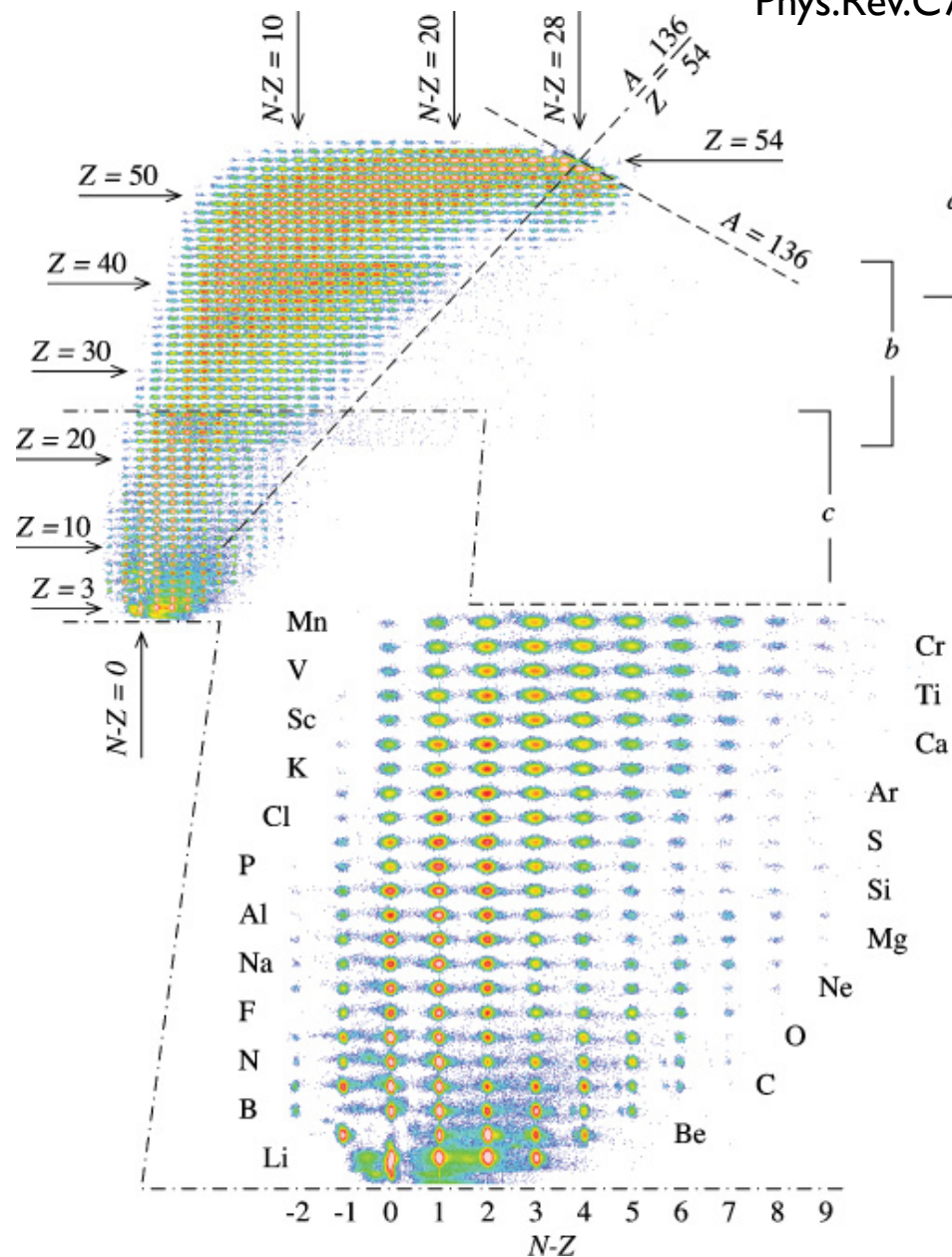
GEANT4 reproduces the production rate satisfactory well for an order estimation.

Spallation in the underground is very small.
(GEANT4)

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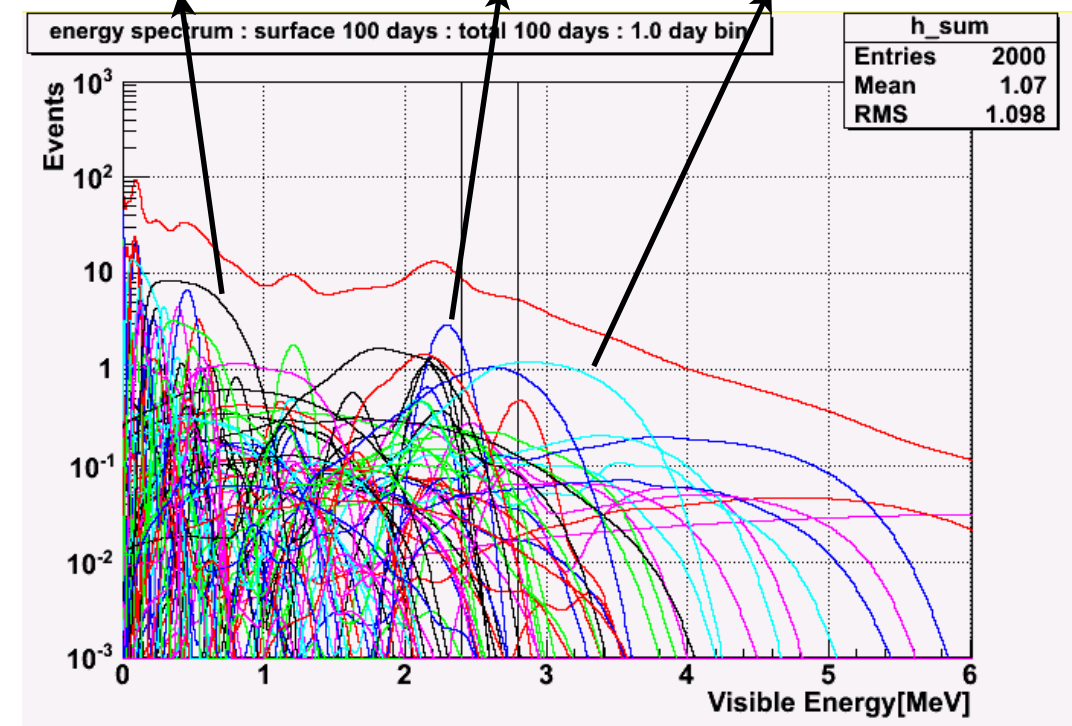


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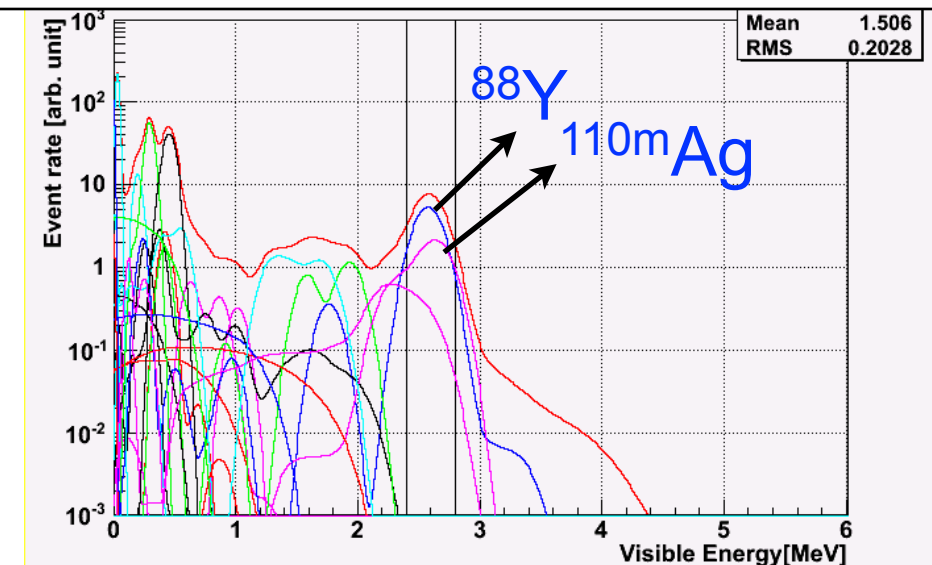
Spallation in the underground is very small.
(GEANT4)

100 days on the surface, 0 day in the mine

$\beta^-: ^{135}\text{Xe}$ 54.7mb, $T_{1/2}=9.14\text{h}$ $\beta+\text{EC}: ^{118\text{m}}\text{Sb}$ 13.3mb, $T_{1/2}=5.0\text{h}$ $\beta^-: ^{134}\text{I}$ 21.9mb, $T_{1/2}=52.5\text{m}$



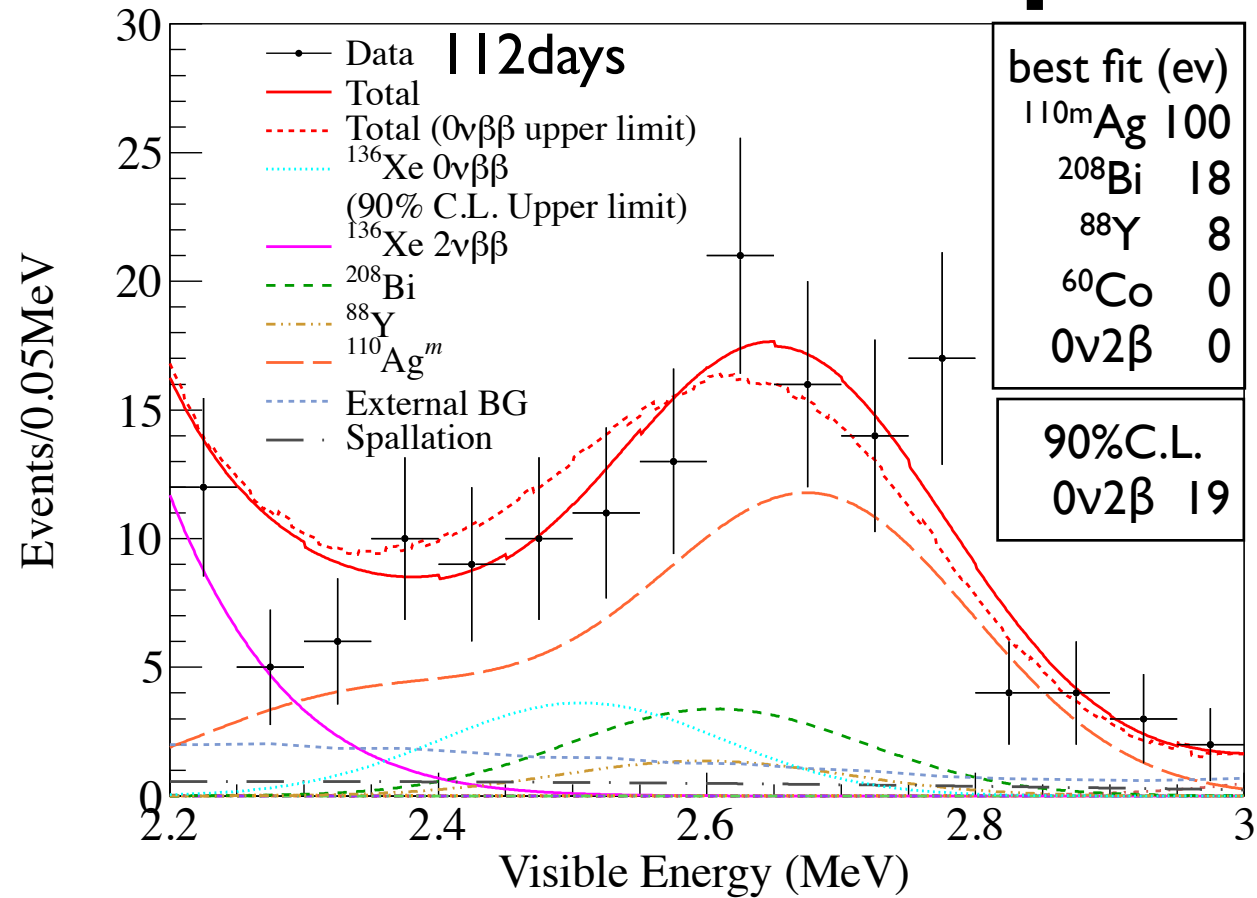
100 days on surface, 300 days in the mine



Estimated ^{110}Ag production rate (aboveground) is
 $\sim 30/\text{day}/400\text{kg-}^{136}\text{Xe}$

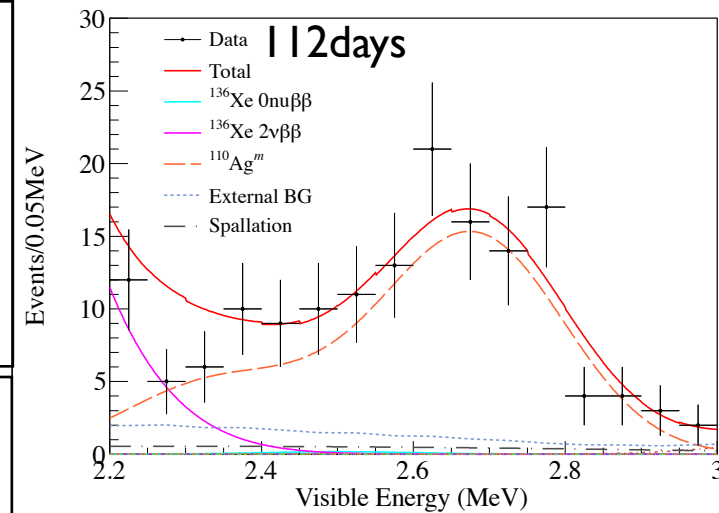
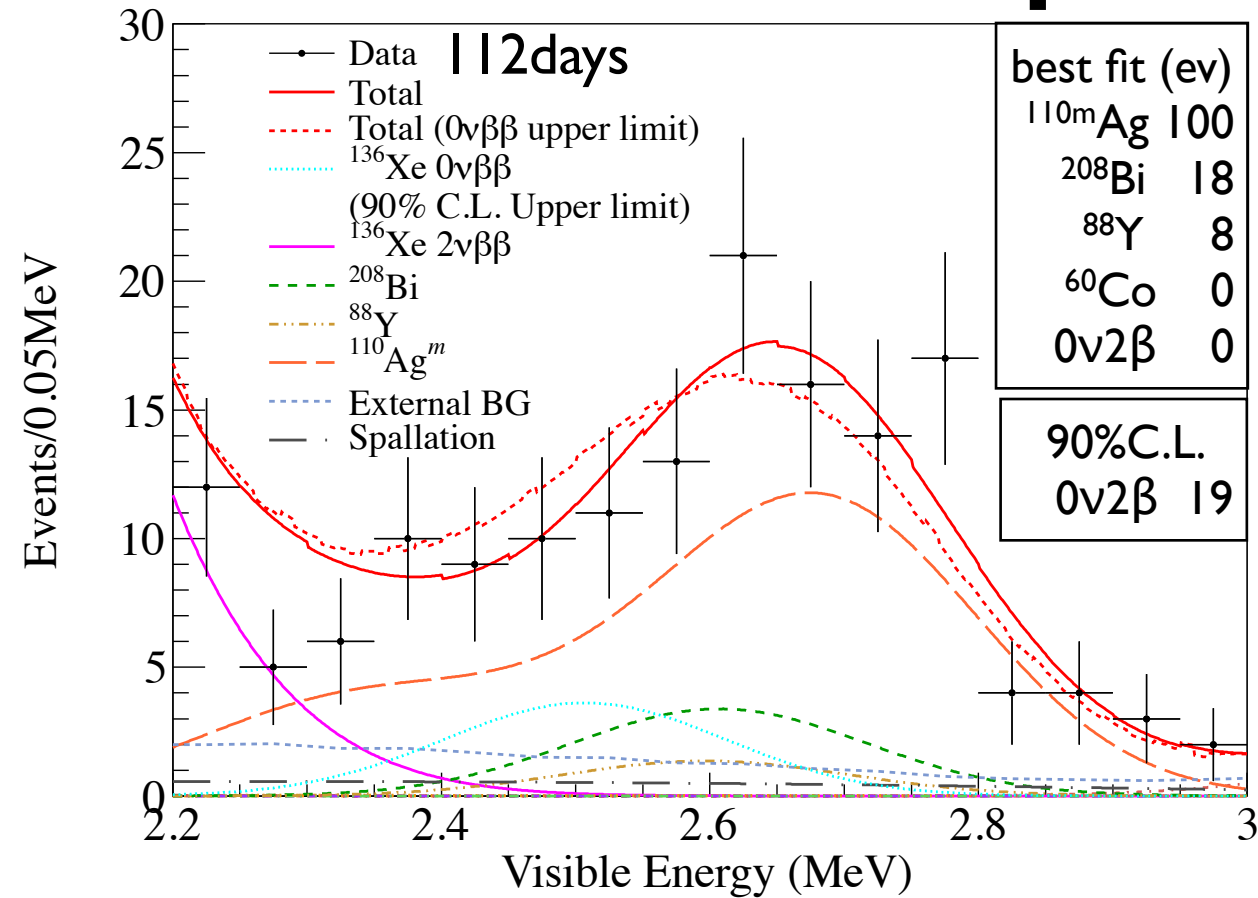
Measured BG rate (underground) is
 $\sim 3/\text{day}/300\text{kg-}^{136}\text{Xe}$

Limit on the $0\nu2\beta$ half life

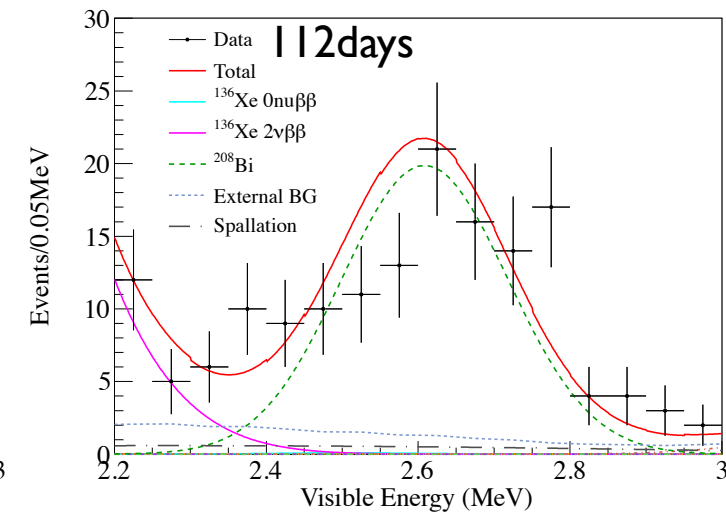


simultaneous fit and 90% CL upper limit for $0\nu2\beta$

Limit on the $0\nu2\beta$ half life



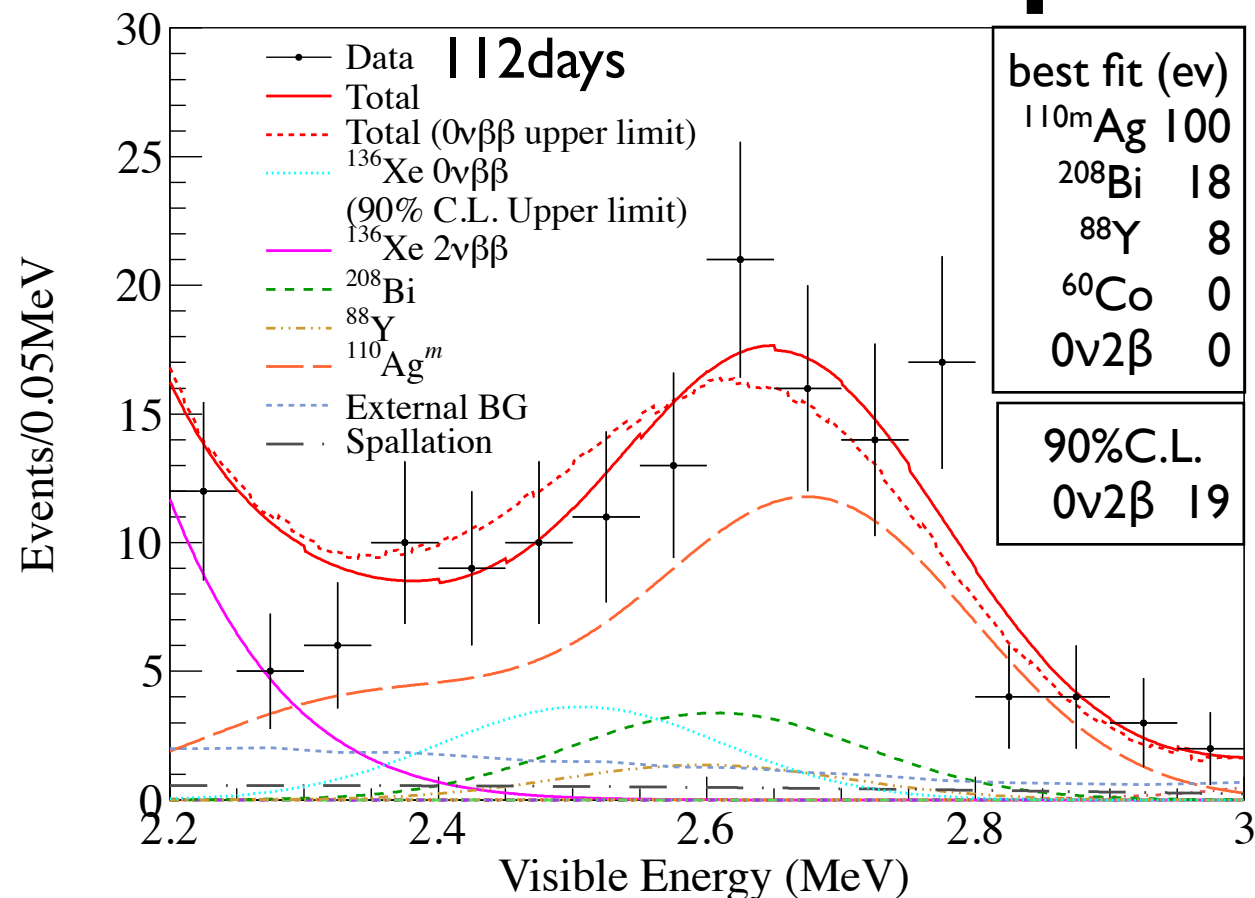
^{110m}Ag provides good fitting



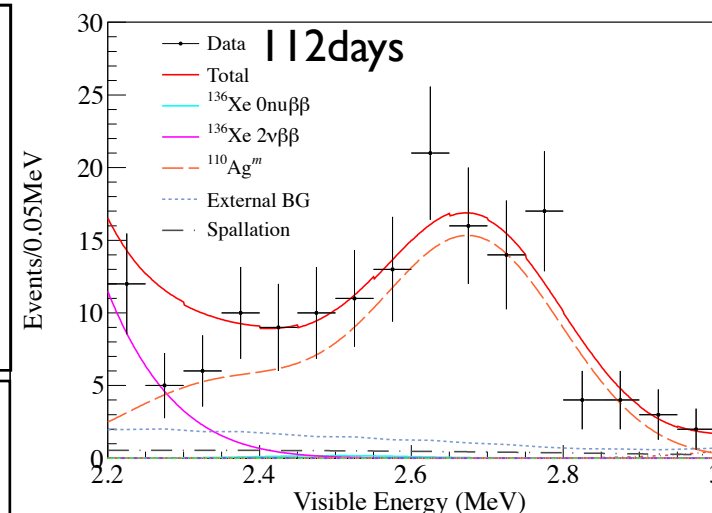
disfavors ^{208}Bi

simultaneous fit and 90% CL upper limit for $0\nu2\beta$

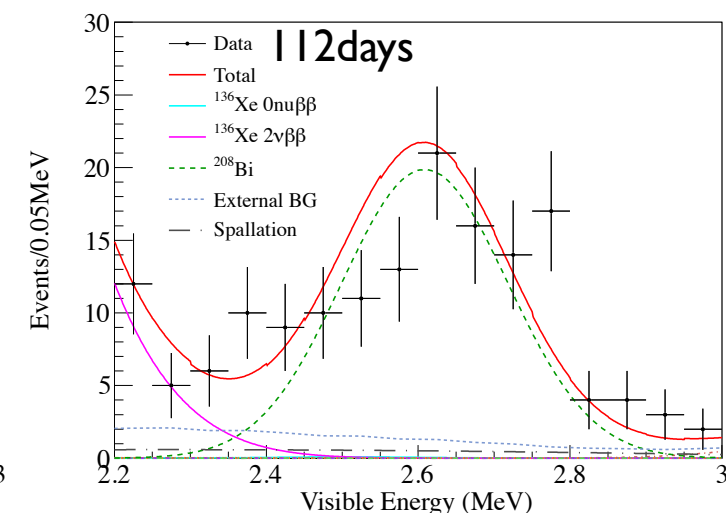
Limit on the $0\nu2\beta$ half life



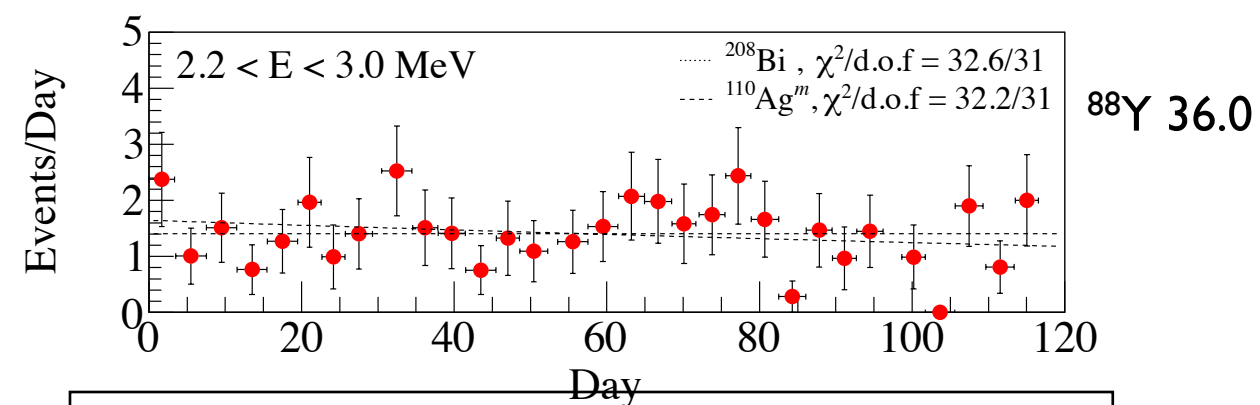
simultaneous fit and 90% CL upper limit for $0\nu2\beta$



^{110}mAg provides good fitting

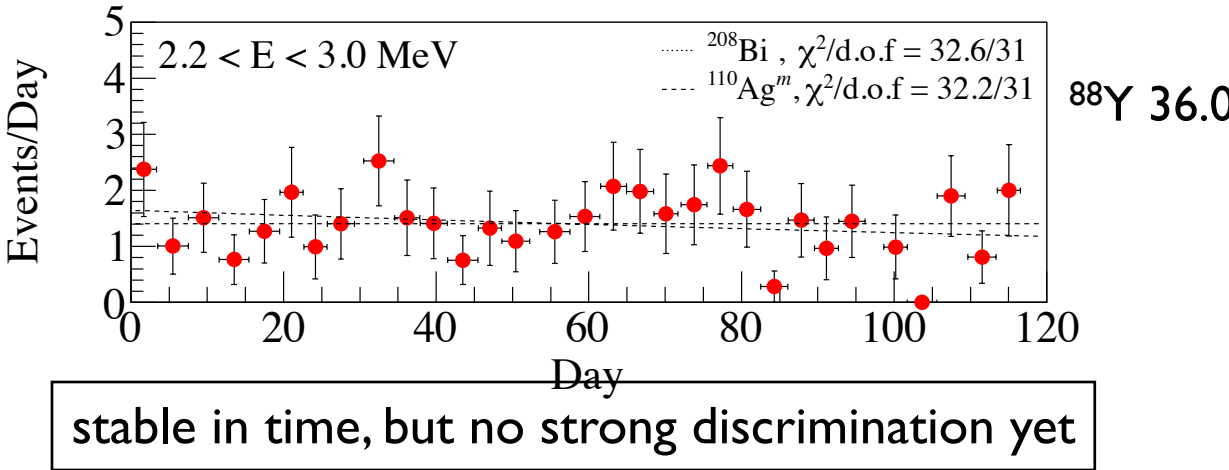
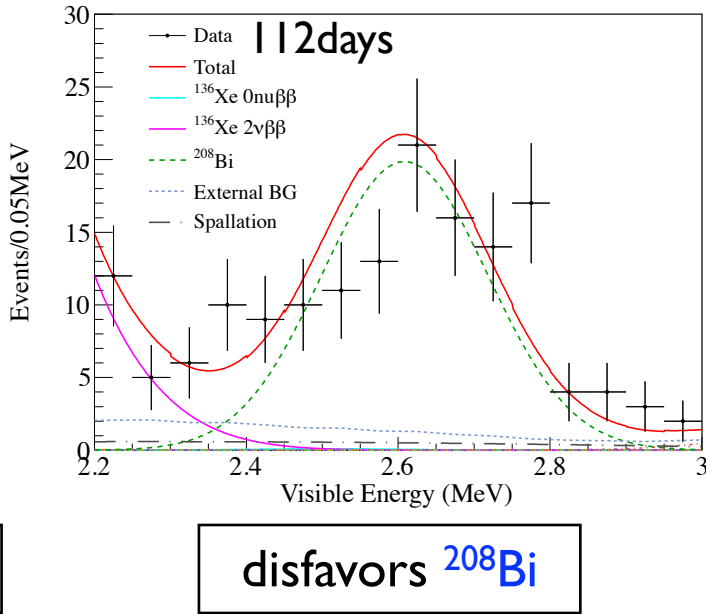
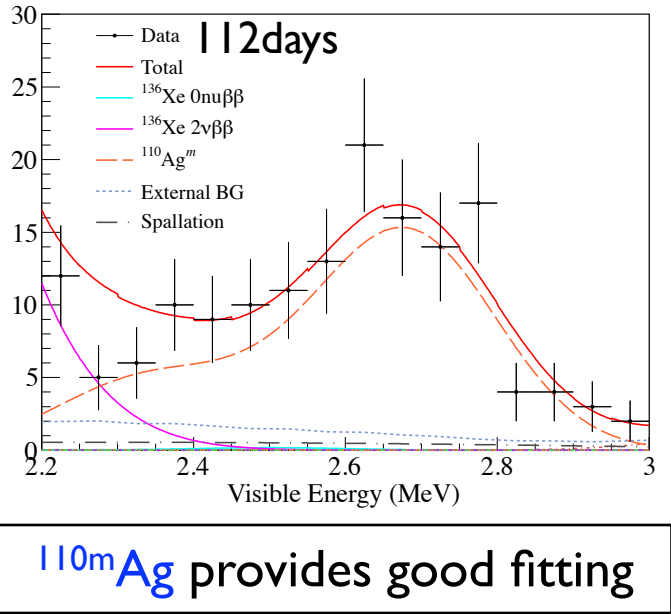
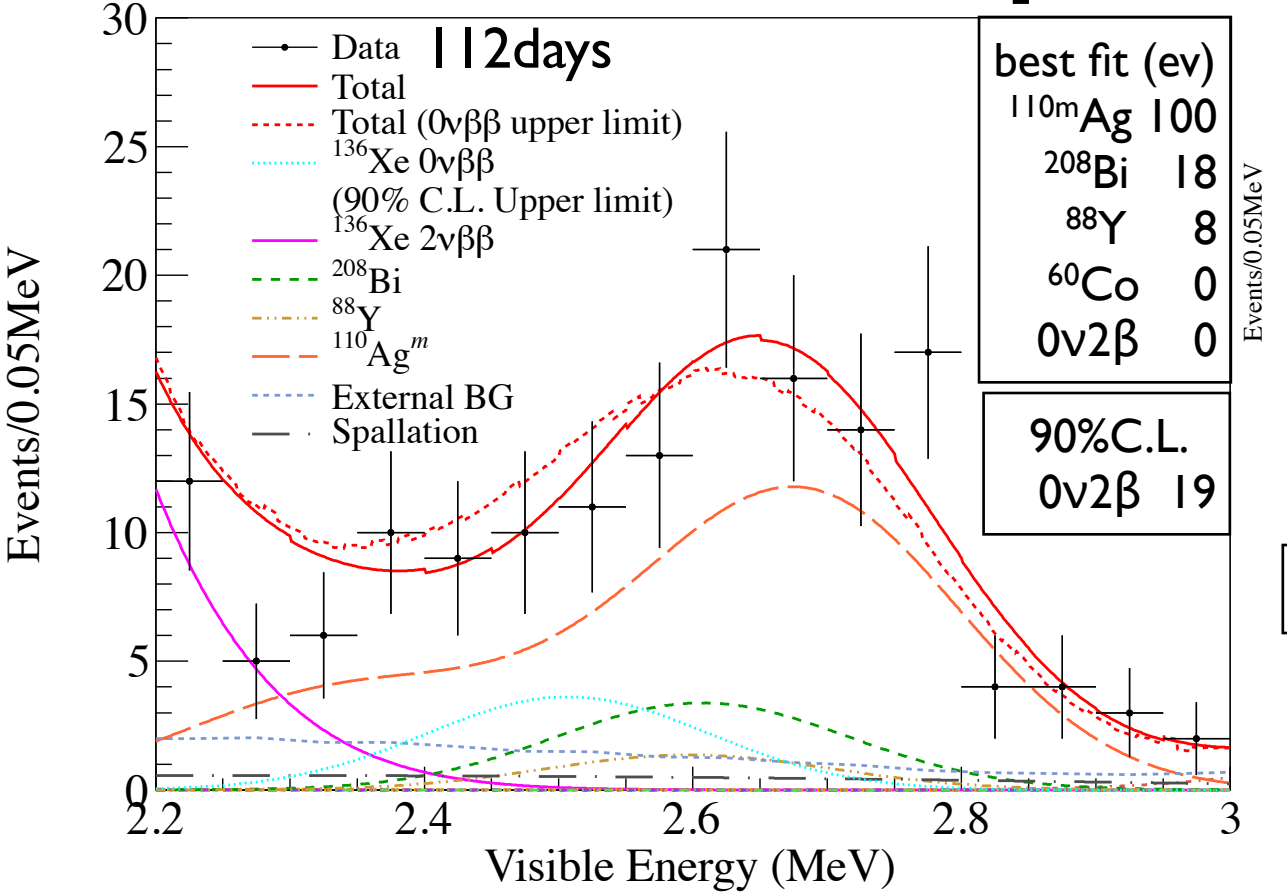


disfavors ^{208}Bi



stable in time, but no strong discrimination yet

Limit on the $0\nu2\beta$ half life



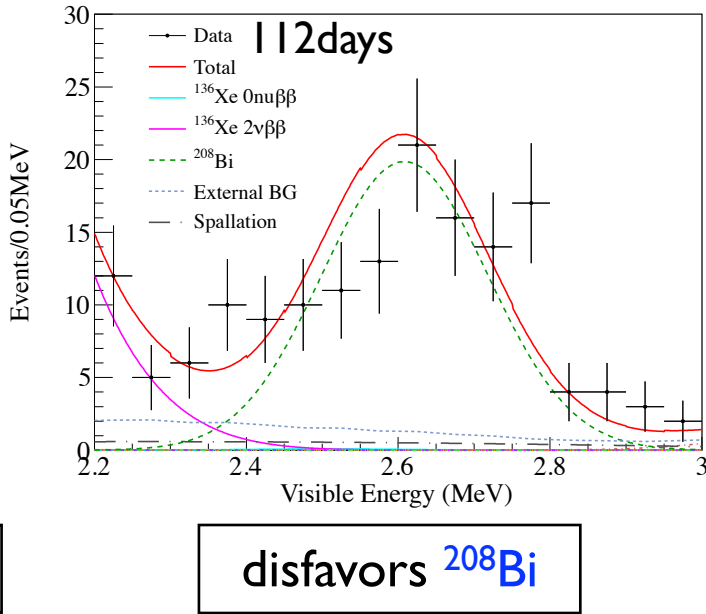
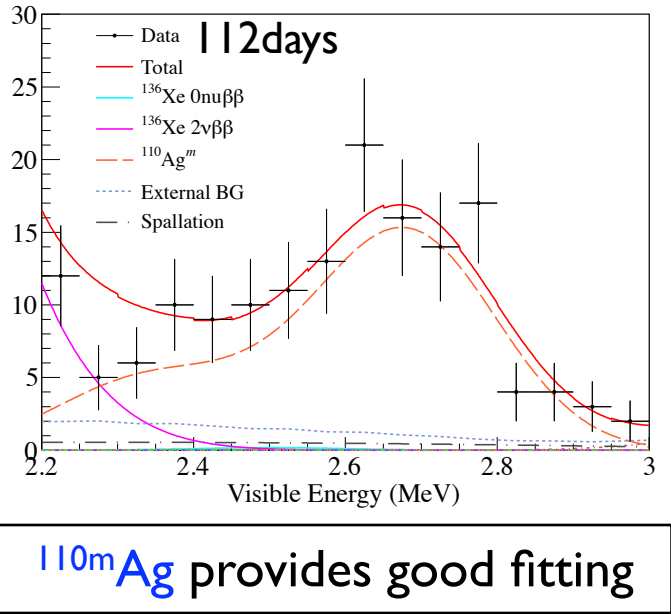
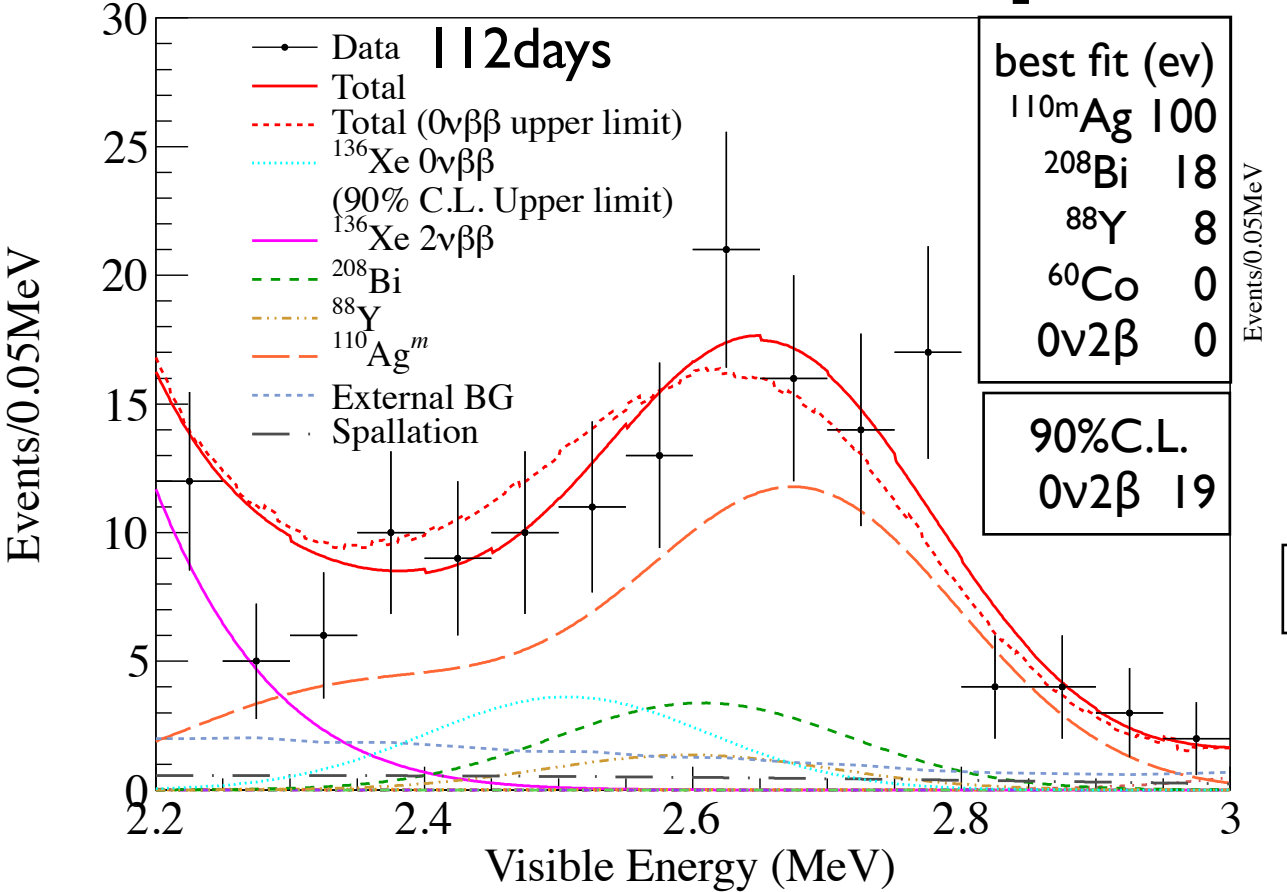
simultaneous fit and 90% CL upper limit for $0\nu2\beta$

(χ^2 at 2.2~3.0MeV)

	χ^2 78days	χ^2 112days
simul. fit	12.4	11.6
$0\nu+^{110m}\text{Ag}$	16.5	13.1
$0\nu+^{208}\text{Bi}$	15.8	22.7 $\triangle$
$0\nu+^{88}\text{Y}$	16.7	22.2 $\triangle$
$0\nu+^{60}\text{Co}$	65.0	82.9 $\times$
0ν only	64.5	85.0 $\times$

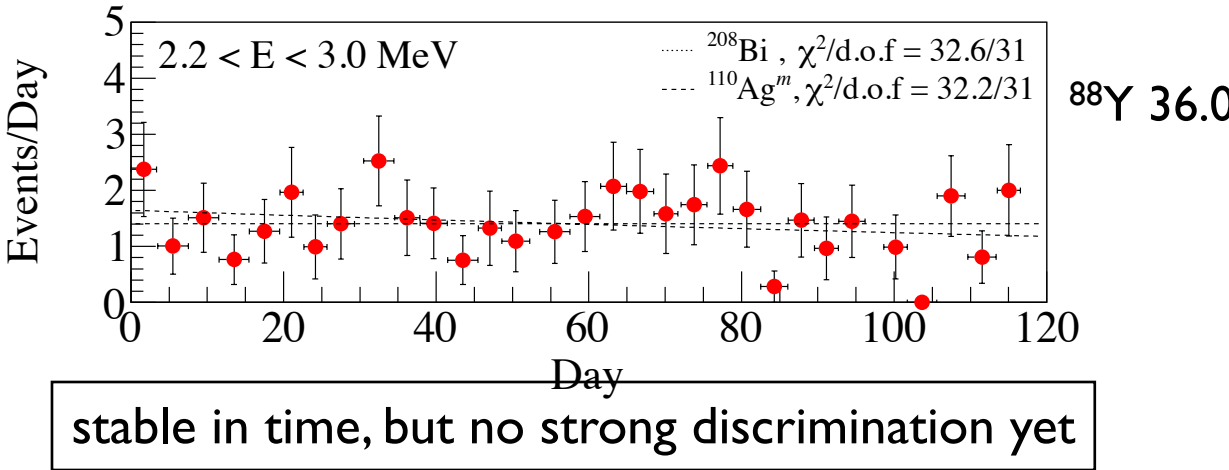
BG is likely to be ^{110m}Ag

Limit on the $0\nu2\beta$ half life



simultaneous fit and 90% CL upper limit for $0\nu2\beta$

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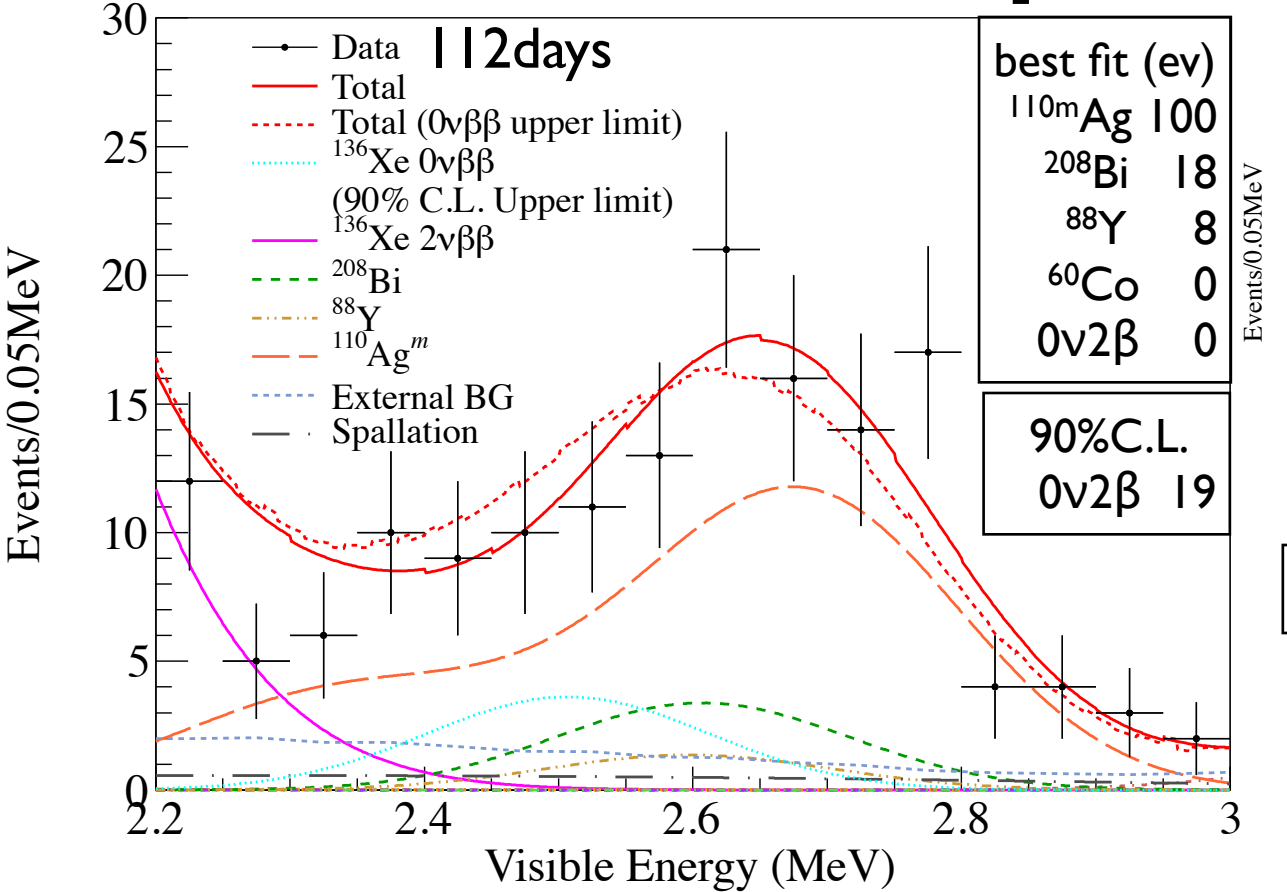


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BG is likely to be ^{110m}Ag

$T^{0\nu}_{1/2} > 5.7 \times 10^{24}$ years at 90% C.L. (78days)
 factor 5 improvement from DAMA
 $T^{0\nu}_{1/2} > 6.2 \times 10^{24}$ years (KL-Zen 112days)
 (ref. current best is 16×10^{24} years from EXO-200)

Limit on the $0\nu2\beta$ half life

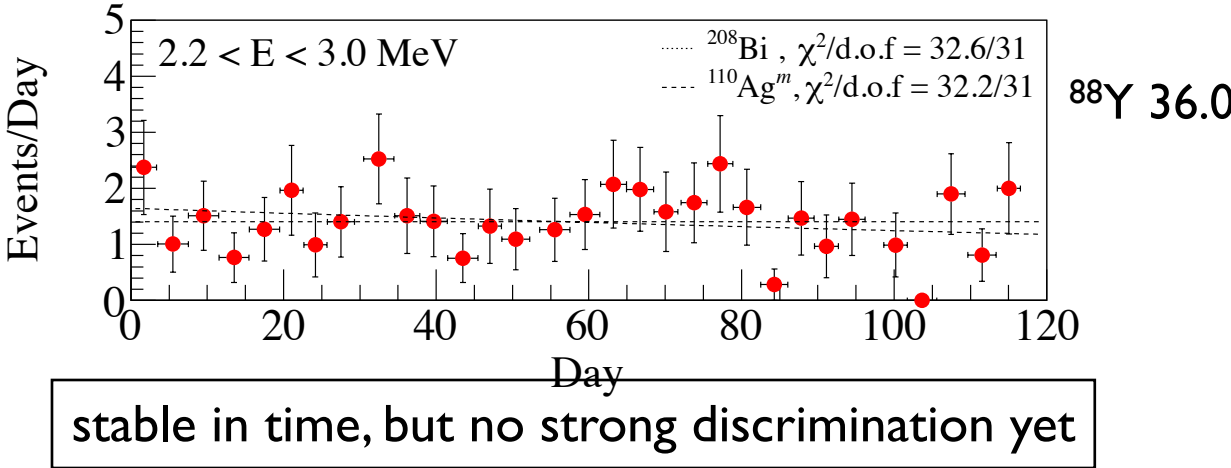
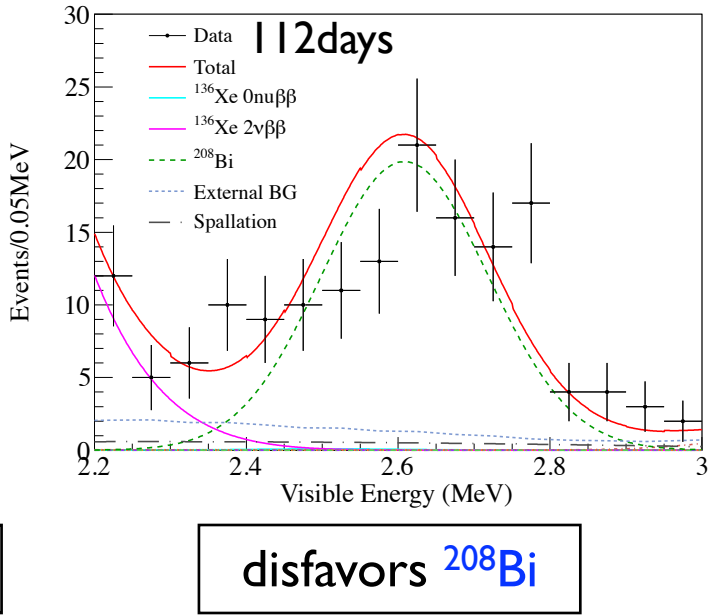
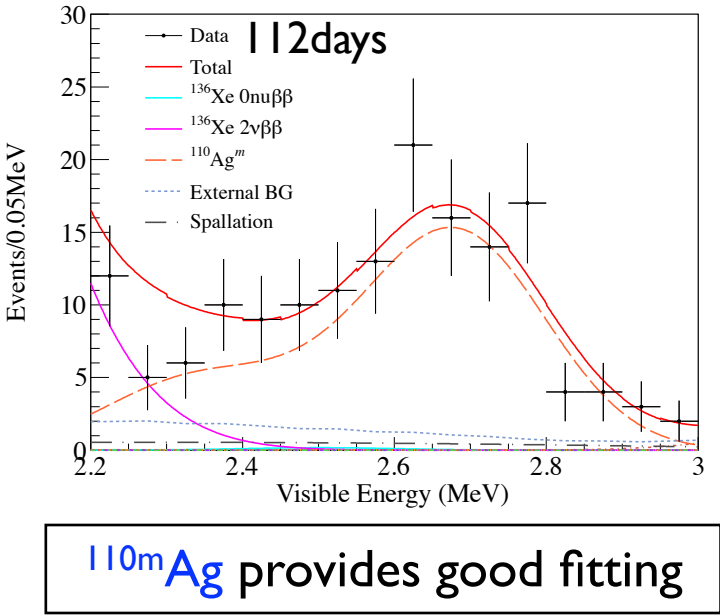


simultaneous fit and 90% CL upper limit for $0\nu2\beta$

(χ^2 at 2.2~3.0MeV)

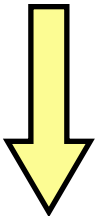
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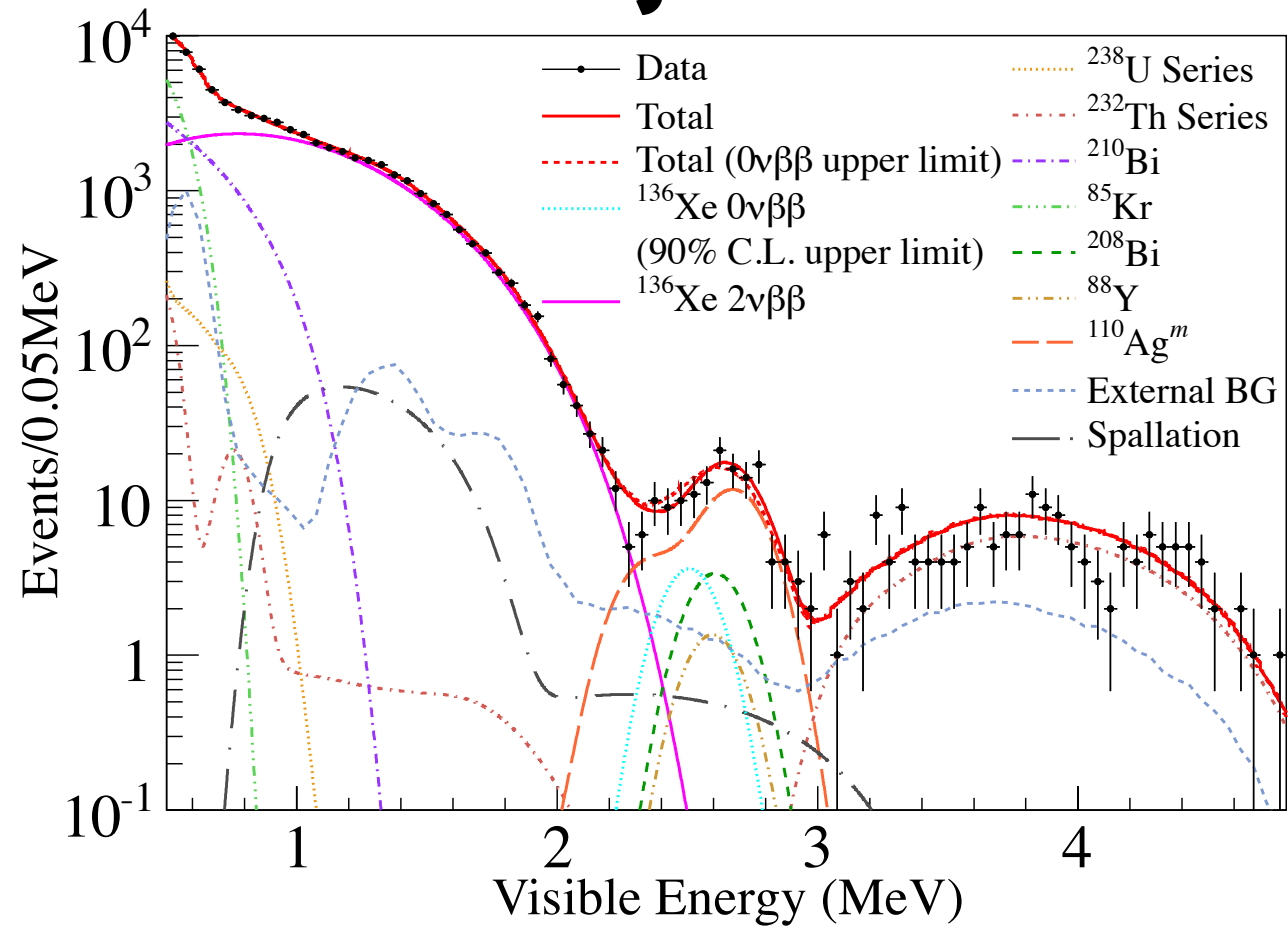
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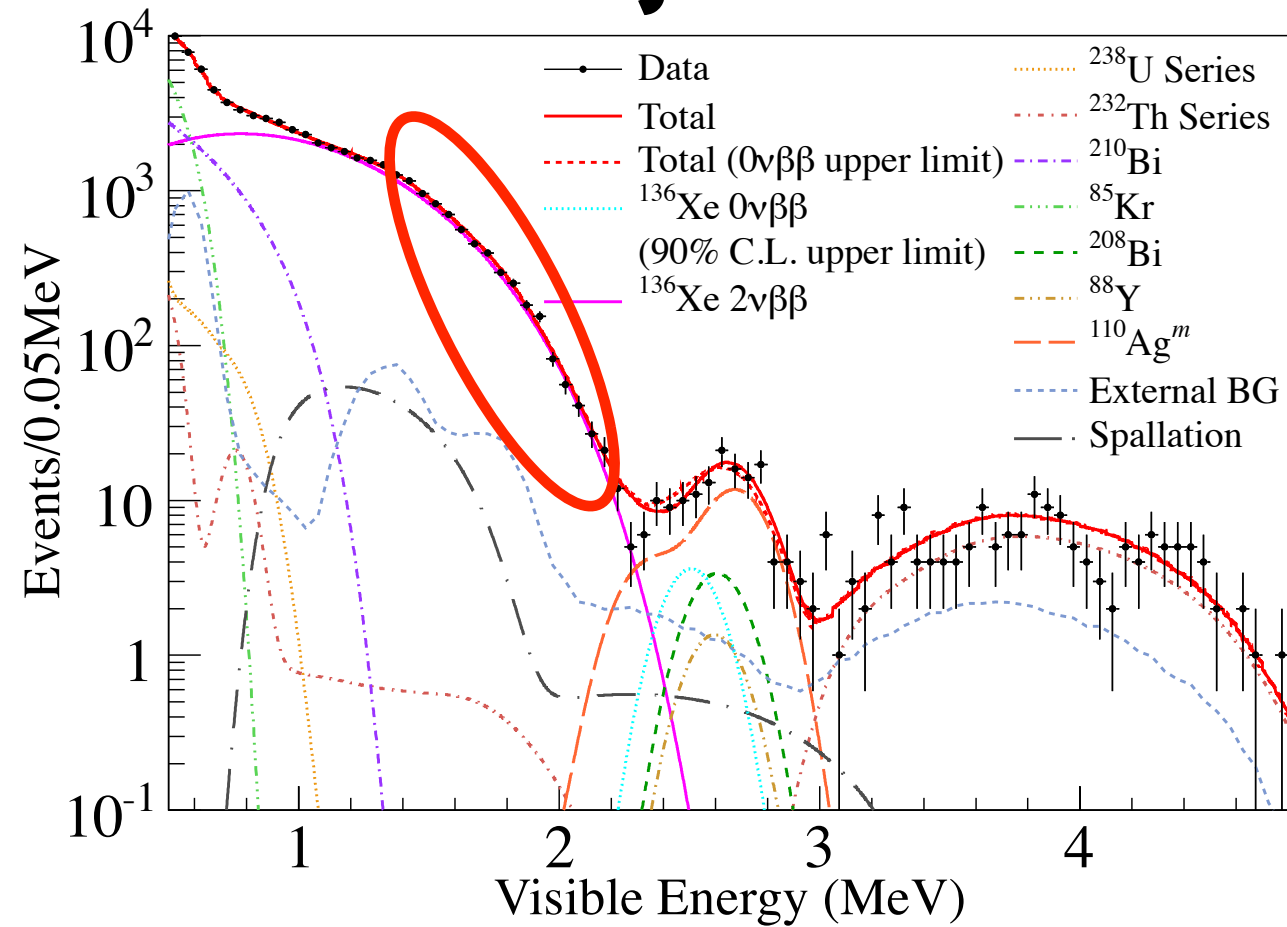
(R)QRPA (CCM SRC)
Phys.Rev.C79,055501 (2009)

$\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54$ eV @90% C.L.₁₈

Limits on Majoron emitting double-beta decays

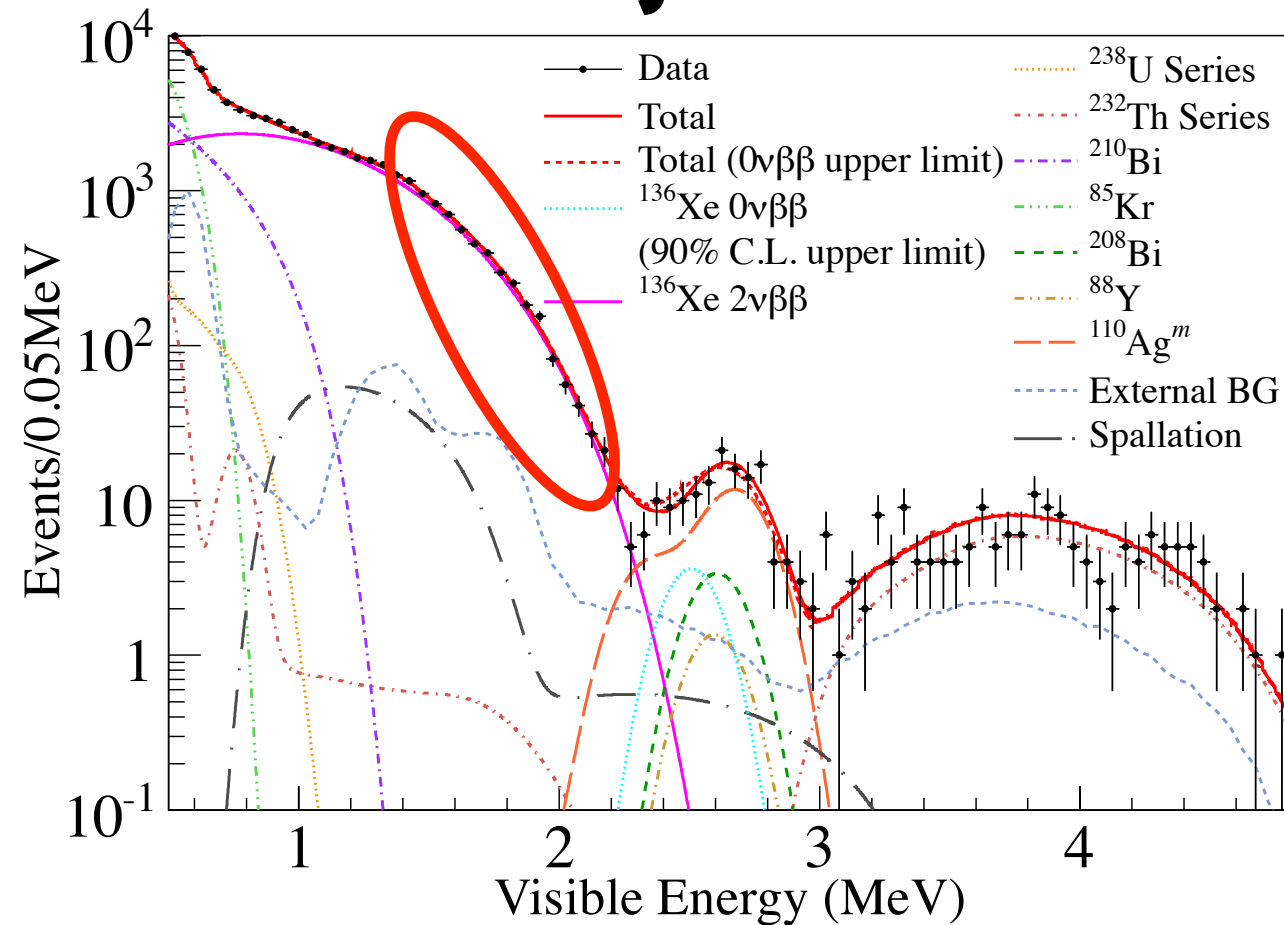


Limits on Majoron emitting double-beta decays

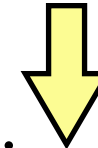


Good S/N ratio in the $2\nu 2\beta$ region and high statistics even with slow ^{136}Xe decay

Limits on Majoron emitting double-beta decays



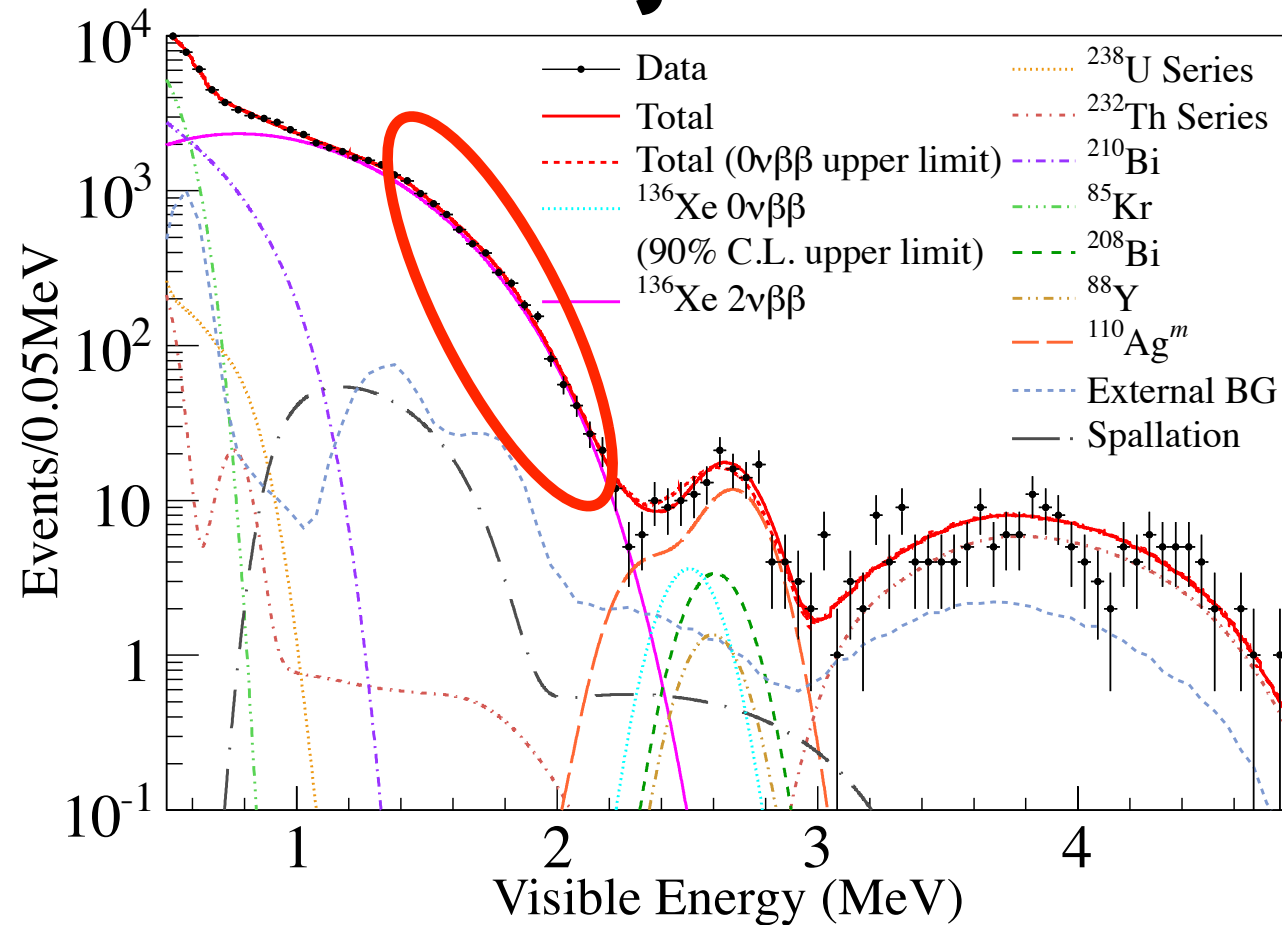
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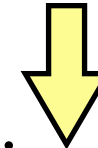
Good sensitivity on Majoron modes

(classically) Nambu-Goldstone boson relevant for the spontaneous symmetry breaking of Lepton number

Limits on Majoron emitting double-beta decays

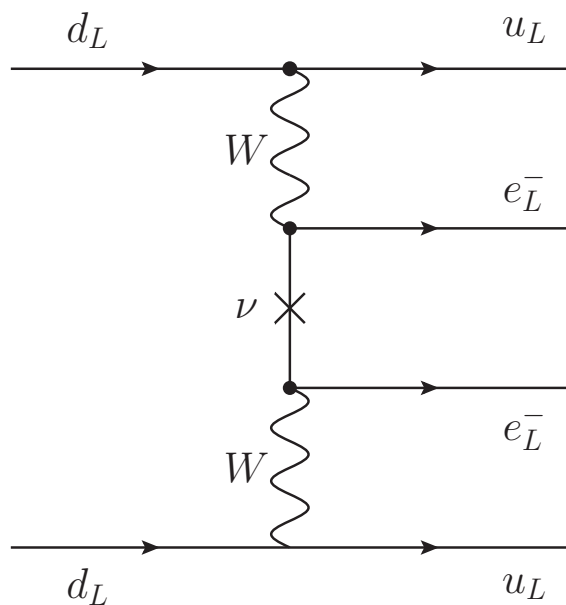


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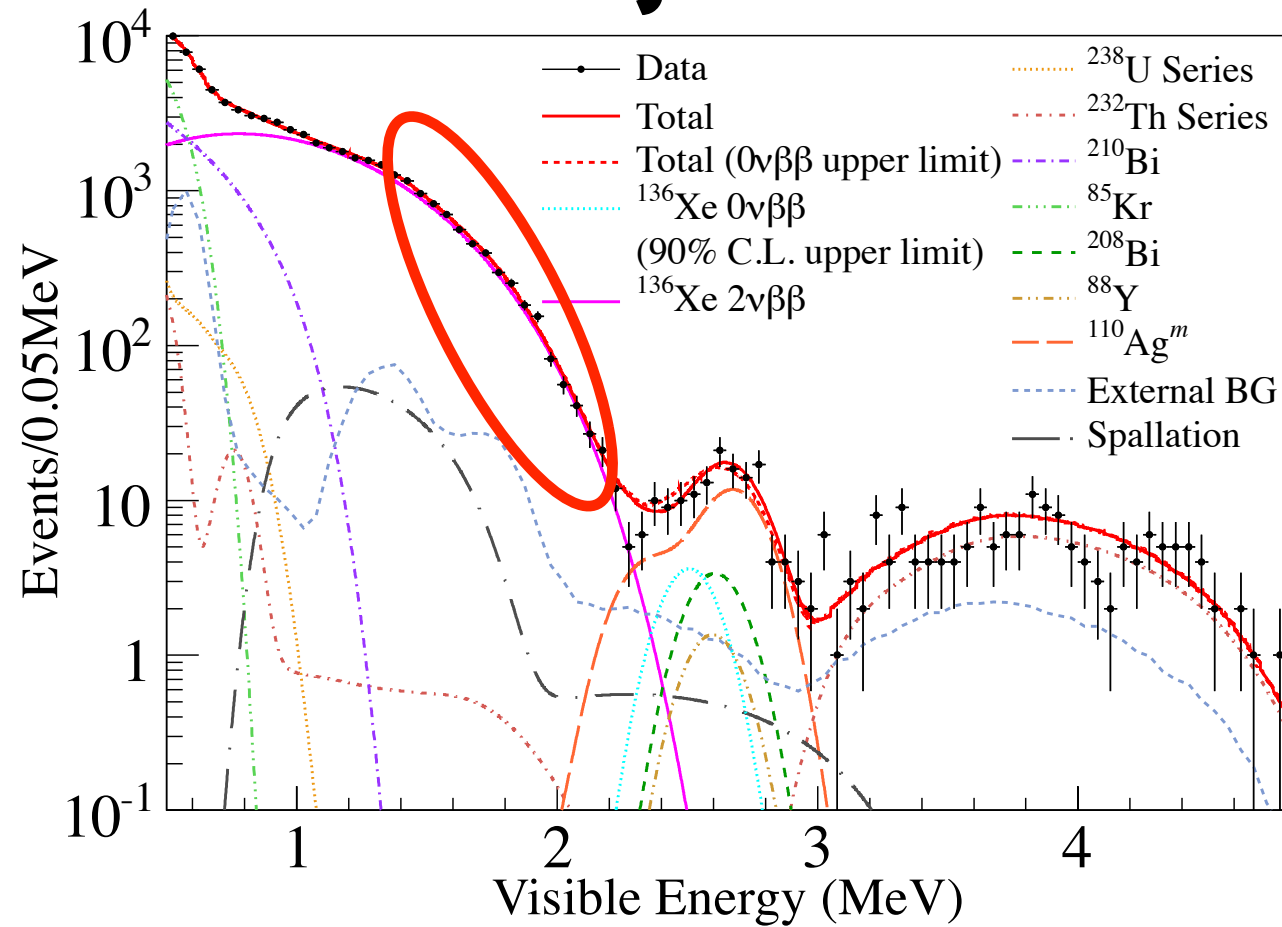
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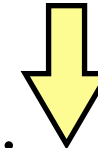


light Majorana neutrino exchange

Limits on Majoron emitting double-beta decays

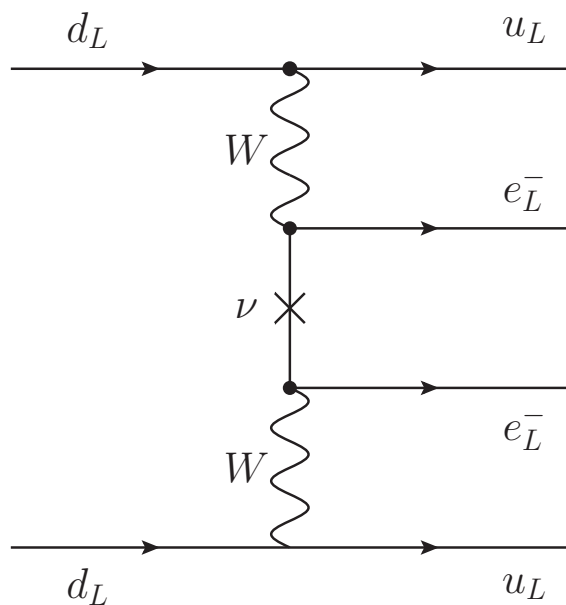


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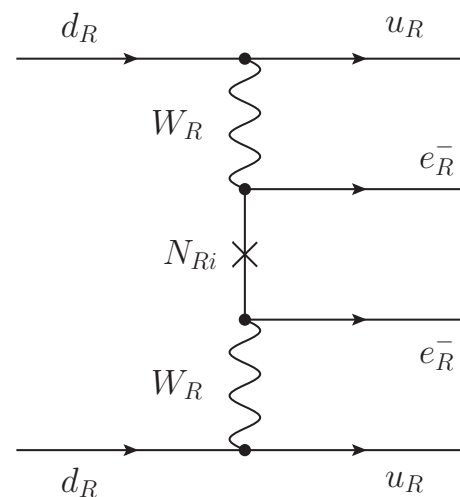


Good sensitivity on Majoron modes

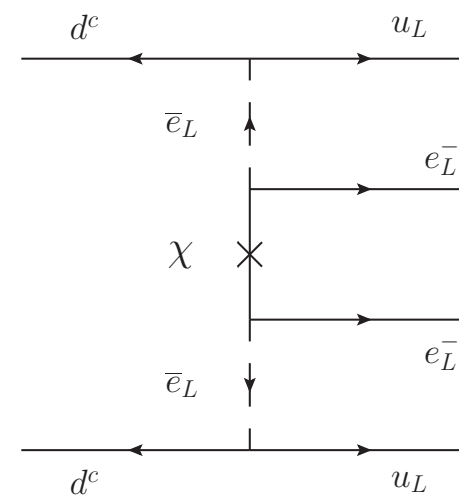
(classically) Nambu-Goldstone boson relevant for the spontaneous symmetry breaking of Lepton number



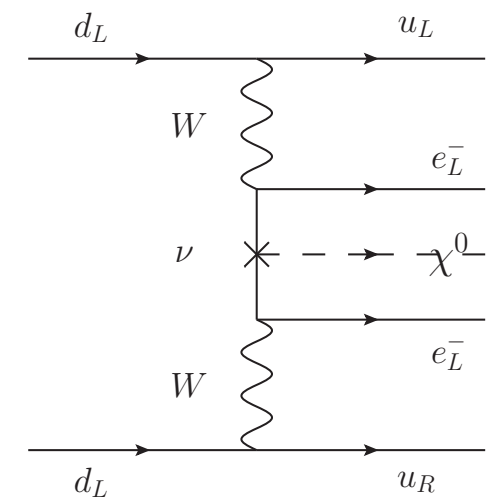
light Majorana neutrino exchange



right-handed current

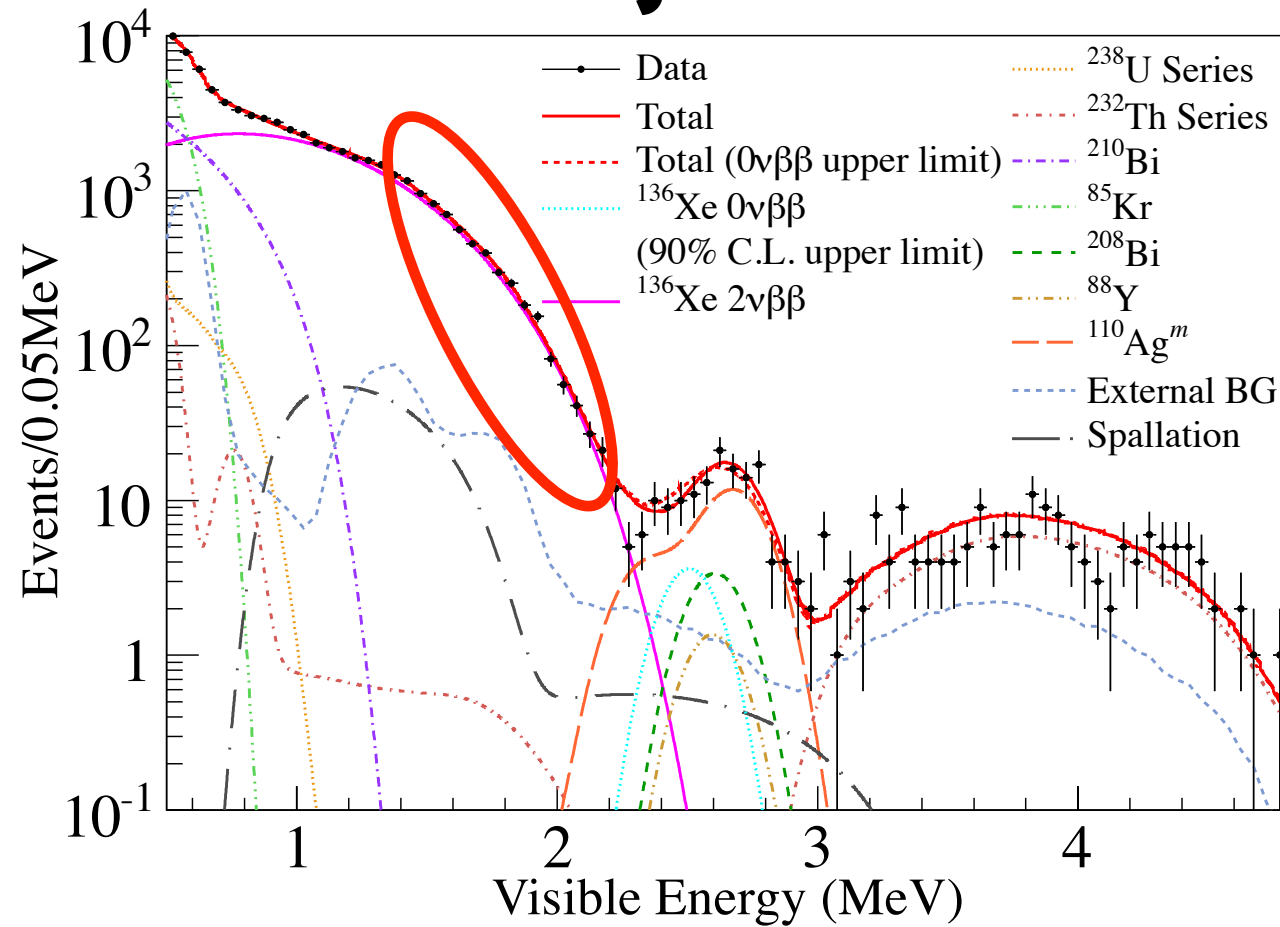


SUSY mediated

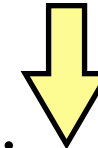


Majoron emission

Limits on Majoron emitting double-beta decays

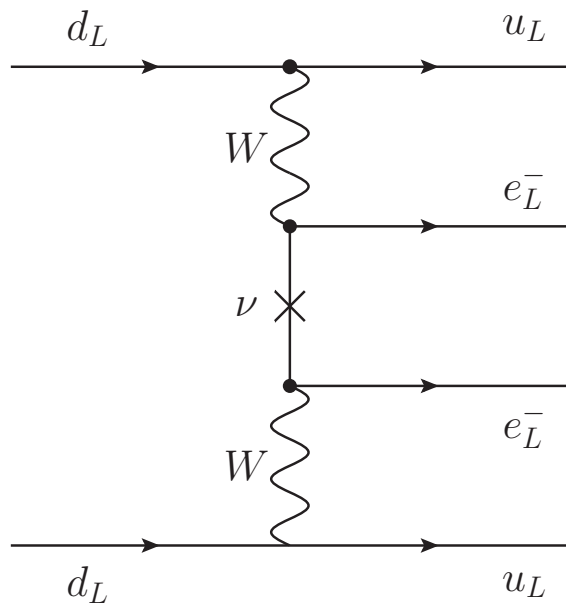


Good S/N ratio in the $2\nu 2\beta$ region and high statistics even with slow ^{136}Xe decay

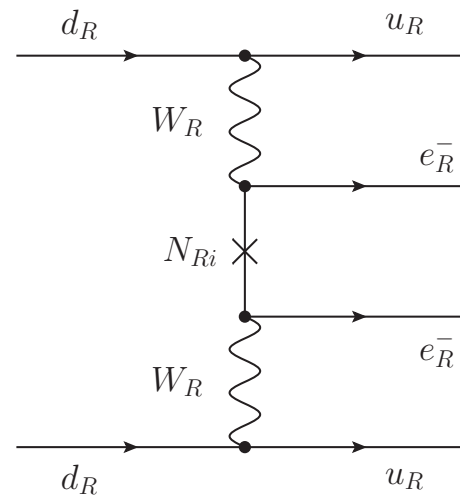


Good sensitivity on Majoron modes

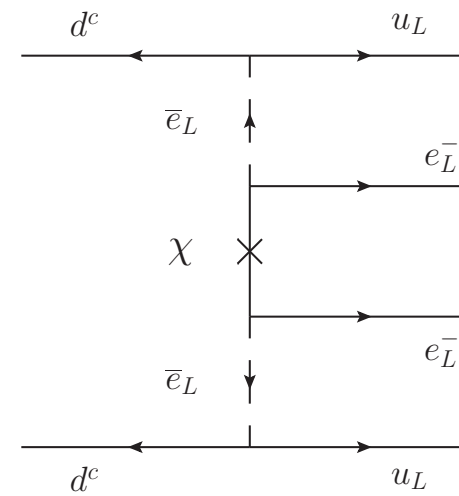
(classically) Nambu-Goldstone boson relevant for the spontaneous symmetry breaking of Lepton number



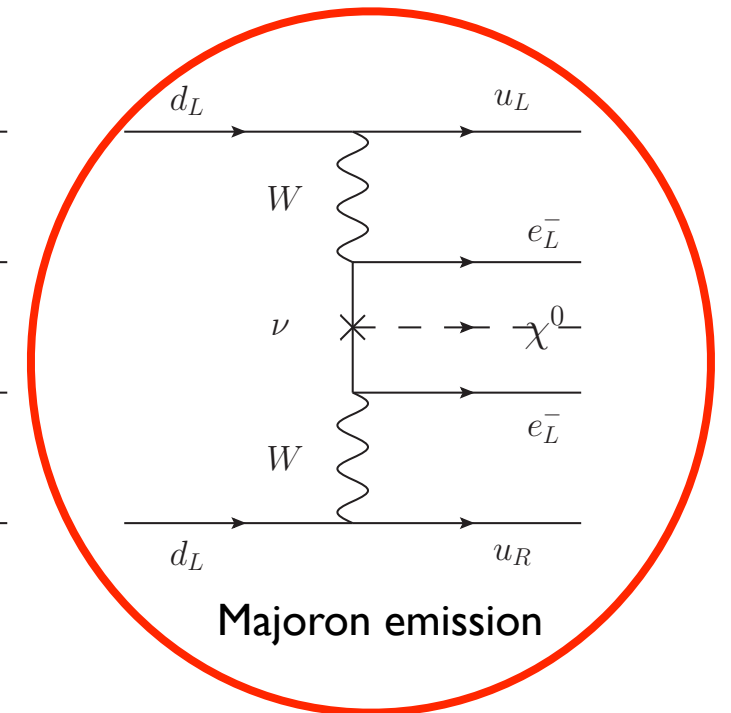
light Majorana neutrino exchange



right-handed current

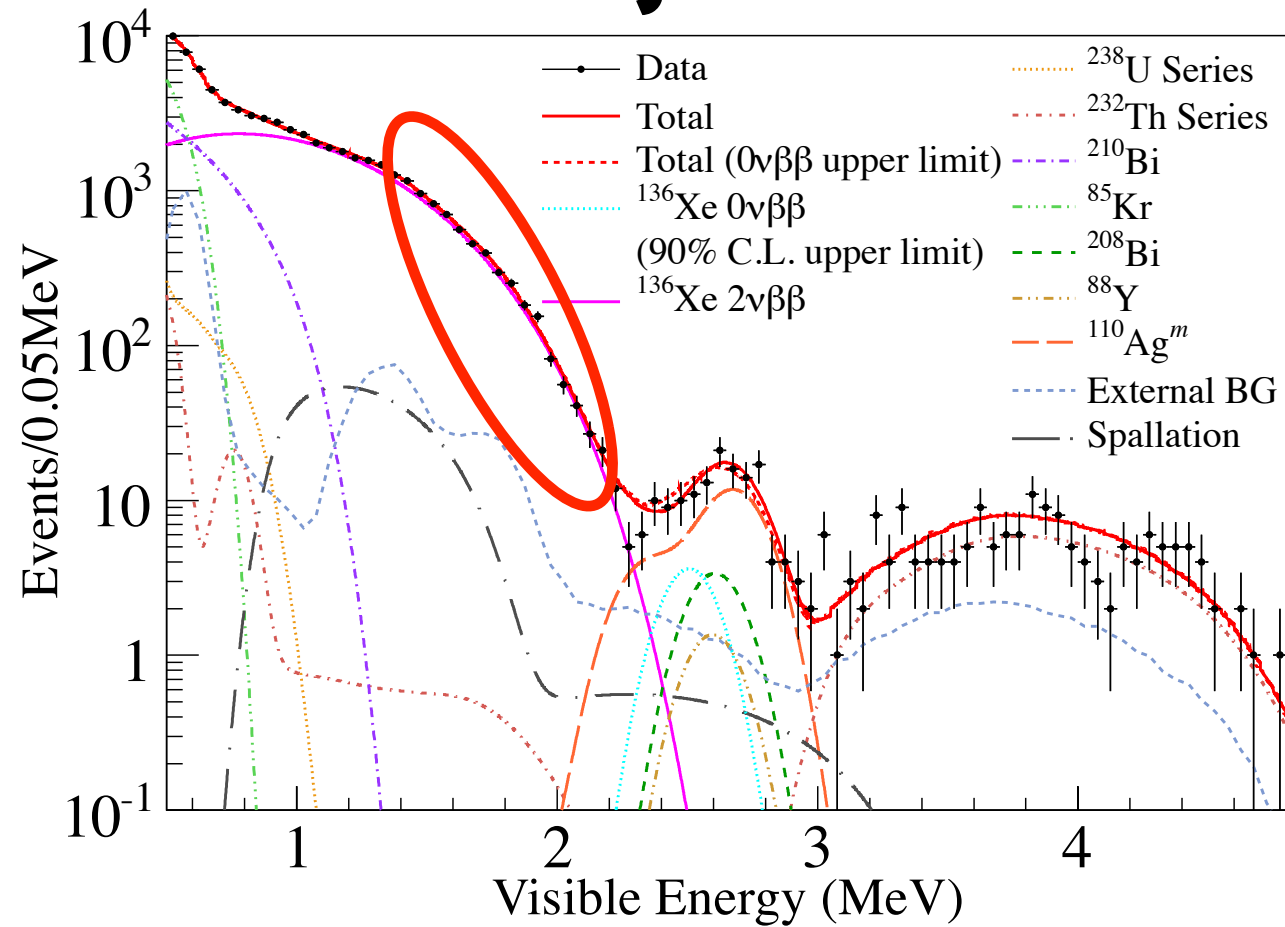


SUSY mediated

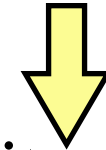


Majoron emission

Limits on Majoron emitting double-beta decays

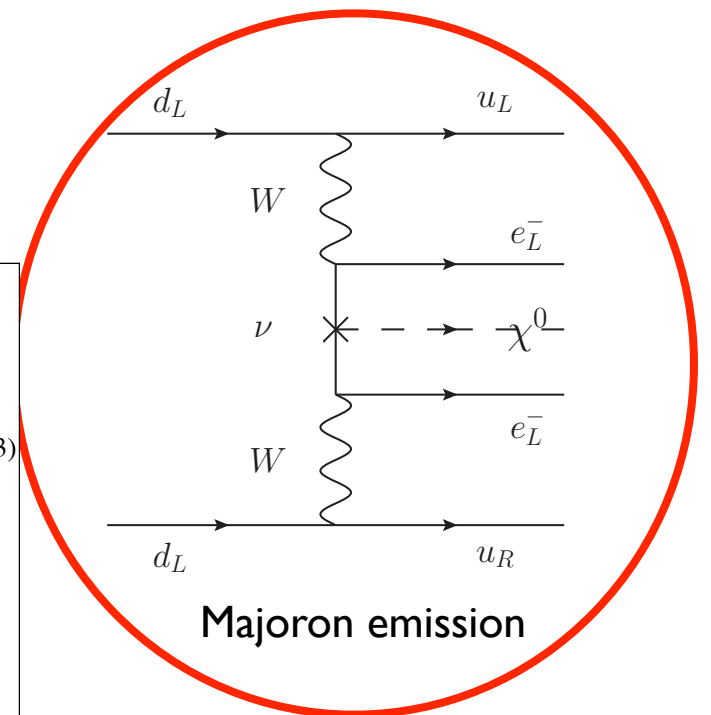
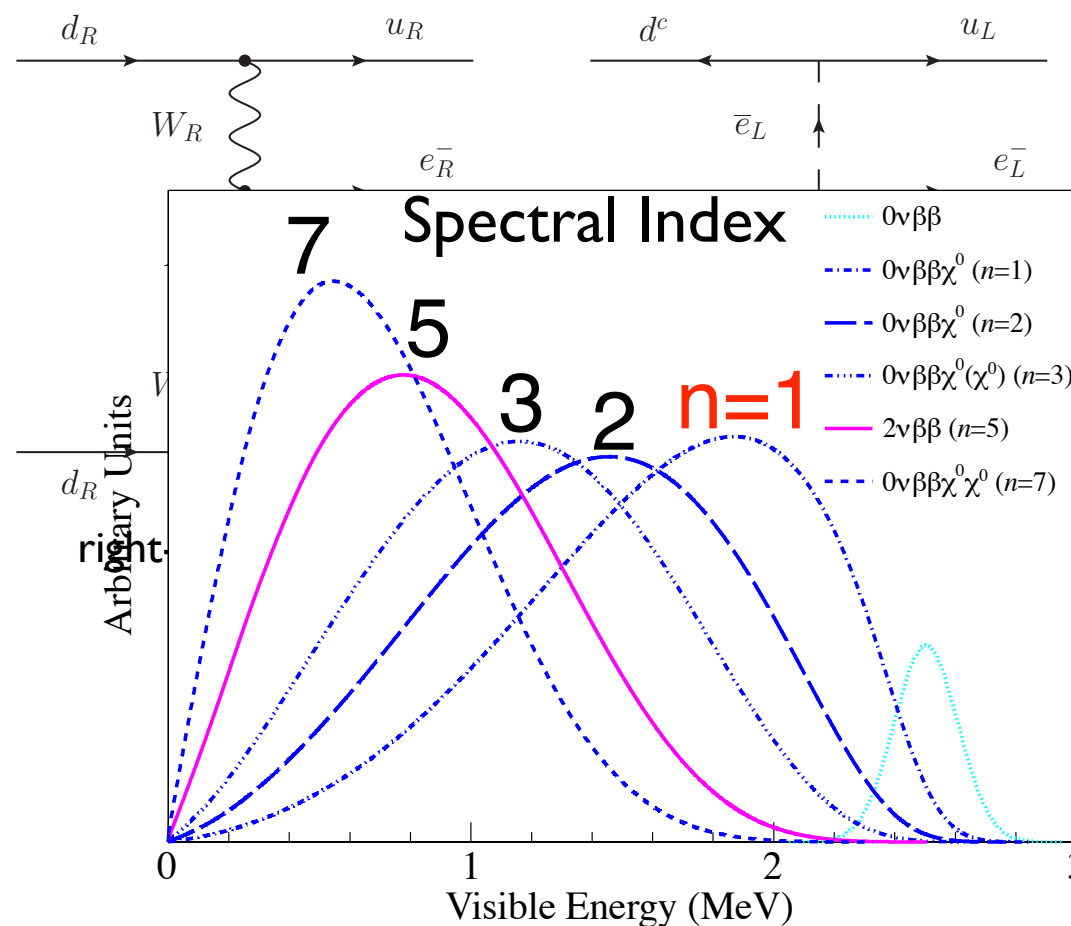
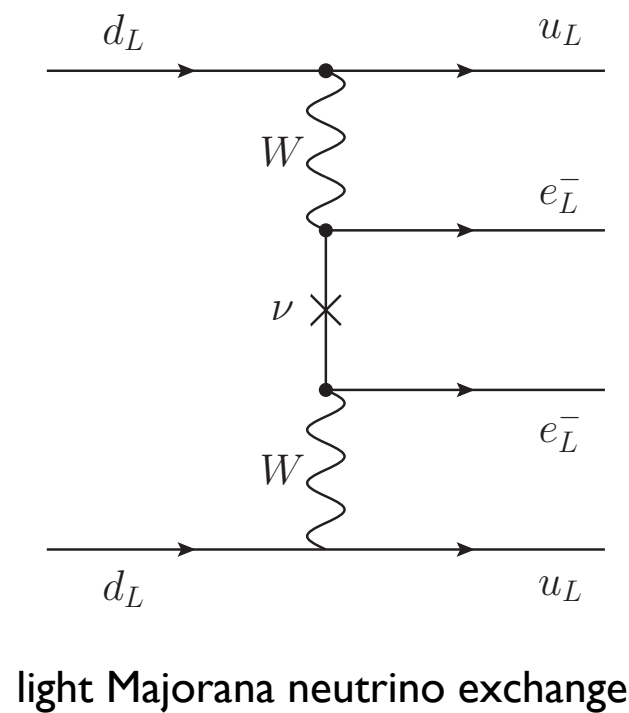


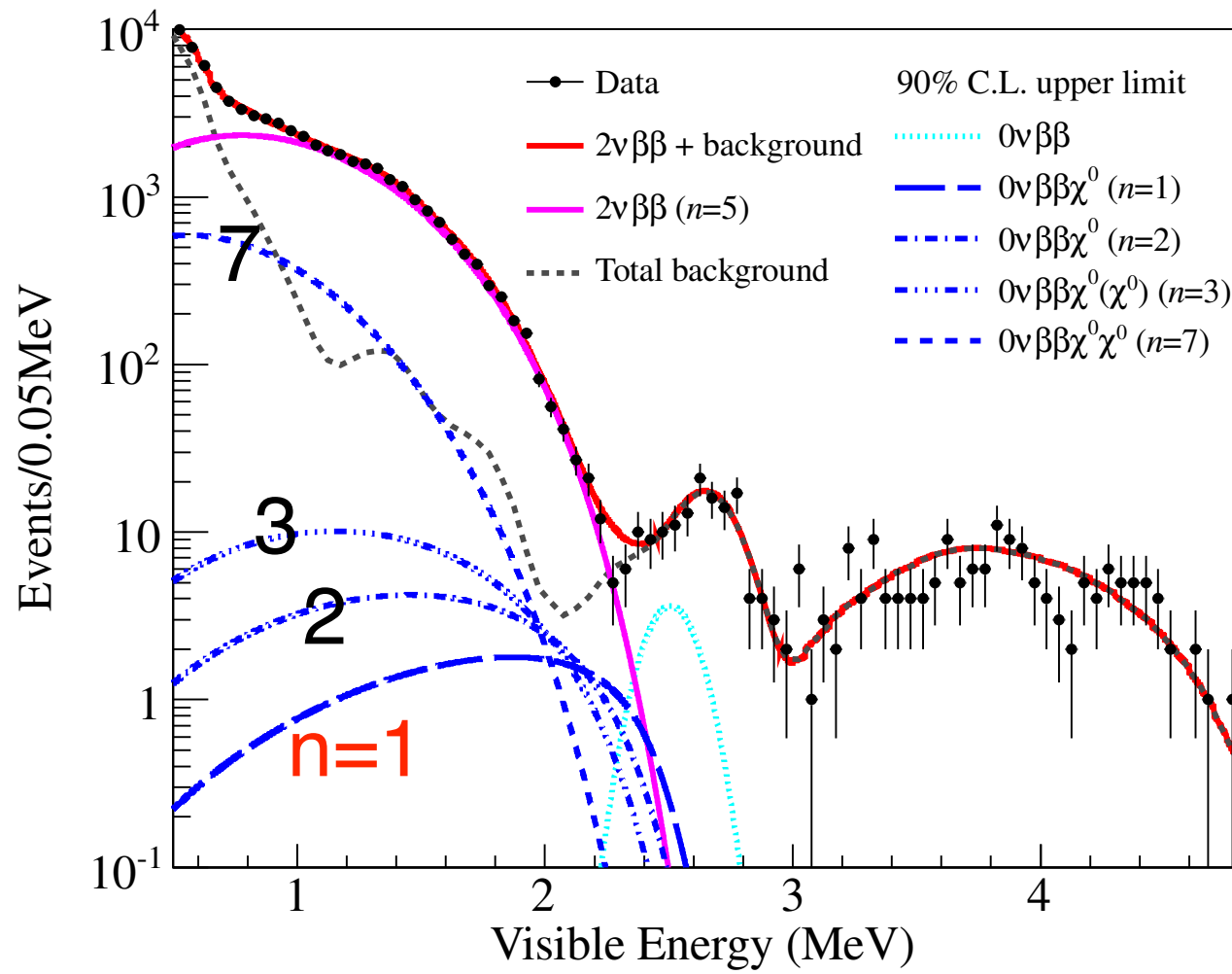
Good S/N ratio in the $2\nu 2\beta$ region and high statistics even with slow ^{136}Xe decay



Good sensitivity on Majoron modes

(classically) Nambu-Goldstone boson relevant for the spontaneous symmetry breaking of Lepton number





for $0\nu 2\beta\chi^0$ (one Majoron emission)

$$T_{1/2}^{-1} = |\langle g_{ee} \rangle|^2 |M|^2 G$$

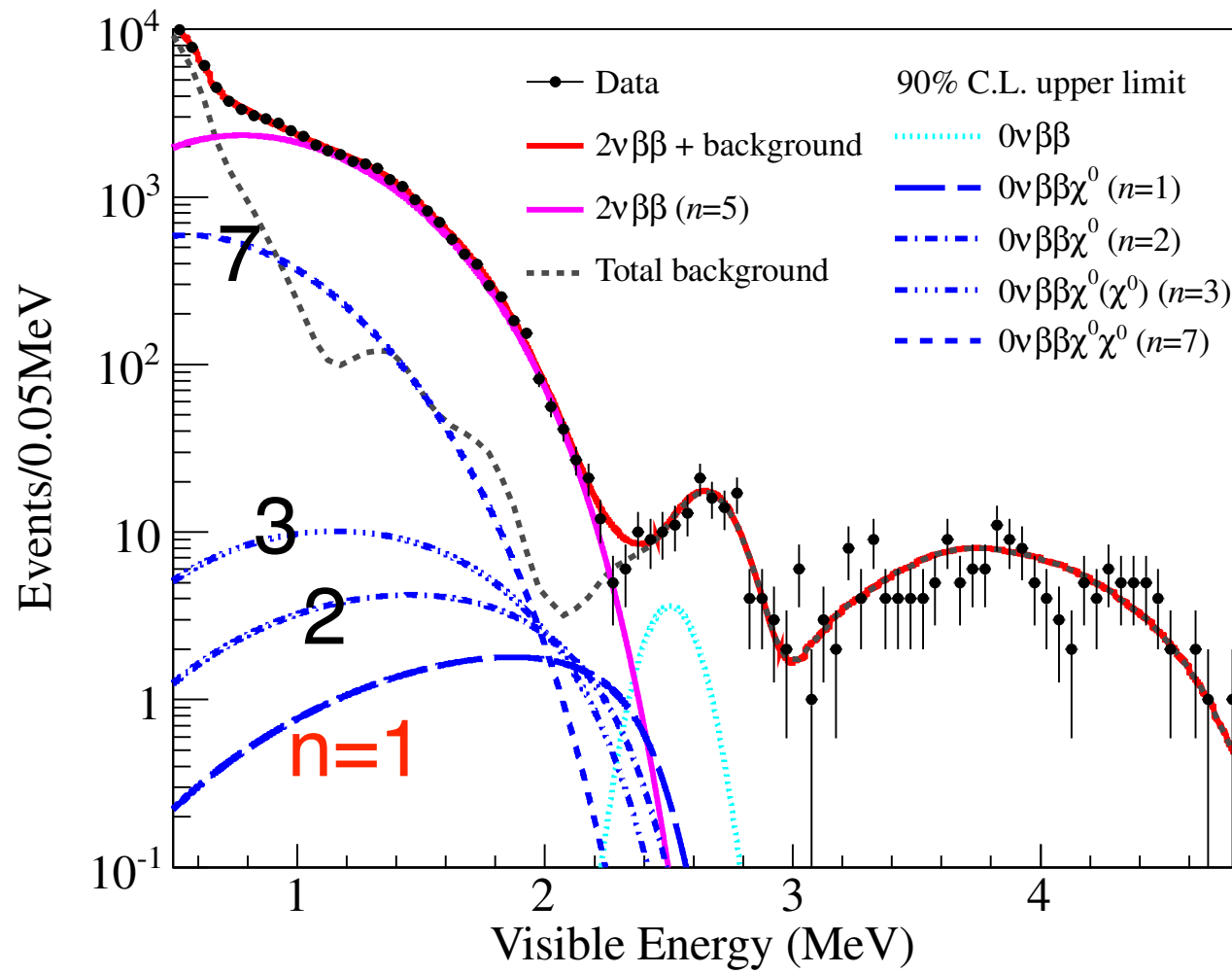
for $0\nu 2\beta\chi^0\chi^0$ (two Majoron emission)

$$T_{1/2}^{-1} = |\langle g_{ee} \rangle|^4 |M|^2 G$$

$$G = a \cdot \int (Q_{\beta\beta} - \epsilon_1 - \epsilon_2)^n \prod_k p_k \epsilon_k f(\epsilon_k) d\epsilon_k$$

Spectral index

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	—	$> 1.0 \times 10^{24}$	—



for $0\nu 2\beta\chi^0$ (one Majoron emission)

$$T_{1/2}^{-1} = |\langle g_{ee} \rangle|^2 |M|^2 G$$

for $0\nu 2\beta\chi^0\chi^0$ (two Majoron emission)

$$T_{1/2}^{-1} = |\langle g_{ee} \rangle|^4 |M|^2 G$$

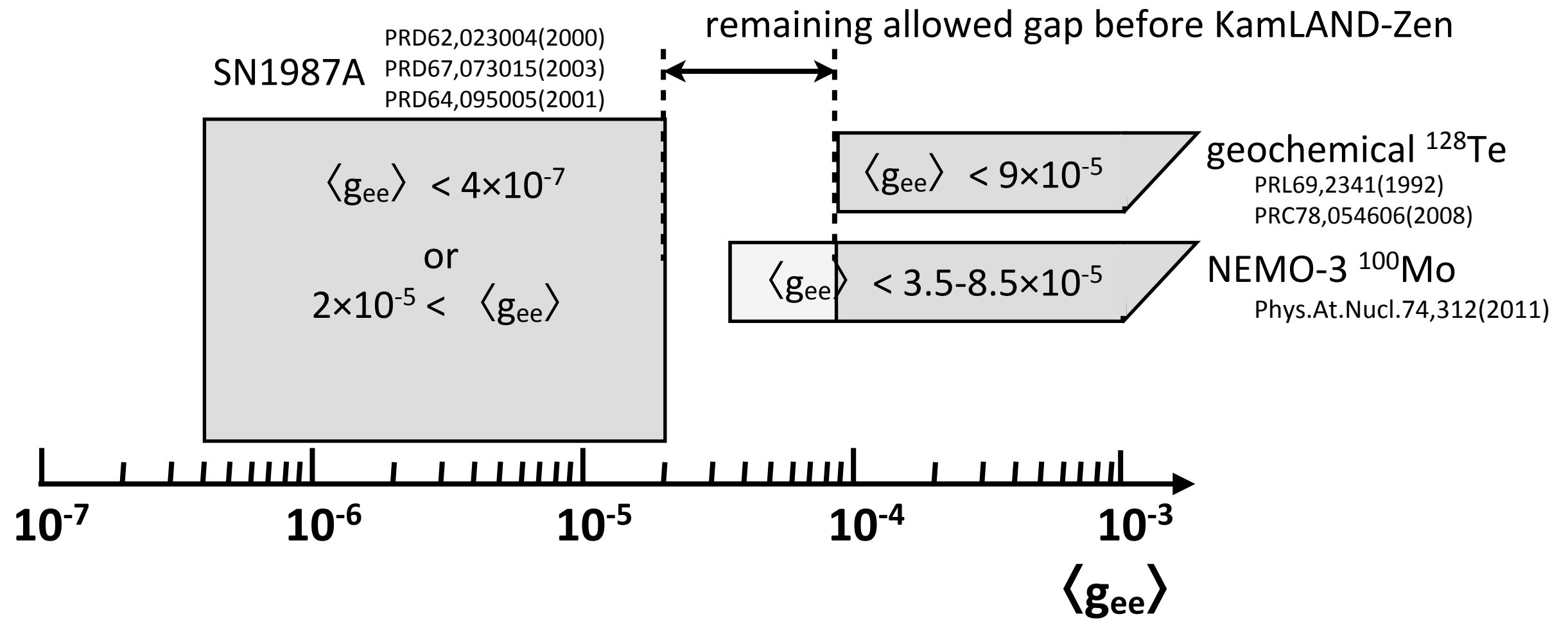
$$G = a \cdot \int (Q_{\beta\beta} - \epsilon_1 - \epsilon_2)^n \prod_k p_k \epsilon_k f(\epsilon_k) d\epsilon_k$$

Spectral index

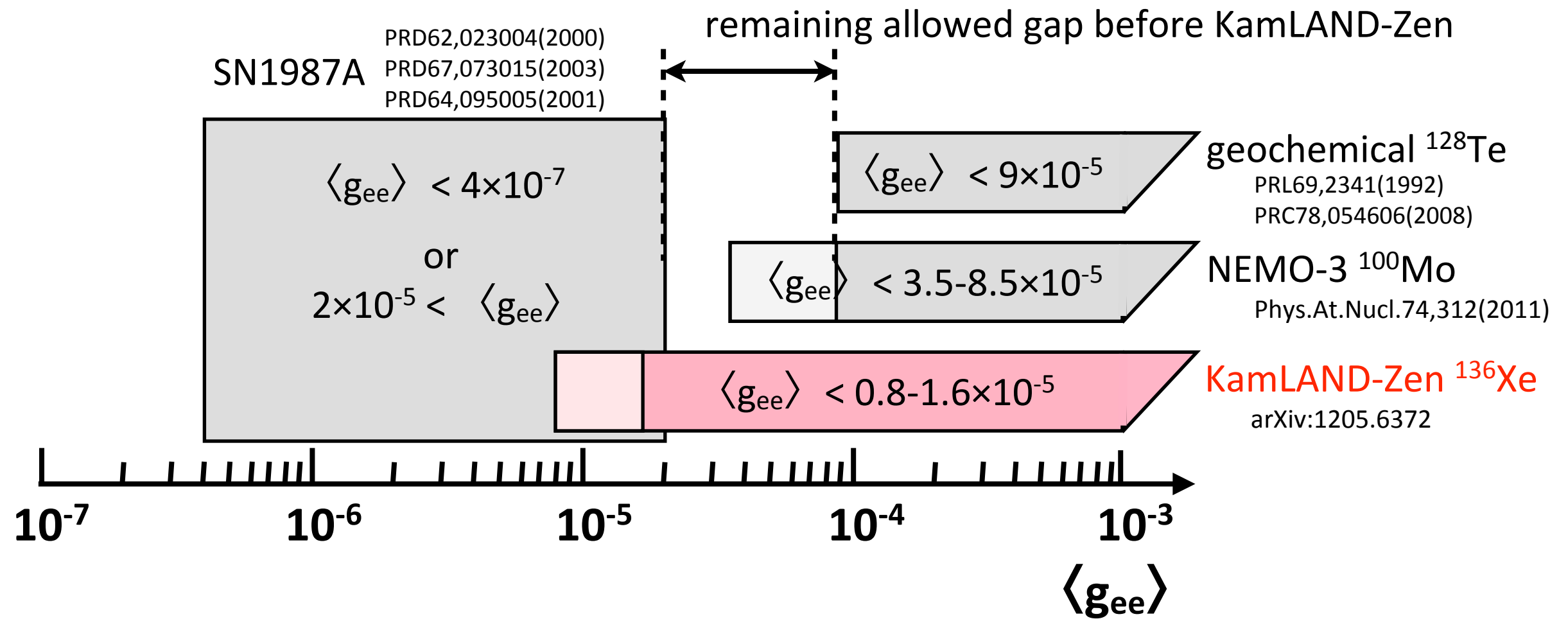
Model	Decay Mode	NG boson	L	n	Matrix Element	Results from this measurement	
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IB	$0\nu\beta\beta\chi^0$	no	0	1	$M_F - M_{GT}$ [12, 13]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
IC	$0\nu\beta\beta\chi^0$	yes	0	1	$M_F - M_{GT}$ [12, 13]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
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 “classical”
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]	$> 2.6 \times 10^{24}$	$< (0.8 - 1.6) \times 10^{-5}$
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IID	$0\nu\beta\beta\chi^0\chi^0$	no	2	3	$M_{F\omega^2} - M_{GT\omega^2}$ [8]	$> 4.5 \times 10^{23}$	< 0.68
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“bulk”	$0\nu\beta\beta\chi^0$	bulk field	0	2	—	$> 1.0 \times 10^{24}$	—

“ordinary” Majoron-emitting mode (n=1)
 $T_{1/2} > 2.6 \times 10^{24}$ years $\Rightarrow \langle g_{ee} \rangle < (0.8-1.6) \times 10^{-5}$

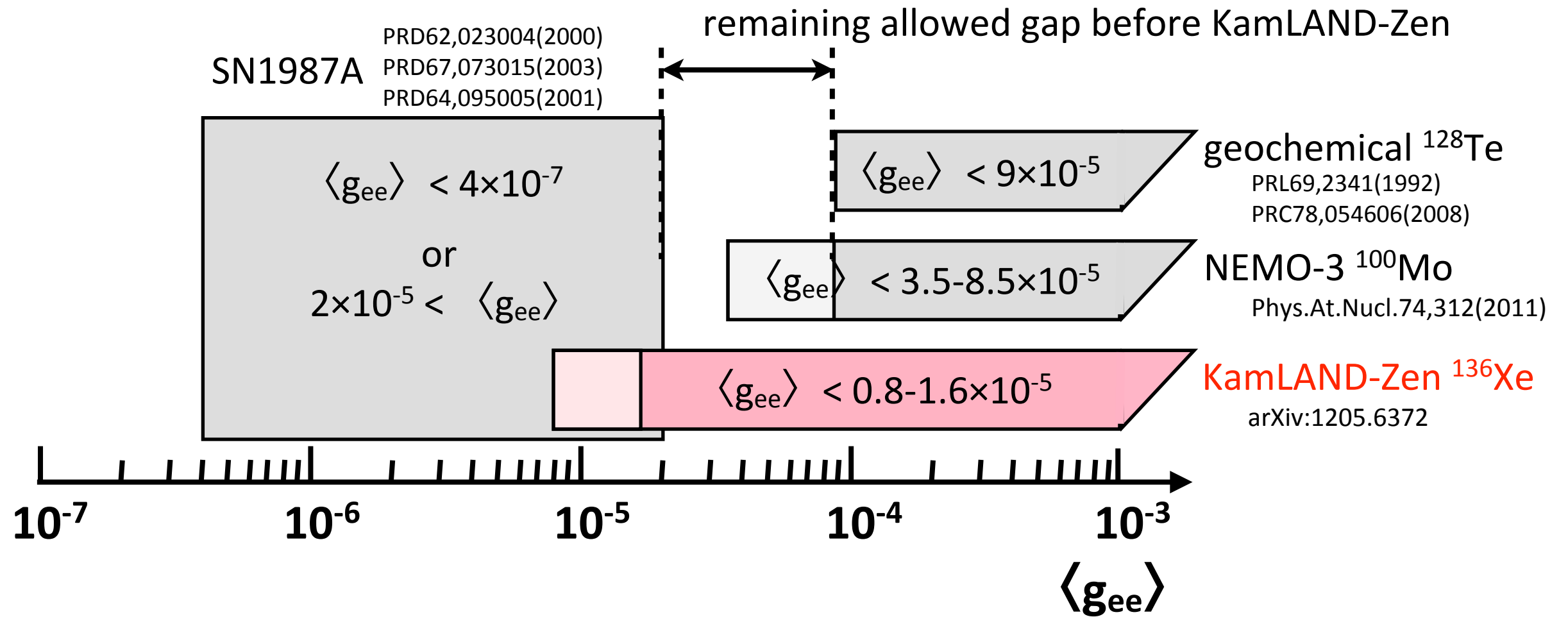
Excluded region for the ordinary Majoron emitting decay (n=1)



Excluded region for the ordinary Majoron emitting decay (n=1)

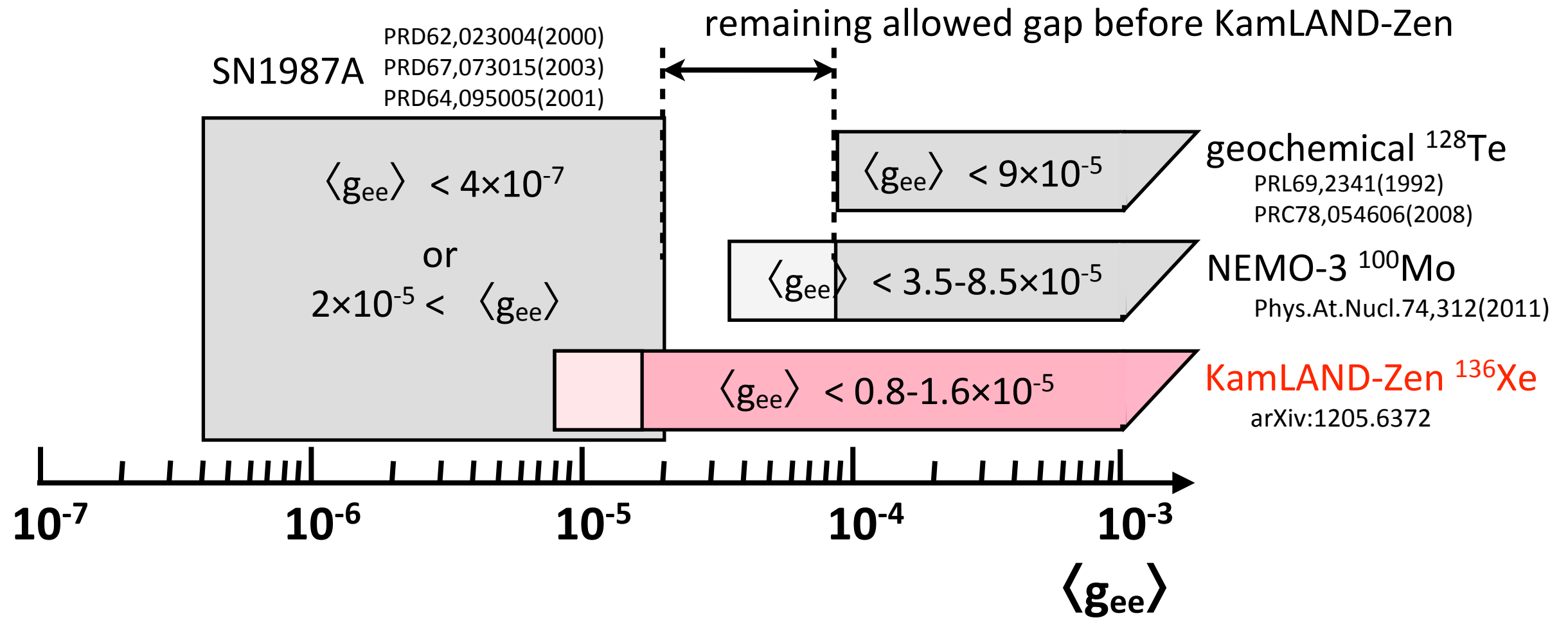


Excluded region for the ordinary Majoron emitting decay (n=1)

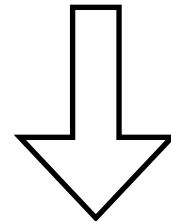


KamLAND-Zen excludes the gap region of 2×10^{-5} to 9×10^{-5} , and entire region above 4×10^{-7} is excluded in combination with the SN1987A limit.

Excluded region for the ordinary Majoron emitting decay (n=1)



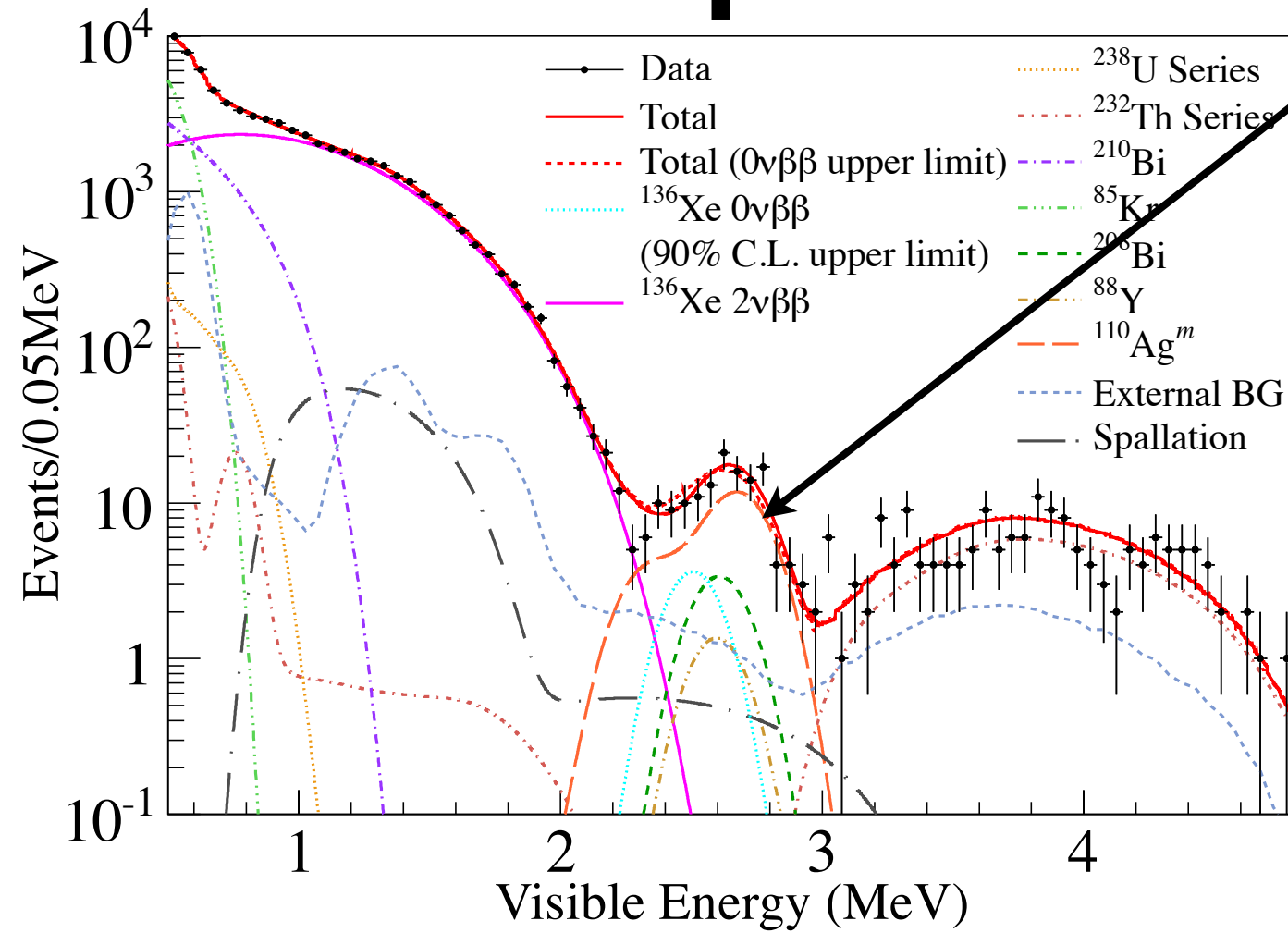
KamLAND-Zen excludes the gap region of 2×10^{-5} to 9×10^{-5} , and entire region above 4×10^{-7} is excluded in combination with the SN1987A limit.



“Ordinary Majoron emitting-decay” is much slower than
“light Majorana neutrino ($>20\text{meV}$) exchange”

Future Prospects

Soon

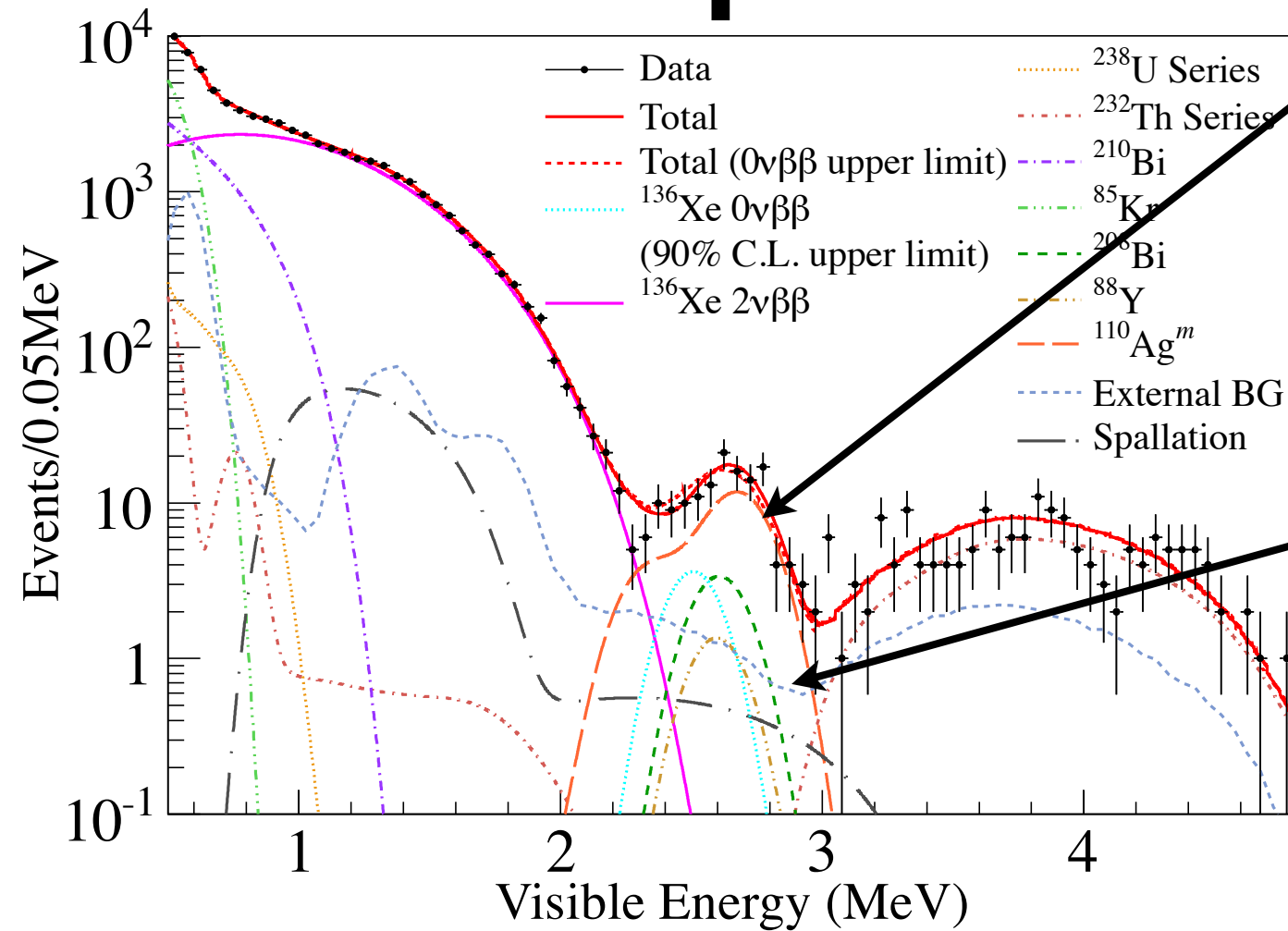


$^{110\text{m}}\text{Ag}$ and maybe ^{208}Bi , ^{88}Y in the Xe-LS are expected to be removed by purification of Xenon **extraction/distillation/adsorption** to be applied from this week. (~100days more data) LS is replaced with new purified one.

TARGET: more than factor 100 reduction

Future Prospects

Soon



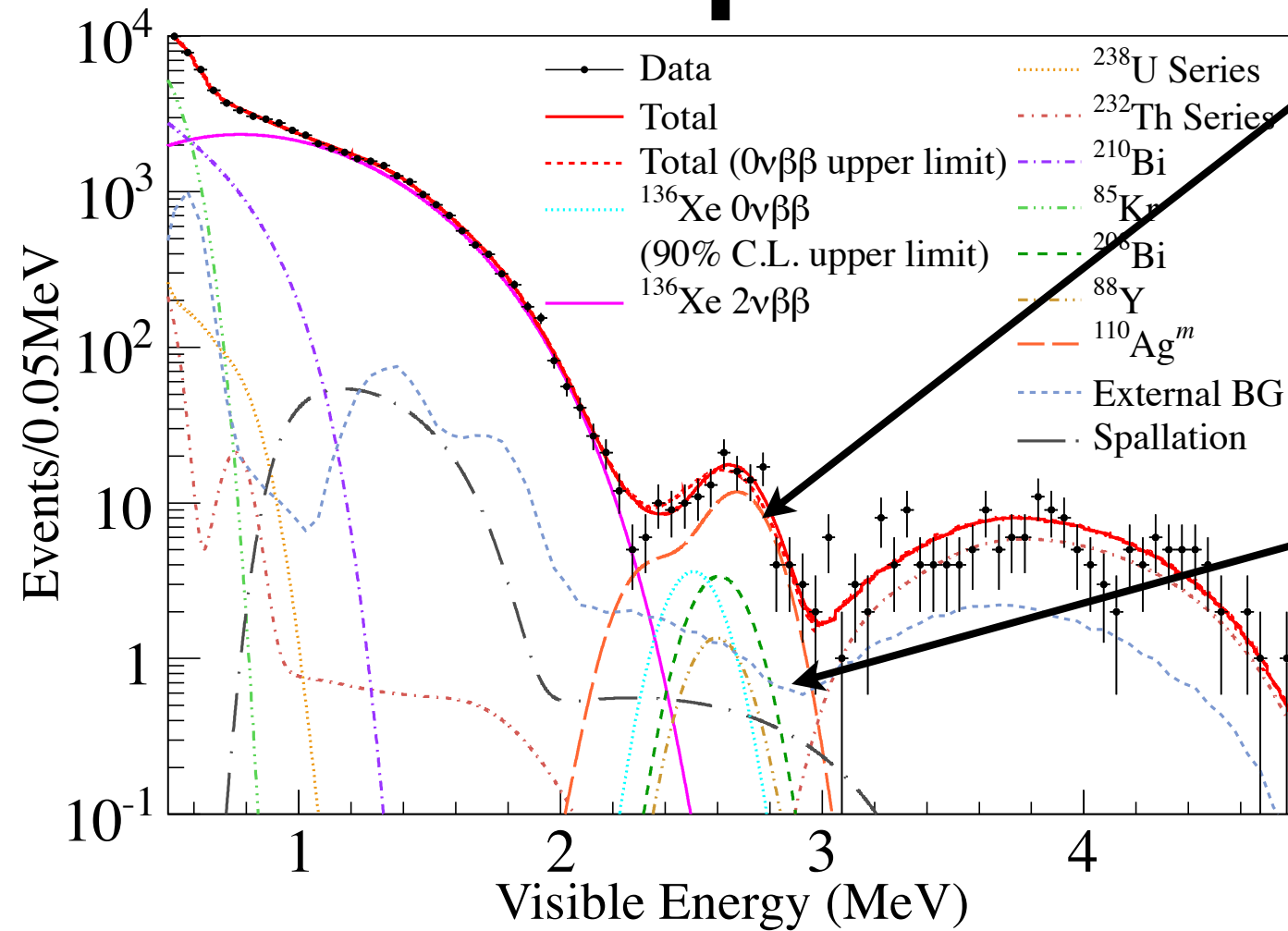
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TARGET: more than factor 100 reduction

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.

Future Prospects

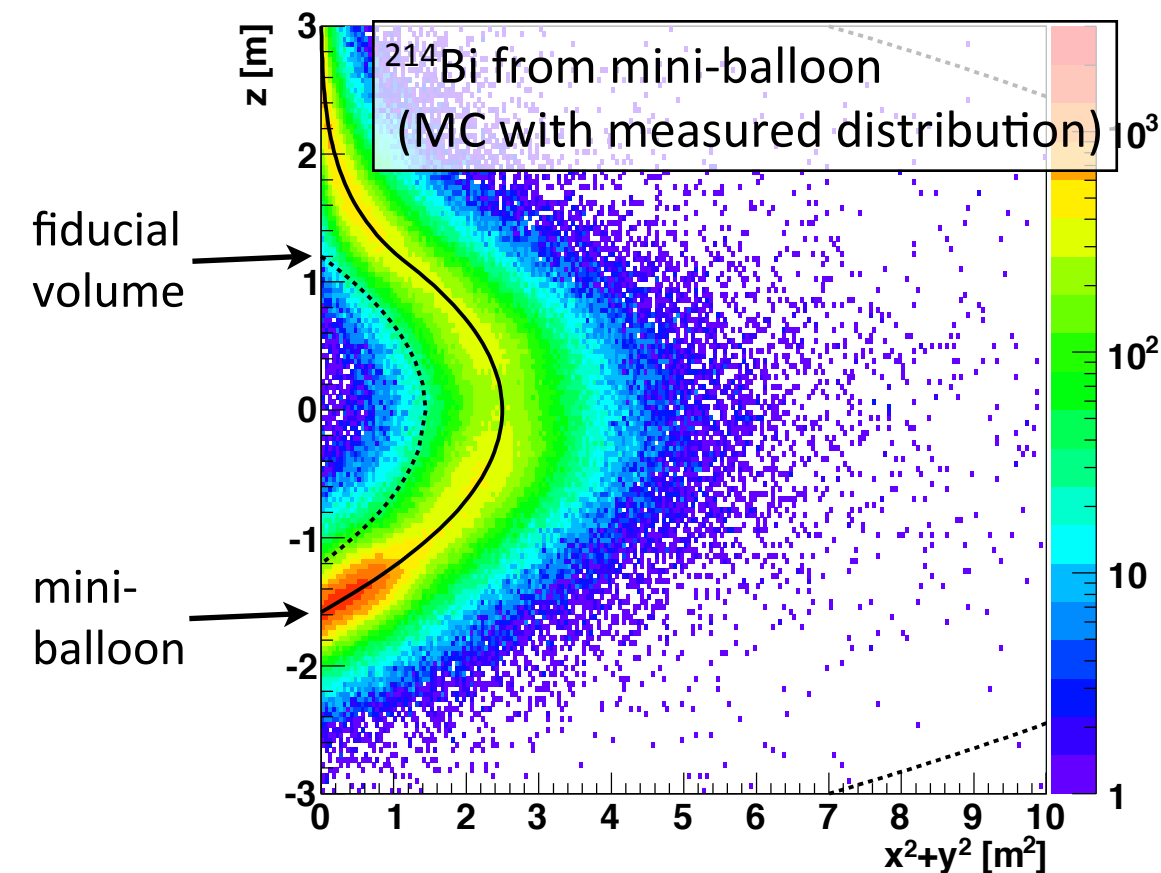
Soon



^{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 this week. (~100days more data) LS is replaced with new purified one.

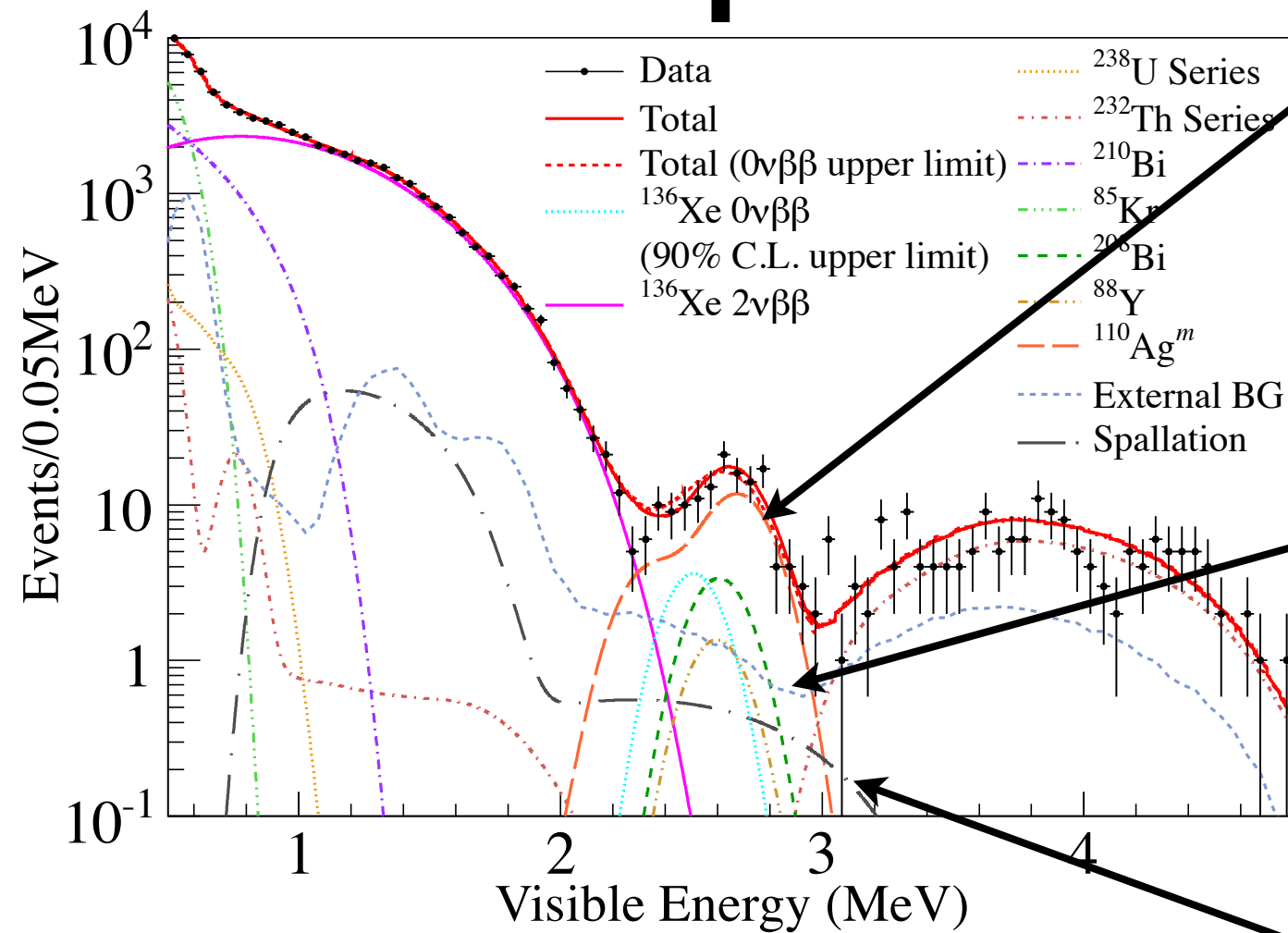
TARGET: more than factor 100 reduction

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.



Future Prospects

Soon

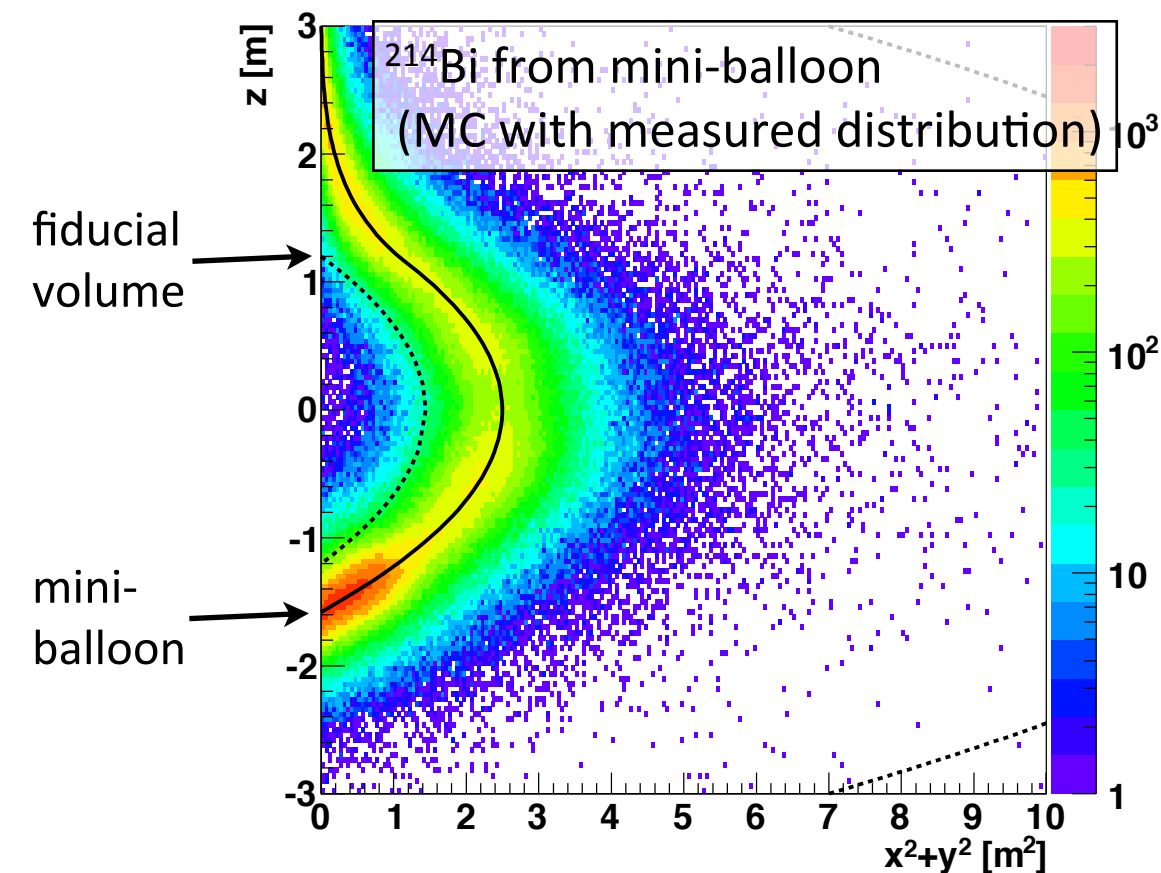


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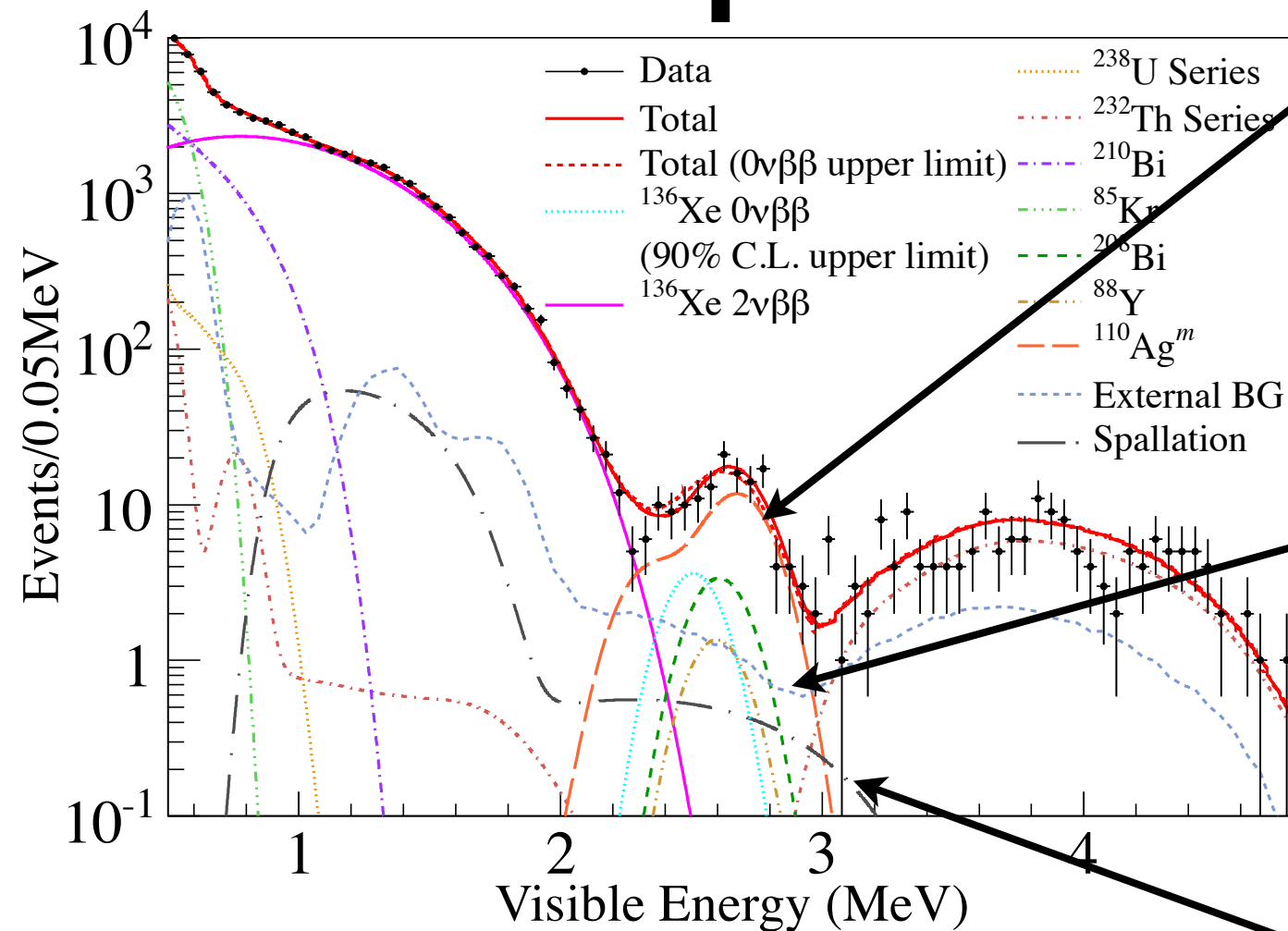
For ^{10}C from spallation, 80+% reduction w/o significant efficiency drop is achieved so far (not applied here yet).



Future Prospects

Soon

TARGET sensitivity : $\sim 80\text{meV}$

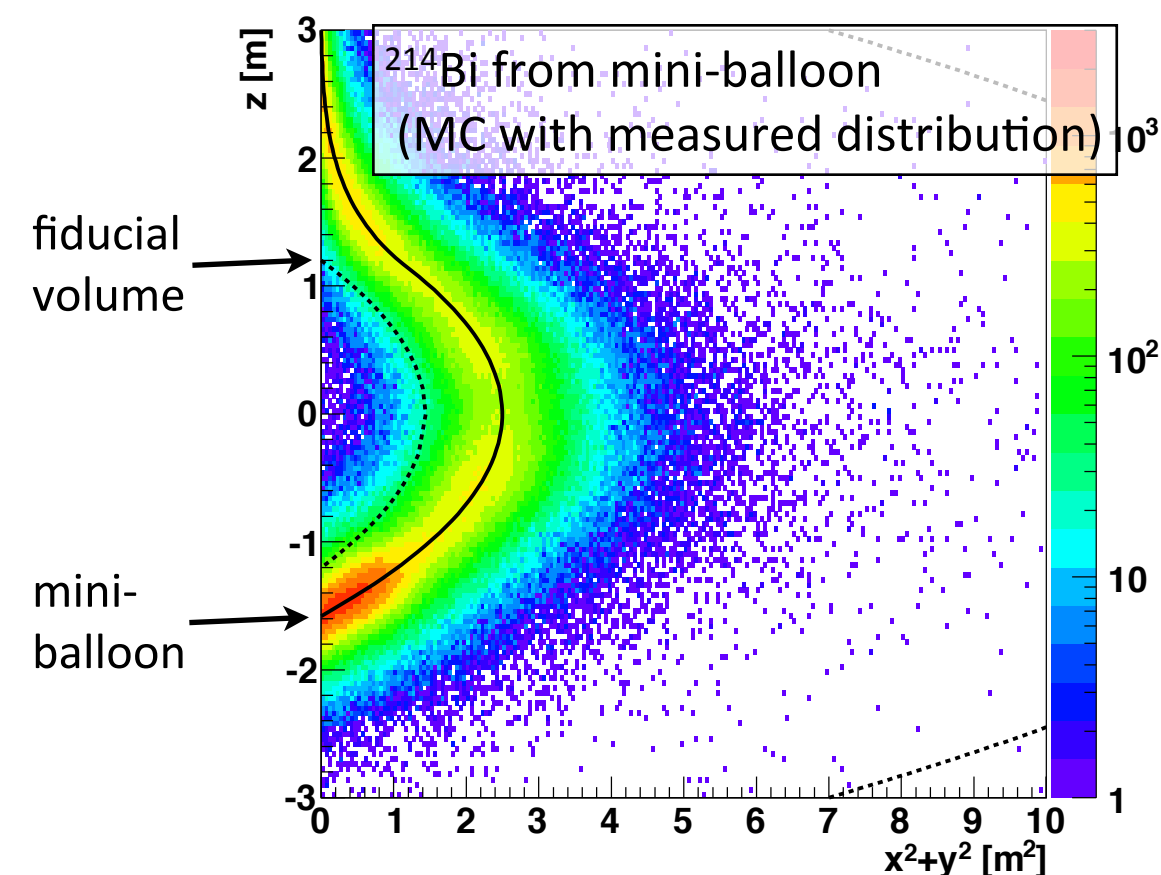


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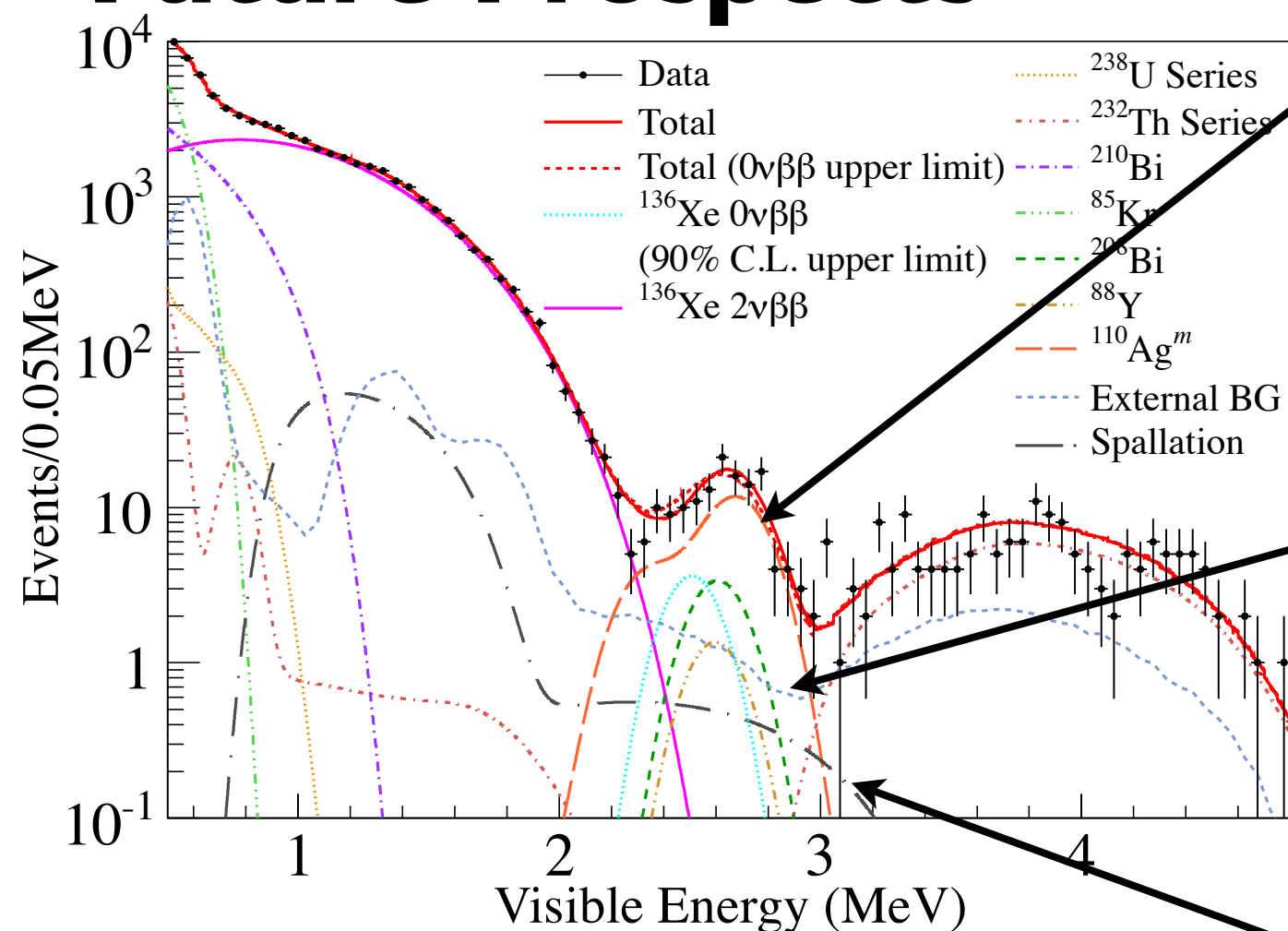
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Soon

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TARGET: more than factor 100 reduction

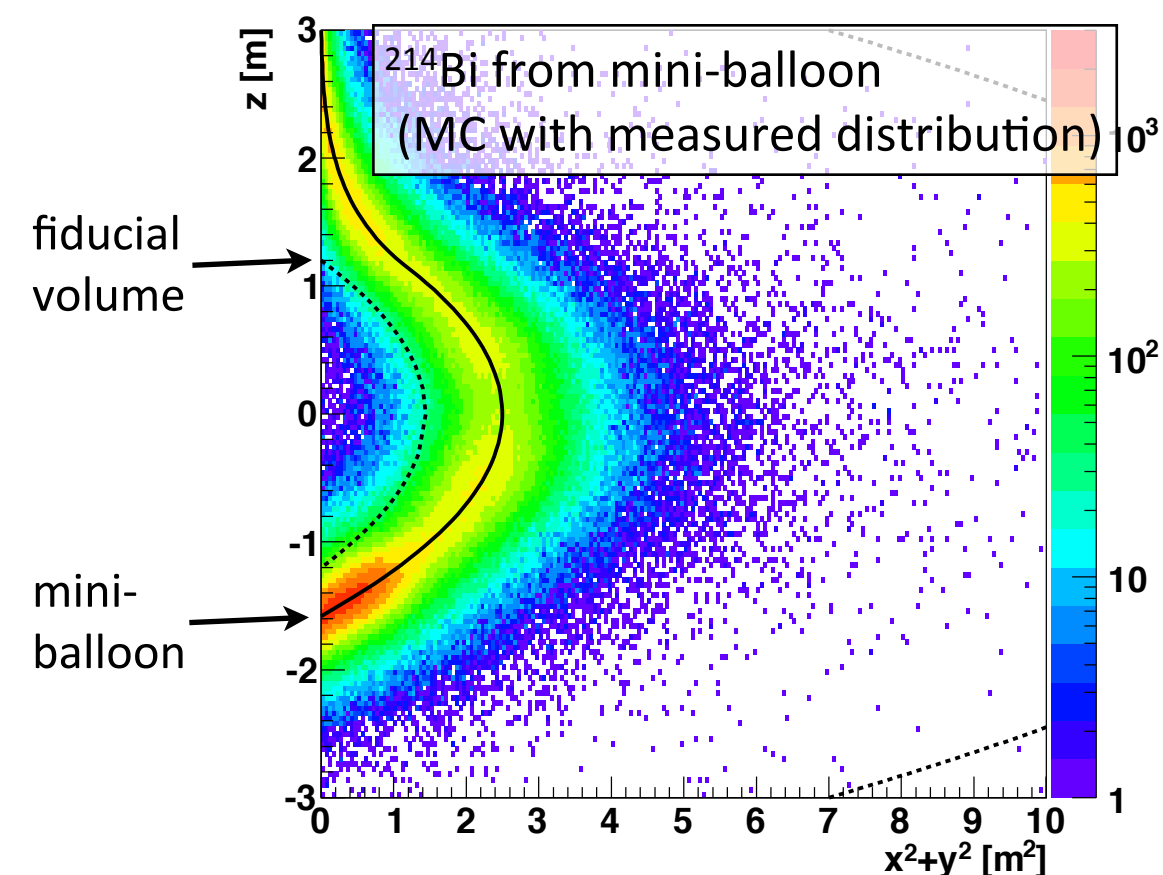
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Near Future

TARGET sensitivity : $\sim 40\text{meV}$

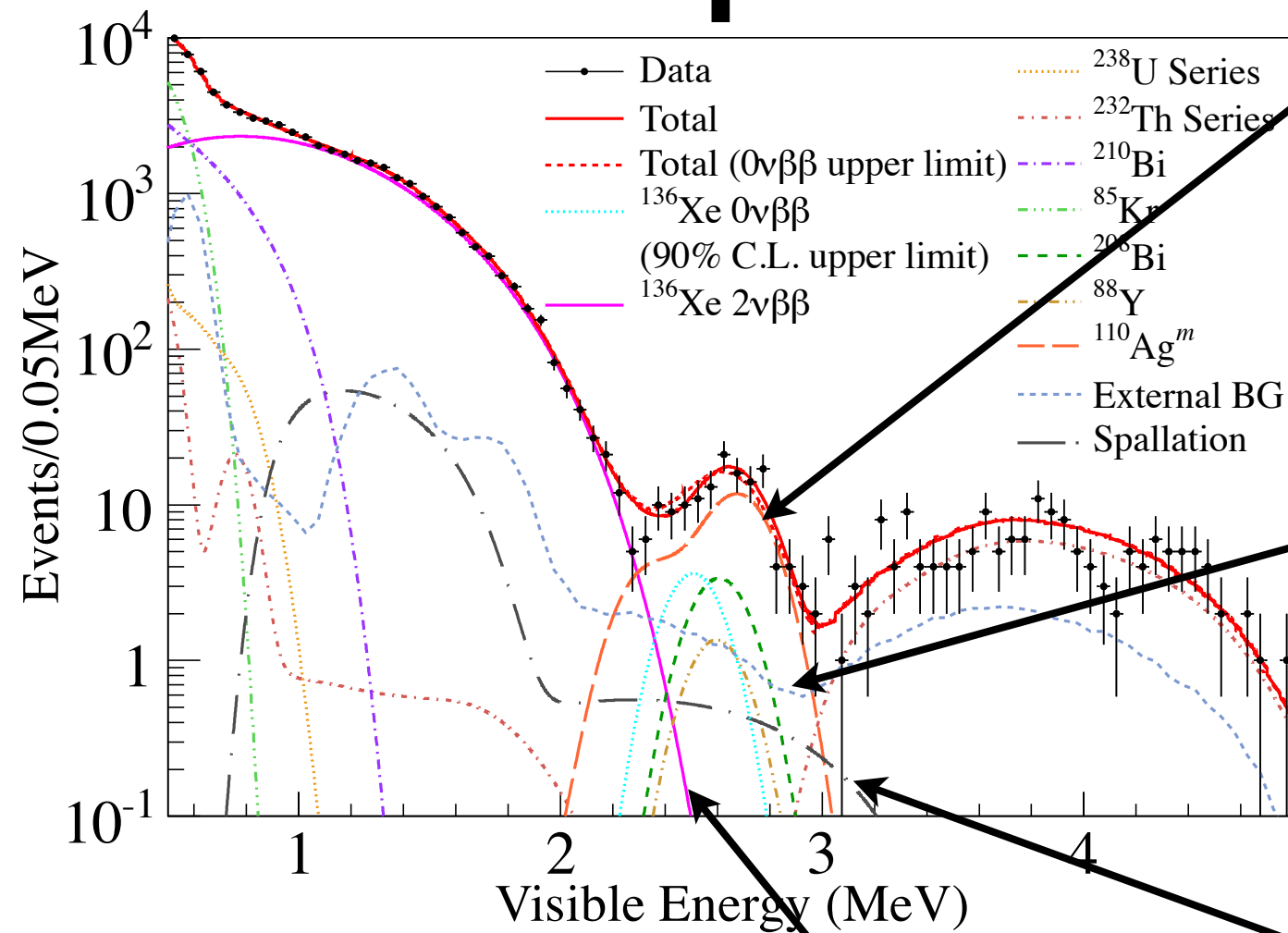
increased Xenon amount and cleaner balloon maybe pressurize for higher concentration (ref posters 50-2)



Future Prospects

Soon

TARGET sensitivity : $\sim 80\text{meV}$



$^{110\text{m}}\text{Ag}$ 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 this week. (~ 100 days more data) LS is replaced with new purified one.

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Near Future

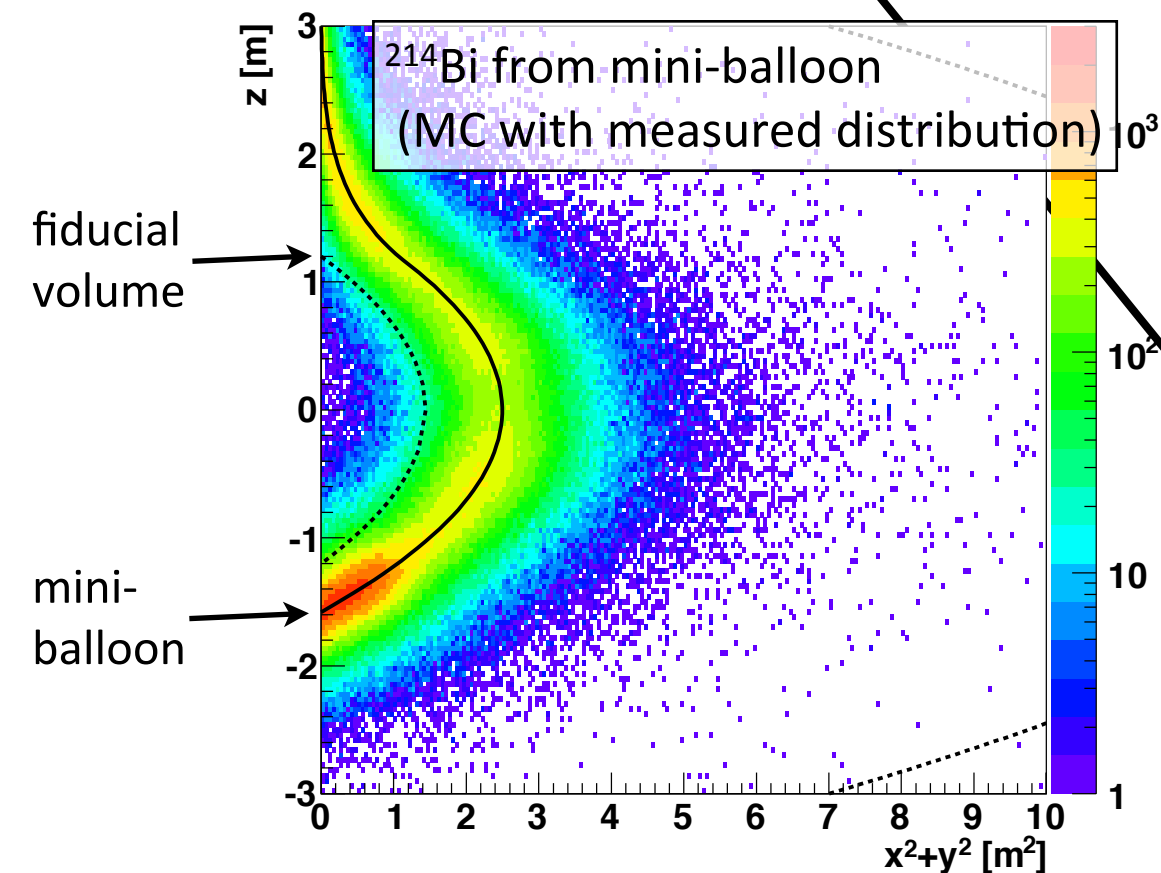
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increased Xenon amount and cleaner balloon maybe pressurize for higher concentration (ref posters 50-2)

Future

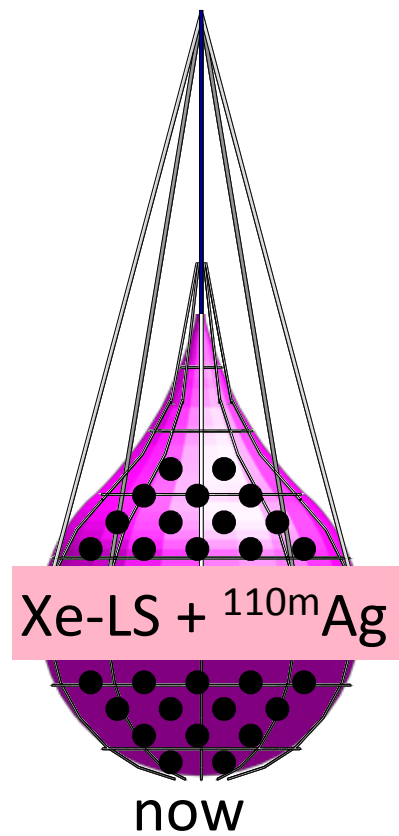
TARGET sensitivity : $\sim 20\text{meV}$

For $2\nu 2\beta$ reduction, **LS replacement, light collector attachment** are planned. ---> KamLAND2-Zen



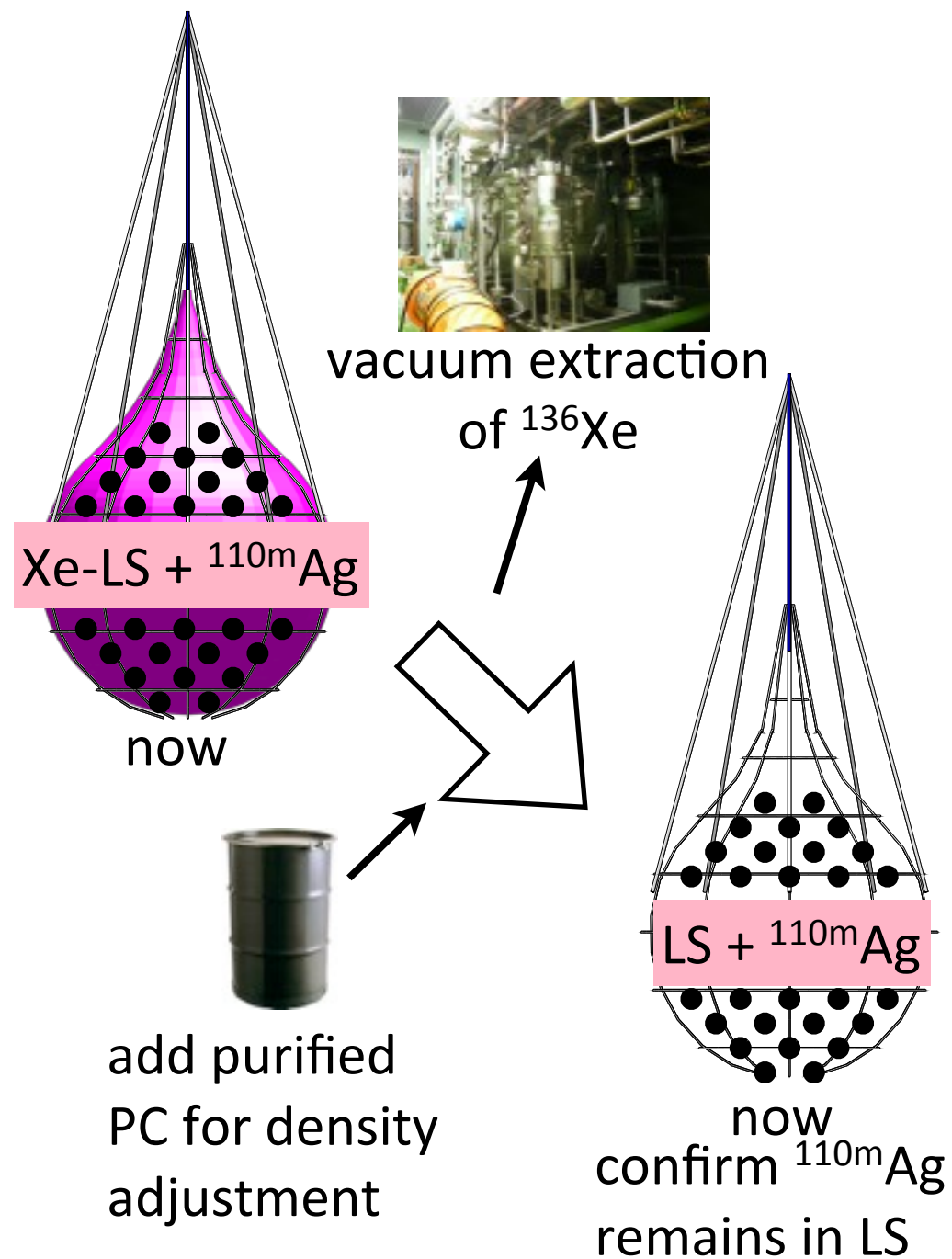
Purification Strategy

June to September, 2012



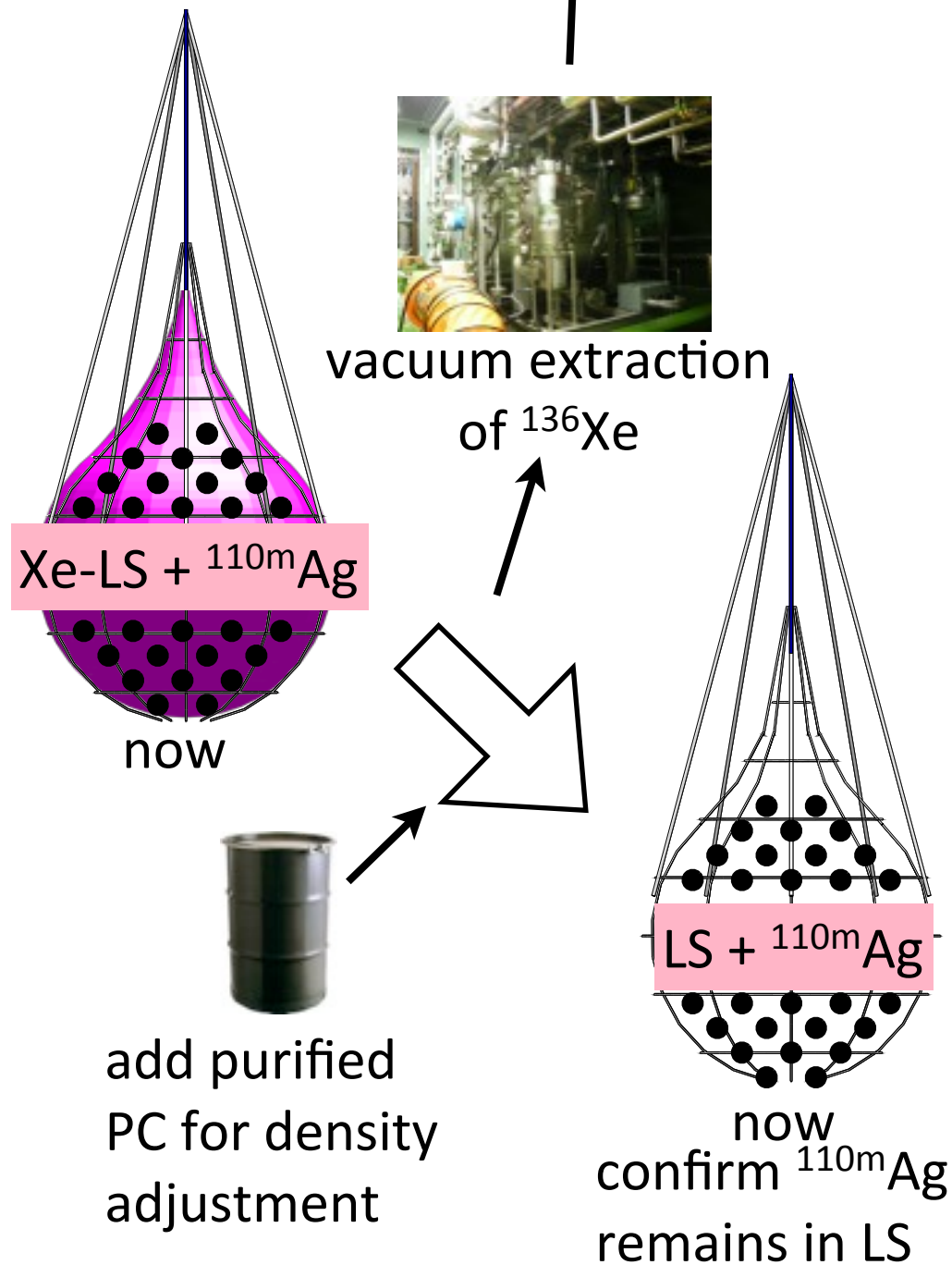
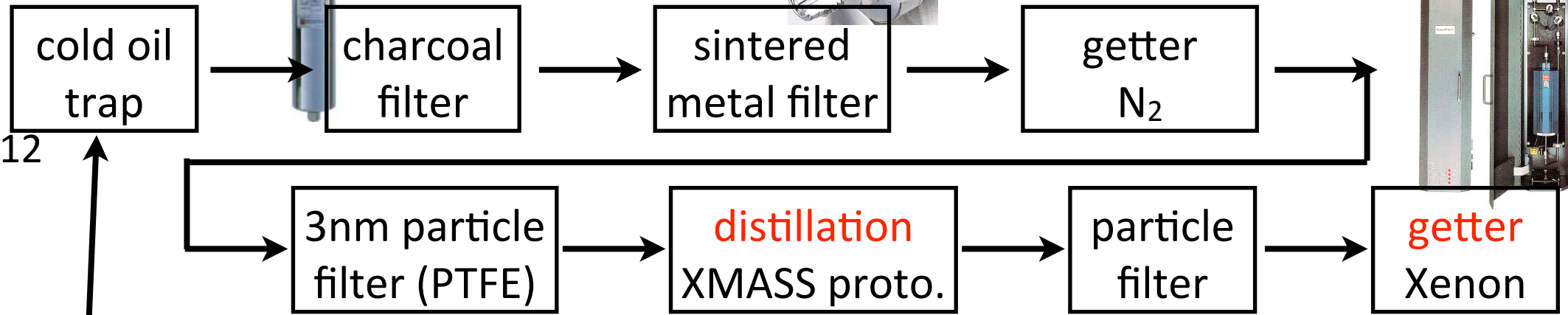
Purification Strategy

June to September, 2012



Purification Strategy

June to September, 2012



Purification Strategy

June to September, 2012

cold oil trap

charcoal filter

sintered metal filter

getter N₂

3nm particle filter (PTFE)

distillation
XMASS proto.

particle filter

getter Xenon

new ¹³⁶Xe



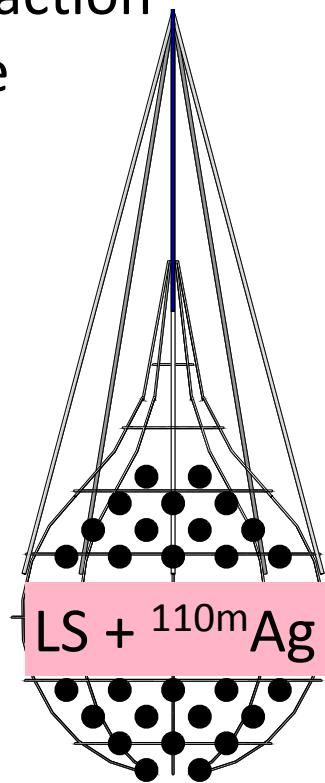
vacuum extraction
of ¹³⁶Xe

Xe-LS + ^{110m}Ag

now



add purified
PC for density
adjustment

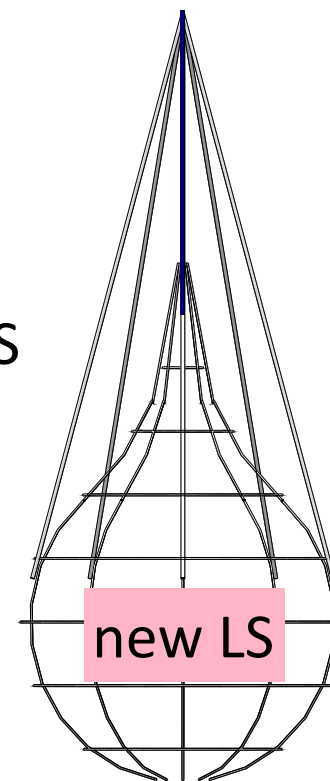


LS + ^{110m}Ag

now
confirm ^{110m}Ag
remains in LS



replace with
new purified LS



new LS

confirm whole ^{110m}Ag
drained

Purification Strategy

June to September, 2012

cold oil trap

charcoal filter

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getter N₂

3nm particle filter (PTFE)

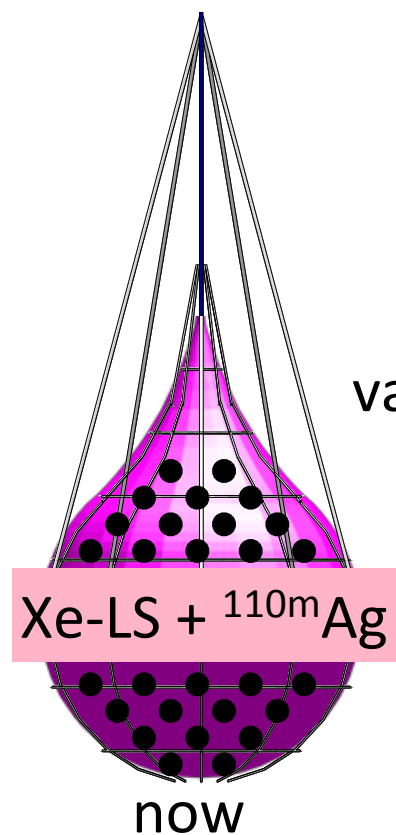
distillation
XMASS proto.

particle filter

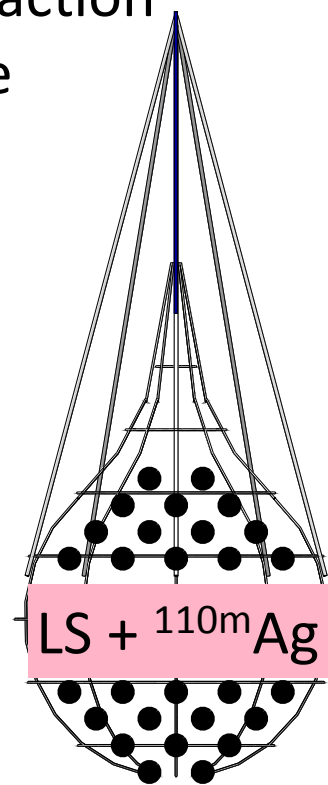
getter Xenon

new purified LS

purified ¹³⁶Xe



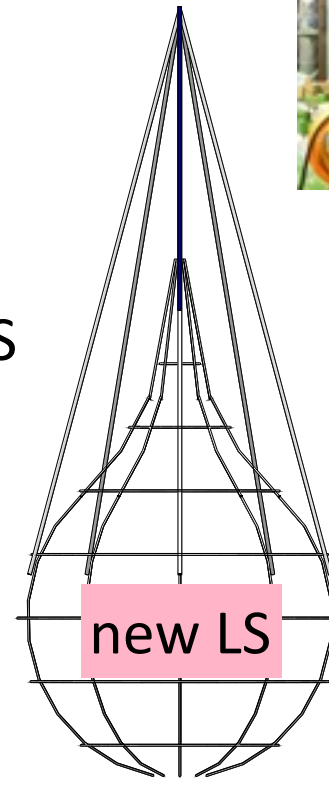
vacuum extraction
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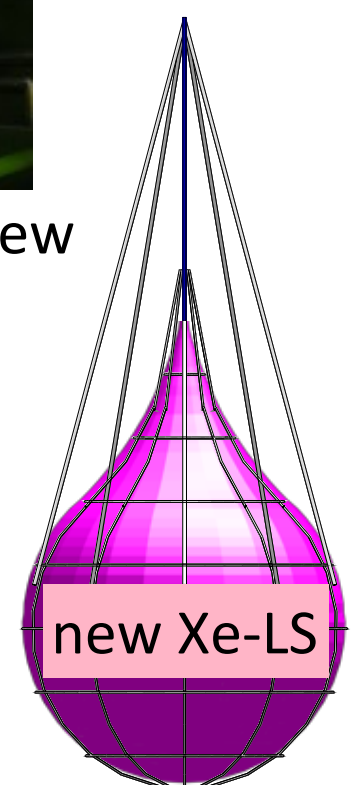
replace with
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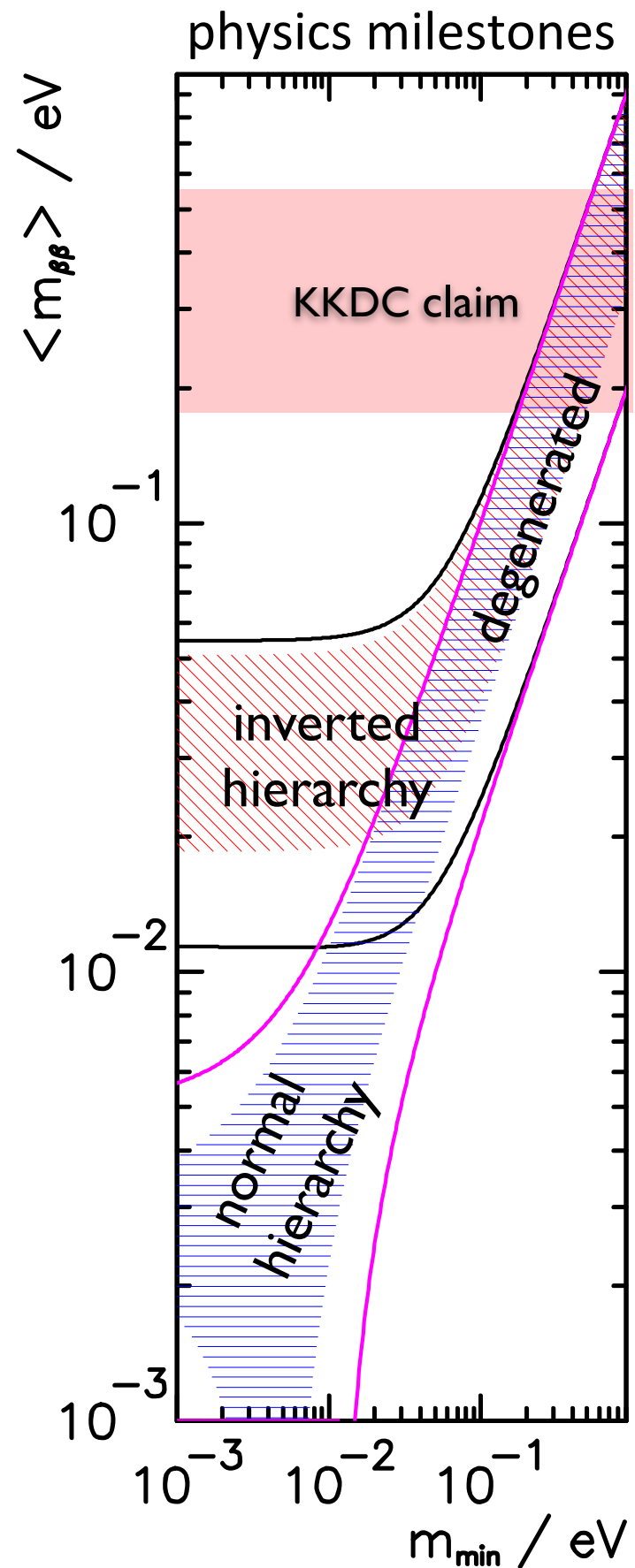


replace with new
purified Xe-LS

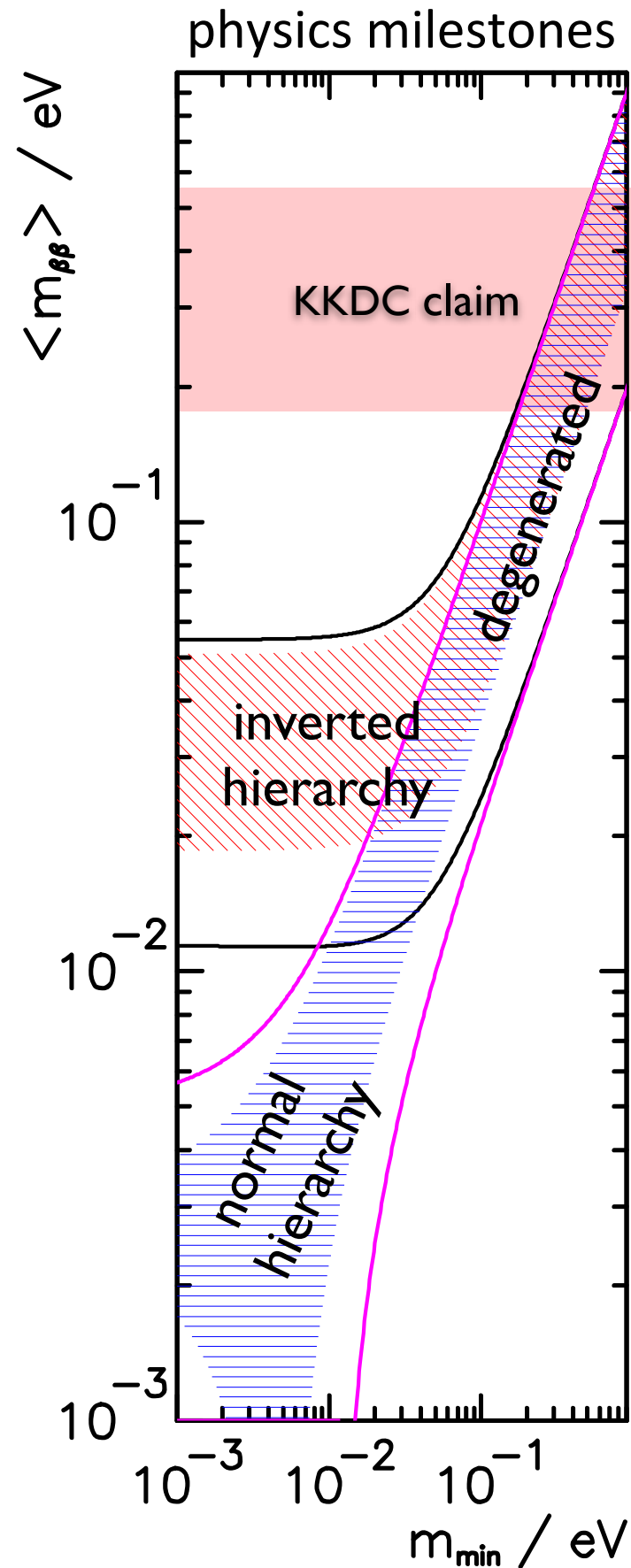


1/100 reduction of
radioactive impurities

Future Prospects continued

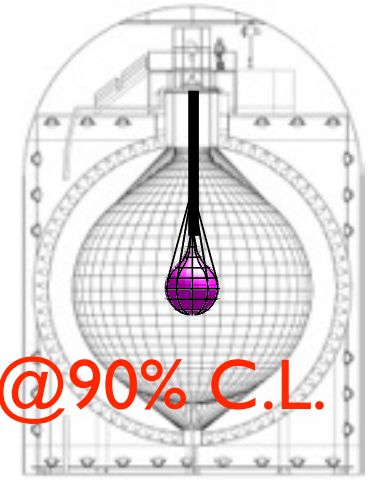


Future Prospects continued

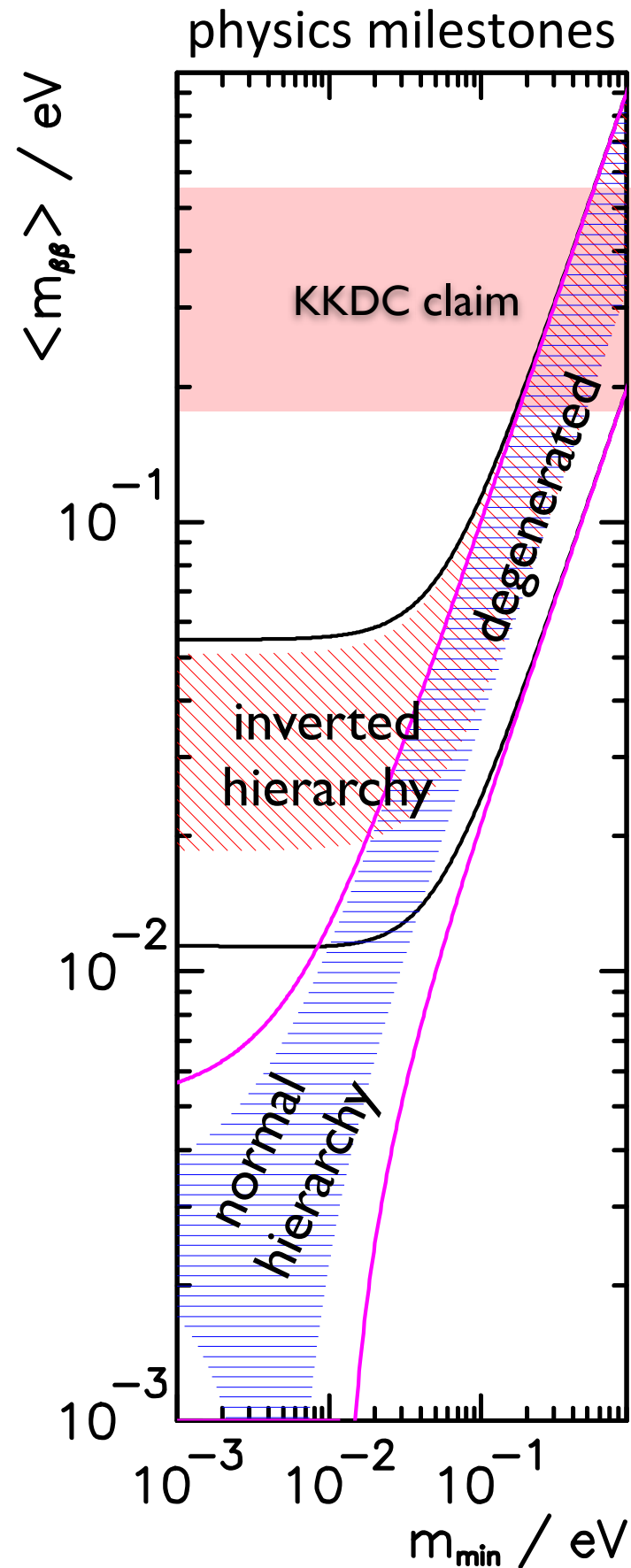


KamLAND-Zen initial 112 days

$$\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54 \text{ eV} @ 90\% \text{ C.L.}$$



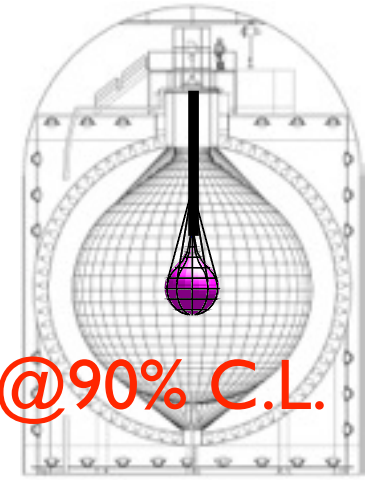
Future Prospects continued



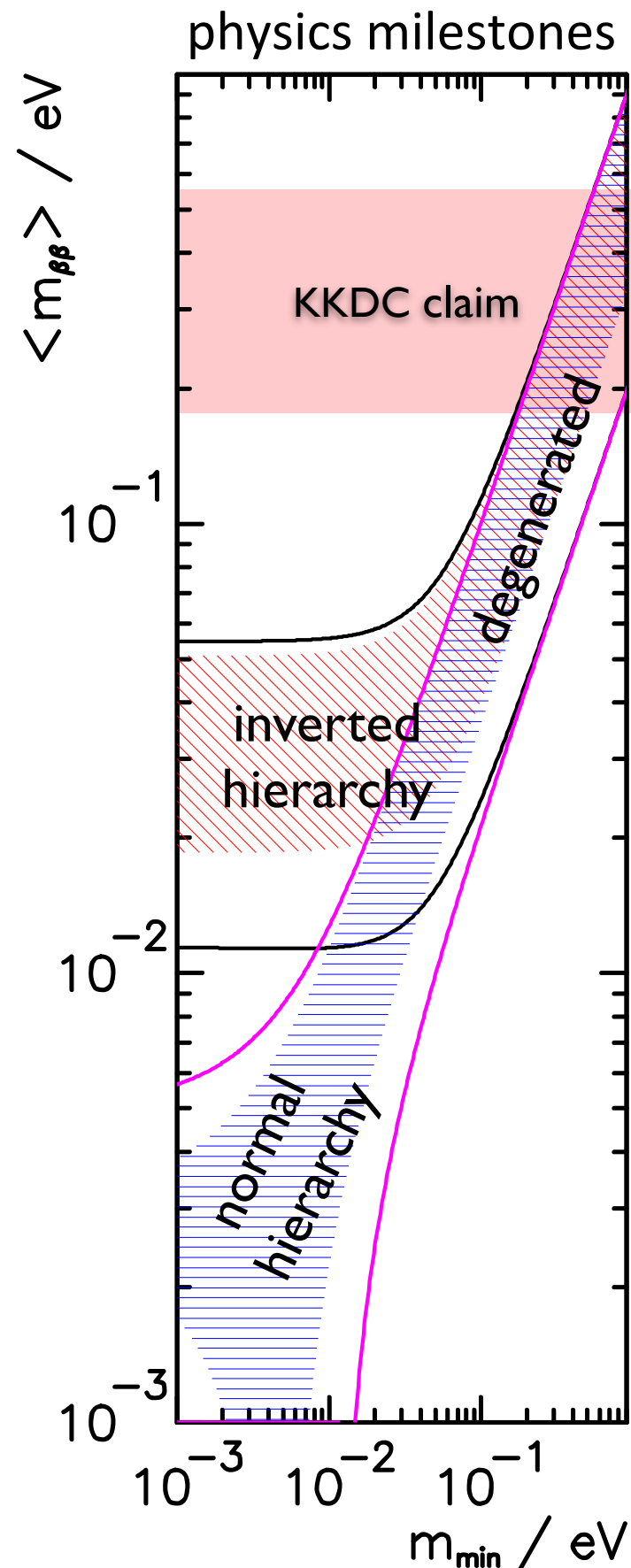
KamLAND-Zen initial 112 days

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KamLAND-Zen ~100 days more data



Future Prospects continued

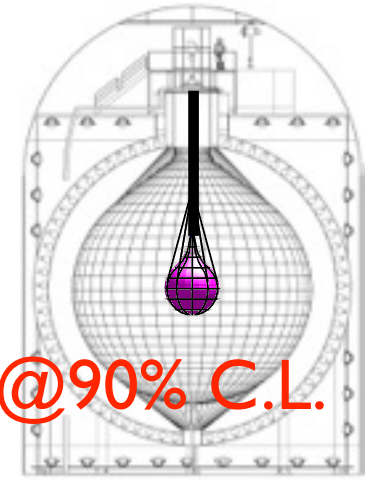


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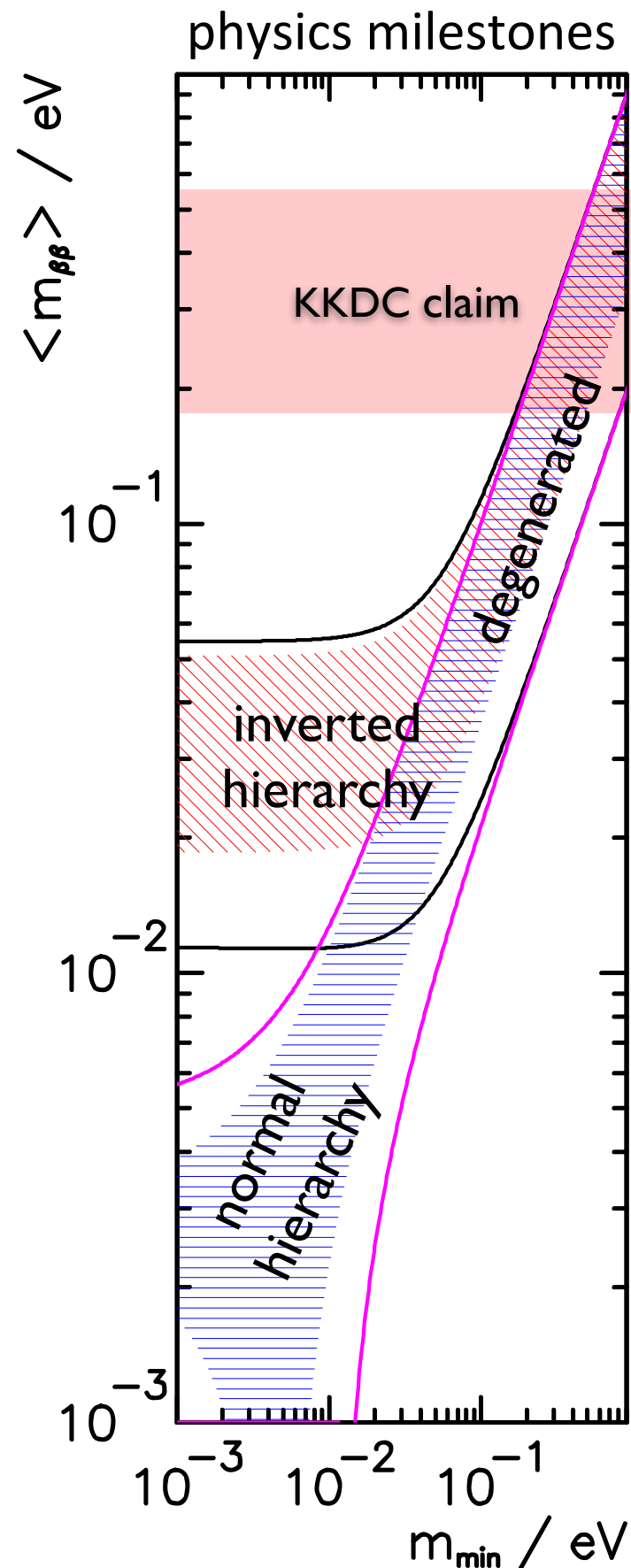
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KamLAND-Zen ~100 days more data

KamLAND-Zen after purification
aiming at 100 times BG reduction



Future Prospects continued



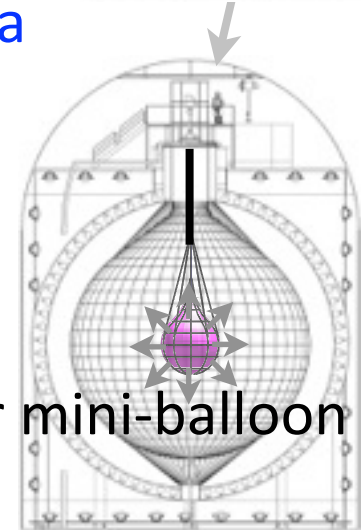
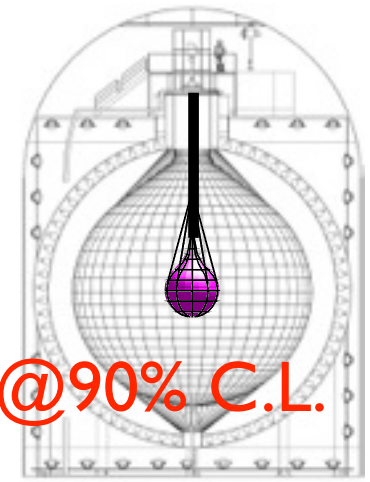
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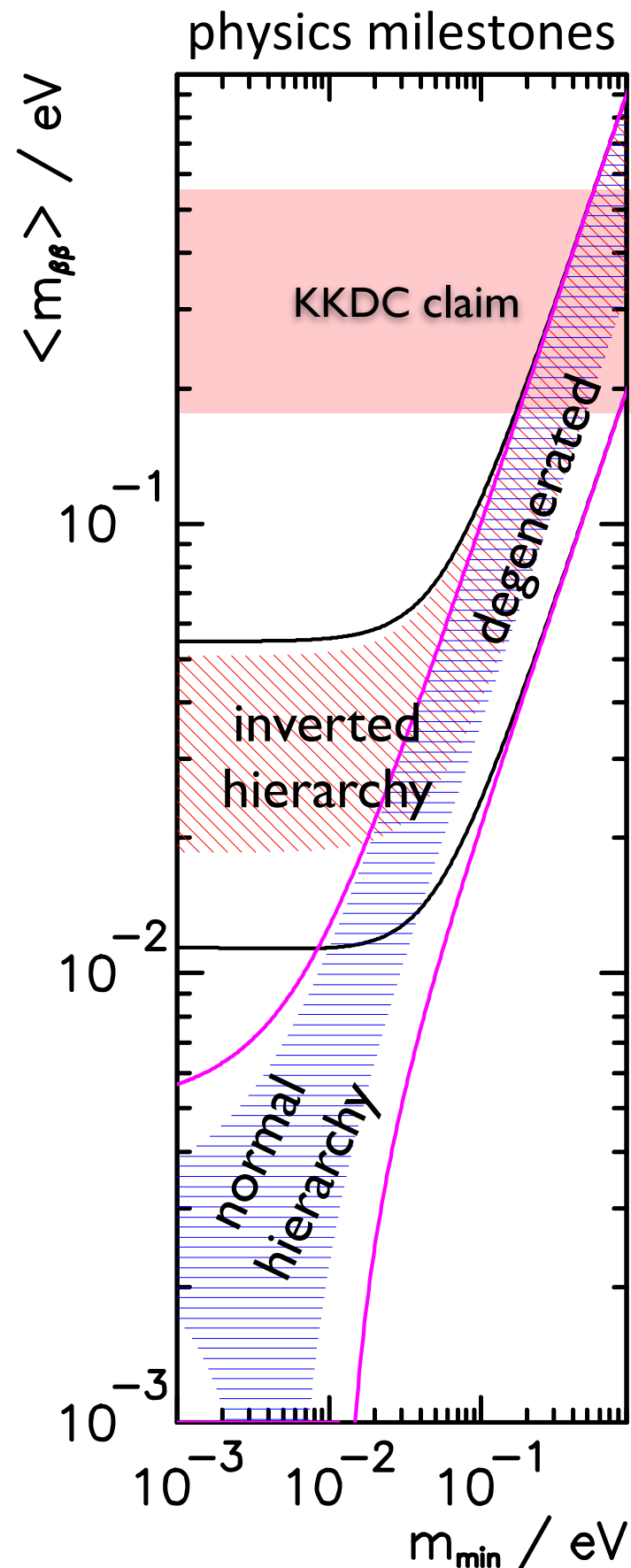
KamLAND-Zen ~100 days more data

KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon



Future Prospects continued



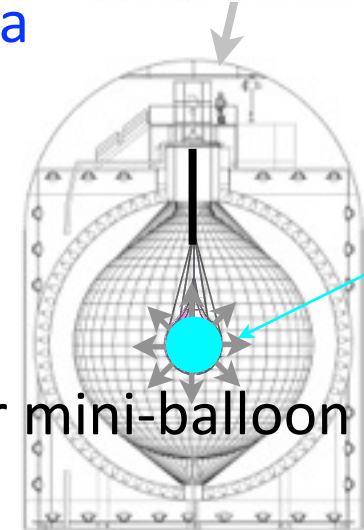
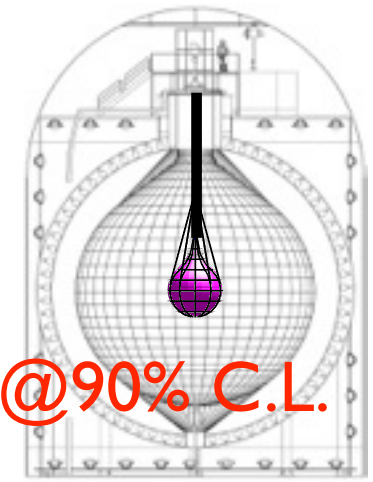
KamLAND-Zen initial 112 days

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KamLAND-Zen ~100 days more data

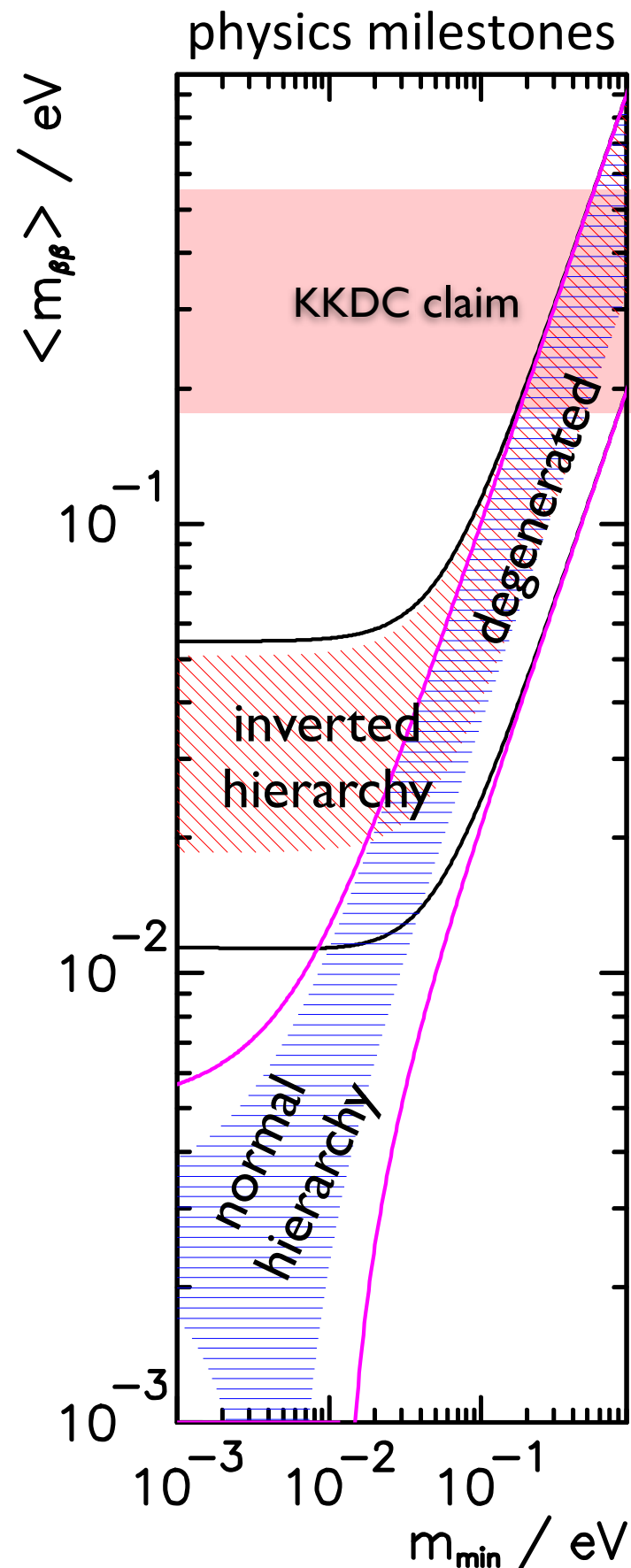
KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon



R&D for
higher Xe
concentration

Future Prospects continued



uncertainty
from NME

to start
planned
proposed

KamLAND-Zen initial 112 days

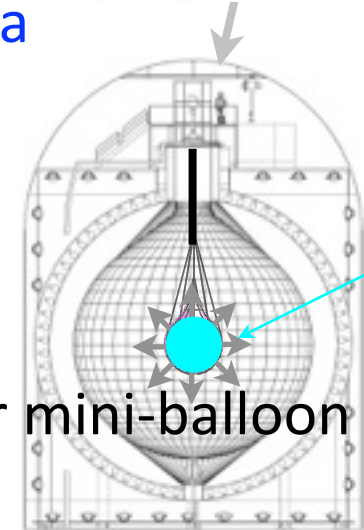
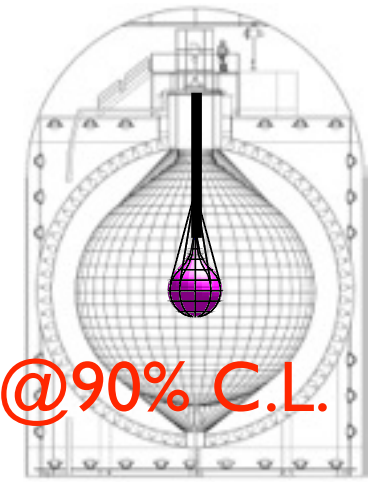
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KamLAND-Zen ~100 days more data

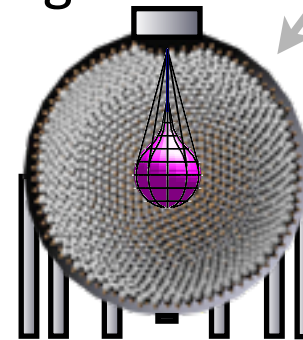
KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon

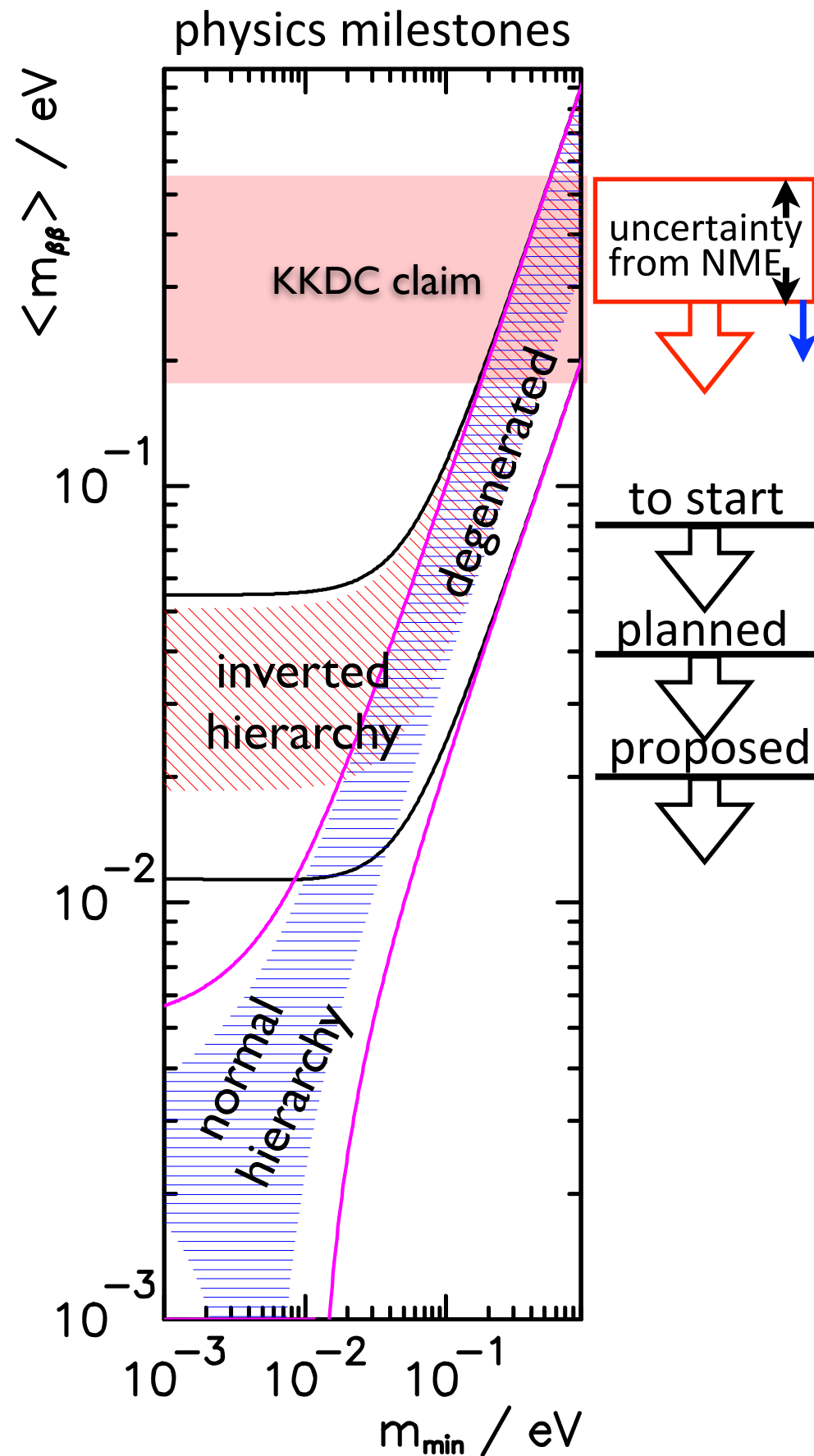
KamLAND2-Zen with brighter LS and light collector
 $\sigma_E(2.6\text{MeV}) \sim 2.5\%$



R&D for
higher Xe
concentration



Future Prospects continued



KamLAND-Zen initial 112 days

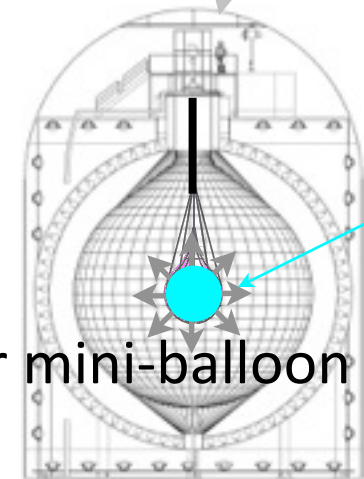
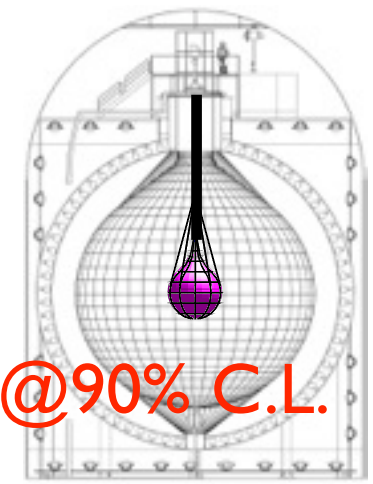
$$\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54 \text{ eV} @ 90\% \text{ C.L.}$$

KamLAND-Zen ~ 100 days more data

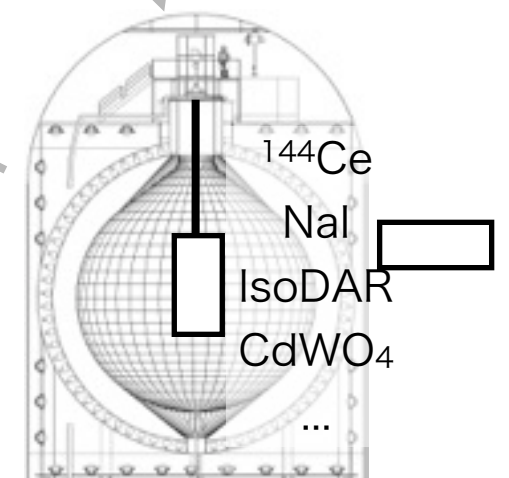
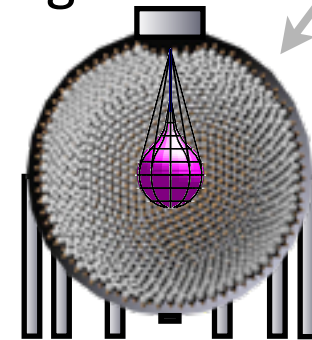
KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon

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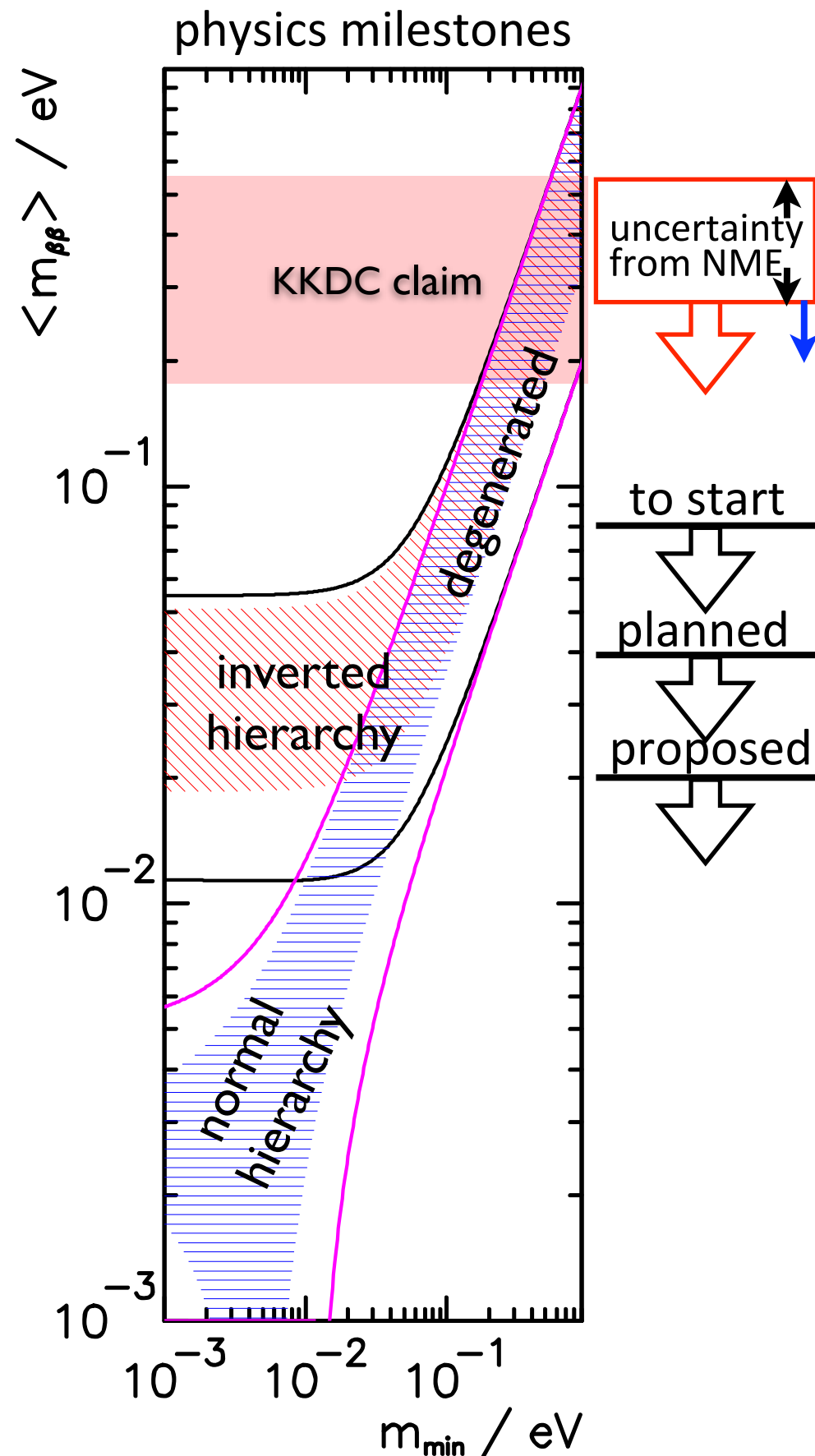


R&D for
higher Xe
concentration



various possibilities
as a low radioactive
background environment

Future Prospects continued



KamLAND-Zen initial 112 days

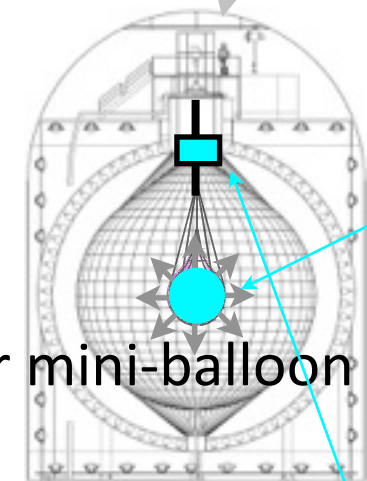
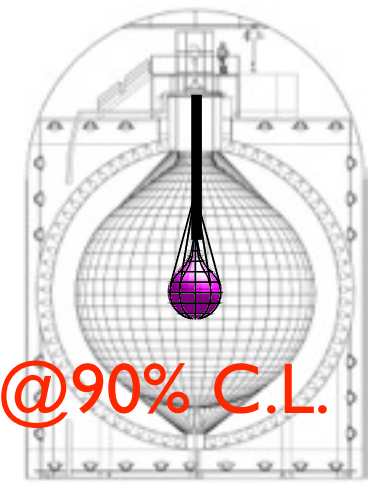
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KamLAND-Zen ~100 days more data

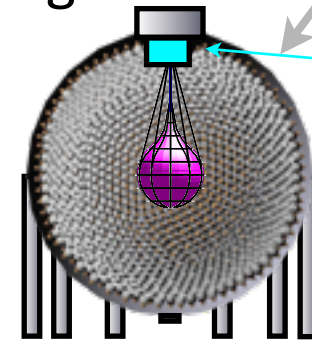
KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon

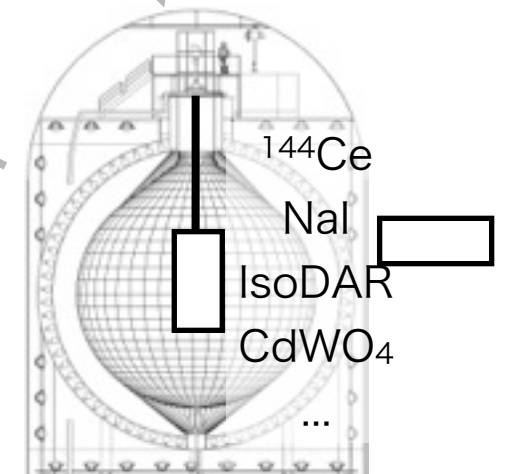
KamLAND2-Zen with brighter LS and light collector
 $\sigma_E(2.6\text{MeV}) \sim 2.5\%$



R&D for
higher Xe
concentration



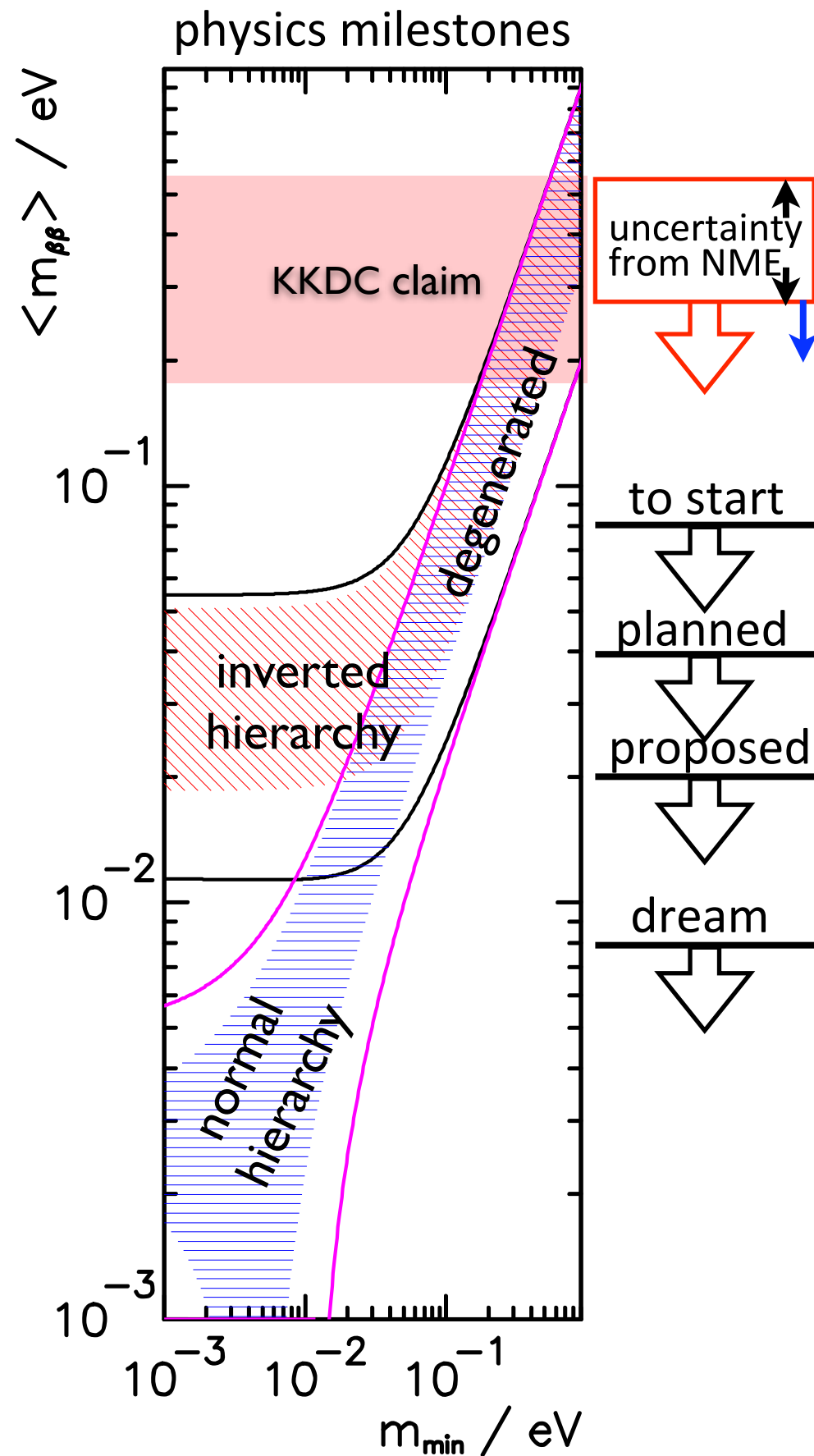
R&D for imaging device
to discriminate β / γ



various possibilities
as a low radioactive
background environment

^{144}Ce
NaI
IsoDAR
 CdWO_4
...

Future Prospects continued



KamLAND-Zen initial 112 days

$$\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54 \text{ eV} @ 90\% \text{ C.L.}$$

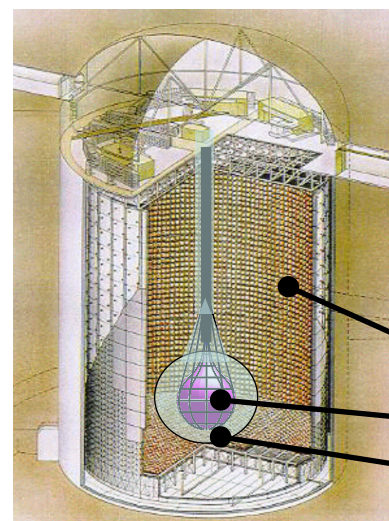
KamLAND-Zen ~100 days more data

KamLAND-Zen after purification
aiming at 100 times BG reduction

KamLAND-Zen 700+kg with cleaner mini-balloon

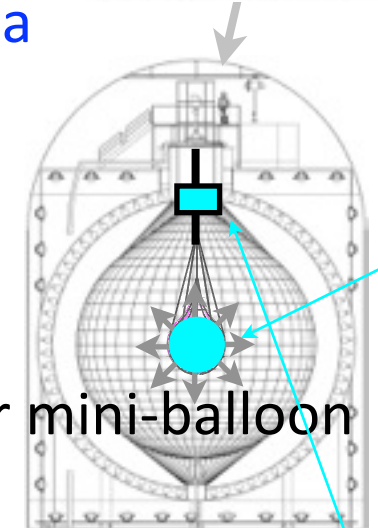
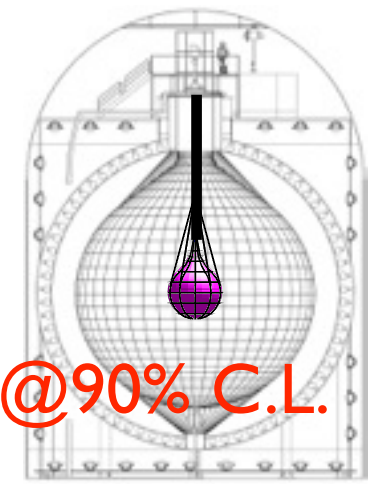
KamLAND2-Zen with brighter LS and light collector
 $\sigma_E(2.6\text{MeV}) \sim 2.5\%$

Super-KamLAND-Zen



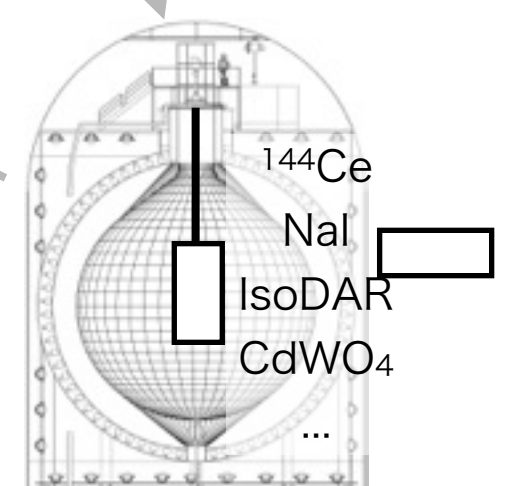
water or LS
Xenon-LS
normal LS

also precise anti-neutrino physics



R&D for
higher Xe
concentration

R&D for imaging device
to discriminate β / γ



various possibilities
as a low radioactive
background environment

Summary

- KamLAND-Zen has started rather quickly and provided initial results from 78 days of data and then updated with 112 days of data (38.6 kg-yr exposure of ^{136}Xe)
 - precise measurement of the $2\nu 2\beta$ half-life
$$T_{1/2}^{2\nu} = 2.30 \pm 0.02(\text{stat}) \pm 0.12(\text{syst}) \times 10^{21} \text{ years}$$
 - lower limit of the $0\nu 2\beta$ half-life
$$T_{1/2}^{0\nu} > 6.2 \times 10^{24} \text{ years at 90\% C.L.}$$
 corresponding to $\langle m_{\beta\beta} \rangle < 0.26 \sim 0.54 \text{ eV at 90\% C.L.}$
 - the most stringent limit on the Majoron coupling constants covering the gap of the excluded region from NEMO-3 and SN1987A
$$\langle g_{ee} \rangle < (0.8 - 1.6) \times 10^{-5} \text{ at 90\% C.L.}$$

“ordinary” Majoron-emission is not dominant anymore
with respect to the light Majorana neutrino exchange in the inverted hierarchy scheme
- KamLAND-Zen demonstrated a validity of using the low radioactivity environment of neutrino detector for a rare phenomena study.
- Backgrounds are better understood and effective purification is about to start aiming at a factor 100 reduction of radioactive impurities.
Sensitivity will be drastically improved after the purification.

KamLAND-Zen collaboration

still growing

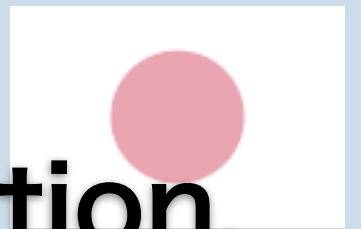
- **Research Center for Neutrino Science, Tohoku University**
A. Gando, Y. Gando, H. Hanakago, H. Ikeda, K. Inoue, R. Kato, M. Koga, S. Matsuda, T. Mitsui, T. Nakada, K. Nakamura, A. Obata, A. Oki, Y. Ono, I. Shimizu, J. Shirai, A. Suzuki, Y. Takemoto, K. Tamae, K. Ueshima, H. Watanabe, B.D. Xu, S. Yamada, H. Yoshida
- **Kavli IPMU, University of Tokyo** A. Kozlov
- **Osaka University** S. Yoshida
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- **Colorado State University** B.E. Berger
- **University of Tennessee** Y. Efremenko
- **TUNL** H.J. Karwowski, D.M. Markoff, W. Tornow
- **University of Washington** S. Enomoto
- **NIKHEF and University of Amsterdam** M.P. Decowski



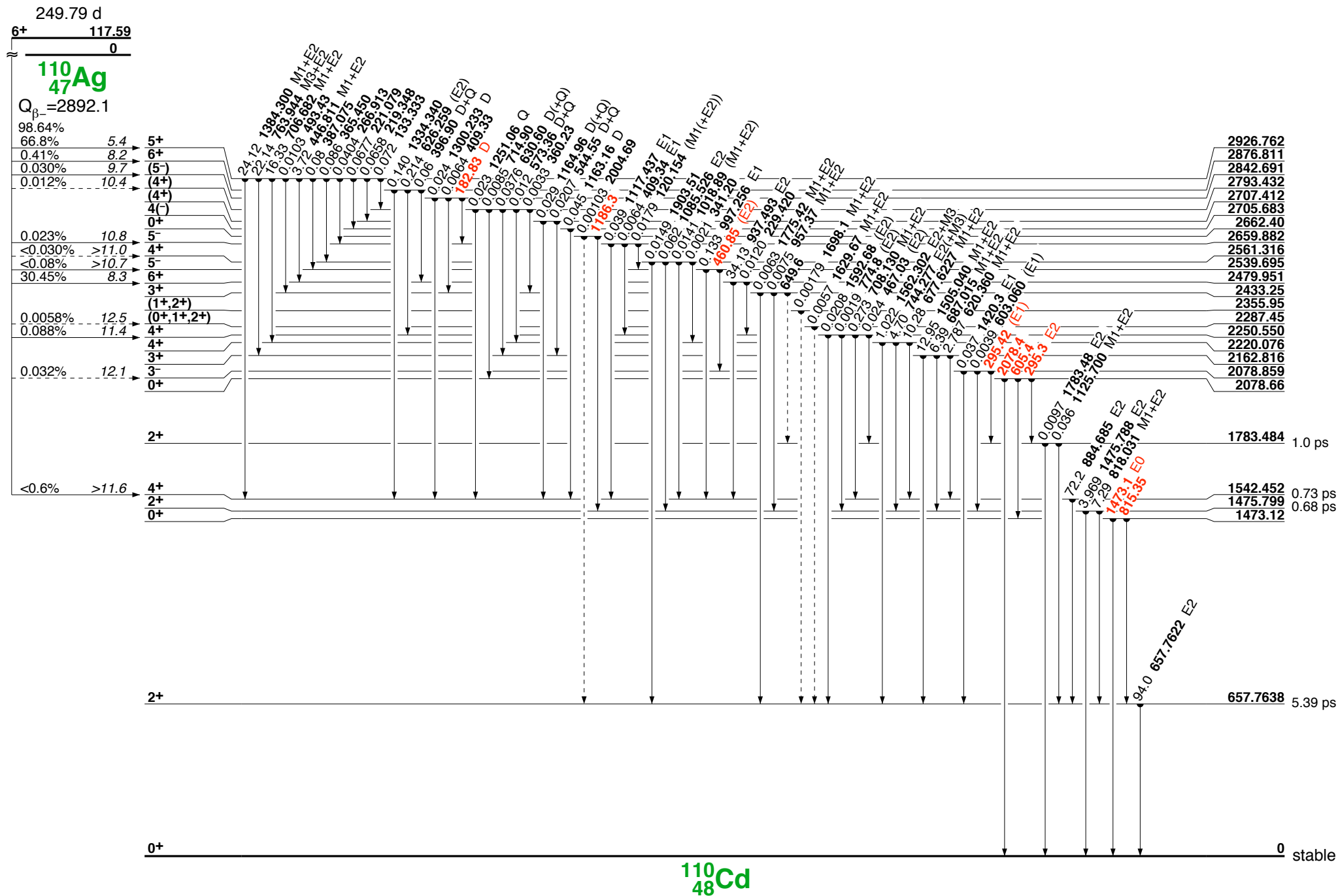
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still growing

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Thank you very much for your attention.



¹¹⁰₄₈Cd

