Double beta decay experiments

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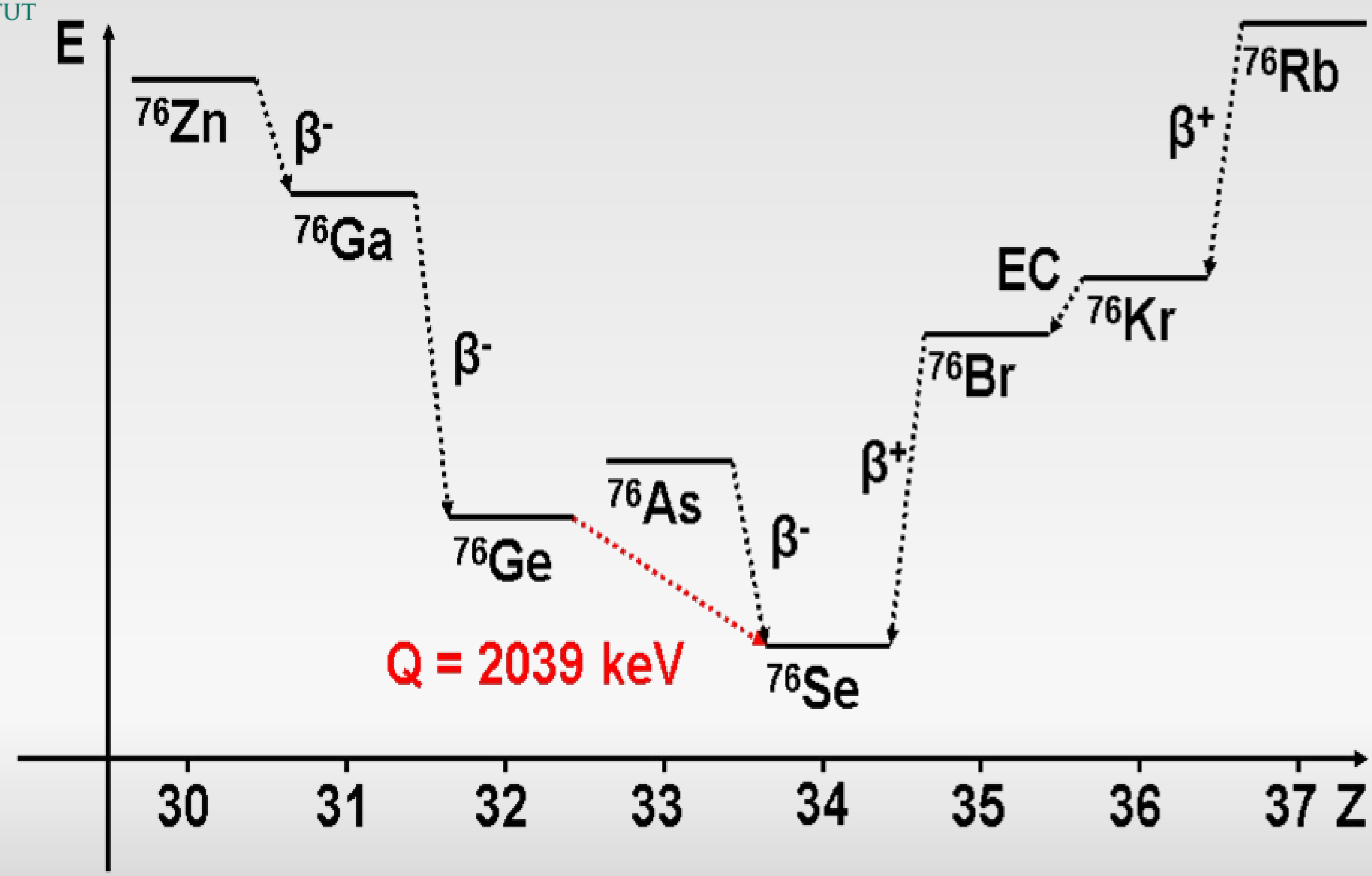
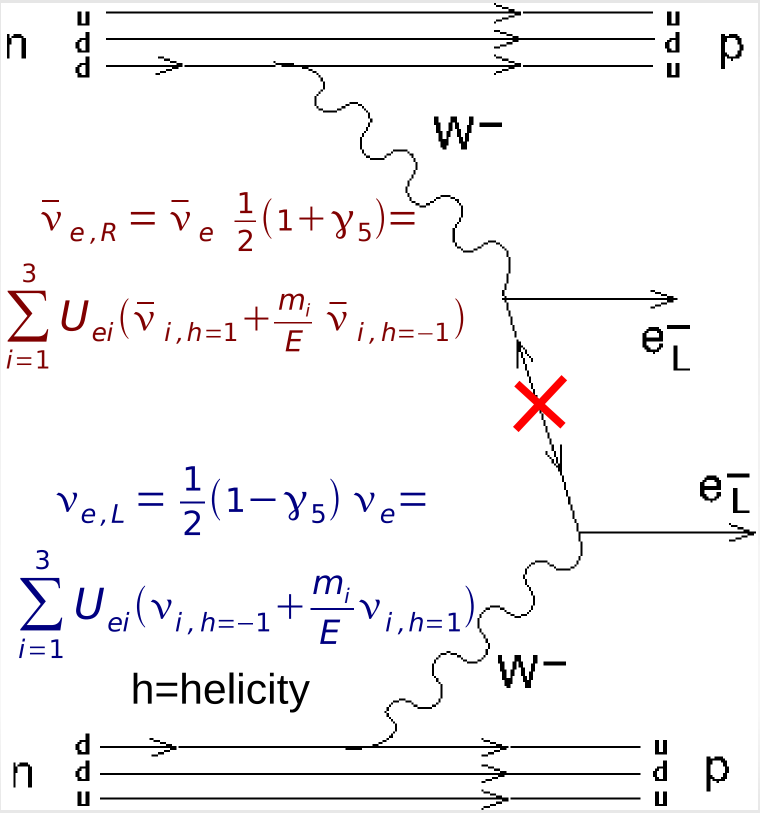


Motivation for 0νββ

Baryon number (B) & Lepton number (L) are accidentally conserved in Standard Model
B is violated (baryogenesis) → expect L violation

Most SM extensions predict $\nu = \bar{\nu}$ →
neutrinoless double beta decay 0νββ should exist: (A,Z) → (A,Z+2) + 2e, ΔL=2

other mechanisms (SUSY, W_R, ...) can cause 0νββ ➔ L violation at LHC, ...
(W. Rodejohann, Nucl. Phys. Proc. Suppl. 229-232 (2012) 113)



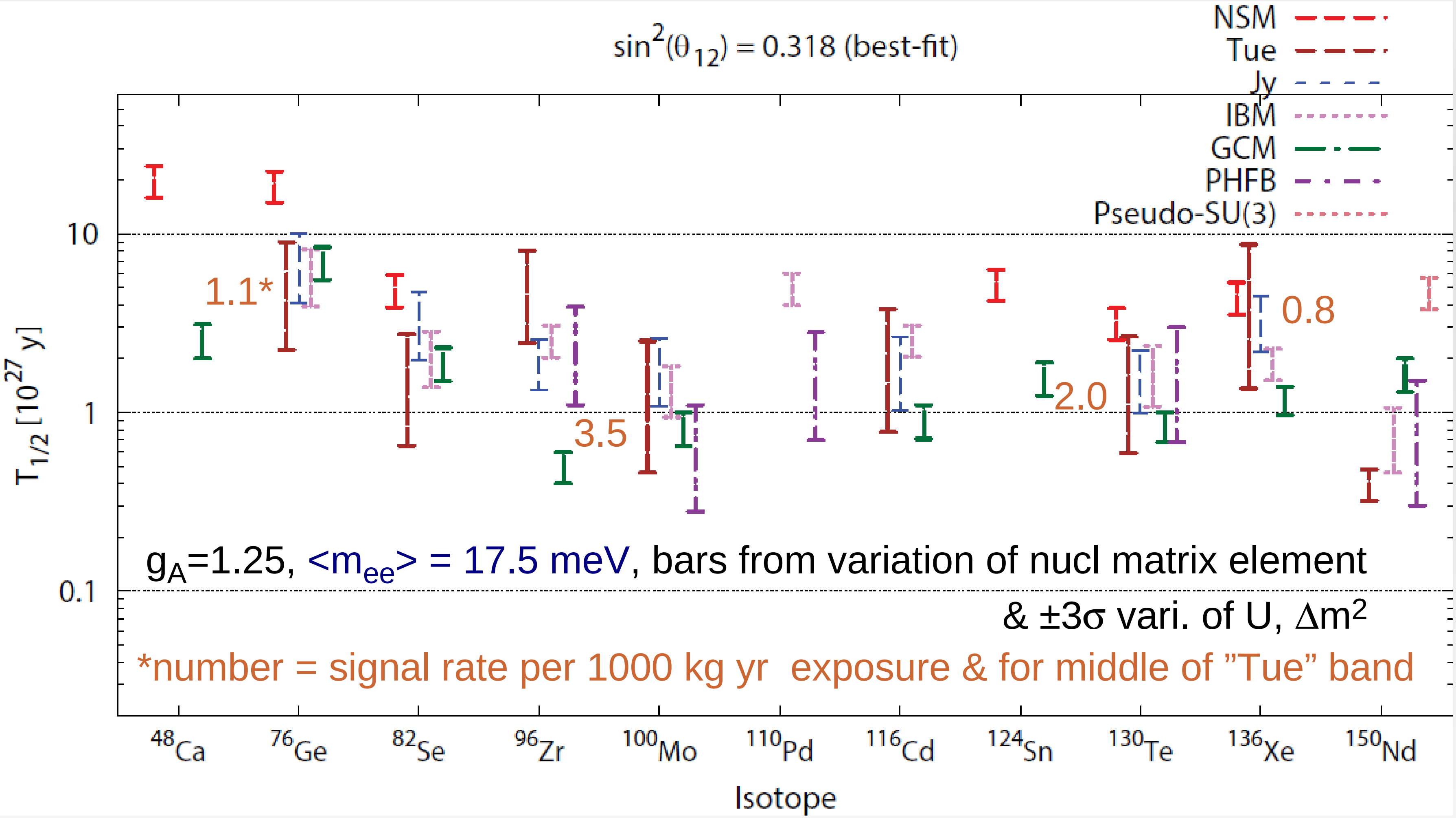
$$\langle m_{ee}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right| = \left||U_{e1}|^2 m_1 + |U_{e2}|^2 e^{i\alpha_1} m_2 + |U_{e3}|^2 e^{i\alpha_2} m_3\right|$$

$$\frac{1}{T_{1/2}^{0\nu}} = g_A^4 G^{0\nu} \left|M'^{0\nu}\right|^2 \frac{\langle m_{ee}\rangle^2}{m_e^2}$$

$T_{1/2}^{0\nu}$ = measured experimentally
g_A = axial vector coupling, assume = 1.25
$G^{0\nu}$ = phase space factor ~ Q^5
$M^{0\nu}$ = nuclear matrix element
m_e = electron mass

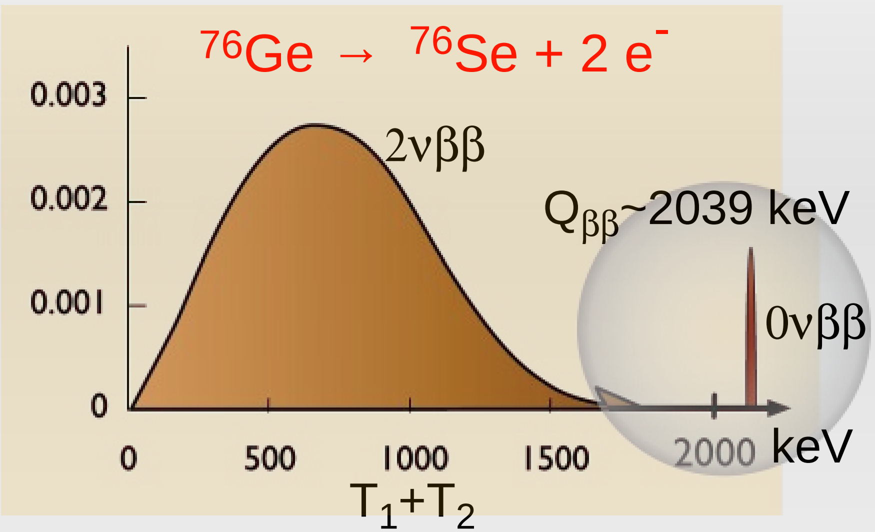
need $M^{0\nu}$ to understand physics mechanism

Expected $T_{1/2}$ for different matrix elements

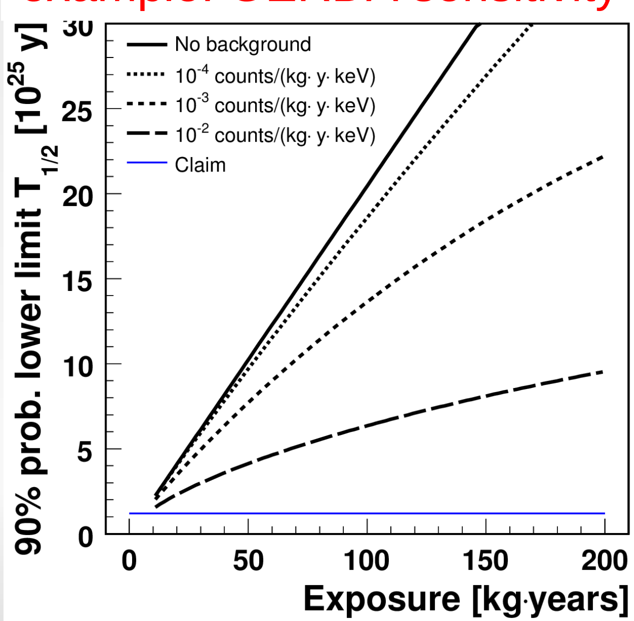


taken from DOE Nuclear Science Advisory Committee report on 0νββ (24 April 2014)
adopted from A. Dueck, W. Rodejohann and K. Zuber, Phys. Rev. D83 (2011) 113010

experimental considerations



example: GERDA sensitivity



How to measure energy?

- (Ge) diode (ionization): 0.1-0.2% FWHM
- bolometer (heat) 0.2% FWHM
  - NTD Ge resistor, TES, MMC } thermometer
- TPC (ionization + light), 3% liquid
  <1% gas FWHM
- solid or liquid scintillator, 5-10% FWHM

How to reduce background?

- radiopure materials: detector + support
- det. purification (for liquids + gases)
- clean shielding materials (water, liquids)
- high $Q_{\beta\beta}$ value
- active veto
- "particle identification" (tracking, pulse shape, light & heat, …)
- good energy resolution

Overview experiments

Name	Nucleus	Mass	Method	Location	Time
Current experiments (under construction or running)					
GERDA I/II	^{76}Ge	15/35	ionization	LNGS	2011/15
Majorana Demonstrator	^{76}Ge	30	ionization	SURF	2015
EXO200	^{136}Xe	170	liquid TPC	WIPP	2011
Cuore0/Cuore	^{130}Te	10/600	bolometer	LNGS	2013/15
Kamland-Zen	^{136}Xe	400	liquid scint.	Kamioka	2011
SNO+	^{130}Te	2340	liquid scint.	Sudbury	2015
NEXT	^{136}Xe	100	gas TPC	Canfranc	2015

R&D, proto-typing phase					
Candles III	^{48}Ca	0.35	scint crystal	Oto Cosmo	2011
DCBA	^{150}Nd	32	tracking		
Cobra	^{116}Cd		solid TPC	LNGS	2013
SuperNEMO	^{82}Se	7/100-200	track./calor.	Modane	2015/-
Lucifer	^{82}Se		bolom+scint	LNGS	
AMoRE	^{100}Mo		bolom+scint	YangYang	
LUMINEU	^{100}Mo		bolom+scint.		

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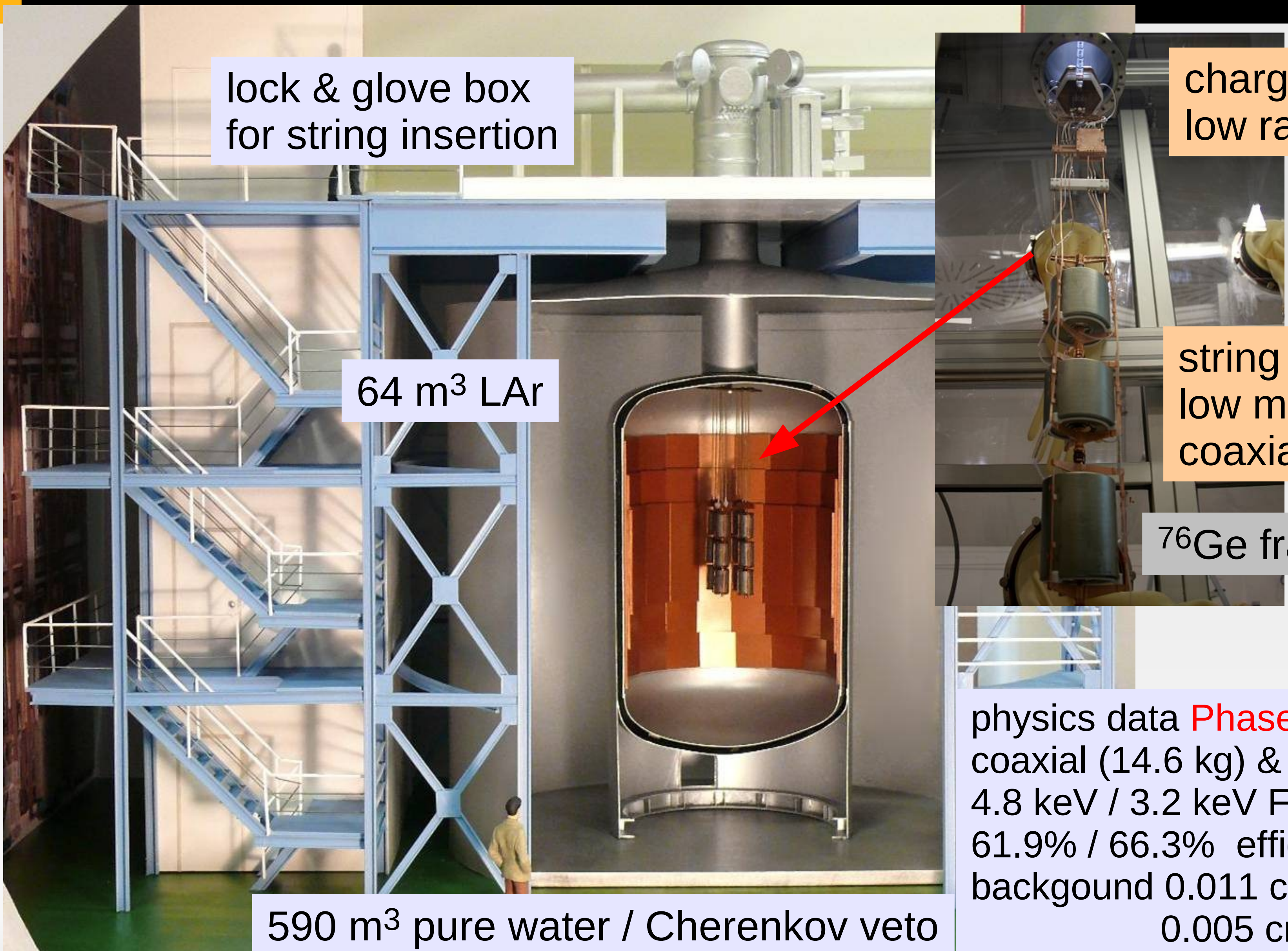
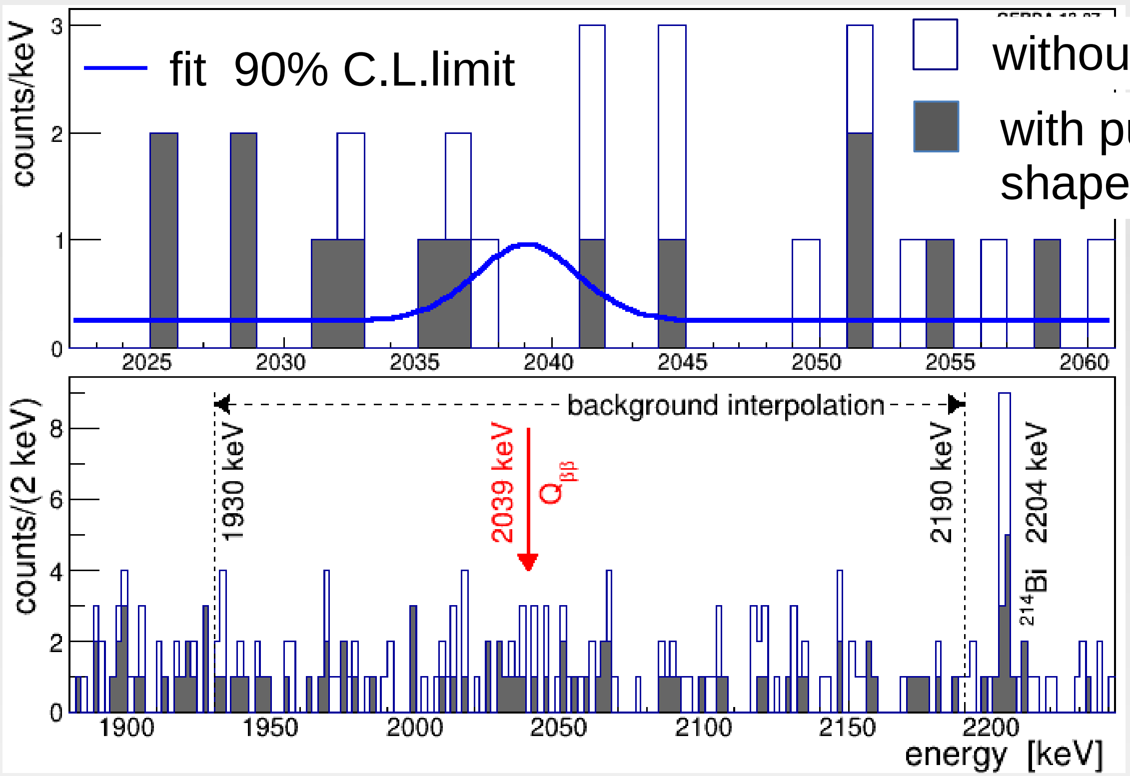
Gerda



^{76}Ge fraction: 7% → 86%

physics data Phase I 2011-13:
coaxial (14.6 kg) & BEGe (3 kg) det
4.8 keV / 3.2 keV FWHM coax/BEGe
61.9% / 66.3% efficiency coax/BEGe
backgound 0.011 cnt/(keV kg yr) coax
0.005 cnt/(keV kg yr) BEGe

Gerda result Phase I



events ±20 keV blinded

after calibration+selection finished
→ unblinding at meeting
in Dubna in June 2013

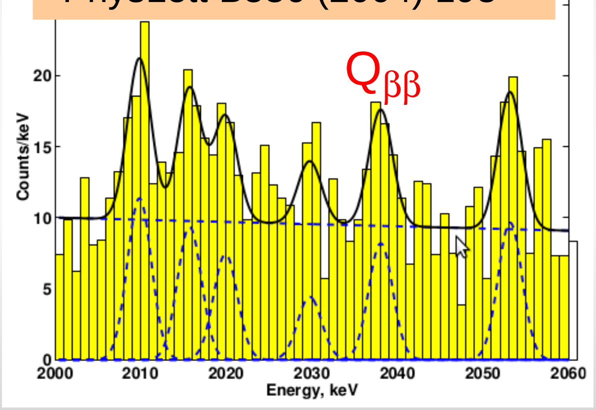
exposure 21.6 kg yr
backgr. 0.01 cnt/(keV kg yr)
after pulse shape cut

$$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\,\text{yr (90\% C.L.)}$$

(sensitivity = 2.4 10^{25} yr)

PRL 111 (2013) 122503.

Klapdor-Kleingrothaus et al
PhysLett B586 (2004) 198

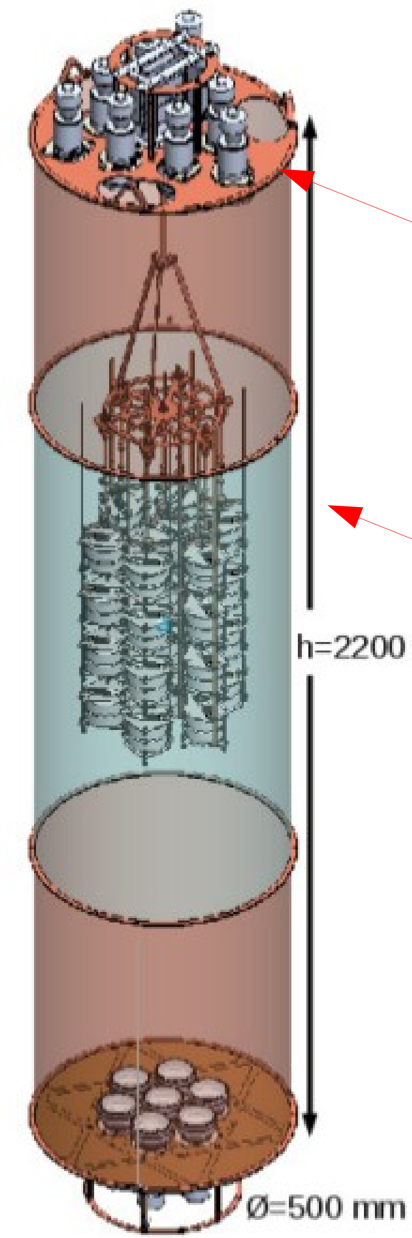


claimed signal: GERDA should see 5.9±1.4 0νββ events in ±2σ interval above background of 2.0±0.3

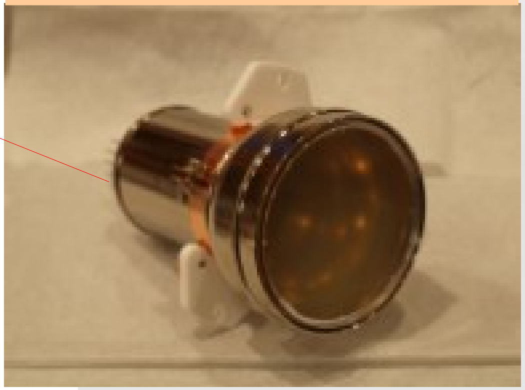
probability p($N^{0\nu}$=0 | H_1=signal+bkg) = 1%, claim ruled out @ 99%

(GERDA best fit signal count $N^{0\nu}$ = 0)

Gerda Phase II

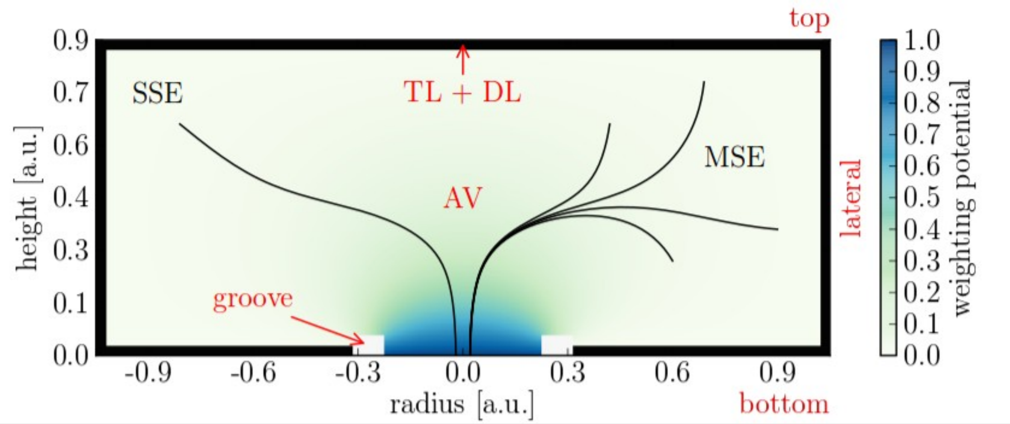


LAr scintillation veto

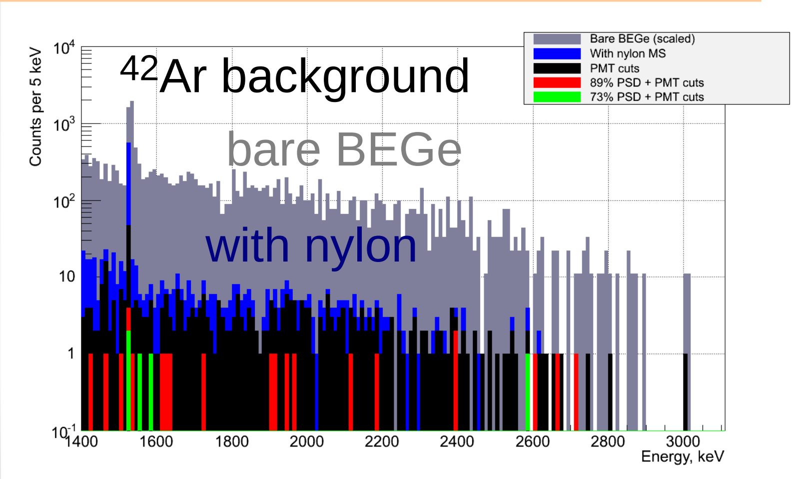


detector mass 2x
background 0.1x
start winter 2014/15

new detector type with better pulse shape discr.
detector support, electronics, contacting

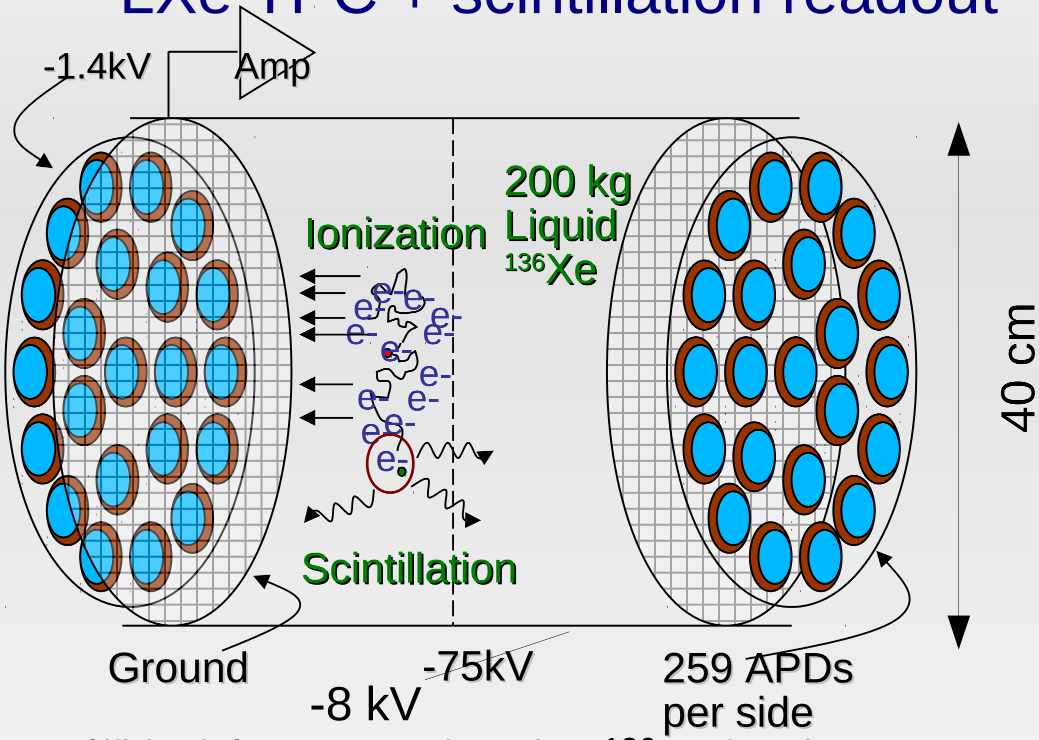


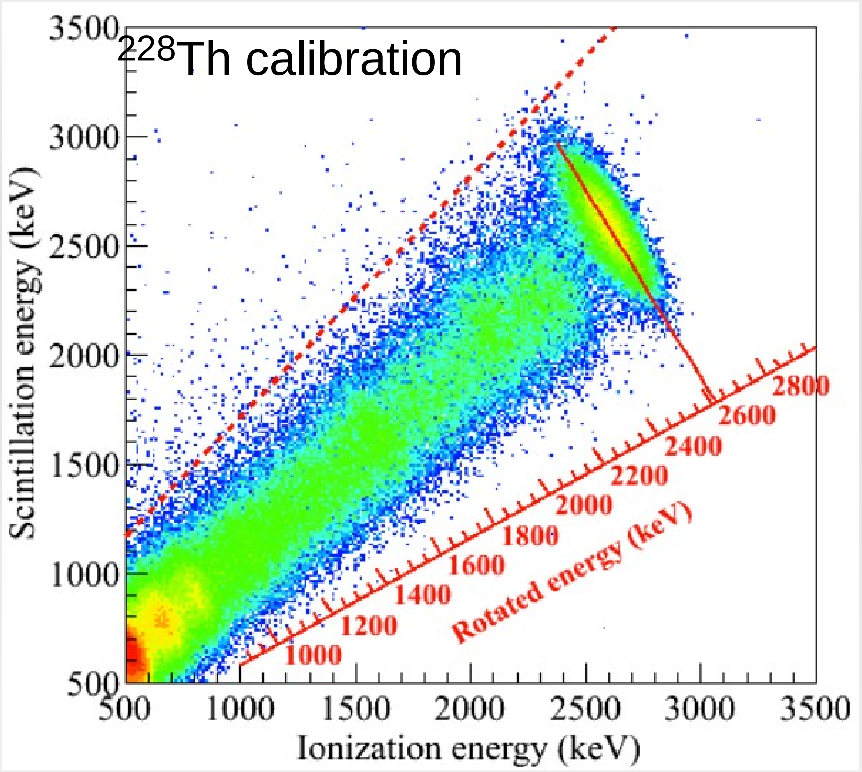
mitigation ^{42}Ar background:
nylon cylinder around detector string



EXO-200

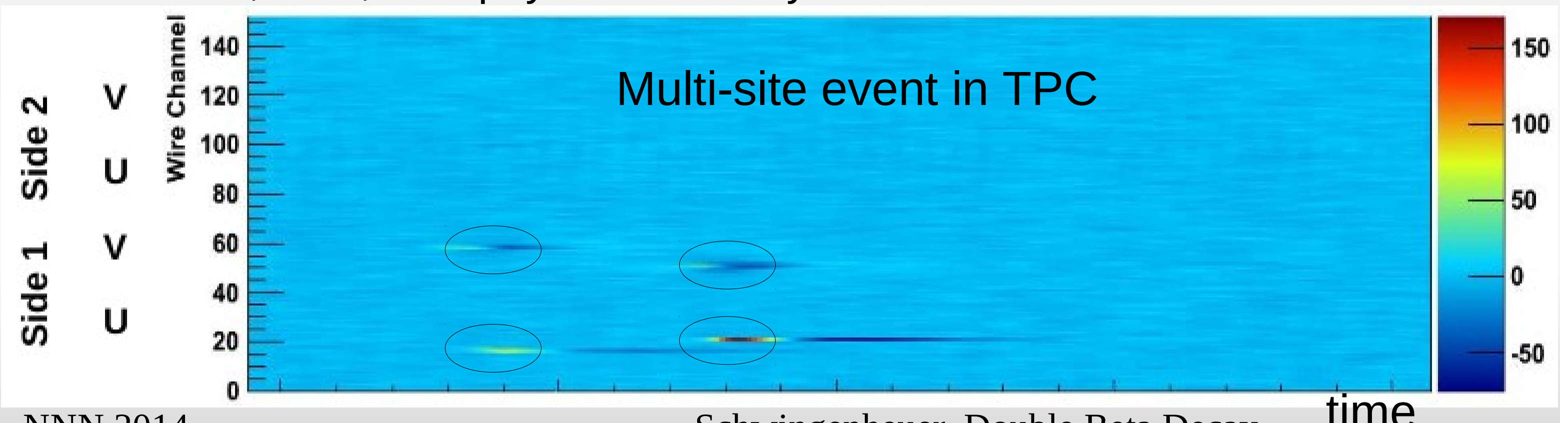
LXe TPC + scintillation readout





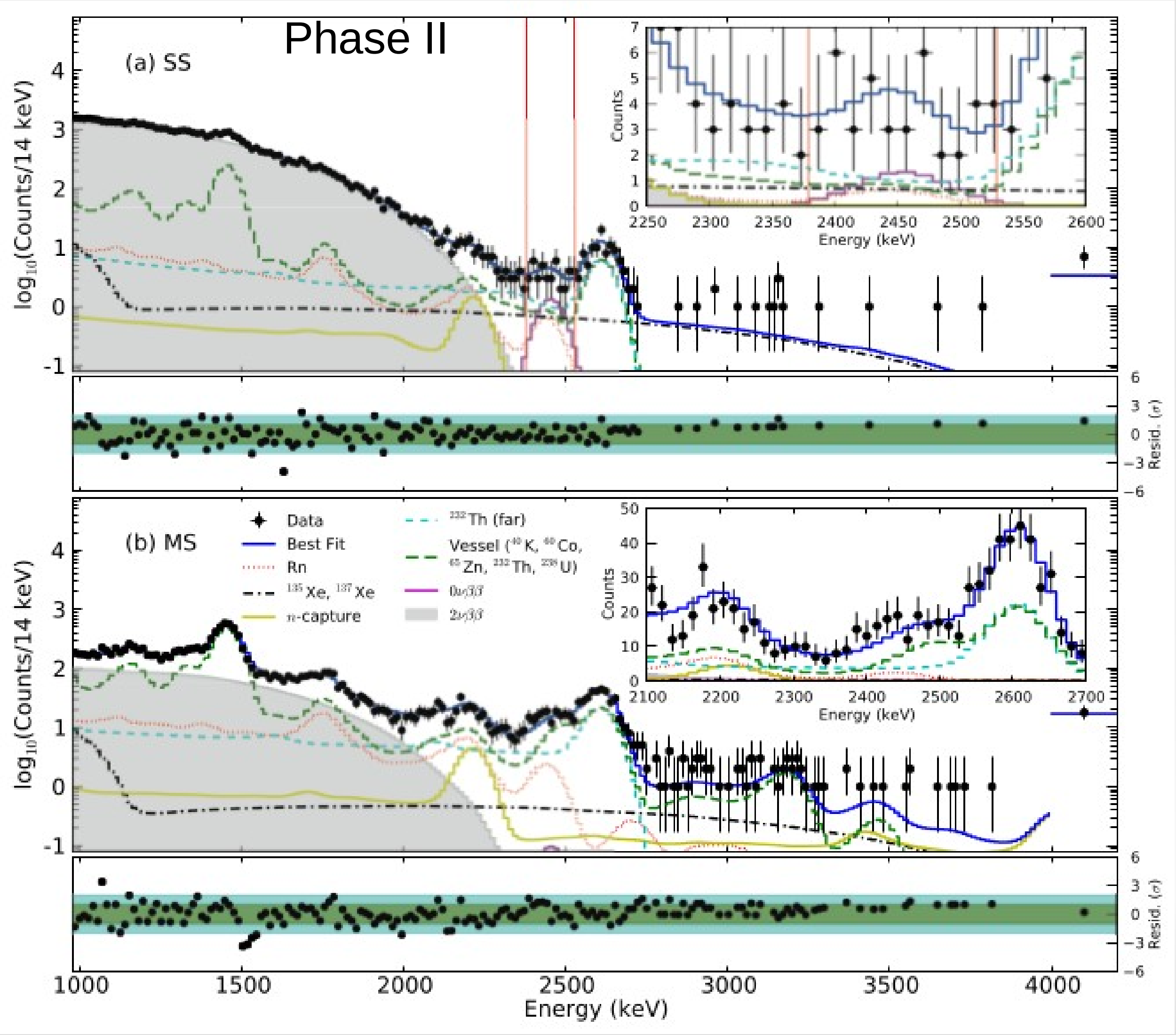
total/fiducial mass 160/100 kg, ^{136}Xe fraction 80.6%
located in WIPP, USA, start physics data May 2011

FWHM for 0νββ ~88 keV @ $Q_{\beta\beta}$



EXO-200

Phase I: 120.7 live days (58% live time), background 0.18 cnt / ((kg fiducial ^{136}Xe) yr FWHM)
Phase II: 447.6 live days (84% live time), $0\nu\beta\beta$ efficiency 84.6%
since Feb 2014: due to fire & airborne radiological event in WIPP stop of data taking



Phase I: PRL 109 (2012) 032505
find/expect 1/4.1 evt @ $Q_{\beta\beta}$ $\pm 1\sigma$

$$T^{0\nu}_{1/2} > 1.6\cdot 10^{25}\ yr\,(@\ 90\ \ C.L.)$$

(sensitivity 1.0 10^{25} yr)

Phase II: Nature 510 (2014) 229-234
find/expect 39/31.1 evt @ $Q_{\beta\beta}$ $\pm 2\sigma$

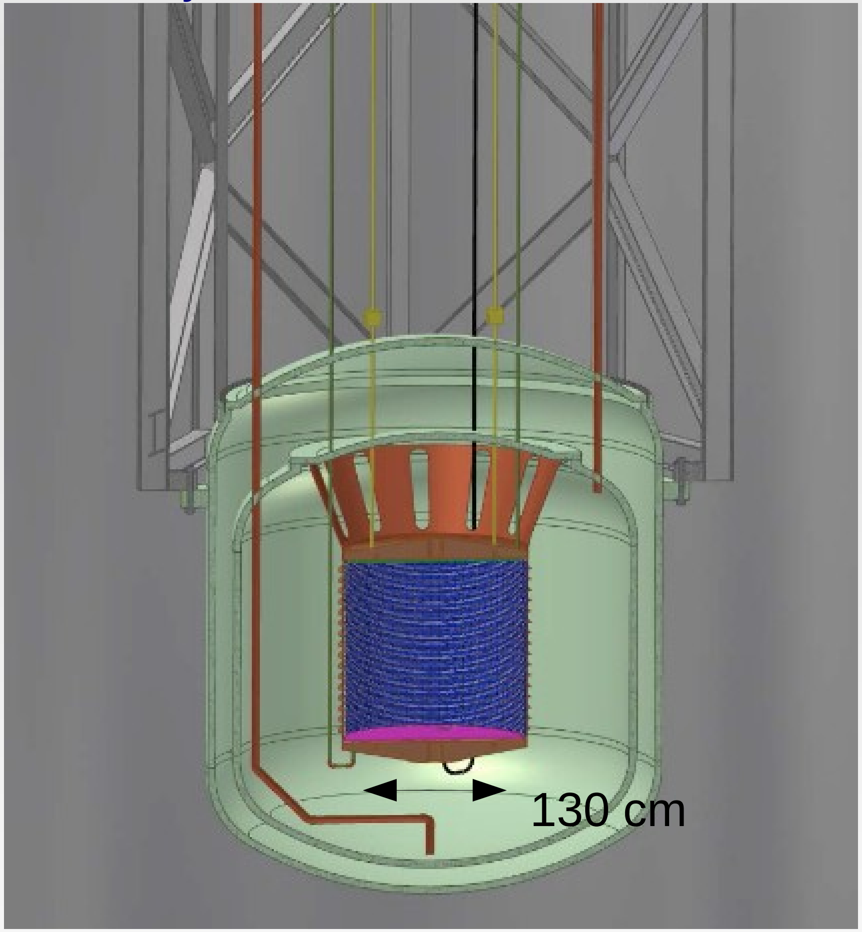
$$T^{0\nu}_{1/2} > 1.1\cdot 10^{25}\ yr\,(@\ 90\ \ C.L.)$$

(sensitivity 1.9 10^{25} yr)

sensitivity after 4 more years of live time ~ 6 10^{25} yr

nEXO proposal

LXe cryostat + TPC in water volume



n(ext)EXO: 5 t of liquid ^{enr}Xe TPC @ SNOlab

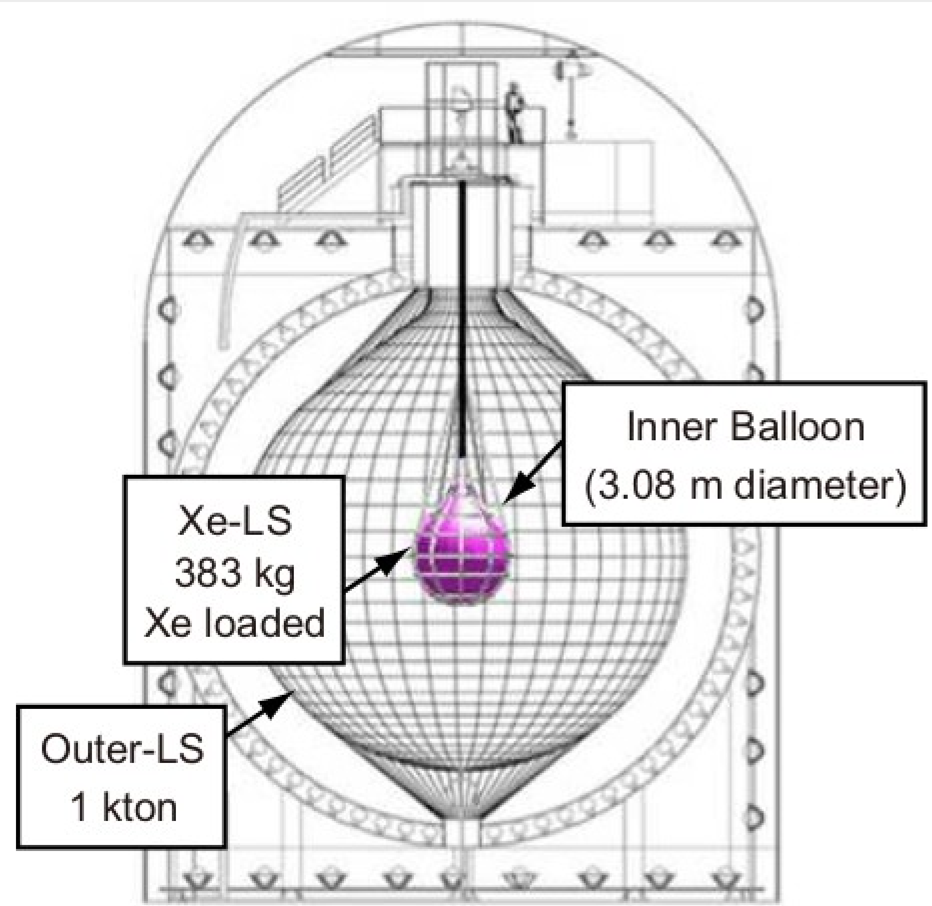
"LXe TPC as similar as possible to EXO-200"

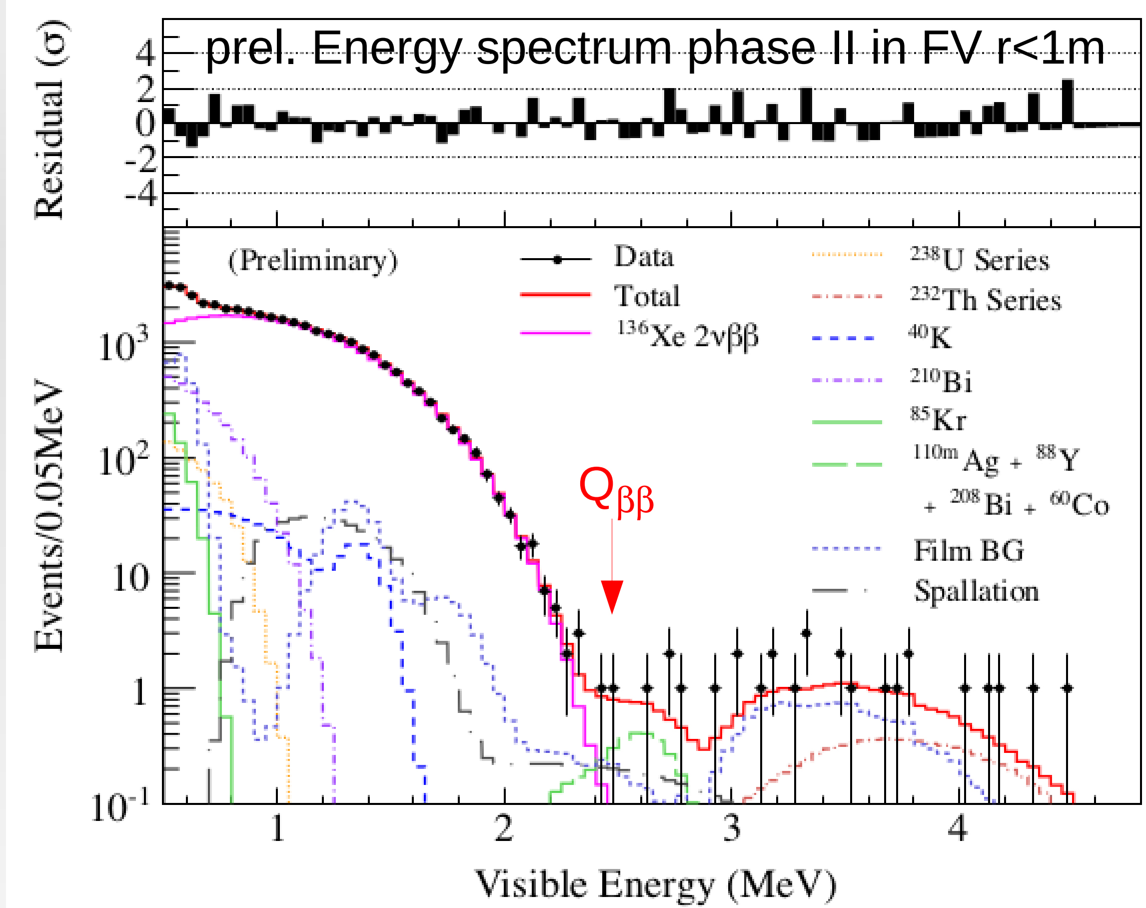
	EXO-200	nEXO (5 yr)
fiducial mass [kg]	100	4780
enrichment	80%	90%
FWHM [keV]	88	58
background in [evt/(mol yr ROI)]	0.022	$6\ 10^{-4}$
$T_{1/2}$ limit sens. (90% CL) [yr]	$6\ 10^{25}$	$6\ 10^{27}$

R&D ongoing to identify spectroscopically daugher nucleus of ^{136}Xe ("Ba tagging") → only $2\nu\beta\beta$ bkg

$T_{1/2}$ limit sensitivity $3\ 10^{28}$ yr after 10 yr (90% eff)

Kamland-Zen





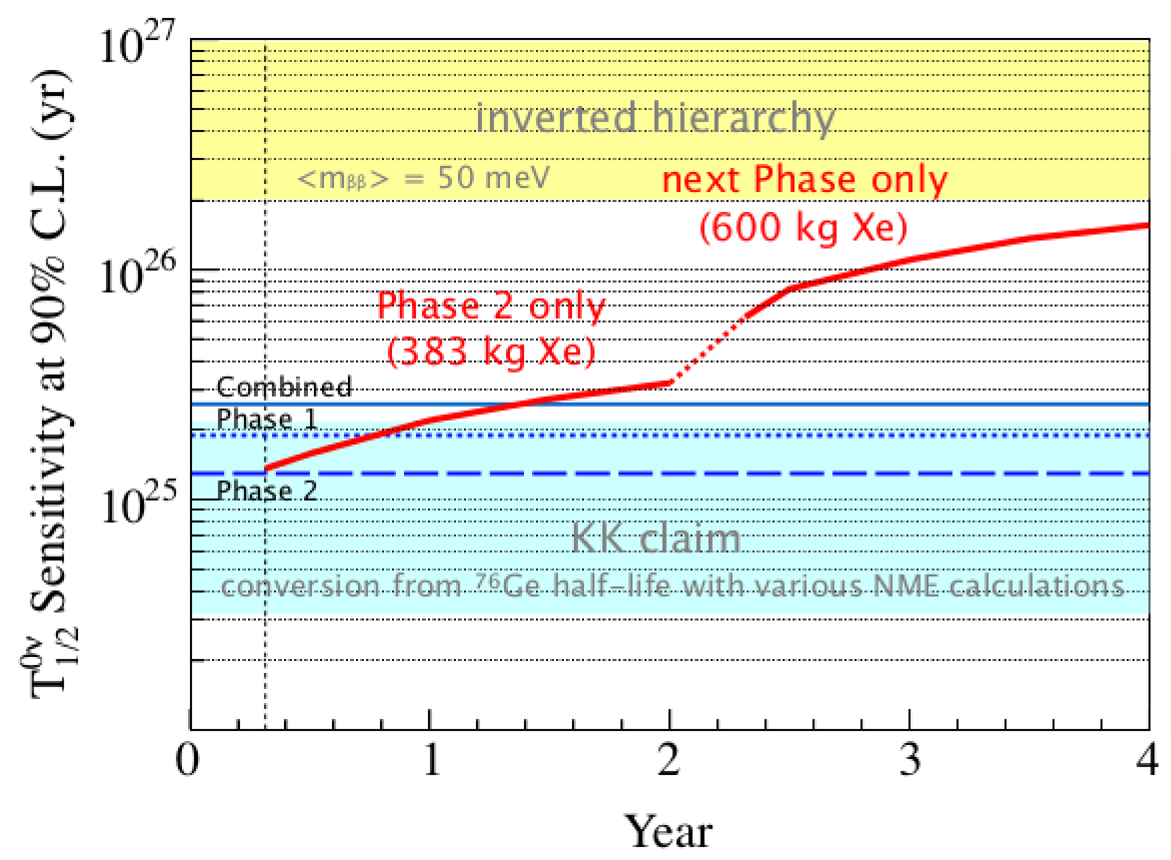
start 2011 (phase I): large background at $Q_{\beta\beta}$

most likely explanation: fall out of ^{110m}Ag from Fukoshima on inner balloon

2012-13: purifications of scintillator and Xe

Dec 2013: start of phase II → ^{110m}Ar background factor 10 reduced, Xe loading 2.44% --> 2.96%

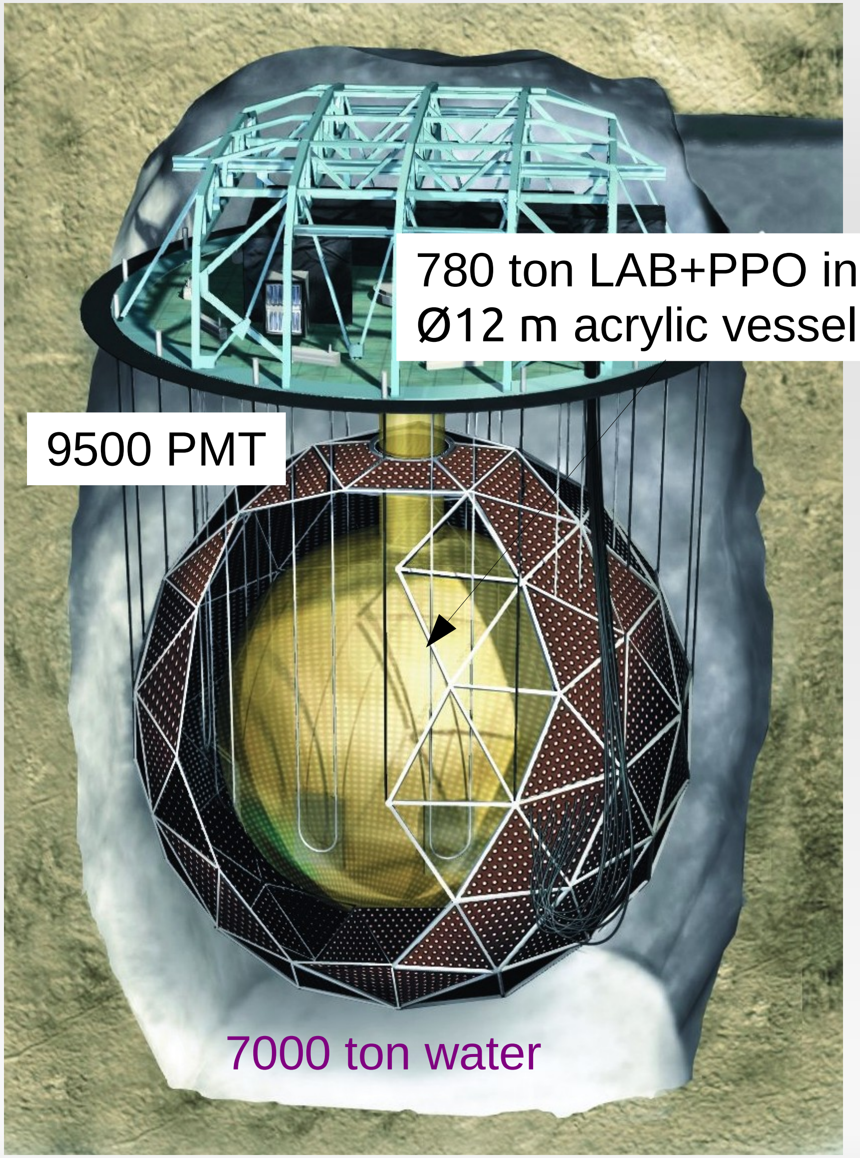
Kamland-Zen



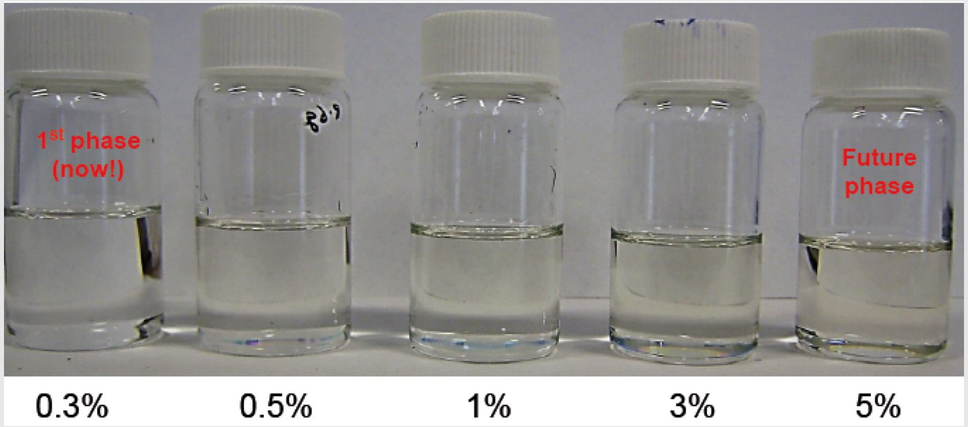
phase I: $T_{1/2}$ > 1.9 10^{25} yr (90% CL), sensitivity 1.0 10^{25} yr (PRL 110 (2013) 062502)
preliminary phase II (Dec 13- May 14): $T_{1/2}$ > 1.3 10^{25} yr (90 % CL), sensitivity 1.3 10^{25} yr
arXiv:1409.0077

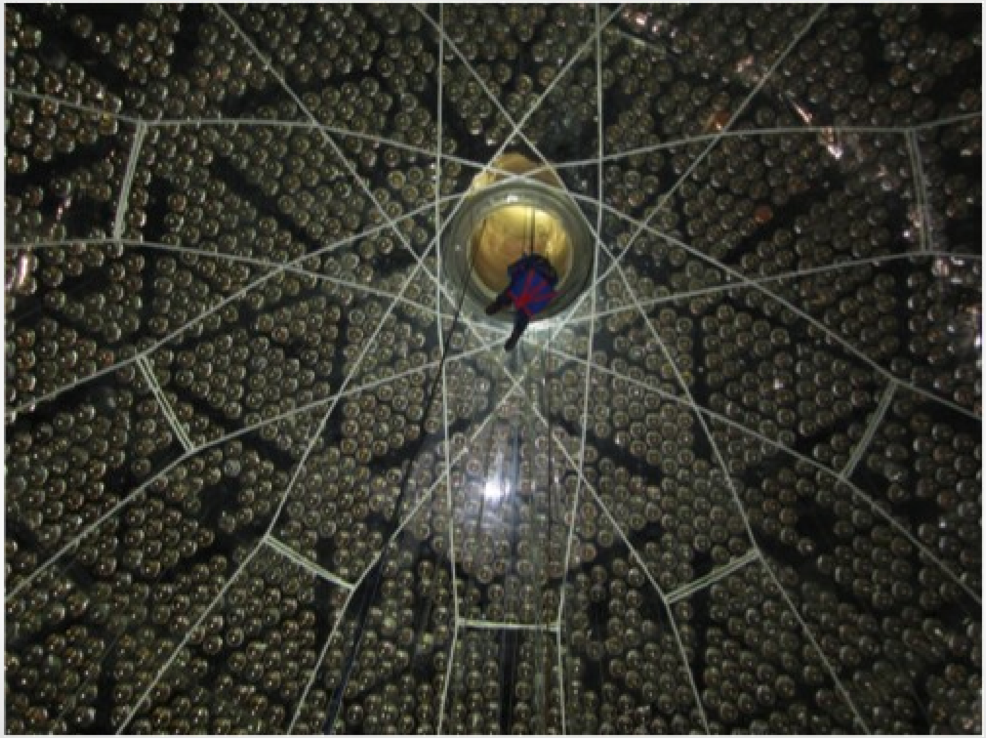
next phase: rebuild mini-balloon, 600 kg ^{136}Xe
Kamland2-Zen: more light 5x, more than 1000 kg ^{136}Xe

SNO+ with ^{nat}Te



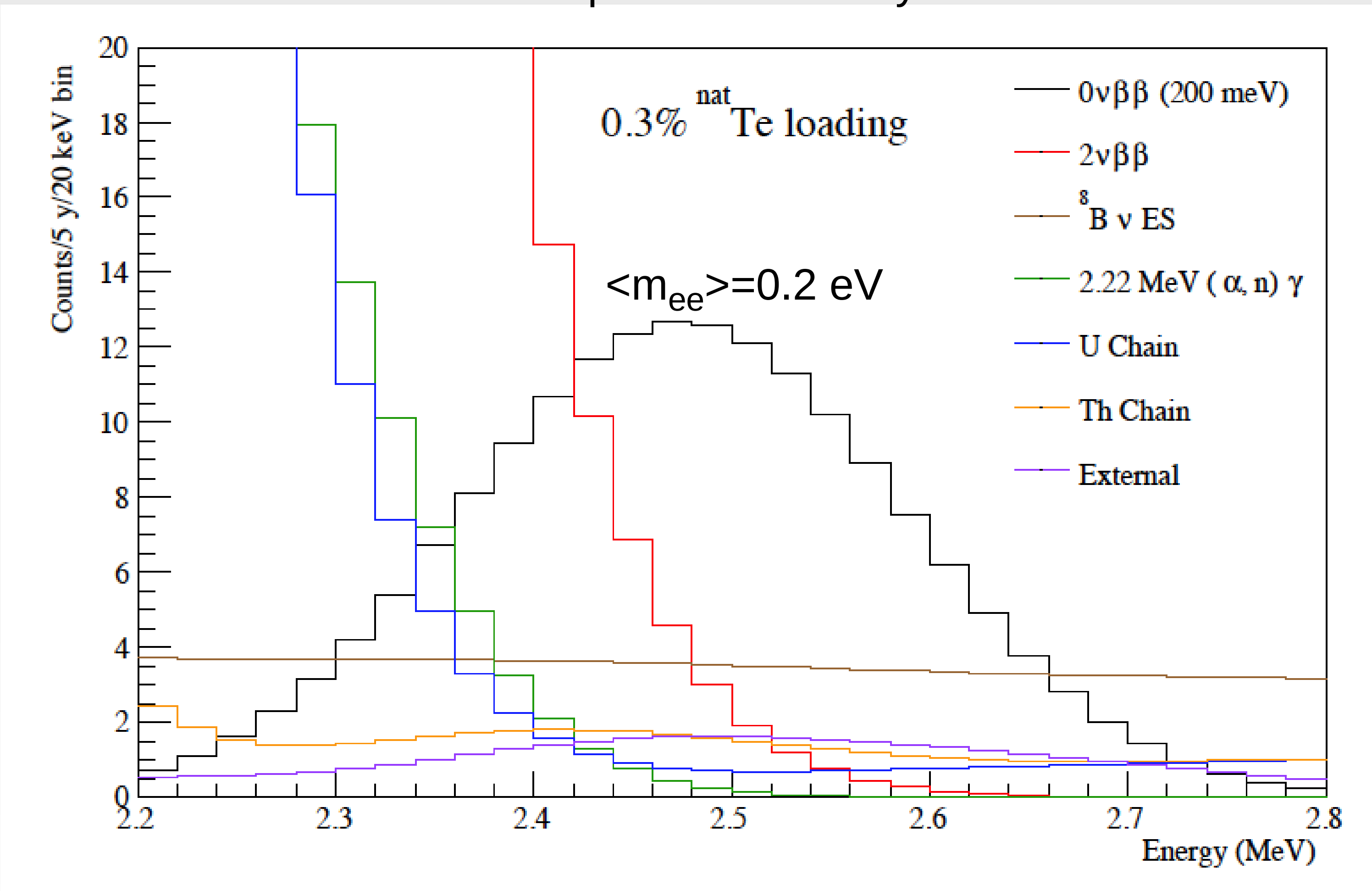
default: 0.3% loading → 2340 kg ^{nat}Te / 800 kg ^{130}Te





SNO+

simulated spectrum after 5 yr

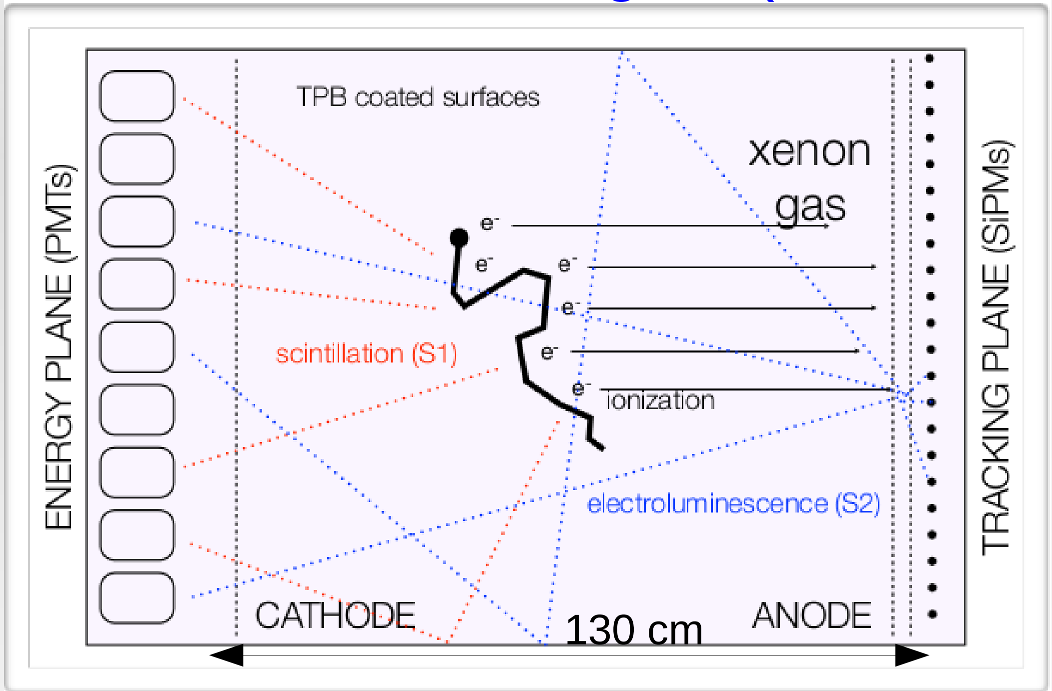


schedule:
soon water filling
scintillator filling 2015
physics run 2016

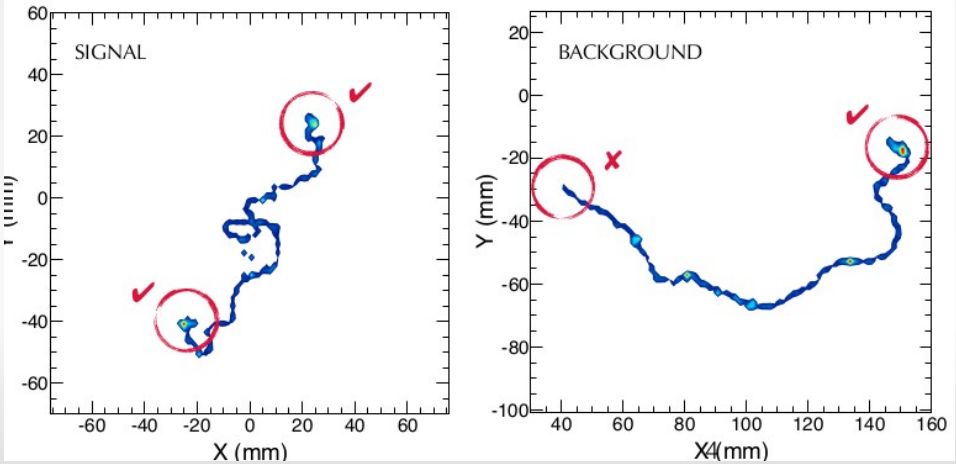
FWHM ~ 270 keV @ $Q_{\beta\beta}$, sensitivity 5 yr $T_{1/2}$ > 1.0 10^{26} yr (90% CL)

NEXT100

gas TPC: 15 bar 100 kg Xe (90% ^{136}Xe)



Electroluminescence:
gas amplification w/o avalanche
→ exploiting Fano factor in gas
→ FWHM @ $Q_{\beta\beta}$ about 0.8%
demonstrated with "DEMO"
(1.5 kg TPC @ 10 bar)



Event topology (SiPM tracking):
larger ionization @ track end
→ ββ have two ends with high E,
background electrons only one
→ > 10 bkg rejection for ^{208}Tl, ^{214}Bi
for 68% efficiency

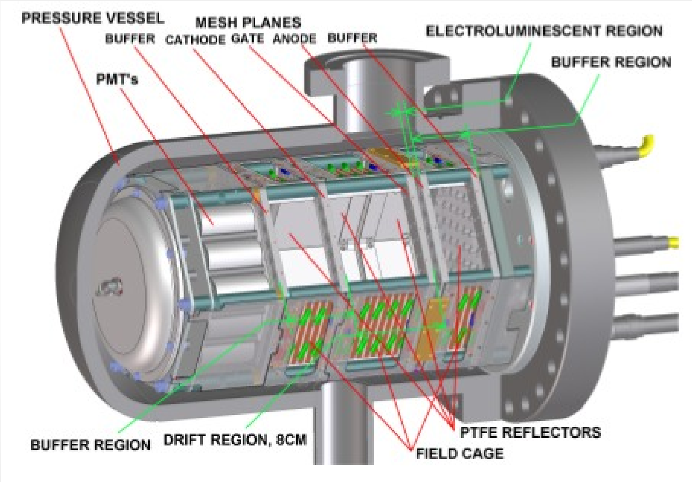
NEXT100

DEMO: 1.5 kg @ 10 bar

NEW: 10 kg

under construction
commissioning 2015

DBDM: 1 kg @ 20 bar

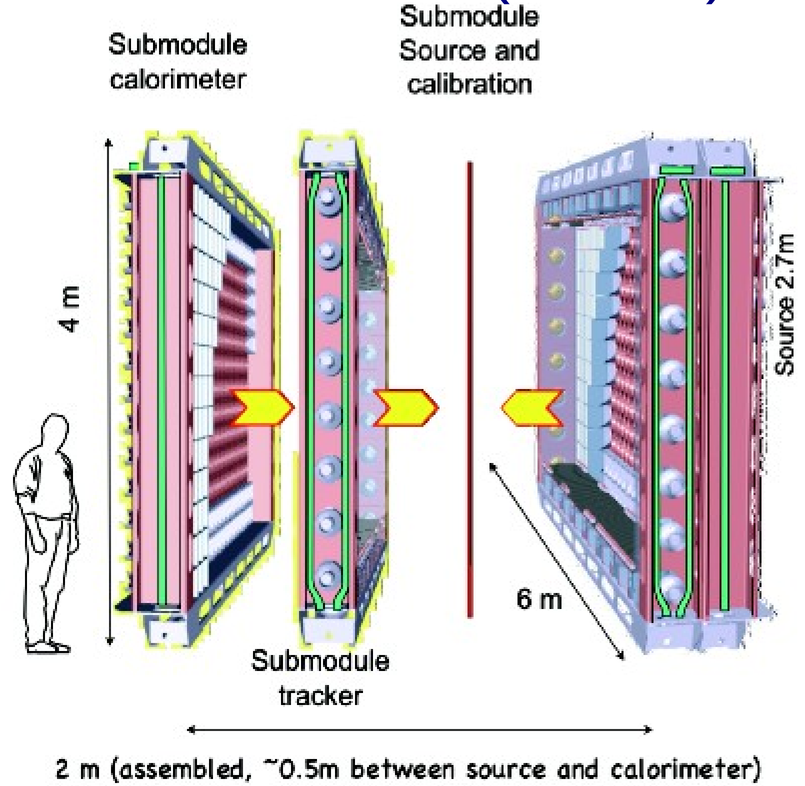


NEXT-100:

- bkg ~ $4\ 10^{-4}$ cnt/(keV kg yr)
- eff ~ 28%
- limit $T_{1/2} > 7\ 10^{25}$ yr (90% C.L.) for 300 kg yr

SuperNemo

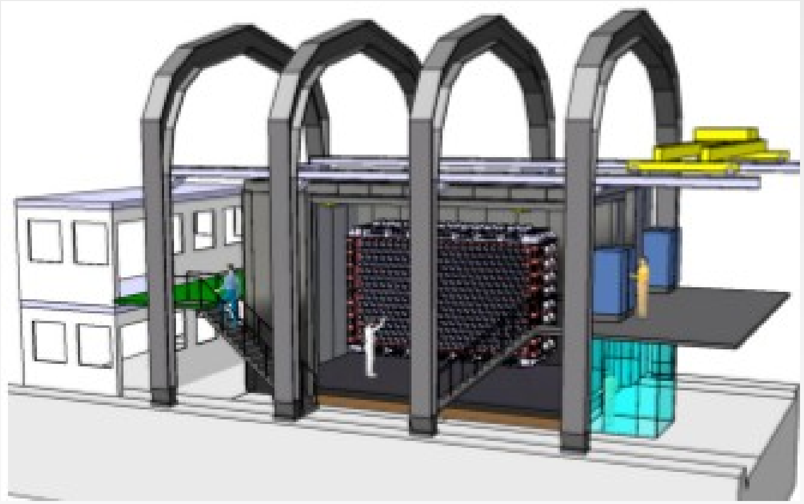
Demonstrator (1 of 20)



target material: 7 kg ^{82}Se, 40 mg/cm^2
background free after 17.5 kg yr
limit $T_{1/2}$ > 6.5 10^{24} yr (90% CL)

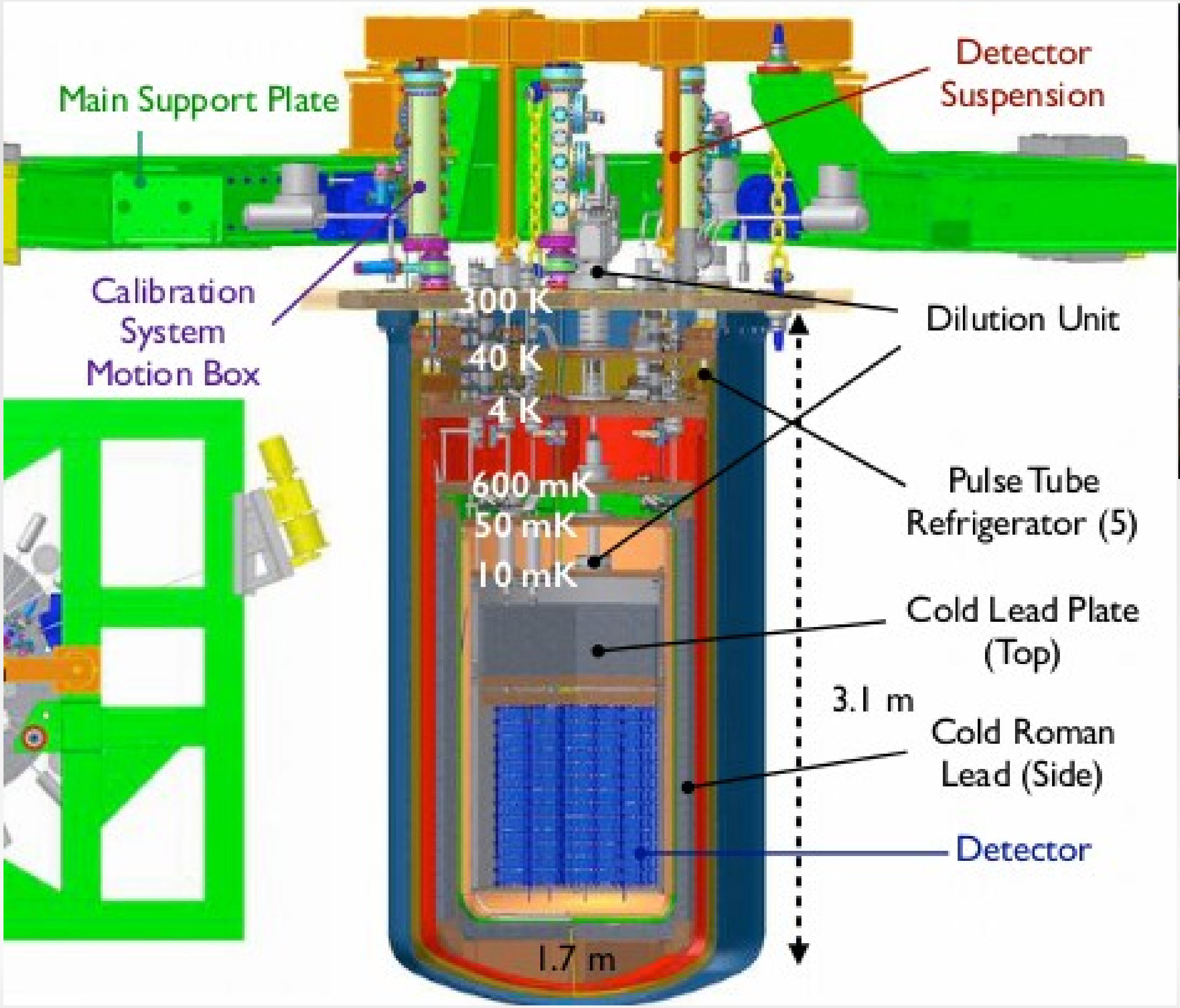
	NEMO3	SuperNEMO	
mass	6.9 kg ^{100}Mo	100 kg ^{82}Se	
FWHM	8%	4%	
efficiency	18%	30%	
foil bkg	1.3 10^{-3}	5 10^{-5}	cnt/(keV kg yr)
sensitivity	1.4 10^{24}	1 10^{26}	$T_{1/2}$ 90% CL

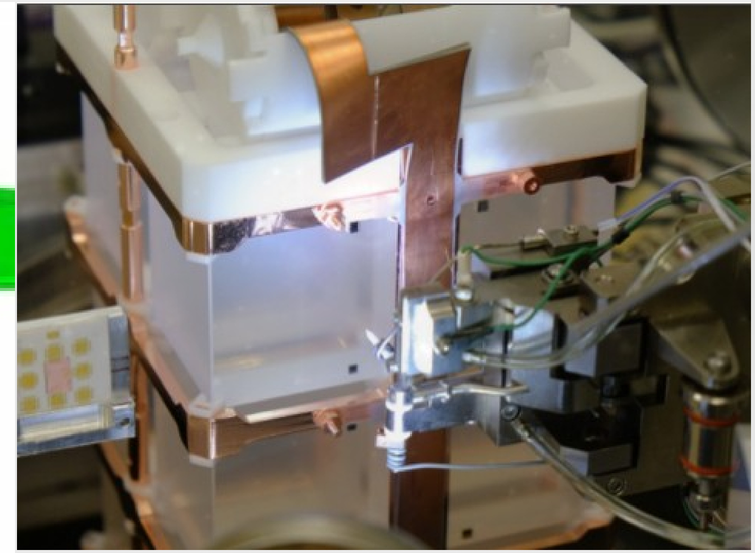
Demonstrator @ LSM



under construction, physics mid 2015

Cuore



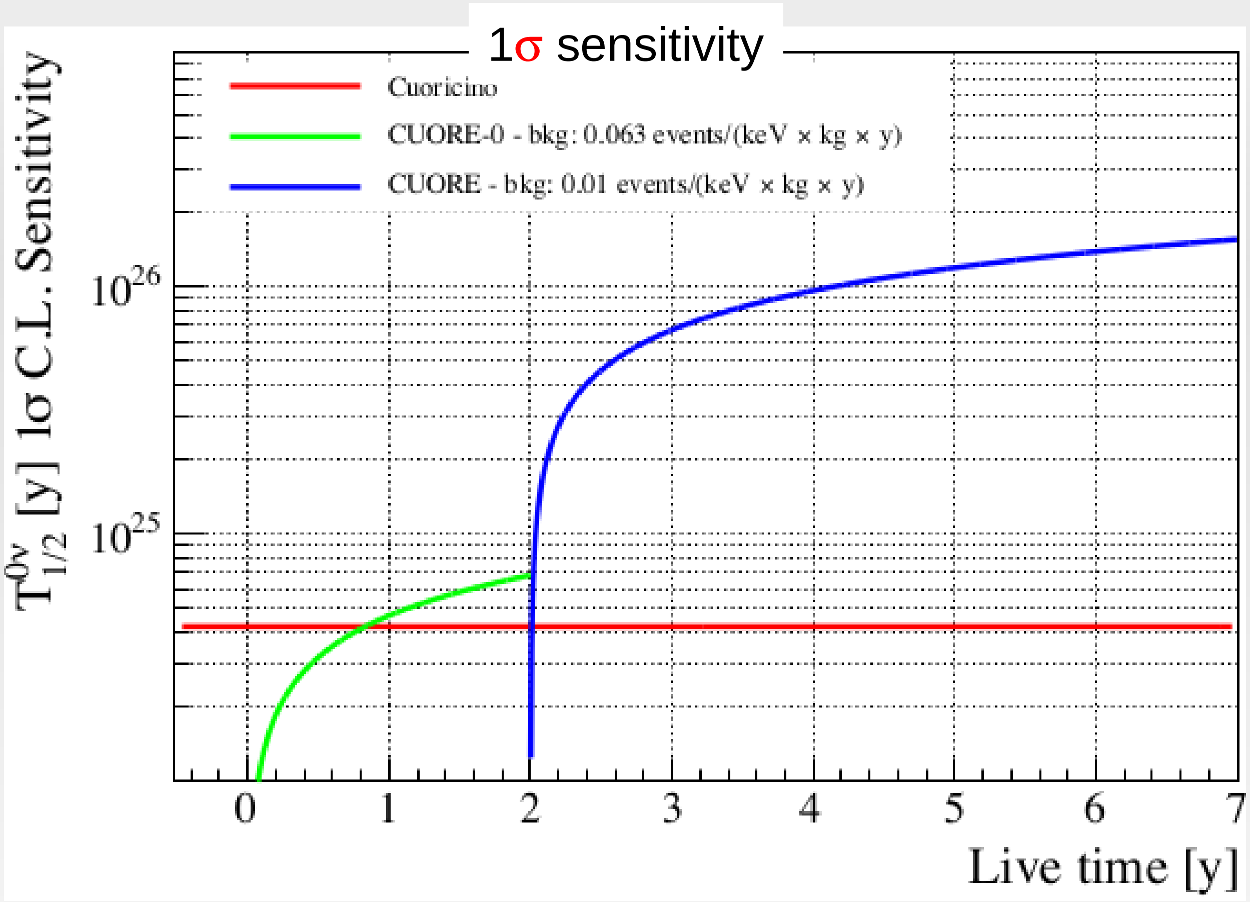


988 $^{nat}TeO_2$ crystals, 19 towers,
206 kg ^{130}Te,
bolometer with Ge NTD readout

Cuore-0: 1 tower runs since 3/13
new cleaning → α bkg factor 6
lower than Cuoricino

all towers assembled!
currently cool down of cryostat

Cuore



start in 2015

FWHM ~ 5 keV
background 0.01 cnt/(keV kg yr)

4 yr sensitivity   9.5 10^{25} yr (90% C.L.)

beyond CUORE:
- use of enriched Te
- Cherenkov light detection (arXiv:1407.6516) to reject α surface events

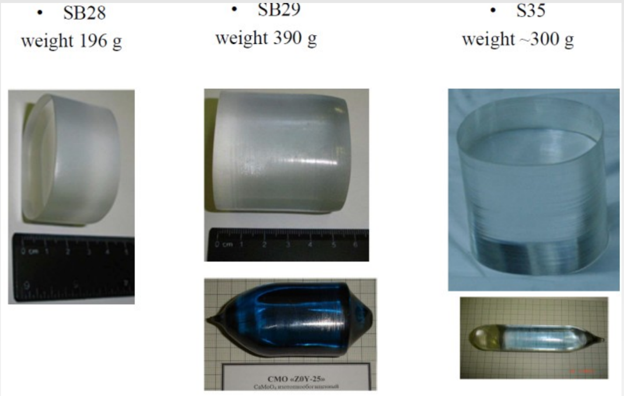
AMoRe and LUMINEU

^{100}Mo ($Q_{\beta\beta}$= 3 MeV) scintil. crystal as bolometer & scintillation light readout

ratio photon energy / phonon energy different for α versus e/γ → background rejection

AMoRE
Advanced Mo-based Rare process Experiment

$^{40}Ca^{100}MoO_4$ scintillating crystals

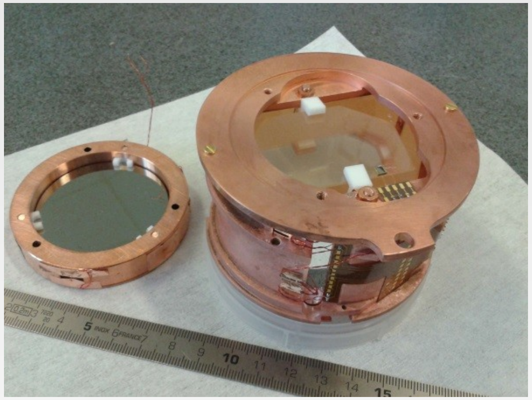


MMC for photon and phonon channel

Metalic Magnetic Calorimeter:
measure magnetization M(T) with SQUID
developped at Universität Heidelberg
for X-ray detector, ECHo, ...

LUMINEU
Luminescent Underground Molybdenum Investigation for NEUtrino mass and nature

$ZnMoO_4$ scintillating crystals



NTD-Ge baseline for photon and phonon channel
MMC R&D for photon channel

Comparison sensitivities

Current experiments and future experiments/propsals

		mass [kg]* (total/FV)	FWHM [keV]	background& [cnt/mol yr FWHM]	$T_{1/2}$ limit [10^{25} yr] after 4 yr	<m_{ee}> limit [meV]	date
Gerda II	Ge	35/27	3	0.0004	15	80-190	-2019
MajoranaD	Ge	30/24	3	0.0004	15	80-190	-2019
EXO-200	Xe	170/80	88	0.03	6	80-220	-2019
NEXT	Xe	120/90	~16	0.003	7	80-220	-2020
Kamland-Zen	Xe	383/88 (600/?)	250	0.03	20	44-120	-2018
Cuore	Te	600/206	5	0.02	9	50-200	-2019
SNO+	Te	2340/160	270	0.02	9	50-200	-2020
Kaml.2-Zen	Xe	1100/?	140	?	130	17-50	2019-24
nEXO	Xe	5000/4300	58	0.0007	600 (3000)$	8-22 (4-10)	?

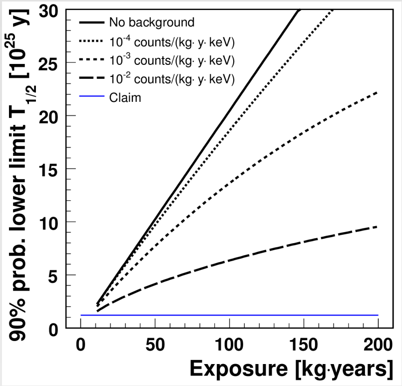
* total= element mass, FV= $0\nu\beta\beta$ isotope mass in fiducial volume (incl enrichment fraction)

& mol of $0\nu\beta\beta$ isotope in active volume and corrected for $0\nu\beta\beta$ efficiency

$ assuming 10 years with 90% efficiency Ba tagging

Summary

claim of 0νββ signal by Klapdor-Kleingrothaus not confirmed by GERDA or Xe experiments (99% exclusion)



of current experiments only GERDA + MajoranaDemo.
plan to be ”background free”
→ a 30 kg Ge experiment has similar sensitivity as others with >150 kg (total) mass

many experiments start next year → new results coming soon

many ideas for next generation exp. and new ideas constantly come up: liquid+gas Xe TPC, tonne-scale Ge, scintillating bolometers, liquid scint.