Review of Recent (but not exhaustive) Double Beta Decay Results

GDR Neutrino
IPNL, Lyon

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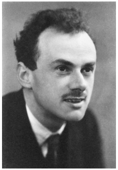
November, 2013

Majorana Neutrinos

- The neutrino is the only fundamental fermion without electric charge
  - instead of being a Dirac particle like the other Standard Model fermions it could be a Majorana particle



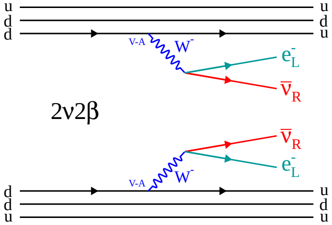
P. Dirac: $\nu \neq \bar{\nu}$

E. Majorana: $\nu \equiv \bar{\nu}$

- The Majorana nature of the neutrino could lead to:
  - Lepton Number Violation
  - Small masses of the neutrinos through the See-Saw mechanism
  - Baryon asymmetry in the Universe through Leptogenesis
- The most sensitive experimental way to search for Majorana nature of the neutrinos it the neutrinoless double beta decay $(0\nu 2\beta)$

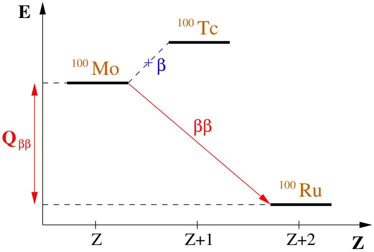
Two Neutrinos Double Beta Decay ($2\nu 2\beta$)

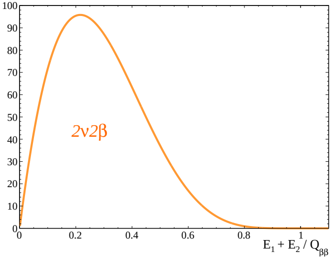
Second order of the weak interaction occurring when β-decay is forbidden for few nuclei: $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$



$$(\mathcal{T}_{1/2}^{2\nu})^{-1} = G_{2\nu} \, |\mathcal{M}_{2\nu}|^2$$

$$\mathcal{T}_{1/2}^{2\nu} \in [7 \; 10^{18} - 3 \; 10^{24}] \text{ y}$$

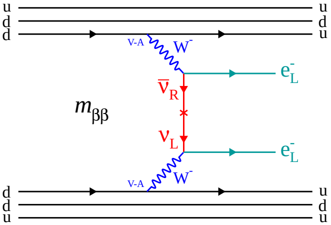




Continuous 2 e^- energy spectrum

Neutrinoless Double Beta Decay ($0\nu2\beta$)

If the neutrinos are Majorana particles the Lepton Number Violating ($\Delta L = 2$) decay could occur: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

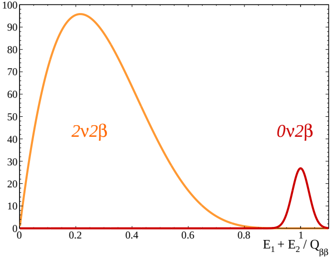


$$(\mathcal{T}^{0\nu}_{1/2})^{-1} = G_{0\nu}\,|\mathcal{M}_{0\nu}|^2\,|m_{\beta\beta}|^2$$

$$\mathcal{T}^{0\nu}_{1/2} > 10^{24} - 10^{25}\text{ y}$$

Several possible $0\nu2\beta$processes:

- Majorana neutrino exchange $m_{\beta\beta}$
- Right Handed Current
- Majoron
- SUSY



2 e^- energy equal to $Q_{\beta\beta}$

Isotopes and Nuclear Matrix Elements

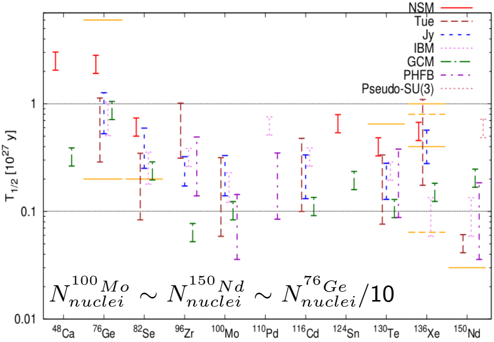
2β	$Q_{\beta\beta}$ [MeV]	$G_{0\nu}$ $[10^{-14}\ \text{y}^{-1}]$	$\mathcal{T}^{2\nu}_{1/2}$ [y]	NA [%]
^{48}Ca	**4.274**	6.35	$4.3\ 10^{19}$	**0.187**
^{76}Ge	**2.039**	**0.62**	$\mathbf{1.3\ 10^{21}}$	7.61
^{82}Se	2.996	2.70	$9.2\ 10^{19}$	8.73
^{96}Zr	**3.348**	5.63	$2.0\ 10^{19}$	2.8
^{100}Mo	3.035	4.36	$\mathbf{7.0\ 10^{18}}$	9.63
^{116}Cd	2.805	4.62	$3.0\ 10^{19}$	7.49
^{130}Te	2.530	4.09	$\mathbf{6.1\ 10^{20}}$	**34.1**
^{136}Xe	2.462	4.31	$\mathbf{2.1\ 10^{21}}$	8.9
^{150}Nd	**3.368**	**19.2**	$7.9\ 10^{18}$	5.6

$$(\mathcal{T}^{0\nu}_{1/2})^{-1} = G_{0\nu}\,|\mathcal{M}_{0\nu}|^2\,|m_{\beta\beta}|^2$$

$$\mathcal{T}^{0\nu}_{1/2} > k\,\frac{\mathcal{N}_A}{A}\,\mathcal{E}_{0\nu}\,\sqrt{\frac{M\ t}{B\ \Delta E}}$$

Necessary life-time sensitivity reach to start testing the inverted hierarchy $|m_{\beta\beta}| \sim 50$ meV

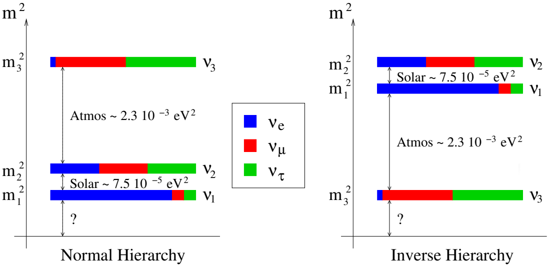
Dueck et al., Phys. Rev. D 83 (2011)



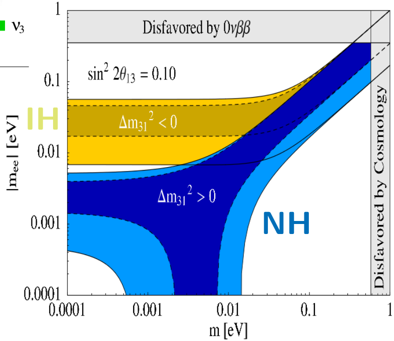
Effective Neutrino Mass for Double Beta Decay

The effective neutrino mass for double beta decay is related to the neutrino mixing parameters:

$$m_{\beta\beta} = c_{12}^2 c_{13}^2\, m_1 + s_{12}^2 c_{13}^2 e^{2i\eta_2}\, m_2 + s_{13}^2 e^{2i(\eta_3-\delta)}\, m_3$$



Inverted Hierarchy approximately between 10 and 50 meV



A. Merle and W. Rodejohann, Phys.Rev.D73:073012,2006

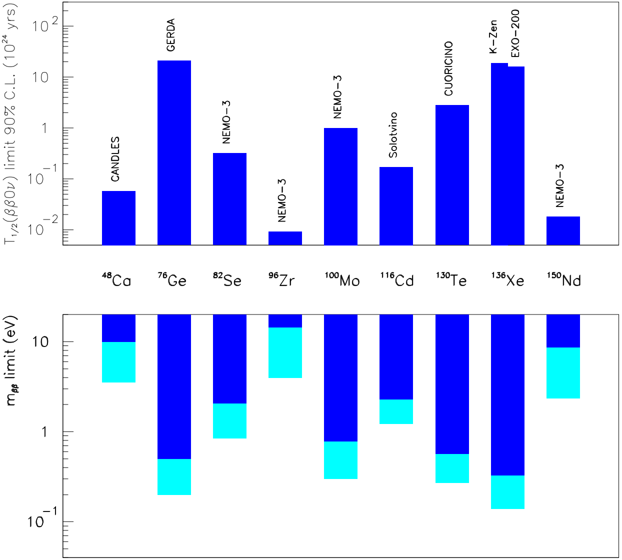
Current Best Limits on the $0\nu 2\beta$ Search

Isotope	Experiment	Technique	Mass	$\mathcal{E}_{0\nu}$ [%]	Bkg [fwhm·kg·y]$^{-1}$	$\mathcal{T}^{0\nu}_{1/2}$ (90%) [y]	$\lvert m_{\beta\beta}\rvert$ [eV]
^{48}Ca	CANDLES	Scintillation	0.01 kg	$\sim$90	-	$>$5.8 10^{22}	3.55 - 9.91
^{76}Ge	GERDA 1	Ionisation	18 kg	$\sim$90	0.05	$>$2.1 10^{25}	0.20 - 0.50
^{82}Se	NEMO-3	Tracko-calo	930 g	$\sim$10	0.3	$>$3.2 10^{23}	0.85 - 2.08
^{96}Zr	NEMO-3	Tracko-calo	9.43 g	$\sim$20	0.2	$>$9.2 10^{21}	3.97 - 14.4
^{100}Mo	NEMO-3	Tracko-calo	6.9 kg	$\sim$10	0.5	$>$1.1 10^{24}	0.30 - 0.80
^{116}Cd	Solotvina	Scintillation	80 g	$\sim$90	-	$>$1.7 10^{23}	1.22 - 2.30
^{130}Te	CUORICINO	Bolometer	10 kg	$\sim$90	1.1	$>$2.8 10^{24}	0.27 - 0.57
^{136}Xe	EXO-200	Liquid TPC	$\sim$90 kg	$\sim$40	0.025	$>$1.6 10^{25}	0.14 - 0.36
^{136}Xe	KamLAND-Zen	Liq. Scint.	125 kg	$\sim$50	^{110m}Ag	$>$1.9 10^{25}	0.13 - 0.33
^{150}Nd	NEMO-3	Tracko-calo	36.5 g	$\sim$10	0.5	$>$1.8 10^{22}	2.35 - 8.65

Xavier Sarazin - HDR

NME from Dueck et al., Phys. Rev. D 83 (2011)

Current Best Limits on the $0\nu2\beta$ Search



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Next Generation Experiments (not exhaustive)

	Experiments	Isotope	Technique	Advantages
Calorimetry	GERDA - Majorana	^{76}Ge	Ge diodes	$\mathcal{E}_{0\nu}$ - ΔE - PSD
Calorimetry	CUORE	^{130}Te	Bolometers	$\mathcal{E}_{0\nu}$ - ΔE - (PID)
Calorimetry	LUCIFER	^{82}Se	Bolometers	$\mathcal{E}_{0\nu}$ - ΔE - (PID)
Calorimetry	LUMINEU - AMoRE	^{100}Mo	Bolometers	$\mathcal{E}_{0\nu}$ - ΔE - (PID)
Calorimetry	EXO-200 - nEXO	^{136}Xe	Liquid TPC	mass - PID
Calorimetry	CANDLES	^{48}Ca	Scintillation	^{48}Ca - $\mathcal{E}_{0\nu}$ - mass
Calorimetry	SNO+	^{130}Te	Scintillation	$\mathcal{E}_{0\nu}$ - mass
Calorimetry	KamLAND-Zen	^{136}Xe	Scintillation	- existing
Tracking	SuperNEMO	^{82}Se (^{150}Nd - ^{48}Ca)	Tracko-calo	bkg - full topology - multi isotopes
Tracking	NEXT - EXO-gas	^{136}Xe	Gas TPC	$\mathcal{E}_{0\nu}$ - tracking - ΔE
Tracking	COBRA	^{116}Cd	Pixels	$\mathcal{E}_{0\nu}$ - tracking

Adapted from Fabrice Piquemal

Majorana Neutrinos and Double Beta Decay

- Introduction
- Current Results
- Next Generation Experiments

Recent Results or Progress

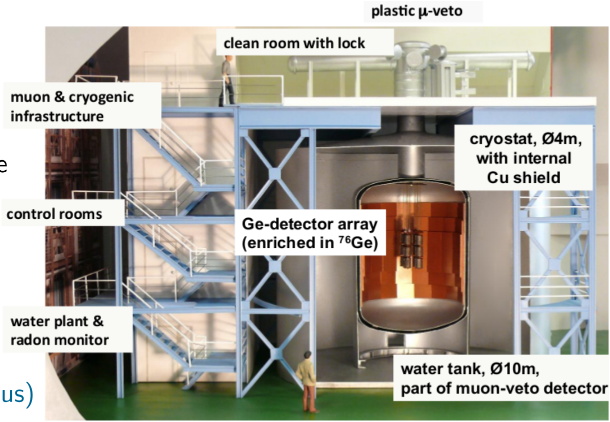
- Germanium Diodes
- Bolometers
- Xe TPC
- Liquid Scintillators
- Tracko-Calo

GERDA

Bare Ge diodes in liquid argon

- enriched in ^{76}Ge at 86 %
- gradual deployment of the detector strings in the 64 m^3 cryostat
- LNGS 3800 m.w.e.

Background target:
$\sim$ 0.01 [keV·kg·y]$^{-1}$
(20 times better than previous)



Phase 1 - 2011-2013:

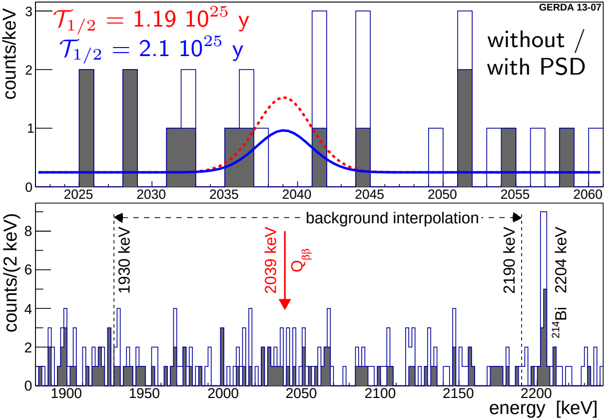
- $\sim$ 18 kg of ^{76}Ge
- 8 old semi-coaxials (HdM - IGEX) 17.7 kg
- 5 new BEGe 3.6 kg
- FWHM @ $Q_{\beta\beta}$: 4.2 - 5.7 keV coaxials and 2.6 - 4.0 keV BEGe

GERDA Phase 1 Results

PSD:
different charge and current collections for single site ($0\nu2\beta$) and multi sites (γ-rays) events
$\rightarrow$A/E cuts

3 events in $Q_{\beta\beta} \pm 5$ keV

^{42}K bkg
(^{42}Ar 32.9 y)



arXiv:1307.4720

Phase 1 - 21.6 kg·y exposure: $\mathcal{T}^{0\nu}_{1/2} > 2.1\ 10^{25}$ y (90% CL)

$m_{\beta\beta} < 0.2 - 0.5$ eV

Bkg [keV·kg·y]$^{-1}$	Before PSD	After PSD
Coaxials	(1.8±0.2) 10^{-2}	(1.1±0.2) 10^{-2}
BEGe	(4.2±1.0) 10^{-2}	(0.5±0.4) 10^{-2}

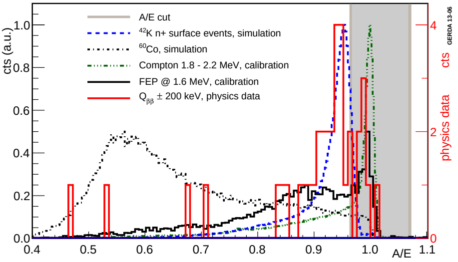
GERDA Phase 2

$\sim$ 50 kg of ^{76}Ge

Factor 10 reduction of the background $\rightarrow 10^{-3}$ [keV·kg·y]$^{-1}$

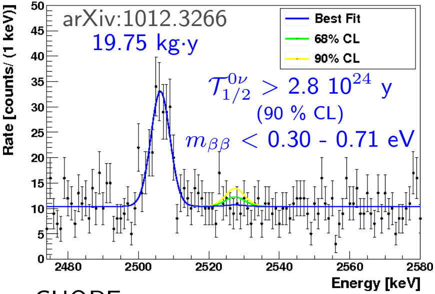
$\mathcal{T}^{0\nu}_{1/2} > 1\ 10^{26}$ in 100 kg·y exposure

- 30 new BEGe diodes $\sim$ 20 kg already produced and characterized
  - better PSD than coaxials
  - PSD single site ($0\nu2\beta$) / multi sites (γ-rays) or surface (^{42}K)
  - FWHM $\sim$ 3 keV @ $Q_{\beta\beta}$
- Detect liquid argon scintillation light to veto backgrounds
  - PMT on top and bottom of Ge diode strings
  - SiPM with fiber curtain
- Estimate if extrapolation to higher masses is possible



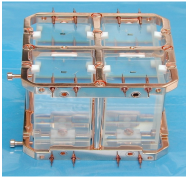
From CUORICINO to CUORE

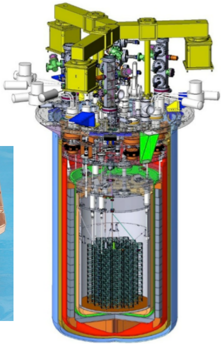
CUORICINO @ LNGS 2003-2008:
62 TeO_2 crystals
11.2 kg of ^{130}Te
FWHM $= 6.3 \pm 2.5$ keV @ $Q_{\beta\beta}$
Background 0.15 [keV·kg·y]$^{-1}$

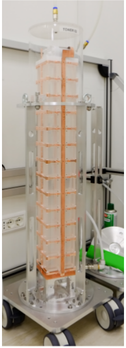


CUORE-0 running since few months to test the α background reduction for CUORE

TeO$_2$ & NTD







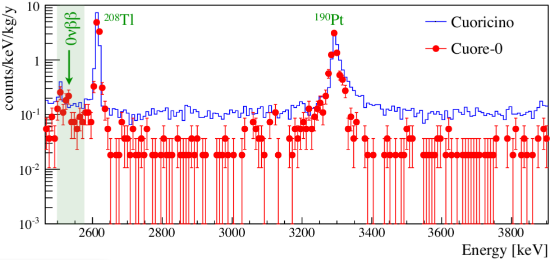
CUORE:

- 206 kg of ^{130}Te
- Improved bolometers assembly and cleaning techniques
- Improved cryostat radiopurity
- Background target 0.01 [keV·kg·y]$^{-1}$
- FWHM $\sim$ 5 keV @ $Q_{\beta\beta}$
- Sensitivity: $\mathcal{T}^{0\nu}_{1/2} > 1\ 10^{26}$ y in 5 years
- First tower already assembled and 18 others by 2014

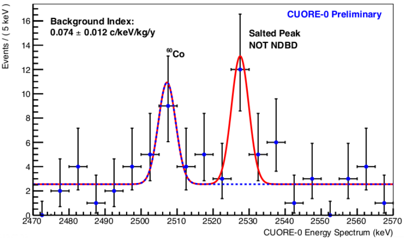
CUORE-0

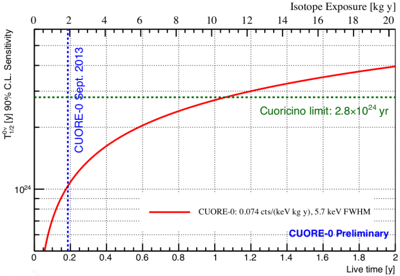
- 11 kg of ^{130}Te
- CUORICINO cryostat
  $\rightarrow$ same γ background
- Bolometers assembly and cleaning techniques improved for radiopurity
- Improved crystals supports
  $\rightarrow$ α background reduction

Blind analysis:
exchange ^{208}Tl events and
$0\nu2\beta$ region events



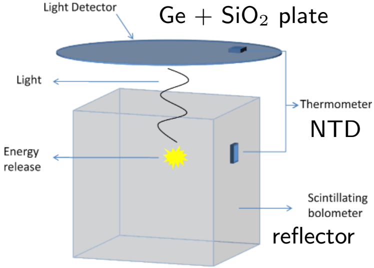
Bkg $[\text{keV}\cdot\text{kg}\cdot\text{y}]^{-1}$	$0\nu2\beta$ region	α bkg region 2.7 - 3.9 MeV
CUORICINO	0.153 ± 0.006	0.110 ± 0.001
CUORE-0	0.074 ± 0.012	0.019 ± 0.002





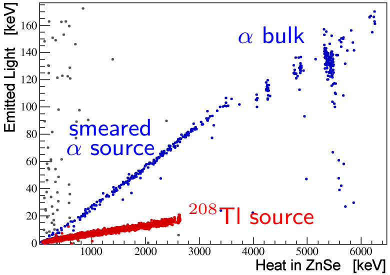
LUCIFER

- $\sim$ 50 ZnSe crystals $\rightarrow$ $\sim$ 18 kg of ^{82}Se
- CUORICINO cryostat after CUORE-0
- $\mathcal{T}^{0\nu}_{1/2} > \sim 10^{26}$ y in 5 years
- Background measurement ongoing with Zn^{nat}Se in LNGS
- Target 10^{-3} [keV·kg·y]$^{-1}$
- Troubles in reproducibility during the production of ZnSe crystals

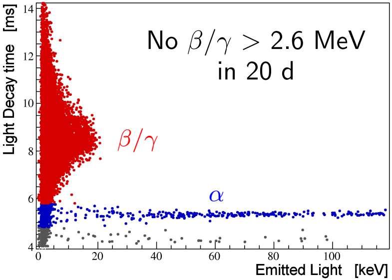


$\beta/\gamma - \alpha$ PSD with light and heat signals

Inverted α quenching!

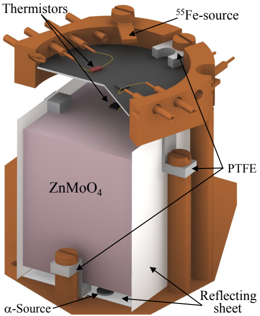


FWHM $\sim$ 13 keV @ $Q_{\beta\beta}$



LUMINEU

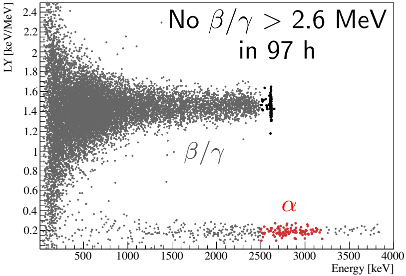
- 4 $ZnMoO_4$ crystals $\rightarrow \sim$ 0.7 kg of ^{100}Mo
- Edelweiss cryostat @ LSM mid 2014
- Sensitivity $\mathcal{T}^{0\nu}_{1/2} > 1\ 10^{24}$ y in 1 year
- Background and PSD measurements with 300 g $Zn^{nat}MoO_4$ in CUORE R&D cryostat
- 4 new 200 g $Zn^{nat}MoO_4$ crystals built
- $2\nu2\beta$ pile-up limiting bkg for 100 kg

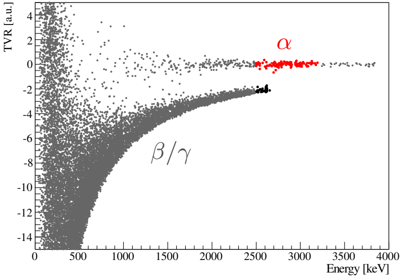


$\beta/\gamma - \alpha$ PSD with light and heat signals

FWHM $\sim$ 6 keV @ $Q_{\beta\beta}$

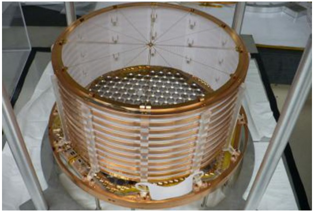
$\beta/\gamma - \alpha$ PSD with heat signal only





arXiv:1207.0433v1

EXO-200

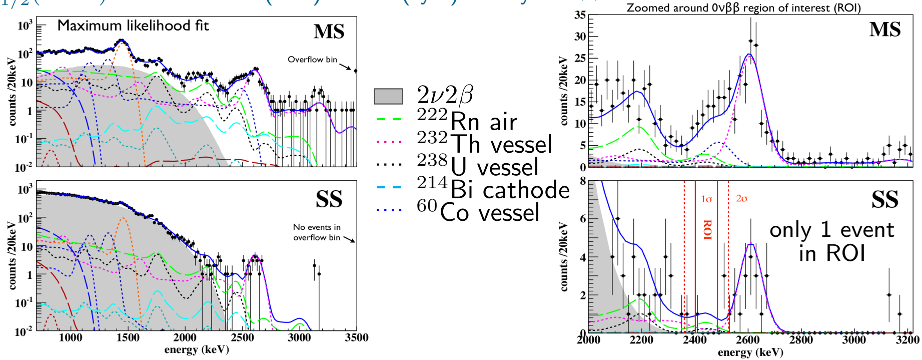


- Easy and cheap ^{136}Xe enrichment (80 %)
- 200 kg liquid xenon TPC in WIPP USA
- Active mass 79.4 kg of ^{136}Xe
- FWHM 3.8 % @ $Q_{\beta\beta}$
- First results in 121 days for 32.5 kg·y exposure
- $\sim$ 50 % bkg from radon $\rightarrow$ reduced for next runs

$\mathcal{T}_{1/2}^{0\nu}(^{136}\text{Xe}) > 1.6\ 10^{25}$ y

$\mathcal{T}_{1/2}^{2\nu}(^{136}\text{Xe}) = 2.17 \pm 0.02\ (\text{stat}) \pm 0.06\ (\text{syst})\ 10^{21}$ y

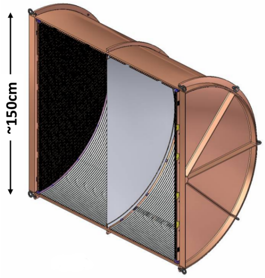
$|m_{\beta\beta}| < 0.14 - 0.38$ eV (90 % CL)

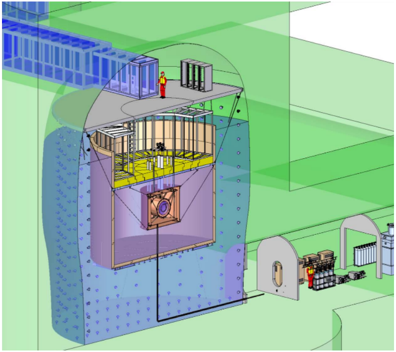


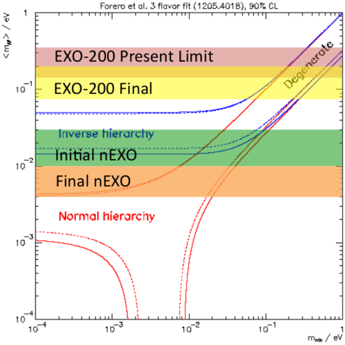
Run2 up to 6/2013 with 3.6 times this exposure analysis: not finalized yet

nEXO

- "As similar to EXO-200 as possible"
- Liquid Xenon TPC in SNOLAB Cryopit
- 5 t enriched at 90 % in ^{136}Xe
- Baseline FWHM 3.5 % @ $Q_{\beta\beta}$
- Scaling EXO-200 bkg and improved discrimination
- Sensitivity: $\mathcal{T}^{0\nu}_{1/2}(^{136}\mathrm{Xe}) > 4.1\ 10^{27}$ y in 10 years
- With barium tagging: $\mathcal{T}^{0\nu}_{1/2}(^{136}\mathrm{Xe}) > 2.1\ 10^{28}$ y

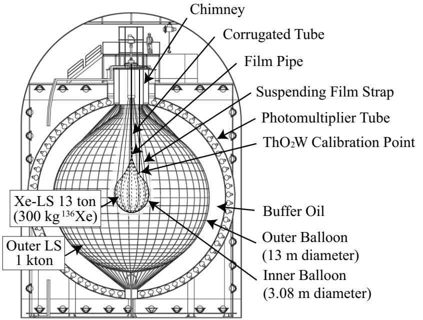






KamLAND-Zen

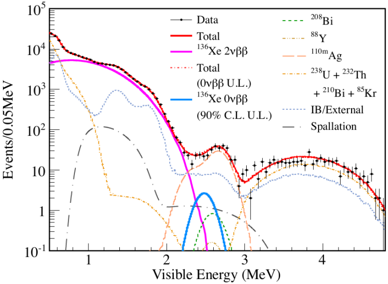
- 13 tons of Xe-loaded liquid scintillator in KamLAND mini balloon
- 320 kg of enriched ^{136}Xe at 90%
- FWHM $\sim$ 10 % @ $Q_{\beta\beta}$
- Exposure 89.5 kg·y 2011-2012
- Fukushima fallout ^{110m}Ag bkg
- LS and Xe extracted and purified
- Restart data taking 11/2013

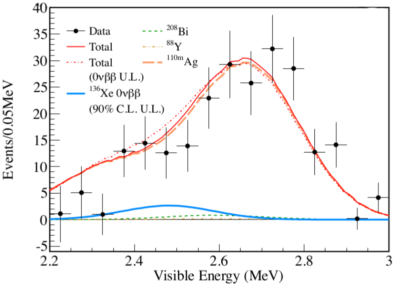


$\mathcal{T}^{2\nu}_{1/2}(^{136}\text{Xe}) = 2.30 \pm 0.02\ (\text{stat}) \pm 0.12\ (\text{syst})\ 10^{21}\ \text{y}$

$\mathcal{T}^{0\nu}_{1/2}(^{136}\text{Xe}) > 1.9\ 10^{25}\ \text{y}$

$|m_{\beta\beta}| < 0.12 - 0.25\ \text{eV}\ (90\ \%\ \text{CL})$



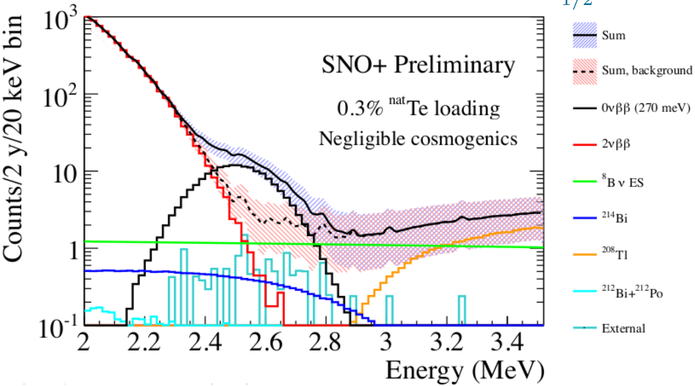


SNO+

- SNO detector filled with liquid scintillator loaded in ^{130}Te
- 0.3 % of ^{nat}Te in 780 t LS $\rightarrow \sim$ 800 kg of ^{130}Te
- Fiducial volume $\sim$ 20 % $\rightarrow \sim$ 160 kg of ^{130}Te
- High light yield of LS Te loaded: FWHM $\sim$ 12 % at $Q_{\beta\beta}$
- High $\mathcal{T}^{2\nu}_{1/2}$(^{130}Te) : $2\nu2\beta$ bkg reduced compared to ^{150}Nd
- LS must be ultra radiopure in ^{238}U and ^{232}Th
- Solar ^{8}B ν is the ultimate background !

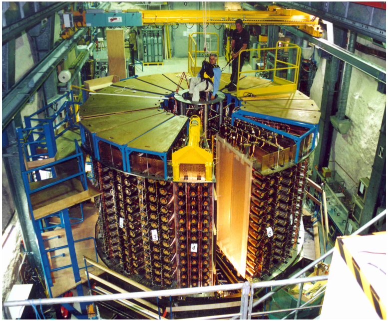
No sensitivity given: $\mathcal{T}^{0\nu}_{1/2} > 6\ 10^{24}$ y ?

First data expected in 2014



NEMO-3: the Neutrino Ettore Majorana Observatory

- Located in the *Laboratoire Souterrain de Modane (LSM)* in France under 4800 m.w.e.
- Shielded by 30 cm of borated water or wood, 19 cm of pure iron and radon-free air tent (2004)

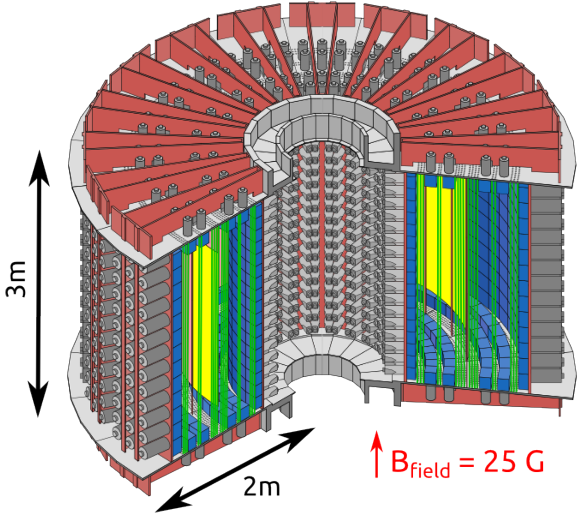


Phase 1
Feb. 2003 - Oct. 2004
$\mathcal{A}_{int}(^{222}\mathrm{Rn}) \sim 30$ mBq/m^3

Phase 2
Dec. 2004 - Jan. 2011
$\mathcal{A}_{int}(^{222}\mathrm{Rn}) \sim 5$ mBq/m^3

NEMO-3 Detector

- NEMO-3 unique tracking and calorimetric double beta decay experiment with 10 kg of sources



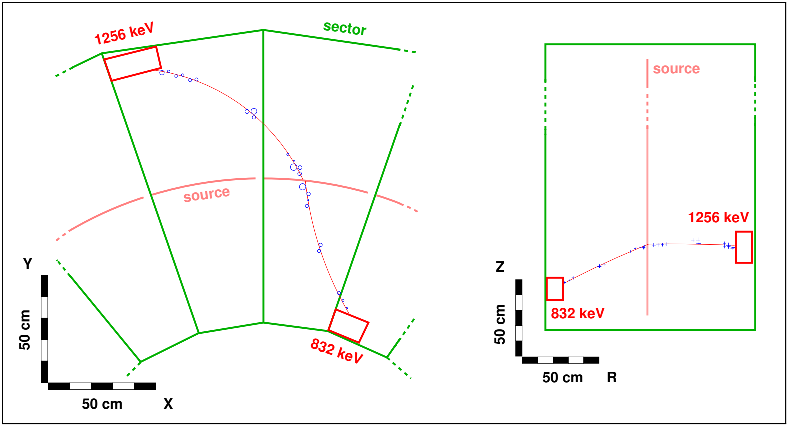
sources
60 mg/cm² foils
10 kg of $\beta\beta$ isotopes

tracker
6180 Geiger cells
vertex resolution :
$\sigma_t = 5$ mm $\sigma_z = 1$ cm

calorimeter
1940 counters :
polystyren scintillator
+ 3" and 5" PMTs
$FWHM_E = 15\% / \sqrt{E_{MeV}}$
$\sigma_T = 250$ ps

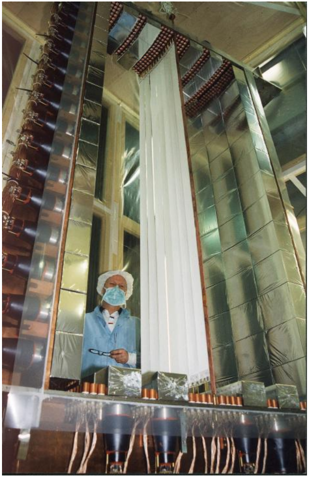
NEMO-3 Unique Features

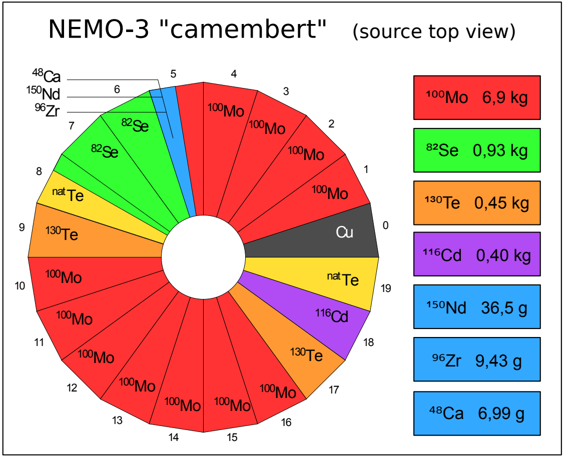
- Unique 2β experiment with the direct reconstruction of the $2e^-$
  $\rightarrow$ full signature of $0\nu2\beta$ events and powerful background rejection
- Individual electron energies (E_1, E_2), time of arrival (t_1, t_2), curvature in magnetic field $(\pm)$, emission vertex and angle $(\cos\theta)$
- Modest energy resolution and efficiency
- Background for $0\nu2\beta$ equivalent to the best calorimeter experiments



NEMO-3 Sources

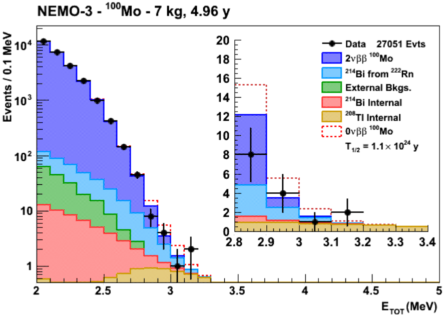
- NEMO-3 technique allows to study most of the double beta decay isotopes





NEMO-3 $0\nu2\beta$ Mass Mechanism Search with ^{100}Mo

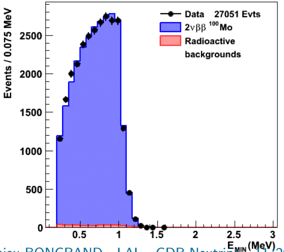
- Total ^{100}Mo exposure of 34.7 kg·y gave no event excess:
  $\mathcal{T}^{0\nu}_{1/2} > 1.1\ 10^{24}$ y (90 % CL) corresponding to $|m_{\beta\beta}| < 0.3 - 0.8$ eV*

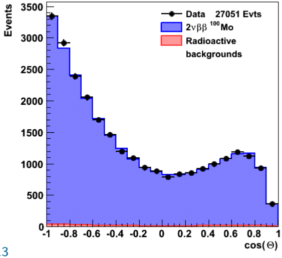


[Including systematics]

Expected background in [2.8 – 3.2] MeV	
$2\nu2\beta$	8.45 ± 0.05
^{214}Bi from radon	5.2 ± 0.5
External	< 0.2
^{214}Bi internal	1.0 ± 0.1
^{208}Tl internal	3.3 ± 0.3
Total	**18.0 ± 0.6**
Data	**15**

[To be submitted to Phys. Rev. Lett. Nov 2013]





* NME:
M. Kortelainen et al., Phys. Rev. C 76 (2007) 024315
F. Šimkovic et al, Phys. Rev. C 87 (2013) 045501
J. Barea et al., Phys. Rev. C 79 (2009) 044301
P. K. Rath et al., Phys. Rev. C 82 (2010) 064310

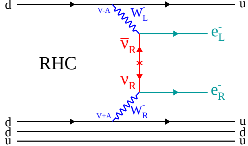
NEMO-3 Other $0\nu2\beta$ LNV Processes Search

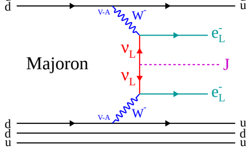
$$(\mathcal{T}^{0\nu}_{1/2})^{-1} = G_{0\nu}\, |\mathcal{M}_{0\nu}|^2\, \chi^2 \quad \text{where} \quad \chi = |m_{\beta\beta}|,\ \langle\lambda\rangle,\ \langle\eta\rangle,\ \langle g_M\rangle$$

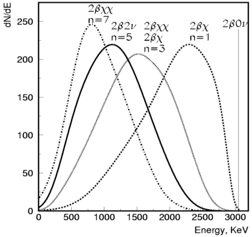
- Upper limits at 90 % CL set on the search for other $0\nu2\beta$ Lepton Number Violating processes with ^{100}Mo in units of 10^{24} y:

$0\nu2\beta$ Process	Only Statistical	Including Systematics	Expected	Physics Parameters*
Mass mechanism $\lvert m_{\beta\beta}\rvert$	1.1	1.1	1.0	0.3 - 0.8 eV
Right-handed current $\langle\lambda\rangle$	0.7	0.6	0.5	$1\ 10^{-6}$
Right-handed current $\langle\eta\rangle$	1.0	1.0	0.9	$0.8\ 10^{-8}$
Majoron emission $\langle g_M\rangle$	0.05	0.04	0.04	2 - $5\ 10^{-5}$

[To be submitted to Phys. Rev. Lett. Nov 2013]



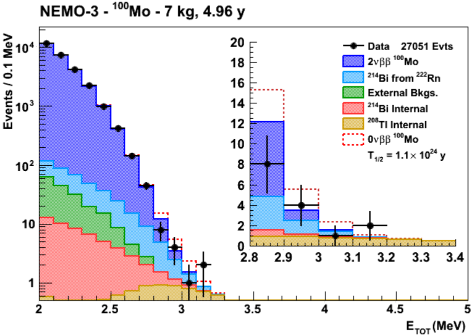


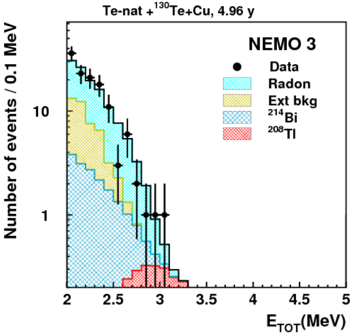


$*$ NME: Mass mechanism on previous slide - J. Suhonen, Nucl. Phys. A700 (2002) 649 - P. K. Rath et al., arXiv:1308.0460 - F. Šimkovic et al, Phys. Rev. C 60 (1999) 055502

NEMO-3 Very Low Background Experiment

- At high energy we can test the backgrounds for the $0\nu2\beta$ search





[To be submitted to Phys. Rev. Lett. Nov 2013]

- No events in ^{100}Mo after 34.7 kg·y exposure above 3.2 MeV
- No events in copper and natural tellurium samples after 13.5 kg·y exposure above 3.1 MeV
- Background free technique for high energy $\mathcal{Q}_{\beta\beta}$ isotopes: ^{48}Ca: 4.272 MeV, ^{150}Nd: 3.368 MeV or ^{96}Zr: 3.350 MeV $\rightarrow$ SuperNEMO

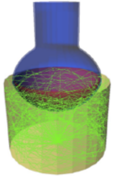
From NEMO-3 to SuperNEMO

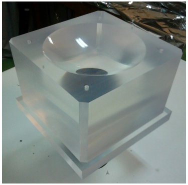
	NEMO-3	SuperNEMO
Mass	7 kg	100 kg
Isotopes	^{100}Mo	^{82}Se
	7 isotopes	^{150}Nd, ^{48}Ca
Foil density	60 mg/cm^2	40 mg/cm^2
Energy resolution (σ | FWHM)		
@ 1 MeV	6.3 | 15 %	3.0 | 7 %
@ 3 MeV	3.4 | 8 %	1.7 | 4 %
Radon in tracker		
$\mathcal{A}(^{222}\mathrm{Rn})$	$\sim$ 5.0 mBq/m^3	$\sim$ 0.15 mBq/m^3
Sources contaminations		
$\mathcal{A}(^{208}\mathrm{Tl})$	$\sim$ 100 μBq/kg	$<$ 2 μBq/kg
$\mathcal{A}(^{214}\mathrm{Bi})$	60 - 300 μBq/kg	$<$ 10 μBq/kg
Detector		
tracking cells	6180	20$\times$2034
calo blocks	1940	20$\times$712
Sensitivity (90 % CL)		
$\mathcal{T}^{0\nu}_{1/2}$	$>$ 1.1 10^{24} y	$>$ 1 10^{26} y
$\lvert m_{\beta\beta}\rvert$	$<$ 0.3 - 0.8 eV	$<$ 40 - 100 meV

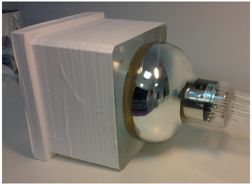
SuperNEMO demonstrator module with 7 kg of ^{82}Se (53 mg/cm^2) is under construction

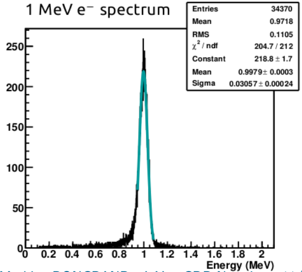
SuperNEMO Calorimeter Improvement

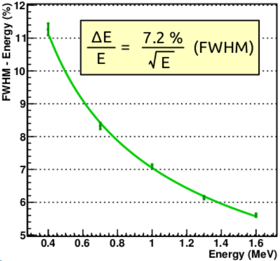
- Energy resolution of 7 % FWHM at 1 MeV achieved:
  - High QE large 8" PMTs (Hamamatsu R5912) directly coupled to the scintillator (no light guide) and improved HV divider
  - PVT plastic scintillators (also 8 % achieved for PS)
  - Optimization of the scintillator blocks geometry
  - Electronics sampling the PMT pulses $\sim$ 2 GS/s (MatAcq/SNFEB)





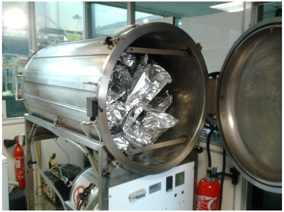




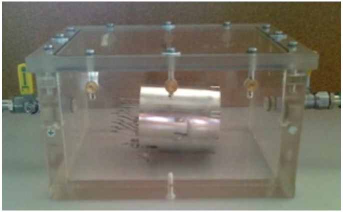


Reduce the Radon Background

- Goal: reduce the internal radon background to 0.15 mBq/m^3
- Facilities to select detector materials and protections (seals, films...)



Bordeaux emanation tank

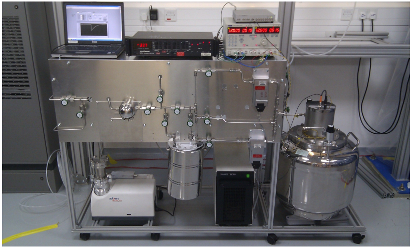


Bratislava emanation setup

Prague permeability setup

- Facilities to measure the radon level in the detector or gases

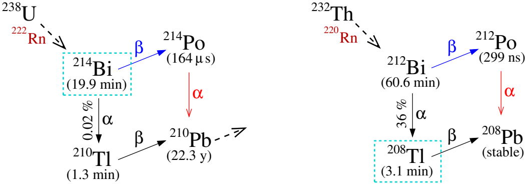
Several electrostatic detectors



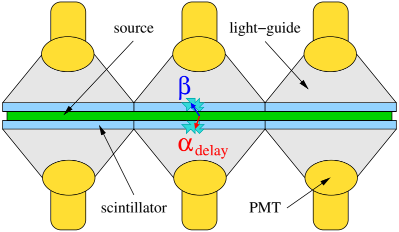
London concentration line

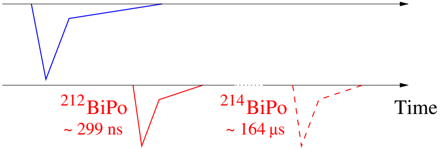
Measure the Radiopurity of the SuperNEMO Sources

- HPGe γ spectroscopy not sufficient to reach few μBq/kg today (factor 50 improvement needed for thin foils)
- Main contaminations for $0\nu2\beta$ search (^{214}Bi and ^{208}Tl) measured through BiPo processes from natural radioactivity chains:



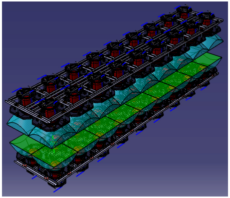
- β and α particles detected by thin radiopure plastic scintillators coupled to light-guides and low radioactivity PMTs:

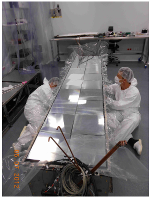


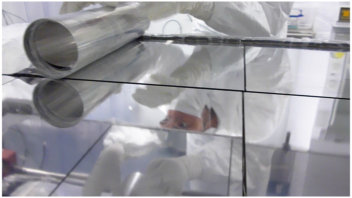


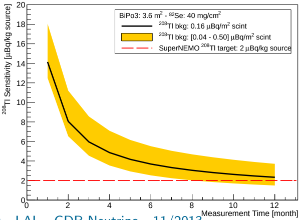
The BiPo3 Detector

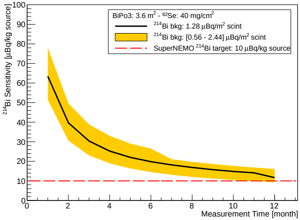
- 2 modules of 3.0x0.6 m^2 can measure 1.4 kg of ^{82}Se foil (40 mg/cm^2)
- 2 mm thick aluminized polystyrene scintillators, PMMA light guides and 5” Hamamatsu low radioactivity PMTs
- PMT pulses digitized by MatAcq boards and dedicated trigger board
- Running since 2012 in Canfranc Underground Lab (LSC, Spain)
- Sensitivity: ^{208}Tl $< 2\ \mu$Bq/kg and ^{214}Bi $< 10\ \mu$Bq/kg





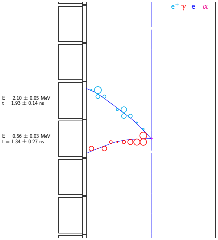




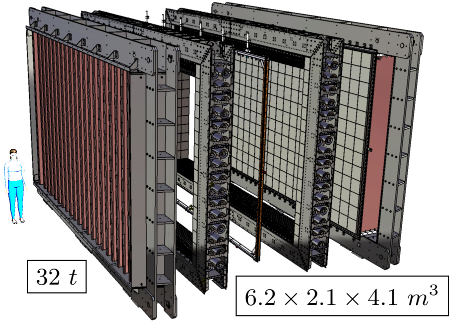


SuperNEMO Demonstrator

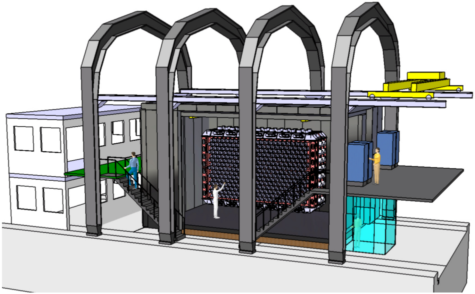
- SuperNEMO demonstrator module construction started in 2012
  - NEMO-3 sensitivity in only 5 months (90 % CL):
    $(\mathcal{T}^{0\nu}_{1/2} > 1.1\ 10^{24}$ y $\rightarrow |m_{\beta\beta}| < 0.3 - 0.8$ eV)
  - No background in the $0\nu2\beta$ region in 2.5 years for 7 kg of ^{82}Se
  - Sensitivity after 17.5 kg·y exposure (90 % CL):
    $\mathcal{T}^{0\nu}_{1/2} > 6.5\ 10^{24}$ y $\rightarrow$ $|m_{\beta\beta}| < 200 - 400$ meV



- Commissioning in the actual LSM expected end of 2014



Replacing NEMO-3 in the actual LSM

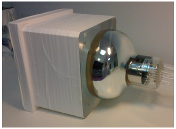


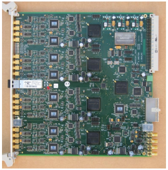
SuperNEMO Demonstrator Construction Status

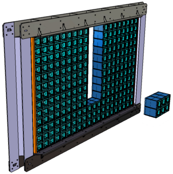
Calorimeter

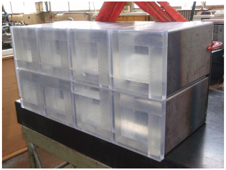
- Scintillators under production and 8" Hamamatsu PMTs in 02/2014
- FE digitizer boards OK, control and trigger boards under development
- Blocks, wall designs and mechanical tests OK $\rightarrow$ construction starting!

$256 \times 256 \times 194$ mm^3



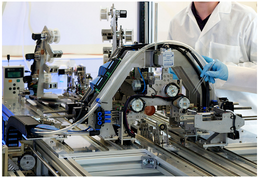


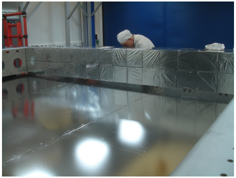


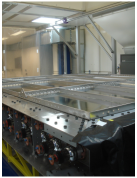


Tracker

- Automated drift cells production ongoing with the wiring robot
- First 1/4 tracker C0 under radon emanation test before cells population
- C0 commissioning: sea-level end of 2013 and underground in 2014







Sources

- Already 5.5 kg of enriched ^{82}Se with 0.5 kg purified
- Source materials (glue, films...) under HPGe and BiPo selection processes
- Calibration sources deployment system prototype under test

Summary

To be completed/updated

Experiment	**Phase**	**Isotope**	**Exposure** [kg·y]	**FWHM @** $Q_{\beta\beta}$ [keV]	**Bkg** [keV·kg·y]$^{-1}$	$\mathcal{T}^{0\nu}_{1/2}$ [y] (90 % CL)	$\lvert m_{\beta\beta}\rvert$ [eV]
GERDA	Phase 1	^{76}Ge	21.6	2.6-5.7	10^{-2}	2.1 10^{25}	0.2 - 0.5
	Phase 2		∼100	3	10^{-3}	1 10^{26}	0.04 - 0.1
CUORE	CUORE-0	^{130}Te	2.2	5	0.074/0.019	-	-
	CUORE		1000	5	0.01	1 10^{26}	0.045 - 0.095
LUCIFER	-	^{82}Se	90	5 (13)	10^{-3}	∼10^{26}	0.05 - 0.12
LUMINEU	4 crystals	^{100}Mo	0.7	5	10^{-3}	1 10^{24}	0.3 - 0.8
	1 tower		35			7 10^{25}	0.04 - 0.10
EXO	EXO-200	^{136}Xe	32.5	100	10^{-3}	1.6 10^{25}	0.14 - 0.38
	nEXO		45 10^{3}	90	2 10^{-5}	4.1 10^{27}	0.005 - 0.030
KamLAND-Zen	-	^{136}Xe	89.5	250	^{110m}Ag	1.9 10^{25}	0.12 - 0.25
NEMO-3	-	^{100}Mo	34.7	450	10^{-3}	1.1 10^{24}	0.3 - 0.8
SuperNEMO	Demons.	^{82}Se	17.5	∼200	5 10^{-5}	6.5 10^{24}	0.2 - 0.4
	20 mod.		500			1 10^{26}	0.04 - 0.10

Many thanks to X. Sarazin, F. Piquemal & TAUP 2013 Speakers for materials and help