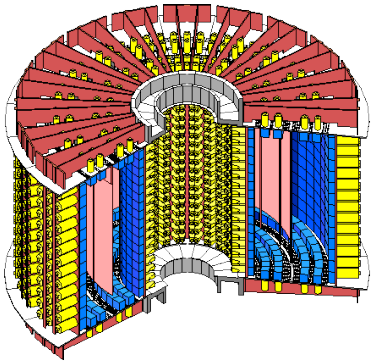
Latest results from NEMO-3
&
Status of SuperNEMO



Pawel Guzowski

MANCHESTER 1824
The University of Manchester

on behalf of the NEMO collaboration

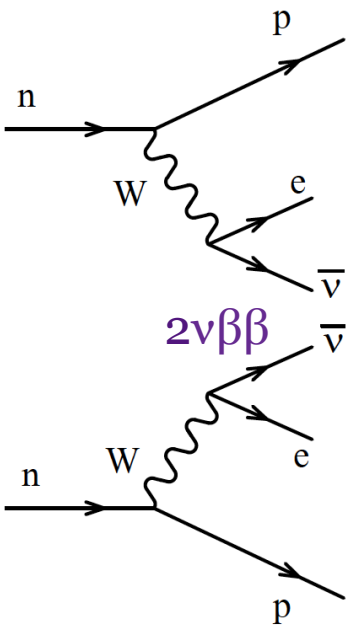
supernemo collaboration

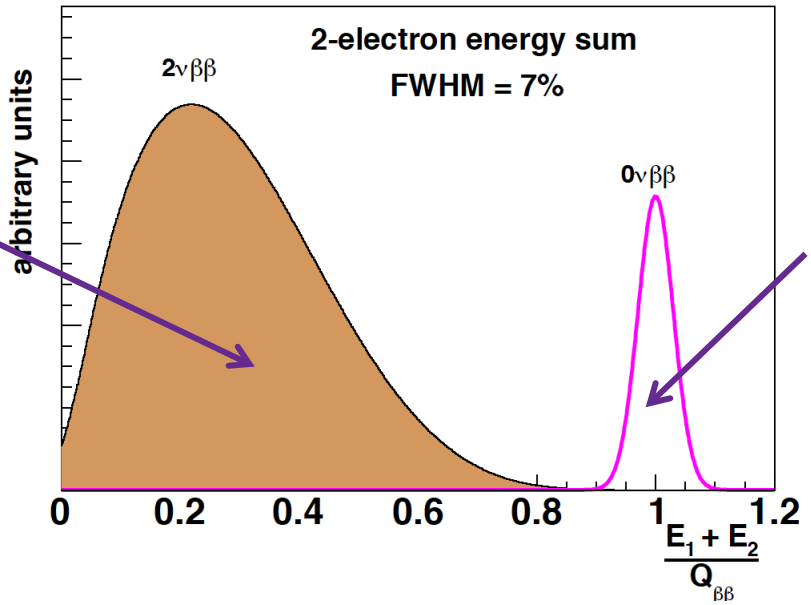
EPS HEP 13
20 July 2013

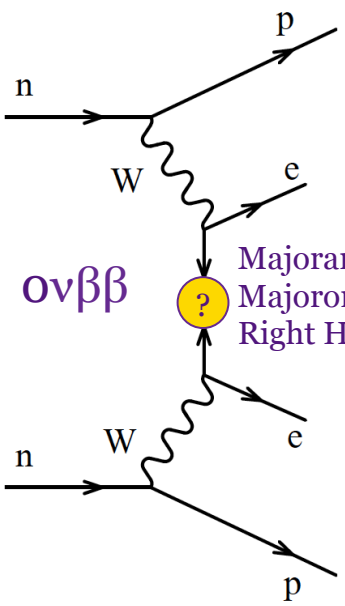
Outline

- $0\nu\beta\beta$ phenomenology
- NEMO experimental technique
- Latest results from NEMO-3
- Status of SuperNEMO construction

0νββ phenomenology

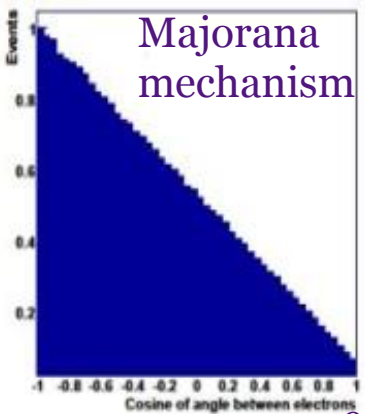


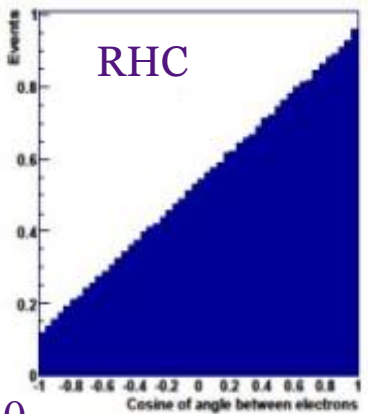




0νββ mechanisms have different kinematic signatures

- Electron energy spectrum
- Angles between electrons





cos θ

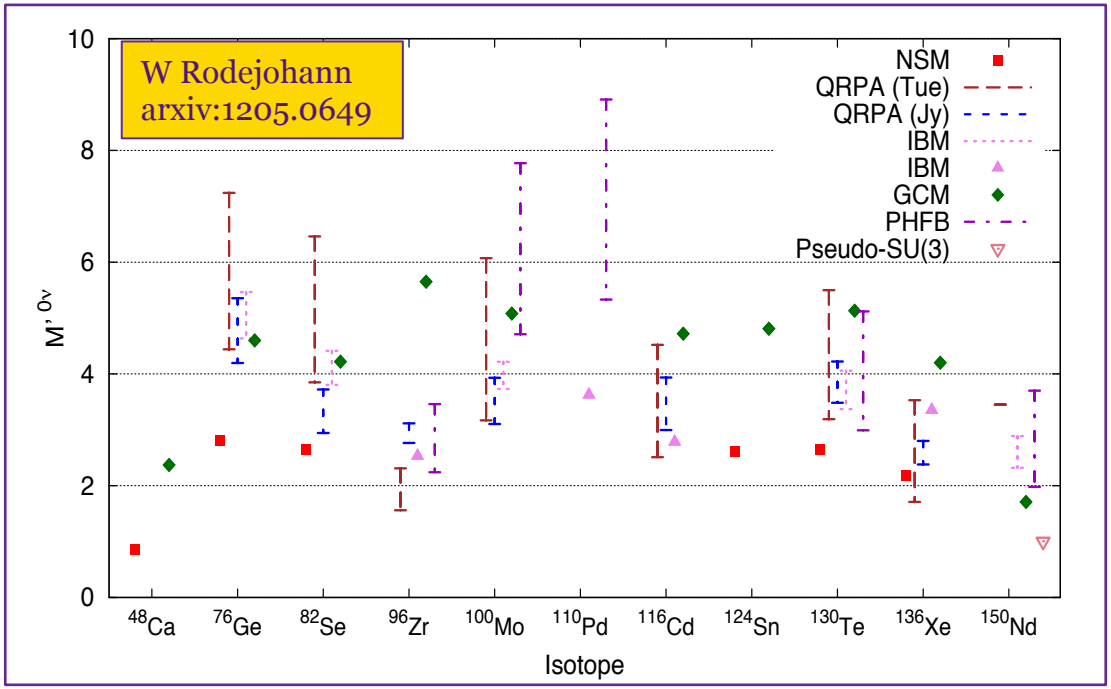
ovββ phenomenology

- $\langle m_\nu \rangle$ – effective ν_e mass
- $G_{0\nu}$ – phase space factor, well known
- Nuclear matrix elements $M_{0\nu}$ currently biggest source of theoretical uncertainty
  - Large variations between nuclear models
- For best sensitivity, want large G & M
- Want large Q for better background rejection
- NEMO allows mixing & matching sources

$$\frac{1}{T_{1/2}^{0\nu}} = G_{0\nu}(Q_{\beta\beta}^5, Z)\left|M_{0\nu}\right|^2 \frac{\langle m_\nu \rangle^2}{m_e^2}$$

(Majorana mechanism)

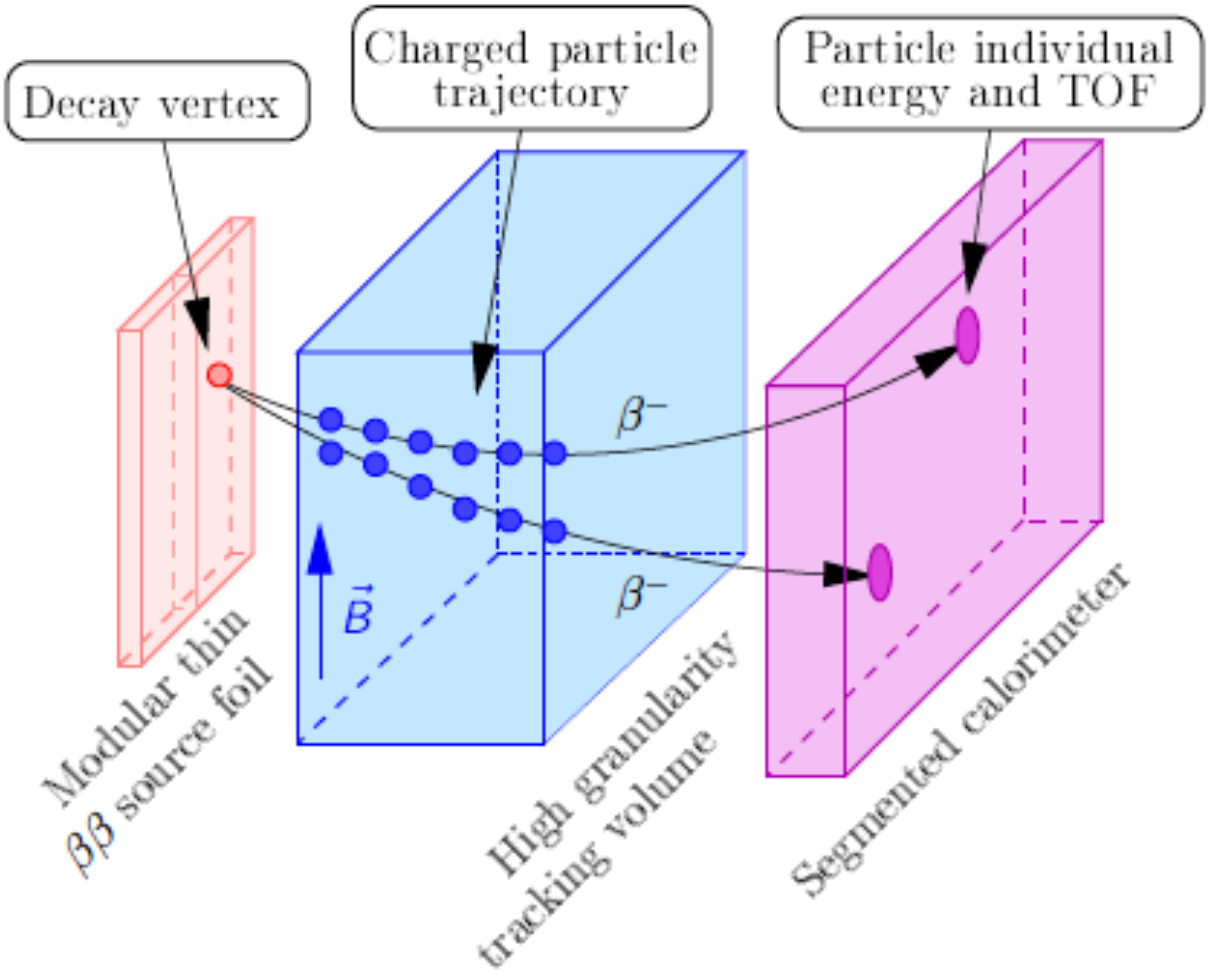
Isotope	Abundance (%)	$Q_{\beta\beta}$ (MeV)	$G_{0\nu}$ (10^{-14} y^{-1})
^{48}Ca	0.19	4.274	6.35
^{76}Ge	7.8	2.039	0.62
^{82}Se	9.2	2.996	2.70
^{96}Zr	2.8	3.348	5.63
^{100}Mo	9.6	3.035	4.36
^{116}Cd	7.6	2.809	4.62
^{130}Te	34.5	2.530	4.09
^{136}Xe	8.9	2.462	4.31
^{150}Nd	5.6	3.367	19.2



Experimental technique

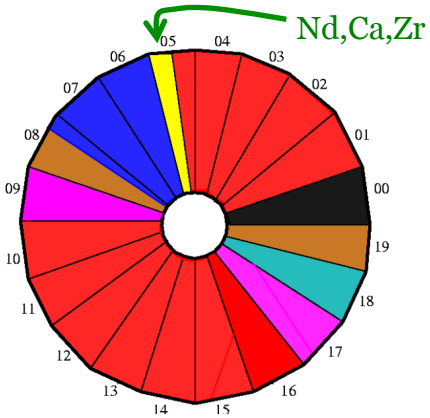
- Calorimeters provide E, t measurements
- Tracker used vertexing, charge ID, angles
- PID: e^-, γ, e^+, α

- Knowledge of full event topology allows disentangling decay mechanisms
- All backgrounds determined experimentally in situ

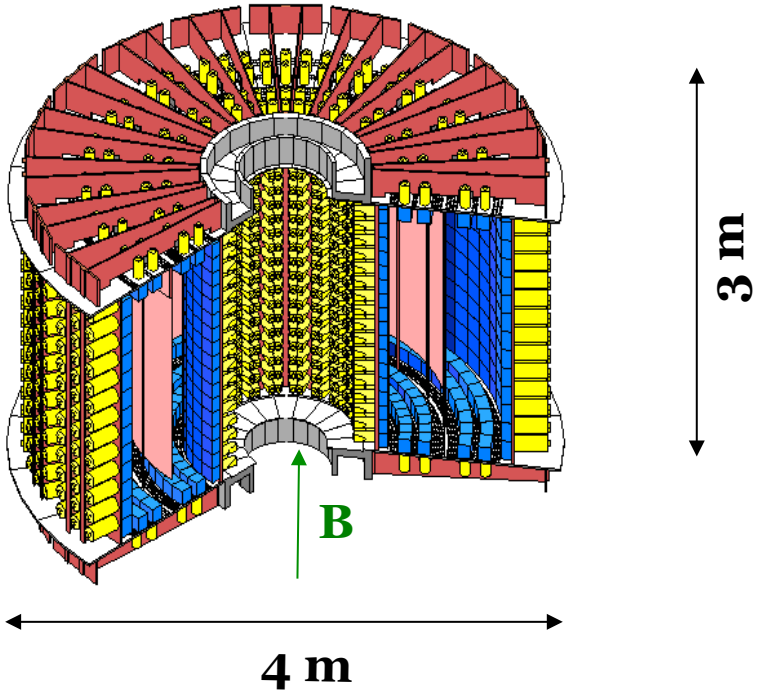


NEMO-3

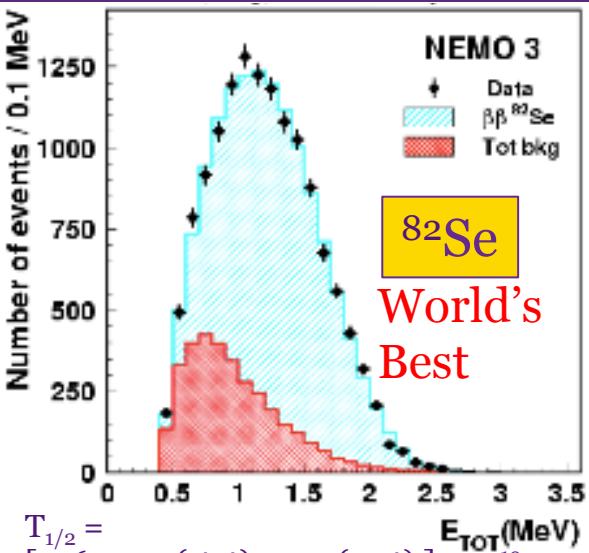
- Location - 4800 m.w.e. underground lab
- Data taking - Feb 2003 to Jan 2011
- Source
  - 20 sectors
  - 10kg, 20m², ~60mg/cm²
  - 7kg ^{100}Mo, 1kg ^{82}Se
  - ^{116}Cd, ^{150}Nd, ^{48}Ca, ^{96}Zr, ^{130}Te
- Tracker
  - Drift wire chamber in Geiger mode
  - 9 layers/side, 6180 cells
  - He, 4% ethyl alcohol, 1% Ar, 0.1% H2O
  - 25G magnetic field
- Calorimetry
  - 1940 plastic scintillator blocks
  - 3”, 5” low-radioactivity PMTs



Top view



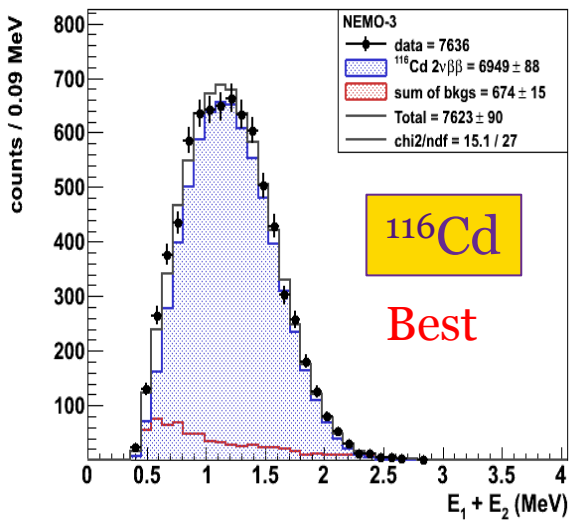
2νββ results



^{82}Se

World's Best

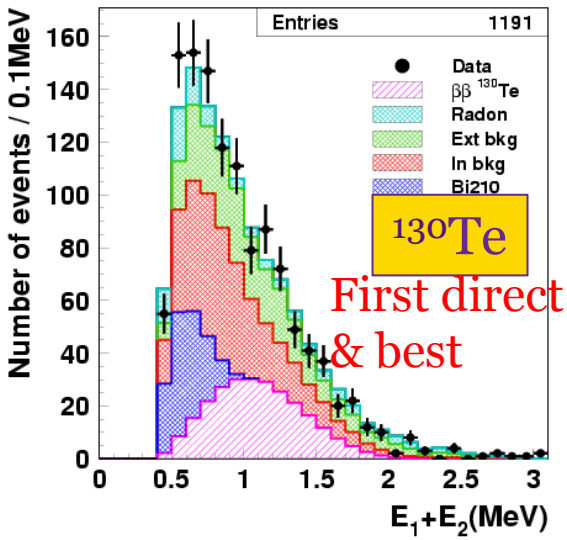
$T_{1/2}$ = [9.6 ± 0.1 (stat) ± 1.0 (syst)] x 10^{19} y



^{116}Cd

Best

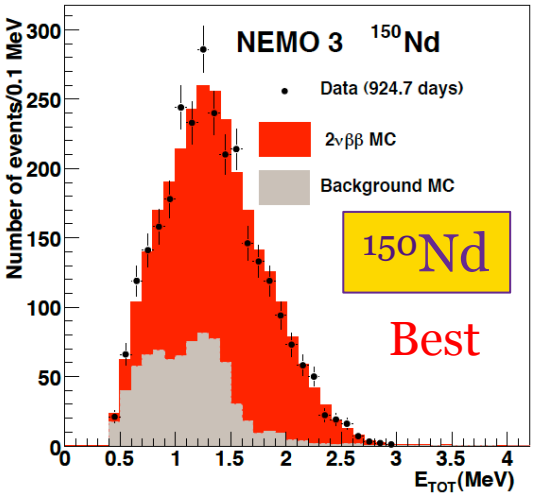
[2.88 ± 0.04 (stat) ± 0.16 (syst)] x 10^{19} y



^{130}Te

First direct & best

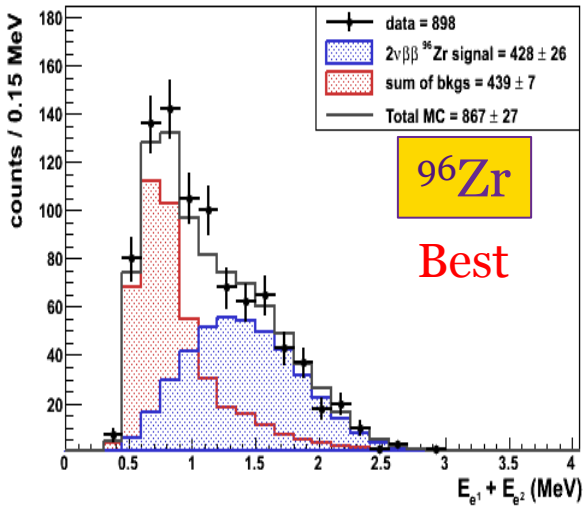
[7.0 ± 0.9 (stat) ± 1.1 (syst)] x 10^{20} y



^{150}Nd

Best

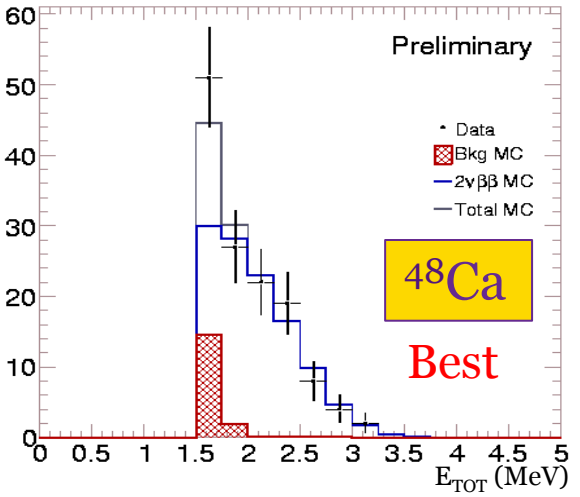
[9.11 ± 0.25 (stat) ± 0.63(syst)] x 10^{18} y



^{96}Zr

Best

[2.35 ± 0.14 (stat) ± 0.16 (syst)] x 10^{19} y

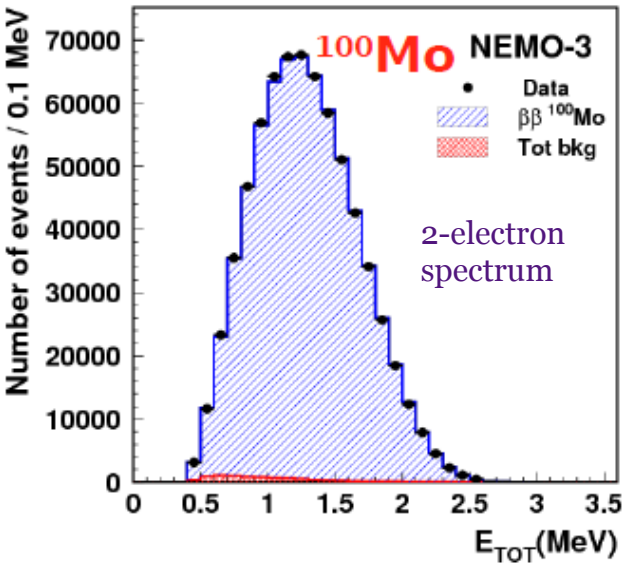


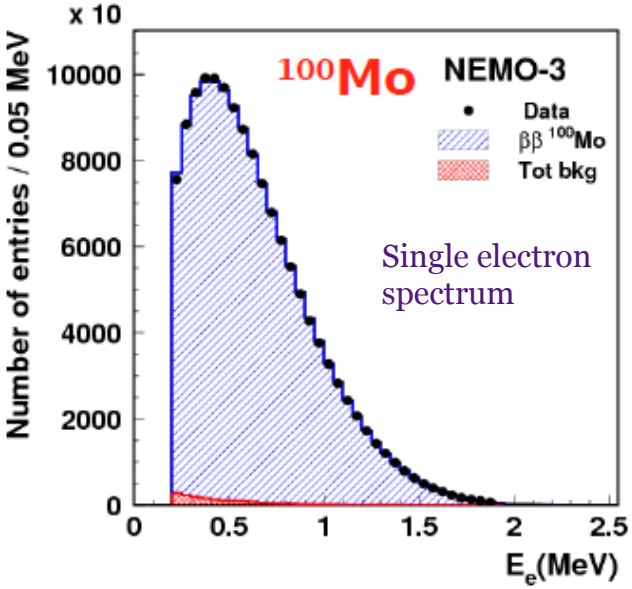
^{48}Ca

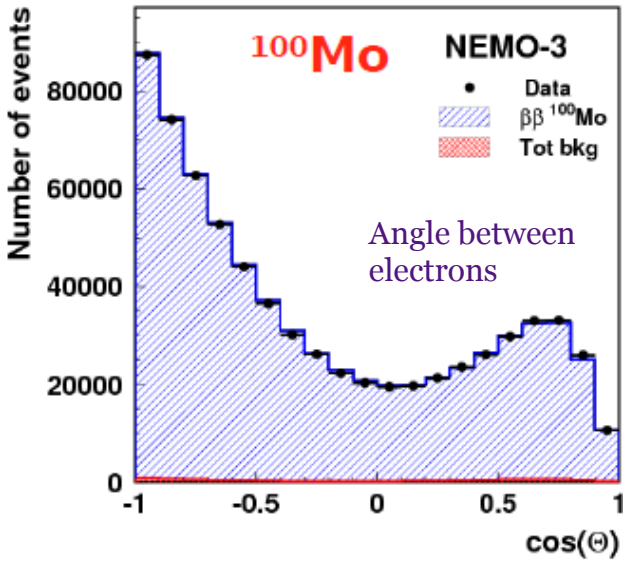
Best

[4.4 ± 0.5 (stat) ± 0.4 (syst)] x 10^{19} y

2νββ results







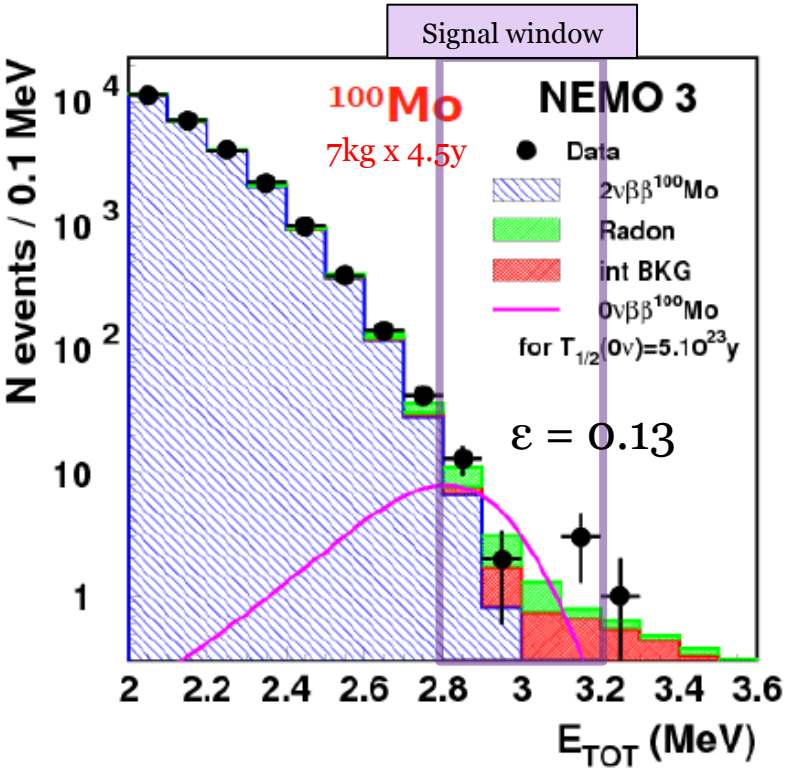
Phase II result:
700,000 2e events from ^{100}Mo foils
Signal efficiency: 0.043; purity: 0.987
$T_{1/2}(2\nu\beta\beta) = (7.16 \pm 0.01\ (stat) \pm 0.54(syst)) \times 10^{18}$ y PRELIM.

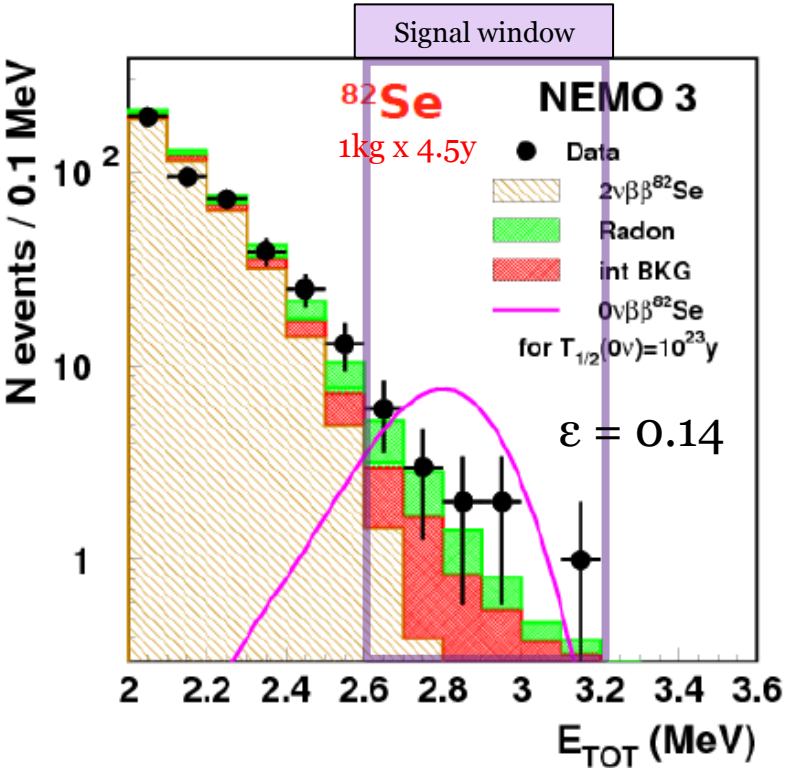
Consistent with Phase I (PRL **95** 182302 (2005))

Publication later this year

Phase I: data until Sep 2004; Phase II: data from Oct 2004

ovββ search results





$T_{1/2}(0\nu\beta\beta) > 1.0 \times 10^{24}$ y (90% C.L.)
$\langle m_\nu \rangle < 0.31 - 0.96$ eV [1—5]

$T_{1/2}(0\nu\beta\beta) > 3.2 \times 10^{23}$ y (90% C.L.)
$\langle m_\nu \rangle < 0.94 - 2.6$ eV [1—4,6]

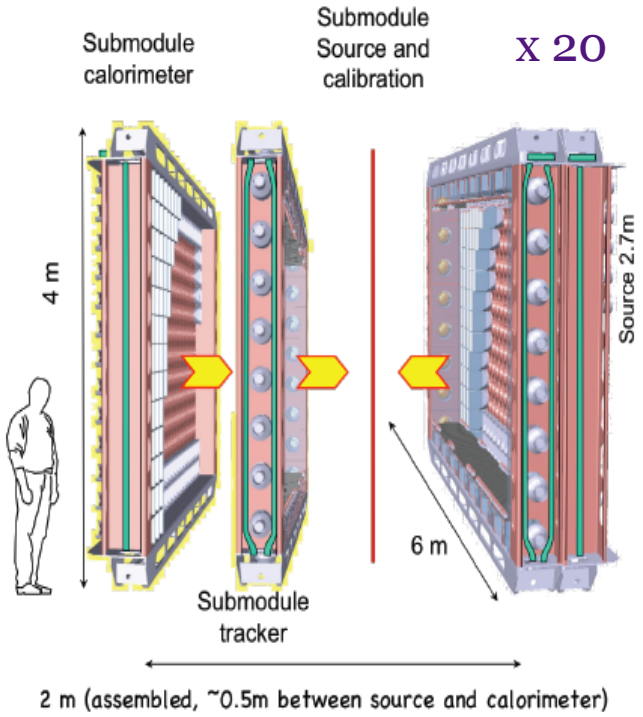
NMEs used:

[1] PRC **75** 051303 (2007)
[2] PRC **76** 024315 (2007)
[3] PRC 77 045503 (2008)
[4] PRC **79** 044301 (2009)
[5] PRC **82** 064310 (2010)
[6] PRL **100** 052503 (2008)

From NEMO-3 to SuperNEMO

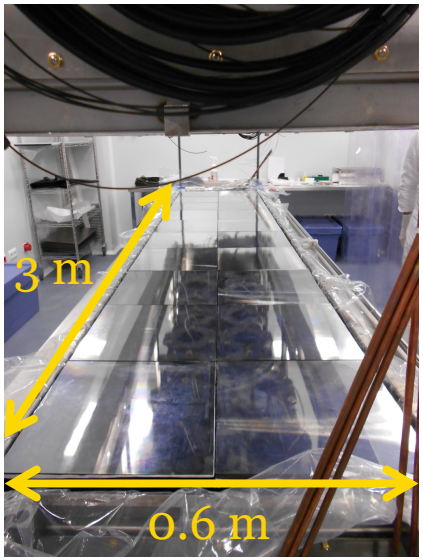
- Planar, modular successor of NEMO-3
  - More than an order of magnitude lower backgrounds
- Demonstrator module under construction, data taking from 2015
  - Prove that zero background is achievable
  - A further 19 modules to be made later
- Extremely low background environment needed also in construction

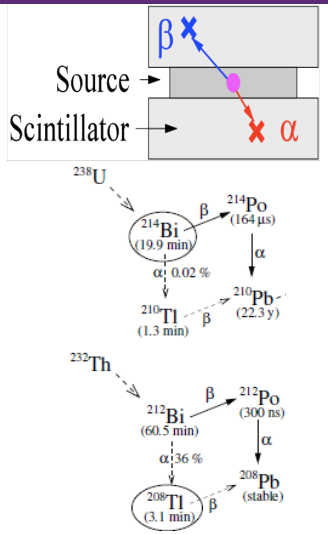
NEMO-3		SuperNEMO
^{100}Mo, ^{82}Se (^{150}Nd, ^{130}Te, ^{116}Cd, ^{96}Zr, ^{48}Ca)	**Isotopes**	^{82}Se (^{150}Nd, ^{48}Ca)
10	**Mass (kg)**	100—200 (*demo: 7*)
^{208}Tl: ~100 ^{214}Bi: <300	**Source contamination (μBq/kg)**	^{208}Tl: <2 ^{214}Bi: <10
5	**Radon level (mBq/m^3)**	<0.15
8%	**Energy resolution (FWHM at 3MeV)**	4%
1	**$T^{1/2}$ sensitivity (10^{24} y)**	100 (*demo: 6.6*)
300—900	**$\langle m_\nu \rangle$ sensitivity (meV)**	40—100 (*demo: 200—400*)

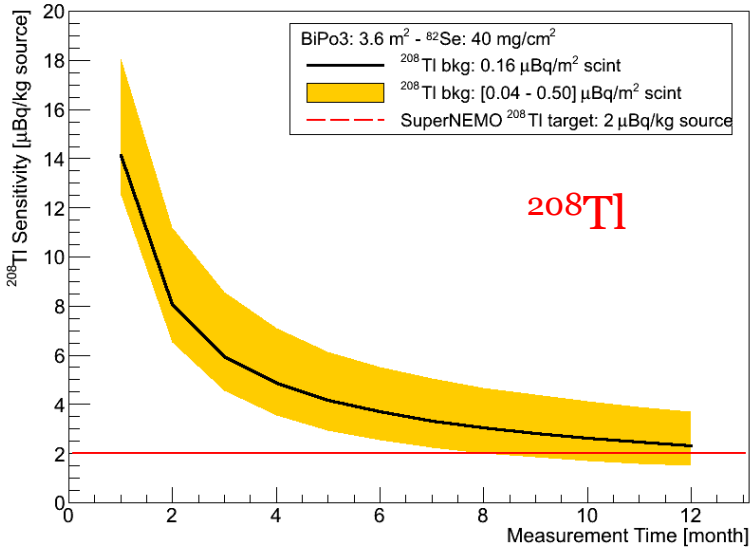


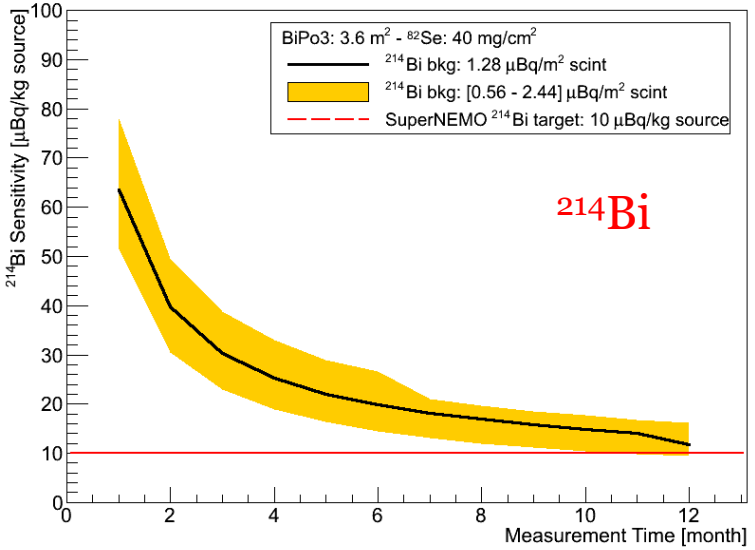
Source production

- 5.5 kg ^{82}Se produced
- 'BiPo' detector operating at Canfranc lab, measuring ^{214}Bi and ^{208}Tl contamination levels in the source foil
  - β-α delayed coincidence



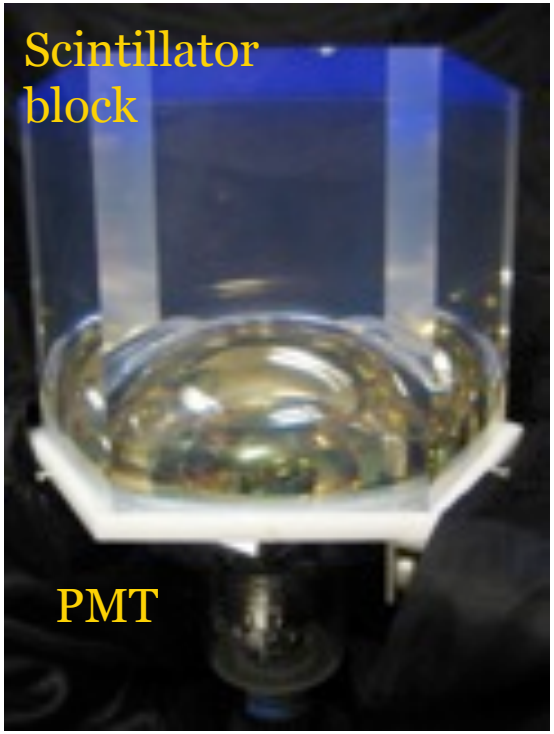


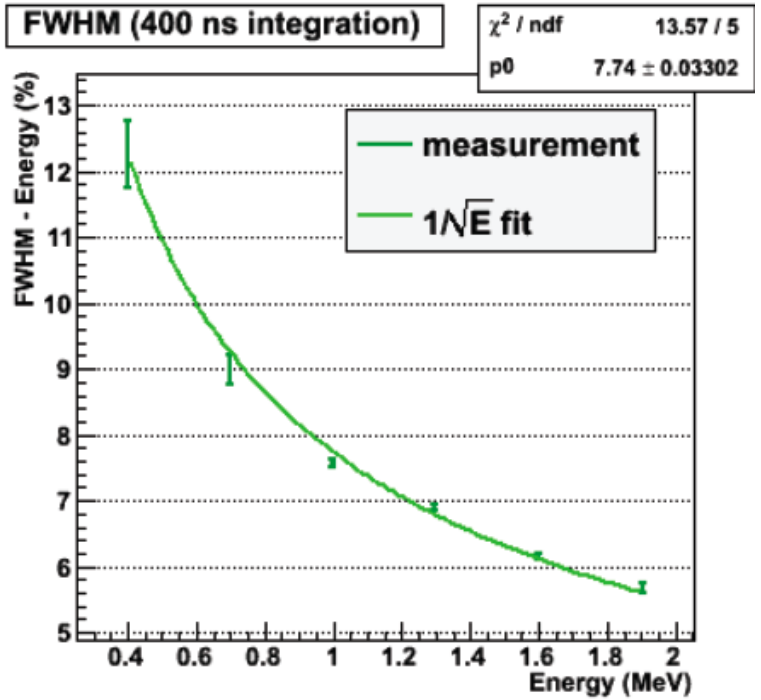




Calorimetry

- Demonstrated $\Delta E/E < 8\%$ for 1 MeV electrons (equivalent to 4% at Q=3MeV)
- Final design: Hamamatsu 8” PMTs, 256 x 256 x 150 mm^3 scintillator blocks





Tracker production

- Tracker construction under way
  - Robot used to make wire cells
  - Cassettes of 18 cells at a time
- One out of the four corners of the frame has been built
  - Optical modules have been attached
  - Currently undergoing radon emanation measurements

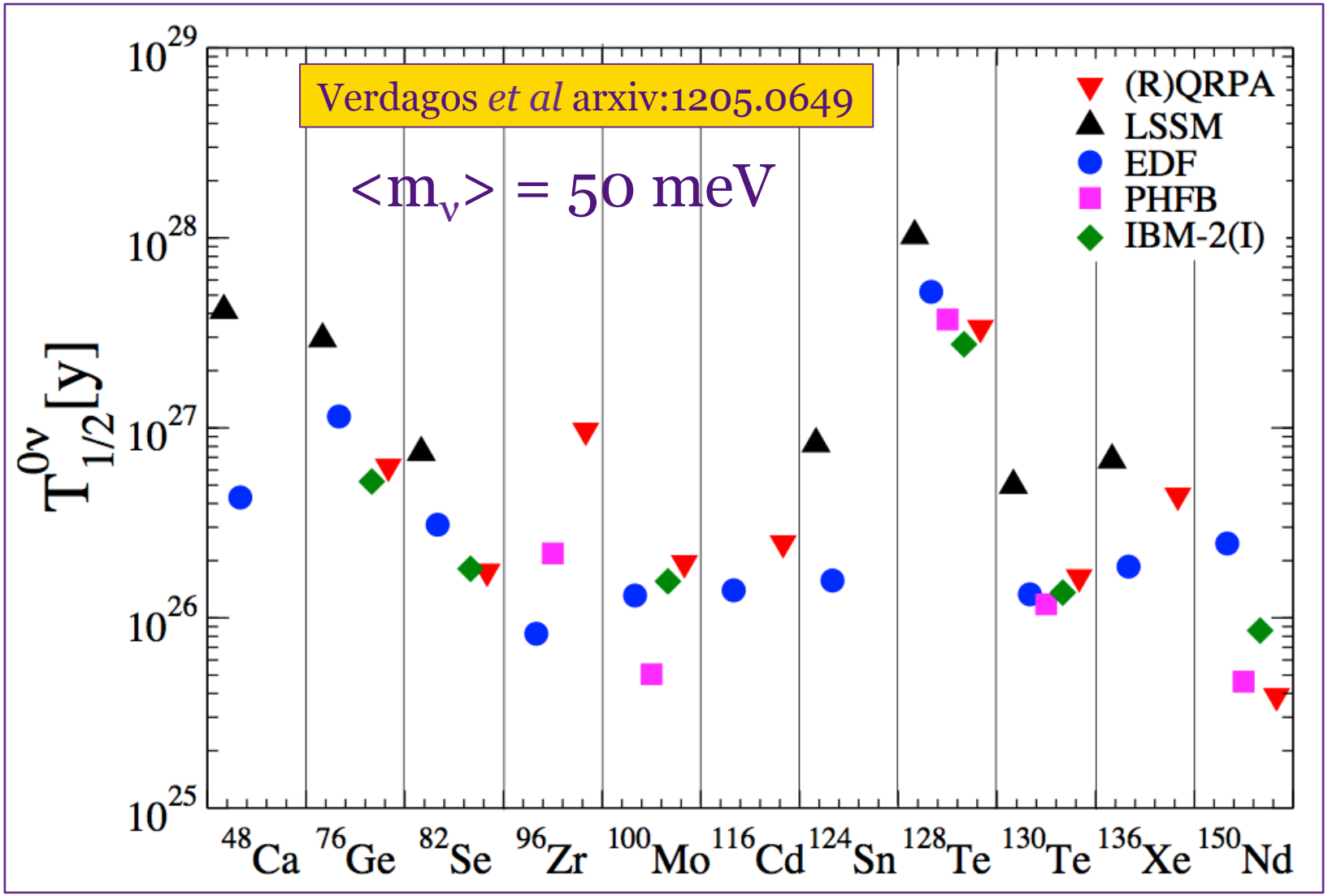
Summary

- NEMO-3 has produced a unique spectrum of results on $0\nu\beta\beta$ and $2\nu\beta\beta$
  - World leading results on seven isotopes
  - Unique capability of investigating different models
  - Currently producing publications of final results
- Full production of the first SuperNEMO module is currently ongoing
  - Demonstrate that zero background is achievable
- Complete SuperNEMO will be sensitive to $T_{1/2} \sim 10^{26}$ y

Thank You

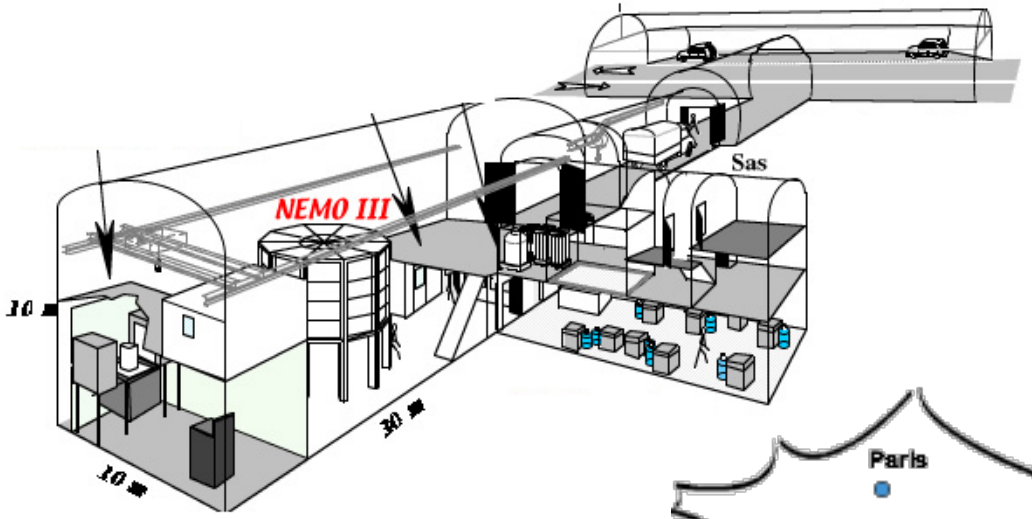
BACKUP SLIDES

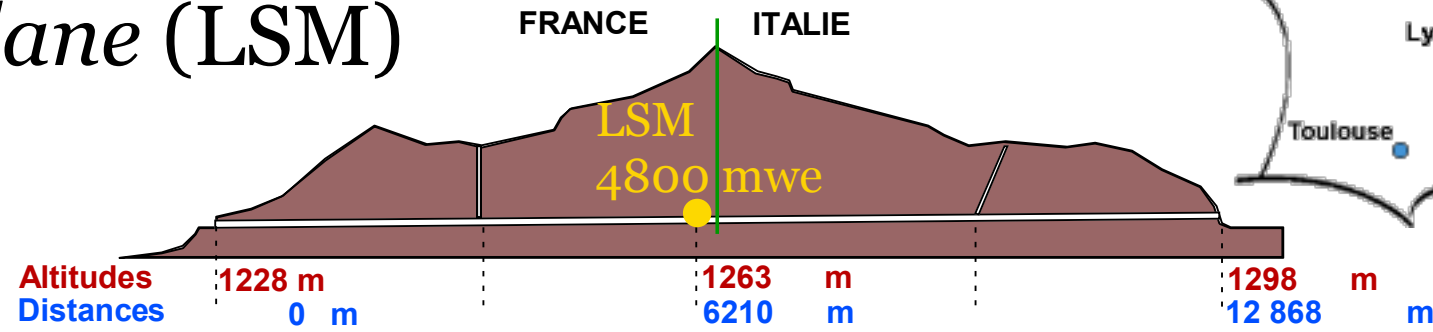
Half lives (MM)

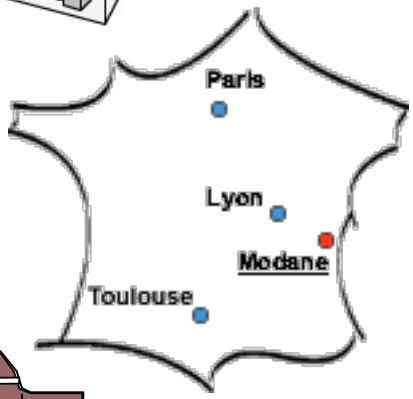


NEMO Collaboration

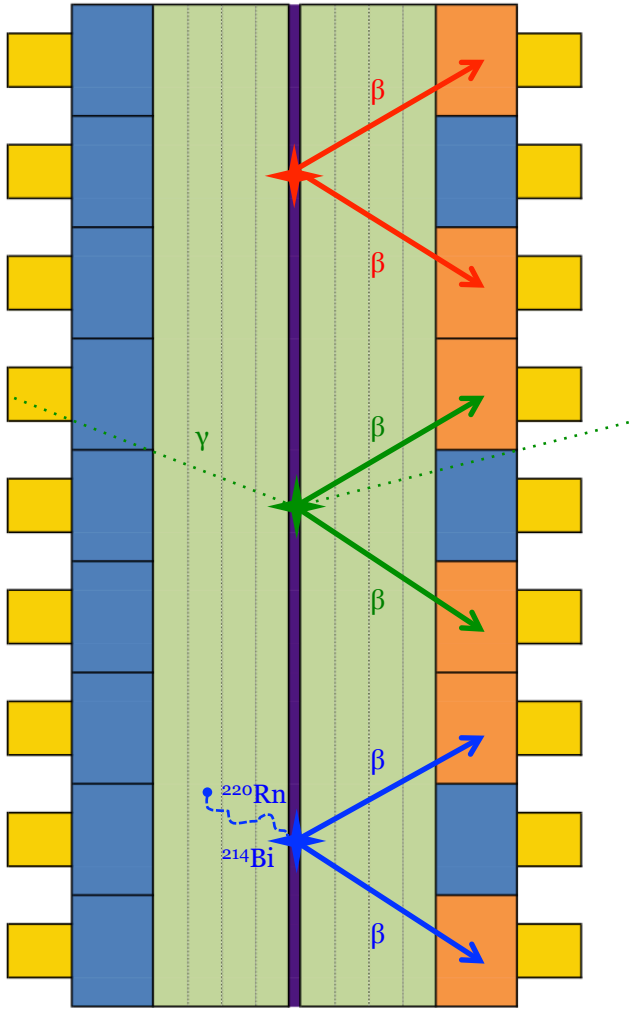
- 12 countries, 27 institutions
- Experiments located in *Laboratoire Souterrain de Modane* (LSM)



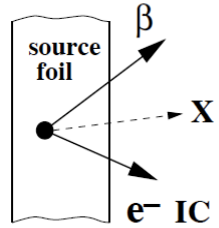




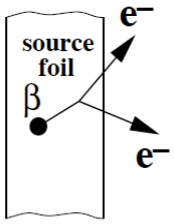
Backgrounds



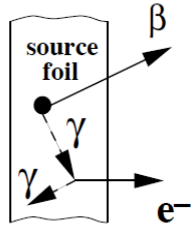
Internal background
Impurities in the source foil, ^{208}Tl, ^{214}Bi



beta + IC

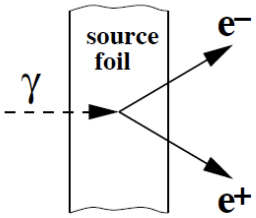


beta + Möller

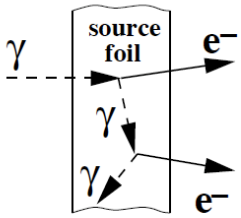


beta + Compton

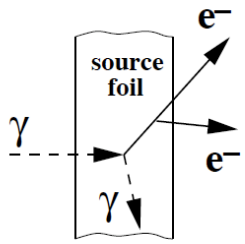
External backgrounds
Impurities in detector materials



pair creation



Compton + Compton



Compton + Möller

Radon background (^{214}Bi)
Deposits on surfaces within the detector

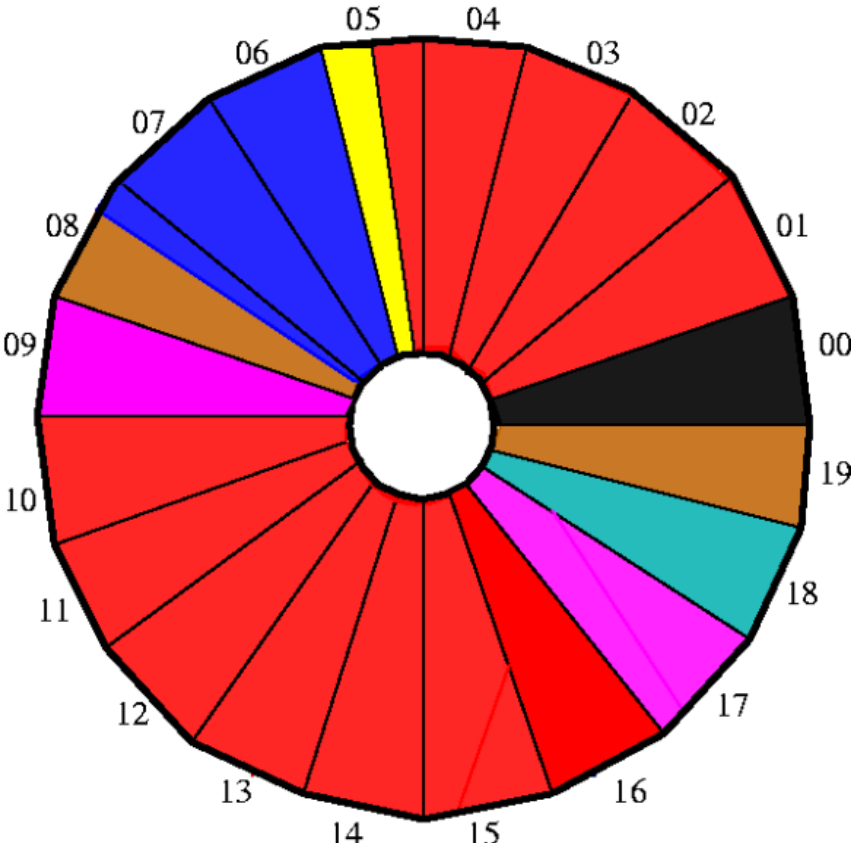
+ irreducible 2νββ background

NEMO-3 shielding

- Gamma:
  - 18cm thick iron wall
- Neutron:
  - 30cm boronated water as outside wall
  - 40cm wood on top/bottom
- Radon:
  - Charcoal trap used from Sep 2004 onwards
  - Separates two data acquisition periods: Phase I (until Sep 2004) and Phase II (from Oct 2004)

NEMO-3 sources

Isotope	Mass (g)
^{100}Mo	6,914
^{82}Se	932
^{130}Te	454
^{116}Cd	405
^{150}Nd	37
^{96}Zr	9.4
^{48}Ca	7
^{nat}Te	491
^{nat}Cu	621



ovββ search results

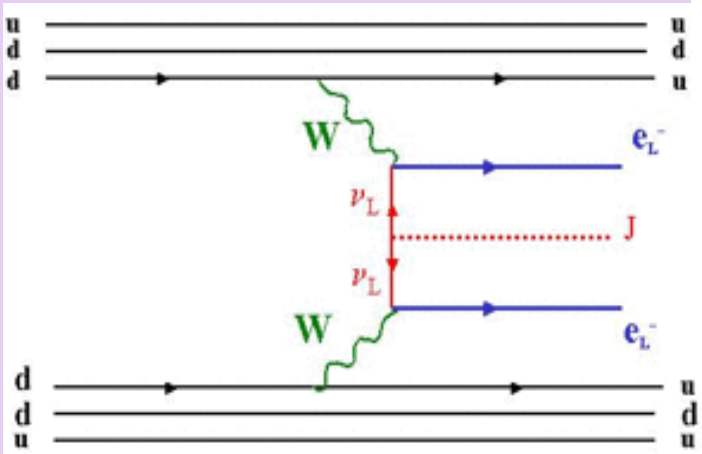
Non Majorana-mass-mechanism results

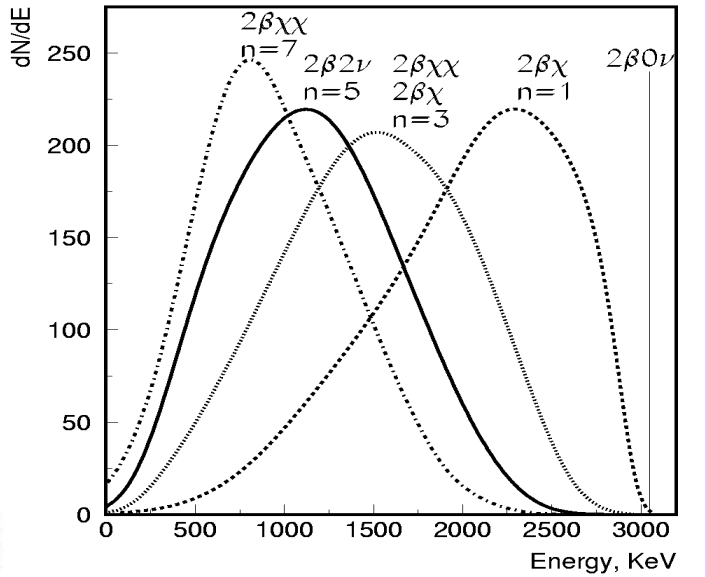
$$\frac{1}{T_{1/2}^{0\nu}} = G_{0\nu}(Q_{\beta\beta}^{5}, Z)\left|M_{0\nu}\right|^{2}\mu^{2}$$

$\mu = \lambda$ (RHC); g_{ee} (Majoron)

	RHC Phase I+II	Majoron emission (n=spectral index) Phase I			
	$T_{1/2}(0\nu\beta\beta)$ (years)	T1/2(ovββ) (years)			
		n = 1	n = 2	n =3	n = 7
^{100}Mo	> 5.7 x 10^{23} λ < 1.4 x 10^{-6}	> 2.7 x 10^{22} g_{ee} < (0.4 - 1.8) x 10^{-4}	> 1.7 x 10^{22}	> 1 x 10^{22}	> 7 x 10^{19}
^{82}Se	> 2.4 x 10^{23} λ < 2 x 10^{-6}	> 1.5 x 10^{22} g_{ee} < (0.7 - 1.9) x 10^{-4}	> 6 x 10^{21}	> 3.1 x 10^{22}	> 5 x 10^{20}

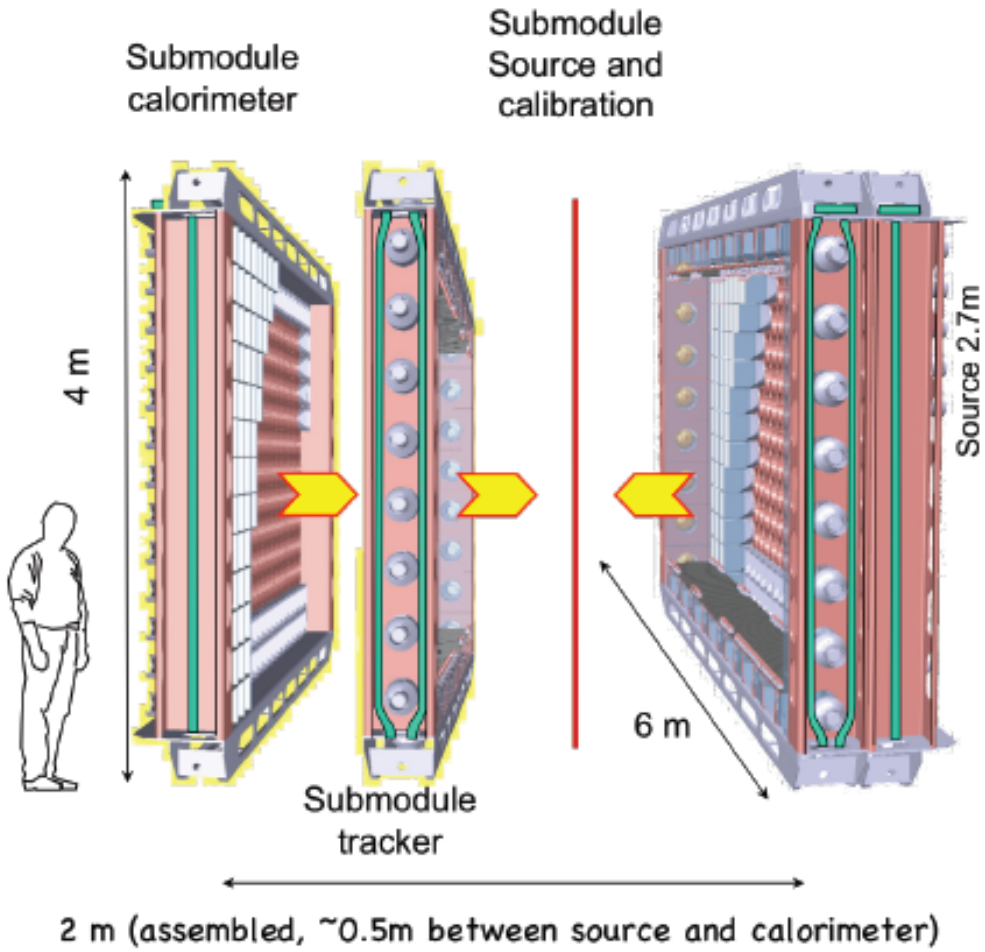
Majoron emission





SuperNEMO module

- 4 x 3.7 m² source foil (~40 mg/cm²)
- ~500 calorimeter modules
- ~2000 tracker cells
- 20 tons
- Background less than 10^{-4} events/ keV/kg/year

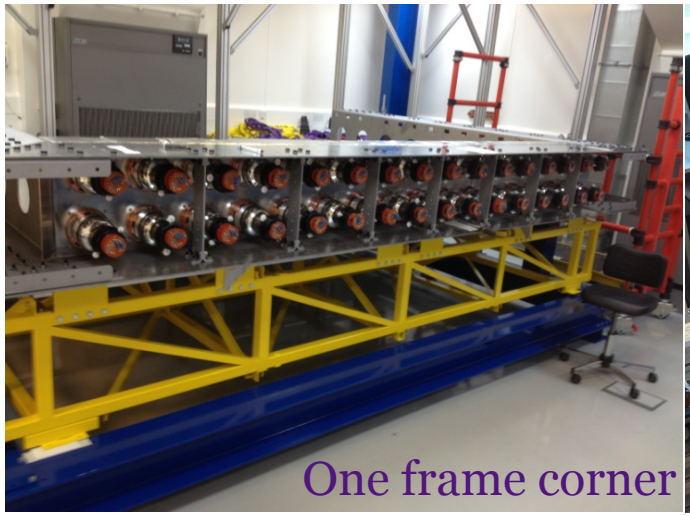


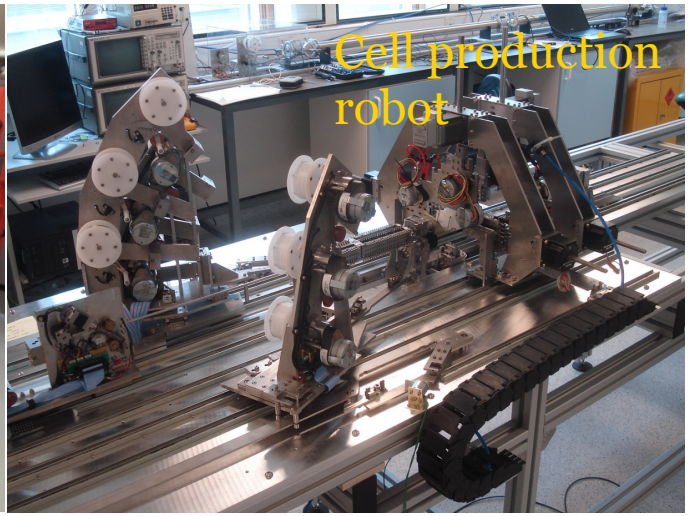
SuperNEMO schedule

2013	2014	2015	2016	2017	2018	2019	2020	2021

Demonstrator module construction and commissioning
Demonstrator operation: Prove low background is achievable $T_{1/2}$ sensitivity ~ 6.6 x 10^{24} years
Construction & operation of remaining 19 modules $T_{1/2}$ sensitivity ~ 10^{26} years (100 kg, 5 years)

Tracker production





- 2 x 9 wire cells per cassette
- 112 cassettes per module
- 1 cassette per day at peak production