SEARCH FOR DOUBLE BETA DECAY WITH NEMO 3 EXPERIMENT

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on behalf of the NEMO 3 Collaboration

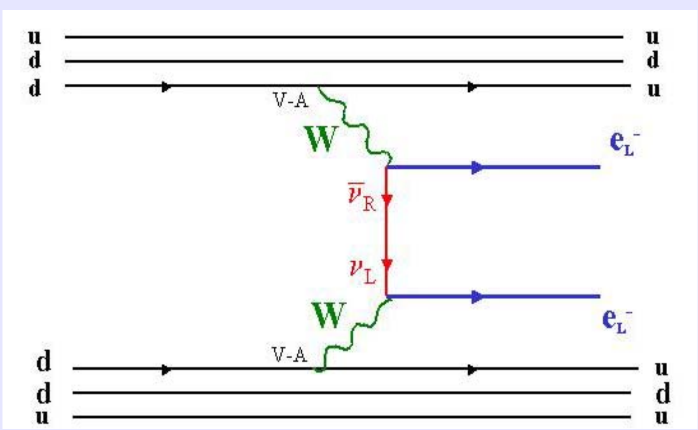
Neutrinoless double beta decay

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

Discovery means ⇨ $\Delta L = 2$ and Majorana neutrino type

mechanism: The exchange of the light Majorana neutrino

parameter: $\langle m_\nu \rangle$



phase space factor

Nuclear matrix element (NME)

$$(T^{0\nu}_{1/2})^{-1} = F(Q^5_{\beta\beta}, Z)\, |M|^2 \langle m_\nu \rangle^2$$

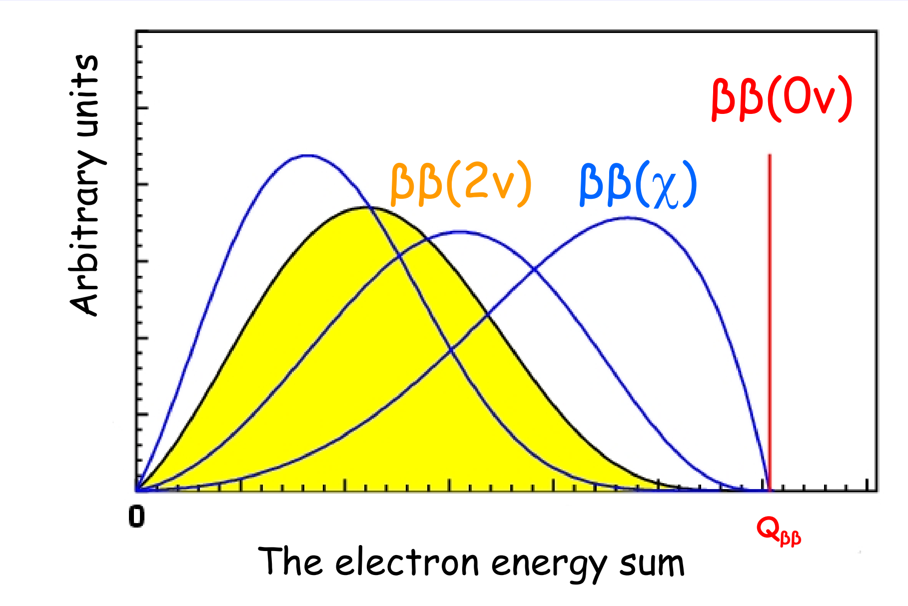
Effective neutrino mass:

$$\langle m_\nu \rangle = m_1 |U_{e1}|^2 + m_2 |U_{e2}|^2 . e^{ia1} + m_3 |U_{e3}|^2 . e^{ia2}$$

$|U_{ei}|$: elements of the mixing matrix

a1 и a2: Majorana phases

Experimental signature of ββ0ν



ββ(0ν) : two electrons energy sum = $Q_{\beta\beta}$ ($T_{1/2} > 10^{24}$ y)

ββ(2ν) : the second order classic process of the weak interactions ($T_{1/2} \sim 10^{19}$ y)

ββ(χ) : others processes of the double beta decay possible by production of one or two Majoron (massless scalar Goldstone boson)

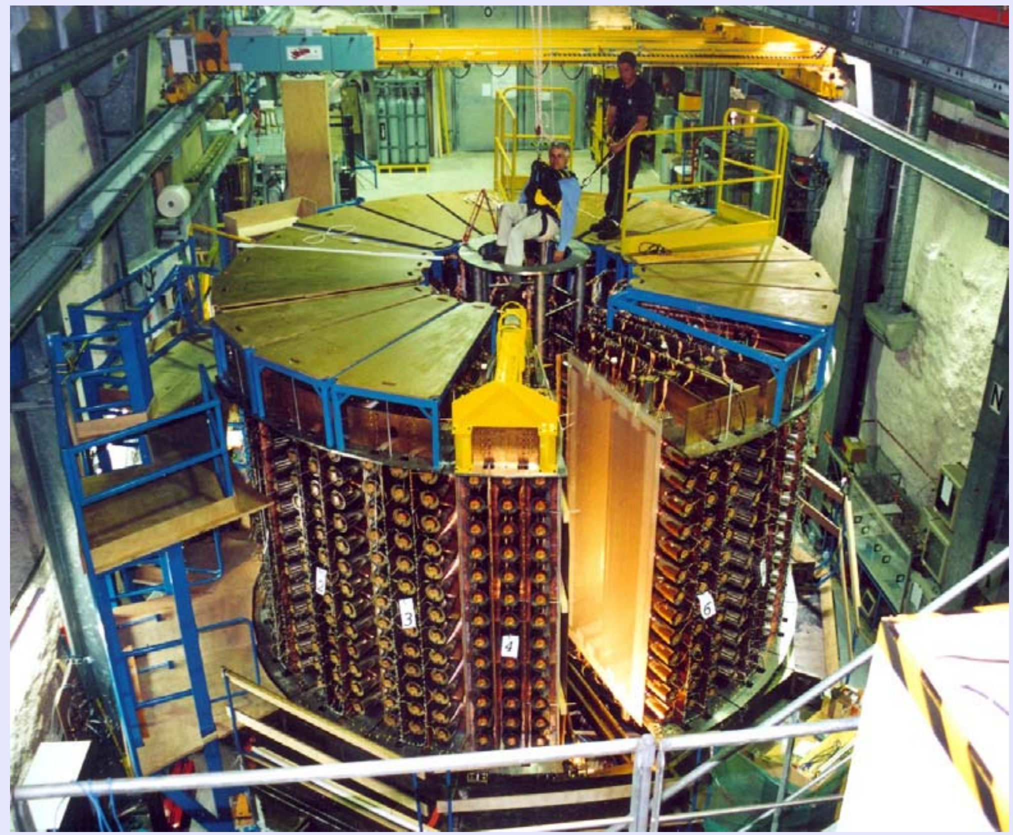
Experimental requests:
- the energy resolution importance,
- background as low as possible,
- $Q_{\beta\beta}$ and NME as high as possible,
- high isotope natural abundance…

⇒ ^{100}Mo; ^{82}Se

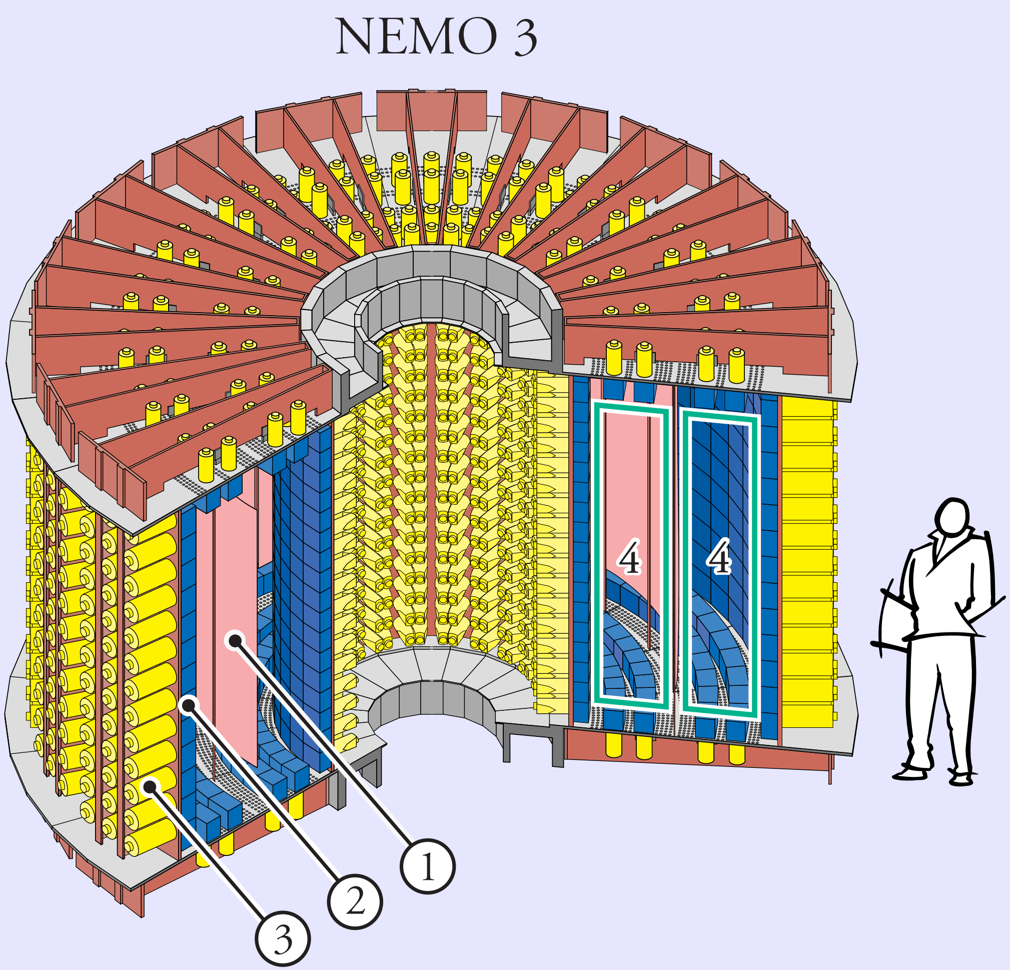
NEMO-3 Collaboration

(Neutrino Ettore Majorana Observatory)

60 physicists, 17 labs



The NEMO 3 detector



① **Source**:

10 kg of ββ-isotopes d~ 50mg/cm^2

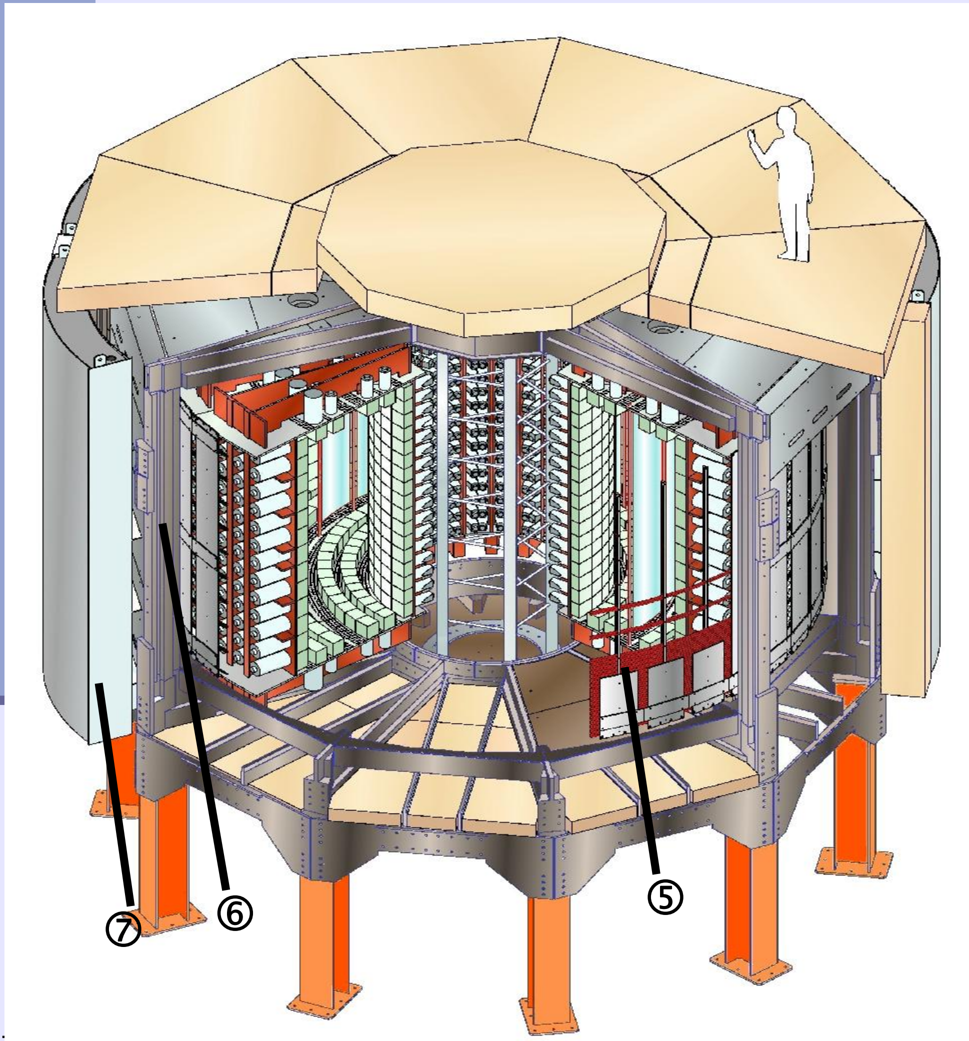
② + ③ **Calorimeter**:

1940 plastic scintillators coupled to low radioactivity PMTs,
FWHM=14% (5")-17% (3") @ 1MeV
Time resolution = 0.25 ns @ 1MeV
γ detection efficiency ≈ 50 %

④ **Tracking detector**:

drift wire chamber operating in Geiger mode (6180 cells) Gas: He+4% ethyl alcohol+1% Ar+0.1% H_2O
σ_{xy}=0,6 cm; σ_z=1,3 cm;

The NEMO 3 detector



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σ_{xy}=0,6 cm; σ_z=1,3 cm;

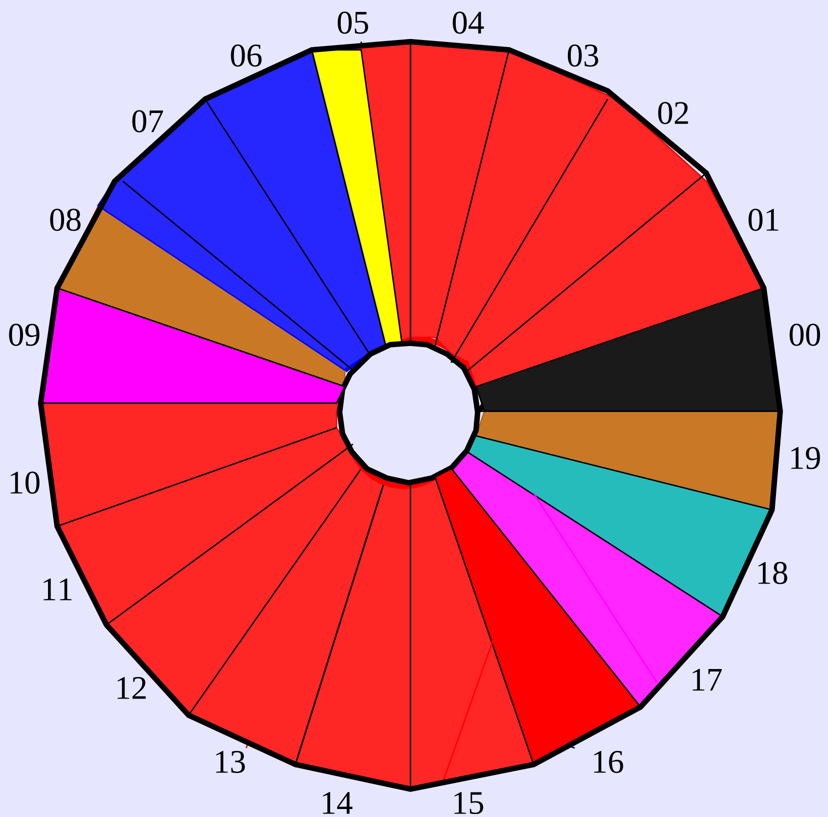
⑤ Magnetic field: 25 Gauss
(3% e^+/e^- confusion @ 1 MeV)

⑥ Gamma shield: Iron (d = 18 cm)

⑦ Neutron shield:
30 cm water + boron (ext. wall);
40 cm wood (top and bottom)

Able to identify e^-, e^+, γ and α

ββ isotopes in NEMO-3



^{100}Mo **6,914 kg**
$Q_{\beta\beta}$ = 3034 keV

^{82}Se **0,932 kg**
$Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd **405 g**
$Q_{\beta\beta}$ = 2805 keV

^{96}Zr **9,4 g**
$Q_{\beta\beta}$ = 3350 keV

^{150}Nd **37,0 g**
$Q_{\beta\beta}$ = 3367 keV

^{48}Ca **7,0 g**
$Q_{\beta\beta}$ = 4272 keV

^{130}Te **454 g**
$Q_{\beta\beta}$ = 2529 keV

^{nat}Te **491 g**

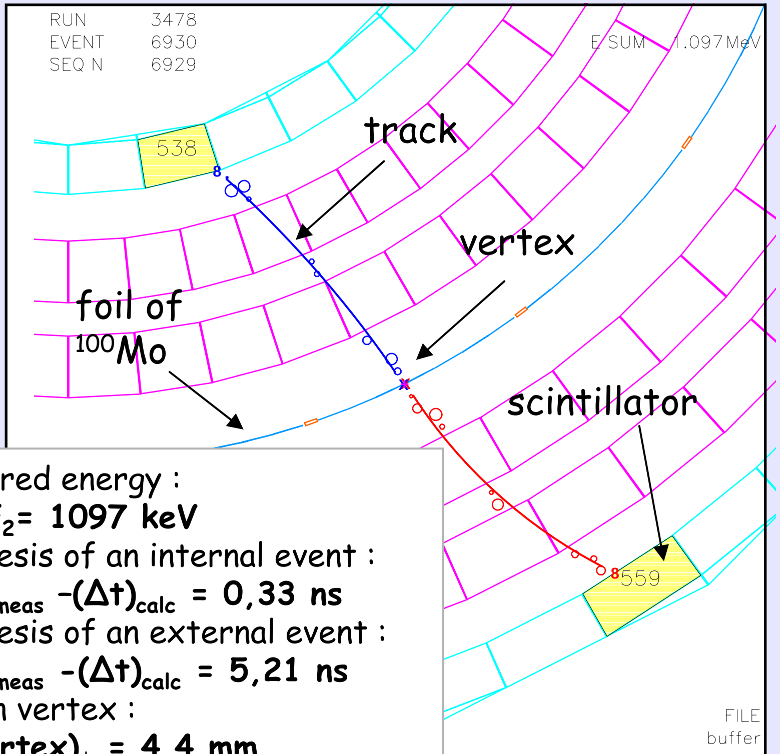
Cu 621 g

Control of the external background

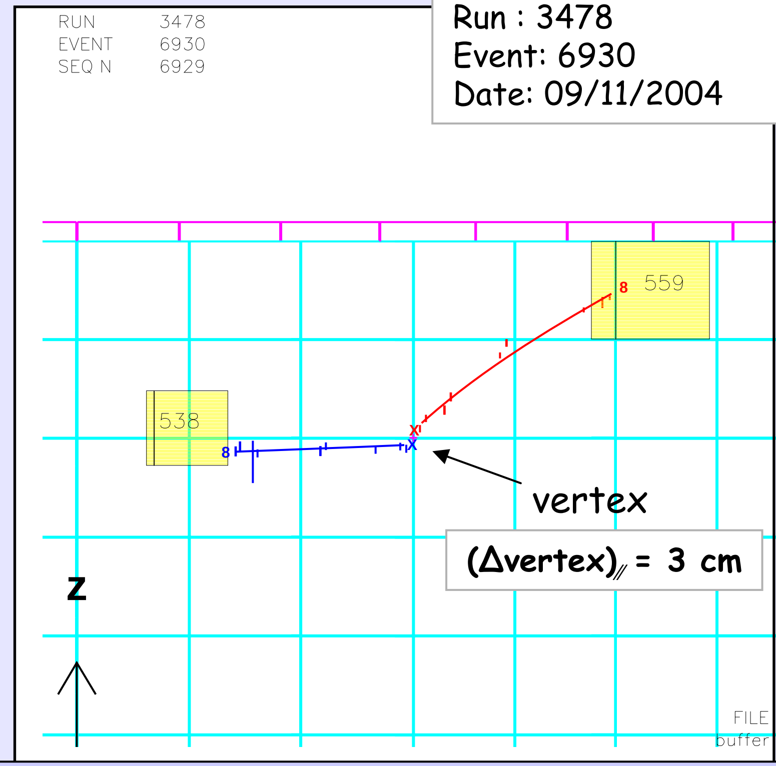
The selection of ββ events

The example of the typical ββ event - candidate for ββ2ν decay of ^{100}Mo

Top view



Side view



Registered energy :

E_1+E_2 = 1097 keV

Hypothesis of an internal event :

$(\Delta t)_{meas} - (\Delta t)_{calc}$ = 0,33 ns

Hypothesis of an external event :

$(\Delta t)_{meas} - (\Delta t)_{calc}$ = 5,21 ns

Common vertex :

$(\Delta vertex)_{\perp}$ = 4,4 mm

1 ββ event each 2,5 minutes

Criteria to select ββ events:

- 2 tracks with charge < 0
- 2 PMT, each > 200 keV
- PMT-Track association
- Common vertex
- Internal hypothesis (external event rejection)
- No other isolated PMT (γ rejection)
- No delayed track (^{214}Bi rejection)

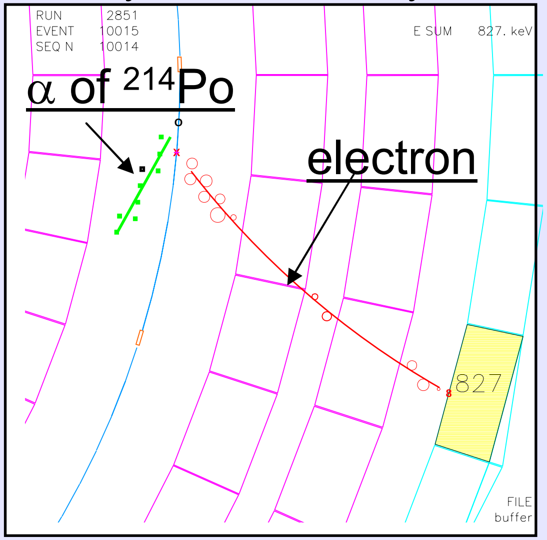
Background in the NEMO 3

Background origins: internal and external

Internal background contributions:
- Natural radioactivity of the ββ isotopes (^{214}Bi, ^{208}Tl)
- ββ2ν decay for ββ0ν decay search

External background contributions:
- Natural radioactivity of the detector materials (^{214}Bi, ^{208}Tl, ...)
- Neutrons and high energy γ-rays
- ^{222}Rn in the tracking chamber:
  - ~ 1 events/ y/ kg in ββ topology inside [2.8-3.2] MeV ("high" radon)
  - < 0.2 events/ y/ kg in ββ-topology inside [2.8-3.2] MeV ("low" radon)

Radon measurement by delayed ^{214}Po α-decay.



^{214}Bi -> ^{214}Po -> ^{210}Pb

^{100}Mo

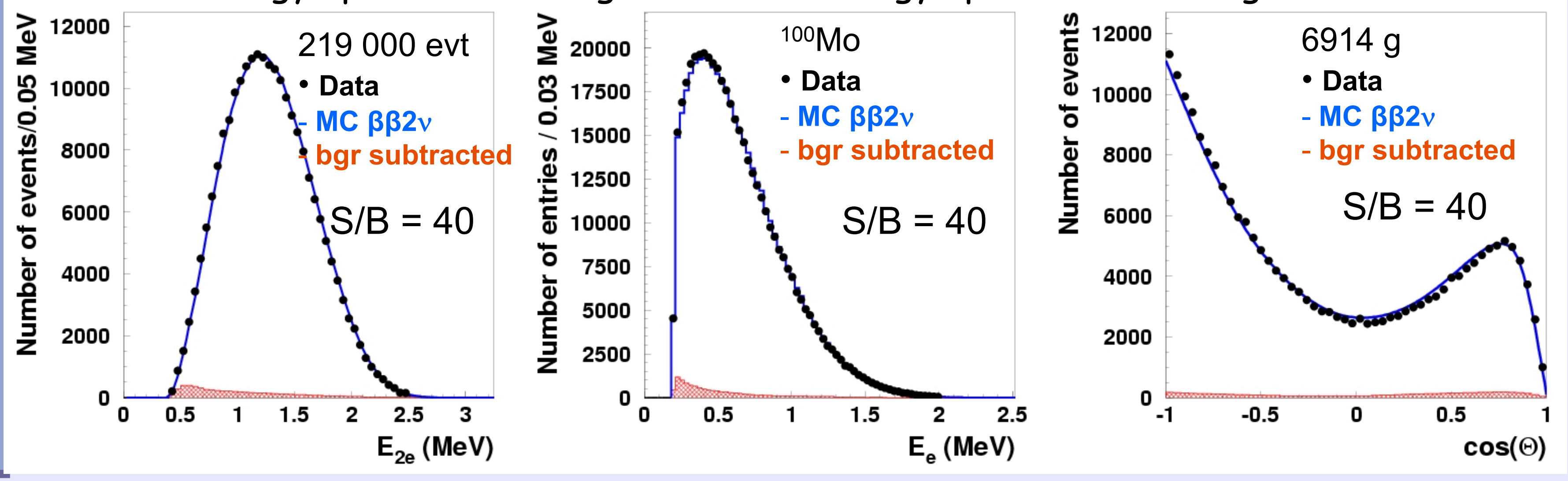
bgr < 1.5 events/ y/ kg in ββ topology inside [2.8-3.2] MeV (high radon period)
bgr < 0.7 events/ y/ kg in ββ topology inside [2.8-3.2] MeV (low radon period)

NEMO measures all background contributions itself!
Nucl. Instr and Methods A606(2009), pp.449-465.

Results for ^{100}Mo: ββ2ν

Phase I (high Radon): Feb 2003 – Dec 2004 (389 days)

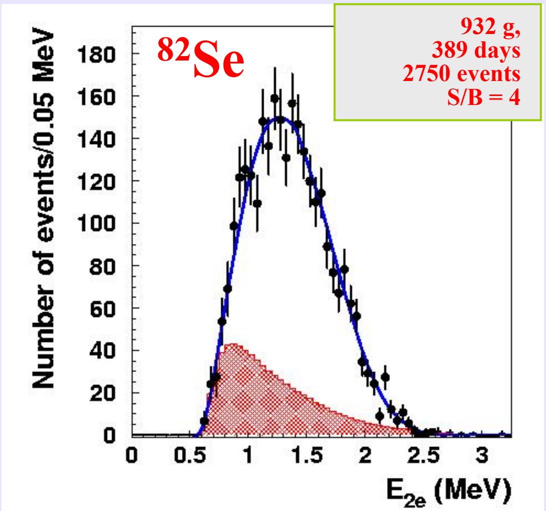
Sum energy spectrum — Single electron energy spectrum — Angular distribution

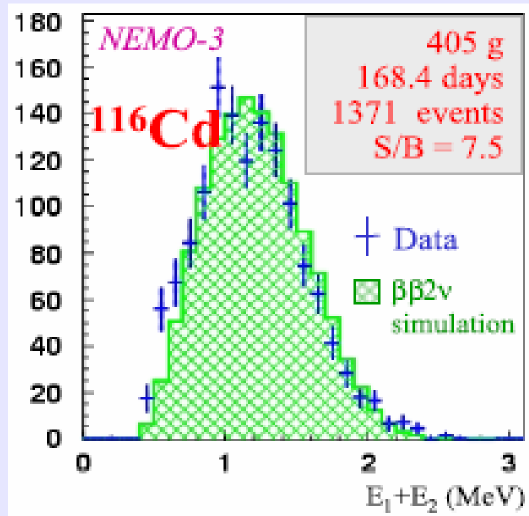


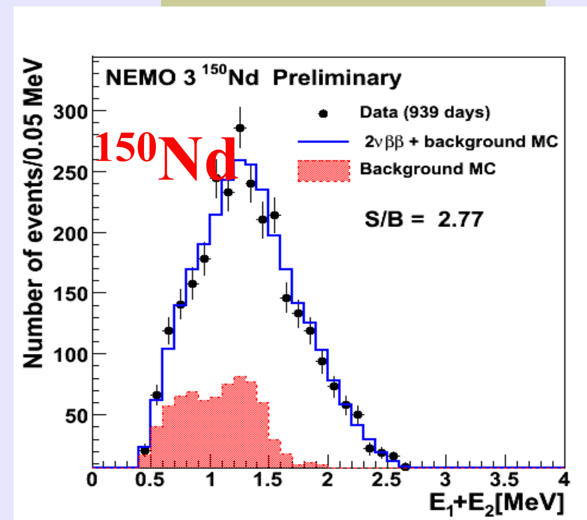
^{100}Mo: $T_{1/2}$(ββ2ν) =(7.11 ± 0.02(stat)±0.54(syst))·10^{18} y
Phys.Rev.Lett. 95, 182302 (2005)

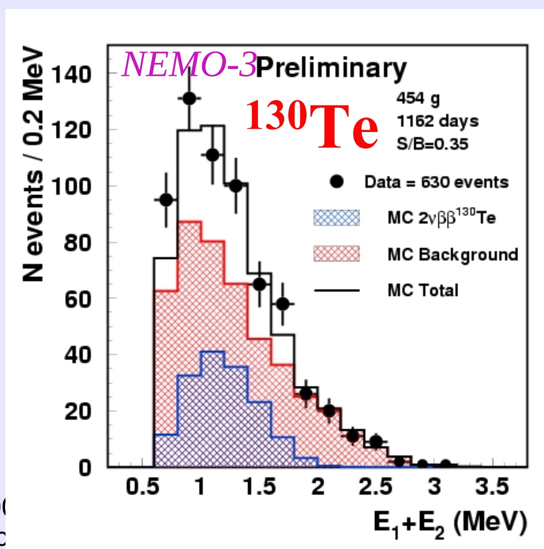
«ββ factory» – tool for precision tests

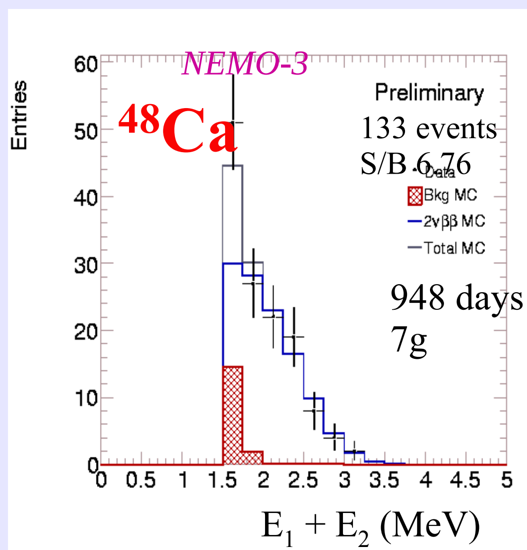
Other nuclei: results of the ββ2ν measurements

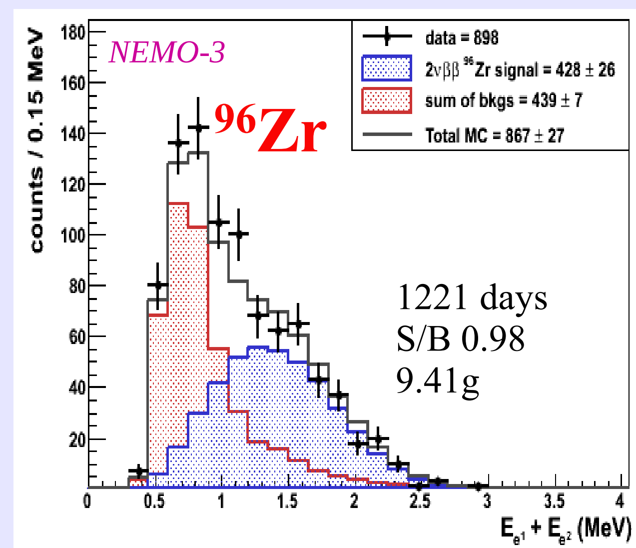












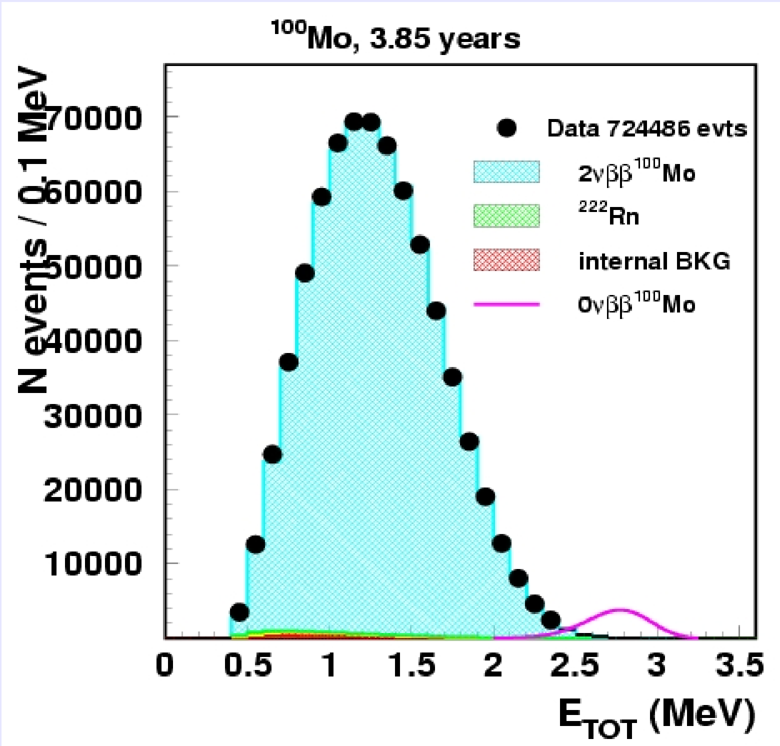
Summary of 2νββ results

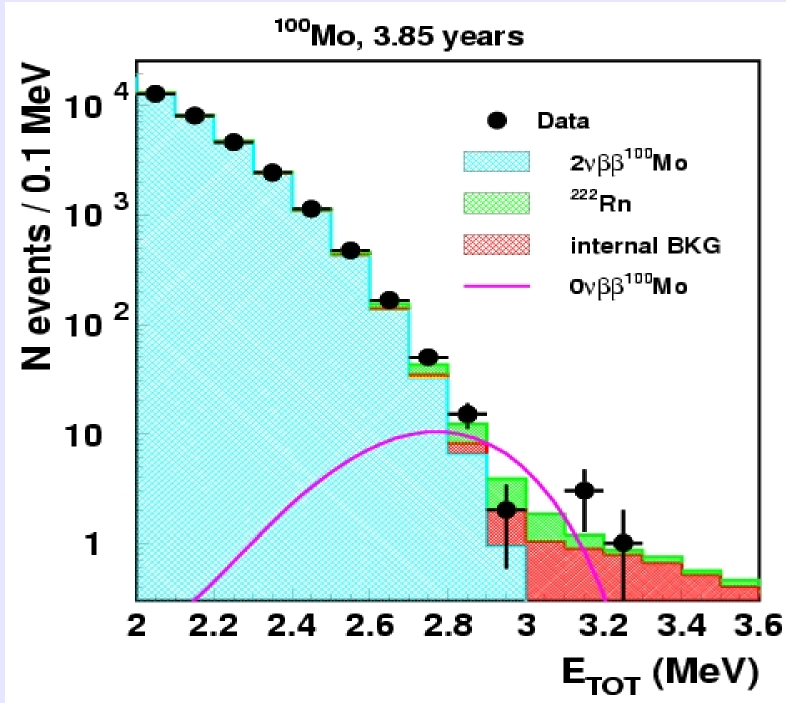
Isotope	S/B	(2νββ), y
^{100}Mo	40	$(7.11 \pm 0.02(stat) \pm 0.54(syst)) \cdot 10^{18}$ (SSD favoured) *
$^{100}Mo(0^+_1)$	3	$(5.7^{+1.3}_{-0.9}(stat)\ ) \pm 0.8(syst)) \cdot 10^{20}$ **
^{82}Se	4	$(9.6 \pm 0.3(stat) \pm 1.0(syst)) \cdot 10^{19}$ *
^{116}Cd	7.5	$(2.8 \pm 0.1(stat) \pm 0.3(syst)) \cdot 10^{19}$ **
^{130}Te	0.35	$(6.9 \pm 0.9(stat) \pm 1.0(syst)) \cdot 10^{20}$ ***
^{150}Nd	2.8	$(9.11^{+0.25}_{-0.22}(stat) \pm 0.63(syst)) \cdot 10^{18}$ ***
^{96}Zr	1.0	$(2.35 \pm 0.14(stat) \pm 0.16(syst)) \cdot 10^{19}$ ***
^{48}Ca	6.8	$(4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)) \cdot 10^{19}$ ***

* Phase 1 data, Phys. Rev. Lett. 95 (2005) 182302. Additional statistics are being analysed, to be published soon.
** Phase 1 data.
*** Phases 1 and 2, preliminary.

$0\nu\beta\beta$ of ^{100}Mo

<u>**Data until the end of 2008**</u>





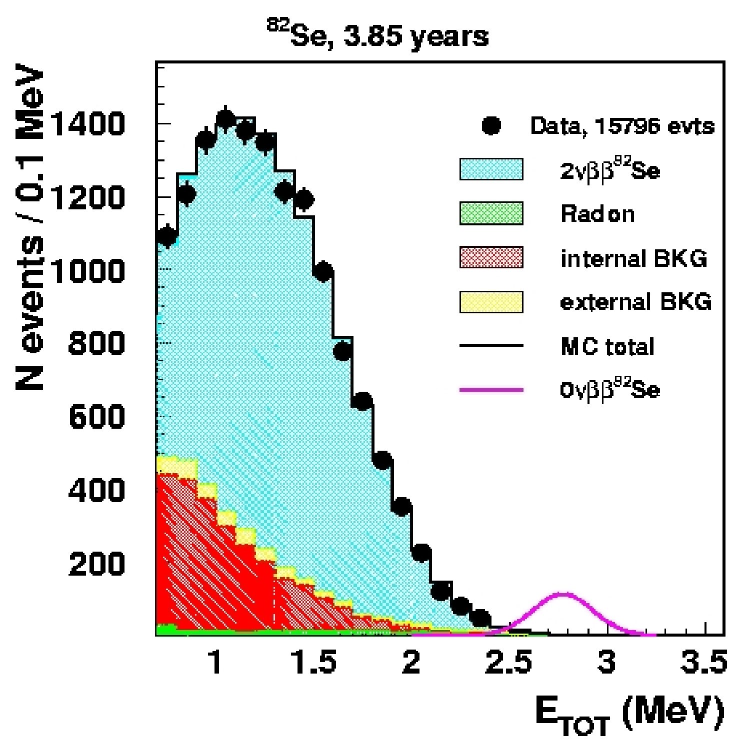
[2.8 , 3.2] MeV:
Data: 20 events, Expected: 18.6 events
Excluded at 90% C.L. 9.6 events
Efficiency ε= 0.0726

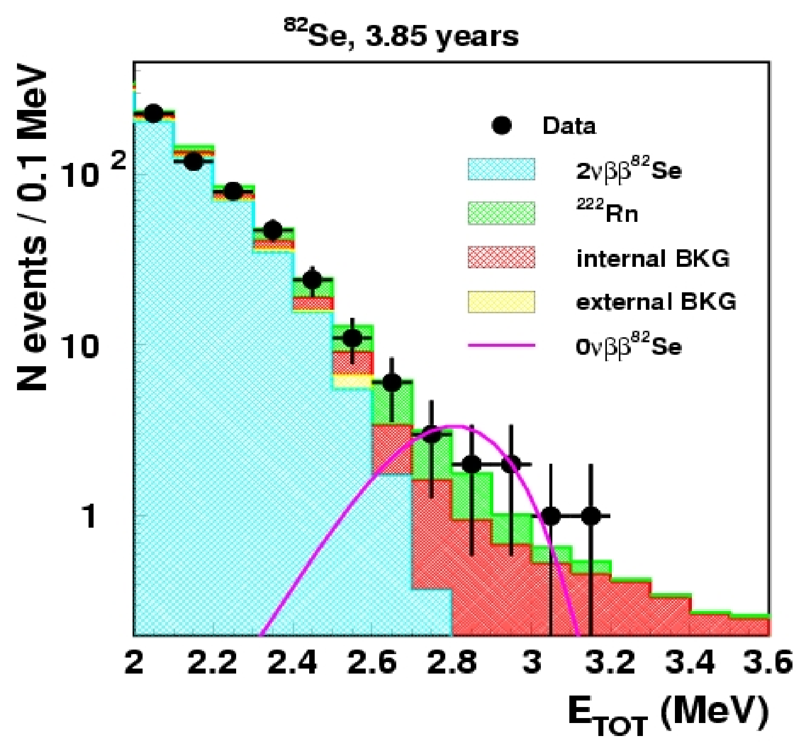
MCLIMIT : [2.0, 3.2] eV
18 events excluded
Total mean 0v efficiency ε = 0.174
$T_{1/2}$ ($0\nu\beta\beta$) > 1.1 · 10^{24} y @90% C.L.
$\langle m_\nu \rangle$ < 0.45 – 0.93 eV

Both simple counting and likelihood methods are consistent

$0\nu\beta\beta$ of ^{82}Se

Data until the end of 2008





[2.6 , 3.2] MeV:
Data: 15 events, Expected: 13.2 events
Excluded at 90% C.L. 8.9 events
Efficiency ε= 0.151

MCLIMIT : [2.0, 3.2] MeV
9.8 events excluded
Total mean 0ν efficiency ε = 0.182
$T_{1/2}$ ($0\nu\beta\beta$) > 3.6 · 10^{23} y @90% C.L.
$\langle m_\nu \rangle$ < 0.89 – 1.61 eV

Summary of 0νββ results

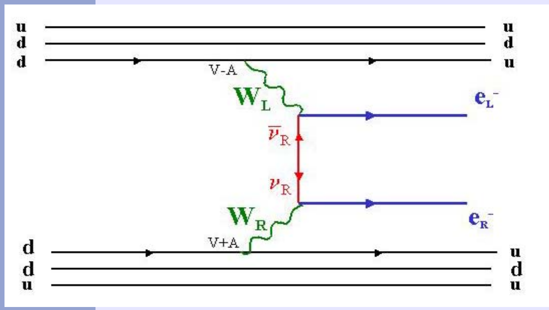
- No evidence for non conservation of the leptonic number
- Current limits on 0νββ (at 90% C.L.):

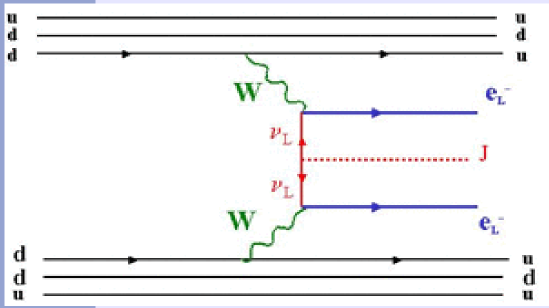
Isotope	Exposure (kg·y)	$T_{1/2}(0\nu\beta\beta)$, y	$\langle m_\nu \rangle$, eV [NME ref.]
^{100}Mo	26.6	$> 1.1 \cdot 10^{24}$	< 0.45 – 0.93 [1-3]
^{82}Se	3.6	$> 3.6 \cdot 10^{23}$	< 0.9 – 1.6 [1-3]; < 2.3 [7]
^{150}Nd	0.095	$> 1.8 \cdot 10^{22}$	< 1.7 – 2.4 [4,5] ;< 4.8 – 7.6 [6]
^{130}Te	1.4	$> 9.8 \cdot 10^{22}$	< 1.6 – 3.1 [2,3]
^{96}Zr	0.031	$> 9.2 \cdot 10^{21}$	< 7.2 – 19.5 [2,3]
^{48}Ca	0.017	$> 1.3 \cdot 10^{22}$	< 29.6 [7]

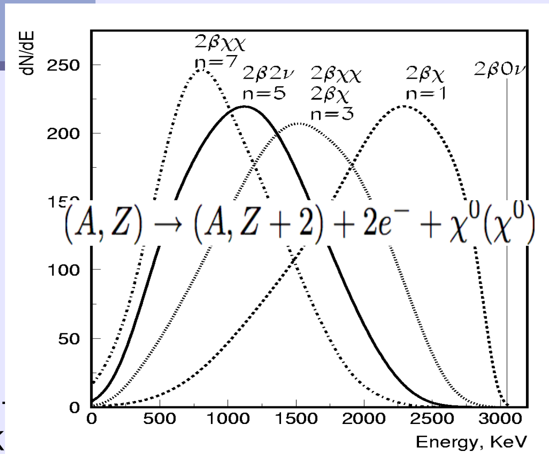
- NME references:

  - [1] M.Kortelainen and J.Suhonen, Phys.Rev. C 75 (2007) 051303(R)
  - [2] M.Kortelainen and J.Suhonen, Phys.Rev. C 76 (2007) 024315
  - [3] F.Simkovic, et al. Phys.Rev. C 77 (2008) 045503
  - [4] V.A. Rodin et al. Nucl.Phys. A 793 (2007) 213
  - [5] V.A. Rodin et al. Nucl.Phys. A 766(2006) 107
  - [6] J.H.Hirsh et al. Nucl.Phys. A 582(1995) 124
  - [7] E.Caurrier et al. Phys.Rev.Lett 100 (2008) 052503

V+A currents and Majoron







V+A currents:

$(T_{1/2})^{-1} = C_{mm}\langle m_\nu\rangle^2 + C_{\eta\eta}\langle\eta\rangle^2 + C_{\lambda\lambda}\langle\lambda\rangle^2 + C_{m\eta}\langle m_\nu\rangle\times\langle\eta\rangle +$
$C_{m\lambda}\langle m_\nu\rangle\times\langle\lambda\rangle + C_{\eta\lambda}\langle\eta\rangle\times\langle\lambda\rangle$, C_{xx} - $F\cdot|M|^2$

$\langle\lambda\rangle,\langle\eta\rangle$ - right currents coupling constants

Majoron emission:

$$(A,Z)\rightarrow(A,Z+2)+2e^-+\chi^0(\chi^0)$$

Isotope	V+A *	Majoron(s) emission **			
	$T_{1/2}(0\nu\beta\beta)$ y	n=1	n=2	n=3	n=7
^{100}Mo	$>5.7\cdot10^{23}$ $\lambda<1.4\cdot10^{-6}$	$>2.7\cdot10^{22}$ $g_{ee}<(0.4\text{-}1.8)\cdot10^{-4}$	$>1.7\cdot10^{22}$	$>1.\cdot10^{22}$	$>7\cdot10^{19}$
^{82}Se	$>2.4\cdot10^{23}$ $\lambda<2.\cdot10^{-6}$	$>1.5\cdot10^{22}$ $g_{ee}<(0.7\text{-}1.9)\cdot10^{-4}$	$>6\cdot10^{21}$	$>3.1\cdot10^{22}$	$>5\cdot10^{20}$

n: spectral index, limits on half-life in years

* Phase I+Phase II data

** Phase I data, *R.Arnold et al. Nucl. Phys. A765 (2006) 483*

Summary

- ββ decay for ^{48}Ca, ^{96}Zr, ^{82}Se, ^{100}Mo, ^{116}Cd, ^{130}Te and ^{150}Nd has been investigated, accurate measurement of half-lives has been performed.
- New limits on 0νββ decay
  - $^{100}Mo > 1.1 \cdot 10^{24}$ y
  - $^{82}Se > 3.6 \cdot 10^{23}$ y

  have been obtained.
- NEMO-3 continues taking data up to end 2010, 0ν sensitivity will be improved.
- Future plans: SuperNEMO with sensitivity $T_{1/2} > 10^{26}$ y (^{82}Se) (see poster of Irina Nasteva)

Backup slides

One sector of the natural tellurium

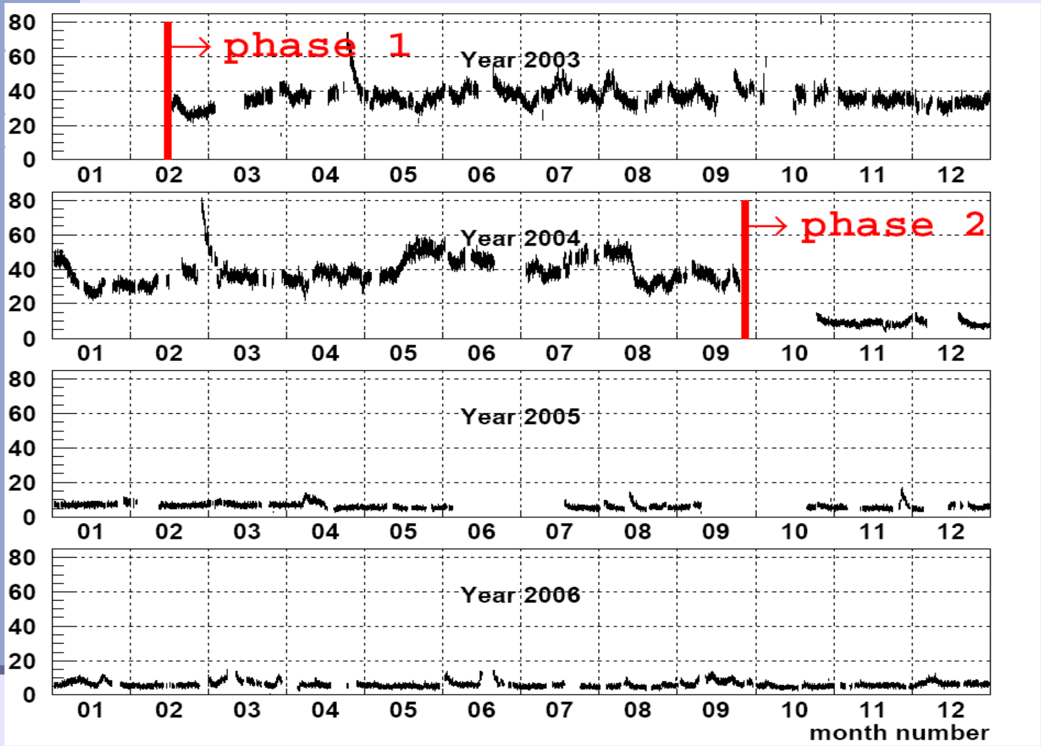
photomultipliers

scintillators

Source foil

calibration tube

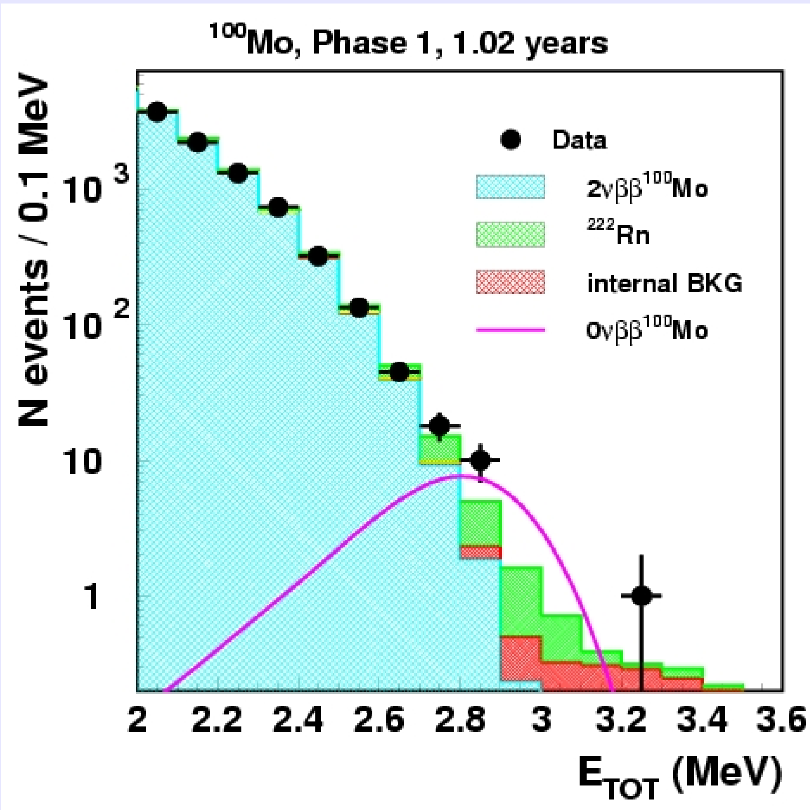
Radon trapping facility

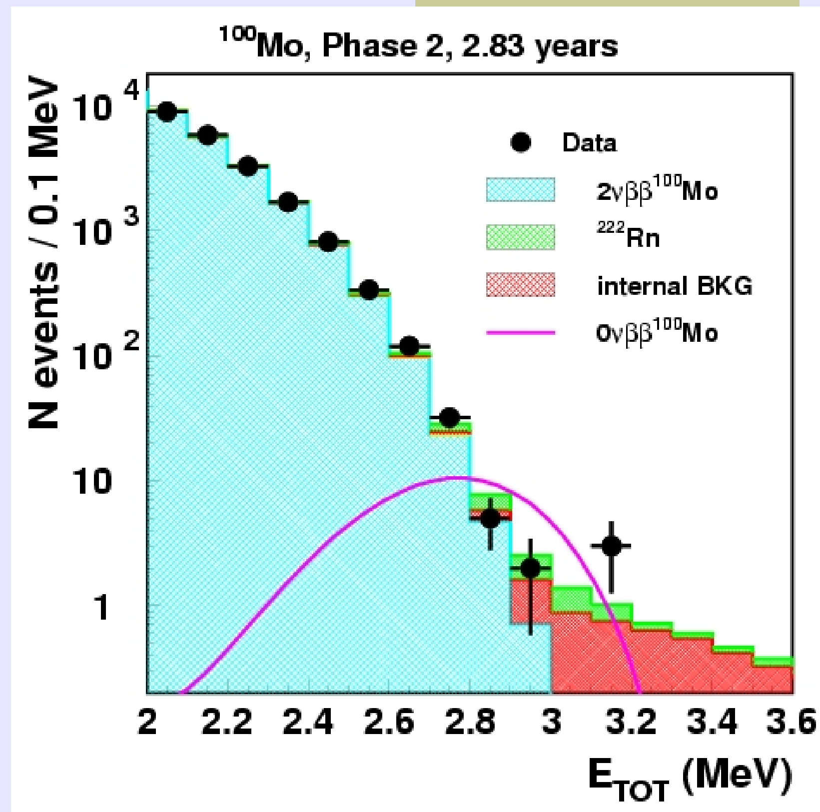


1 ton of charcoal @ –50°C, 9 bars
air flux = 150 m^3/h
Input: $A(^{222}Rn)$ 15 Bq/m^3
Output: $A(^{222}Rn) < 15\ mBq/m^3$!!!
reduction factor of 1000

Inside the NEMO 3 tent: reduction factor of 100÷300
Inside the NEMO 3: reduction factor of ~ 6
$A(^{222}Rn) \approx 6\ mBq/m^3$

$0\nu\beta\beta$ of ^{100}Mo

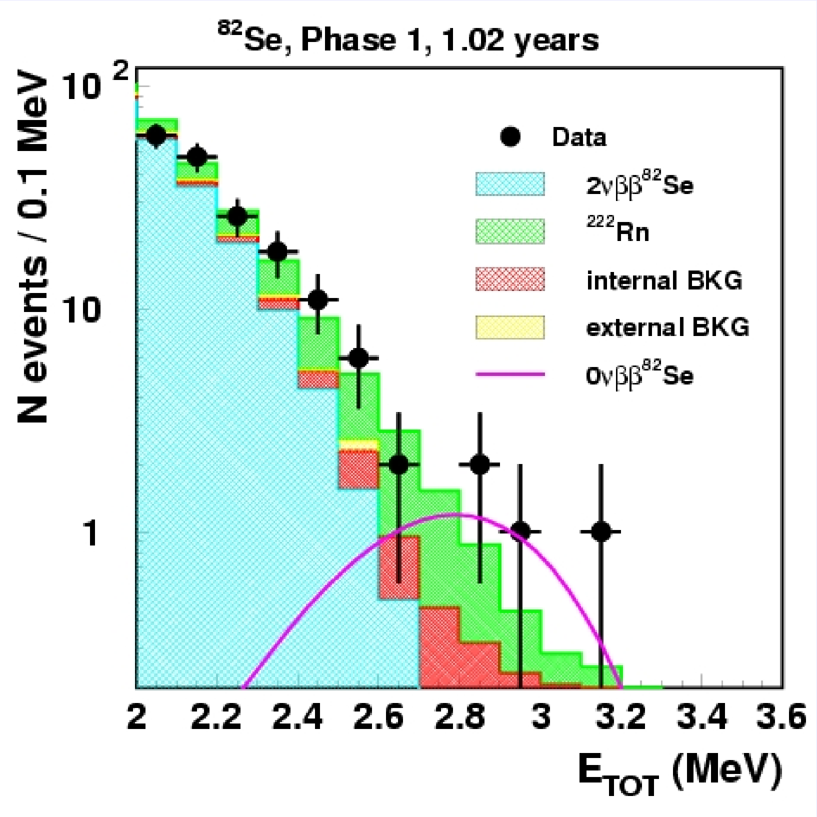


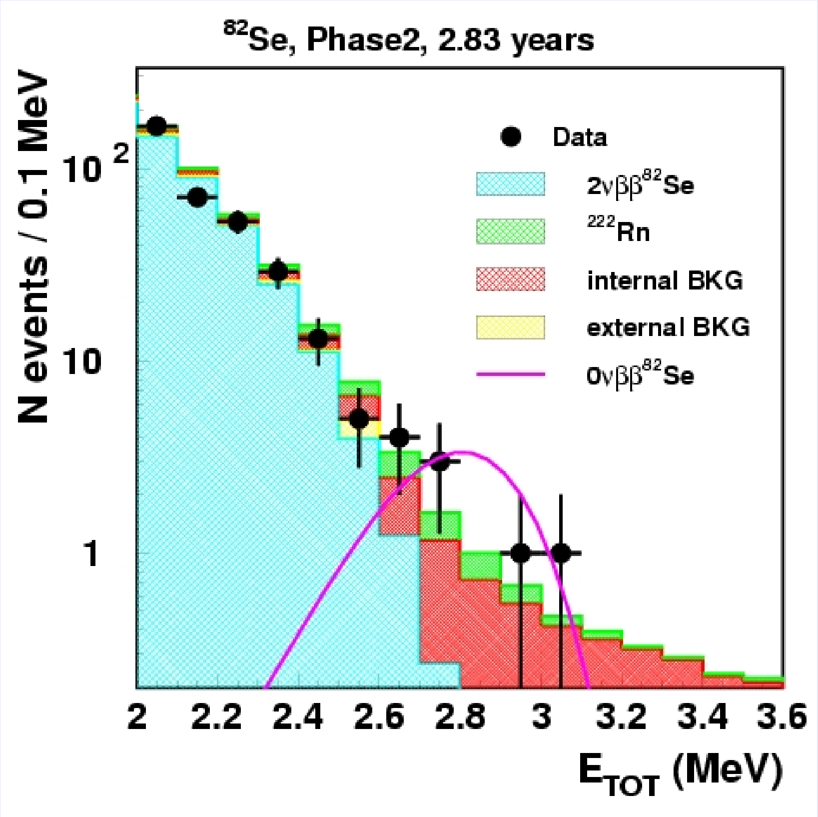


[2.8 , 3.2] MeV:
Data: 10 events, Expected: 7.4 events
Excluded at 90% C.L. 8.3 events
Efficiency ε= 0.0786

[2.8 , 3.2] MeV:
Data: 10 events, Expected: 11.2 events
Excluded at 90% C.L. 6.1 events
Efficiency ε= 0.0706

0νββ of ^{82}Se





[2.6 , 3.2] MeV:
Data: 6 events, Expected: 5.8 events
Excluded at 90% C.L. 5.6 events
Efficiency ε= 0.159

[2.6 , 3.2] MeV:
Data: 9 events, Expected: 7.4 events
Excluded at 90% C.L. 7.4 events
Efficiency ε= 0.148