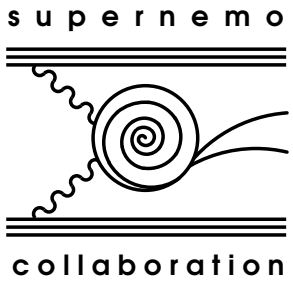
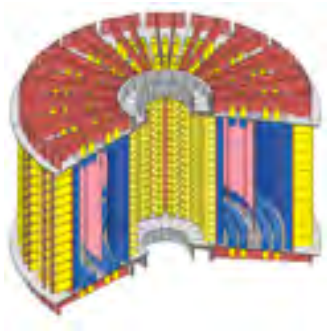
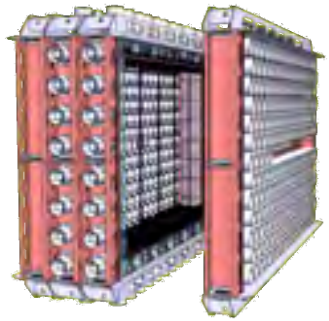






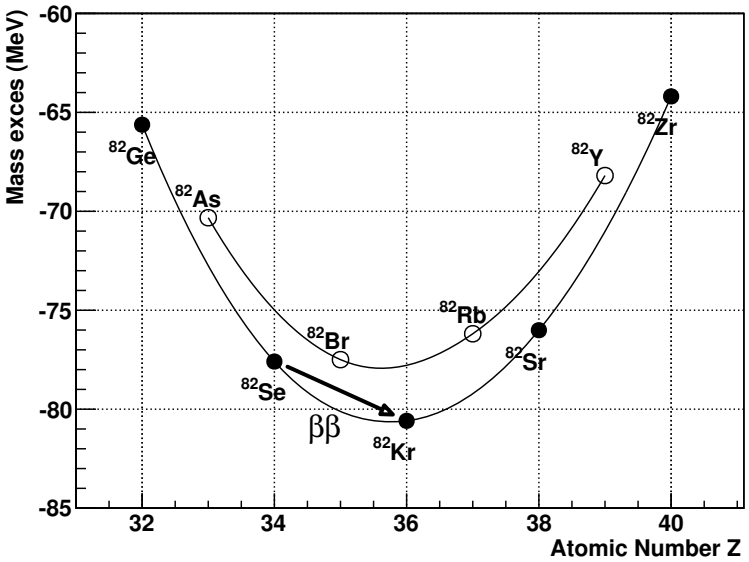
Double beta decays study with NEMO 3 and SuperNEMO

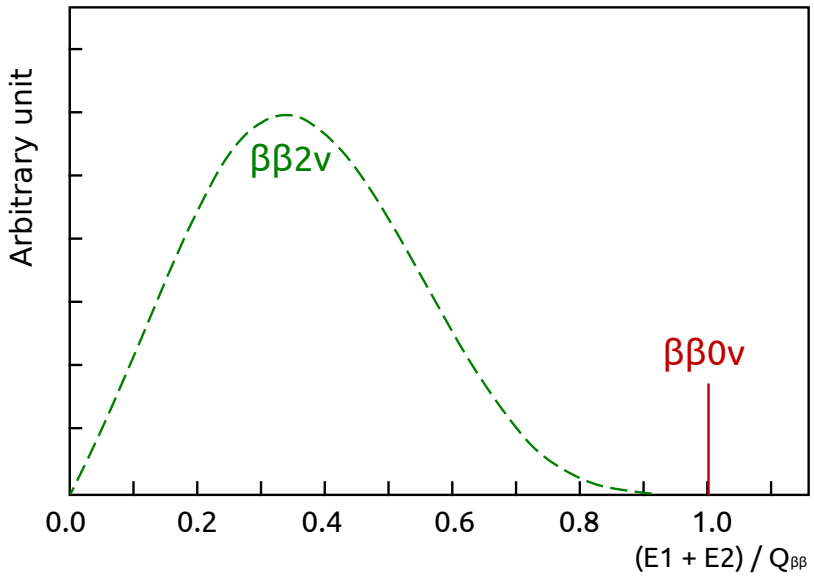
CHAUVEAU Emmanuel
on behalf of the NEMO collaboration

University of Manchester

Rencontres de Moriond, Electroweak session

Two-neutrinos and neutrinoless double beta decays





Two-neutrino double beta decay ($\beta\beta 2\nu$)

$(A, Z) \longrightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$

- second-order weak process
  $T^{\beta\beta 2\nu}_{1/2} \sim 10^{20}$ years
- allowed by Standard Model and observed
- input to nuclear physics model

Neutrinoless double beta decay ($\beta\beta 0\nu$)

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

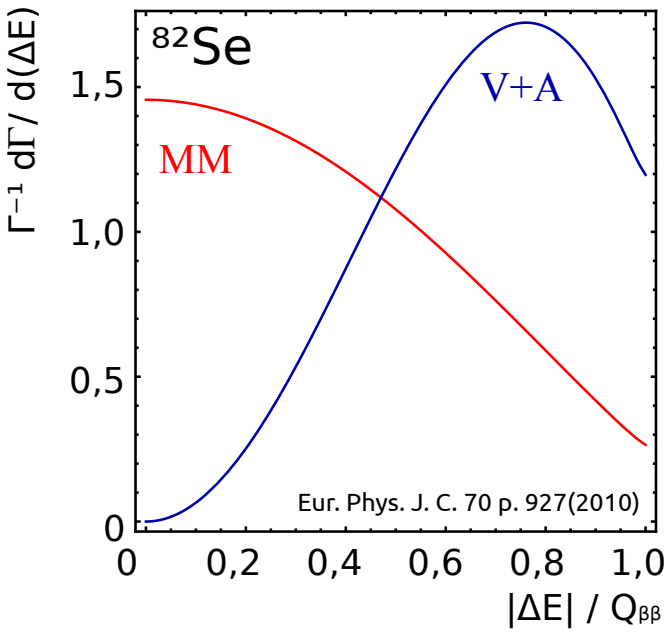
- violates lepton number conservation
- requires a Majorana neutrino ($\nu = \bar{\nu}$)
- new physics : $m_{\beta\beta}$, V+A, Majoron, SUSY...

Available observables

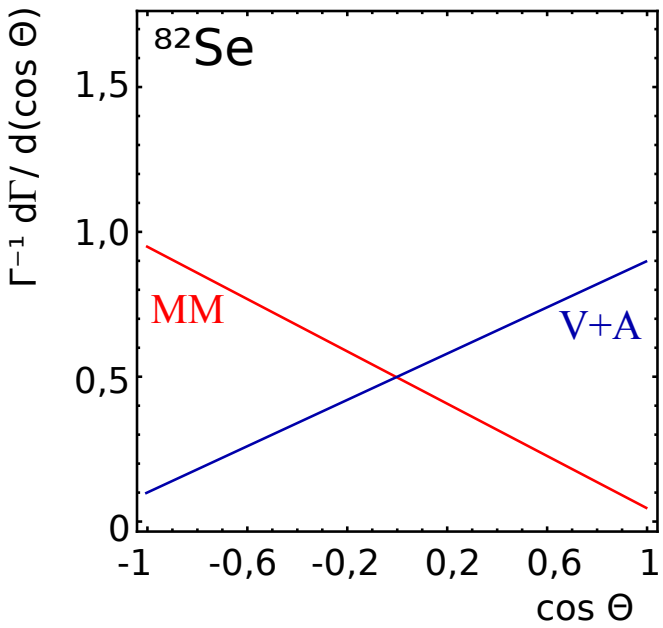
- Electron energy sum $E_1 + E_2$ — Discrimination $\beta\beta2\nu$ vs. $\beta\beta0\nu$
- Individual energy E_1, E_2
- Angular distribution $\cos\theta$

} Study on possible $\beta\beta0\nu$ mechanisms

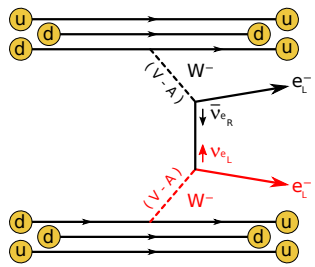
Electron energy difference



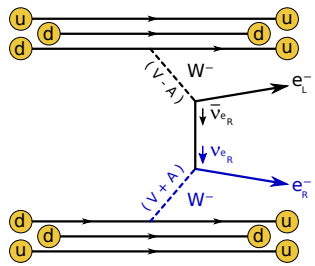
Angular distribution



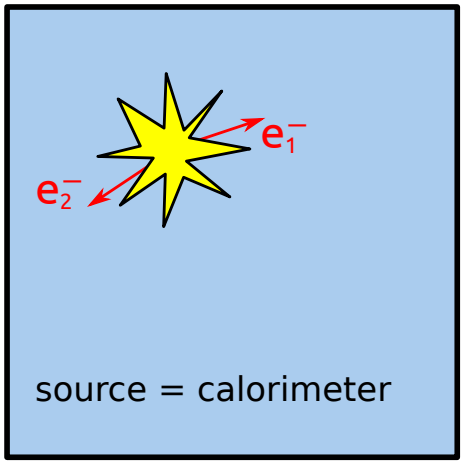
Mass Mechanism (MM)



Right Handed Current (V+A)

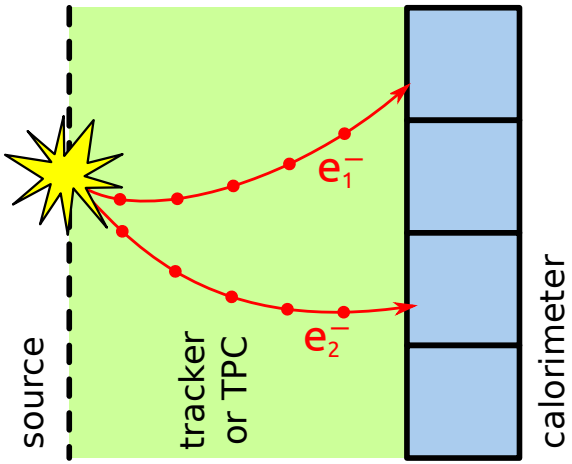


Double beta decay experiments categories



pure calorimeter approach

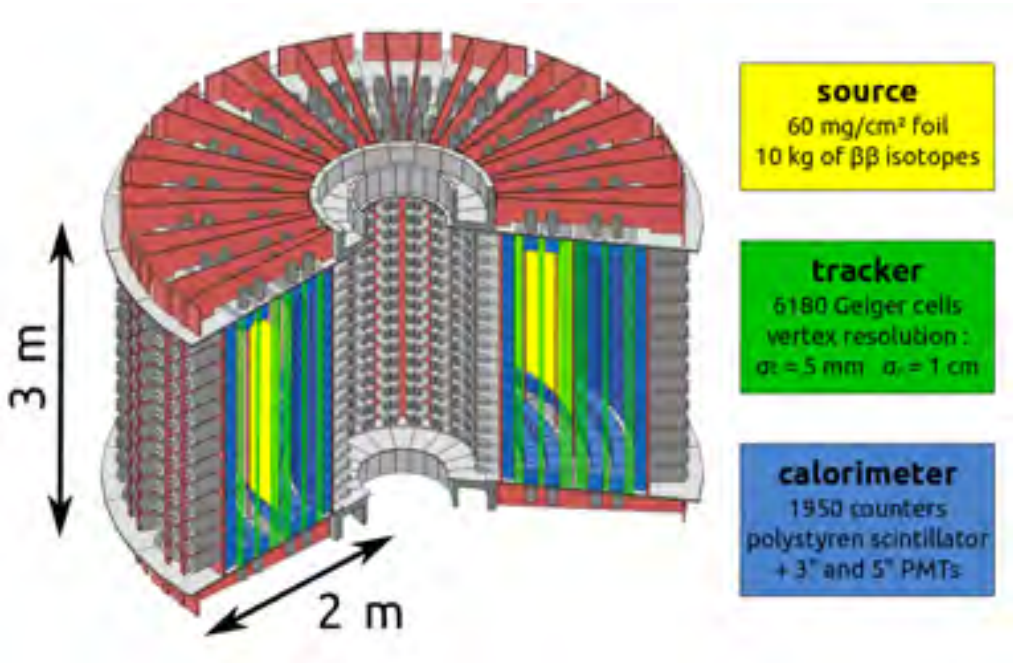
- ☑ excellent detection efficiency
- ☑ good energy resolution
- ☒ no identification of electrons
- ☒ high background



tracker + calorimeter approach

- ☒ low detection efficiency
- ☒ poor energy resolution
- ☑ electron recognition, $\beta\beta$ kinematic
- ☑ background measurement + rejection

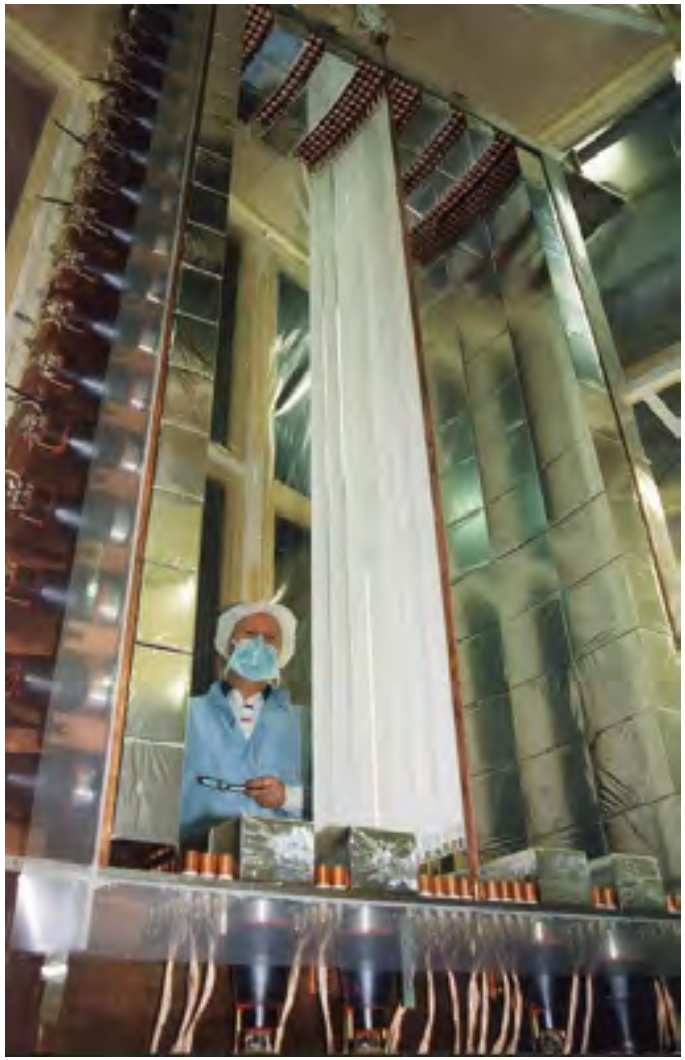
The NEMO 3 detector (1)



Ultra low background detector

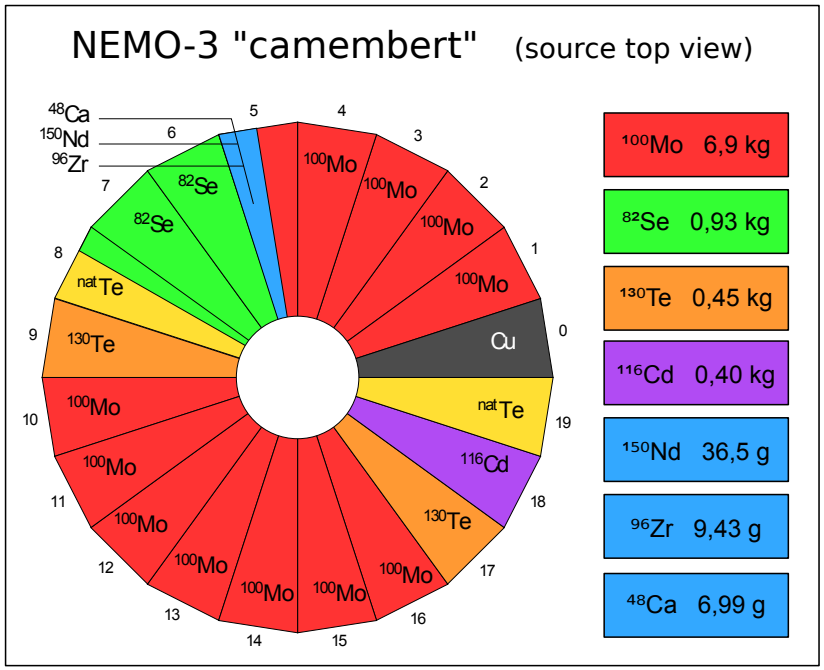
- γ shielding : pure Iron (18 cm)
- n shielding : borated water (30 cm) + wood (40 cm)
- radon trapping facility from october 2004
  $\rightarrow$ radon-free air buffer around detector
- location in Modane underground laboratory (LSM)
  in Frejus tunnel : 4800 m.w.e.

A(NEMO 3) $\sim$ 1000 Bq / 200 tons



zoom in a NEMO 3 sector

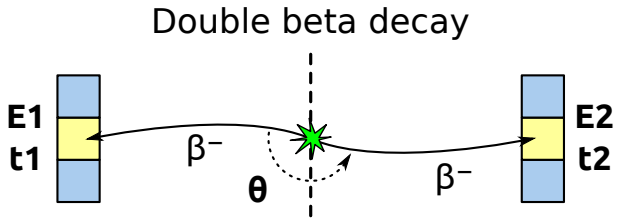
The NEMO 3 detector (2)

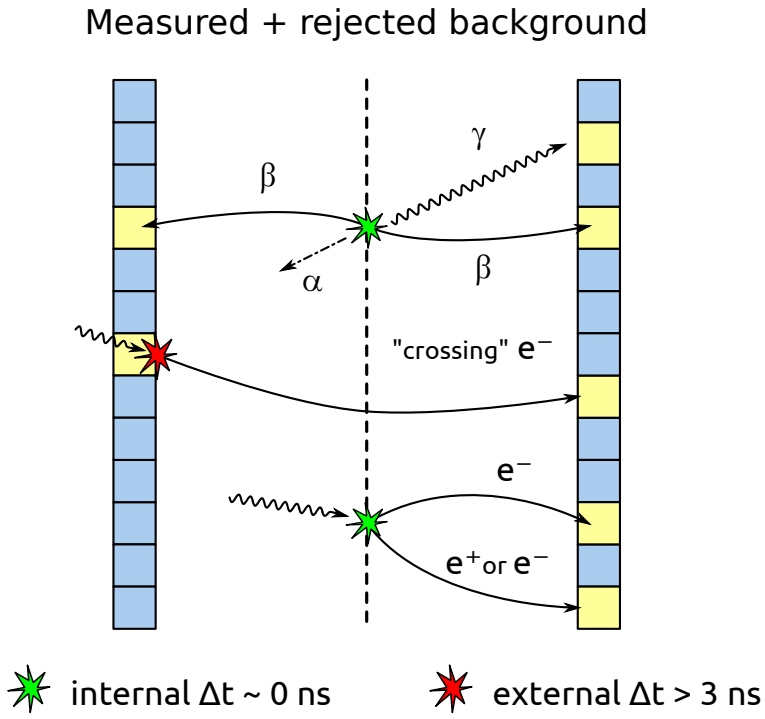


Unique features

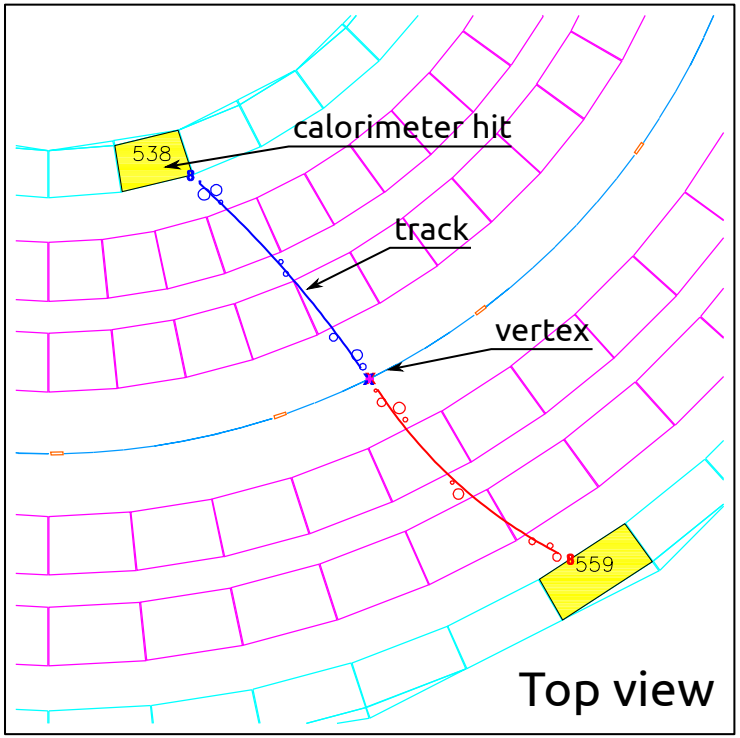
- ✓ Multi-source detector : 7 $\beta\beta$ isotopes
- ✓ Particles identification : α, β^-, β^+, γ
- ✓ Kinematics of $\beta\beta$ decay : E_1, E_2, cos θ, Δt

$\Rightarrow$ Topological signature of events
$\Rightarrow$ Background rejection + measurement
$\Rightarrow$ Study of $\beta\beta0\nu$, $\beta\beta2\nu$, $\beta\beta$*, ...





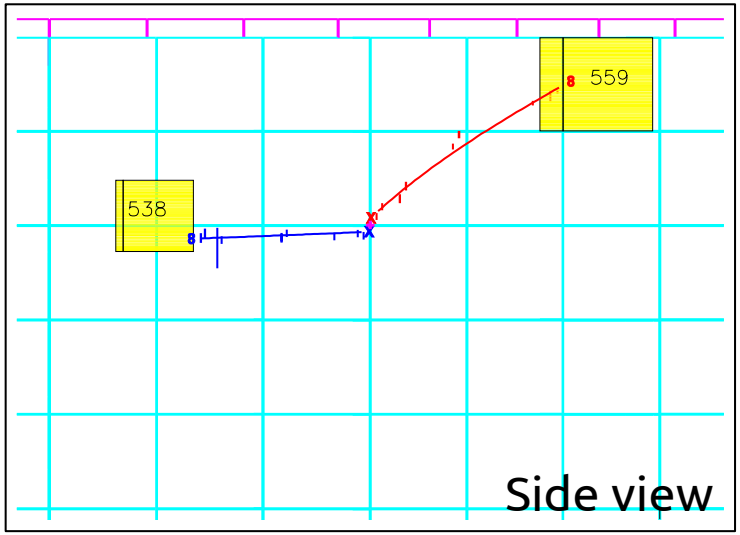
Selection of candidate $\beta\beta$ events



Event candidate for ββ2v decay from ^{100}Mo foil

Run : 3478
Event : 6930
Date : 09/11/2004

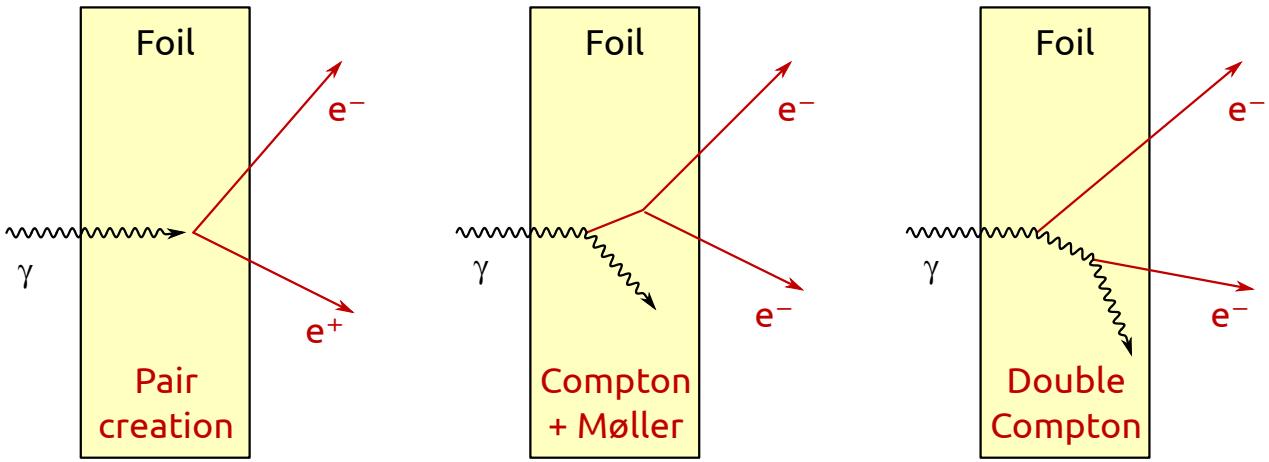
E1 + E2 = 1.097 MeV
internal hyp. : $|\Delta t_{meas} - \Delta t_{calc}| = 0.33$ ns
external hyp. : $|\Delta t_{meas} - \Delta t_{calc}| = 5.21$ ns
$(\Delta vertex)_t = 4.4$ mm $(\Delta vertex)_z = 3$ cm



- Two tracks Q $<$ 0
- Two calorimeter E $>$ 200 keV
- Association track – calorimeter hit
- Common vertex
- Internal hypothesis (external event rejection)
- No other calorimeter hit (γ rejection)
- No delayed track (^{214}Bi rejection)

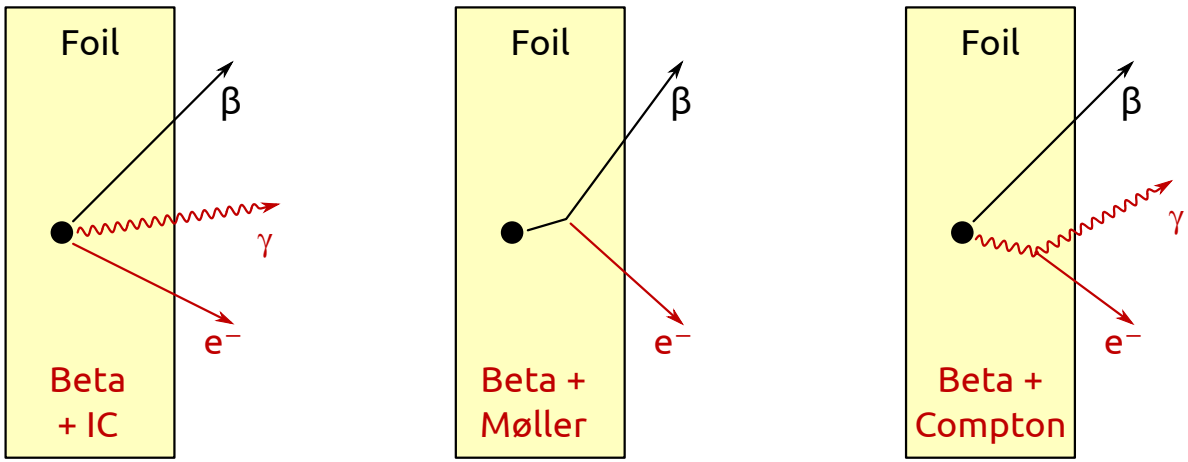
Origin and mechanisms of NEMO 3 background

- External γ
  from detector radioactivity, neutrons and cosmics
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta}$ (≈ 3 MeV)
  ^{214}Bi in ^{238}U chain ($Q_\beta = 3.3$ MeV)
  ^{208}Tl in ^{232}Th chain ($Q_\beta = 4.9$ MeV)
- Radon inside tracking detector
  decay then deposit of daughter on wire and foil surfaces
  $\rightarrow$ feed contamination in ^{214}Bi
- $\beta\beta2\nu$ background for $\beta\beta0\nu$ signal



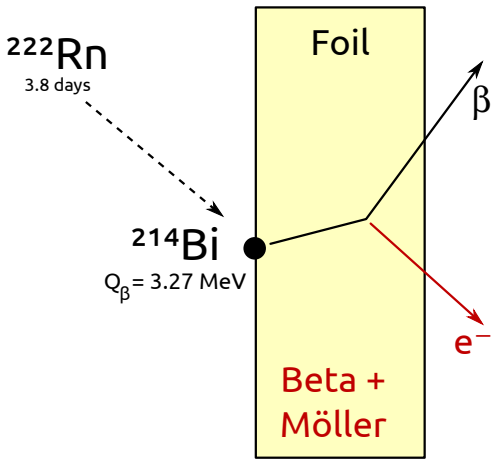
Origin and mechanisms of NEMO 3 background

- External γ
  from detector radioactivity, neutrons and cosmics
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta}$ (≈ 3 MeV)
  ^{214}Bi in ^{238}U chain ($Q_\beta = 3.3$ MeV)
  ^{208}Tl in ^{232}Th chain ($Q_\beta = 4.9$ MeV)
- Radon inside tracking detector
  decay then deposit of daughter on wire and foil surfaces
  $\rightarrow$ feed contamination in ^{214}Bi
- $\beta\beta2\nu$ background for $\beta\beta0\nu$ signal



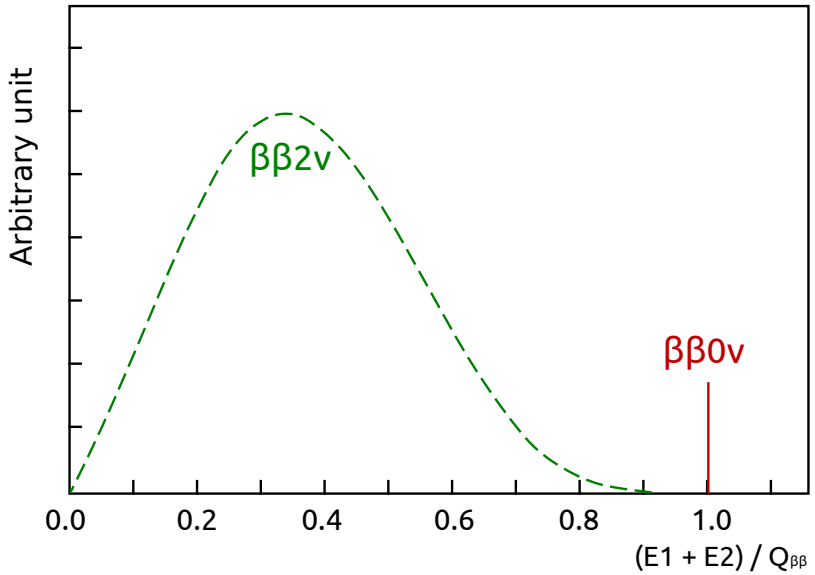
Origin and mechanisms of NEMO 3 background

- External γ
  from detector radioactivity, neutrons and cosmics
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta}$ (≈ 3 MeV)
  ^{214}Bi in ^{238}U chain ($Q_\beta = 3.3$ MeV)
  ^{208}Tl in ^{232}Th chain ($Q_\beta = 4.9$ MeV)
- Radon inside tracking detector
  decay then deposit of daughter on wire and foil surfaces
  $\rightarrow$ feed contamination in ^{214}Bi
- $\beta\beta2\nu$ background for $\beta\beta0\nu$ signal



Origin and mechanisms of NEMO 3 background

- External γ
  from detector radioactivity, neutrons and cosmics
- Internal contamination in β emitter with $Q_\beta \geq Q_{\beta\beta}$ (≈ 3 MeV)
  ^{214}Bi in ^{238}U chain ($Q_\beta = 3.3$ MeV)
  ^{208}Tl in ^{232}Th chain ($Q_\beta = 4.9$ MeV)
- Radon inside tracking detector
  decay then deposit of daughter on wire and foil surfaces
  $\rightarrow$ feed contamination in ^{214}Bi
- $\beta\beta2\nu$ background for $\beta\beta0\nu$ signal

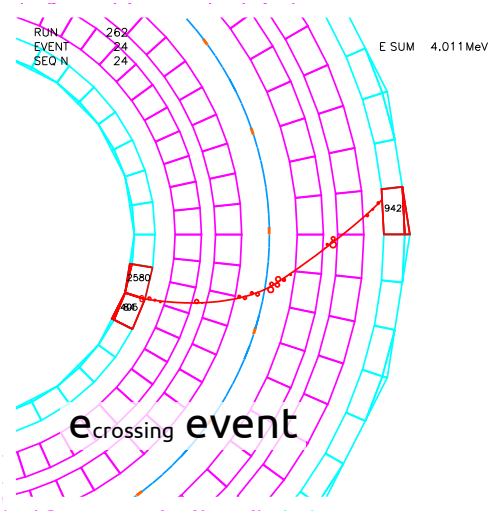


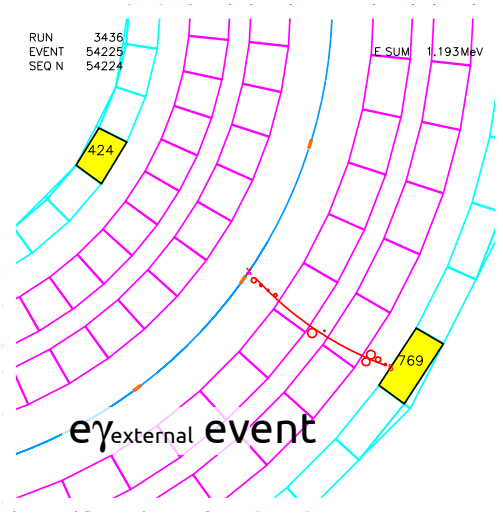
Measurement of NEMO 3 background

CHANNEL	BACKGROUND MEASUREMENT
$e\gamma_{external}$ $e_{crossing}$	external background : ^{40}K, ^{60}Co, ^{226}Ra, ...
e	pure β emitters in foil : ^{234m}Pa, ^{40}K, ^{90}Y, ...
$e\gamma$ $e\gamma\gamma$ $e\gamma\gamma\gamma$	$\beta+\gamma$ emitters in foil : ^{207}Bi, ^{208}Tl, ^{214}Bi, ...
$e\alpha$	^{222}Rn in gas, ^{214}Bi on foil and wires

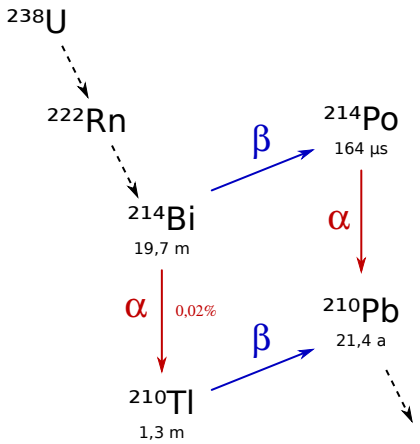
- ✓ Internal, external and radon background measurement
- ✓ Analysis through independent channels
- ✓ Model validation with a dedicated control foil (pure Cu)

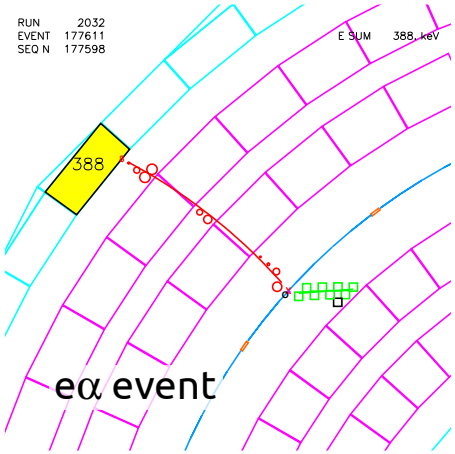
[NIM A606 (2009) 449-465]

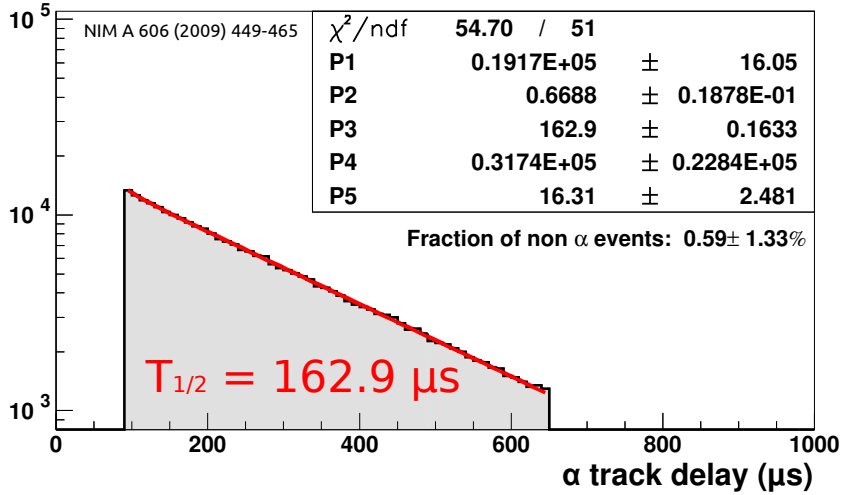




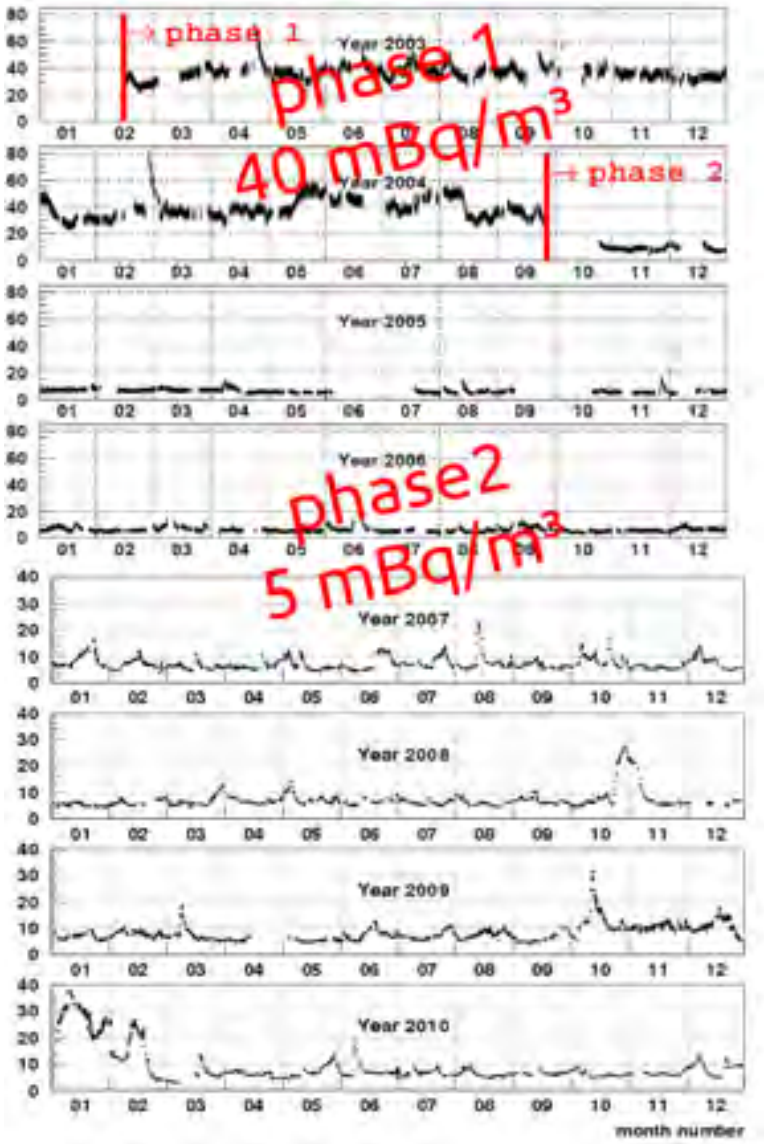
channel $e\alpha$: pure sample of "BiPo" events





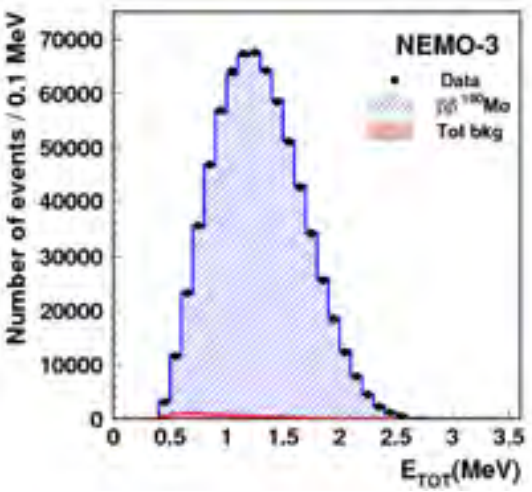


^{222}Rn activity in NEMO 3 (mBq/m^3)

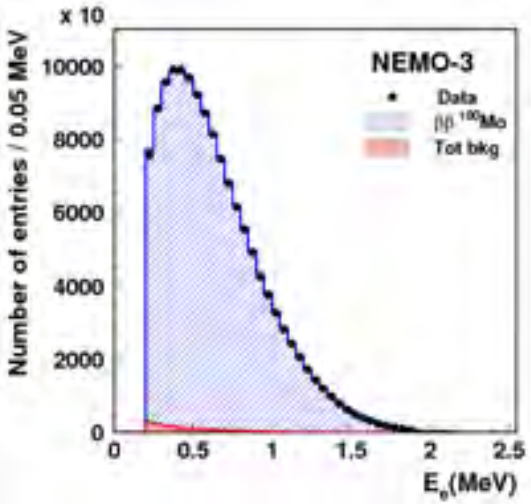


NEMO 3 results : $\beta\beta2\nu$ with ^{100}Mo (phase 2 : 7 kg x 4 years)

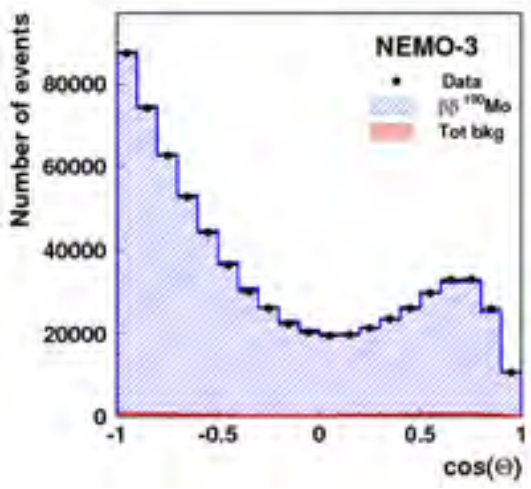
Energy sum of 2 electrons



Single electron energy



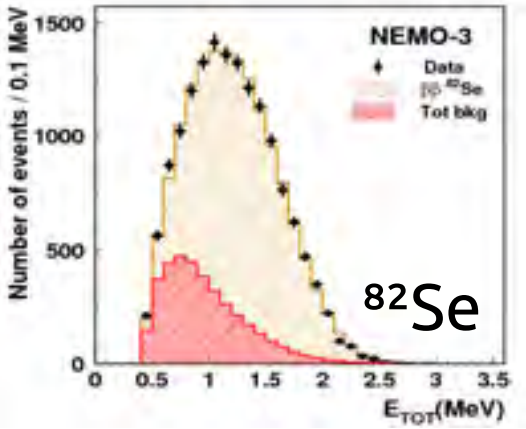
Angular distribution



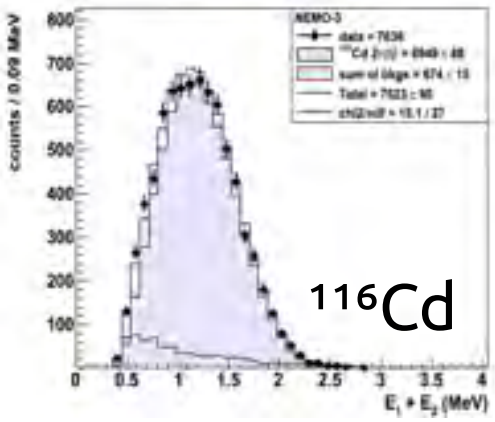
- $>$ 700000 events from ^{100}Mo
- signal / background ratio = 76
- $T_{1/2}^{\beta\beta2\nu} = 7.16 \pm 0.01\ (\text{stat}) \pm 0.54\ (\text{sys}) \times 10^{18}$ years [preliminary]

  phase 1 : $7.11 \pm 0.02\ (\text{stat}) \pm 0.54\ (\text{sys}) \times 10^{18}$ years [Phys. Rev. Lett. 95 182302 (2005)]
- ultimate background component for $\beta\beta0\nu$ signal

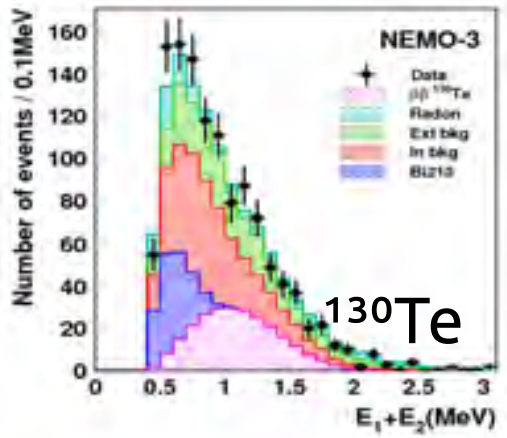
NEMO 3 results : $\beta\beta2\nu$ summary



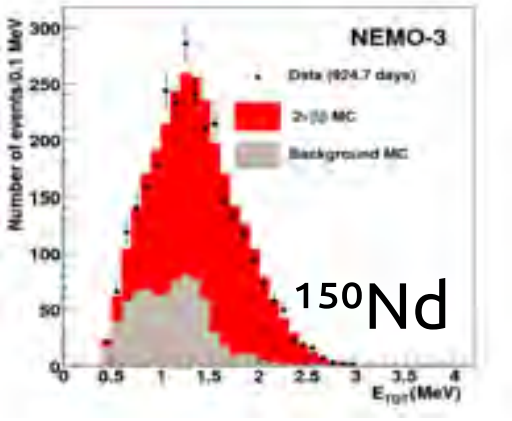
9.6 ± 0.1 (stat) ± 1.0 (sys) x 10^{19} y
[preliminary result]



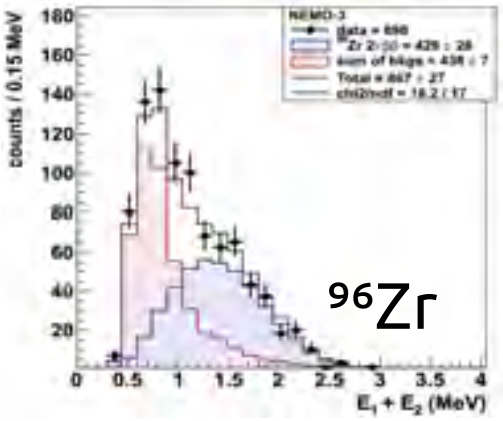
2.88 ± 0.04 (stat) ± 0.16 (sys) x 10^{19}
[preliminary result]



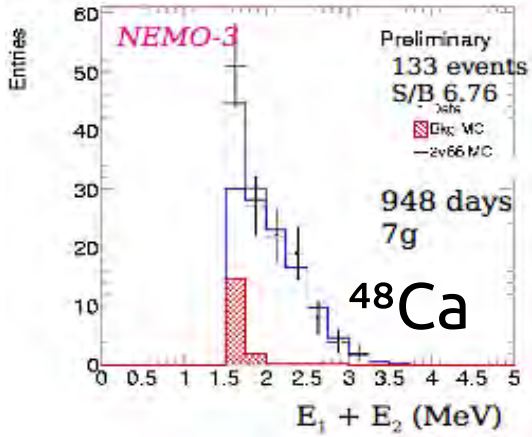
7.0 ± 0.9 (stat) ± 1.1 (sys) x 10^{20} y
[Phys. Rev. Lett. 107, 062504 (2011)]



9.11 ± 0.25 (stat) ± 0.63 (sys) x 10^{18} y
[Phys. Rev. C 80, 032501 (2009)]



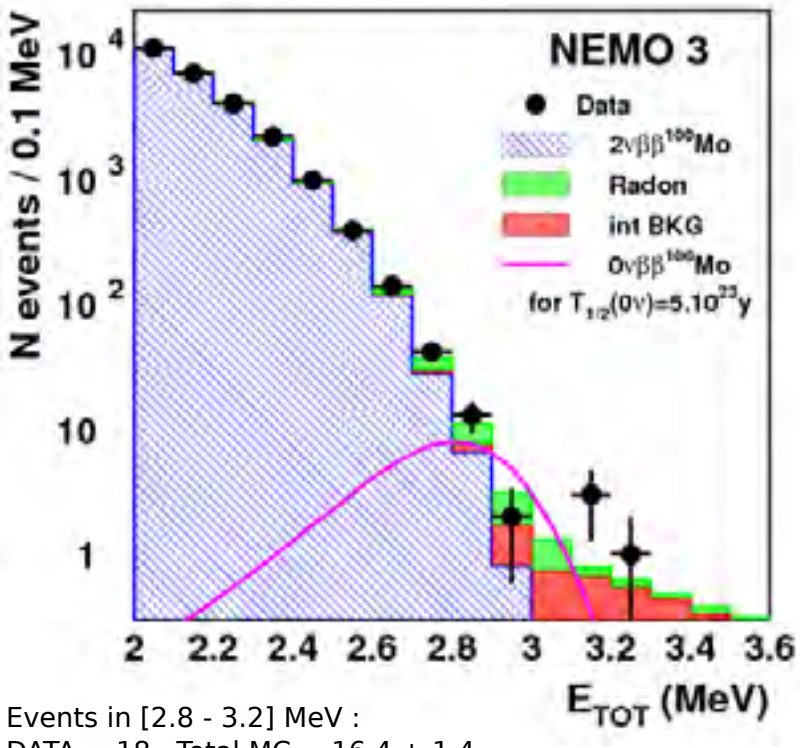
2.35 ± 0.14 (stat) ± 0.16 (sys) x 10^{19} y
[Nucl. Phys. A 847 (2010)]



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

World best catalogue of $\beta\beta2\nu$ half-lifes **first direct detection for ^{130}Te**

^{100}Mo : 7.0 kg x 4.5 years

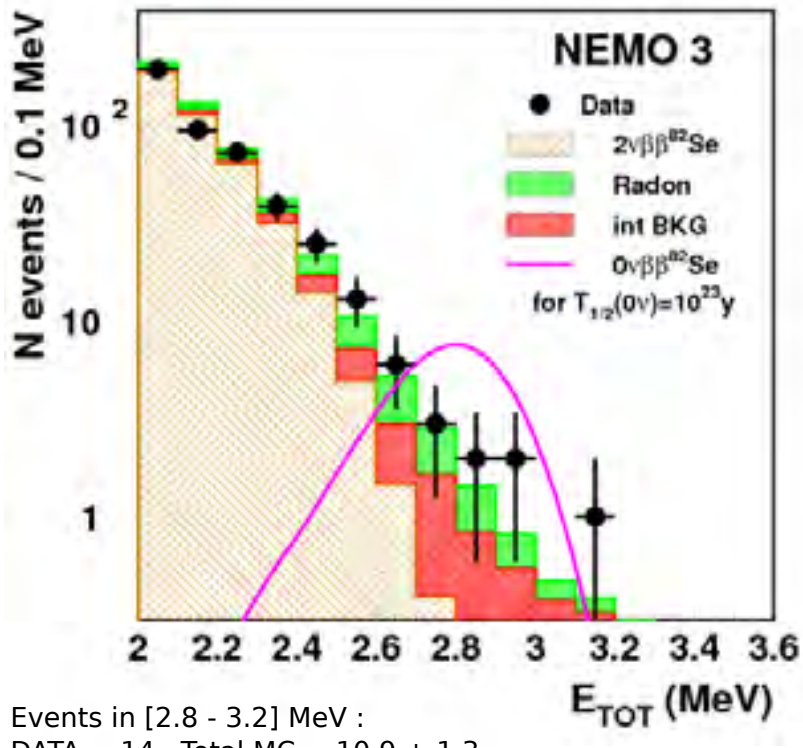


Events in [2.8 - 3.2] MeV :
DATA = 18 Total MC = 16.4 ± 1.4

$$T^{\beta\beta0\nu}_{1/2} > 1.0 \times 10^{24} \text{ years} \quad (90\ \%\ \text{CL})$$
$$m_{\beta\beta} < 310 - 960 \text{ meV}$$

NME		
	QRPA	Kortelainen and Suhonen, Phys. Rev. C75 051303 (2007)
	QRPA	Simkovic et al., Phys. Rev. C77 045503 (2008)
	PHFB	Rath et al., Phys. Rev. C82 064310 (2010)

^{82}Se : 0.9 kg x 4.5 years



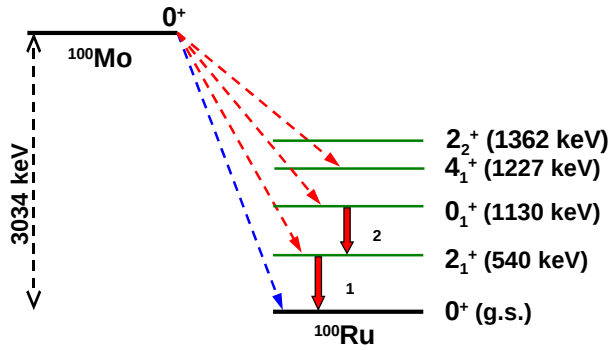
Events in [2.8 - 3.2] MeV :
DATA = 14 Total MC = 10.9 ± 1.3

$$T^{\beta\beta0\nu}_{1/2} > 3.2 \times 10^{23} \text{ years} \quad (90\ \%\ \text{CL})$$
$$m_{\beta\beta} < 940 - 2600 \text{ meV}$$

	QRPA	Kortelainen and Suhonen, Phys. Rev. C76 024315 (2007)
	IBM2	Barea and Iachello, Phys. Rev. C79 044301 (2009)
	SM	Caurrier at al., Phys. Rev. Lett. 100 052503 (2008)

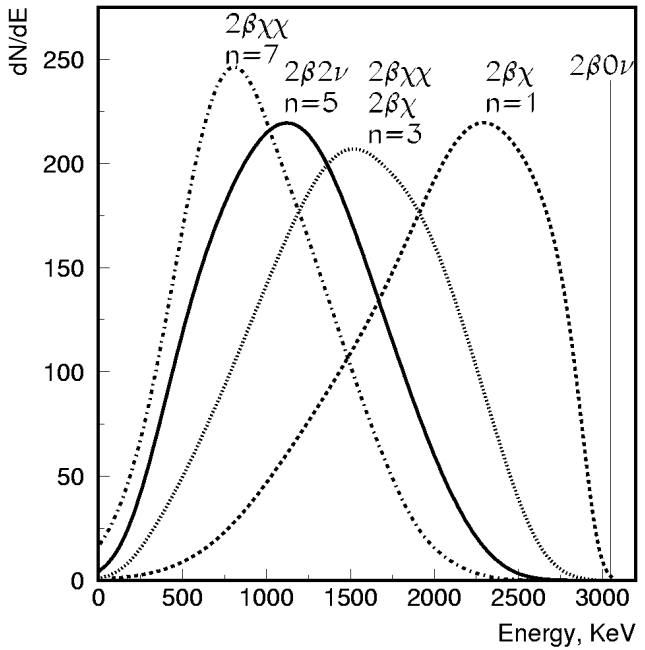
$\beta\beta$* of ^{100}Mo [Nucl. Phys. A781 (2006) 209]

$\beta\beta 2\nu$ $0^+ \to 0_1^+$	$T_{1/2} = 5.7^{+1.3}_{-0.9}$ (stat) $\pm$ 0.8 (syst) x 10^{20} y
$\beta\beta 0\nu$ $0^+ \to 0_1^+$	$T_{1/2} > 8.9$ x 10^{22} y (90 % C.L.)
$\beta\beta 2\nu$ $0^+ \to 2_1^+$	$T_{1/2} > 1.1$ x 10^{21} y (90 % C.L.)
$\beta\beta 0\nu$ $0^+ \to 2_1^+$	$T_{1/2} > 1.6$ x 10^{23} y (90 % C.L.)



$\beta\beta 0\nu$B (Majoron) [Nucl. Phys. A765 (2006) 483]

mode	^{100}Mo	^{82}Se
n = 1	$T_{1/2} > 2.7$ x 10^{22} y	$T_{1/2} > 1.5$ x 10^{22} y
n = 2	$T_{1/2} > 1.7$ x 10^{22} y	$T_{1/2} > 6.0$ x 10^{21} y
n = 3	$T_{1/2} > 1.0$ x 10^{22} y	$T_{1/2} > 3.1$ x 10^{21} y
n = 7	$T_{1/2} > 7.0$ x 10^{19} y	$T_{1/2} > 5.0$ x 10^{20} y



$\beta\beta 0\nu$ V+A

^{100}Mo :	$T_{1/2} > 5.7$ x 19^{23} years	$\lambda < 1.4$ x 10^{-6}
^{82}Se :	$T_{1/2} > 2.4$ x 19^{23} years	$\lambda < 2.0$ x 10^{-6}

– january 2011 –

– october 2011 –

NEMO 3 experiment

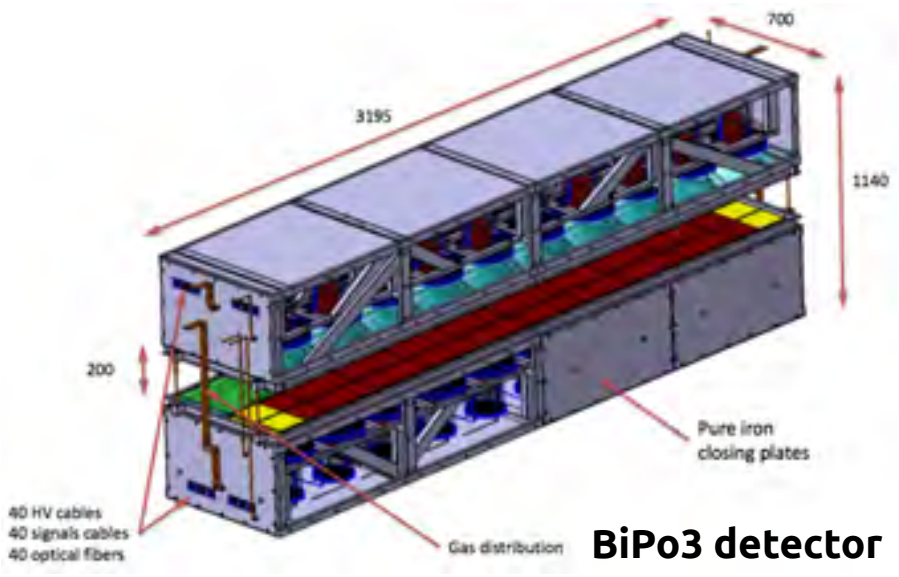
- 8 years of successfull data taking
- fully disassembled during 2011
- final analysis in progress

Target sensitivity : $T_{1/2}^{\beta\beta 0\nu} > 1 \times 10^{26}$ years $\Longleftrightarrow$ $m_{\beta\beta} < 50 - 100$ meV

	NEMO 3	SuperNEMO
Isotope	^{100}Mo	^{82}Se (or ^{150}Nd, or ^{48}Ca)
Exposure	7 kg x 5 years	100 kg x 5 years
Efficiency	18 %	30 %
Energy resolution (FWHM)	8 % @ 3 MeV	4 % @ 3 MeV
A(^{208}Tl) foil	$\sim$ 100 μBq/kg	$\leq$ 2 μBq/kg
A(^{214}Bi) foil	$<$ 300 μBq/kg	$\leq$ 10 μBq/kg
A(^{222}Rn) gas	5 mBq/m^3	$\leq$ 0,15 mBq/m^3

A SuperNEMO module (x 20)

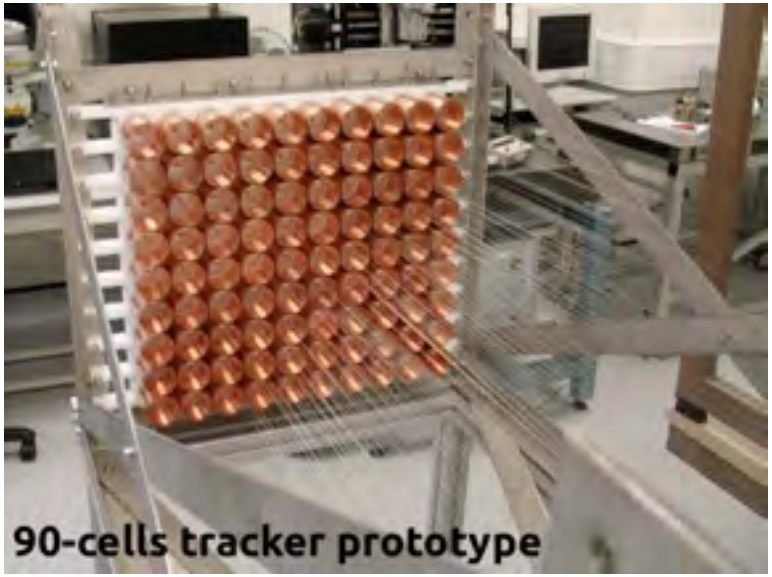
- 5 kg of $\beta\beta$ source
- drift chamber of 2000 Geiger cells
- 550 PVT scintillators + 8" PMTs

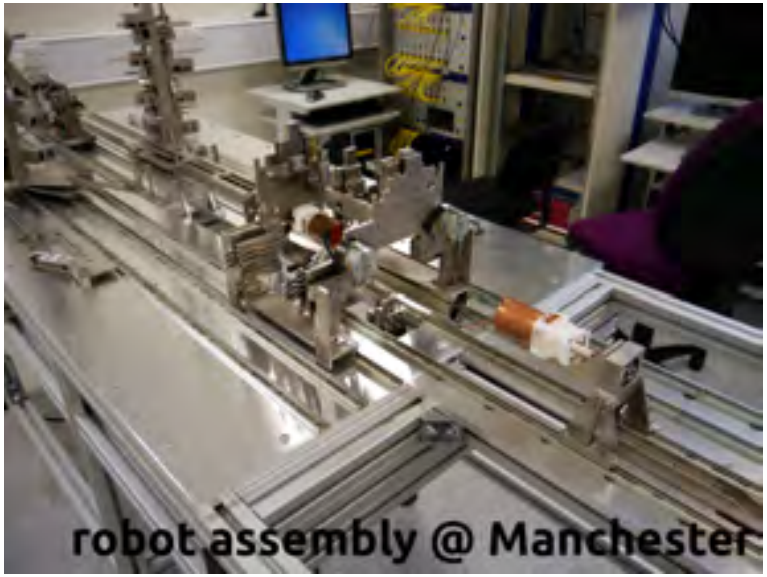


BiPo3 detector

- Source : 5 kg already ready
  ^{214}Bi and ^{208}Tl radiopurity control by a dedicated detector (BiPo3)
- Tracker : required performances demonstrated with a 90-cells protoype
  automated wiring robot under construction (mass production + ultra clean condition)
- Calorimeter : 7.2 % FWHM @ 1 MeV reached (NEMO 3 : 14 % @ 1 MeV)
- Radon : emanation and permeability measurement being lead
  radon concentration line for high sensitivity measurement (100 μBq/m^3)

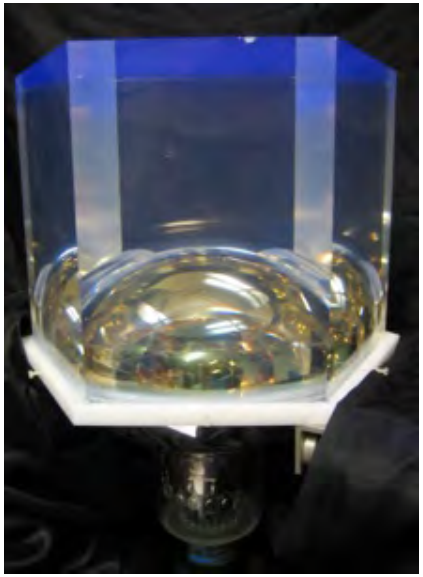
SuperNEMO : Research & Developmentm status

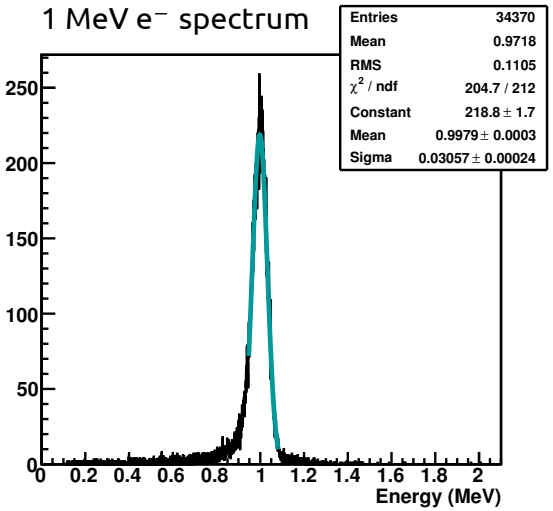


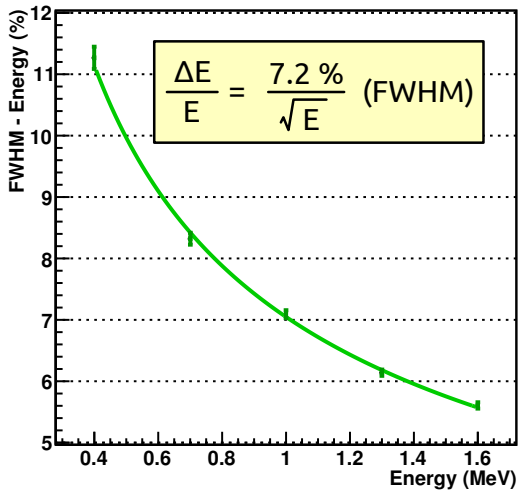


- Source : 5 kg already ready
  ^{214}Bi and ^{208}Tl radiopurity control by a dedicated detector (BiPo3)
- Tracker : required performances demonstrated with a 90-cells protoype
  automated wiring robot under construction (mass production + ultra clean condition)
- Calorimeter : 7.2 % FWHM @ 1 MeV reached (NEMO 3 : 14 % @ 1 MeV)
- Radon : emanation and permeability measurement being lead
  radon concentration line for high sensitivity measurement (100 μBq/m^3)

SuperNEMO : Research & Developmentm status





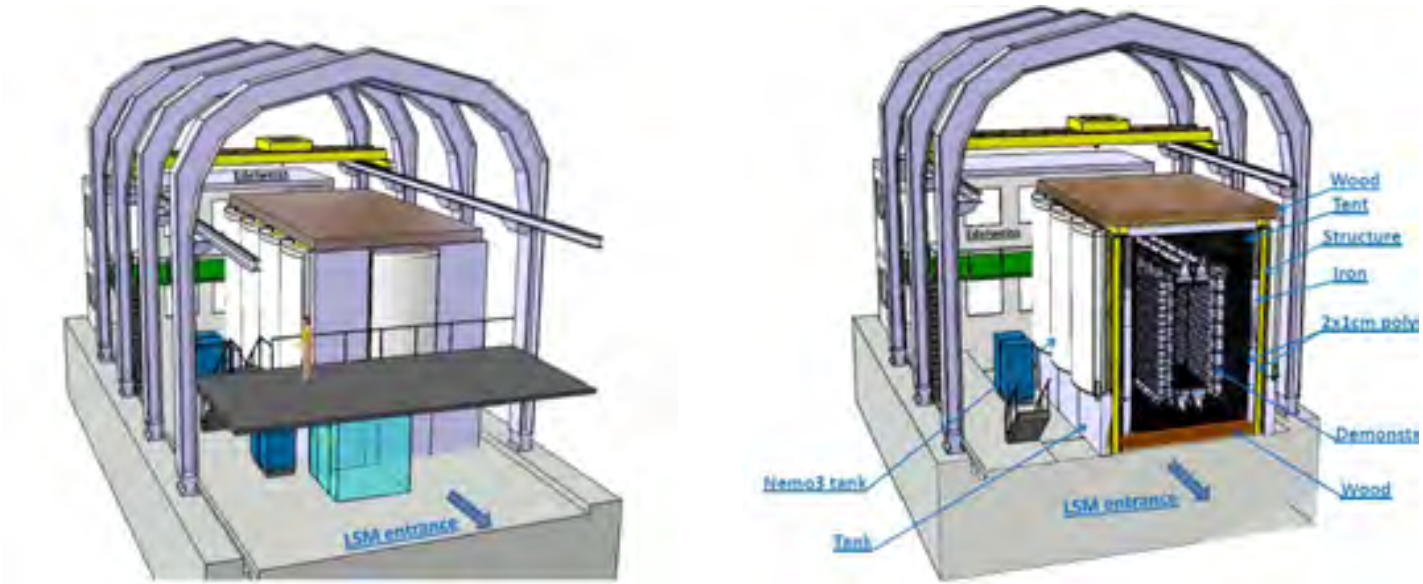


- Source : 5 kg already ready
  ^{214}Bi and ^{208}Tl radiopurity control by a dedicated detector (BiPo3)
- Tracker : required performances demonstrated with a 90-cells protoype
  automated wiring robot under construction (mass production + ultra clean condition)
- Calorimeter : 7.2 % FWHM @ 1 MeV reached (NEMO 3 : 14 % @ 1 MeV)
- Radon : emanation and permeability measurement being lead
  radon concentration line for high sensitivity measurement (100 μBq/m^3)

- Source : 5 kg already ready
  ^{214}Bi and ^{208}Tl radiopurity control by a dedicated detector (BiPo3)
- Tracker : required performances demonstrated with a 90-cells protoype
  automated wiring robot under construction (mass production + ultra clean condition)
- Calorimeter : 7.2 % FWHM @ 1 MeV reached (NEMO 3 : 14 % @ 1 MeV)
- Radon : emanation and permeability measurement being lead
  radon concentration line for high sensitivity measurement (100 μBq/m^3)

SuperNEMO demonstrator (first module)

- a ZERO background experiment (< 0.06 events/years)
- physics with 2.5 years x 7 kg of ^{82}Se
  - $T^{\beta\beta 0\nu}_{1/2}$ sensitivity of 2.6 x 10^{24} years
  - test Klapdor-Kleingrothaus claim
- construction has started (tracker)
- installation for 2014 in LSM at NEMO 3 place



Demonstrator integration at LSM

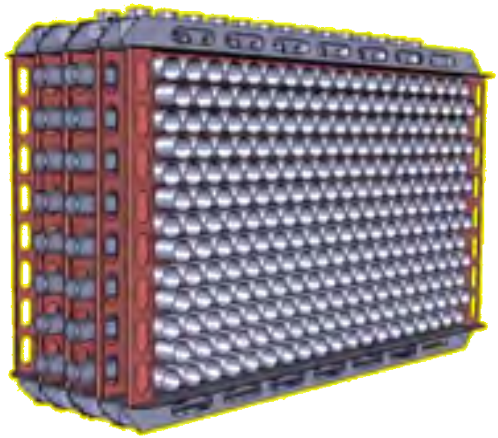
Conclusions

NEMO 3

- 8 years of successful data taking
- a reference for $\beta\beta$ decays study :
  $\beta\beta2\nu$, $\beta\beta0\nu$, $\beta\beta$*, $\beta\beta0\nu B$, ...
- analysis of full dataset on progress
  $\rightarrow$ final results by end 2012

SuperNEMO

- successful R&D
- unique detector approach :
  event topology, isotope flexibility, modularity, ...
- first module will start taking data in 2014
- sensitivity of 50 – 100 meV on $m_{\beta\beta}$ by 2020
- possibility to probe $\beta\beta0\nu$ mechanism



Thank you for your attention !

NEMO 3/SuperNEMO collaboration meeting at Caen, October 2011