

# Neutrinoless double beta decay and the NEMO experiments

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Quarks 2006, Repino, St. Petersburg, May 19-25, 2006

## Contents

- ▶ About neutrinoless double beta decay
- ▶ The NEMO 3 experiment
- ▶ The SuperNEMO project

## About neutrinoless double beta decay

## Some questions about neutrinos. . .

- ▶ Neutrinos are massive particles :
  - ↪ What is their mass hierarchy ?
  - ↪ What is the absolute mass scale for  $m_\nu$  ?
- ▶ Neutrinos have no electric charge :
  - ↪ Dirac or Majorana particles ?
  - ↪ Existence of total leptonic number violating processes ?

## Some questions about neutrinos. . .

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- ▶ Neutrinos have no electric charge :
  - ↪ Dirac or Majorana particles ?
  - ↪ Existence of total leptonic number violating processes ?

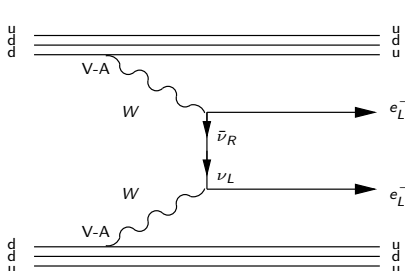
## Neutrinoless double beta decay ( $\beta\beta 0\nu$ )

Experimental test for new physics. . .

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

$$(A, Z) \rightarrow (A, Z + 2) + 2 e^{-} \quad (\Delta L = 2)$$

Interpretation : massive Majorana neutrino exchange



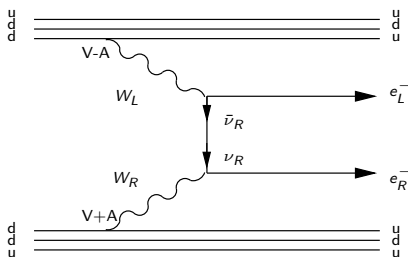
$$T_{1/2, \beta\beta 0\nu}^{-1} = G_{0\nu} | M_{0\nu} |^2 \langle m_\nu \rangle^2$$

- $G_{0\nu}$  : phase space factor ( $\propto Q_{\beta\beta}^5$ )
- $M_{0\nu}$  : nuclear matrix element
- $\langle m_\nu \rangle$  : effective mass of the exchanged neutrino
- $T_{1/2, \beta\beta 0\nu}^{\text{exp}} > 10^{25} \text{ y}$

## Other interpretations...

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

Light Majorana neutrino exchange and V+A coupling



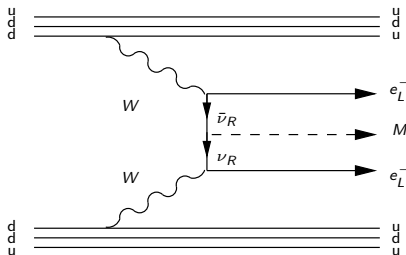
$$T_{1/2, \beta\beta 0\nu}^{-1} = C_1 \langle m_\nu \rangle^2 + C_2 \langle \eta \rangle^2 + C_3 \langle \lambda \rangle^2 + \dots$$

- $C_i$  : phase space + n.m.e.
- $\langle m_\nu \rangle$  : effective neutrino mass
- $\langle \eta \rangle, \langle \lambda \rangle$  : RHC coupling constants

... through emission of Majorons

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

$M$  bosons : break symmetry associated to  $L$  conservation



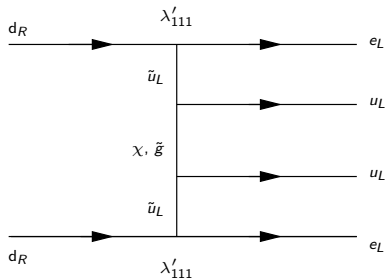
$$T_{1/2, \beta\beta 0\nu M}^{-1} = G_{0\nu M} |M_{0\nu M}|^2 \langle g_M \rangle^2$$

- $G_{0\nu M}$  : phase space
- $M_{0\nu M}$  : n.m.e.
- $\langle g_M \rangle$  : neutrino/Majoron coupling constant

... or through SUSY process

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

SUSY particles exchange (gluinos, neutralinos)



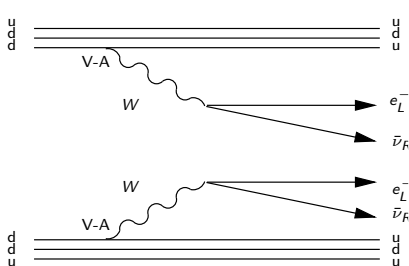
$$T_{1/2, \beta\beta 0\nu}^{-1} = F(\lambda'_{111}, \dots)$$

- $\lambda'_{111}$  : SUSY coupling constants

Two neutrinos double beta decay ( $\beta\beta 2\nu$ )

$$(A, Z) \rightarrow (A, Z + 2) + 2 e^- + 2 \bar{\nu}_e \quad (\Delta L = 0)$$

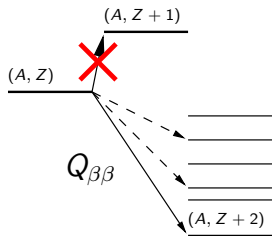
Allowed process in the framework of Standard Model



$$T_{1/2, \beta\beta 2\nu}^{-1} = G_{2\nu} M |M_{2\nu}|^2$$

- $G_{2\nu}$  : phase space factor ( $\propto Q_{\beta\beta}^{11}$ )
- $M_{2\nu}$  : n.m.e.
- observed :

$$T_{1/2, \beta\beta 2\nu}^{\text{exp}} = 10^{18+} \text{ y}$$

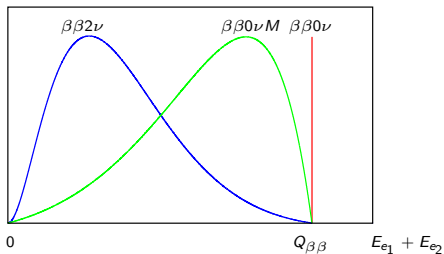
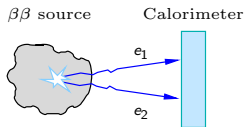
$\beta\beta$  isotopes

Nuclei of experimental interest  
(even-even) :

Isotope	$Q_{\beta\beta}$ (keV)	Abundance (%)
$^{48}\text{Ca}$	4271	0.187
$^{76}\text{Ge}$	2039	7.8
$^{82}\text{Se}$	2995	9.2
$^{100}\text{Mo}$	3034	9.6
$^{130}\text{Te}$	2530	34.5
$^{136}\text{Xe}$	2478	8.9
$^{150}\text{Nd}$	3200	5.6

## Experimental approach

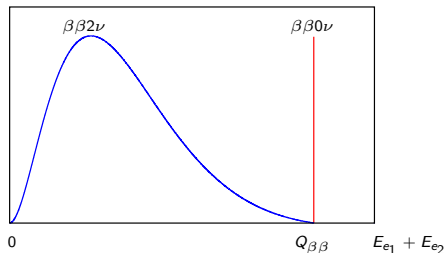
### Measurement of the energy from both emitted electrons



## Backgrounds

Many processes may mimic the  $\beta\beta 0\nu$  signal

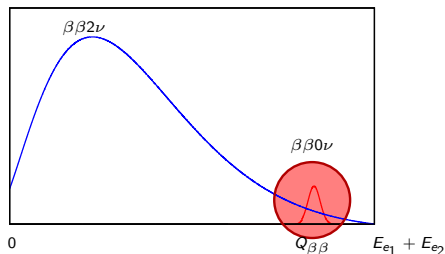
- ▶  $\beta\beta 2\nu$  at the end-point  $E_{e_1} + E_{e_2} \simeq Q_{\beta\beta}$



## Backgrounds

Many processes may mimic the  $\beta\beta 0\nu$  signal

- ▶  $\beta\beta 2\nu$  at the end-point  $E_{e_1} + E_{e_2} \simeq Q_{\beta\beta}$  : energy resolution !



## Backgrounds

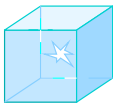
Many processes may mimic the  $\beta\beta 0\nu$  signal

- ▶  $\beta\beta 2\nu$  at the end-point  $E_{e_1} + E_{e_2} \simeq Q_{\beta\beta}$  : energy resolution !
- ▶ Natural radioactivity :  $^{214}\text{Bi}$  ( $Q=3.2$  MeV),  $^{208}\text{Tl}$  ( $Q=5$  MeV,  $\gamma_{2615}$  keV),  
neutrons, cosmic rays

## Experimental approaches

### Calorimeter

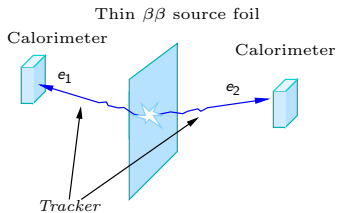
Calorimeter  $\equiv \beta\beta$  source



HPGe (HM, IGEX)

Te bolometer (CUORICINO)

### Calorimeter + tracking



NEMO 3

Both approaches : underground lab and low radioactivity materials.

## Experimental approaches

### Calorimeter

- ▶ observable :  
total deposited energy
- ▶ excellent energy resolution
- ▶ large efficiency (>50%)
- ▶ compact setup
- ▶ No particle identification

### Calorimeter + tracking

- ▶ 3 observables : individual energy, total energy, angle distribution
- ▶ modest energy resolution
- ▶ modest efficiency
- ▶ large setup
- ▶ particle identification

Sensitivity of a  $\beta\beta$  experiment (with background)

$$T_{1/2, \beta\beta 0\nu}^{lim} \simeq \mathcal{N}_A \times \log 2 \times \frac{a}{A} \times \sqrt{\frac{M \times t}{b \times \Delta E}} \times \varepsilon$$

HM ( $^{76}\text{Ge}$ , calorimeter) $M=10$  kg $A=76$  g/mol $a=85\%$  $t=10$  y $\varepsilon=50\%$  $b \simeq 6 \cdot 10^{-2}$  ev./y/keV/kg $\Delta E = 4$  keV (FWHM) $\rightsquigarrow T_{1/2, \beta\beta 0\nu}^{lim.} \simeq 10^{25}$  y $\rightsquigarrow \langle m_\nu \rangle \lesssim 0.5-1.0$  eVNEMO 3 ( $^{100}\text{Mo}$ ,  
calo+tracking) $M=10$  kg $A=100$  g/mol $a=100\%$  $t=5$  y $\varepsilon=10\%$  $b \simeq 10^{-3}$  ev./y/keV/kg $\Delta E=300$  keV $\rightsquigarrow T_{1/2, \beta\beta 0\nu}^{lim.} \simeq 10^{24}$  y

## Best limits : HPGe calorimeter (86% $^{76}\text{Ge}$ )

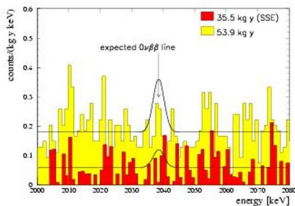
Heidelberg-Moscow  
(1990-2000, LNGS)

5 Ge detectors (10.9 kg)

FWHM = 3.85 keV

$b = 0.06$  BKGD ev./y/kg/keV

Klapdor et al., Eur. Phys. J. 12 (2001) 147



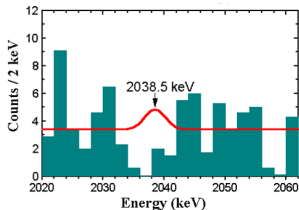
IGEX (1994-2000, Baksan,  
Canfranc)

3 Ge detectors (6 kg)

FWHM = 4 keV

$b = 0.07$  BKGD ev./y/kg/keV

Gonzales et al., Nucl. Phys. B (P.S.) 87 (2000) 278



## Best limits : HPGe calorimeter (86% $^{76}\text{Ge}$ )

Heidelberg-Moscow  
(1990-2000, LNGS)

5 Ge detectors (10.9 kg)

FWHM = 3.85 keV

$b = 0.06$  BKGD ev./y/kg/keV

$T_{1/2, \beta\beta 0\nu} > 1.9 \cdot 10^{25}$  y (90%CL)

$\langle m_\nu \rangle < 0.35 - 1.0$  eV

IGEX (1994-2000, Baksan,  
Canfranc)

3 Ge detectors (6 kg)

FWHM = 4 keV

$b = 0.07$  BKGD ev./y/kg/keV

$T_{1/2, \beta\beta 0\nu} > 1.57 \cdot 10^{25}$  y (90%CL)

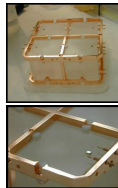
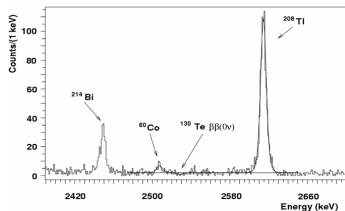
$\langle m_\nu \rangle < 0.4 - 1.1$  eV

## The CUORICINO experiment (running in LNGS)

### CUORICINO : characteristics

- Bolometer : 40 kg de  $\text{TeO}_2$  (10 kg  $^{130}\text{Te}$ )
- FWHM = 8 keV
- $b = 0.18$  BKGD ev./y/kg/keV (surface)

### CUORICINO : 2005 (no evidence)



## The CUORICINO experiment (running in LNGS)

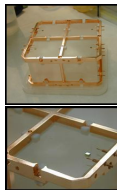
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### CUORICINO : 2005

$$T_{1/2, \beta\beta 0\nu} > 1.8 \cdot 10^{24} \text{ y (90\%CL)}$$
$$\langle m_\nu \rangle < 0.4 - 1.3 \text{ eV}$$

(hep-ex/0505045)



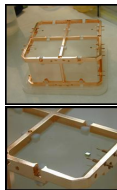
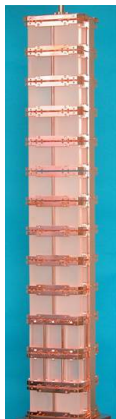
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- $b = 0.18$  BKGD ev./y/kg/keV (surface)

### CUORICINO : 2009

$$T_{1/2, \beta\beta 0\nu} > 4 \cdot 10^{24} \text{ y (90\%CL)}$$
$$\langle m_\nu \rangle < 0.25 - 0.85 \text{ eV}$$

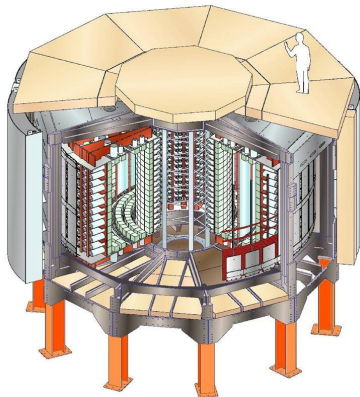


## The NEMO 3 experiment

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(NEMO Collaboration : Czech Rep., Finland, France, Japan, Marocco, Russian Fed., Spain, UK, Ukraine, USA, )

Fréjus Underground Laboratory (LSM, 4800 m.w.e.)

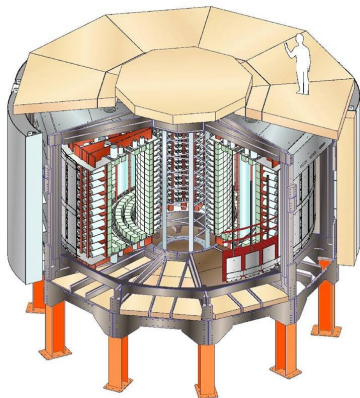


- ▶ Source :  
10 kg different  $\beta\beta$  isotopes,  
20 m<sup>2</sup>, 60 mg/cm<sup>2</sup>
- ▶ Tracking detector
- ▶ Calorimeter
- ▶ Magnetic field
- ▶ Shielding

## The NEMO 3 experiment

(NEMO Collaboration : Czech Rep., Finland, France, Japan, Marocco, Russian Fed., Spain, UK, Ukraine, USA, )

Fréjus Underground Laboratory (LSM, 4800 m.w.e.)



- ▶ Source
- ▶ Tracking detector :  
drift chamber (Geiger), 6180 cells  
(99.5% OK)  
Vertex resolution :  $\simeq$  cm
- ▶ Calorimeter
- ▶ Magnetic field
- ▶ Shielding

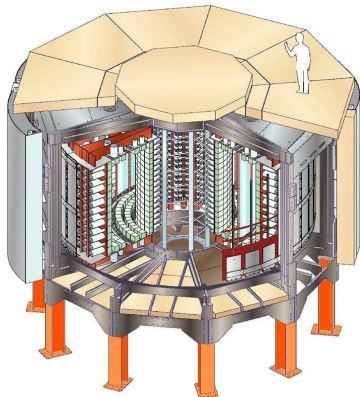




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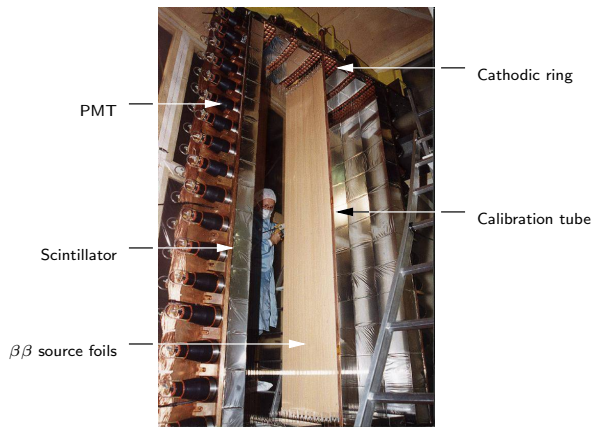
Fréjus Underground Laboratory (LSM, 4800 m.w.e.)



- ▶ Source
- ▶ Tracking detector
- ▶ Calorimeter
- ▶ Magnetic field
- ▶ Shielding :  
 $\gamma$  (Iron 18 cm),  $n$  (borated water, wood) +  $\overline{\text{Rn}}$  device



## A NEMO 3 sector





## Shielding (2002)

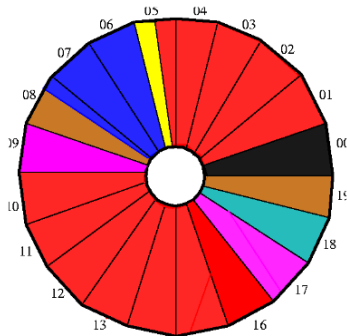


## NEMO 3 with shielding and $\overline{Rn}$ tent (Dec. 2004)



└ The NEMO 3 experiment

## $\beta\beta$ isotopes in the NEMO 3 experiment



enrichment : Russia  
purification : USA/Russia

### $\beta\beta 0\nu$ study

$^{100}\text{Mo}$  : 6.914 kg ( $Q_{\beta\beta}=3.034$  MeV)

$^{82}\text{Se}$  : 0.932 kg ( $Q_{\beta\beta}=2.995$  MeV)

### $\beta\beta 2\nu$ study + external BKG measurements

$^{116}\text{Cd}$  : 405 g ( $Q_{\beta\beta}=2.805$  MeV)

$^{96}\text{Zr}$  : 9.4 g ( $Q_{\beta\beta}=3.350$  MeV)

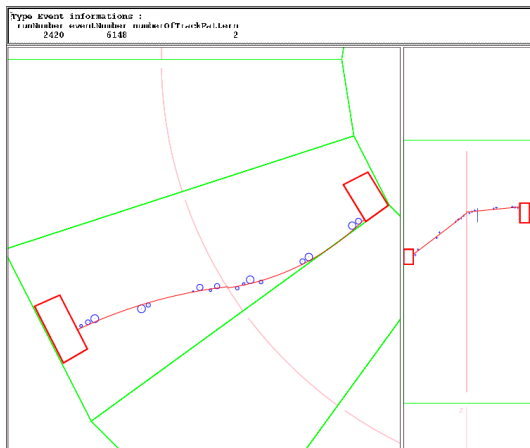
$^{150}\text{Nd}$  : 37.0 g ( $Q_{\beta\beta}=3.367$  MeV)

$^{48}\text{Ca}$  : 7.0 g ( $Q_{\beta\beta}=4.272$  MeV)

$^{130}\text{Te}$  : 454 g ( $Q_{\beta\beta}=2.529$  MeV)

$^{\text{nat}}\text{Te}$  : 491 g

Cu : 621 g

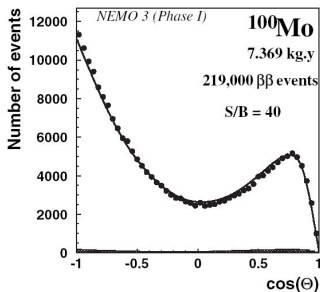
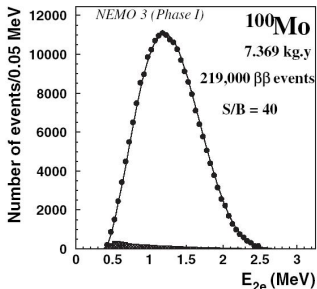
Typical  $\beta\beta$  event ( $^{100}\text{Mo}$ )

## Results for $\beta\beta 2\nu$ ( $^{100}\text{Mo}$ and $^{82}\text{Se}$ ) – phase 1 (high radon)

Phase 1 (Feb. 2003–Dec. 2004) : high radon

$^{100}\text{Mo}$  : 219000 events (7.369 kg.y)

$^{82}\text{Se}$  : 2750 events (0.993 kg.y)

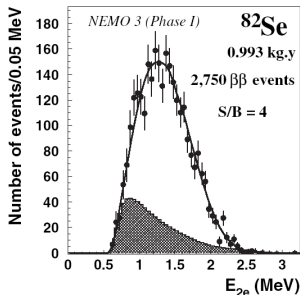
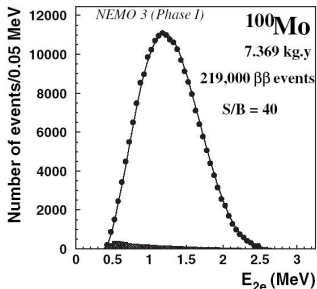


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Results for  $\beta\beta 2\nu$  ( $^{100}\text{Mo}$  and  $^{82}\text{Se}$ ) – phase 1 (high radon)

$\beta\beta 2\nu$  results :

- ▶  $^{100}\text{Mo} \rightsquigarrow T_{1/2, \beta\beta 2\nu} = 7.11 \pm 0.02$  (stat)  $\pm 0.54$  (syst)  $10^{18}$  y
- ▶  $^{82}\text{Se} \rightsquigarrow T_{1/2, \beta\beta 2\nu} = 9.6 \pm 0.3$  (stat)  $\pm 1.0$  (syst)  $10^{19}$  y

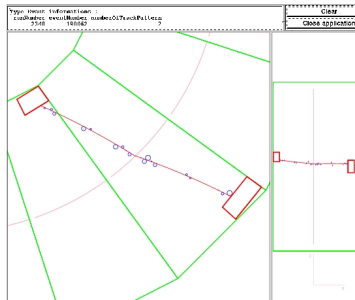




## Background identification and measurement

With NEMO 3 we are able to measure each background component using independent analysis channels/event topologies

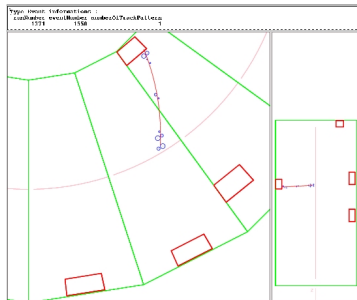
- ▶  $\beta\beta 2\nu$  background
- ▶ External BKGD :  
 $^{208}\text{Tl}$  in PMT  
 $(e^-, \gamma)$  external,  $(e^+e^-)$   
 $n, \gamma > 3 \text{ MeV}$   
crossing  $(e^-) > 4 \text{ MeV}$
- ▶ Internal BKGD ( $^{208}\text{Tl}$ )
- ▶ Internal BKGD ( $^{214}\text{Bi}$ )



## Background identification and measurement

With NEMO 3 we are able to measure each background component using independant analysis channels/event topologies

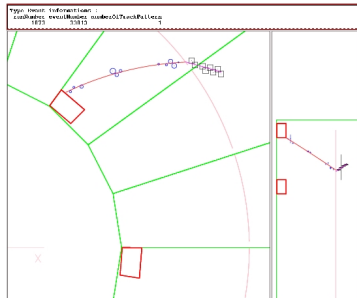
- ▶  $\beta\beta 2\nu$  background
- ▶ External BKGD
- ▶ Internal BKGD ( $^{208}\text{Tl}$ ) :  
in source foils  
 $80 \pm 20 \mu\text{Bq/kg}$   
internal ( $e^-, 2\gamma$ ), ( $e^-, 3\gamma$ )
- ▶ Internal BKGD ( $^{214}\text{Bi}$ )



## Background identification and measurement

With NEMO 3 we are able to measure each background component using independant analysis channels/event topologies

- ▶  $\beta\beta 2\nu$  background
- ▶ External BKGD
- ▶ Internal BKGD ( $^{208}\text{Tl}$ )
- ▶ Internal BKGD ( $^{214}\text{Bi}$ ) :  
in source foils,  
 $^{222}\text{Rn}$  deposit  
internal ( $e^-$ ,  $\gamma$ ,  $\alpha$ )

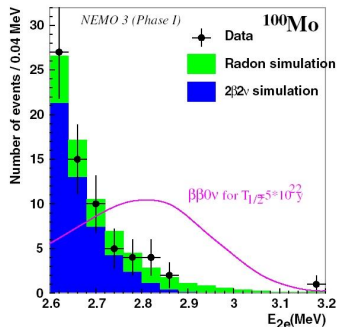


Search for  $\beta\beta 0\nu$  process – phase 1 with radon

R. Arnold et al., Phys. Rev. Lett. 95, 182302 (2005)

 $^{100}\text{Mo}$  (6.914 kg, 389 j)  $\rightsquigarrow$  no evidence for  $\beta\beta 0\nu$ Efficiency  $\beta\beta 0\nu$  : 8 %Expected BKGD :  $8.1 \pm 1.3$ 

Observed : 7 events

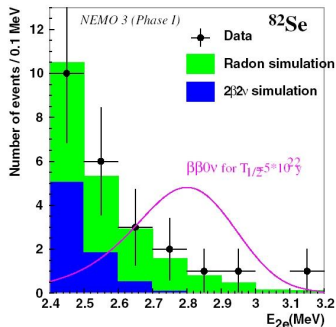
 $T_{1/2, \beta\beta 0\nu} > 4.6 \cdot 10^{23}$  y (90%CL) $\langle m_\nu \rangle < 0.7\text{--}2.8$  eV

Search for  $\beta\beta 0\nu$  process – phase 1 with radon

R. Arnold et al., Phys. Rev. Lett. 95, 182302 (2005)

 $^{82}\text{Se}$  (0.932 kg, 389 j)Efficiency  $\beta\beta 0\nu$  : 13 %Expected BKGD :  $3.1 \pm 0.6$ 

Observed : 5 events

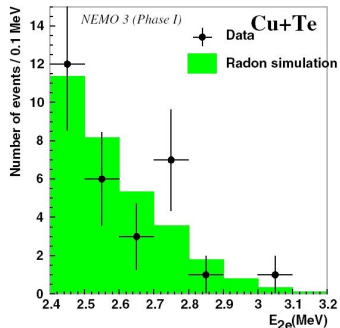
 $T_{1/2, \beta\beta 0\nu} > 1.0 \cdot 10^{23}$  y (90%CL) $\langle m_\nu \rangle < 1.7\text{--}4.9$  eV

## Search for $\beta\beta 0\nu$ process – phase 1 with radon

R. Arnold et al., Phys. Rev. Lett. 95, 182302 (2005)



BKGD is compatible with expectation from radon contamination



## Phase 1 (2003-2004) : radon in NEMO 3

- ▶ Radon issue :
  - radon diffusing from outside ( $\simeq 10 \text{ Bq/m}^3$ ) to the inside of the tracking chamber ( $\simeq 10 \text{ mBq/m}^3$ )
  - $^{214}\text{Bi}$  deposit on source foils and wires
  - ↪ induced BKGD  $\times 10$  too high for  $\beta\beta 0\nu$  study
- ▶ End 2004 :
  - anti-radon factory to clean air around NEMO 3 (using SuperK technique)
  - ↪ factor 100 improvement
  - radon proof tent around the detector
  - ↪ factor  $\lesssim 10$  decrease of radon rate inside NEMO 3
- ▶ Phase 2 (2005-2009) : good running conditions

## Phase 2 (2005...) : low radon period

### Very preliminary 2006 results

- ▶ no evidence for  $\beta\beta 0\nu$  signal
- ▶  $^{100}\text{Mo}$  :  $T_{1/2,\beta\beta 0\nu} > 5.8 \cdot 10^{23}$  y (90 %CL)  
 $\langle m_\nu \rangle < 0.6 - 1.0$  eV
- ▶  $^{82}\text{Se}$  :  $T_{1/2,\beta\beta 0\nu} > 2.1 \cdot 10^{23}$  y (90 %CL)  
 $\langle m_\nu \rangle < 1.2 - 2.5$  eV
- ▶  $\beta\beta 2\nu$  results for many  $\beta\beta$  isotopes to be published soon...

## Expected $\beta\beta 0\nu$ sensitivity after 5 y

Expected in 2009 :

- ▶  $^{100}\text{Mo} : T_{1/2,\beta\beta 0\nu} > 2 \cdot 10^{24} \text{ y (90 \%CL)}$   
 $\langle m_\nu \rangle < 0.3 - 1.3 \text{ eV}$
- ▶  $^{82}\text{Se} : T_{1/2,\beta\beta 0\nu} > 8 \cdot 10^{23} \text{ y (90 \%CL)}$   
 $\langle m_\nu \rangle < 0.6 - 1.7 \text{ eV}$
- ▶ or... a discovery!

## Conclusion about NEMO 3

### The NEMO 3 experiment

- ▶ NEMO 3 : the only « Calo+Tracking » detector running at this level of sensitivity
- ▶ Very low BKGD large detector : 200 t is 300 Bq  $\rightsquigarrow$   $\sim$  6 Hz
- ▶ Reliable techniques : no aging for tracker and calorimeter
- ▶ Identification and measurements of backgrounds
- ▶ Control of internal and external background for 10 kg  $\beta\beta$  enriched source
- ▶ 15 years experience in  $\beta\beta$  decay research field
- ▶ International collaboration, strong contributions from Russian institutions : sources, mechanics, calorimeter, running, data analysis

## The SuperNEMO project

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## Future $\beta\beta$ projects (2006-2015)

- CUORICINO  $\rightsquigarrow$  CUORE ( $\sim 200$  kg  $^{130}\text{Te}$ , bolometer  $\text{TeO}_2$ , LNGS)
- HM  $\rightsquigarrow$  GERDA ( $\sim 300$  kg  $^{76}\text{Ge}$ , HPGe, LNGS), Majorana (USA)
- Others : EXO ( $^{136}\text{Xe}$  TPC)...
- Expected sensitivity :

$$T_{1/2, \beta\beta 0\nu} \gtrsim 10^{26-27} \text{ y} \rightsquigarrow \langle m_\nu \rangle \simeq 50 \text{ meV}$$

- ▶ The SuperNEMO project : using NEMO 3 techniques to reach this level...

## SuperNEMO – Goals

### Goals and experimental techniques

- ▶ Discovery of the  $\beta\beta 0\nu$  process within 5 years :  
sensitivity :  $T_{1/2,\beta\beta 0\nu} \sim 10^{26}$  y  $\rightsquigarrow \langle m_\nu \rangle \simeq 50$  meV
- ▶ Calorimeter + particle identification (tracking)
- ▶ Ability to confirm a signal from another  $\beta\beta$  experiment using pure calorimeter (Ge, Te)

## SuperNEMO – Choice of the $\beta\beta$ isotope

### Criteria

- ▶ Nuclear matrix elements :  $M_{0\nu}$  as large as possible
- ▶ Enrichment : large  $M \rightsquigarrow$  cost, production time
- ▶ Large  $Q_{\beta\beta} \rightsquigarrow$  large  $G_{0\nu}$  and less BKGD issues
- ▶  $T_{1/2, \beta\beta 2\nu}$  as large as possible (reduce  $\beta\beta 2\nu$  induced BKGD)
- ▶ Source purification
- ▶ Candidates :  $^{82}\text{Se}$ ,  $^{150}\text{Nd}$

## SuperNEMO – Numbers

Hypothesis : using  $^{82}\text{Se}$  ( $Q_{\beta\beta} \simeq 3 \text{ MeV}$ )

- ▶ Mass :  $M = 100 \text{ kg}$  ( $250 \text{ m}^2 @ 40 \text{ mg/cm}^2$ )
- ▶ Running time :  $t = 5 \text{ y}$
- ▶ Efficiency :  $\varepsilon = 30 \%$
- ▶ Sensitivity for a  $\beta\beta 0\nu$  discovery without BKGD :

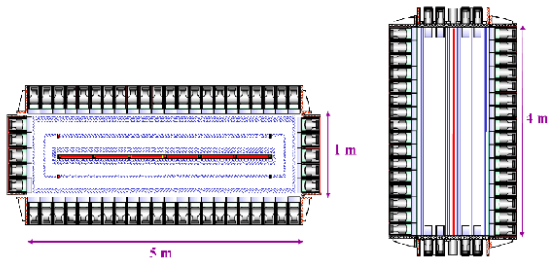
$$T_{1/2, \beta\beta 0\nu} \simeq 3 \cdot 10^{26} \text{ y}$$

- ▶ Constraints on source radiopurity (from simulations) :
  - ▶  $A(^{214}\text{Bi}) < 10 \mu\text{Bq/kg}$  ( $< 1 \text{ ev./100 kg/y}$ )
  - ▶  $A(^{208}\text{Tl}) < 2 \mu\text{Bq/kg}$  ( $< 1 \text{ ev./100 kg/y}$ )
- ▶  $\beta\beta 2\nu$  BKGD ( $\simeq 1 \text{ ev./100 kg/y}$ ) : FWHM = 4% @ 3 MeV
- ▶ Sensitivity :  $T_{1/2, \beta\beta 0\nu} > 2 \cdot 10^{26} \text{ y}$  and  $\langle m_\nu \rangle = 40 - 100 \text{ meV}$

## Preliminary design

### NEMO 3 extrapolation , modular, planar layout

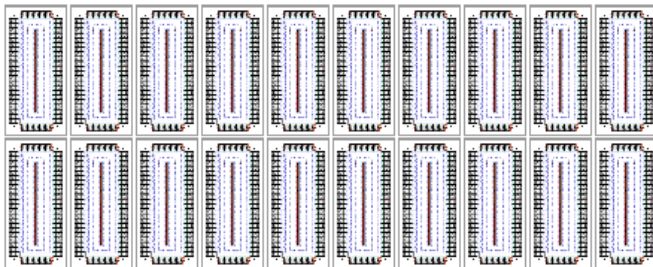
- ▶ Module with 5 kg of  $\beta\beta$  source (12.5 m<sup>2</sup> @ 40 mg/cm<sup>2</sup>)  
     $\rightsquigarrow$  1000 PMTs + 3000 tracking cells



## Preliminary design

### NEMO 3 extrapolation , modular, planar layout

- ▶ Module with 5 kg of  $\beta\beta$  source (12.5 m<sup>2</sup> @ 40 mg/cm<sup>2</sup>)
- ▶ Full detector : 20 modules for  $M=100$  kg (250 m<sup>2</sup>)  
     $\rightsquigarrow$  Total  $> 200000$  channels and 1500 m<sup>3</sup> (water shielding)

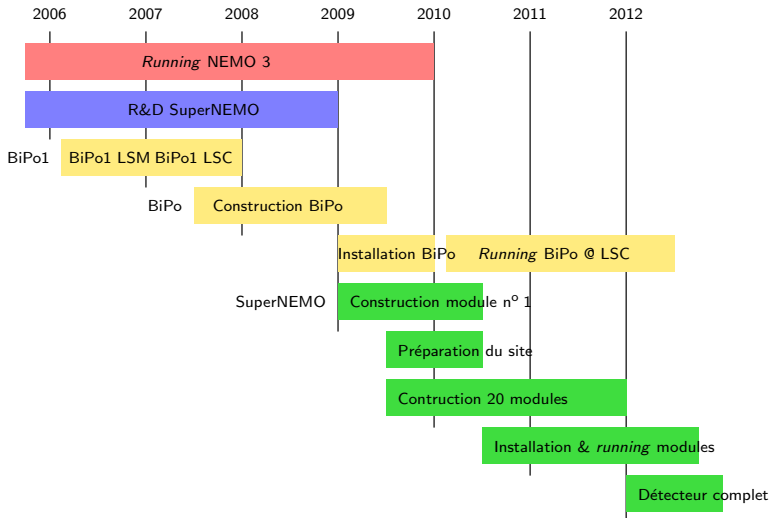


## The SuperNEMO R&D program

### Key points

- ▶  $\beta\beta$  sources : Enrichment and purification :
  - Production of enriched  $\beta\beta$  source ( $a > 95\%$ ) ( $^{82}\text{Se}$  in Russia,  $^{150}\text{Nd}$  in France...)
  - Purification
  - Radiopurity measurement (HPGe, *BiPo*)
- ▶ Calorimeter :
  - Improvement of the energy resolution (FWHM=4% @ 3 MeV), scintillator and PMT
  - Scintillator study and R&D for PMT
- ▶ Tracking detector : wires and gas radiopurity (radon  $< 0.1$  mBq/m<sup>3</sup>)
- ▶ Hosting site : Fréjus (France), Canfranc (Spain), LNGS (Italy) ?

## Schedule for R&D program and SuperNEMO (preliminary)







## Conclusion

- ▶ What we could learn from observation of the  $\beta\beta 0\nu$  process :
  - $L$  is not conserved
  - Majorana neutrino
  - neutrino mass hierarchy
  - neutrino absolute mass scale
- ▶ NEMO 3 :
  - running from Feb. 2003 (Dec. 2004 « without » radon)
  - BKGD sources are identified and measured
  - expected  $\beta\beta 0\nu$  sensitivity in 2009 :  $2 \cdot 10^{24}$  y ( $^{100}\text{Mo}$ )
  - extrapolation of this technique is possible

## Conclusion

- ▶ R&D SuperNEMO :
  - towards a future and large NEMO 3-like experiment using  $\sim 100$  kg  $\beta\beta$  source (2010-2020)
  - sensitivity :  
 $T_{1/2,\beta\beta 0\nu}^{lim} = 2 \cdot 10^{26}$  y (NEMO 3  $\times$  100)  
 $\langle m_\nu \rangle^{lim} \simeq 50$  meV
  - R&D program is funded in France and UK (2006-2008)
  - SuperNEMO international collaboration = Czech Rep., Finland, France, Japan, Russian Fed., Spain, UK, Ukraine, USA... 15 years experience

## NEMO 3, SuperNEMO et R&D – Bibliography

-  R. Arnold et al., *Technical design and performance of the NEMO 3 detector*, NIM A536 (2005) 79-122
-  Ph. Adamson et al., Collaboration NEMO, *Expression of Interest in the Super-NEMO double beta decay experiment*, June 11, 2004
-  F. Piquemal, Collaboration NEMO, *Présentation du projet de R&D SuperNEMO*, Conseil Scientifique de l'IN2P3, mars 2005
-  C. Augier et al., NEMO group at LAL, *Proposal for an R&D program for a double beta decay experiment sensitive to a 50 meV neutrino effective mass*, Conseil Scientifique du LAL, 23/09/2005
-  R. Arnold et al., *First results of neutrinoless double beta decay search with the NEMO 3 detector*, Phys. Rev. Lett. 95 (2005) 182302