The BiPo detector for ultralow radioactivity measurements

LRT 2010 - SNOLAB

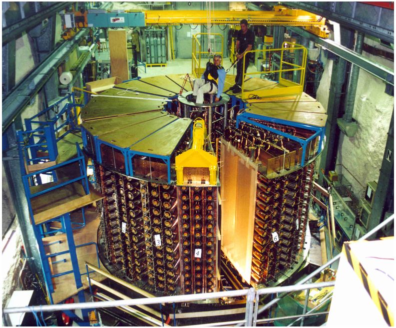
Mathieu BONGRAND
for the SuperNEMO Collaboration

LAL Orsay

2010/08/28

The NEMO3 Experiment

The NEMO3 experiment is running in the *Laboratoire Souterrain de Modane* since 2003



High radon phase I
Feb. 2003 - Oct. 2004
$\mathcal{A}_{int}(^{222}\mathrm{Rn}) \sim 38$ mBq/m^3

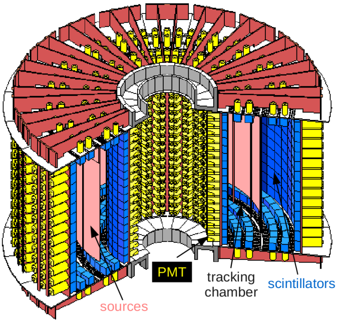
Low radon phase II
Dec. 2004 - Now
$\mathcal{A}_{int}(^{222}\mathrm{Rn}) \sim 6.5$ mBq/m^3

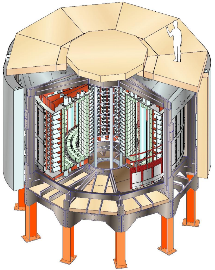
[NEMO collaboration, NIM A 606 (2009) 449-465]

$\rightarrow$ *see also Frederic Perrot's talk on SuperNEMO*

The NEMO3 Detector

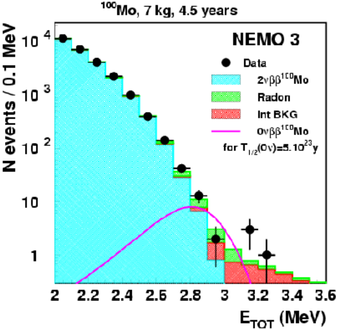
- About 10 kg of 2β enriched isotopes in thin vertical foils (60 mg/cm^2):
  - **$0\nu2\beta$: ^{100}Mo (6.9 kg) & ^{82}Se (932 g)**
  - $2\nu2\beta$: ^{130}Te (454 g), ^{116}Cd (405 g), ^{150}Nd (37 g), ^{96}Zr (9 g) & ^{48}Ca (7 g)
- Tracking chamber: 6180 drift cells in geiger mode + B field (25 G)
- Calorimeter: 1940 polystyrene scintillators, PMMA light-guides & low radioactivity PMTs
- Shielding: LSM (4800 m.w.e.), borated water, wood & pure iron

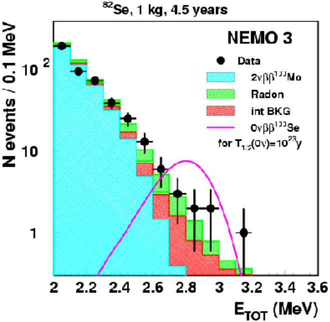




NEMO3 Results: $0\nu2\beta$ Search

^{100}Mo (6.9 kg) & ^{82}Se (932 g): $\sim$ 4.5 yr [phase I + II]





$Q_{\beta\beta}(^{100}\text{Mo}) = 3.034$ MeV
$\mathcal{T}^{0\nu}_{1/2}(^{100}\text{Mo}) > 1.0\ 10^{24}$ yr
[90 % C.L.]

$m_{\beta\beta} < 0.47 - 0.96$ eV

$Q_{\beta\beta}(^{82}\text{Se}) = 2.995$ MeV
$\mathcal{T}^{0\nu}_{1/2}(^{82}\text{Se}) > 3.2\ 10^{23}$ yr
[90 % C.L.]

$m_{\beta\beta} < 0.94 - 2.5$ eV

- ^{208}Tl & ^{214}Bi in the sources is one of the main backgrounds

$\rightarrow$ *see also Frederic Perrot's talk on SuperNEMO*

NEMO3 Sources Radiopurity

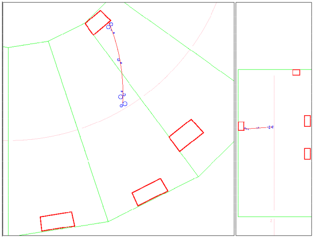
- ^{100}Mo requirements: $\mathcal{A}(^{208}\text{Tl}) < 20$ & $\mathcal{A}(^{214}\text{Bi}) < 300\ \mu$Bq/kg
- HPGe measurements (CENBG/LSM) in mBq/kg:

Source	Mass	Meas	Time	^{40}K	^{214}Bi	^{208}Tl
^{100}Mo [m]	2.5 kg	0.73 kg	840 h	<5	<0.39	<0.11
^{100}Mo [c]	4.4 kg	0.74 kg	648 h	<6	<0.34	<0.10
^{82}Se [c]	932 g	800 g	628 h	55±5	1.2±0.5	0.4±0.1

[m]: metallic, [c]: composite - [R. Arnold et al, NIM A 536 (2005) 79-122]

- The NEMO3 measurements show small tensions (mBq/kg):

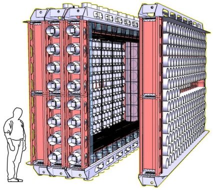
Source	^{214}Bi $(\beta-\alpha)$	^{208}Tl $(\beta-n\gamma)$
^{100}Mo [m]	<0.1	0.11±0.01
^{100}Mo [c]	<0.15	0.12±0.01
^{82}Se [c]	0.53±0.18	0.44±0.04

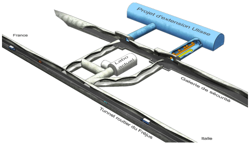


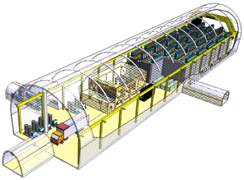
- *^{100}Mo & ^{82}Se foils will be remeasured by the BiPo detector*

The SuperNEMO Project

	NEMO3	SuperNEMO
Mass	7 kg	100 kg
Isotope	^{100}Mo	^{82}Se or ^{150}Nd
Foil density	60 mg/cm^2	40 mg/cm^2
Energy resolution (FWHM)		
@ 1 MeV	15 %	7 %
@ 3 MeV	8 %	4 %
Radon (^{222}Rn)	$\sim$ 6.5 mBq/m^3	$\sim$ 0.1 mBq/m^3
Sources contaminations		
$\mathcal{A}(^{208}\text{Tl})$	<20 μBq/kg	<2 μBq/kg
$\mathcal{A}(^{214}\text{Bi})$	<300 μBq/kg	<10 μBq/kg





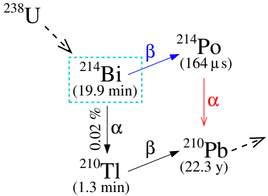


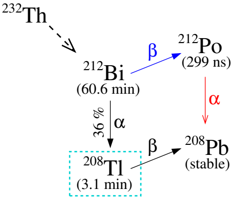
First module with 7 kg of ^{82}Se in 2013: $\mathcal{T}_{1/2}^{0\nu} > 6.5\ 10^{24}$ yr in 2 years

Full detector 2016 in LSM extension: $\mathcal{T}_{1/2}^{0\nu} > 1\ 10^{26}$ yr in 3 years

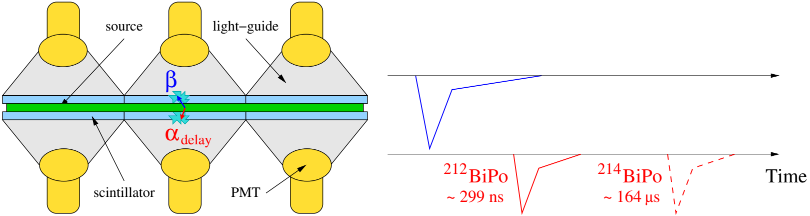
The BiPo Detector Principle

- ^{214}Bi and ^{208}Tl contaminations measured by BiPo processes from natural radioactivity chains:





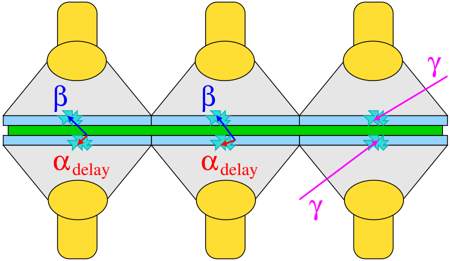
- β & α particles detected by thin radiopure plastic scintillators coupled to light-guides and low radioactivity PMTs:



The BiPo Detector Backgrounds

3 sources of backgrounds should be considered:

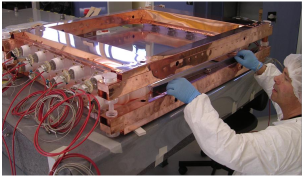
- ^{238}U (^{214}Bi) and ^{232}Th (^{208}Tl) contaminations on the surface of the scintillators
  (include volume contaminations within $\sim$100 μm thickness)
- ^{222}Rn and ^{220}Rn migration between the source and the scintillators
- random coincidences (external γ)

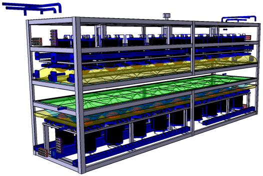


The R&D Phase for the BiPo Detector

4 years of R&D to test the feasibility and measure the backgrounds to determine the sensitivity:

- Starting tests and constructions in 2006
- BiPo1 prototype: 0.8 m^2 - Feb 2008 to now in LSM
  $\rightarrow$ first results with 10 d data presented @ LRT 2006 Aussois
  Recent publication: doi:10.1016/j.nima.2010.07.037
- BiPo2 prototype: 0.56 m^2 - Jul 2008 to now in LSM
- BiPo3 detector: 3.24 m^2 - under construction in LAL

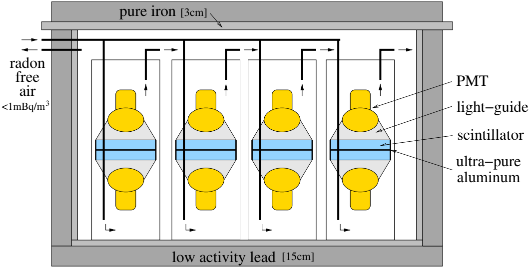




The BiPo1 Prototype

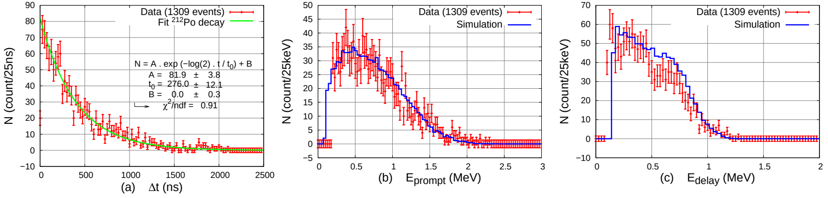
BiPo1 prototype: 0.8 m^2 - Feb 2008 to now in LSM

- 20 similar high radiopurity modules:
  - 200x200x3 mm^3 Polystyrene scintillators [POPOP + pTp]
  - entrance face aluminized with 200 nm of ultra pure aluminum
  - PMMA light guides
  - side reflector in Teflon (0.2 mm)
  - 5" Hamamatsu R6594-MOD low background PMTs
- Lead and pure iron shielding, radon free air flushing
- MatAcq VME digitizer boards: 2.5 μs @ 1 GS/s, 1 V & 12 bit
- trigger boards for longer delays (^{214}Bi)



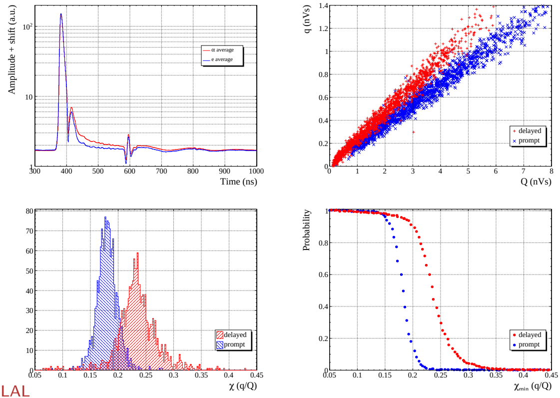
BiPo1 Foils Measurement

- Calibrated 150 μm aluminium foil (40 mg/cm^2) in one module with $\mathcal{A}(^{212}\text{Bi} \rightarrow^{212}\text{Po}) = 0.19 \pm 0.04$ Bq/kg
- 160 days of data and 1309 BiPo events detected:
  - $\mathcal{A}(^{212}\text{Bi} \rightarrow^{212}\text{Po}) = 0.16 \pm 0.01\ stat. \pm 0.03\ syst.$ Bq/kg
  - $\mathcal{T}_{1/2} = 276 \pm 12\ (stat.)$ ns [$\mathcal{T}_{1/2}(^{212}\text{Po}) = 299$ ns]
  - β and α spectra in good agreement with expectation
- Validation of the BiPo1 technique!



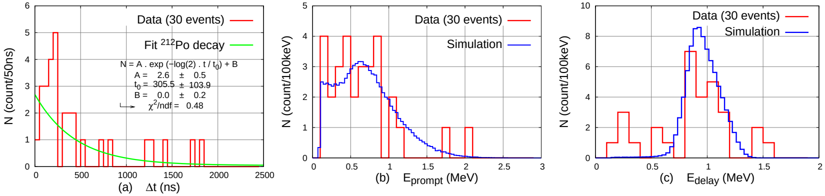
BiPo1 e^-/α Discrimination

- Longer half-life scintillation states excited by α particles but not by e^- because of much larger energy loss
- The signal tail is higher for α particles than e^-
- ^{241}Am / ^{207}Bi runs and aluminium calibrated to determine discrimination parameters: $\chi = \frac{q_{tail}}{Q_{total}}$
- Cut $\chi > 0.2$: 90% α saved and 85% e^- rejected



BiPo1 Backgrounds Measurements

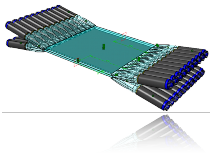
- Random coincidences: $\tau_{BiPo1} \sim 20$ mHz @ 150 keV
  - negligible for coincidences within 1 μs: ^{208}Tl @ 2 μBq/kg
  - e^-/α discrimination needed to reduce the rate of coincidences within 1 ms: ^{214}Bi @ 10 μBq/kg
- Scintillators ^{208}Tl background:
  - bulk: $\mathcal{A}(^{208}\text{Tl}) < 0.3$ μBq/kg (90 % C.L.)
  - surface: $\mathcal{A}(^{208}\text{Tl}) = 1.5 \pm 0.3\ (stat.) \pm 0.3\ (syst.)$ μBq/m^2

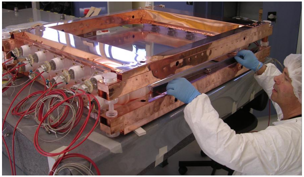


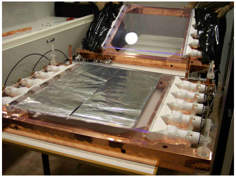
- Scintillators ^{214}Bi background:
  - dominated by radon background
  - solutions under test: radon protection film (EVOH), improvement of radon free air flushing system...

The BiPo2 Prototype

- More compact and sophisticated technique with spatial position reconstruction ($\sim$ 2 cm resolution) to significantly reduce background
- 2 polished scintillator plates 0.56 m^2:
  - 75x75x1 cm^3 Polystyrene scintillators [POPOP + pTp]
  - naked scintillators
  - PMMA light guides
  - side reflector in Teflon (0.2 mm)
  - 3" Hamamatsu R6091-MOD low background PMTs
- BiPo2 encountered several problems (calibration, acquisition...) from the beginning and it was long and difficult to solve $\rightarrow$ results coming soon

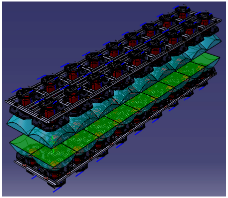
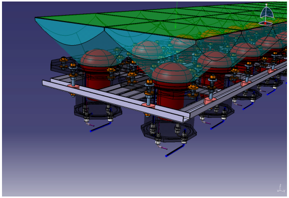
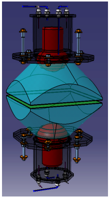
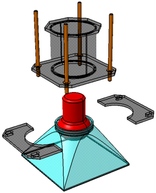






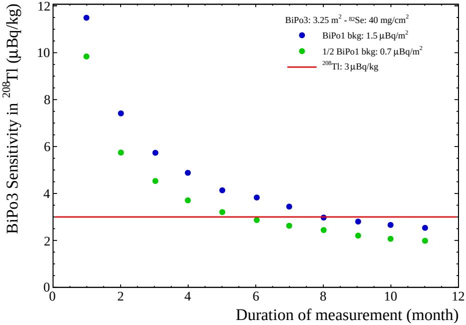
The BiPo3 Detector Design

- The BiPo3 detector of 3.24 m^2 can measure 1.3 kg of SuperNEMO ^{82}Se foil (40 mg/cm^2) with 6.5 % efficiency
- 2 identical modules of 2.7x0.6 m^2
- Each high radiopurity module consists of 18x2 light lines (total 72):
  - 300x300x2 mm^3 Polystyrene scintillators [POPOP + pTp]
  - entrance face aluminized with 200 nm of ultra pure aluminum
  - PMMA light guides
  - side reflector in Tyvek (0.2 mm)
  - 5" Hamamatsu R6594-MOD low background PMTs

The BiPo3 Detector Sensitivity

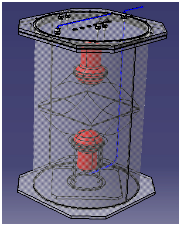
- The BiPo3 detector of 3.24 m^2 can measure 1.3 kg of SuperNEMO ^{82}Se foil (40 mg/cm^2) with 6.5 % efficiency
- We assume BiPo1 background from the scintillator surface: $\mathcal{A}(^{208}\text{Tl}) \sim 1.5\ \mu\text{Bq/m}^2$ (^{214}Bi is still unknown in BiPo1)
- Surface background reduced by factor 3 with the source
- BiPo3 sensitivity for SuperNEMO ^{82}Se sources is:
  - $\mathcal{A}(^{208}\text{Tl}) <$ 10 - 12 μBq/kg in 1 month
  - $\mathcal{A}(^{208}\text{Tl}) <$ 3 - 4 μBq/kg in 6 months

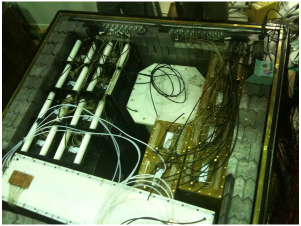


The BiPo3 Prototype

A new BiPo3 prototype in June 2010 with 2 light-lines to:

- validate improvements and new features compared to BiPo1
- decide the thickness of the scintillators (counting rate)
- test cross-talks and LED calibration
- check again the backgrounds





After 43 days of data [preliminary]:

- no ^{212}BiPo (^{208}Tl) event observed: $\mathcal{A}(^{208}\text{Tl}) < 10\ \mu\text{Bq/m}^2$
- radon background comparable with BiPo1
  (no improvement made for this prototype before BiPo1 results)

Summary

- NEMO3 data and HPGe measurements of 2β sources show a small tension in ^{208}Tl
  $\rightarrow$ the BiPo detector should remeasure these sources
- The BiPo1 prototype validated the technique a gave very good results [doi:10.1016/j.nima.2010.07.037]
- The BiPo2 prototype running was problematic from the beginning
- The BiPo3 prototype is helping us to finalize BiPo3 design
- The BiPo3 detector should be running before summer 2011 with sensitivity for SuperNEMO ^{82}Se sources:
  - $\mathcal{A}(^{208}\text{Tl}) < 10$ - 12 μBq/kg in 1 month
  - $\mathcal{A}(^{208}\text{Tl}) < 3$ - 4 μBq/kg in 6 months