Low background techniques in SuperNEMO for the radon

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LRT2010, 28-29th of August at SNOLAB, Canada

Outline

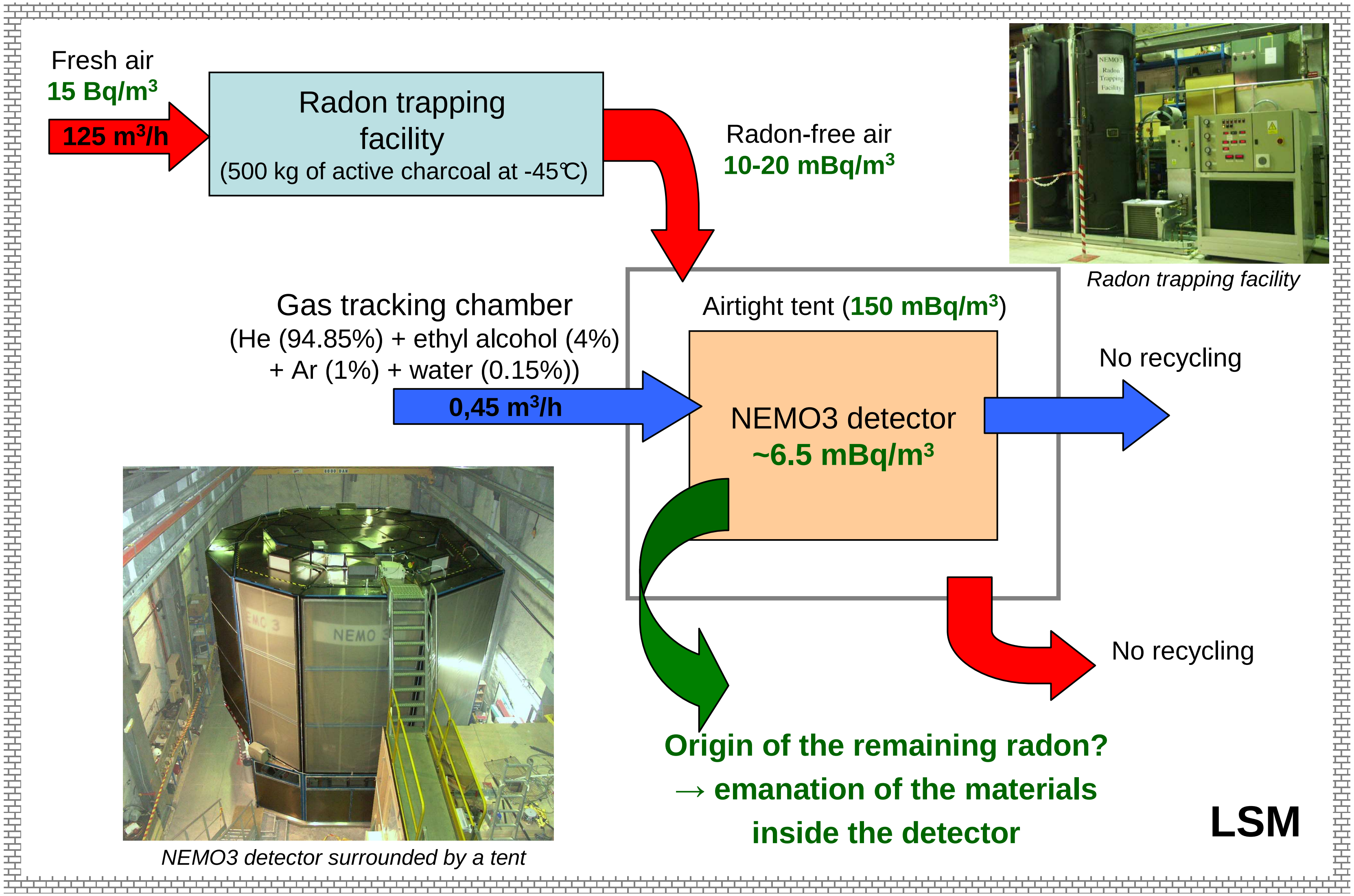
- Status of the radon background in NEMO3
- New radiopurity requirements for SuperNEMO
- Status of radon R&D for SuperNEMO

Radon in NEMO-3

- 2003: start of the NEMO3 detector at LSM (A_{radon}~38 mBq/m³)
- 2004: installation of an anti-radon facility (A_{radon}~6.5 mBq/m³)

} gain of a factor 6

NEMO Collaboration, NIM A 606 (2009), p449-465

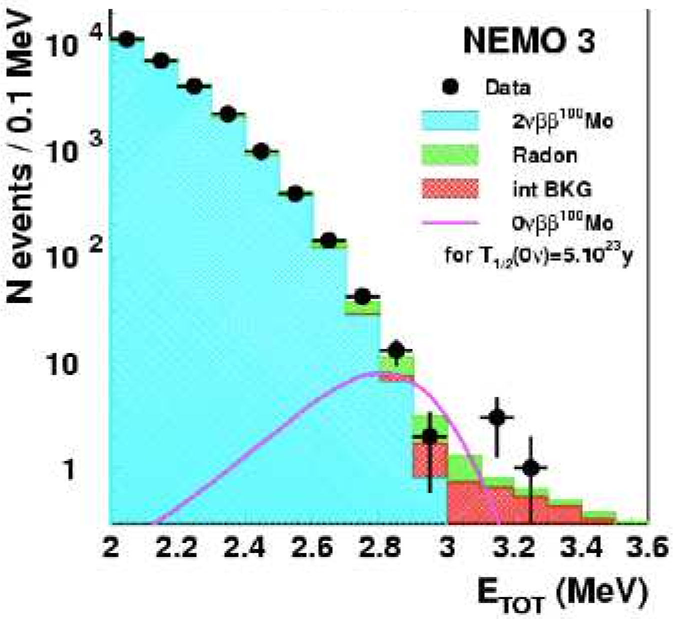


Radon trapping facility

NEMO3 detector surrounded by a tent

$\beta\beta0\nu$ results for ^{100}Mo and ^{82}Se

^{100}Mo (6.9kg, 4.5y)

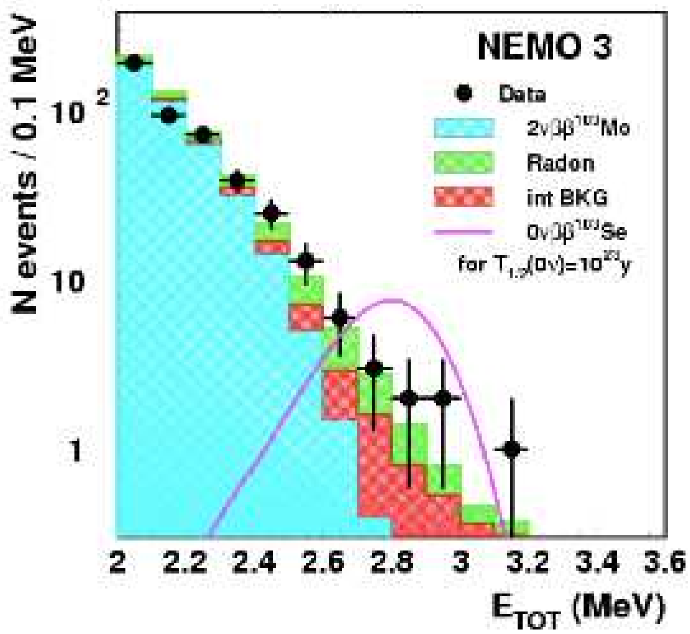


[2.8-3.2] MeV: DATA = 18; MC = 16.4±1.4

$T_{1/2}(0\nu) > 1.0\times10^{24}$ y at 90%CL

$<m_\nu> < (0.47 - 0.96)$ eV *

^{82}Se (0.9kg, 4.5y)



[2.6-3.2] MeV: DATA = 14; MC = 10.9±1.3

$T_{1/2}(0\nu) > 3.2\times10^{23}$ y at 90%CL

$<m_\nu> < (0.94 - 2.5)$ eV *

**Using NME from Kortelainen, Suhonen (2007), Simkovic (2008), Rodin (2007), Caurier (2008)*

Three background components:

→ events from $\beta\beta2\nu$

→ events from the radon in the gas

→ events from ^{214}Bi and ^{208}Tl in the $\beta\beta$ foil

From NEMO-3 to SuperNEMO

NEMO-3	R&D since 2006 →	SuperNEMO
^{100}Mo	Isotope	^{82}Se (or ^{150}Nd or ^{48}Ca)
7kg	Mass	100+ kg
A(^{208}Tl) < 20 μBq/kg A(^{214}Bi) < 300 μBq/kg	Radiopurity of the ββ foil	A(^{208}Tl) < 2 μBq/kg A(^{214}Bi) < 10 μBq/kg
Rn: ~5-6 mBq/m^3	Radon in the tracker	Rn ≤ 0.1 mBq/m^3
18%	Efficiency	~ 30%
8% @ 3 MeV	Calorimeter energy resolution (FWHM)	4% @ 3 MeV
$T_{1/2}$ > 2·10^{24} y **$\langle m_\nu \rangle$ < 0.3 - 0.9 eV ***	**Sensitivity**	**$T_{1/2}$ > 1·10^{26} y** **$\langle m_\nu \rangle$ < 0.04 - 0.11 eV ***

**Using NME from Kortelainen, Suhonen (2007), Simkovic (2008), Rodin (2007), Caurier (2008)*

- Radiopurity of the ββ foil in ^{214}Bi/^{208}Tl : development of the BiPo detector (see Mathieu Bongrand's talk)
- Radiopurity of the gas in ^{222}Rn/^{220}Rn : R&D in progress (this talk)

SuperNEMO Design

Collaboration: France, England, Russia, Czech Republic, USA, Japan, Slovakia, Spain

20 modules, each containing:

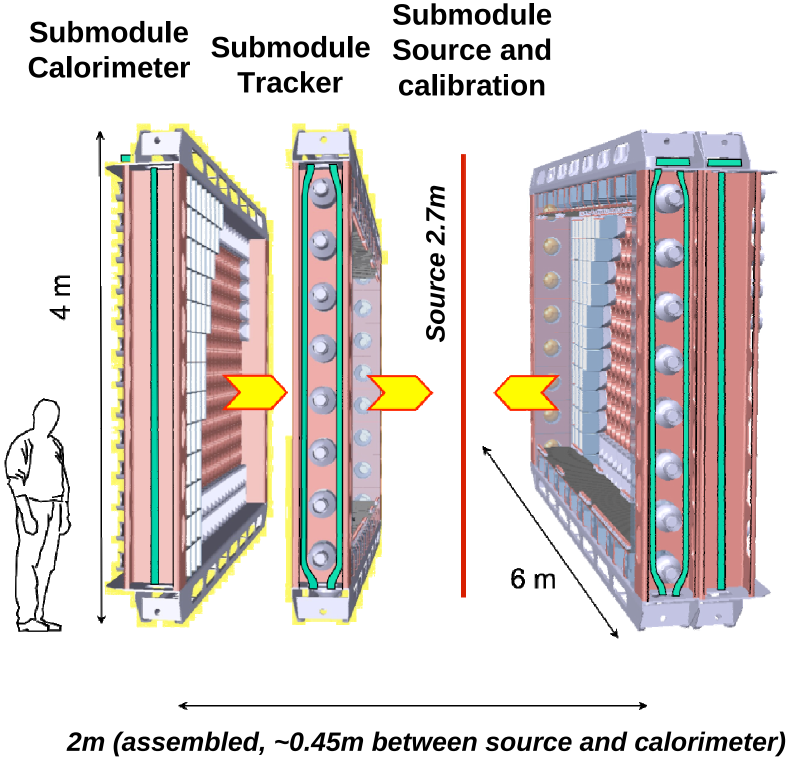
Source
- 40 mg/cm^2, 4 x 2.7 m^2 $\rightarrow$ ~5 kg per module
- ^{82}Se first choice: high $Q_{\beta\beta}$, long $T_{1/2}(2\nu)$, proven enrichment technology
- ^{150}Nd and ^{48}Ca under consideration

Tracking:
Drift chamber ~2000 cells in Geiger mode

Calorimeter:
550 PMTs + scintillator blocks

Modules surrounded by water passive shielding

Planar Geometry



2013: running of the SuperNEMO demonstrator with 7kg of ^{82}Se

Sensitivity in 2 years: $T_{1/2} > 6.5 \cdot 10^{24}$ yr (90% C.L.)

Radon R&D for SuperNEMO

Goal : A(^{222}Rn) < 0.1 mBq/m^3 in the tracking chamber

Main sources of the radon background:

- Emanation from the materials inside the detector
- Diffusion of the radon coming from outside the detector
- Radiopurity of the gas tracking chamber

Possible solutions :

- Emanation measurements of some crucial materials that will be installed inside the detector (glass from PMT, wires…)
- Isolation of the tracking chamber from the calorimeter part using thin foils with low radon diffusion coefficient
- Increase of the gas flow by a factor up to 10 to lower the radon level in the tracking chamber → recycling of the gas
- Purification of the gas before entering the tracking chamber
- Development of radon detectors sensitive to ~0.1 mBq/m^3

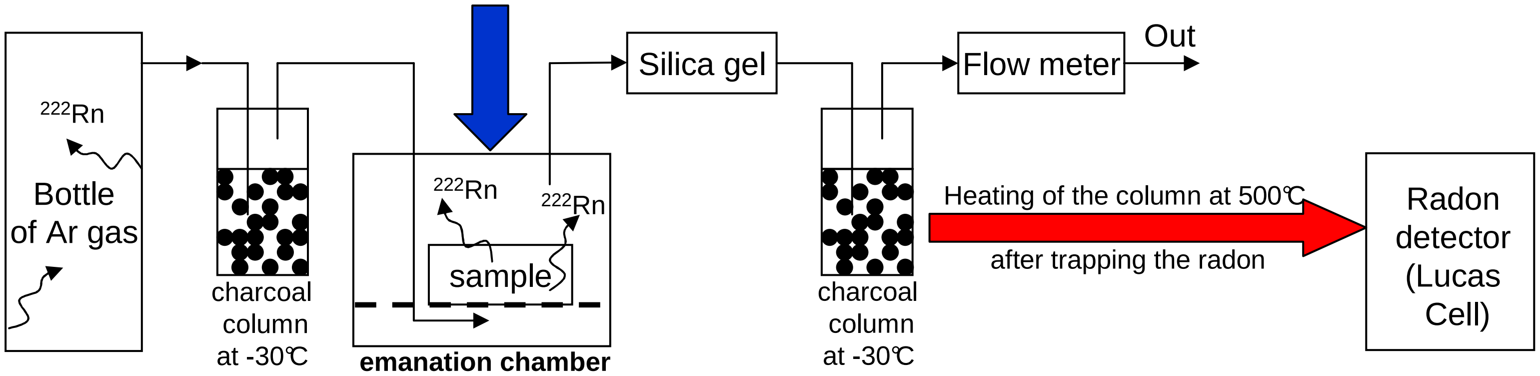
Radon emanation measurements

NEMO-3: no separation between calorimeter and tracking chamber
→ radon emanation from calorimeter components (PMT glass, mylar…)

SuperNEMO:
First step: best radiopurity of the PMT glass in ^{214}Bi (^{222}Rn) and ^{208}Tl (^{220}Rn)
→ low background Ge measurements at LSM

PMT glass	A(^{214}Bi) (Bq/kg)	A(^{208}Tl) (Bq/kg)
NEMO-3	~0.8	~0.04
Target for SuperNEMO	0.04	0.003
First results with glass from Hamamatsu	0.12	0.06

Second step: emanation measurement of a whole PMT
→ setup dedicated to emanation measurements in Bq.s^{-1}

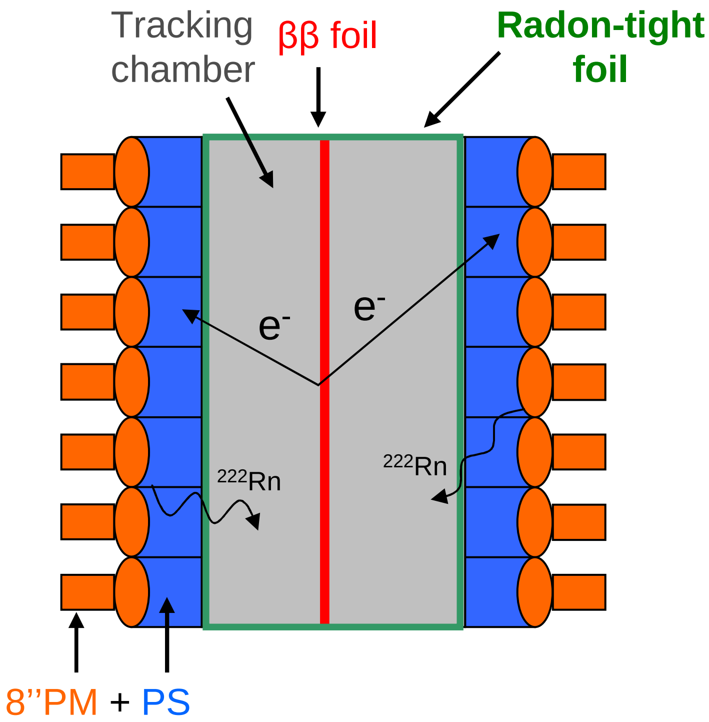


- Radon transfer efficiency to the detector: ~99.5%
- Minimum measurable exhalation rate E of radon: ~5.10^{-9} Bq.s^{-1}
- Future plan: reduction by a factor ~5 of the radon exhalation rate of the emanation chamber

First result: emanation measurement of a R6594 Hamamatsu PMT (like those used in NEMO3)
$E_{exp}=(5.7 \pm 2.1)\cdot 10^{-7}$ Bq.s^{-1} → 0.3 atom.s^{-1}

→ ready to measure and select future components of the SuperNEMO demonstrator

Isolation of the tracking chamber

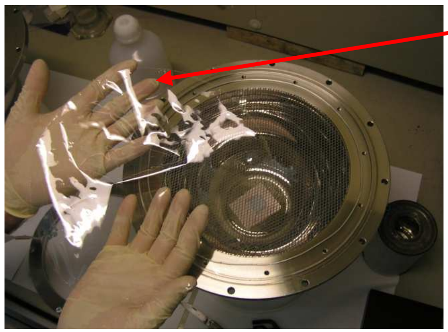


- Goal: to remove the possible diffusion of the radon from the calorimeter to the tracking chamber

- Requirements for the airtight foil:
  - very good radiopurity in ^{214}Bi and ^{208}Tl
  - low diffusion coefficient for radon
  - very thin foil to minimize the electron energy loss and to keep a good energy resolution

- R&D: development of a sensitive set-up to measure the diffusion coefficient for various kind of foils

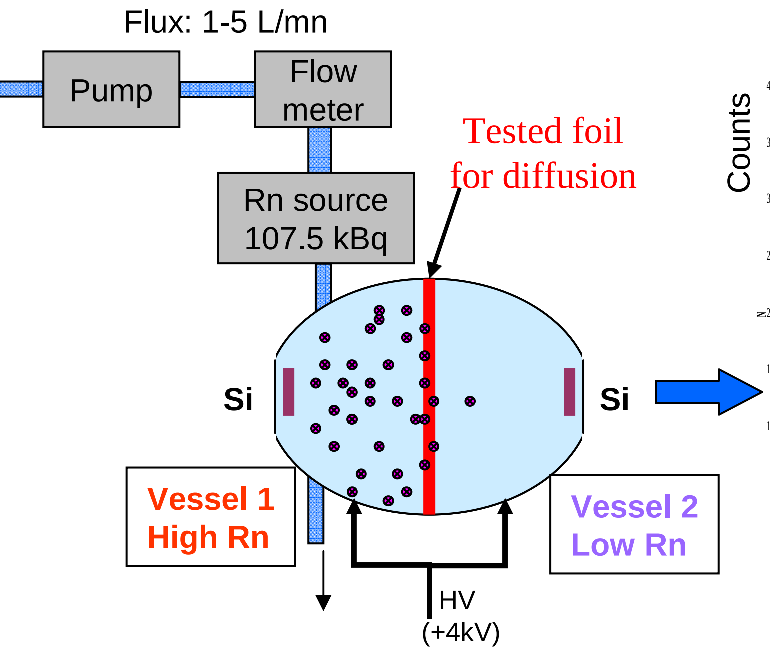
First test on energy resolution with a foil of EVOH (ethylene vinyl alcohol used for food)



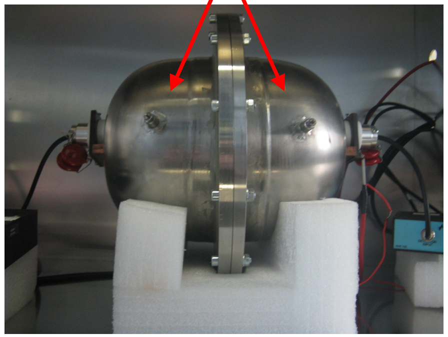
8''PMT + Plastic scintillator +	No EVOH	EVOH (15 µm)	EVOH (20 µm)	EVOH (25 µm)
Energy resolution FWHM at 1 MeV (%)	8.5 ± 0.1	8.7 ± 0.1	8.8 ± 0.1	8.7 ± 0.1

→ small effect on energy resolution (no difference between 15 and 25µm)

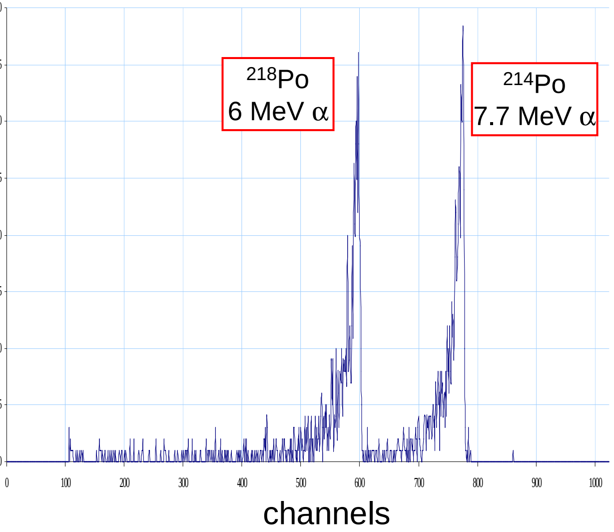
Setup for the radon diffusion measurements



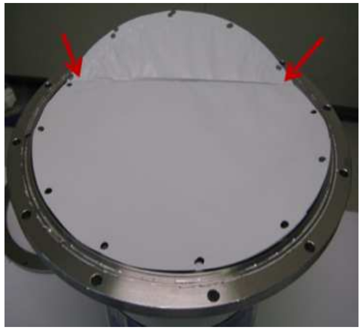
V=2.8L for each vessel



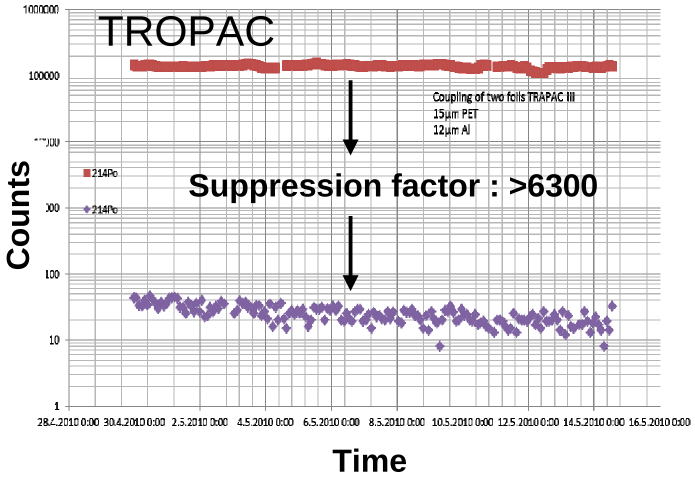
Background: ~7-8 counts/day



Preliminary results : foils of mylar, EVOH or TROPAC



TROPAC coupling foil (15 mm PET, 12 mm Al, 75 mm HDPE+LDPE)



Material	Thickness d (µm)	Diff. coefficient D (10^{-12} $m^2 \cdot s^{-1}$)	Diff. length L (µm)
Glue RTV	1 000	795	19 473
EVOH	15	0.68	571
mylar	20	0.030	120
TROPAC junction	102	< 0.0051	< 50

Presence of holes: to be re-measured

Optimisation of the gas flow in SuperNEMO

Hypothesis:

- source of radon emanation inside the tracking chamber with a rate $\omega_{\text{emanation}}$ in Bq/m^3/s
- no radon in the gas

→ the volumic activity A_{in}^{eq} in Bq/m^3 at equilibrium in the tracking chamber is:

$$A_{in}^{eq} \approx \frac{\omega_{\text{emanation}}}{1/\tau_{\text{radon}} + \phi_{gas}/V}$$

τ_{radon}: lifetime of radon

ϕ_{gas}: gas flow

V: tracker volume

→ Increase of the gas flow will decrease the radon activity in the tracking chamber. Effective lifetime τ_{eff} of the radon is defined by:

$$\frac{1}{\tau_{\text{eff}}} = \frac{1}{\tau_{\text{radon}}} + \frac{\phi_{\text{gas}}}{V}$$

Expected gas flow for SuperNEMO: 1-5 m^3/h

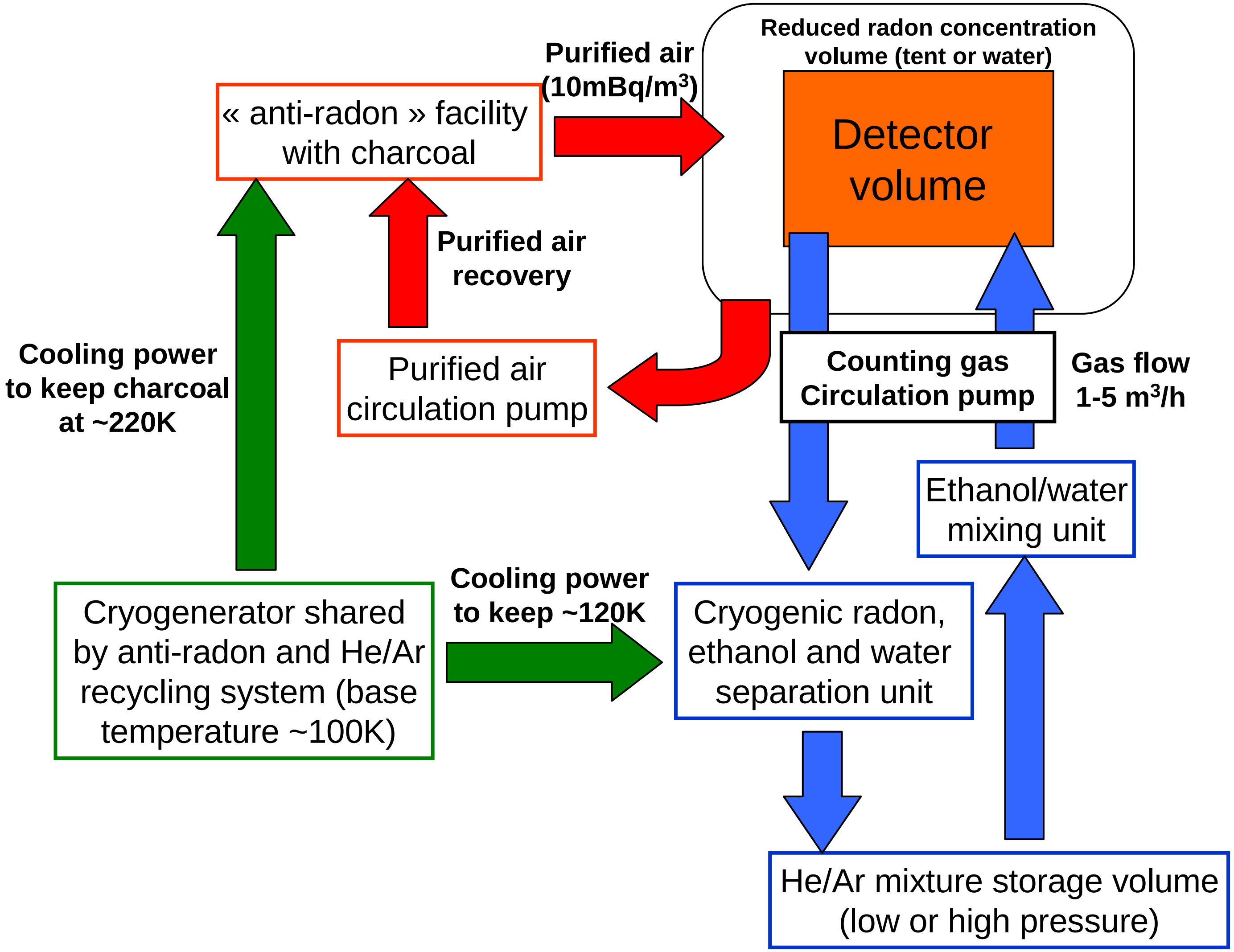
	Tracker volume (m^3)	**Gas flow (m^3/h)**	**Effective lifetime τ_{eff} (d)**
NEMO-3	28	0.45	1.76
SuperNEMO	~15	2	0.3

} Gain of a factor 6

Problem: a large gas flow requires gas recycling because of the cost of raw helium

Possible gas handling system design for SuperNEMO

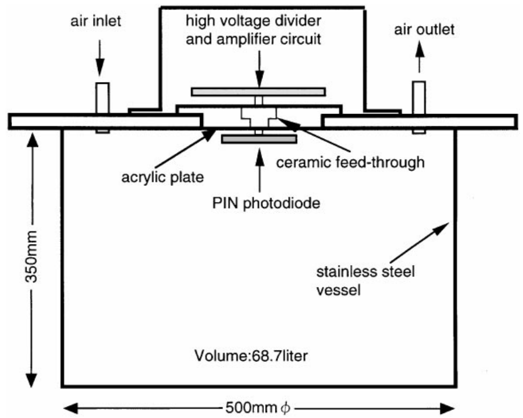
Composition of the gas: He (94.85%), Ar (1%), ethanol (4%), water (0.15%)



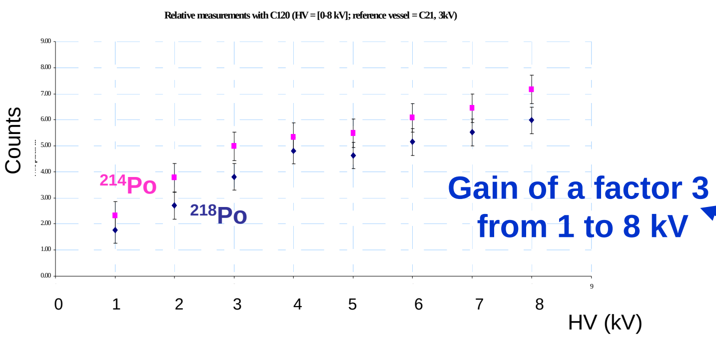
Improvement of the sensitivity of radon detectors

Goal: gas radiopurity measurement, emanation measurements of the internal materials…

Detectors used for monitoring the air surrounding NEMO3 :
- Electrostatic collection of the radon daughters on a Si PIN diode
- Volume: 70L
- Background: 1-2 counts/day
- Detection limit or sensitivity: ~1-2 mBq/m^3



→ need to improve the sensitivity by a factor 10 to be able to measure the radiopurity of the gas



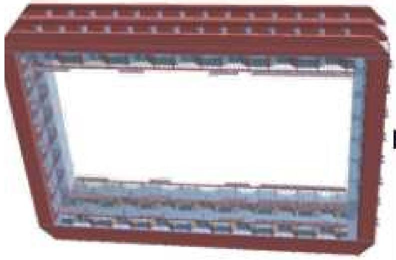
Better collection efficiency for hemispherical detector

Ideas to improve the sensitivity of this type of detectors:
- increase of the volume (70L to 200L at least)
- increase of the HV to improve the collection efficiency
- optimisation of the geometry of the detector
  - hemispherical rather than cylindrical shape
  - optimal size of the detector for Po ions collection
- improvement of ceramic and stainless steel radiopurity

→ R&D in progress

Development of a new concentration line

Filled with He or, perhaps better, N_2

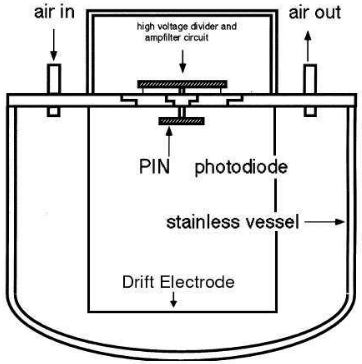


Tracker module

Cryopump

Radon concentration line
(like MoReX in Heidelberg)

Transfer line



Electrostatic detector

Radon concentration line

- ^{222}Rn and gas mix is pumped through an ultra-pure activated carbon trap – ^{222}Rn is adsorbed
- Once sample collection is complete, trap is evacuated at -196 ºC and then at -100 ºC to remove any trapped N_2
- Trap can then be heated and helium purged to transfer the more concentrated ^{222}Rn into a detector

→ design/construction in progress

Sensitivity expected

- V=4 m³ of concentrated gas
- Radon detector: background~20 counts/d (pessimistic) and efficiency~10% (idem)
- Sensitivity for 1 day measurement: A_{Rn}<0.23 mBq/m³ at 90% C.L.

→ very promising with better detector characteristics

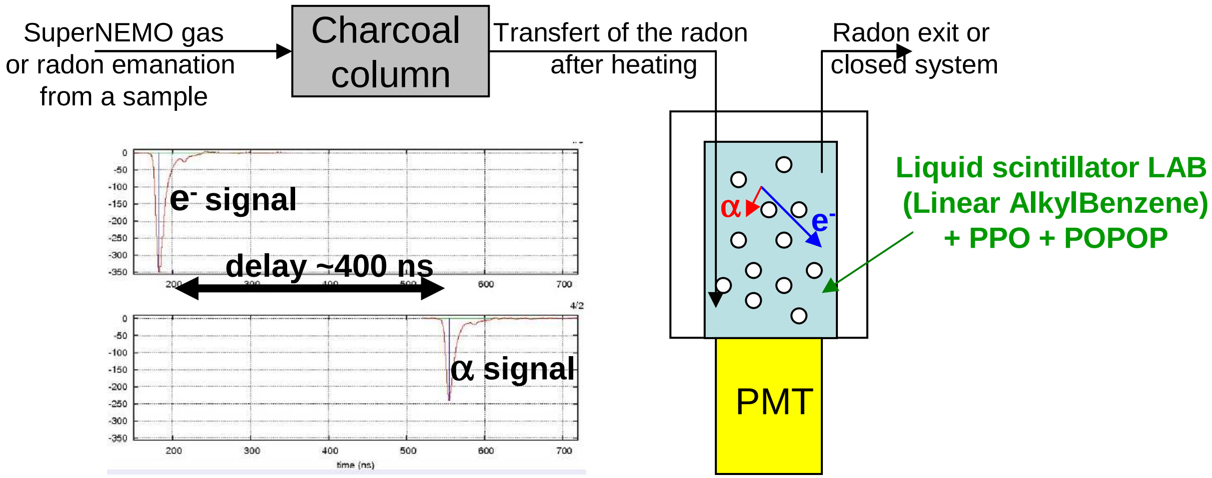
Measurements to be performed

- Radiopurity of different components of the gas: He, Ar, He+Ar mix, He+Ar+Alcohol…
- Emanation measurements of the tracker sub-modules and of other components for SuperNEMO

Development of a new sensitive radon detector

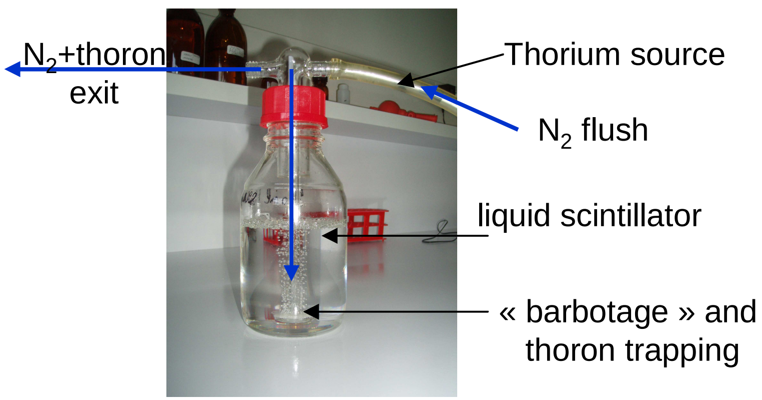
Principle: to trap the radon/thoron in liquid scintillator and to measure the e-α BiPo coincidence

Basic setup :

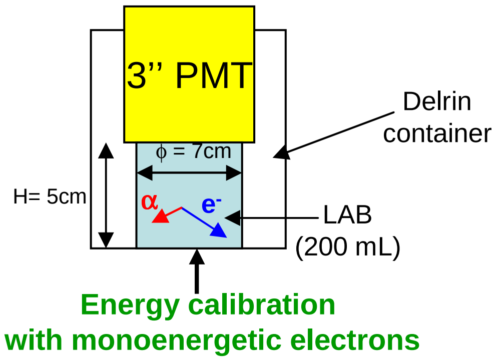


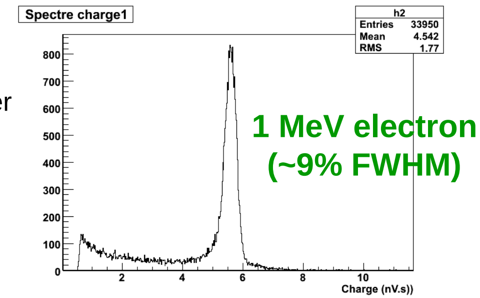
First tests with a thoron source

1st step : trapping the thoron



2nd step : measuring the BiPo events

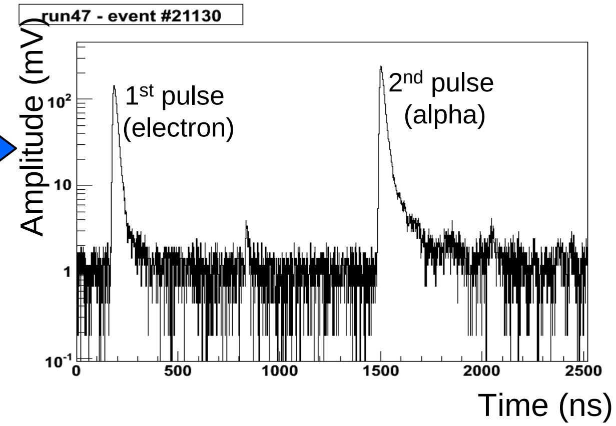




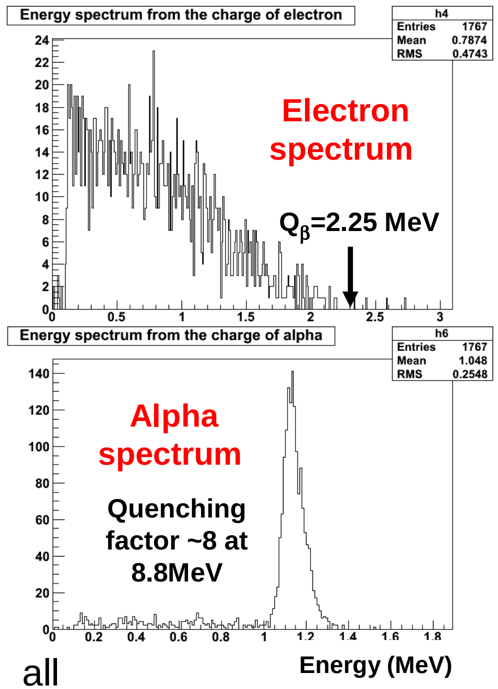
Development of a new sensitive radon detector

Basic conditions to select a ^{212}Bi-Po event coming from thoron:

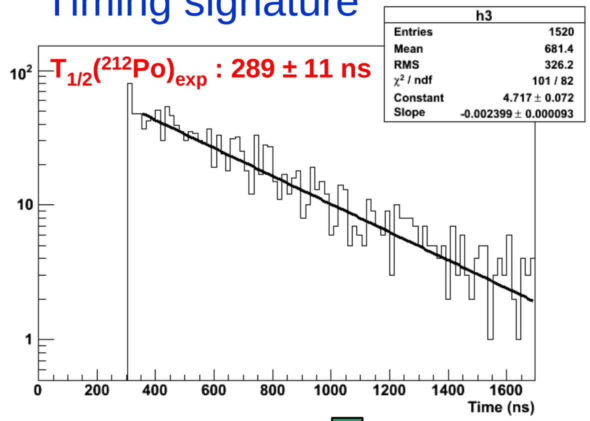
- 2 pulses are required in the 2.5 µs window of the MATACQ board
- energy of the electron (1st pulse) between 0.1 and 2.25 MeV (Q_β)



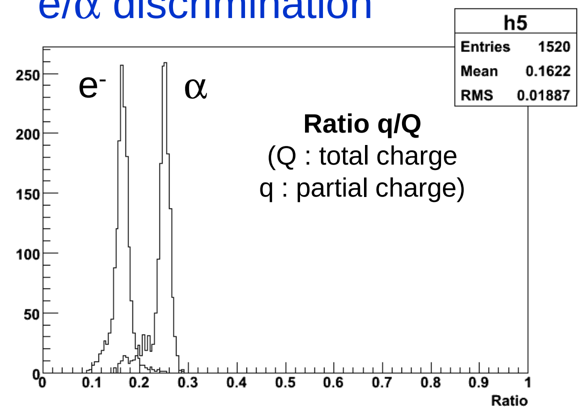
Energy signature



Timing signature



e/α discrimination



- Very good background rejection with all these selection criteria
- 1st background measurement (~3 days): only 1 « thoron » event kept among 7.5 10^6 raw events (single counting rate : ~30 Hz at Bordeaux with no lead shielding)

- Need to measure the trapping efficiency of the setup
- Need to adapt the MATACQ board for the ^{222}Rn measurement (time window of 500 µs for the delayed event)

Conclusions

- Knowledge from NEMO-3 : radon is one of the background components that limits the sensitivity of the detector
- A reduction factor of 50 (~0.1 mBq/m^3) of the gas radiopurity in the tracking chamber has to be reached for SuperNEMO
- Radon R&D is shared in different directions
  - Radon emanations measurements with existing setup
  - Radon diffusion measurements of thin airtight foils to isolate the tracking chamber
  - Development of a new radon concentration line in connexion with new radon detectors designed to be sensitive to 0.1 mBq/m^3
  - Design/development of a gas handling system for SuperNEMO

→ Radon R&D in progress in order to reach the radon level for the SuperNEMO demonstrator in 2013