Status of SuperNEMO Demonstrator

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On behalf of the SuperNEMO collaboration

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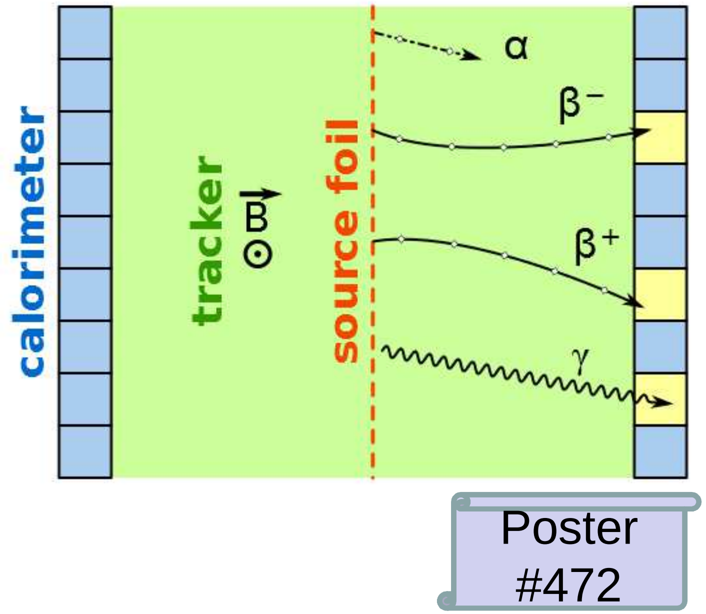
Outline

- The SuperNEMO experiment with the Tracker-Calorimeter technique
- Radiopurity strategies to achieve a « 0-background » Demonstrator module
- Status of the SuperNEMO Demonstrator construction & integration
- Conclusion

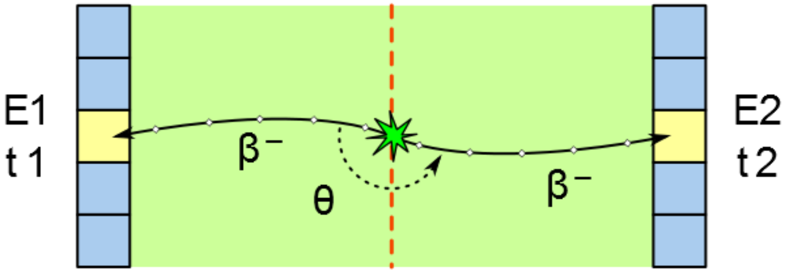
The SuperNEMO experiment with the Tracker-Calorimeter technique

The Tracker-Calorimeter technique

Particle identification



ββ event



- ✓ Choice of the ββ isotopes (source ≠ detector)
- ✓ Full topological event reconstruction (vertex, energy, TOF) including α-particle, $e^{\pm}$ and γ-ray identification

→ Strong background suppression

→ Ability to disentangle different mechanisms for ββ0ν by looking at several observables (E_1, E_2, E_1+E_2, cos(θ), γ's for decay to excited states)

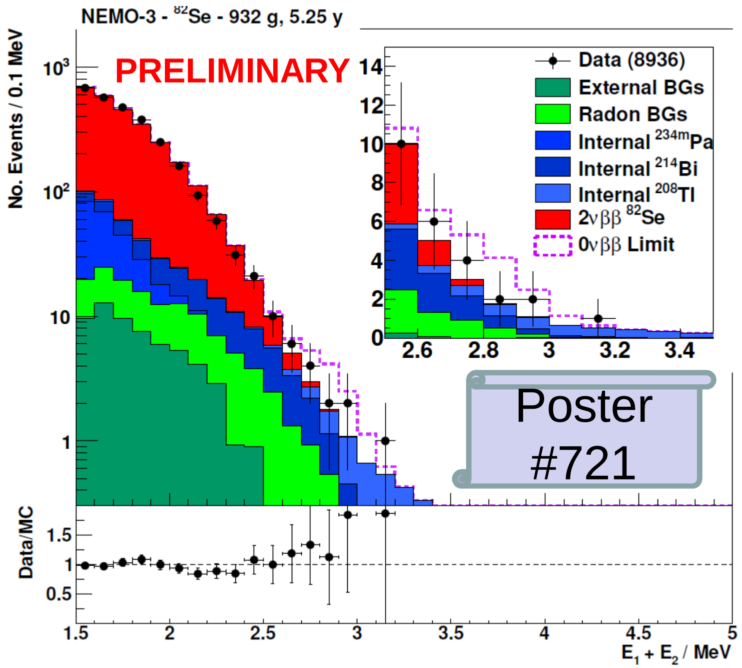
- ✓ Poorer efficiency and energy resolution compared to pure calorimeter techniques

From NEMO-3 to SuperNEMO

	NEMO-3	SuperNEMO
Mass	6.9 kg	100 kg
Main ββ isotope	^{100}Mo	^{82}Se
Other ββ isotopes	*^{82}Se, ^{130}Te, ^{116}Cd, ^{150}Nd, ^{96}Zr, ^{48}Ca*	*^{150}Nd or ^{48}Ca ?*
Energy resolution FWHM @ 3 MeV	8%	4%
ββ sources radiopurity		
A(^{208}Tl)	~100 μBq/kg	<2 μBq/kg
A(^{214}Bi)	60 - 300 μBq/kg	<10 μBq/kg
Radon in Tracker		
A(^{222}Rn)	5.0 mBq/m^3	< 0.15 mBq/m^3
Total background		
cts.keV^{-1}.kg^{-1}.y^{-1}	1.3×10^{-3}	5.0×10^{-5}
Sensitivity (90% C.L.)		
$T_{1/2}^{0\nu}$	> 1.1×10^{24} y	**> 1.0×10^{26} y**
$<m_\nu>$	< 0.3 - 0.6 eV	**< 0.05 – 0.10 eV**

^{82}Se baseline and other possible isotopes

Final NEMO-3 results for ^{82}Se



$$T^{0\nu}_{1/2} > 2.5 \times 10^{23}\ \mathrm{y}\ (90\%\ \mathrm{C.L.})$$
$$\langle m_\nu \rangle < (1.2 - 3.0)\ \mathrm{eV}$$

with 7 times less mass and dirtier foils, only a factor 3 less sensitive than ^{100}Mo

- **^{82}Se** has $Q_{\beta\beta}$ = 3.0 MeV (above the 2.6 MeV γ-ray)
- Enrichment up to 98% of ^{82}Se
- High $T_{1/2}^{2\nu}$ ~10^{20} y (14 times higher than for ^{100}Mo)

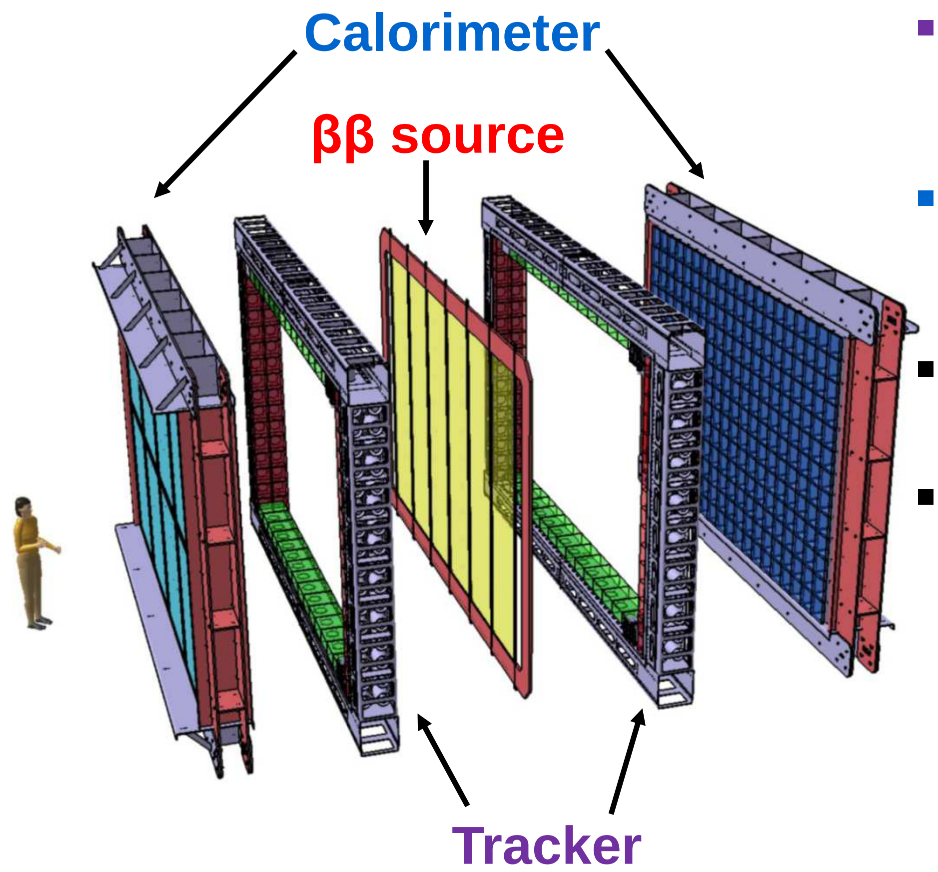
→ contribution of 2β2ν events in 2β0ν energy window strongly reduced

→ **baseline isotope for SuperNEMO**

- Other promising isotopes :
  - **^{150}Nd** ($Q_{\beta\beta}$=3.37 MeV) with a high phase space factor, even in 2β0ν decay to excited states
  - **^{48}Ca** ($Q_{\beta\beta}$=4.28 MeV)

SuperNEMO Demonstrator Module

Full SuperNEMO: 20 modules
First step: Demonstrator Module



- 7 kg of ^{82}Se in thin foils with e~250 μm (~50 mg/cm^2)
- 2034 Tracker Cells operating in Geiger mode
- 712 Calorimeter Modules with Polystyrene Scintillators + 8''(5'') PMTs
- Magnetic field for particle identification
- Passive shieldings (iron, water)

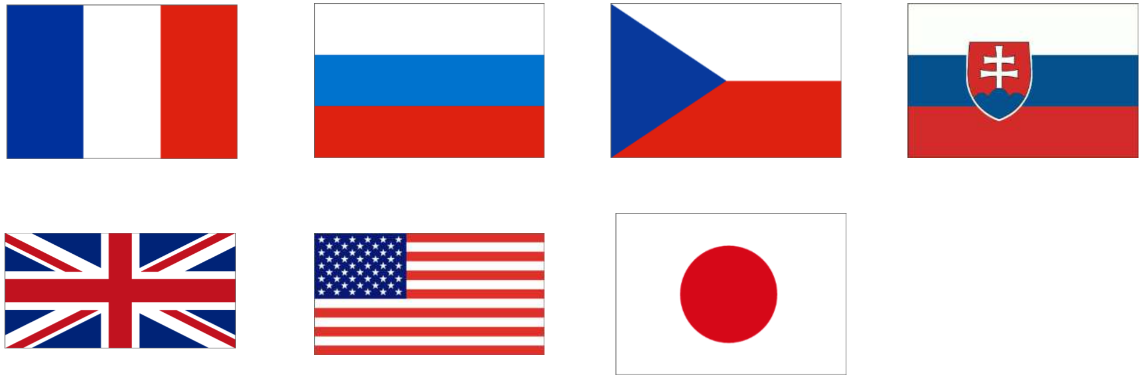
Expected sensitivity for a 17.5 kg·y exposure (90 % CL)

$T_{1/2} > 6.0 \times 10^{24}$ y

$<m_\nu> < 0.2 – 0.4$ eV

The SuperNEMO Collaboration

supernemo collaboration



Radiopurity strategies

Radiopurity strategies

- Goal : to reach a **« 0-background » level** for the Demonstrator module

- Strategies :

  ✓ Purification and measurement of the ^{82}Se ββ foil internal radiopurity at the **level of 2-10 µBq/kg**
  → development of the BiPo3 detector

  ✓ Selection of radiopure internal materials to reach **a Radon level of 150 µBq/m³** in the Tracker
  → development of several Radon facilities

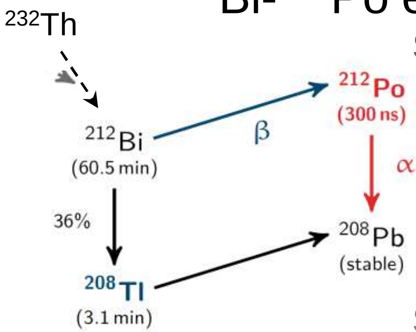
  ✓ Selection of radiopure surrounding materials
  → large screening process using low-background γ spectrometry with HPGe detectors

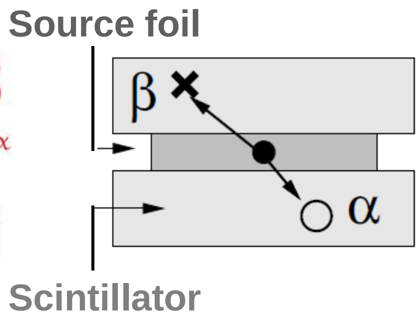
BiPo-3 detector

Goal : to measure ^{82}Se ββ foils at 2 μBq/kg (10 μBq/kg) level for ^{208}Tl (^{214}Bi)

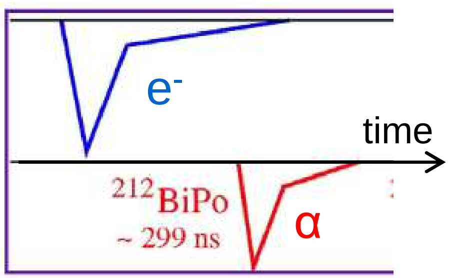
Principle : ^{82}Se foil placed between two PS scintillators + 5''PMTs

^{212}Bi-^{212}Po effect

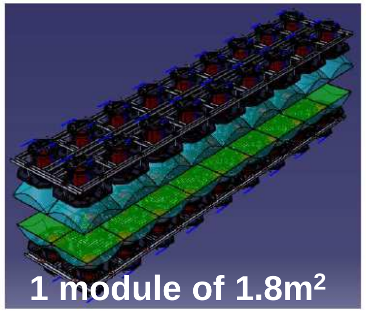


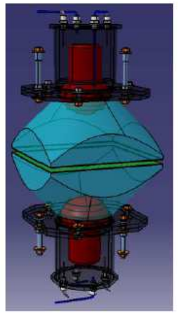


^{208}Tl measured by electron-alpha coincidence from ^{212}BiPo cascade with ΔT~300 ns

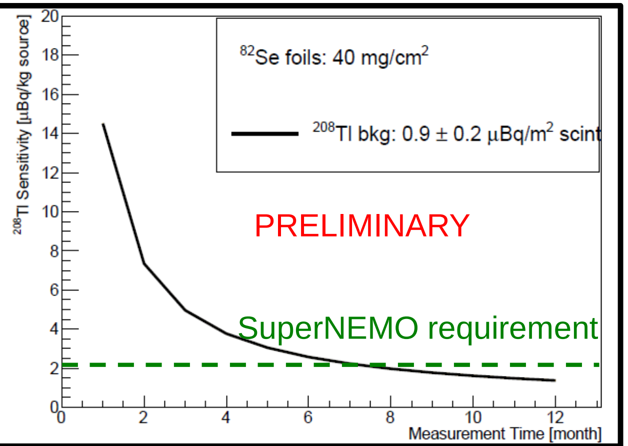


In operation in Canfranc lab. since 2013





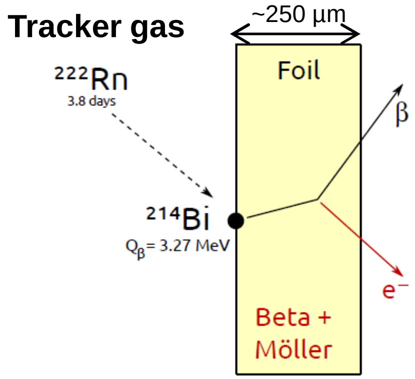
^{208}Tl sensitivity is achieved in 6-8 months for a 3.6 m² ββ foil



→ first ^{82}Se foils are under qualification with BiPo-3 detector

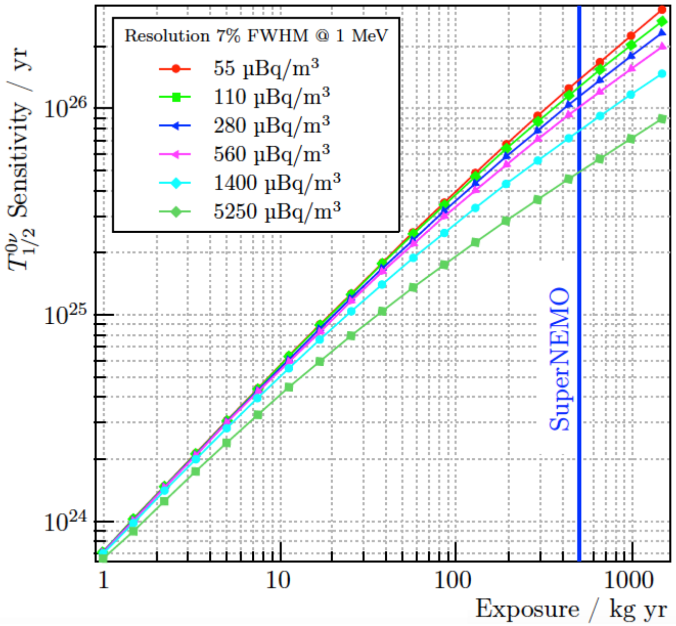
Radon Challenges

Goal : to reach 150 µBq/m³ in the tracker gas (i.e. 70 atoms of Rn/m³ !)



- **^{222}Rn** is a noble gas coming from ^{238}U chain with $T_{1/2}$ = 3.8 d
- If **^{222}Rn** is present in the tracker gas, its daughter nuclei can stick to the ββ foil leading to **^{214}Bi**-like internal contamination

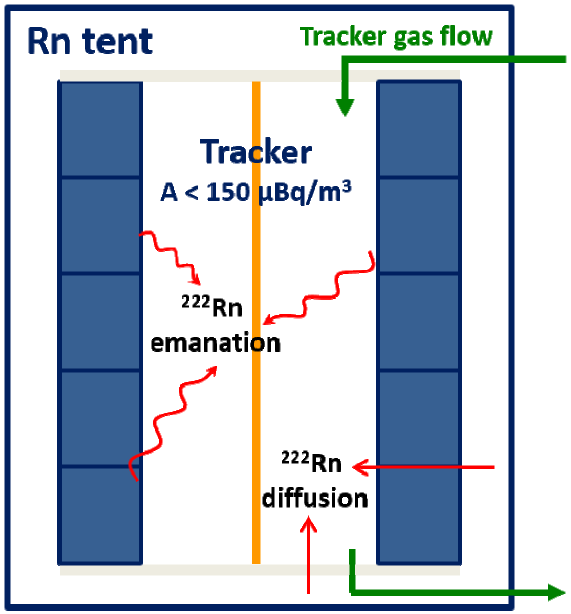
→ ^{214}Bi decay: emission of 2 electrons *via* several mechanisms



Sensitivity vs exposure
depending on ^{222}Rn contamination

Sources of ^{222}Rn contamination
in the Tracker gas

Poster #644



Strategies against Radon

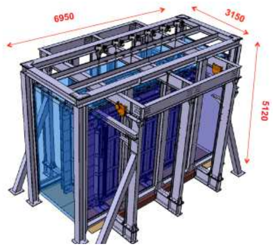
Radon emanation of critical materials

Large emanation facility with V~700L well-adapted to large volume or surface samples (films, PMTs…)

Small emanation facilities with V~3L well-adapted to smaller samples with a higher sensitivity

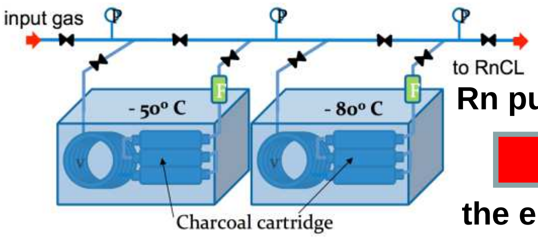
Radon diffusion in the Tracker

Rn diffusion facility to select ultra tight barriers (nylon film, sealing) to prevent Radon diffusion in the Tracker



Rn tent and 'Rn-free' air to prevent diffusion into the Demonstrator module from normal air in the lab.

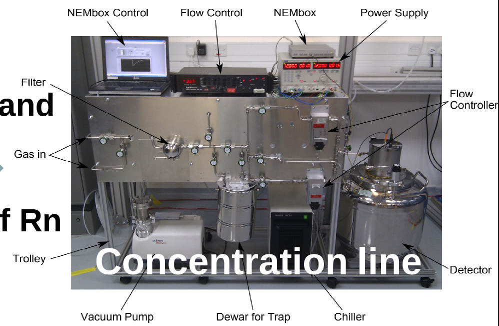
Radon Concentration Line to measure the final volumic activity in the Tracker



Rn trapping system

Rn purification of the entrance gas

Concentration and Measurement of Rn



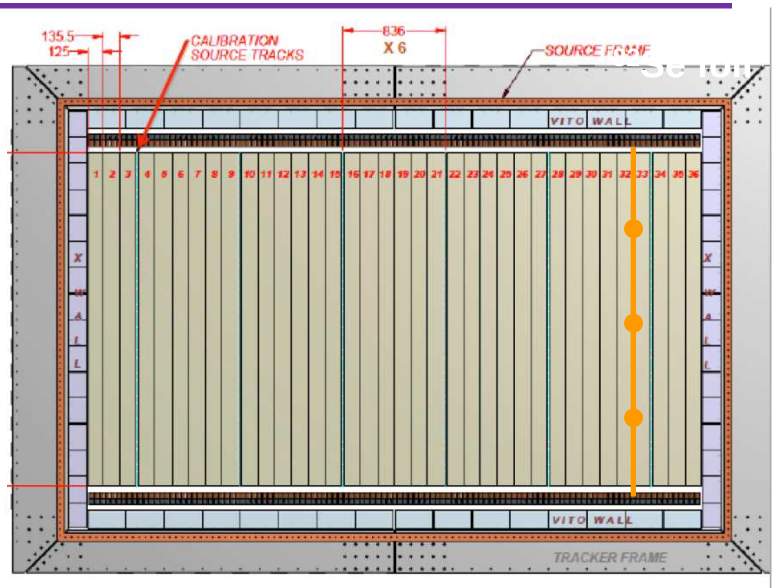
→ for 2 m³/h flow rate, the 150 µBq/m³ level is achievable !

Status of the
SuperNEMO Demonstrator
construction & integration

SuperNEMO ^{82}Se foils production

- 7 kg of ^{82}Se ββ source divided into 36 foils of 270 x 13.5(12.5) cm^2 with a 250 µm thickness
- 3 different ^{82}Se powder purification techniques have been used
- 11 foils among 36 (30% complete) already produced and under qualification with BiPo-3
- Other foils prepared in an ISO 6 clean room (1000 class room)

Poster #442

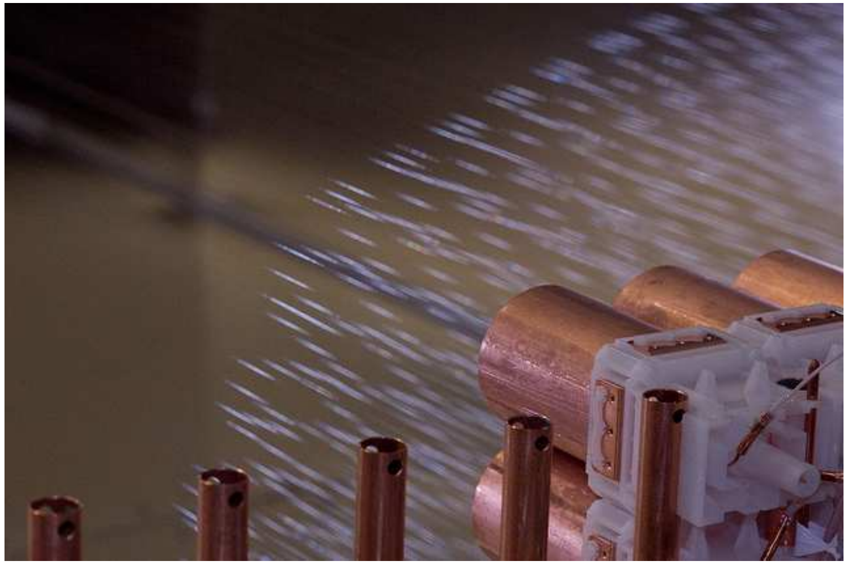


- Calibrations will be performed with radioactive sources at controlled positions thanks to an automatic deployement system

Poster #479

→ End of production and installation of the ^{82}Se foils planned for the end of 2016

SuperNEMO Tracker Construction

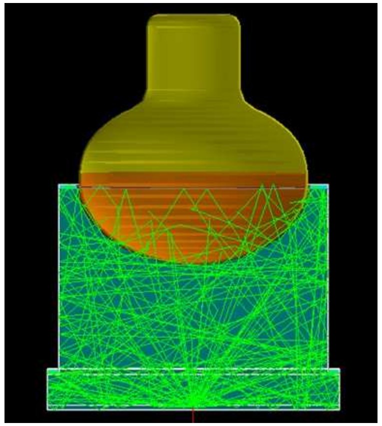


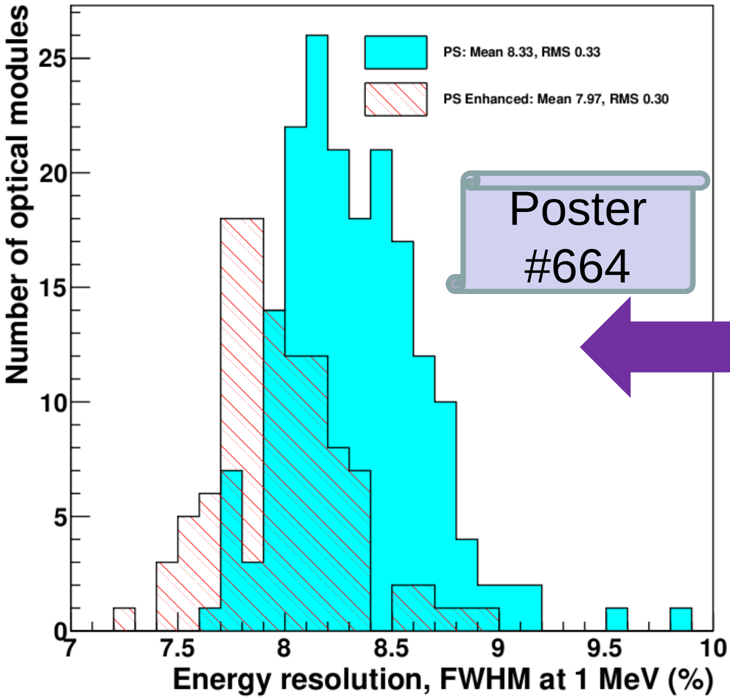
- Geiger-mode multi-wires drift chamber
- Robotic construction of 2034 drift cells containing approx. 15,000 wires
- Restricted set of materials : copper, steel, duracon
- Ultra-clean construction, assembly and testing conditions

→ 93% of the Tracker Cells is completed with only 1% rate of dead channels

→ full Tracker completed in autumn 2016

SuperNEMO Calorimeter Construction





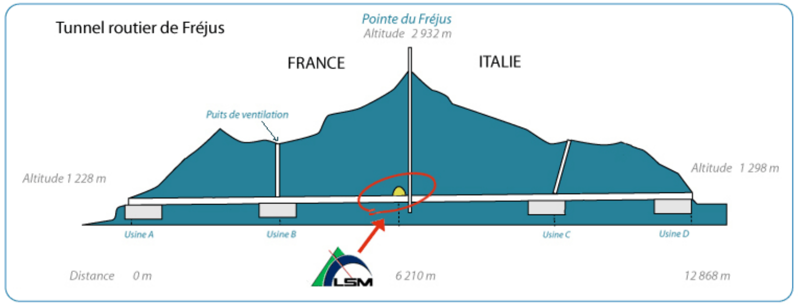
Poster #664

- 520 Calorimeter Modules
  - PS Scint.+ 8'' High QE Radiopure PMTs
  - **<FWHM> = 8.0-8.3% @ 1 MeV**
  - Time resolution of 400 ps @ 1 MeV
- Calibration systems to maintain energy stability better than 1%
- Validation with detailed optical simulations

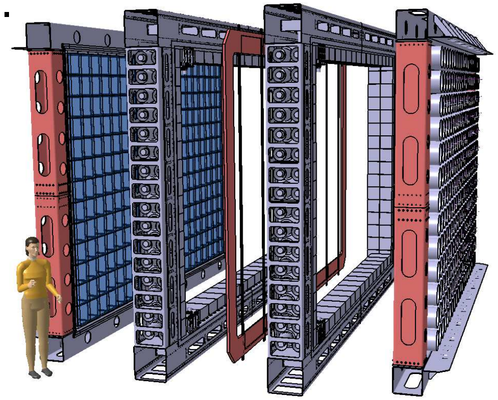
Poster #449

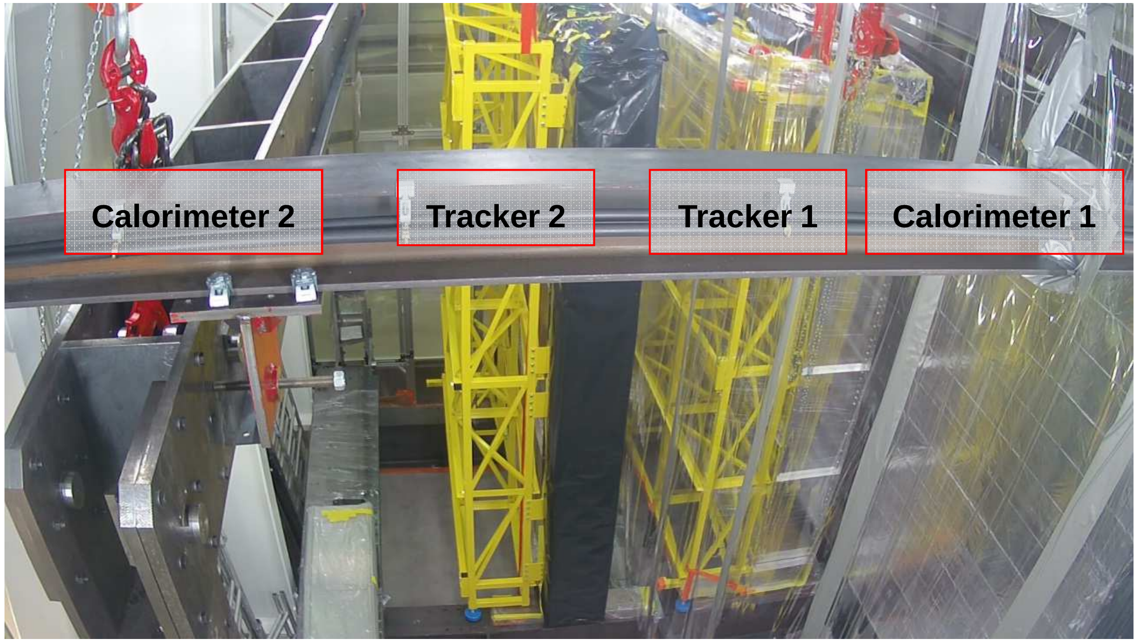
→ **Calorimeter completed and delivered in July!**

SuperNEMO Integration @ Fréjus (LSM)



- More than ½ detector installed at Modane Underground Lab. (LSM, Fréjus, 4800 m.w.e.)
- Remaining sub-detectors delivered in 2016
- **Commissionning of ½ Demonstrator Module starts in autumn 2016 !**





Conclusion

- SuperNEMO is an experiment using the tracking calorimeter technique, very powerful to identify and reject the backgrounds for ββ studies
- A first Demonstrator Module is in construction with 7 kg of ^{82}Se with an expected sensitivity of $\langle m_\nu \rangle < 0.2 – 0.4$ eV with a 17.5 kg·y exposure
- Several strategies have been successfully initiated to reach a « zero-background » level:
  - BiPo-3 Detector able to measure the ^{208}Tl at the level of 2 µBq/kg
  - Radon facilities developed to reduce the Radon contamination in the Tracker and to measure it at the level of 150 µBq/m^3
- Status of SuperNEMO Demonstrator :
  - All production will be completed in 2016
  - Integration under progress
  - Early commissionning of ½ detector by the end of 2016
  - First ββ events expected in 2017

Poster session

Saturday 6th August at 6:00 PM

- Poster #479 : Radioactive source deployment system for the calibration of the SuperNEMO detector – R. Salazar, J. Bryant

Monday 8th August at 6:30 PM

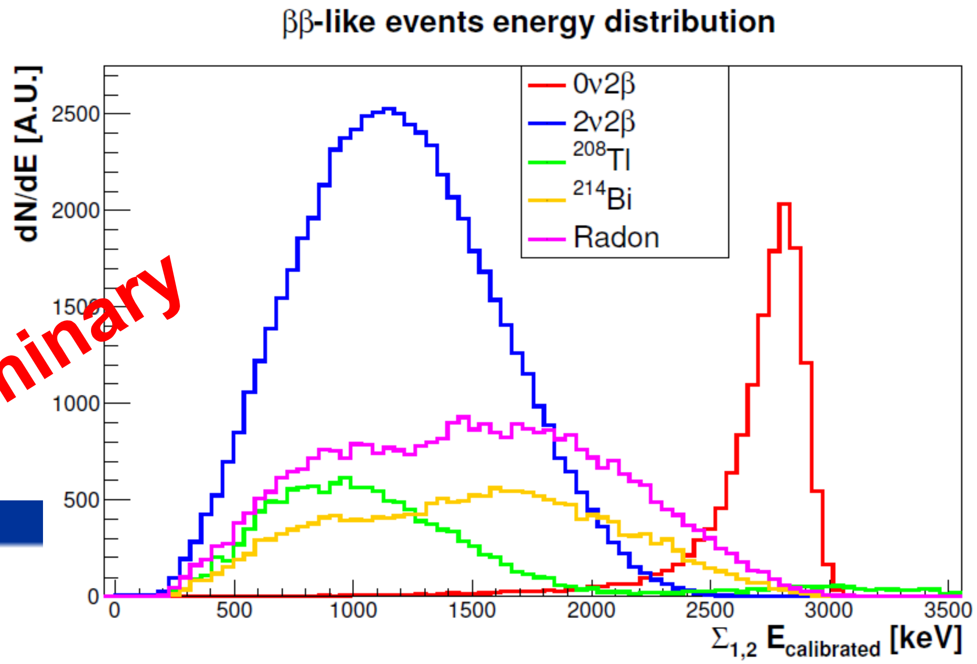
- Poster #442 : The SuperNEMO ββ source production – A. Jérémie, A. Remoto
- Poster #449 : The SuperNEMO Light Injection & Monitoring System – Th. Le Noblet, J. Cesar, R. Salazar
- Poster #472 : Gamma-tracking and sensitivity to gamma-emitting backgrounds in SuperNEMO – S. Calvez
- Poster #644 : Sensitivity to Radon induced background in SuperNEMO – Th. Le Noblet, A. Remoto
- Poster #664 : The SuperNEMO Calorimeter – Ch. Marquet, C. Cerna

Thank you for your attention

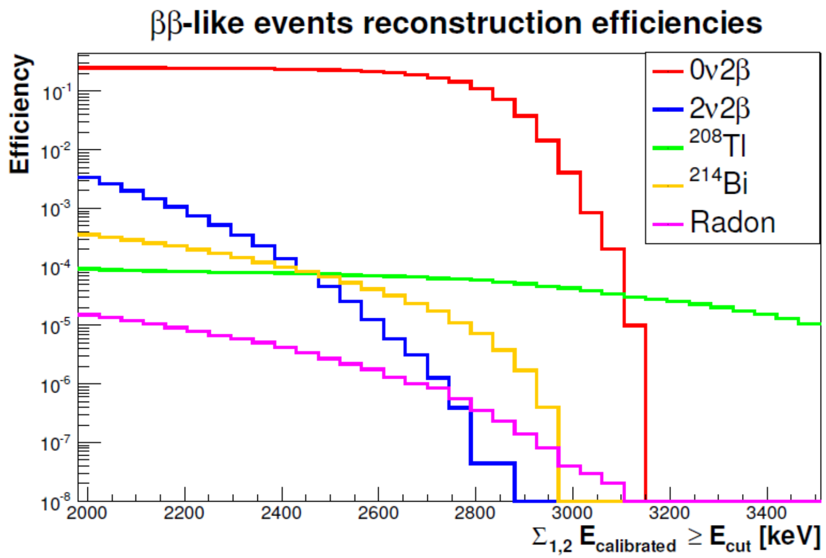
Backup slides

Demonstrator sensitivity and Rn studies

Simulations of ββ decays and main backgrounds : Rn, ^{208}Tl and ^{214}Bi internal



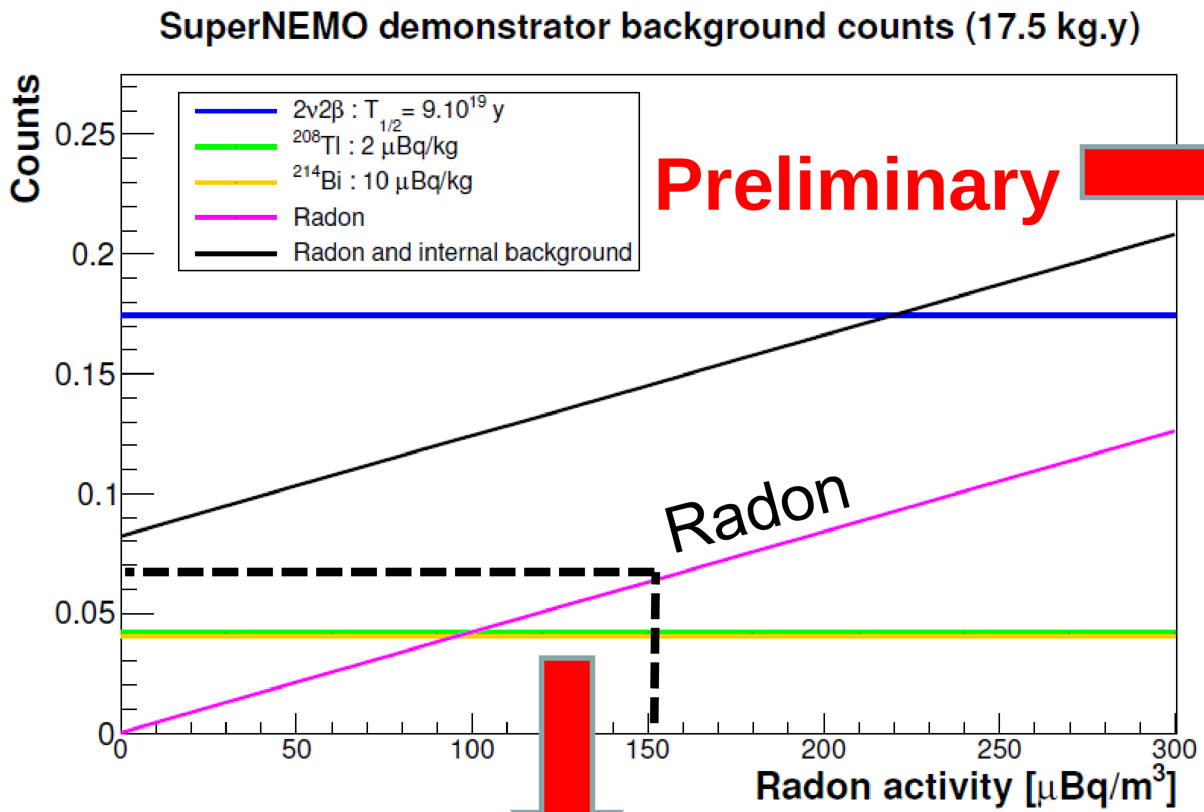
Efficiencies after combined cuts



ββ0ν efficiency ~ 25%

Demonstrator sensitivity and Rn studies

For 2.8 MeV $\leq$ E $\leq$ 3.2 MeV :



$2\beta2\nu$	0.175 count
^{222}Rn	0.070 count
^{208}Tl	0.040 count
^{214}Bi	0.040 count
Total	0.325 count

$4.6.10^{-5}$ cts/kev/kg/y

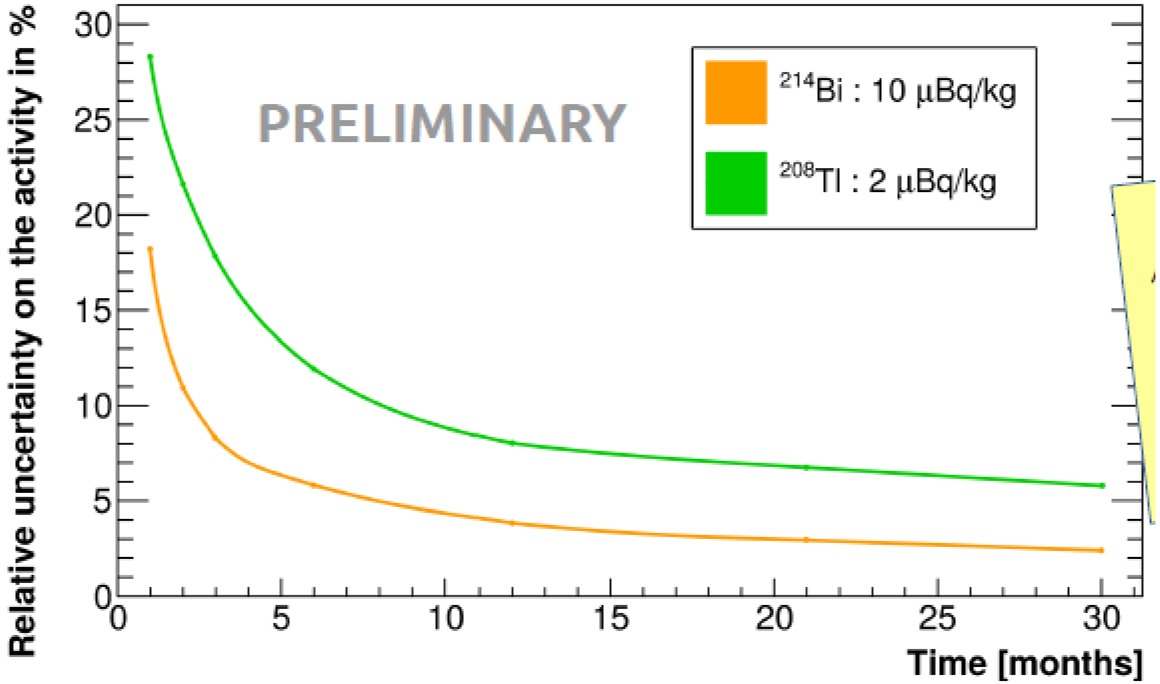
~50% from $2\beta2\nu$
~50% from ^{222}Rn + internal contaminations

Ability to measure its own background

With combined 1e1g and 1e2g channels and gamma-tracking:

- ^{208}Tl: activity measured with 10% of uncertainty in 8 months
- ^{214}Bi: activity measured with 10% of uncertainty in 2 months

Poster #472

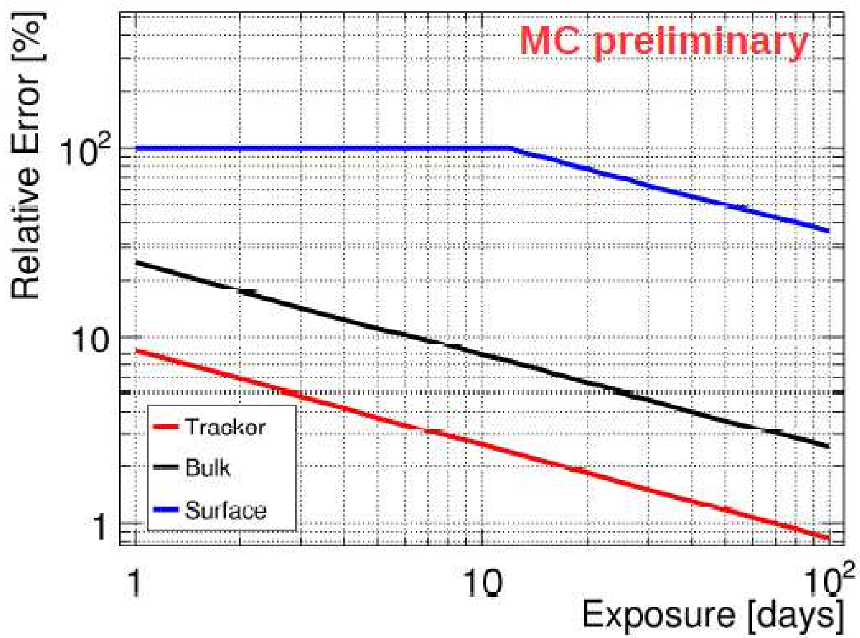


Ability to measure its own background

With 1e1α channel + alpha track lenght, the Demonstrator is able to distinguish the different Radon contributions from:

- **The bulk of the source foil**
- **The surface of the source foil**
- **The surface of the Tracker wires**

Poster #644

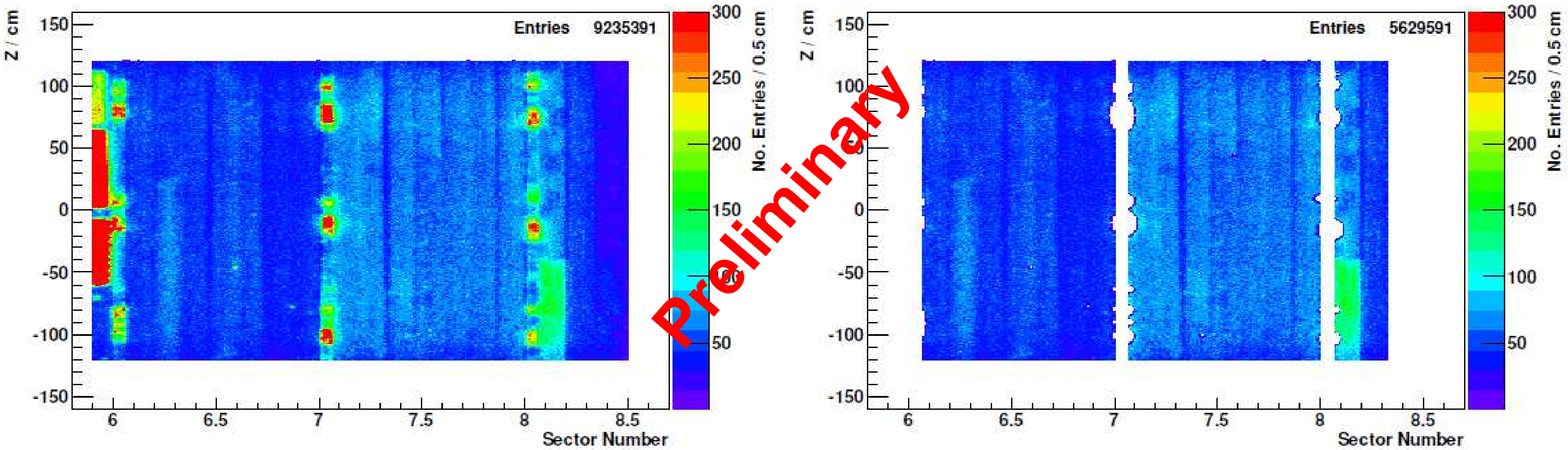


- Radon level known at 4% in 1 week (not hoped!)

Ability to measure its own background

With 1e channel, the Demonstrator will be able to detect and remove « hot spots »

Exemple of « hot spots » in the ^{82}Se foils in NEMO3



(a) Before Removal (b) After Removal

How To Build a ββ-Experiment

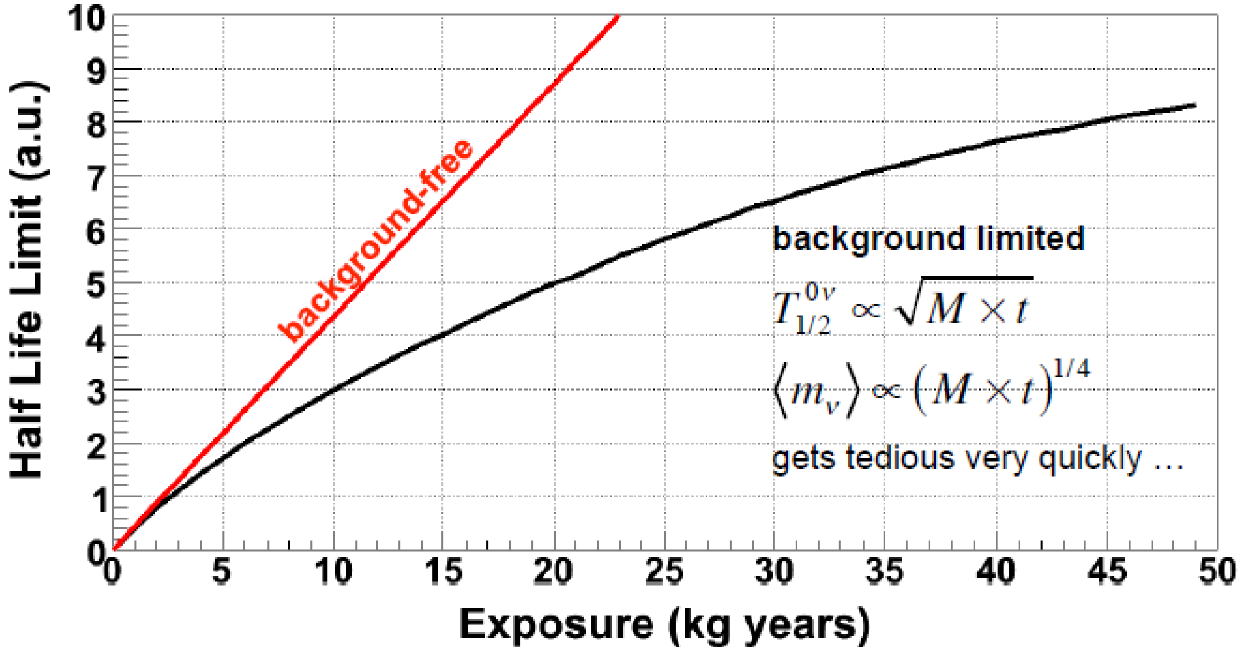
maximise efficiency (ε) & isotope abundance (a)

maximise exposure = mass (M) × time (t)

$$T_{1/2}^{0\nu}(90\%\ \mathrm{C.L.}) = 2.54\times10^{26}\,\mathrm{y}\left(\frac{\varepsilon\times a}{W}\right)\sqrt{\frac{M\times t}{b\times\Delta E}}$$

W = atomic weight

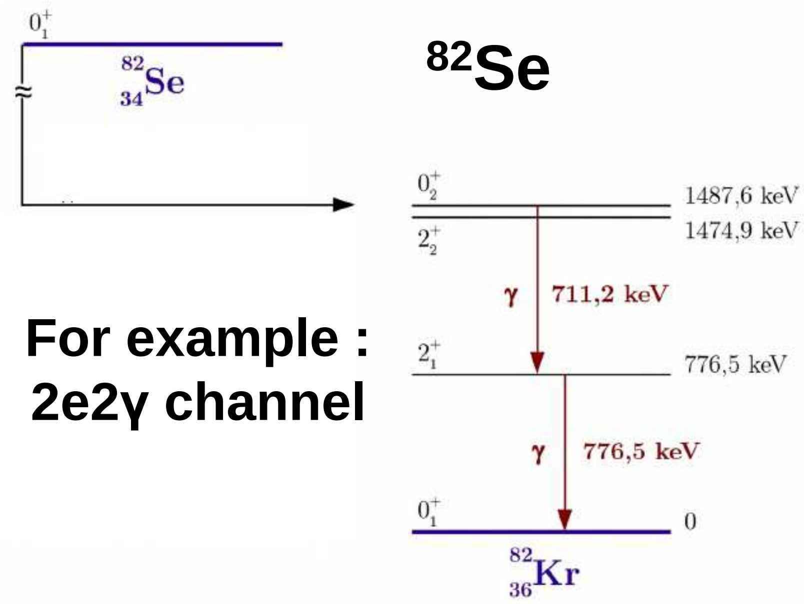
minimise background (b) & energy resolution (ΔE)



Other observables with the Demonstrator

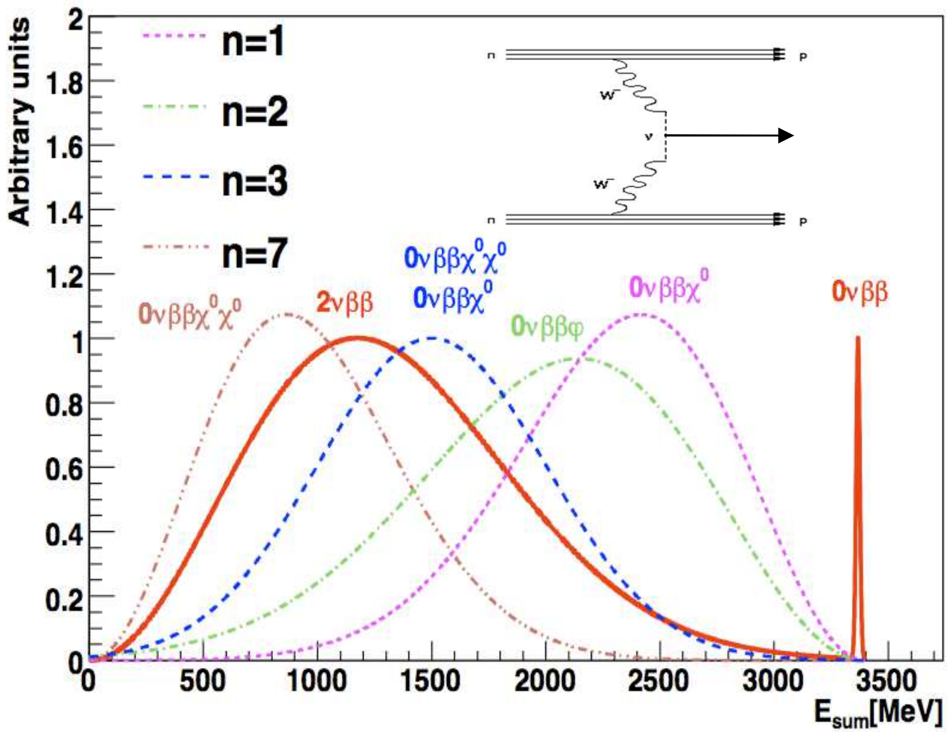
Decays to Excited States

^{82}Se



For example :
2e2γ channel

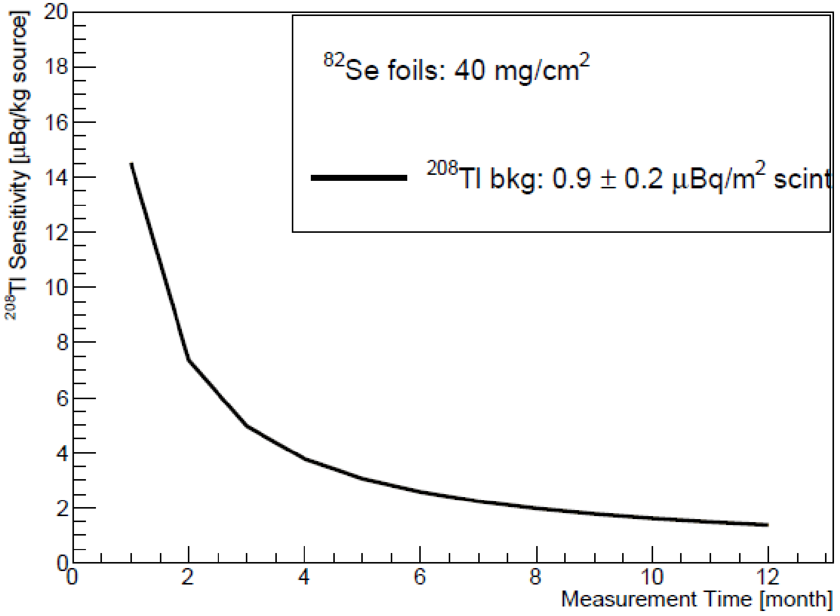
Majoron Emission



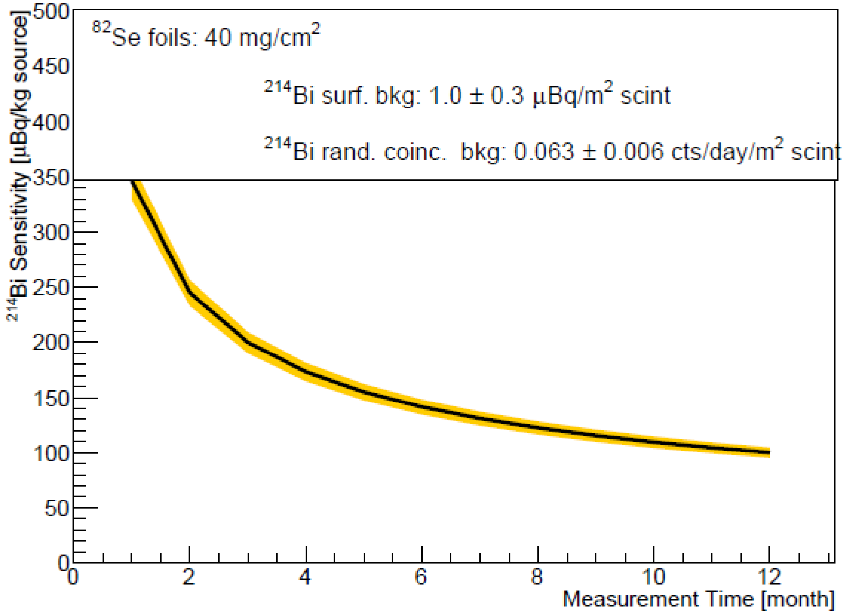
Right-handed current…

BiPo3 sensitivity

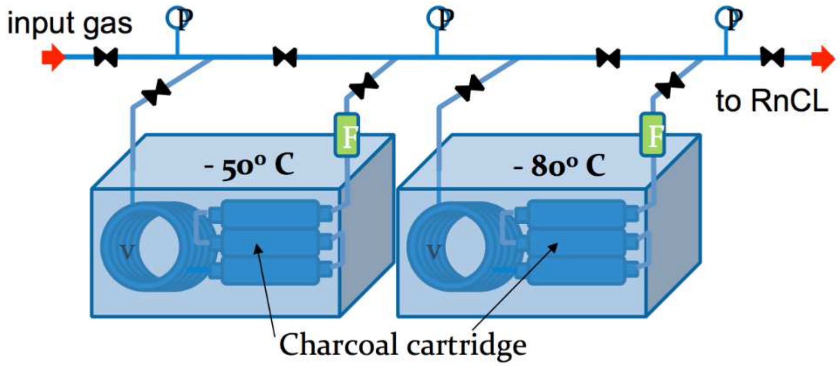
^{208}Tl

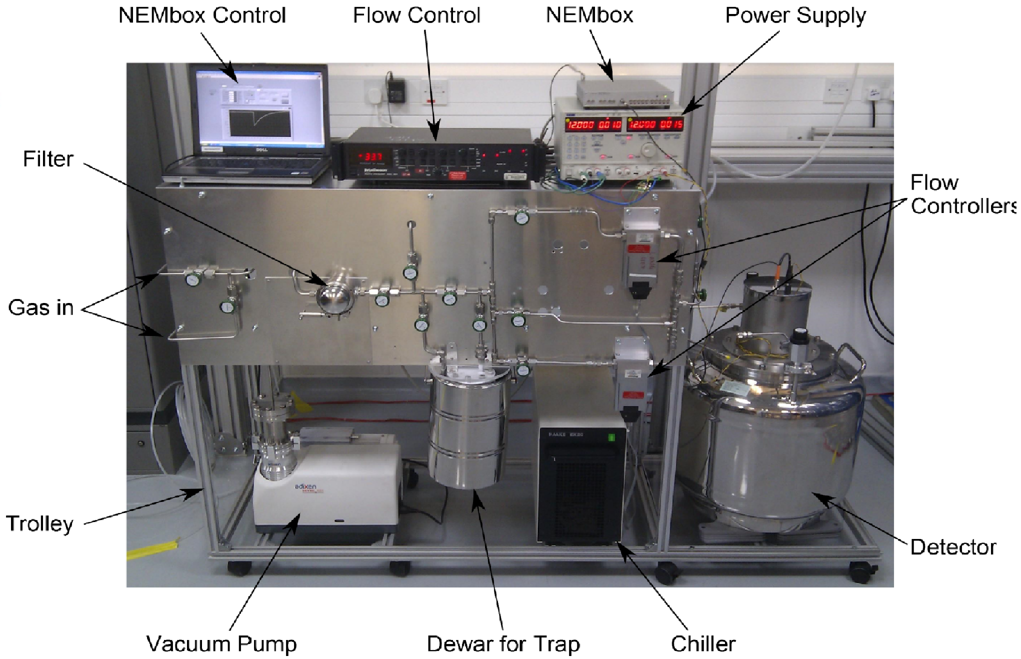


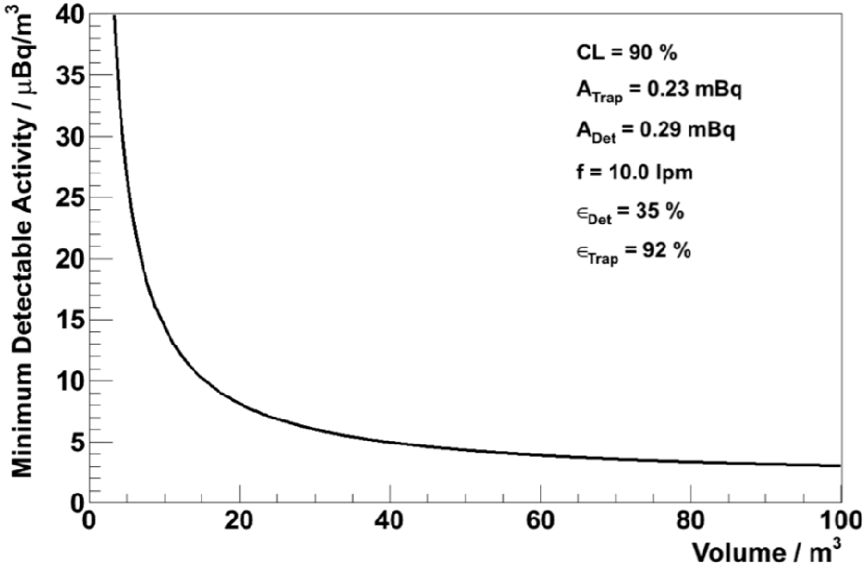
^{214}Bi



The Radon Concentration Line







Sensitivity extrapolated depending on the volume of Helium trapped

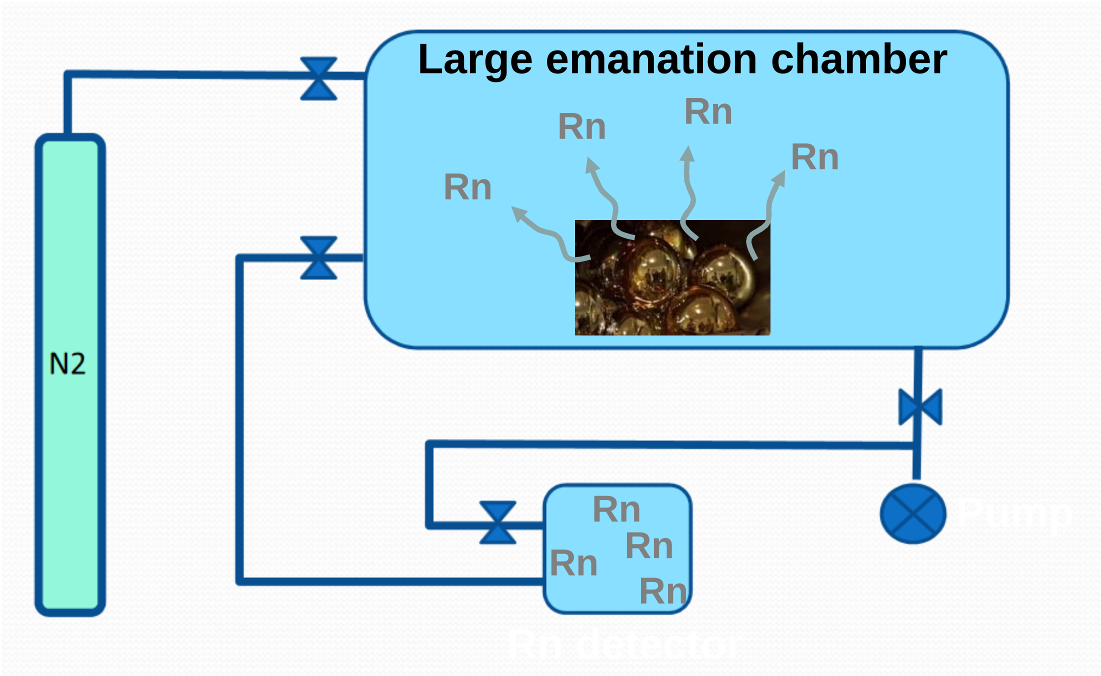
Radon emanation results for Tracker

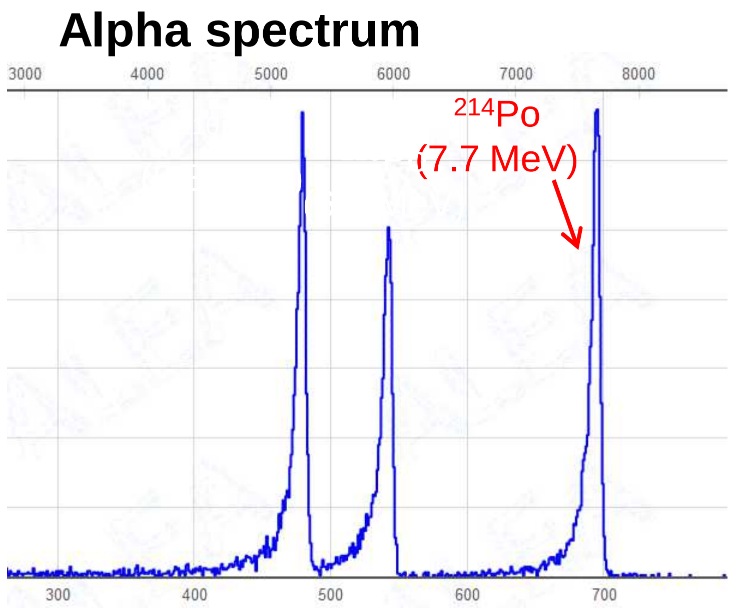
Tracker was divided in 4 sections labelled C0, C1, C2 and C3.

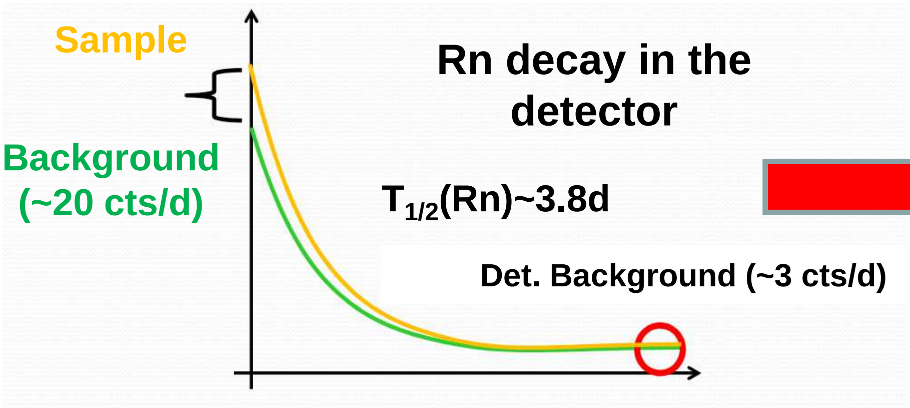
Extrapolation of Radon activity in the Tracker by using the average emanation value of C0, C1 and C2

Input Flow (m^3/hr)	Suppression Factor	Activity in the Tracker with tent (mBq/m^3)
0.5	5.4	0.51 ± 0.06
1.0	9.7	0.28 ± 0.03
2.0	**18.4**	**0.15 ± 0.02**

Large Rn emanation chamber: principle

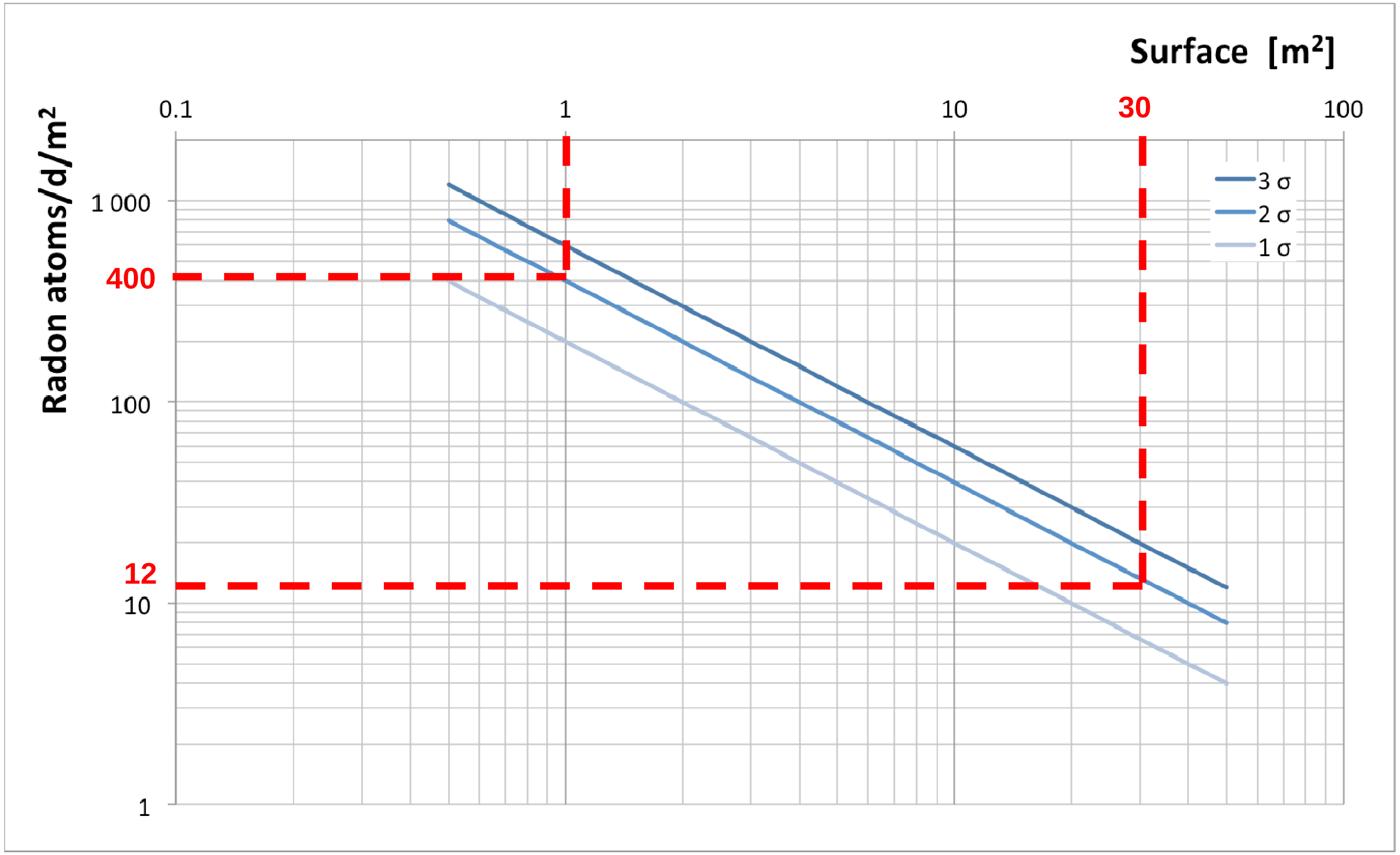






Determination of the Radon emanation rate from the sample

Sensitivity of the Rn emanation setup



For 1 m^2 surface sample → emanation rate < 400 Rn atoms/day (95% C.L.)

For 30 m^2 surface sample → emanation rate < 12 Rn atoms/day (95% C.L.)