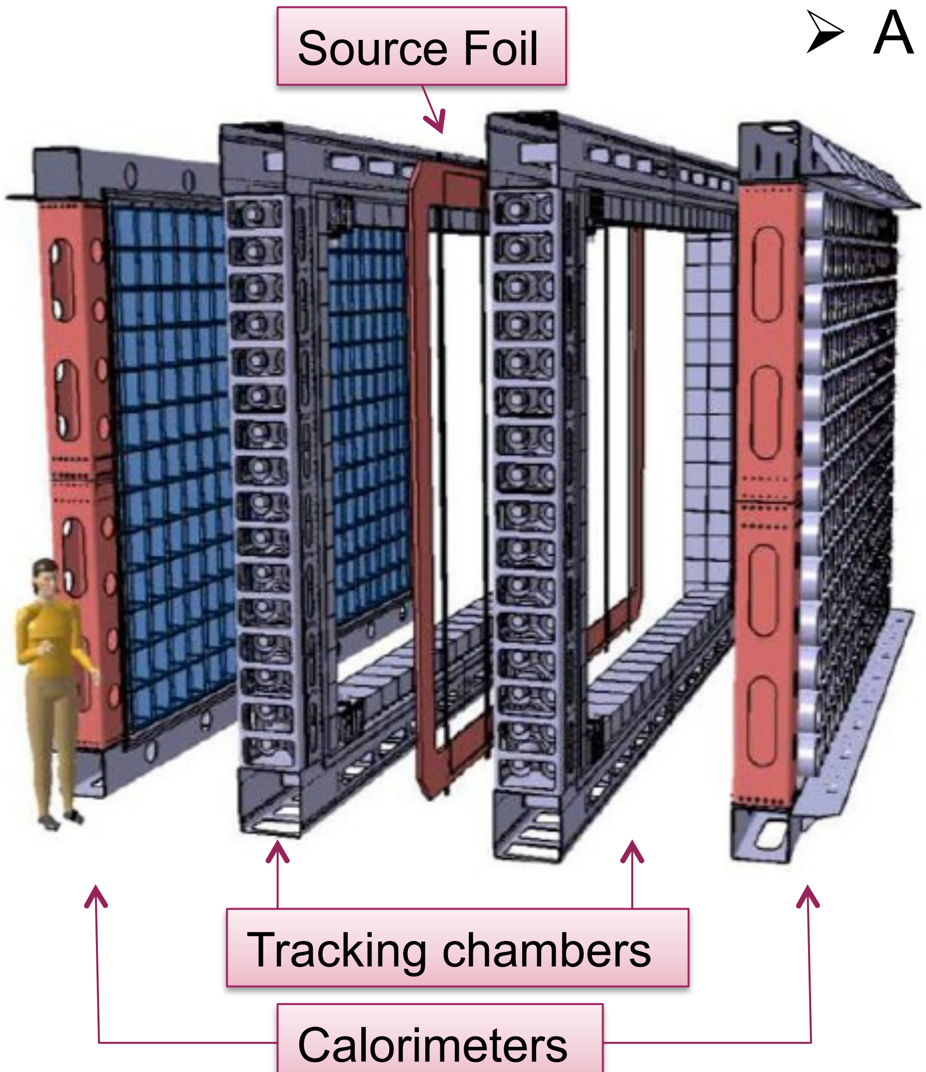
Ultra-low Level Radon Assays in Gases

Xin Ran Liu

On behalf of the SuperNEMO collaboration

LRT2015, 18-20 March 2015
Pacific Northwest National Laboratory
and the University of Washington

SuperNEMO



- A next generation $0\nu\beta\beta$ experiment.

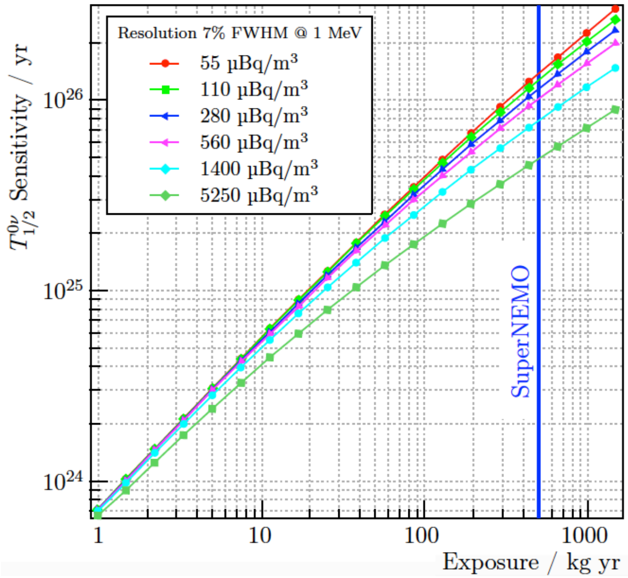
- Source Foil: 5-7 kg of ^{82}Se. (or ^{150}Nd/^{48}Ca etc).

- Gas Tracking Chamber: Drift chamber (2000 cells).

- Calorimeter: Consists of 712 PMTs and scintillator blocks.

- **Phase 1:** Demonstrator (7kg of ^{82}Se).
- **Phase 2:** Up to 20 identical modules (100 kg).

The Challenge



SuperNEMO Demonstrator

	activity	events in 17.5 kg·yr
$2\nu 2\beta$	$(96 \pm 10 \times 10^{18}\ \mathrm{y})^{-1}$	0.319 ± 0.041
Radon[1]	$< 0.15\ \mathrm{mBq\,m^{-3}}$	0.033 ± 0.013
^{214}Bi	$< 10\ \mathrm{\mu Bq\,kg^{-1}}$	0.019 ± 0.003
^{208}Tl	$< 2\ \mathrm{\mu Bq\,kg^{-1}}$	0.030 ± 0.003

Region of interest (2.8 – 3.2 MeV)

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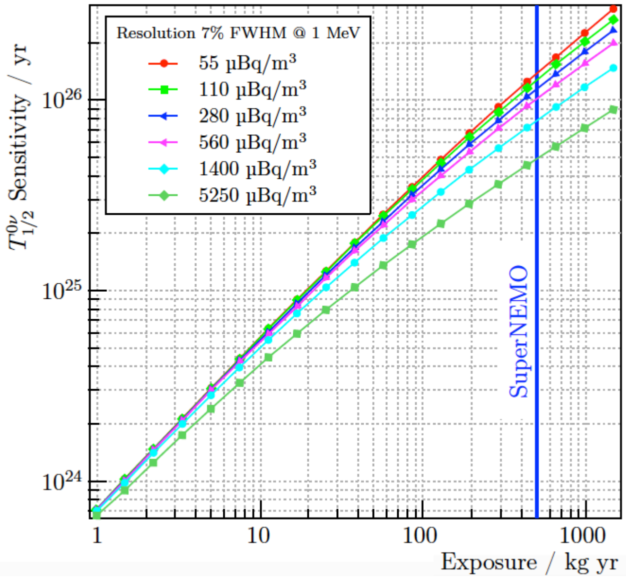

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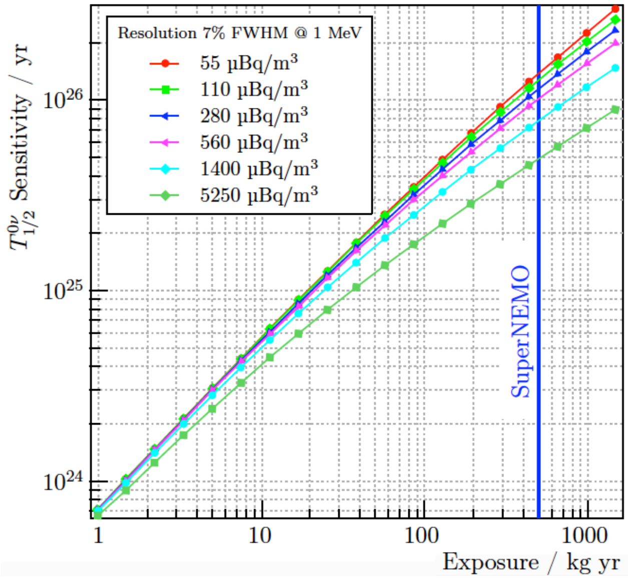

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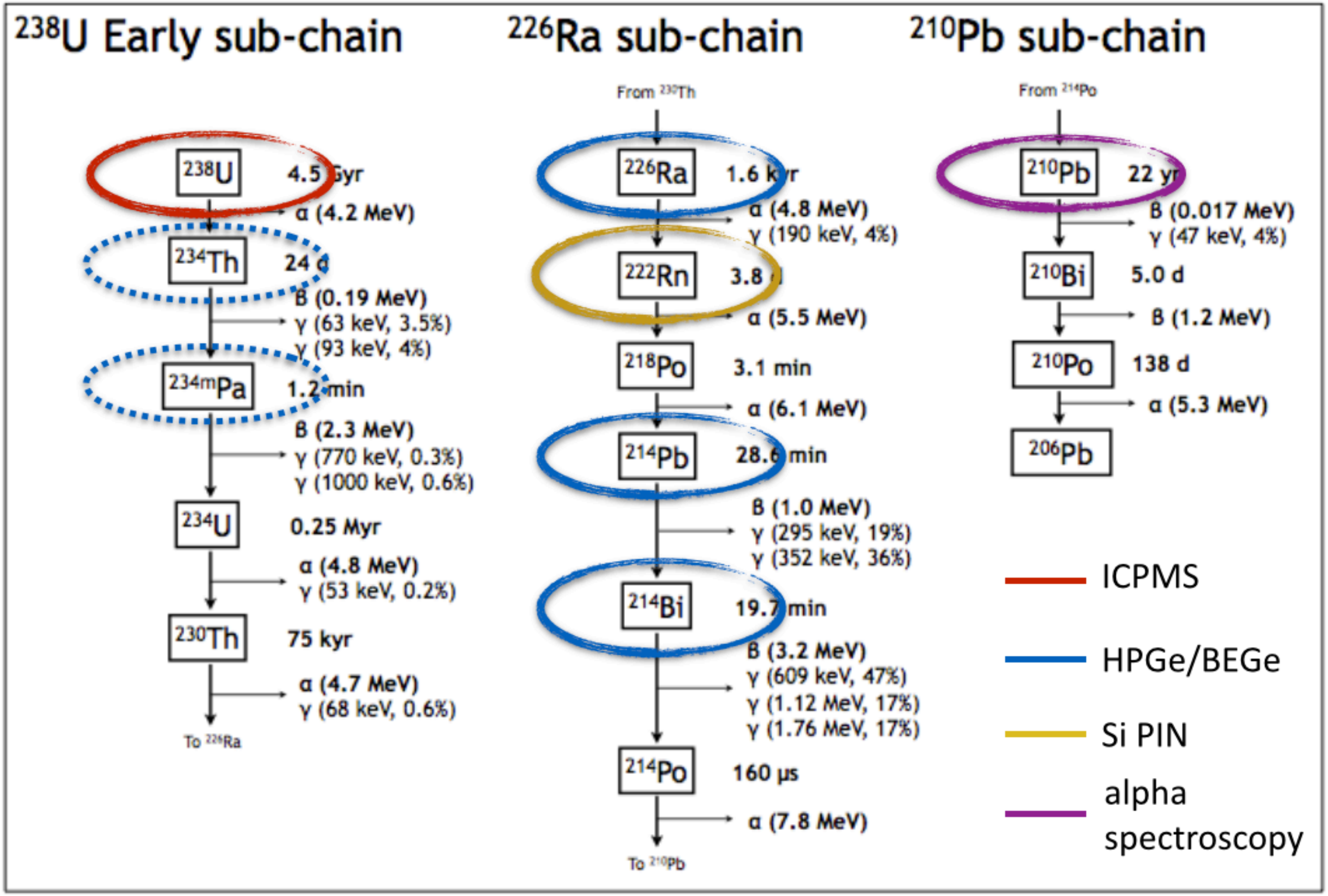
Backgrounds: ^{238}U Chain

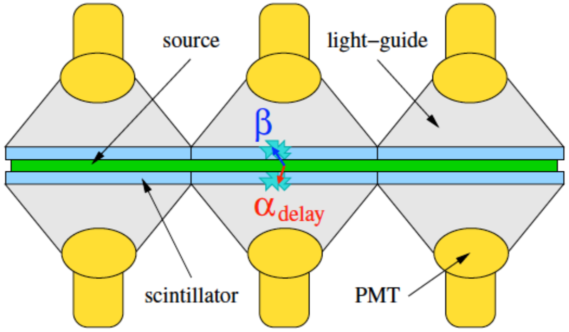


Radiopurity Strategy for Demonstrator Module

Source Foil | **Tracker** | **(Radon Barrier)** | **Calorimeter**

Source Foil

- **HPGe detectors** (0.1-1 mBq/kg for ^{238}U, ^{232}Th chains and ^{40}K).



- **BiPo** detector for source foil (2-10 μBq/kg for ^{208}Tl and ^{214}Bi).

(See Xavier Sarazin's talk yesterday.)

Tracker

- **HPGe detectors** (similar to source foil).
- **Emanation chambers** for radon.

(See Cedric Cerna's talk this morning.)

- **Radon concentration line (RnCL)** (< 0.15 mBq/m^3).
- R&D for more efficient and radiopure radon absorbents.

(See Raymond Noel's talk before this.)

Calorimeter

- Calorimeter components inside the tracker (0.1-1 mBq/kg).

- Outside the gas volume (1-10 mBq/kg).

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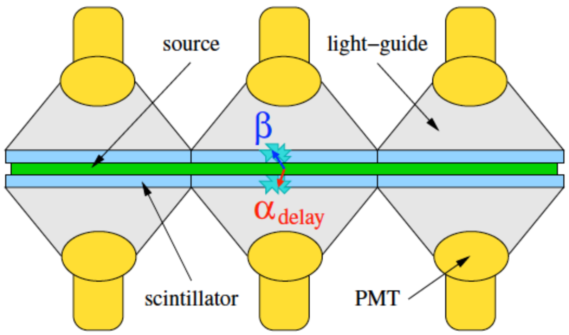

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(Radon Barrier)

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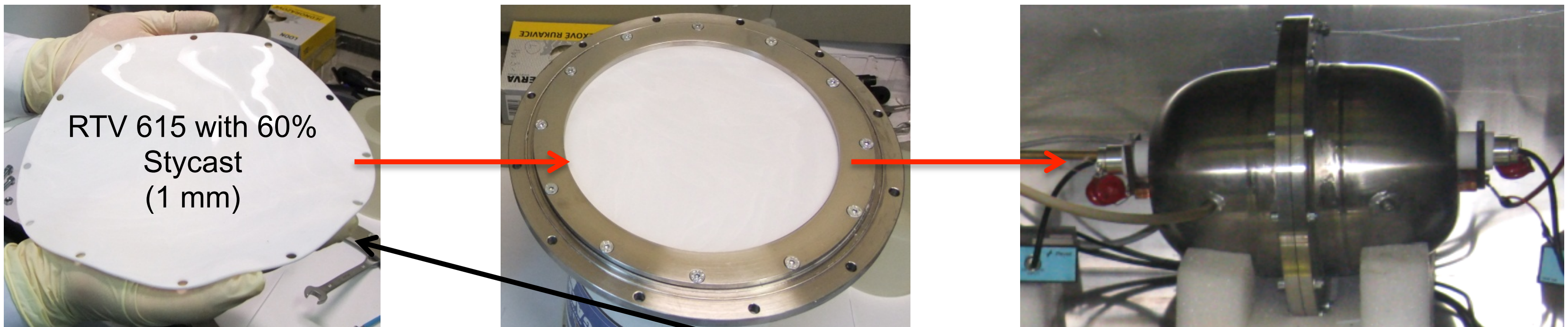
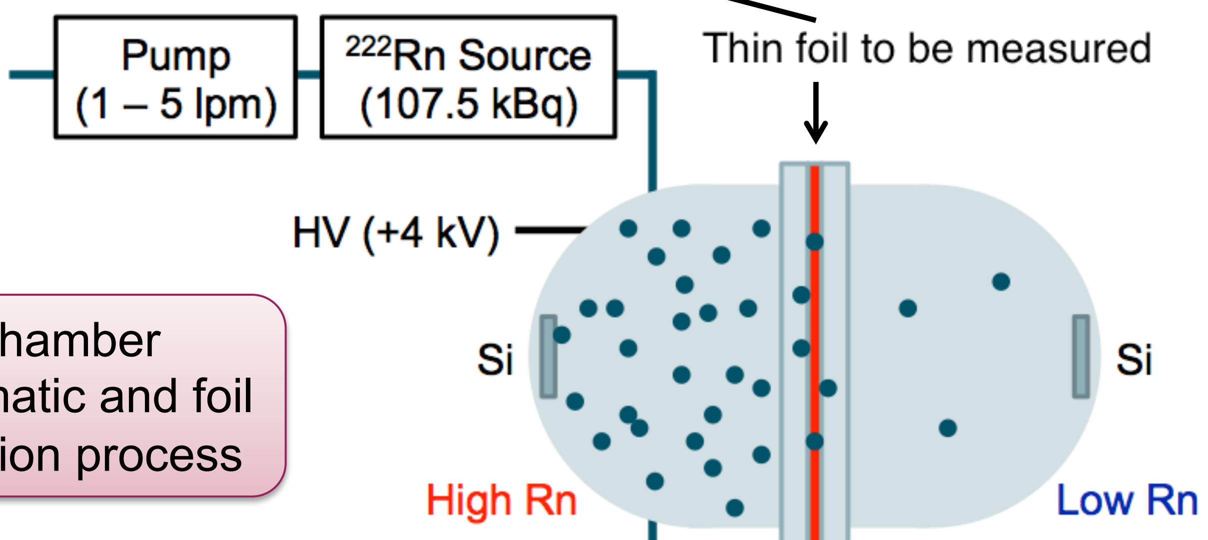
Everything is radioactive unless proven otherwise through screening!

Diffusion R&D

➢ Possible introduction of a radon barrier to reduce emanation into the tracker.





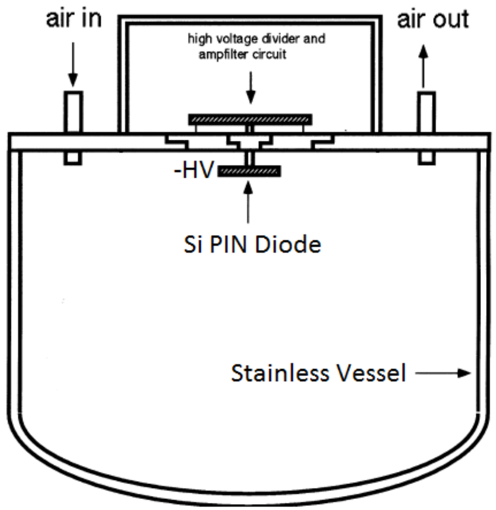
Chamber schematic and foil insertion process

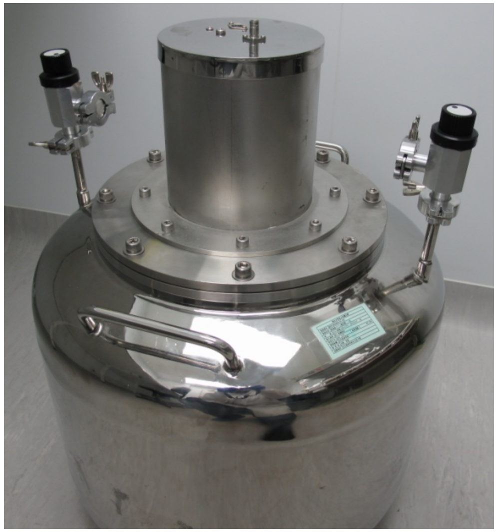
(See Fadahat Mamedov's poster.)

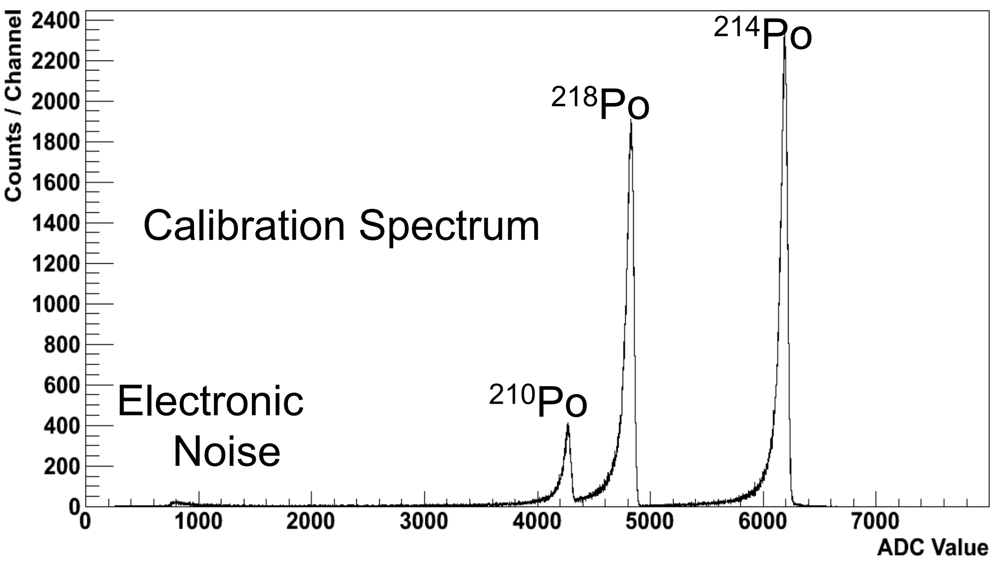
Diffusion R&D: Selected results

Material	Thickness (µm)	Diffusion Coefficient (10^{-12} m^2s^{-1})	Diffusion Length (µm)	Radon Suppression Factor (15 µm)
Adhesives/Sealants				
Silicone (RTV 615)	2100	1080	22800	1.002
Stycast 1264	2000	<0.43	<455	> 6.9
SBR (Synthomer 47B40) + HDPE	700 + 120	0.27	406	8.3
Delrin Sheets	2100	<0.072	186	36
Butyl	6 + 11	<0.00038	<13	1.02
Foils				
EVOH (2 layers)	2×15	< 0.00035	< 13	> 8900
Mylar (2 layers)	2×20	< 0.0012	< 24	> 2300
TROPAC III	102	< 0.0043	< 46	> 600
NYLON	50	0.00047	15	6380

Electrostatic Detector



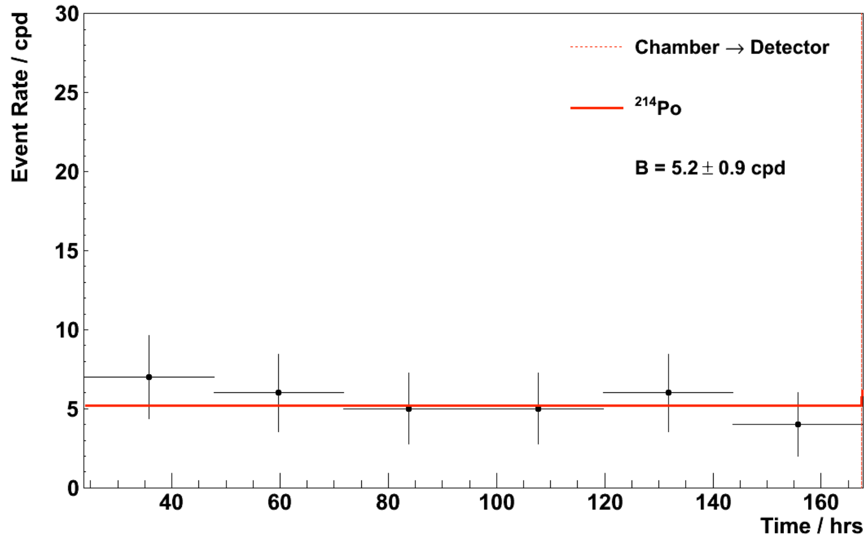


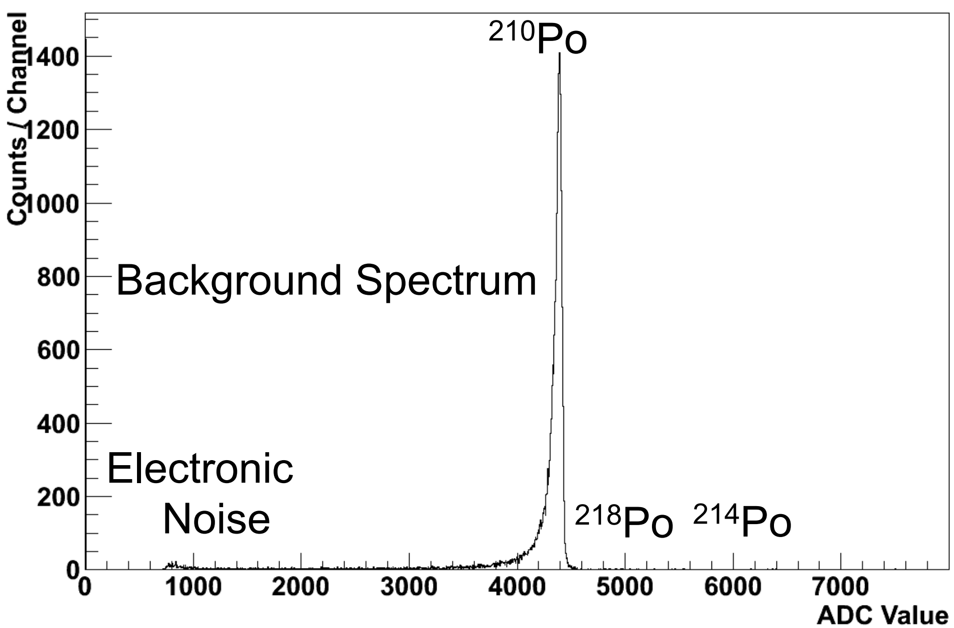


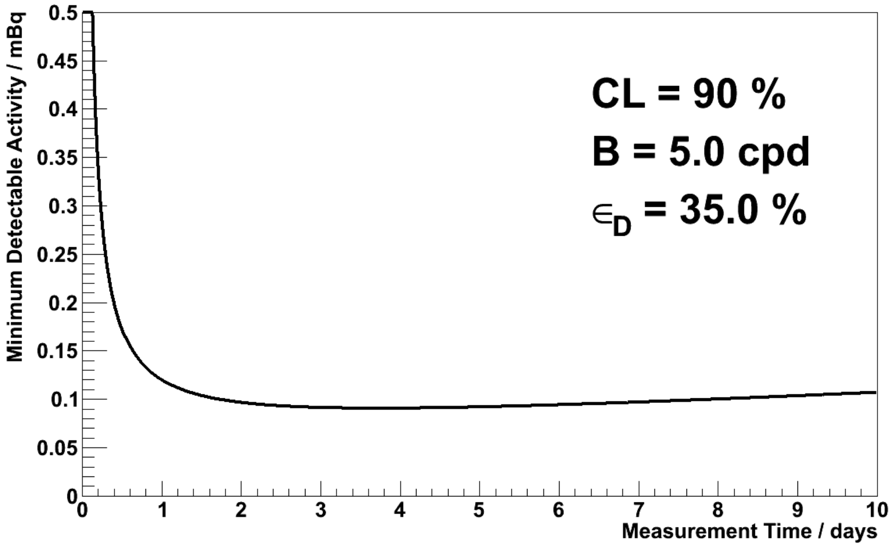
- Electro-polished stainless steel 70 L vessel.
- Contains a silicon PIN diode with -1500 V applied.
- Two valves coated with SBR.
- Calibrated using a Rn flow-through source.

Detector Background and Sensitivity

- Measurement of detector background shows **~ 5 cpd**
- Gives sensitivity of ~ **0.09 mBq** (1.3 mBq/m^3) @ 90% CL







Radon Concentration Line (RnCL): Concept

- Monitor radon concentration at < 0.15 mBq/m^3 **during construction**.

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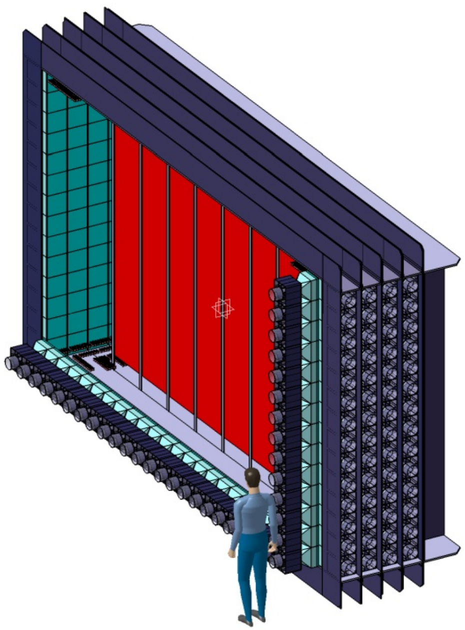
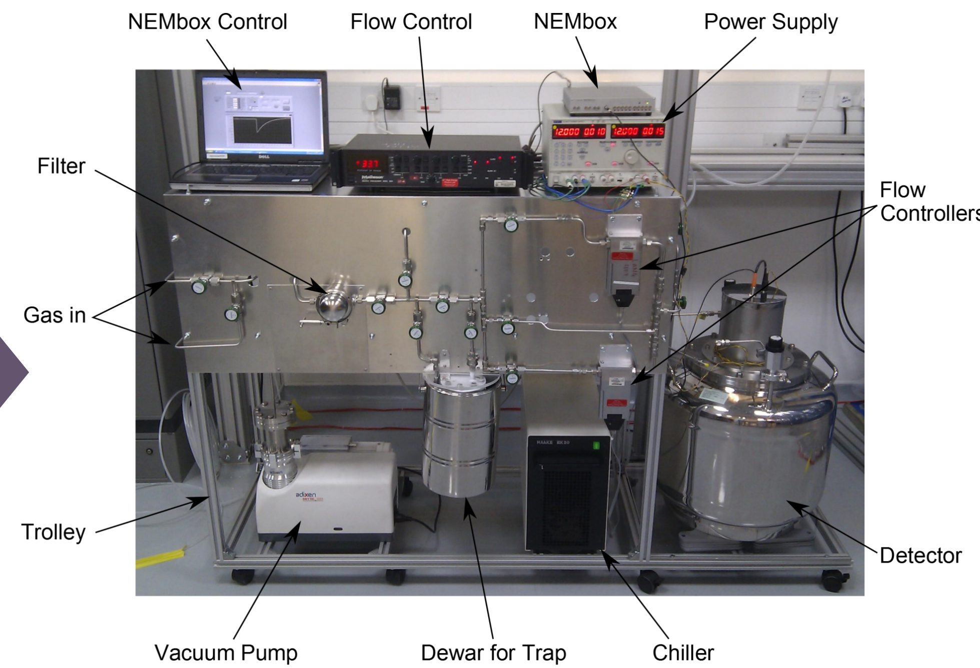


¼ SuperNEMO tracker (~ 3.8 m^3)

Electrostatic detector



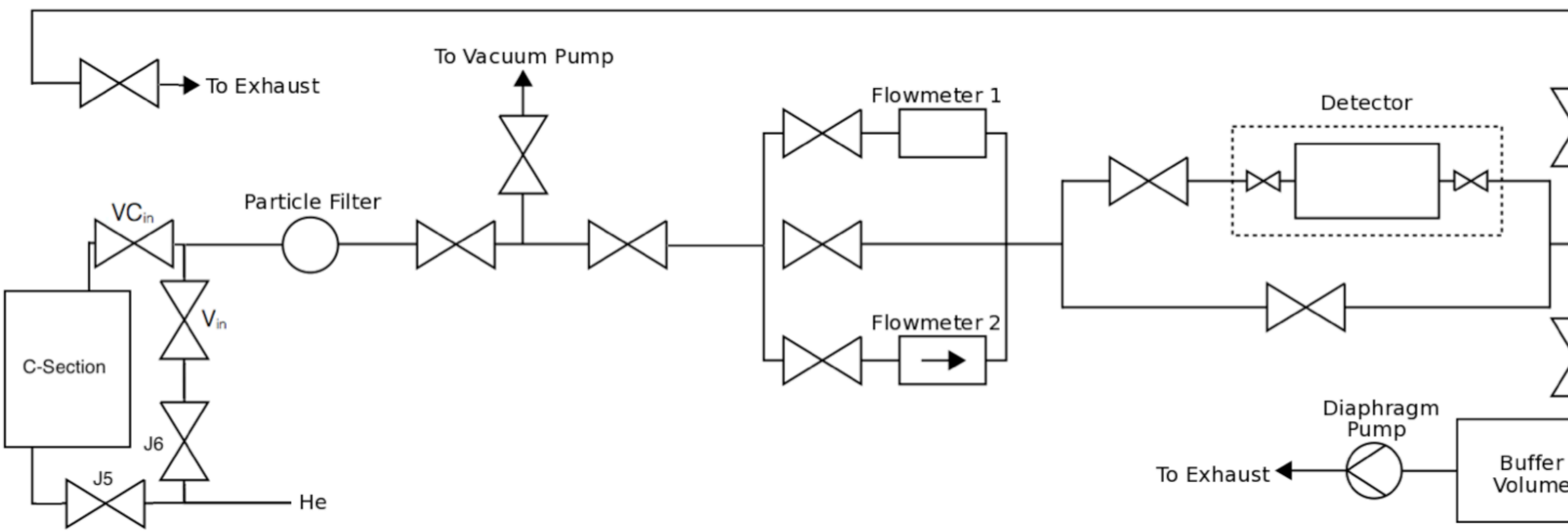
Radon concentration line (similar to MoReX in Heidelberg)

- Tracker gas (He/N2/Ar etc) is pumped through a **carbon trap** at **-50°C** and the ^{222}Rn in the gas is adsorbed. The concentrated sample is then heated and transferred to the electrostatic detector via helium purge.

Tracker Sub-Module

- SuperNEMO modules are constructed in four parts, each part is called a C-Section (due to the shape).

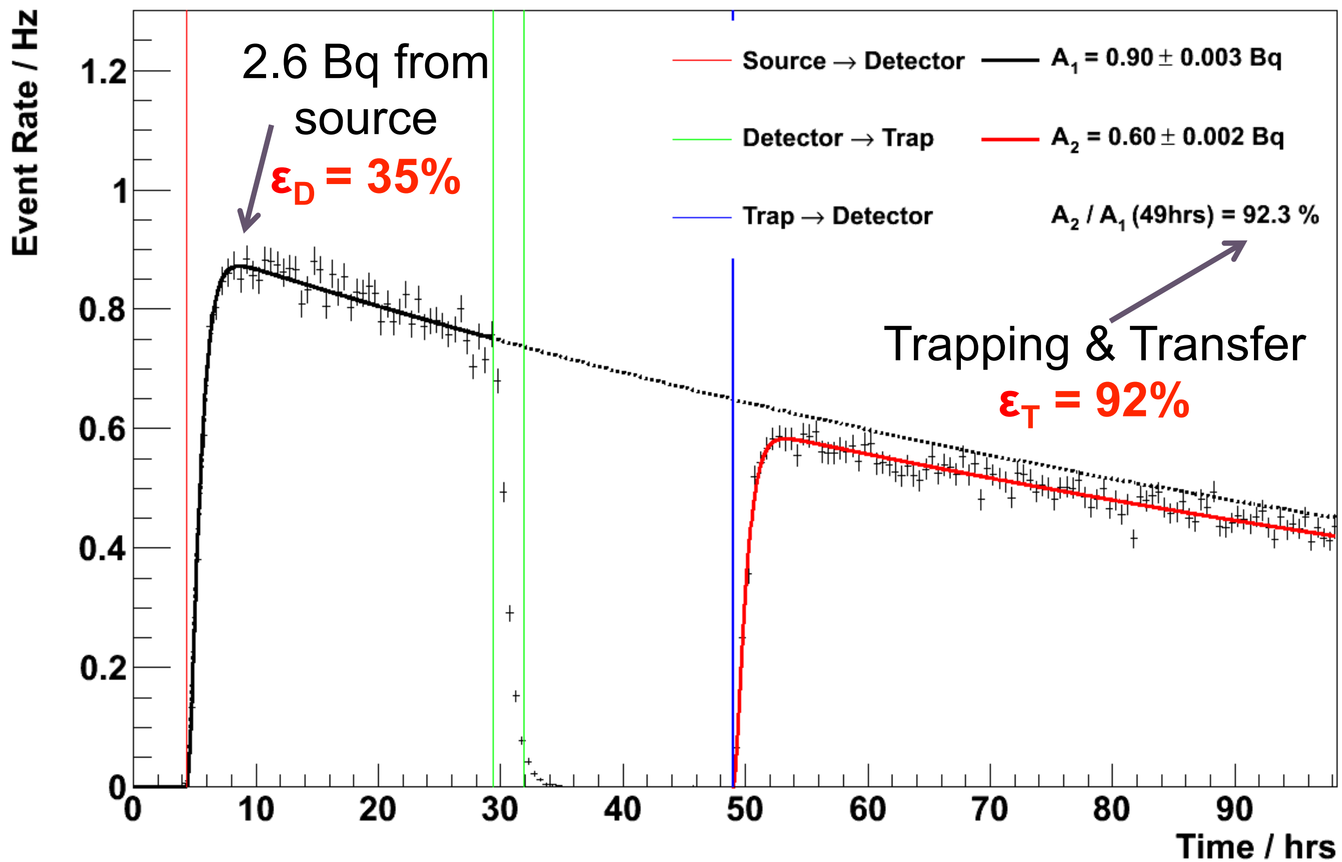
- Each completed C-Section is sealed using electro-polished stainless steel plates and then tested to ensure gas tightness.



RnCL: Detection, Trap & Transfer Efficiencies

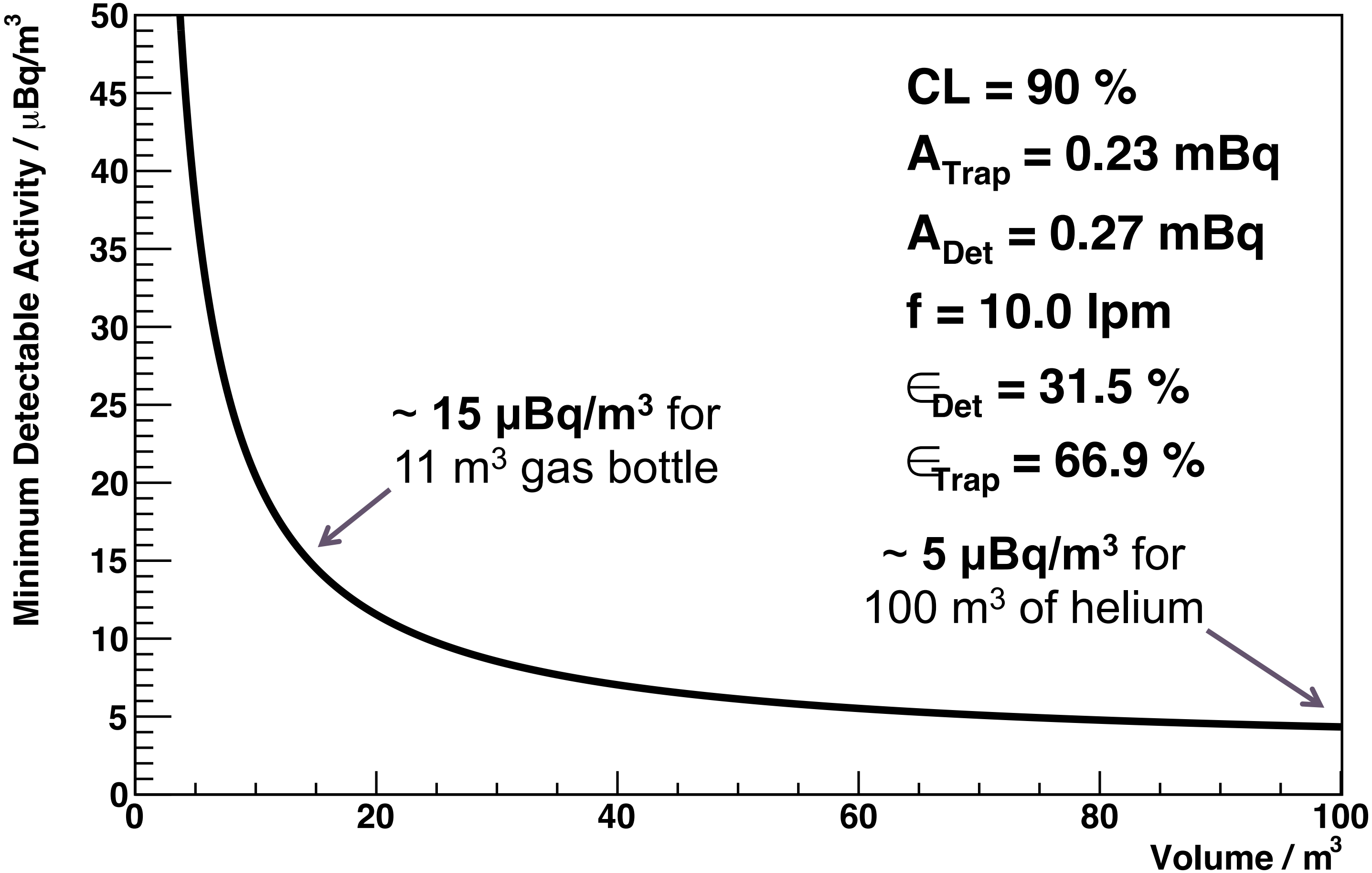
- To measure **detection efficiency**, put a known amount of radon from a source in detector.

- Then transfer into trap and back to get **trapping & transfer efficiency**:



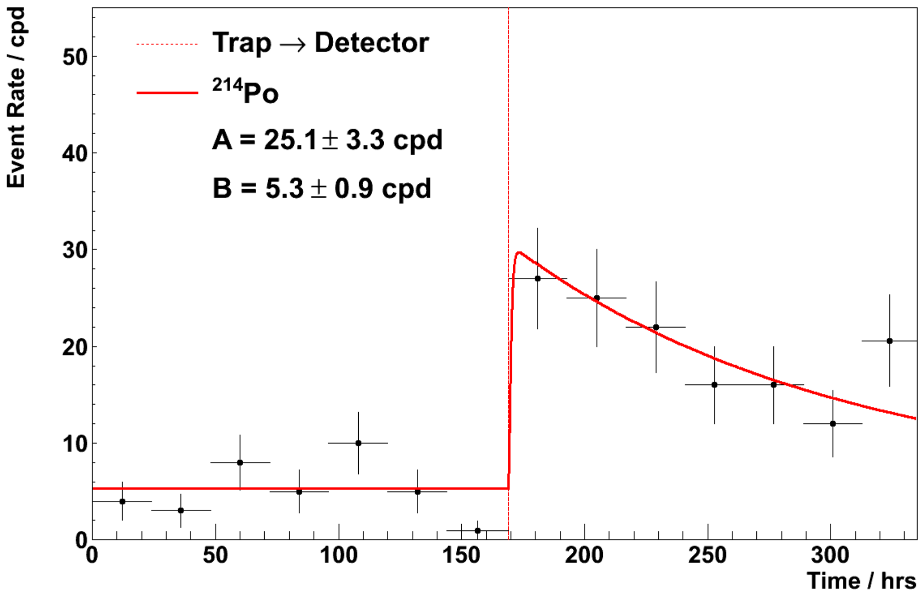
RnCL: Sensitivity Estimates

- Assuming a supply of gas of constant activity leads to the following sensitivity for a given volume of gas:

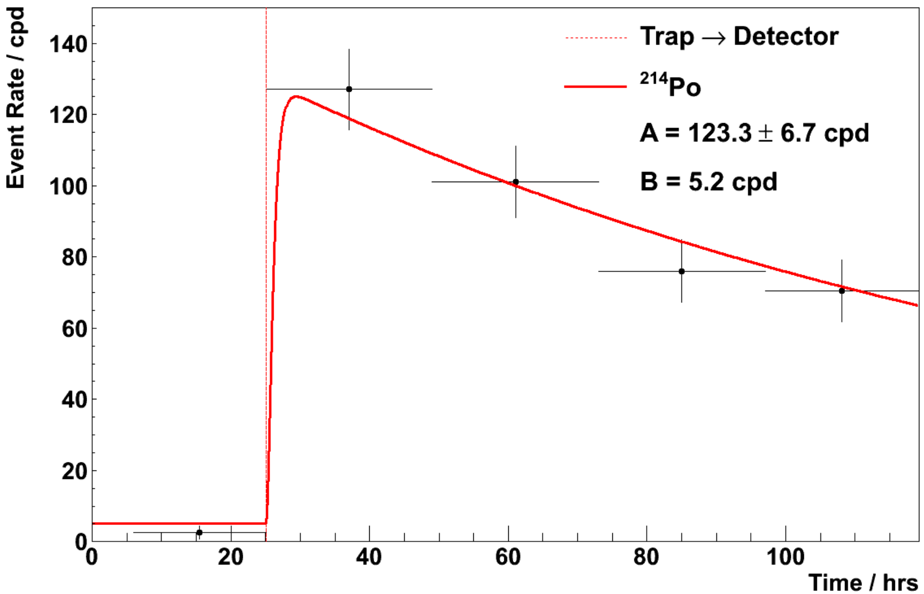


RnCL: Gas Bottles Measurement

- The background emanation from the gas supply line and the activity from the output of the cylindered gas were measured separately in order to disentangle the two.



Po214 activity from 0.075 m^3 of helium and the supply line.



Po214 activity from the supply line and 10.7 m^3 of nitrogen

RnCL: Gas Bottles Measurement

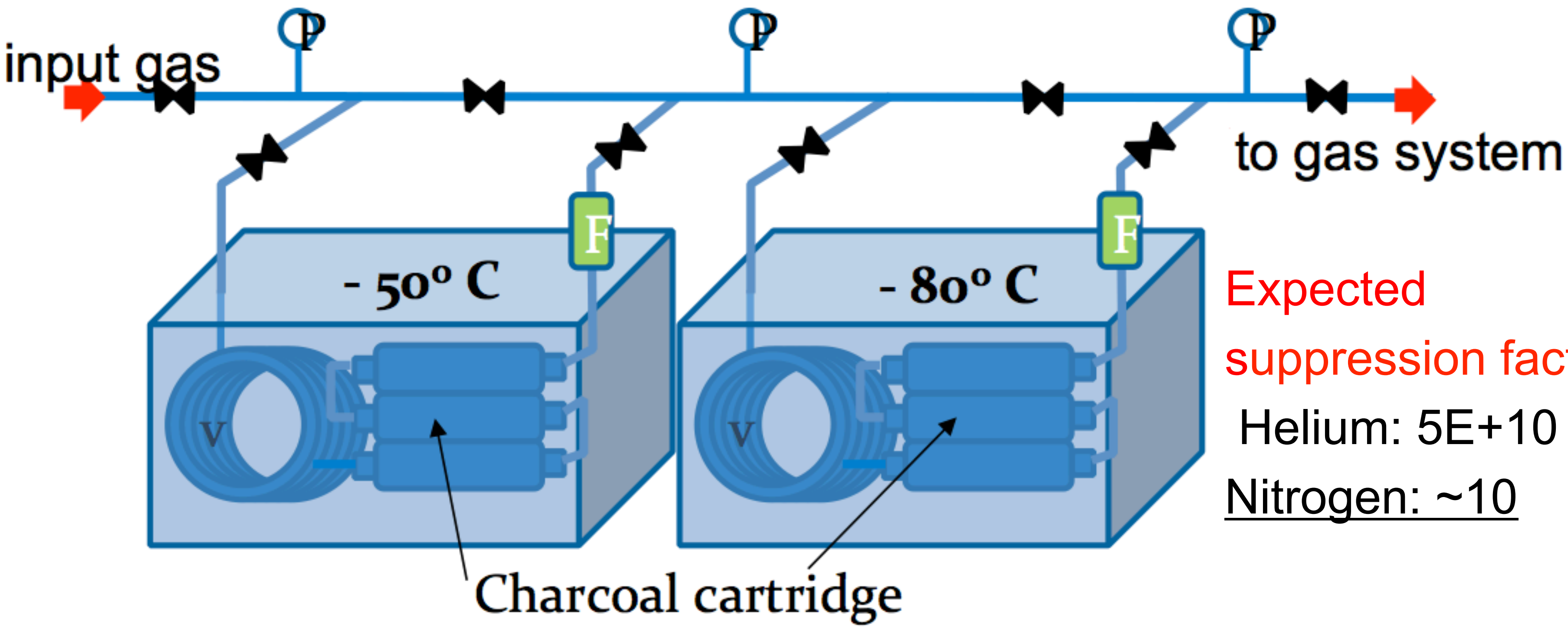
- It has been observed that there is a large variation to the radon levels from the nitrogen cylinders. Therefore it's key to measure the gas cylinders used so their contribution may be subtracted.

Gas	Source	Radon Level (μBq/m^3)
He	Cylinder	70-100
N_2	Cylinder	400-1000
N_2	Boil-off	90-140

- This contamination (and variation in contamination) in the carrier gas is a problem for the tracker (C-section) measurement, i.e. large *detector* volume measurements.

Radon Trap System

- Hence a radon trap system was designed and built, capable of removing the radon from the carrier gas by up to 10 orders of magnitude depending on the gas.



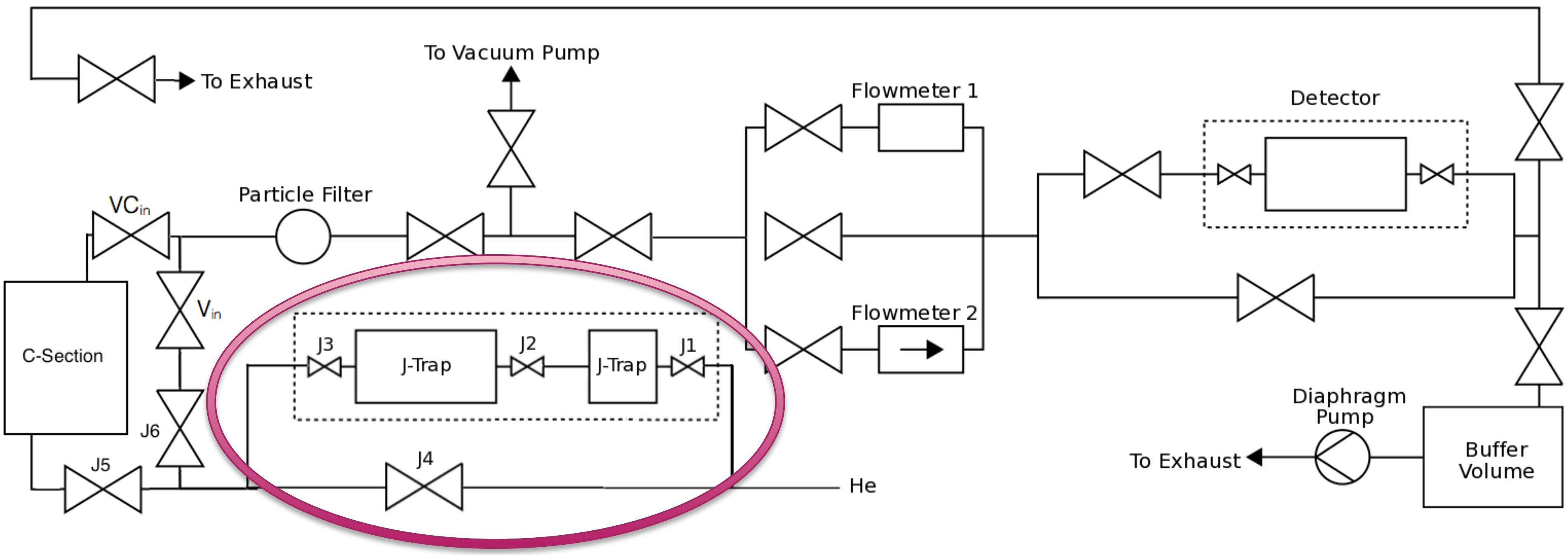
Expected suppression factor:

Helium: 5E+10

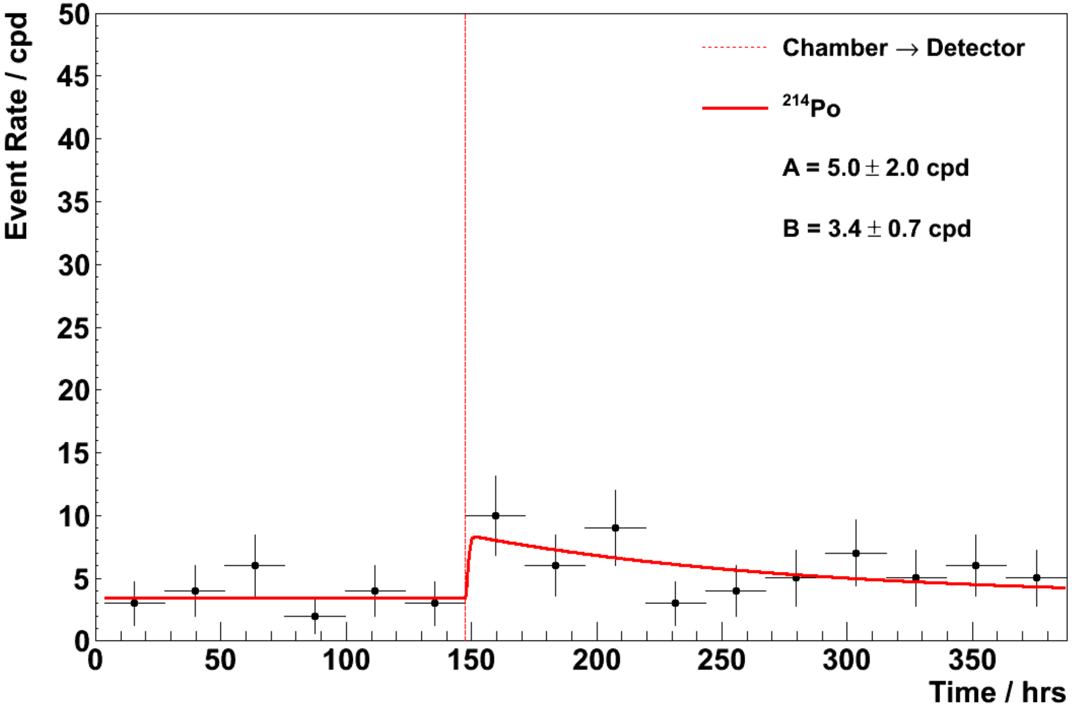
<u>Nitrogen: ~10</u>

Tracker Sub-Module

- For each emanation measurement of the C-Section, the radon trap system is installed prior to the measurement setup and used to purify the carrier gas at the input



Nitrogen Gas Measurement



Activity;

Po214 = 20.2 ± 12.5 μBq/m^3

Po218 = 35.0 ± 15.8 μBq/m^3

Gas	Source	Radon Level (μBq/m^3)
He	Cylinder	70 – 100
N_2	Cylinder	400 – 1000
N_2	Boil-off	90 – 140
N_2	Rn-Trap	20 ± 12

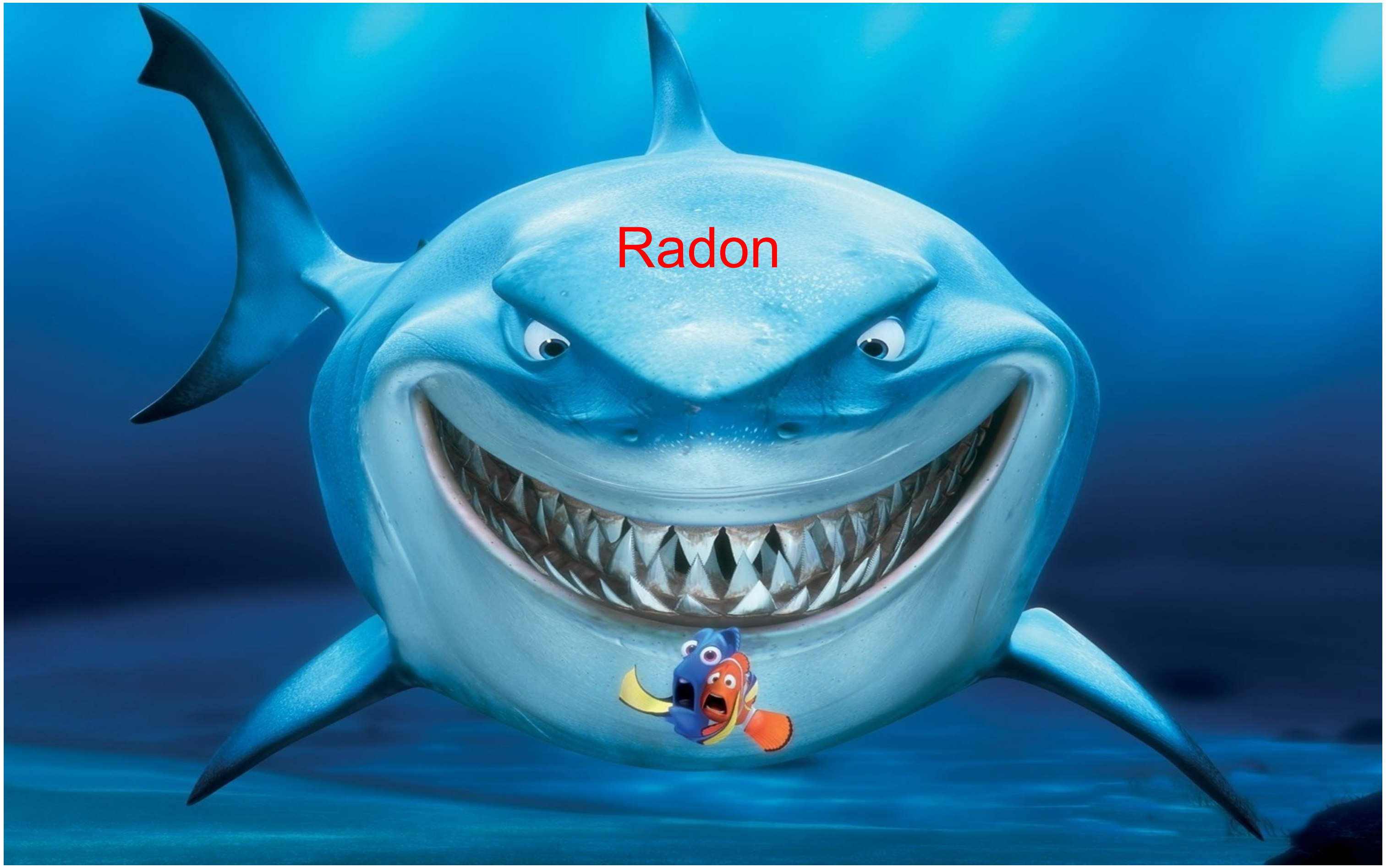
- Cylindered nitrogen was flown first through the Rn trap system and then the RnCL trap with a flow rate of 7 lpm for 20 hours.
- Expect 1.6 ± 0.5 cpd from trap background (flushed, then closed for 24 hours).

Summary and Outlook

- The required ^{222}Rn level for SuperNEMO is **< 0.15 mBq/m³**.
- This challenging target has resulted in a large programme of radon R&D including:
  - A dedicated setup for diffusion studies of different materials to form **anti-radon barriers and radon proofing seals**.
  - Development of a **RnCL** capable of measuring a ¼ tracker at ~ 0.05 mBq/m³ and large volumes of gas at ~ 5 μBq/m³.
  - A **radon trap system** was developed capable of radon suppression by at least a factor of 20 in nitrogen.
- A measurement of a fully populated tracker sub-module is on going.
- Due to measure the Rn trap system purification level on helium and expect to have < 5μBq/m³.

Thank you for listening!

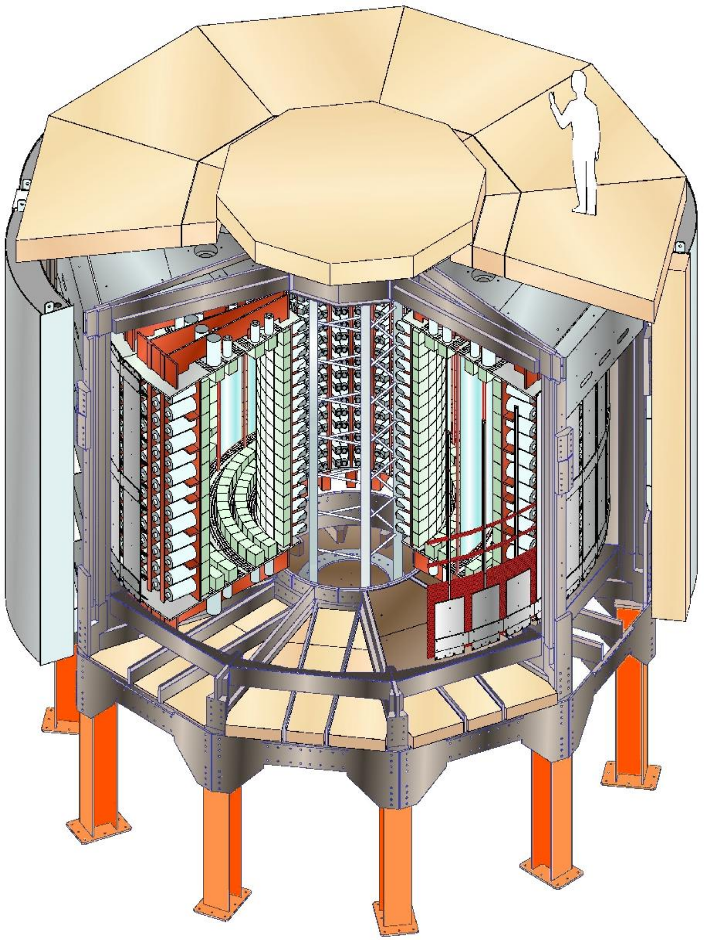
Any questions?



Backup Slides

The NEMO-3 Experiment

- NEMO-3 was the predecessor to SuperNEMO, which ran from Feb 2003 – Jan 2011.



- Cylindrical design with source foils of different ββ isotopes surrounded by a gas tracker and a calorimeter.
- Employed a 'smoking-gun' approach:
  - Particle ID, event topology reconstruction & strong background rejection
  - Compromise on energy resolution
- World's best $T_{1/2}$ measurements of seven 2νββ isotopes (out of only 12 observed):

^{100}Mo, ^{82}Se, ^{150}Nd, ^{96}Zr, ^{48}Ca, ^{116}Cd, ^{130}Te

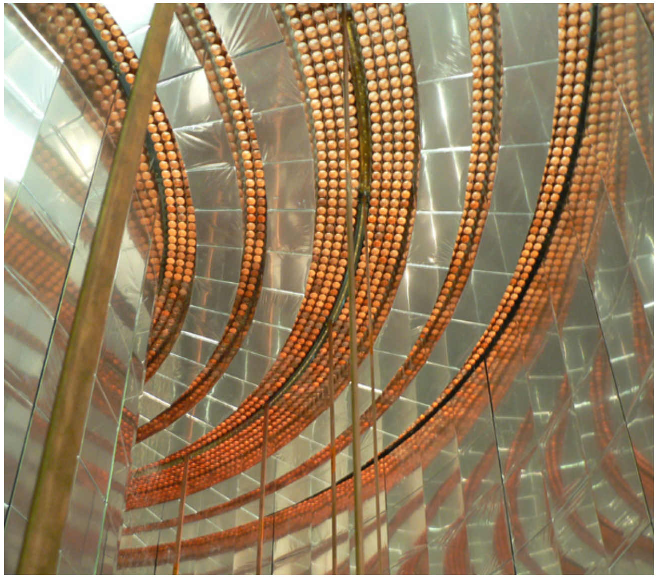
The NEMO-3 Experiment

Source foil: 10kg of different ββ isotopes

Tracker: Drift chamber with 6180 vertical cells in He, Ar, alcohol & water.

Calorimeter: 1940 PMTs & plastic scintillator blocks

Shielding: Wood, iron & borated water to stop different external backgrounds



Some important measurements:

^{100}Mo: $T_{1/2}(2\nu) = [7.16 \pm 0.01(stat) \pm 0.54(sys)] \times 10^{18}$ y
$T_{1/2}(0\nu) > 1.0 \times 10^{24}$ y @ 90% CL

^{82}Se: $T_{1/2}(2\nu) = [9.6 \pm 0.1(stat) \pm 1.0(sys)] \times 10^{19}$ y
$T_{1/2}(0\nu) > 3.2 \times 10^{23}$ y @ 90% CL

SuperNEMO Schedule

Demonstrator module construction and commissioning

Construction and deployment of successive SuperNEMO modules

Sensitivity with 100 kg:

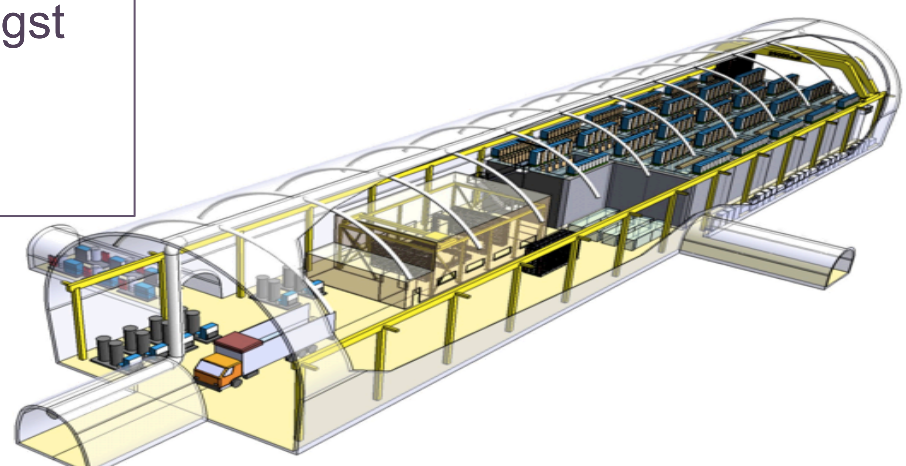
$T_{1/2}(0\nu\beta\beta) \sim 10^{26}$ yr $\rightarrow \langle m_\nu \rangle \sim$ 40—110 meV

2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**

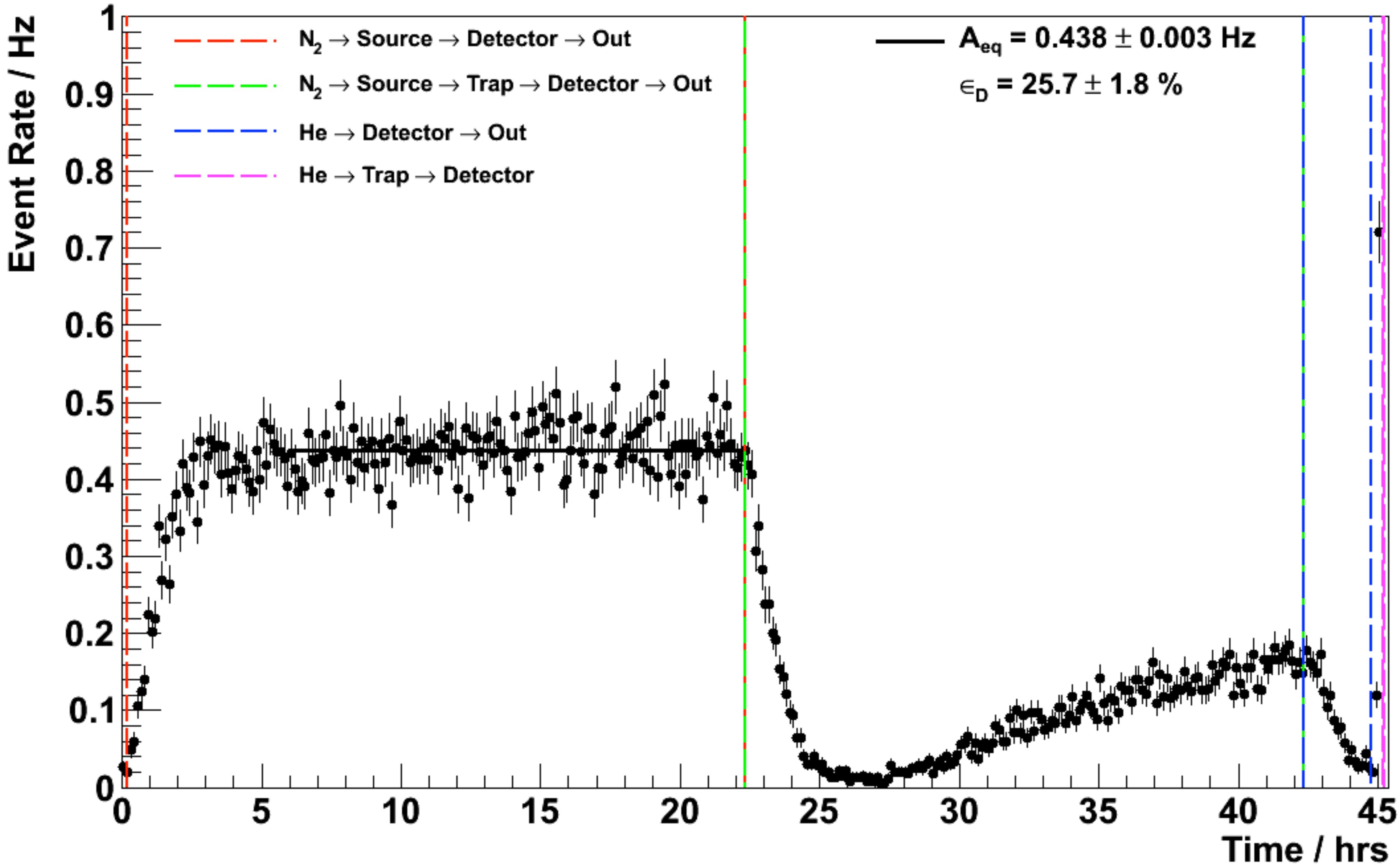
Demonstrator module running

- Prove $B \sim 10^{-4}$ cts/keV/kg/yr: amongst best of any experiment
- Limit on $T_{1/2} \sim 6.5\text{x}10^{24}$ yr

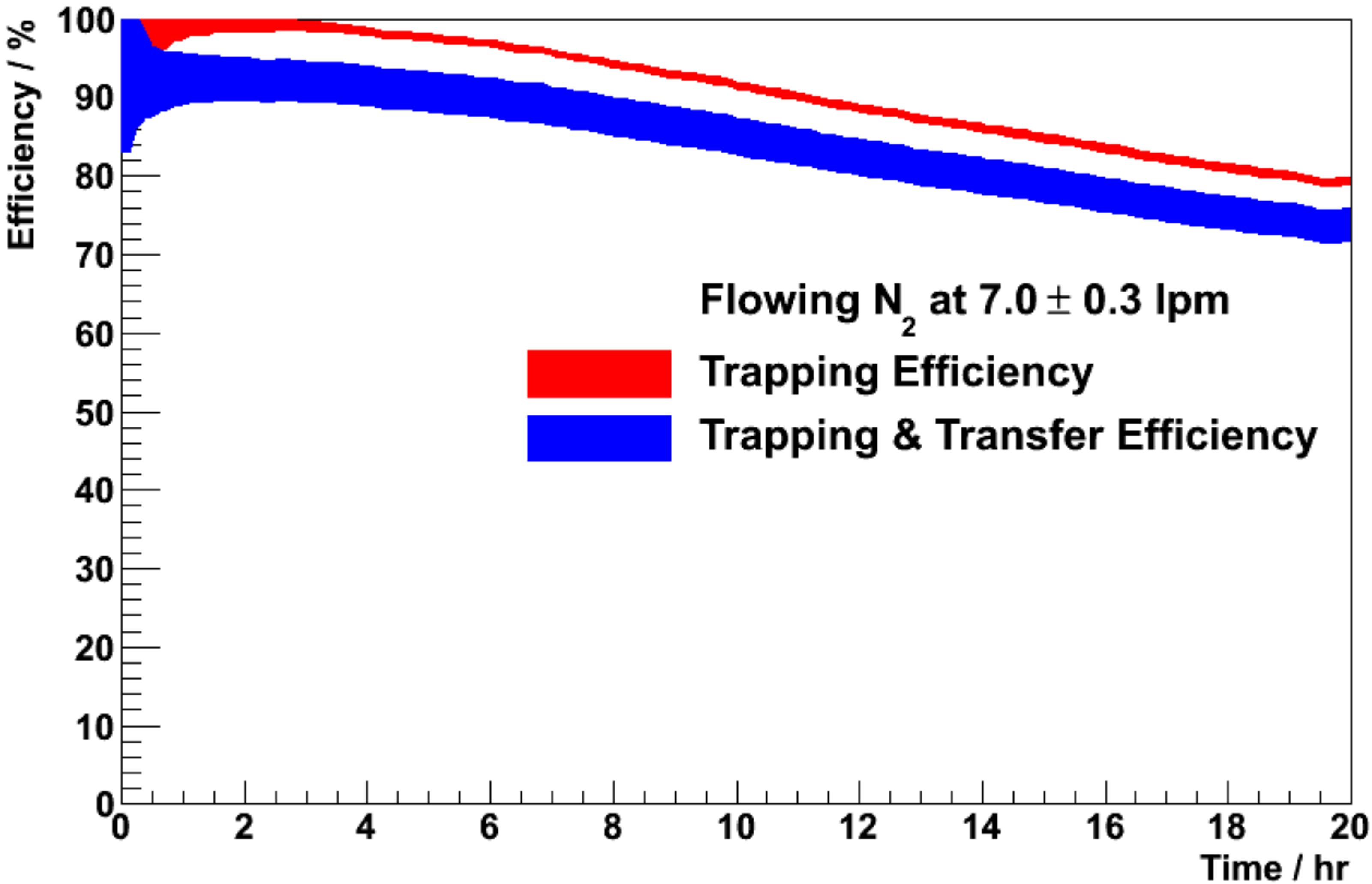
LSM extension has been funded



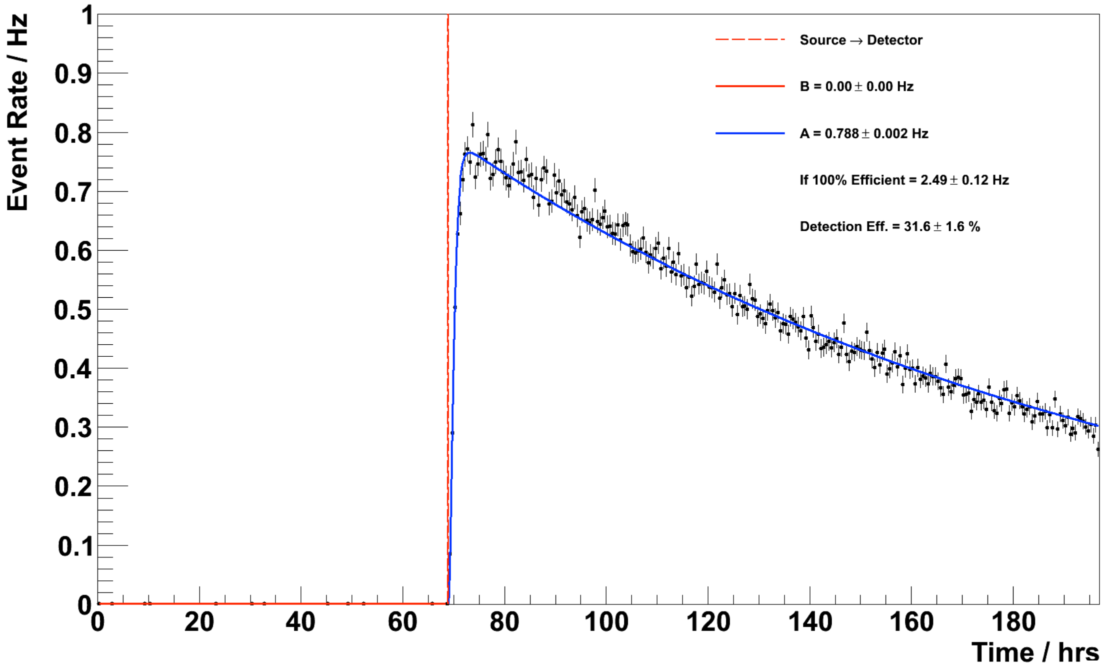
Flow-through Efficiency: ^{214}Po Rate



Flow-through Calibration



Detection Efficiency Calibration



Last calibrated over 1 year ago with a different HV unit. Repeated using helium as the carrier gas;

Po214 = 31.6 ± 1.6%

Po218 = 27.1 ± 1.4%

This result is comparable to the previous calibration result;

Po214 = 31.5 ± 1.3%

Po218 = 28.4 ± 1.1%