Facility Development for Ultra-Sensitive Radon Assaying Based on Electrostatic Counters at the University of Windsor

AboBakr Emara · PhD Candidate, Department of Physics
Email: emaraa@uwindsor.ca
Supervisor: **Dr. Caio Licciardi** · University of Windsor, Canada

University of Windsor

September 2026 · York, United Kingdom

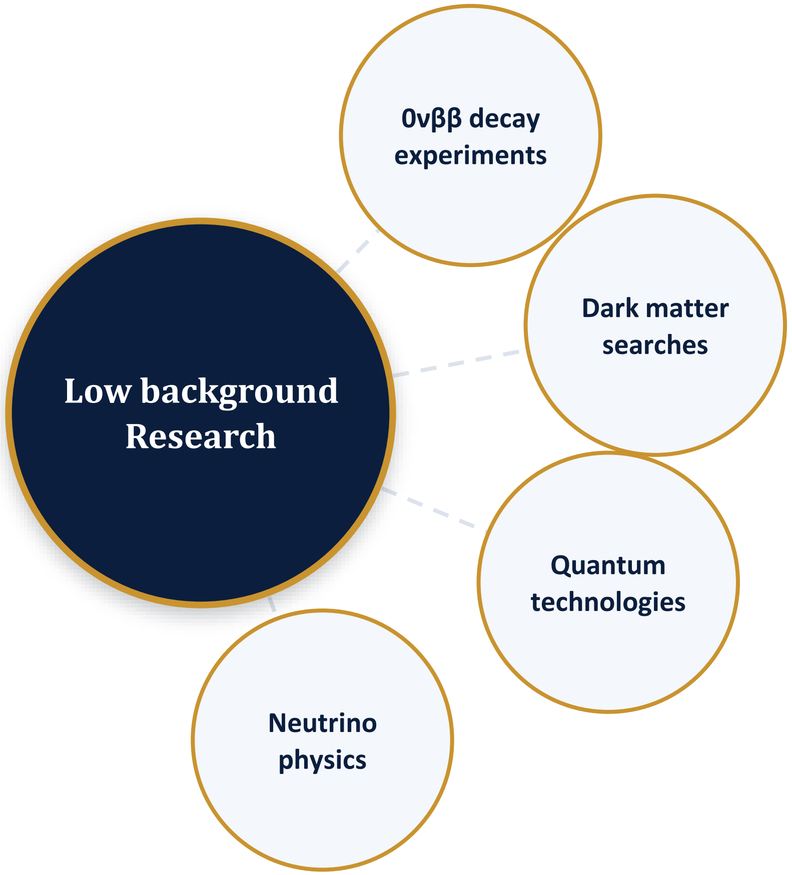
THE CHALLENGE

Radon: the background you cannot screen away

1. Rare-event searches, neutrinoless double-beta decay (e.g., nEXO), dark matter (e.g., XLZD) need detectors with vanishingly low background.

2. Radon-222 is a noble gas: it outgasses from ordinary detector materials and mixes freely through experimental volumes.

3. Its short-lived progeny plate out onto detector surfaces, leaving long-lived radioactive contamination that can mimic the very signals being searched for.



3.8 days half-life of ^{222}Rn long enough to travel far from where it emanates, short enough that its damage outlives the measurement.

WHY IT HIDES IN PLAIN SIGHT

One gamma line away from the signal itself

Q-value coincidence

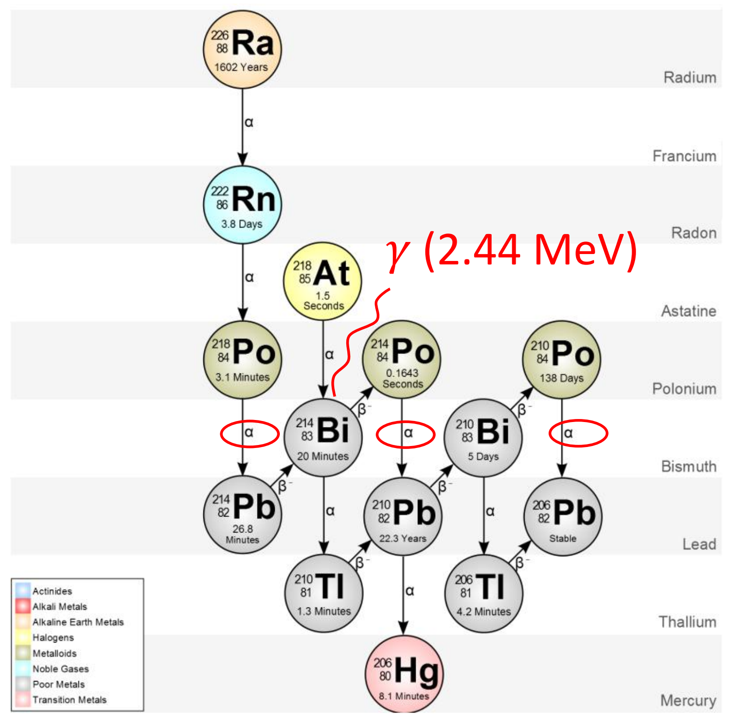
The 0νββ Q-value of ^{136}Xe (≈2458 keV) sits right beside the 2.44 MeV γ-ray emitted by ^{214}Bi, a radon daughter — a near-perfect background overlap.

(α,n) reactions

Alpha particles from the radon chain can drive (α,n) reactions that produce neutron-capture ^{137}Xe, itself a β-emitter mimicking signal-like events.

Surface memory

Plated-out ^{210}Pb and ^{210}Po (half-life 22 years, 138 days) keep contaminating detector surfaces long after the radon itself has decayed away.



Bi-214 / Po-214 sit at the heart of the lower decay chain — exactly where ultra-sensitive alpha spectroscopy must do its work.

To build a clean detector, you must already have a sensitive one

Every part of a rare-event detector from its housing to its photosensors must be screened for trace uranium and thorium before it is trusted. Doing that screening itself demands ultra-sensitive assay instruments, matched to where in the decay chain a technique is most sensitive.

Upper chain

ICP-MS · Neutron Activation Analysis

Bulk U / Th content of raw materials

Medium chain

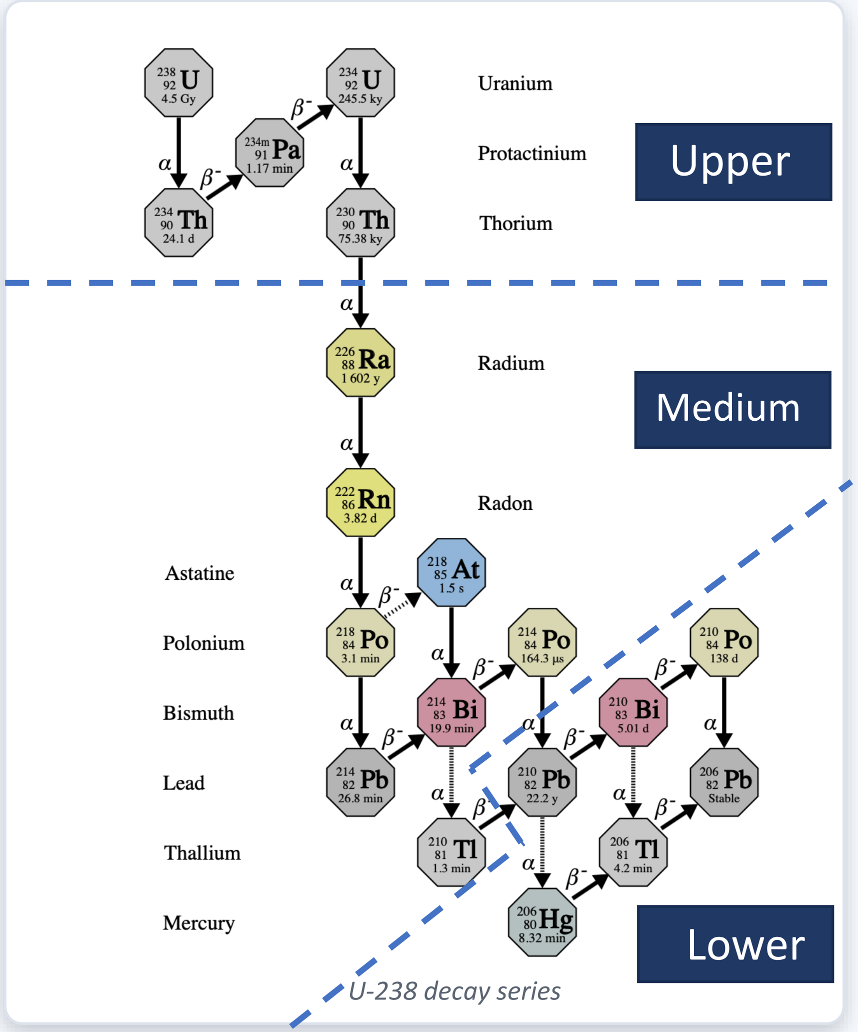
HPGe γ-spectroscopy · Radon emanation

Screens components — where this work sits

Lower chain

Ultra-sensitive α / β counting · Low-energy HPGe

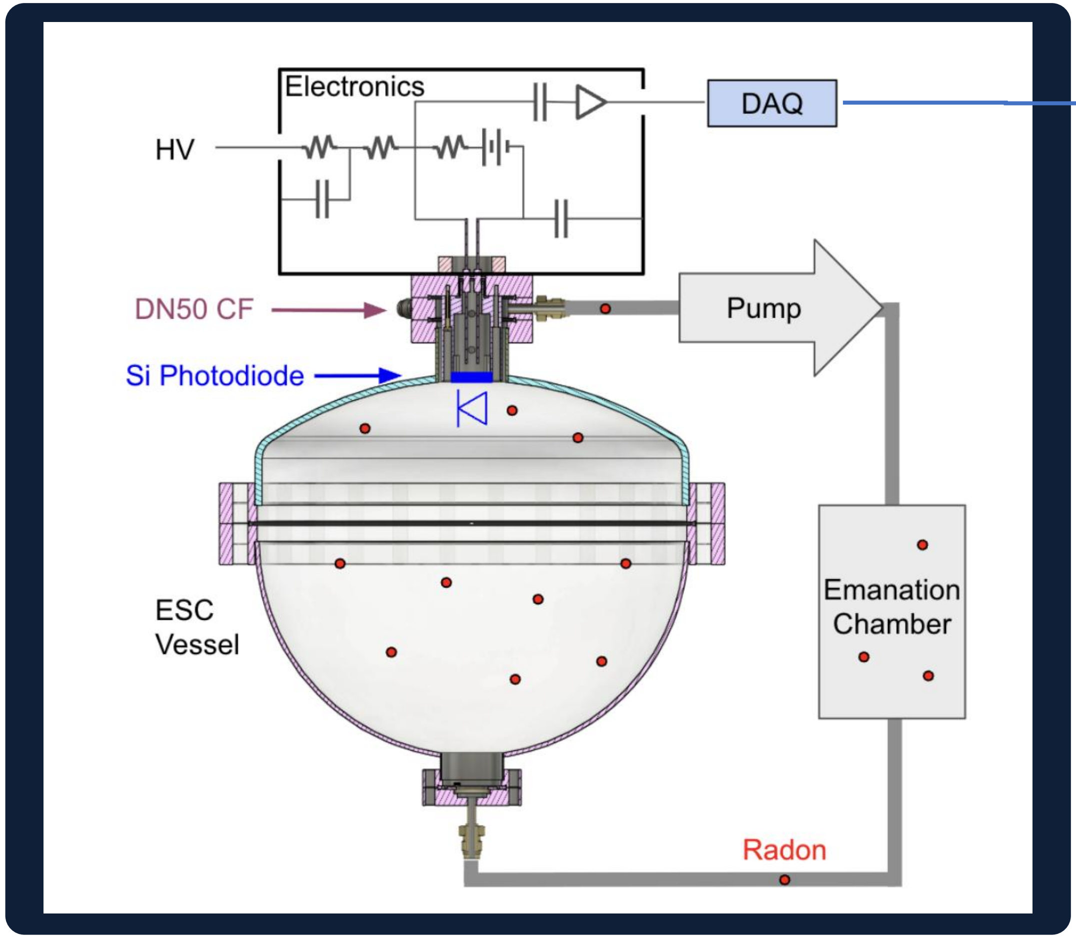
The final, most stringent checkpoint



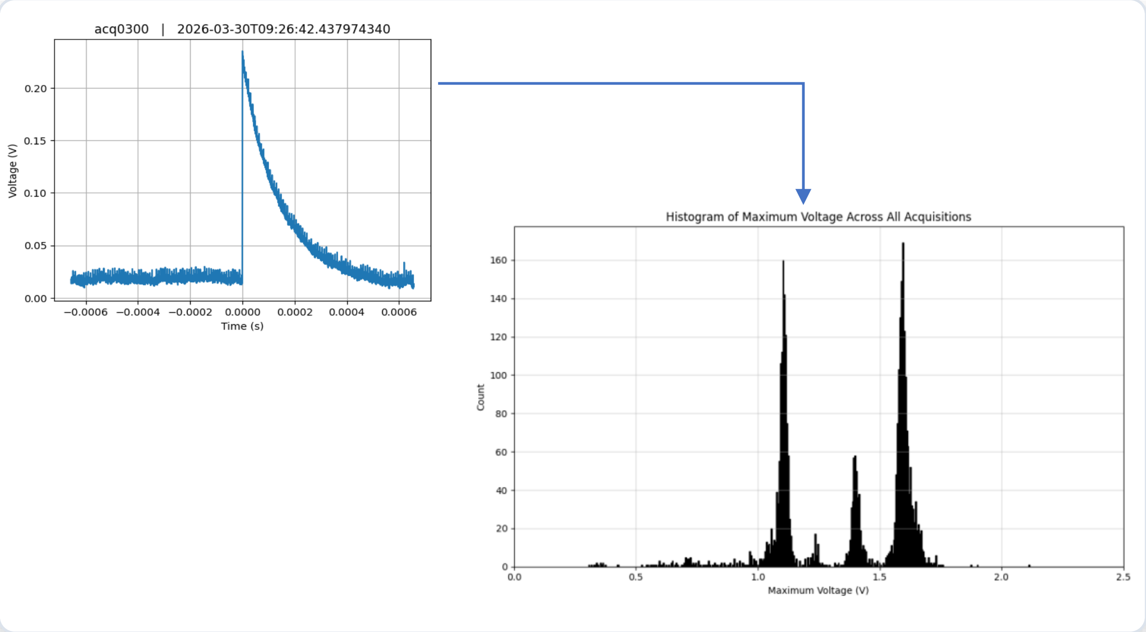
U-238 decay series

cf. I. Arnquist, "Radioassay for Future Low-Background Experiments" — sensitivity increases, and material coverage narrows, deeper down the chain.

Electrostatic collection chambers (ESCs)



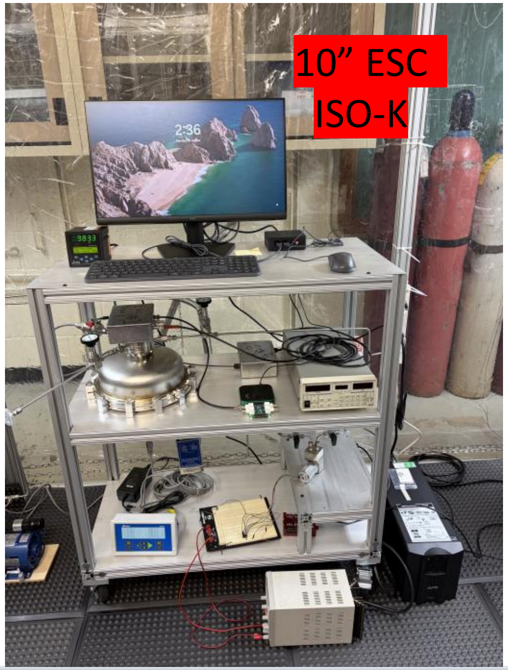
SLAC ESC design (arXiv:2504.15464)



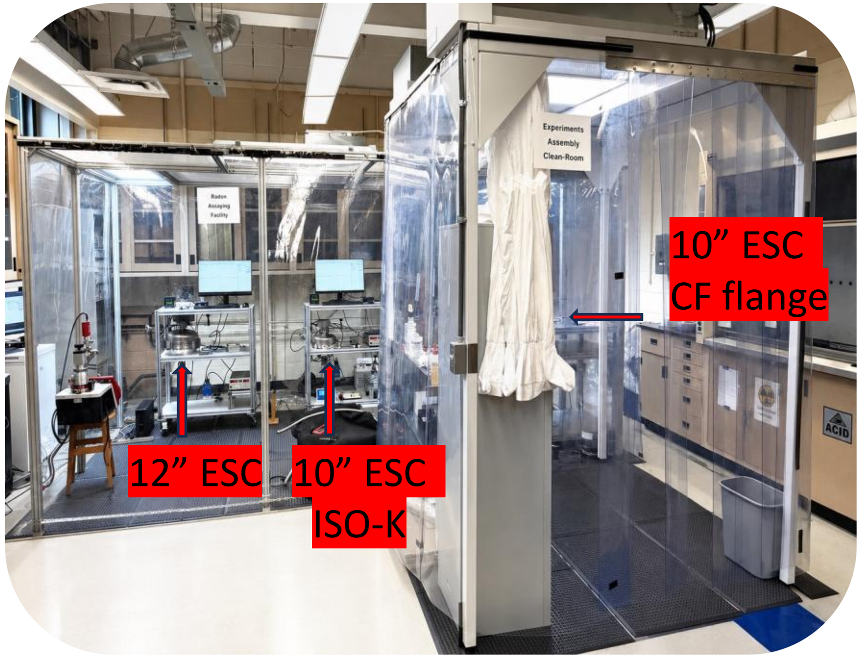
1. Progeny of ^{222}Rn are positively charged after alpha decay.
2. An applied electric field drifts the ion onto a biased silicon detector.
3. Alpha spectroscopy resolves characteristic energies to quantify radon activity.

A dedicated radon assay facility at the University of Windsor

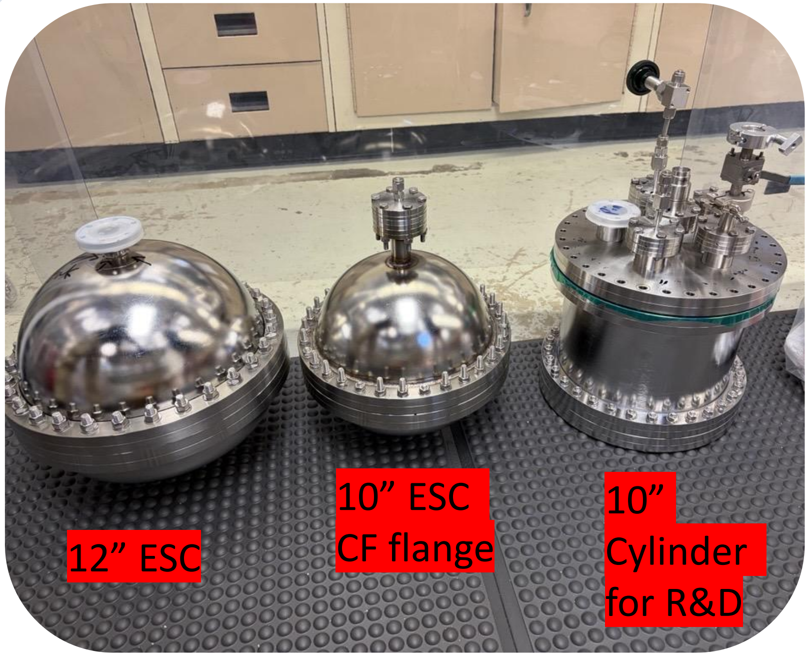
Multiple ESC volumes, 5–15 L, spherical and cylindrical, operating side by side to cross-check performance and optimize sensitivity housed inside a dedicated clean room to keep intrinsic background low.



Recirculating ESC gas system



Experiments assembly clean room



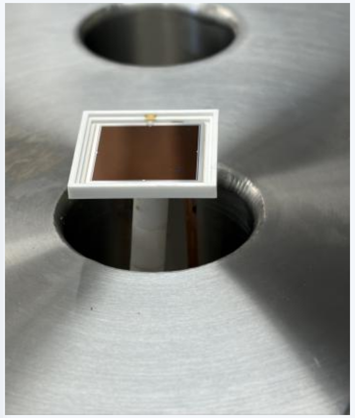
Different sizes and shapes ESC vessels

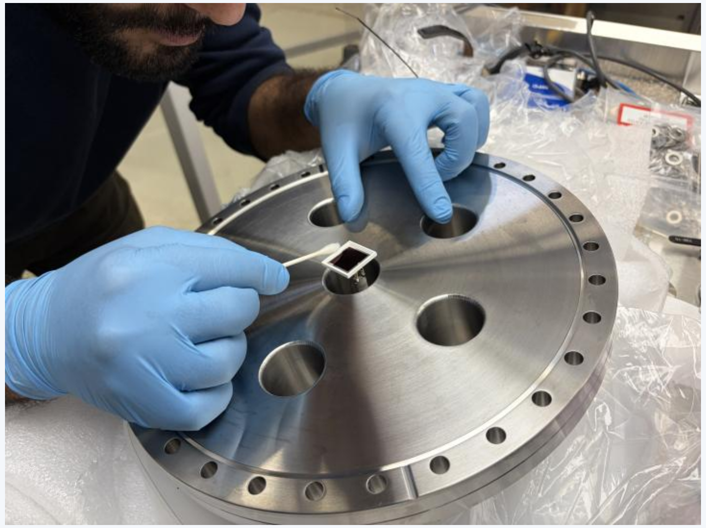
Design target: operate multiple ESCs at tens-of-μBq sensitivity inside a low-background clean-room environment.

THE FACILITY

ESC detectors main features

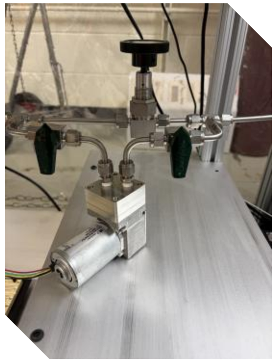
- Stainless steel metal
- CF flanges and VCR connections
- Electropolished surfaces
- Clean ¼” Swagelok tubing
- Ultra clean recirculation pumps
- Clean assembled
- Helium leak checked before assembly
- Vacuumed to 10^{-6} mbar before start assaying





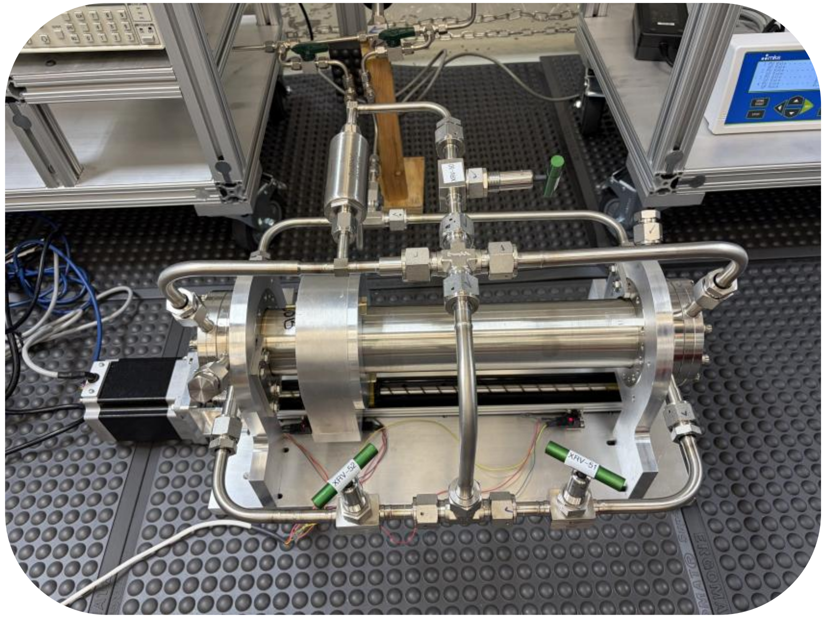
Ultra clean ESC system require ultra clean pump

- KNF (N96STDC-B-M) diaphragm pump
- EXO-200 magnetically coupled pump replica
- Iwaki (BA-330SN) bellow pump customized head in progress
- SLAC collaborators custom ultra-clean bellow pump rebuilding in progress



KNF (N96STDC-B-M)

Iwaki (BA-330SN)

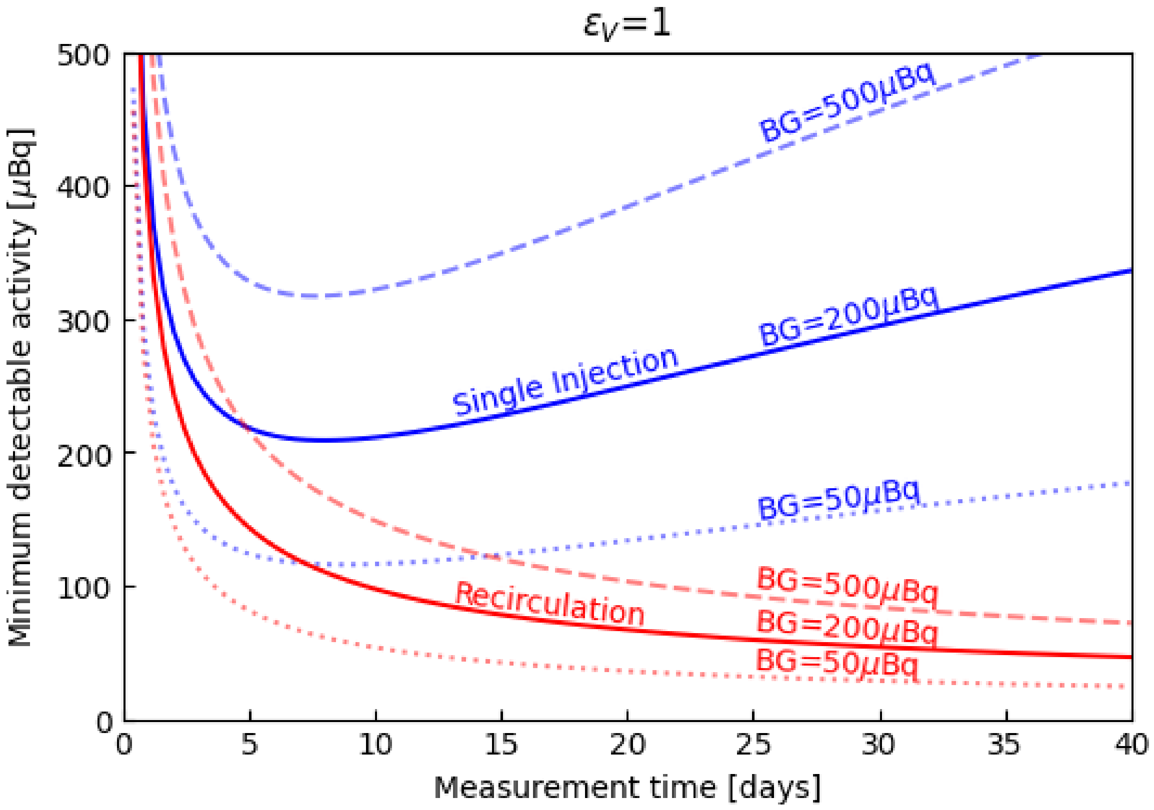


EXO-200 recirculation pump (arXiv:1104.5041)

Different recirculation pump technologies are being tested for the most radioactive clean and reliable for long term running

Minimum Detectable Efficiency (MDA) and current backgrounds

You don’t need your detector background to be tens of µBq, but you can still measure very low background materials. Simulation for recirculation system shows that you can get a better MDA even with higher background



Minimum detectable activity Vs Time— credit: Brian Mong

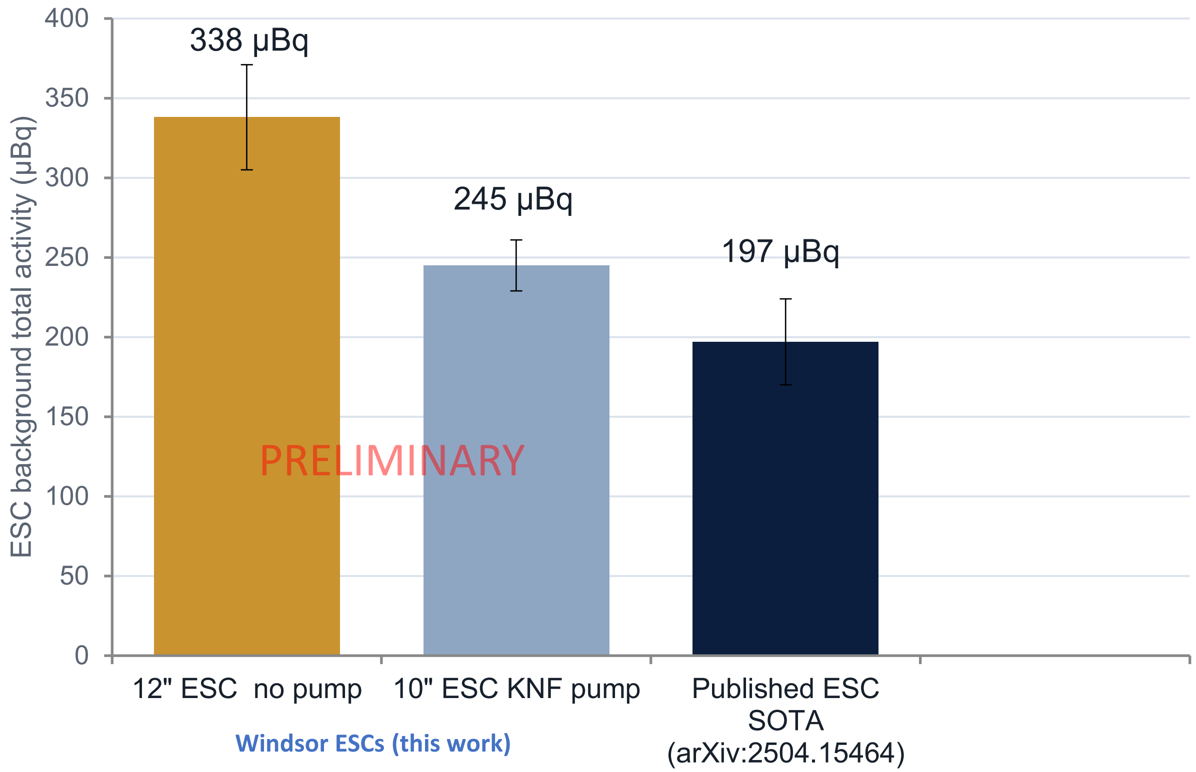
Run longer

Recirculation mode

Start with clean ESC

Already competitive with the published literature

Background runs with both custom semi-spherical ESCs, during commissioning:



< 300 µBq

reached in commissioning runs on both ESC geometries.

197 µBq

published benchmark for a comparable recirculating ESC (arXiv:2504.15464).

tens of µBq

the facility's design target as R&D upgrades come online.

WHAT LIMITS SENSITIVITY

Deconstructing the detection efficiency

$$\varepsilon_{\text{Detection}} = 0.25\text{-}0.45 = f_{\alpha} \times f_{S} \times f_{E} \times f_{V}$$

fα

Ionization fraction

~88% R&D focus

fS

Solid-angle fraction

~50% isotropic decay

fE

Field collection efficiency

Based on geometry

fV

Volume-sharing factor

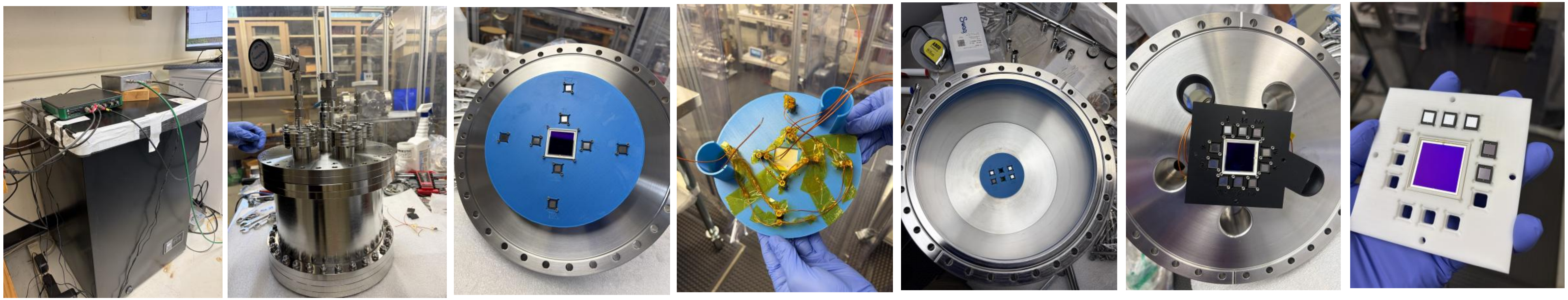
future work

R&D · EFFORTS

Cylinder ESC with SiPM VUV scintillation detectors

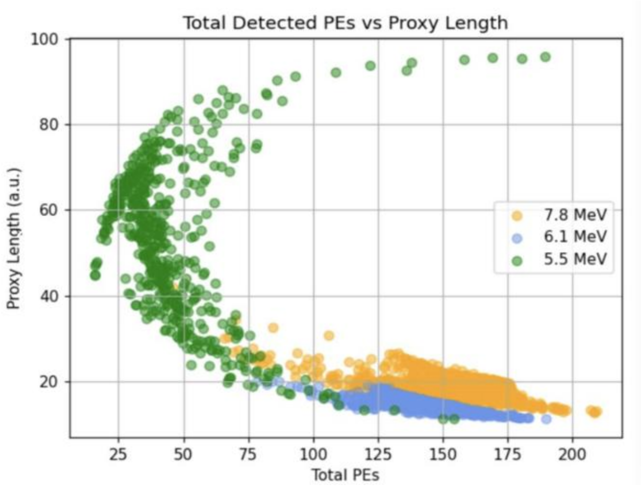
Implementing Hamamatsu VUV4 SiPM inside a cylindrical ESC. Along with the PIN diode to study the ^{218}Po fractionation factor in argon gas and increase ESC detection efficiency

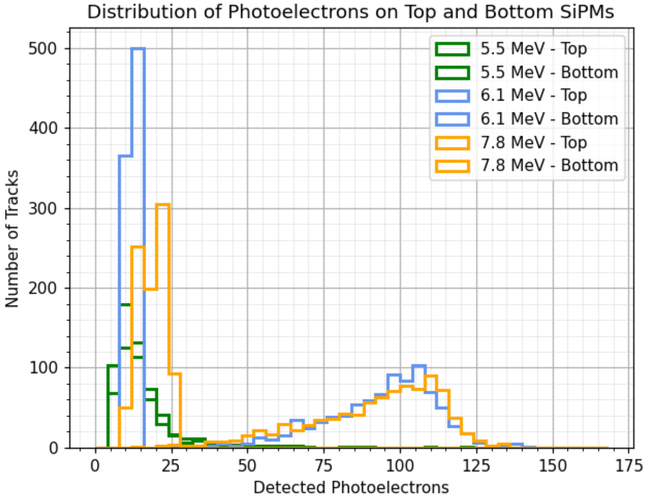
1. SiPMs collect scintillation light from the argon fill gas, alongside the PIN-diode alpha signal.
2. Detectors are cooled to −40°C to suppress SiPM dark counts, in a commercial freezer.
3. A joint energy and topological measurement sharpens particle identification and improves the total detection efficiency.

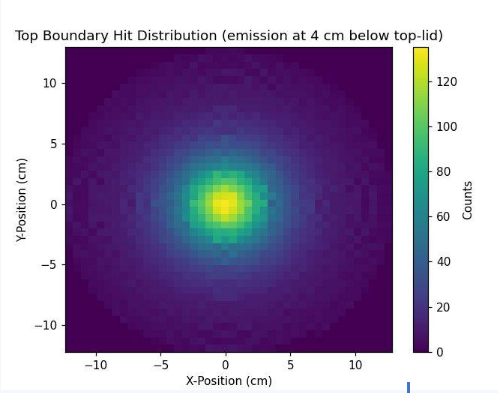


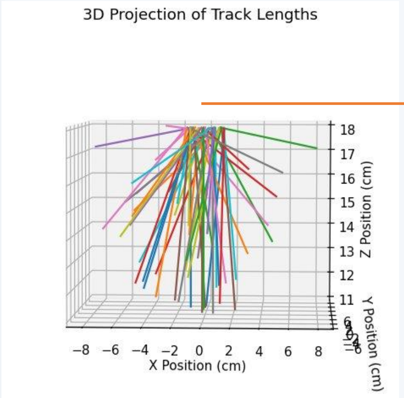
Adding scintillation light to the alpha signal

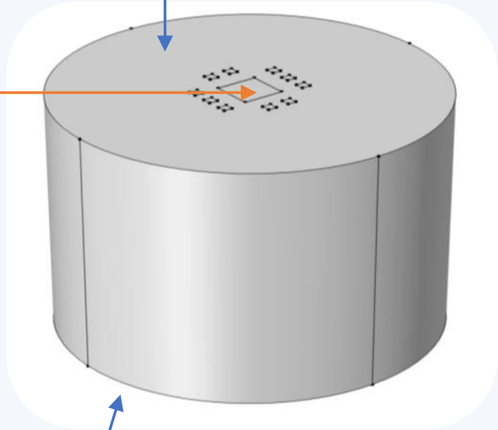
- 3 channels of SiPMs, two concentric at top and one at bottom. Each has 4 SiPMs in parallel
- COMSOL simulations show light collection across the cylindrical ESC
- A promising population separation based on the alpha energies
- Very helpful for measuring the ^{222}Rn ionization fraction



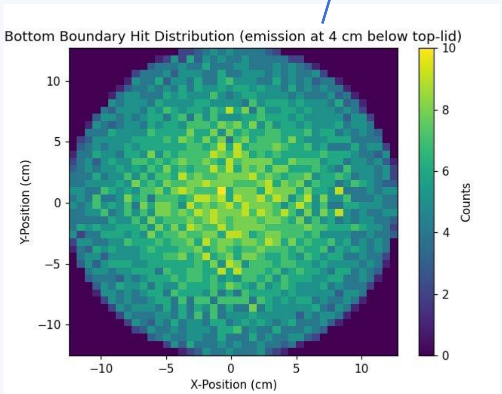






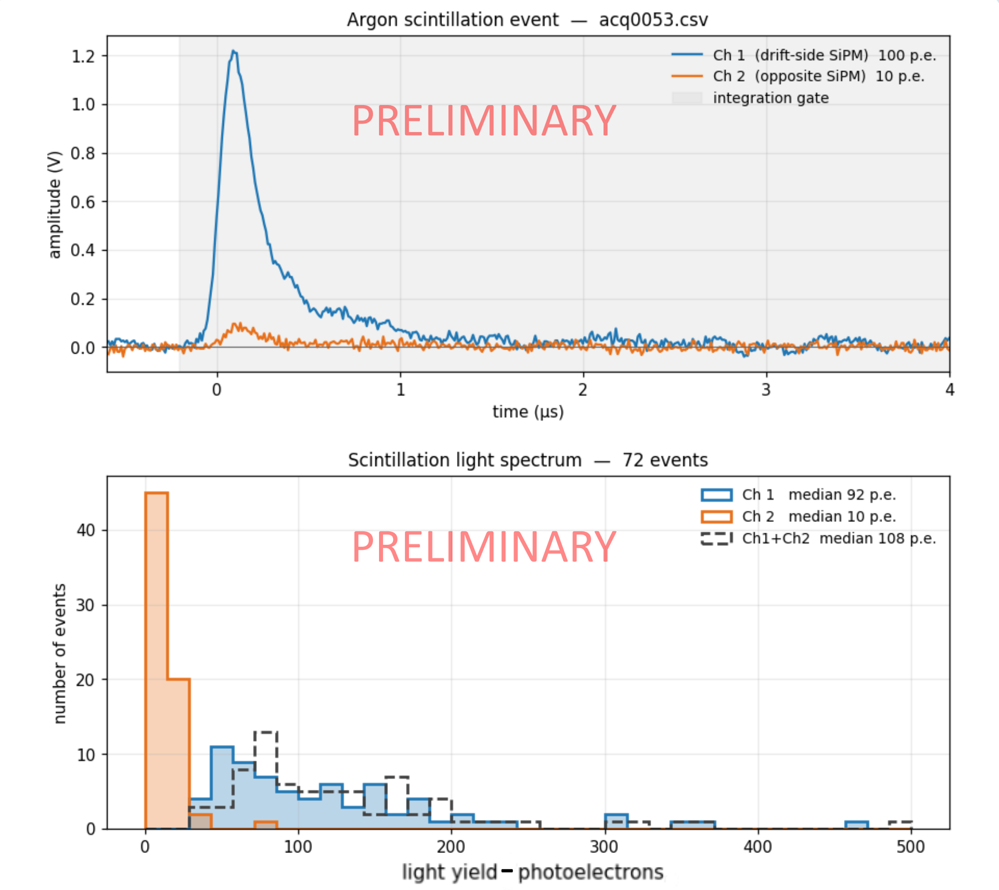


New cylindrical ESC design

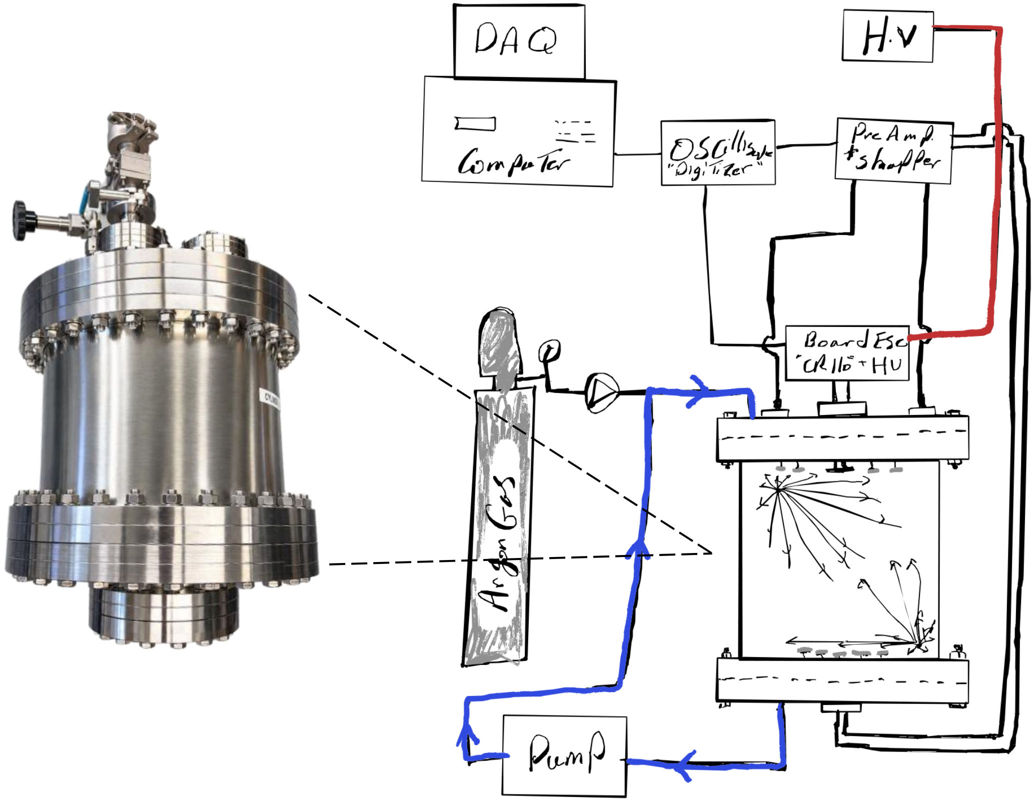


Simulated light collection on the SiPM plane — credit: S. Bottrill

First light: alpha energy and scintillation light



Measured alpha scintillation light on SiPMs



Correlated alpha-energy and scintillation-light measurements deepen our understanding of the decay physics inside the chamber — and point directly to a higher total ESC efficiency.

CLOSING THE LOOP

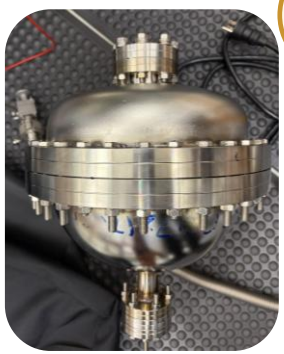
Calibrating the remaining efficiency factors

An absolute, known-activity radon source and a dedicated emanation chamber let us pin down fα and fV directly — turning the efficiency model into a calibrated, absolute measurement.

fα

^{222}Rn calibration source

A known-activity source provides an absolute reference for the ionization fraction and overall detection efficiency (led by Dr. T. Shetty). We use AlphaGuard detector to quantify the uncertainty of this 74 bq calibration source



fV

Emanation chamber

Dedicated emanation studies quantify the volume-sharing factor within the recirculating gas system (background measurements led by Dr. S. Rahman).

THE BIGGER PICTURE

A central radon-assaying hub using ESC technology

Positioned to support material screening and radon-detector R&D across next-generation rare-event experiments nationwide.

Sensitivity

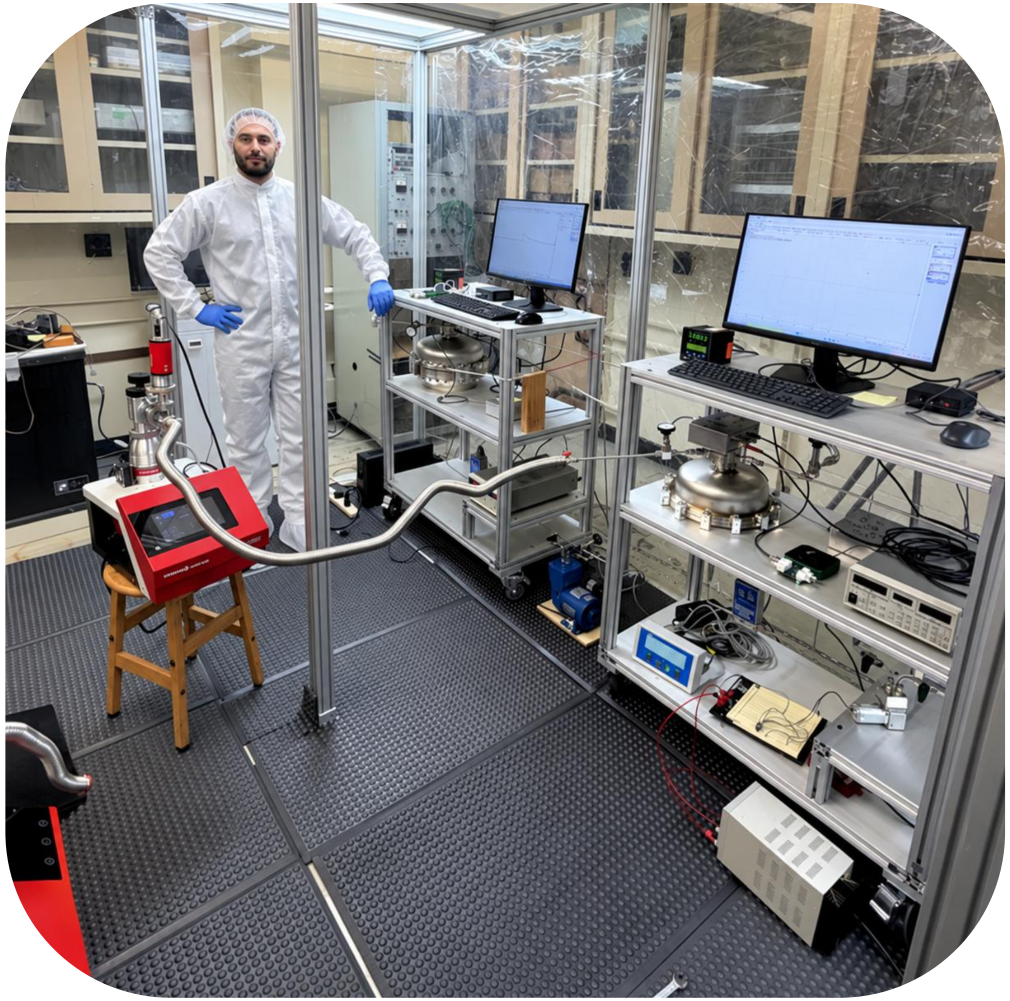
Tens-of-µBq detection target across all active ESC lines.

Capacity

Multiple parallel chambers (5–15 L) inside one clean-room, screening in parallel.

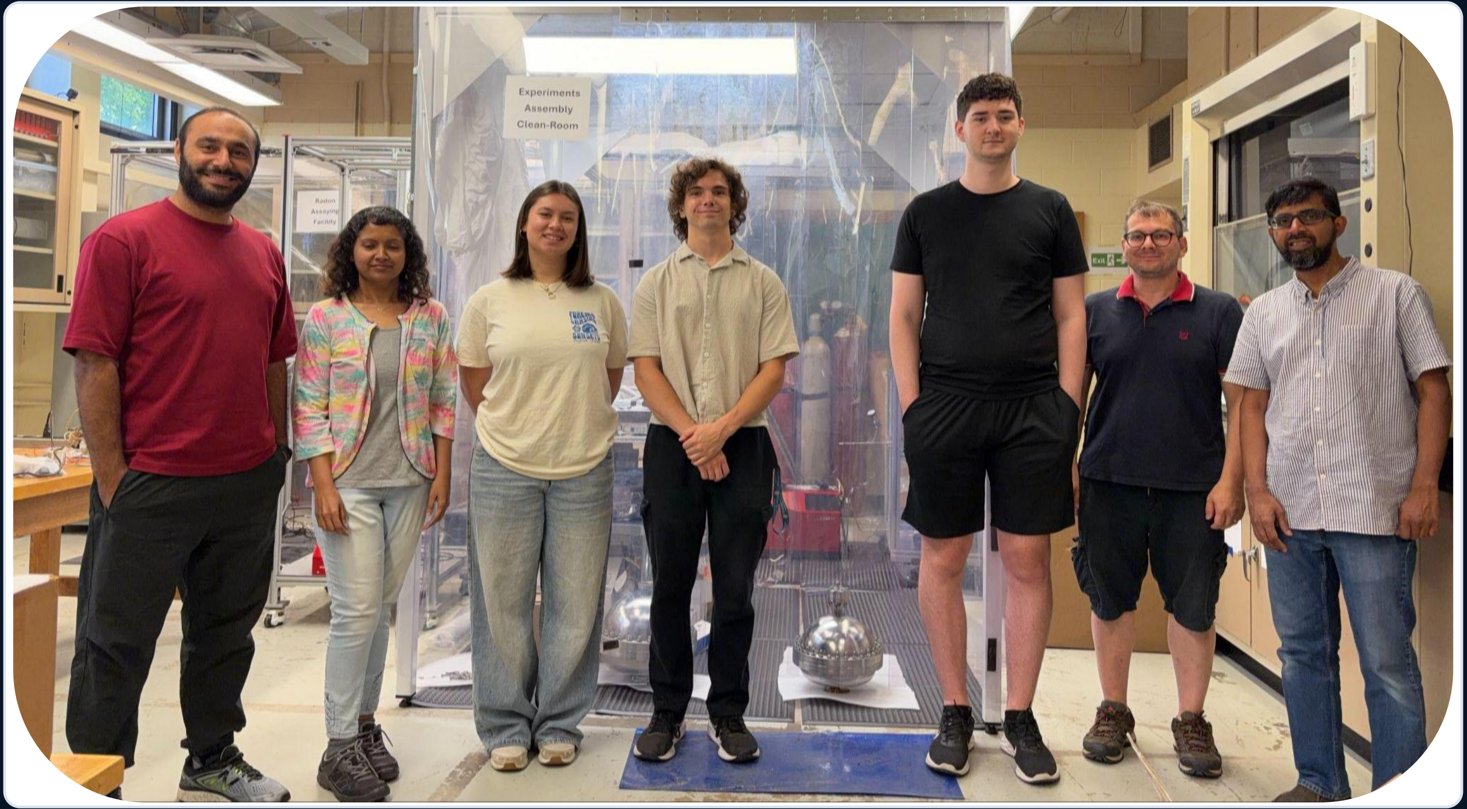
Collaboration

Shared assay service and detector R&D platform for the rare-event community. Windsor is XLZD collaborator now



THANK YOU

The Licciardi Group, University of Windsor



Dr. Caio Licciardi — PI

Dr. Saydur Rahman — Research Associate

Dr. Trilochana Shetty — Postdoc

AboBakr Emara — PhD Student

Akira Lee — Undergraduate

Simon Bottrill — Undergraduate

Matthew Beemer — Undergraduate

Questions and collaboration welcome — **reach out via LinkedIn or email.**