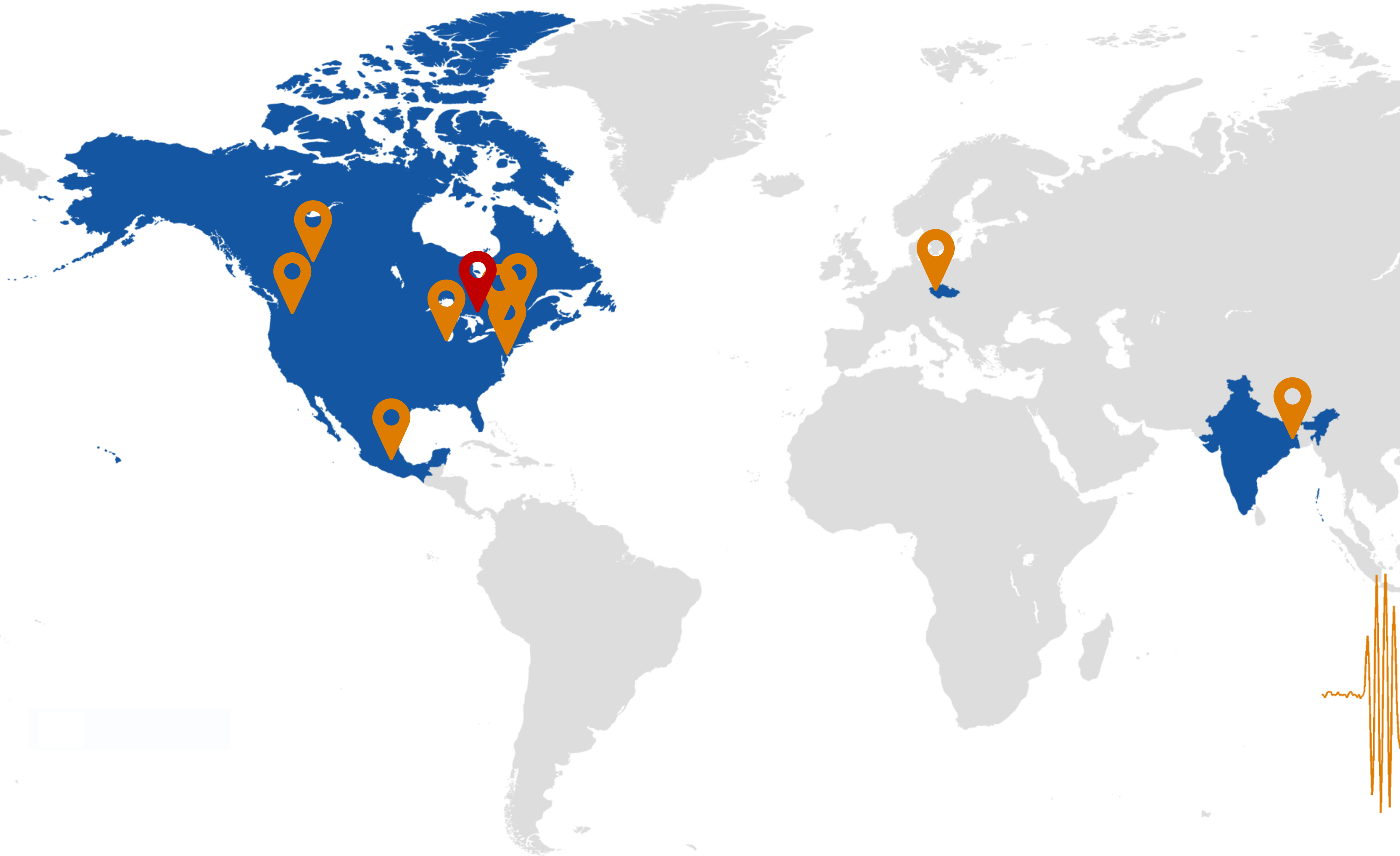
The PICO Dark Matter Search

William Woodley
University of Alberta

On behalf of the PICO Collaboration

TeVPA 2026
31 August 2026

The PICO Collaboration



5 Countries

8 Institutions

35 Members

PICO

The PICO Collaboration

- 6 km.w.e., one of the deepest labs in the world.
- 10^8 reduction in μ flux.

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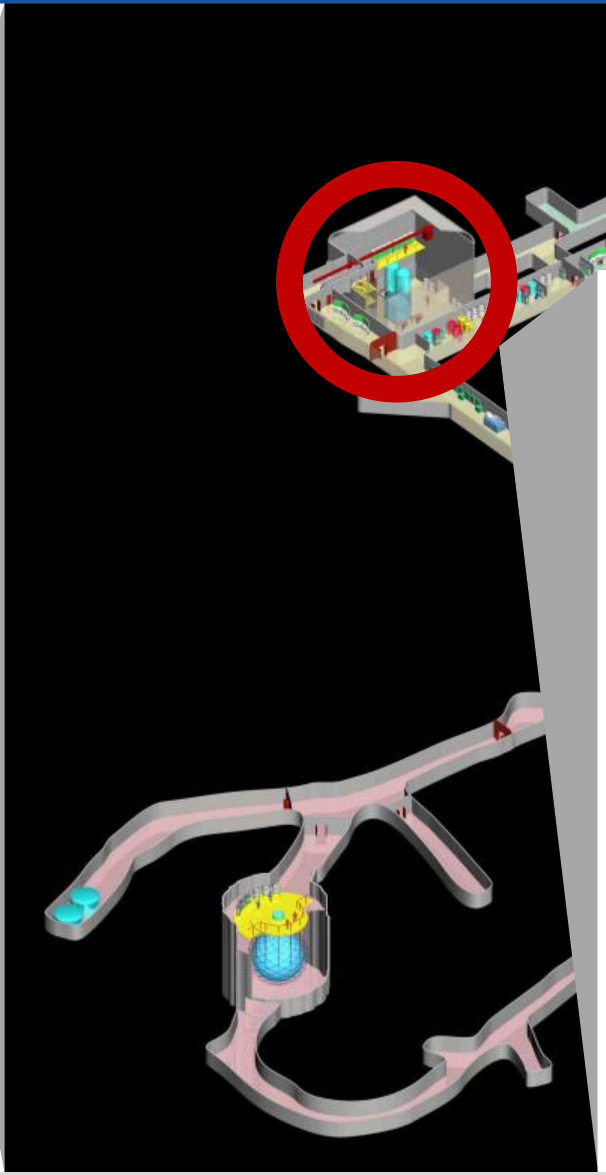
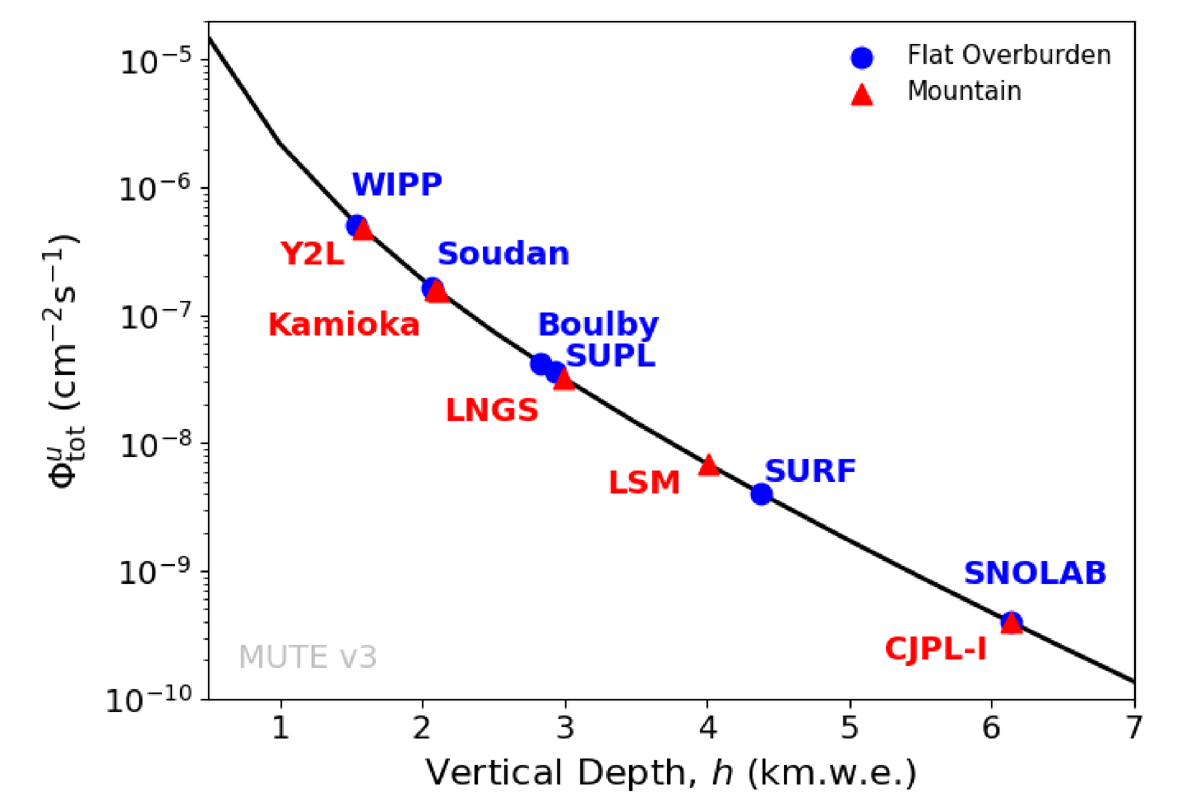
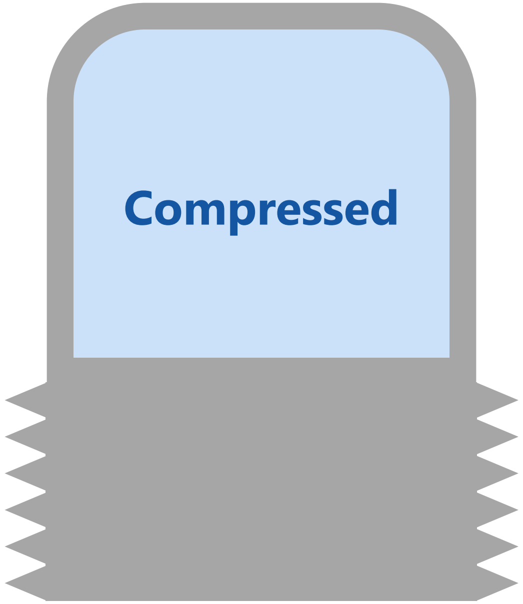




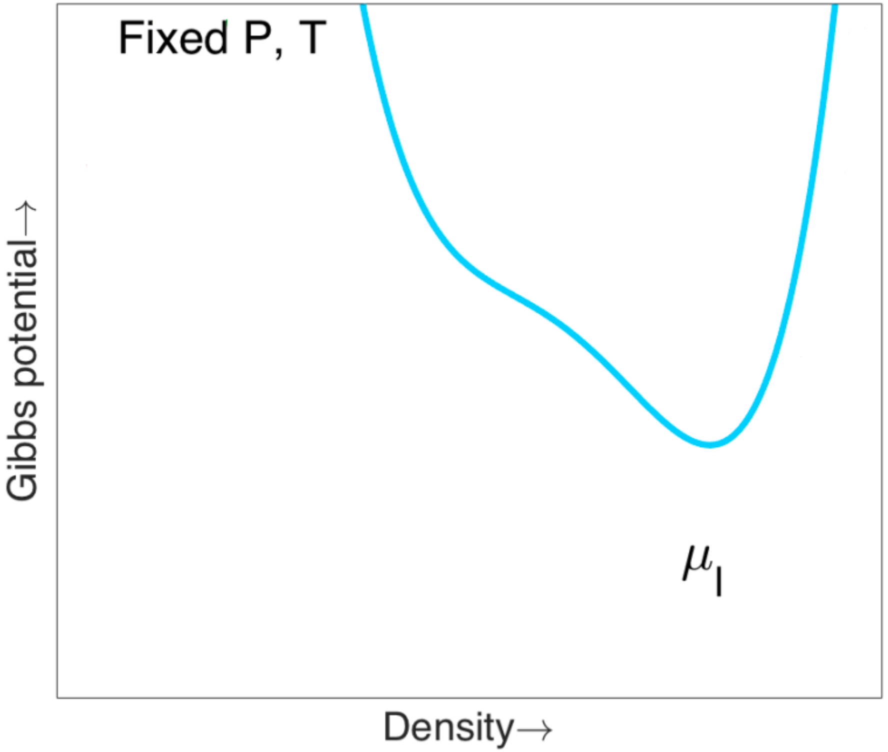
W. Woodley, et al. (2024).
https://github.com/wjwoodley/mute

Bubble Chambers



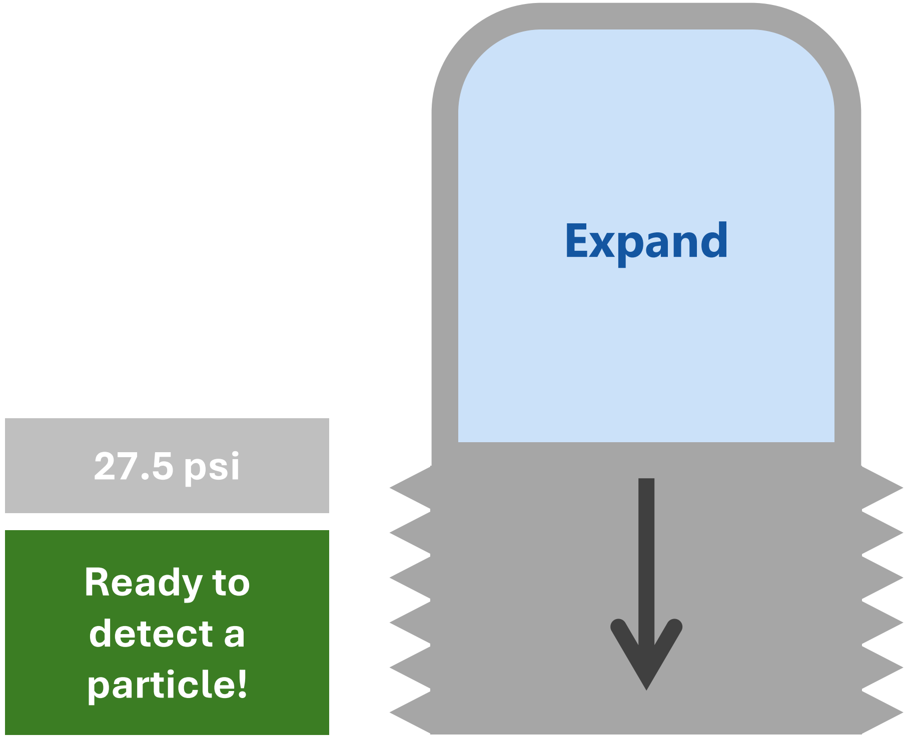
200 psi

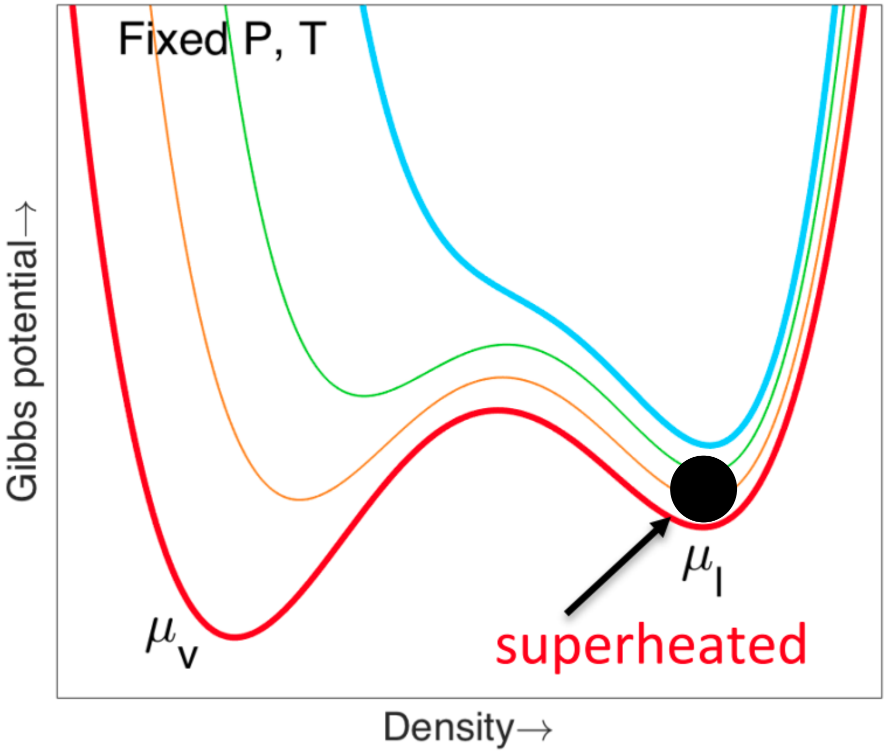
Not ready to detect a particle!



$$Q_{\text{Seitz}} = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4\pi r_c^3}{3}\rho_b(h_b - h_l) - \frac{4\pi r_c^3}{3}(P_b - P_l)$$

Bubble Chambers





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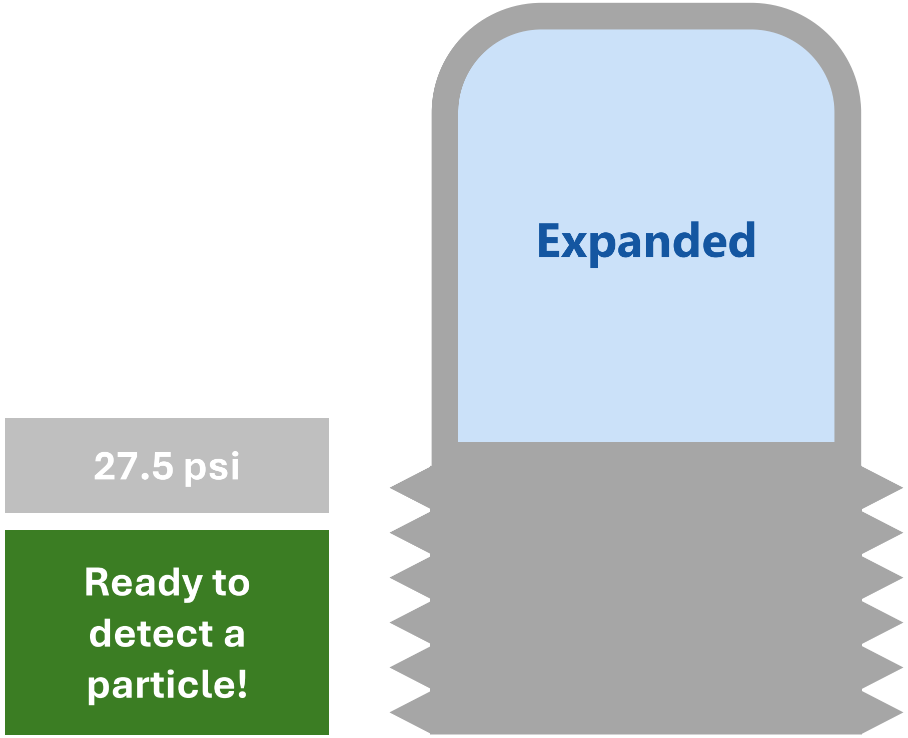
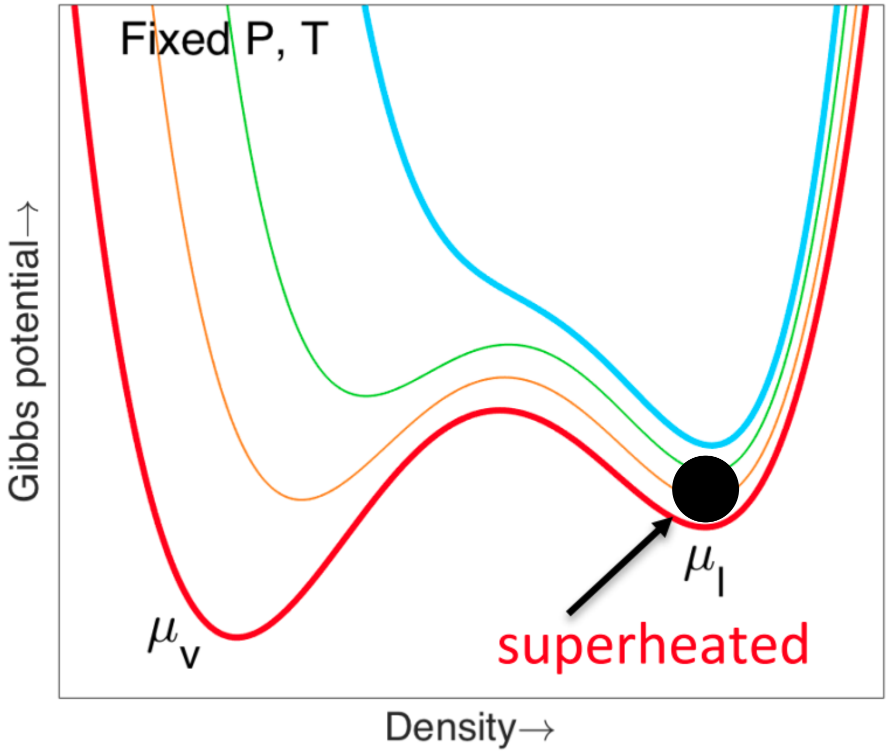
Bubble Chambers





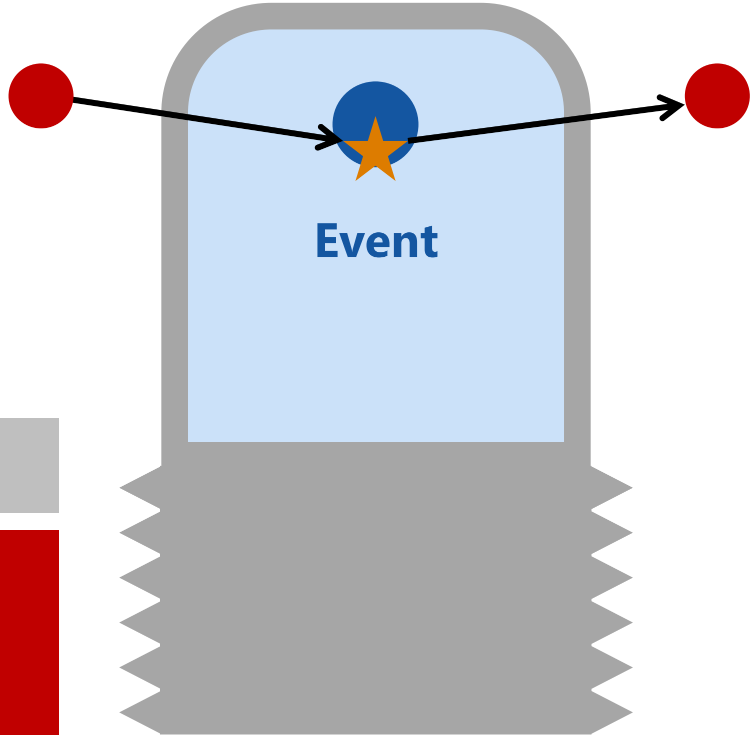
Surface Tension | Phase Transition | Expansion of Vapour

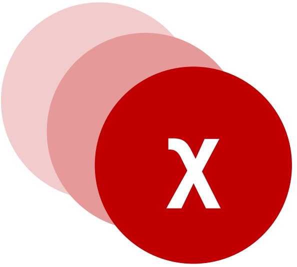
$$Q_{\text{Seitz}} = \boxed{4\pi r_c^2\left(\sigma - T\frac{\partial\sigma}{\partial T}\right)} + \boxed{\frac{4\pi r_c^3}{3}\rho_b(h_b - h_l)} - \boxed{\frac{4\pi r_c^3}{3}(P_b - P_l)}$$

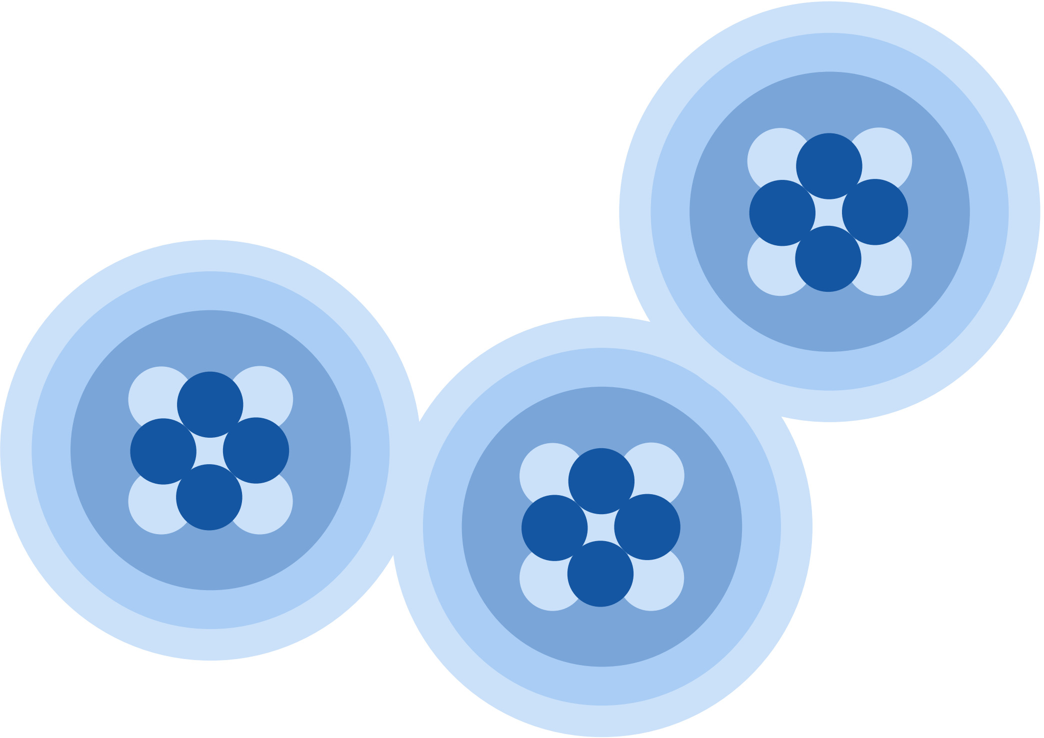
Bubble Chambers

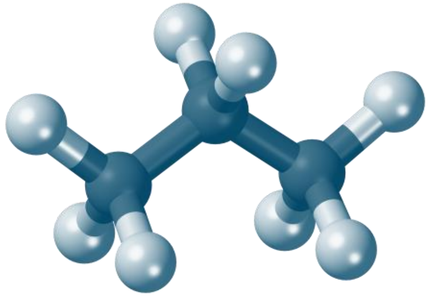
27.5 psi

Detects a particle!









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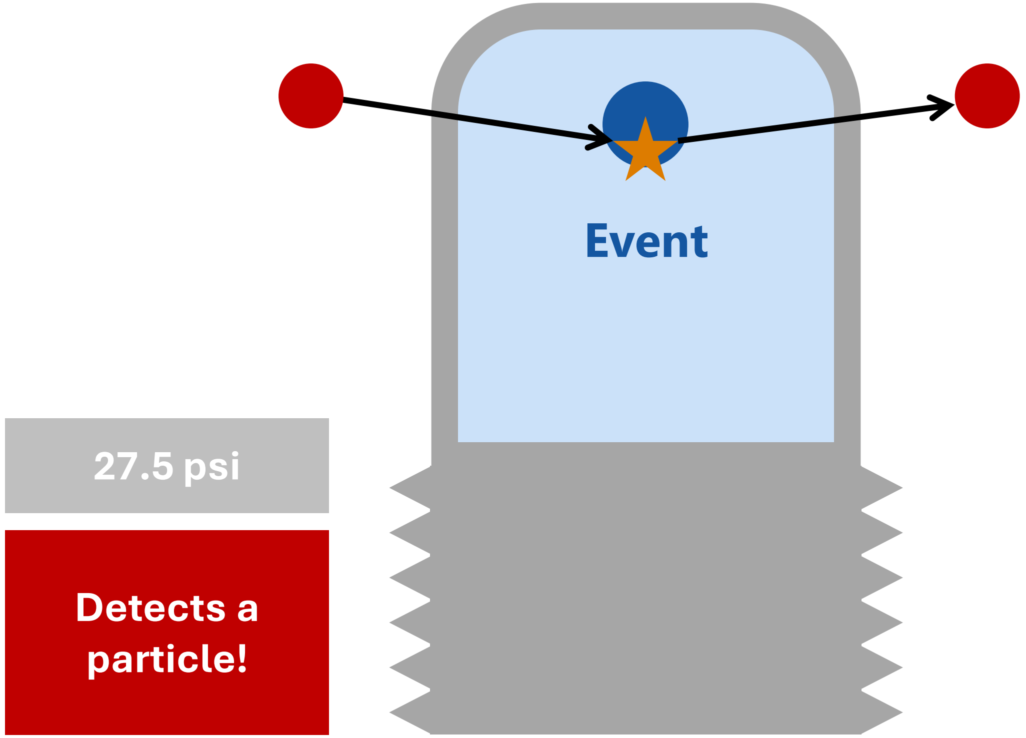
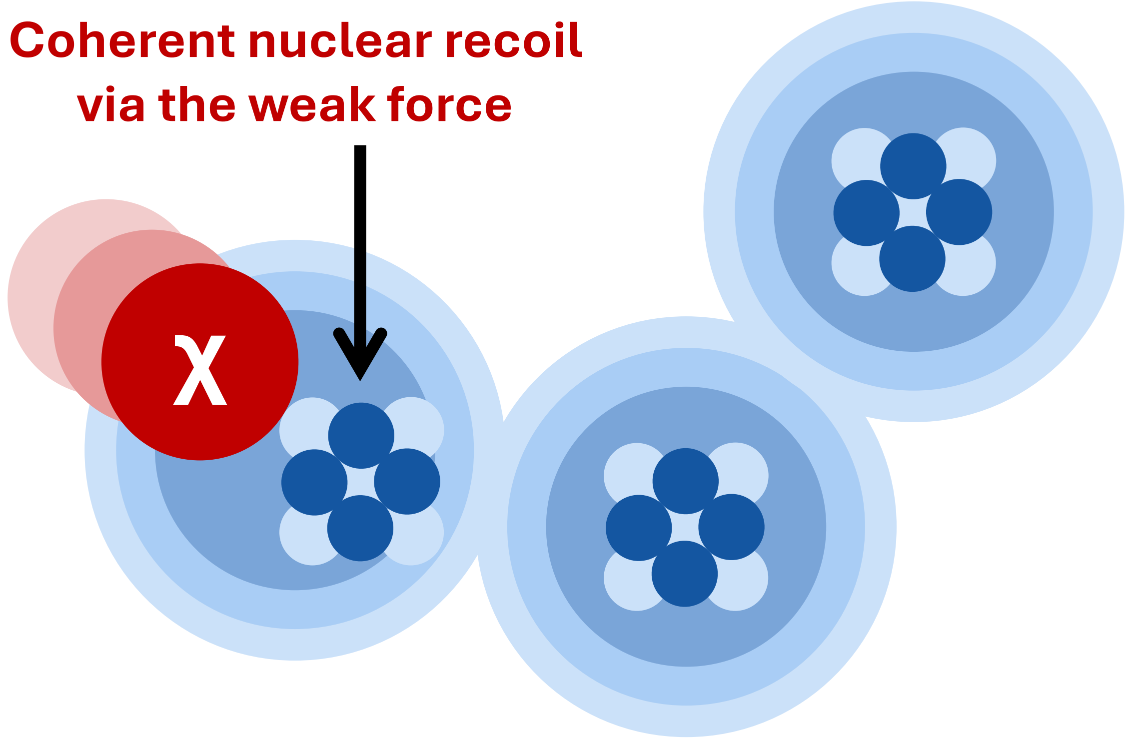
Bubble Chambers





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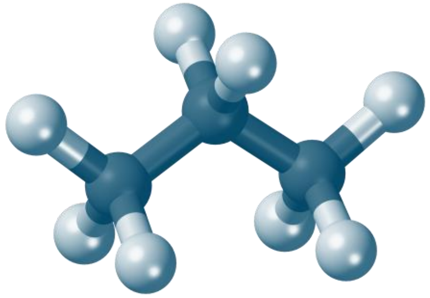

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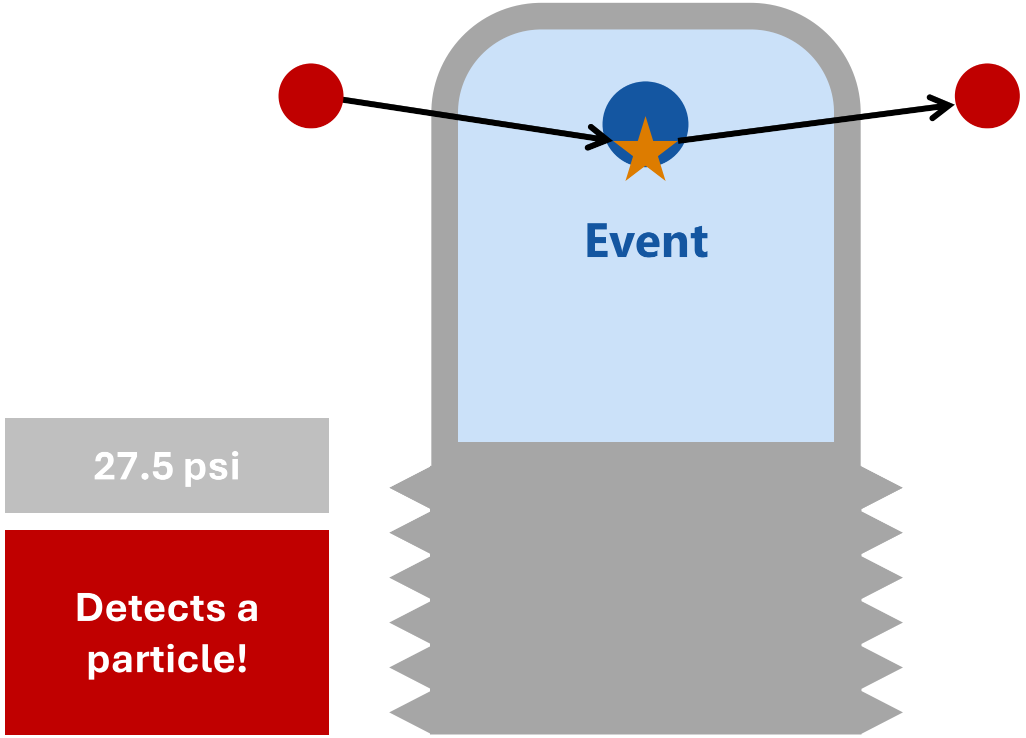

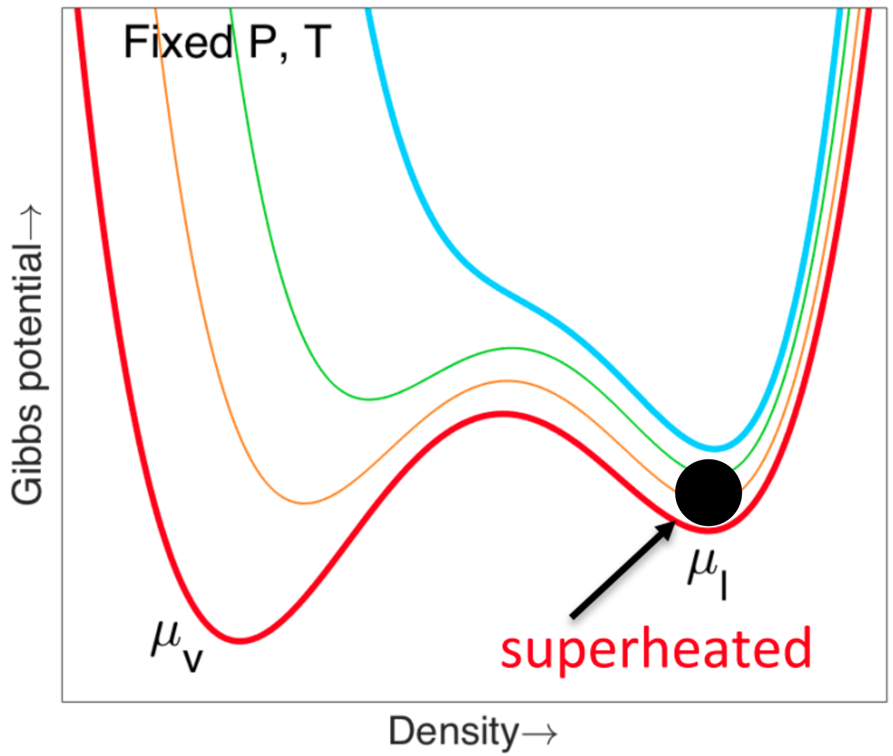

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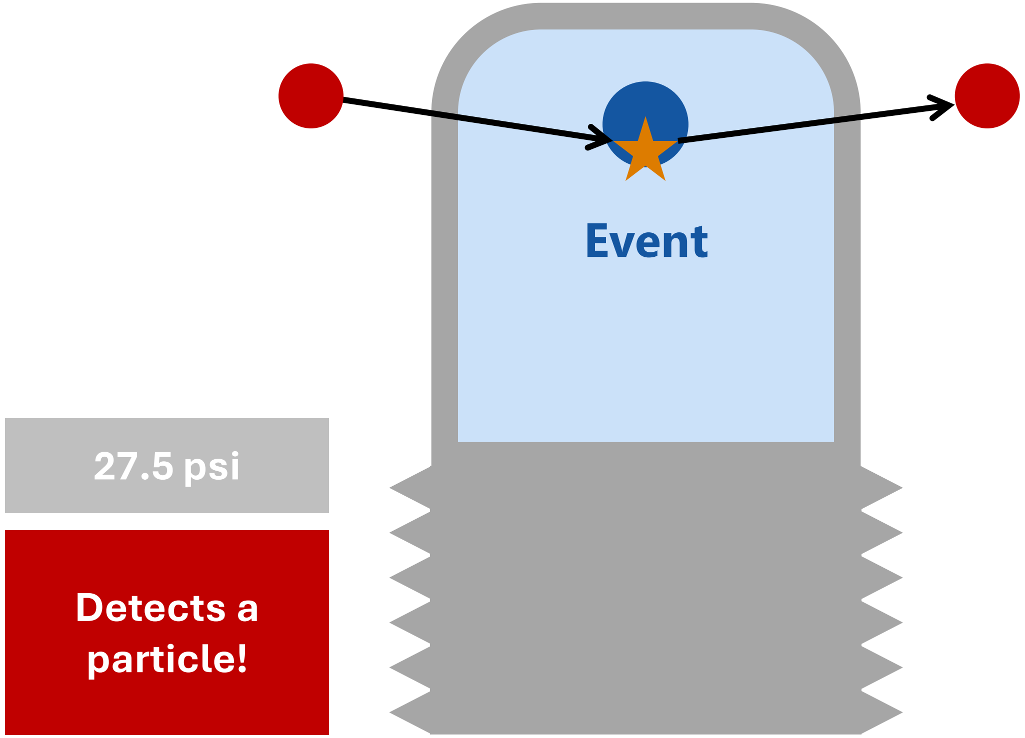
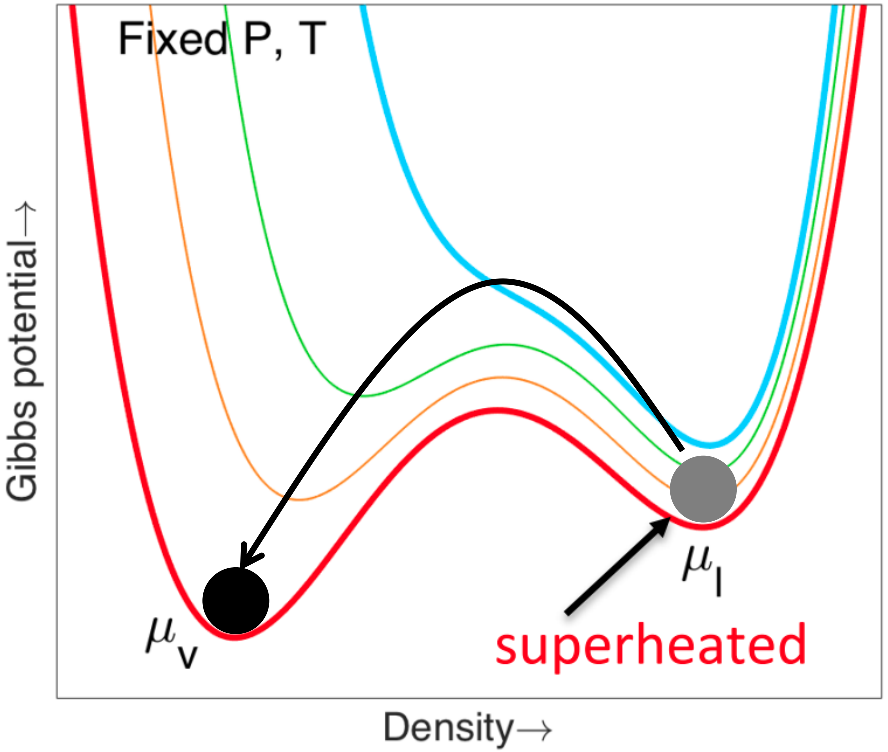
Bubble Chambers





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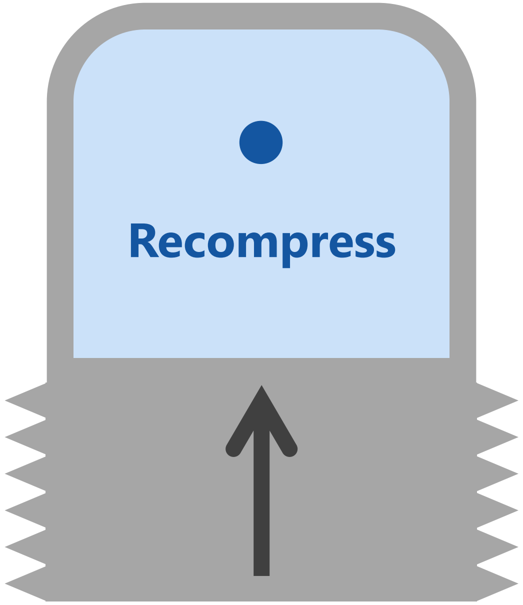
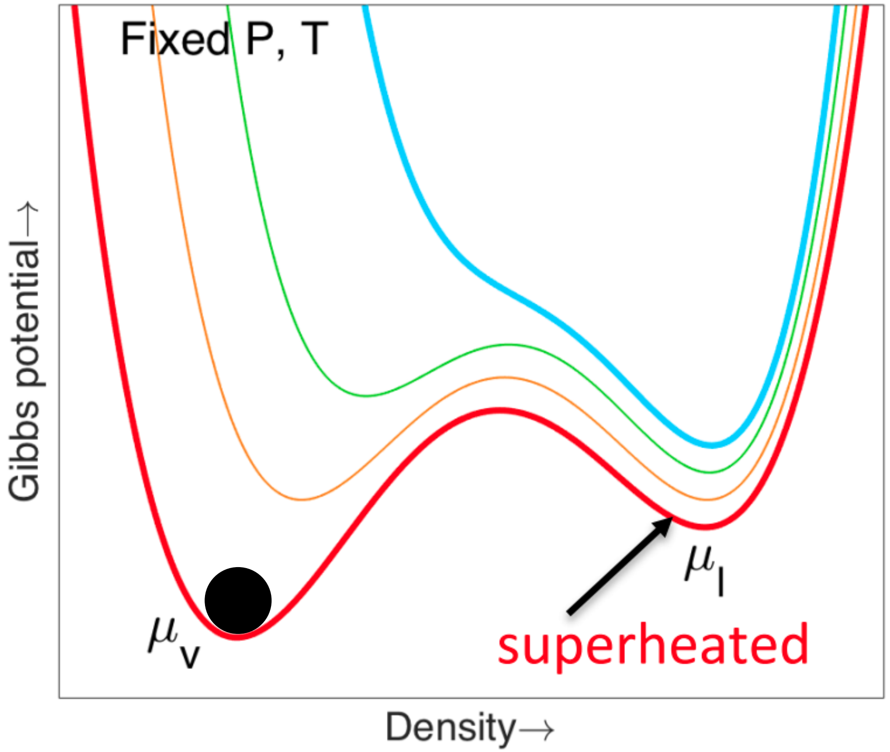
Bubble Chambers

200 psi

Not ready to detect a particle!





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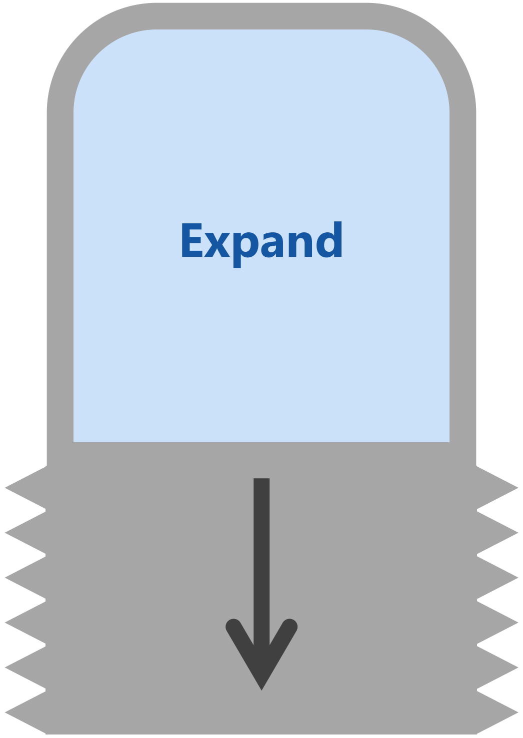
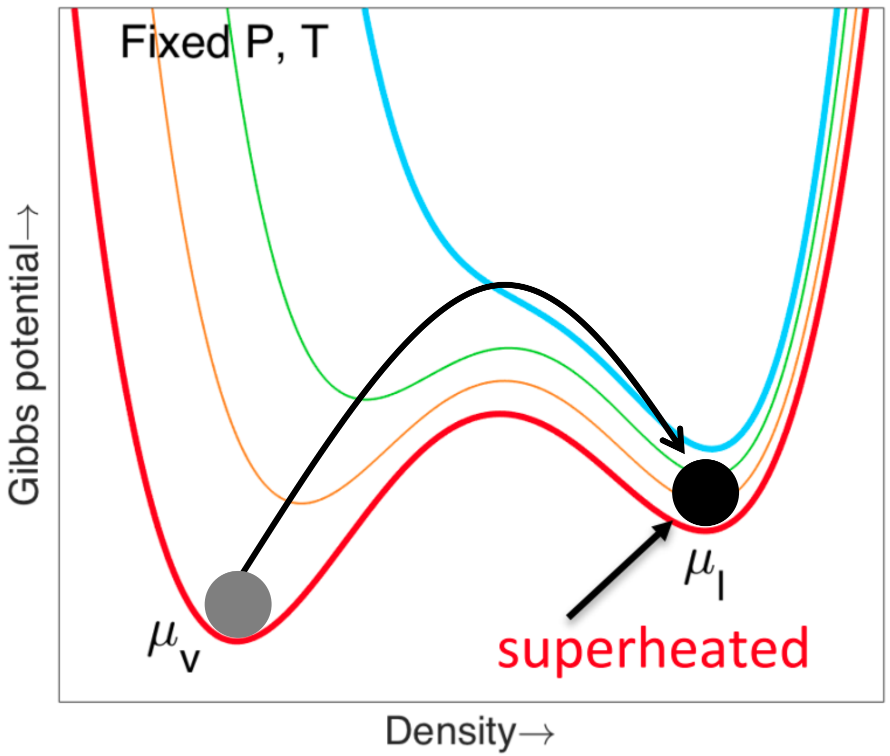
Bubble Chambers

80 psi

Not ready to detect a particle!





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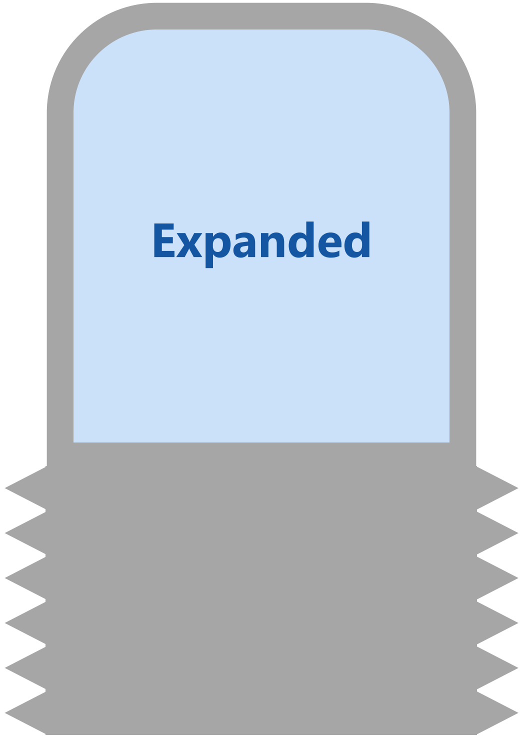
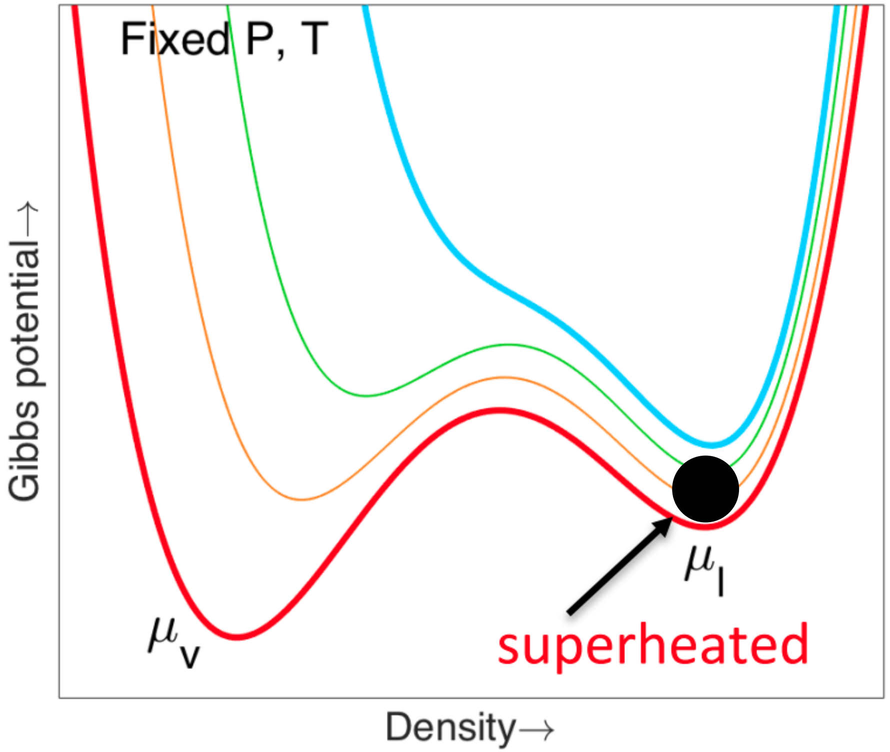
Bubble Chambers

27.5 psi

Ready to detect a particle!





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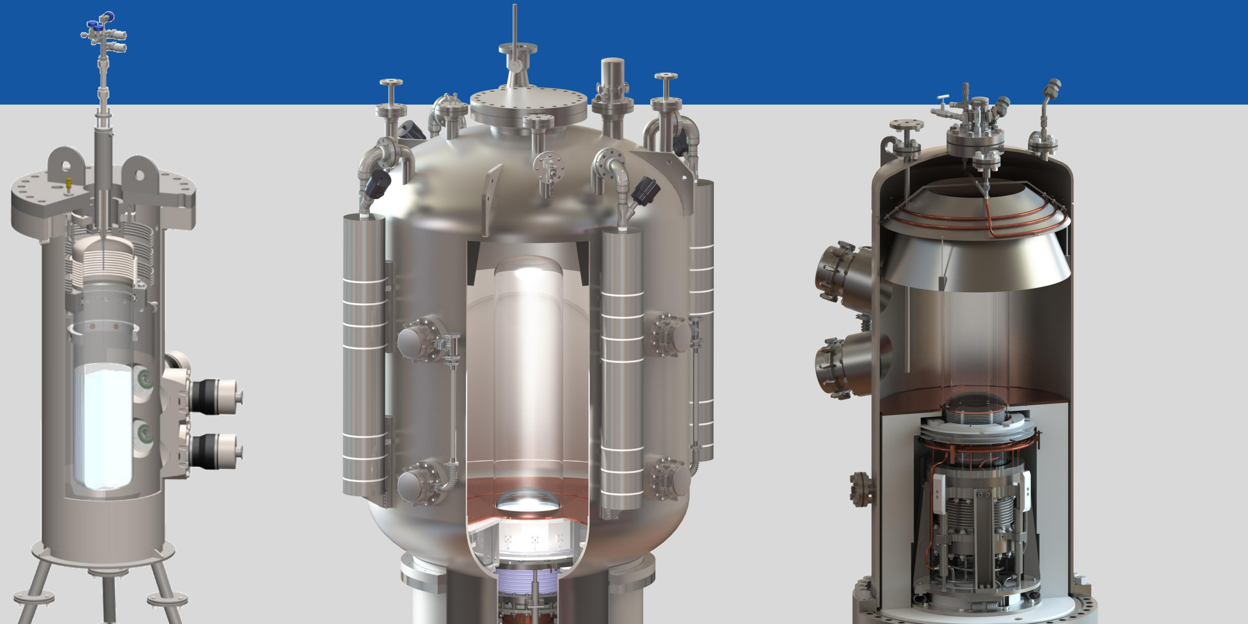
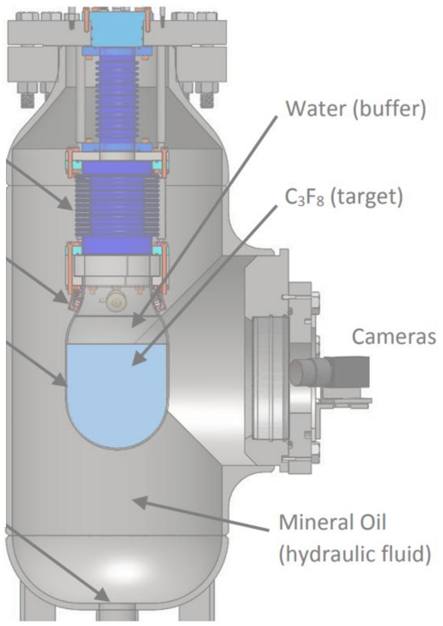
PICO Bubble Chambers



PICO Bubble Chambers



Right-Side-up

PICO-2L
2 L of C_3F_8
2013—2016

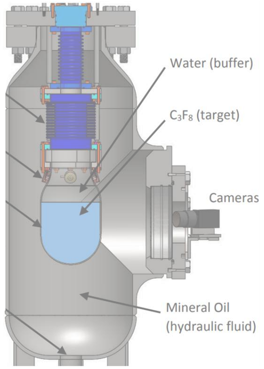
PICO-60
35 L of CF_3I and C_3F_8
2016—2017

PICO-40L
35 L of C_3F_8
2019—Present

PICO-500
260 L of C_3F_8
Proj. 2026

PICO Bubble Chambers

Rig



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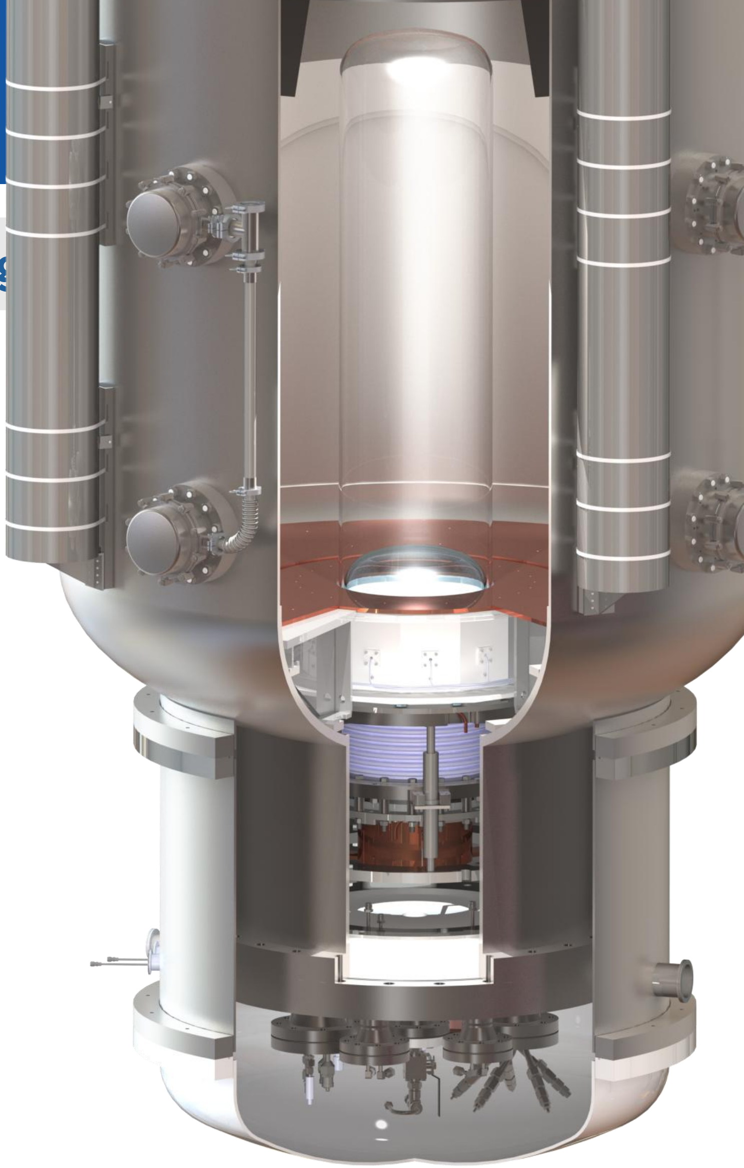
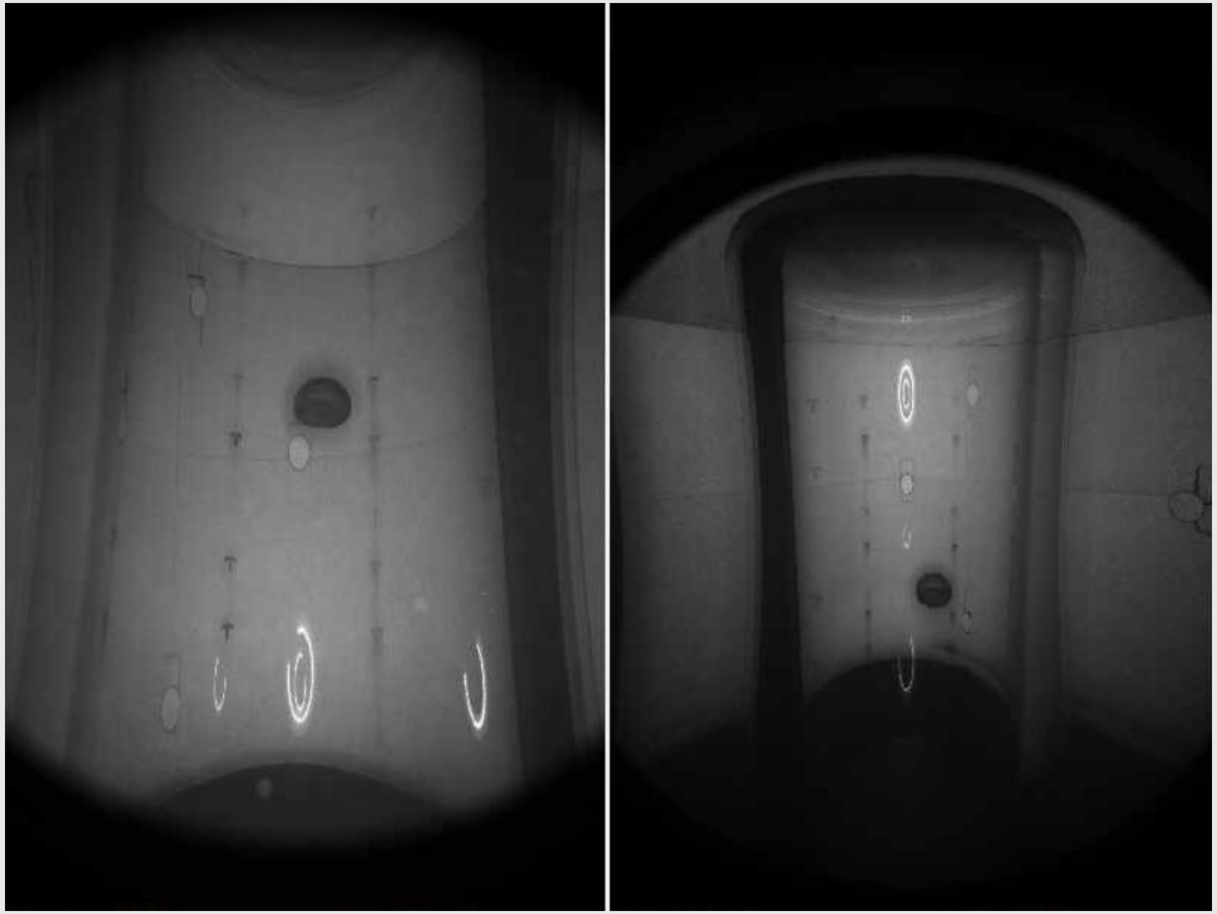
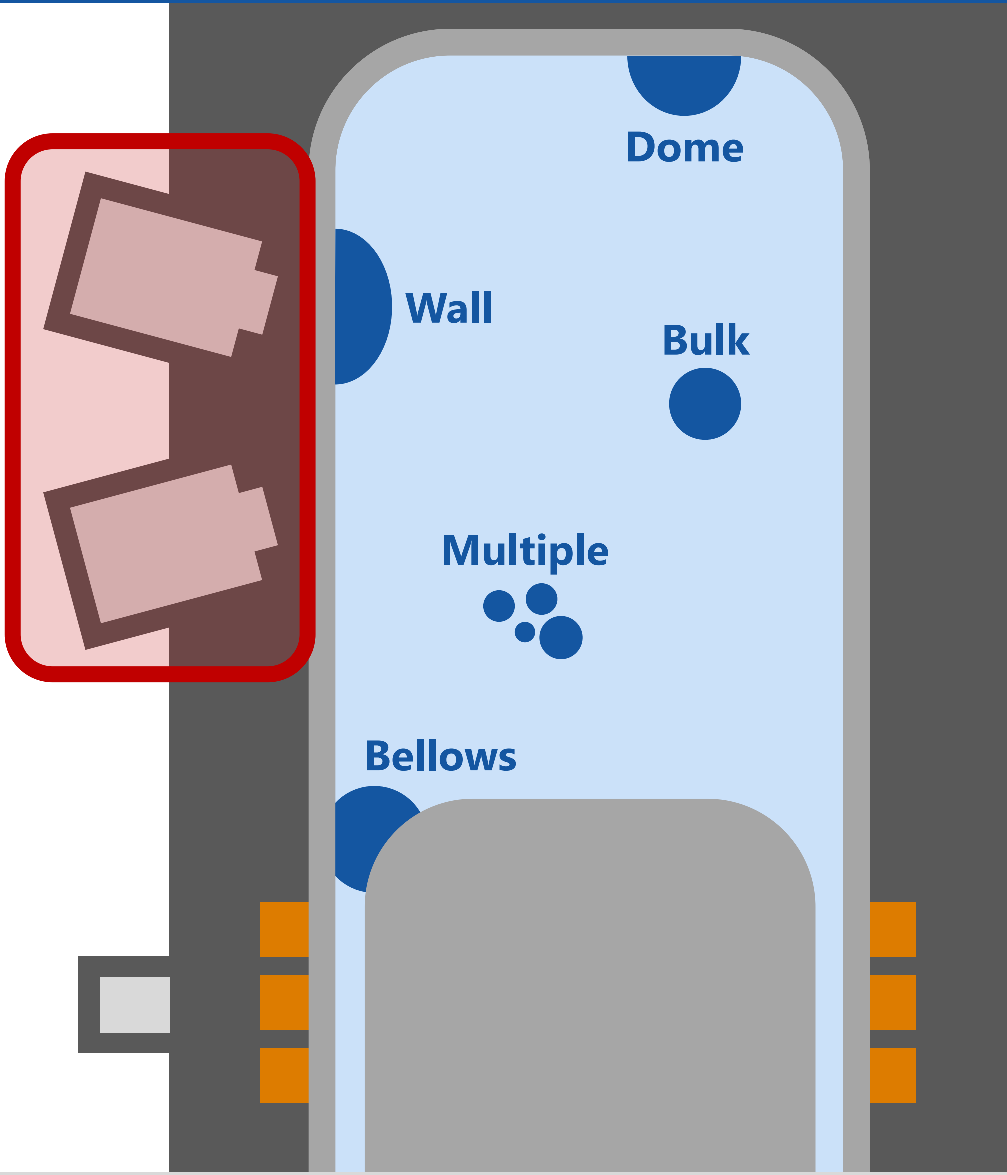


PICO-500
260 L of C_3F_8
Proj. 2027

Detection Channels

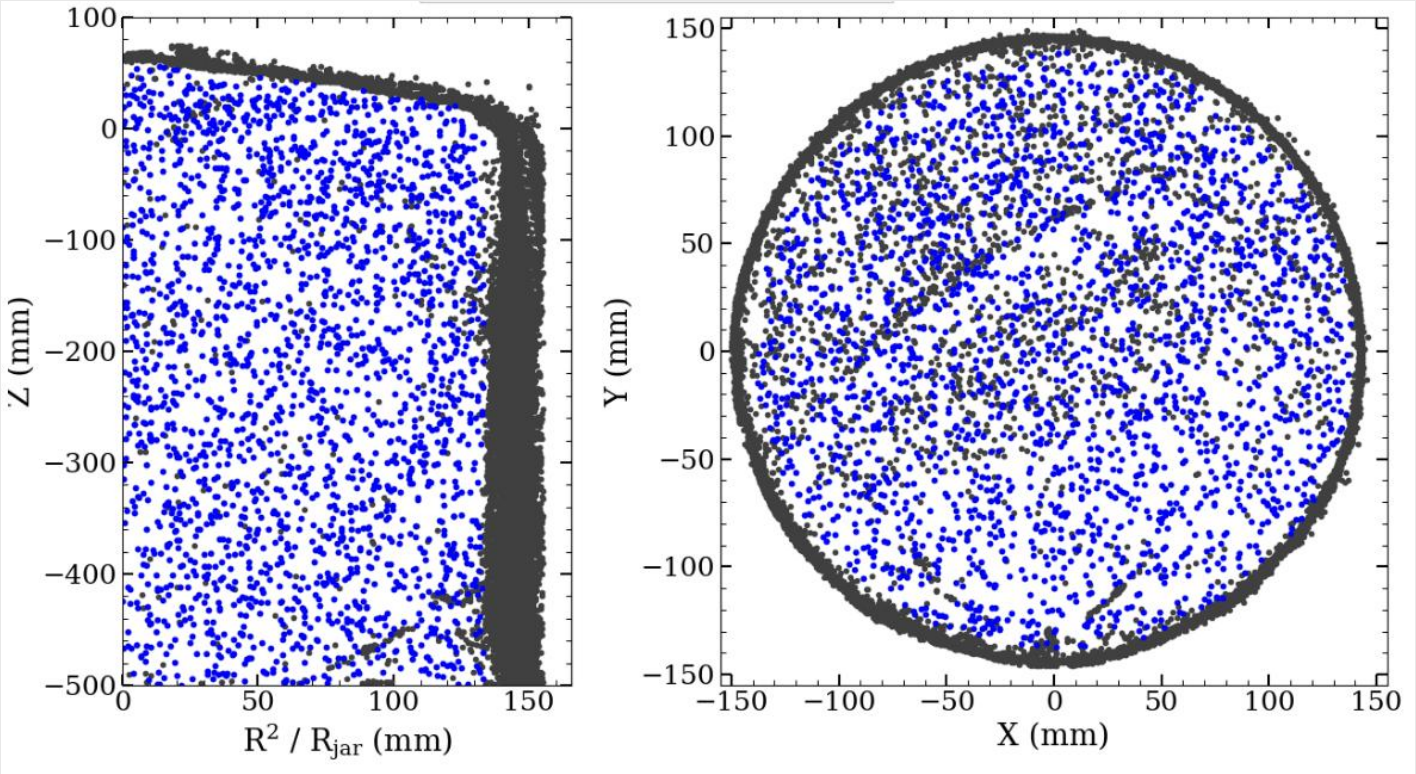
Cameras | Piezoelectric Sensors | Pressure Transducers

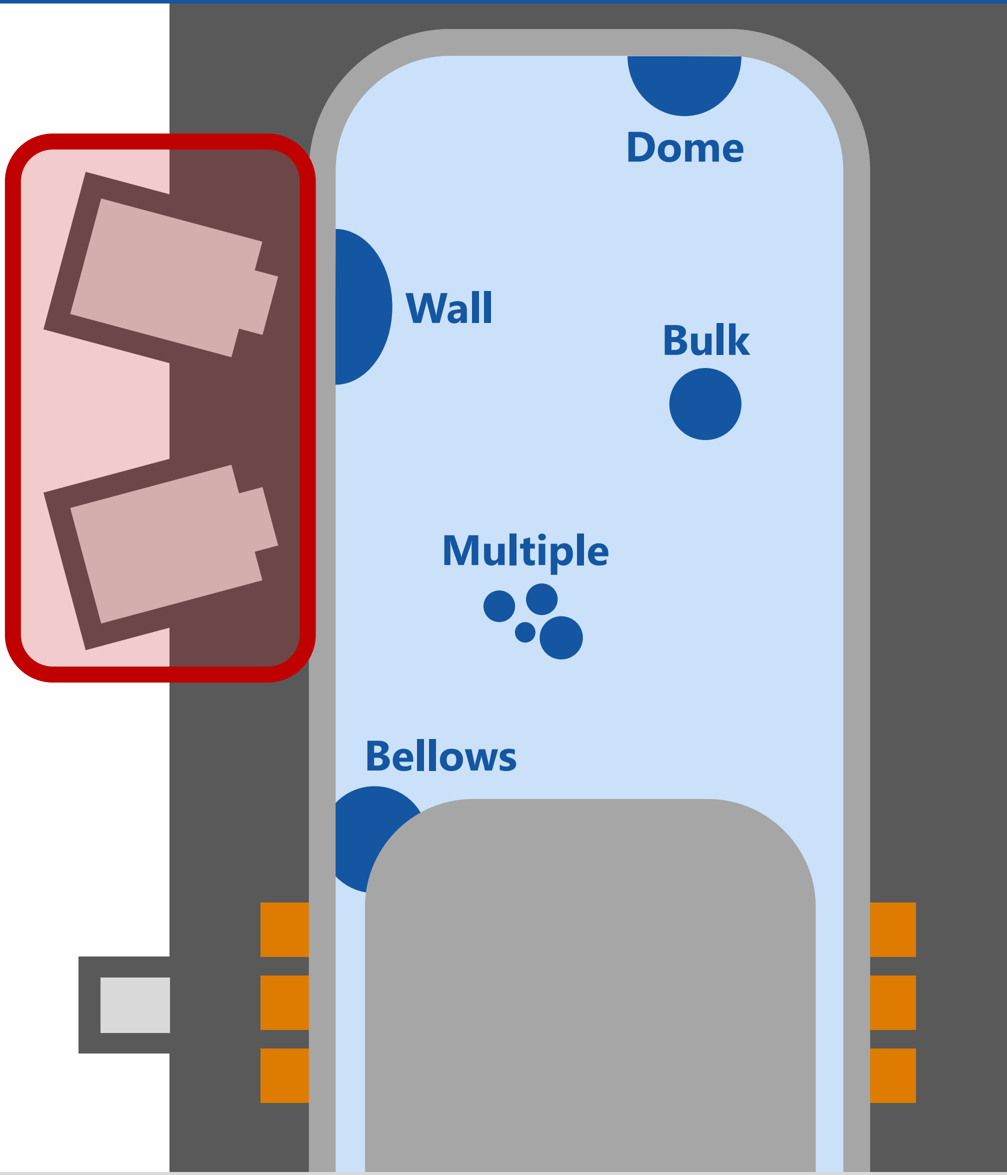




Detection Channels

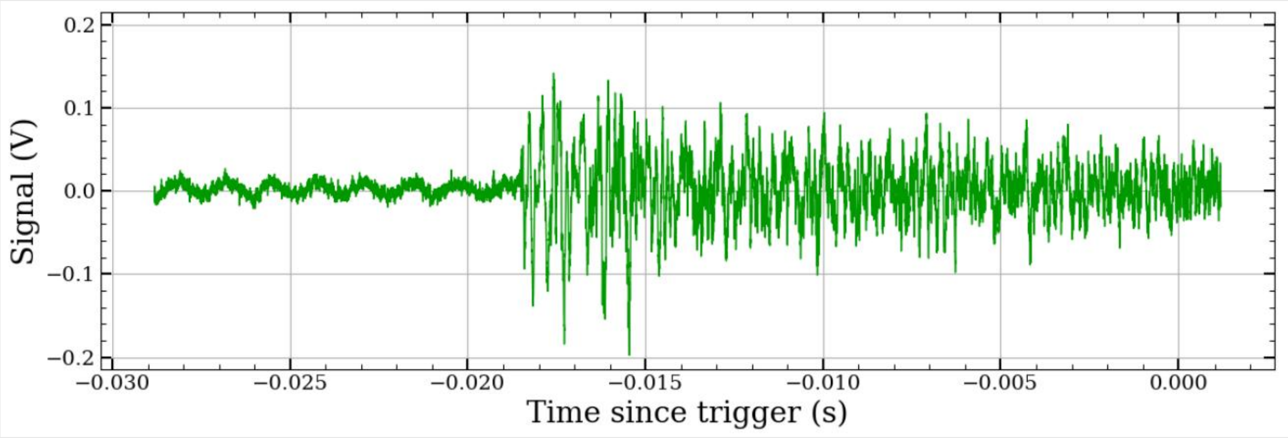
Cameras | Piezoelectric Sensors | Pressure Transducers

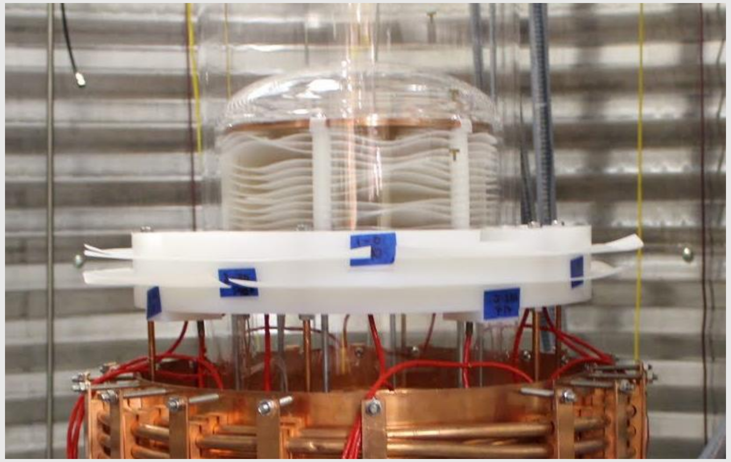


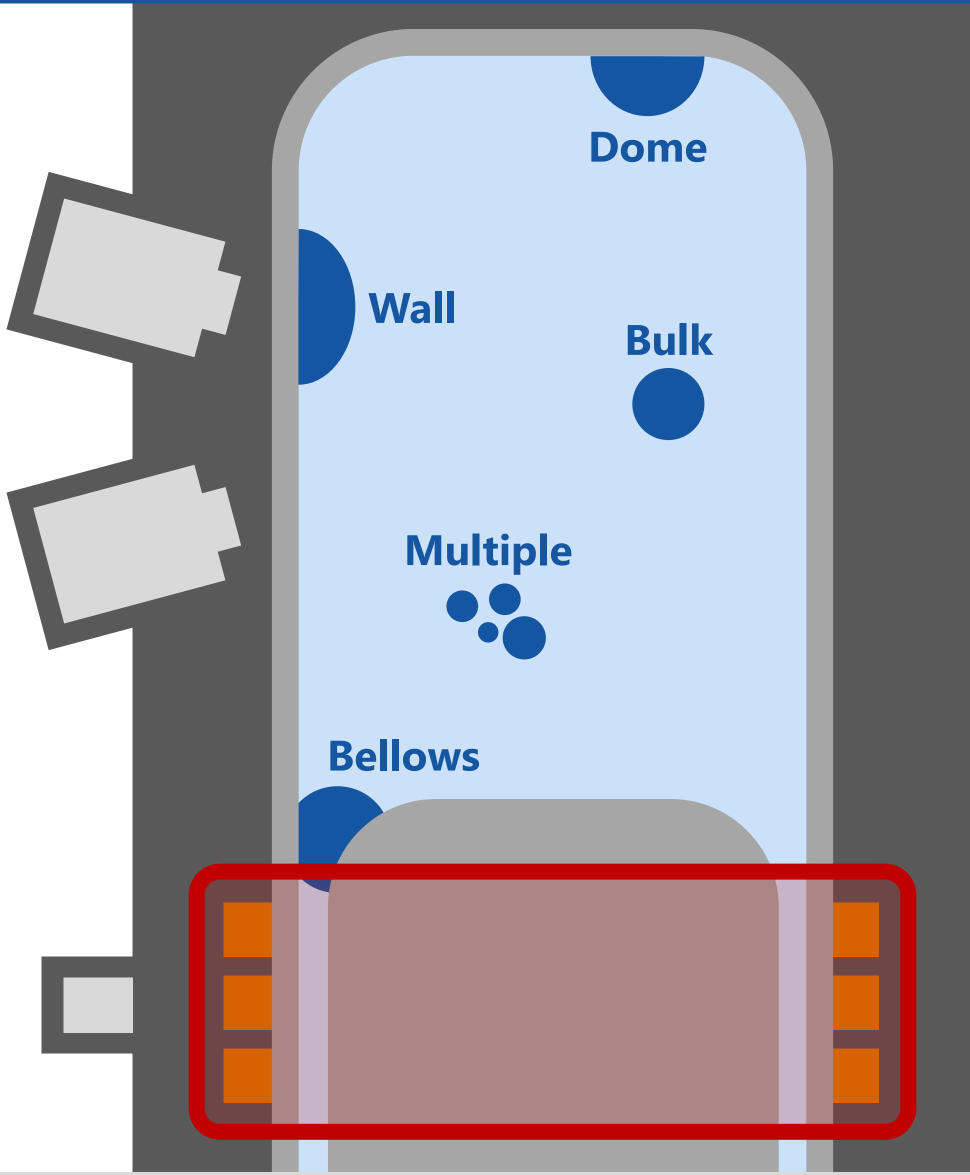


Detection Channels

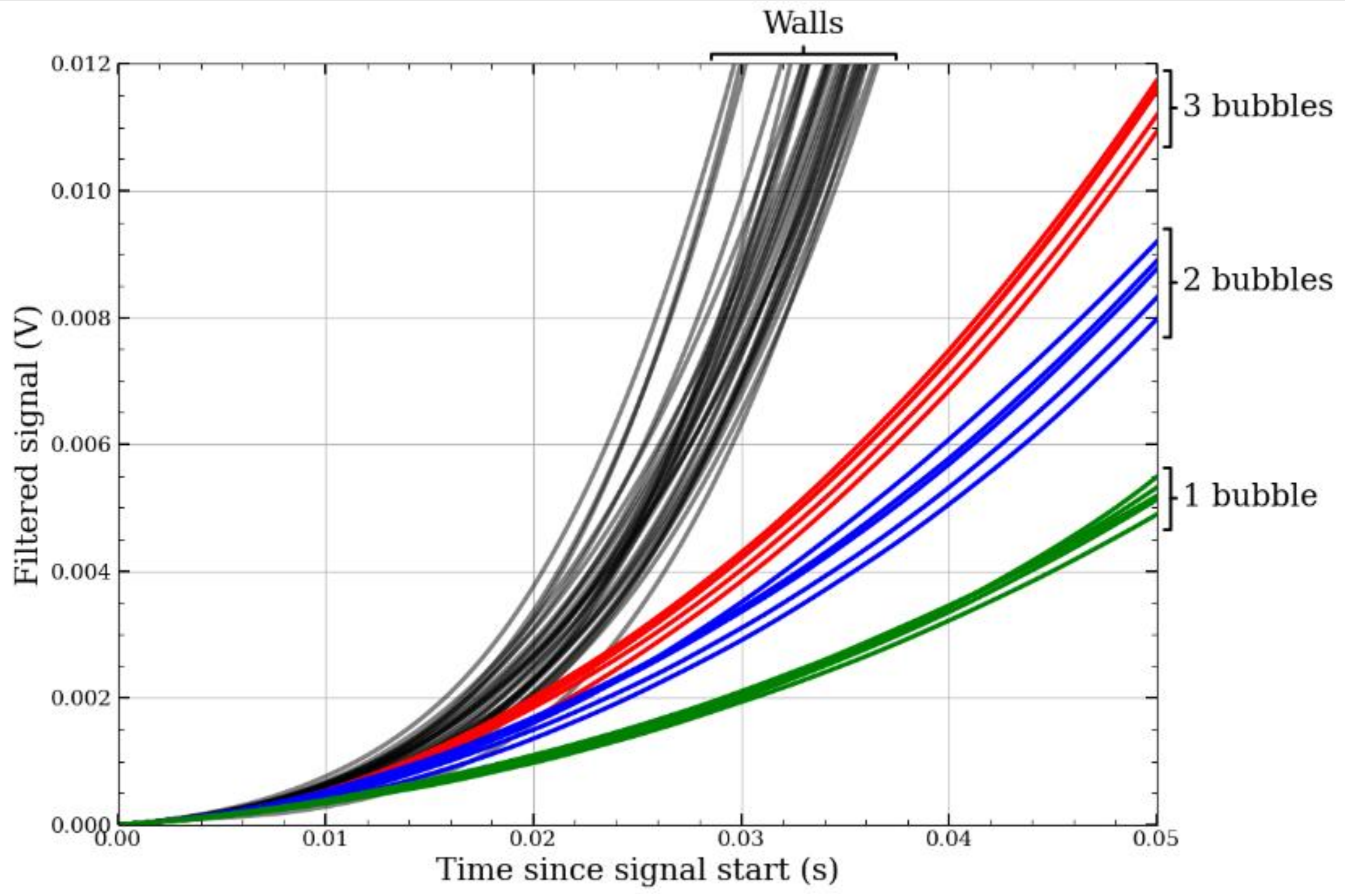
Cameras | **Piezoelectric Sensors** | Pressure Transducers

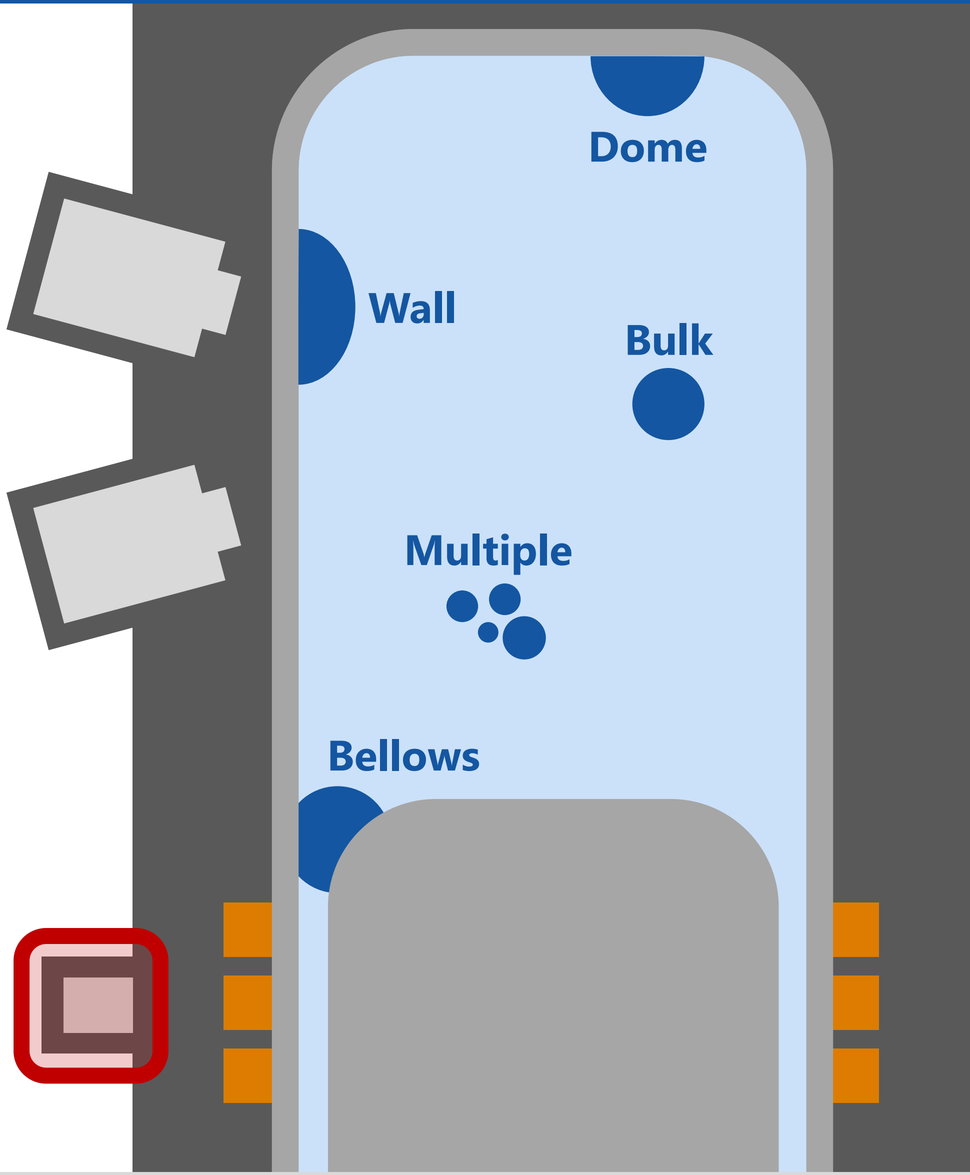






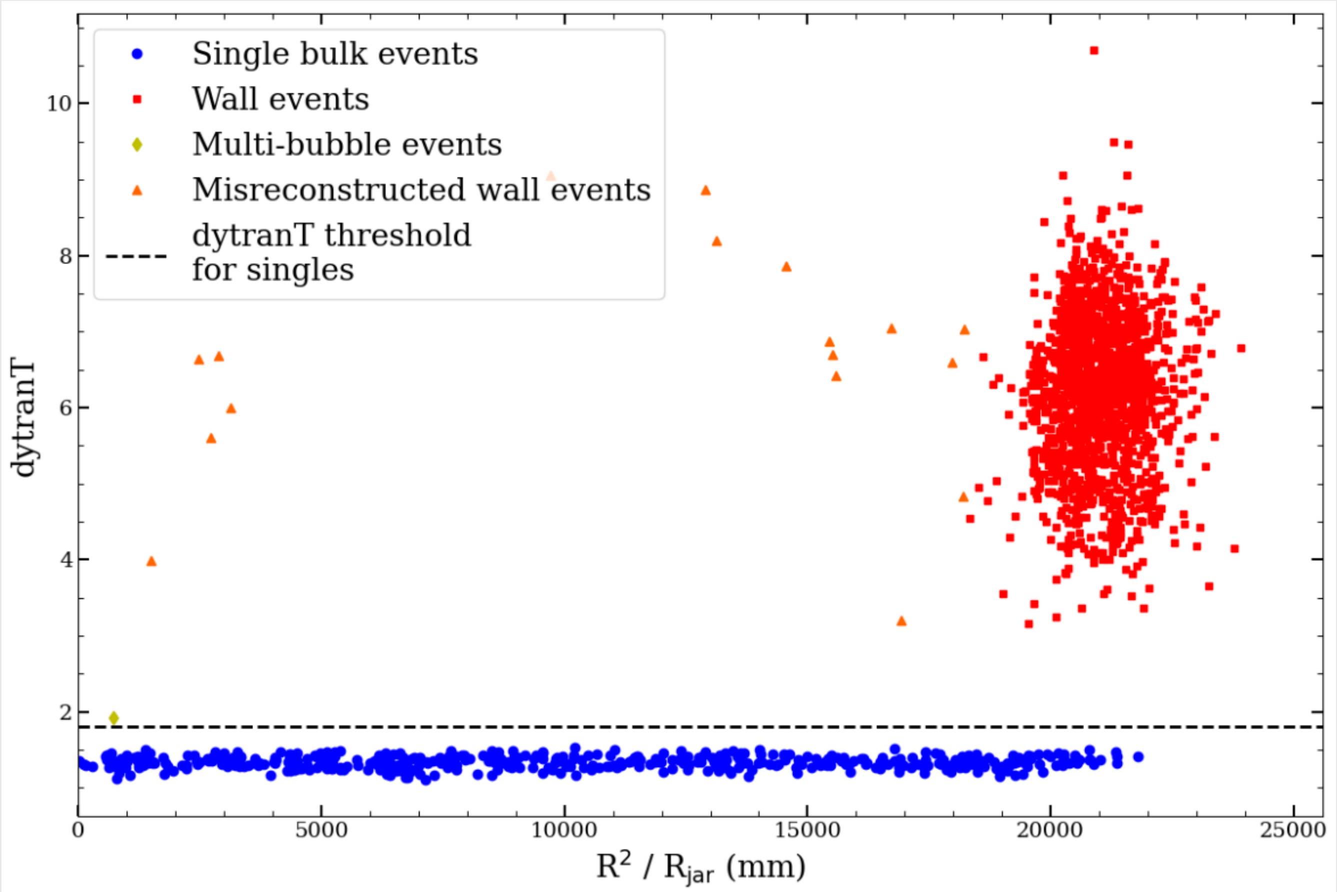
Cameras · Piezoelectric Sensors · **Pressure Transducers**

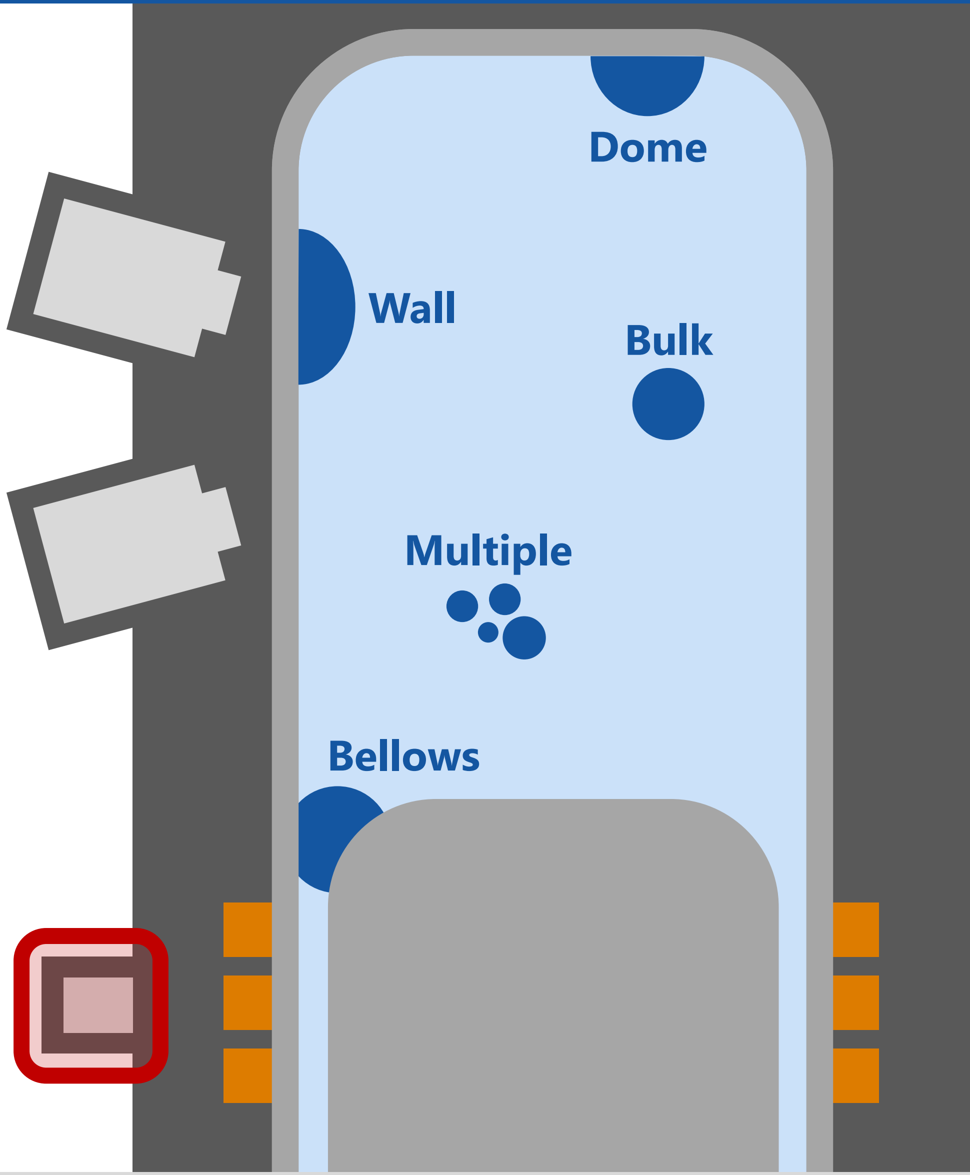




Detection Channels

Cameras | Piezoelectric Sensors | **Pressure Transducers**



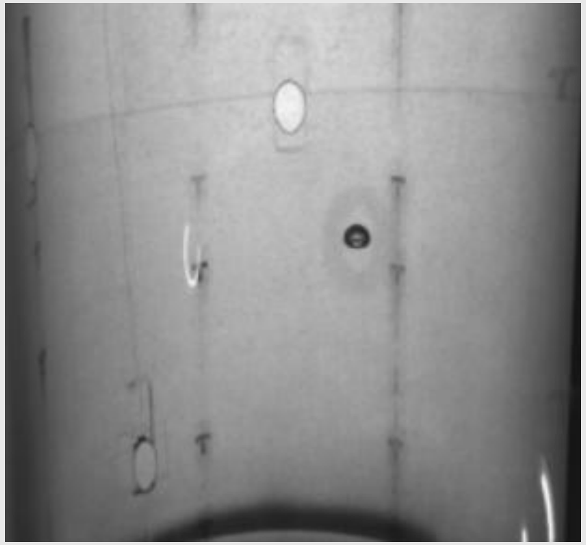


Backgrounds

Nuclear Recoils

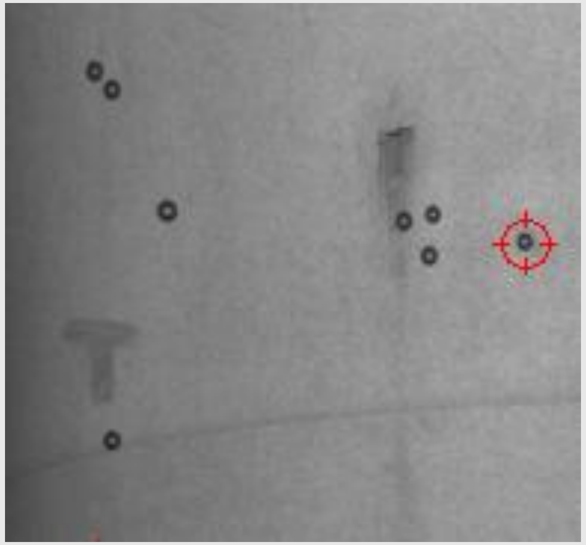
Alpha Particles

- Internal background. From ^{222}Rn and ^{220}Rn from ^{238}U and ^{232}Th decay chains.
- Single bubbles.



Neutrons

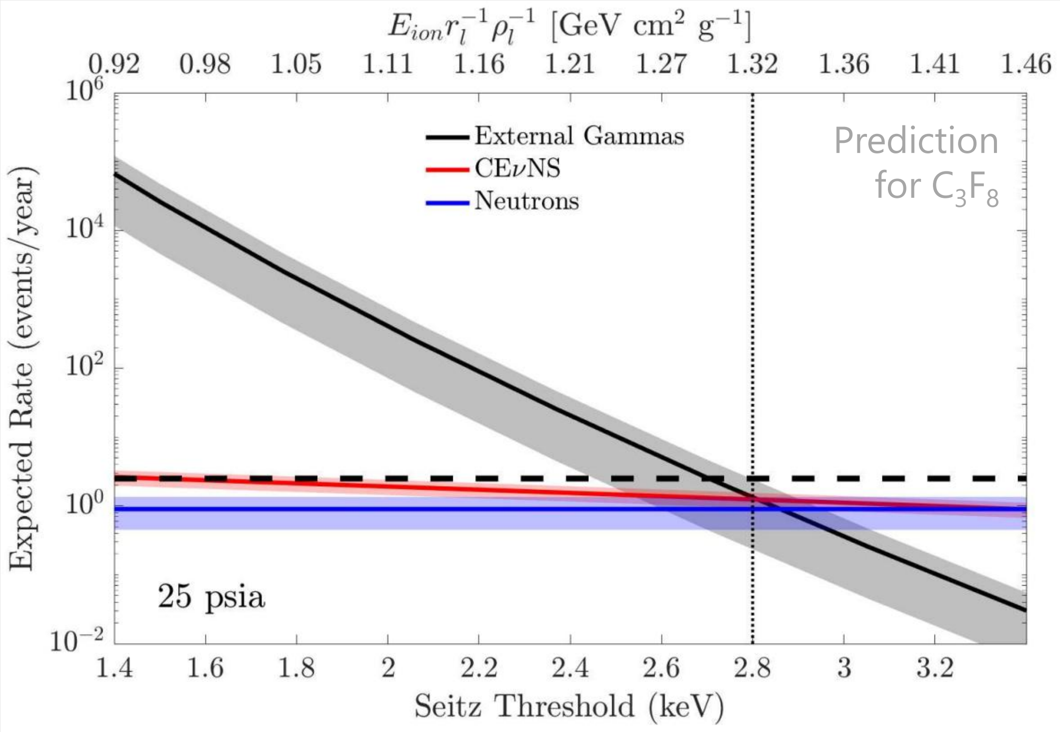
- Internal from spontaneous fission and (α, n), and external from CR muons.
- Single or multi-bubbles.



Electron Recoils

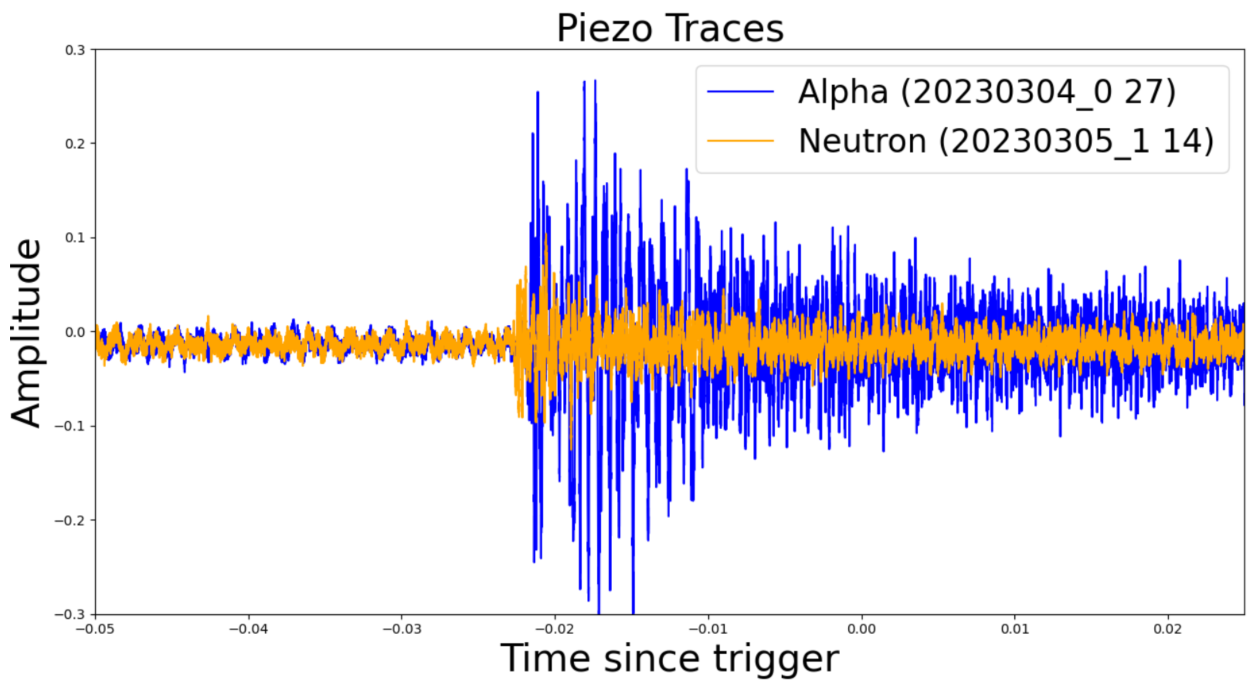
Gammas

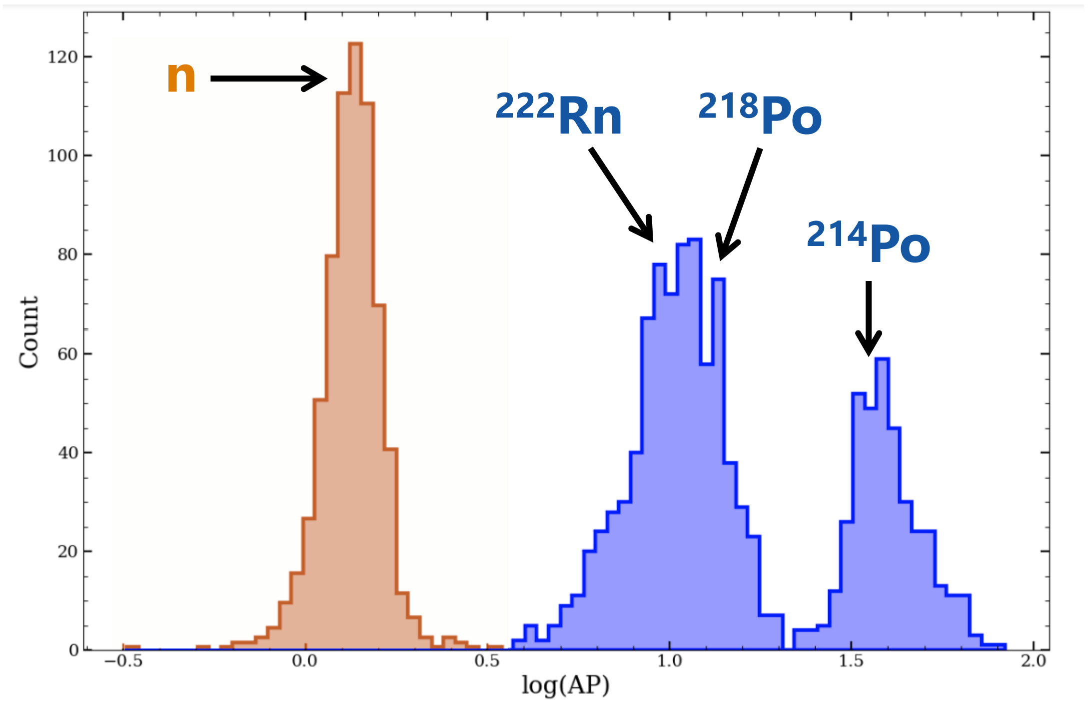
https://inspirehep.net/literature/1737408



Insensitive to gammas at operating thresholds.

Background Rejection

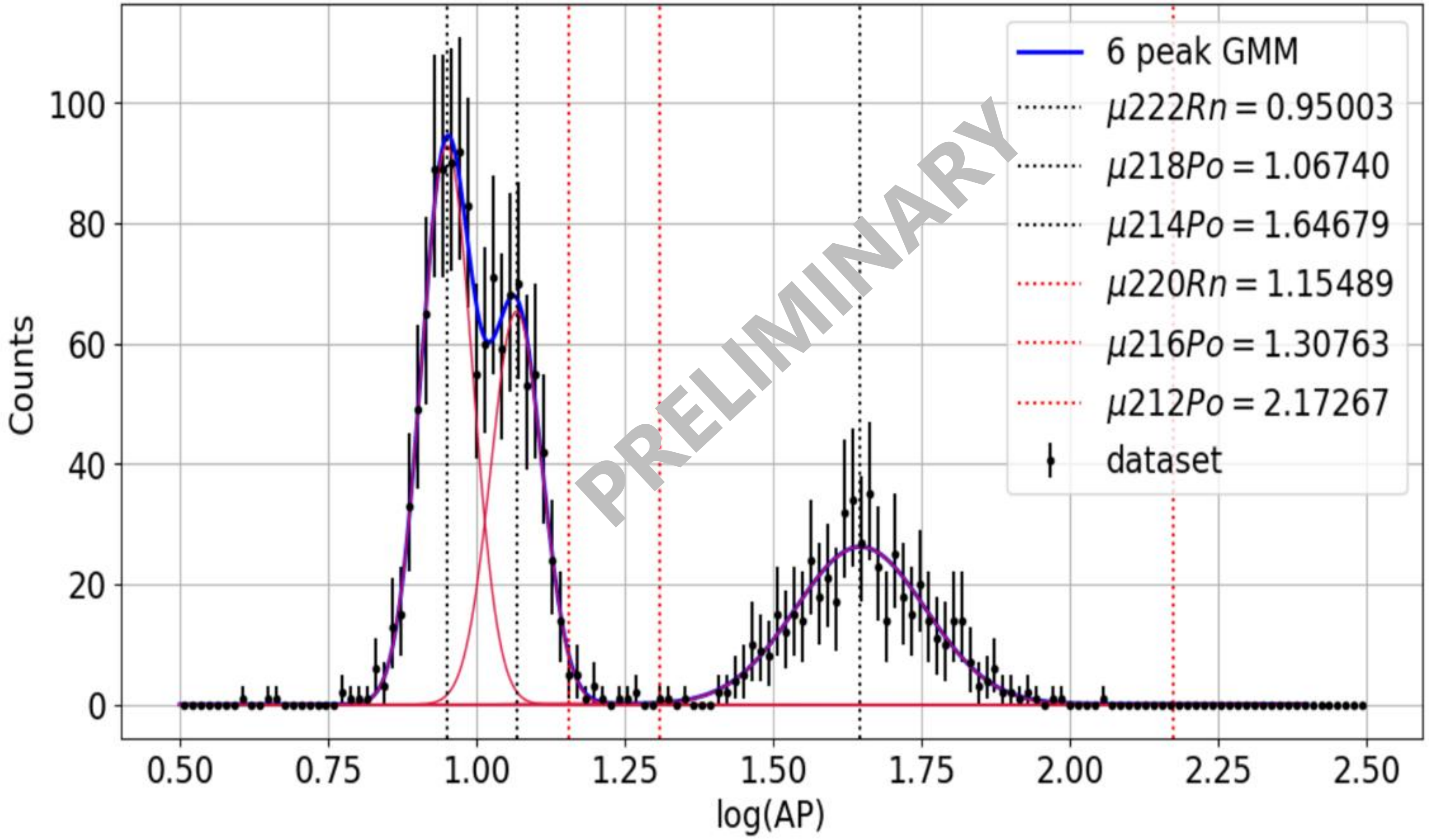




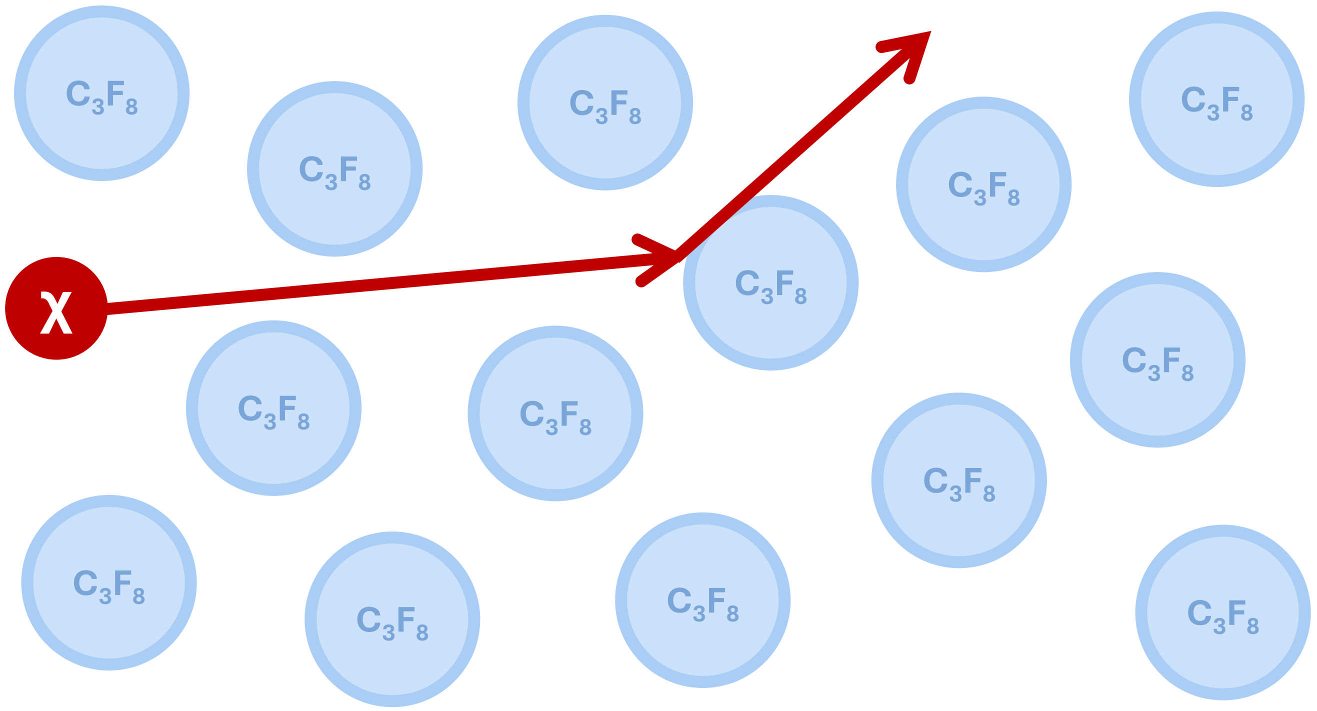
- Calculate acoustic parameter (AP) from resonant energy of piezoelectric sensors.
- Energy depositions from alpha particles have higher AP than those from neutrons.
- Different alpha decays from ^{222}Rn decay chain are identifiable.
- This is used to reject alpha backgrounds in PICO.

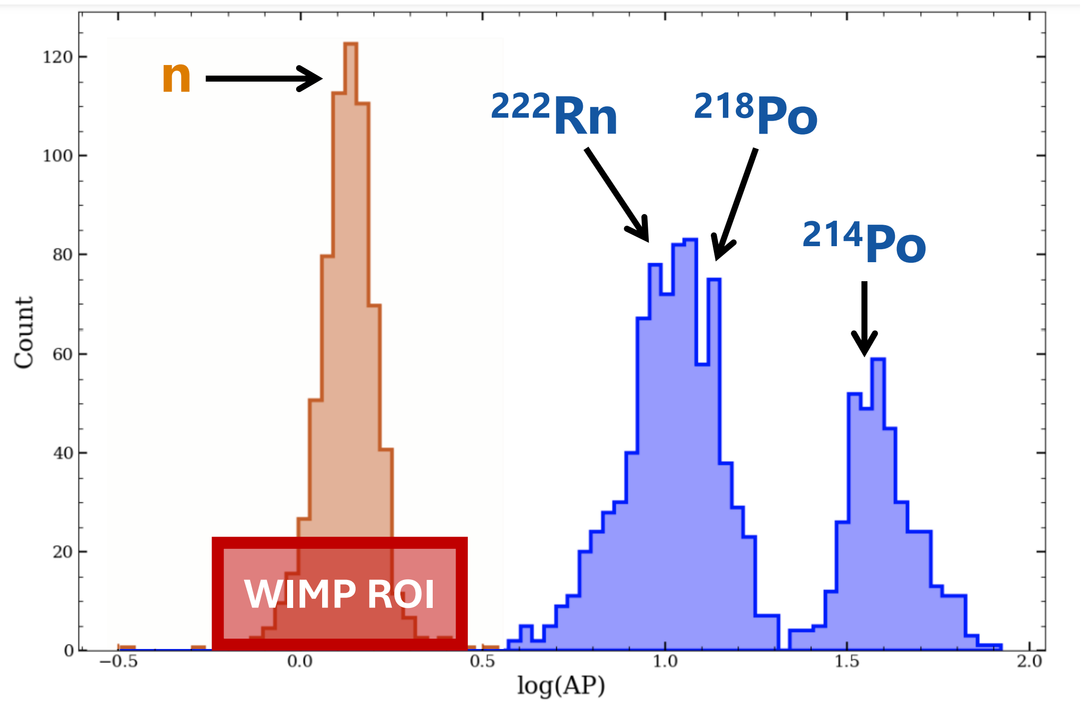
Alpha Spectroscopy

- We have been able to resolve the alpha peaks from ^{238}U and ^{232}Th in our PICO-40L acoustic data, allowing us to do alpha spectroscopy. Paper in preparation at the moment.



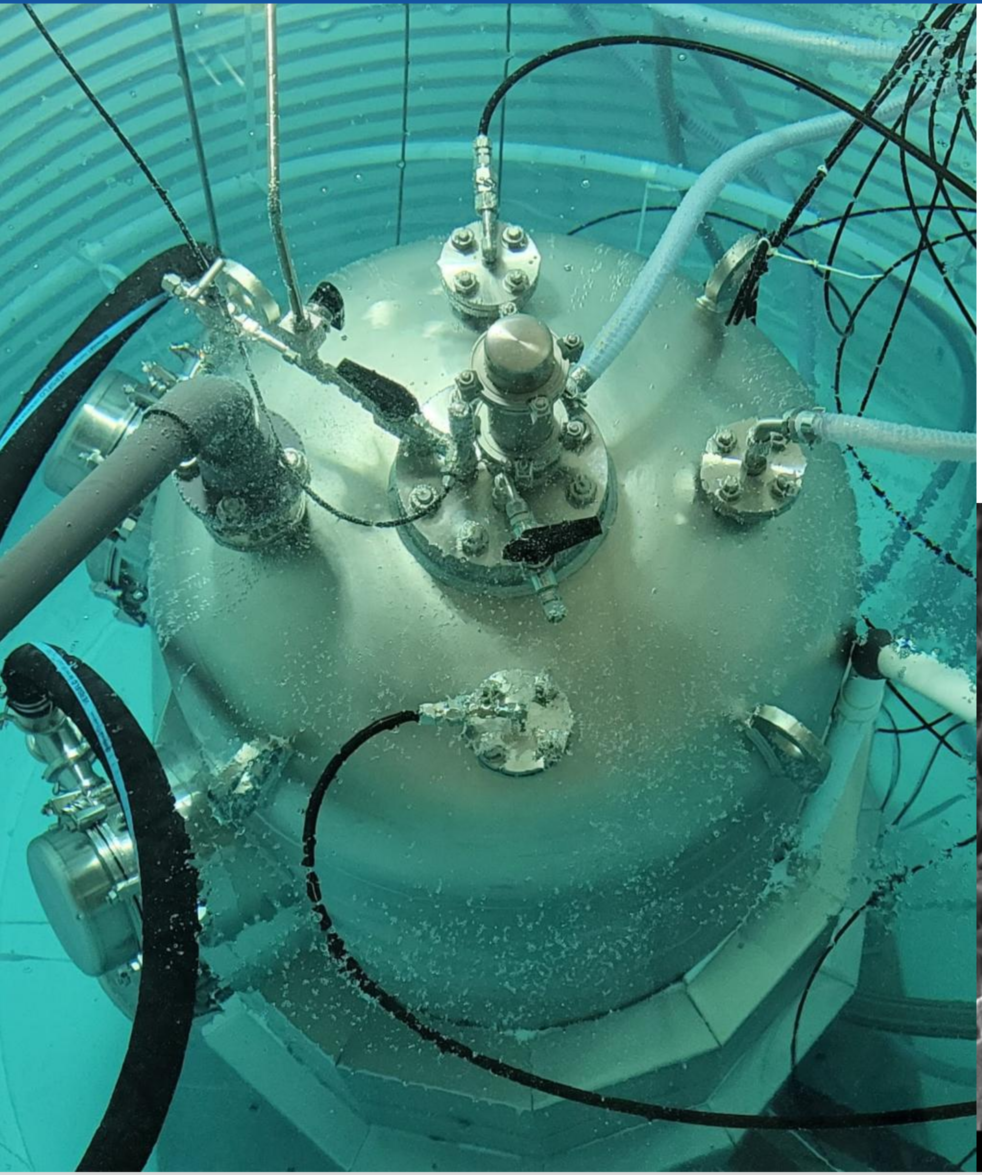
Backgrounds in the WIMP ROI



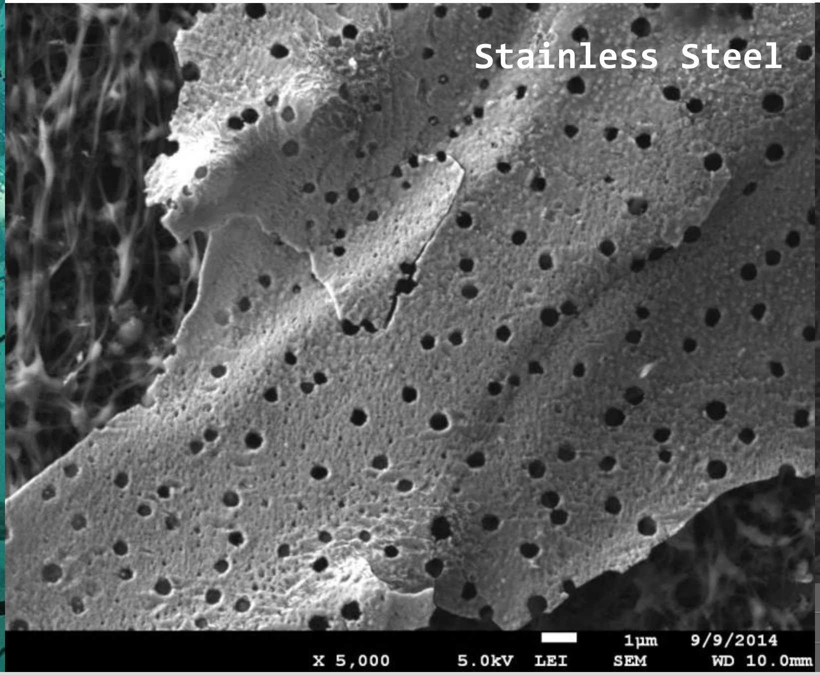


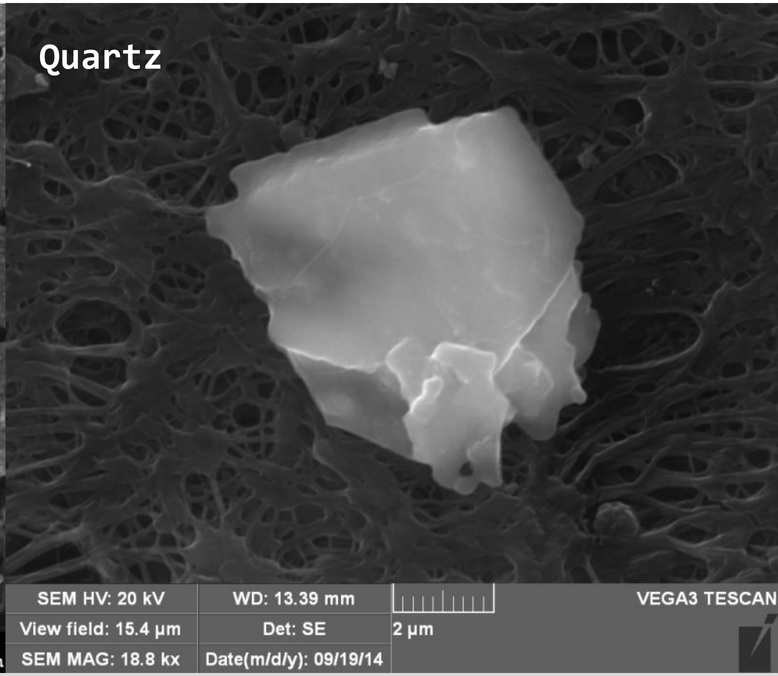
- Because **WIMPs** are weakly interacting, we do not expect them to interact more than once in the C_3F_8.
- They will create single bubbles with low energy deposition given the hypothesised mass range tested by PICO.
- They will look exactly like **single-scatter neutron events**.
- We must therefore mitigate backgrounds as much as possible.

Background Mitigation

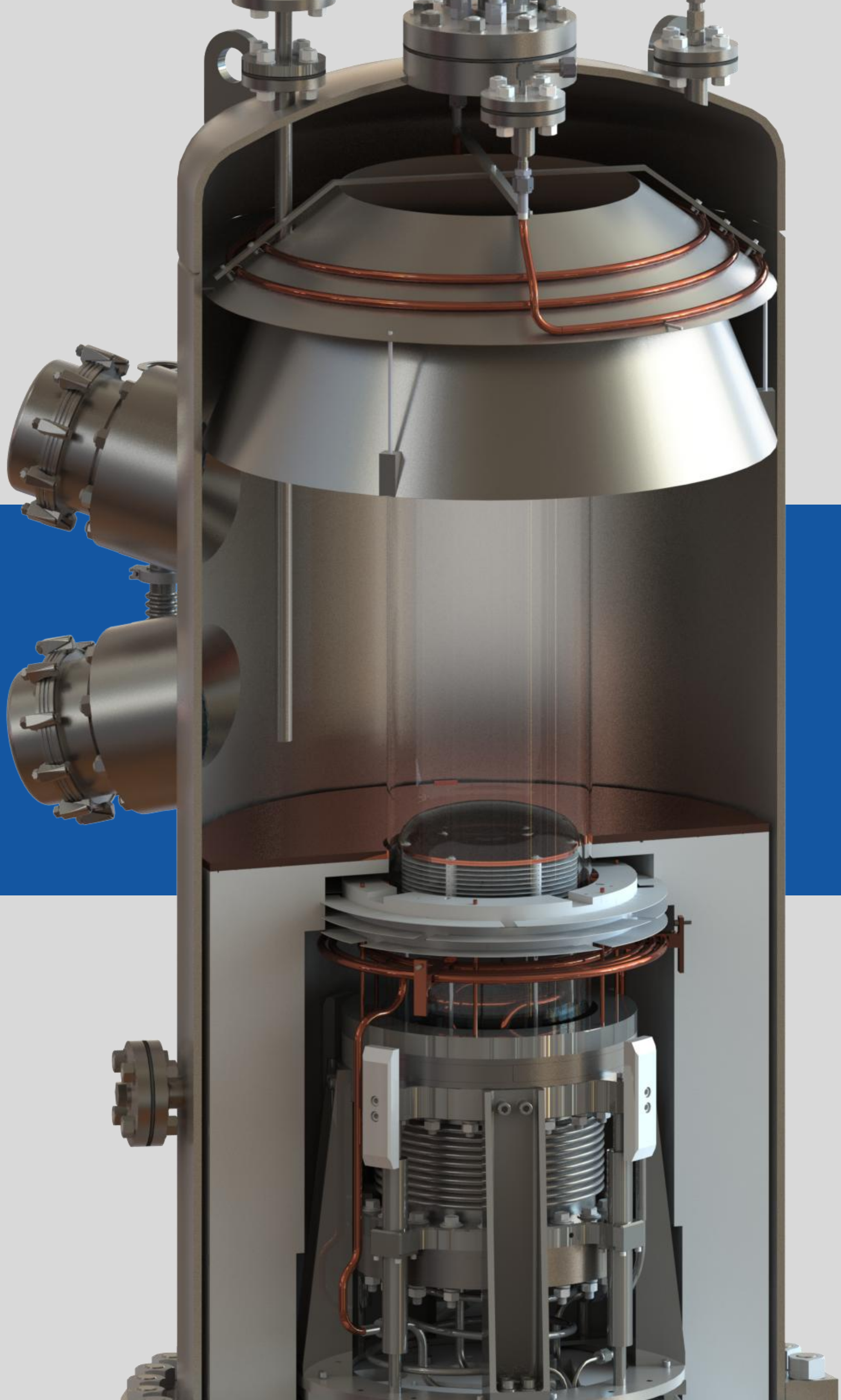


- **External Neutron Backgrounds:**
  - Shielded by large water tank surrounding the pressure vessel.
- **Internal Alpha and Neutron Backgrounds:**
  - Careful selection of materials.
  - Rigorous efforts to mitigate radon and extensively clean detector.



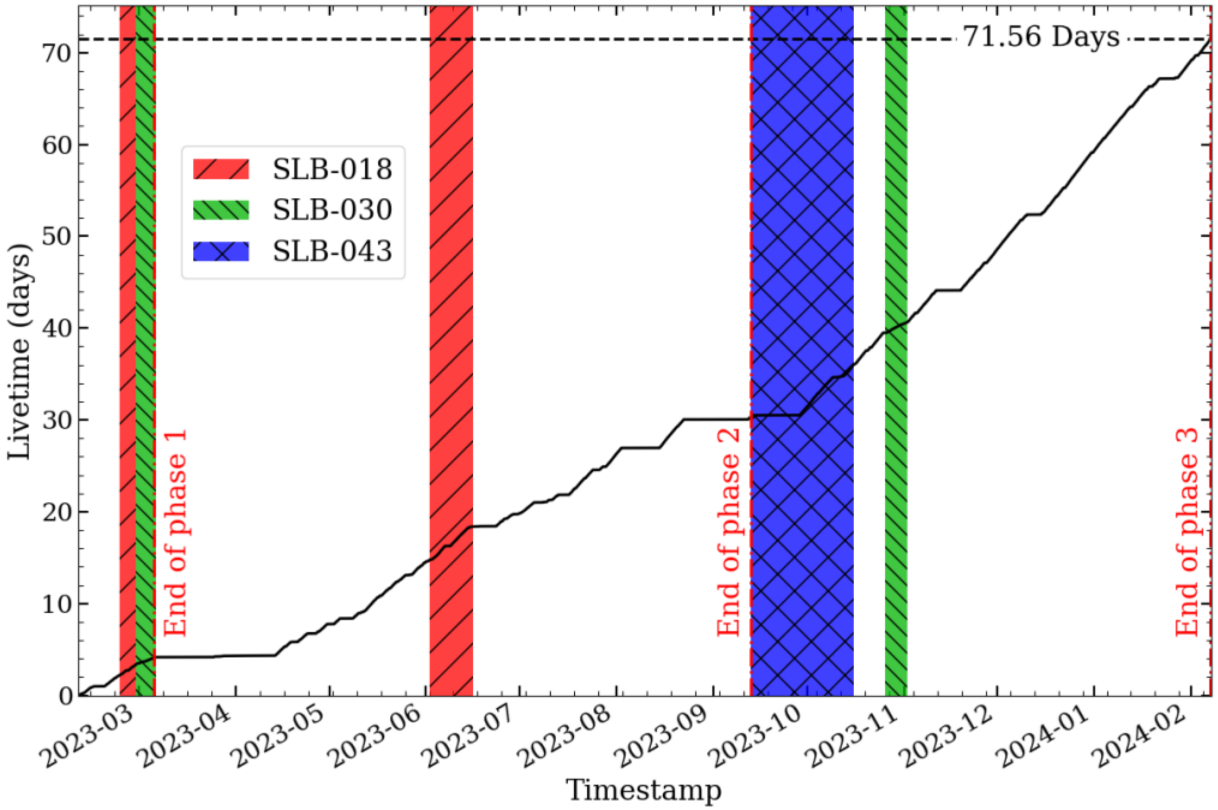


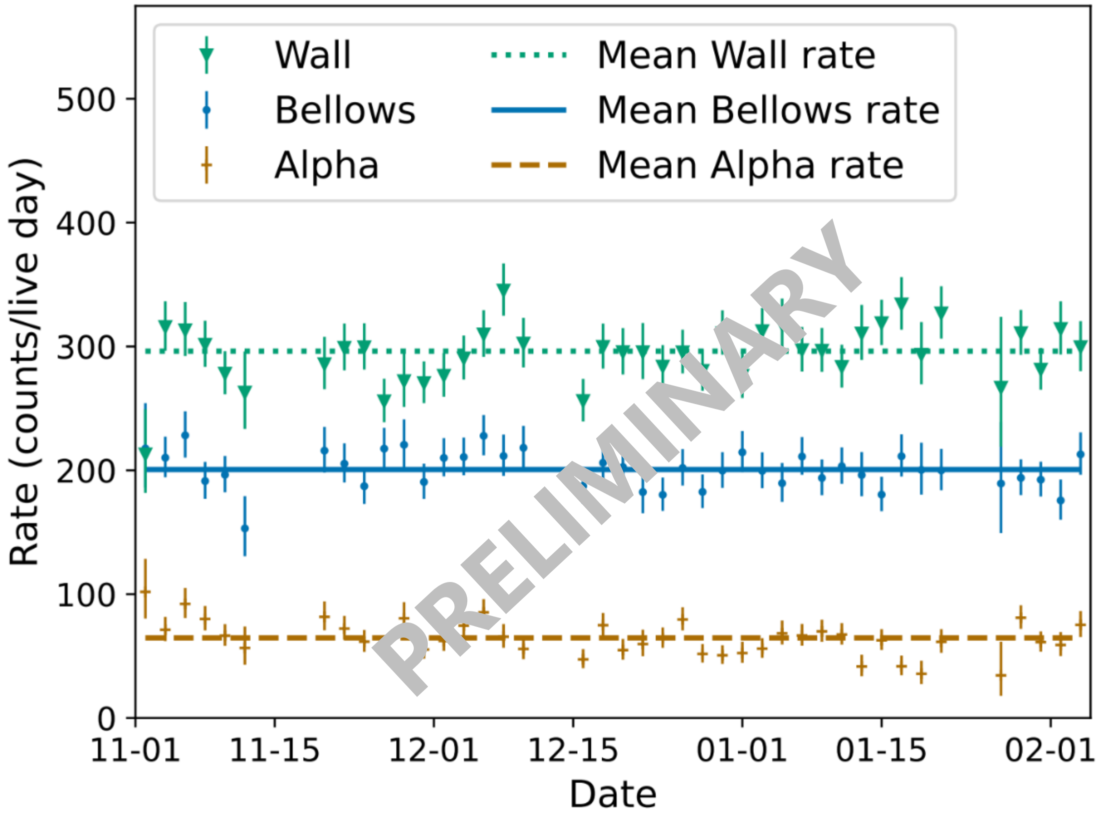
PICO-40L Update



PICO-40L Data Collected

- PICO-40L collected data between October 2023 and February 2024, reaching up to 72 live days of data.
- The detector ran stably over this period of time.
- Issues with chiller unit and a leak have paused operations since then.

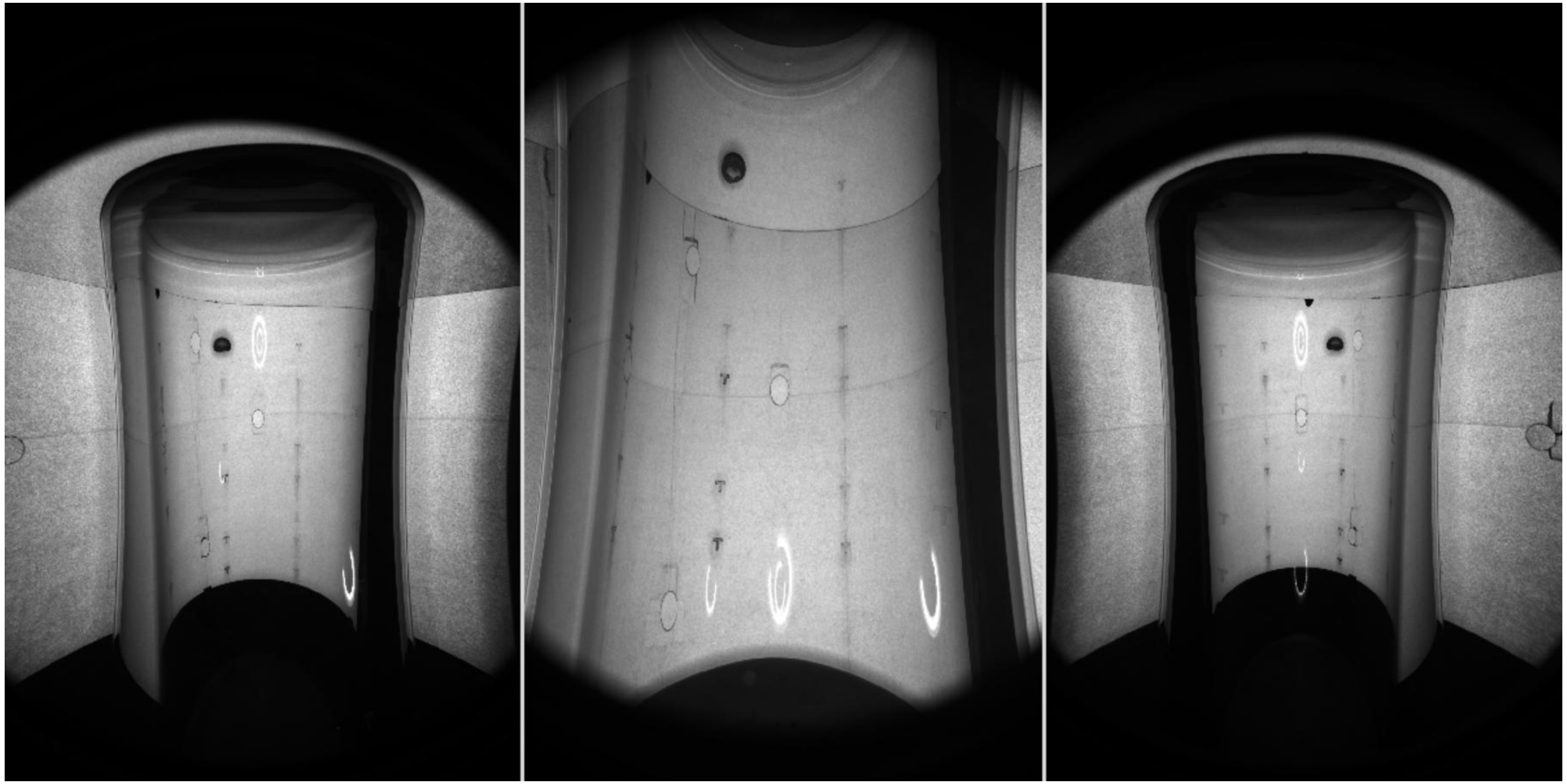




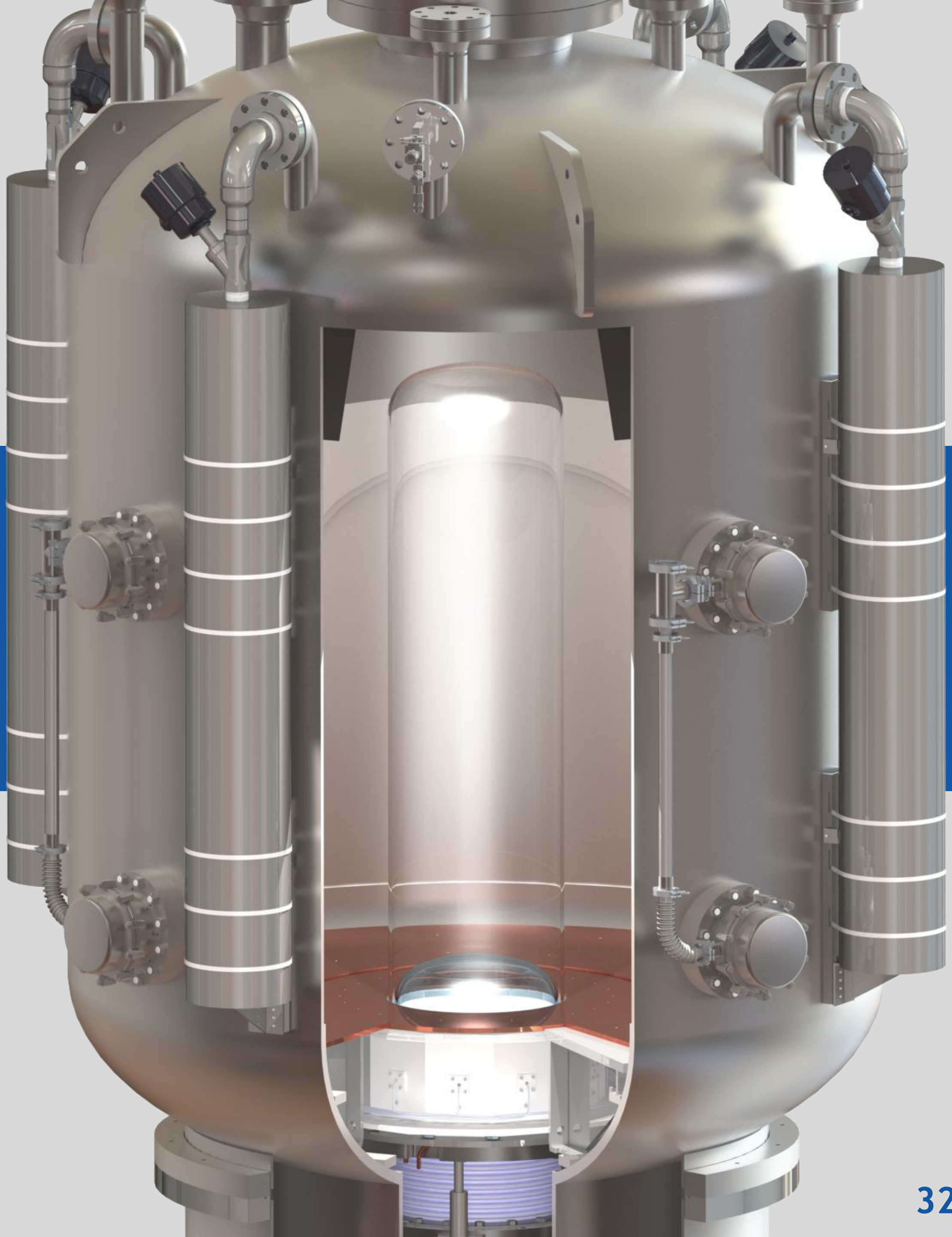
C. Moore, Ph.D. Thesis (2024), https://inspirehep.net/literature/2829909

PICO-40L Current Status

- The detector was fixed and operated in July 2026.
- Bulk events recorded with average expansion time of 2.5 minutes.
- Will resume data collection in September after the SNOLAB planned maintenance period ends.
- Will focus on engineering runs to understand detector response under different conditions (P, T, Q).



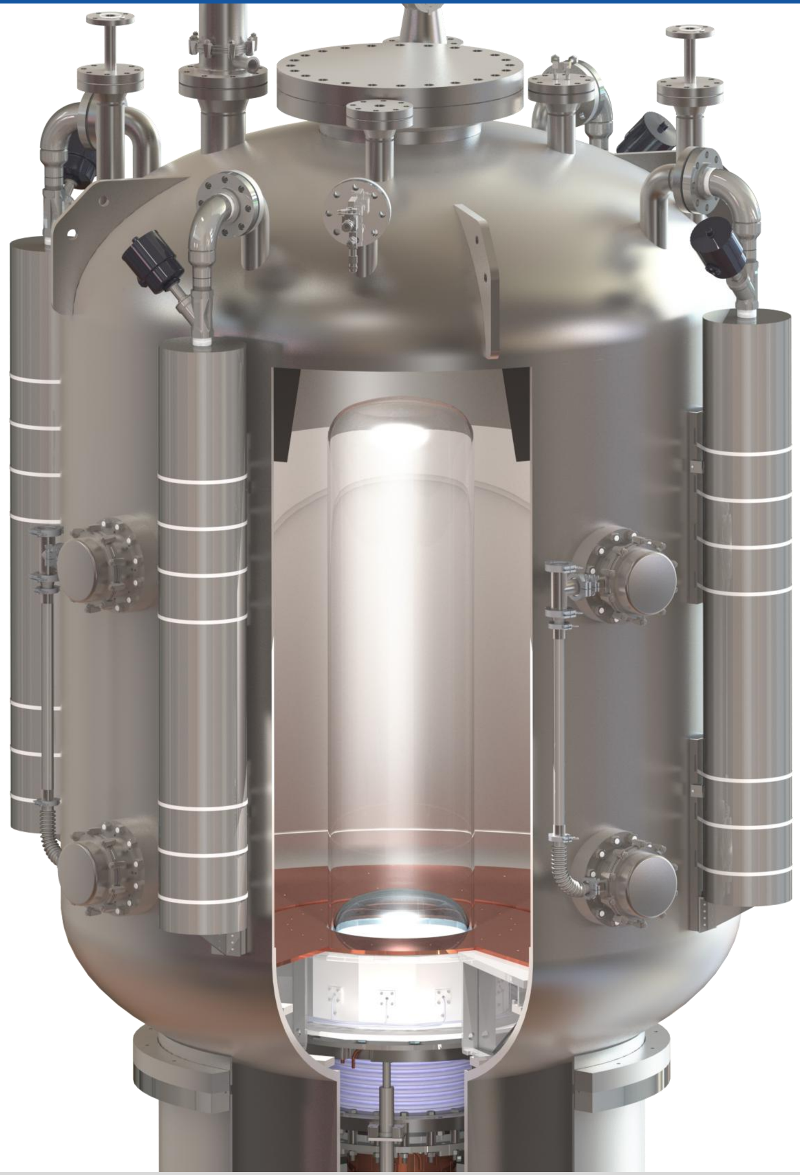
PICO-500 Update



PICO-500 Overview

- Next, larger generation of the PICO bubble chamber programme.
- At 260 L, this is the largest synthetic quartz vessel ever made.
- PICO-40L RSU design acts as a proof-of-concept for PICO-500.
- Design and operation informed by the successes, difficulties of PICO-40L.

- **Improvements in PICO-500:**
  - New **cleaning** and **radon mitigation** techniques
  - New **muon veto** system
  - Improved **heater design**
  - **Vacuum jacket** to help keep temperatures stable in the cold region.
  - **Degassing tank** removes air from mineral oil and reduces dead time.
  - Spring-energised **PTFE seal** prevents radon permeation and allows for colder temperatures.



Key assembly milestones recently passed!

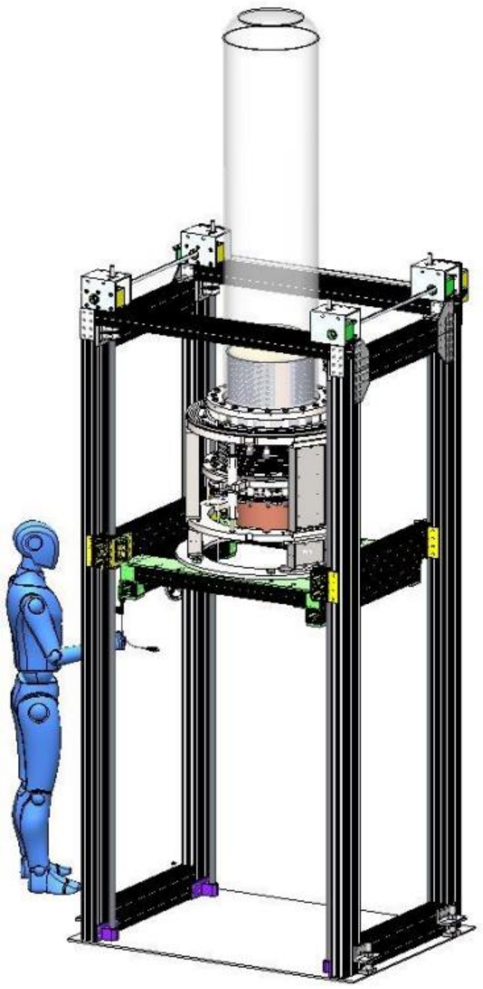
Pressure Vessel

- The pressure vessel has been welded and leak-checked. Now in place inside the water tank in the Cube Hall.



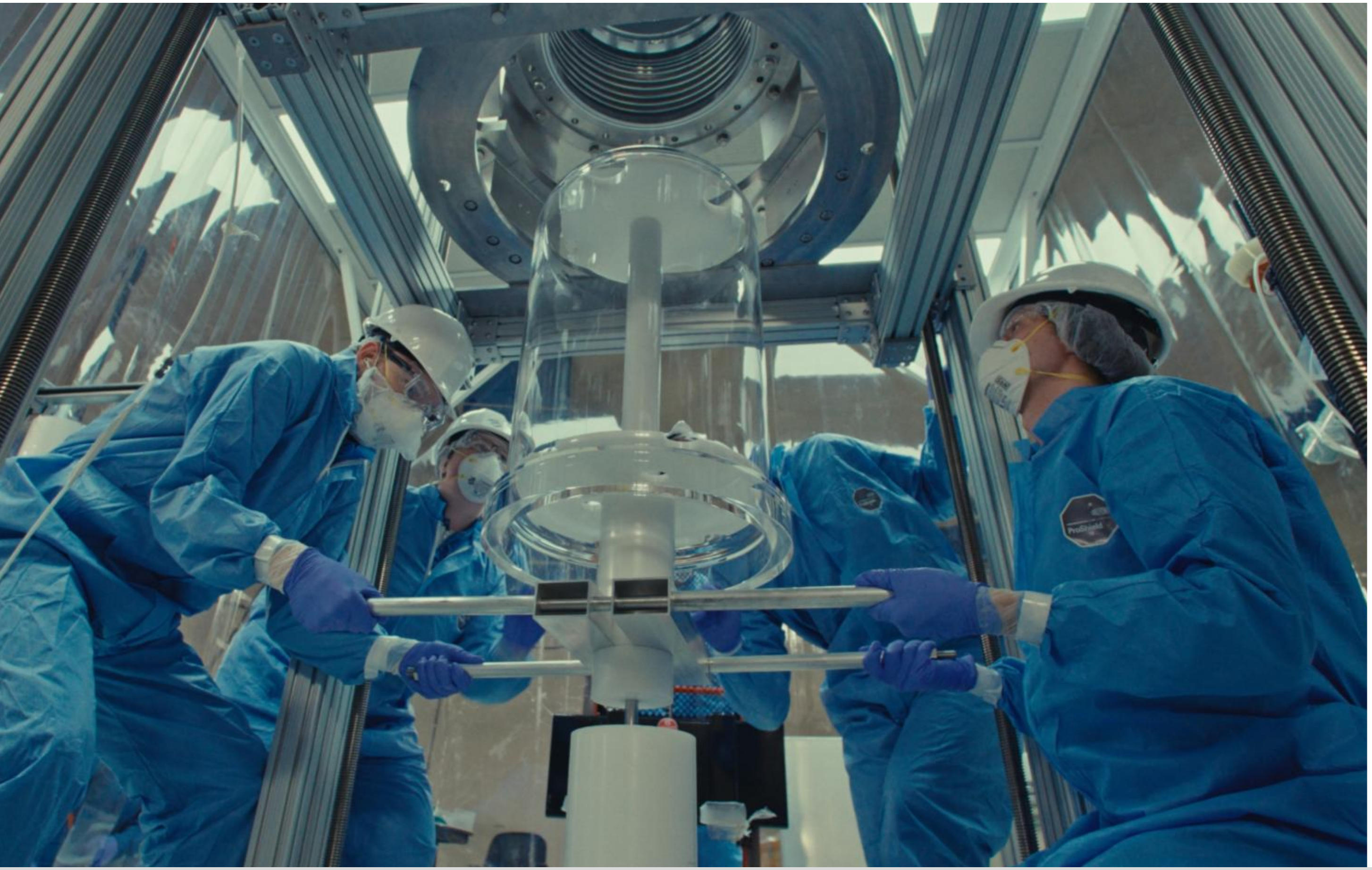
Inner Vessel

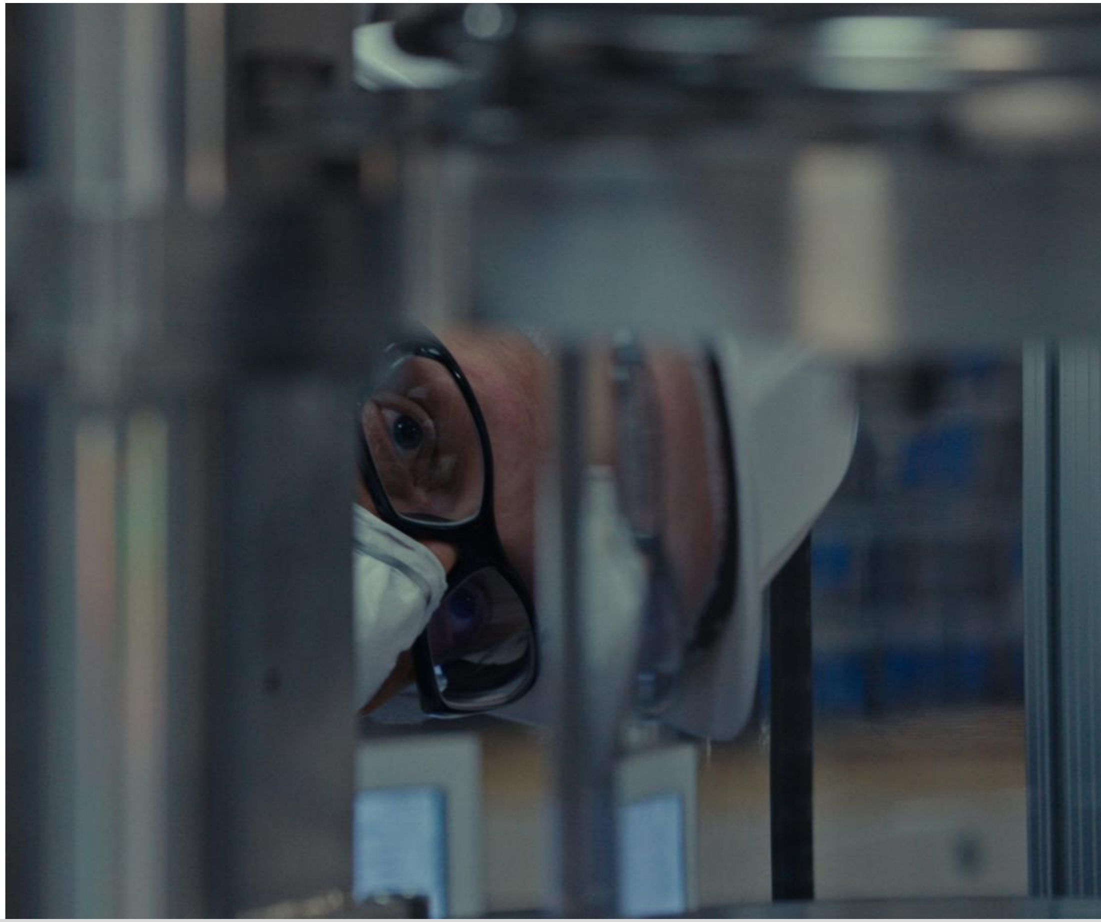
- The inner jar, outer jar, and bellows have been cleaned. We have done test runs for IV assembly.



Upcoming Work

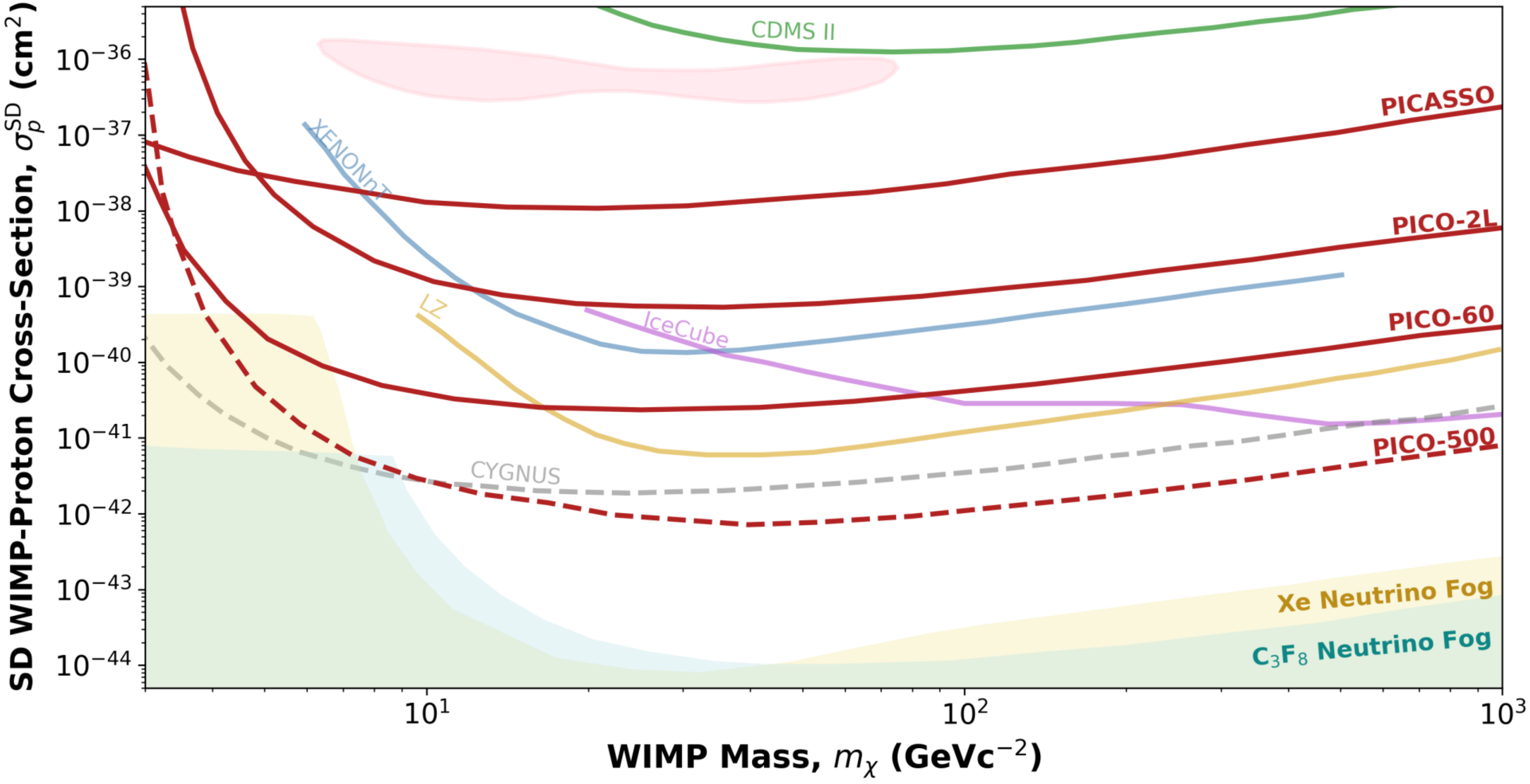
- Currently installing heating and cooling components as well as temperature sensors.
- In September, will prepare heating components inside the pressure vessel, and do all plumbing and wiring.
- Expect to install the jars inside the pressure vessel by end of 2026 and start commissioning mid-2027.





Projected Sensitivities

- Plan to run PICO-500 at a threshold of 8.2 keV for three years.
- PICO-500 is expected to set world-leading limits in the spin-dependent parameter space.



Neutrino fog from F. Ruppin, et al. (2014)
https://inspirehep.net/literature/1311290

Summary

- Bubble chambers remain an exciting technology for direct dark matter searches, offering substantial background control and rejection for little cost.
- PICO-40L will be coming back online in the coming month.
- PICO-500 assembly is progressing well and will be completed next year.
- PICO-500 is expected to set world-leading limits on SD WIMP dark matter interactions.

Summary

- Bubble chambers remain an exciting technology for direct dark matter searches, offering substantial background control and rejection for little cost.
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Thank You

PICO

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B. Ali, R. Filgas, D. Mamedov, E. Rukhadze, I. Stekl

INDIANA UNIVERSITY SOUTH BEND

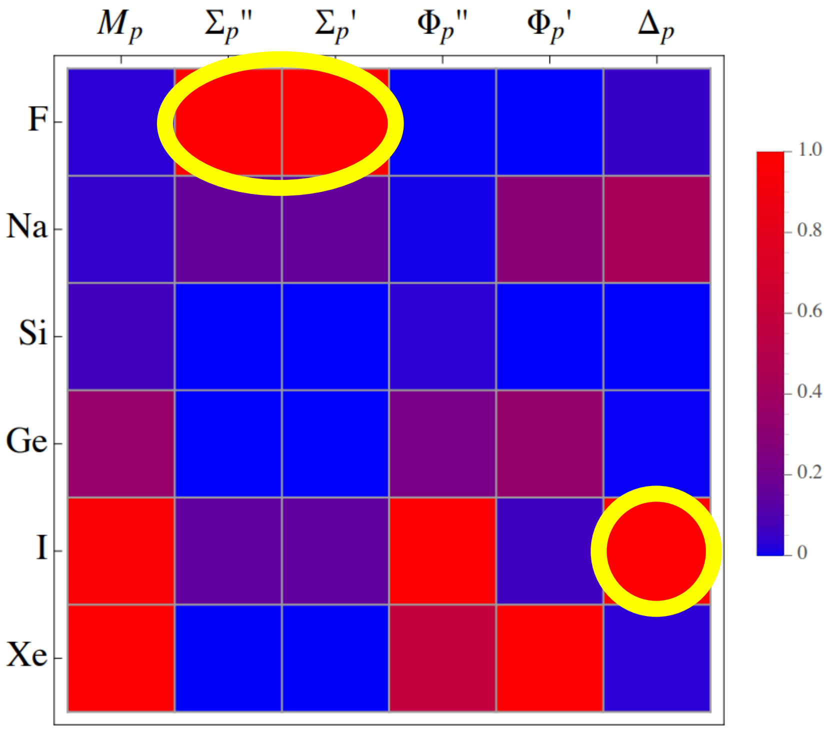
E. Behnke, C. Cripe, I. Levine

Kavli Institute for Cosmological Physics at The University of Chicago

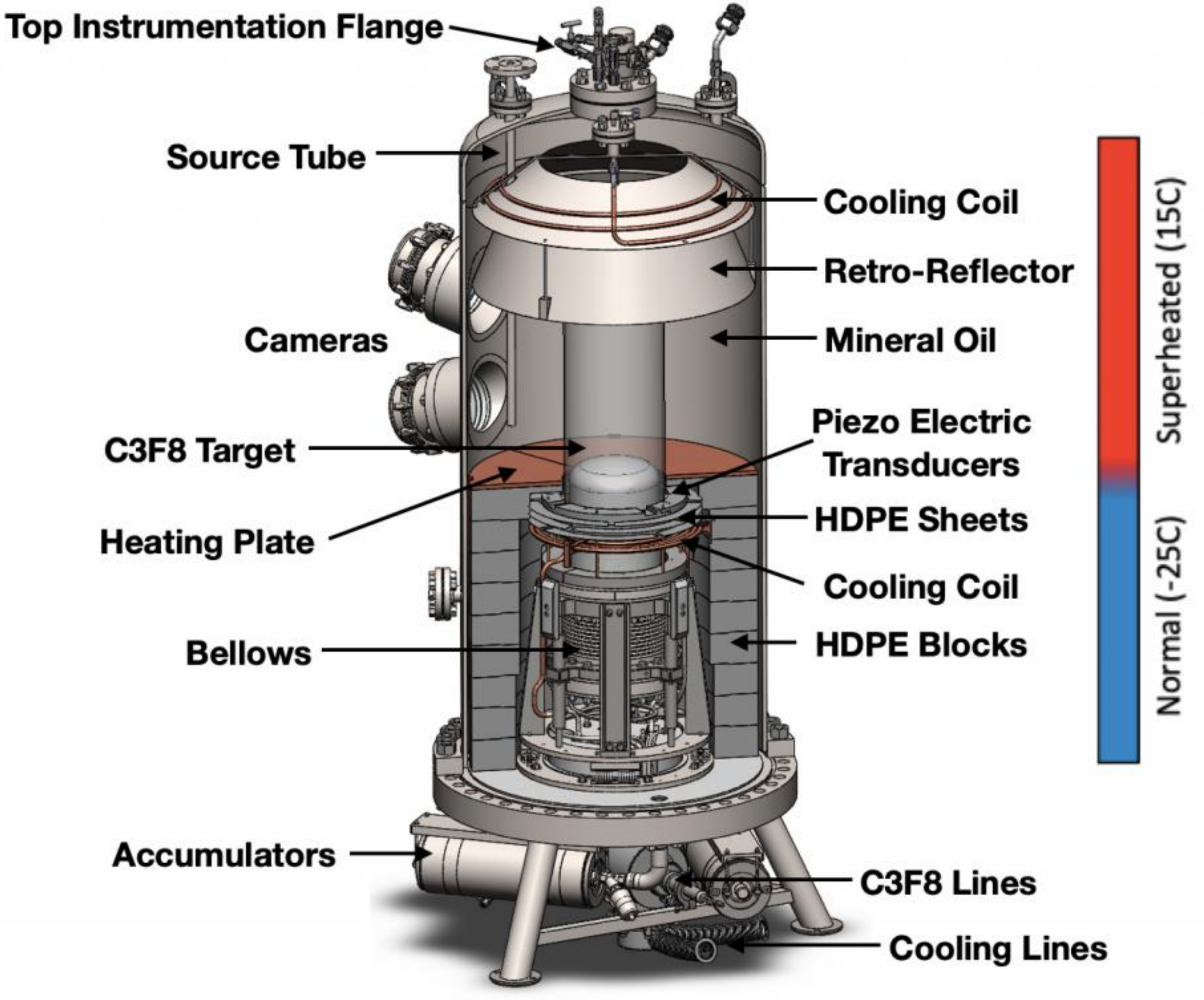
J. I. Collar, M. Tripathi

PICO Bubble Chambers

- Search for spin-dependent WIMP dark matter.
- Sealed synthetic quartz vessel.
- Filled with C_3F_8 for ^{19}F sensitivity to proton spin.
- Recompression deadtime requires low event rate.



L. Fitzpatrick, INT Workshop (2014): https://archive.int.washington.edu/talks/WorkShops/int_14_57W.



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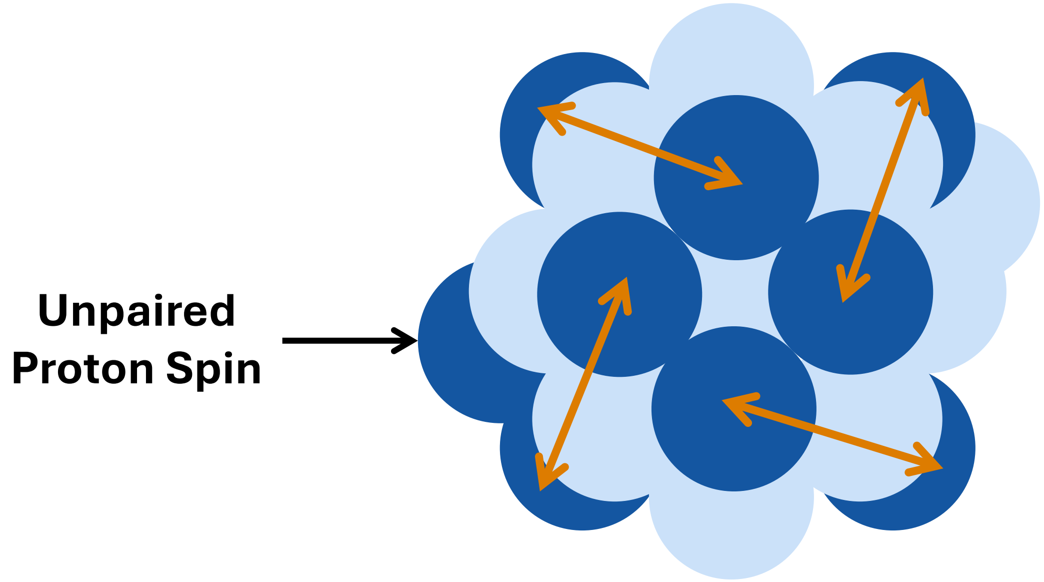
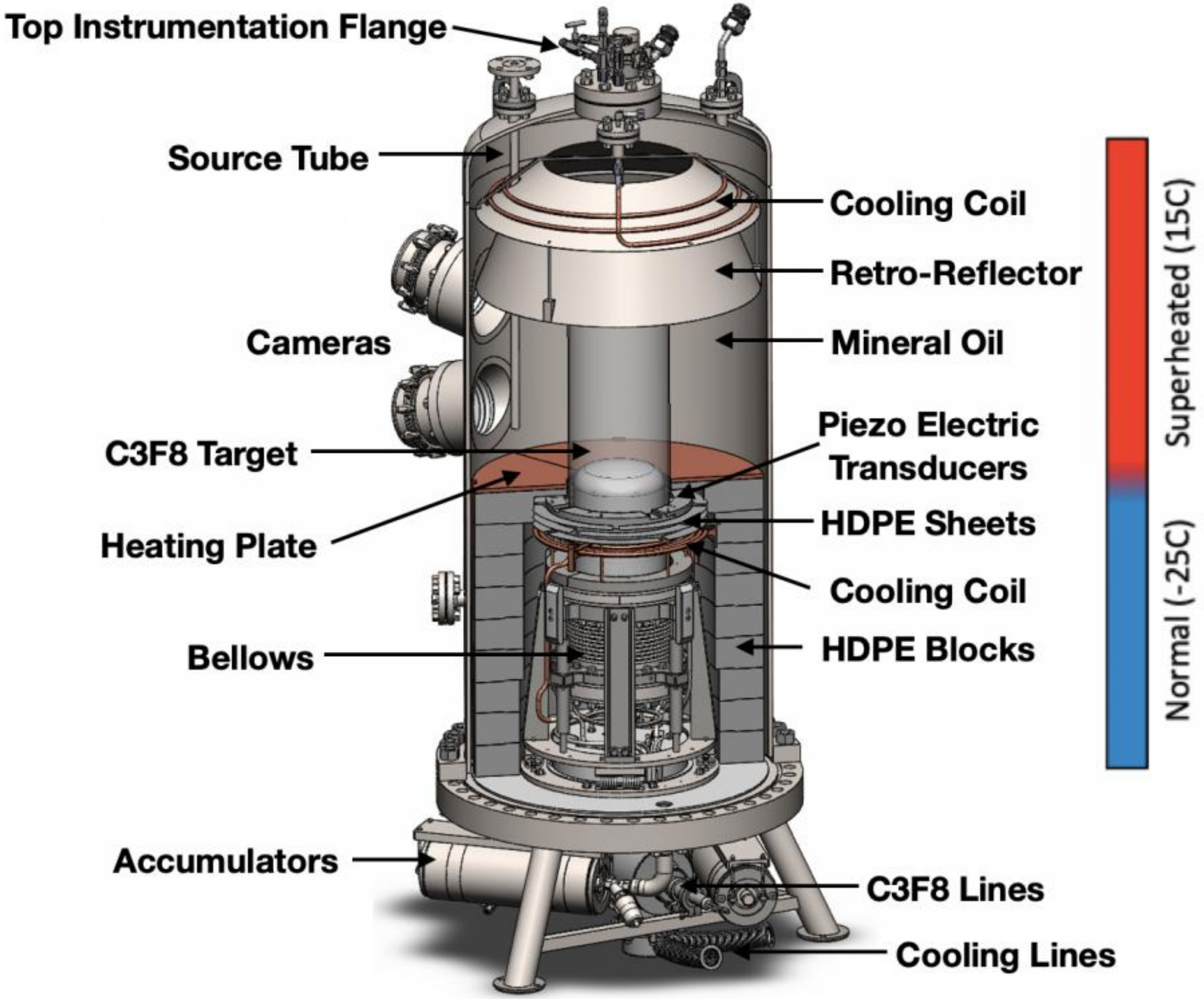


$^{19}_{9}\mathrm{F}$



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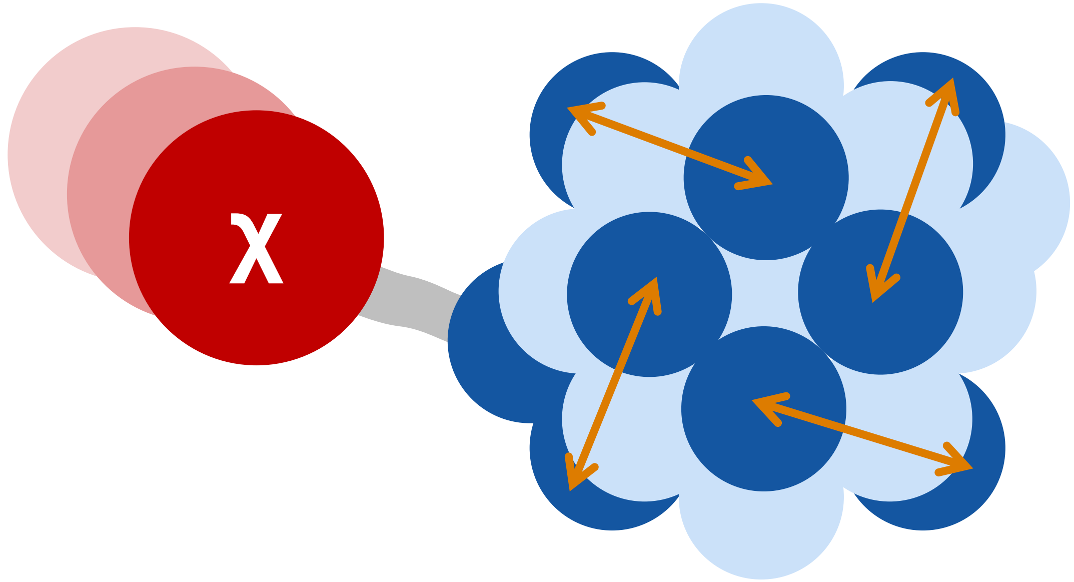

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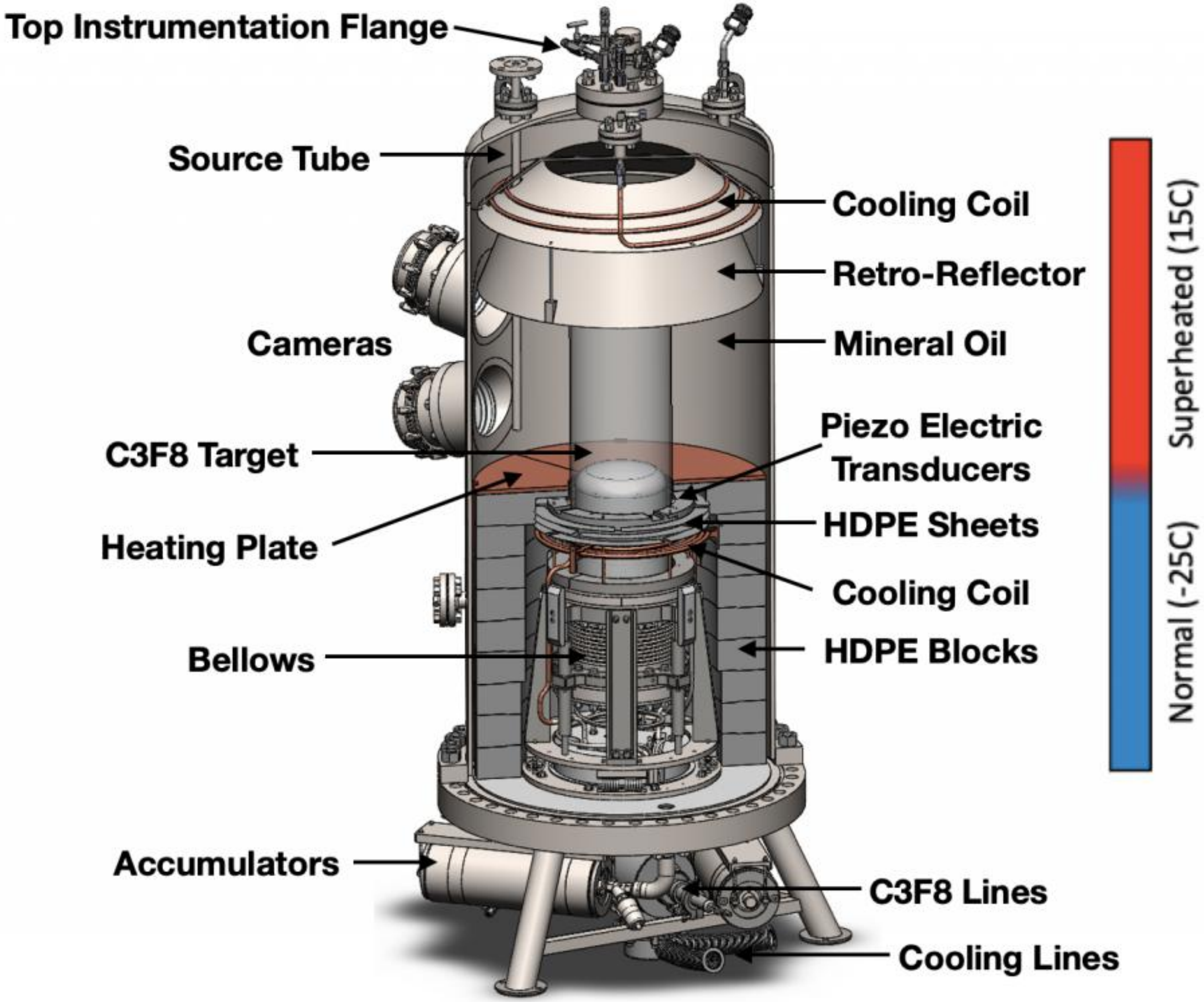
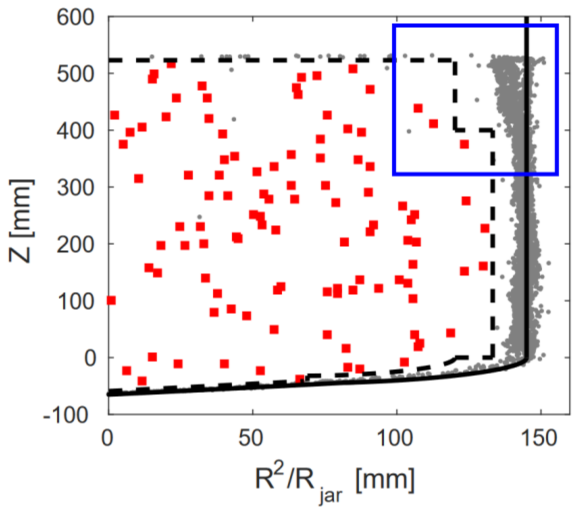
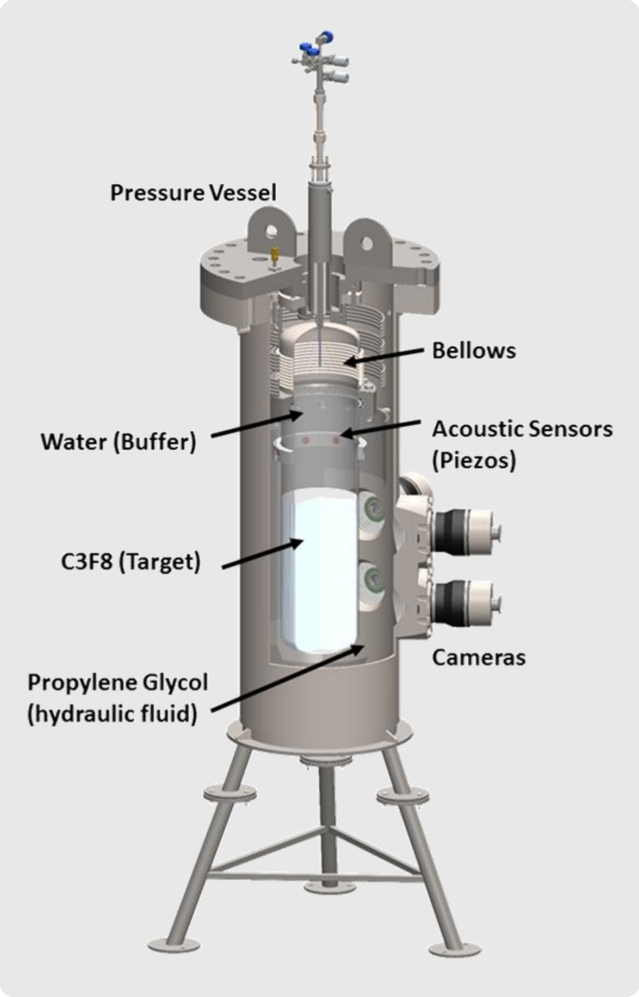


Right-Side-up Design

Upside Down





- Bellows above buffer.
- Particulates from water cause higher wall rates.
- Particulates may gather at bottom of the jar.

Right-Side-up

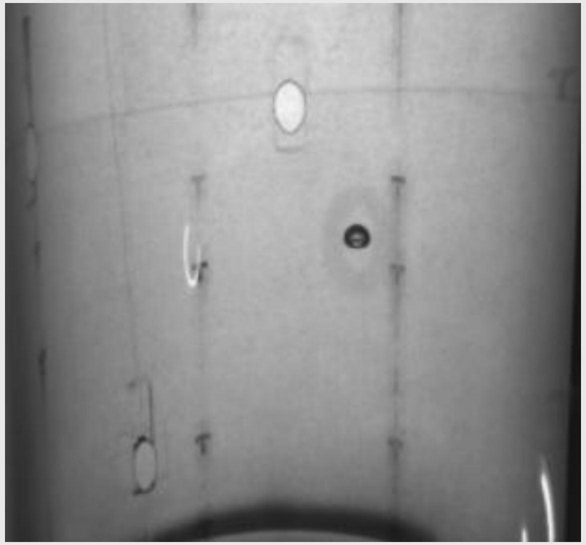
- **Inverted Geometry:** Bellows on bottom, no buffer liquid.
- Introduce quartz inner jar to compress liquid.
- **Hot Region:** Establish superheat in C_3F_8.
- **Cold Region:** Prevent C_3F_8 in contact with the bellows from boiling.
- PICO-40L is first large-scale implementation. Acts as a proof-of-concept for PICO-500.

Backgrounds

Nuclear Recoils

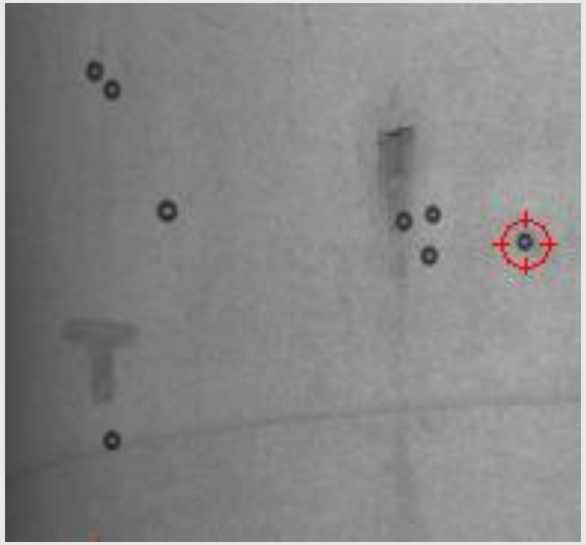
Alpha Particles

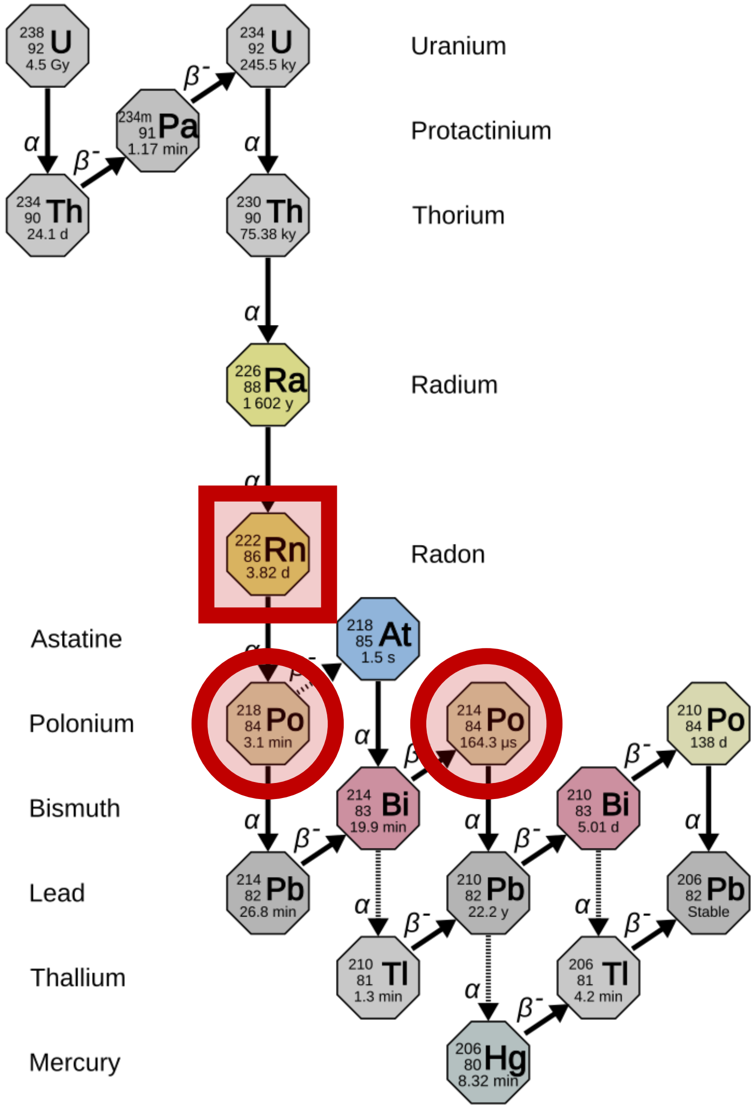
- Internal background. From ^{222}Rn and ^{220}Rn from ^{238}U and ^{232}Th decay chains.
- Single bubbles.



Neutrons

- Internal from spontaneous fission and (α, n), and external from CR muons.
- Single or multi-bubbles.





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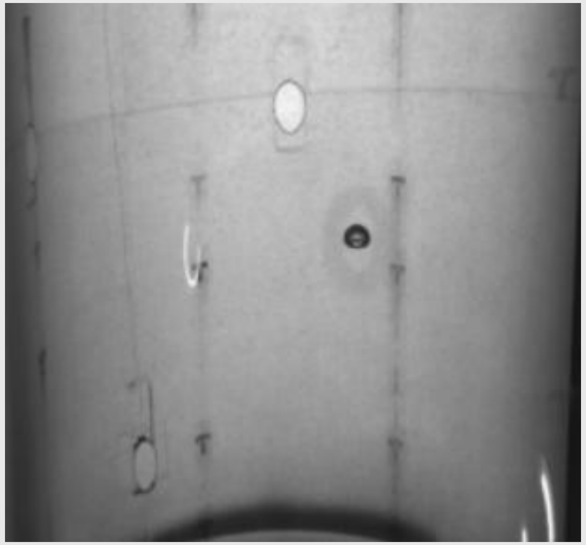

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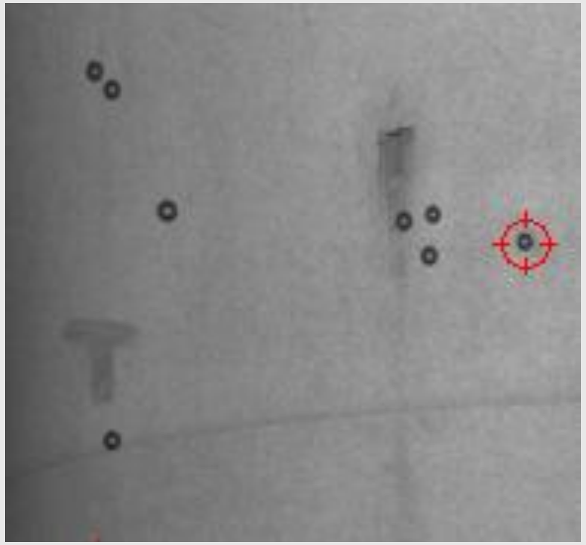

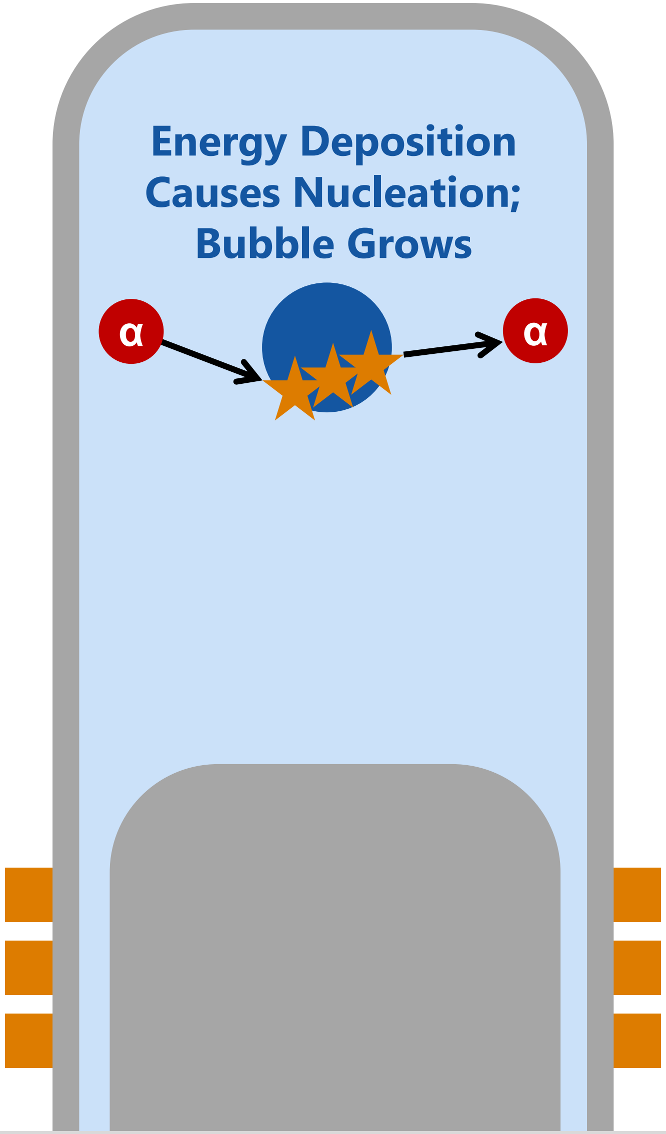

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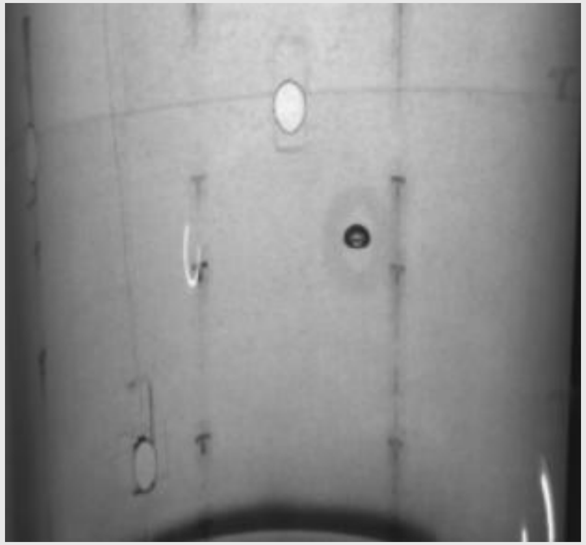

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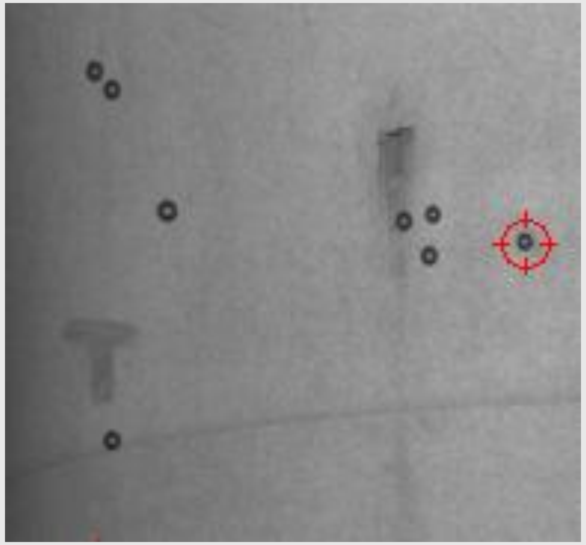

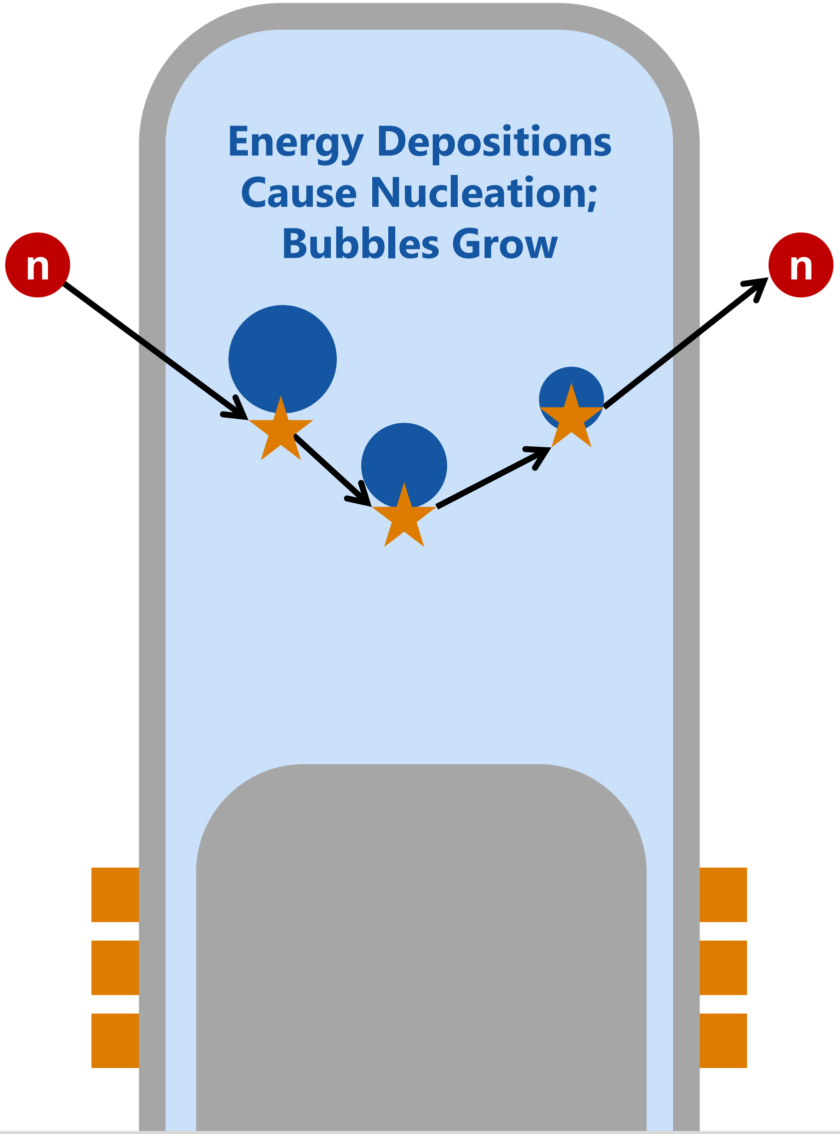

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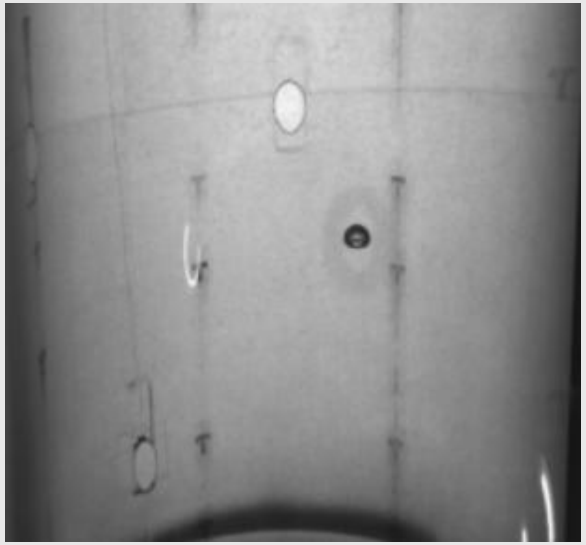

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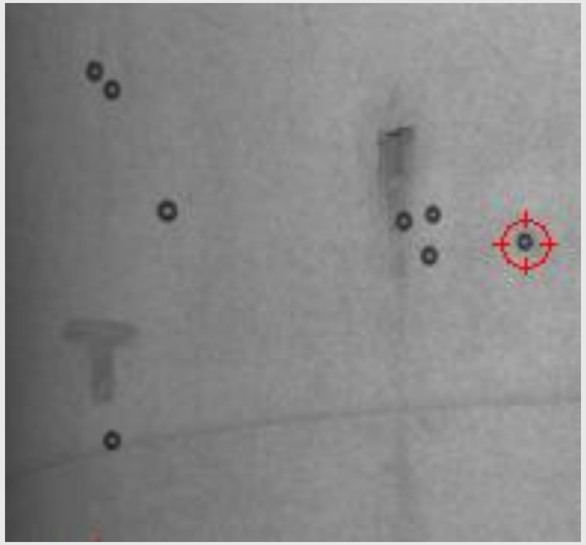
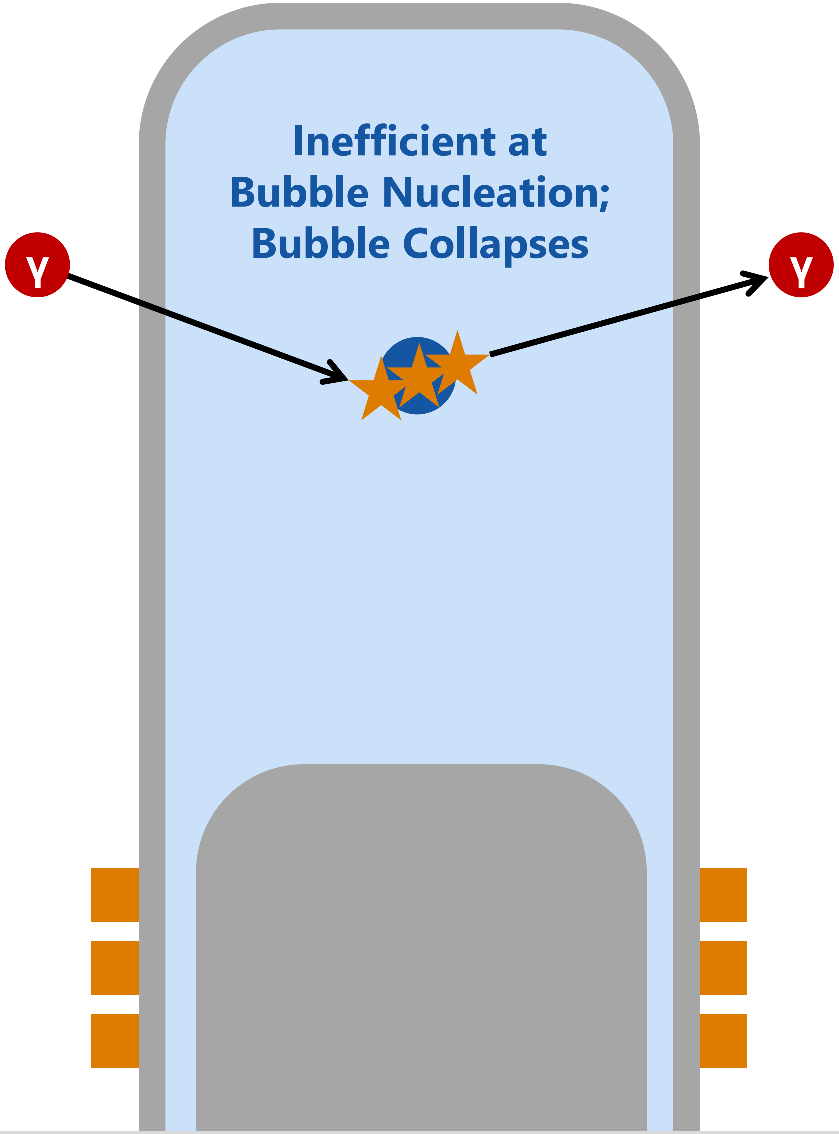




PICO-40L Timeline and Current Status

2020 Assembly finished, commissioning began.

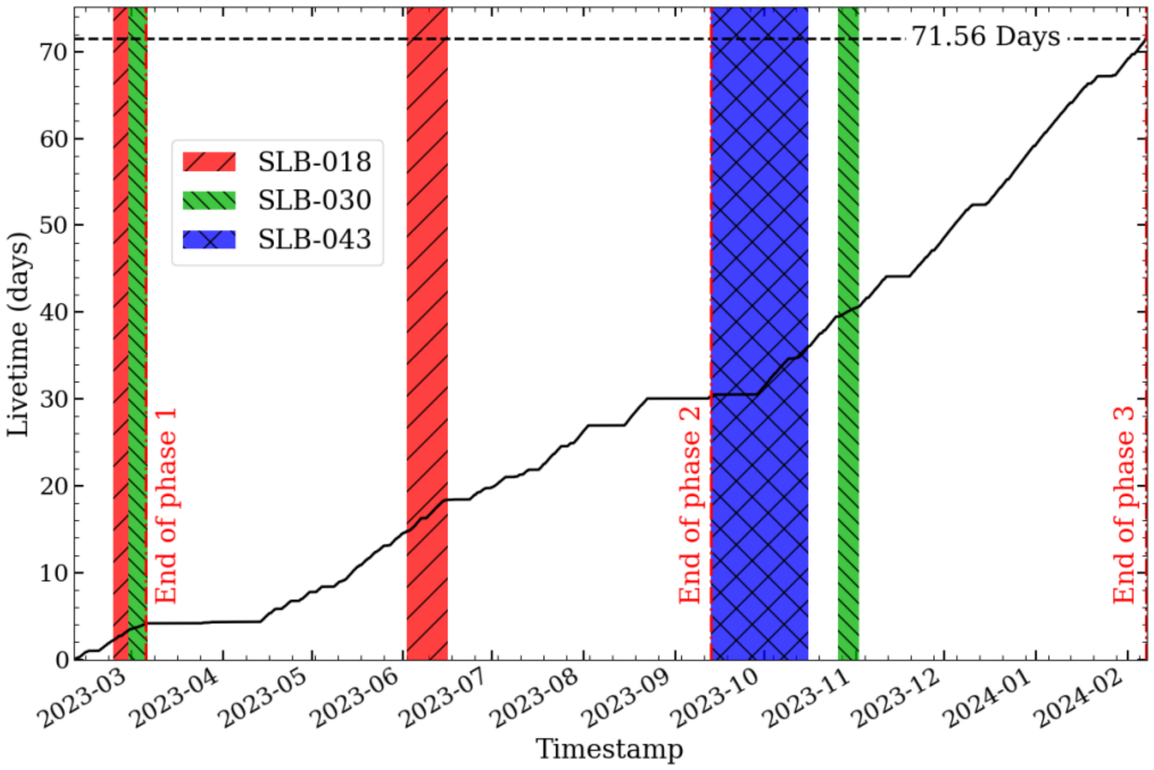
2021 Found leak inside detector, disassembled.

2022 Fixed leak, reassembled, calibration runs.

2023 Start of first physics run.

2024 Chiller issues, operations paused.

2025 **Fixed chiller, but experiencing issues with expanding the detector. Looking into this now.**



C. Moore, Ph.D. Thesis (2024)
https://inspirehep.net/literature/2829909