The PICO Bubble Chamber Program

Special thanks to Colin Moore, Derek Cranshaw, and Eric Vazquez-Jauregui

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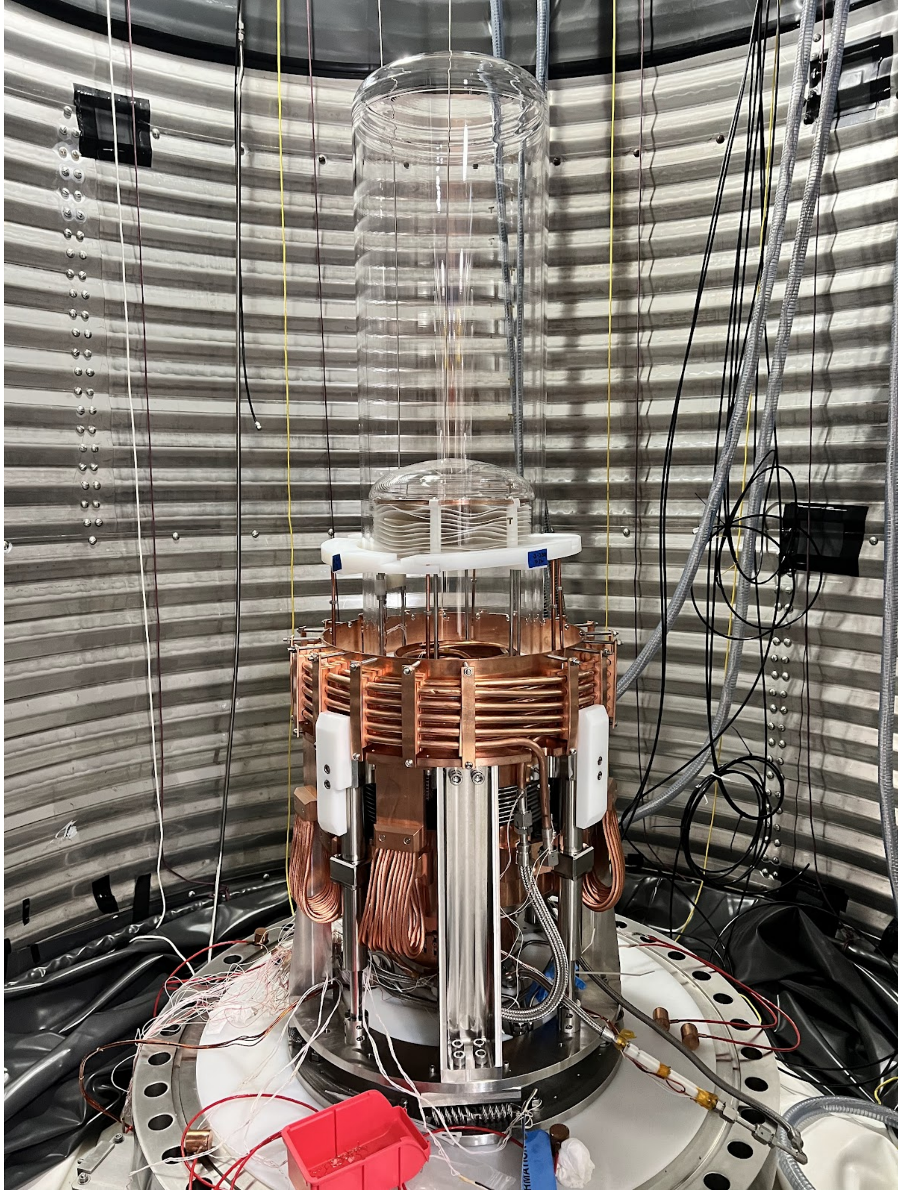
Professor of Physics, Queen's University

Presented at the 2024 McDonald Institute National Meeting
on behalf of the PICO Collaboration
August 9, 2024

Overview

- Introduction to the PICO Collaboration
- Basic Principles of Bubble Chambers
- The PICO-40L Experiment: Operations and Projections
- The PICO-500 Experiment: The Near Future
- Conclusions and Outlook



THE COLLABORATION

PICO

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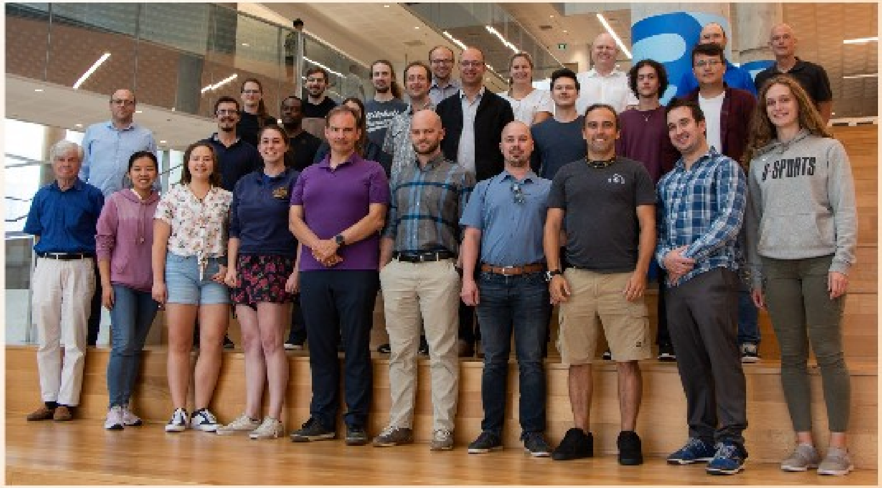

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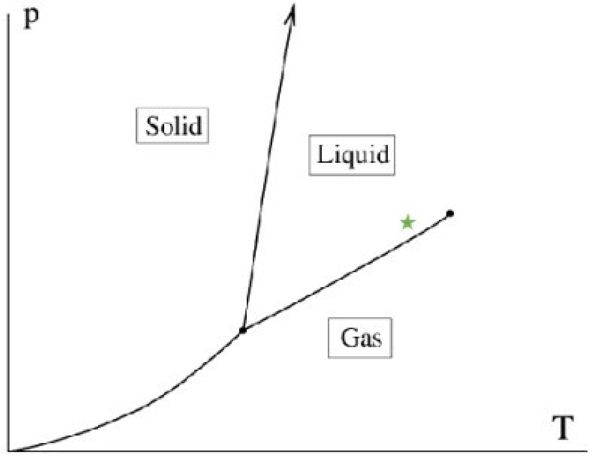
SNOLAB

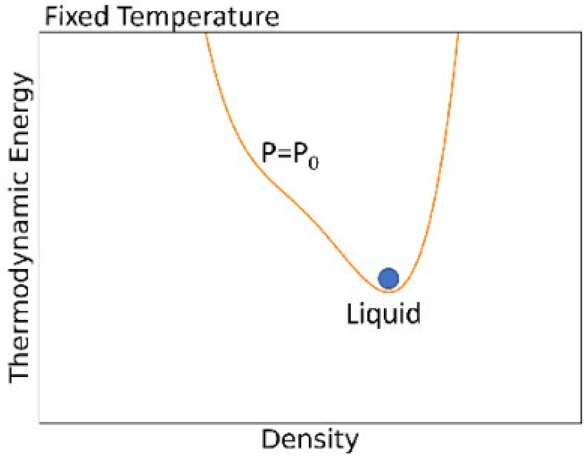
EDI committee formed in August 2023

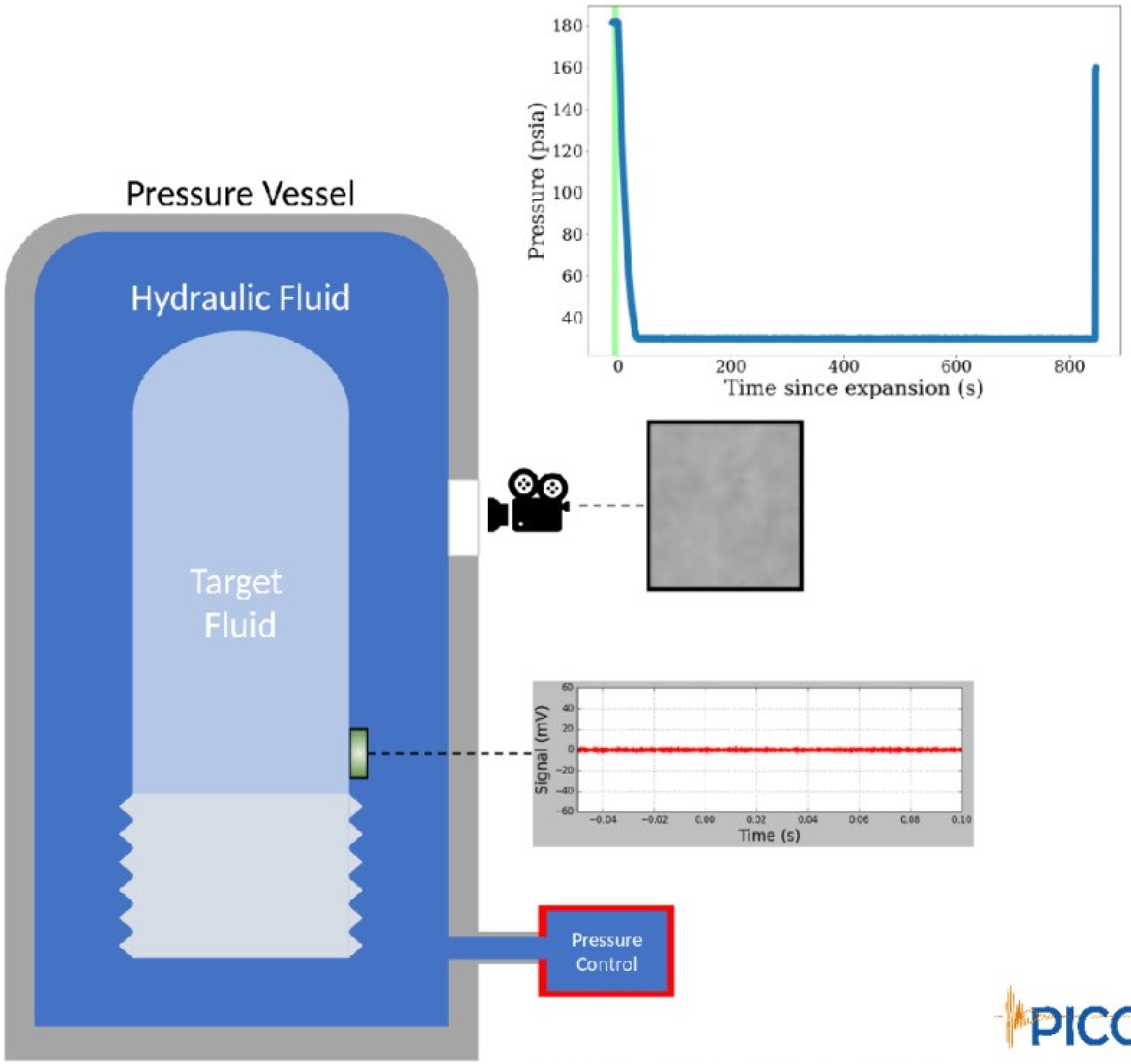
- 6 inaugural members, elected its own chair. 2 external advisors (Alex Pedersen and Erica Caden)
- reports to Science Board with member(s) on the board and is empowered with a budget
- conducting activities (e.g., mental health workshop)
- finalizing its own self-governance document
- working toward a climate survey as a baseline

BASIC PRINCIPLES AND OPERATION

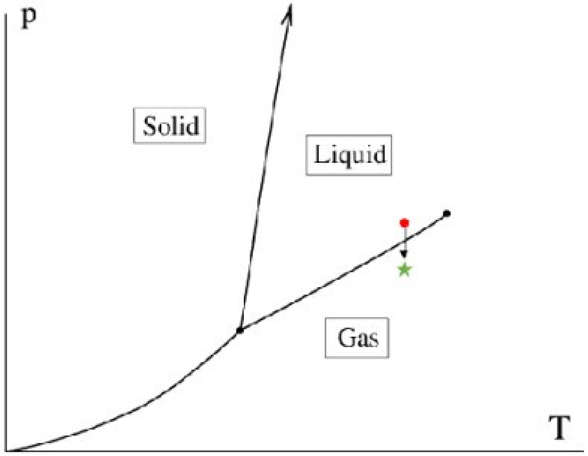
COMPRESSED STATE

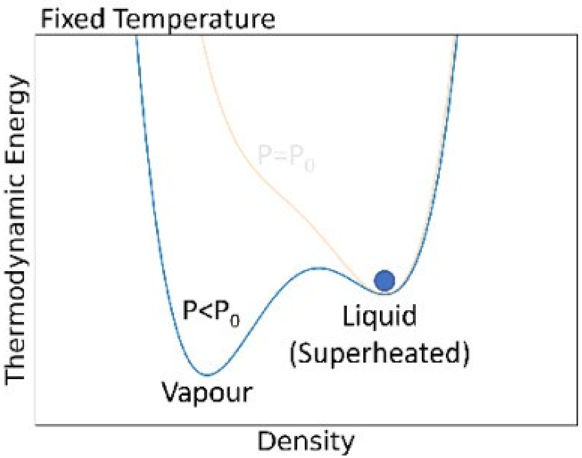


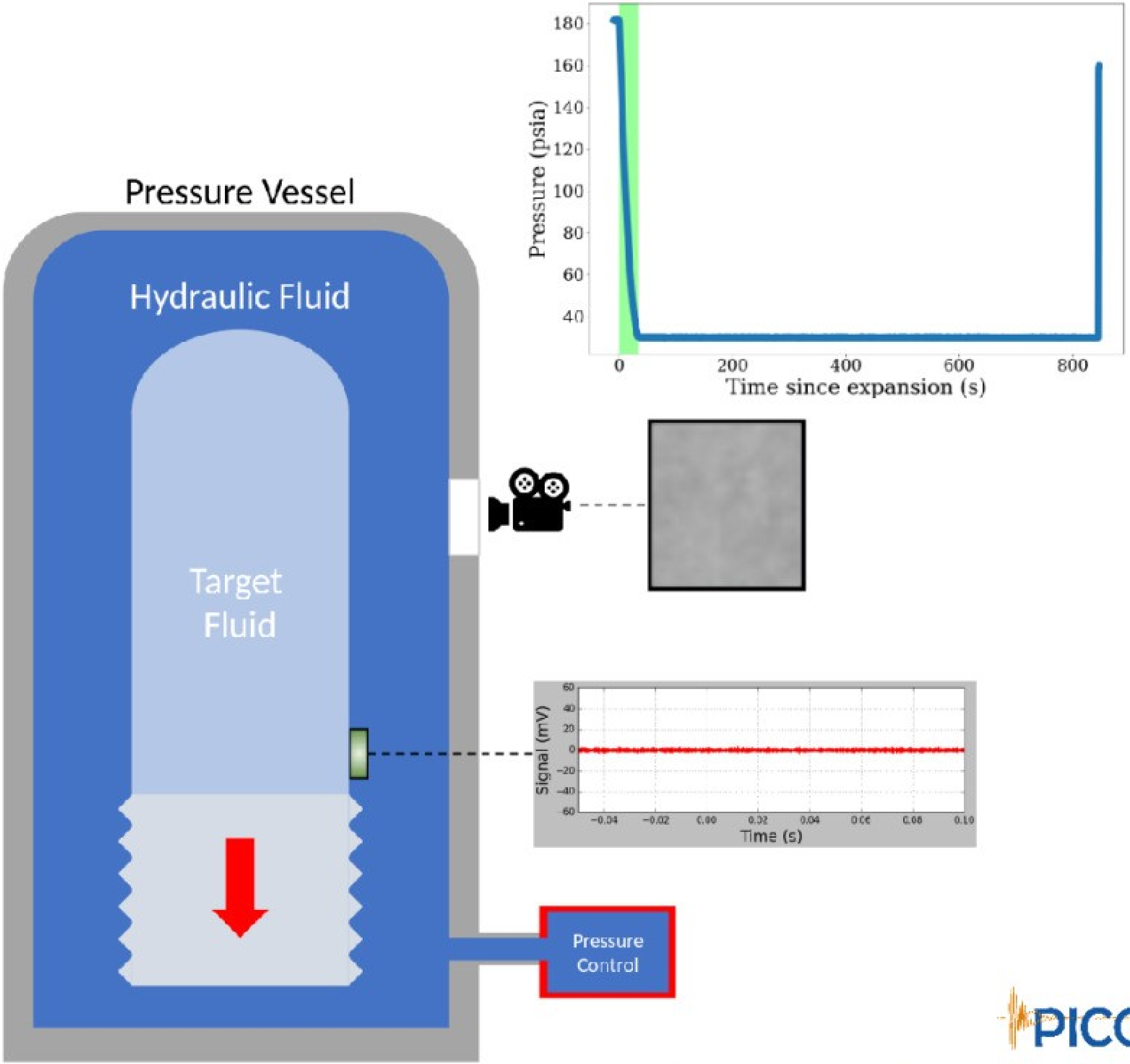




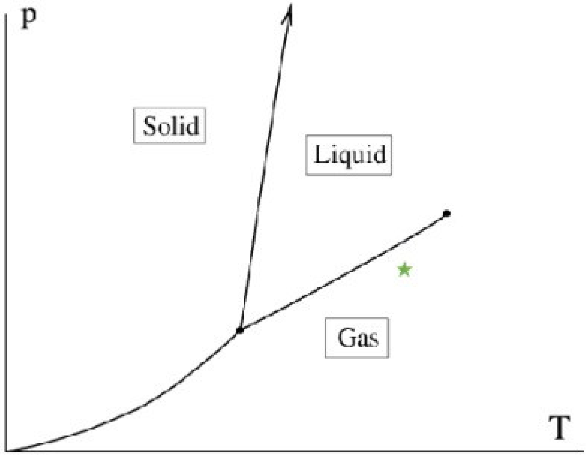
EXPANSION

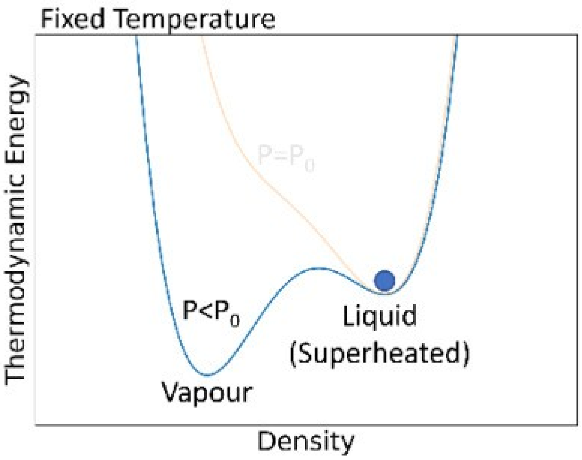

p
T
Solid
Liquid
Gas

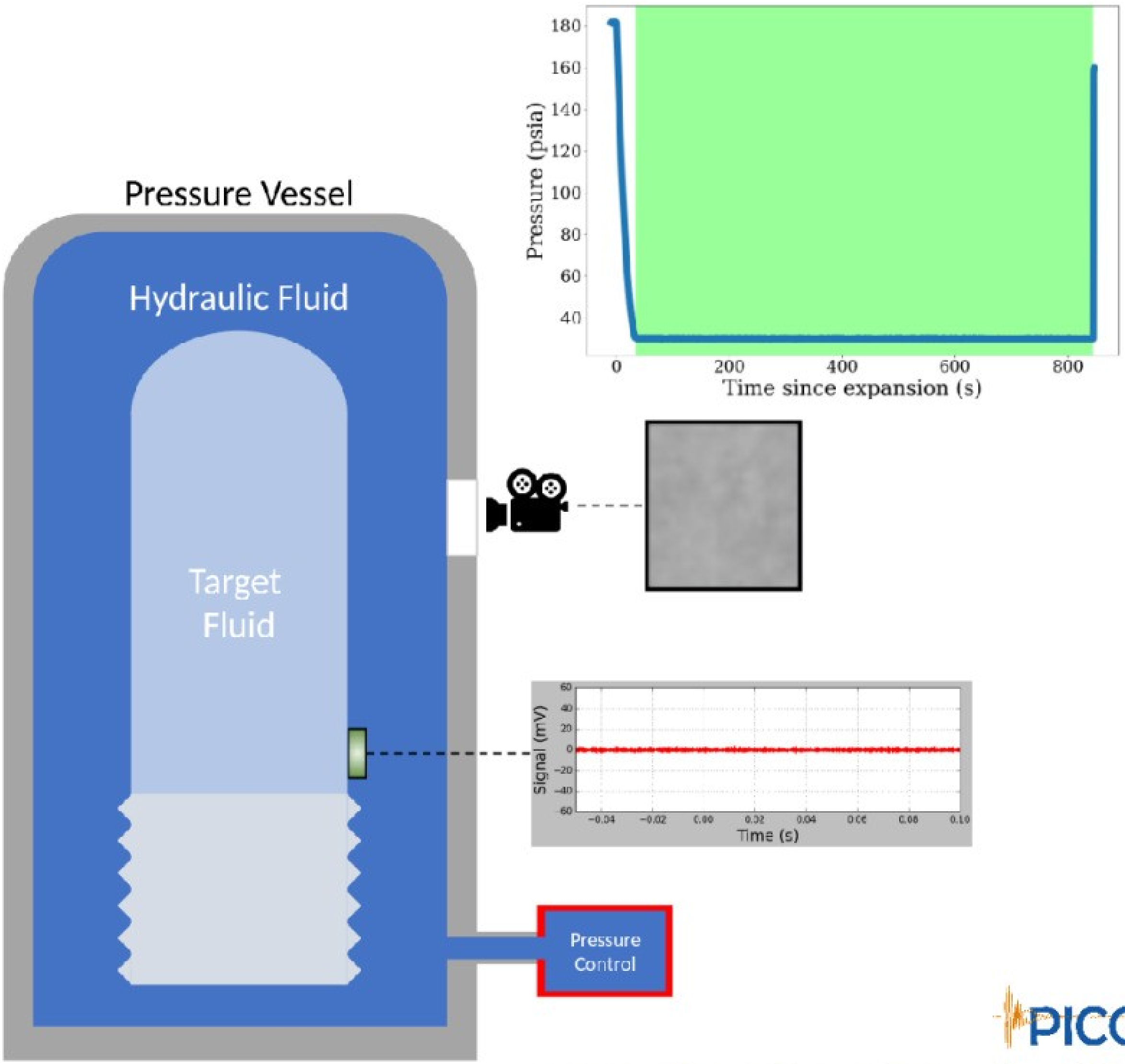

Fixed Temperature
Thermodynamic Energy
Density
P=P0
P<P0
Vapour
Liquid
(Superheated)


Pressure Vessel
Hydraulic Fluid
Target
Fluid
Pressure
Control
Pressure (psia)
Time since expansion (s)
Signal (mV)
Time (s)

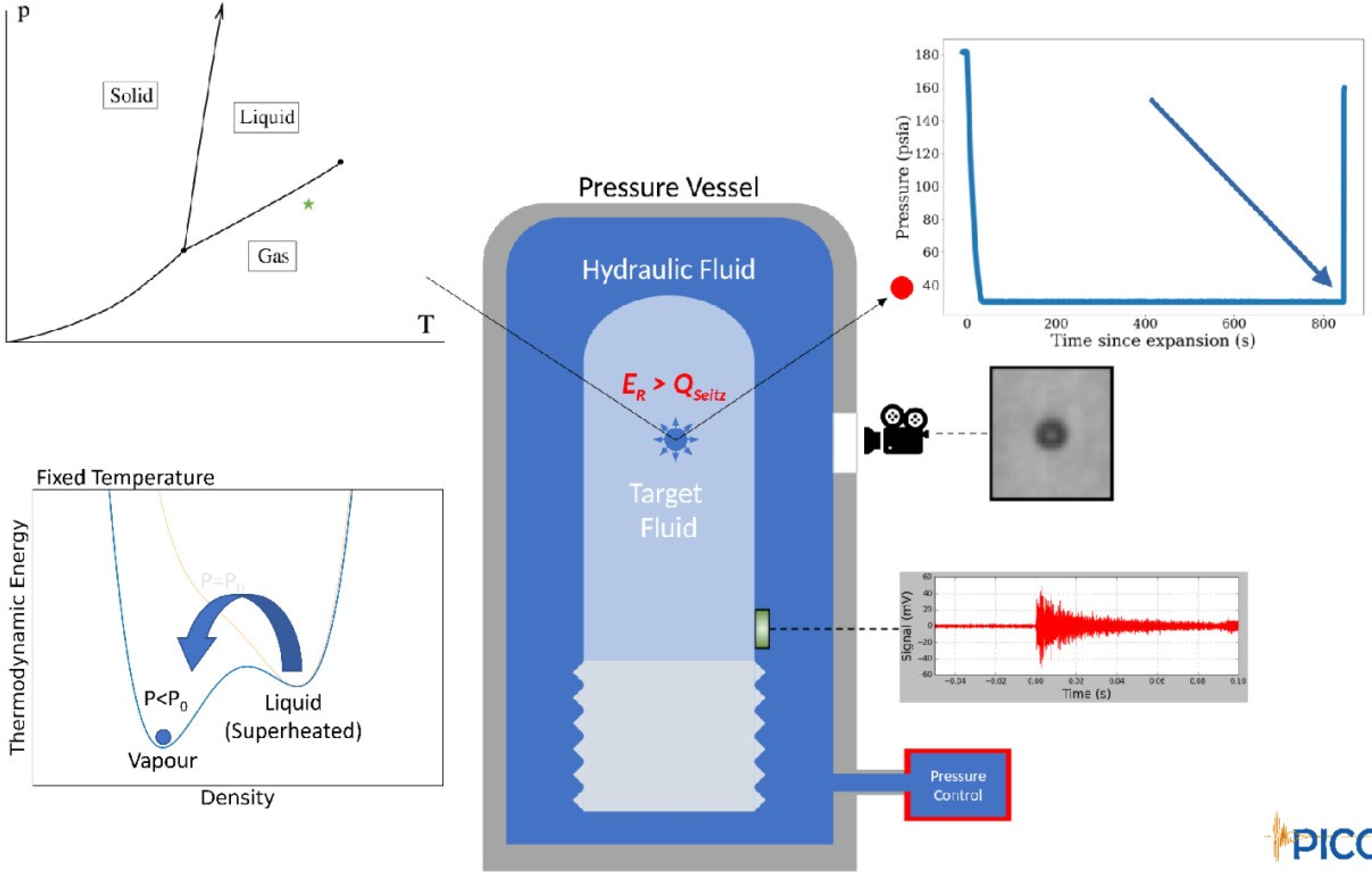
EXPANDED STATE



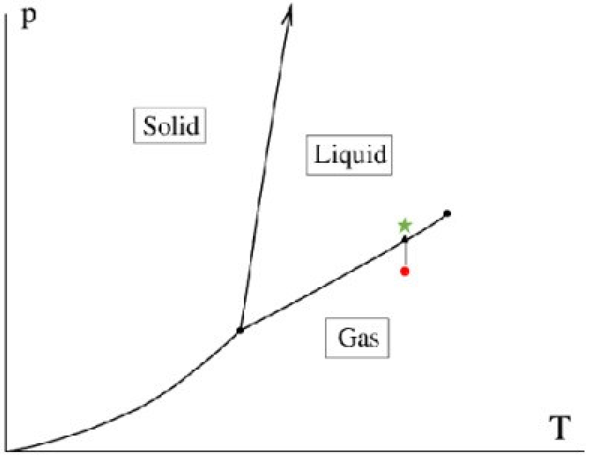


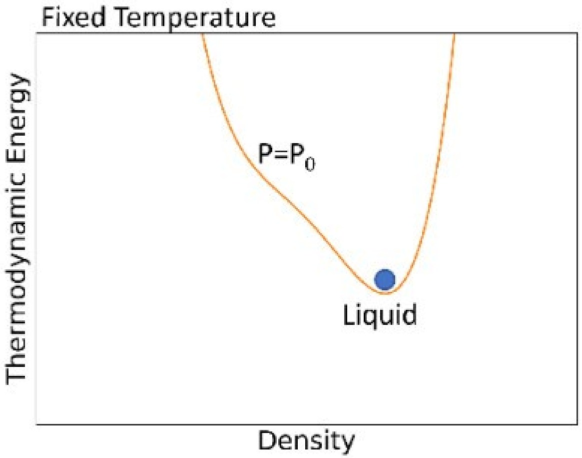


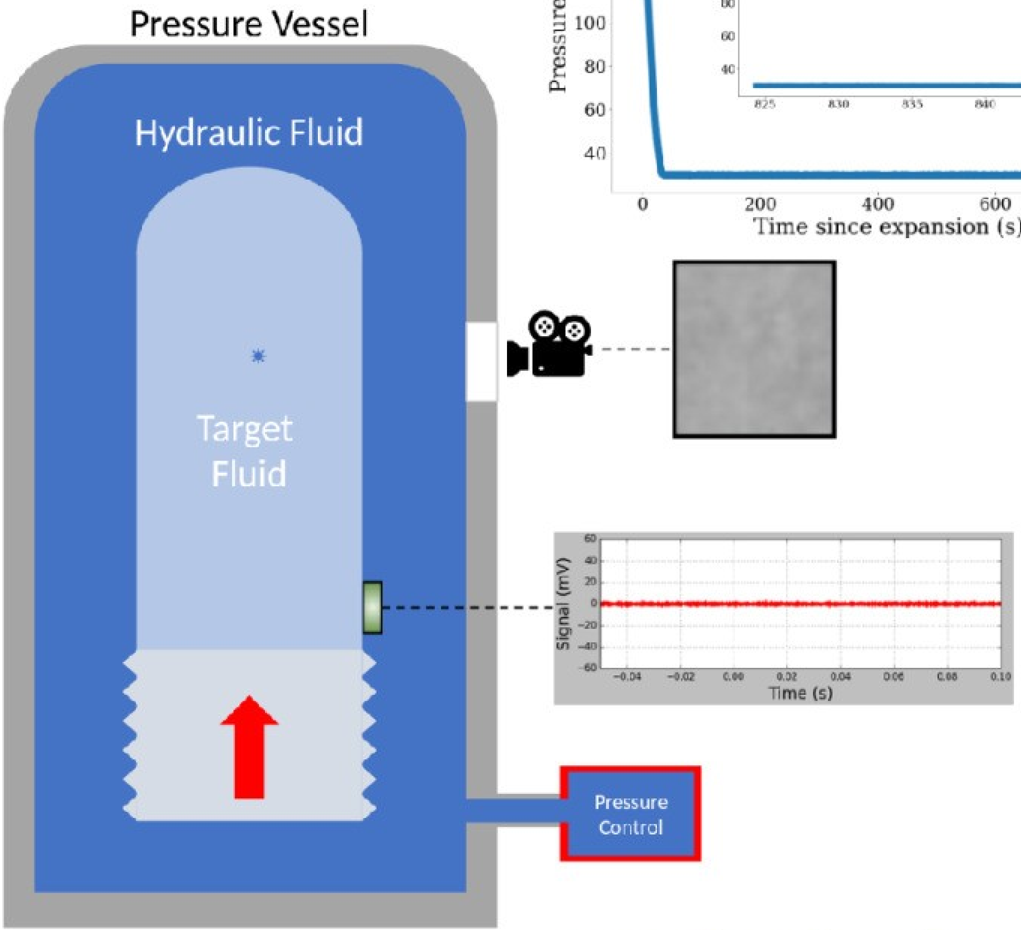
NUCLEATION AND TRIGGER

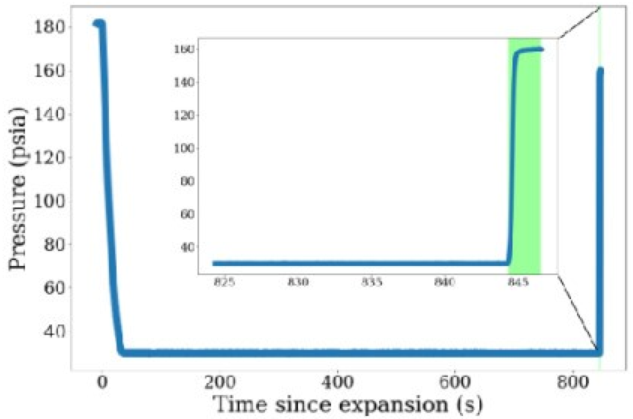


RECOMPRESSION









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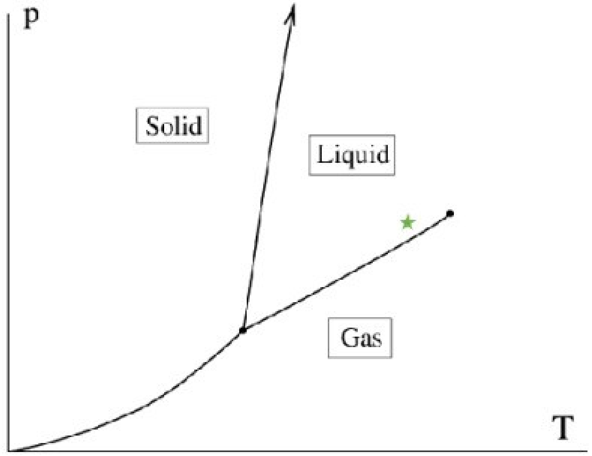
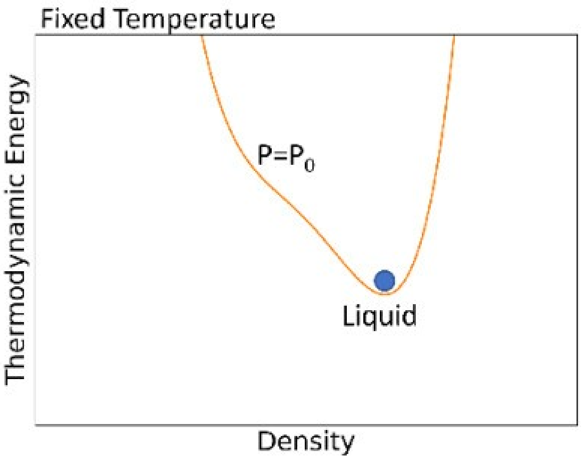
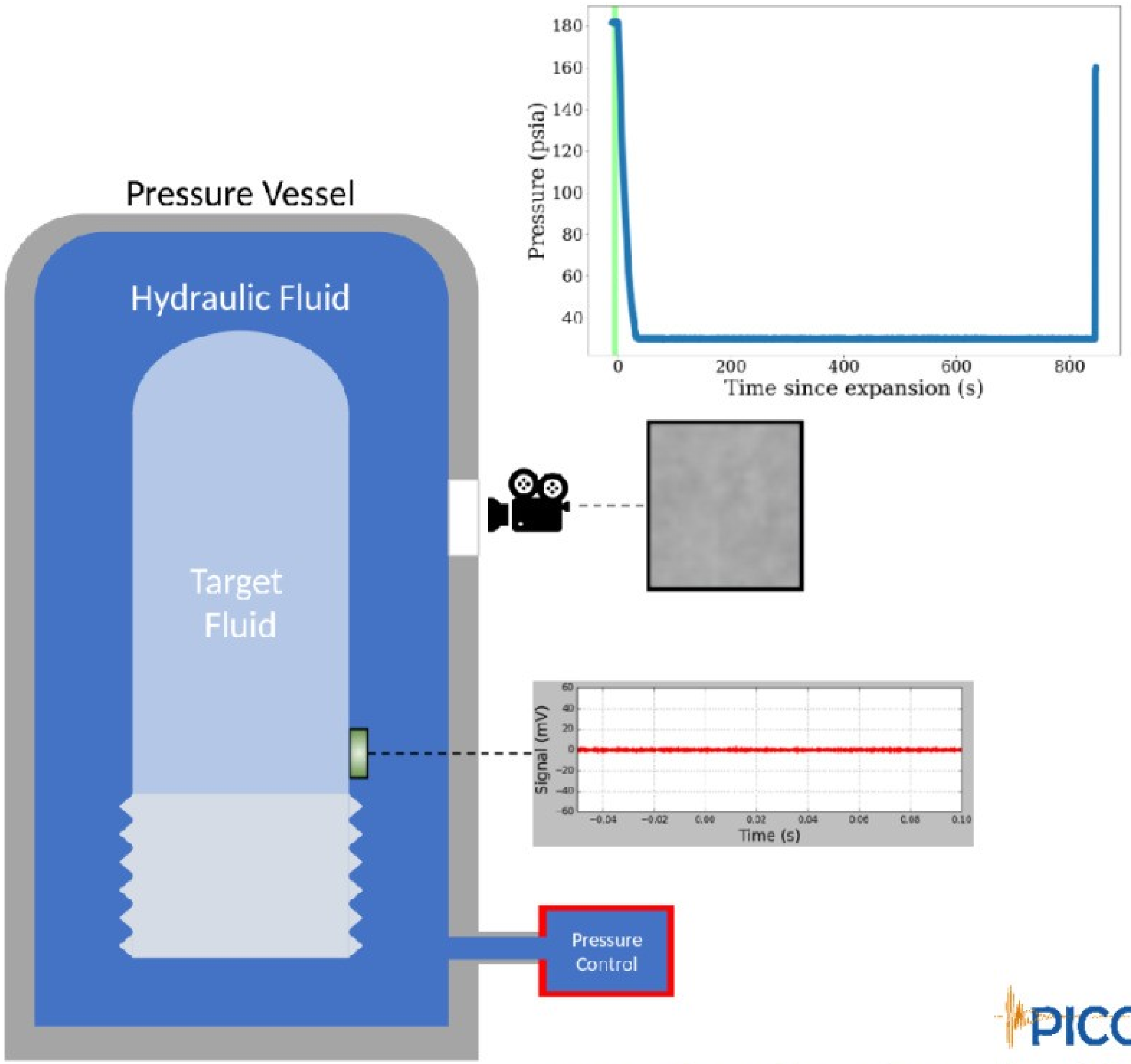
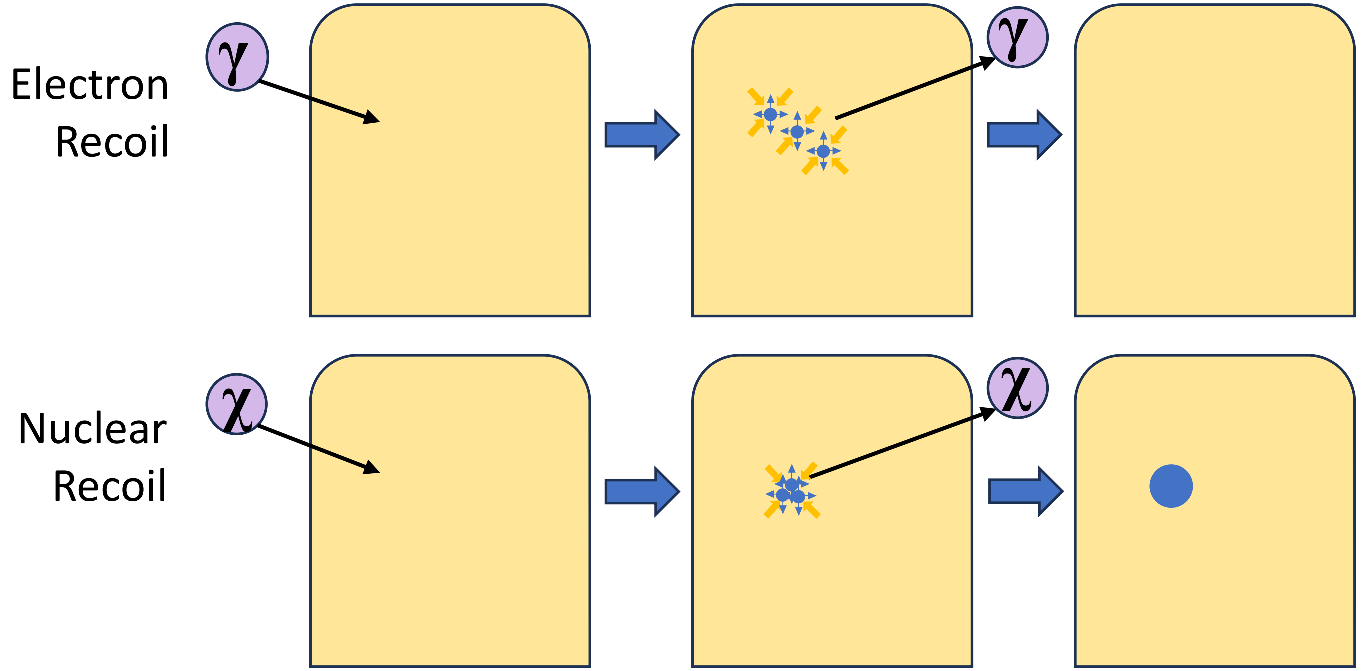






PICO

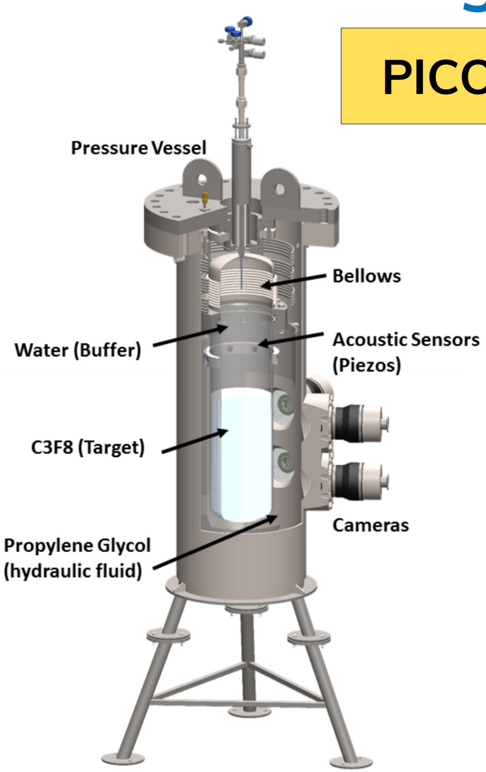
Main Advantage: Background Rejection

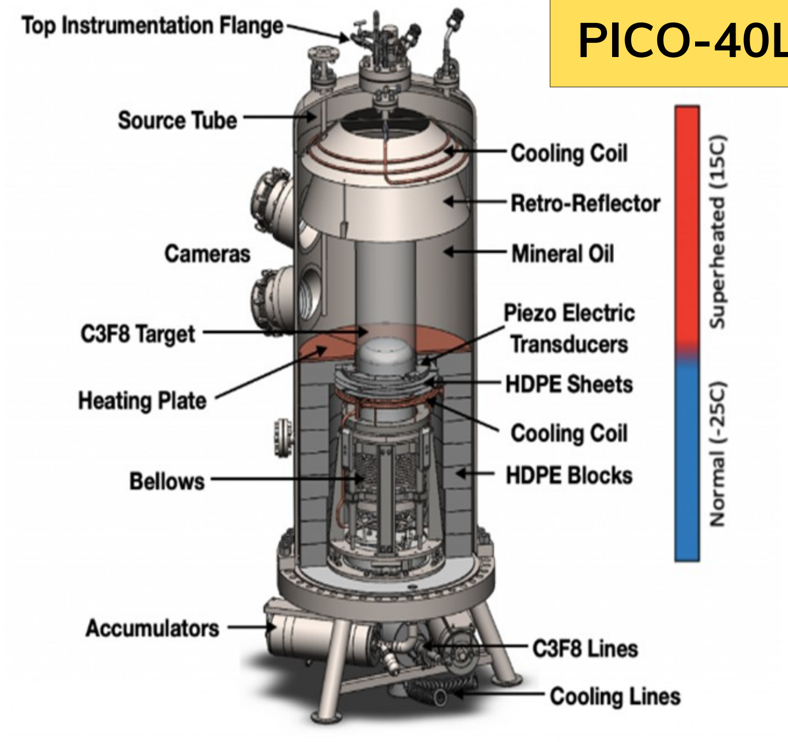


2024-01-11 Single Bubble Event

- Energy depositions from electron recoils insufficiently localized to form a bubble.
- Chamber is effectively blind to electron recoil interactions.

PICO-40L and the Right-Side-Up (RSU) Design





- World-leading spin-dependent WIMP-proton cross-section limits in 2019. (https://arxiv.org/abs/1902.04031)
- Bellows above the active fluid, separated by a buffer fluid (water).
- Excess of background events at buffer-target interface.

- Geometry inverted relative to PICO-60, buffer fluid removed.
- Thermal gradient suppresses bubbles near bellows.
- Additionally validates the RSU design in anticipation of larger detectors.

PICO-40L and the Right-Side-Up (RSU) Design

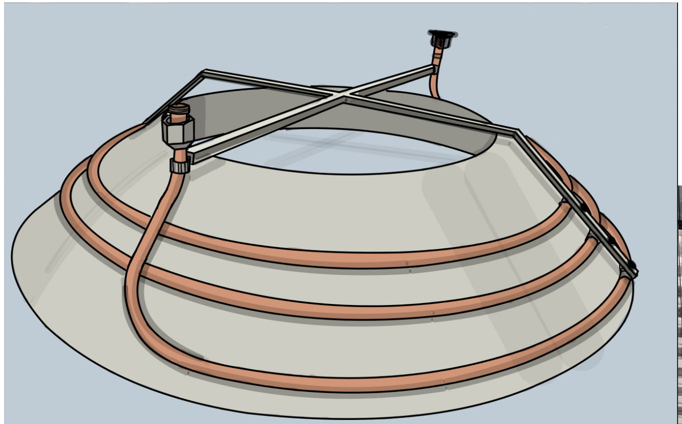
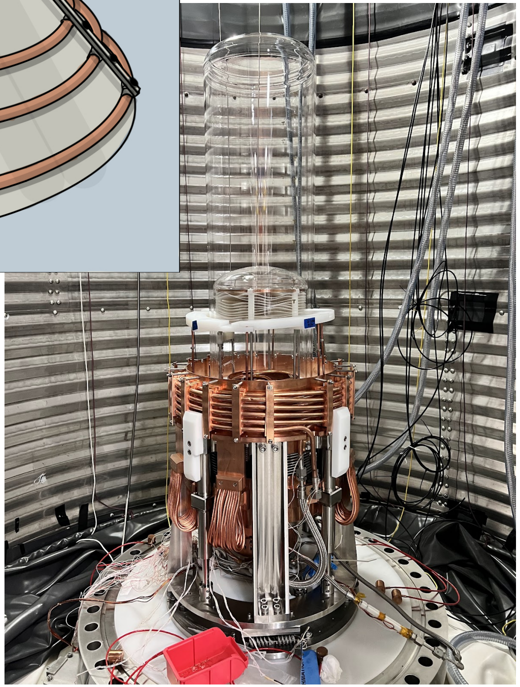
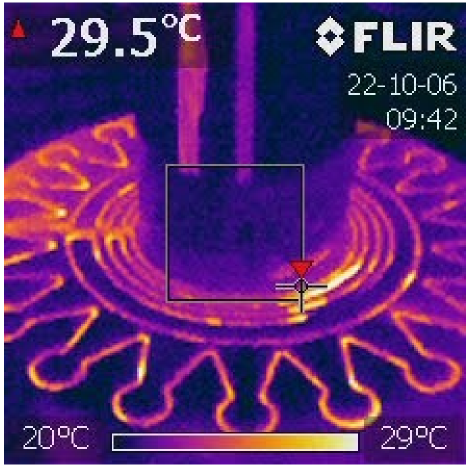
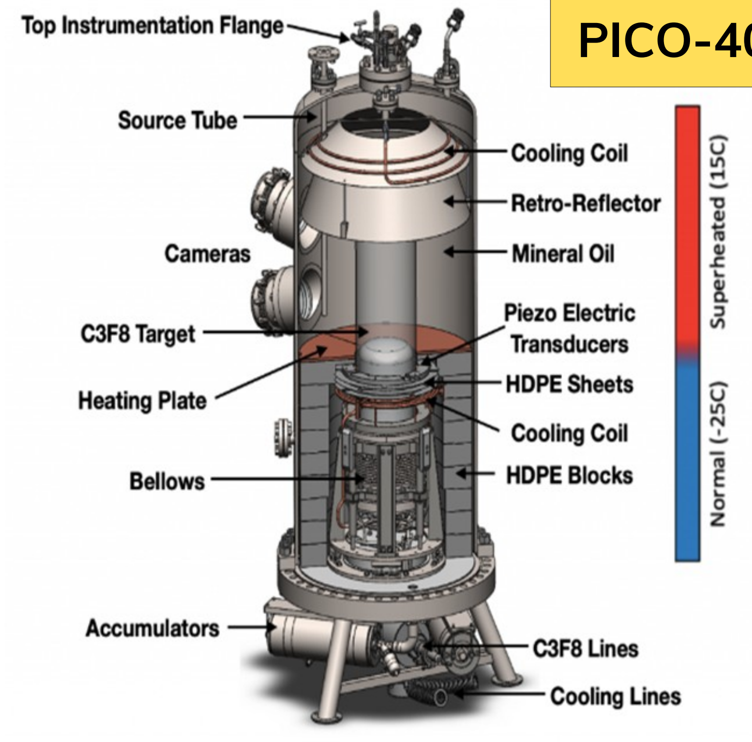


Illustration by Lily Hines (MI/Queen's)





PICO-40L



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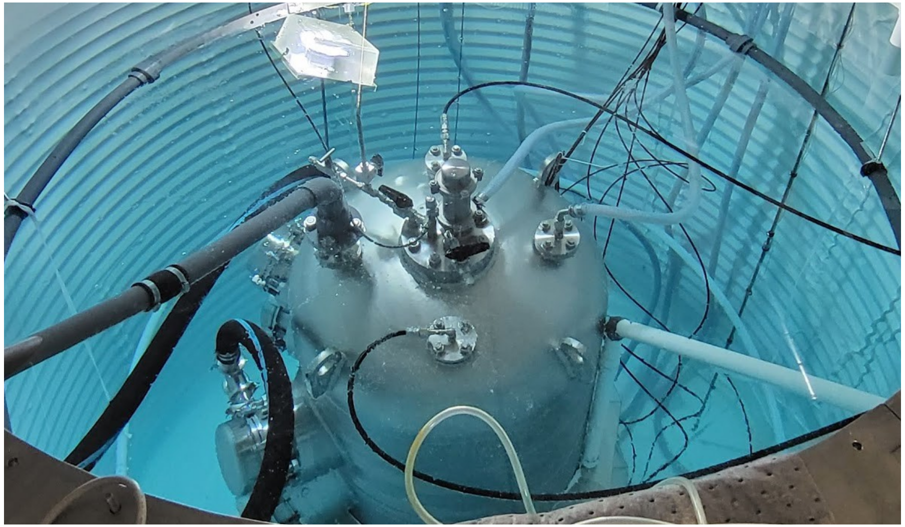
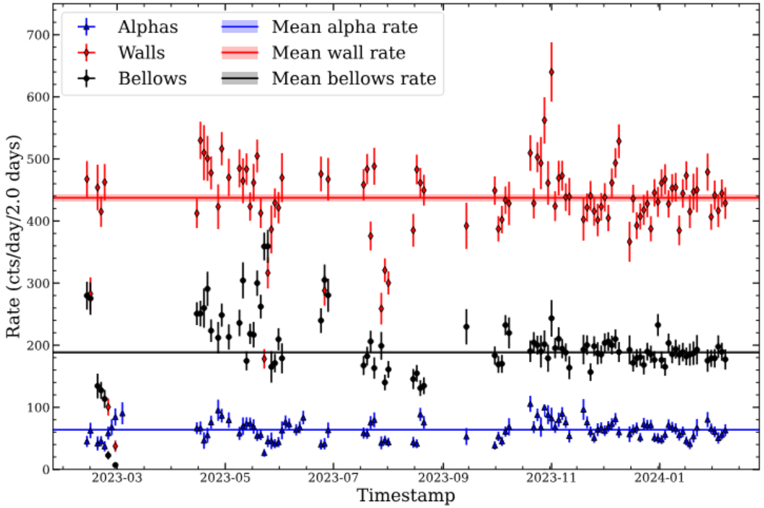
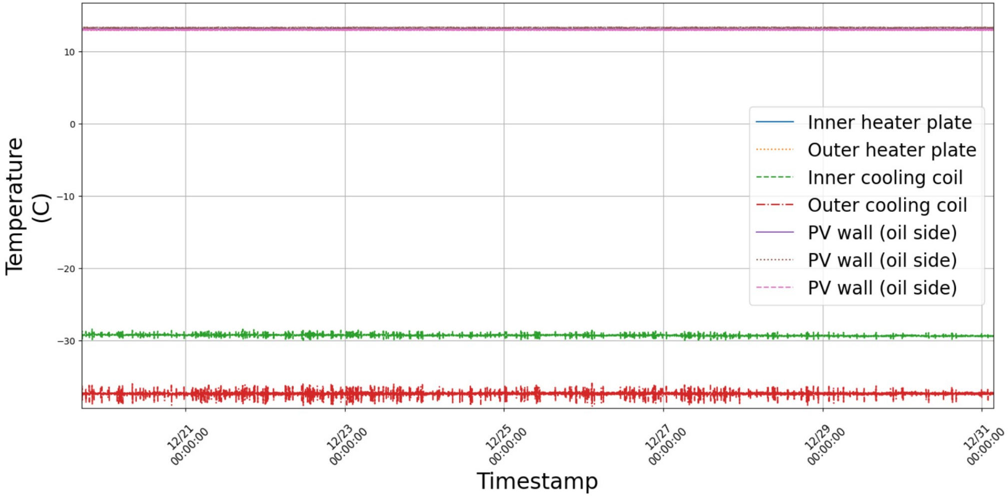
PICO-40L

Current Status



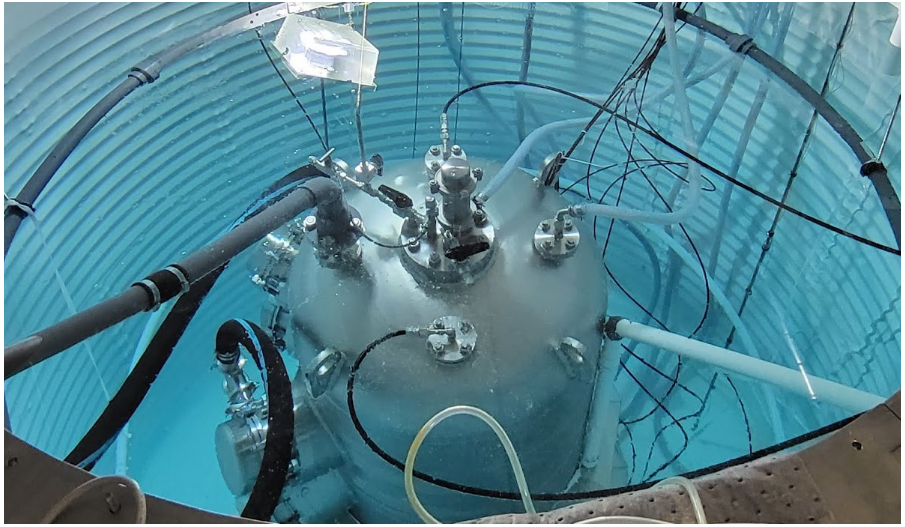


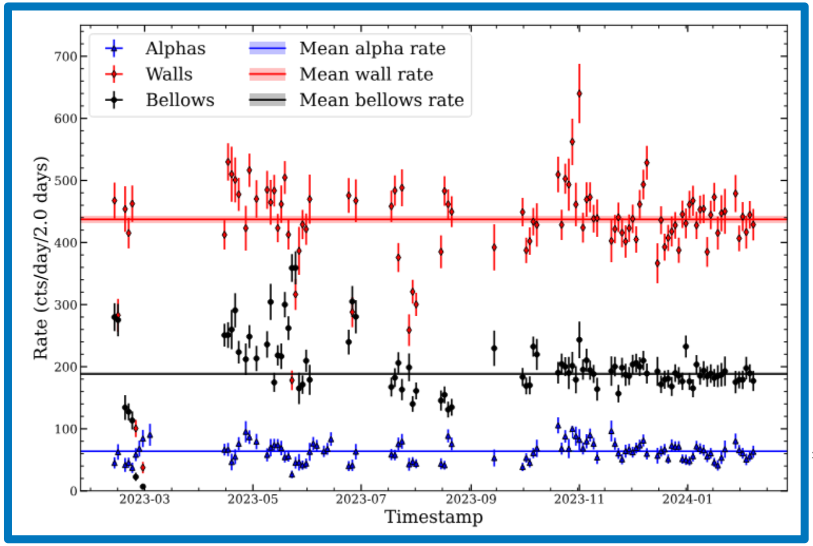
*Plot by C. Moore



- **Detector fully assembled and operational, water shielding in place.**
- Stable long term event rates.
- Exquisite thermal stability and control during operation.

Current Status





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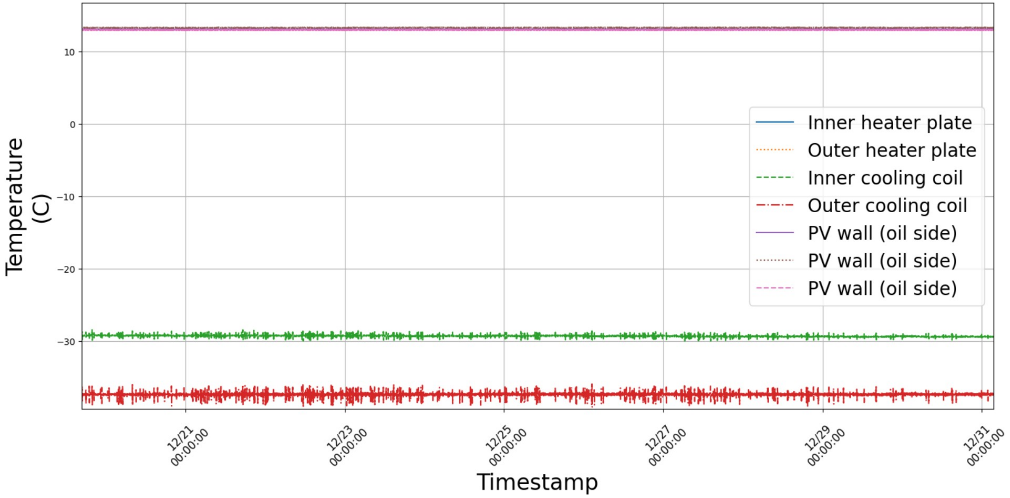

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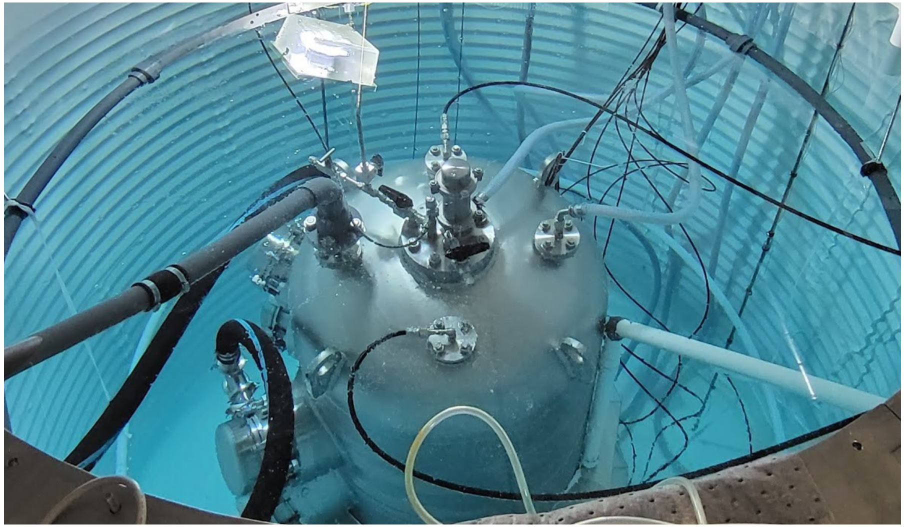

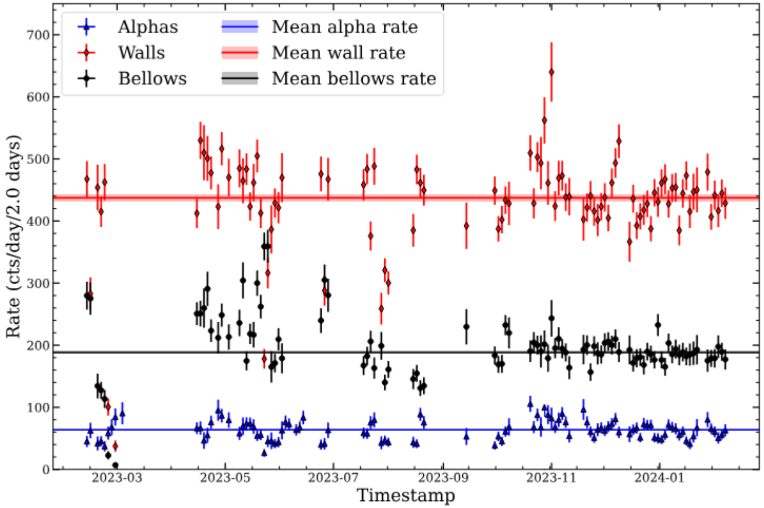

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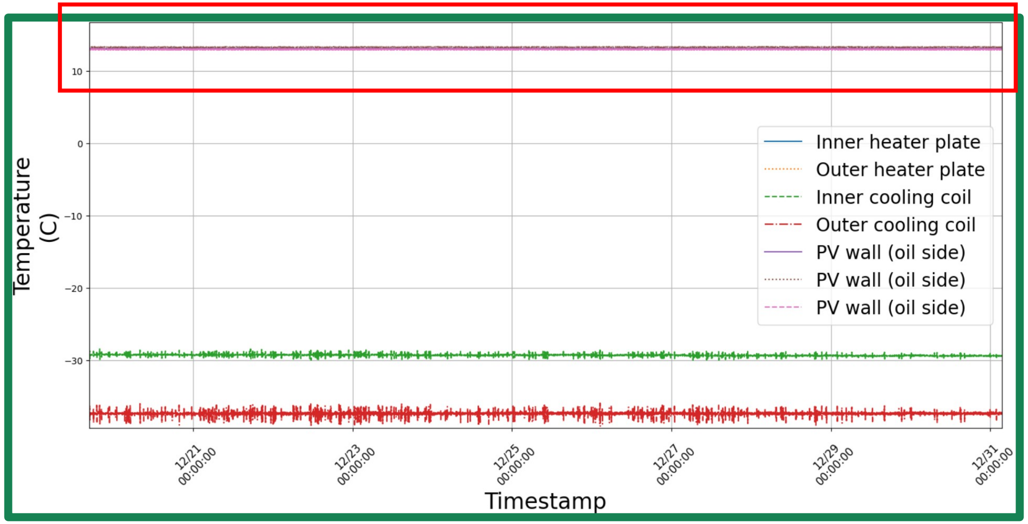

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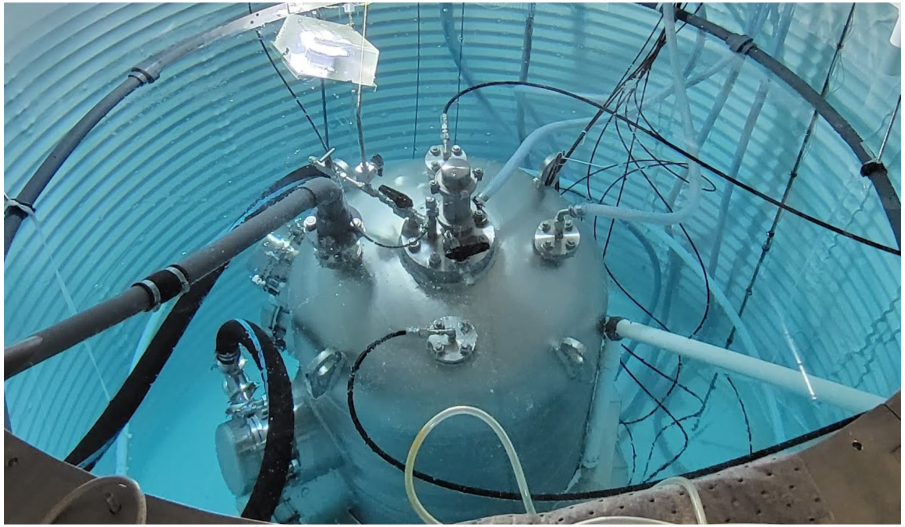

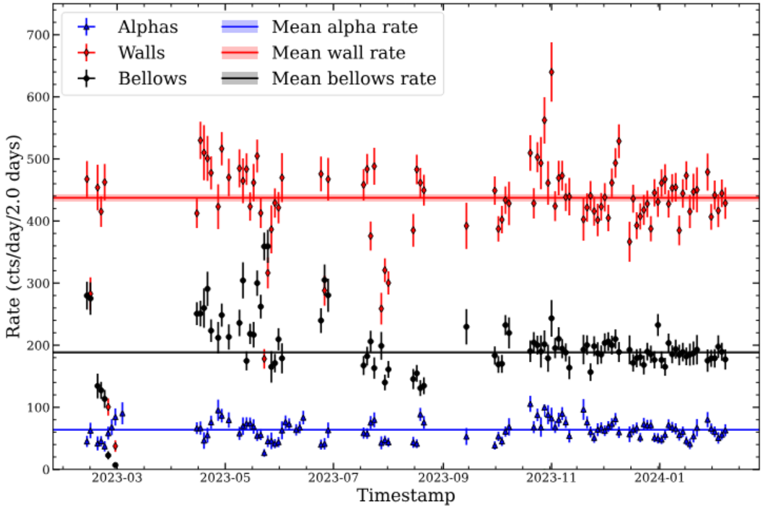

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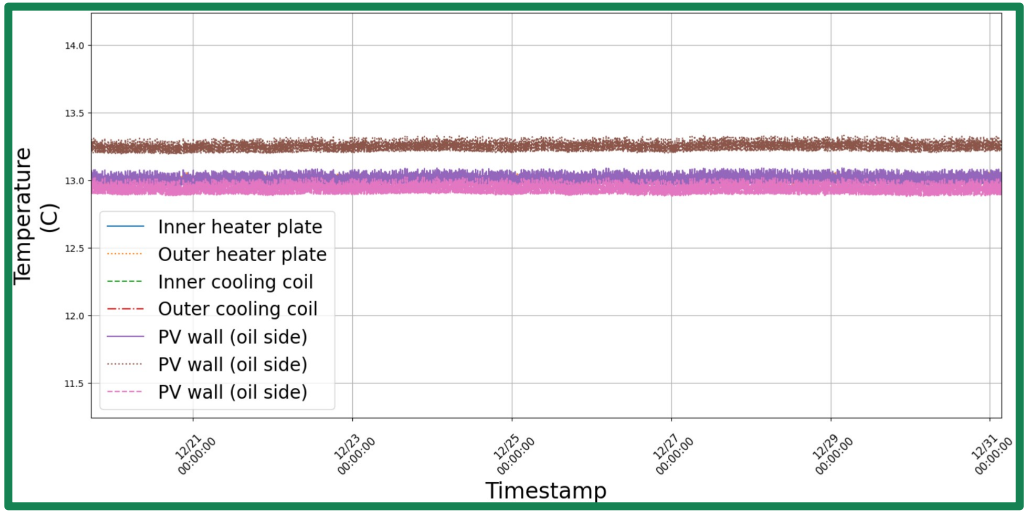
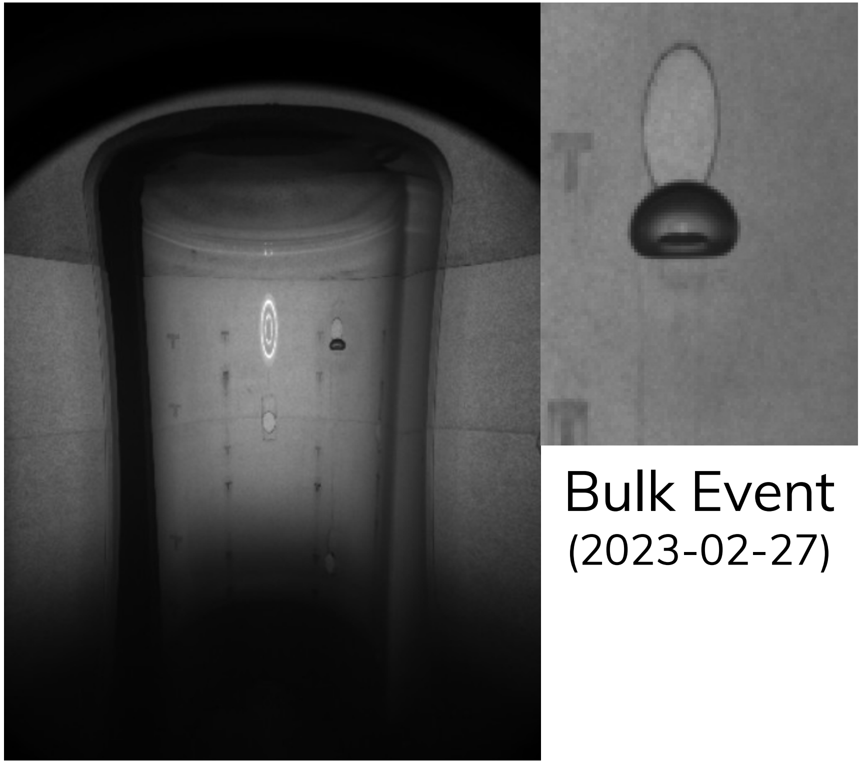


Wall Events and Bulk Events

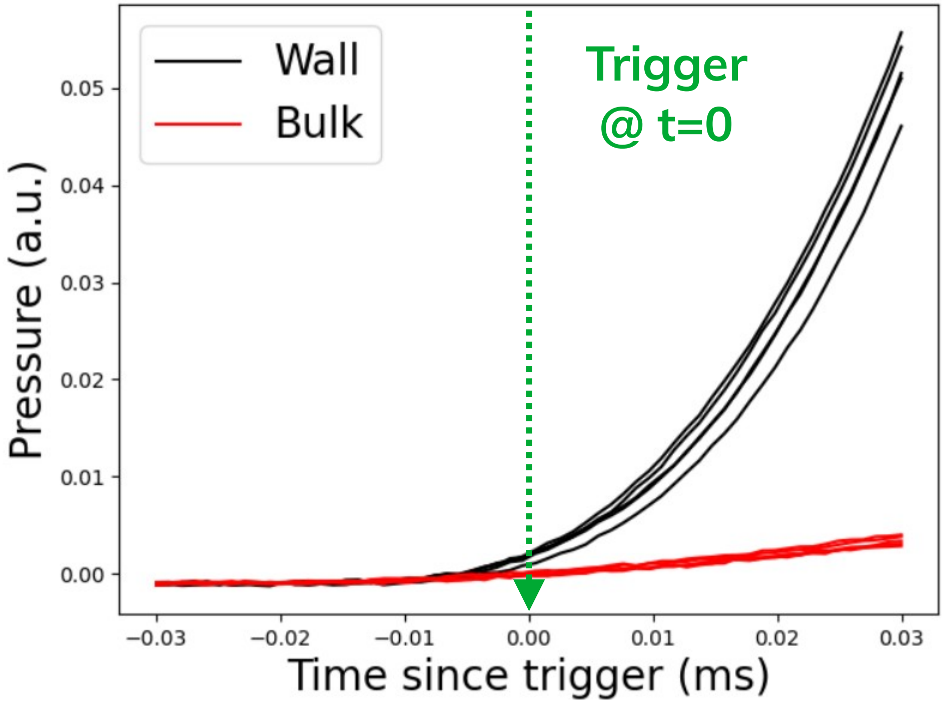


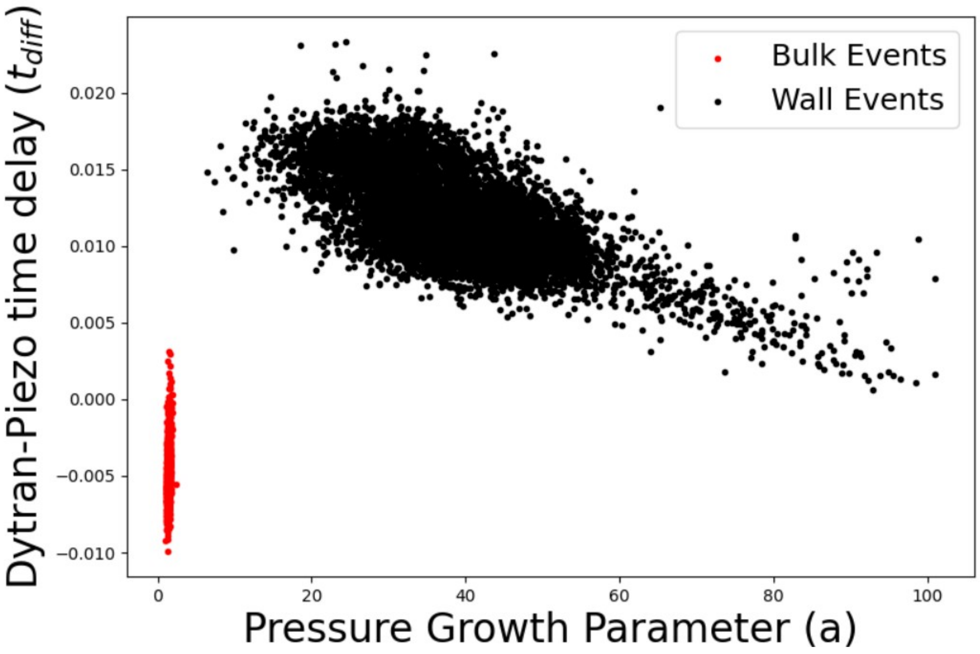
Bulk Event
(2023-02-27)

Wall Event
(2023-02-09)

- DM expected to scatter in target bulk, but imperfections in vessel can trigger bubble nucleation on the walls.
  - Distinguishable by eye from bulk events – can “handscan” to remove wall events.

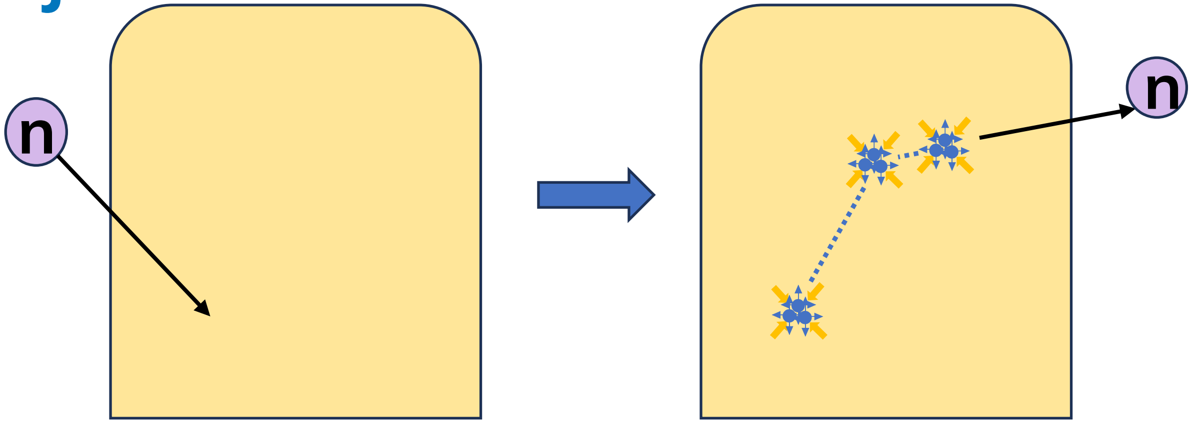
Wall Events and Bulk Events

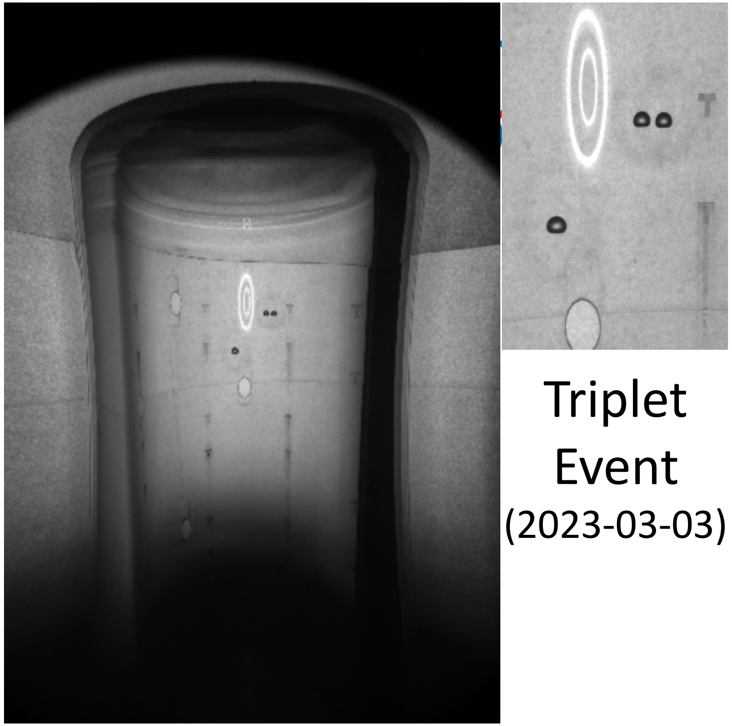




- PICO is instrumented with "Dytran" pressure sensors at top and bottom of pressure vessel – records *fast pressure change* during event.
- Dytran traces can be used to **distinguish wall from bulk** events.

Neutron Suppression and Rejection



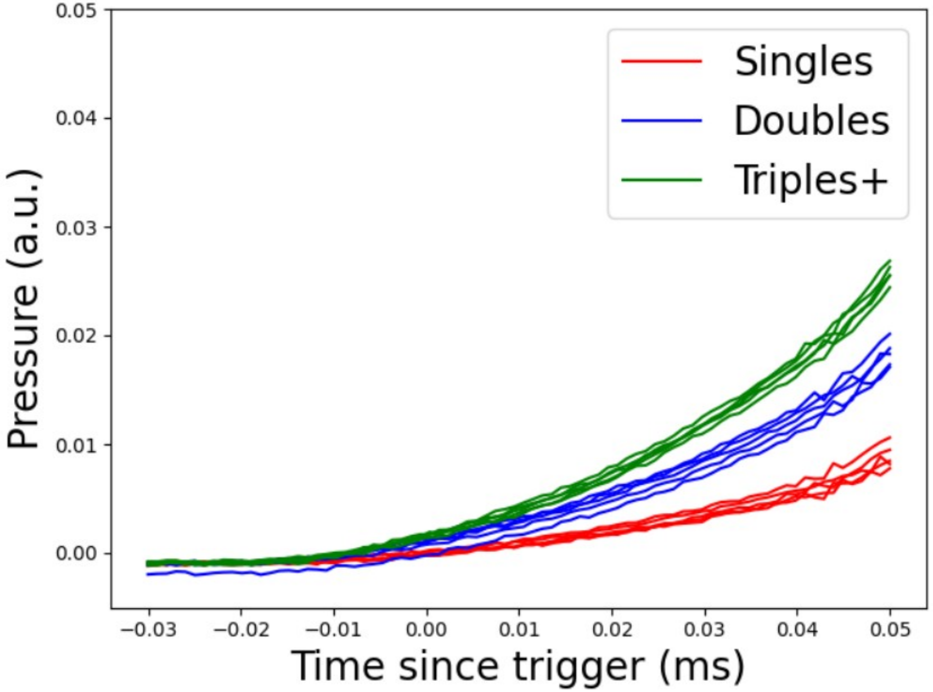


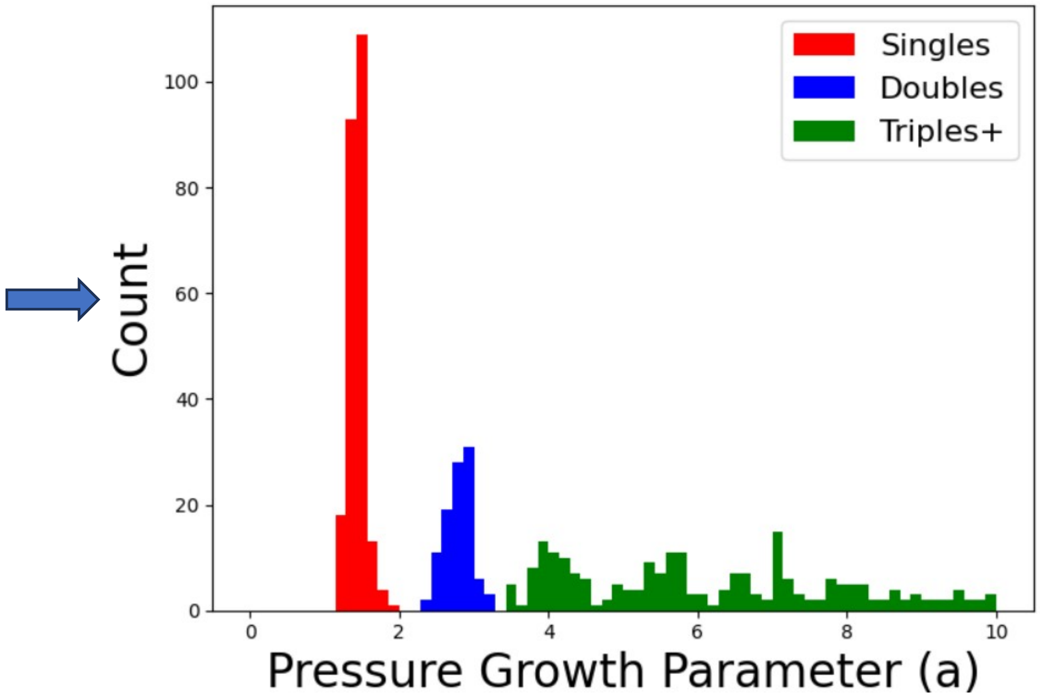
Triplet Event (2023-03-03)

- Single scatter neutrons indistinguishable from WIMPs.
  - ➢ Large water shielding tank and careful material selection minimizes neutron background from external and internal sources, respectively.

- Neutrons likely to scatter multiple times in PICO-40L, leading to a multi-bubble event.
  - ➢ Ratio of multiples to singles (3:1) allows estimate of neutron contribution to signal.
  - ➢ Less than 1.0 single bubble event from neutrons per year expected.

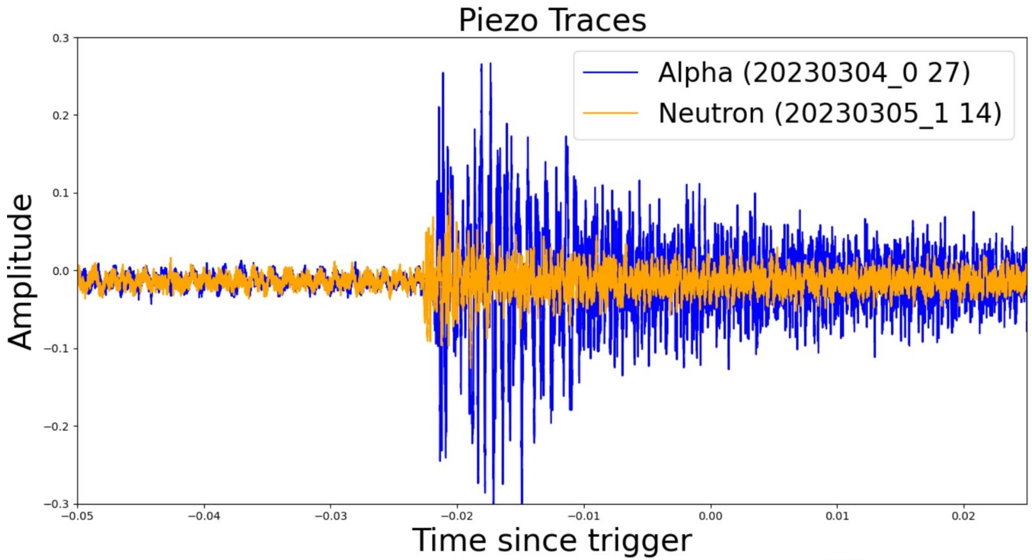
Multiple Scatter Counting

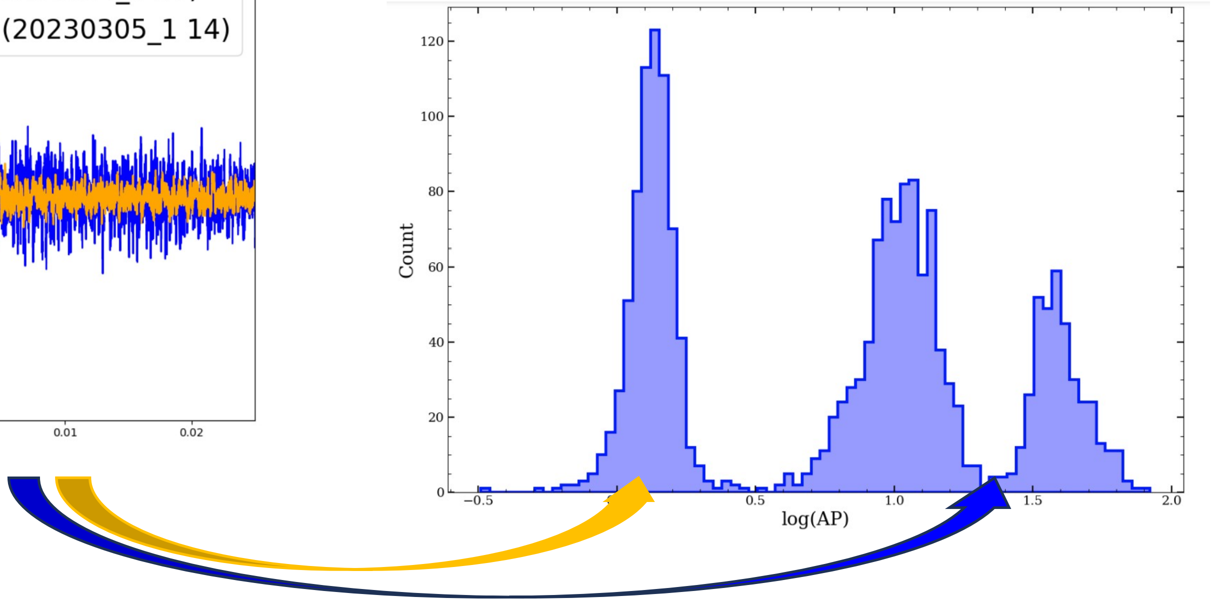




Dytran sensors can also distinguish between single and multiple scattering events.

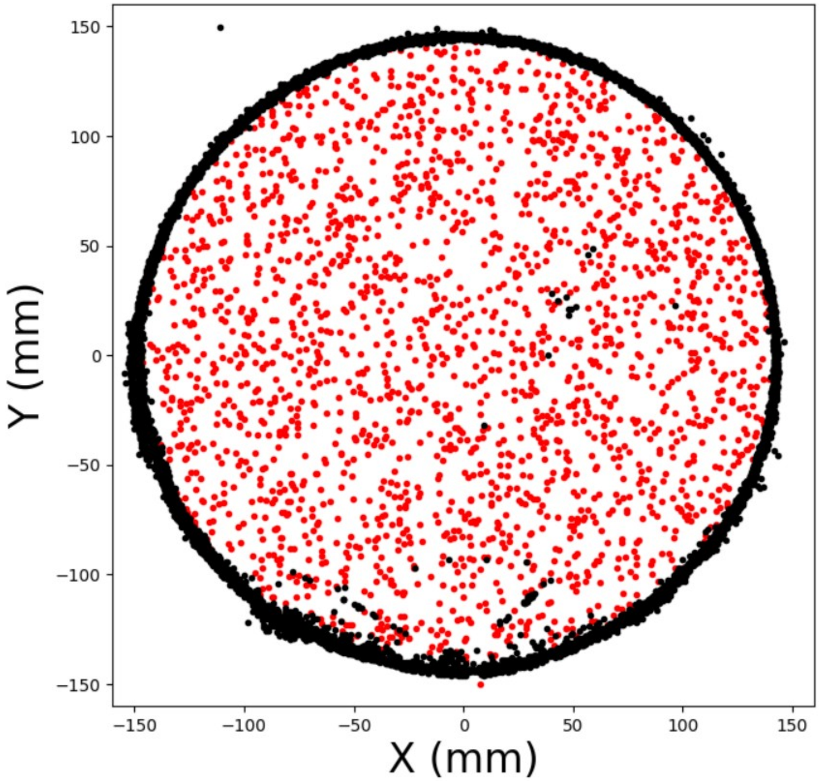
Background Rejection – Alphas

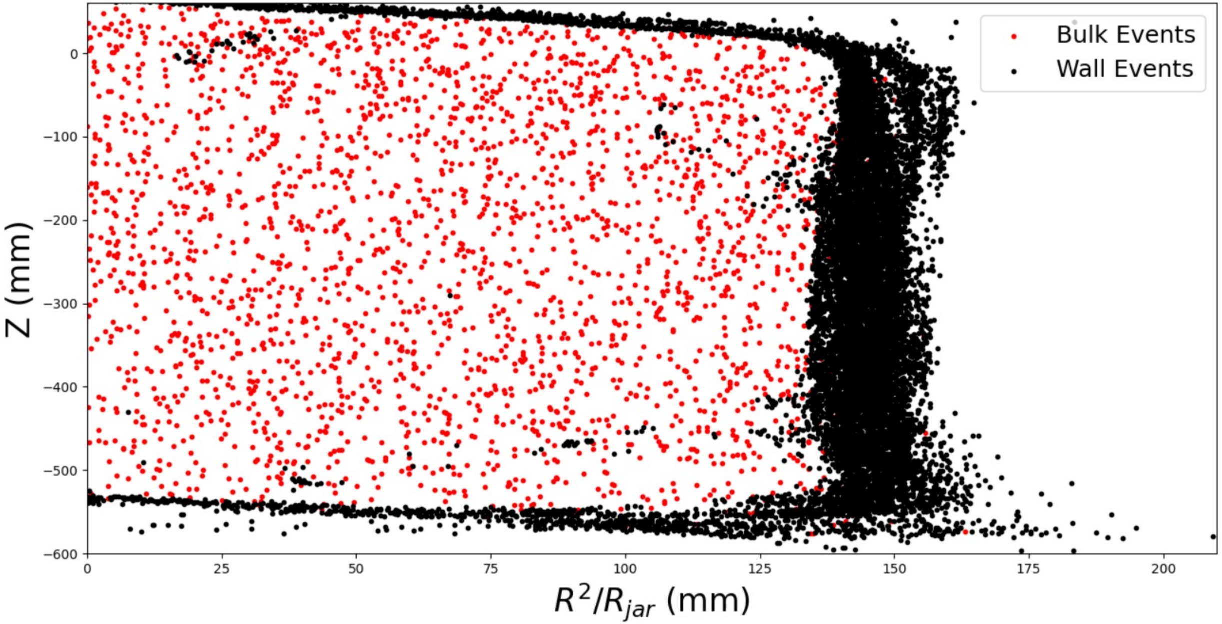




- 10 piezoelectric sensors provide acoustic data during bubble formation.
- Alpha-induced bubbles several times louder than neutron-induced bubbles.
- Discrimination achieved using Acoustic Parameter (AP) – ***a measure of acoustic power.***
    - α's from different parts of the ^{222}Rn decay chain are distinguishable in AP

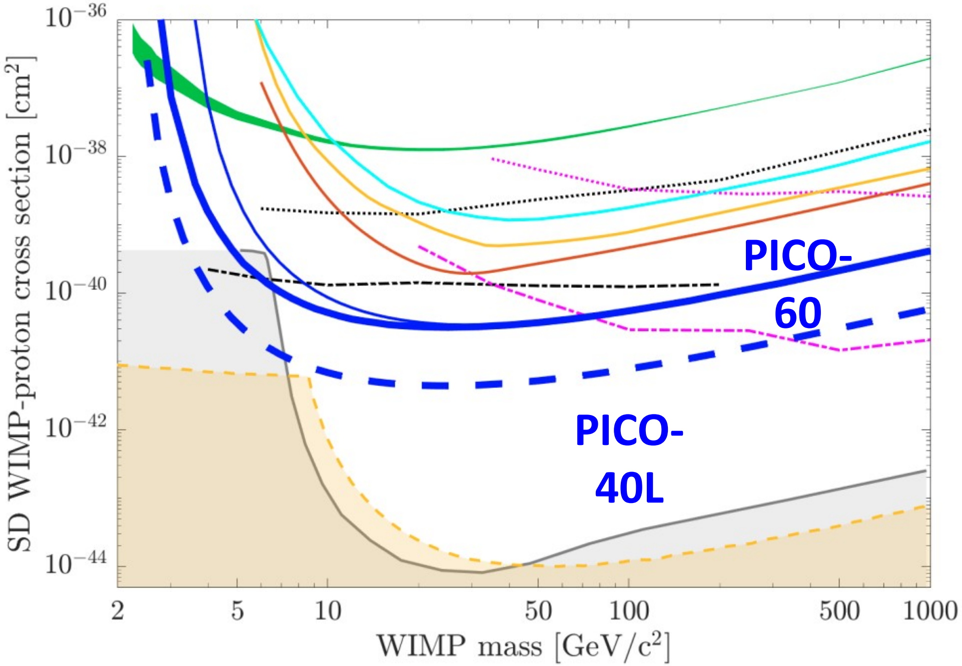
Position Reconstruction

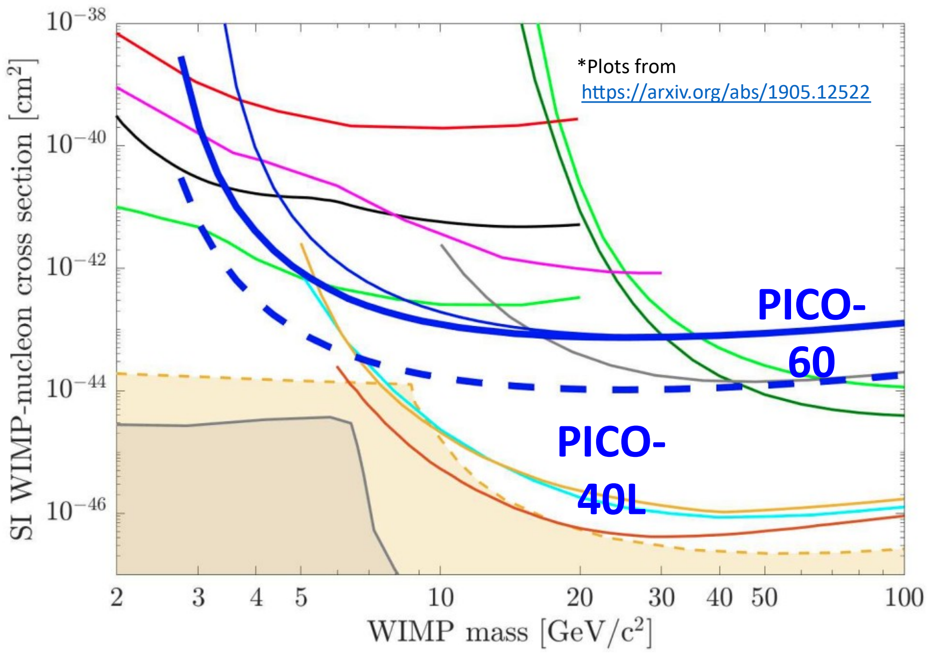




- Position reconstruction achieved by calculating intersection of light rays from the cameras through the detector
  - Obtained from detailed ray-tracing simulation using full detector geometry.

Projected Sensitivity





- Factor of 5 improved sensitivity vs. PICO-60 despite similar mass, due to expected reduction in background (assuming 1 live-year of running).
  - ➢ Right-side-up design removed buffer fluid and therefore excess events at buffer-target interface.
  - ➢ Larger pressure vessel provides better neutron shielding.

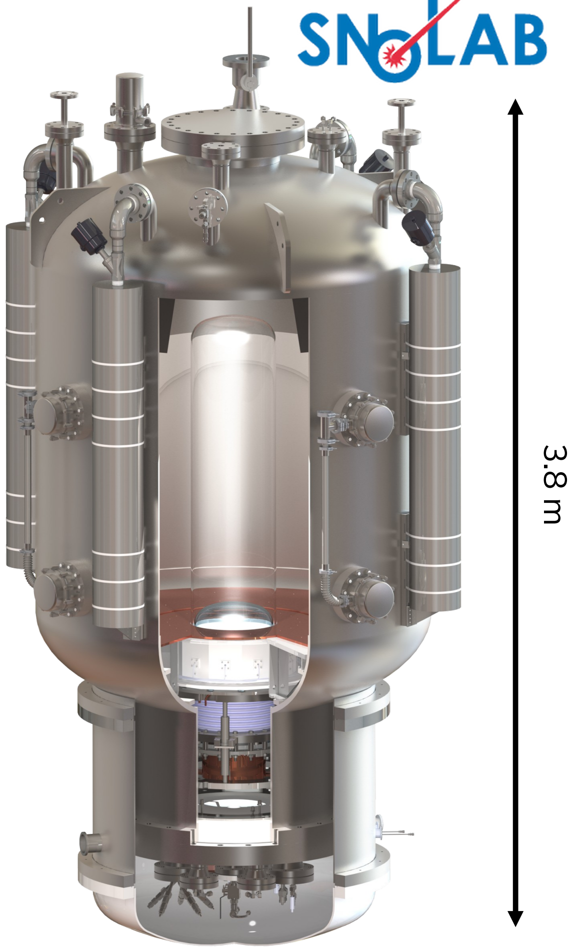
PICO-500

PICO-500: The Near Future

- Tonne-scale right-side-up bubble chamber.
  - Scaling up the PICO-40L concept
  - PICO-40L validates and informs the design of PICO-500

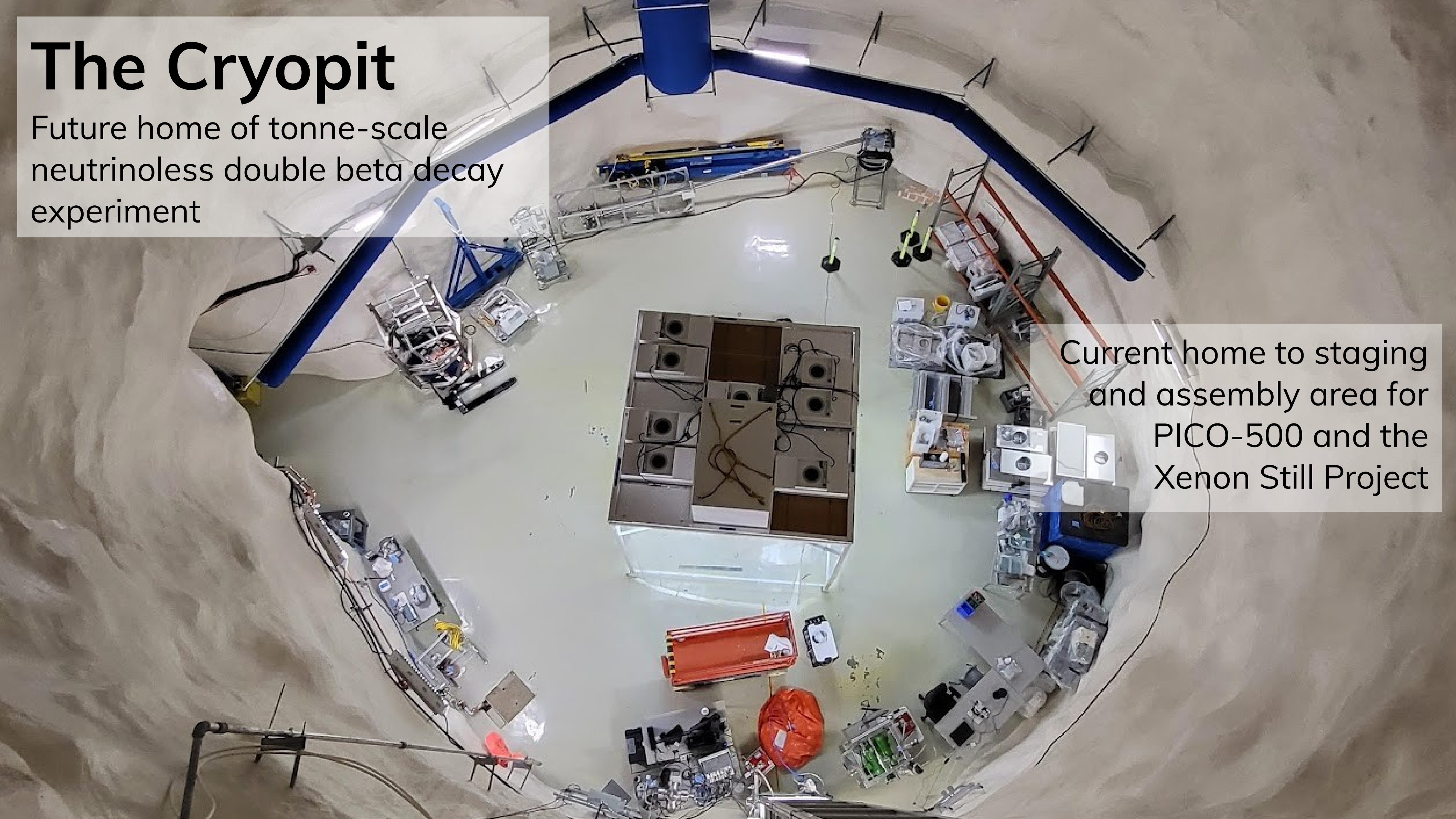
- To be constructed in Cube Hall at SNOLAB – parts have already begun to arrive!

- Scheduled to begin operations in late 2025.



The Cryopit

Future home of tonne-scale neutrinoless double beta decay experiment

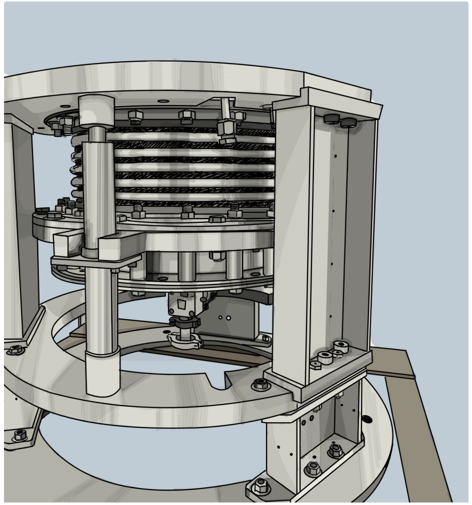


Current home to staging and assembly area for PICO-500 and the Xenon Still Project

SOME RECENT ACTIVITY

Cube Hall: Final Installation Area for PICO-500 next to DEAP-3600 and NEWS-G

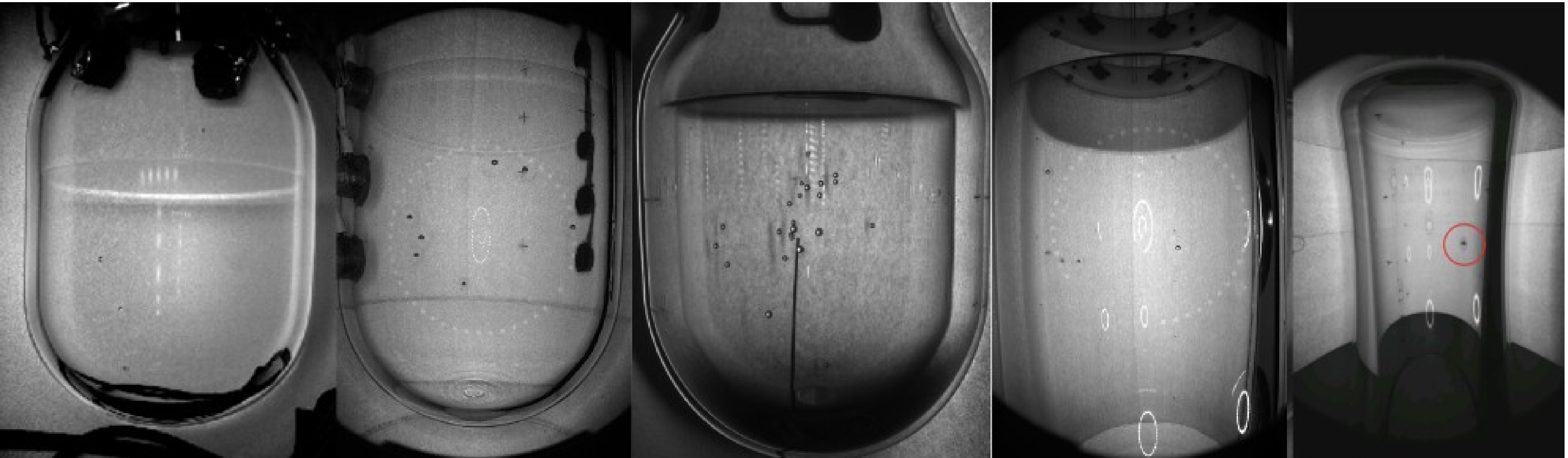
Cryopit: “Dishwasher” and Inner Vessel Assembly Facility



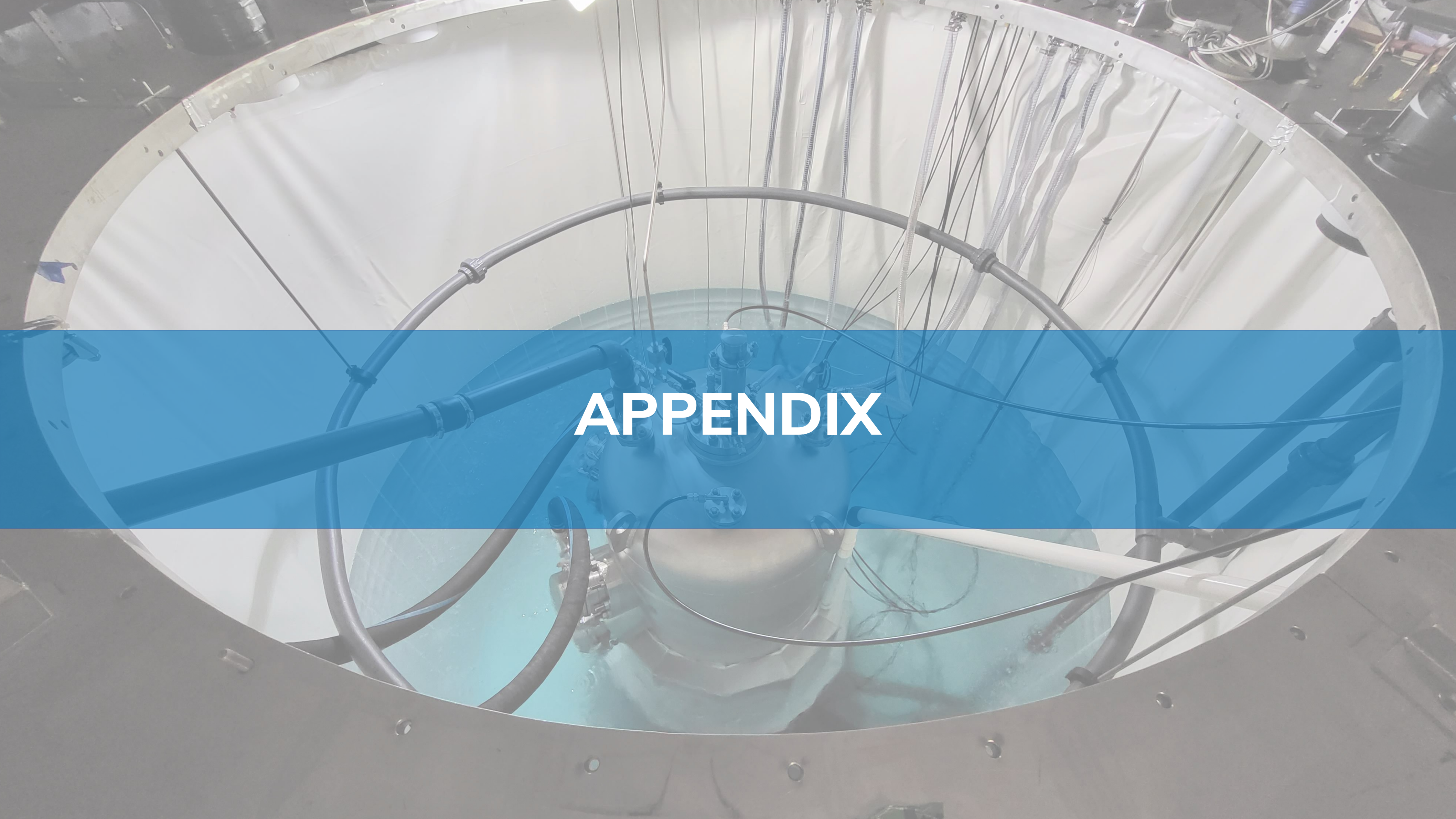
PICO-500 bellows, illustrated by Lily Hines (MI/Queen’s)

Summary

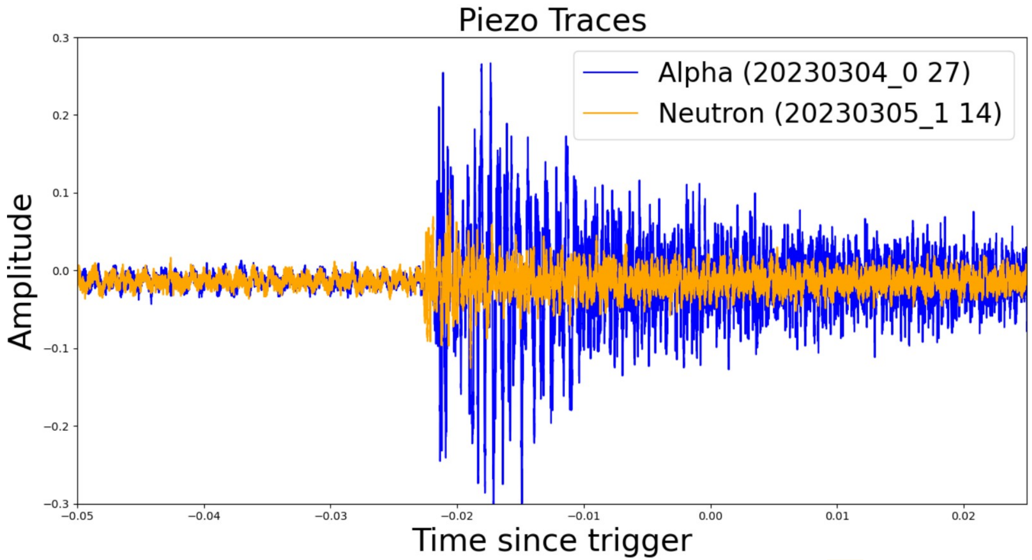
- PICO-40L physics program underway while validating right-side-up design.
- PICO-40L has completed a period of stable running → detailed analysis of the data is underway.
- PICO-500 construction ramping up
- This is a busy and exciting time for the PICO collaboration!

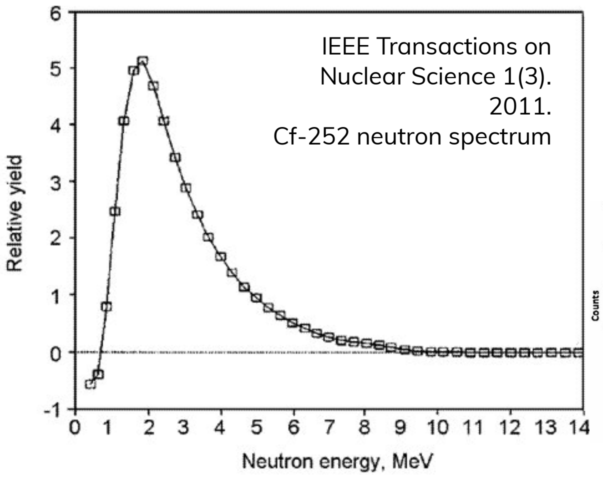


APPENDIX

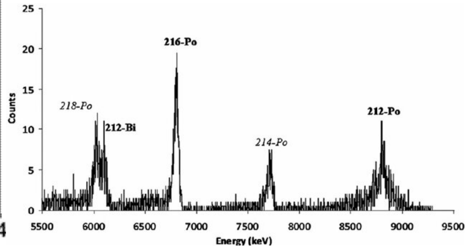


Background Rejection – Alphas





April 2014. Radiation
Protection Dosimetry 160(1-3)
Rn-222+220 alpha spectrum



- 10 piezoelectric sensors provide acoustic data during bubble formation.
- Alpha-induced bubbles several times louder than neutron-induced bubbles.
- Discrimination achieved using Acoustic Parameter (AP) – ***a measure of acoustic power.***
  - α’s from different parts of the ^{222}Rn decay chain are distinguishable in AP

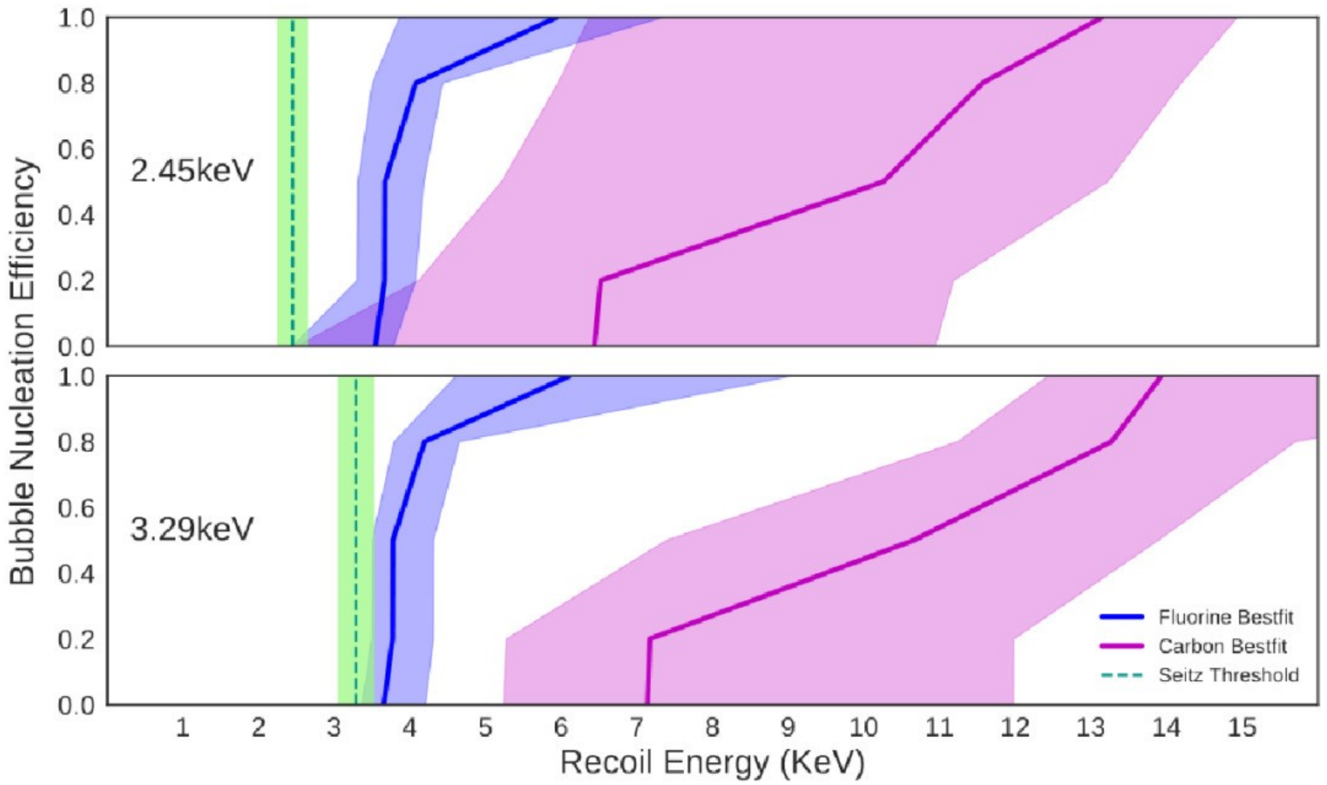
Stable Bubble Nucleation Threshold

$$r_c = \frac{2\sigma}{P_b - P_\ell}$$

$$Q_{Seitz} = \underbrace{4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)}_{Surfacetension} + \underbrace{\frac{4\pi}{3} r_c^3 \rho_b (h_b - h_\ell)}_{Convertingliquidtogas} - \underbrace{\frac{4\pi}{3} r_c^3 (P_b - P_\ell)}_{Gasexpansion}$$

$$E_i on = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4\pi}{3} r_c^3 P_\ell$$

Efficiency Curves: Carbon and Fluorine



arXiv:1902.04031