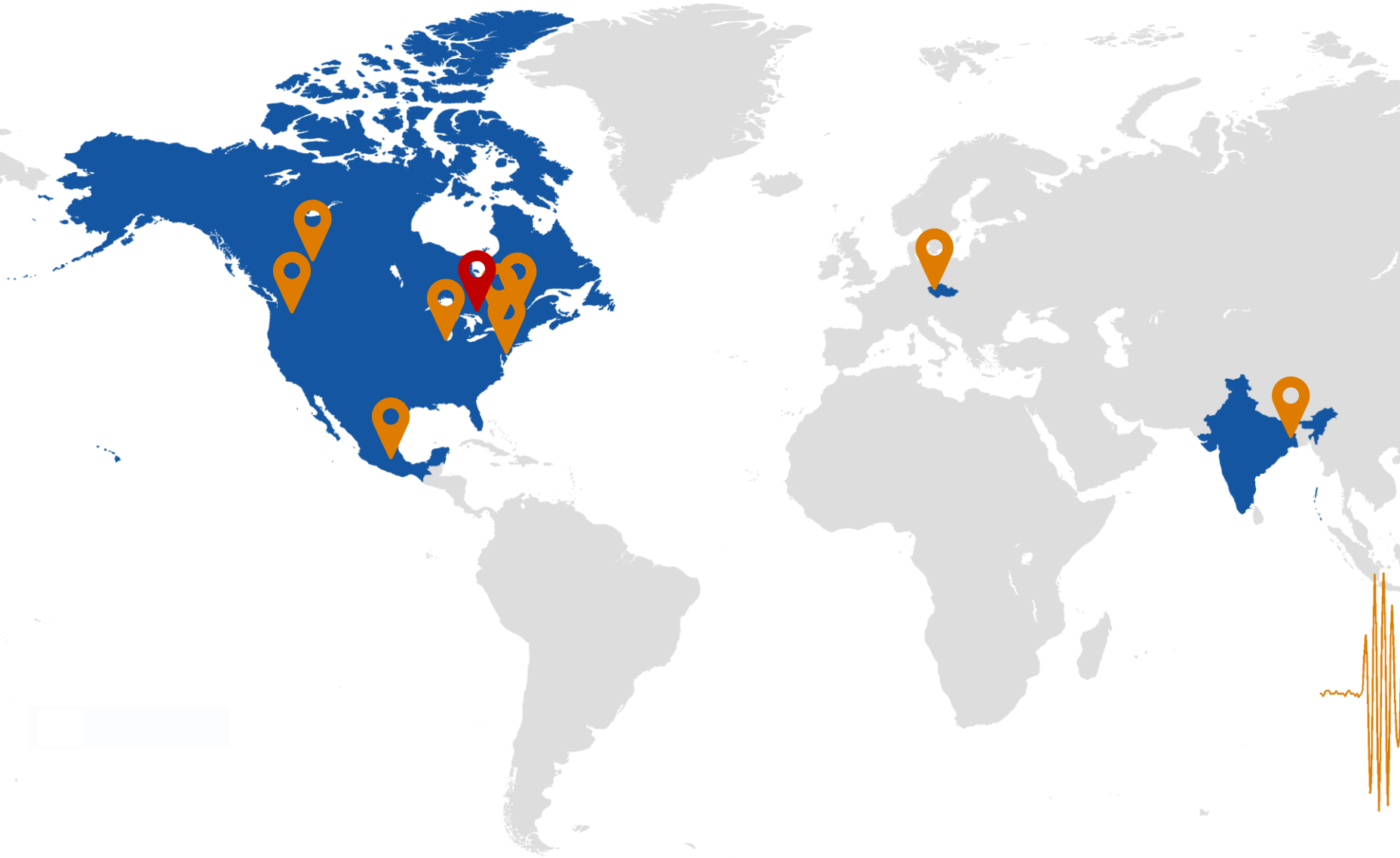
The PICO-40L Dark Matter Search

William Woodley
University of Alberta

On behalf of the PICO Collaboration

TAUP 2025
26 August 2025

The PICO Collaboration



5 Countries

16 Institutions

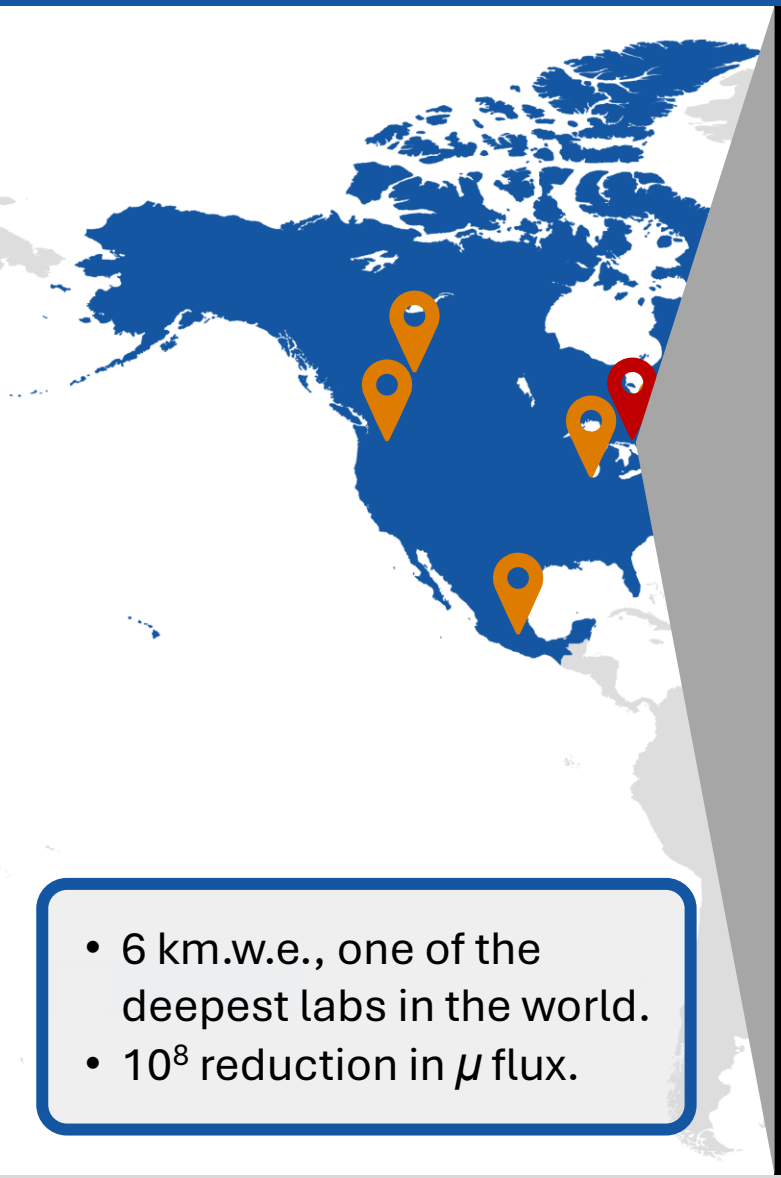
60 Members

PICO

The PICO Collaboration

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

The PICO Collaboration



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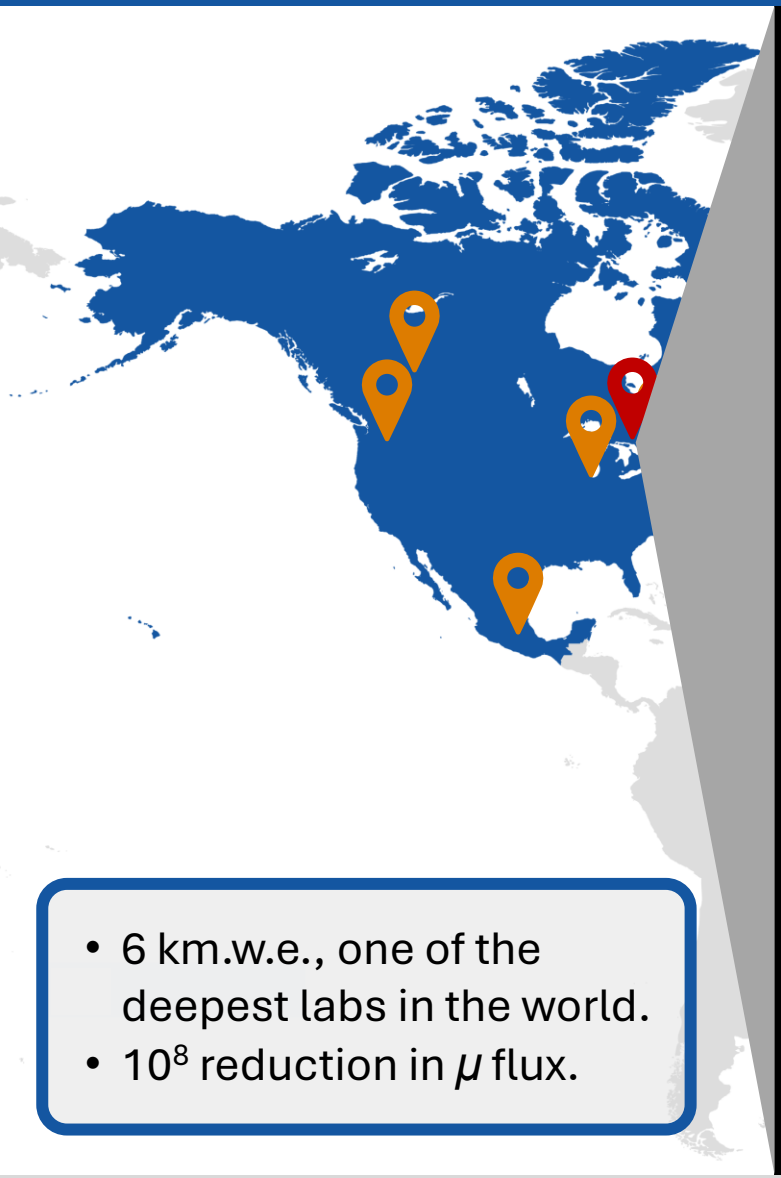

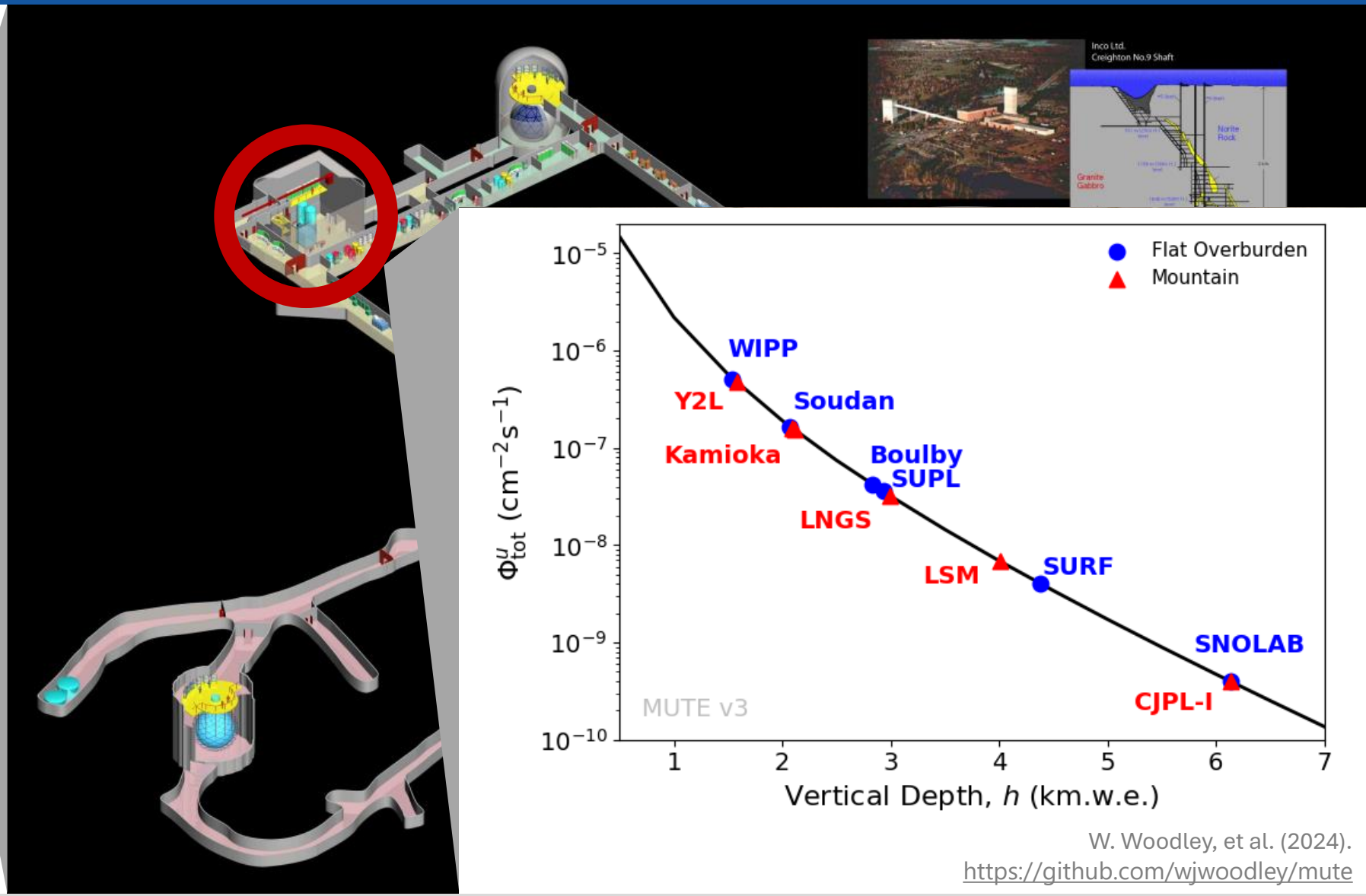

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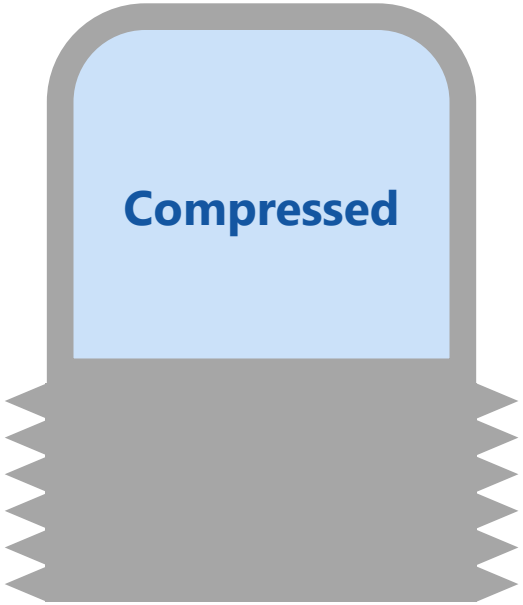
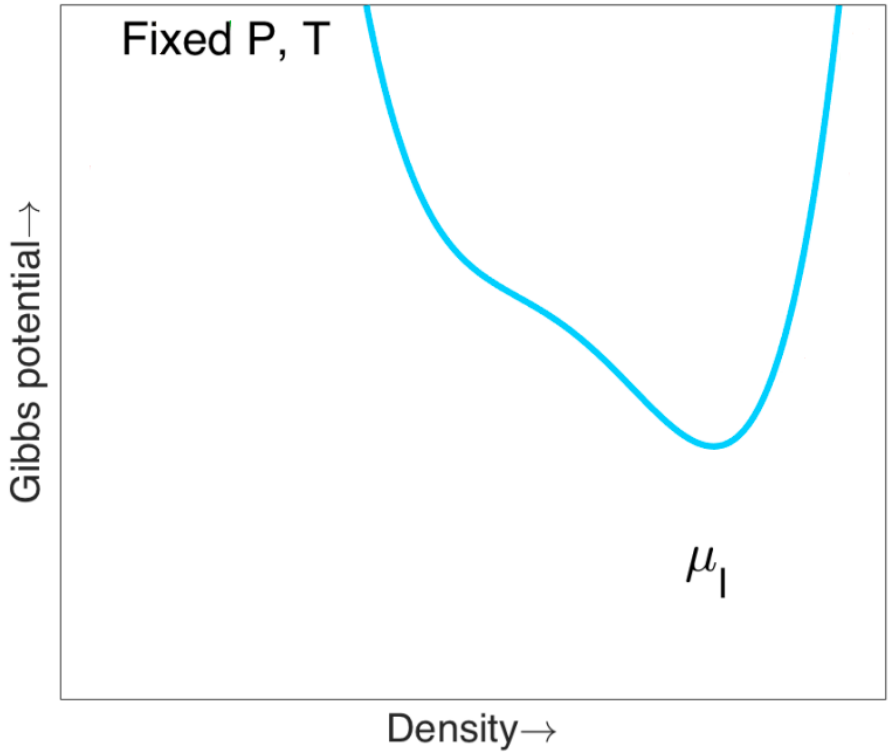
- 10^8 reduction in μ flux.

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

Bubble Chambers



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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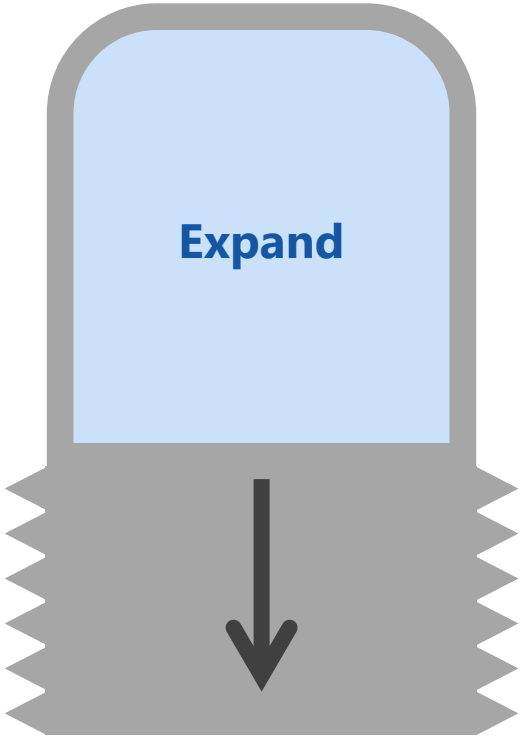

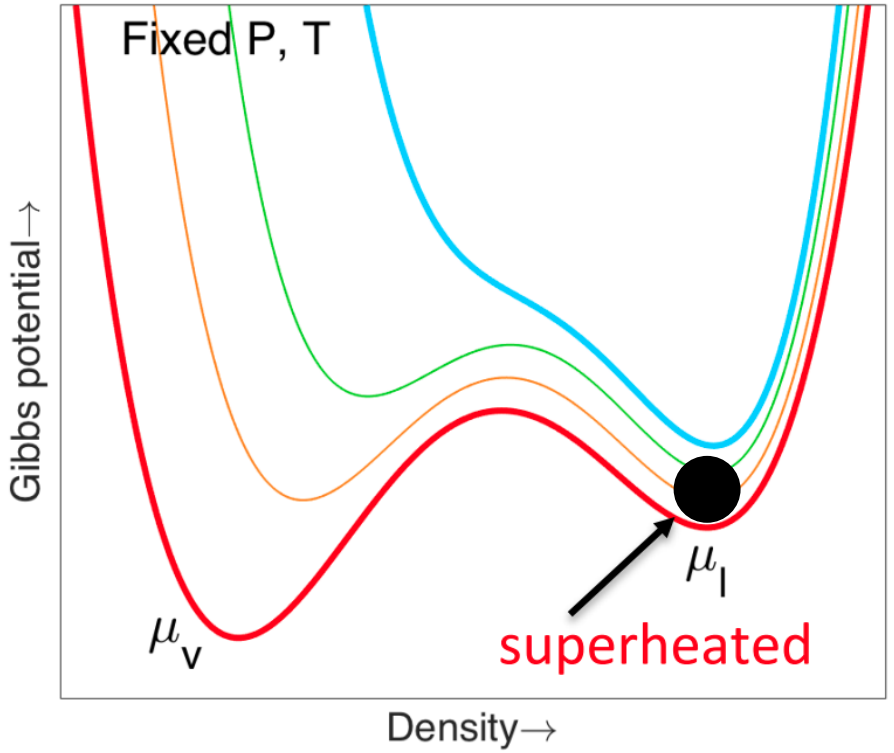

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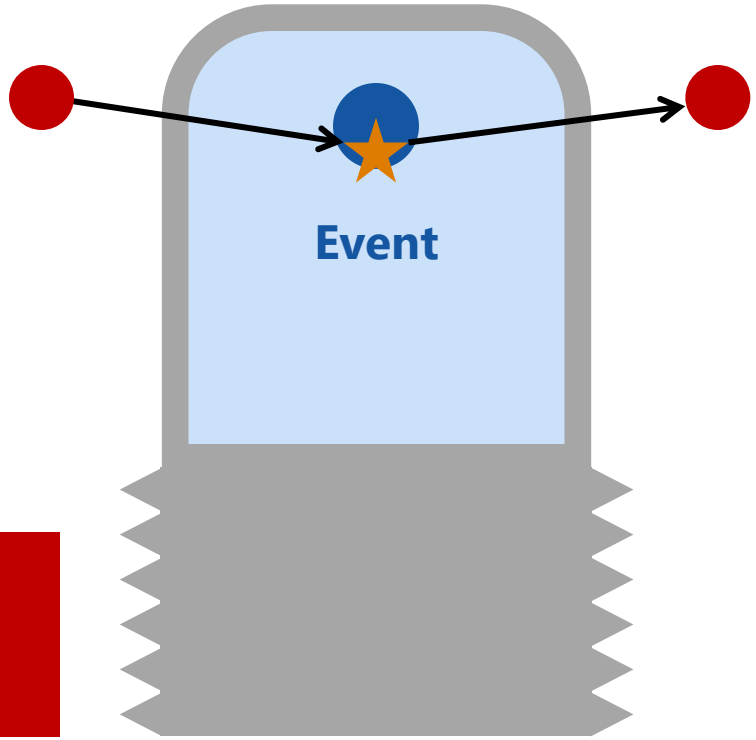

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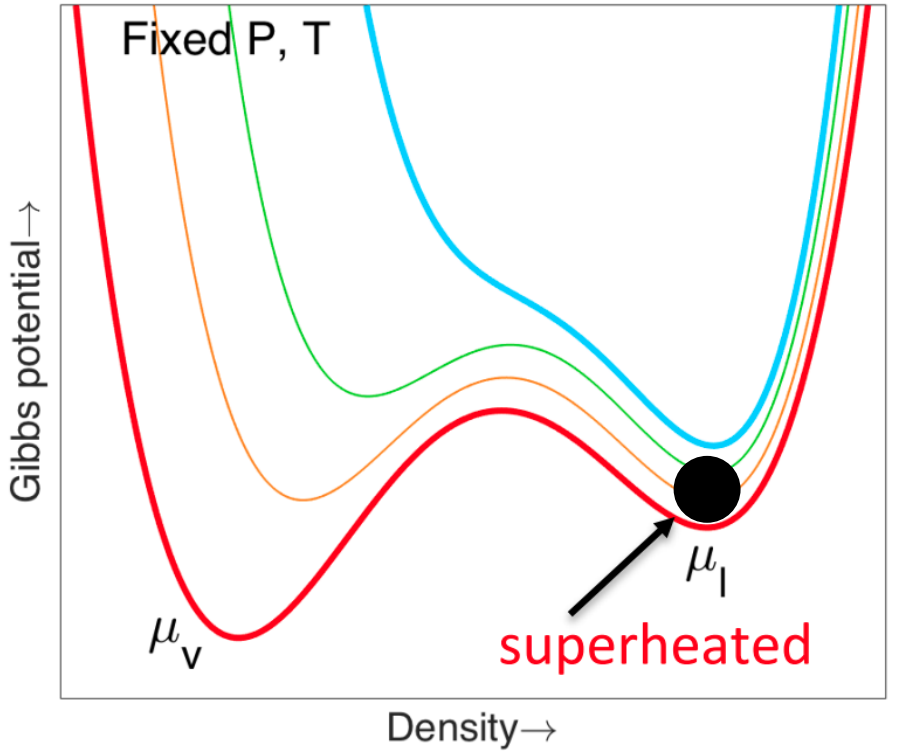

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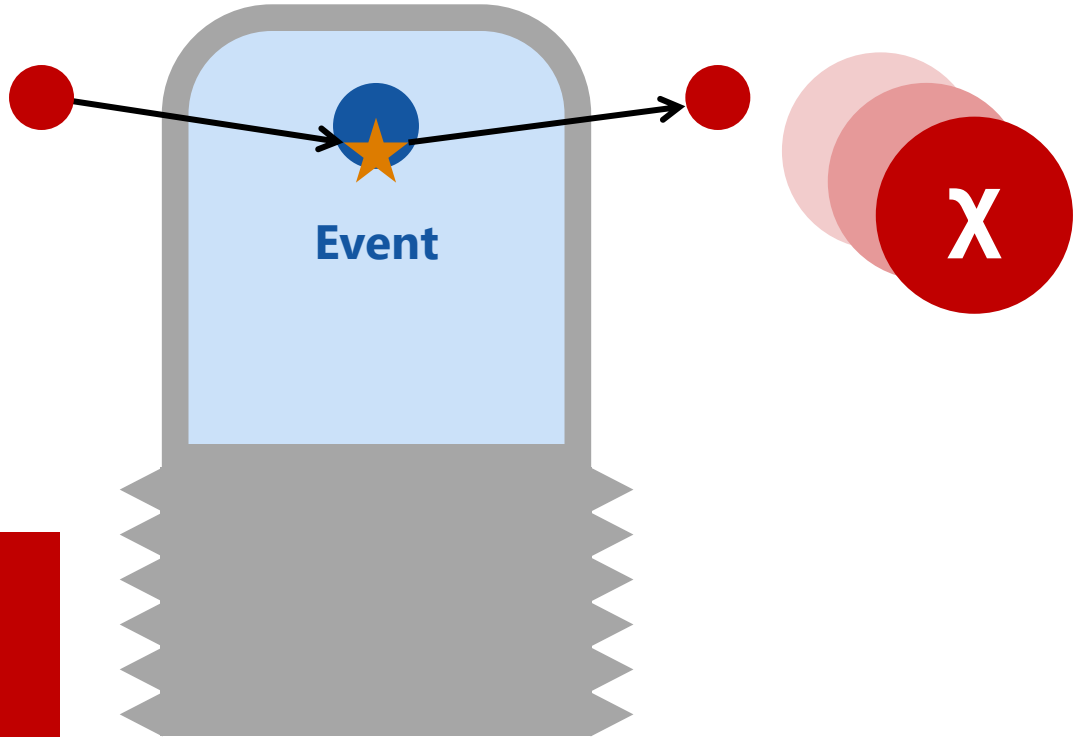

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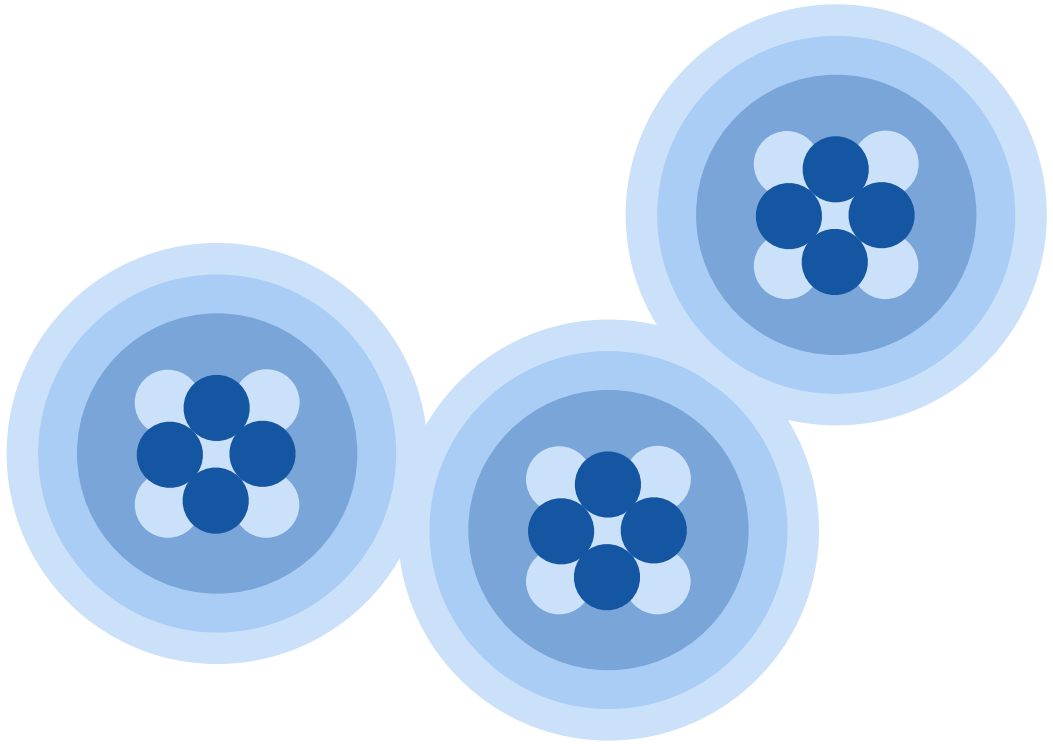

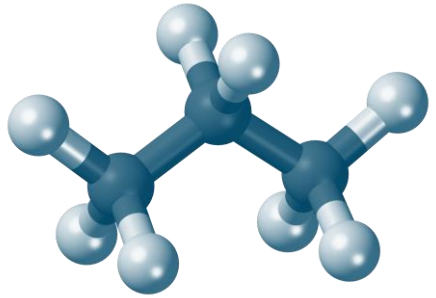

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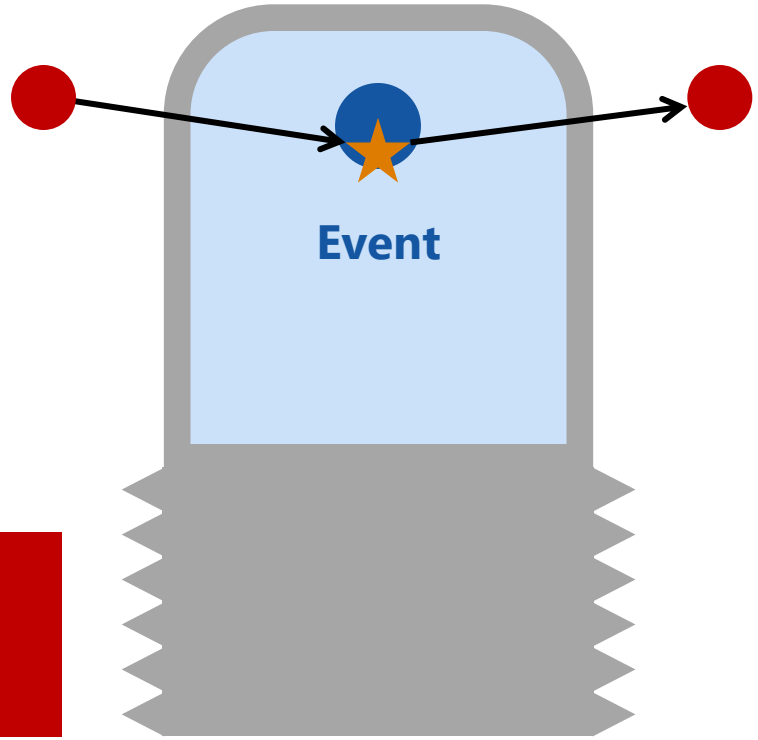
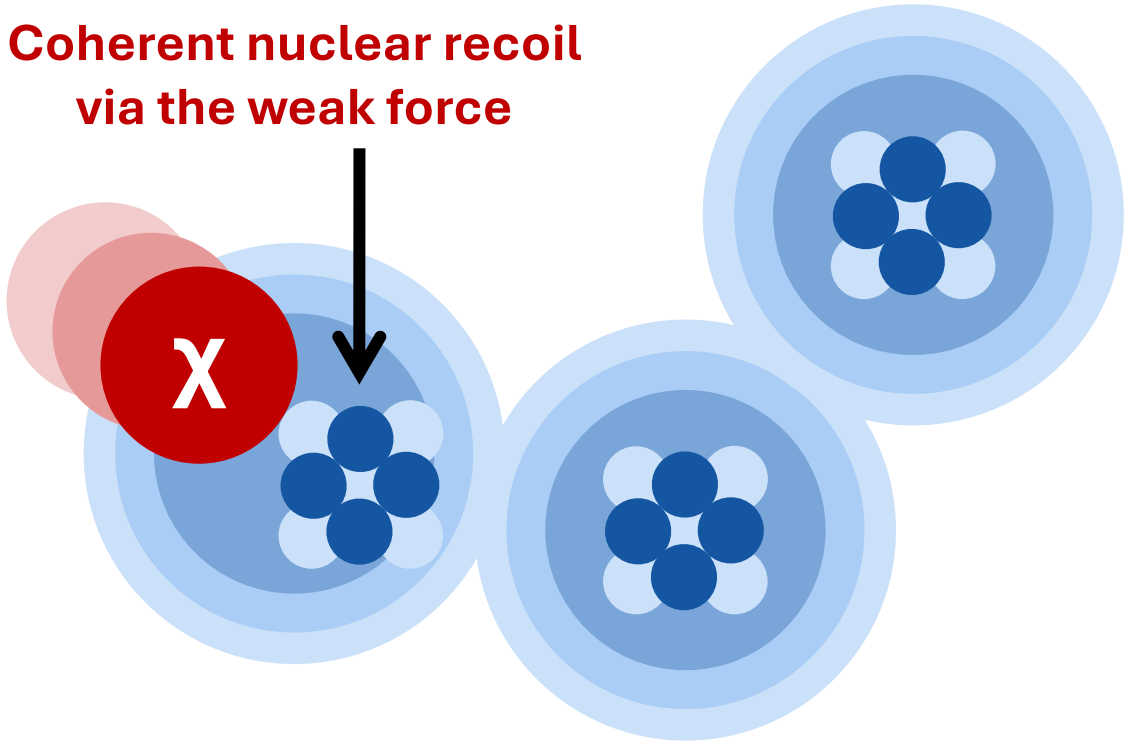


Detects a particle!

Coherent nuclear recoil via the weak force



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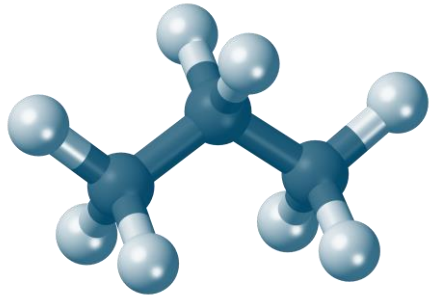

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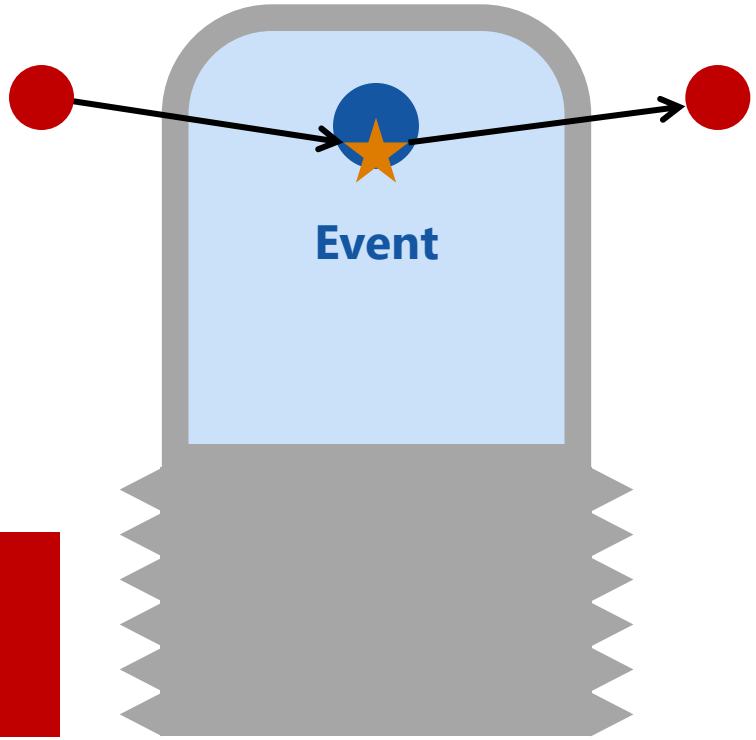

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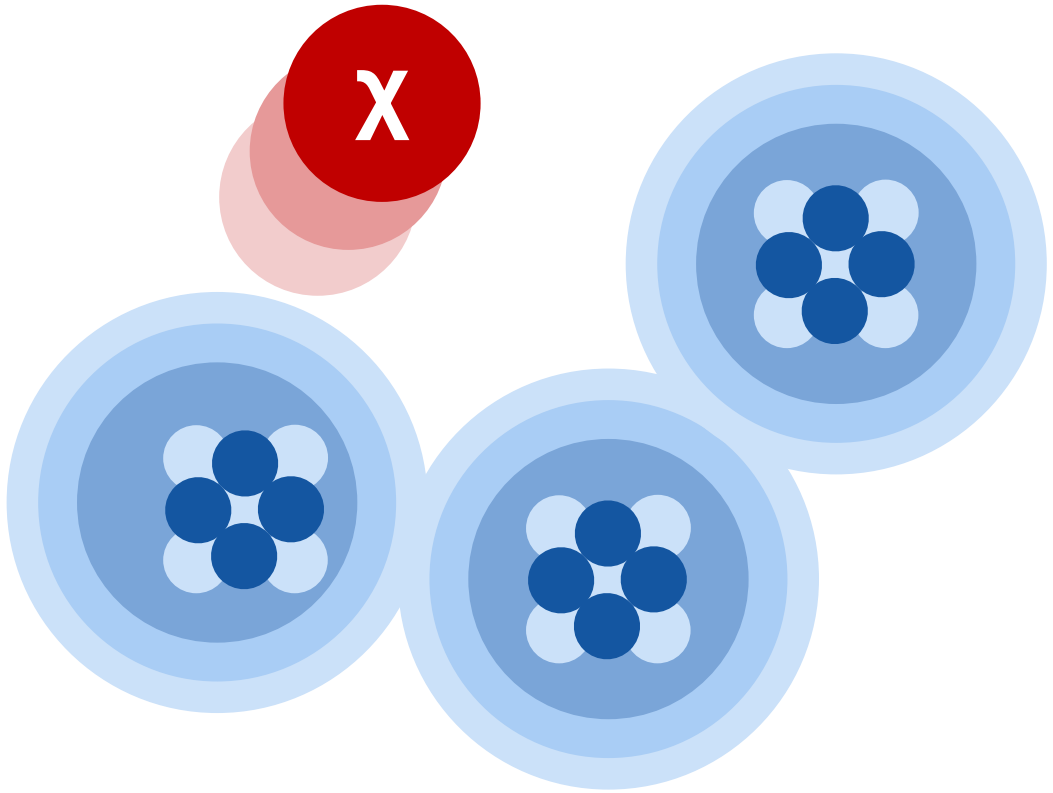

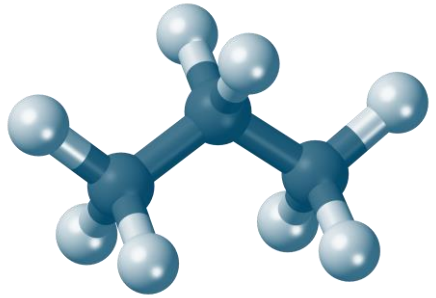

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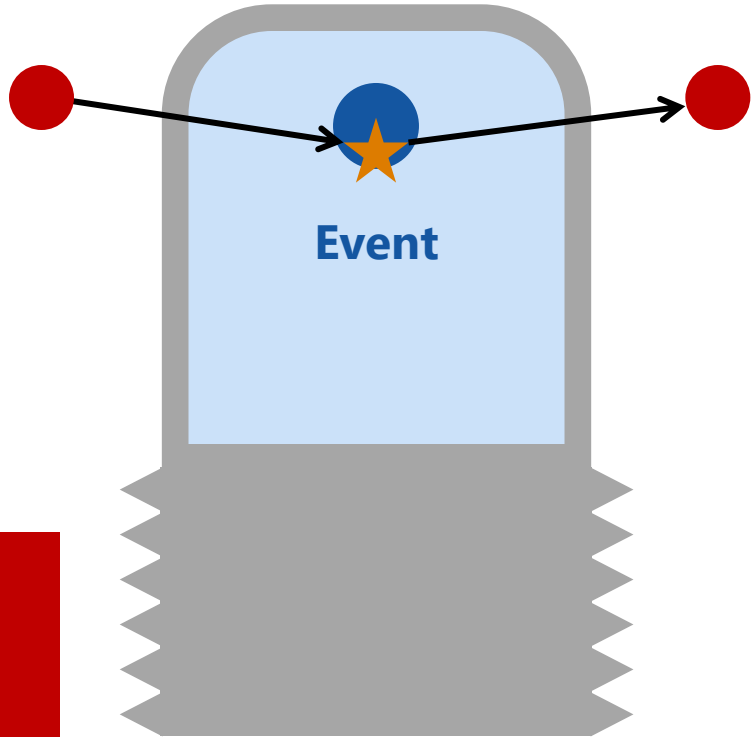

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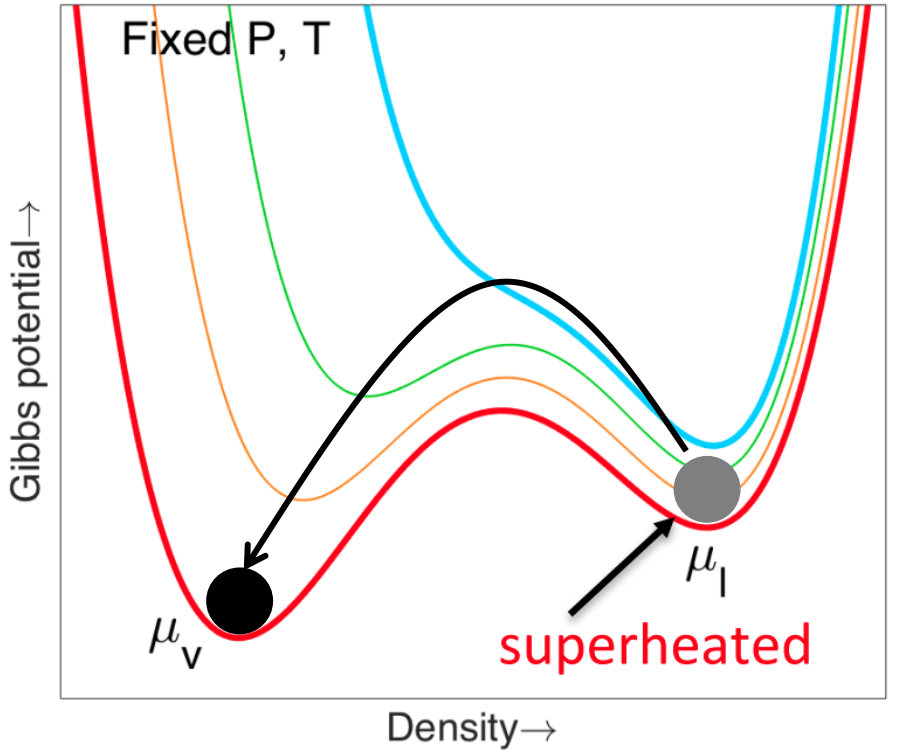

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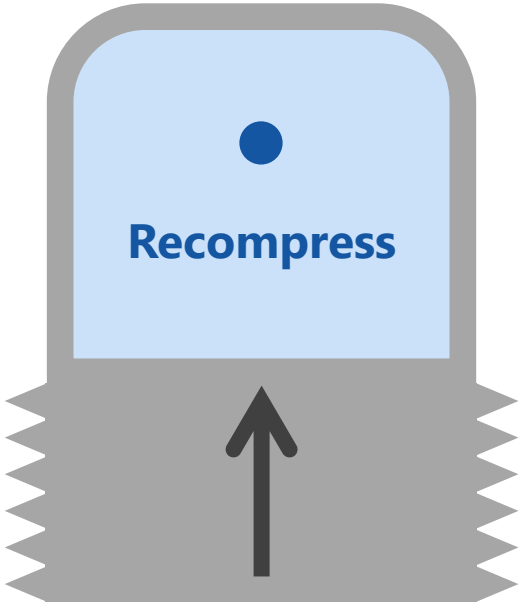

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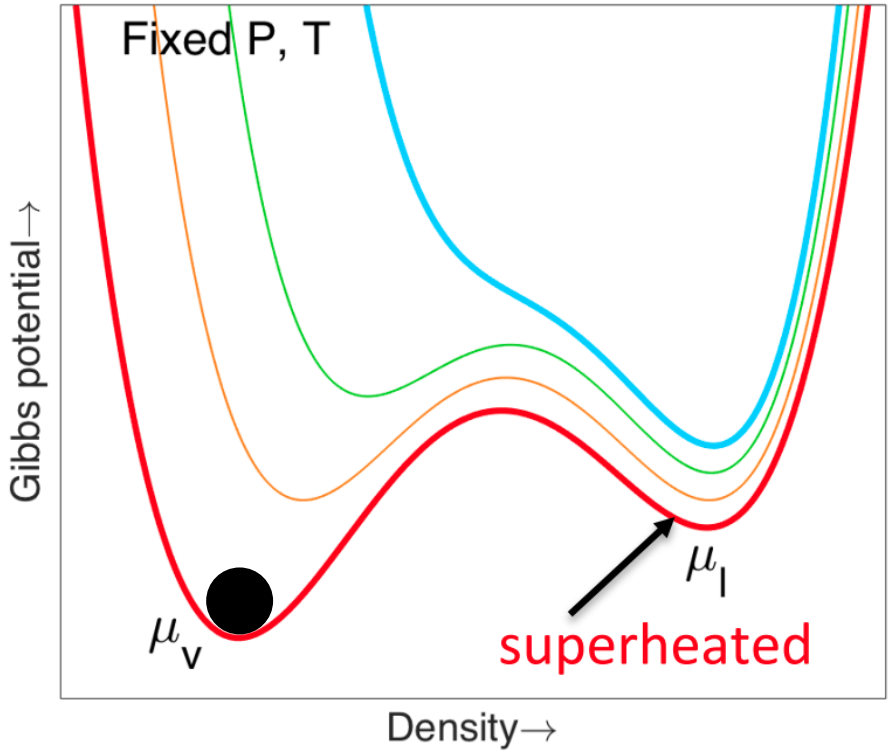

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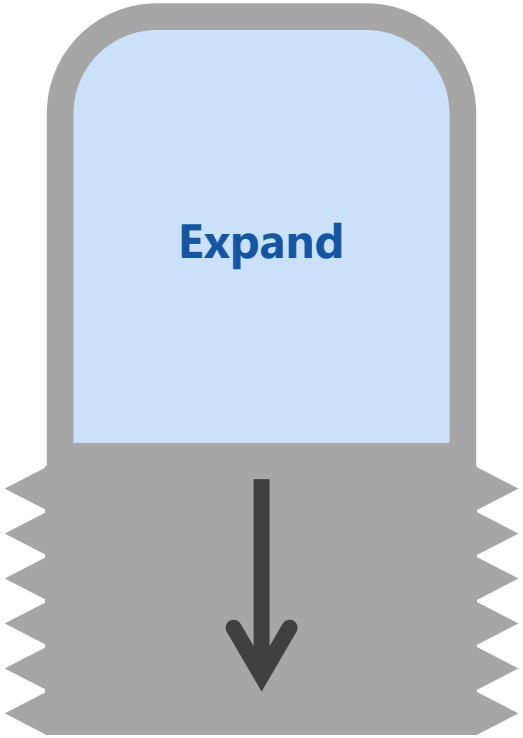

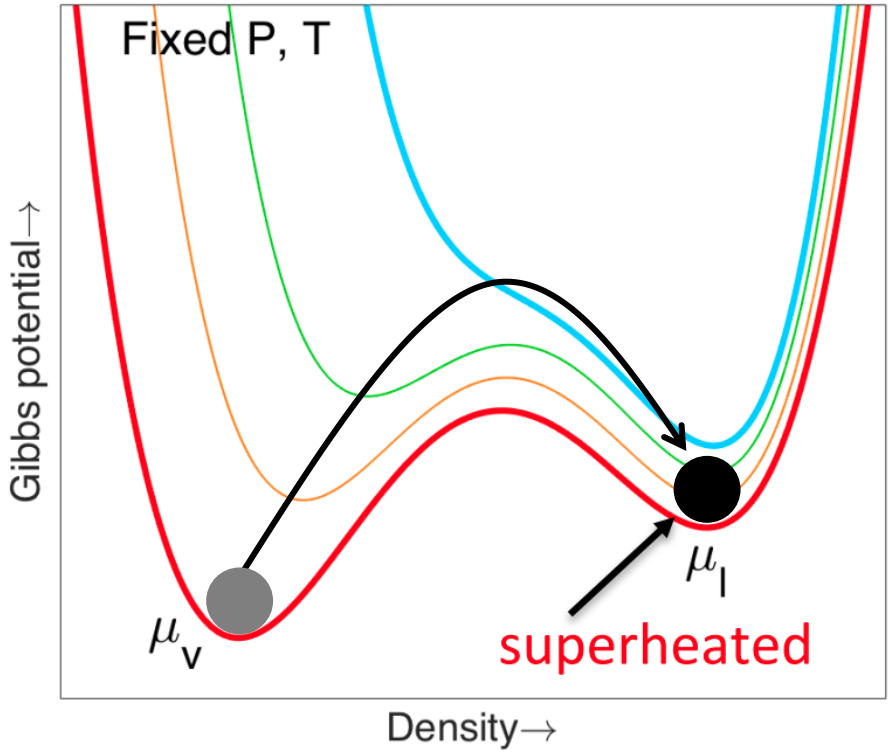

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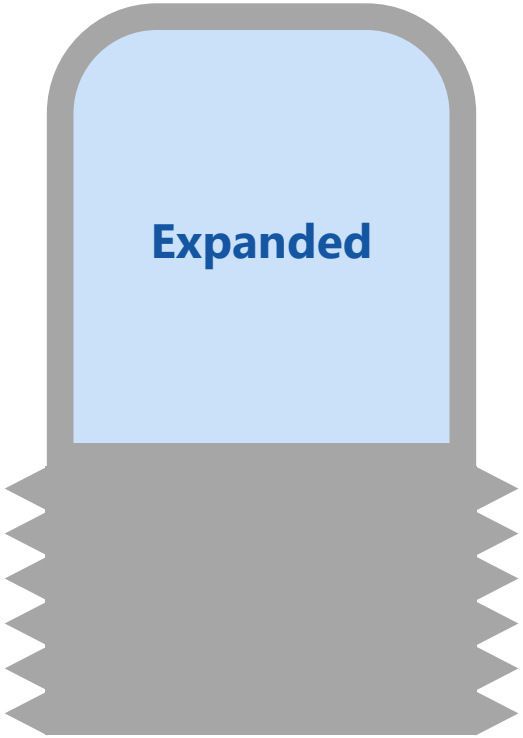

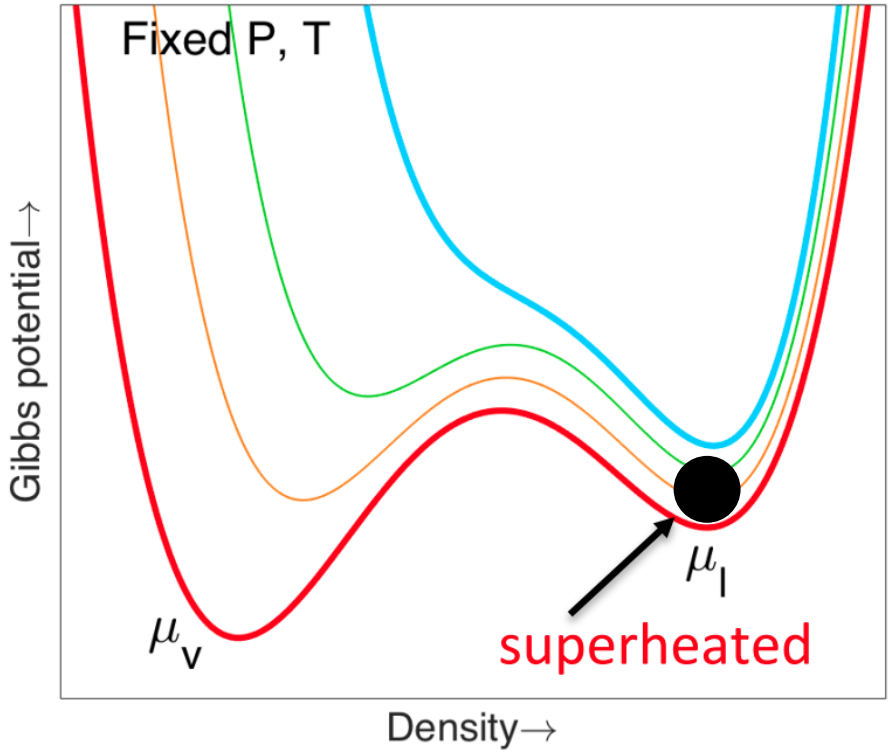

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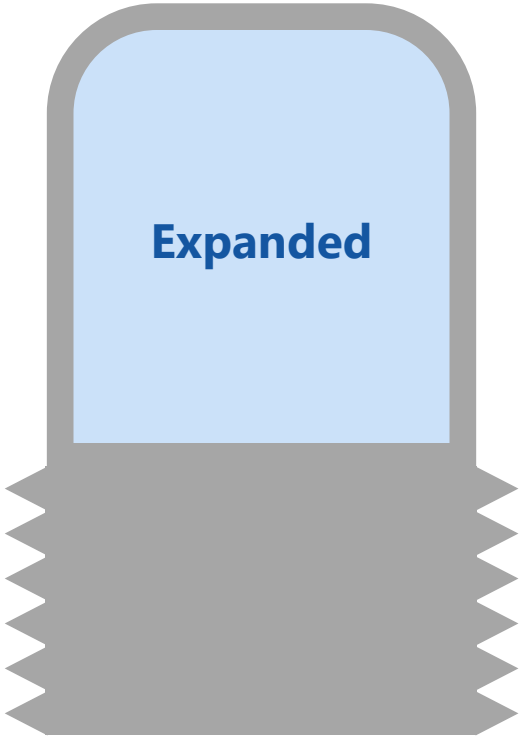

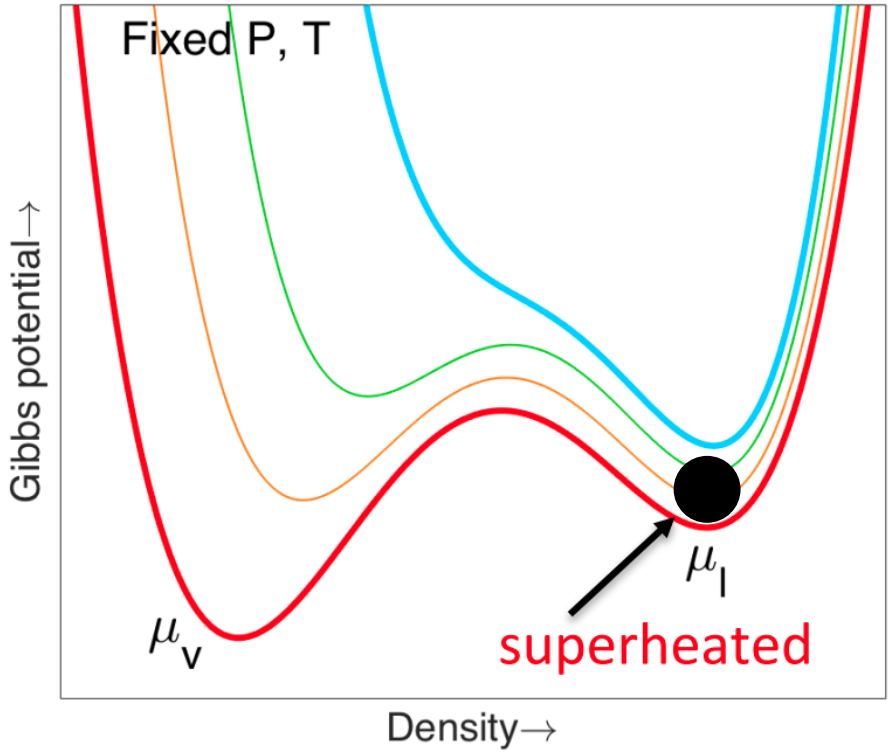

Surface Tension | Phase Transition | Expansion of Vapour

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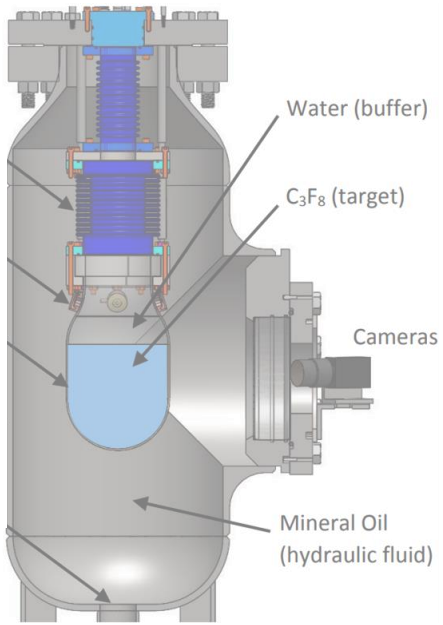
PICO Bubble Chambers



PICO-2L
2 L of C_3F_8
2013—2016

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

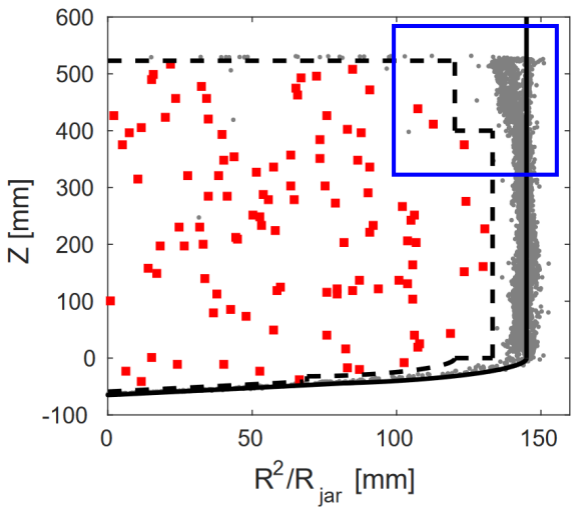
Right-Side-up

PICO-40L
35 L of C_3F_8
2019—Present

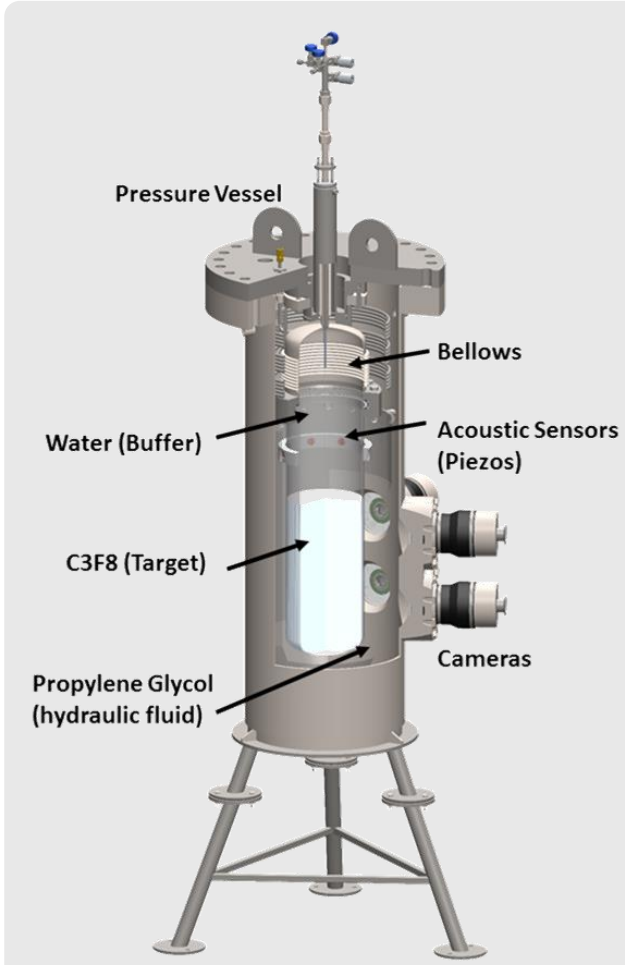
PICO-500
260 L of C_3F_8
Proj. 2026

Right-Side-up Design

Upside Down



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

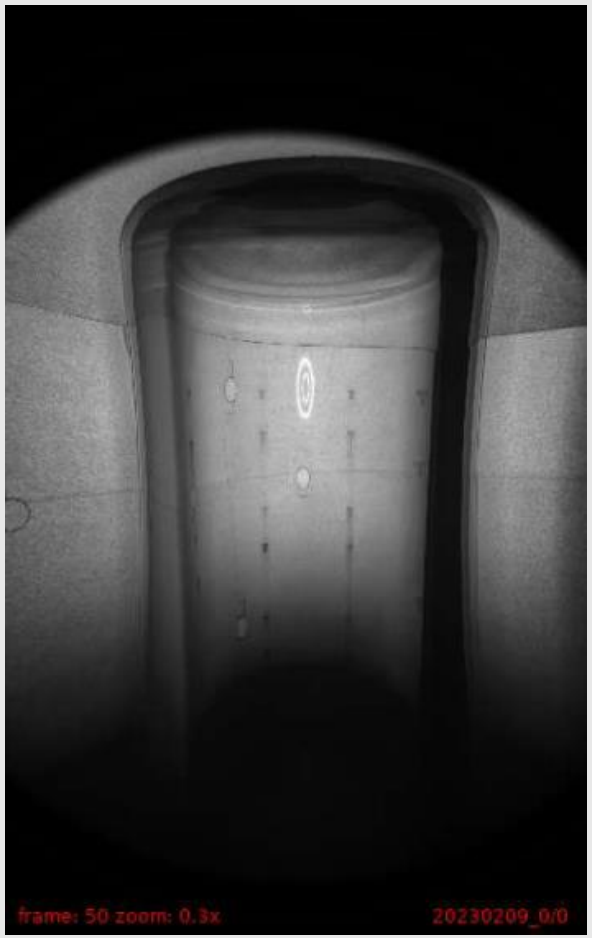


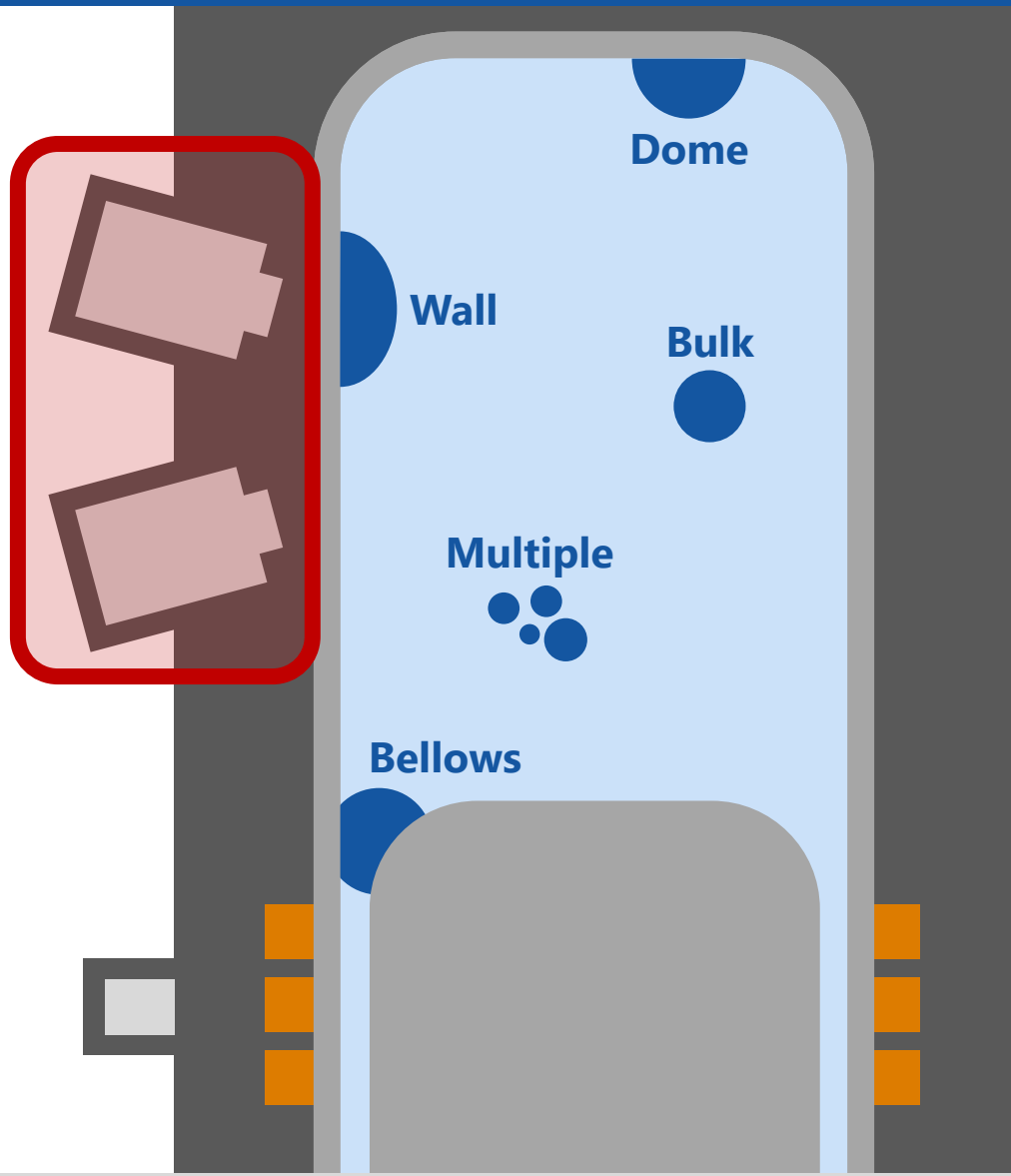
Right-Side-up

- **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.

Detection Channels

Cameras | Piezoelectric Sensors | Pressure Transducers





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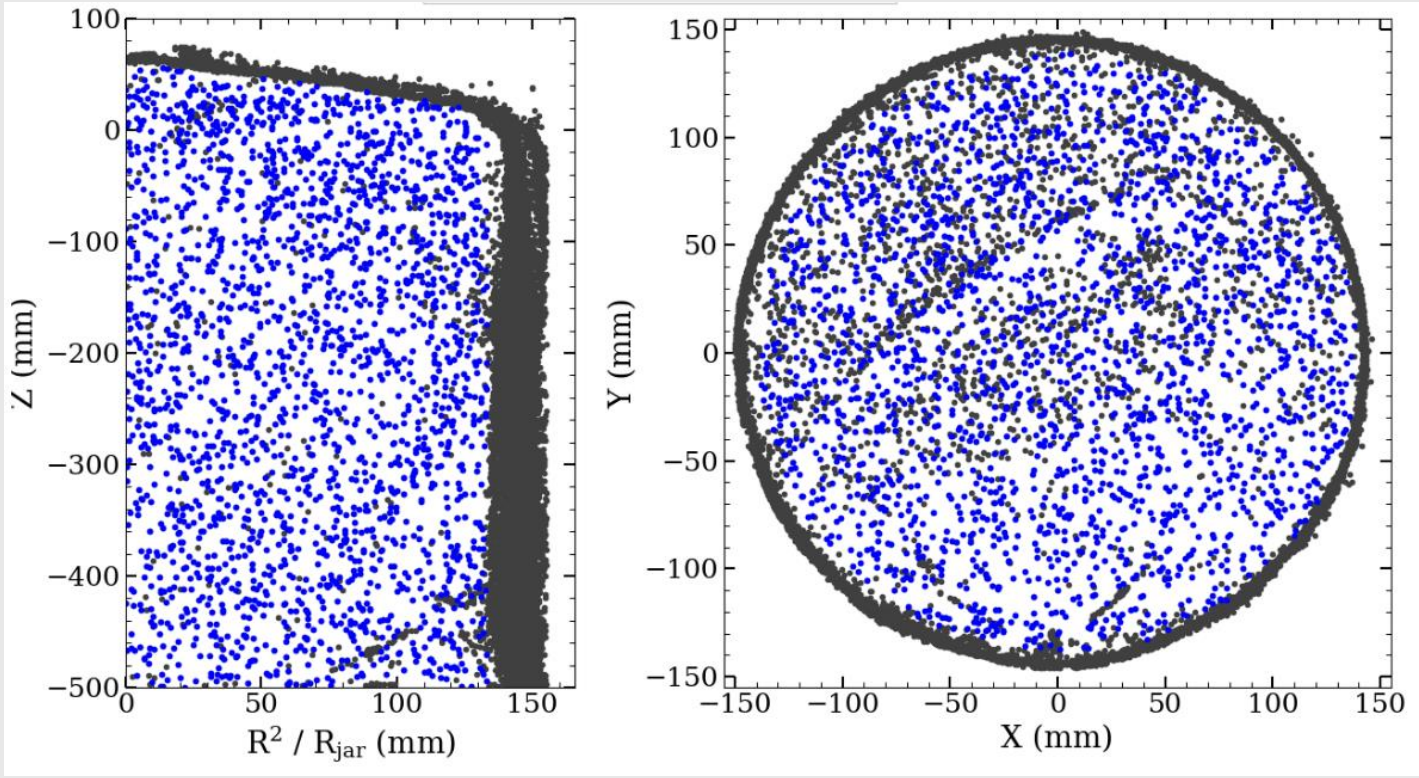
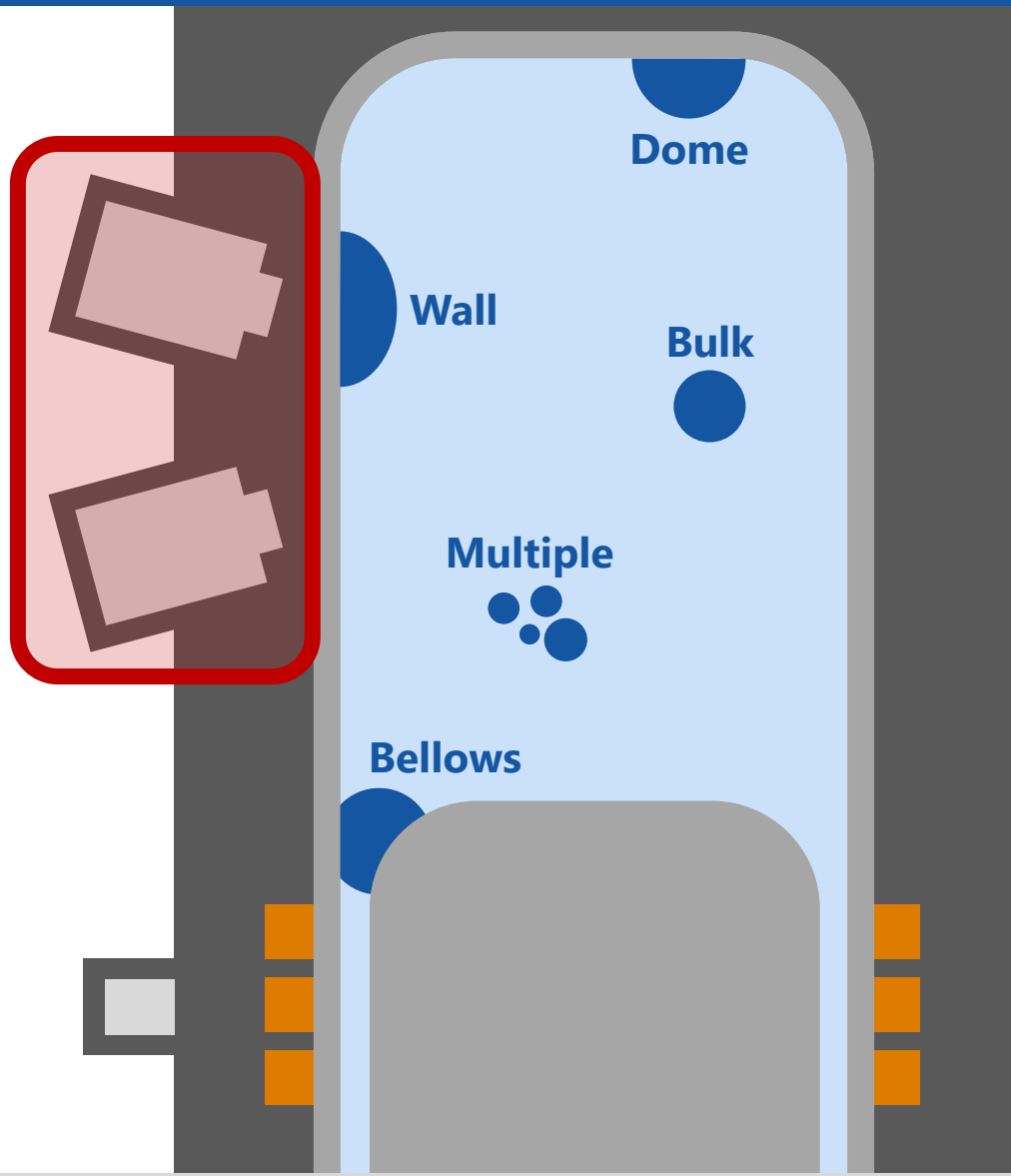
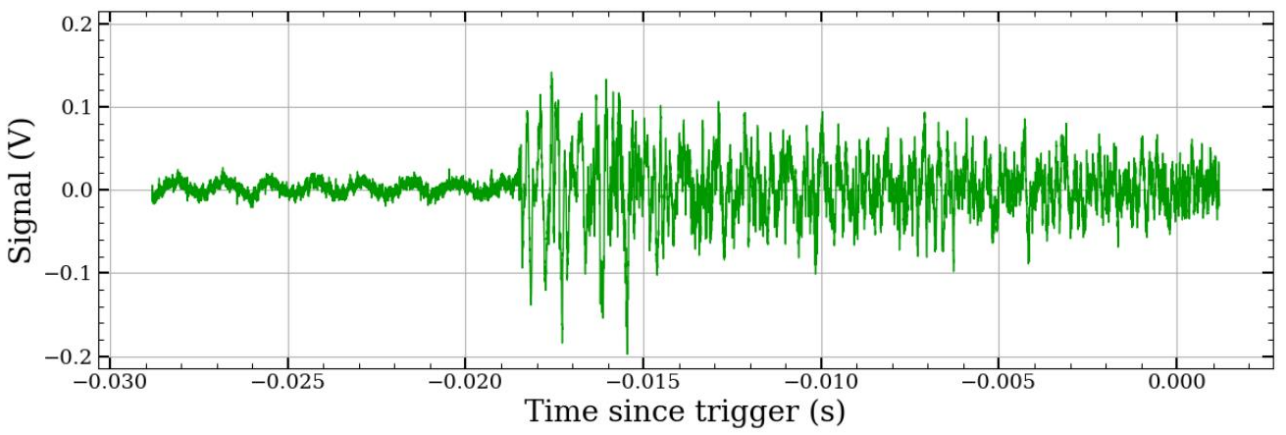
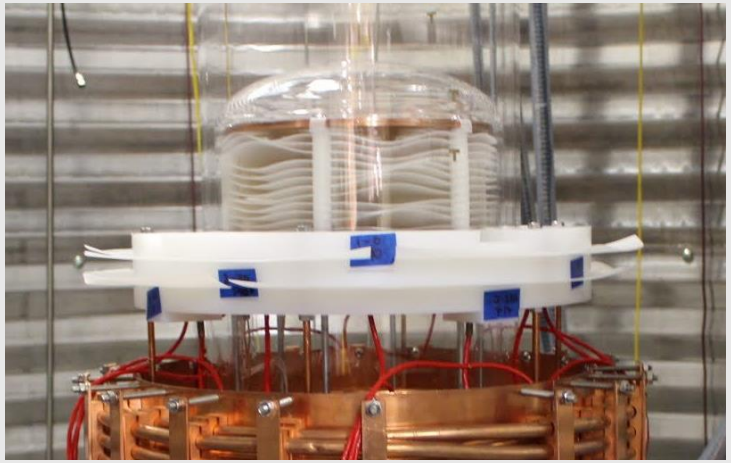


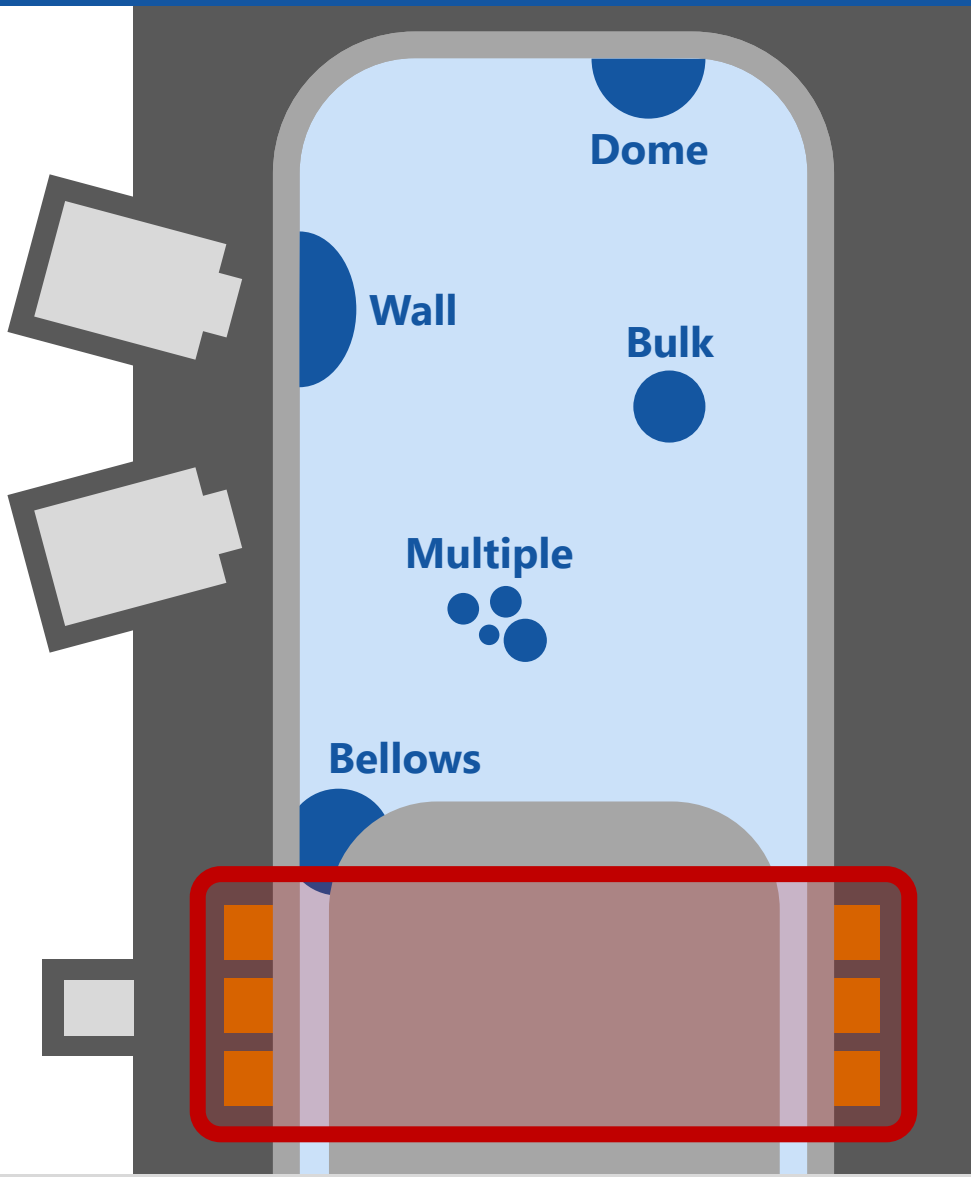


Detection Channels

Cameras | **Piezoelectric Sensors** | Pressure Transducers

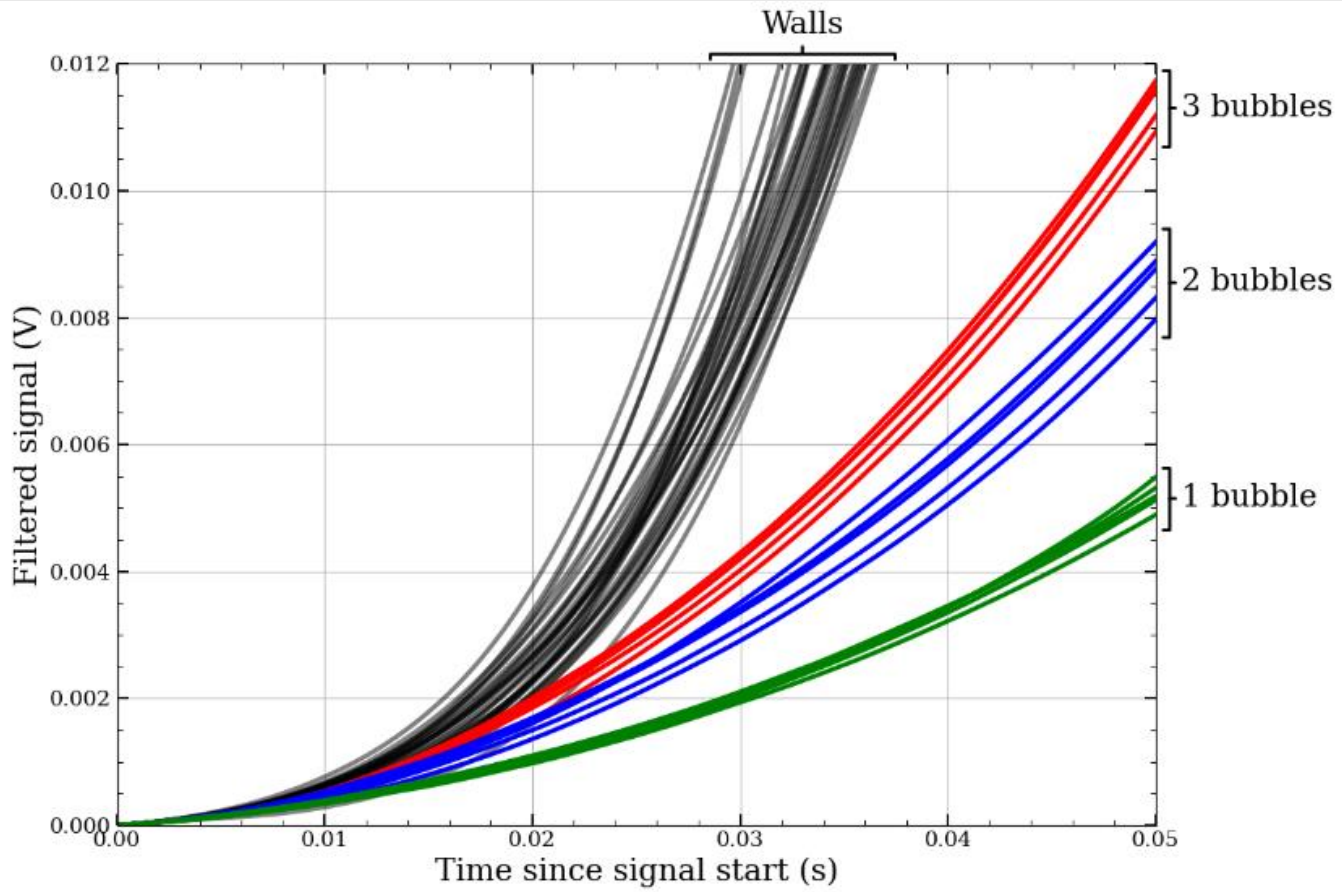


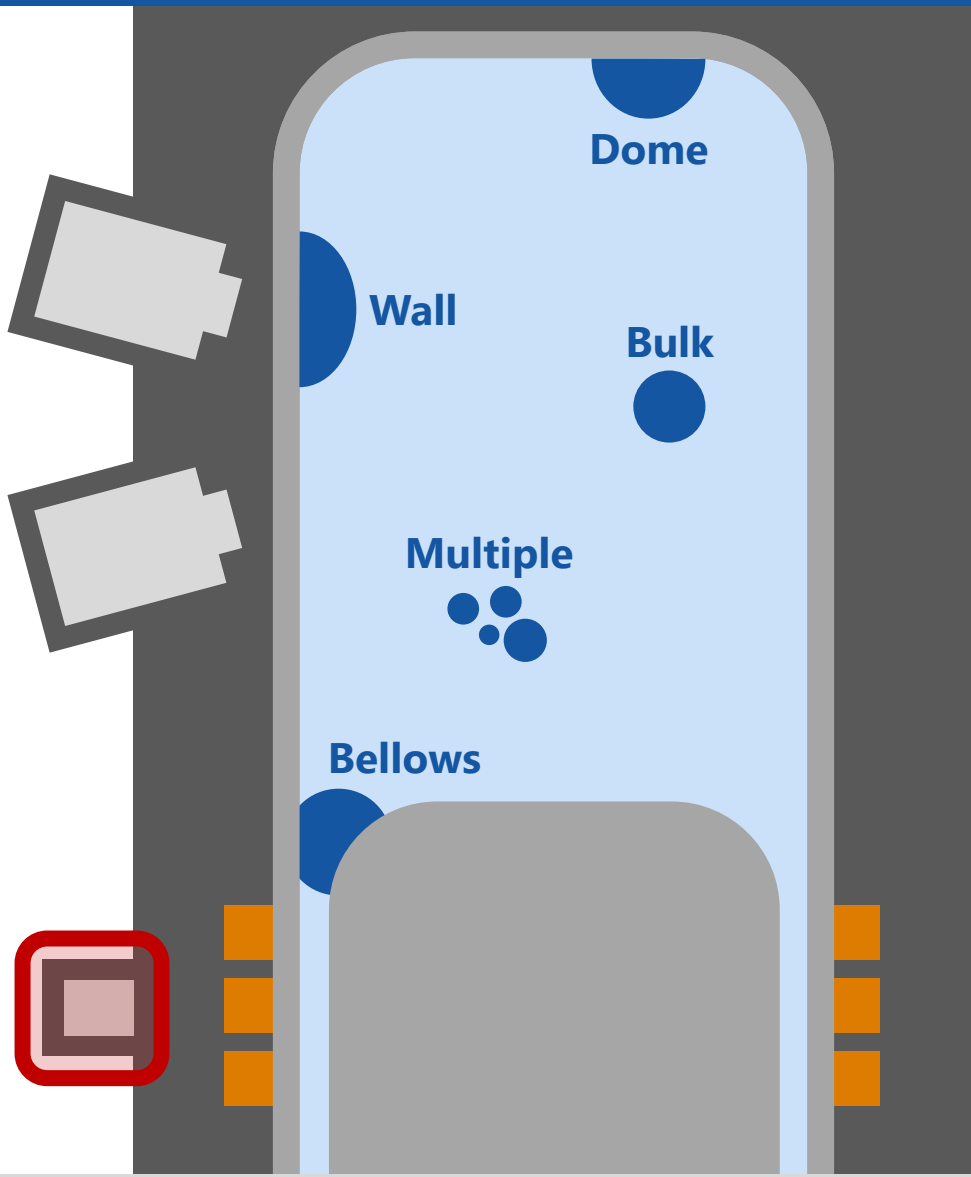




Detection Channels

Cameras | Piezoelectric Sensors | **Pressure Transducers**



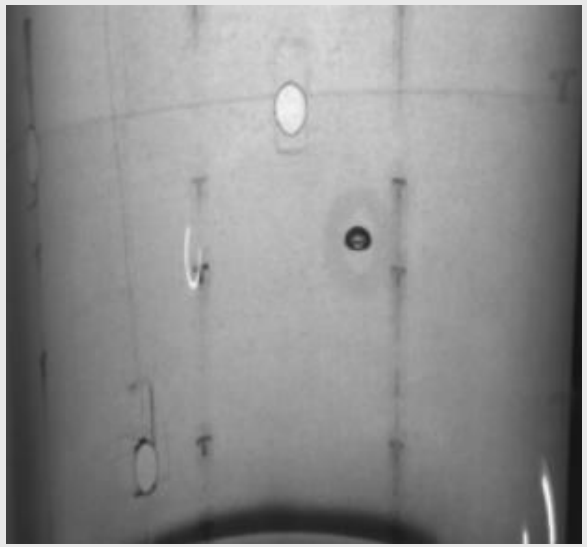


Backgrounds

Nuclear Recoils

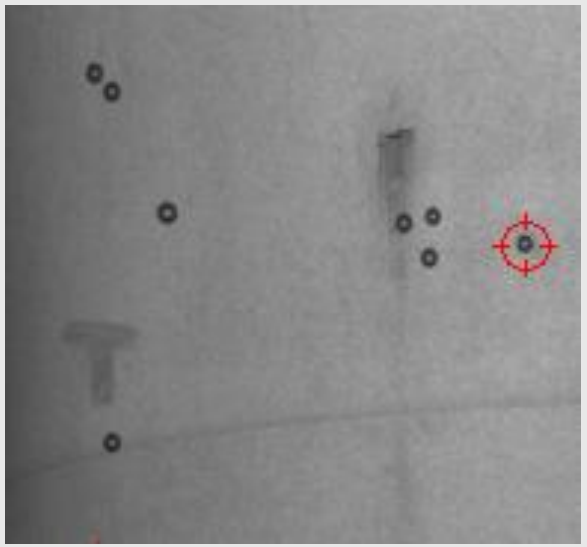
Alpha Particles

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



Neutrons

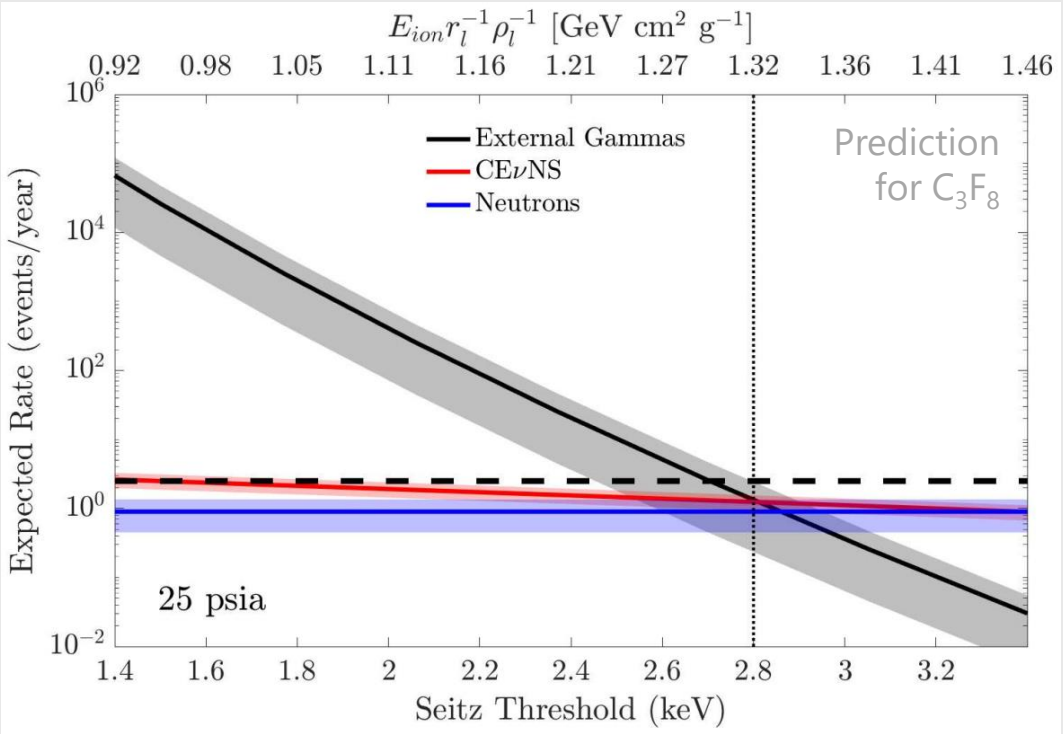
- Internal from spontaneous fission and (α, n), and external from CR muons.
- Single or multi-bubbles.



Electron Recoils

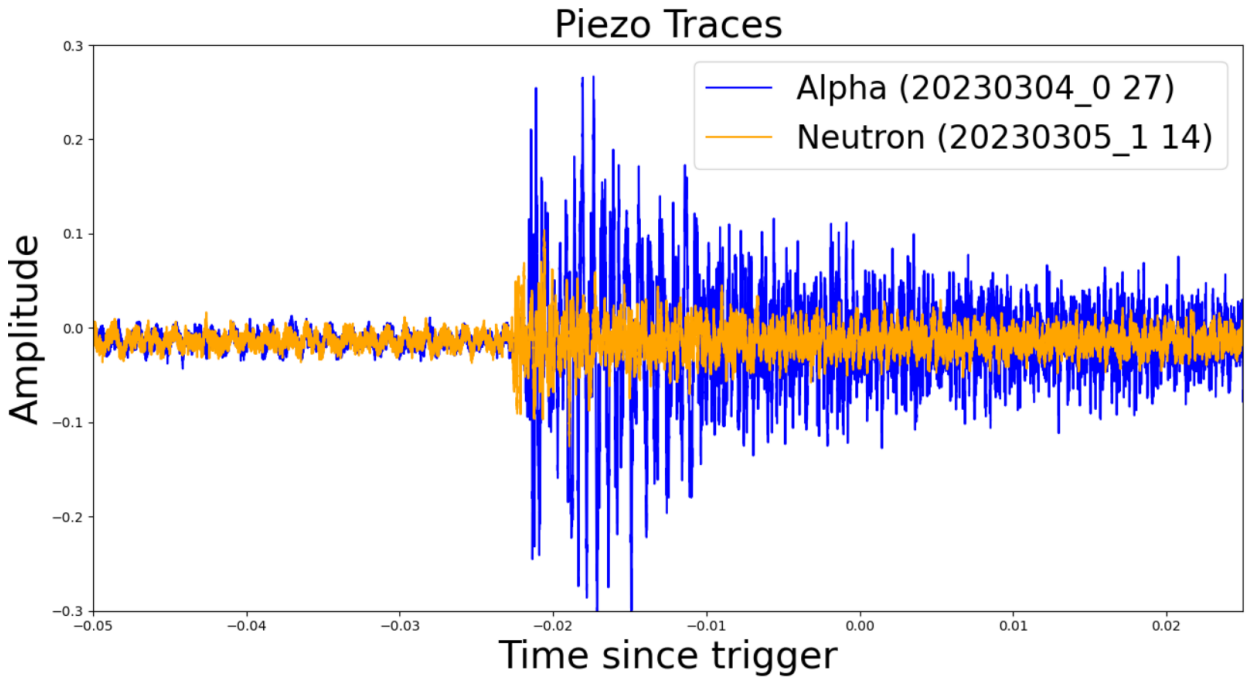
Gammas

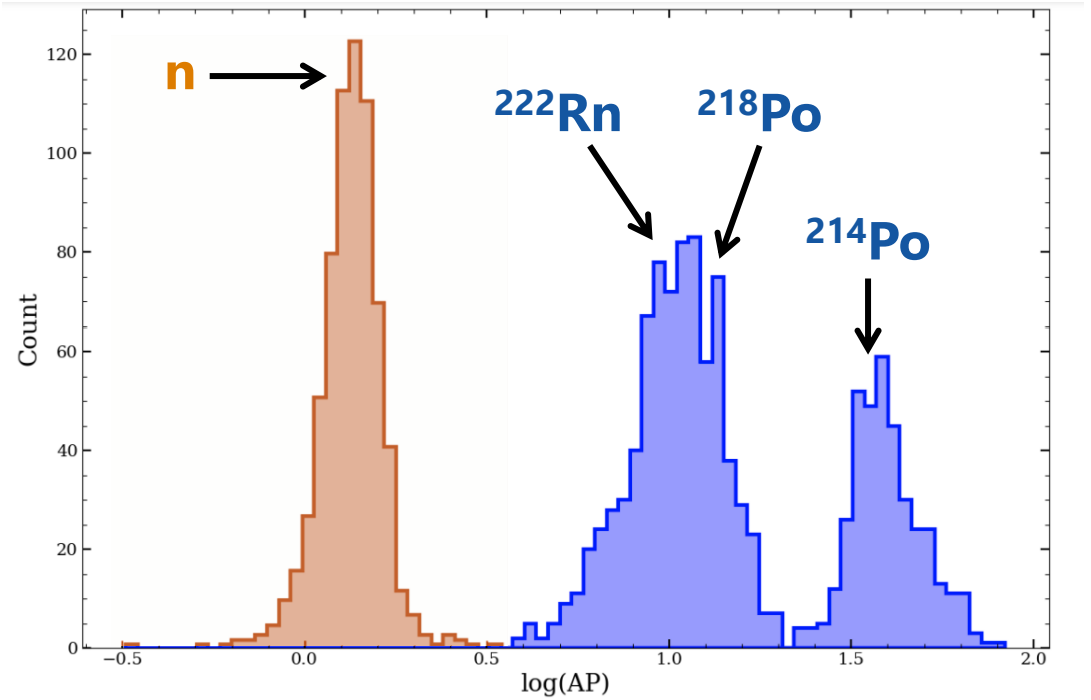
https://inspirehep.net/literature/1737408



Insensitive to gammas at operating thresholds.

Background Rejection

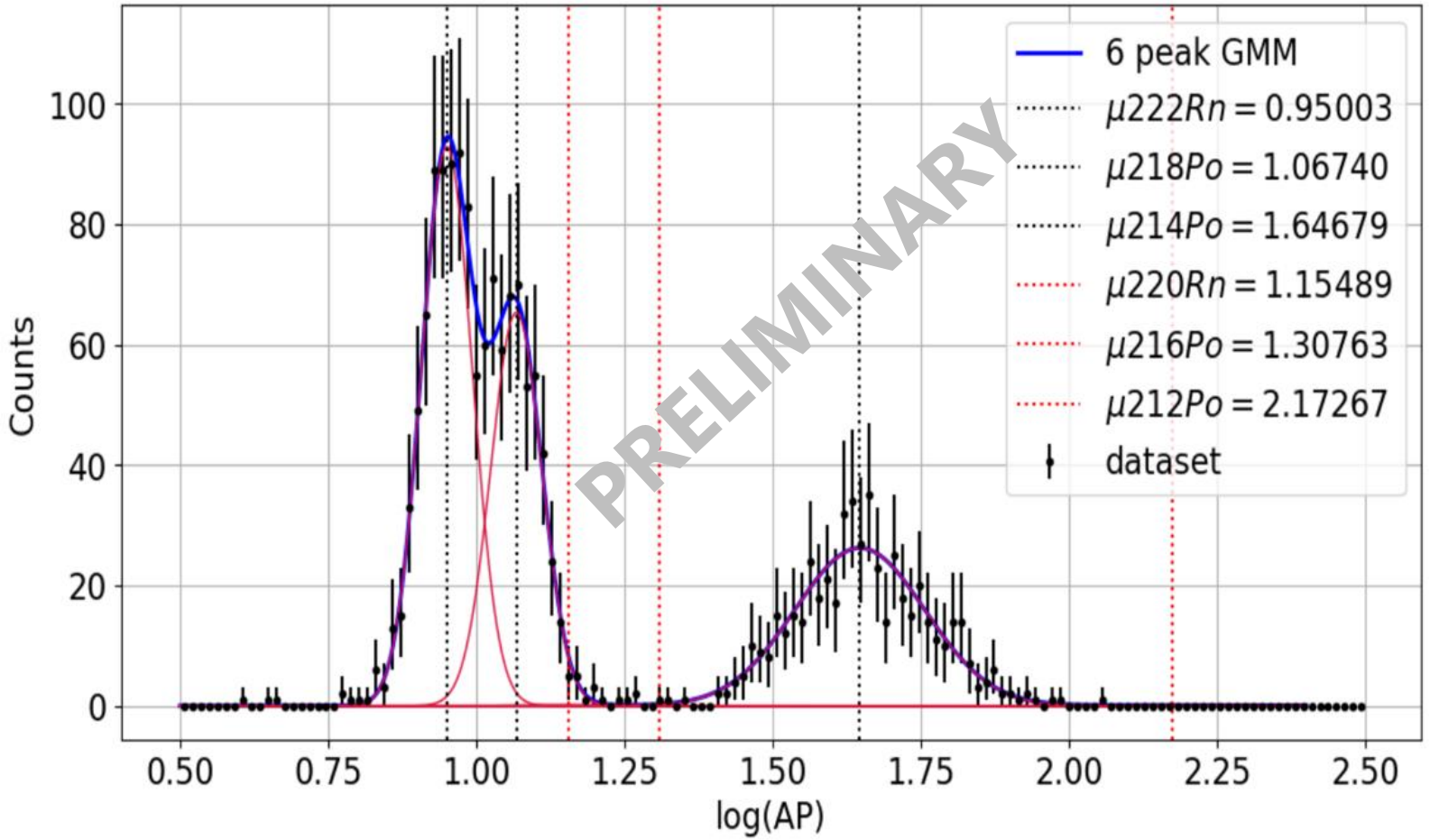




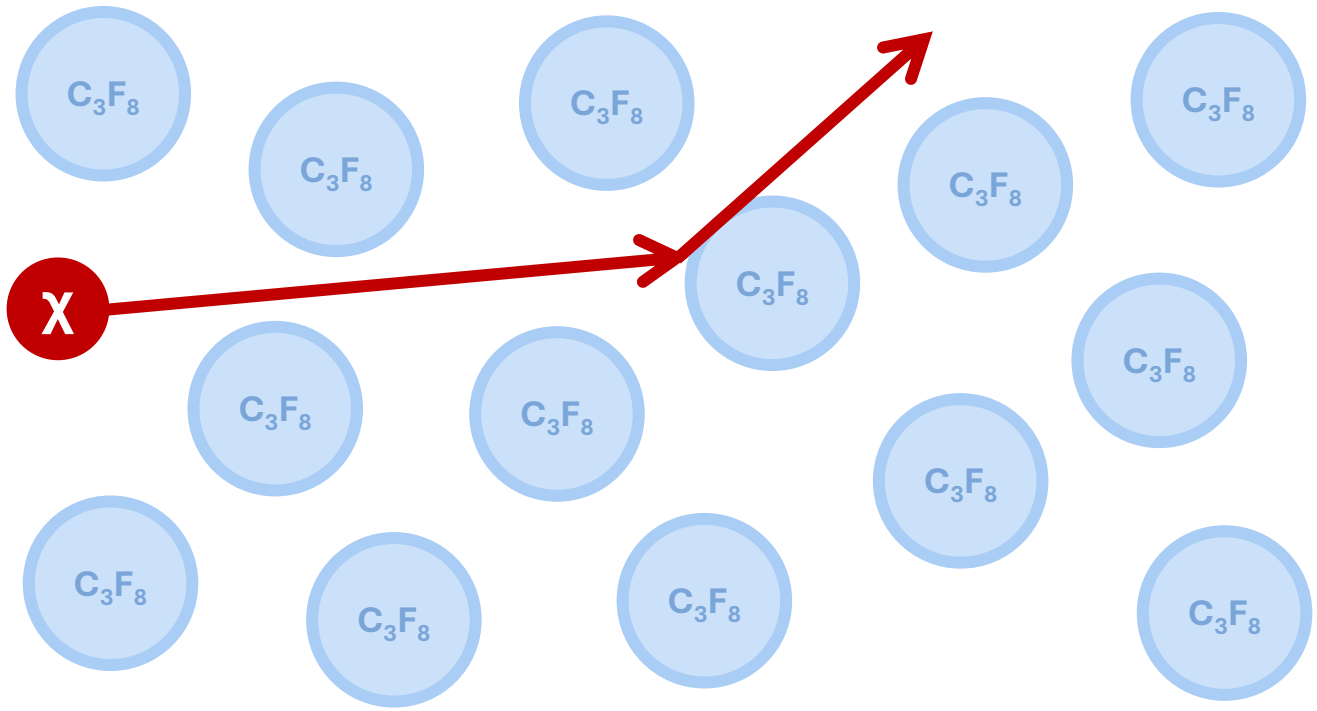
- Calculate acoustic parameter (AP) from resonant energy of piezoelectric sensors.
- Energy depositions from alpha particles have higher AP than those from neutrons.
- Different alpha decays from ^{222}Rn decay chain are identifiable.
- This is used to reject alpha backgrounds in PICO.

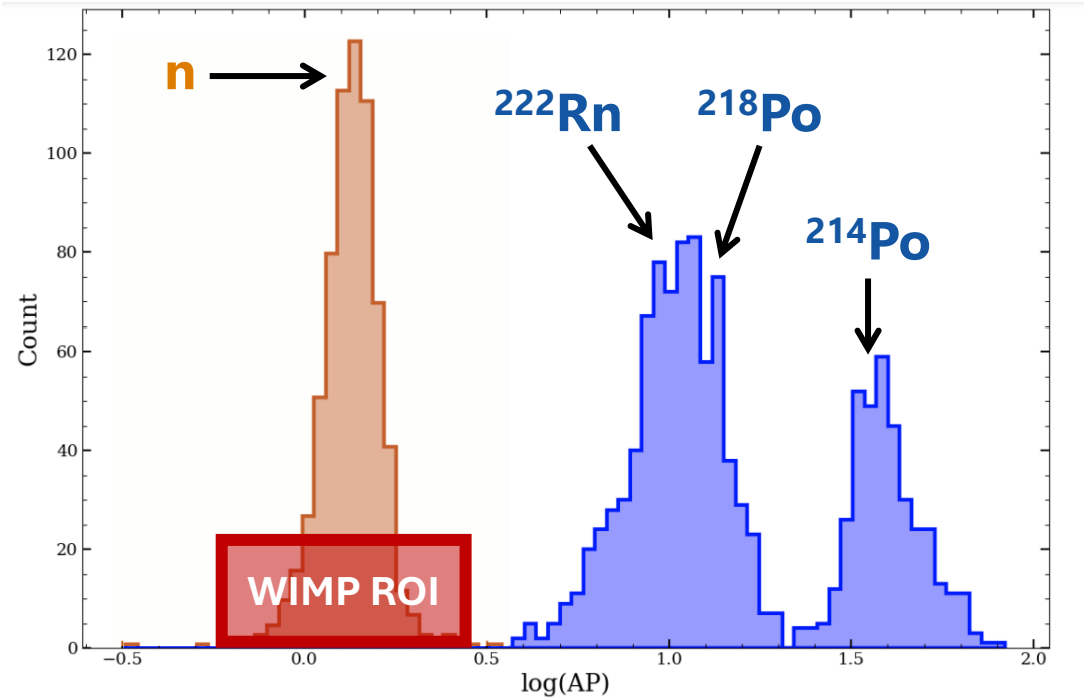
Alpha Spectroscopy

- 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.



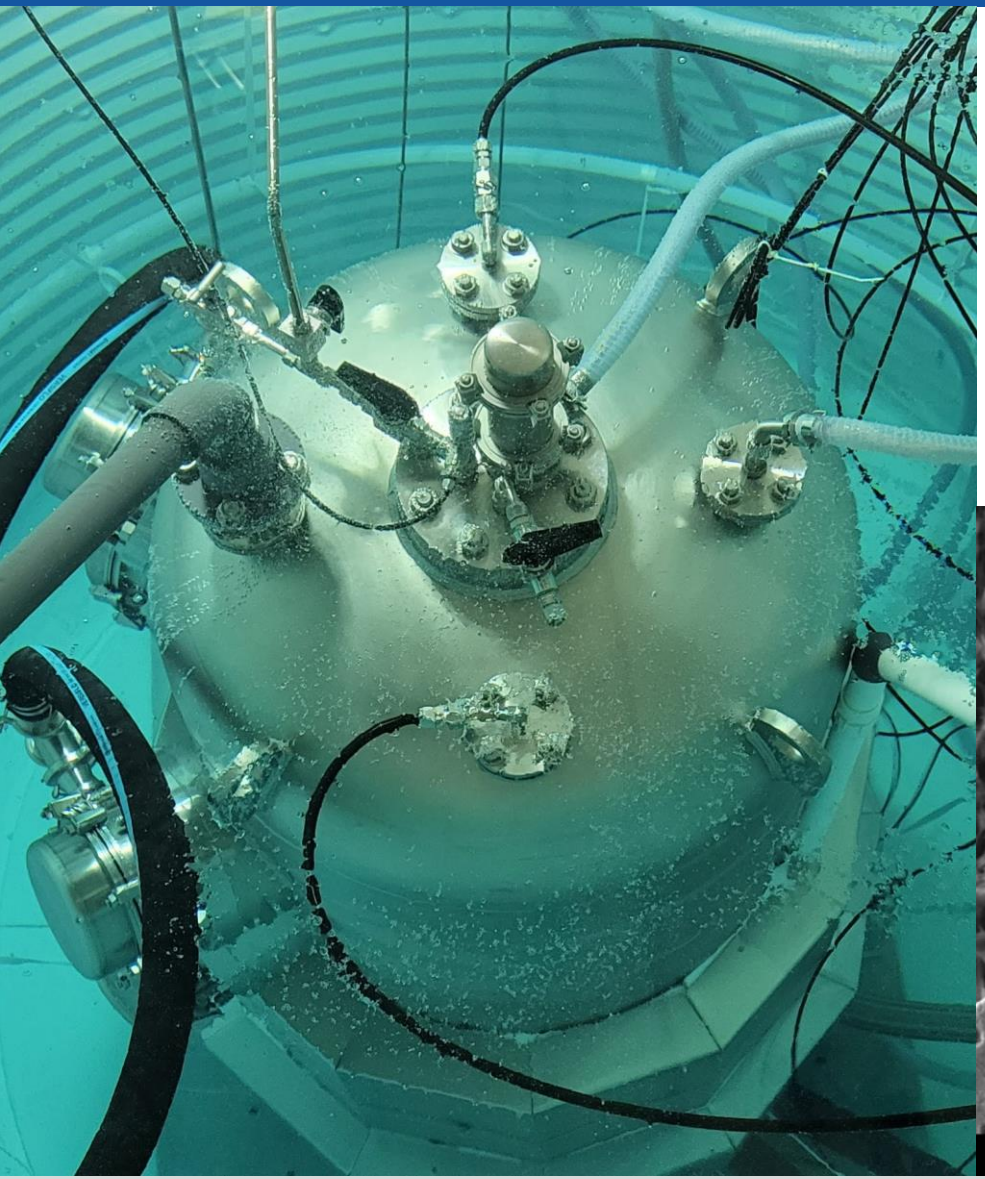
Backgrounds in the WIMP ROI



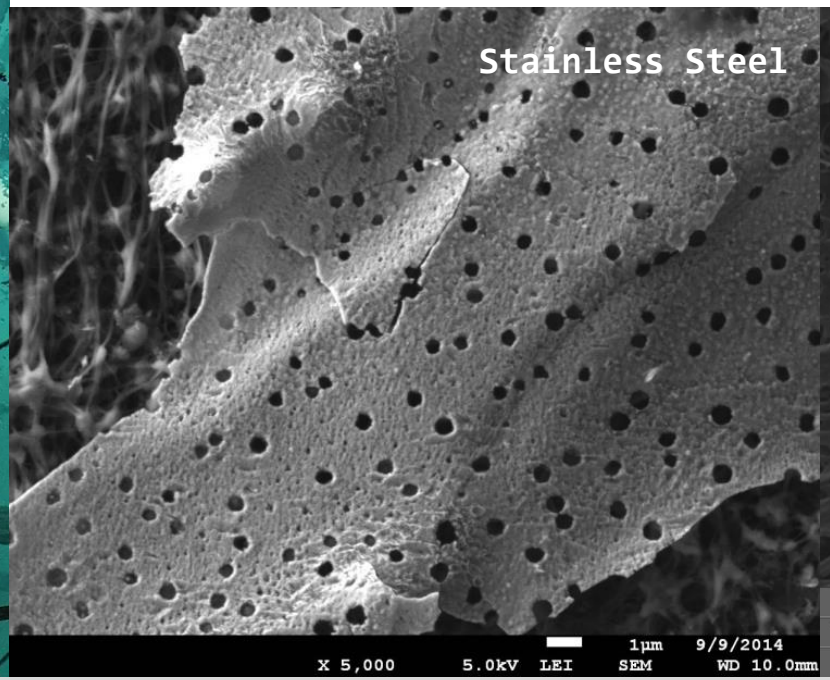


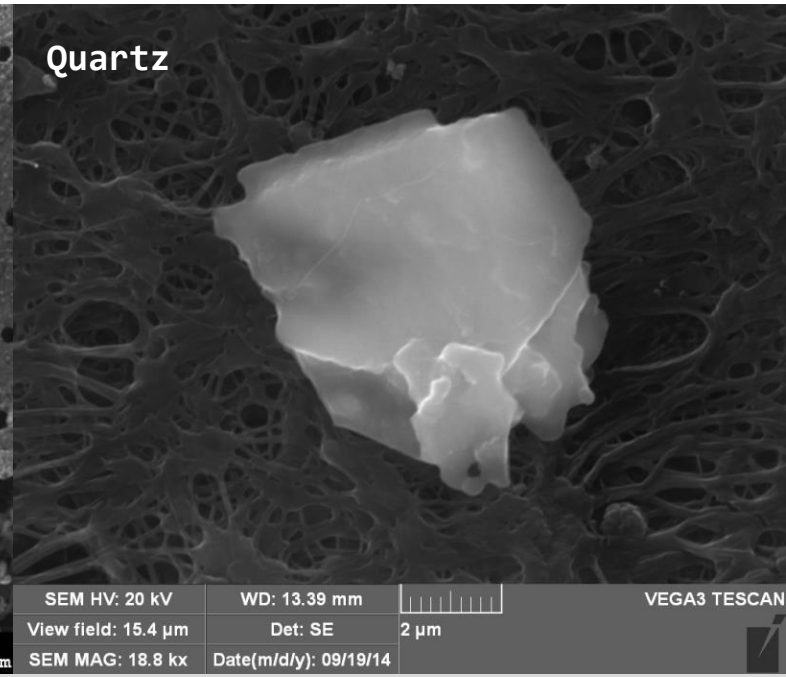
- Because **WIMPs** are weakly interacting, we do not expect them to interact more than once in the C_3F_8.
- They will create single bubbles with low energy deposition given the hypothesised mass range tested by PICO.
- They will look exactly like **single-scatter neutron events**.
- We must therefore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

Background Mitigation



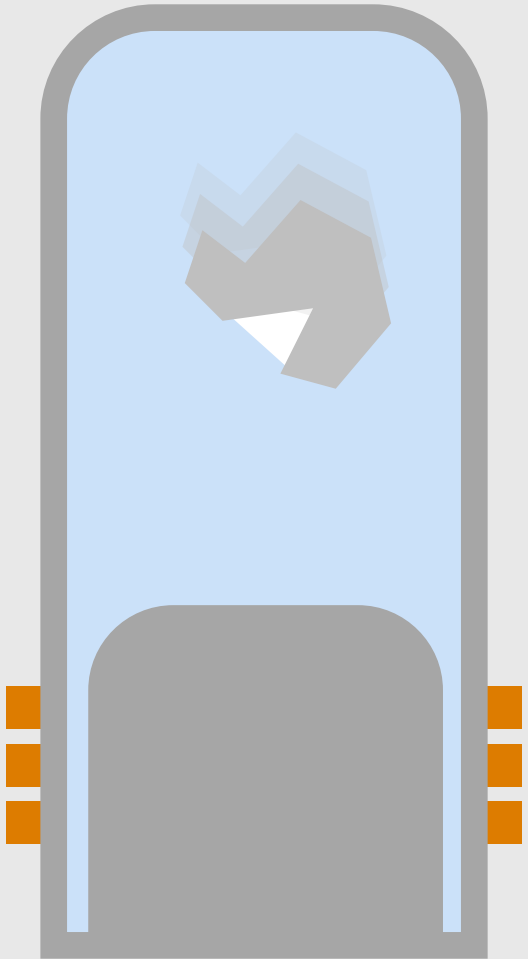
- **External Neutron Backgrounds:**
  - Shielded by large water tank surrounding the pressure vessel.
- **Internal Alpha and Neutron Backgrounds:**
  - Careful selection of materials.
  - Rigorous efforts to mitigate radon and extensively clean detector.





Current PICO-40L Analyses

Particulate Physics



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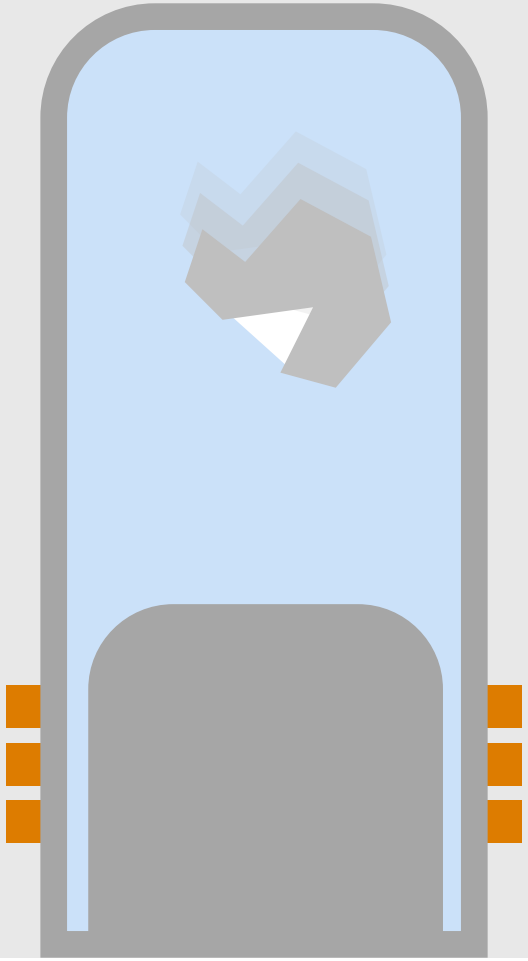
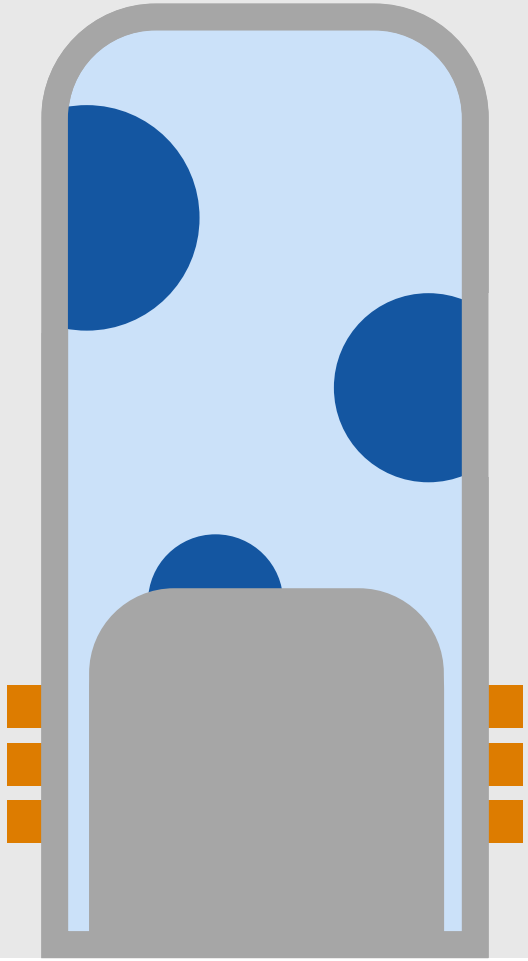


Wall Event Rate



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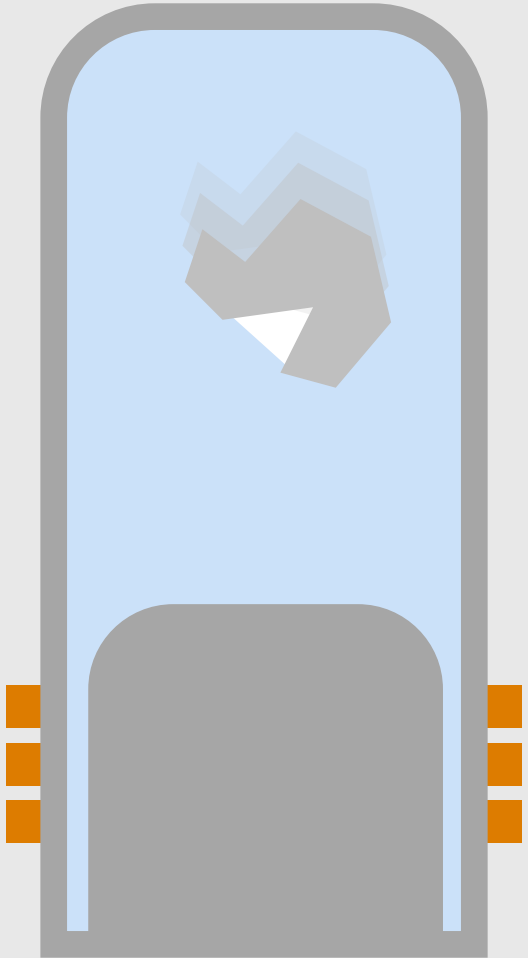

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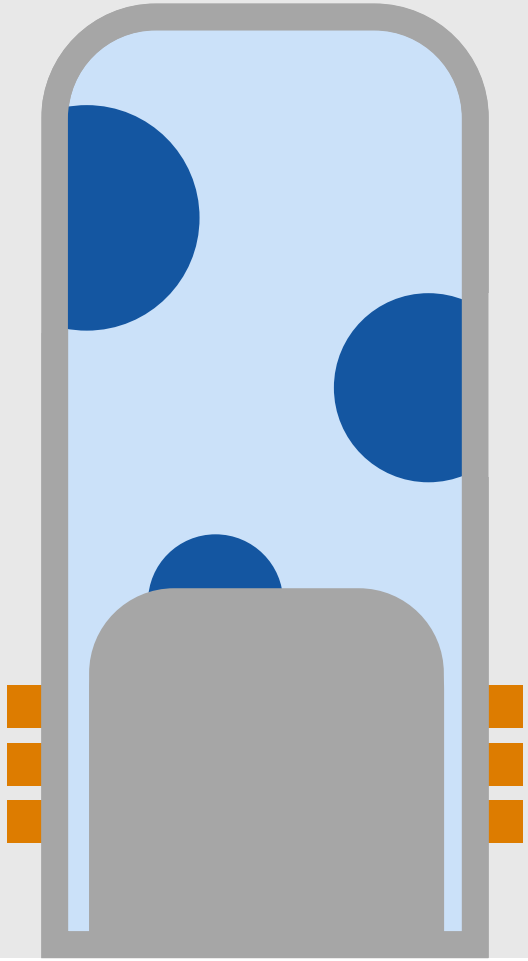
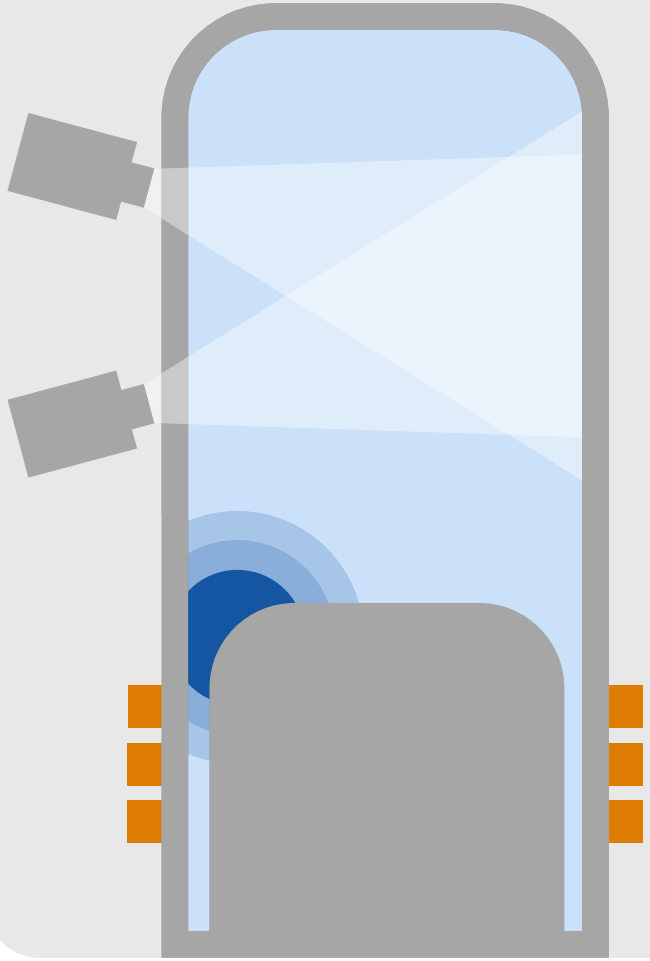


Acoustic Position Recon.



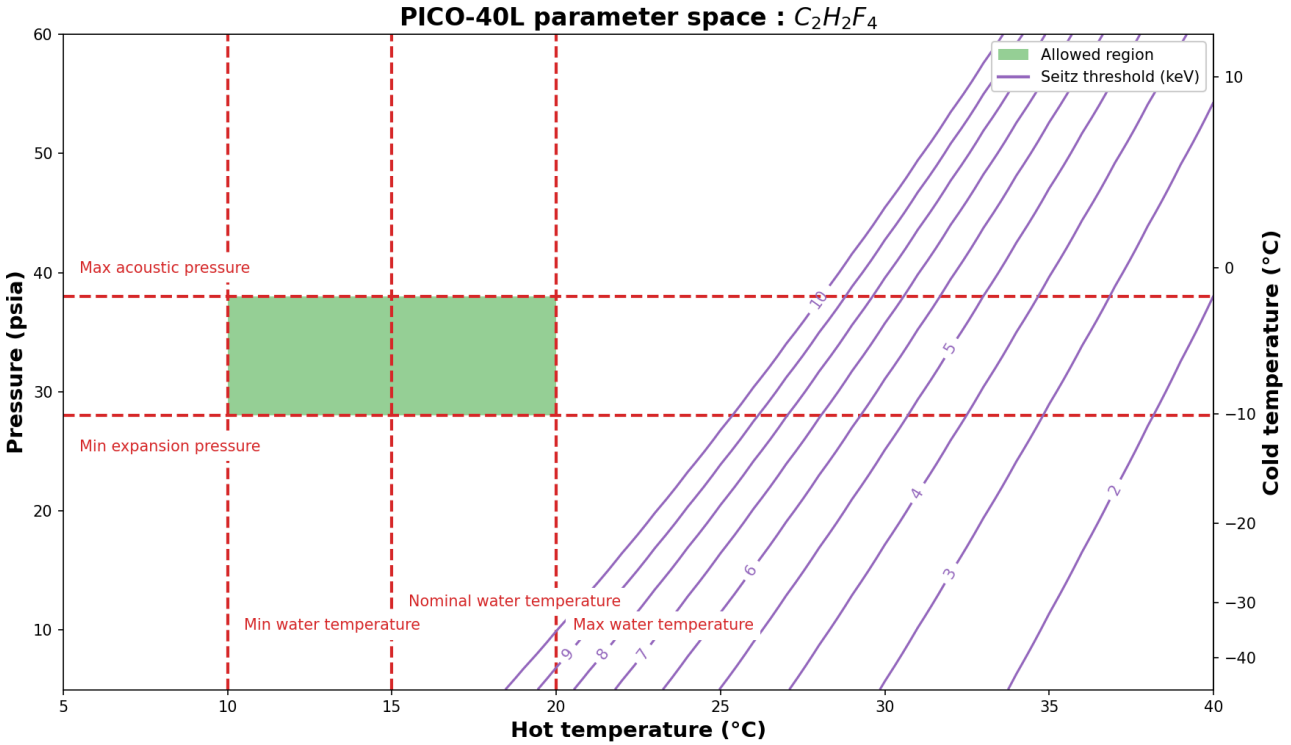
Expanded Physics Programme

- Our main physics goal is SD WIMP detection, but we have wide potential for physics analyses beyond this.

- **WIMPs with Other Active Fluids:**
  - Search for WIMPs using different operating conditions, Seitz thresholds, and sensitivies.
  - $C_2H_2F_4$, C_4F_{10}, C_5F_{12}
  - CF_3I (for SI WIMPs); see PRD 92 (2016) 5.

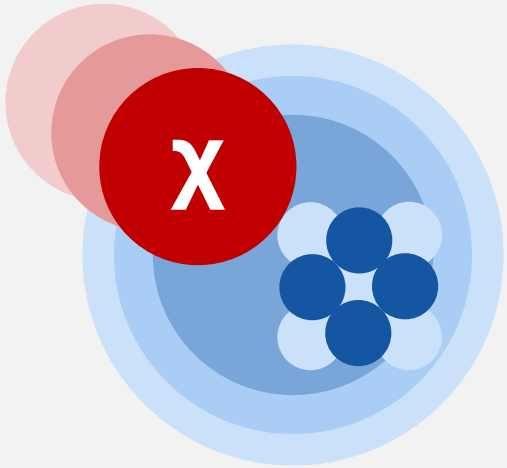
- **MIMPs:**
  - High mass of MIMPs would appear as multiple bubbles in collinear tracks.

- **Supernova Detection and SNEWS:**
  - Multi-bubble CEvNS events from supernovae up to 10 kpc away. See *Astropart. Phys.* 105 (2019) for details.



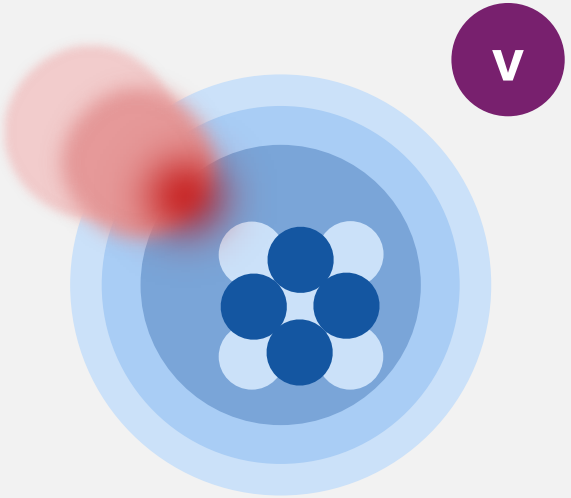
Dark Matter Absorption with PICO-60

Scattering



$$\chi + N \longrightarrow \chi + N'$$

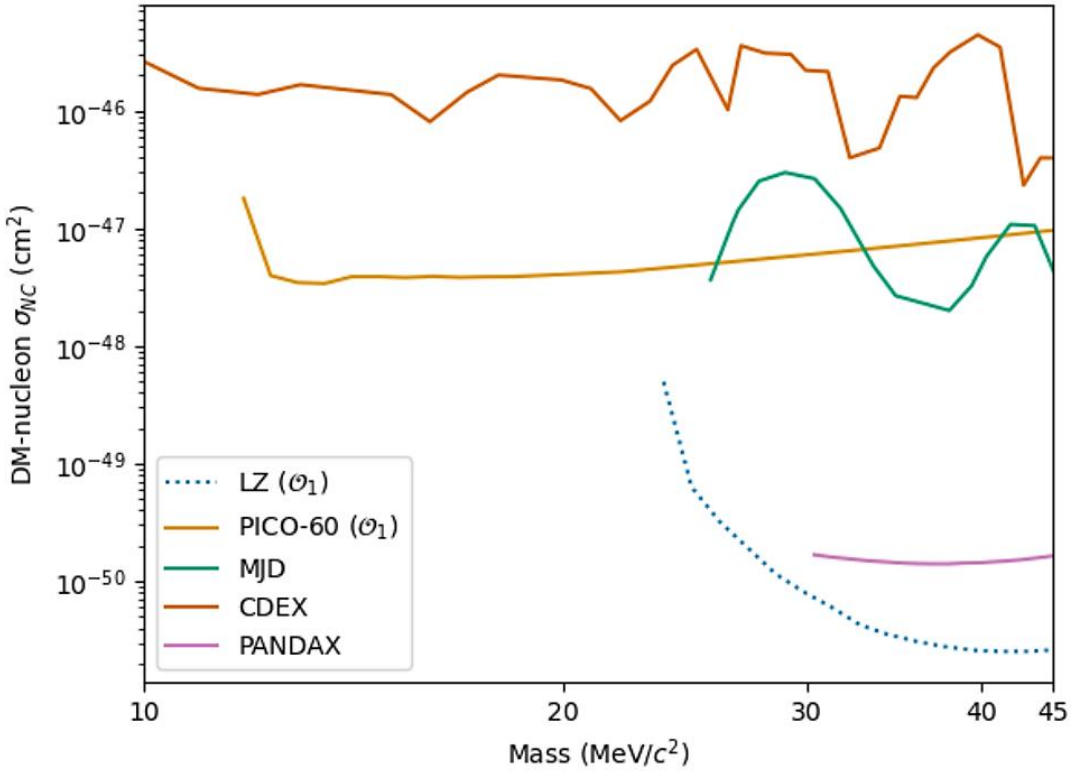
Absorption



$$\chi + N \longrightarrow \nu + N$$

- $\mathcal{O}_1$: NREFT operator for spin-independent response.
- World-leading limits set using PICO-60 data.

- $\mathcal{O}_4$: NREFT operator for spin-dependent response.
- First ever limits set using PICO-60 data.

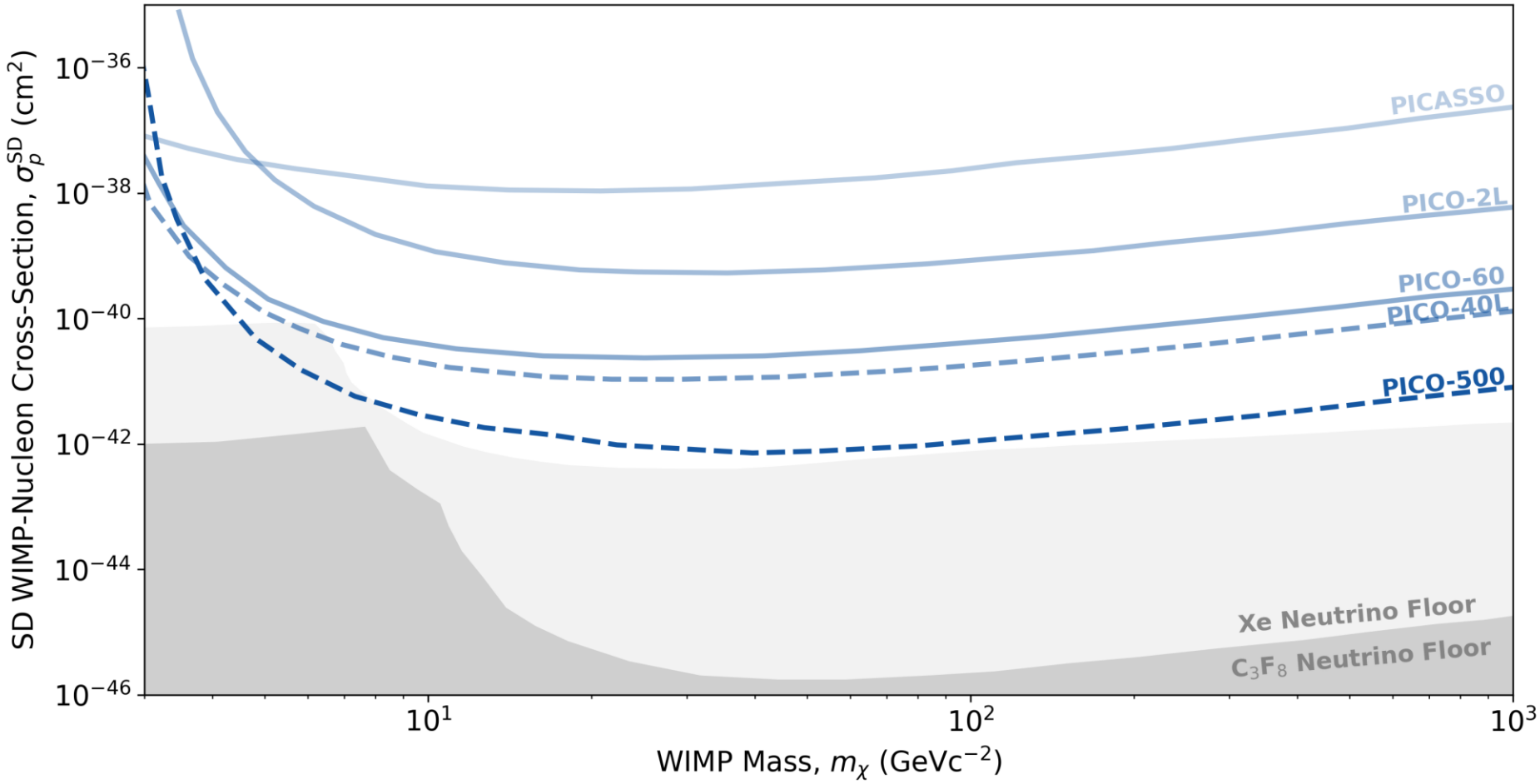


Published in PRL
Editor's Suggestion

https://doi.org/10.1103/1cwz-m1c3

Projected Sensitivities

- PICO-40L is expected to improve sensitivity over PICO-60 by a factor of 5x due to decreased backgrounds.
- Low neutrino fog for C_3F_8 allows PICO to probe the parameter space more deeply than many other experiments.



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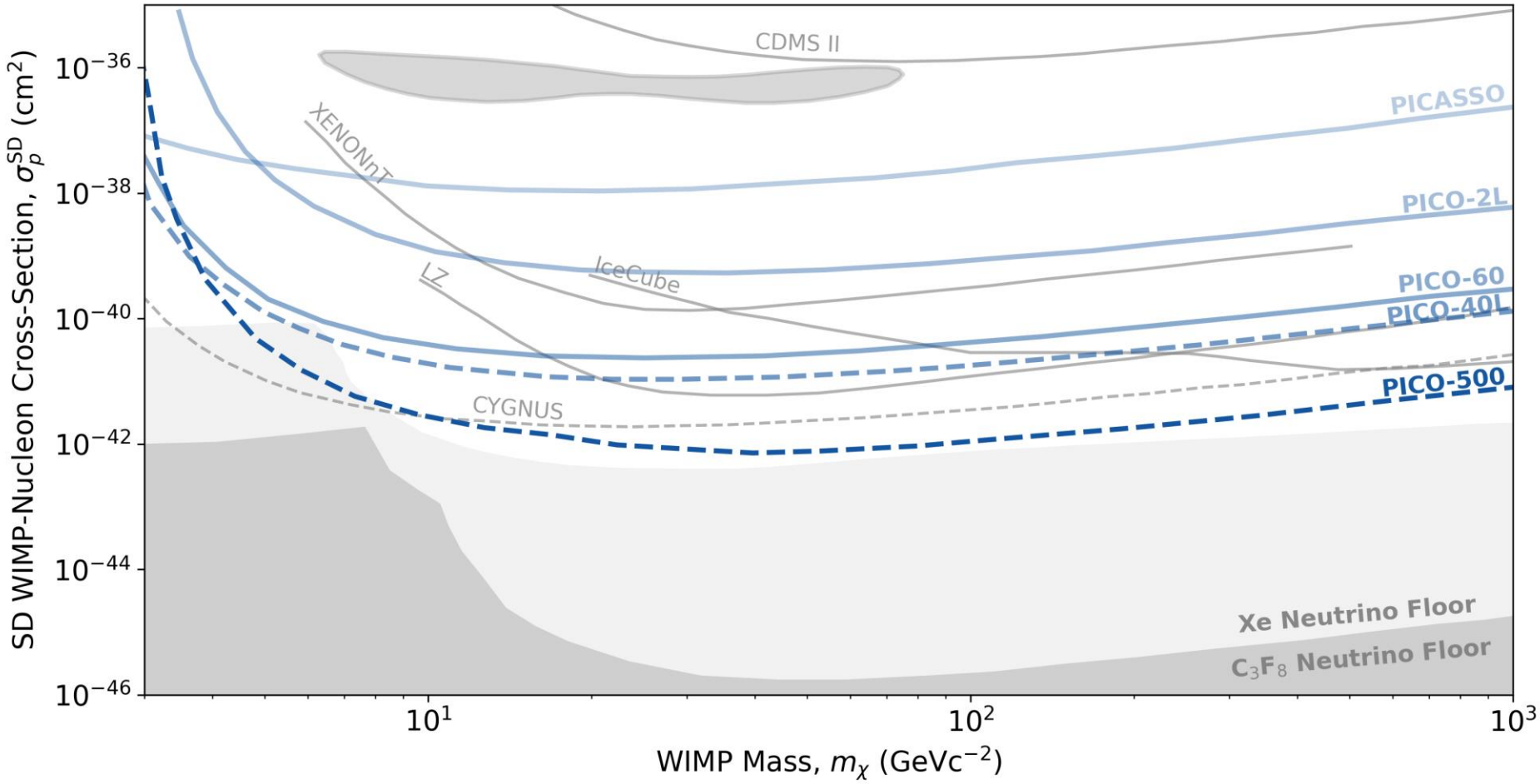


PICO-500

- 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.

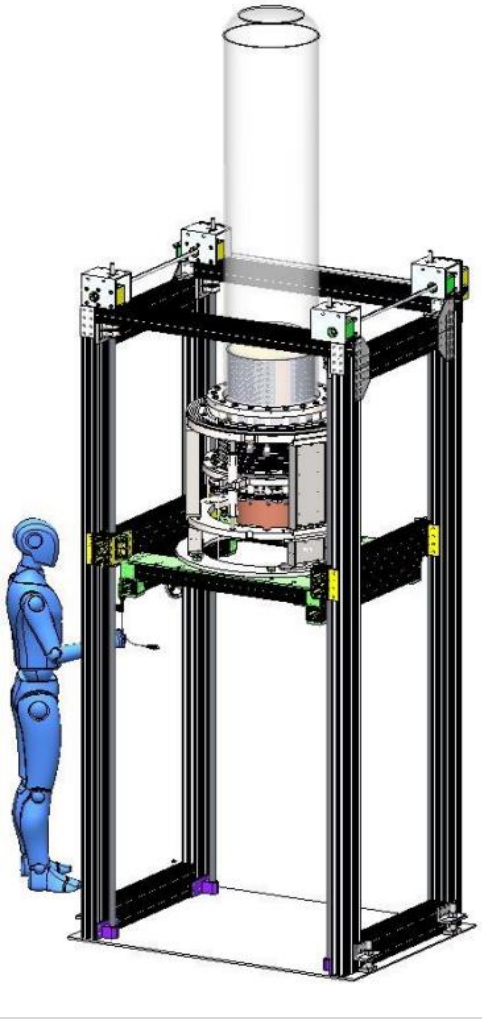
- **Improvements in PICO-500:**
  - New **cleaning** and **radon mitigation** techniques
  - New **muon veto** system
  - Improved **heater design**
  - **Vacuum jacket** to help keep temperatures stable in the cold region.
  - **Degassing tank** removes air from mineral oil and reduces dead time.
 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

PICO-500 Status - Pressure Vessel

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

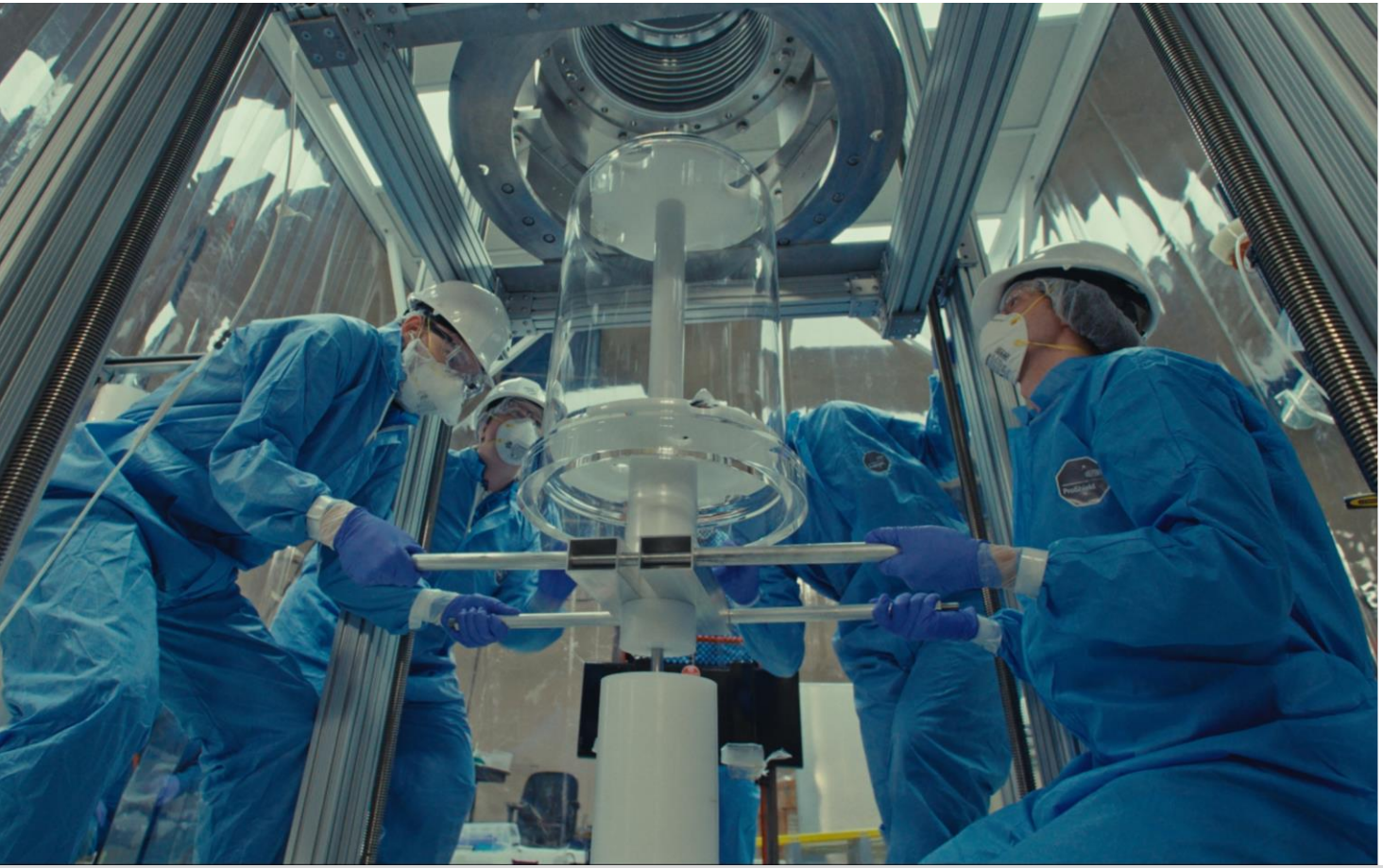
PICO-500 Status - Inner Vessel

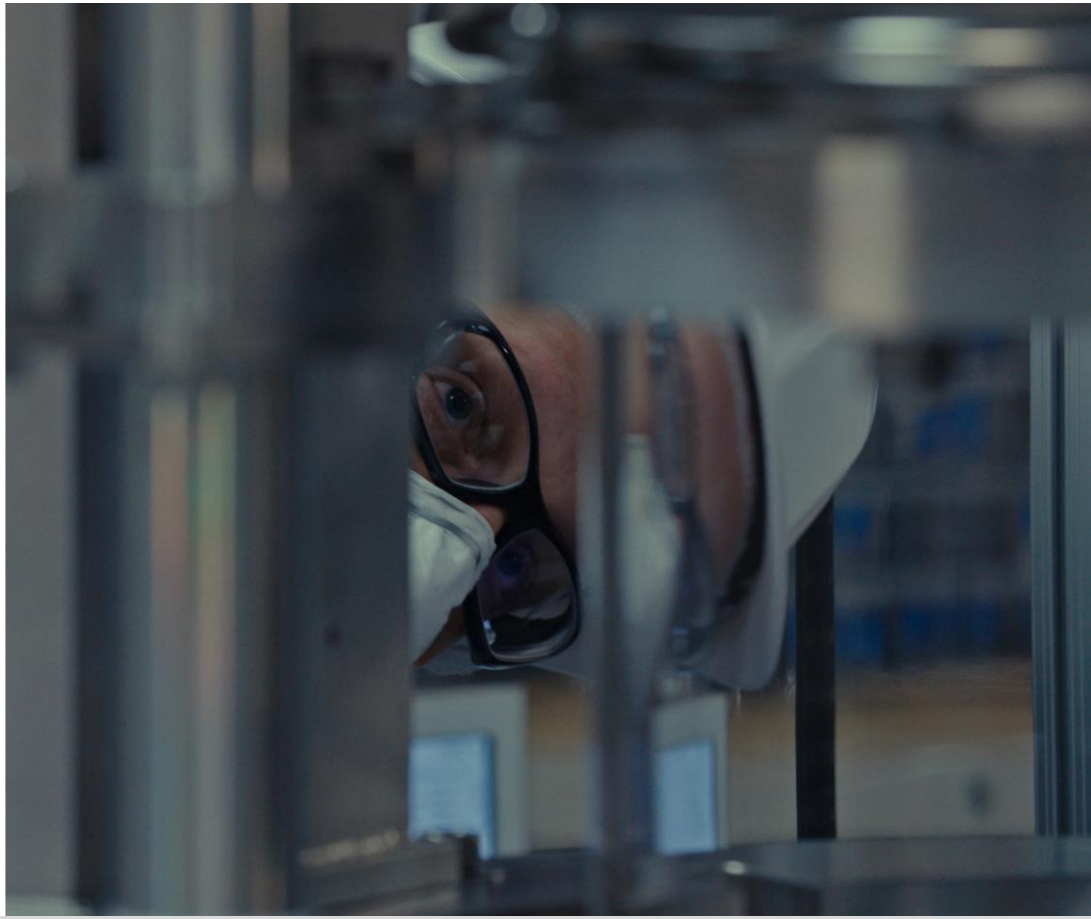
- The inner jar, outer jar, and bellows have been cleaned. We have done test runs for IV assembly.



PICO-500 Status – Upcoming Work

- The Vale mine holding SNOLAB is currently closed for maintenance.
- Jars will be installed in late September, with the IV fully assembled by early October.
- Expect to start commissioning the detector in May 2026.





Summary

- Wide potential for analyses with PICO-40L data, with many analyses in progress at the moment.
- 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.
- Stay tuned for more PICO papers coming soon!

Summary

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Thank You

PICO

Saha Institute of Nuclear Physics, Calcutta
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Northwestern University
C. E. Dahl

Northeastern Illinois University
O. Harris

Queen's University
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R. Neilson

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D. Priya, S. Priya, Y. Yan

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Fermilab
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České vysoké učení technické v Praze
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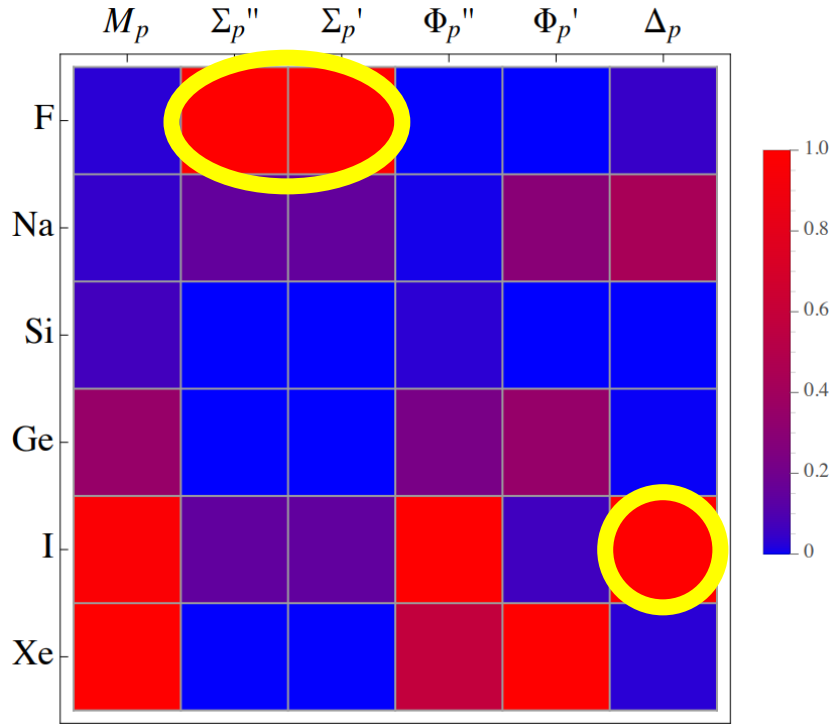
Indiana University South Bend
E. Behnke, C. Cripe, I. Levine

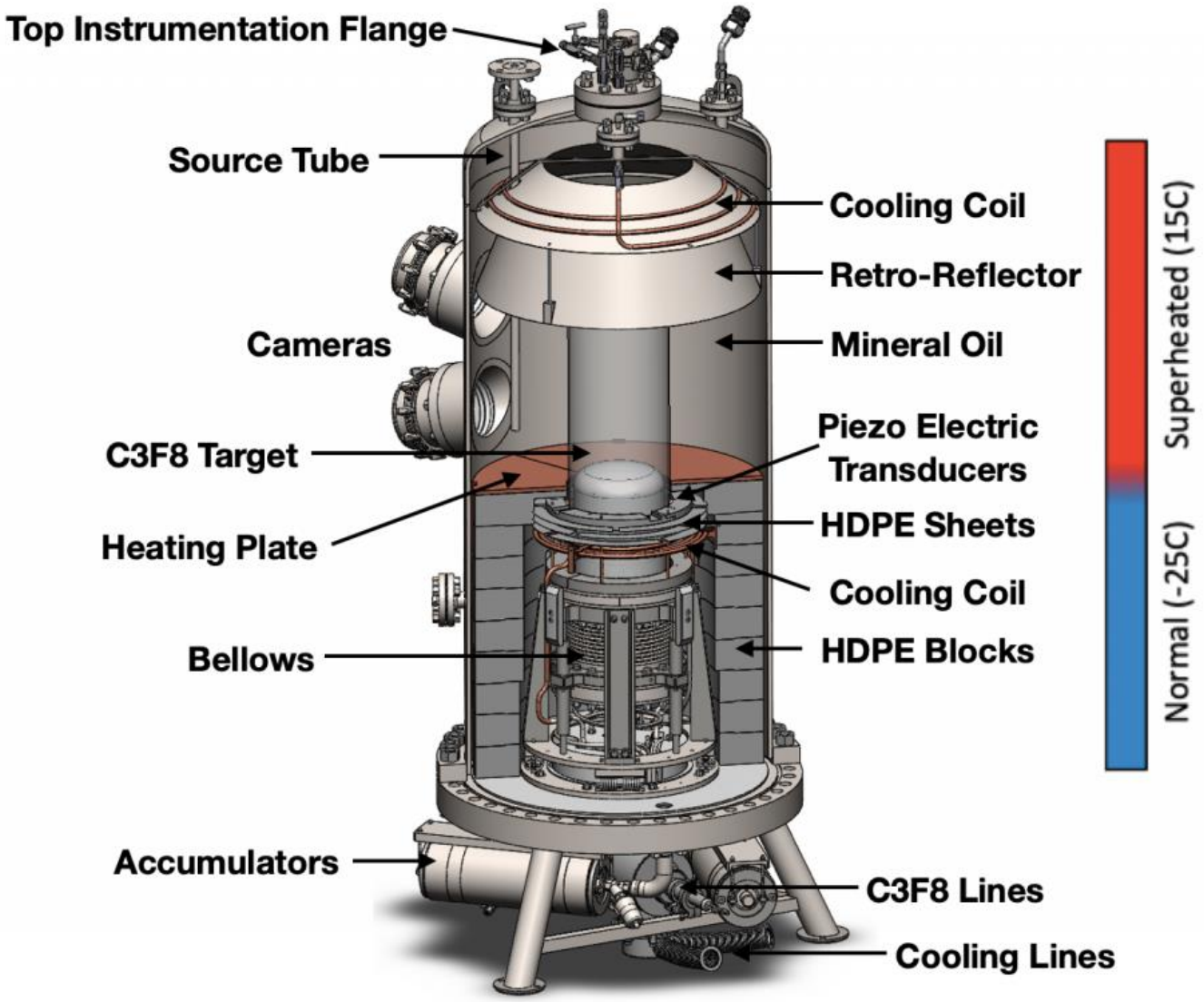
Kavli Institute for Cosmological Physics at The University of Chicago
J. I. Collar, M. Tripathi

PICO Bubble Chambers

- Search for spin-dependent WIMP dark matter.
- Filled with C_3F_8 for ^{19}F sensitivity to proton spin.
- Active liquid can be changed.
- 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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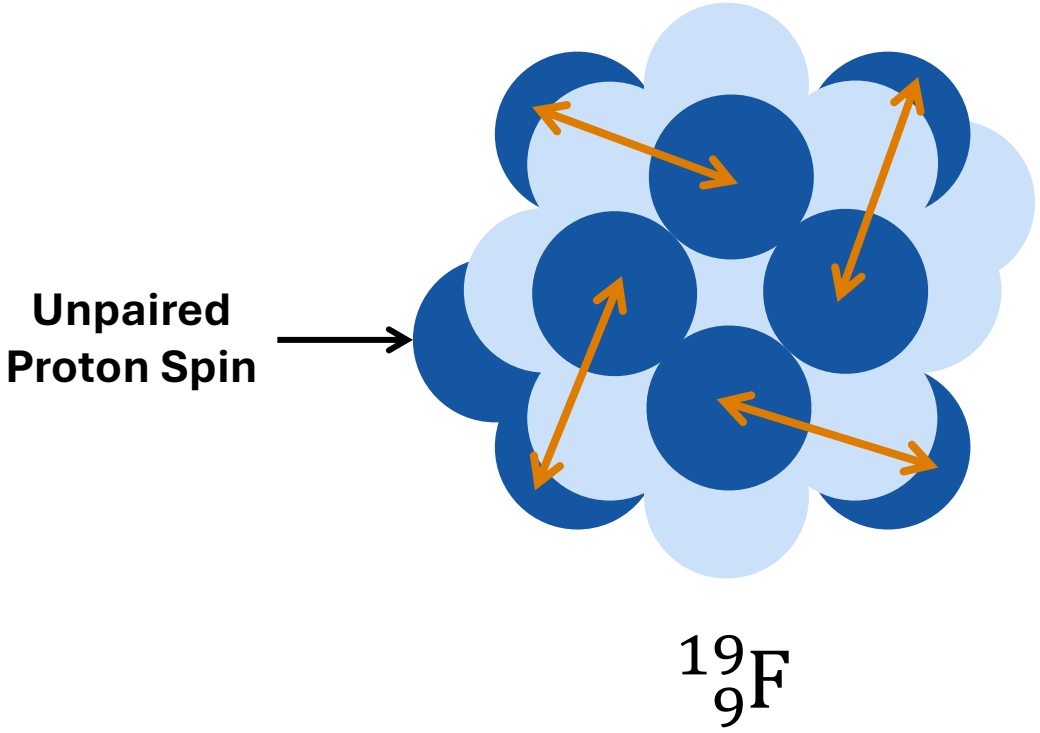

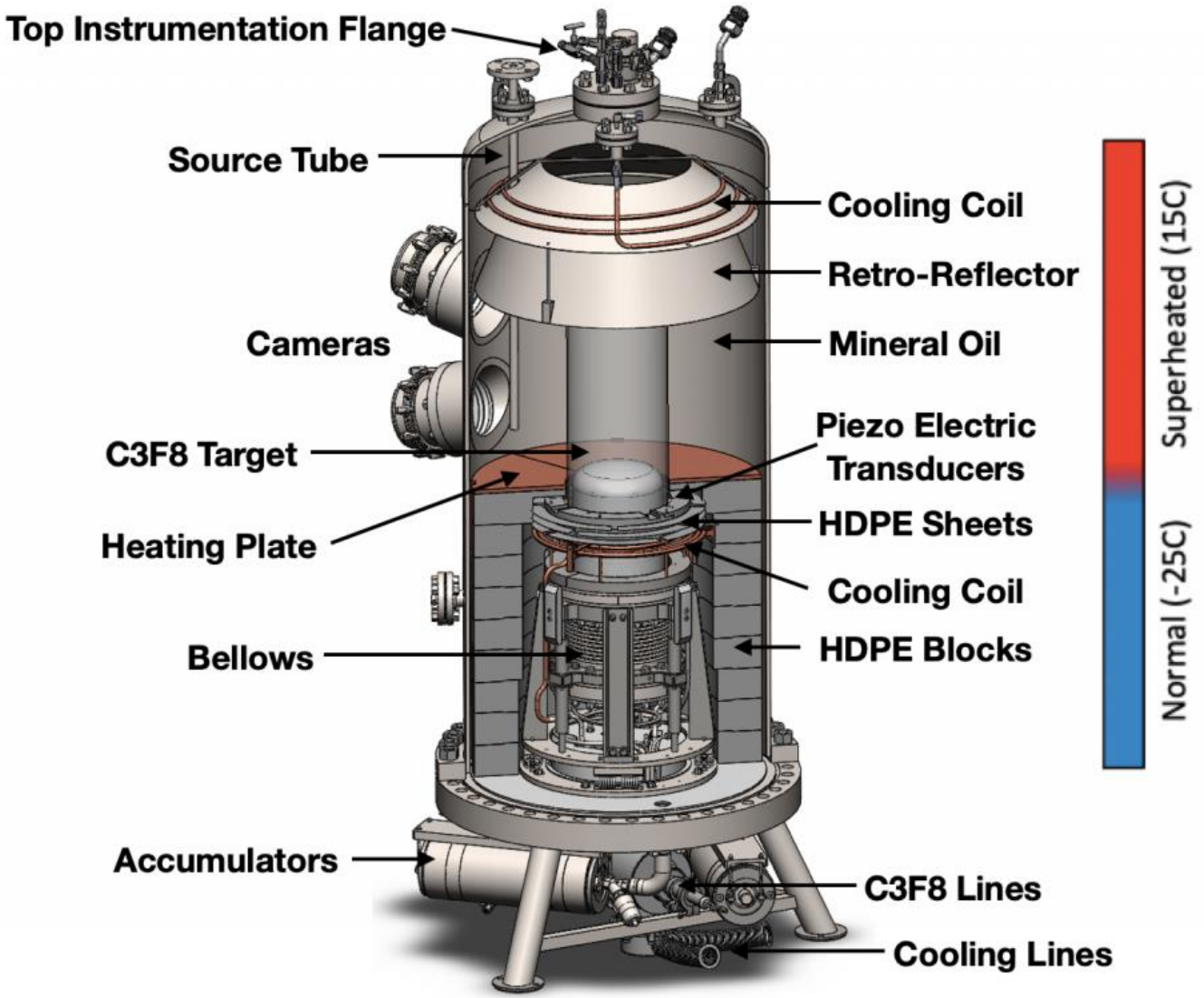

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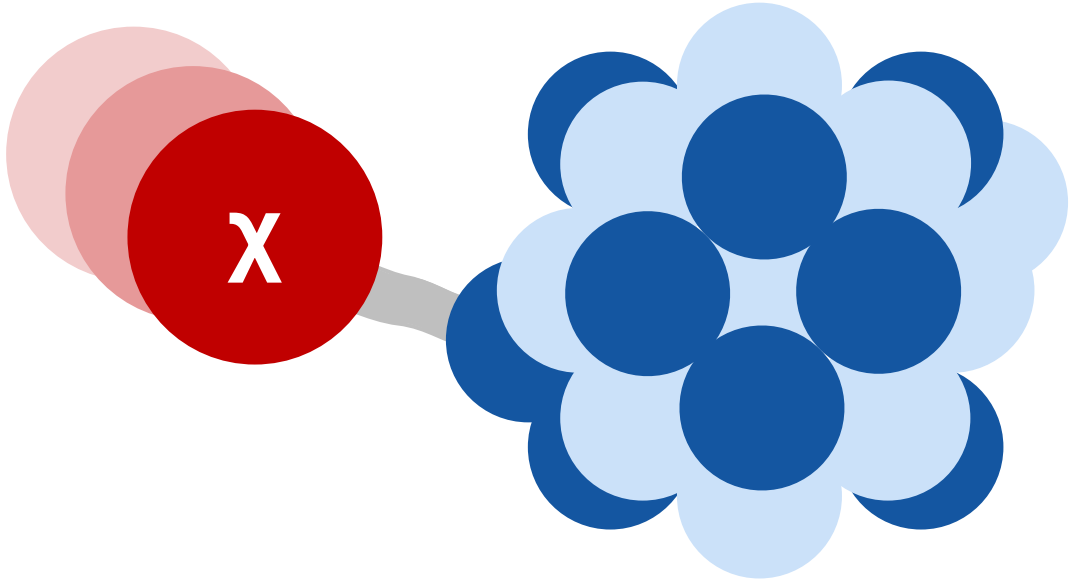
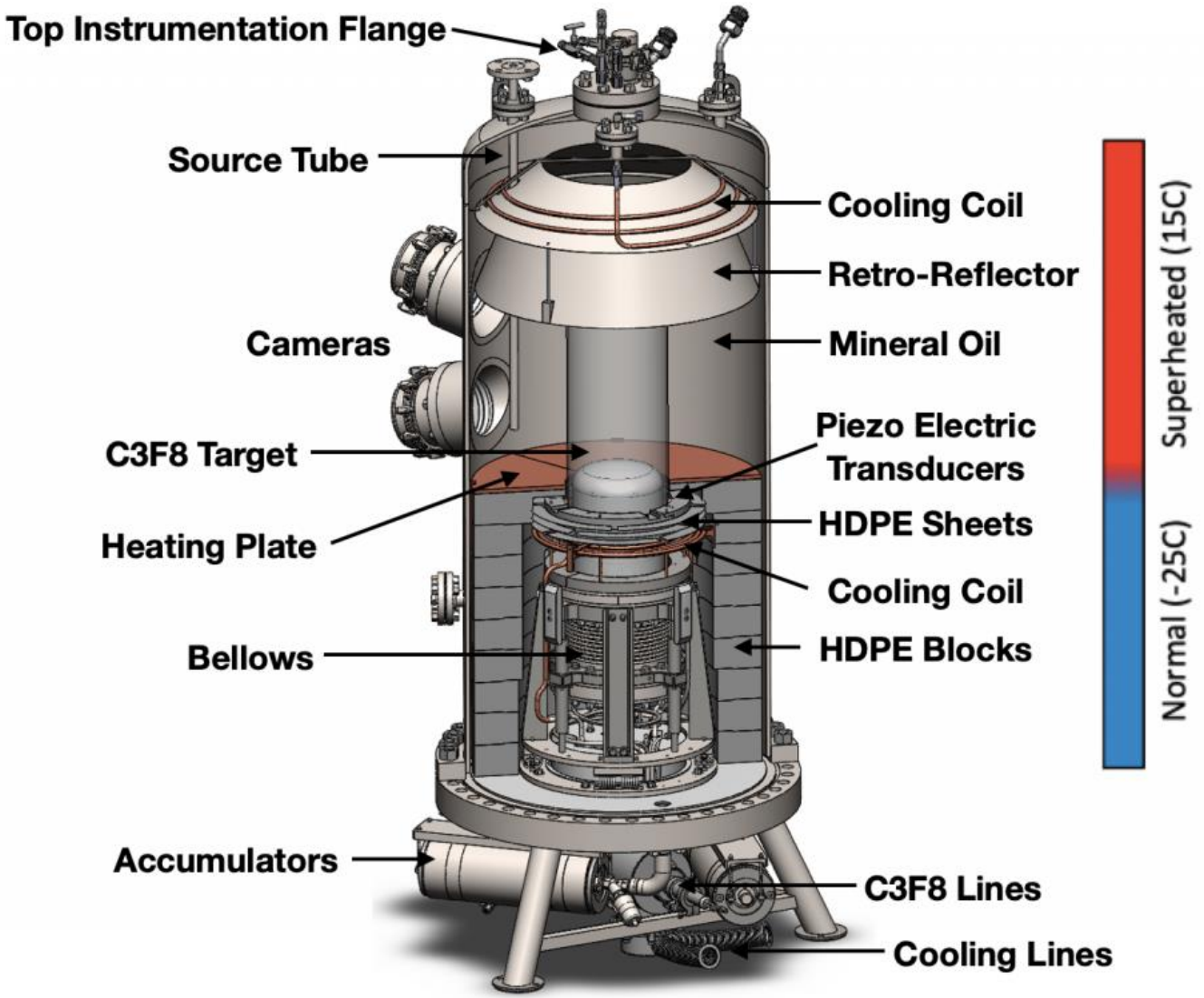


$^{19}_{9}\mathrm{F}$

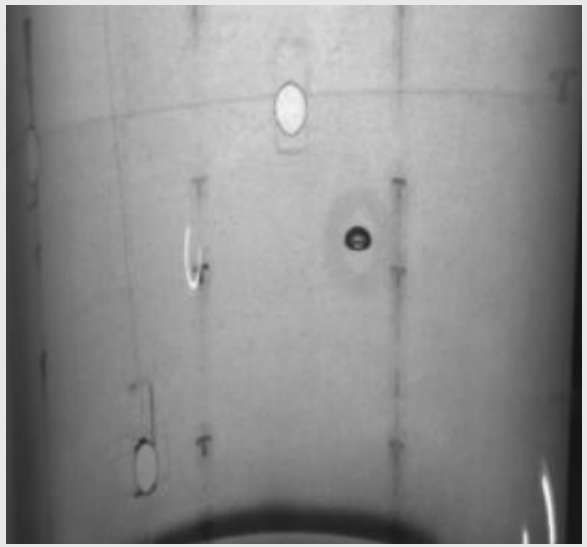


Backgrounds

Nuclear Recoils

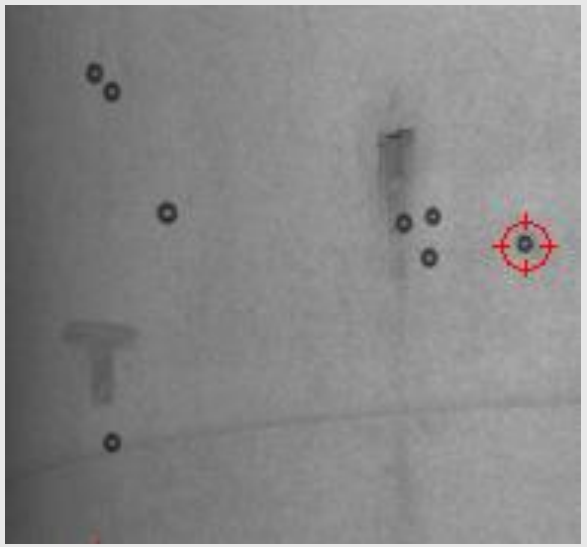
Alpha Particles

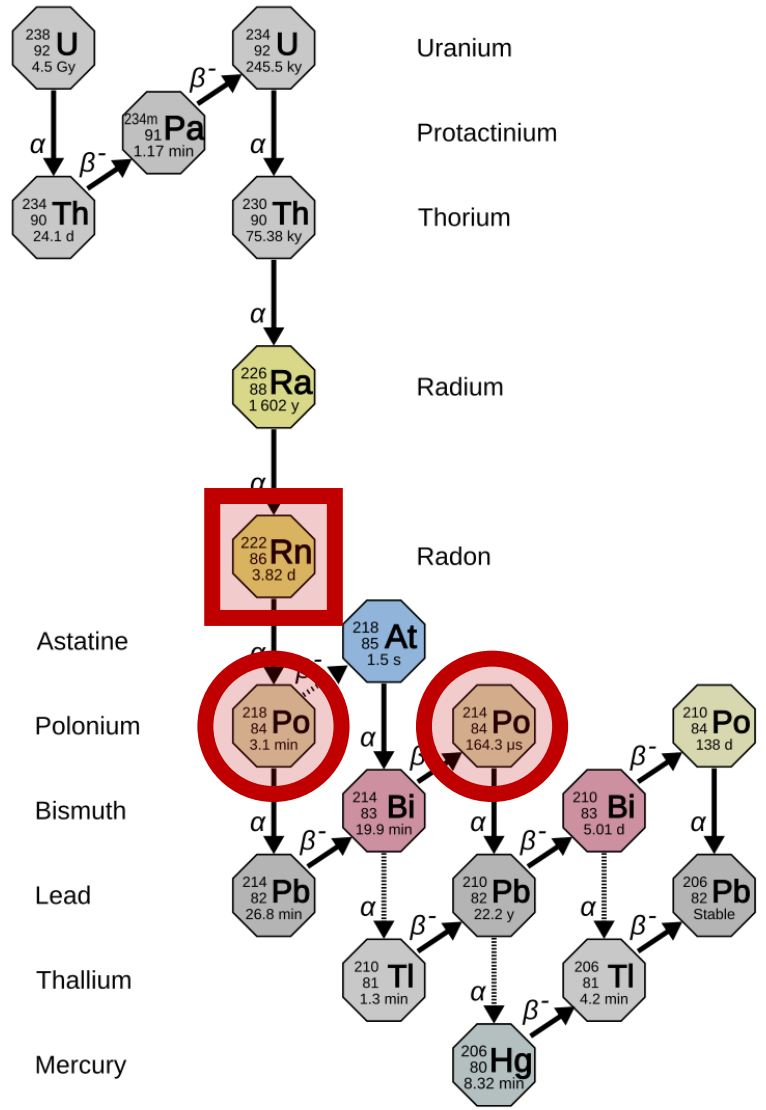
- Internal background. From ^{222}Rn and ^{220}Rn from ^{238}U and ^{232}Th decay chains.
- Single bubbles.



Neutrons

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





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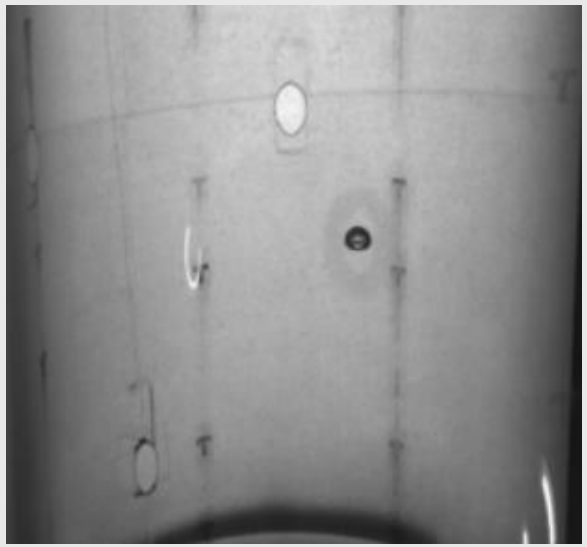

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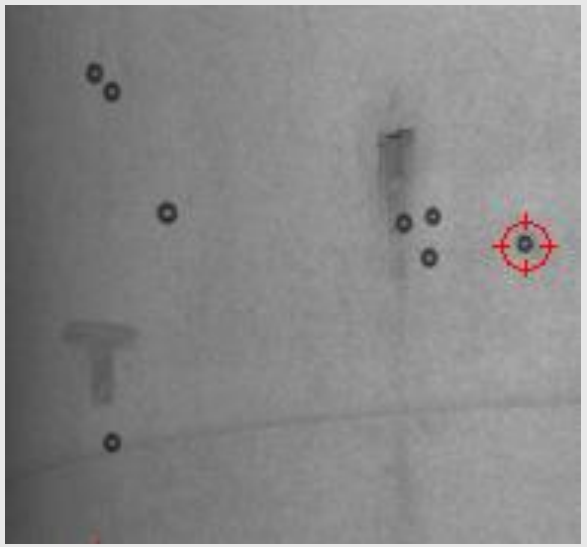

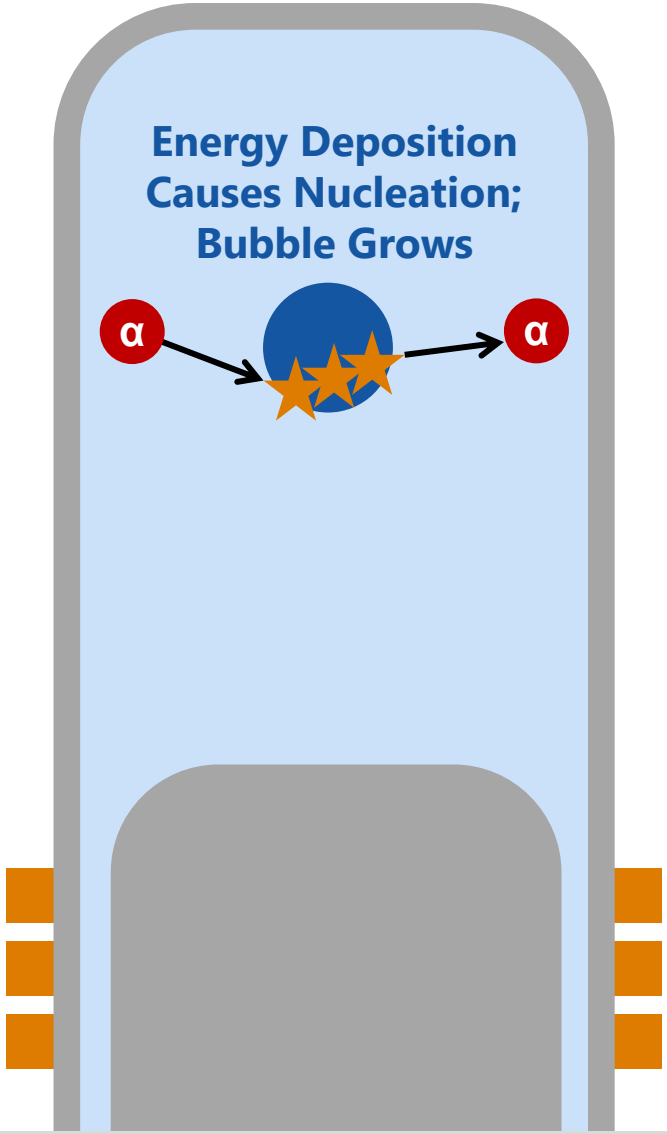

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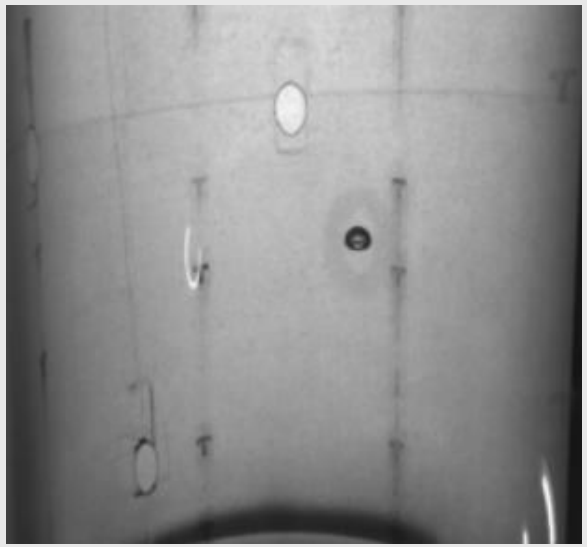

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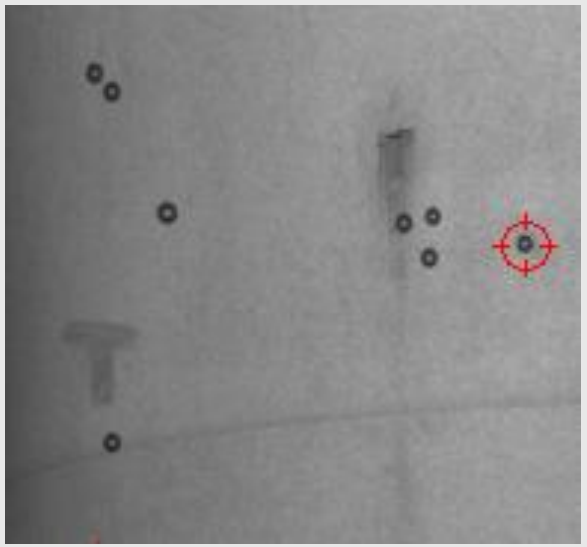

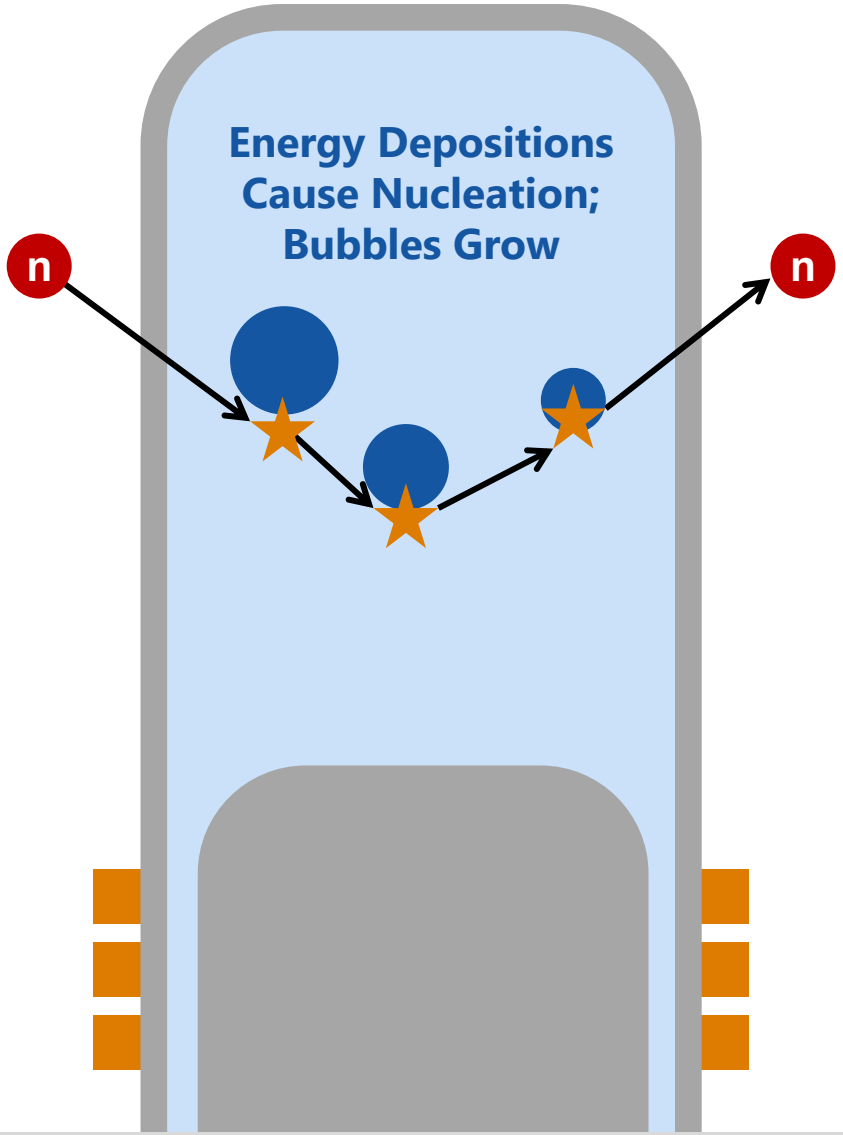

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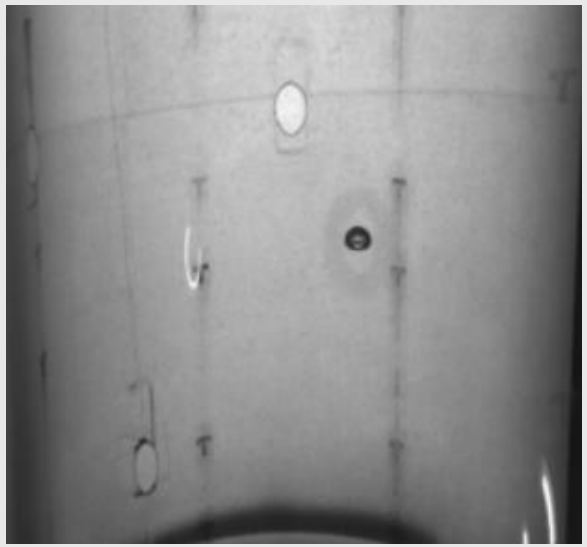

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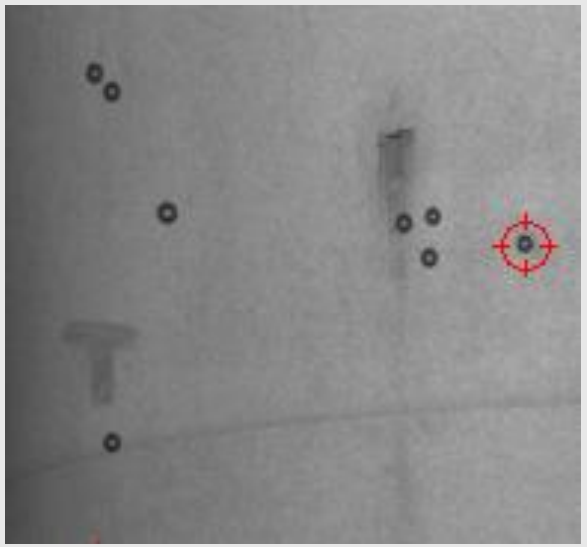
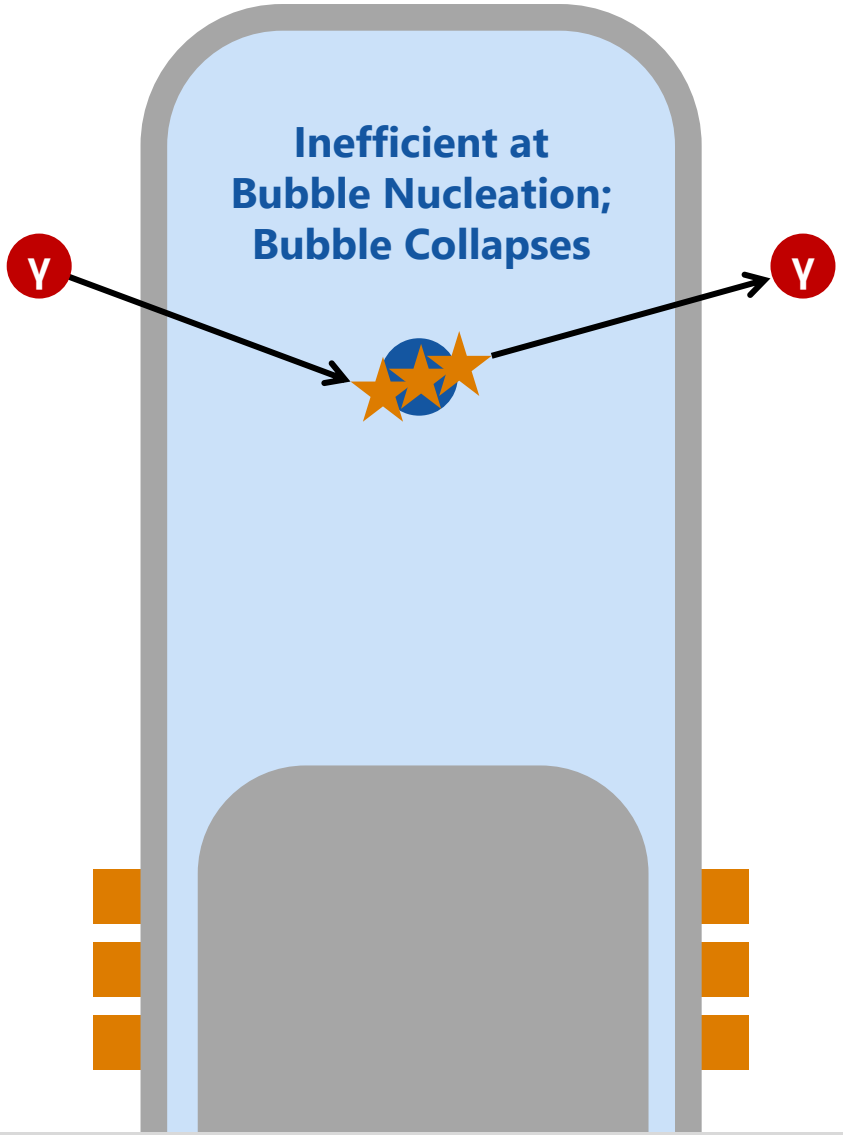




PICO-40L Timeline and Current Status

2020 Assembly finished, commissioning began.

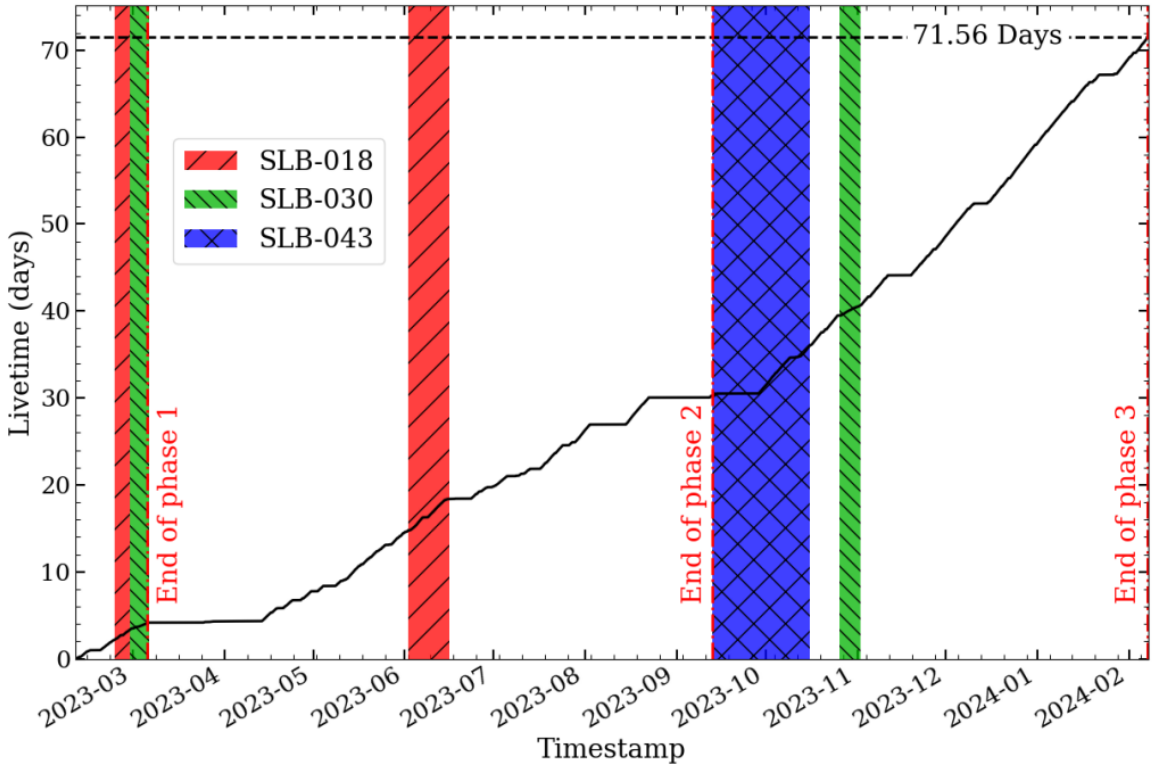
2021 Found leak inside detector, disassembled.

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