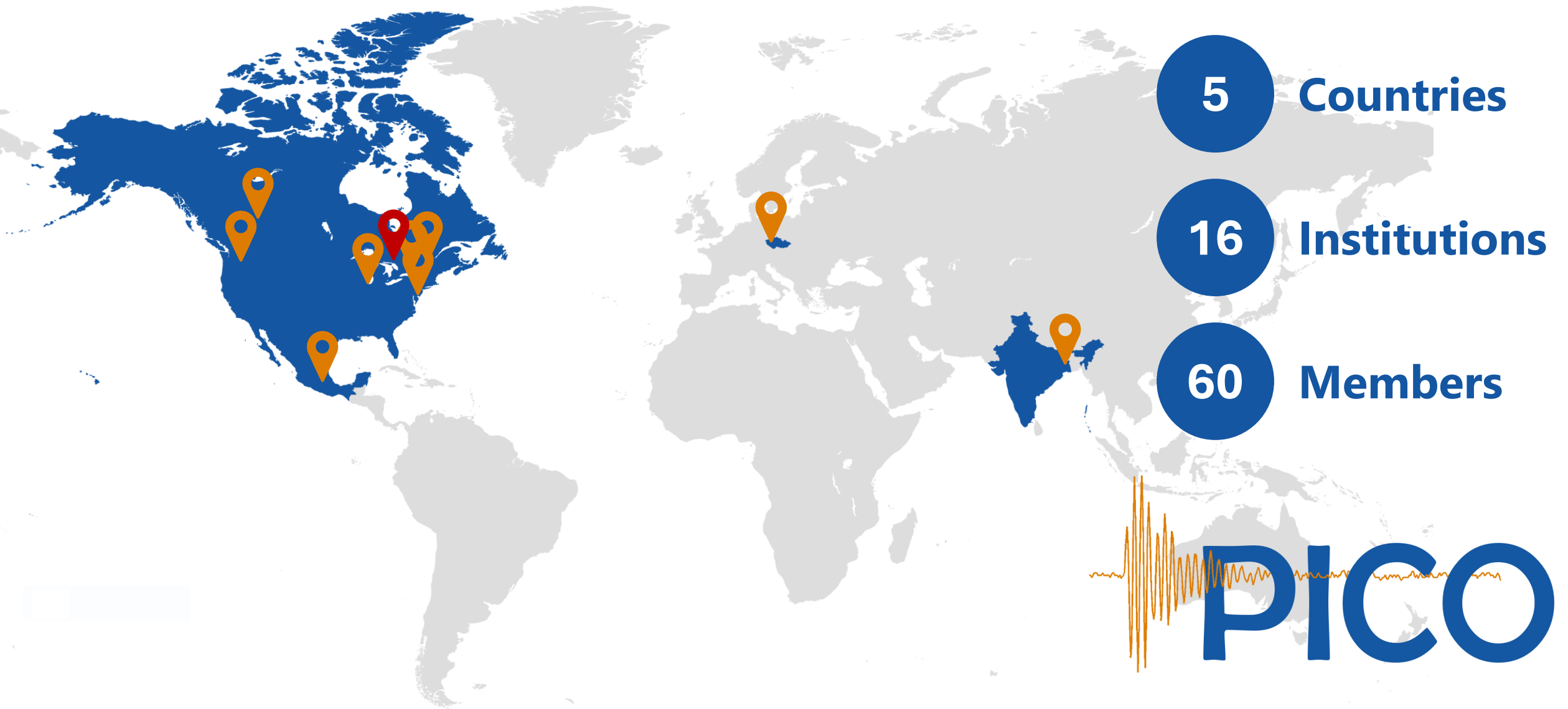


The PICO-40L Dark Matter Search

William Woodley
University of Alberta

The PICO Collaboration



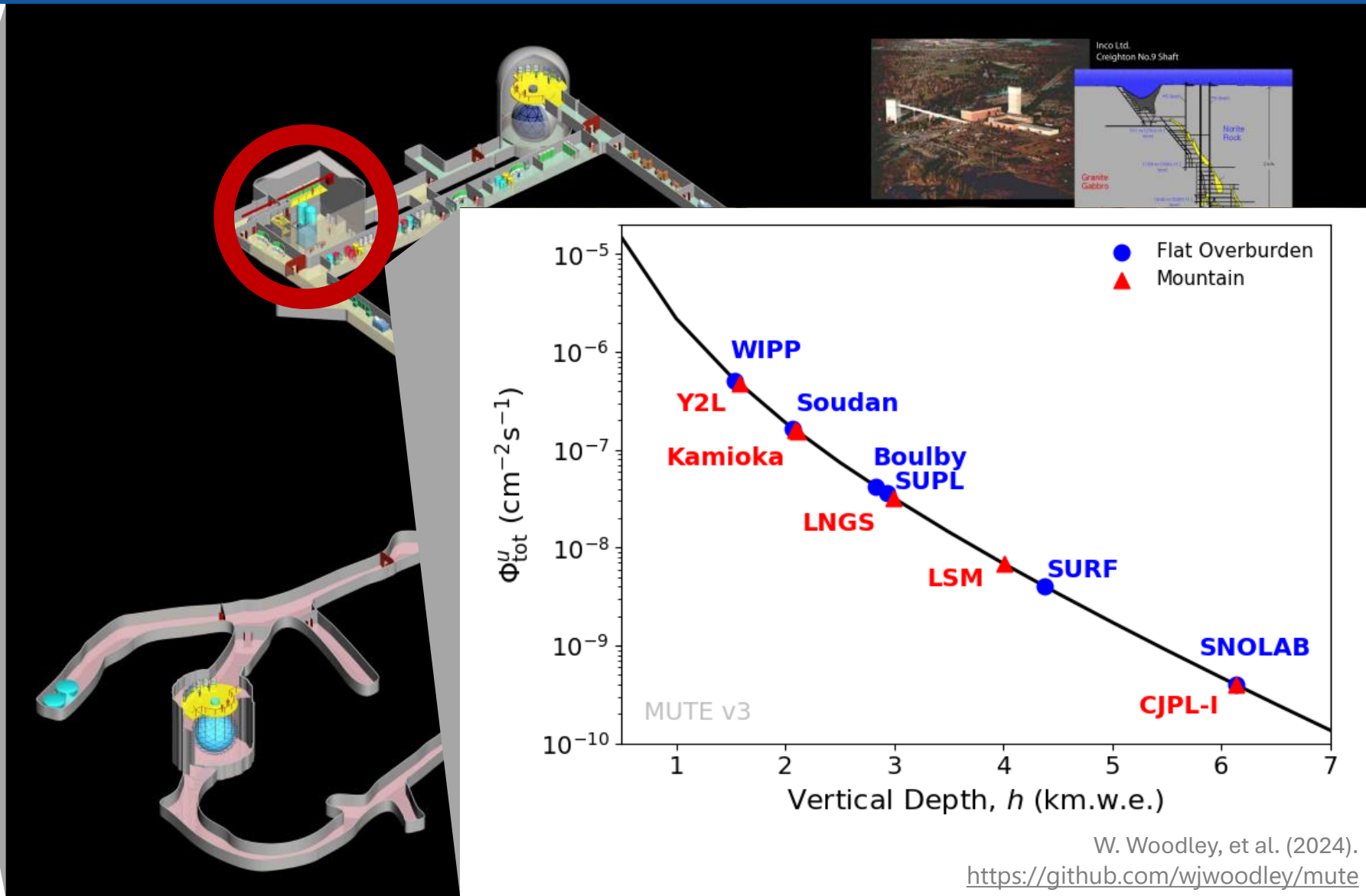
The PICO Collaboration



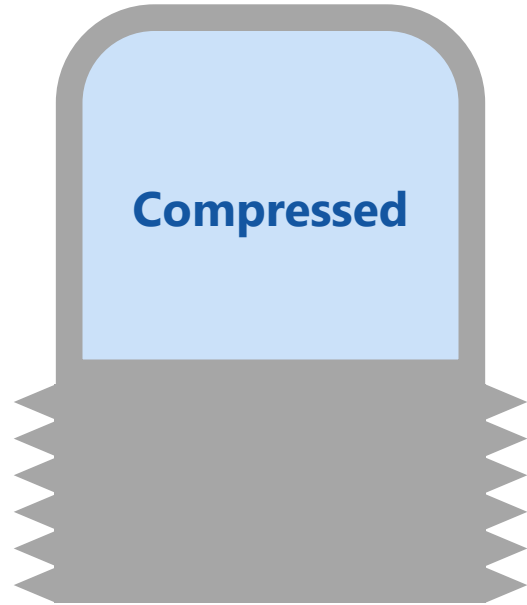
The PICO Collaboration



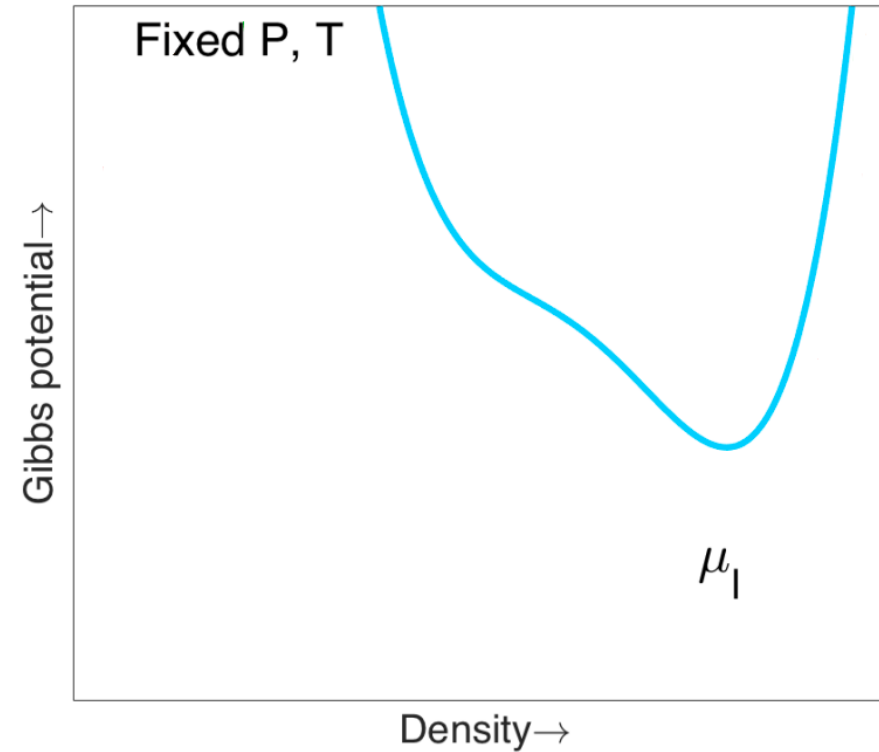
The PICO Collaboration



Bubble Chambers

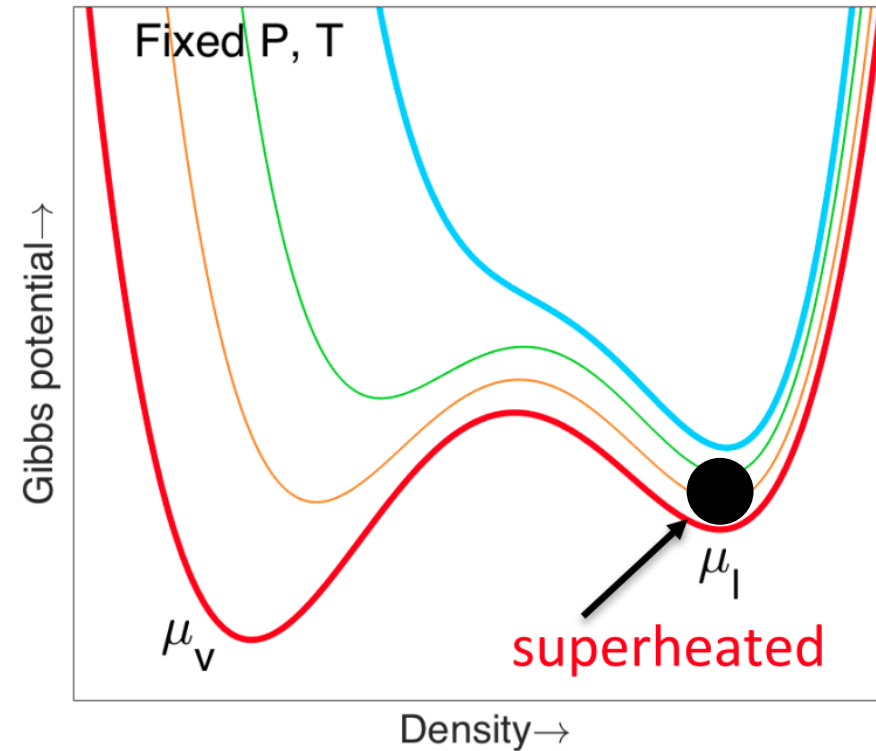
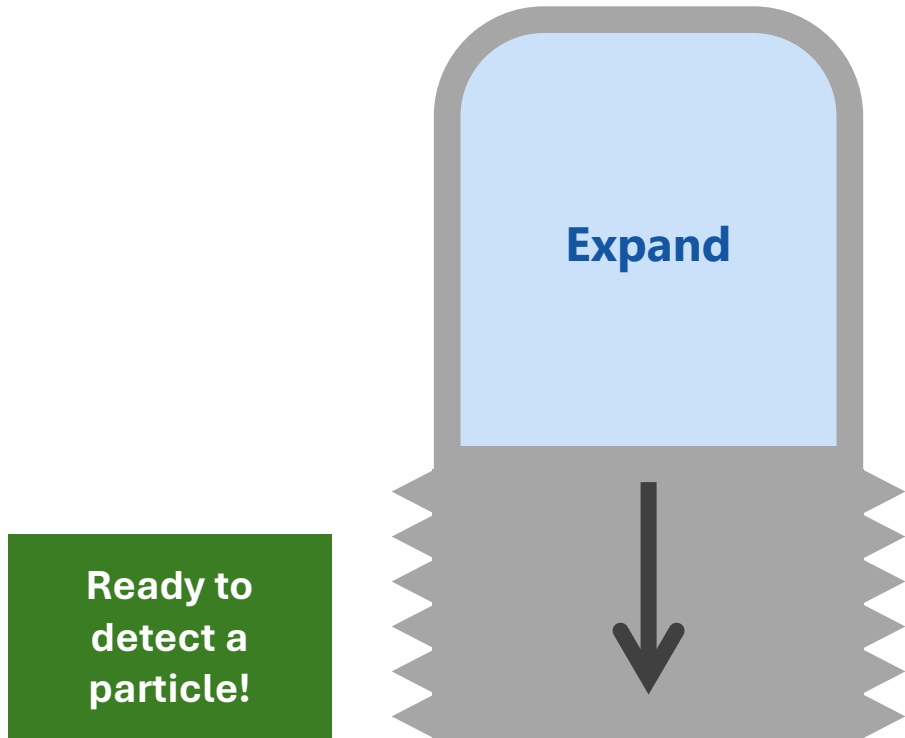


Not ready to
detect a
particle!



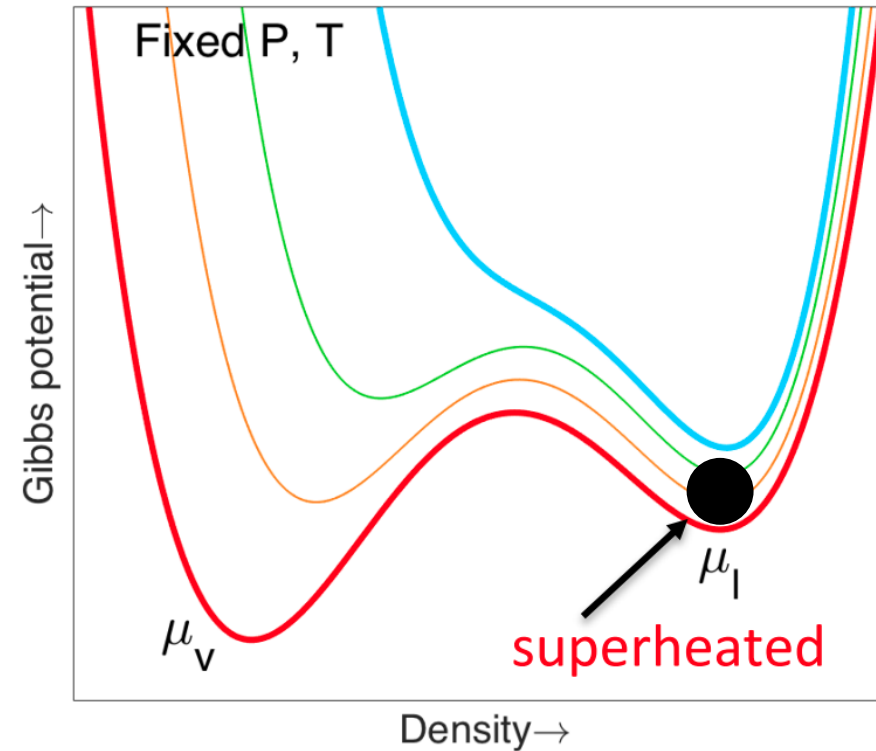
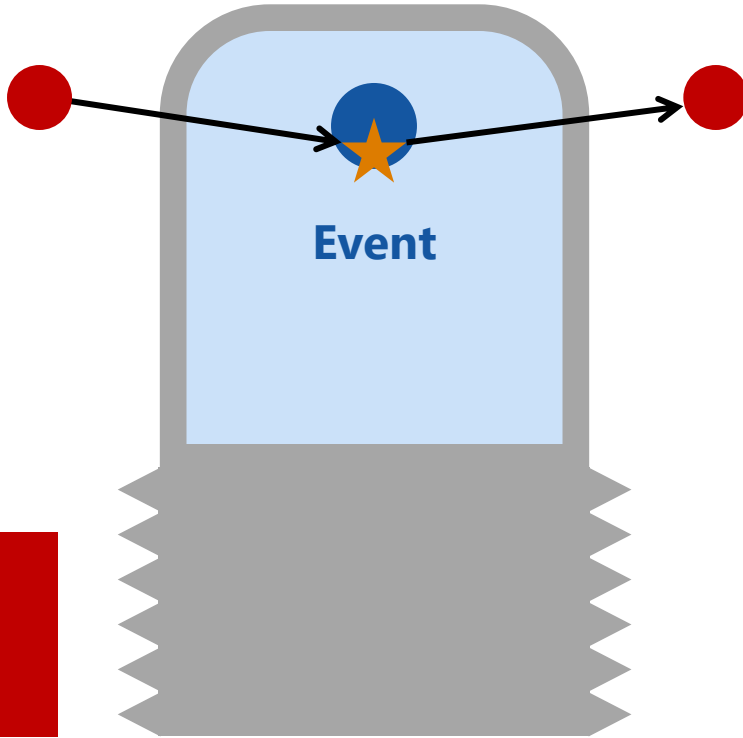
$$Q_{\text{Seitz}} = 4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) + \frac{4\pi r_c^3}{3} \rho_b (h_b - h_l) - \frac{4\pi r_c^3}{3} (P_b - P_l)$$

Bubble Chambers



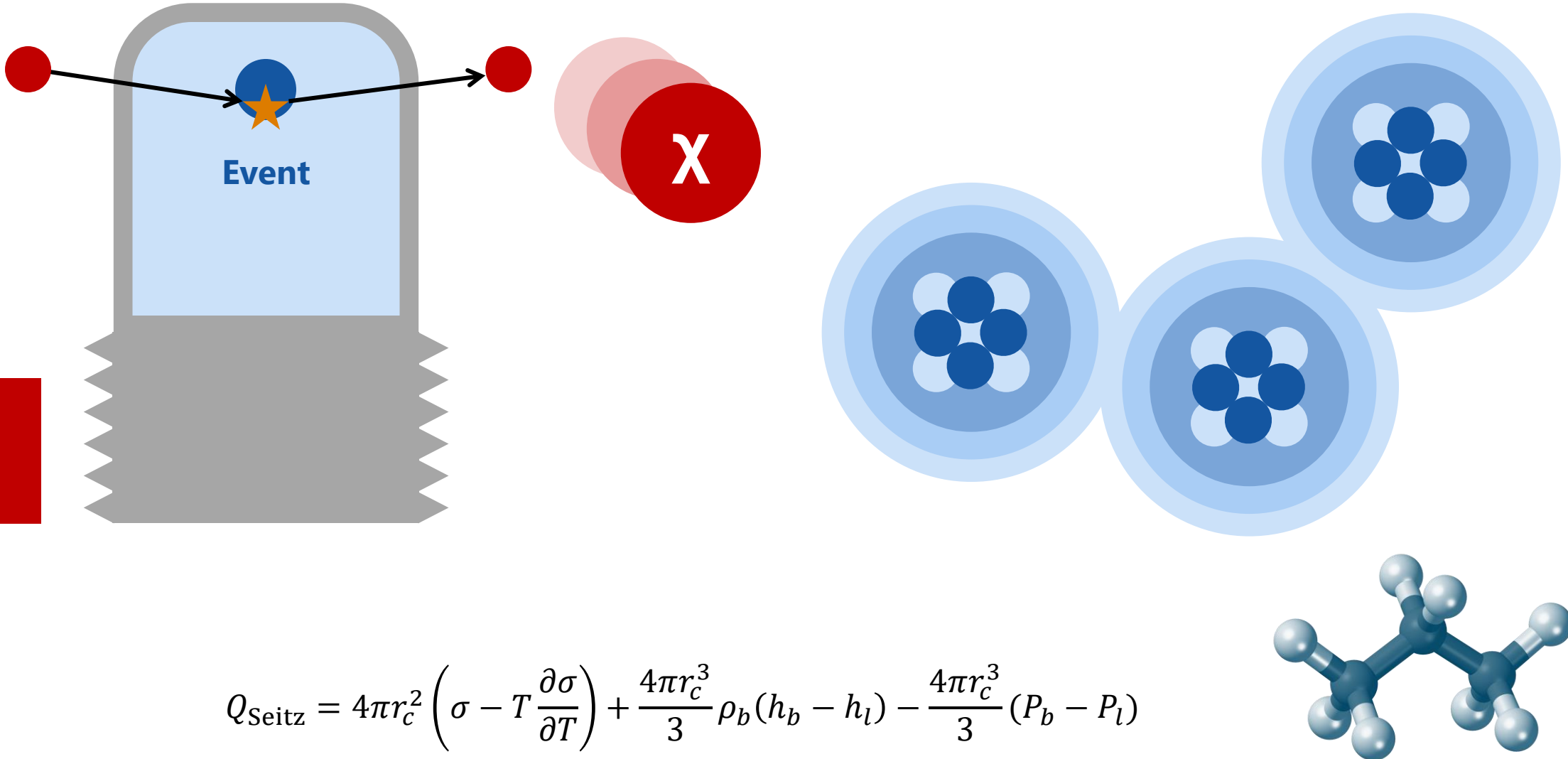
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Bubble Chambers

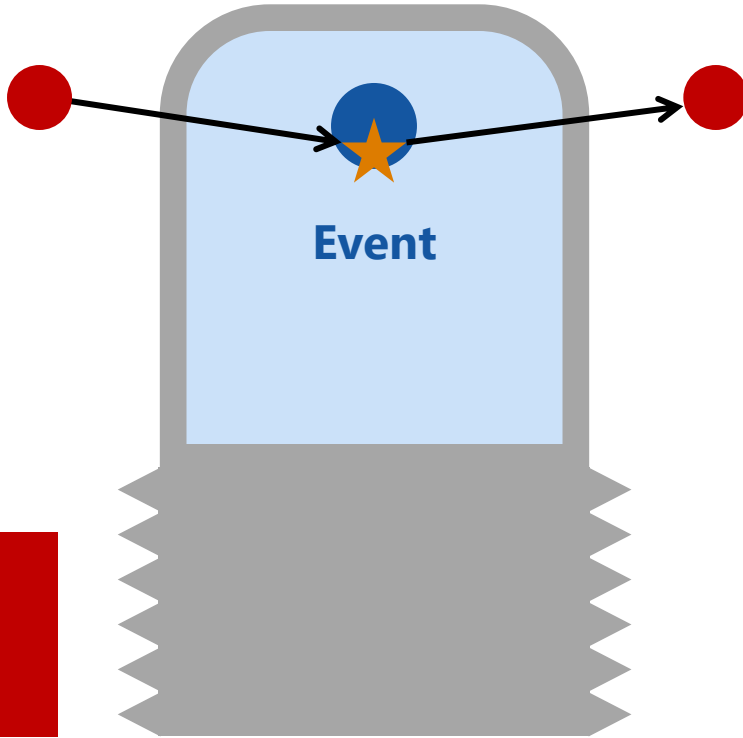


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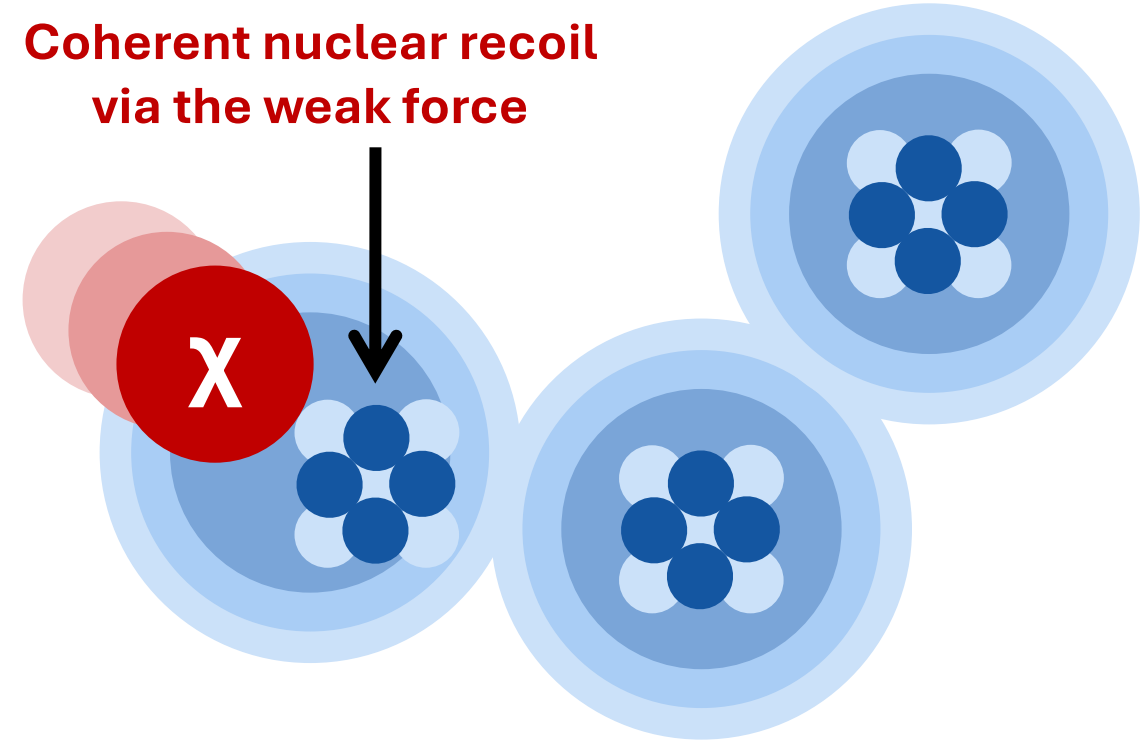
Bubble Chambers



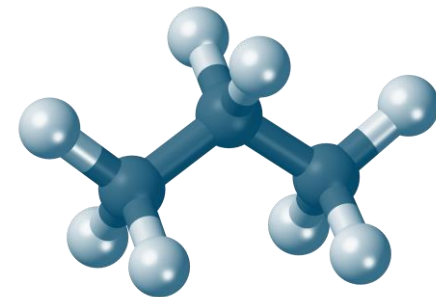
Bubble Chambers



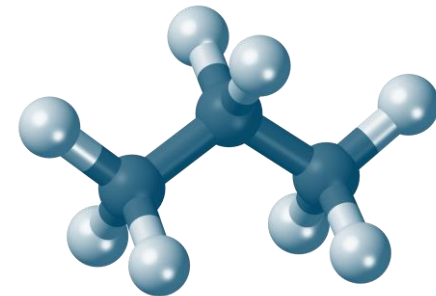
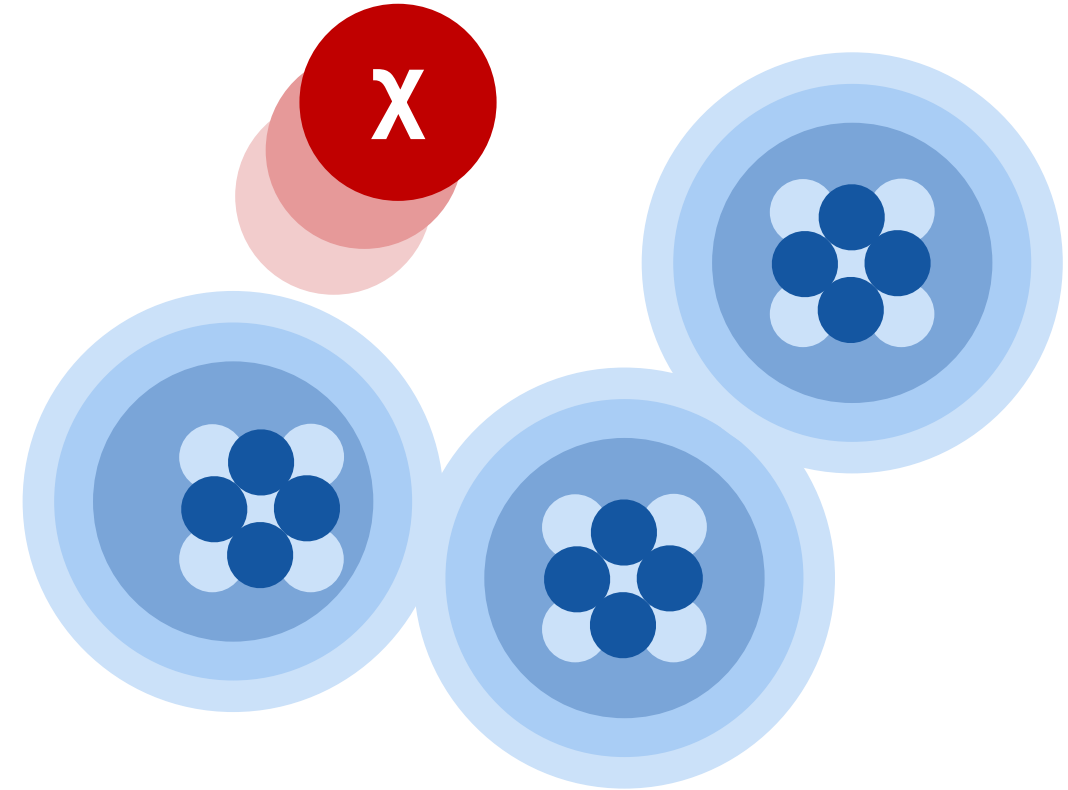
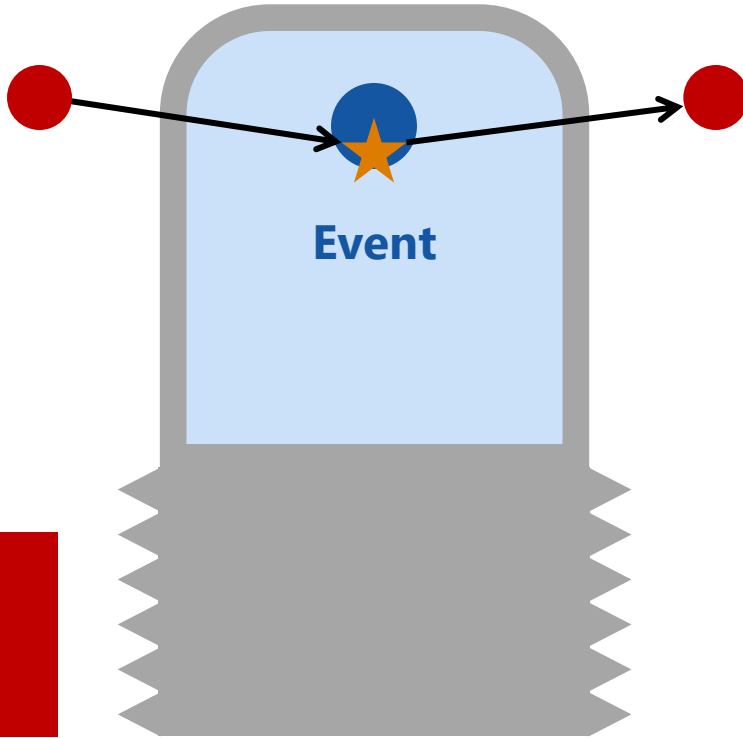
Coherent nuclear recoil
via the weak force



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

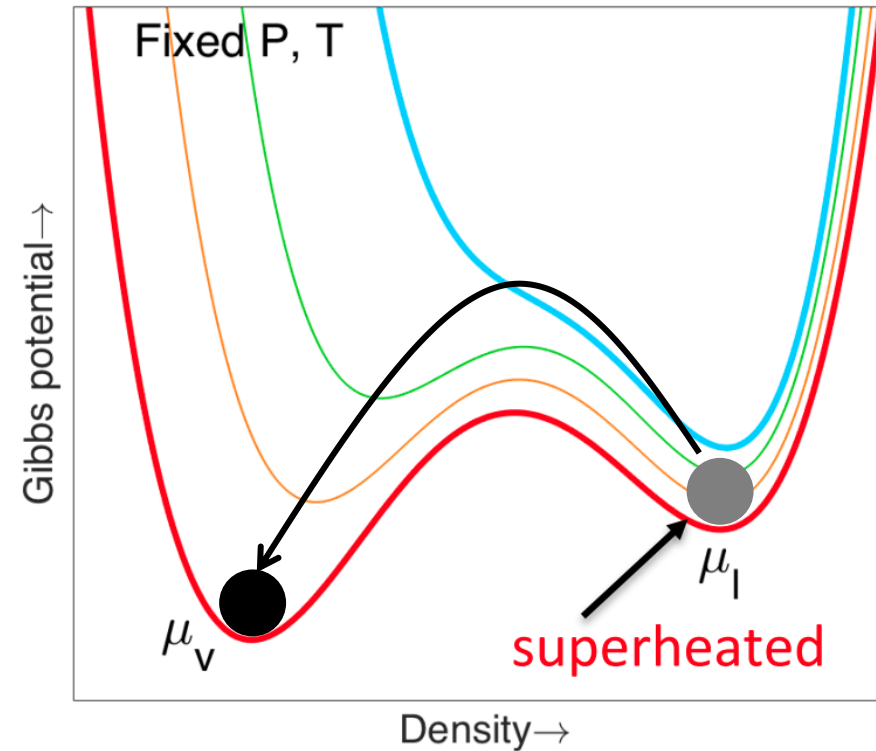
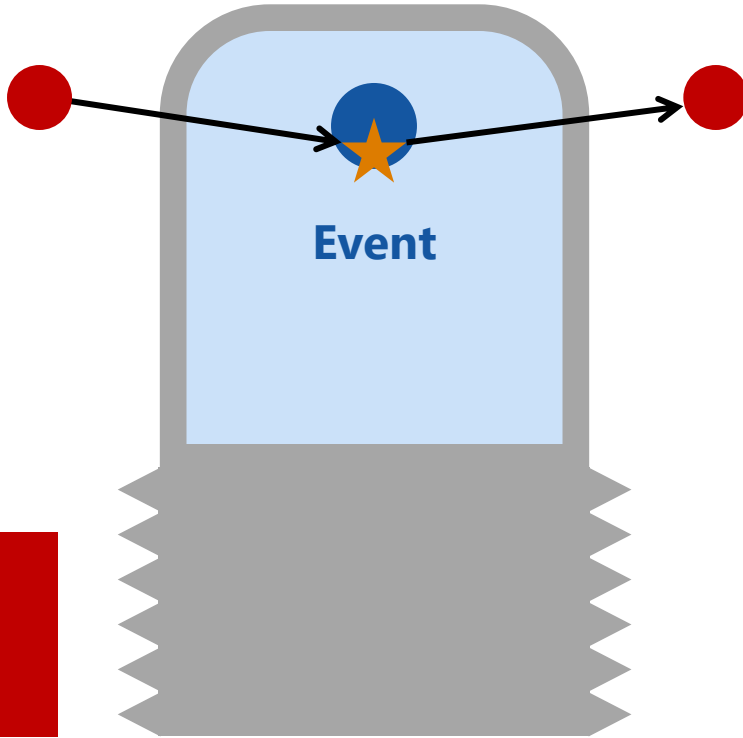


Bubble Chambers



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

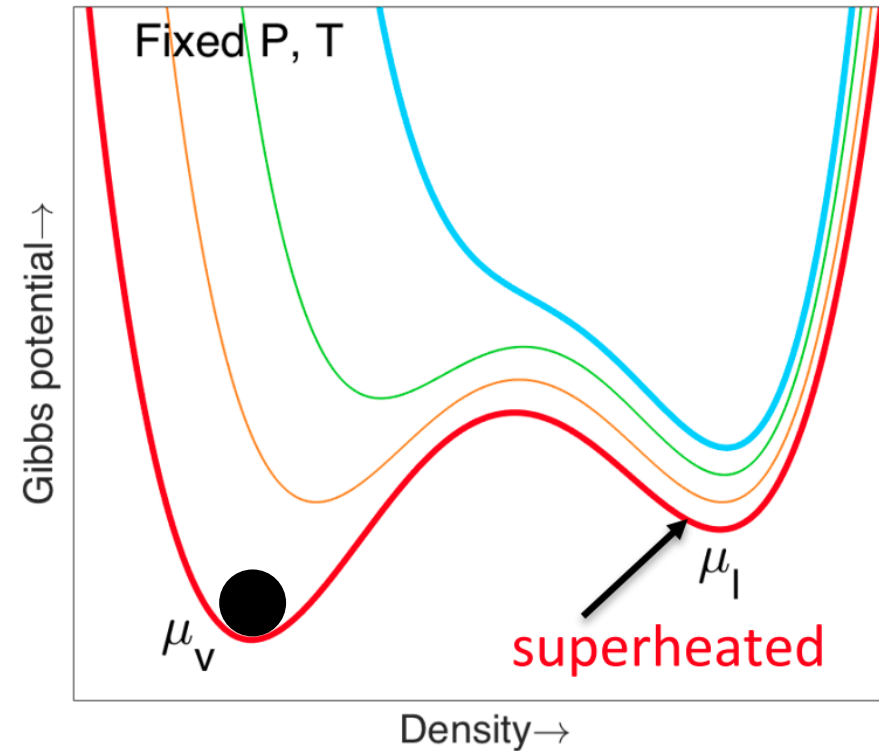
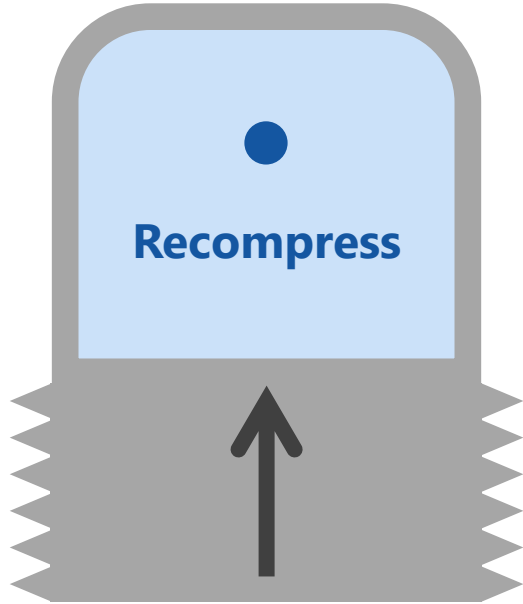
Bubble Chambers



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

Bubble Chambers

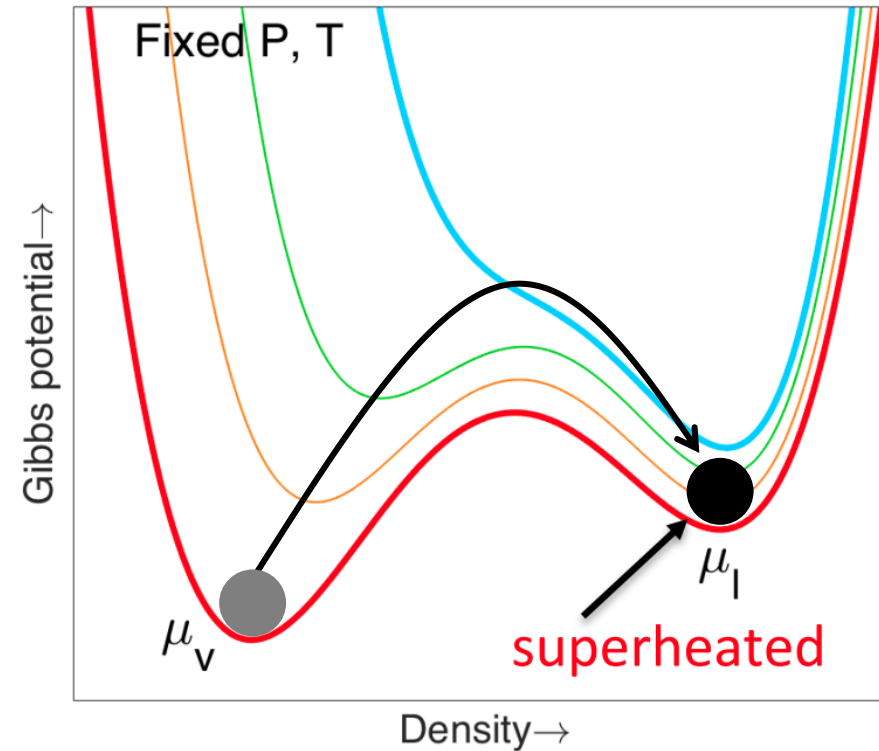
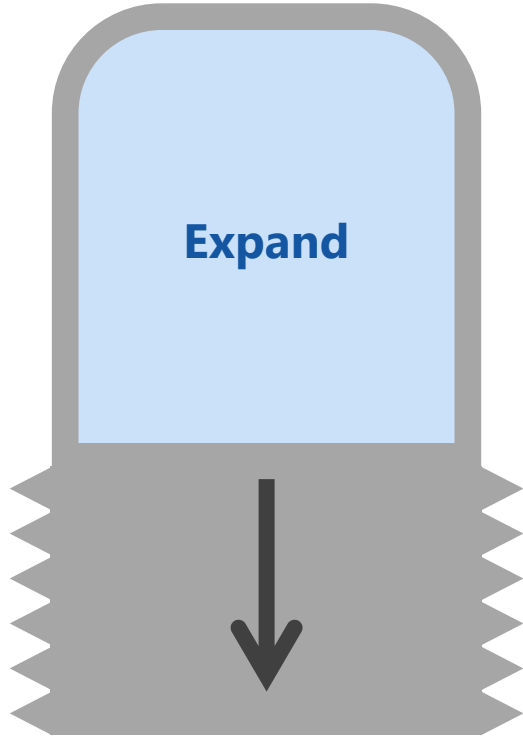
Not ready to
detect a
particle!



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

Bubble Chambers

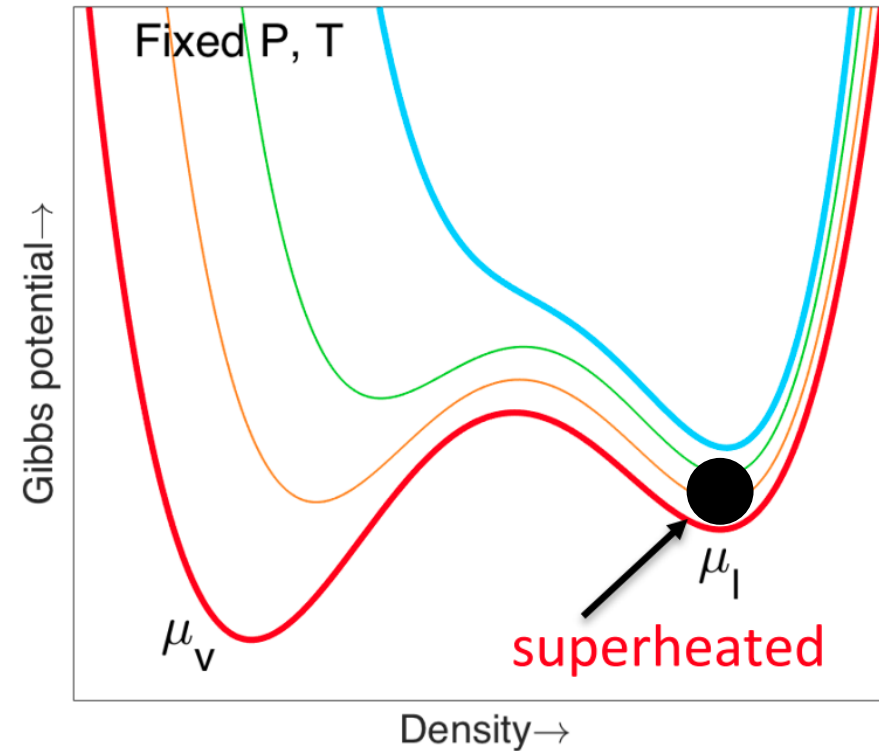
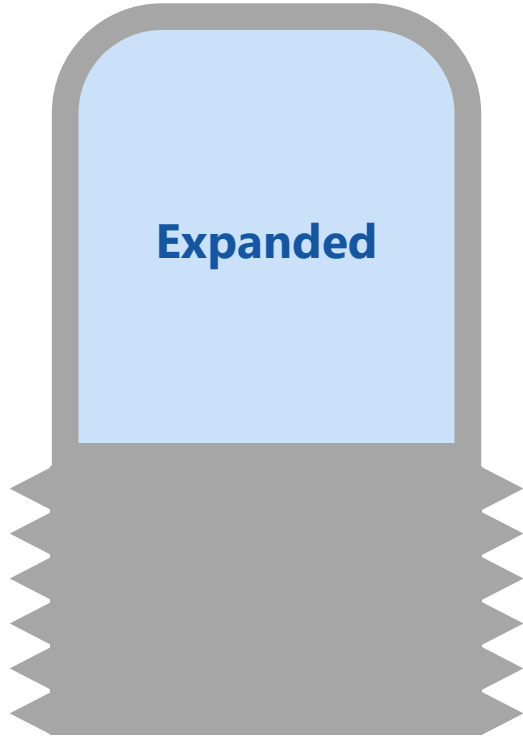
Not ready to
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particle!



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

Bubble Chambers

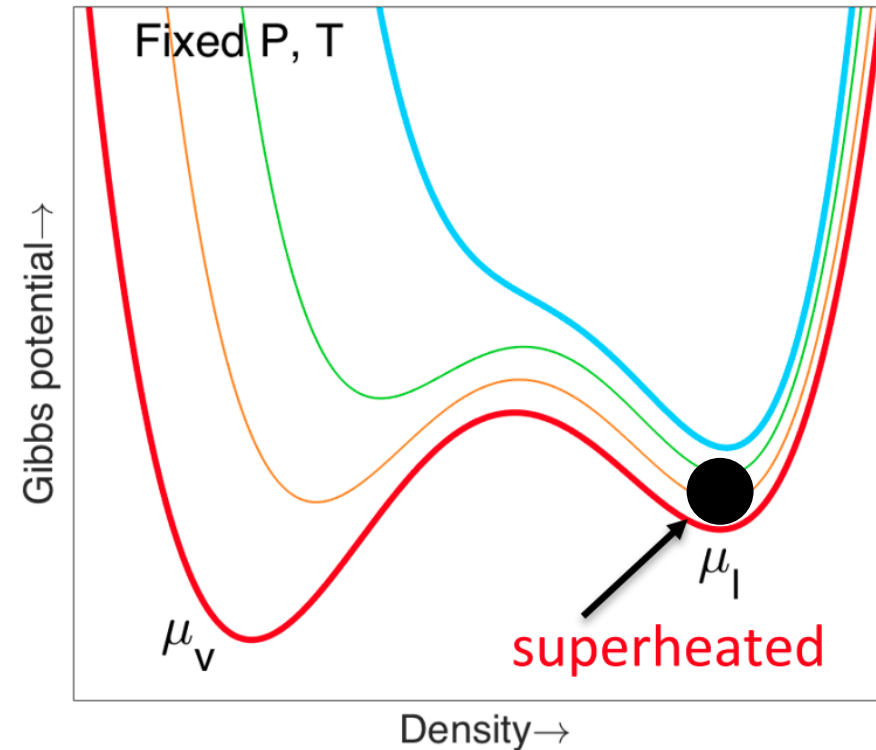
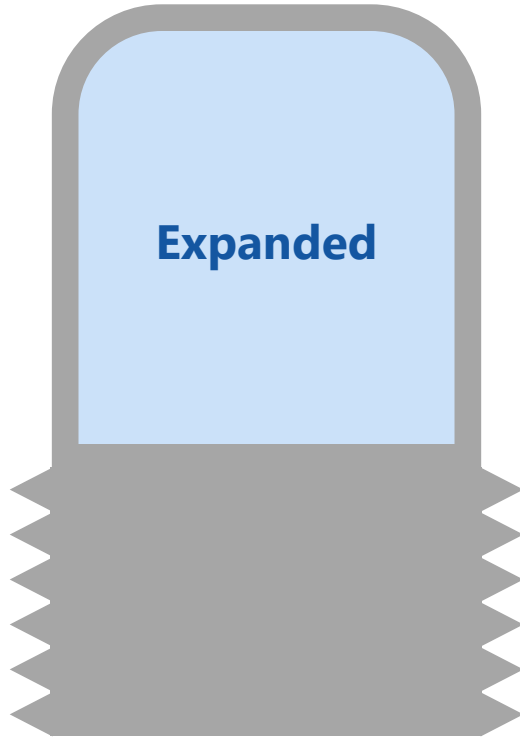
Ready to
detect a
particle!



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

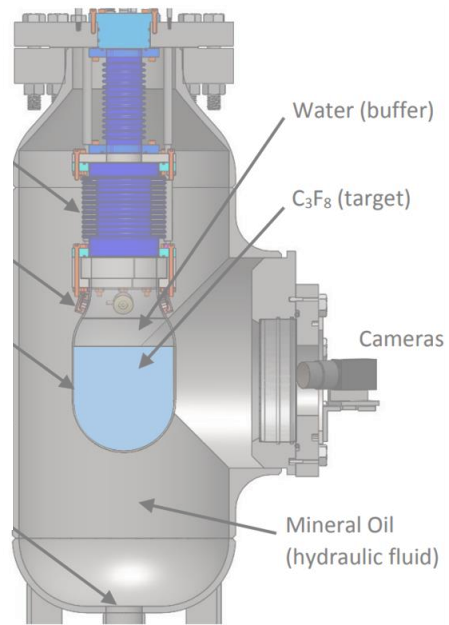
Bubble Chambers

Ready to
detect a
particle!



$$Q_{\text{Seitz}} = \underbrace{4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right)}_{\text{Surface Tension}} + \underbrace{\frac{4\pi r_c^3}{3} \rho_b (h_b - h_l)}_{\text{Phase Transition}} - \underbrace{\frac{4\pi r_c^3}{3} (P_b - P_l)}_{\text{Expansion of Vapour}}$$

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



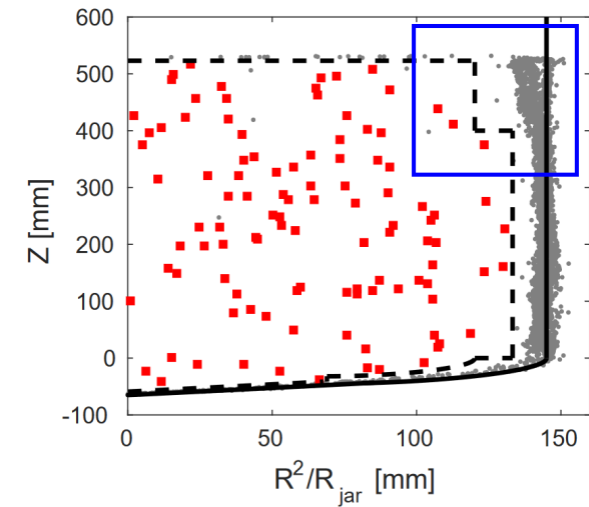
PICO-40L
35 L of C_3F_8
2019–Present



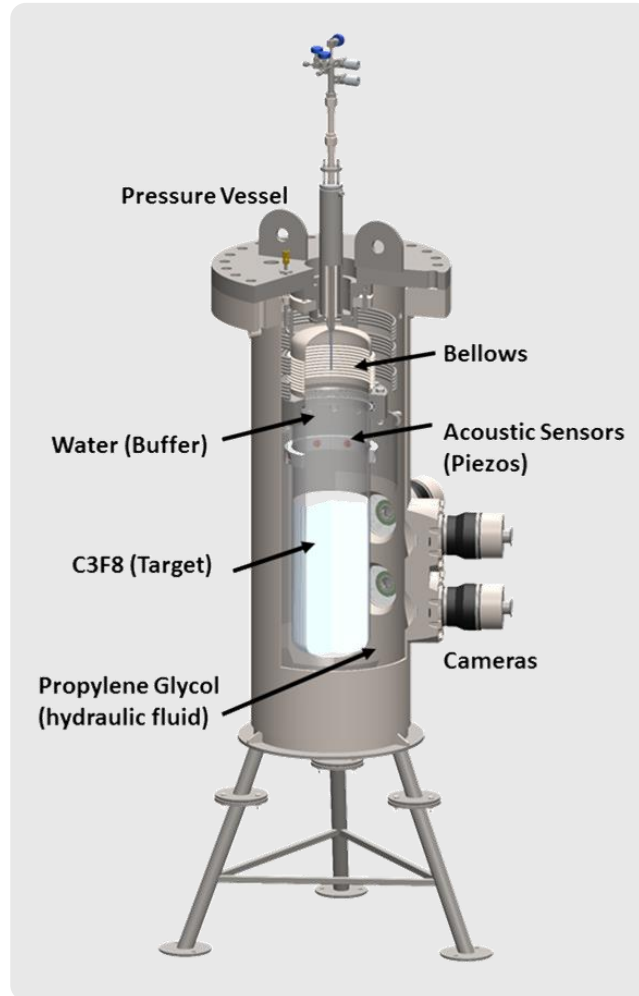
PICO-500
260 L of C_3F_8
Proj. 2026

Right-Side-up Design

Upside Down



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



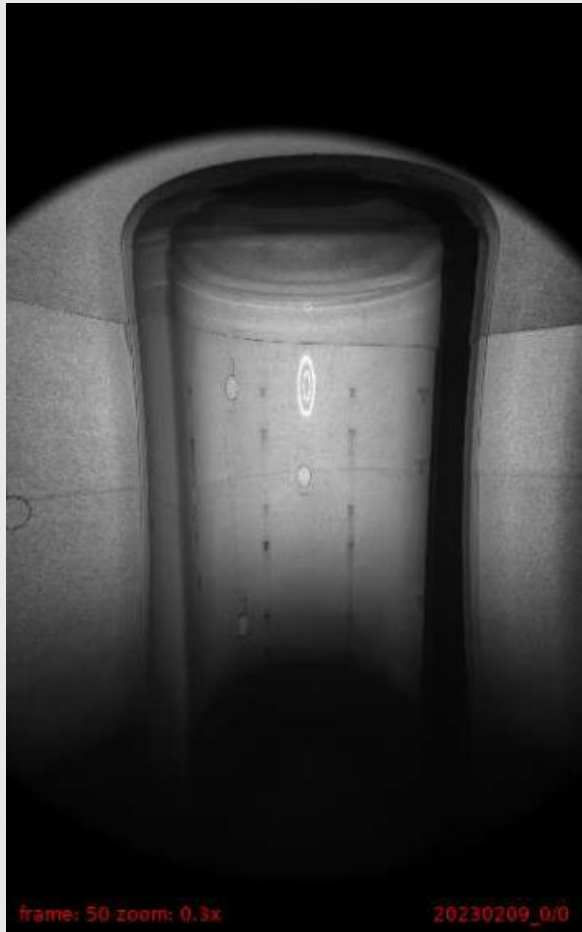
Right-Side-up



- **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

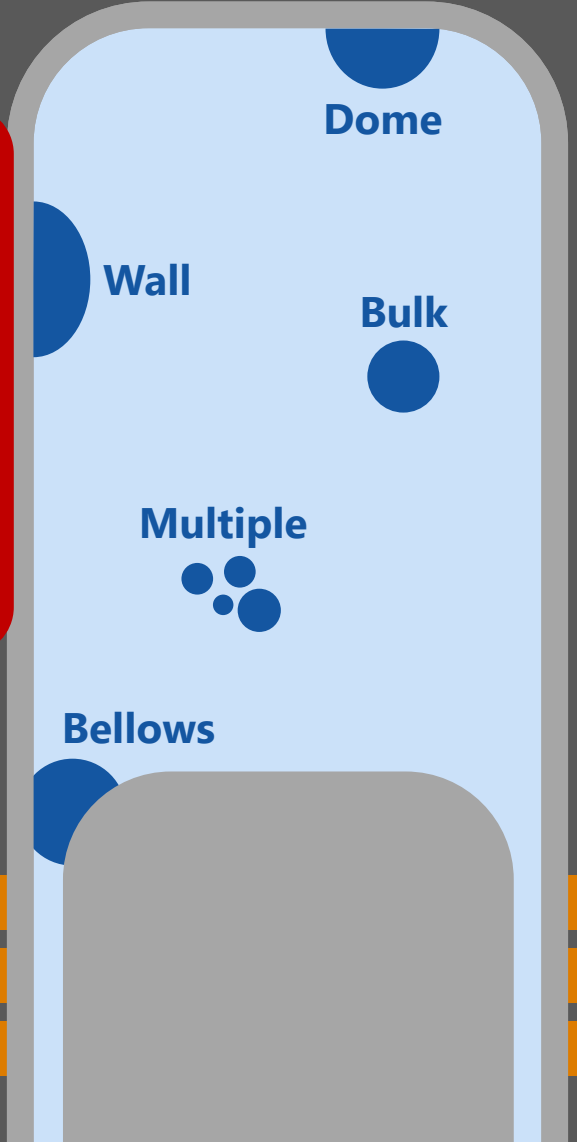
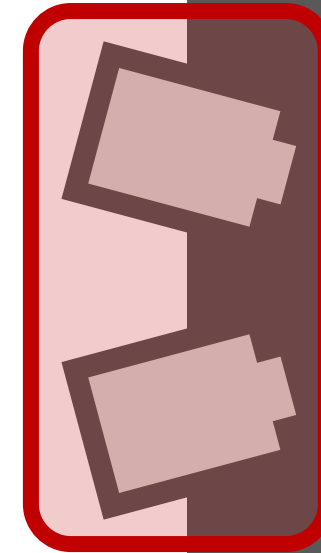
Cameras



Piezoelectric Sensors



Pressure Transducers

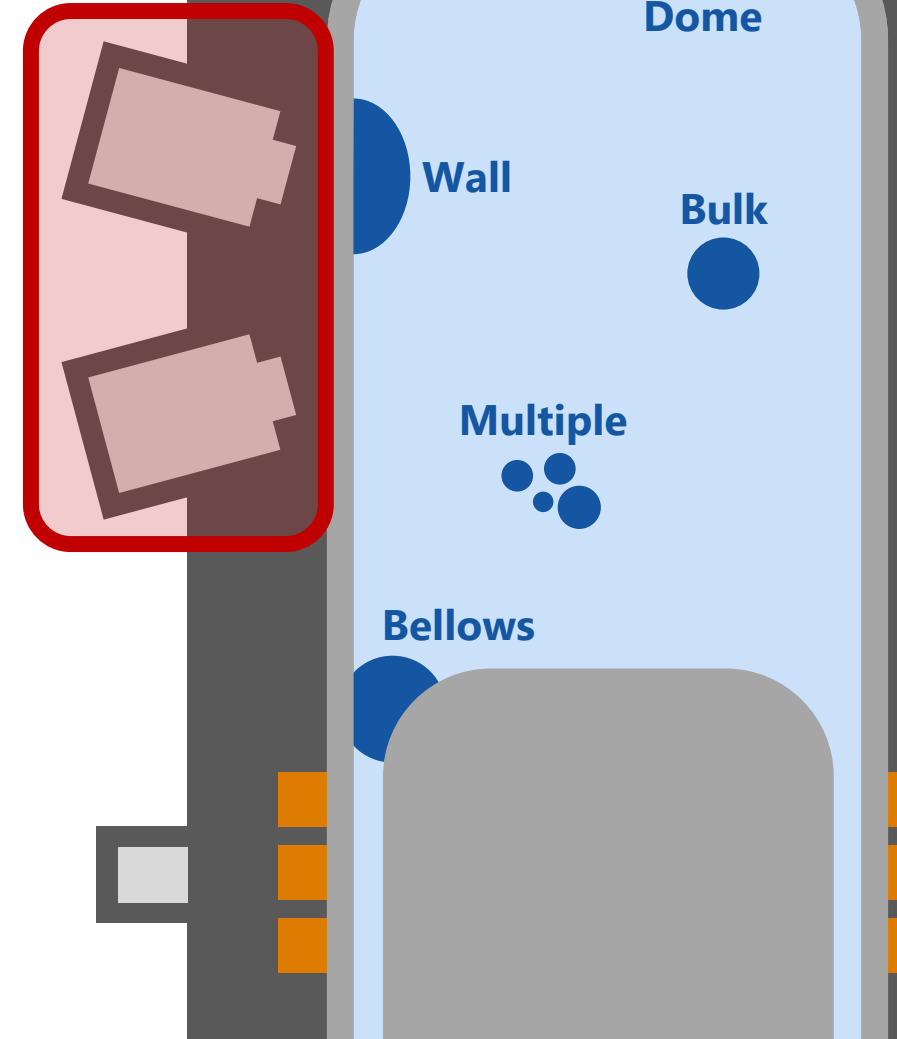
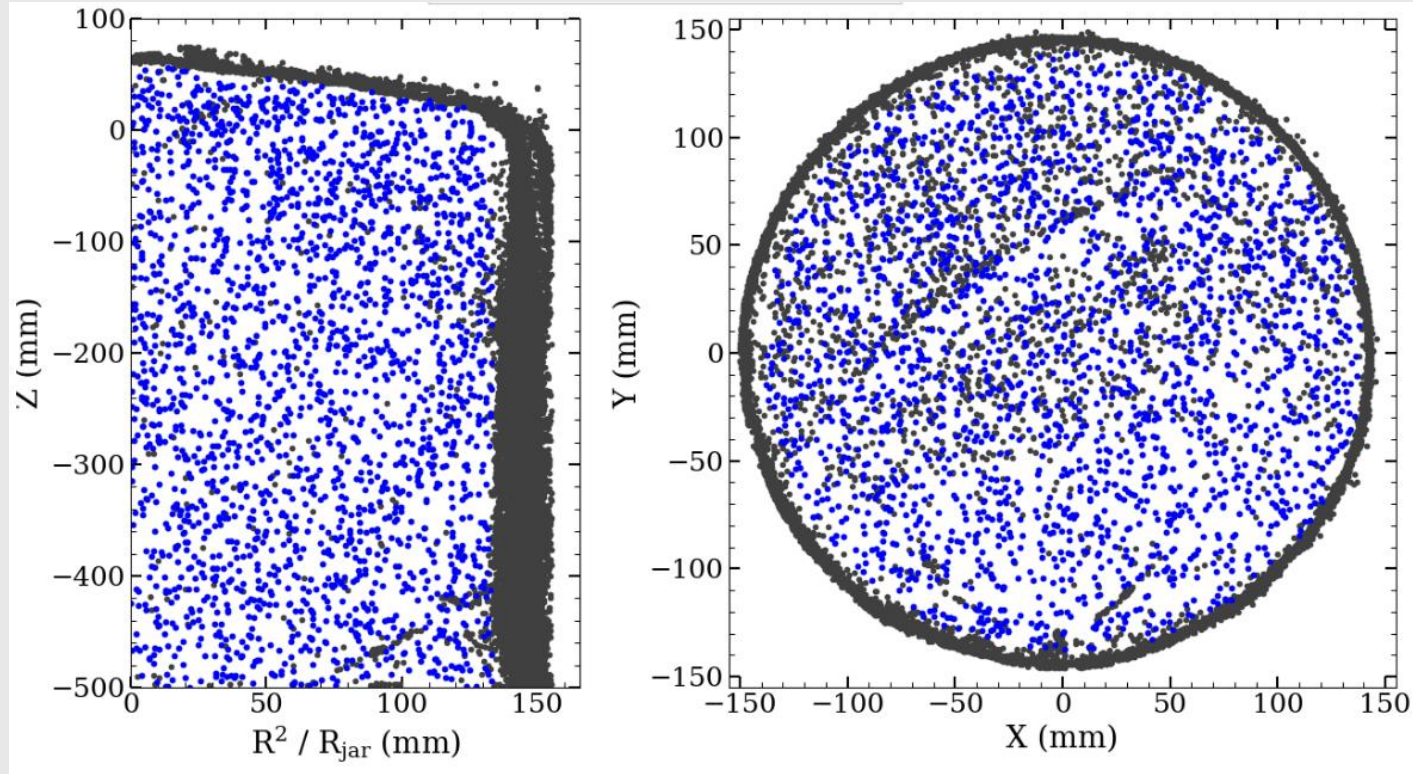


Detection Channels

Cameras

Piezoelectric Sensors

Pressure Transducers

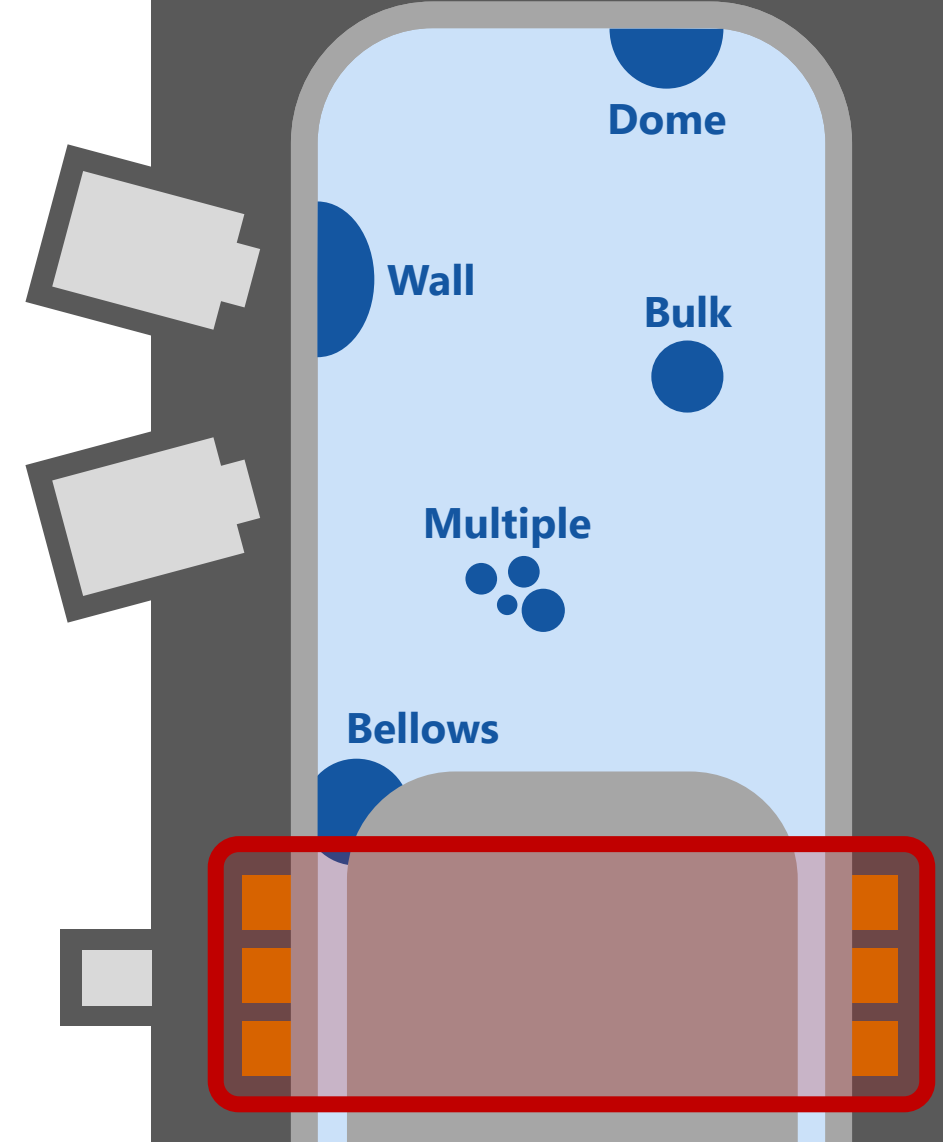
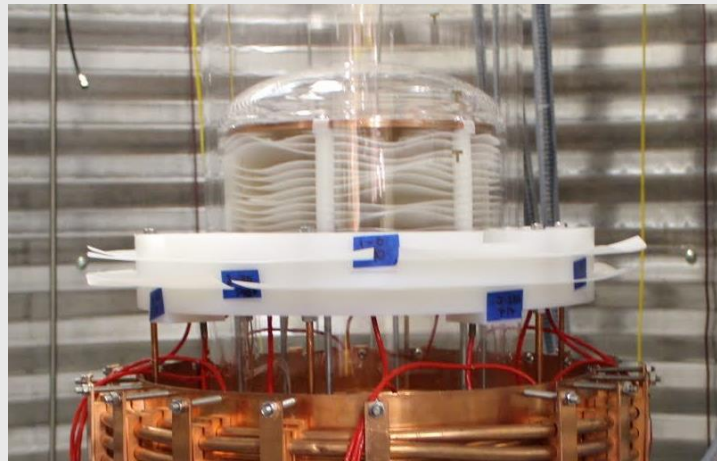
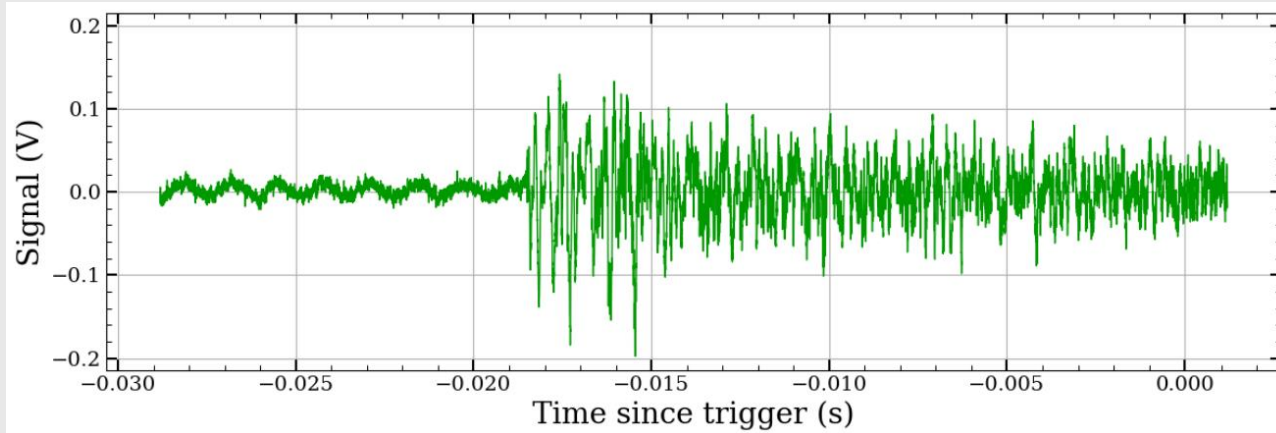


Detection Channels

Cameras

Piezoelectric Sensors

Pressure Transducers

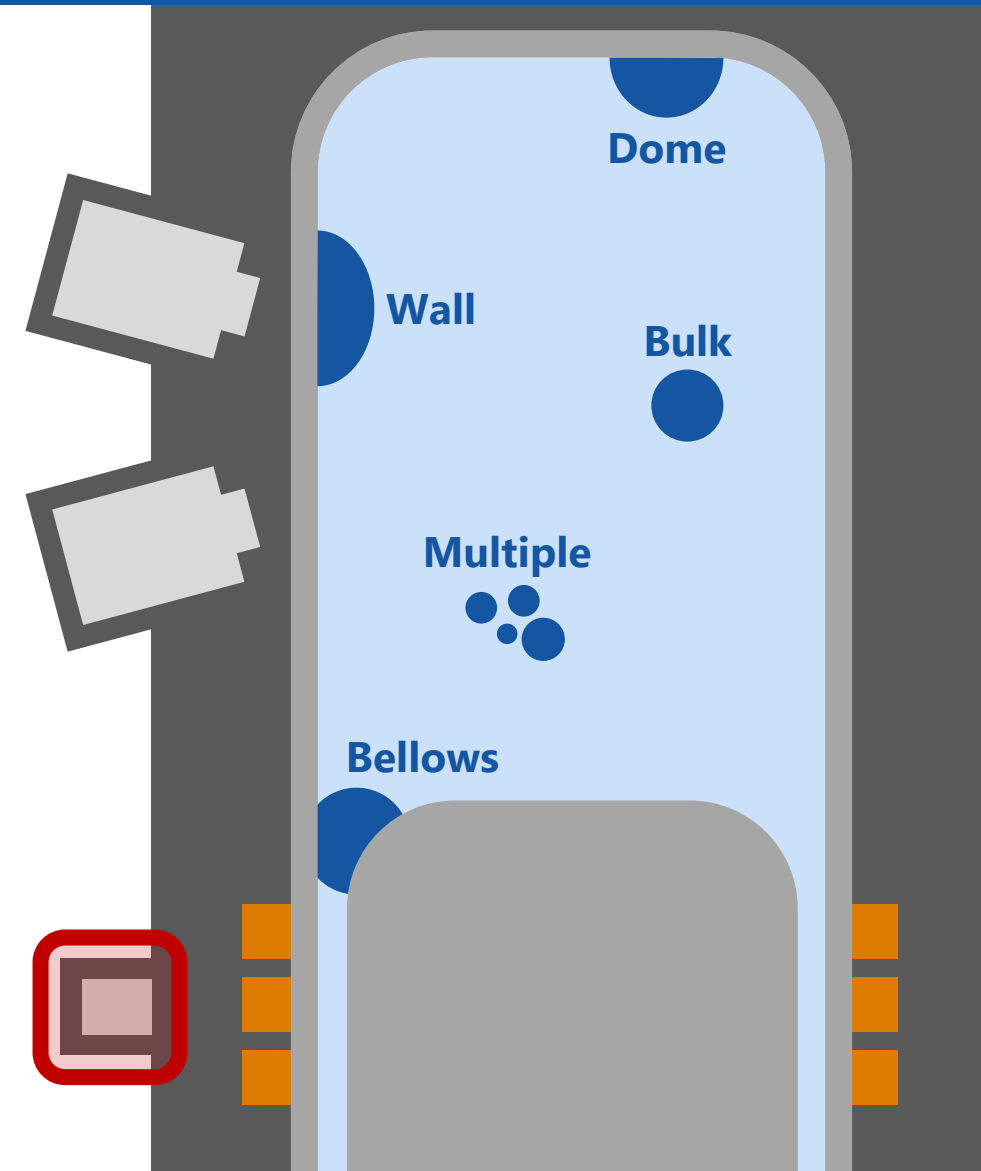
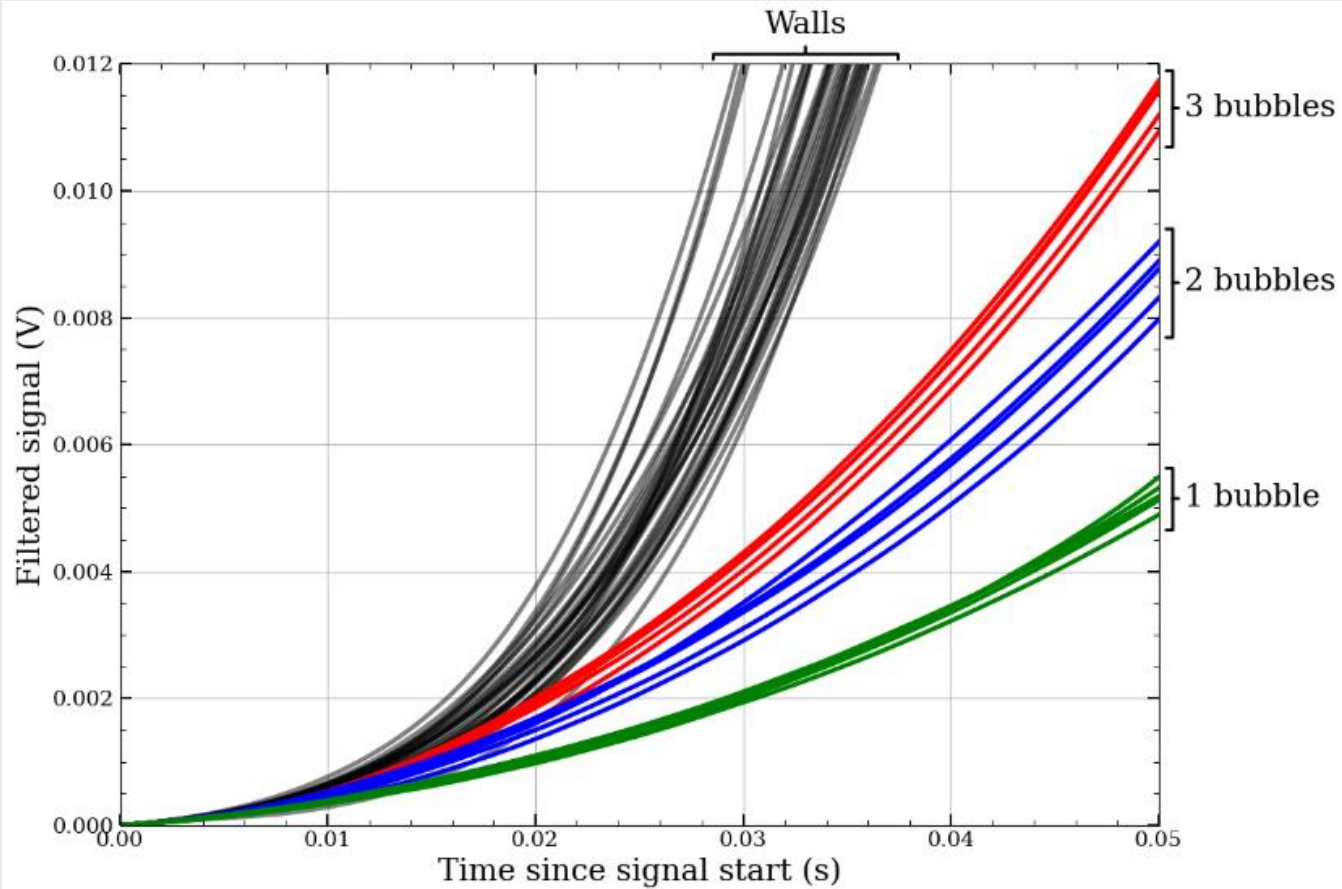


Detection Channels

Cameras

Piezoelectric Sensors

Pressure Transducers

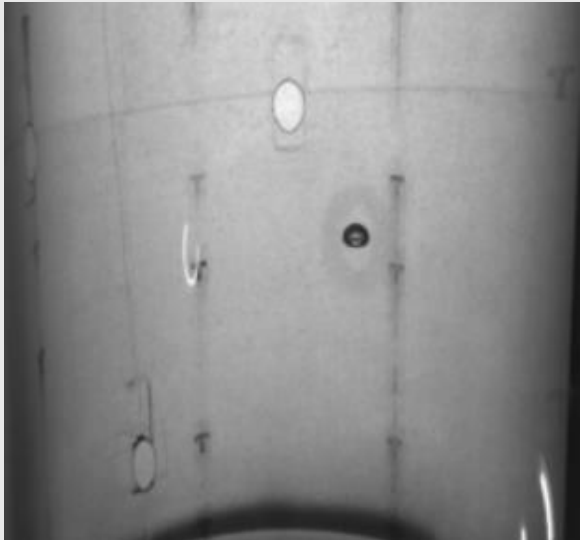


Backgrounds

Nuclear Recoils

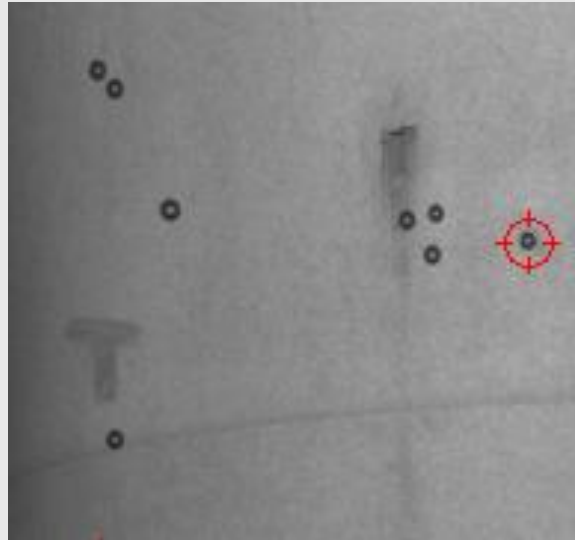
Alpha Particles

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



Neutrons

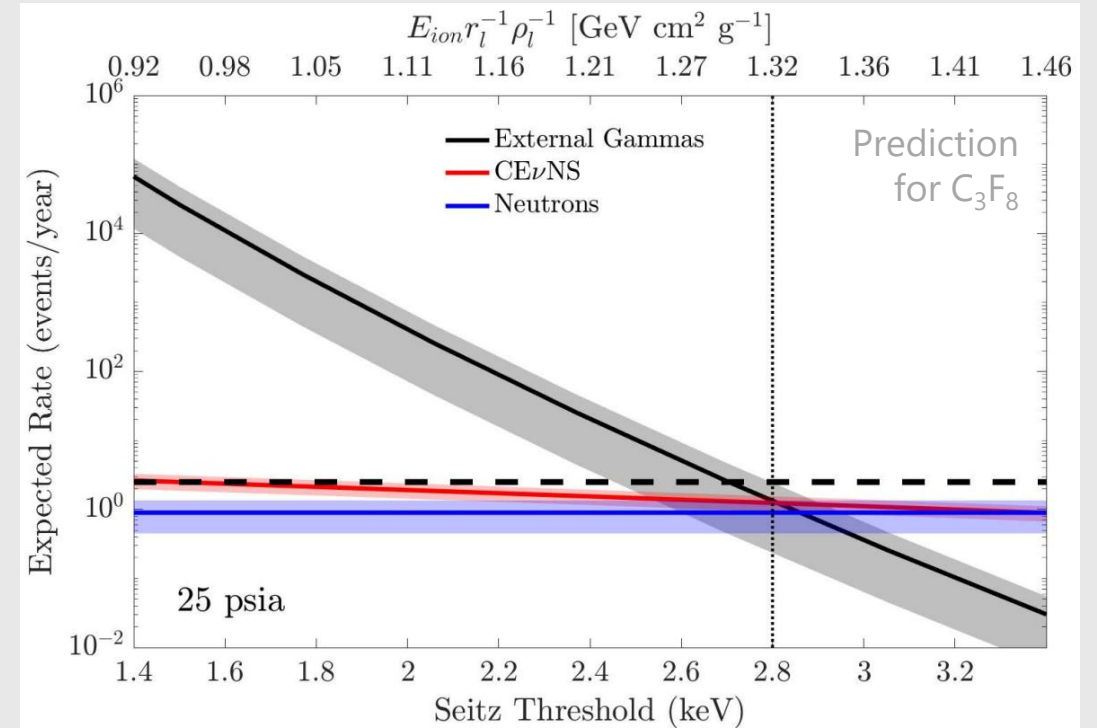
- Internal from spontaneous fission and (α, n) , and external from CR muons.
- Single or multi-bubbles.



Electron Recoils

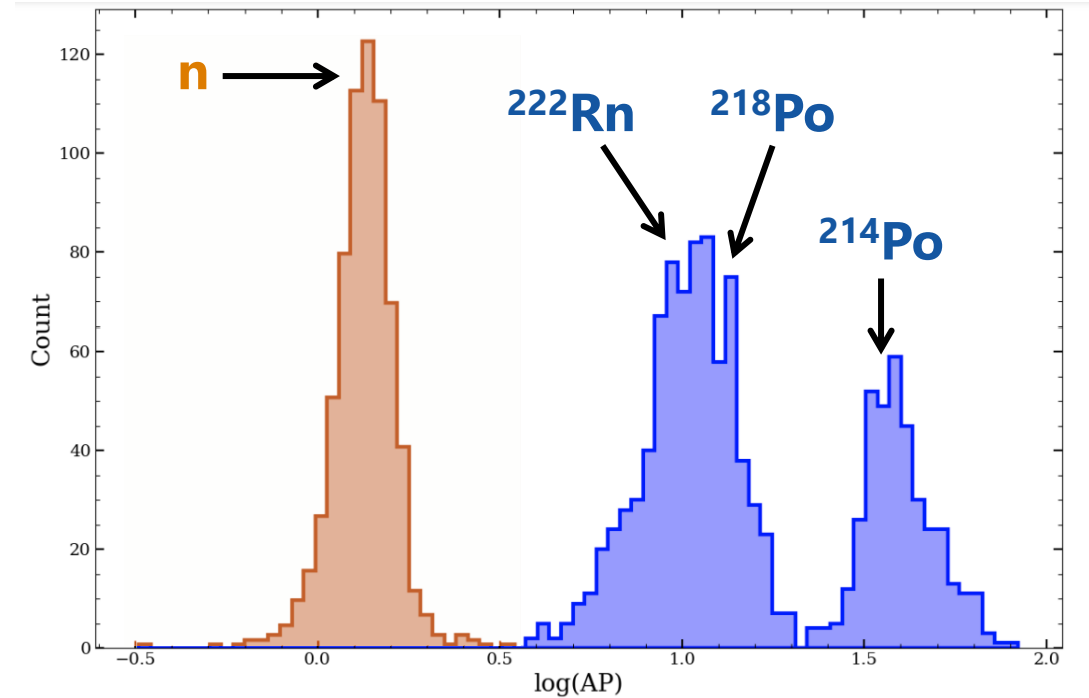
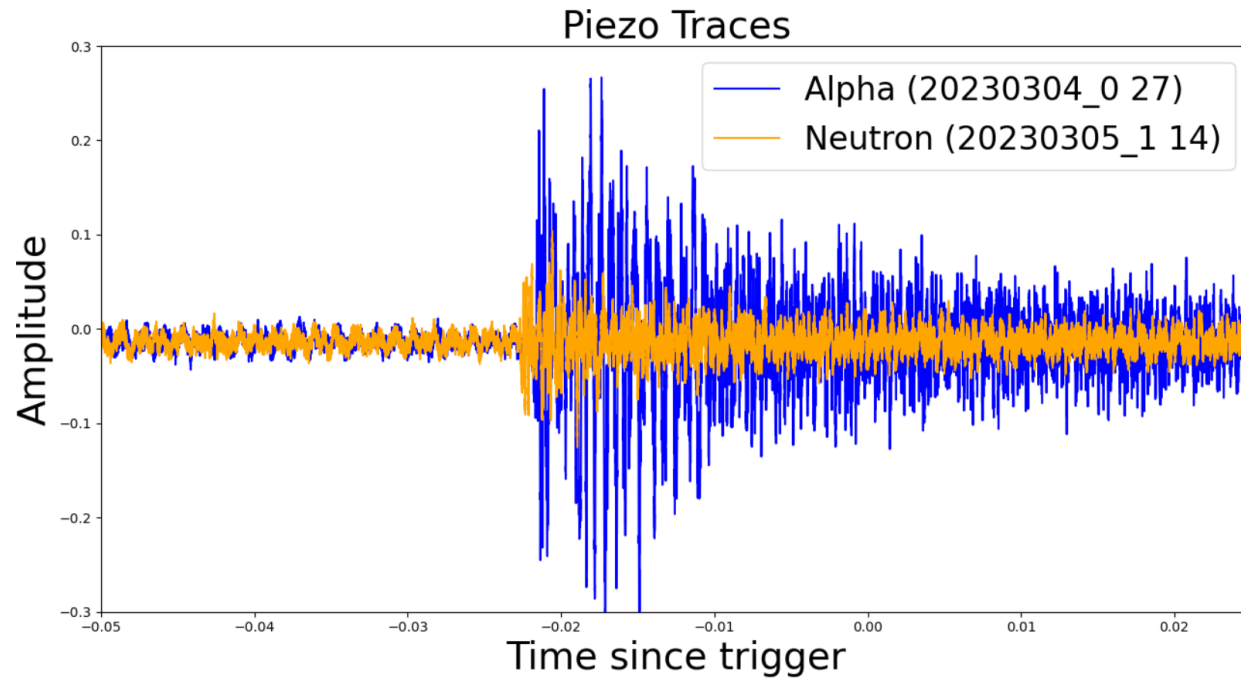
Gammas

<https://inspirehep.net/literature/1737408>



Insensitive to gammas at operating thresholds.

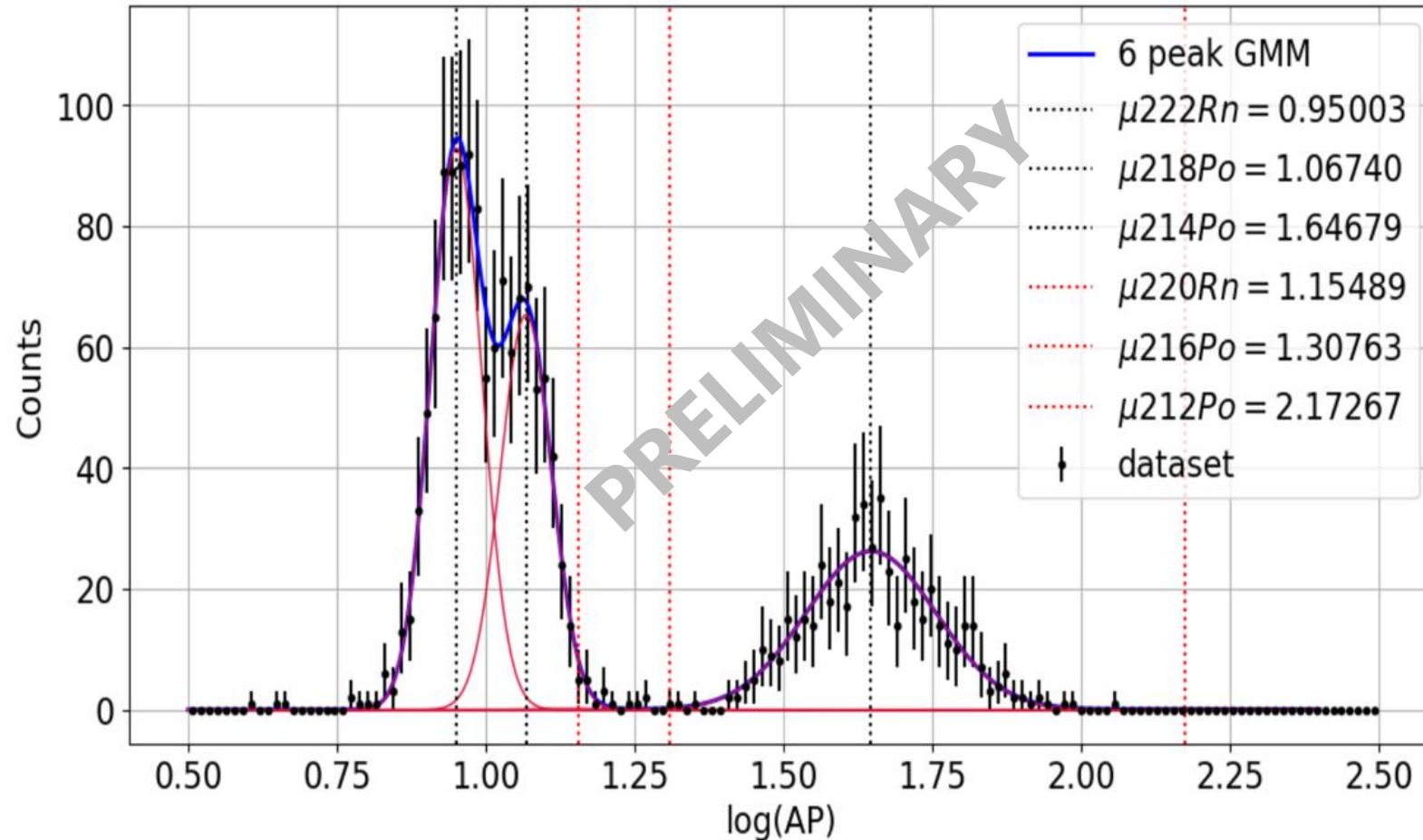
Background Rejection



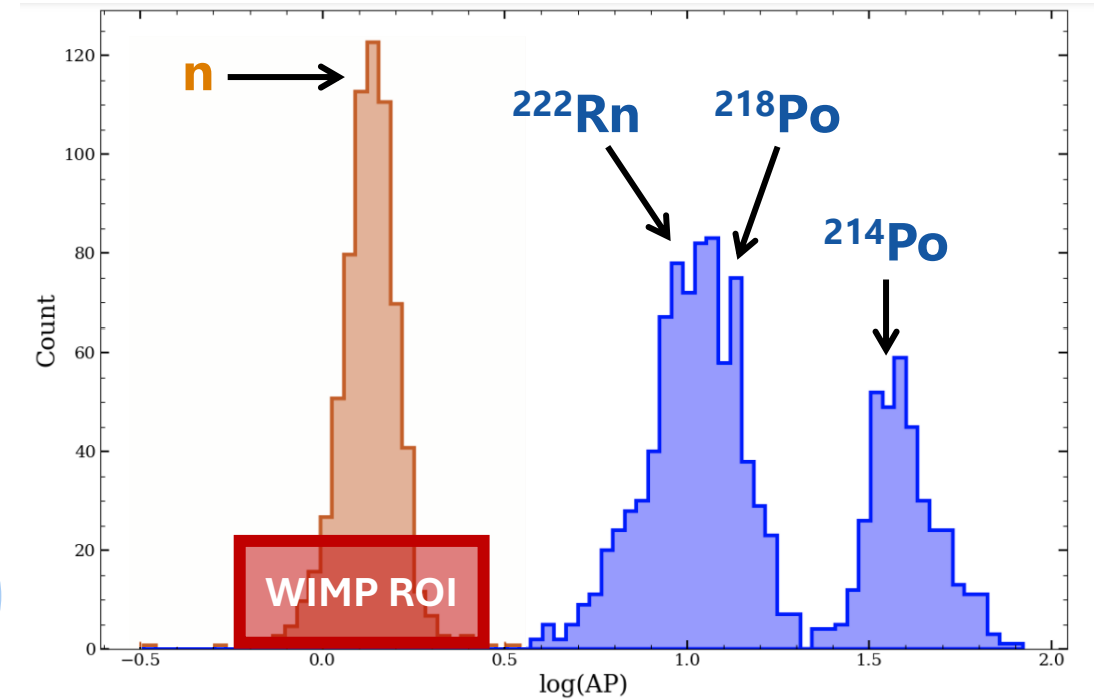
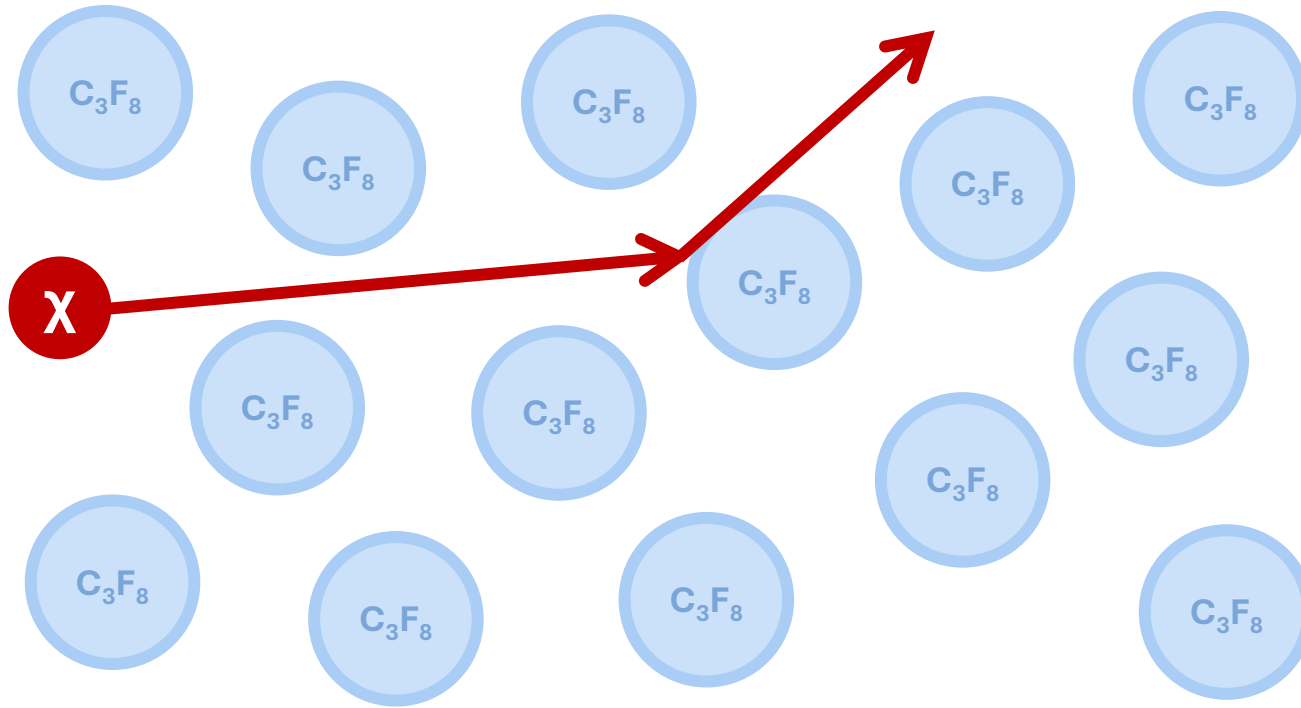
- Calculate acoustic parameter (AP) from resonant energy of piezoelectric sensors.
- Energy depositions from alpha particles have higher AP than those from neutrons.
- Different alpha decays from ^{222}Rn decay chain are identifiable.
- This is used to reject alpha backgrounds in PICO.

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.

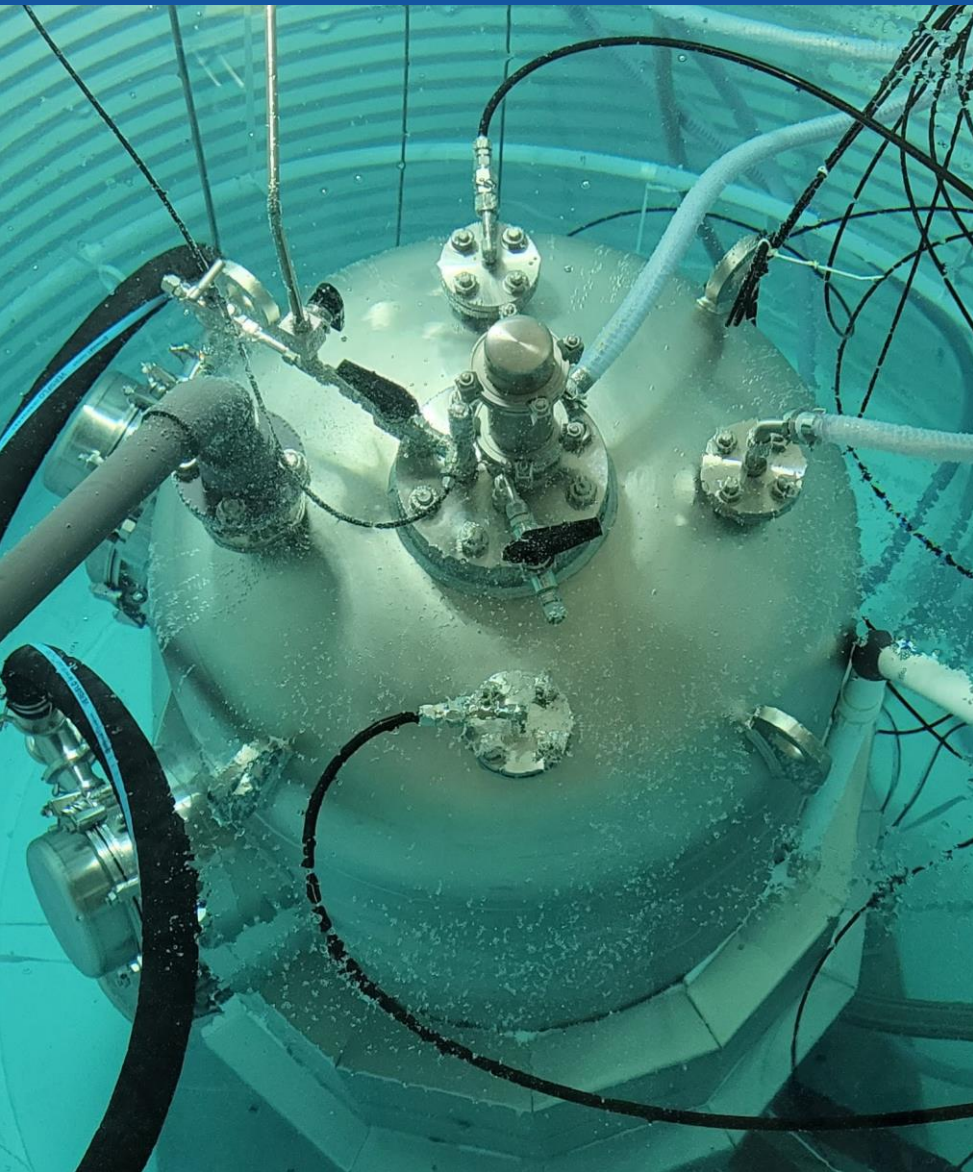


Backgrounds in the WIMP ROI

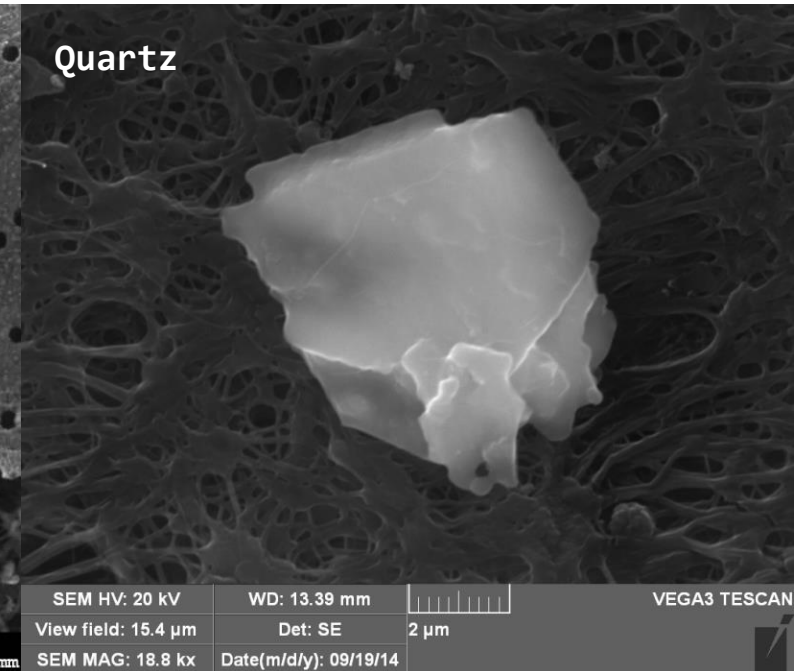
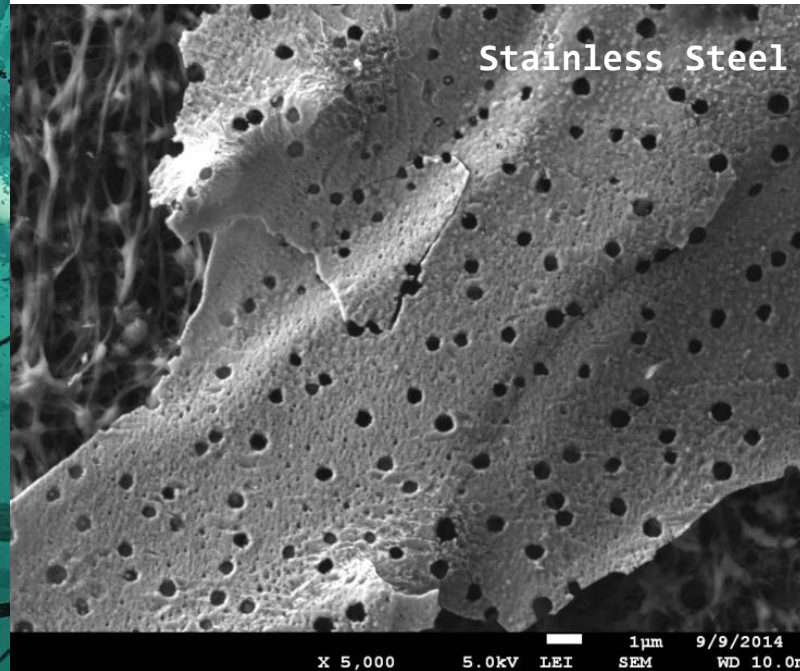


- Because **WIMPs** are weakly interacting, we do not expect them to interact more than once in the C_3F_8 .
- They will create single bubbles with low energy deposition given the hypothesised mass range tested by PICO.
- They will look exactly like **single-scatter neutron events**.
- We must therefore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

Background Mitigation

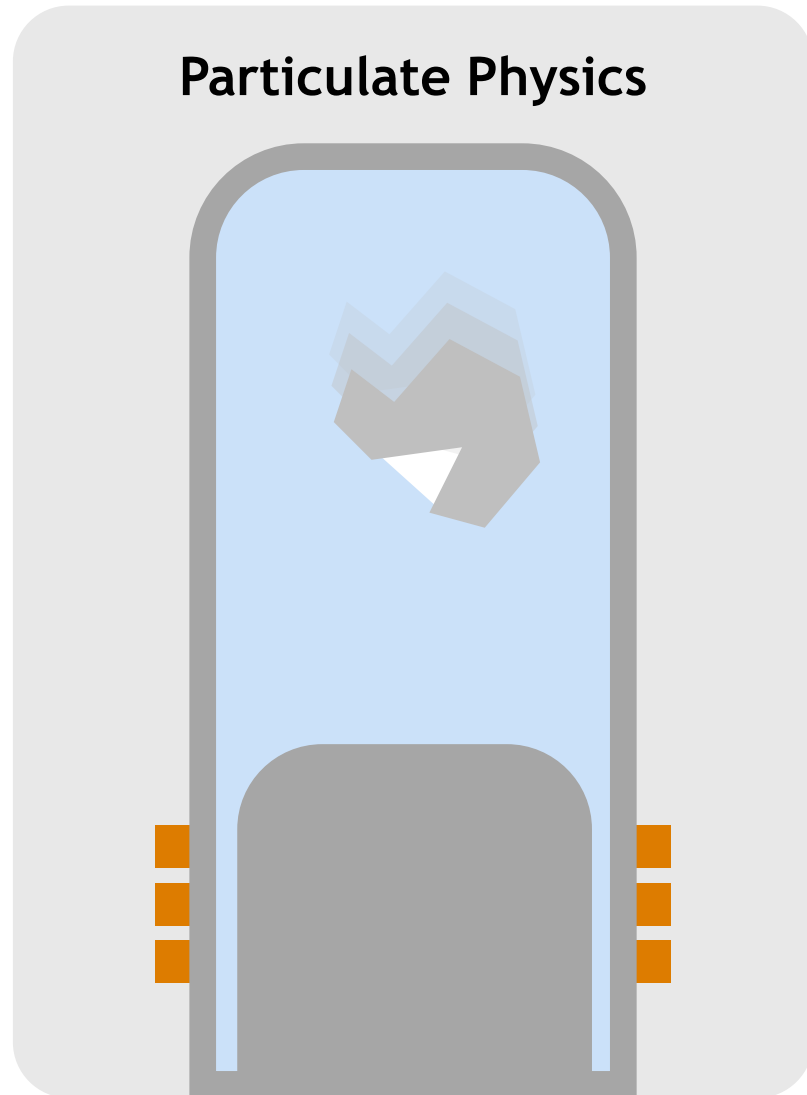


- **External Neutron Backgrounds:**
 - Shielded by large water tank surrounding the pressure vessel.
- **Internal Alpha and Neutron Backgrounds:**
 - Careful selection of materials.
 - Rigorous efforts to mitigate radon and extensively clean detector.



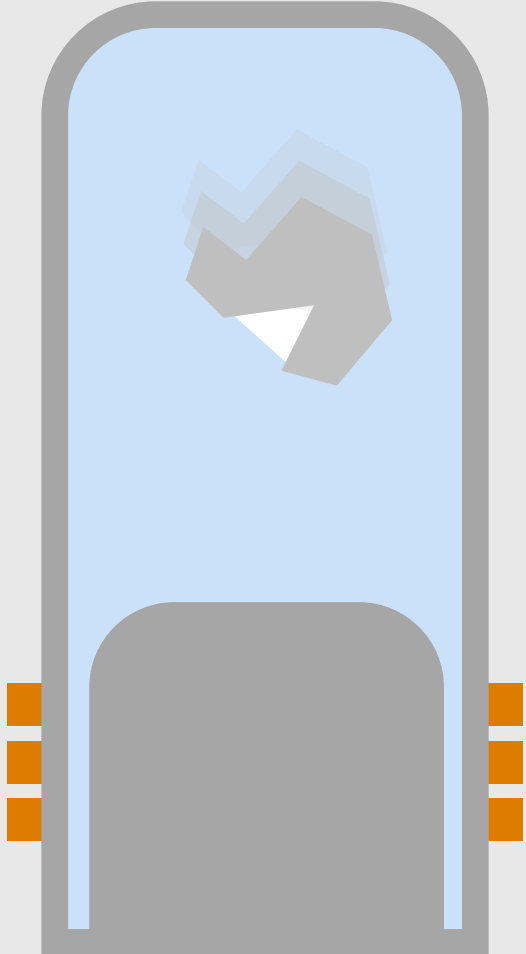
SEM HV: 20 kV	WD: 13.39 mm	1µm	9/9/2014	VEGA3 TESCAN
View field: 15.4 µm	Det: SE	2 µm		
SEM MAG: 18.8 kx	Date(m/d/y): 09/19/14			

Current PICO-40L Analyses

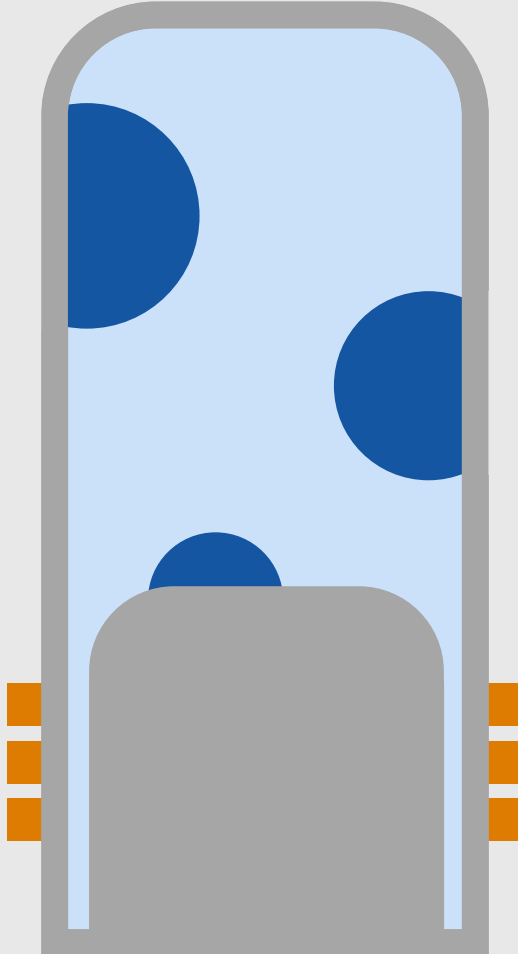


Current PICO-40L Analyses

Particulate Physics

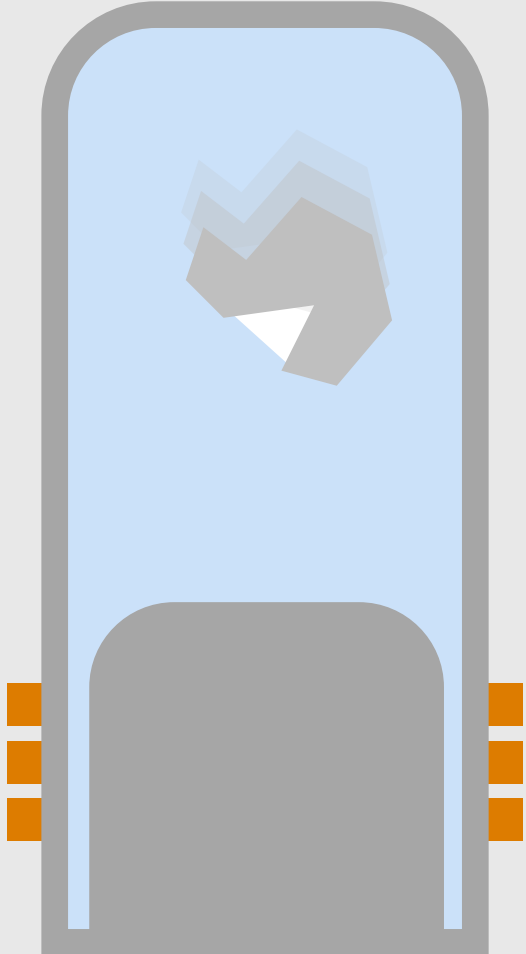


Wall Event Rate

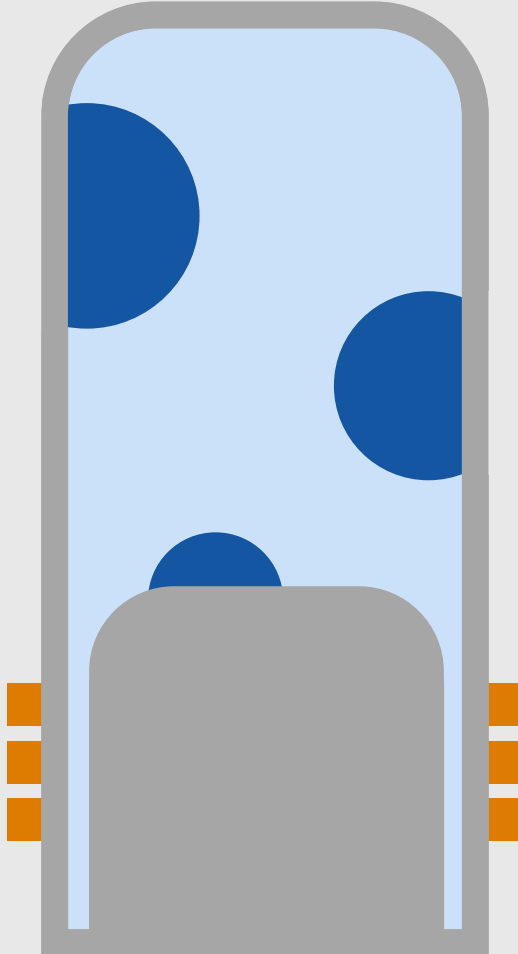


Current PICO-40L Analyses

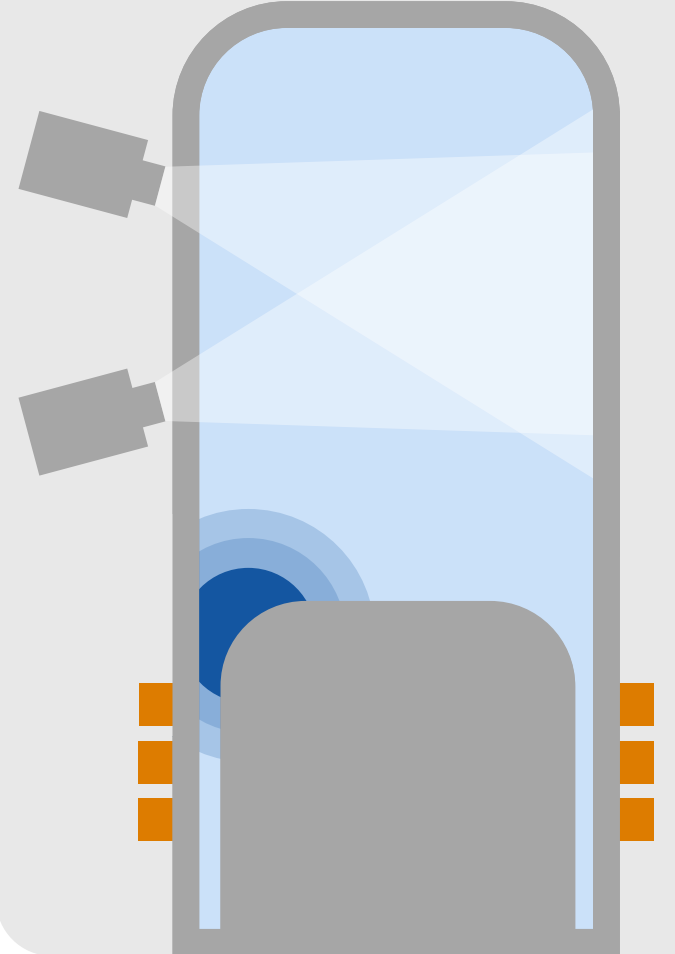
Particulate Physics



Wall Event Rate

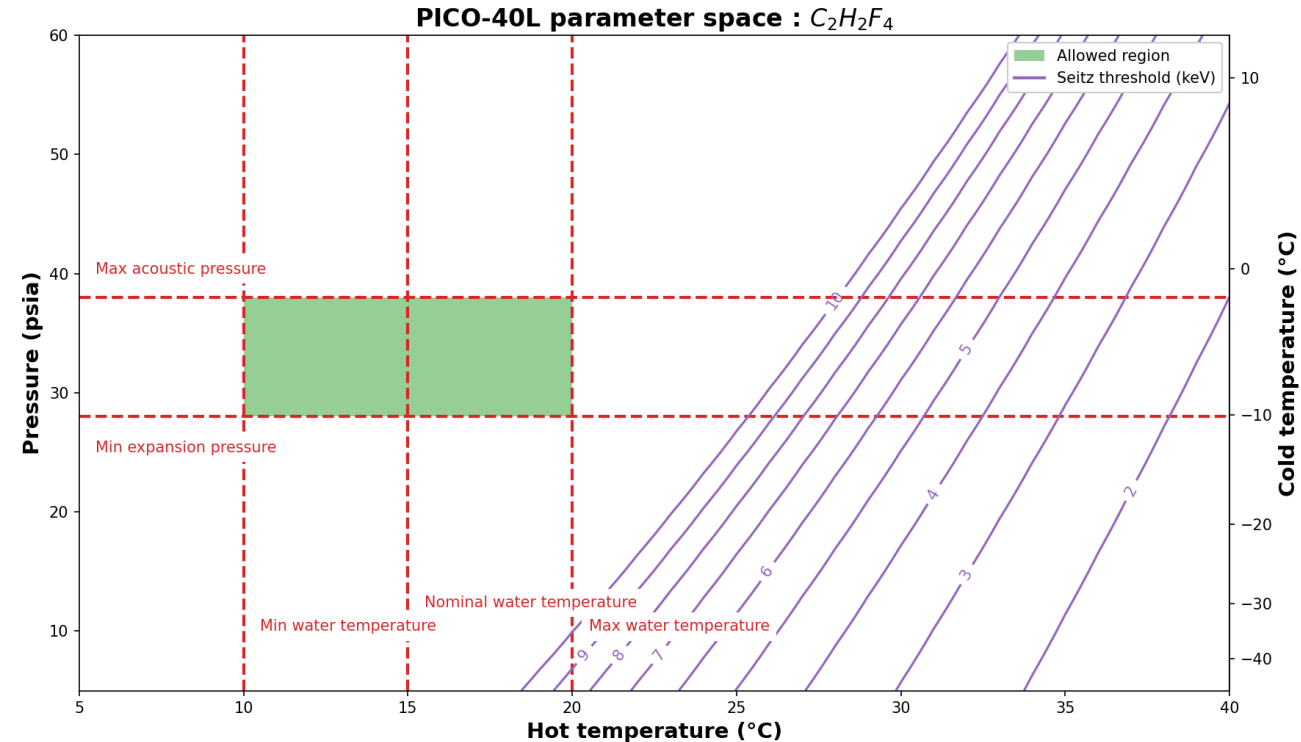


Acoustic Position Recon.



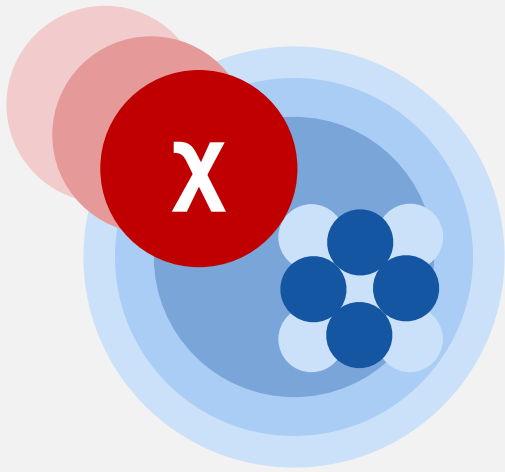
Expanded Physics Programme

- 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 sensitivities.
 - $C_2H_2F_4$, 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:**
 - Multi-bubble CEvNS events from supernovae up to 10 kpc away. See [Astropart. Phys. 105 \(2019\)](#) for details.



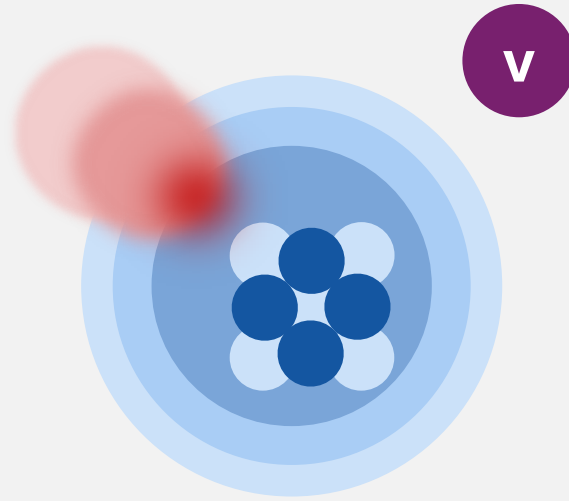
Dark Matter Absorption with PICO-60

Scattering



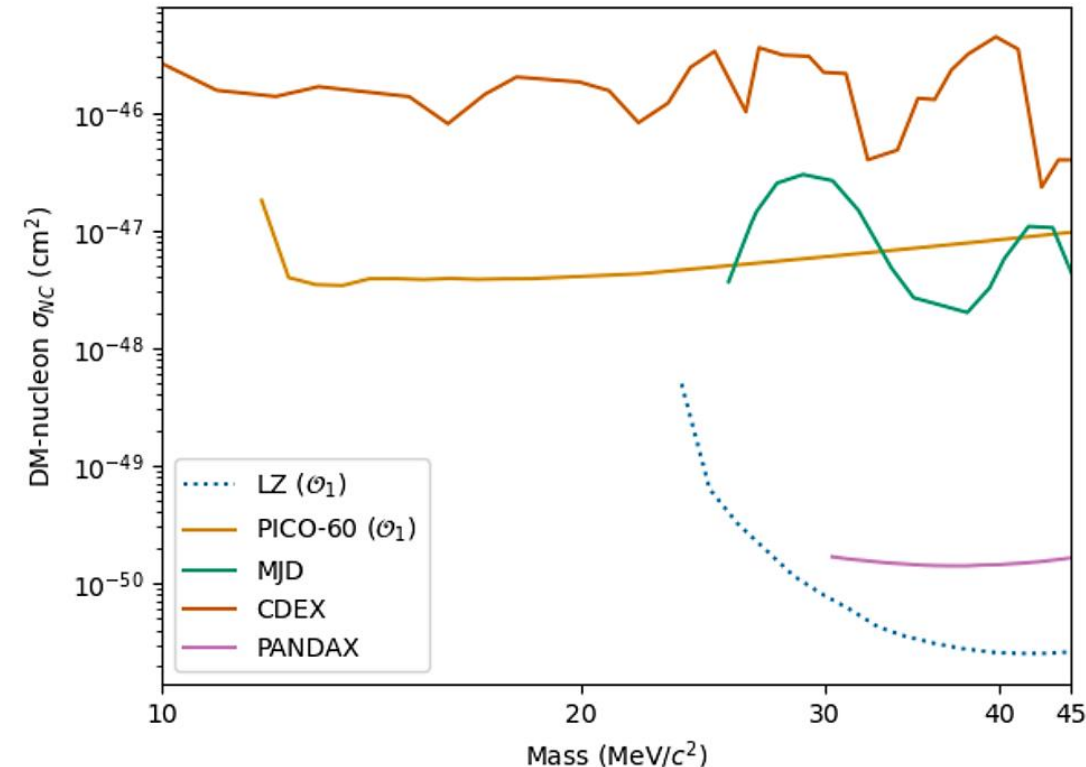
$$\chi + N \rightarrow \chi + N'$$

Absorption



$$\chi + N \rightarrow \nu + N$$

- $\mathcal{O}_1$: 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.

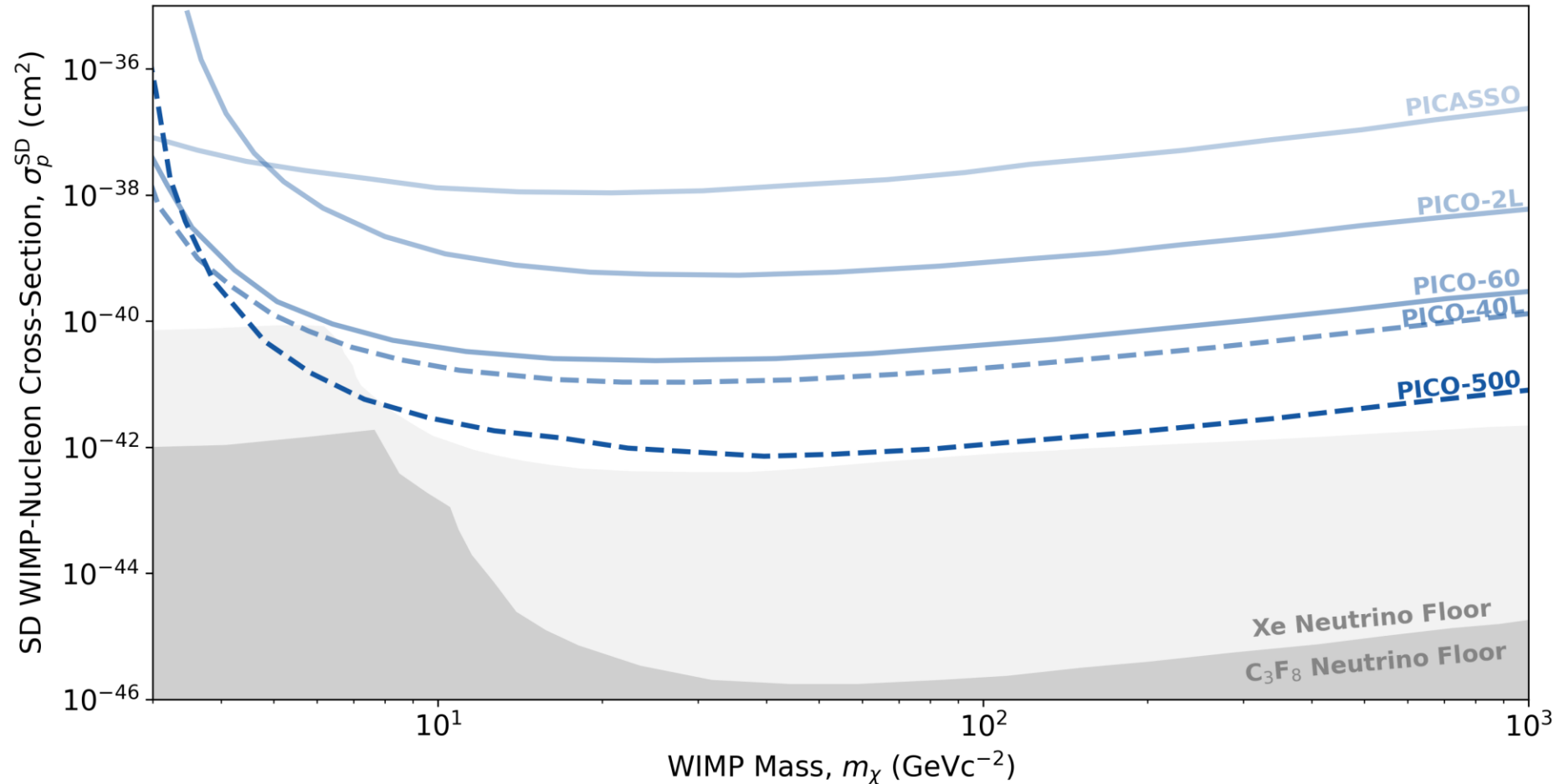


Published in PRL
Editor's Suggestion

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

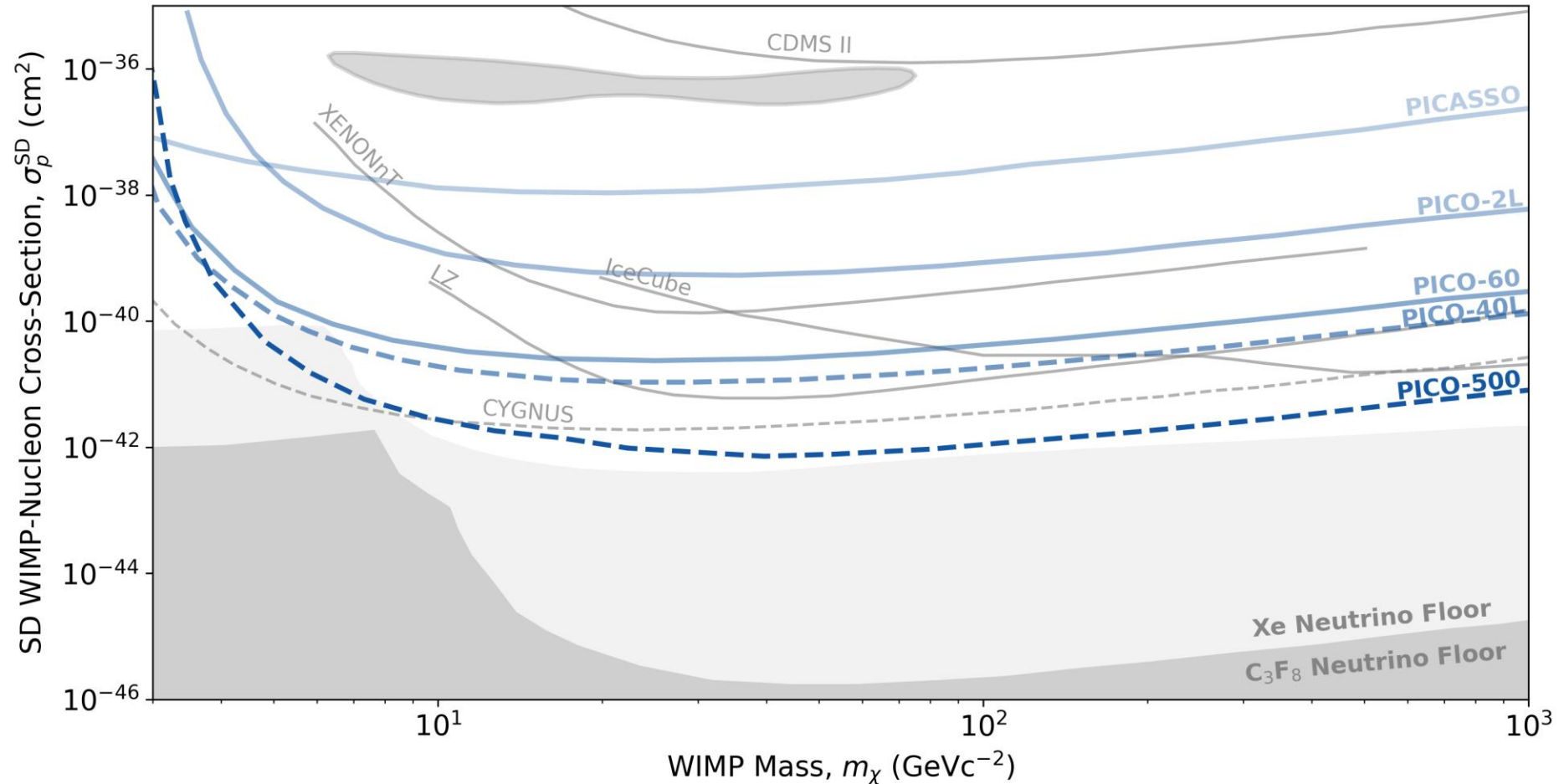
Projected Sensitivities

- 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.



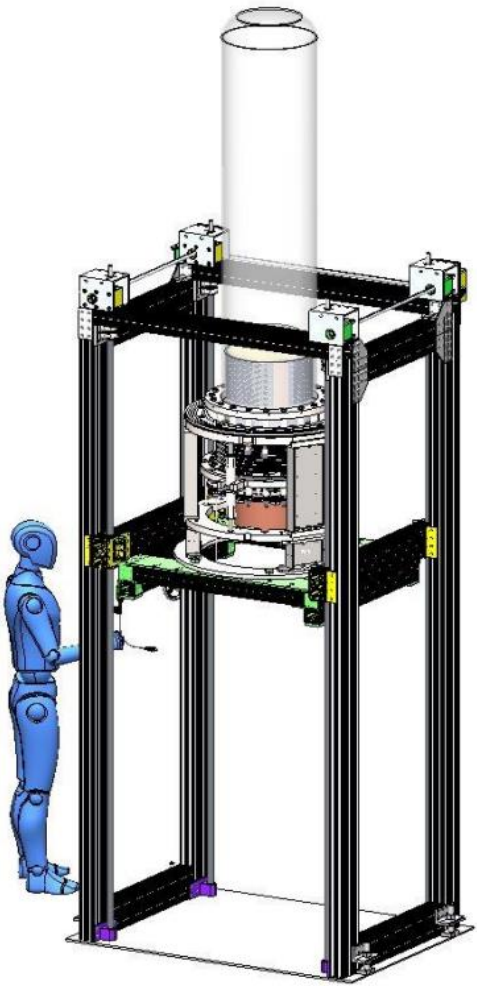
PICO-500 Status - Pressure Vessel

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



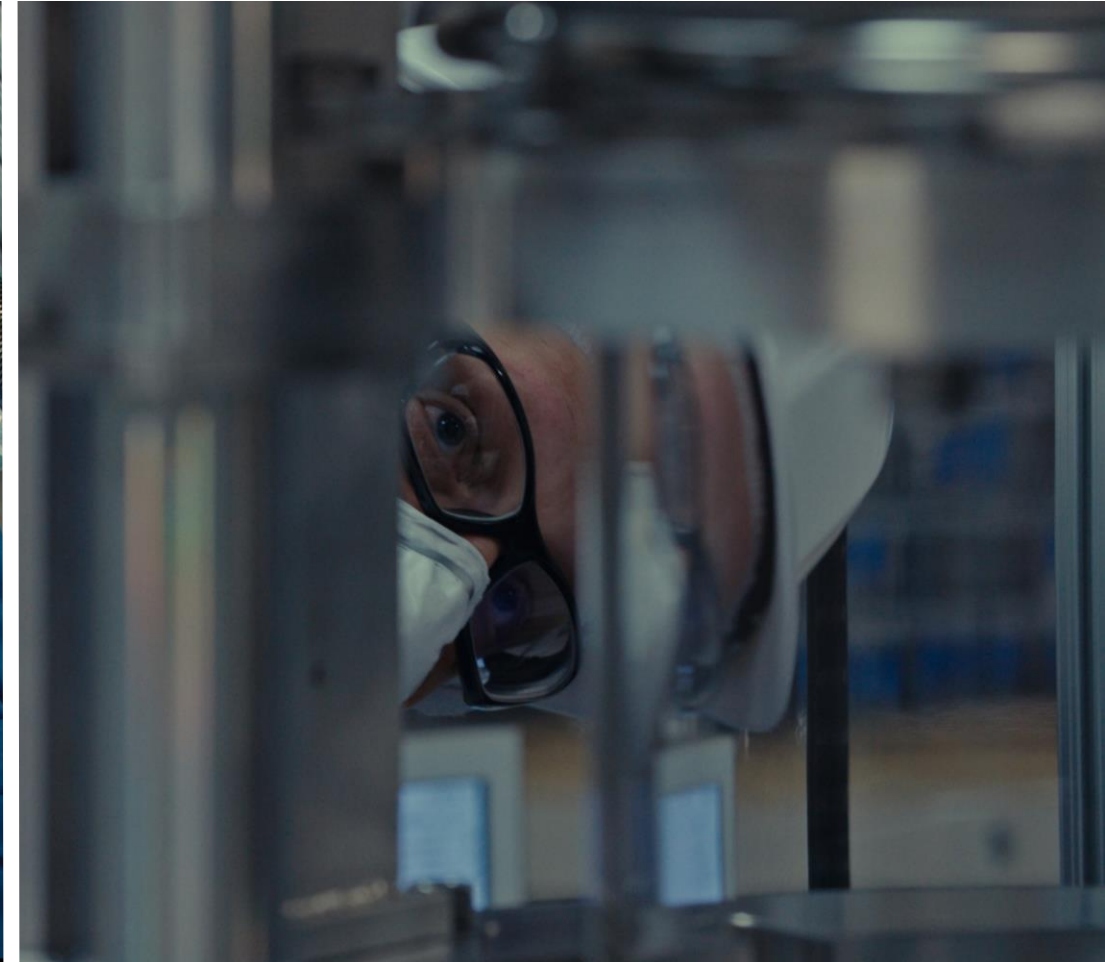
PICO-500 Status - Inner Vessel

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



PICO-500 Status - Upcoming Work

- The IV will be fully assembled soon.
- We expect to start commissioning the detector in July 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

- 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!

Thank You



J. Basu, M. Das,
V. Kumar



J. Farine, A. Leblanc,
C. Licciardi, U. Wichoski



R. Anderson,
E. Vázquez-Jáuregui



NORTHWESTERN
UNIVERSITY

C. E. Dahl



O. Harris



Pacific Northwest
NATIONAL LABORATORY

I. Arnquist, C. M. Jackson,
B. Loer



R. Neilson



PennState

D. Priya, S. Priya, Y. Yan



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E. Adams, J. Corbett,
D. Cranshaw, M. Dean, K. Dering,
G. Giroux, R. Hill, S. Meister,
A. Mir, A. Noble



D. Auty, Z. Doucet, M. Gill,
C. Krauss, Q. Malin, E. Pattison,
M. Rangen, W. Woodley



M. Laurin, H. Nozard,
A. Robinson, J. Savoie



C. Gaudreau, P. Grylls,
A. Mathewson,
I. Lawson, S. Sekula



P. S. Cooper, M. Crisler,
A. Sonnenschein



B. Ali, R. Filgas, D. Mamedov,
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I. Levine



Kavli Institute
for Cosmological Physics
at The University of Chicago

J. I. Collar, M. Tripathi