PICO-40L Bubble Chamber Status and First Results

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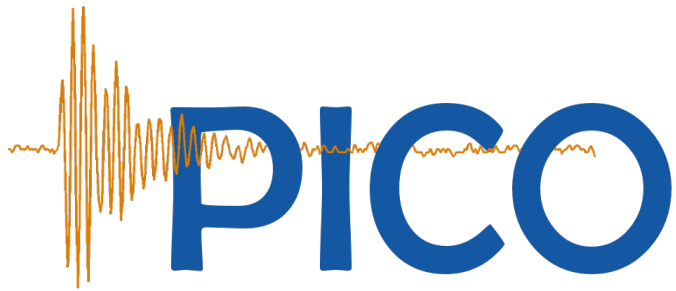
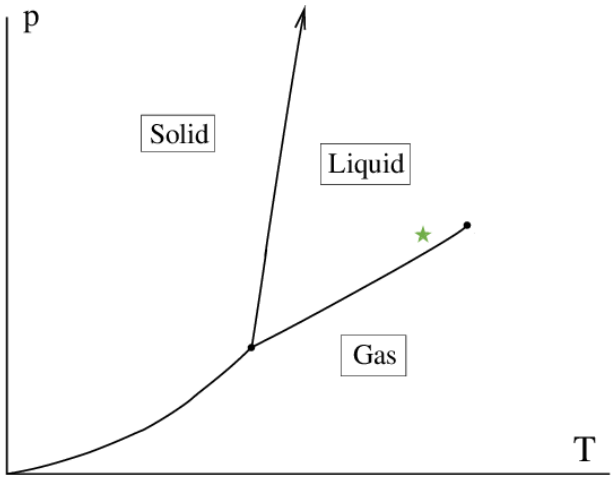
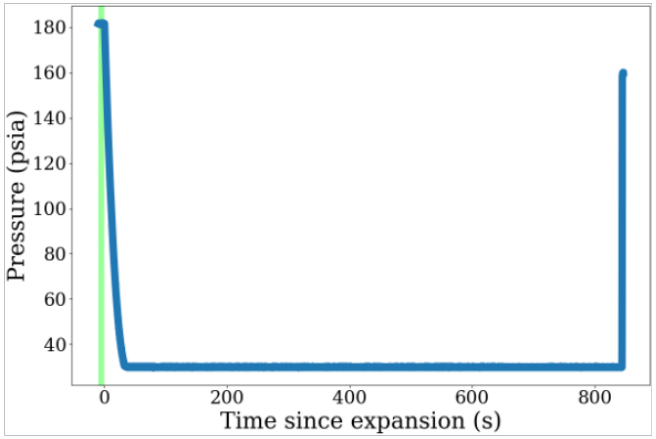
Queen's University

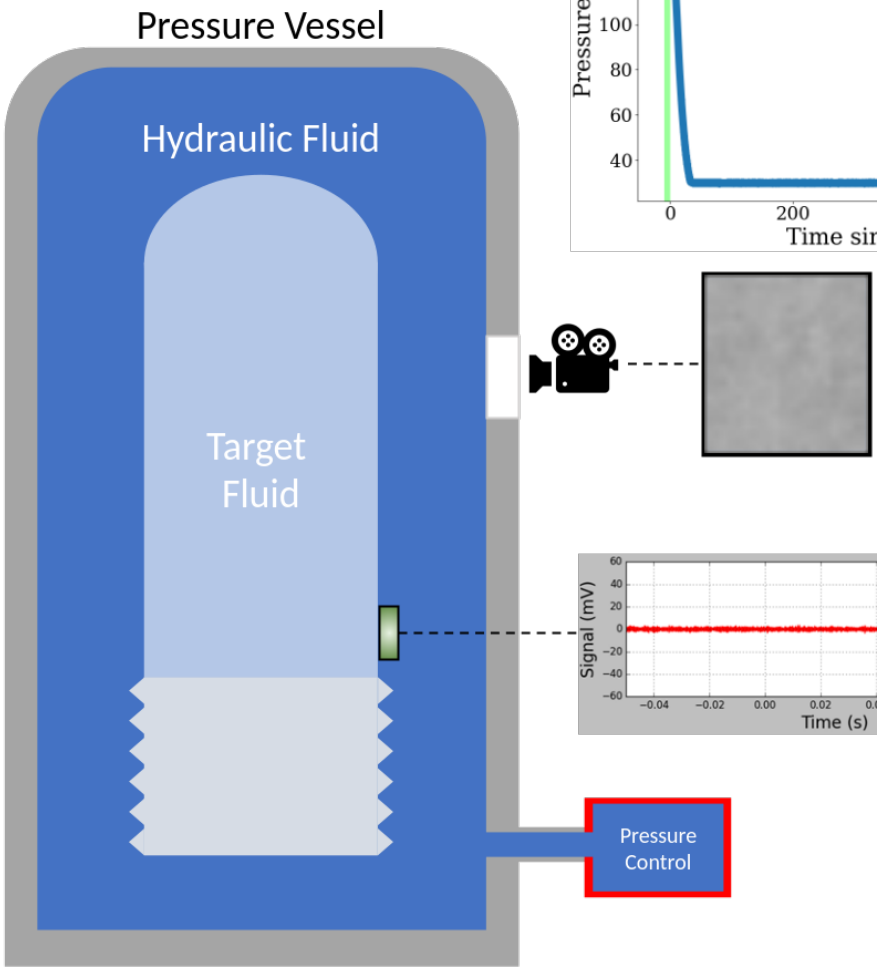
August 30, 2023

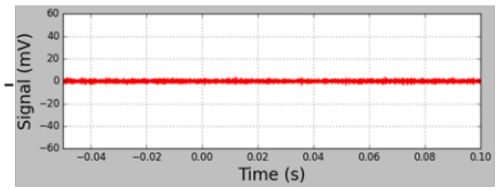


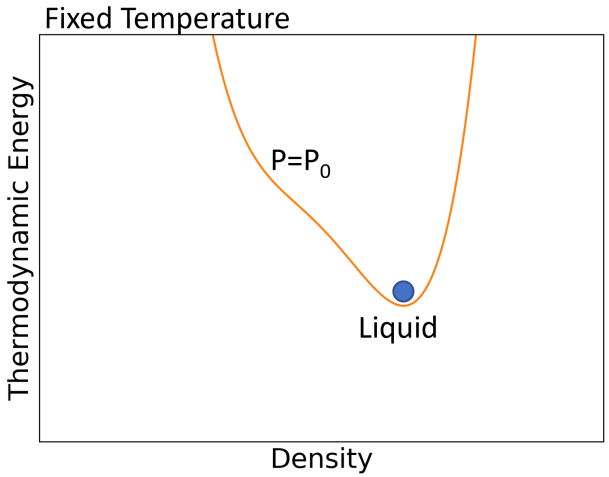
Bubble Chambers as Particle Detectors











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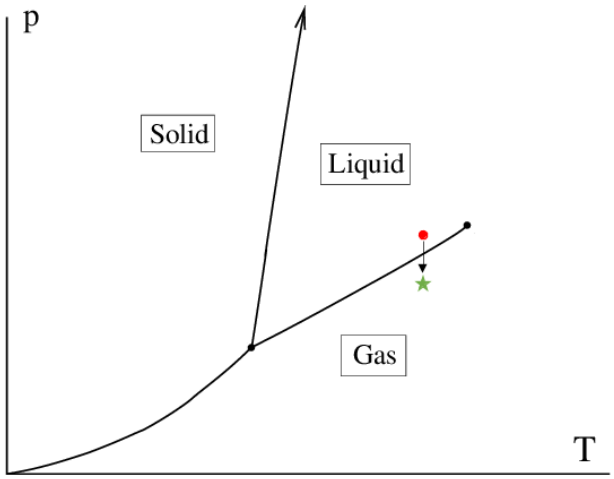
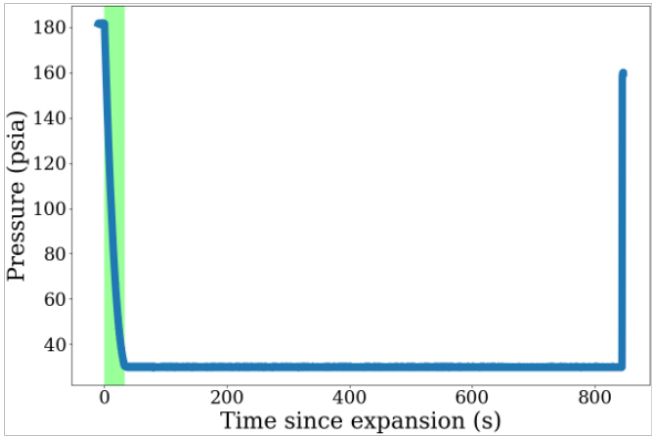
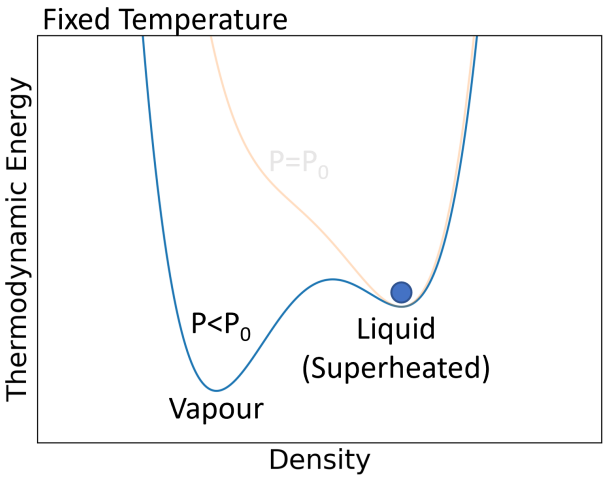
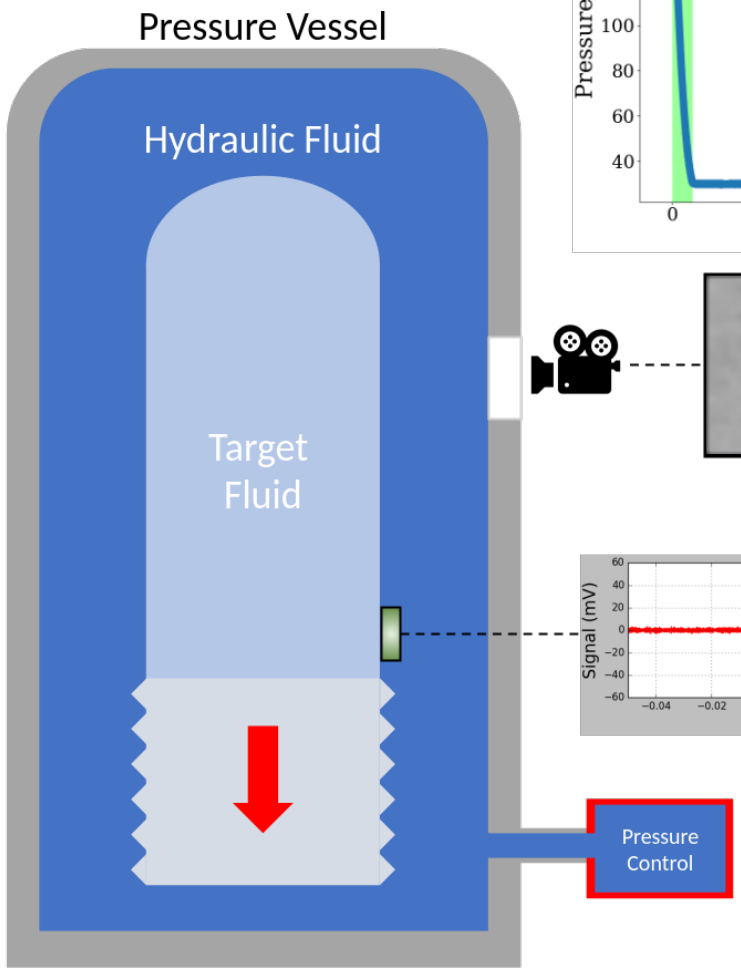
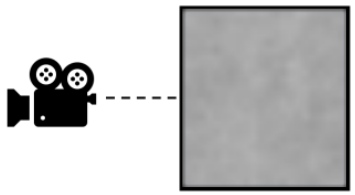
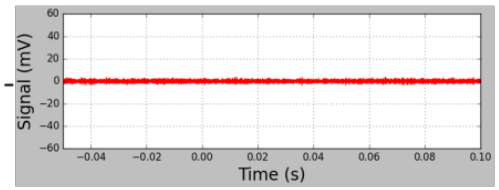




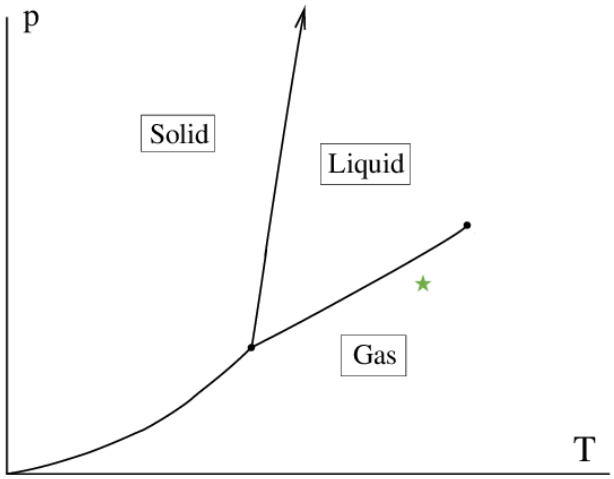


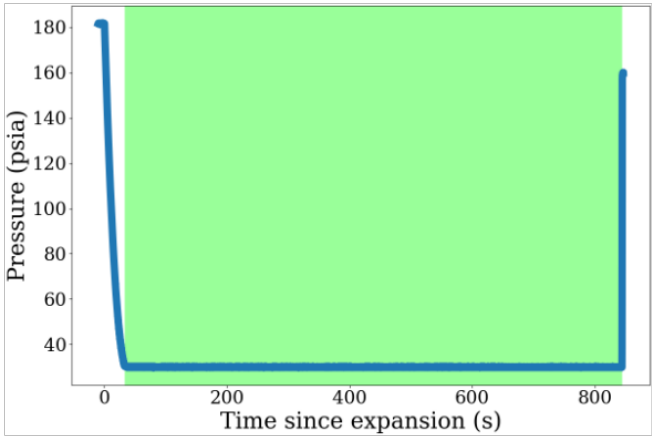


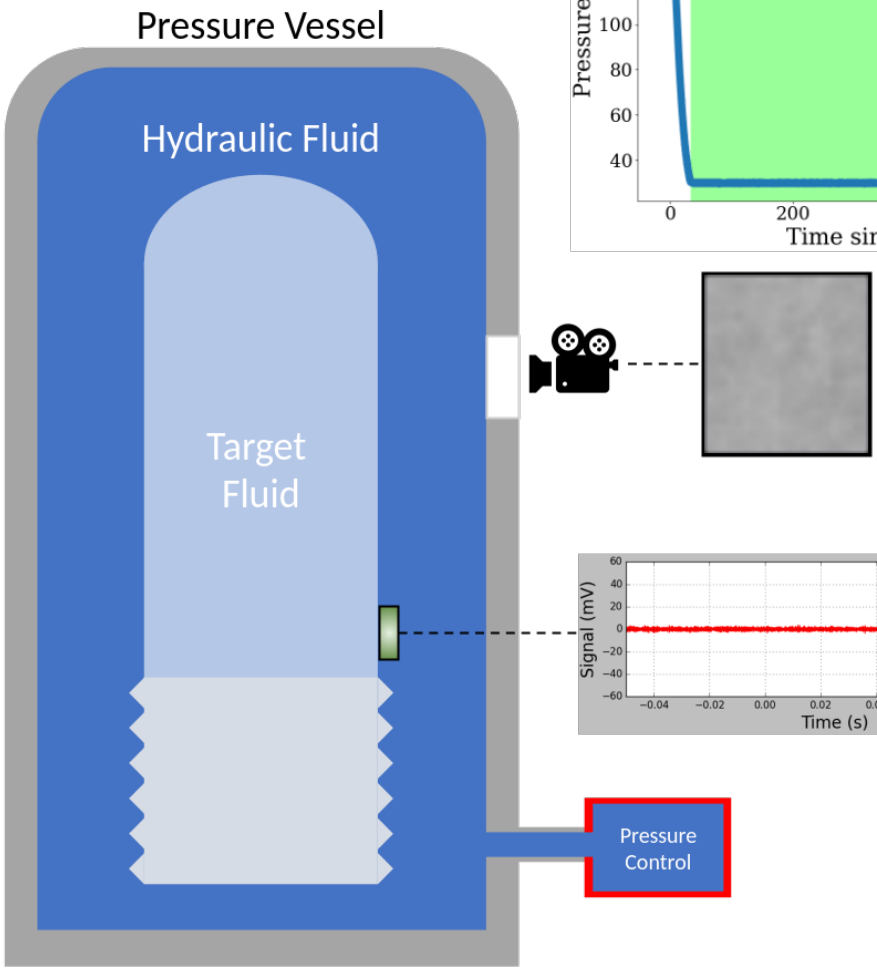


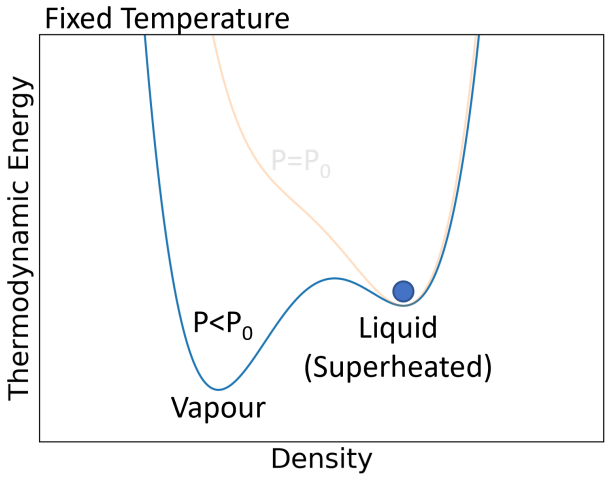


Bubble Chambers as Particle Detectors









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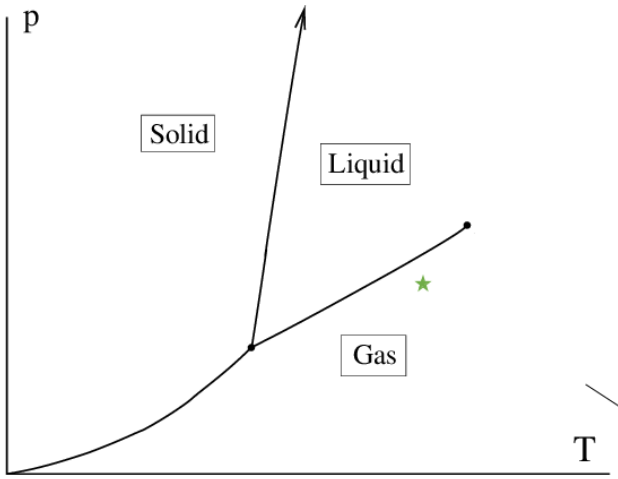
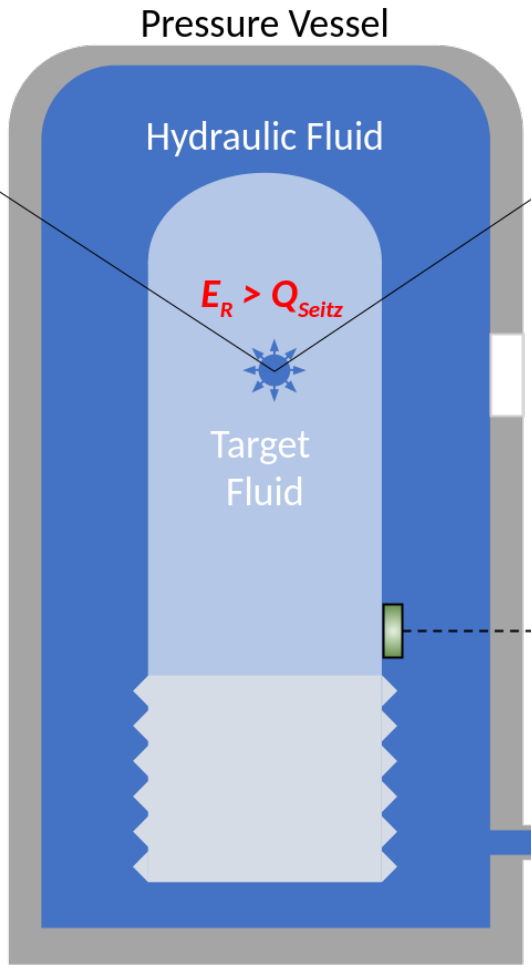
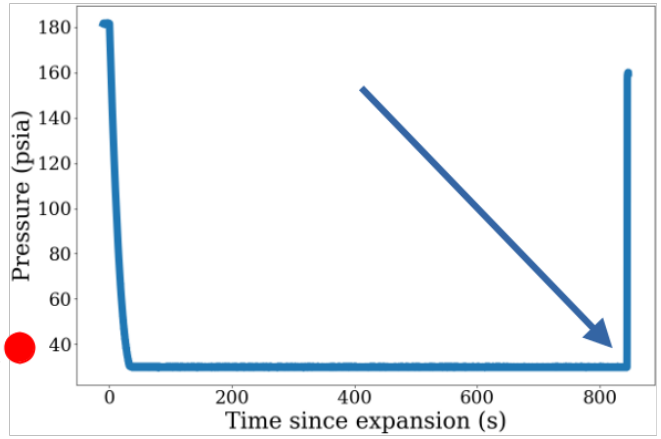
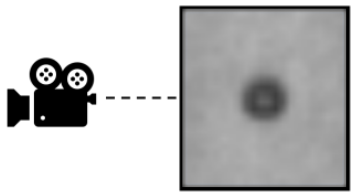
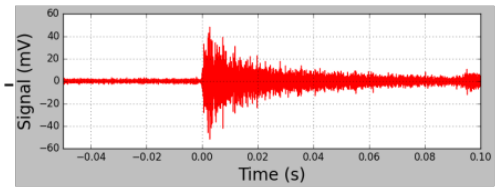
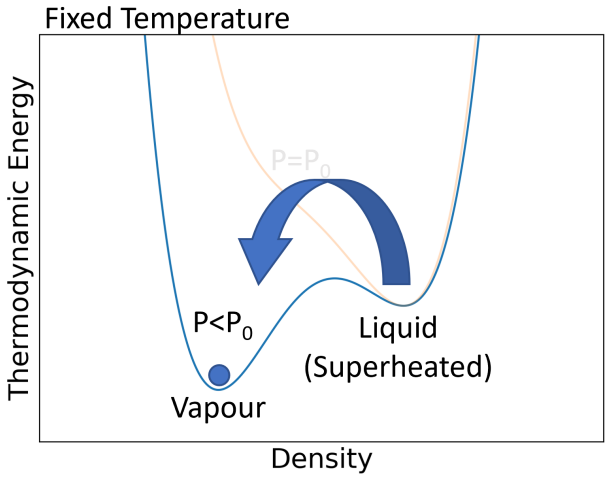




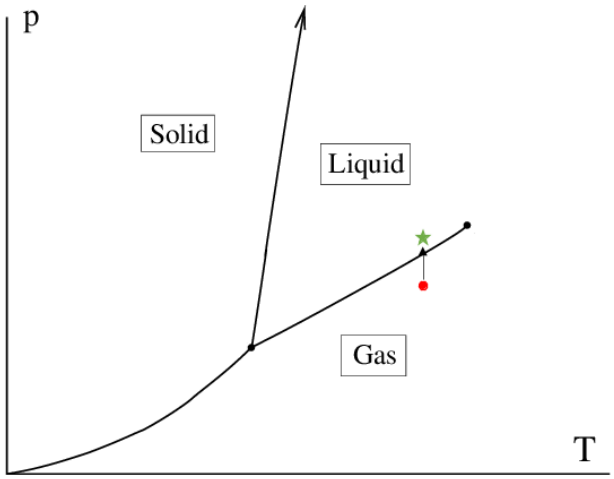


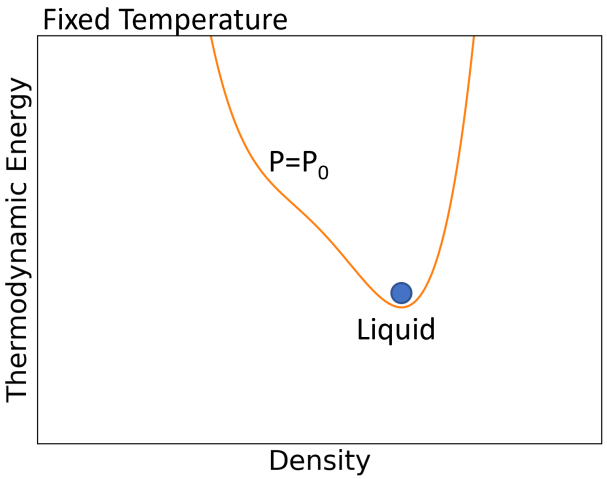


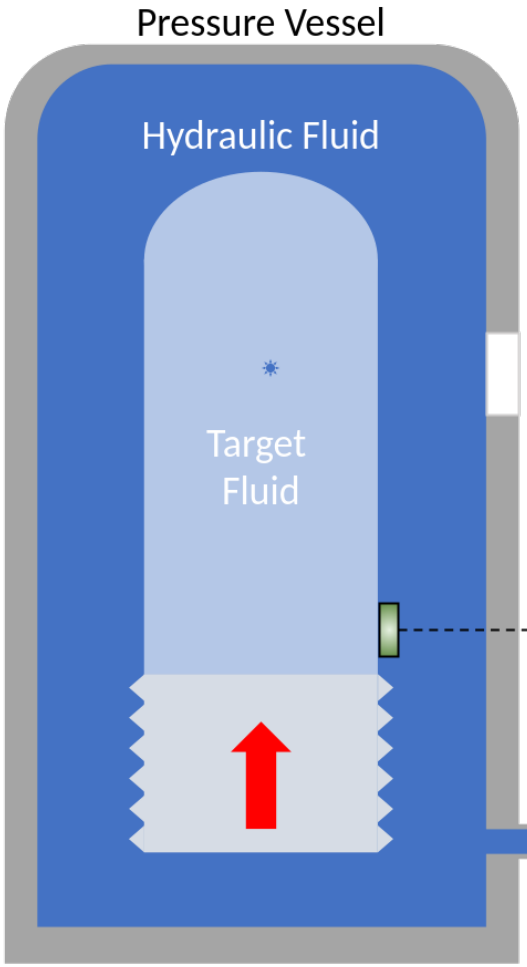


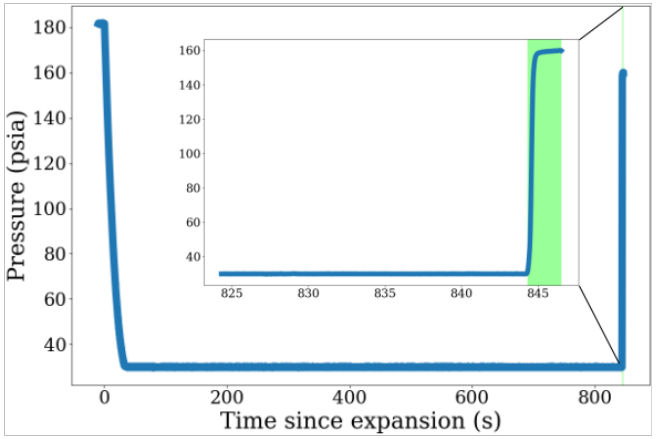


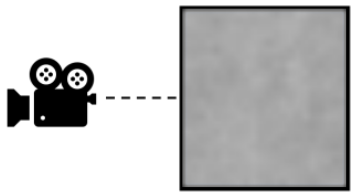
Bubble Chambers as Particle Detectors

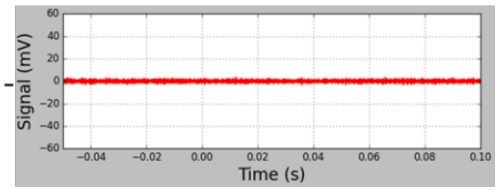






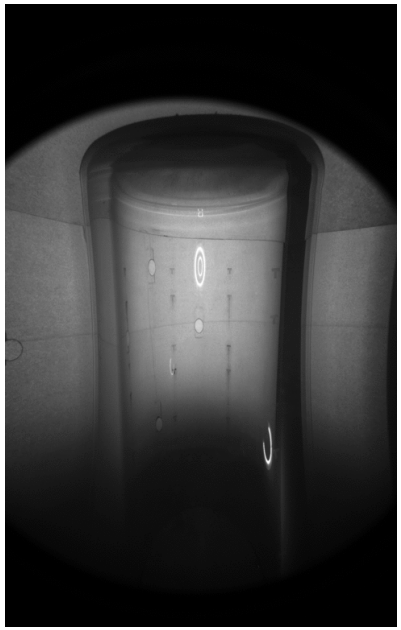


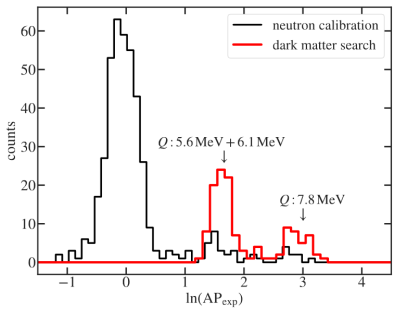




Background Events in Bubble Chambers

Alphas





Nuclear Recoils

Electron Recoils

Background Events in Bubble Chambers

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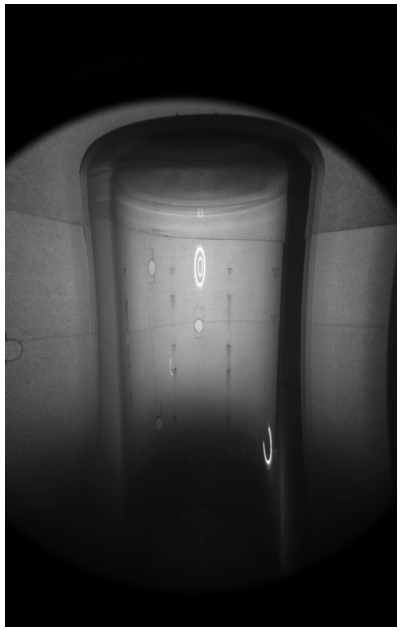

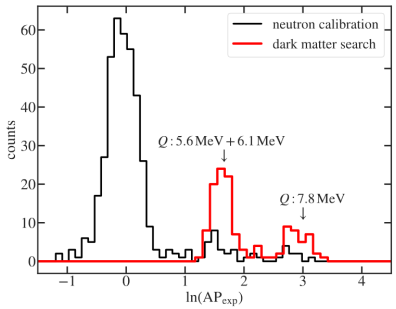

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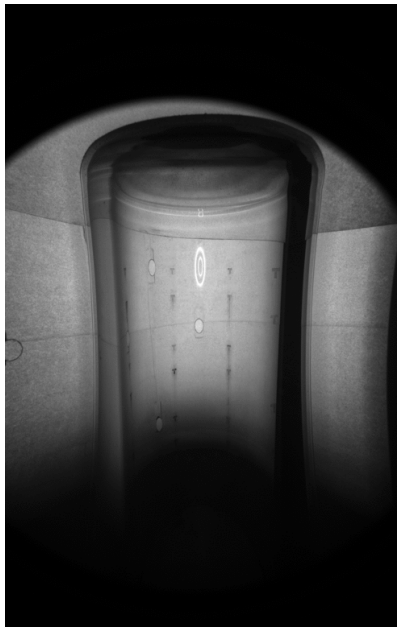

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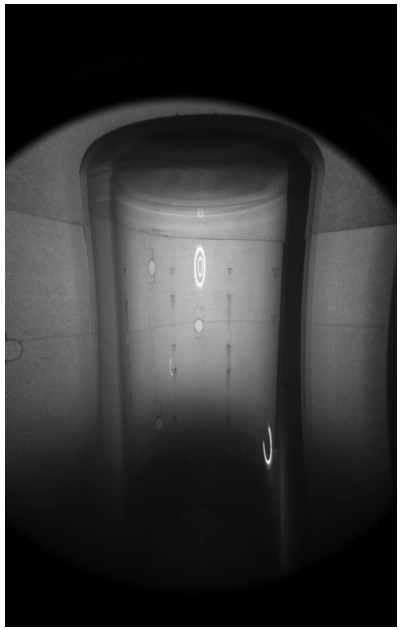

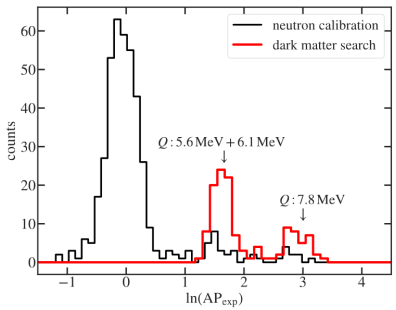

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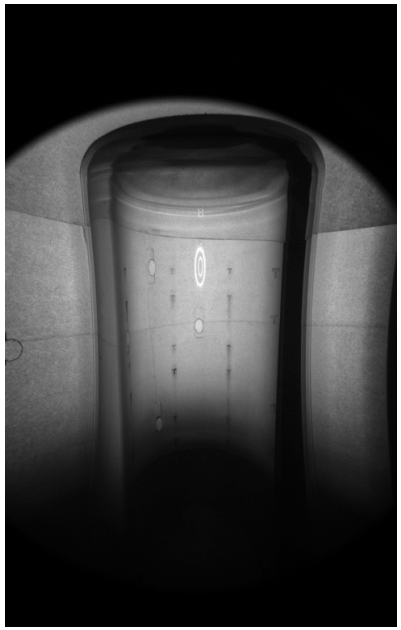

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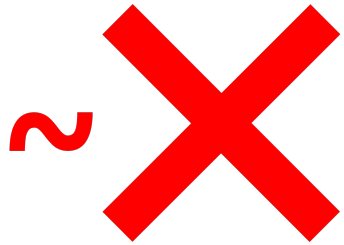
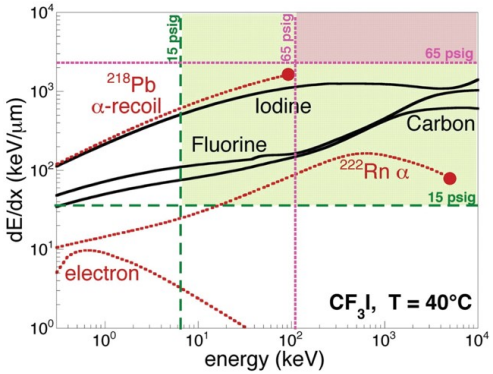
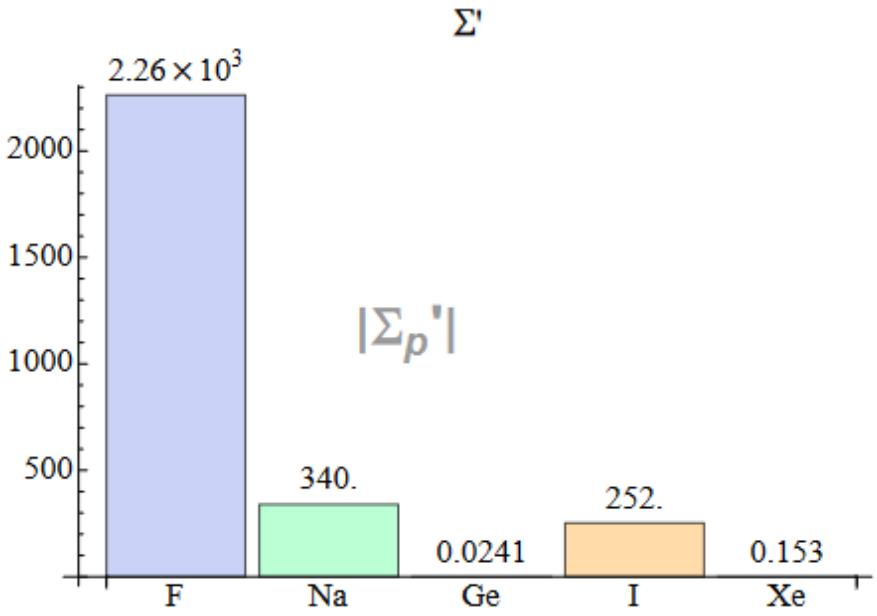
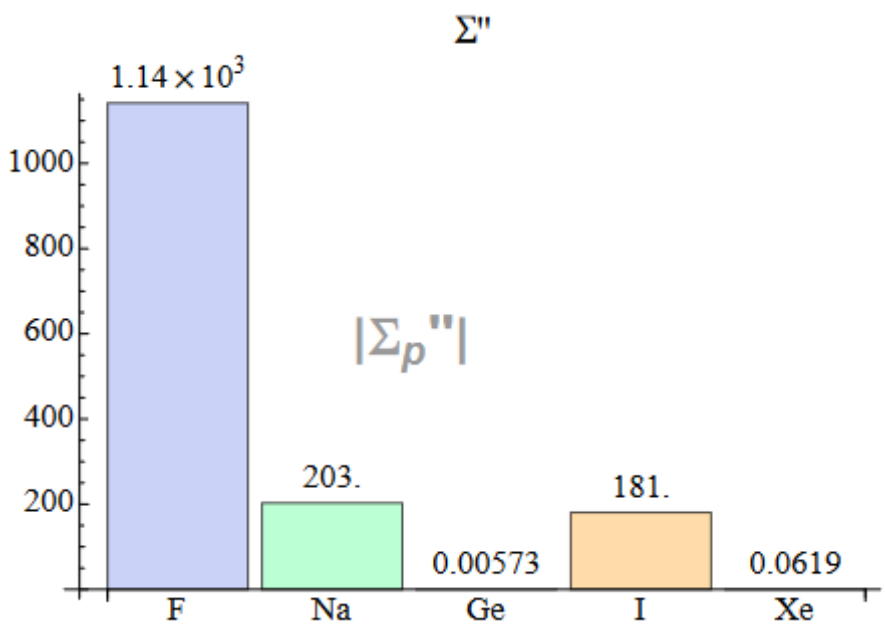




Why Bubble Chambers?

- Very low sensitivity to electron recoil events
- Ability to change target fluids to exploit sensitivities
- Large unexplored parameter space with promising physics results





A. Liam Fitzpatrick et al JCAP02(2013)004

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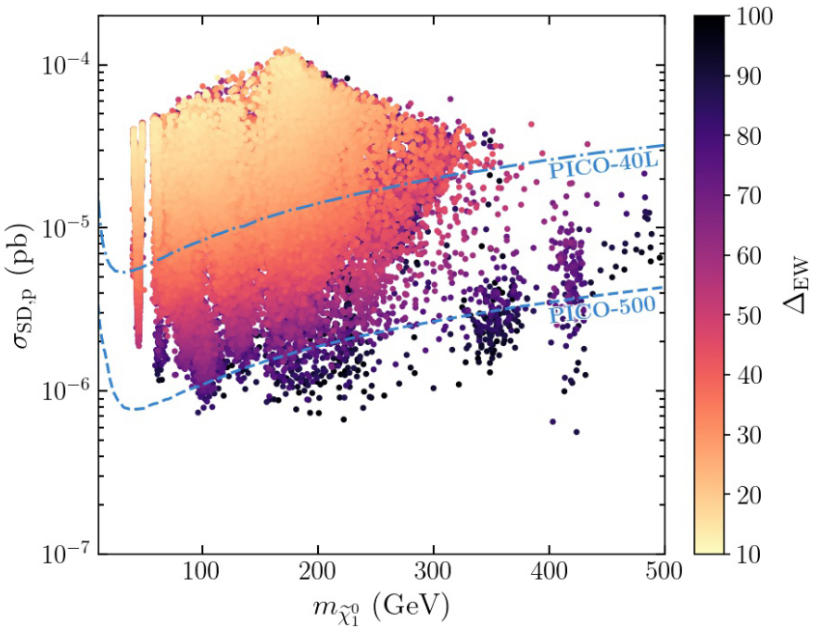
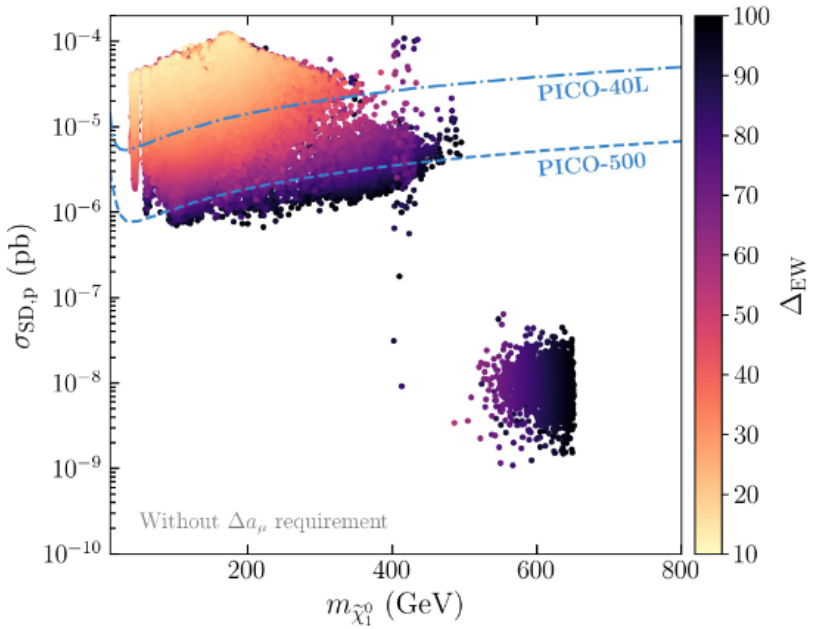
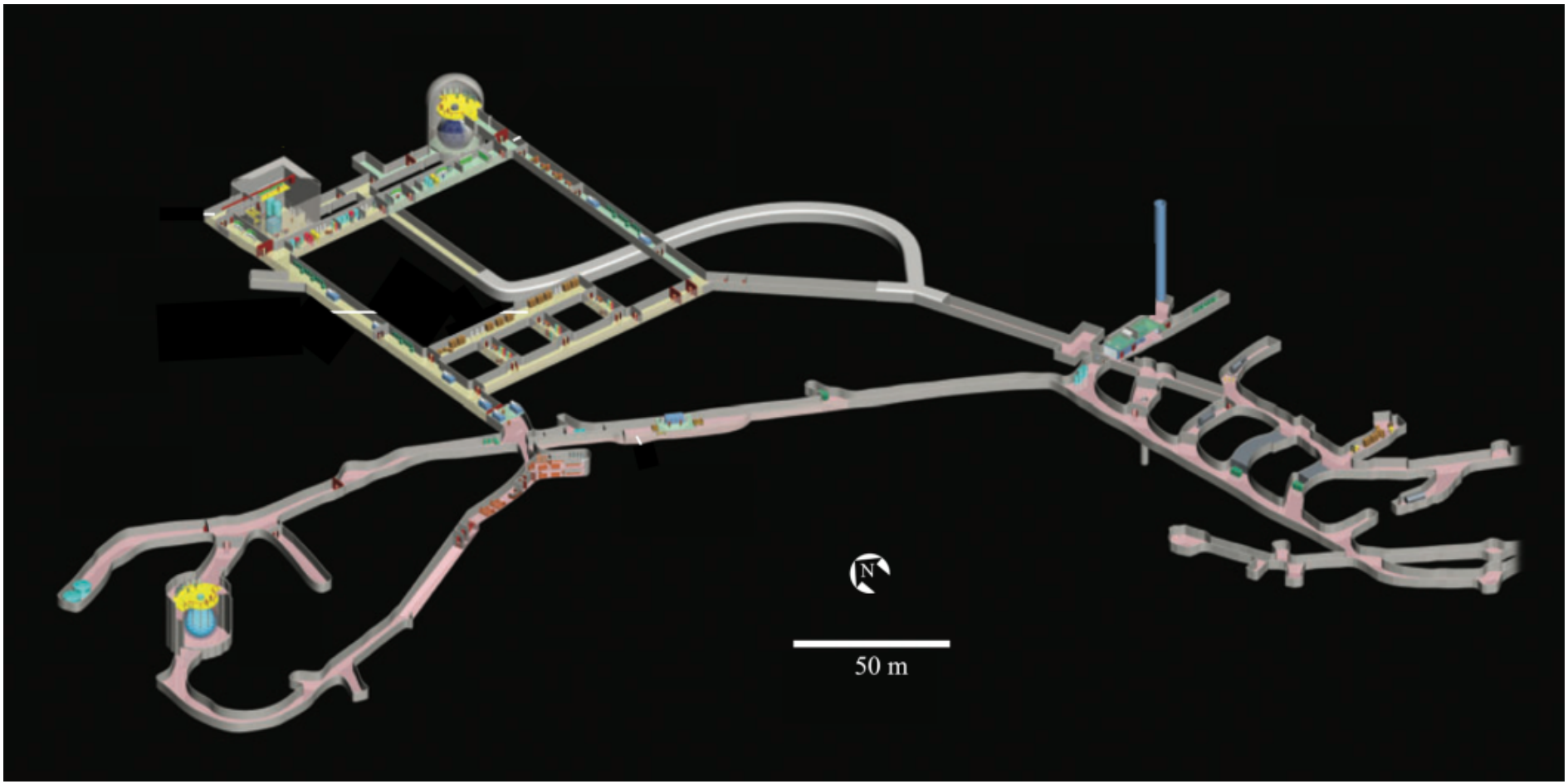




Beekveld *et al.* SciPost Phys. 11, 049 (2021)

PICO-40L at SNOLAB



(Adapted from) Jillings, Chris. (2016). The SNOLAB Science Program. Journal of Physics: Conference Series. 718. 062028. 10.1088/1742-6596/718/6/062028

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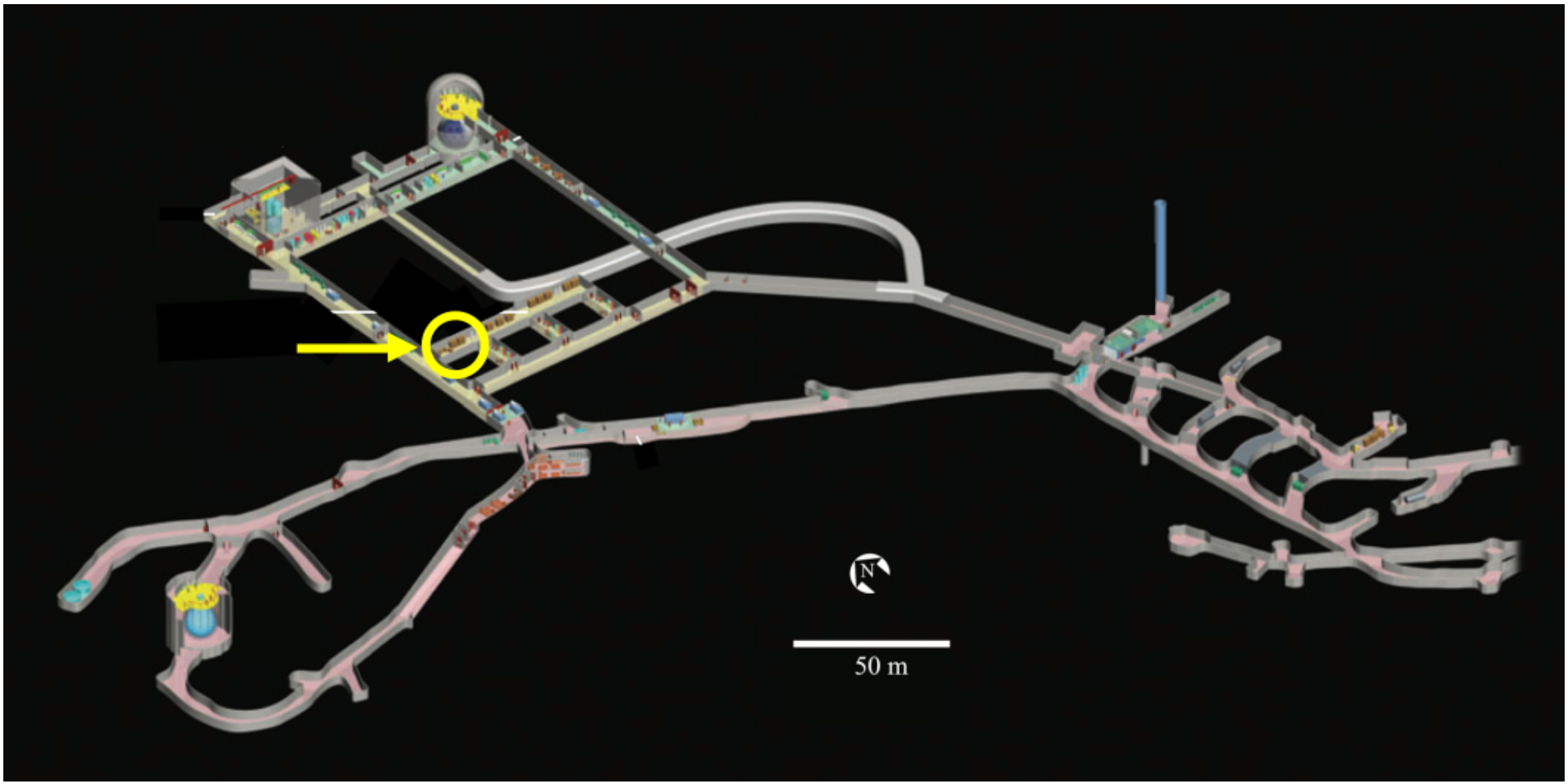
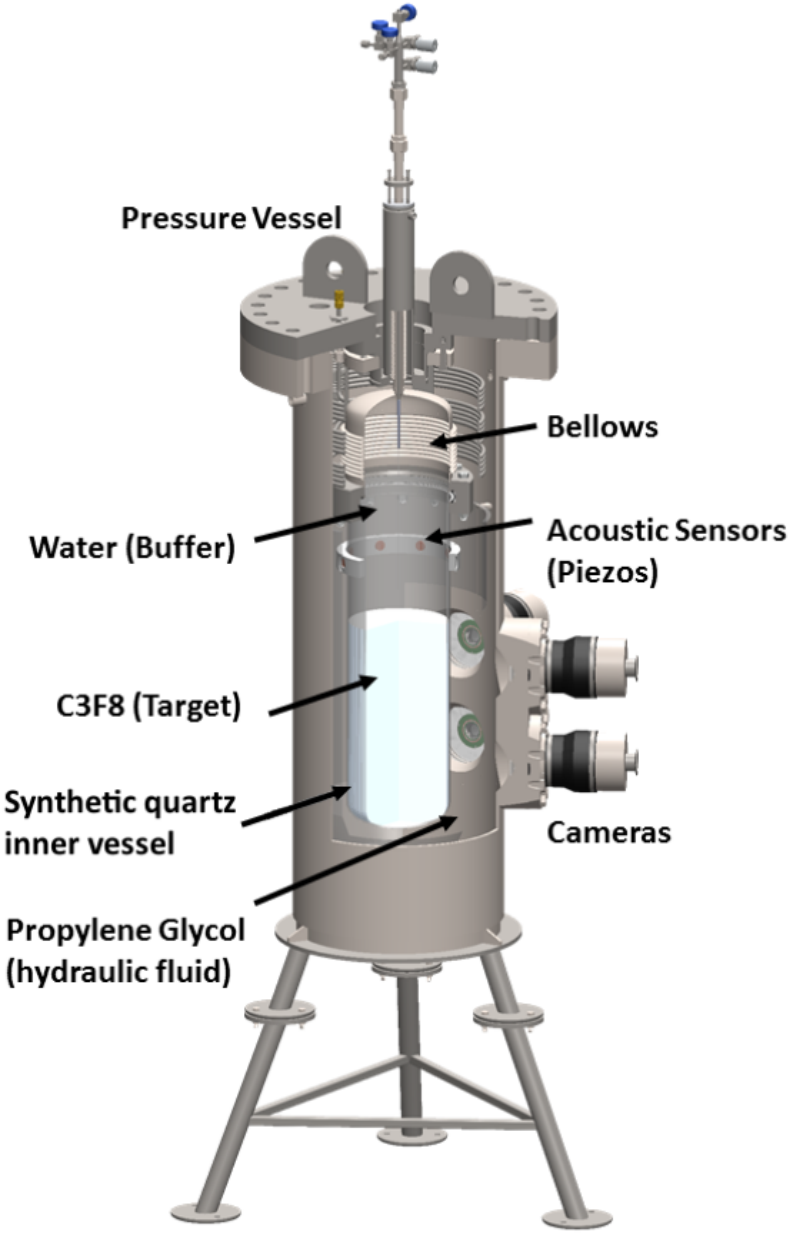


(Adapted from) Jillings, Chris. (2016). The SNOLAB Science Program. Journal of Physics: Conference Series. 718. 062028. 10.1088/1742-6596/718/6/062028

PICO-60

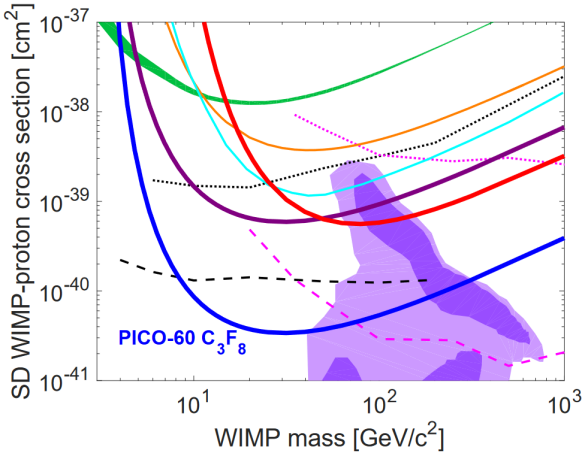
- 60 kg fiducial volume
- "Upside-down" design
- Full detector at constant temperature
- Superheated freon separated from bellows by layer of water

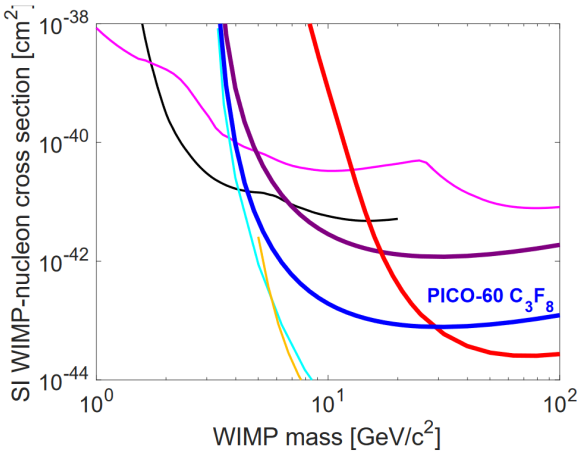
- World-leading WIMP-proton limit set in 2016 and 2017



PICO-60 Results

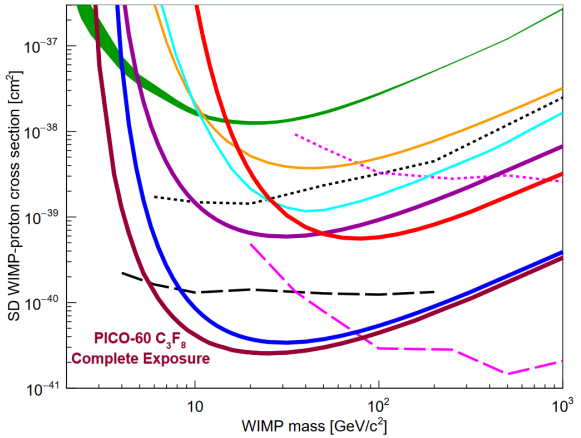
Run 1

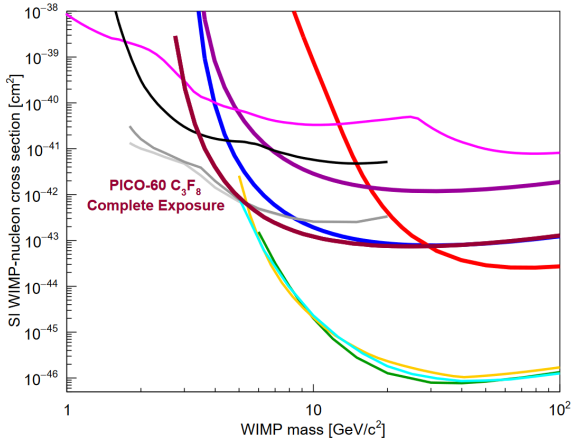




C. Amole et al. (PICO Collaboration) Phys. Rev. Lett. 118, 251301 (2017)

Combined (Run 1 + 2)

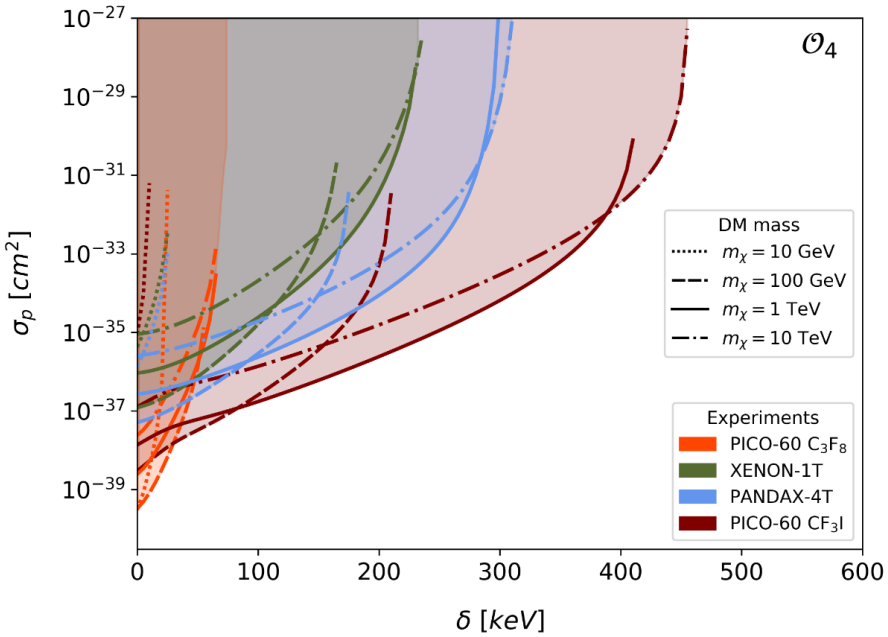


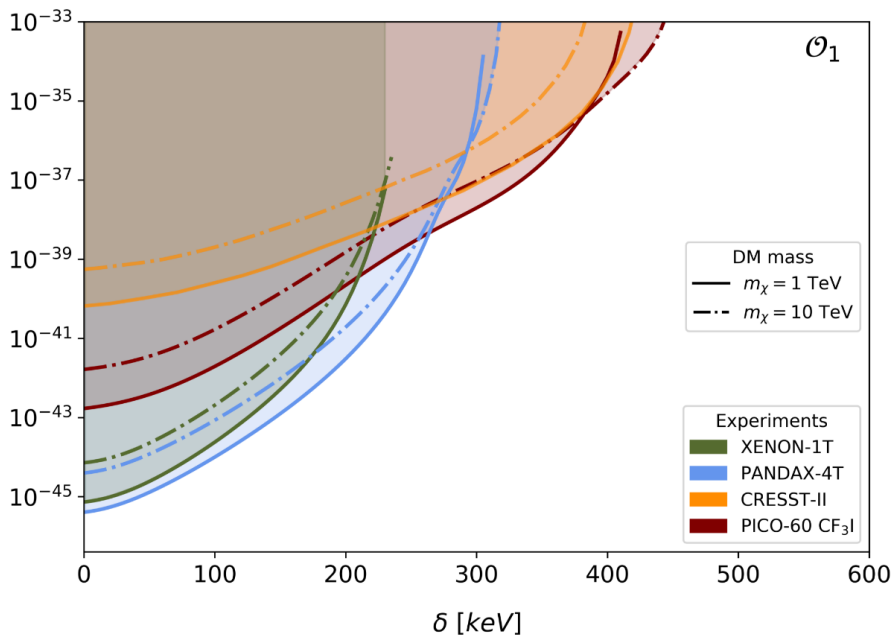


C. Amole et al. (PICO Collaboration) Phys. Rev. D 100, 022001 (2019)

PICO-60 Results

Inelastic DM Scattering Results

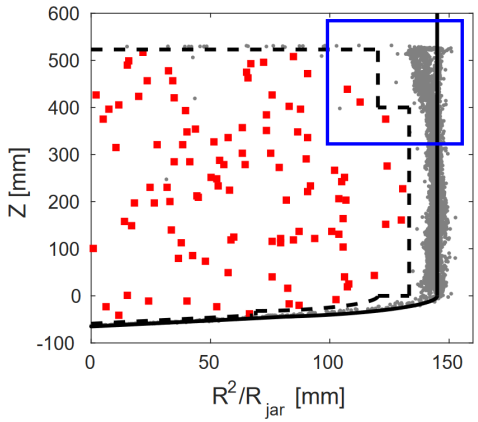




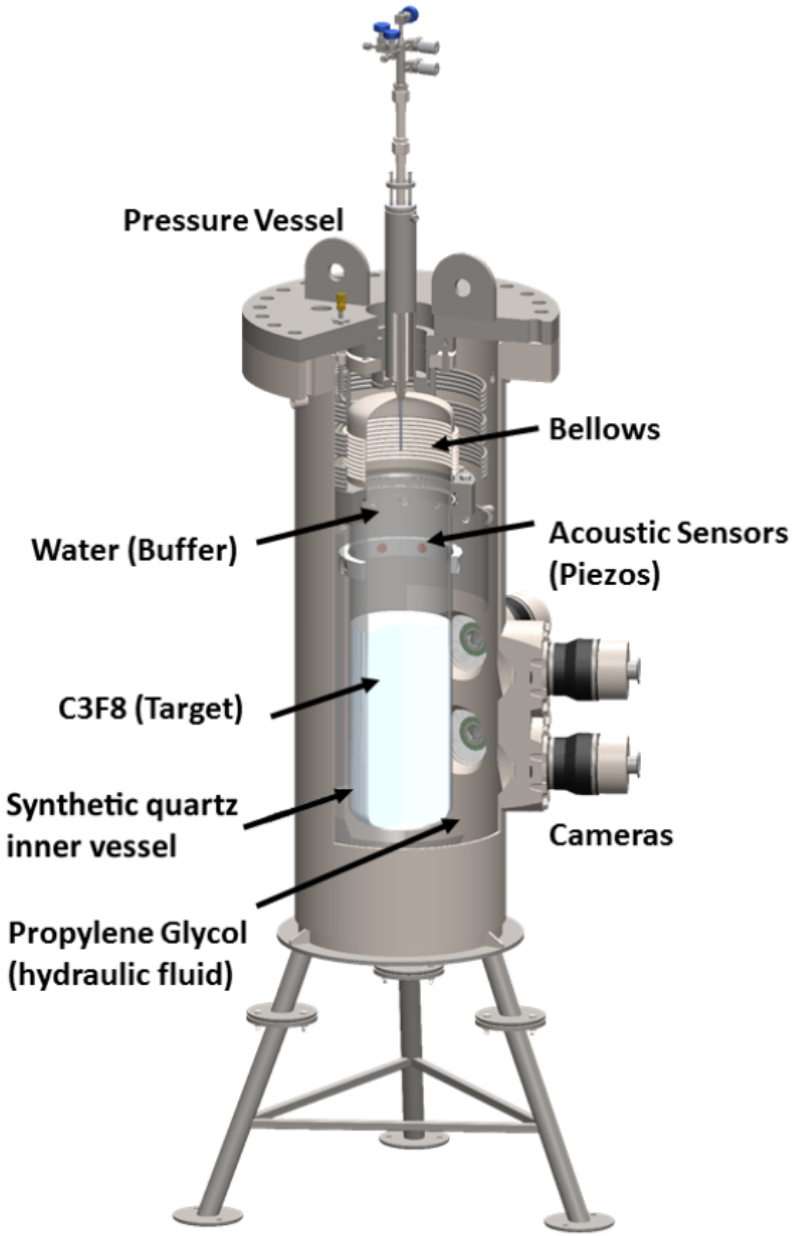
Adams, E. et al. Preprint at https://doi.org/10.48550/arXiv.2301.08993 (2023). Accepted to Physical Review D.

PICO-60 Issues

- Water and freon mixed at interface
  - Water droplets stick to jar wall
  - Far higher rates observed near wall/freon/water interface

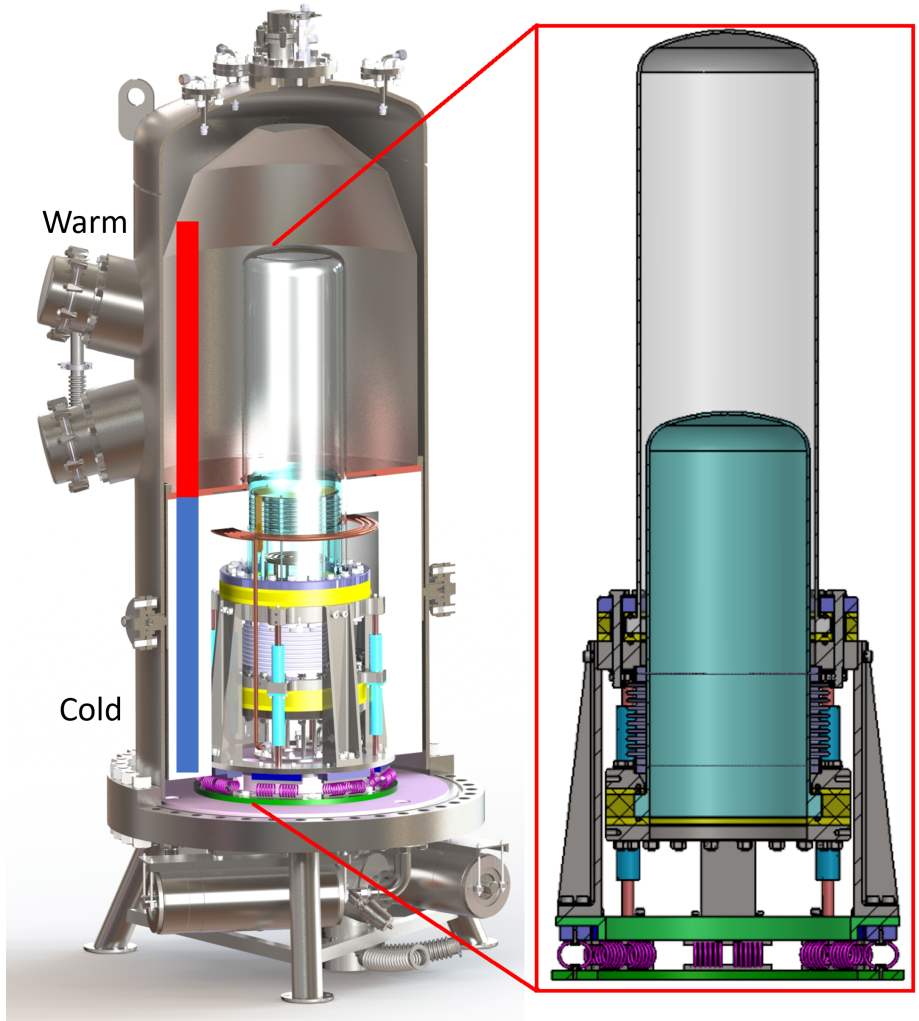


- Orientation of jar may lead to debris accumulating at bottom of jar



PICO-40L

- First large-scale implementation of "right-side up" design:
  1. Eliminate water buffer, replace with second jar
  2. Flip inner vessel, bellows at the bottom
  3. Keep bellows region cold to prevent nucleation on bellows



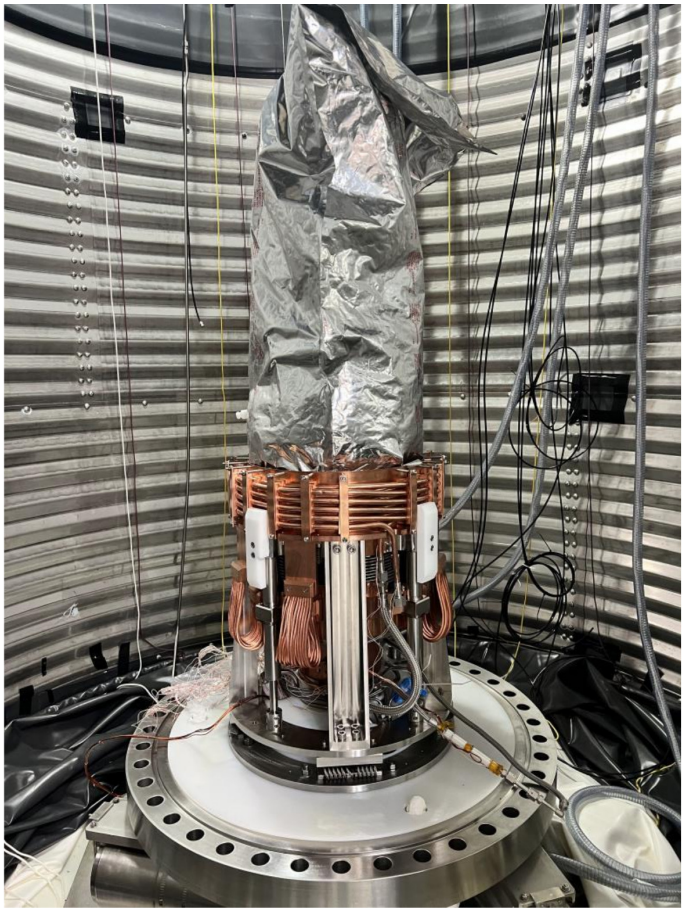
PICO-40L Timeline

- 2019: Assembly and system tests
- May 2020: Commissioning begins with all systems active
- September 2020: Commissioning halted due to chiller issues
- May 2021: Leak appears internal to detector; disassembly begins
- 2021-2022: Fix leak, upgrades to address shortcomings of thermal system
- 2022: Reassembly

COVID

- Q2-Q3 2023: Recommissioning and Calibrations
- Imminent: Start of physics run

PICO-40L Installation and Commissioning



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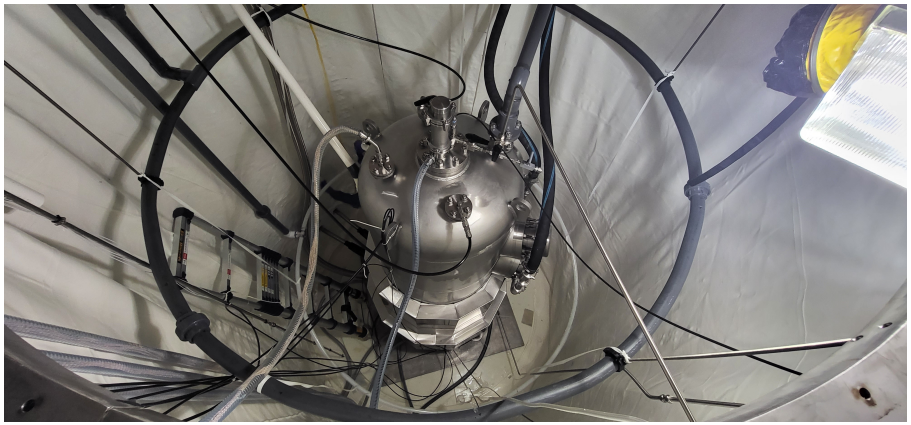
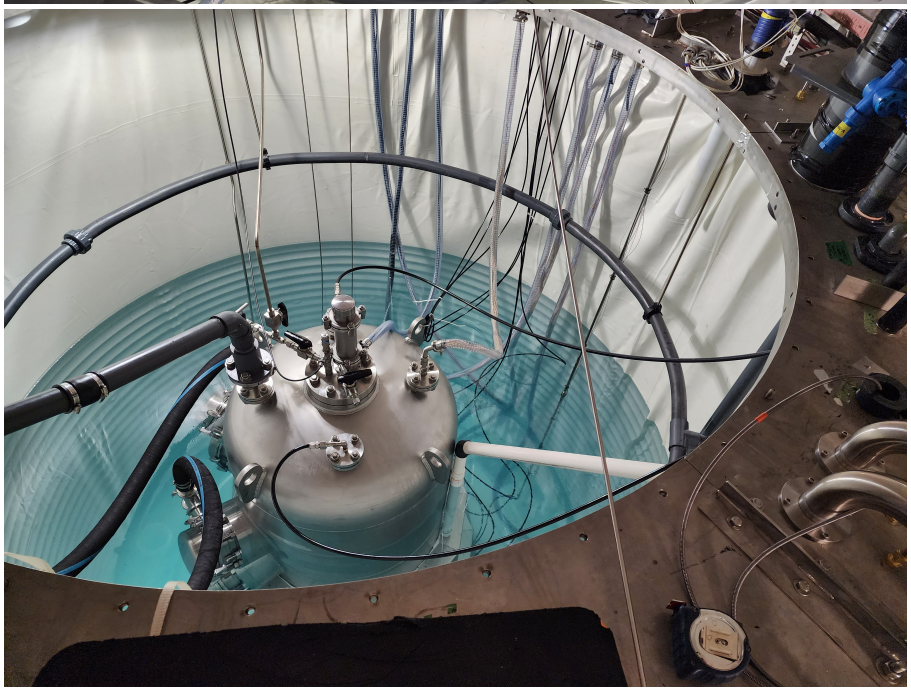
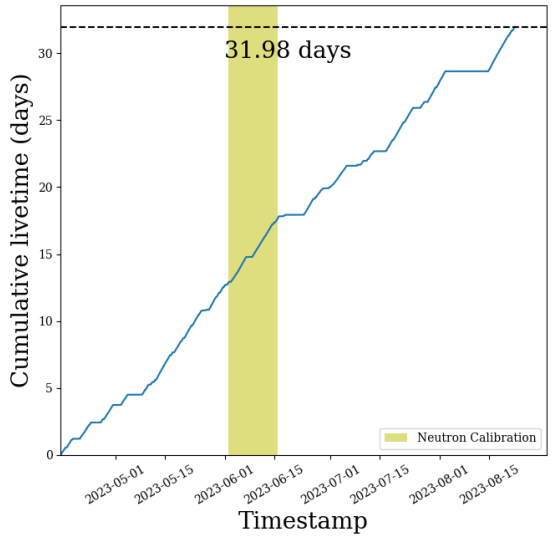
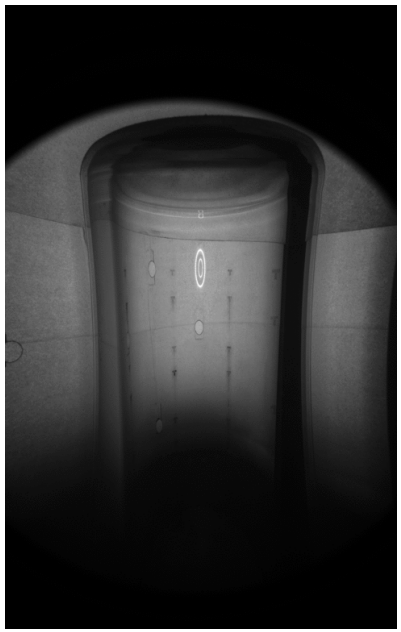
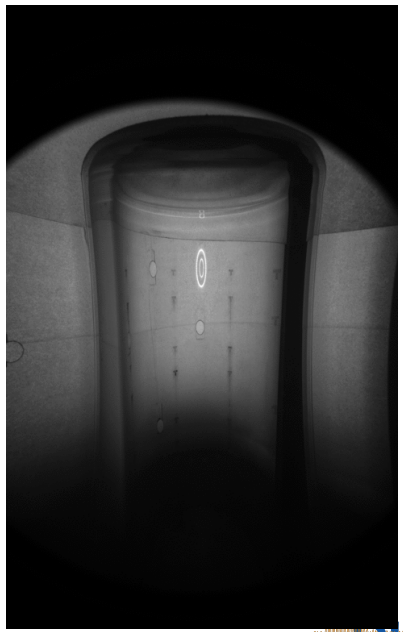






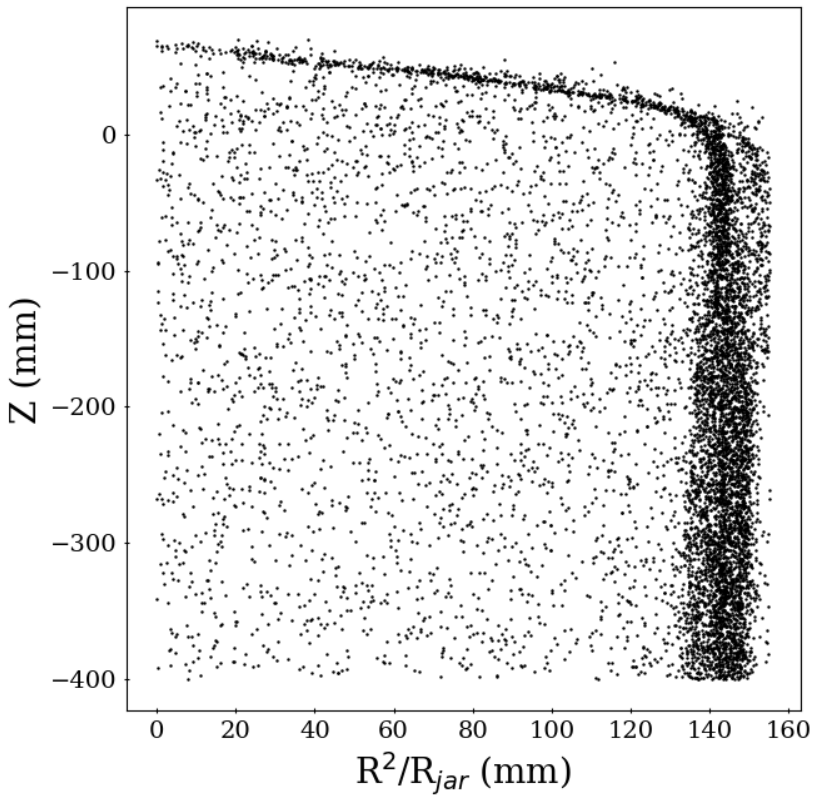




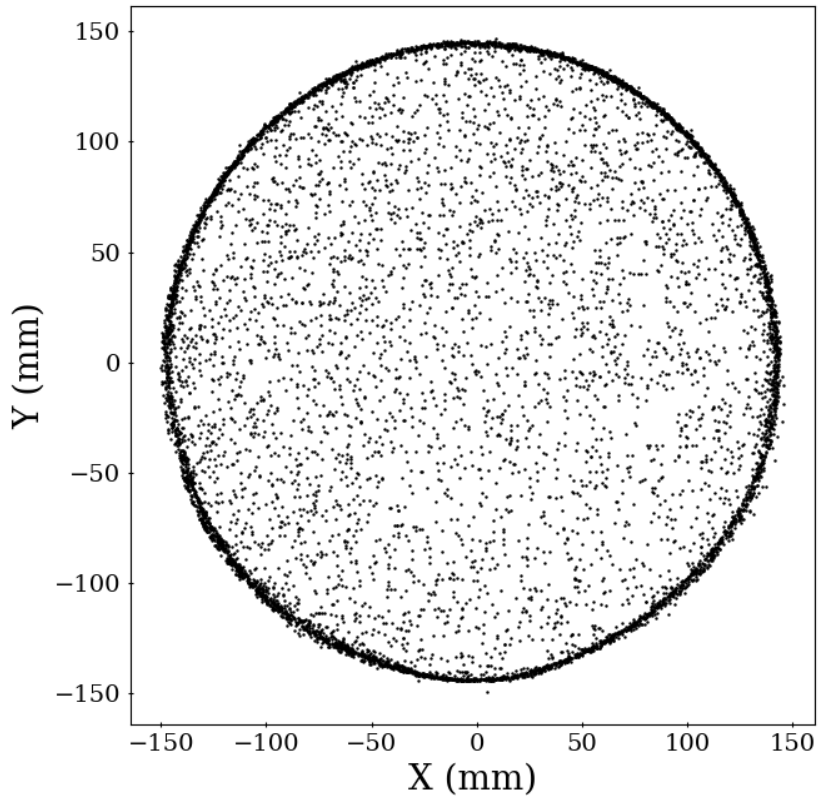
PICO-40L: Position Reconstruction

- Stereoscopic images allow for 3D position
- Improved position reconstruction, with 2 mm spatial resolution

R^2 vs. Z



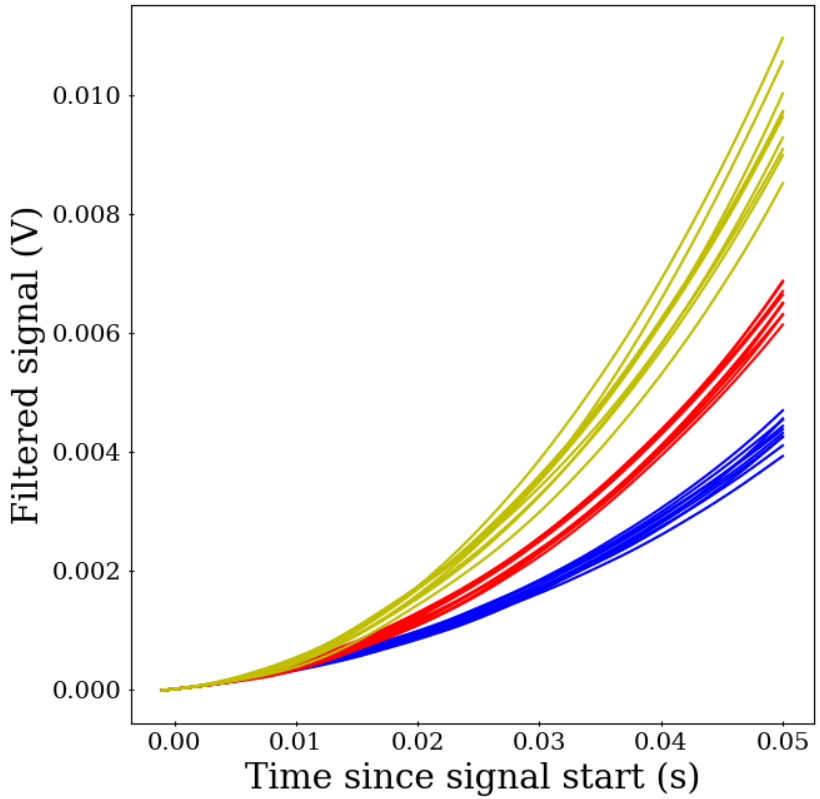
X vs. Y



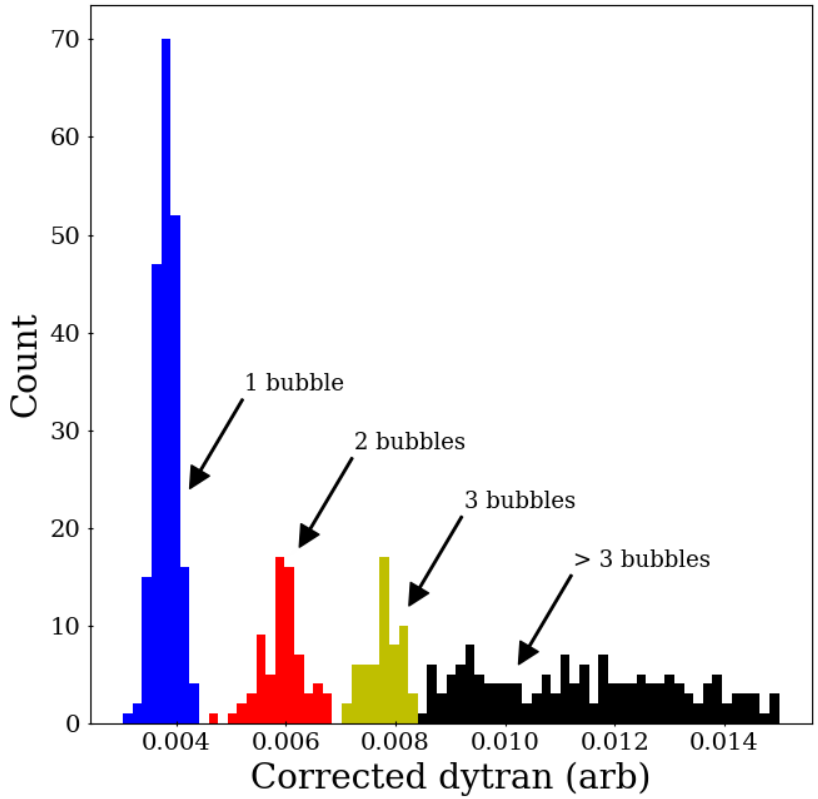
PICO-40L: Bubble Counting with Dytran

- Fast pressure transducer measures change in pressure
- Pressure rise allows for precise bubble counting and fiducialization

Filtered Dytran



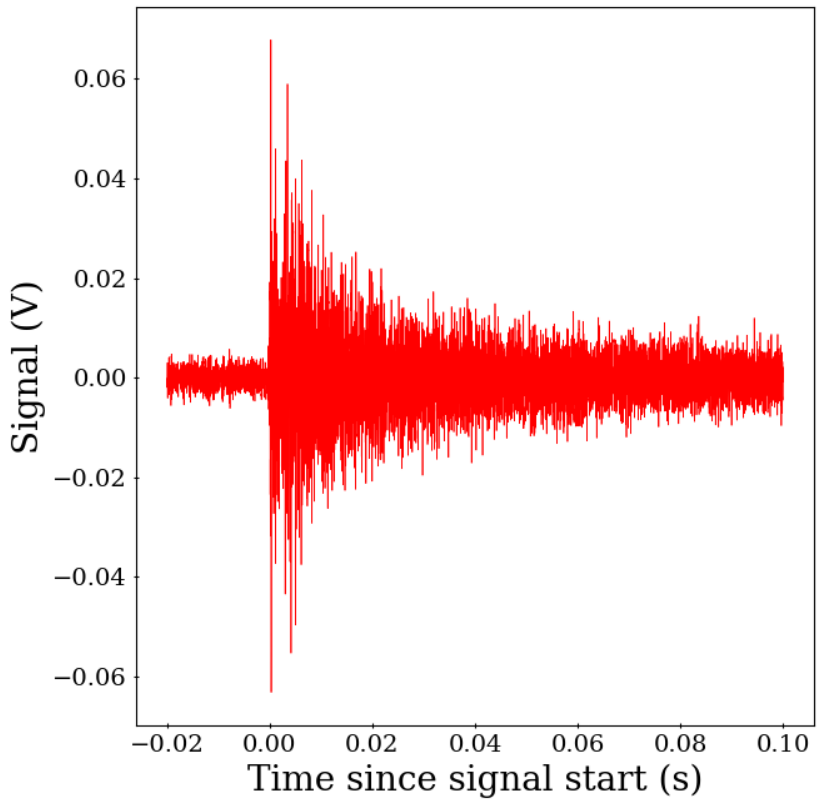
Corrected Dytran



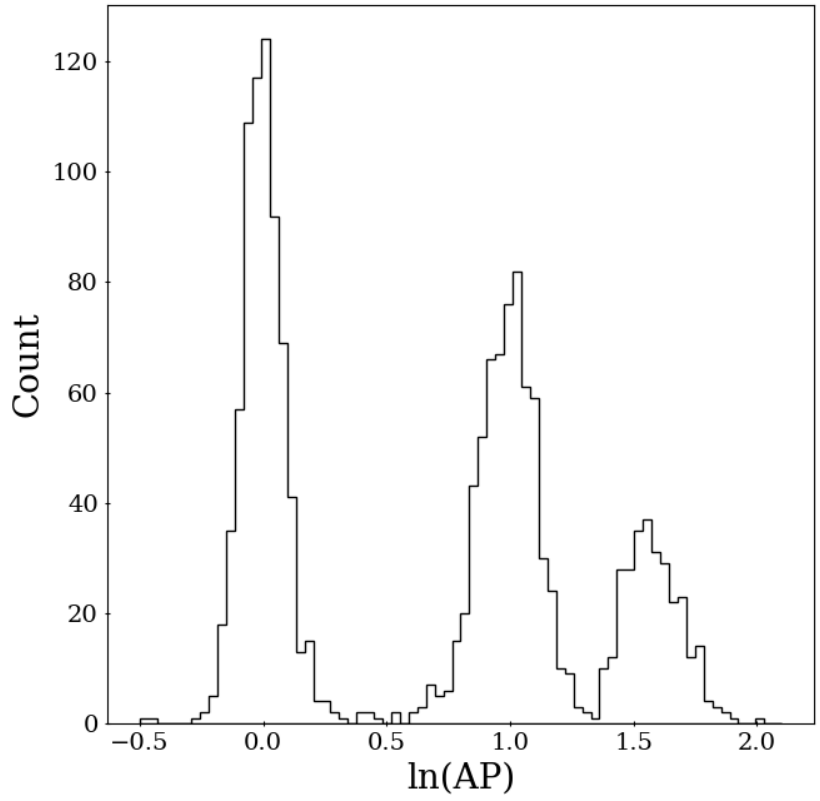
PICO-40L: Particle Identification by Acoustics

- Piezoelectric sensors coupled to outer jar wall capture acoustic signal
- Magnitude of acoustic signal allows for discrimination of event types

Acoustic Signal



Acoustic Parameter



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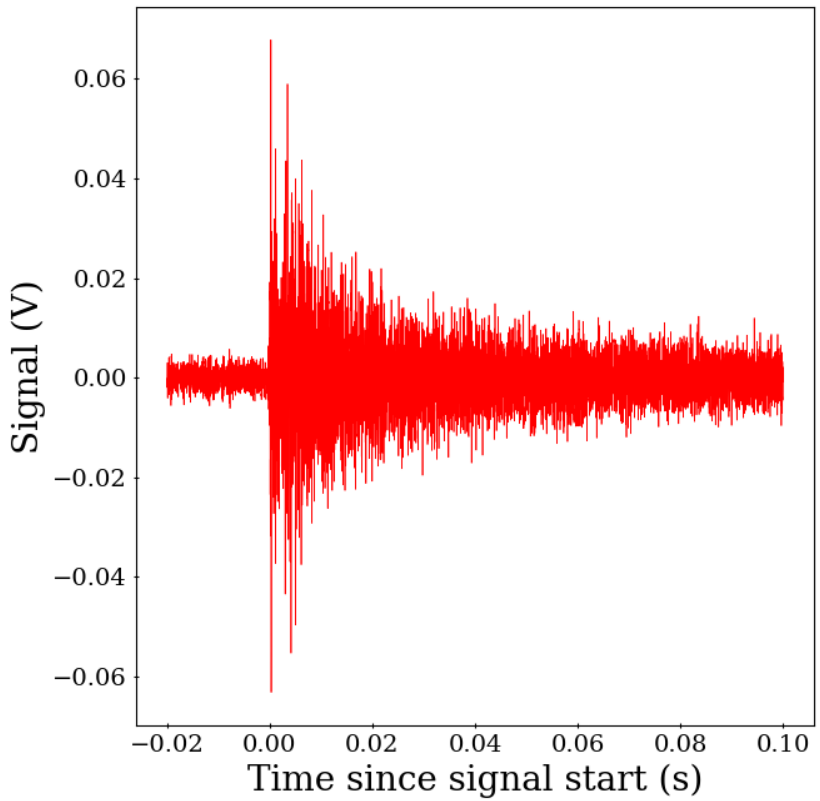
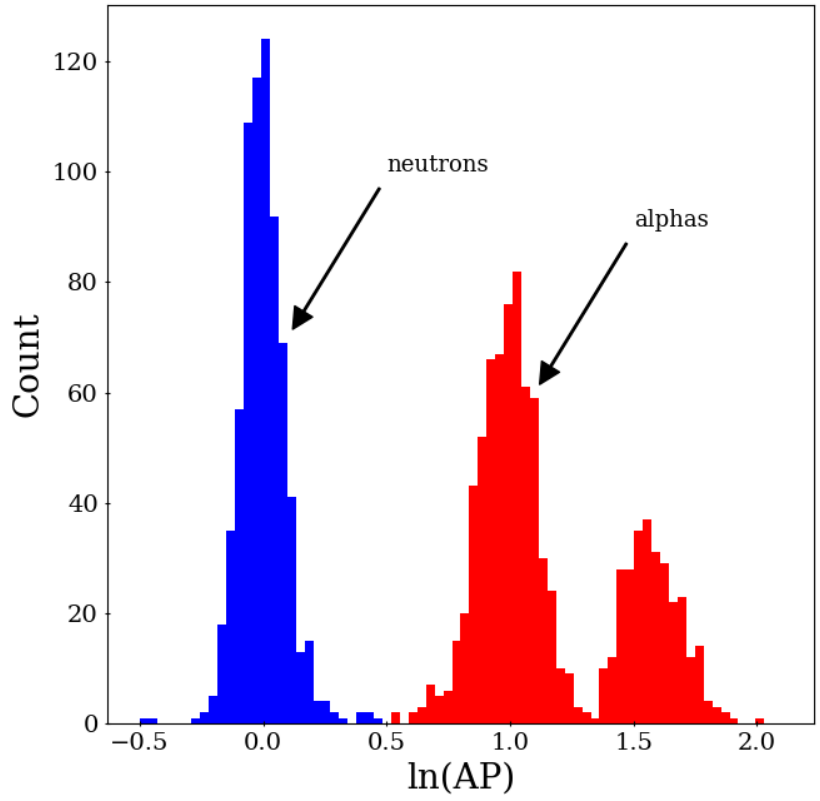


Acoustic Parameter



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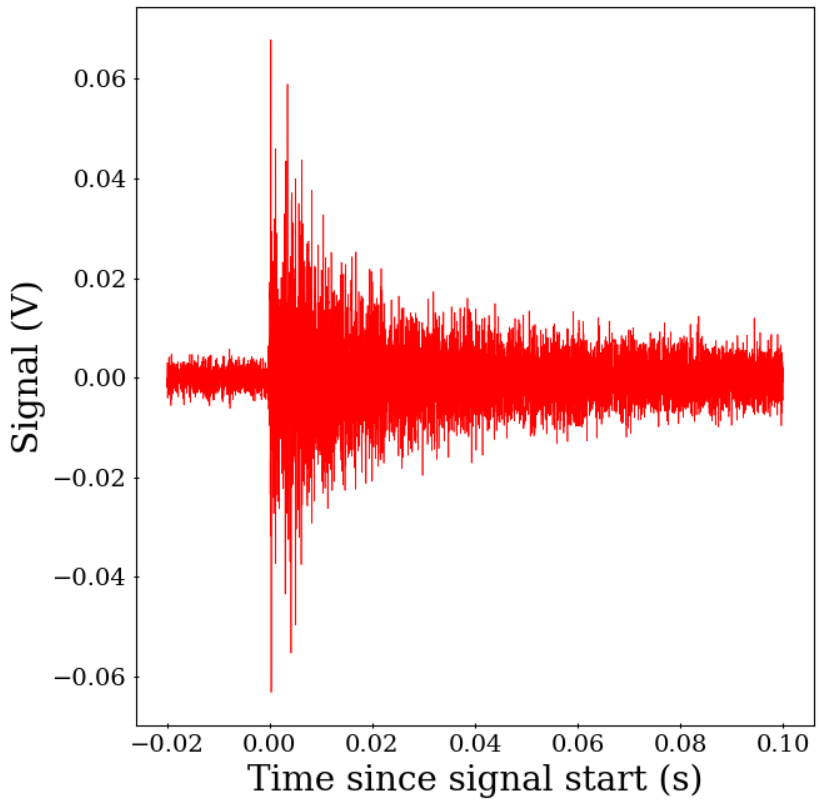
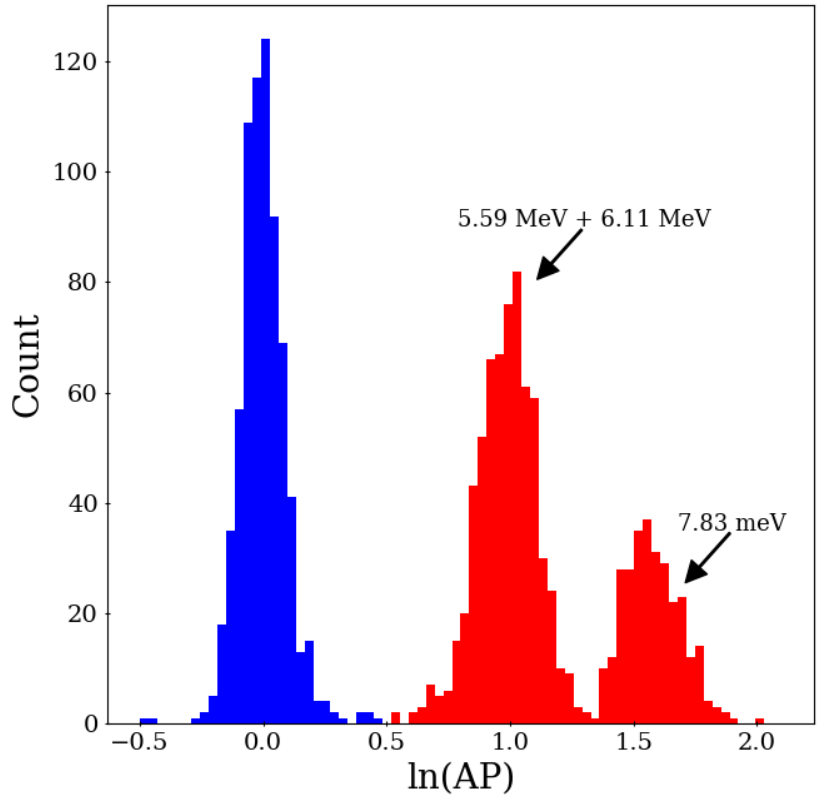


Acoustic Parameter



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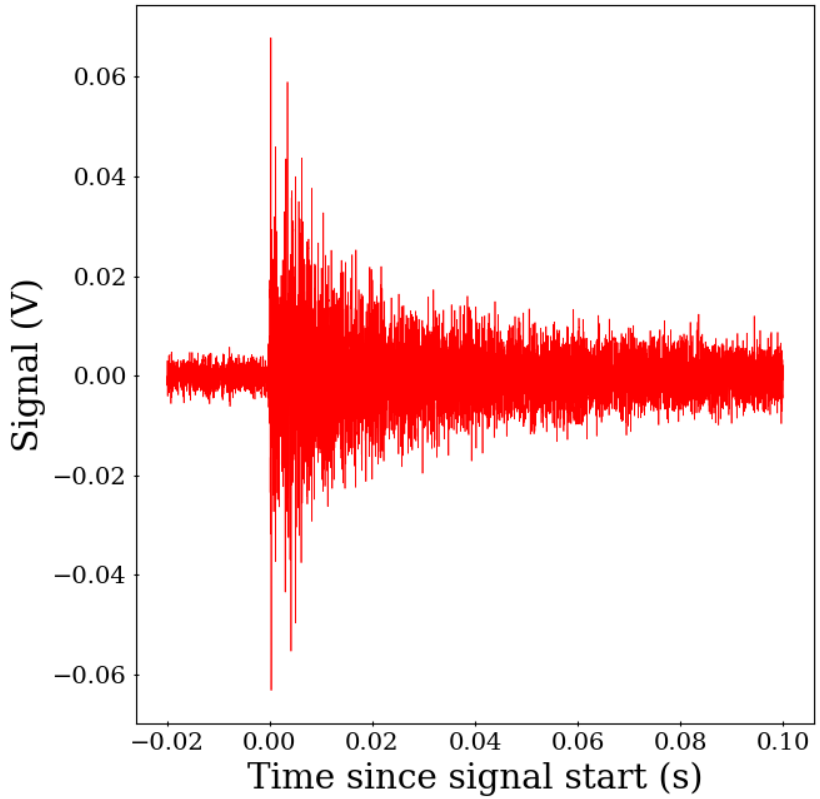
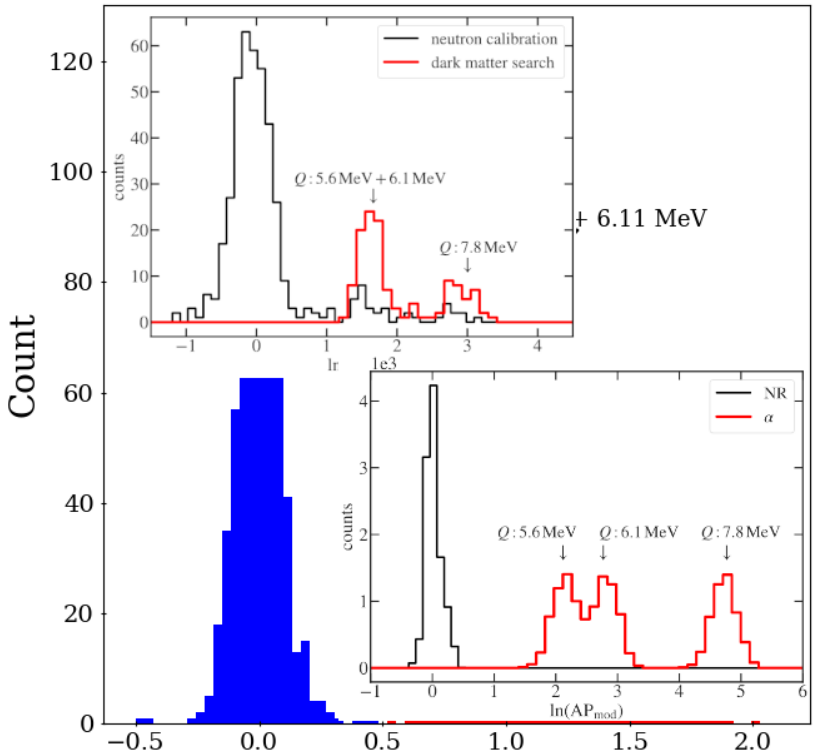
Acoustic Signal



Acoustic Parameter

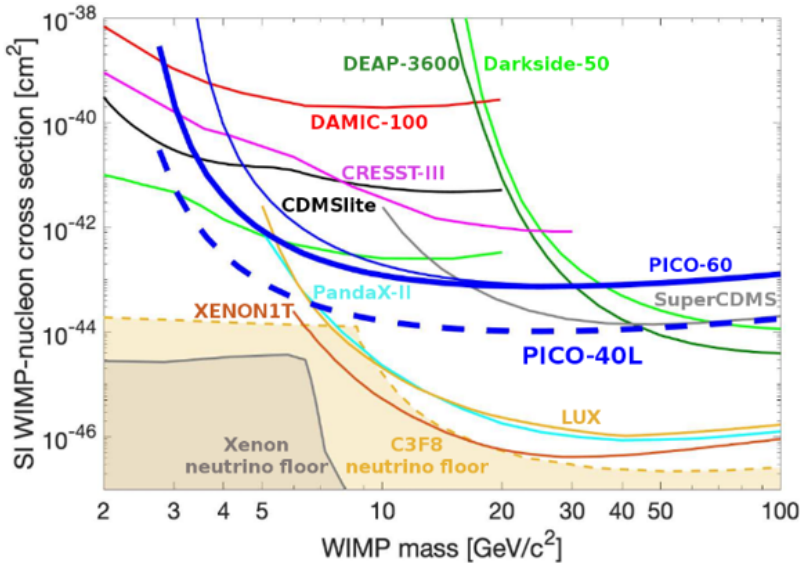


Kozynets, T., Fallows, S. & Krauss, C. B. Astroparticle Physics 105, 25–30 (2019).

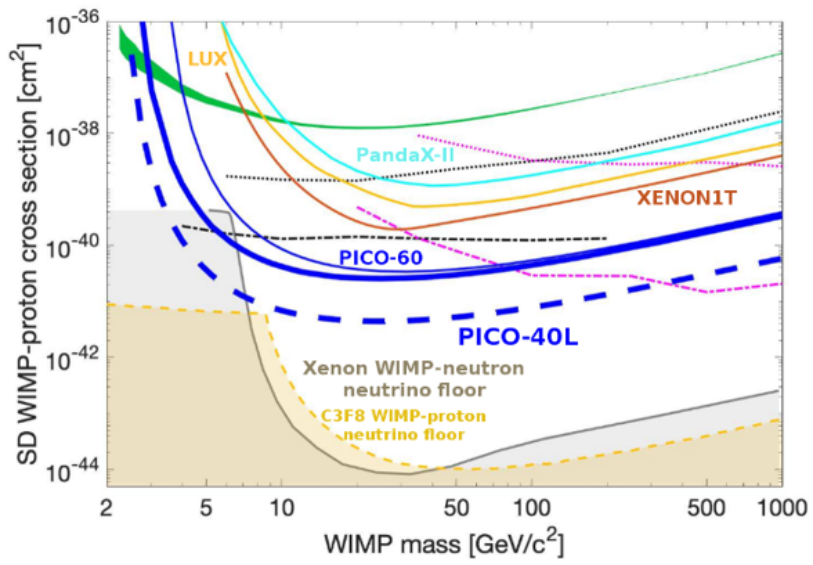
PICO-40L Projected Limits

Approximately 1 live year of data at 2.8 keV, with 2 background events.

Spin Independent Limit



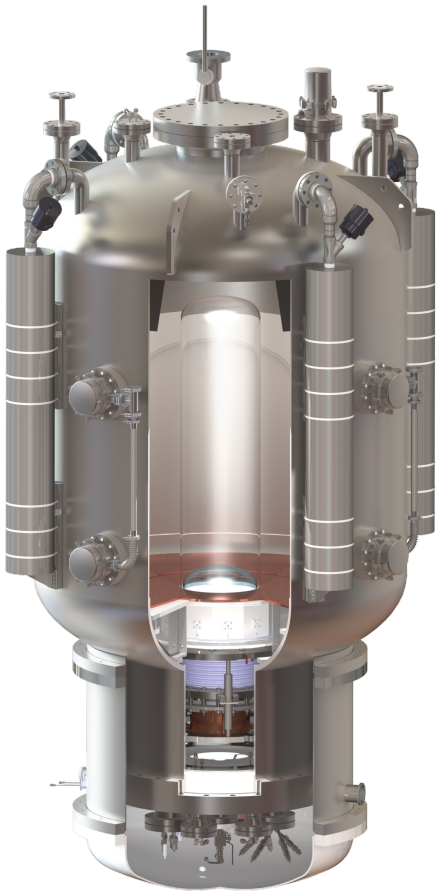
Spin Dependent Limit

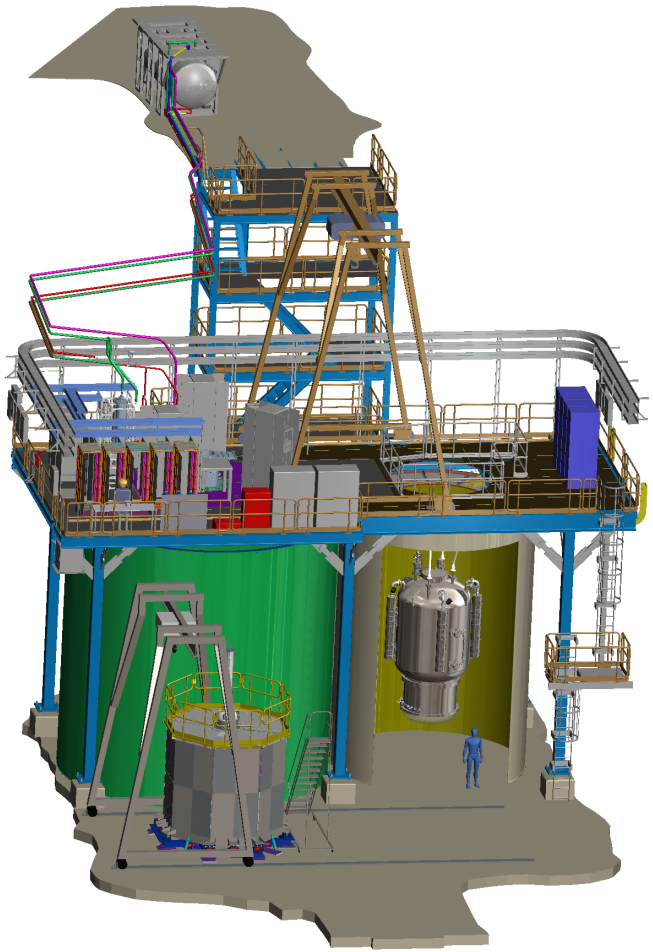


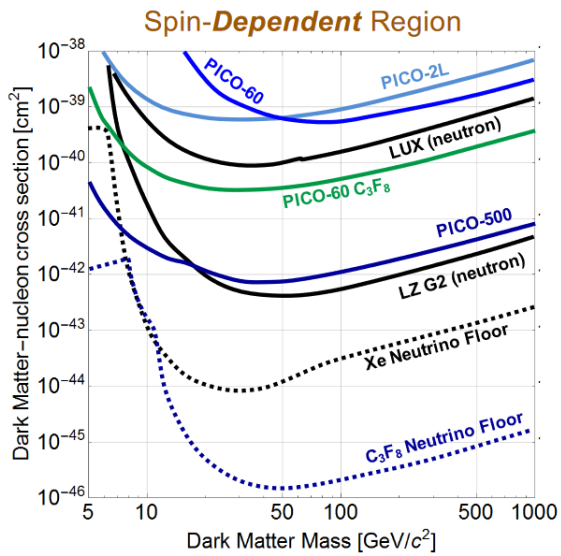
C. Amole *et al.* (PICO Collaboration), Phys. Rev. D 100, 082006 (2019)

PICO-500: The Next Generation Bubble Chamber

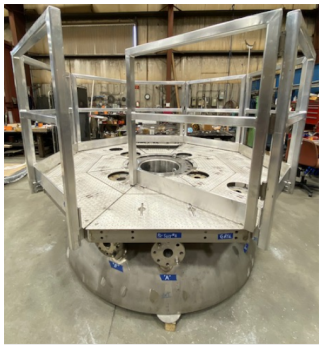
- 250 L of C_3F_8
- Situated in cube hall at SNOLAB
- Preparing for installation







PICO-500: The Next Generation Bubble Chamber



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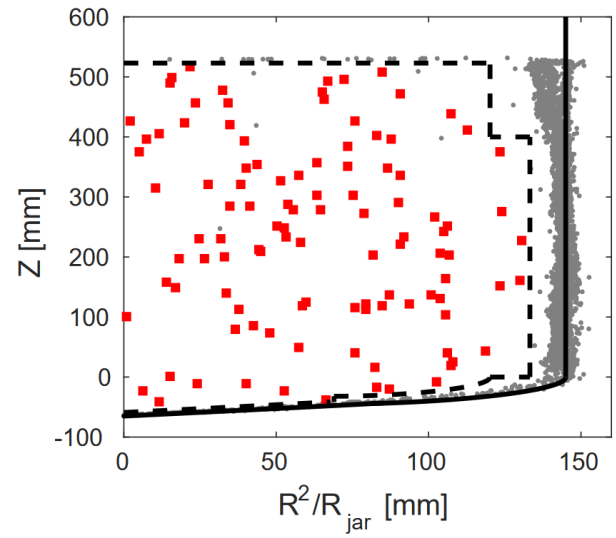
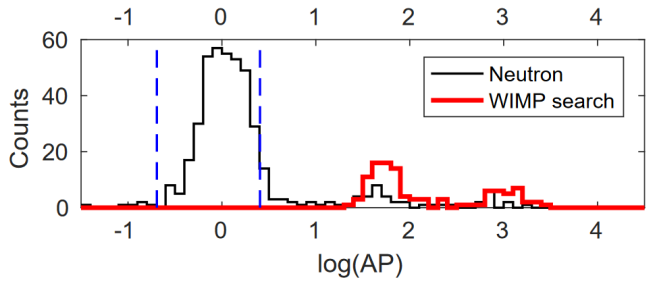
LaurentianUniversity UniversitéLaurentienne
J. Farine, A. Le Blanc, C. Licciardi, U. Wichoski

Extra Slides

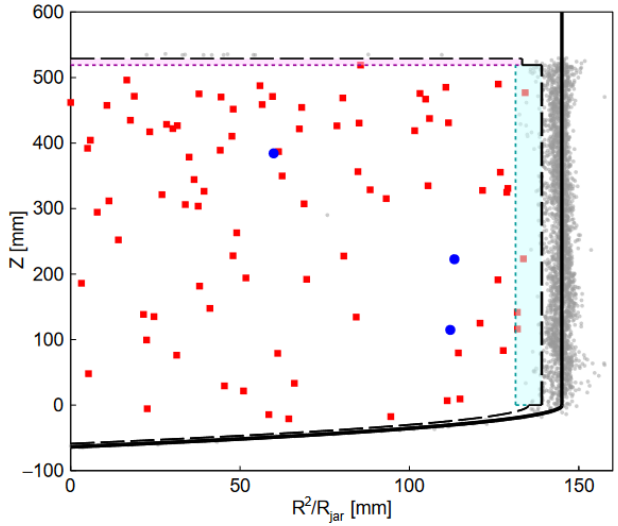
PICO-60 Results

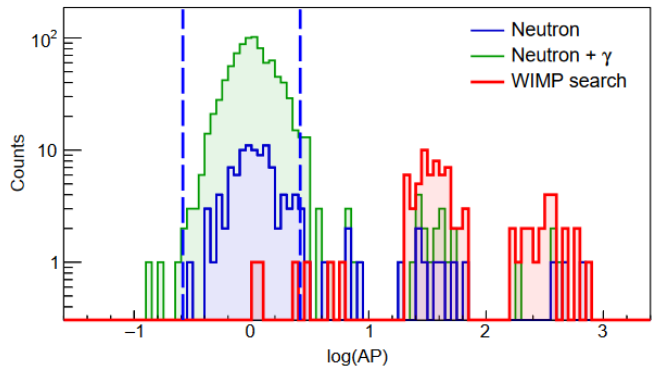
Run 1 ($Q_{Seitz} = 3.29$ keV)





Run 2 ($Q_{Seitz} = 2.45keV$)





PICO-60 Results

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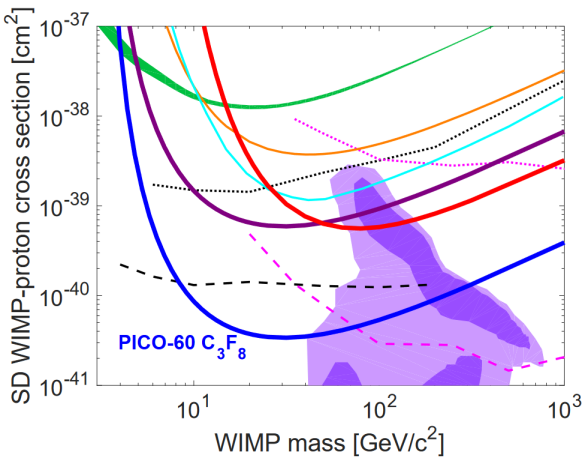
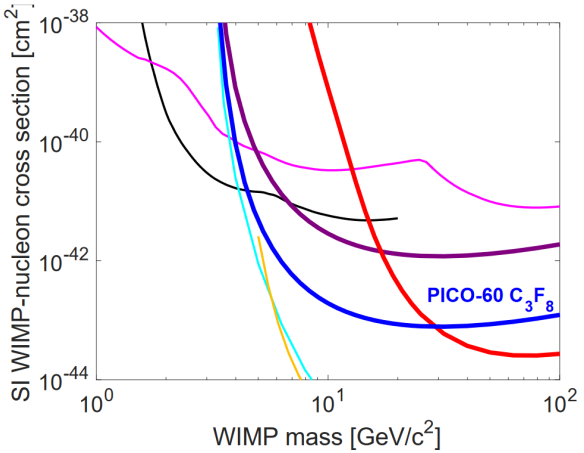
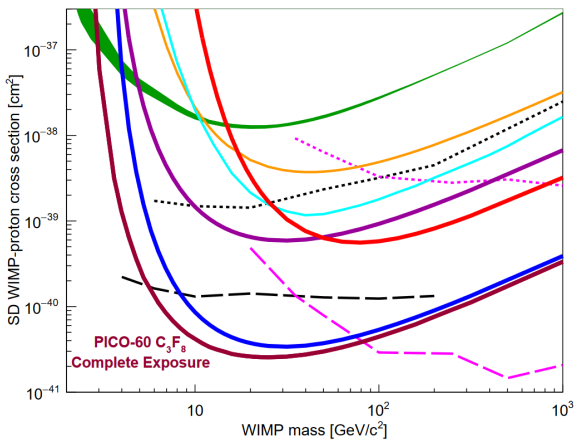
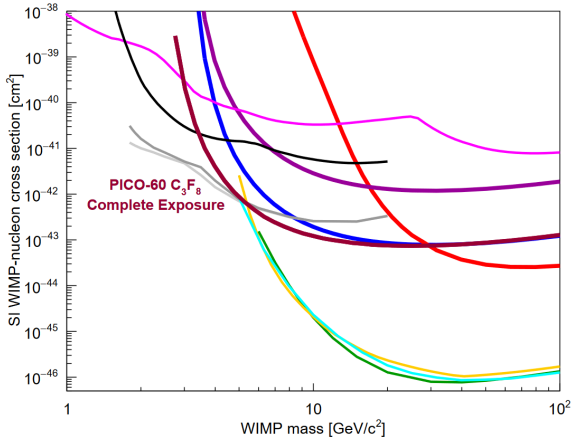




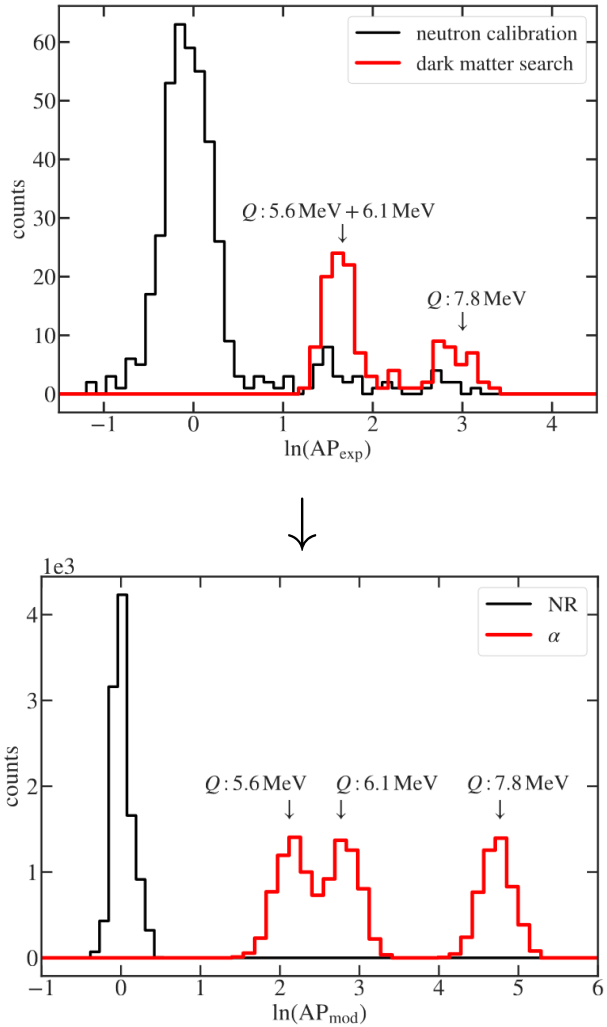
Combined (Run 1 + 2)





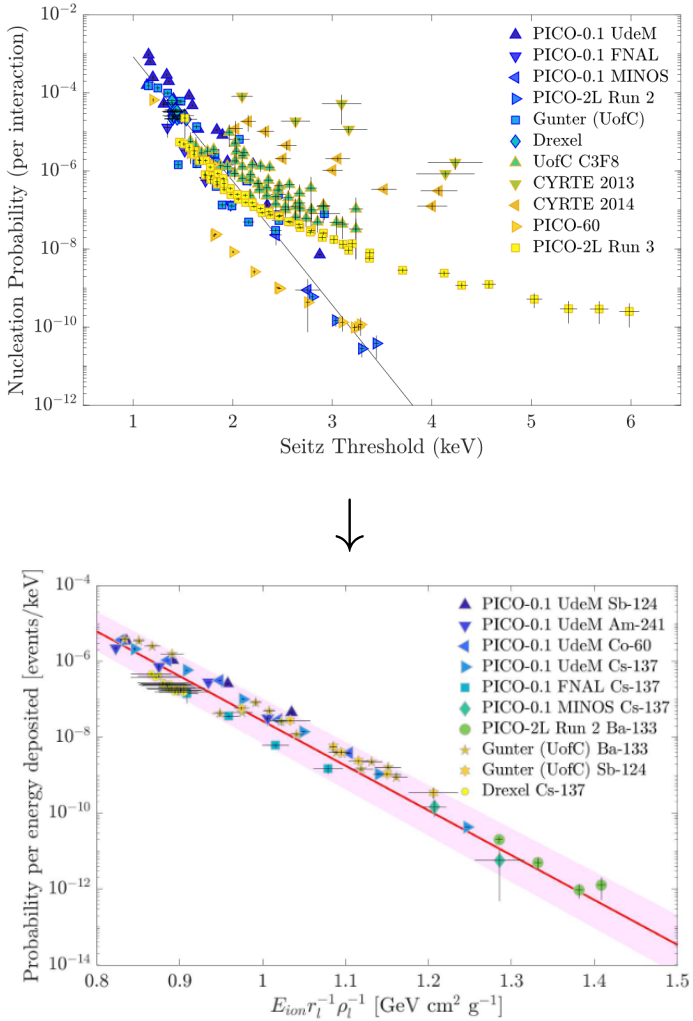
Other Physics

Molecular dynamics to model AP



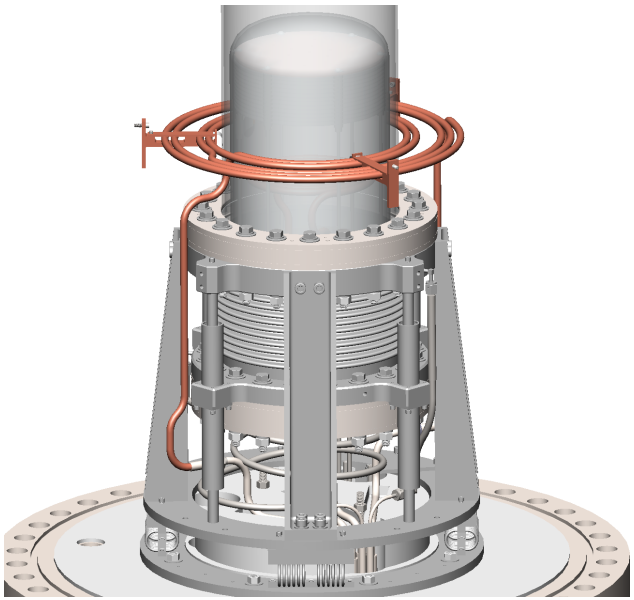
arXiv:1906.04712

Improved ER model

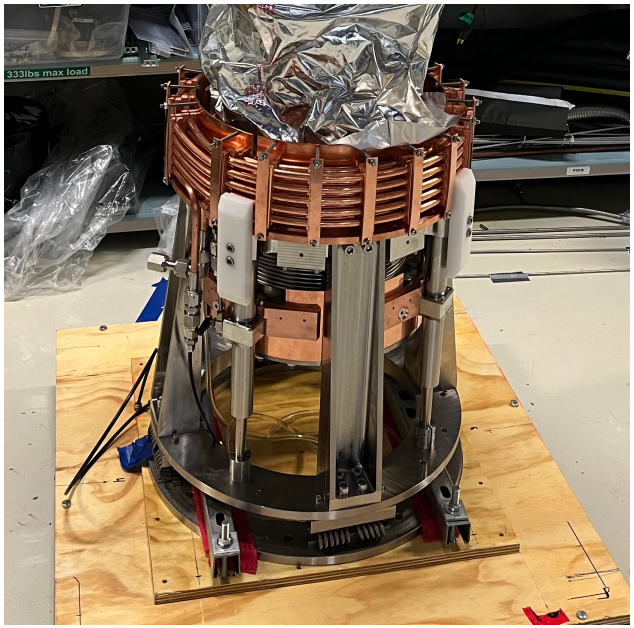


arXiv:1905.12522

Post-disassembly Work



Old cooling coil. Relied on convection of hydraulic fluid.



New cooling coil. Relies on conduction to cool critical components.

Current Status

- Jars reassembled
- New cooling coils reinstalled
- Internals being reassembled

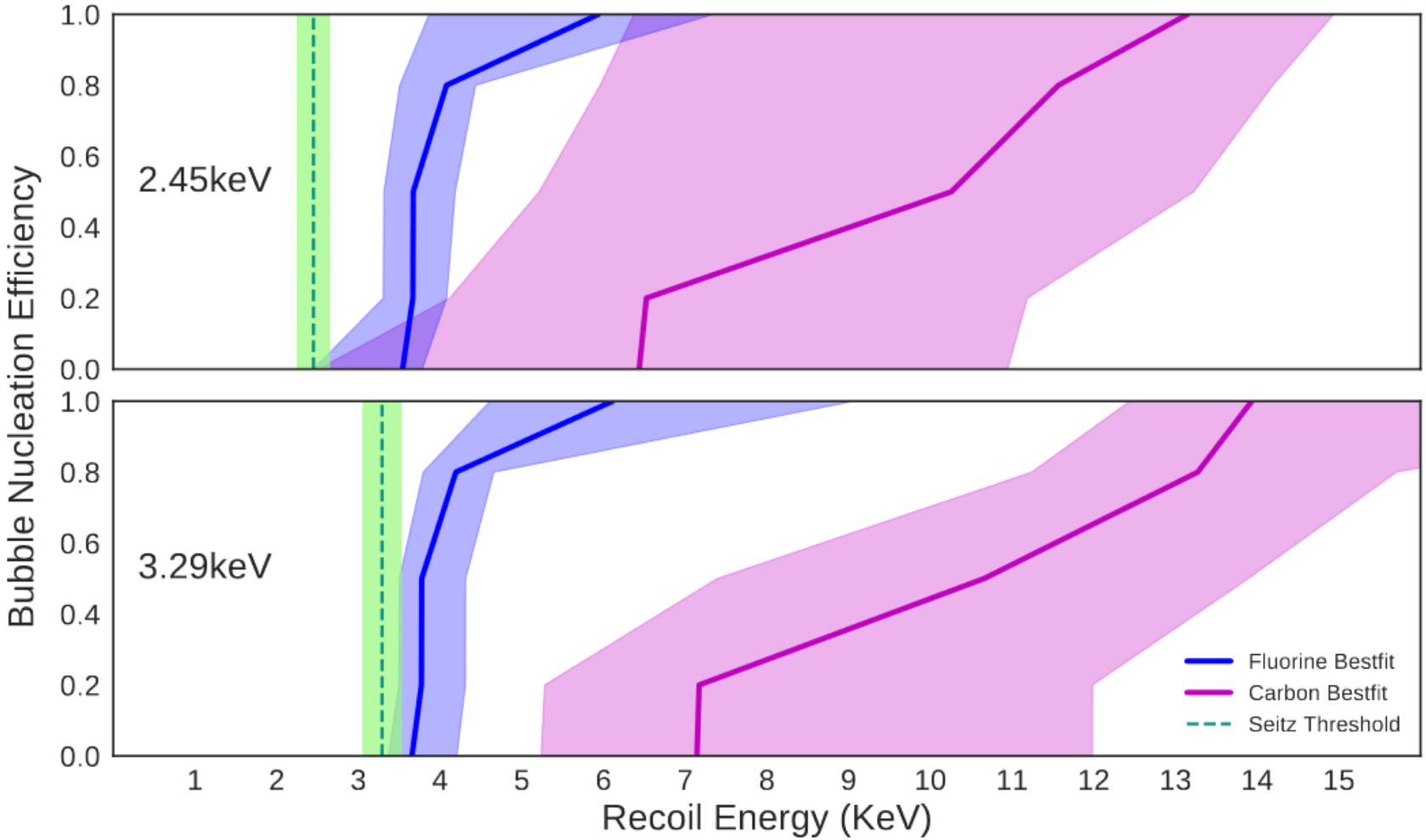
Thresholds

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

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

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

Efficiency Curves



arXiv:1902.04031