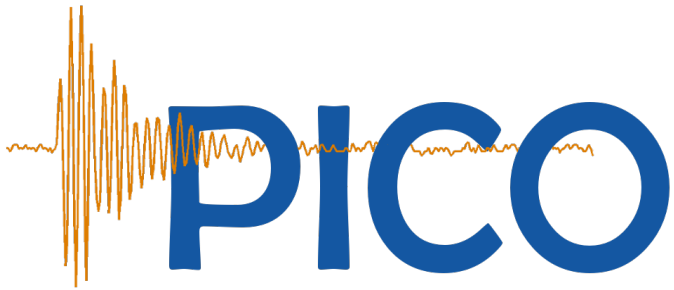
Recent developments of the PICO dark matter detectors

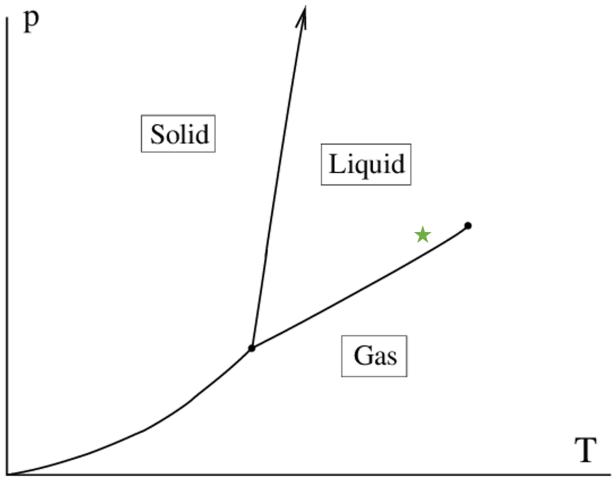
Colin Moore

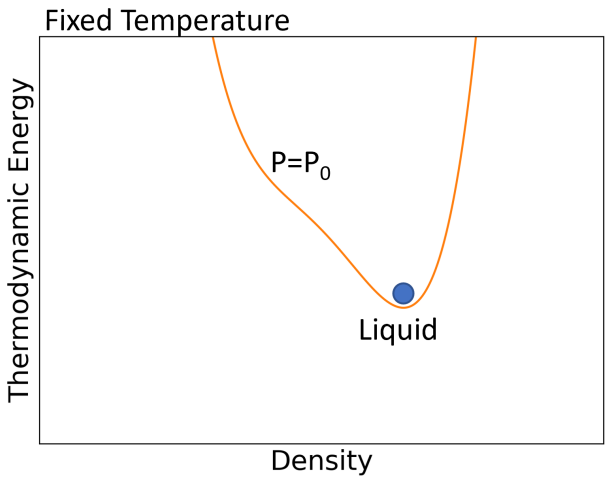
Queen's University

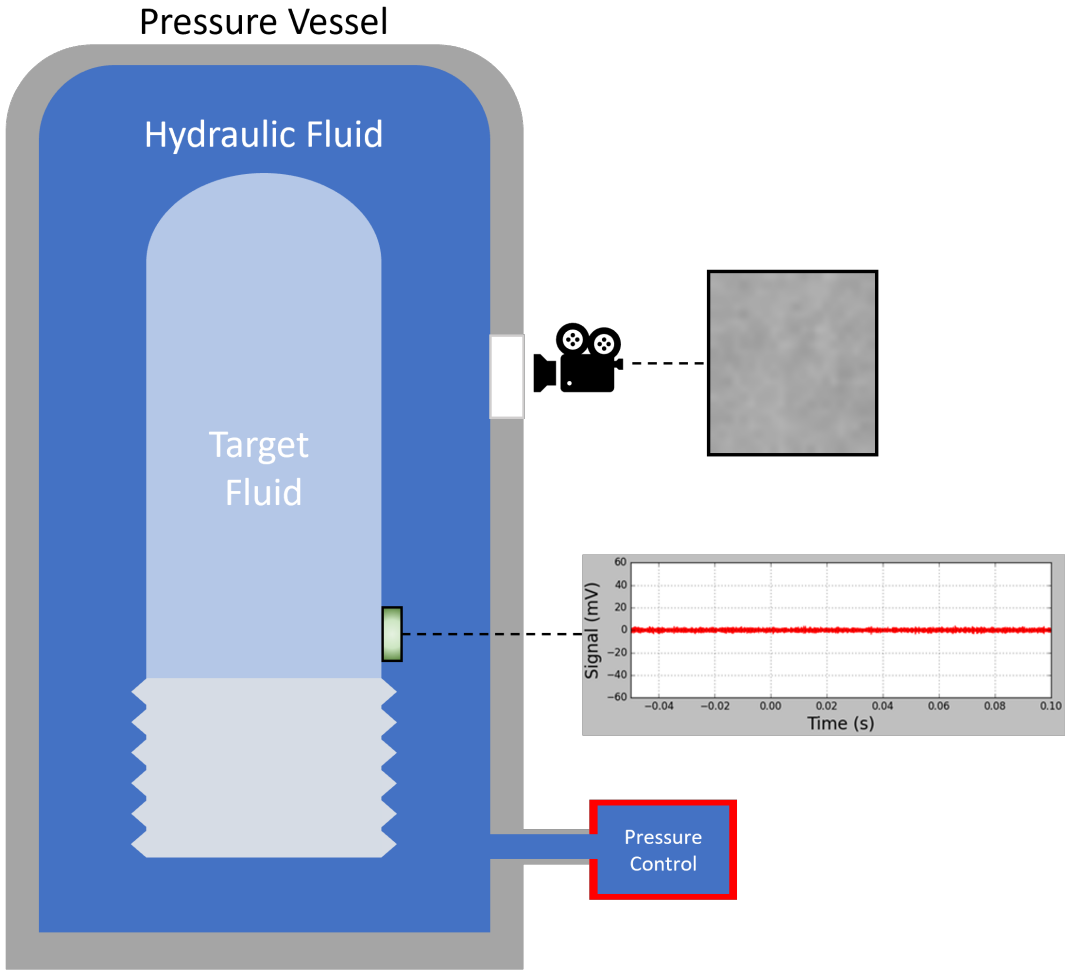
March 31, 2023



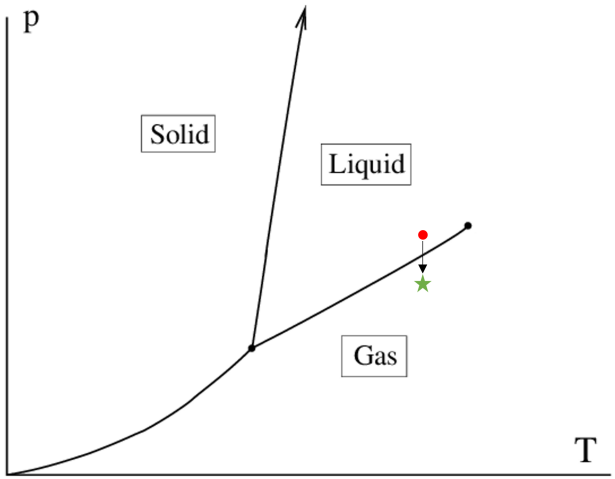
Bubble Chambers as Particle Detectors

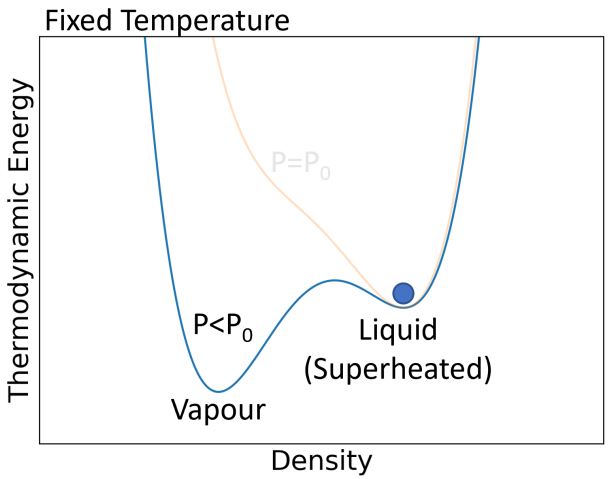


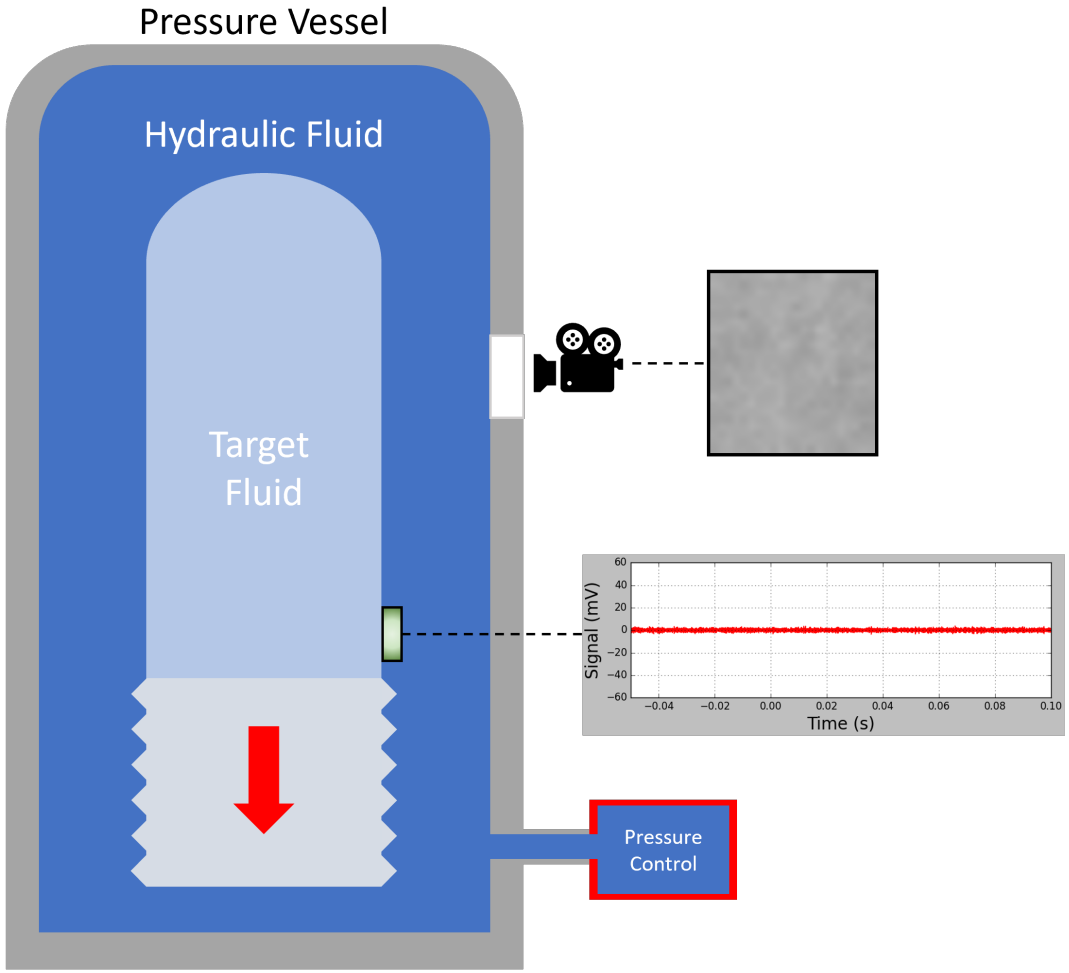




Bubble Chambers as Particle Detectors







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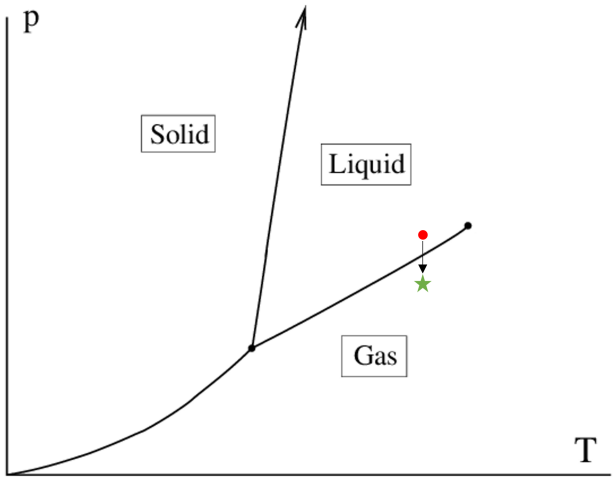
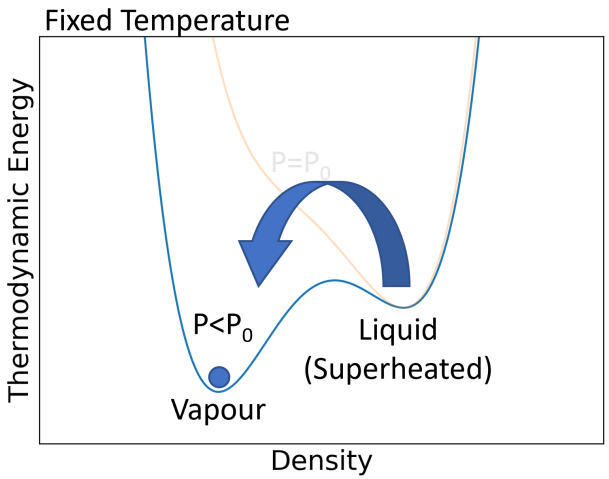
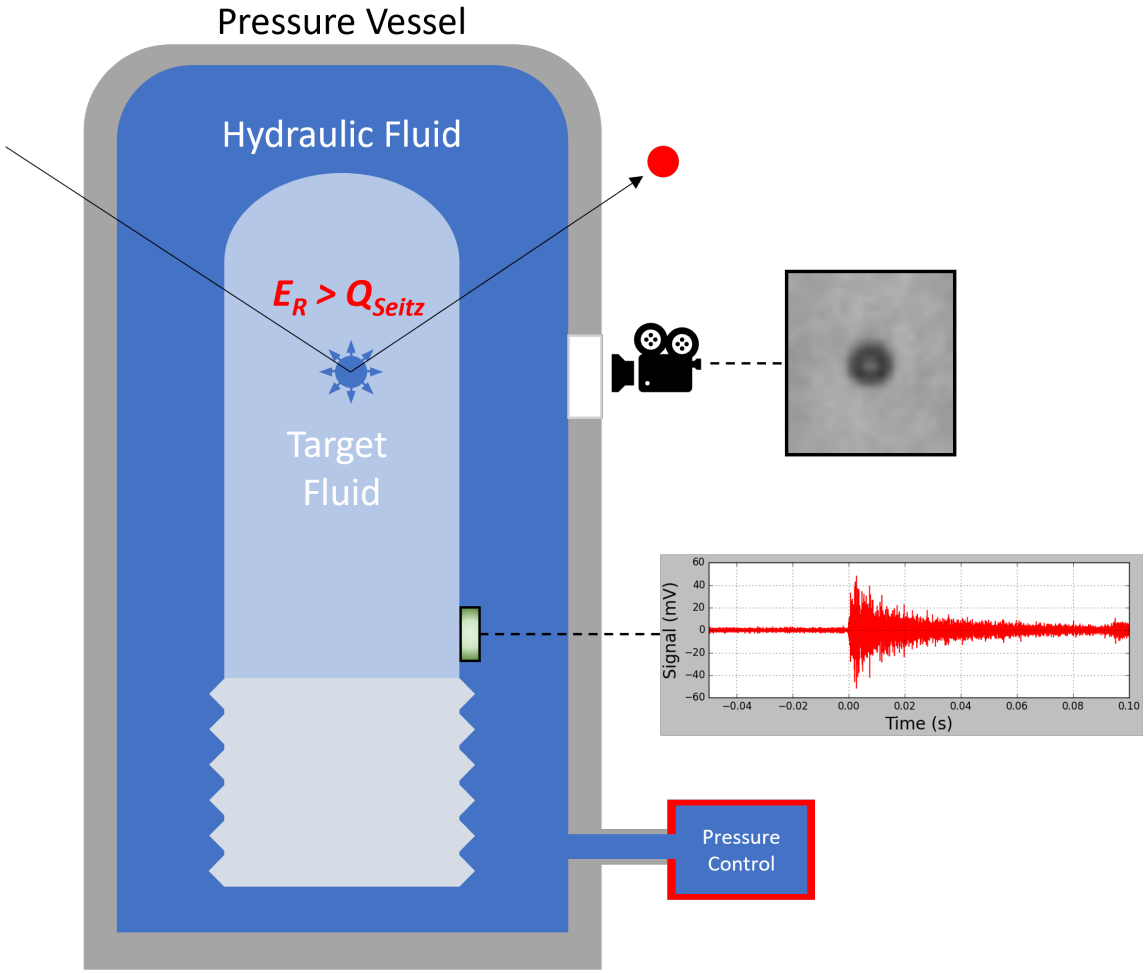
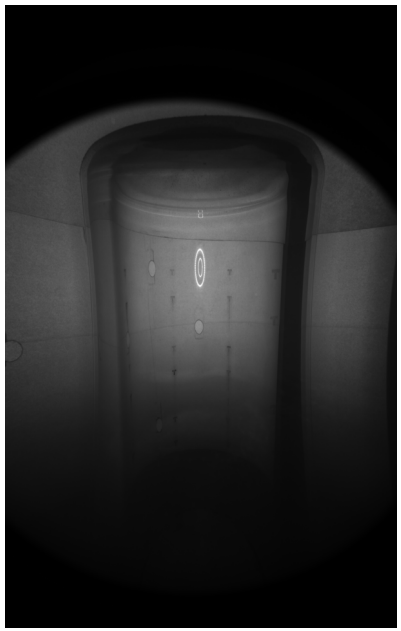


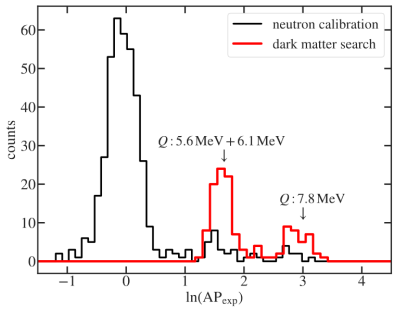




Background Events in Bubble Chambers

Alphas



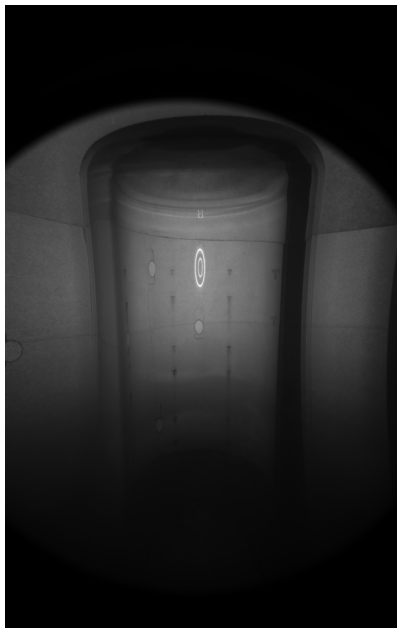


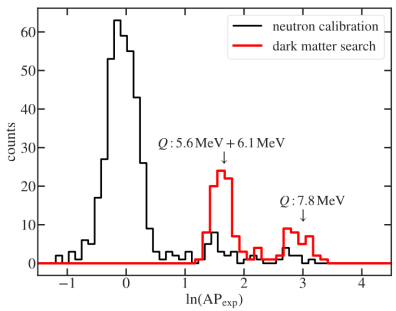
Nuclear Recoils

Electron Recoils

Background Events in Bubble Chambers

Alphas





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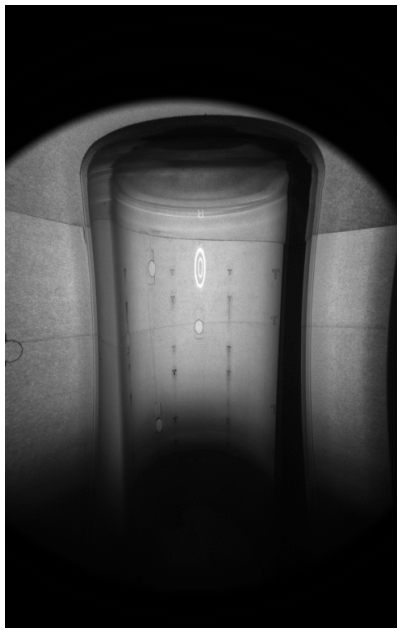

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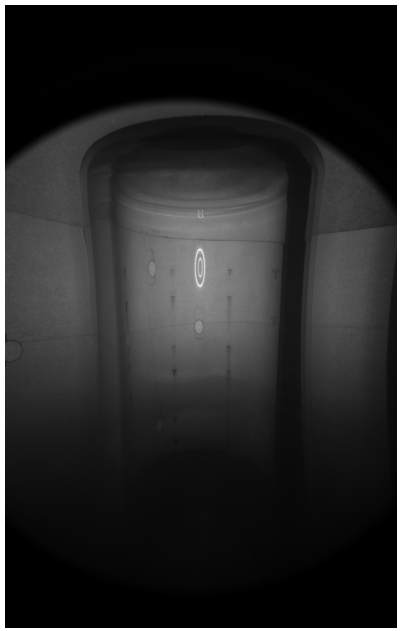

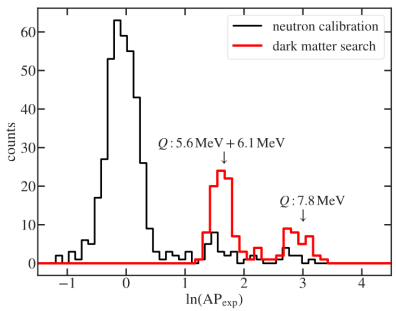

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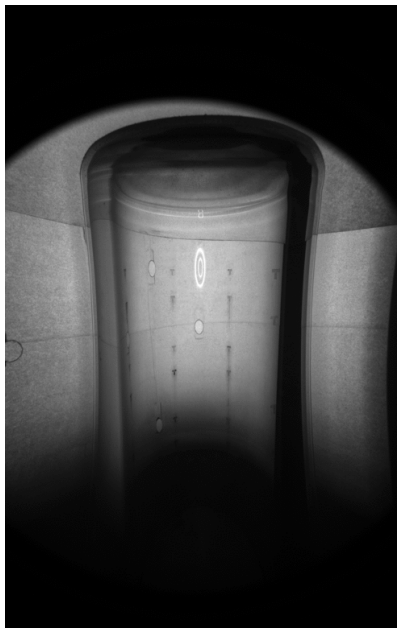

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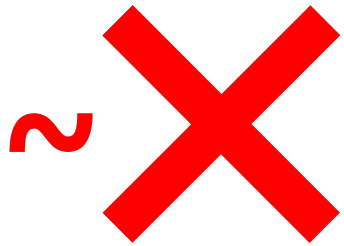
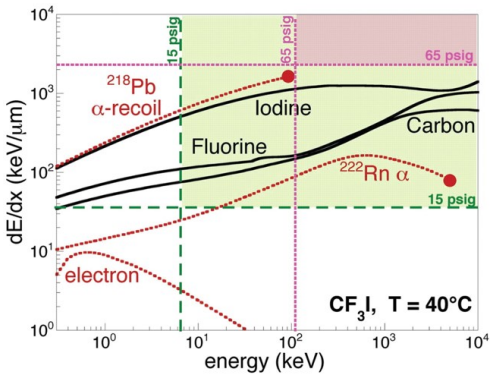
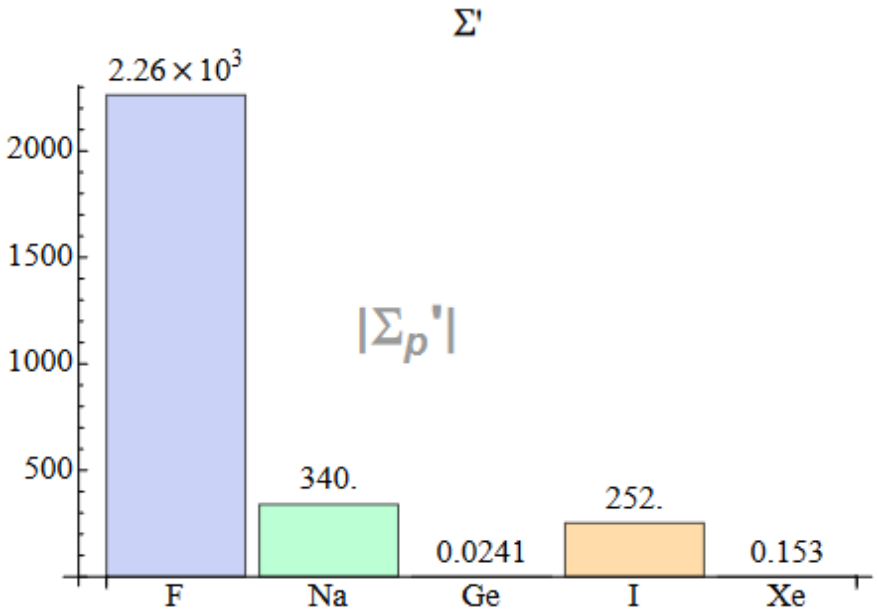
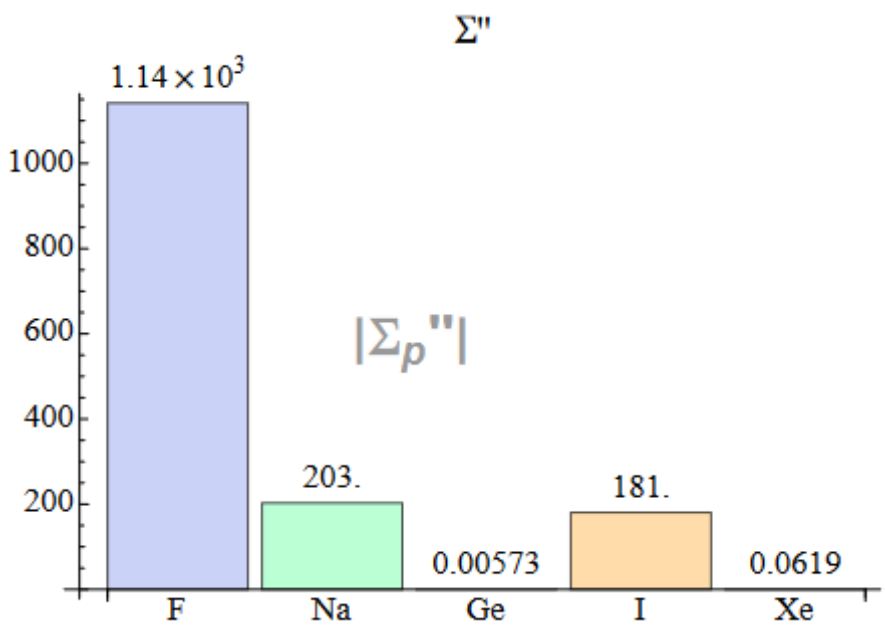




Why Bubble Chambers?

- 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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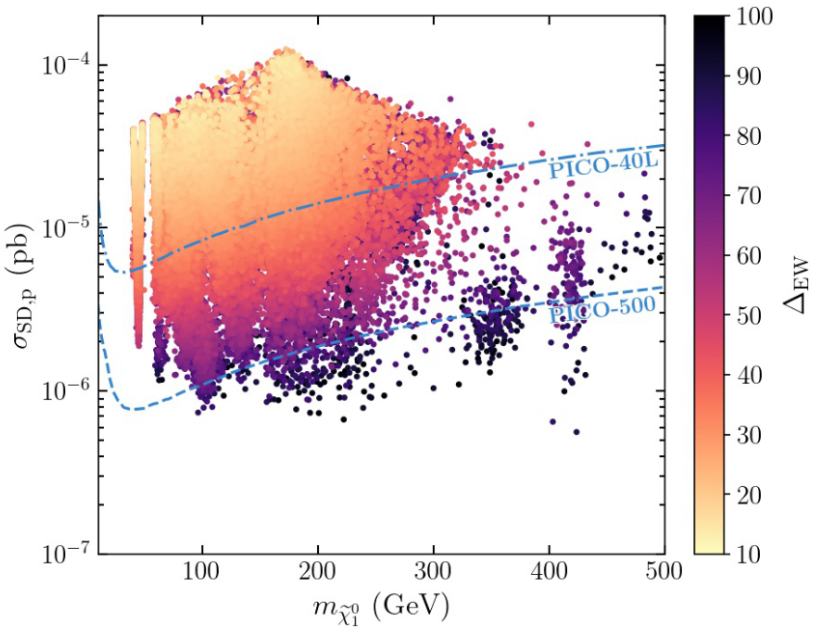
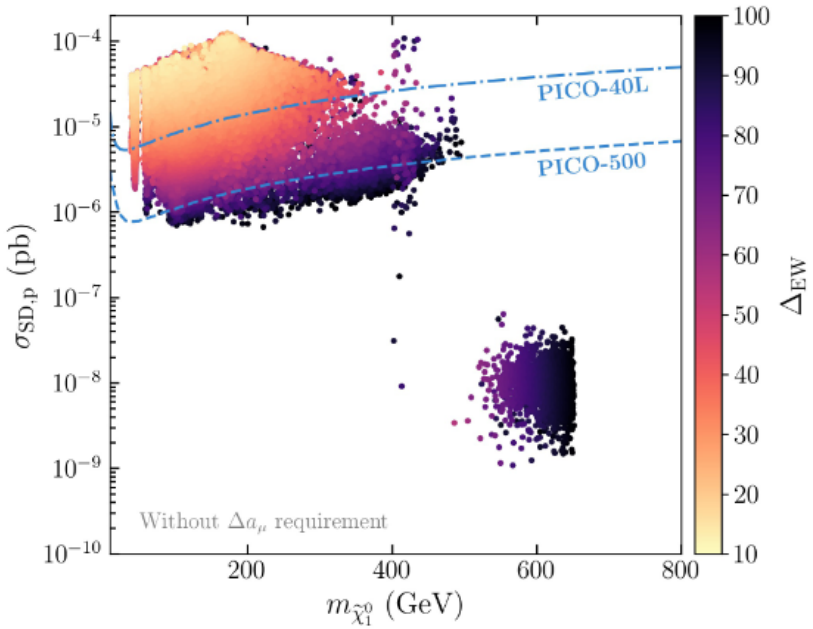
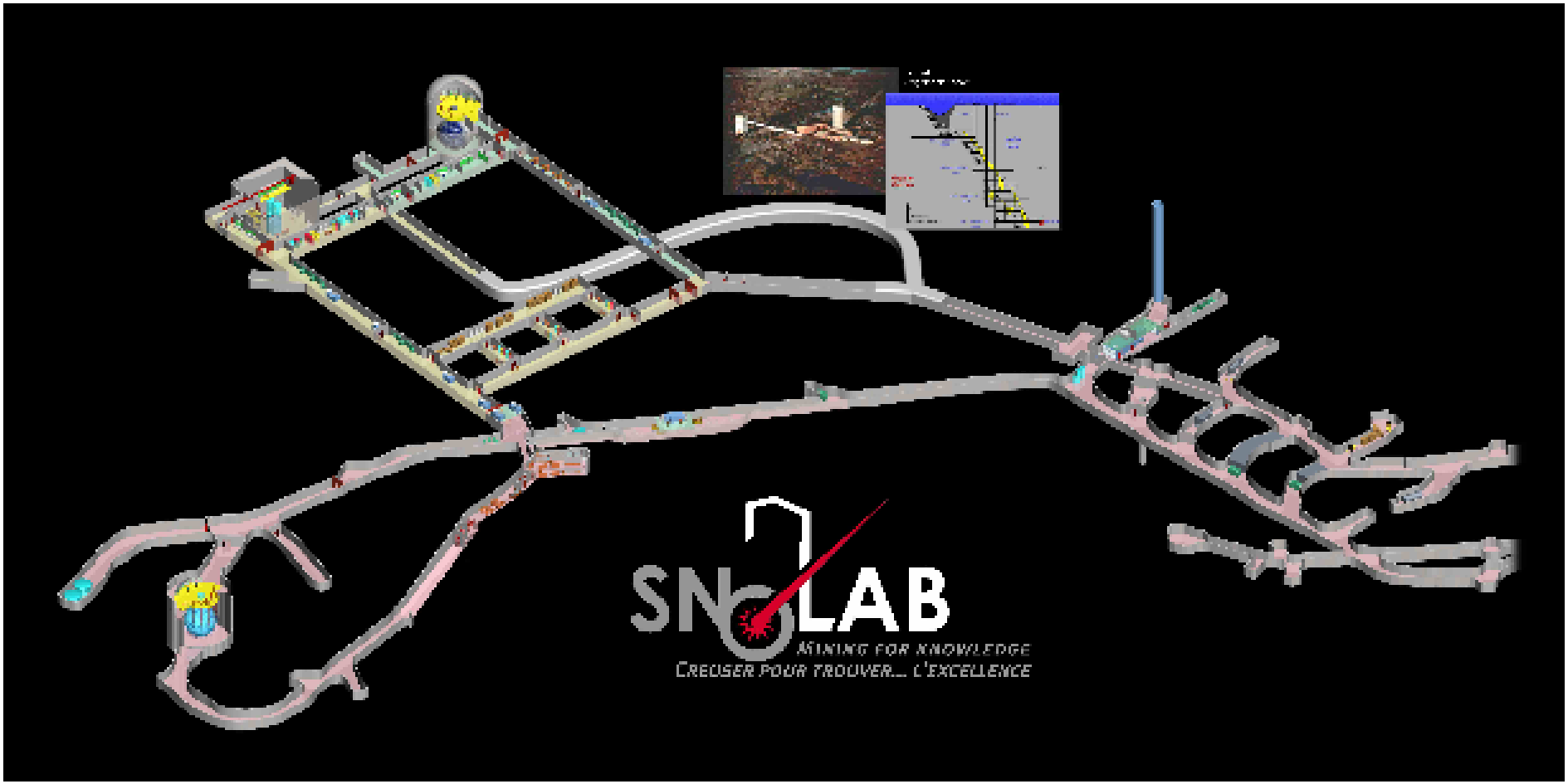




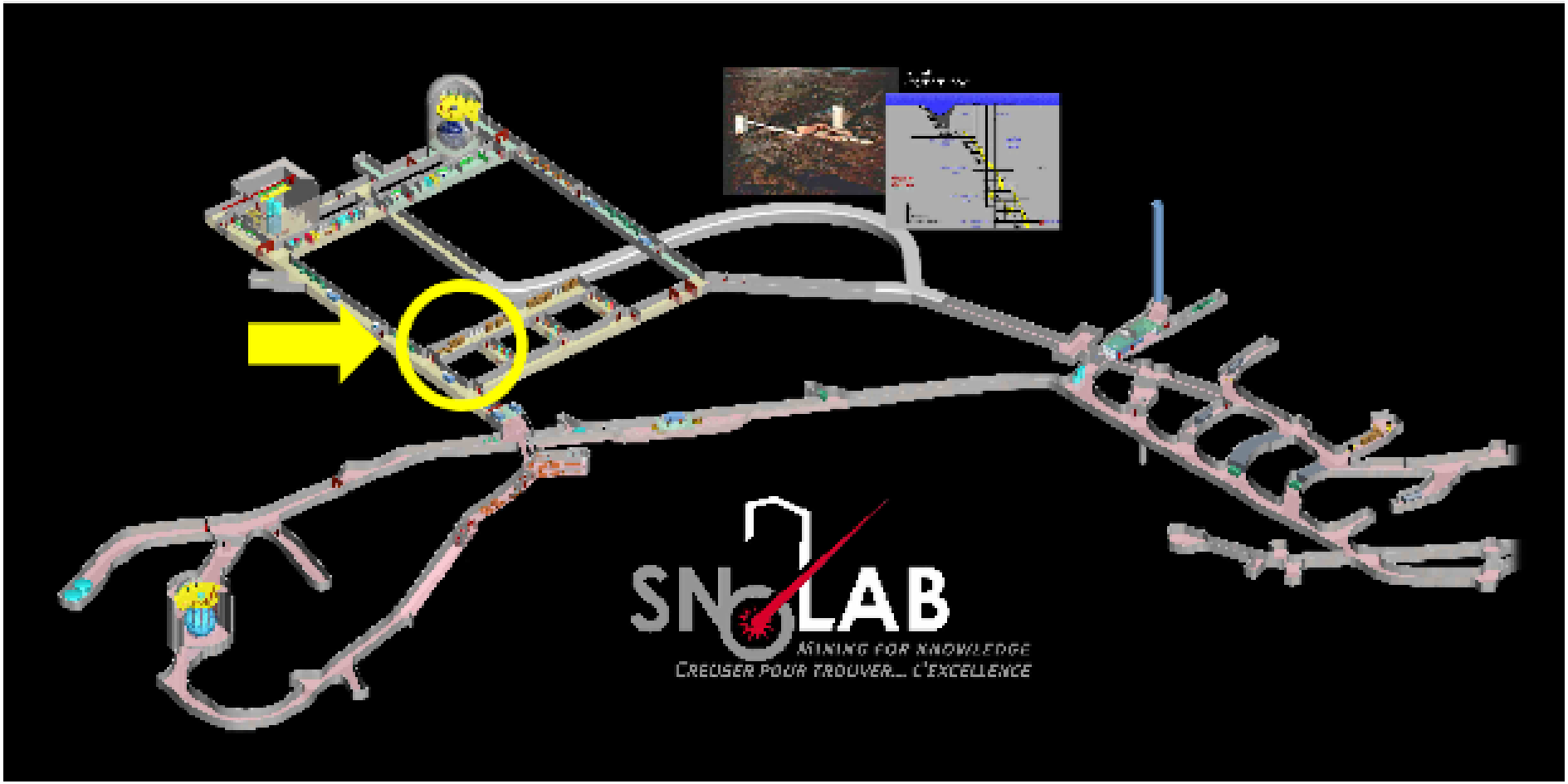
Beekveld *et al.* SciPost Phys. 11, 049 (2021)

PICO-40L at SNOLAB



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

PICO-40L at SNOLAB

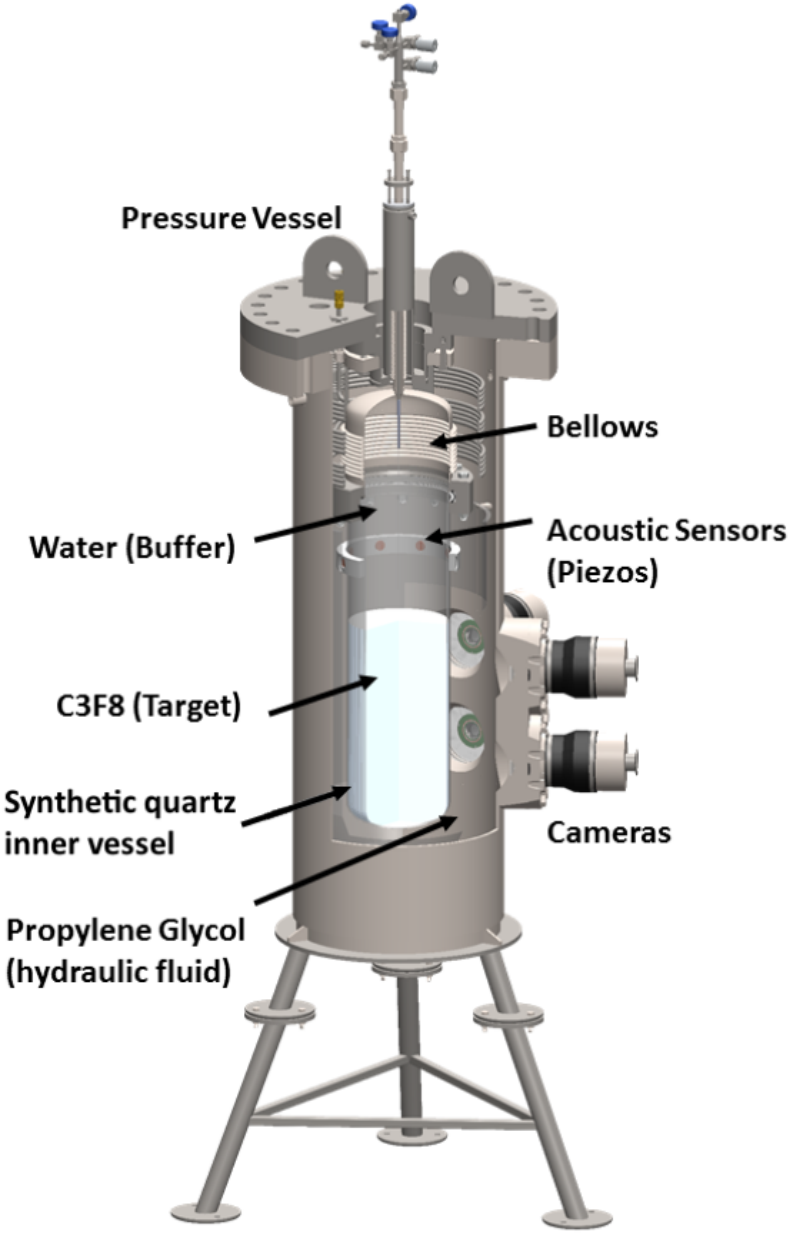


Jillings, Chris. (2016). The SNOLAB Science Program. Journal of Physics: Conference Series. 718. 062028. 10.1088/1742-6596/718/6/062028

PICO-60

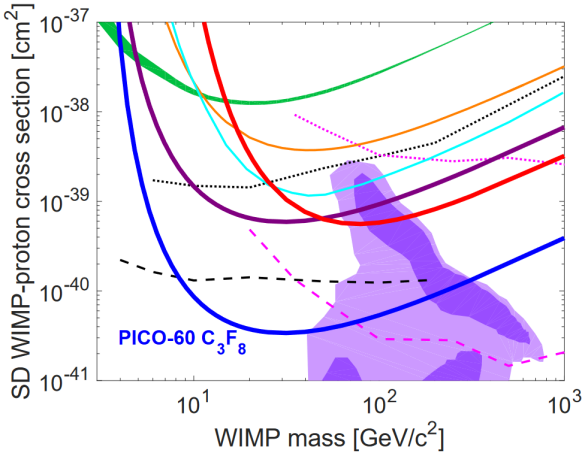
- 60 kg fiducial volume
- "Upside-down" design
- Full detector at constant temperature
- Superheated freon separated from bellows by layer of water

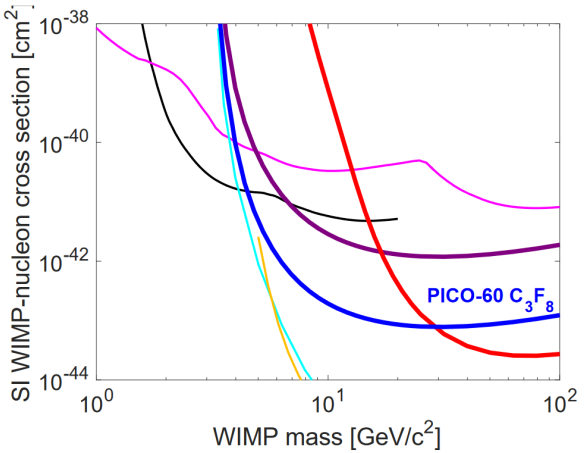
- World-leading WIMP-proton limit set in 2016 and 2017



PICO-60 Results

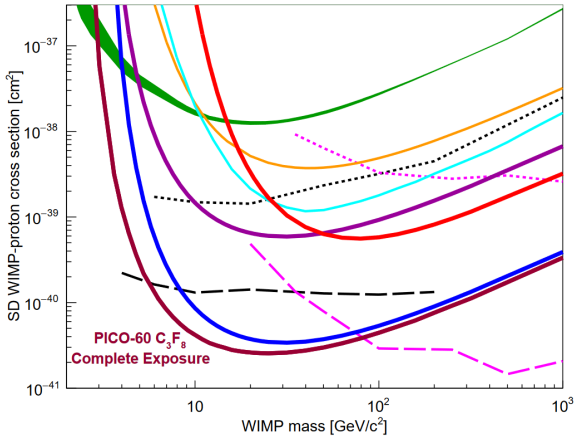
Run 1

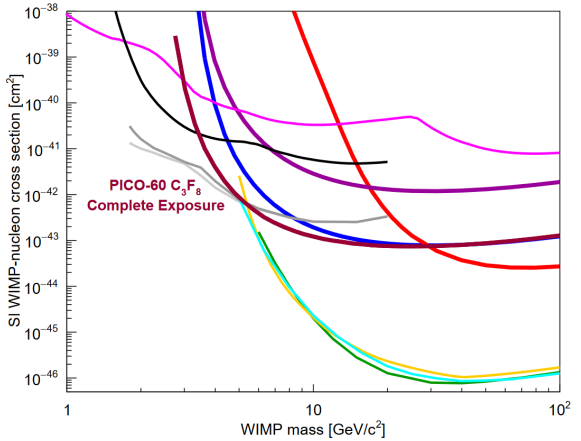




C. Amole et al. (PICO Collaboration) Phys. Rev. Lett. 118, 251301 (2017)

Combined (Run 1 + 2)

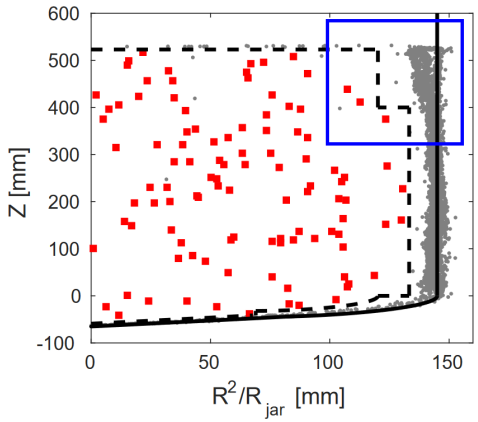




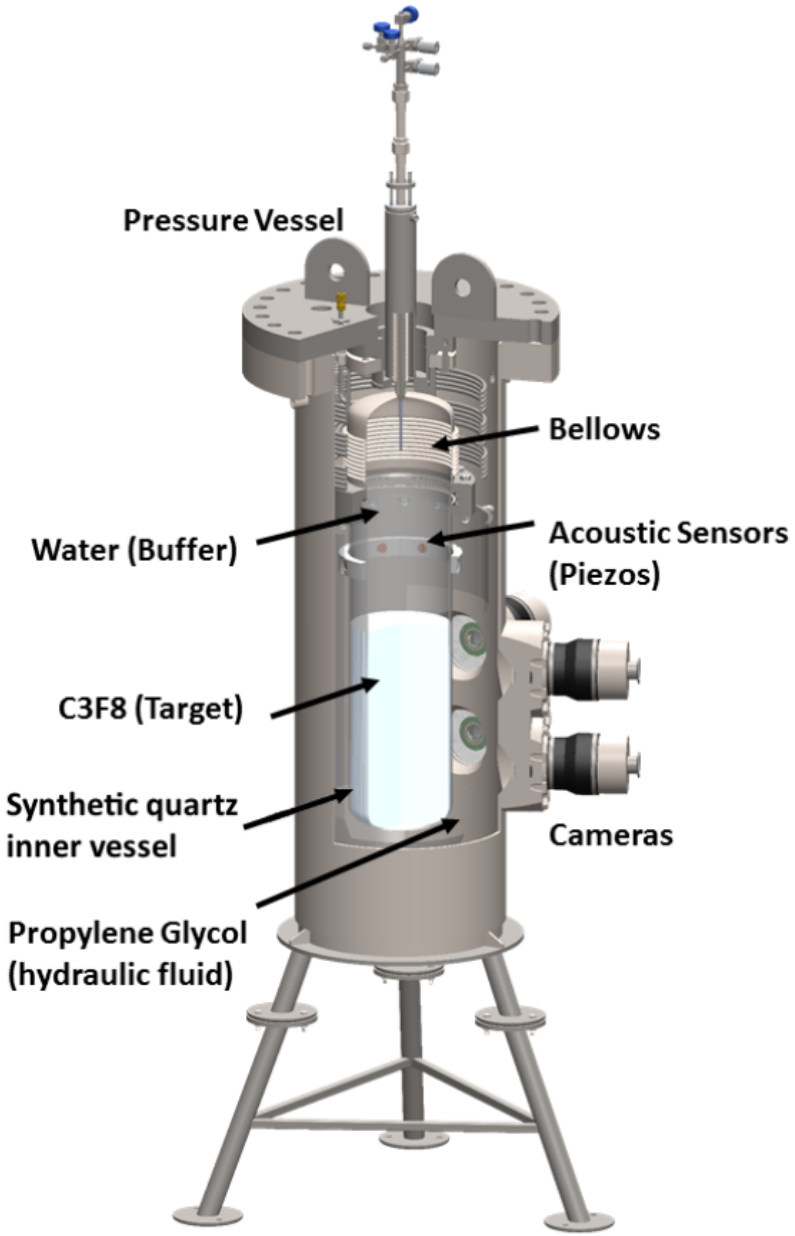
C. Amole et al. (PICO Collaboration) Phys. Rev. D 100, 022001 (2019)

PICO-60 Issues

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

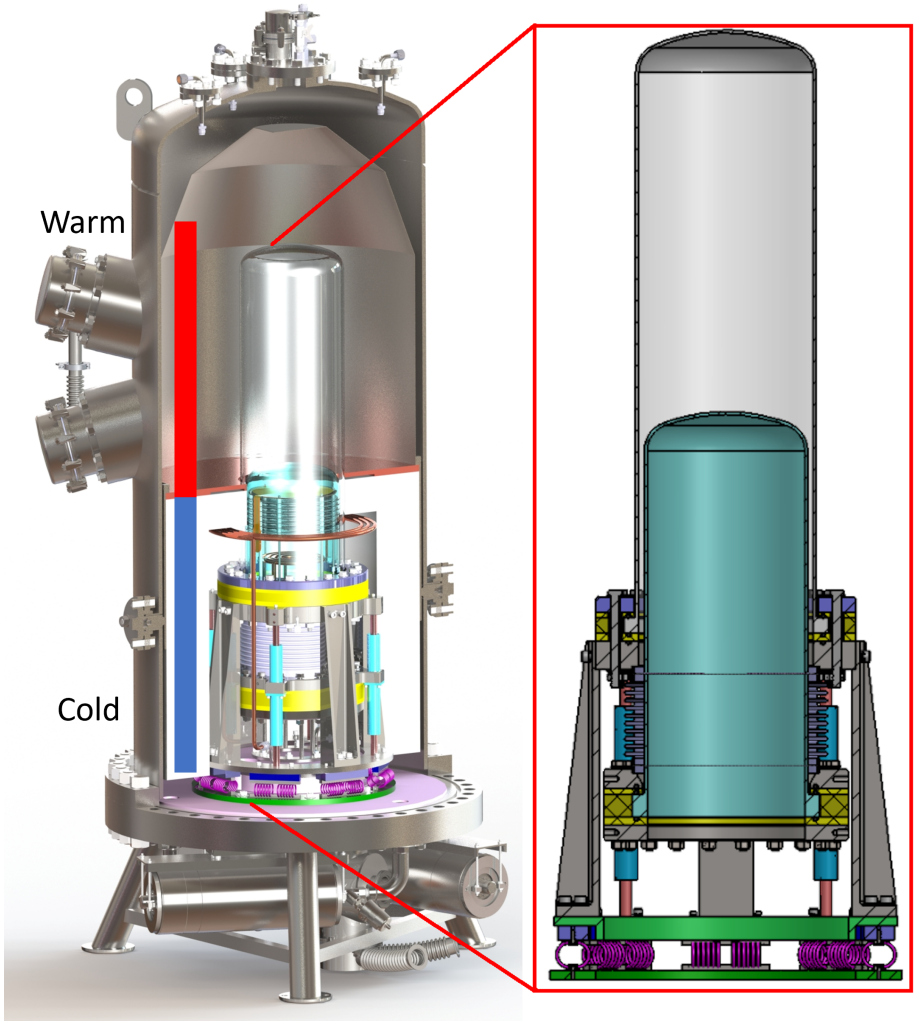


- Orientation of jar may lead to debris accumulating at bottom of jar



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

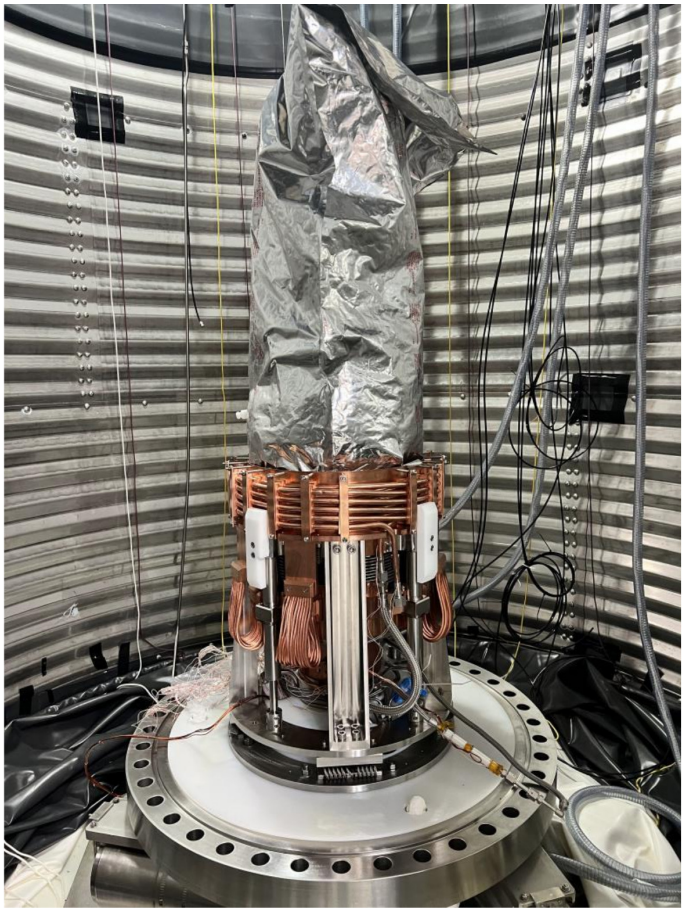


PICO-40L Timeline

- 2019: Assembly and system tests
- May 2020: Commissioning begins with all systems active
- September 2020: Commissioning halted due to chiller failure
- May 2021: Leak appears internal to detector; disassembly begins
- 2021-2022: Fix leak, upgrades to address shortcomings of thermal system
- 2022: Reassembly
- December 2022-Q1 2023: Recommissioning
- Imminent: Start of physics run

COVID

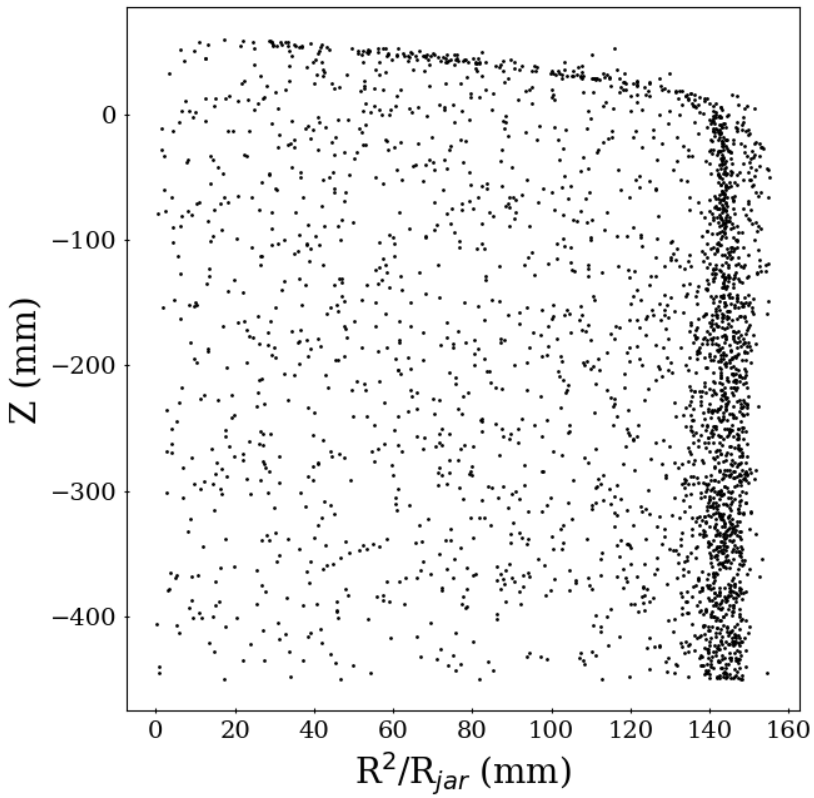
PICO-40L Construction



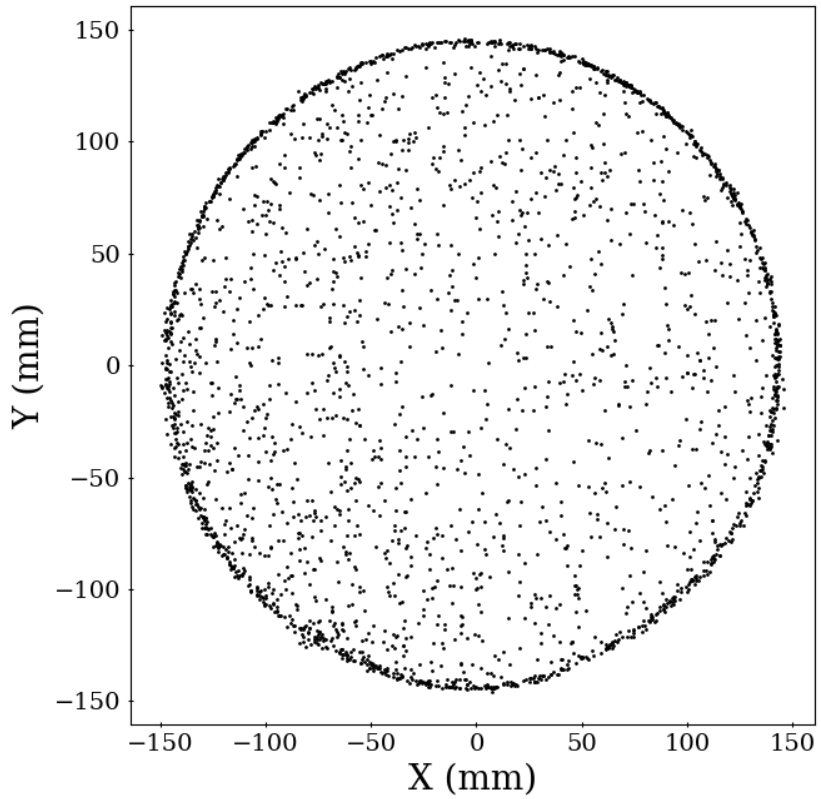
Position Reconstruction

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

R^2 vs. Z



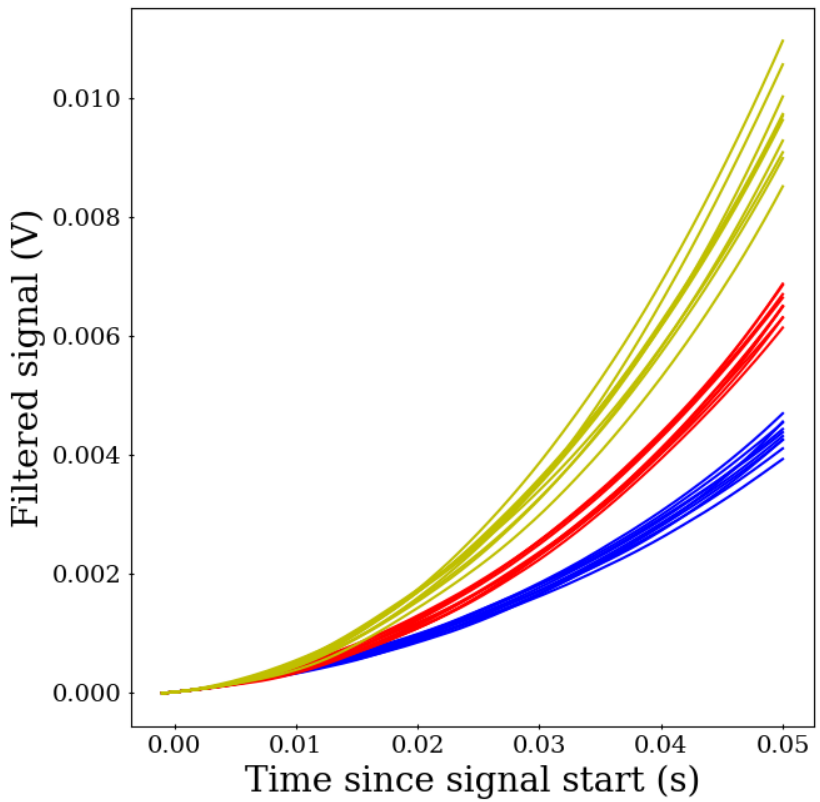
X vs. Y



Bubble Counting with Dytran

- Fast pressure transducer records change in pressure

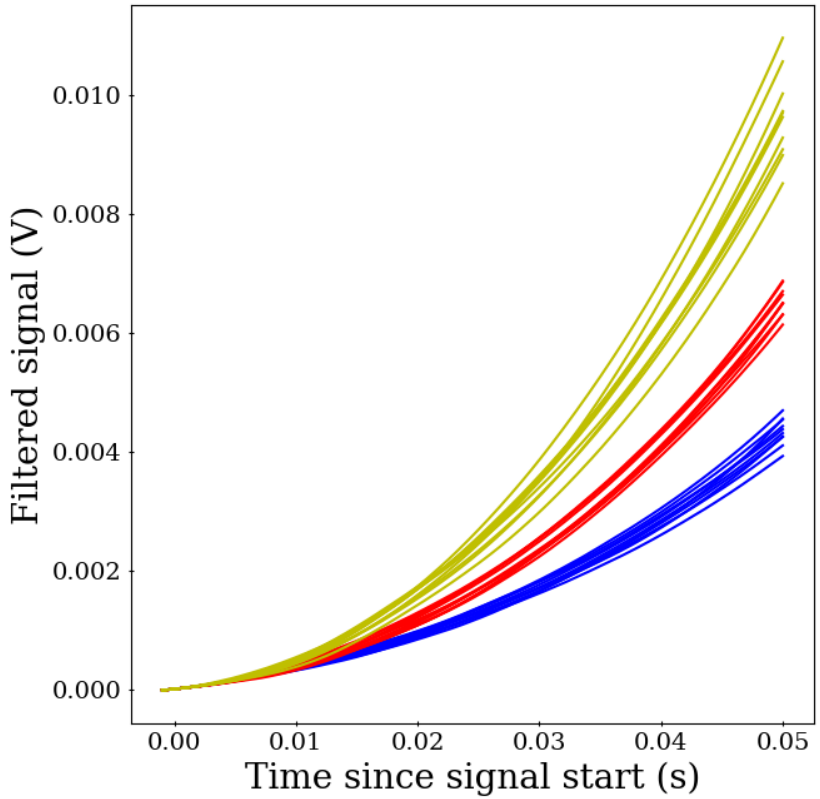
Filtered Dytran



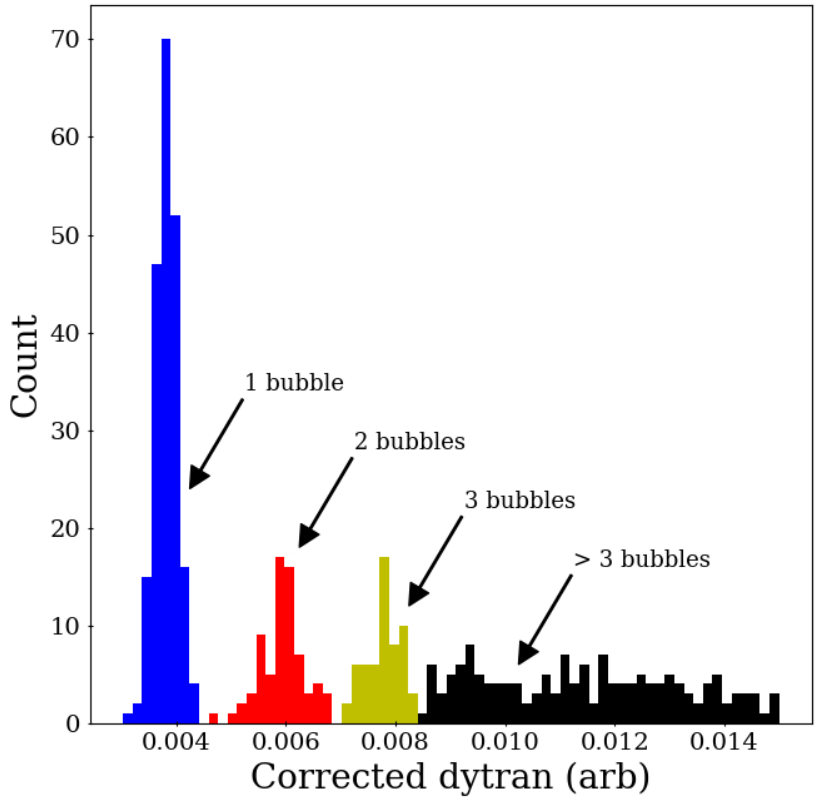
Bubble Counting with Dytran

- Fast pressure transducer records change in pressure
- Measuring pressure rise allows for precise bubble counting

Filtered Dytran



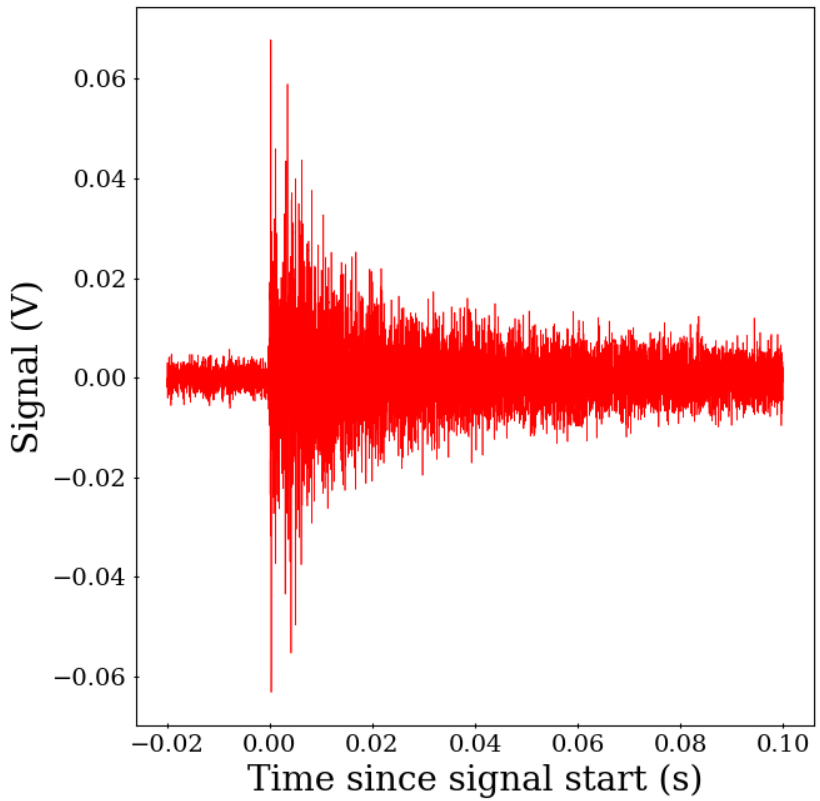
Corrected Dytran



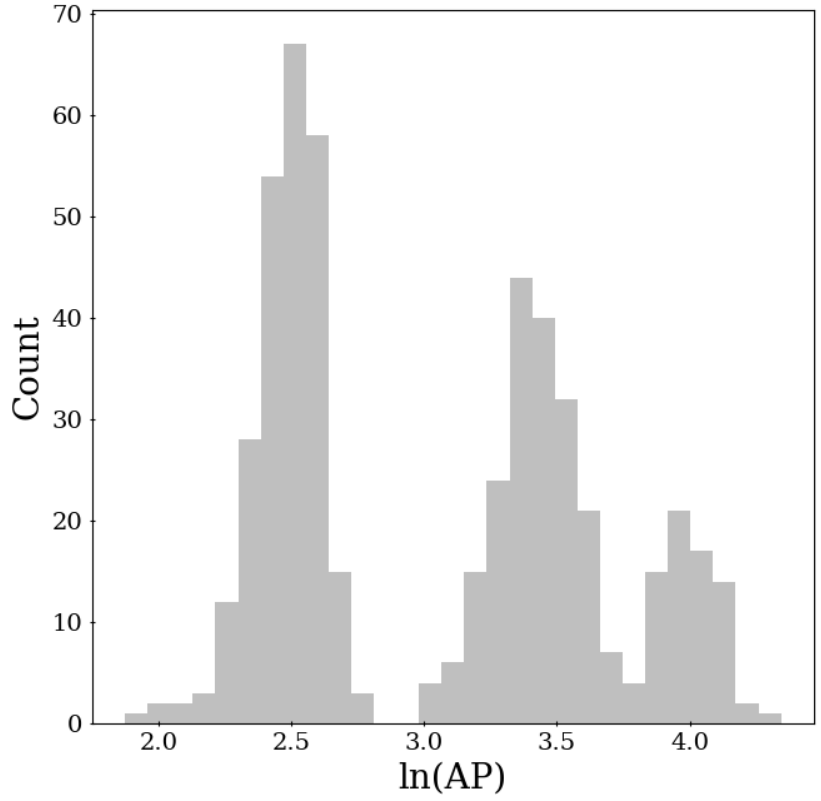
Particle Identification by Acoustics

- 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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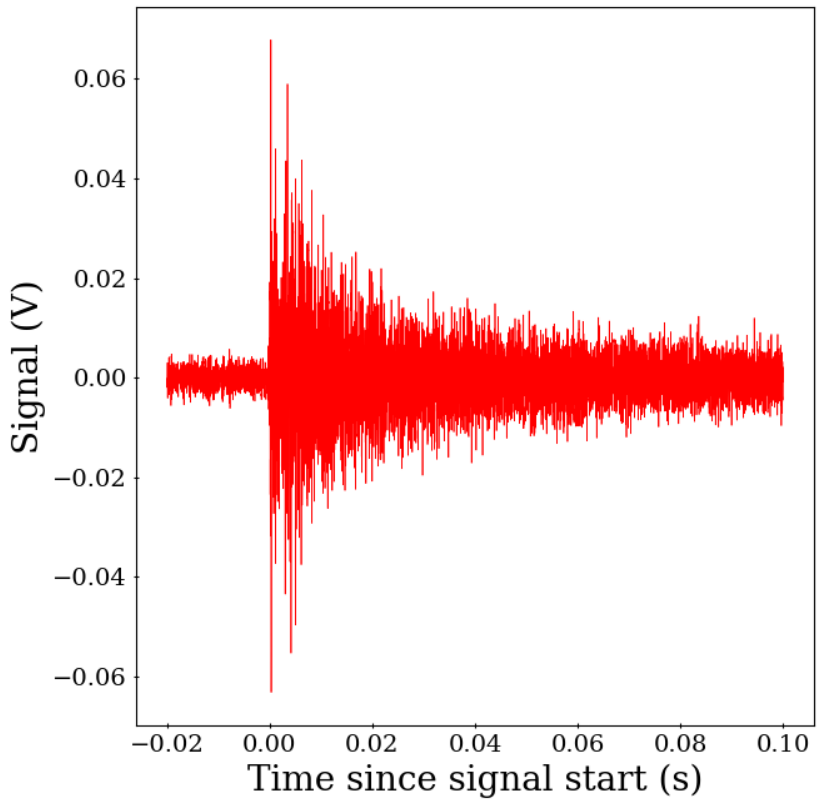

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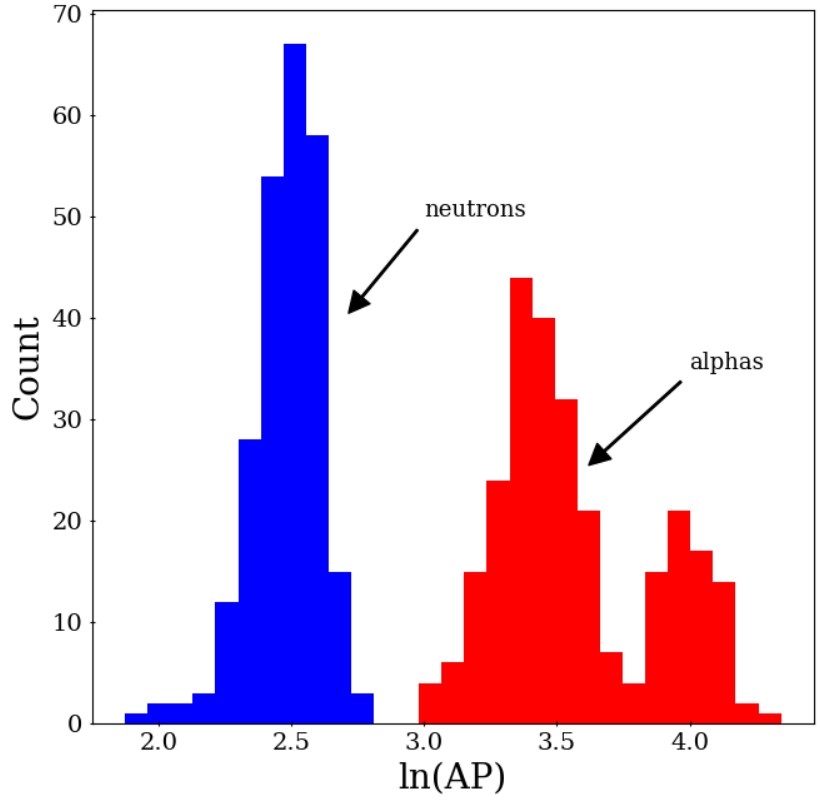

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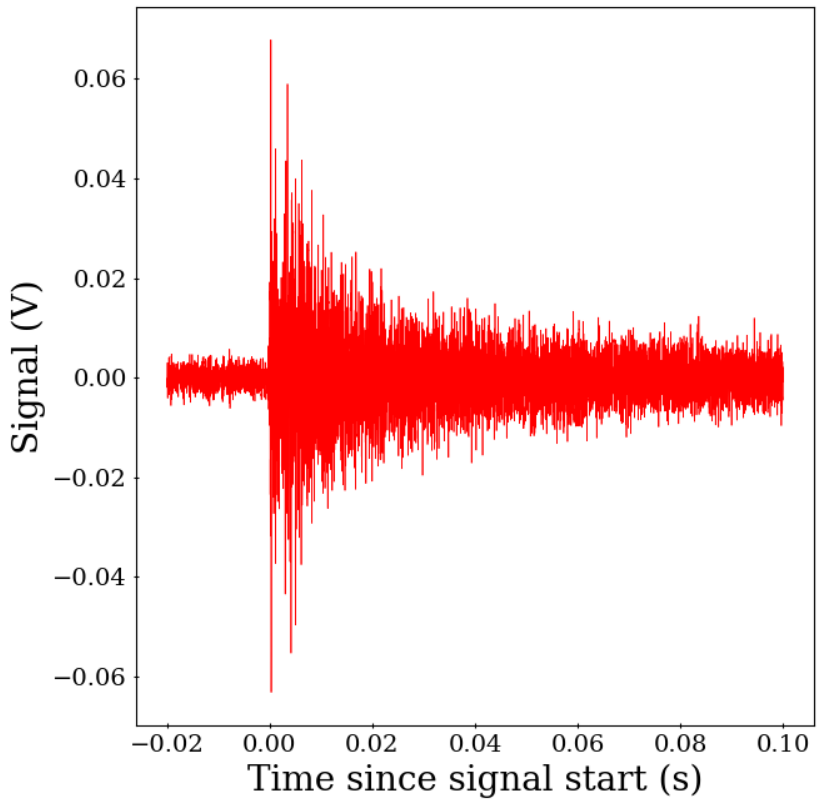

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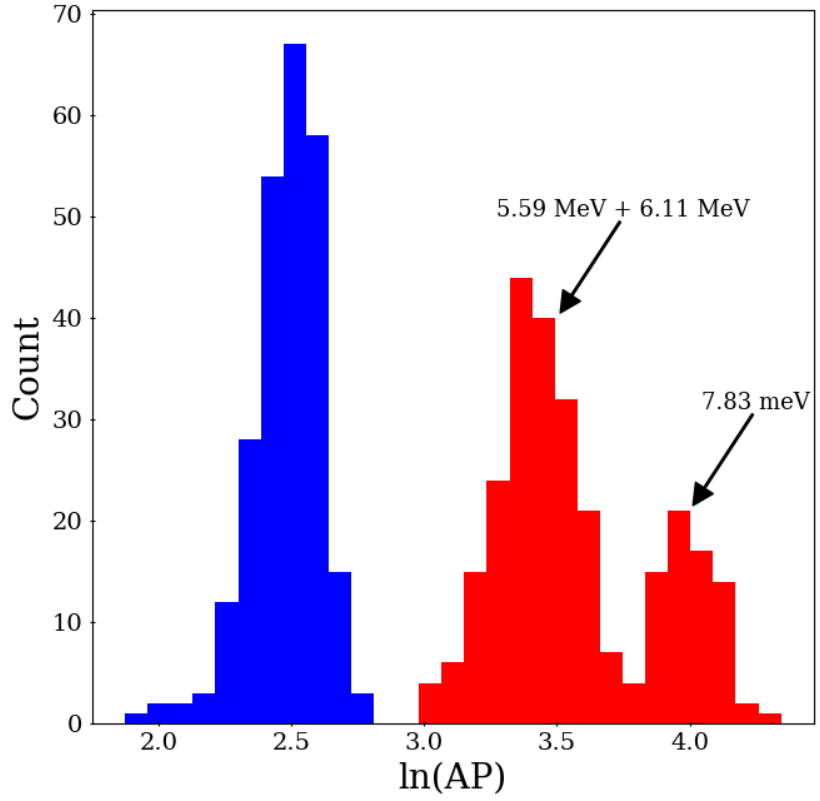

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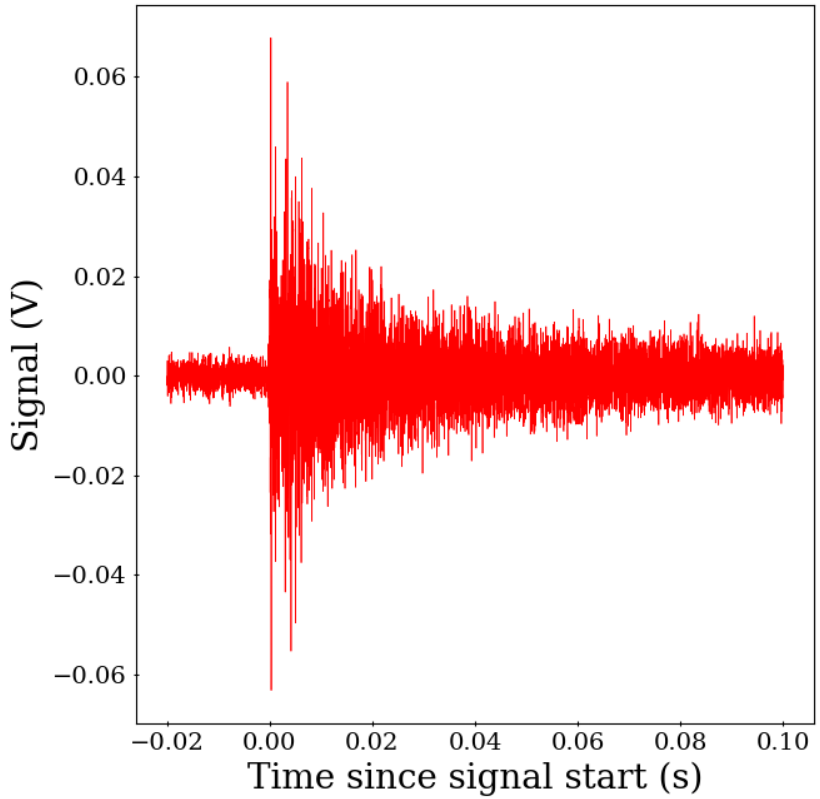
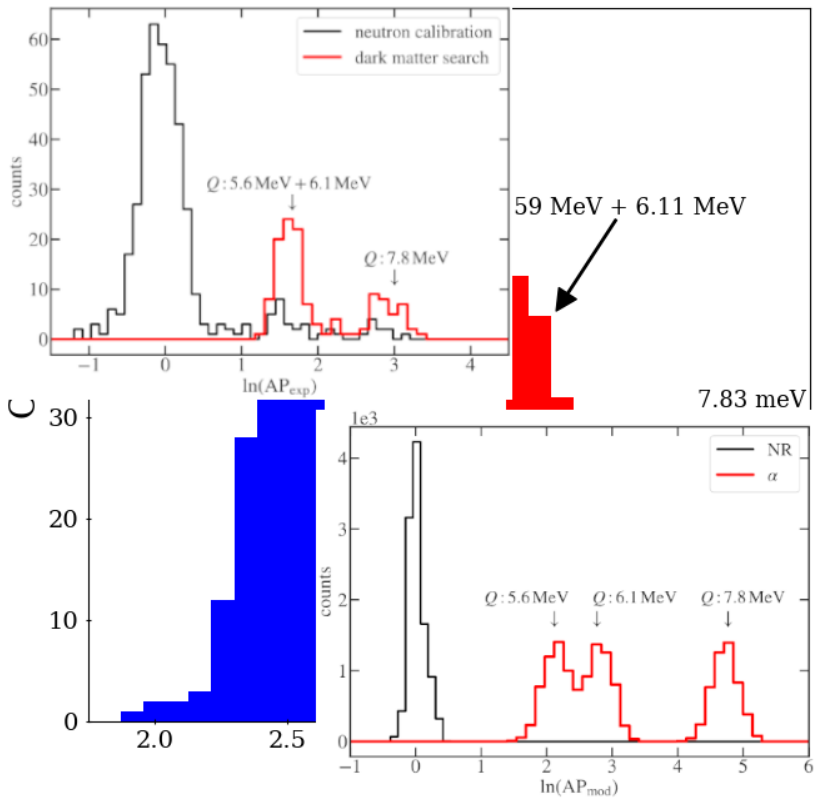


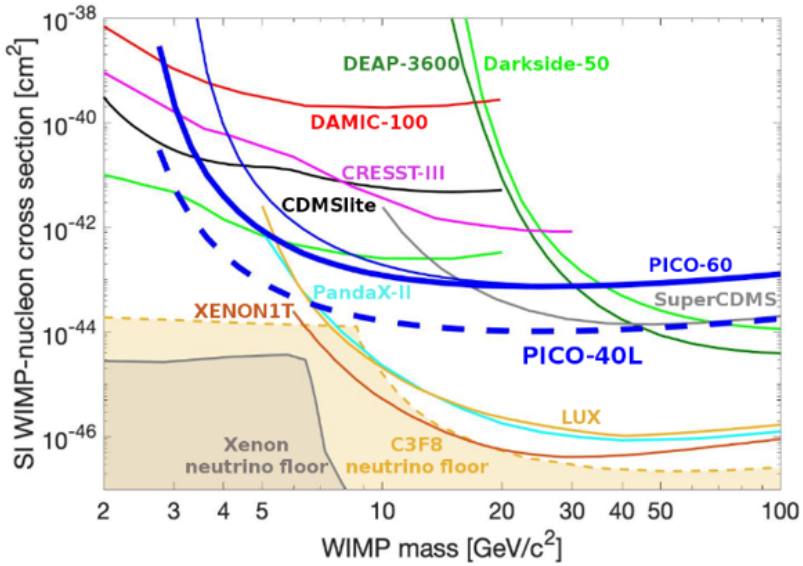
Acoustic Parameter



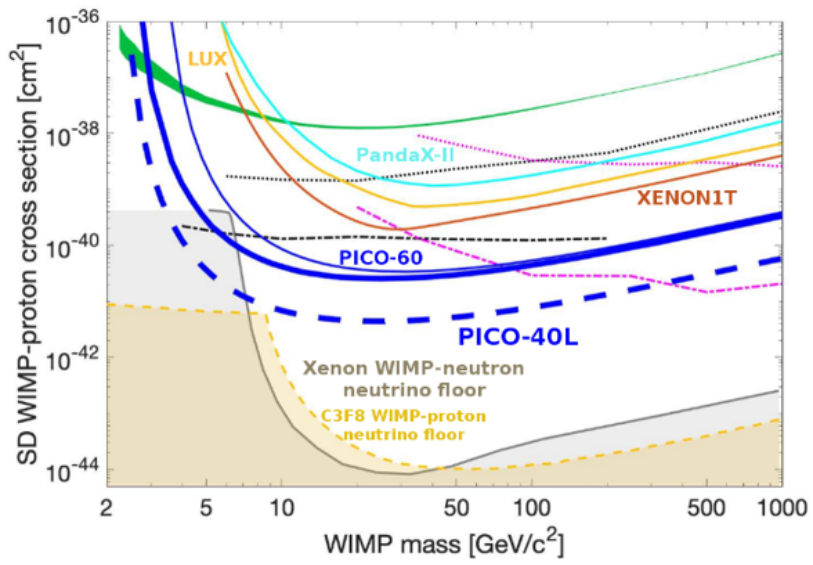
PICO-40L Projected Limits

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

Spin Independent Limit



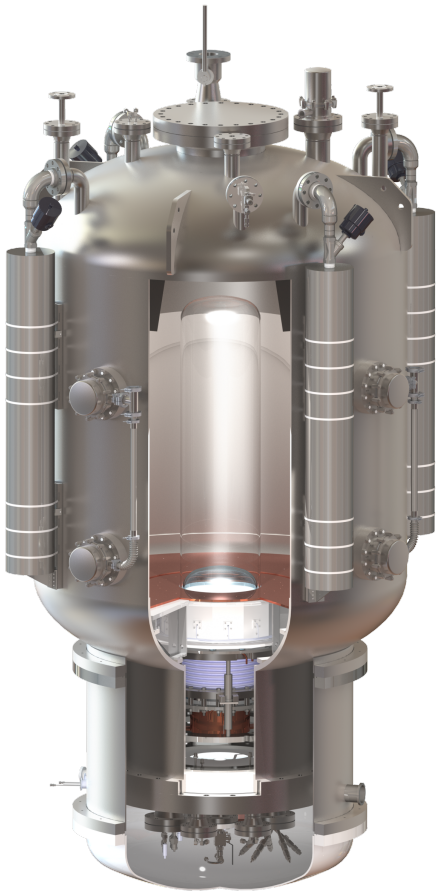
Spin Dependent Limit

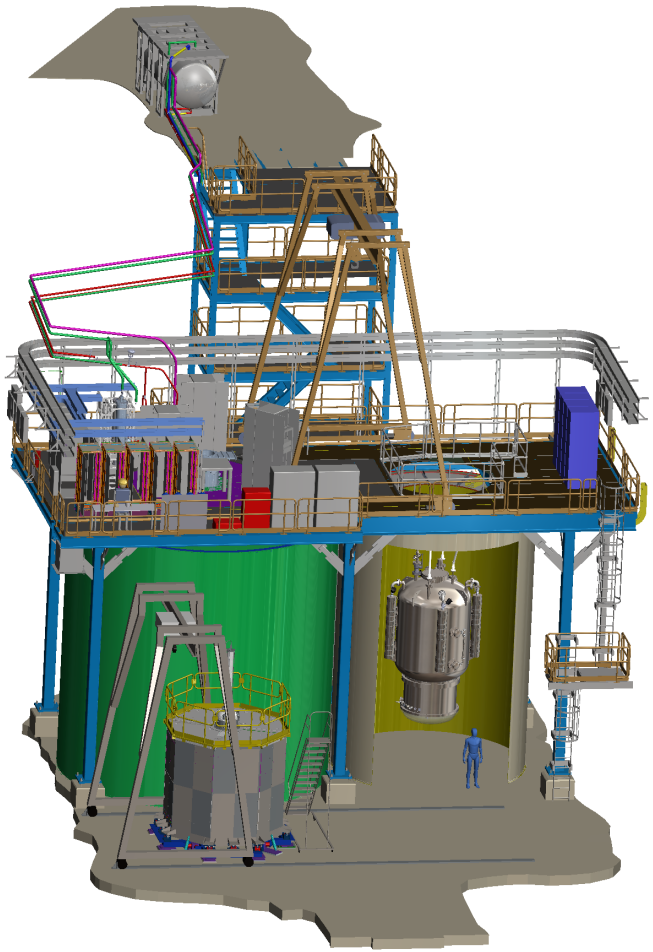


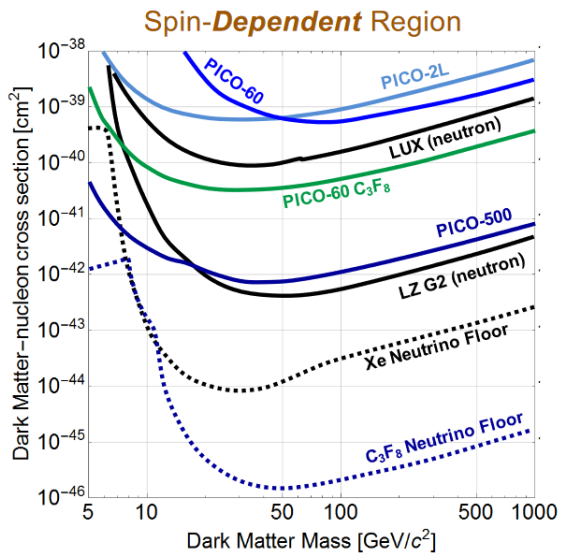
C. Amole *et al.* (PICO Collaboration), Phys. Rev. D 100, 082006 (2019)

PICO-500: The Next Generation Chamber

- 250 L of C_3F_8
- Situated in cube hall at SNOLAB
- Currently in procurement phase







Thanks

PICO

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
R. Filgas, D. Mamedov, E. Rukhadze, I. Stekl

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

Northeastern ILLINOIS UNIVERSITY
O. Harris

Fermilab
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Drexel UNIVERSITY
R. Neilson

A. Acevedo-Rentería, A. García-Viltres, E. Vázquez-Jáuregui

KICP Kavli Institute for Cosmological Physics at The University of Chicago
J.I. Collar

J. Basu, M. Das, V. Kumar

UNIVERSITY OF ALBERTA
M. Baker,S. Fallows, C. Krauss, Q. Mallin, S. Miller, M. Rangen, C. Rethmeier, P. Welingampola

INDIANA UNIVERSITY SOUTH BEND
E. Behnke, C. Cripe, I. Levine,

Pacific Northwest NATIONAL LABORATORY
I. Arnquist, C.M. Jackson, B. Loer

Queen's UNIVERSITY
E. Adams, M. Bai, K. Clark, D. Cranshaw, K. Dering, G. Giroux, H. Herrera, C. Moore, A. Noble, M. Robert

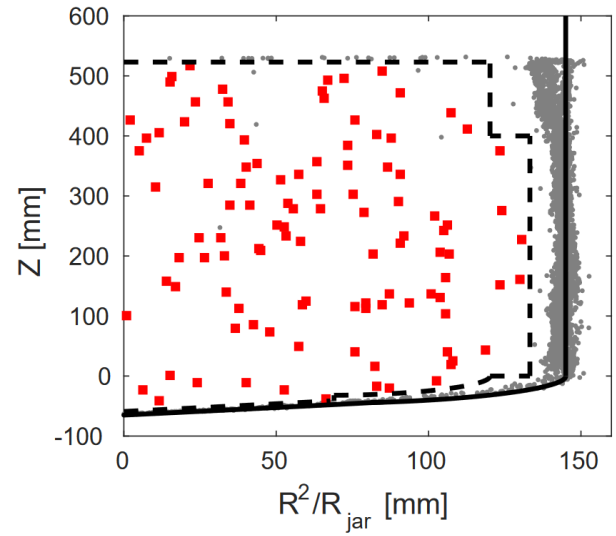
Université de Montréal
I. Brooklyn Varela, L. Desmmarais, P. Frédérick, M. Laurin, V. Monette, H. Nozard, A. Robinson, J. Savoie, N. Starinski, V Zacek, C. Wen Chao

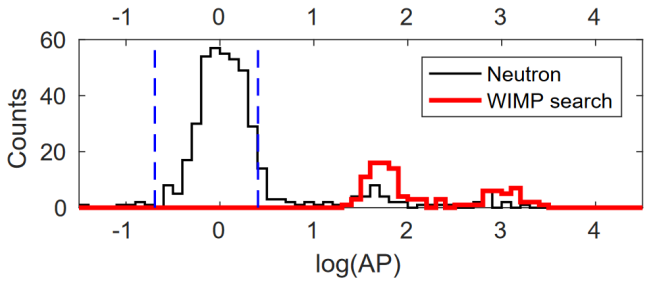
LaurentianUniversity UniversitéLaurentienne
J. Farine, A. Le Blanc, C. Licciardi, U. Wichoski

Extra Slides

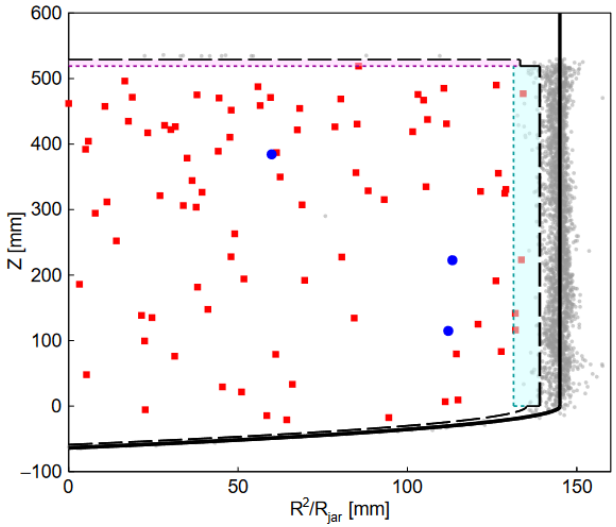
PICO-60 Results

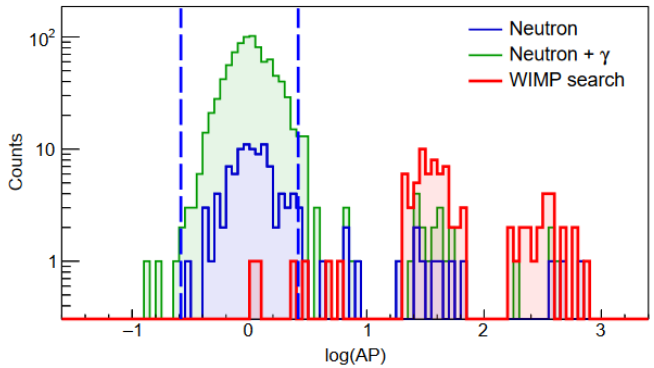
Run 1 ($Q_{Seitz} = 3.29$ keV)





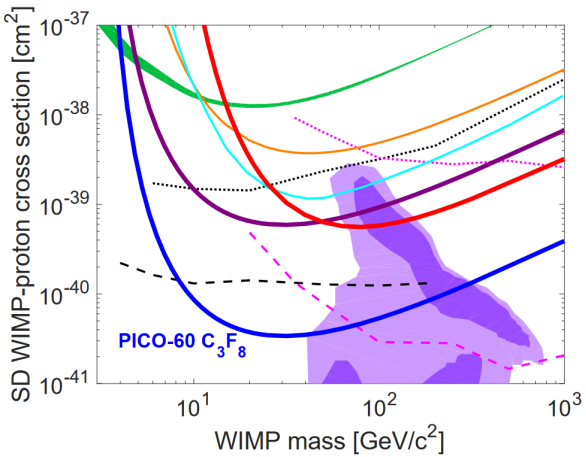
Run 2 ($Q_{Seitz} = 2.45keV$)

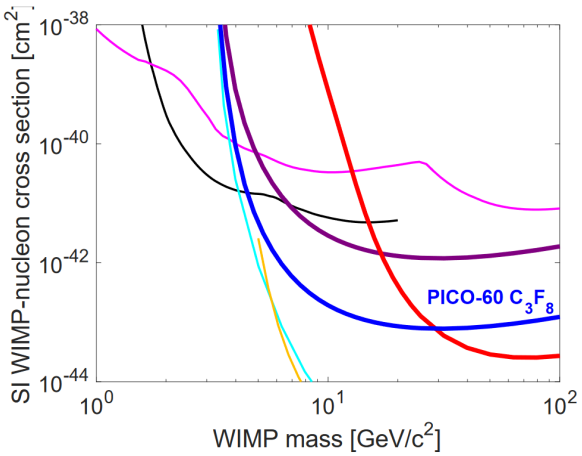




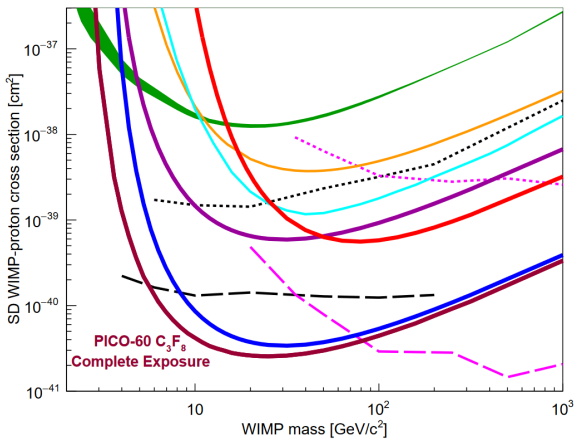
PICO-60 Results

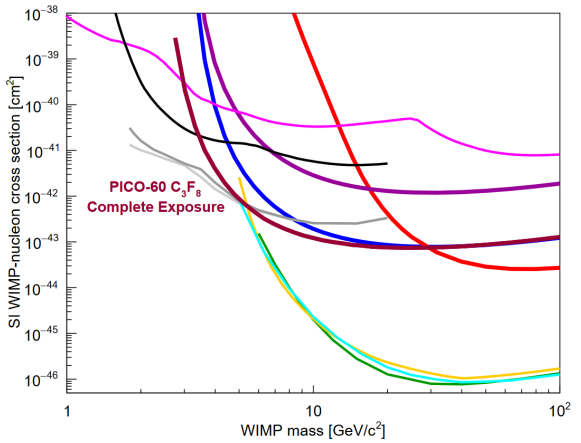
Run 1 ($Q_{Seitz} = 3.29$ keV)





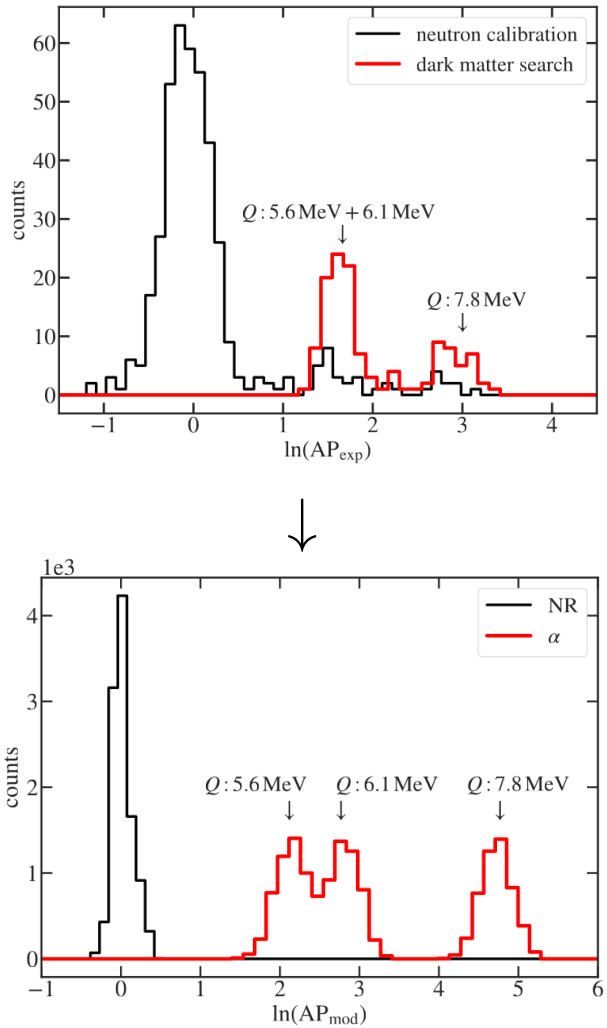
Combined (Run 1 + 2)





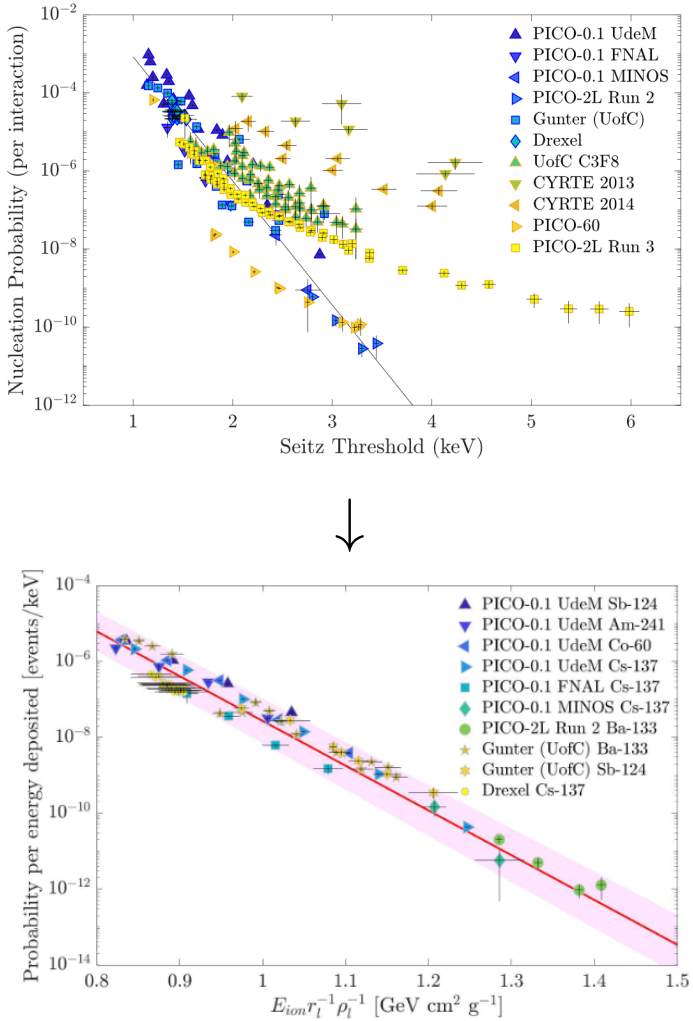
Other Physics

Molecular dynamics to model AP



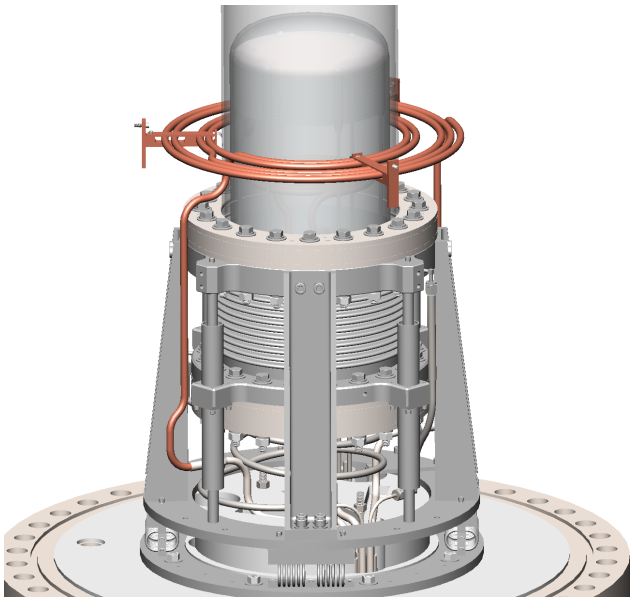
arXiv:1906.04712

Improved ER model

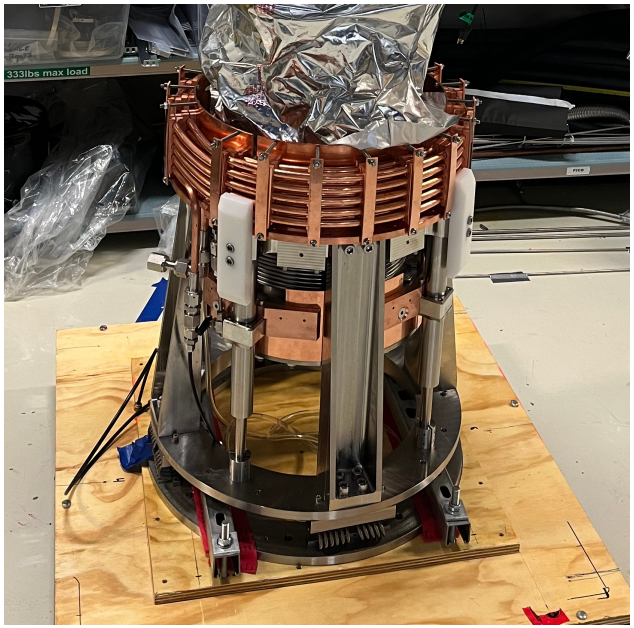


arXiv:1905.12522

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

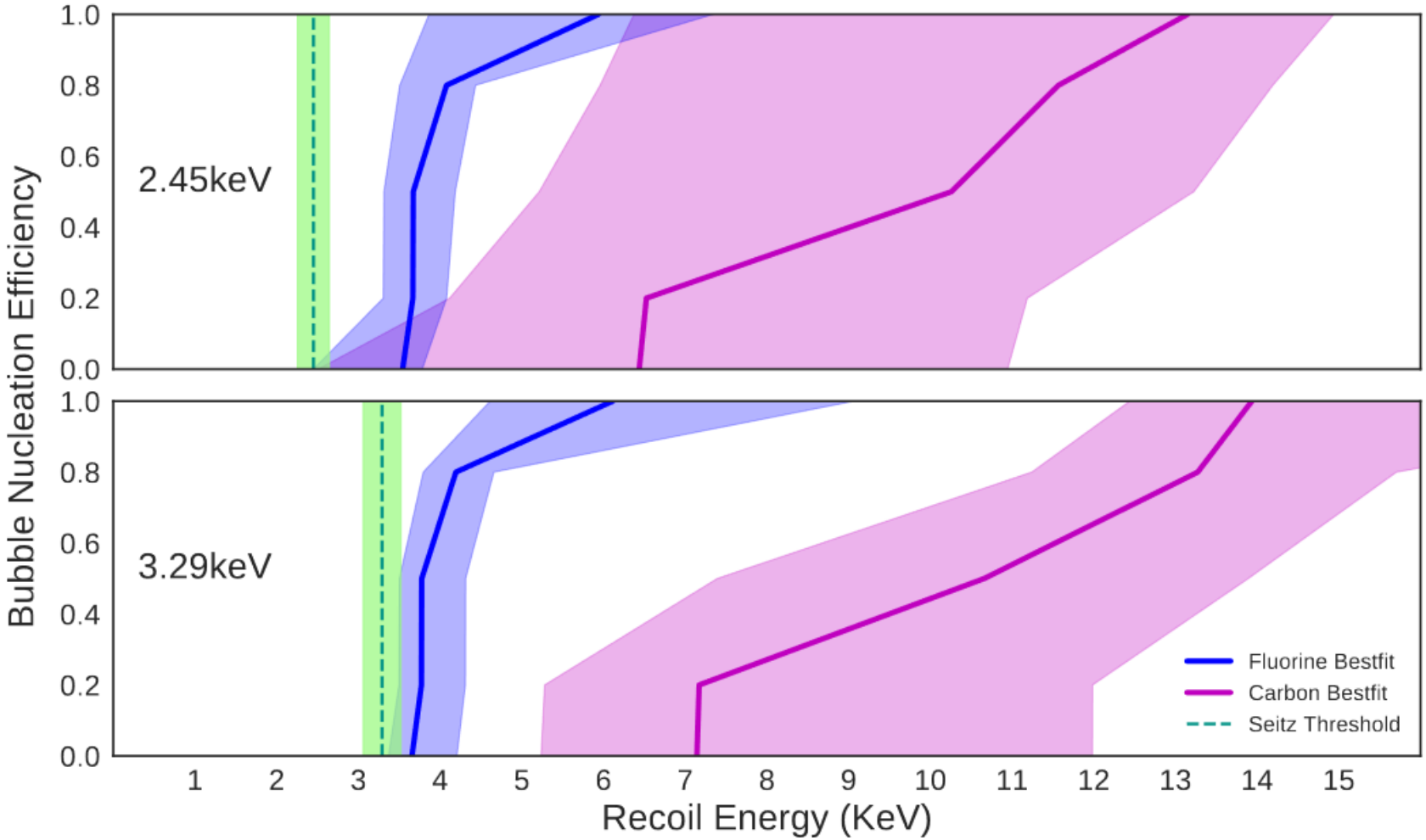
Thresholds

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

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

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

Efficiency Curves



arXiv:1902.04031

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away, because LaTeX now knows how many pages to expect for t
document.