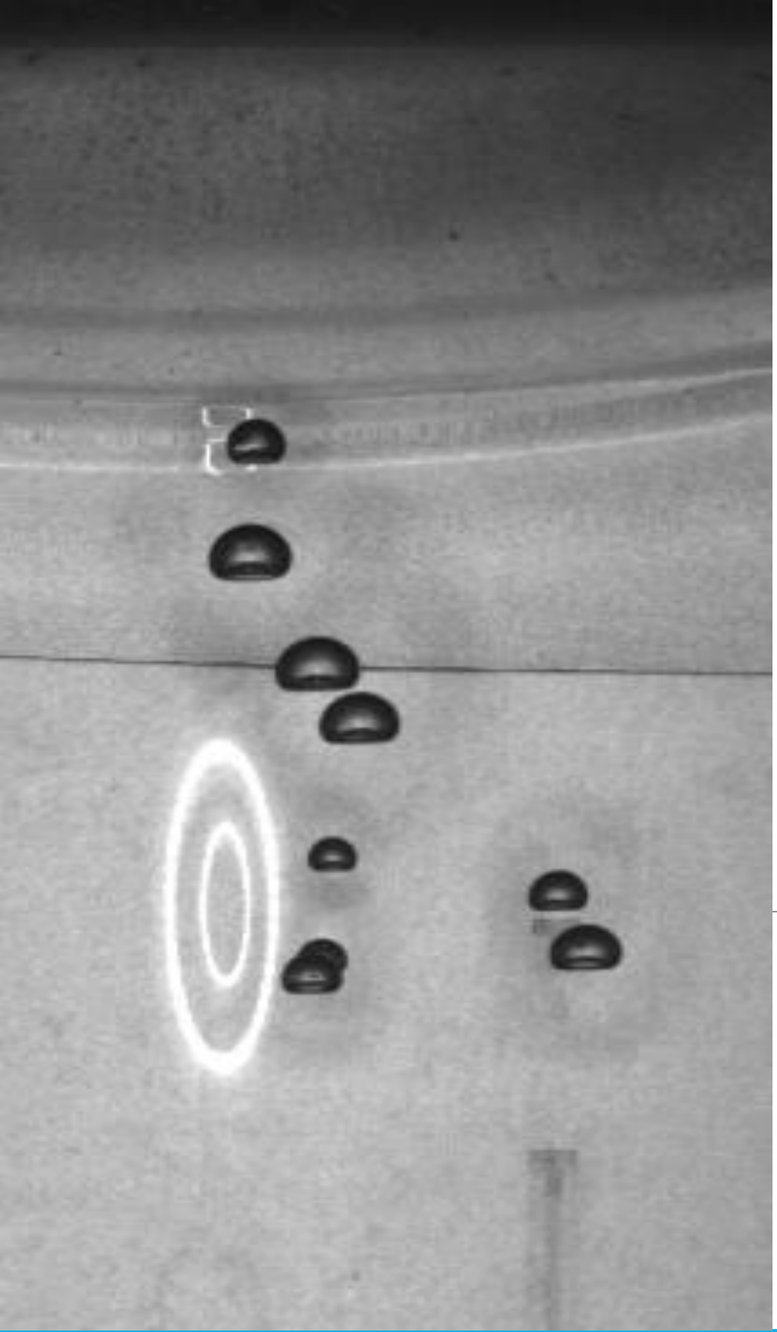


PICO-500 Detector Calibrations

MICHAELA ROBERT, QUEEN'S UNIVERSITY

WNPPC 2024

Queen's UNIVERSITY

PICO

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

What is the PICO Experiment?

- Series of WIMP dark matter detectors operated at SNOLAB

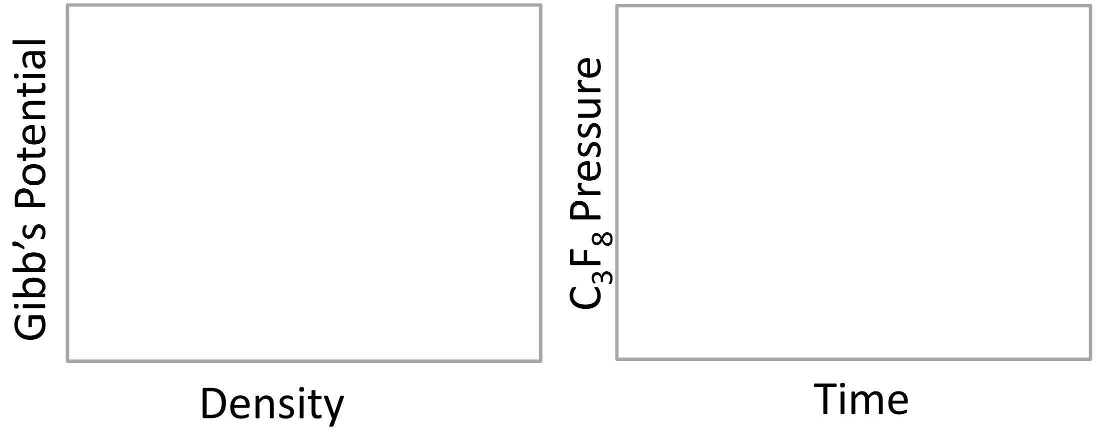
  PICO-60 → PICO-40L → PICO-500

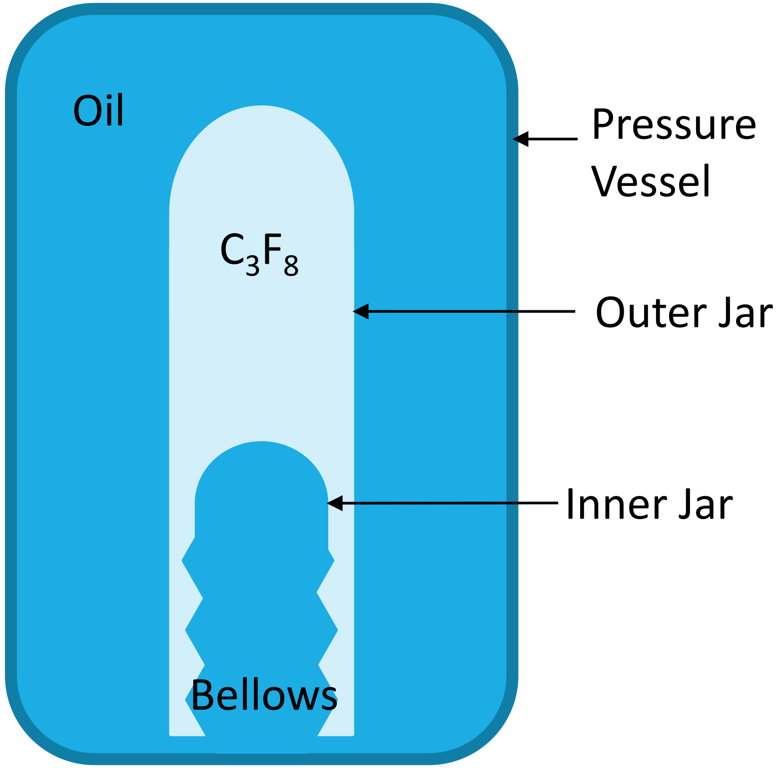
- Fluorine-rich superheated fluid is used to probe for WIMP-proton interactions in a bubble chamber

- Cameras look, piezoelectric transducers listen, and pressure transducers feel for bubbles

PICO-40L: 2020305_3/93 multiple bubble event

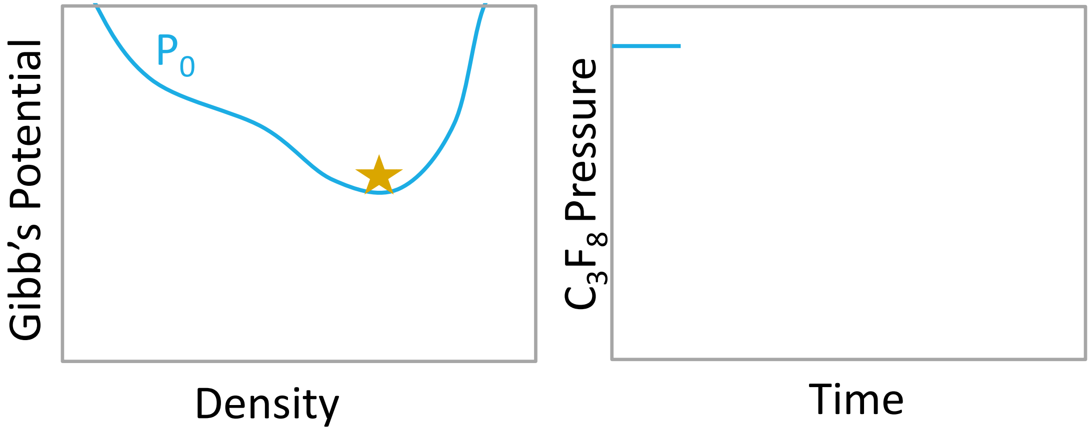
PICO Detector Operation

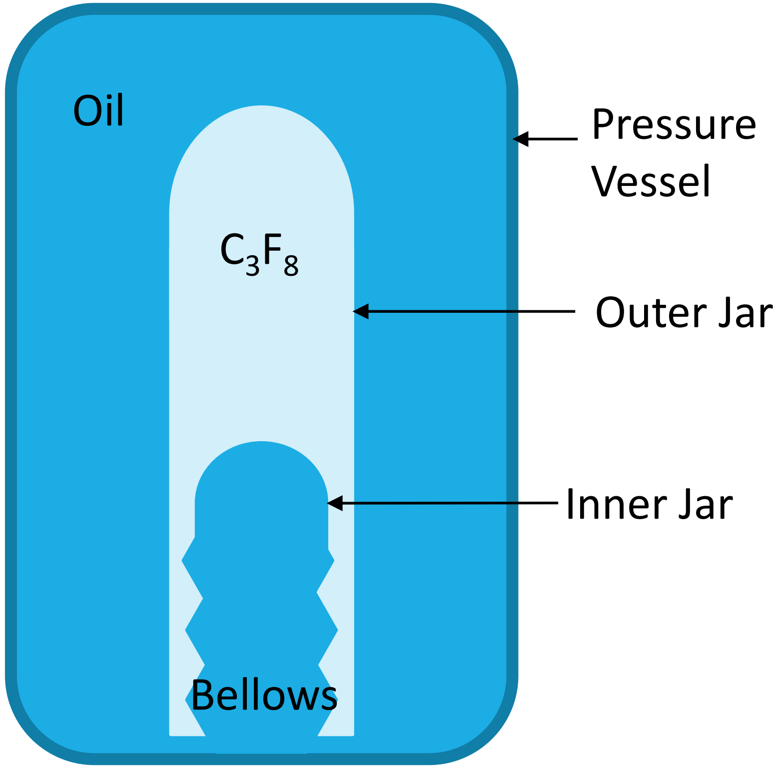




PICO Detector Operation

1. C_3F_8 is pressurized to stable liquid state

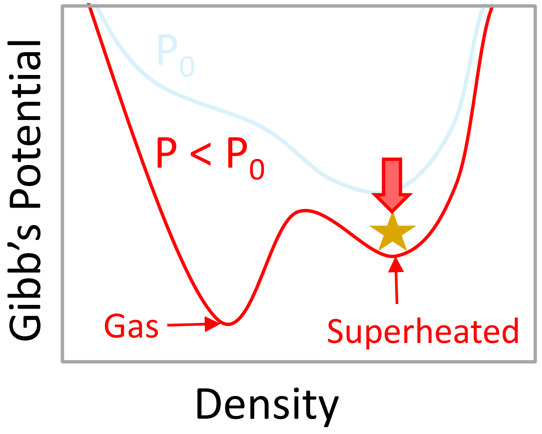


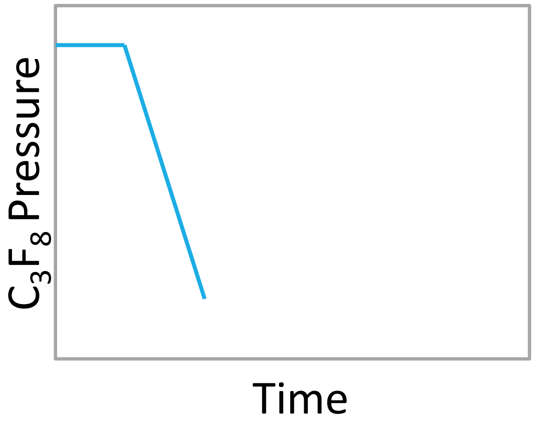


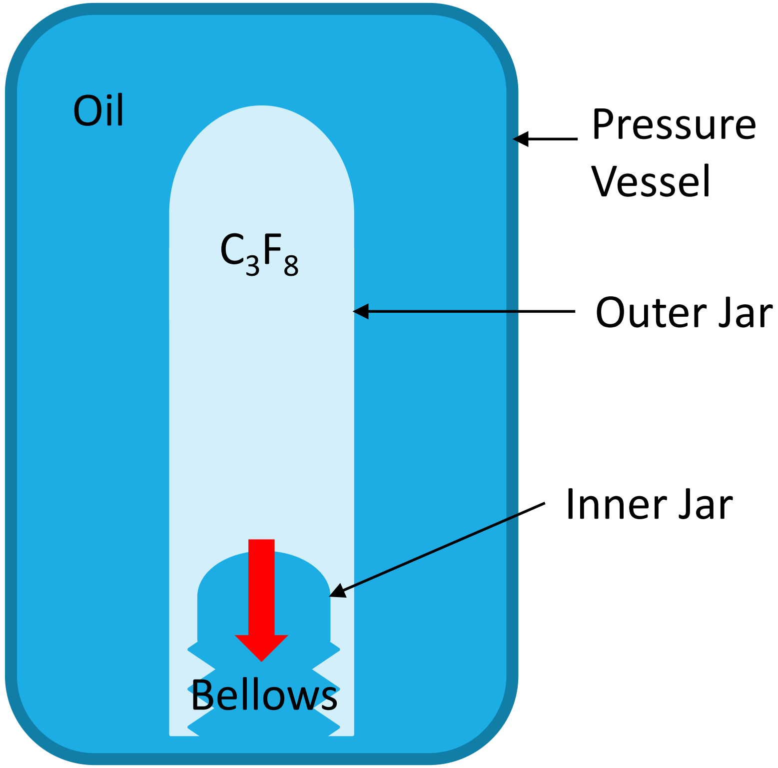
PICO Detector Operation

1. C_3F_8 is pressurized to stable liquid state

2. C_3F_8 volume is slowly expanded





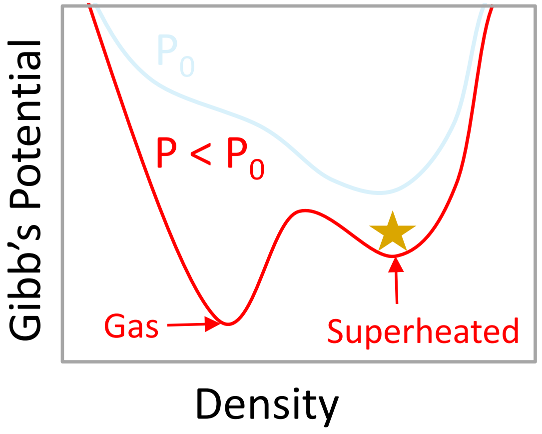


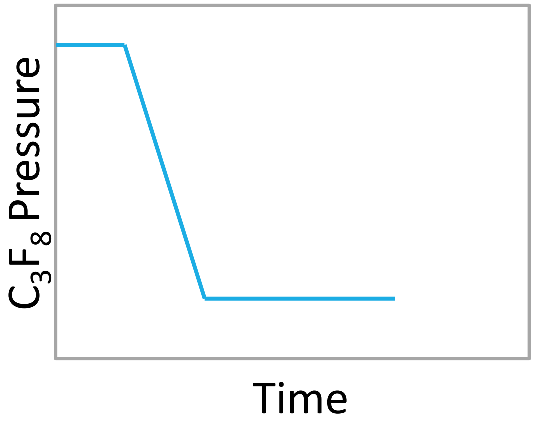
PICO Detector Operation

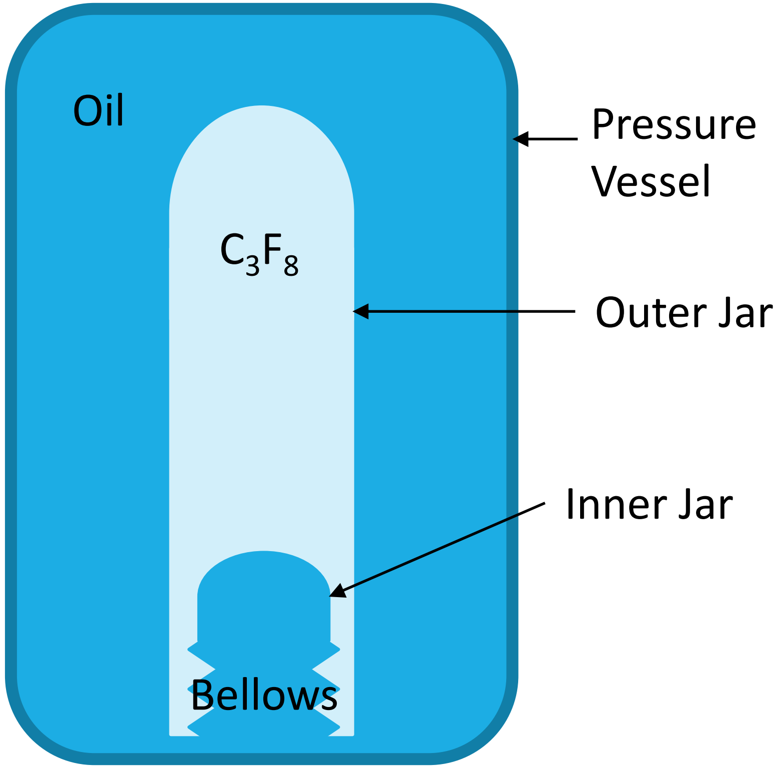
1. C_3F_8 is pressurized to stable liquid state

2. C_3F_8 volume is slowly expanded

3. Detector waits for a bubble in superheated state







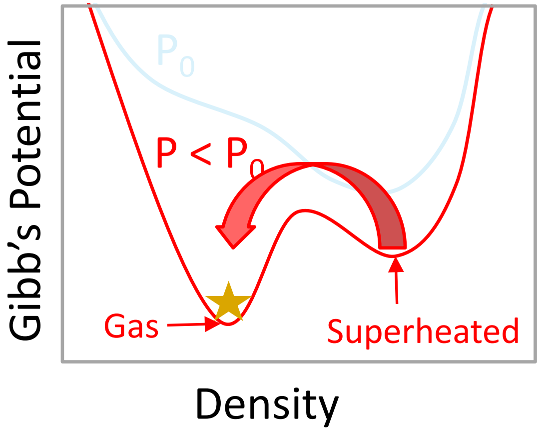
PICO Detector Operation

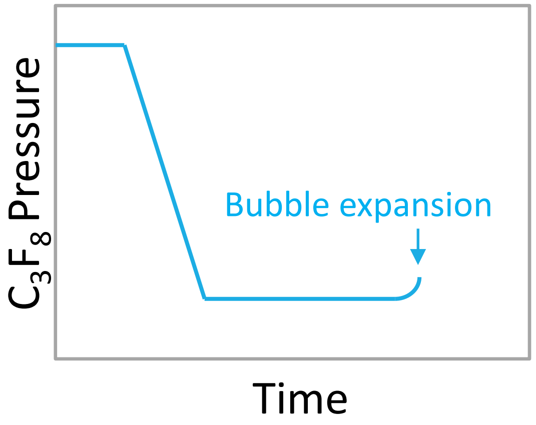
1. C_3F_8 is pressurized to stable liquid state

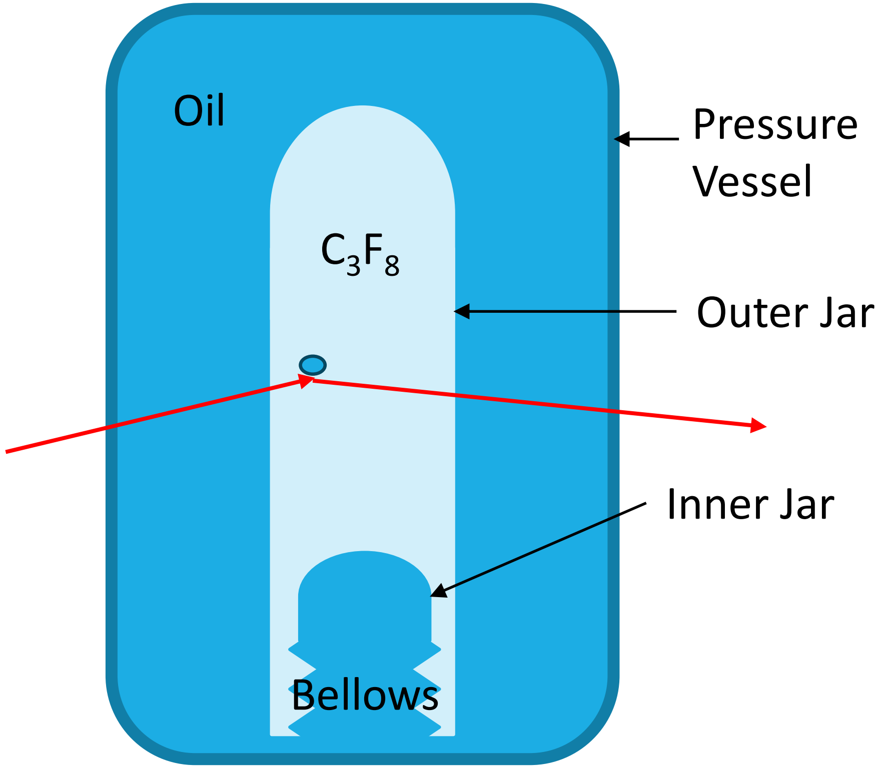
2. C_3F_8 volume is slowly expanded

3. Detector waits for a bubble in superheated state

4. Incoming particle causes a nuclear recoil resulting in a bubble - images, pressure and acoustic data are recorded







PICO Detector Operation

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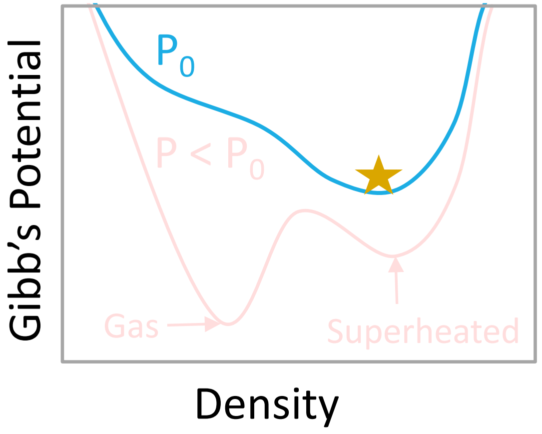
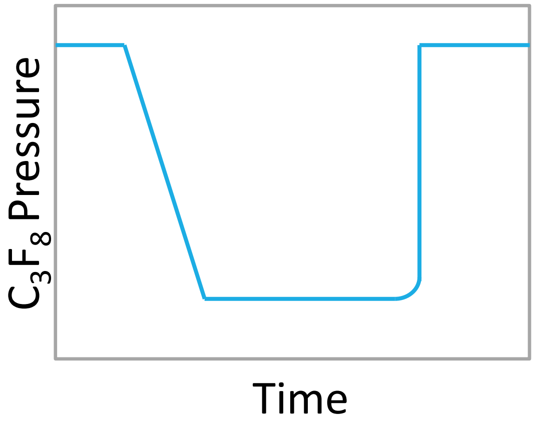
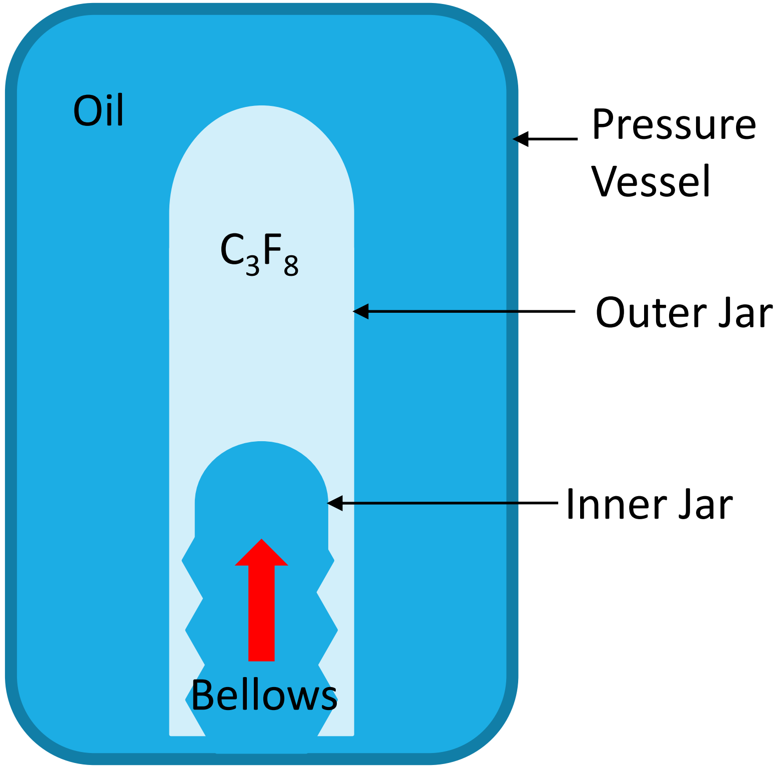
5. Detector compresses to collapse the bubble and reset for next event







Detector Thresholds

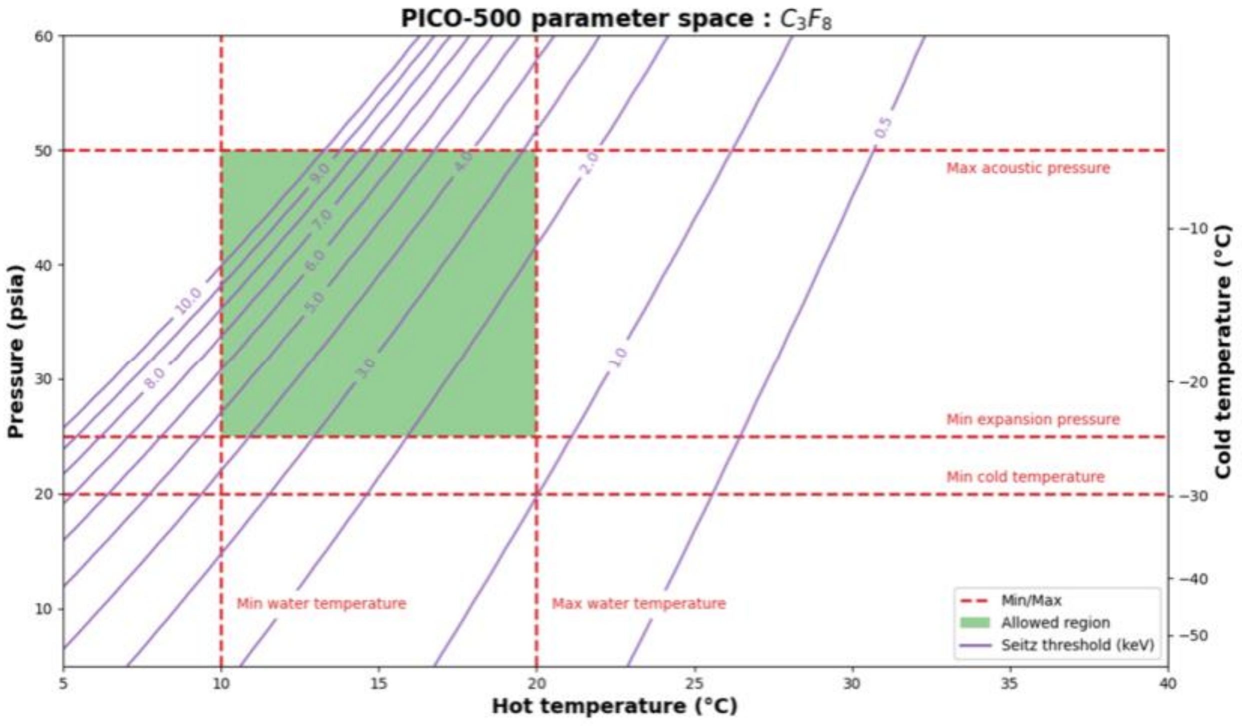
- A small addition of energy, such as a nuclear recoil caused by a WIMP, can trigger a phase transition

- Seitz model: if a threshold amount of energy is deposited within a localized volume, then a critically sized bubble can form

  Typically, $r_c \sim 25$ nm

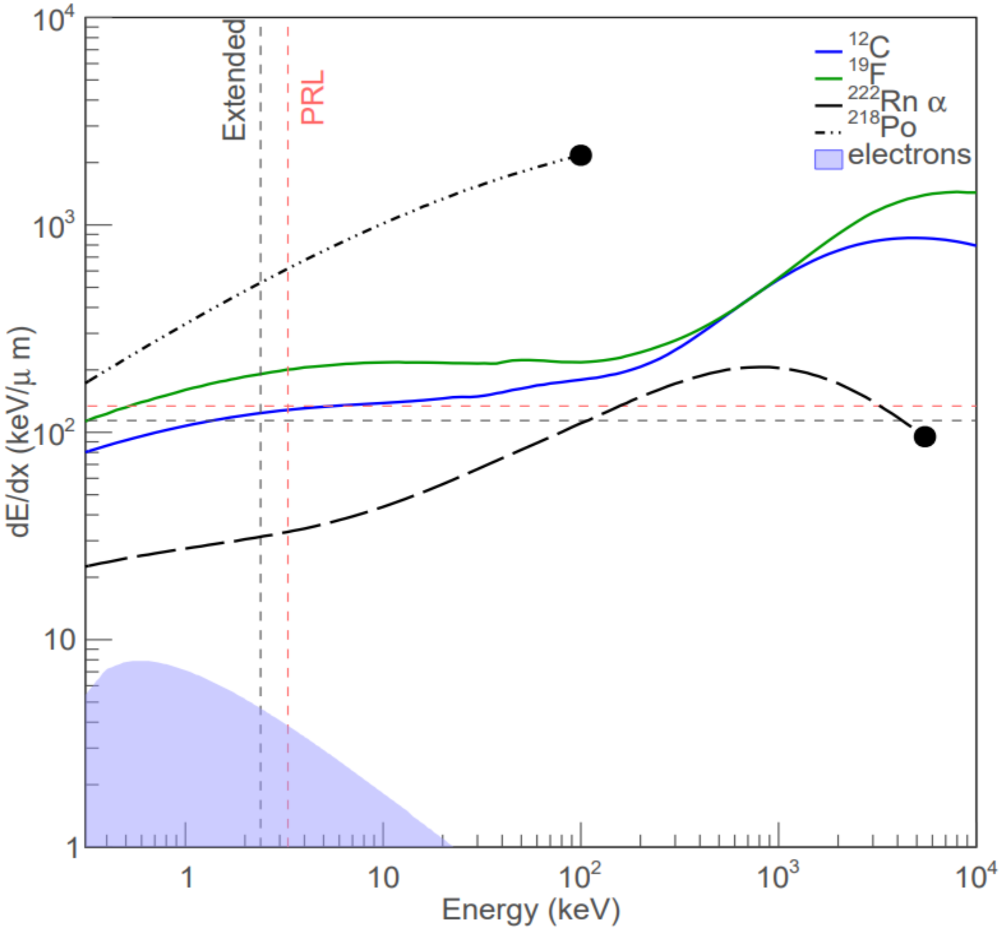
- PICO detectors can be run at various energy thresholds by setting the appropriate fluid pressure and temperature

  Typically, $Q_{Seitz} \sim 3$ keV



Calibrating for Gamma Rejection

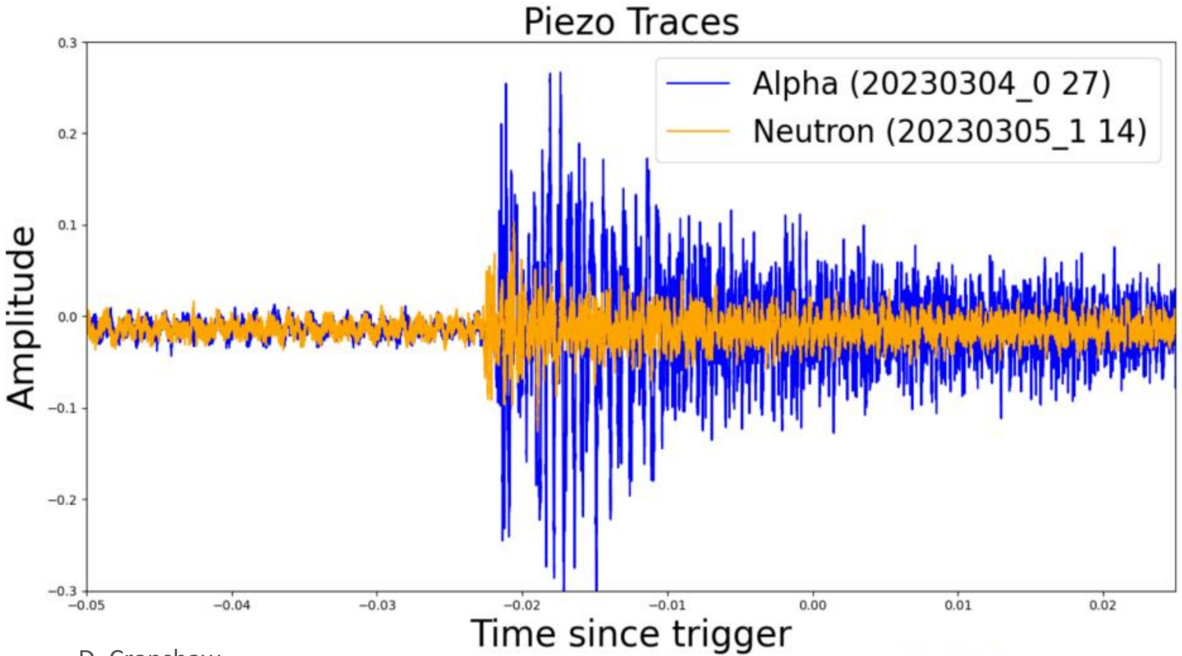
- Electron stopping power is low
  → electron recoils are extremely inefficient at nucleating bubbles
- Optimal threshold has high WIMP sensitivity and excellent gamma insensitivity
- ~18 MBq ^{60}Co source to probe detector response to electron recoils via 1.17 and 1.33 MeV gammas



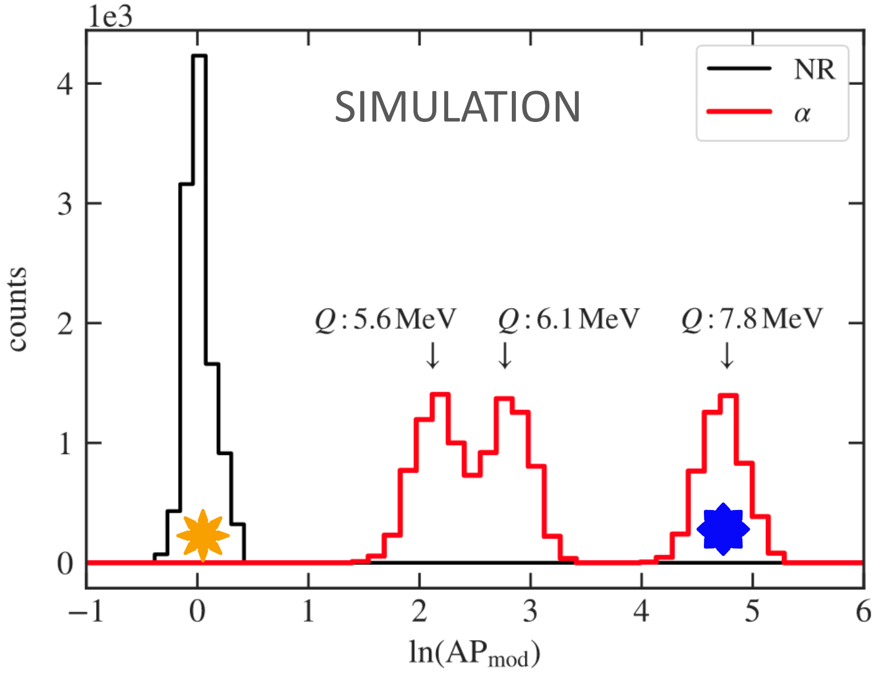
P. Mitra (2018). PhD thesis

Calibrating for Alpha Rejection

- Acoustic parameter (AP) describes the bubble's acoustic power
- ^{241}AmBe and/or ^{252}Cf calibration data is used to tune AP coefficients for separation between neutrons/WIMPs and alphas



D. Cranshaw

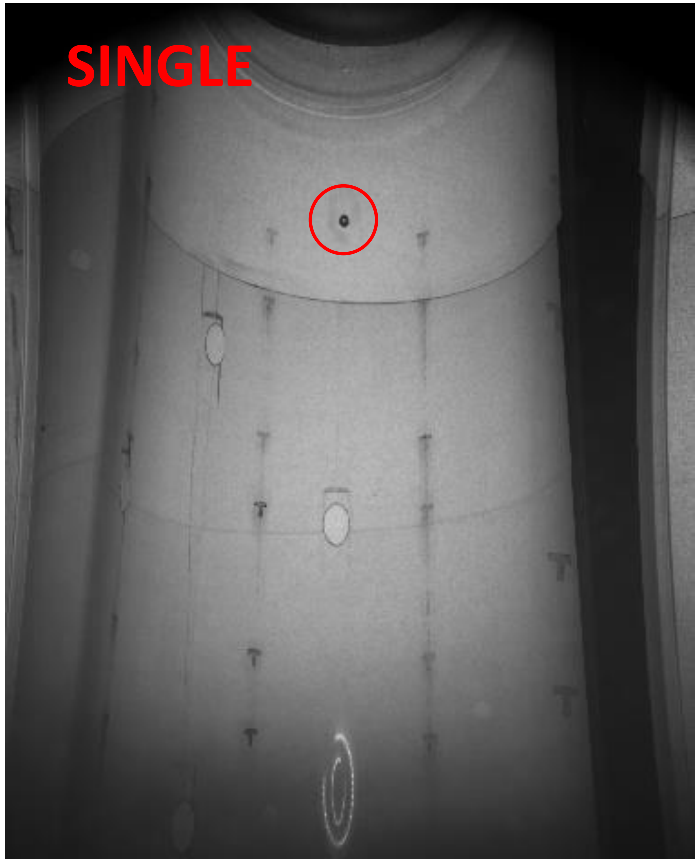


T. Kozynets et al. (2019). DOI: 10.1103/PhysRevD.100.052001

Calibrating for Neutron Rejection

- Neutron MFP ~cm
  → single / multiple bubble events
- WIMPs interact rarely
  → single bubble events
- Ratio of neutron multiple bubble events to single bubble events must be analyzed for a given size of detector

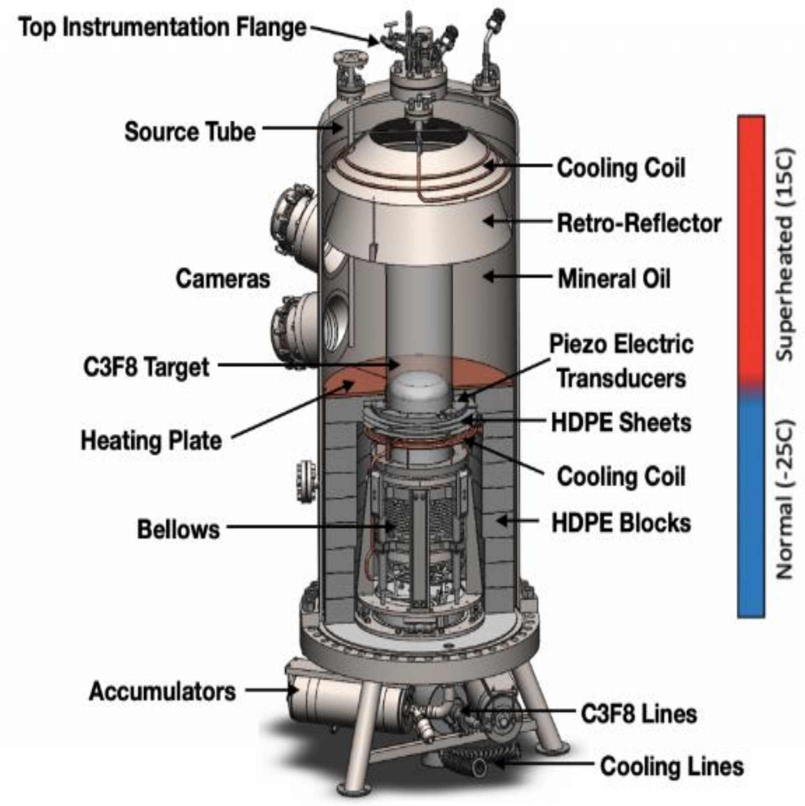
PICO-40L: 20230304_3/83

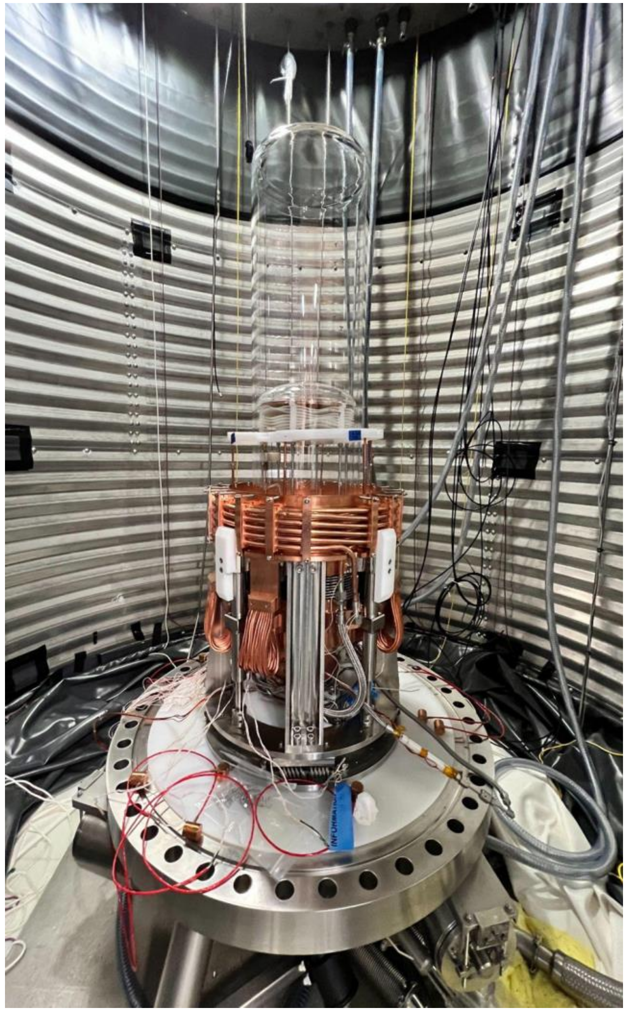


PICO-40L: 20230304_3/97

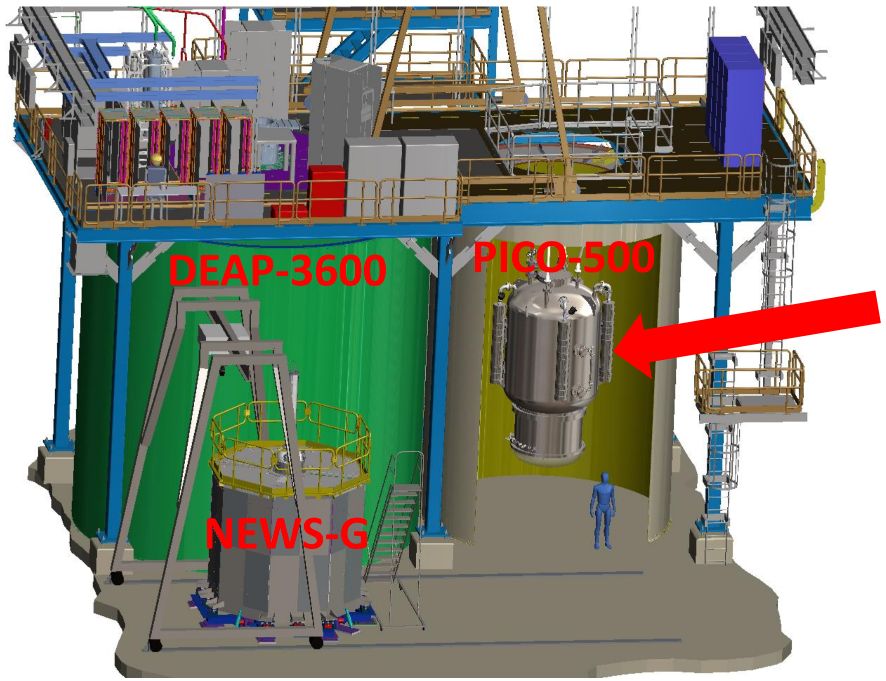
PICO-40L

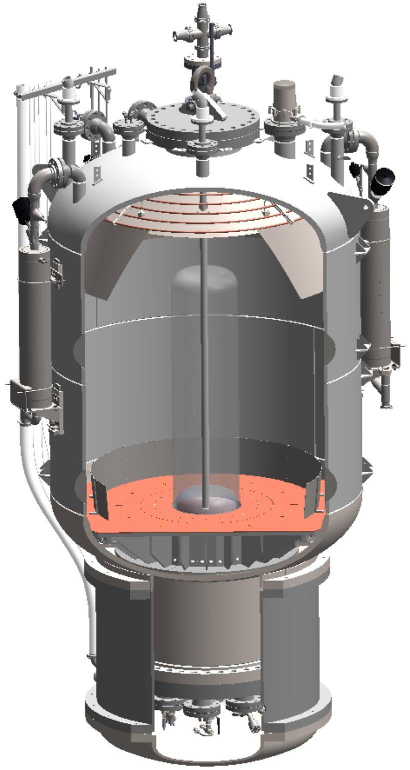
- Constructed at SNOLAB between 2019-2023
- Currently commissioning
- Testbench for new technology aimed to reduce backgrounds seen in prior detector





Upgscaling to PICO-500





- ~250 litre sensitive volume → 5 times larger than PICO-40L
- Upgrades to piezos, thermal system, hydraulics, calibration system and more
  - See E. Adams' talk at 9:15pm on February 16th
- Construction underway in Cube Hall at SNOLAB

Calibration System Upgrades

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- 3 source tubes
  → enable illumination of large active volume in less calibration run time

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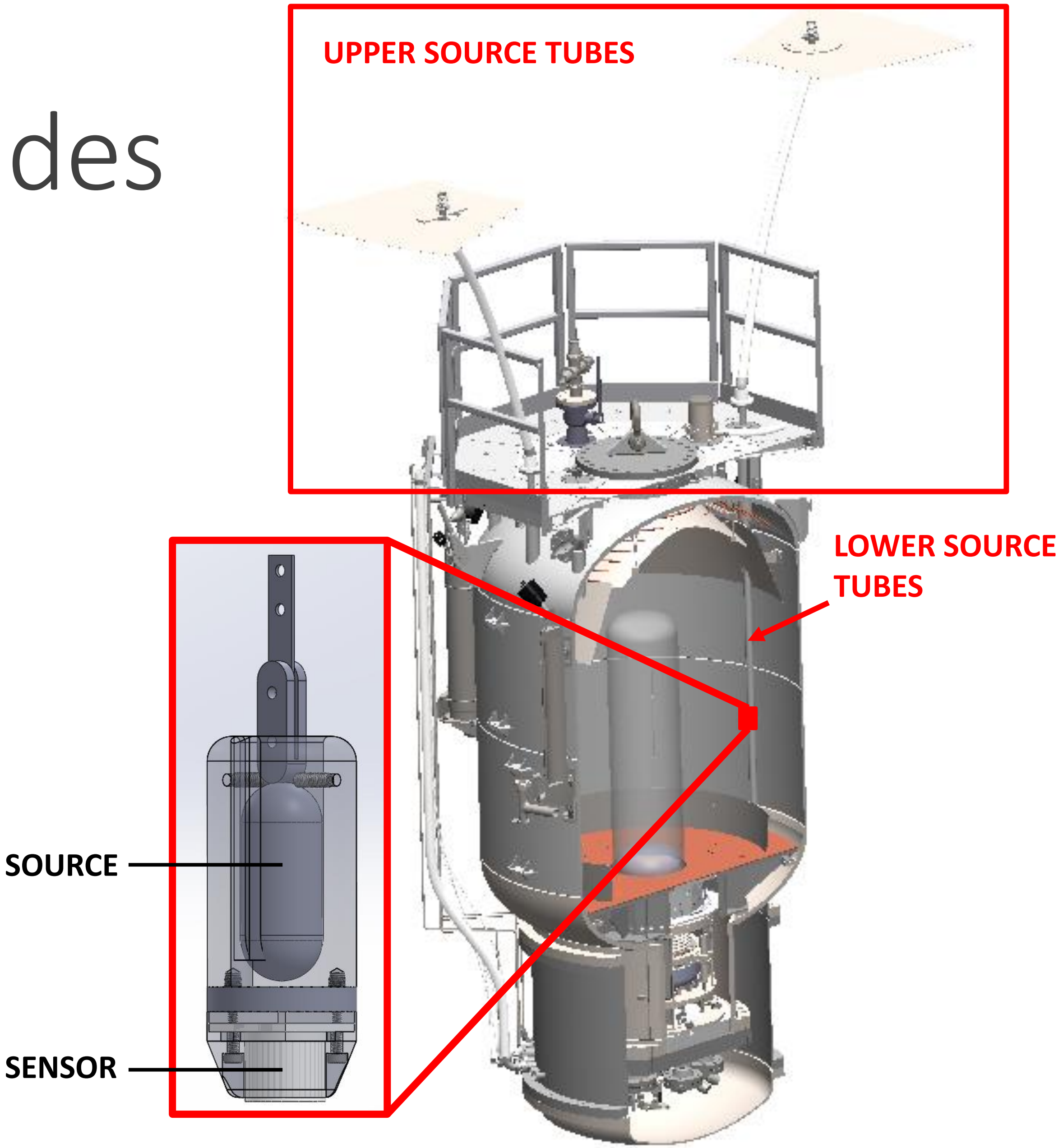
Calibration System Upgrades

- 3 source tubes
  → enable illumination of large active volume in less calibration run time
- Nitrogen flushing
  → keep radon out of the source tubes
- Ultrasonic position monitoring system
  → improve reliability and accuracy of source position measurements



Summary

- PICO is searching for WIMP-proton interactions by looking, listening and feeling for bubbles in superheated fluid.

- Dark matter search can be carried out once calibrations are complete to reject:
  - Gammas by energy threshold setpoint
  - Alphas by AP
  - Neutrons by bubble multiplicity

- Upgrades to the PICO-500 calibration system will benefit calibration data quality, helping to understand detector response and achieve very low background rates

PICO-40L: 2020305_3/93 multiple bubble event

PICO

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D. Priya, S. Priya, Y. Yan

NORTHWESTERN UNIVERSITY
C.E. Dahl

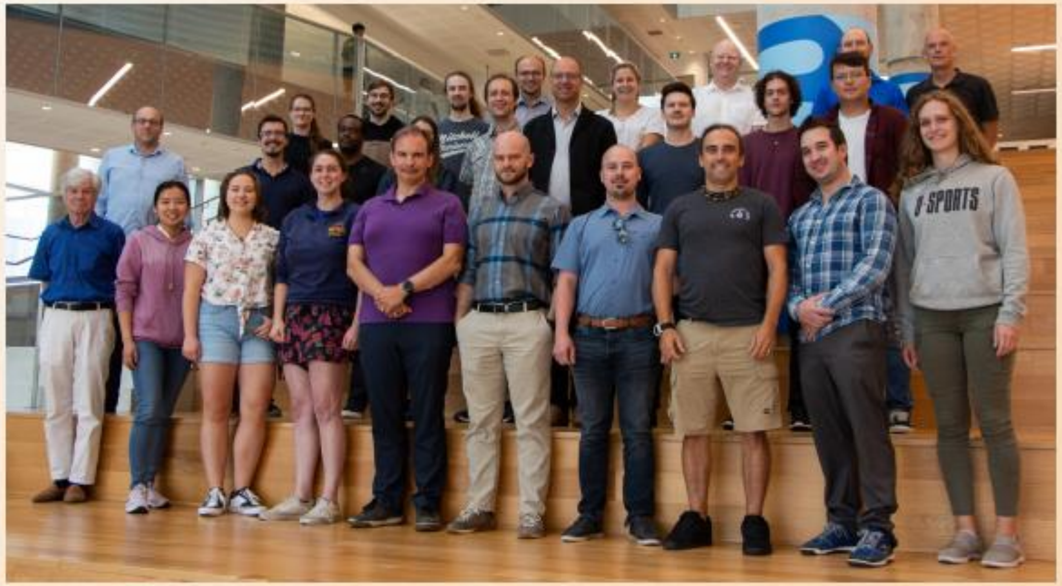
SNOLAB
P. Grylls, A. Mathewson,
I. Lawson, S. Sekula

Northeastern ILLINOIS UNIVERSITY
O. Harris

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

Drexel UNIVERSITY
R. Neilson

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



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C. Moore, A. Noble, M. Robert

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H. Nozard, A. Robinson, J. Savoie,
N. Starinski, V Zacek, C. Wen Chao

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

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

Backup

Seitz Threshold

$$E_T = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) - \frac{4\pi}{3} r_c^3 (P_b - P_l), \qquad P_b - P_l \geq \frac{2\sigma}{r_c}$$

Bubble surface | Latent heat of vaporization | Double counted Work

where,

E_T = Seitz threshold
r_c = critical bubble radius
T = temperature
ρ_b = bubble vapor density
h_i = specific enthalpy of bubble vapor (b) or superheated liquid (l)
P_i = Pressure in bubble (b) or superheated liquid (l)
σ = surface tension

E. Behnke et al., First dark matter search results from a 4-kg CF3I bubble chamber operated in a deep underground site DOI: 10.1103/PhysRevD.86.052001

Acoustic Parameter

$$AP = A(T)\sum_{j} G_j \sum_{n} C_n(\vec{x}) \sum_{f_{min}^{n}}^{f_{max}^{n}} f \times psd_f^j$$

Where,

$A(T)$ = scale factor

G_j = gain of jth acoustic transducer

$C_n(\vec{x})$ = position dependence correction factor for nth frequency bin

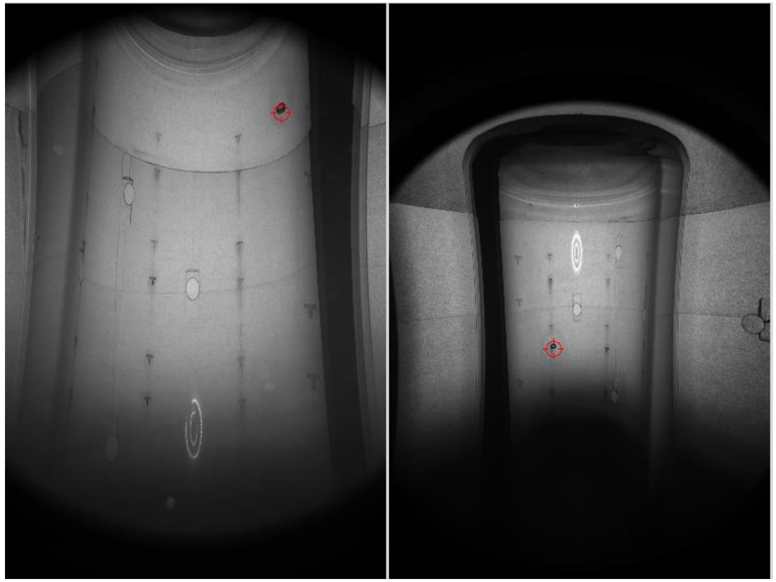
f = center frequency of nth frequency bin

psd_f^j = power spectral density for nth frequency bin and jth acoustic transducer

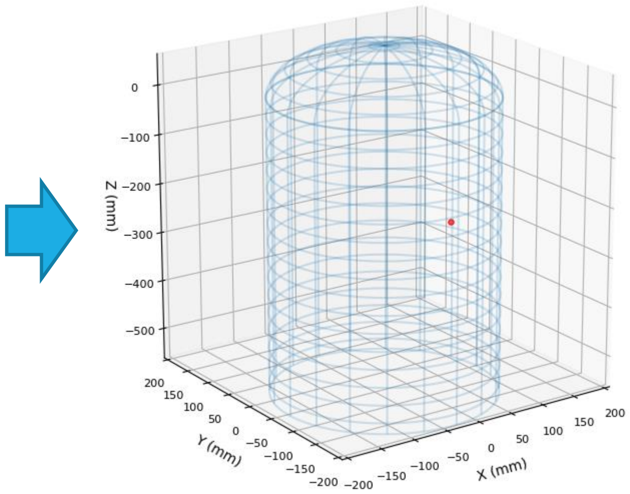
E. Behnke et al., First dark matter search results from a 4-kg CF3I bubble chamber operated in a deep underground site DOI: 10.1103/PhysRevD.86.052001

Wall Events

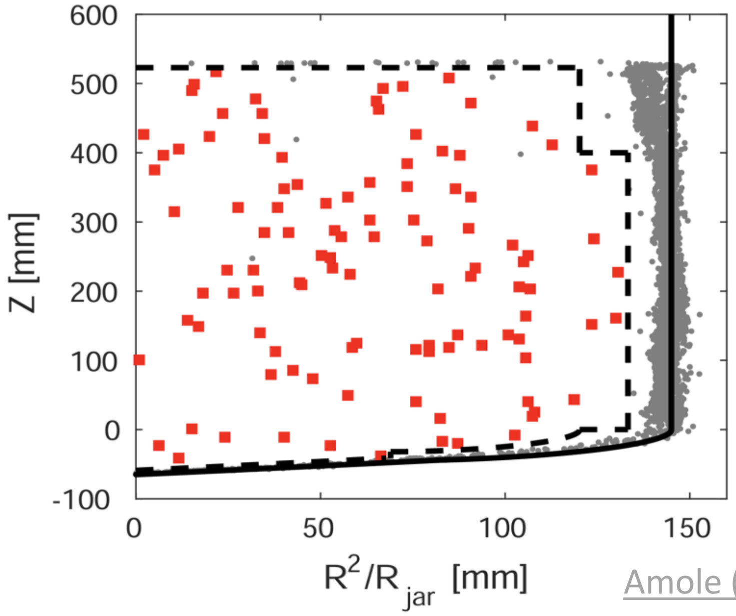
- 4 cameras record images of bubbles, software reconstructs the bubble's location from the images
- Bubbles that nucleate near the walls of the jars are often alphas from the jars or wall events -> Bubbles outside of the fiducial volume are rejected
- ^{241}AmBe and/or ^{252}Cf neutron sources are chosen to induce bubbles at a desired rate



PICO-40L Event



PICO-60 Data



Amole (2017)

PICO-500 Operation

- 1 month of initial calibration
- 2 years of blind physics data in C_3F_8 at multiple thresholds
  - Low threshold run time limited by neutrino backgrounds
- Projected O(10) times improvement on spin-dependent WIMP sensitivity over PICO-40L
- Potential operation with other liquids:
  - CF_3I → spin-independent sensitivity
  - CF_3CH_2F (R134a) → low WIMP mass sensitivity
- Designed for future sensitive volume upsizing if larger vessels become available