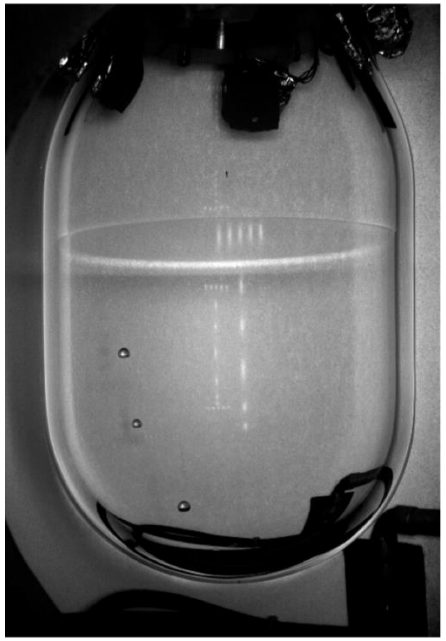
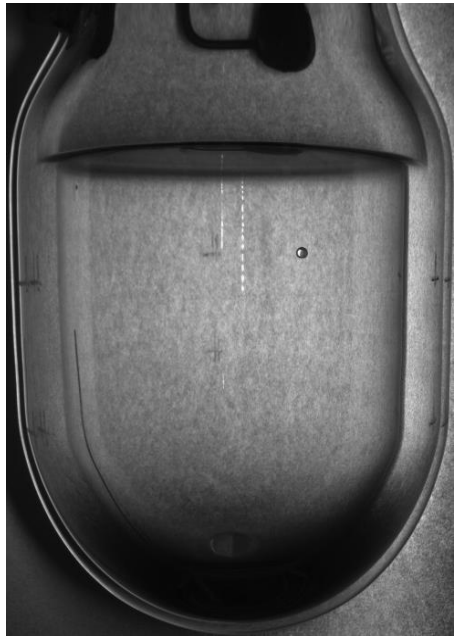
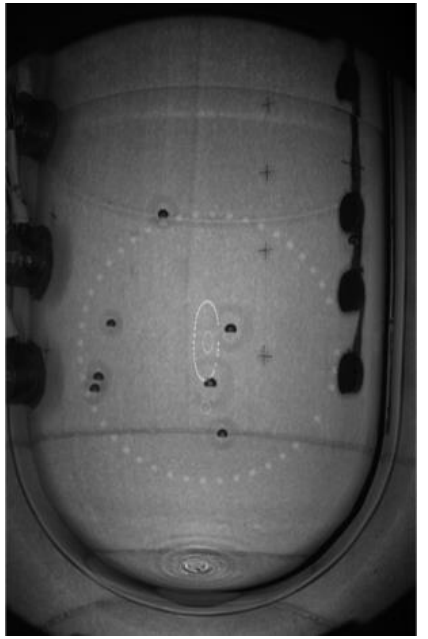
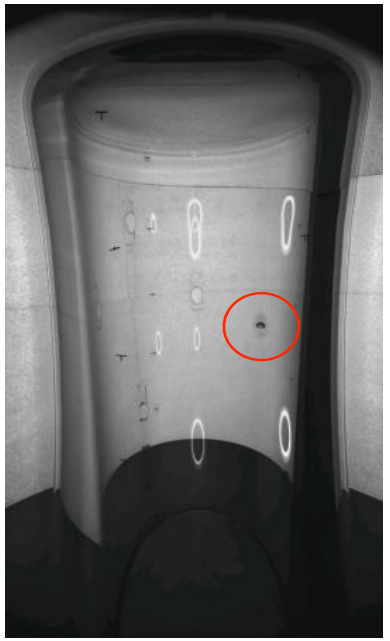
PICO

Northeastern ILLINOIS UNIVERSITY

Orin Harris at TeVPA, 2024

The PICO Bubble Chamber Program

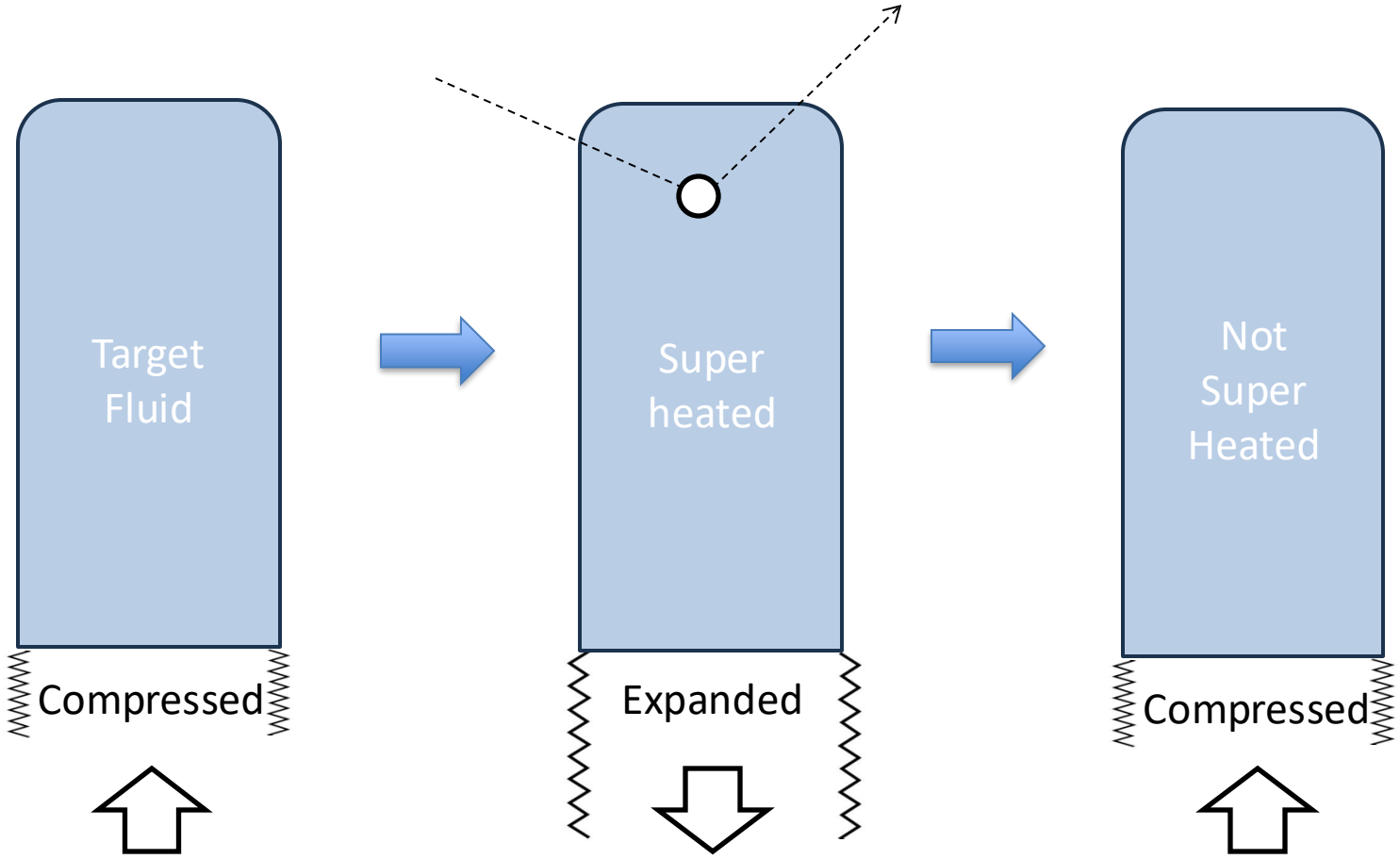


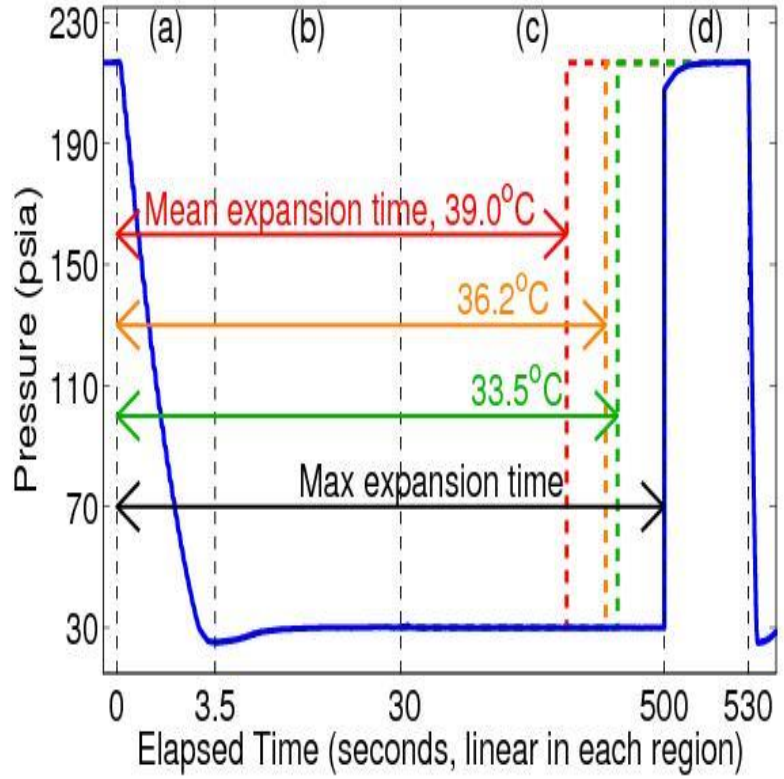





Bubble chamber cycle

Pressure expansion puts target fluid in superheated state

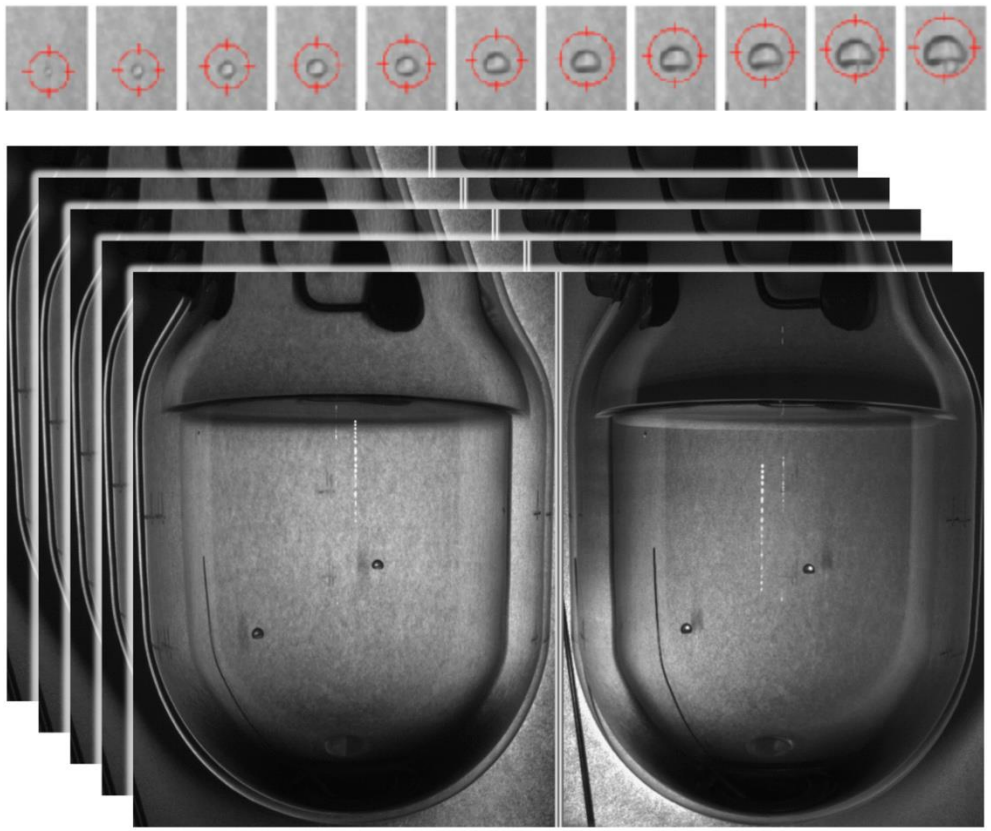
Wait for particle interaction to nucleate a bubble, recompress



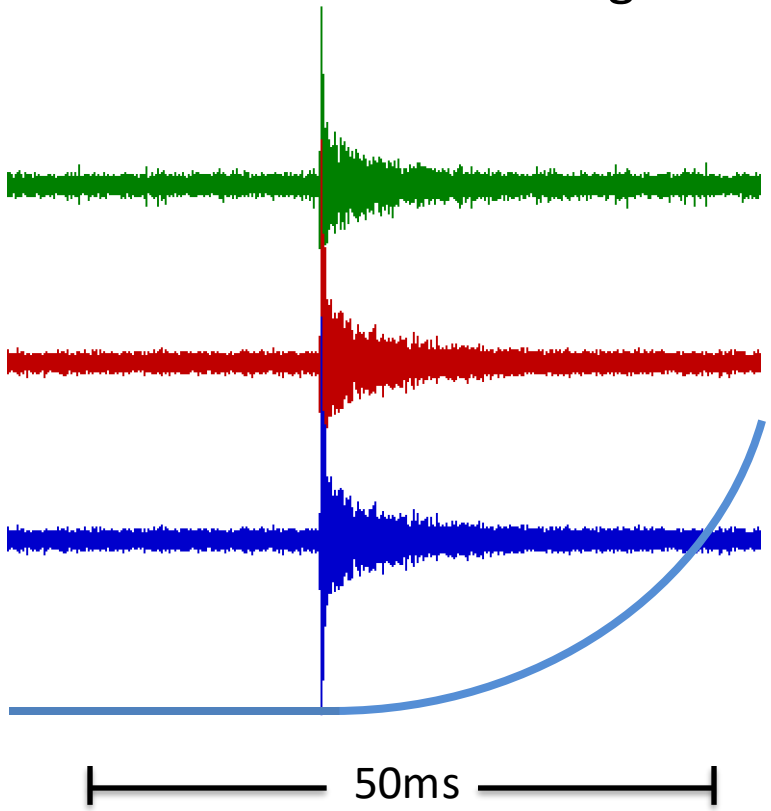


Data acquisition

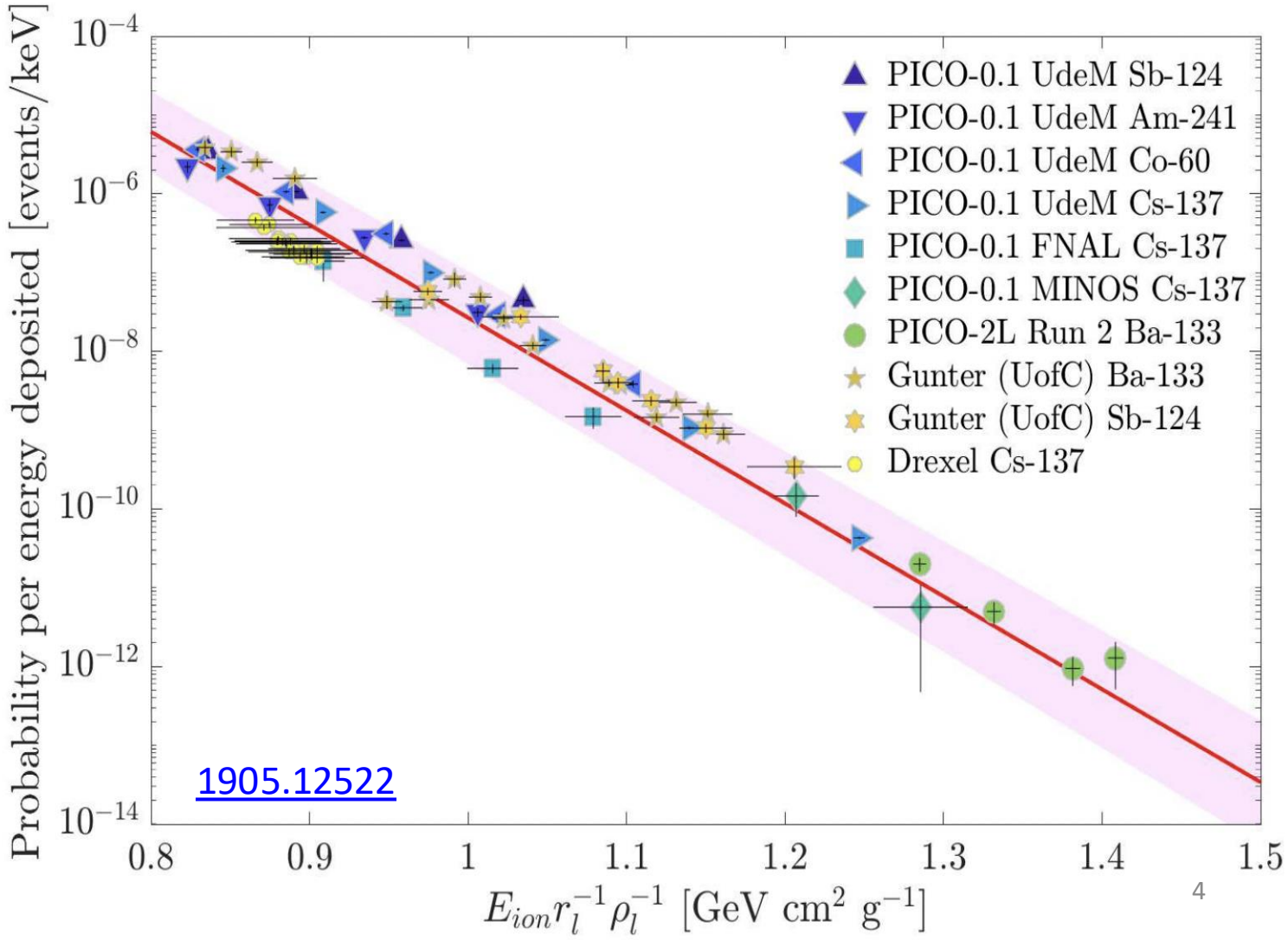
Cameras capture stereoscopic bubble images @ ~200 fps



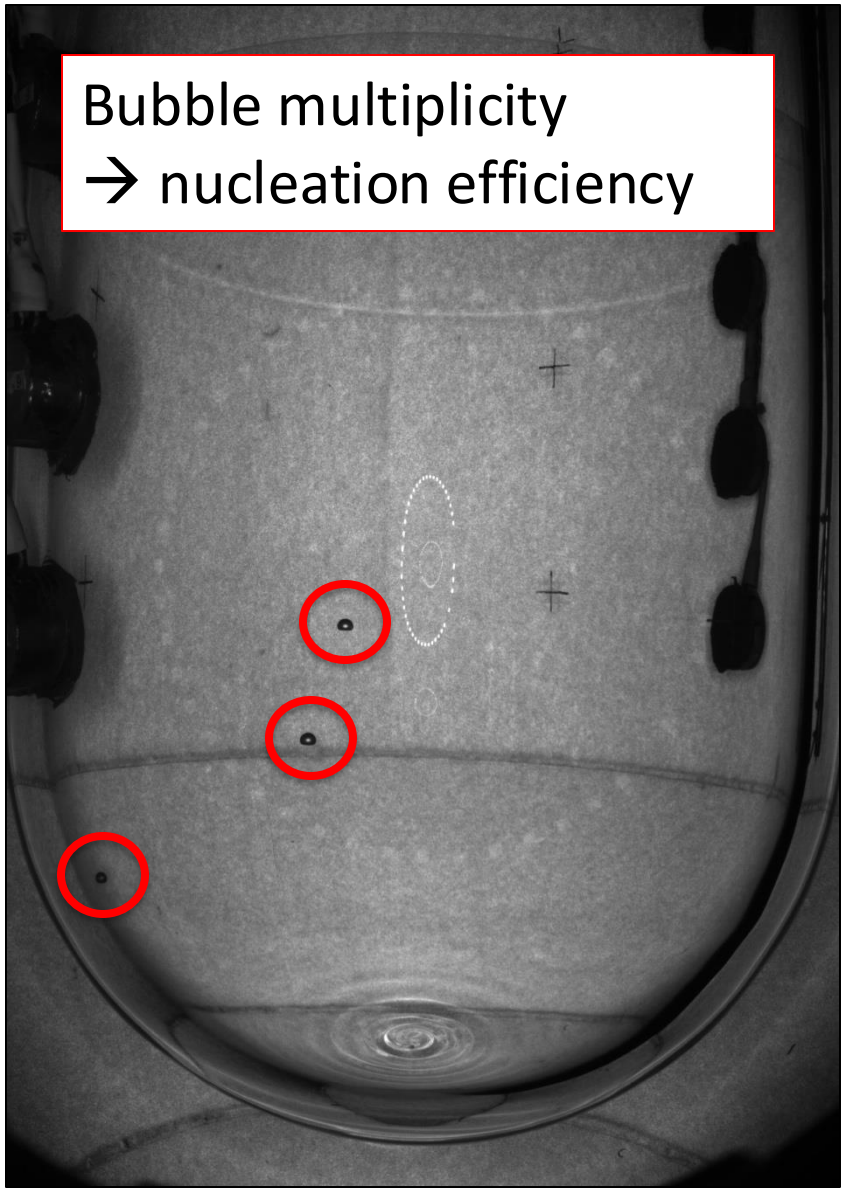
Acoustic sensors & fast pressure transducer capture sound & pressure rise from bubble growth

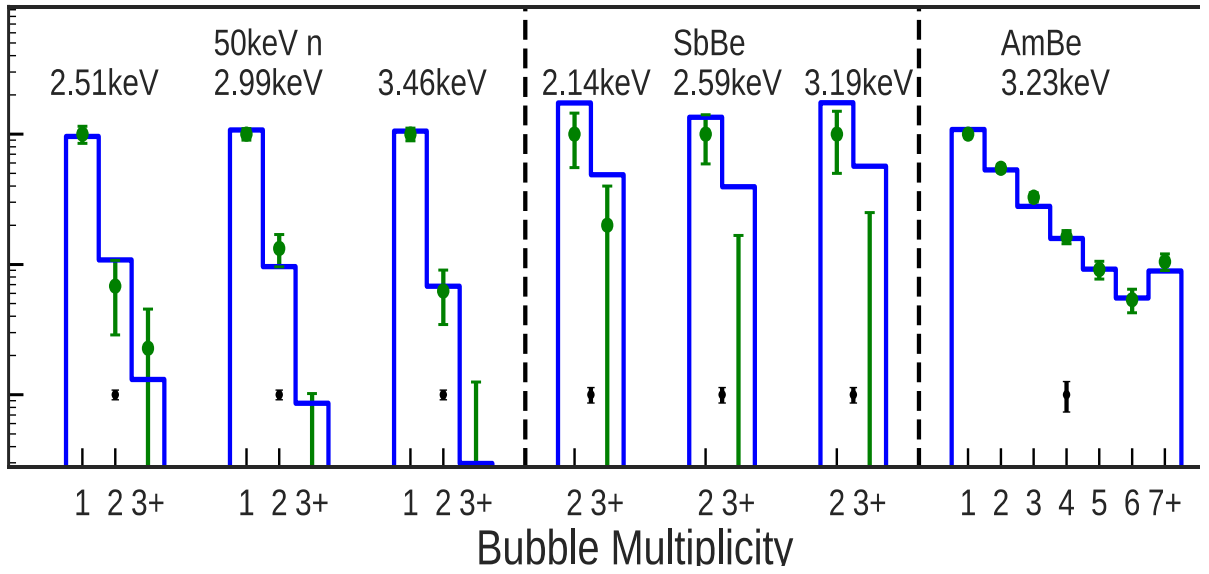


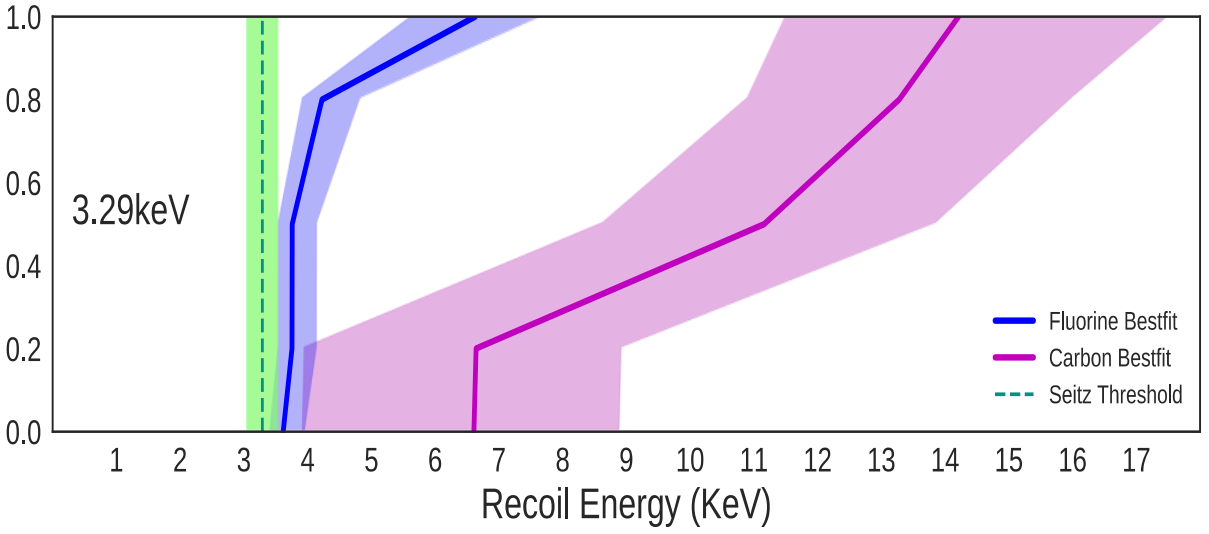
Adjust (P, T) to control both E_{th} and sensitivity to electron recoils



Confirm E_{th} by neutron calibration



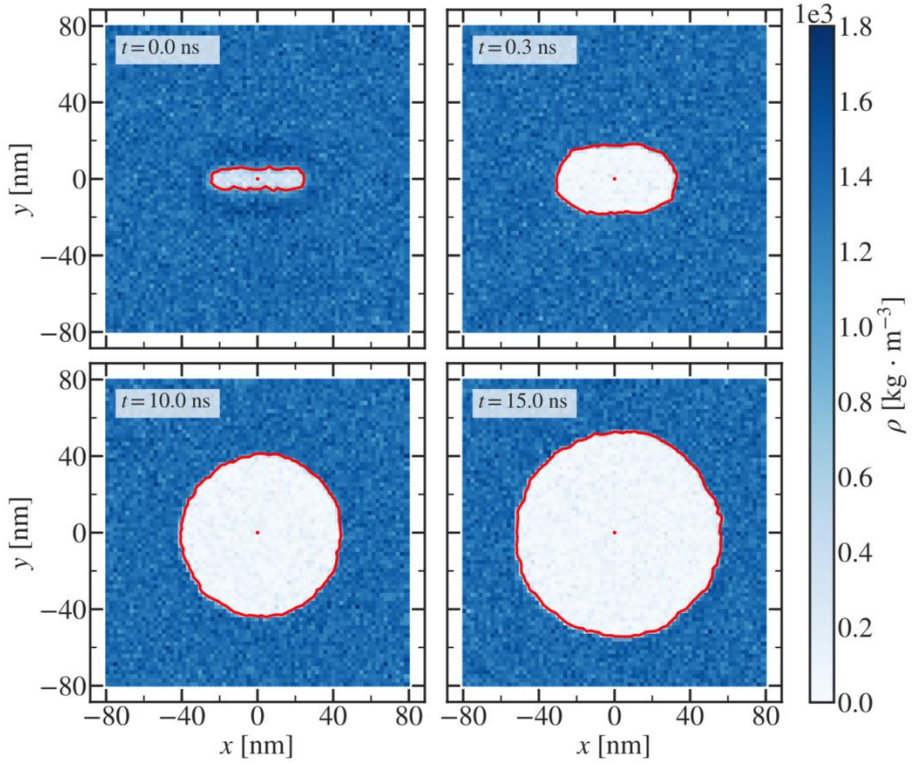




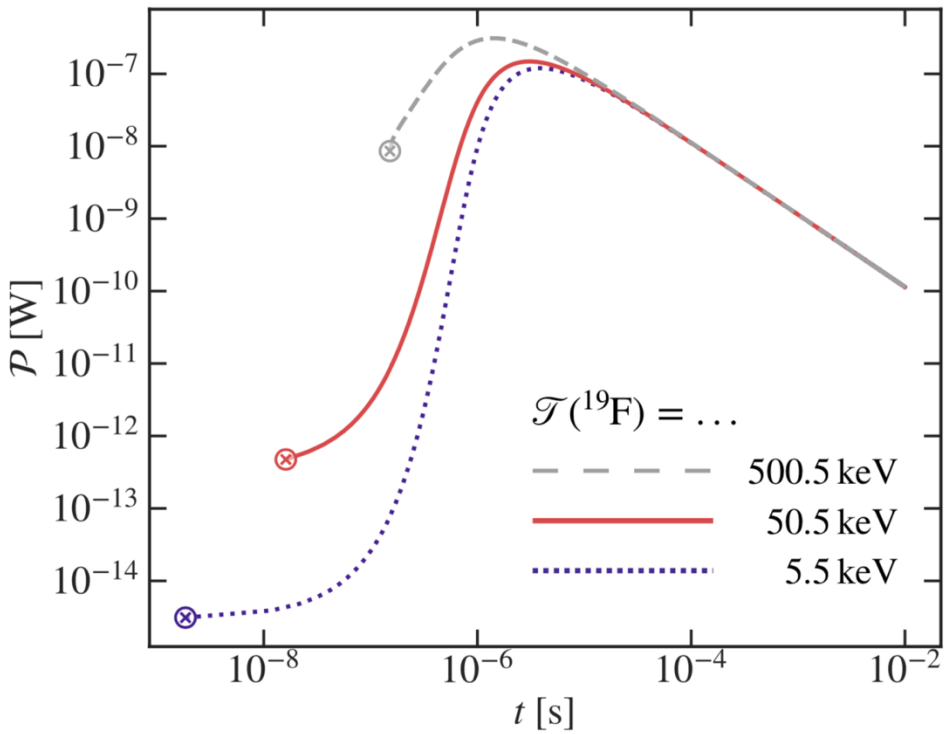
What about backgrounds that nucleate bubbles? Acoustic discrimination

- Sound emission peaks at $r_{bubble} \approx 10\ \mu m$ at $t \approx 1\ \mu s$
- Characteristic acoustic signature of single nuclear recoil (track < μm)

Molecular Simulation

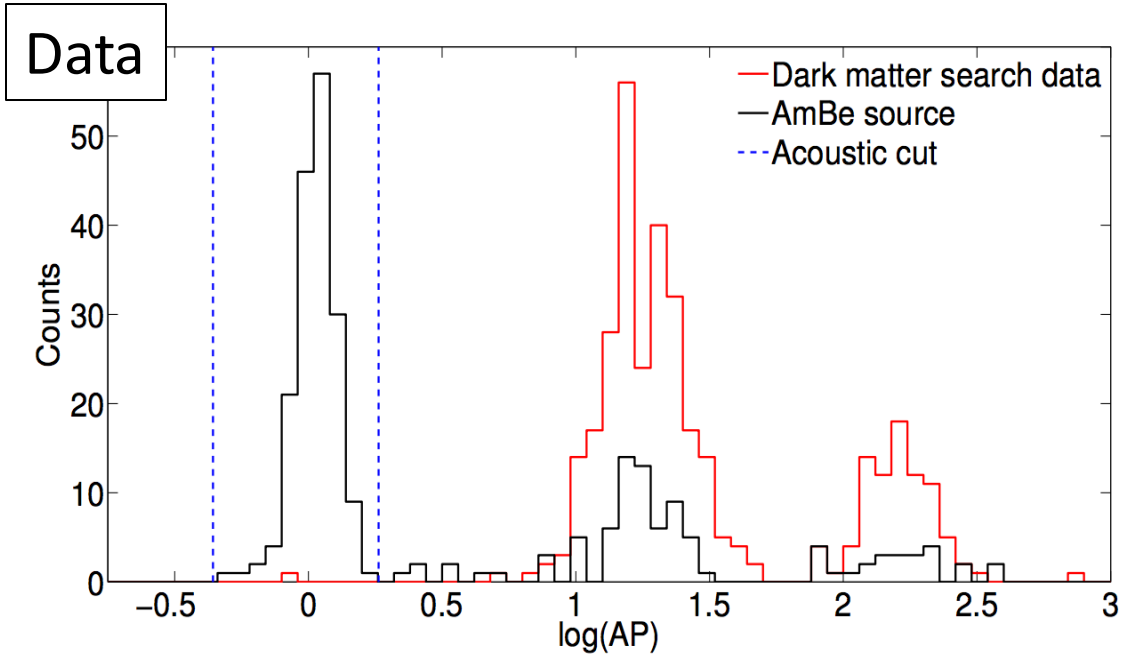


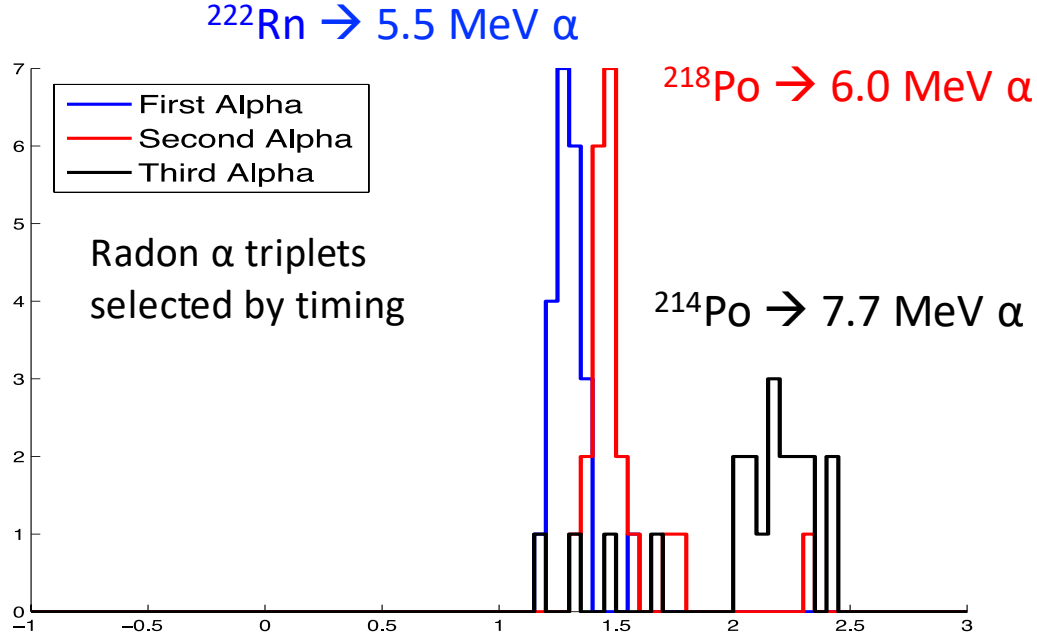
Acoustic power vs time



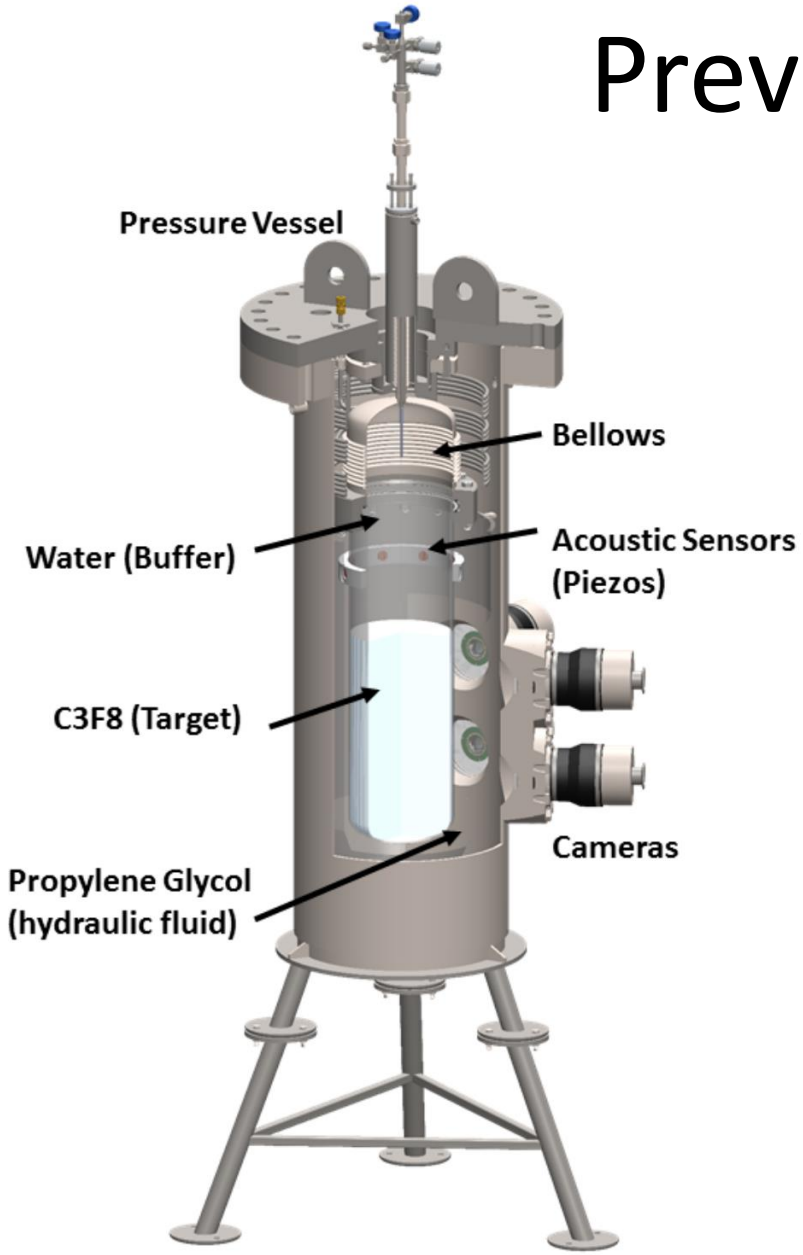
What about backgrounds that nucleate bubbles? Acoustic discrimination

- Sound emission peaks at $r_{bubble} \approx 10\ \mu m$ at $t \approx 1\ \mu s$
- Characteristic acoustic signature of single nuclear recoil (track < μm)
- Length scale of α track much larger (~40 μm)
  → separate nucleation sites → **α's several times louder**





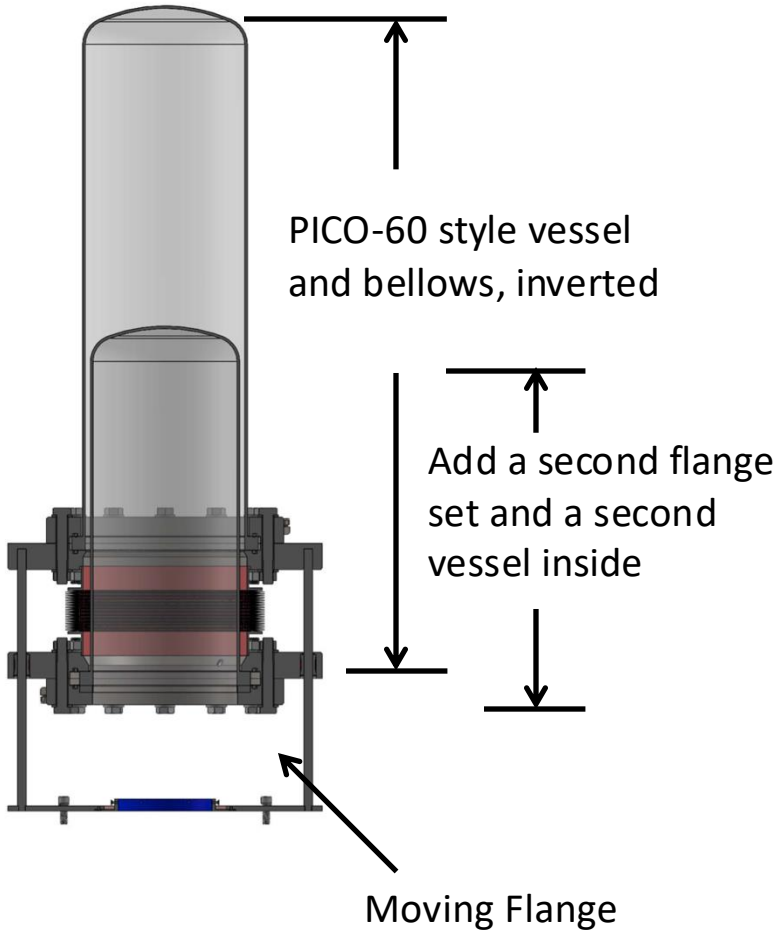
Previously: PICO-60



- 50 kg C_3F_8, ran stably down to E_{th}=1 keV
- World-leading WIMP-proton limits (2019) (https://arxiv.org/abs/1902.04031)
- Bellows above the active fluid, separated by a buffer fluid (water).
- Excess of background events at buffer-target interface.

PICO-40L: Right Side Up Design

Elimination of buffer fluid, plumbing on bottom

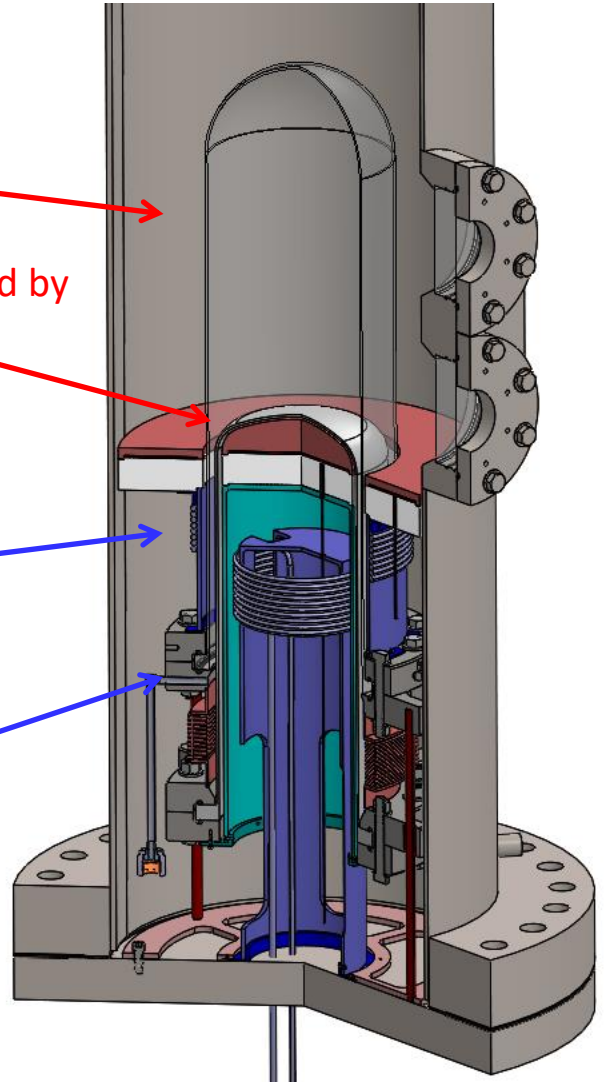


Warm active region
15C for C_3F_8

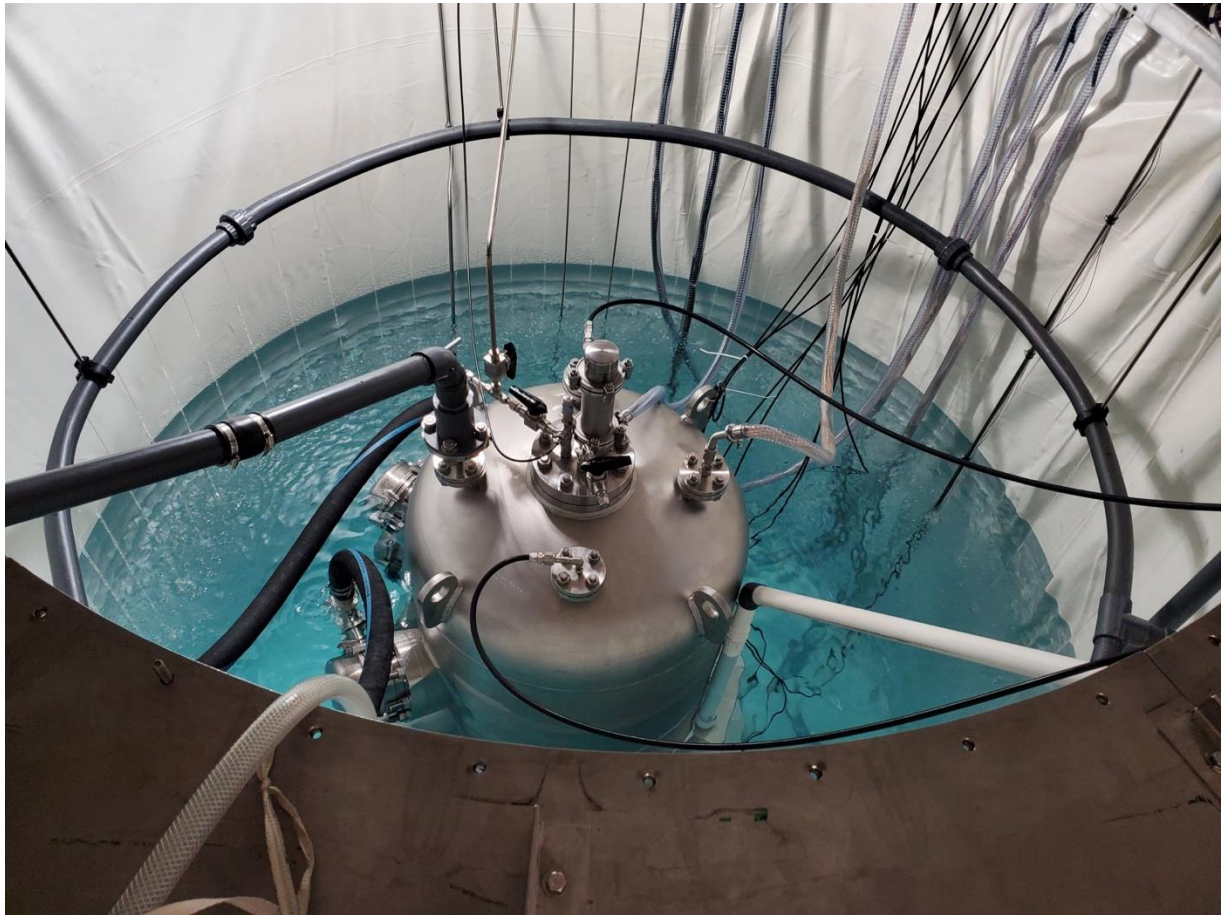
Water “piston” replaced by
second fused silica
(moving) vessel

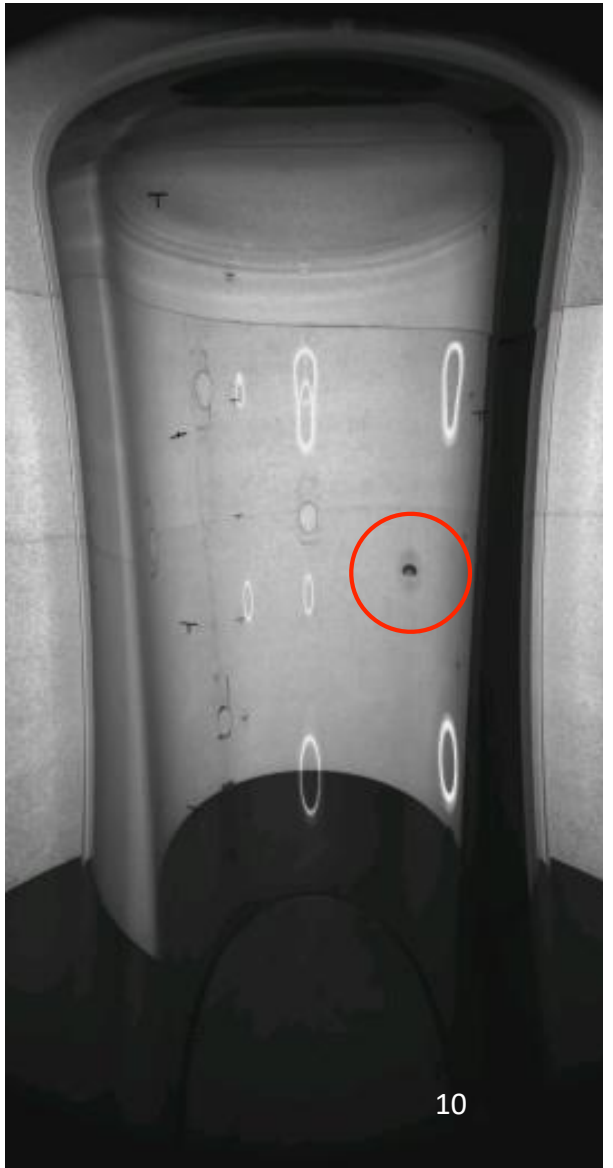
Thermal gradient
Maintained in thin
annulus

Cold plumbing region
-25C for C_3F_8
In-place circulation
/filtration possible



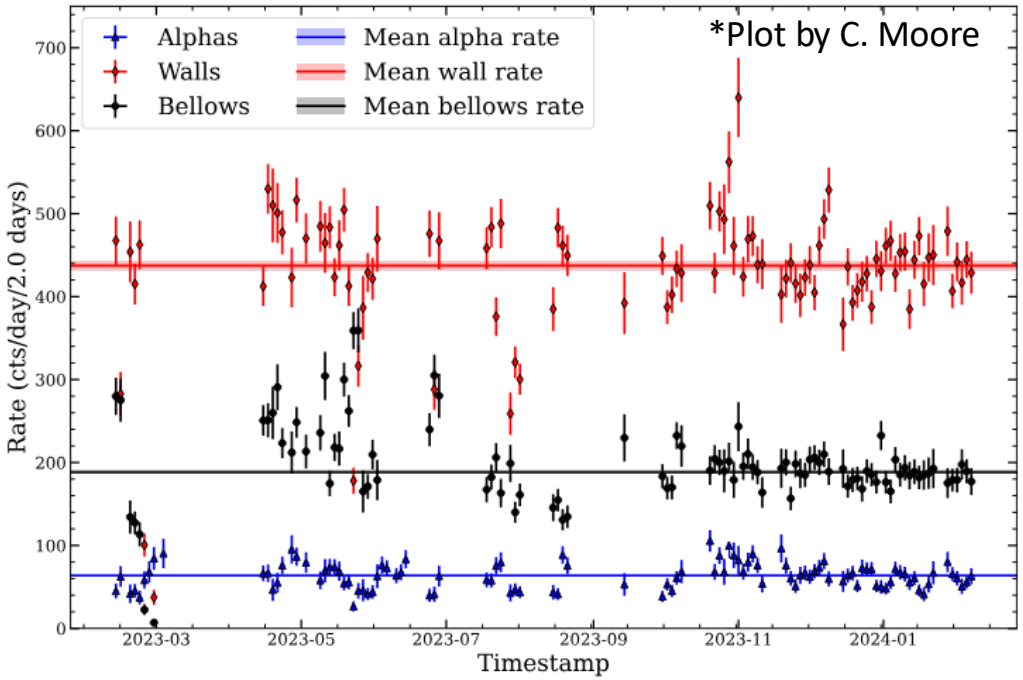
PICO-40L (C_3F_8) Current Status

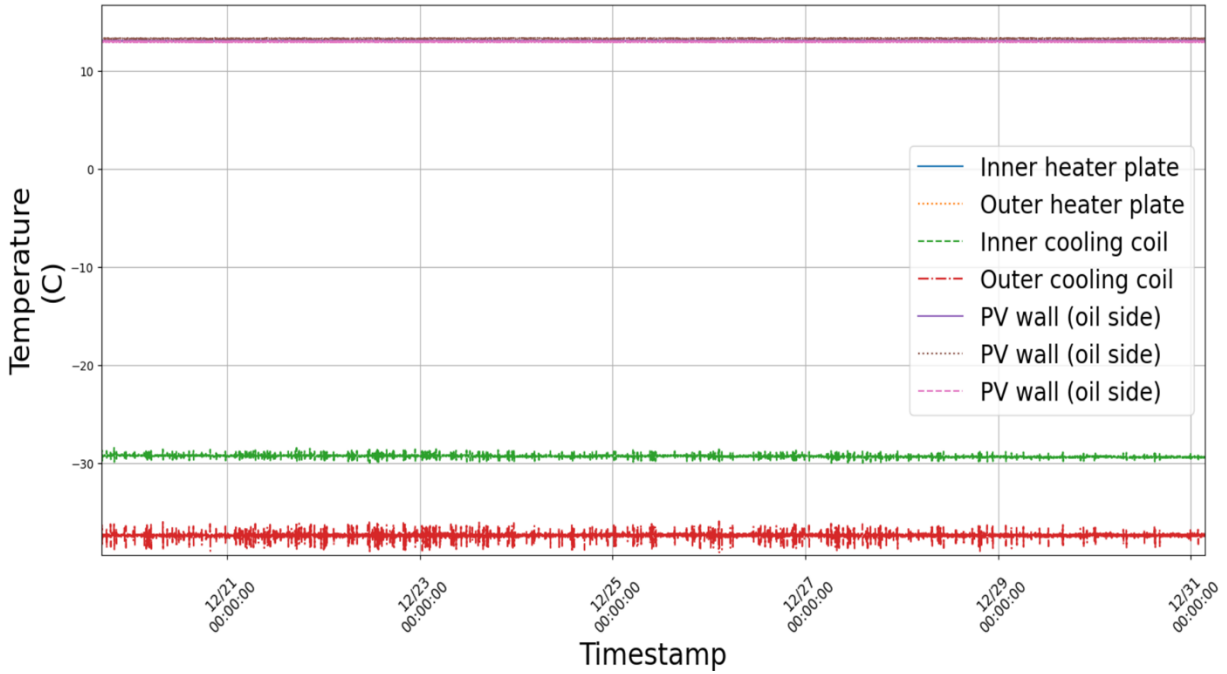




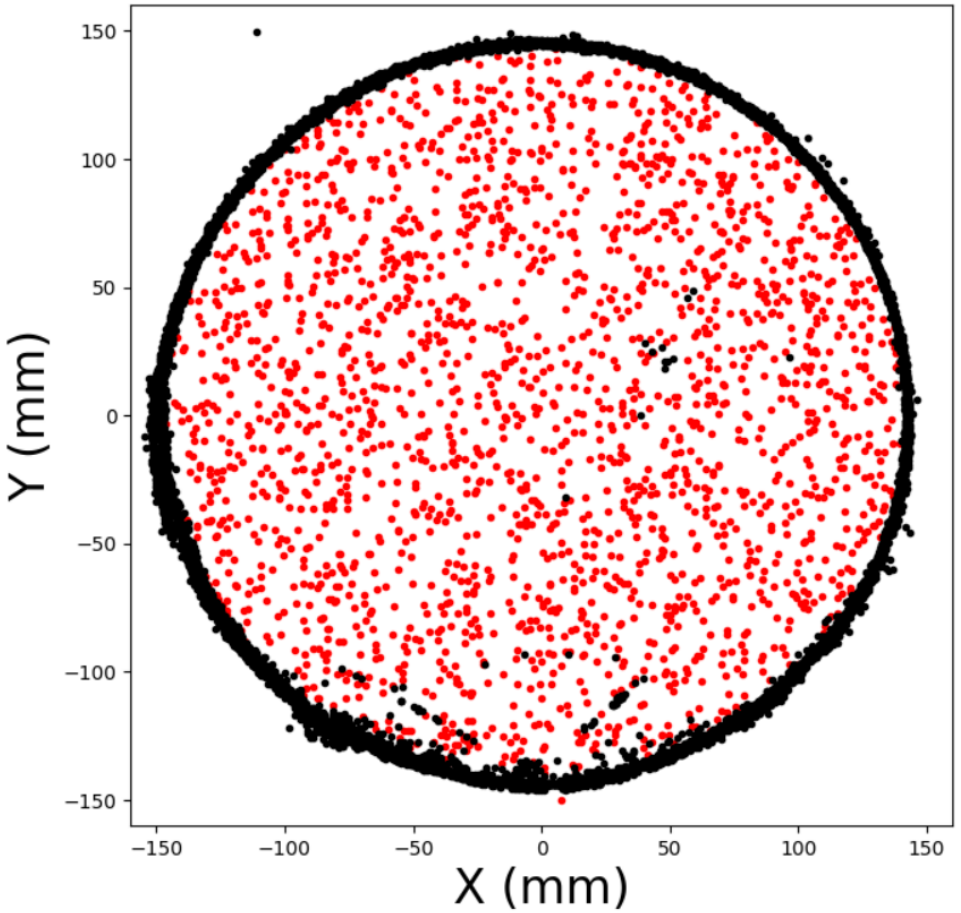
PICO-40L (C_3F_8) Current Status

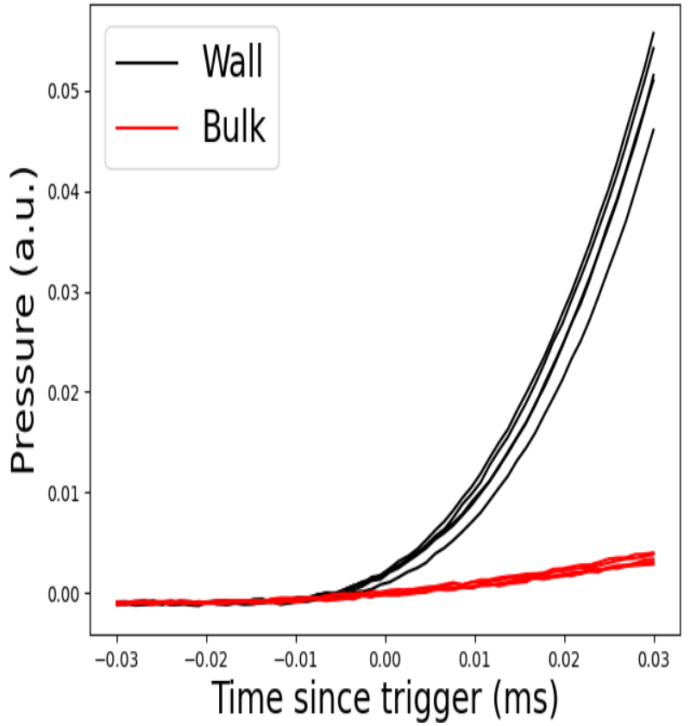
- Detector fully assembled and operational in 2023-2024
- Stable long-term event rates.
- Exquisite thermal stability and control

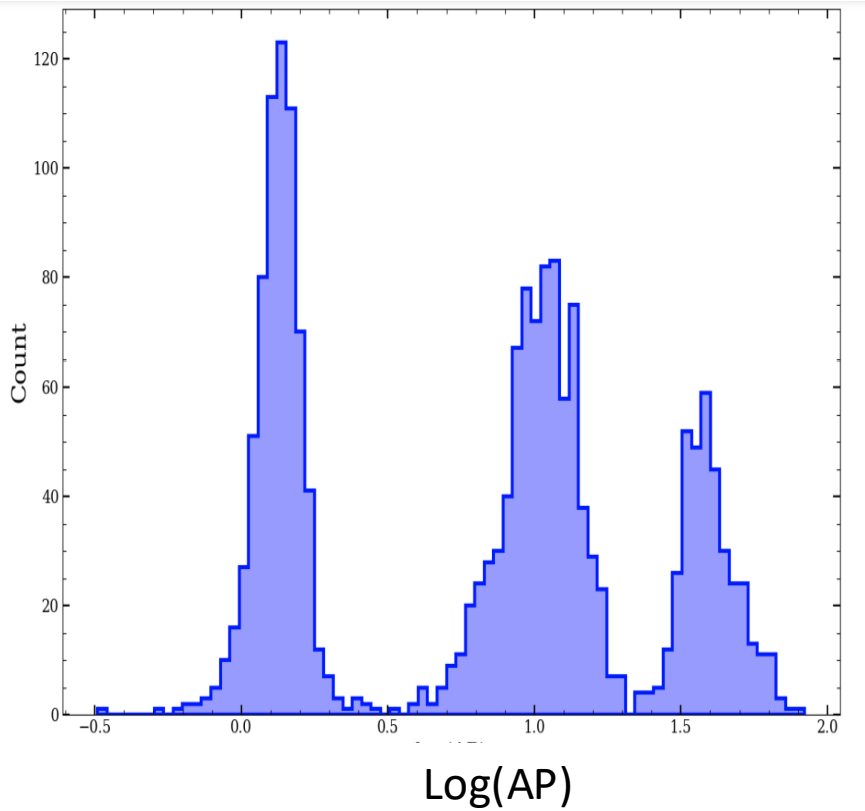




Optical/Pressure/Acoustic data





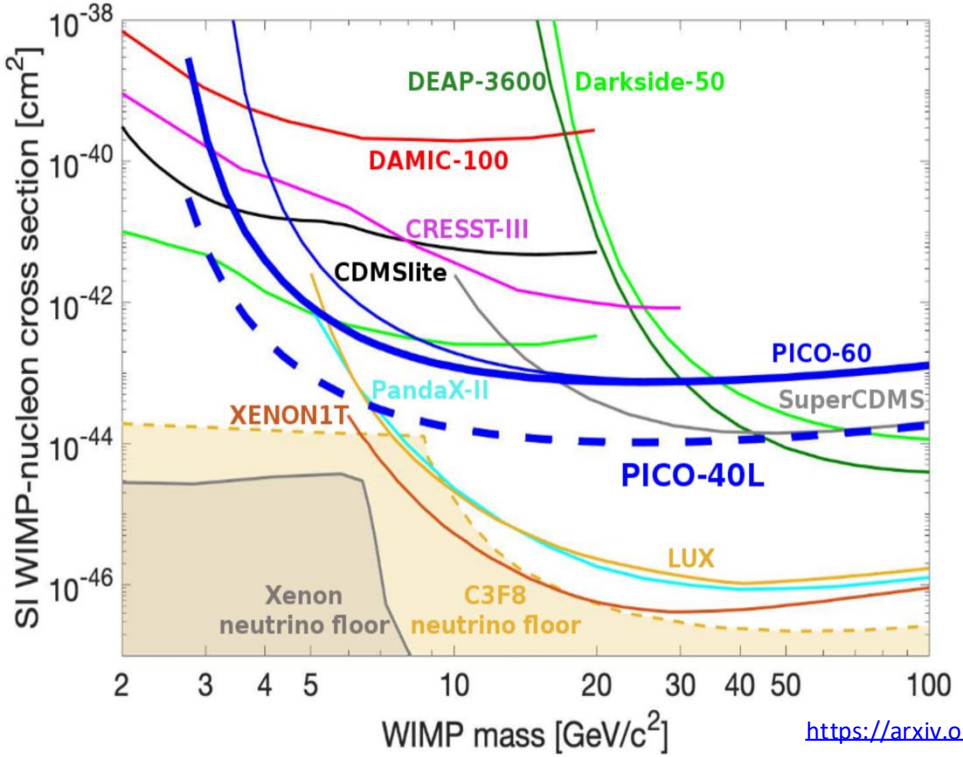


- Optical position reconstruction + Dytran: excellent wall vs bulk, multiplicity reconstruction
- Acoustic sensors confirm previous results: good alpha rejection, observation of radon chain

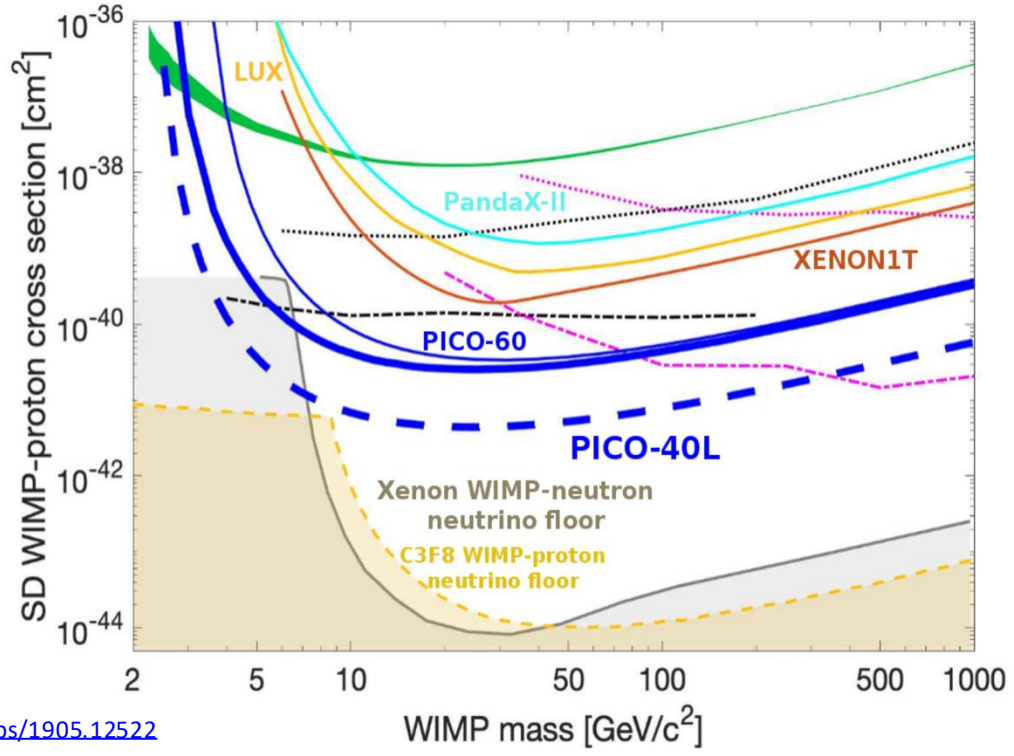
Projected sensitivity

- Improvement over PICO-60 due to better neutron shielding (2 background events over 1 live year, 1.64x10^4 kg-days, Q_{seitz}=2.8 keV)
- Right-side-up design removed buffer fluid and therefore excess events at buffer-target interface, validates PICO-500 design

Spin independent



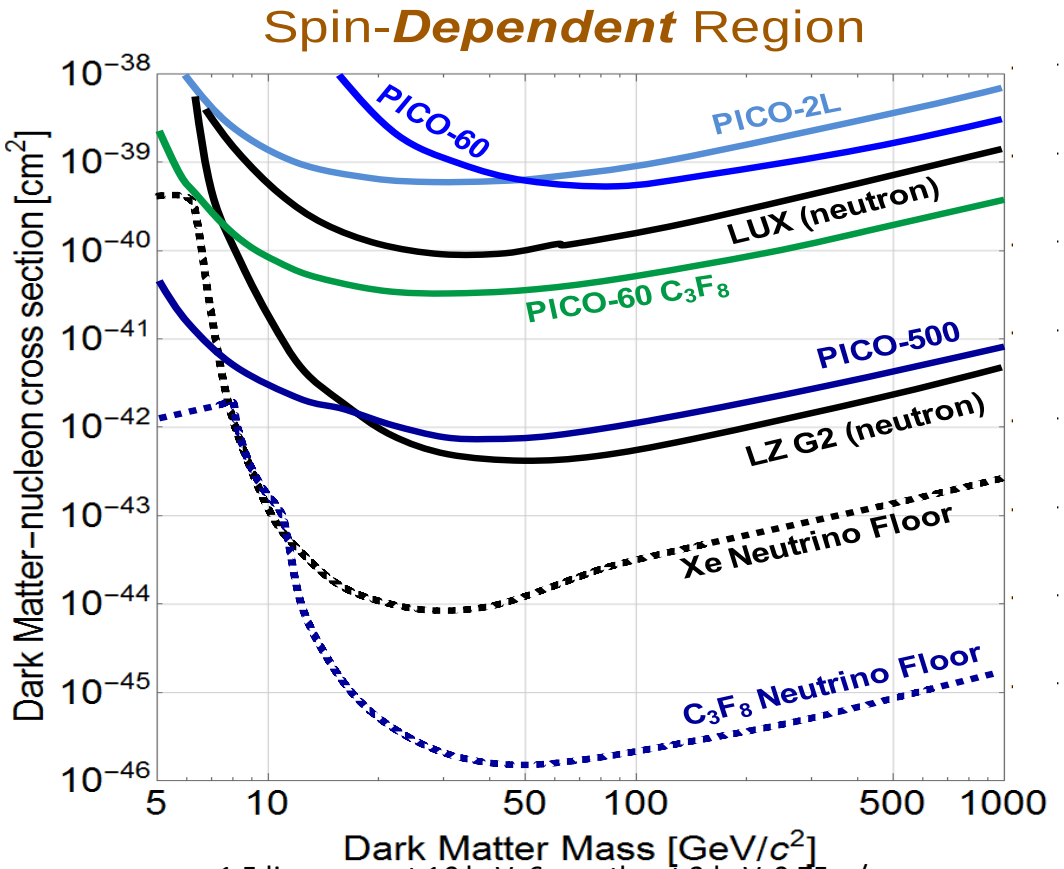
Spin dependent



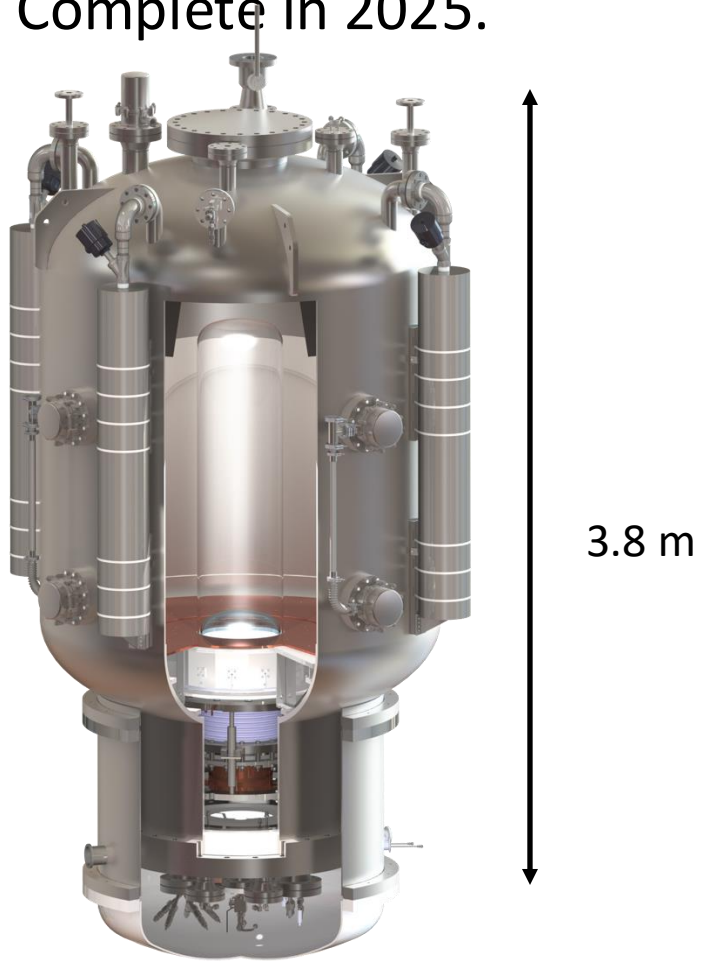
https://arxiv.org/abs/1905.12522

Future: PICO-500

- Ton-scale, C_3F_8 same "right side up" design as PICO-40L
  - 250L jar, 9000kg pressure vessel, 26ft tall, 18.5ft wide water tank
- Assembly in SNOLAB cube hall has begun. Complete in 2025.

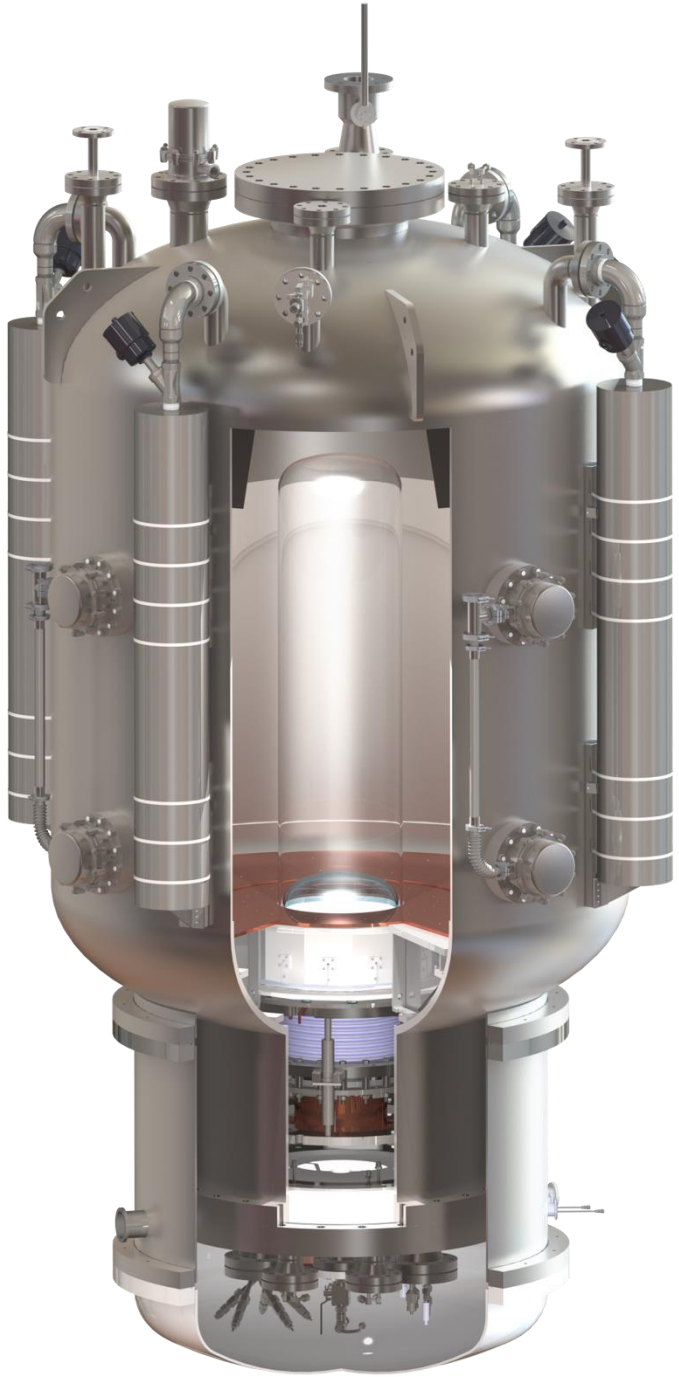


1.5 live years at 10 keV, 6 months at 3 keV, 0.75 n/yr.



Summary

- PICO-40L validates Right-Side-Up design in anticipation of PICO-500
  - Completed period of stable running. Detailed analysis underway
- PICO-500 underground assembly is underway. Data in 2025!



PICO

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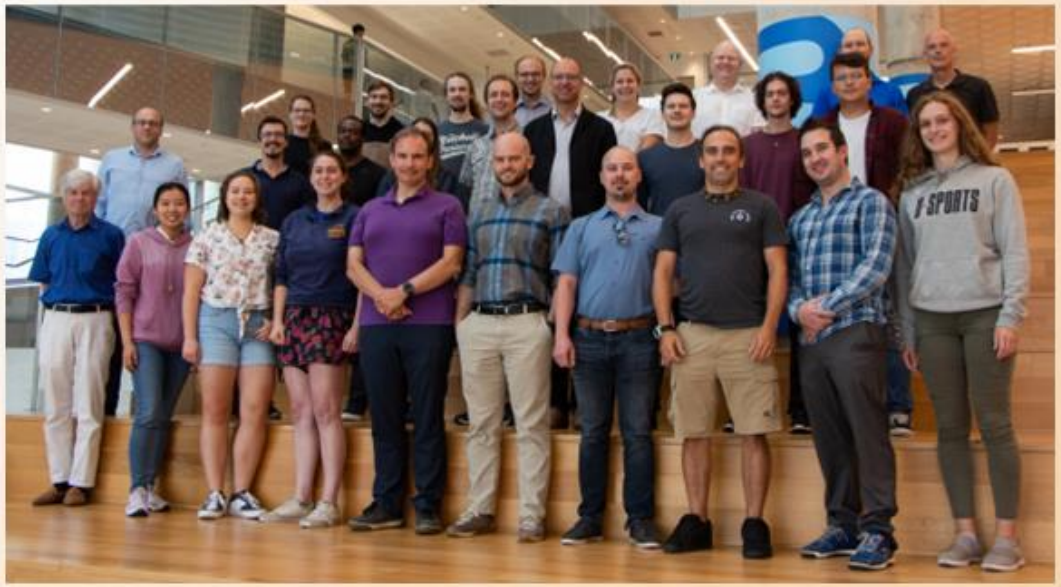

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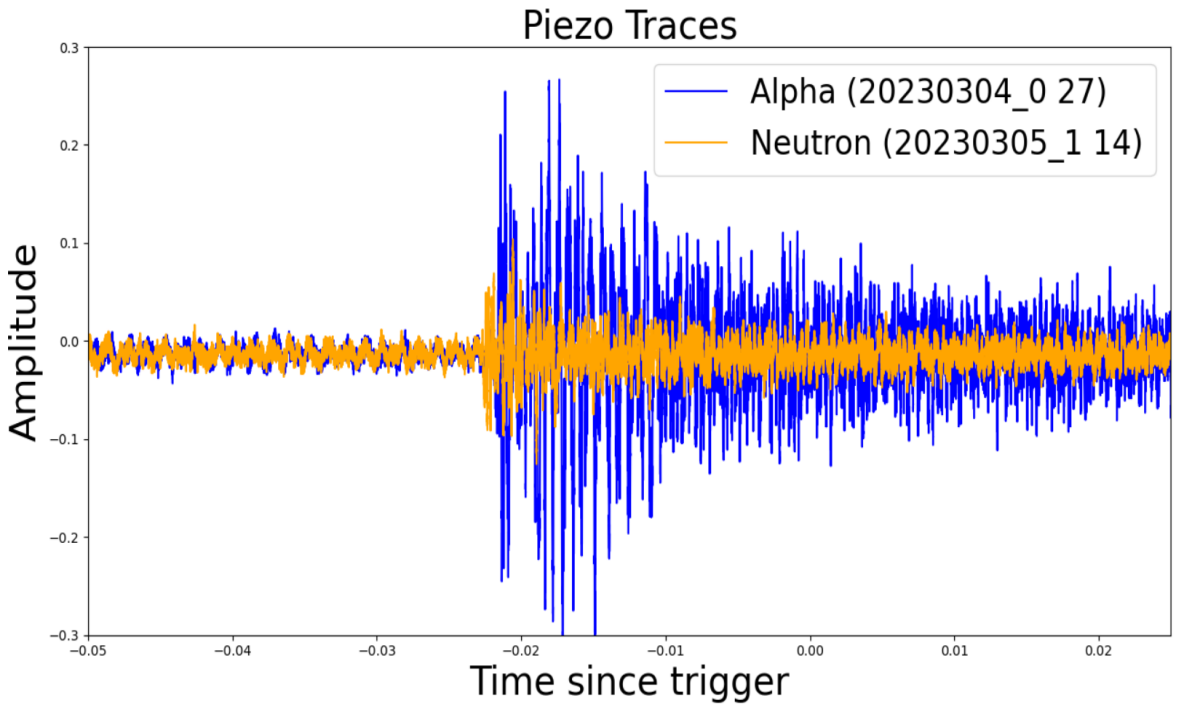
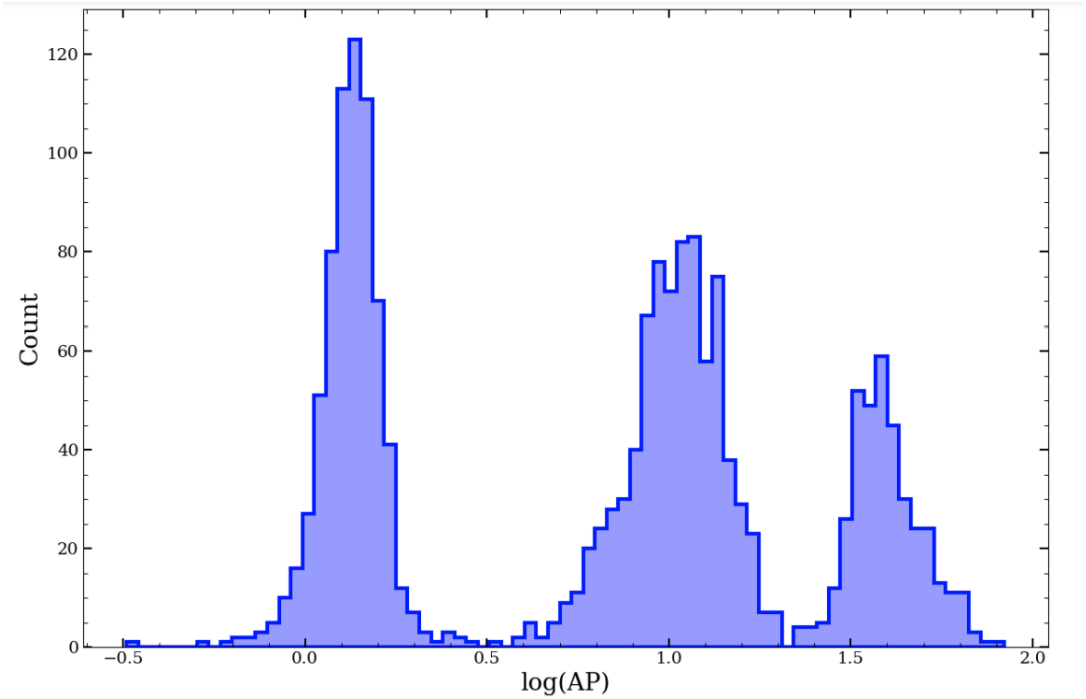
BACKUP

Acoustics


Piezo Traces
Alpha (20230304_0 27)
Neutron (20230305_1 14)
Amplitude
Time since trigger
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.05
−0.04
−0.03
−0.02
−0.01
0.00
0.01
0.02

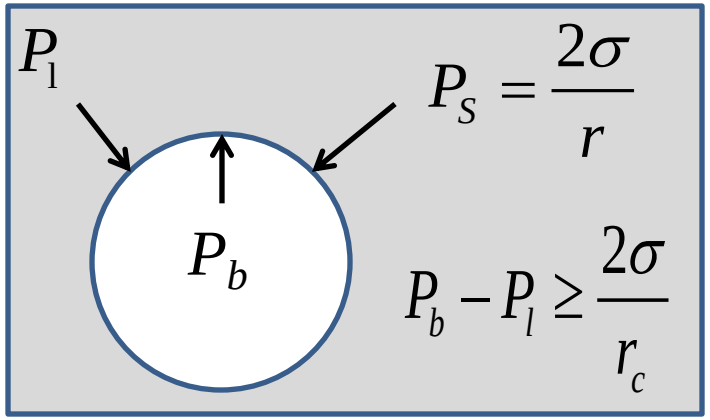

Count
log(AP)
120
100
80
60
40
20
0
−0.5
0.0
0.5
1.0
1.5
2.0

Particle detection with bubble chambers

- In a superheated fluid, bubbles will collapse unless they are large enough to overcome surface tension

- Roughly: bubble nucleation requires energy E_{th} deposited within a "critical radius" r_c

  → Both E_{th} & dE/dx thresholds



- Classical Thermodynamics gives (E_{th}, r_c) in terms of (P, T) for a given fluid:

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

Surface energy Latent Heat (but see 1905.12522) Reversible work

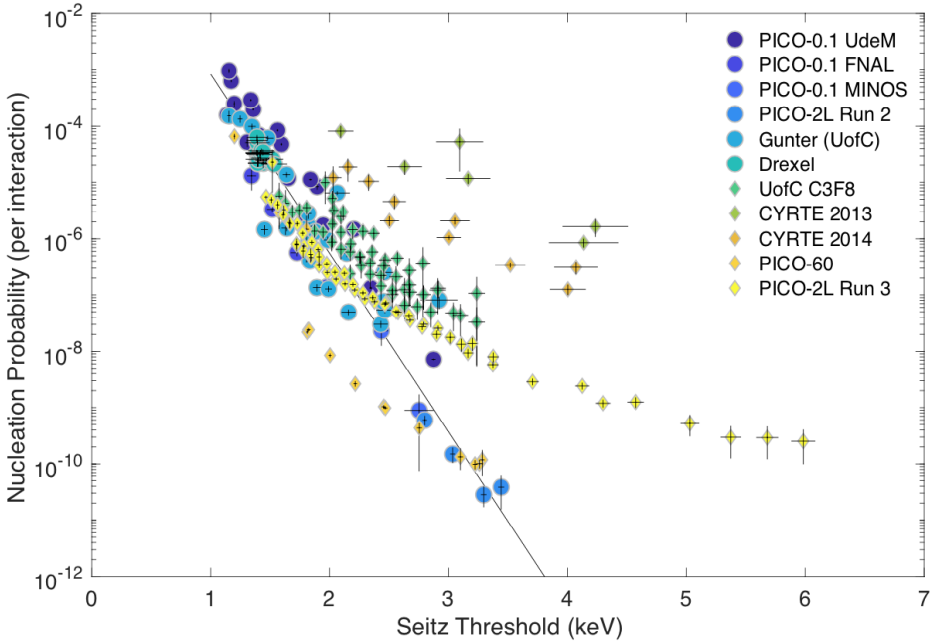
Gamma rejection: model comparison

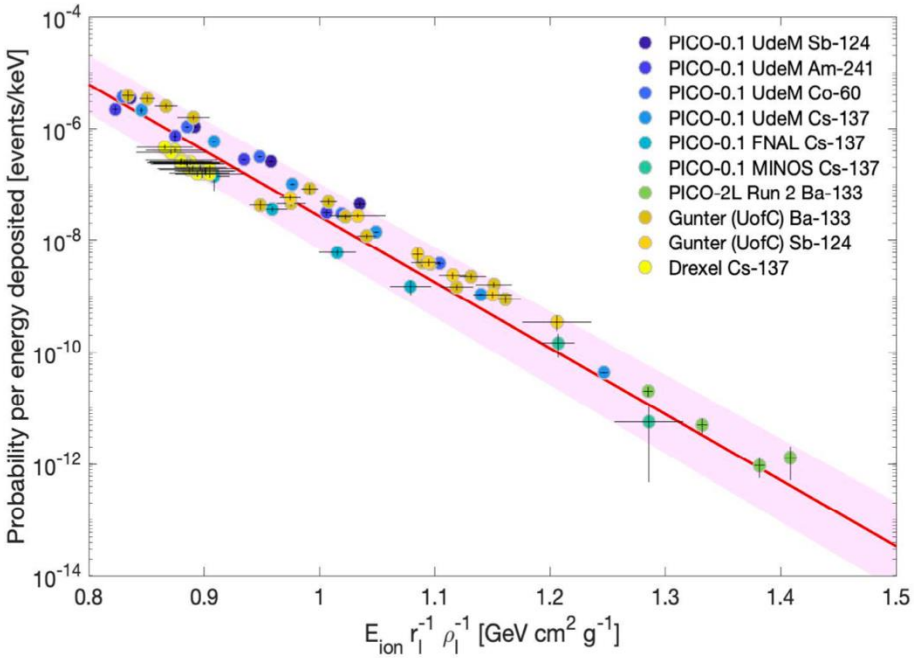
$$\mathcal{P} = Ae^{-Bf(P,T)}$$

Seitz: $f(P,T) = Q_{Seitz}$ Baxter: $f(P,T) = E_{ion}/r_I\rho_I$

New model accounts for the production of delta electrons: nucleation probability per energy deposition per unit length (not per incident # of photons)

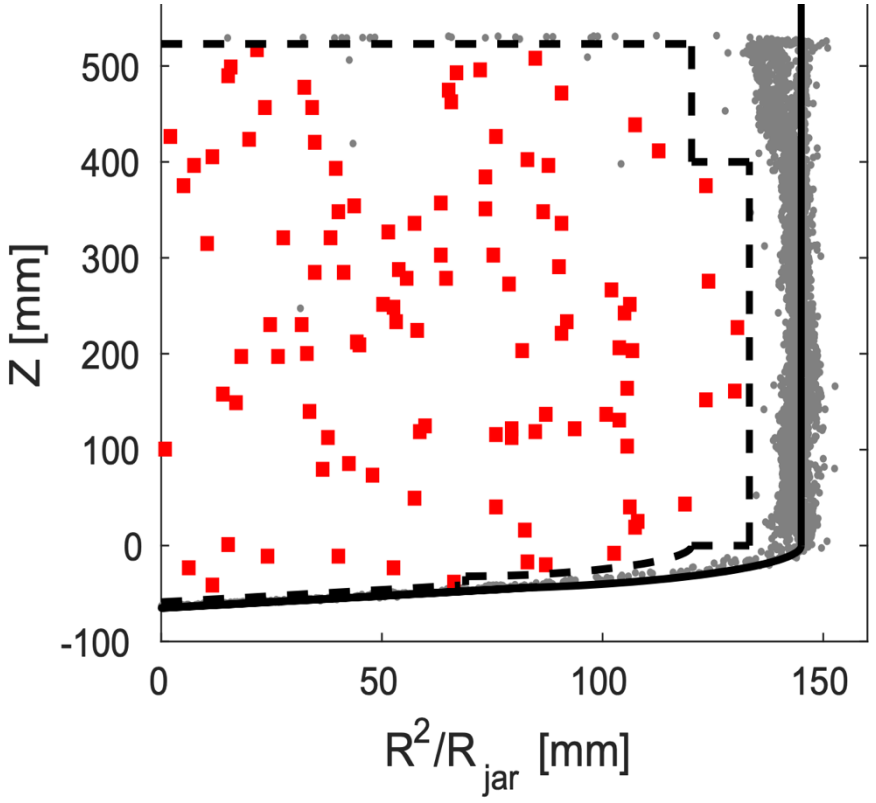
- With the new model, all gamma calibration data with pure C_3F_8 line up well.
- The different response of CF_3I is understood due to the production of Auger electrons on the higher Z nucleus, I.



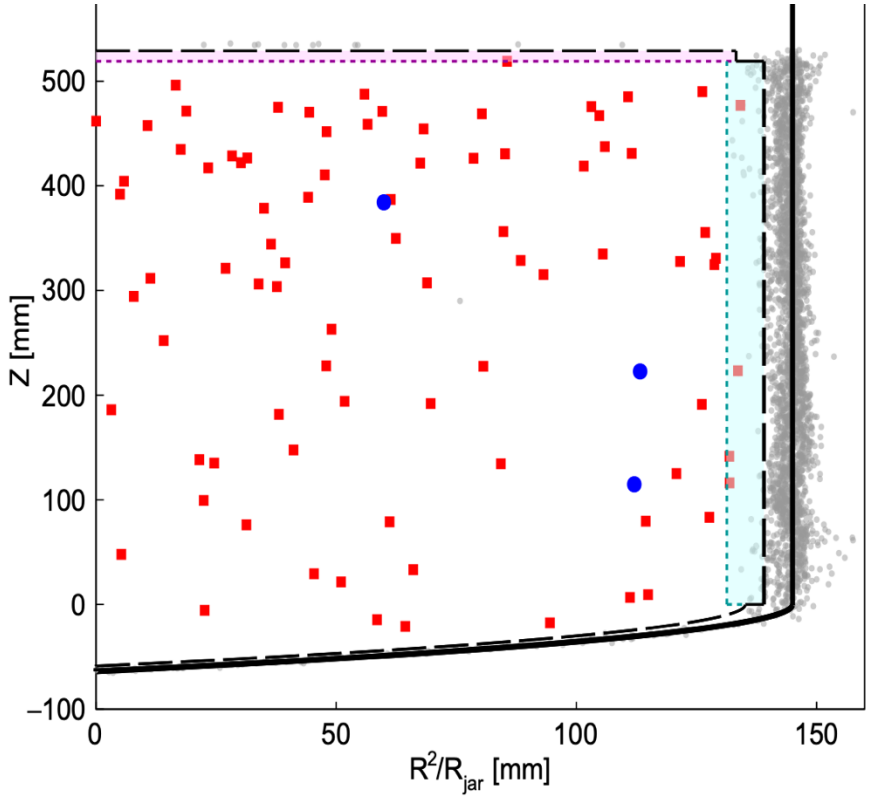


PICO-60 (C_3F_8)

Run 1 (2016)
30 livedays at 3.3 keV
Blind (deaf) analysis
0 nuclear recoil candidates
~1 neutrons expected



Run 2 (2017)
30 livedays at 2.5 keV
Blind (deaf) analysis
3 nuclear recoil candidates
Consistent with ~1 expected



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Consistent with ~1 expected