PICO

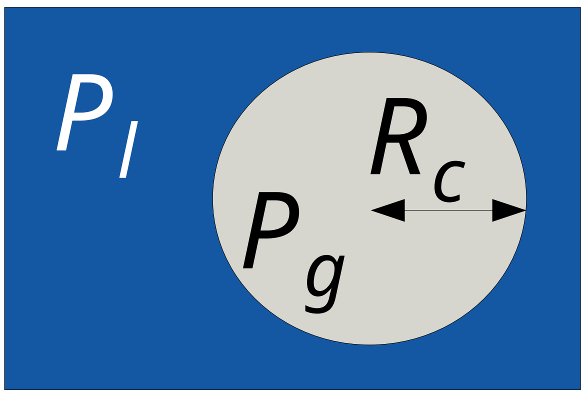
Bubble Chambers 2023 update

Alan Robinson
Université de Montréal
PICO Collaboration

August 9, 2023
McDonald Institute National Meeting

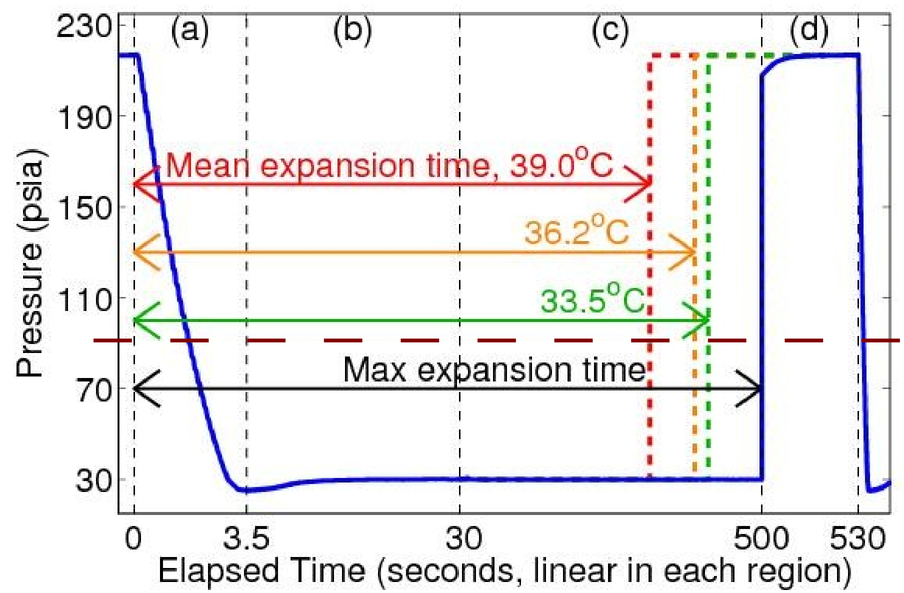
PICO How it works

Radiation induced boiling of superheated fluid.



$$P_g - P_l = \frac{2\sigma}{R_c}$$

Bubble Chamber operation cycle

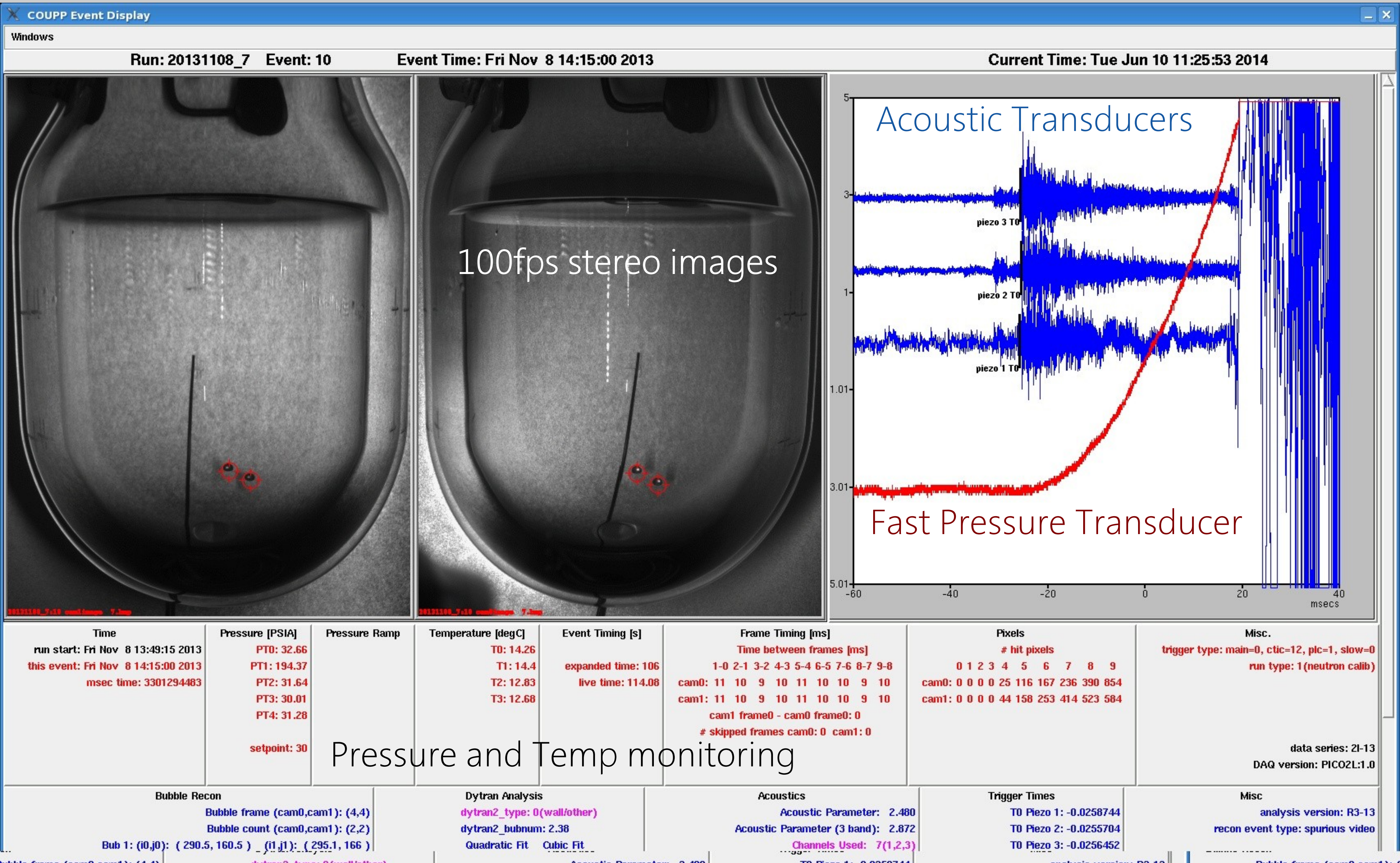


Boiling Point
(33.5° C, 90 psia)

Latent Heat — Surface Formation

$$Q = \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) + 4\pi r_c^2 \left(\sigma - T \frac{d\sigma}{dT} \right)$$

PICO How it works



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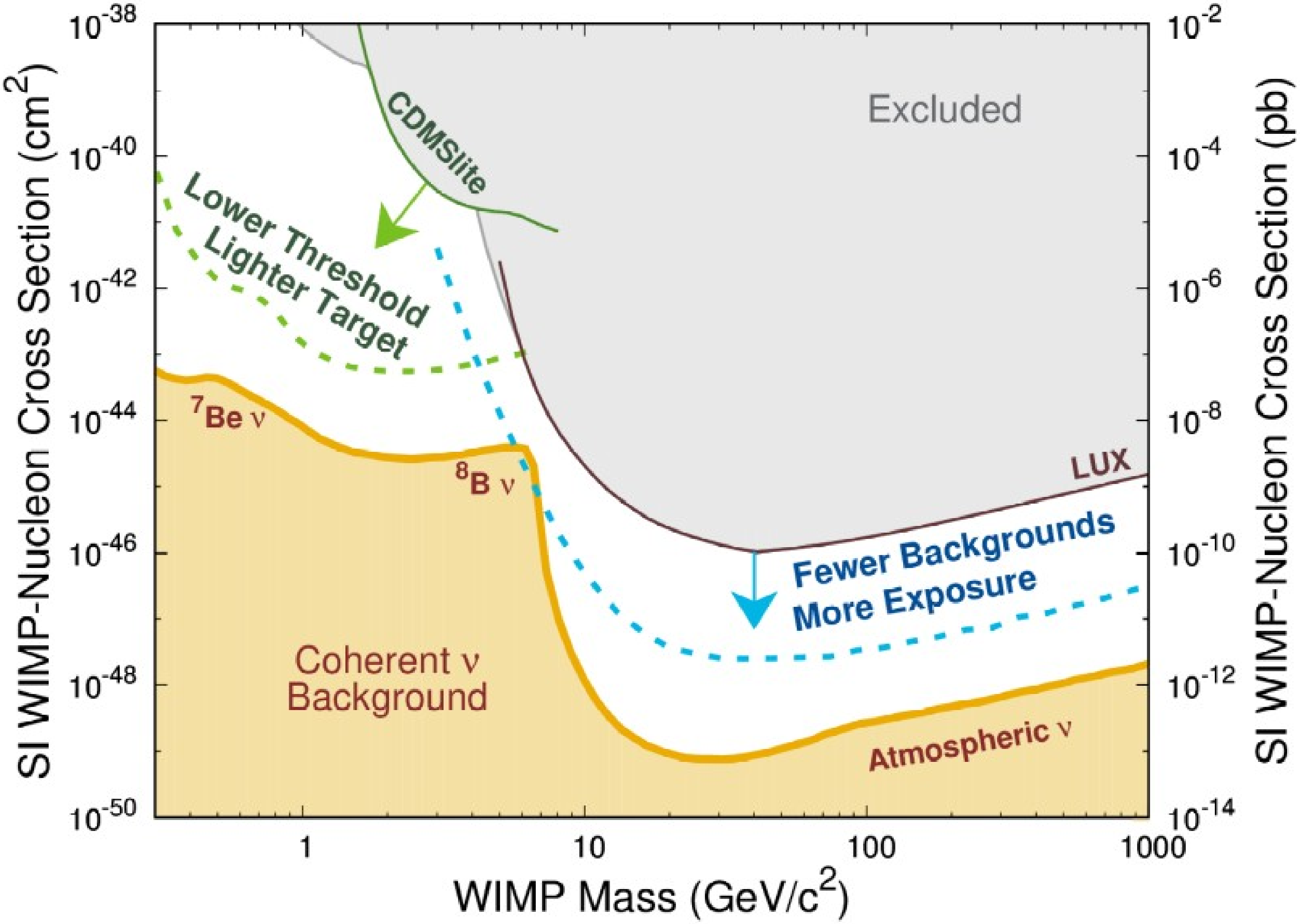
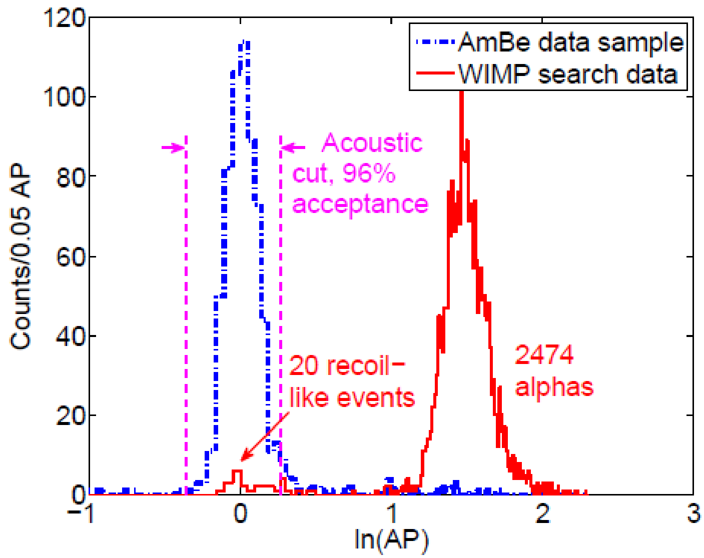
Why Bubble Chambers?

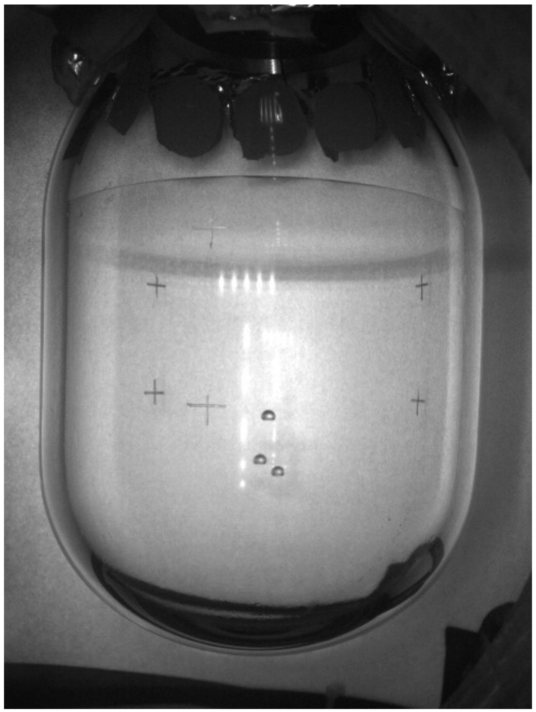


Impressive Background Rejection

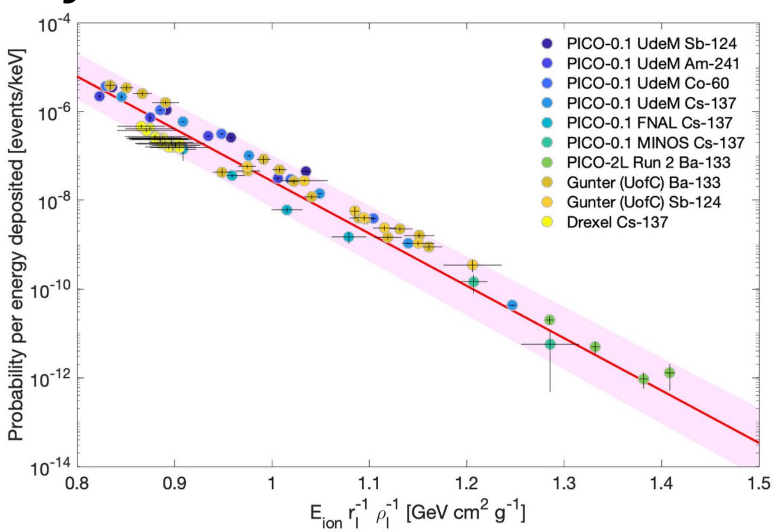
Acoustic Alpha Discrimination



Multiple Neutron Scattering

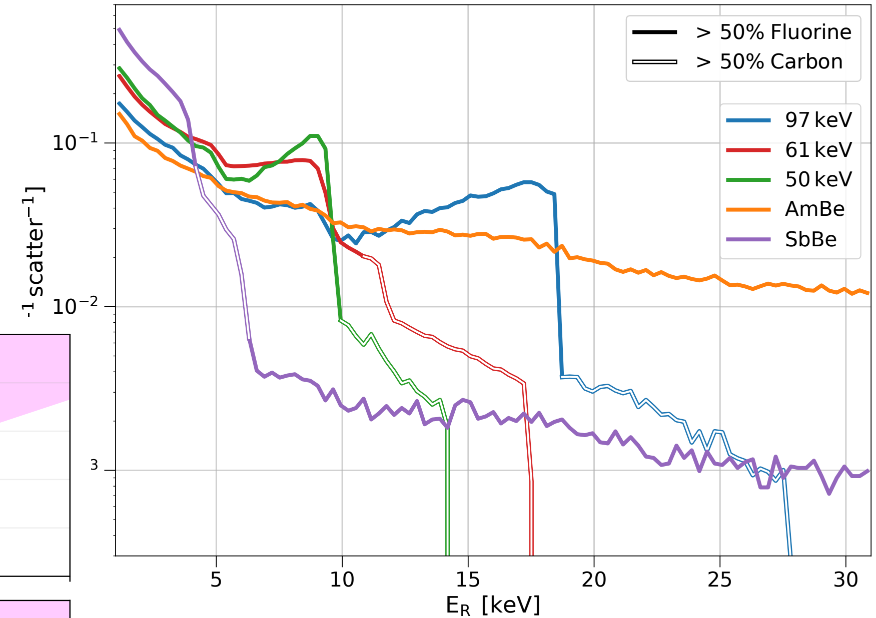


Gamma Interaction Insensitivity



PICO keV-threshold

Calibration paper
PRD **106** 122003 (2022)



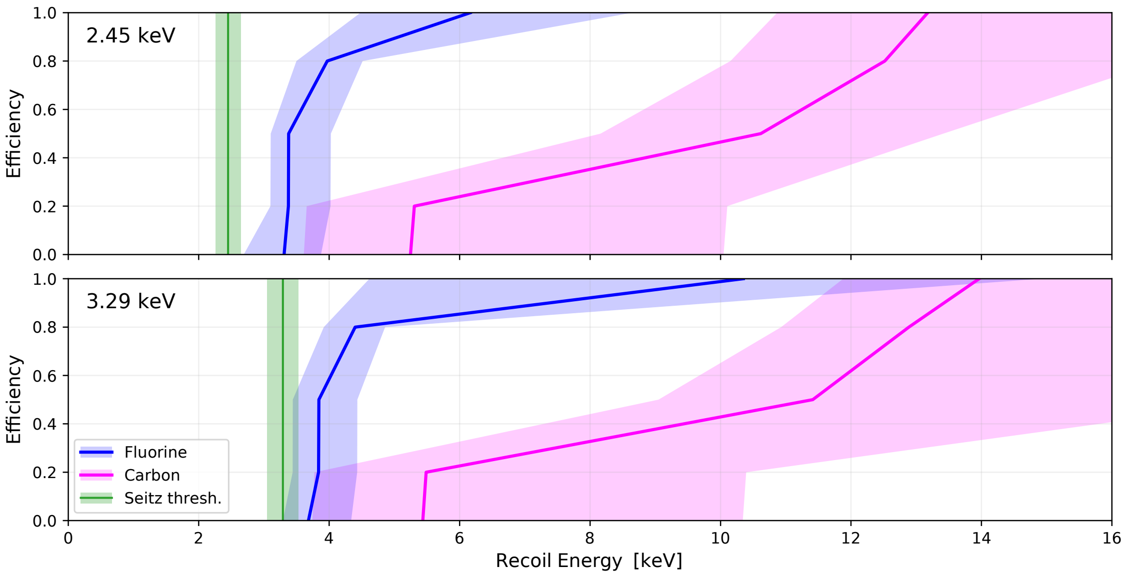
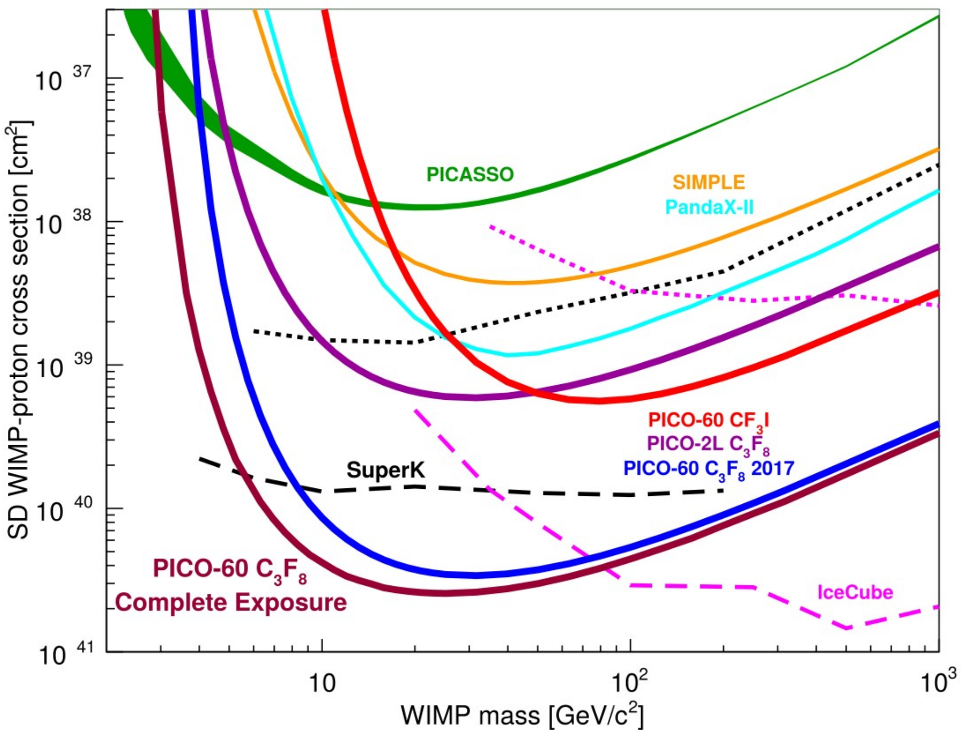


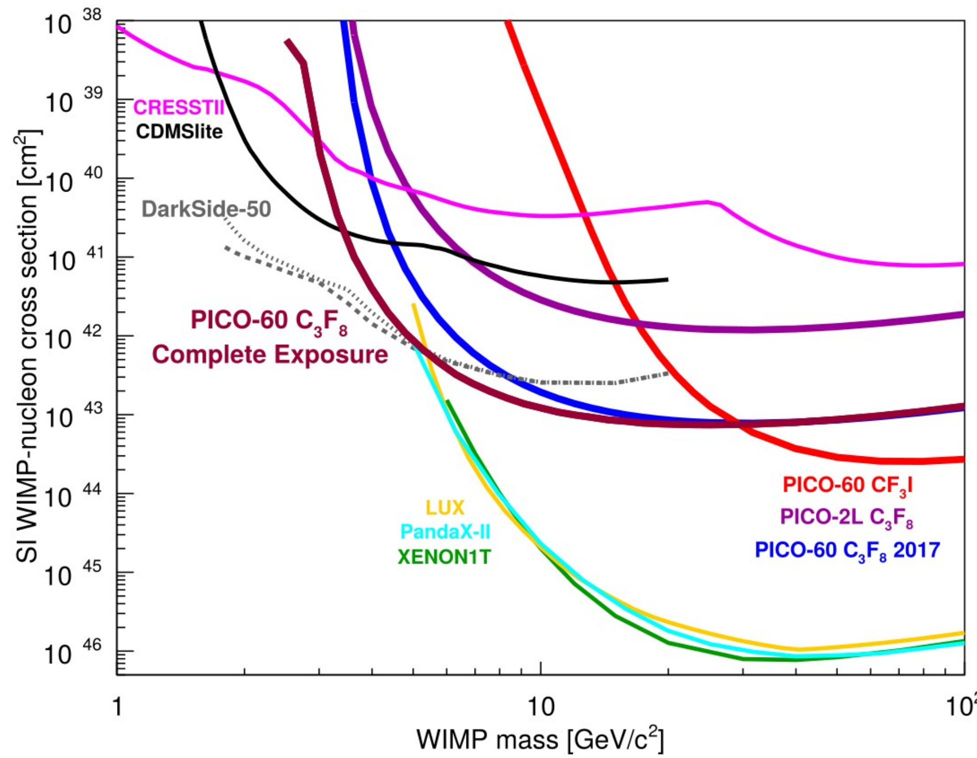
FIG. 16. Best-f t and 1σ error envelopes for the nucleation eff ciency curves off uorine (blue) and carbon (magenta), for both thermodynamic threshold fence posts. The corresponding Seitz thresholds and error bars are shown as well (green).

PICO Why Bubble Chambers?

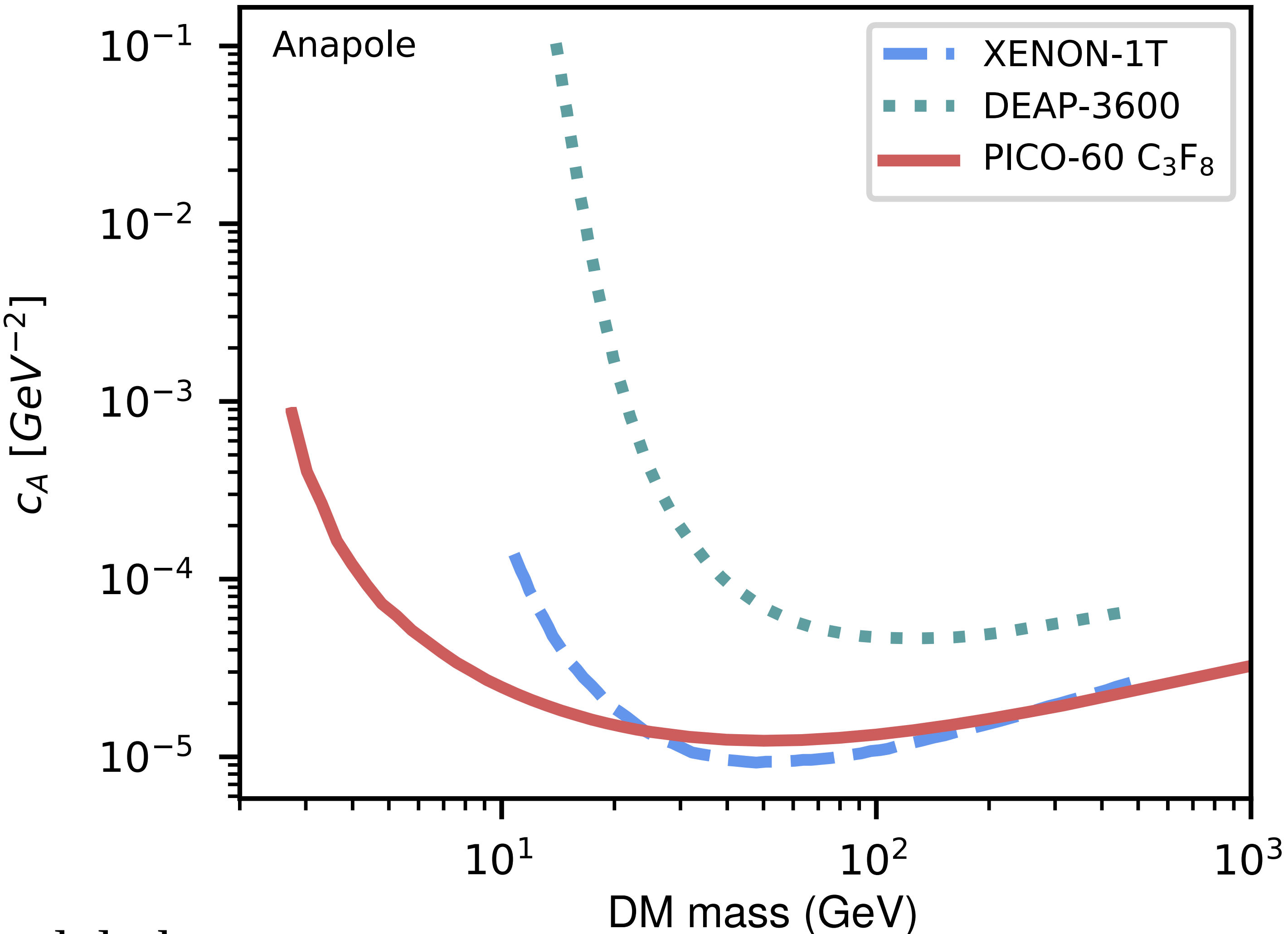
Spin-dependent & Low-ish mass

Ability to change target fluid





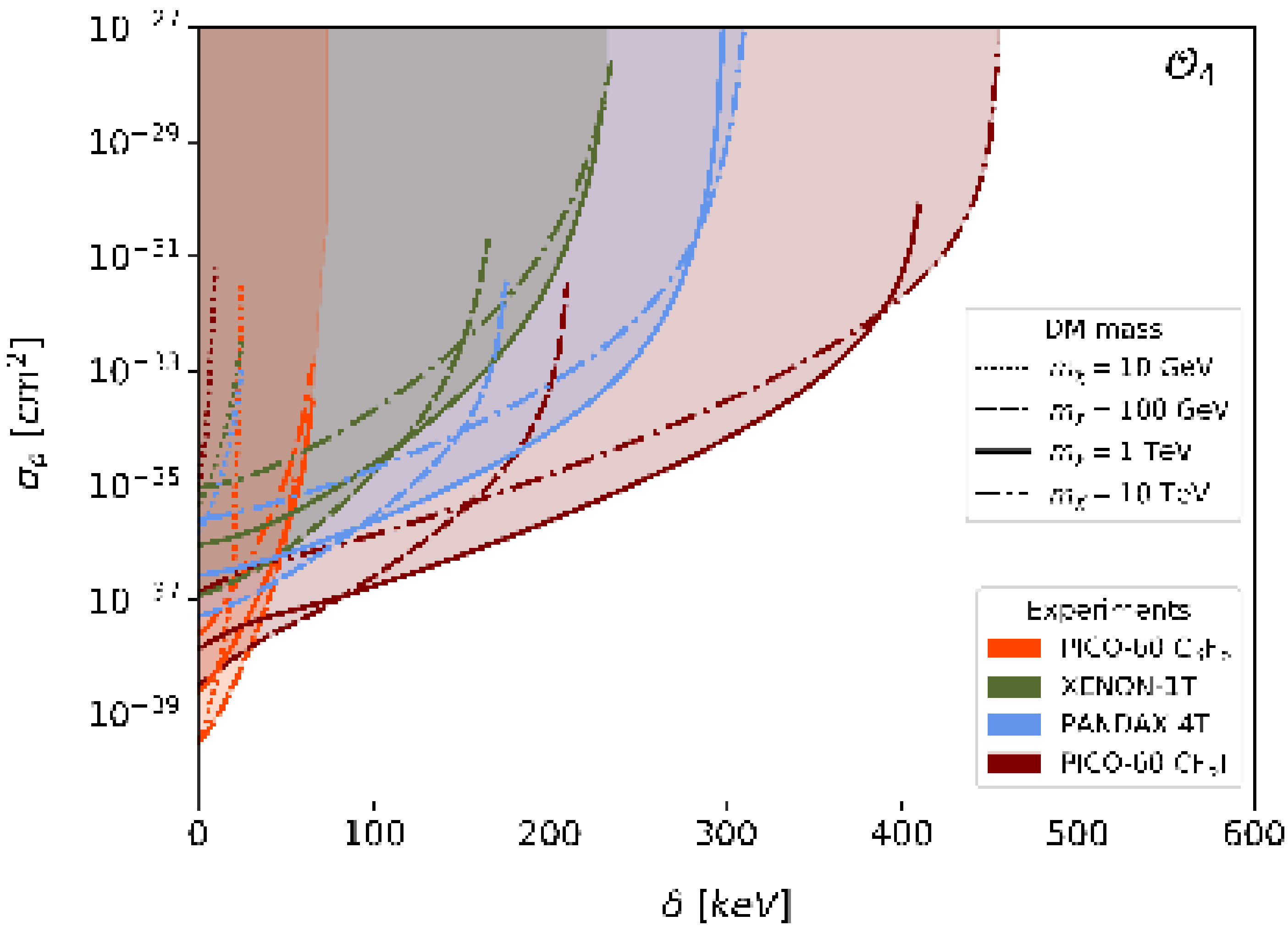
Recent Limits



Photon-mediated dark matter
PRD **106** 042004 (2022)

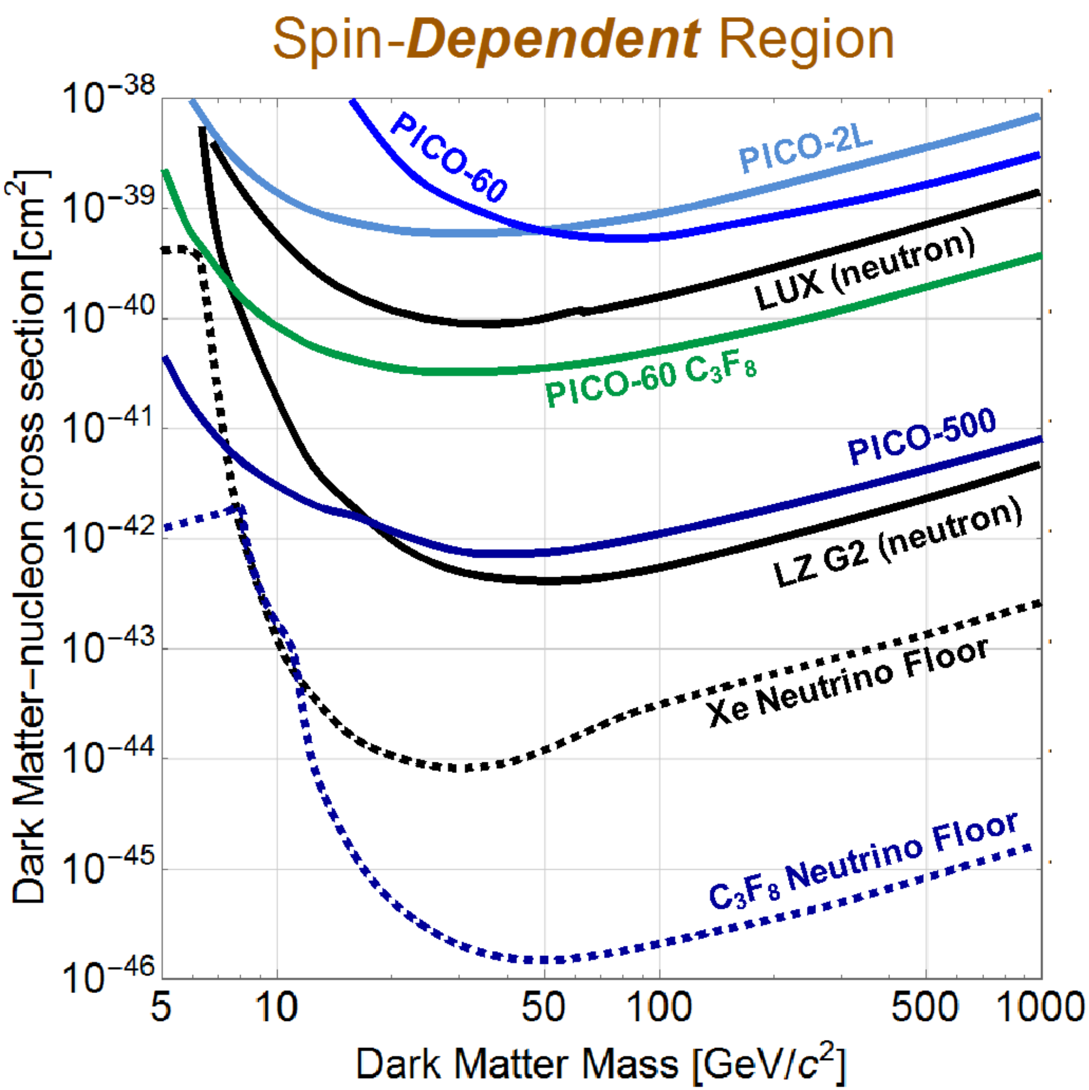
Recent Limits

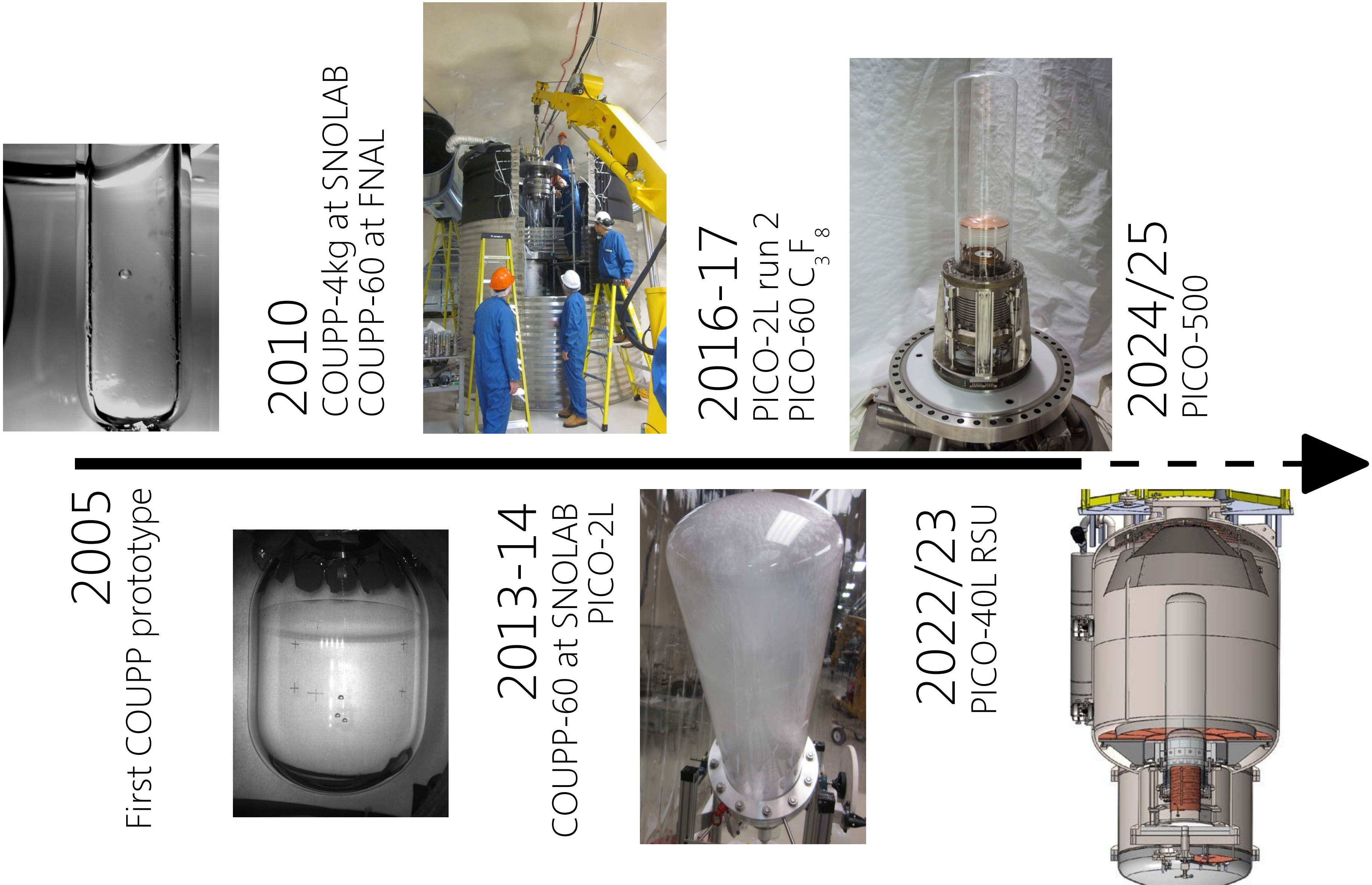
Inelastic dark matter arXiv 2301.08993



PICO Going bigger

- PICO-500: complementary reach to G2 experiments
- Lower neutrino floor than for LXe
- Projection using
  - 0.5 live-year at 3.2 keV Seitz
  - 1 live-year at 10 keV Seitz
  - 250 L fiducial volume
  - 0.75 singles/year background, mostly from muon spallation

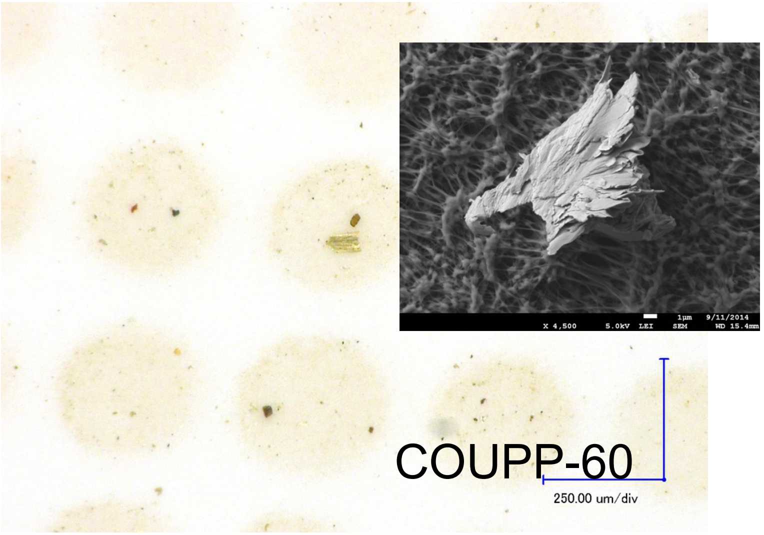


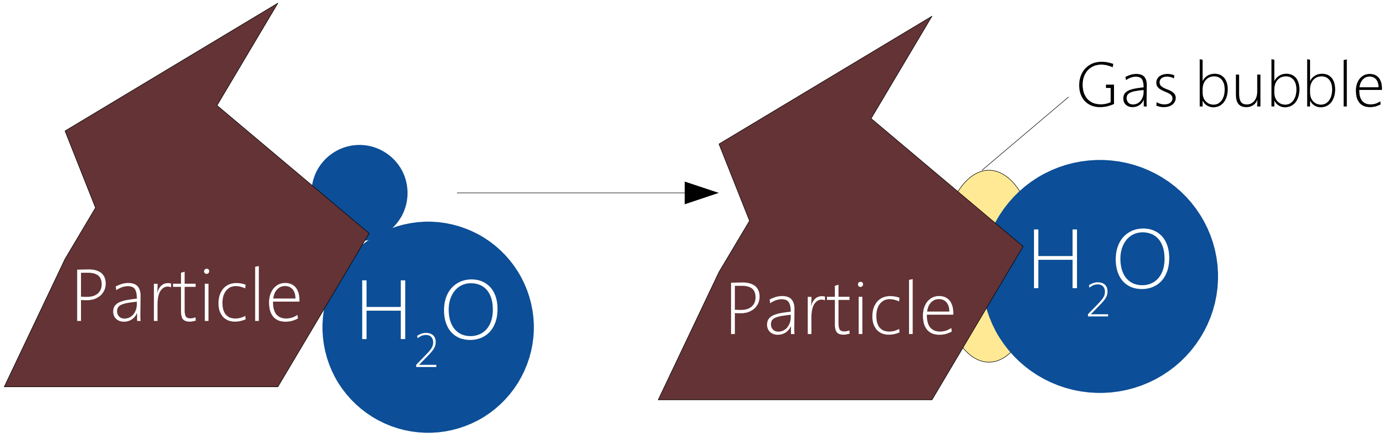


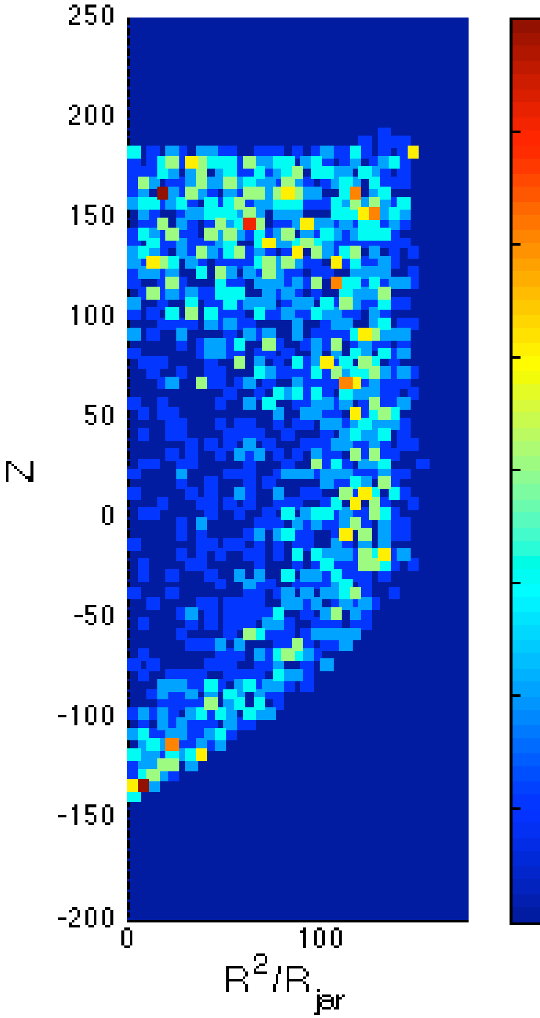
α-decay	X	solved	-	-	-	-
Neutrons	-	X	■	■	■	■
Particulates	-	unidentified	X	■	solved	-
γ/β	solved	-	-	-	■	■
ν/μ	-	-	-	-	-	■

PICO Particulates

- Metal oxide and silica particulates
  - Trapped then dislodged from freon/water interface

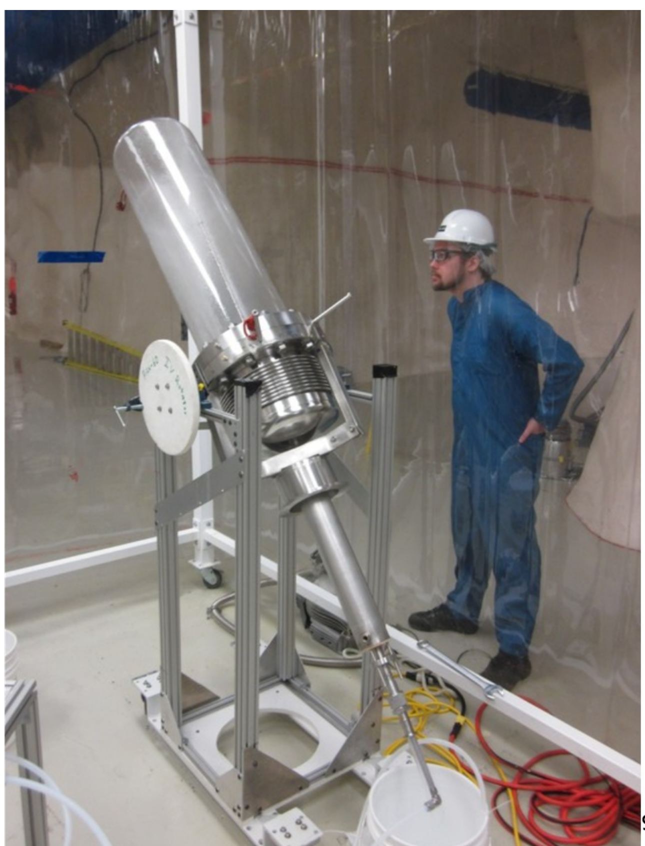


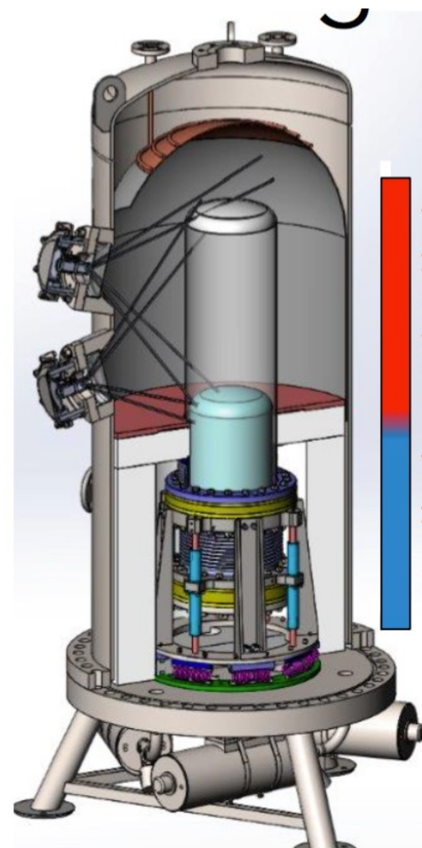




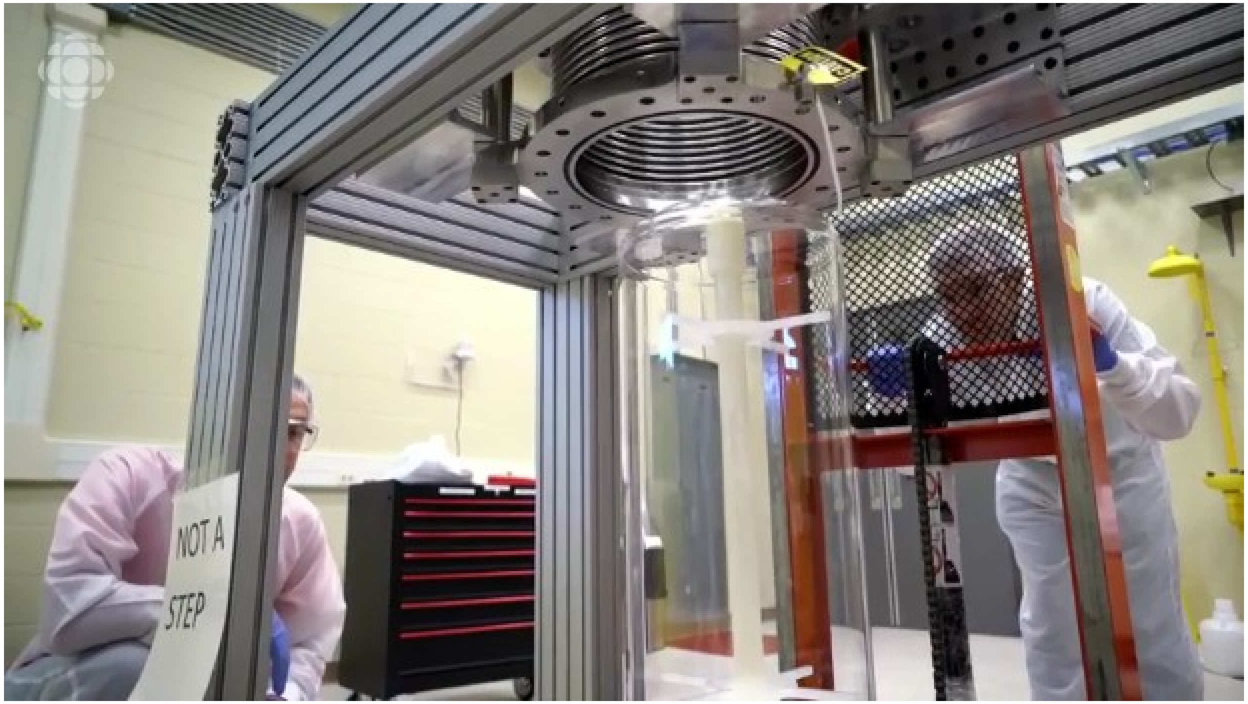
PICO Particulates

- Mitigation
  - Cleaning in PICO-2L run 2, PICO-60 C_3F_8
  - Eliminate water in PICO-40L RSU



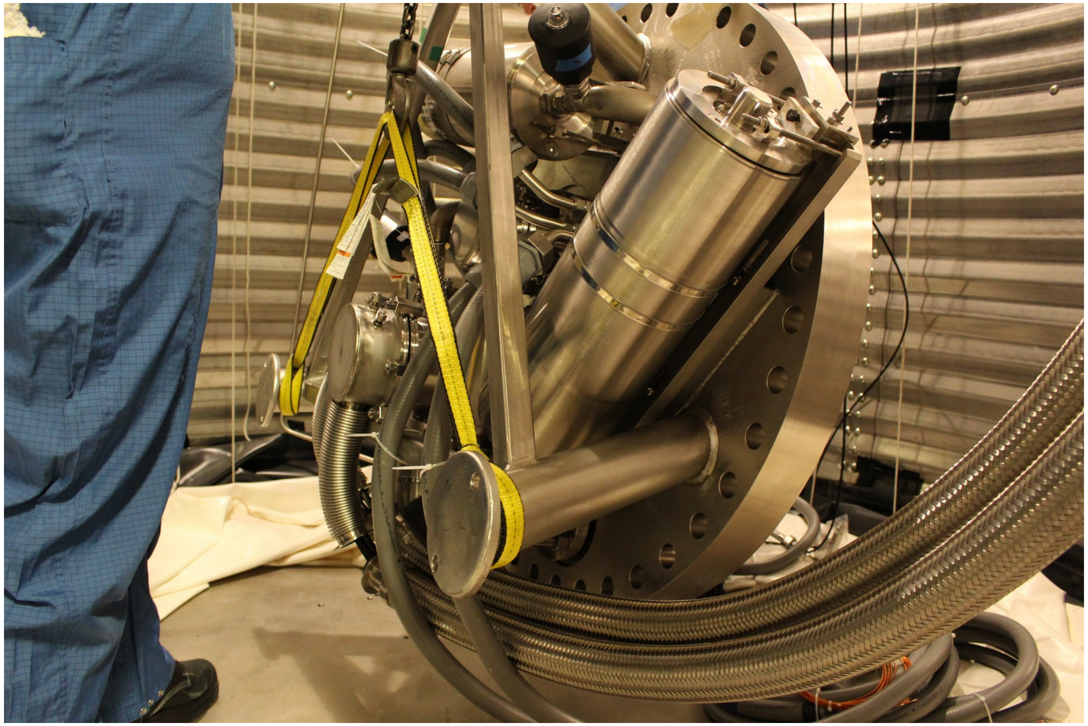


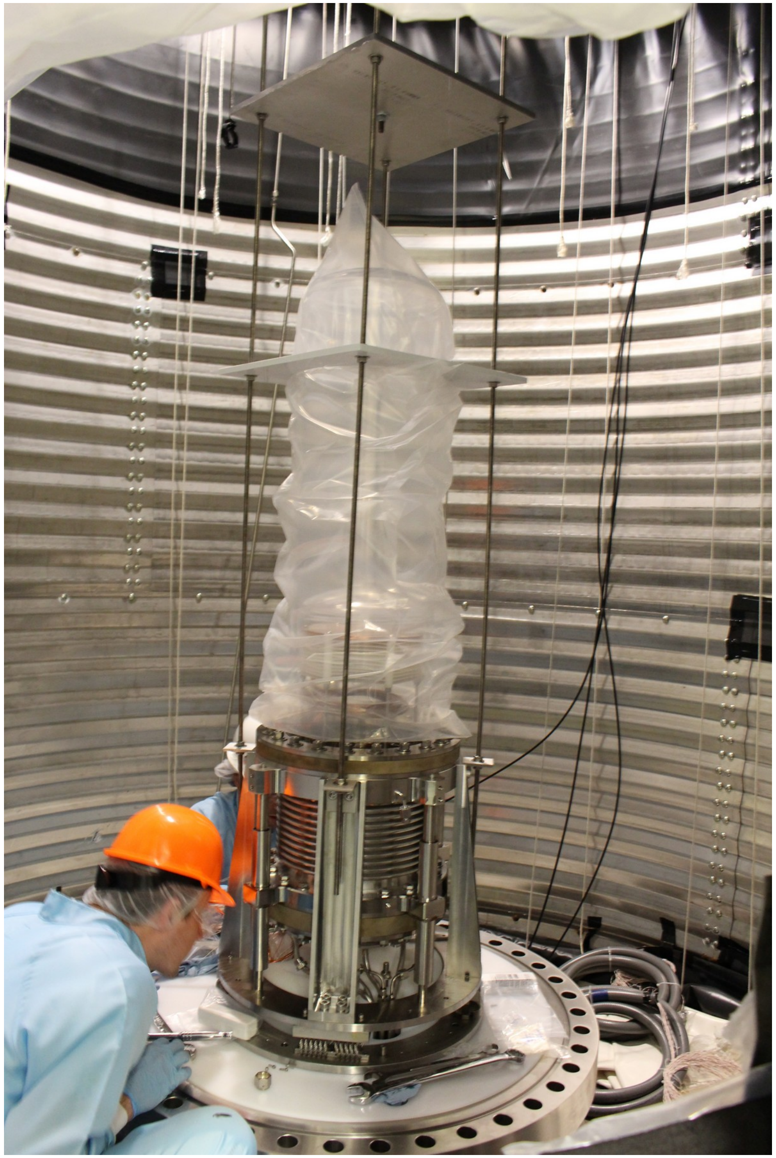
PICO-40L



IV Assembled on surface and shipped
Late 2018

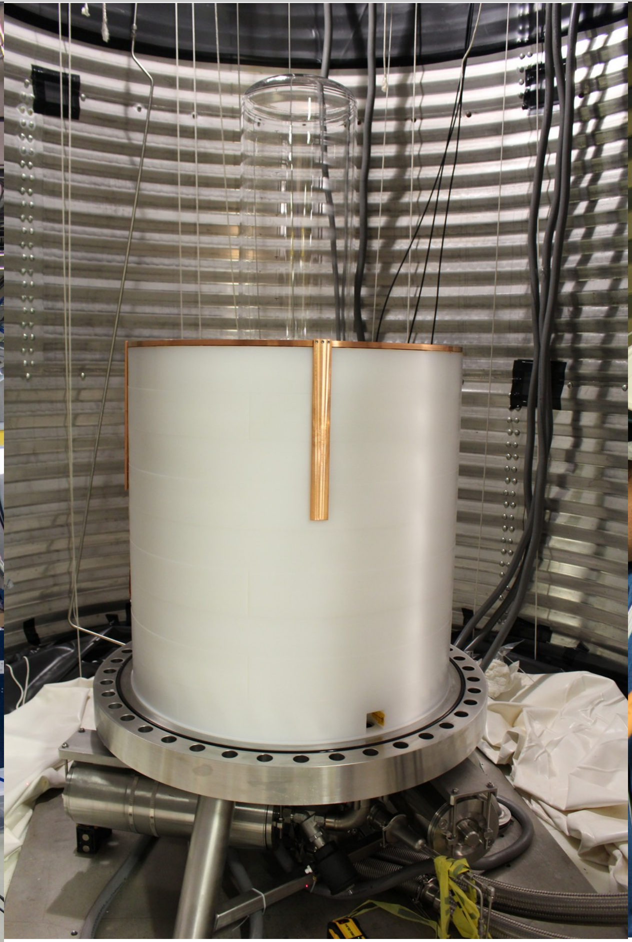
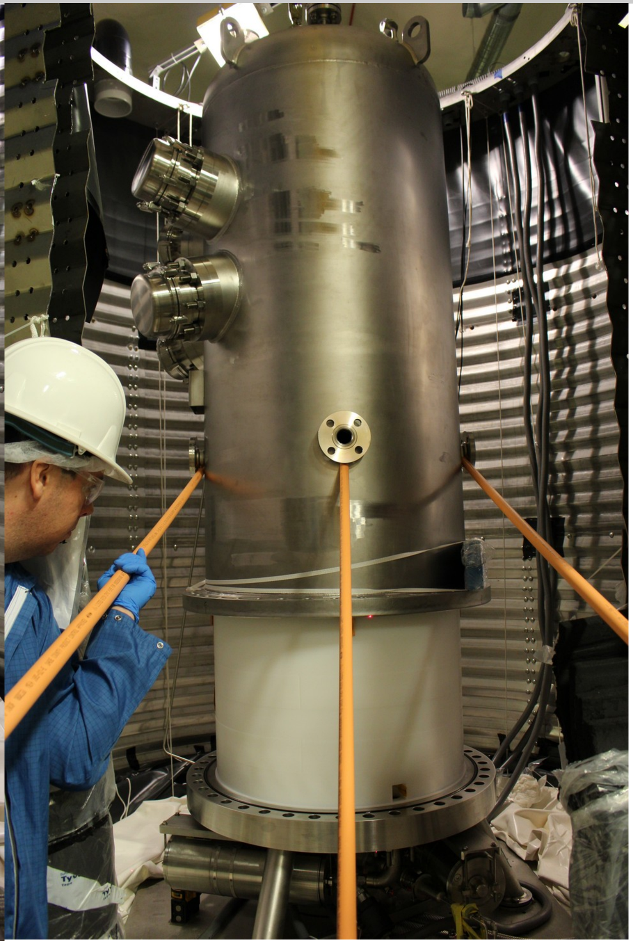
PICO-40L





Base Flange assembled
IV installed
February

PICO-40L

Insulation & instrumentation installed
PV in place
April

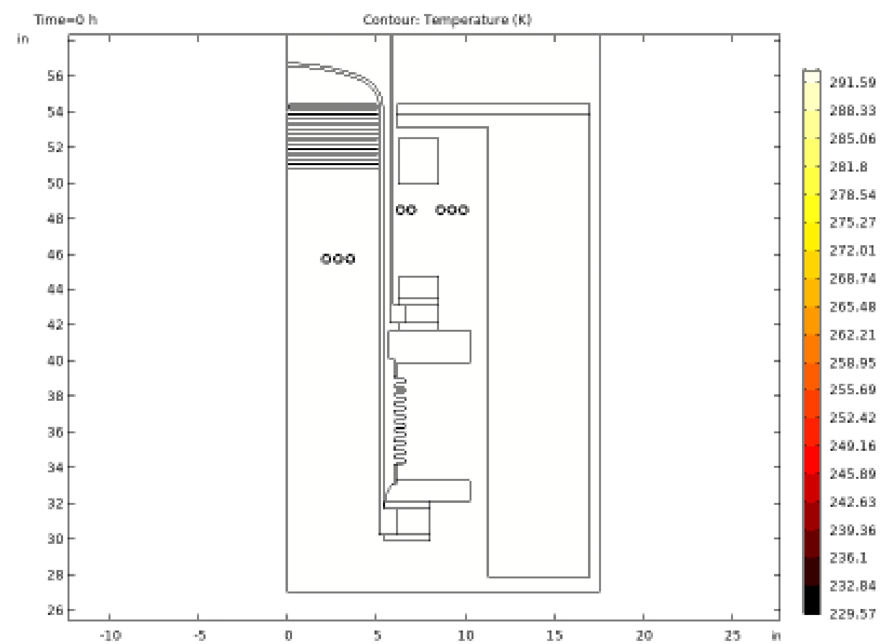
PICO-40L Timeline

- 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

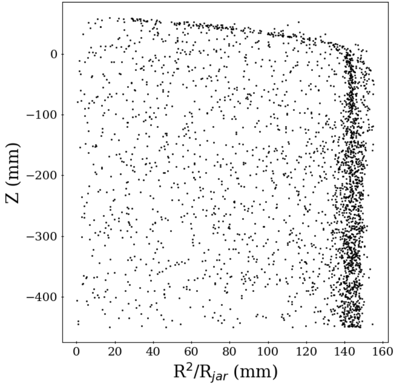
- Thermal control problems
  - Cannot rely on convection of mineral oil
  - Design problem masked by chiller failure.
- Reassembly with new thermal paths



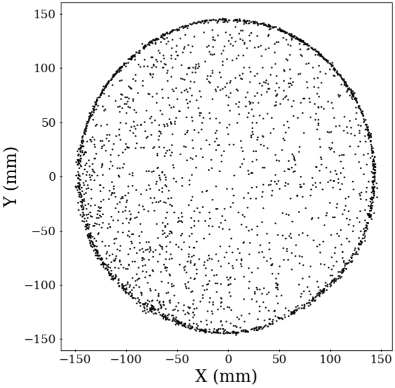
Position Reconstruction

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

R^2 vs. Z



X vs. Y



PICO-500 construction

- Highest-risk components in delivery
- Full TDR this fall

PICO

Neutron Sensitivity

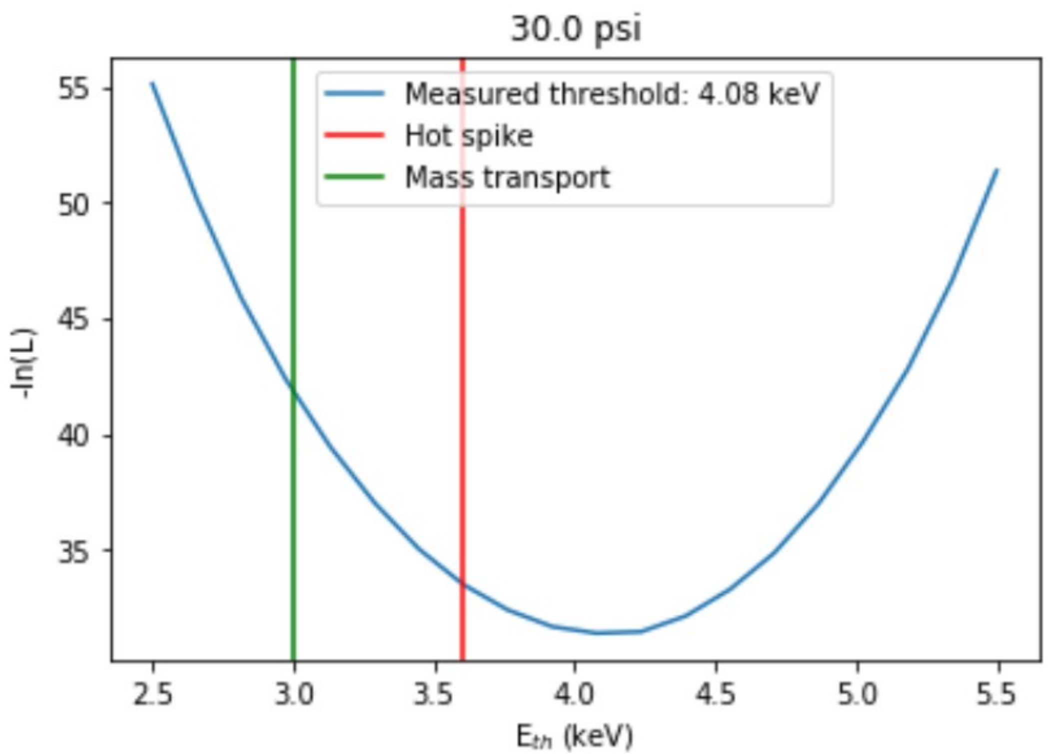
- Ongoing evaluation & mitigation of neutron backgrounds. e.g.
  - Custom fabricated piezoelectric tranducers
  - Maximizing pressure vessel size to move sources away
  - Minimize radon daughter deposition

	Prototype	COUPP-4	2L & 60	Run 2	PICO-40L	PICO-500
α-decay	X	solved	-	-	-	-
Neutrons	-	X	■	■	■	■
Particulates	-	unidentified	X	■	solved	-
γ/β	solved	-	-	-	■	■
ν/μ	-	-	-	-	-	■

Freon mixtures

Use of freon mixtures provides fine control of operating temperature.

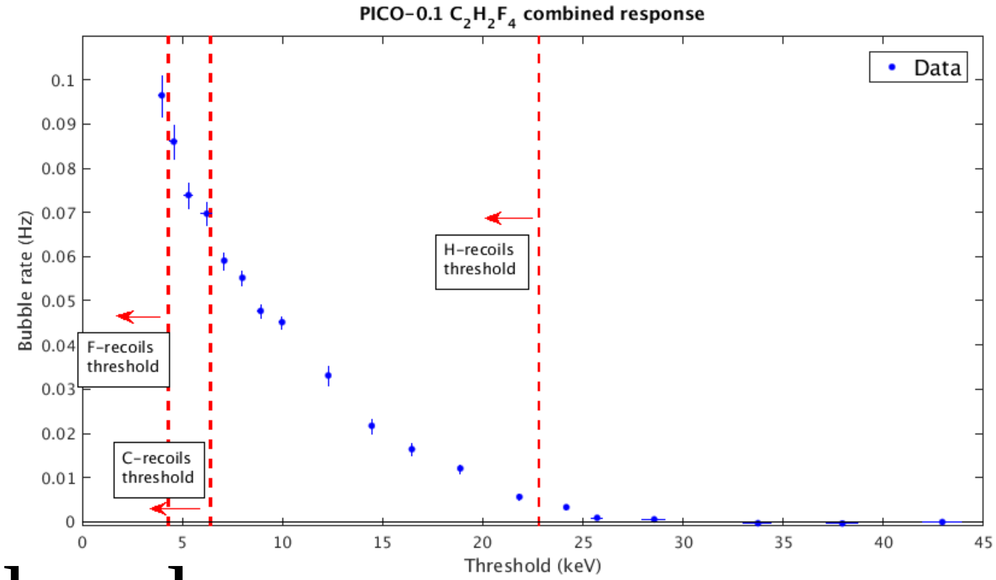
Recent calibration shows that mixed C_3F_8 / C_4F_{10} have similar, and calculable, NR sensitivity to pure fluids.



J. Savoie
MSc thesis U de Montréal (2022)

PICO Development

- Replacement of silica glass
  - Limited by both size of vessel and radiopurity
- Hydrogenated targets
  - Proton recoils seen in $C_2H_2F_4$.
    - F. Tardif MSc thesis, UdeM 2018



- Scintillating Bubble Chamber
  - Separate collaboration using liquid Xe, Ar, Ne

PICO

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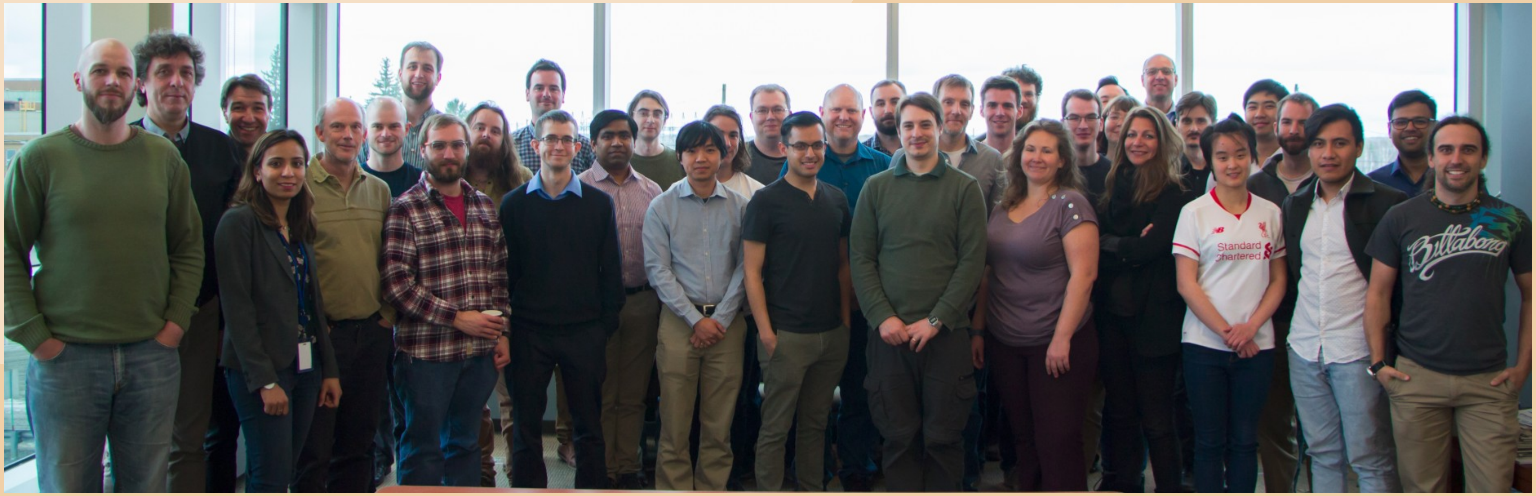

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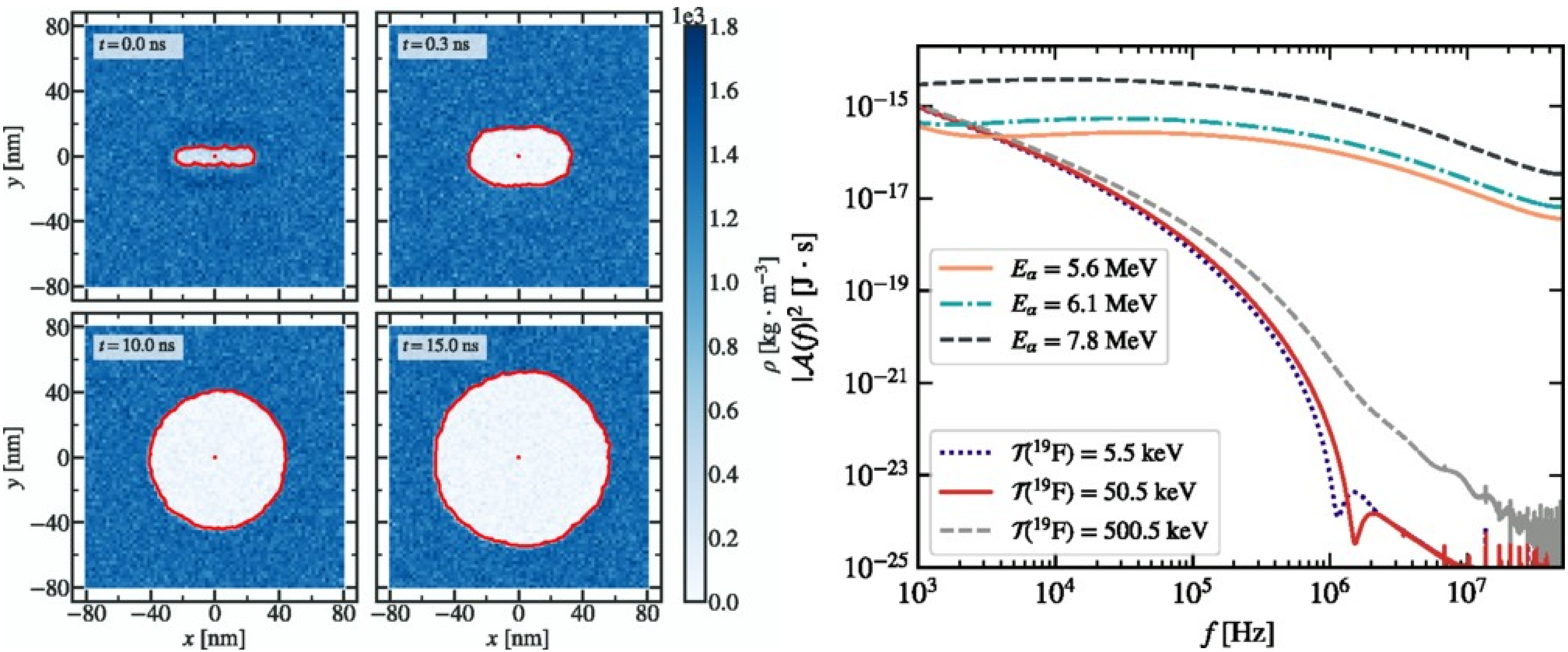
PICO How it works

Alphas discrimination demonstrated in MD simulations.

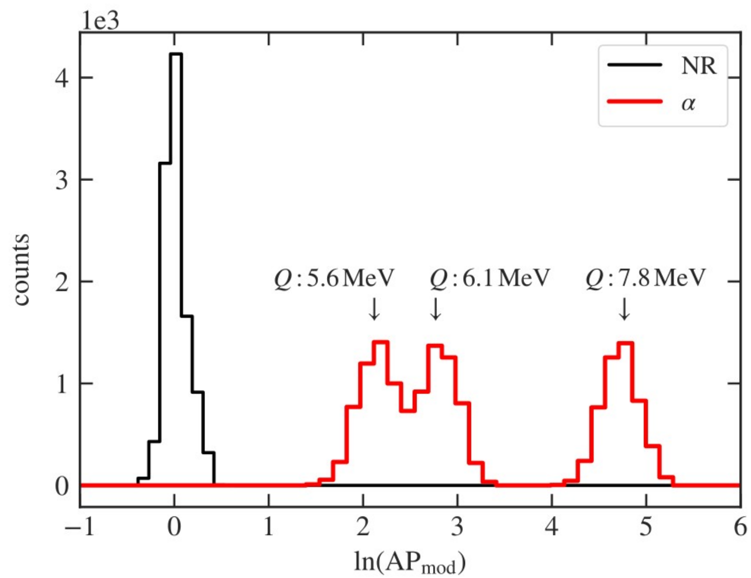
Kozynets, Fallows, and Krauss, PRD 100 052001 (2019)



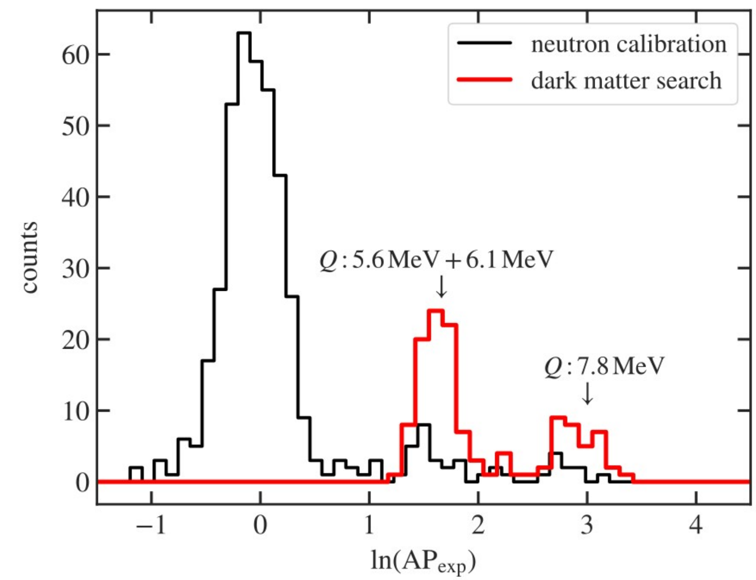
PICO How it works

Alphas discrimination demonstrated in MD simulations and data.

Kozynets, Fallows, and Krauss, PRD 100 052001 (2019)



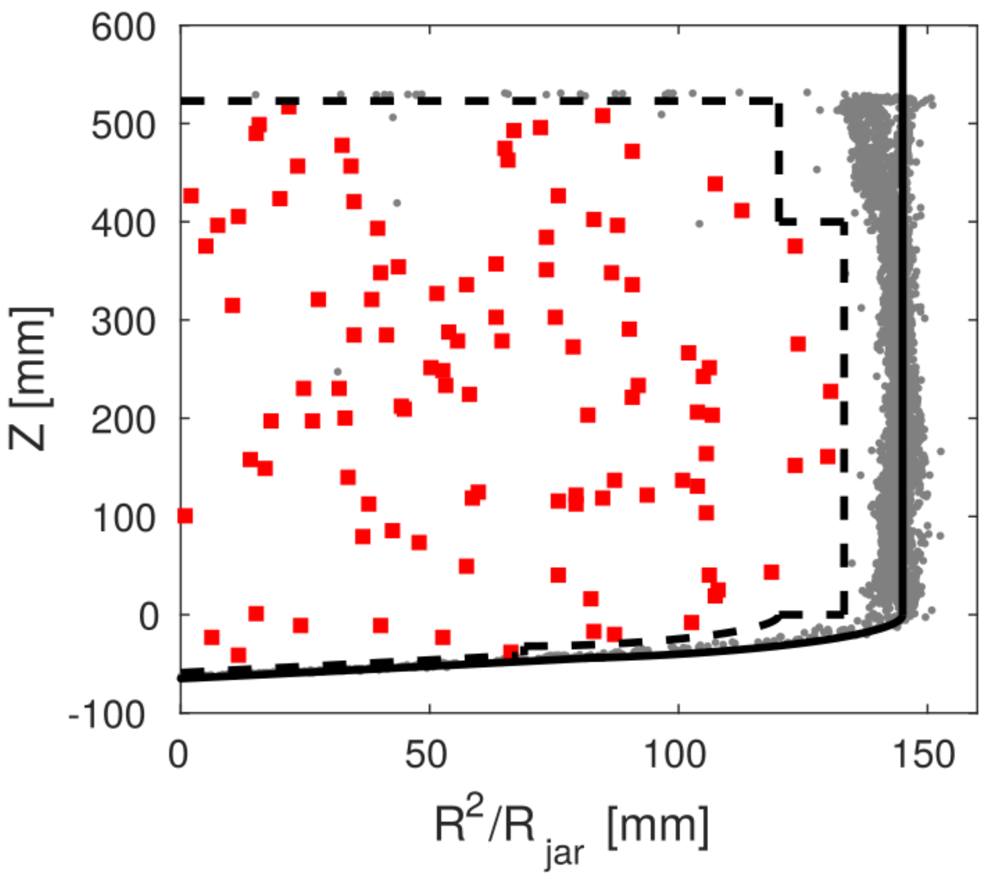
(a) Distribution of the modeled AP values for bubbles nucleated by neutron-induced C/F recoils and the three ^{222}Rn decay chain α-particle populations (7). The data is normalized so that the Gaussian center of the NR peak has an AP_{mod} value of 1. The procedure followed to arrive at the AP_{mod} distribution is described in Sec. III.



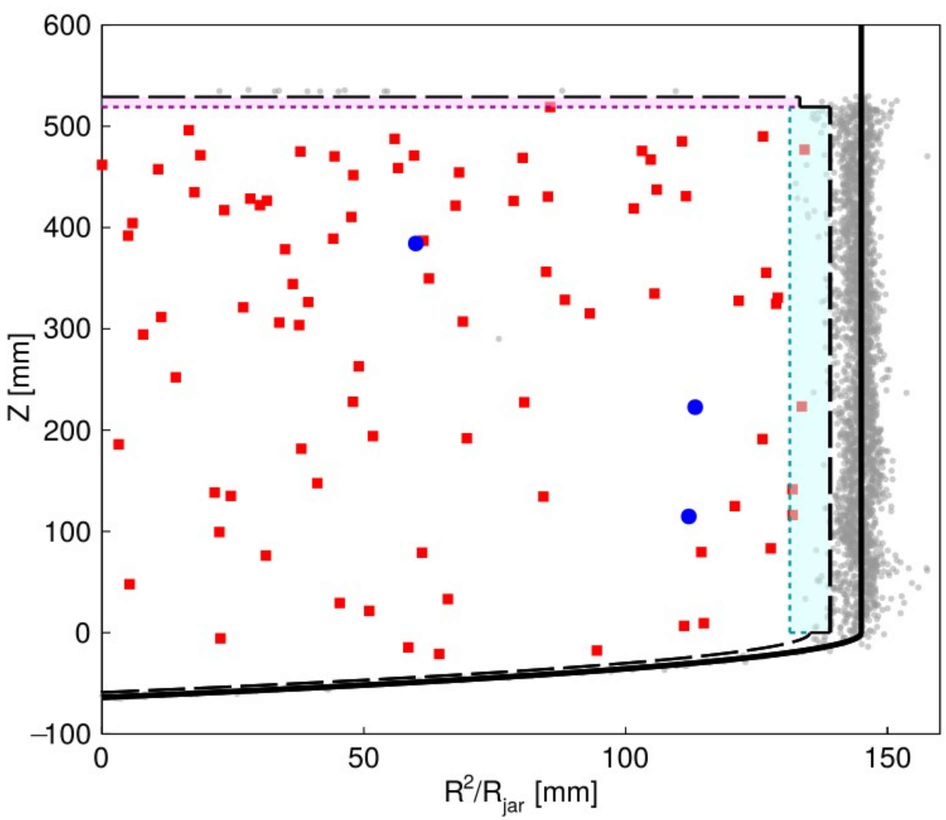
(b) AP distribution as obtained from the PICO-60 run at temperature $T_0 = 13.9°C$ and pressure $P_1 = 30.2$ psia (208 kPa), corresponding to the bubble nucleation energy threshold of 3.3 keV [2, 3]. Both $^{241}Am/^{9}Be$ and ^{252}Cf sources were used for neutron calibration.

PICO-60 C_3F_8

PICO-60 Run 2
0 candidate events in 1167 kg-day
3.29 keV Seitz threshold
PRL 251301 (2017)

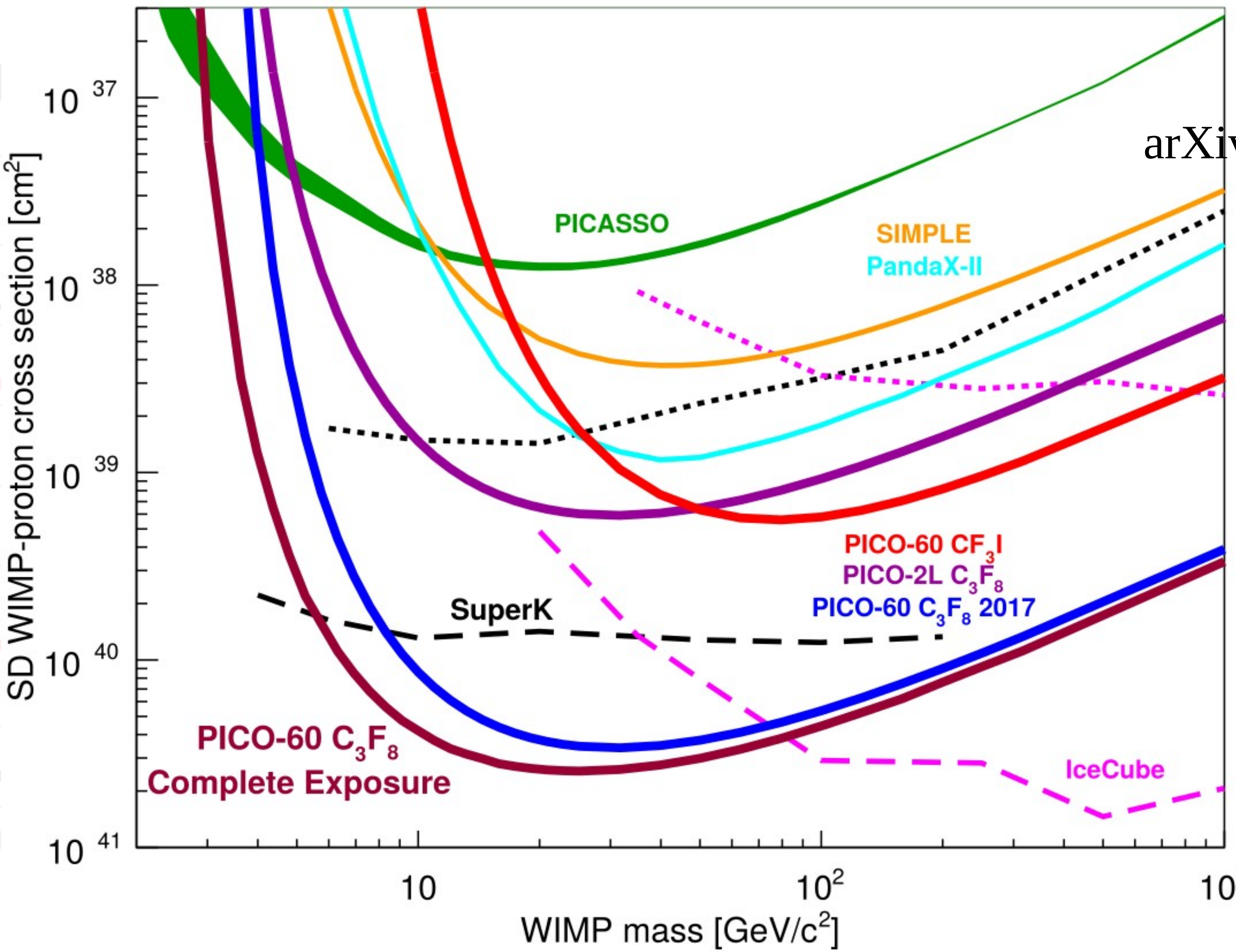


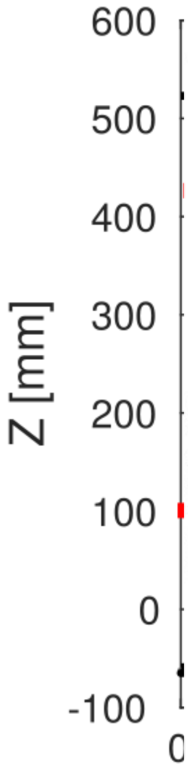
PICO-60 Complete exposure
3 candidate events in 1404 kg-day
2.45 keV Seitz threshold
Accepted to PRD, arXiv 1902.04031

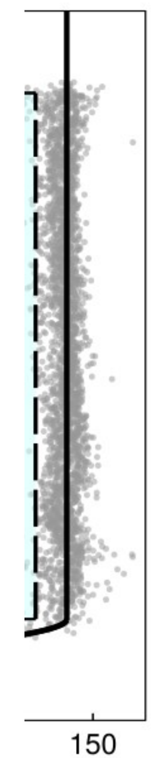


PICO-60 C_3F_8

PICC
0 can … g-day
3.29 …
PRL … arXiv 1902.04031

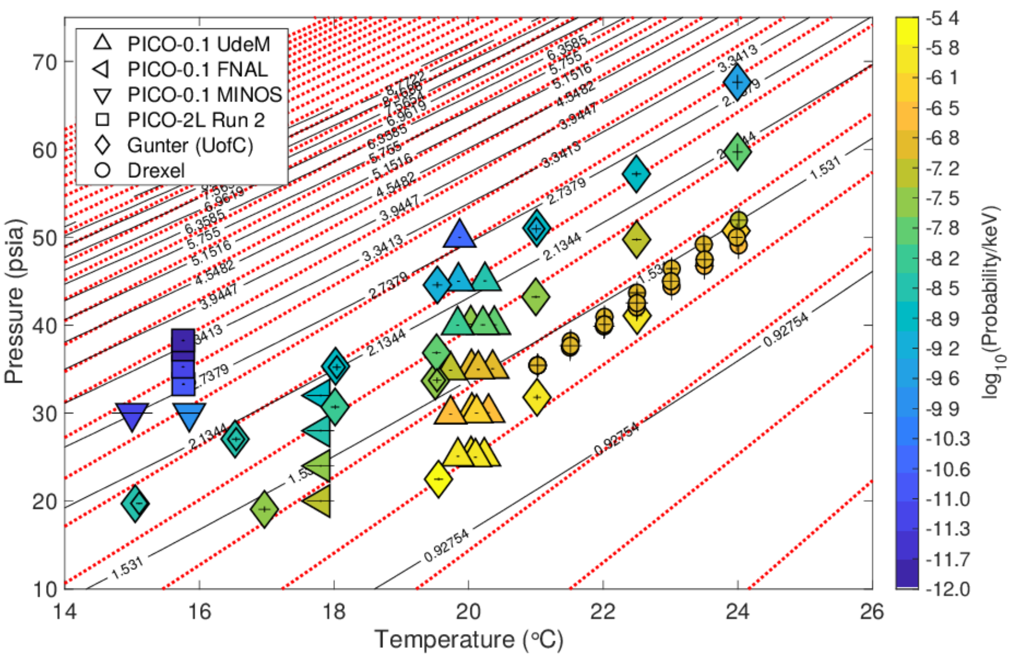


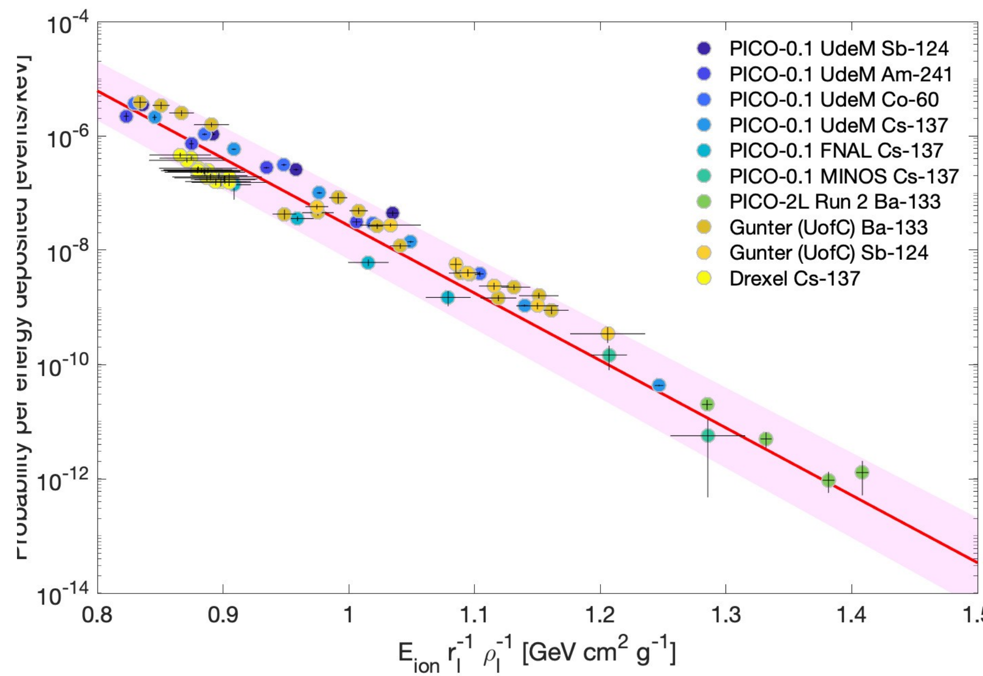




PICO γ & β Rejection

- New analysis of ER sensitivity
  - ► Bubble formed by either semi-adiabatic expansion or Auger cascades of high-Z contaminants
  - ► arXiv: 1905.12522





PICO γ & β Rejection

- New analysis of ER sensitivity
  - We can lower NR threshold without additional sensitivity to ER