PICO Bubble Chambers: Past, Present, and Future

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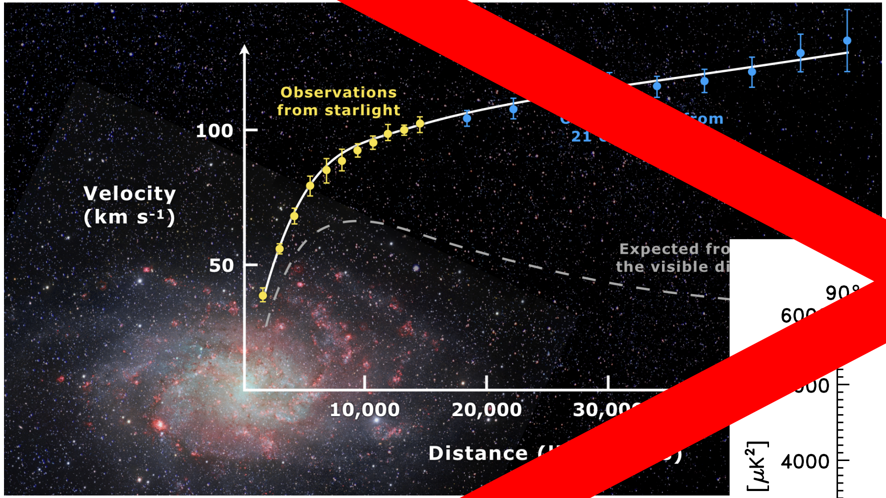
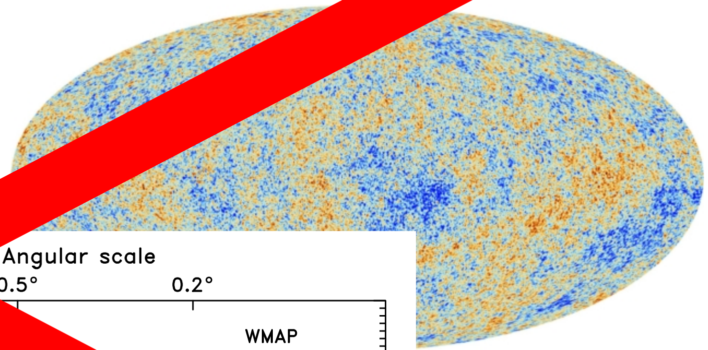
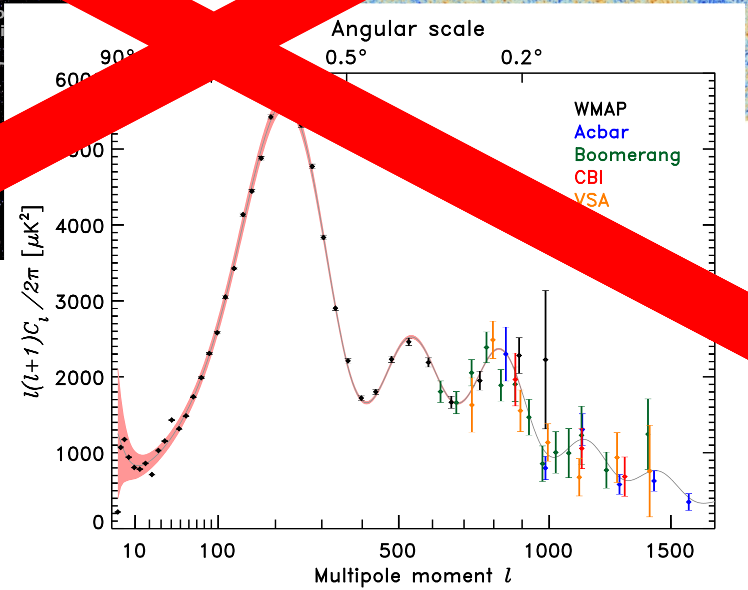
What is dark matter?







What is PICO?

- Dark matter direct detection experiment with bubble chambers
- Combination of two previous collaborations: PICASSO and COUPP
- Bubble chambers provide excellent electron recoil rejection

The Seitz Model

- Seitz “hot spike” model describes nucleation
- Deposited energy must be greater than

$$Q_{Seitz} = \underbrace{4\pi r_c^2\left(\sigma - T\frac{\partial \sigma}{\partial T}\right)}_{\text{Energy to form bubble surface}} + \underbrace{\frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l)}_{\text{Energy to convert liquid to gas}} - \underbrace{\frac{4\pi}{3} r_c^3 (P_b - P_l)}_{\text{Work to grow Bubble to critical radius}}$$

Energy to form bubble surface

Energy to convert liquid to gas

Work to grow Bubble to critical radius

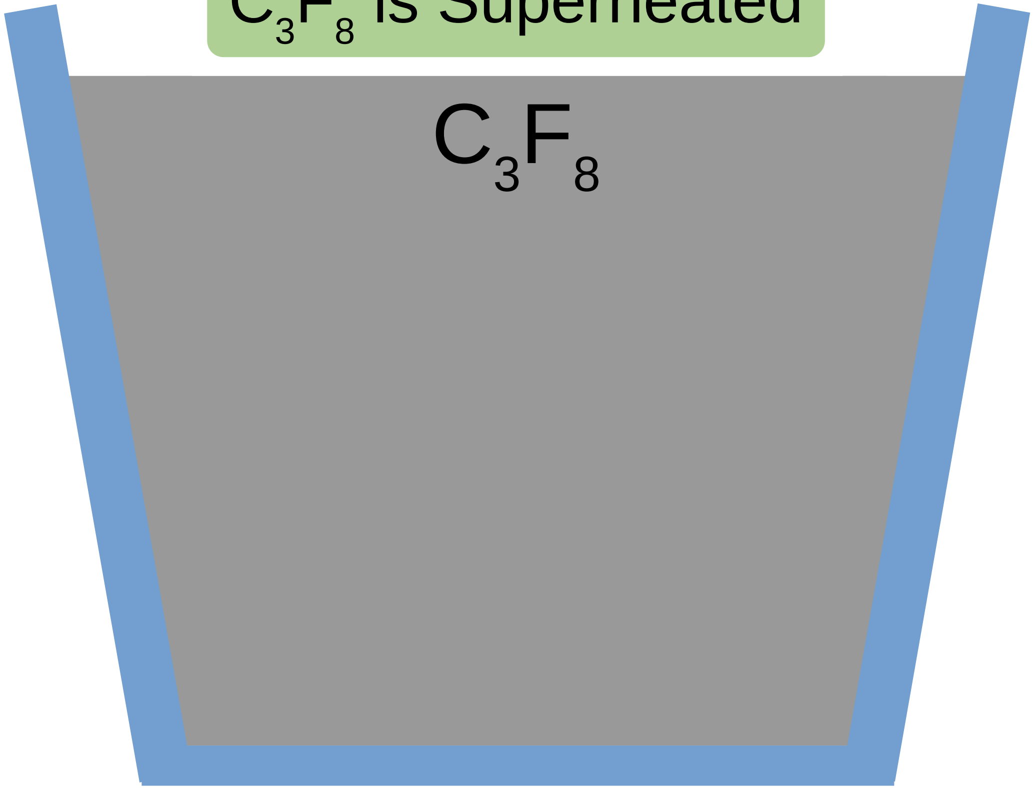
σ = Surface tension
T = fluid temperature
ρ_b = bubble density
P_b = pressure in bubble
P_l = pressure in fluid
h_b = specific enthalpy of bubble
h_l = specific enthalpy of fluid

- Additionally, the energy must be deposited in a comparable length scale as the critical radius:

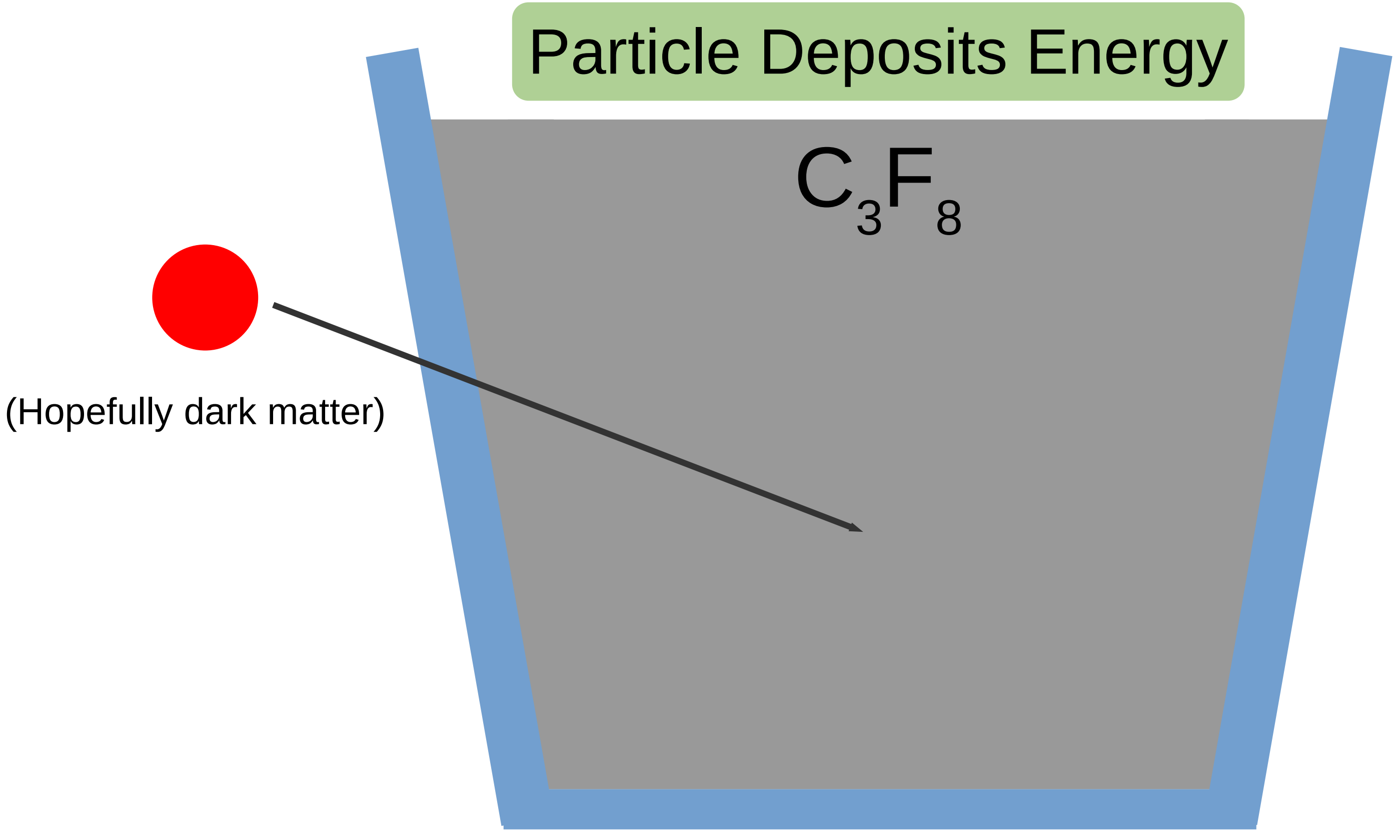
$$r_c = \frac{2\sigma}{P_b - P_l}$$

Bubble Chambers

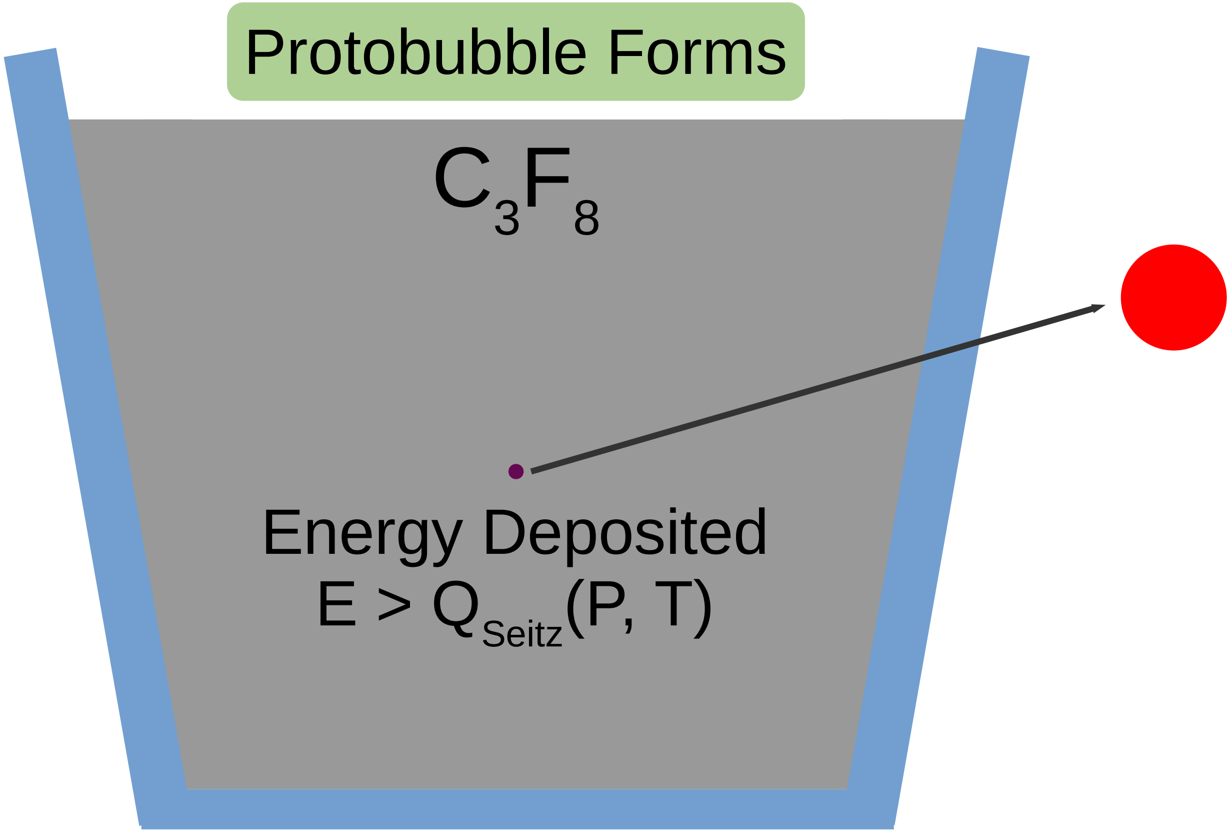
C_3F_8 is Superheated



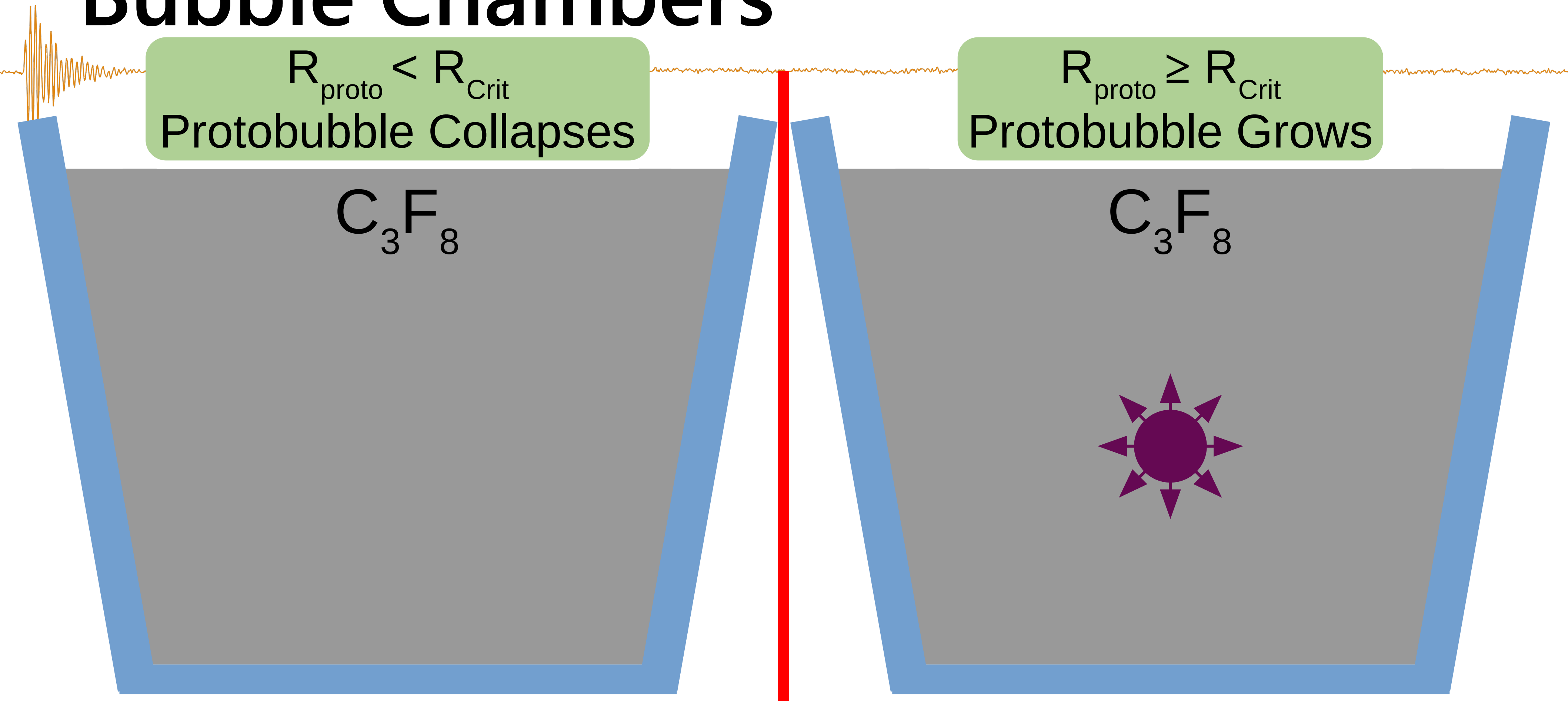
Bubble Chambers



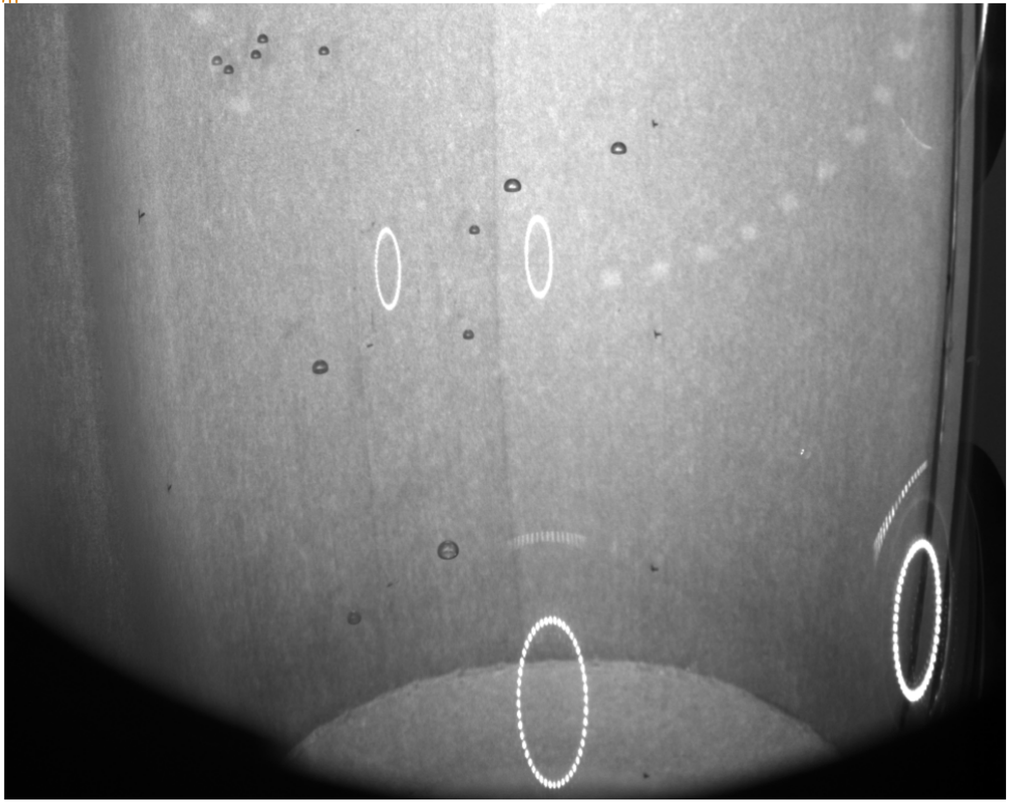
Bubble Chambers

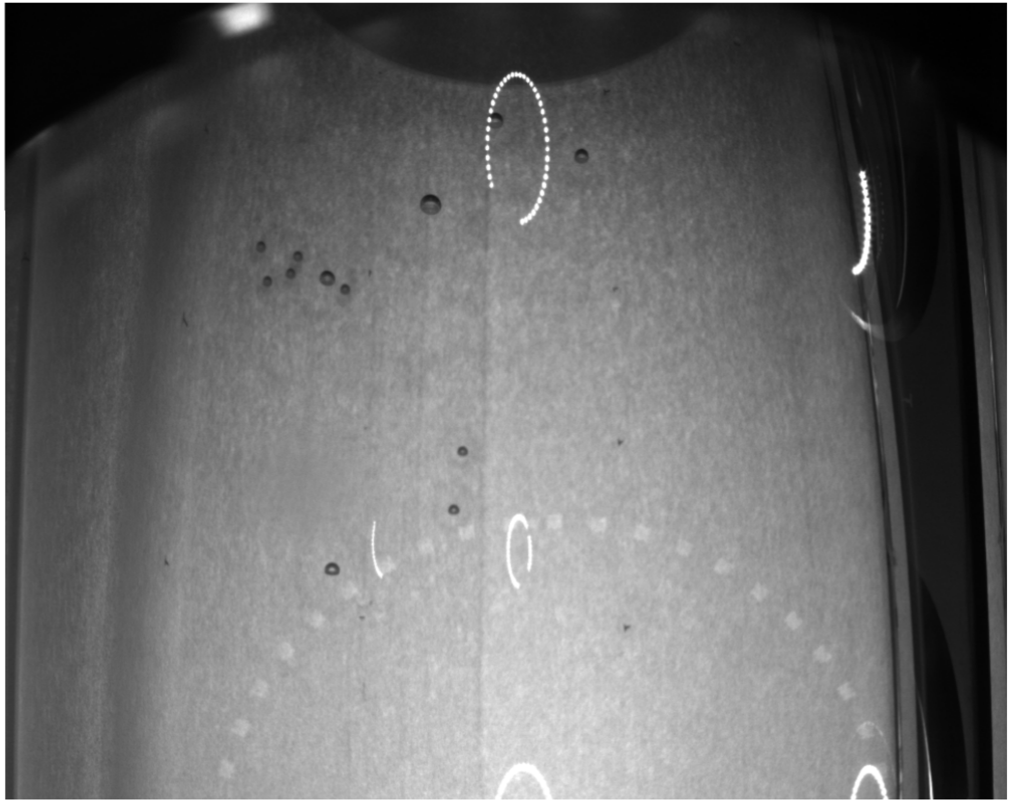


Bubble Chambers



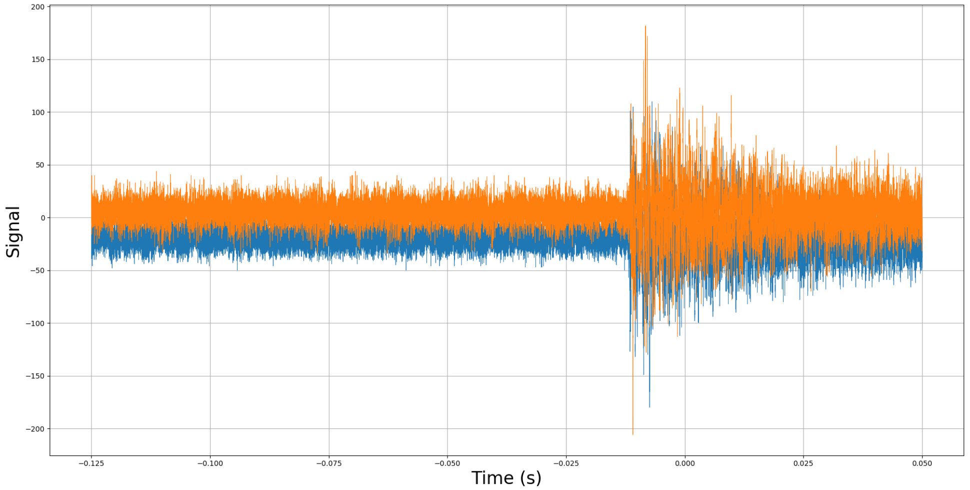
Bubble Chambers

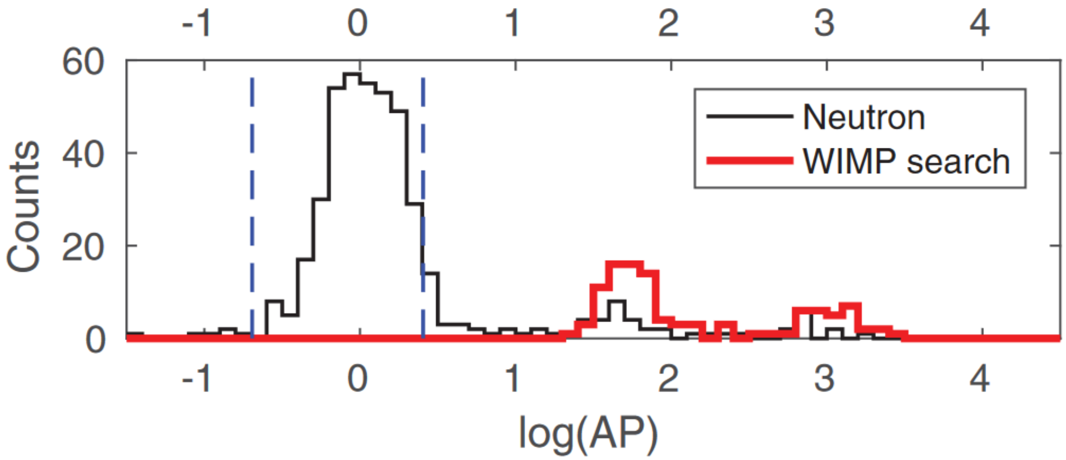




Seitz and Sounds

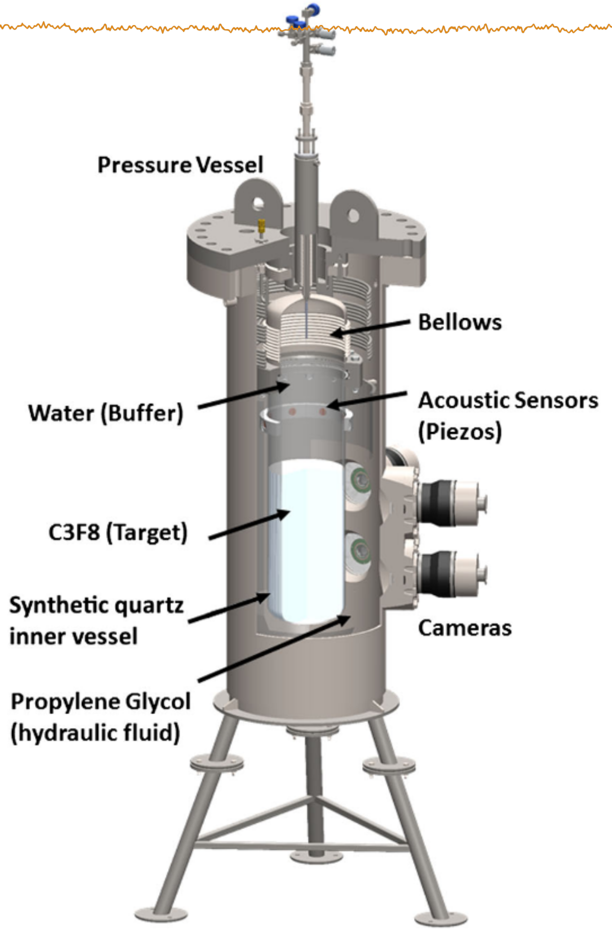
Discriminate bubbles caused by alphas from WIMP-like neutrons via “Acoustic Parameter”





PICO-60 C_3F_8

- Bubble chamber filled with 52 kg C_3F_8
- Ran at SNOLAB Nov 2016-Jan 2017
- Achieved background-free 30 live-day run
- Three multi-bubble events during run implied neutrons limited continued exposure



PICO-60 C_3F_8 Run 2

- PICO-60 Run 1: 30 Live Days @ Q_{Seitz} = 3.29 keV
- Run 2 goals: investigate stability at lower thresholds

T (°C)	P (psia)	Q_{Seitz} (keV)	Live Time (days)	Exposure (kg·day)
19.9	25.5	1.20 ± 0.1(exp) ± 0.1(th)	0.21	8.2
19.9	34.3	1.58 ± 0.1(exp) ± 0.1(th)	1.29	50.3
15.9	21.7	1.81 ± 0.1(exp) ± 0.1(th)	7.04	311
15.9	30.5	2.45 ± 0.1(exp) ± 0.2(th)	29.95	1404
13.9	30.2	3.29 ± 0.1(exp) ± 0.2(th)	29.96	1167

Run 1 → (13.9 / 30.2 row)

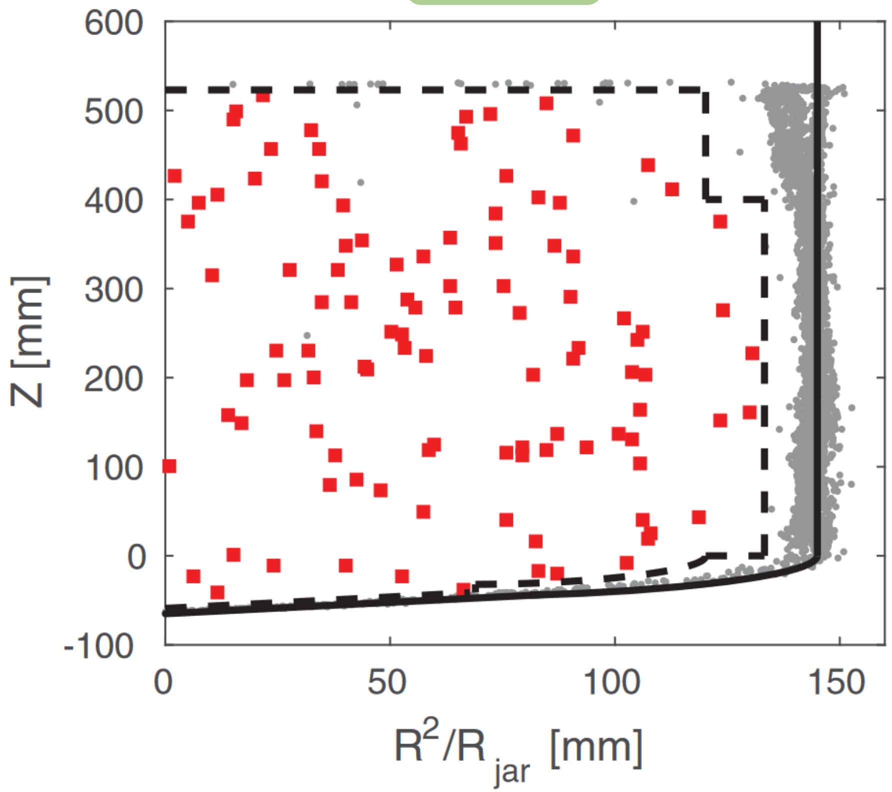
PICO-60 C_3F_8 Run 2

- 3 Singles, 2 Multiples in 30 live days (within 90% C.L. of predictions)

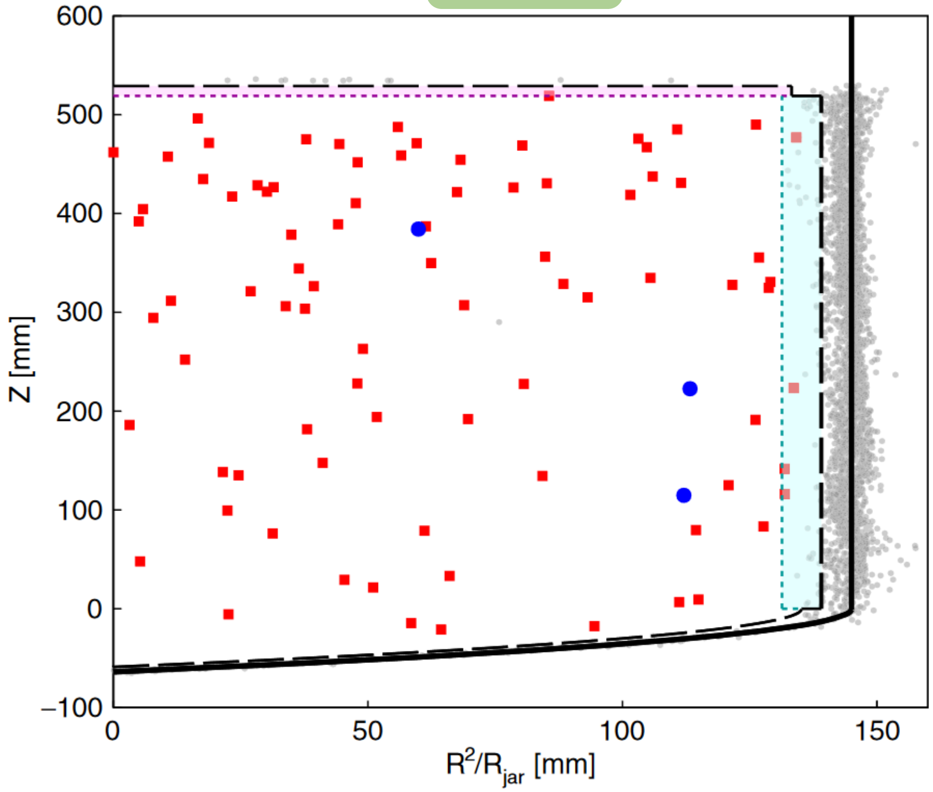
Run 1: Q_{Seitz} = 3.29 keV				
	Acceptance	Fiducial Mass	Exposure	Number of Events
Singles	85.1 ± 1.8	45.7 ± 0.5	1167 ± 28	0
Multiples	99.4 ± 0.1	52.2 ± 0.5	1555 ± 15	3
Run 2: Q_{Seitz} = 2.45 keV				
	Acceptance	Fiducial Mass	Exposure	Number of Events
Singles	$95.9^{+1.9}_{-3.4}$	48.9 ± 0.8	1404^{+48}_{-75}	3
Multiples	$99.9^{+0.0}_{-0.1}$	52.0 ± 0.1	1556^{+3}_{-5}	2

PICO-60 C_3F_8 Events

Run 1

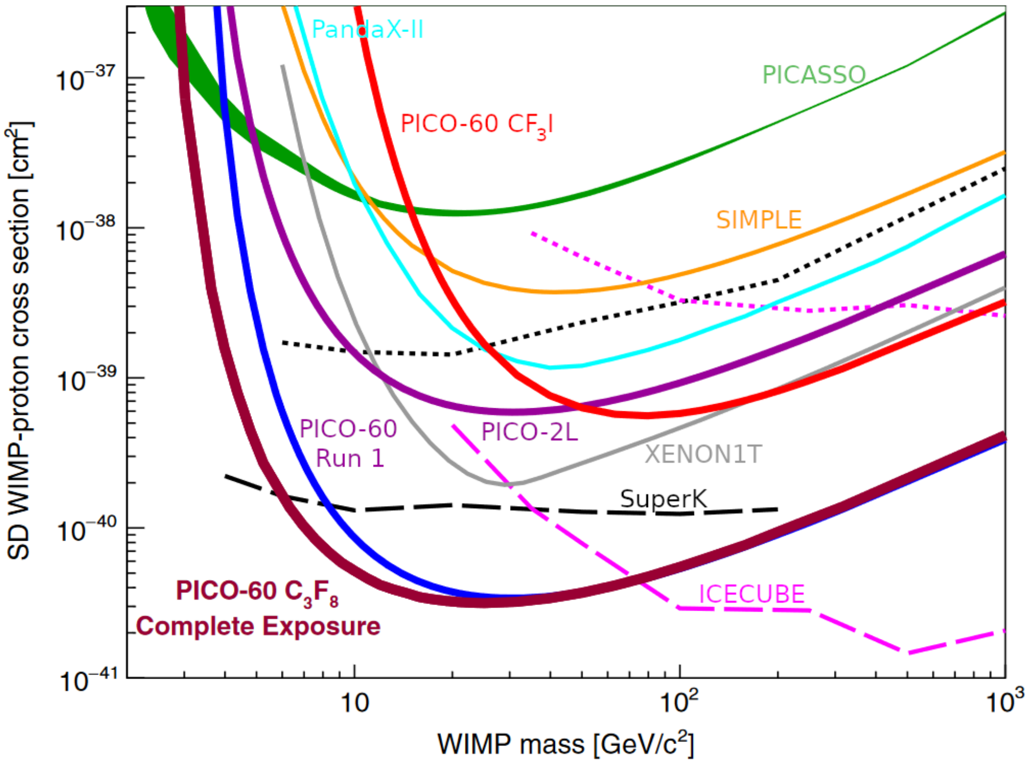


Run 2

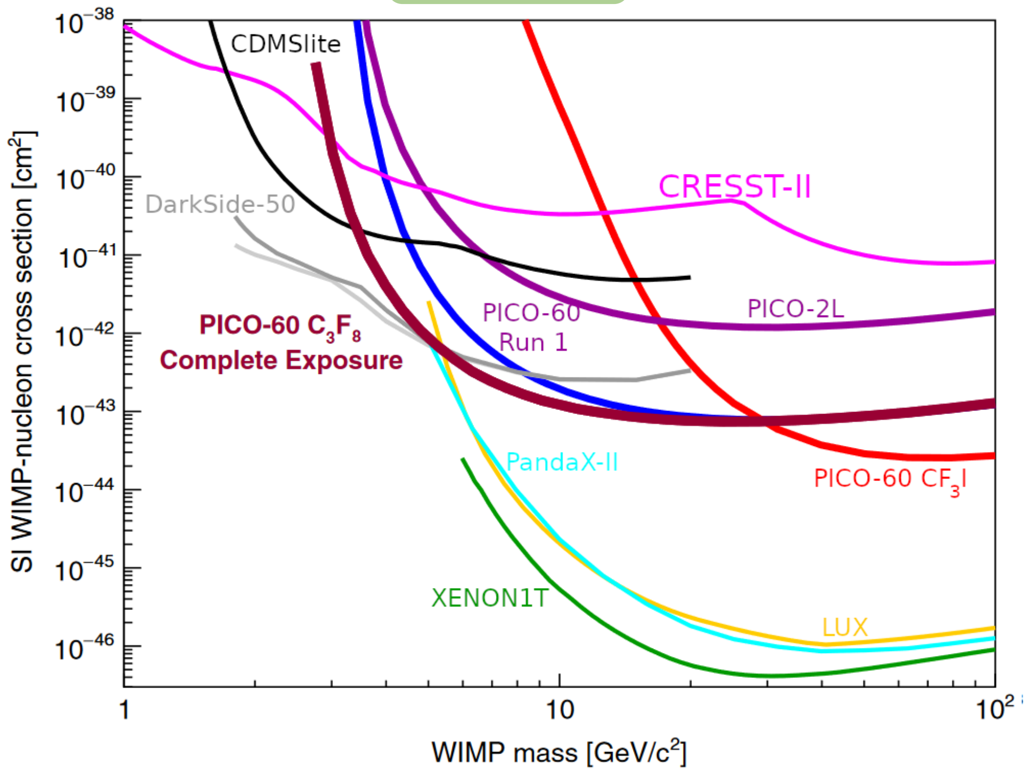


PICO-60 C_3F_8 Events

SD Limit

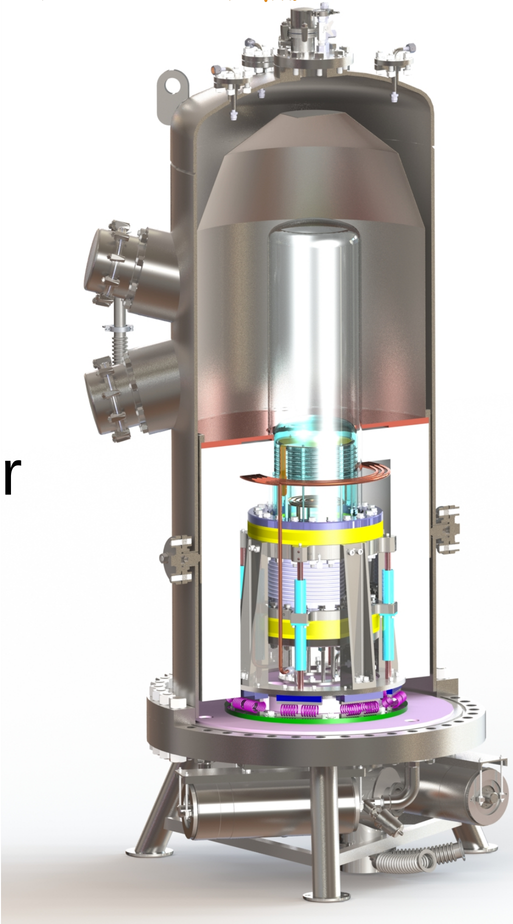


SI Limit



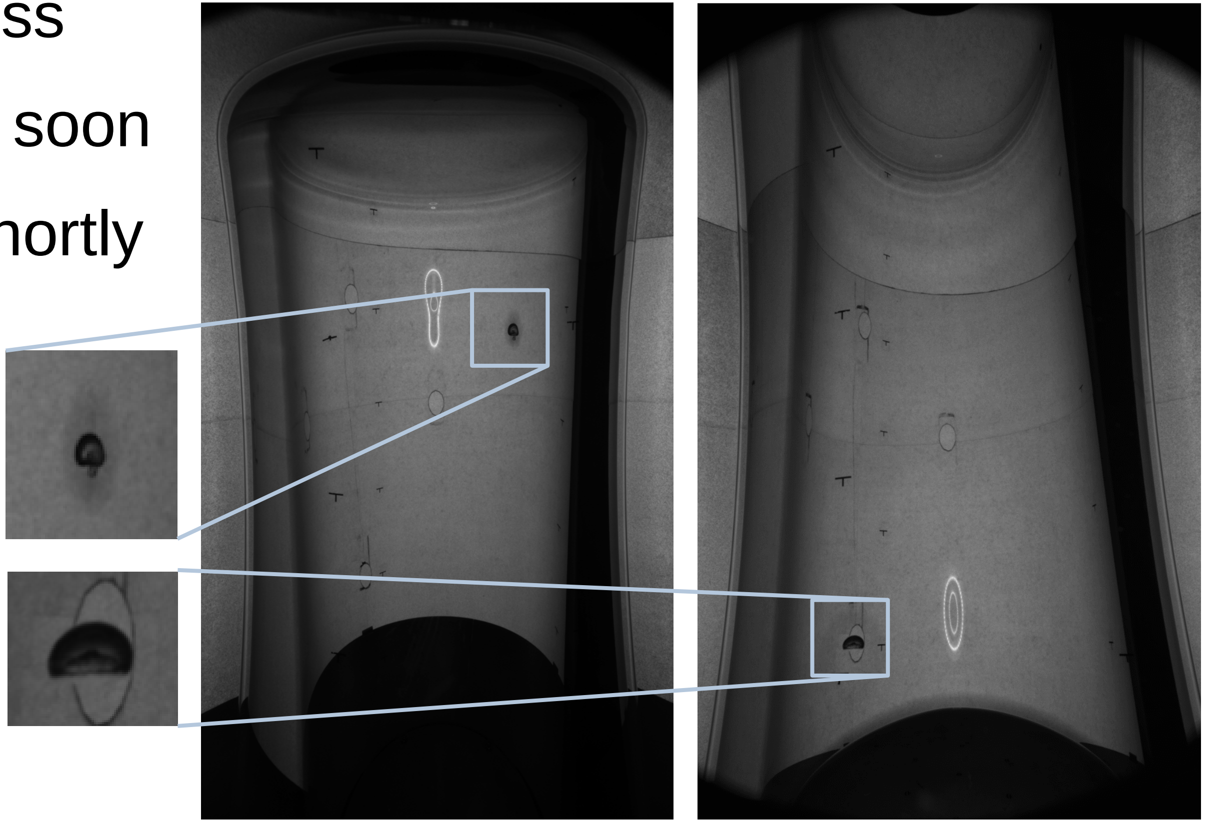
PICO-40L

- New detector design: “Right Side Up”
- Two temperature regions:
  - warm (superheated) upper region
  - cold (liquid) lower region
- Lower backgrounds expected from lack of water buffer and reduced effect of microscopic debris



PICO-40L Status

- Commissioning in progress
- Water tank fill happening soon
- Physics runs will begin shortly after water shield is full



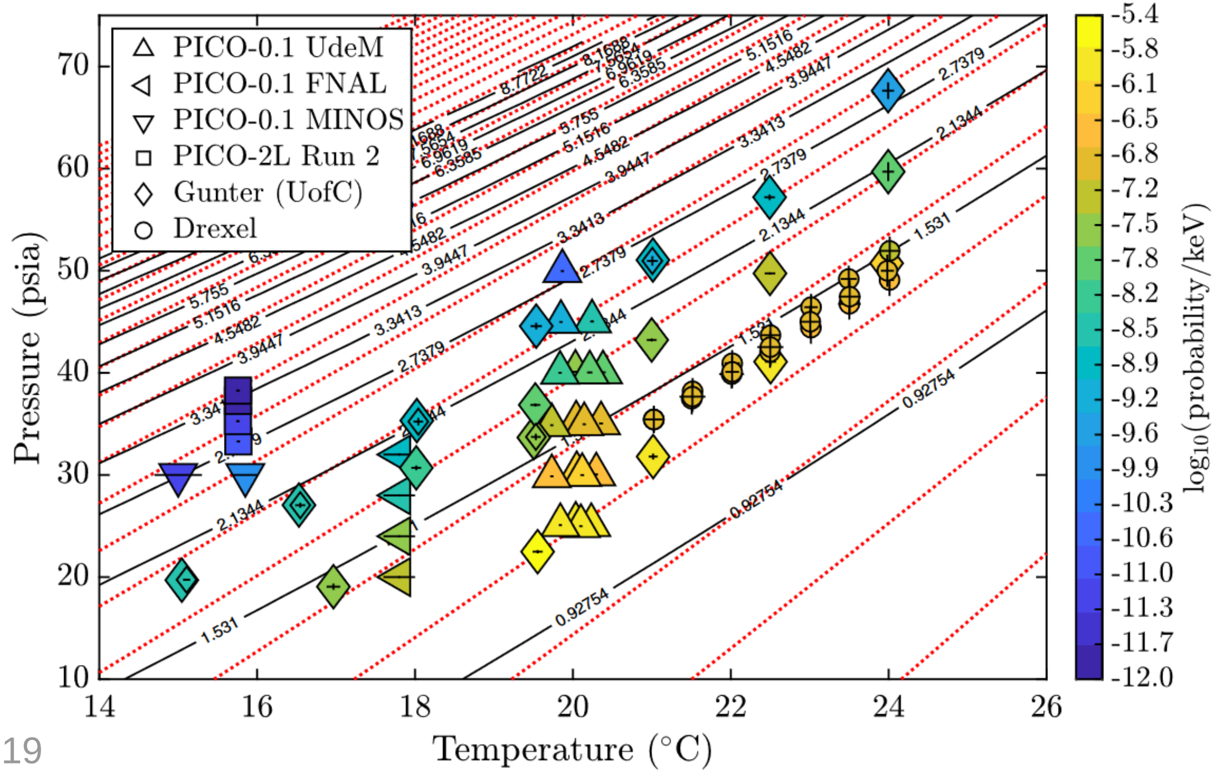
PICO-40L Physics

- Plan to explore parameter space outlined in recent electron recoil nucleation paper, and run at optimal (P, T)

Solid Black: Constant **Seitz** Threshold

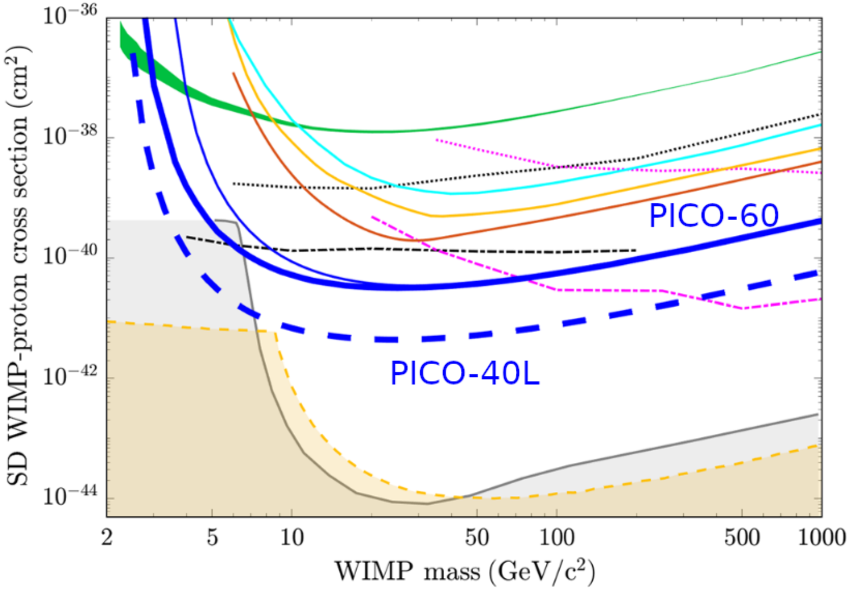
Dotted Red: Constant **Ionization** Threshold

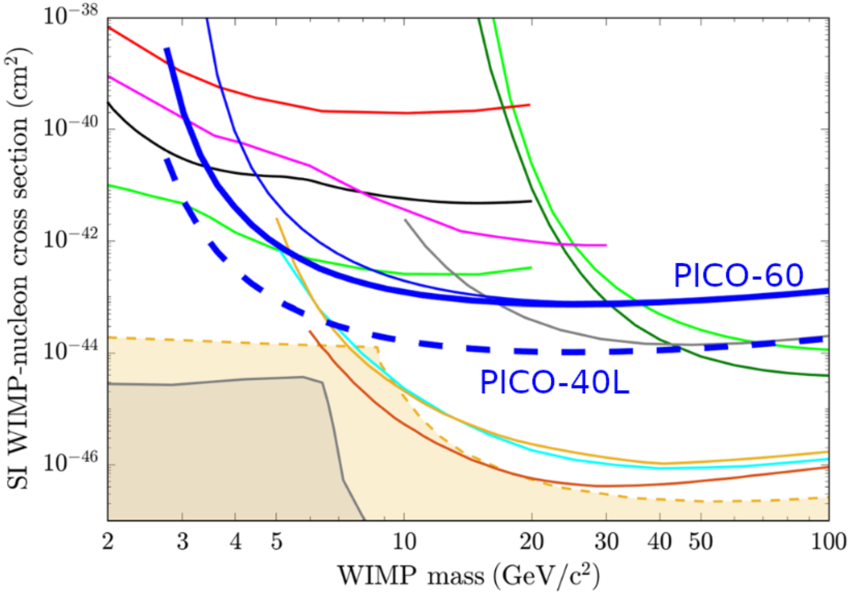
arxiv: 1905.12522



PICO-40L Physics

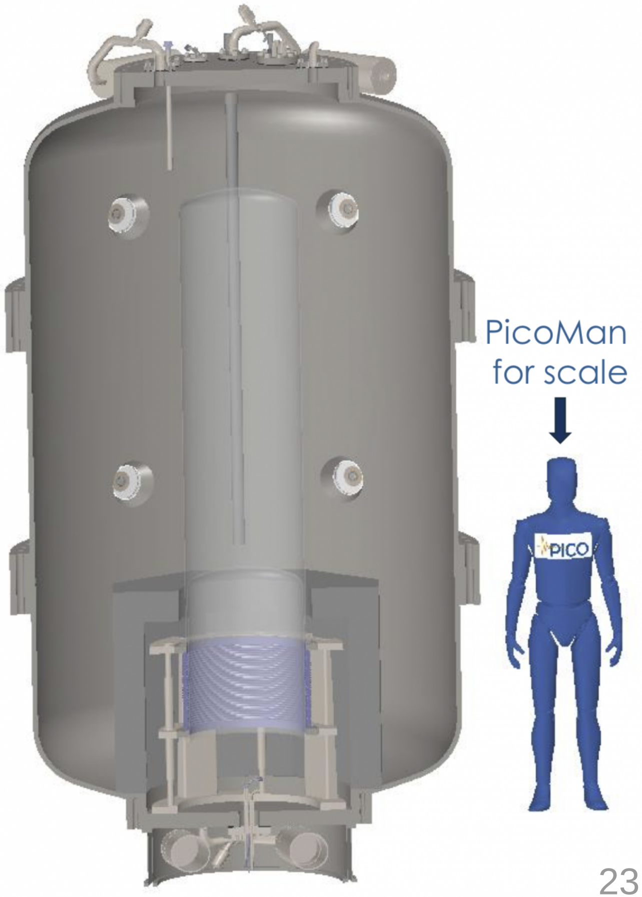
- Plan to explore parameter space outlined in recent electron recoil nucleation paper, and run at optimal (P, T)
- Expect ~1 order of magnitude improvement over PICO-60 limits





PICO-500

- Tonne-scale bubble chamber with Right Side Up design
- Located in Cube Hall in SNOLAB
- Currently in design phase



PICO

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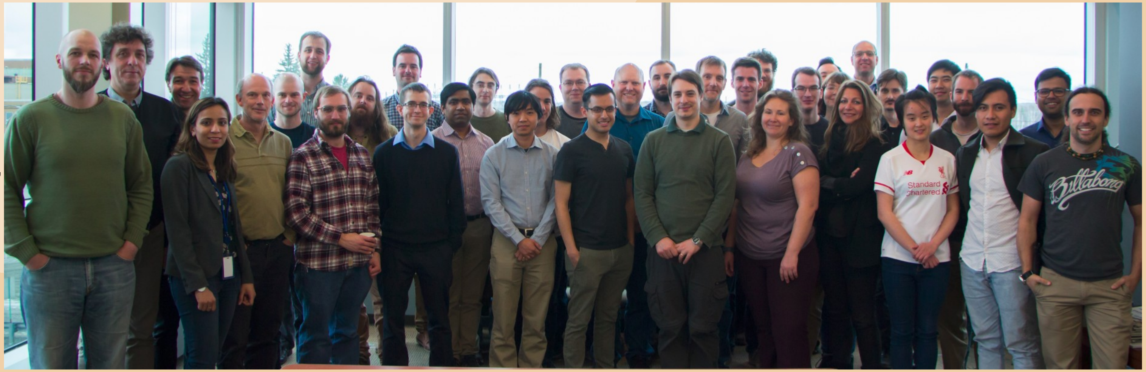

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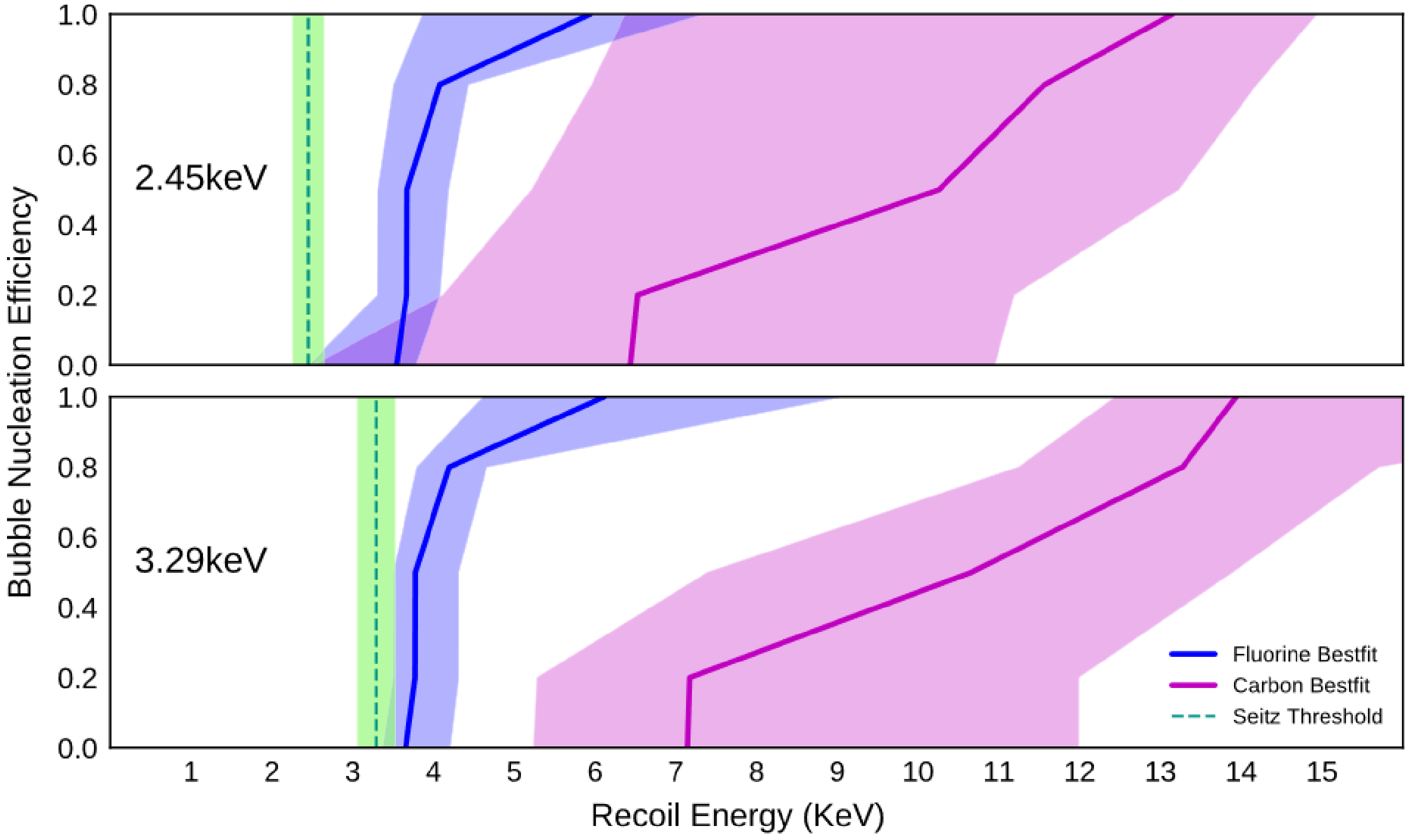
PICO-60 Efficiency



PICO-40L Physics

- Plan to explore parameter space outlined in recent electron recoil nucleation paper, and run at optimal (P, T)

Nucleation probability: $P = Ae^{-Bf(P,T)}$

Nuclear recoils: $f(P,T) = Q_{Seitz} = 4\pi r_c^2 (\sigma - T\frac{\partial\sigma}{\partial T}) + \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) - \frac{4\pi}{3} r_c^3 (P_b - P_l)$

Electron recoils: $f(P,T) = \frac{E_{ion}}{r_l \rho_l}$

$$E_{ion} = 4\pi r_c^2 (\sigma - T\frac{\partial\sigma}{\partial T}) + \frac{4\pi}{3} r_c^3 P_l$$

$$r_l = r_c \left(\frac{\rho_b}{\rho_l}\right)^{\frac{1}{3}}$$

Seitz Threshold vs Stopping Power