# Dark matter direct detection with the PICO collaboration

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WHY BUBBLE CHAMBERS

# What a bubble chamber buys us

Three features make the technology well suited to a dark-matter search.

electromagnetic blindness

### We ignore gamma backgrounds

We can make electron recoils invisible by adjusting our threshold, allowing us to eliminate a large background that other experiments need to contend with.

light target nucleus

### Reach toward low masses

Fluorine is light, so a light WIMP transfers a useful kick to it. A nuclear-recoil target like this pushes a little deeper toward the ~1 GeV region than heavy-nucleus detectors.

interchangeable fluid

### Swap the target to suit the physics

Change the active fluid without rebuilding, to look at a wide array of potential nuclear responses that might be induced. $C_3F_8$ for spin-dependent fluorine coupling, $CF_3I$ for spin-independent reach, $C_2H_2F_4$ for lighter masses.

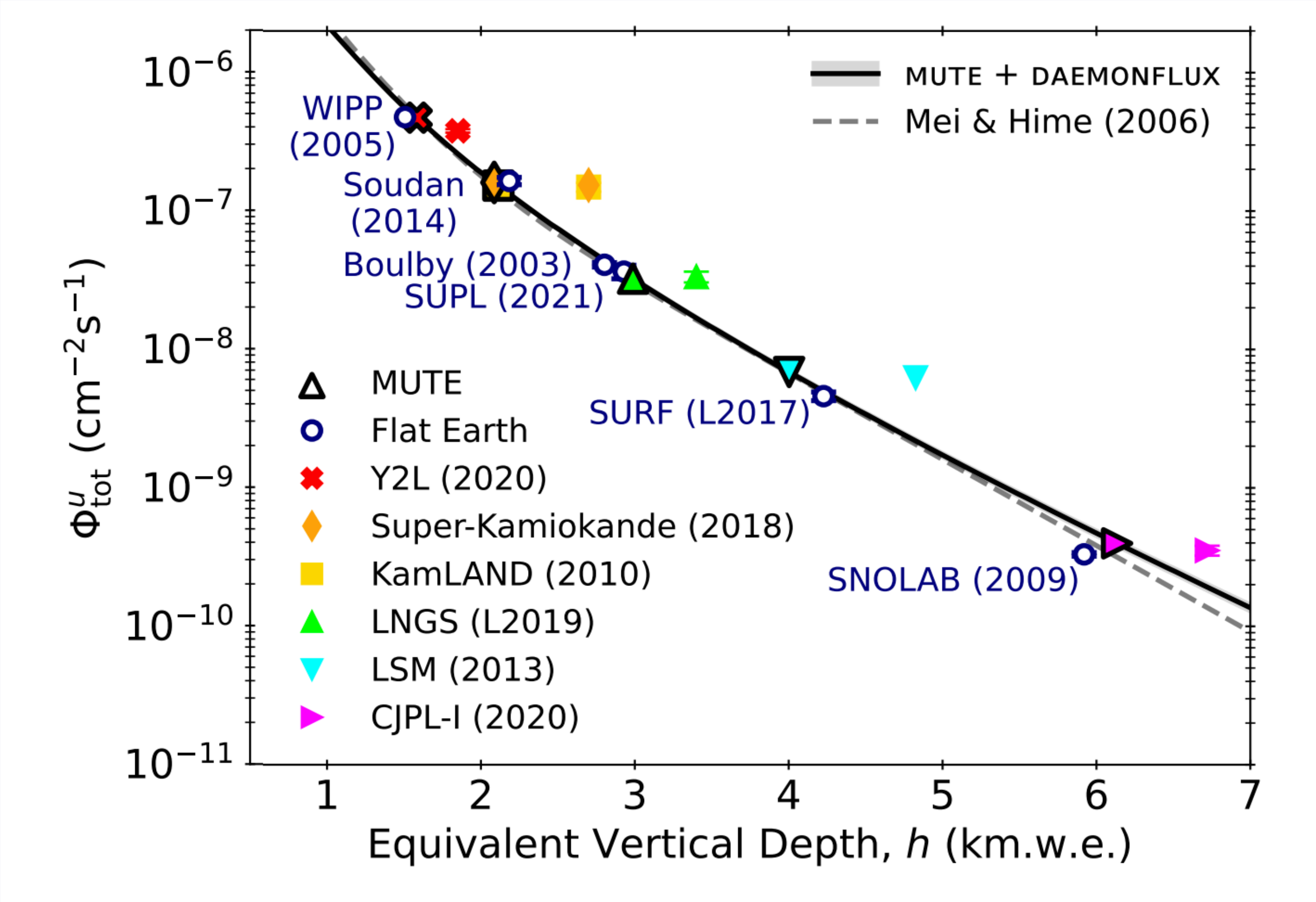
THE EXPERIMENT

# The PICO experiment at SNOLAB

- We look for dark matter with superheated bubble chambers . They only react when a nucleus gets hit hard, and stay quiet for almost everything else.

- All of our chambers run 2 km underground at SNOLAB , in the Creighton mine outside Sudbury. The 2072 m of rock overhead (about 6000 m water-equivalent), with around 0.27 cosmic-ray muons crossing each m² per day.

- Previously have operated PICO 60, with PICO 40L currently in operation and PICO 500 under construction




W. Woodley, A. Fedynitch, and M.-C. Piro, Phys. Rev. D 110, 063006 (2024).

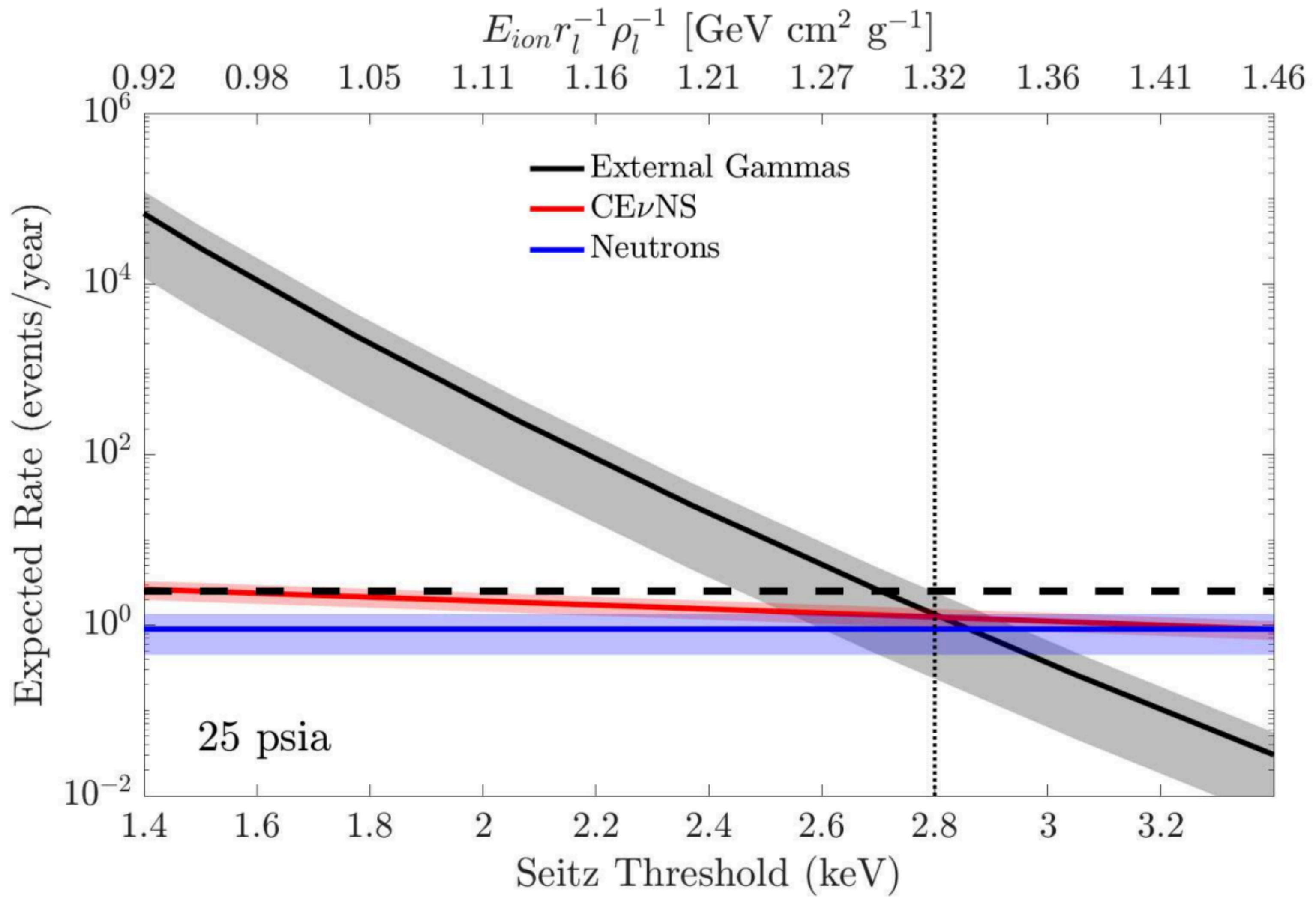
2072 m rock ≈ 6000 m.w.e.

0.27 muons / m² / day

THE DETECTOR

# How a bubble chamber detects a particle

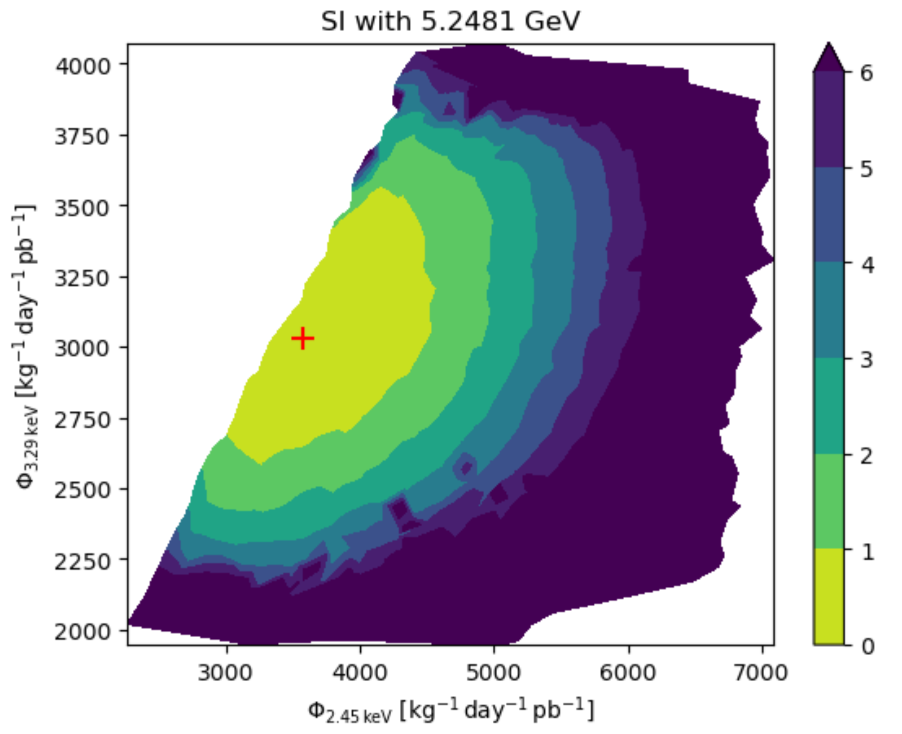
- The active fluid, ( most commonly $C_3F_8$ ), is kept above its boiling point but under enough pressure to stay liquid. It sits there superheated and metastable.
- Knock a nucleus hard in a small enough spot and the liquid boils right there. A single bubble grows to about a centimetre in a few milliseconds.
- Cameras tell us where it formed, the piezos hear the bubble and we recompress to look for new events.
- Crucially, gammas and electron recoils spread their energy too thinly to ever boil the fluid, so PICO is blind to that dominant background.

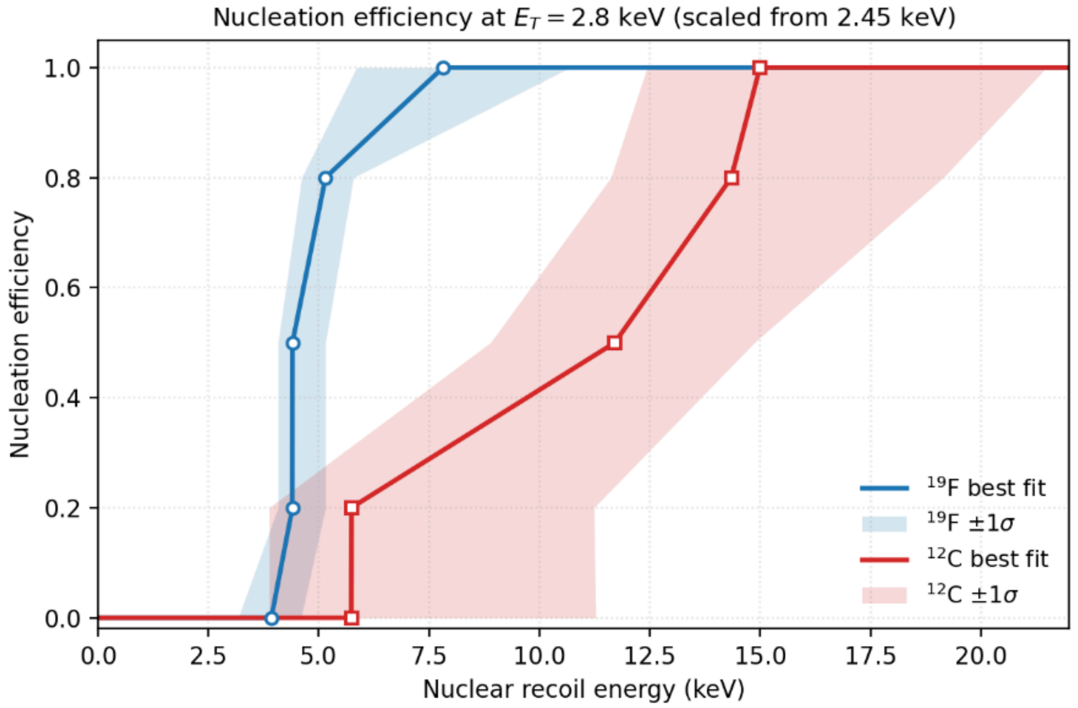



Phys. Rev. D 100, 082006 (2019) · arXiv:1905.12522

# What it takes to make a bubble

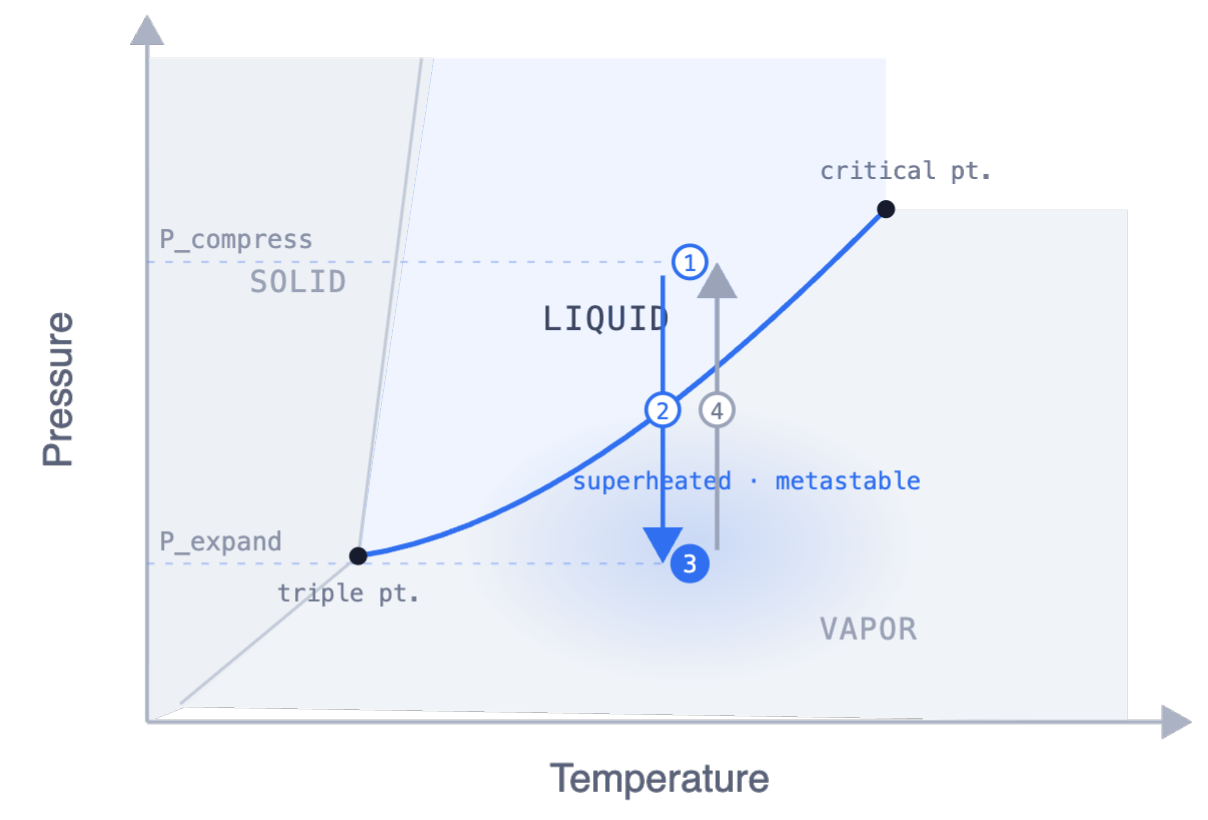
- A recoil dumps its energy into a microscopic region and tries to grow a tiny vapour seed.
- Surface tension fights back. Below a critical radius the seed collapses; past it, vapour pressure wins and the bubble runs away.
- The energy to clear that barrier is the Seitz threshold dependent on the temperature and pressure we run our system.
- In order to capture the full physics we use piecewise linear efficiency curves, or likelihood surfaces trained on neutron calibration data.



# The pressure cycle, traced in phase space

1. **Compress.** High pressure holds the fluid as an ordinary liquid — the chamber is reset.
2. **Expand.** Pressure drops below the vaporization curve — the fluid is now superheated and live.
3. **Trigger.** An interaction nucleates a bubble in the metastable liquid.
4. **Recompress.** Pressure returns, the bubble collapses, and the cycle begins again.



THE DETECTOR

# How we read out an event

Three independent channels record every bubble — together they drive the whole analysis that follows.

optical · cameras

### Where it happened

Stereo cameras photograph the chamber many times a second. From the images we reconstruct where each bubble sat in 3D, and we count how many there were.

→ 3D position · fiducial cuts · counting

acoustic · piezos

### What kind of event

Piezos on the vessel pick up the sound a bubble makes as it forms. How loud it is tells us whether the bubble came from a nuclear recoil or an alpha.

→ alpha rejection

pressure · Dytran

### How many, and where

Fast Dytran pressure transducers track how the pressure grows after nucleation. That growth helps count the bubbles and tell wall events from fiducial ones.

→ bubble counting · wall vs fiducial

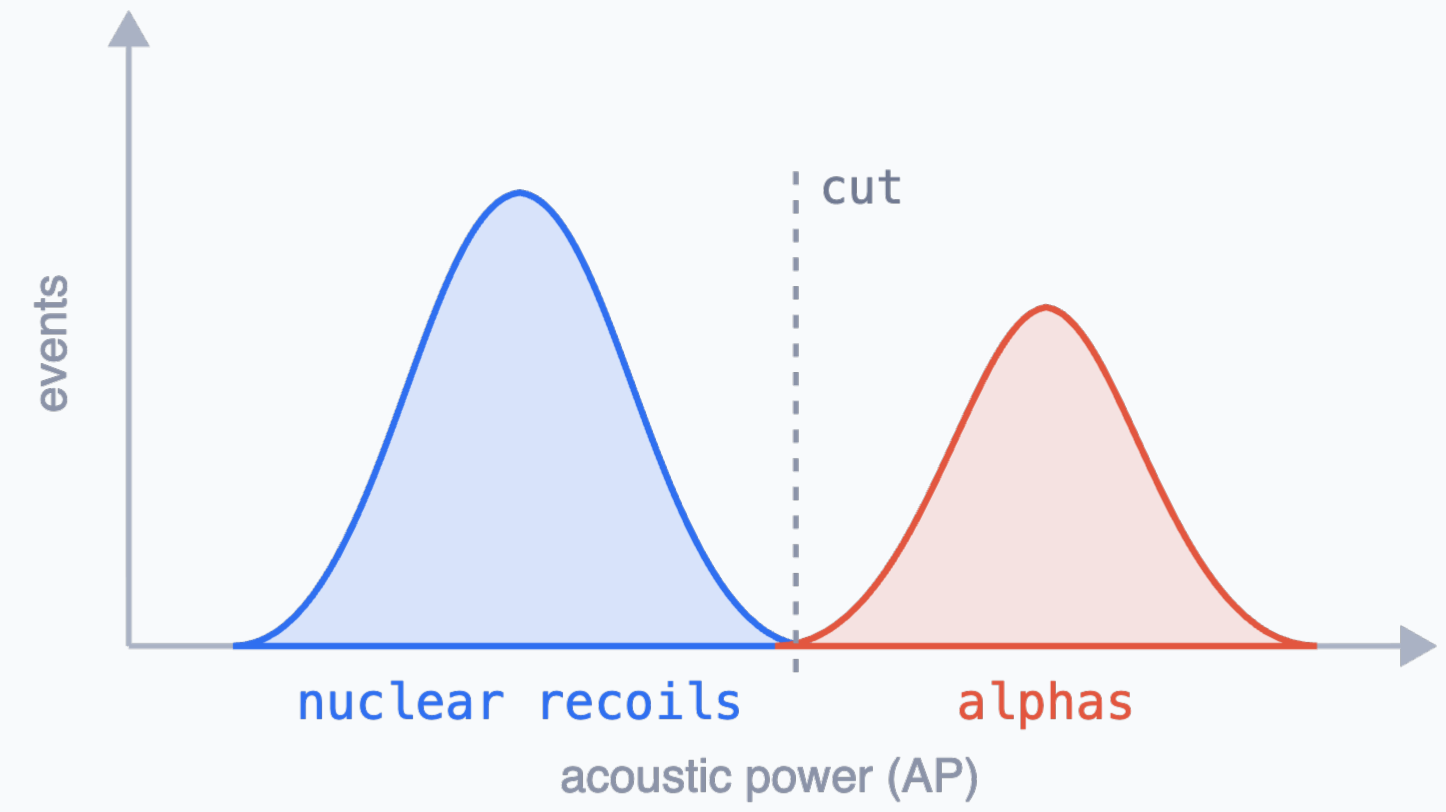
BACKGROUNDS

# The backgrounds that do make bubbles

Gammas can't trigger us. Alphas and neutrons can — and each gets its own handle.

alphas

## Louder, so we can hear them

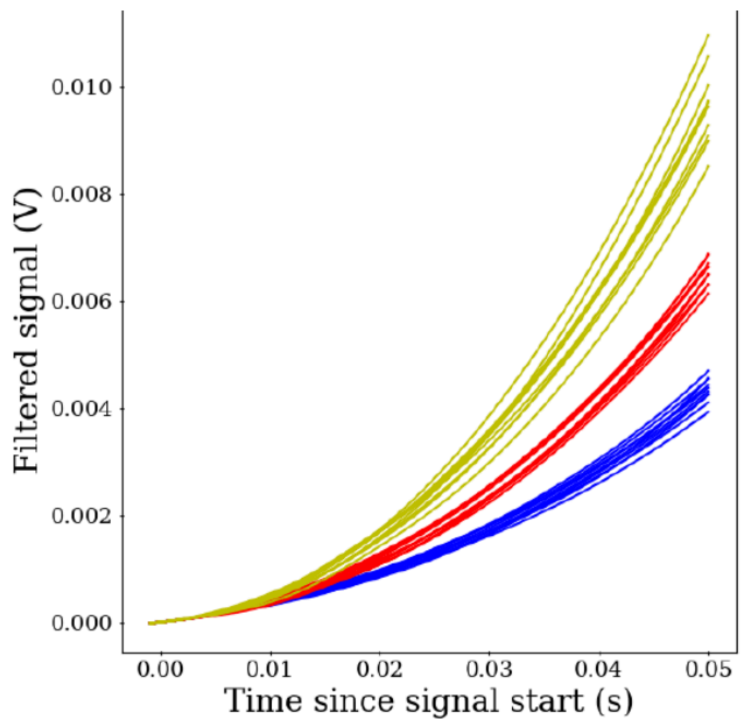


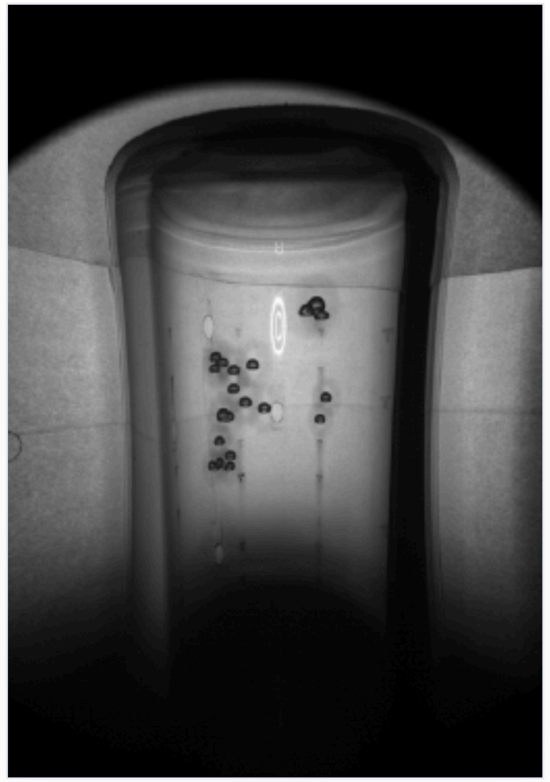

Radon and the U/Th chains are the source. An alpha releases more acoustic energy than a nuclear recoil, so a cut on acoustic power separates them cleanly.

neutrons

## The irreducible one

A neutron usually scatters more than once before it leaves, so it tends to make several bubbles. We throw those events out, because real dark matter only ever gives us one.



TRACK RECORD · PICO-60

# What PICO-60 delivered

spin-dependent · WIMP–proton

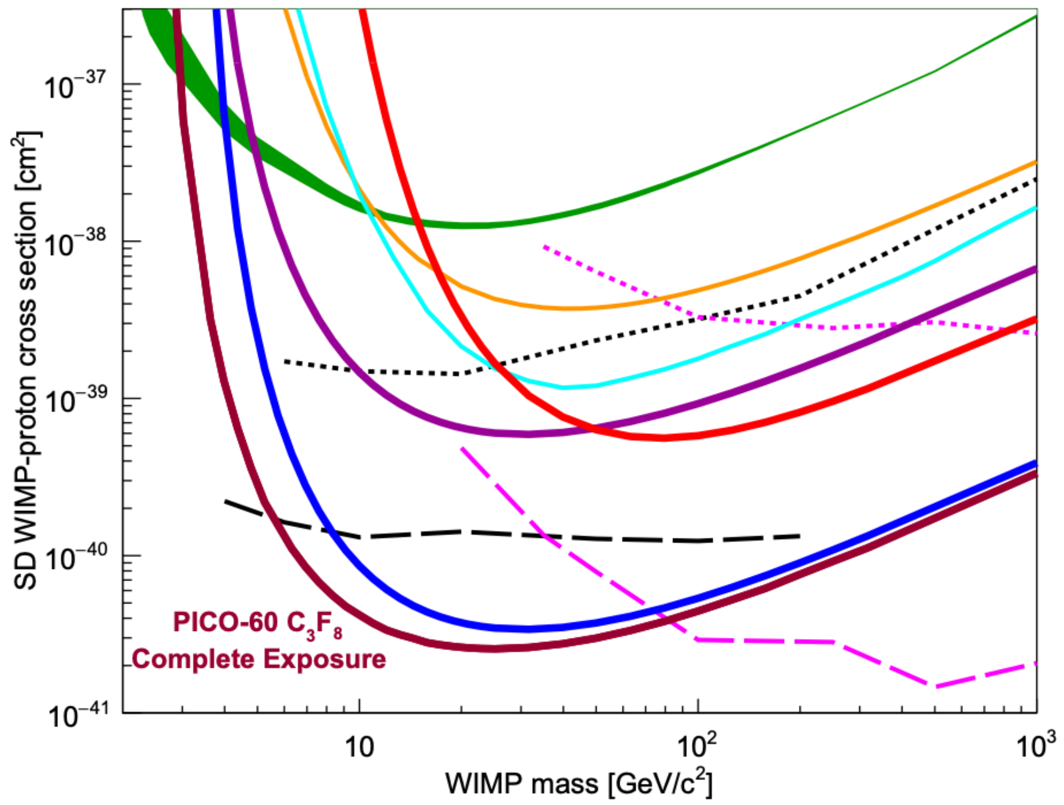
## 2.5 × $10^{-41}$ cm²

The world's most stringent direct-detection limit on spin-dependent WIMP–proton scattering, at a 25 GeV/c² WIMP when published in 2019. Still leads at smaller masses (order 10 GeV) if the interaction preferentially couples to protons.

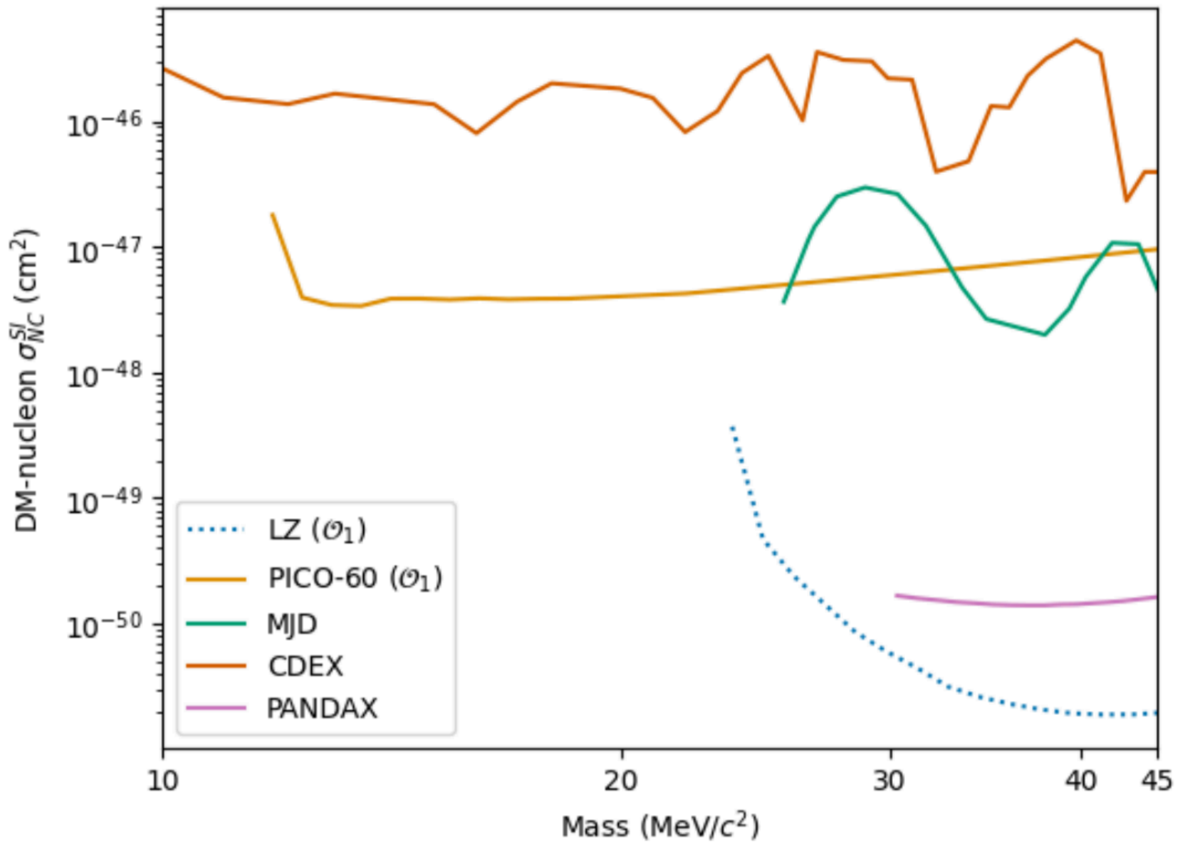
fermionic absorption

## Still world-leading, years later

Long after it stopped taking data, the same PICO-60 dataset set the first, world-leading limits on the absorption of fermionic dark matter in the MeV range.




PICO Collaboration, Phys. Rev. D 100, 022001 (2019)

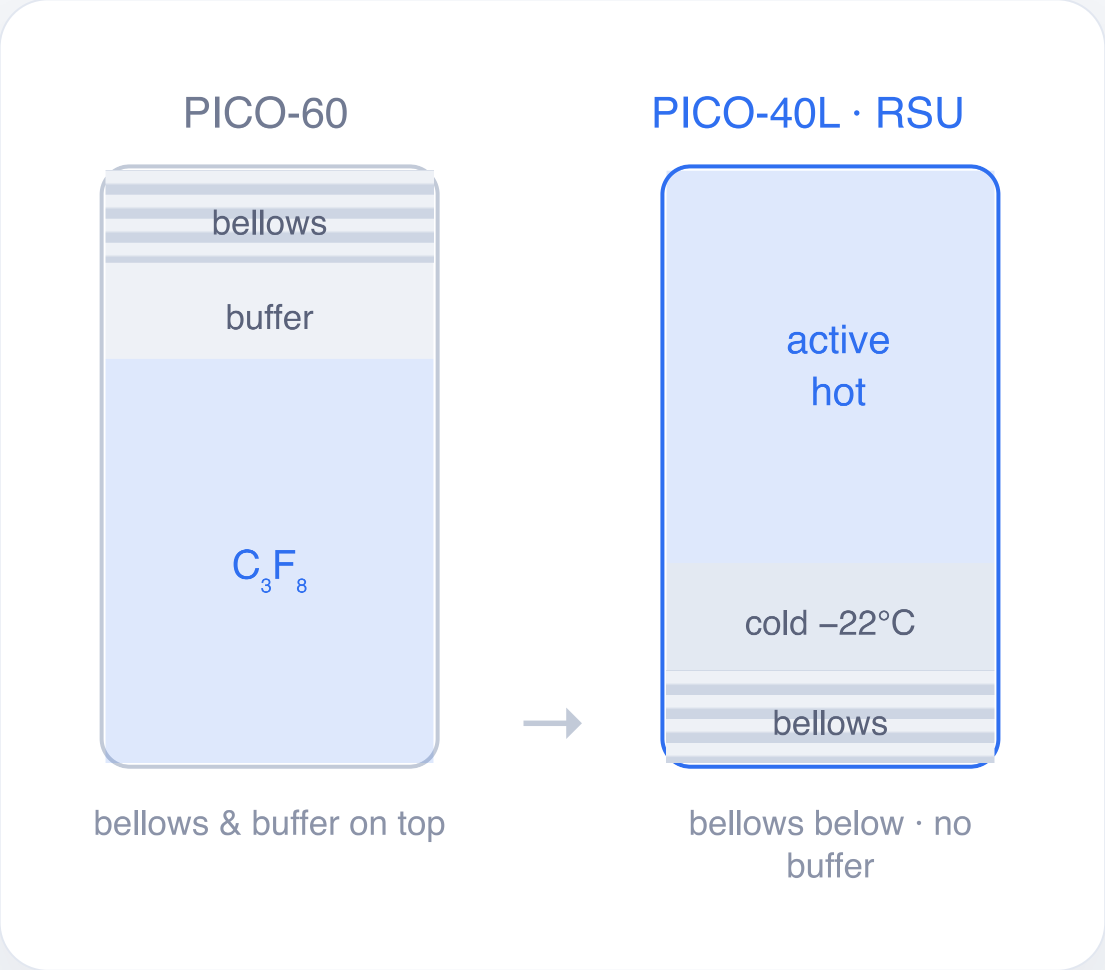



PICO Collaboration, Phys. Rev. Lett. (2025)

PICO-40L

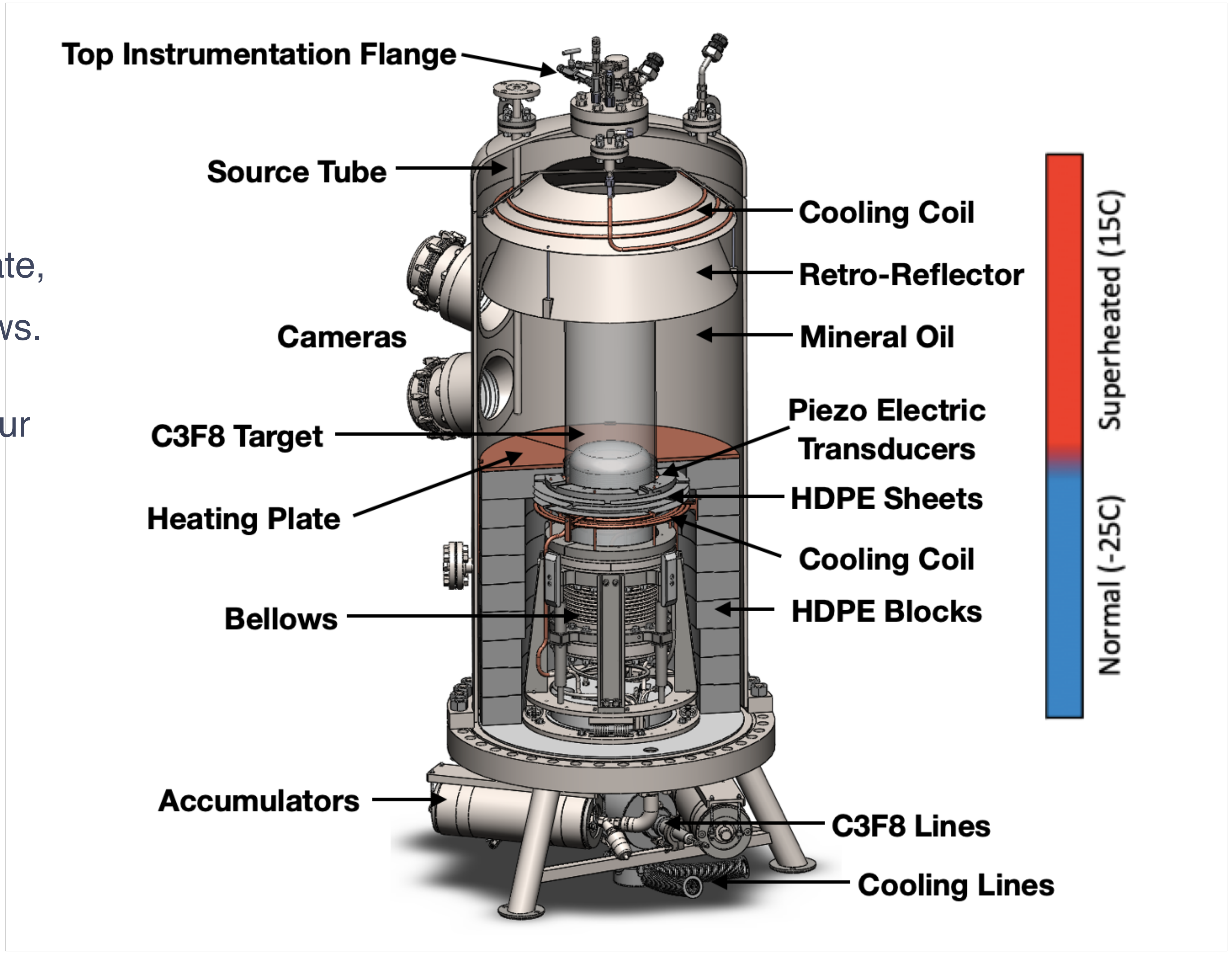
# A right-side-up redesign

- In PICO-60, pressure reached the target through a buffer fluid floating on top , with the bellows above the active volume.
- PICO-40L is right-side-up : nested quartz vessels with the bellows moved below the target, and no buffer fluid at all.
- Dropping the buffer removes backgrounds from the fluid–fluid interface; the bellows below, plus a cold lower zone, suppresses particulate-induced nucleation at seals and steel.
- It's a proof-of-concept for the geometry of the next-generation PICO-500.



# Status

- Valuable data being obtained around wall rate, alpha rate, and potential particulate induced events from the bellows.
- We have been able to identify specific alpha peaks in our acoustic data. Paper hopefully coming this summer.
- Detector paper coming sometime this summer.




PICO 40L detector

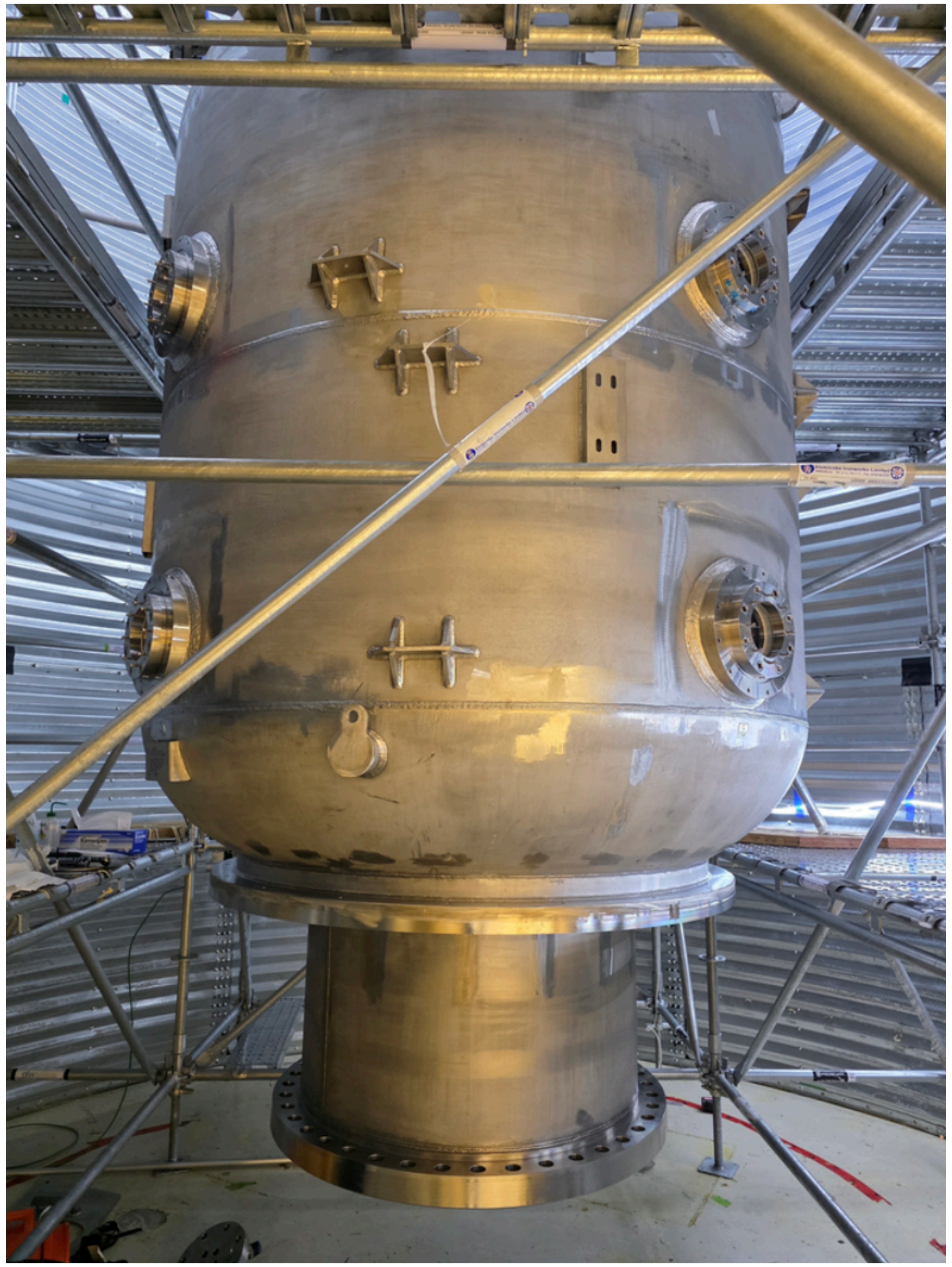
# PICO 500 Status

active volume

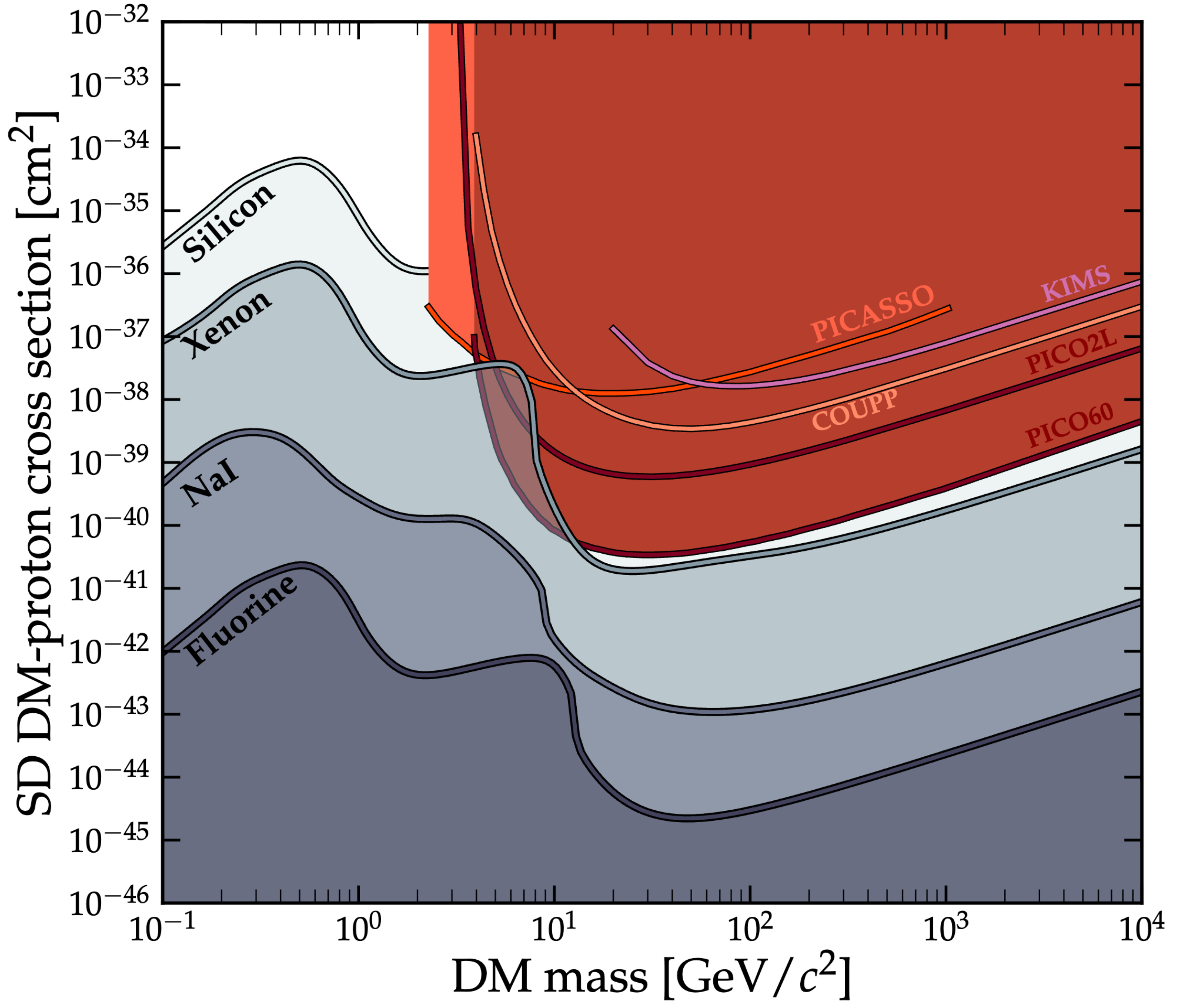
## 260 L

About six times PICO-40L — the largest PICO chamber yet, under construction at SNOLAB now.

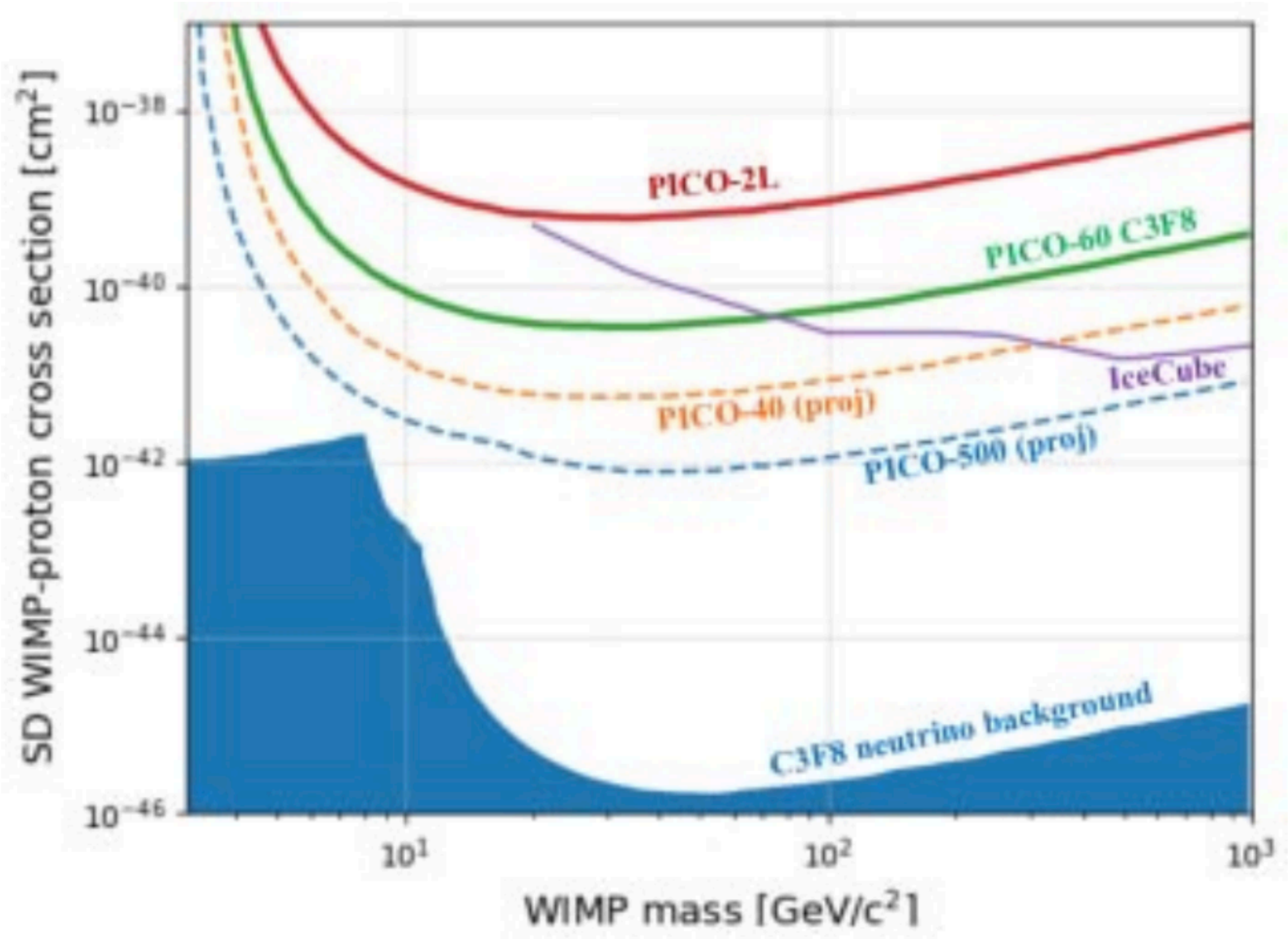
- It carries the right-side-up design straight from PICO-40L, whose commissioning fixes how PICO-500 will run.
- Because of detector size (largest ever silica jar) assembly is being performed right now underground.
- Fluid fill, sometime in early 2027



# Projected Limits




O'Hare, C. A. J., Phys. Rev. Lett. 127, 251802 (2021).




A.S. García-Viltres et al. (PICO Collaboration), Nuovo Cim. C 45, 7 (2021).

# Thank you for Listening!