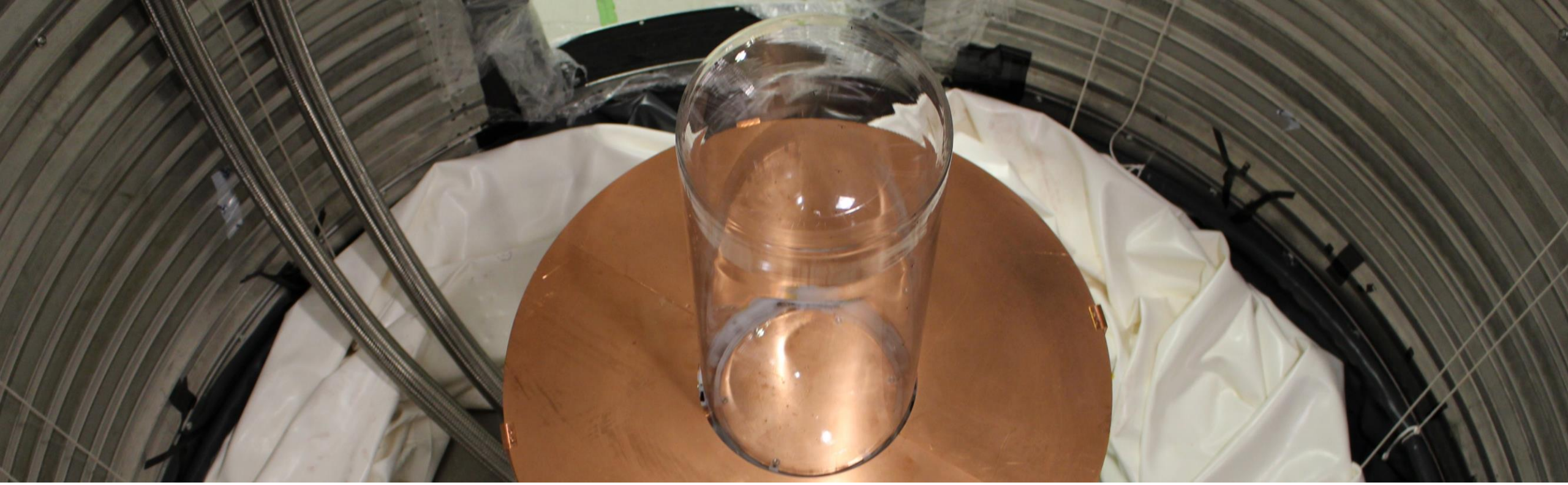


Introduction to PICO

William Woodley
24 May 2019

PICO

Dark Matter

- Although evidence of dark matter exists, dark matter has not been found yet

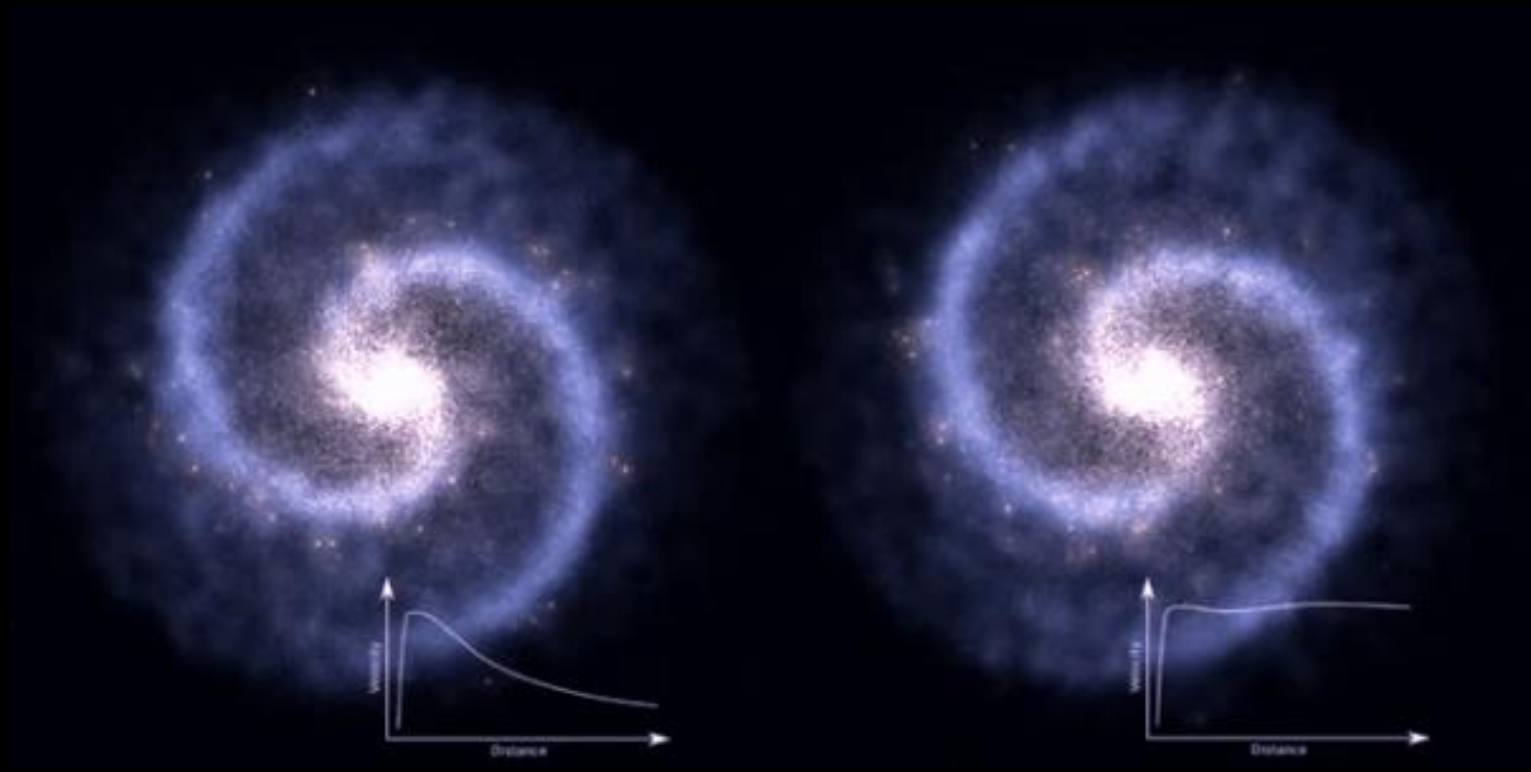
- WIMPs: **W**eakly-**I**nteracting **M**assive **P**articles
  - Weakly-interacting
  - Massive
  - Neutral
  - Non-relativistic
  - Non-baryonic
  - Non-Standard Model particles

Dark Matter

- In 1979, Vera Rubin observed that stars at the edges of galaxies had rotational speed greater than expected

$$F_G = \frac{Gm_1m_2}{r^2} = \frac{v_{rot}^2 m_2}{r}$$

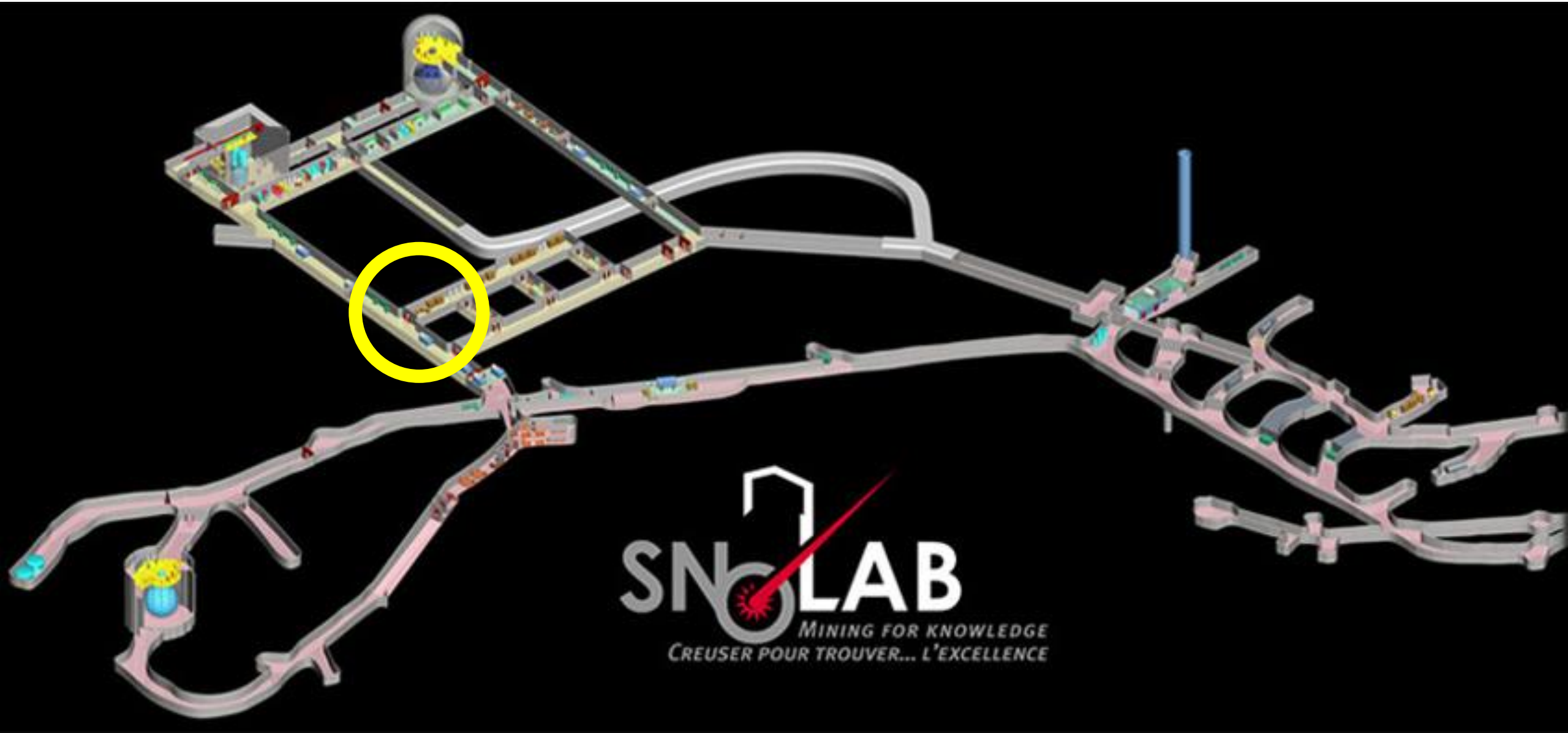
$$v_{rot} = \sqrt{\frac{Gm_1}{r}}$$



The PICO Collaboration

- **PICO** is a combination of:
  - **PI**CASSO: **P**roject **I**n **CA**nada to **S**earch for **S**upersymmetric **O**bjects (superheated droplets dispersed in polymerized gel)
  - **CO**UPP: **C**hicagoland **O**bservatory for **U**nderground **P**article **P**hysics (bubble chamber)
- PICO is located at SNOLAB

The PICO Collaboration



PICO

Northeastern ILLINOIS UNIVERSITY
O. Harris

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
R. Filgas, I. Stekl

KICP Kavli Institute for Cosmological Physics at The University of Chicago
J.I. Collar

Université de Montréal
S. Chen, M. Laurin, J.-P. Martin, A. Plante, A.E. Robinson, N. Starinski, F. Tardif, D. Tiwari, V. Zacek, C. Wen Chao,

SNOLAB
I. Lawson

INDIANA UNIVERSITY SOUTH BEND
E. Behnke, I. Levine, T. Nania

UNIVERSITAT POLITÈCNICA DE VALÈNCIA
M. Ardid, M. Bou-Cabo, I. Felis

SAHA INSTITUTE OF NUCLEAR PHYSICS CALCUTTA ADVANCEMENT OF KNOWLEDGE
M. Das, S. Sahoo, S. Seth

Drexel UNIVERSITY
M. Bressler, R. Neilson

PennState
D. Maurya, S. Priya, Y. Yan

Fermilab
P.S. Cooper, M. Crisler, W.H. Lippincott, A. Sonnenschein

UNIVERSITY OF ALBERTA
C. Coutu, N. A. Cruz-Venegaz, S. Fallows, T. Kozynets, C. Krauss, S. Pal, M.-C. Piro, W. Woodley

NORTHWESTERN UNIVERSITY
D. Baxter, C.E. Dahl, M. Jin, J. Zhang

UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
iF
E. Vázquez-Jáuregui

Queen's UNIVERSITY
B. Broerman, G. Cao, K. Clark, G. Giroux, C. Hardy, C. Moore, A. Noble

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

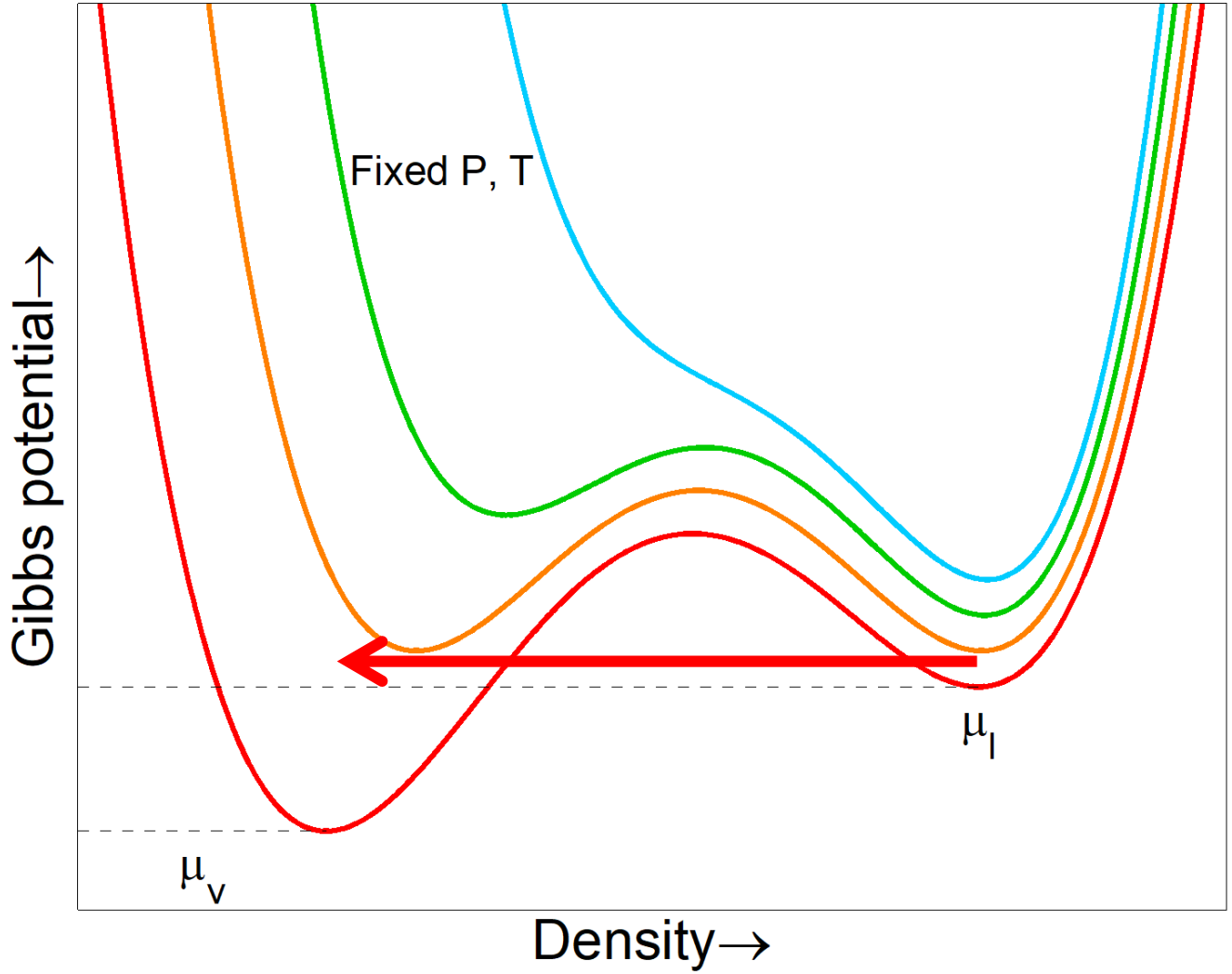
Laurentian University Université Laurentienne
J. Farine, A. Le Blanc, C. Licciardi, O. Scallon, U. Wichoski

Bubble Chambers

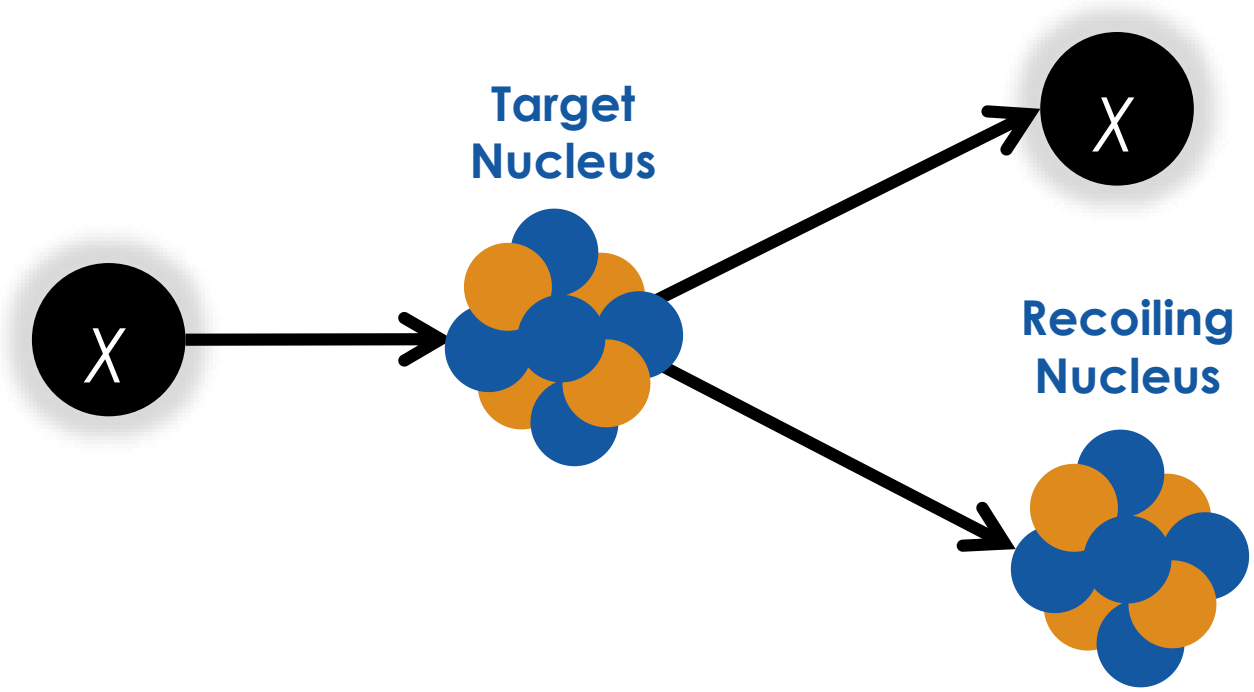
- PICO searches for dark matter directly using superheated bubble chamber technology
- Bubble chambers were invented in 1952 by Donald Glaser
- Last bubble chamber, before COUPP, was used in the 1960s

Detection Principle

- Vessel filled with superheated liquid (a metastable state)
- As particles pass through the superheated liquid, they lose energy
- Depending on the amount of energy, this can cause the liquid to boil, which creates bubbles



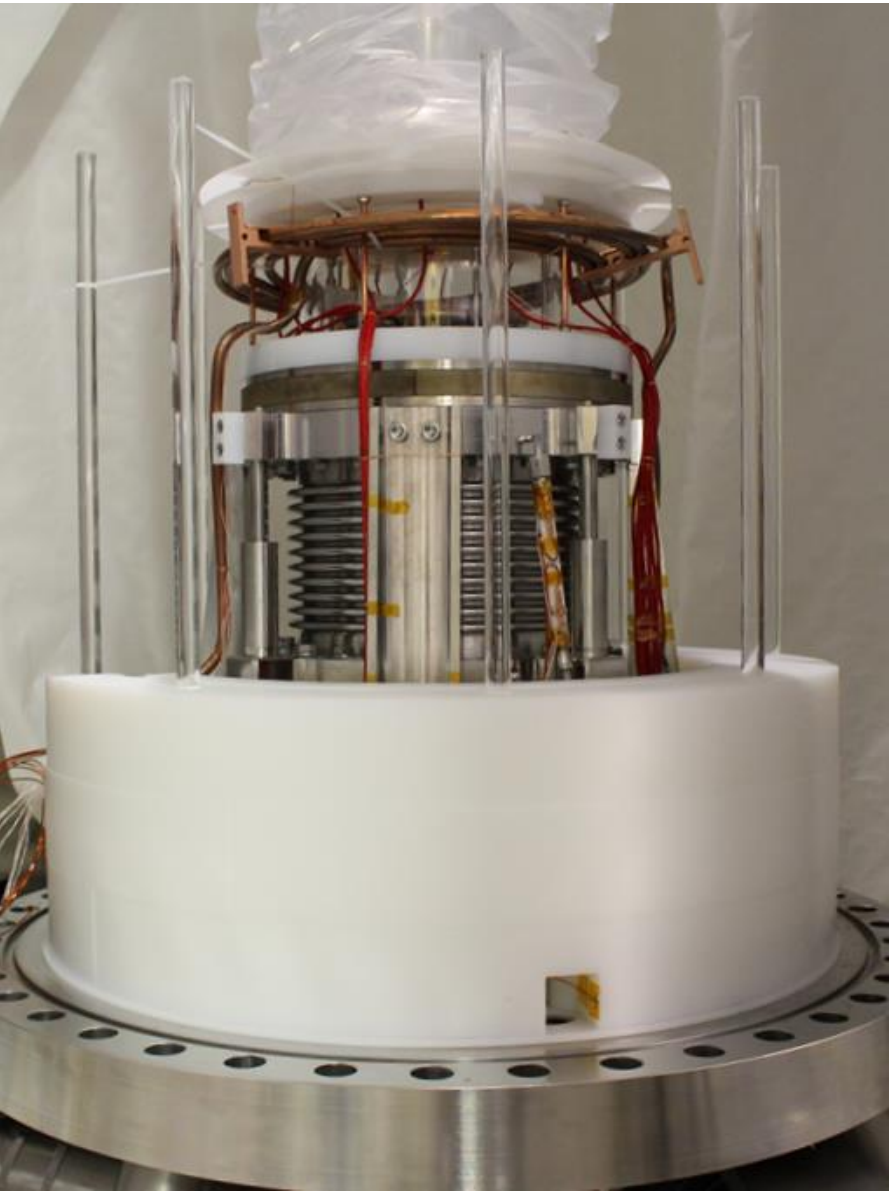
Dark Matter Direct Detection



- When a dark matter particle hits a nucleus, it will cause the nucleus to recoil at very low energies (1-100 keV)

- The nuclear recoil will cause nucleation

PICO Bubble Chambers



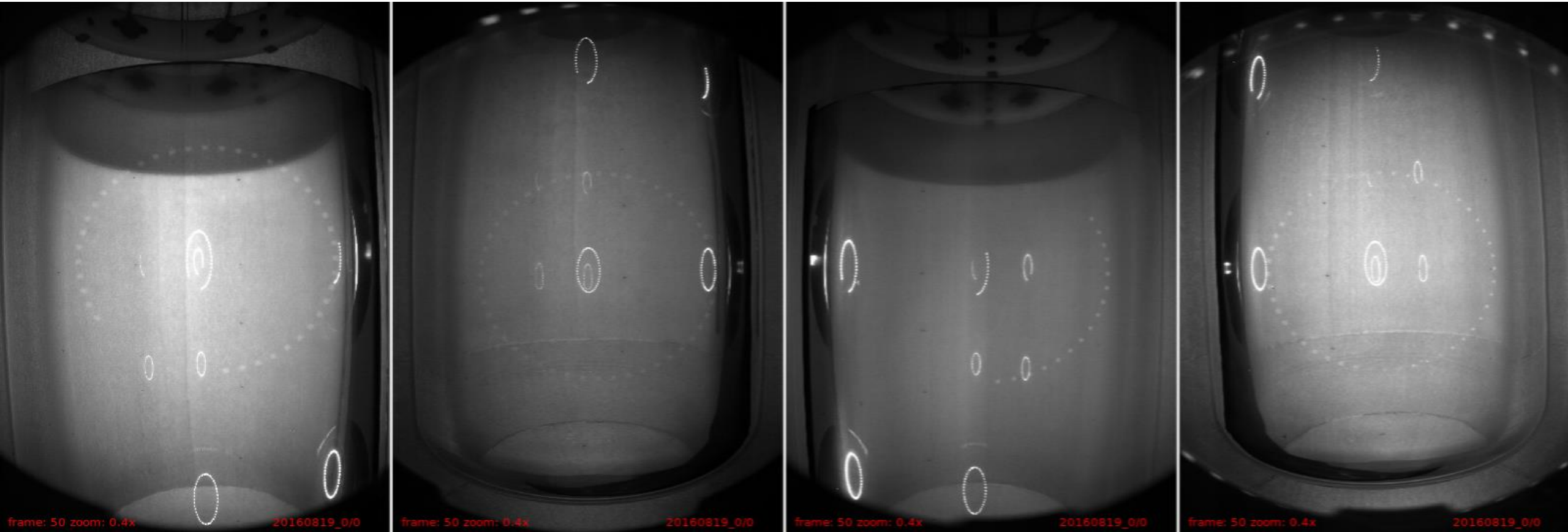
- Filled with C_3F_8
- Temperature and pressure can be controlled using a hydraulic system
- After a bubble is detected, pressure system is used to compress and collapse the bubble, then C_3F_8 is put back into an active state after expansion

Advantages of PICO Bubble Chambers

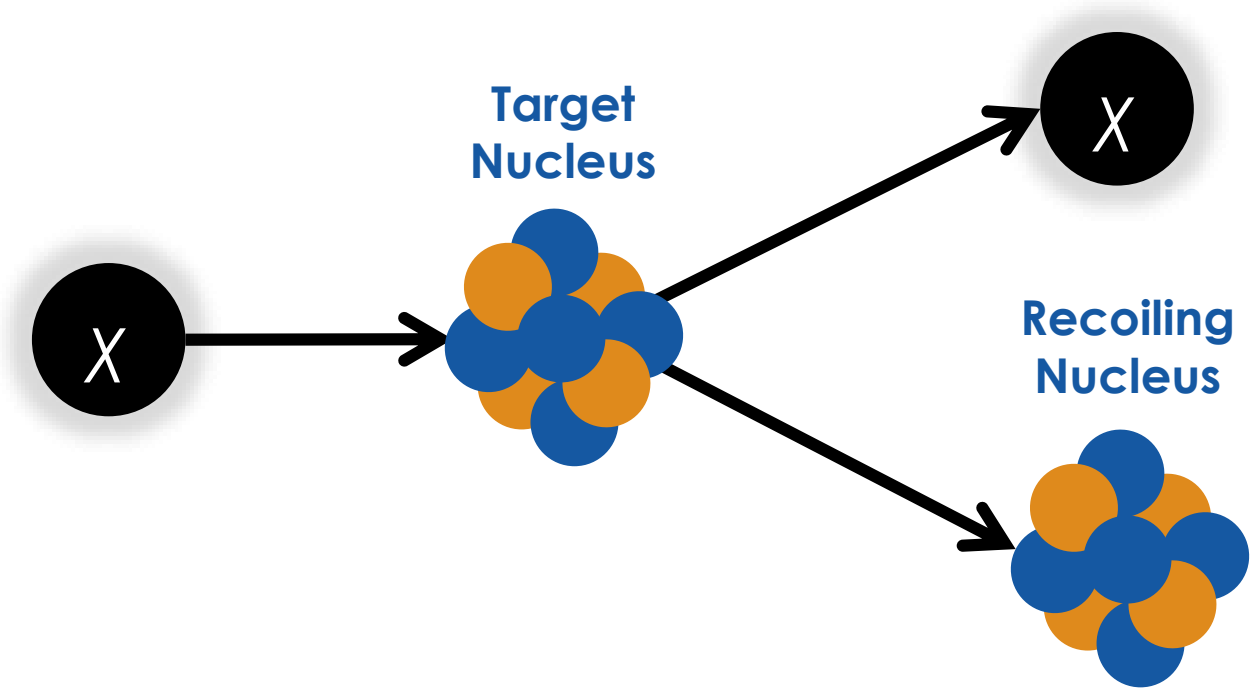
- Threshold detector
- Insensitivity to gammas at the threshold we operate at
- Acoustic discrimination between events from alpha particles and neutrons
- Multiple neutron scattering makes it easy to reject neutron events

Event Detection

- Bubbles are observed with four cameras
- Trigger when bubbles reach a certain size



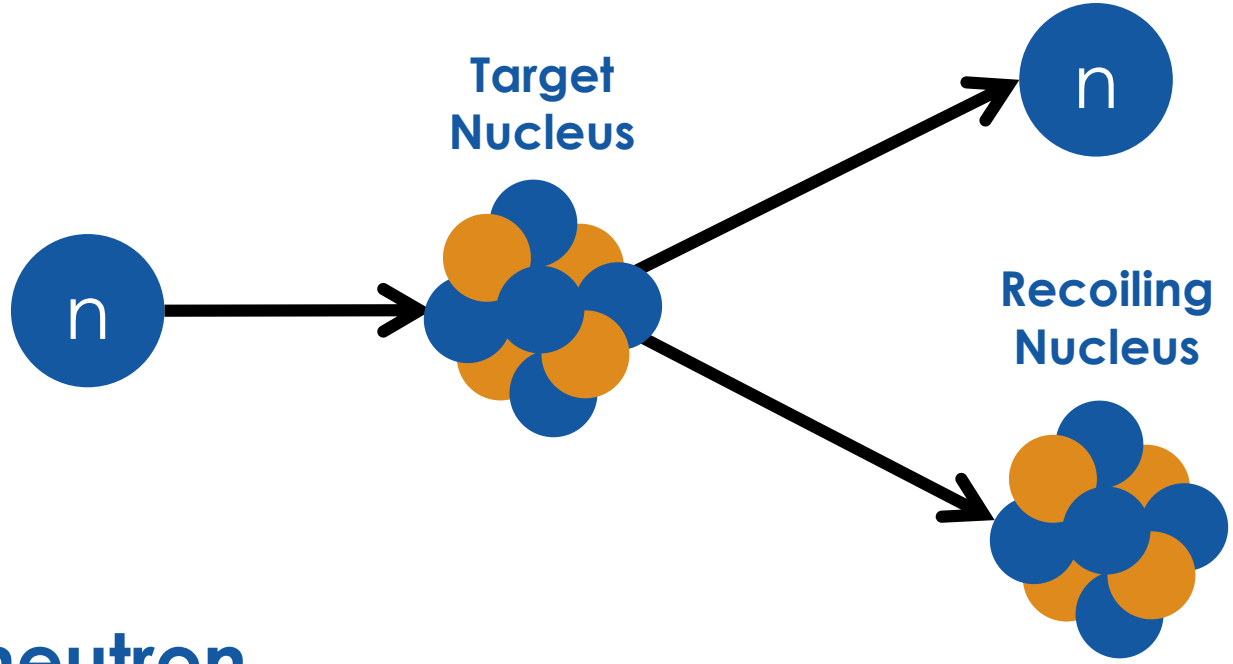
Dark Matter Direct Detection



- When a dark matter particle hits a nucleus, it will cause the nucleus to recoil at very low energies (1-100 keV)

- The nuclear recoil will cause nucleation

Dark Matter Direct Detection



- When a ~~dark matter particle~~ hits a nucleus, it will cause the nucleus to recoil at very low energies (1-100 keV)

- The nuclear recoil will cause nucleation

Main Backgrounds

- Muons from cosmic rays
  - Build detector underground, beneath 2 km of norite rock
- Neutrons
  - Surround detector with a tank of water
- Alpha particles from ^{238}U and ^{232}Th
  - Purification and screening to ensure low-radioactivity
  - ^{222}Rn ($t_{1/2}$ = 3.8 days) can diffuse into many materials
  - Techniques are being explored here to mitigate radon

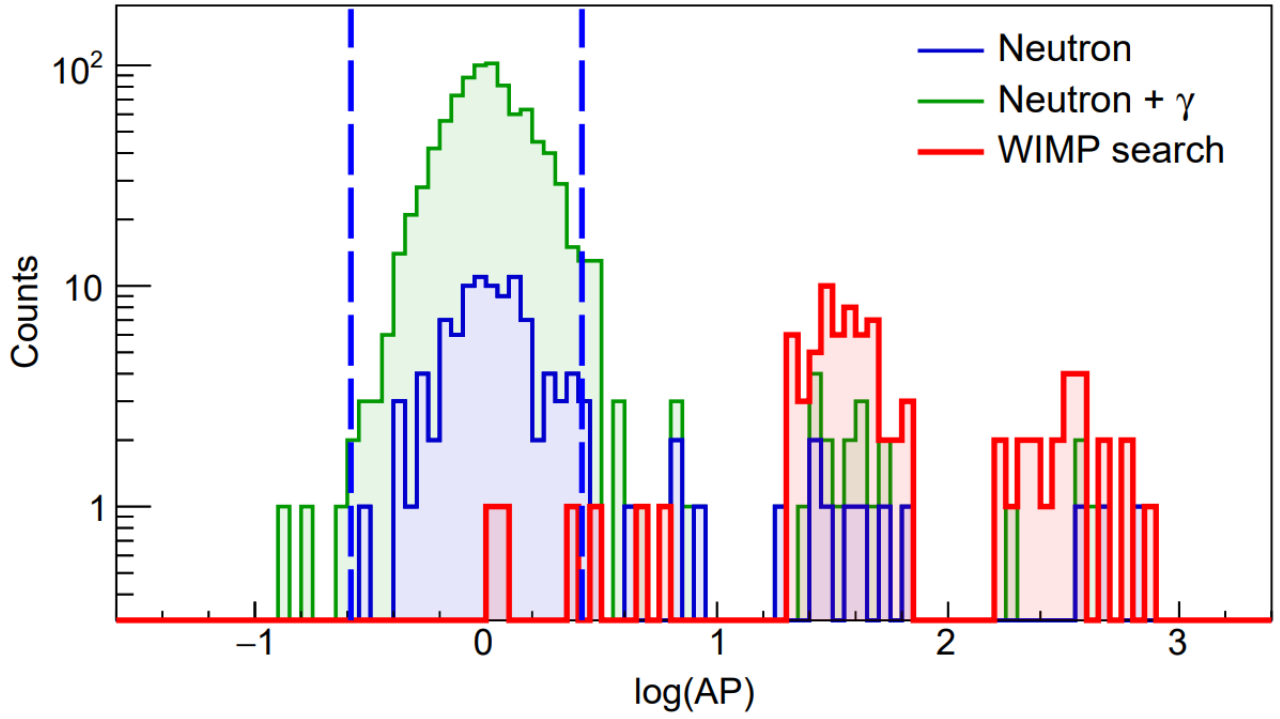
Main Backgrounds

Acoustic Discrimination

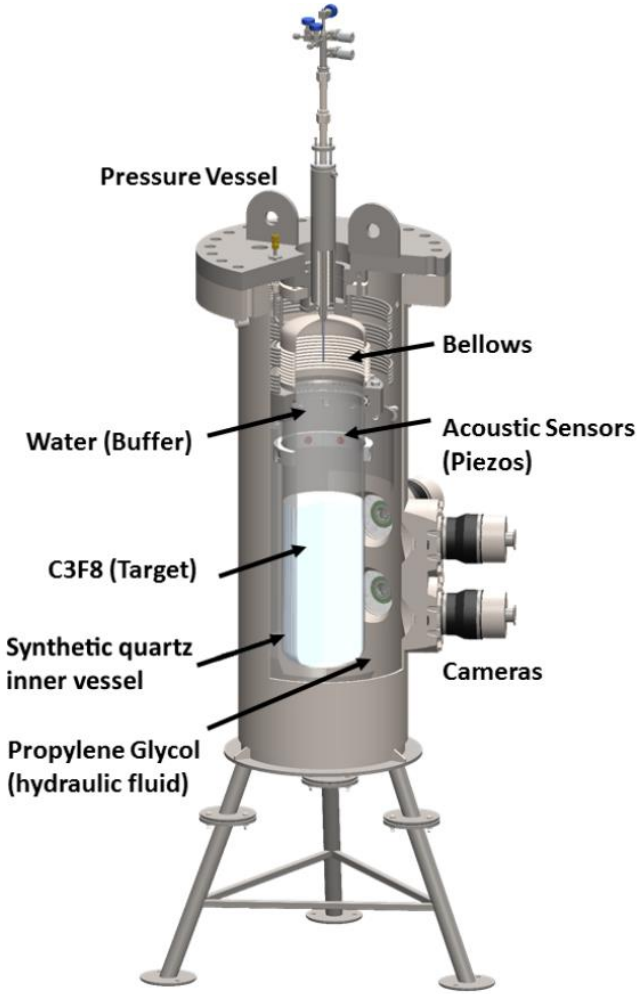
- Bubbles produce sound, and alpha events sound louder than neutron events

- PICASSO discovered they can be discriminated with **A**coustic **P**arameter

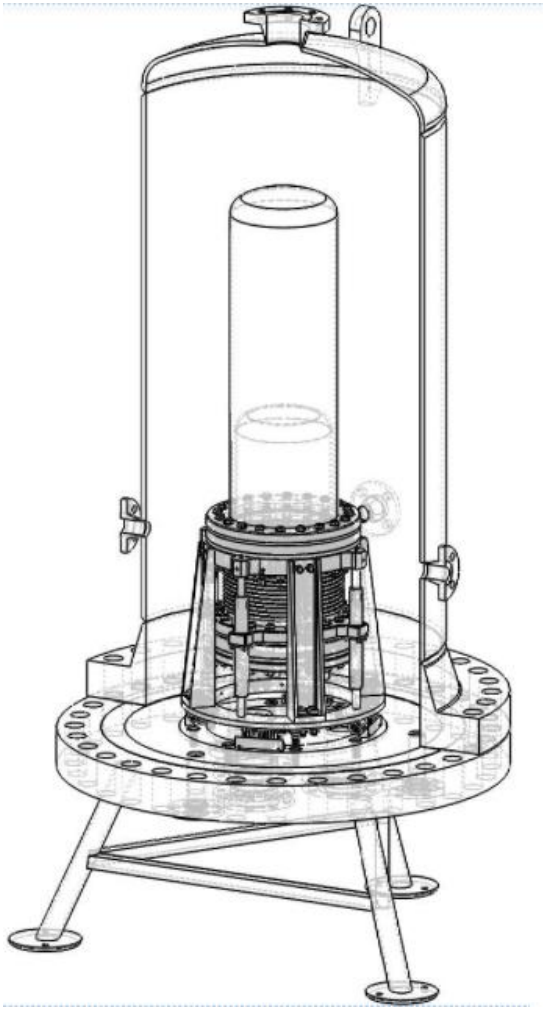
- Install piezoelectric detectors around the vessel



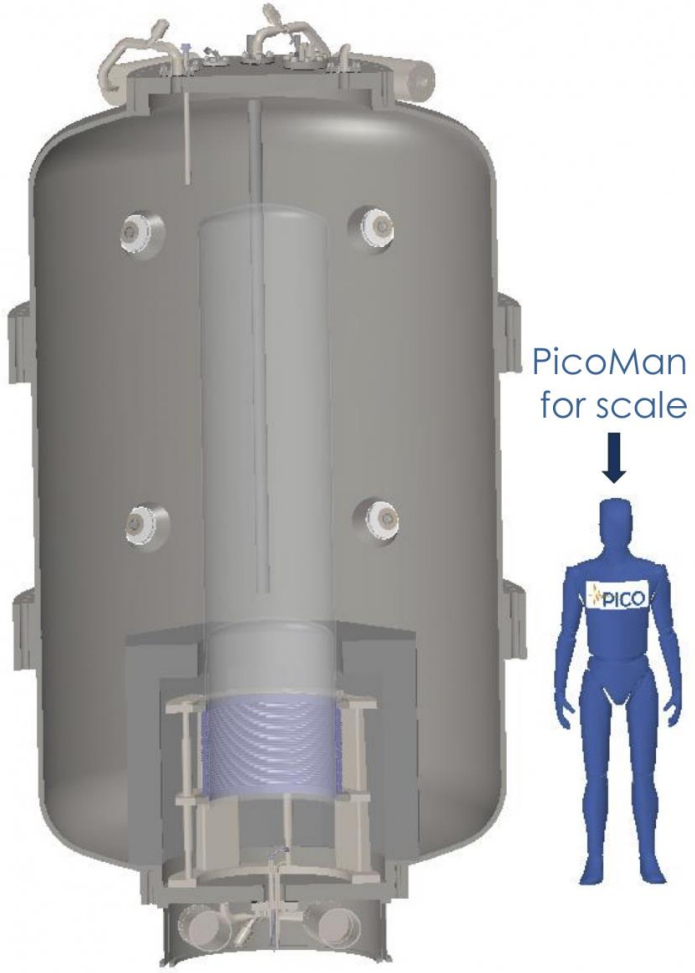
PICO Bubble Chambers



PICO-60



PICO-40L

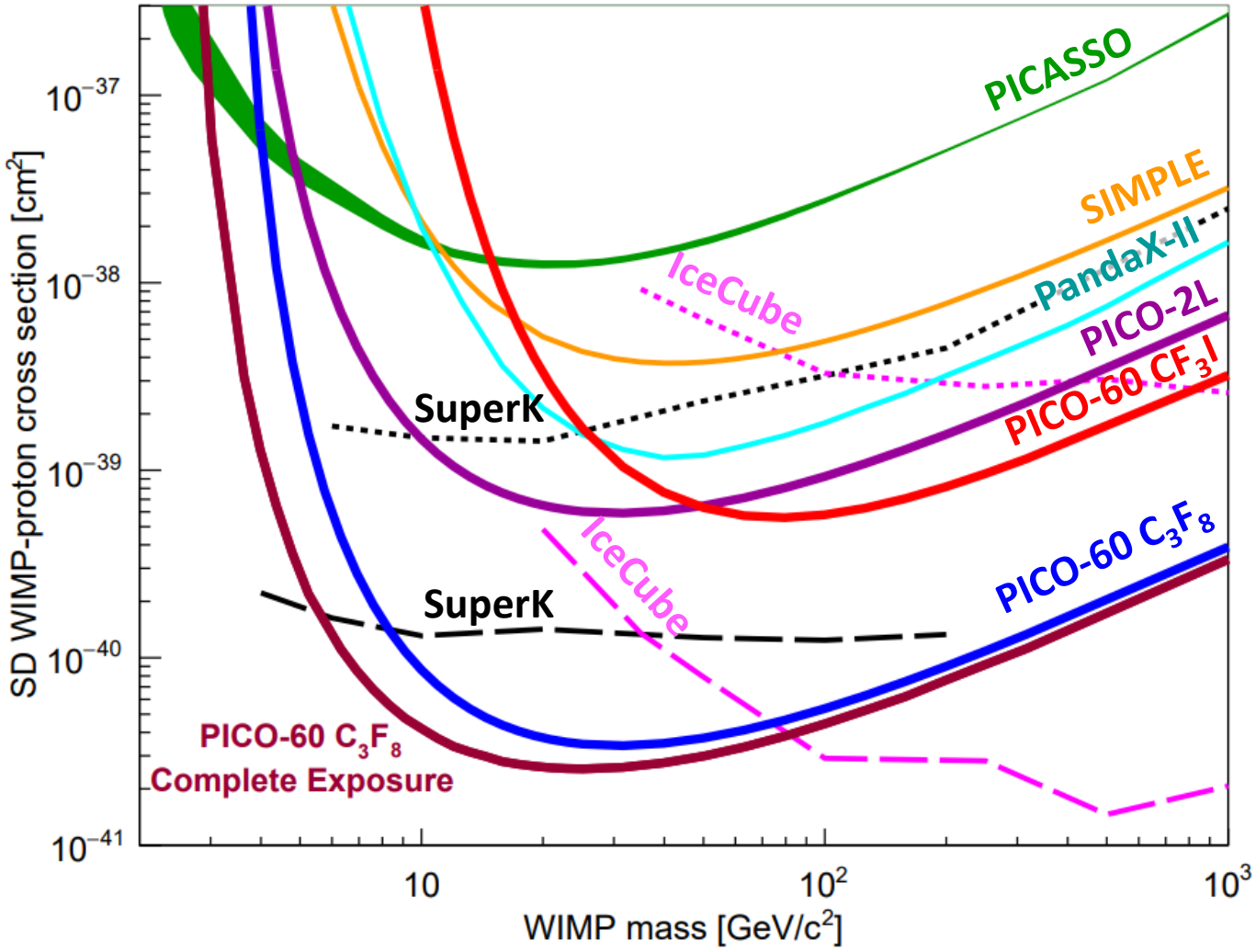


PICO-500

PICO-60: Most Recent Results

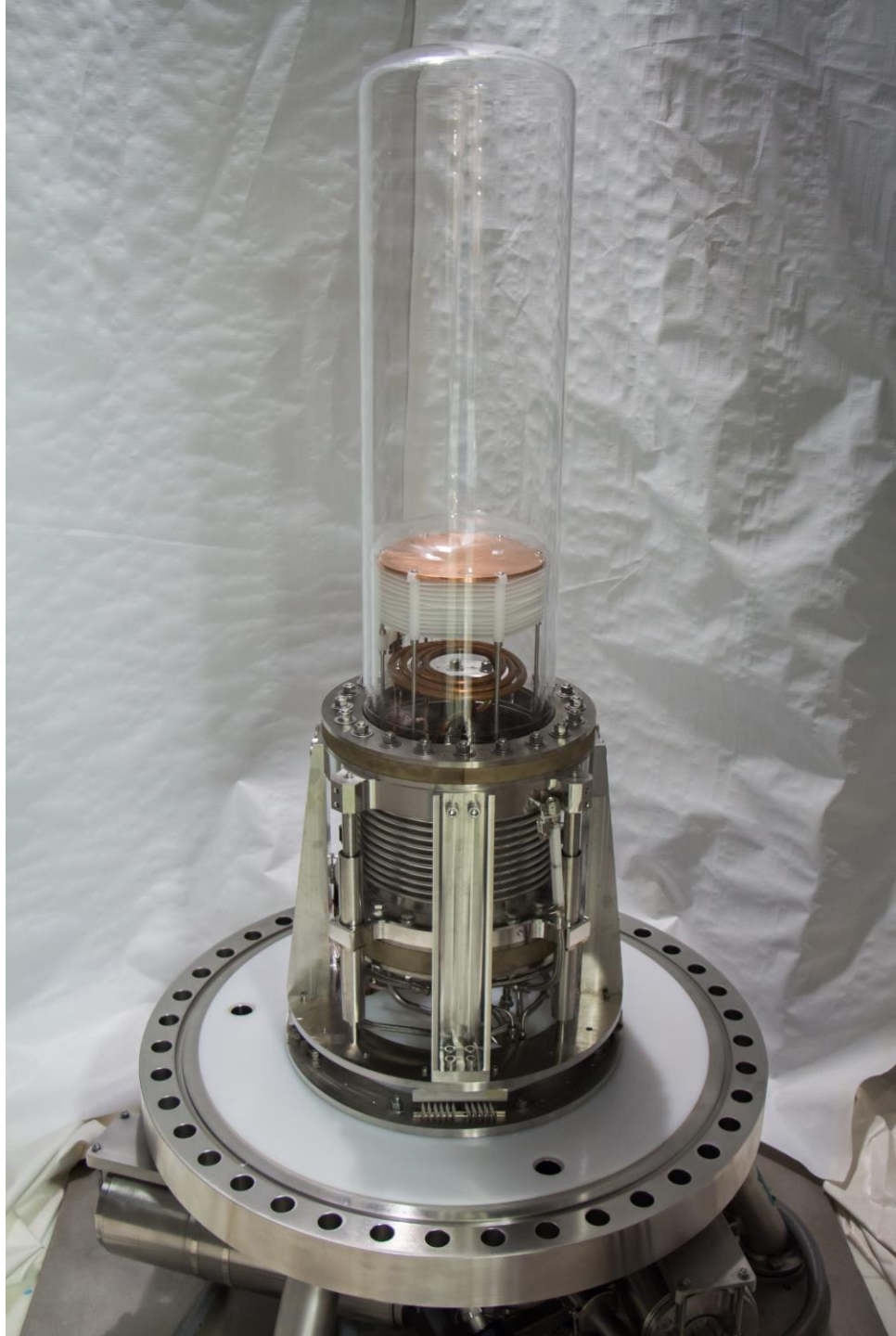
- C. Arnole *et al*. (2019). arXiv:1902.04031

- Presented as exclusion curve since dark matter has not yet been found:
  - Above = Excluded
  - Below = WIMP parameter space



PICO-40L

- Currently being assembled
- New design: right-side-up, to prevent particles from entering the liquid from above
- Will help with design of the next-generation detector, PICO-500



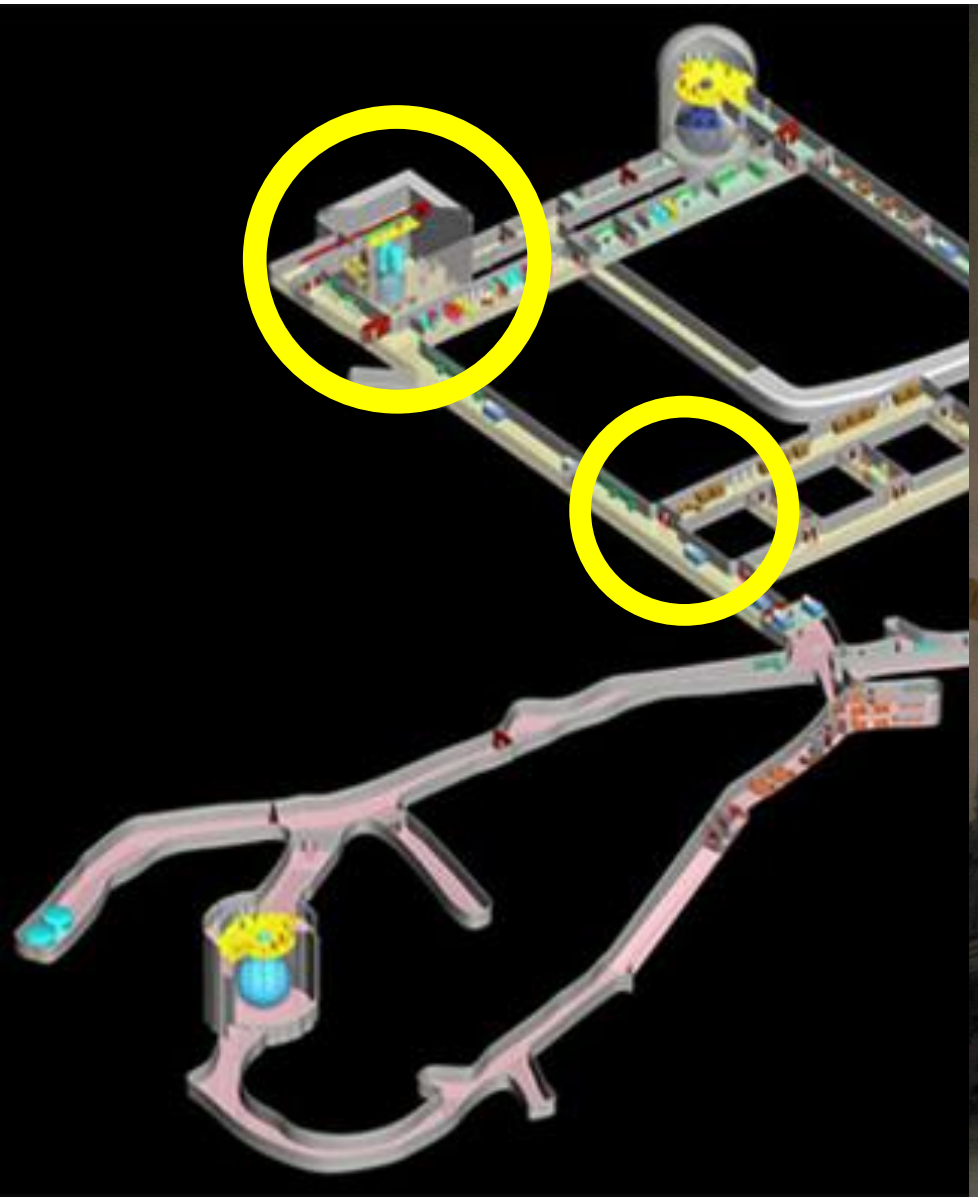
PICO-40L Assembly

- Retroreflector
- Cold flange / spider
- Inner thermal tower / vessel
- Outer cooling coil
- Piezos
- Insulation tower
- Pressure vessel lift
- Cameras
- Leak check

PICO-500 Plans

- Currently being designed
- ~260L of C_3F_8
- Assembly will begin next year
- Installed in SNOLAB Cube Hall, where MiniCLEAN currently is

PICO-500 Plans



Local Work

- **Scott Fallows:** Analysis, cameras, publications
- **Sumanta Pal:** Alberta test chamber
- **Clayton Coutu:** Multi-bubble event reconstruction
- **Noel Alberto Cruz-Venegaz:** Alberta test chamber
- **William Woodley:** Background simulations
- **Tetiana Kozynets:** Molecular dynamics simulations
- **Shawn Miller:** PICO-500 vessel seal design
- **Biswajit Biswas:** Machine learning for bubble finding
- Led by Profs. Carsten Krauss and Marie-Cécile Piro

Local Work

- PICO-500 simulations:
  - Muon propagation from atmosphere to underground
  - External neutron background
  - Internal neutron background
  - Alpha background

- Expect ~10^{-5} alpha events per hour, corresponding to one event every 2-6 years

Thank you