PICO-2L: A bubble chamber to search for light WIMPs

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for the PICO Collaboration

TAUP 2013 Asilomar, California

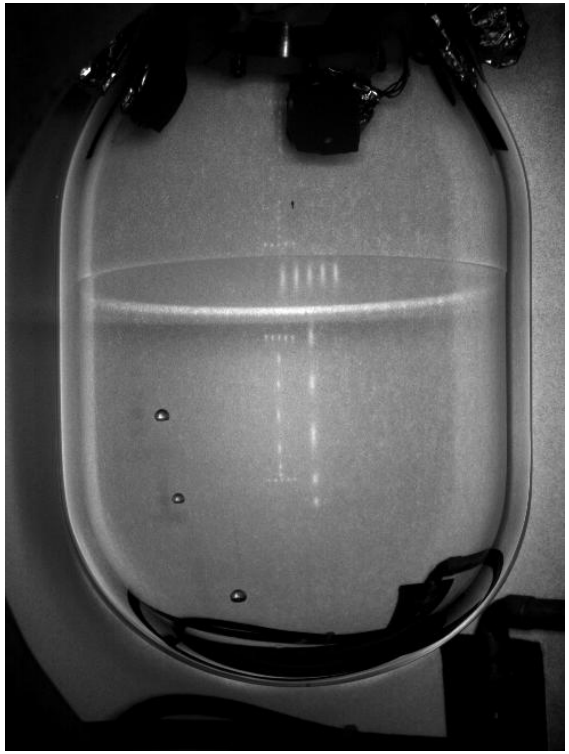
What is PICO-2L?

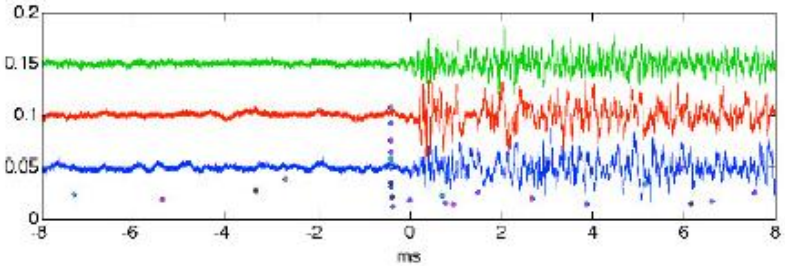
- A follow on from COUPP-4.
- A prototype for a ton-scale bubble chamber.
- A low-mass WIMP search.

PICO-2L: a follow on from COUPP-4

- COUPP-4: superheated fluid 4 kg of CF_3I
  - F for spin dependent
  - I for spin independent

- Observe bubbles with two cameras and piezo-acoustic sensors.





Particle detection with bubble chambers

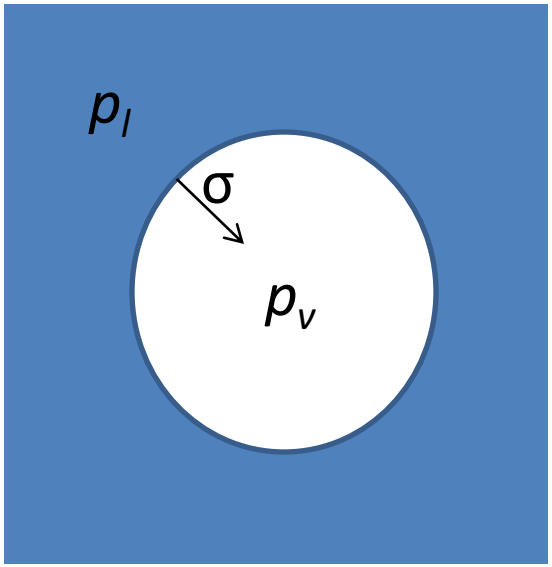
- A bubble chamber is filled a superheated fluid in meta-stable state.
- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble *(Seitz "Hot-Spike" Model).*
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses.
- Classical Thermodynamics says-

$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

Latent heat

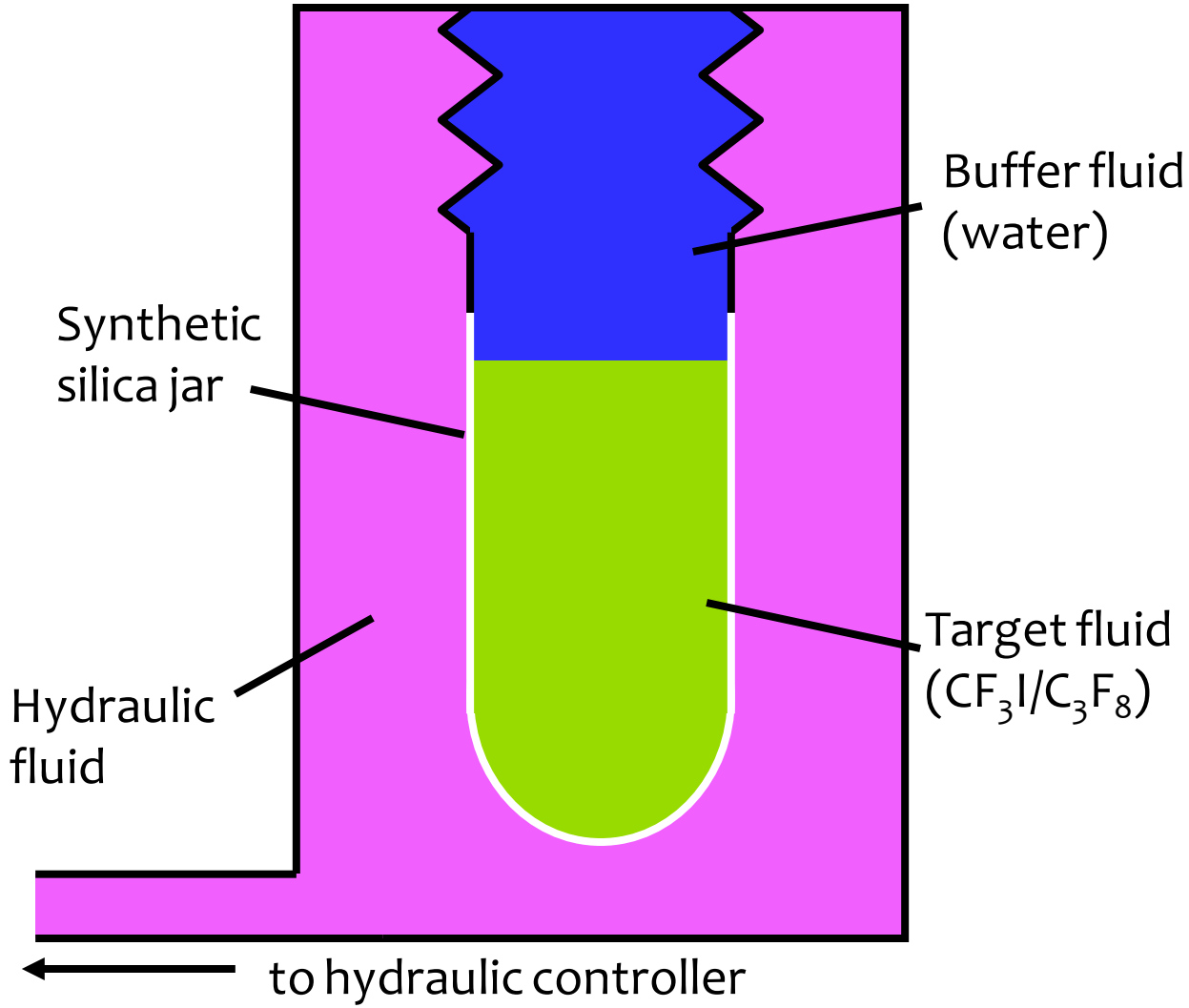


Bubble chamber operation

- Expand the chamber to the superheated state (10sec).

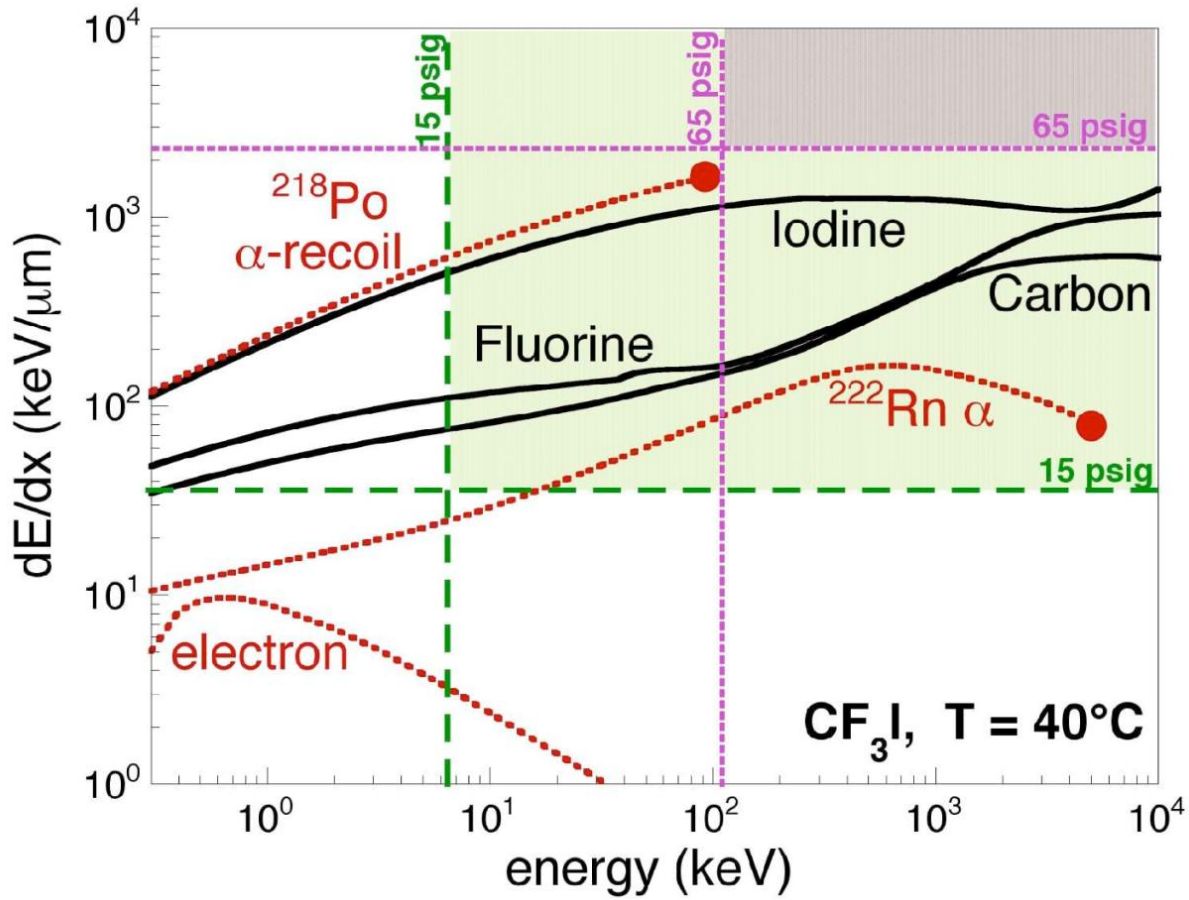
- Cameras see the bubble
  - Trigger
  - Stereoscopic position information

- Recompress the chamber (100msec) and wait 30sec after every bubble.



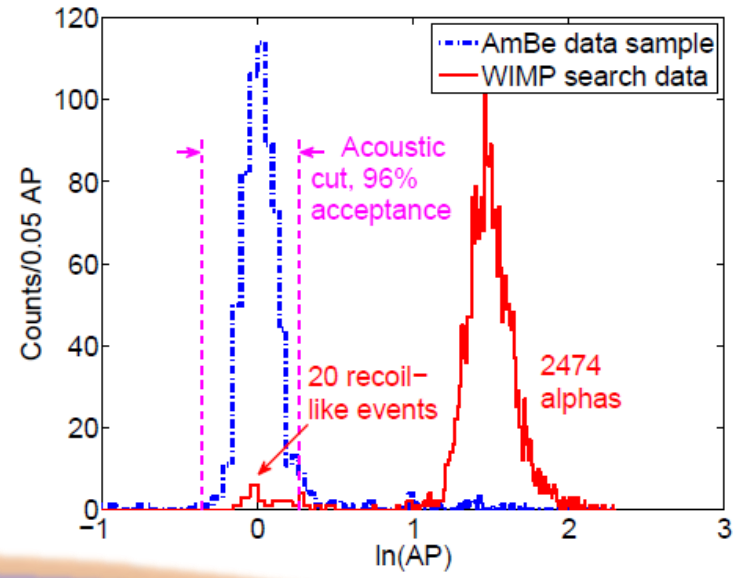
Bubble chambers as nuclear recoil detectors

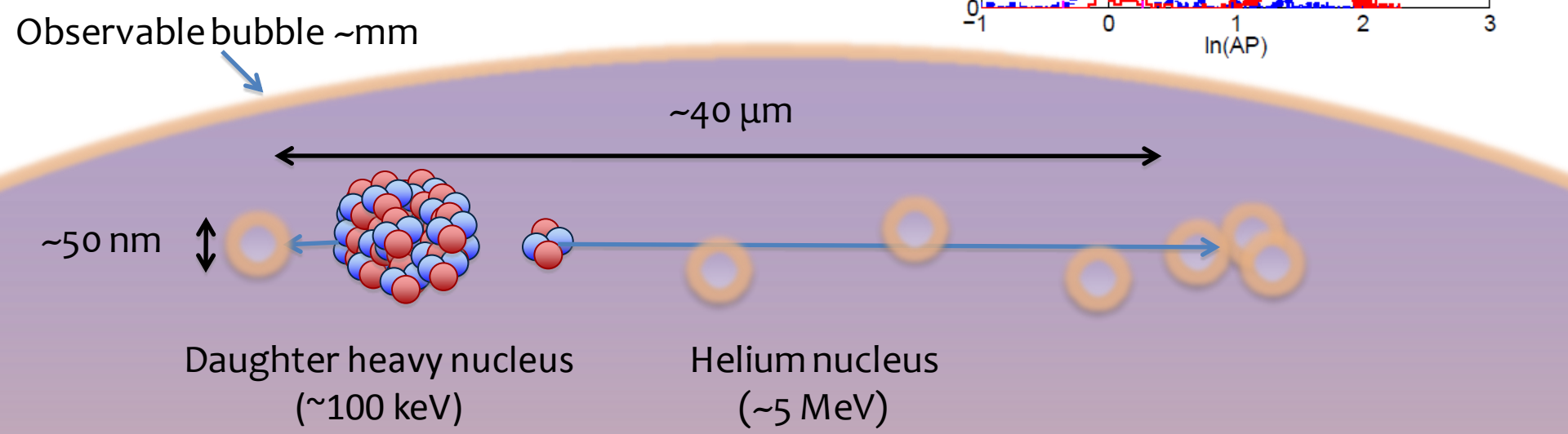
- Thermodynamic parameters are chosen for sensitivity to nuclear recoils but not electron recoils.
- Better than 10^{-10} rejection of electron recoils (betas, gammas).
- Alphas are (were) a concern because bubble chambers are threshold detectors.



Acoustic discrimination

- Discovery of acoustic discrimination against alphas (Aubin et al., New J. Phys.10:103017, 2008)
  - Alphas deposit their energy over tens of microns.
  - Nuclear recoils deposit theirs over tens of nanometers.
- In COUPP bubble chambers alphas are several times louder.





COUPP-4 results

PRD 86:052001 (2012)

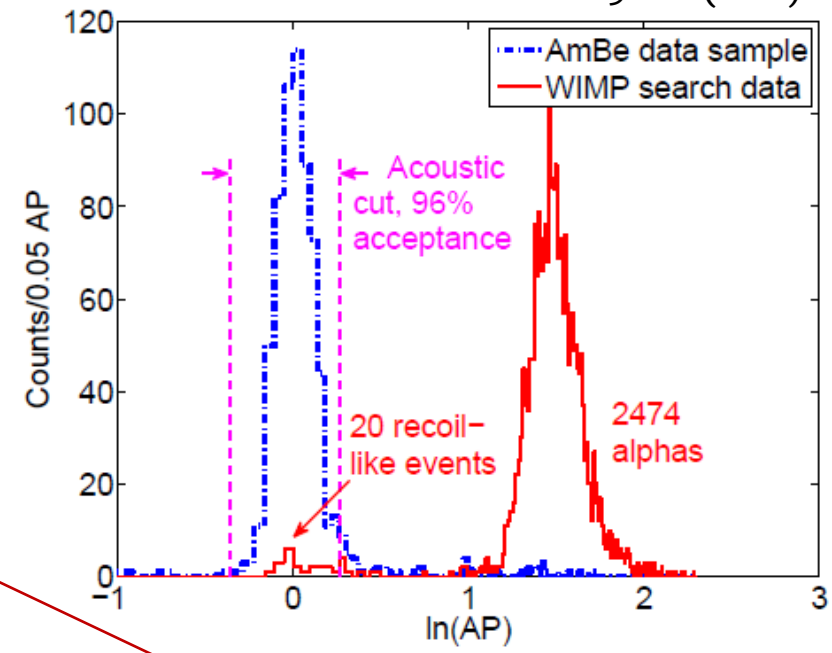
- 20 WIMP candidates
  - 6 at 8keV
  - 6 at 11keV
  - 8 at 16keV

- 3 multiple bubble events → **neutrons**

- 5 expected neutron events from U, Th (α,n) in piezo-acoustic sensors and viewport windows.

- Recoil-like events at low threshold show time clustering, inconsistent with both WIMPs and neutrons.

- A second run in 2012 after replacing known neutron sources had similar results (Eric Vazquez Jauregui, Moriond, 2013).



What next?

COUPP-60: 15 times the mass of CF_3I.

Taking data now

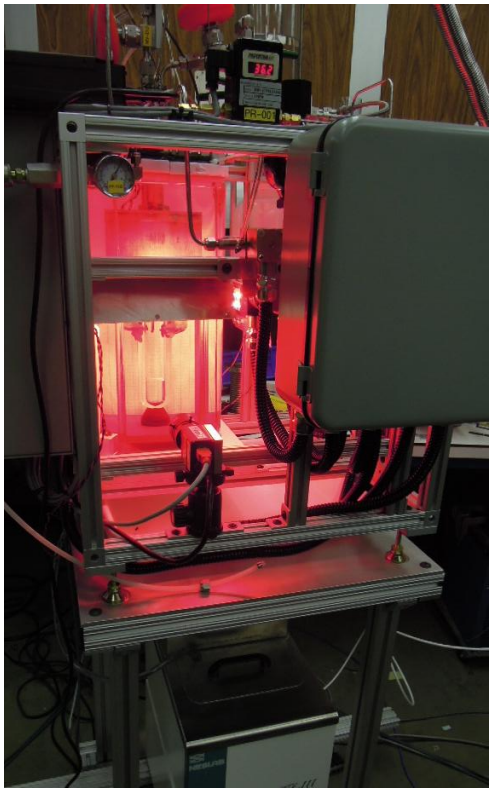
See talk by H. Lippincott, DM V

PICO-2L: Same size and location as COUPP-4 but with new target fluid – C_3F_8

Improved SD and low-mass sensitivity. (Twice the F density as CF_3I).

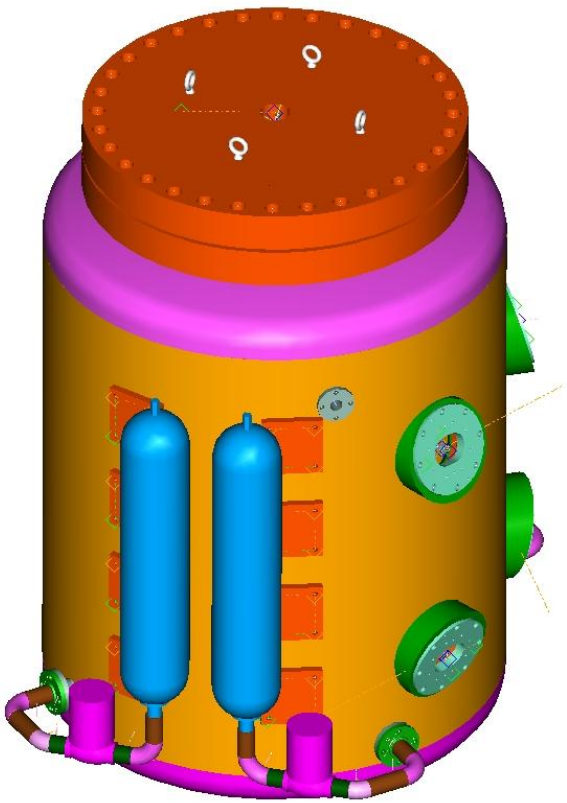
New inner detector components to address neutron background.

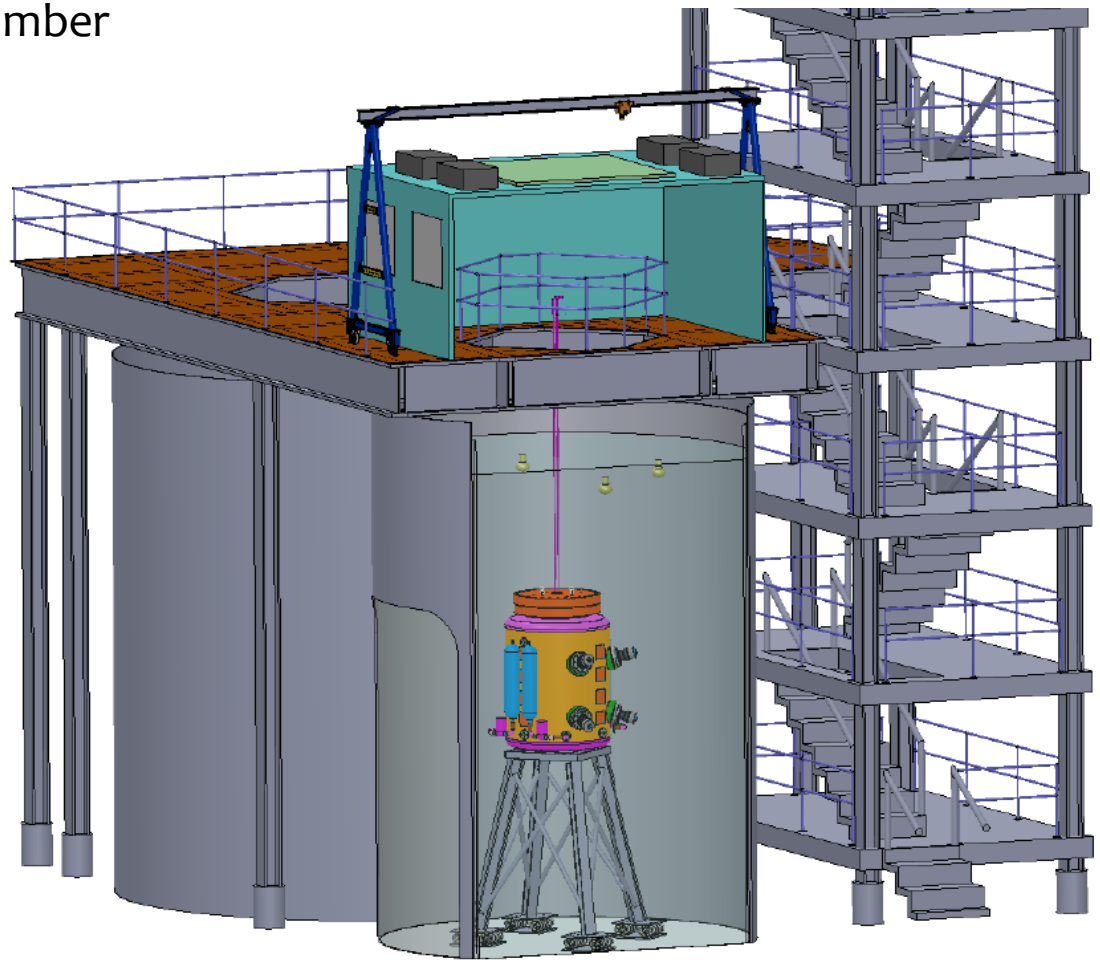
30mL C_3F_8 calibration chamber



PICO-2L: a prototype for ton-scale detector

PICO-250L: ton-scale bubble chamber designed for CF_3I or C_3F_8 target





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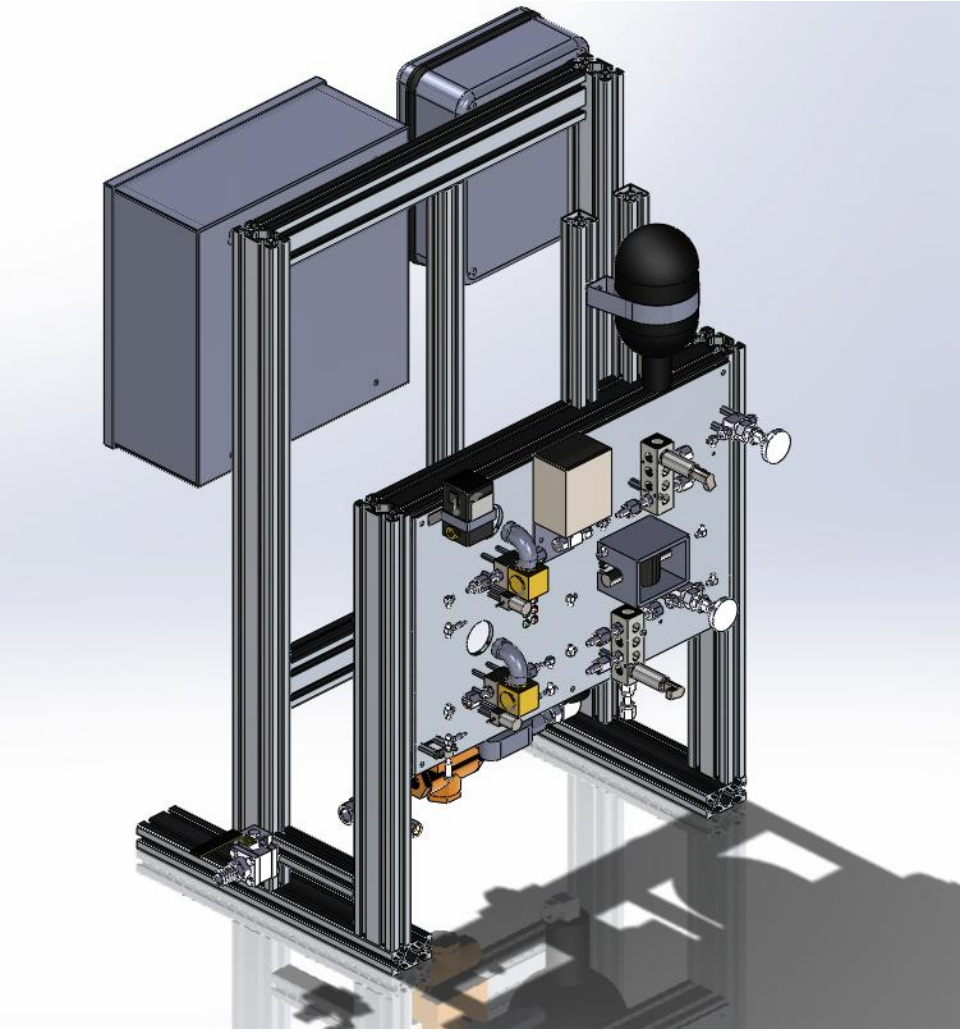
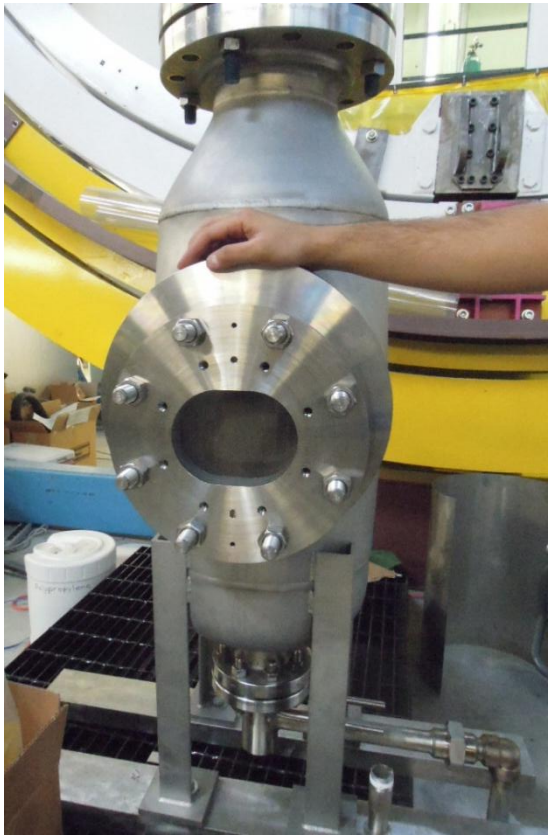
PICO-2L hydraulic controller

- PICO-250L prototype.
- Robust design.
- Expansion and compression pressures set by two accumulators permanently set to those pressures.
- Valves to the accumulators control bubble chamber pressure cycling.



PICO-2L new vessels

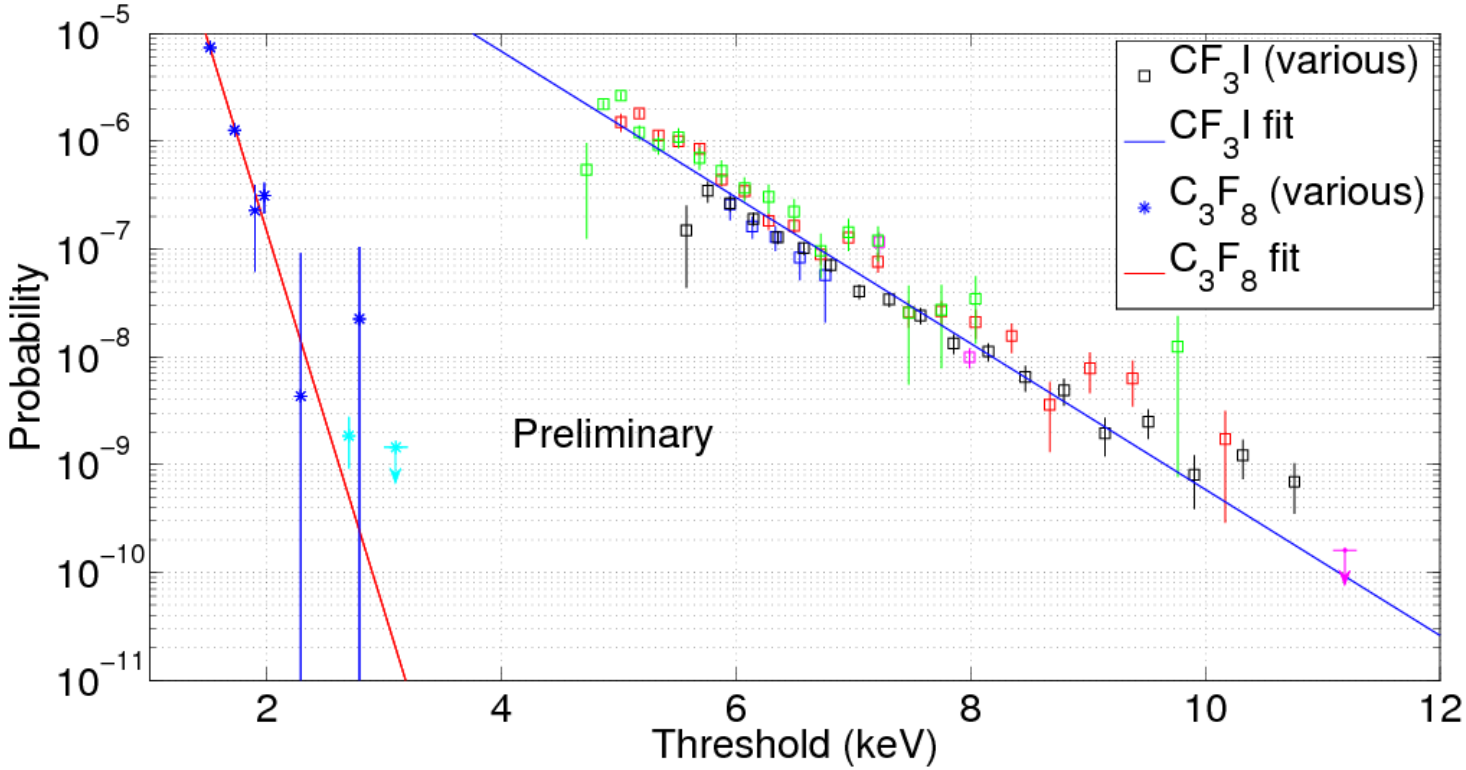
New two-bellows design inner vessel assembly. Silica jar is an exact replica of COUPP-4 jar.



Simplified pressure vessel – ¼ the mass of steel as COUPP-4.

PICO-2L: a low-mass WIMP search

Bubble nucleation probability from gamma interactions in C_3F_8 and CF_3I



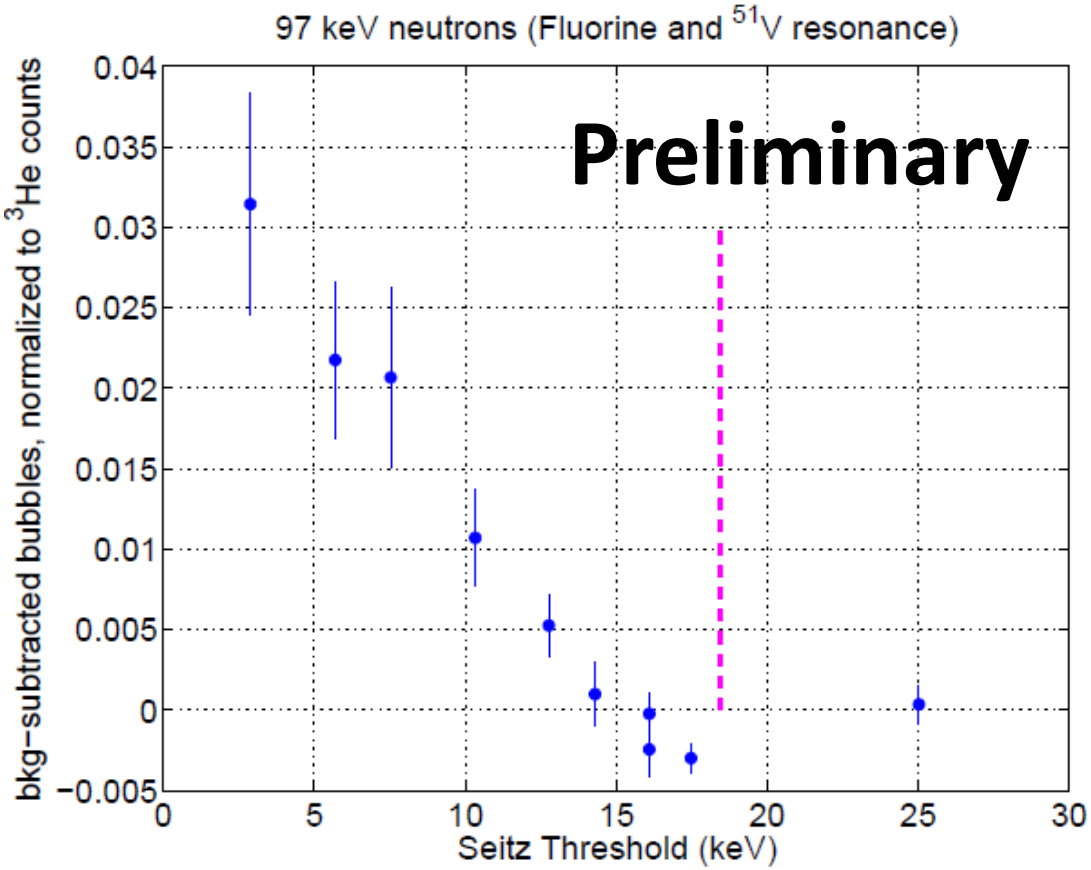
Preliminary results suggest the same 10^{-10} gamma rejection is possible with C_3F_8, and at a lower nuclear recoil threshold. A lower threshold extends the sensitivity to lower mass WIMPs.

Neutron calibrations of C_3F_8

PICO has started a program of neutron calibrations of C_3F_8:

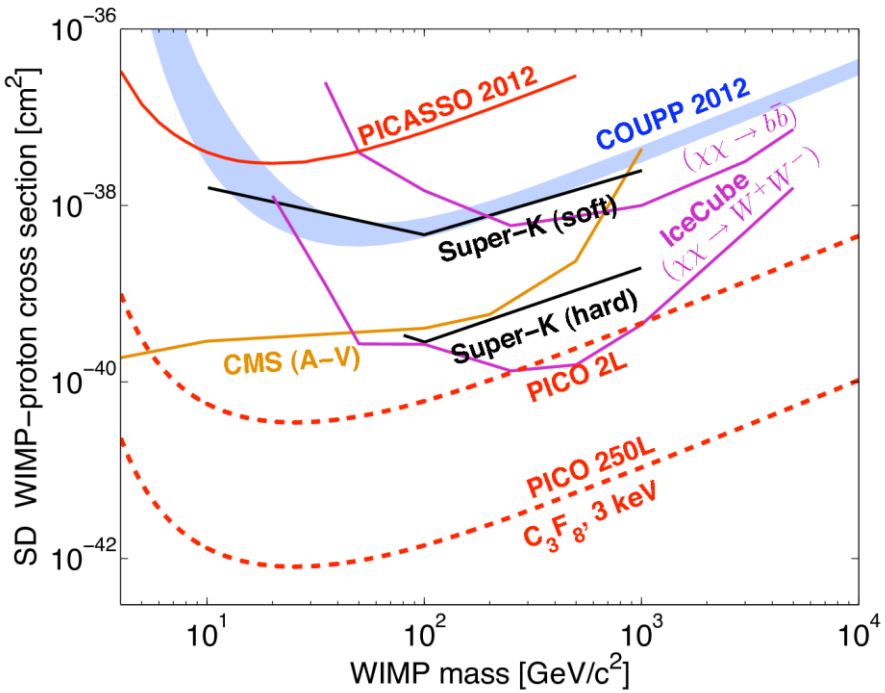
- Monoenergetic neutron beams at Universite de Montreal.
- Low energy Y/Be neutron source at University of Chicago.
- In-situ Am/Be neutron source at SNOLAB.

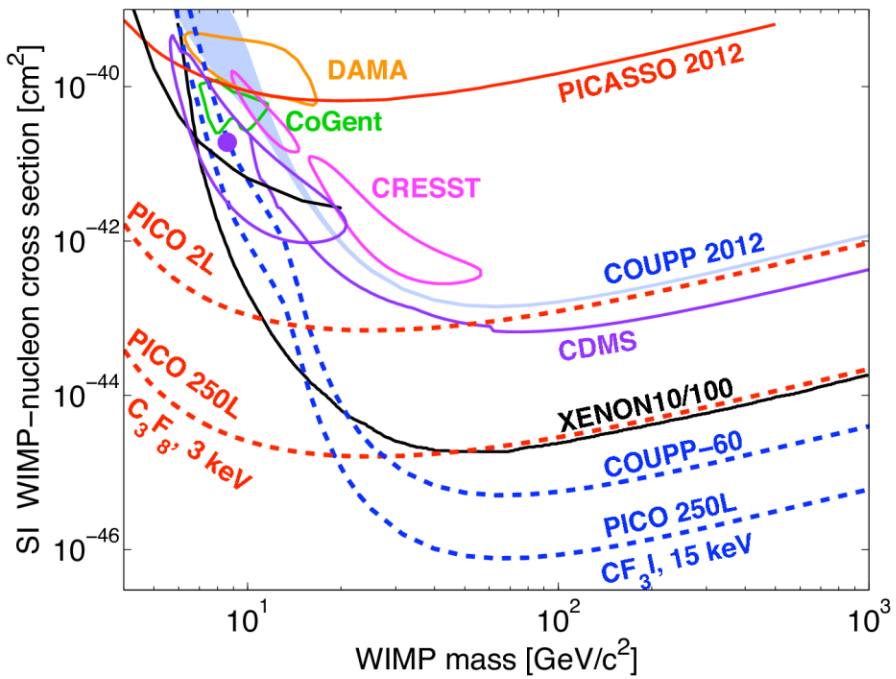
The PICASSO collaboration has extensive calibrations with C_4F_{10}.



Monoenergetic neutron beam data on C_3F_8. Monte-Carlo work needed for data analysis ongoing.

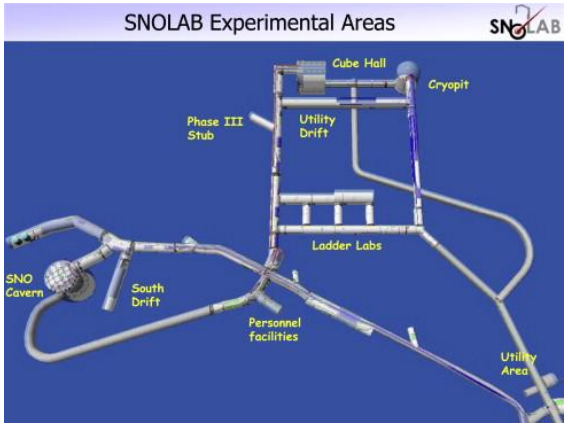
Sensitivity projections

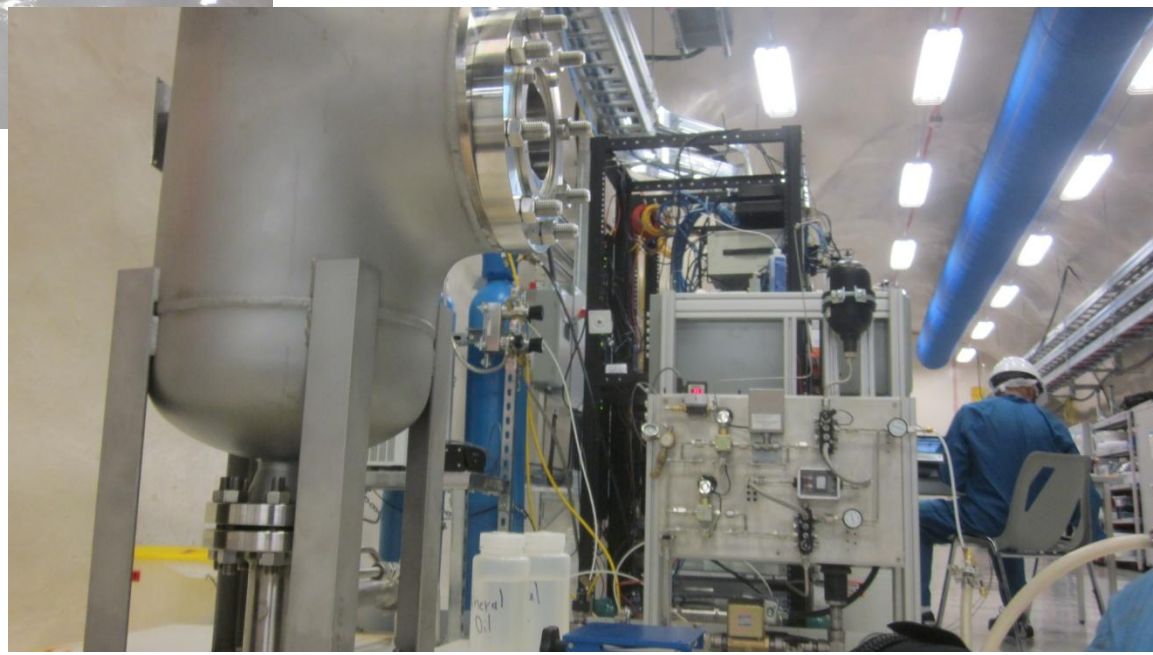




PICO-2L projection based on 100 live-days of data.

PICO-2L installation at SNOLAB





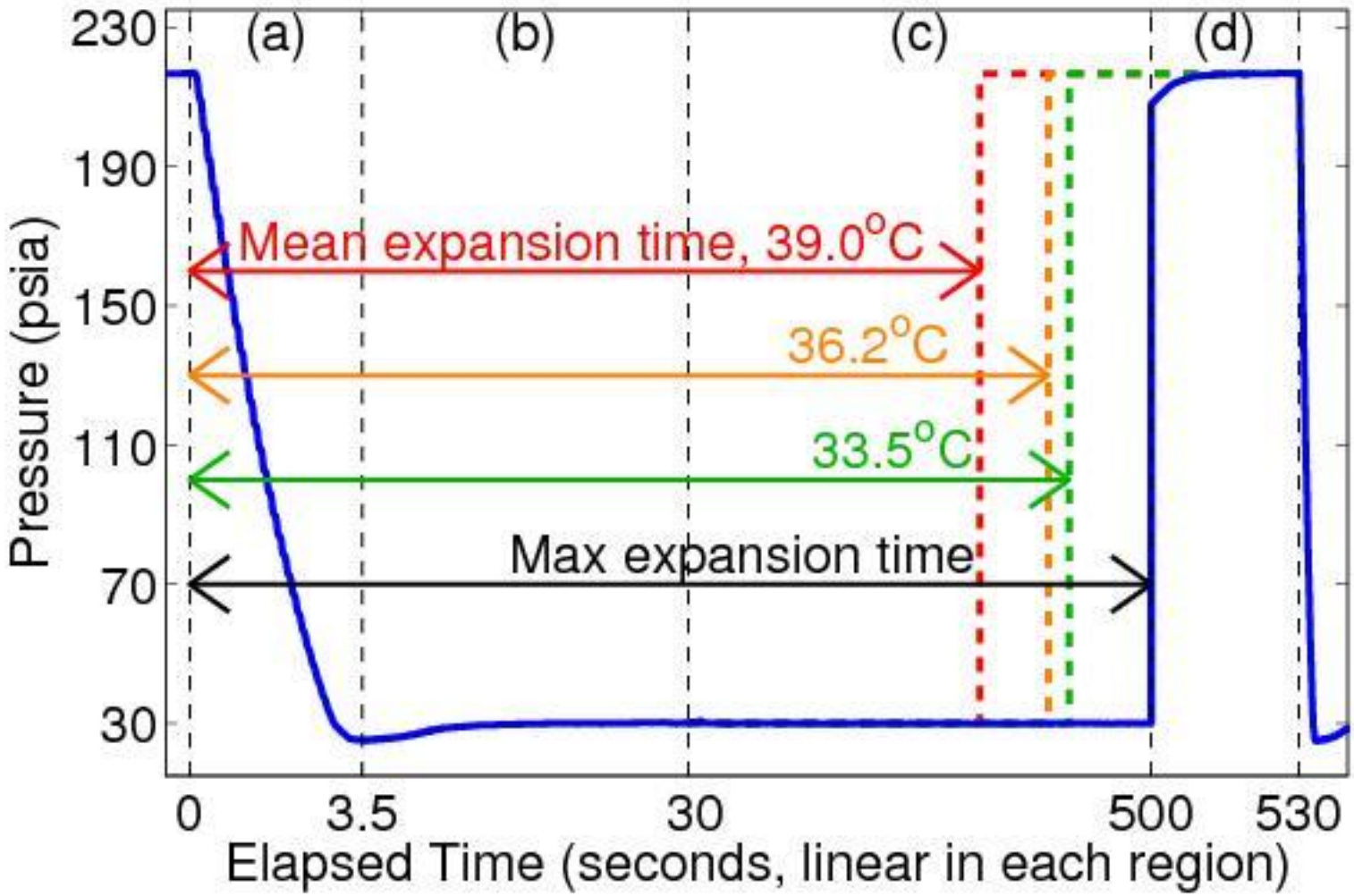
Inner vessel assembly shipping to SNOLAB this week.

Summary

- PICO-2L is the first experiment for the new PICO collaboration, formed from the merger of COUPP and PICASSO.
- Combines the large target mass and low backgrounds demonstrated with COUPP bubble chambers with the low nuclear recoil threshold demonstrated by PICASSO for superheated fluorocarbon targets.
- Installation at SNOLAB is well underway with the inner vessel arriving this week.
- Projected world leading sensitivity for 3-10 GeV WIMPs and spin-dependent couplings.
- Results later in 2013.

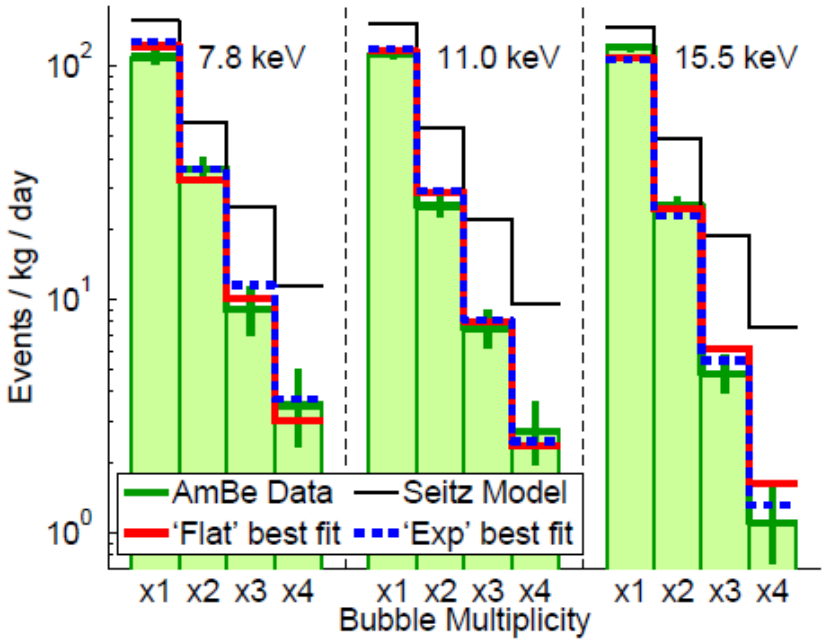
Backup slides

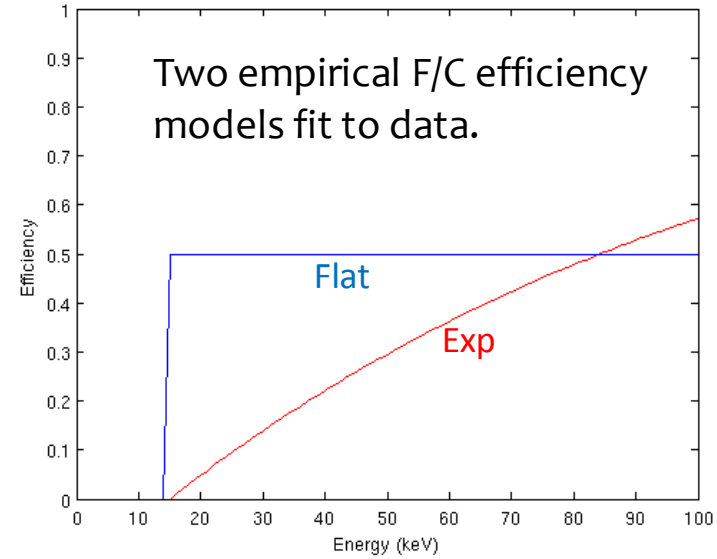
Pressure cycling



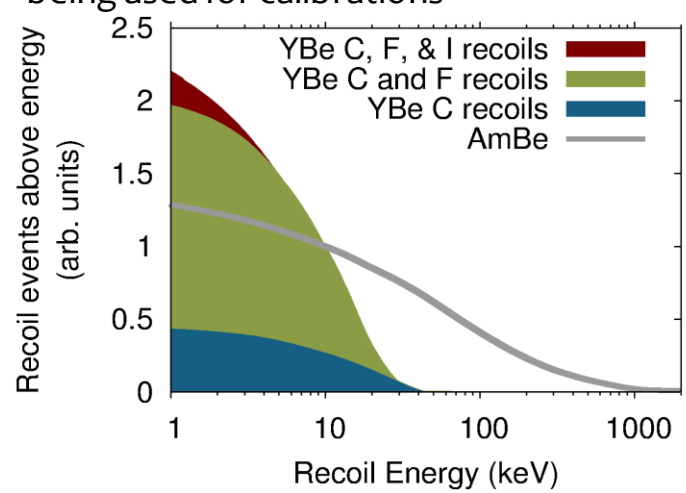
COUPP-4 neutron calibrations

- Threshold is determined using Seitz 'Hot Spike' Model, Phys. Fluids 1, 2 (1958).
- Checked with neutron sources (AmBe, ^{252}Cf) employed regularly during the run.
- Evidence for a soft threshold in fluorine/carbon.



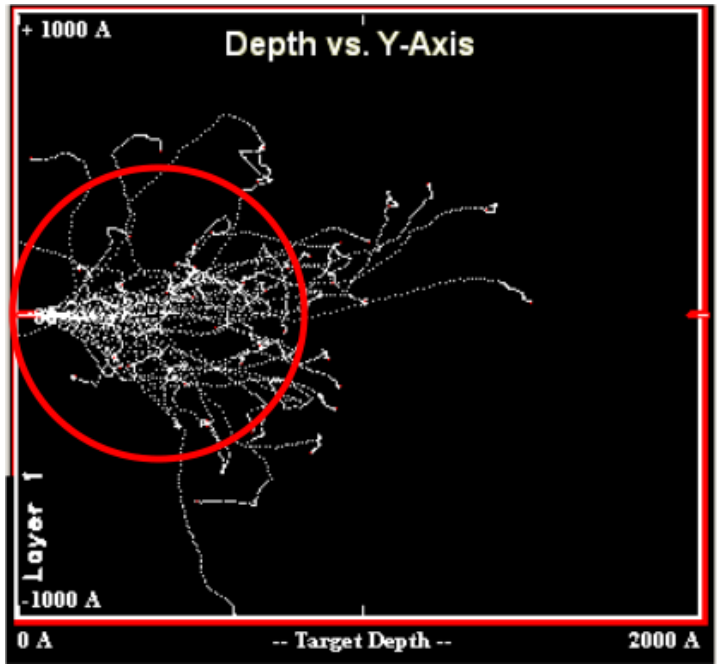


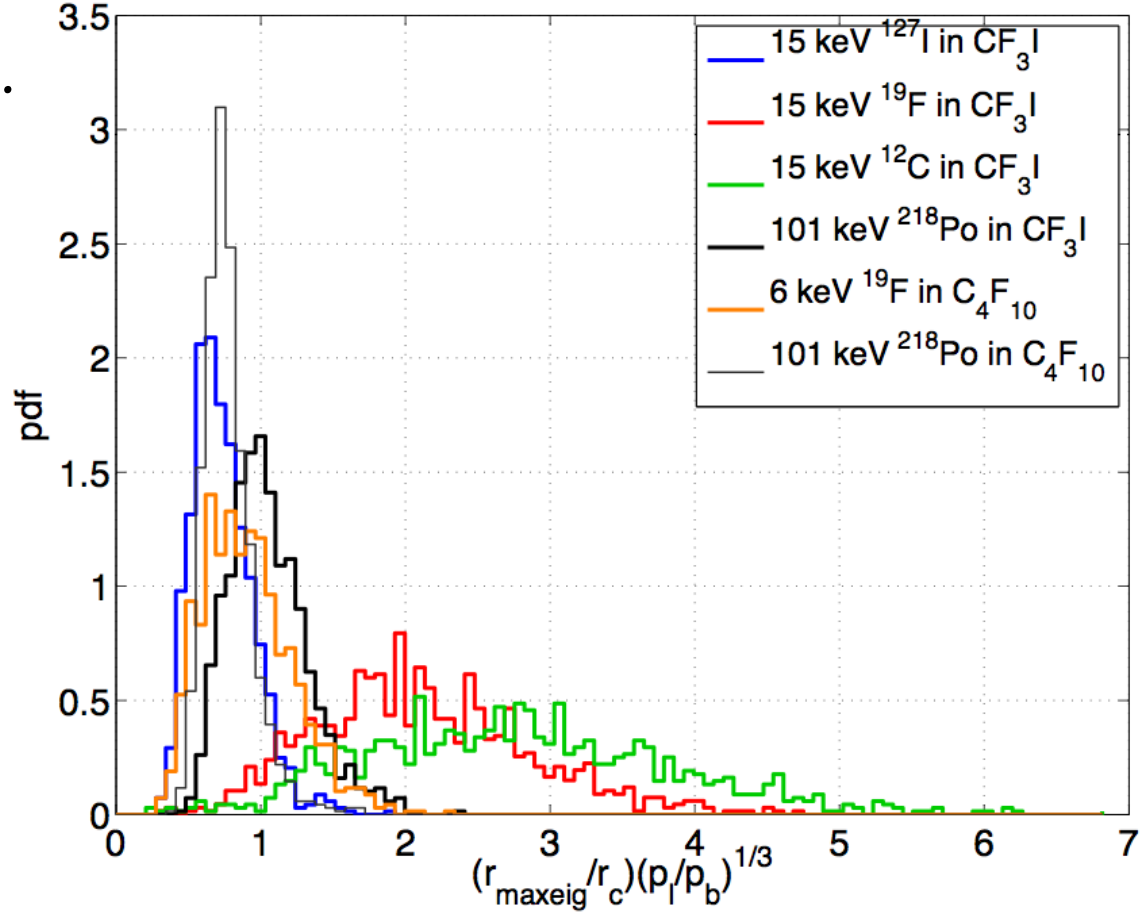
Y/Be low energy neutron source now being used for calibrations



Understanding low efficiency from fluorine recoils

SRIM simulation of 15keV F recoils.

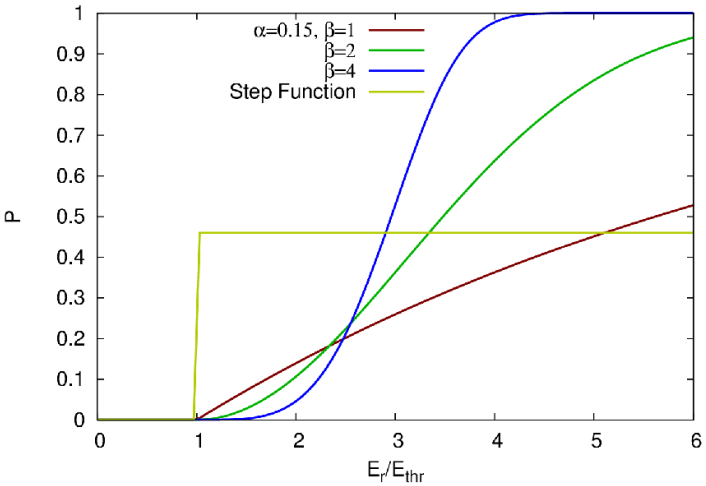


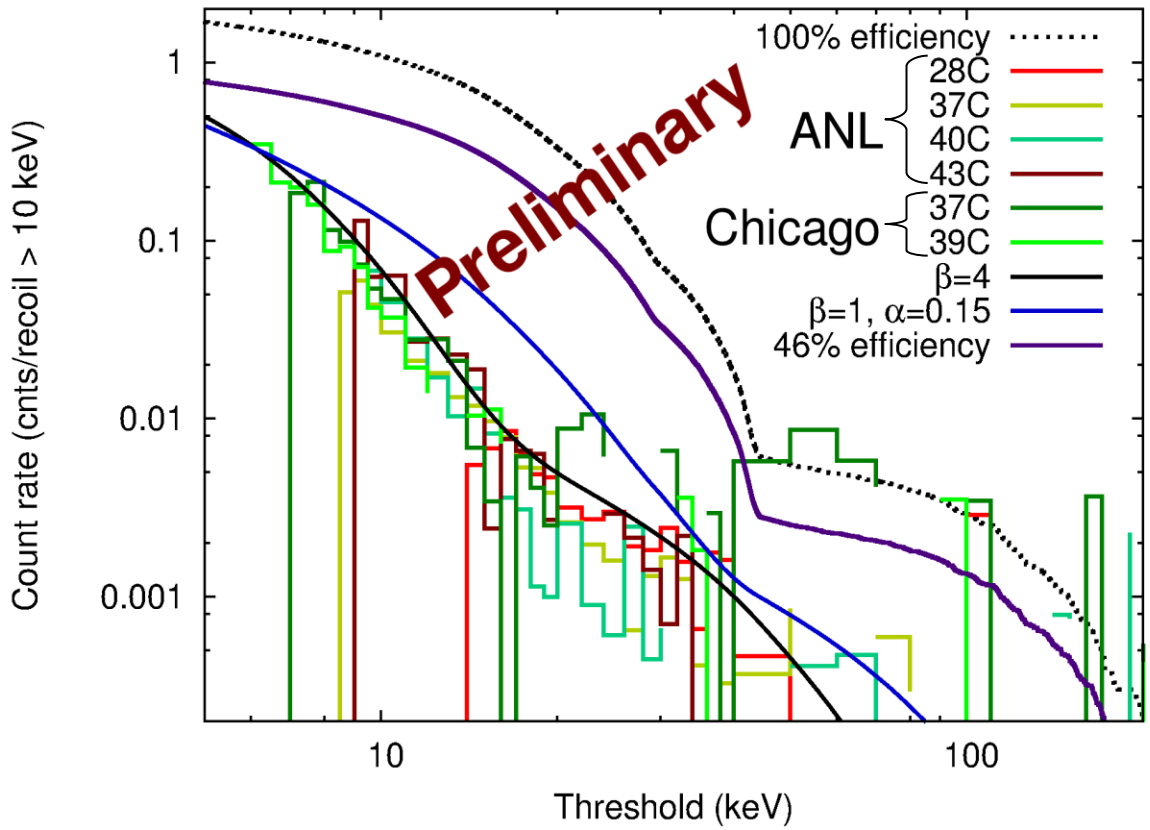


Preliminary ^{88}YBe results on CF_3I

New empirical efficiency curve

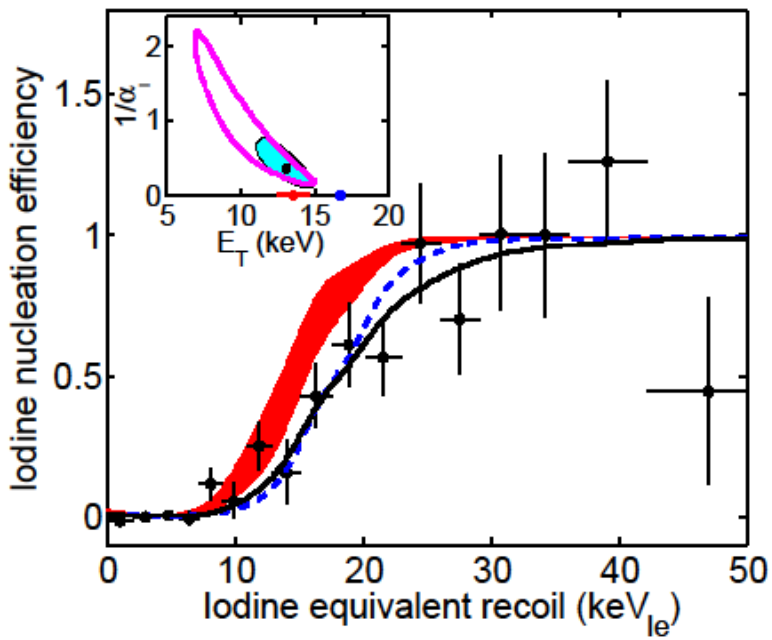
$$P = 1 - \exp\left(-\alpha\left(\frac{E_r - E_{th}}{E_{th}}\right)^{\beta}\right)$$

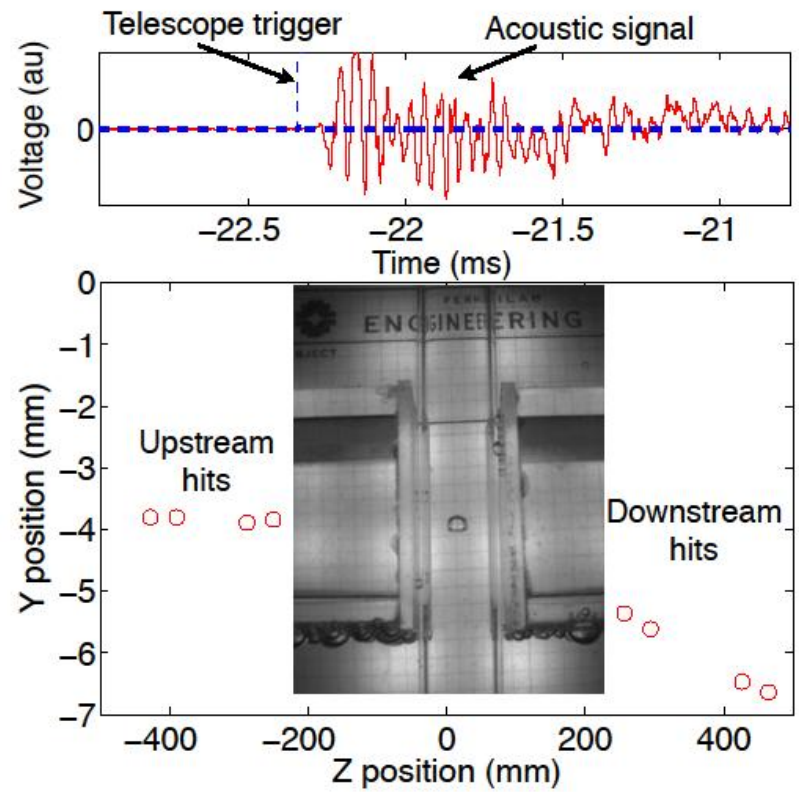




Nuclear recoil efficiency (iodine)

- Pion-scattering calibration of iodine threshold in CF_3I.



arXiv:1304.6001

- 12GeV pion beam with silicon pixel telescope to measure scattering angle.
- Example event: 6mrad scatter, 20keV Iodine recoil.