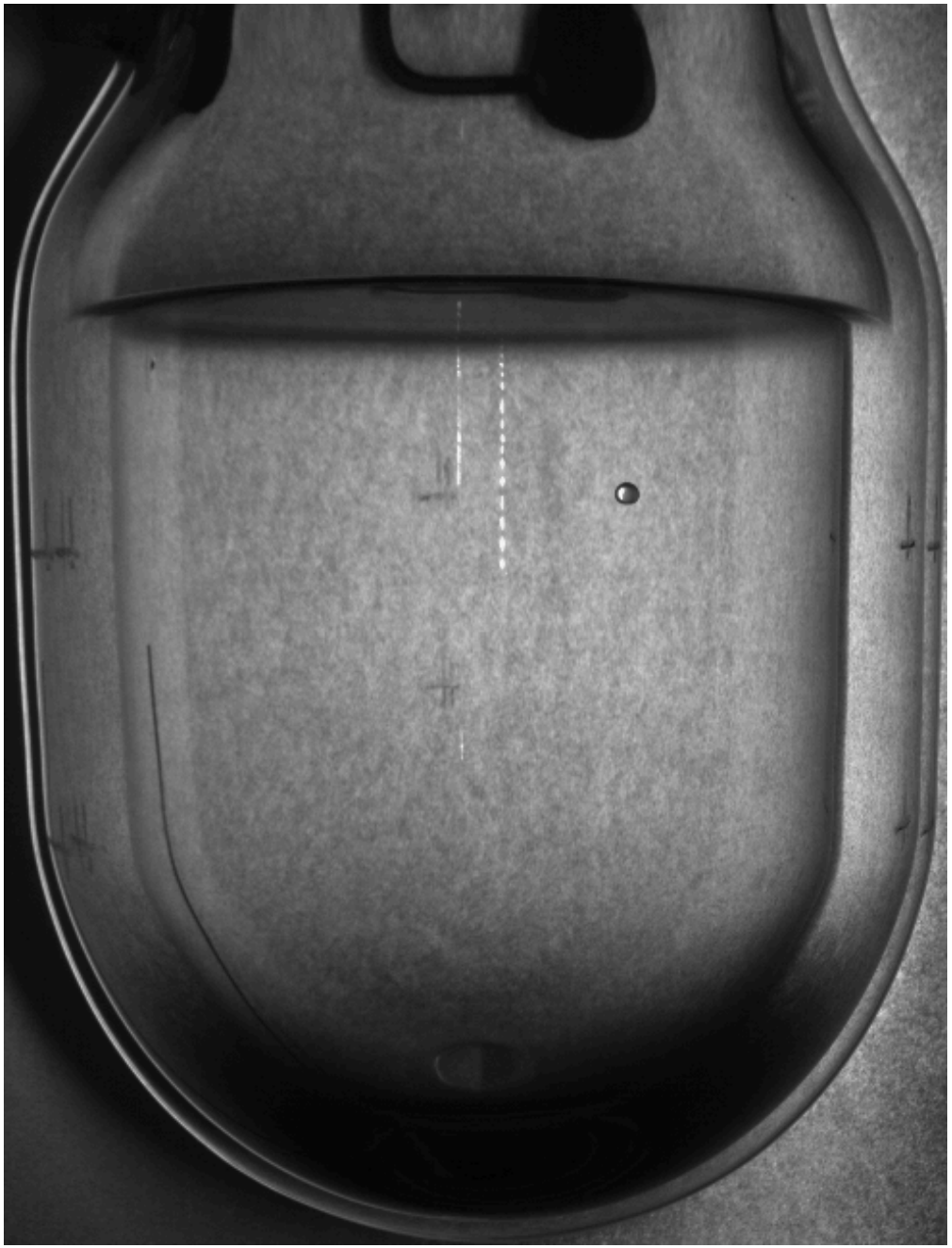
PICO: Dark Matter Searches With Bubble Chambers

DM 2016
UCLA
February 19, 2016

Andrew Sonnenschein



WIMP Dark Matter Detector Wish List

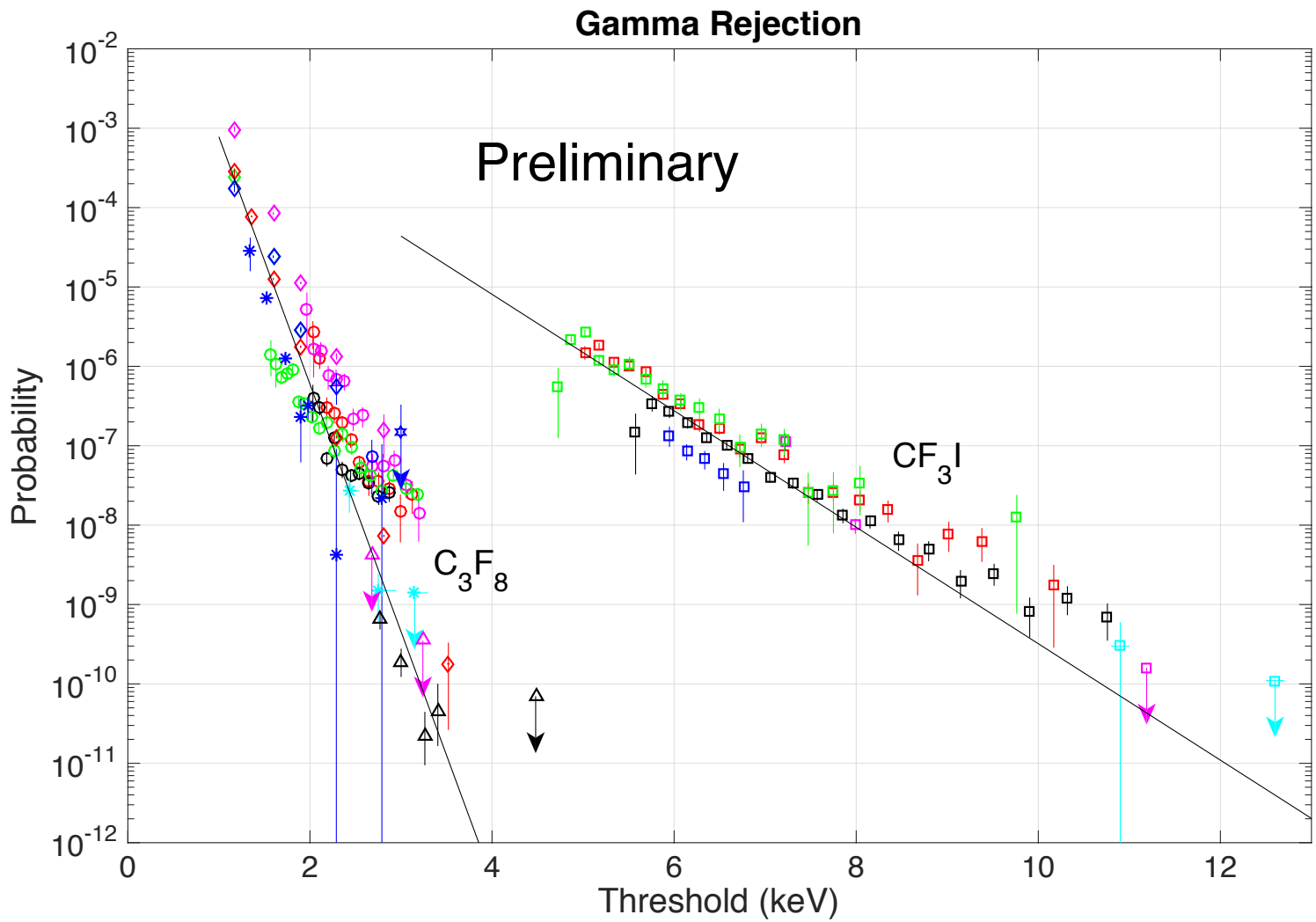
- Zero background.
- Large target mass (>1 ton for next generation)
- Low energy threshold. (~ 10 keV for standard WIMPs, ~ 2 keV for current light WIMP models)
- Multiple target nuclei- test expected cross section dependences on atomic number and nuclear spin.
- Measure nuclear recoil energies.
- Measure nuclear recoil direction.

Bubble Chambers?

- Zero background? TBD. See rest of talk
- Large target mass (>1 ton for next generation) ✔
- Low energy threshold. ✔
- Multiple target nuclei- test expected cross section dependences on atomic number and nuclear spin. ✔
  Fluorine, Iodine, Chlorine, Xenon, Argon, Bromine, Hydrogen…
- Measure nuclear recoil energies. Yes, by varying threshold
- Measure nuclear recoil direction. Sorry 

Gamma Insensitivity: Current Data

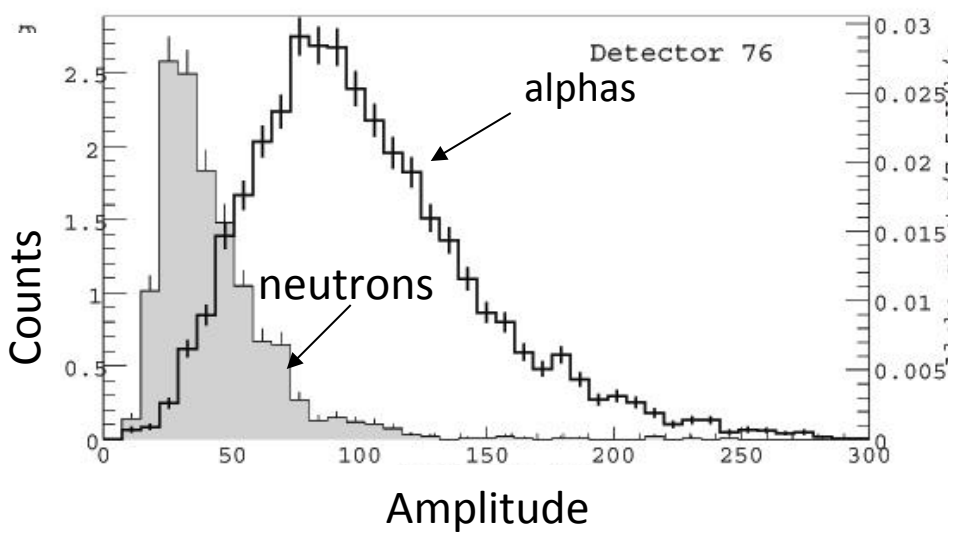
Bubble nucleation probability for a gamma interaction in C_3F_8 or CF_3I



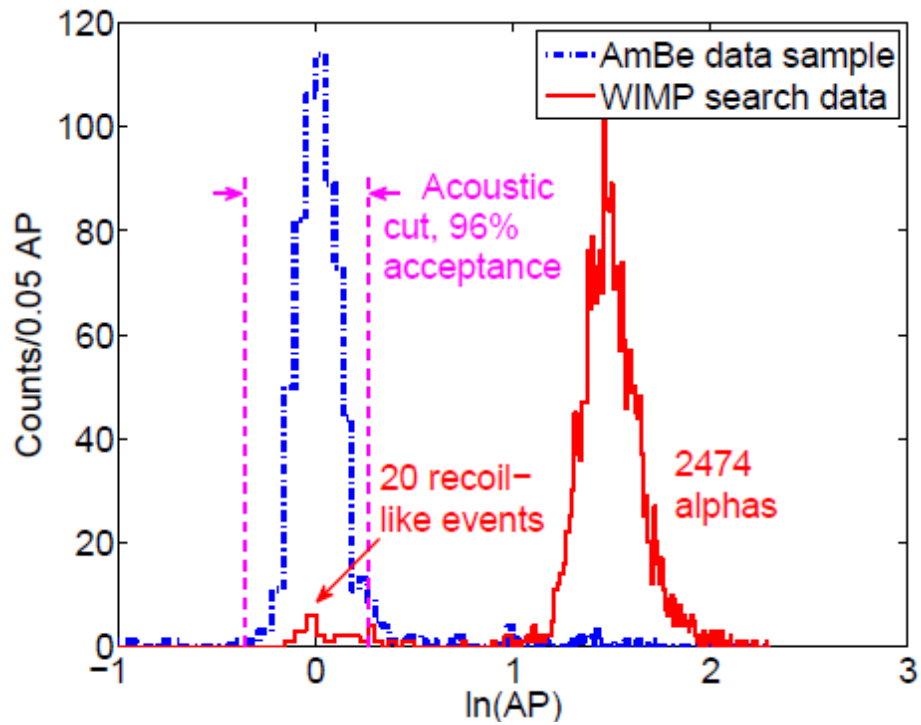
Acoustic Discrimination: Alphas vs Nuclear Recoils

- Bubble nucleation detected acoustically with piezoelectric sensors.
- Surprise discovery in PICASSO superheated droplet detectors: alphas louder than nuclear recoils! (PICASSO, 2008)
- Followup measurement in COUPP bubble chambers showed same effect, with much better separation of alpha and recoil populations.

PICASSO (2008)



COUPP (2012)



PICO = PICASSO + COUPP

SNOLAB
Mining for knowledge
Creuser pour trouver... l'excellence
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University of Toronto
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Laurentian University / Université Laurentienne
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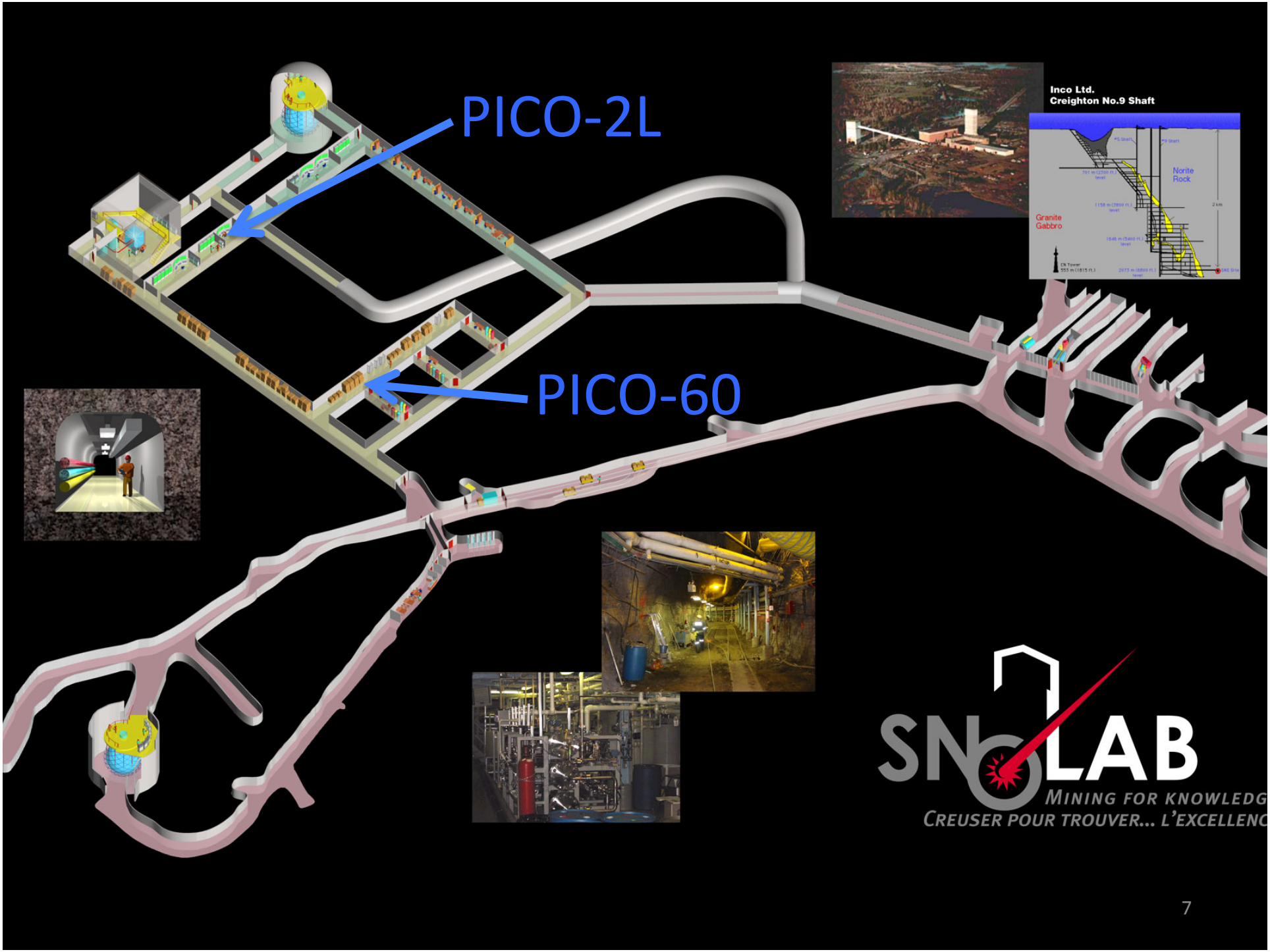
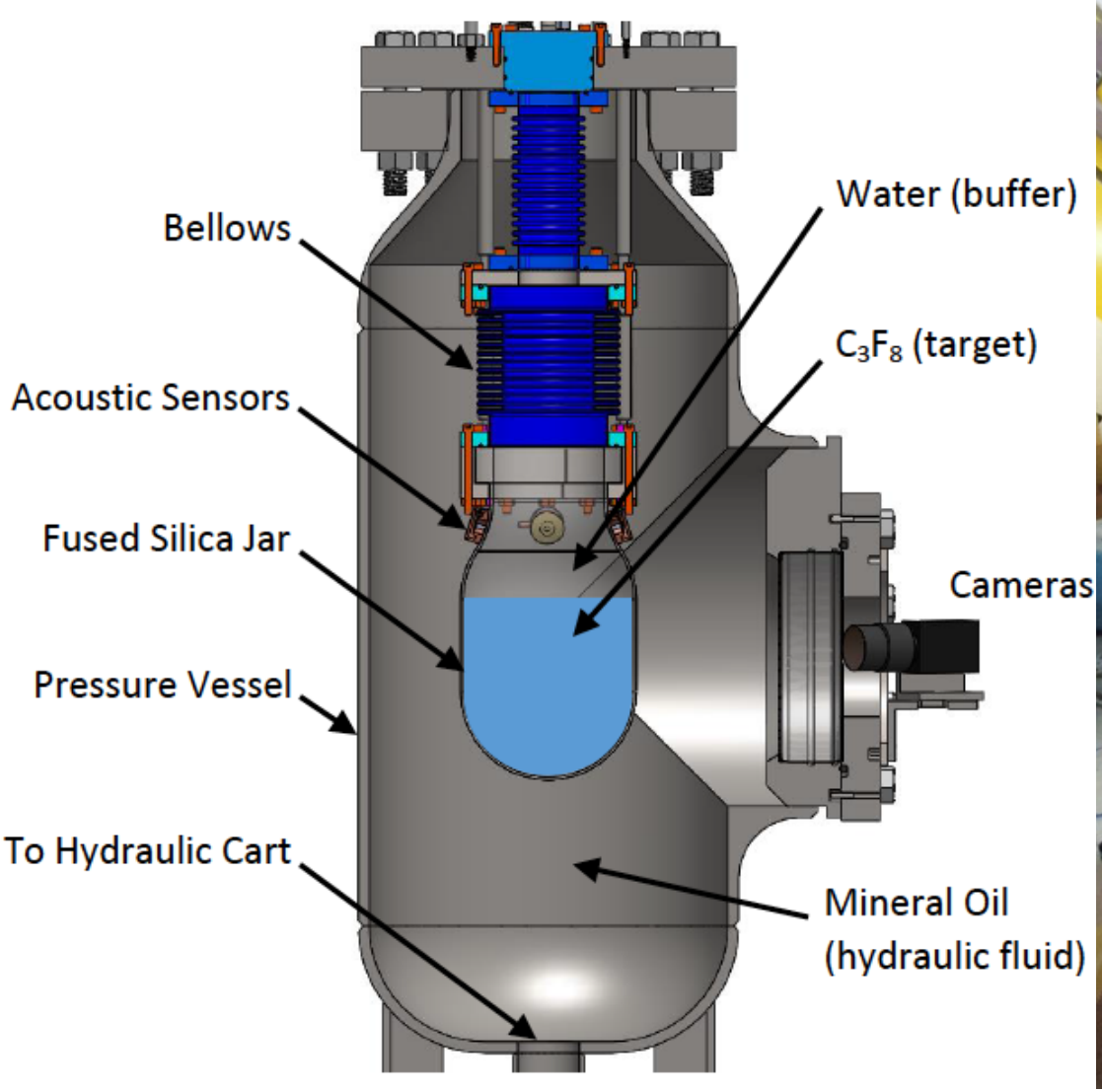
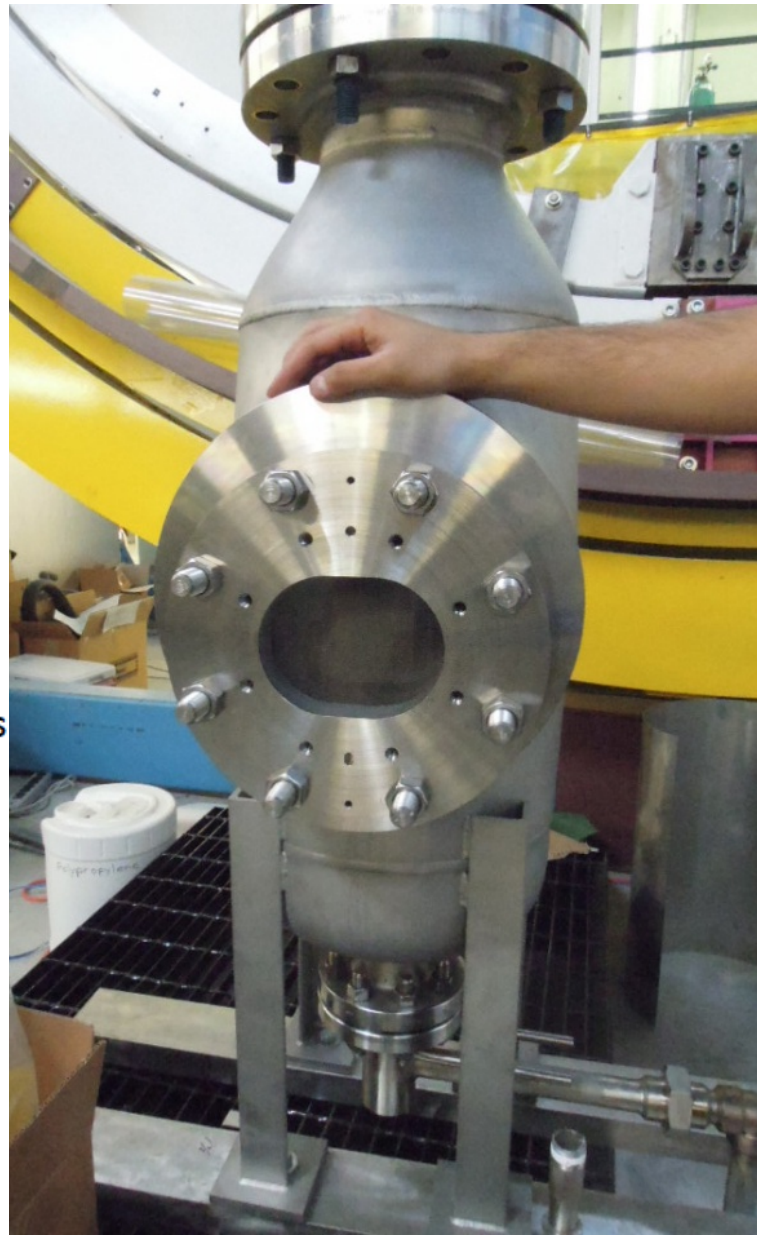
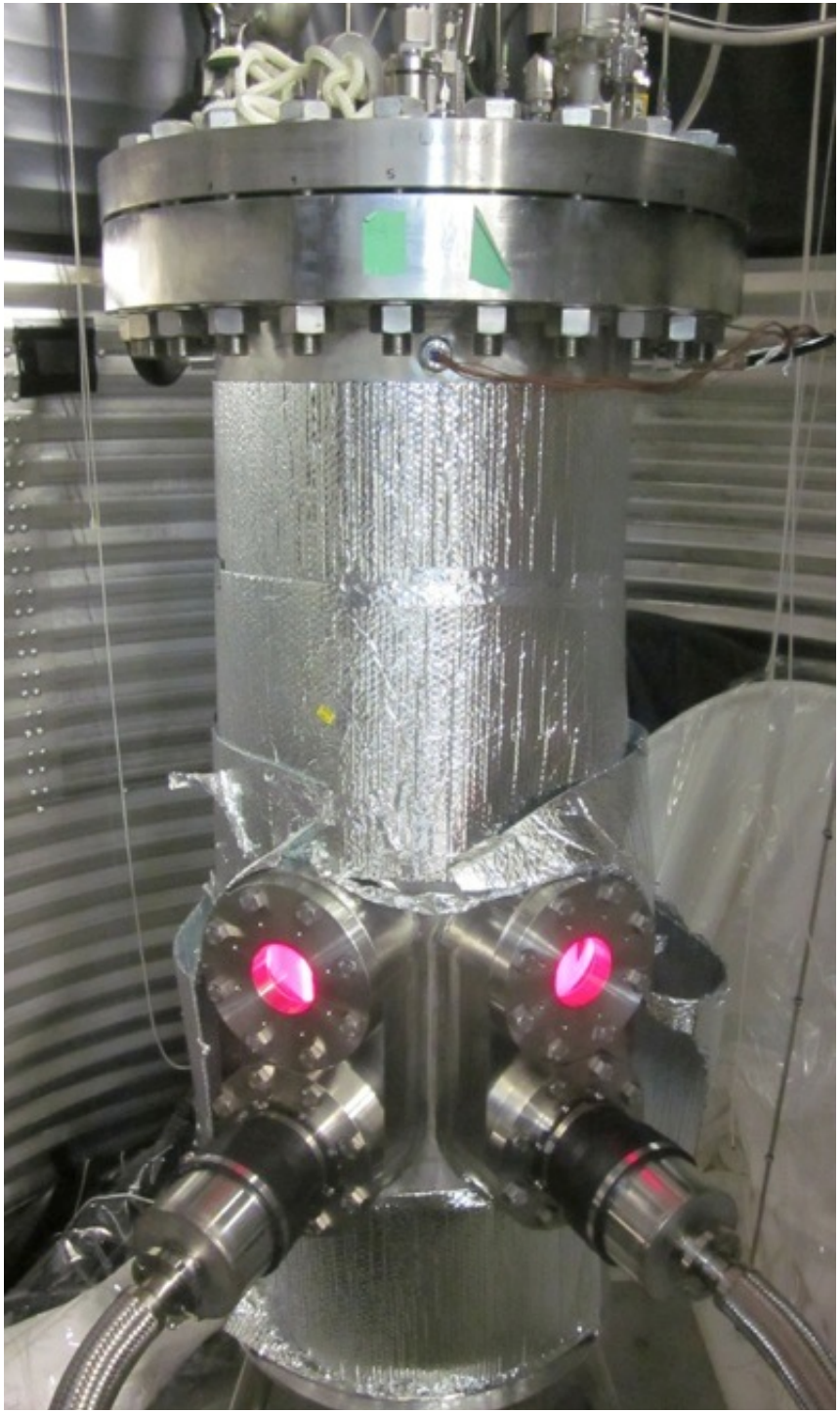

PICO-2L
PICO-60
Inco Ltd.
Creighton No.9 Shaft
Norite Rock
Granite Gabbro
SNOLAB
MINING FOR KNOWLEDG
CREUSER POUR TROUVER... L'EXCELLENC

PICO-2L (2 Liters)





PICO-60 (40 Liters)

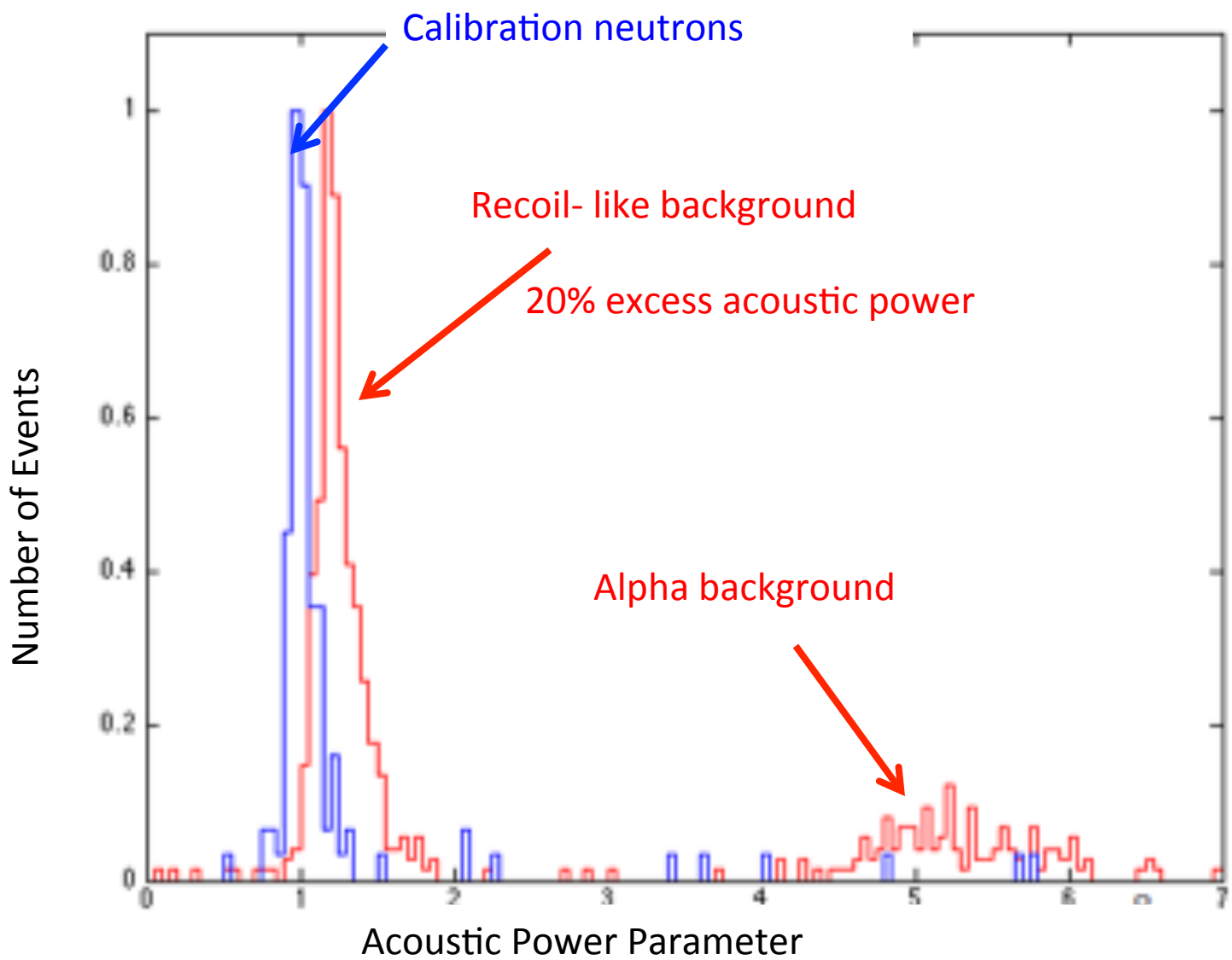


PICO-60 2013-2014 Physics Run

- Target: 37 kg CF_3I. Sensitivity to spin-independent WIMP-nucleon couplings on Iodine; spin-dependent on Fluorine.
- 93 live day effective exposure beginning June 2013.
- Different operating modes explored: fixed threshold points (temperature, pressure), threshold scans from 7 keV to 30 keV.
- Extensive neutron calibration data.
- Run was ended in May '14 to allow inspection of detector and fluids for particulate contamination.

Publication: ArXiv:1510.07754

Acoustic Distribution in PICO-60



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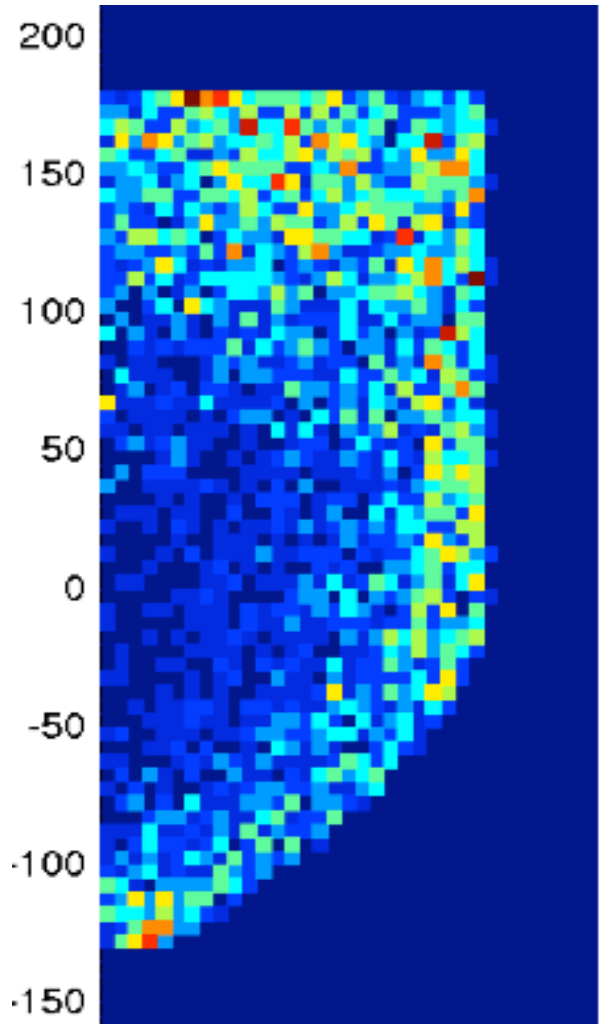
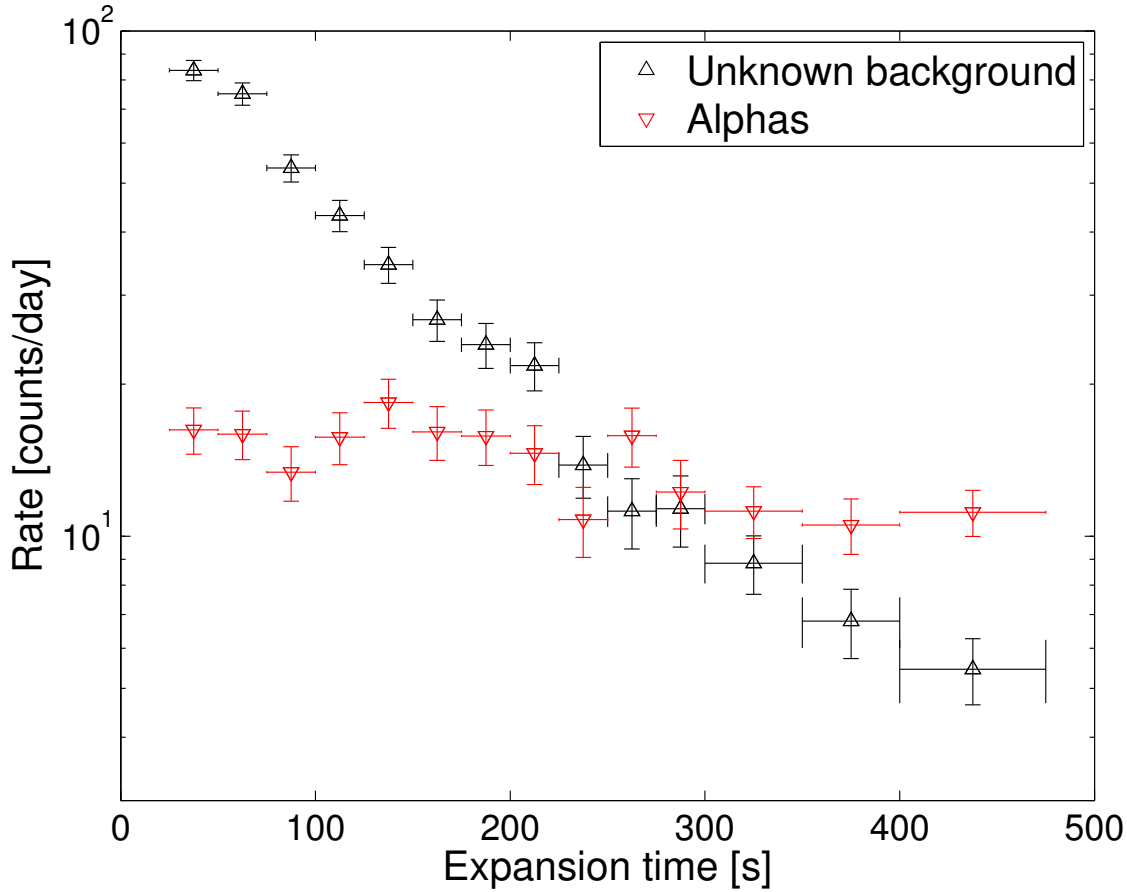
Anomalous Background Events

- ~20% excess acoustic power
- Non-uniform spatial distribution, with highest rates near top and walls of chamber.
- Fluctuating rate from ~10-100 counts per day (2111 events total).
- Highest rates during periods of temperature instability.
- Highest rates at beginning of bubble chamber expansion cycle.



Expansion Time Dependence

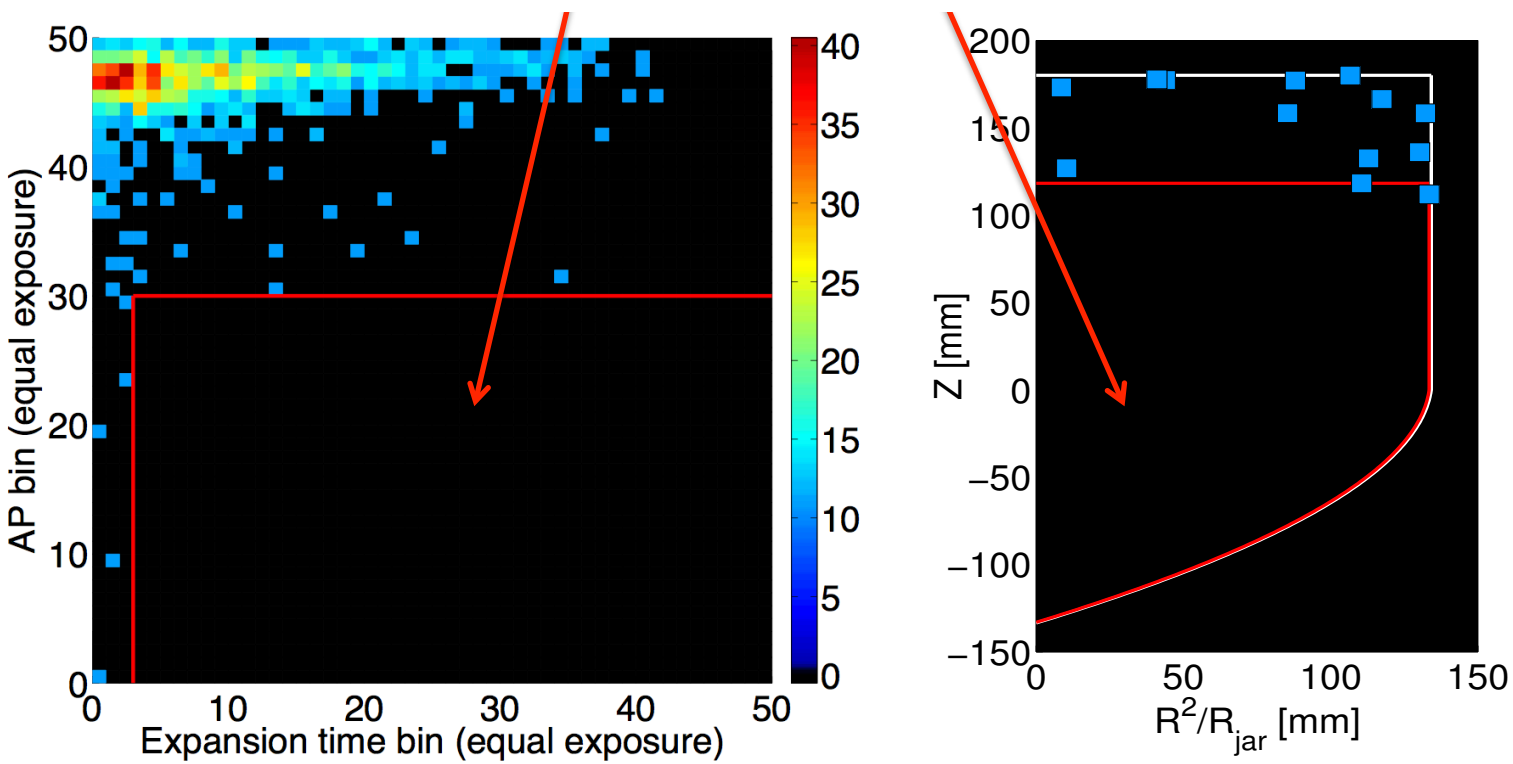
- Probability of seeing a background event decreases the longer the chamber is expanded.



Optimization of Cuts

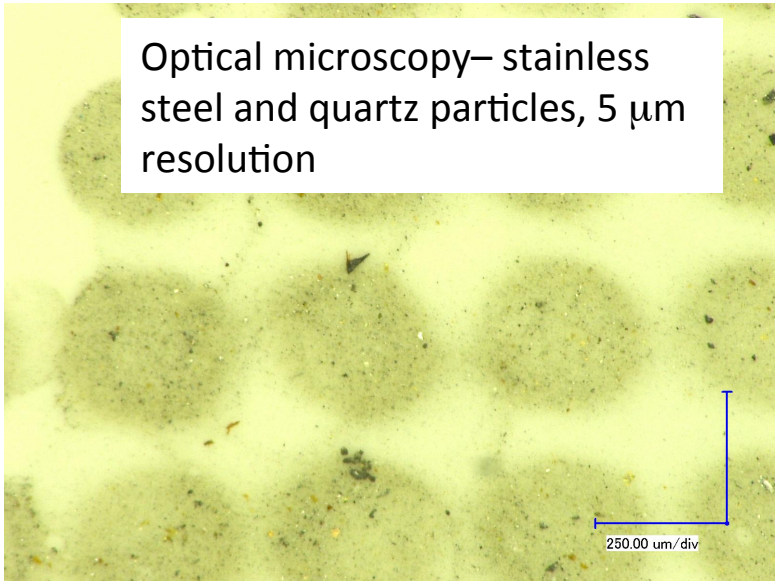
- Combined cuts on position, expansion time and acoustic amplitude yield background free region.
- Monte Carlo methods used to estimate sensitivity. See arXiv: 1510.07754

A background free region with 48% signal acceptance by cutting on AP, expansion time, and Z

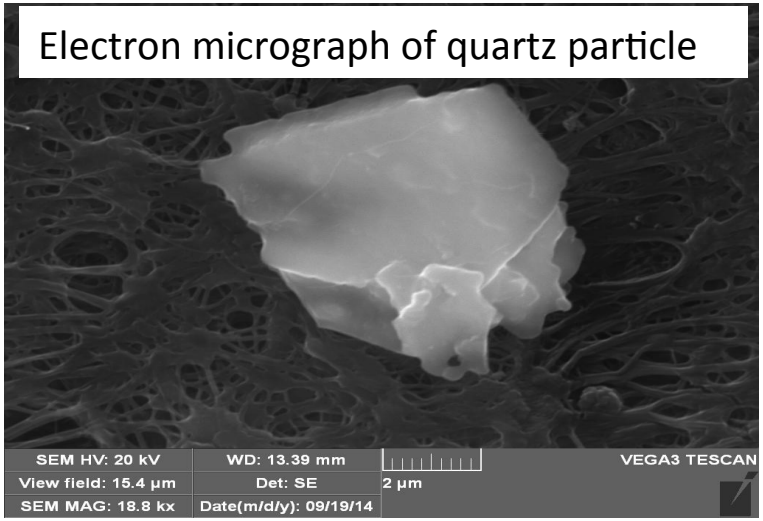


Looking for Dust with Microscopes

- Temporal and spatial distribution of background suggests particulate origin.
- To test: Liquids passed through Teflon filters with 200 nm pore size.
- Studied using optical and electron microscopy, X-ray fluorescence, Alpha spectroscopy, mass spectroscopy at PNNL and University of Alberta.
- Result: majority of contamination from quartz and stainless steel materials used in chamber construction.
- PICO-60 sample:
  - 7 μg quartz particles
  - 240 μg stainless steel and iron oxide



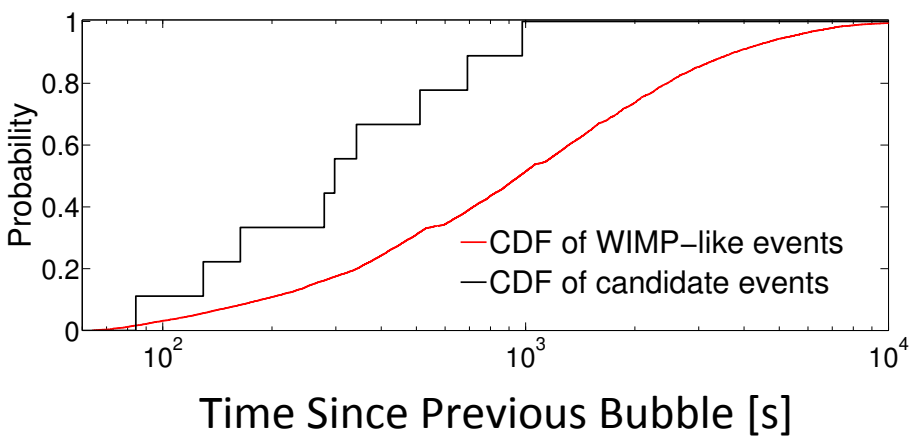
Optical microscopy– stainless steel and quartz particles, 5 μm resolution

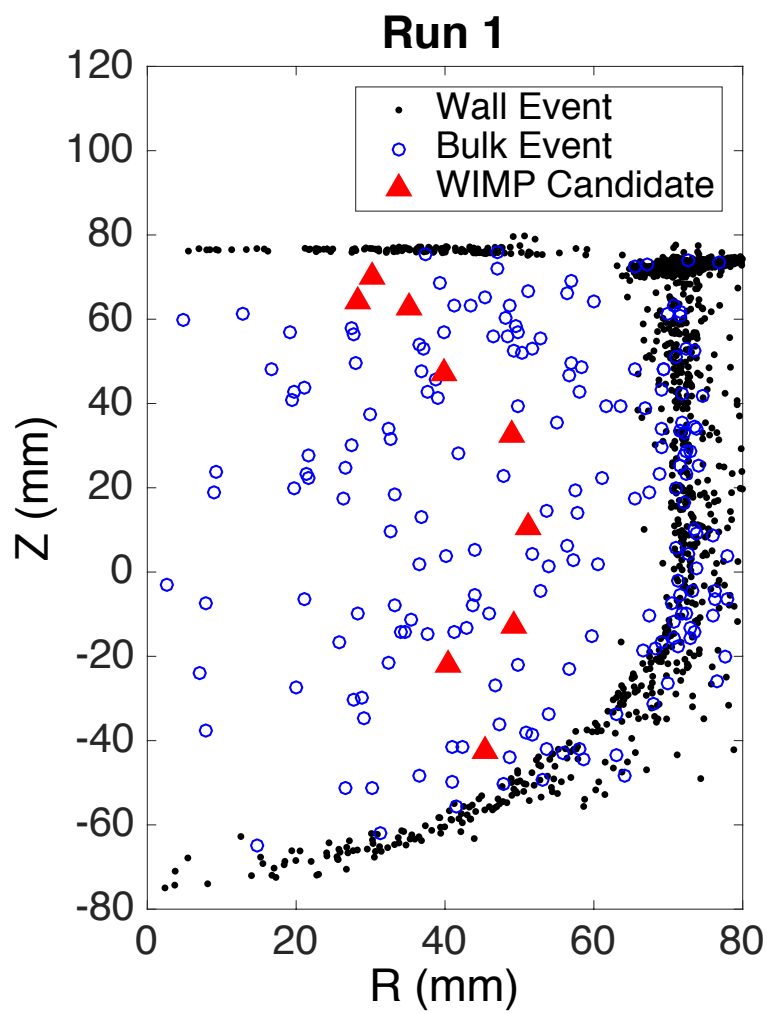


Electron micrograph of quartz particle

PICO-2L 2013-2014 Run

- Smaller PICO-2L chamber running with C_3F_8 and low threshold (3.2 keV).
- Better sensitivity to lighter WIMPs.
- Lower backgrounds: 9 background events in 32 live days at 3.2 keV.
- Time correlations with previous expansions.

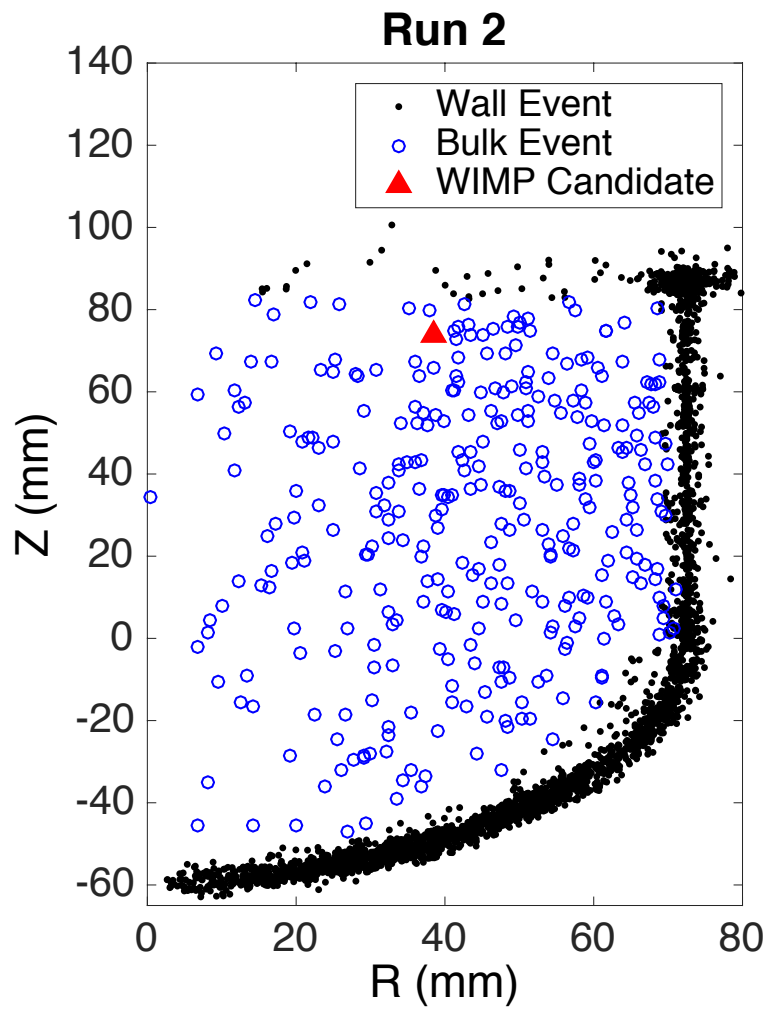




arXiv:1503.00008

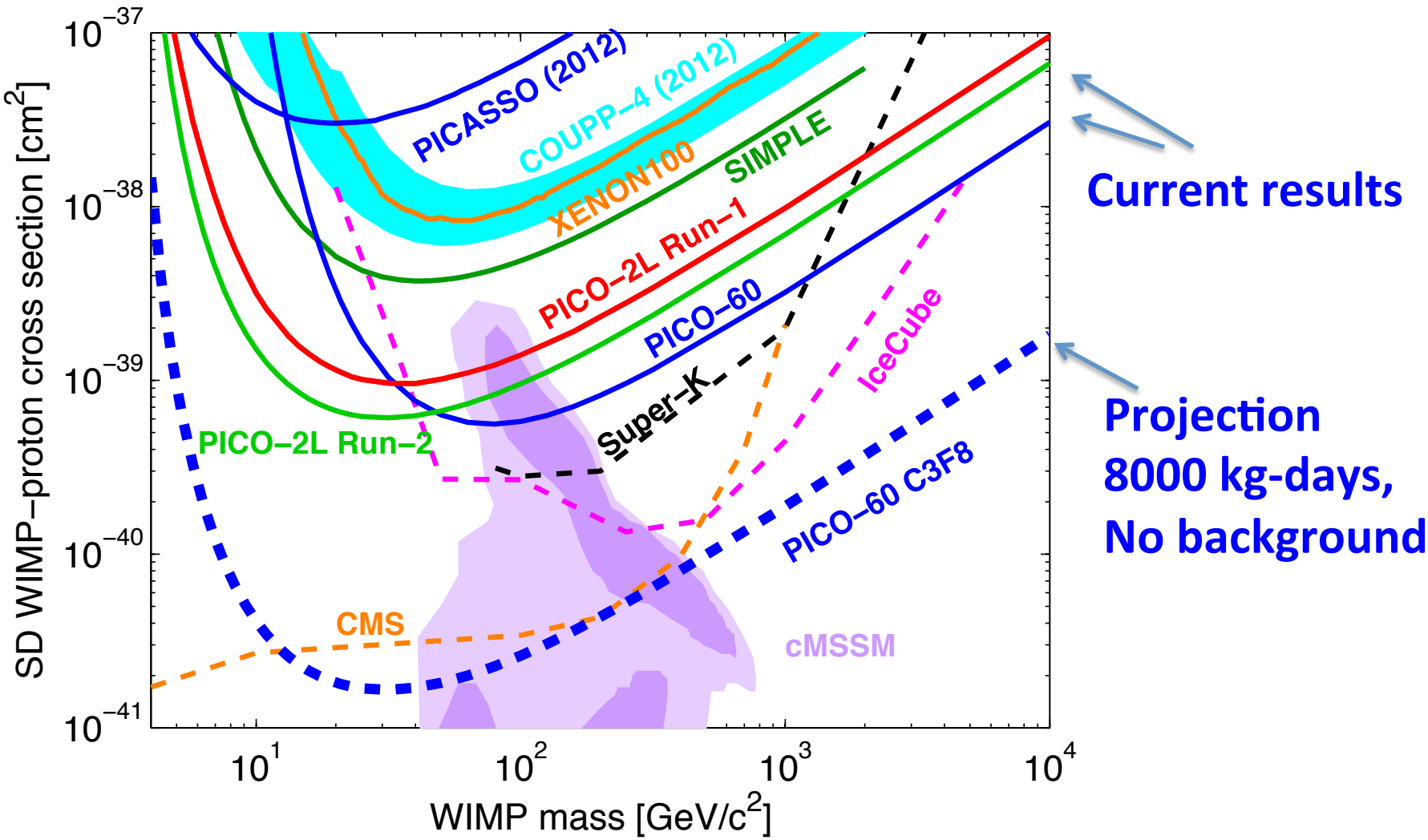
New: PICO-2L 2015 Run

- Improved cleaning and assembly procedures.
- Higher purity quartz inner vessel.
- One recoil-like event in 66 live days at 3.2 keV threshold, *consistent with estimated neutron rate.*
- <u>Anomalous background reduced by at least an order of magnitude with respect to previous run at same threshold.</u>



arXiv:1601.03729

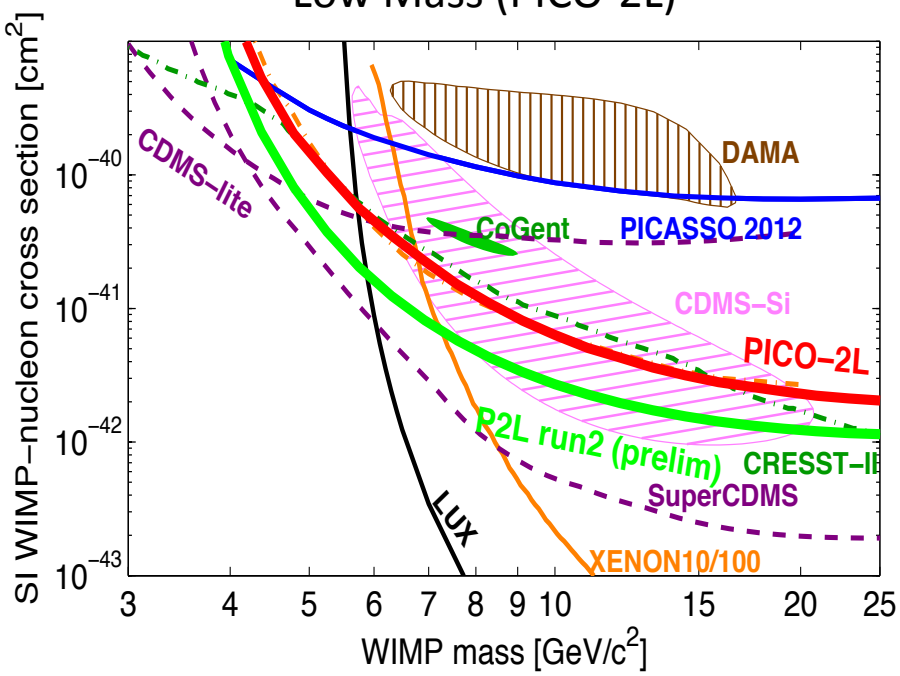
PICO- Spin Dependent Sensitivity



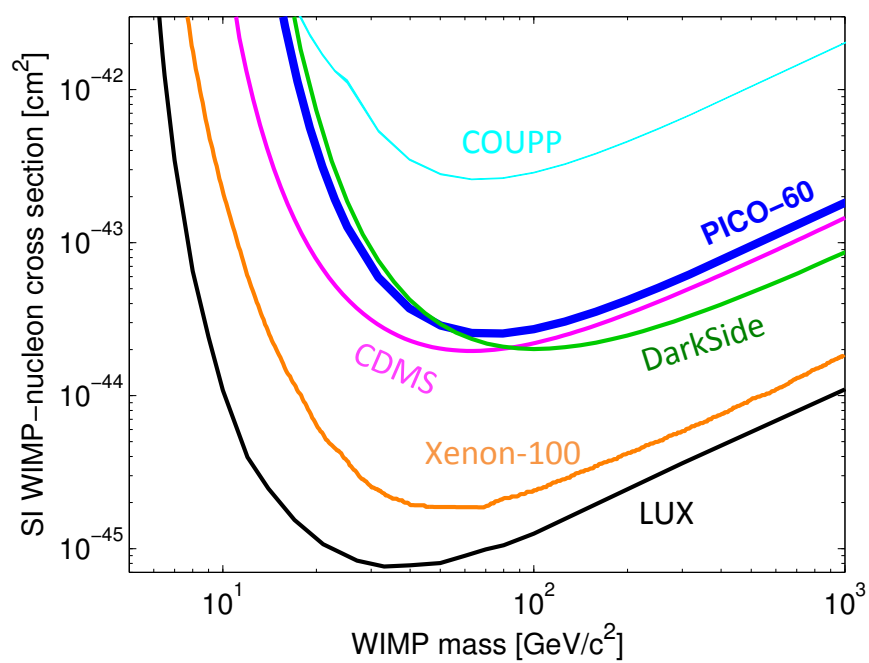
Spin-Independent Sensitivity

- Most competitive at low mass due to light target (Fluorine) and low thresholds in PICO-2L.
- Iodine in CF_3I (PICO-60) efficient for heavy WIMPs, but less exposure, higher backgrounds than in LUX & Xenon-100

Low Mass (PICO-2L)



High Mass (PICO- 60)



The Future of PICO

- Near term goal: background free run of PICO-60 with 55 kg of C_3F_8 target liquid.
  - Higher quality initial cleaning of inner vessel.
  - On-line filtration and particulate monitoring of inner vessel liquids.
  - Run will start this Spring.

- Medium term: R&D on improved bubble chambers designs to reduce particulate load. Eliminate problematic water/ target liquid interface.

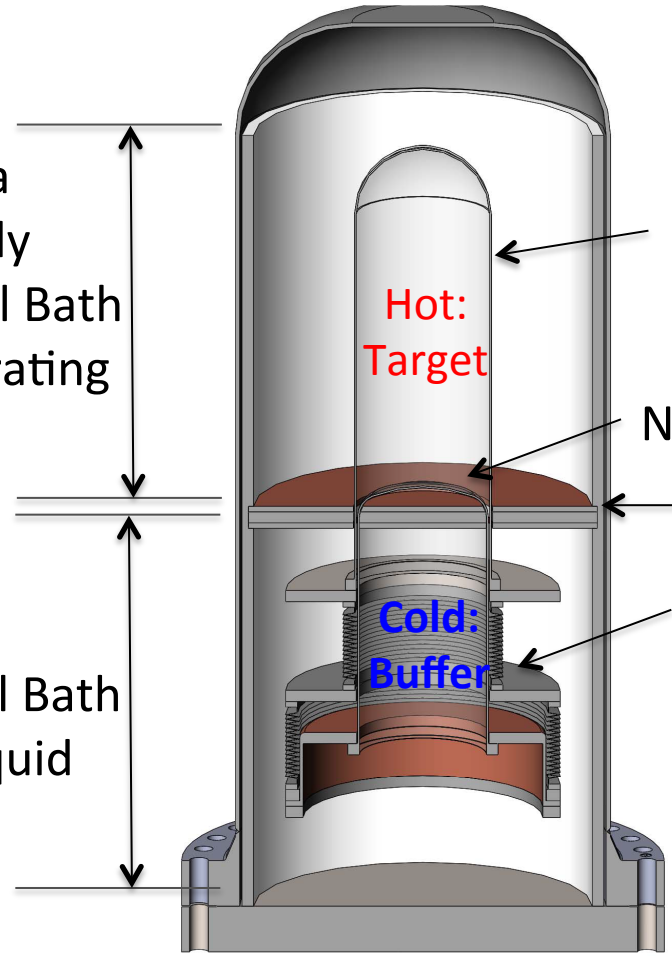
- Longer term: larger bubble chamber(s)
  - ~Ton scale target mass.
  - Maintain capability to run multiple target liquids, covering spin dependent, spin-independent, low- mass, high- mass, exotic couplings…
  - Proposal for larger scale device to be submitted this year in Canada (CFI) .

R&D: Eliminate Target Liquid/ Water Interface

- Exploit thermal gradients to avoid need for 2nd liquid (water) in inner vessel. Aka "Rightside Up Chamber"

Synthetic Fused Silica Bubble Chamber Body Immersed in Thermal Bath at Superheated Operating Temperature

Pressure Balancing Bellows Assembly Immersed in Thermal Bath at Cooler, Normal Liquid Temperature



PICO-60 Synthetic Silica Vessel (12 inch Diameter)

Nested Silica Vessel

Thermal Control Plane

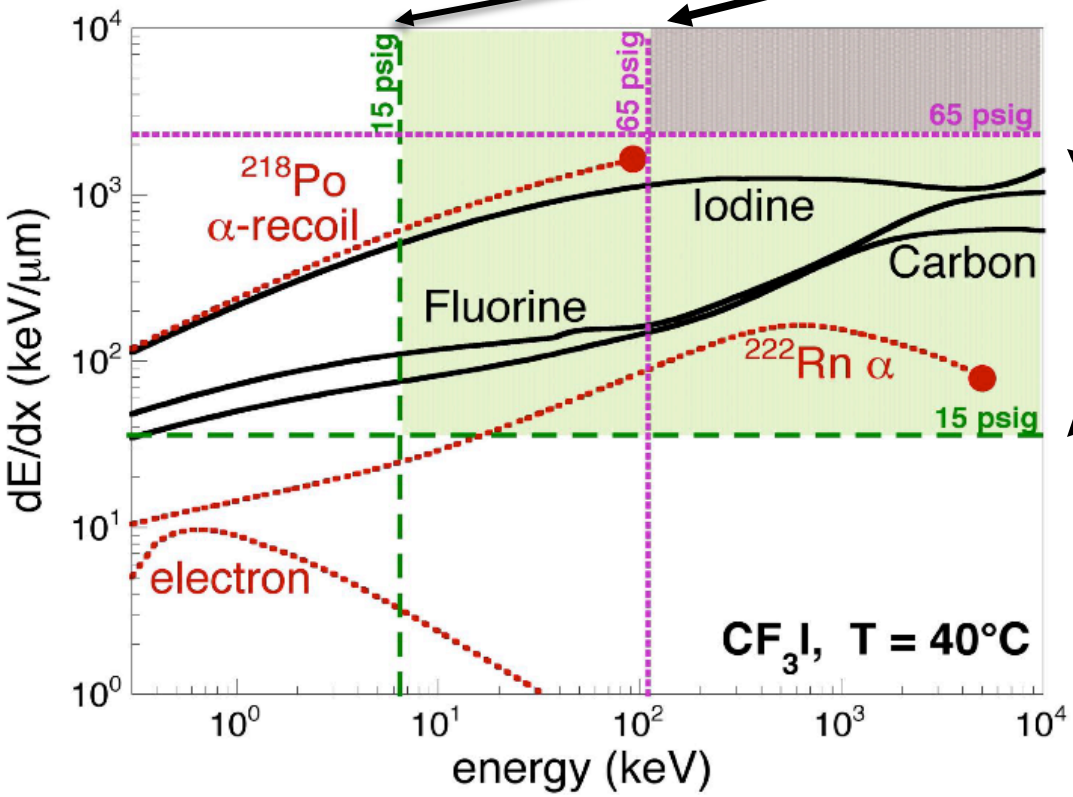
Bellows Assembly

M. Crisler design

Tuning the dE/dX Threshold for Bubble Nucleation

- The bubble chamber operator chooses a pressure and temperature, fixing the minimum size of bubbles that are allowed to grow against surface tension.
- This simultaneously determines minimum deposited energy and energy loss density (dE/dX) that will nucleate bubbles.
- Example below: superheated CF_3I at fixed temperature, two operating pressures.

Energy Thresholds



dE/dX threshold at 15 psi and 65 psi

Possible Mechanism for Generating Events- Embedded Alpha Emitters

- When an alpha decay occurs in liquid, alpha particle and daughter nucleus recoil contribute about equally to amplitude of acoustic signal → alpha decay acoustic amplitude approximately 2 x nuclear recoil from a neutron or WIMP.

- If the alpha-emitting isotope is embedded in solid material <10 microns thick, alpha particle can escape to make a bubble, but nuclear recoil is hidden in the solid. Acoustic amplitude similar to nuclear recoil.

- Ongoing R&D: We are attempting to demonstrate suppressed acoustic signal from alpha activity in particulates with test chambers at Northwestern, Queen's University.