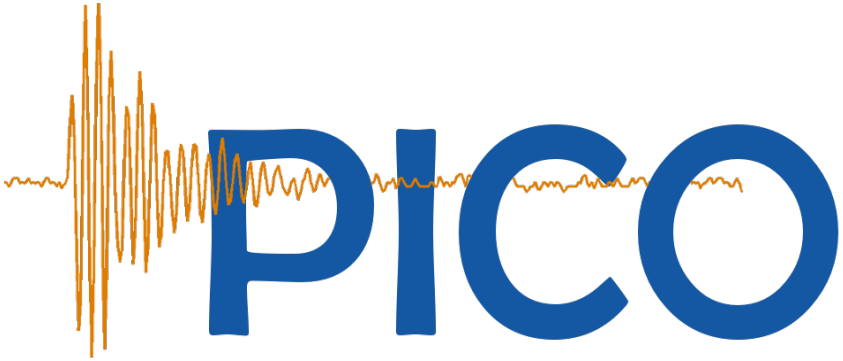


Status of the PICASSO and PICO experiments

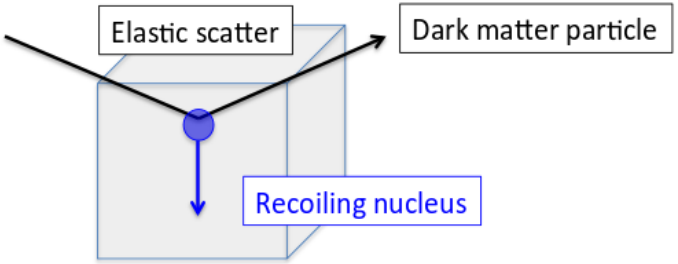
Guillaume Giroux, Queen's University

For the PICO collaboration

CAP Congress 2015, University of Alberta

Detection with superheated liquids

- In a superheated fluid, energy deposition greater than E_{th} in a radius less than r_c will result in a bubble (proto-bubble) large enough to overcome surface tension (Seit "Hot-Spike Model")
- Low E or dE/dx result in smaller bubbles that immediately collapse

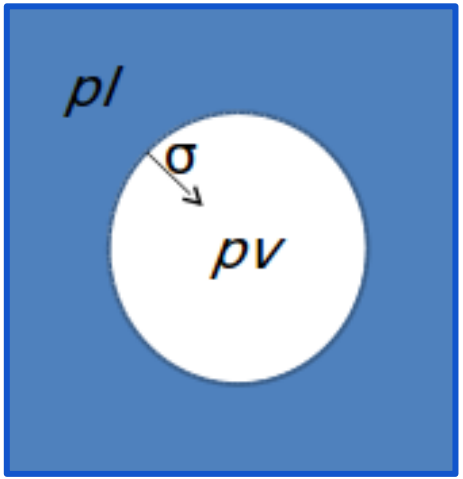


$$p_v - p_l = \frac{2\sigma}{r_c}$$

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

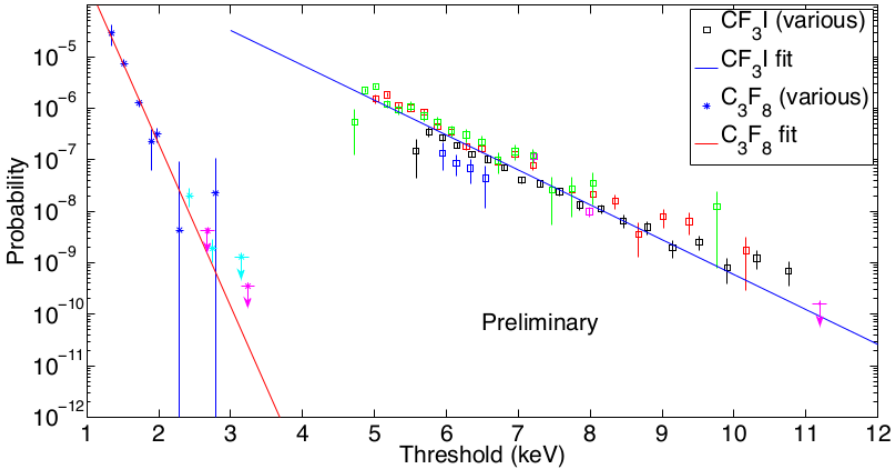
Surface energy

Latent heat

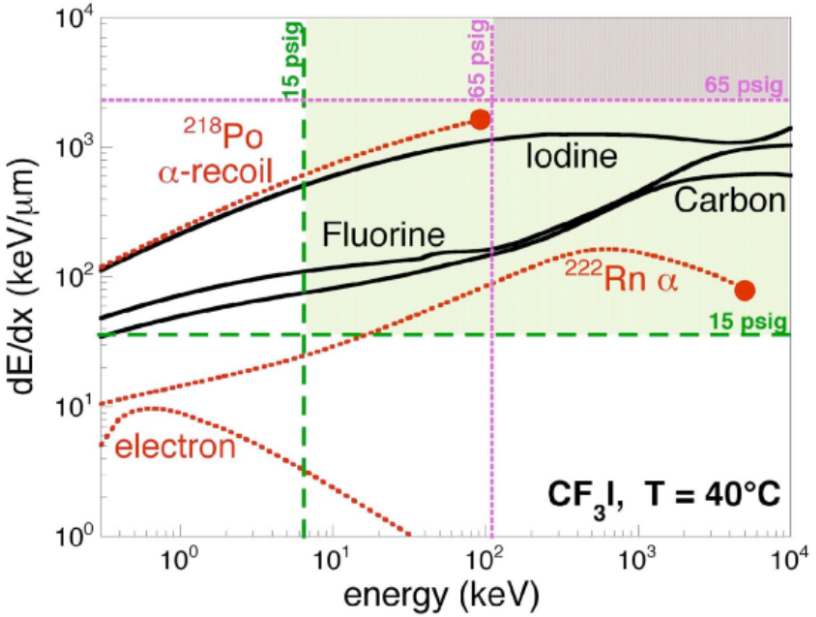


Detection with superheated liquids

Threshold detector:
We can choose superheat parameters (T, P) so that the bubble chamber is blind to electronic recoils (10^{-10} rejection or better)



The probability for gamma interaction to produce a bubble

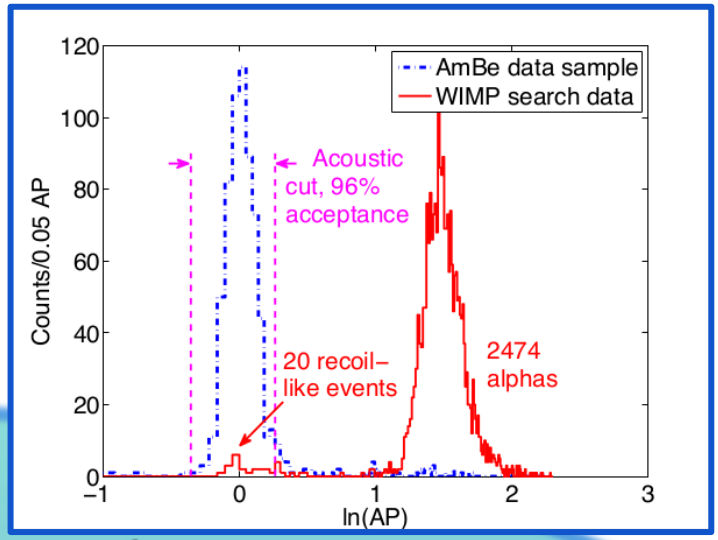


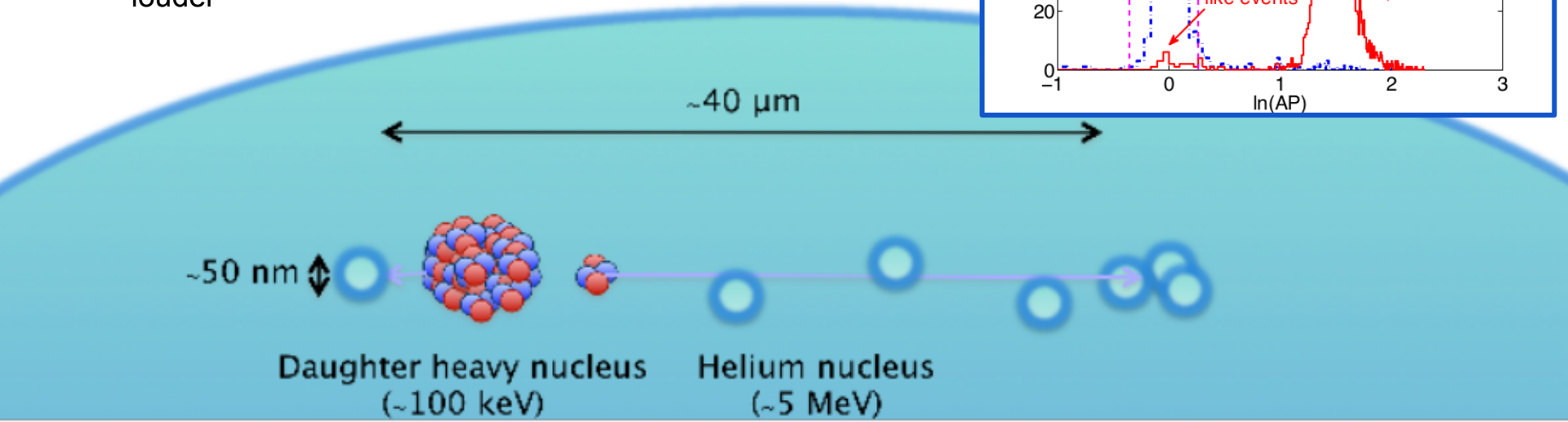
At normal operating thresholds the bubble chamber is sensitive to alpha particle

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 PICO bubble chambers alphas are several times louder





Collaboration

SNOLAB
Mining for knowledge
Creuser pour trouver... l'excellence

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Czech Technical University in Prague

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Indiana University South Bend

E. Behnke, H. Borsodi, O. Harris, I. Levine, E. Mann, J. Wells

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University of Alberta

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University of Toronto

K. Clark

Laurentian University / Université Laurentienne

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Université de Montréal

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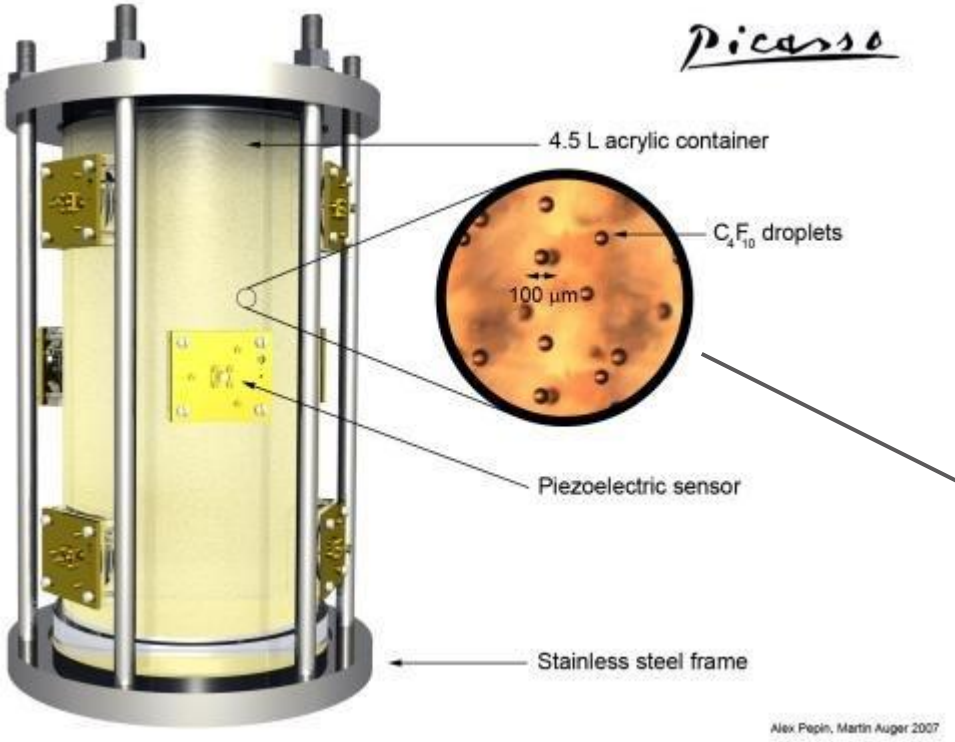
KICP Kavli Institute for Cosmological Physics

J.I. Collar, R. Neilson, A.E. Robinson

Virginia Tech

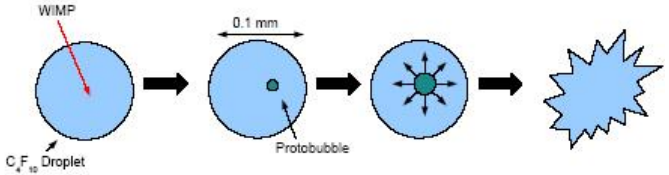
D. Maurya, S. Priya

PICASSO

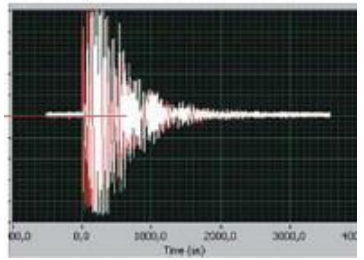


C_4F_{10} droplet PICASSO detector module

Each superheated droplet its own bubble chamber



Acoustic signals are acquired by 9 piezoelectric transducers (bubble position reconstruction)



PICASSO detection modules can be recompressed to revert bubbles to liquid state

PICASSO-32

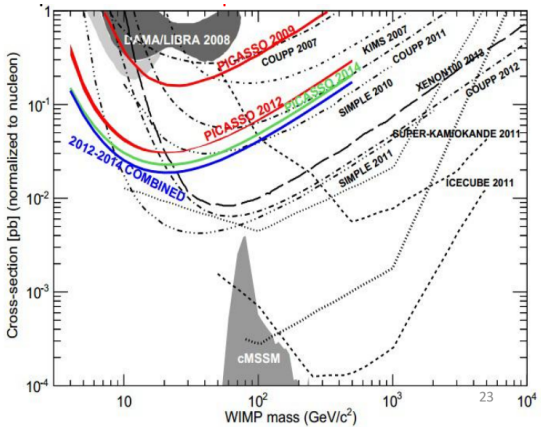
4 PICASSO detector modules in a TPCS
(Temperature and Pressure Control System)

8 PICASSO TPCS (32 modules) inside a water shield
deep underground at SNOLAB
~2 kg active mass

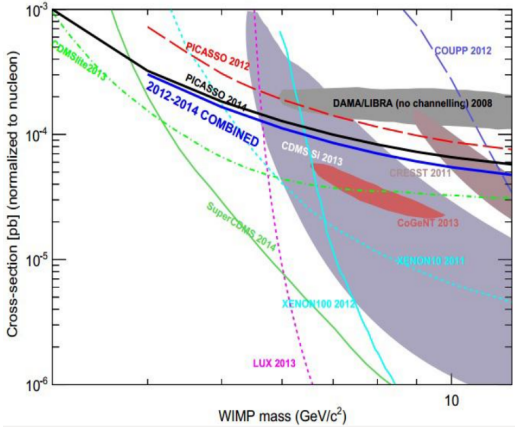
PICASSO-32 results

- Presence of poorly understood backgrounds “mystery events”
- Restrictive fiducial cut and wavelet decomposition analysis used to obtain low background data set
- Final analysis underway
- Sensitivity limited by superheated droplets technology:
  - **Low active liquid loading (~2%)**
  - **Large amount of non active mass (water based polymer gel)**
  - **Acoustic discrimination incomplete in droplet detectors (geometry)**
  - **Unknown backgrounds**

PRELIMINARY



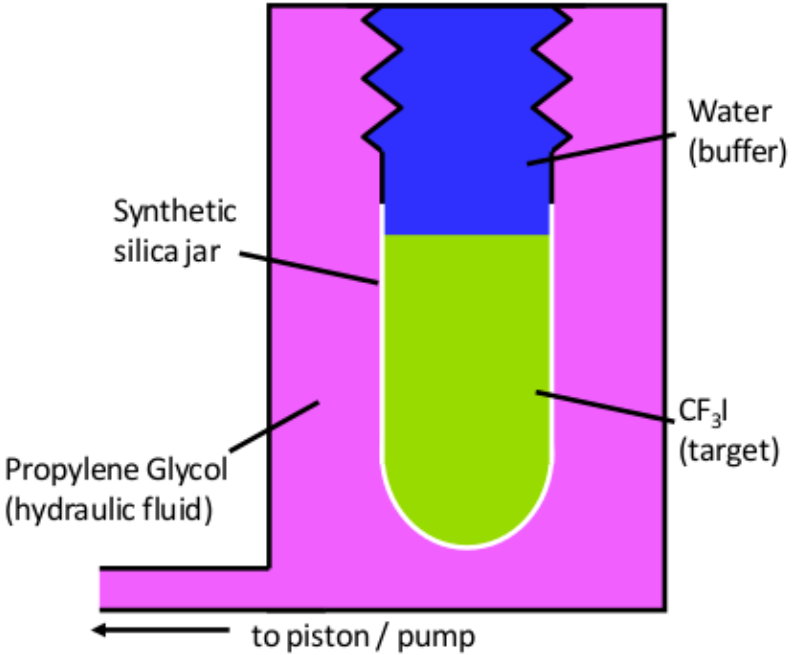
PRELIMINARY



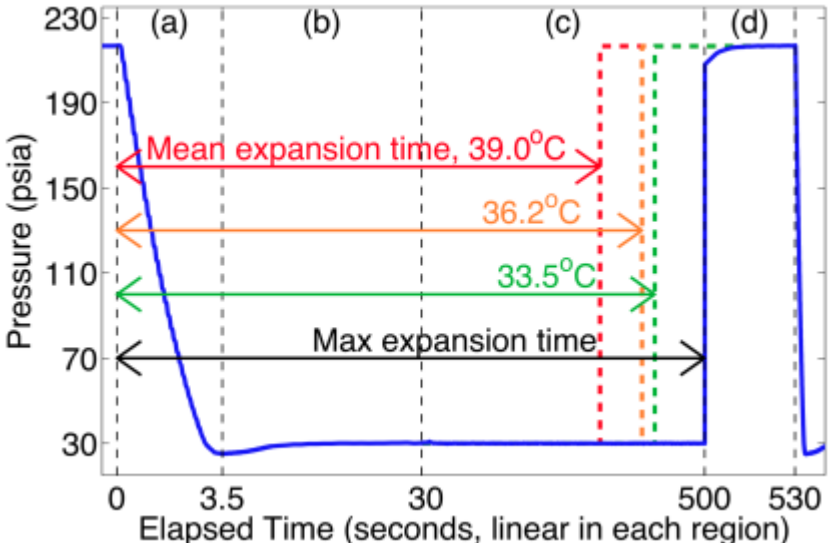
Alvine Kamaha PhD thesis,Queen’s University, 2015

Preliminary final limits for PICASSO using 32 detector modules at Snolab.

COUPP type bubble chambers

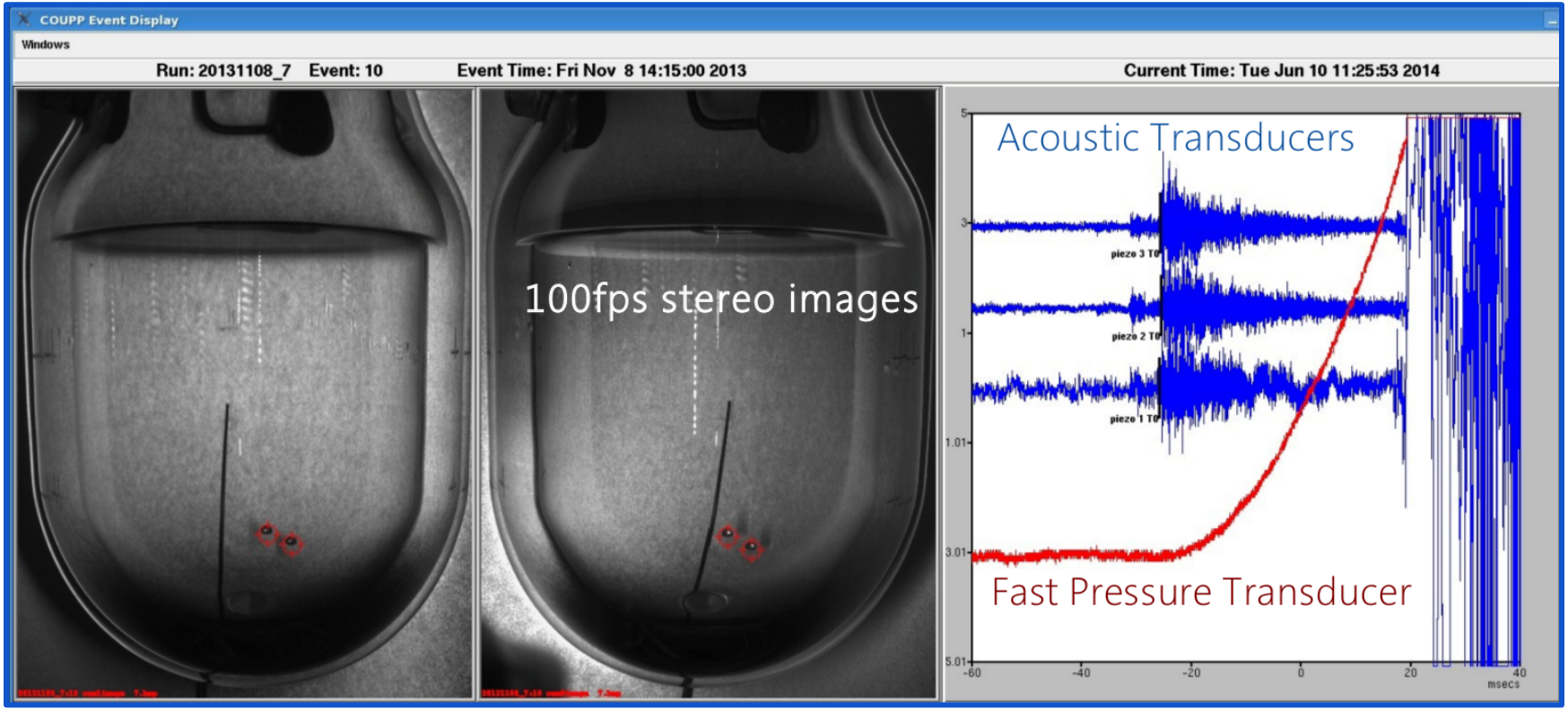


PICO type bubble chamber pressure control



PICO type bubble chamber pressure cycle

COUPP type bubble chambers



PICO-2L

- First joint COUPP/PICASSO detector deployment: a 2-litre C_3F_8 detector to replace COUPP-4
- **C_3F_8** has better fluorine sensitivity than **CF_3I** (COUPP-4):
  - Twice the F density
  - Lower threshold
  - More stable chemistry
- Installed at deep underground at Snolab
- Prototyping for PICO-250L

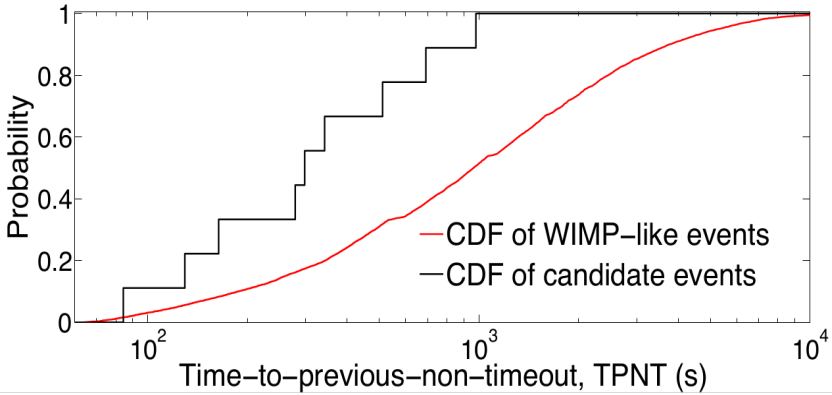
PICO-2L 2-bellow design inner vessel assembly

PICO-2L pressure vessel

Phys. Rev. Lett. 114, 231302 – Published 11 June 2015

PICO-2L results

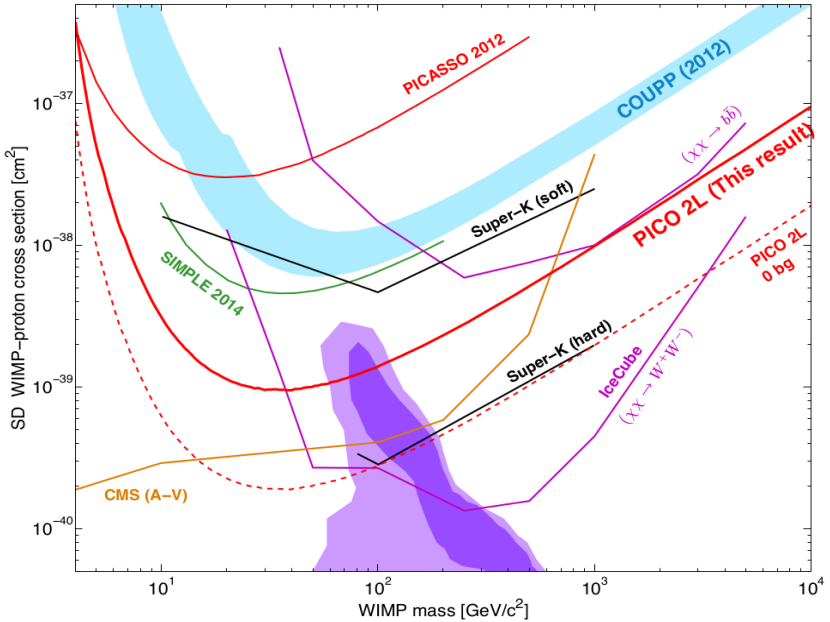
- Total exposure 211.15 kg-days
- 4 energy thresholds ranging from 3.2 to 8.1 keV
- **12 nuclear recoil candidate events (expected 1 background event from neutrons)**
- Timing not consistent with uniform distribution
- **No evidence for a dark matter signal**



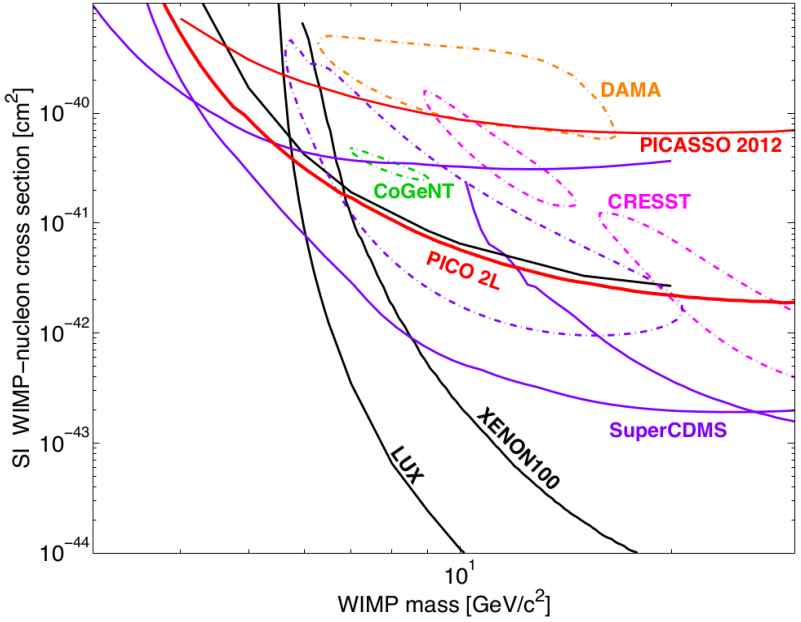
Seitz threshold, E_T (keV)	Livetime (d)	WIMP exposure (kg-d)	Candidates
$3.2 \pm 0.2(\text{exp}) \pm 0.2(\text{th})$	32.2	74.8	9
$4.4 \pm 0.3(\text{exp}) \pm 0.3(\text{th})$	7.5	16.8	0
$6.1 \pm 0.3(\text{exp}) \pm 0.3(\text{th})$	39.7	82.2	3
$8.1 \pm 0.5(\text{exp}) \pm 0.4(\text{th})$	18.2	37.8	0

Phys. Rev. Lett. 114, 231302 – Published 11 June 2015

PICO-2L results



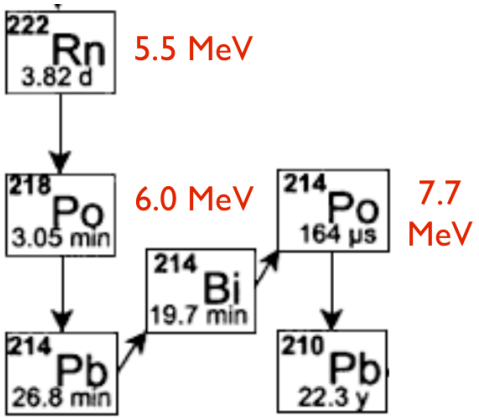
Spin dependent WIMP-proton 90% C.L.
World's best for direct detection!

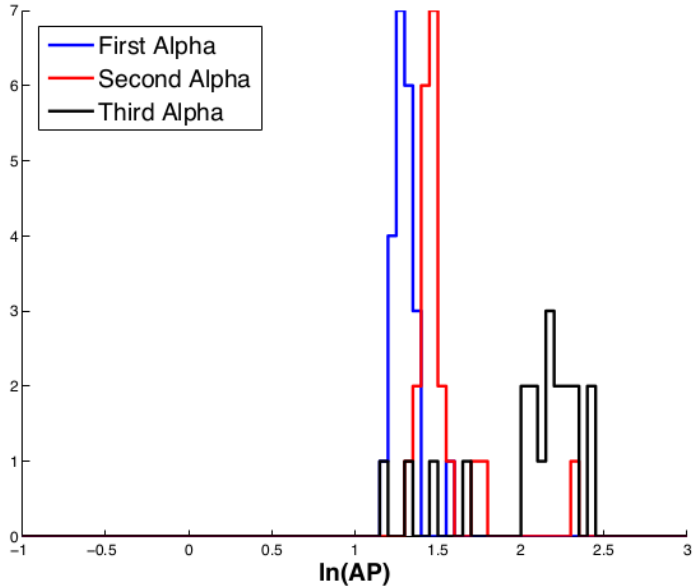


Spin independent WIMP-nucleon 90% C.L.
PICO-2L challenges signal claims in the low mass region!

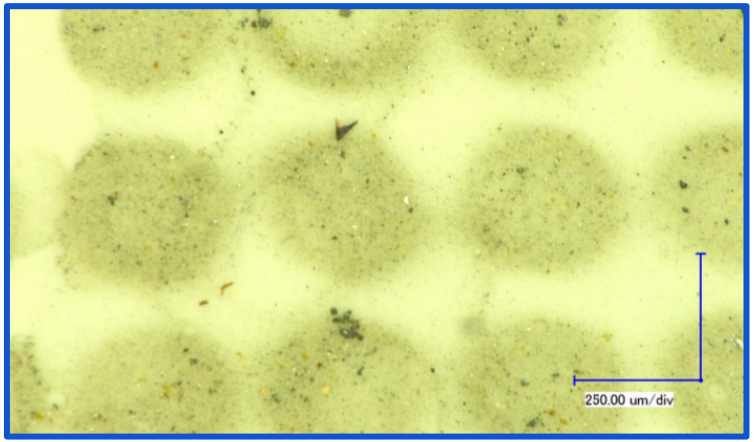
Alpha spectrometry

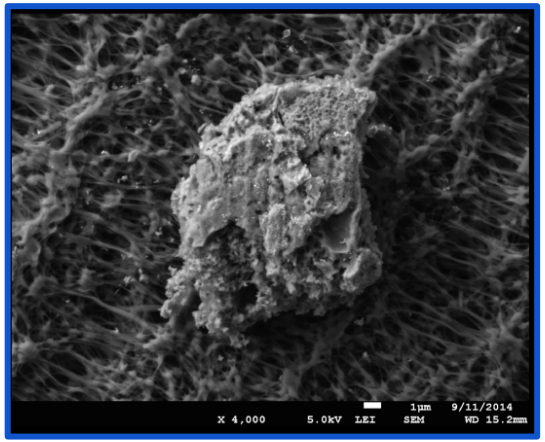
- Two distinct alpha peaks, well separated from neutron data
- Timing of events is consistent with Rn decay, and higher energy alphas are louder
- First observation of *acoustic calorimetry*!

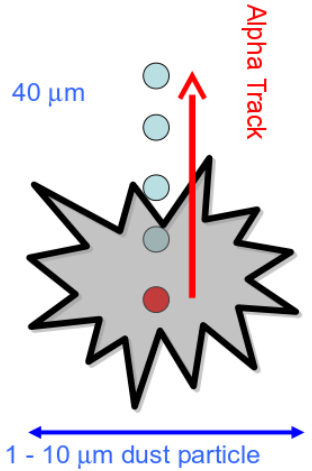




PICO-2L results







Filter sample from PICO-2L

- Leading hypothesis - particulate contamination
- ICP-MS has found enough thorium to explain PICO-2L rate

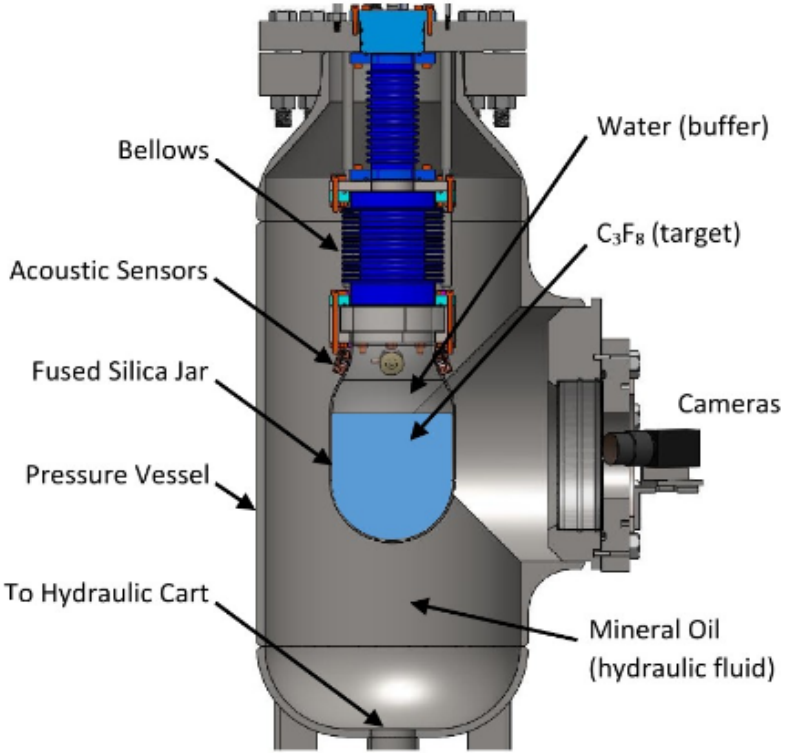
XRF has identified many components chemically

- Stainless steel
- Quartz
- Gold (from seal)
- Silver (VCR parts?)

Anomalous background from degraded alpha tracks?

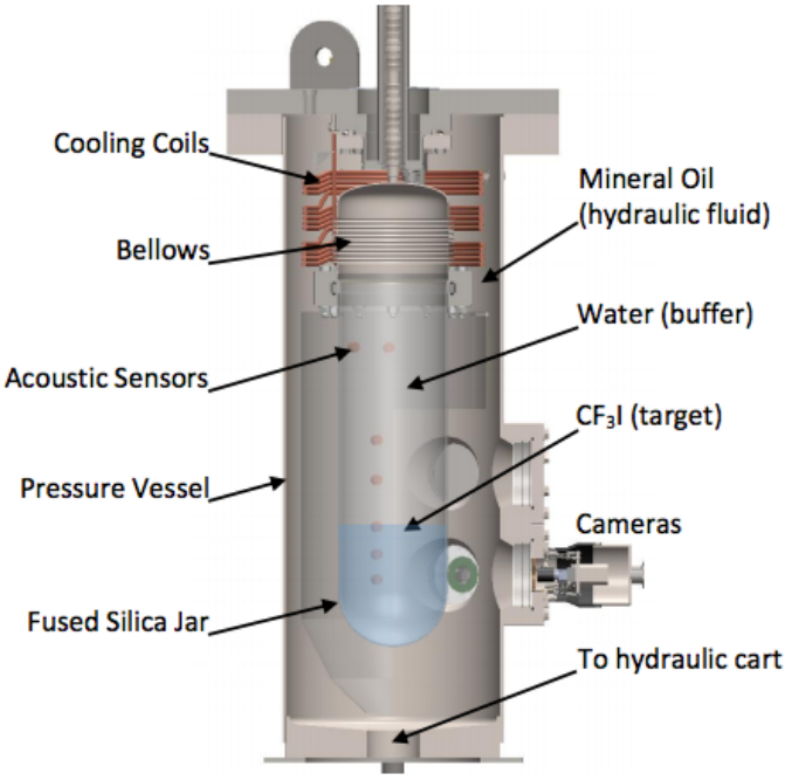
PICO-2L status

- PICO new run started early 2015
  - **Natural quartz jar flange replaced with fused silica**
  - **6 new piezo transducers**
  - **Cleaner fill**
  - **Better temperature control**
  - **New cameras**
  - **Camera cooling system**
- Currently in stable operations and collecting data at 3 keV threshold



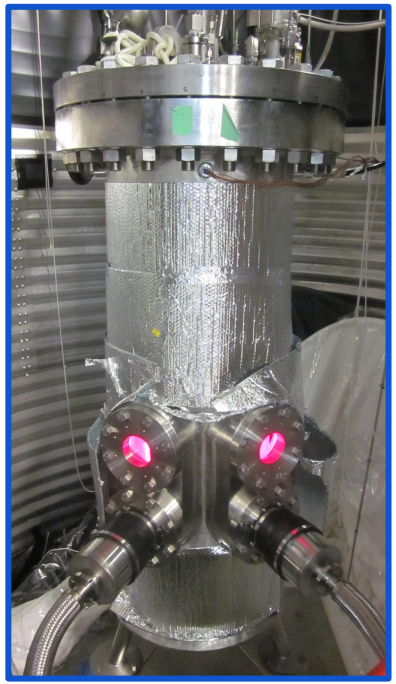
PICO-60

- 30L bubble chamber with **60 kg CF_3I** target ← SD and SI interactions
- Formerly know as **COUPP-60**
  - **Engineering run in shallow site at Fermilab**
  - **Low background and acoustic discrimination**
  - **Fluid darkening due to photodissociation of iodine**
  - **Excessive surface rate**
  - **Solutions tested in second engineering run in 2011**
  - **Moved at Snolab**



PICO-60

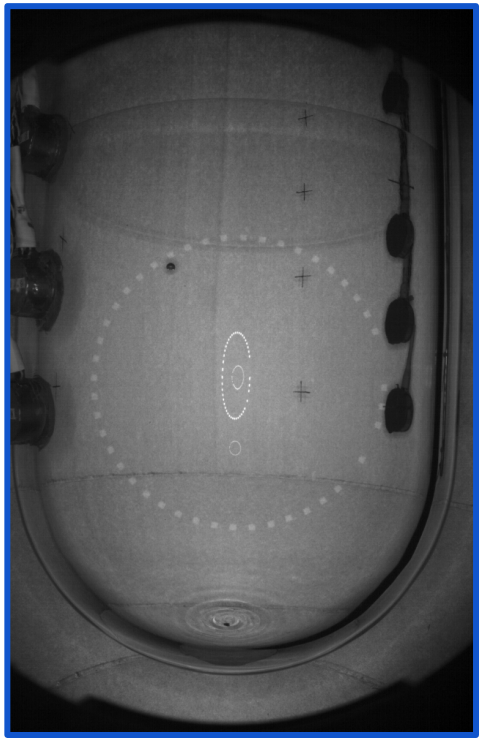
PICO-60 installation in water tank at Snolab



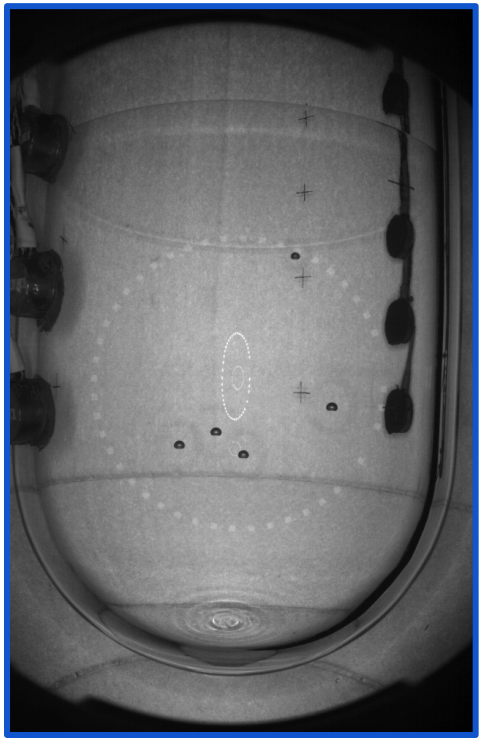
PICO-60 Pressure vessel inside the water tank at Snolab

PICO-60 inner vessel preparation

PICO-60



1-bubble event

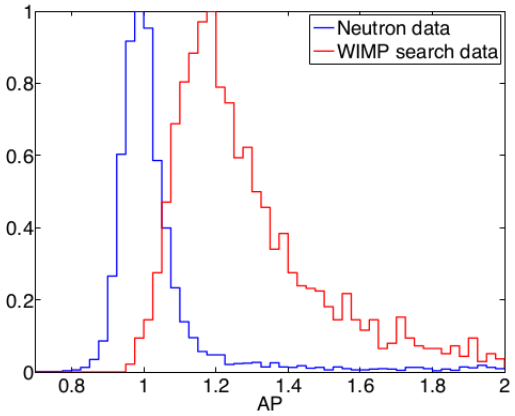


5-bubble event

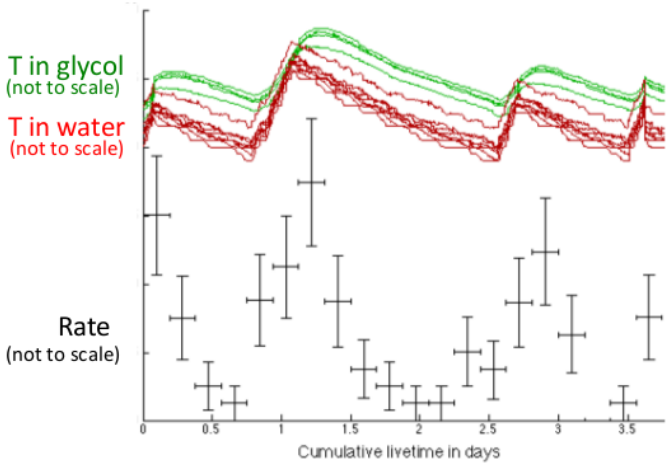
- Filled with 36.8 kg of **CF_3I**
- Physics data started mid-June 2013
- Collected >2700 kg-days of dark matter search data between 9 and 25 keV thresholds
- Analysis near completion
- Zero multiple bubble events in LB data
- Excellent acoustic discrimination

PICO-60 anomaly

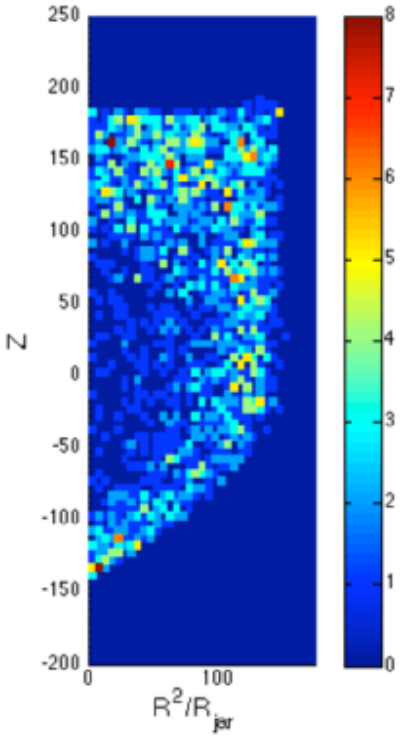
- Bad news: **population of events that sound like nuclear recoils but are clearly not WIMPS**
- Large number of anomalous events: we can study them in detail



Background as a slightly different acoustics than nuclear recoils



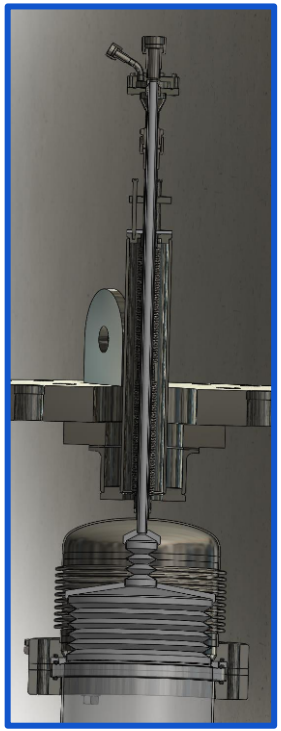
Background rate is correlated with the change in temperature during operation



Not distributed evenly in volume

PICO-60 upgrade

- Particulate control:
  - **New fluid handling system: Removal of particulates from buffer and target liquids. 1L per minute flows through 100 nm filter**
  - **Inner volume high purity plastic below liner**
  - **Inner vessel cleaning with new spray wash system**
- Swap the target from CF_3I to C_3F_8 (Lower threshold, better sensitivity in SD sector)
- Swap buffer liquid to LAB (Linear Alkyl Benzene)**?**



Summary

Conclusions

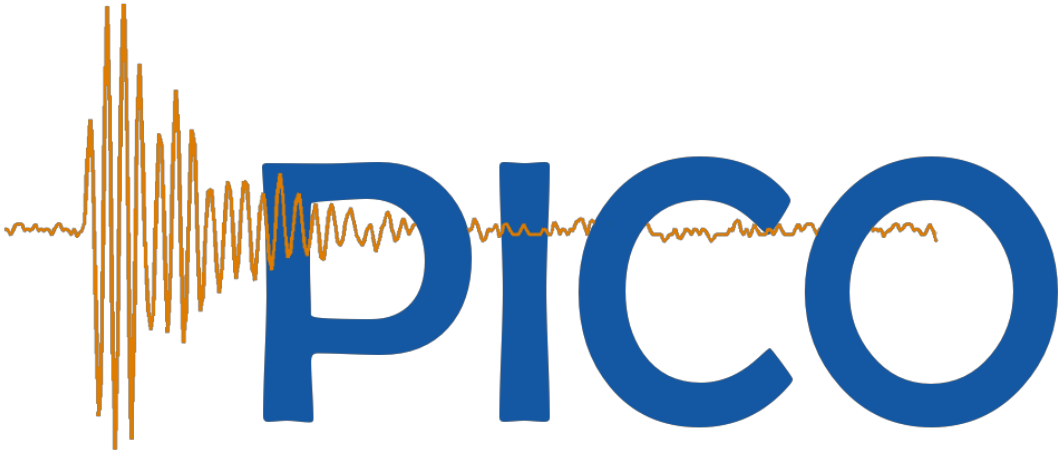
- Bubble chambers for dark matter are coming of age.
- Background free potential
- Should “own” the Spin-Dependent sector with C_3F_8
- Inexpensive, engineering understood

PICO-2L has demonstrated

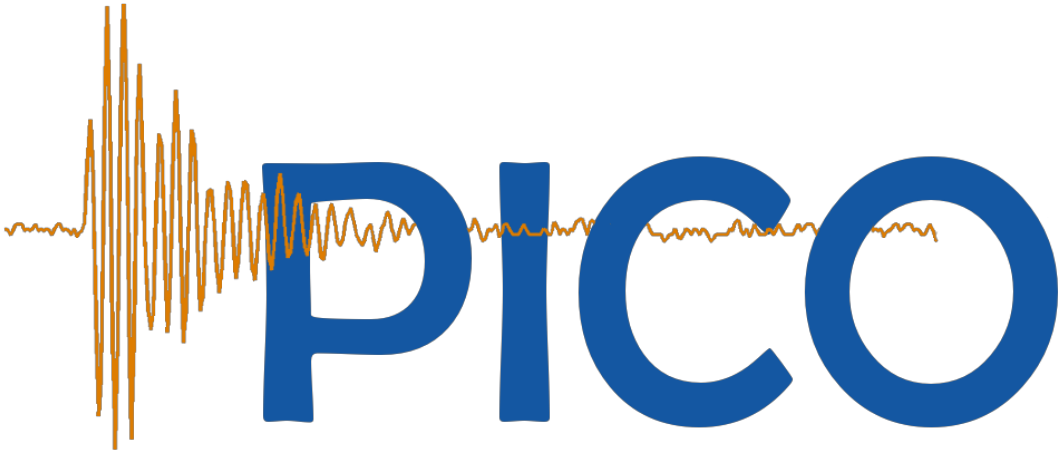
- Successful operation with C_3F_8 at 3 keV nuclear recoil threshold
- No neutron background observed and good acoustic rejection of alphas
- **PICO-2L has a new world-best SD WIMP-proton limit**

Ongoing work

- Program to understand background (assays of particulate contamination, spiked test chambers)
- Clean runs at SNOLAB with PICO-2L and soon PICO-60



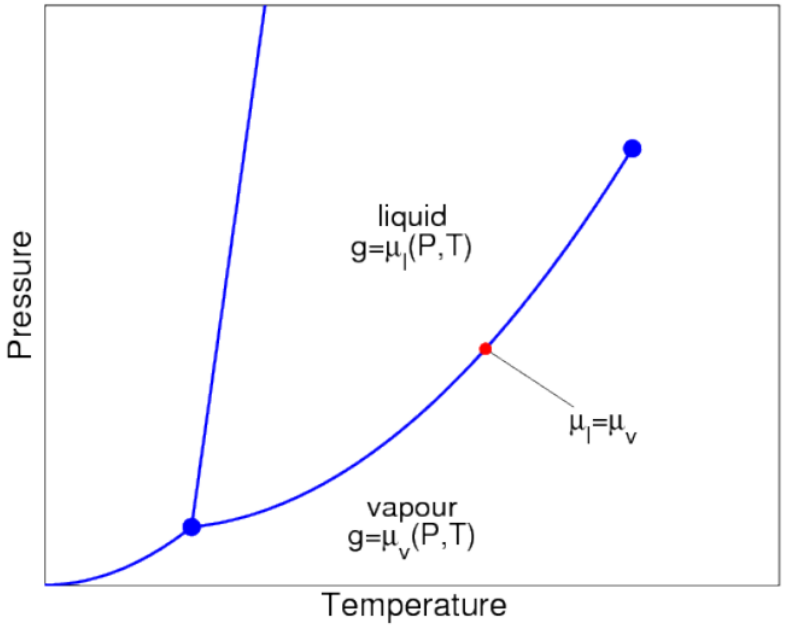
Thank you



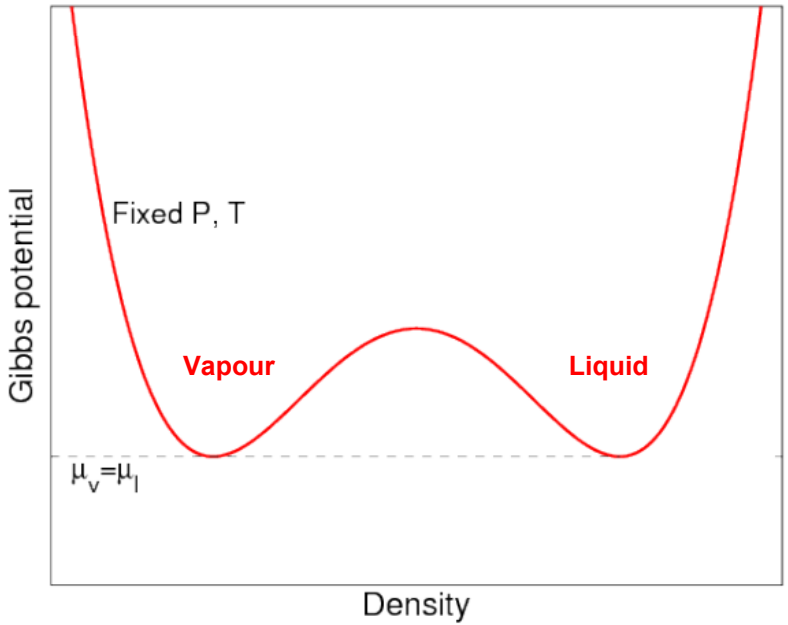
Extra slides

Superheated liquids

Phase diagram



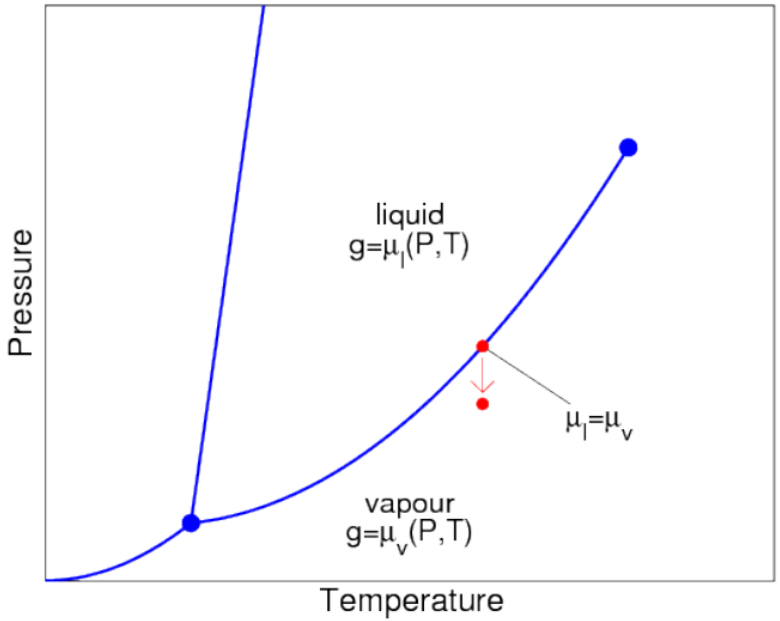
Gibbs free energy



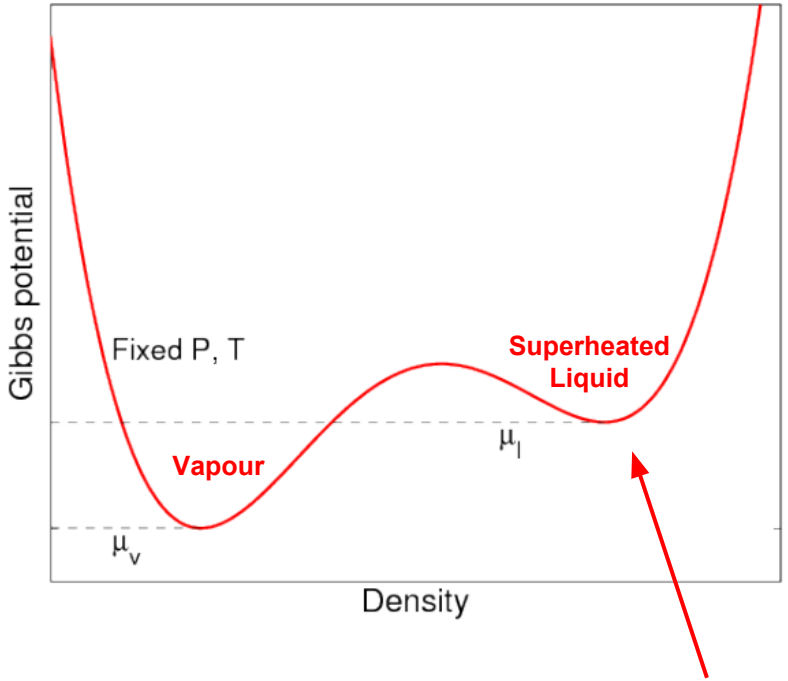
Liquid vapour equilibrium: on the coexistence curve, two equal minima to Gibbs potential exist

Superheated liquids

Phase diagram



Gibbs free energy



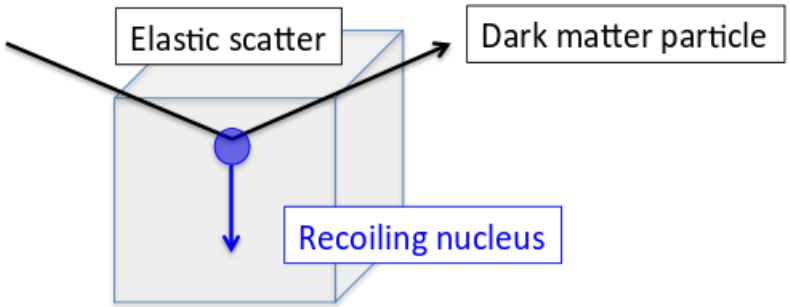
Under the coexistence curve, slightly off curve, still two minima to Gibbs potential one stable, one *metastable*

Dark matter direct detection

Dark matter:

- **Massive**: interact gravitationally
- **Dark**: not interacting with light or electromagnetism
- **Slow**: non-relativistic
- **Weak** interaction with matter

→ **WIMPs** (**W**eakly **I**nteracting **M**assive **P**articles)



Two types of interaction could exist:

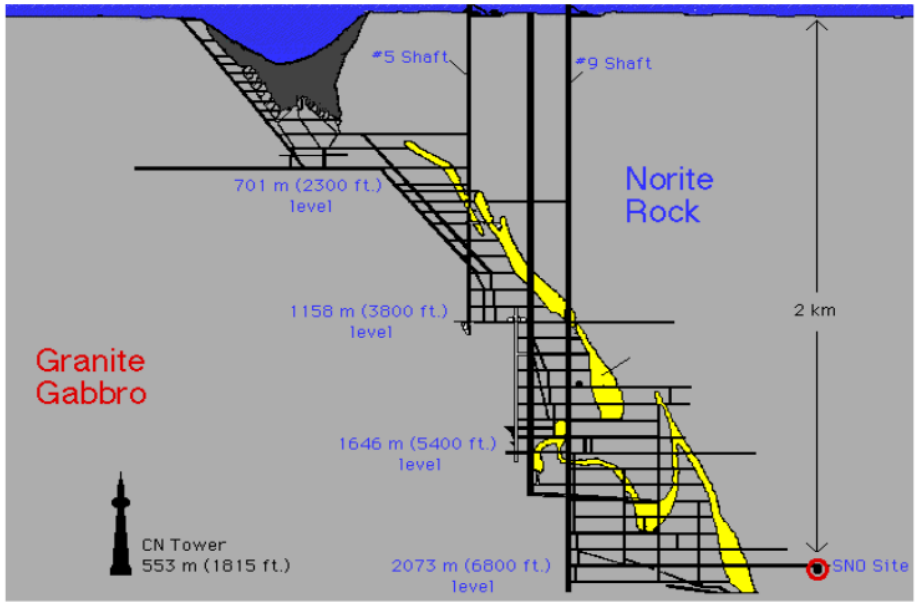
- **Spin independent (SI):**
  - Couples to all nucleons
  - Enhancement for high Z (**Ge, Xe, I**)
- **Spin dependent (SD)**
  - couples to the spin of the nucleus (unpaired spin of one nucleon
  - Enhancement depends on nuclear shell structure (^{19}**F**)

Backgrounds

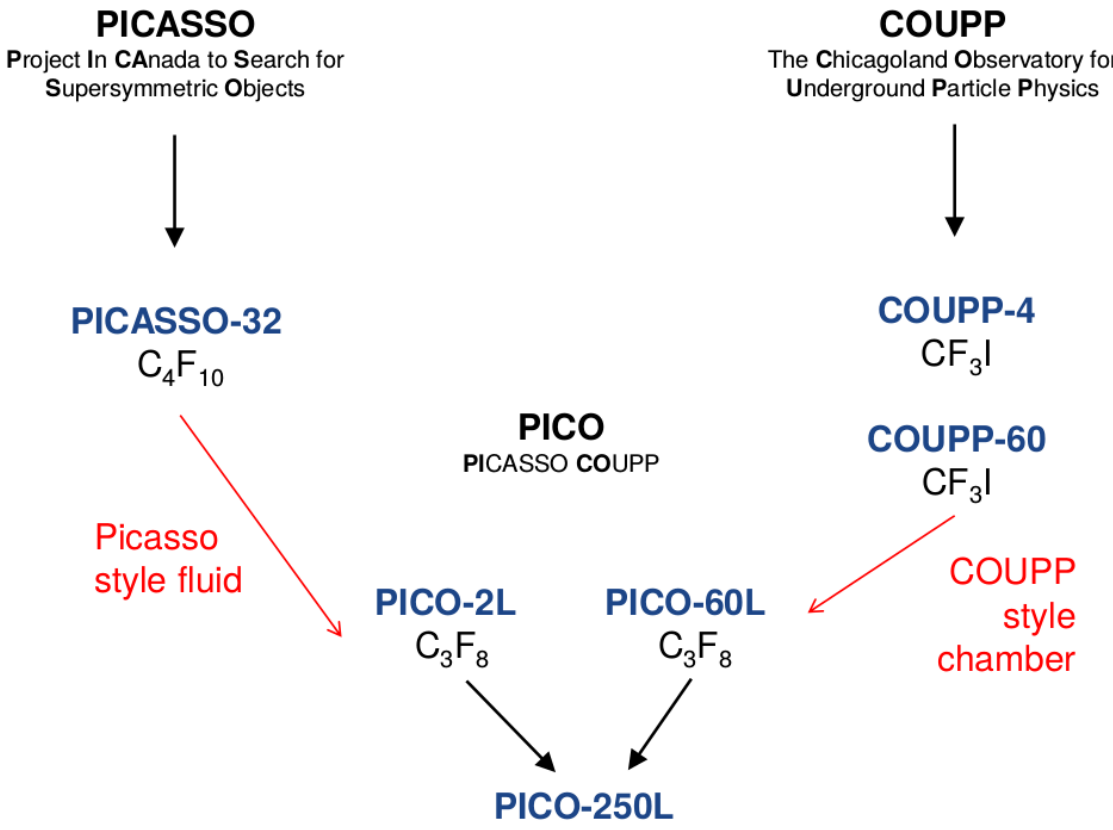
Require very low background environment to see rare events ….

- Go deep underground to escape cosmic rays.
- Provide local shielding
- Use materials with ultra-low levels of radioactivity
- **Develop particle discrimination techniques….**

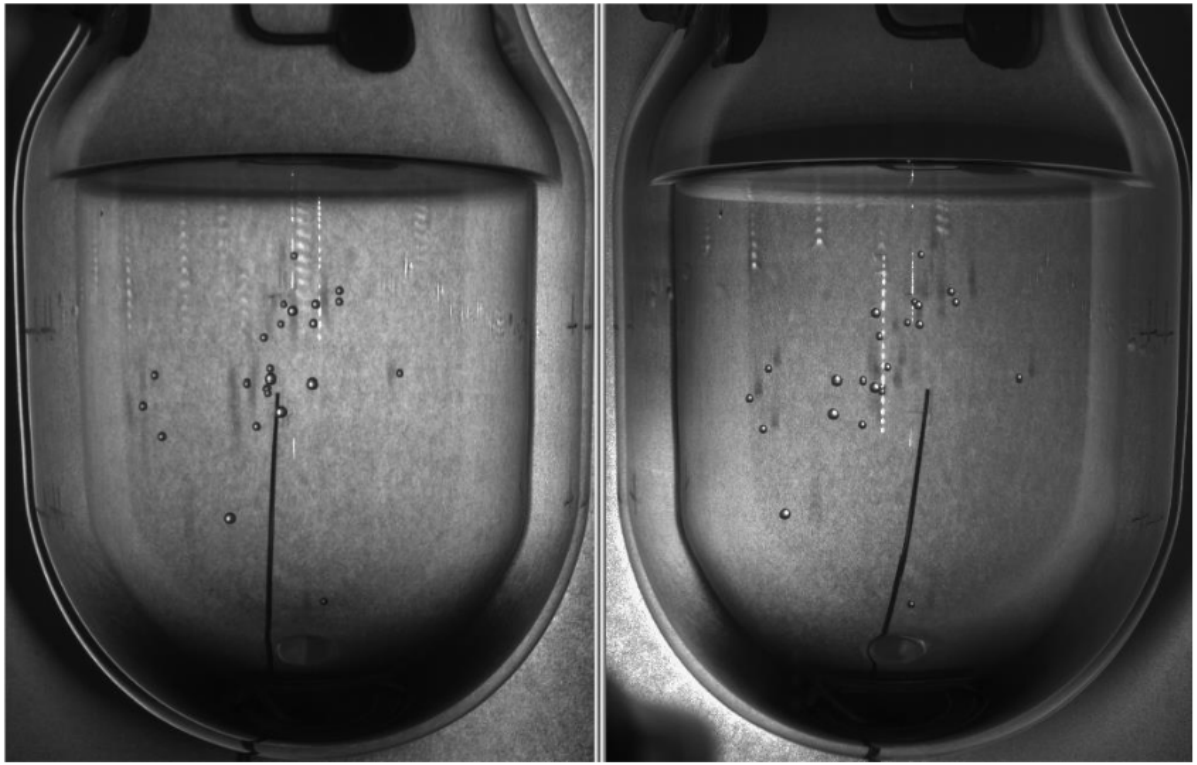
SNOLAB, CANADA



The PICO collaboration

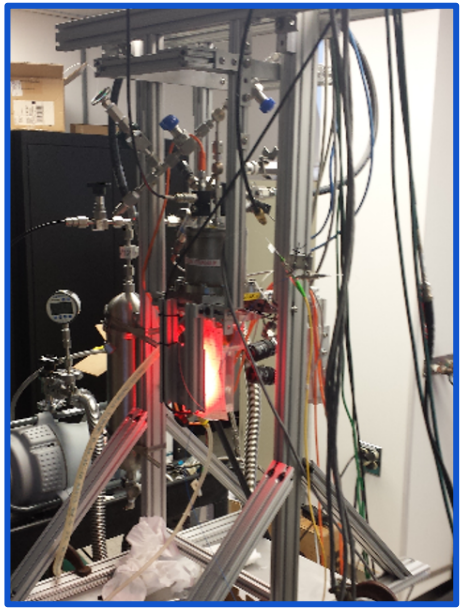


23 bubble AmBe neutron event



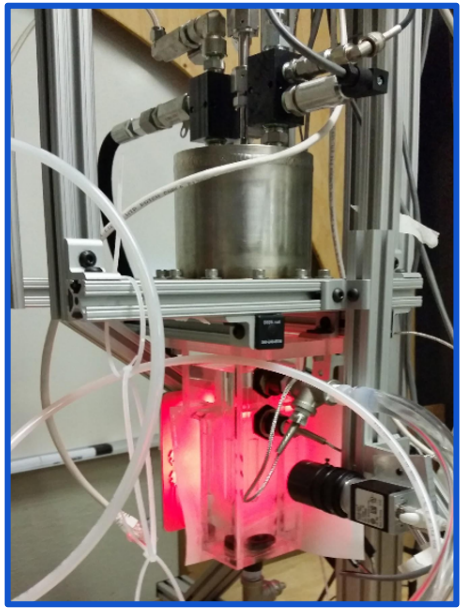
High multiplicity is a result of high bubble nucleation efficiency; 60% of neutron calibration events in C_3F_8 are multiples.

Small test chambers



PICO-30ml (CYRTE)
Fermilab/NU

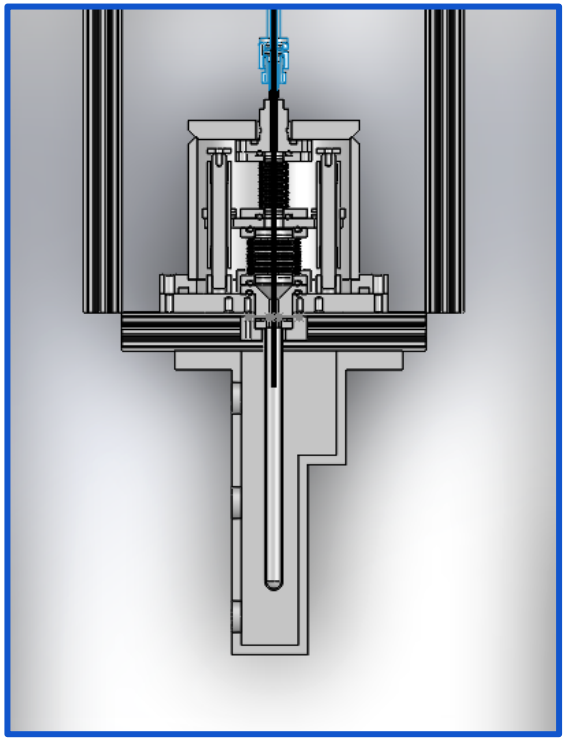
PICO-0.1
Université de Montréal



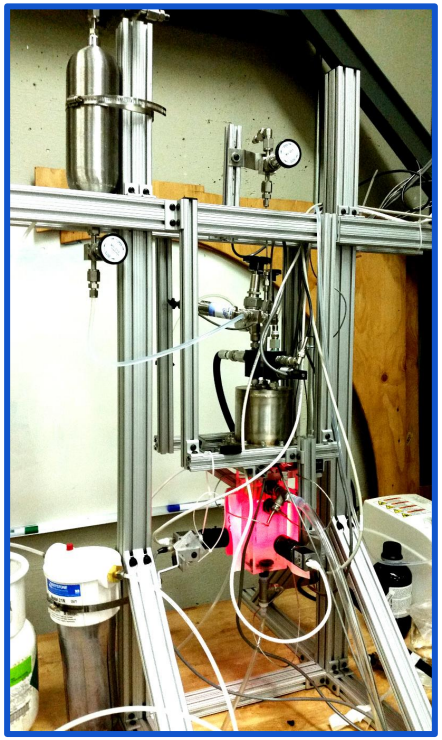
Queen's test chamber
Queen's University

The Queen's test chamber

- Construction of a ~30 ml bubble chamber at Queen's (Sep. 2014)
- CYRTE (NU) clone
- **Chamber fully functional:**
  - Stereo high speed cameras
  - 2 piezo transducers + fast digitizer
  - fast differential pressure transducer
- **Physics programme**
  - Demonstrate alpha/recoil acoustic discrimination in a test chamber
  - Test particulates hypothesis for the observed backgrounds in PICO-2L and PICO-60

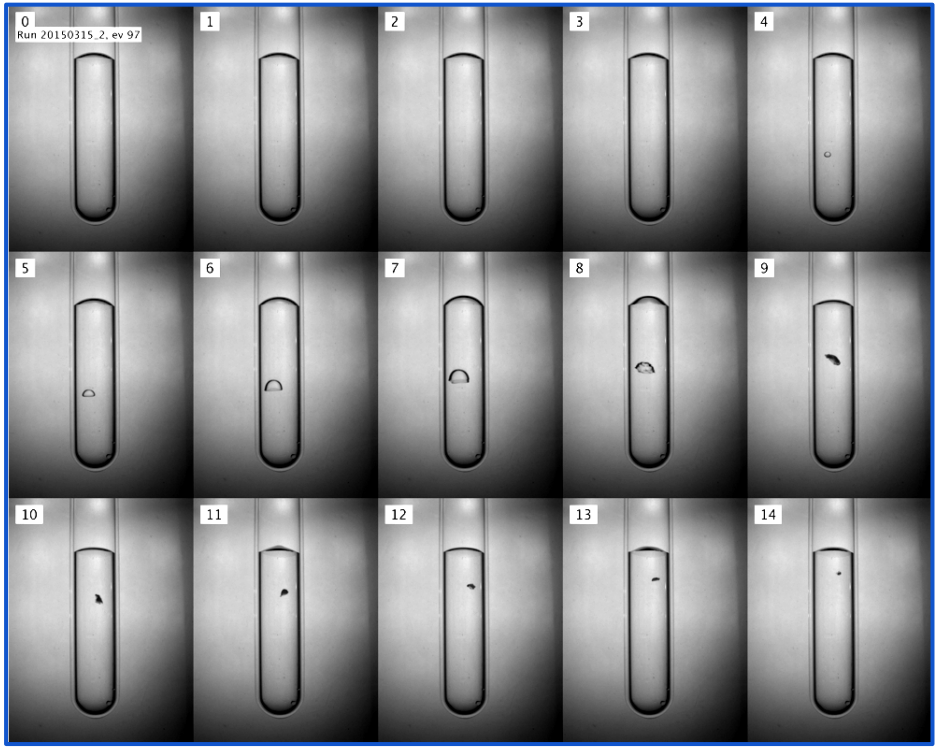


CAD cross section

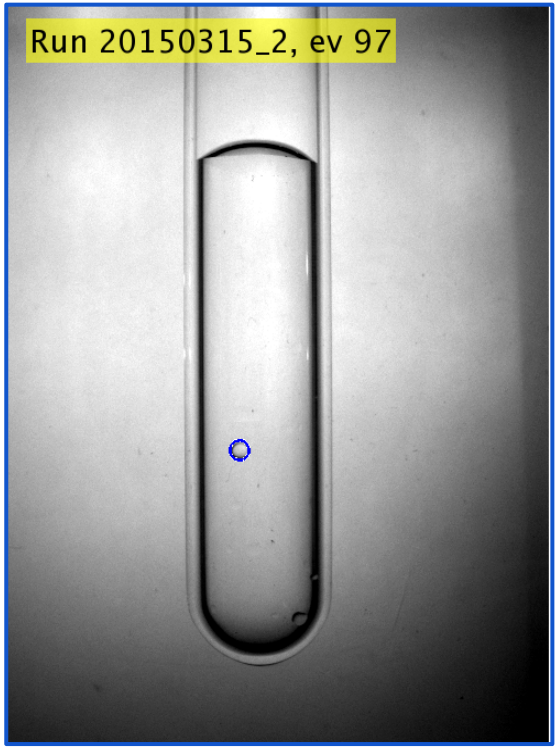


Queen's test chamber

The Queen's test chamber

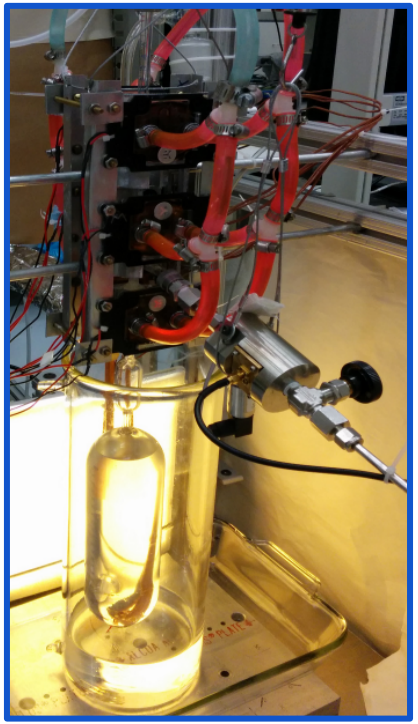


50 Hz camera acquisition



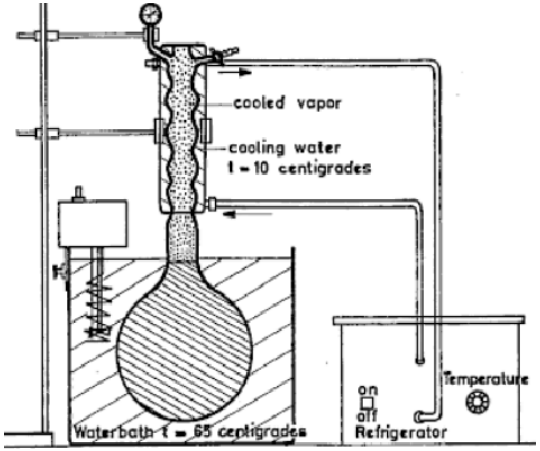
Bubble finding with pattern recognition

Geysers



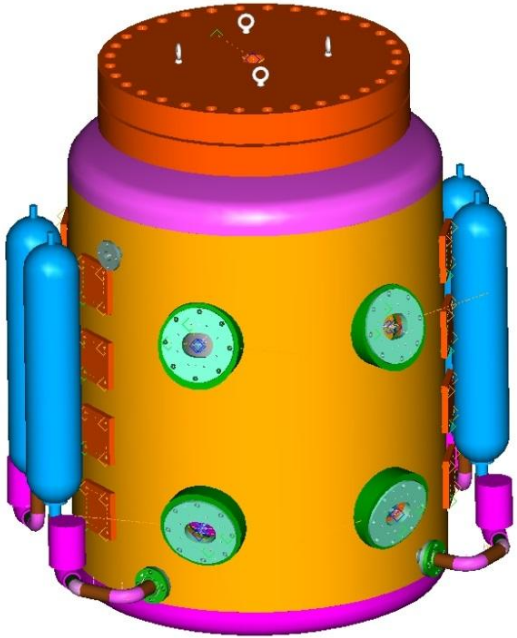
U. of Alberta Geyser

U. de Montréal Geyser

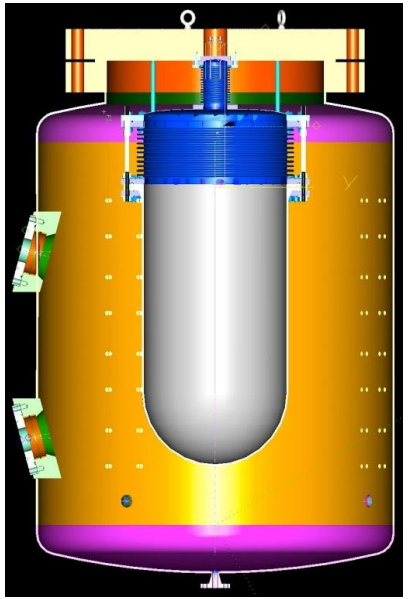


- Hahn and Reist (1973)
- Low dead time detector (continuous operation)
- No moving parts
- Temperature gradient used to condense gas

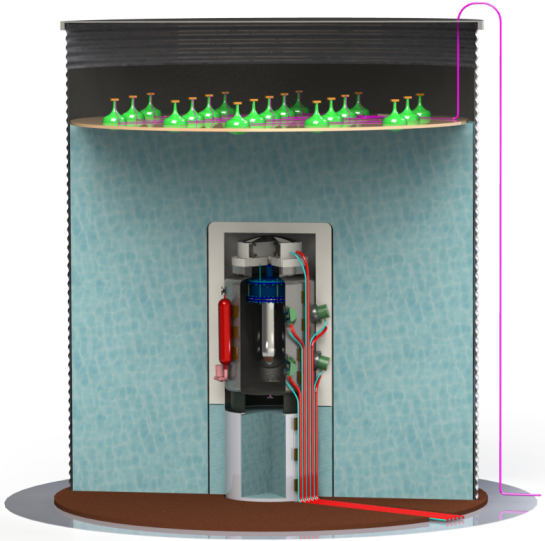
PICO-250L



Outer vessel

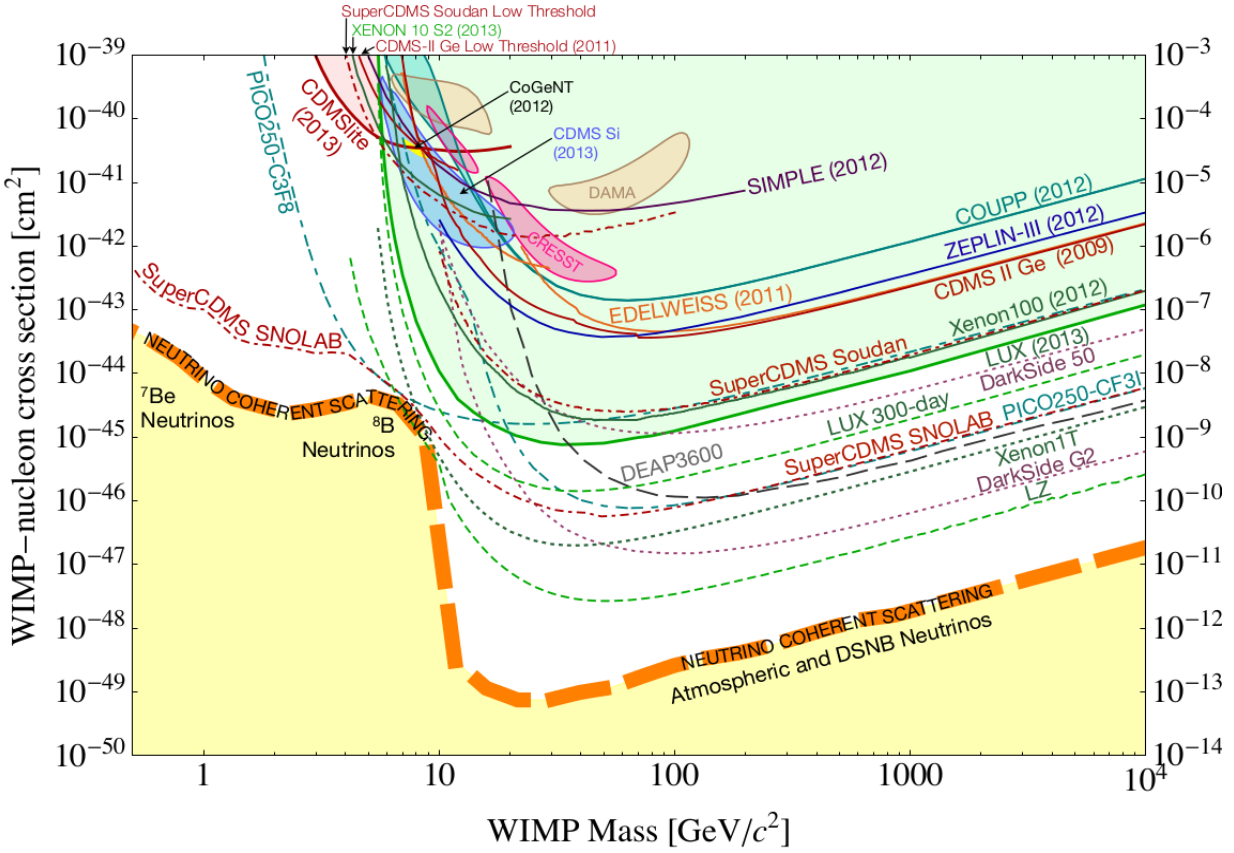


Inner vessel



Water tank

PICO-250L


SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
DarkSide 50
LUX 300-day
PICO250-CF3I
SuperCDMS SNOLAB
Xenon1T
DarkSide G2
LZ
DEAP3600
CRESST
CDMSlite (2013)
PICO250-C3F8
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
^{7}Be Neutrinos
^{8}B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
WIMP–nucleon cross section [cm^2]
WIMP Mass [GeV/c^2]

PICO-60 results