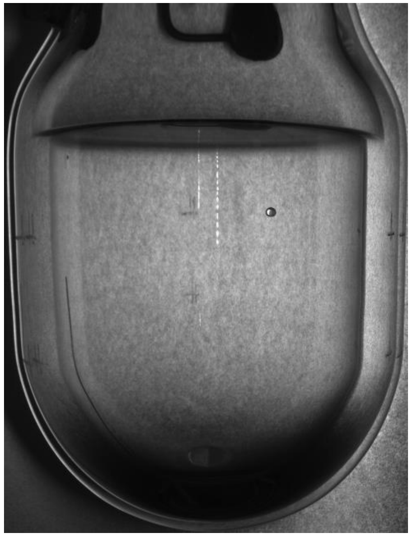
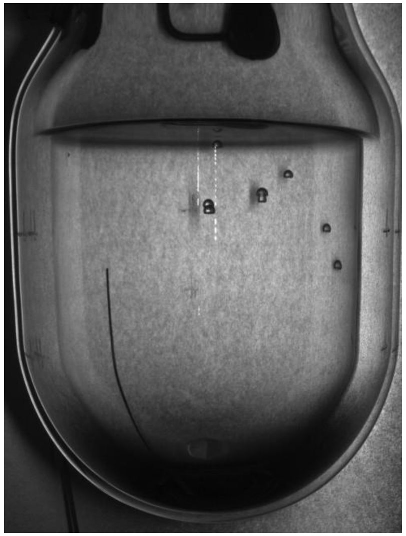
PICO

# Anticipated activities for the PICO project during the next SAP Long Range Planning period.

Tony Noble,
Queen's University
(For the PICO Collaboration)





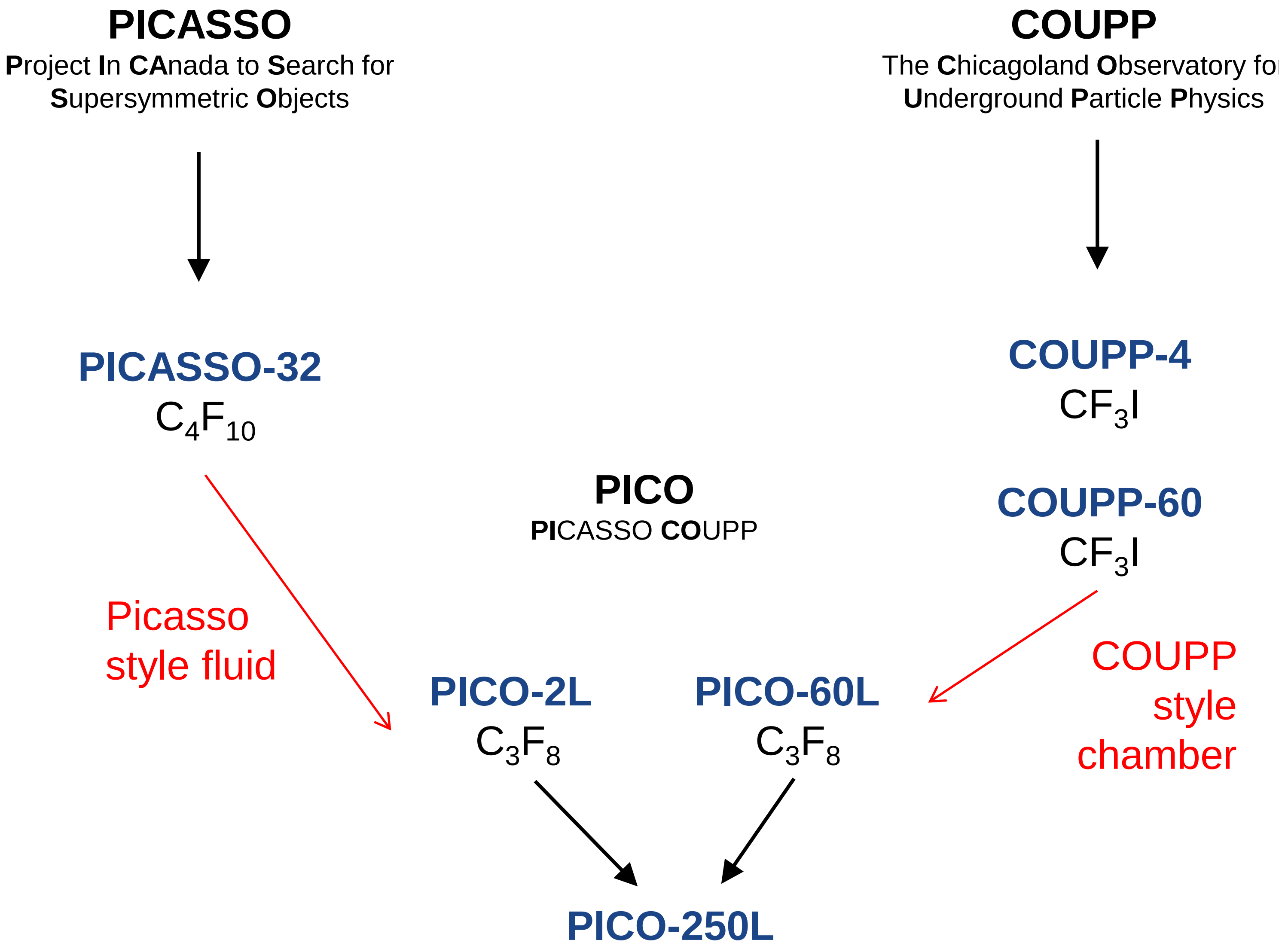
PICO = Merger of **PI**CASSO & **CO**UPP collaborations

## The Objectives of the PICO Collaboration:

- To develop the bubble chamber technology with the ultimate goal of building a **tonne scale detector**.
- Physics Niche area;
  - To fully explore the **Spin-Dependent** sector,
  - To be able to switch to Spin-Independent to confirm any signal appearing in that sector, and
  - To have excellent sensitivity to **low mass WIMPS**
- To reach this capability with a series of detectors of increasing mass and sophistication.

**PICO 2L → PICO 60 L → PICO 250 L**

# The marriage of PICASSO and COUPP



# Particle detection with bubble chambers

- Energy deposition greater than $E_{th}$ in radius less than $r_c$ from particle interaction will result in expanding bubble *(Seitz "Hot-Spike" Model).*

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

Depends on T, P and choice of fluid

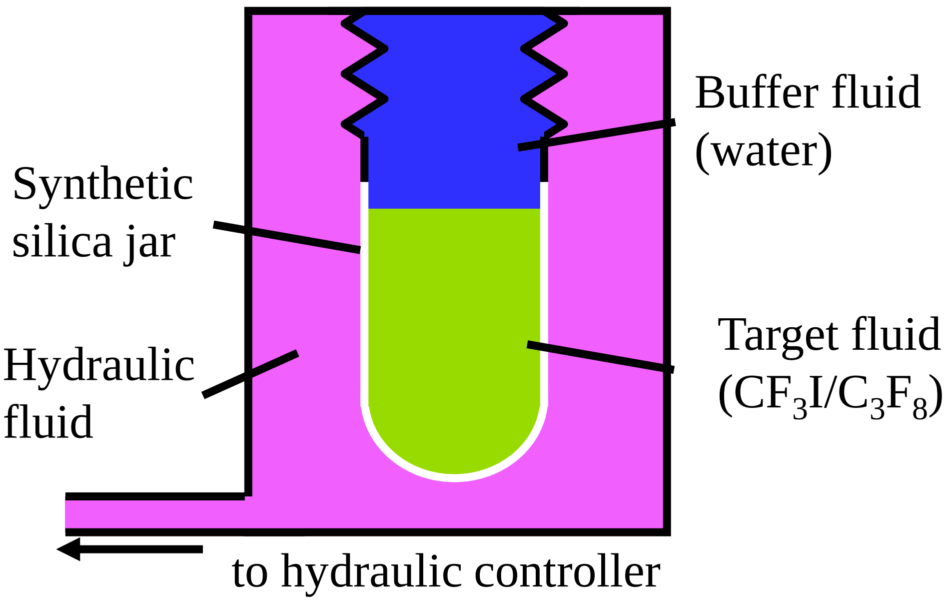
Surface energy    Latent heat

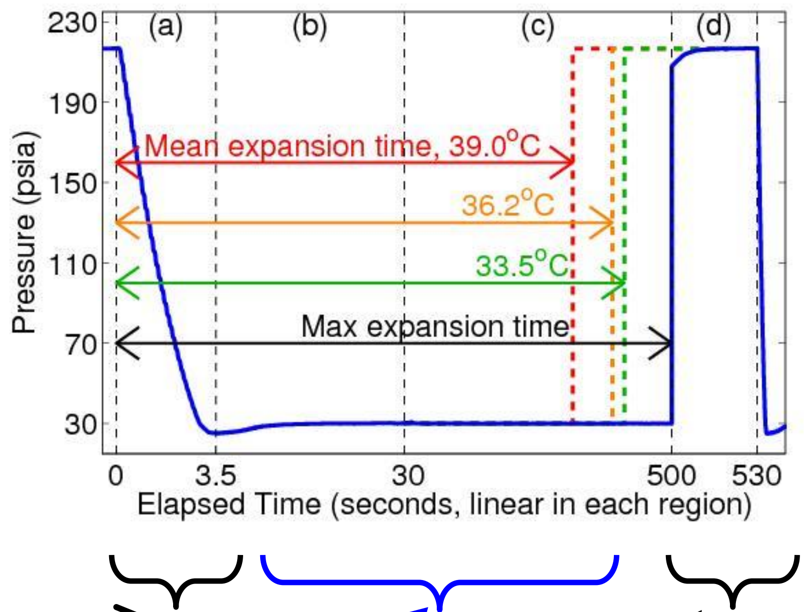
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses.

**Take away message:**

- To be sensitive, particle must deposit enough energy within a critical radius.
- Energy deposition depends on particle type. So can tune detector to be sensitive to certain types only. → Particle discrimination

# Principle of Operation: Bubble Chamber




1. Lower the pressure to a superheated state.

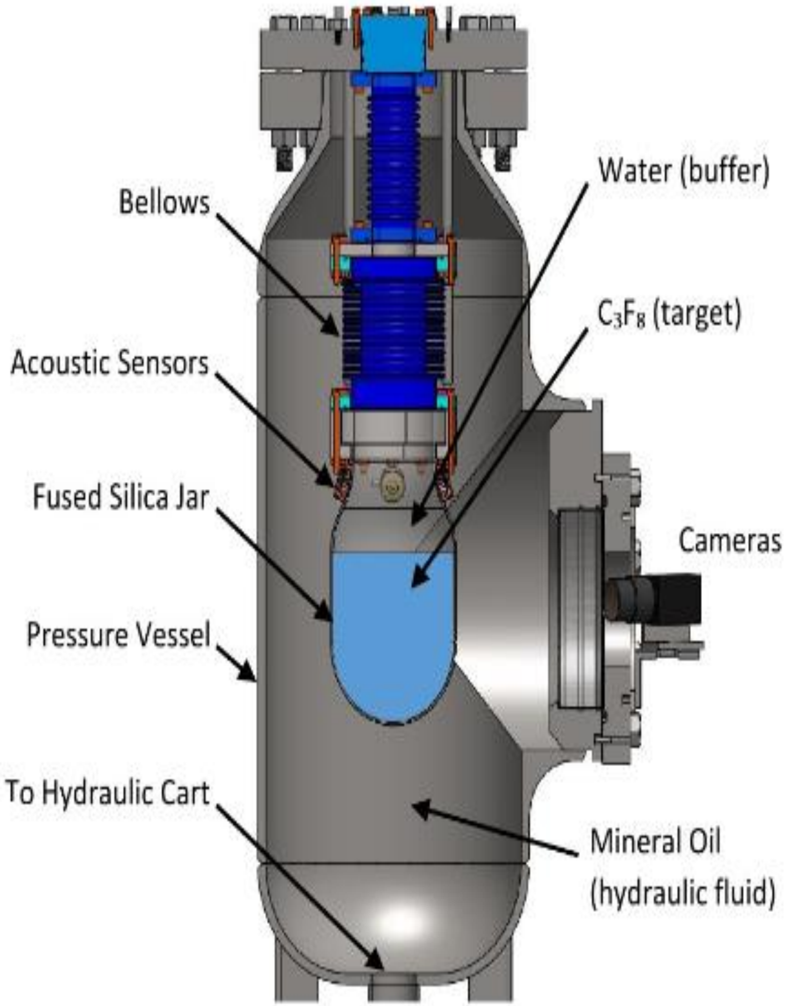
2. See the bubble:
   - Cameras trigger. record position, multiplicity
   - Microphones record acoustic trace
   - Fast pressure transducer recording.

3. Raise pressure to stop bubble growth (100ms), reset chamber (30sec)

# PICO-2L

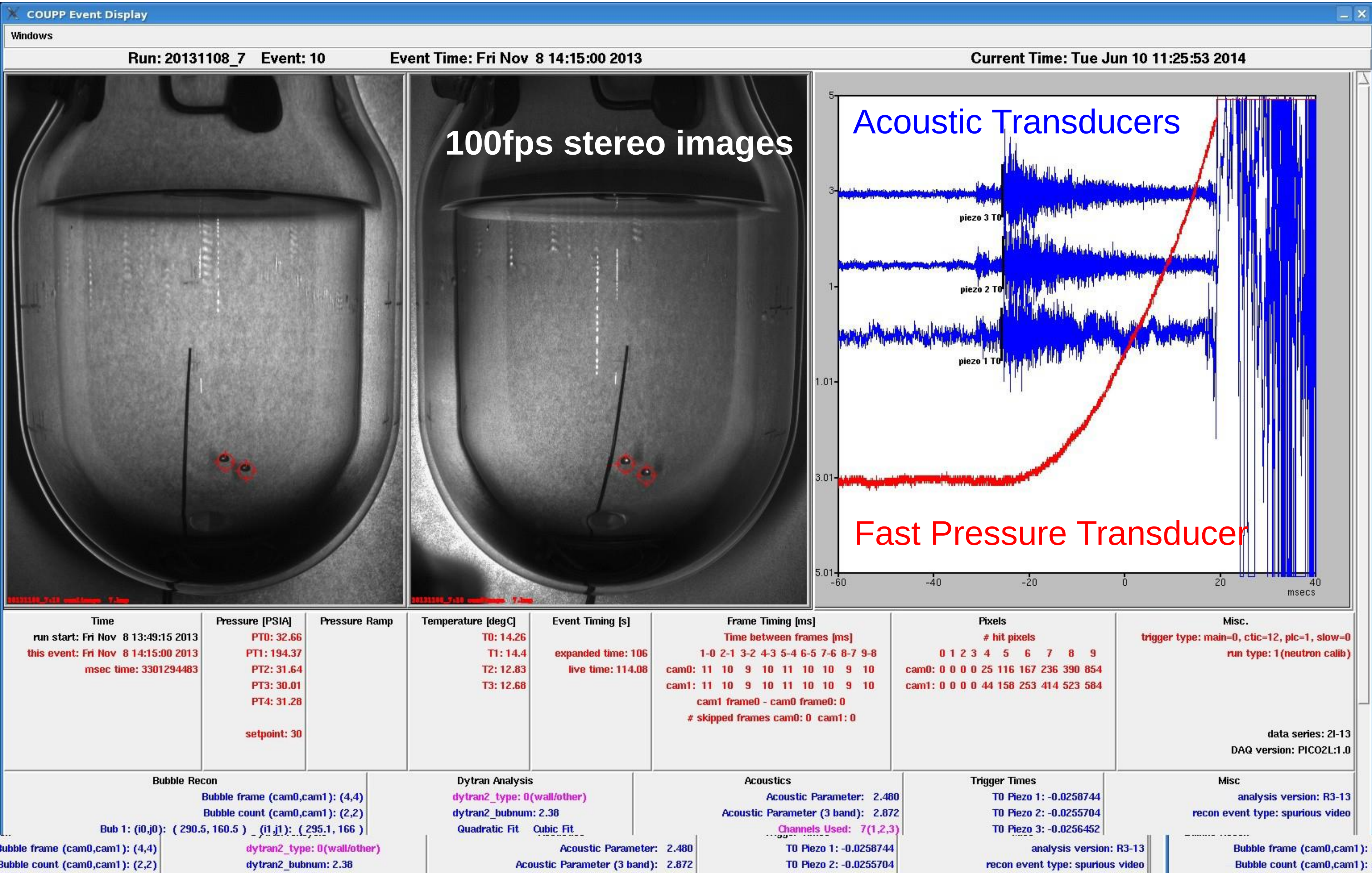
First joint PICO detector: a 2-litre detector filled with $C_3F_8$

$C_3F_8$ has better fluorine sensitivity, lower threshold, more stable chemistry

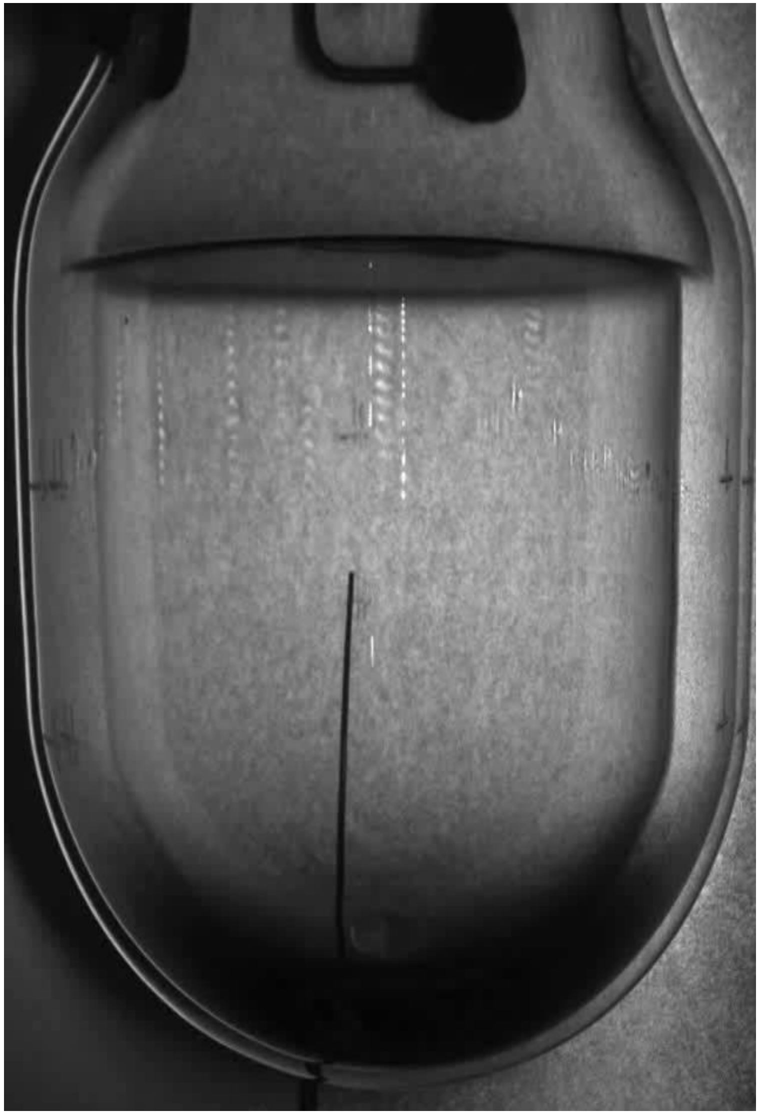


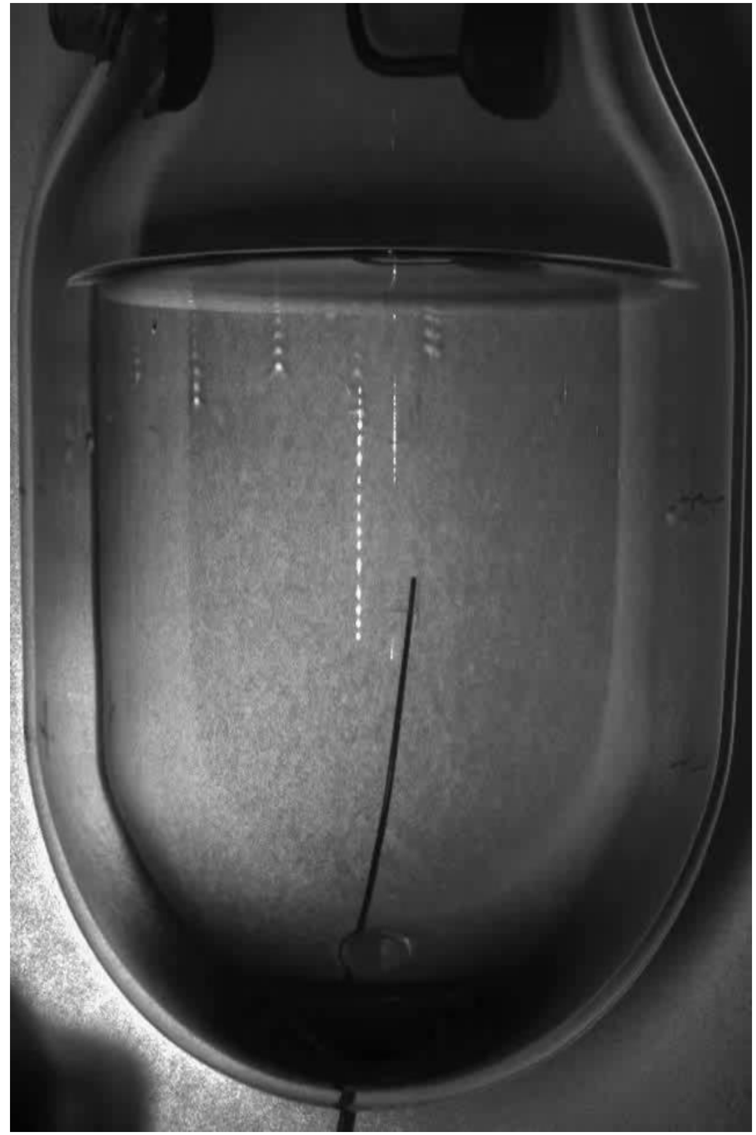

PICO-2L bellows & inner vessel assembly

PICO-2L pressure vessel




Screen Display during operations

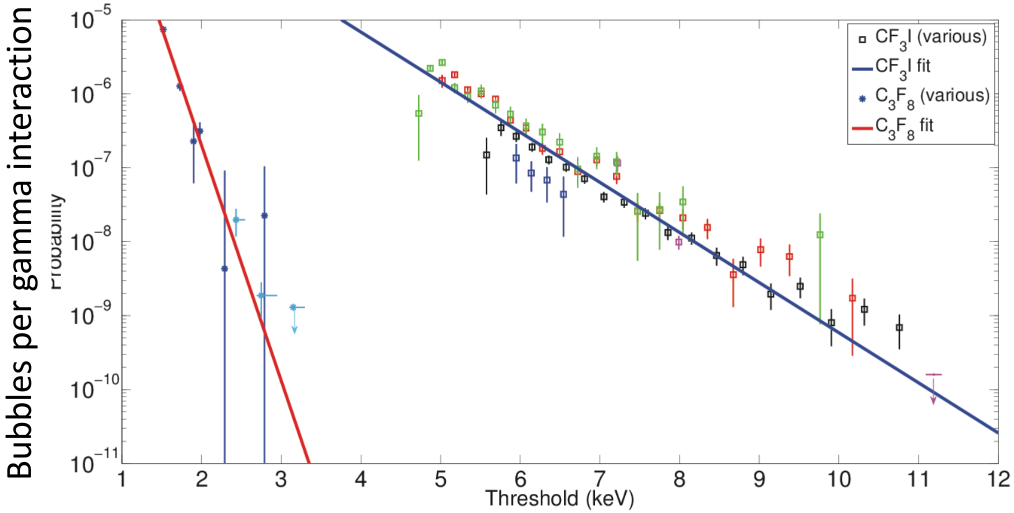




# Background Rejection Summary

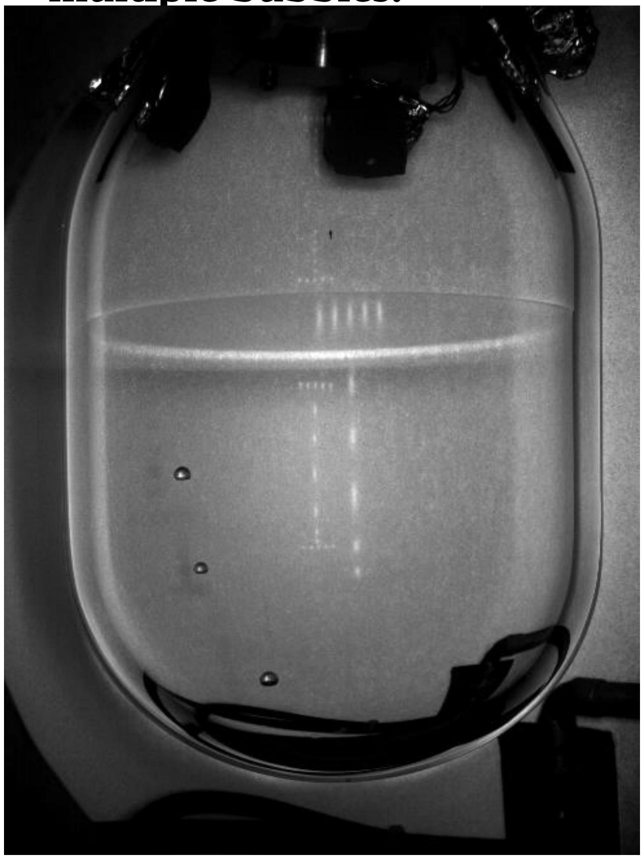
**Gamma/Beta:**

- tune detector to be sensitive only to heavily ionizing
- →$10^{10}$ rejection with $C_3F_8$ at 3 keV




**Neutrons:**

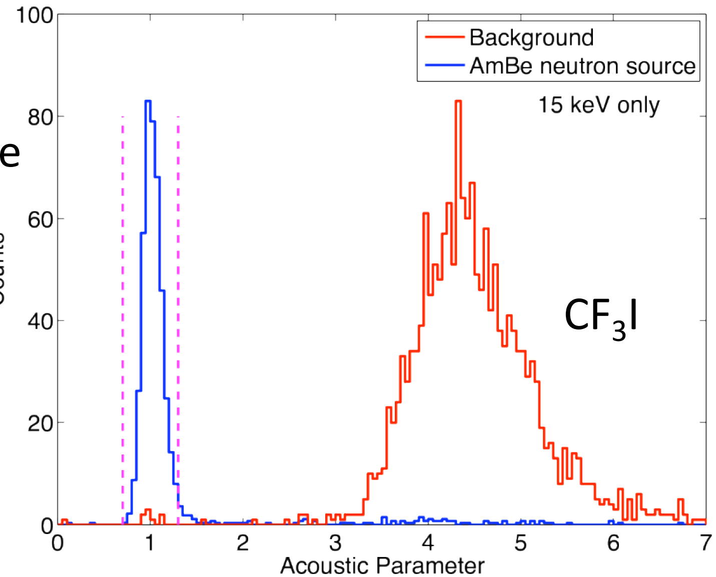
- Go deep underground
- Add local shielding (water tanks)
- **Use multiplicity; 60% of neutron interactions produce multiple bubbles.**



**Alpha-decay:**

- Alpha particles have greater acoustic energy than recoils

>99.3% Rejection

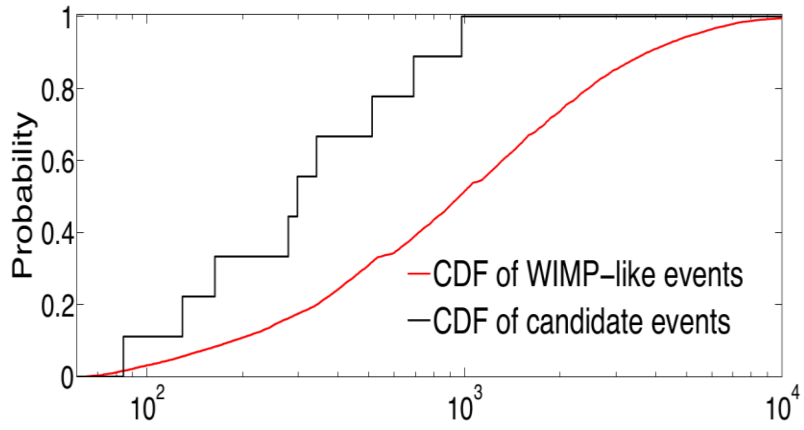


# PICO-2L Results

arXiv:1503:00008

- Total exposure 212 kg-days
- 4 energy thresholds ranging from 3.2 to 8.1 keV
- **12 nuclear recoil candidate events (expected ~ 1 background event from neutrons and other sources)**
- Timing not consistent with uniform distribution. Use modified Yellin optimal inteval method
- **No evidence for a dark matter signal. We now know there was some dust…**

K-S test p-value = 0.04

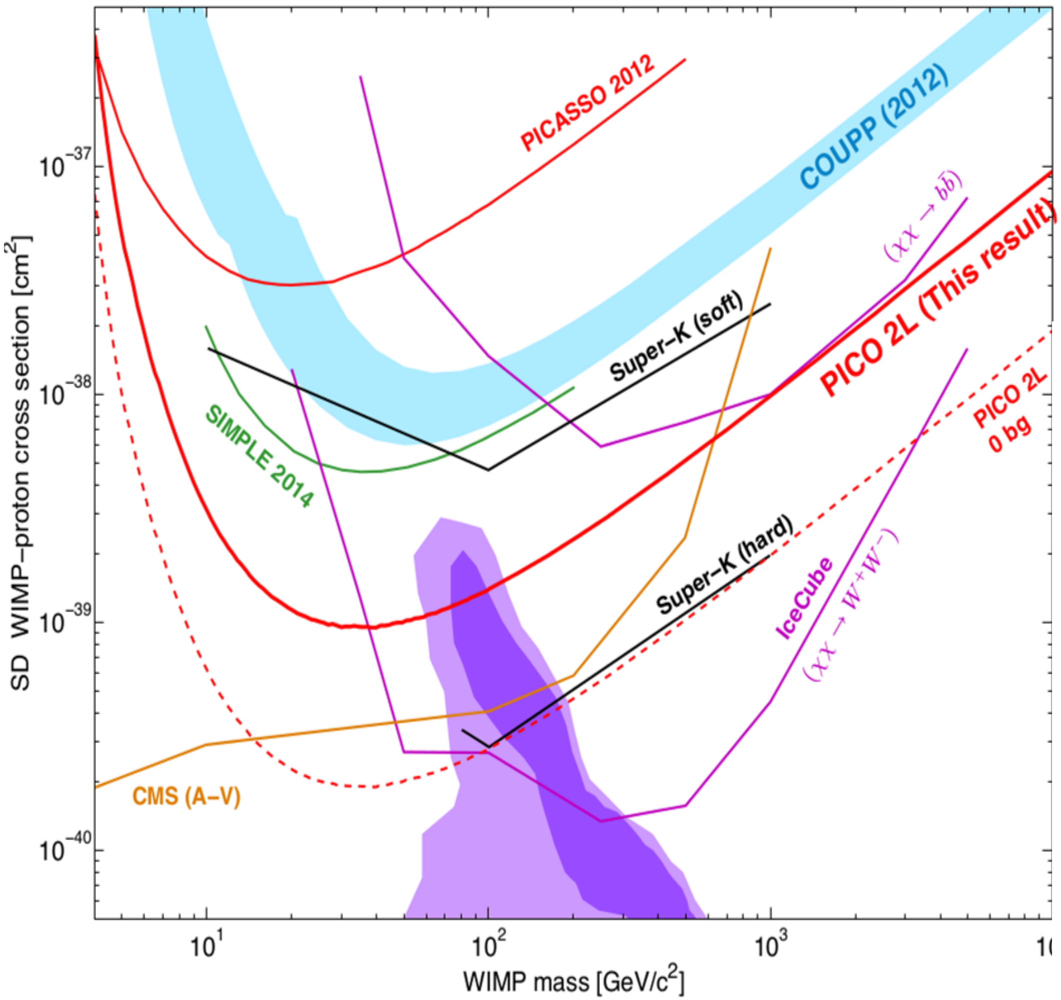


Time to previous event (s)

| 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 |

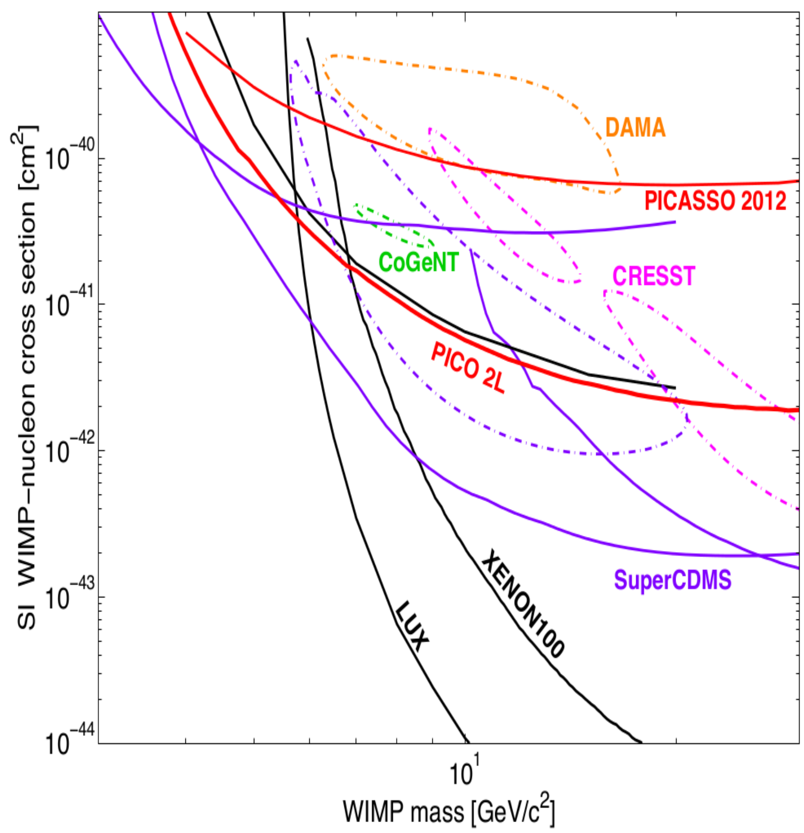
# PICO-2L results

arXiv:1503:00008




**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!



# Current PICO-2L status

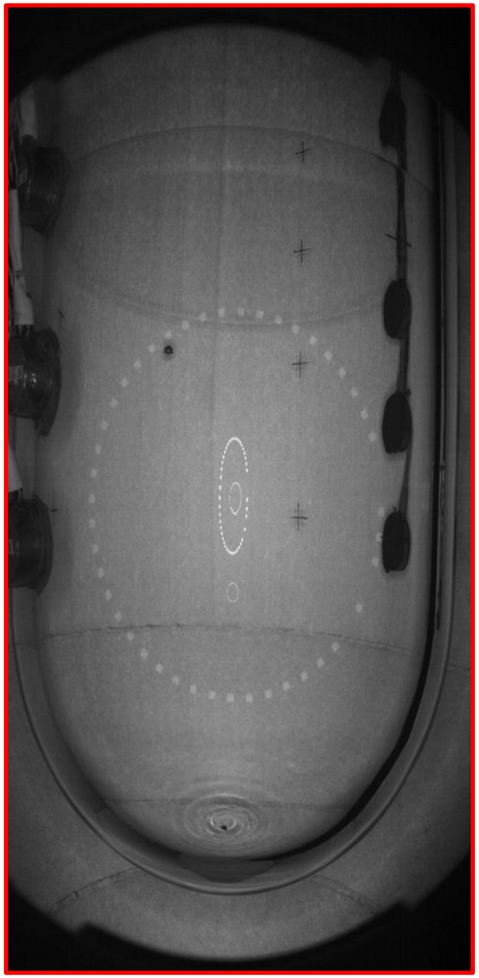
- PICO new run started in 2015
  - Natural quartz flange replaced with fused silica
  - 6 new piezo transducers
  - Cleaner fill
  - Better temperature control
  - New cameras
  - Camera cooling system
- Currently in stable operations and collecting data at 3 keV threshold

# PICO-60

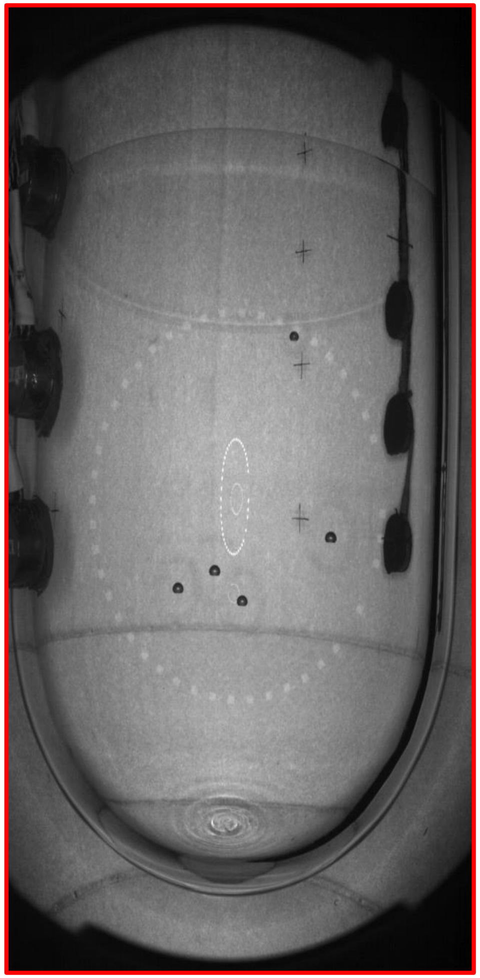
PICO-60 installation in water tank at Snolab

PICO-60 Pressure vessel inside the water tank at Snolab

PICO-60 inner vessel preparation



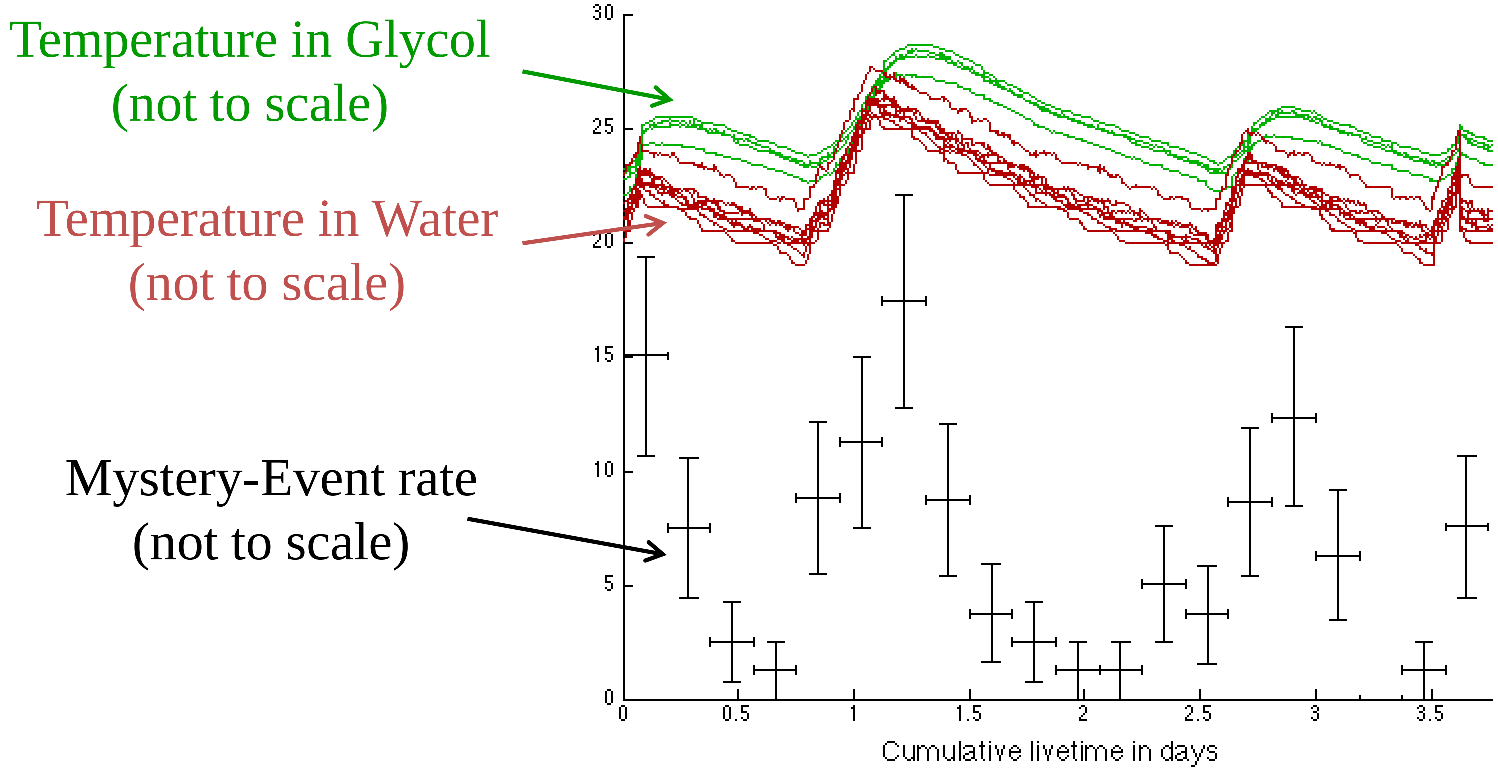
1-bubble event



5-bubble event

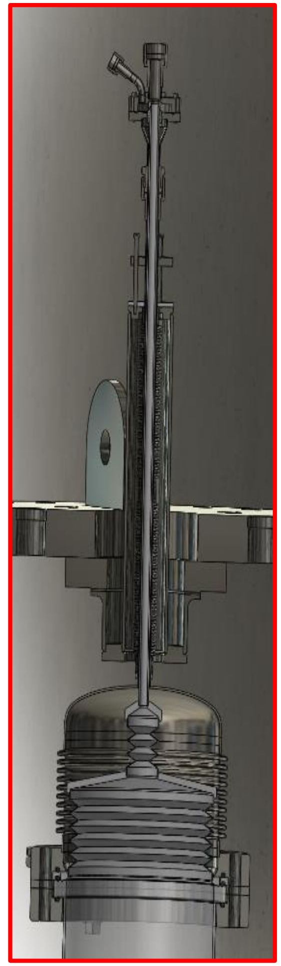
- Filled with 36.8 kg of $CF_3I$ at the end of April 2014
- Physics data started mid-June
- Collected >2700 kg-days of dark matter search data between 9 and 25 keV thresholds
- Good live fraction (>80%)
- Good detector performance
- Collected >1500 neutron events from calibration runs

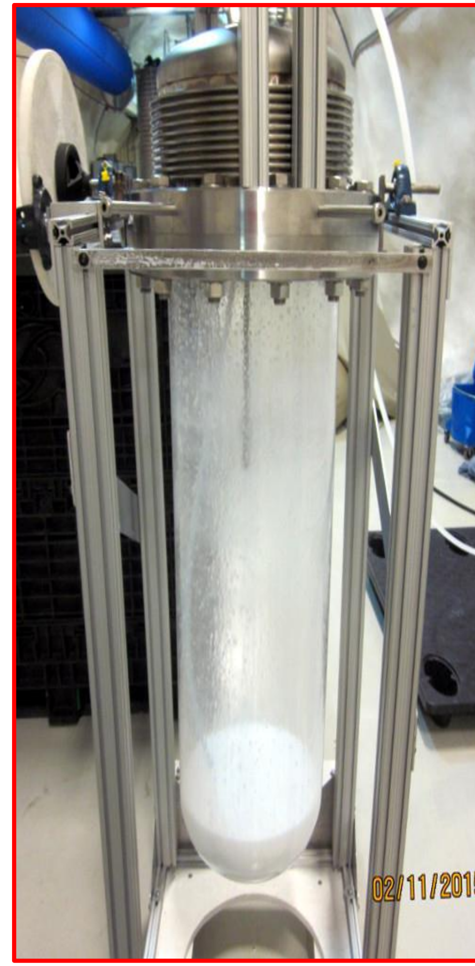
Some classes of events clearly correlated with the temperature of the water and glycol …. Correlation with pump, heaters, electrical noise, vibrations, convection…?



# PICO-60 upgrade

- Particulate controls being worked on:
  - 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 bellows 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)**?**



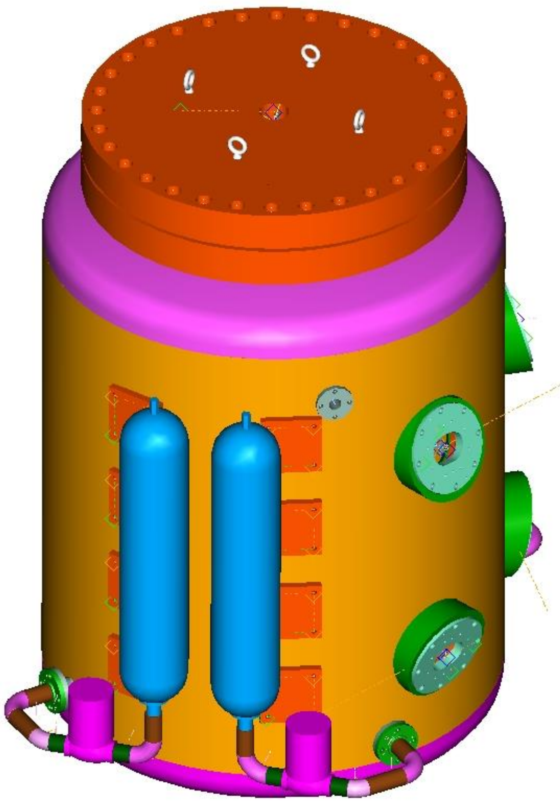


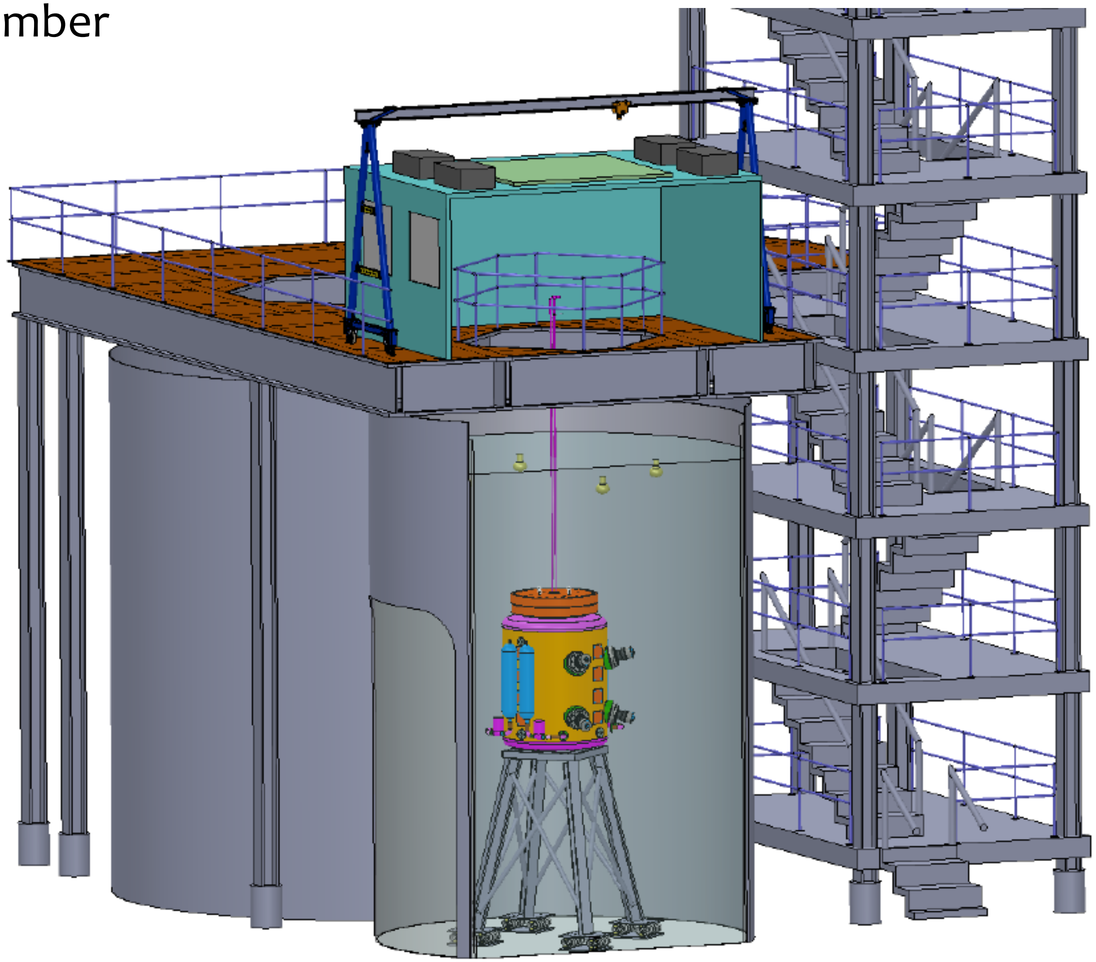

**Engineering runs to begin this summer.**

**Publication on first results in preparation**

# PICO-250L

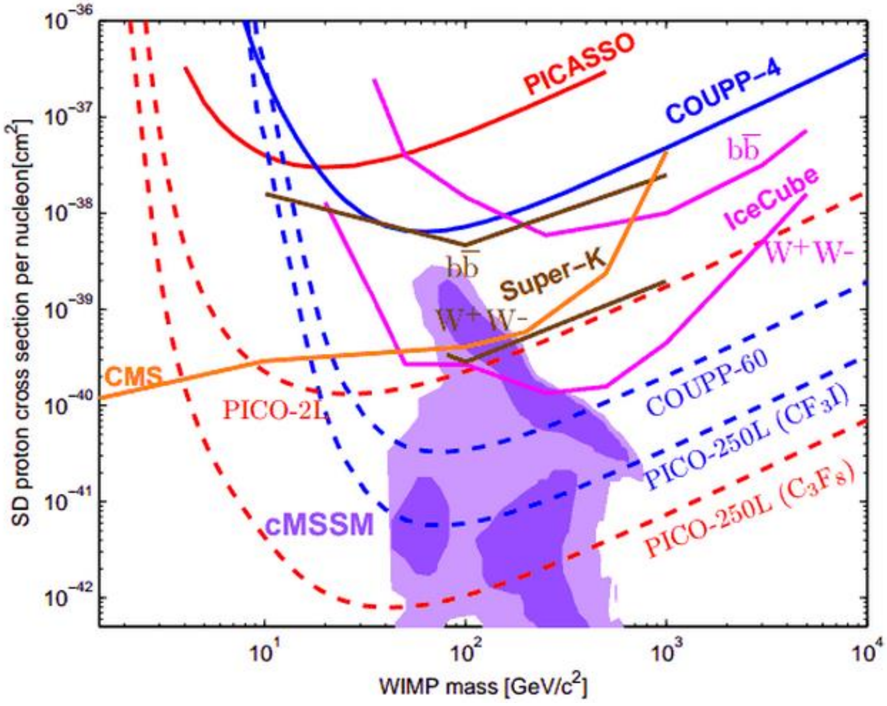
PICO-250L: ton-scale bubble chamber designed for $CF_3I$ or $C_3F_8$ target



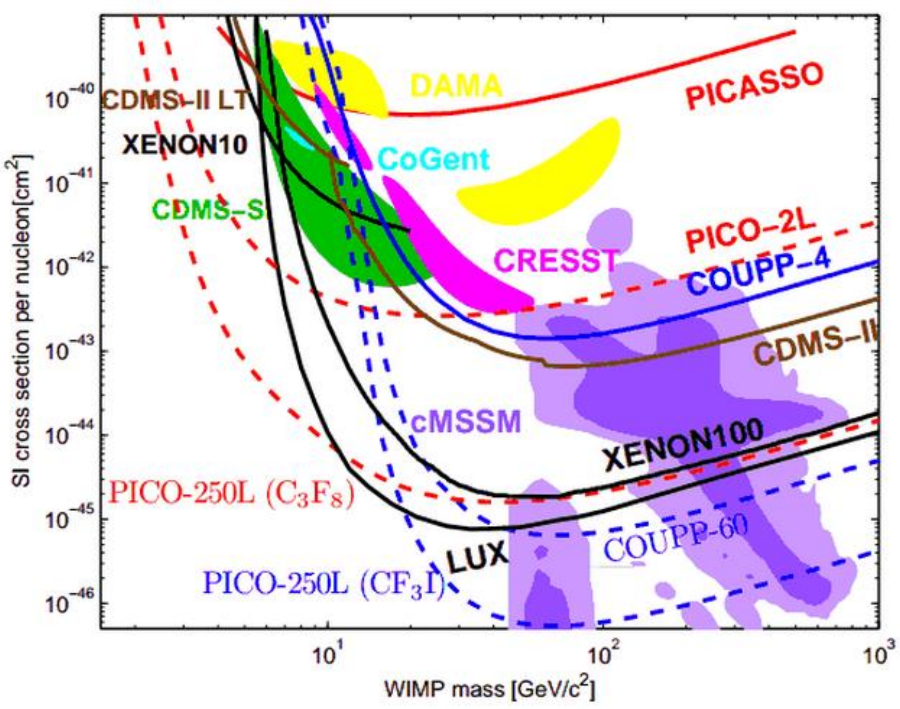


# Sensitivity projections

Spin-Dependent




Spin-Independent




cMSSM model space from Roszkowski et. al., JHEP 0707:075 (2007).

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

# PICO run plan 2015 →
# (as best we know it now)

**PICO 2L:**

Will operate in physics mode and as a test bed for the larger detectors in 2015 – 2016. By end of 2016 the larger detectors will have made PICO 2L obsolete.

**PICO 60:**

Will resume operations in 2015 (starting with an engineering run to test whether recent upgrades have been effective against particulate backgrounds). Physics running is expected to resume in 2016 with complete set of upgrades.

**PICO "Right Side Up":**

We are investigating a modification to have the vessel inverted relative to the current design, with a thermal profile such that the lower zone is inert. This would enable us to remove the buffer fluid and likely all the problems associated with that. A small test module is currently being built. A larger scale version could run in late 2016 after PICO 2L. Much of the existing hardware could be used.

**PICO "250":**

When the technology is well demonstrated we plan to move to a tonne scale detector. Construction for this would commence in 2017, and operations is foreseen for 2018 – 2022.

# PICO

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

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# HQP

HQP training has long been one of the strengths of PICASSO, and this continues today with the Canadian consortium on PICO. As we are predominantly University based, we tend to have more postdocs and students than our US colleagues from their National Labs. Of the 26 Canadian collaborators currently listed on PICO:

- 8 are faculty members or research scientists (4 FTE).
- 1 is an engineer
- 5 are post doctoral fellows, and
- 12 are graduate students, and there is in addition, average 6 undergraduates per summer

The **postdocs** have taken responsibility on PICASSO/PICO as follows:

- Leader of the final PICASSO analysis
- Construction of test facility at queens and analysis leader on PICO
- Design of muon veto system and analysis
- Implementation of multivariate analysis for PICASSO
- Development of new DAQ systems and handling of multiple cameras

The grad students are contributing to all aspects of the experiment. Some particular roles include;

- leader/run coordinator for PICO 2L
- Final analysis and wavelet implementation for PICASSO
- Leader of the particulate assays
- Leading the calibration effort with neutron beams and much of the detector design work.

# Equipment Needs 2017 →

**PICO 2L:**
Expected to be complete.

**PICO 60:**
Fully funded for equipment. Ongoing requests to NSERC and partner agencies expected for operations.

**PICO "Right Side Up":**
Most of the money required for this is in hand through US NSF funding. We anticipate a modest RTI request of order 50k$ to support the Canadian contribution to the hydraulic/pressure control system for this new configuration.

**PICO "250":**
Funds to construct the full detector will be applied for in 2017, and costs will be shared between Canada and the partners. We anticipate a request to CFI for a project cost in Canada of order 2.5M$ .

# Computing Needs 2017 →

**PICO "250":**

The computing needs for PICO have quite modest compared to other experiments.

**Our current usage includes:**

- Data storage of order 10 TB (for images and acoustic traces)
- Occasional access to west grid for analysis and Monte Carlo simulation.

**Our future needs**

- do not scale with detector volume provided backgrounds are low as we will likely only double the number of cameras as now (to cover the entire volume) and we will have a similar number of acoustic sensors. Hence an event for PICO 250 will only be ~double the current size.
- Another few 10's of TB can be expected.
- Ongoing occasional access to west grid or similar. ~20 core years/year

# Support required 2017 →

**SNOLAB:**

We do not anticipate significant equipment support through SNOLAB (as we have benefitted from before …. Mainly as we are not aware of the existence of such funds). However we will rely heavily on SNOLAB for:

- Engineering support surrounding tank design (seismicity), hydraulics, pressure vessels, safety and technical reviews.
- Ongoing support from research scientists (particularly, but not limited to Ian Lawson)
- Installation support and 'minor' day-to-day support, Core Services, IT ….

**TRIUMF:**

We do not expect a big draw on TRIUMF resources at the moment. Areas where we could benefit include access to engineering resources for technical and safety reviews and possibly some electrical/detector support if we succeed with a scintillation active veto.

**MRS:**

We will continue to rely on several of the Canadian MRS programs including engineering and technical support provided by MRS's at Alberta, Carleton, and Queen's. The main use of these resources will be for:

- Production of electronic components and development of DAQ
- Engineering design of various mechanical devices
- Radon emanation and low background studies
- Technical support for underground installations.

We have been a fairly minor user compared to other experiments to date, but we expect to make heavy use of these resources for PICO 250L

# Synergy with other Canadian Initiatives

PICO is unique in the world effort, as the only current direct detection experiment with good sensitivity to spin-dependent interactions. Hence it is also unique in Canada. However, the Canadian effort is extremely well balanced with different technologies, different targets, and physics capabilities that nicely covers much of the favoured parameter space.

**PICO:**
Focused on spin-dependent interactions and low mass WIMPs. Will be able to explore most of the hitherto unexplored SUSY inspired parameter space in this sector. Uses $^{19}F$ in $C_3F_8$ bubble detectors.

**DEAP:**
With a higher threshold DEAP is primarily sensitive to spin-independent interactions at mid to high WIMP masses. DEAP will compete with the best in the world in this sector. Uses LAr as detector medium.

**SuperCDMS:**
Has strong US support through the G2 program, but with an emphasis on lower mass/threshold searches (and mainly the spin-independent sector. Makes use of cryogenic Ge and Si crystals as detector technology.

# Synergy with other Canadian Initiatives

**NEWS:**

An emerging program which will use high pressure gasses in spherical TPCs to observe interactions. This enables a very low threshold to be reached and these detectors will focus mainly on the very low mass region with a variety of gasses, including access to both SI and SD (with $CH_4$ ).

**Beam Dump Experiments (e.g APEX, HPS):**

Members of the PI are collaborating on a proposal to use the beam dump at Jefferson Lab to search for evidence of dark matter particles that appear in certain interaction models (the Vector portal with new interactions producing MeV – GeV scale dark matter … partially motivated by g-2 anomaly, gamma and positron excesses…).

**ATLAS:**

May be able to produce DM particles in collisions. If observed, harder to identify as DM but have access to more particle properties

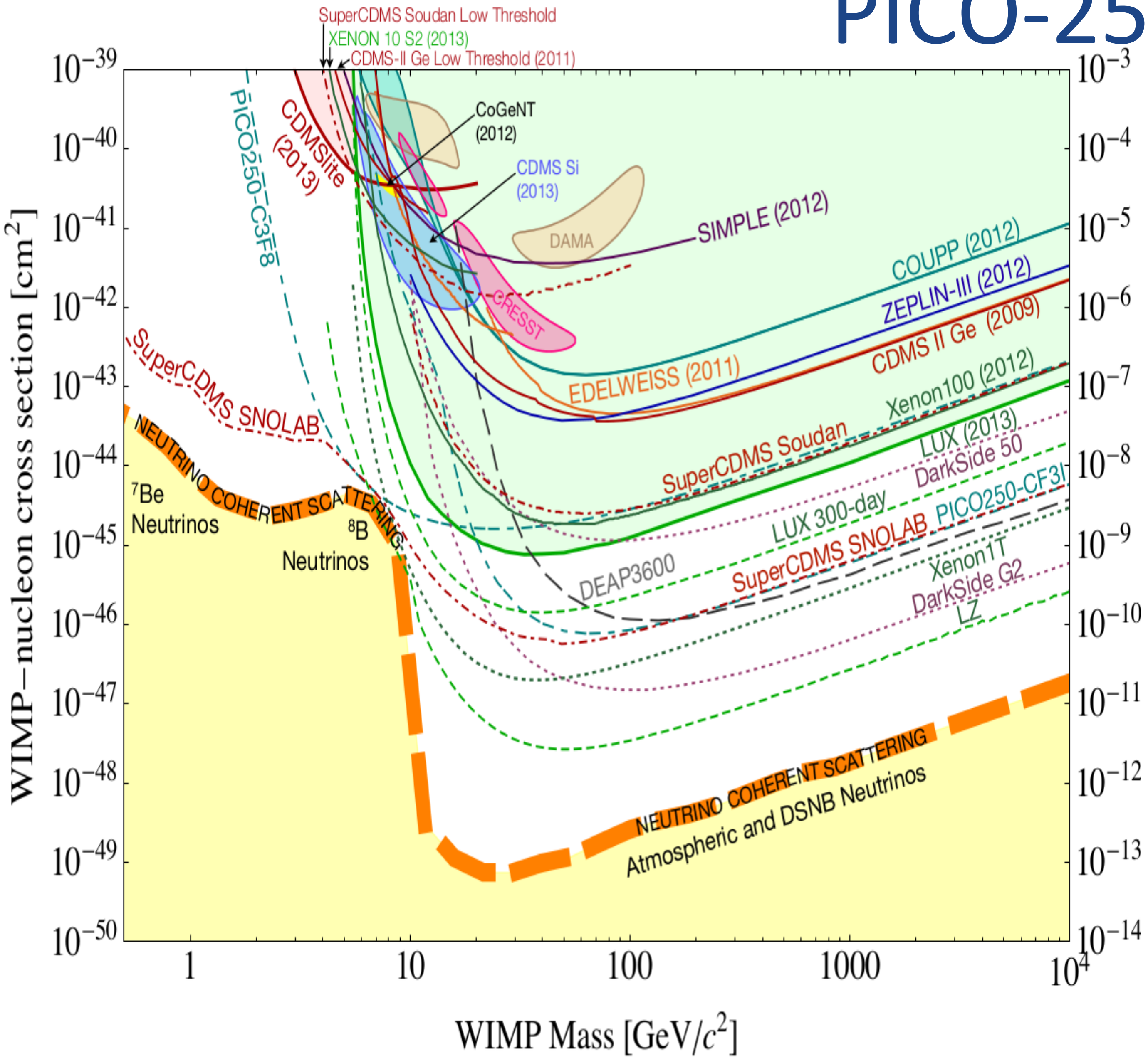
**ICECUBE:**

May observe indirect evidence for DM as WIMP-WIMP annihilation products (neutrinos) at the centres of dense objects.

**VERITAS:**

May observe indirect evidence for DM as WIMP-WIMP annihilation products (gammas) at the centres of dense objects.

# 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
SuperCDMS Soudan
LUX 300-day
PICO250-CF3I
SuperCDMS SNOLAB
DEAP3600
Xenon1T
DarkSide G2
LZ
CRESST
CDMSlite (2013)
PICO250-C3F8
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
WIMP–nucleon cross section [cm2]
WIMP Mass [GeV/c2]

# International Partners

PICO currently has 61 collaboration members from 17 institutions in 6 countries, with the demographics split as:

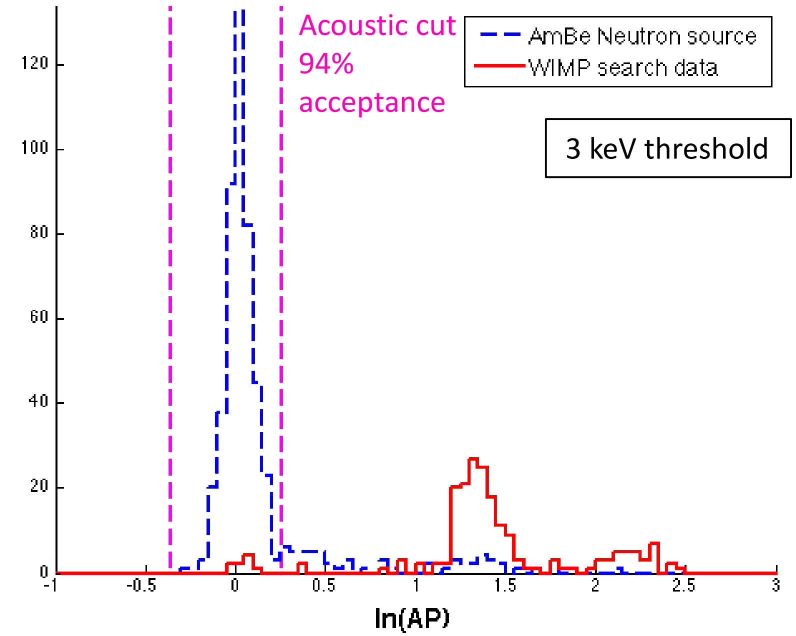
| Country | Institutions | Collaborators | % of total |
|---|---|---|---|
| Canada | 6 | 26 | 43 |
| United States | 7 | 26 | 43 |
| Mexico | 1 | 1 | 2 |
| India | 1 | 3 | 5 |
| Spain | 1 | 3 | 5 |
| Czech Rep | 1 | 2 | 3 |

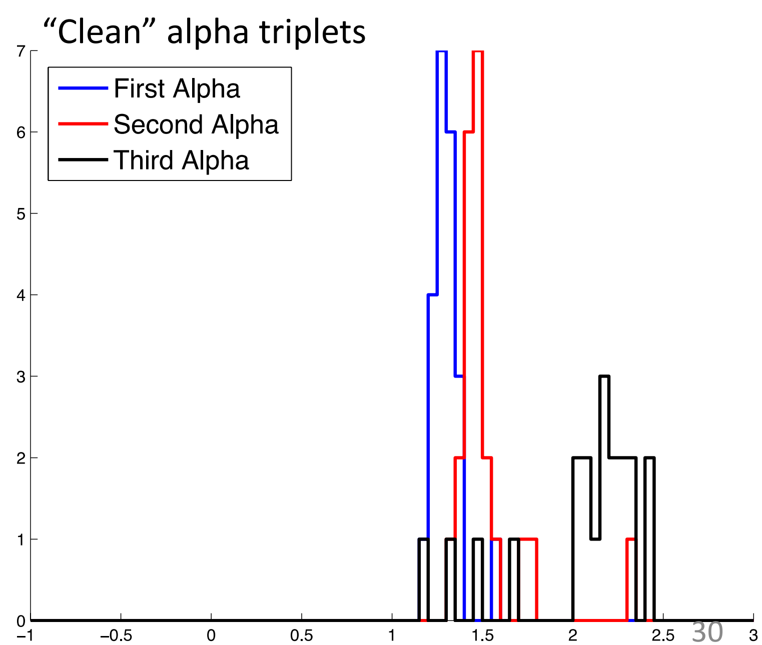
# PICO-2L Analysis: Acoustic discrimination

- No multiple bubble events in the low background data
- Two distinct alpha peaks, clearly separated from nuclear recoils
- Timing of events in high AP peaks consistent with radon chain alphas, and indicate that the higher energy $^{214}$Po alphas are significantly louder (a new effect not seen in $CF_3I$)

$^{222}$Rn α(5.6 MeV) → $^{218}$Po α(6.1 MeV) → $^{214}$Po α(7.9 MeV)

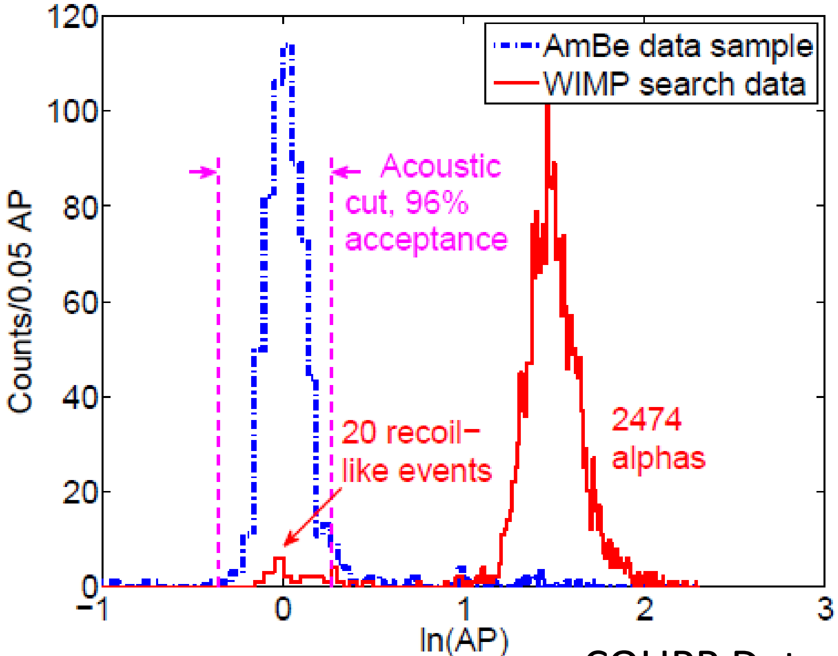
3 minutes    55 minutes



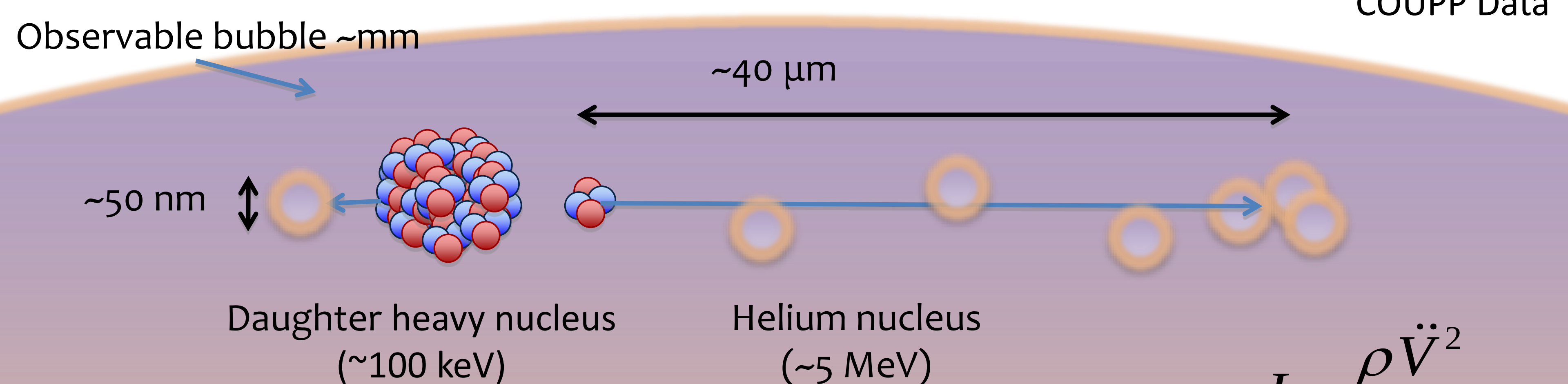



# Alpha Acoustic Discrimination

- Discovery of acoustic discrimination between recoils and alphas in PICASSO (Aubin et al., New J. Phys.10:103017, 2008)
  - **Nuclear recoils** deposit their energy over tens of nanometers.
  - **Alphas** deposit their energy over tens of microns.
- In bubble chambers alphas are several times louder due to the expansion rate difference.

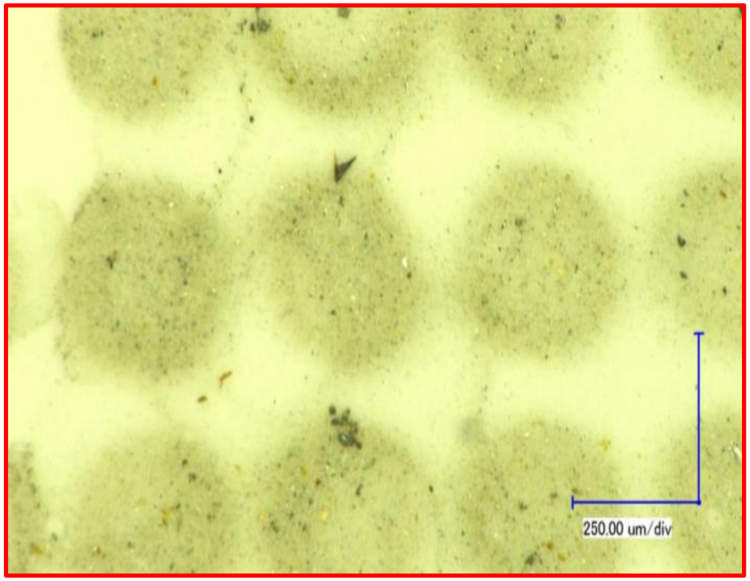



COUPP Data



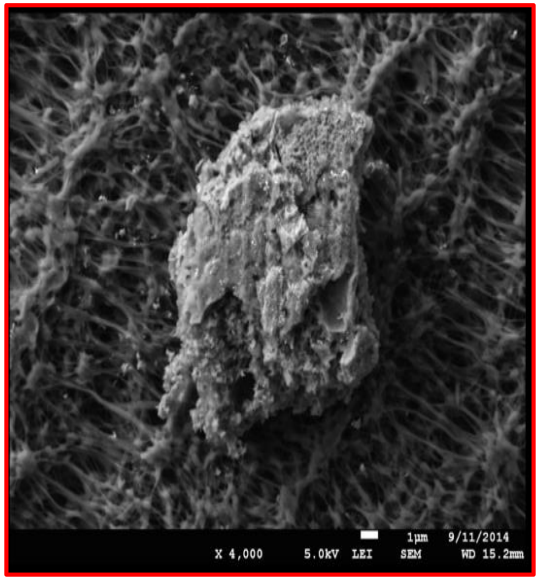

$$I = \frac{\rho \ddot{V}^2}{4\pi c}$$

# PICO-2L background forensics:



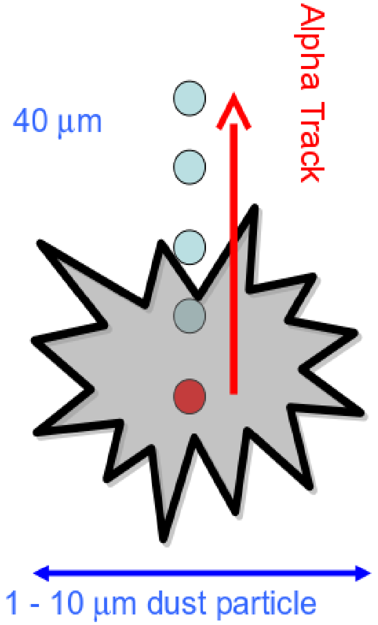

**Filter sample from PICO-2L**

- Leading hypothesis - particulate contamination
- ICPMS 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?**