Recent Results and Future Plans for Dark Matter Searches with PICO

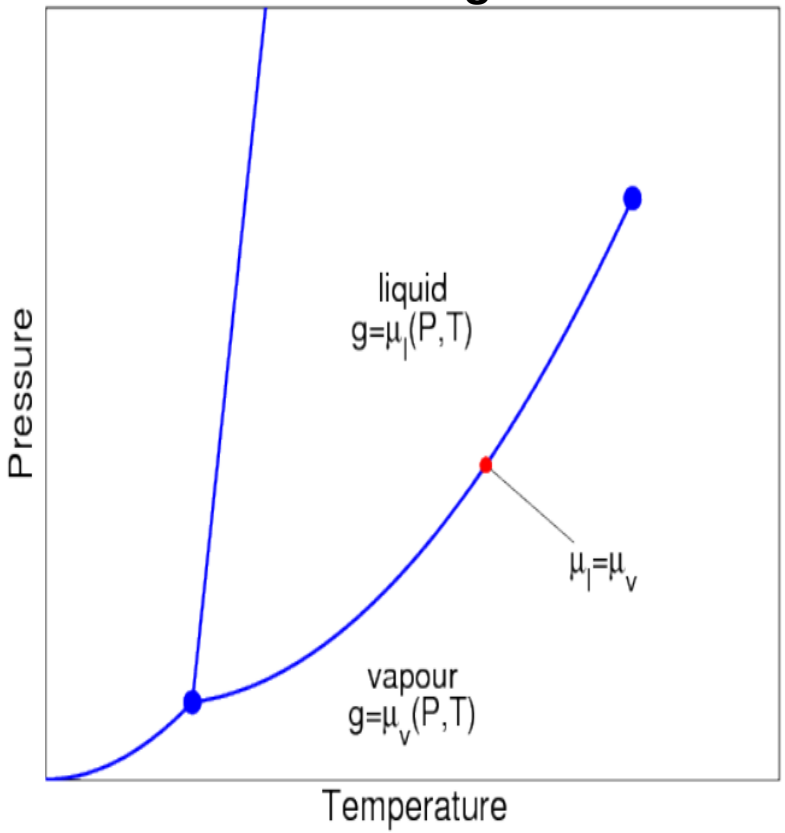
Tony Noble
Queen's University

Outline

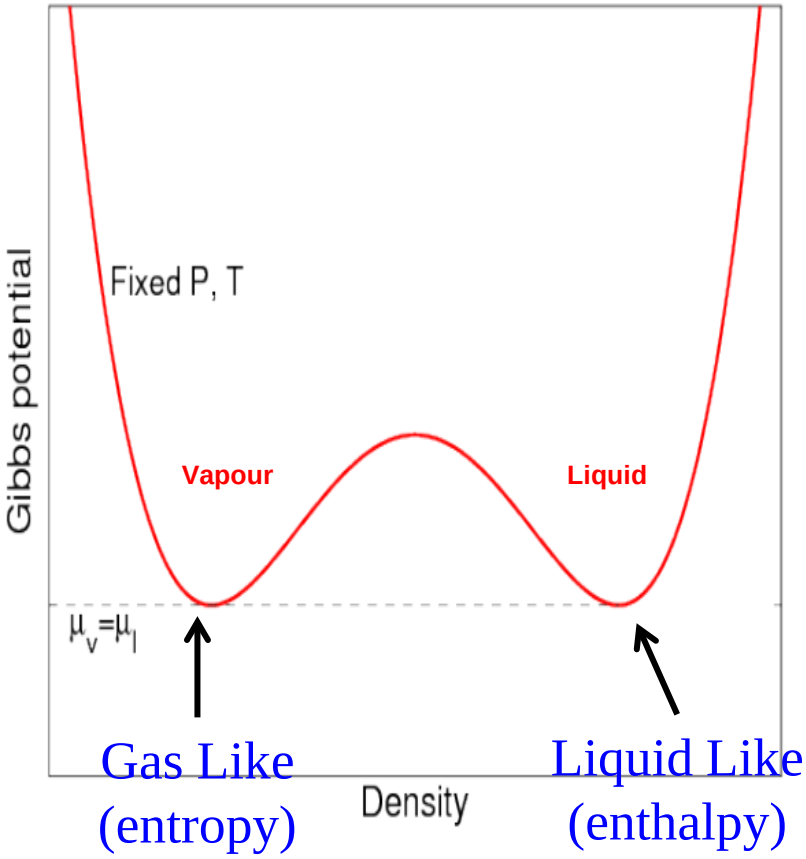
- PICO superheated liquid technology
- PICO Program
- Recent Results
- Future Plans

Bubble Chamber Operation

Phase diagram



Gibbs free energy

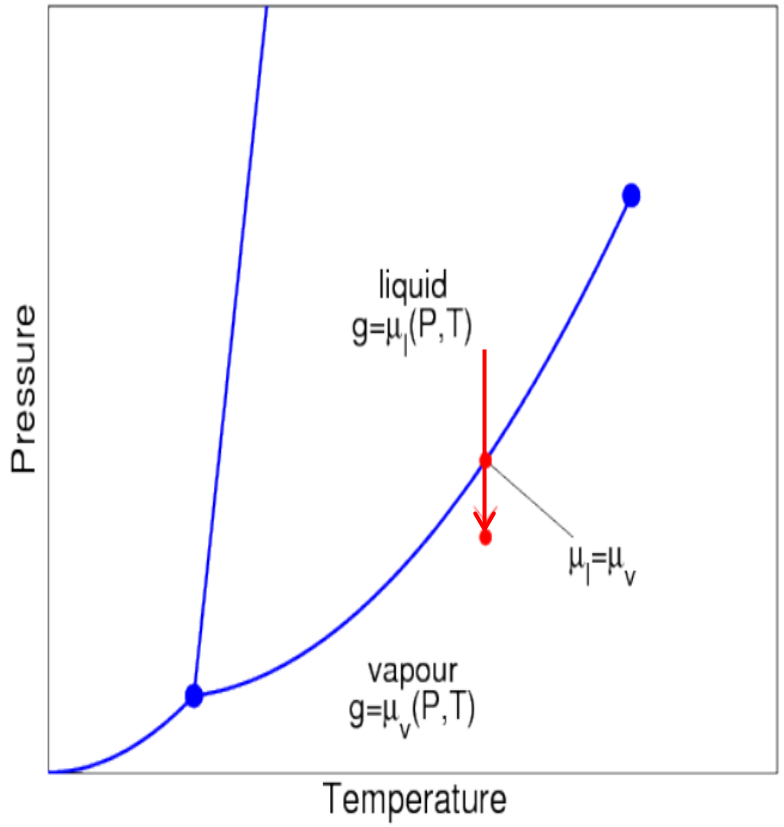


When on the saturation curve, liquid and gas are in equilibrium. (Same pressure, temperature and chemical potential).

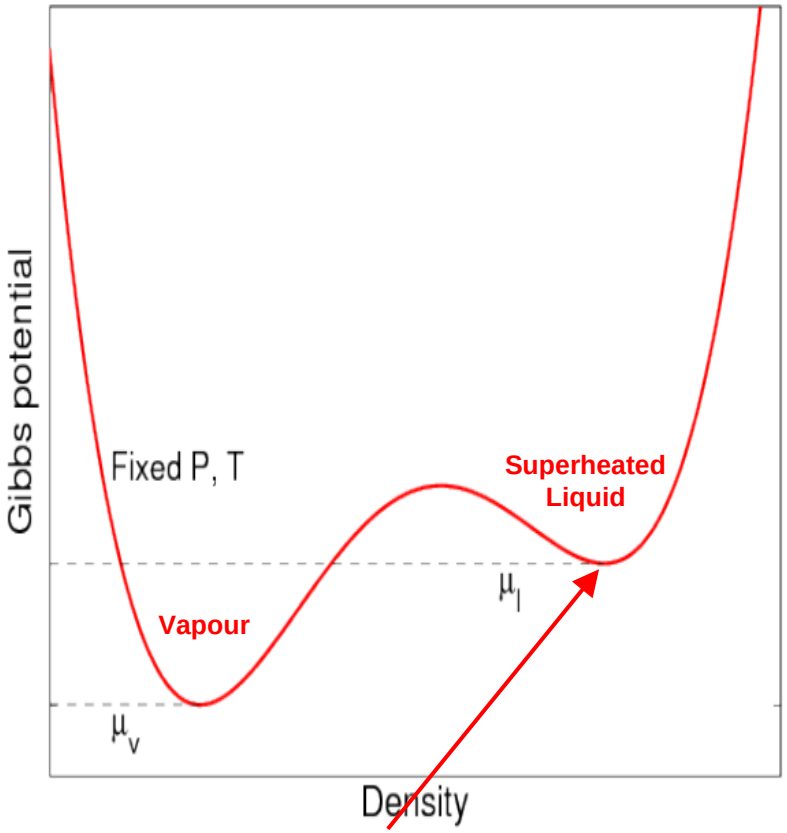
At equilibrium, the potential has two minima (one dominantly gas like and one liquid dominated)

Bubble Chamber Operation

Phase diagram



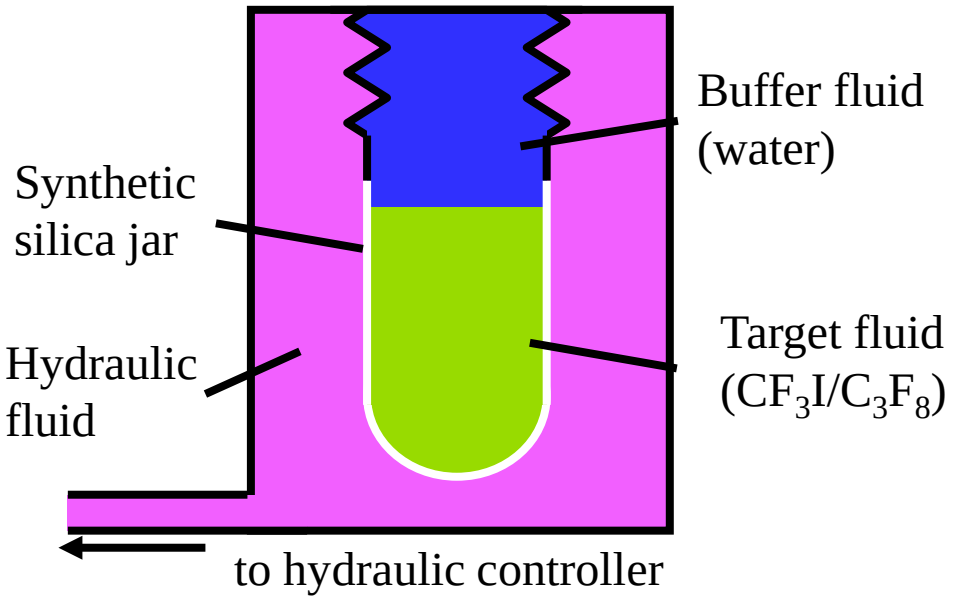
Gibbs free energy

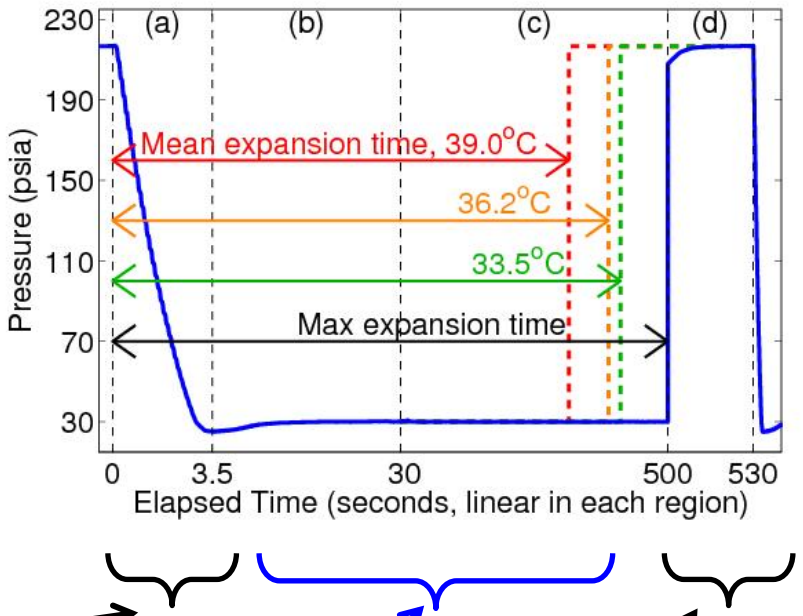


We now lower the pressure of the chamber carefully….starting from the pure liquid phase.

This distorts the potential, leading to a **meta-stable** superheated liquid state. Unless sufficient energy is added, it will stay in meta-stable state.

Principle of Operation: Bubble Chamber

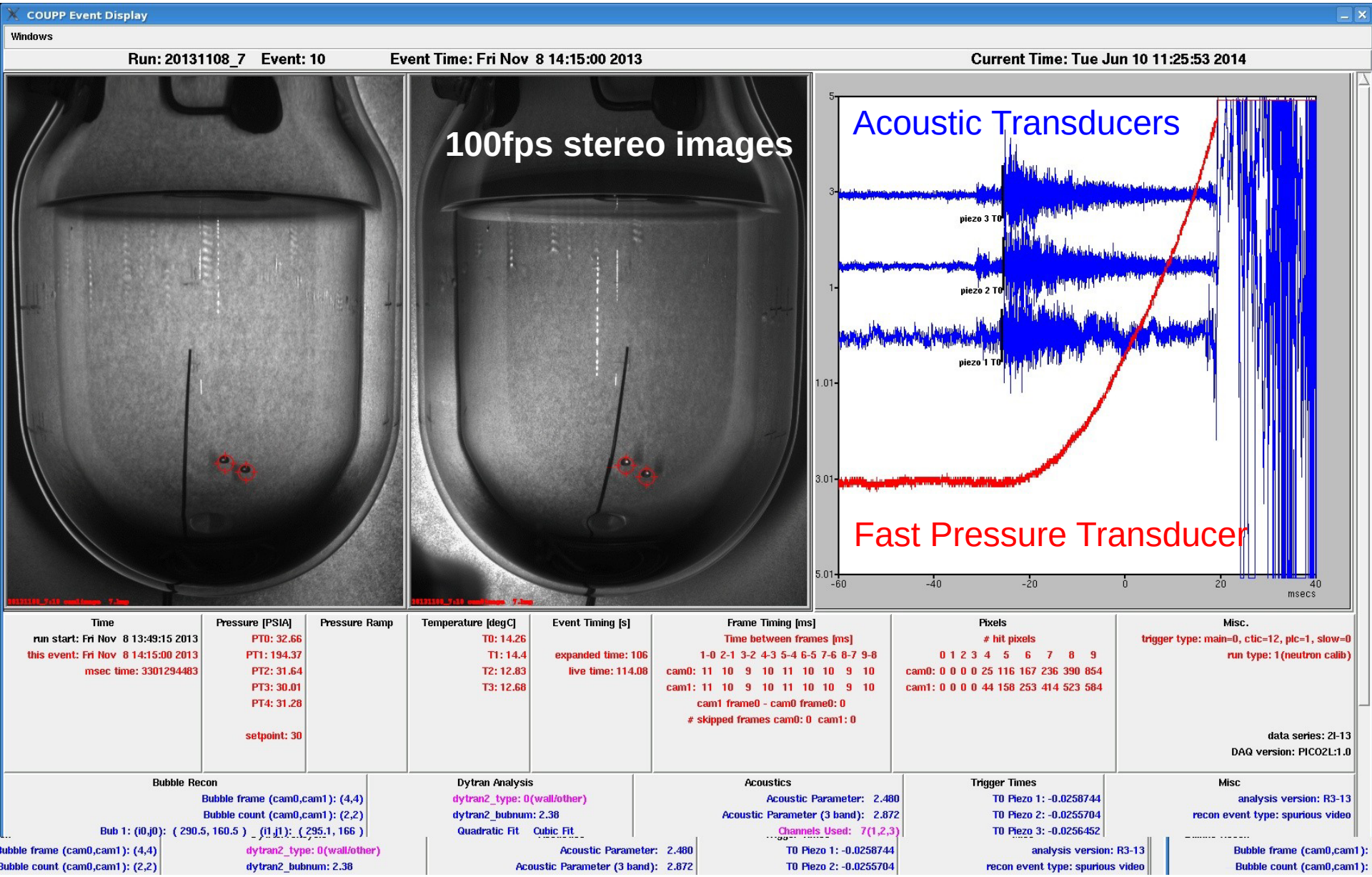




1. Lower the pressure to a superheated state.

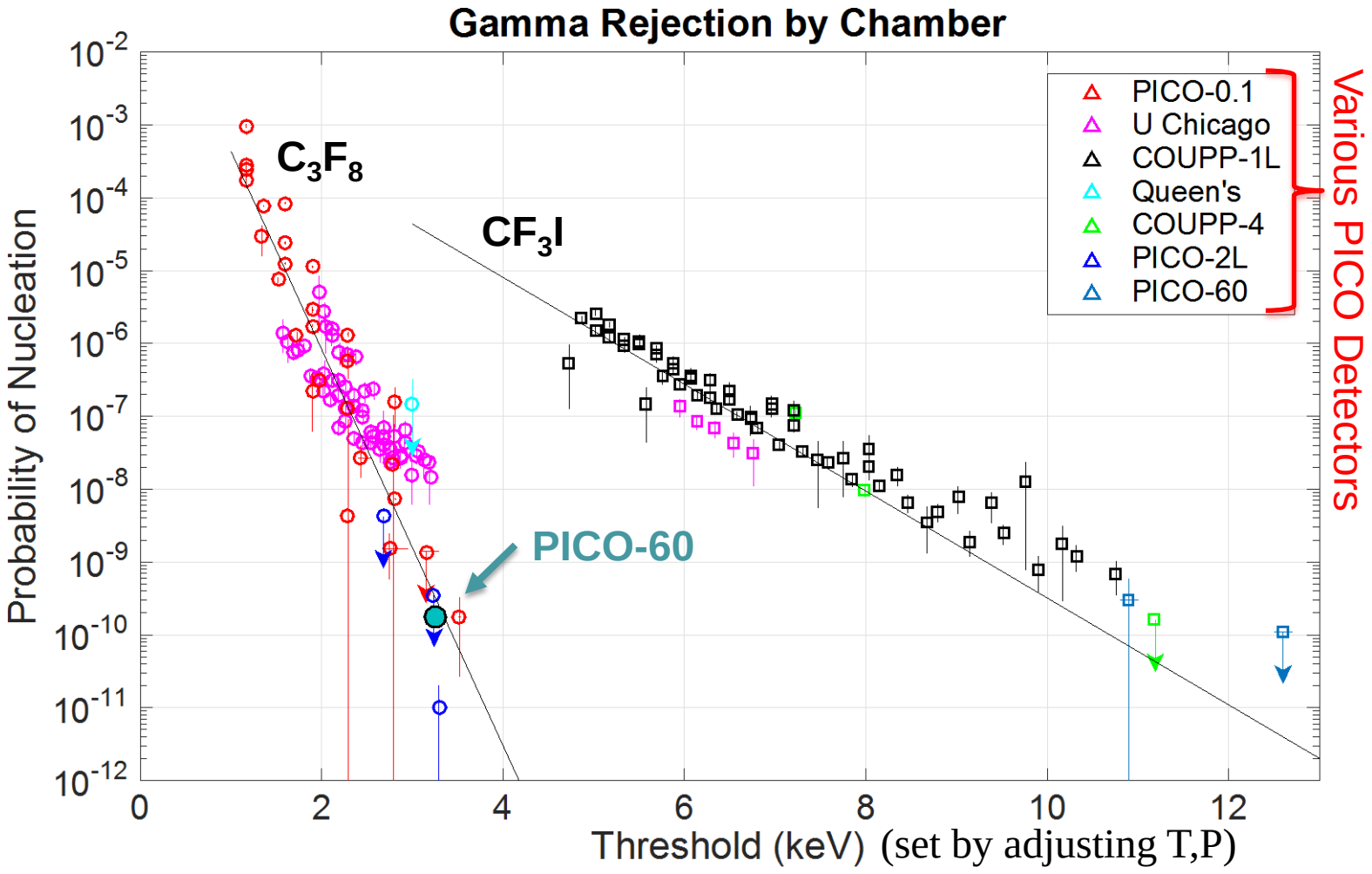
2. See the bubble:
   - Cameras trigger. record position, multiplicity
   - Microphones record acoustic trace
   - Fast pressure transducer recording.

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



Screen Display during operations

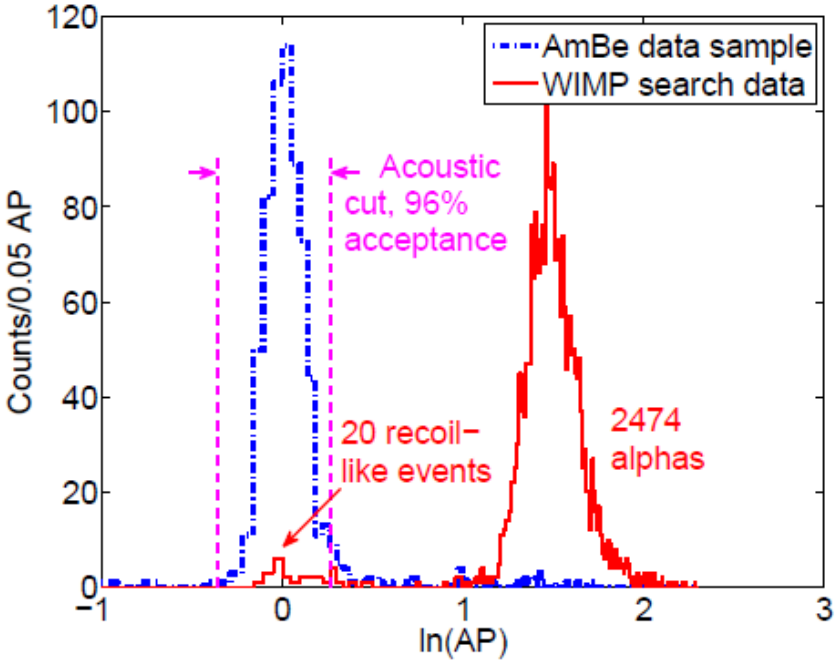
Gamma/Beta Background Rejection

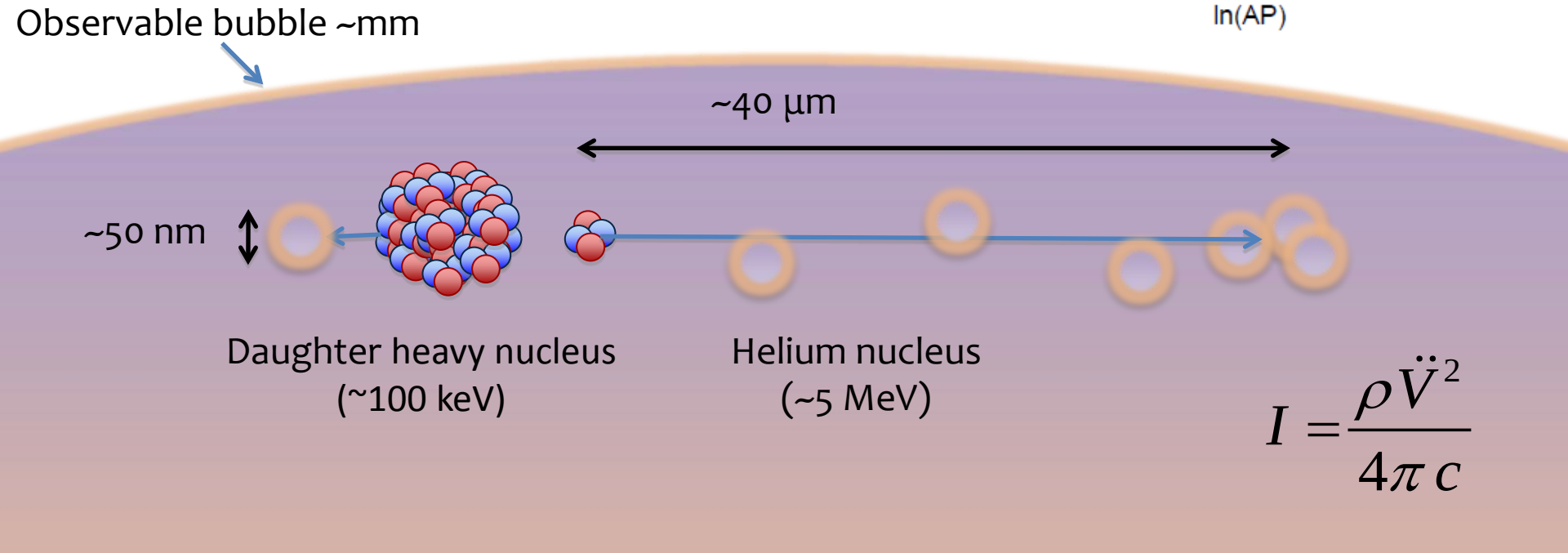


- Excellent electron/gamma rejection has been demonstrated.
- C_3F_8 can reach lower thresholds than CF_3I for same rejection.
- A lower threshold extends the sensitivity to lower mass WIMPs.

Alpha Acoustic Discrimination

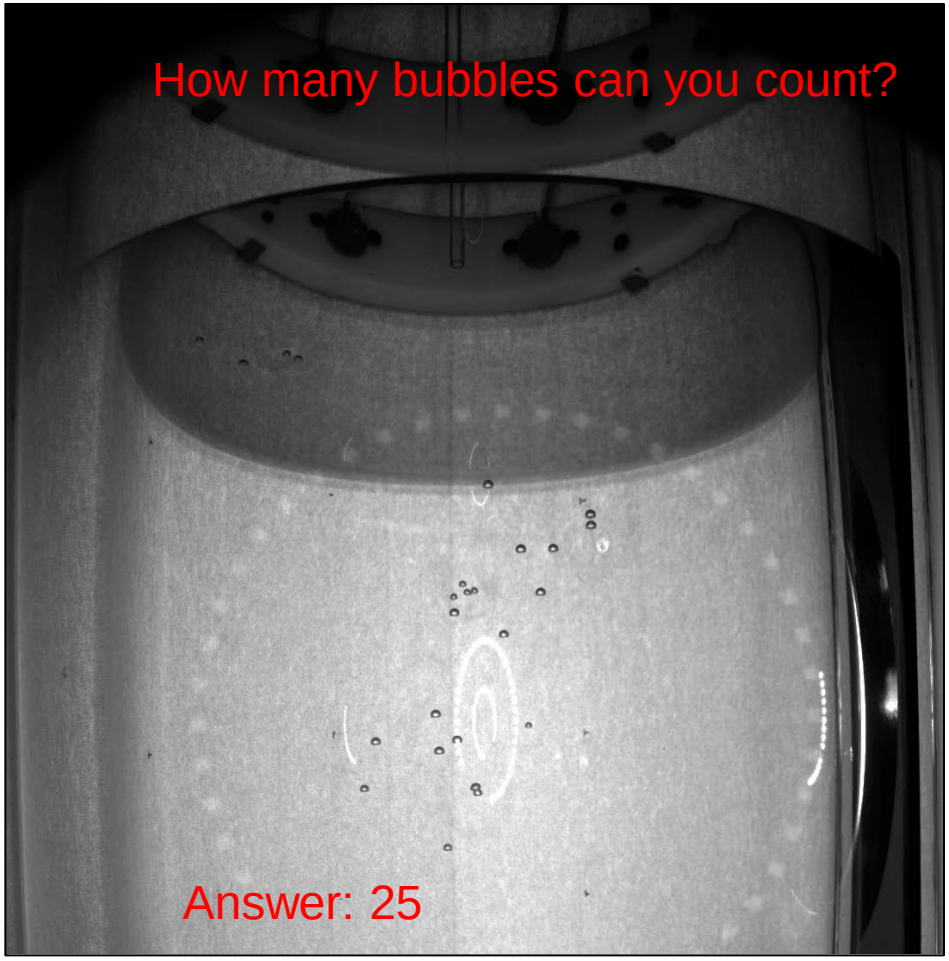
- Discovery by PICASSO of acoustic discrimination against alphas
  - **Nuclear recoils** deposit their energy over tens of nanometers.
  - **Alphas** deposit their energy over tens of microns.
- In bubble chambers alphas are several times louder due to the difference in the rate of expansion.





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

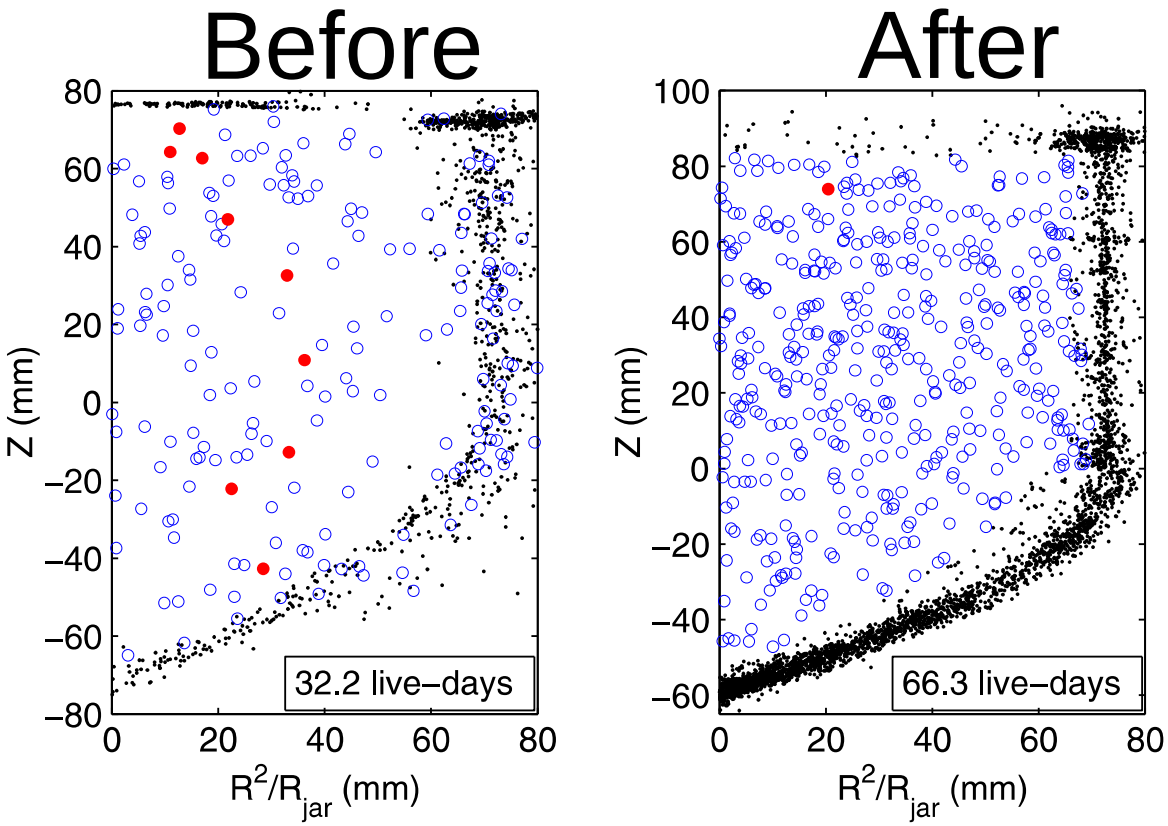
Neutron Backgrounds



- Preferentially Multiple-scatter
  - Allows us to measure background rate directly
- Simulation tells us to expect 3:1 multiples to singles ratio in PICO 60
- With water tank to shield external sources, residual background dominated by detector materials

Anomalous Background

- PICO-2L Run1
  - 9 candidate events in 32 live-days at 3.2keV
  - **Inconsistent with known radioactive backgrounds AND dark matter**
- PICO-2L Run2
  - 1 candidate event in 66 live-days at 3.2keV
  - **Consistent with neutron expectations**
- Between runs, the detector was cleaned of particulate contamination



C. Amole *et al*. Phys. Rev. D 93, 061101(R) (2016)

Hypothesis: combination of particulate matter and water leads to anomalous nucleation mechanism

PICO Program

COUPP-4 (2011)

CF_3I Target

PICO Program

COUPP-4 (2011)

CF_3I Target

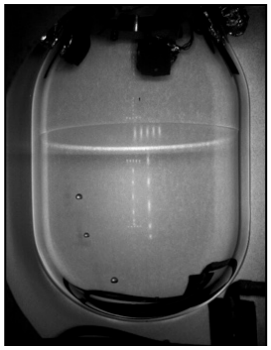
Unknown background discovered

Only a handful of events. Difficult to understand origin, but limits physics reach

PICO Program

COUPP-4 (2011)

CF_3I Target



Try switching target fluids

PICO-2L (2014)

C_3F_8 Target

Unknown background discovered

PICO-60 (2014)

CF_3I Target

Try scaling to study with increased statistics

PICO Program

COUPP-4 (2011)

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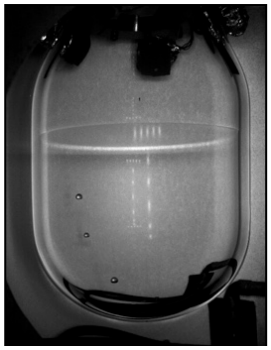

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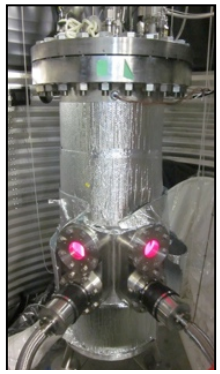


Anomalous background

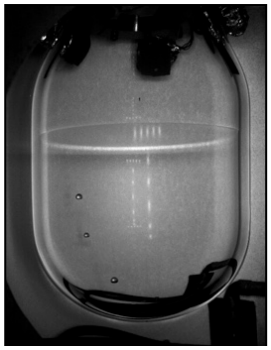
Try scaling to study with increased statistics

Anomalous background discovered. Appears to be related to particulates at 10's of nm scale

PICO Program

COUPP-4 (2011)

CF_3I Target



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PICO-2L (2014)

C_3F_8 Target

Anomalous background

Try removing particulate

PICO-2L (2016)

C_3F_8 Target

PICO-60 (2C

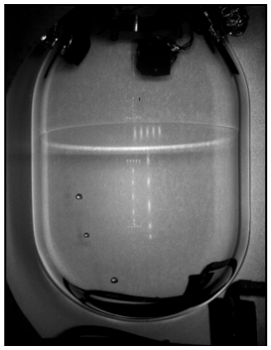
CF_3I Target

Anomalous background

Try scaling to study with increased statistics

PICO Program

COUPP-4 (2011)
CF_3I Target



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PICO-2L (2014)
C_3F_8 Target

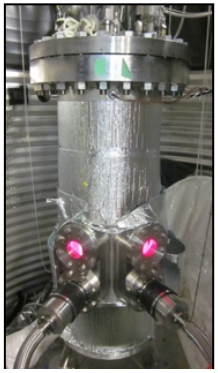
Anomalous background

Try removing particulate

PICO-2L (2016)
C_3F_8 Target

Neutron Limited!

PICO-60 (2C
CF_3I Target



Anomalous background

Try scaling to study with increased statistics

Detector is clean! Only a few neutrons (at expected level in small chamber)

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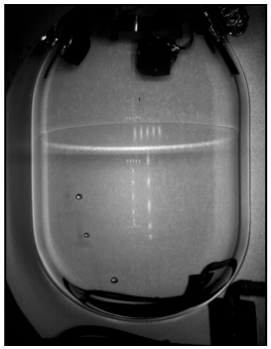
PICO Program

COUPP-4 (2011)
CF_3I Target



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Try switching target fluids

PICO-2L (2014)
C_3F_8 Target

Anomalous background

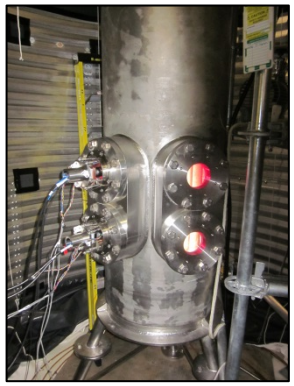
New fine cleaning methods

PICO-2L (2016)
C_3F_8 Target

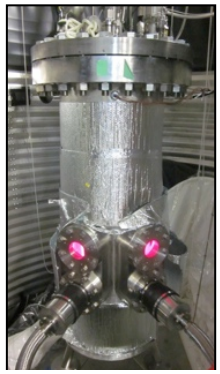
Neutron Limited!

Go Big

PICO-60 (2017)
C_3F_8 Target



PICO-60 (2C
CF_3I Target



Anomalous background

Try scaling to study with increased statistics

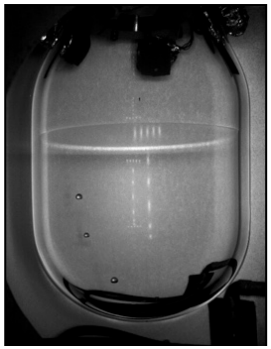
Queen's University

SNOLAB

PICO Program

COUPP-4 (2011)

CF_3I Target



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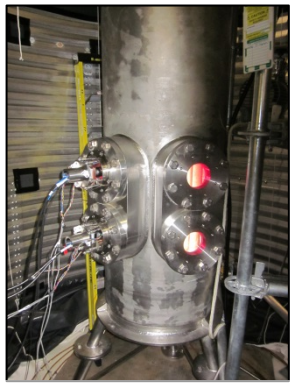
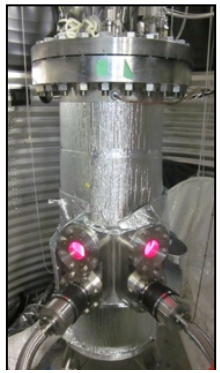


New result

PICO-60 (2C

CF_3I Target

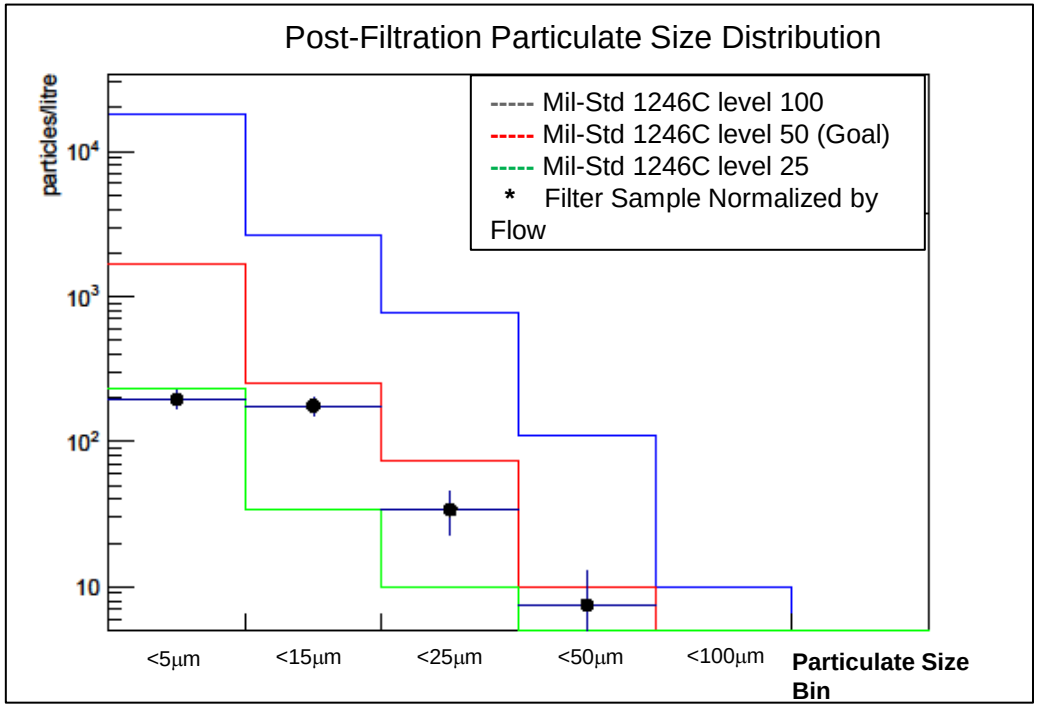


Anomalous background

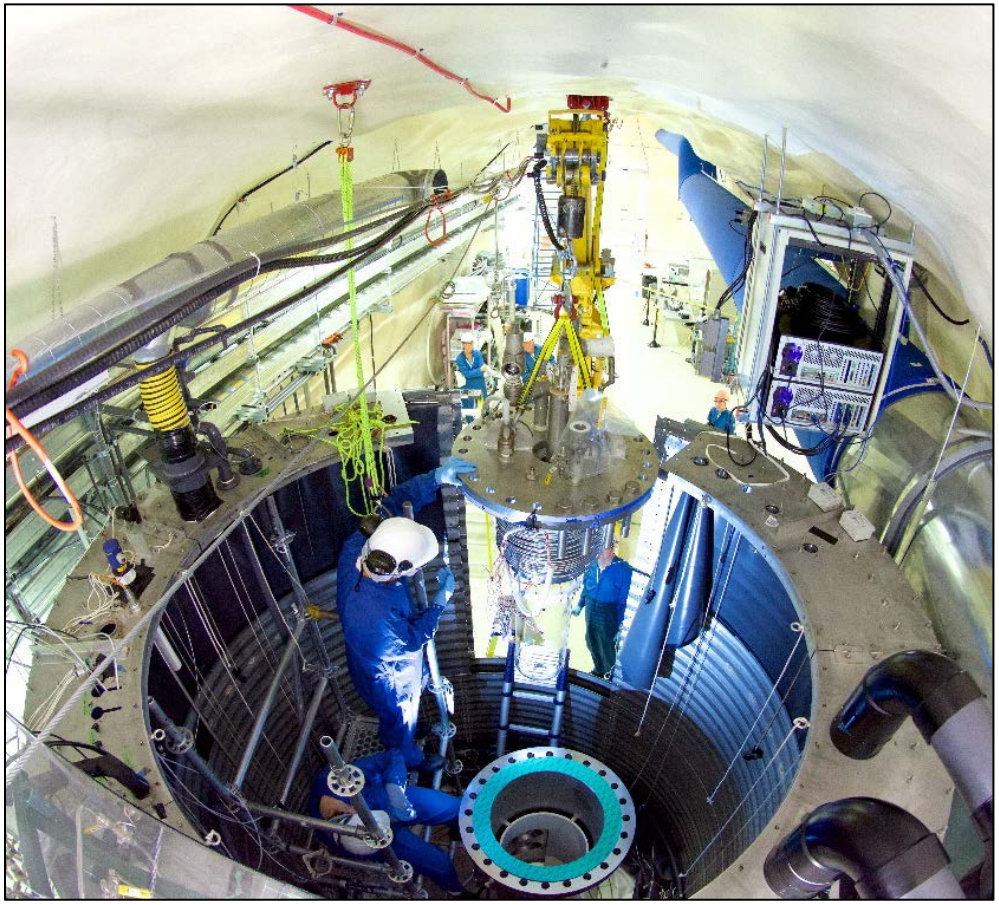
Try scaling to study with increased statistics

PICO-60 Cleaning

- Every component touching the inner volume was cleaned against MIL-STD-1246C level 50



Commissioning



- Filled with 40L C_3F_8 on June 30, 2016
- First physics run Nov. 2016 – Jan. 2017

What do we measure?

- Camera images (primary trigger)
  - How many bubbles were there? — **Neutron Rejection**
  - What was the bubble's position? — **Surface Rejection**
- Temperature
- Pressure (secondary trigger) — **Threshold Determination**
- Acoustic signal — **Alpha Rejection**

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- Camera images (primary trigger)
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- Temperature
- Pressure (secondary trigger)

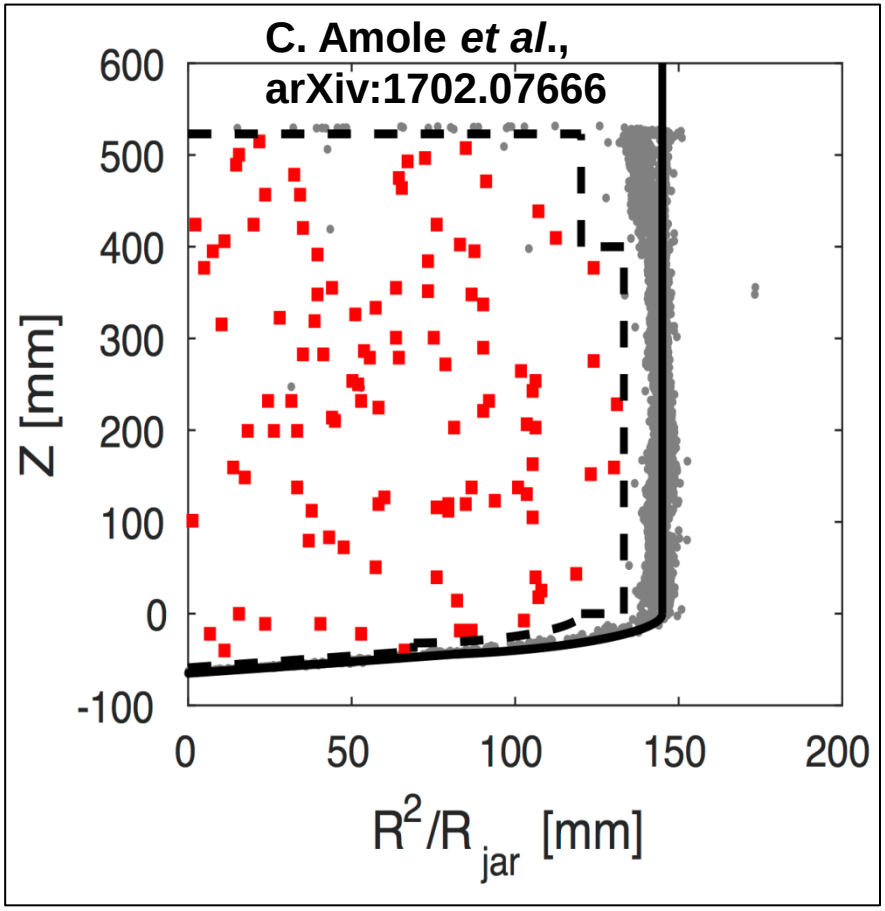
} **Threshold Determination**

- Acoustic signal — **Alpha Rejection**

Blind this information

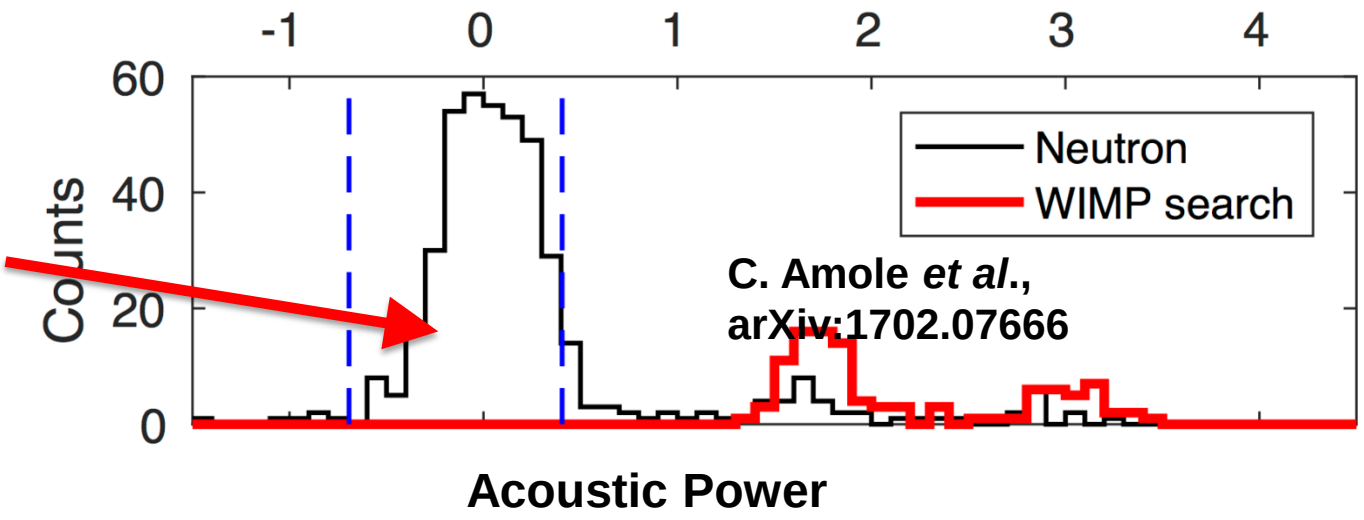
Before Opening the Box

- 106 bulk singles in WIMP search dataset
  - *Acoustics Still Blind*
  - Consistent with Rn decay rate in pre-WIMP search unblinded data
- Neutron Background
  - Not blinded to multiplicity
  - 3 multiple bubble events in the physics data
  - Multiples to singles ratio is approximately 3:1 from calibration and simulation
- **Conclusion: 0-3 bulk singles would be consistent with neutrons and no anomalous background**



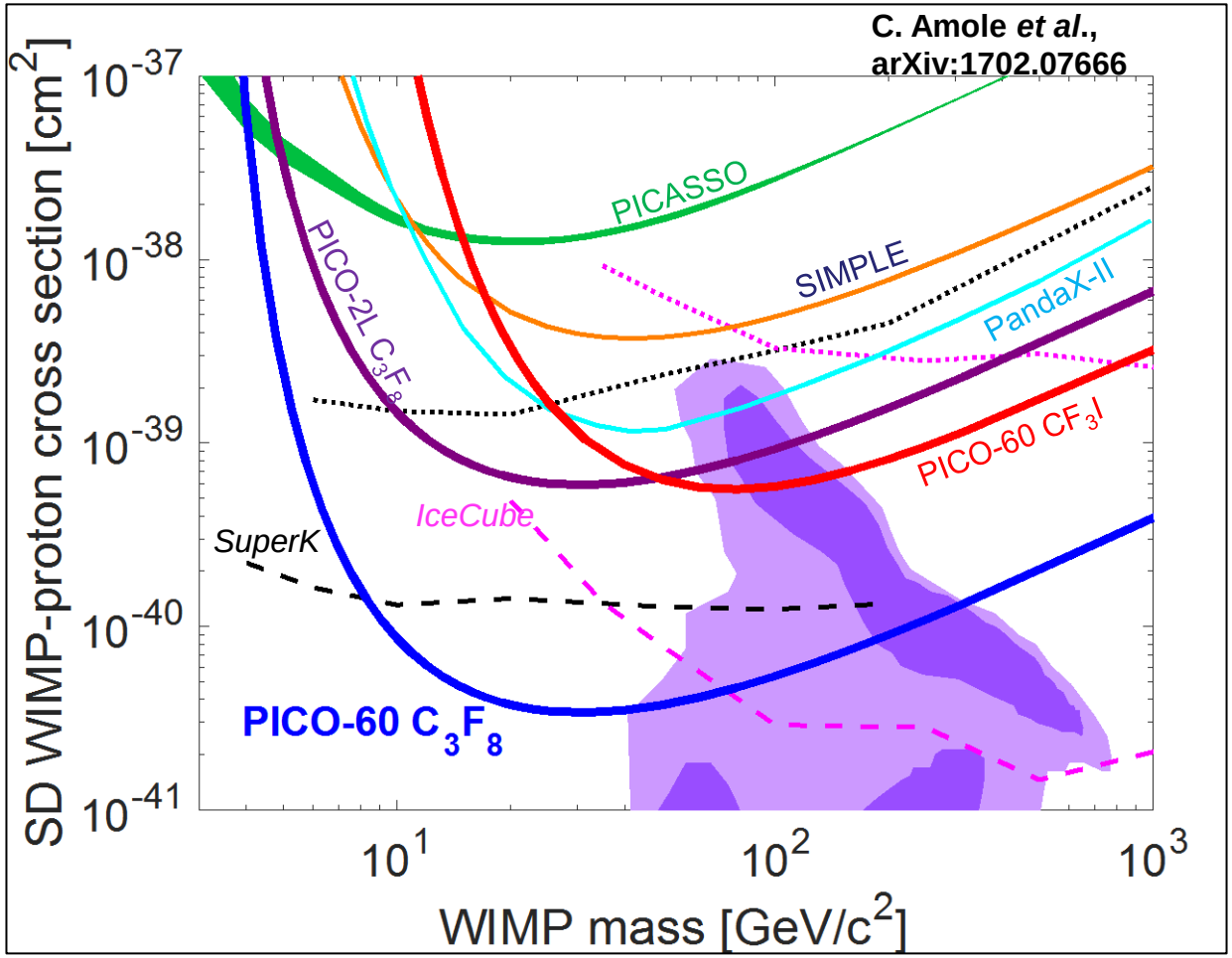
After Opening the Box

No events in signal region!



- Of the 106 fiducial-bulk singles, **none** are consistent with nuclear recoil hypothesis (all are consistent with radon chain alphas)
- No background events observed !
- Blind analysis

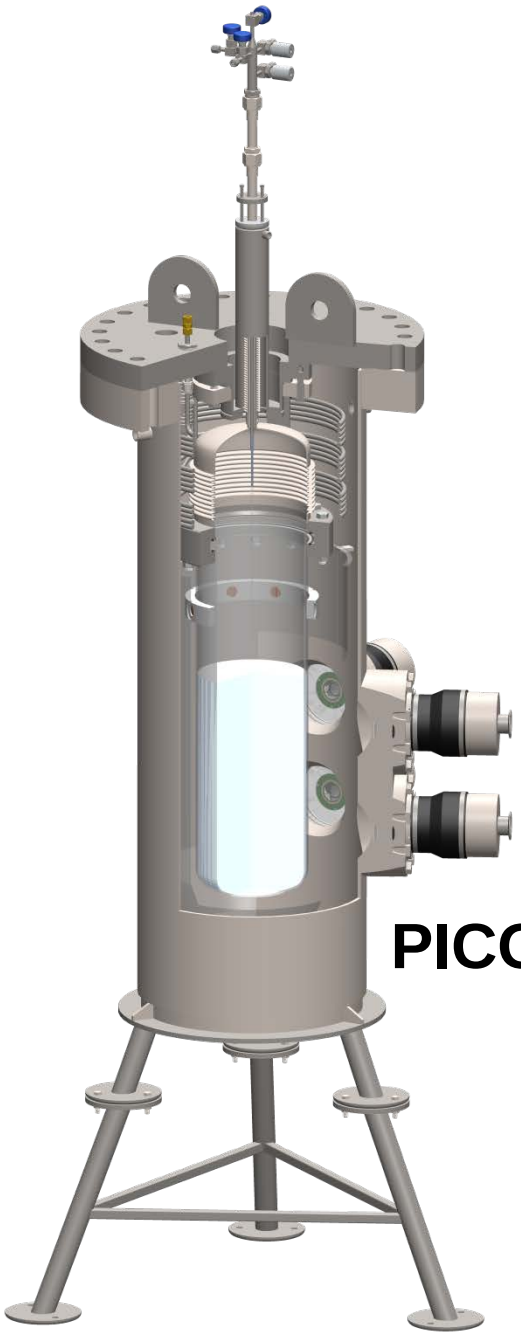
Spin-Dependent WIMP-Proton Coupling
Recent Limits from PICO-60



- PICO-60 – Blind analysis, 0 events observed, x17 improvement to set world best limit on spin dependent proton coupling

PICO-40L

Eliminate buffer fluid

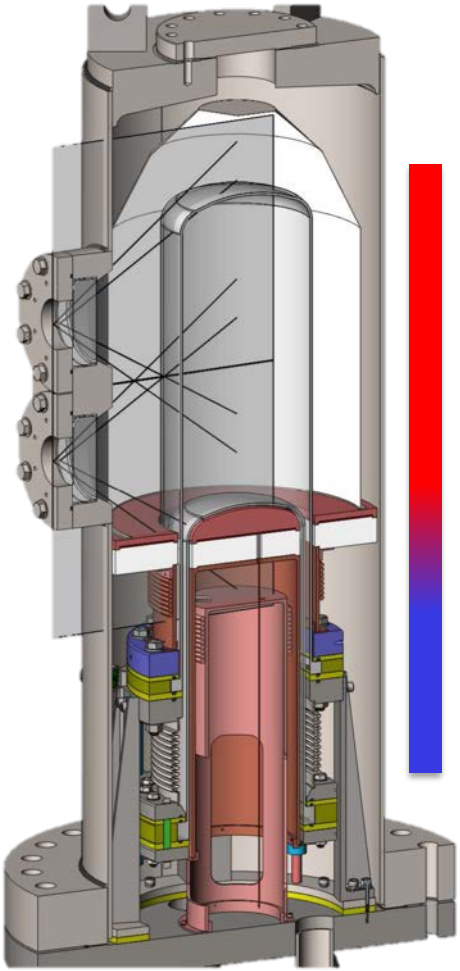


Purpose of buffer liquid is to isolate the active liquid from the stainless parts

PICO-60

PICO-40L

Thermal gradient can ensure that target fluid near stainless parts is not active

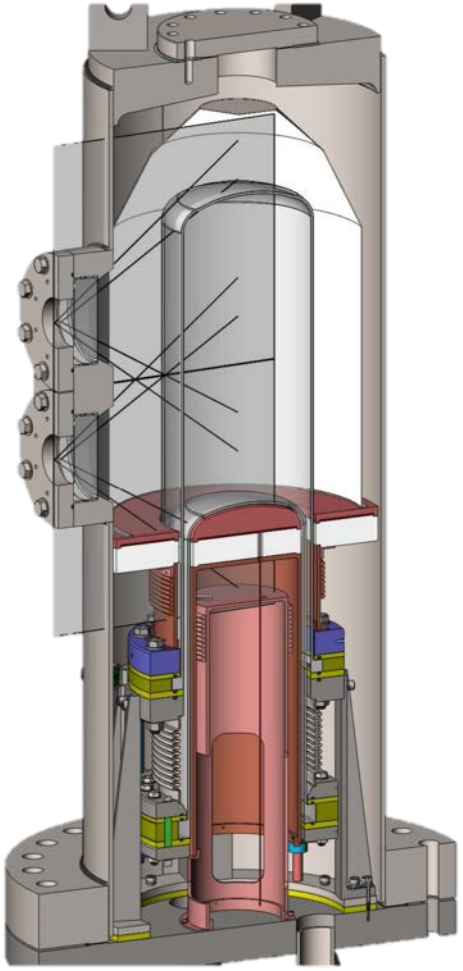


Thermal Gradient

PICO-40L

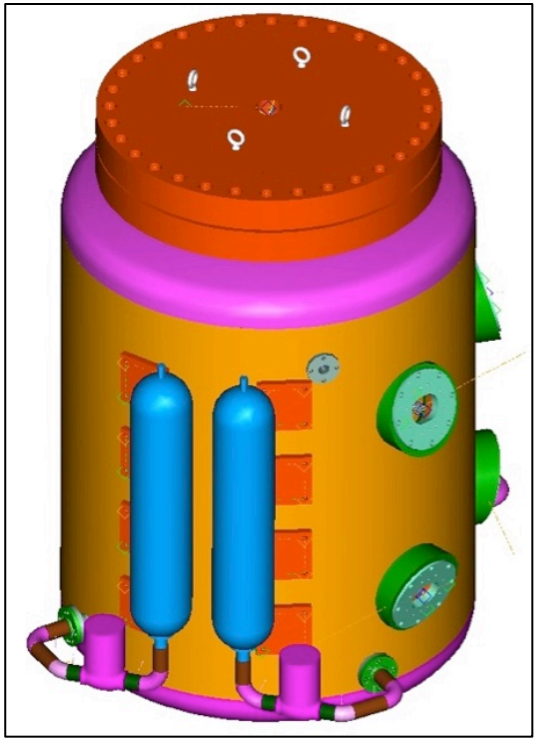
Physics reach

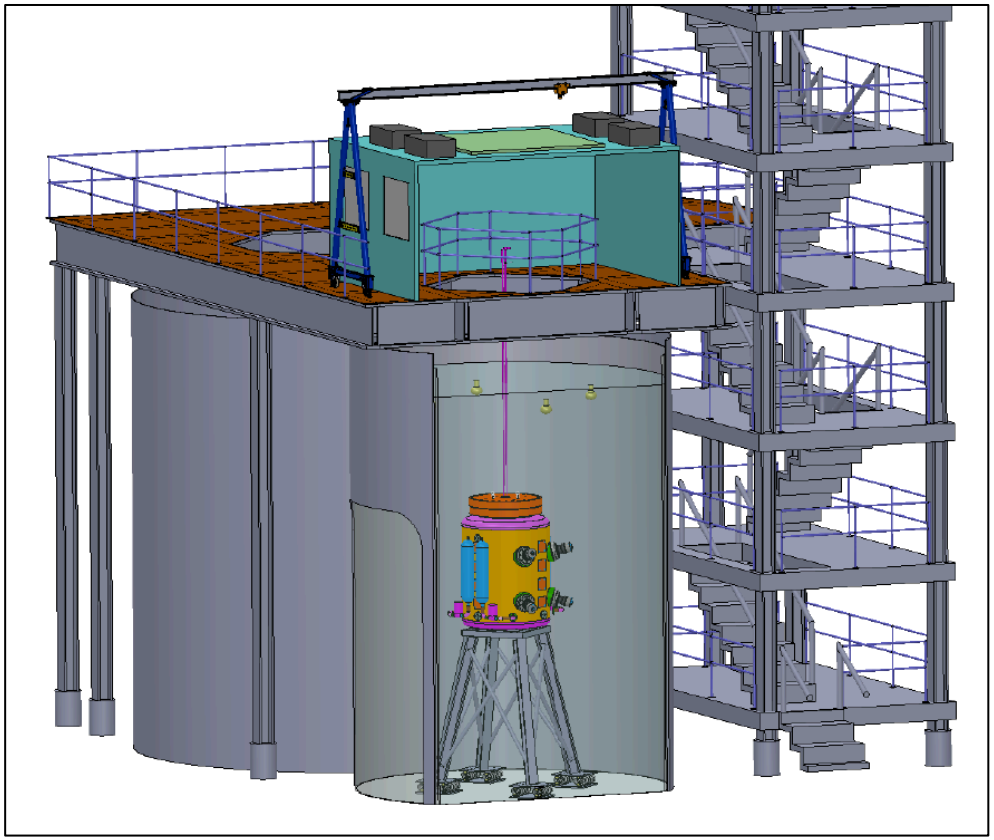
- Added stability could allow us to push down in threshold (WIMP mass) until we hit electron-recoil backgrounds
- Ability to use new target fluids optimized for different WIMP masses
- Reduced neutron backgrounds, allowing us to push down in cross-section
- Tests technology for future tonne scale detector: PICO 500



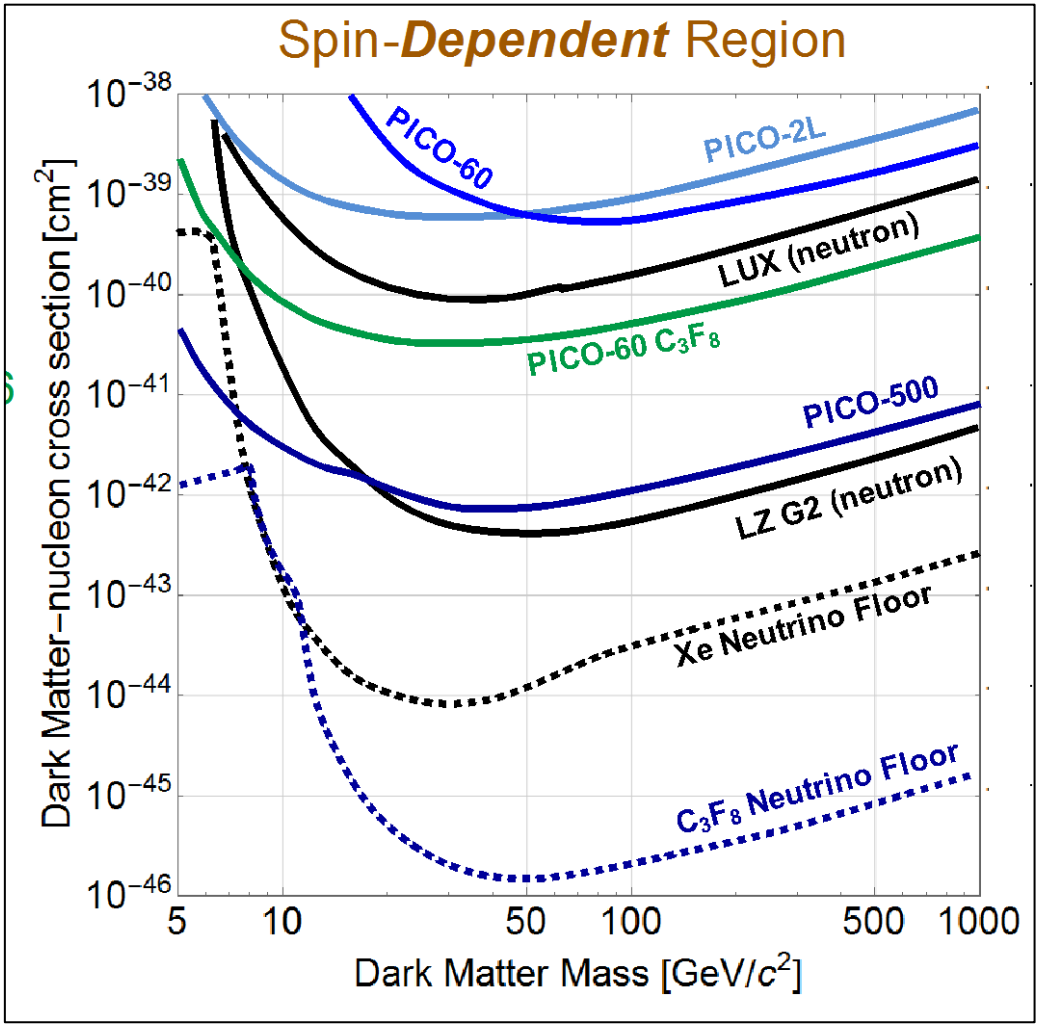
PICO-500

- Engineering work ongoing as part of R&D program
- Proposal for full detector (~$5M CAD) currently being adjudicated by CFI, decision expected June 2017
- Construction envisioned for early 2018





Spin-Dependent Future



- PICO program has significant reach in parallel to G2 experiments
- Lower neutrino floor opens unique phase to PICO

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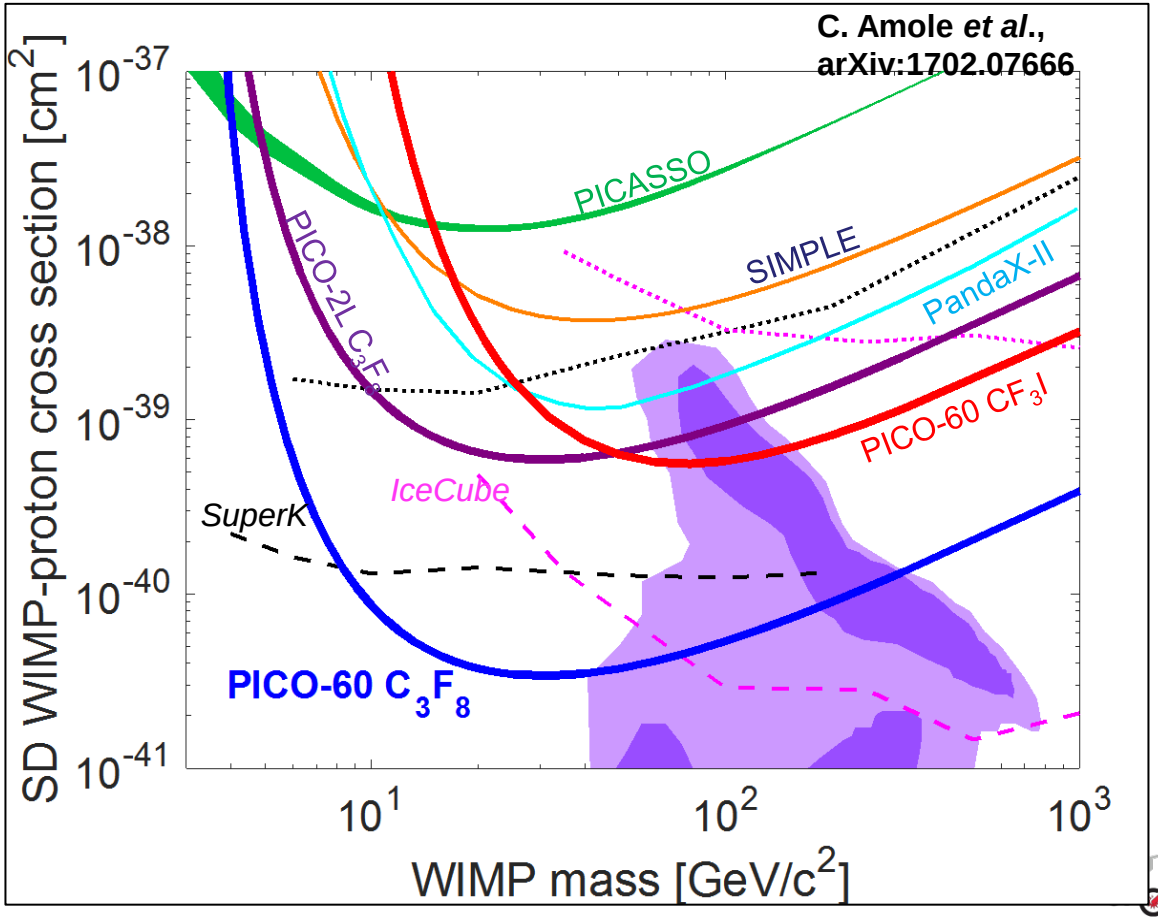
Summary

- PICO bubble chambers at the 40L scale can be built background-free
- PICO dominates the search for spin-dependent WIMP-proton couplings
- Construction of PICO 40 is well underway
- The design of PICO 500 is very advanced. Final technology choice for inner vessel to be made based on PICO 40 experience.



PICO

Laurentian University / Université Laurentienne
J. Farine, F. Girard, A. Leblanc, R. Podviyanuk, O. Scallon, U. Wichoski

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C. Amole, G. Cao, U. Chowdhury, G. Crowder, G. Giroux, A.J. Noble, S. Olson

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Northwestern University
D. Baxter, C.J. Chen, C.E. Dahl, M. Jin, J. Zhang

P. Bhattacharjee, M. Das, S. Seth

KICP Kavli Institute for Cosmological Physics
J.I. Collar, A. Ortega

Fermilab
P.S. Cooper, M. Crisler, W.H. Lippincott, A.E. Robinson, R. Rucinski, A. Sonnenschein

Drexel University
P. Campion, R. Neilson

University of Alberta
S. Fallows, C. Krauss, P. Mitra

Université de Montréal
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Czech Technical University in Prague
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Indiana University South Bend
E. Behnke, H. Borsodi, I. Levine, T. Nania, A. Roeder, J. Wells

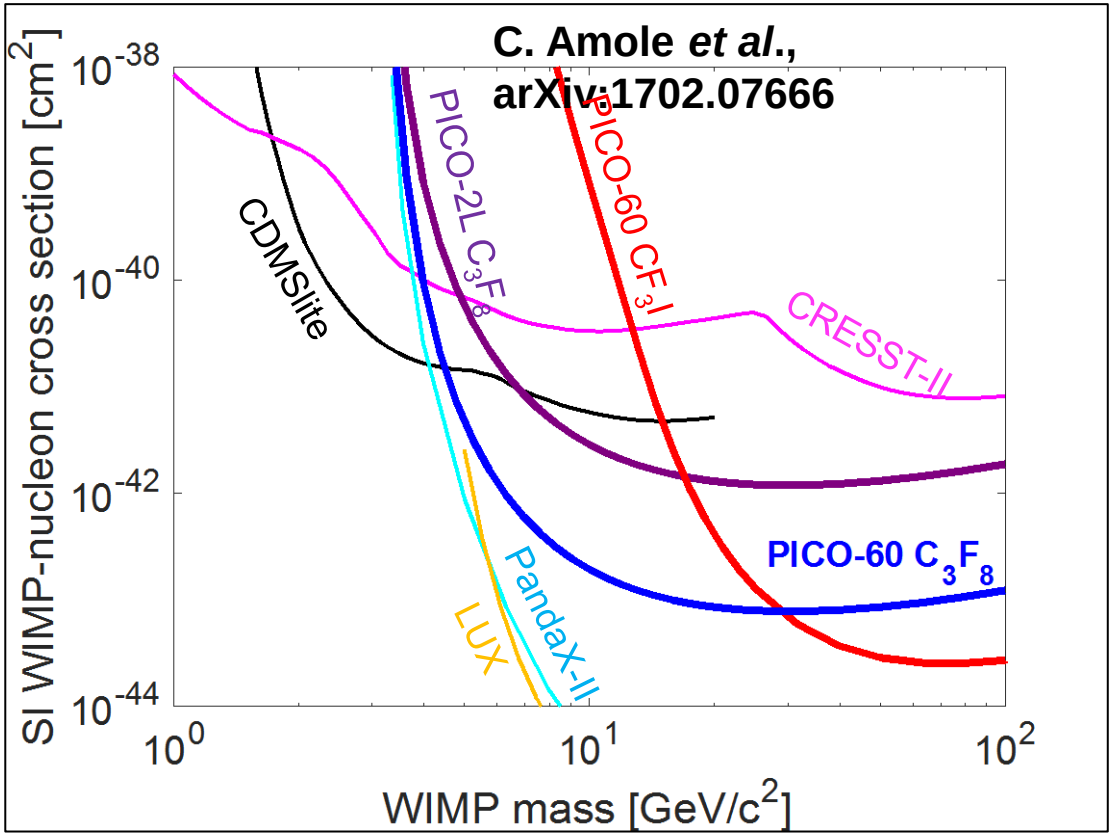
VirginiaTech
D. Maurya, S. Priya, Y. Yan

Northeastern Illinois University
O. Harris

Instituto de Física
E. Vázquez-Jáuregui

Spin-independent Limits

- Light nuclear targets give sensitivity to low-mass WIMPs
- Unexplored phase space would be accessible with slightly reduced threshold



Right Side Up design virtues:

- Superheated/normal transition is maintained by a thermal gradient with no buffer fluid
  - No buffer fluid means *no surface tension effects*
  - No buffer fluid means *no constraint on target fluid*
  - Works with any refrigerant, hydrocarbon, even xenon.
- Thermal gradient is naturally stable
- All metals at the bottom
  - Cold zone, no boiling to liberate particulate
  - No convection to move particulate up
- Geometry naturally lends itself to a recirculation loop