PICO at SNOLAB: Status and Future

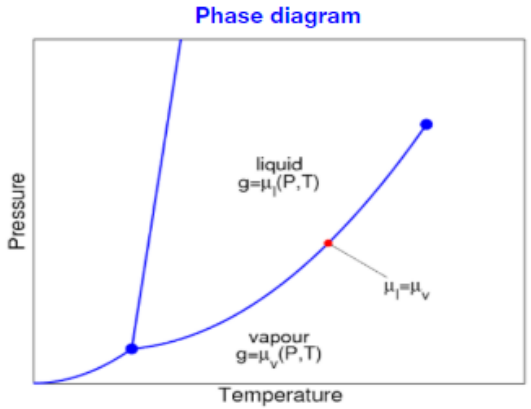
GUILLAUME GIROUX

FUTURE PROJECTS WORKSHOP

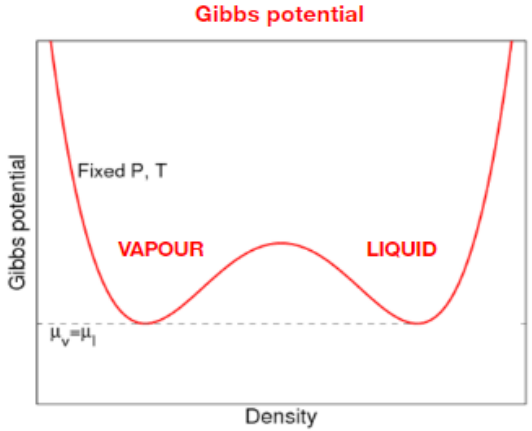
SNOLAB, JULY 2019

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

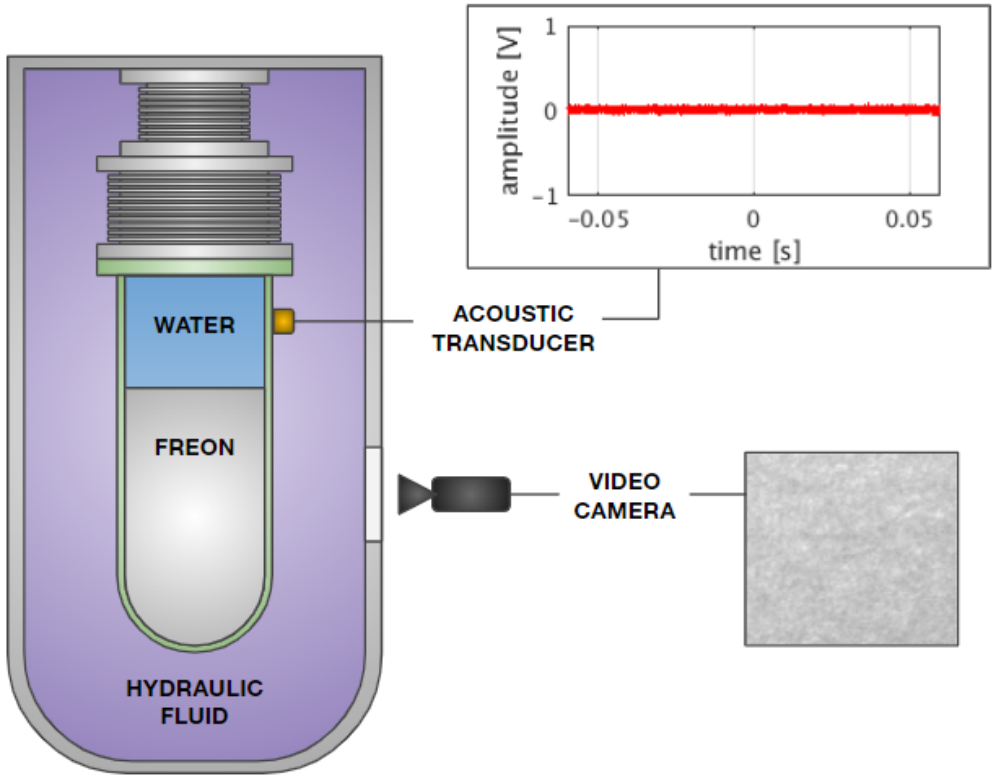
The PICO Bubble Chamber



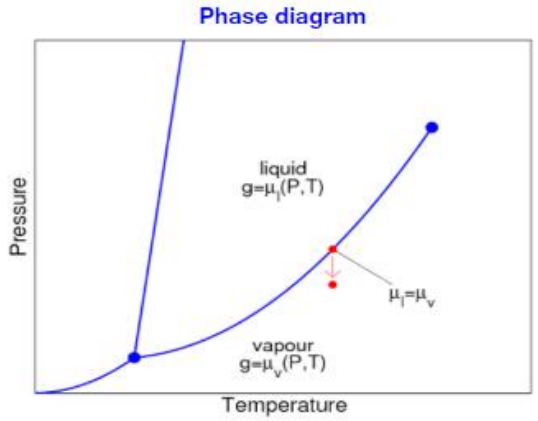
On the saturation curve, two minima exist in the Gibbs potential

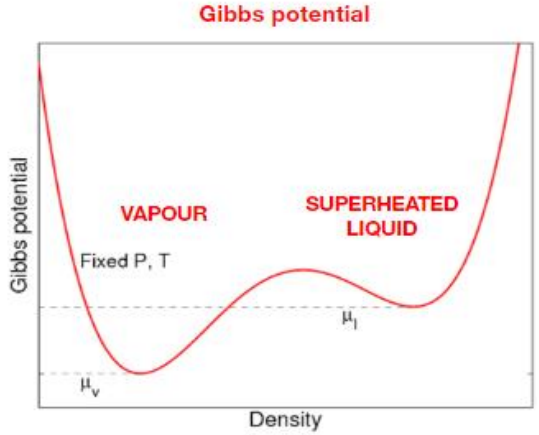


Vapour and liquid phase coexist



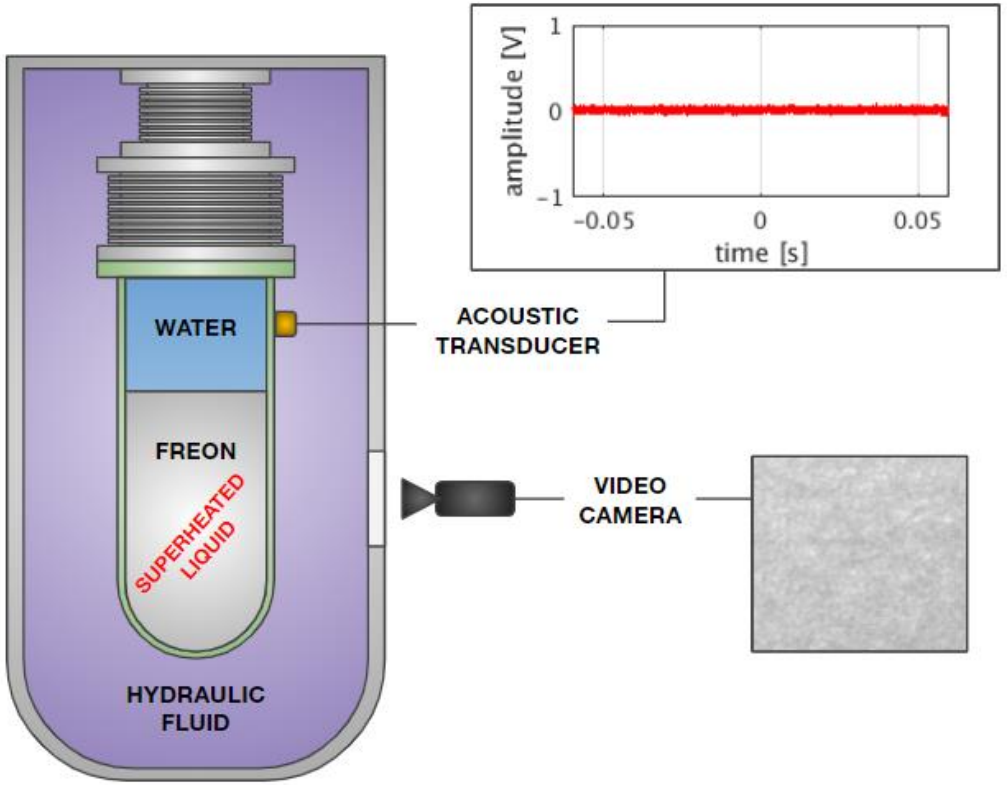
The PICO Bubble Chamber





If the pressure is lowered, the Gibbs potential is modified

Still two minima, but one is a metastable state: **superheated liquid**



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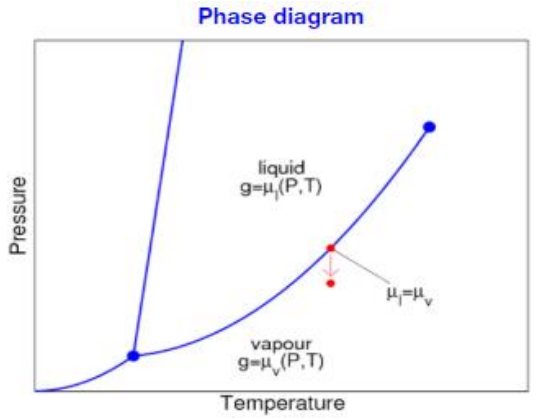

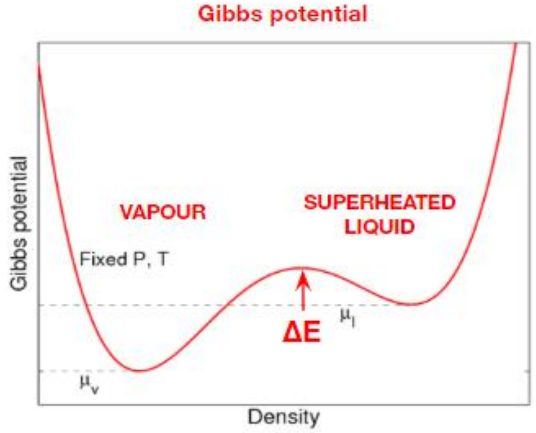

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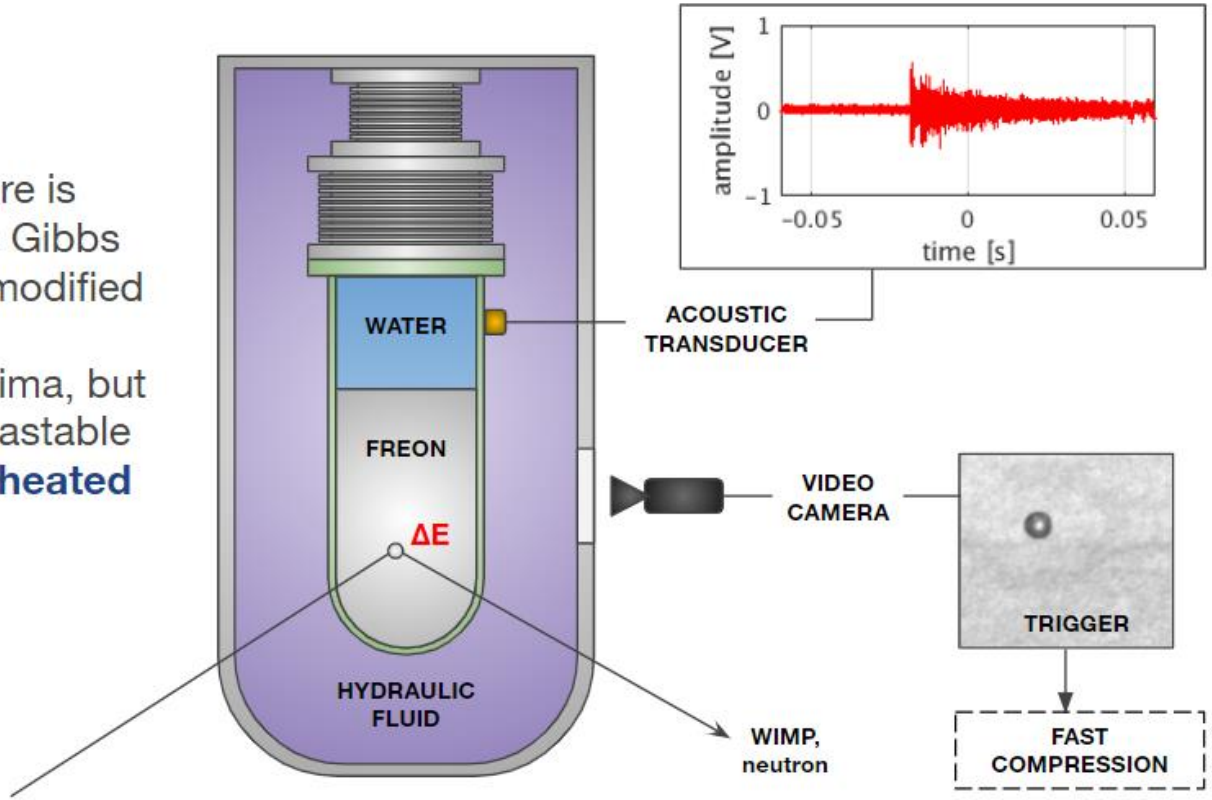
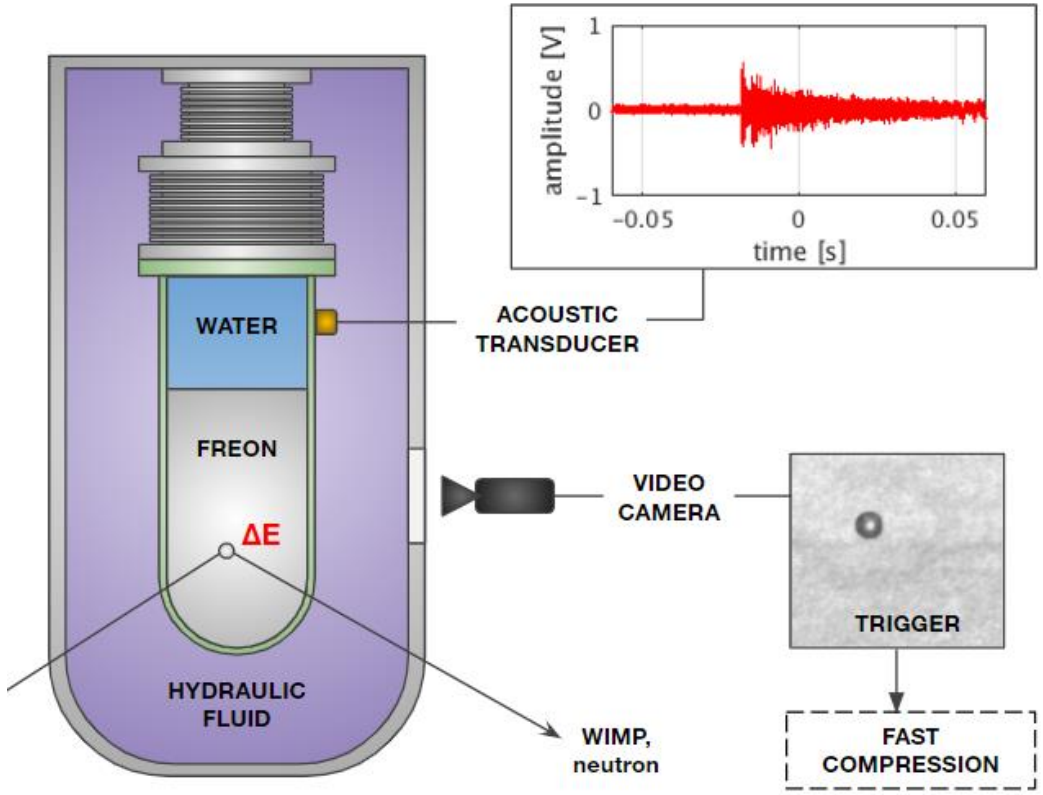


The PICO Bubble Chamber

Complementarity with existing dark matter searches:

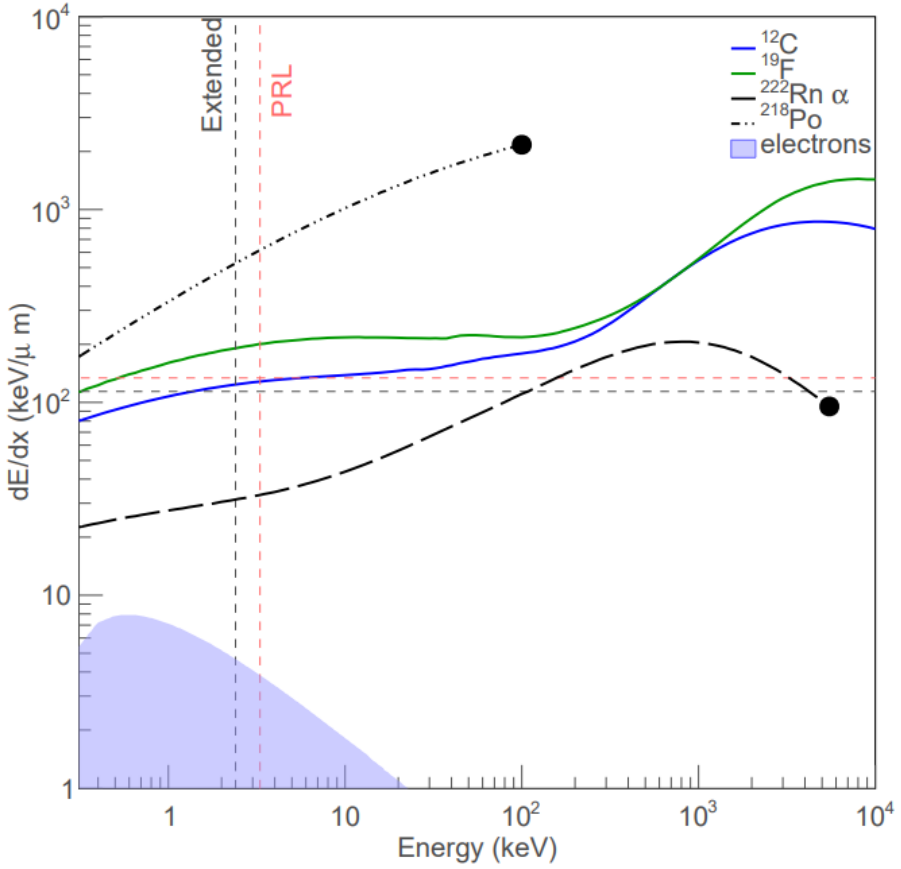
- Filled with fluorine-rich liquids
  → WIMP-proton spin dependent sensitivity

- Operated at high levels of superheat: low threshold for nuclear recoil nucleation
  → low WIMP mass sensitivity



Background Control

- **Gamma/beta radiation**
  - S.H. liquid detector have intrinsic electron-recoil rejection (dE/dx threshold)
  - At 3.2 keV nuclear-recoil energy threshold: **< 10^{-11}** efficiency for electron-recoils
- **Alpha decays**
  - Acoustic discrimination of nuclear recoils: multiple nucleation sites on longer alpha particle tracks
  - *Alpha calorimetry* (^{222}Rn chain decay ID)
- **Fast neutrons**
  - Unambiguous multiple scattering signature
  - Shielding: underground laboratory, radio-pure construction material, additional water/PE shielding



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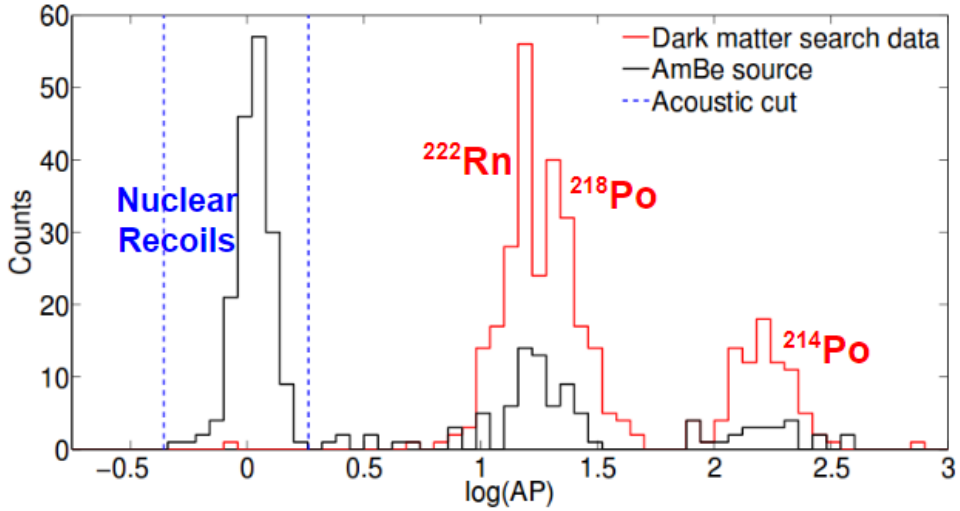

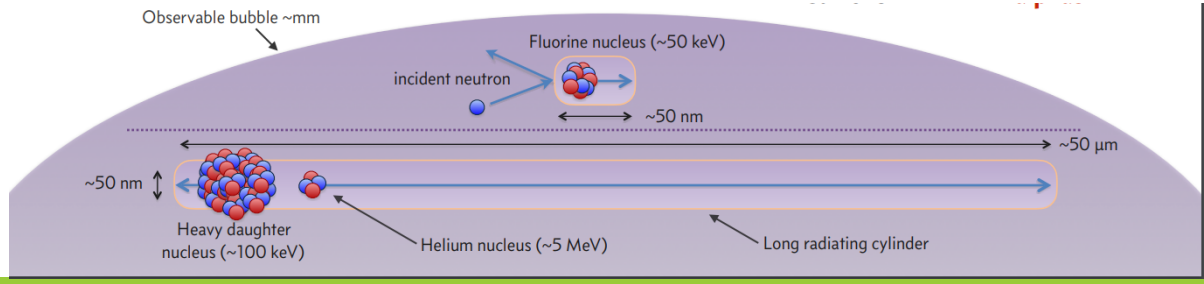

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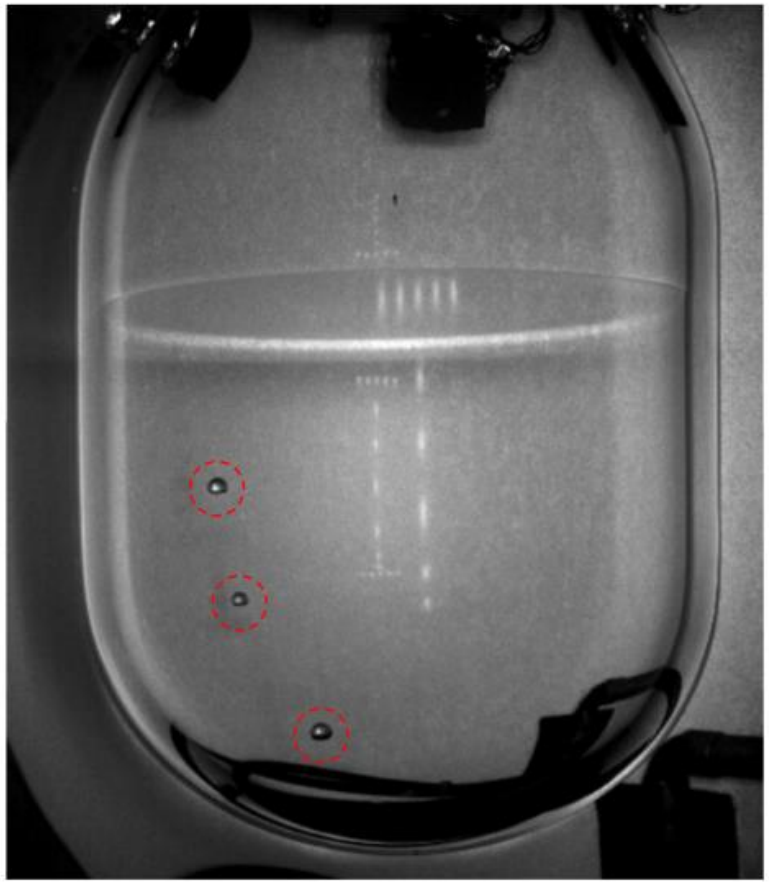
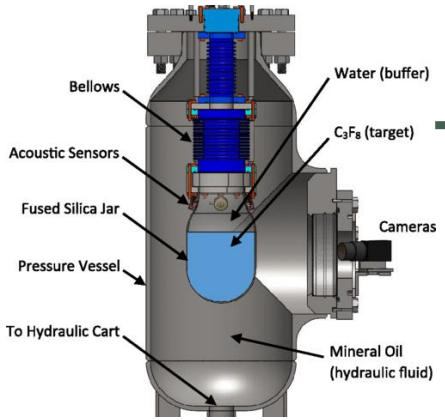


Roadmap

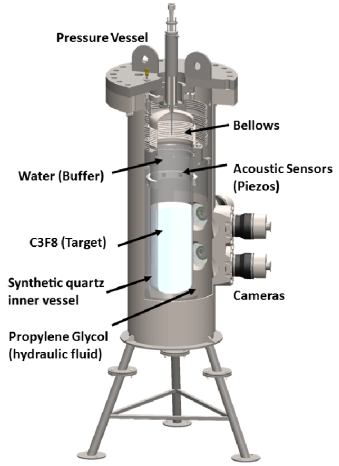
PICASSO

COUPP

PICO-2L Run 1 & 2

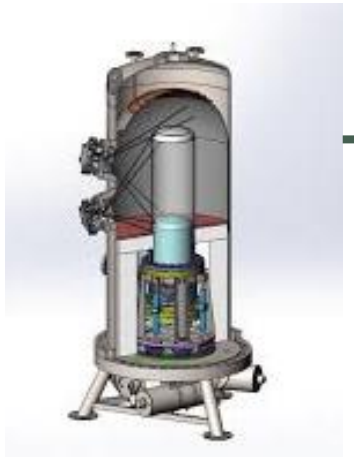


PICO-60

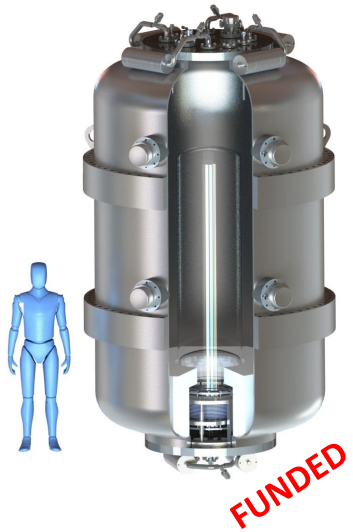


Past | **Present** | **Future**

PICO-40L



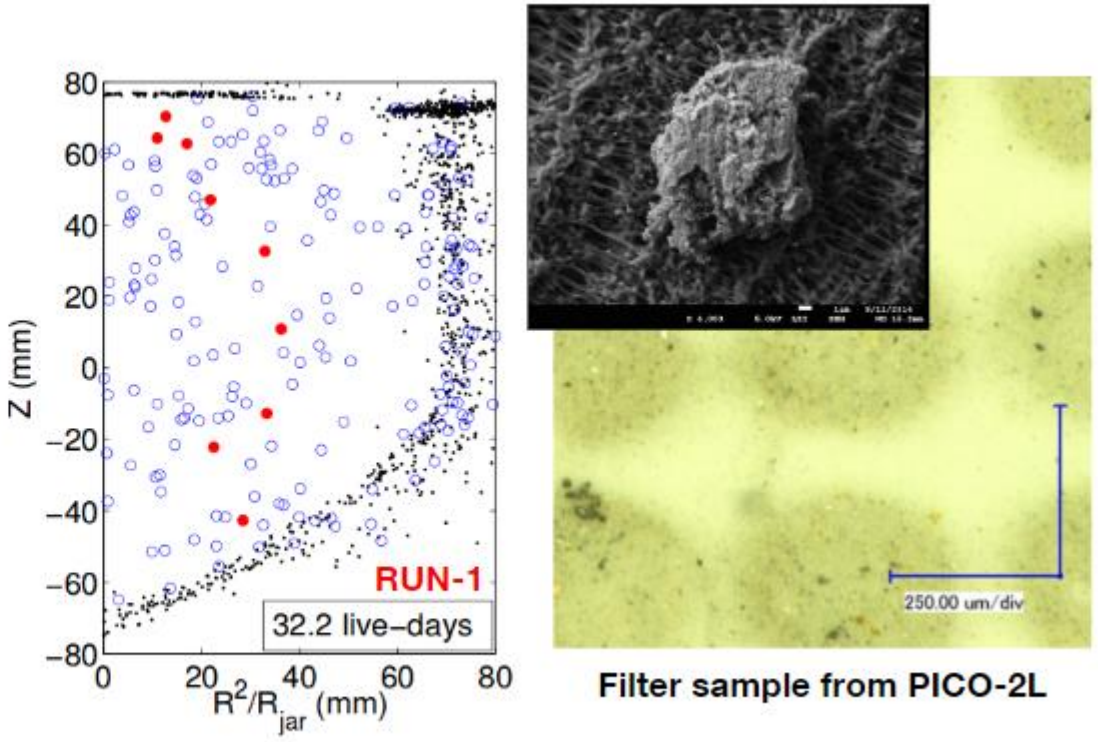
PICO-500



FUNDED

Particulates Background

- Anomalous nuclear-recoil-like surplus of events in first run of PICO-2L (C_3F_8) and PICO-60 (CF_3I)
- Post-run assays indicate the presence of a particulate matter contamination (stainless steel, quartz)

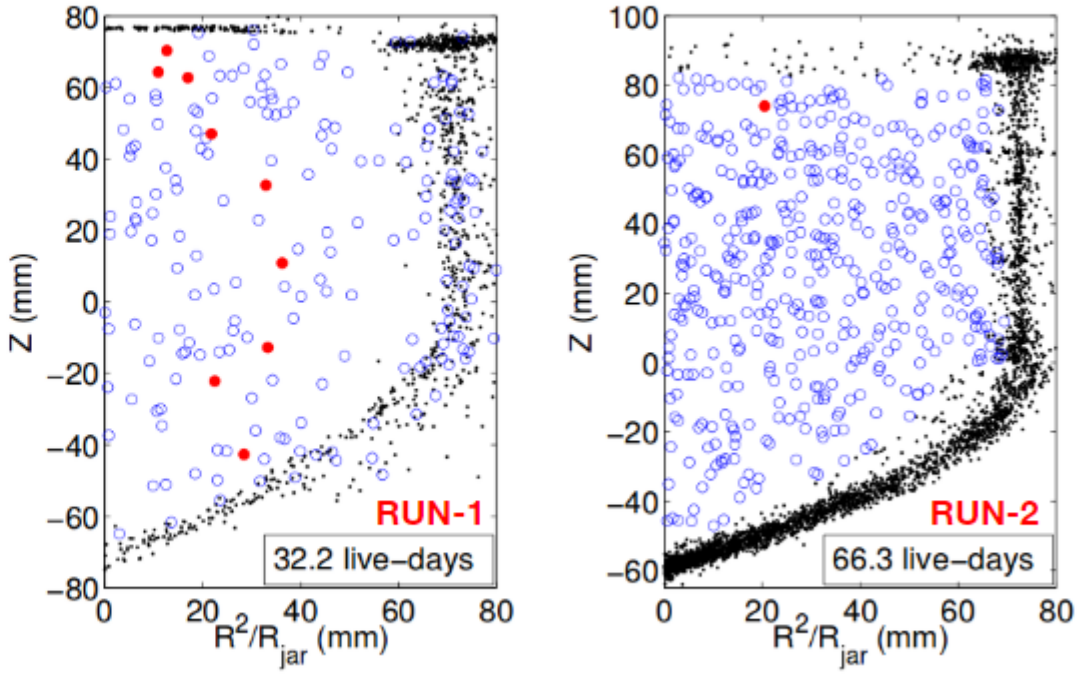


Filter sample from PICO-2L

Particulates Background

- Anomalous nuclear-recoil-like surplus of events in first run of PICO-2L (C_3F_8) and PICO-60 (CF_3I)
- Post-run assays indicate the presence of a particulate matter contamination (stainless steel, quartz)
- **Focus on particulate mitigation eradicated the anomalous background in the second run of PICO-2L**

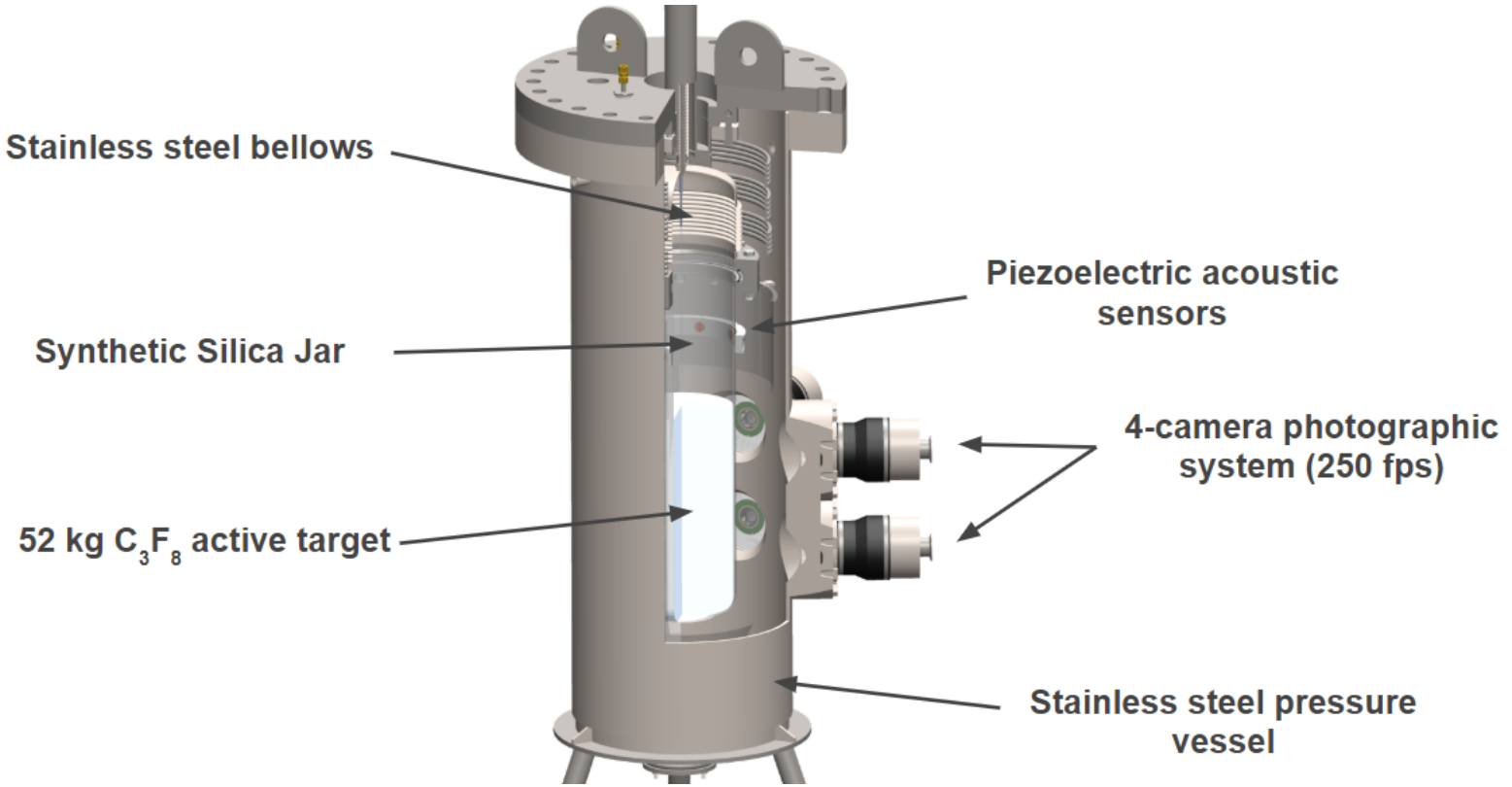
C. Amole *et al.*, Phys. Rev. D 93, 061101 **(2016)**



The PICO-60 Detector

First Run with **36.8 kg CF_3I**
(formerly COUPP-60)

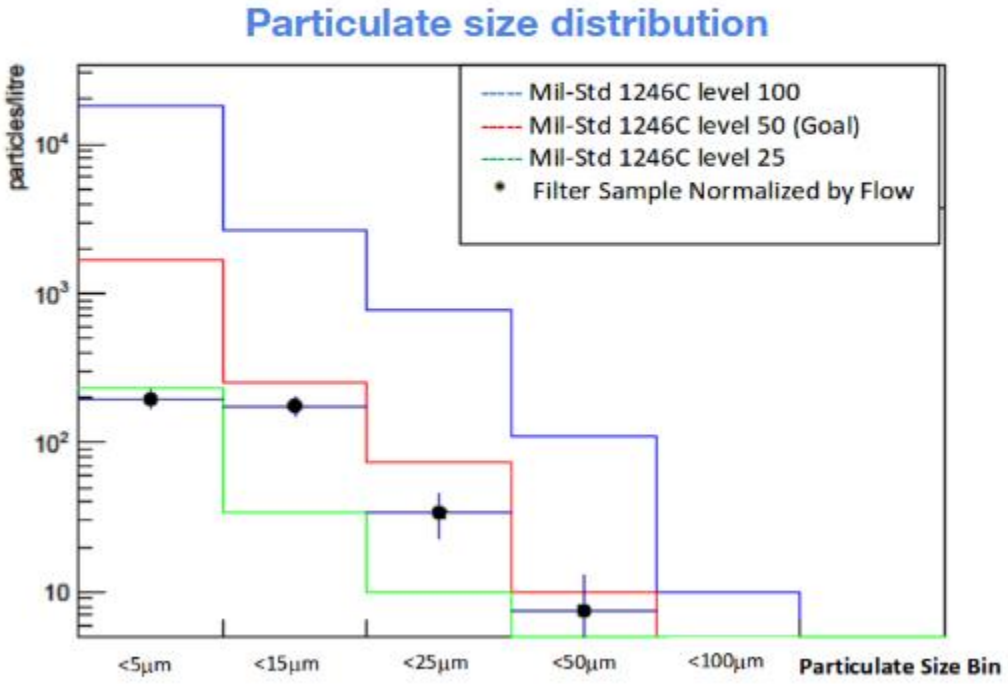
Phys. Rev. D 93, 052014 (2016)



Second commissioning with **52 kg C_3F_8**

The PICO-60 Detector

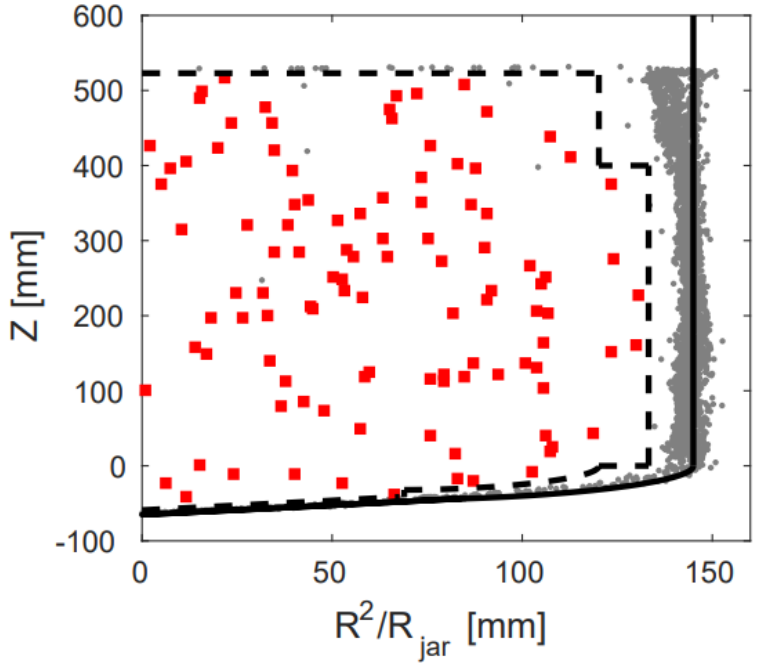
Inner volume components cleaned to MIL-STD-1246C level 50

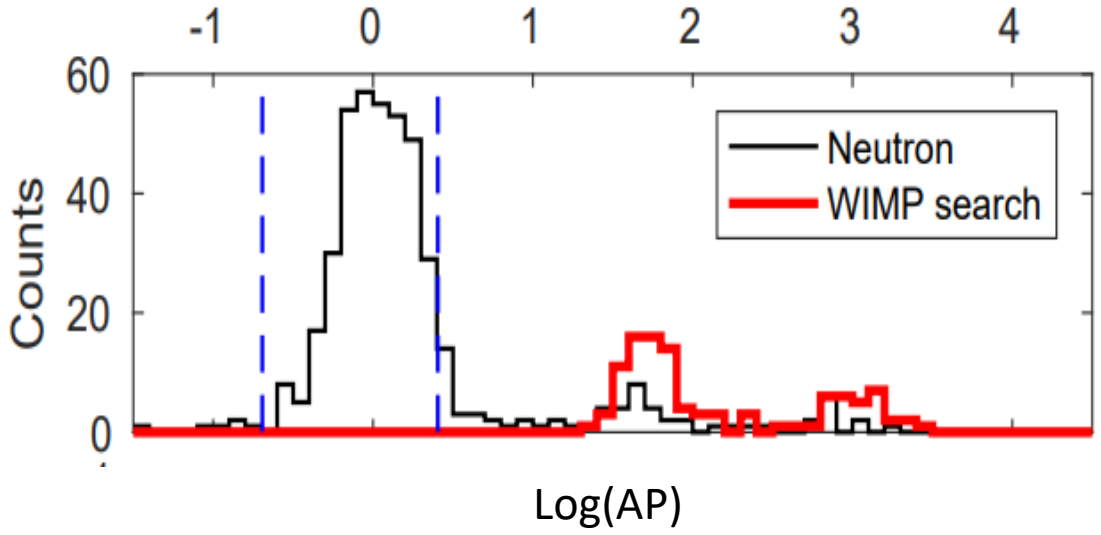


The "dishwasher"

PICO-60 First Run (3.3 keVnr)

Phys. Rev. Lett. **118**, 251301 (2017)

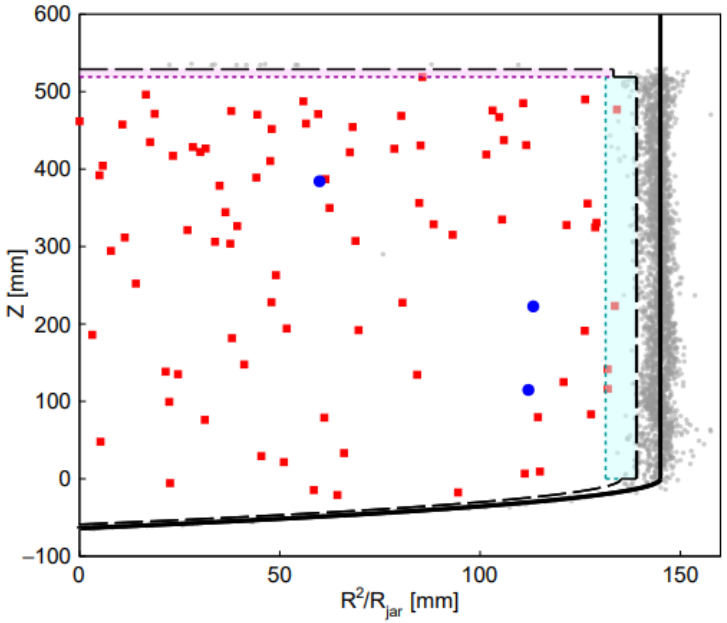


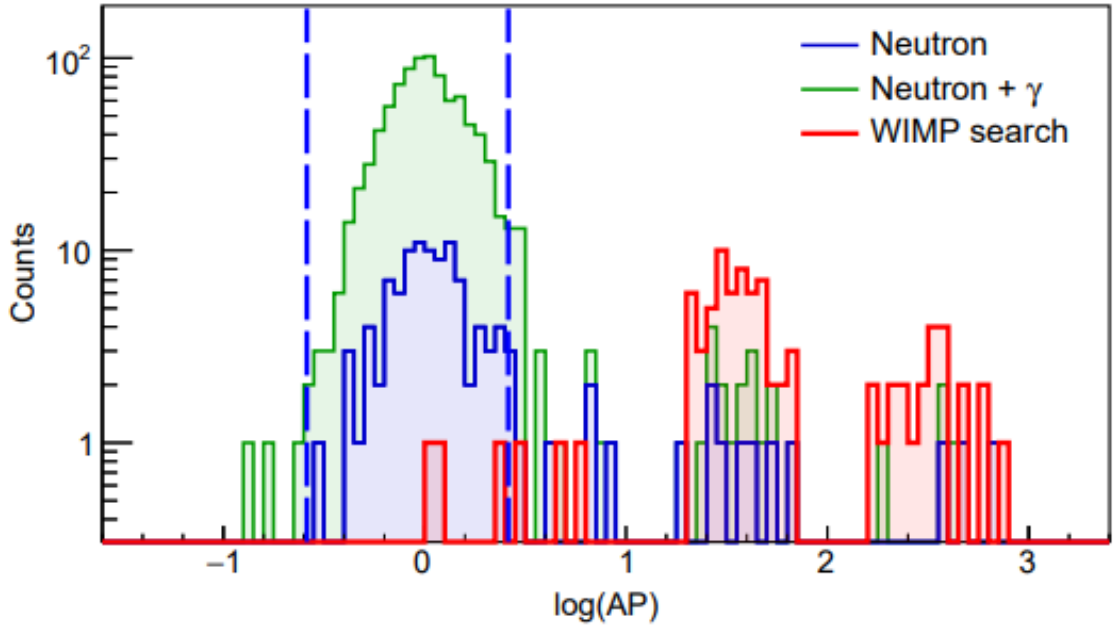


30 live-days (1.3 ton-days) blinded run reveal 106 single bubble in the bulk (3 multiples), no nuclear recoil AP candidates.

PICO-60 Second Run (2.4 keVnr)

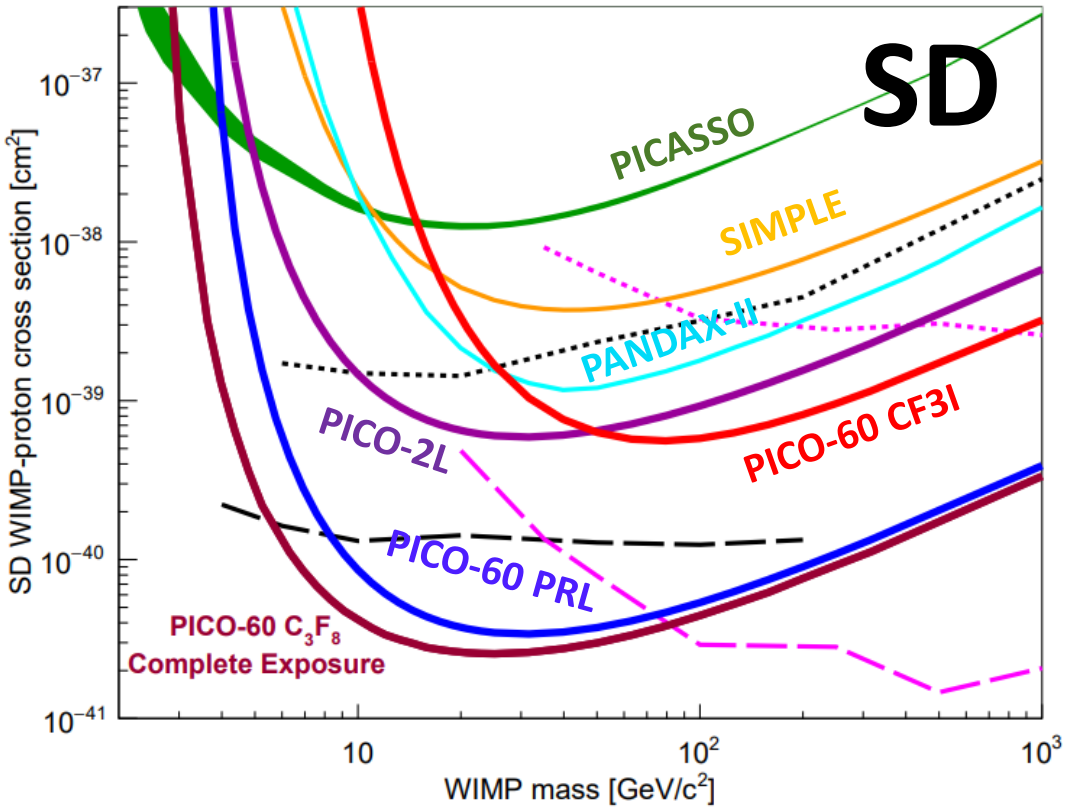
Phys. Rev. D **100**, 022001 (2019)

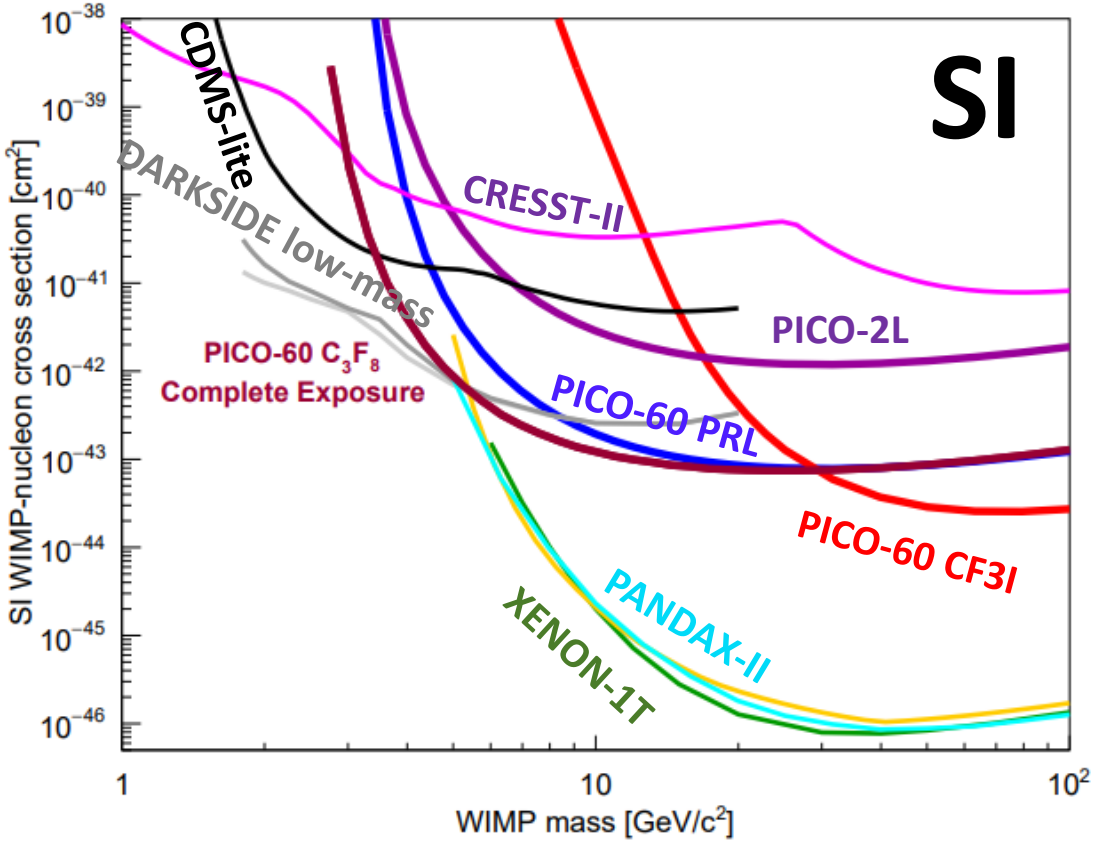




2nd run at lower threshold, 30 live-days (1.4 ton-days) blinded run reveal 87 single bubble in the bulk (2 multiples), 3 nuclear recoil AP candidates.

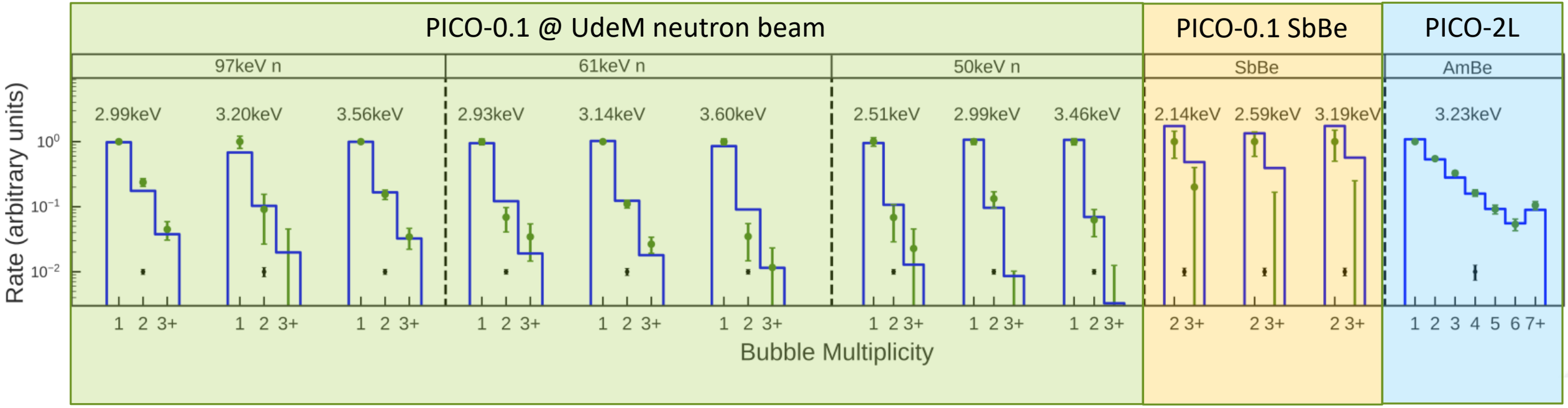
Results from PICO-60





*New paper in preparation! *

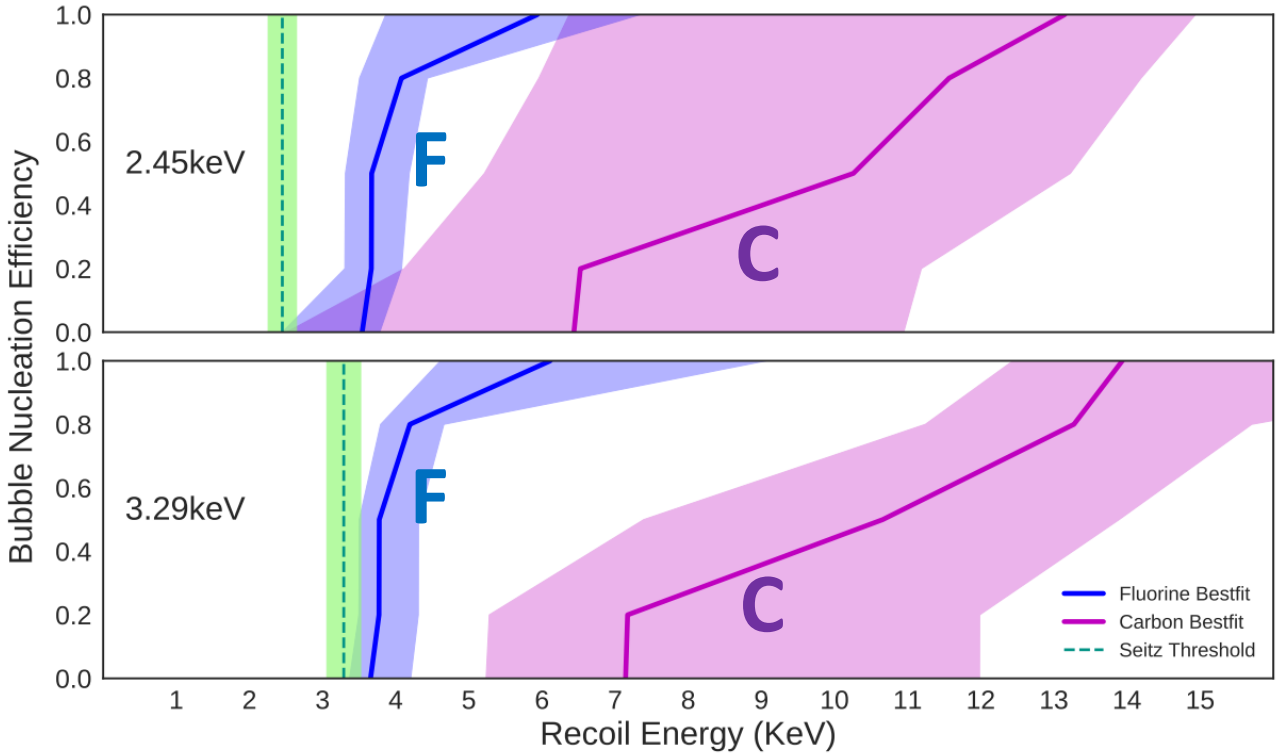
Nuclear Recoil Nucleation Efficiency



New global fit on the nuclear recoil nucleation efficiency using MCMC technique.
Constrained using simulation (Geant4 & MCNP) of nucleation rate and bubble multiplicity

*New paper in preparation! *

Nuclear Recoil Nucleation Efficiency

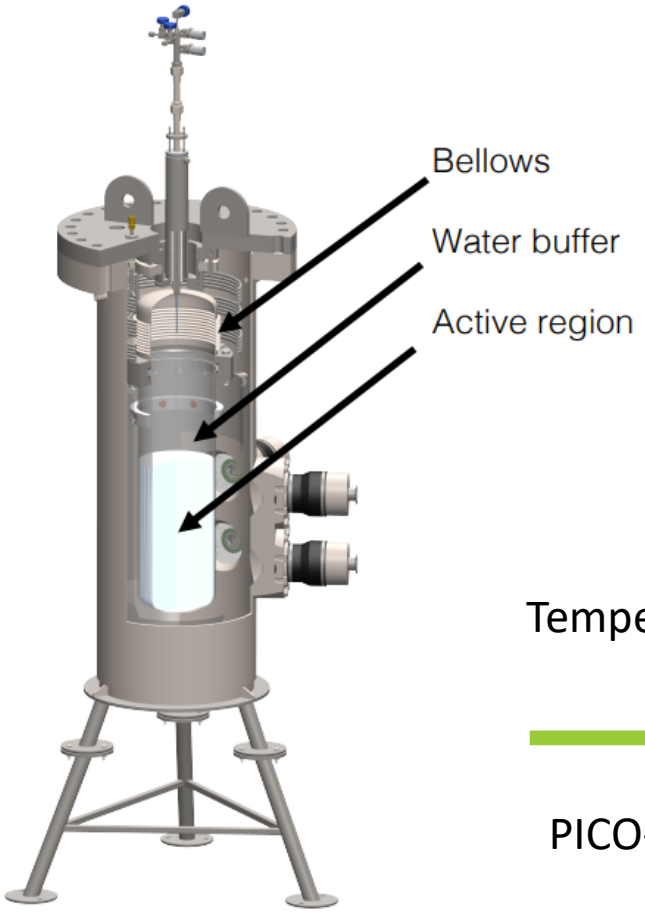


Best-fit for fluorine and carbon efficiency curves for 2.45 and 3.29 keVnr

Shaded regions showing 1-sigma uncertainty

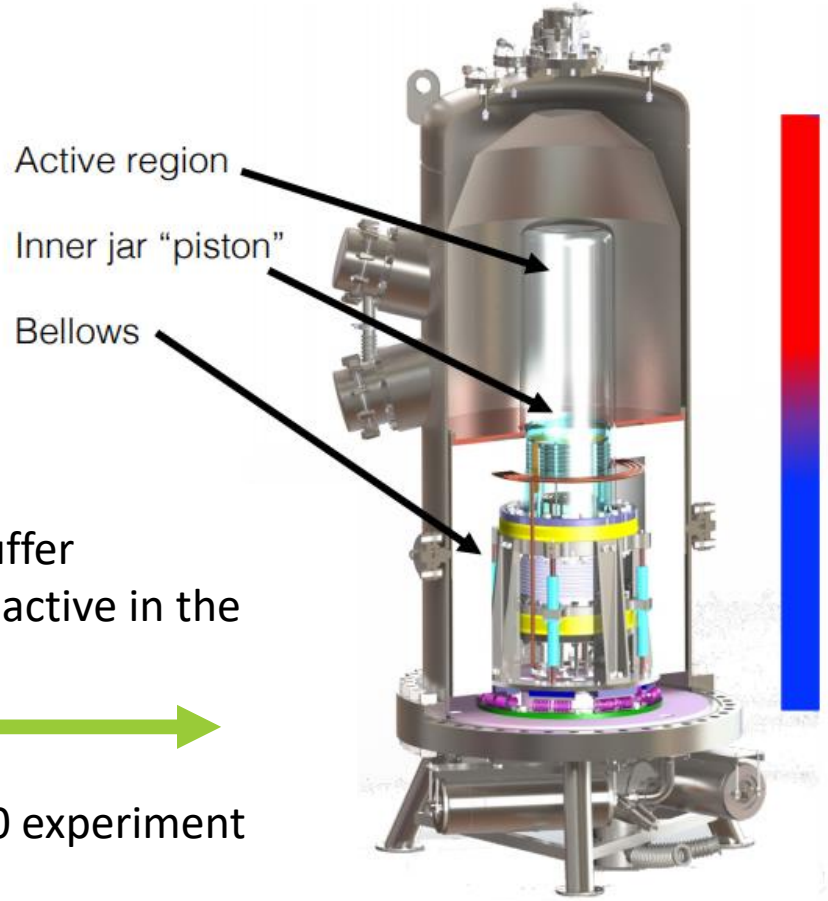
Green dashed lines are “Seitz” thresholds

PICO-60 → PICO-40L

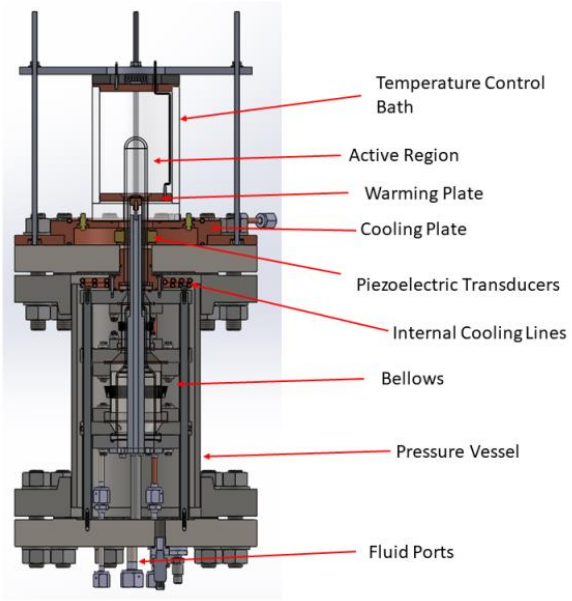


Putting the "Right-Side-Up"
Eliminated the need for water buffer
Temperature Gradient renders the C_3F_8 inactive in the bellows/plumbing

PICO-40L is a prototype for the PICO-500 experiment

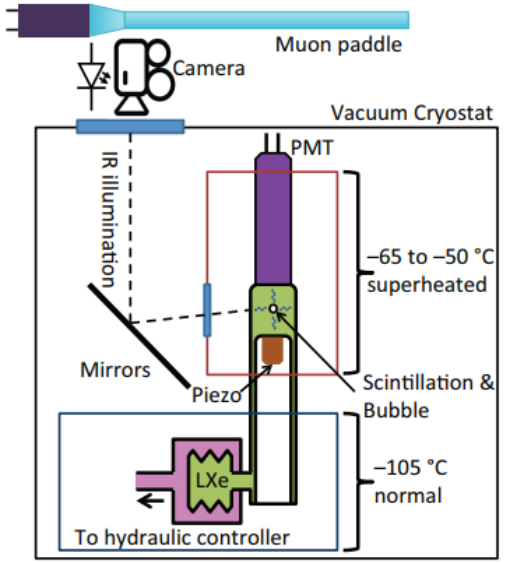


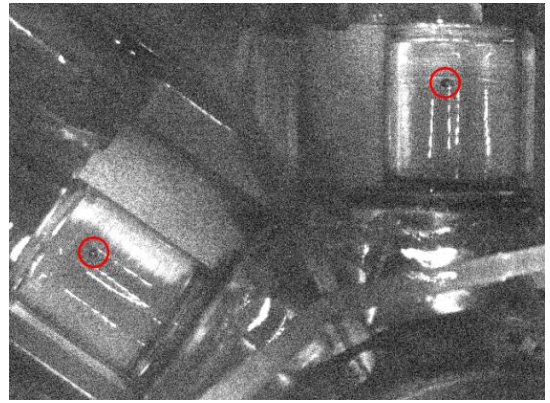
Right-Side-Up Proofs of Concept



A buffer-free concept bubble chamber for PICO dark matter searches

M. Bressler et al., arXiv:1905.07367 [physics.ins-det]



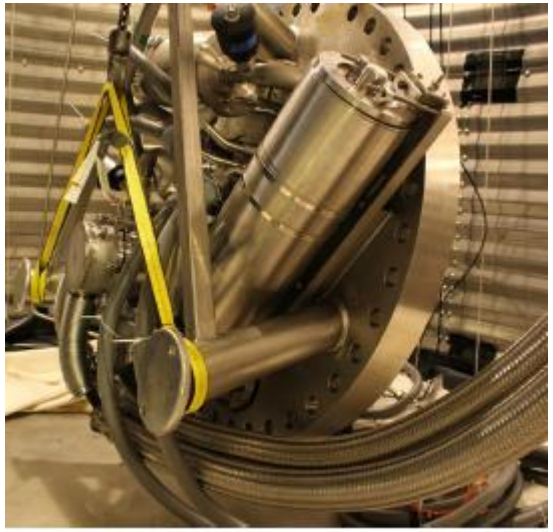


First Demonstration of a Scintillating Xenon Bubble Chamber for Detecting Dark Matter and Coherent Elastic Neutrino-Nucleus Scattering

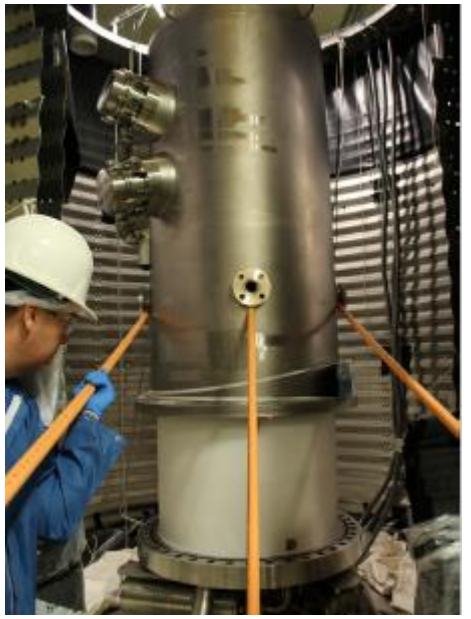
D. Baxter, et al., Phys. Rev. Lett. 118, 231301 (2017)

PICO-40L Installation Status

Inner volume components cleaned and assembled on surface, shipped UG late 2018

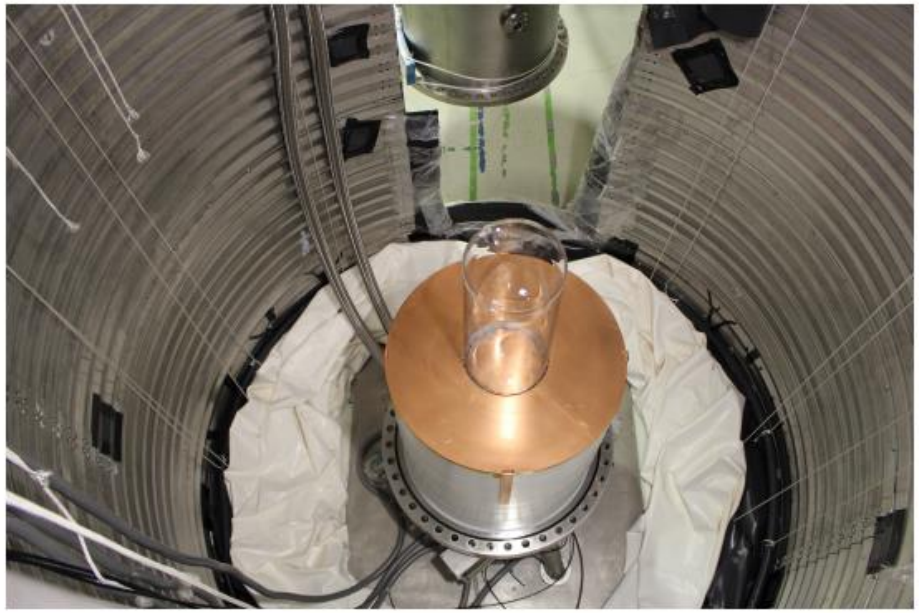


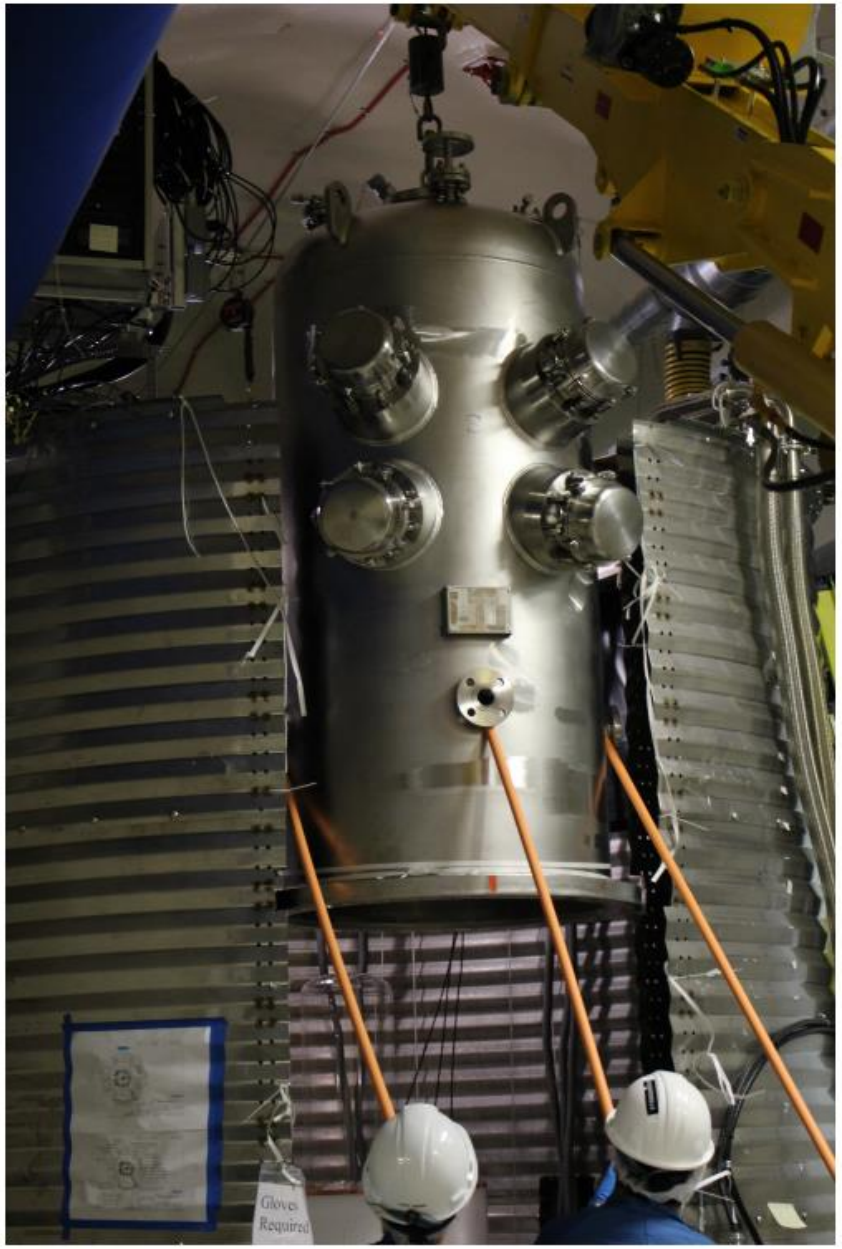
Base flange assembly February 2019

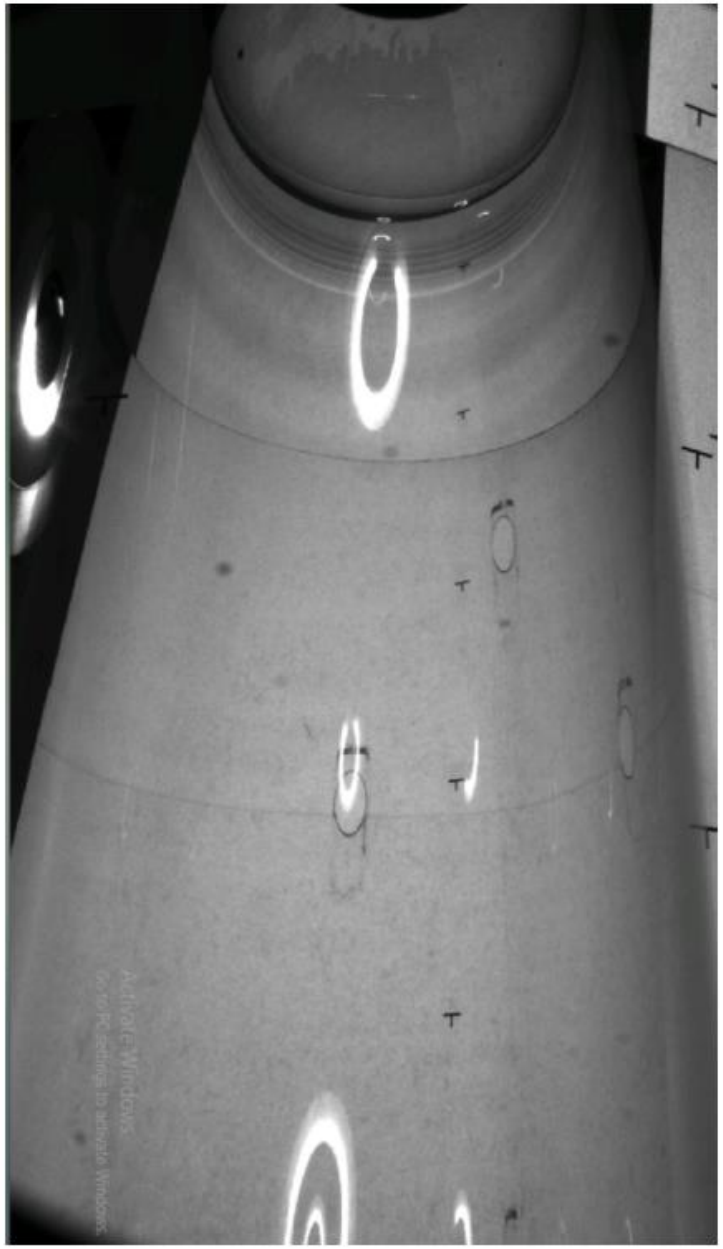


IV, instrumentation and Insulation installed in pressure vessel April 2019

Pressure Vessel filled with oil July 2019




Gloves
Required



PICO-40L Installation Status

Inner volume fill with C3F8 planned for… Tomorrow!

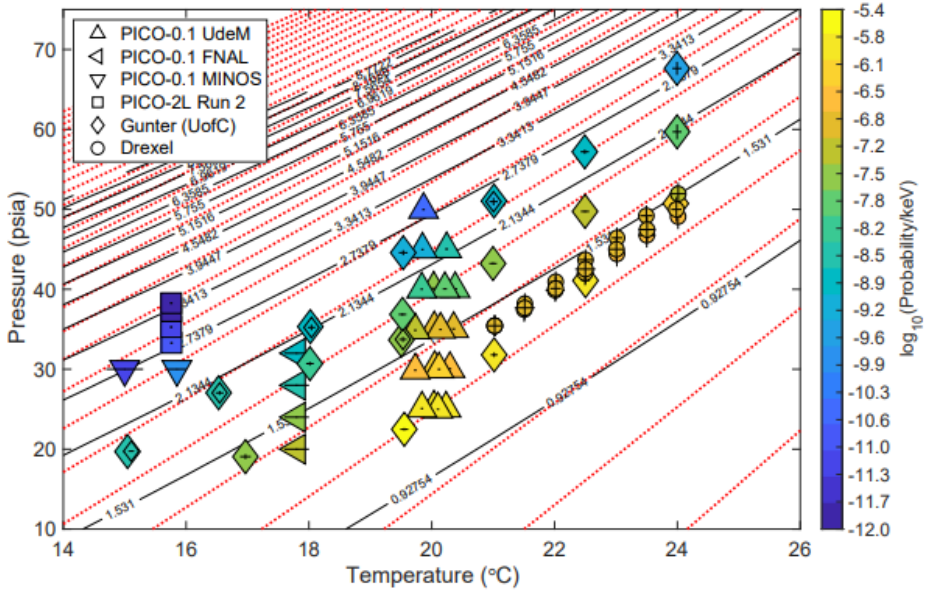
Fill system, thermal control, monitoring tools ready.

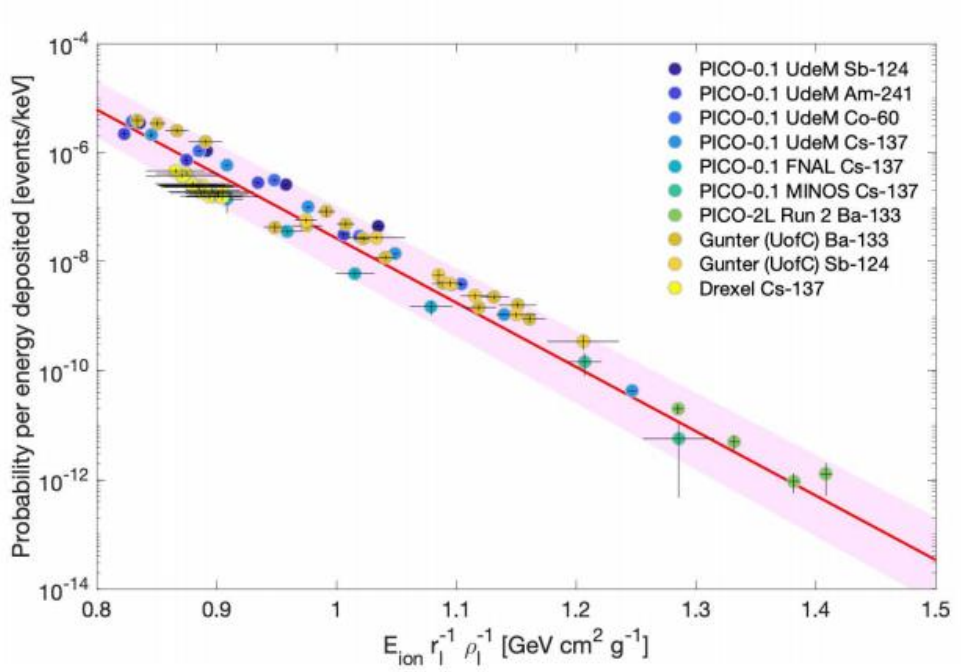
Water tank closing, PVC lining and filling planned after SNOLAB shutdown

Detector commissioning and data taking early Fall 2019

New Understanding of Electron-Recoil Nucleation Efficiency

arXiv:1905.12522 [physics.ins-det] (submitted to PRD)

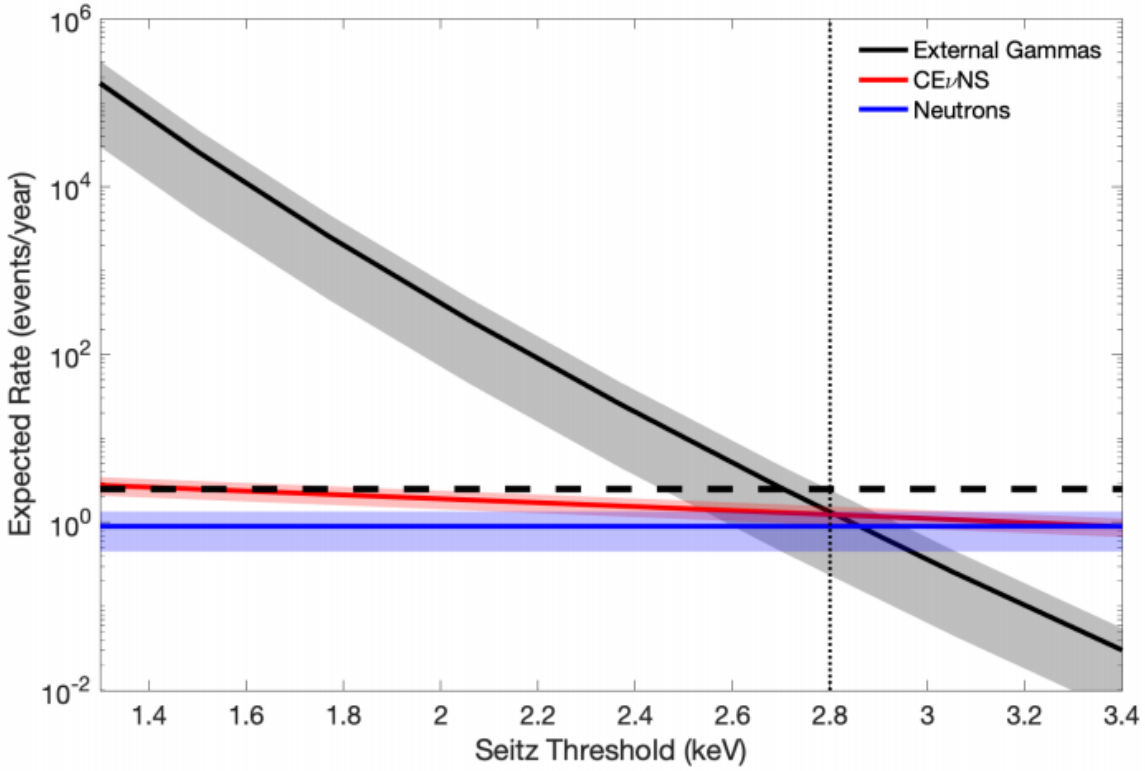




ER nucleation efficiency depends on stopping power (SH liquid density, P, T)
We can lower the NR threshold in PICO-40L without increasing ER nucleation efficiency

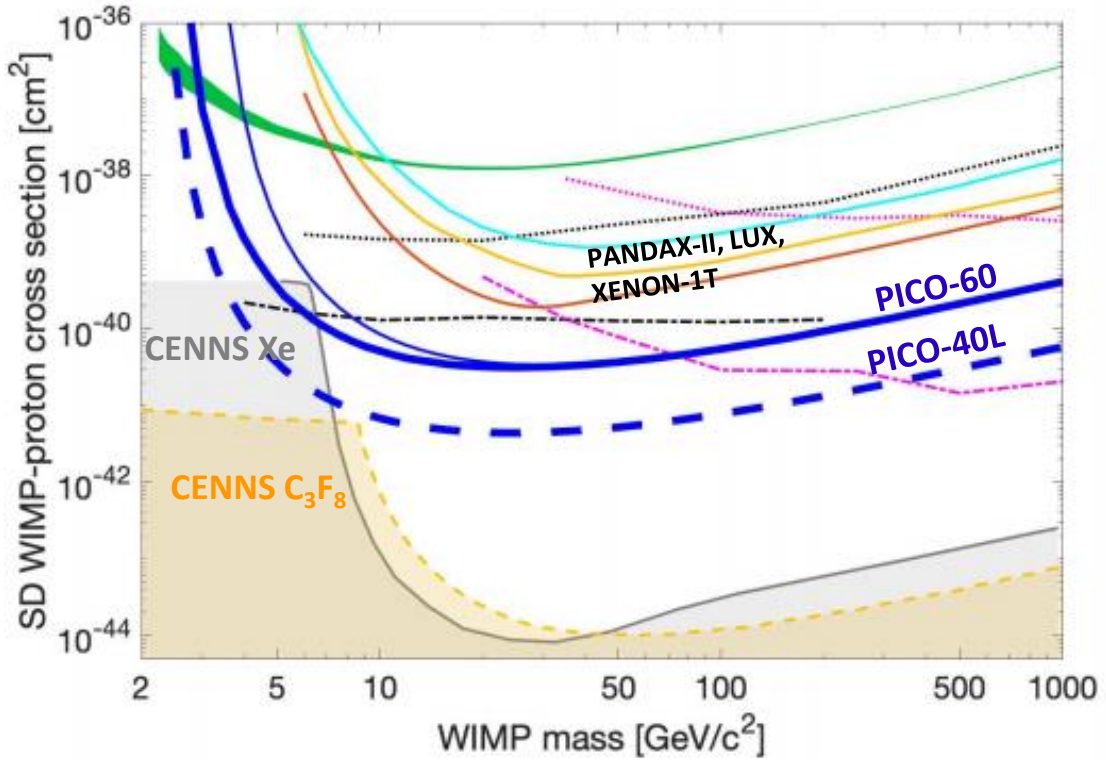
PICO-40L Expected Backgrounds

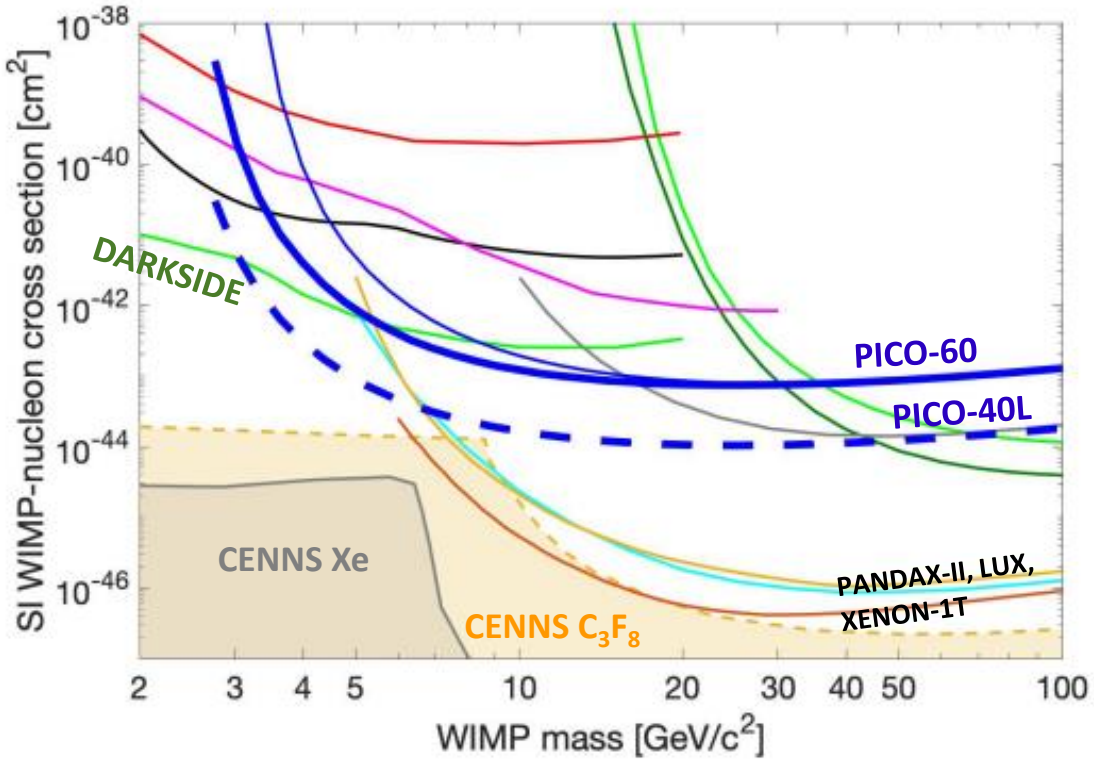
- **Similar active mass than PICO-60, but enhanced background control:**
  - Larger pressure vessel (farther away from active volume)
  - Enhanced electron recoil rejection at lower pressure and temperature



Expected background rates at 2.8 keV NR threshold (25 psia, 13 °C)

PICO-40L Projected Sensitivity





Projected 90% C.L. limits for PICO-40L for 1-year exposure at 2.8 keV NR threshold (25 psia)
PICO-40L gains a factor 10 sensitivity from PICO-60 (lower background, longer exposure)

Future

PICO-500

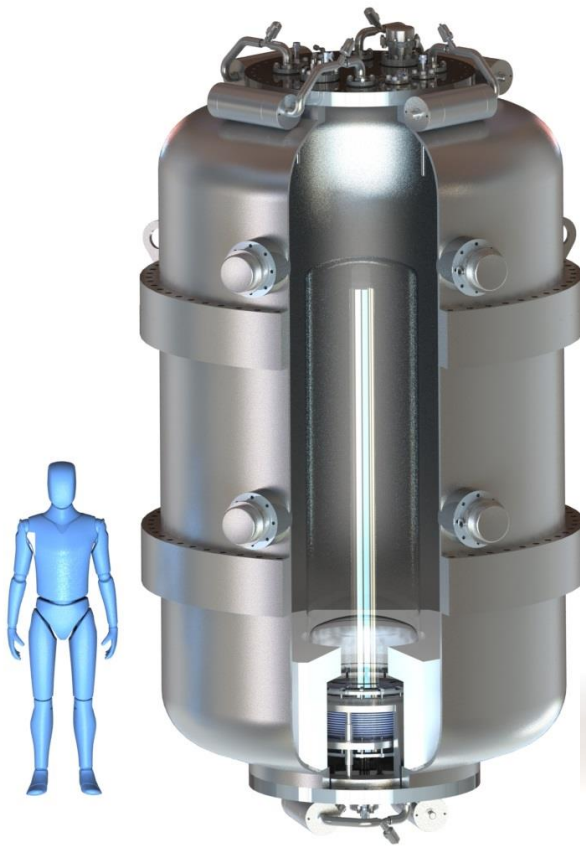
The next step is the scale-up to **PICO-500** (CFI funded)

To be located inside MiniCLEAN water shield

Original idea was tonne-scale, synthetic silica jar manufacture currently limits the scale up.

Massive SS pressure vessel need to be shipped underground in sections

Pressure vessel and inner vessels design and procurement are where our current efforts are directed



PICO-500 Jars and PV Status

Vendors identified for synthetic silica jars

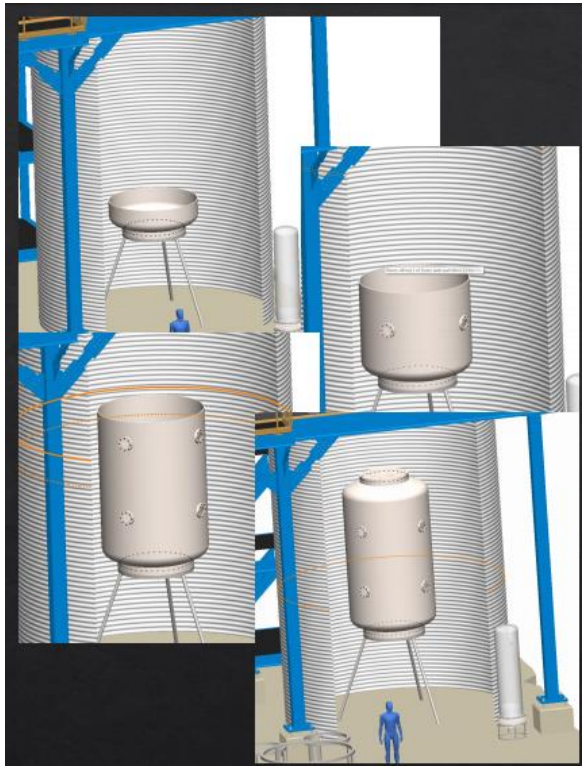
Active volume limited to 300L (420 kg) due to manufacture constraints

PICO-500 Jars and PV Status

Now planning to welding the pressure vessel sections underground and pressure certify underground

This makes us save ~ 10,000 lbs of flanges

2 domes and 2 cylindrical sections



PICO-500: Expected Sensitivity

- Similar and complementary reach to G2 experiments
- The neutrino floor is lower for C_3F_8 than for Xenon

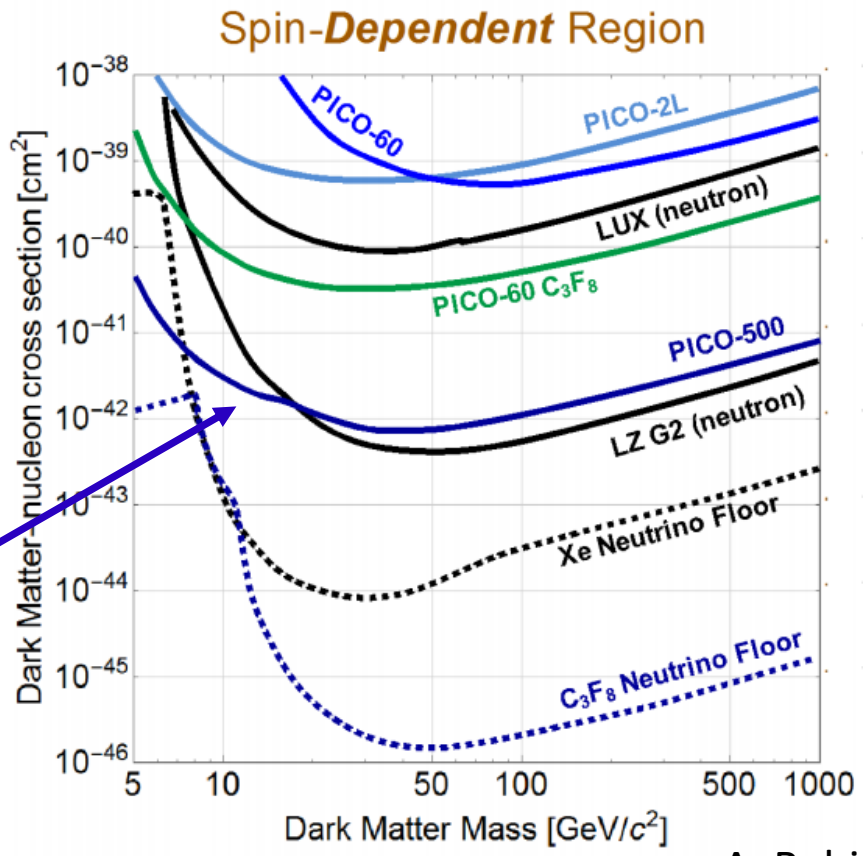
0.5 live-year at 3.2 keVnr

1 live-year at 10 keVnr

250 L fiducial volume

0.75 singles/year background,

mostly from muon spallation



A. Robinson (UdeM)

Beyond 500: Scaling Up

Current issues involving synthetic silica jar manufacture could be resolved with:

- Plastic jars (acrylic, polycarbonate, etc.)
- All metal jars (e.g. coated low radioactivity titanium)

Sensitivity of lower WIMP masses:

- Lowering the threshold
- Hydrogenated freons as targets

Background Control:

- Enhanced background discrimination
- Material screening
- Self shielding
- Radon removal using distillation column (M.C. Piro, U. of Alberta)

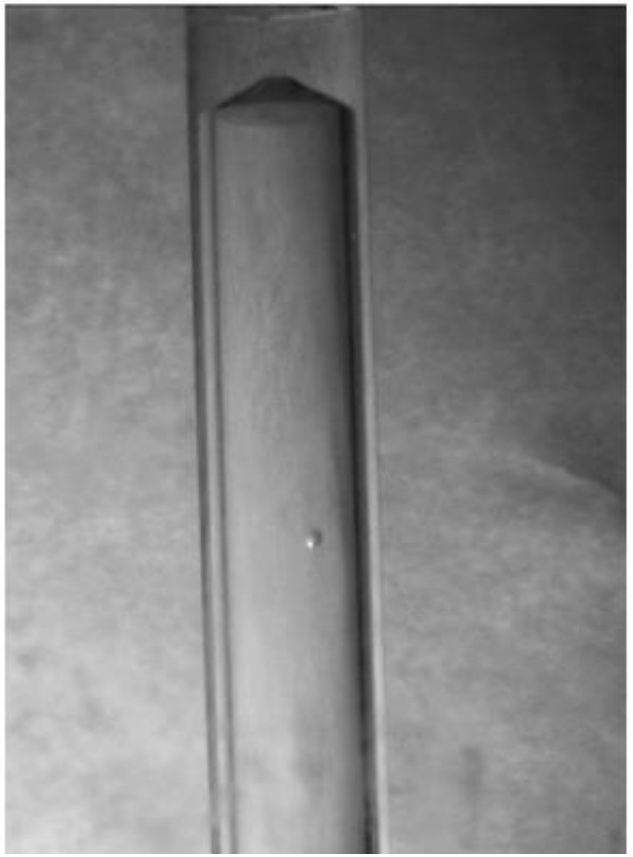
Beyond 500: Plastic Chambers

Bored-Through Acrylic Tubing (Ben Broerman)

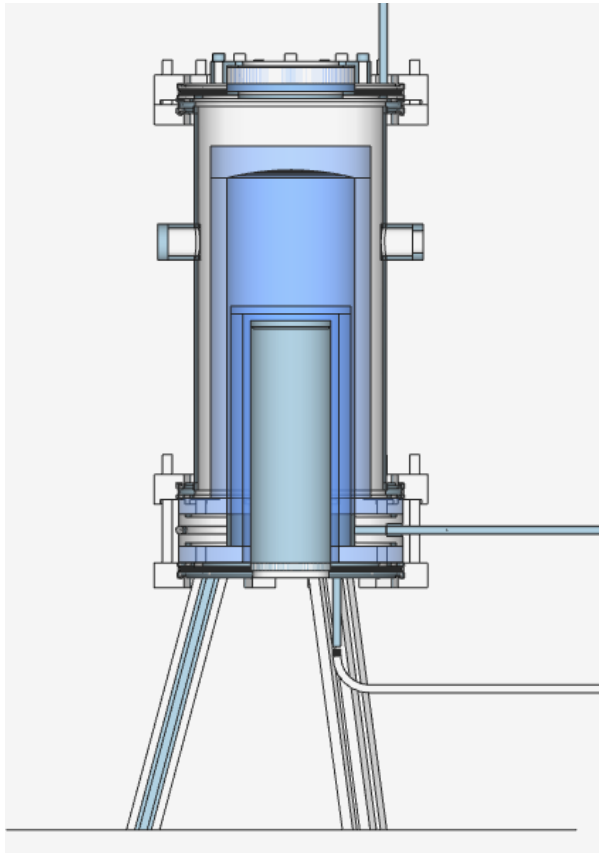
Successful operation at 7 keV with C_4F_{10}

Heavy bubbling at the top after 24 h

Next step: scale up to allow surface treatment and machining techniques



PATCH: PICO Acrylic Test Chamber



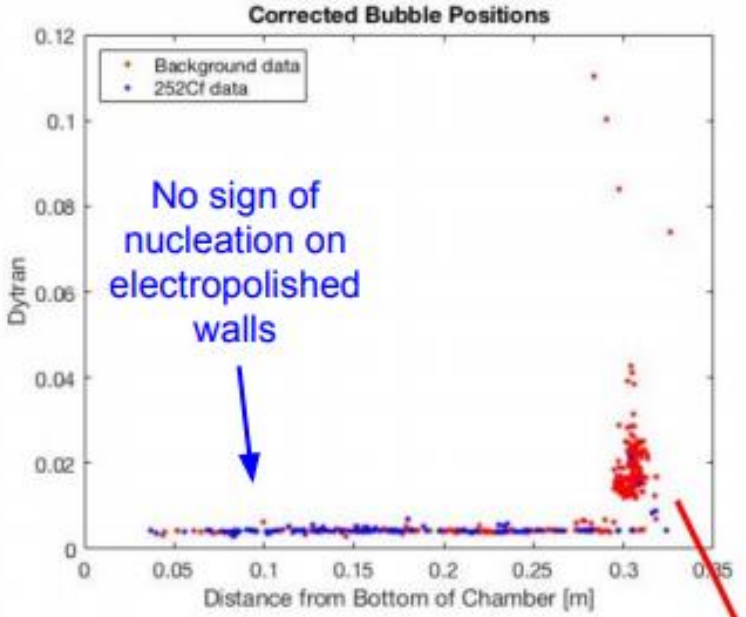
1-kg Scale C_4F_{10} bubble chamber with RSU design and all-acrylic inner volume being developed at Queen's University (Ben Broerman)

Pressure vessel, pressure system, instrumentation ready at Queen's

Acrylic Components are being built at the University of Alberta, shipping expected Fall 2019

Goal: demonstration of an all-plastic bubble chamber for the development of tonne-scale detectors.

Beyond 500: All-Metal Chambers



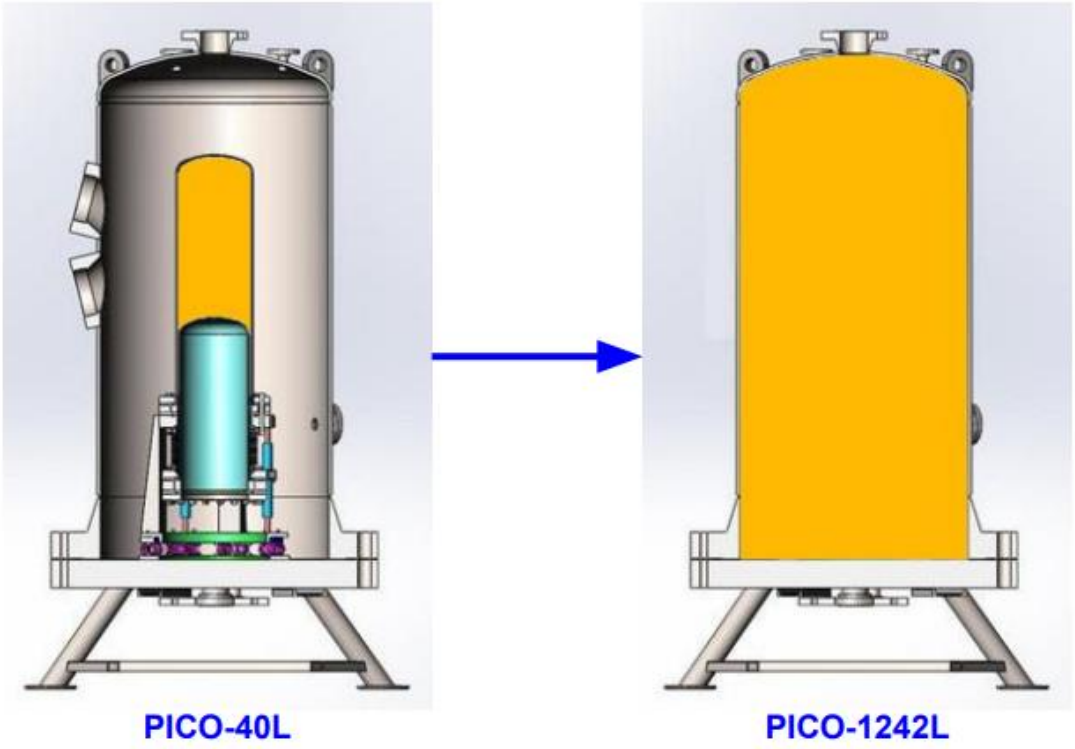
Z-position from t_0 difference

Nucleation site at the top indicated by high dytran values

Radial position is absolutely necessary for AP...

Beyond 500: All-Metal Chambers

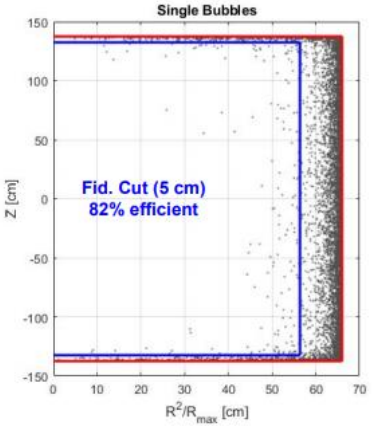
Toward multi-ton-scale detectors

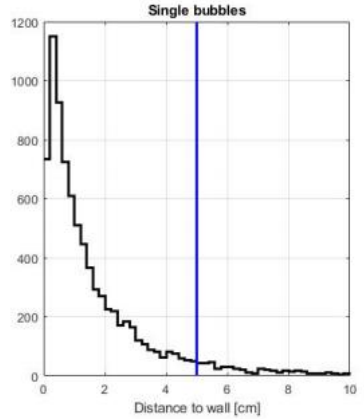


In an all-metal bubble chamber, the pressure vessel can be the inner vessel at the same time

Commercial low-activity titanium + fiducial volume could allow for background control

Can a quartz/transparent plastic piston allow for photography? (needed to AP alpha-discrimination)





Beyond 500: All-Metal Chambers

Beyond 500: Low-Mass WIMPs

Hydrogenated freons available at low-cost.

PICO-0.1 (U. of Montreal) operated successfully with $C_2H_2F_4$

Proton recoils seen.

(Frédéric Tardif, PhD Thesis, Université de Montréal)

→ need to measure nuclear and electronic recoil efficiency to determine feasible threshold

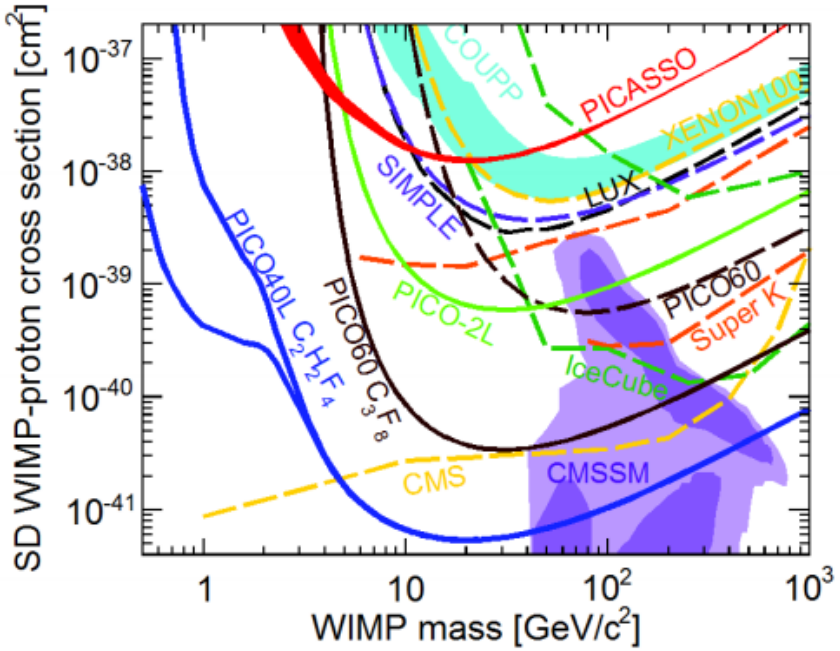


FIG. 6.23. Potential new exclusion limits of the PICO experiment for the search dark matter (blue), using $C_2H_2F_4$ in PICO-40L, with an exposure of 120 live-days (5400 kg-days) at a threshold about 1 keV. Current exclusion limits of PICO are shown in black. The two blue curves are calculated assuming two different hydrogen nucleation efficiencies at 1 keV, as shown on figure 6.24

Beyond 500: backgrounds

Electron Recoil Acoustic Discrimination (the Holy Grail)

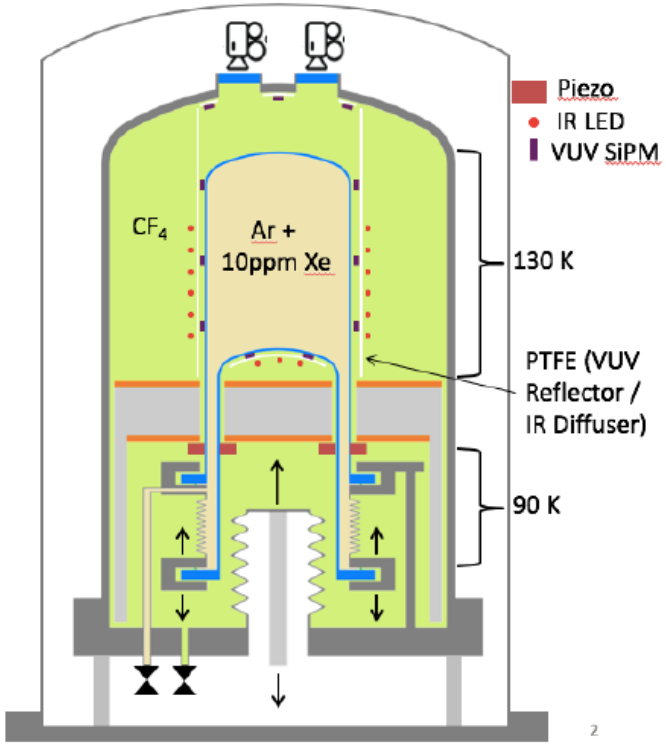
- Many attempts using large and small chambers were unsuccessfull
- Many attempts using AI on existing data so far unsuccessful
- Plans at Queen's University to probe new bandwidth using opto-acoustic sensing

Goal: Catch the first wave form directly (not through jar vibration) form the bubble (1-100 MHz)

Will equip QTC with LCLAD later this fall.

Beyond 500: Scintillating Bubble Chambers

→ **See talk by Ken Clark today at 5:30 pm**



Future of PICO at SNOLAB

Current suite of experiments: PICO-40L and PICO-500

- Operated with C_3F_8 until background limit is reached
- Filled with hydrogenated freon to enhance low-mass WIMP sensitivity

Future multi-ton-scale PICO to continue probing parameter space

- R&D needed to determine scaling up strategy (Plastic, Metal, 1 large or an array of modest-sized?)
- Need to identify background targets: scintillating veto, material screening, etc.
- Location to be identified: Can such an experiment fit in MiniCLEAN tank? Or should it be placed in a DEAP-sized tank? Or even larger?

PICO-500 construction and operation as well as R&D with small chambers will provide guidance

PICO

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Queen's UNIVERSITY
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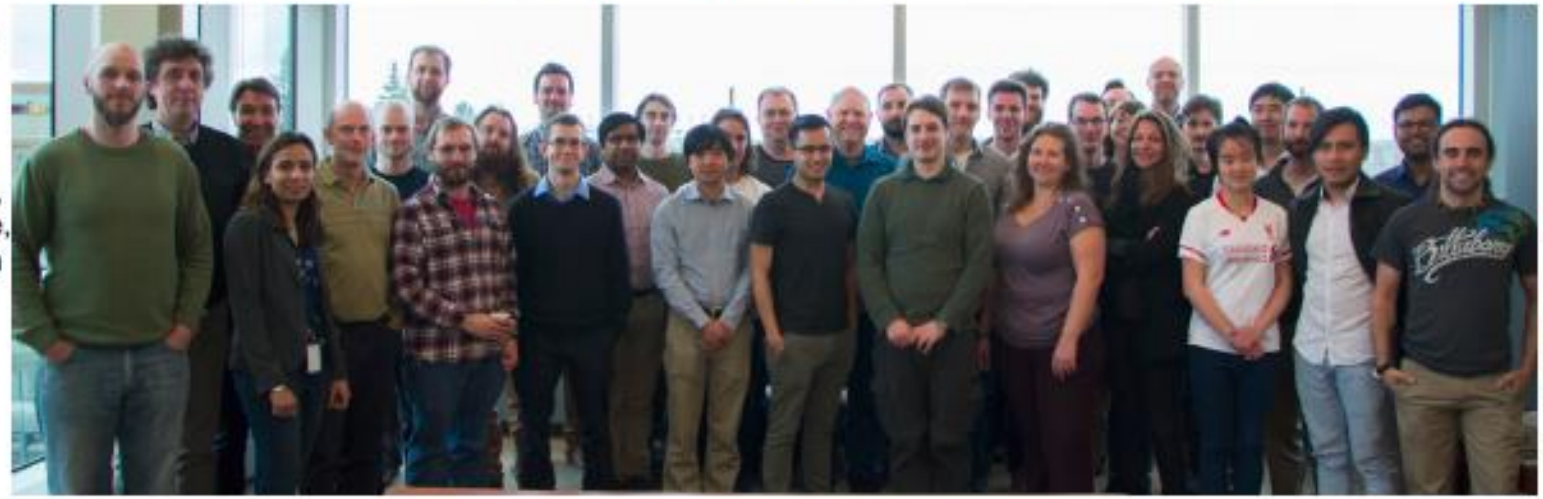

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Extra Slides