Searching for Dark Matter with the PICO Bubble Chambers

Guillaume Giroux

CAP Congress
Queen's University
June 1st, 2017

Other PICO Talks at the Congress

Arthur Plante (Université de Montréal)
Dark Matter Search Results of the PICO experiment in the Effective Field Theory Context
29 May 2017, 13:30

Scott Fallows (University of Alberta)
WIMP Search at Low Energy Threshold with PICO-60 C_3F_8
29 May 2017, 14:00

Alexandre Le Blanc (Laurentian University)
Bubble growth studies in superheated liquids for the PICO experiment
29 May 2017, 16:45

Olivia Scallon (Laurentian University)
Simulations of the Muon Veto for the PICO Experiment
30 May 2017, 13:45

Direct Searches for WIMPs

Goal:

Detecting nuclear recoils from ***Weakly Interacting Massive Particles*** **(WIMPs)** elastic scattering

Challenges:

Small nuclear recoil energy (1-100 keV)

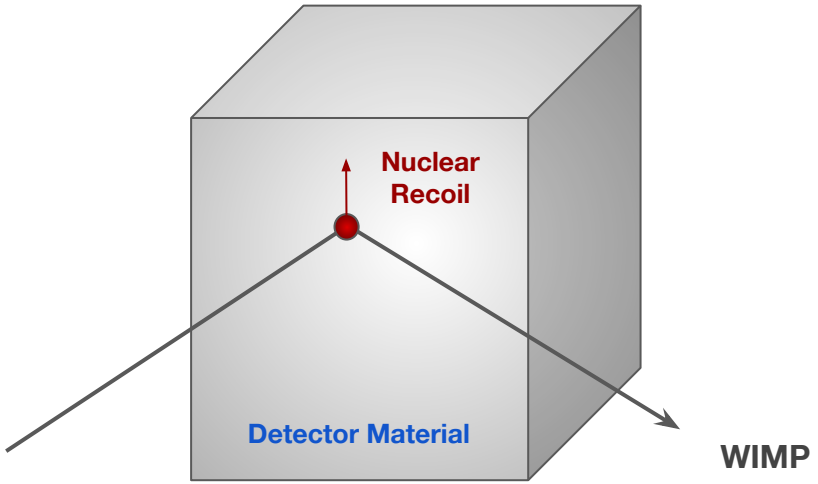
Small scattering cross-section

Requirements:

Low threshold

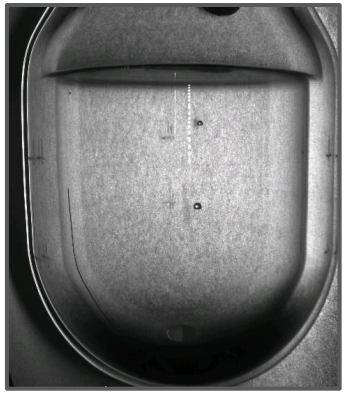
Large exposure

Low background

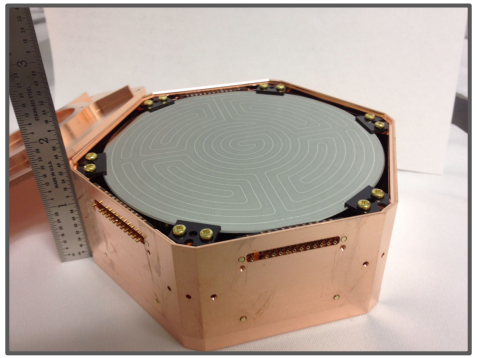


Dark Matter Direct Detection

PICO



SuperCDMS



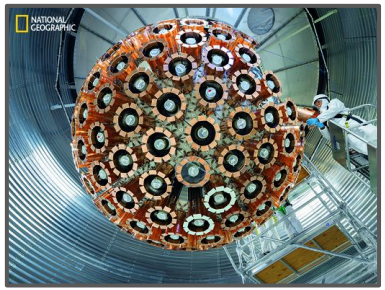
Superheated Liquid Detectors

HEAT

Scintillating Cryogenic Bolometers

Cryogenic Bolometers

DEAP-3600



Scintillating Crystals, LAr

Scintillation

Ionization

Ge/Si Gas TPC

TPCs

NEWS-G

SNOLAB

MINING FOR KNOWLEDGE

CREUSER POUR TROUVER... L'EXCELLENCE

CPARC

Canadian Particle Astrophysics Research Centre

WIMP-Matter Couplings

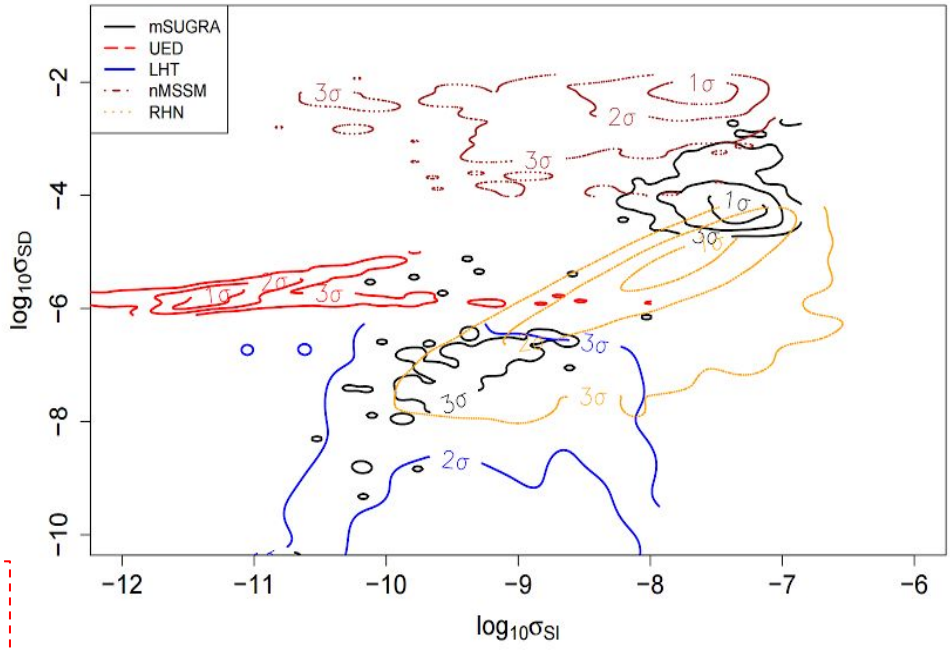
Unknown how WIMPs couple with matter:

- **Spin-Independent**
  Enhancement with nucleus A^2: Argon Germanium, Xenon

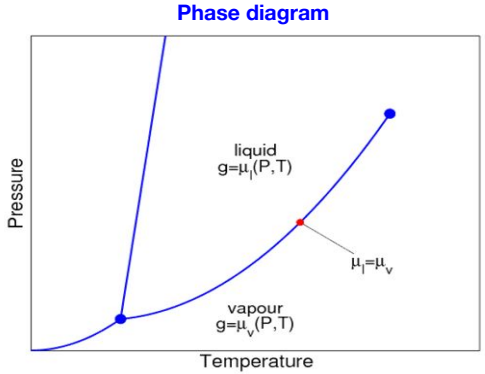
- **Spin-Dependent**
  Enhancement with nuclear spin: ^{19}F, ^{129}Xe, ^{131}Xe

Searches with multiple targets are essential to covering the available parameter space

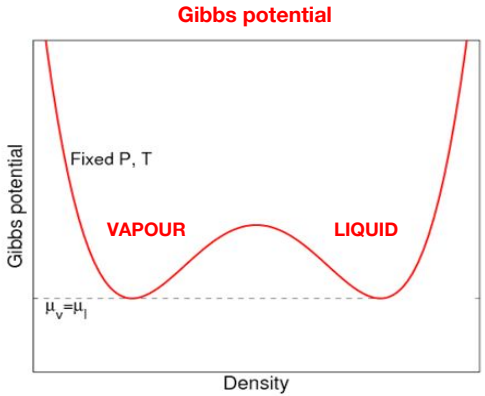
Spin-dependent vs. Spin-Independent Interactions



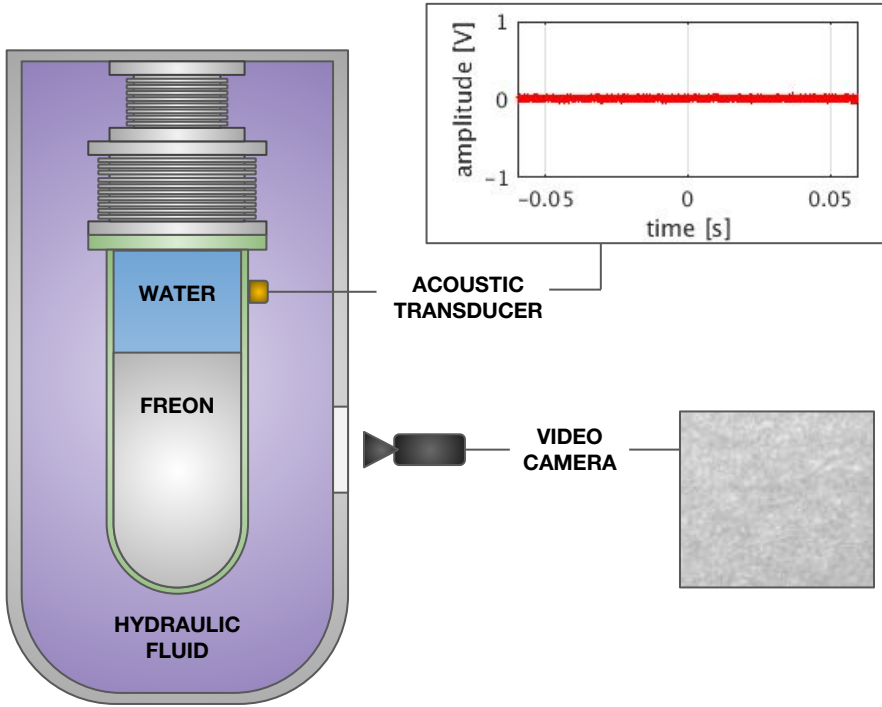
Superheated Liquid Detectors



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

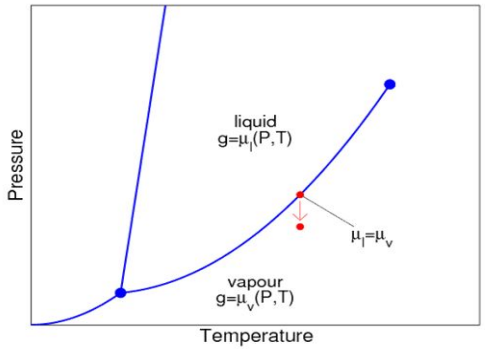


Vapour and liquid phase coexist

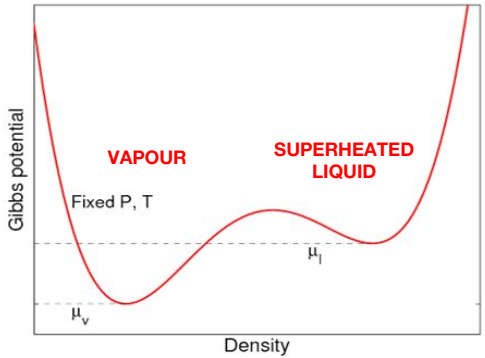


Superheated Liquid Detectors

Phase diagram

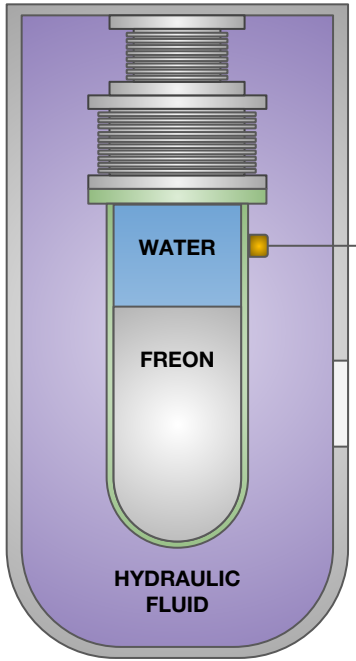


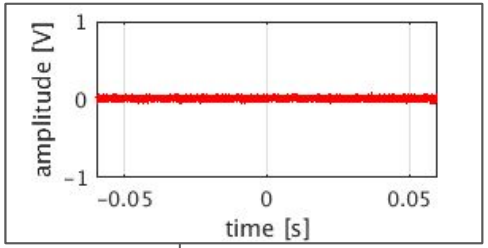
Gibbs potential



If the pressure is lowered, the Gibbs potential is modified

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

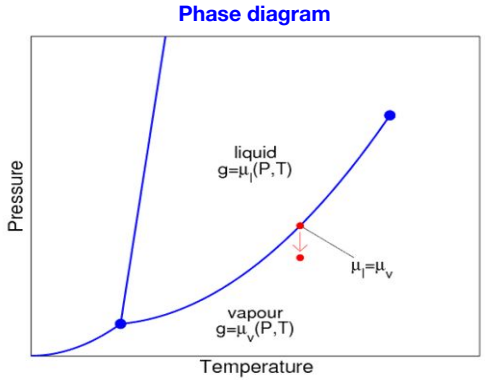


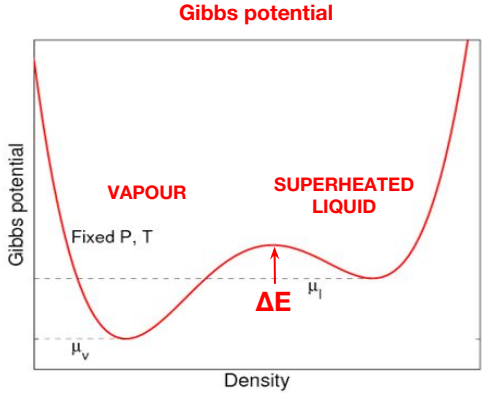


ACOUSTIC TRANSDUCER

VIDEO CAMERA

Superheated Liquid Detectors





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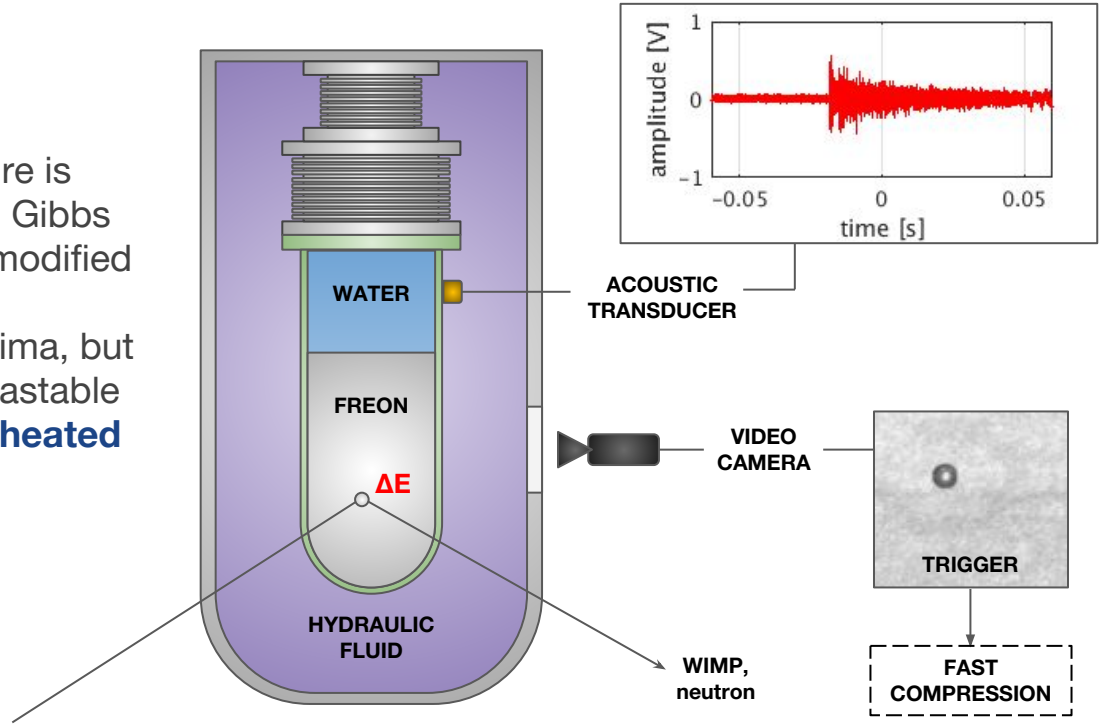
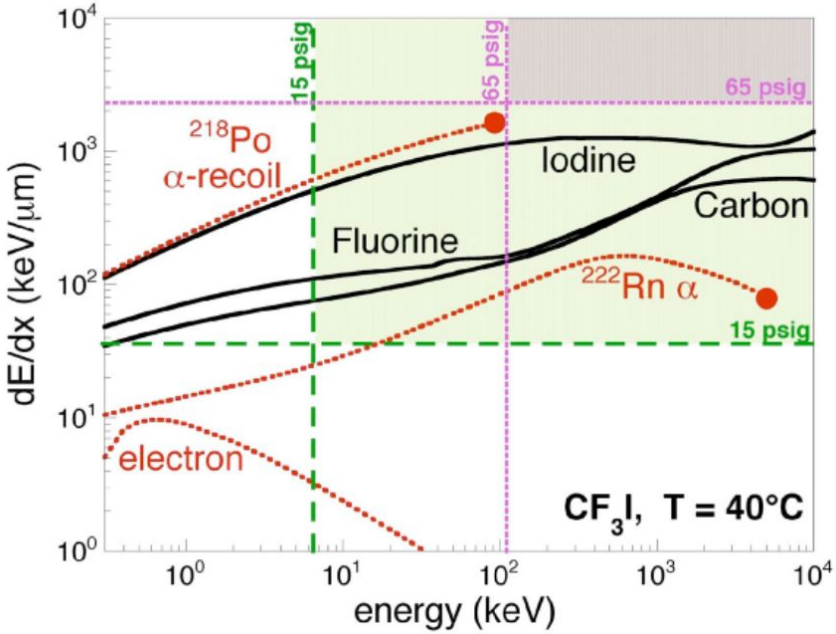


Background Control

- **Gamma/beta radiation**
  - S.H. liquid detector have intrinsic electron-recoi 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 particl 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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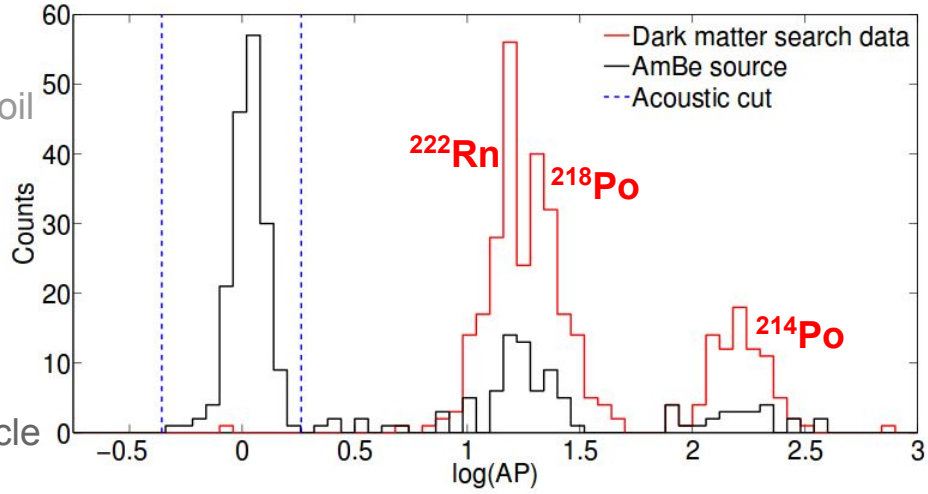

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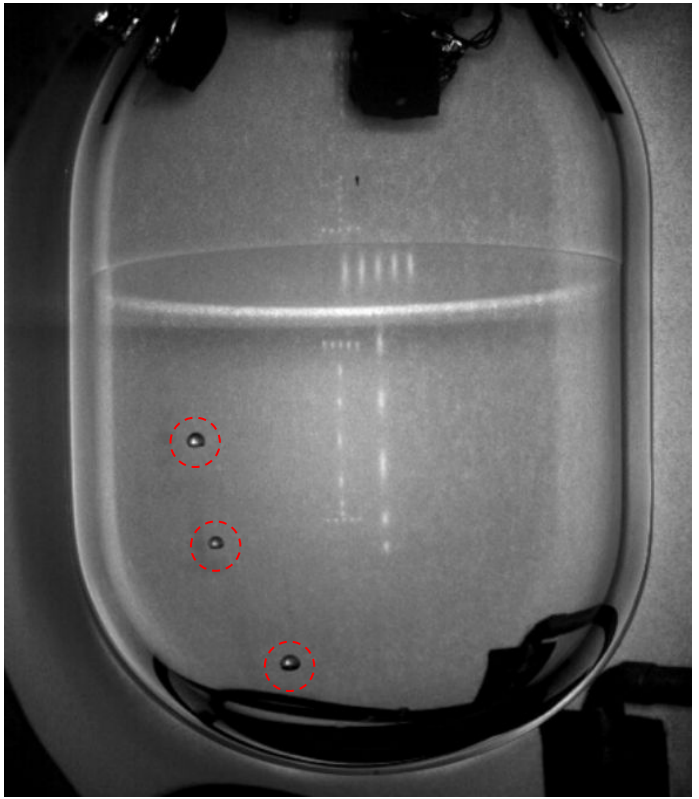
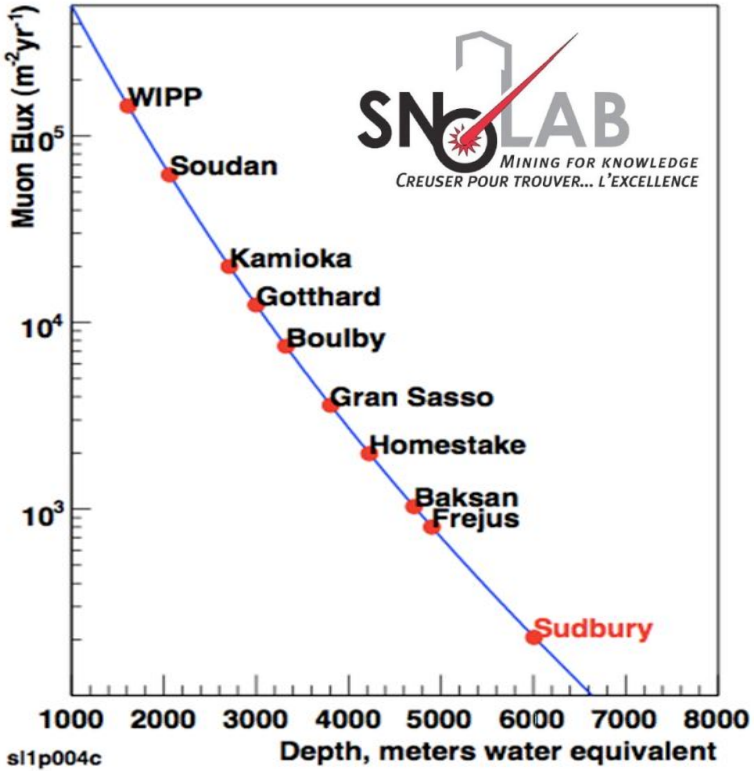


The **SNOLAB** Underground Laboratory

- Cleanroom environment 2 km (6800 ft.) underground
  (6000 m water equivalent)

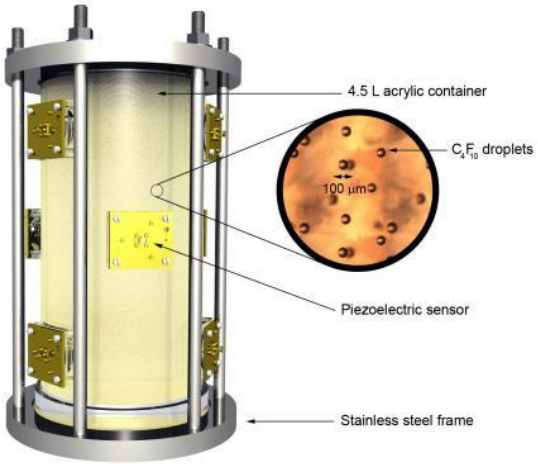
- Cosmic ray shielding: 1 muon per m^2 every 3 days
  (5 X 10^7 reduction)

- PICO bubble chambers operating since 2010



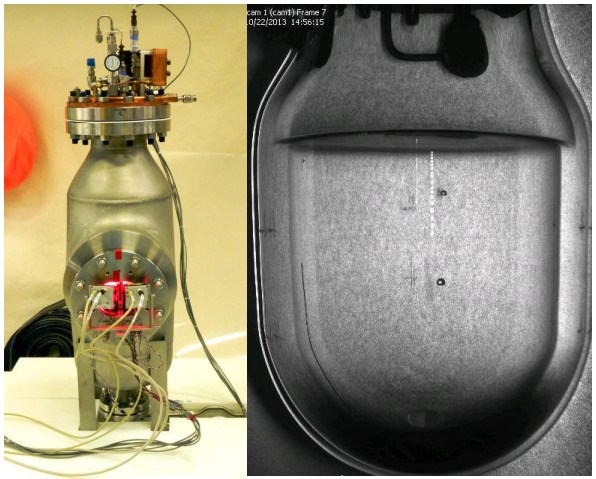
Previous Results

PICO and COUPP merger: PICO



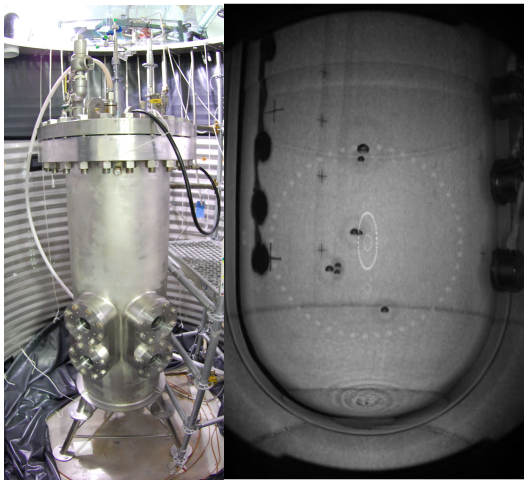
PICASSO-32
C_4F_{10}

Barnabé-Heider *et al.,* Phys. Lett. B624 **(2005)**
S. Archambault *et al.*, Phys. Lett. B682, **(2009)**
Final results: Behnke E. *et al.*, Astropart. Phys. 90 **(2017)**



PICO-2L
C_3F_8

C. Amole *et al.*, Phys. Rev. Lett. 114, 231302 **(2015)**
C. Amole *et al.*, Phys. Rev. D 93, 061101 **(2016)**

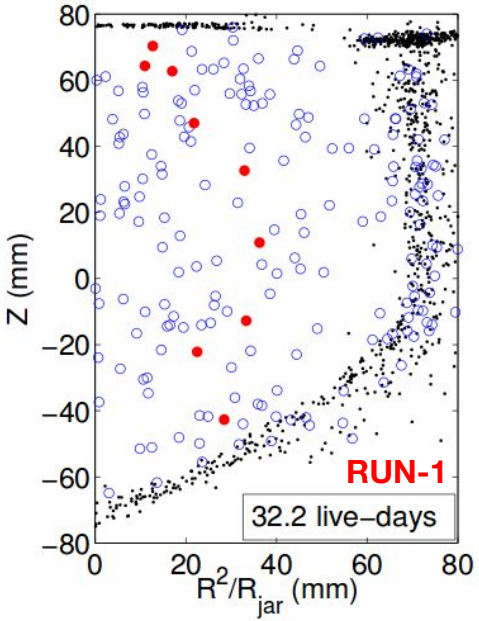


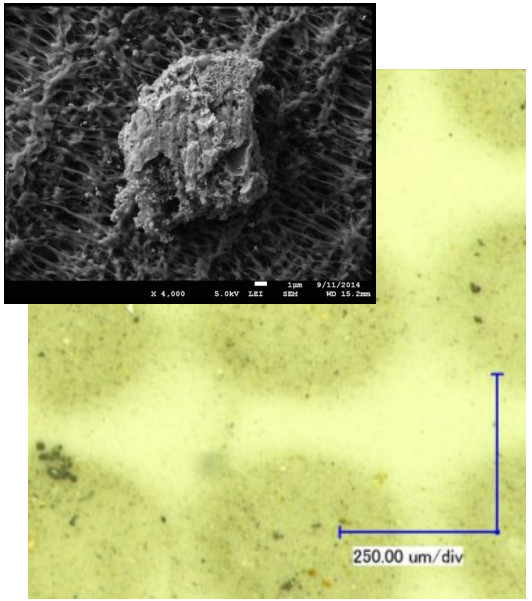
COUPP-60 → PICO-60
CF_3I

C. Amole *et al.*, Phys. Rev. D 93, 052014 **(2016)**

Previous Results

- 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)



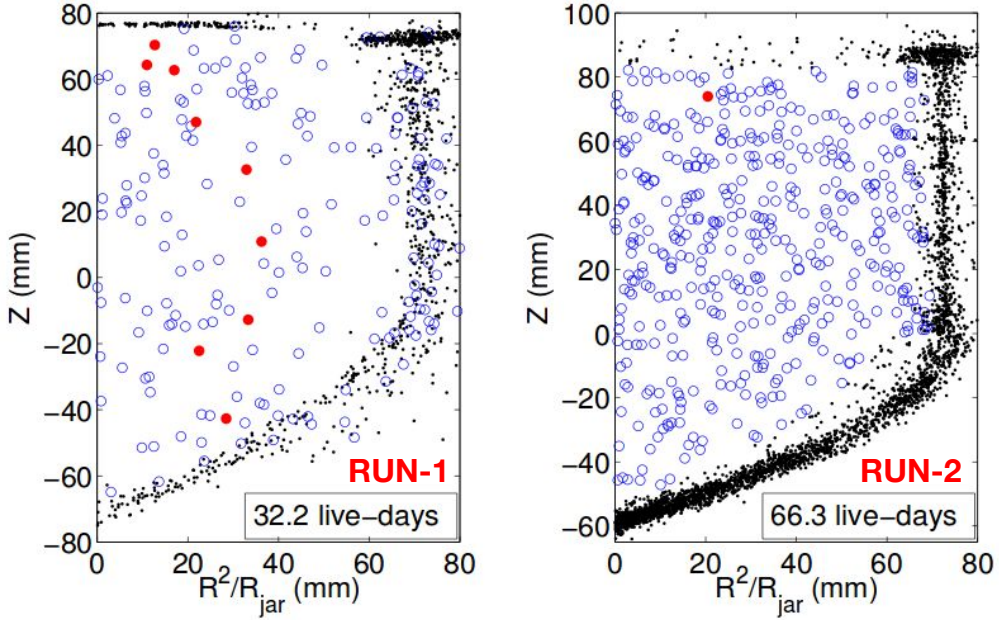


Filter sample from PICO-2L

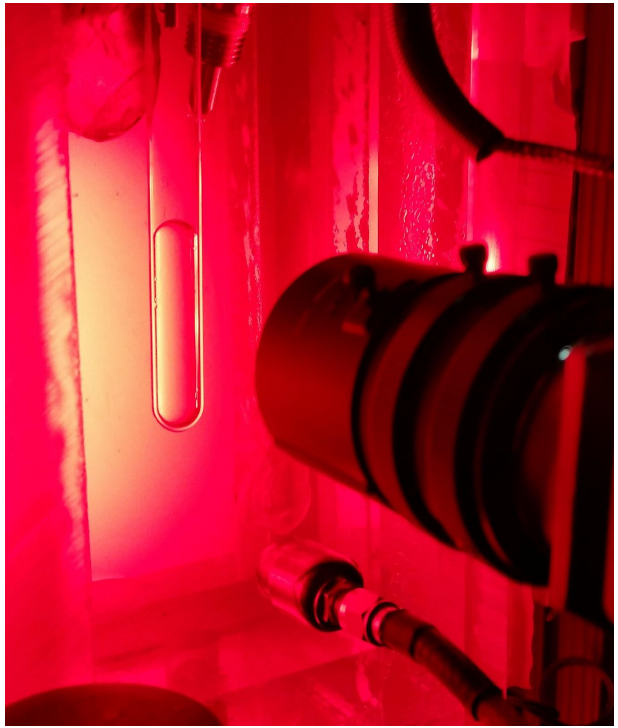
Previous Results

- 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**

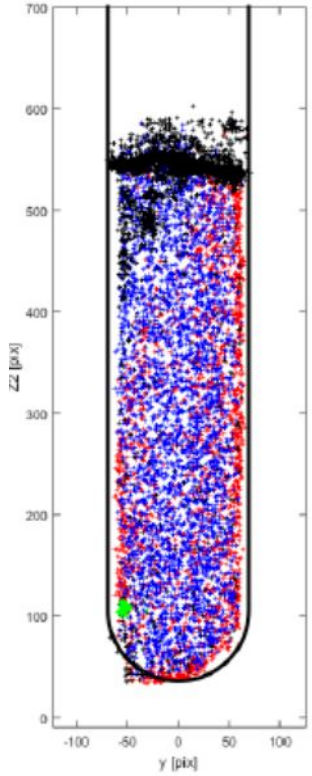
C. Amole *et al.*, Phys. Rev. D 93, 061101 **(2016)**



Surface Tension Effects



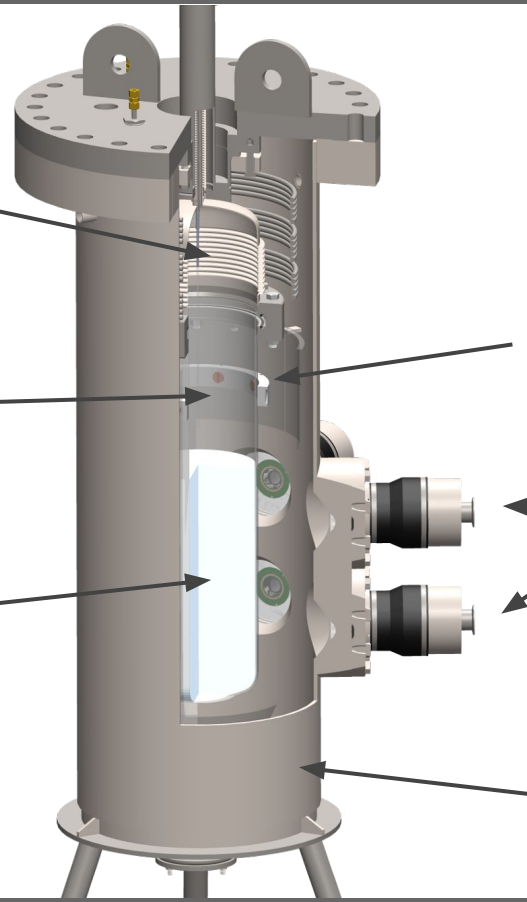
Queen's test Chamber
(10 ml bubble chamber)



"Collar" (meniscus) activity

Quartz particulates stay
in the water buffer

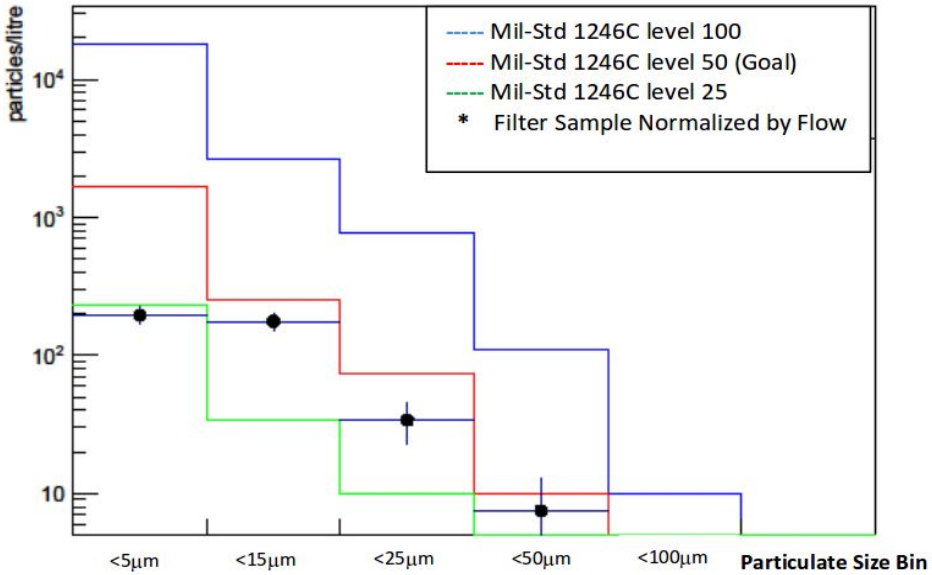
The PICO-60 Bubble Chamber



The PICO-60 Bubble Chamber

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

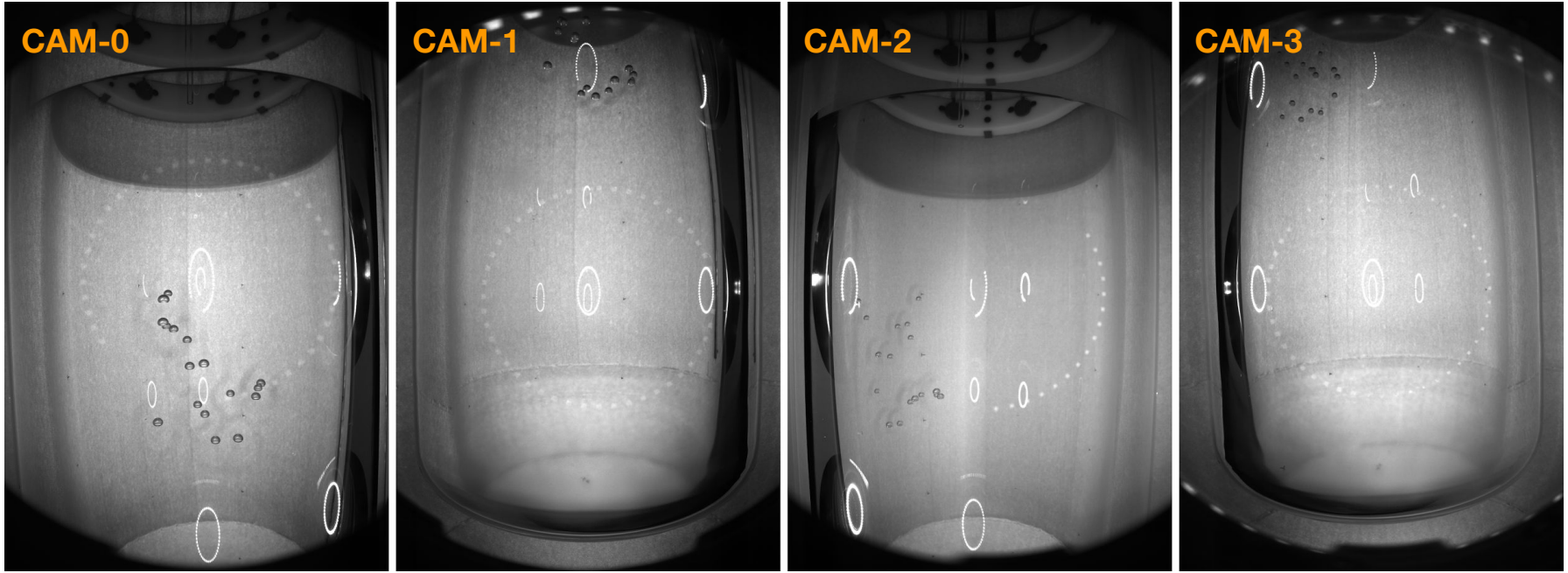
Particulate size distribution



The "dish-washer"

4-Camera Photographic System

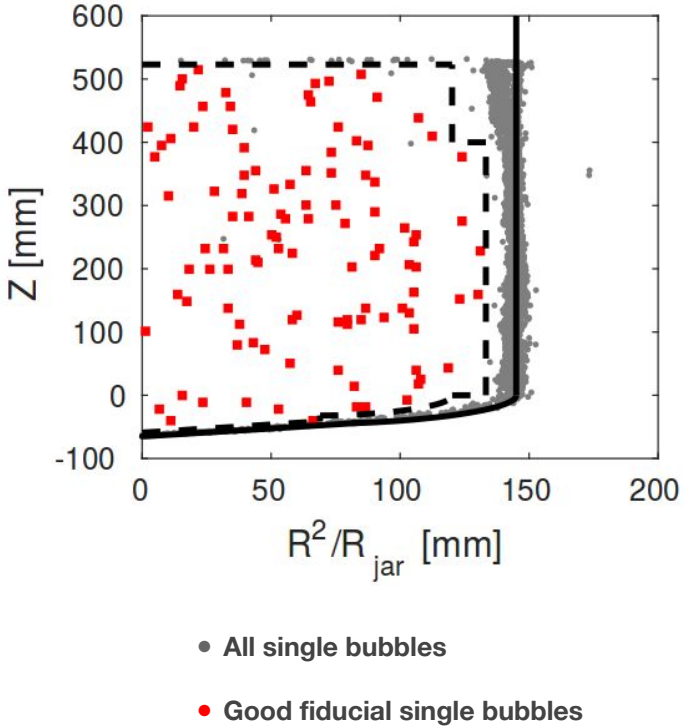
250 fps acquisition: trigger based on image entropy difference between consecutive images



17-bubble neutron multiple-scattering event

Blind (Deaf) Analysis

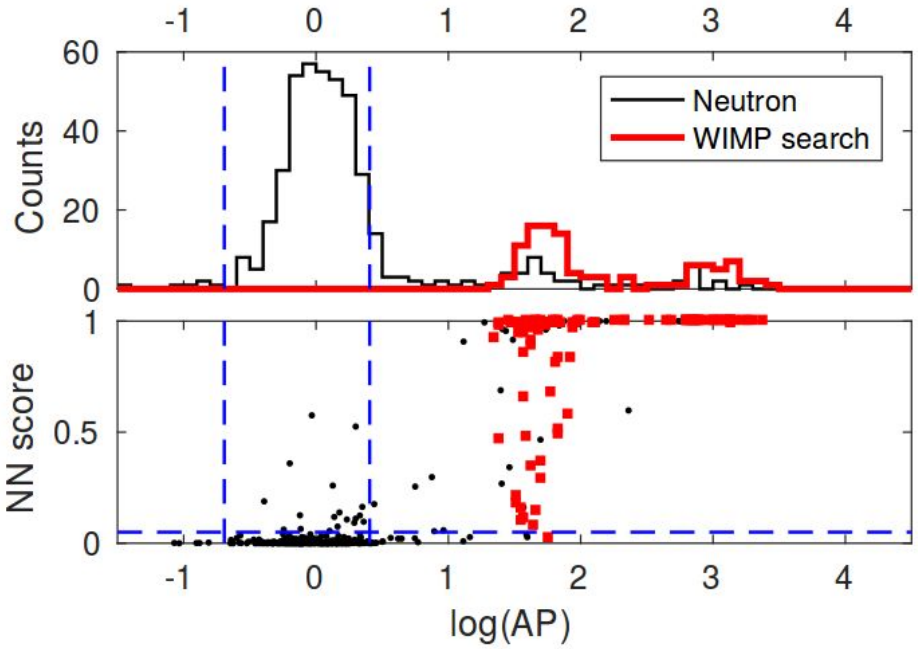
- **Blinded acoustics analysis:** alpha decays indistinguishable from nuclear recoils
- 45.7 kg fiducial mass
- 30 days live-time
- 85.1% WIMP selection efficiency
- **106 events considered after all cuts**
- **3 multiple-bubble events**
- **1.3 ton-days efficiency-corrected exposure**



C. Amole *et al.*, arXiv:1702.07666 [astro-ph.CO] 2017

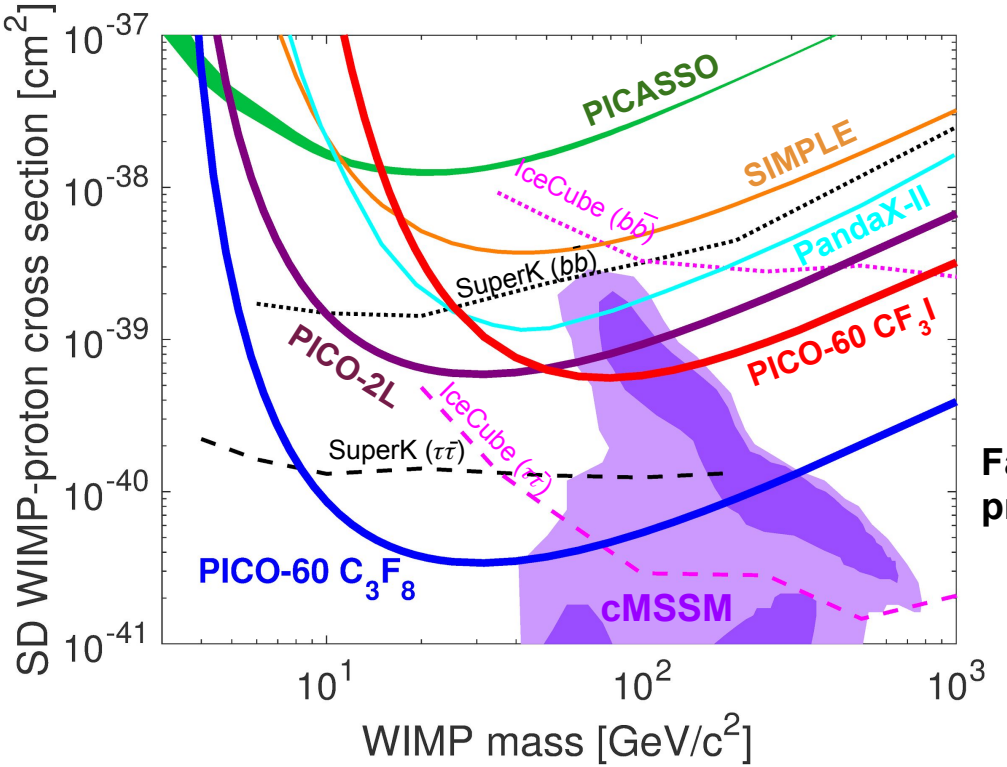
Blind (Deaf) Analysis

- **Blinded acoustics analysis:** alpha decays indistinguishable from nuclear recoils
- **106 events considered after all cuts**
- **3 multiple-bubble events**
- **1.3 ton-days efficiency-corrected exposure**
- **Unmasking reveals no nuclear-recoil candidates**



C. Amole *et al.*, arXiv:1702.07666 [astro-ph.CO] 2017

Spin-Dependent Coupling

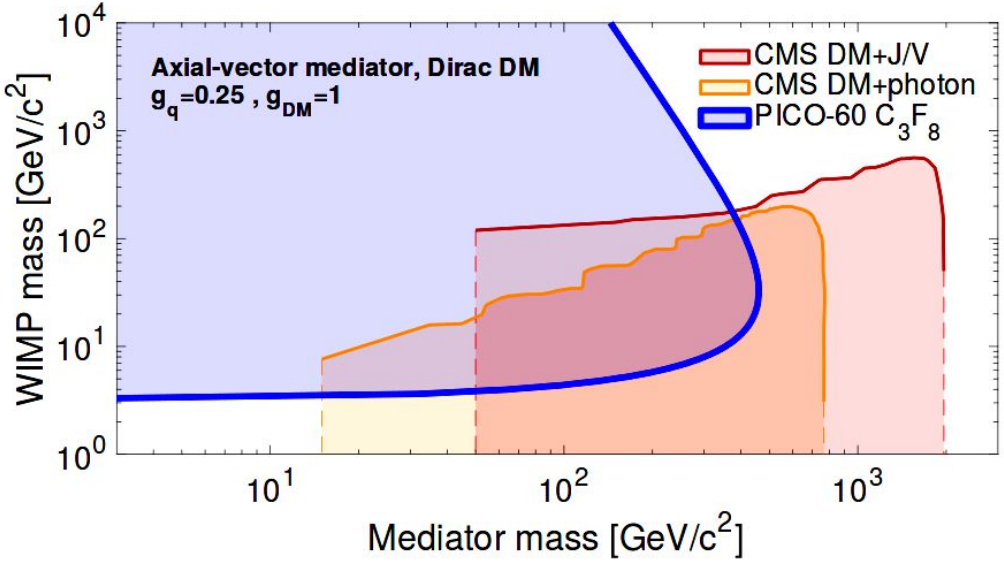


Factor 17 improvement on our previous result!

C. Amole *et al.*, arXiv:1702.07666 [astro-ph.CO] 2017

Comparison with LHC Searches

LHC Dark Matter Working Group recommendations on simplified models



For a mediator exchanged in the s-channel: 4 free parameters:

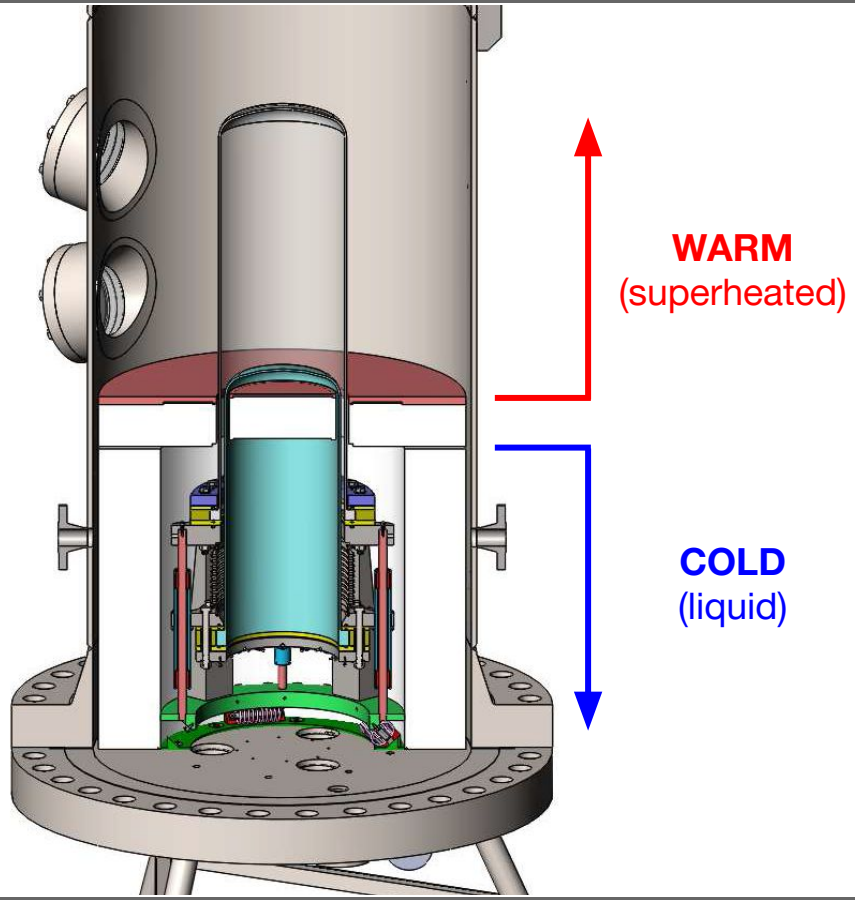
- Dark matter mass: m_{DM}
- Mediator mass: m_{med}
- Universal mediator coupling to quarks: g_q
- Mediator coupling to dark matter: g_{DM}

We present constraints on m_{DM} and m_{med} for g_q **= 0.25** and g_{DM} **= 1** for an axial-vector mediator exchanged in the **s-channel**

C. Amole *et al.*, arXiv:1702.07666 [astro-ph.CO] 2017

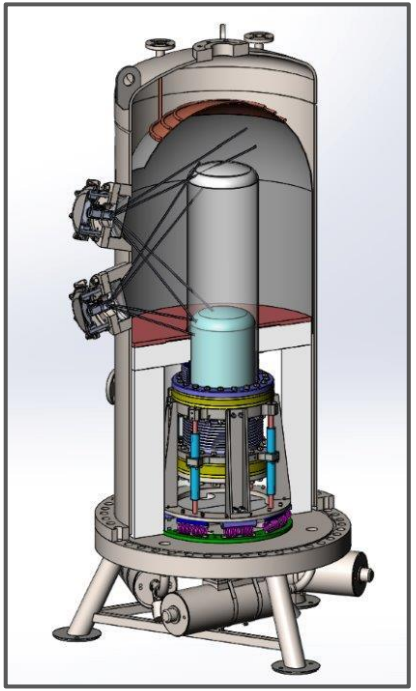
Future Chambers: PICO-40L

- 40-liter chamber "***Right-Side-Up***"
- New pressure vessel and detector assembly to replace PICO-60 at SNOLAB
- **Buffer liquid-free** bubble chamber
  - Background control
  - Target fluid flexibility
- **Construction beginning this summer**



Future Chambers: PICO-40L

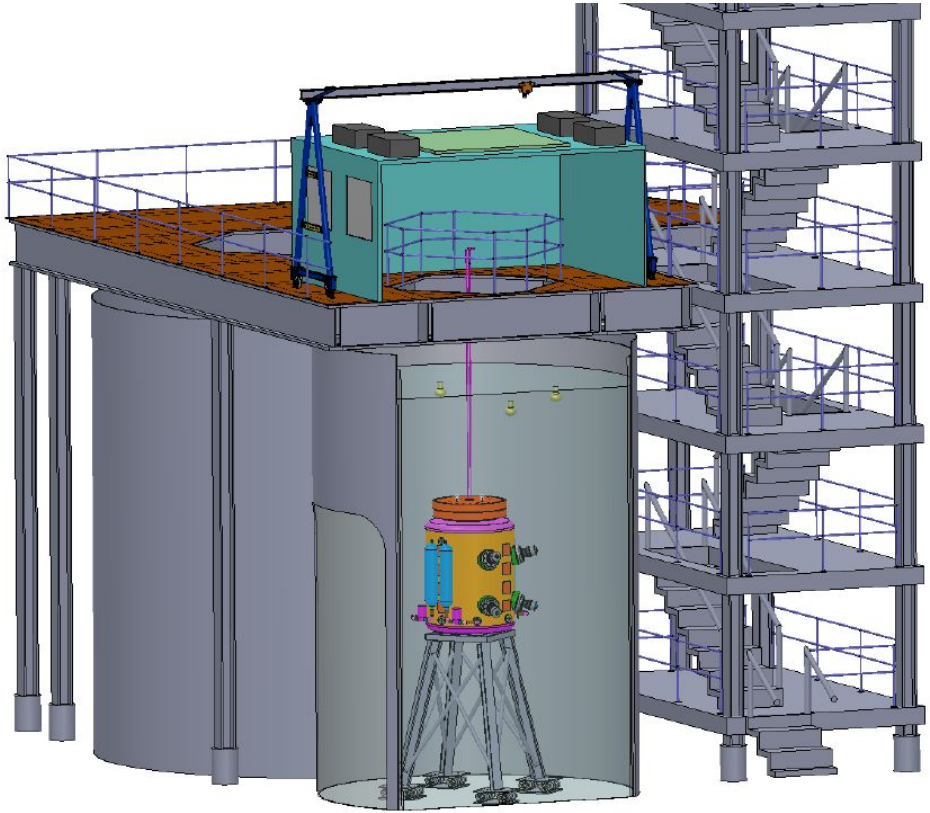
New pressure vessel has arrived at SNOLAB surface labs



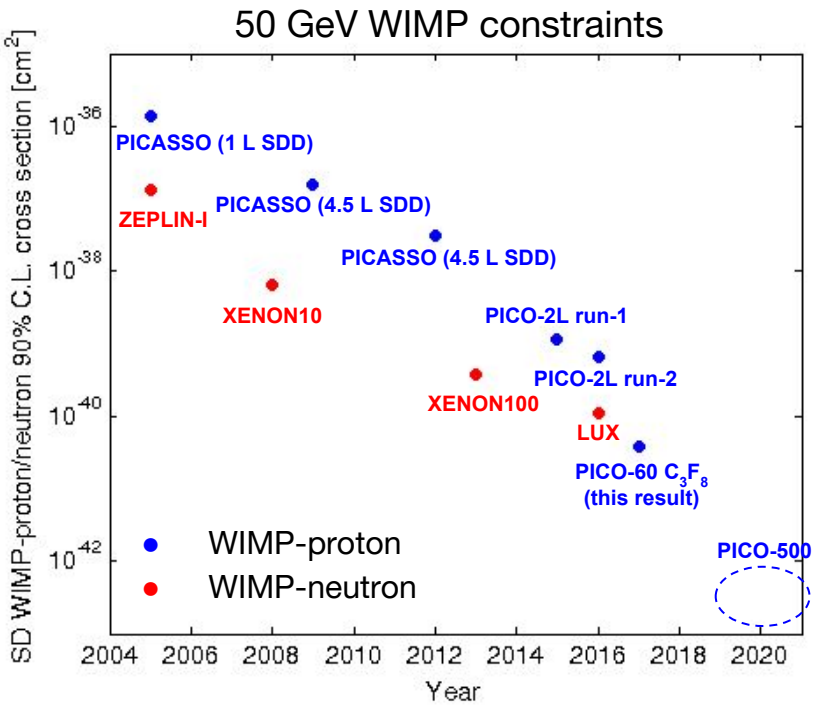
Inner volume assembly tests at Fermilab

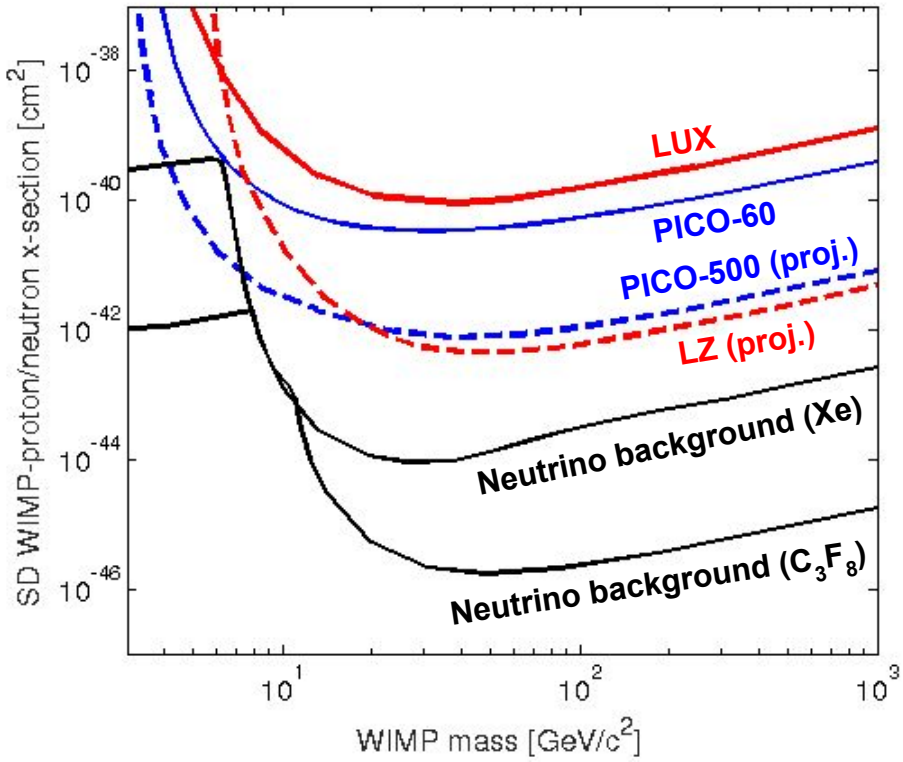
Future Chambers: PICO-500

- Funding requested in Canada for the construction of a **500-liter bubble chamber**
- Choice of bubble chamber configuration after PICO-40L demonstration
- **Construction starting 2018**



Future Prospects





WIMP-proton couplings can be probed longer with fluorine targets before hitting the neutrino floor

The PICO Collaboration

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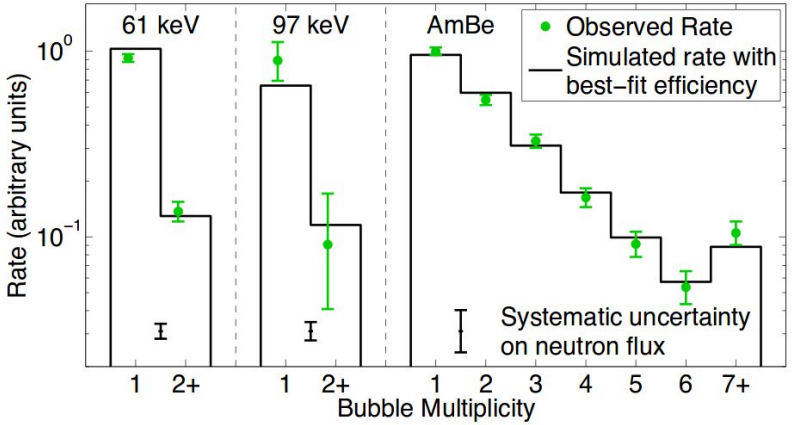
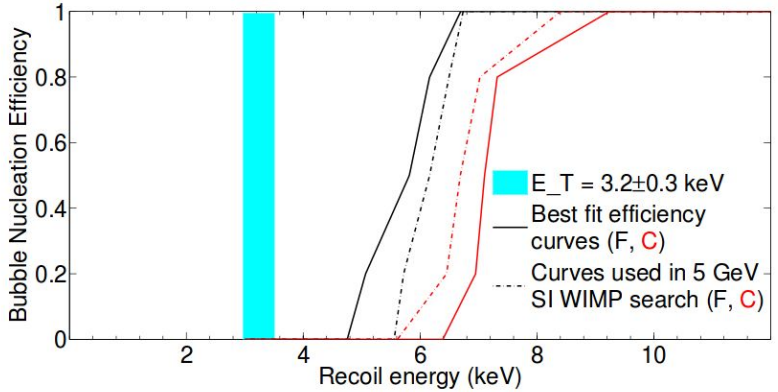
Extra Slides

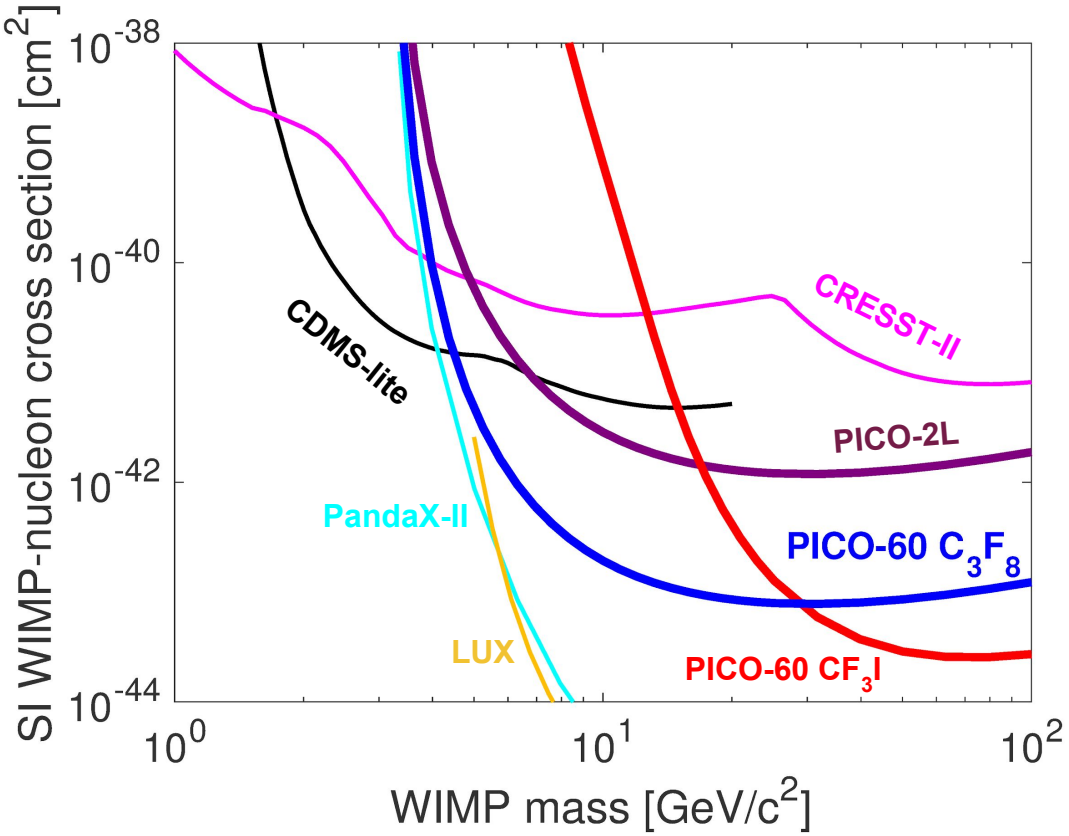
Nuclear-Recoil Nucleation Efficiency

- Seitz *"**hot-spike model**"* gives 100% n.r. nucleation efficiency above thermodynamic threshold
- Measured in C_3F_8 with PICO-2L detector AmBe neutron calibration and with 30 ml test detector **quasi-mono-energetic neutron beam calibration** at U. of Montreal Tandem Van de Graaff facility
- <u>Conservative approach:</u> for a given WIMP mass and coupling, we select the efficiency curves for F and C that give the worst efficiency within 1-sigma of the best fit





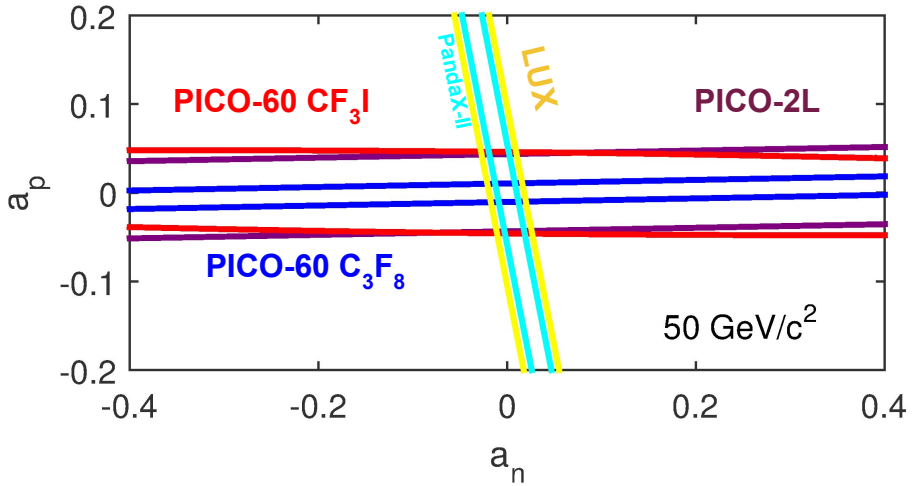
Spin-Independent Coupling



Constraints on the Effective WIMP Couplings a_n-a_p

Constraints on the effective WIMP-proton (a_p) and WIMP-neutron (a_n) couplings are calculated according to the method proposed in

D. R. Tovey *et al.*, Phys.Lett. B488 (2000) 17-26



C. Amole *et al.*, arXiv:1702.07666 [astro-ph.CO] 2017