

Dark Matter Search Results from the PICO-60 C₃F₈ Bubble Chamber

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52^e Rencontres de Moriond, La Thuile, Aosta Valley, Italy
March 23rd, 2017

Dark Matter Direct Detection

Goal:

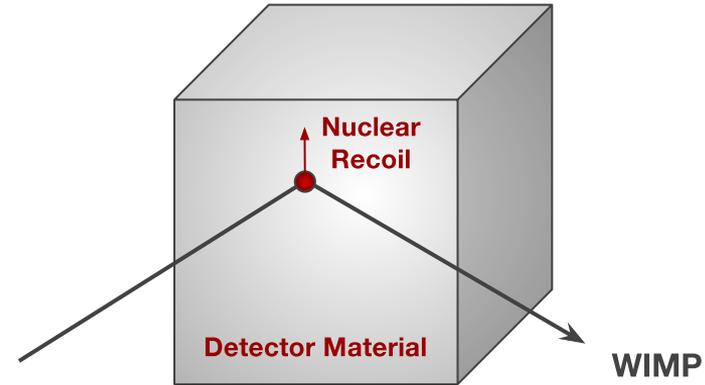
Detecting nuclear recoils from *Weakly Interacting Massive Particles* (WIMPs) elastic scattering

Challenges:

Small nuclear recoil energy (1-100 keV)
Small scattering cross-section

Requirements:

Low threshold
Large exposure
Low background
Various detector targets



Dark Matter Direct Detection

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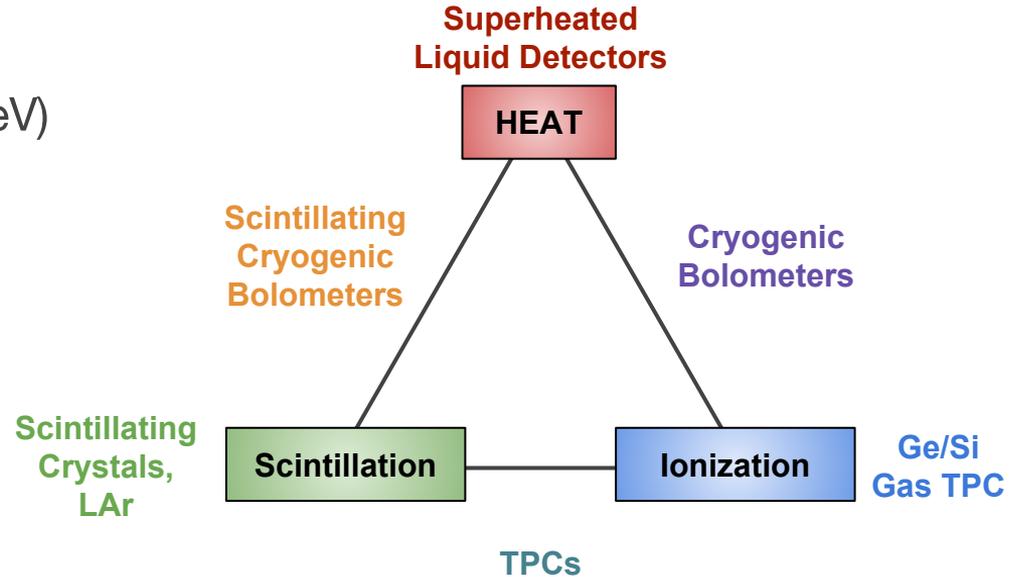
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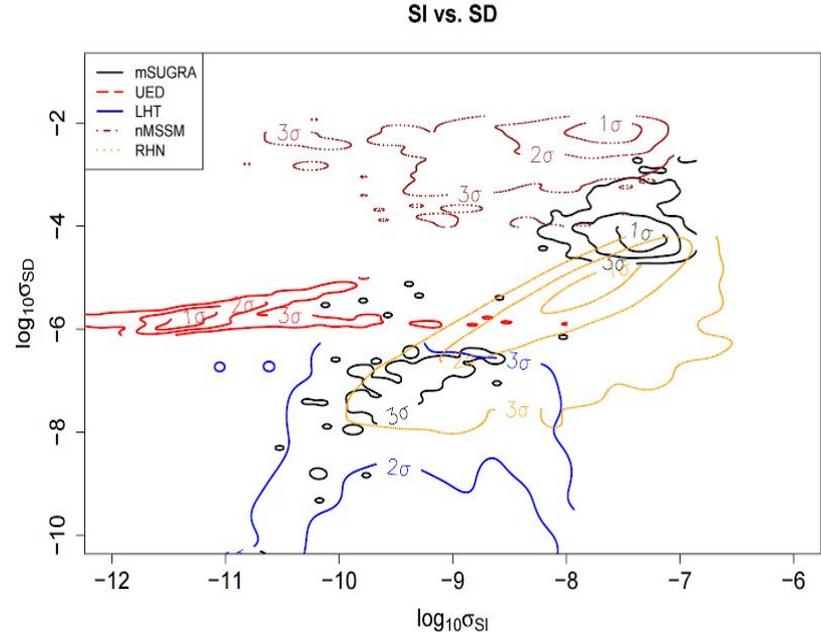
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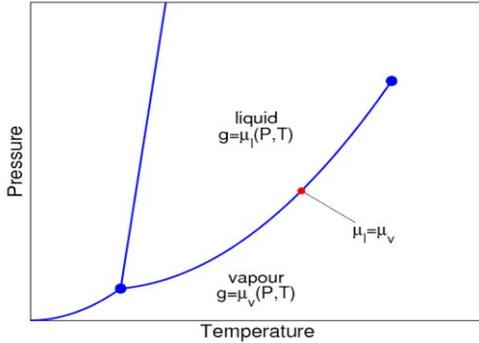
Unknown how WIMPs couple to matter



V. Barger, W-Y Keung and G. Shaughnessy, Phys. Rev. D78 (2008) 056007

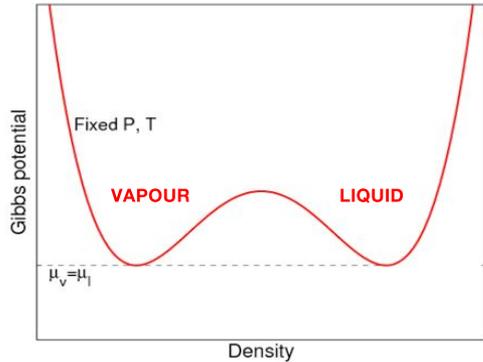
Superheated Liquid Detectors

Phase diagram

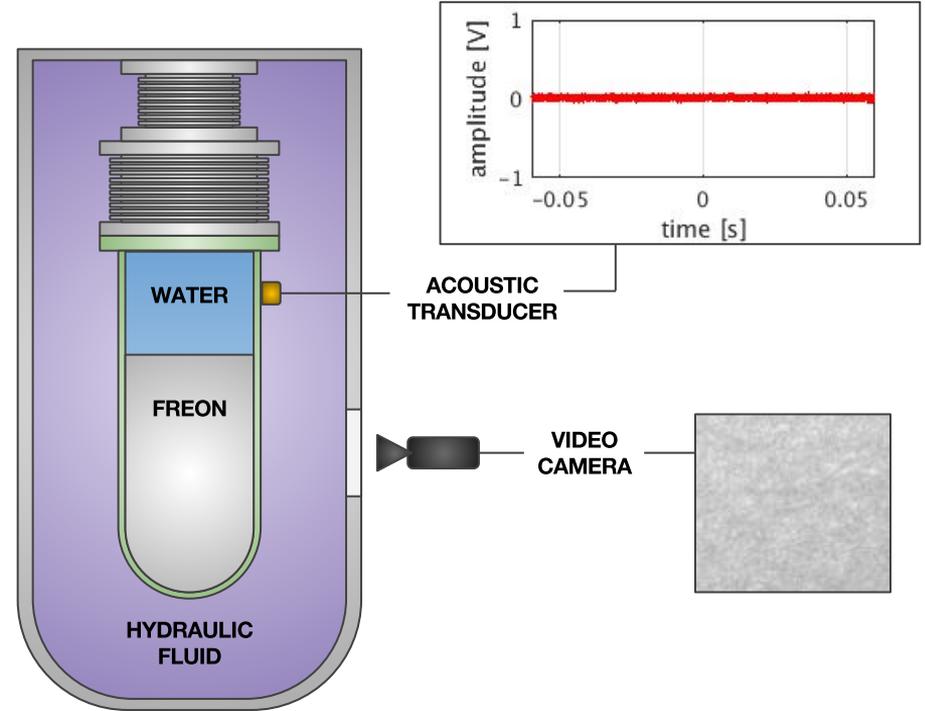


On the saturation curve, two minima exist in the Gibbs potential

Gibbs potential

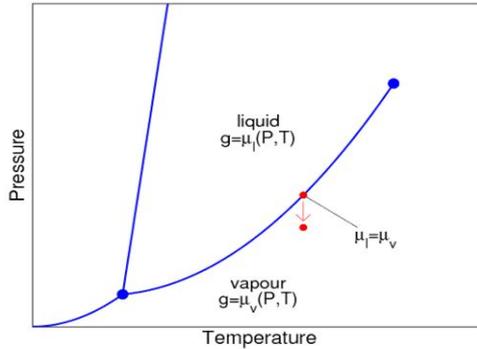


Vapour and liquid phase coexist



Superheated Liquid Detectors

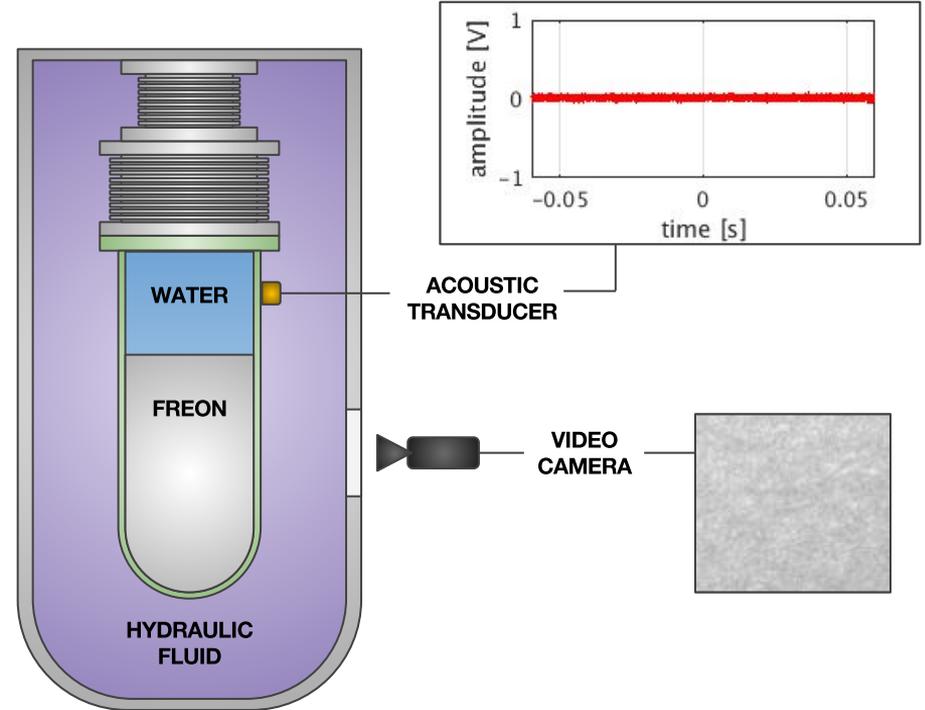
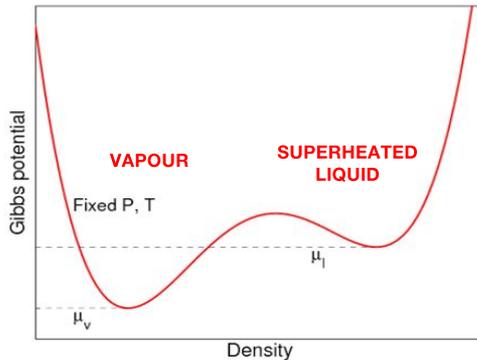
Phase diagram



If the pressure is lowered, the Gibbs potential is modified

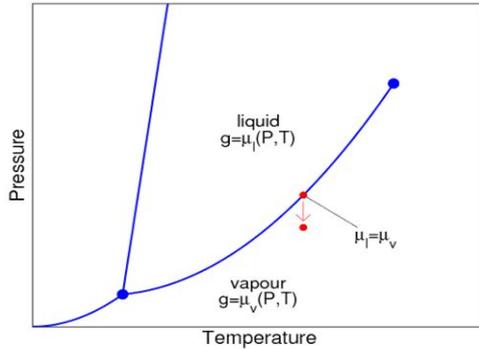
Still two minima, but one is a metastable state: **superheated liquid**

Gibbs potential

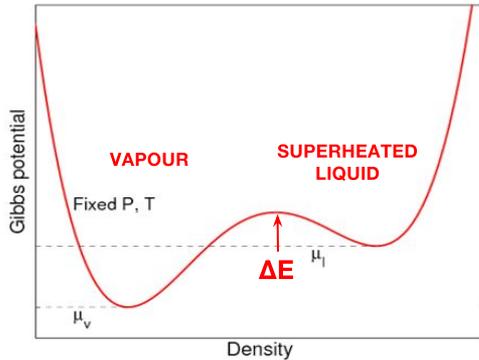


Superheated Liquid Detectors

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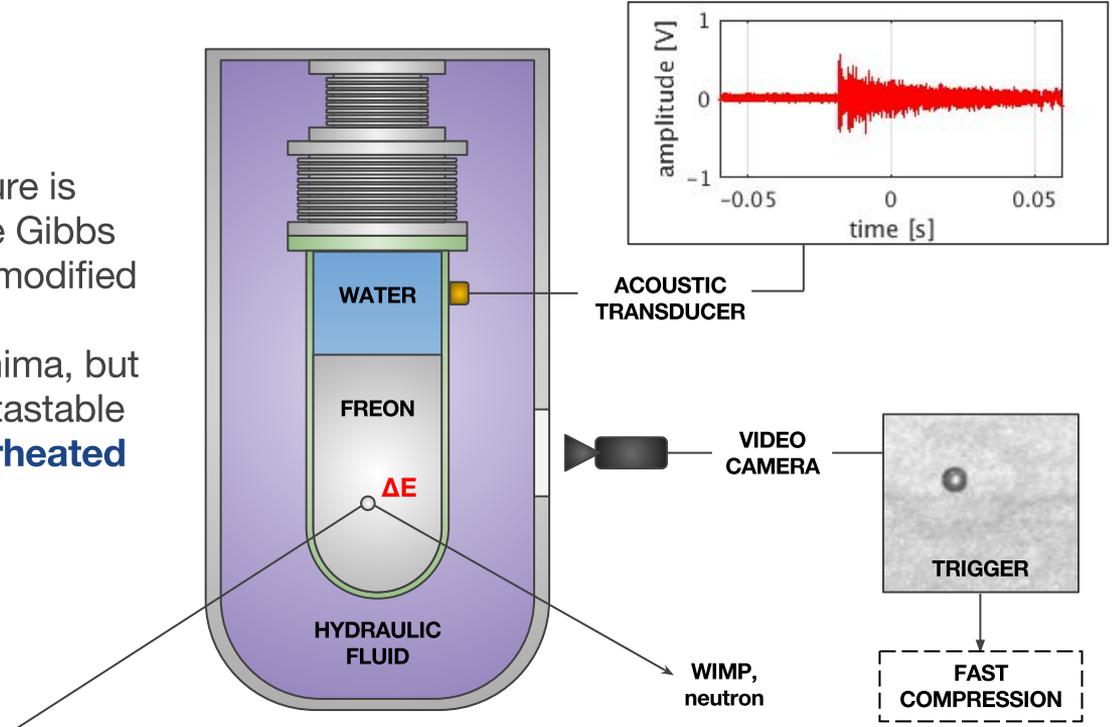


Gibbs potential



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Background Control

- **Gamma/beta radiation**

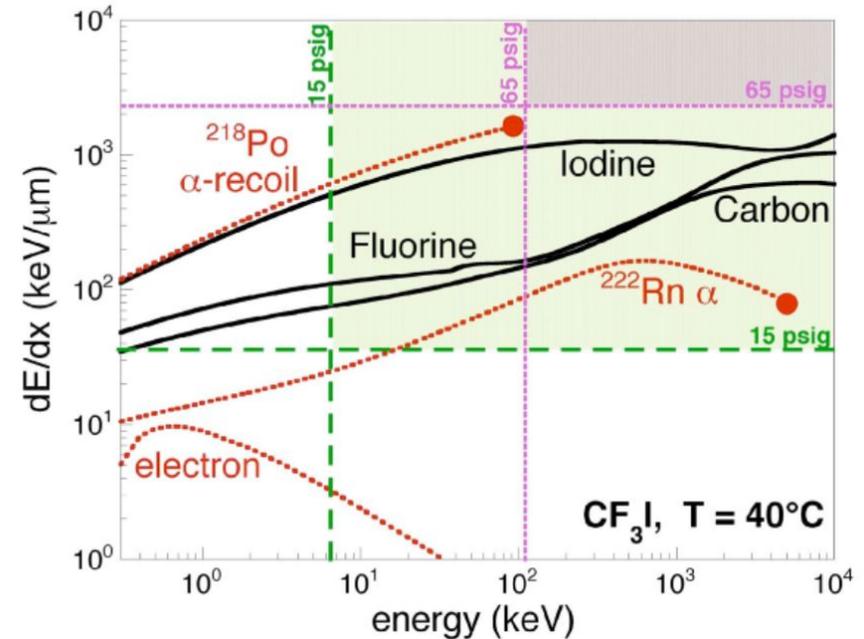
- S.H. liquid detector have intrinsic electron-recoil rejection (dE/dx threshold)
- At 3.2 keV nuclear-recoil energy threshold: $< 10^{-11}$ efficiency for electron-recoils

- **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



Background Control

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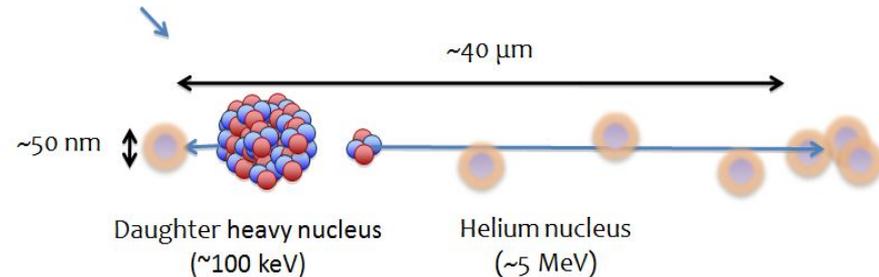
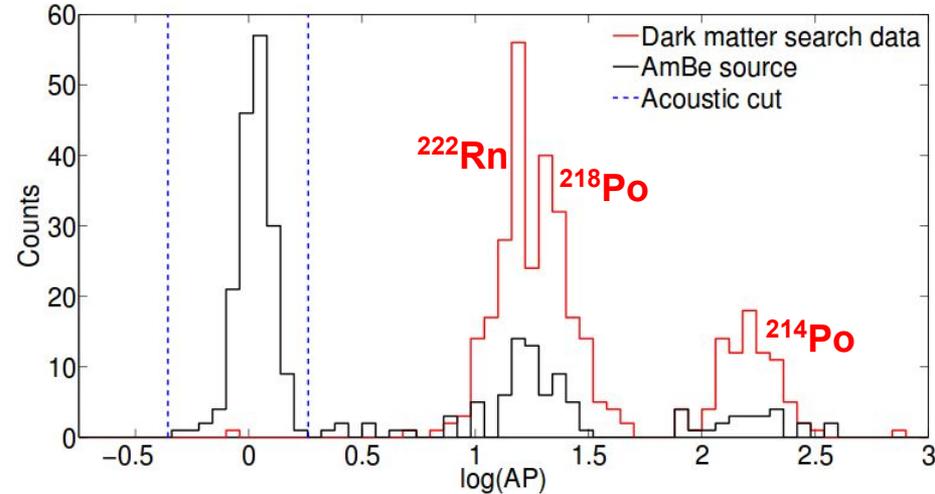
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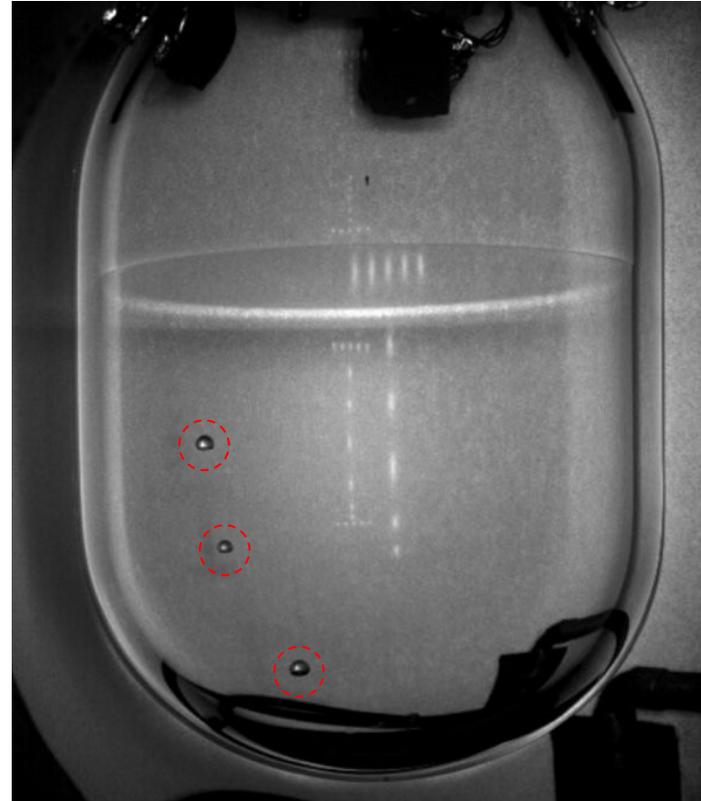
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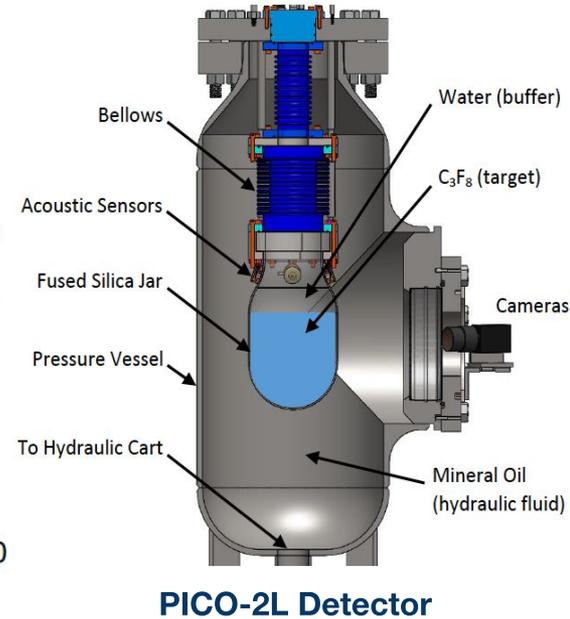
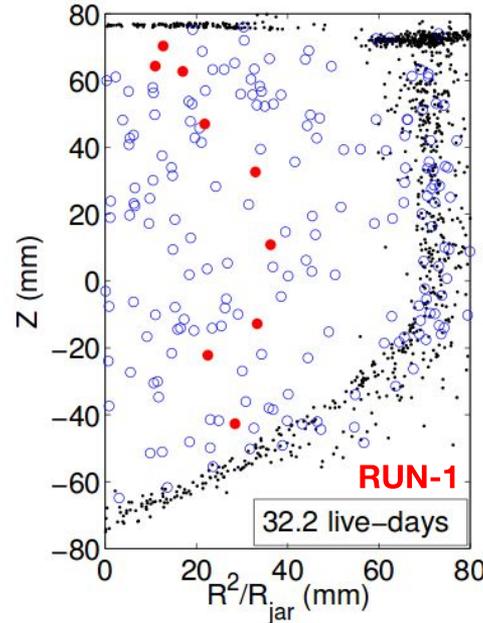
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Previous Results

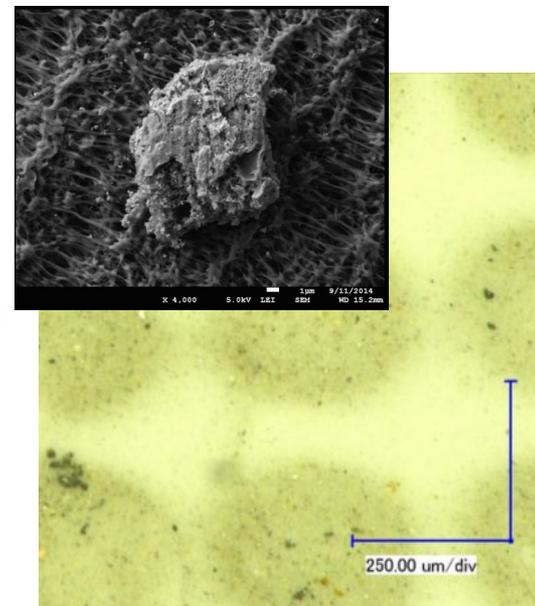
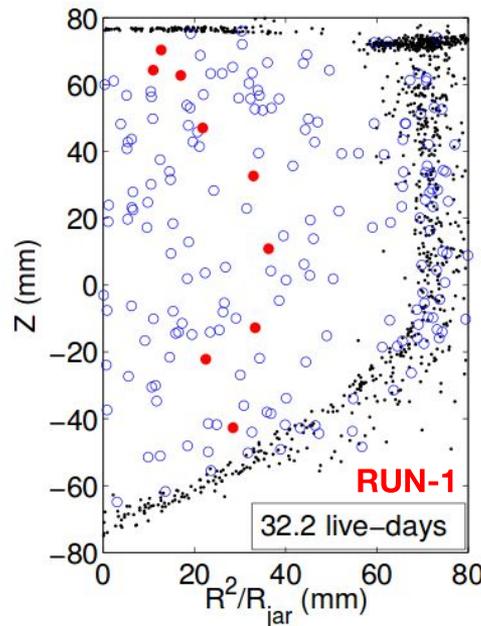
- Anomalous nuclear-recoil-like surplus of events in first run of PICO-2L (C_3F_8) and PICO-60 (CF_3I)

C. Amole *et al.*, Phys. Rev. Lett. 114, 231302 (2015)



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)

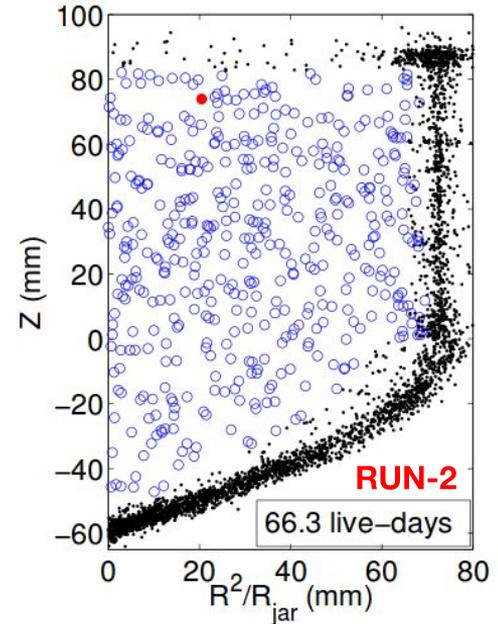
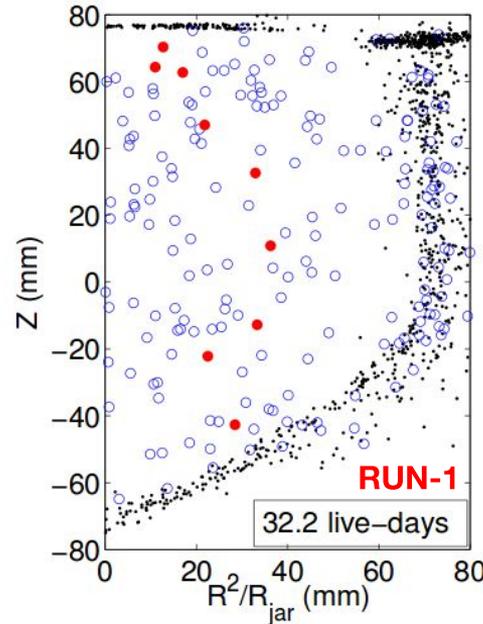


Filter sample from PICO-2L

Previous Results

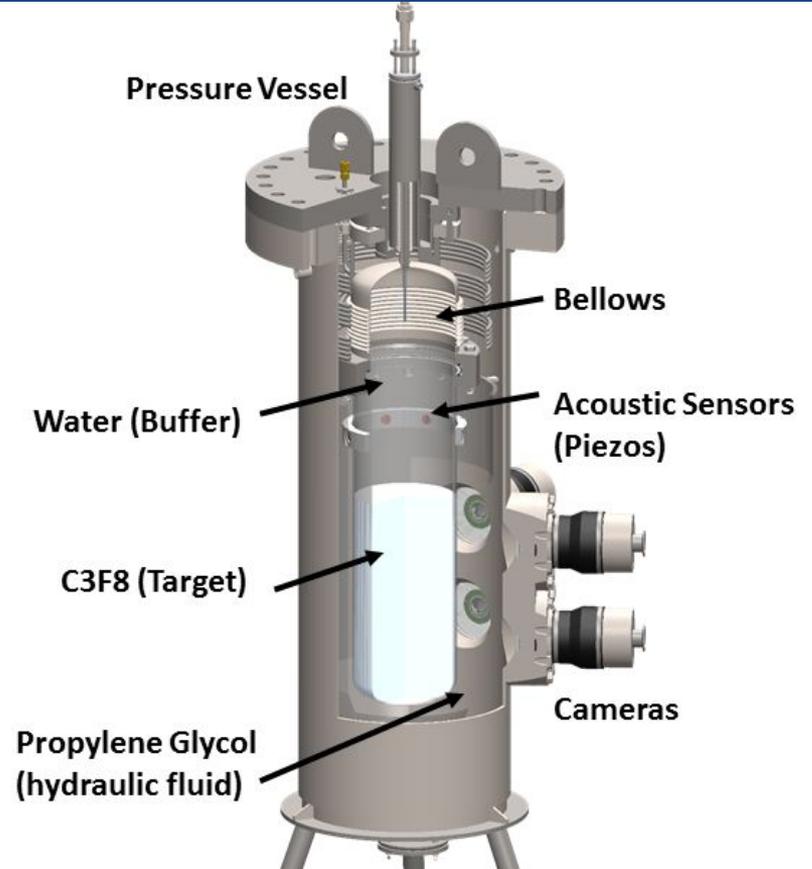
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- Post-run assays indicate the presence of a particulate matter contamination (stainless steel, quartz)
- **Focus on particulate mitigation eradicated the anomalous background in the second run of PICO-2L**

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



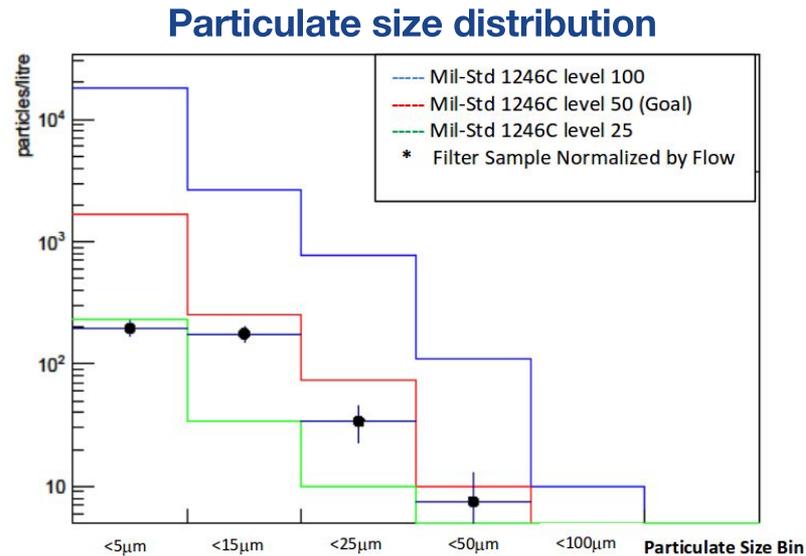
The PICO-60 Bubble Chamber

- Recommissioned and filled with 52 kg of C_3F_8 during summer 2016
- 4 cameras at 300 fps



The PICO-60 Bubble Chamber

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- 4 cameras at 300 fps
- **Inner volume components cleaned to MIL-STD-1246C level 50**

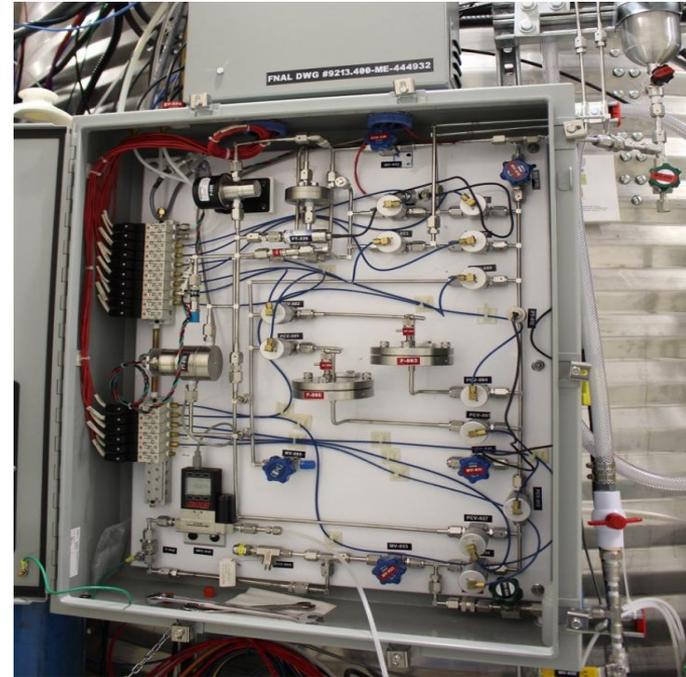


The “dish-washer”

The PICO-60 Bubble Chamber

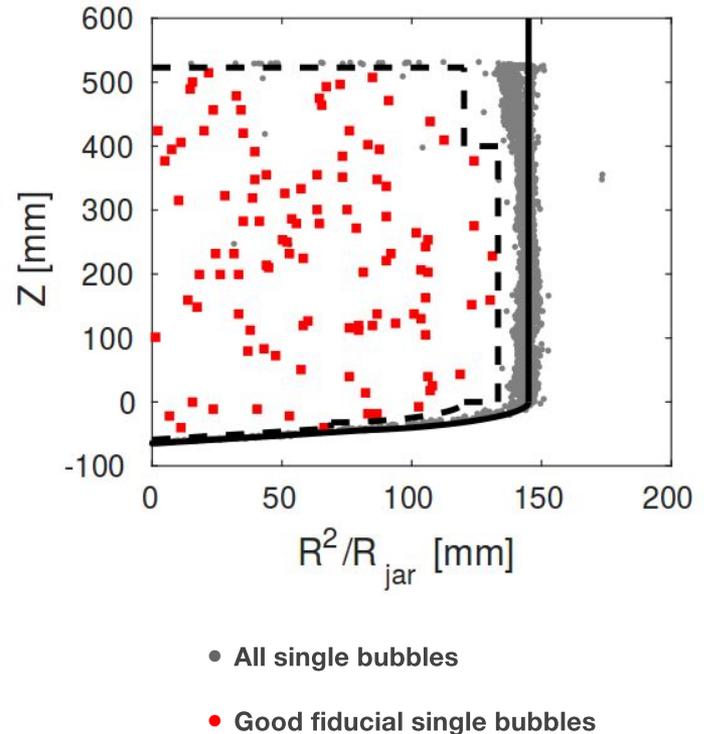


- Recommissioned and filled with 52 kg of C_3F_8 during summer 2016
- 4 cameras at 300 fps
- Inner volume components cleaned to MIL-STD-1246C level 50
- **Active filtration panel**



Blind (Deaf) Analysis

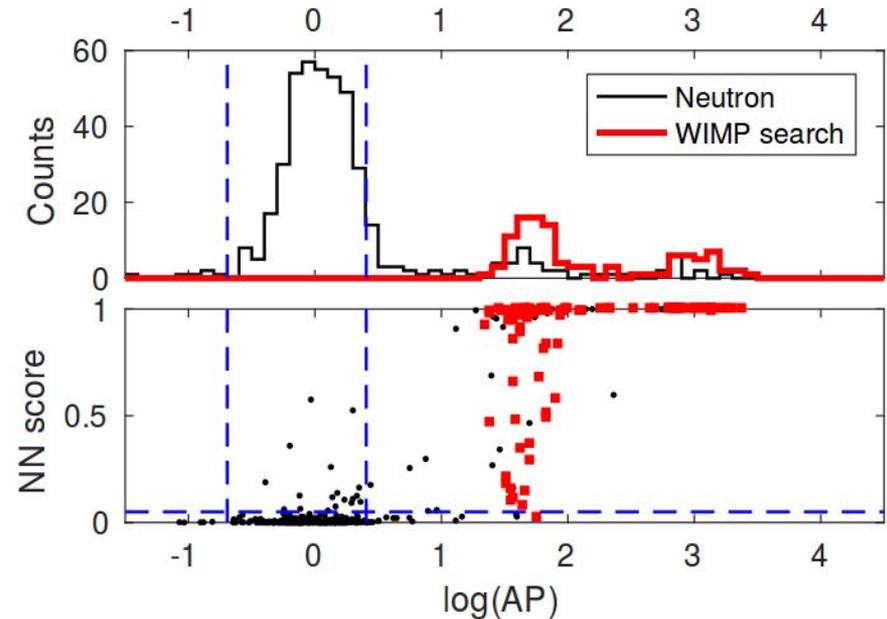
- **Blinded acoustics analysis:** alpha decays indistinguishable from nuclear recoils
- 45.7 kg fiducial mass
- 30 days live-time
- 85.1% WIMP selection efficiency
- **106 events considered after all cuts**
- **3 multiple-bubble events**
- **1.3 ton-days efficiency-corrected exposure**



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

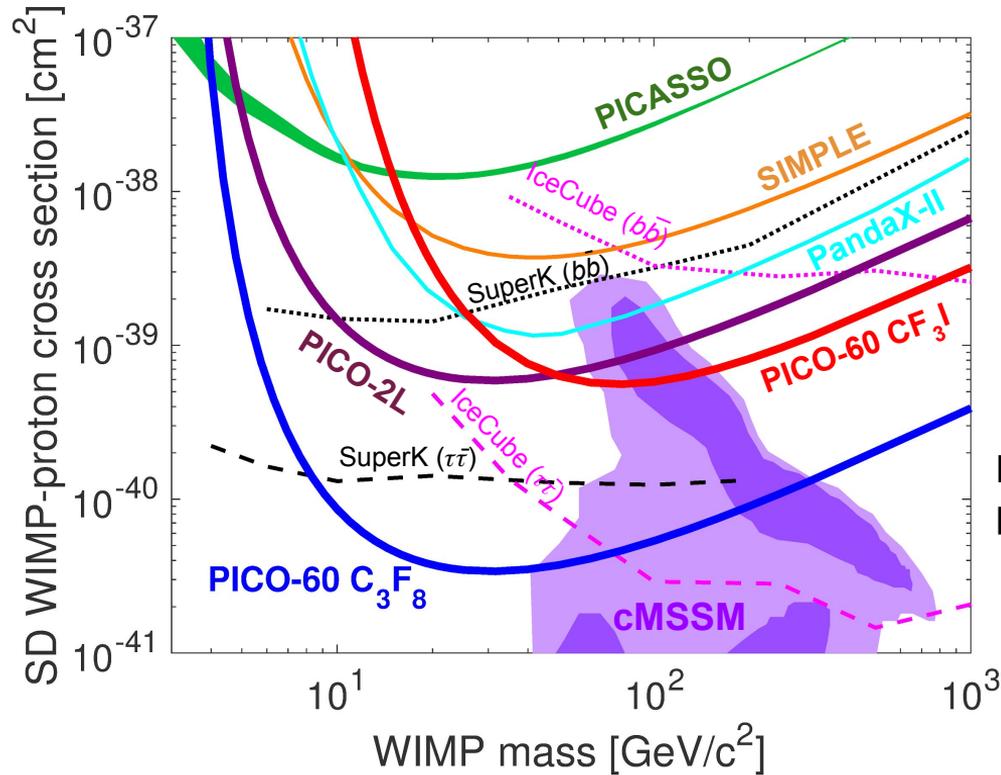
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- **Blinded acoustics analysis:** alpha decays indistinguishable from nuclear recoils
- **106 events considered after all cuts**
- **3 multiple-bubble events**
- **1.3 ton-days efficiency-corrected exposure**
- **Unmasking reveals no nuclear-recoil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



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

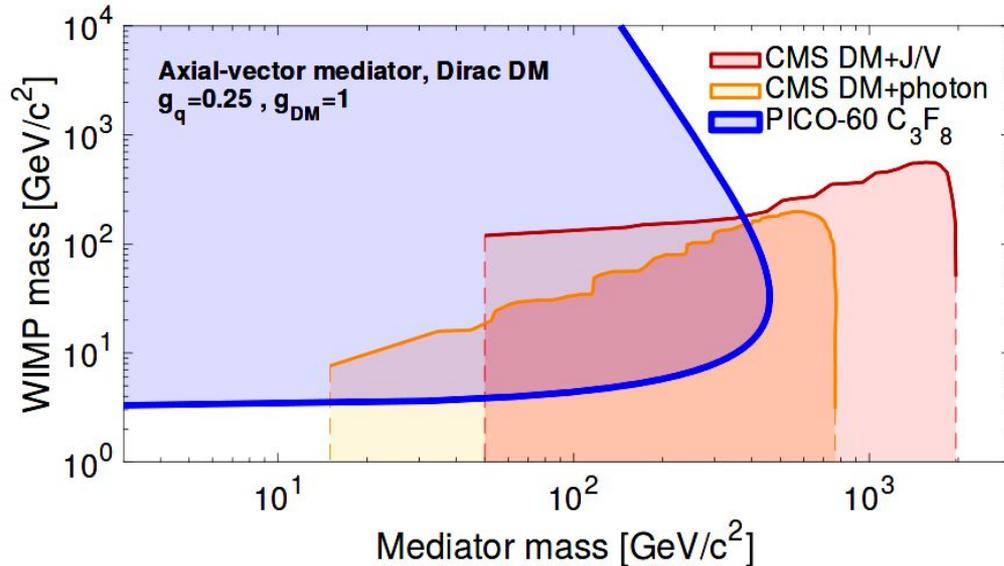
Spin-Dependent Coupling



Factor 17 improvement on previous result!

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

LHC Dark Matter Working Group (LHCDMWG) recommendations on simplified models



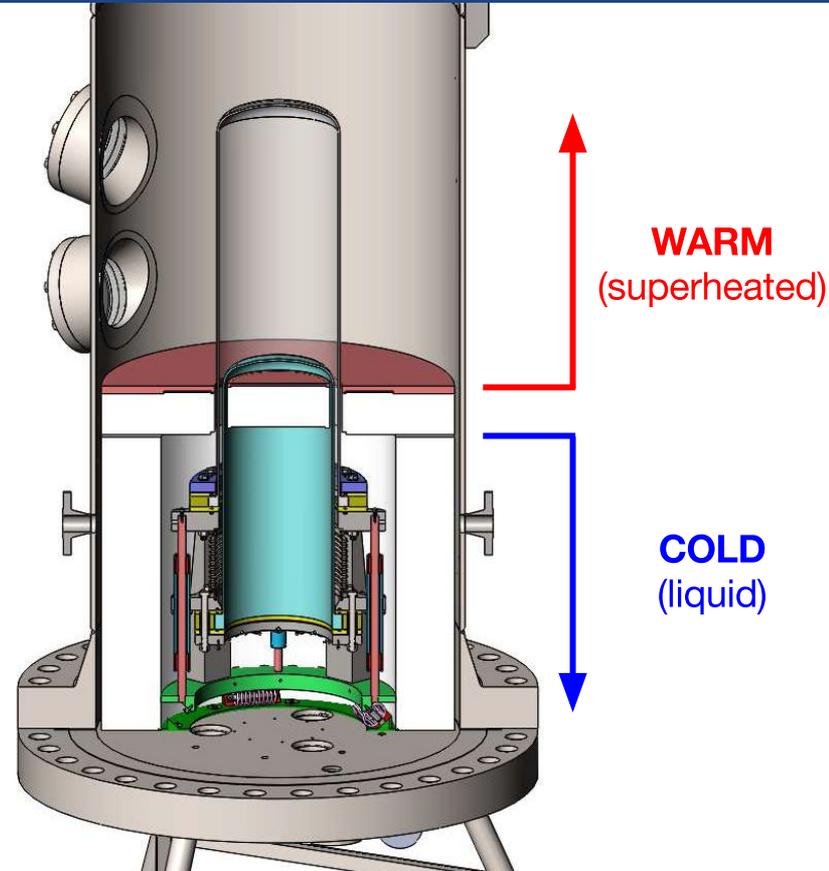
For a mediator exchanged in the s-channel: 4 free parameters:

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

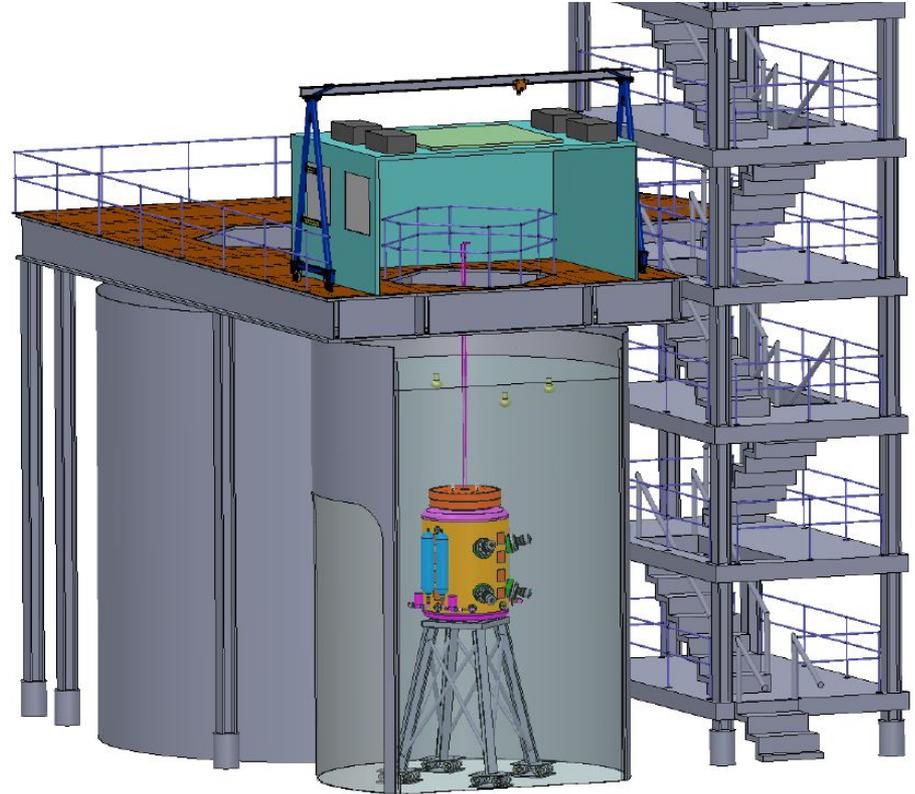
We present constraints on m_{DM} and m_{med} for $g_q = 0.25$ and $g_{DM} = 1$ for an axial-vector mediator exchanged in the **s-channel**

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

- 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
- **Funded: Construction begins this summer**



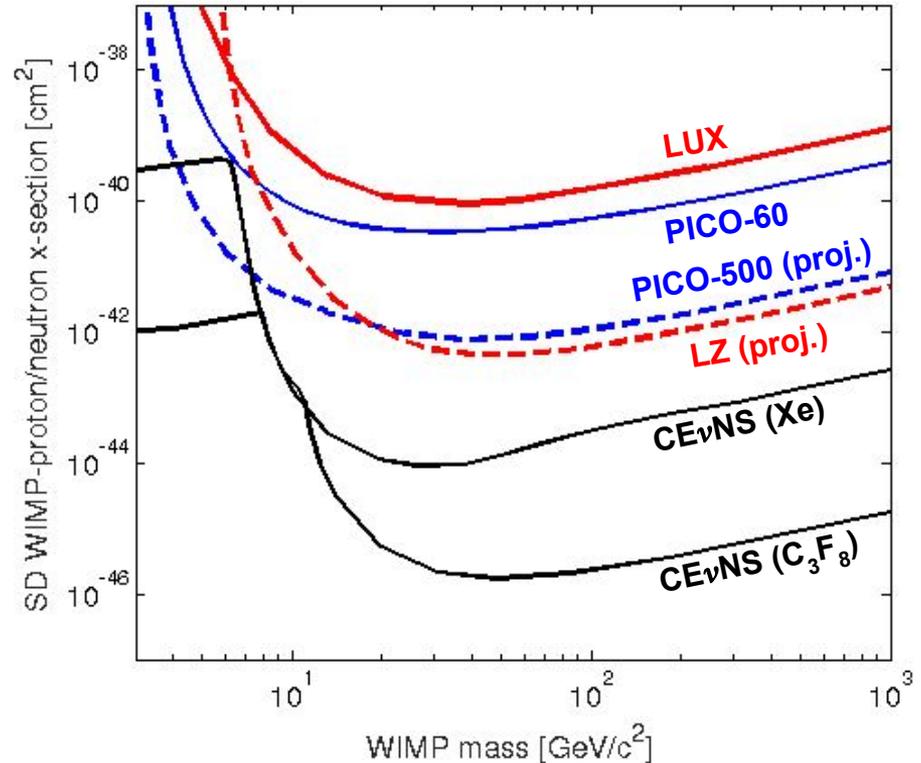
- Funding requested in Canada for the construction of a **500-liter bubble chamber**
- Choice of bubble chamber configuration after PICO-40L demonstration
- **Construction starting 2018**



Future Chambers: PICO-500

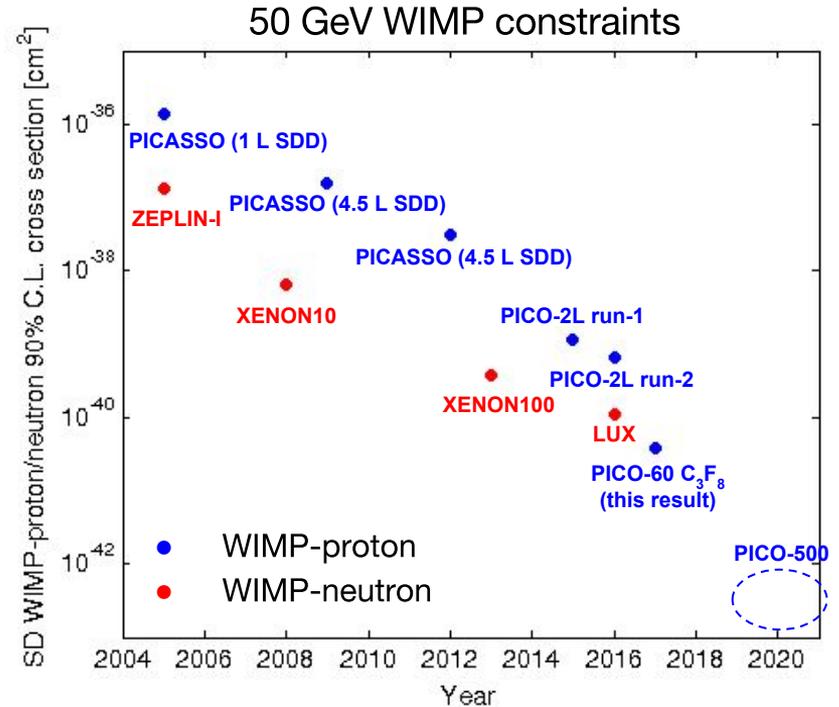


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Summary

- No WIMP-candidates in recent PICO-60 C_3F_8 blind analysis with 1.3 ton-days exposure
- We report a factor 17 improvement our world-leading SD WIMP-proton constraints with PICO-60 C_3F_8
- Backgrounds are under control and the bubble chamber technology is ready to be scaled-up to ton-scale





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C. E. Dahl, M. Jin, J. Zhang



**Drexel University,
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P. Champion, R. Neilson



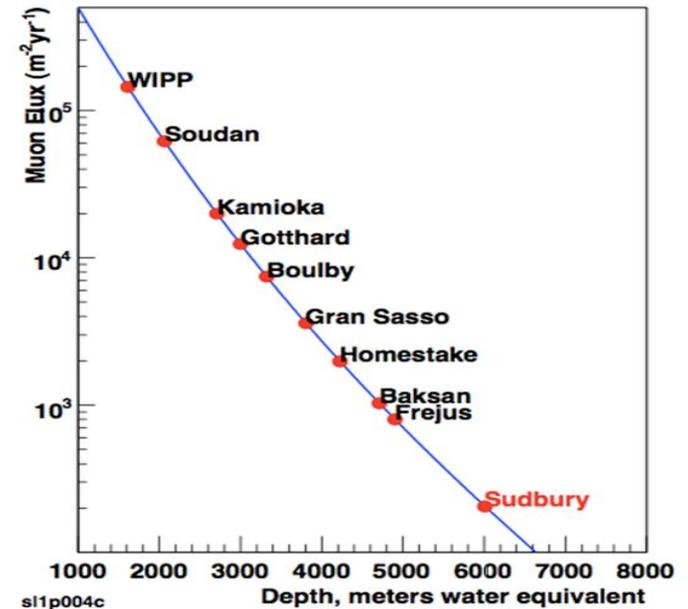
**Fermi National Accelerator
Laboratory, Batavia, IL, USA**
P. S. Cooper, M. Crisler, W. H.
Lippincott, A. E. Robinson, R.
Rucinski, A. Sonnenschein

Extra Slides

- Cleanroom environment 2 km (6800 ft.) underground (6000 m water equivalent)
- Cosmic ray shielding: 1 muon per m² every 3 days (5 X 10⁷ reduction)
- PICO bubble chambers operating since 2010



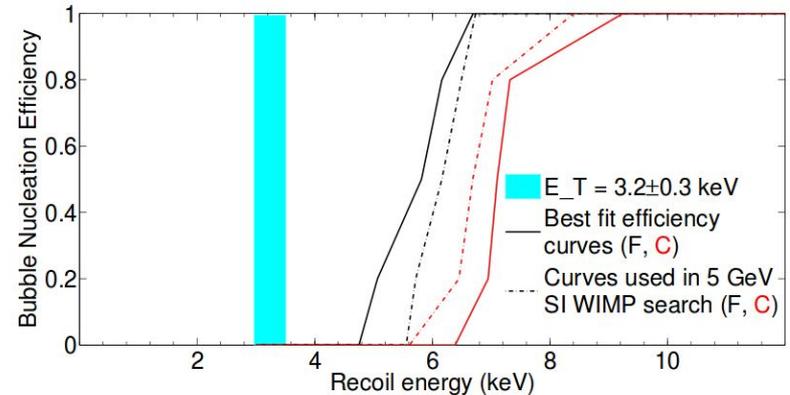
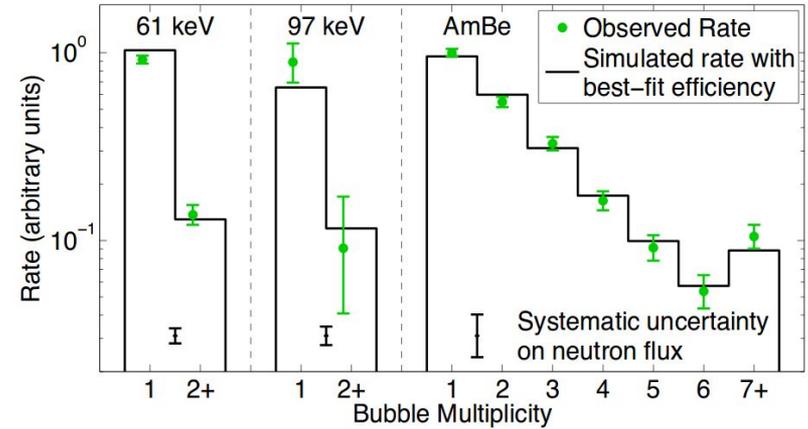
Muon flux comparison



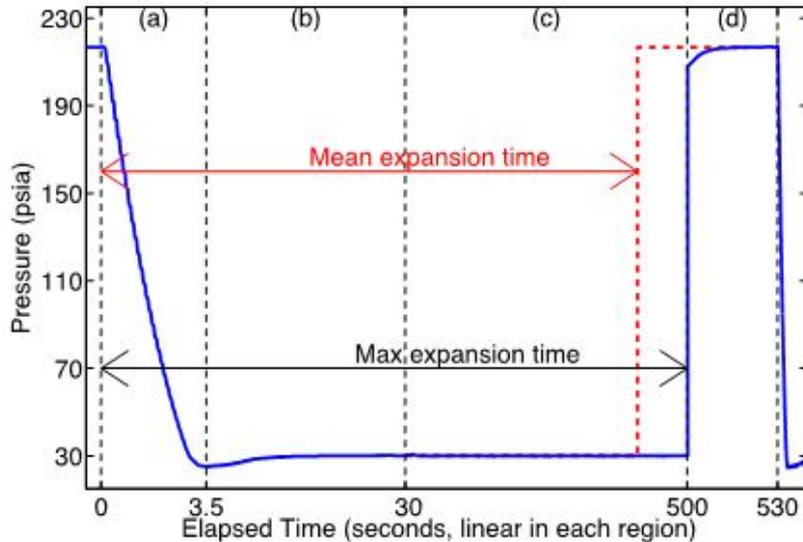
Nuclear-Recoil Nucleation Efficiency



- 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
- Conservative approach: 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

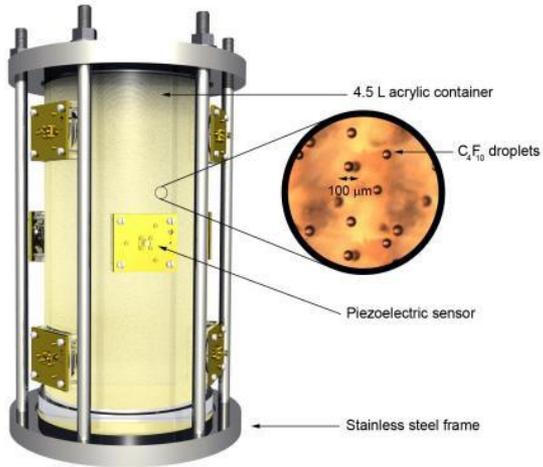


PICO Bubble Chamber Operation



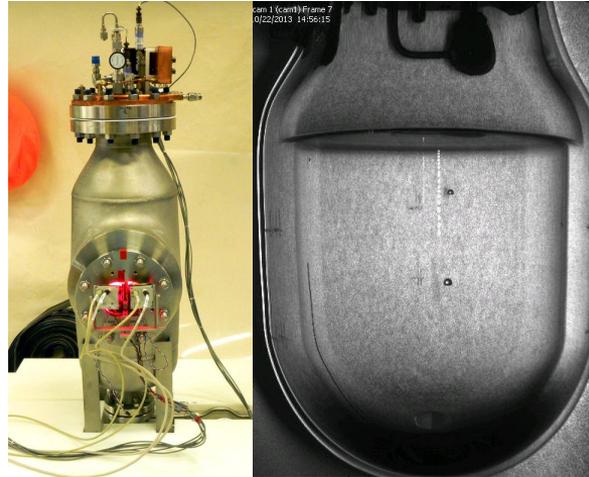
- Clean and non-porous quartz jar allows sustained target liquid superheat
- When a bubble is formed the camera triggers the fast recompression (100 ms) of the pressure vessel and bellows system
- After a period of compression to condense any remanent gas, the chamber is ready for another cycle

Previous Results



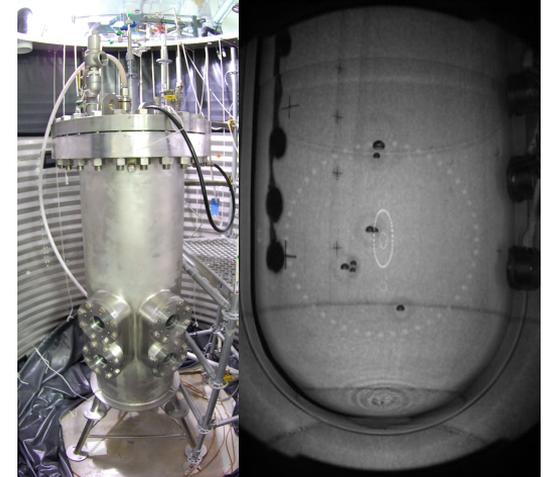
PICASSO-32
 C_4F_{10}

Barnabé-Heider et al, Phys. Lett. B624 (2005)
S. Archambault et al., Phys. Lett. B682, (2009)
Final results: [arXiv:1611.01499](https://arxiv.org/abs/1611.01499) [hep-ex] (2016)



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)

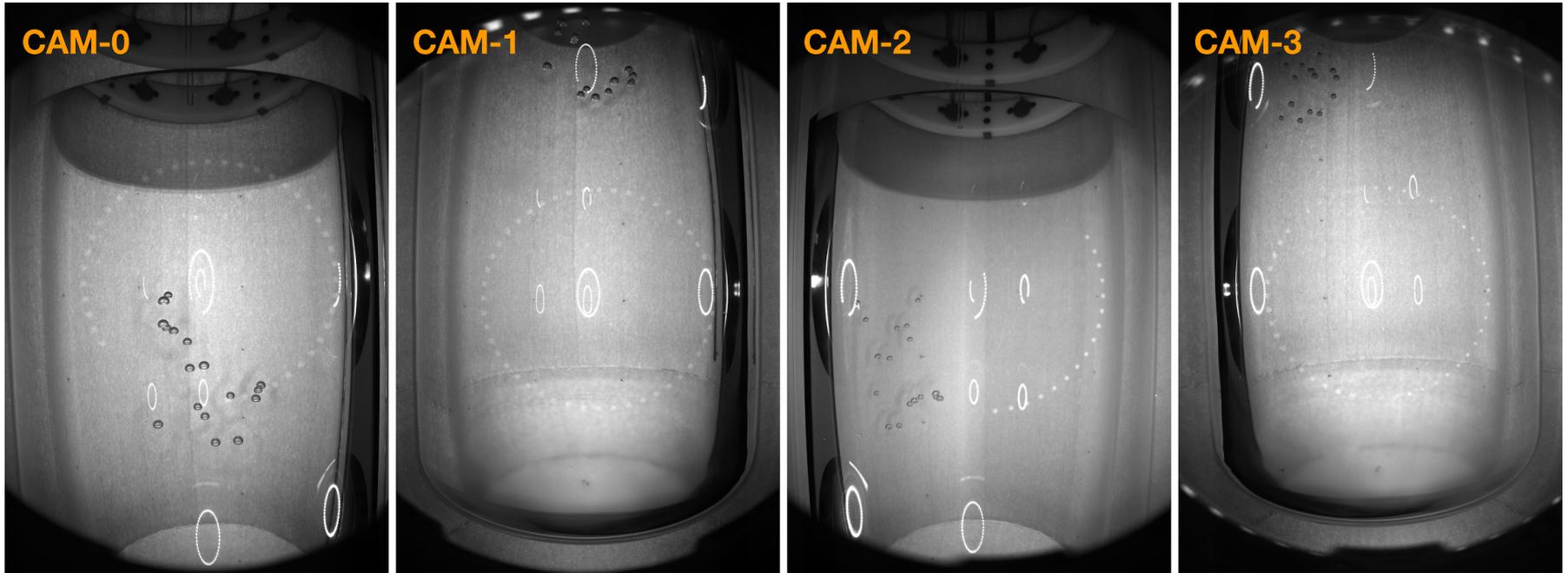


COUPP-60 → PICO-60
 CF_3I

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

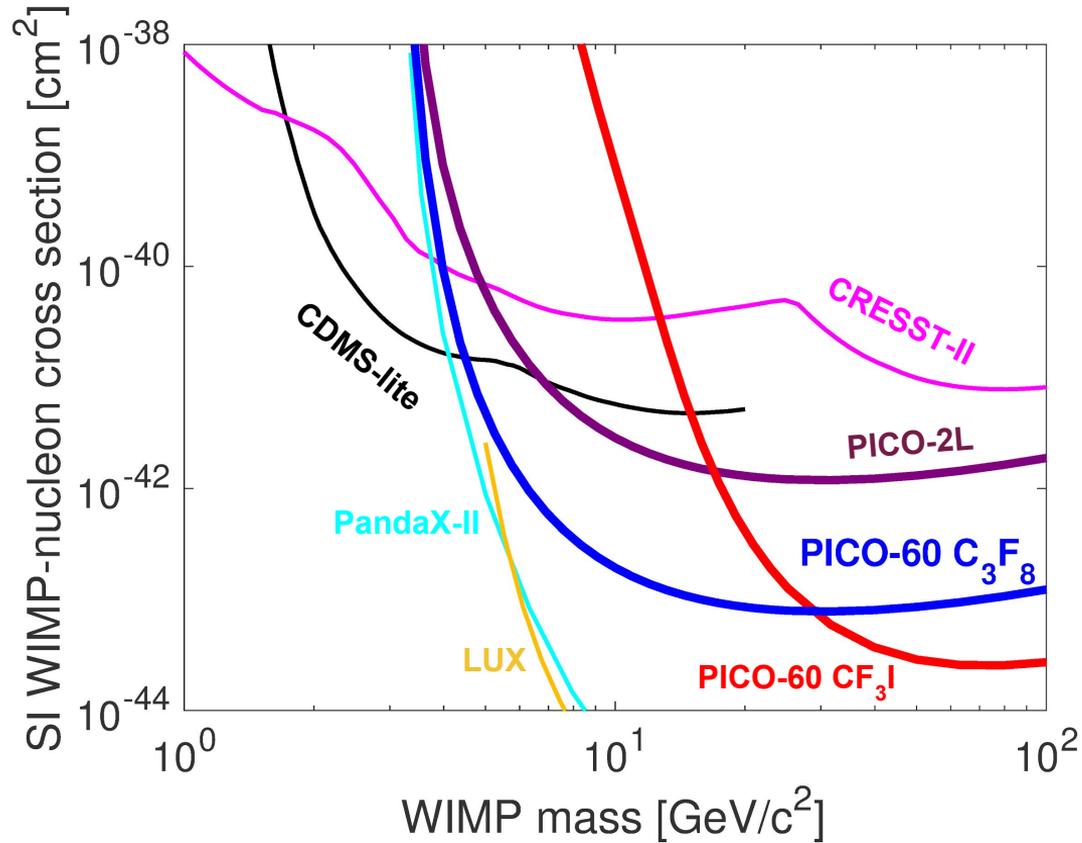
4-Camera Photographic System

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



17-bubble neutron multiple-scattering event

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

