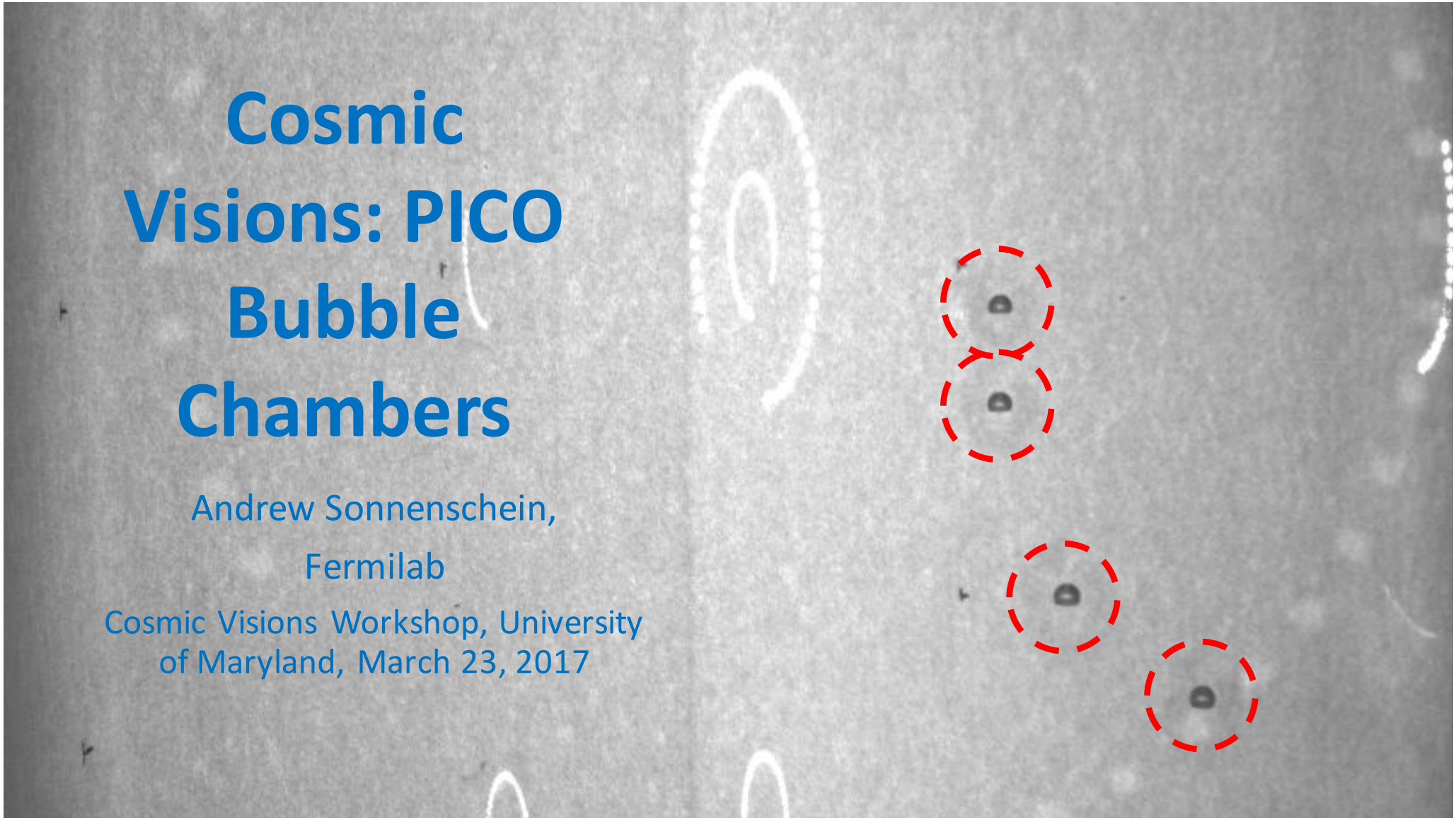
Cosmic Visions: PICO Bubble Chambers

Andrew Sonnenschein,

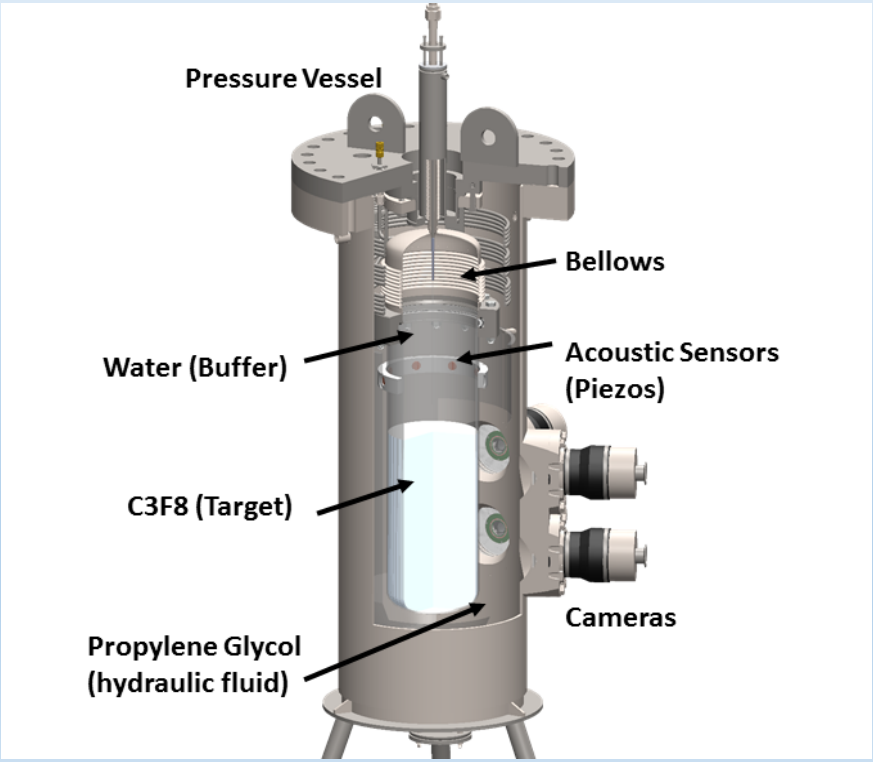
Fermilab

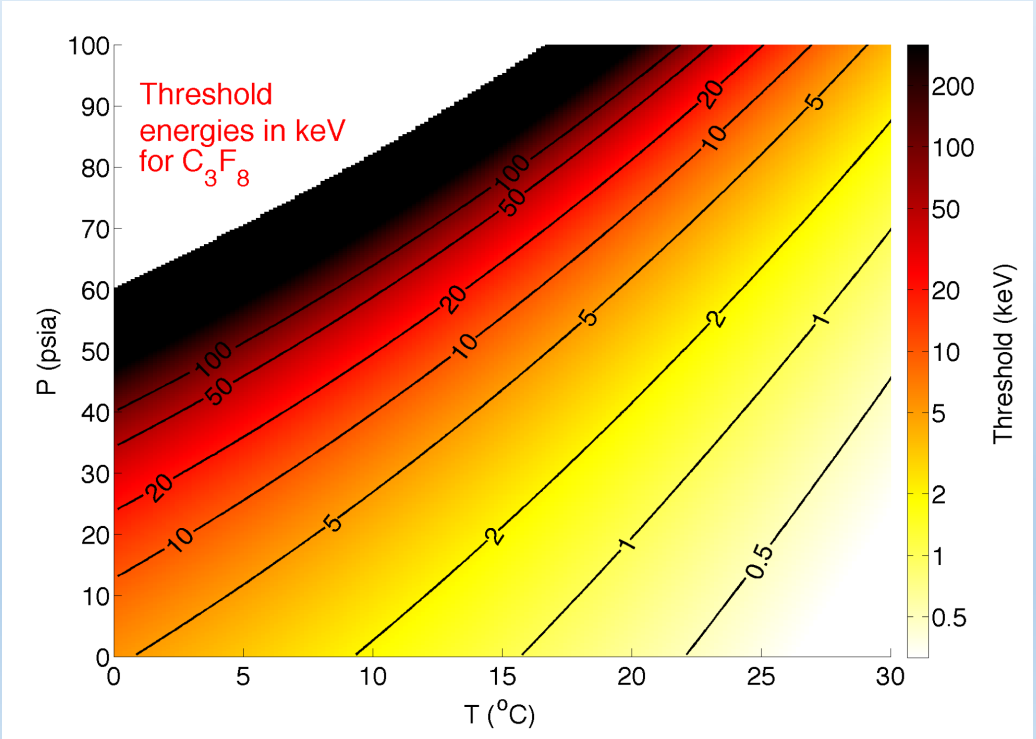
Cosmic Visions Workshop, University of Maryland, March 23, 2017



Bubble Chamber Technology for WIMP Detection

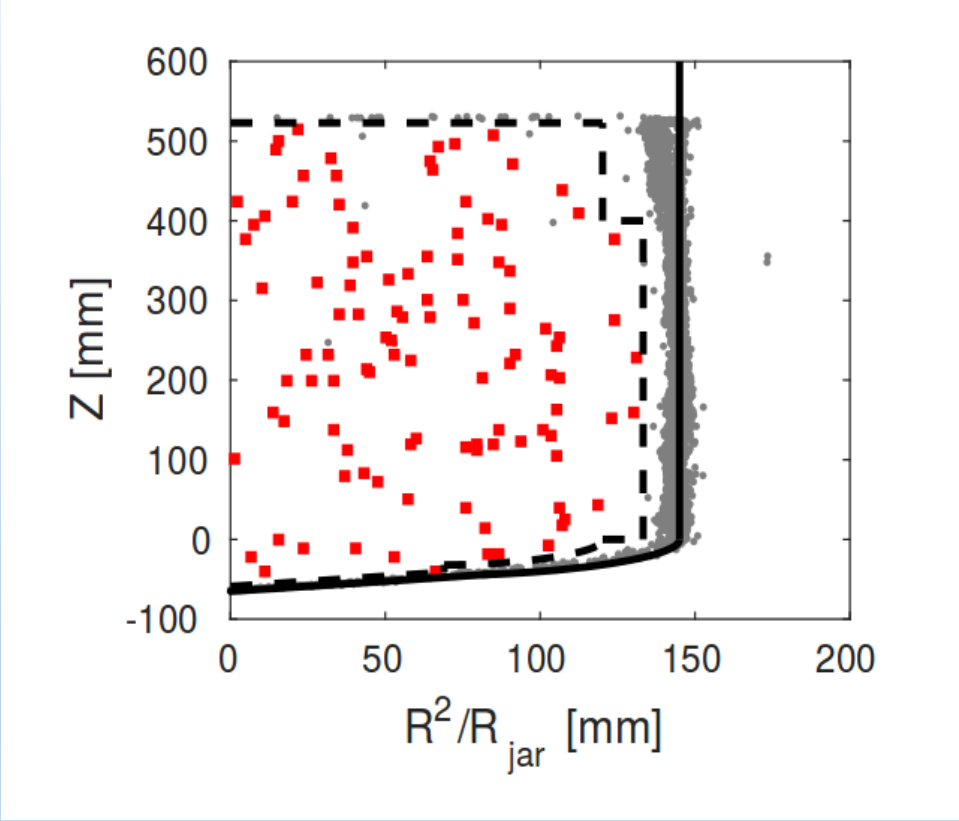
• Bubble chamber operator chooses a pressure and temperature, determining the minimum deposited energy and energy loss density (dE/dX) that will nucleate bubbles.
• Video cameras and piezoelectric acoustic sensors record the signals from bubble nucleation.





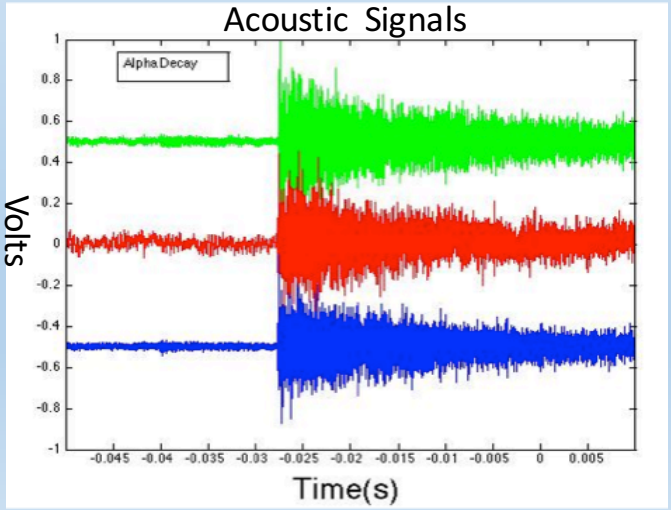
New Result from PICO-60

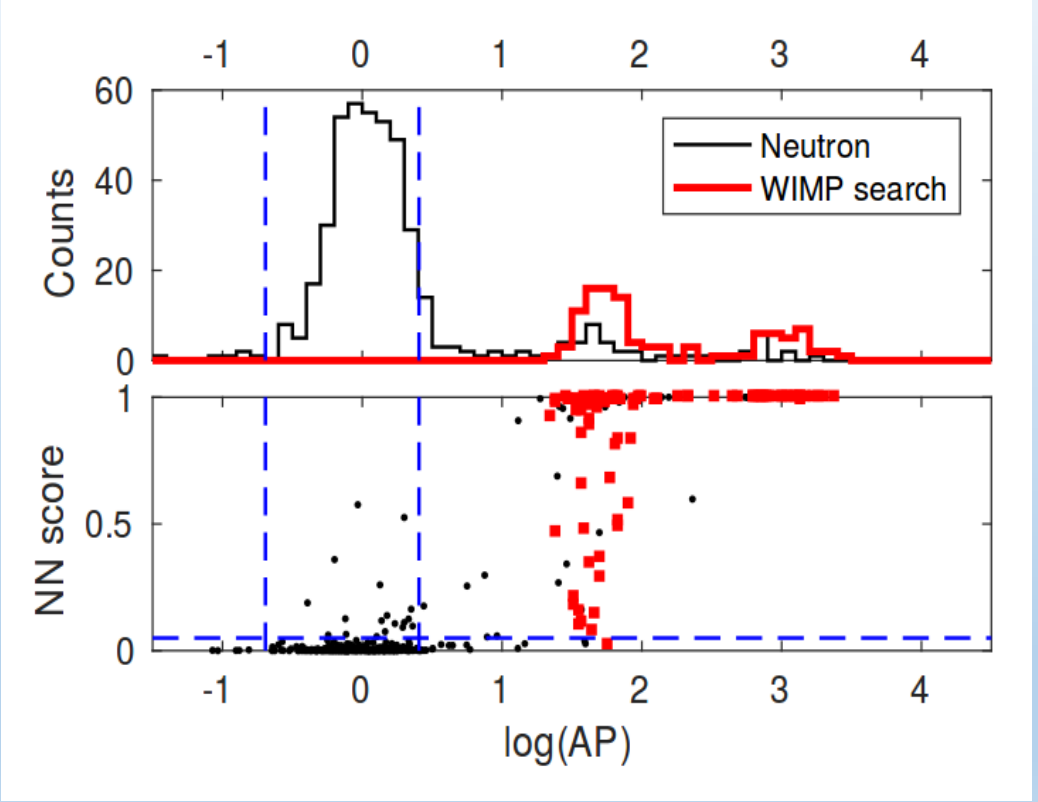
- Data taken November 2016- January 2017.
- Aggressive cleaning to remove Inner Vessel particulate contamination.
- 52 kg of C_3F_8 target liquid (46 kg fiducial)
- 1167 kg-day efficiency-corrected exposure.
- 3.3 keV threshold (14 degrees C, 30 psi)
- 106 single bubble events passing basic data quality and optical fiducial volume cuts.
- Details in [arXiv:1702.07666]



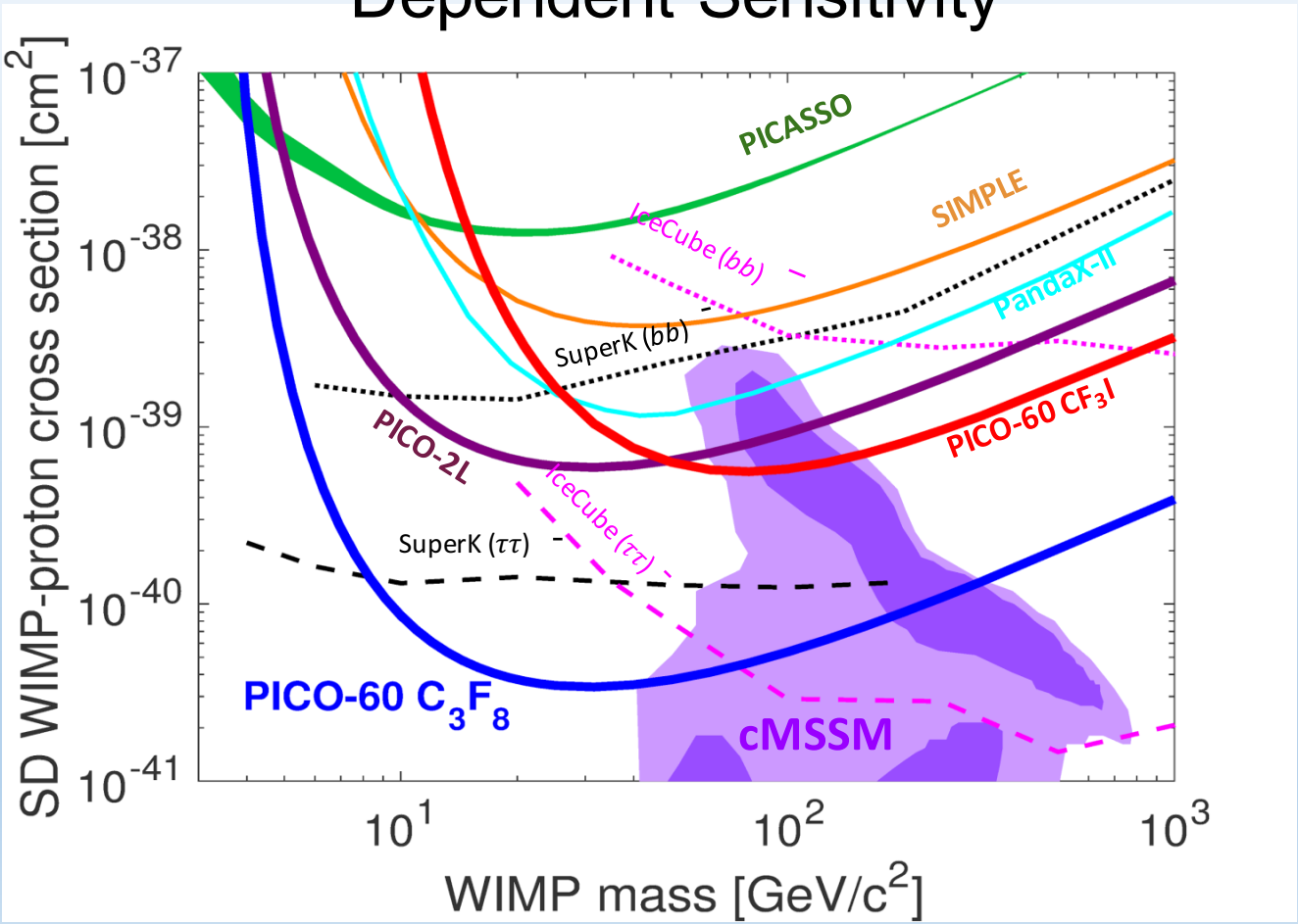
PICO-60 2017 Acoustic Analysis

- Two parameter acoustic analysis:
  - Acoustic Power (AP)
  - Neutral Network score
- Blind analysis- first time for PICO.
- Zero WIMP candidates passing acoustic cuts!



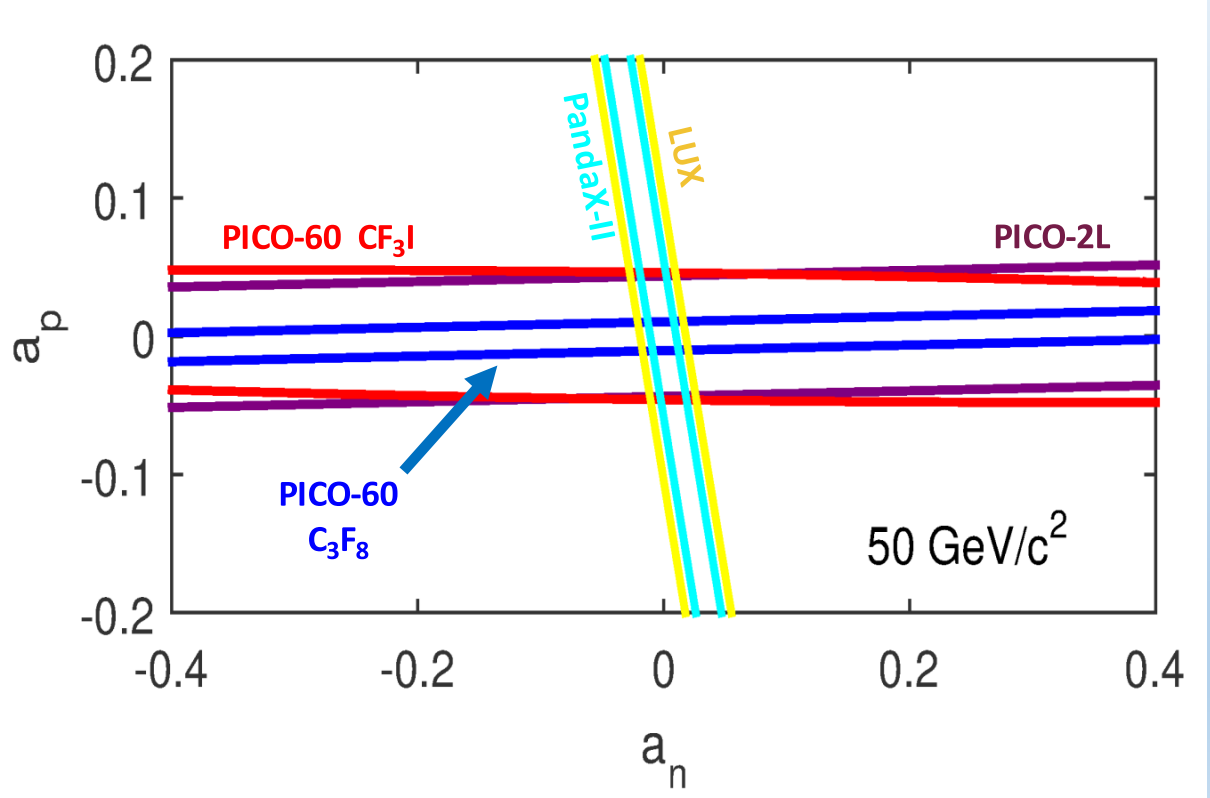


2017 PICO Result: Factor of 17 Improvement in Spin-Dependent Sensitivity



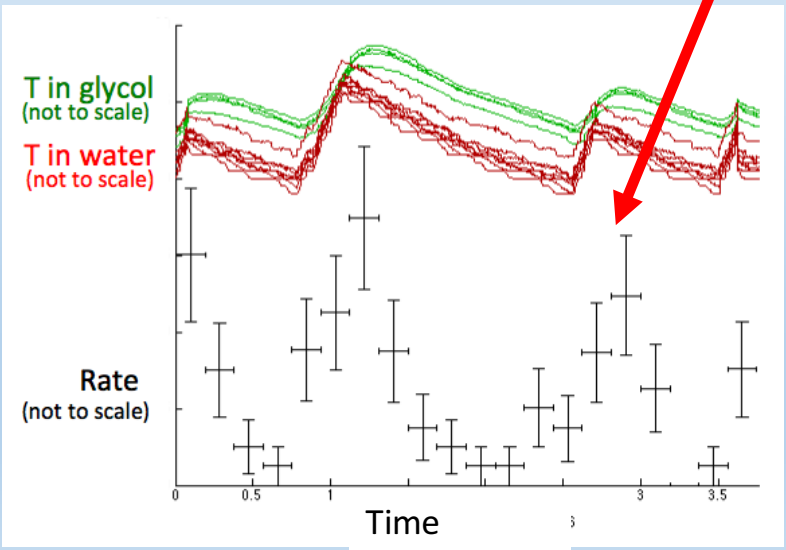
Comparison LUX, PandaX Spin-Dependent Sensitivity

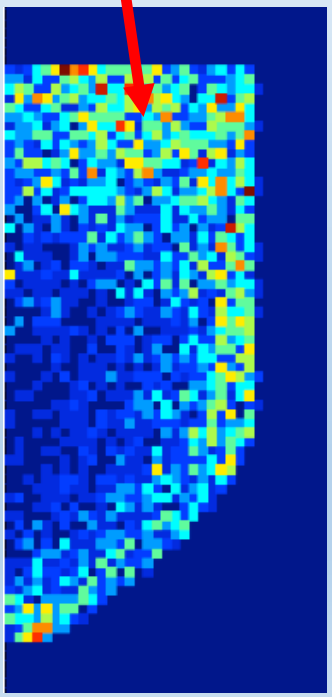
- Comparison of sensitivity to effective proton (a_p) and neutron (a_n) spin coupling.

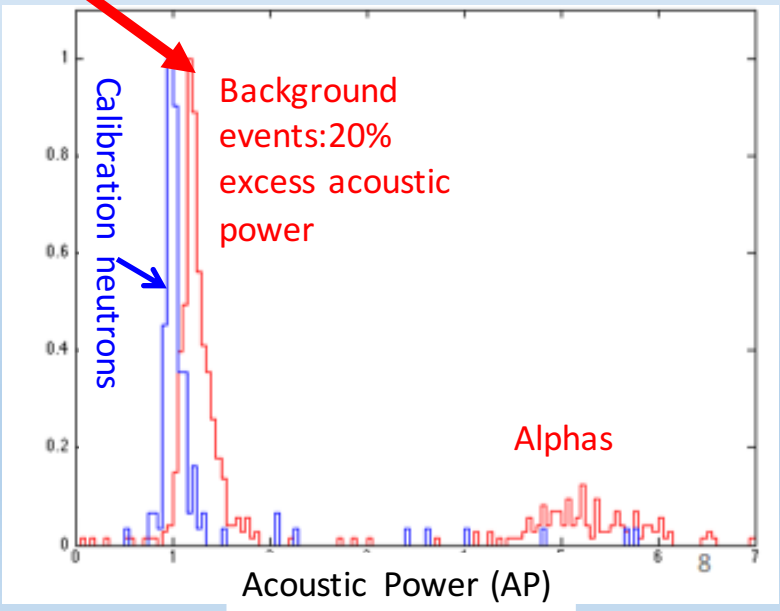


Time & Spatially Dependent Background in 2013-2014 Run

Time-dependent background



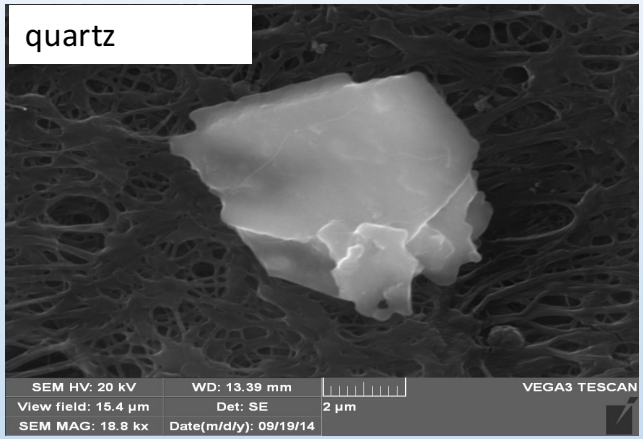


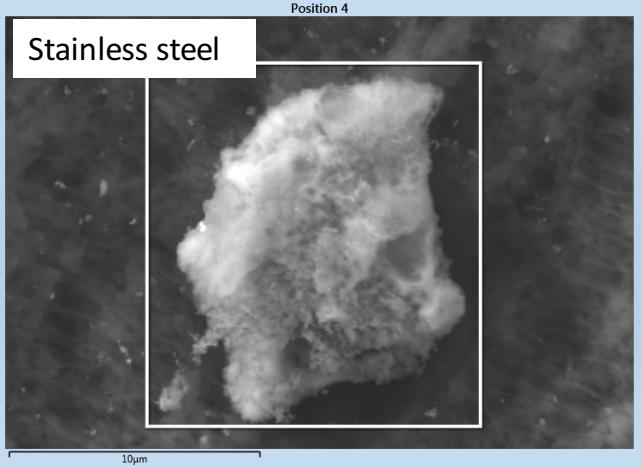


Studies of Particulates in Inner Vessel After 2013-2014 Run

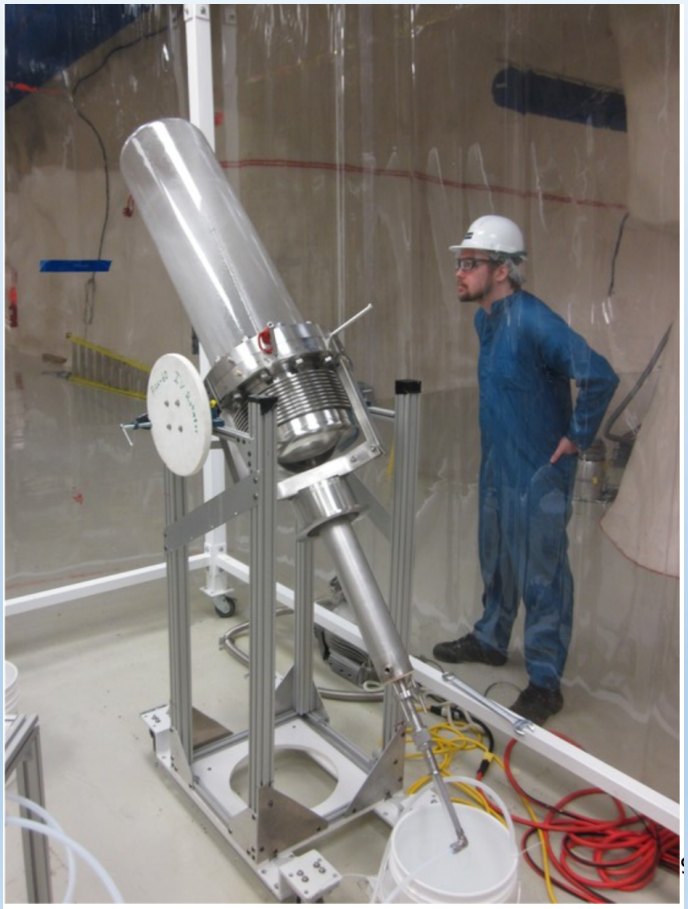
- Liquids passed through Teflon filters with 200 nm pore size.
- Studied using optical and electron microscopy, X-ray fluorescence, Alpha spectroscopy, mass spectroscopy.
- Result: majority of contamination from quartz and stainless steel materials used in chamber construction.

- PICO-60 sample:
  - 7 μg quartz particles
  - 240 μg stainless steel and iron oxide

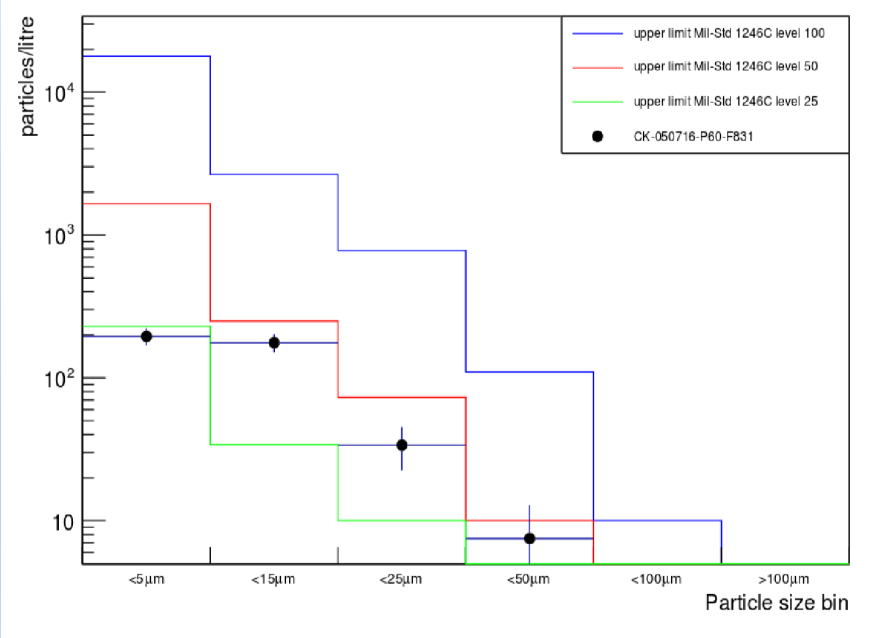




Improved Cleaning Procedures for 2016-2017 Run

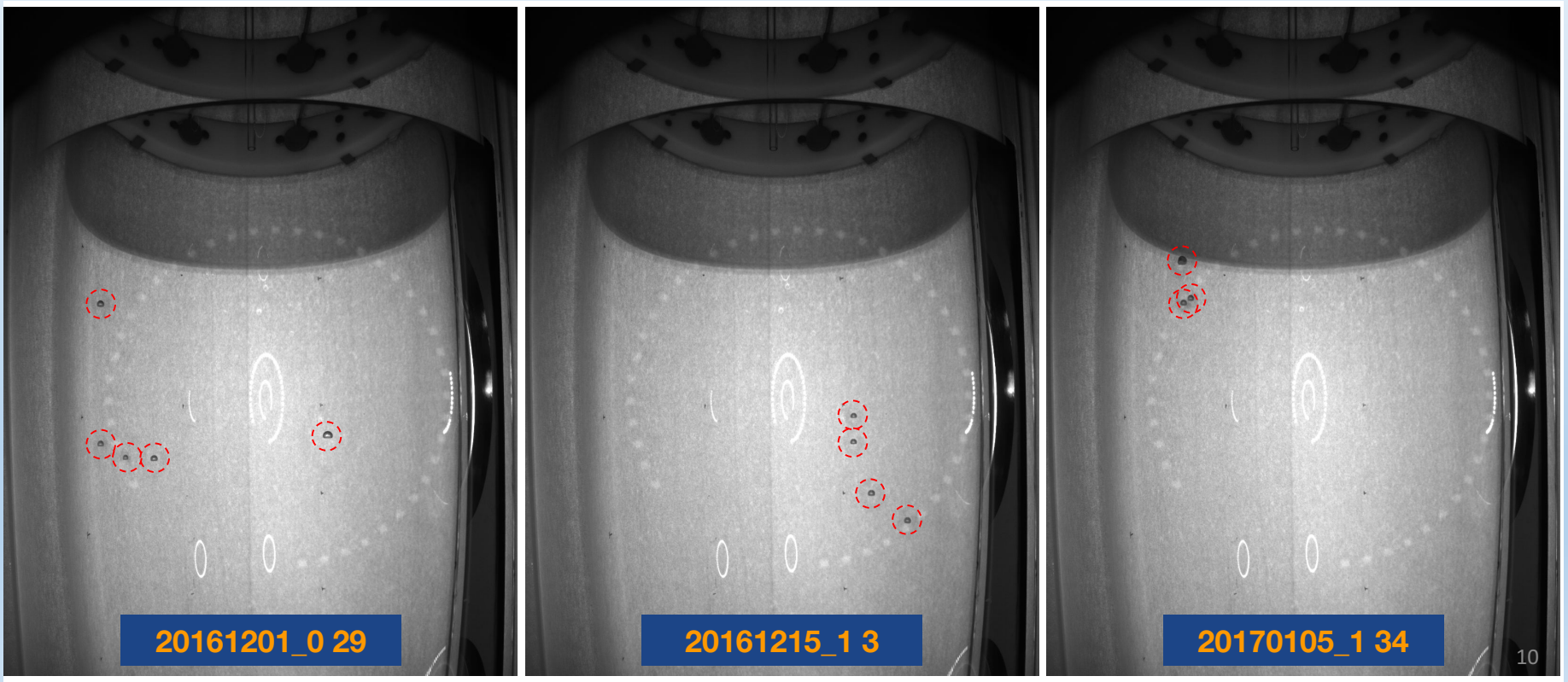


- Spray jet cleaning with high purity, hot detergent system.
- Measurements of fluid particle counts for quality control.



PICO-60 Incipient Neutron Background

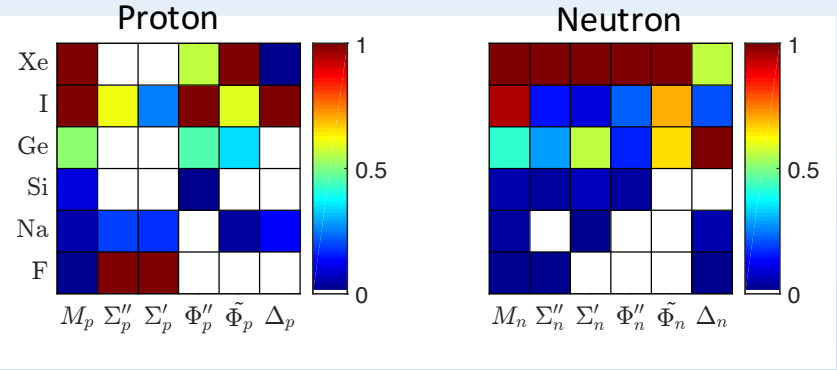
- Three multiple scatters observed, no singles.
- Marginally compatible with background model expectation (0.96 multiple, 0.25 single)

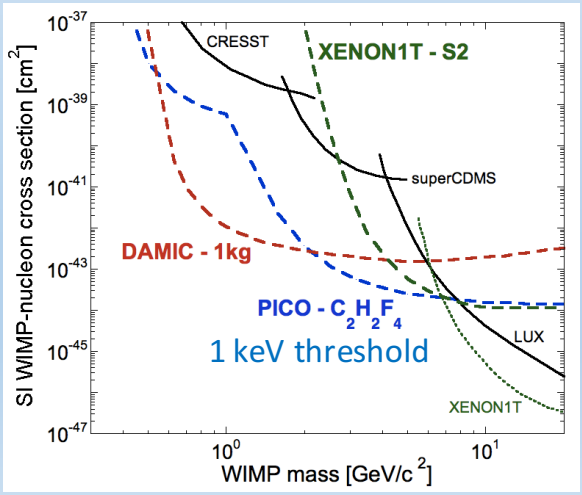


Bubble Chambers Offer A Diversity of Target Nuclei

- Capability to instrument a wide range of target nuclei with sensitivity to diverse WIMP-nucleon couplings. For example,
  - **^{19}Fluorine:** Best sensitivity to spin-dependent interactions.
  - **Iodine, Bromine, Xenon, Argon:** High-A targets to exploit A^2 dependence of spin-independent cross section.
  - **Hydrogen:** Enhanced sensitivity to low-mass particles.
- Very low backgrounds, due to unique discrimination mechanisms.
- Thresholds below 3 keV nuclear recoil energy.
- Lowest cost per ton of target mass.

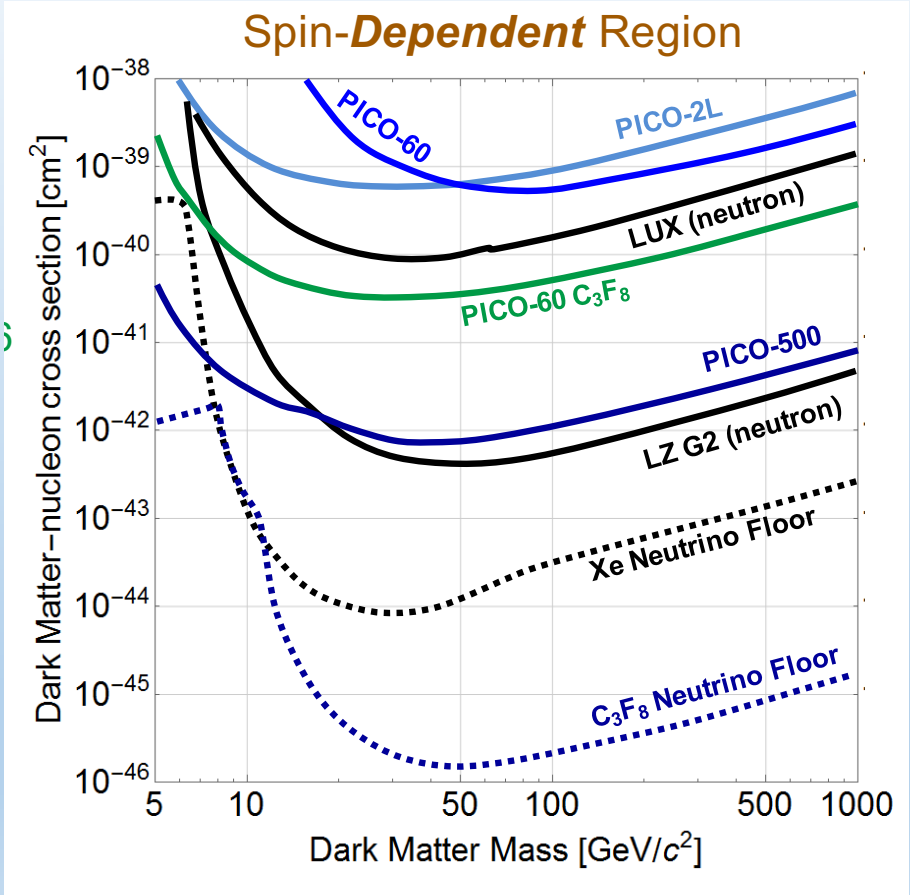
Fitzpatrick, Haxton et al. Effective Field Theory Couplings



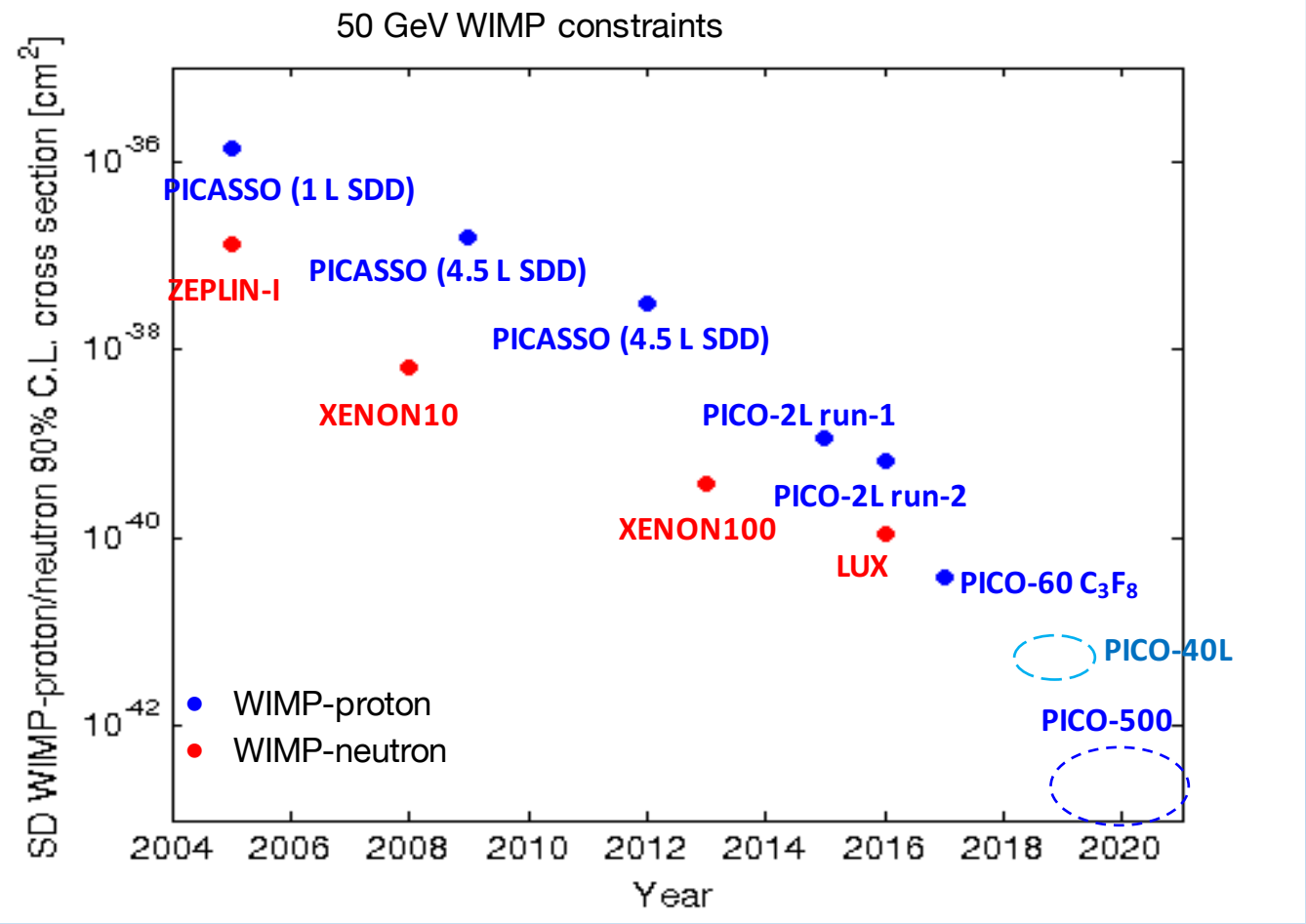


Neutrino Floor Lower for Fluorine Than Xenon

- WIMP searches ultimately will be limited by background from coherent scattering of atmospheric neutrinos.
- Xenon will be limited first due to larger nucleus.
- Fluorine target sensitivity (E.g. C3F8) extends another two orders of magnitude.

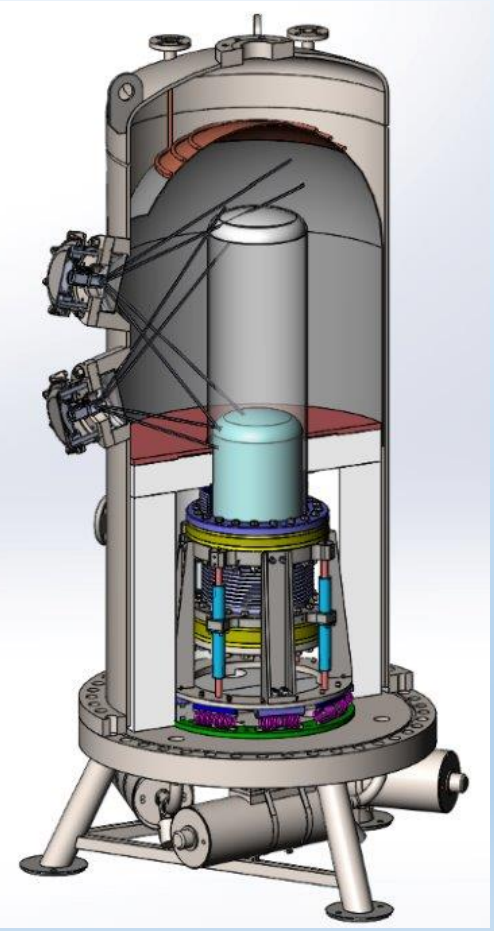


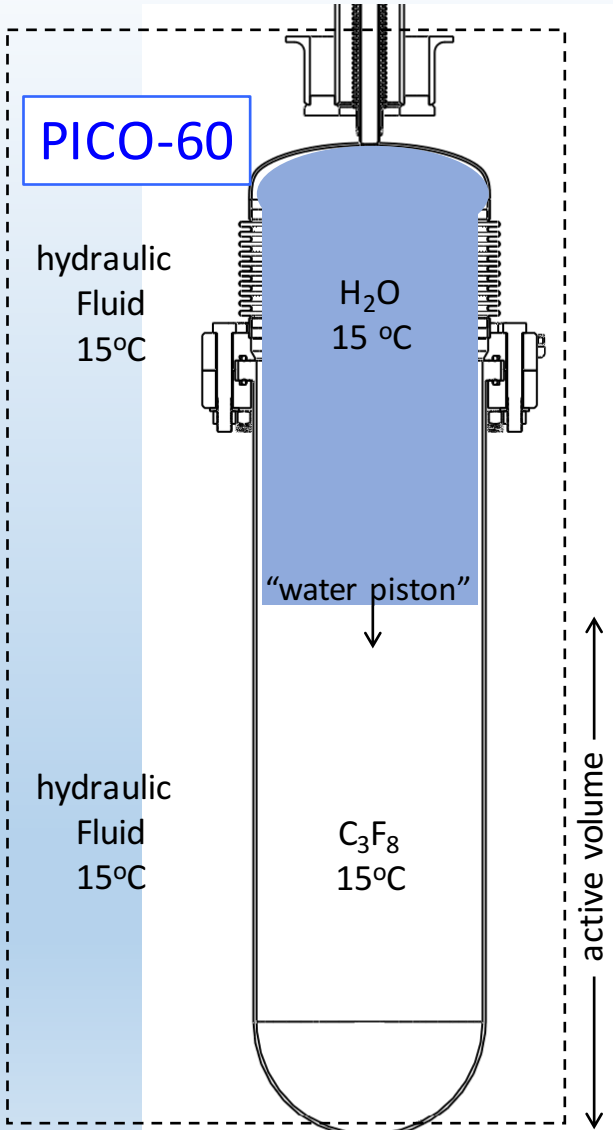
Progress of PICASSO/COUPP/ PICO Program

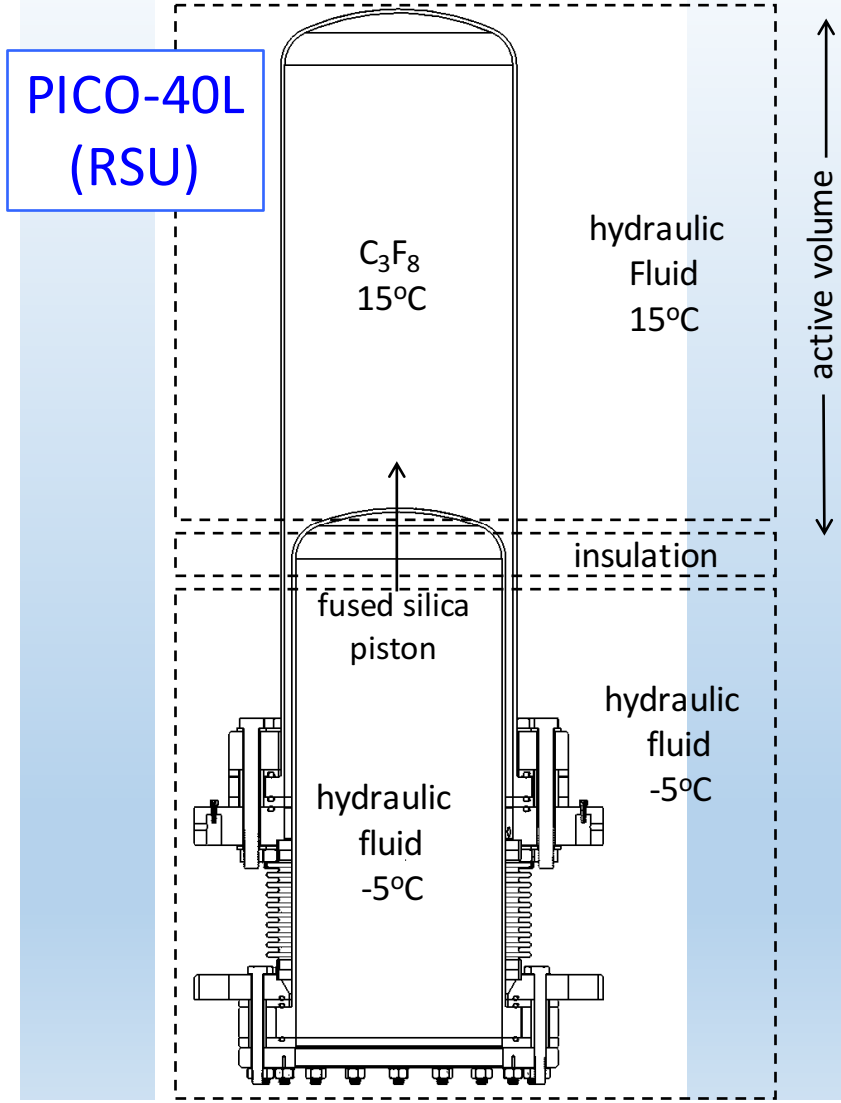


PICO-40L: A ”Right Side Up” Bubble Chamber without Water

- New design concept eliminates water buffer layer from chambers.
  - Water/ target liquid interface traps contamination.
  - Water coating of particulates suspected to play a role in bubble nucleation mechanism.
- Goal: background-free 15 ton-day physics run.
- Pacific Northwest National Lab (PNNL) R&D Initiative with FY17 DOE funding & PNNL institutional investments.

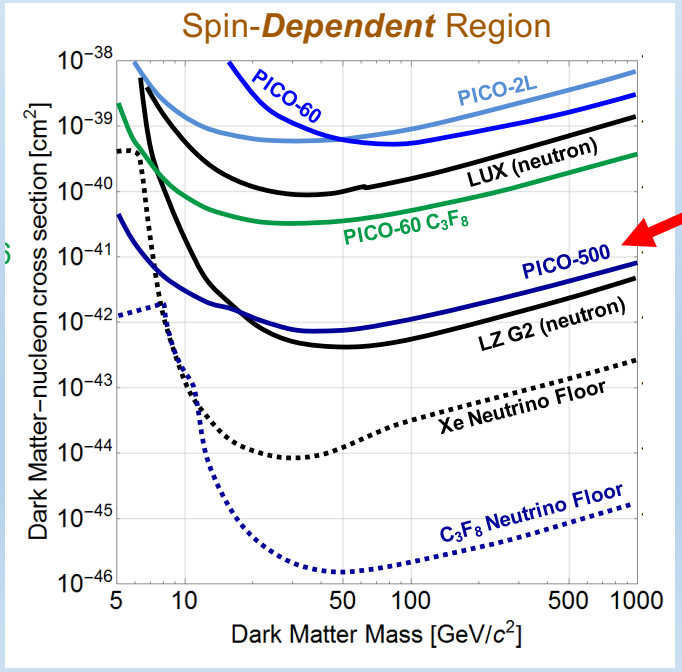



PICO-60
hydraulic
Fluid
15°C
H_2O
15 °C
"water piston"
hydraulic
Fluid
15°C
C_3F_8
15°C
active volume

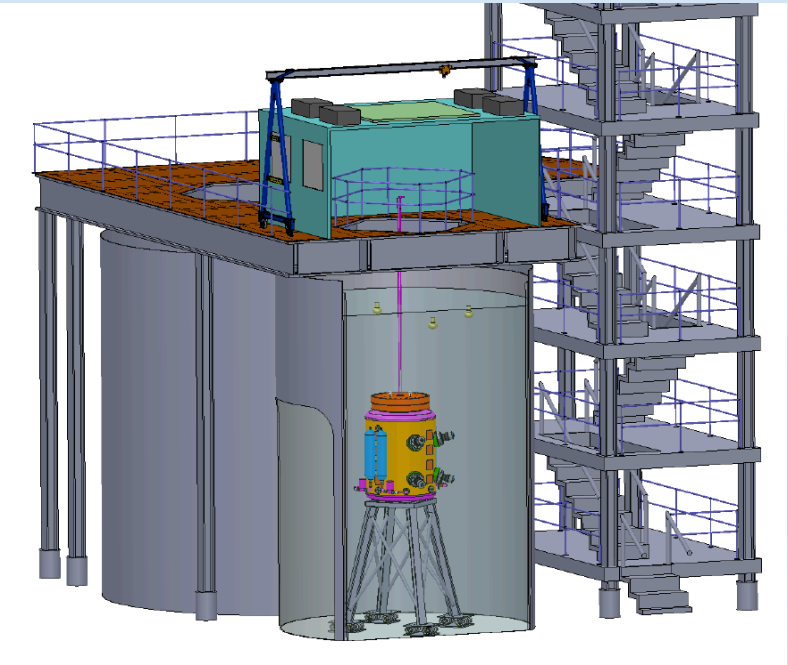

PICO-40L
(RSU)
C_3F_8
15°C
hydraulic
Fluid
15°C
active volume
insulation
fused silica
piston
hydraulic
fluid
-5°C
hydraulic
fluid
-5°C

PICO-500: ~1 Ton Scale Detector at SNOLAB

- Ton – scale detector builds on design work originally funded by NSF and DOE for G2 project.
- PICO-500 proposal submitted to Canada Foundation for Innovation (CFI) last year. Decision expected in June 2017. Budget is $4M CAD.
- PNNL will provide scientific and technical leadership for US contribution.



This Project



The PICO Collaboration

Queen's University, Kingston, ON, Canada
C. Amole, G. Cao, U. Chowdhury, G. Crowder, G. Giroux, A. J. Noble, S. Olson

Universitat Politècnica de València, València, Spain
M. Ardid, M. Bou-Cabo, I. Felis

Pacific Northwest National Laboratory, Richland, WA, USA
I. J. Arnquist, D. M. Asner, J. Hall, E. W. Hoppe

Saha Institute of Nuclear Physics, Kolkata, India
P. Bhattacharjee, M. Das, S. Seth

Indiana University South Bend, South Bend, IN, USA
E. Behnke, H. Borsodi, I. Levine, T. Nania, A. Roeder, J. Wells

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

Northeastern Illinois University, Chicago, IL, USA
O. Harris

University of Chicago, Chicago, IL, USA
J. I. Collar, A. Ortega

SNOLAB, Lively, ON, Canada
K. Clark, I. Lawson

Laurentian University, Sudbury, ON, Canada
J. Farine, F. Girard, A. Leblanc, R. Podviyanuk, O. Scallon, U. Wichoski

Drexel University, Philadelphia, PA, USA
P. Campion, R. Neilson

University of Alberta, Edmonton, AB, Canada
S. Fallows, C. B. Krauss, P. Mitra

Université de Montréal, Montréal, QC, Canada
M. Laurin, A. Plante, N. Starinski, F. Tardif, V. Zacek

Virginia Tech, Blacksburg, VA, USA
D. Maurya, S. Priya, Y. Yan

Universidad Nacional Autónoma de México, México D. F., México
E. Vázquez-Jáuregui

Czech Technical University in Prague, Prague, Czech Republic
R. Filgas, F. Mamedov, I. Štekl

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

Summary / What Should Cosmic Visions White Paper Say About PICO?

- By incorporating a diversity of target nuclei, bubble chambers are sensitive to WIMP dark matter interactions beyond the reach of other techniques.
- Fluorine target has potential spin-dependent sensitivity two orders of magnitude beyond xenon due to lower neutrino backgrounds.
- In the last year, PICO achieved a factor of 17 increase in sensitivity to spin-dependent WIMP couplings by reducing backgrounds to zero for 1.2 ton-days.
- A future bubble chamber project (PICO-500) has been proposed in Canada (funding decision expected in June 2017).
- There are opportunities for DOE to either continue its leadership role (larger investment) or to be in a supporting role (smaller investment).