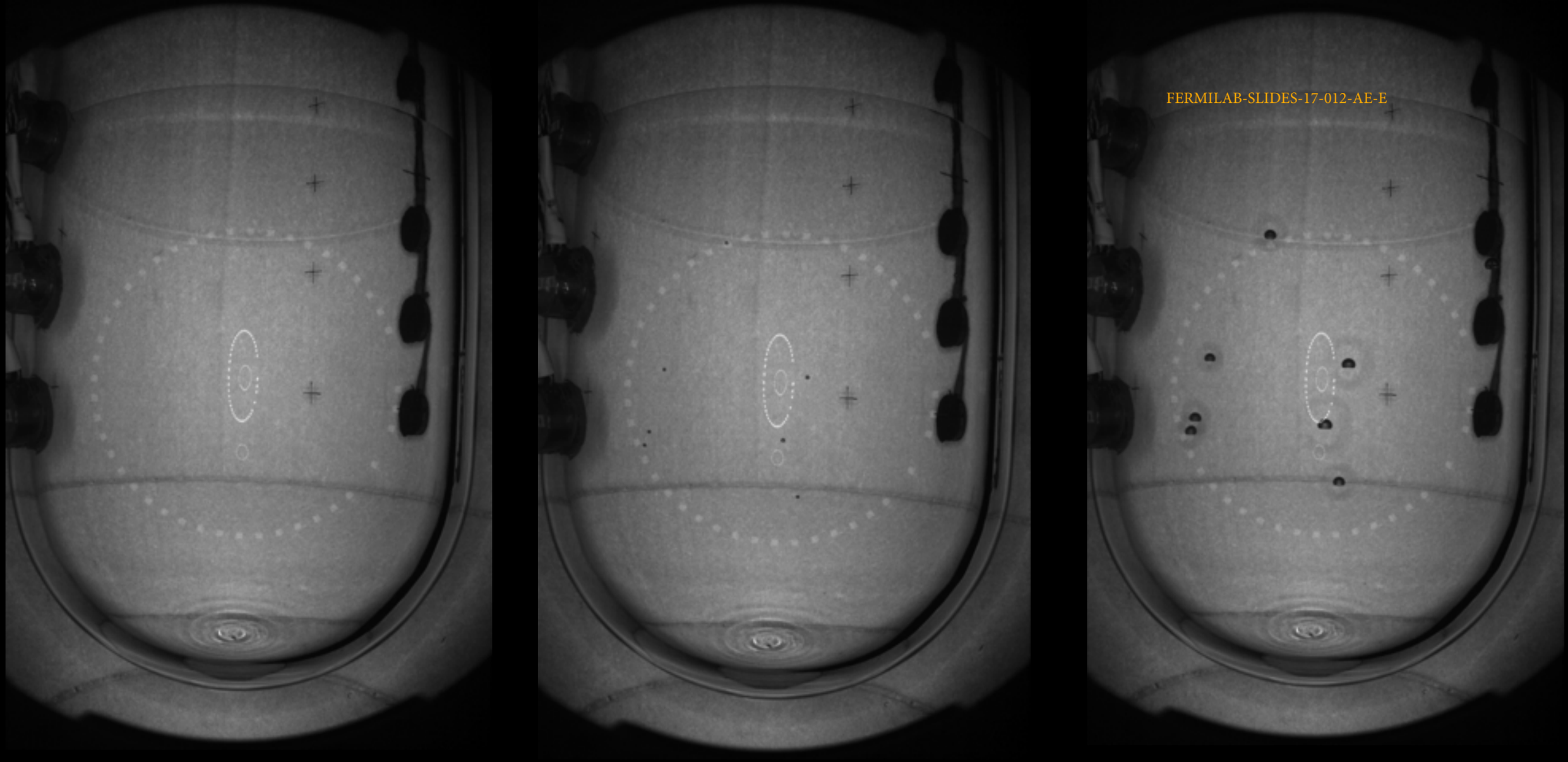

FERMILAB-SLIDES-17-012-AE-E

PICO Results and Future Plans

Hugh Lippincott, Fermilab
for the PICO Collaboration

EDU 2017

This document was prepared by [PICO Collaboration] using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

PICO

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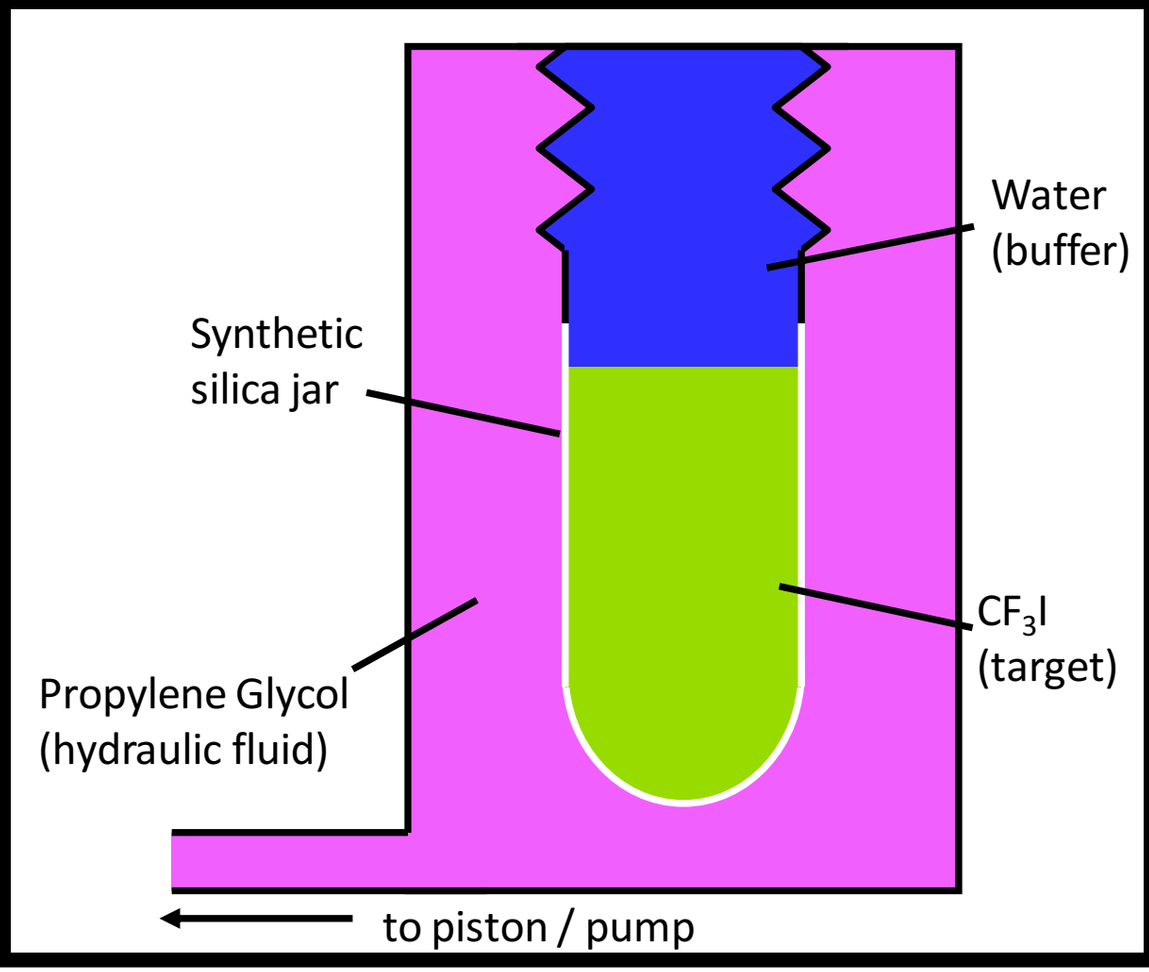
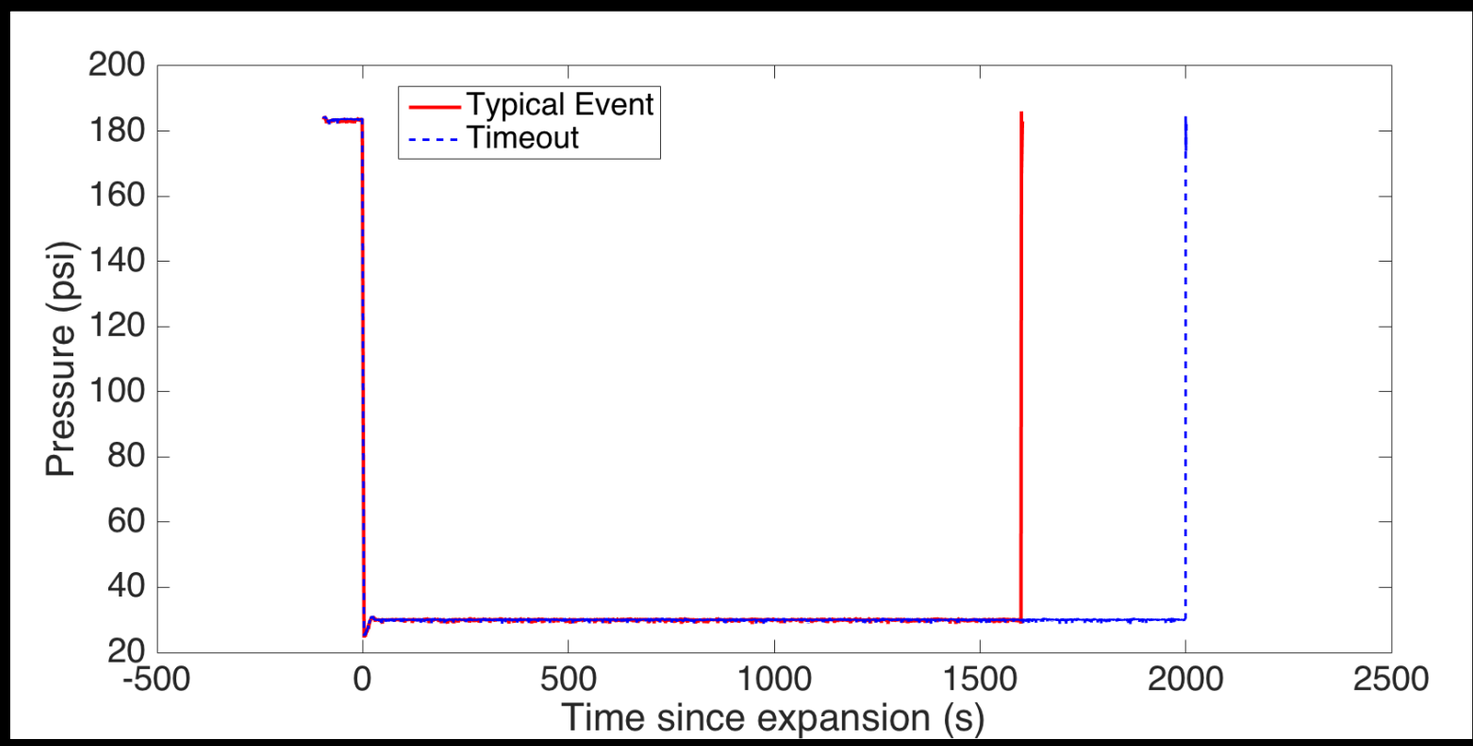
PICO fast compression bubble chamber

- Pressure expansion creates superheated fluid, CF_3I or C_3F_8
  - I for spin-independent
  - F for spin-dependent
- Particle interactions nucleate bubbles
- Cameras see bubbles
- Recompress chamber to reset

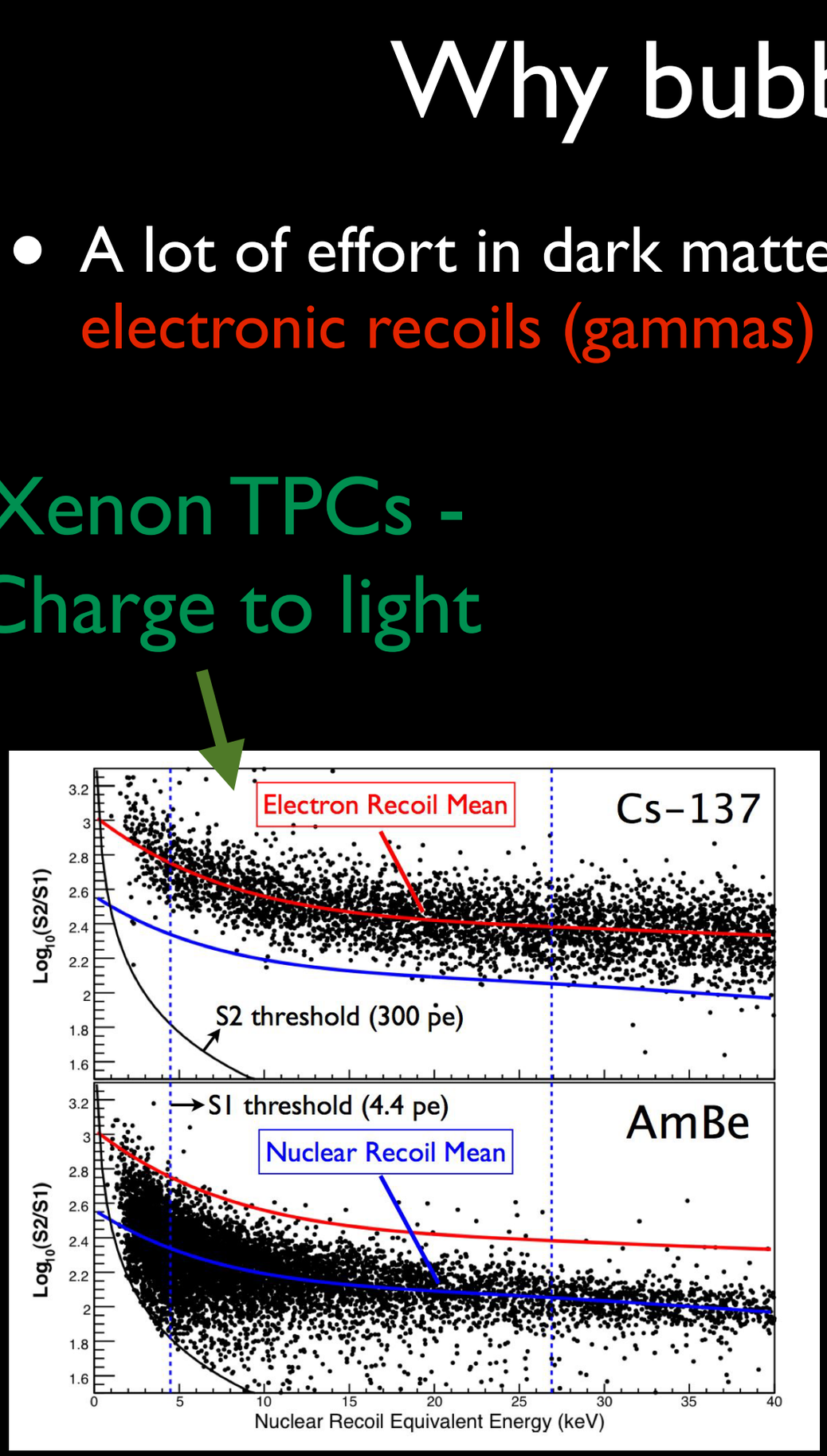




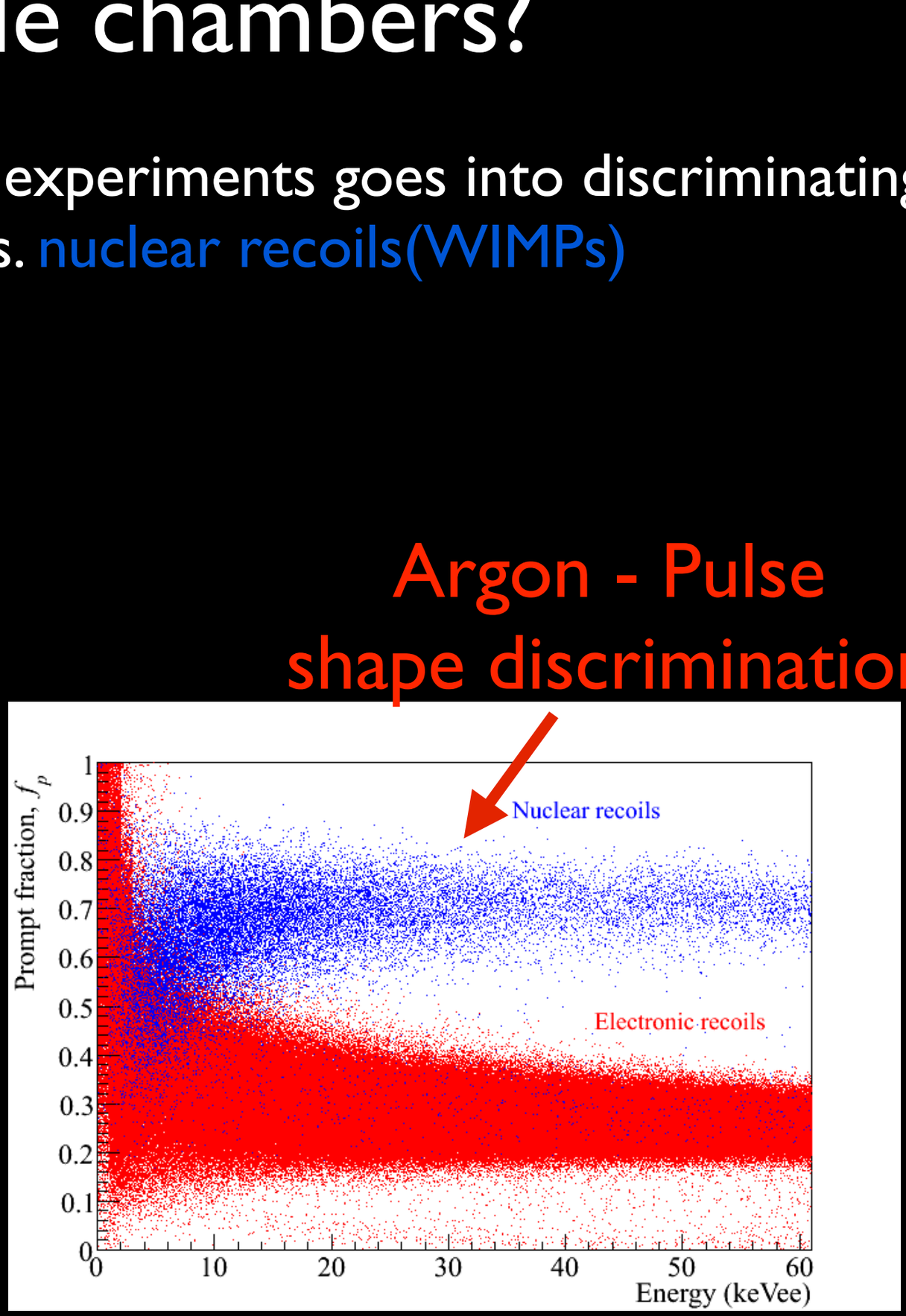
Why bubble chambers?

- A lot of effort in dark matter experiments goes into discriminating electronic recoils (gammas) vs. nuclear recoils(WIMPs)

Xenon TPCs - Charge to light

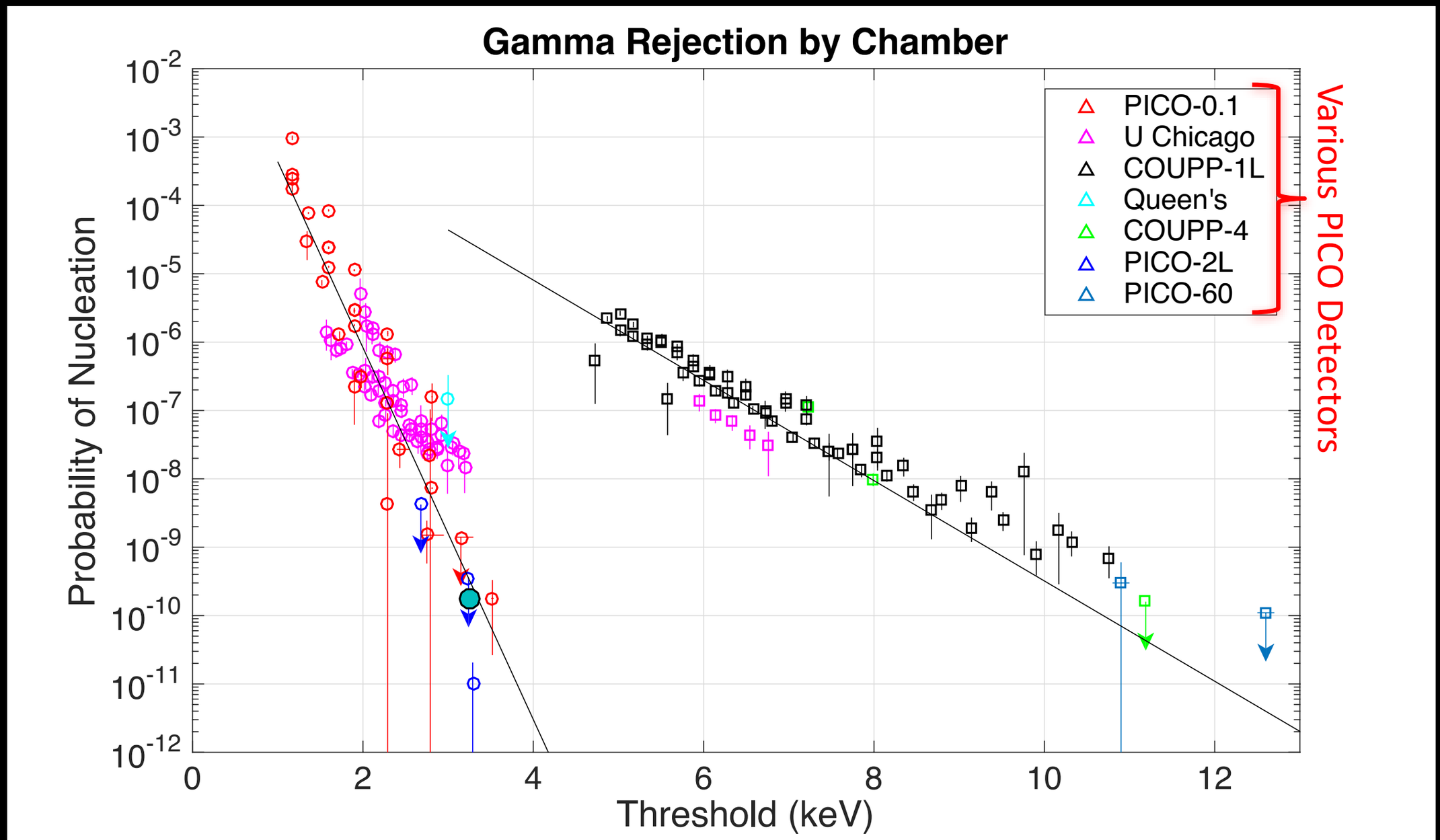


Argon - Pulse shape discrimination



Why bubble chambers?

- By choosing superheat parameters appropriately (temperature and pressure), bubble chambers are blind to electronic recoils (10^{-10} or better)



Why bubble chambers?

- By choosing superheat parameters appropriately (temperature and pressure), bubble chambers are blind to electronic recoils (10^{-10} or better)

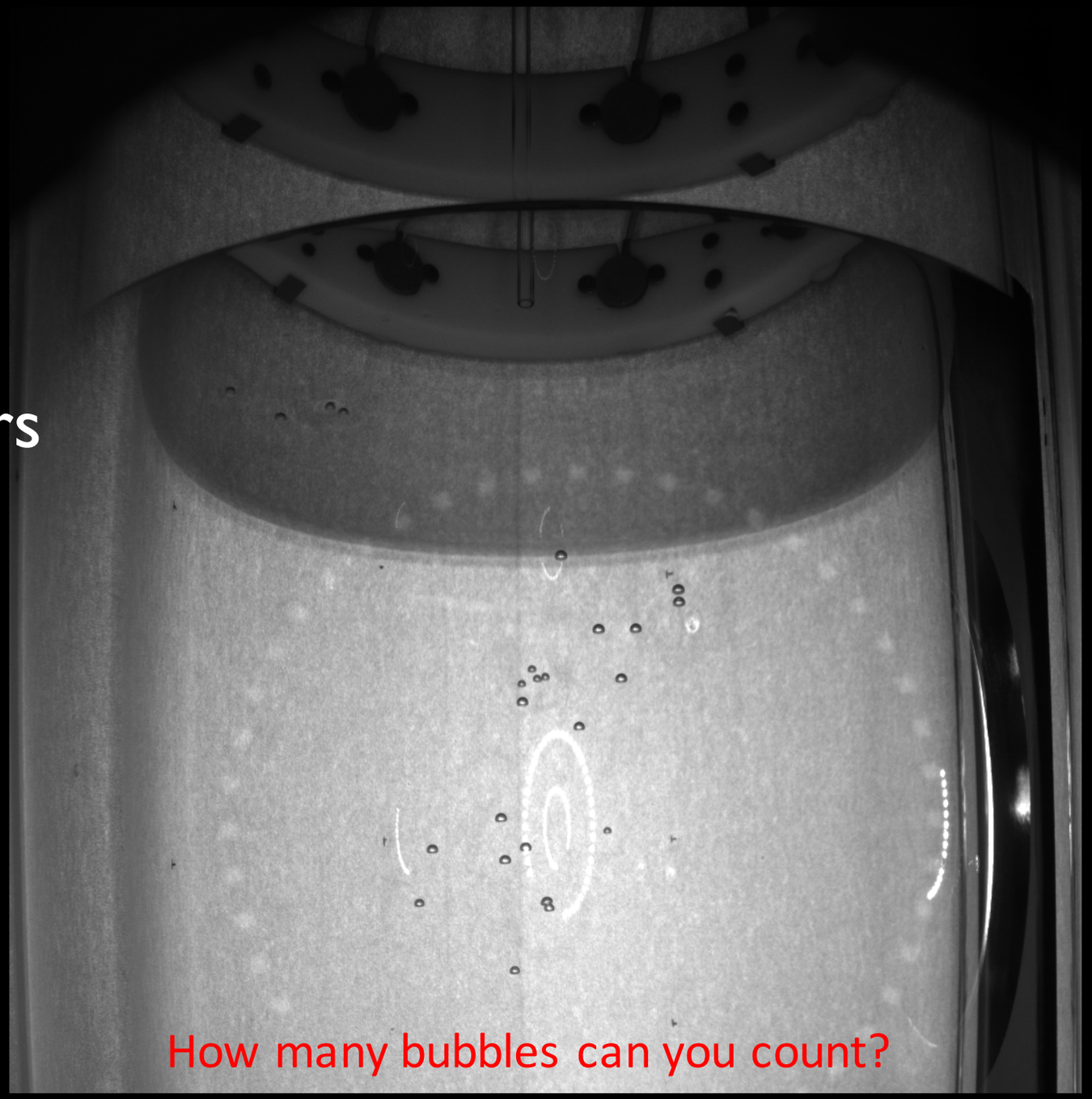
- To form a bubble requires two things
  - Enough energy
  - Enough energy density - length scale must be comparable to the critical bubble size

- Electronic recoils never cross the second threshold!

Why bubble chambers?

- Easy to identify multiple scattering events → Neutron backgrounds

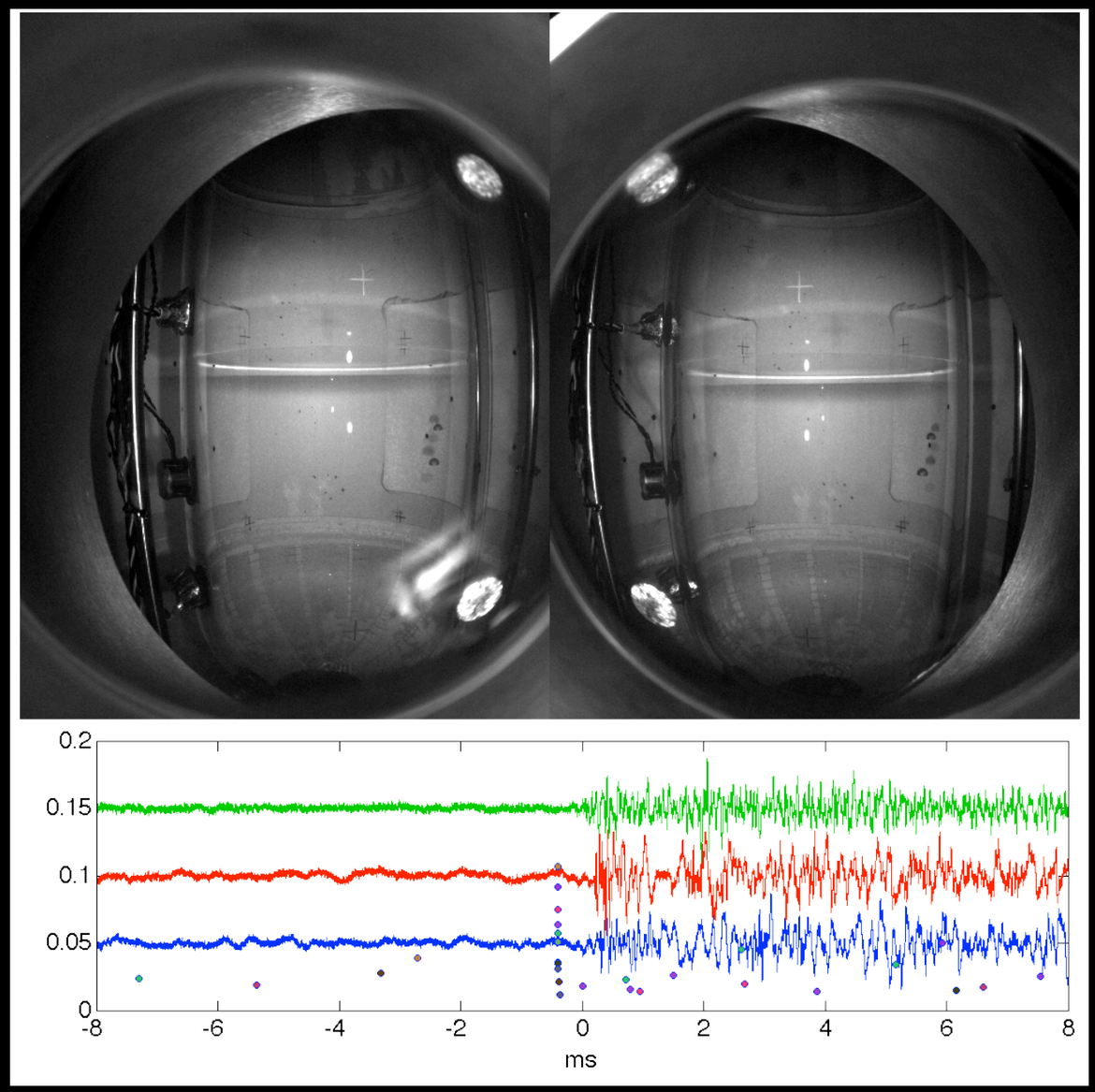
- Direct measurement of neutron backgrounds by measuring multiple scatters



How many bubbles can you count?

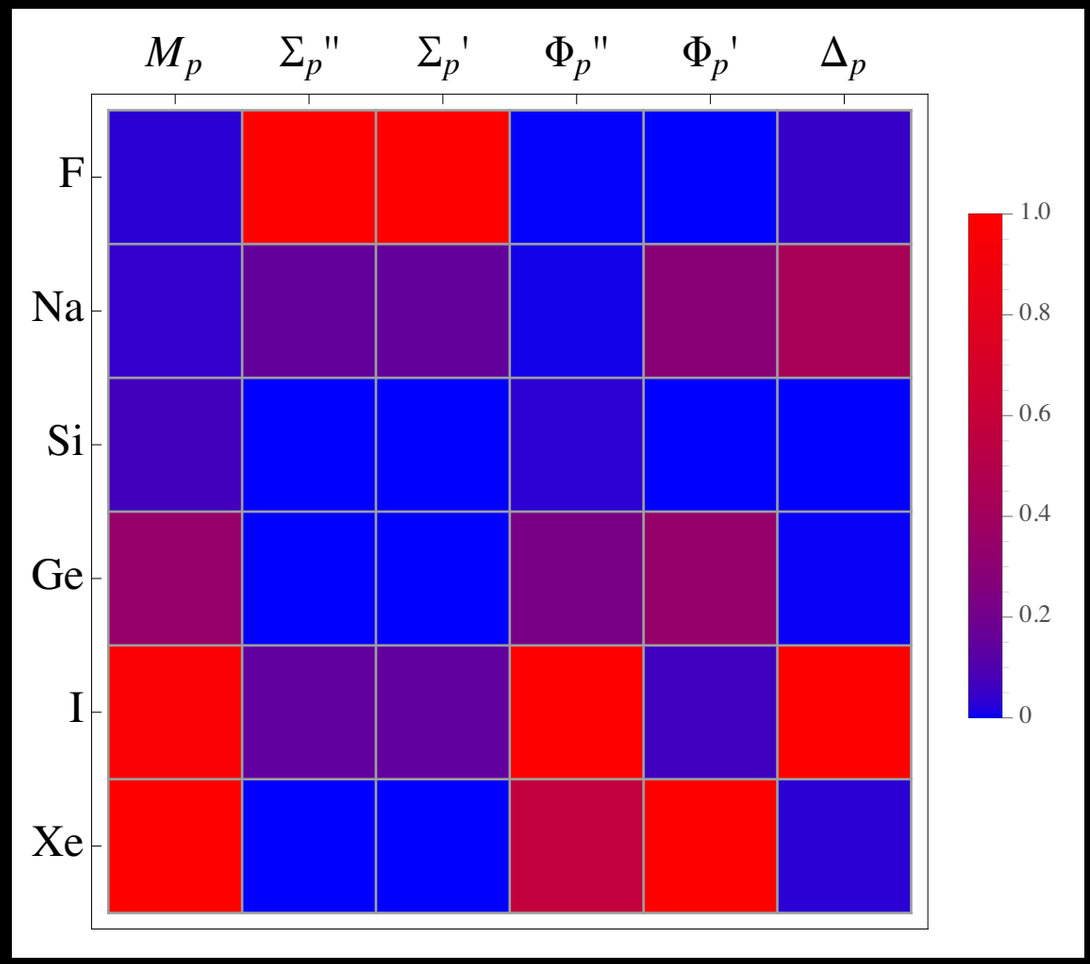
Why bubble chambers?

- Easy DAQ and analysis chain
  - Cameras
  - Piezos
- No PMTs, no cryogenics



Why bubble chambers?

- Fluorine gives unique sensitivity to spin dependent proton couplings
- (Pseudo) Interchangeable targets in same detector can pin down dark matter characteristics



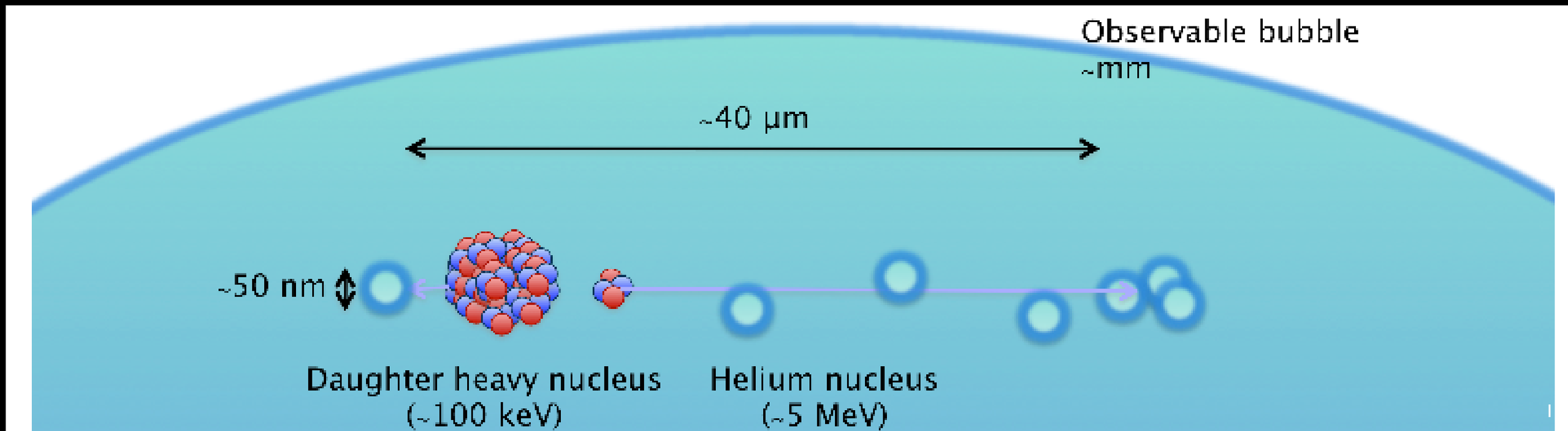
Sensitivity of different p-coupling operators to various nuclear targets
(from L. Fitzpatrick at INT Workshop, 2014)

Why not bubble chambers?

- Threshold detectors - no energy resolution
  - Harder to distinguish some backgrounds, less information about any potential signal
    - Energy threshold calibrations are hard and important
- Bubble chambers are slow - ~60 s of deadtime for every event
  - Overall rate must be low

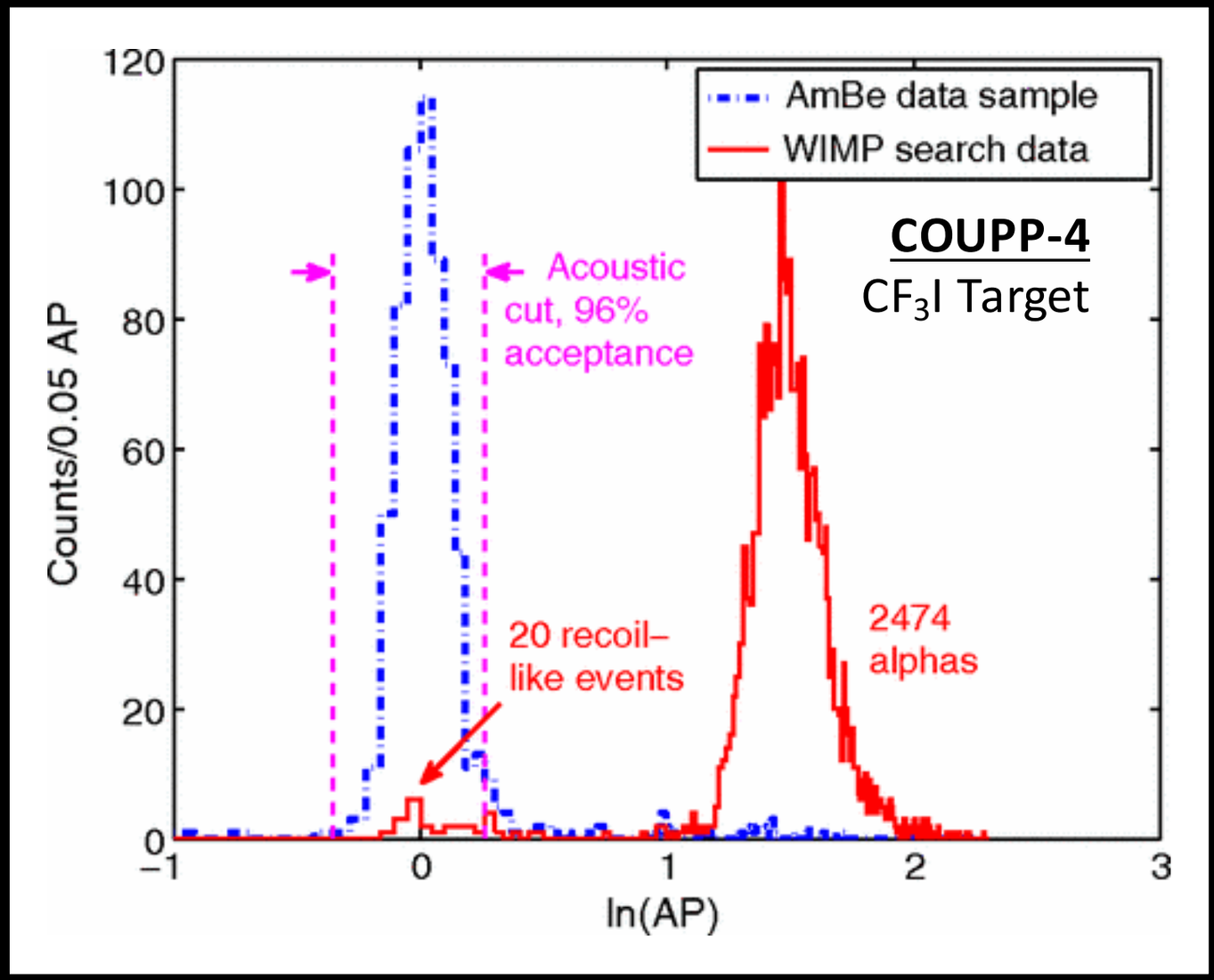
Acoustic discrimination

- Discovery that alphas were louder than nuclear recoils by PICASSO (Aubin et al, New J. Phys 10:103017, 2008), and then confirmed by COUPP
  - Alphas deposit energy over tens of microns
  - Nuclear recoils deposit theirs in tens of nanometers



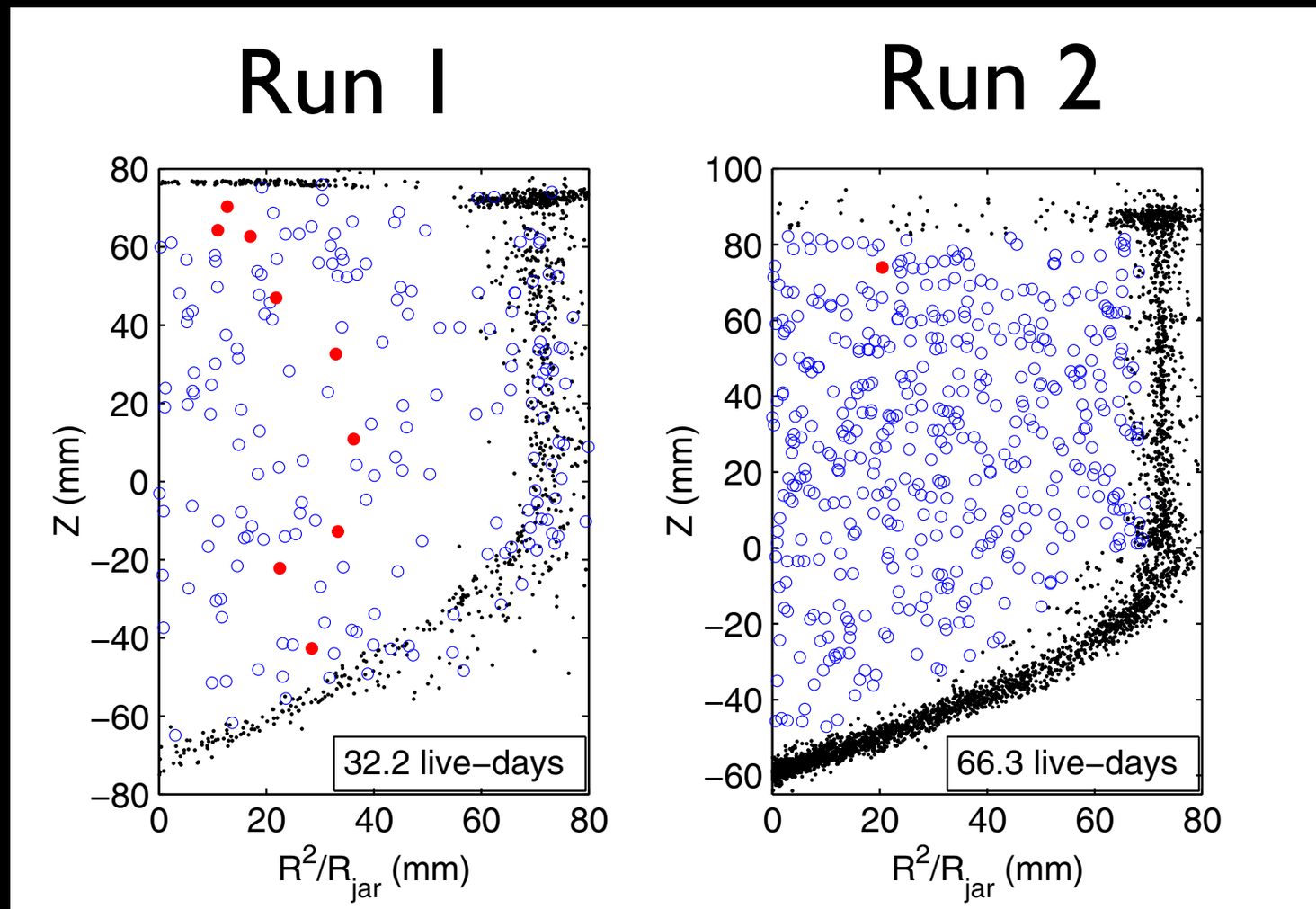
Acoustic discrimination

- Acoustic Parameter (AP) - measurement of the acoustic power of an event
- Three populations
  - Neutrons (normalized to AP =1)
  - Alphas (louder)
  - Recoil-like background…



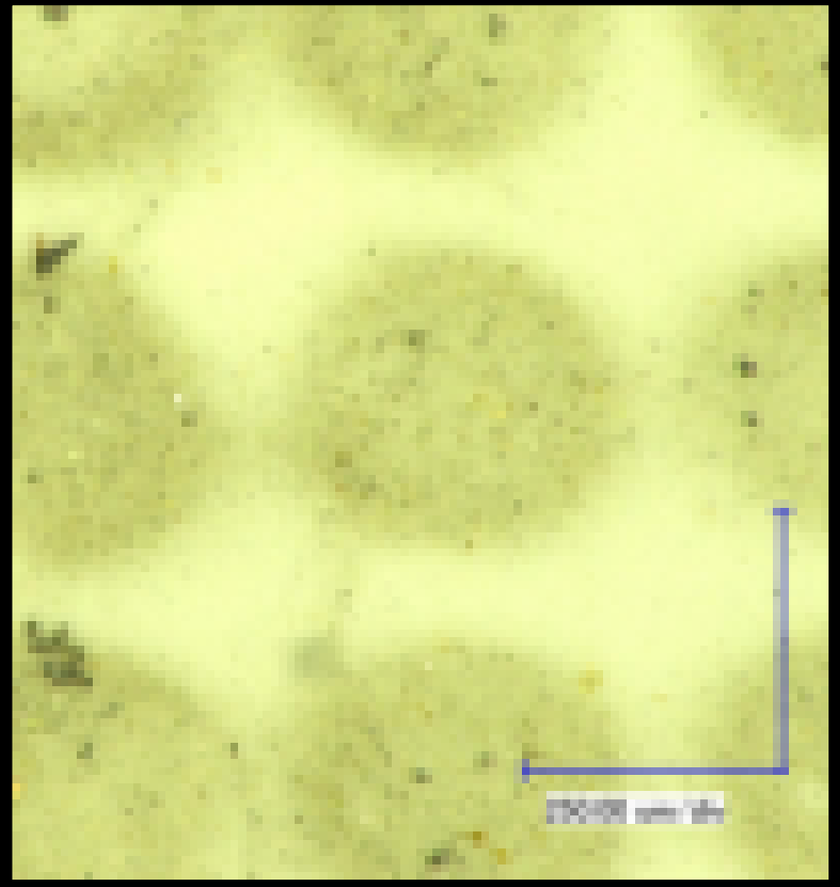
Anomalous background

- Recoil-like sounding events that otherwise do not have the characteristics of dark matter
  - Spatially and temporally inhomogeneous
- PICO2L Run1
  - 9 events in 32 days
    - Inconsistent with known backgrounds and dark matter
- Cleaned detector of particle contamination
- PICO2L Run2
  - 1 candidate event in 66 days
  - Consistent with neutron expectations



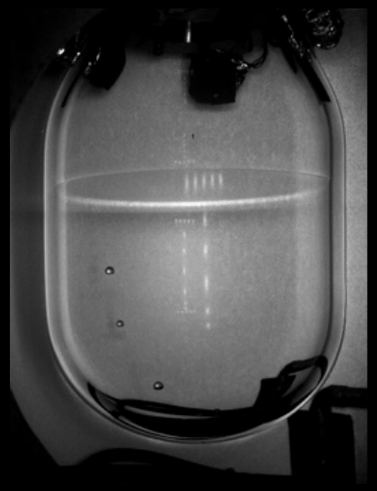
Anomalous background

- Our hypothesis - particulate and buffer fluid (water) can lead to bubble nucleation
  - Surface effects
- We need to get more serious about cleanliness



PICO Timeline

COUPP4 (2011-2012)
CF3I



PICO Timeline

COUPP4 (2011-2012)
CF3I

Background Discovered

COUPP4 (2011-2012)
CF3I

Background Discovered

Try changing fluids

PICO-2L (2014)
C3F8

Try scaling up

PICO-60 (2014)
CF3I

PICO Timeline

COUPP4 (2011-2012)
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Background Limited

Try scaling up

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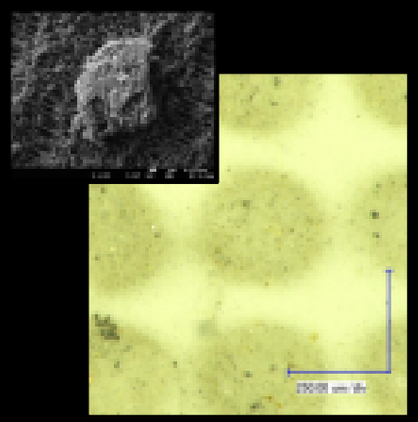
Background Limited



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Try scaling up

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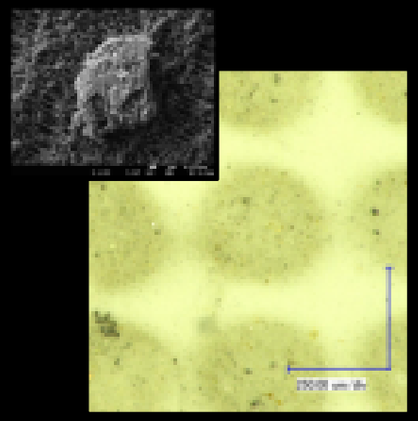
CF3I

Background Limited



PICO Timeline

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PICO-2L (2014)
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Background Limited

Try improved cleaning

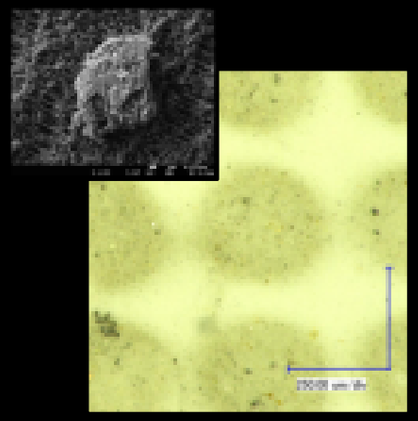
PICO-2L (2016)
C3F8

Neutron Limited!

Try scaling up

PICO-60 (2014)
CF3I

Background Limited



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PICO-60 (2014)
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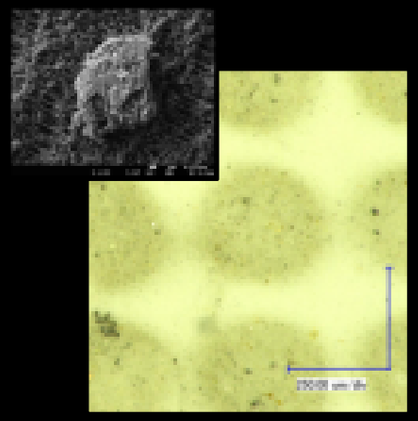
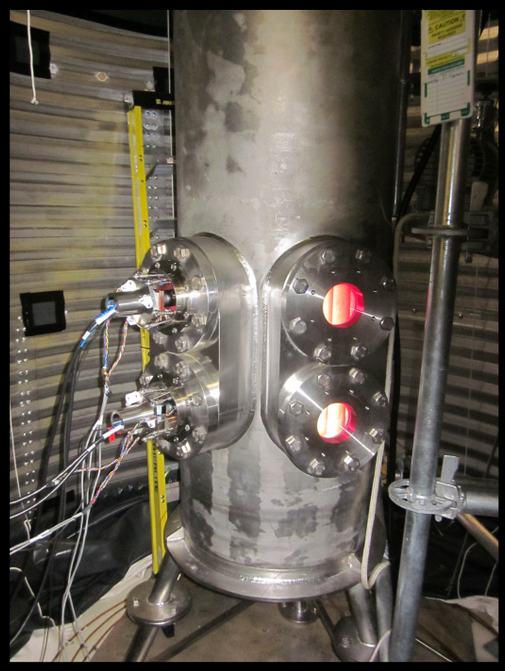
Background Limited



PICO-60 (2017)
C3F8



Scaling?

PICO Timeline

COUPP4 (2011-2012)
CF3I

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Try changing fluids

PICO-2L (2014)
C3F8

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Try improved cleaning

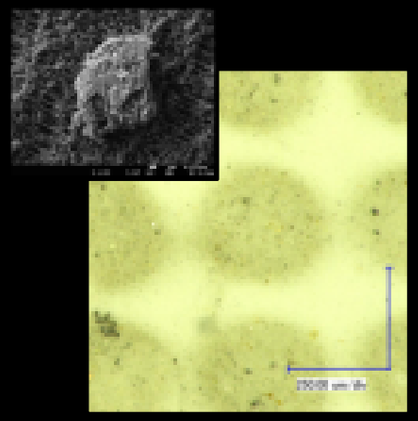
PICO-2L (2016)
C3F8

Neutron Limited!

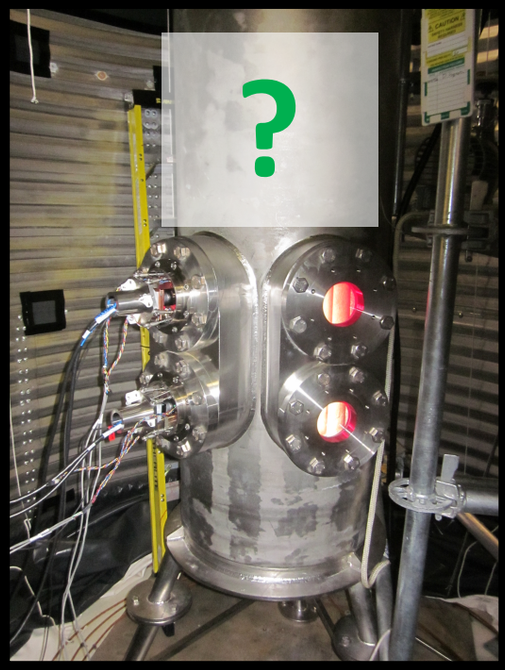
Try scaling up

PICO-60 (2014)
CF3I

Background Limited



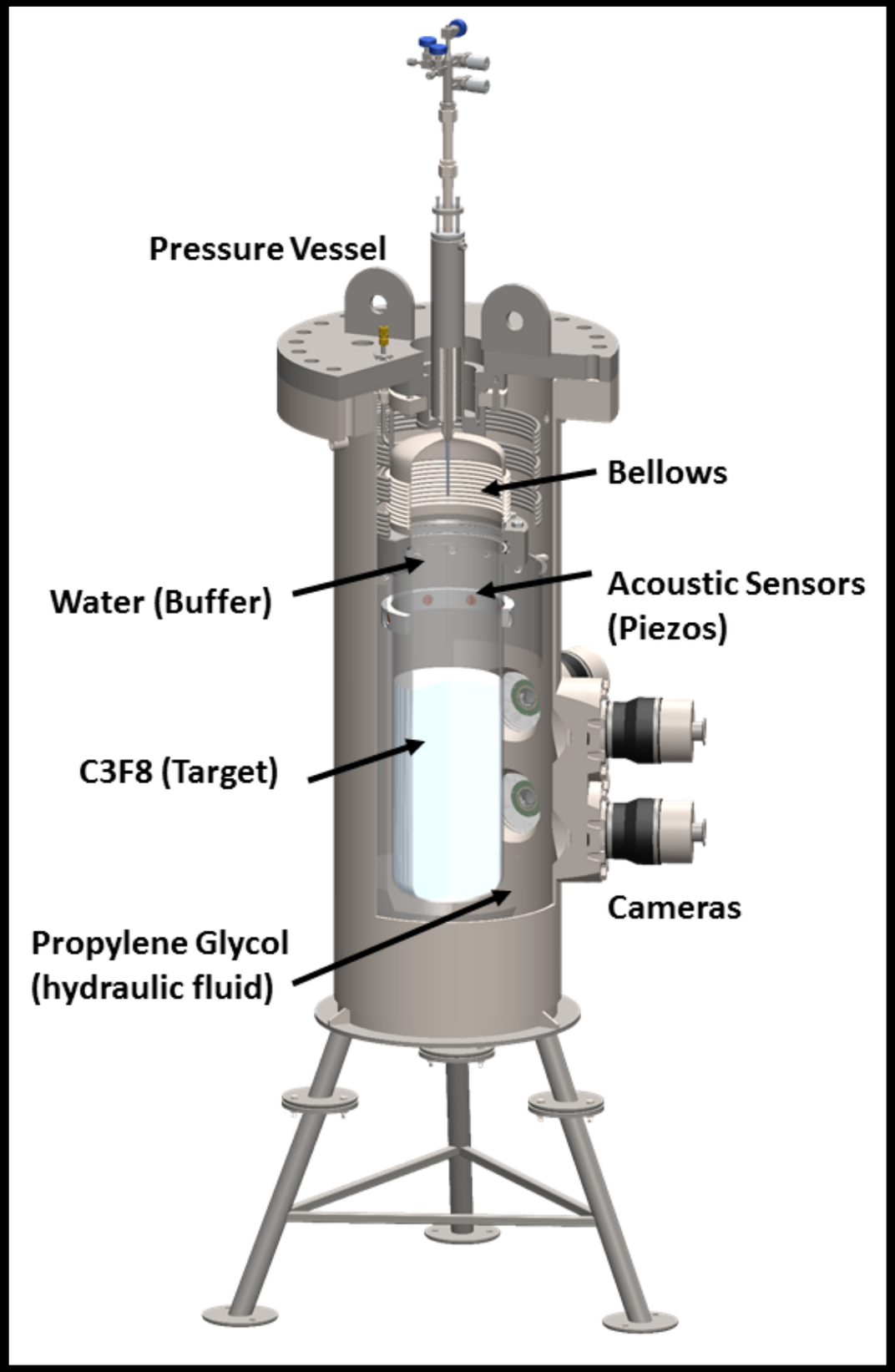
PICO-60 (2017)
C3F8



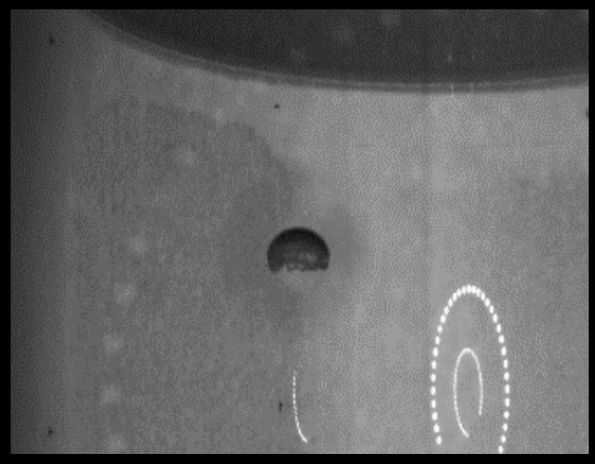
?

Scaling?

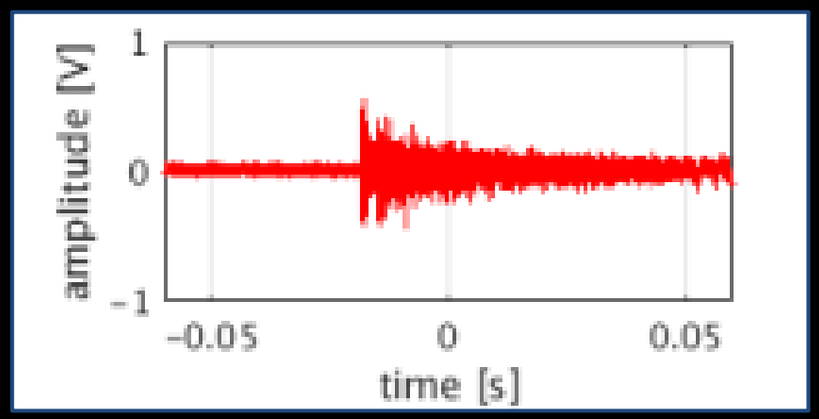
PICO-60 (Run 2)



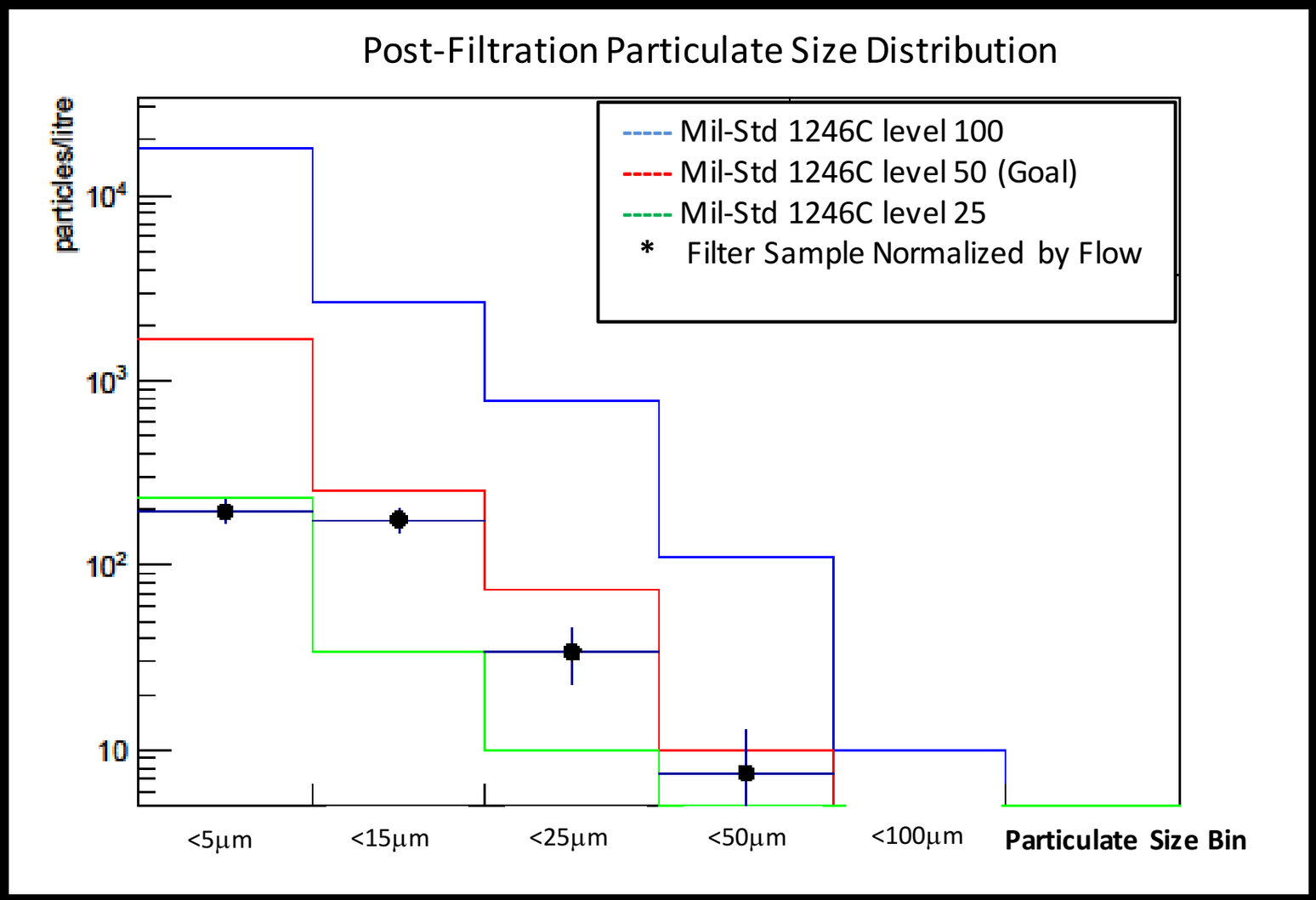
- Four cameras to observe bubbles over larger target



- Eight piezo to listen to bubble growth
  - Five died early in the run

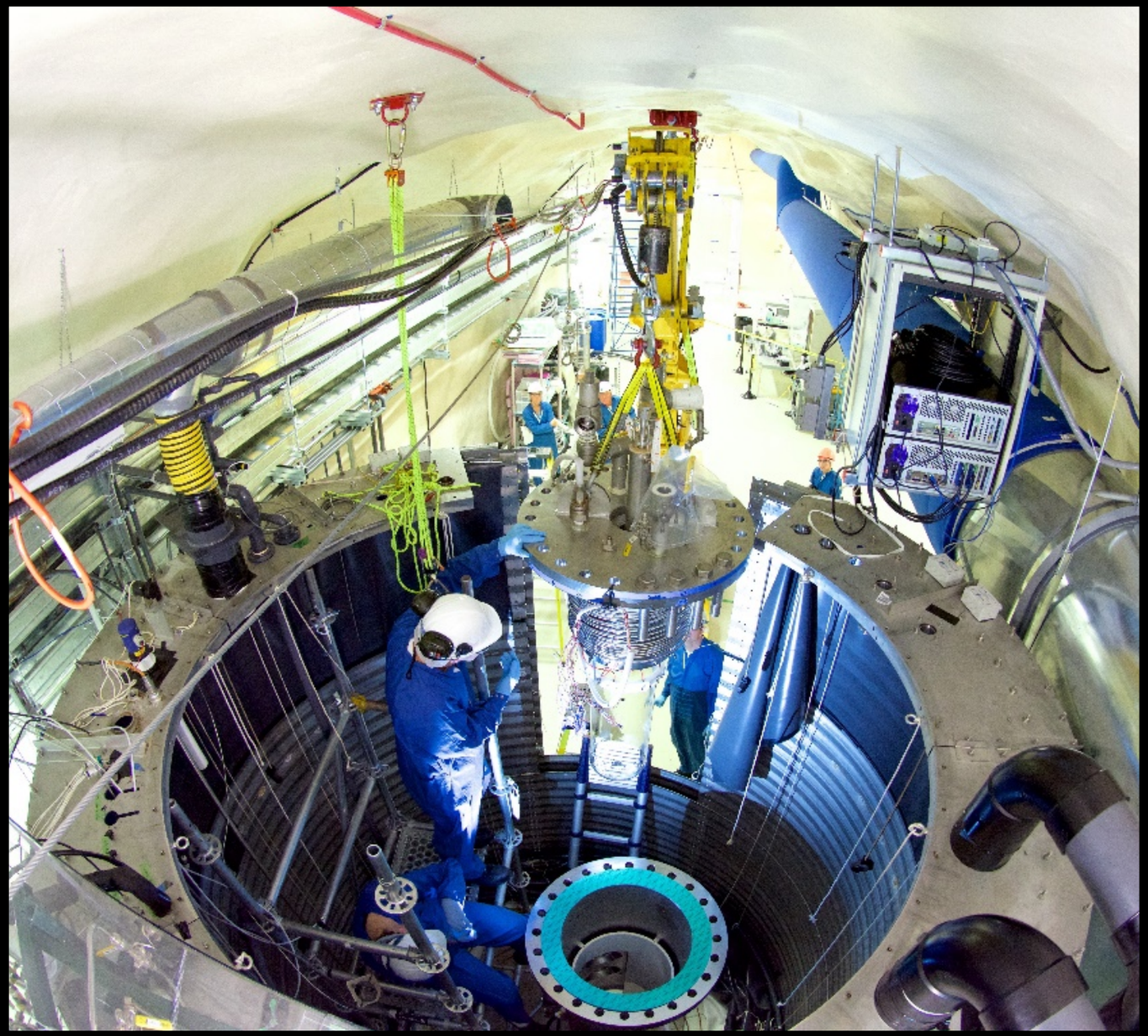


PICO-60 Run 2 Cleaning



- Inner vessel and all plumbing cleaned to IEST-STD-1246 Level 50


CYLINDER
EMPTY
IN USE



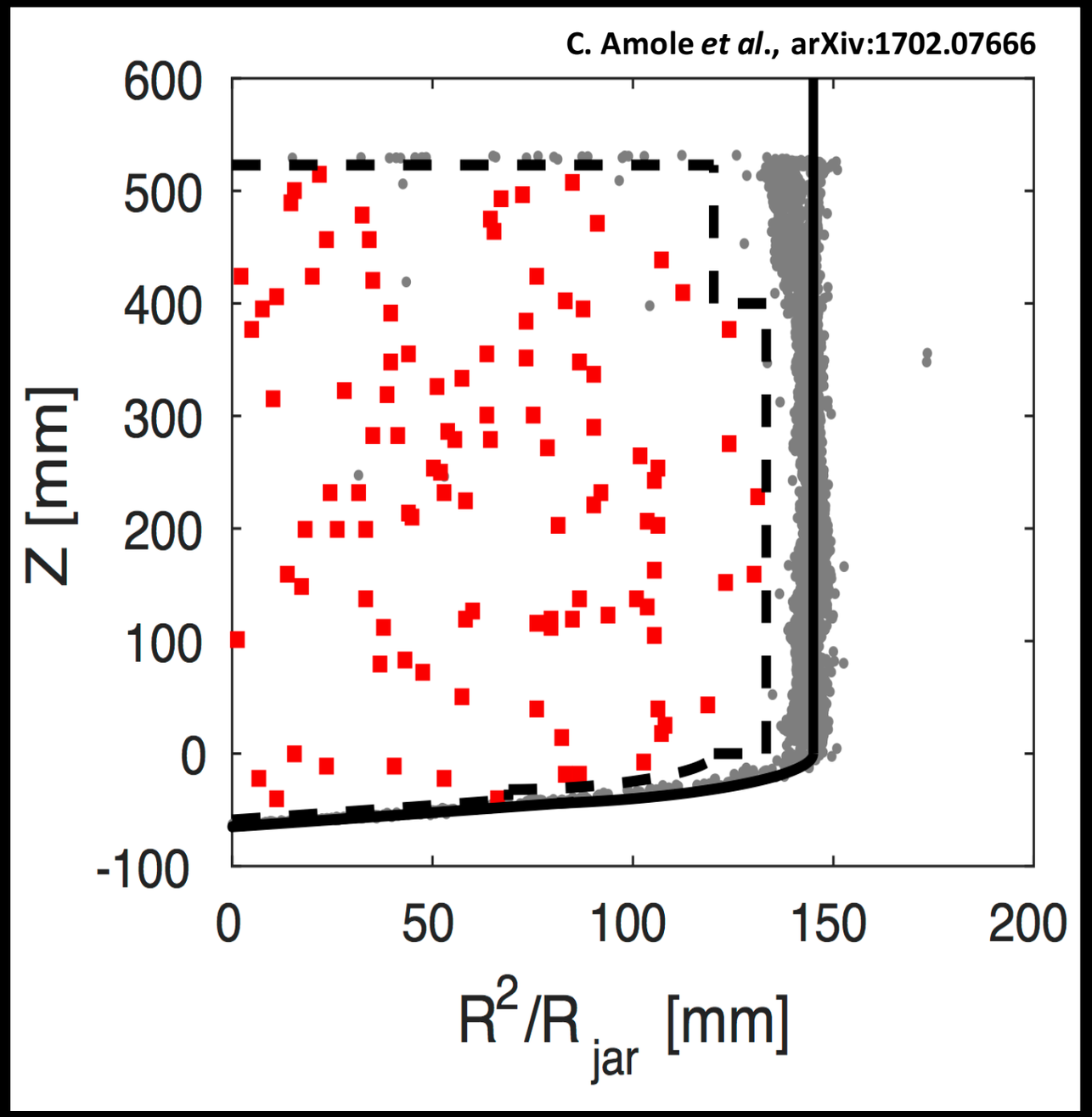
- Filled with 40 liters of C3F8 on June 30, 2016
- First physics run Nov 2016-Jan 2017

PICO-60 Blinding Strategy
"Deafening"

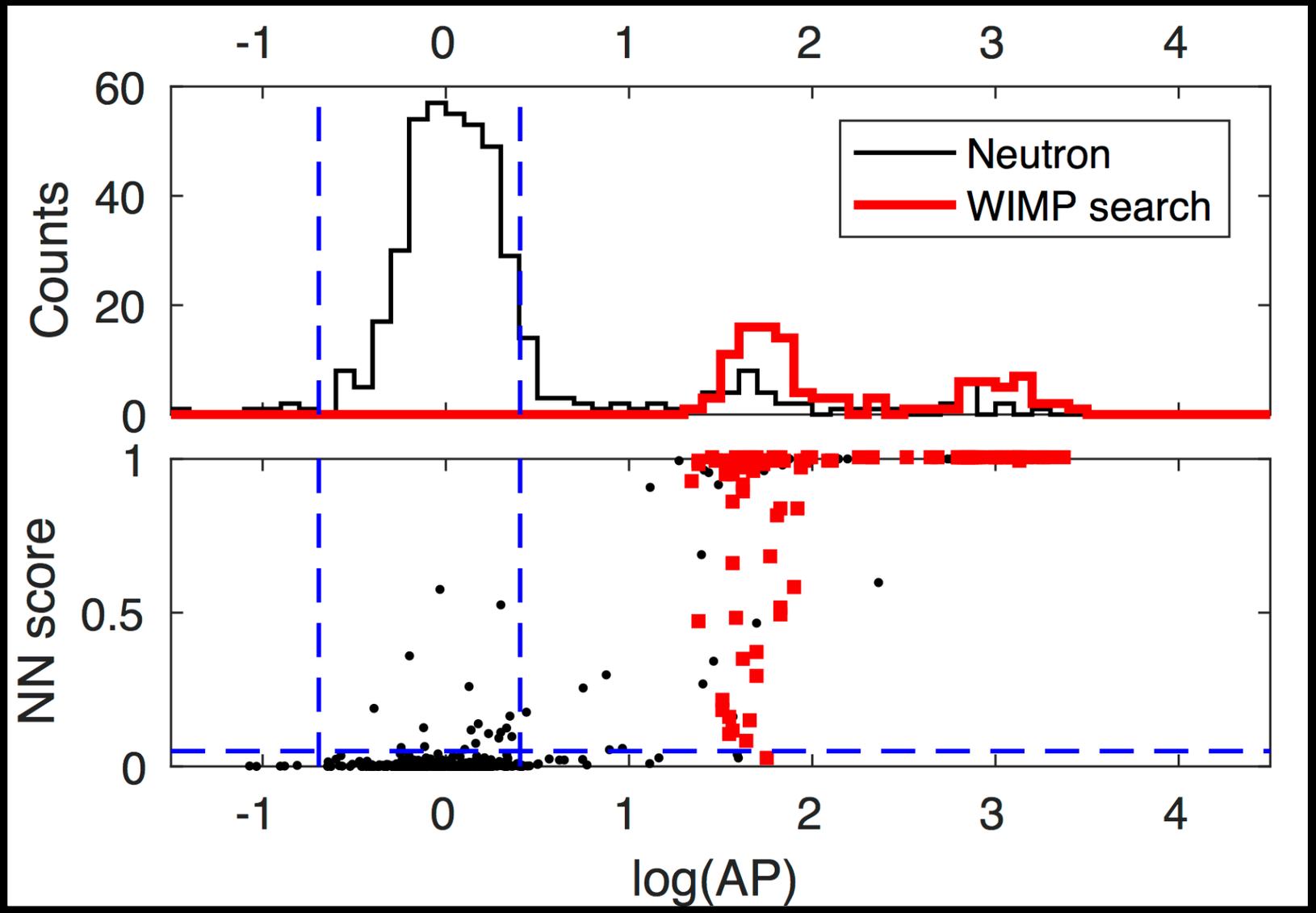
- Alpha events create single bulk bubbles that look like nuclear recoils except for acoustics
- Go deaf by not analyzing acoustic information for physics run
  - Neutron calibrations to define nuclear recoil acceptance cuts
  - All data to define fiducial volume/data cleaning/etc

Pre-unblinding

- 106 bulk singles in WIMP search dataset
  - Consistent with Rn decay rate in pre-WIMP search data
  - <20 microBq (<500 nBq/kg)
- Neutron backgrounds
  - Not blinded to multiplicity, observe 3 multiples
  - Multiple to single ratio is 3:1 (simulation and calibration)



Post-unblinding



- No signal events!

PICO-60 Results

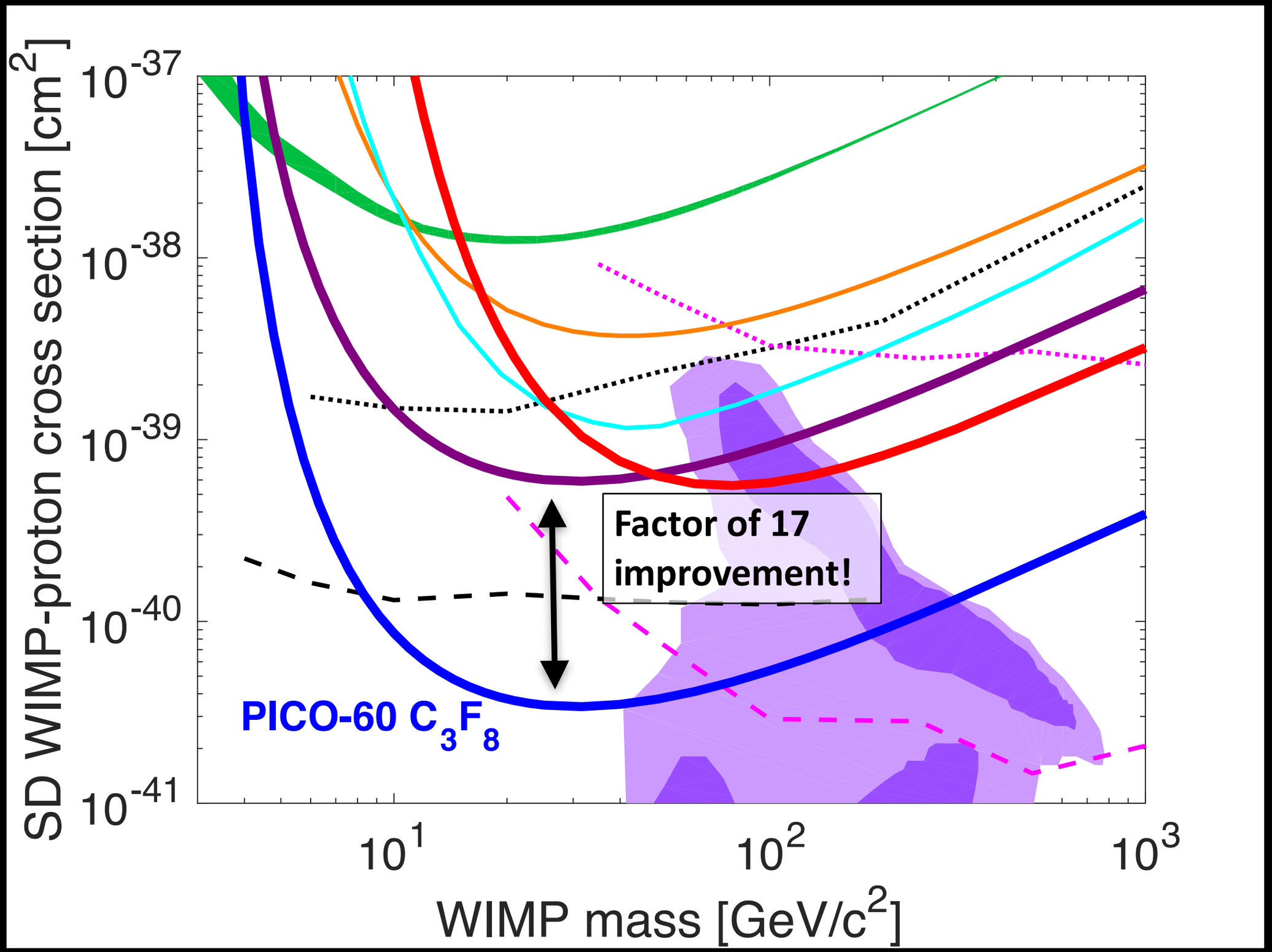
Dataset	Efficiency (%)	Fiducial Mass (kg)	Exposure (kg-days)	No. of events
Singles	85.1 ± 1.8	45.7 ± 0.5	1167 ± 28	0
Multiples	99.4 ± 0.1	52.2 ± 0.5	1555 ± 15	3

TABLE I. Summary of the final number of events and exposure determination for singles and multiples in the 30.0 live-day WIMP search dataset of PICO-60 C_3F_8 at 3.3 keV thermodynamic threshold.

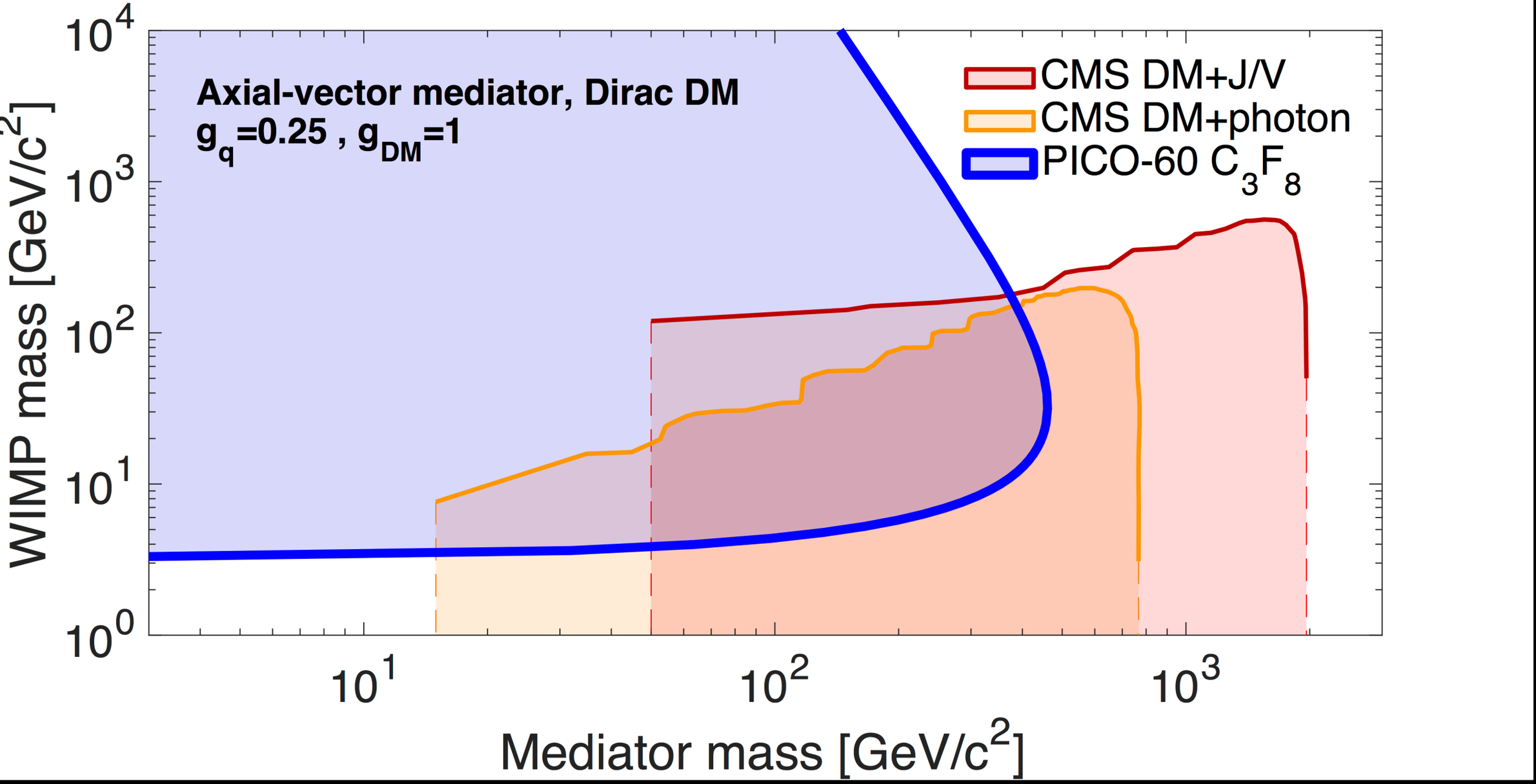
C. Amole *et al.*, arXiv:1702.07666

- Multiples efficiency is higher because there are no acoustic cuts
- We simulate and measure a 3:1 ratio of multiples to singles in neutron calibration data
- Of the 106 fiducial-bulk singles, none are consistent with nuclear recoil hypothesis
  - No dark matter
  - No anomalous background

PICO-60 Results



Comparison to Collider



- Sensitivity to common model

PICO-60 Since January

- Calibration runs at variety of thresholds
  - Scanning gamma sensitivity
- 30 days of blind running at lower threshold
  - Still “deaf” to acoustics
- Updating optical reconstruction algorithms to improve efficiency before opening the box

PICO-60 Decommissioning

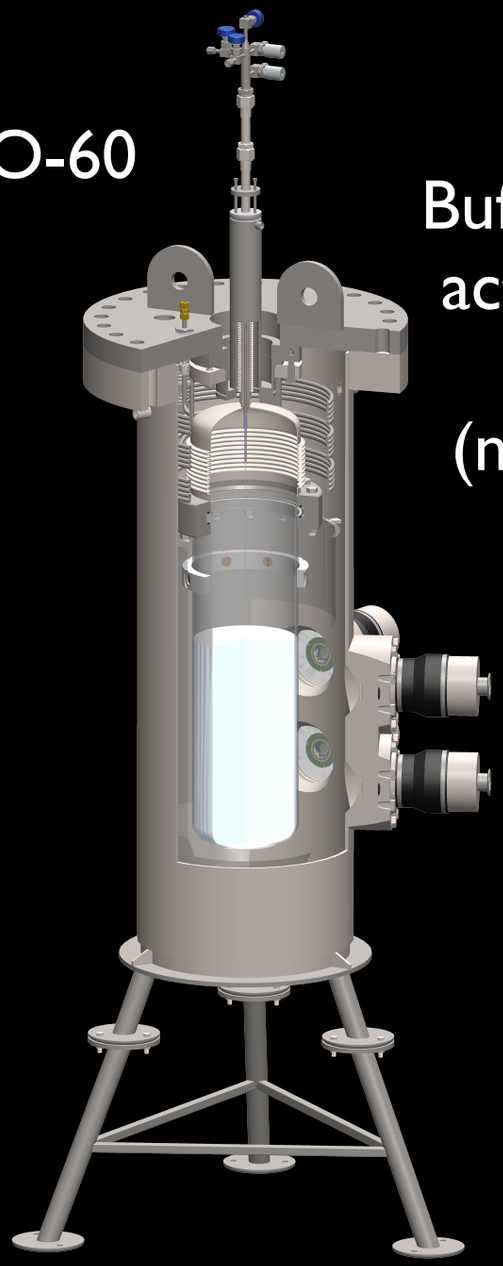
- Emptied and removed from water tank end of June

- Making room for PICO-40L

PICO-40L

- We've shown that particulate contamination can create bulk bubbles
  - Mechanism remains uncertain, but we believe it is the interaction of the particulate with the buffer fluid

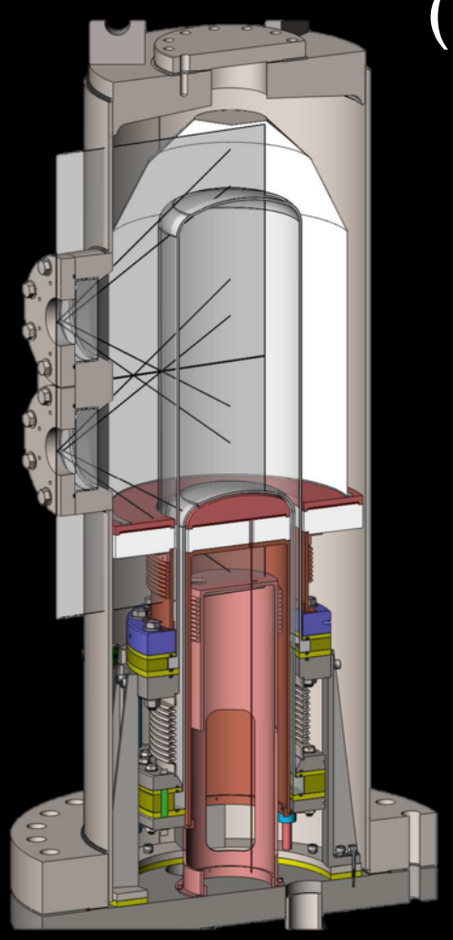
PICO-60



Buffer fluid isolates active target from plumbing (nucleation sites)

Same results can be accomplished with thermal gradient - Eliminates buffer!

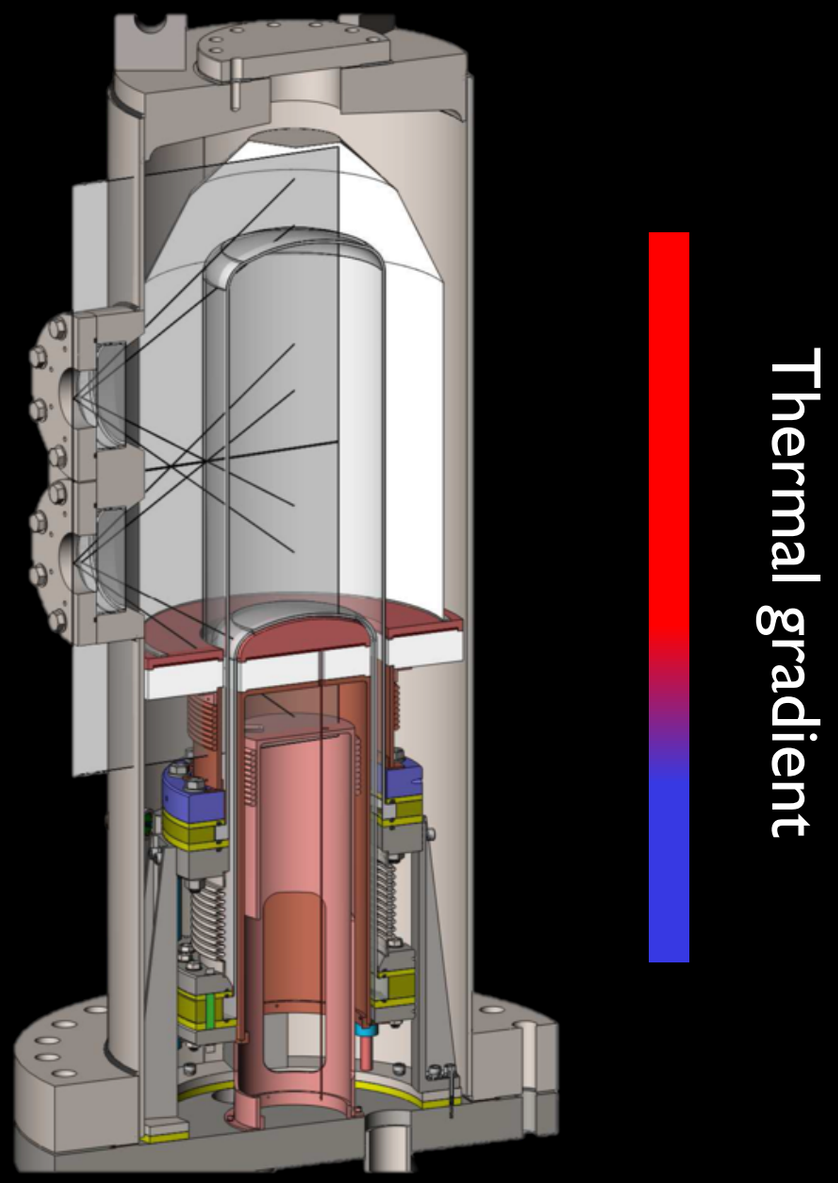
PICO-40L
(Right-side up)



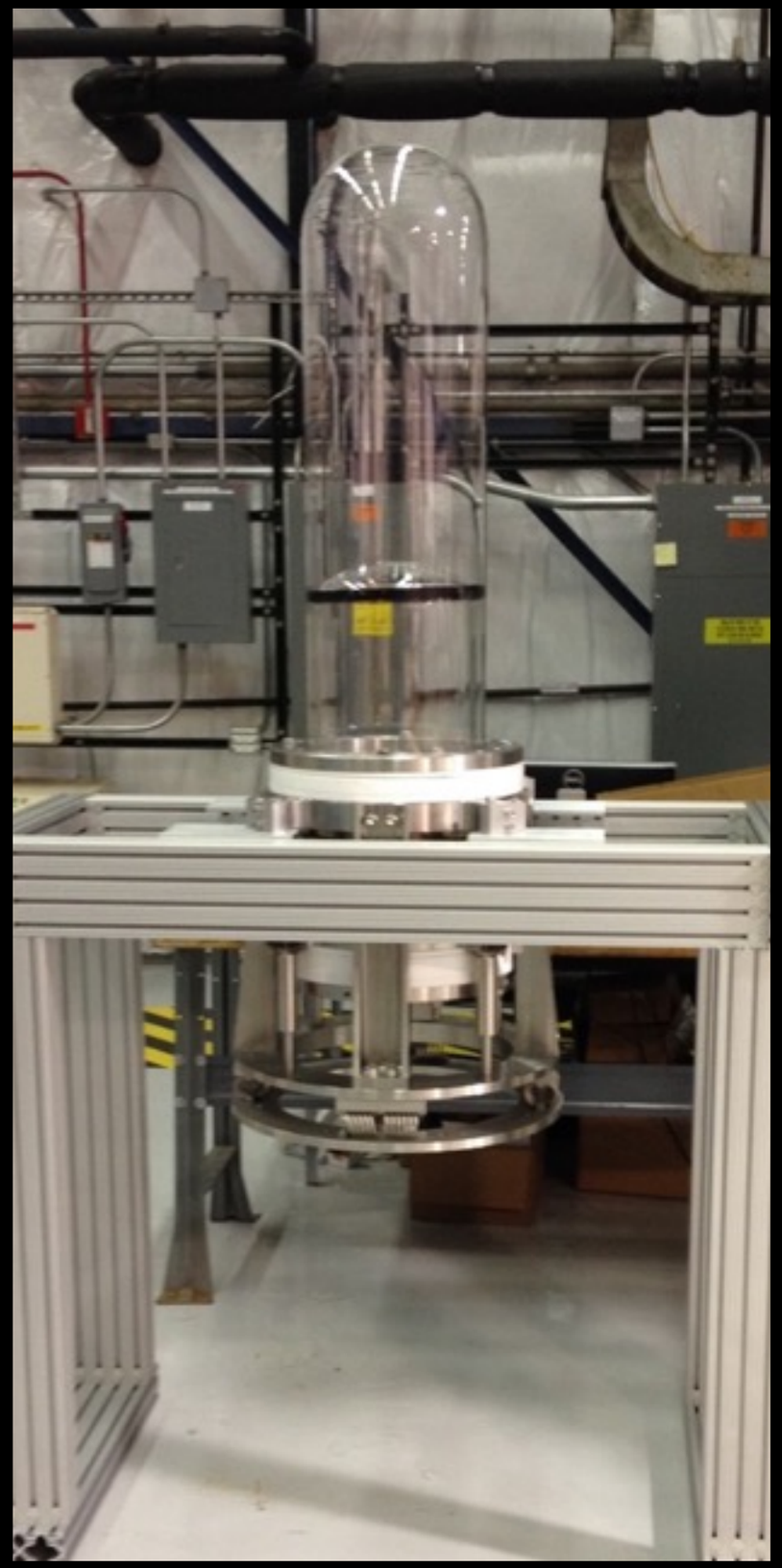
Thermal gradient

PICO-40L

- PICO-40L is first large scale RSU device
  - Northwestern xenon bubble chamber
  - Drexel C3F8 chamber
- Re-using PICO-60 water tank
- Increased physics reach
  - Expected improvements in stability allow for lower threshold running
  - Larger pressure vessel allows major neutron sources to be moved out - reduction by factor ~5
- Commissioning this winter

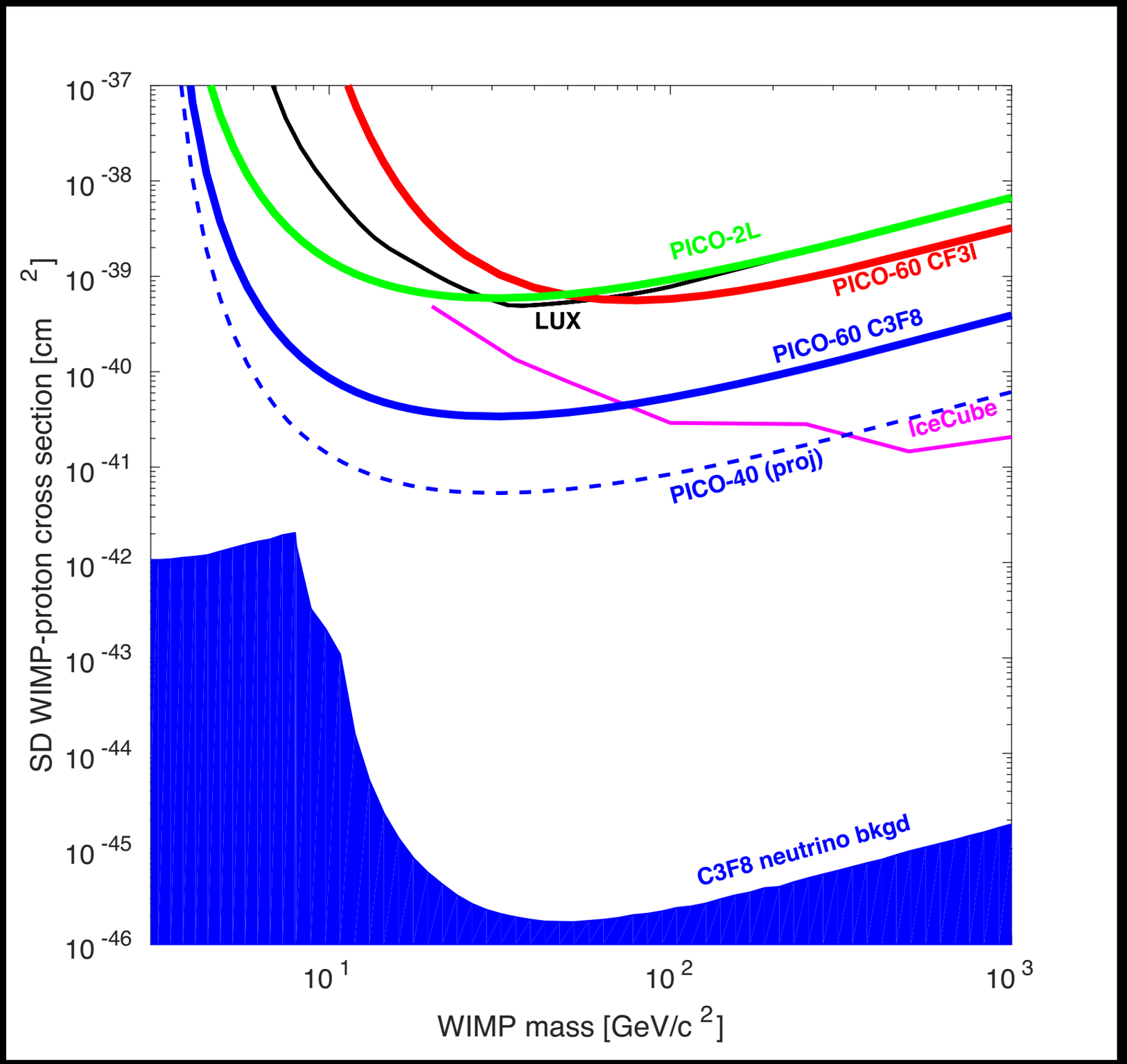


PICO-40L



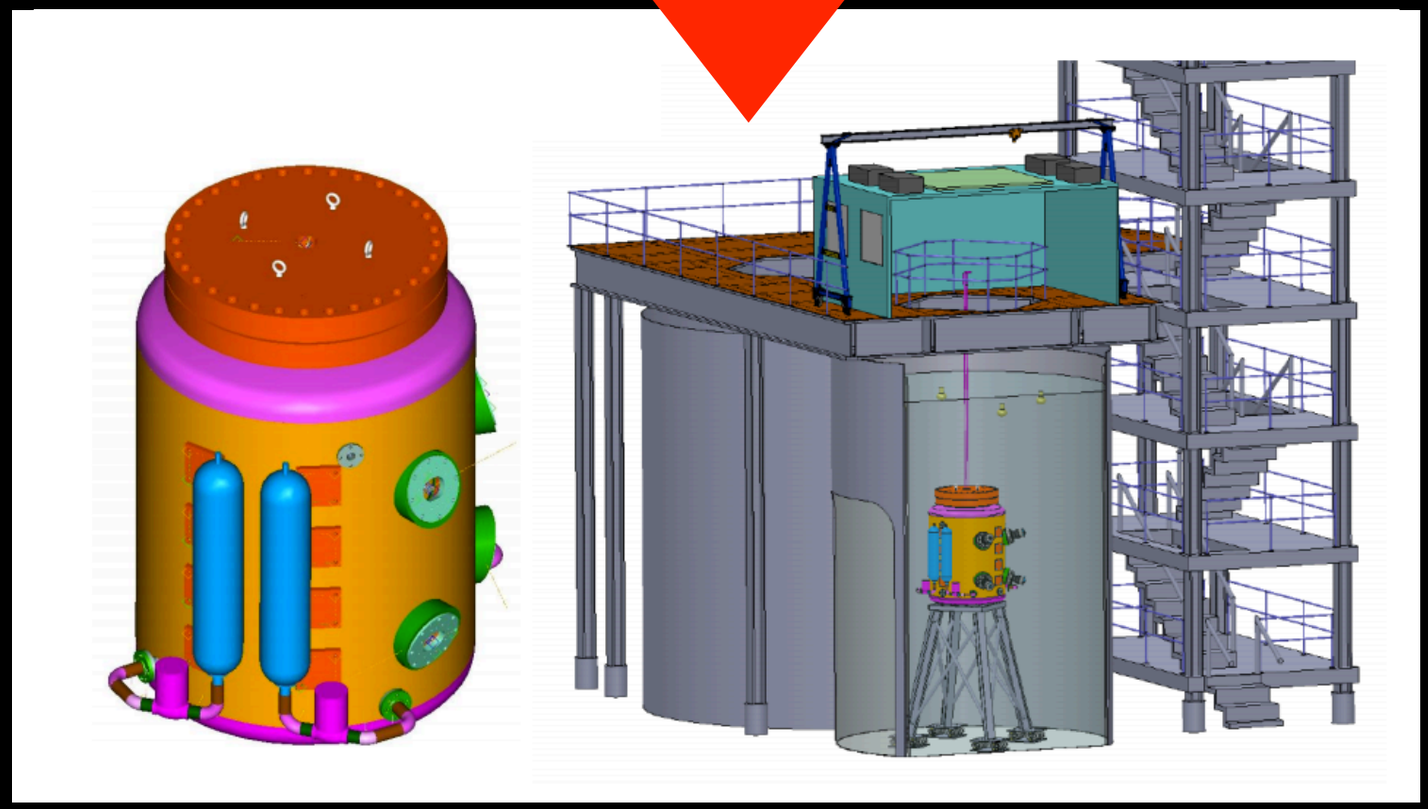
PICO-40L

- Pressure vessel arrived in May
- Cleaning of assembly on surface now ongoing
- Shipping underground this winter
- First data in January



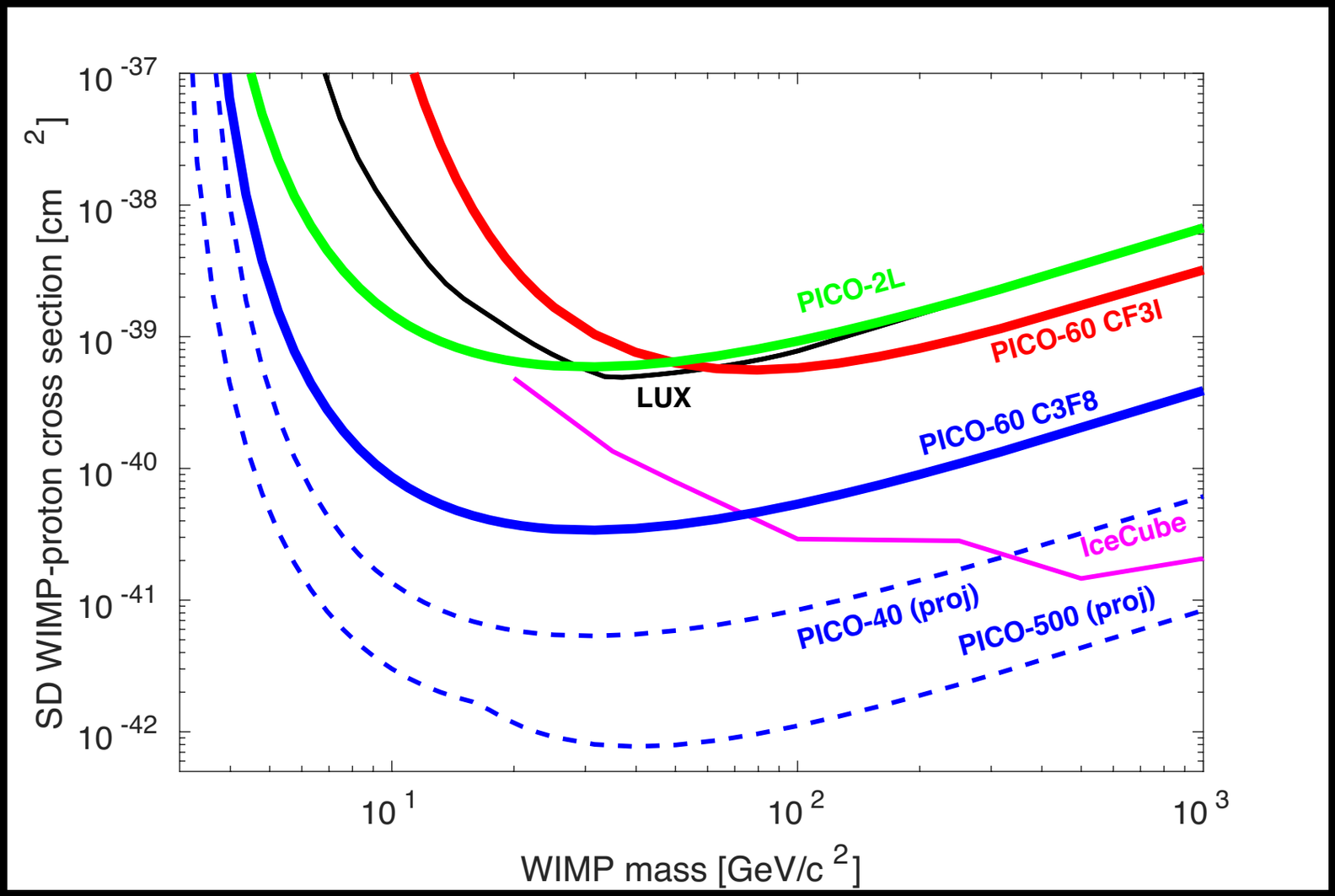
Scaling to PICO-500

- Background free at ~50 kg scale
- PICO sensitivity (spin-dependent, proton) complementary to other areas of DM program
- At multi-tonne scale, fluorine better at SD coupling than than heavy nuclei
  - Coherent neutrino scattering scales like N^2, while SD sensitivity is "flat"

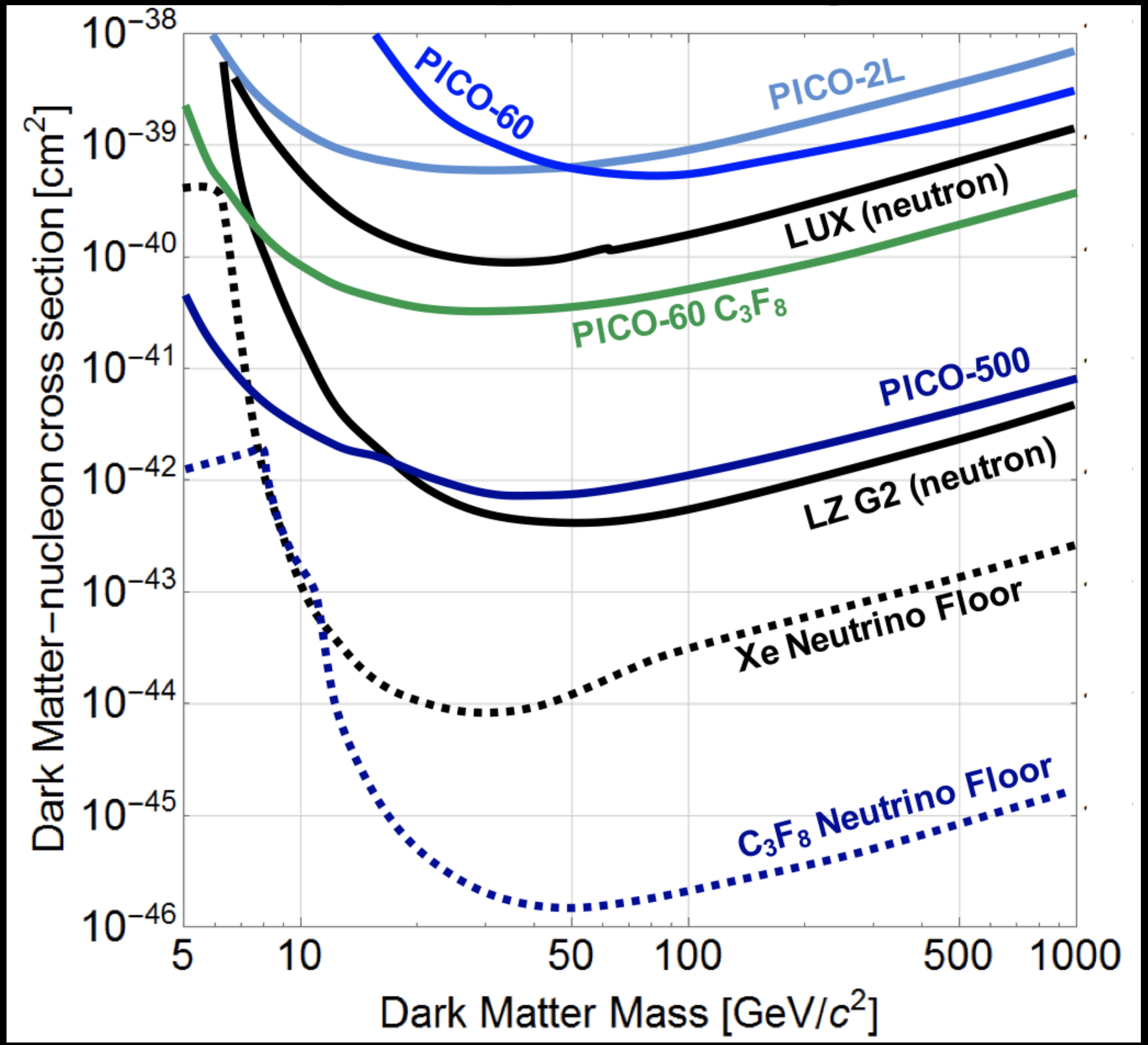


Scaling to PICO-500

- PICO-500 is proposal for ton-scale device to be built at SNOLAB
  - Proposed project start in 2018
  - Simulations and background control protocols are well underway
  - Final detector design will depend on PICO-40L results

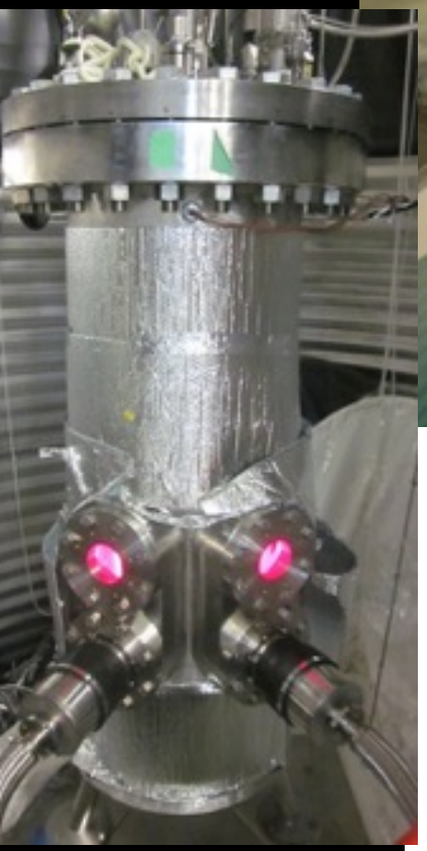


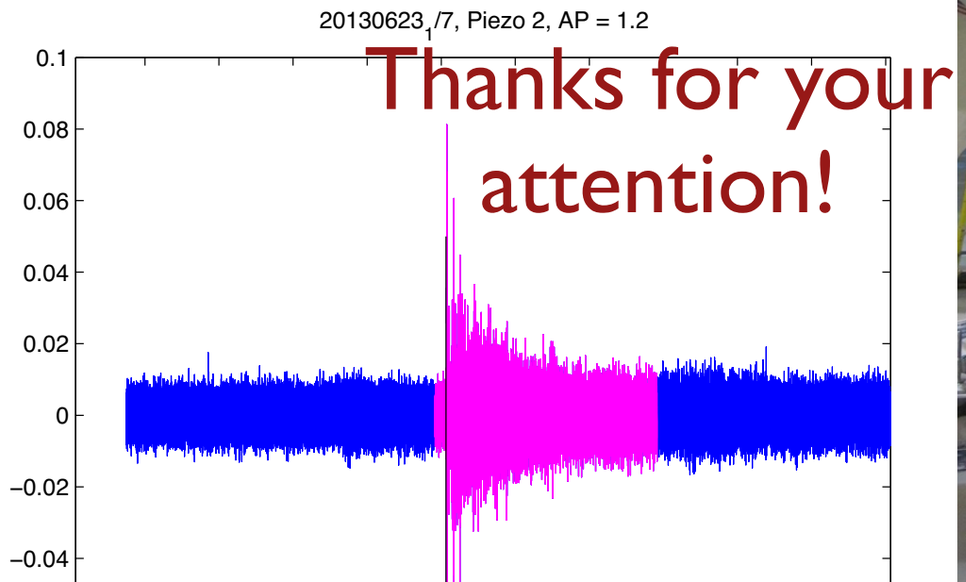
Scaling to PICO-500



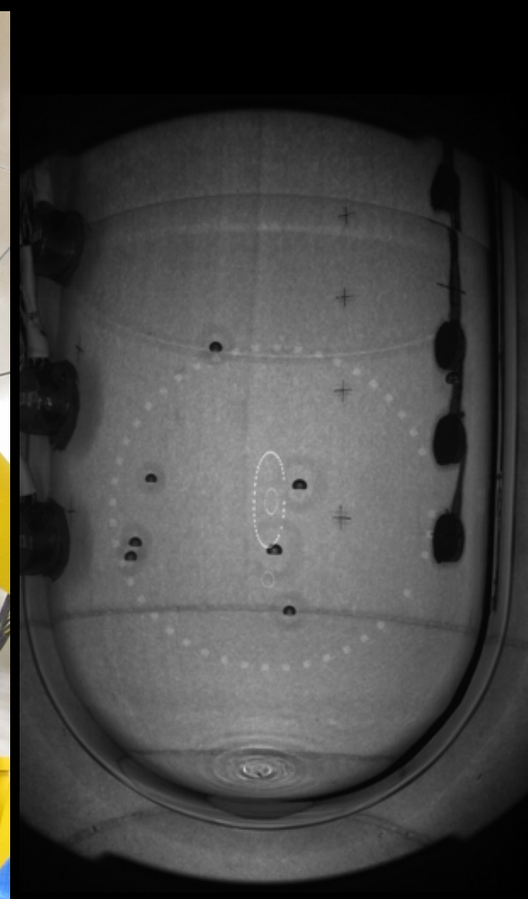
Conclusion

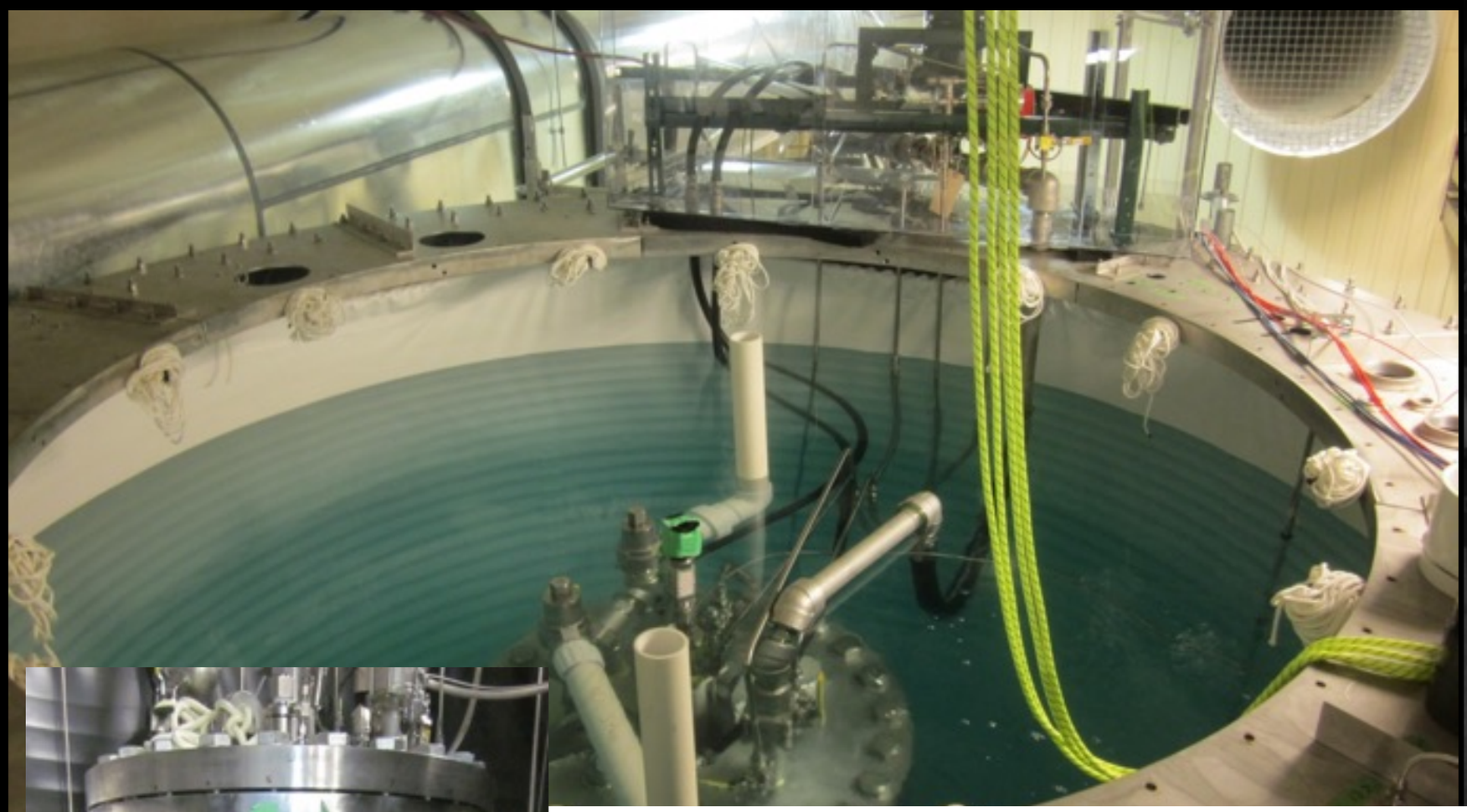
- PICO bubble chambers at the 40 liter/50 kg scale can be made background-free
- PICO setting world-leading constraints on spin-dependent WIMP proton coupling
- Moving on to the next phase of the program

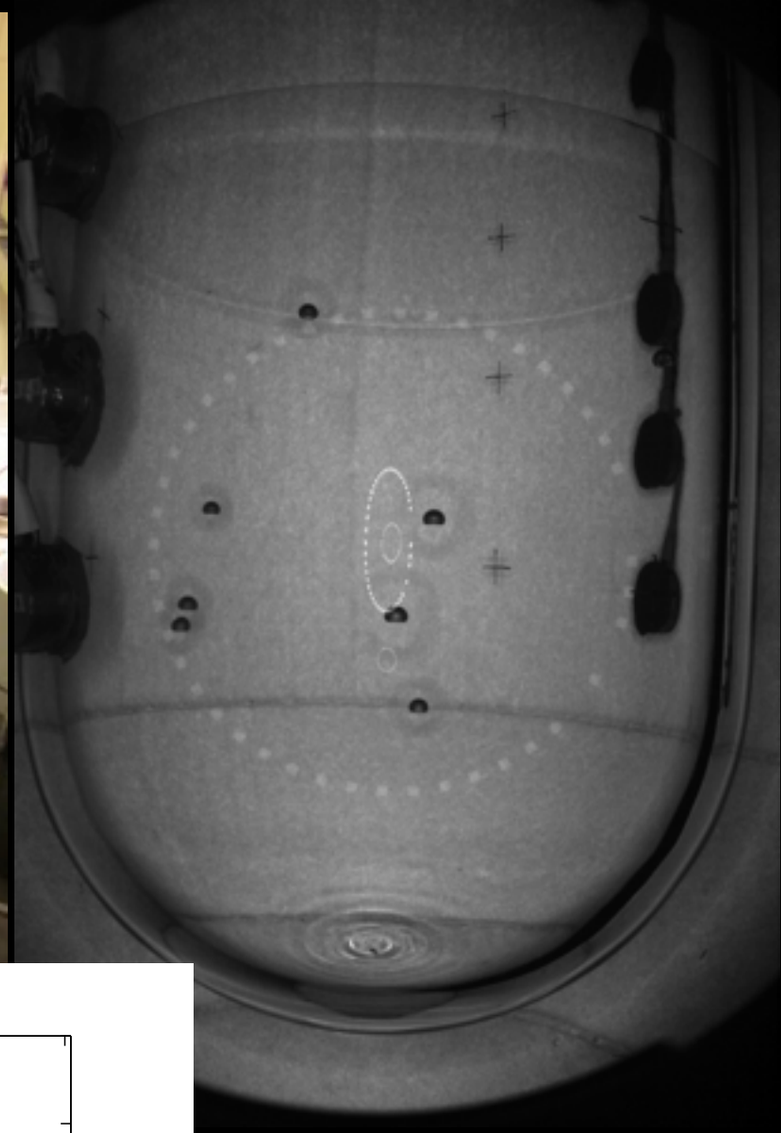


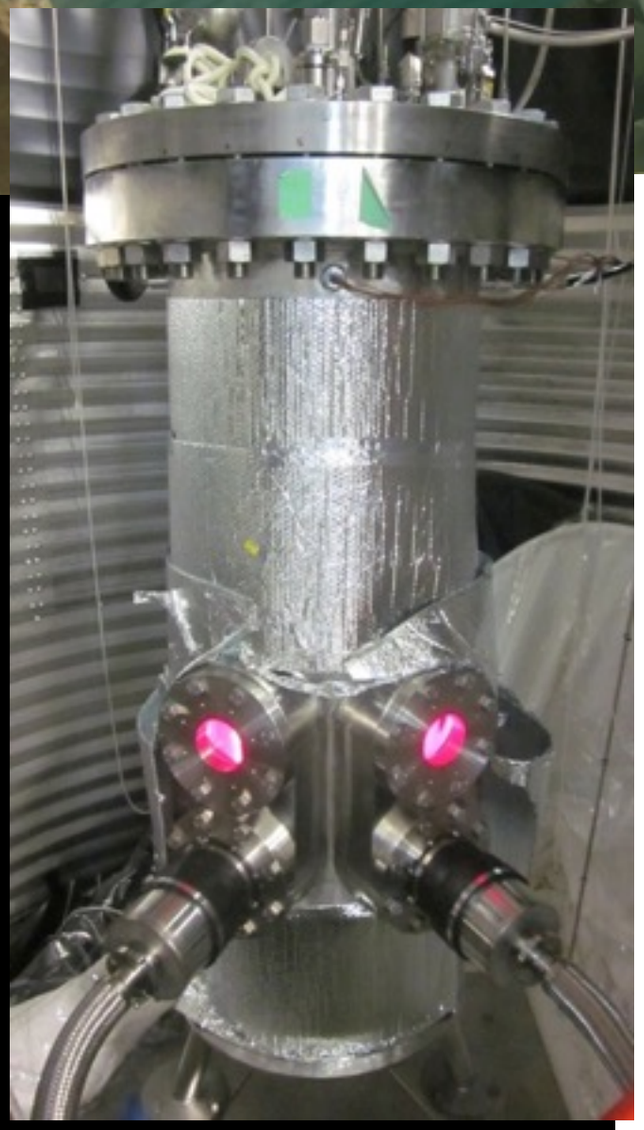


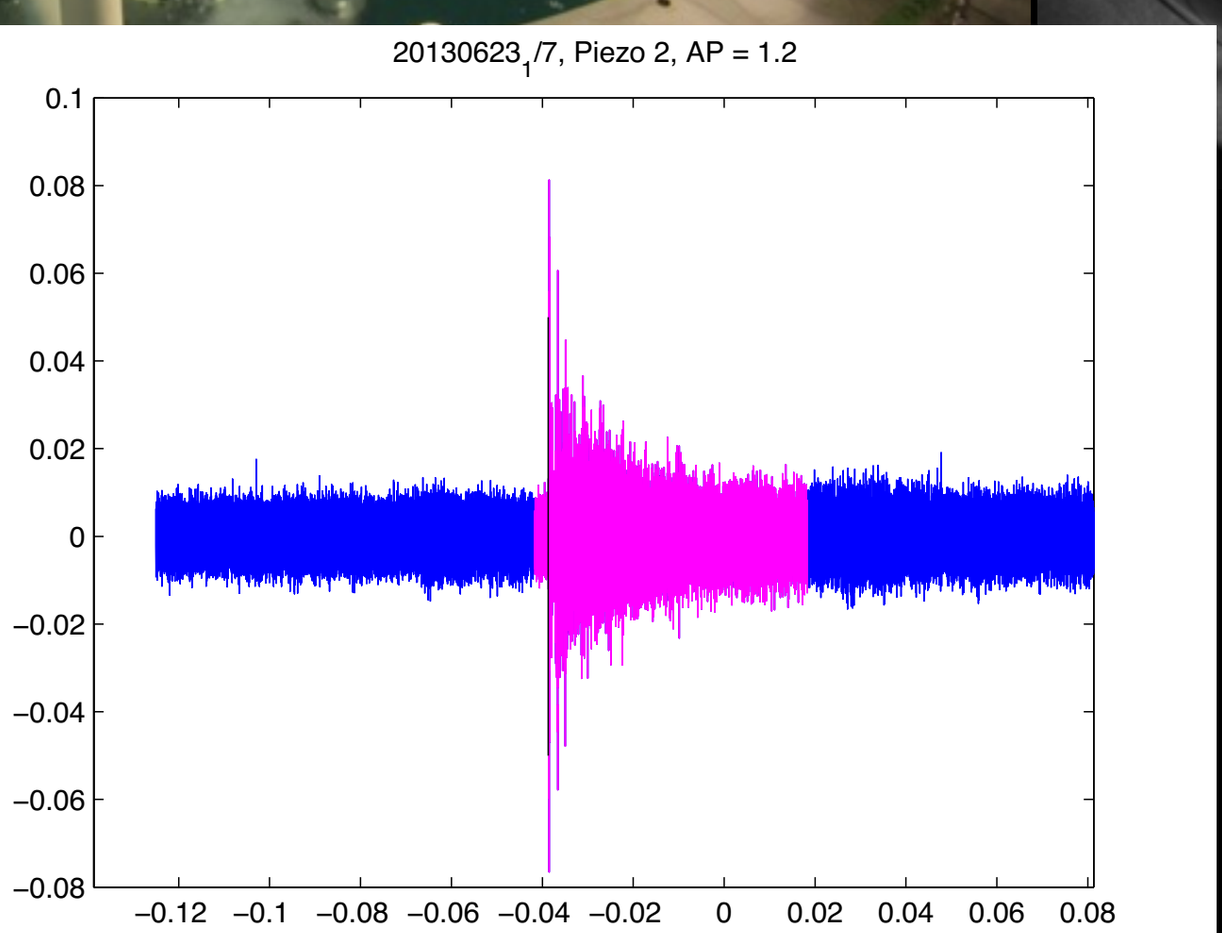
Thanks for your attention!









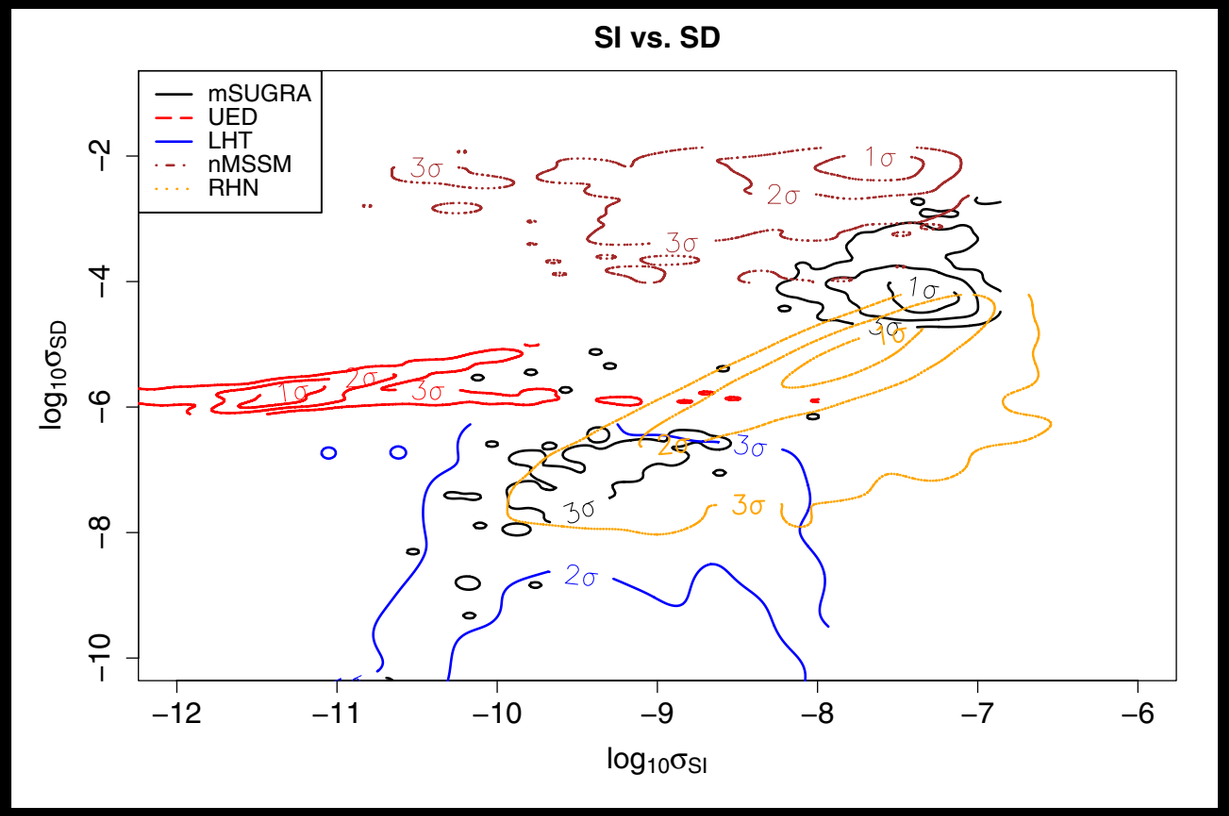


Thanks for your attention!

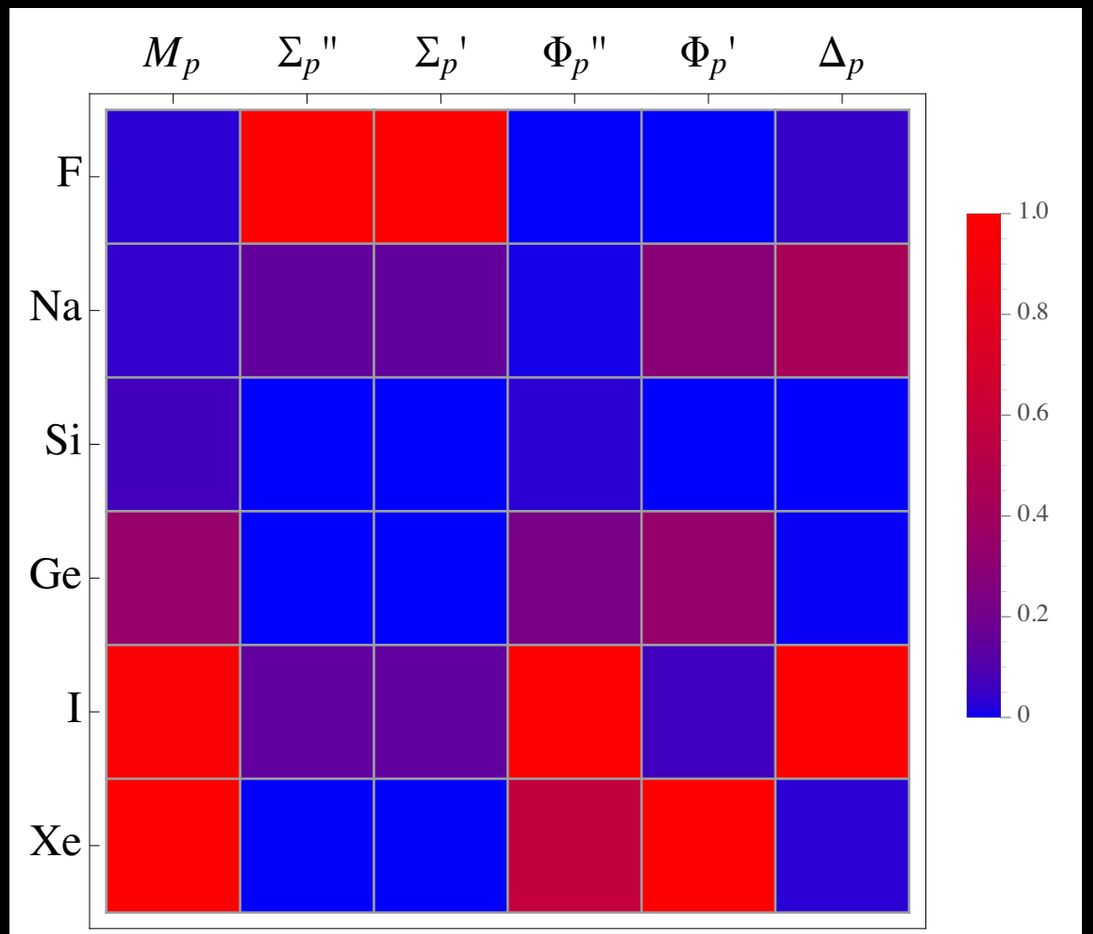
Extra

SI vs. SD (vs. nuclear physics)

- Spin-independent historically dominates the news because of the rate enhancement (x16000 for an atom like xenon)
- True interaction is still unknown

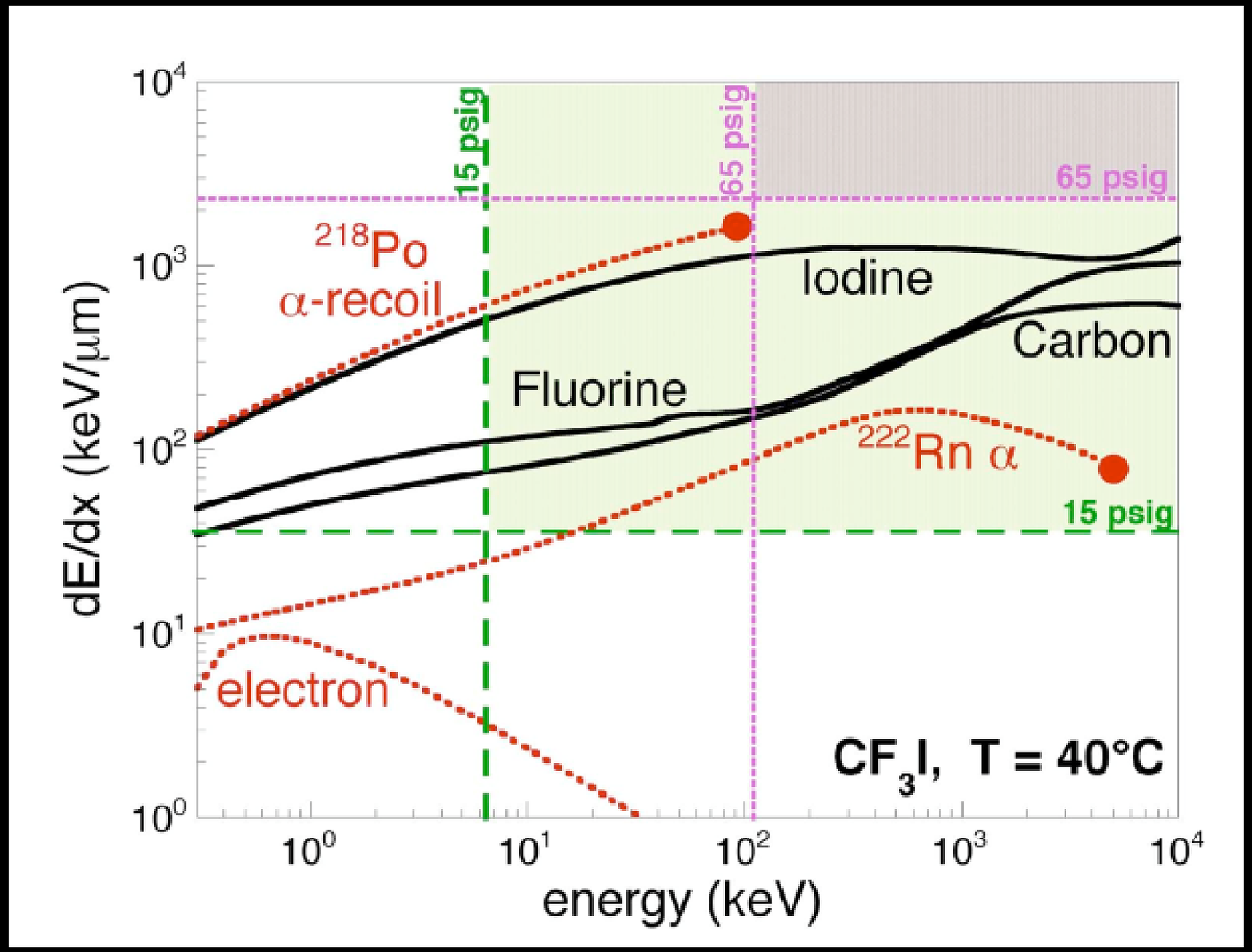


SD vs. SI cross section predictions for different models (Barger, PRD, 78 056007)



Sensitivity of different p-coupling operators to various nuclear targets (from L. Fitzpatrick at INT Workshop, 2014)

Why bubble chambers?



Detour: Threshold and efficiency

- Threshold determined from Seitz, Phys. of Fluids 1, 2 (1958)

$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = 4\pi r_c^2 \left(\sigma - T\frac{\partial \sigma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

Latent heat

- Energy deposition E_{th} within length R_c will nucleate a bubble (Hot Spike model)

- Theory assumes a step function above threshold