The PICO Dark Matter Search Program

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SNOLAB

Dark Matter Detection

- Many detectors able to see small deposit of energy
- Detection really comes down to method of distinguishing background
- Several different ways to approach this challenge

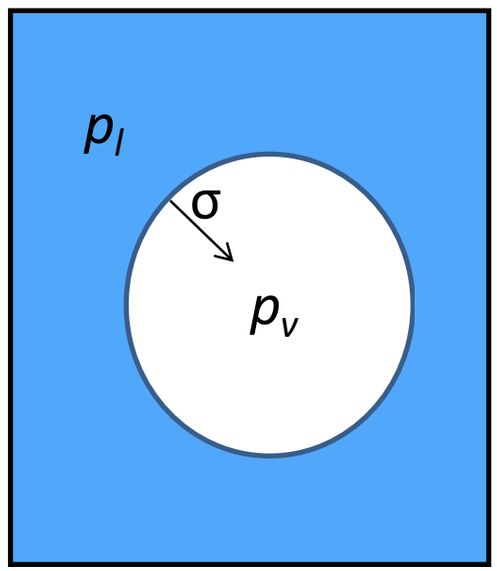
Bubble Chambers

- Filled with superheated fluid in metastable state
- Sufficient energy deposited causes an exploding bubble
- Insufficient or too sparse energy deposits will not cause nucleation

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

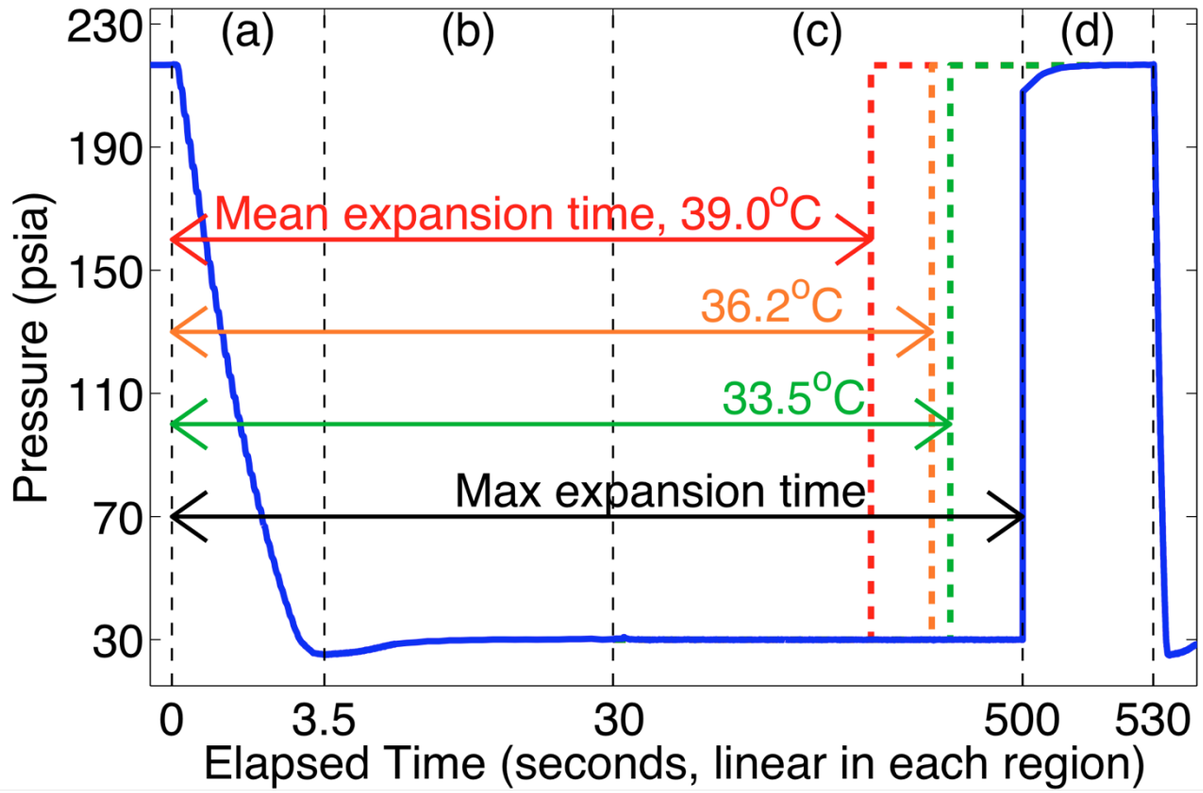
$$E_{th} = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v h$$

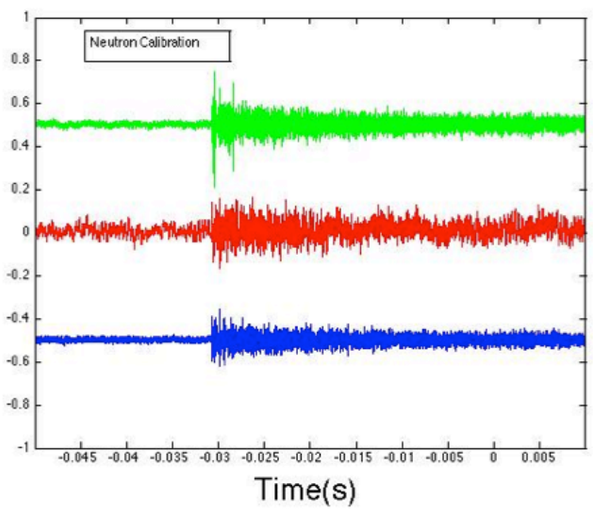
Surface energy Latent heat

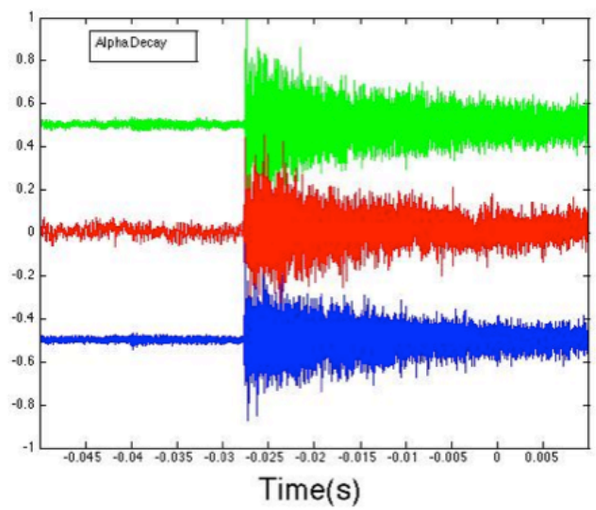


Chamber Operation

- Detector is made sensitive by depressurizing chamber
- A trigger causes pressurization to force back into liquid state

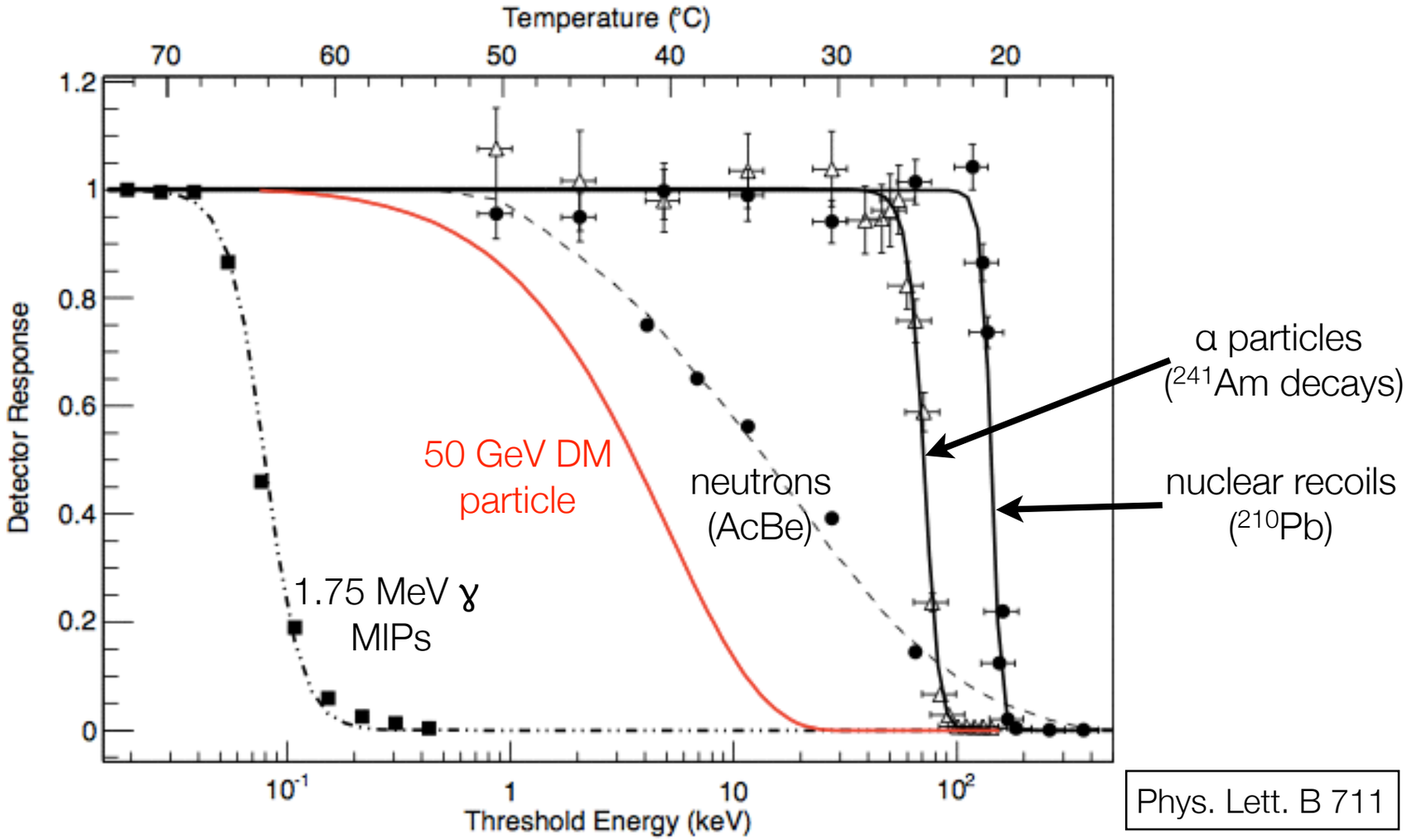






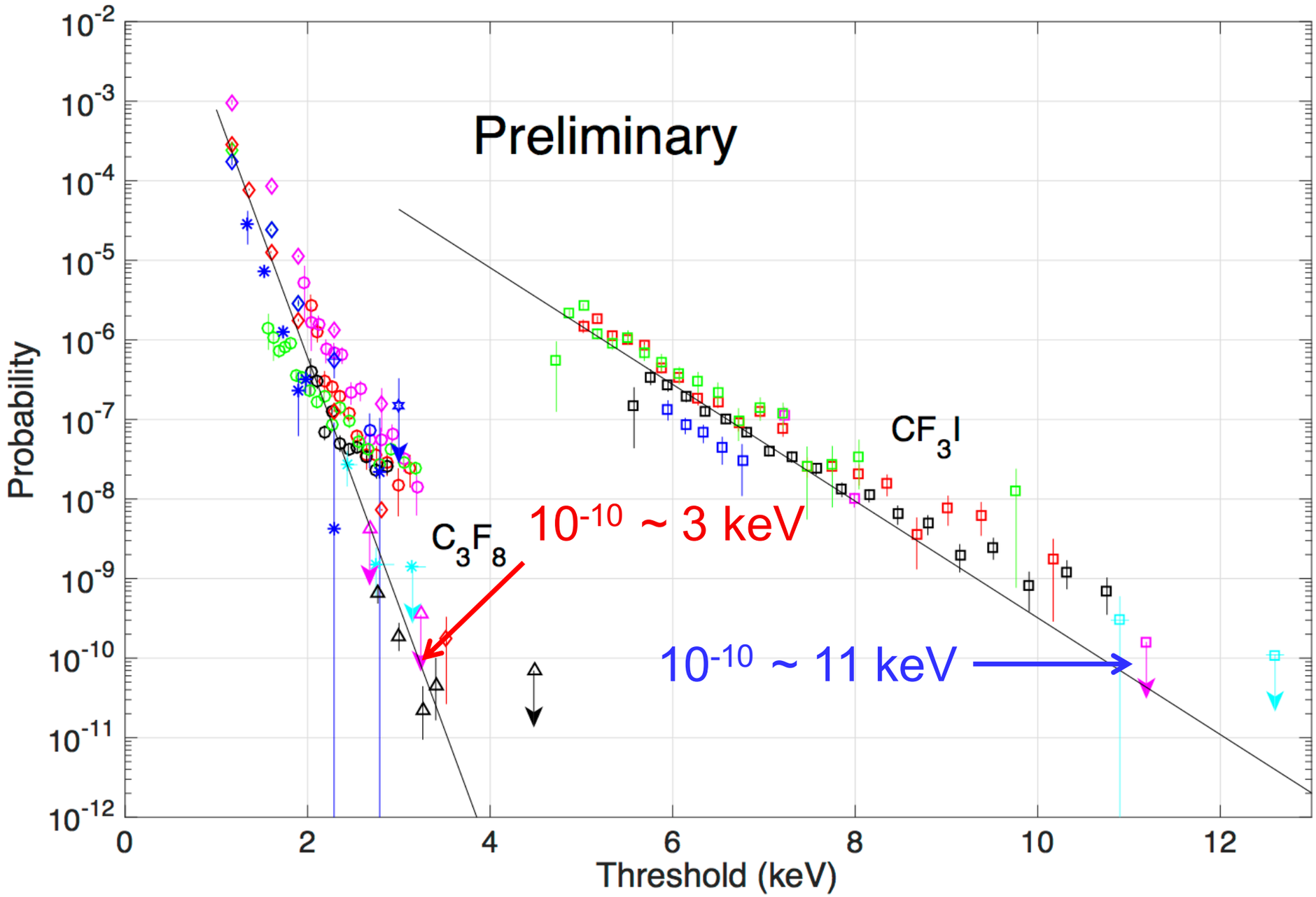
Background Discrimination

- Gammas and betas are effectively not detected by the detector as they do not meet the $E_{threshold}$ in r_c requirement.



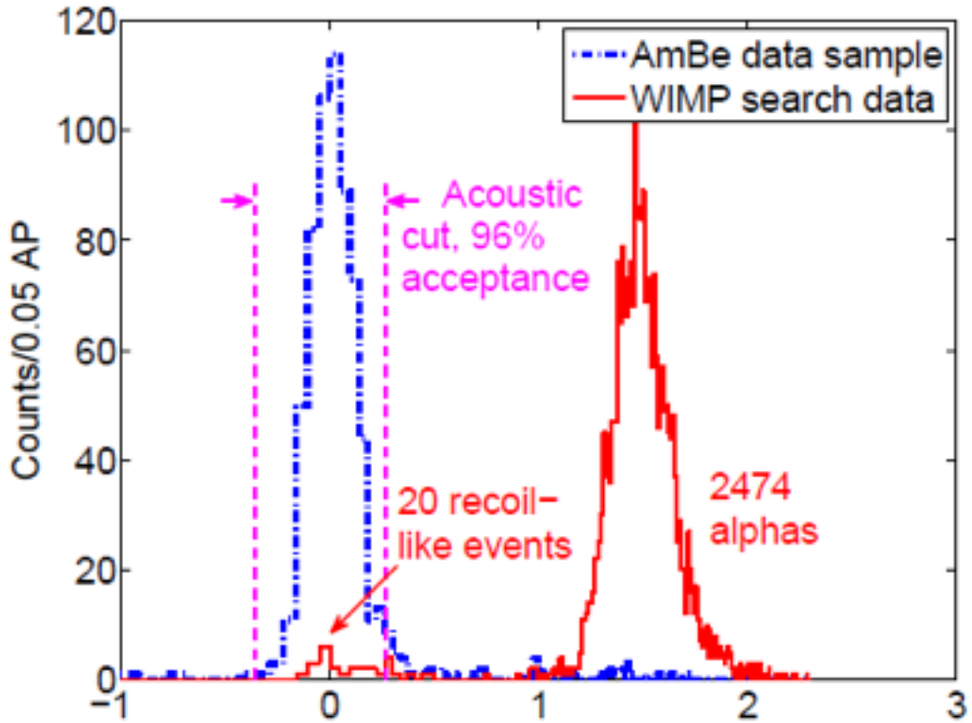
Phys. Lett. B 711

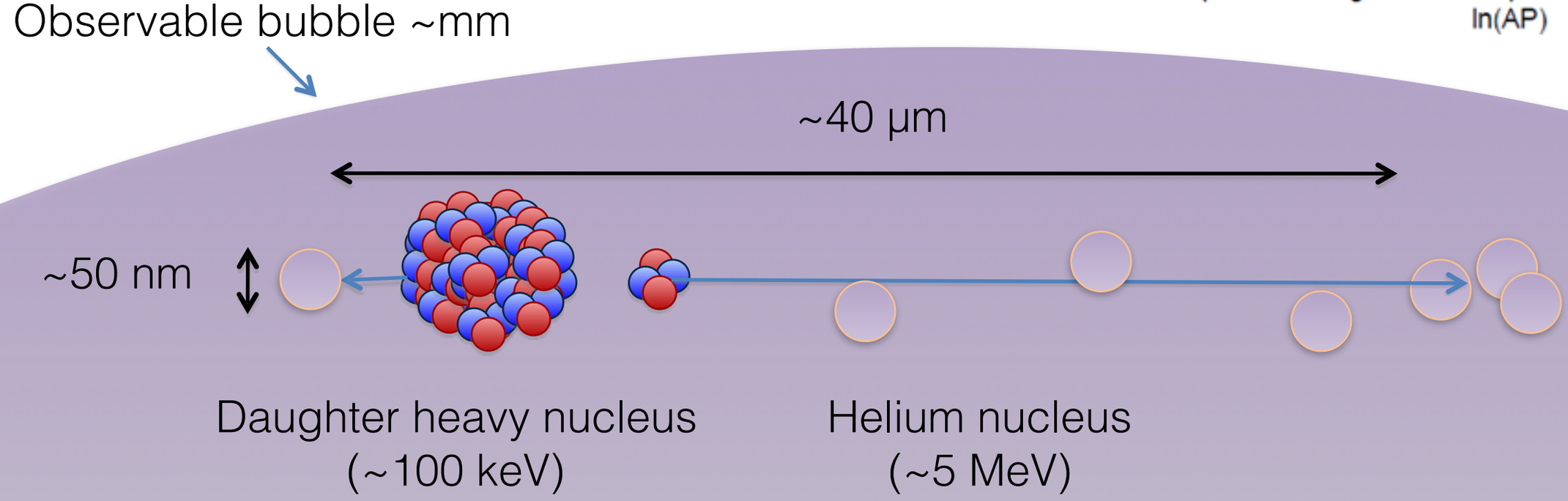
Gamma Rejection



Acoustic Discrimination

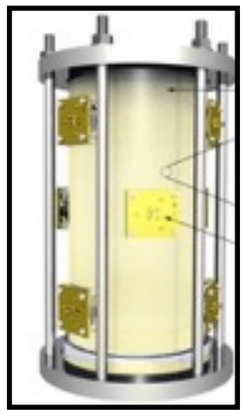
- Alphas deposit their energy over tens of microns
- Nuclear recoils deposit theirs over tens of nanometers



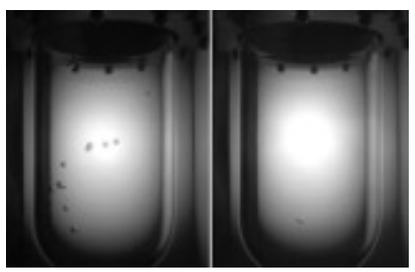


PICO Timeline

PICASSO

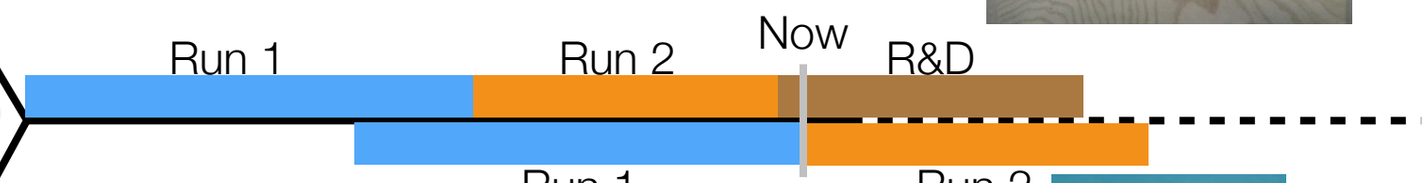


COUPP

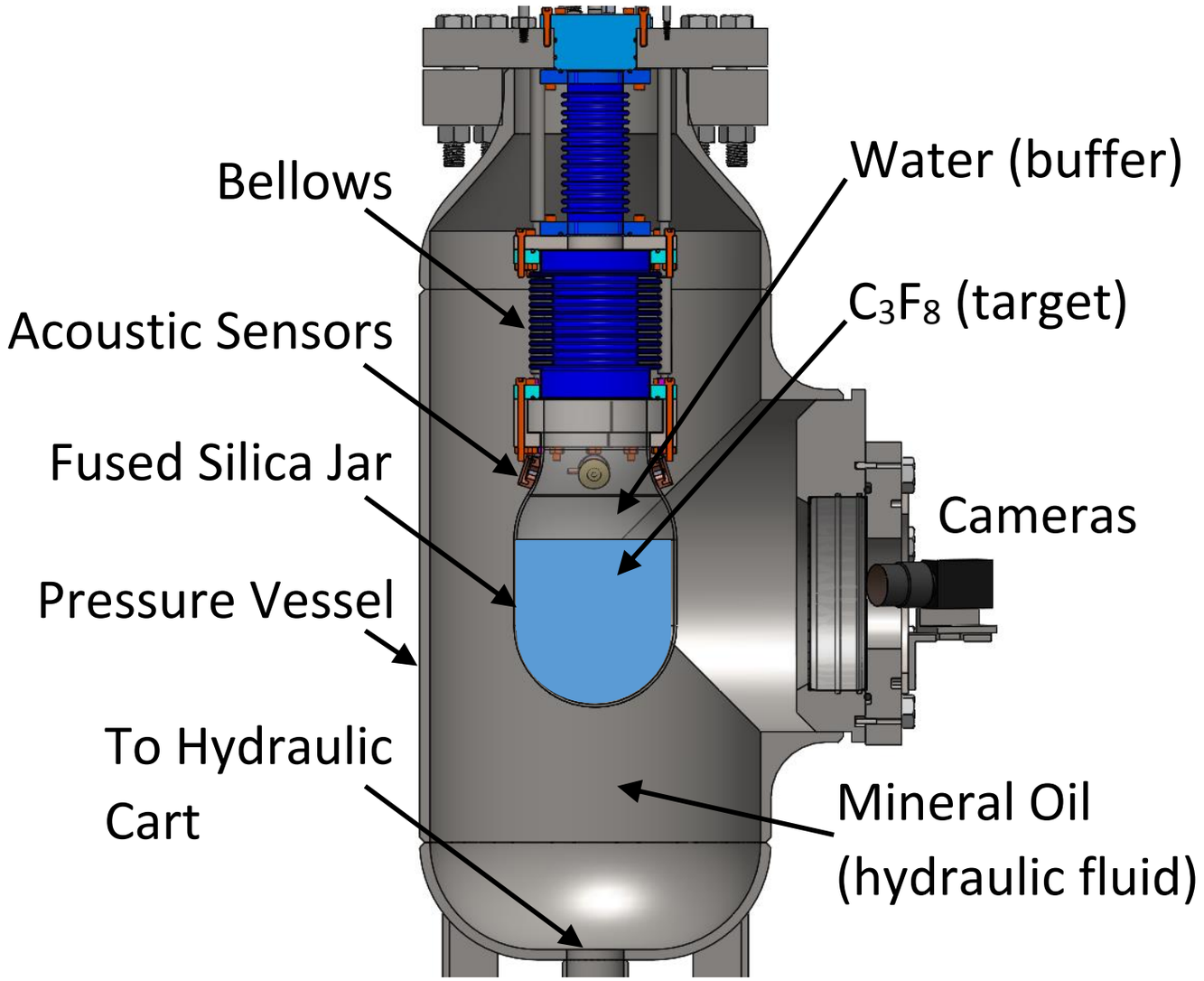


PICO-2L

PICO-60



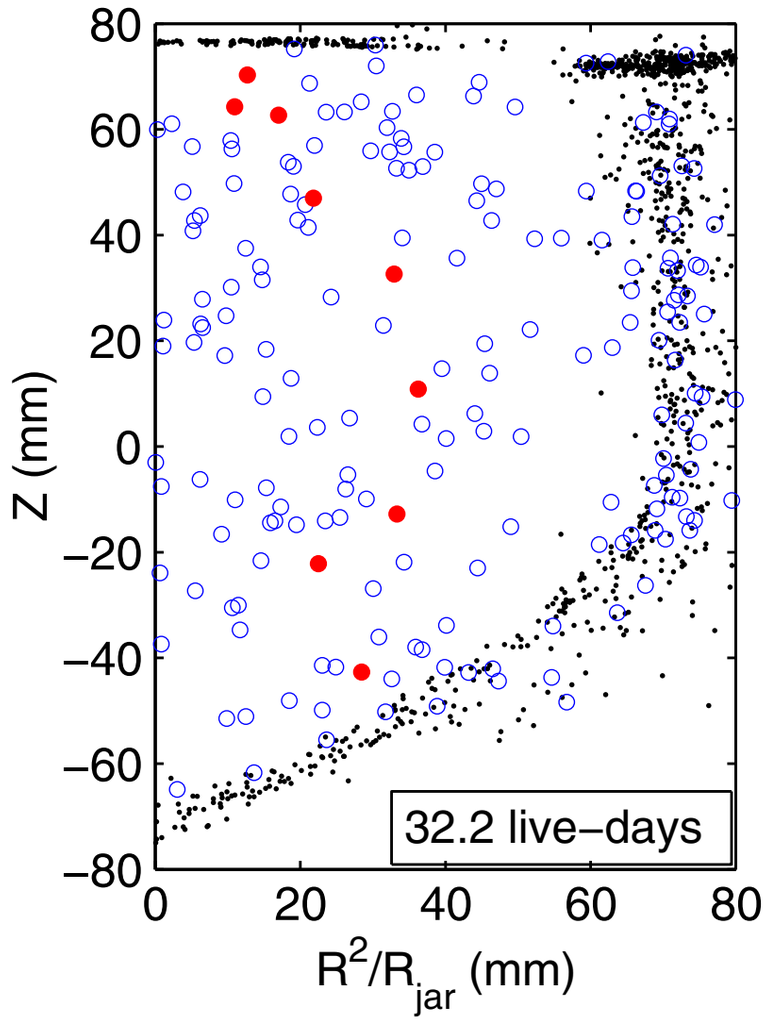
PICO-2L



- 2L (2.9kg) active mass of C_3F_8
- Change from CF_3I gives better gamma rejection, more active mass for proton-interaction search

PICO-2L Run 1

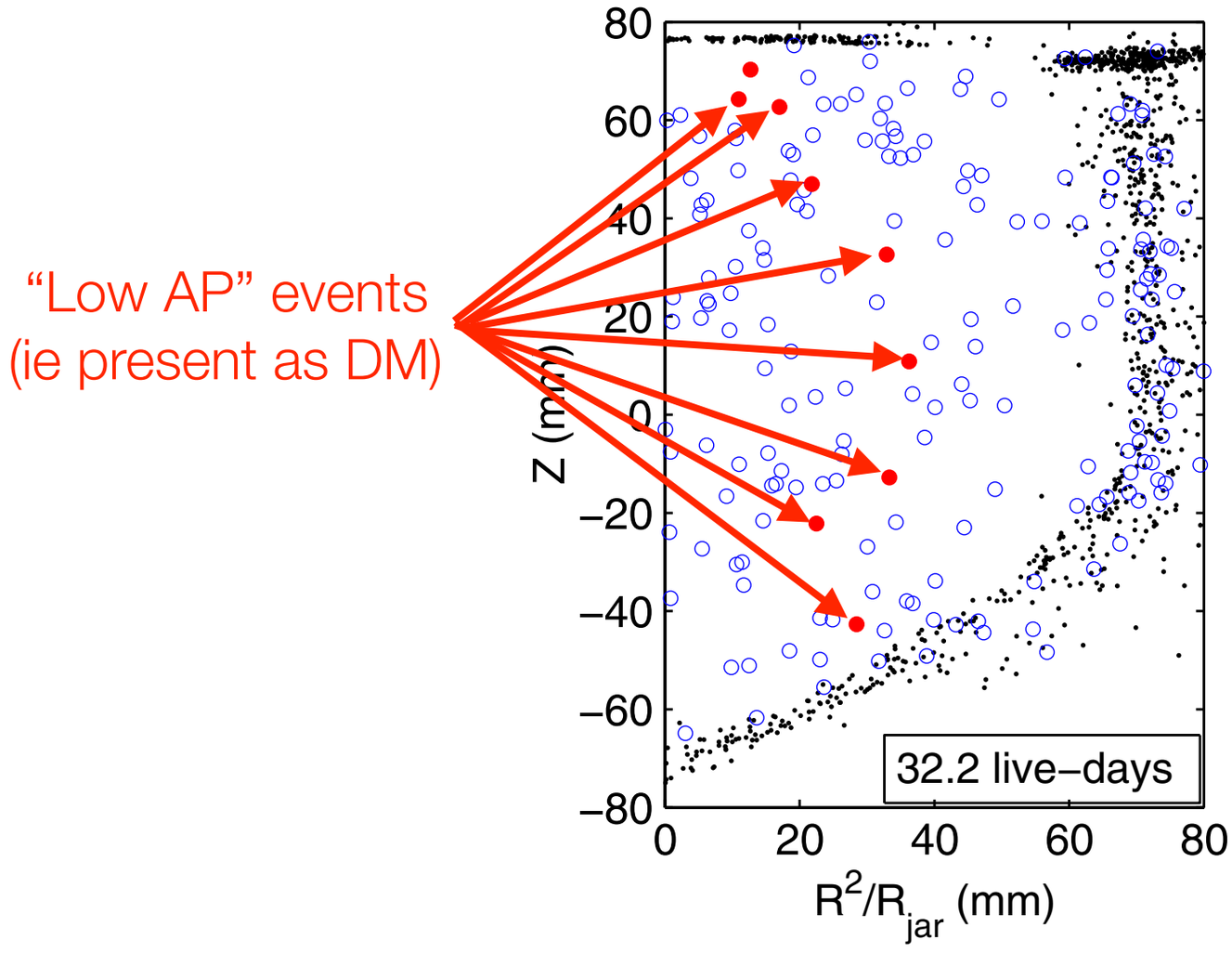
- First run showed that C_3F_8 worked and had the expected gamma rejection



Neutron expectation: $0.6^{+0.2}_{-0.4}$

PICO-2L Run 1

- First run showed that C_3F_8 worked and had the expected gamma rejection
- But what are those events?
- Cleanliness was immediately suspected

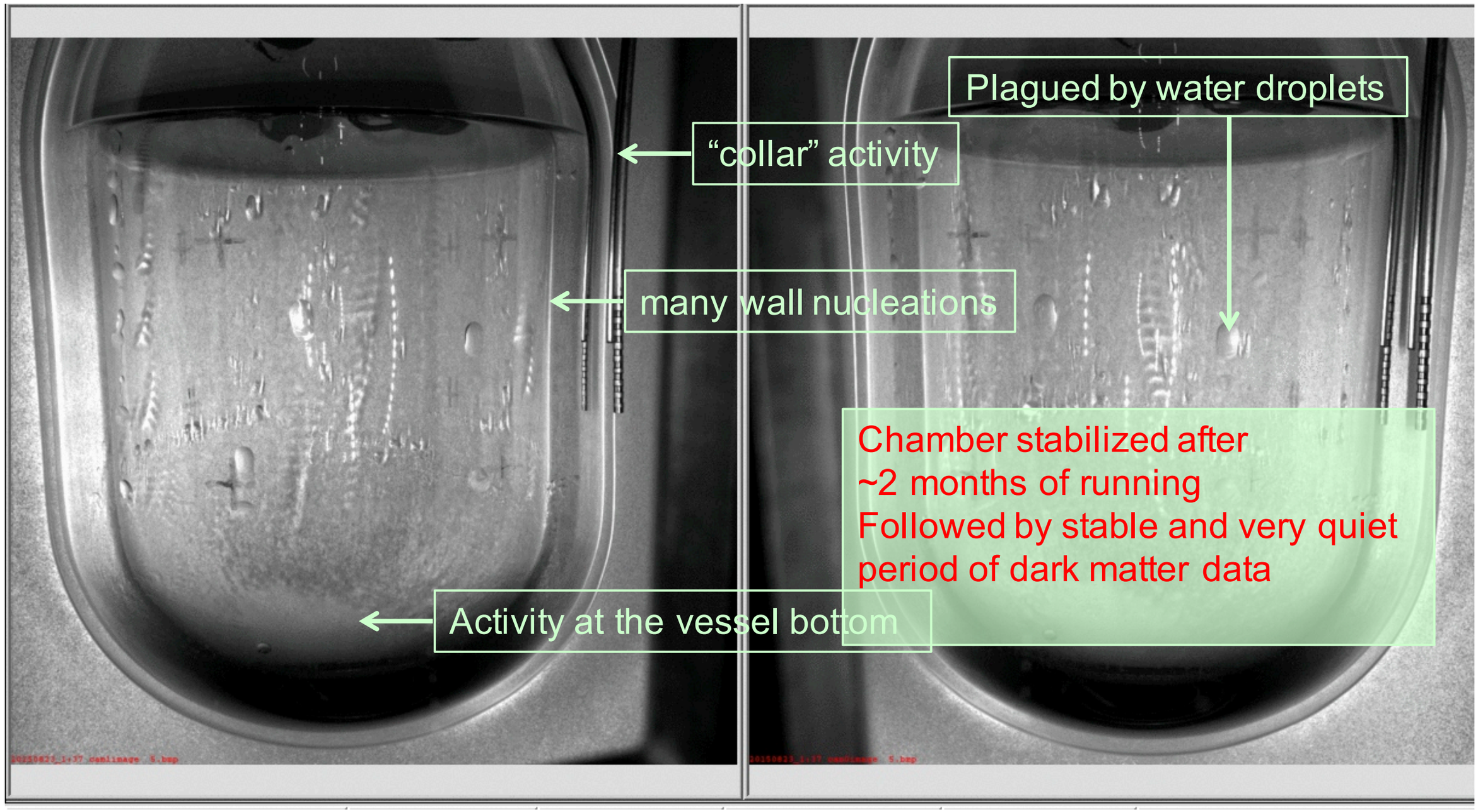


Neutron expectation: $0.6^{+0.2}_{-0.4}$

PICO-2L Results

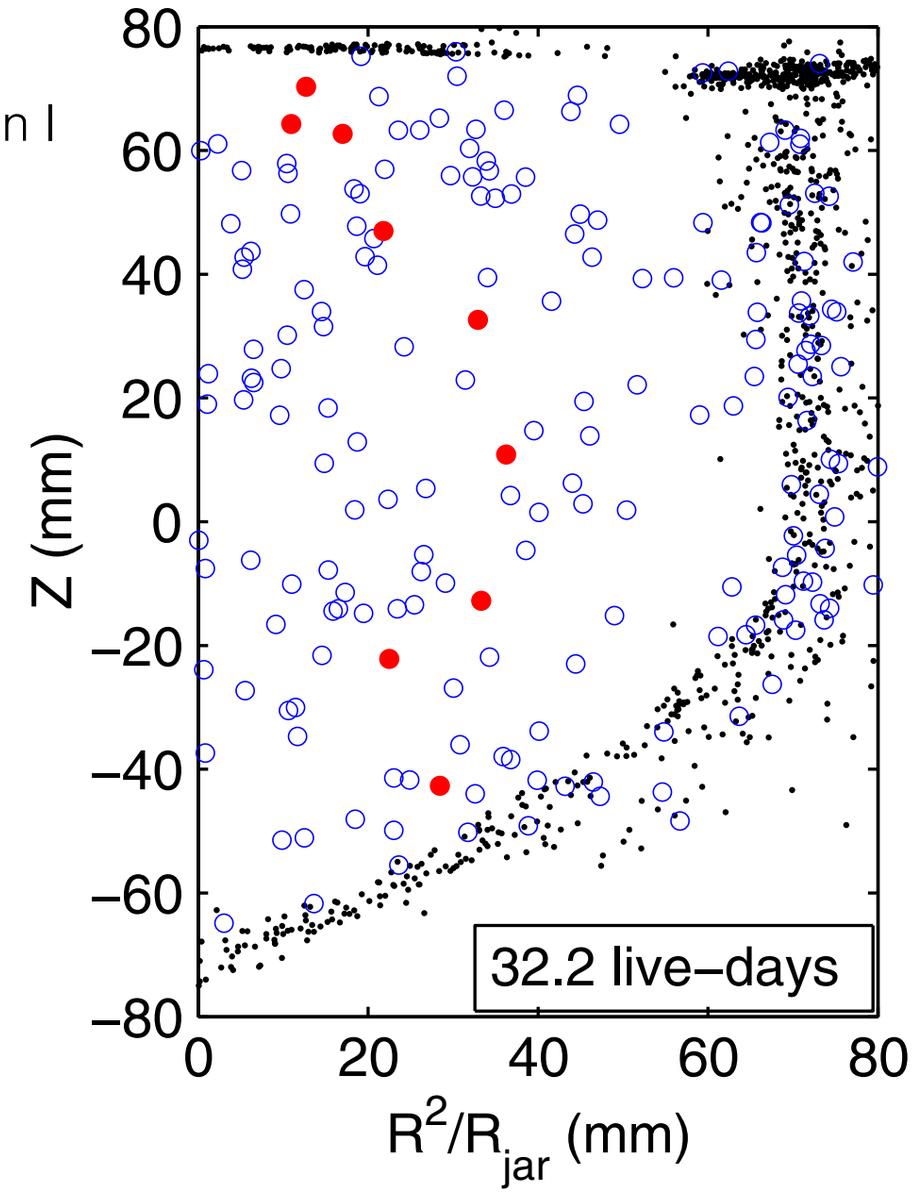
- ALL candidates seen were within 1000 seconds of a previous expansion
- Also noted to cluster near the surface and the walls
- Some particulate was seen with an indication that it was quartz
- Fused silica replaced the quartz jar
- Extensive cleaning undertaken

PICO-2L Run 2


Plagued by water droplets
“collar” activity
many wall nucleations
Chamber stabilized after
~2 months of running
Followed by stable and very quiet
period of dark matter data
Activity at the vessel bottom

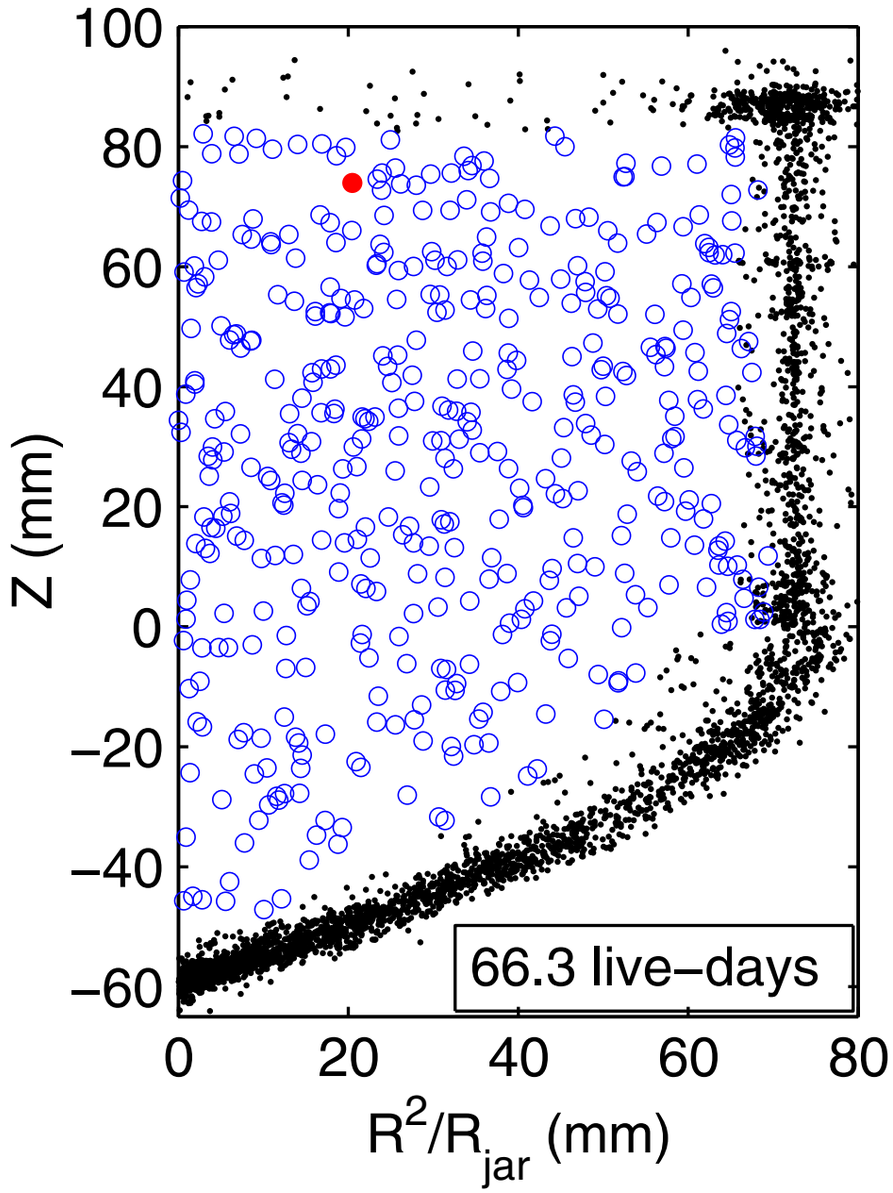
PICO-2L Results

run I



Neutron expectation: $0.6^{+0.2}_{-0.4}$

run II

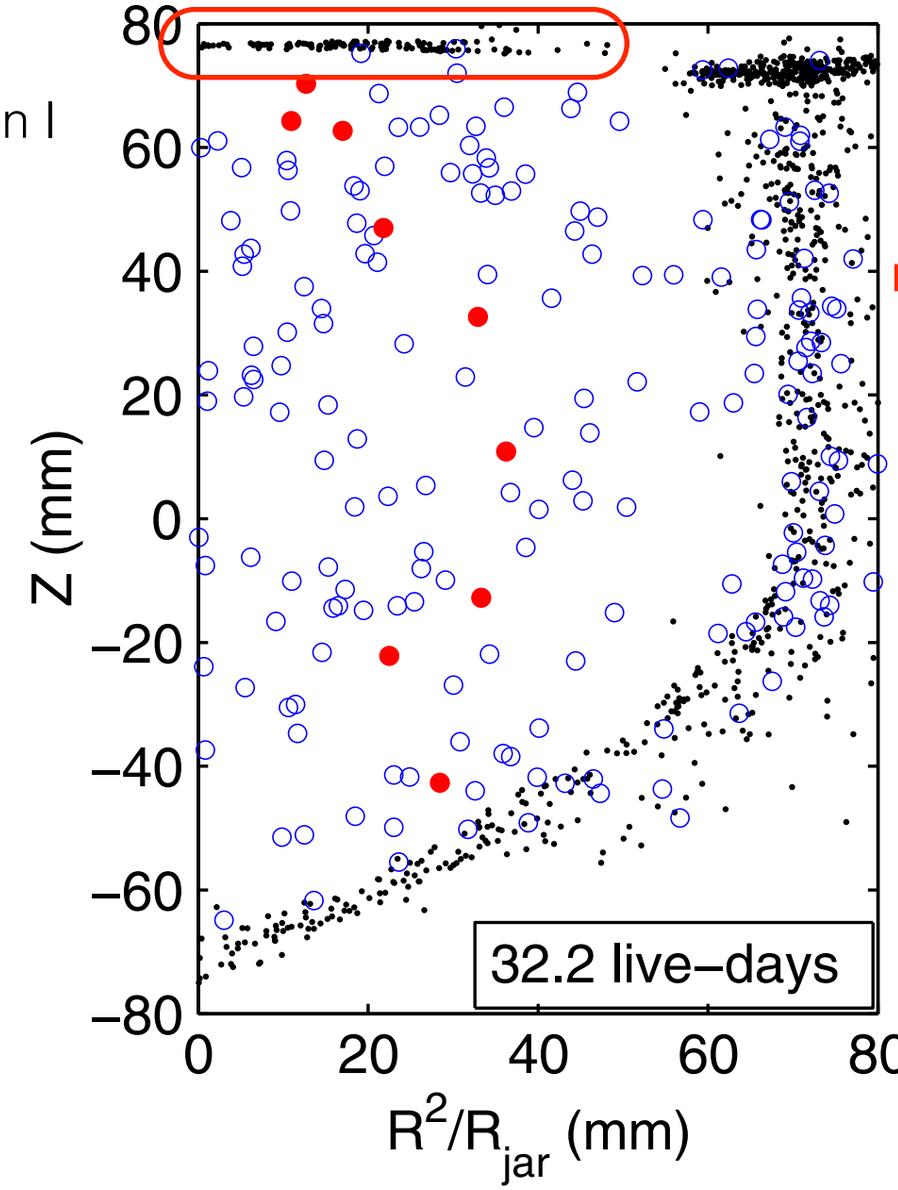


Neutron expectation: $1.0^{+0.2}_{-0.7}$

- Anomalous rate dramatically reduced, now in line with neutron expectation

PICO-2L Results

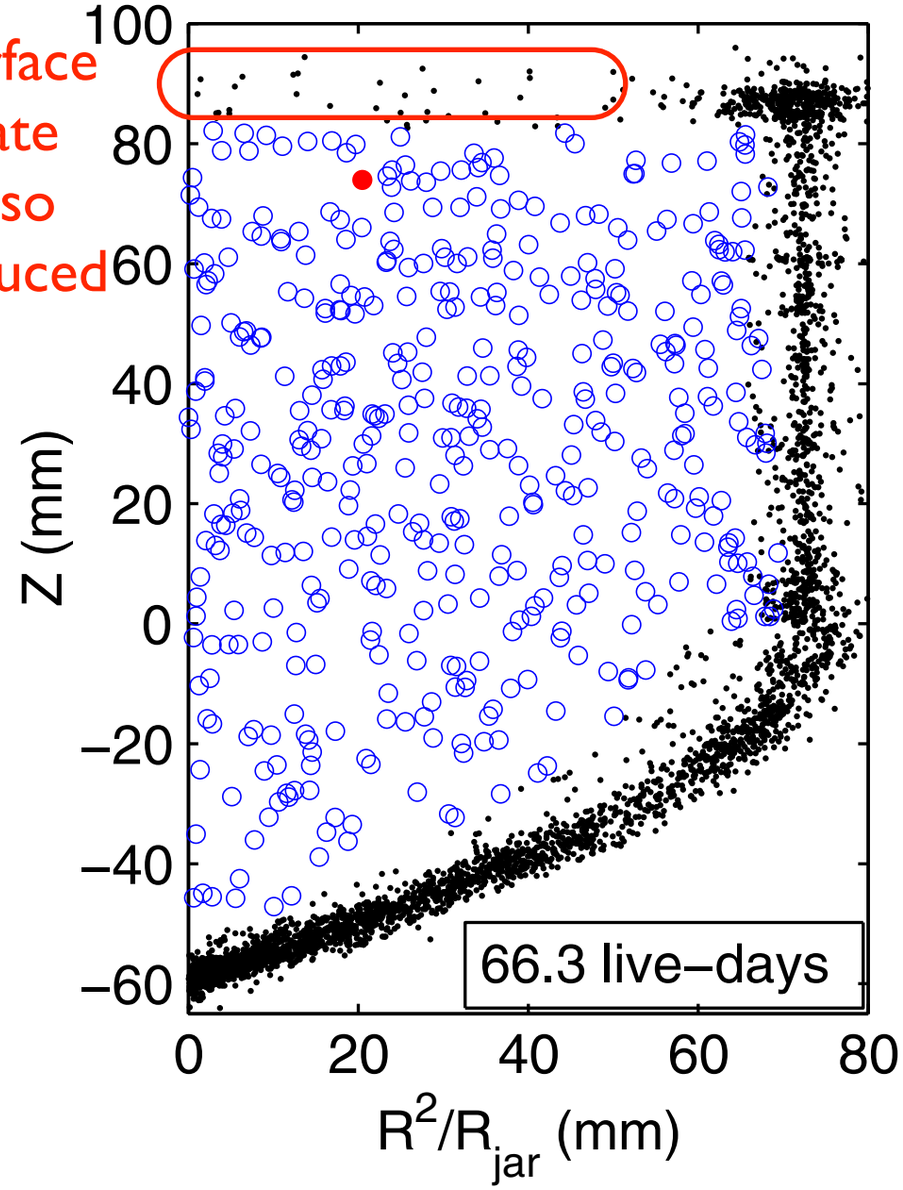
run I



Neutron expectation: $0.6^{+0.2}_{-0.4}$

Surface rate also reduced

run II



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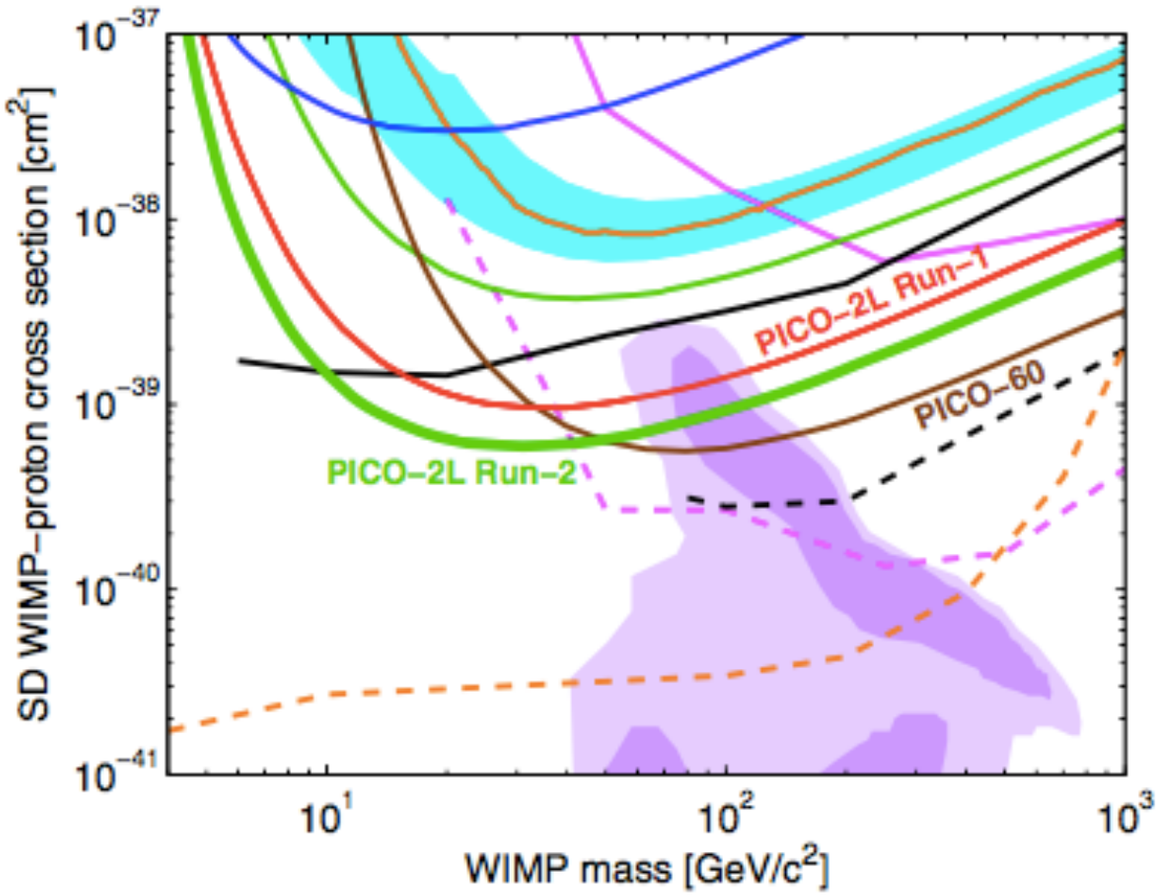
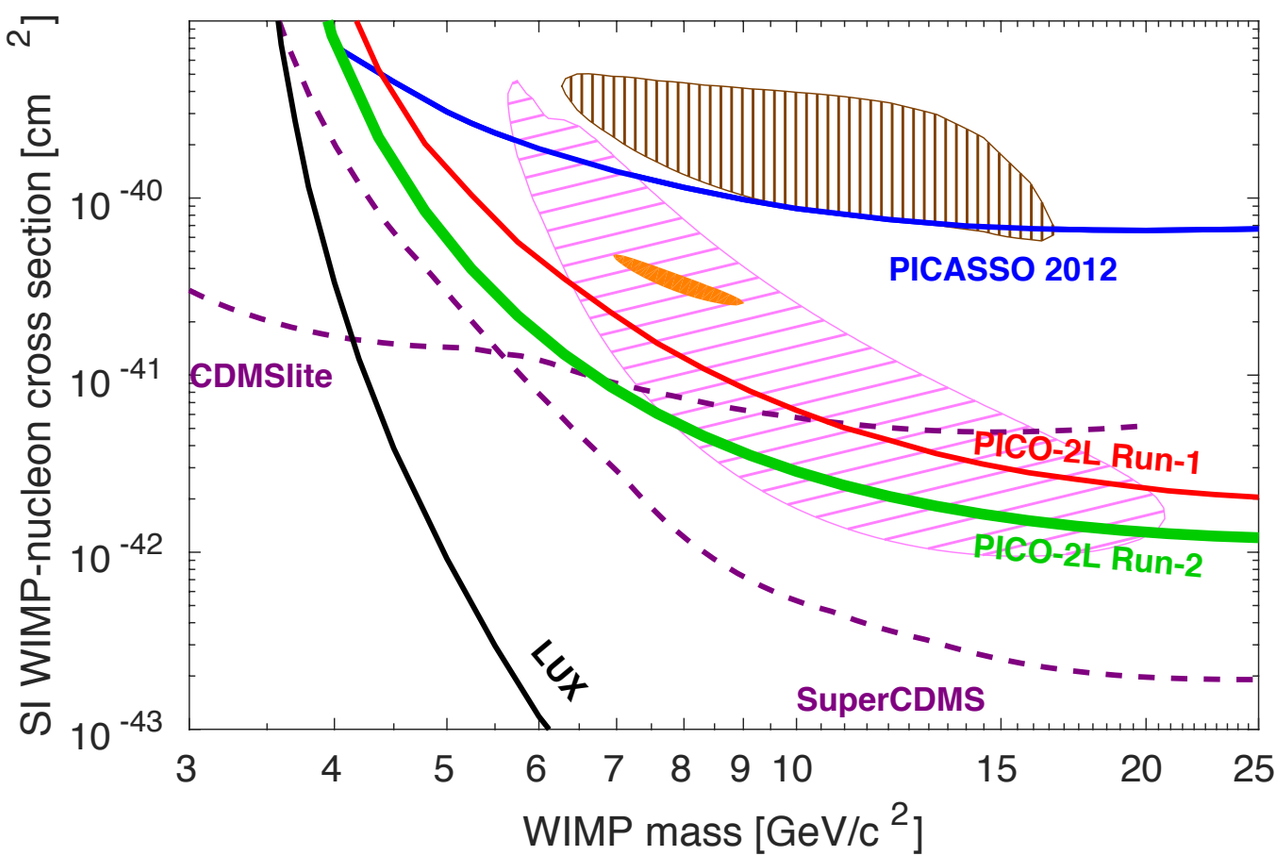
PICO-2L Results

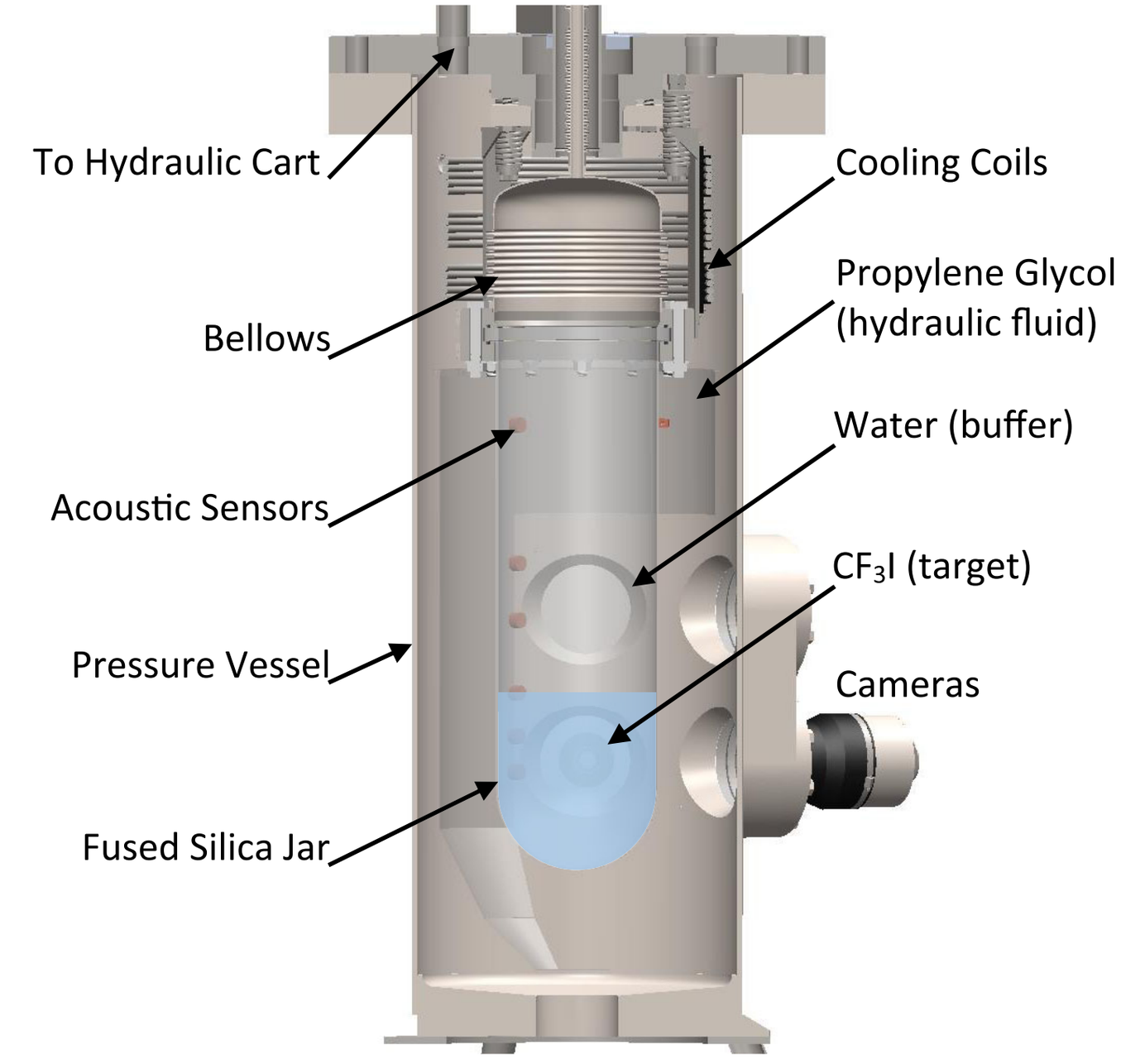




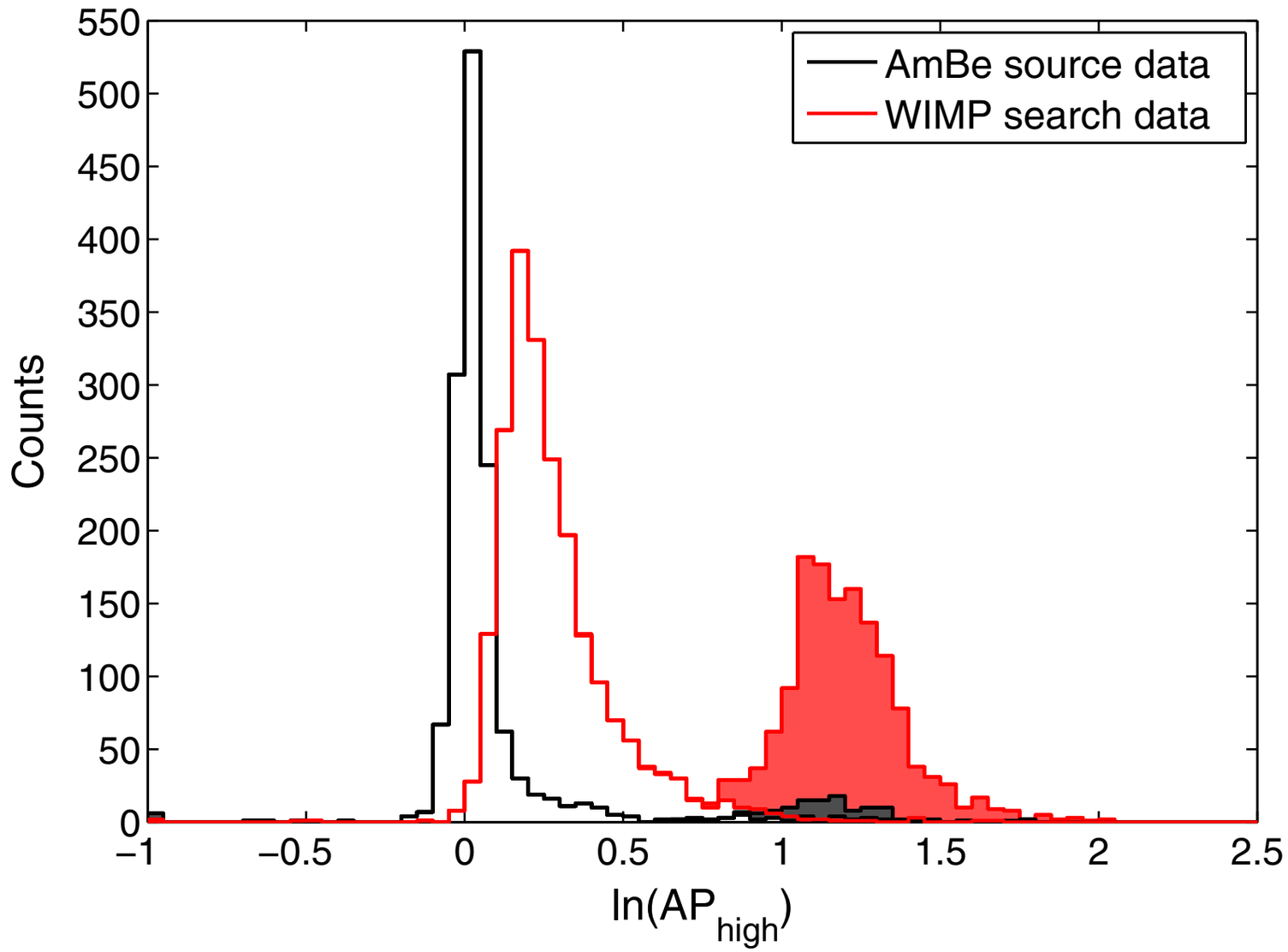
Run 1: Phys. Rev. Lett. 114, 231302 (2015)
Run 2: Phys. Rev. D 93, 061101 (2016)

PICO-60

- Active material: 36.8kg of C_3FI
- This is where we really dug into the anomalous background…



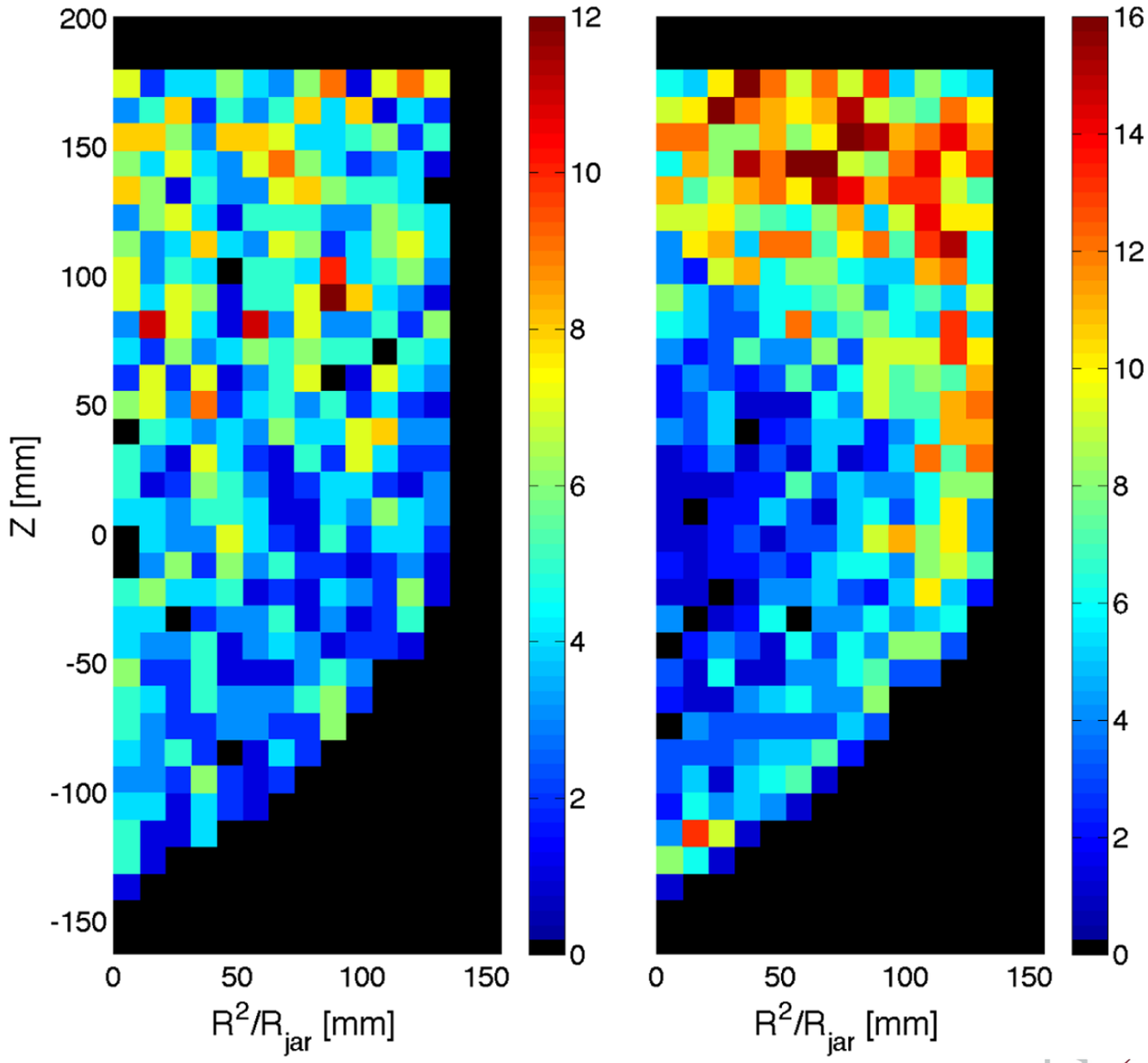
PICO-60 Background - Acoustically



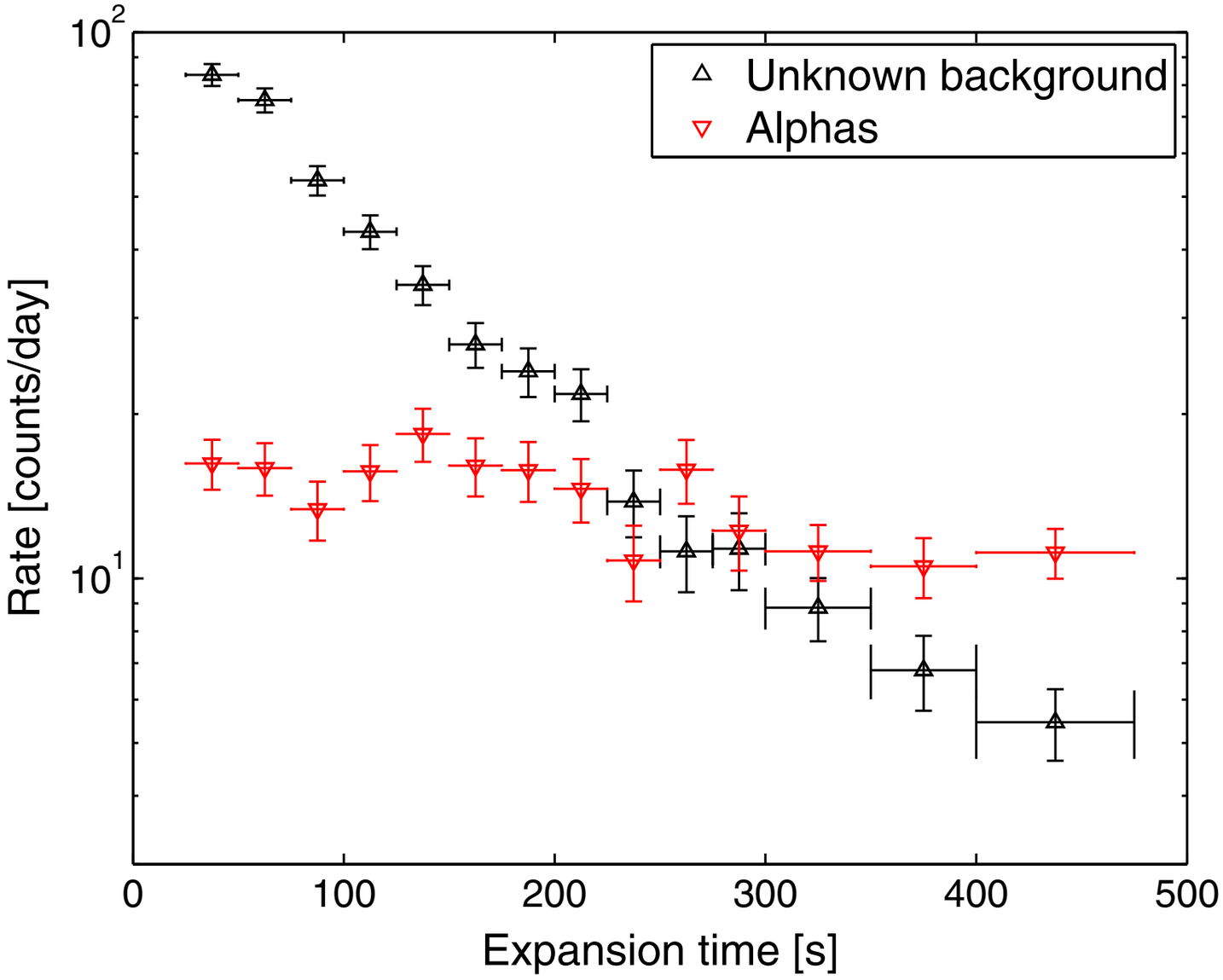
- Calibrations showed us a class of events which we did not understand

PICO-60 Background - Geographically

- These events were preferentially located at the surface
- Also some increase along the wall



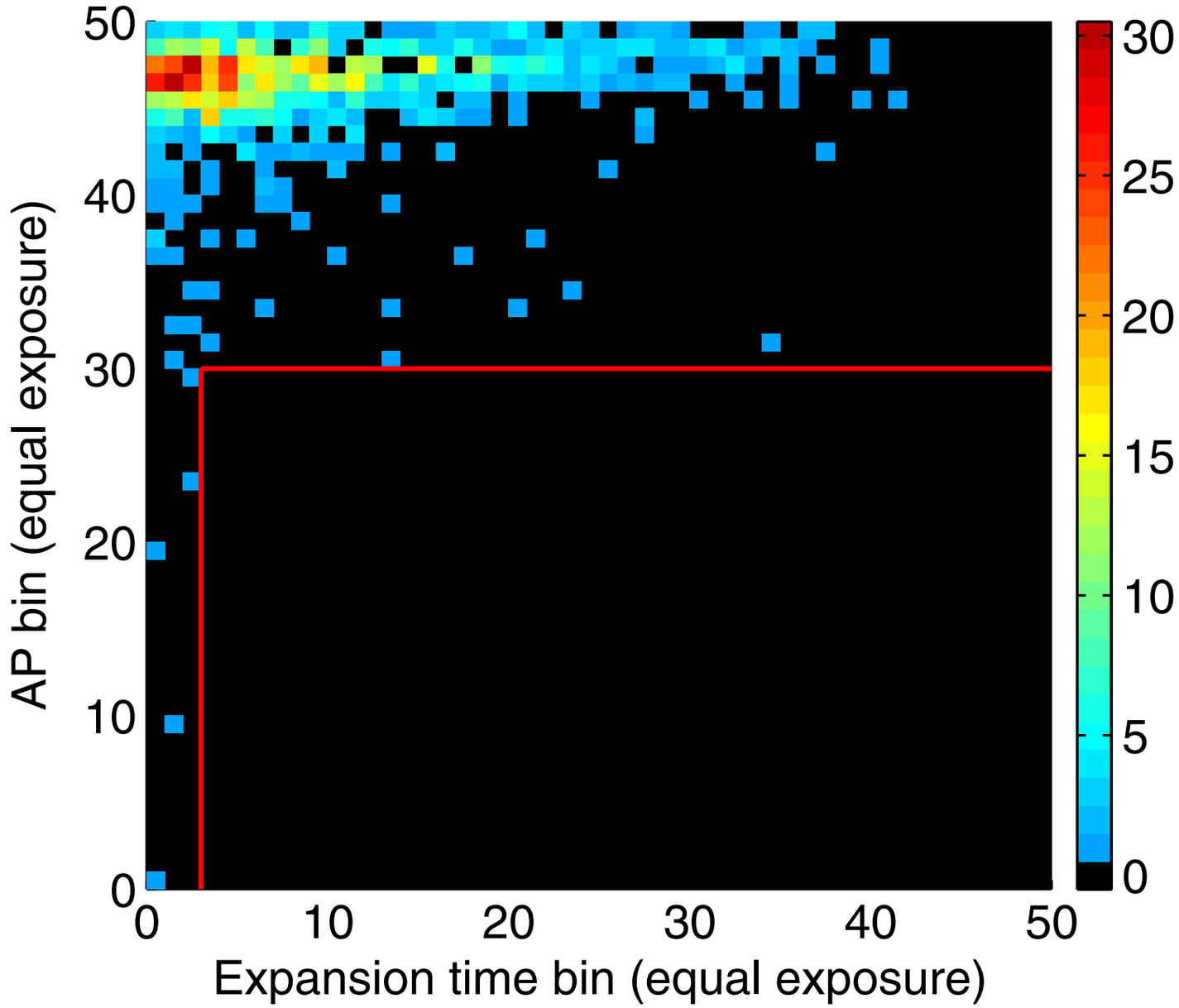
PICO-60 Background - Temporally



- Isolating low-AP events showed a time correlation with expansions

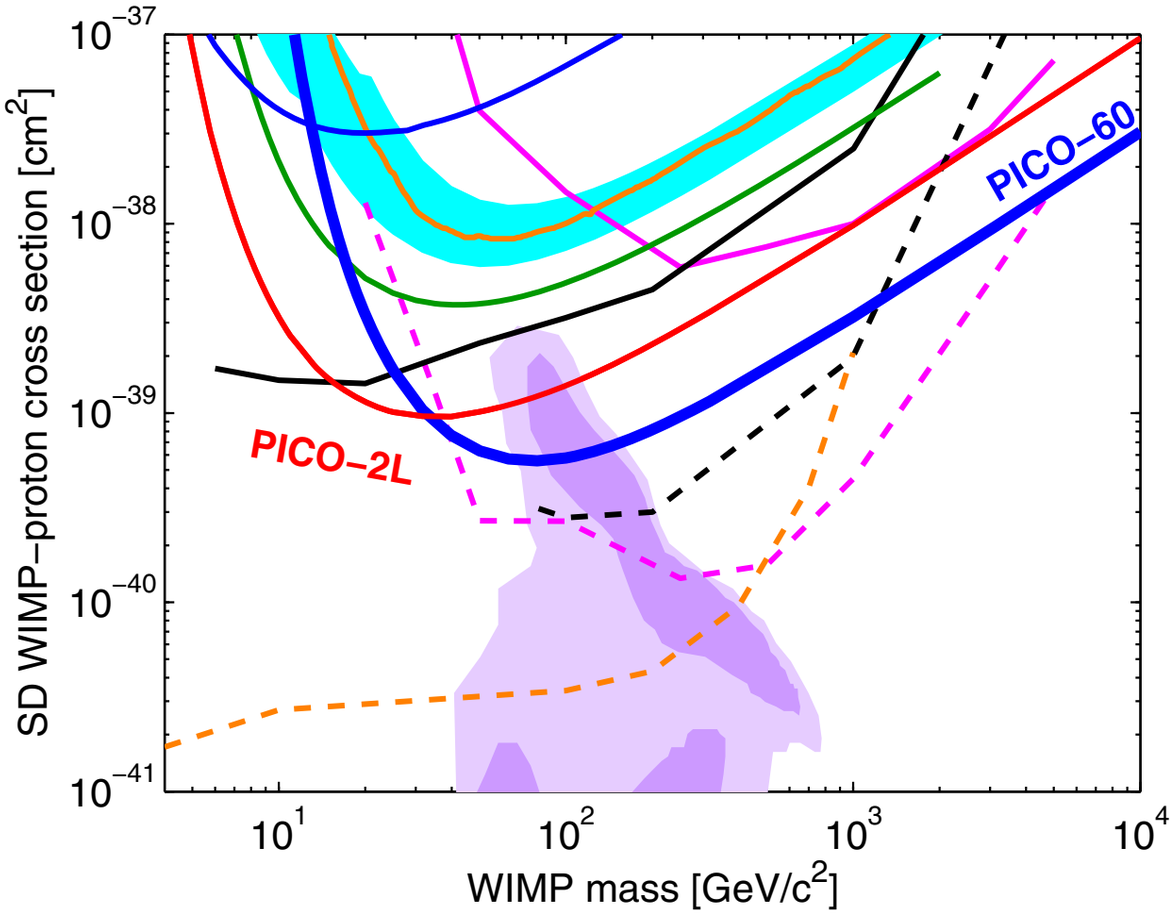
PICO-60 Run 1 Results

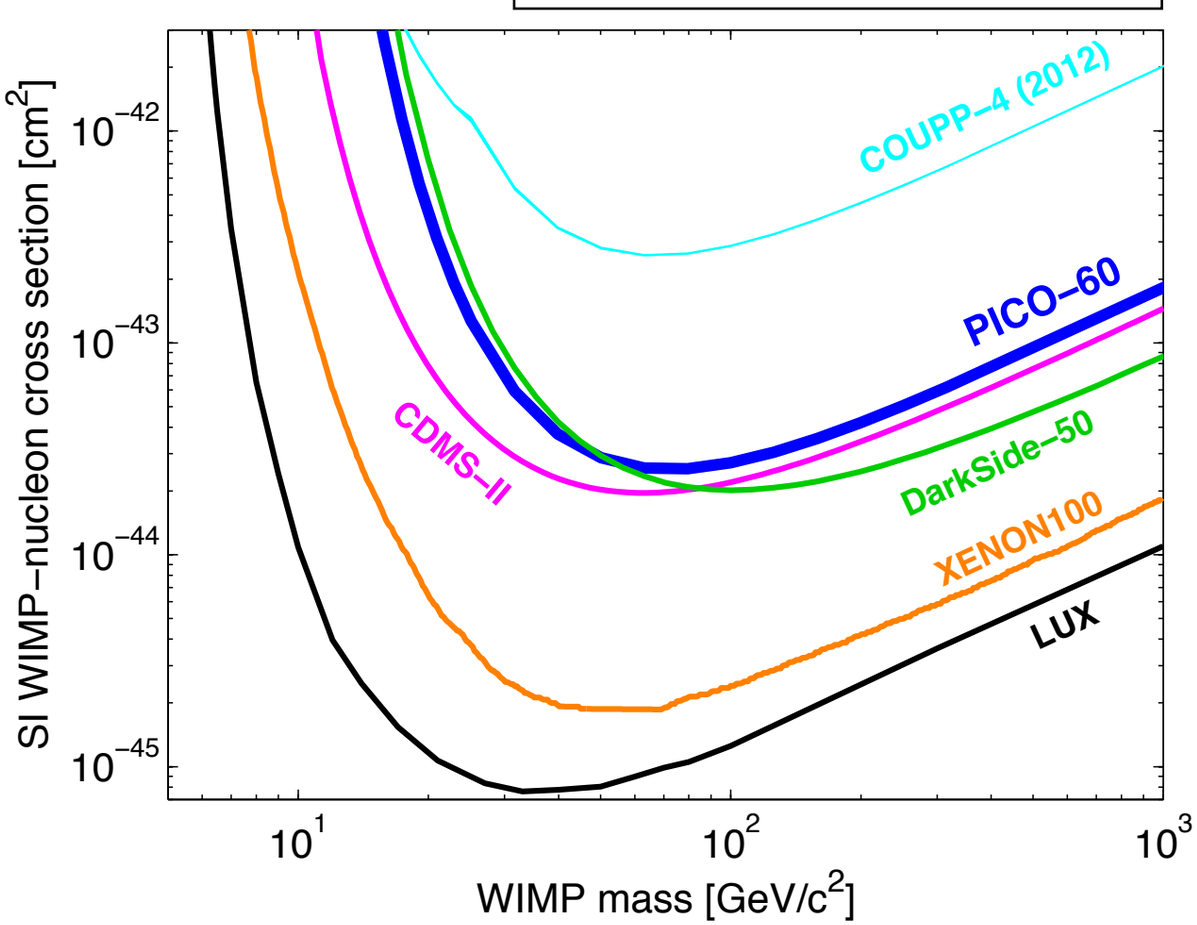
- Defined a “clean” region away from this class of events to produce a result



PICO-60 Run 1 Results

Phys. Rev. D 93, 052014 (2016)

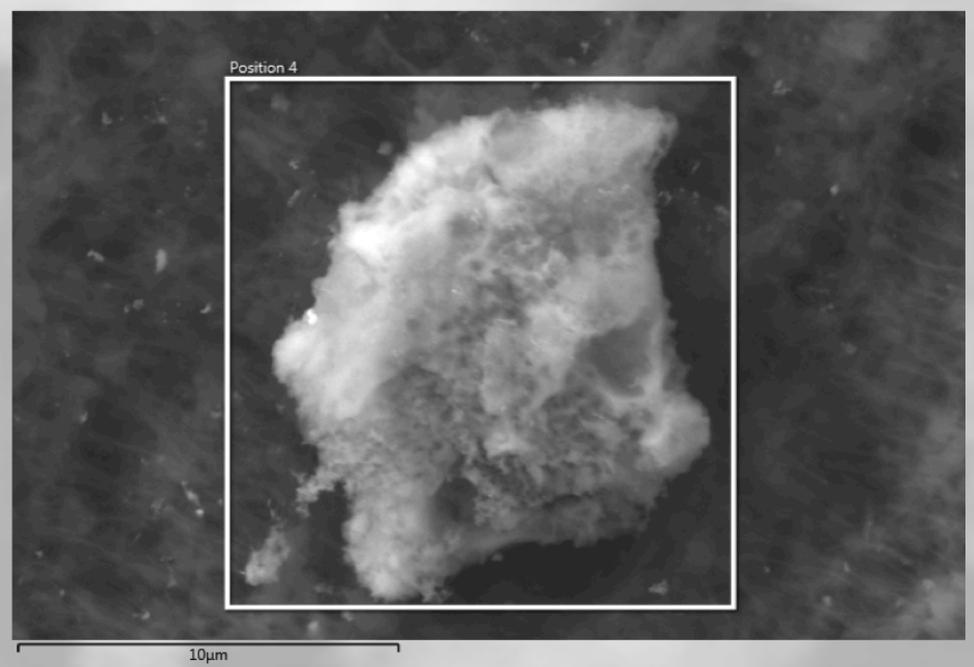


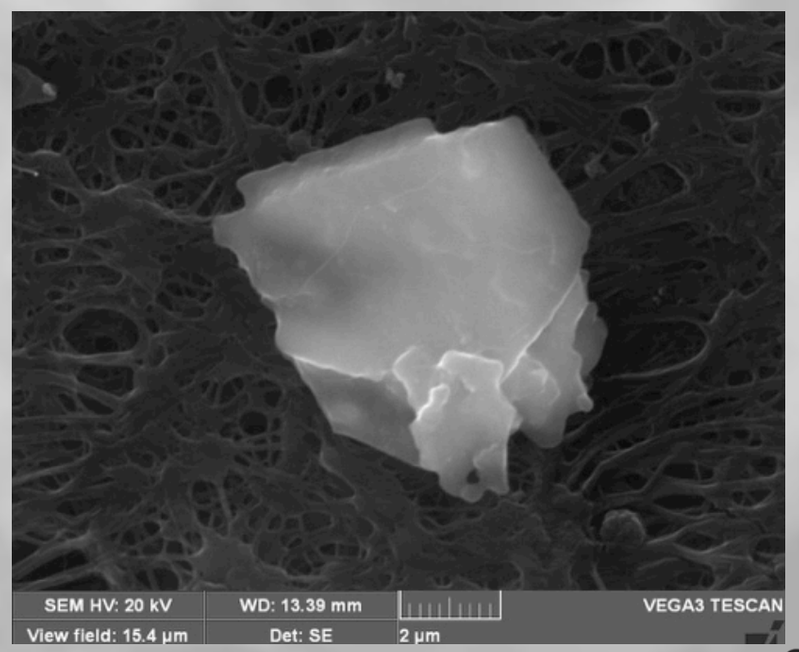


- World-leading SD WIMP proton above 25GeV
- Statistical penalty for cutting data calculated via Monte Carlo

PICO-60 Assay

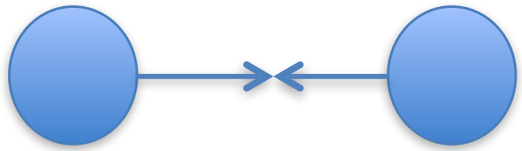
- Radioactive particulates were suspected to be part of the problem after run I ended. Careful assays of the liquids after the end of the fill revealed contamination with mostly steel and silica particulates
- The radioactivity of the material is not sufficient to explain the backgrounds observed



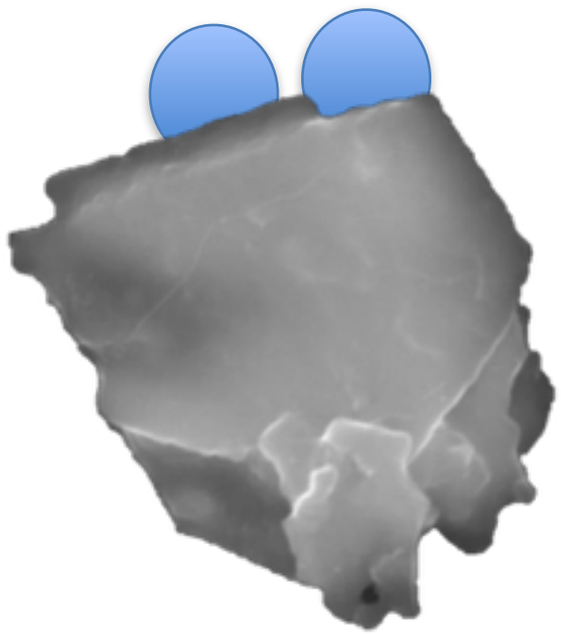


Surface Tension

- Surface tension in a 50nm bubble ~3.5keV



- Merging bubbles release a significant fraction of that energy

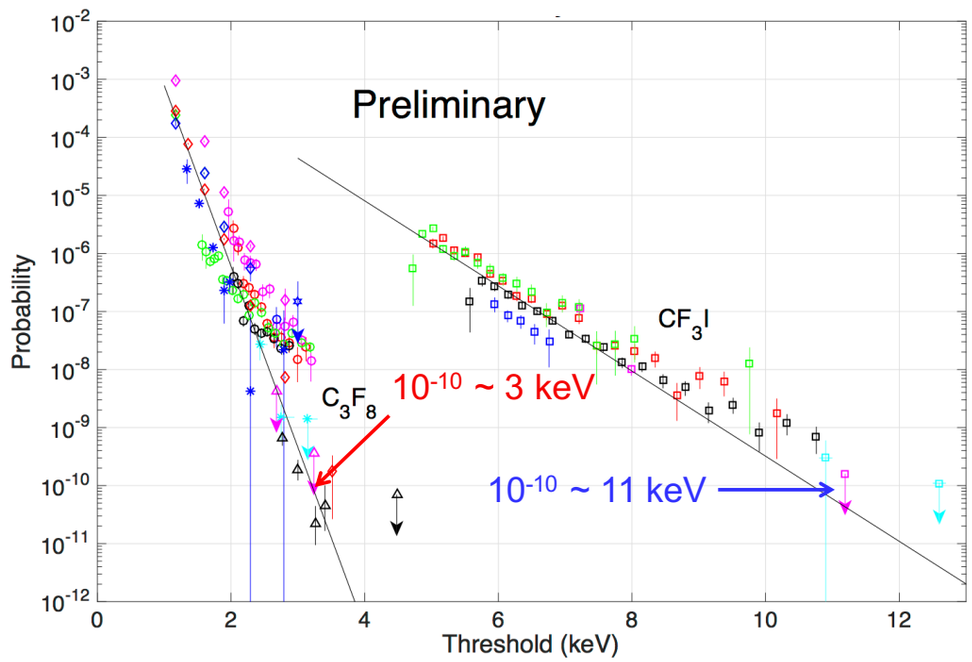


- The water also lowers the bubble nucleation threshold, so the released energy can nucleate bubbles at PICO operating thresholds of a few keV

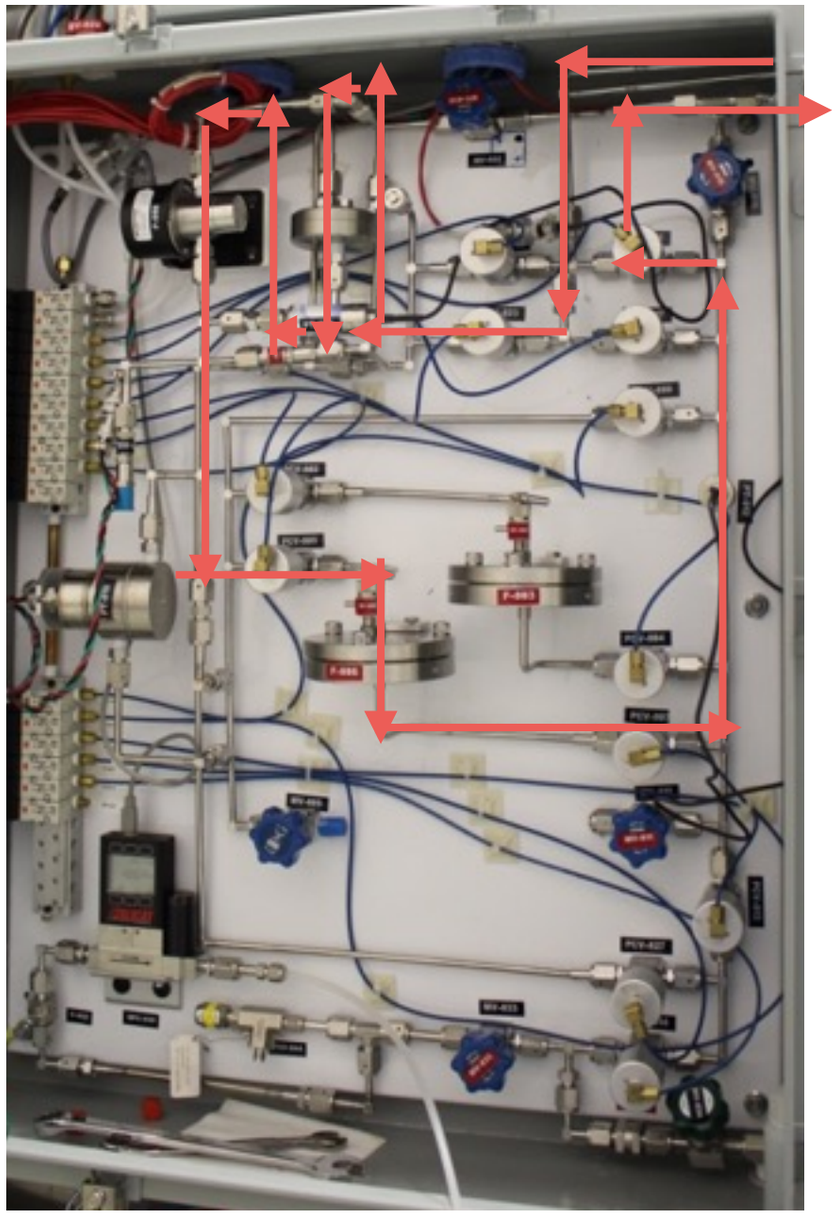
- Solid particulate is a location for the bubbles to merge

PICO-60 Run 2

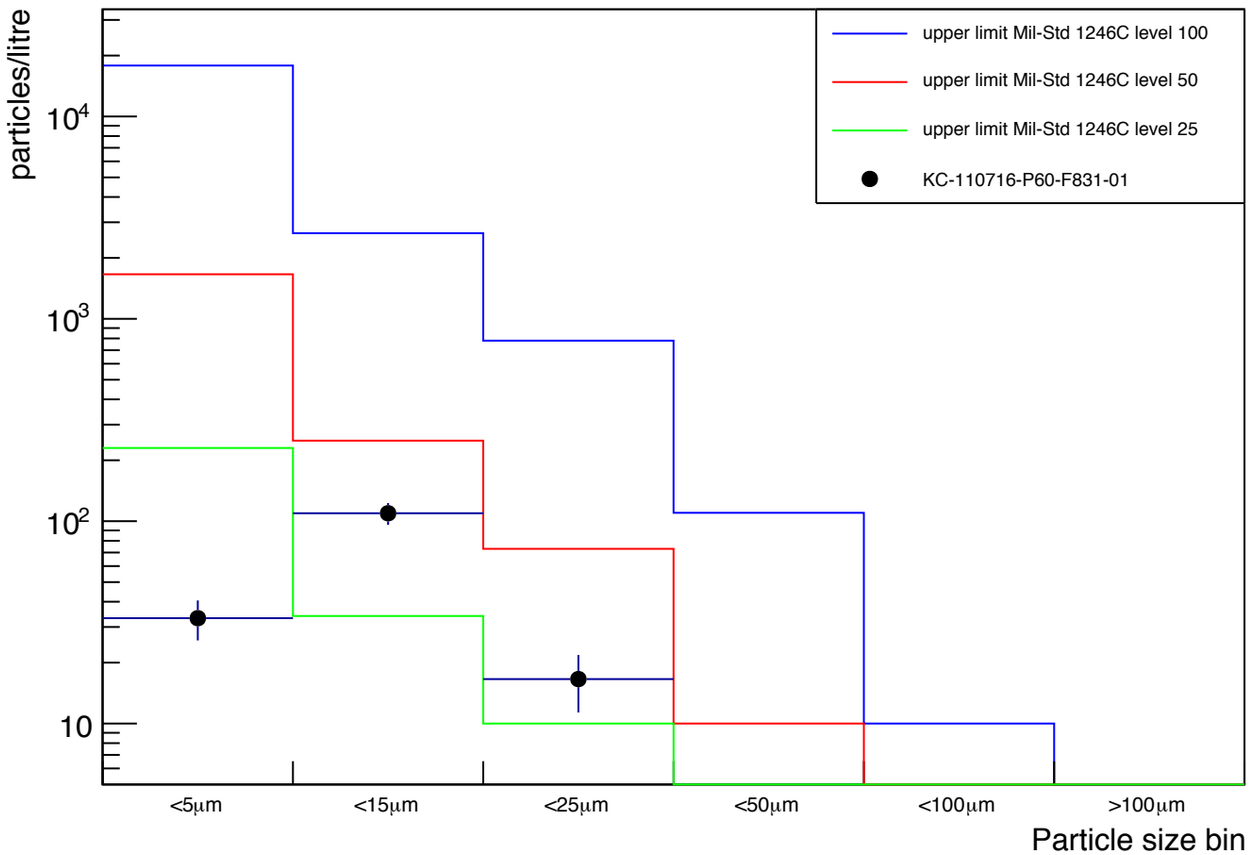
- After our experience with PICO-2L, pretty confident we know what the issue is
- Since we are making changes, let's do everything we can with this detector
- Start by switching to C_3F_8 to increase gamma rejection



PICO-60 Run 2



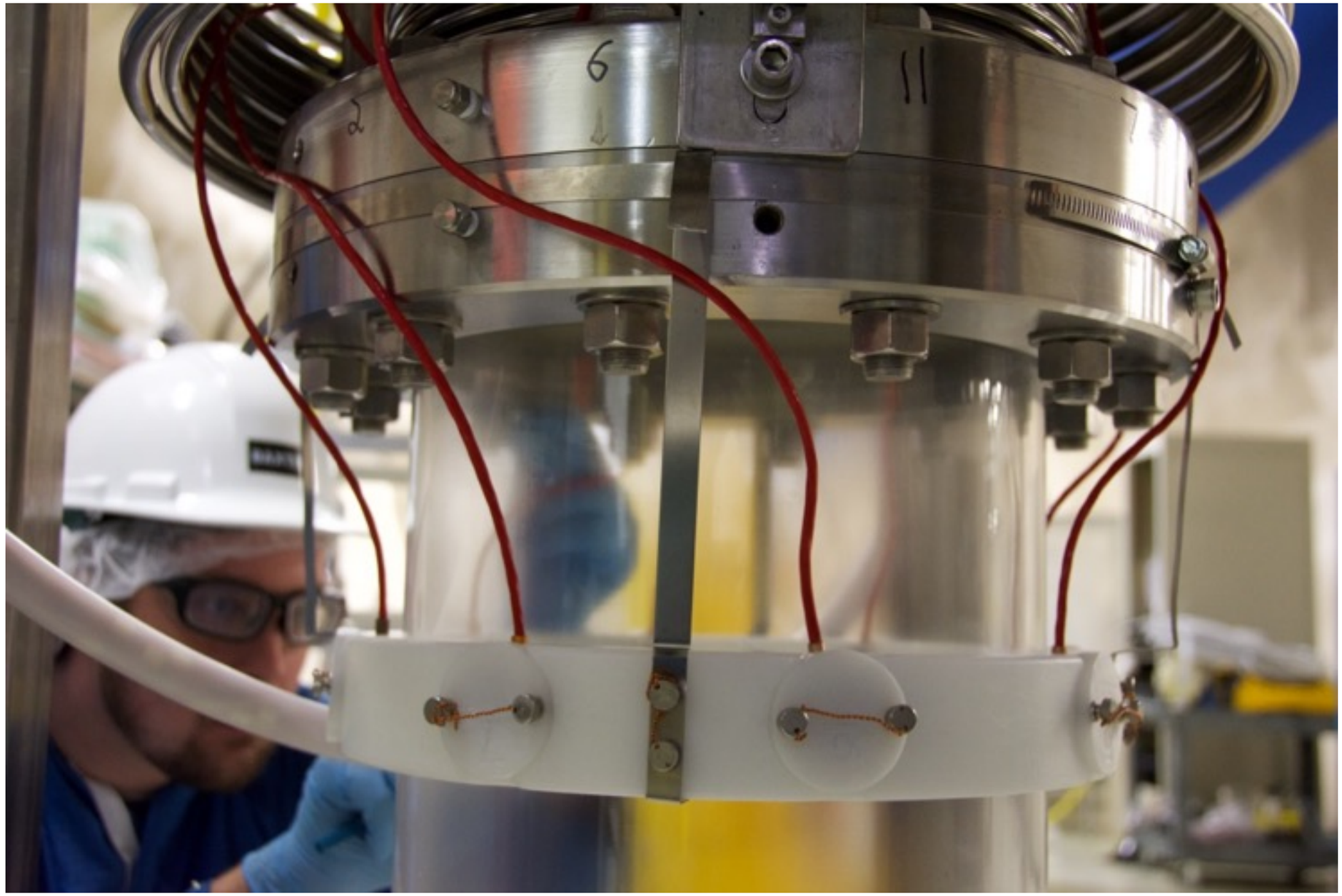
- Add a filtration system to remove the particulates
- This is monitored and has achieved military specifications



PICO-60 Run 2

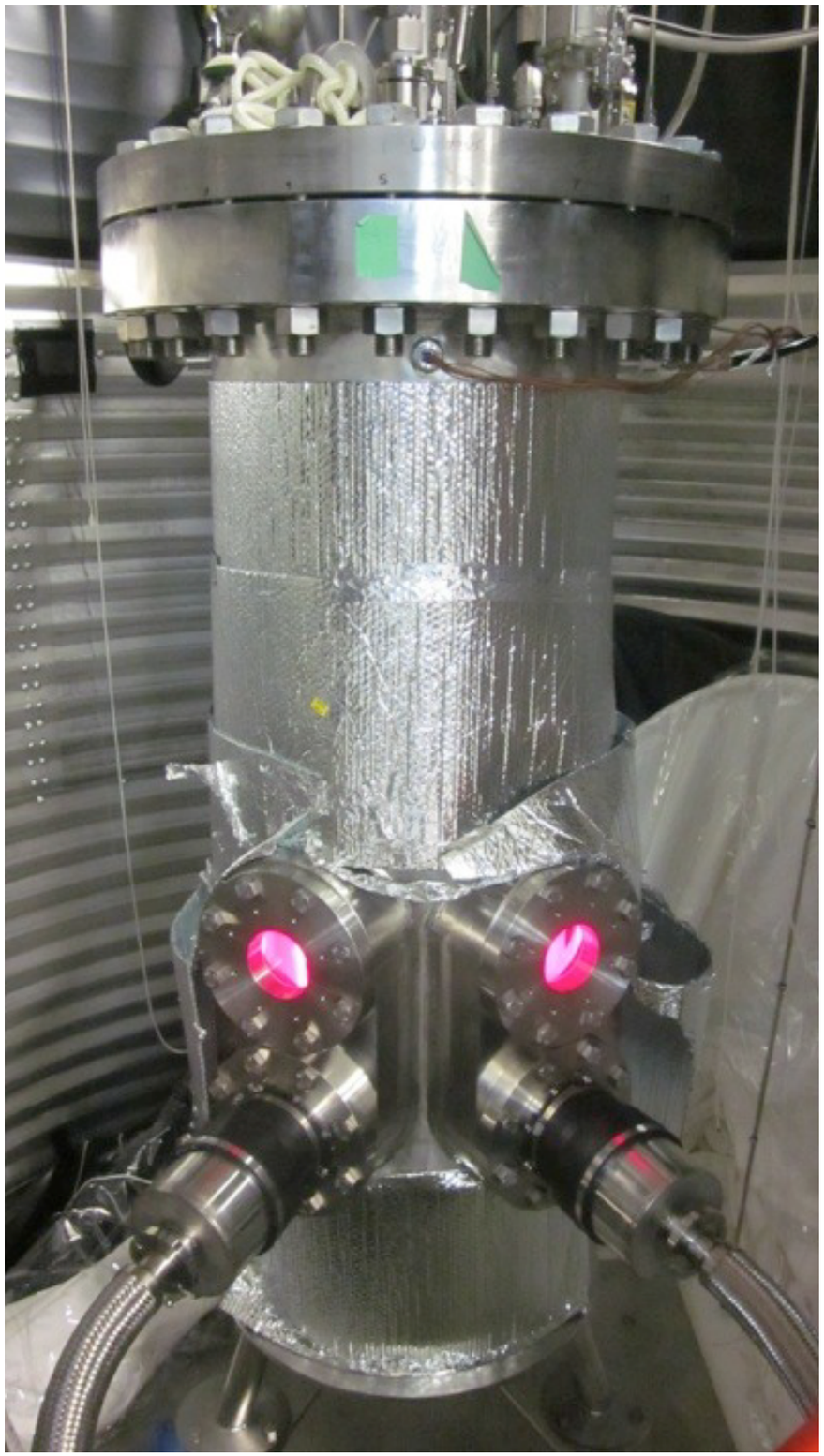
- Cleaning was even more stringent than previous runs
- A special rig was designed to clean the jar with heated surfactant

PICO-60 Run 2



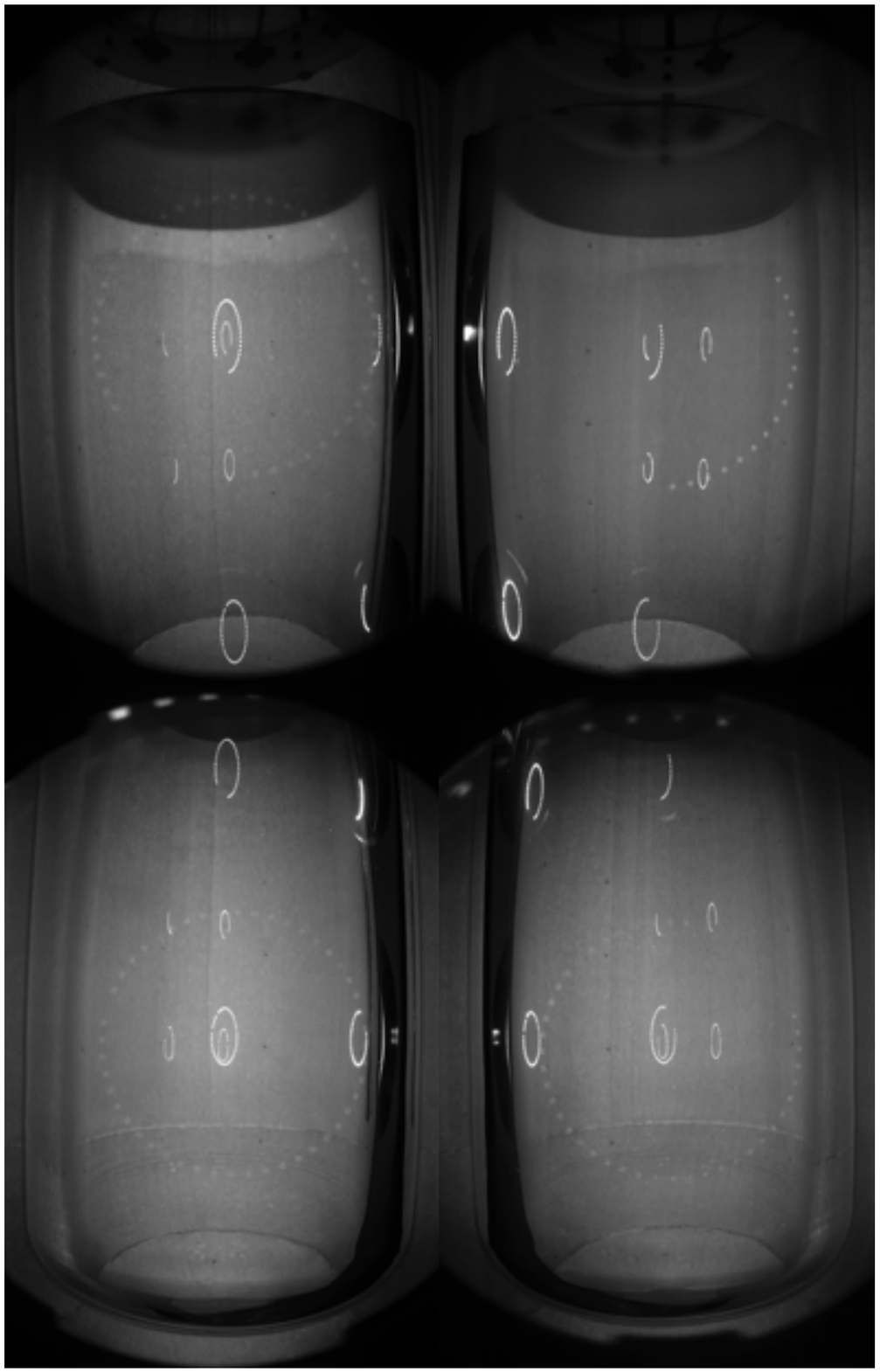
- The number of piezos was increased and the mounting system upgraded

PICO-60 Run 2



- Double the number of cameras (from 2 to 4)
  - Doubles the active mass viewed
- Increase the rate to 340 frames per second

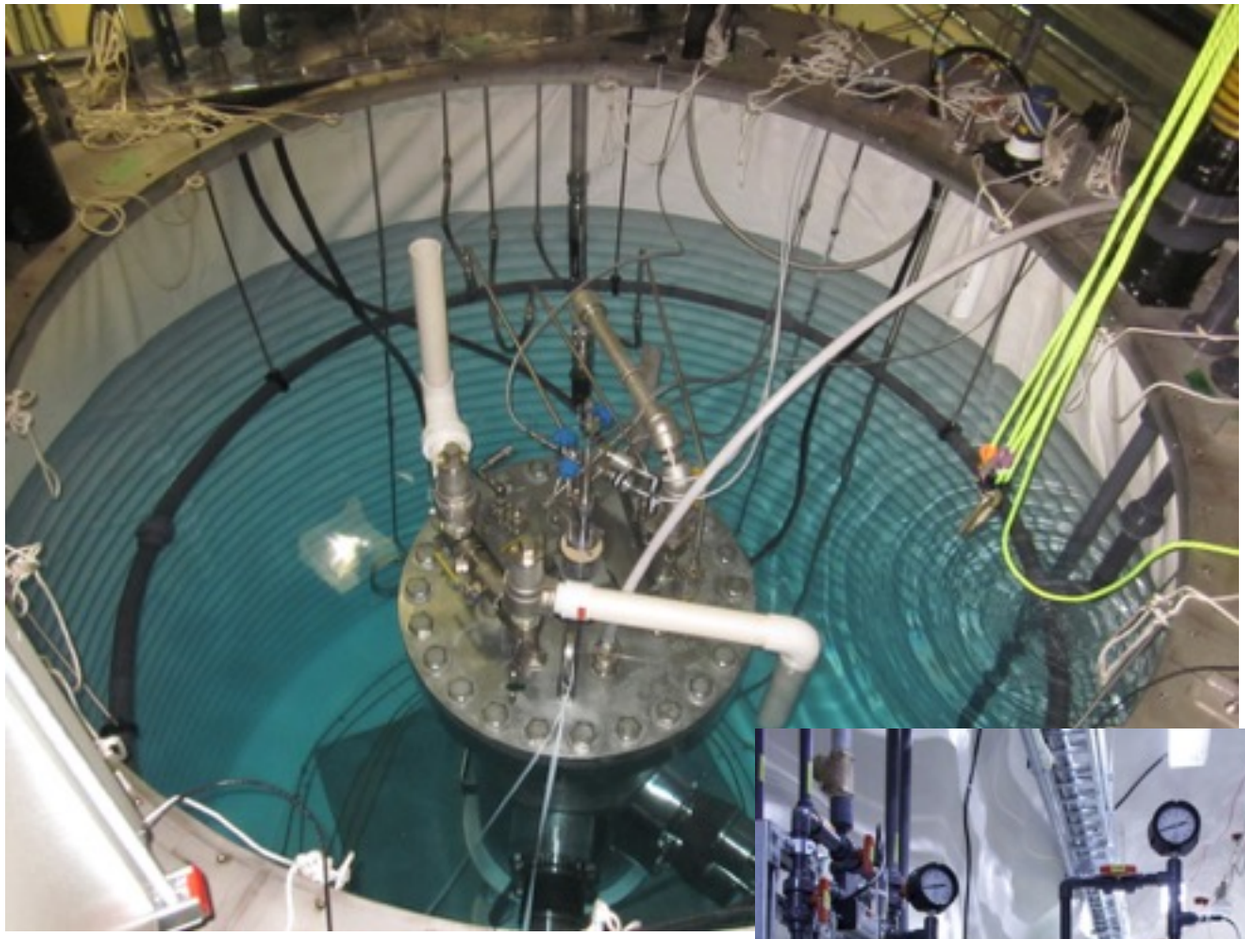
PICO-60 Run 2



- Double the number of cameras (from 2 to 4)
  - Doubles the active mass viewed
- Increase the rate to 340 frames per second

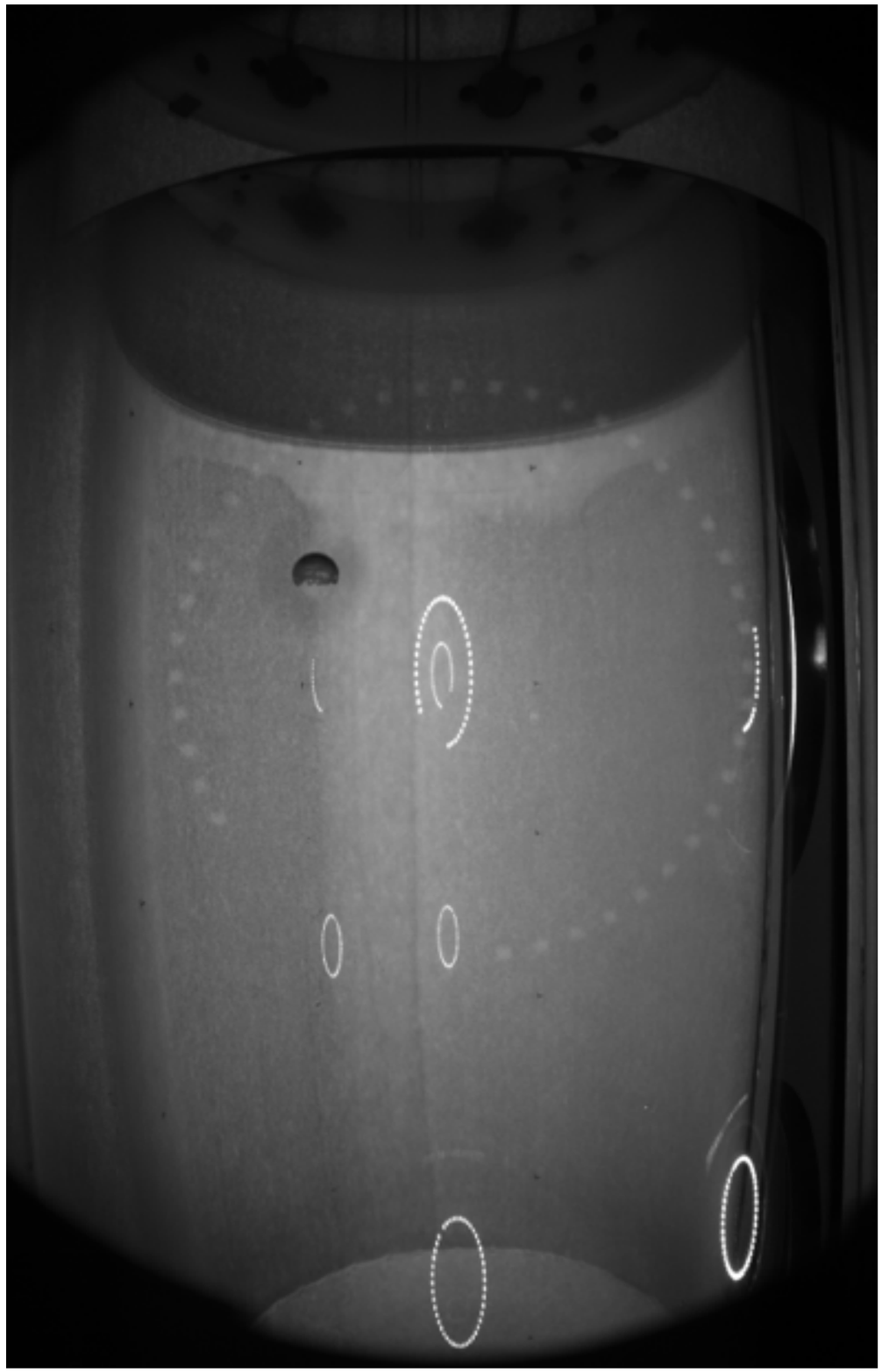
PICO-60 Run 2

- The water tank temperature control system also improved
- Significantly aids in the threshold setting



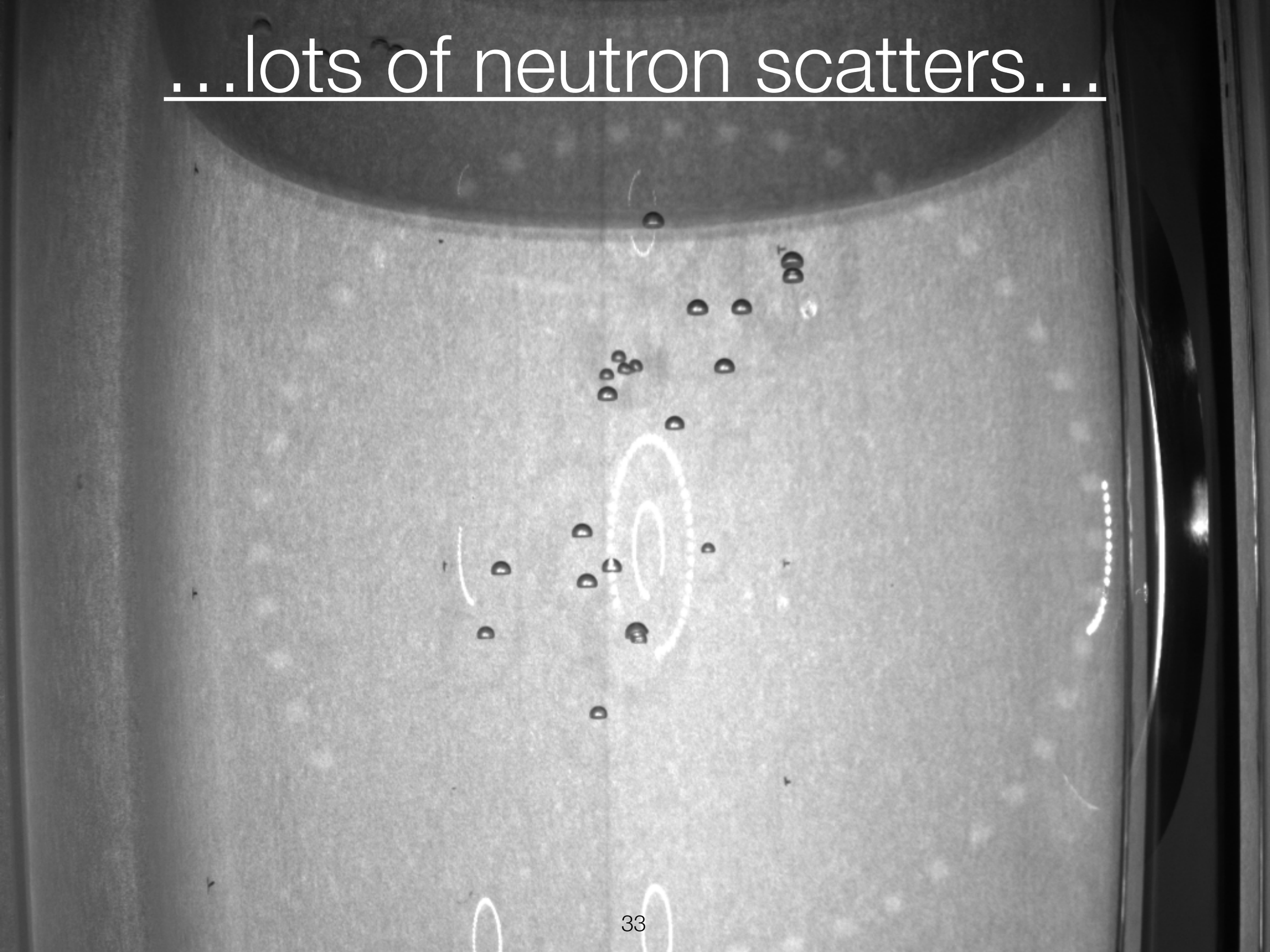
- A filtration system was also included to remove biological contaminants

PICO-60 Data!



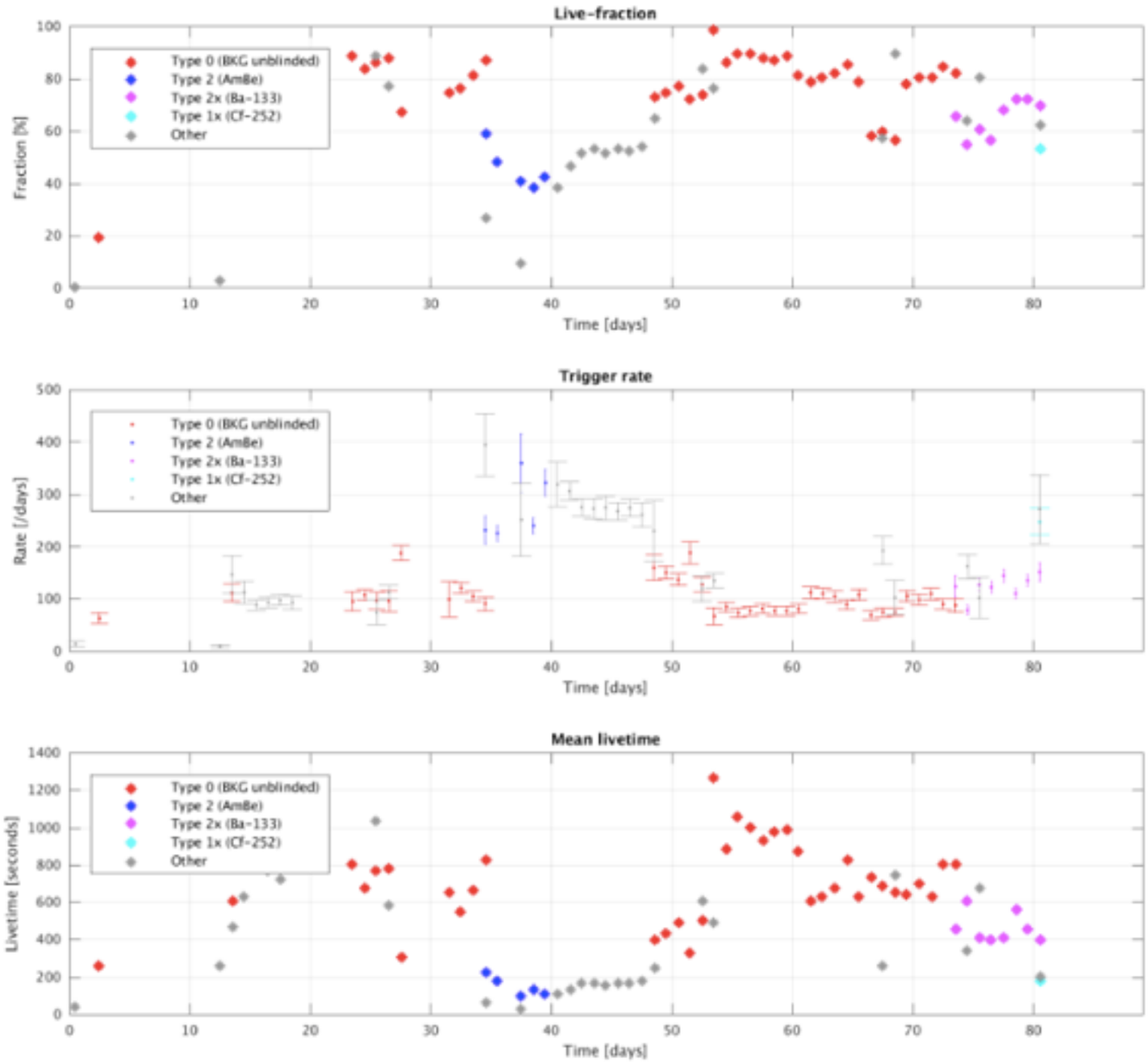
- The first bubble was seen August 1, 2016
- This was without the water shield, which was filled over the next week
- Lack of an active shield meant muons were seen…

…lots of neutron scatters…

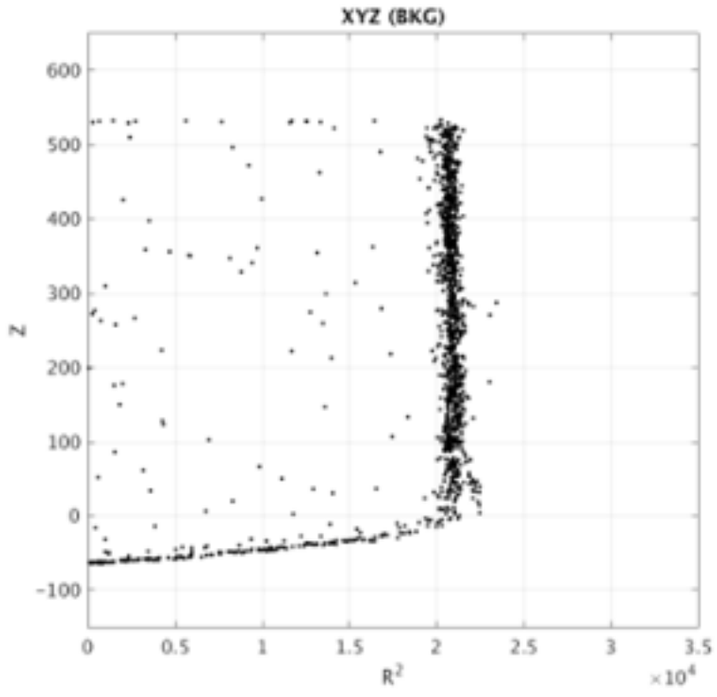


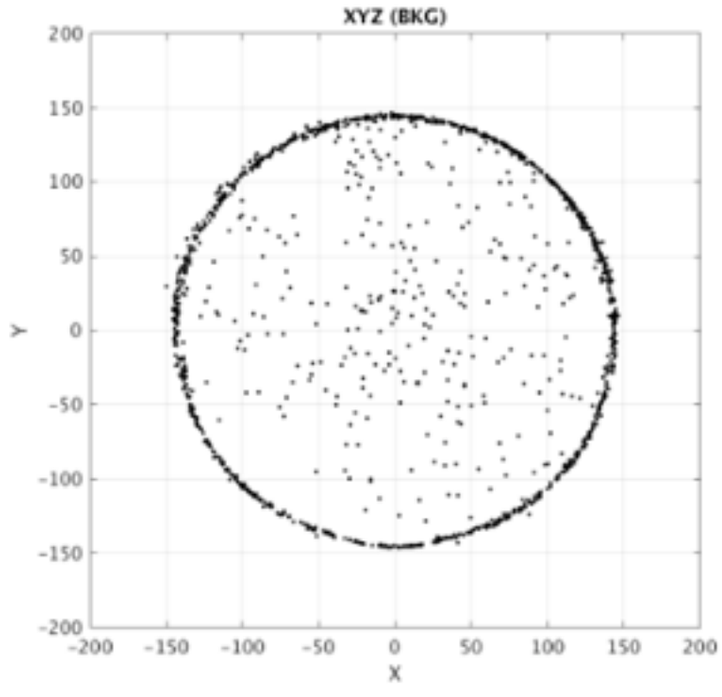
PICO-60 Running

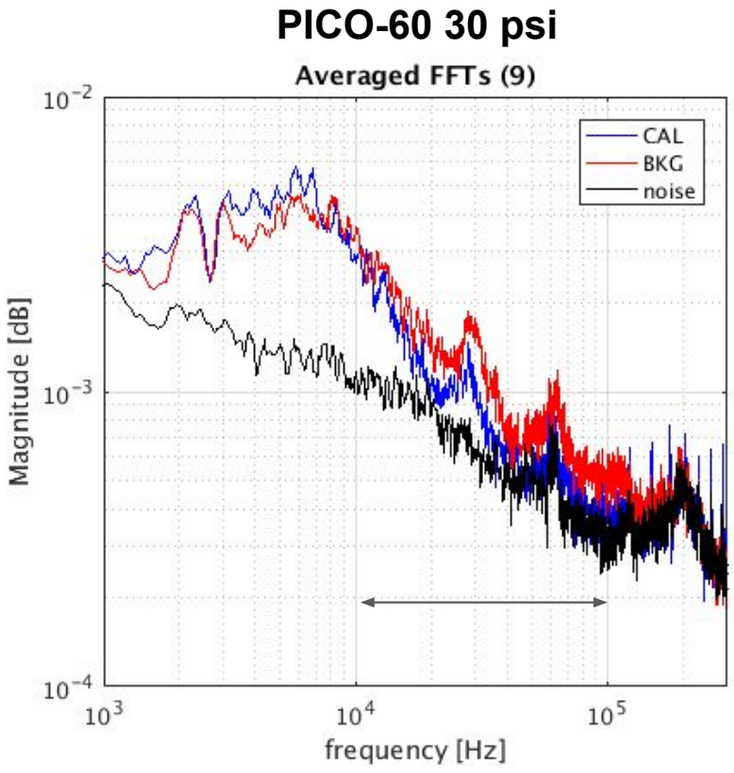
- Primarily calibration runs for now, with some other tests mixed in

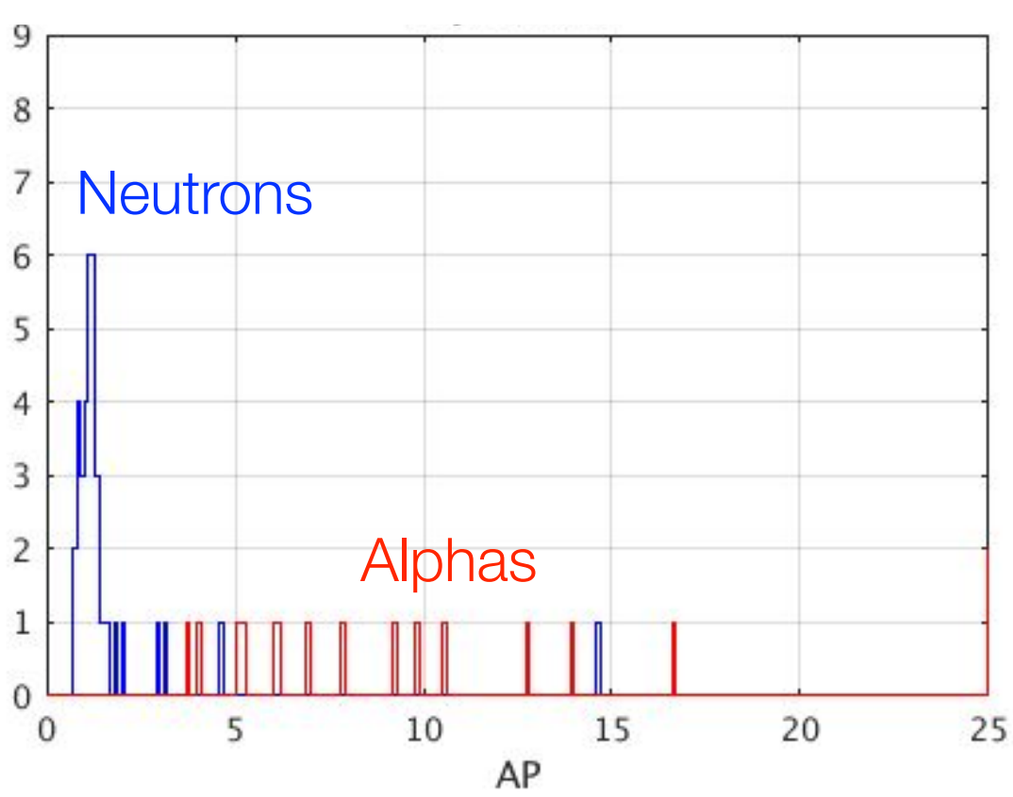


All Systems go!

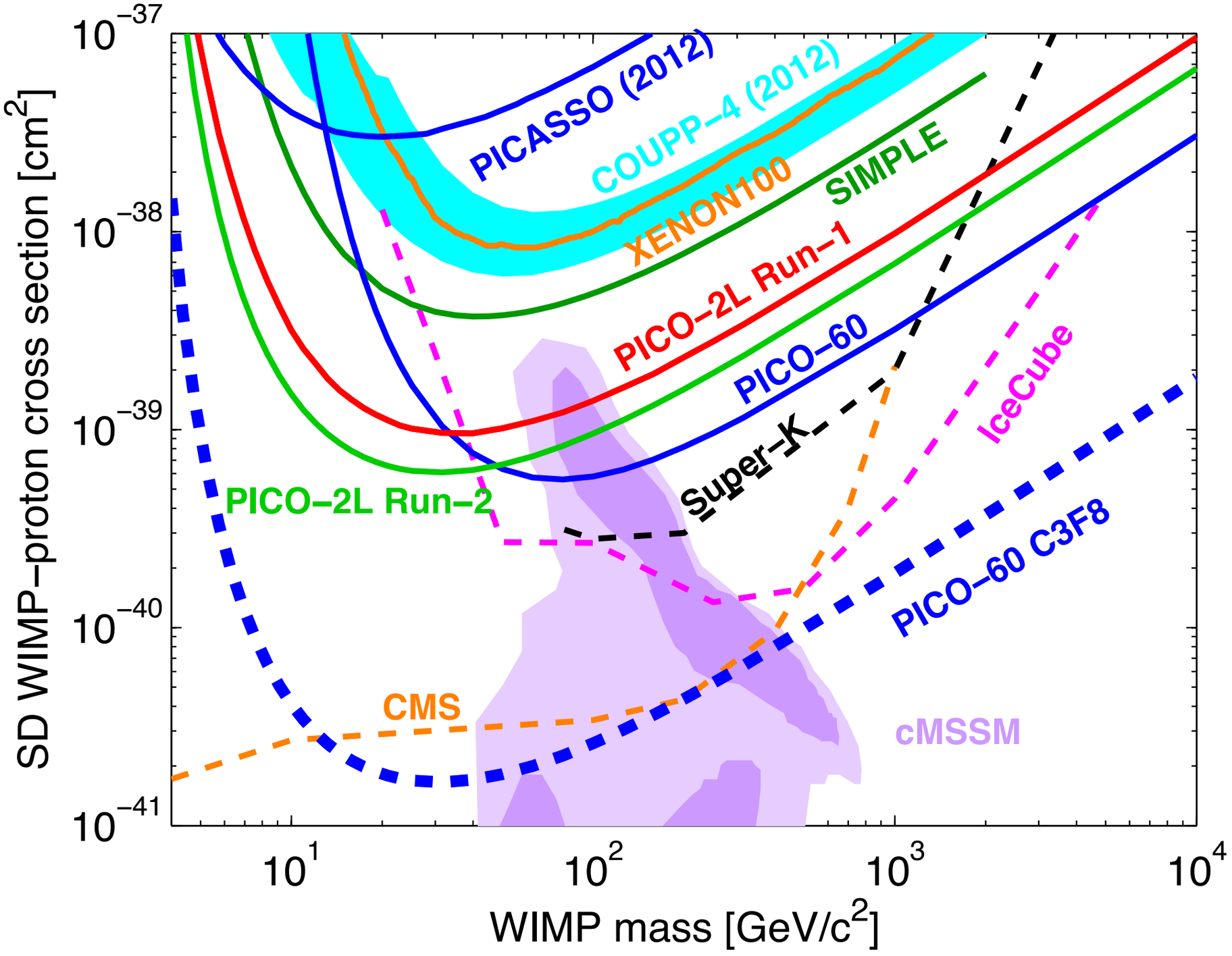








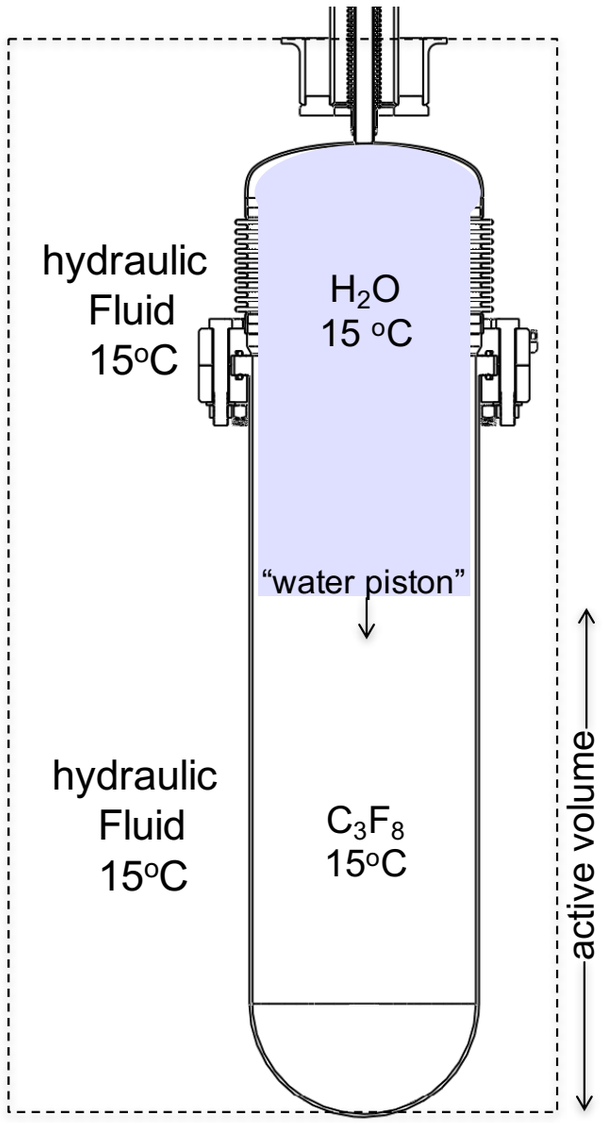
PICO-60 Run 2 Projection



The Future

- Many problems seem connected to water/active fluid interface

PICO-60



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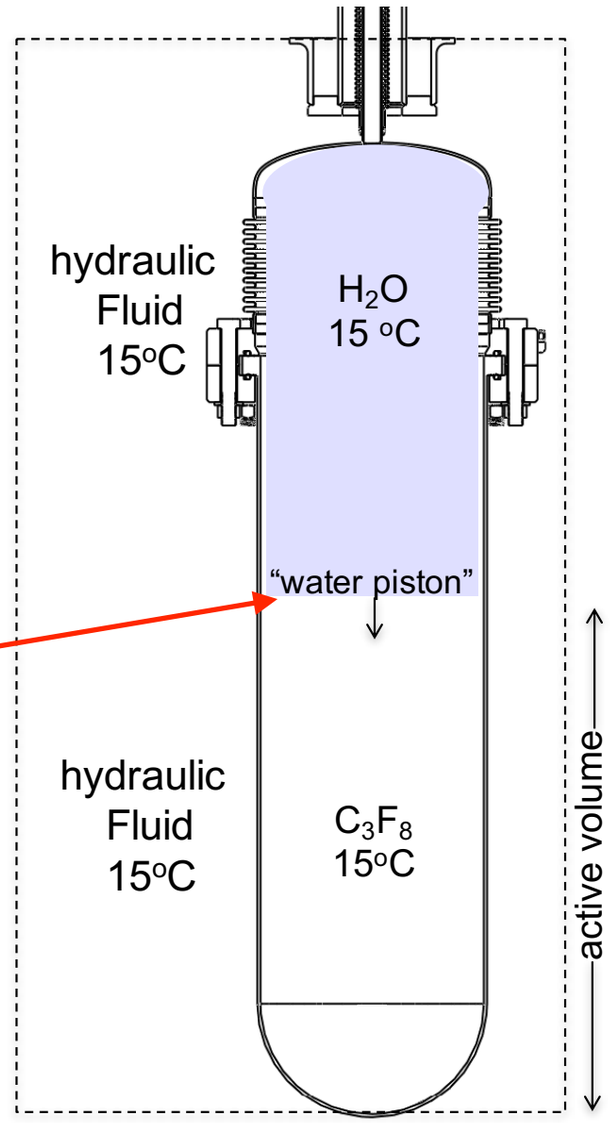
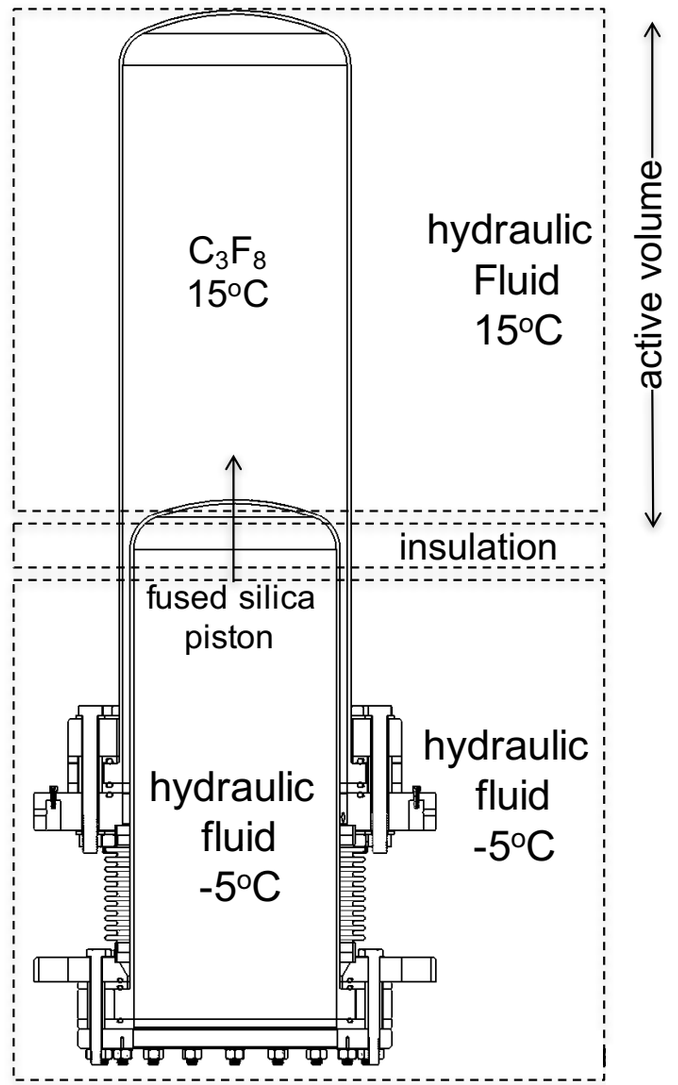


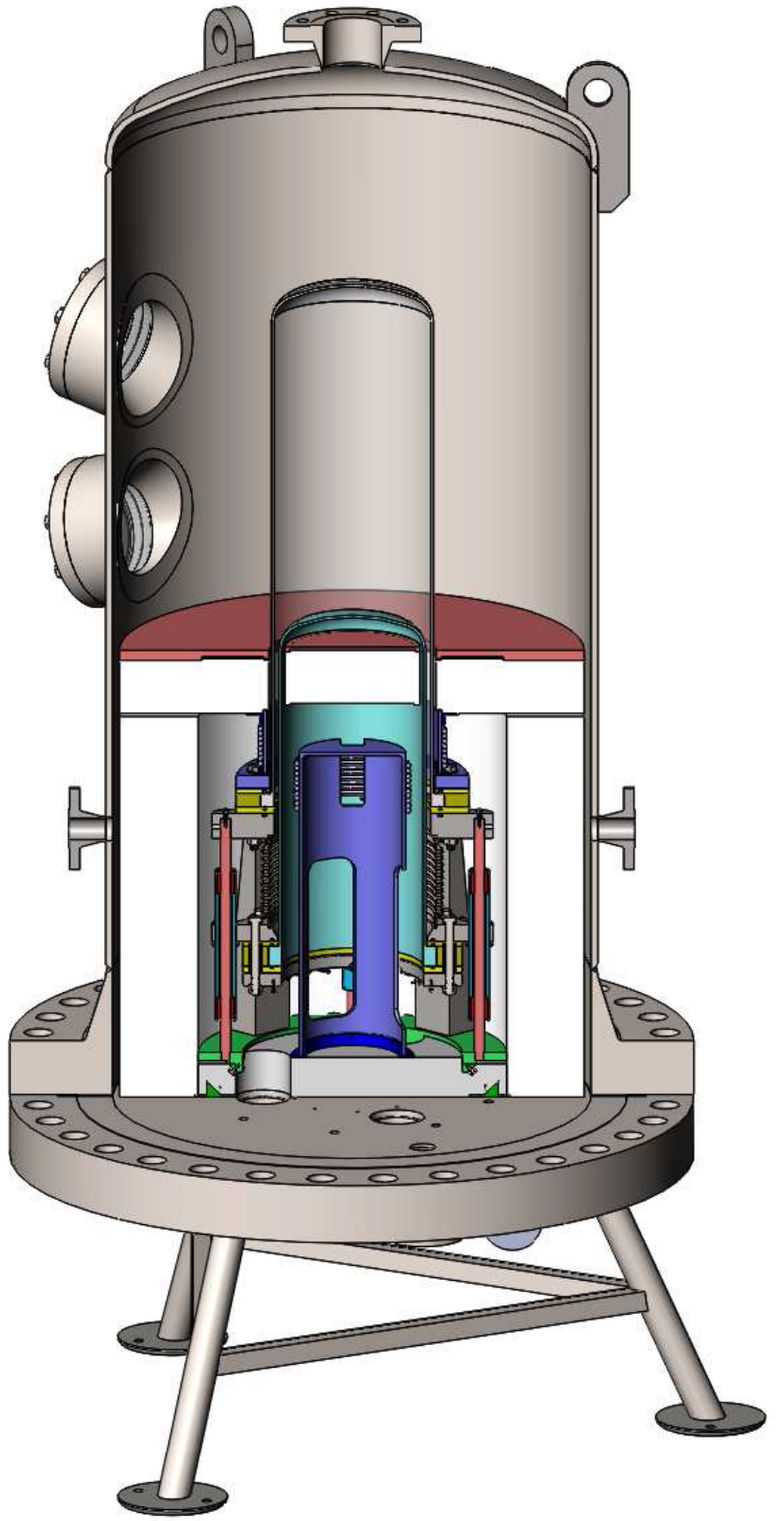
Remove this interface, contact between active fluid H_2O



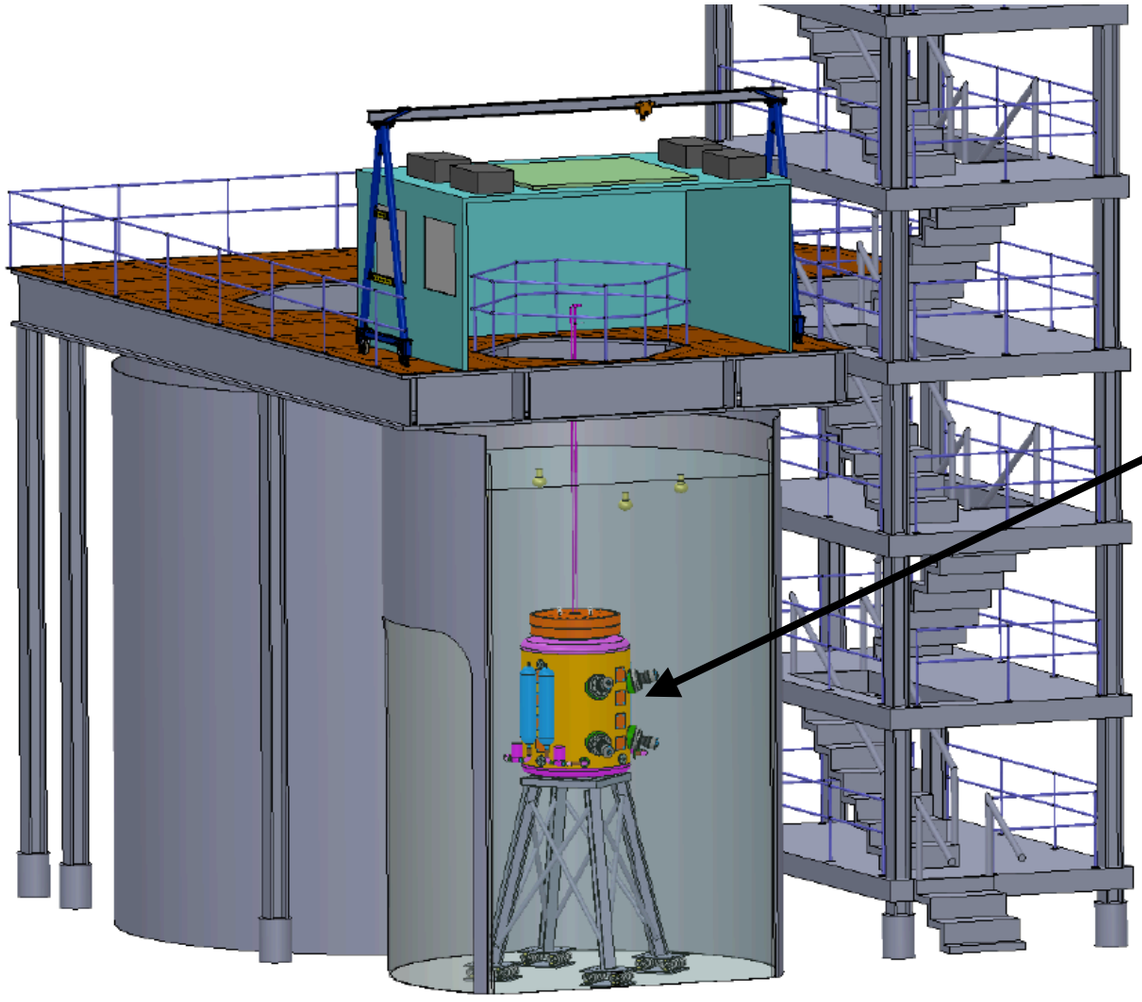
PICO-40L

PICO-40L

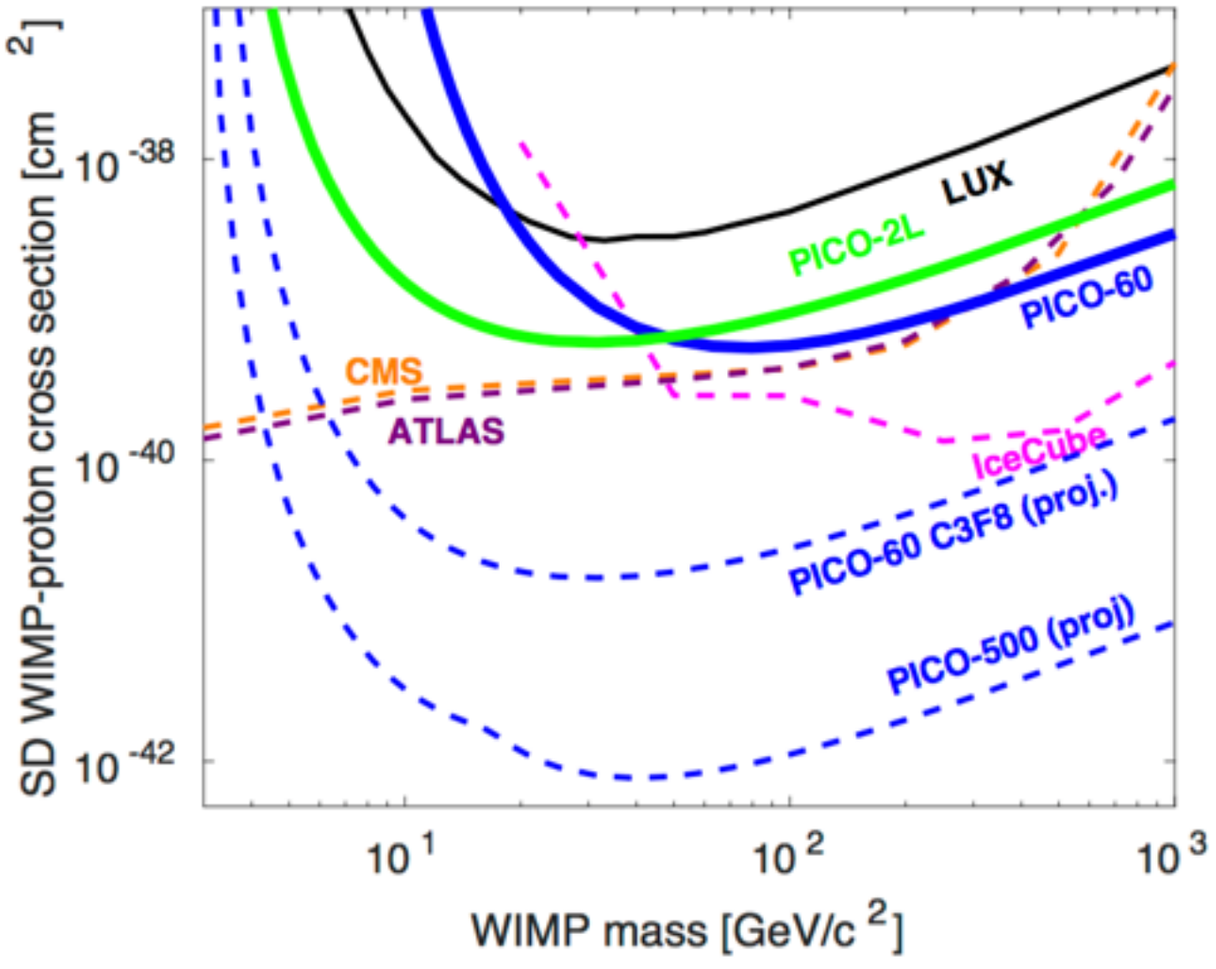
- Longer lead time items already under construction
- Location in SNOLAB secured
- Currently looking into improving piezo mounts, temperature control



The Further Future



Increase from 40L (our planned detector) to 500L



Conclusion

- PICO has investigated many backgrounds, developed a detector sensitive to small energy deposits
- PICO-60 (currently running) and PICO-40L (construction early 2017) will explore a large area of SD parameter space
- PICO-500 scheduled to operate in 2018

PICO

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

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