

PICO Dark Matter Searches

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PICO



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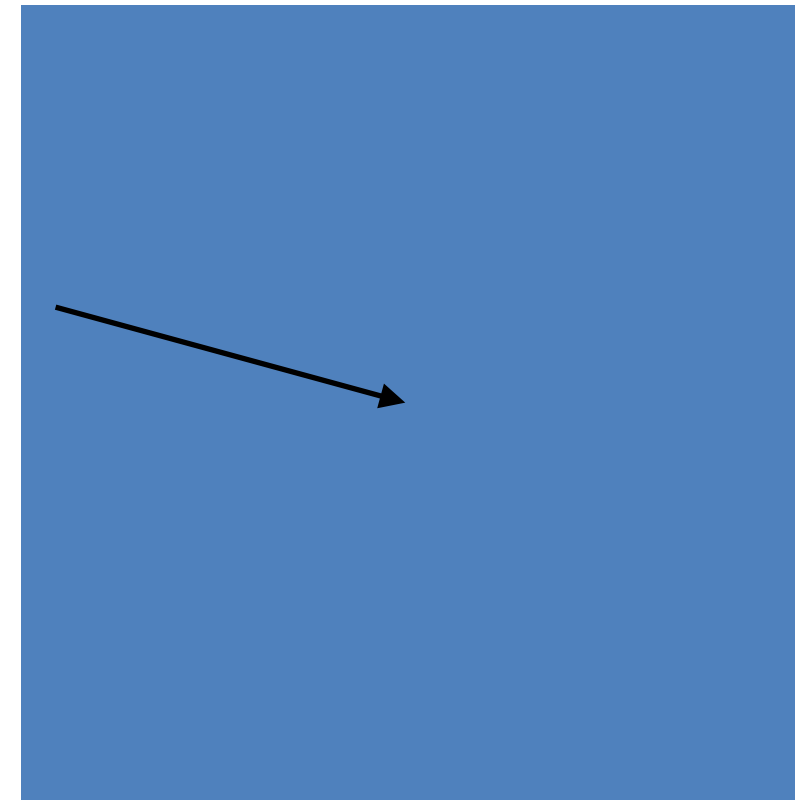
Particle detection with bubble chambers

- A bubble chamber is filled with a superheated fluid in meta-stable state



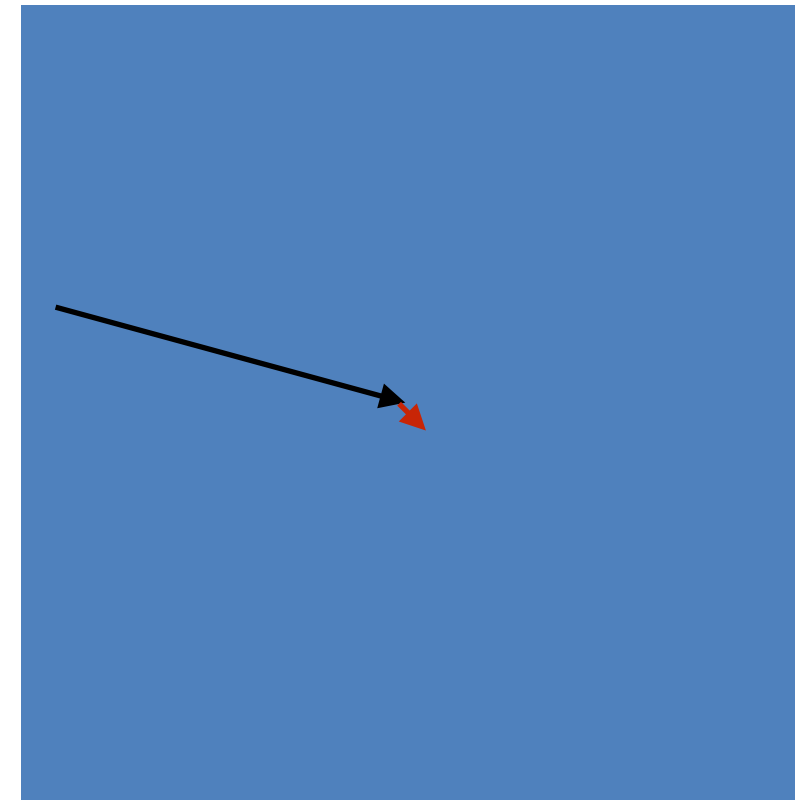
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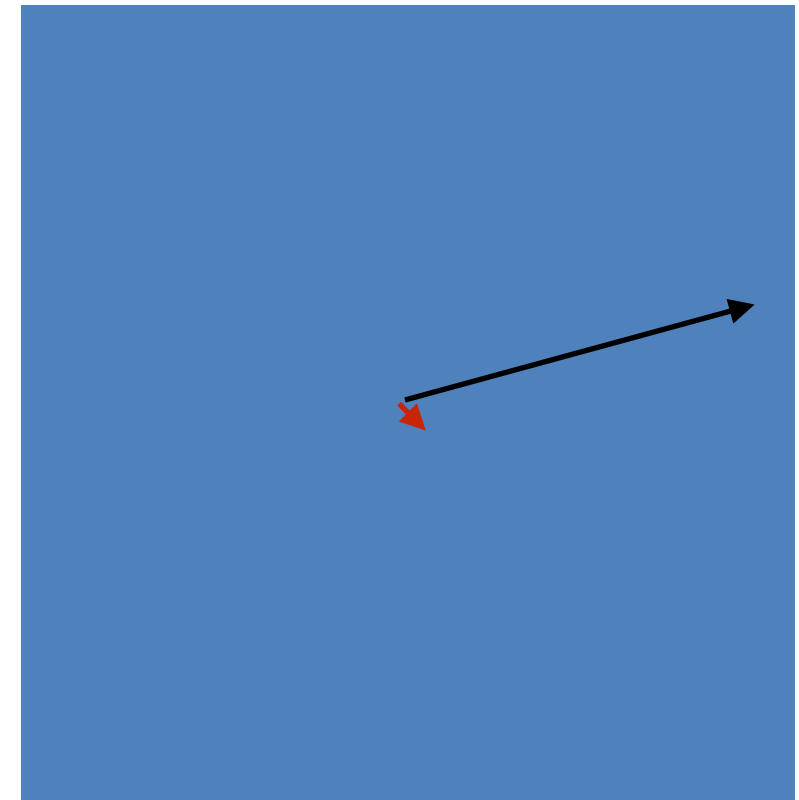
Particle detection with bubble chambers

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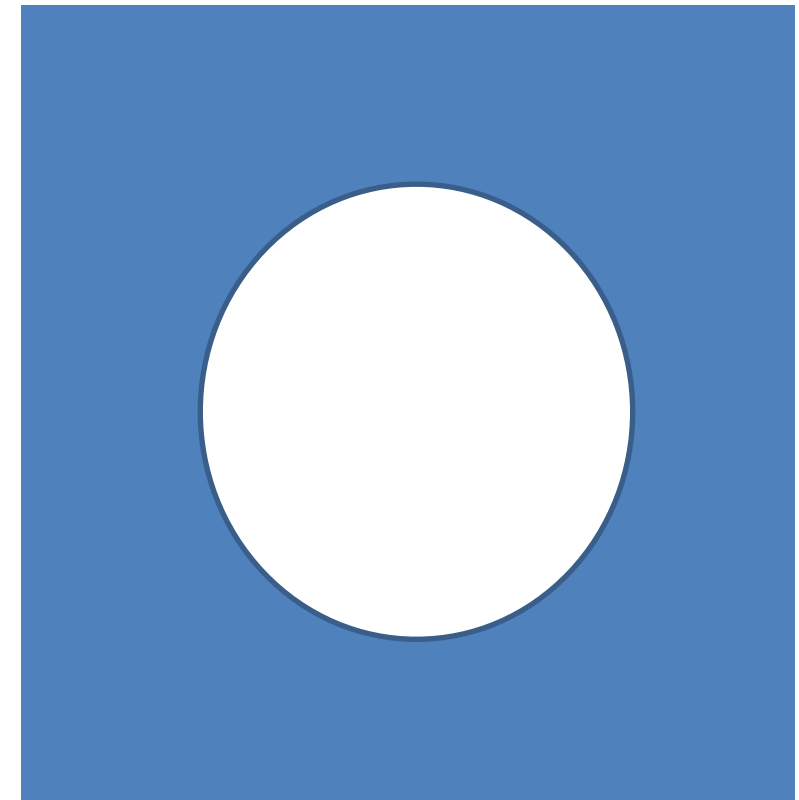
Particle detection with bubble chambers

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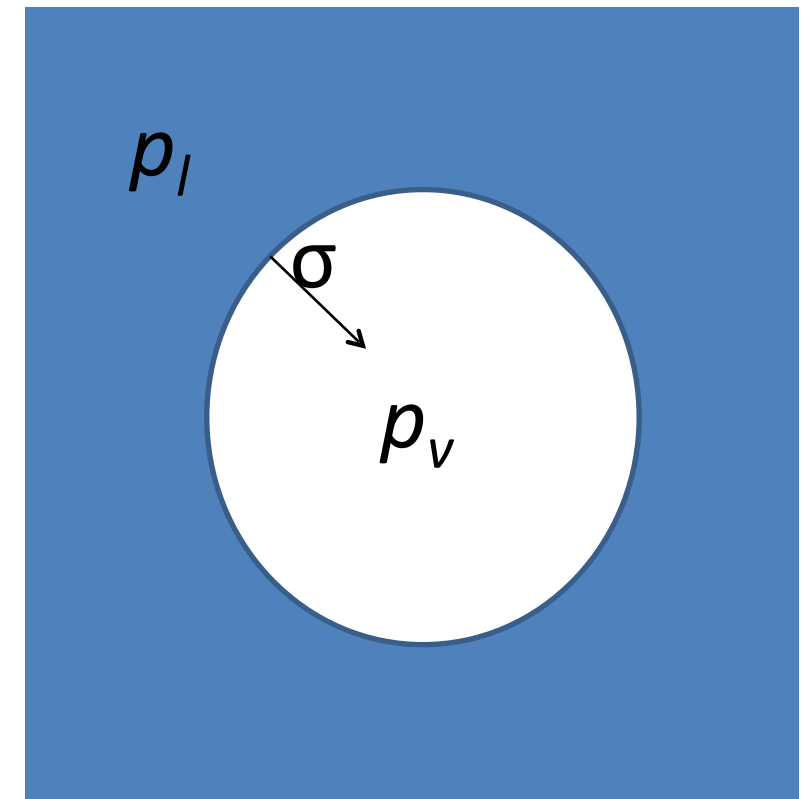
Particle detection with bubble chambers

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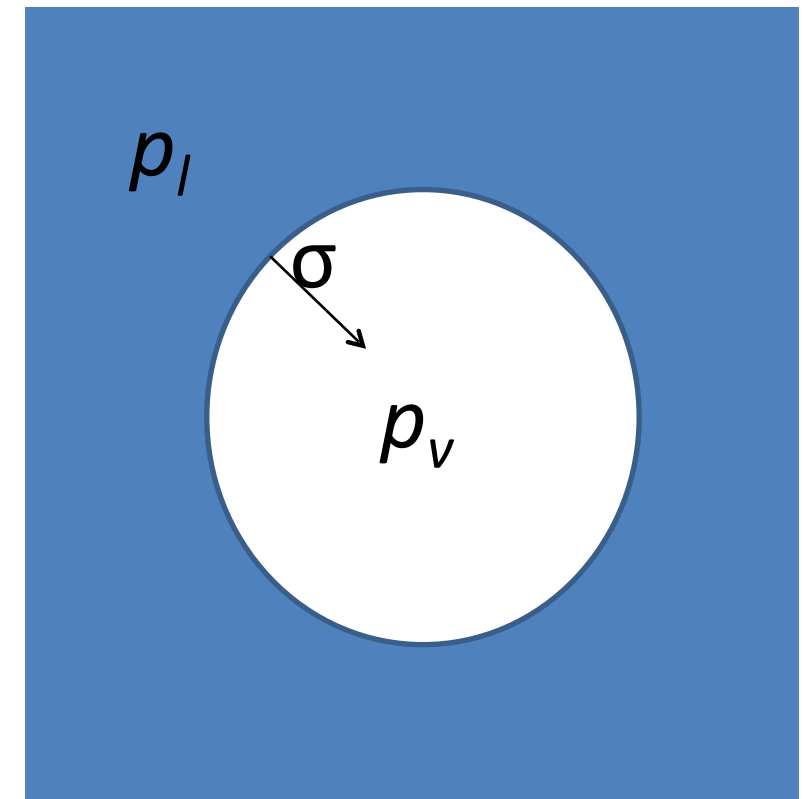
Particle detection with bubble chambers

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- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble (Seitz “Hot-Spike” Model)



Particle detection with bubble chambers

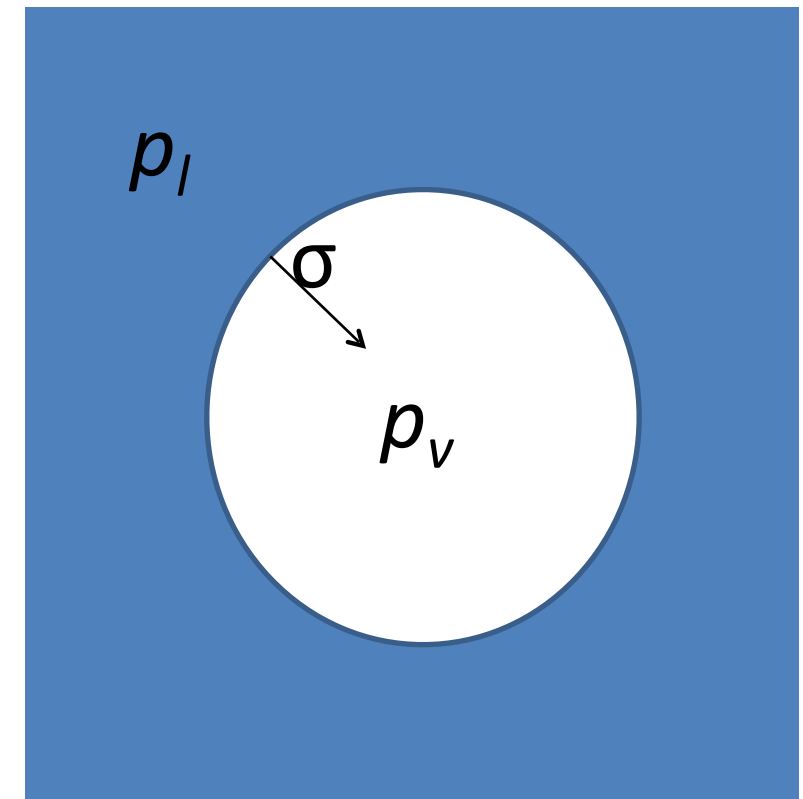
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Particle detection with bubble chambers

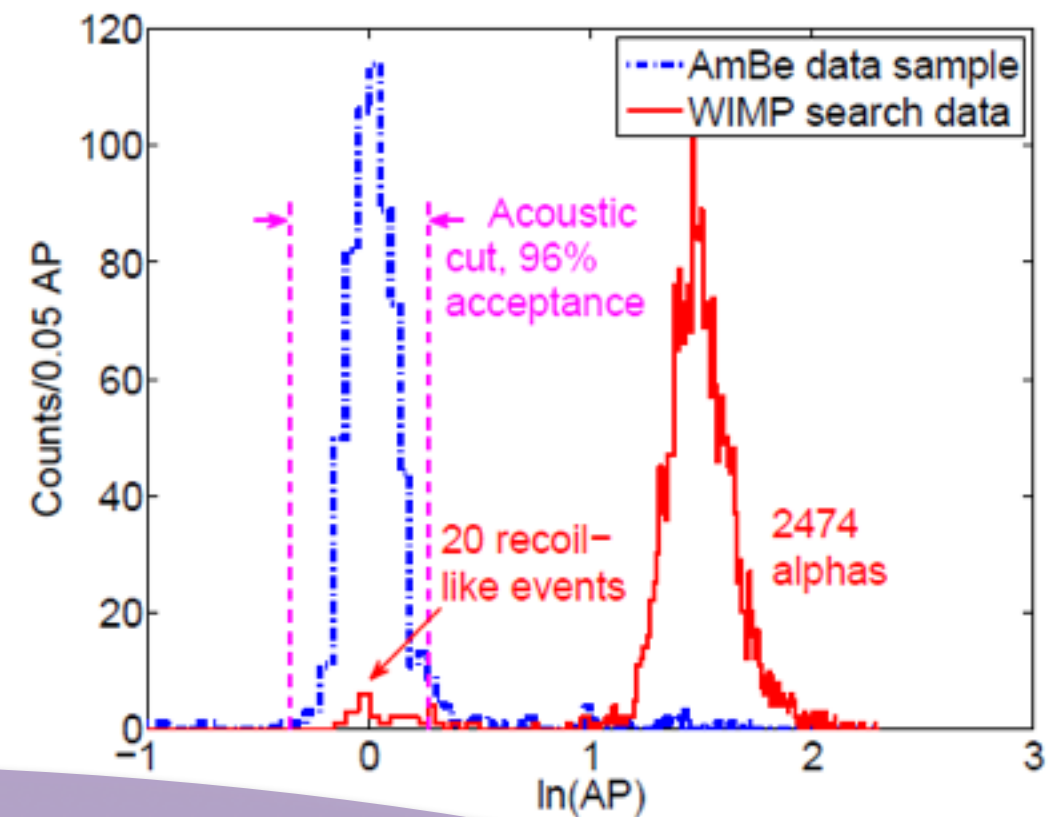
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- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble (Seitz “Hot-Spike” Model)
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses
- Classical Thermodynamics says:

$$E_{th} = \underbrace{4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right)}_{\text{Surface energy}} + \underbrace{\frac{4}{3}\pi r_c^3 \rho_v h}_{\text{Latent heat}}$$



Acoustic discrimination

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



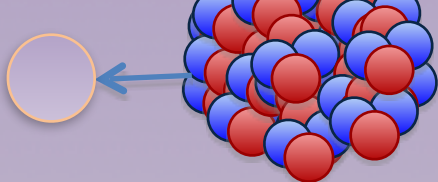
Observable bubble ~mm



~40 μm



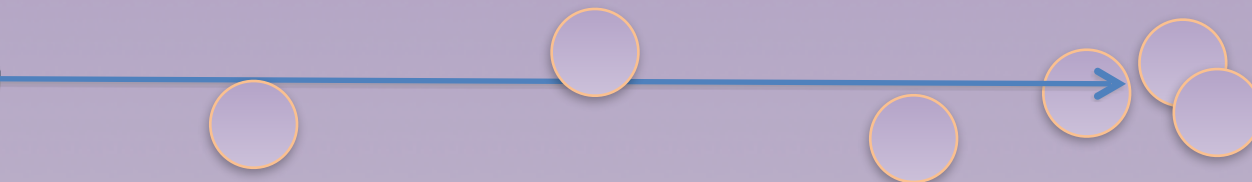
~50 nm



Daughter heavy nucleus
(~100 keV)



Helium nucleus
(~5 MeV)



PICO Program Overview

PICASSO

COUPP

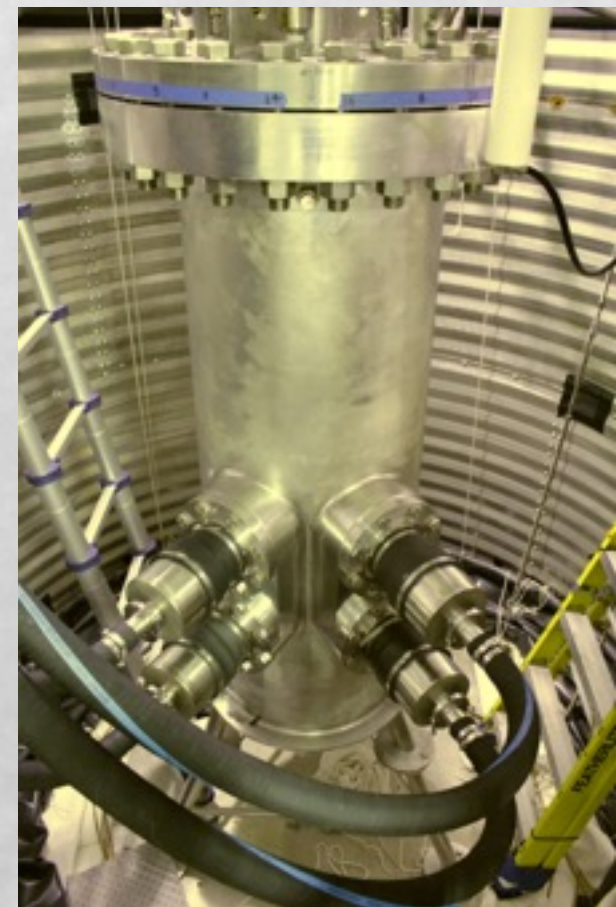
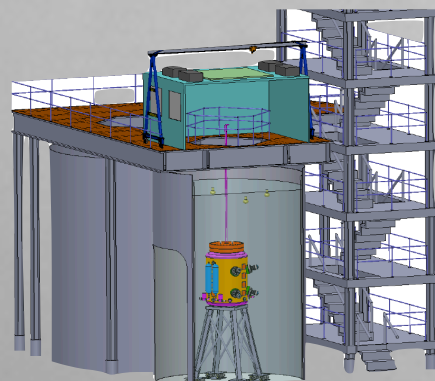
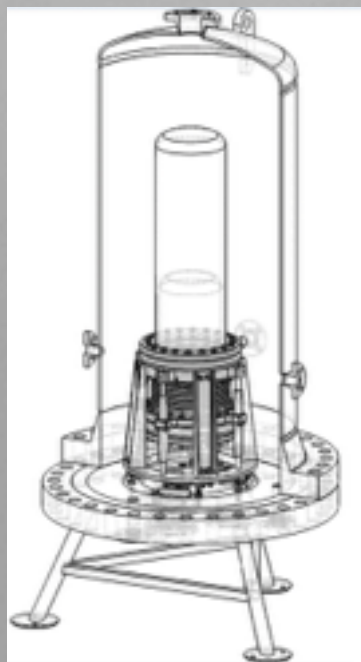
PICO

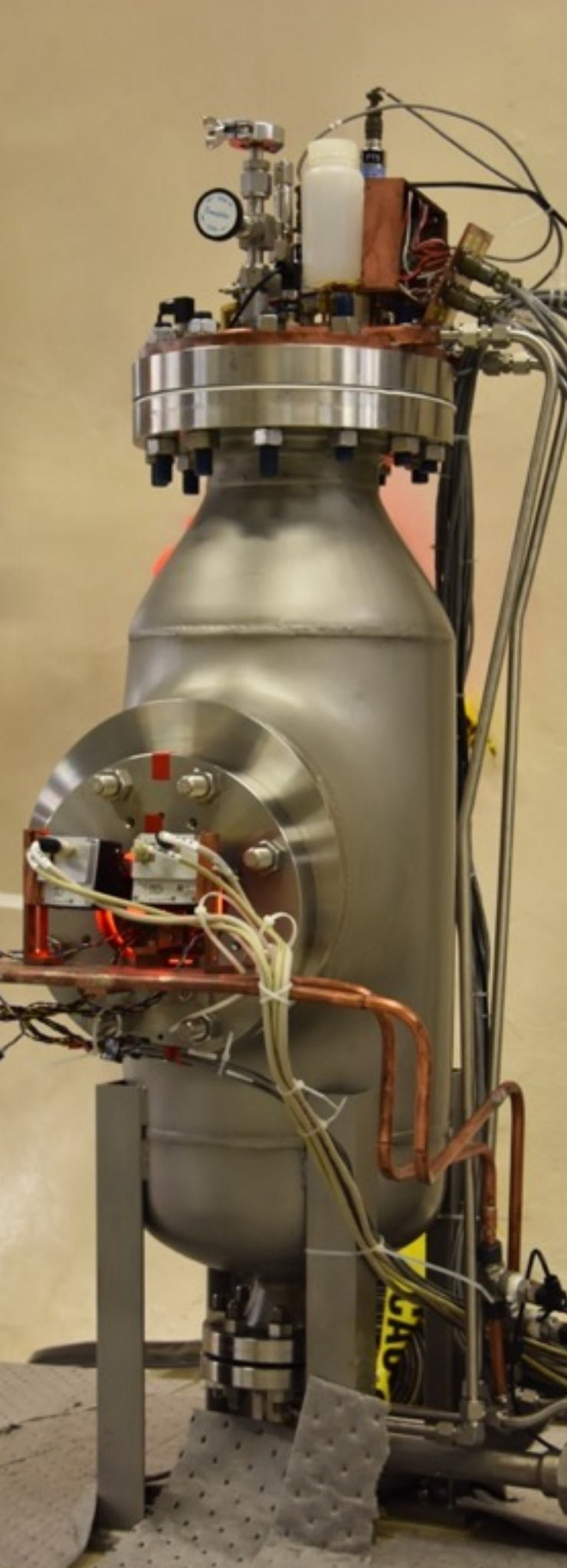
PICO 2L
 C_3F_8

PICO 60
 $CF_3I \rightarrow C_3F_8$

PICO 40L
 C_3F_8 , Right Side Up

PICO 500
 C_3F_8

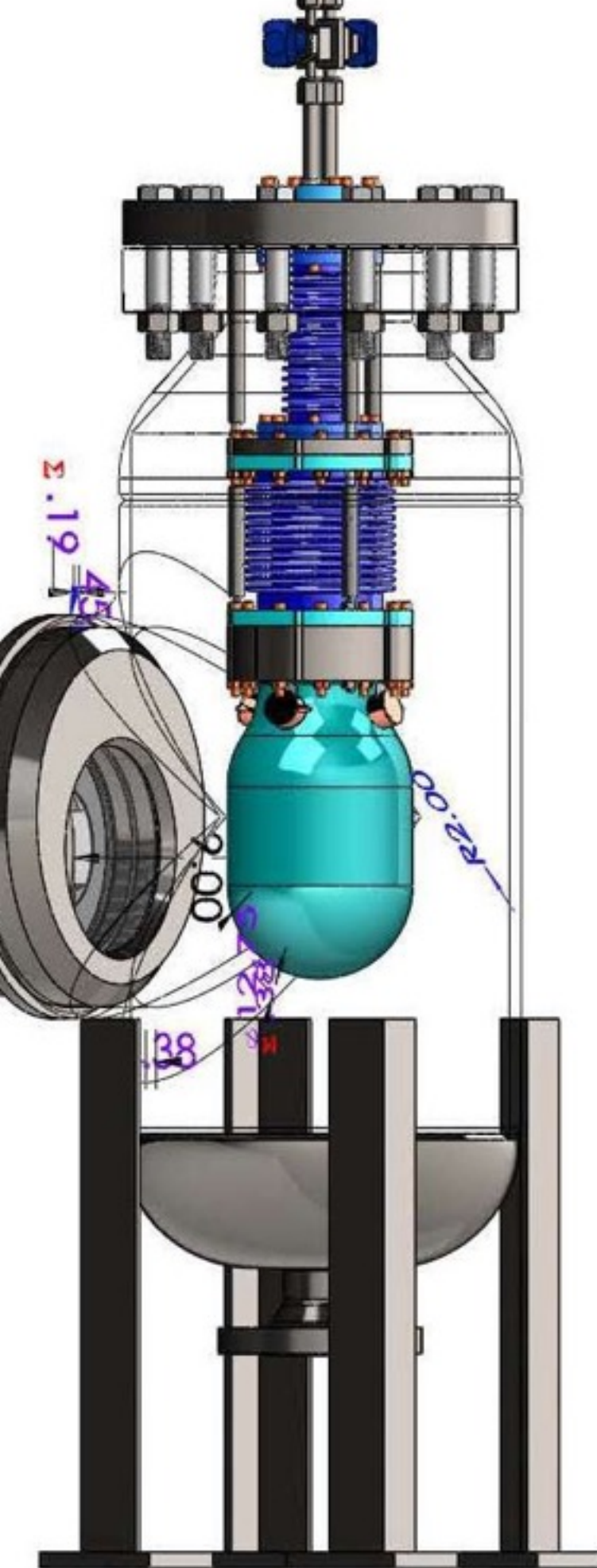




PICO 2L - Proof of Principle

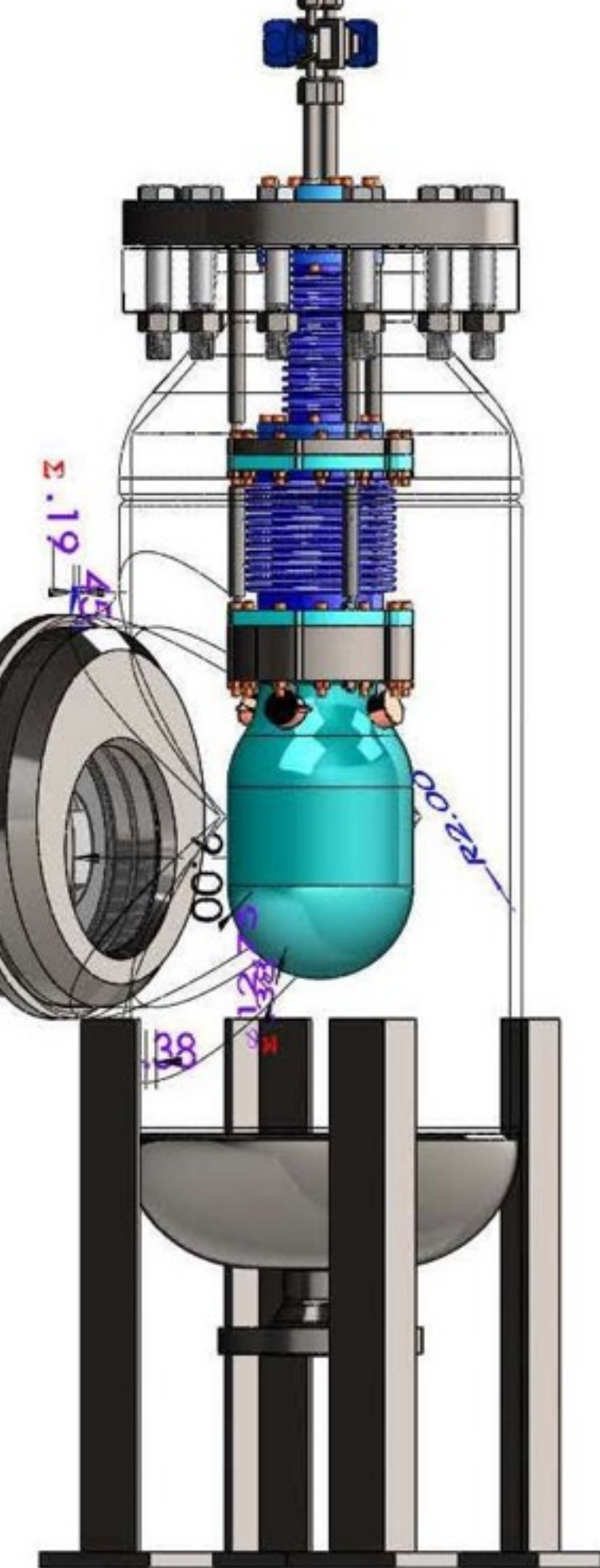
- Change of target fluid from CF_3I to C_3F_8
- Better gamma rejection, lower threshold operation
- Focusing on spin-dependent WIMP-proton interactions
- Fully synthetic quartz vessel with extensive cleaning protocol of wetted surfaces (Run 2)

PICO 2L - Proof of Principle

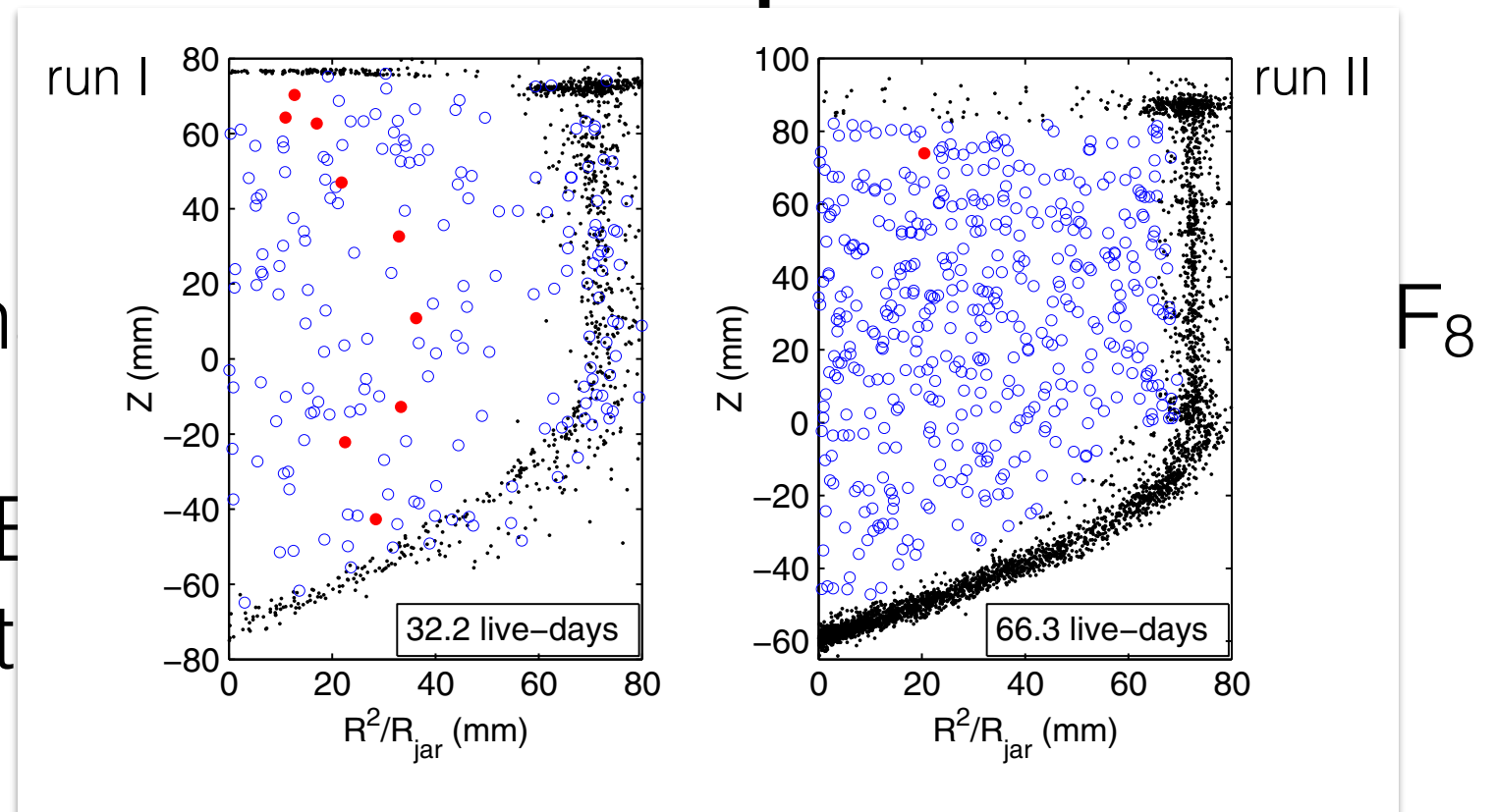


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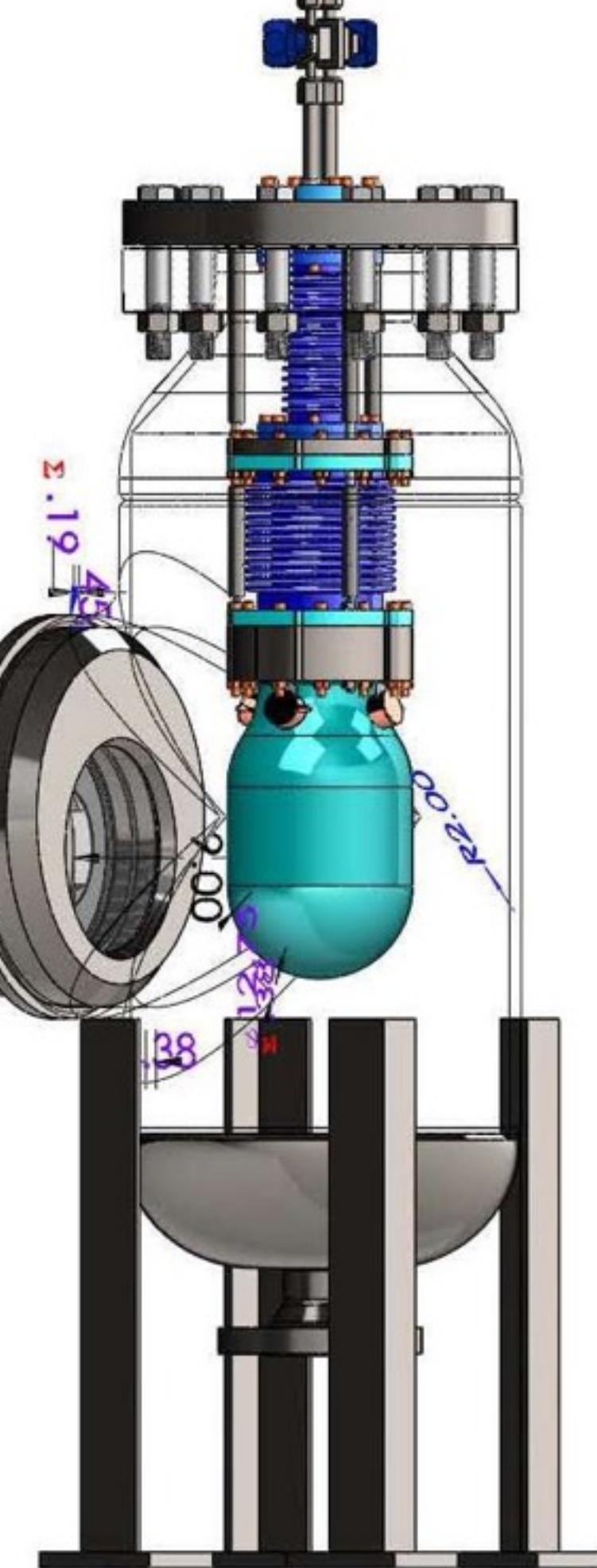
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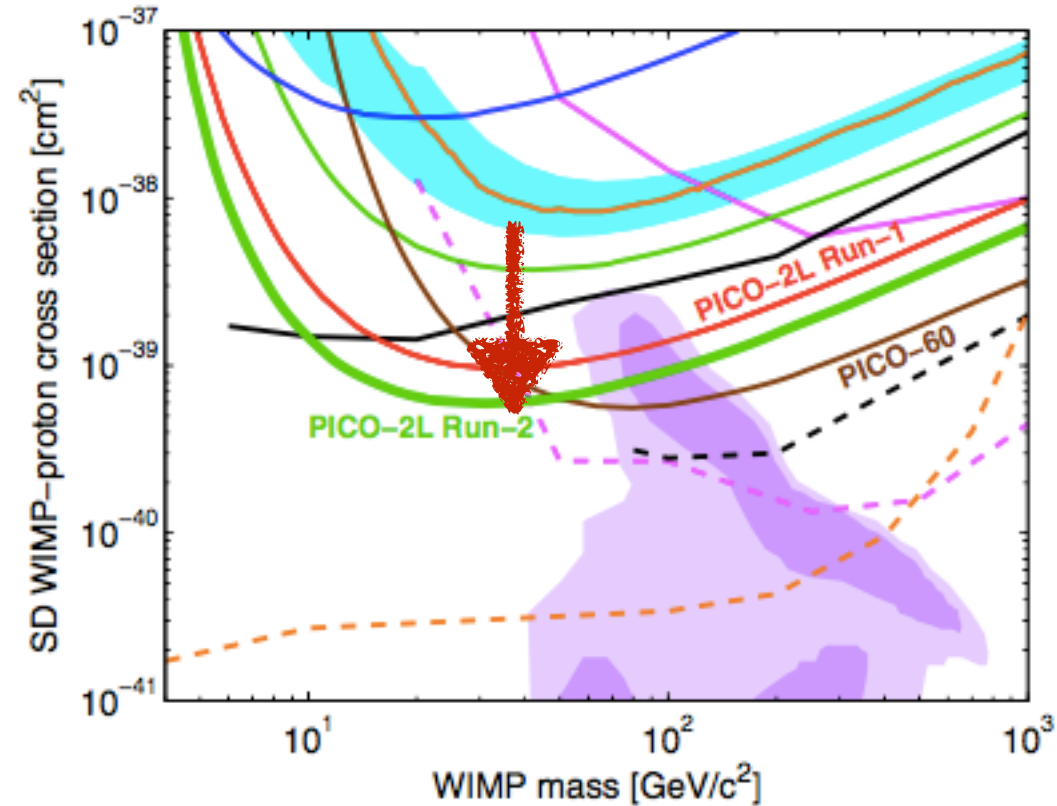
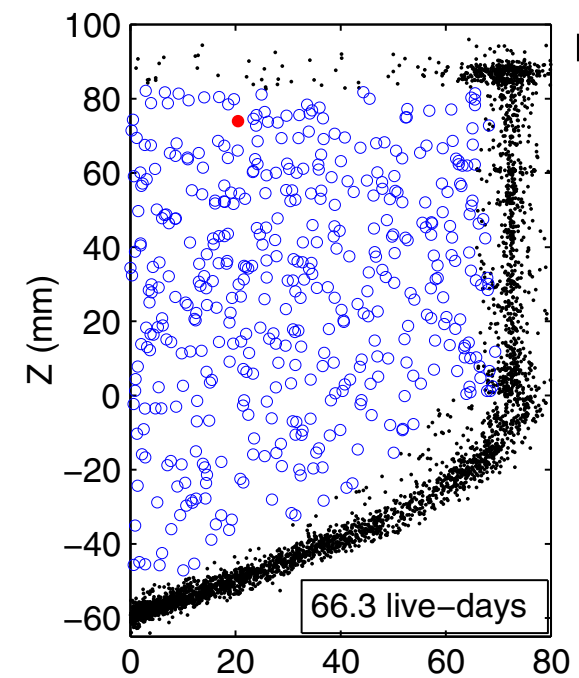
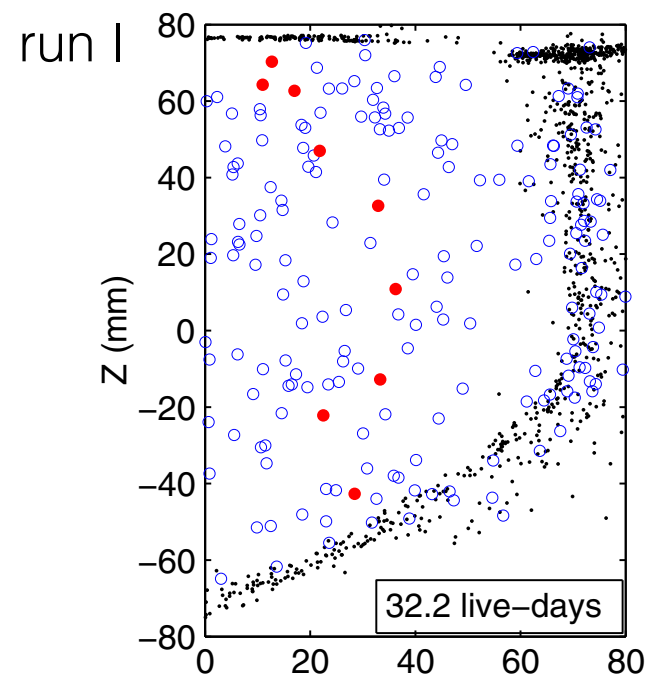
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PICO 2L - Proof of Principle



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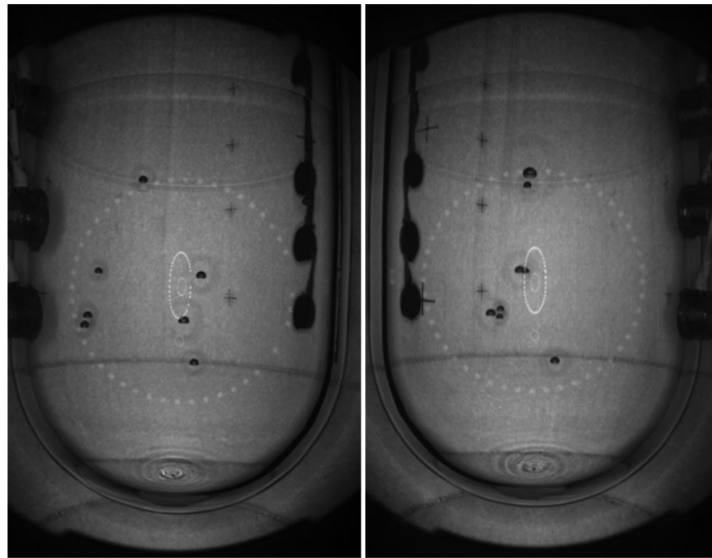


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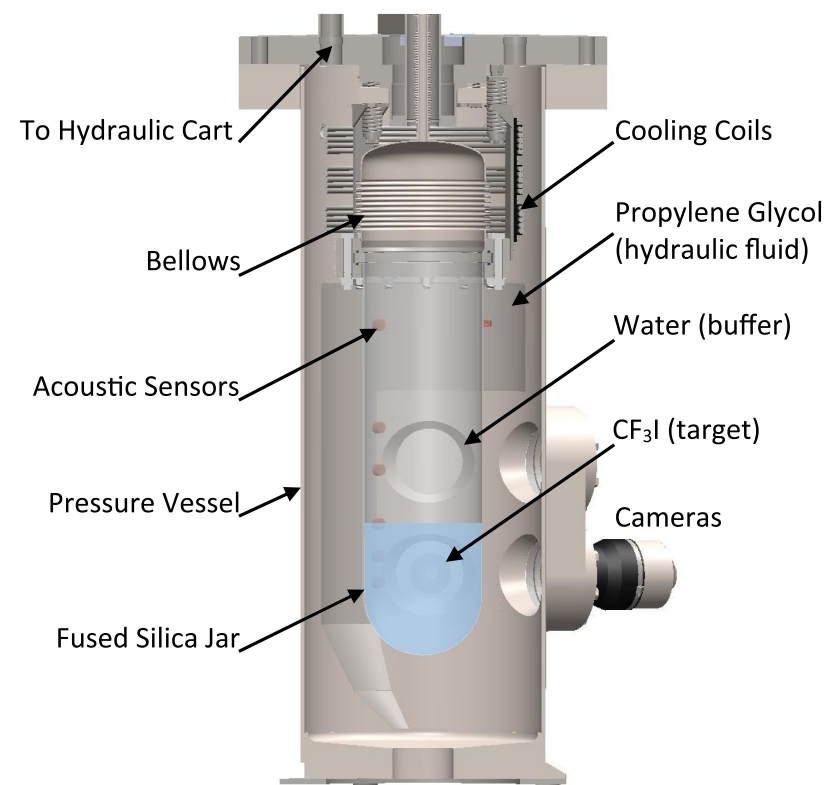
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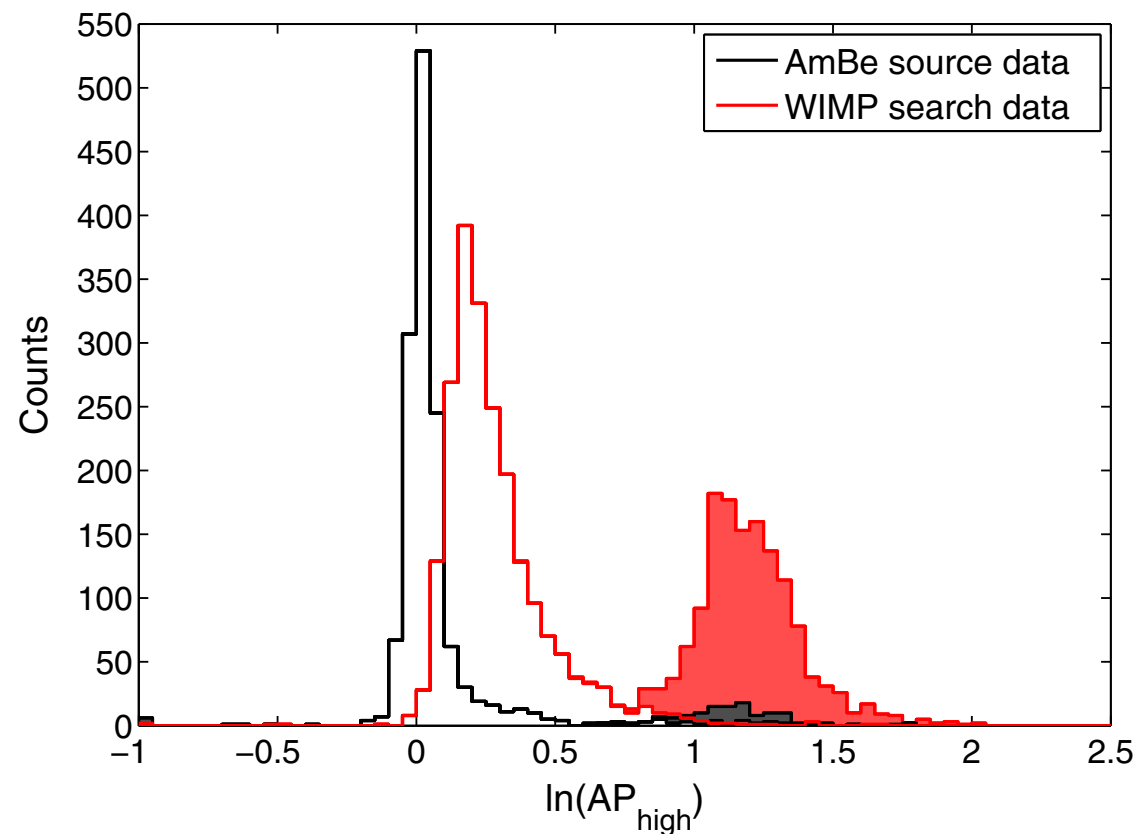
PICO 60 - Run I



- PICO 60 is currently the largest operational bubble chamber, made using very radio pure material: synthetic quartz
- Operated with CF_3I between June 2013 and May 2014 at SNOLAB
- Very stable operation with 36.8 kg of target liquid
- An anomalous background that correlates with the time since expansion was observed

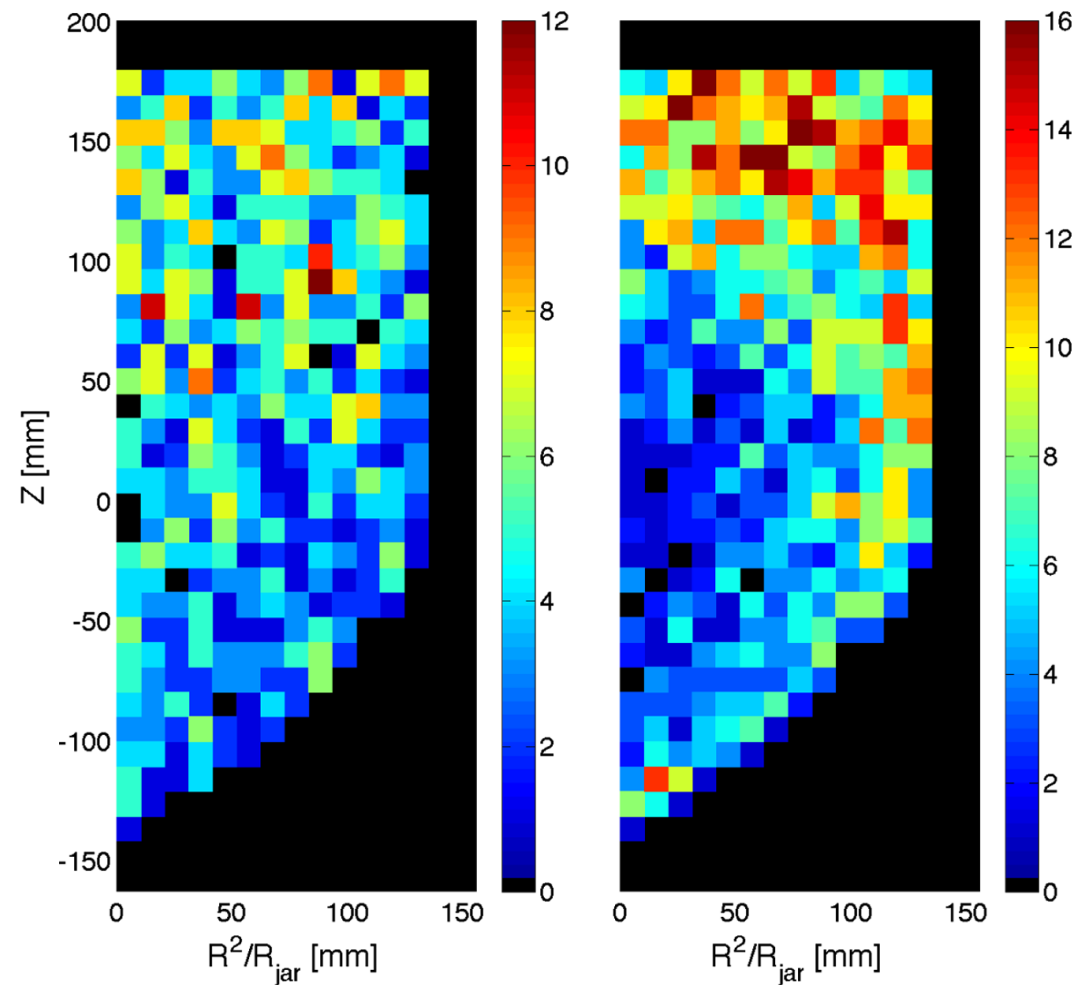


PICO 60 Run I Results



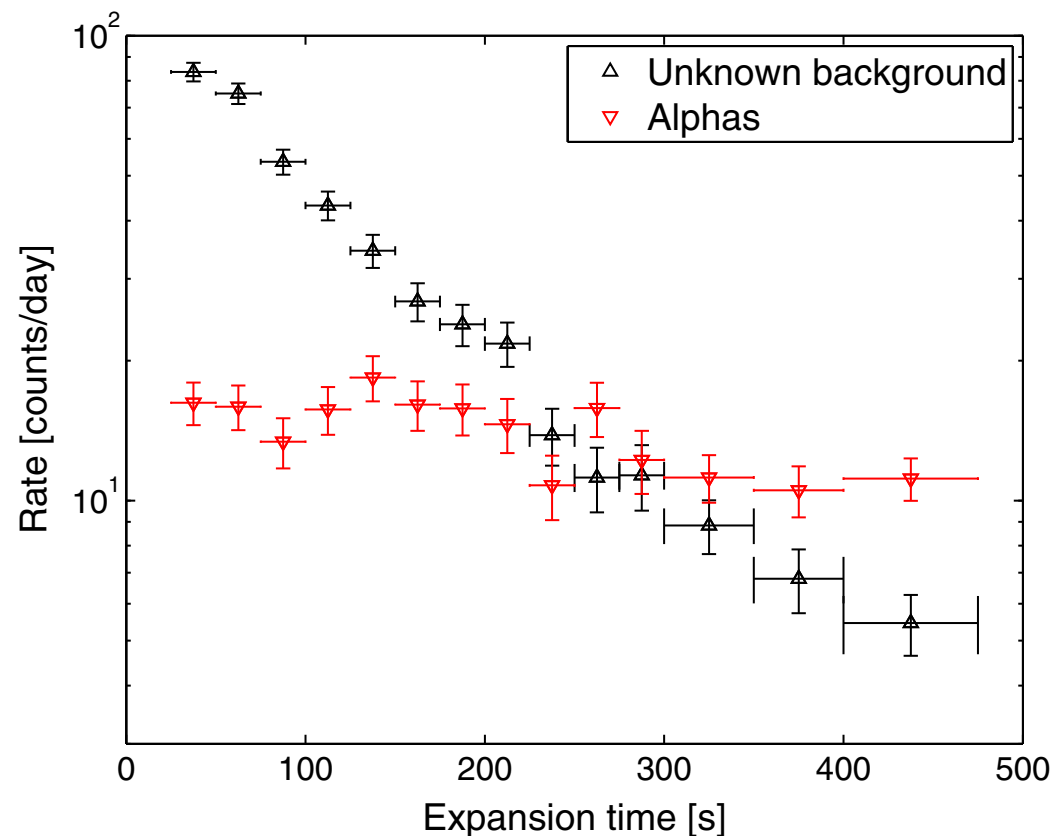
- The anomalous background is overlapping with nuclear recoil data in acoustic power

PICO 60 Run I Results



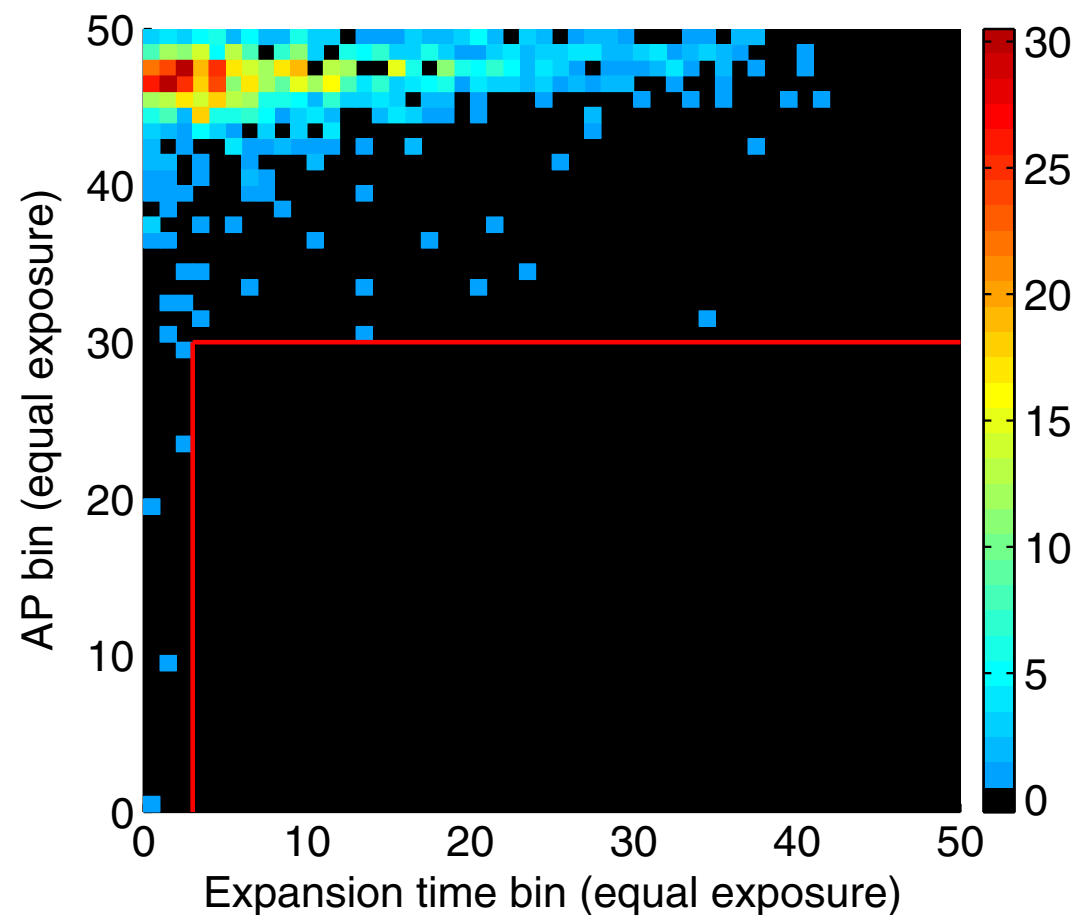
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- The background is unevenly clustered in space

PICO 60 Run I Results



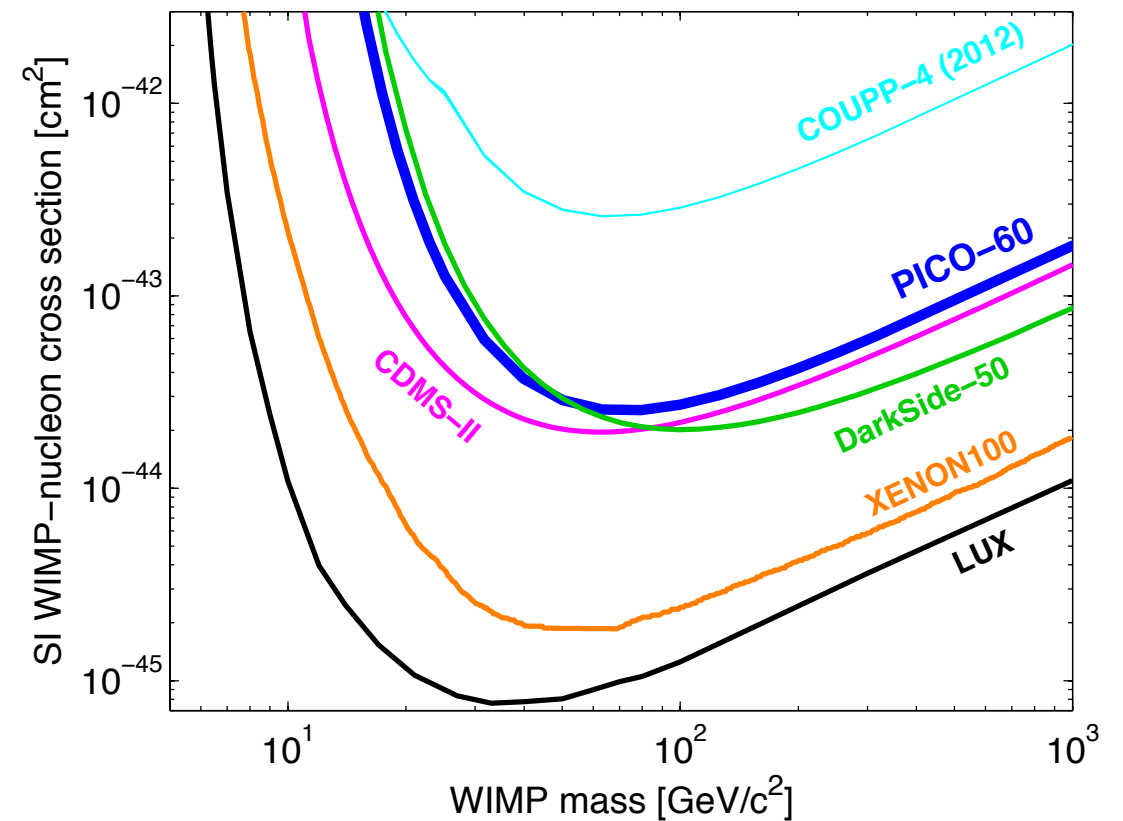
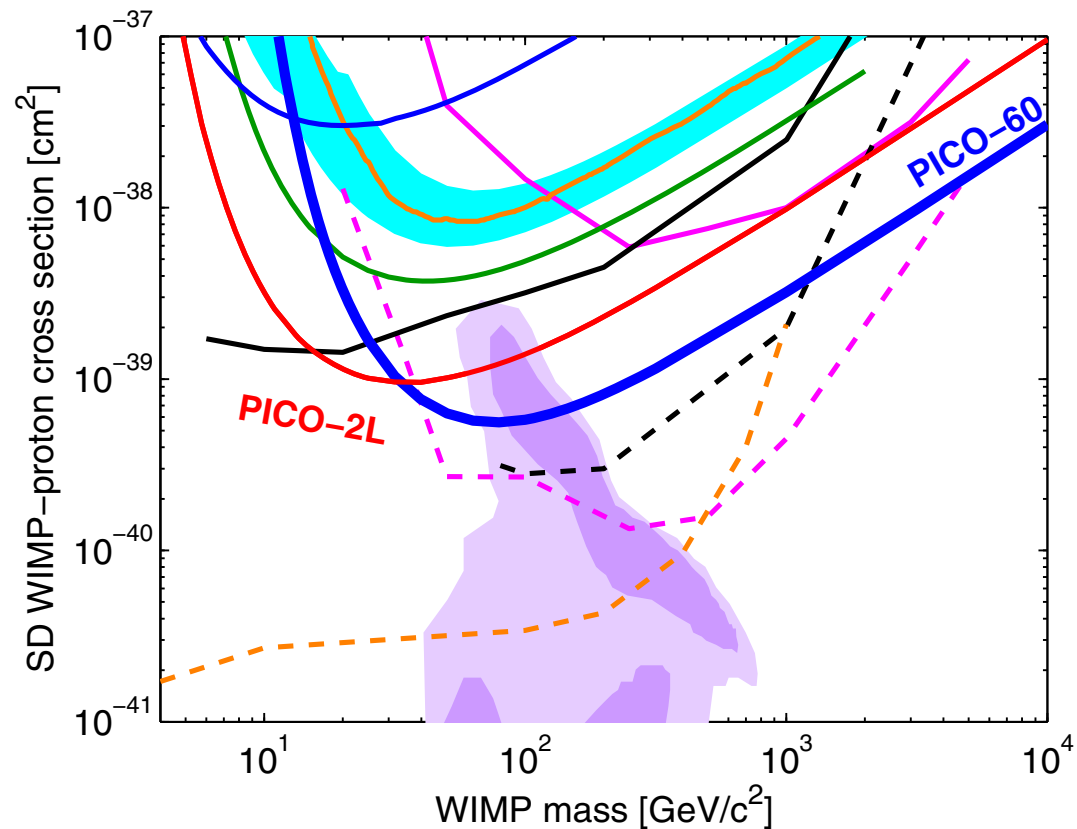
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- The background decays away quickly after expansions

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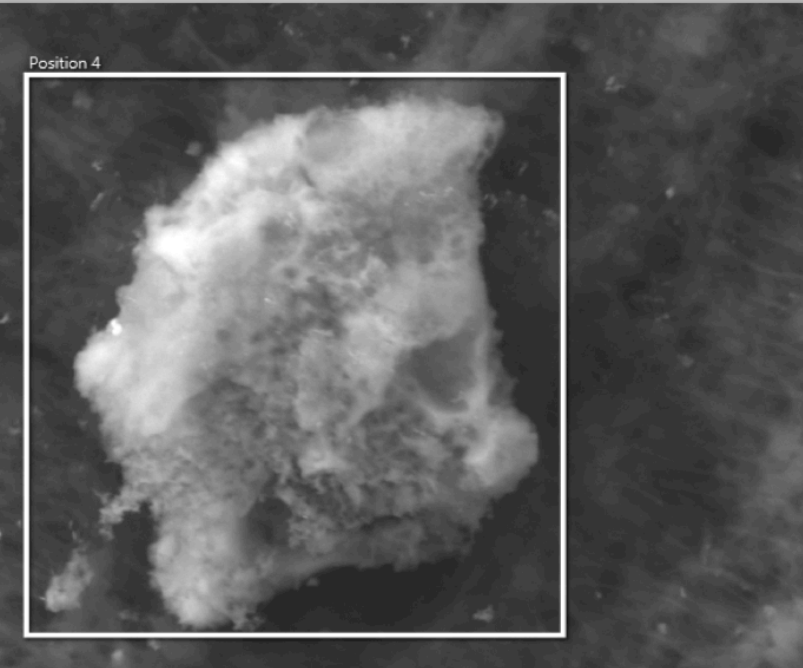


- The anomalous background is overlapping with nuclear recoil data in acoustic power
 - The background is unevenly clustered in space
-
- The background decays away quickly after expansions
 - A background free window was established based on acoustic power, event location and time after expansion

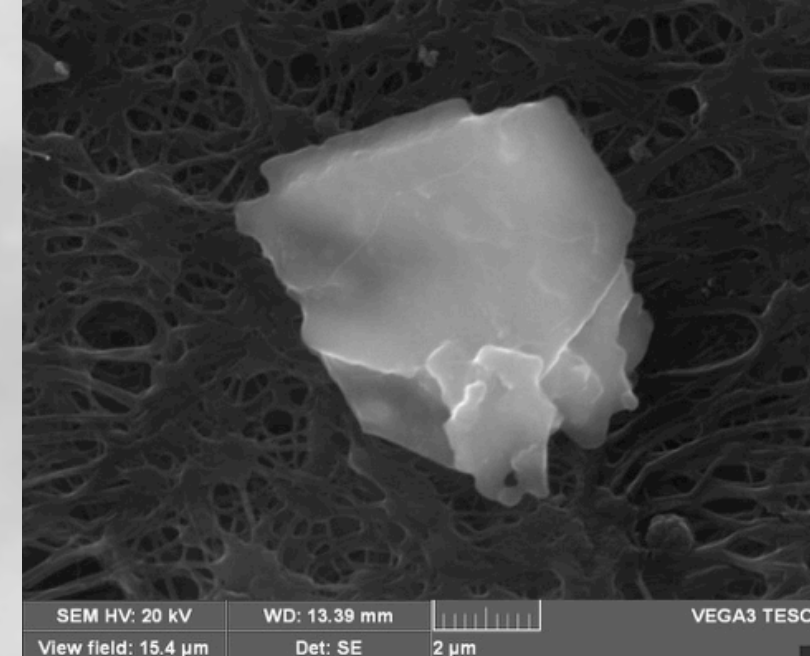
PICO 60 Run I - Limits



- World leading SD WIMP proton sensitivity for WIMP masses above 25 GeV .
C. Amole, *et al.*, Phys. Rev. D 93, 052014 (2016)
- Statistical penalty for setting cuts on data is calculated with Monte Carlo



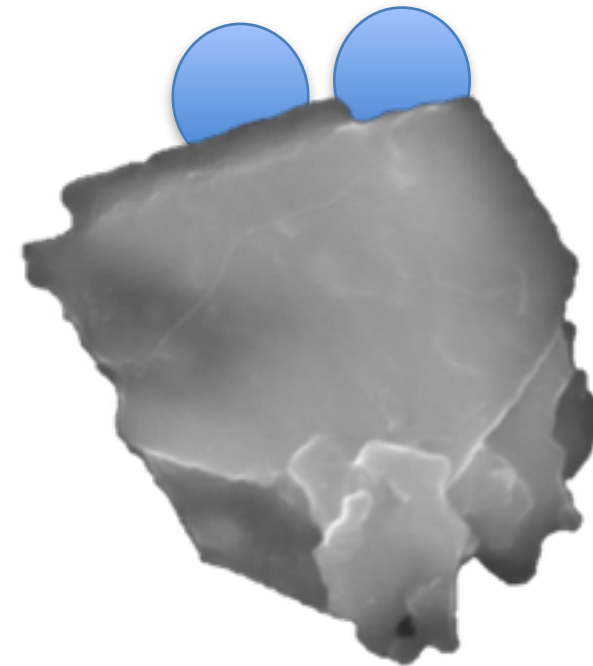
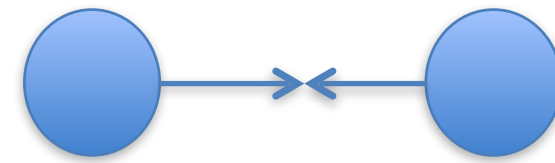
After Run I - Assay



- 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

Bubble nucleation by surface tension

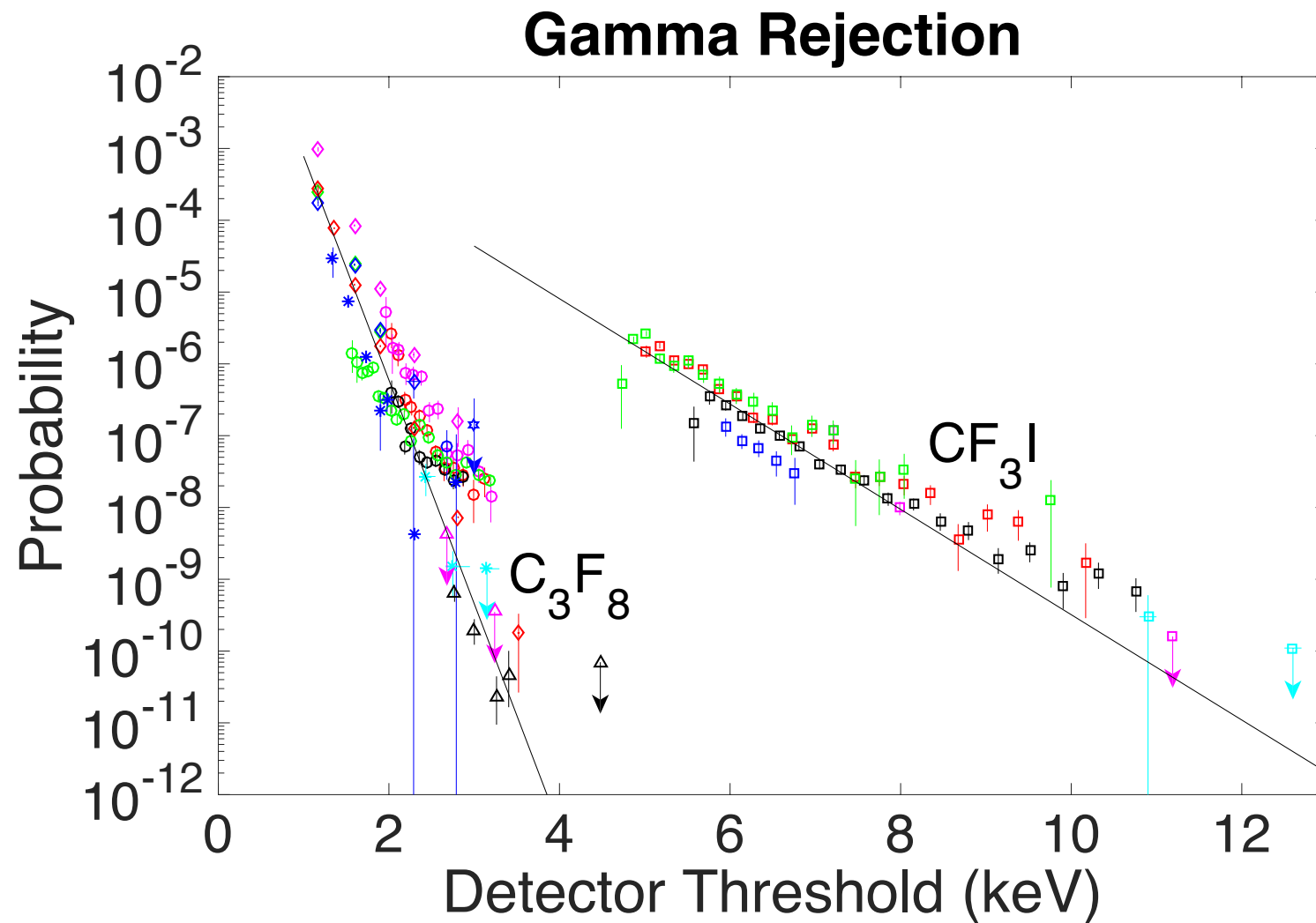
- Merging of two water droplets releases $O(1 \text{ keV})$ of surface tension energy
- The water lowers the bubble nucleation threshold, so the released energy can nucleate bubbles at PICO operating thresholds of a few keV
- The merging water droplets could be attached to solid particulate



Run II of PICO 60

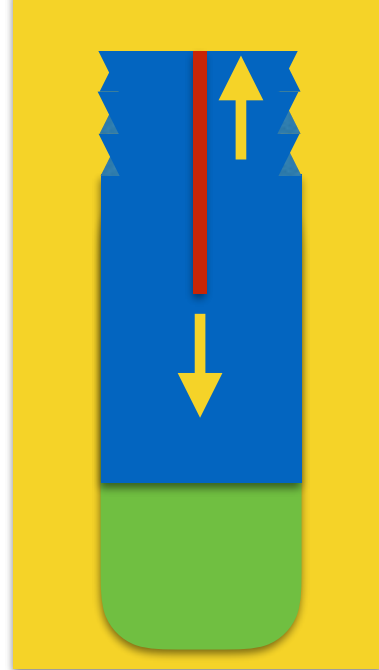
- New active liquid: C_3F_8
 - New water system and cooler
- New vessel, new geometry and now both flange and vessel from synthetic quartz
- Four cameras, allows operation with ~45L of target volume
- Online filtration system to study development of particulate contamination during operation
- Muon veto installed

Switch to C_3F_8

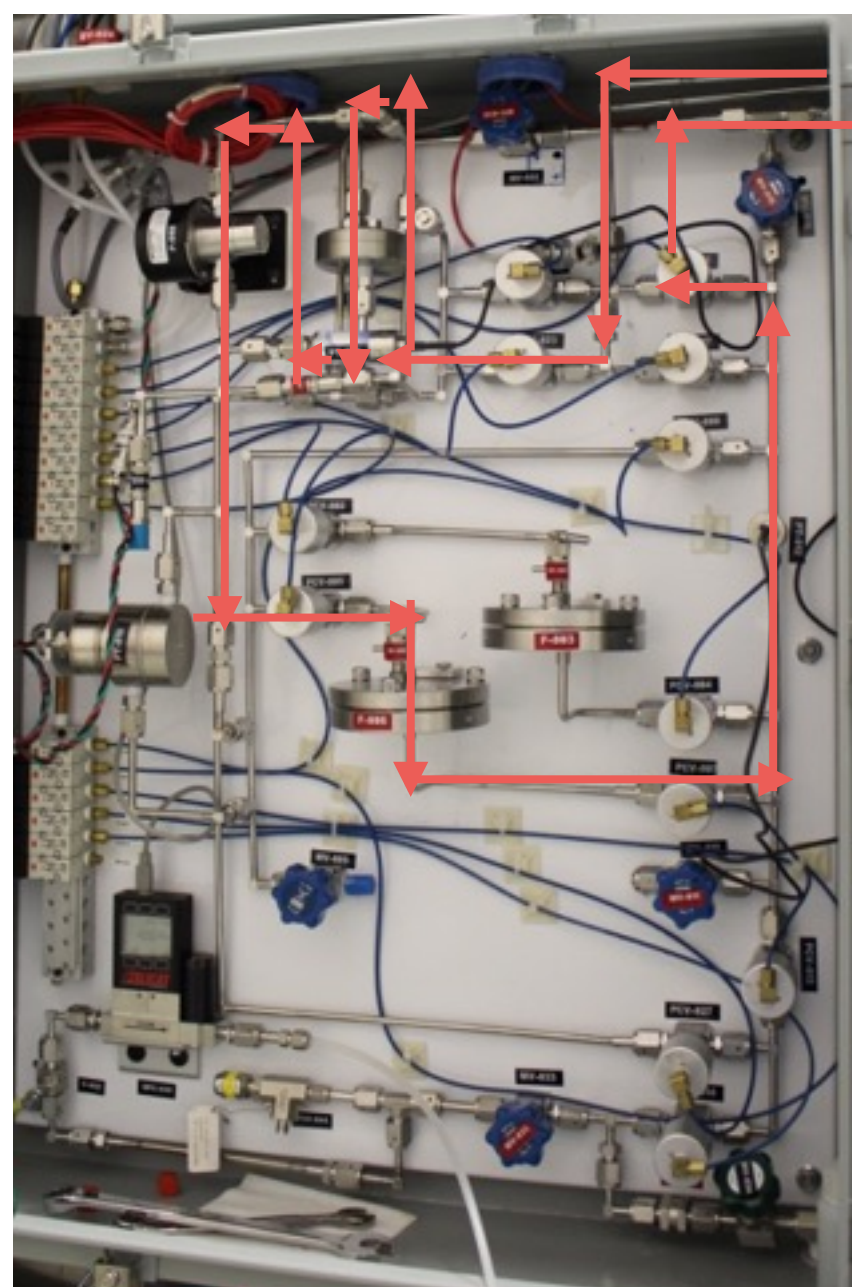
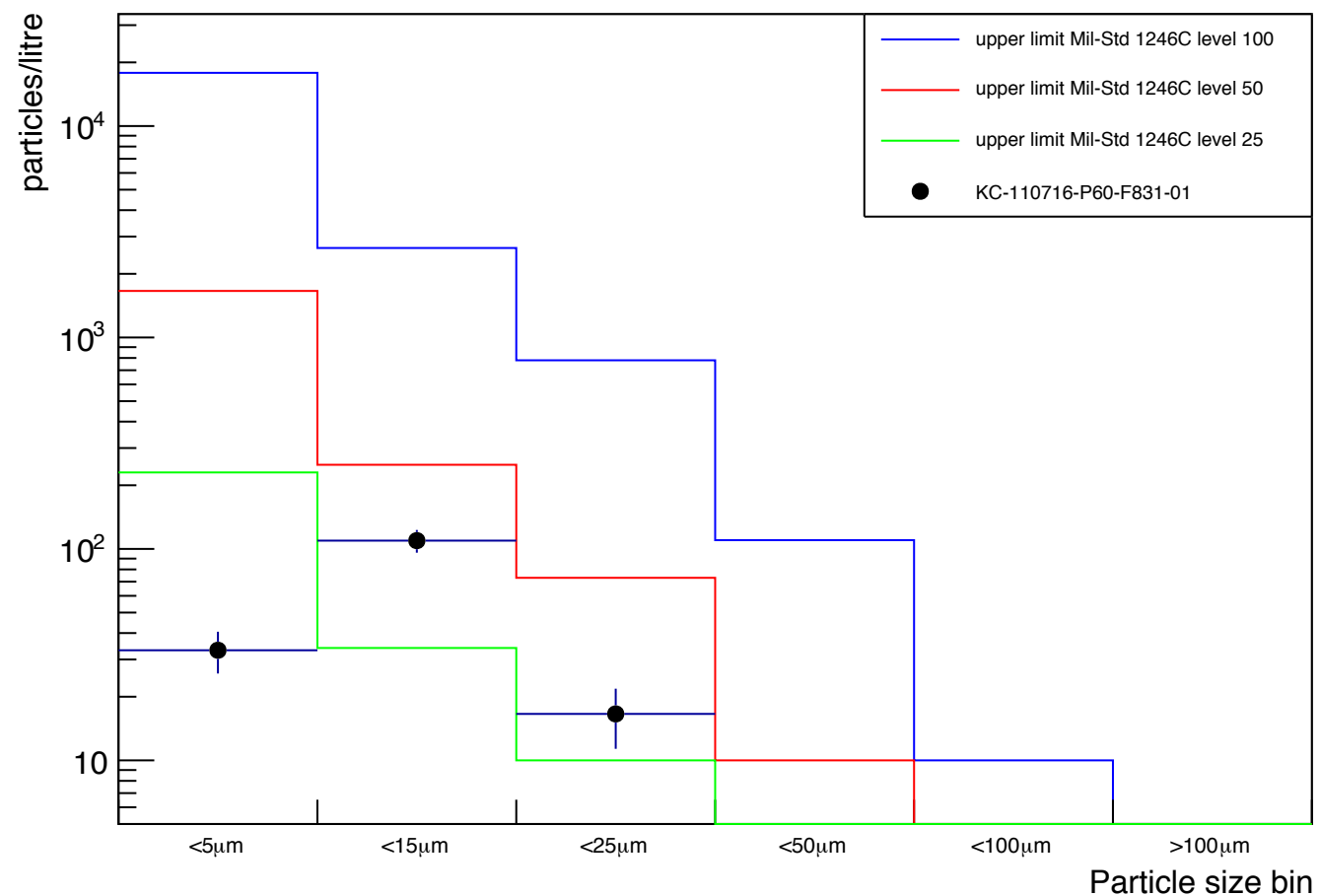


- Probability of detecting gamma interactions in CF_3I and in C_3F_8

Filtration system



- The system already helped to establish that the detector is as clean after the fill as it was after the cleaning procedure



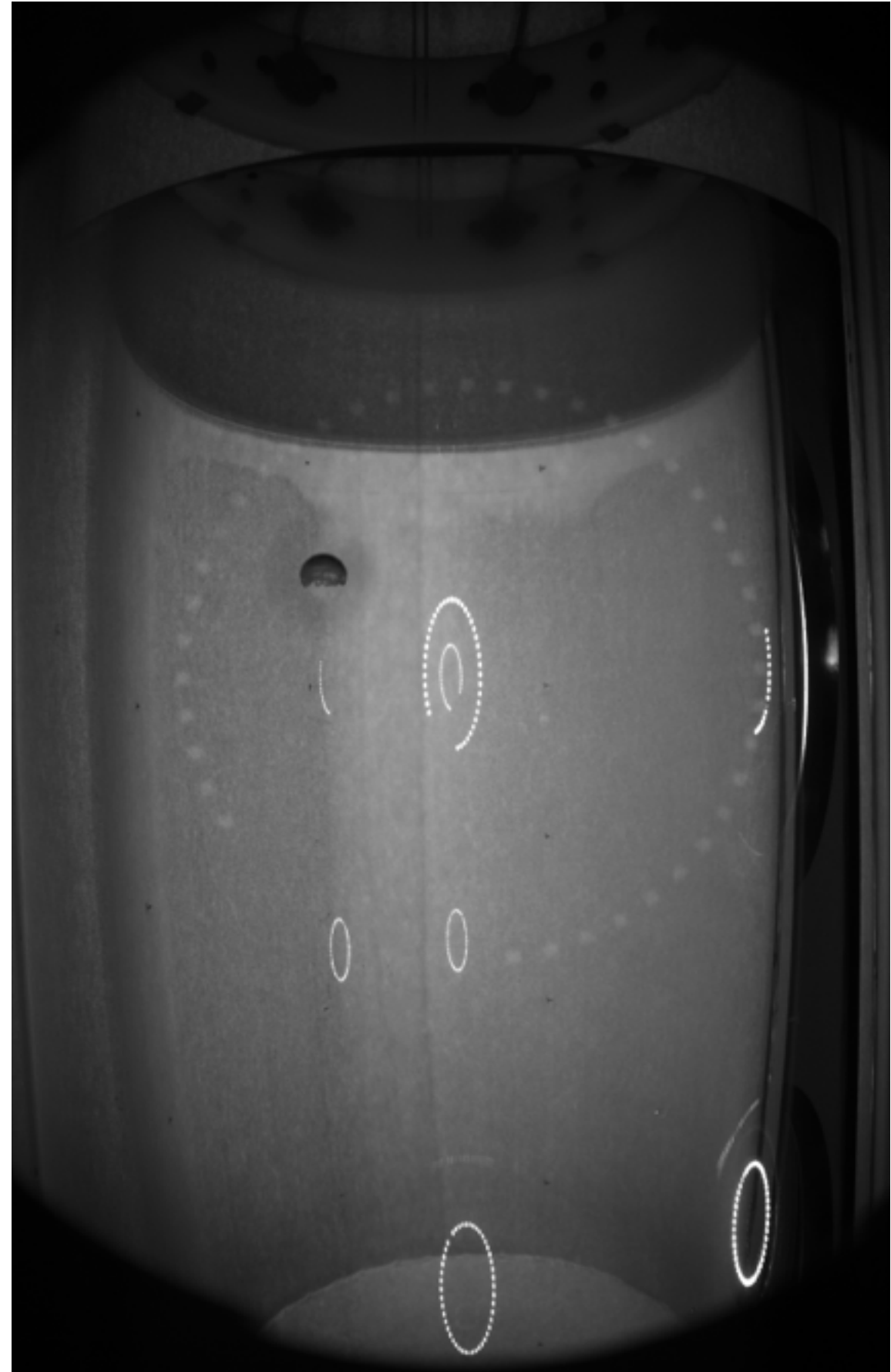
Detector Cleaning



- A pump-filter-heater assembly was constructed for detector cleaning
- All plumbing in contact with inner vessel fluid was also cleaned with the system
- All parts met MIL-STD1246C-level 50

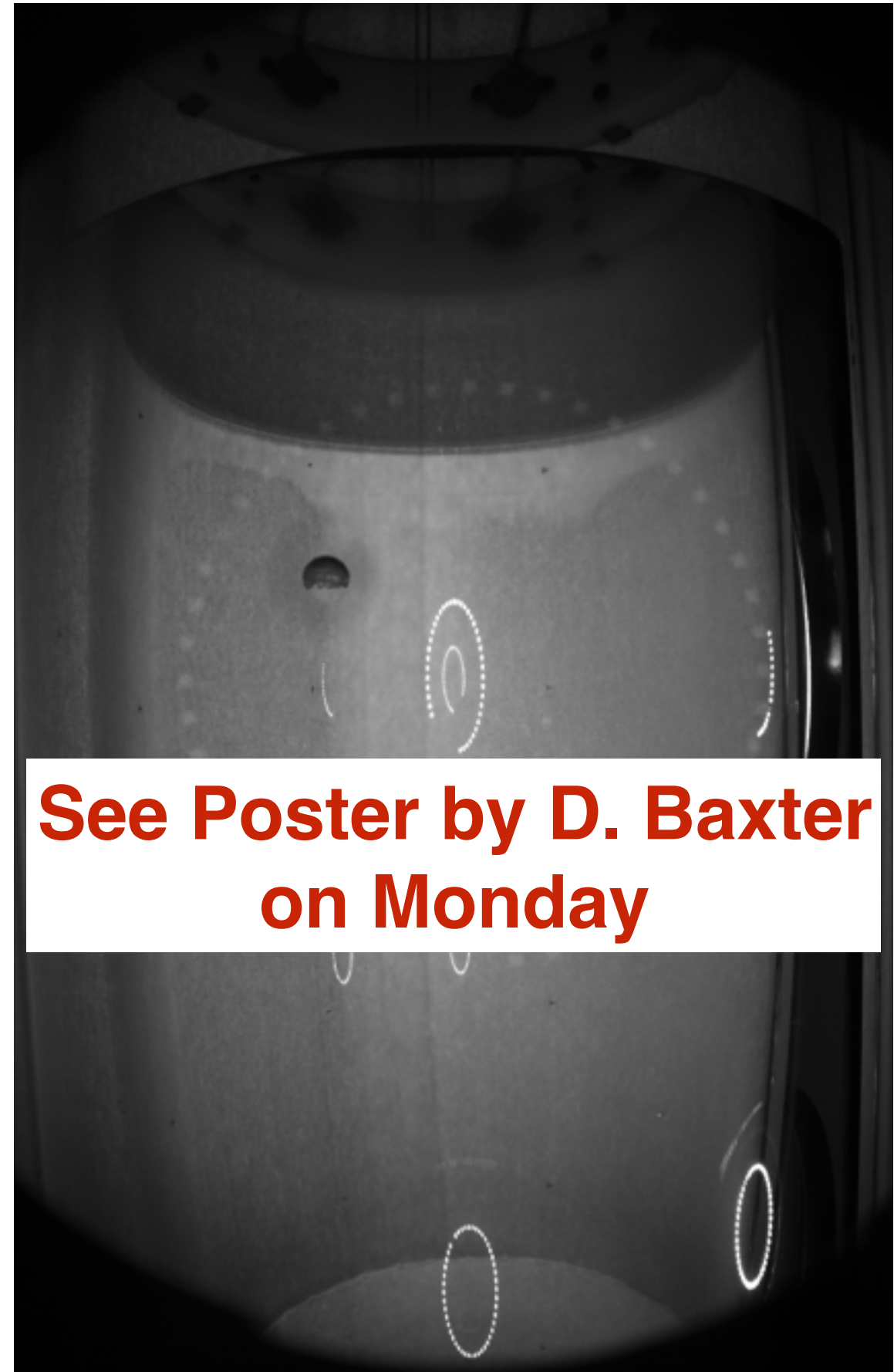
First Bubble

- PICO 60 has observed the first bubble on August 1st 2016!
- The water shield was filled on August 3rd and 4th
- Regular data taking will start as early as next week

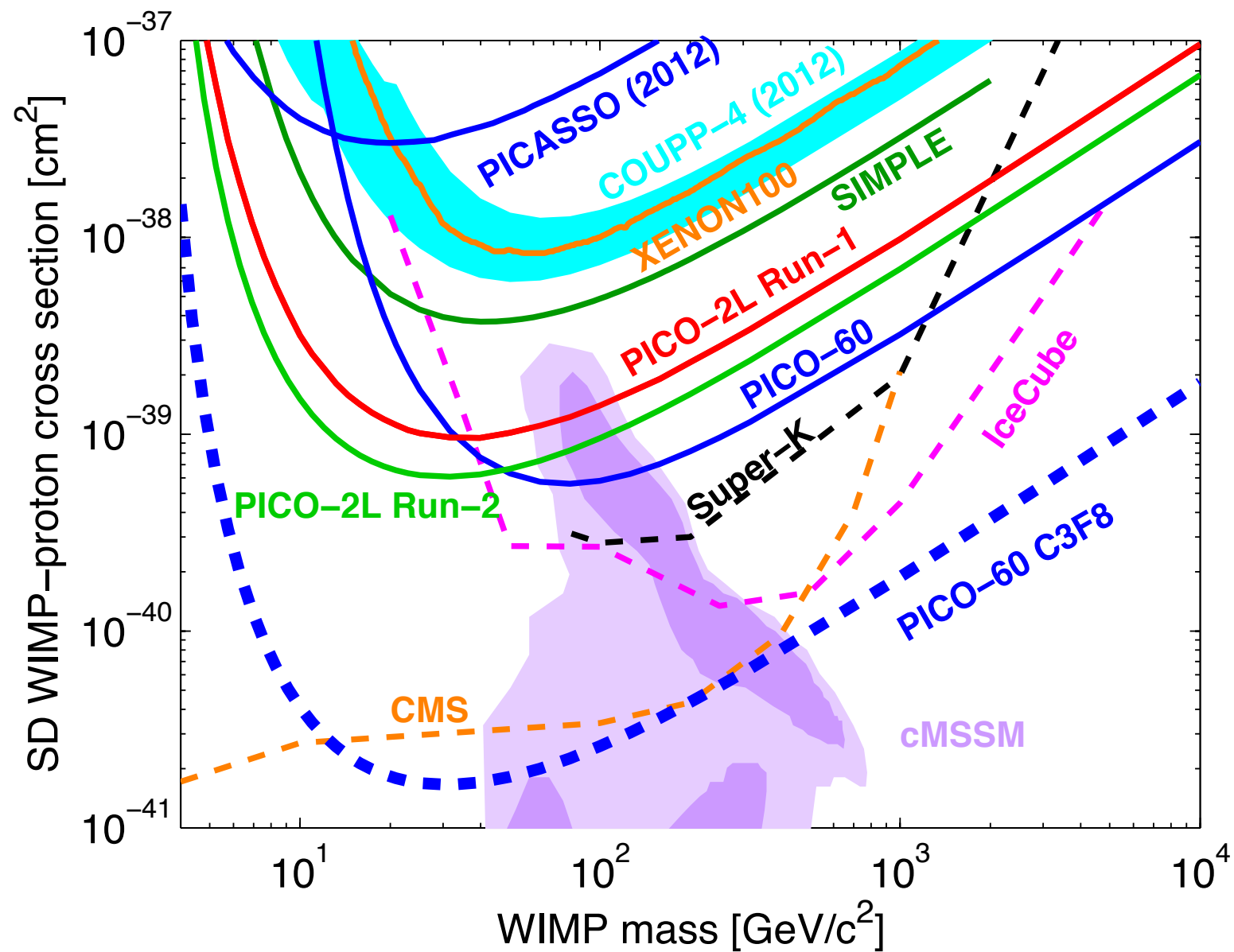


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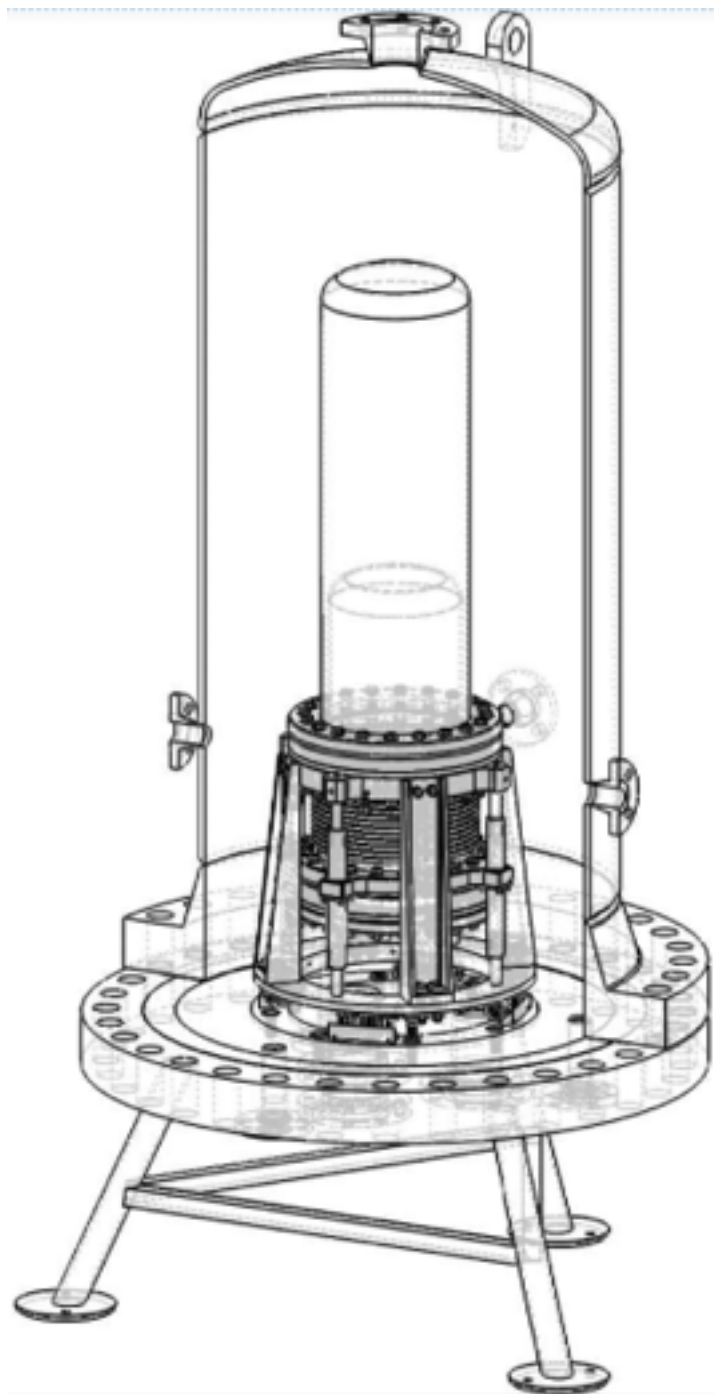
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Run II Sensitivity Projection



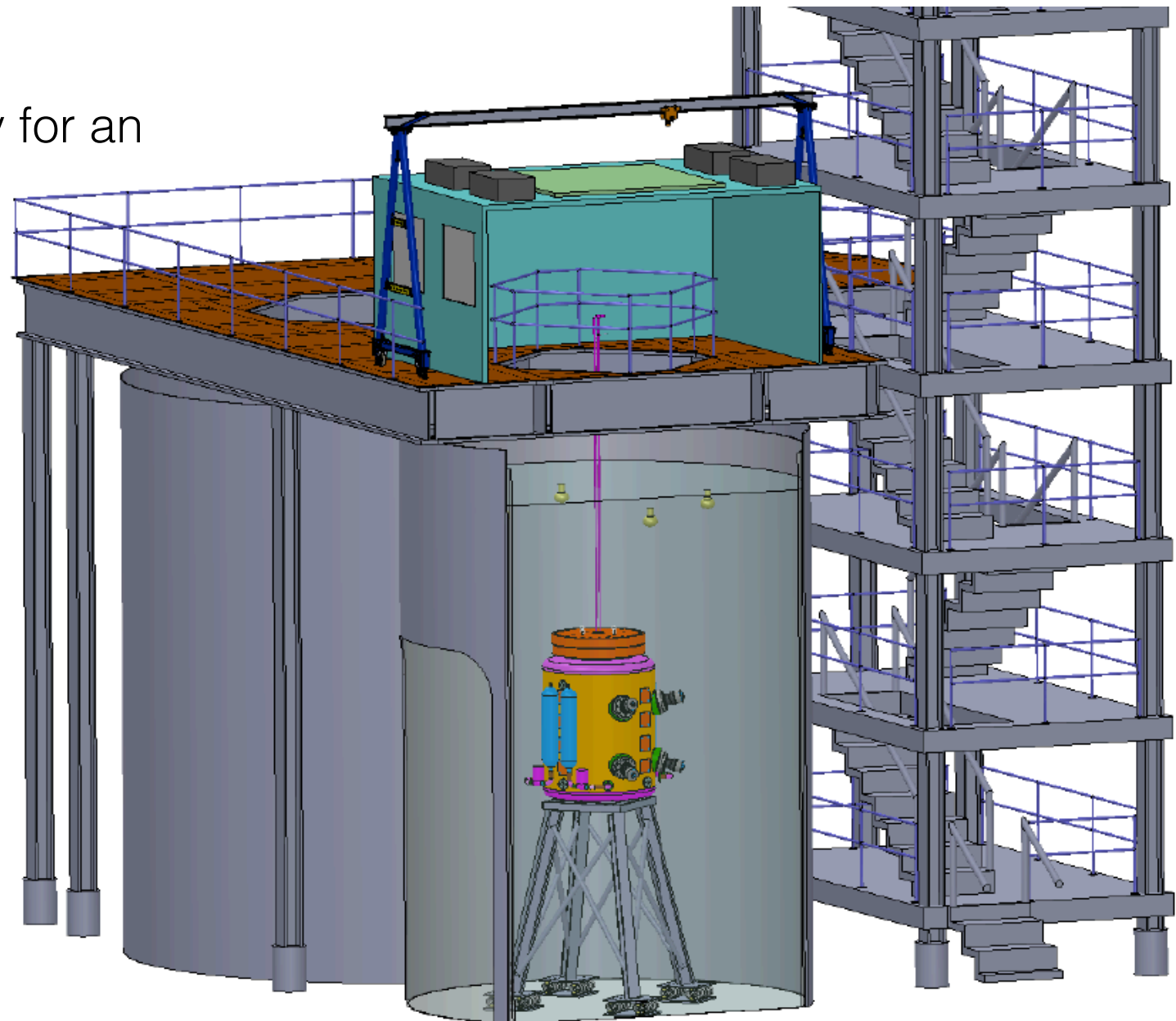
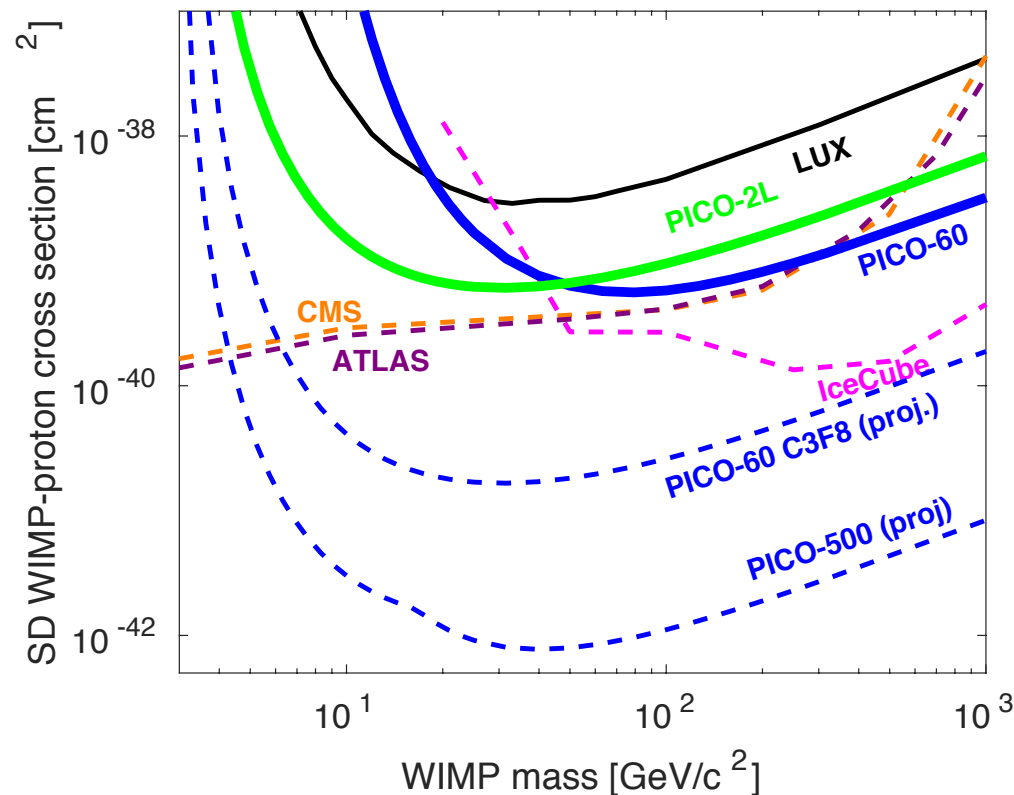
PICO 40L - right side up



- To eliminate the water as source of background events, an inverted chamber without any buffer liquid was developed
- This chamber will be deployed at SNOLAB in 2017 to explore the ultimate sensitivity of a 40 litre chamber
- This design also incorporates various improvements based on the PICO 60 operational experience

Next Up: PICO 500

- PICO 500 will explore the ultimate sensitivity of a low background bubble chamber
- It will be located at SNOLAB
- The bubble chamber technology is ready for an experiment of this scale



Summary

- The PICO bubble chamber technology has been shown to have excellent sensitivity for nuclear recoil events down to $O(\text{keV})$ thresholds
- PICO 60 and PICO 40L will explore the the spin-dependent parameter space of WIMP-proton interactions in the coming two years
- PICO 500 is planned to be operating in 2018+
- PICO detectors can be easily reconfigured for other target liquids in case a discovery makes this necessary