Bubble Chambers for Dark Matter Searches and Recent PICO 60 Results

Carsten B Krauss

WIN 2107 Irvine — June 23 2017

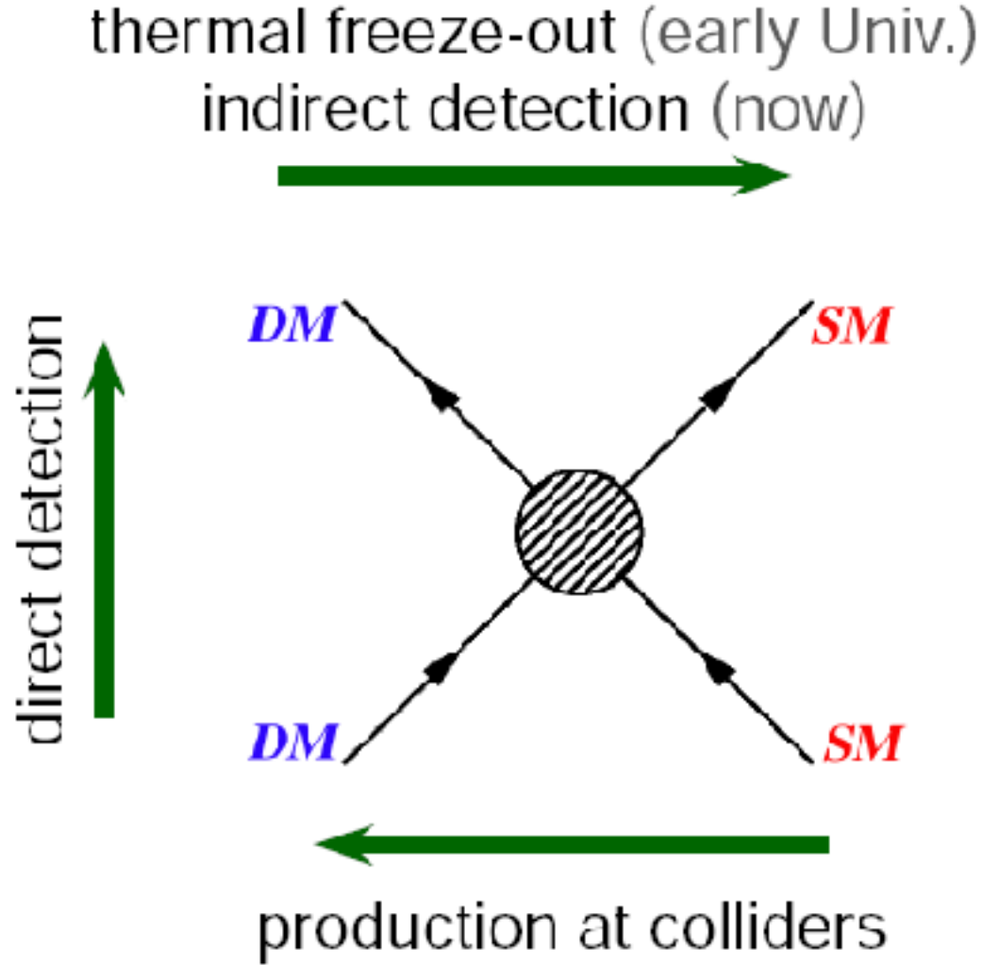
Overview

- **The PICO Programme**
  - PICO 60
  - PICO 40L - PICO 500

PICO

Dark Matter Searches

- Dark matter needs to couple to standard model particles for us to find it.
- Searches are ongoing using
  - Direct detection
  - Indirect detection
  - Collider production



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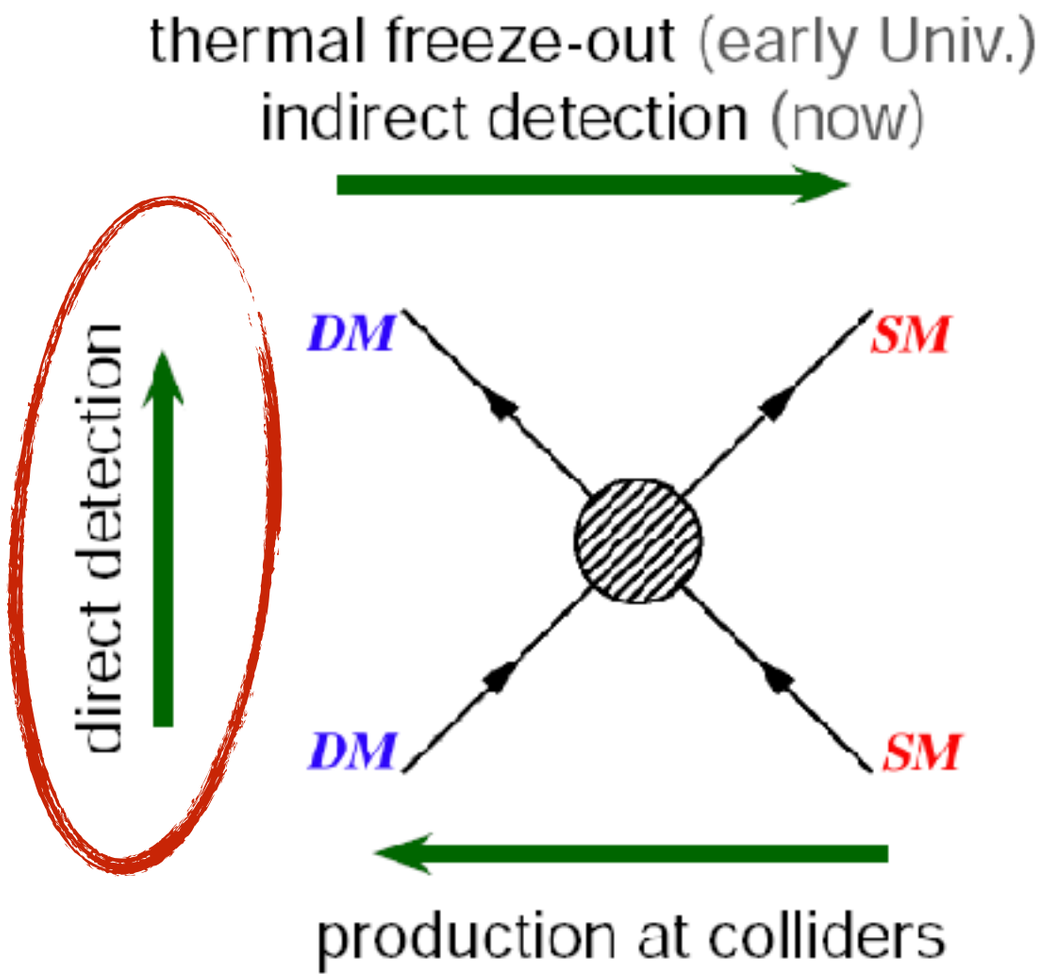

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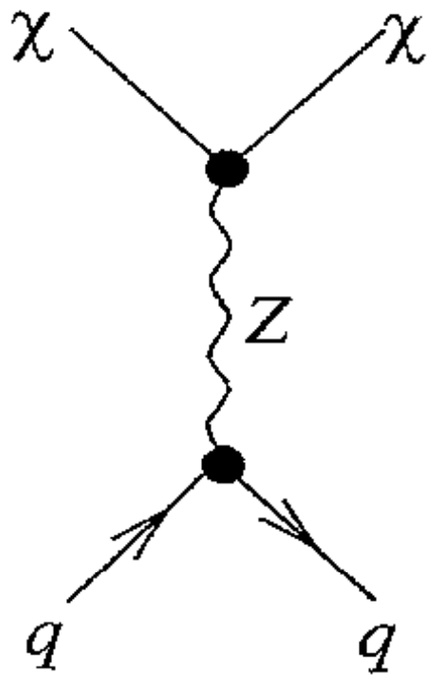
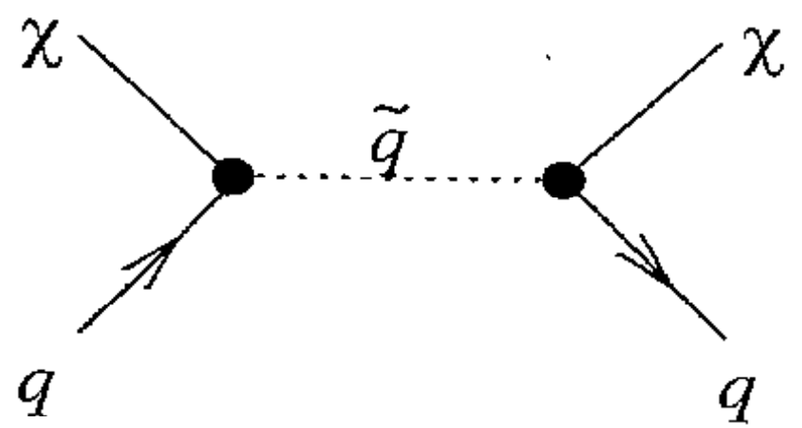
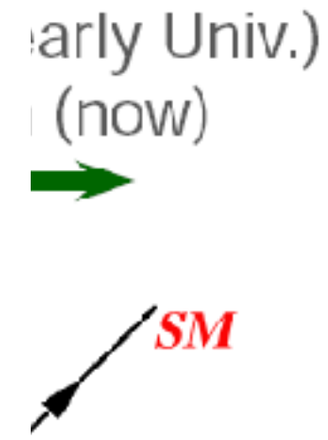
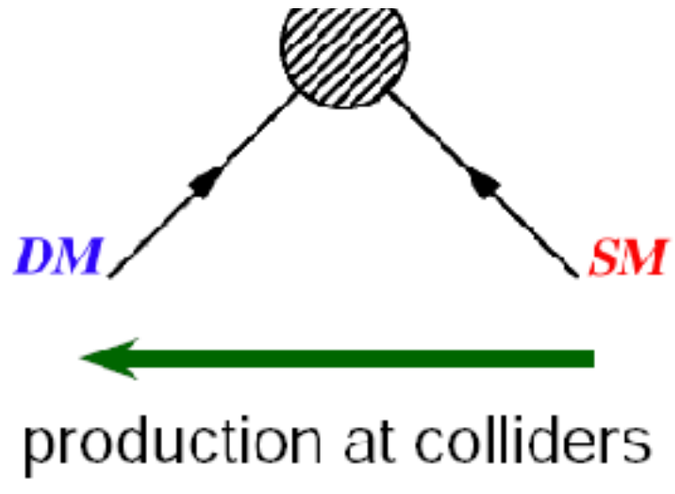


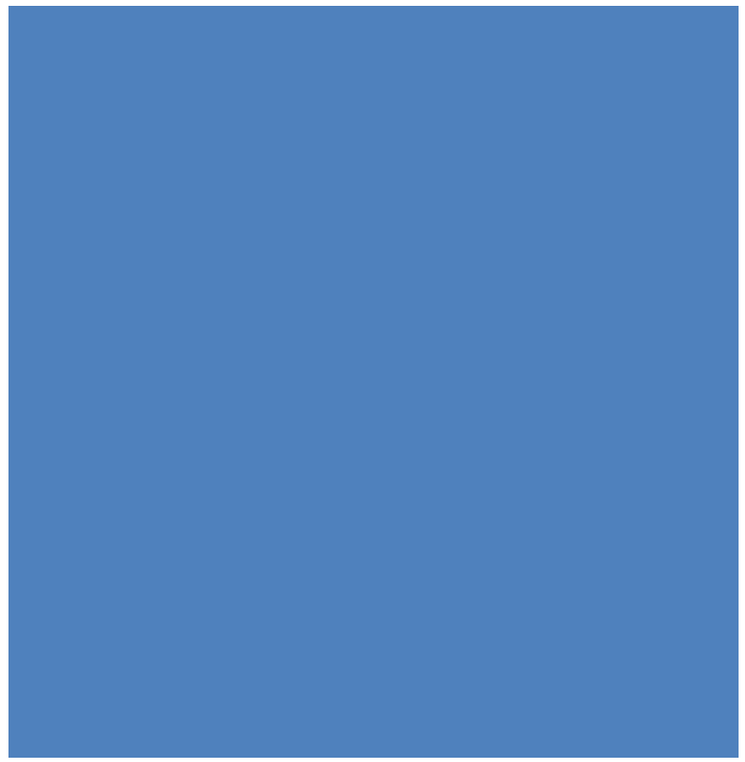
Spin dependent







Particle Detection with Bubble Chambers



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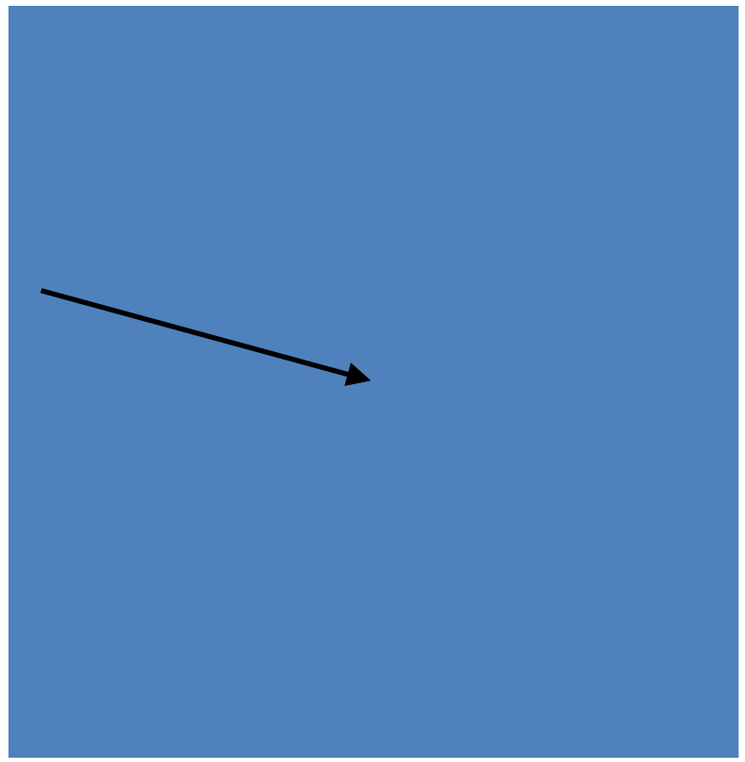

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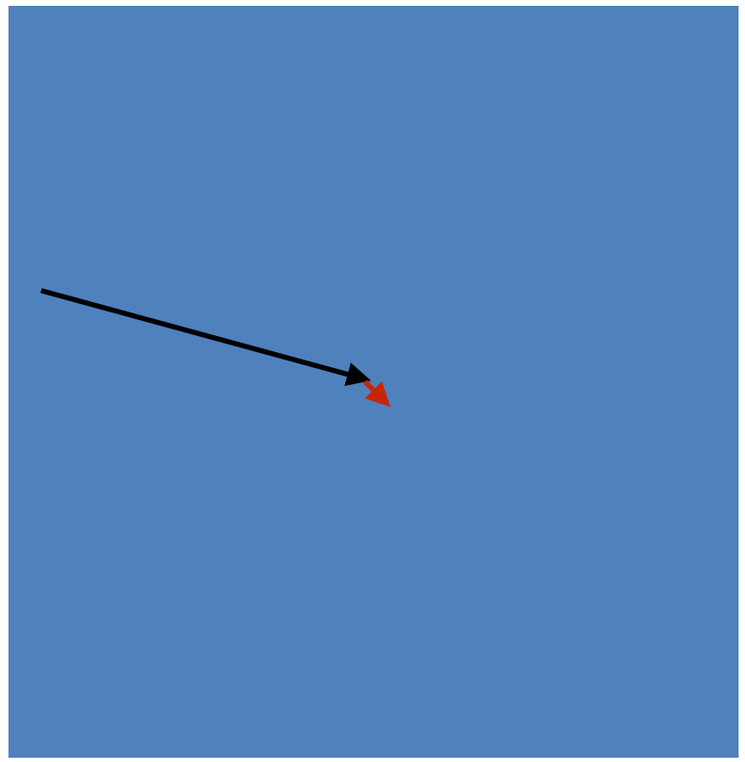

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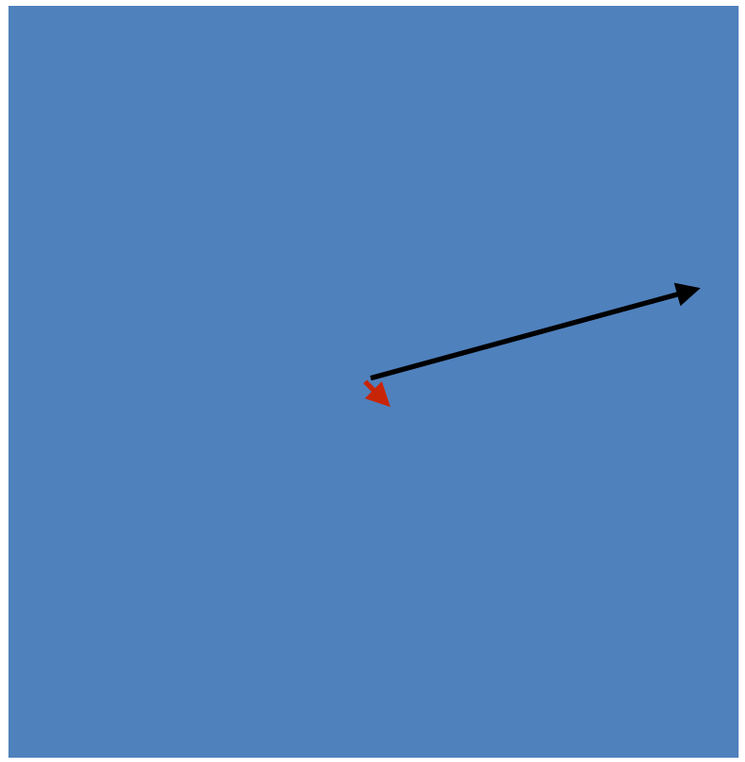

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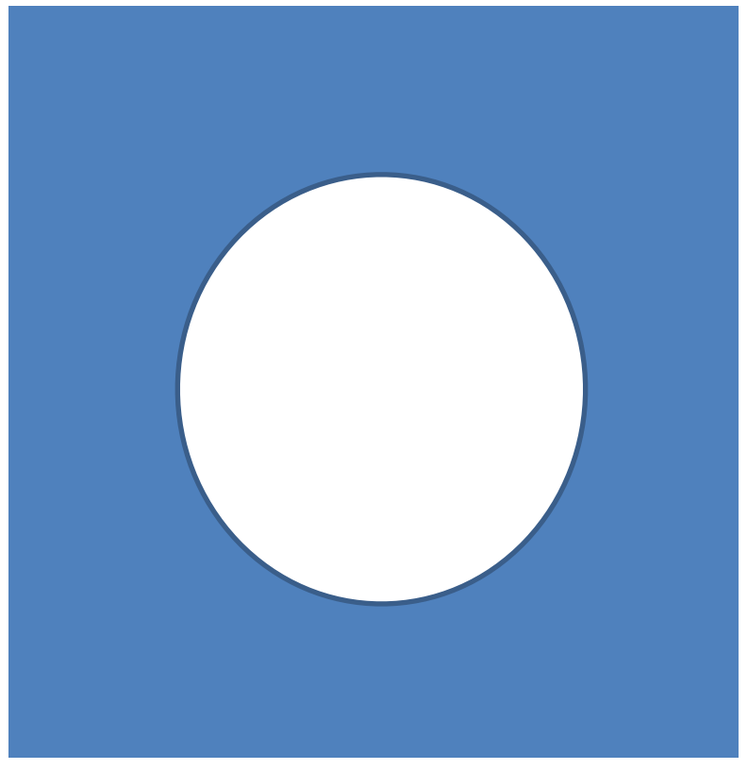
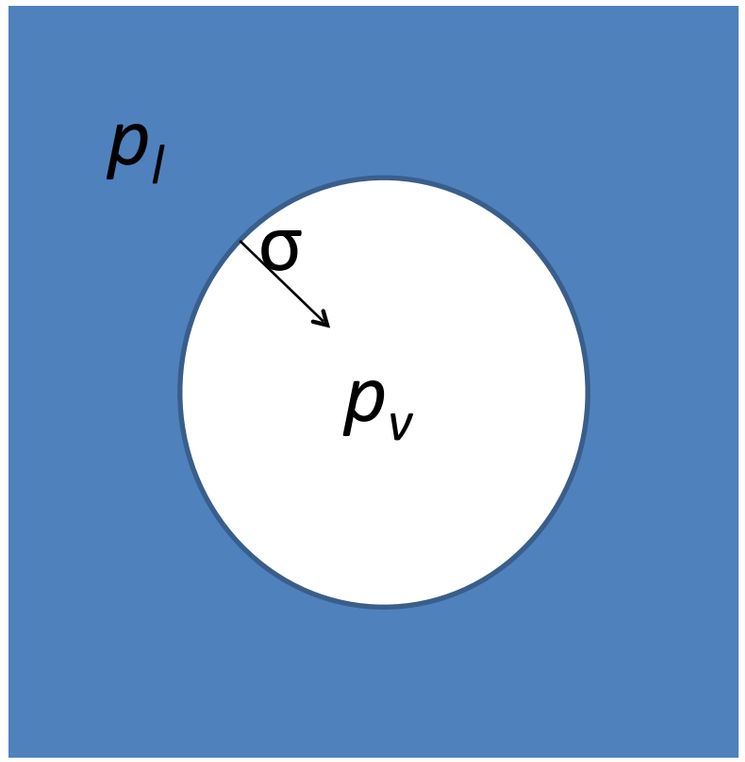


Particle Detection with Bubble Chambers

- A bubble chamber is filled with a superheated fluid in meta-stable state
- Energy deposition greater than E_{th} in radius larger than r_c from particle interaction will result in expanding bubble (Seitz “Hot-Spike” Model)



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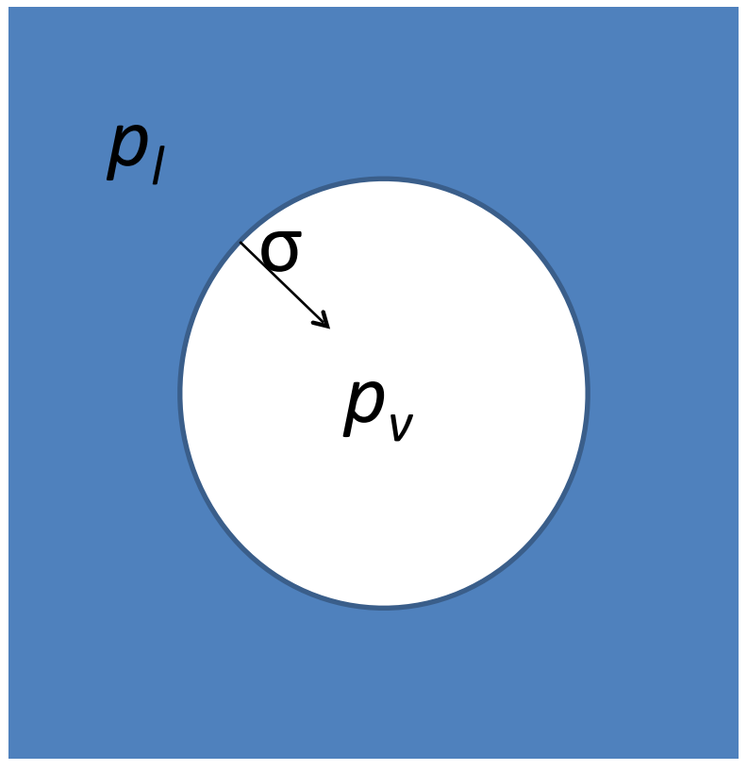

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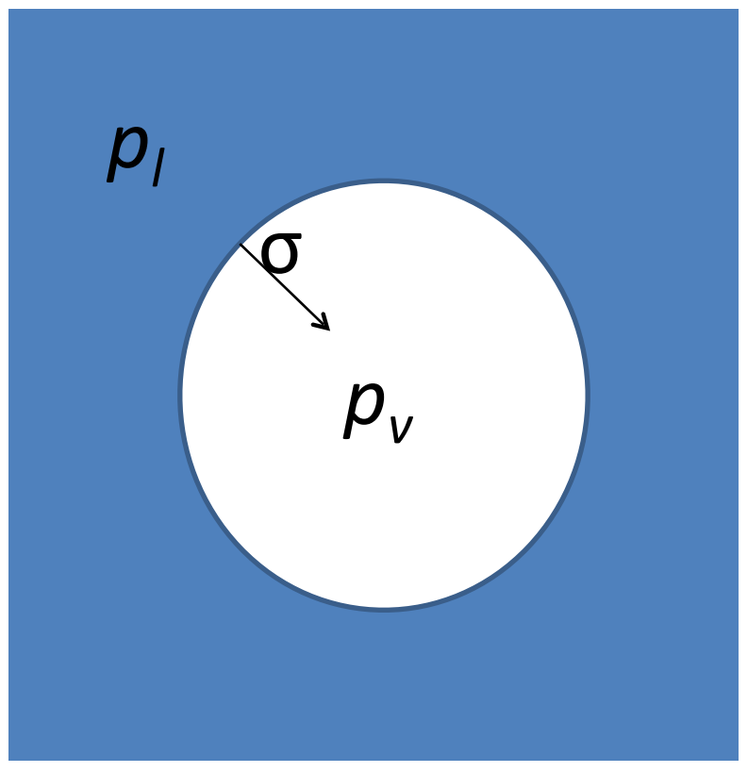
- Classical Thermodynamics says:

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

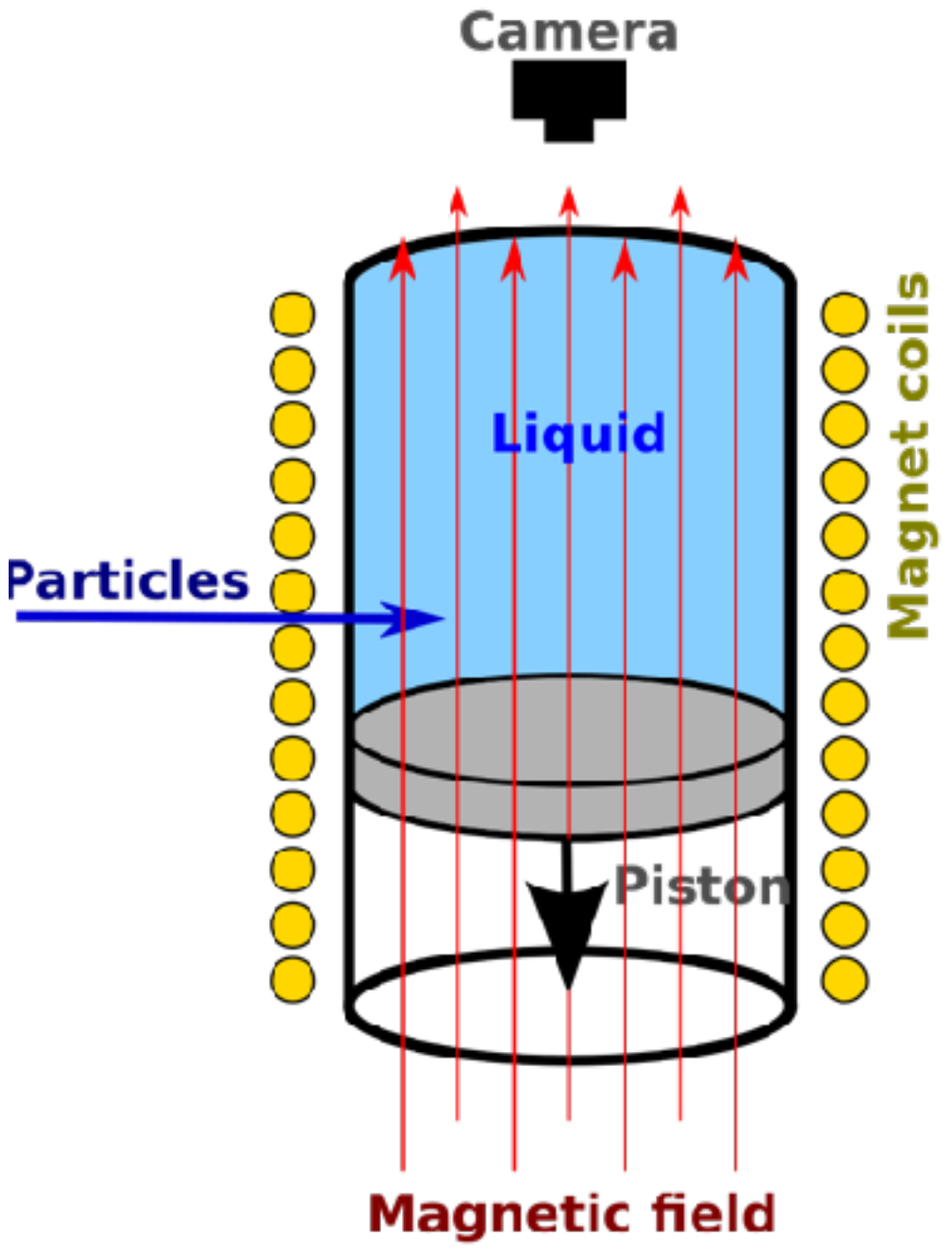
$$E_{th} = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

Latent heat



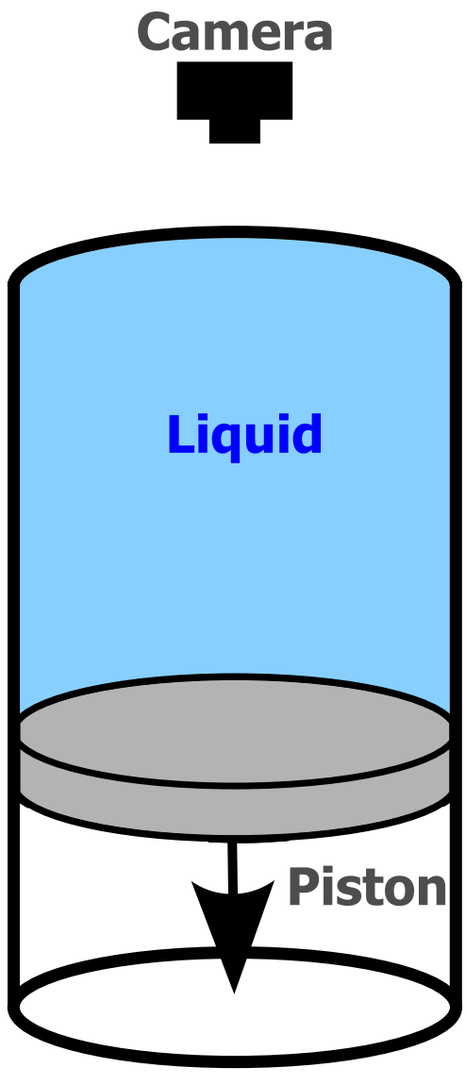
Dark Matter Bubble Chamber



- Any bubble chamber has:
  - optical system with camera, lights
  - expansion system, piston, temperature control

From Wikipedia: “Bubble Chamber”

Dark Matter Bubble Chamber



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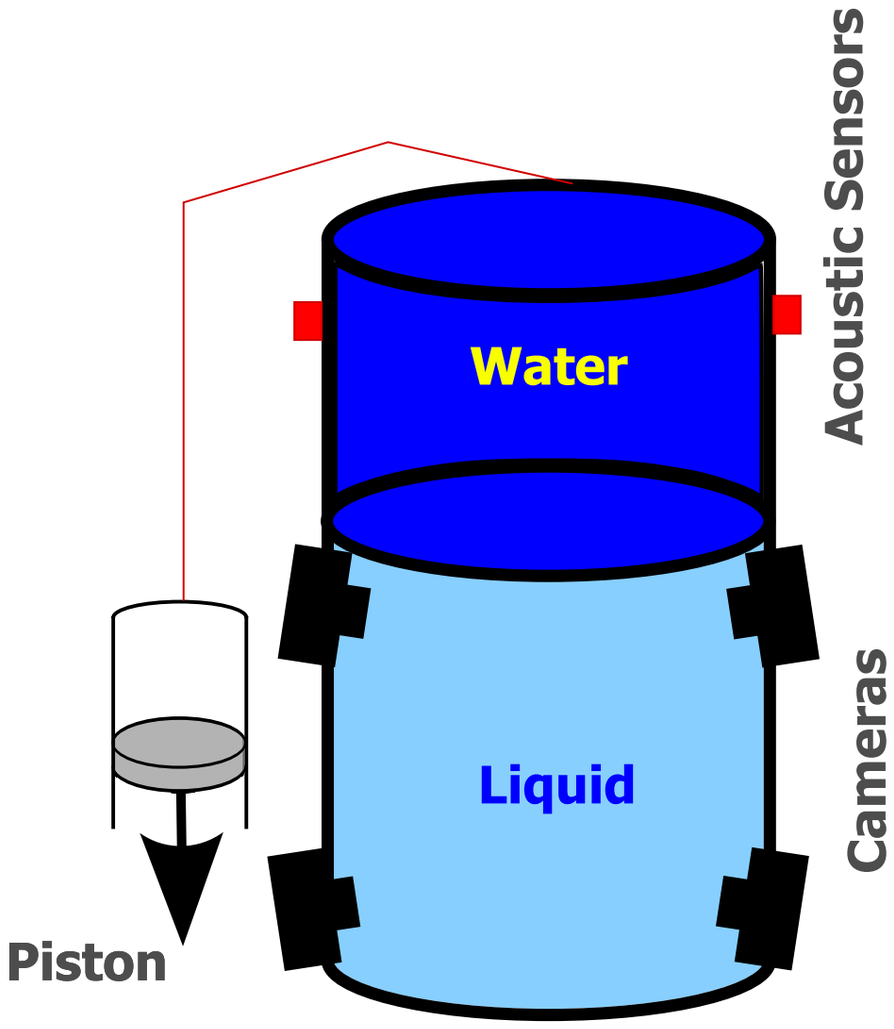

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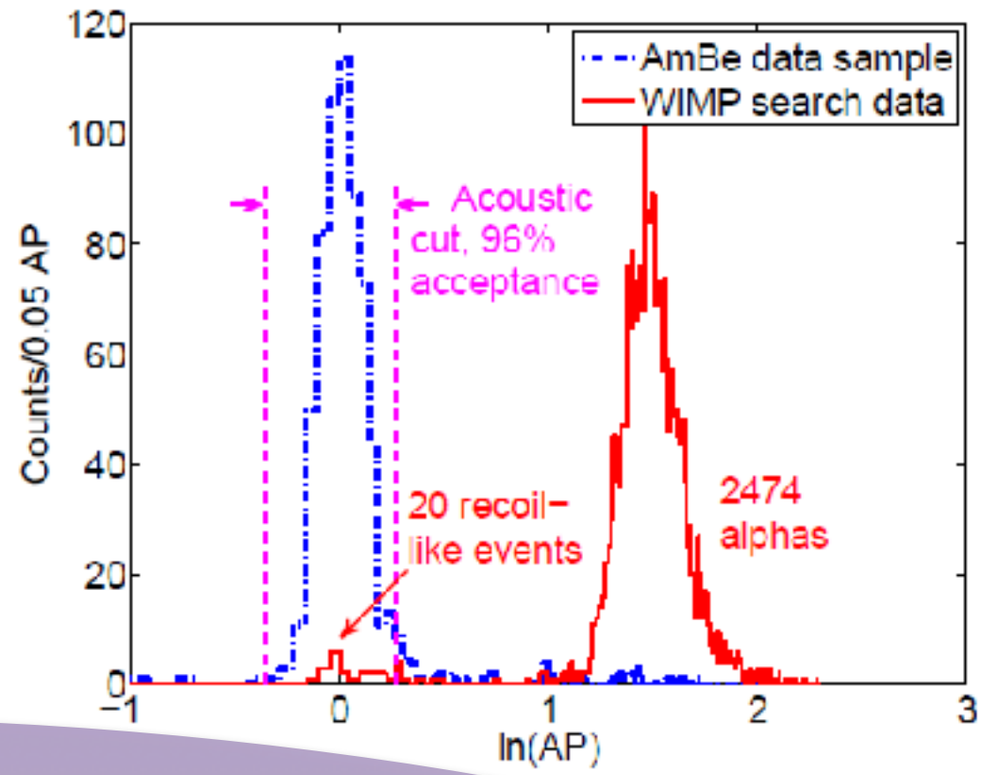
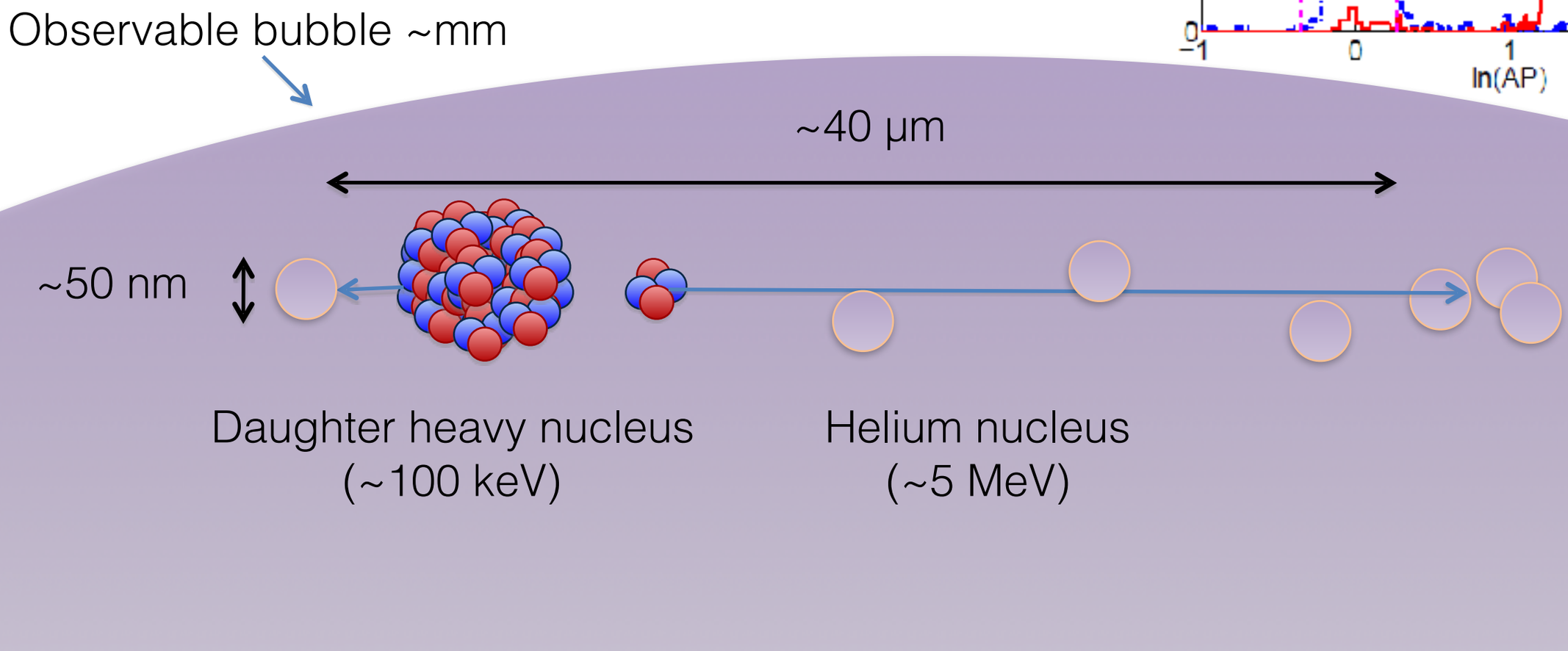
PICO uses acoustic background discrimination

Acoustic Discrimination

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





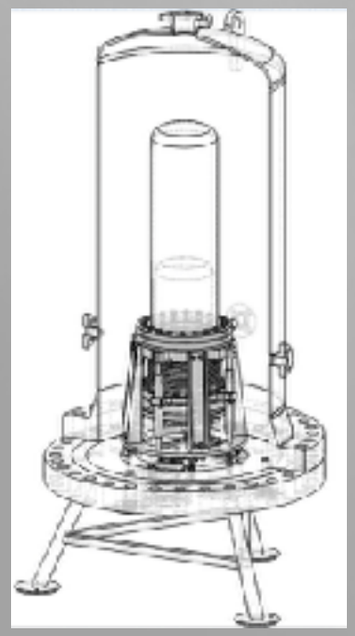
PICO Program Overview

PICASSO

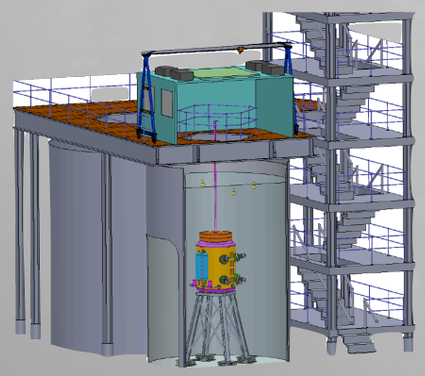
COUPP

PICO

PICO 2L
C_3F_8



PICO 40L
C_3F_8, Right Side Up



PICO 500
C_3F_8

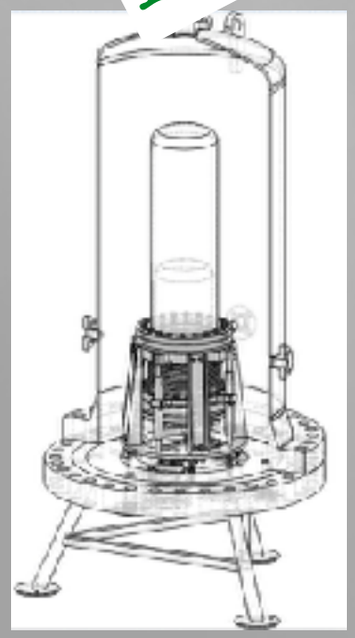
PICO 60
$CF_3I \rightarrow C_3F_8$

PICO Program Overview

PICASSO

Backgrounds

Neutron Limited



PICO 2L
C_3F_8

PICO

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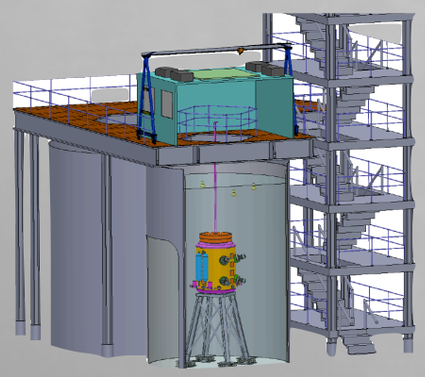

PICO 500
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COUPP

Backgrounds

Overview

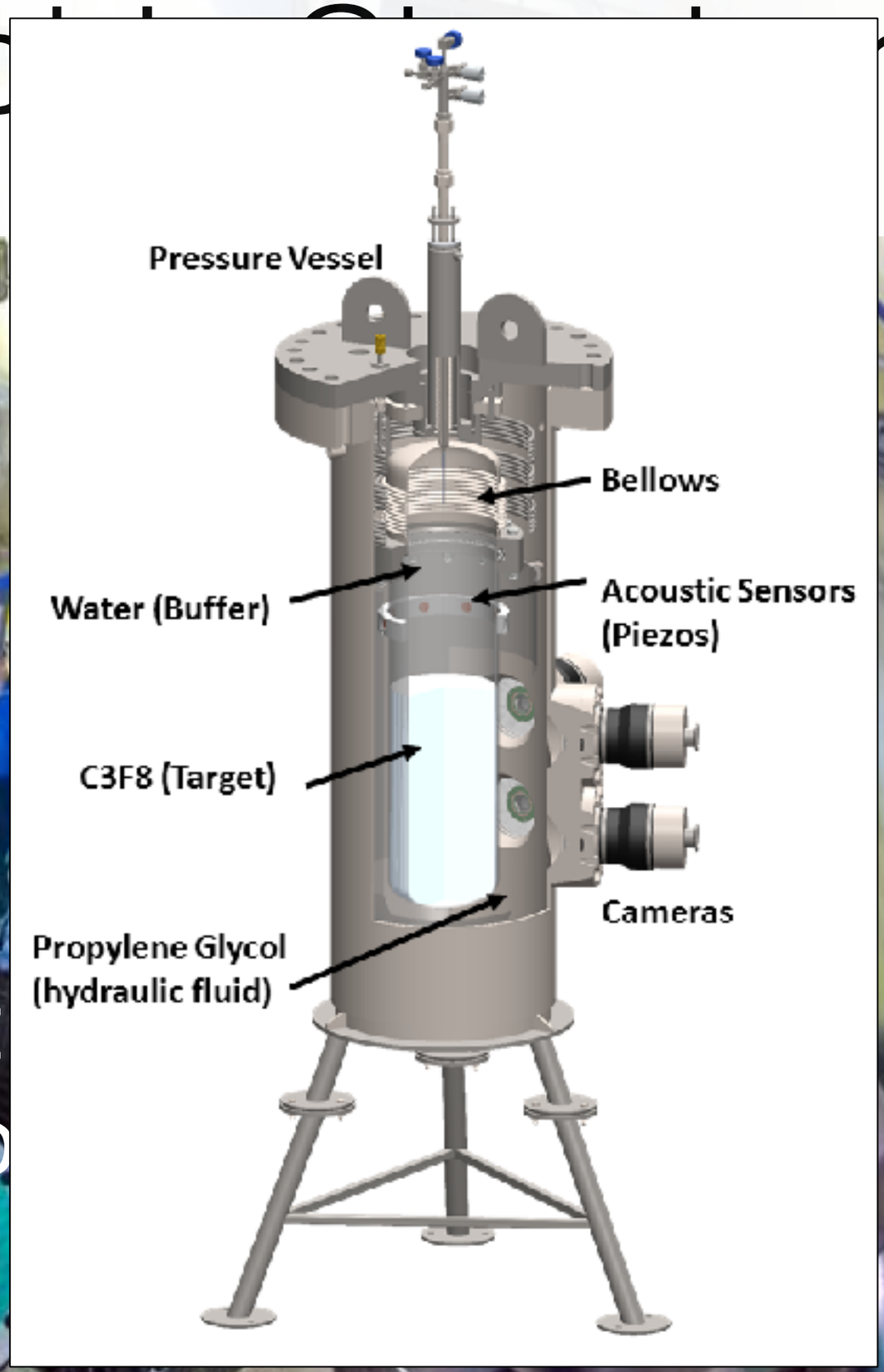
- The PICO Programme
- **PICO 60**
- PICO 40L - PICO 500

PICO

The PICO 60 Bubble Chamber

- World's largest current bubble chamber, installed 2km underground at SNOLAB, Sudbury, Ontario

The PICO 60 Bub



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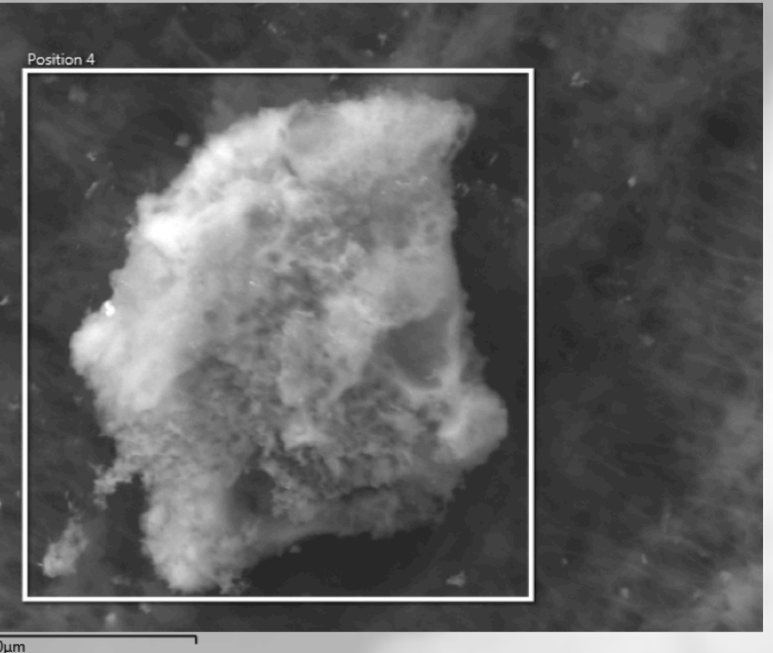
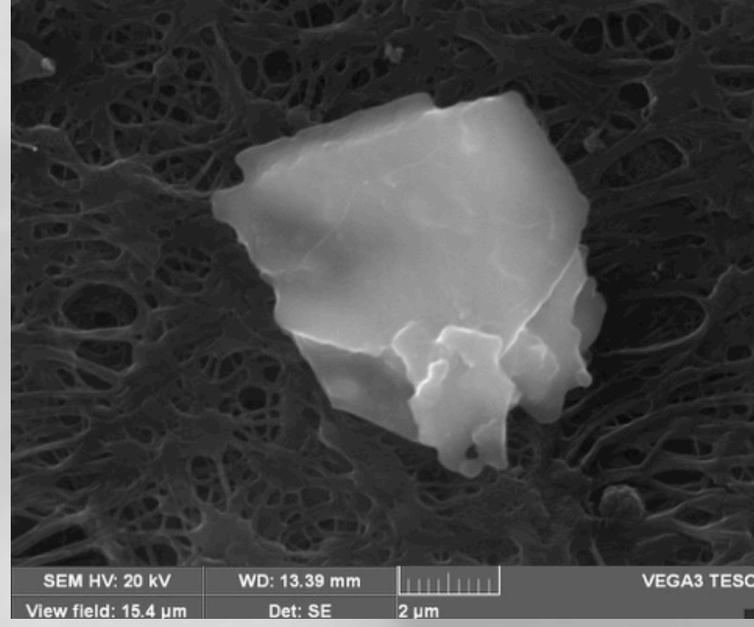


After Run I - Assay

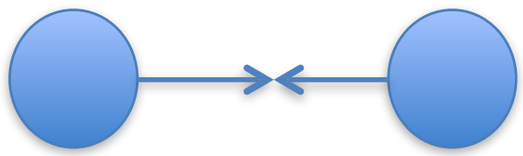


- Radioactive particulates were suspected to be part of the problem after run I ended. Careful assays of the liquids after the end of the fill revealed contamination with mostly steel and silica particulates

- The radioactivity of the material is not sufficient to explain the backgrounds observed

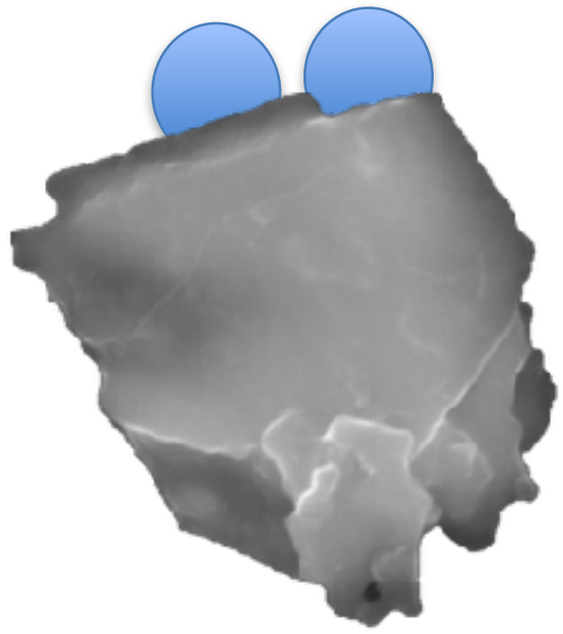
Bubble Nucleation by Surface Tension

- Merging of two water droplets releases O(1 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

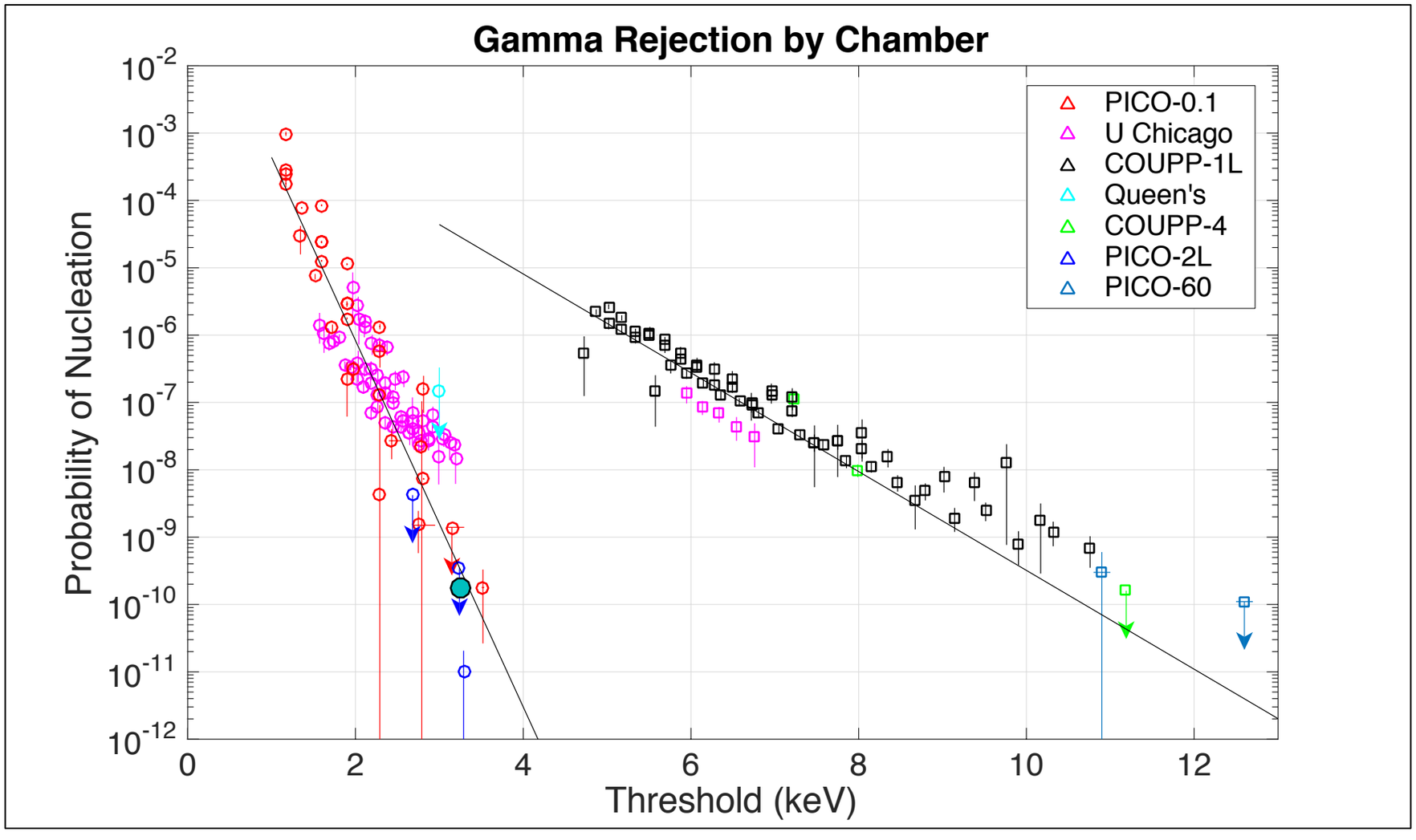
- The merging water droplets could be attached to solid particulate



Run II of PICO 60

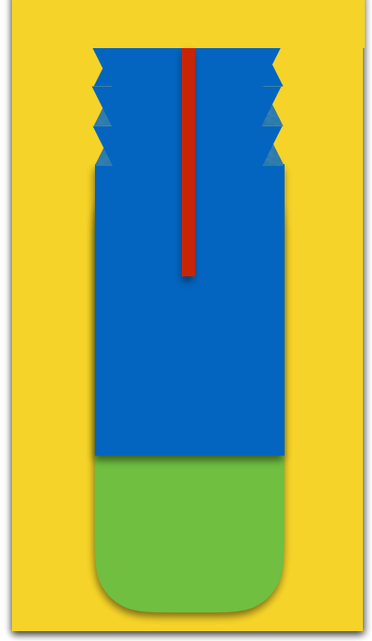
- New active liquid: C_3F_8
  - New water system and cooler
- New vessel, new geometry with both flange and vessel from synthetic quartz
- extensive QC of cleanliness during installation
- Four cameras, allows operation with 52kg of target volume

Switch to C_3F_8



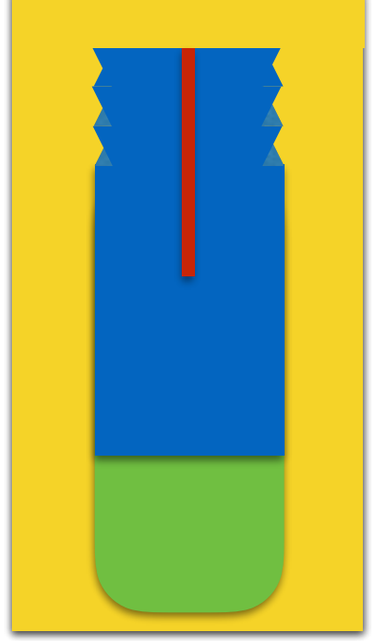
- Probability of detecting gamma interactions in CF_3I and in C_3F_8

Detector Cleaning



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

Detector Cleaning



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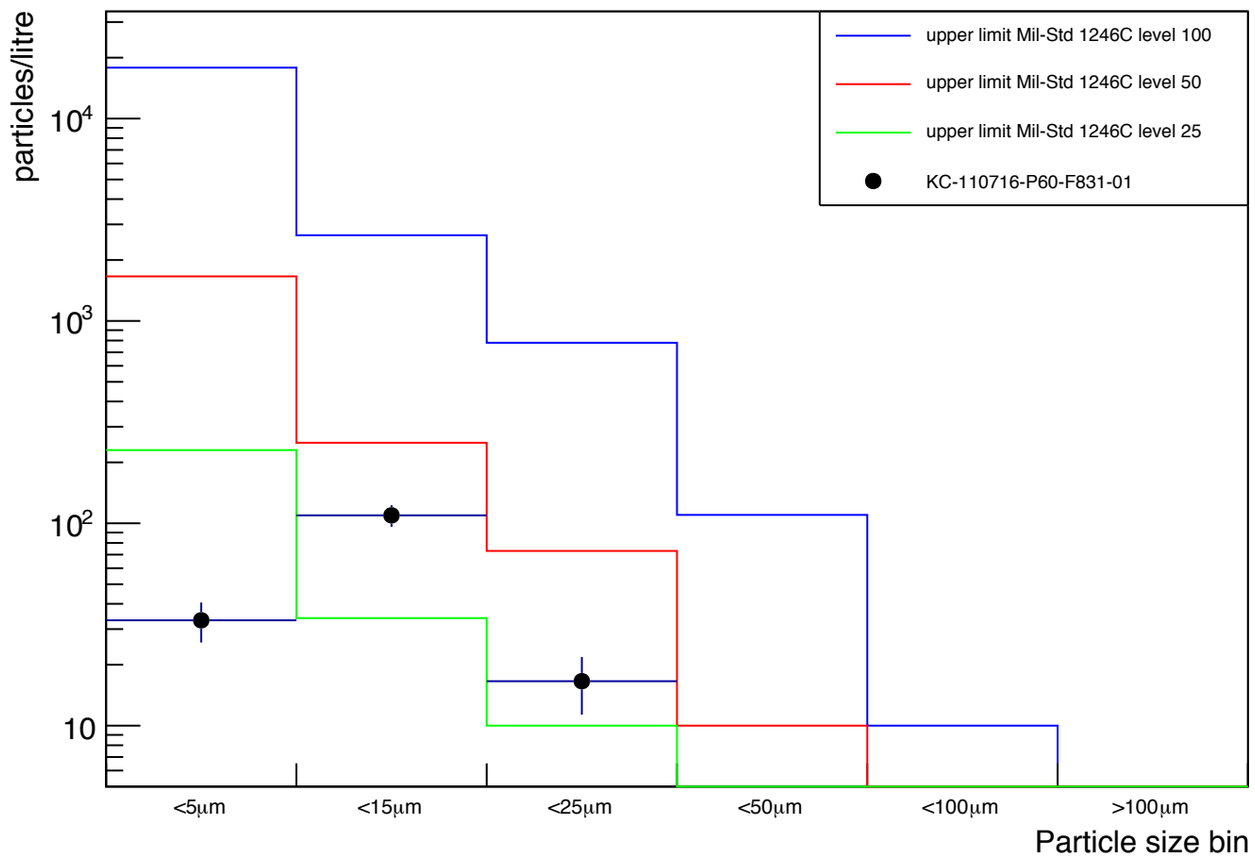
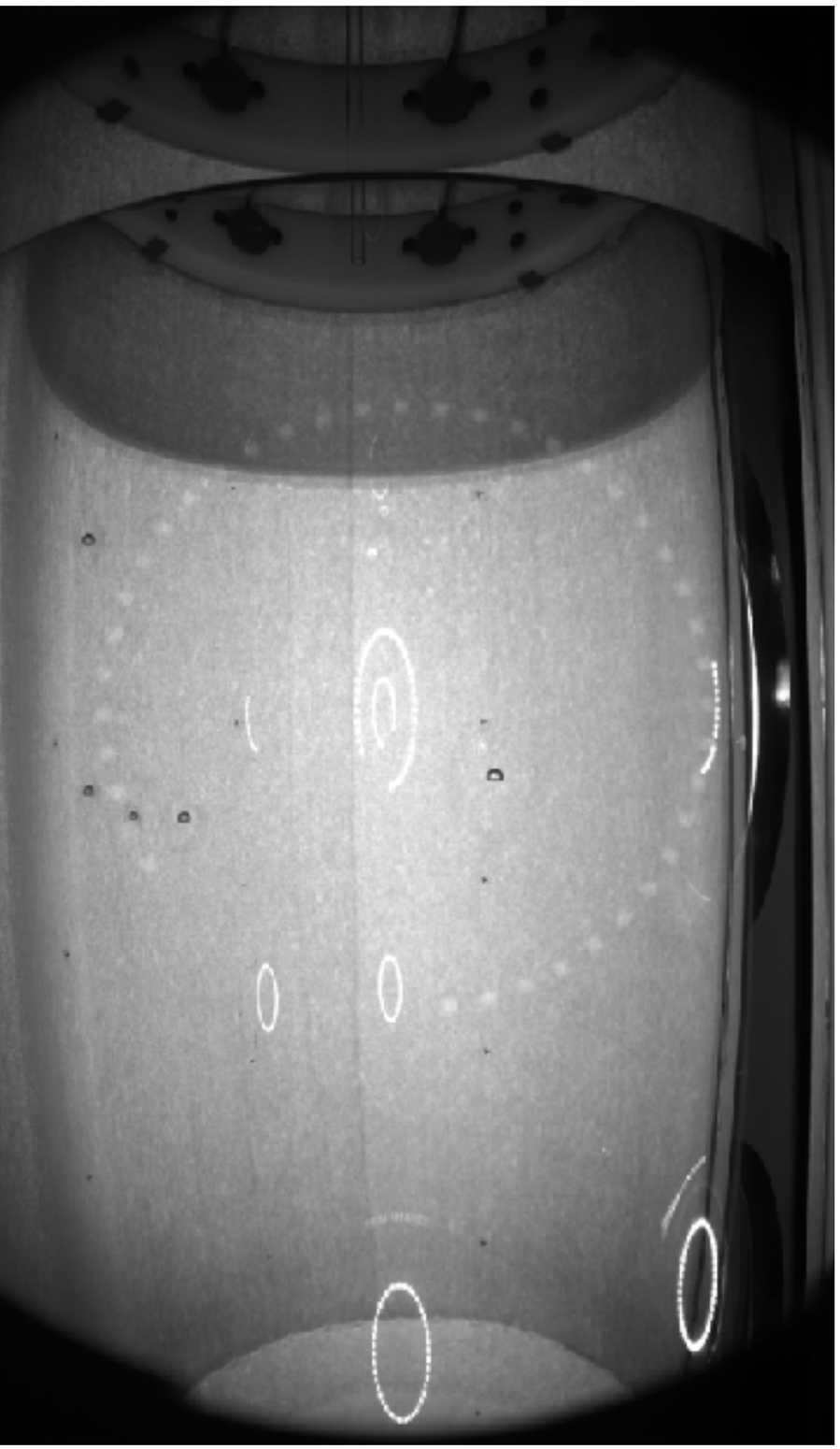




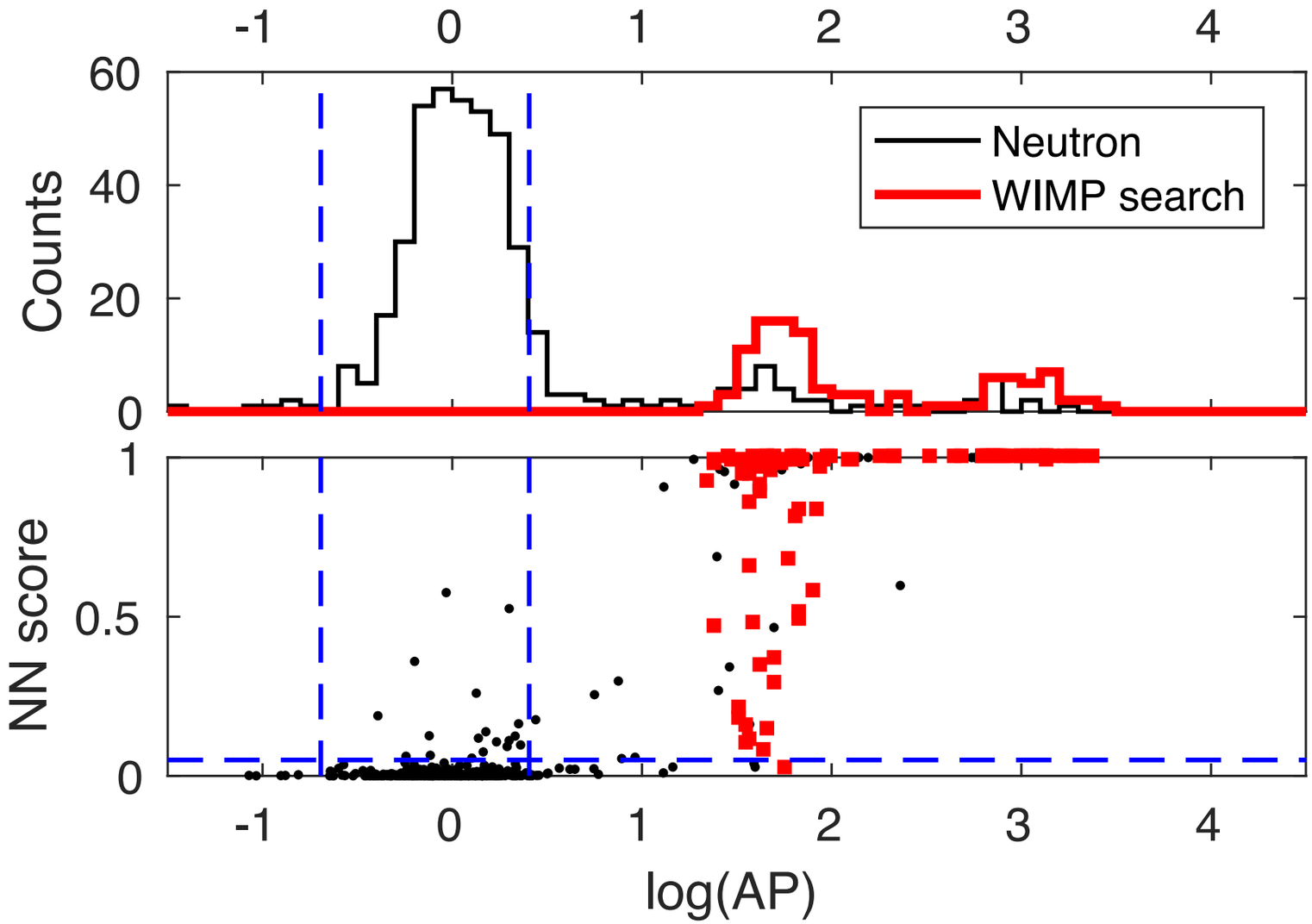
Data Taking

- Very smooth operation before and after the run type was switched to “blind running” (November 28 2016)

- Three multi bubble events were collected during the blind run

  - This shows that the detector materials are not permitting a longer run with this detector, unfortunately. We need a better setup with reduced neutron background

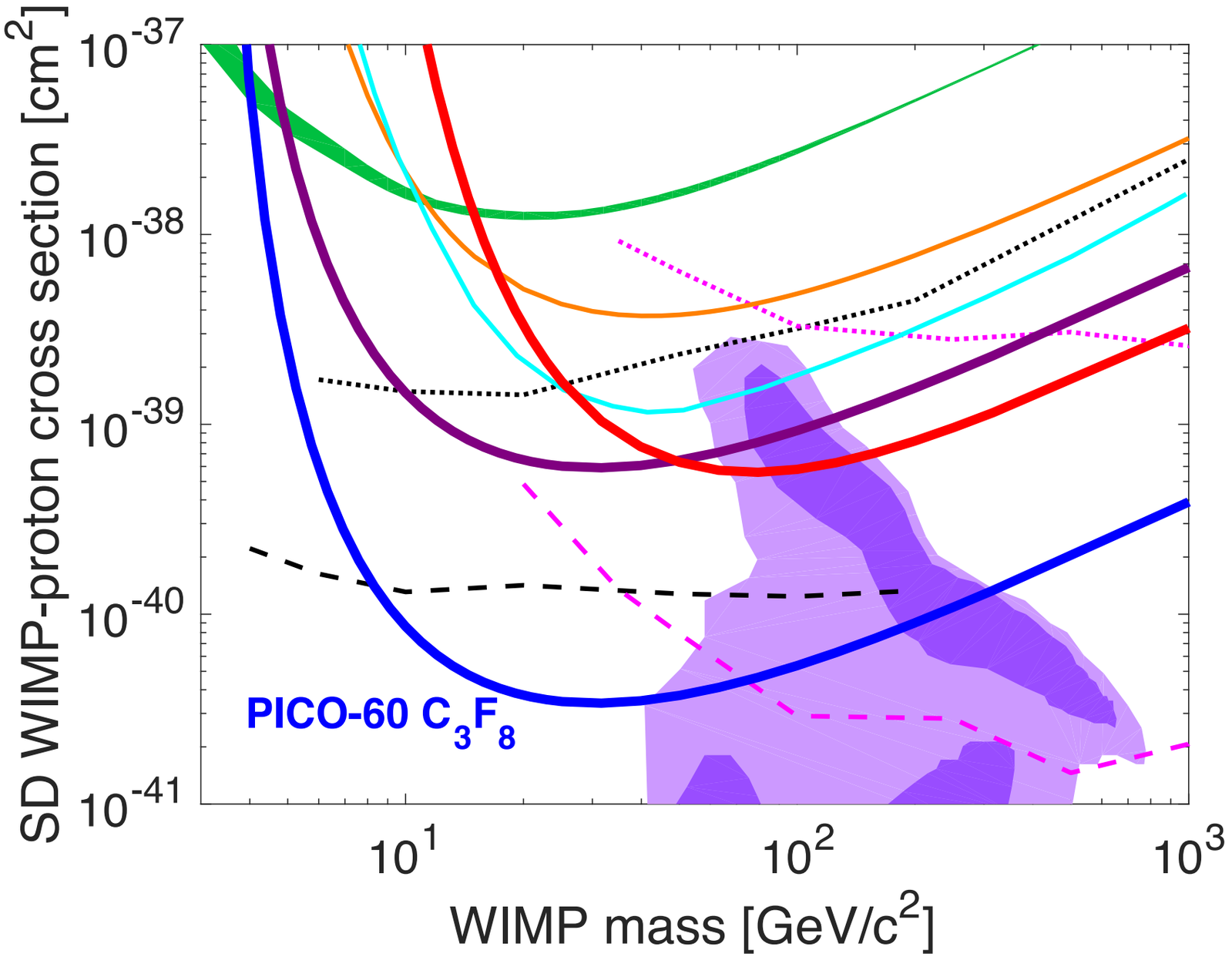
Acoustic Data



- Blind data talking, acoustic data was removed from data stream
- Zero events in the nuclear recoil parameter space

C. Amole *et al.*, Phys. Rev. Lett. 118, 251301

WIMP - Proton Exclusion

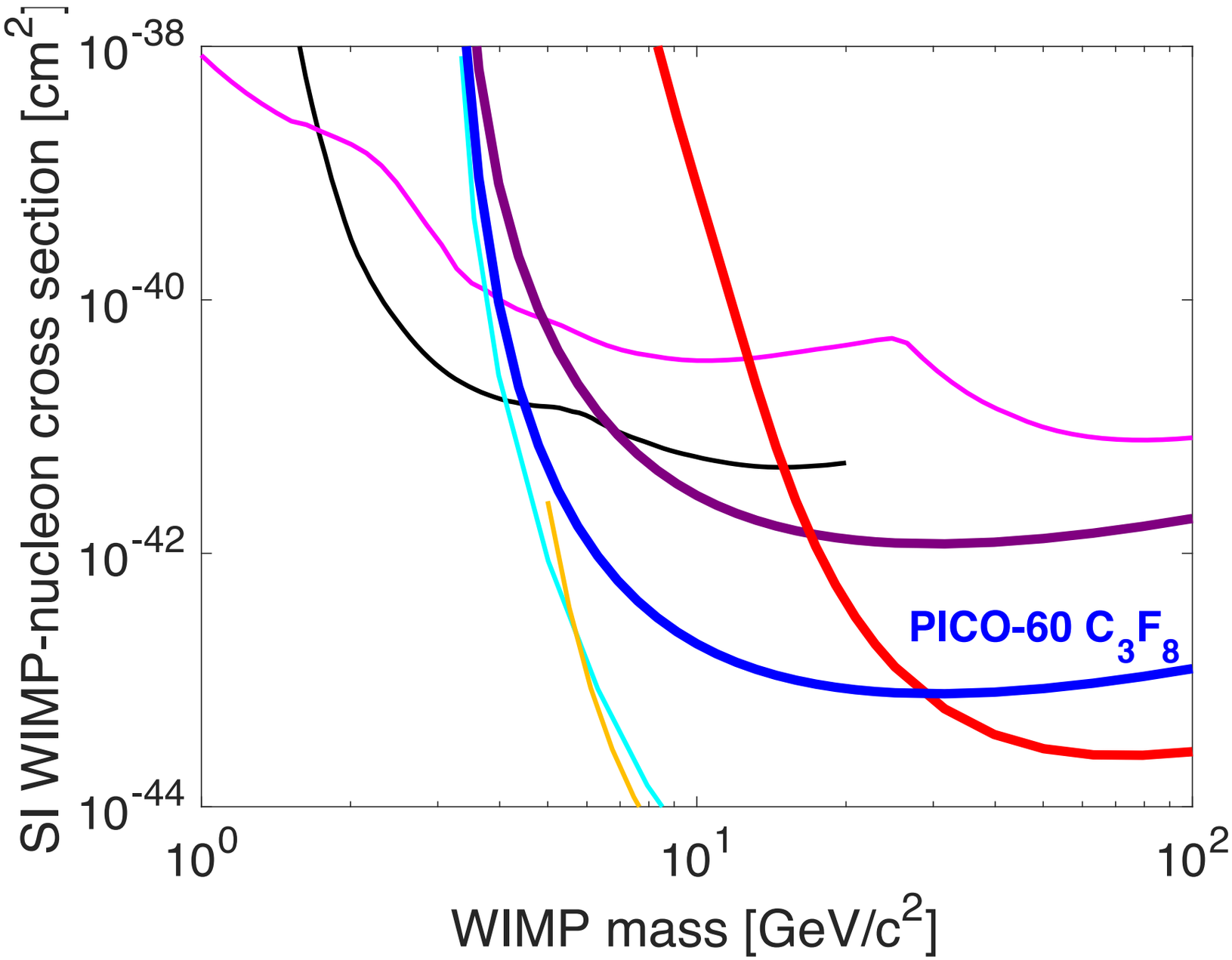


The 90% C.L. limit on the SD WIMP-proton cross section from PICO-60 C_3F_8 blue, along with limits from PICO-60 CF3I (red), PICO-2L (purple), PICASSO (green), SIMPLE (orange), PandaX-II (cyan), IceCube (dashed and dotted pink), and Su-perK (dashed and dotted black)

C. Amole *et al.*, Phys. Rev. Lett. 118, 251301

Spin Independent

The 90% C.L. limit on the SI WIMP-nucleon cross-section from PICO-60 C3F8 plotted in blue, along with limits from PICO-60 CF3I (red), PICO-2L (purple), LUX (yellow), PandaX-II (cyan), CRESST- II (magenta), and CDMS-lite (black).



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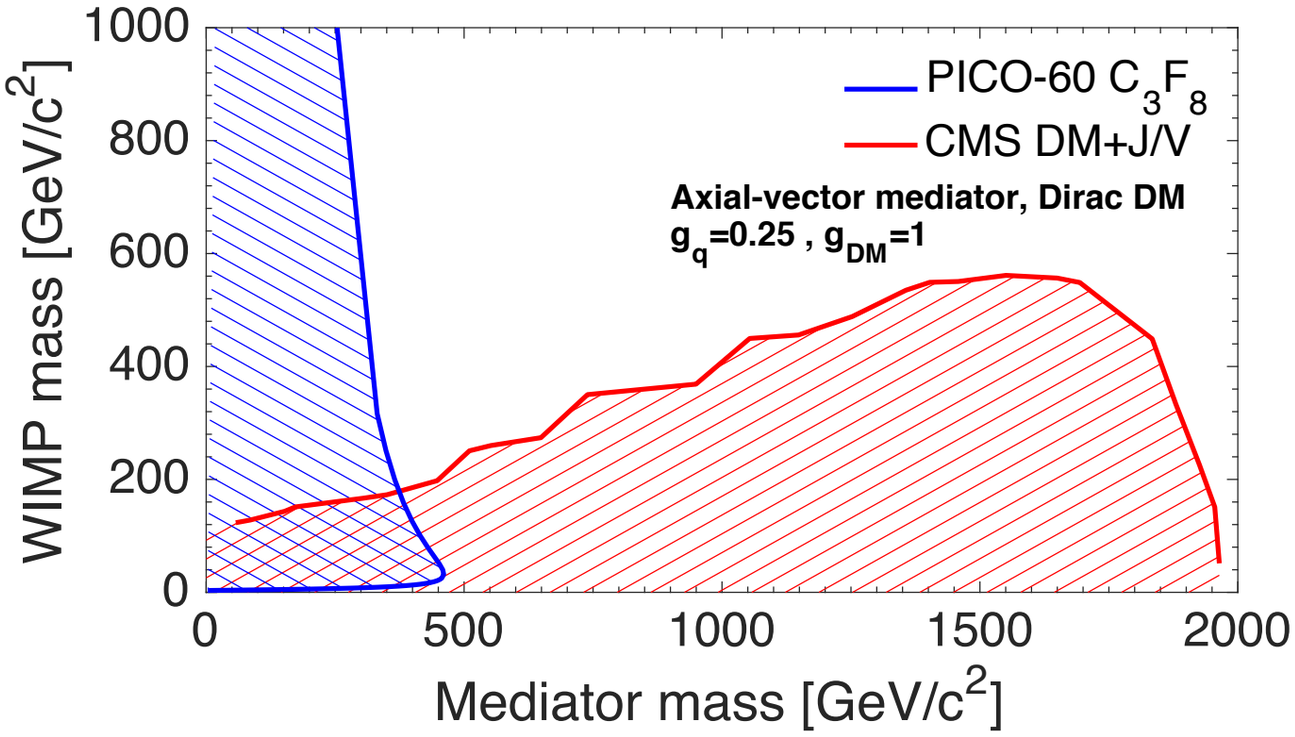
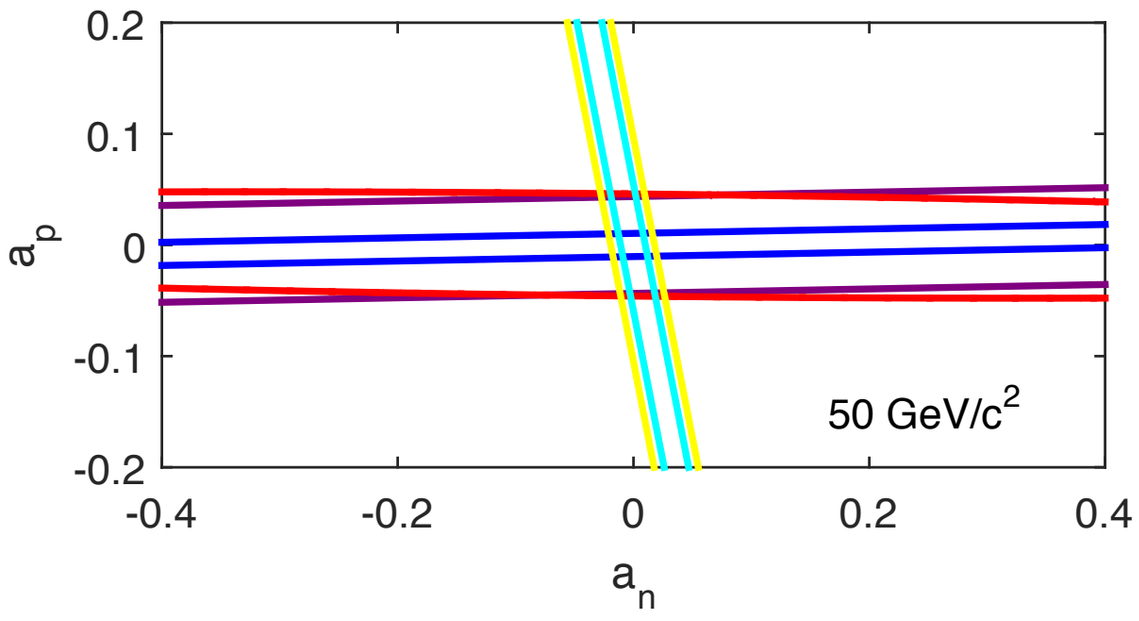
Results





Left: WIMP mass exclusion limits in comparison with accelerator results

Right: PICO-60 constraints (blue) on the effective spin- dependent WIMP-proton and WIMP-neutron couplings, a_p and a_n, for a 50 GeV/c^2 WIMP mass
Also shown are results from PANDAX-II (cyan), LUX (yellow), PICO-2L (purple), and PICO-60 C3FI (red)

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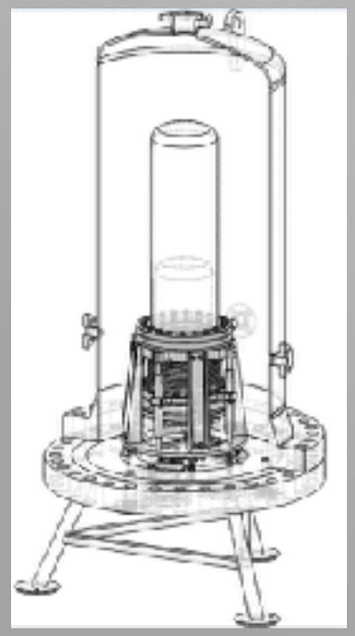

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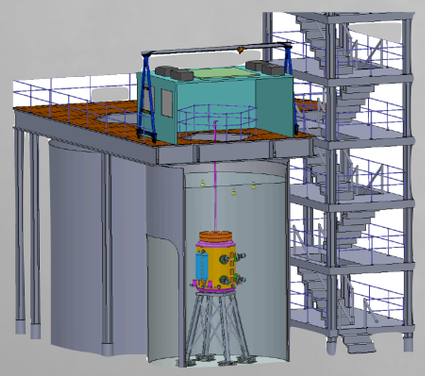

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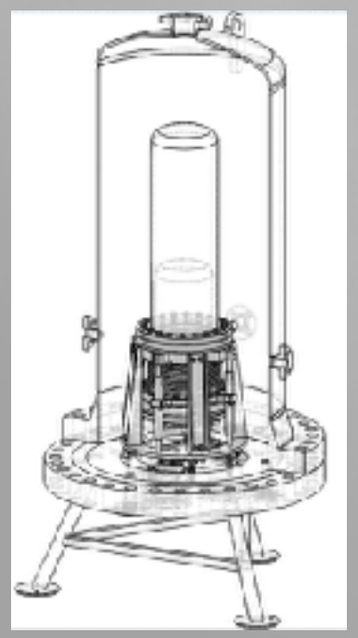

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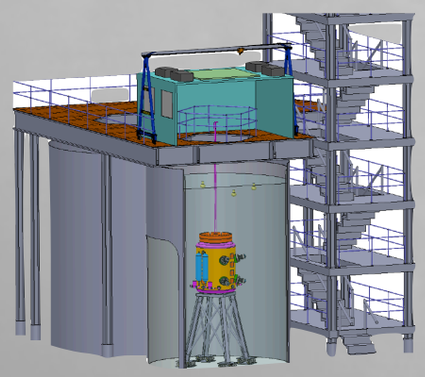

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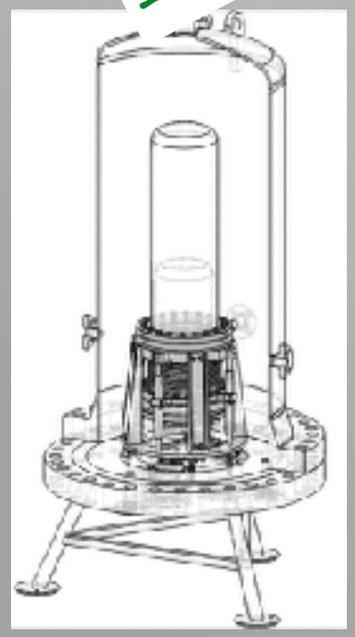

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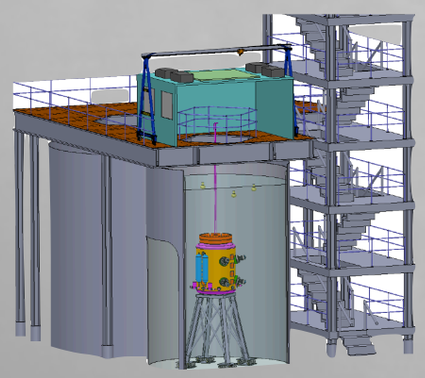

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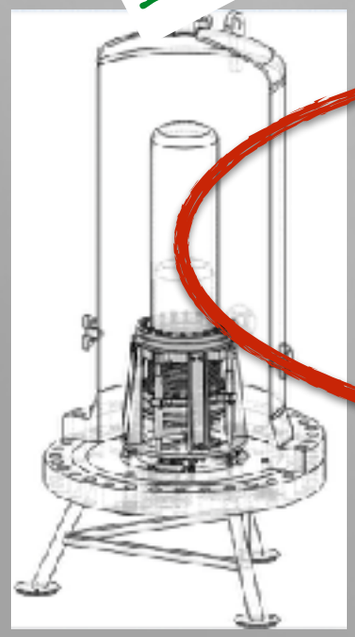

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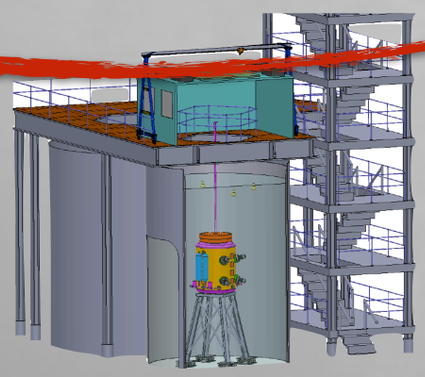
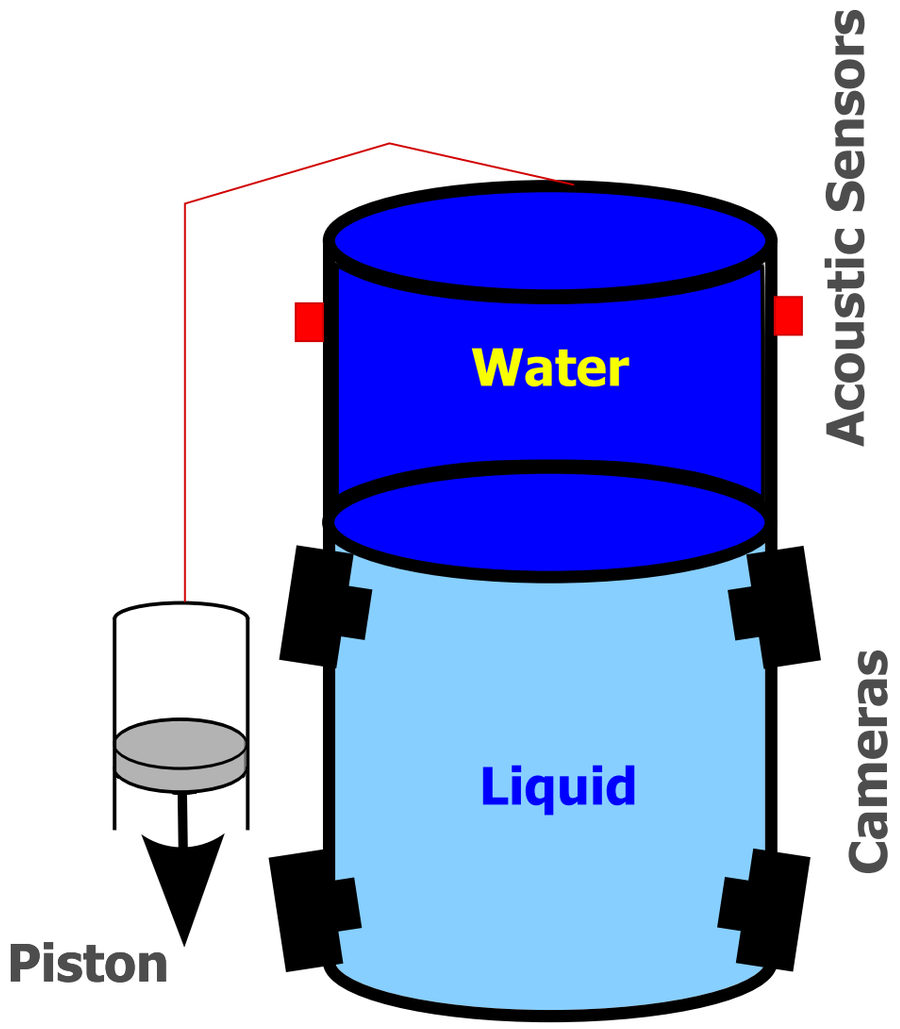
PICO 40L
C_3F_8, Right Side Up



PICO 500
C_3F_8

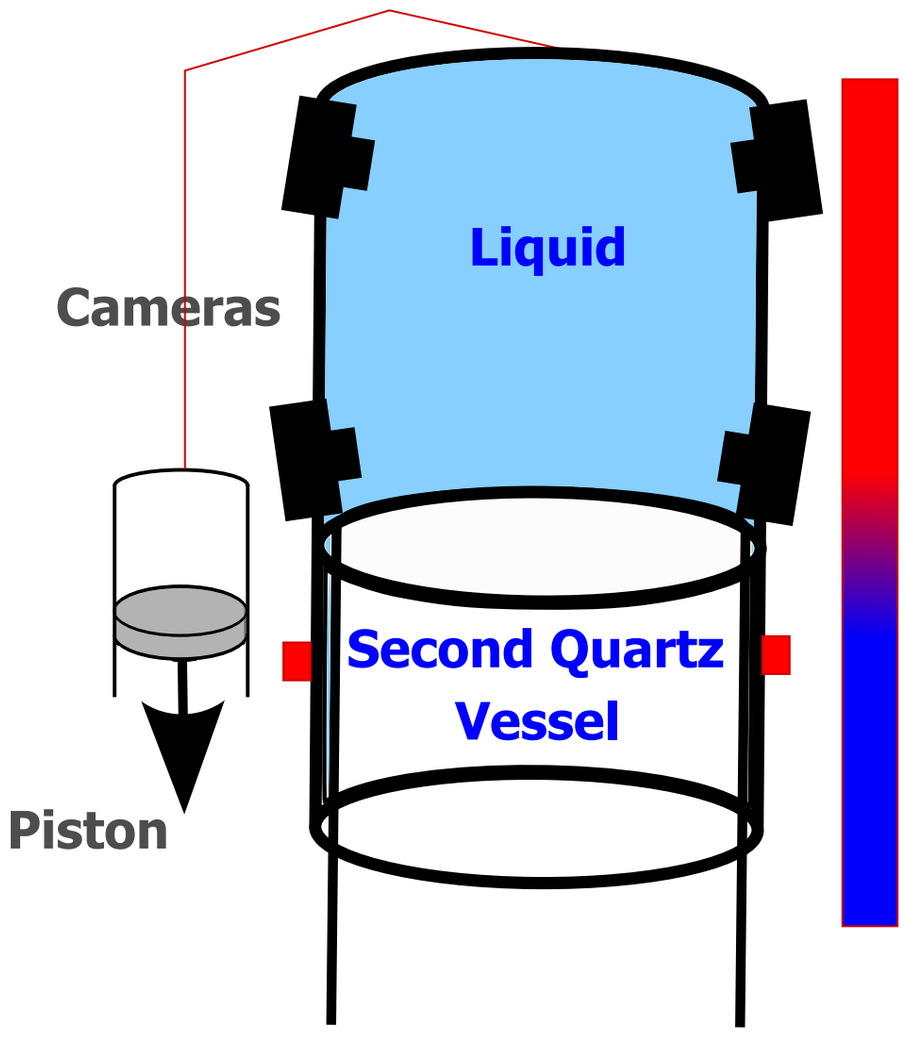
Dark Matter Bubble Chamber



- Any bubble chamber has:
  - optical system with camera, lights
  - expansion system, piston, temperature control

PICO uses acoustic background discrimination

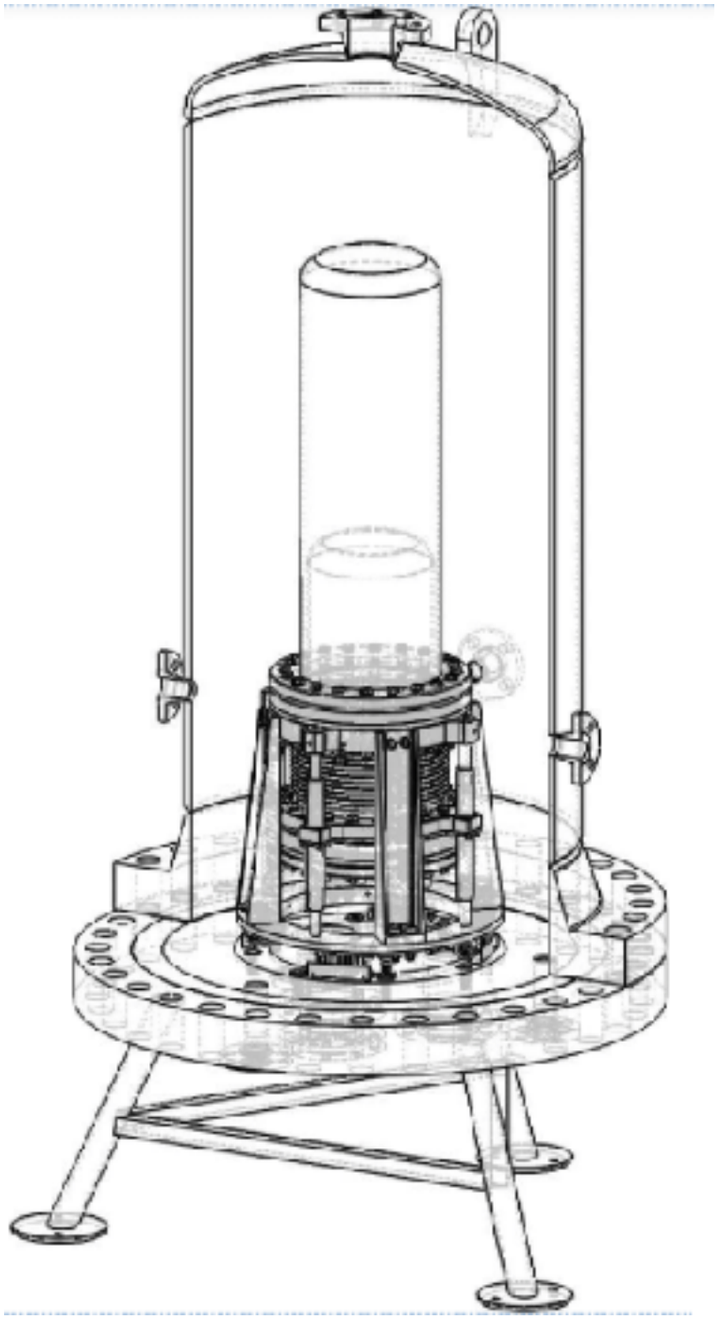
Dark Matter Bubble Chamber



- Any bubble chamber has:
  - optical system with camera, lights
  - expansion system, piston, temperature control

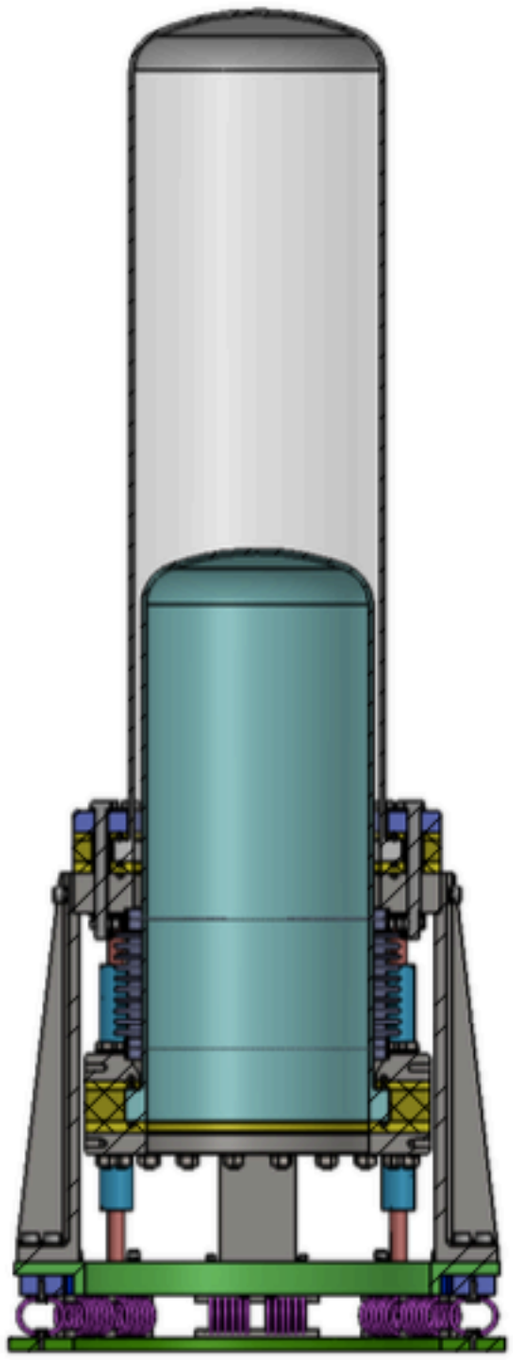
PICO uses acoustic background discrimination

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

PICO 40L Status



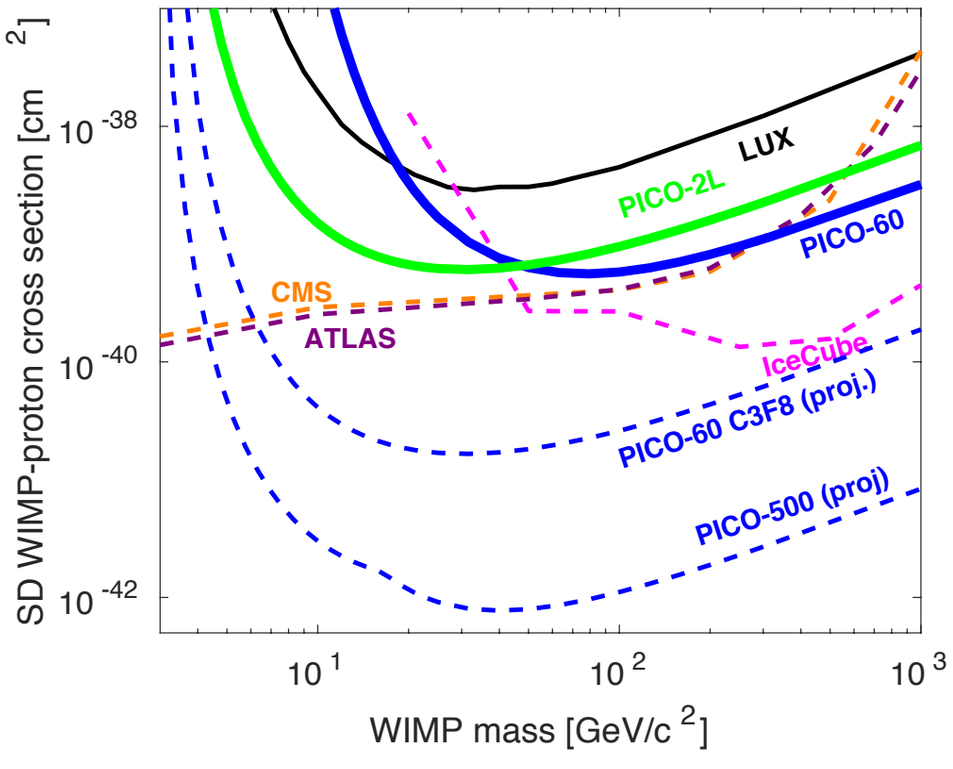
PICO 40L Status

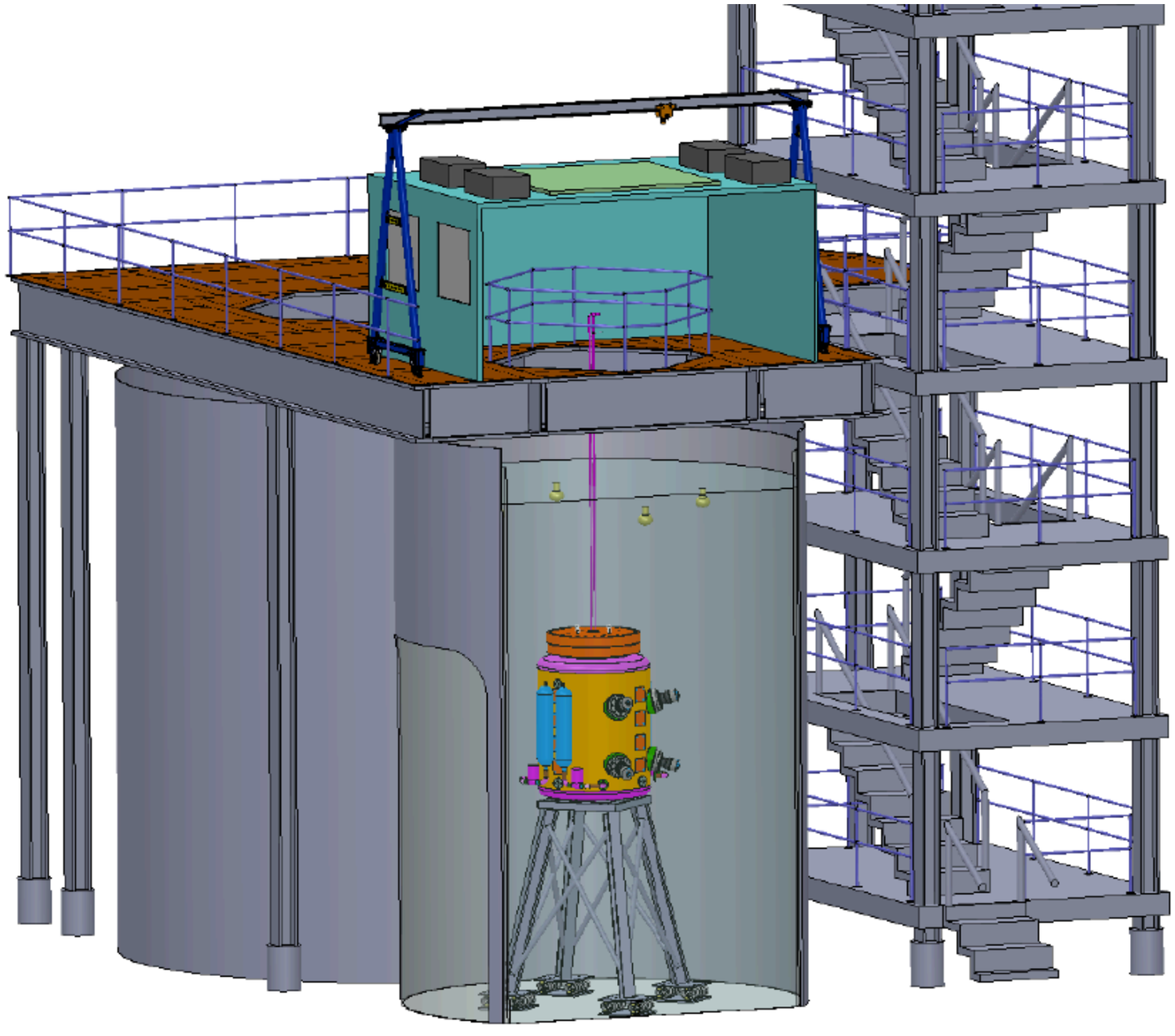
PICO 40L Status

- PICO 40L parts are arriving at SNOLAB
- The detector is expected to be operational by the end of the year 2017
- The system is expected to demonstrate better operational stability due to the absence of water
- The neutron background will be significantly reduced due to the larger new pressure vessel
- PICO 40L is expected to run for about two years at SNOLAB

Next Up: PICO 500

- PICO 500 will explore the ultimate sensitivity of a low background bubble chamber
- It will be located at SNOLAB
- Development on the engineering of this detector has started





Summary

- PICO 60 stopped data taking two days ago
  - The system performed exceptionally well
  - Blind analysis for this data set puts PICO results at a fundamentally different level of significance compared to previous work
    - The stable operation of the detector at at a threshold as low as 1.1 keV is a significant step forward. The analysis of the final data is going on, expect another PICO publication later this year
- PICO 40L will be installed in the coming months
- We are getting ready for PICO 500 as the next big bubble chamber

PICO

SNOLAB
Mining for knowledge
Creuser pour trouver... l'excellence

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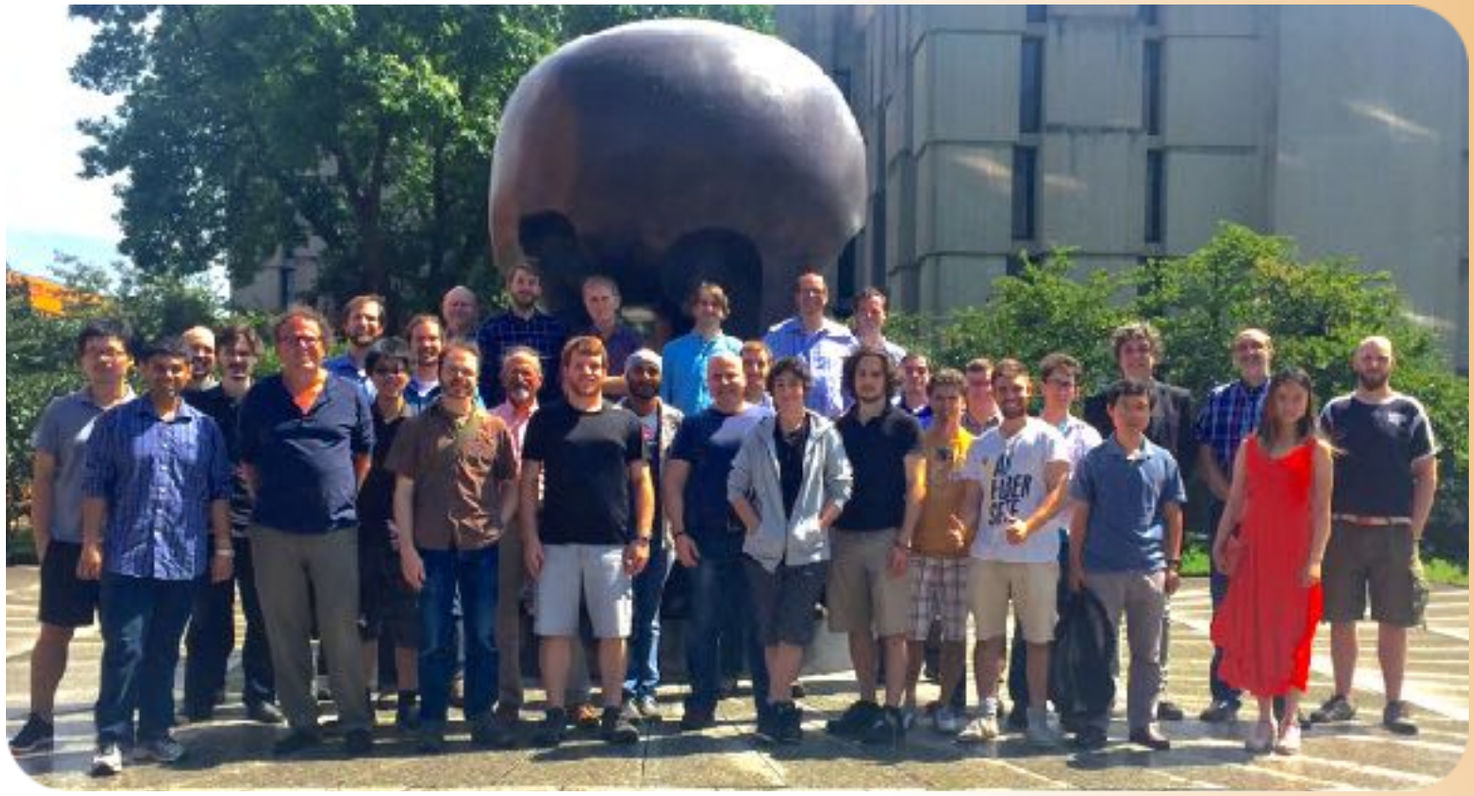

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