

Recent PICO 60 Results and Future PICO Chambers

Carsten B. Krauss for the PICO Collaboration

TAUP 2017 Sudbury — July 25 2017



UNIVERSITY OF
ALBERTA

Overview

- **The PICO Programme**

- PICO 60
- PICO 40L - PICO 500

Other PICO related Talks
and Posters at TAUP:

J. Zhang-Monday 1:15pm

P. Mitra-Monday 2:45pm

S. Fallows-Monday 4:45pm

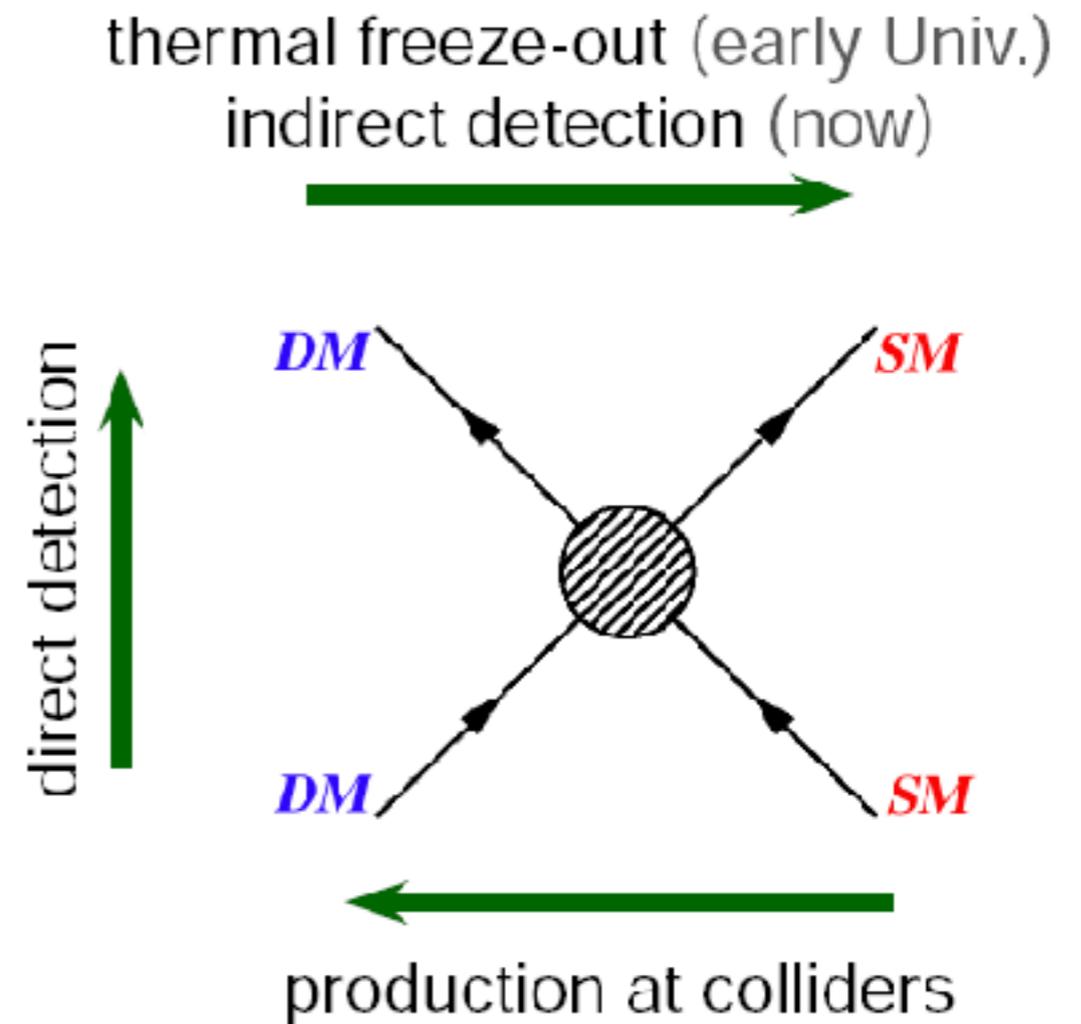
E. Vázquez Jáuregui-

Tuesday 4:30pm

Posters by: M. Jin, U.
Chowdhury, B. Loer

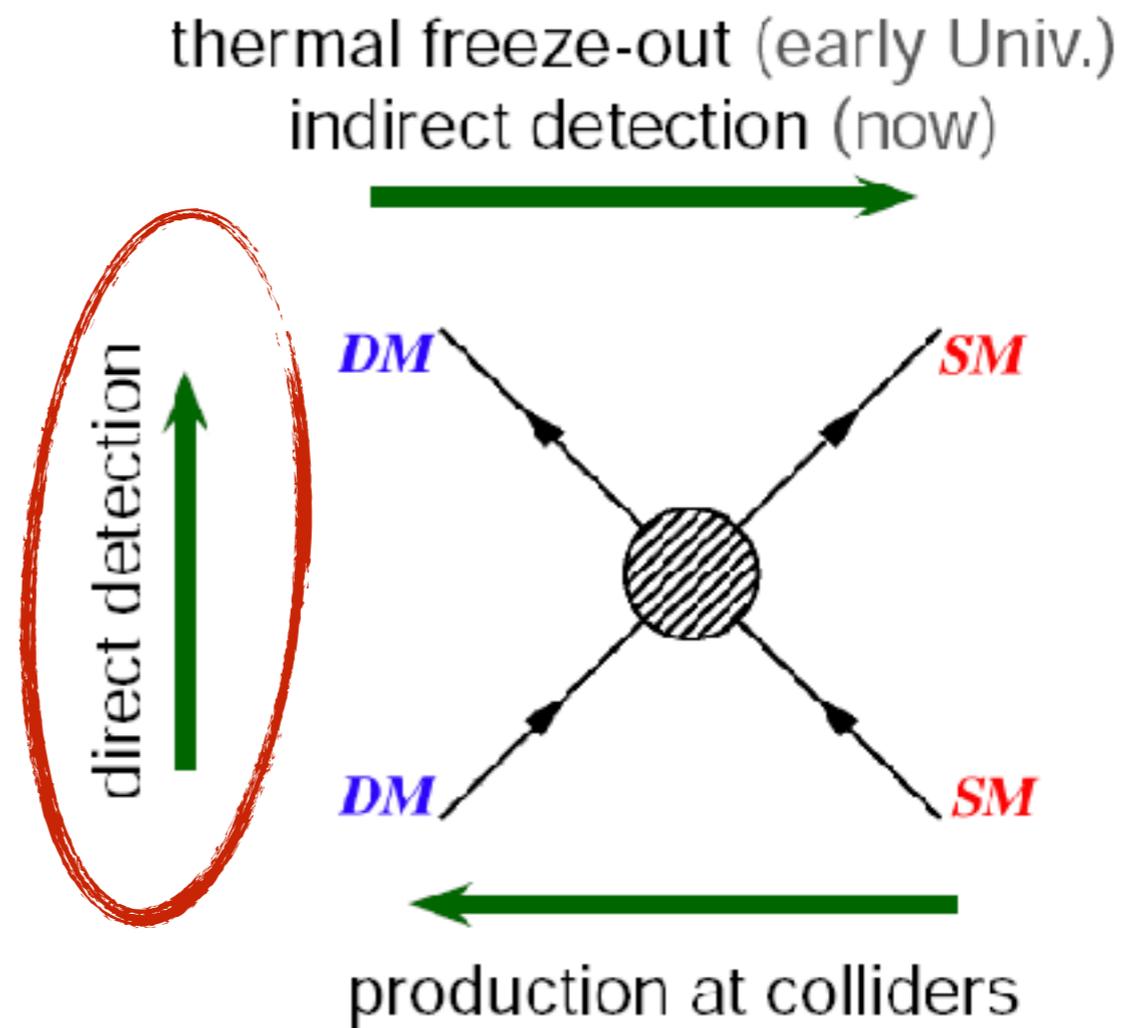
Dark Matter Searches

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



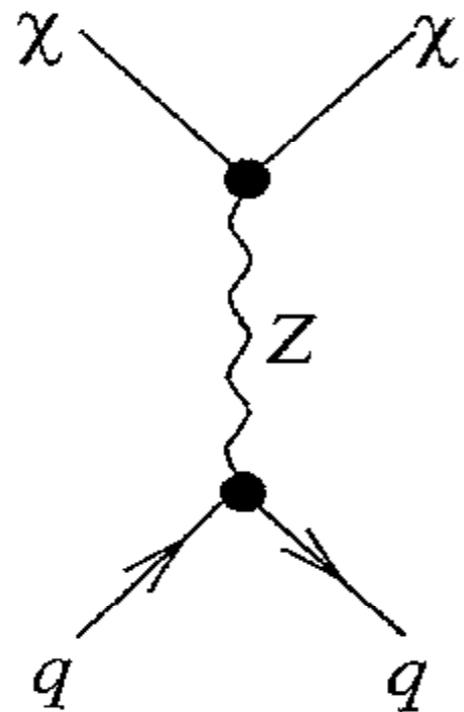
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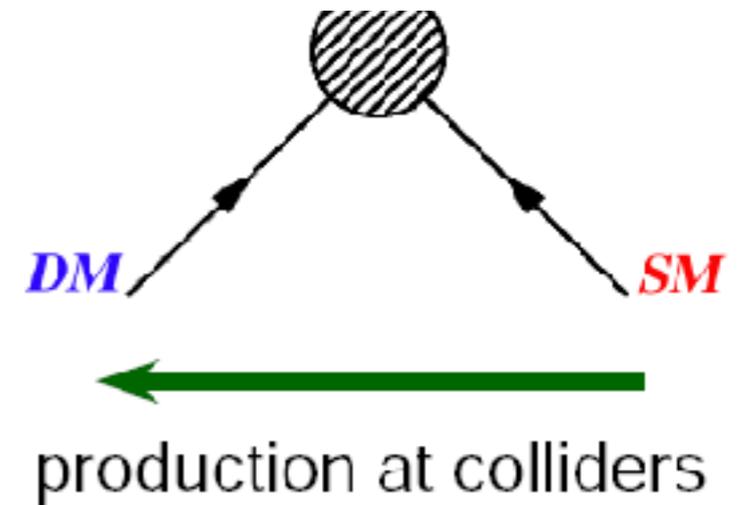
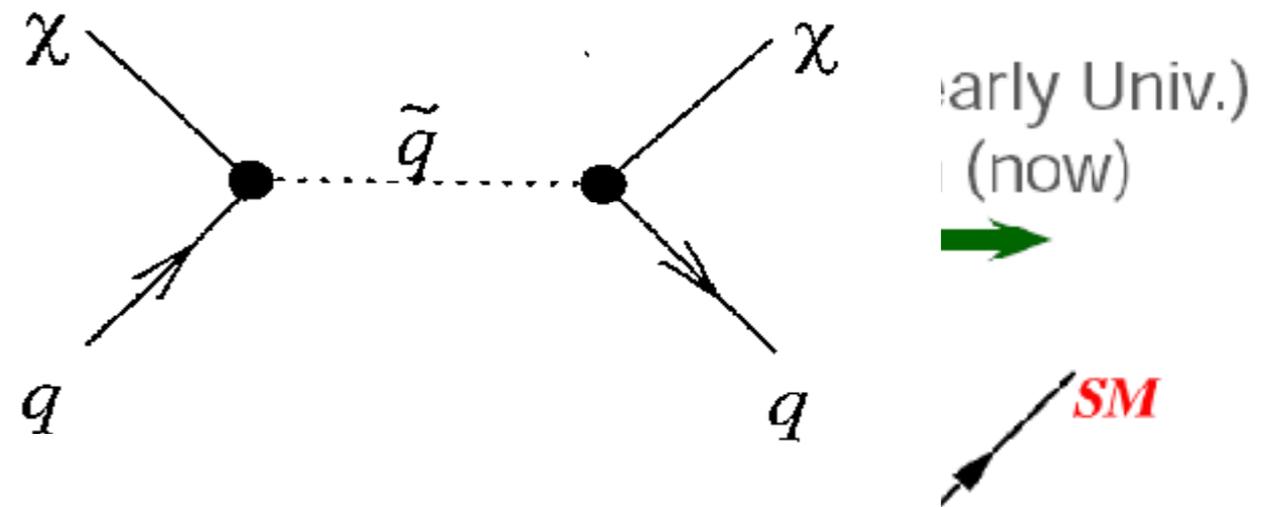


Dark Matter Searches

- Dark matter searches for us
- Search for dark matter
- Direct detection
- Indirect detection
- Collider production



Spin dependent



Particle Detection with Bubble Chambers



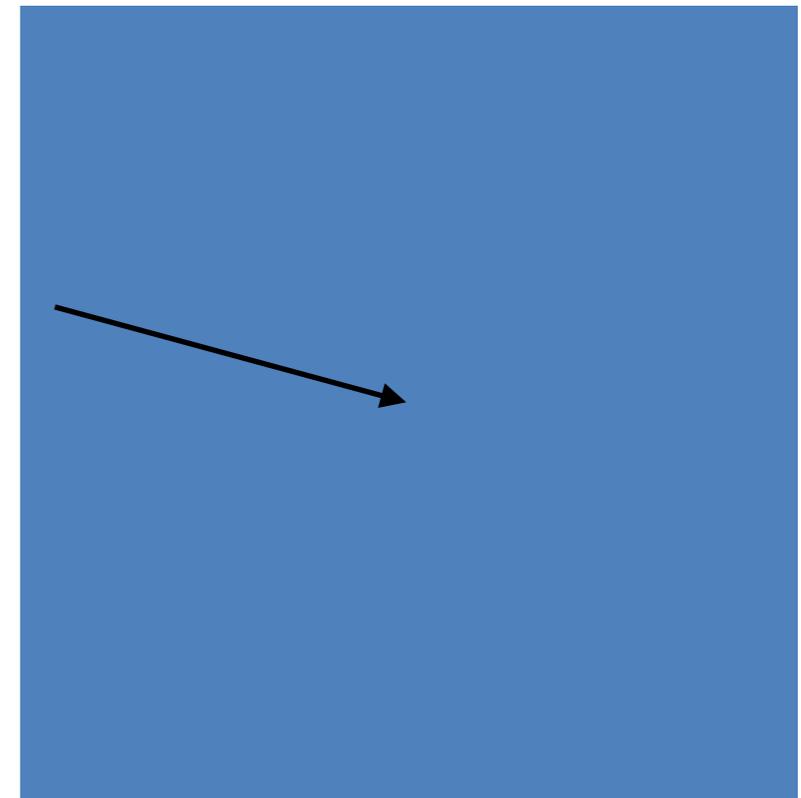
Particle Detection with Bubble Chambers

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



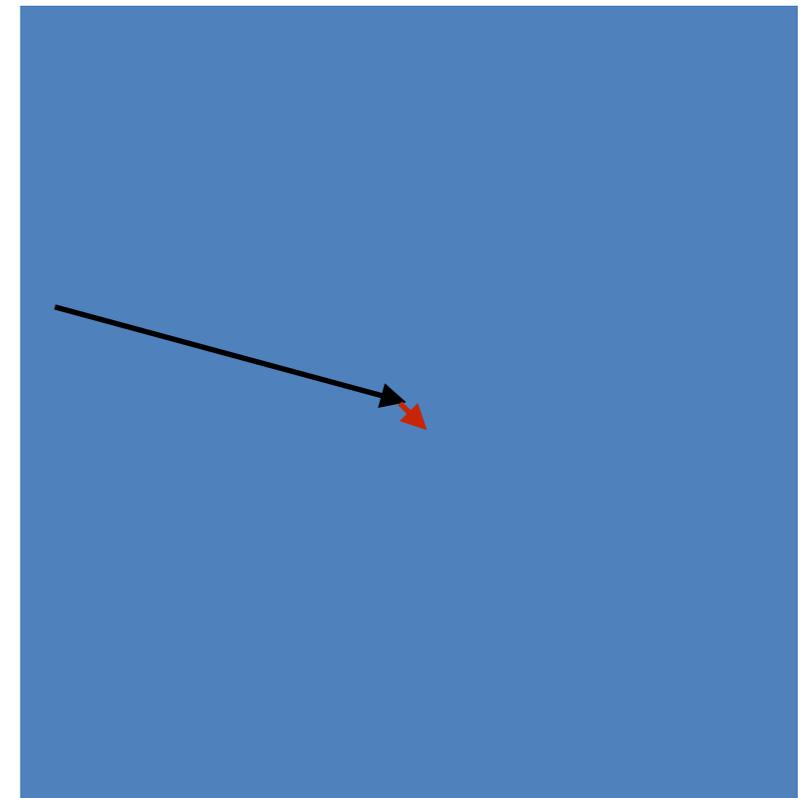
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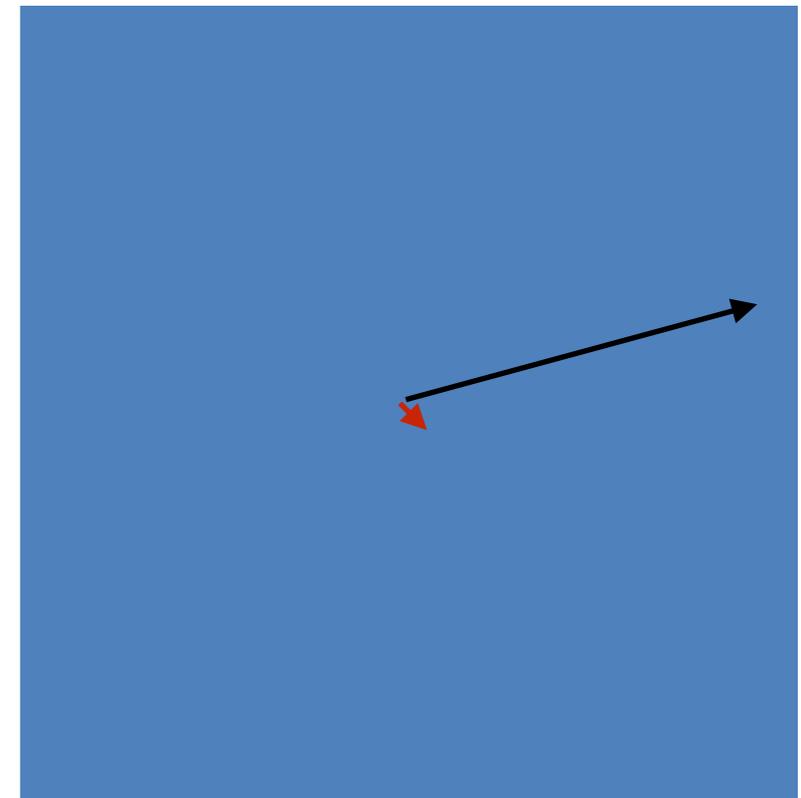
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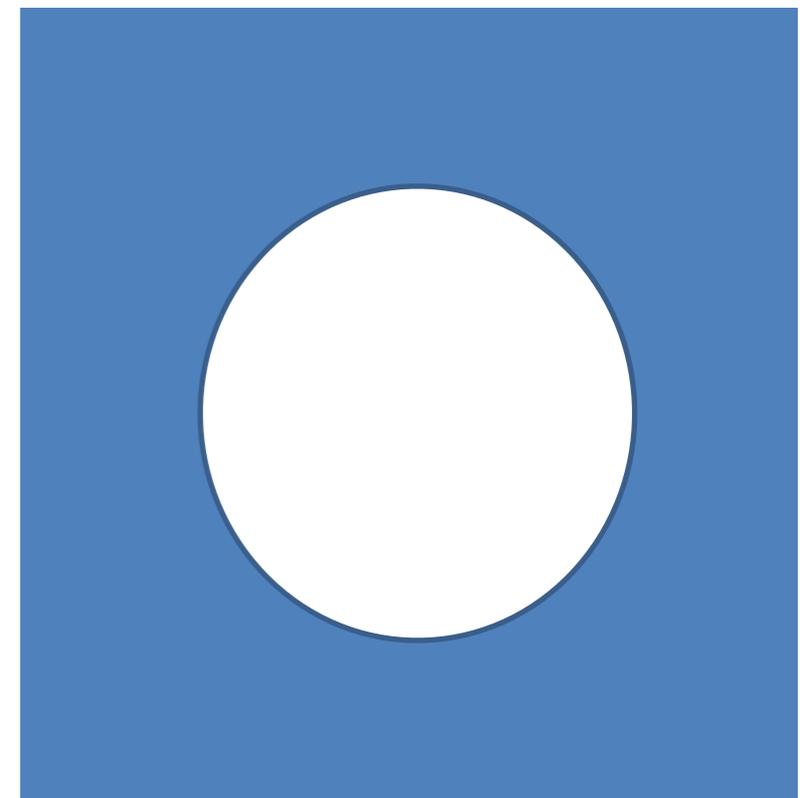
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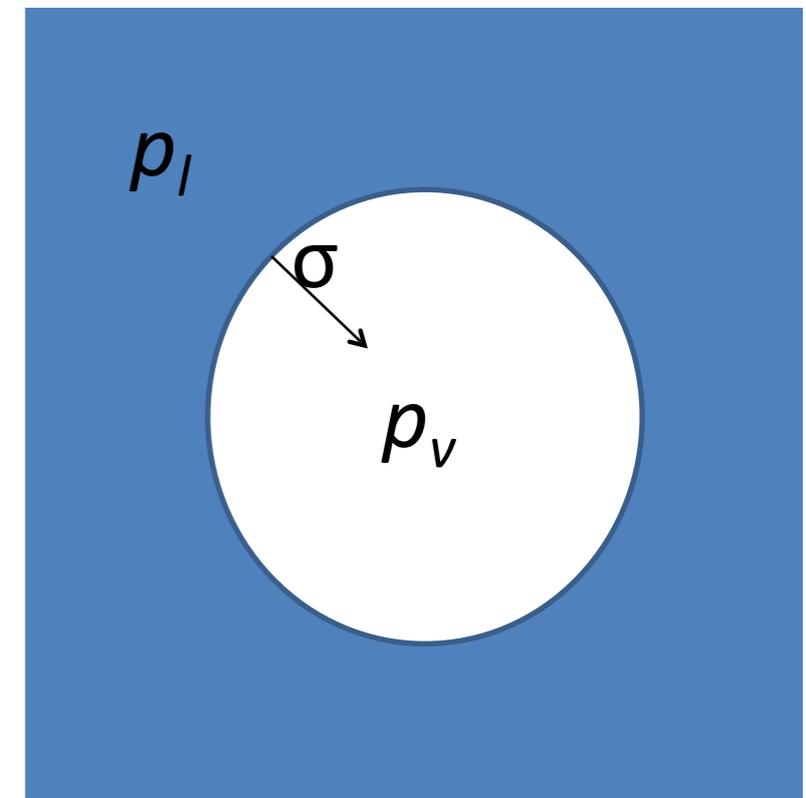
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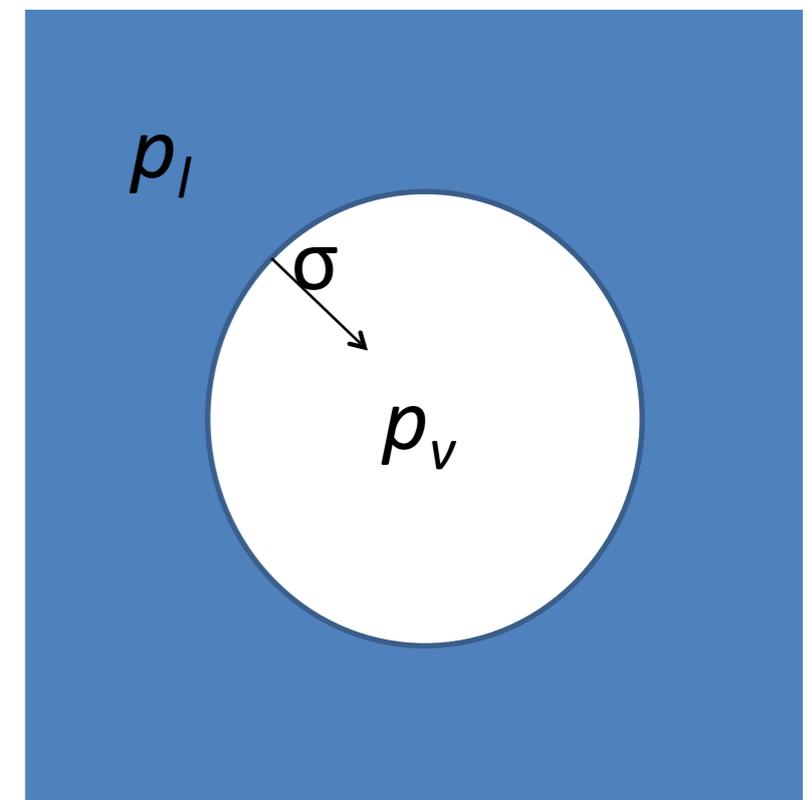
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Particle Detection with Bubble Chambers

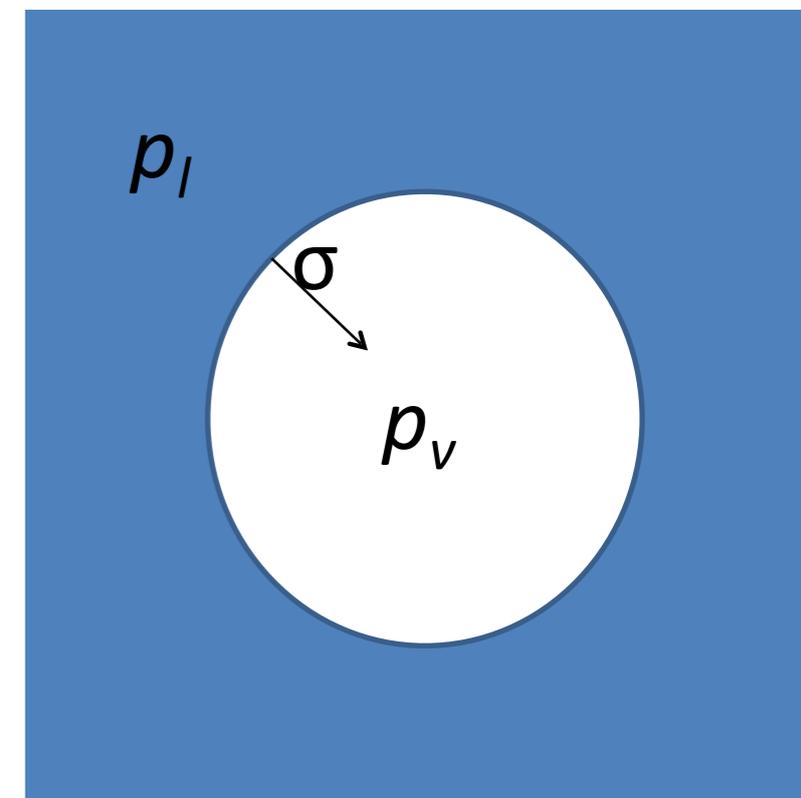
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- Energy deposition greater than E_{th} in radius larger than r_c from particle interaction will result in expanding bubble (Seitz “Hot-Spike” Model)
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses
- Classical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

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

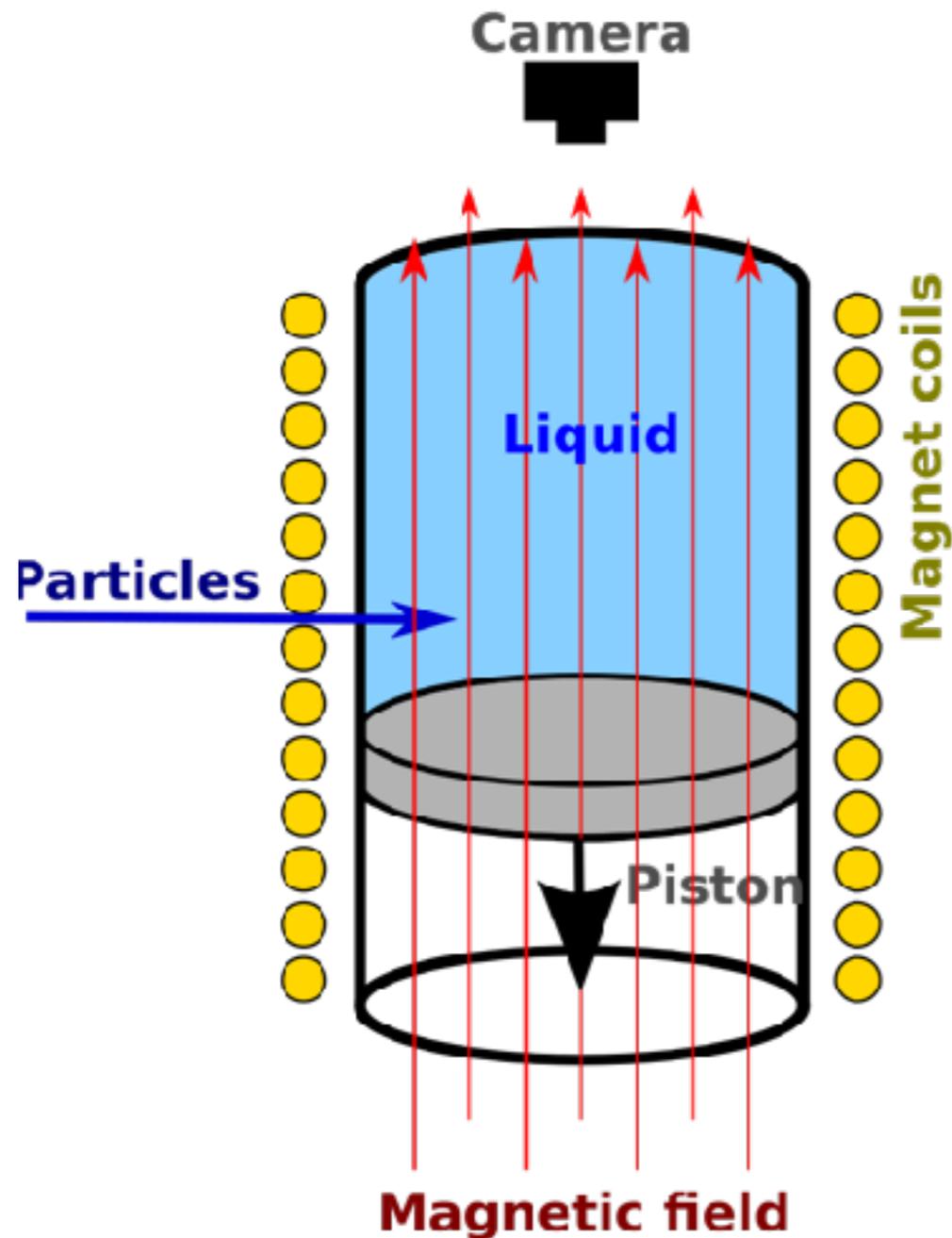
$$E_{th} = 4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) + \frac{4}{3} \pi r_c^3 \rho_v h$$

Surface energy

Latent heat

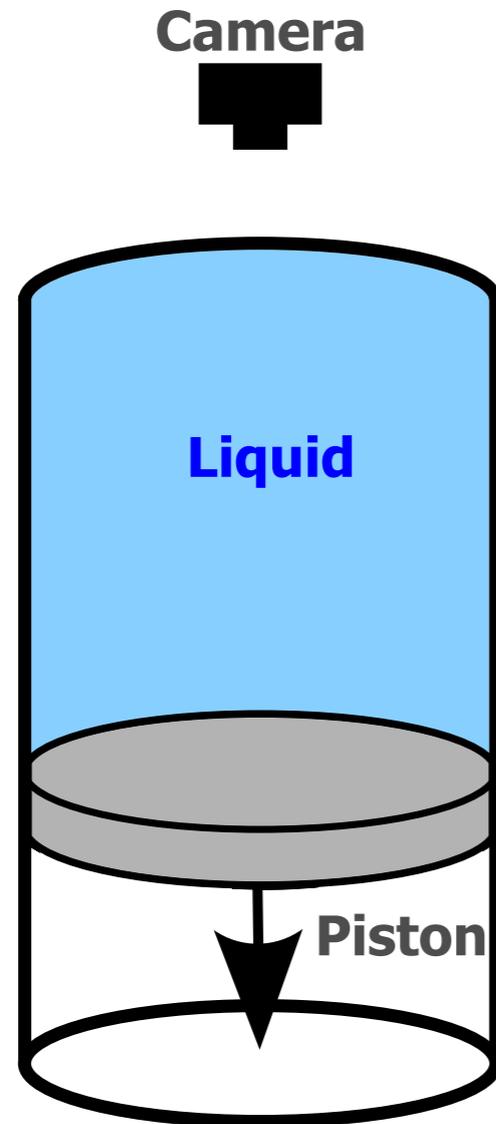


Dark Matter Bubble Chamber



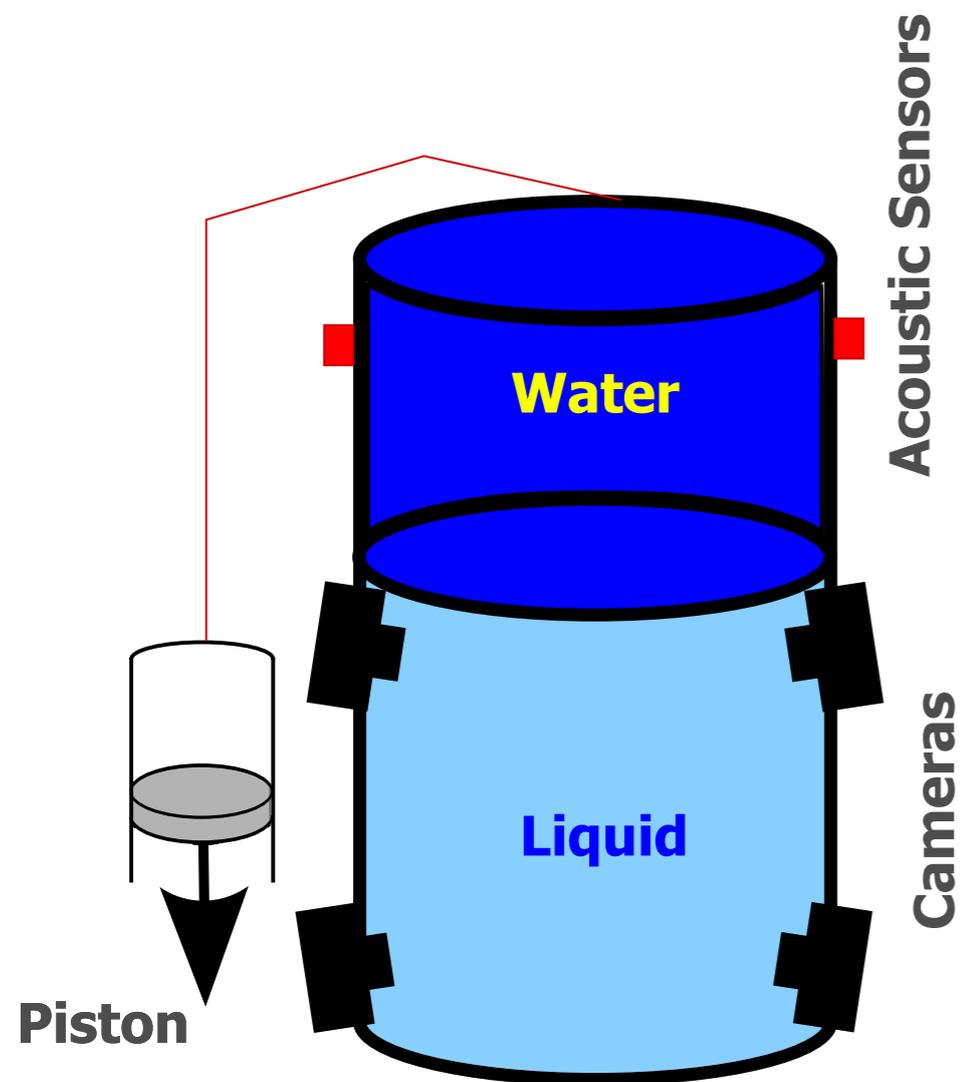
- Any bubble chamber has:
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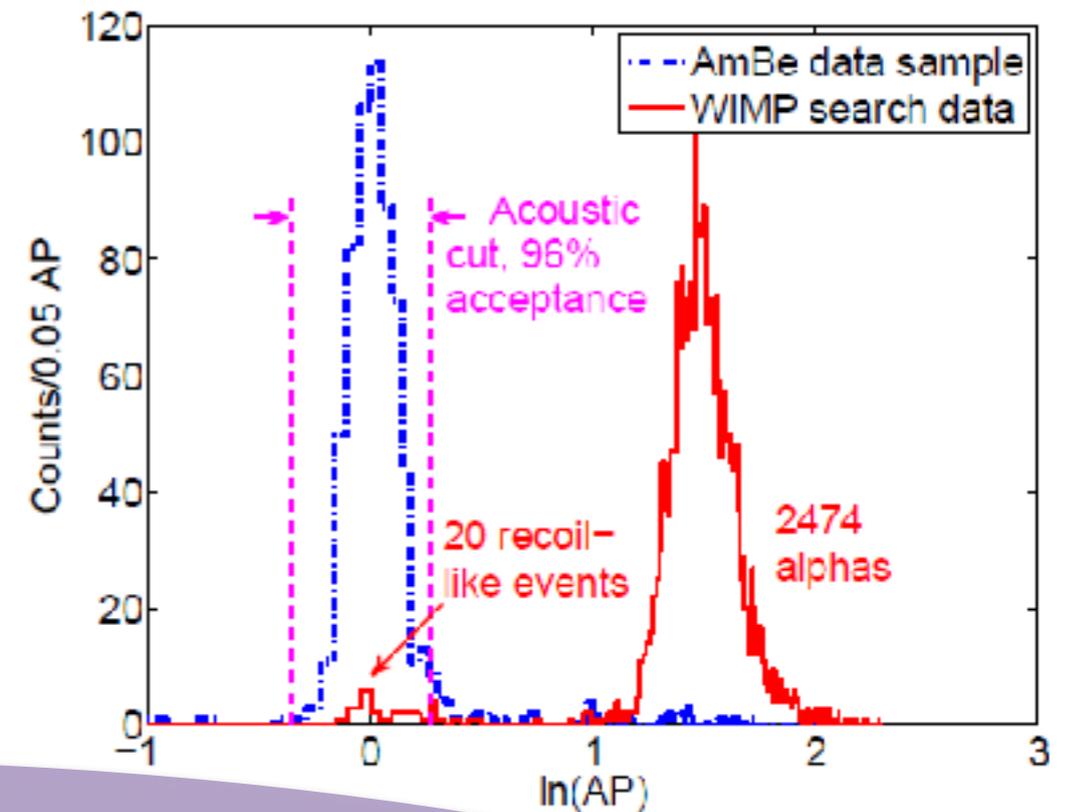


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PICO uses acoustic background discrimination

Acoustic Discrimination

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



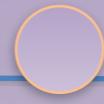
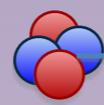
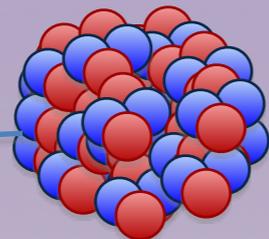
Observable bubble ~mm



~40 μm



~50 nm



Daughter heavy nucleus
(~100 keV)

Helium nucleus
(~5 MeV)

PICO Program Overview

PICASSO

COUPP

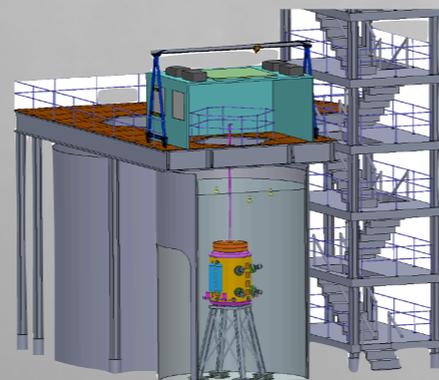
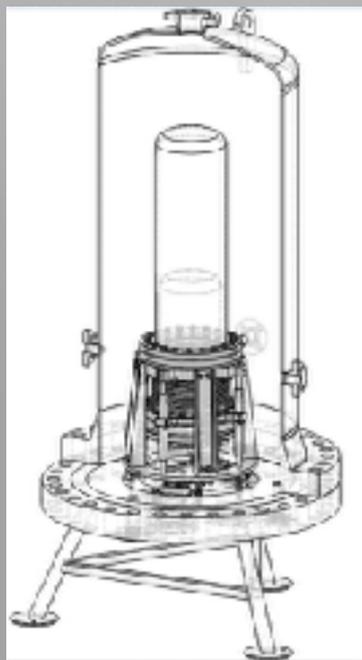
PICO

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 Program Overview

PICASSO

Backgrounds

Neutron Limited

PICO 2L
 C_3F_8

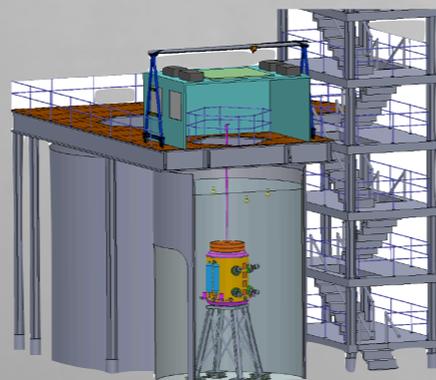
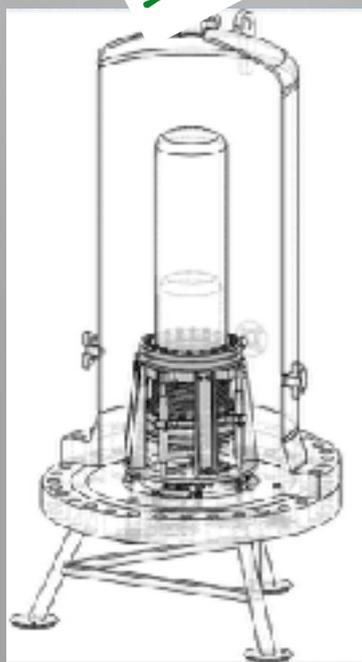
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Overview

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- **PICO 60**
- PICO 40L - PICO 500

The PICO 60 Bubble Chamber

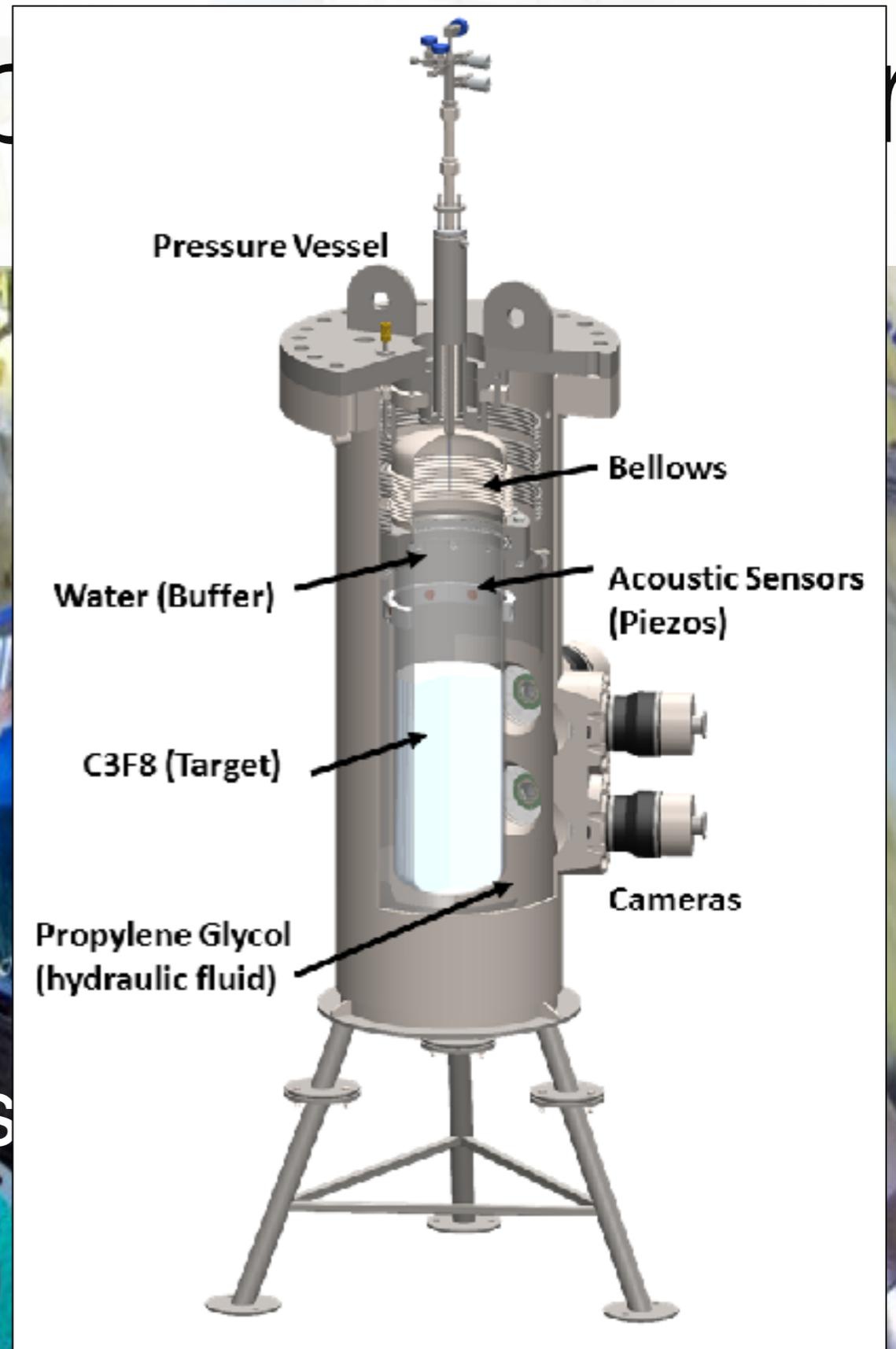
- Was the world's largest operating bubble chamber until June 2017

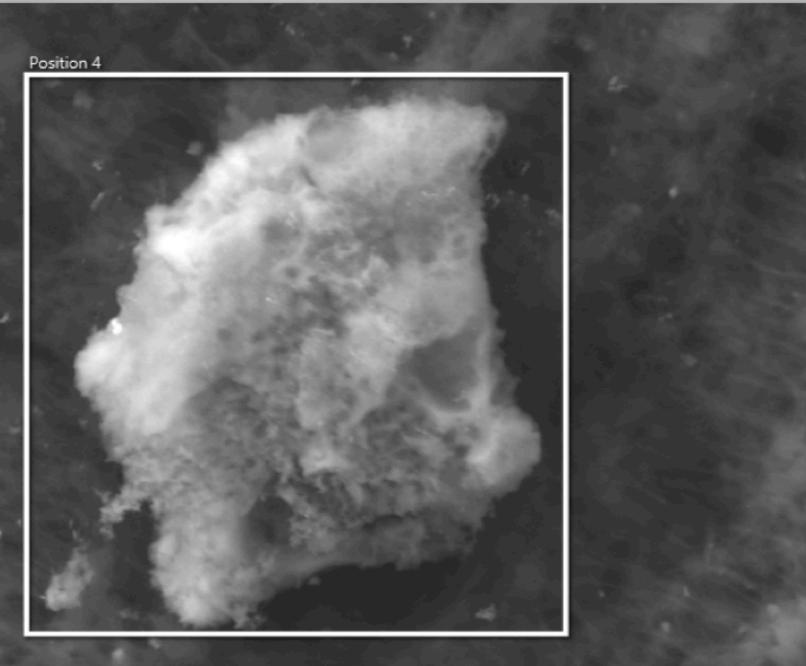


The PICO 60 Bubble

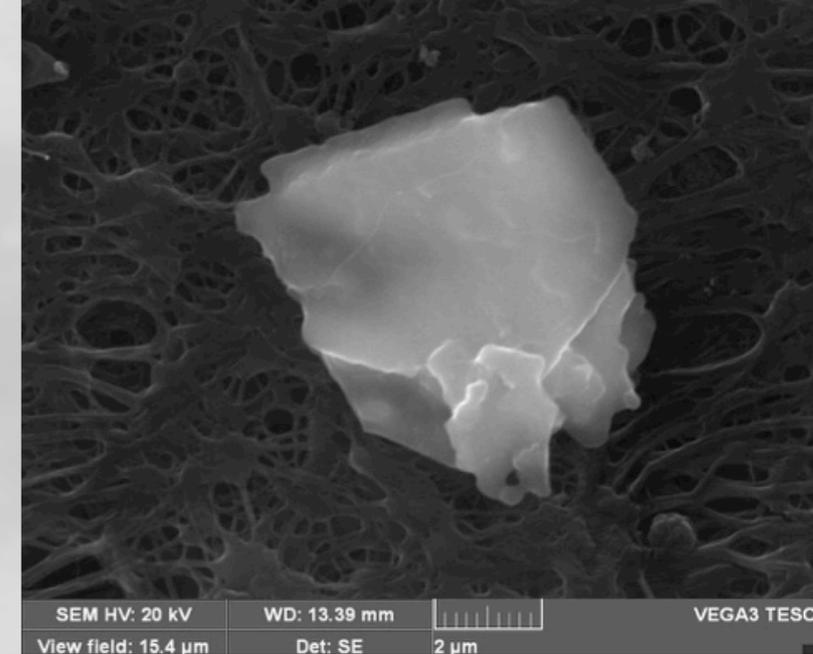


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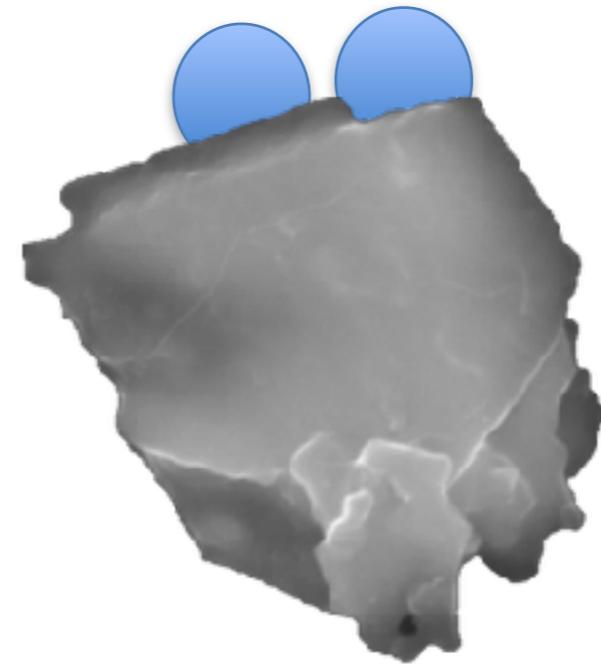
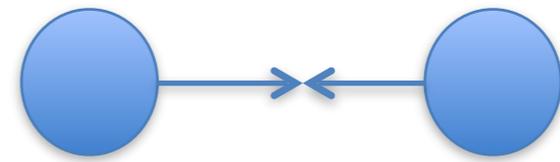
After Run I - Assay



- 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

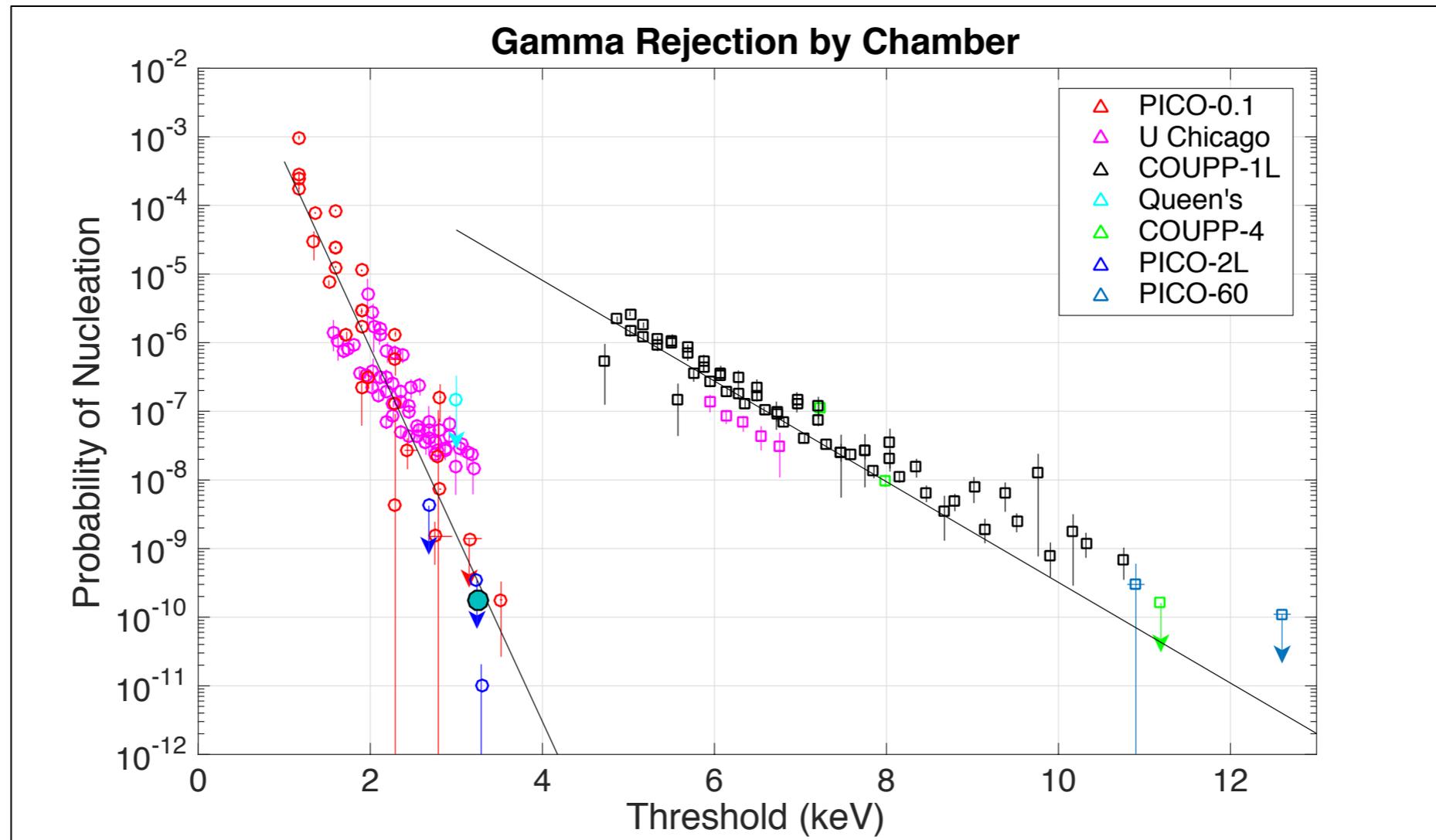
- Merging of two water droplets releases $O(1 \text{ keV})$ of surface tension energy
- The water lowers the bubble nucleation threshold, so the released energy can nucleate bubbles at PICO operating thresholds of a few keV
- The merging water droplets could be attached to solid particulate



Run II of PICO 60

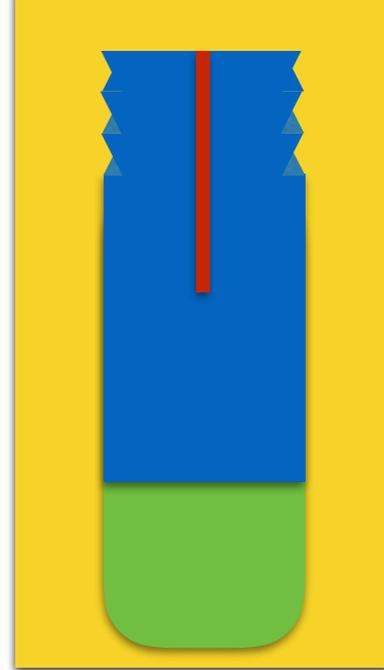
- New active liquid: C_3F_8
 - New water system and cooler
- New vessel, new geometry with both flange and vessel from synthetic quartz
- extensive QC of cleanliness during installation
- Four cameras, allows operation with 52kg of target volume

Switch to C_3F_8



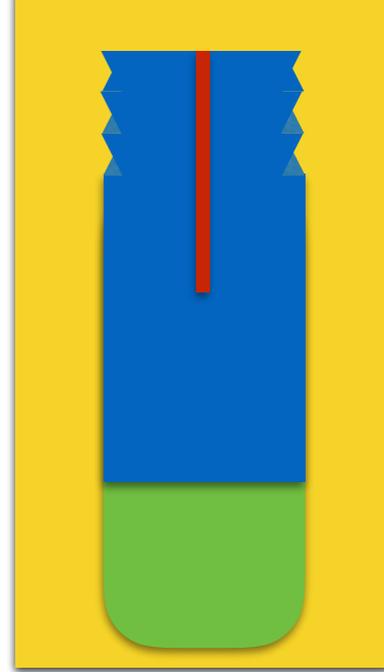
- Probability of detecting gamma interactions in CF_3I and in C_3F_8

Detector Cleaning

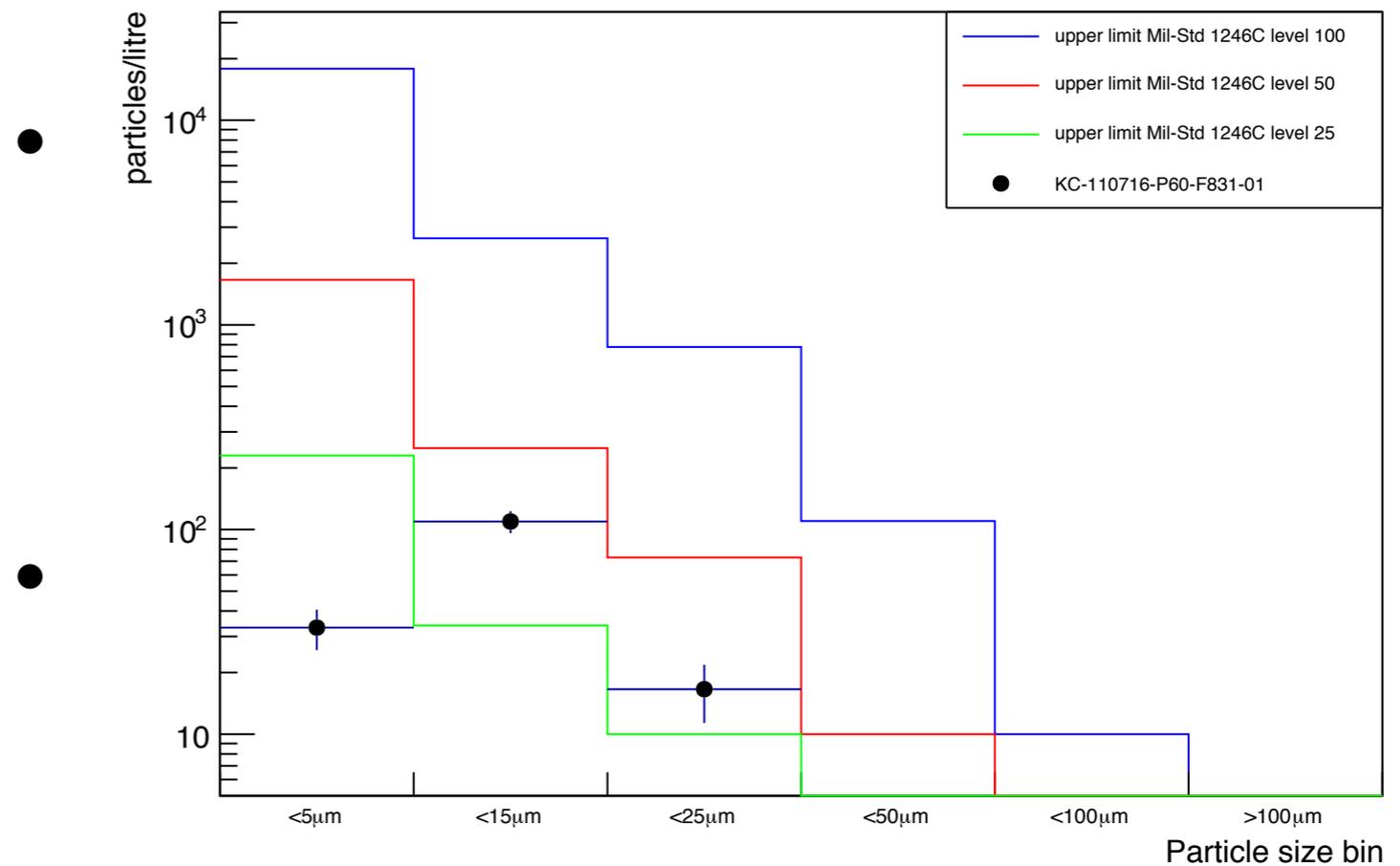


- A pump-filter-heater assembly was constructed for detector cleaning
- All plumbing in contact with inner vessel fluid was also cleaned with the system
- All parts met MIL-STD1246C-level 50

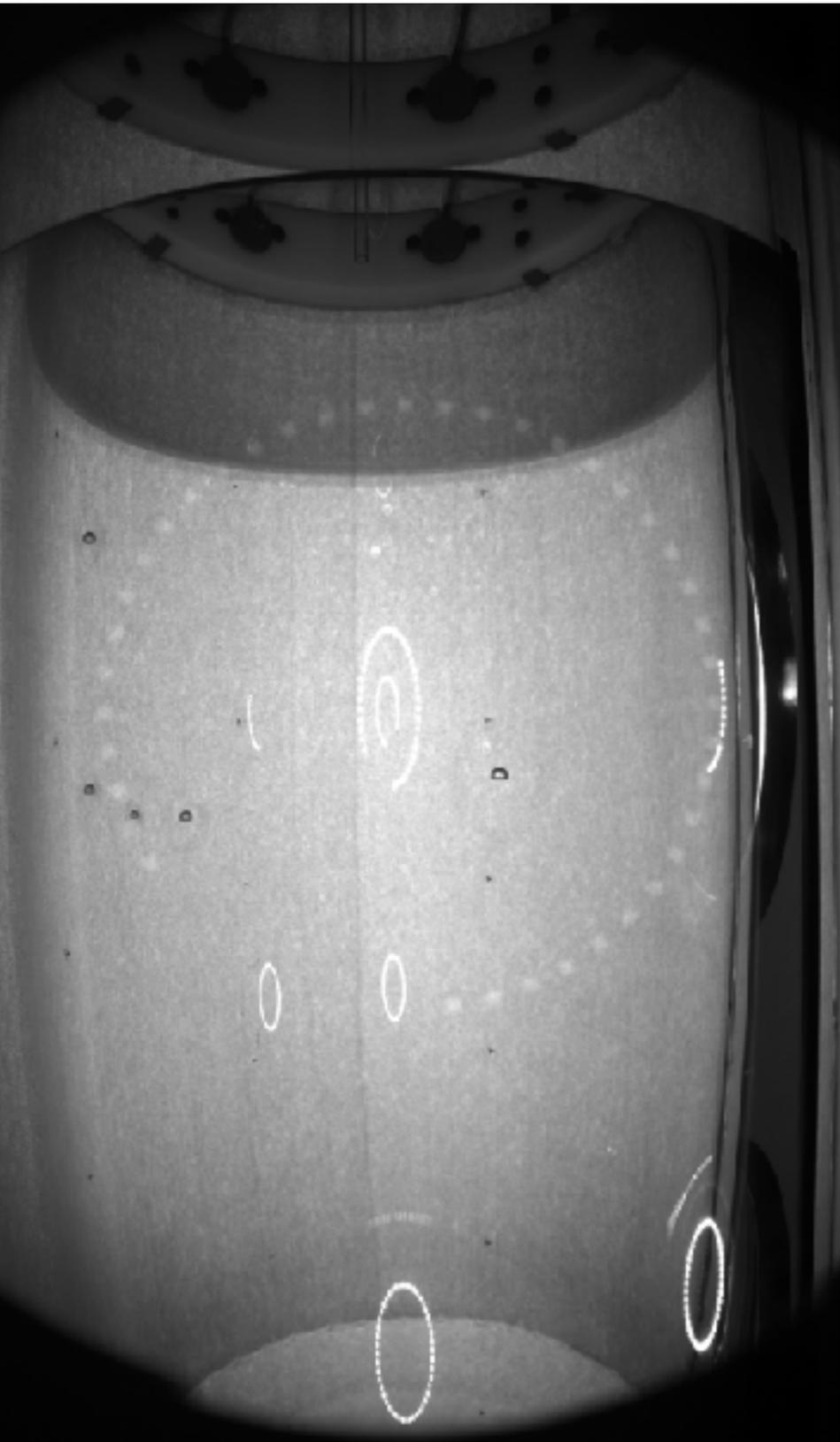
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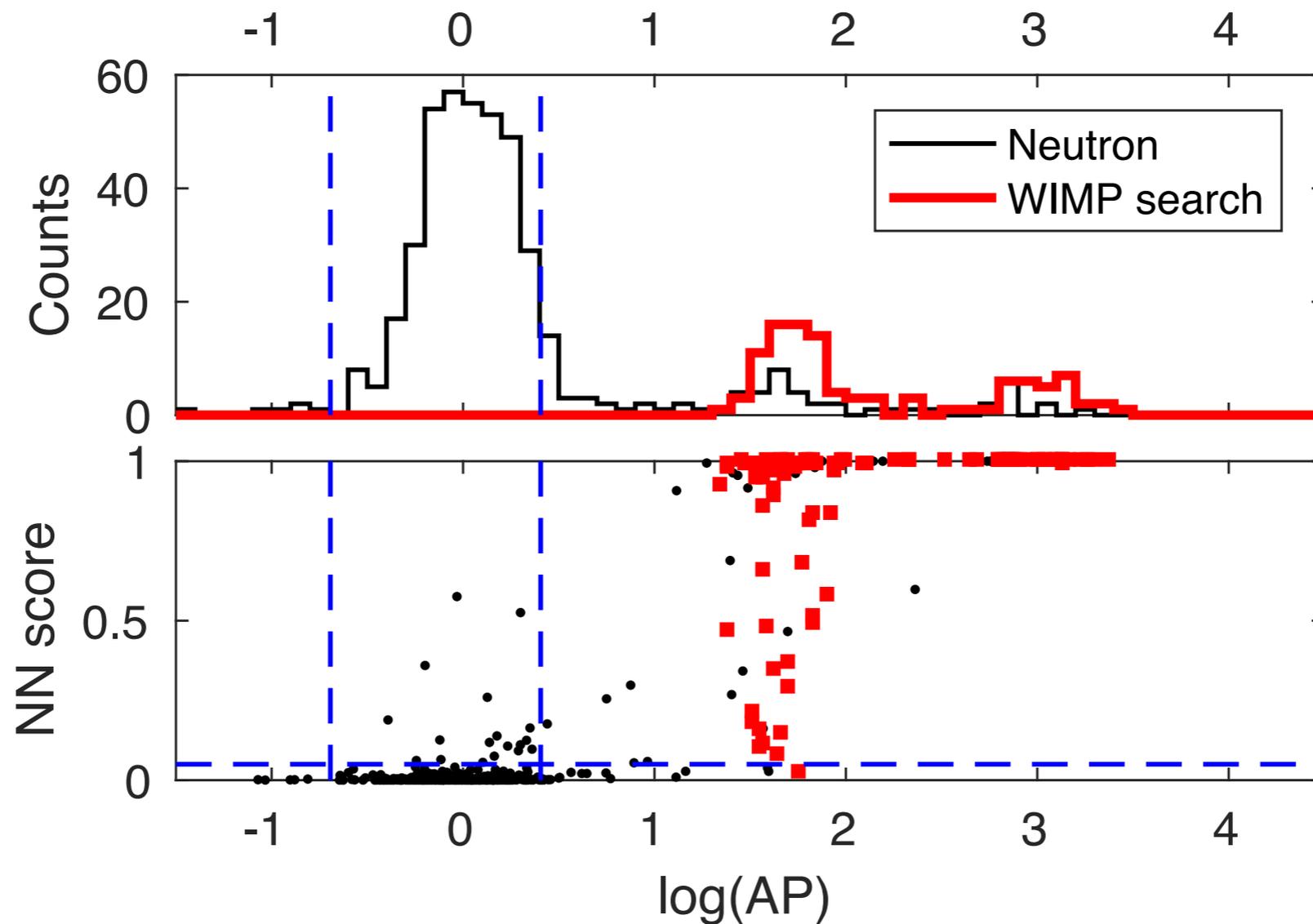


Data Taking



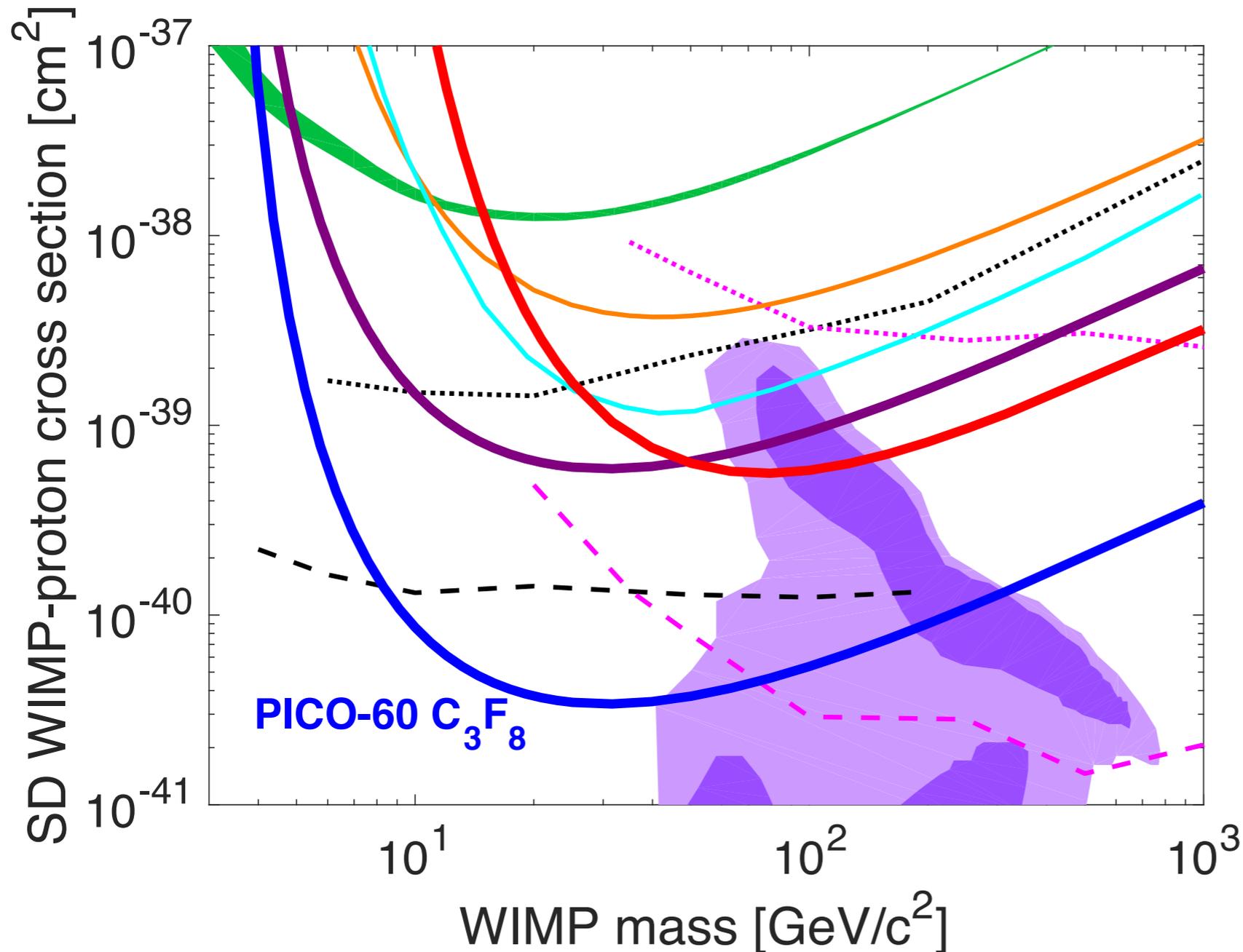
- Very smooth operation at 3.3 keV threshold before and after the run type was switched to “blind running” (November 28 2016), acquiring a total exposure of 1167 kg days
- Three multi bubble events were collected during the blind run
 - This shows that the detector materials are not permitting a longer run with this detector, unfortunately. We need a better setup with reduced neutron background

Acoustic Data



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

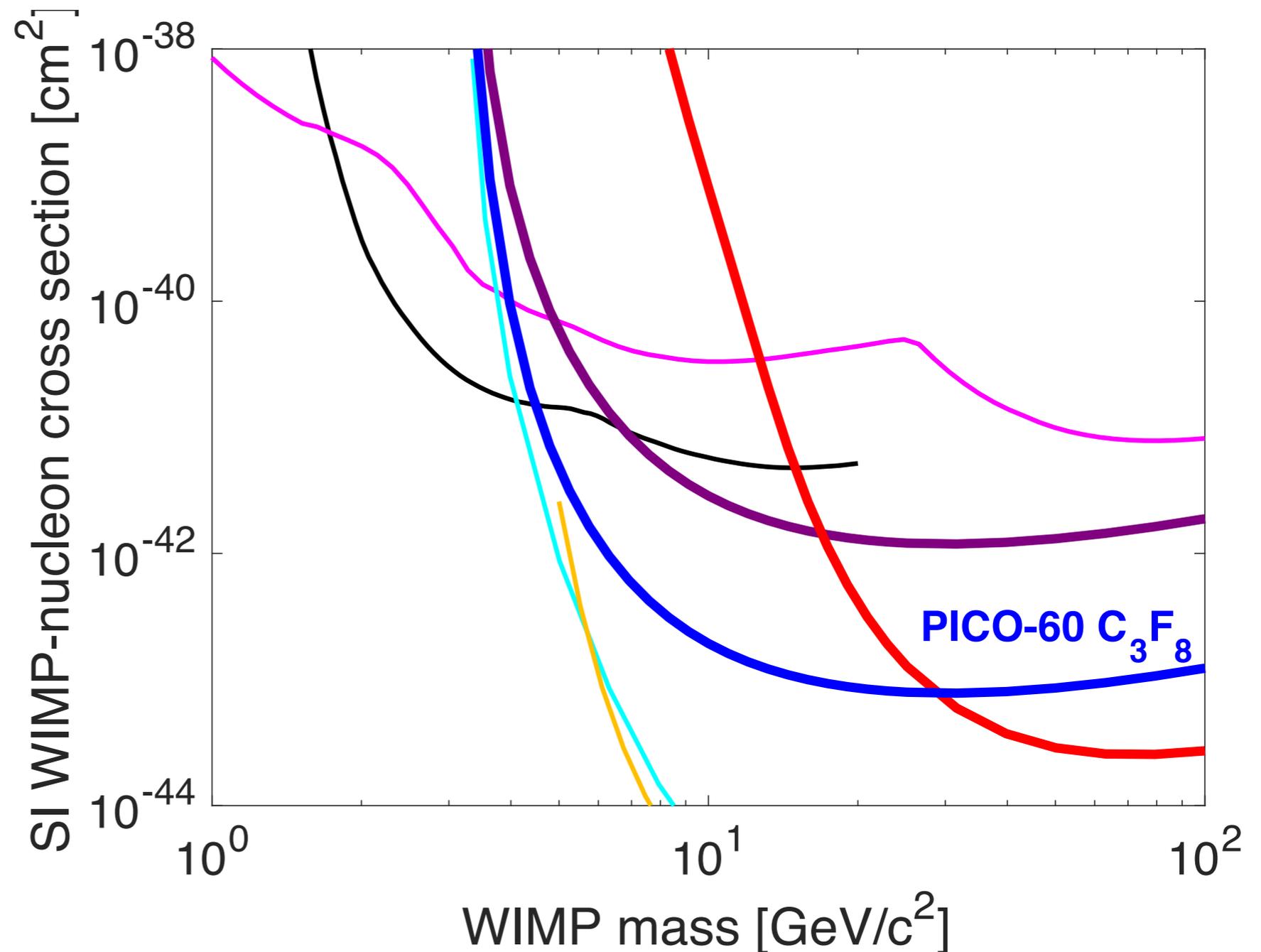
WIMP - Proton Exclusion



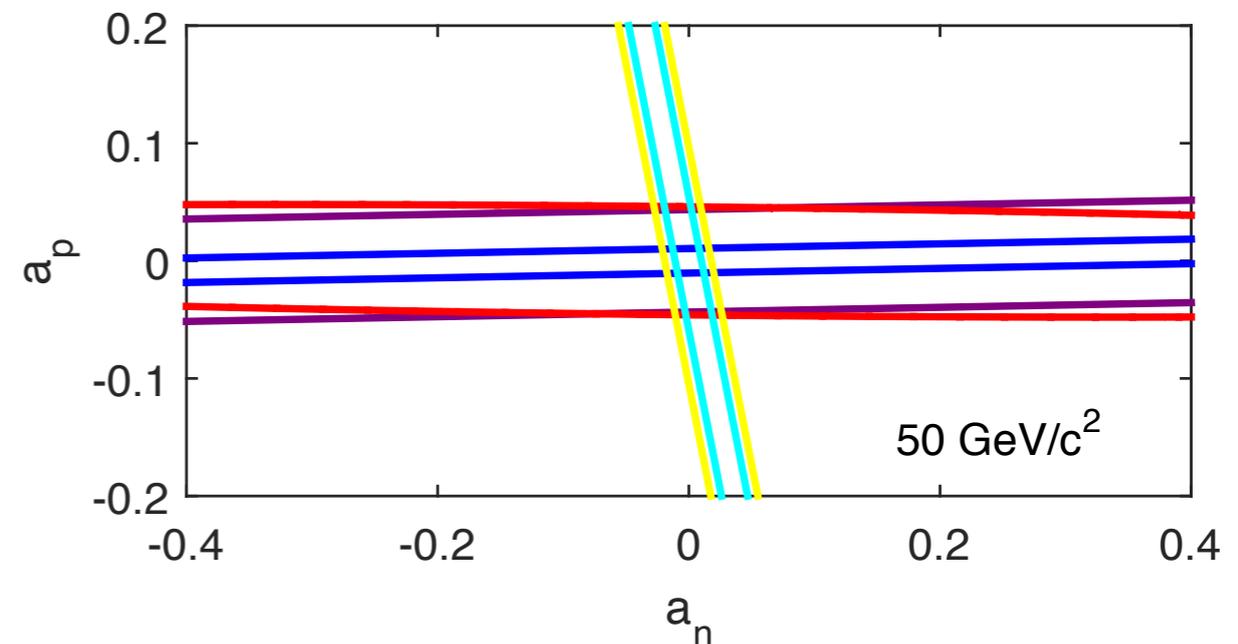
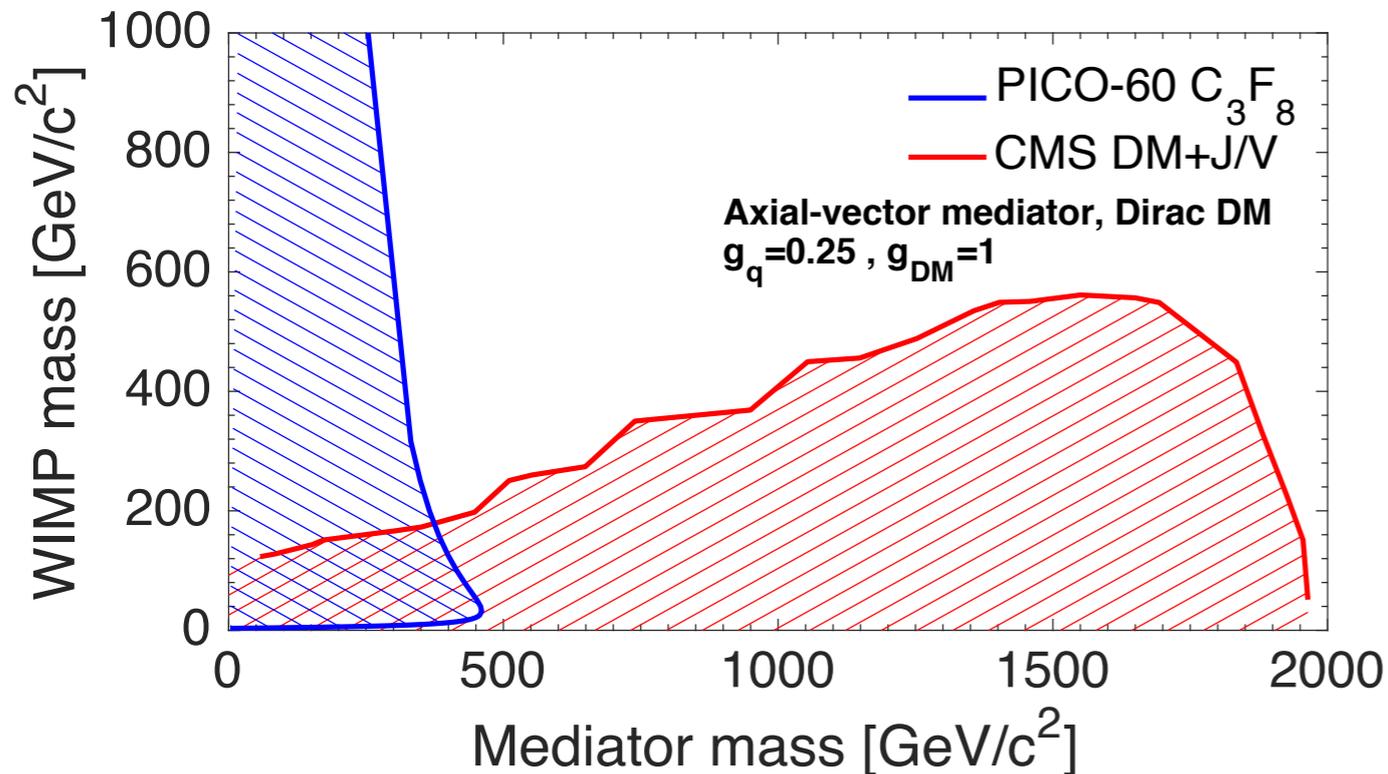
The 90% C.L. limit on the SD WIMP-proton cross section from PICO-60 C_3F_8 (blue), along with limits from PICO-60 CF_3I (red), PICO-2L (purple), PICASSO (green), SIMPLE (orange), PandaX-II (cyan), IceCube (dashed and dotted pink), and SuperK (dashed and dotted black)

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).



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/c² WIMP mass
Also shown are results from PANDAX-II (cyan), LUX (yellow), PICO-2L (purple), and PICO-60 C₃FI (red)

Post PRL Work

- PICO 60 ran from February to June to develop faster frame acquisition (see talk by P. Mitra from yesterday) and
- The detector was operated at lower thresholds (with fast camera operation) between March and June. Another month of blind data was taken at 2.3 keV threshold. The analysis of this data set is not complete. Expect another PICO result soon
- The new analysis is aiming to include improved fiducial volume, improved threshold curves from calibration work and the low threshold data set

Overview

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

PICO Program Overview

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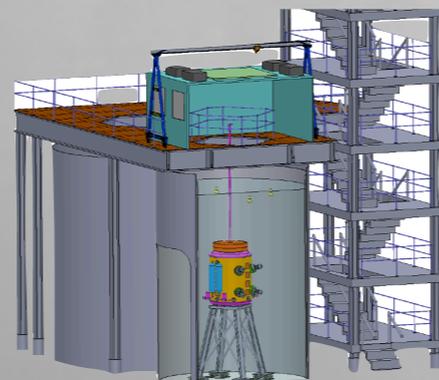
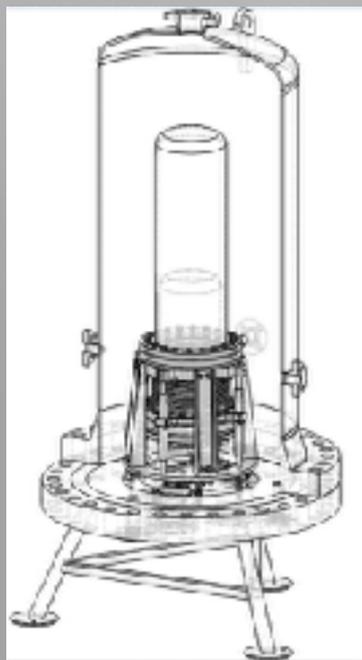
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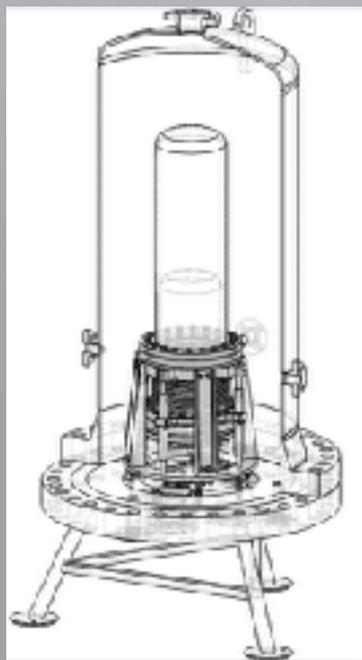
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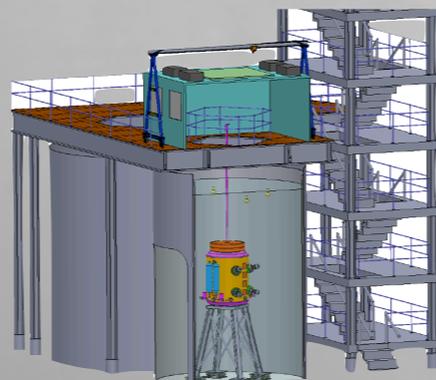
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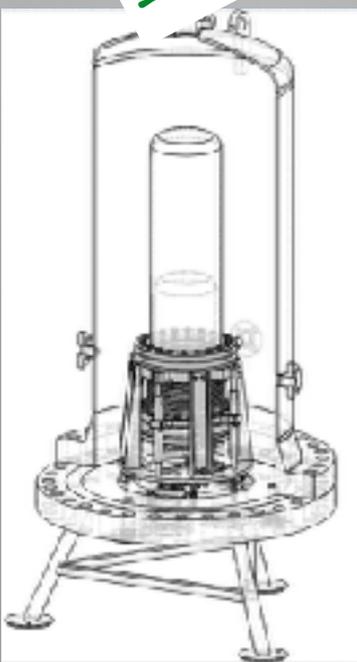
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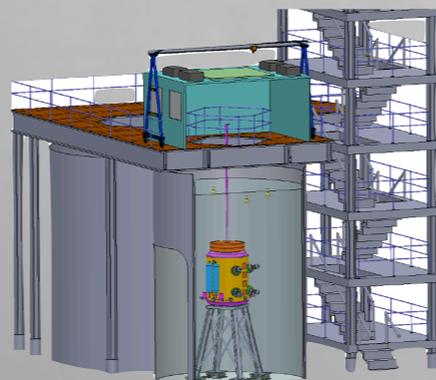
Neutron Limited



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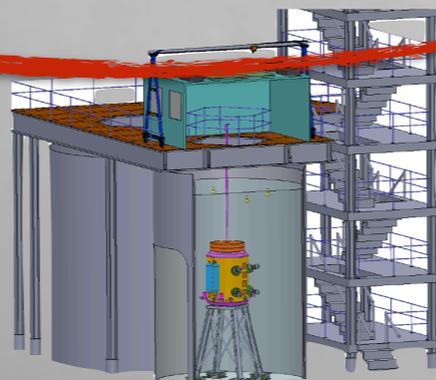
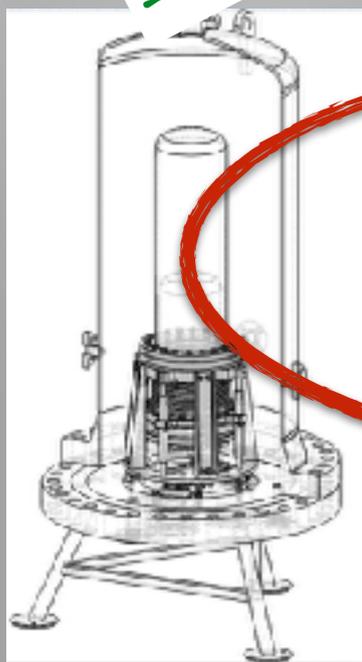
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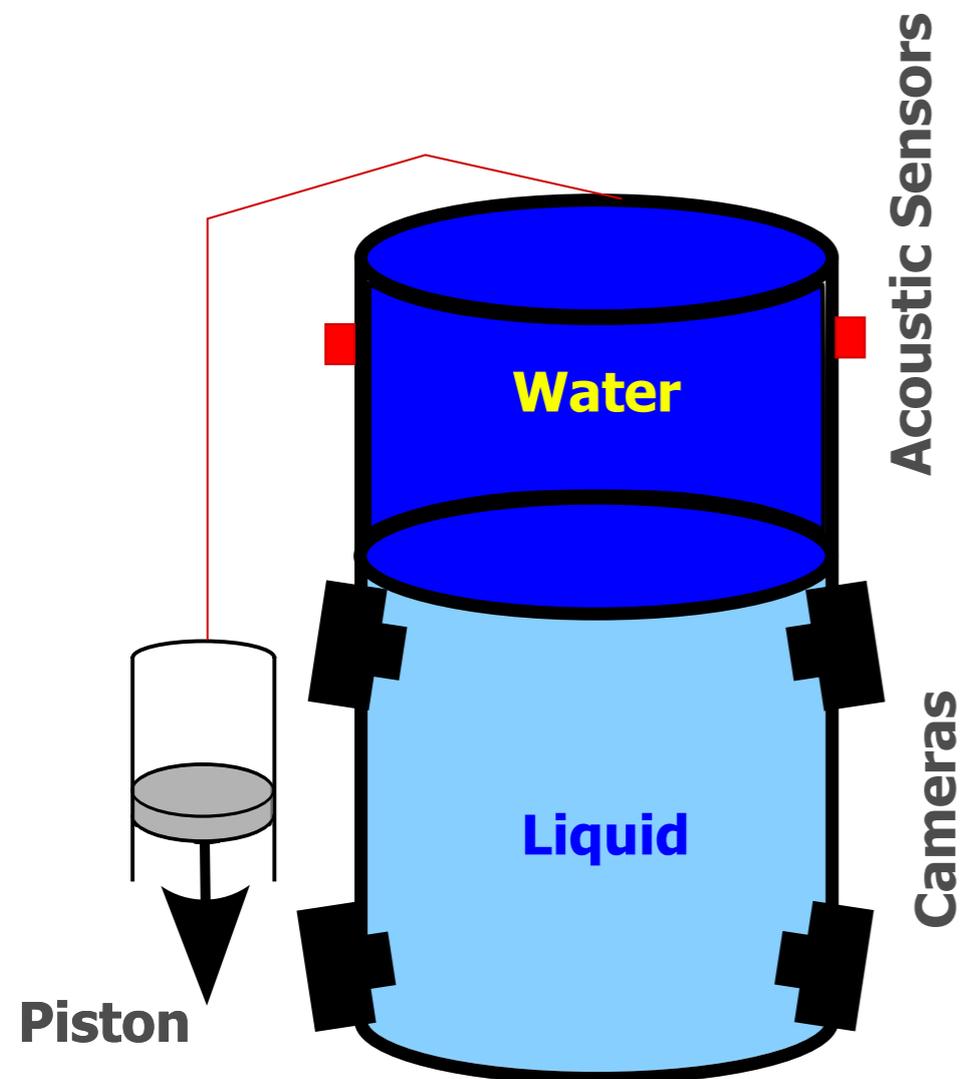
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Neutron Limited



Dark Matter Bubble Chamber

PICO 60

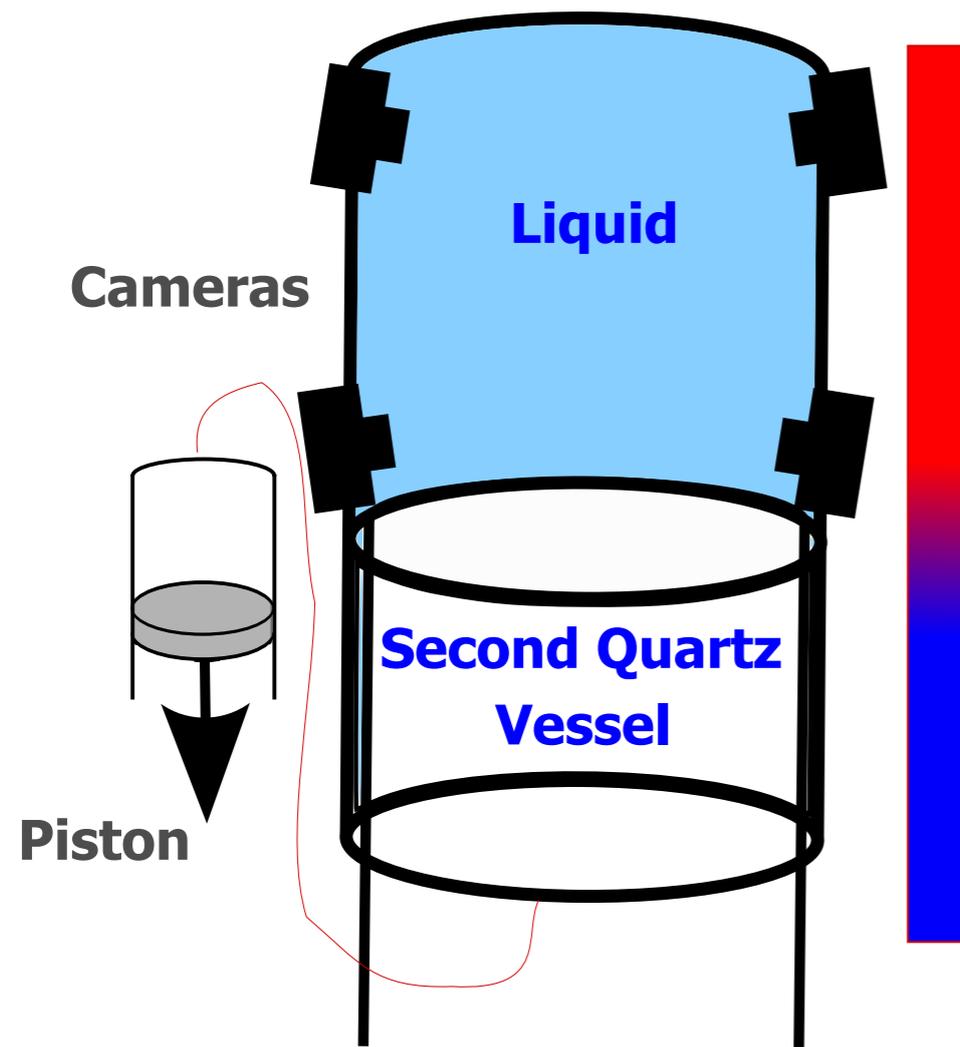


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 - expansion system, piston, temperature control

PICO uses acoustic background discrimination

Dark Matter Bubble Chamber

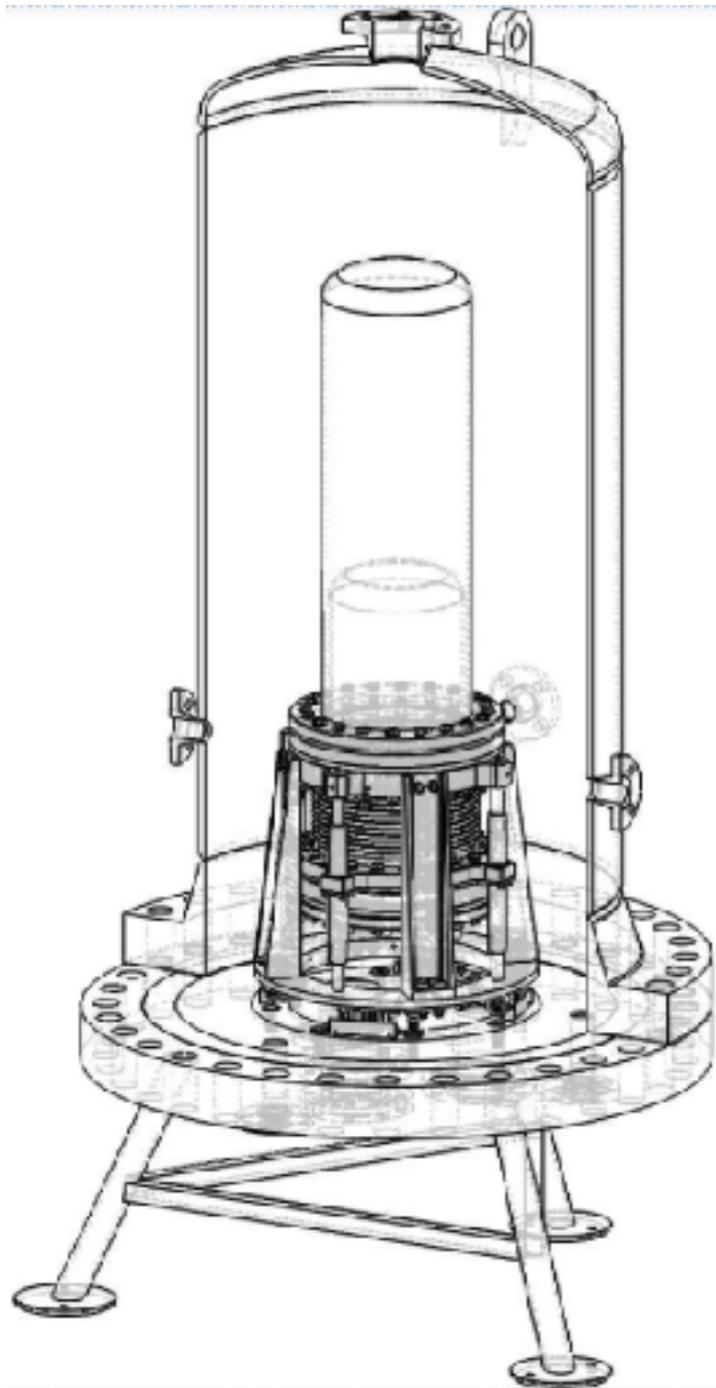
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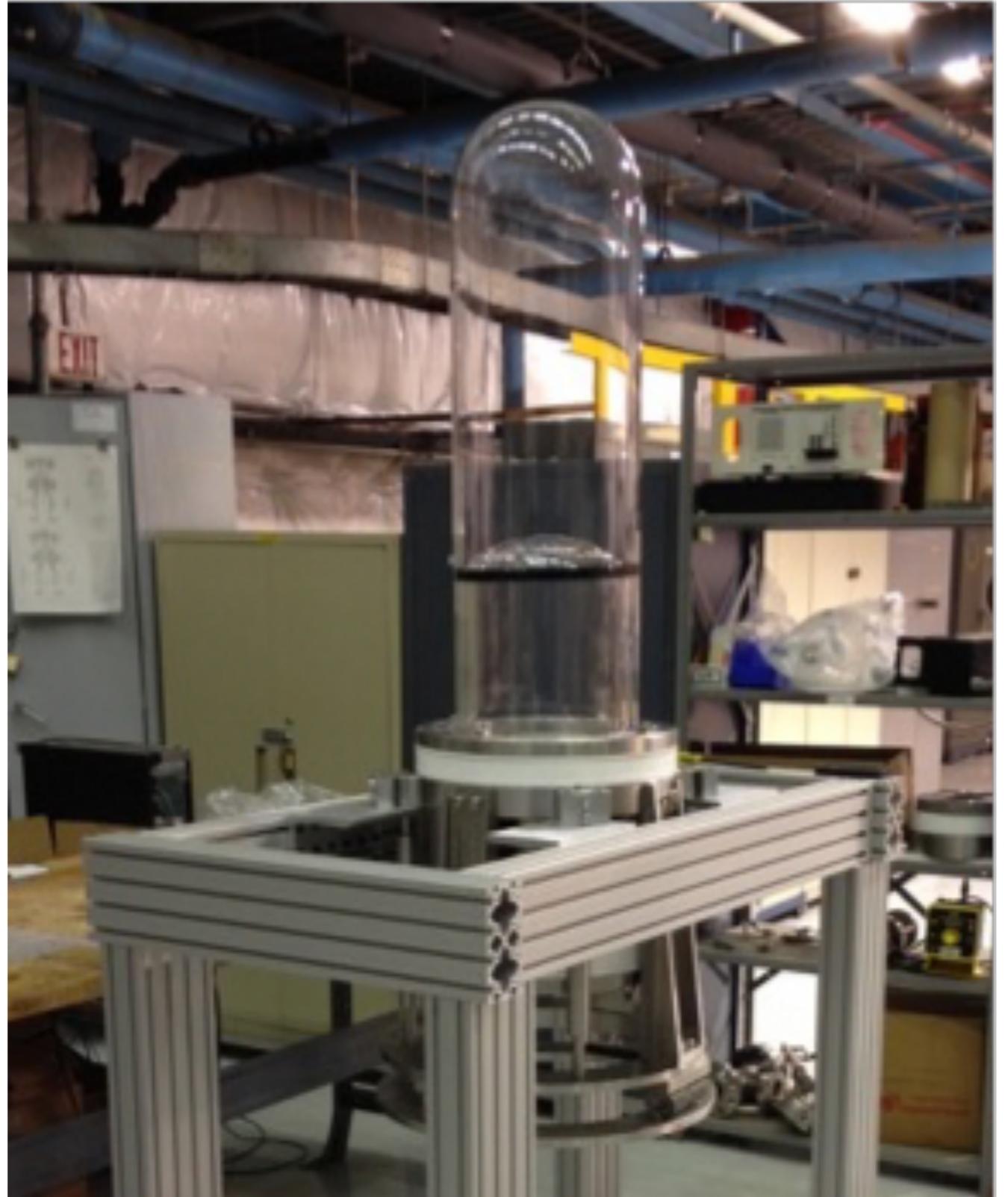
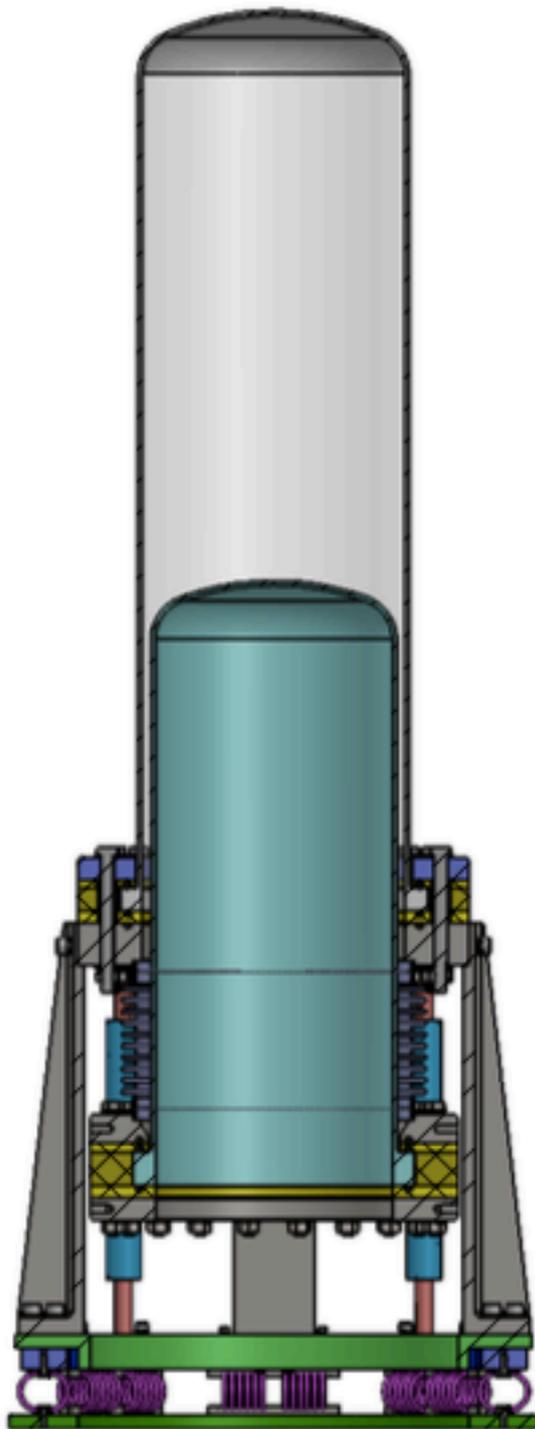
PICO uses acoustic background discrimination

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 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

PICO 40L Status

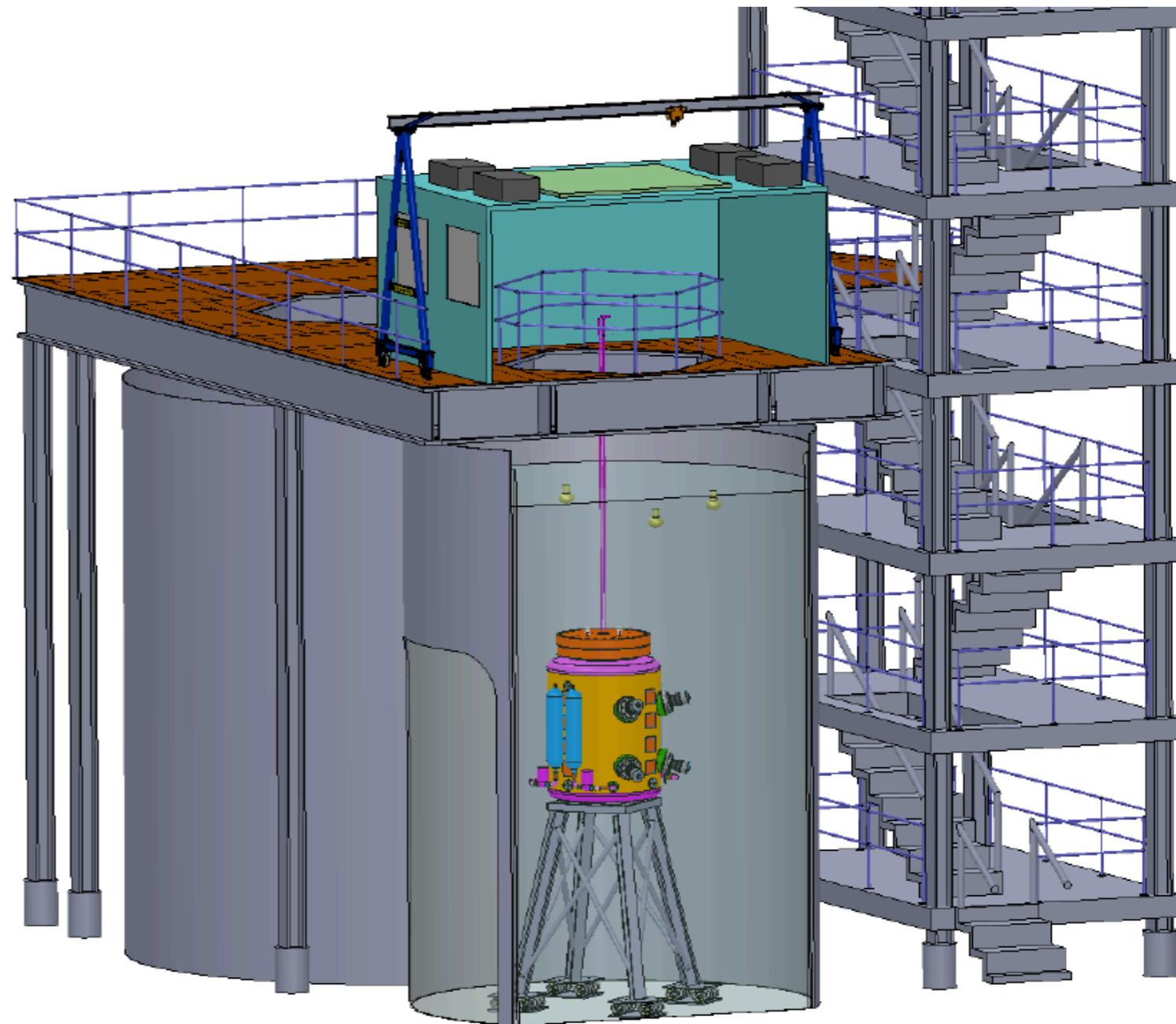
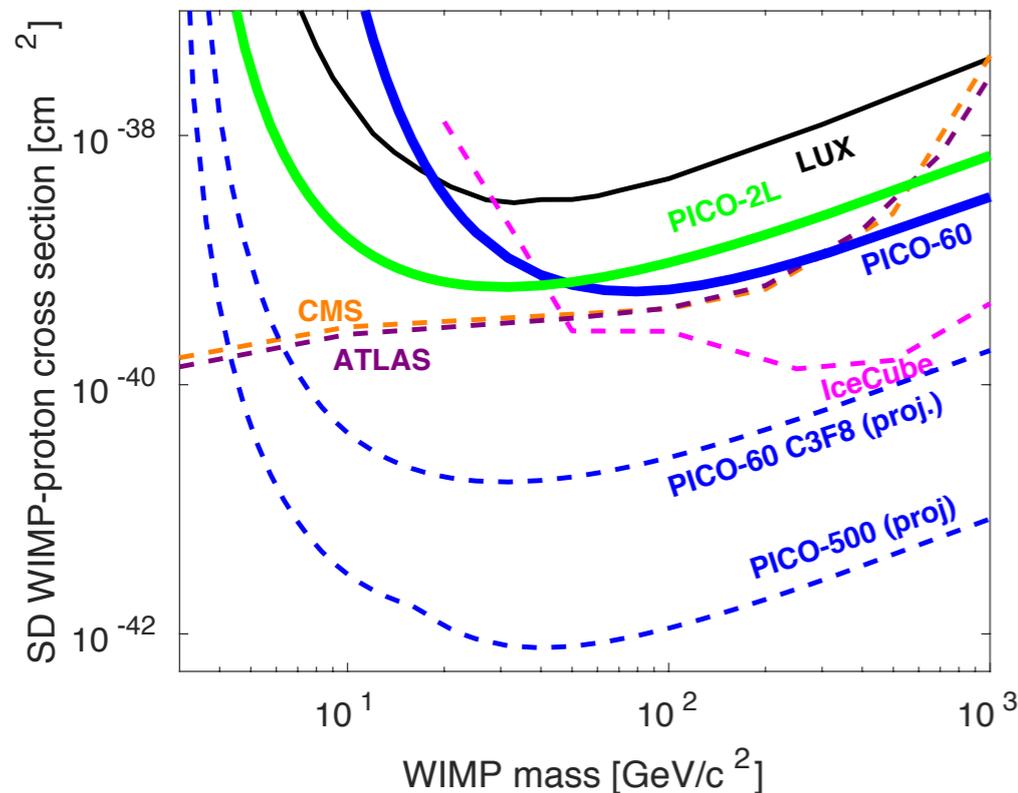


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For details see talk by S. Fallows from yesterday

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 four weeks 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 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 soon
- PICO 40L will be installed in the coming months
 - Lower backgrounds will push the SD limit even lower with a year of exposure
 - This detector will serve as verification of the “right-side-up” detector and as testbed for PICO 500
- We are getting ready for PICO 500, construction should start in 2018

PICO



K. Clark, I. Lawson



M. Ardid, M. Bou-Cabo, I. Felis



NORTHWESTERN UNIVERSITY

D. Baxter, C.E. Dahl, M. Jin, J. Zhang



P. Bhattacharjee, M. Das, S. Seth



E. Behnke, H. Borsodi, O. Harris, A. LeClair, I. Levine, A. Roeder



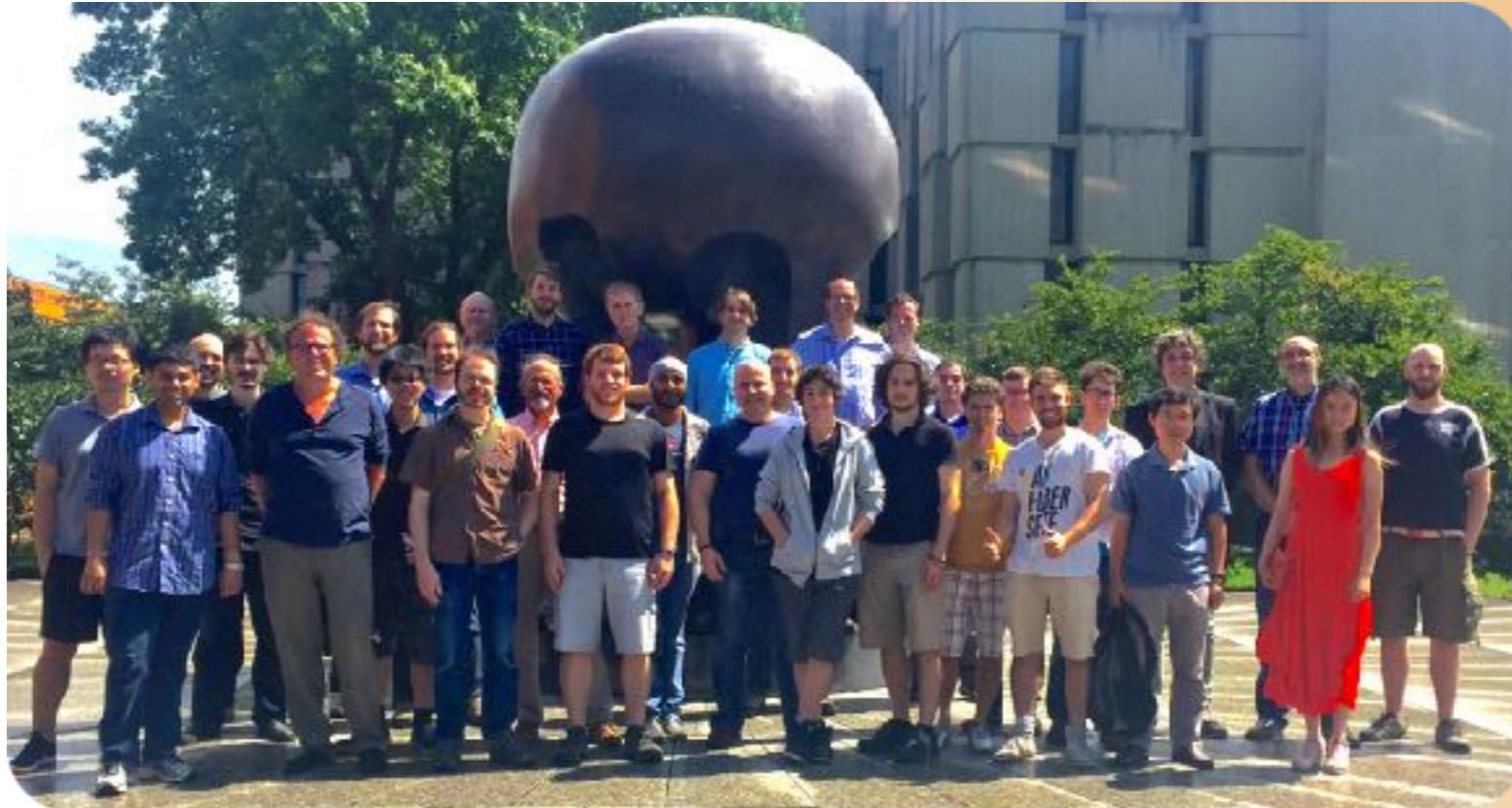
R. Filgas, I. Stekl



J.I. Collar, A. Ortega



F. Debris, M. Fines-Neuschild, C.M. Jackson, M. Lafrenière, M. Laurin, J.-P. Martin, A. Plante, N. Starinski, V. Zacek



R. Neilson



S.J. Brice, D. Broemmelsiek, P.S. Cooper, M. Crisler, W.H. Lippincott, E. Ramberg,, A.E. Robinson, M.K. Ruschman, A. Sonnenschein



D. Maurya, S. Priya



O. Harris



E. Vázquez-Jáuregui, G



Queen's UNIVERSITY

C. Amole, G. Giroux, A. Noble, S. Olson



Pacific Northwest NATIONAL LABORATORY

D.M. Asner, J. Hall



S. Fallows, C. B. Krauss, P. Mitra



J. Farine, F. Girard, A. Le Blanc, R. Podvianuk, O. Scallon, U. Wichoski