Dark Matter Search Results from the PICO-60 C_3F_8 Bubble Chamber

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PICO: search for dark matter with superheated liquids

PICO Collaboration

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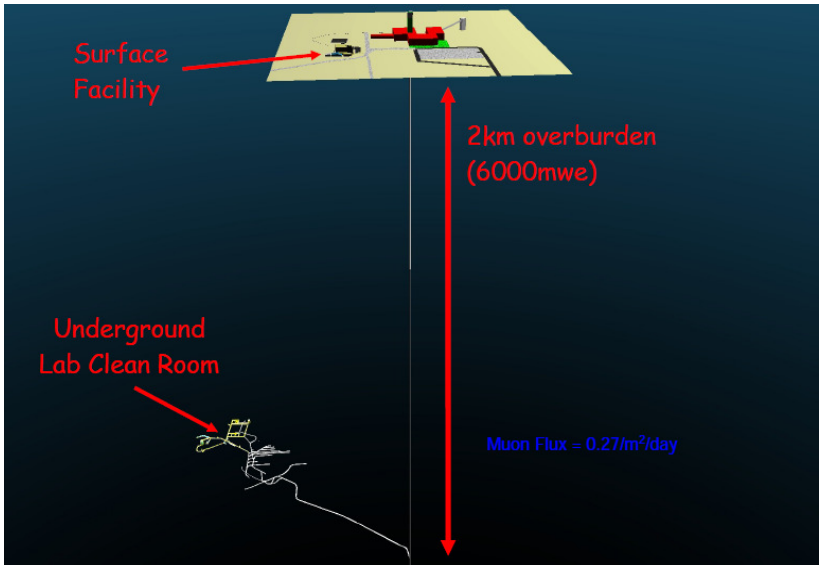
Sudbury Neutrino Observatory Laboratory

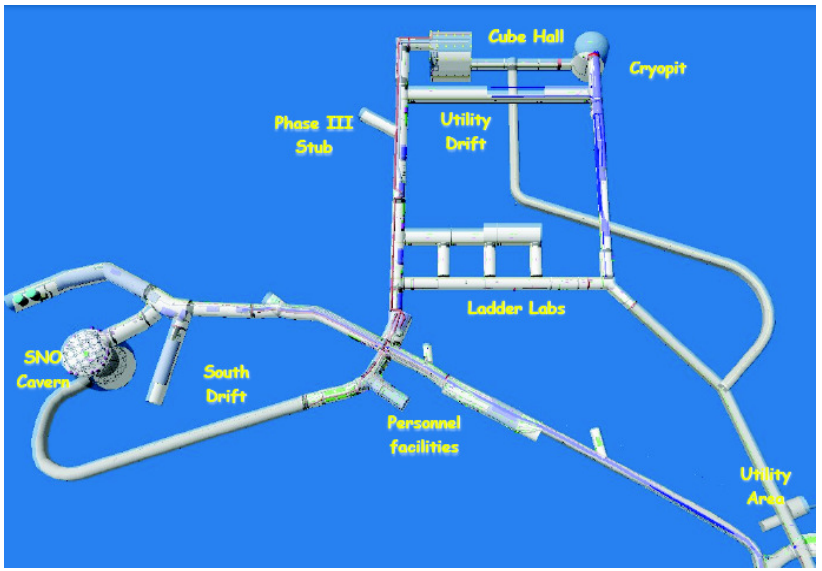
SNOLAB

deepest and cleanest large-space international facility in the world

- 2 km underground near Sudbury, Ontario
- ultra-low radioactivity background environment Class 2000
- Physics programme focused on neutrino physics and direct dark matter searches

Home of the SNO experiment
2015 Nobel prize in Physics





PICO bubble chambers

- Target material:
  superheated CF_3I,
  C_3F_8, C_4F_{10}
  spin-dependent/independent

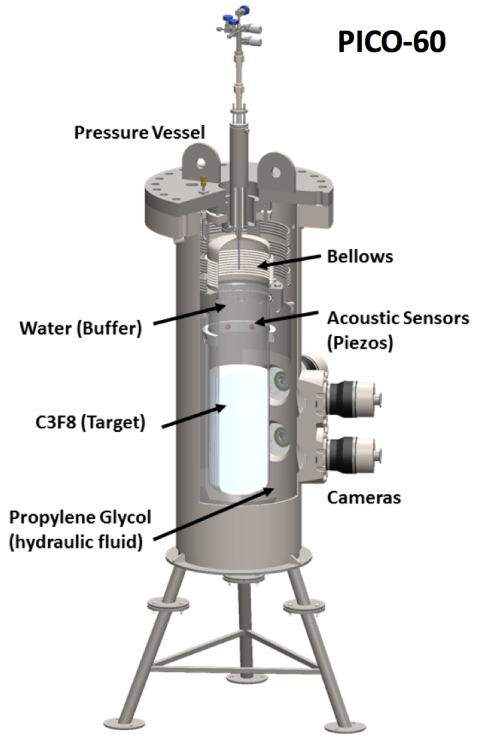
  Could make a
  dark matter bubble
  chamber with any liquid!

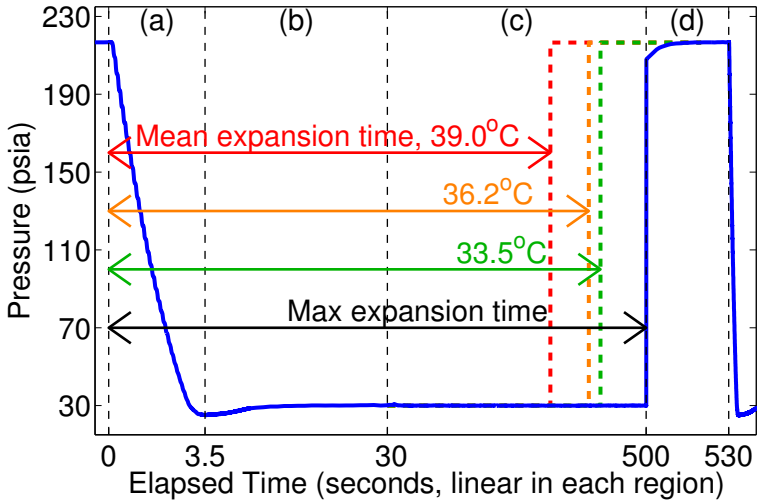
- Particles interacting
  evaporate a small
  amount of material:
  bubble nucleation

- Four Cameras record bubbles

- Eight piezo-electric acoustic
  sensors detect sound

- Recompression after
  each event



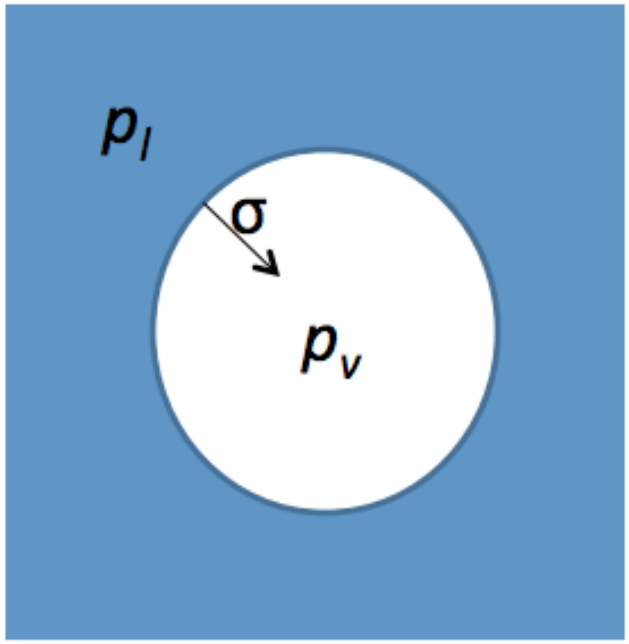


PICO bubble chambers

- In a superheated fluid, energy deposition greater than E_{th} in a radius less than r_c will result in a bubble large enough to overcome surface tension (Seitz "Hot-Spike" Model)
- Low E or dE/dx result in smaller bubbles that immediately collapse
- Classical Thermodynamics:

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

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

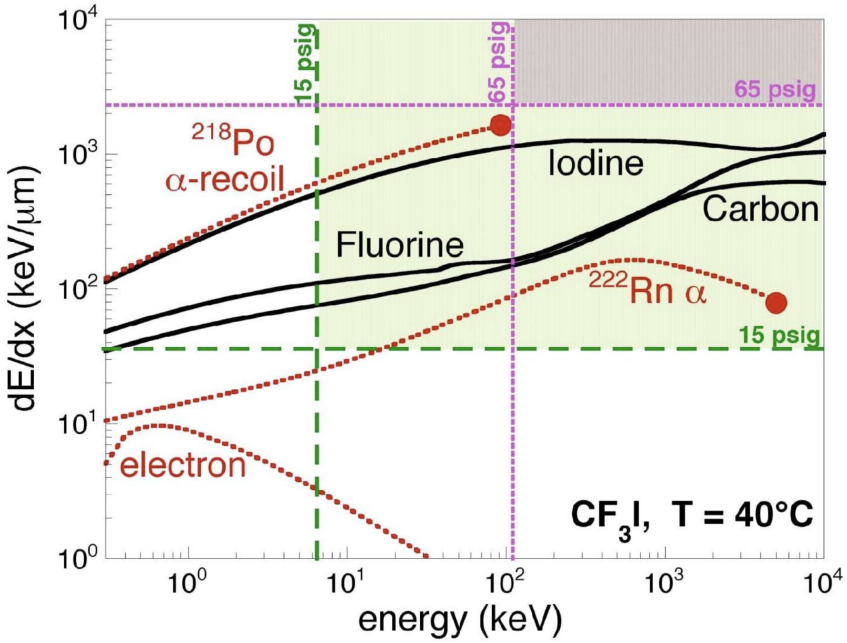


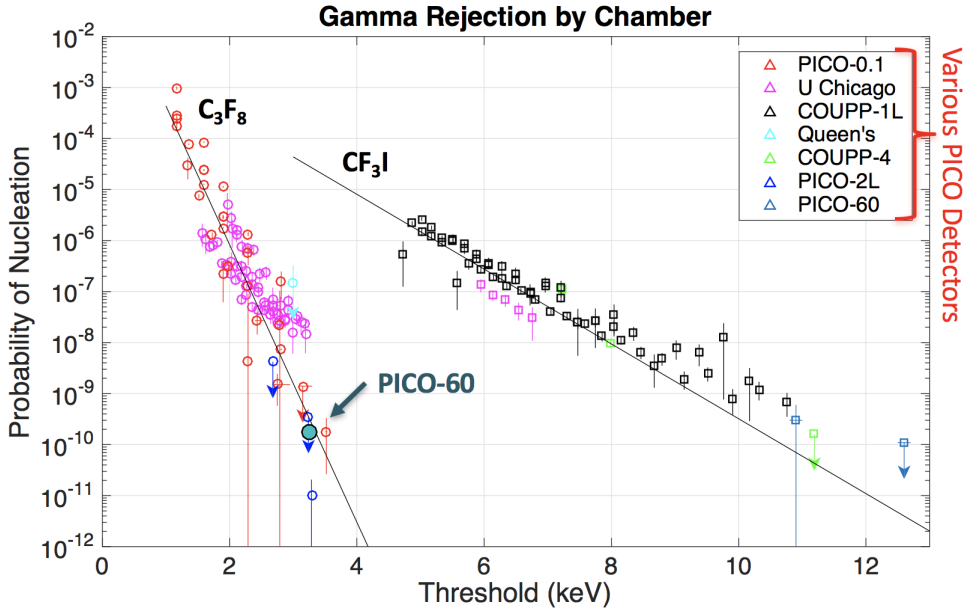
Bubble nucleation

Dependence of bubble nucleation on the total deposited energy and dE/dx

- Region of bubble nucleation at 15 psig
- Backgrounds: electrons, ^{218}Po, ^{222}Rn
- Signal processes of Iodine, Fluorine and Carbon nuclear recoils

insensitive to electrons and gammas



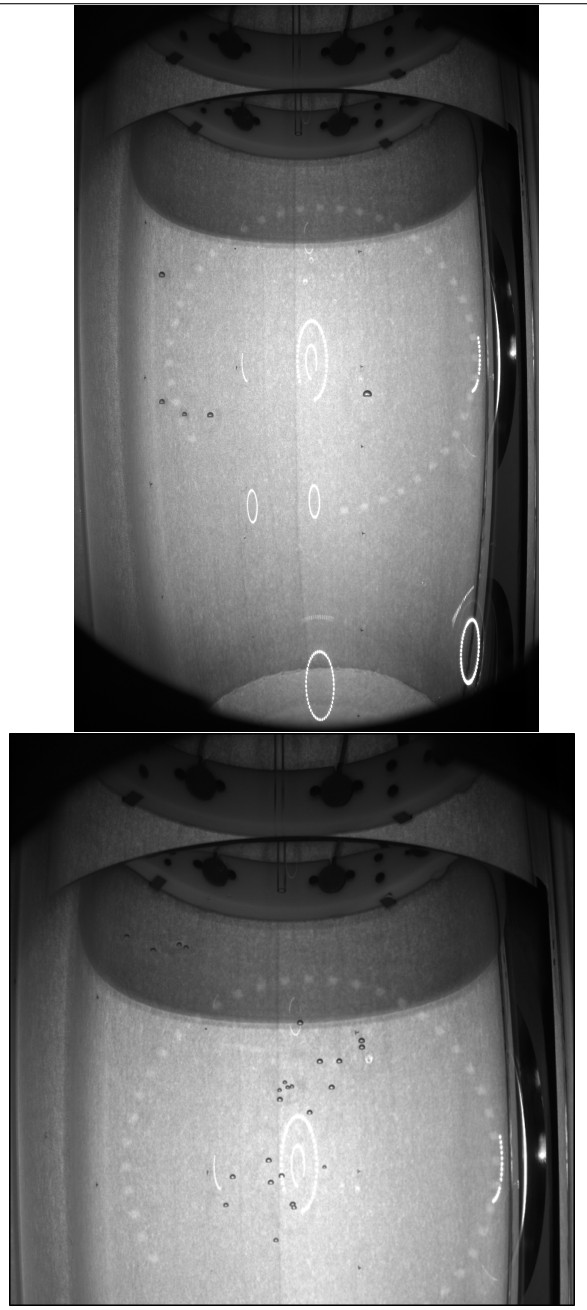


PICO bubble chambers

- **Alpha decays:**
  Nuclear recoil and
  40 μm alpha track
  1 bubble

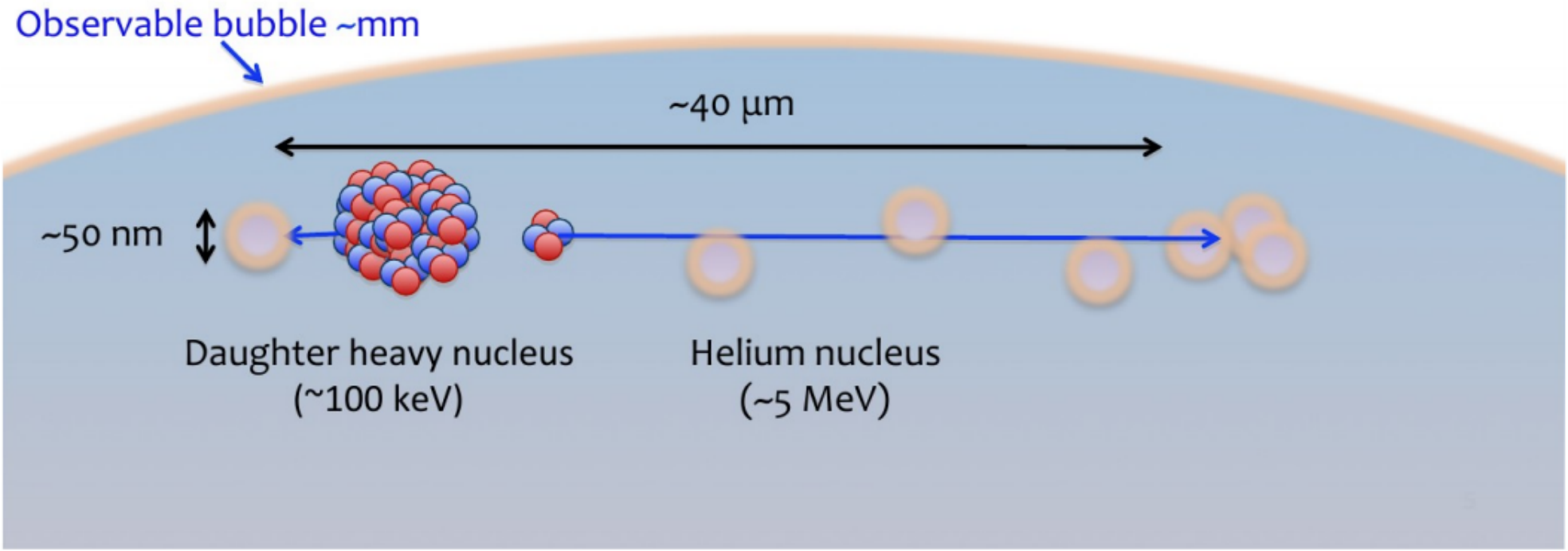
- **Neutrons:**
  Nuclear recoils
  mean free path $\sim$20 cm
  3:1 multiple-single ratio
  in PICO-60

- **WIMPs:**
  Nuclear recoil
  mean free path $> 10^{12}$ cm
  1 bubble



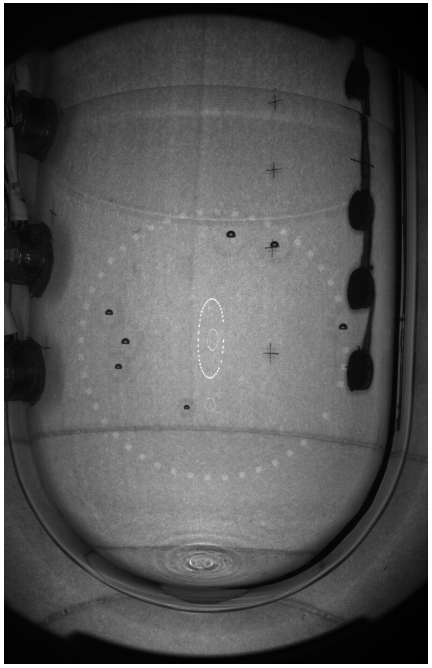
PICO bubble chambers

- Alphas are ~ 4 times louder than nuclear recoil bubbles
- $> 99.4\%$ discrimination against alpha events demonstrated
- Discovered by the PICASSO collaboration



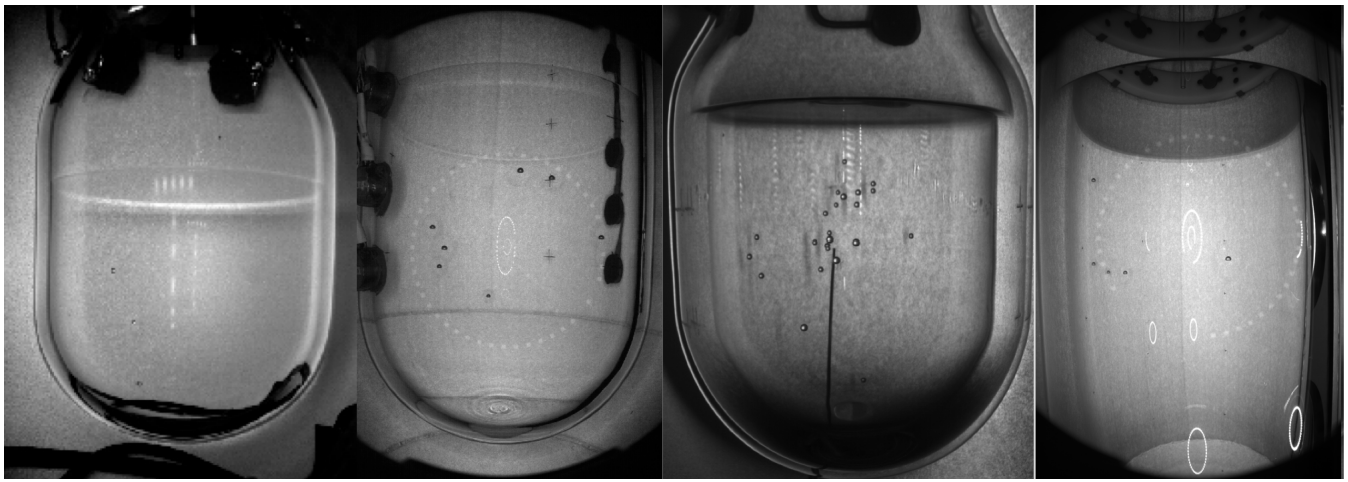
PICO detectors features

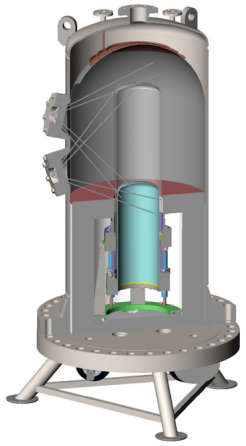
- **Energy: threshold detector**
- **Background suppression:**
  - **UG at SNOLAB**
  - **Water shielding**
  - **Clean materials**
- **Background discrimination:**
  - **Neutrons:**
    multiples bubbles
    Nuclear recoil, $l \sim 20$ cm
  - **α: acoustic parameter**
    Nuclear recoil, 40 μm track
- **Large target mass:**
  COUPP4 to COUPP60
  PICO-2L to PICO-60
  PICO40L-RSU, PICO-500L

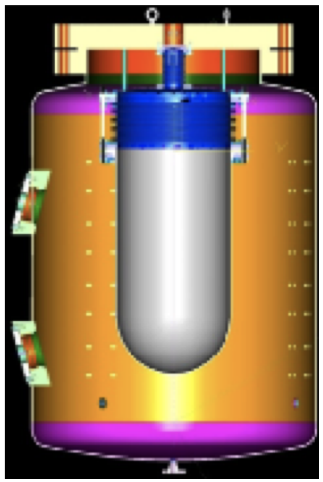


Meet the family: PICO bubble chambers

- **COUPP4: a 2l CF3I chamber run at SNOLAB in 2010 and 2012**
- **COUPP60: up to 40l CF3I chamber run at SNOLAB 2013-14**
- **PICO-2L: a 2l C3F8 chamber run at SNOLAB 2013-14 and 2015-16**
- **PICO-60: up to 45l C3F8 chamber run at SNOLAB 2016-17**
- **PICO40L: currently being deployed (summer 2017)**
- **PICO-500L: future ton-scale experiment 2018**

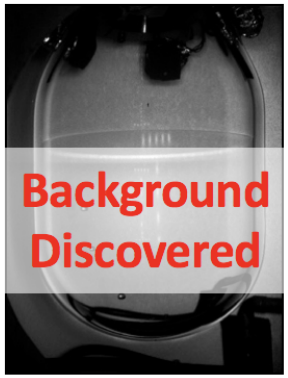






COUPP and PICO timeline

COUPP-4 (2011)
CF_3I Target



Try switching target fluids

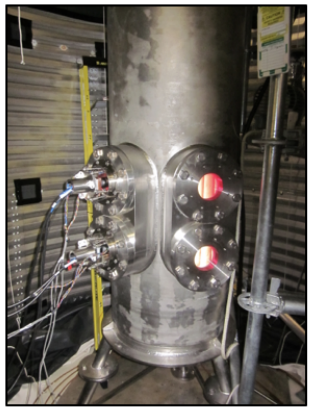
PICO-2L (2014)
C_3F_8 Target

Try removing particulate

PICO-2L (2016)
C_3F_8 Target

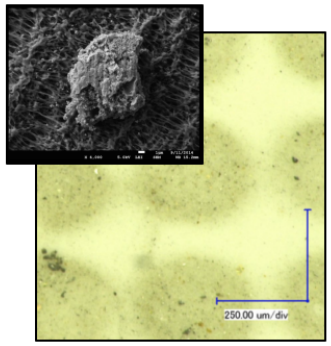
Try scaling

PICO-60 (2017)
C_3F_8 Target



Try scaling to increase statistics

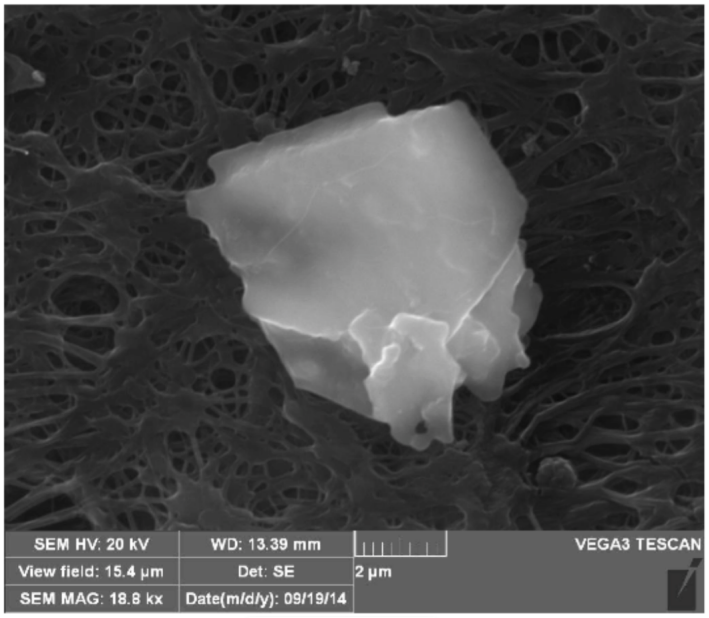
PICO-60 (2014)
CF_3I Target



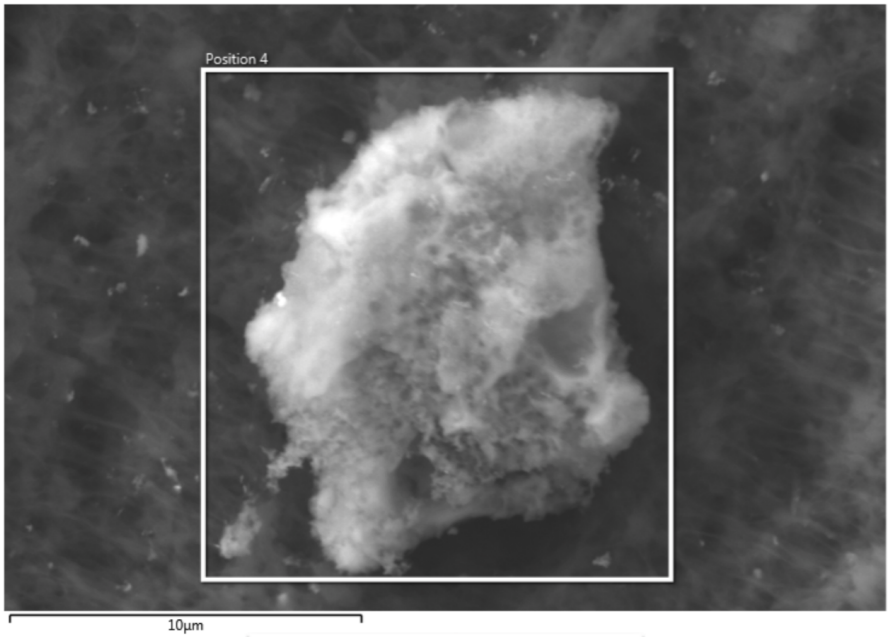
Anomalous backgrounds in PICO

Radioactive particulates suspected to be part of the problem.
Careful assays of the liquids after the end of fill revealed contamination (radioactivity not enough to account for backgrounds observed)

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

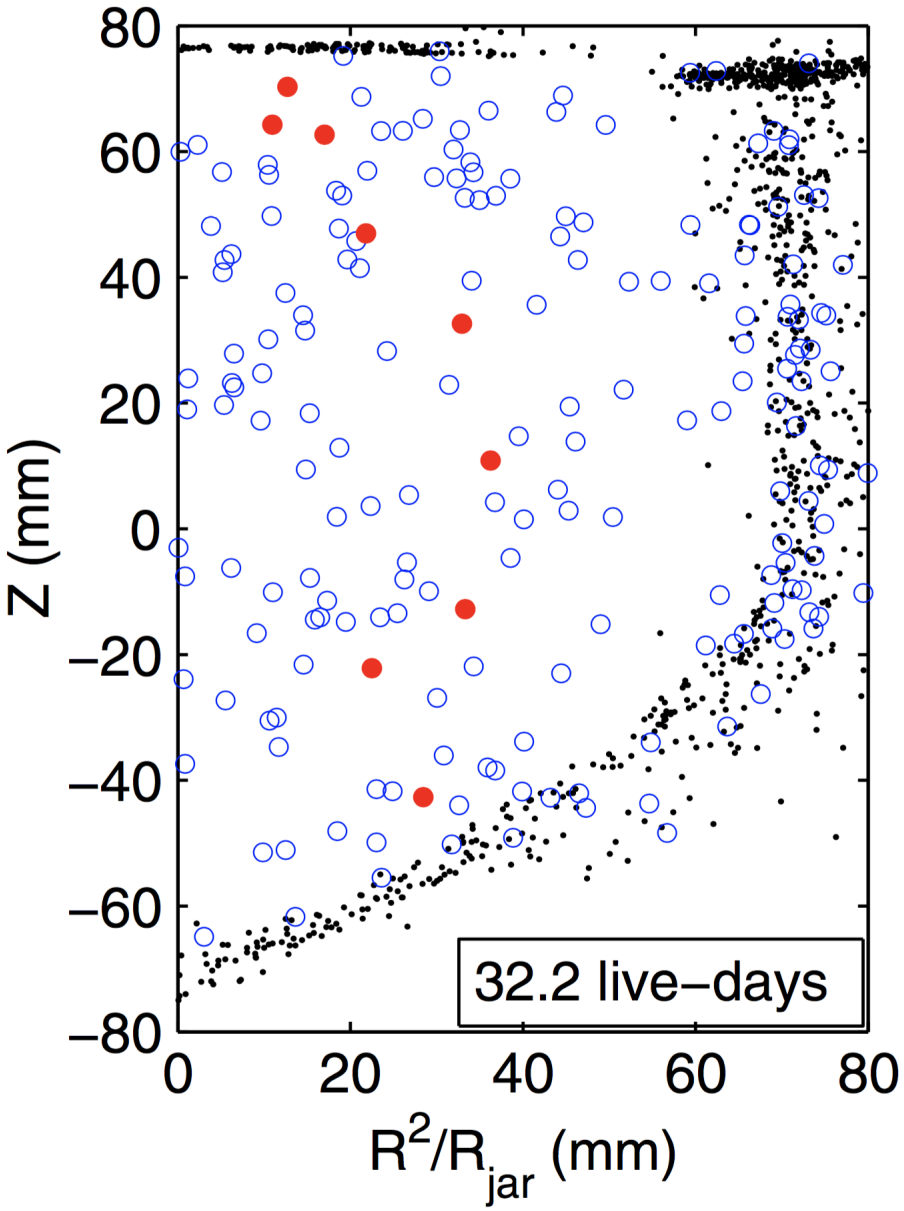


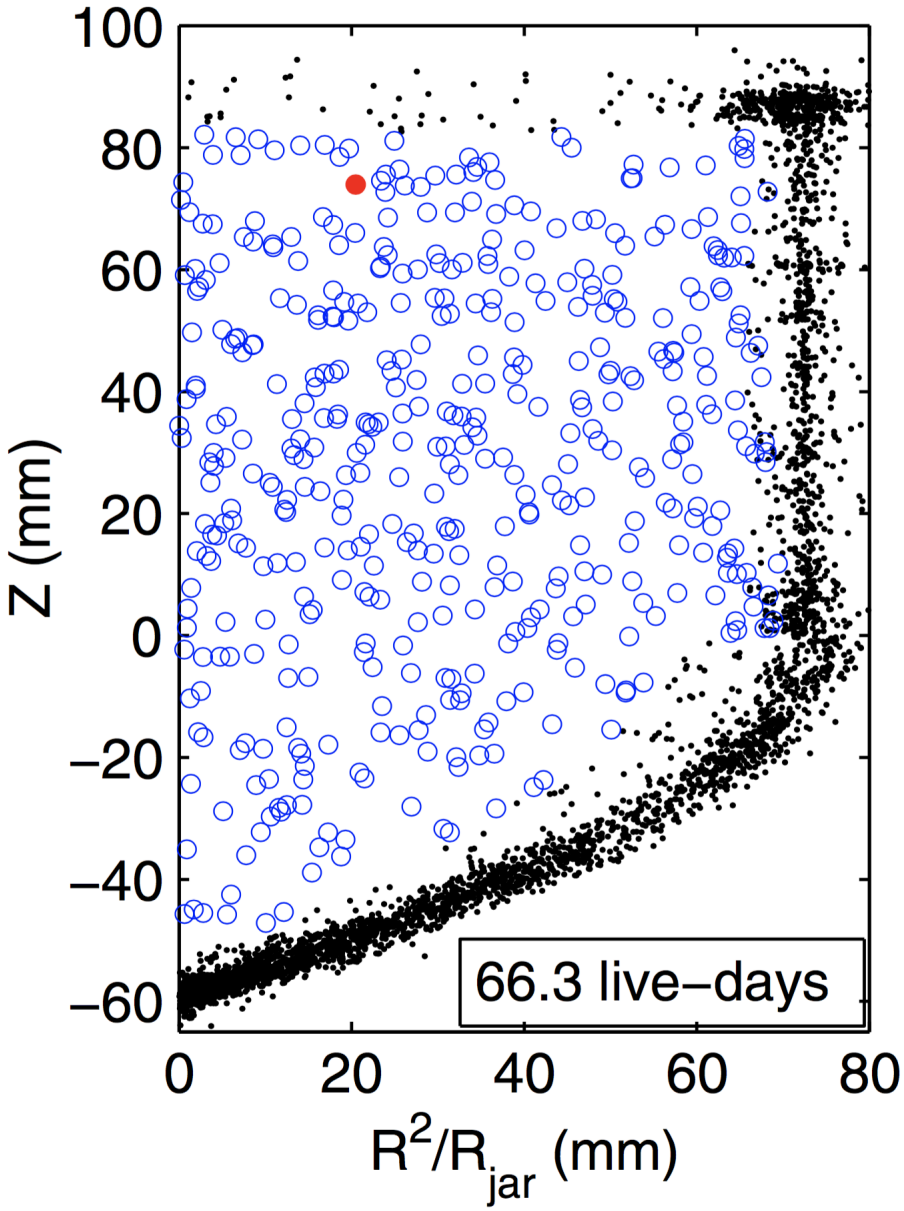
Quartz



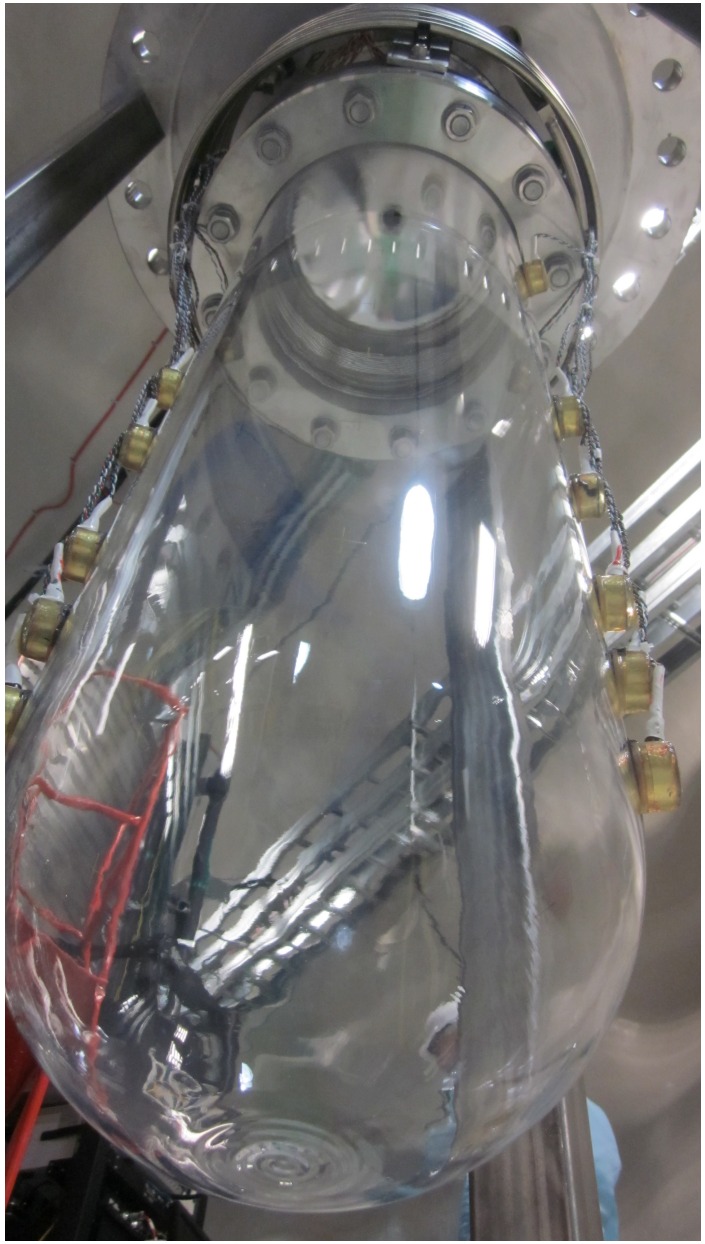
Stainless steel

This is what happened in PICO-2L

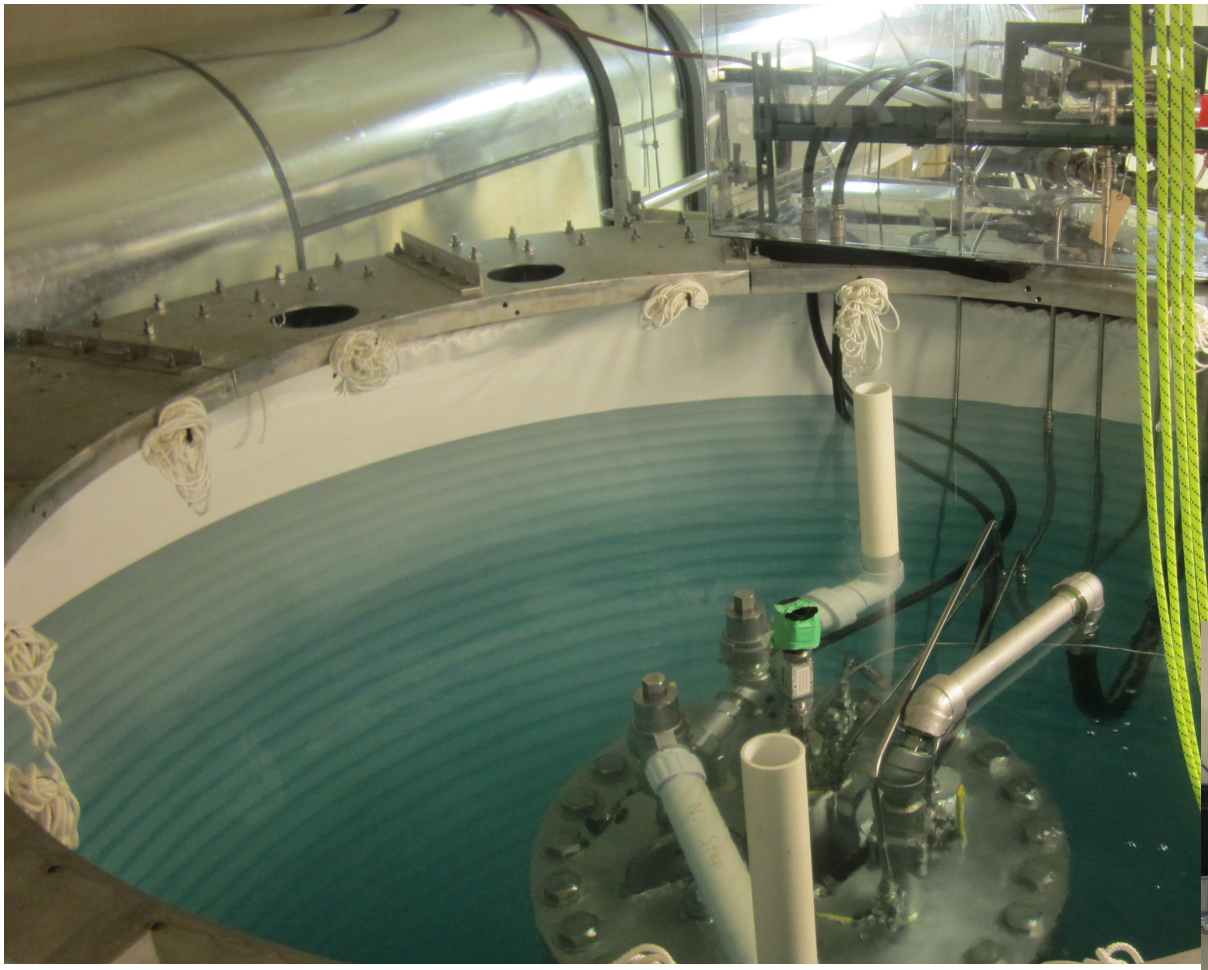


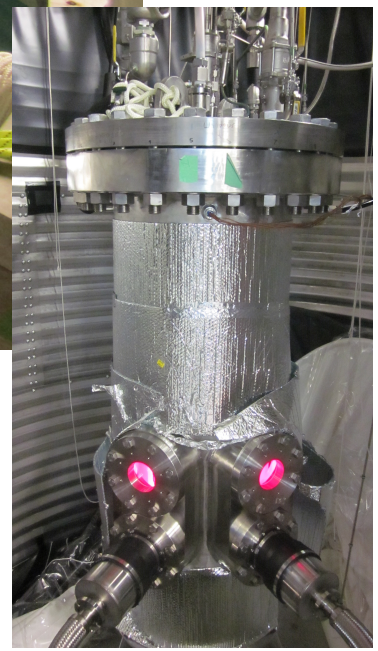


COUPP60 and PICO-60



COUPP60 and PICO-60





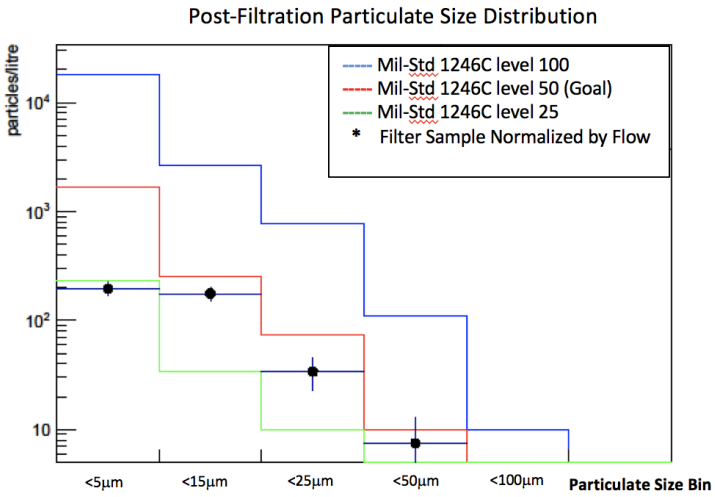
PICO-60 physics run

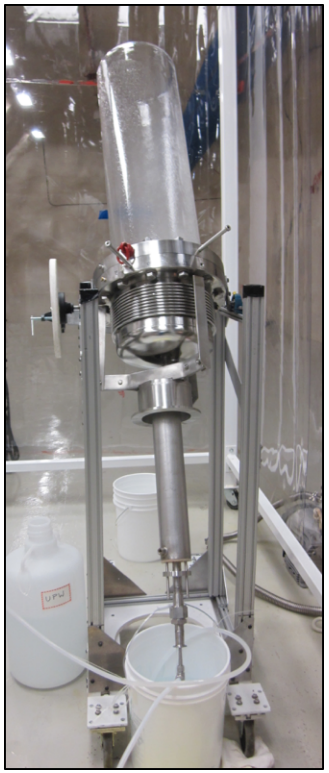
Physics run: Nov 2016-Jan 2017 (30 days live-time)

- **Filled with 52kg of C_3F_8 on June 30, 2016**
- **Collected 1167 kg-days of dark matter search data**
- **3.3 keV threshold**
- **Inner volume components cleaned to MIL-STD-1246C level 50 and active filtration**

Blind(deaf) analysis

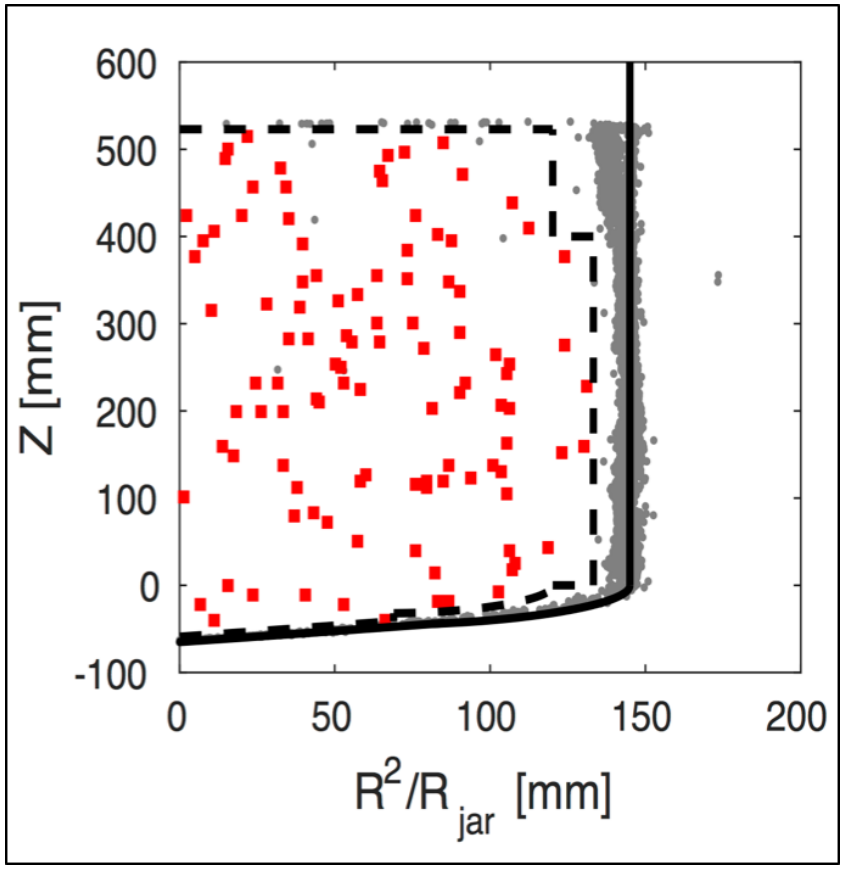
Three multiple bubbles observed

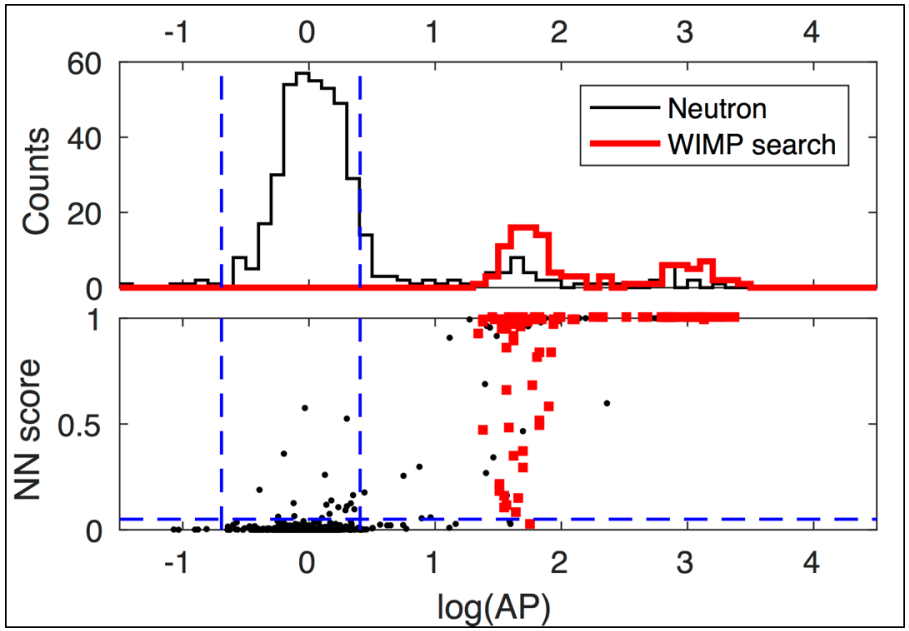




PICO60 physics run

- 45.7 kg fiducial mass
- 85.% WIMP slection efficiency
- 106 events considered after cuts

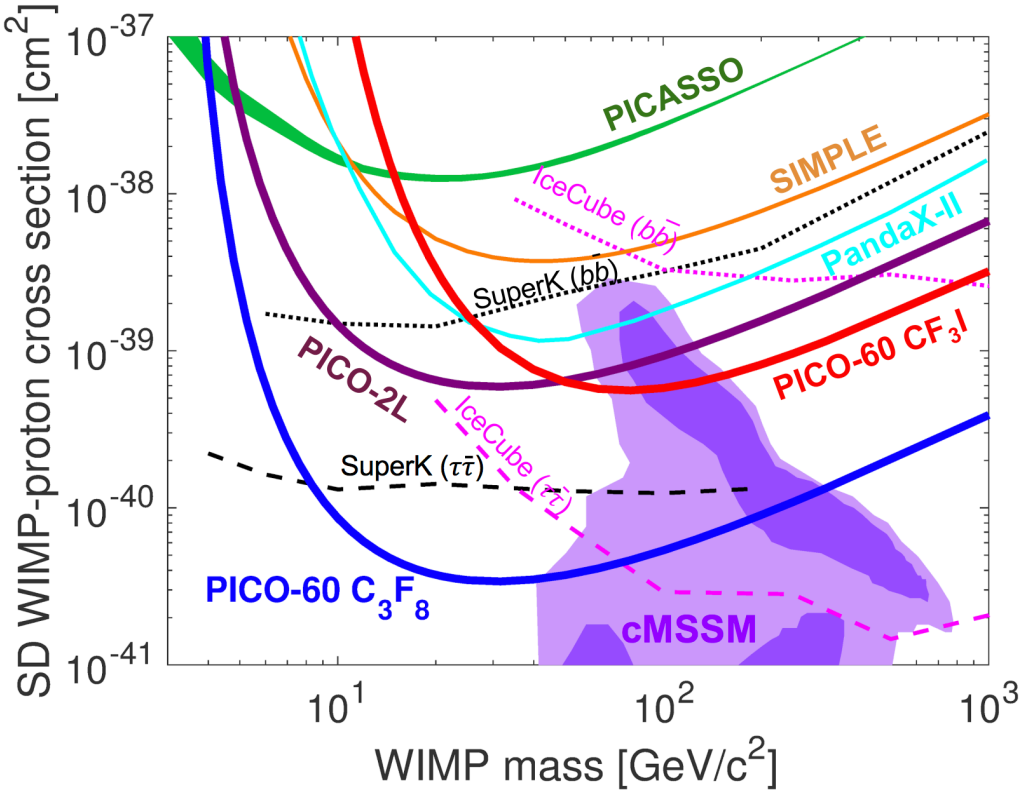




Blinded acoustics analysis:
alpha decays indistinguishable
from nuclear recoils

Unmasking revealed
no nuclear recoil candidates

PICO limits

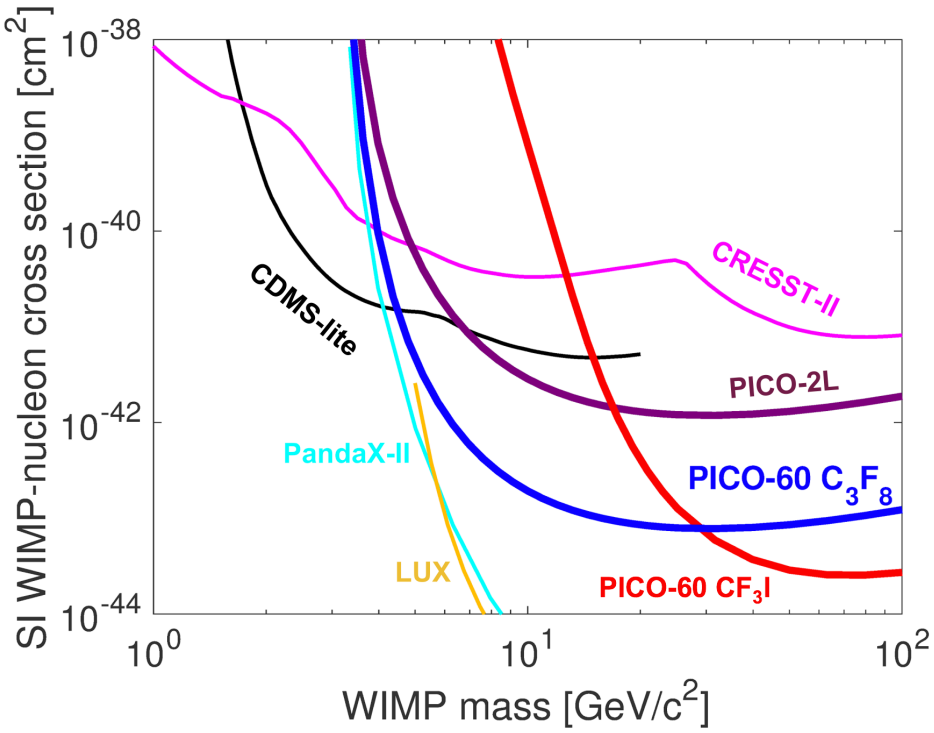


Phys. Rev. D 93, 052014 (2016)

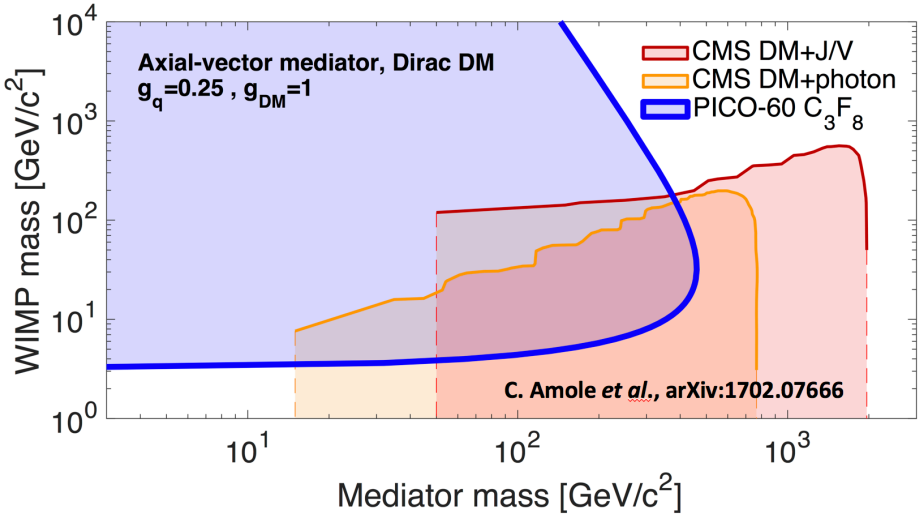
arXiv:1702.07666 (accepted in Phys. Rev. Lett., Editor's suggestion)

Phys. Rev. Lett. 114, 231302 (2015)

Phys. Rev. D 93, 061101 (R) (2016) (Editor's suggestion)



PICO limits



$$\sigma_A^p = \frac{32 G_F^2 \mu_A^2}{\pi} \left(a_p \langle S_p \rangle\right)^2 \frac{J+1}{J}$$

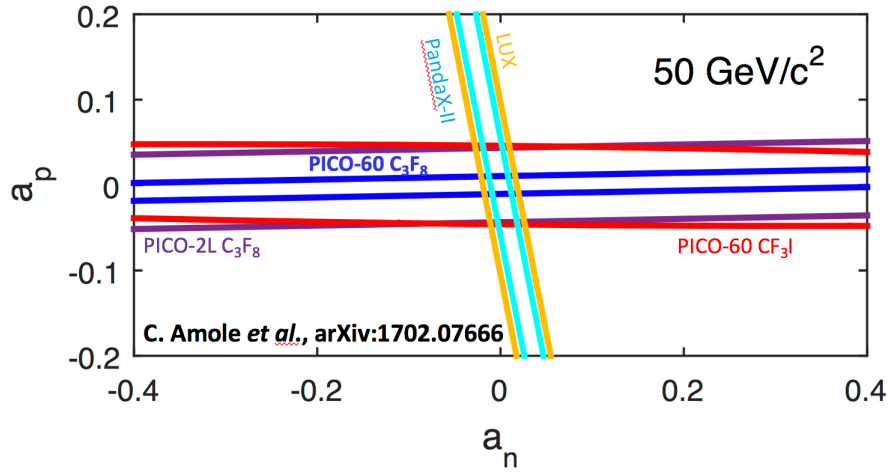
See Tovey for details:
D.R. Tovey, *et al.*, Phys. Lett. B 488, 17 (2000)

LHC Dark Matter Working Group (LHCDMWG) recommendations on simplified models:

For a mediator exchanged in the s-channel, 4 free parameters:

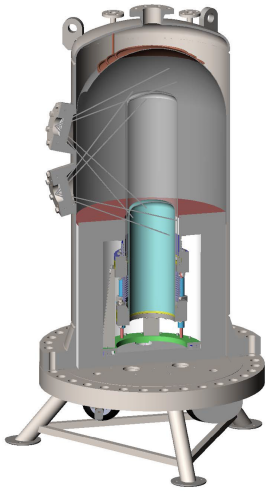
- Dark matter mass: m_{DM}
- Mediator mass: m_{med}
- Universal mediator coupling to quarks: g_q
- Mediator coupling to dark matter: g_{DM}

(constraints presented on m_{DM} and m_{med} for g_q = **0.25** and g_{DM} = **1** for an axial-vector mediator exchanged in the **s-channel)**



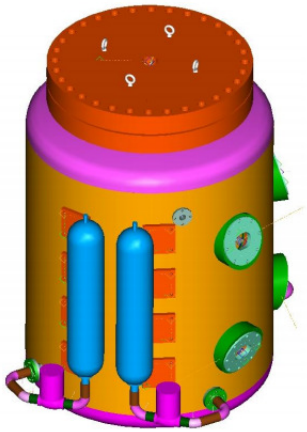
PICO40L-RSU, PICO-500L, et al.

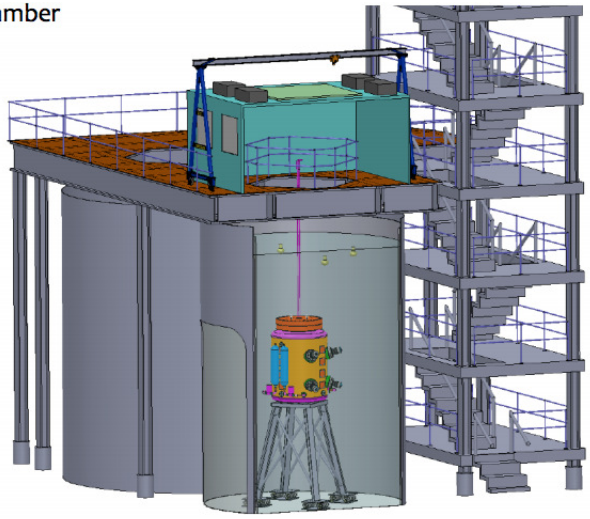
Deploying new detector (this summer) PICO40L: Right Side Up



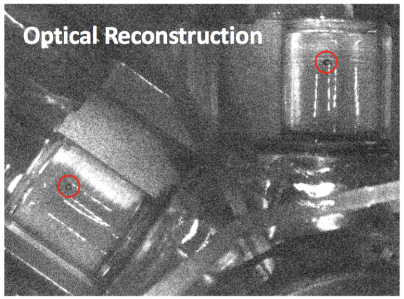
PICO-500L on 2018

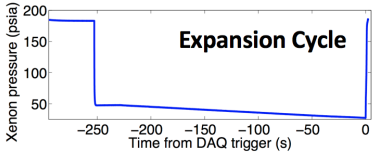
PICO-250L: ton-scale bubble chamber designed for CF_3I or C_3F_8 target

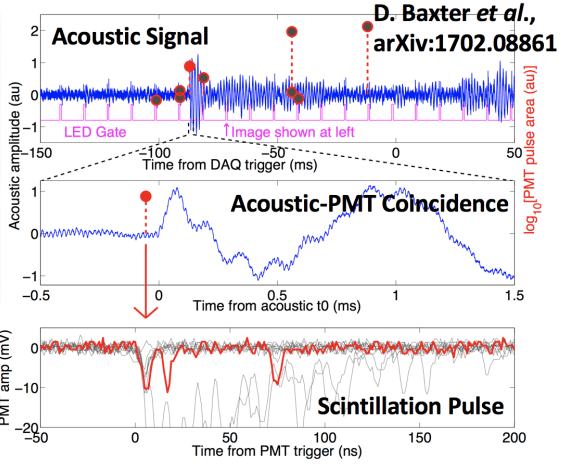


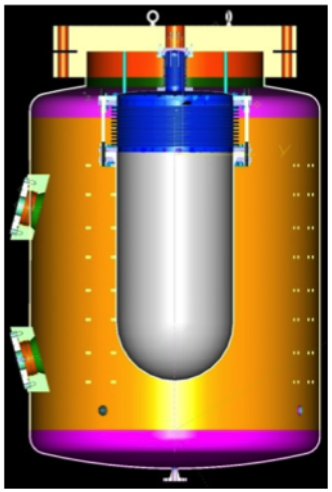


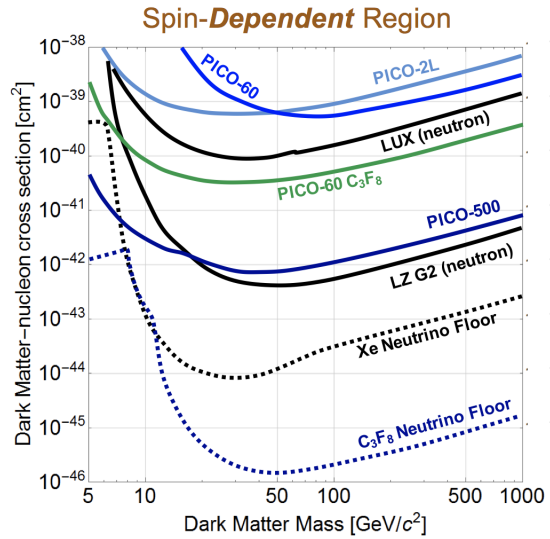
XENON bubble chamber



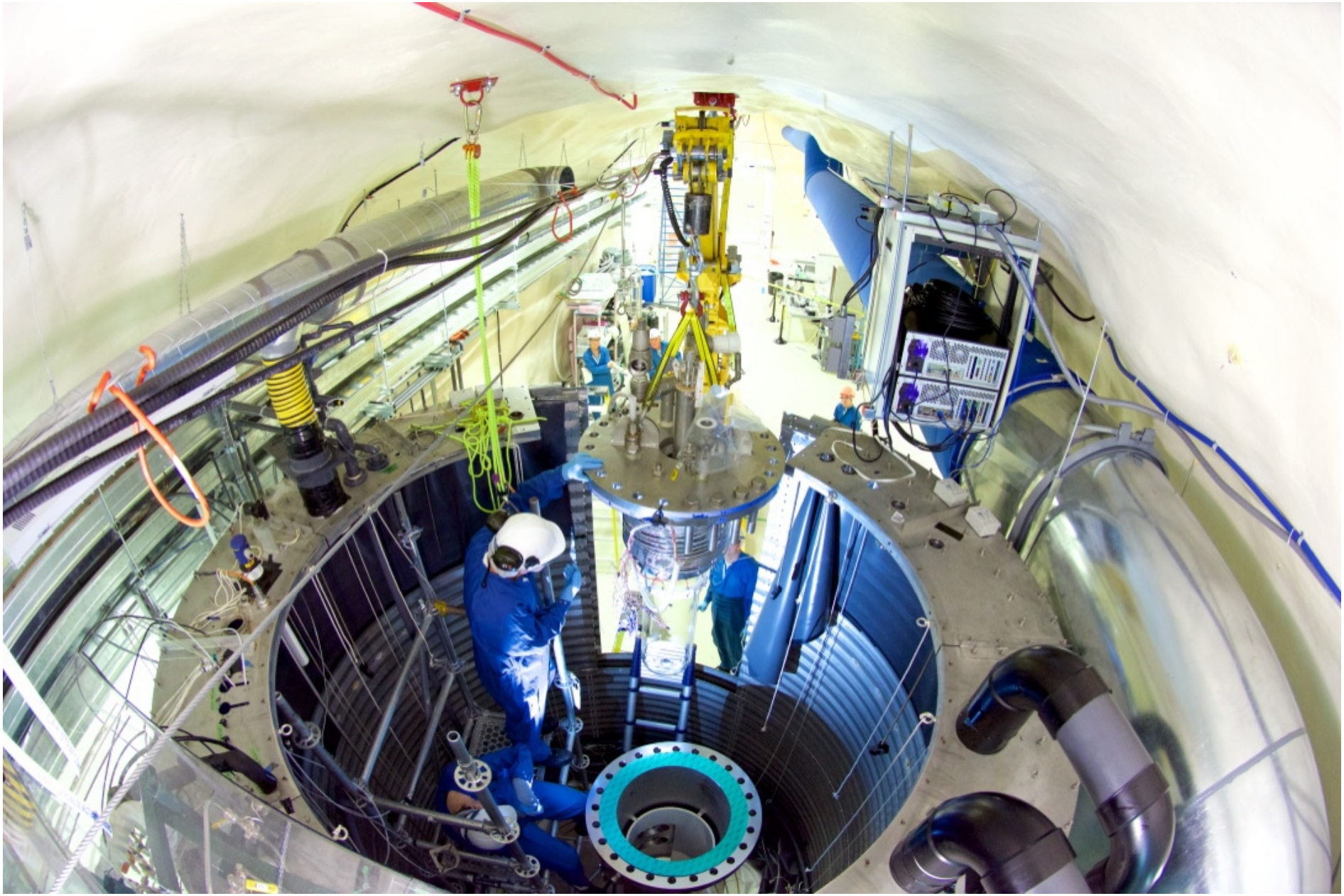






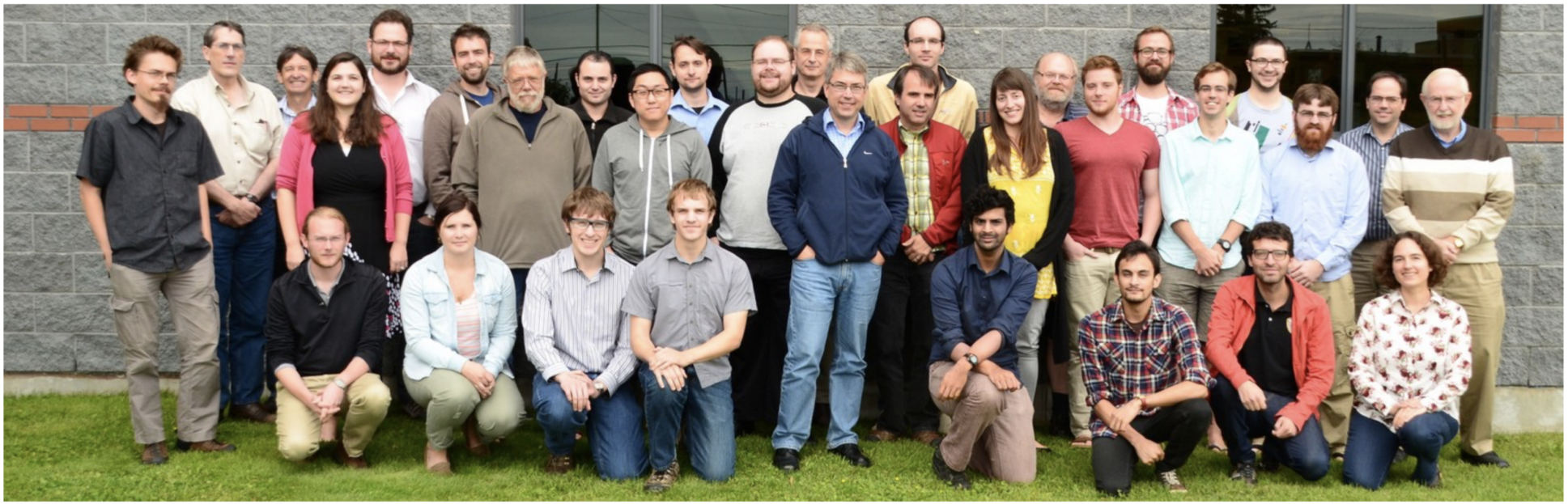


This is PICO...



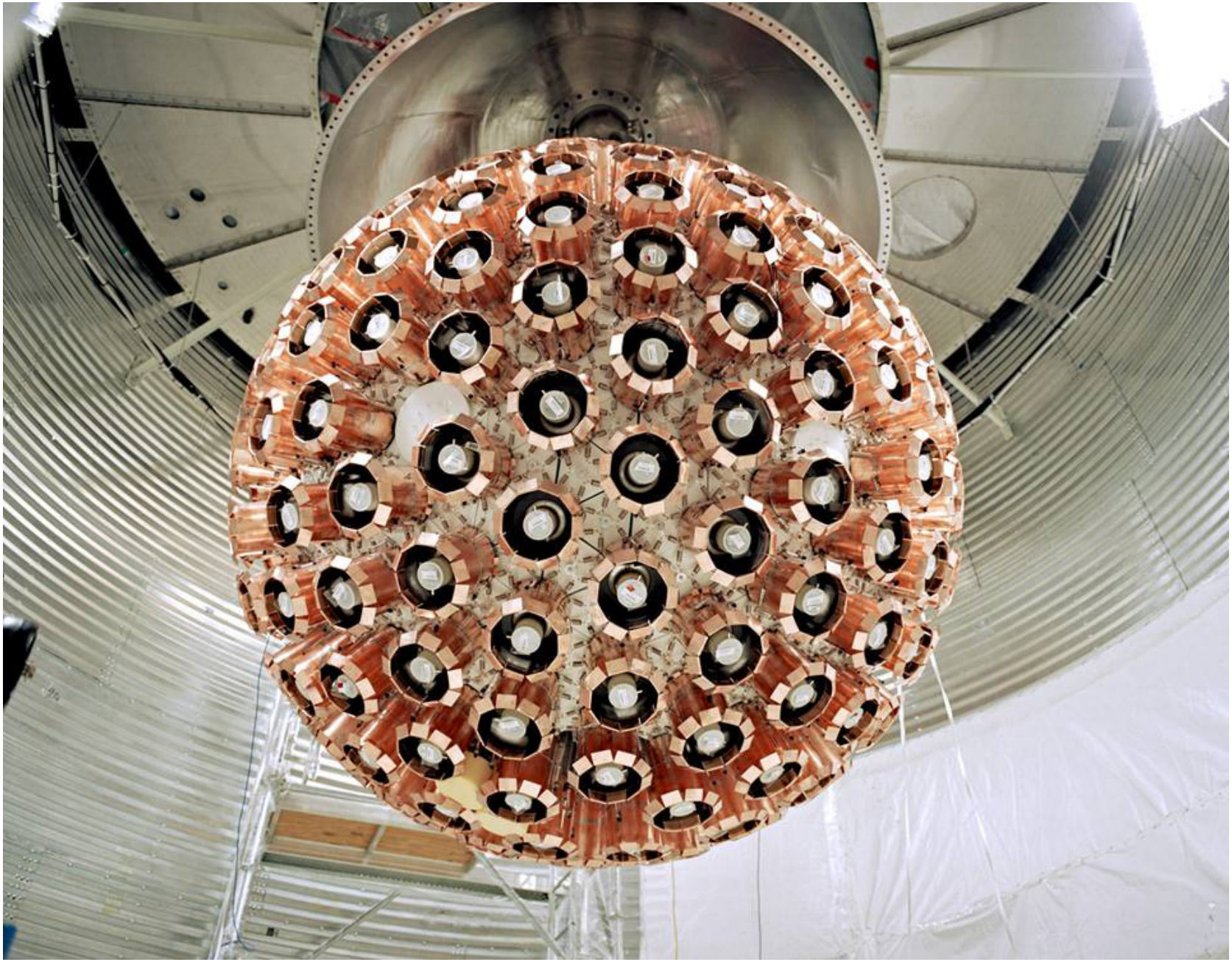
DEAP-3600: search for dark matter with liquid Argon

DEAP Collaboration

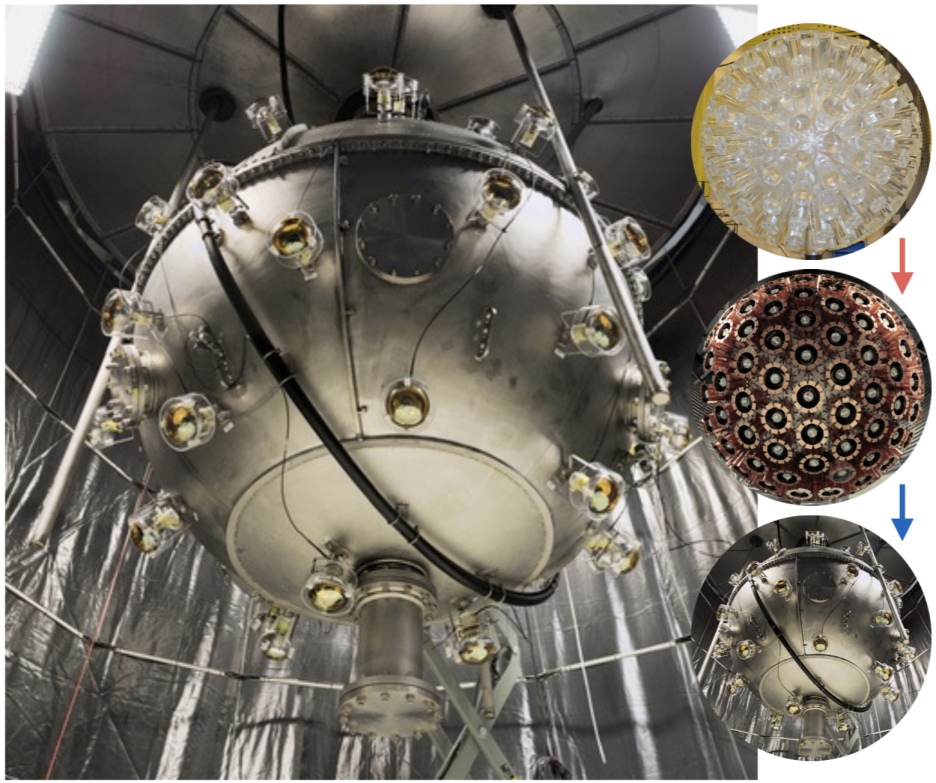


65 researchers in Canada, UK, and Mexico

DEAP-3600



DEAP-3600



First Physics results this summer!

- DEAP-3600 detector is taking data
- Detector is filled with 3350 kg liquid argon (the neck is empty) and operating well
- Half a year of data has been collected and is being analyzed

Conclusions

- PICO bubble chambers are producing world leading direct detection limits using flourine targets
- PICO-60 C_3F_8: a factor 17 improvement on SD WIMP-proton constraints
- Backgrounds under control: bubble chamber technology is ready to be scaled-up to ton-scale

- DEAP-3600 will be the first demonstration of single-phase liquid Argon technology.
- Data taking now, first Physics results this summer

A bright future for amazing science!

Conclusions

- **PICO bubble chambers are producing world leading direct detection limits using flourine targets**
- **PICO-60 C_3F_8: a factor 17 improvement on SD WIMP-proton constraints**
- **Backgrounds under control: bubble chamber technology is ready to be scaled-up to ton-scale**

- **DEAP-3600 will be the first demonstration of single-phase liquid Argon technology.**
- **Data taking now, first Physics results this summer**

A ~~bright~~ (dark) future for amazing science!