Toward a next-generation dark matter search with the PICO-40L bubble chamber

Scott Fallows

TAUP2017 – Laurentian University

24 July 2017

PICO

Laurentian University / Université Laurentienne

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Northwestern University

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Northeastern Illinois University

O. Harris

Instituto de Física

E. Vázquez-Jáuregui

Other PICO talks at TAUP

- **First demonstration of a scintillating xenon bubble chamber for dark matter and CEνNS detection**
  (J. Zhang) Mon 1:15pm

- **Threshold verification in the PICO-60 detector and study of the growth and motion of nucleation bubbles**
  (P. Mitra) Mon 2:45pm

- **PICO Results and Outlook** **plenary*
  (C. Krauss) Tue 9:50am

- **Calibrating Inner-Shell Electron Recoils in a Xenon Time Projection Chamber**
  (D. Baxter) Tue 1:15pm

- **PICO-500: Simulations for a 500L Bubble Chamber for Dark Matter Search**
  (E. Vázquez Jáuregui) Tue 4:30pm

PICO posters at TAUP

- **Nuclear recoil calibration for PICO bubble chambers**
  (M. Jin)

- **PICO-60: World's largest bubble chamber for dark matter detection**
  (U. Chowdhury)

- **The PICO-40L detector design**
  (B. Loer)

Overview

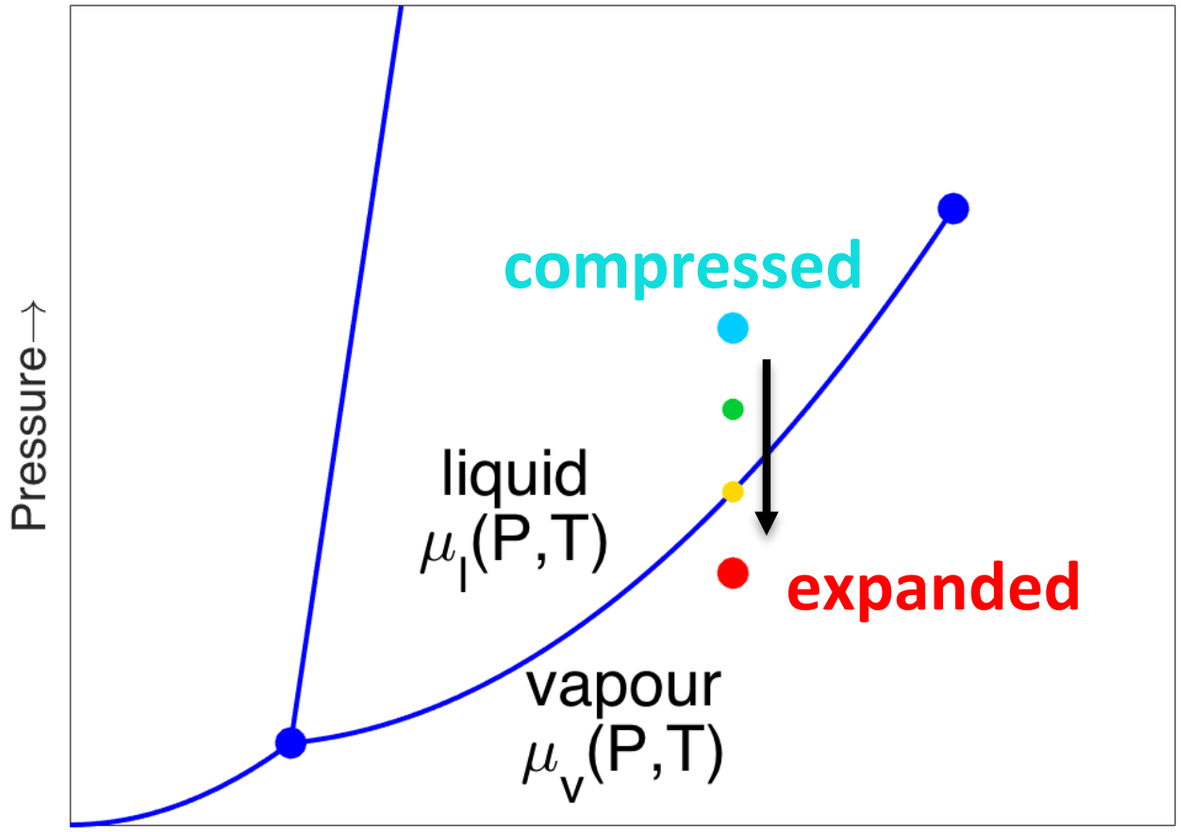
- Bubble chambers for dark matter direct detection and the PICO programme
- PICO-40L:
  - “Right side up” (RSU) detector design: hardware improvements and background reduction
  - Commissioning and operations timeline
  - Projected physics reach
- Proposed tonne-scale chamber: PICO-500

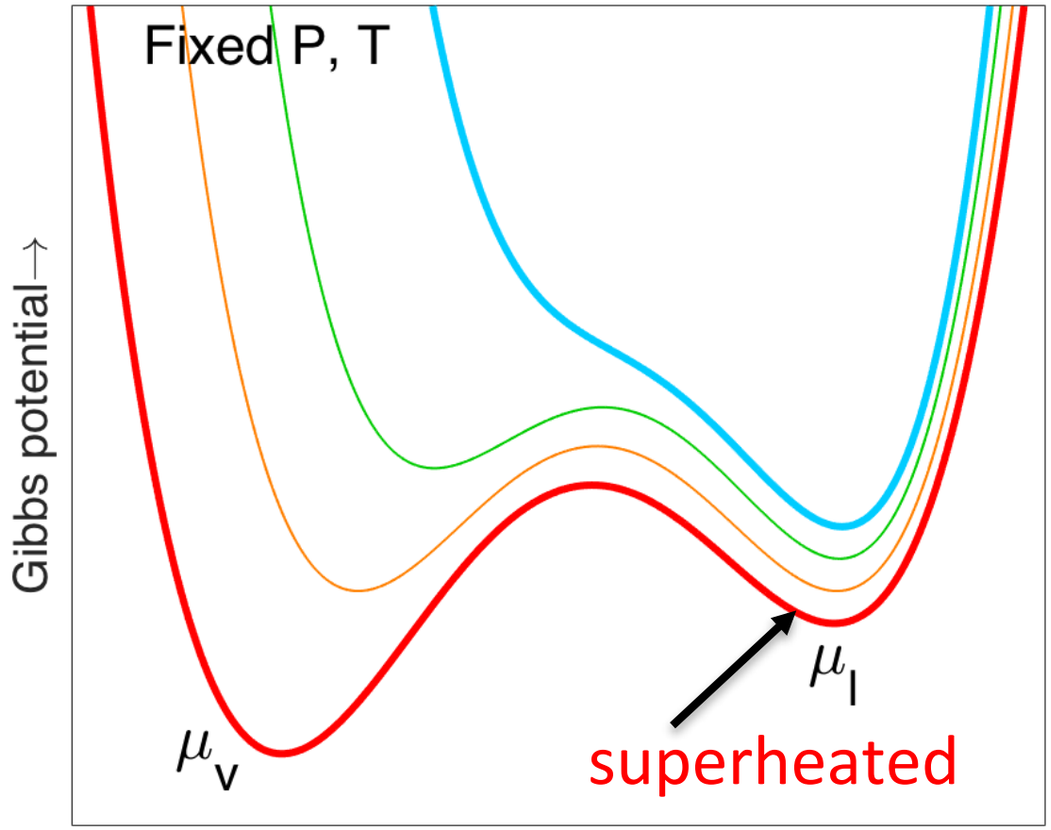
Bubble chamber principle

Lower pressure in target liquid until it is in **metastable superheated** state

Energy deposition **nucleates** small bubble that grows to visible size

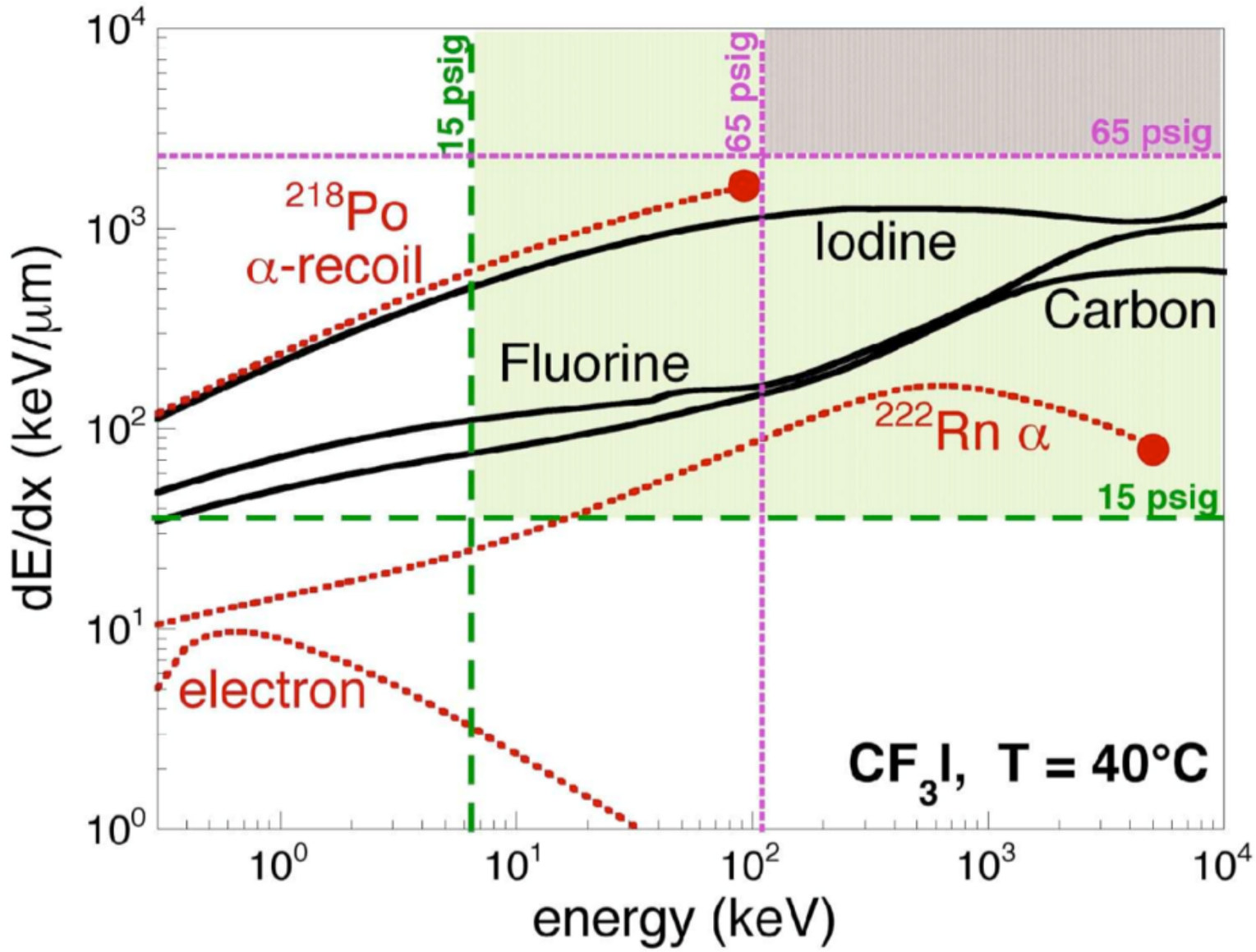
Cameras watch for visible bubble and issue the **primary trigger**





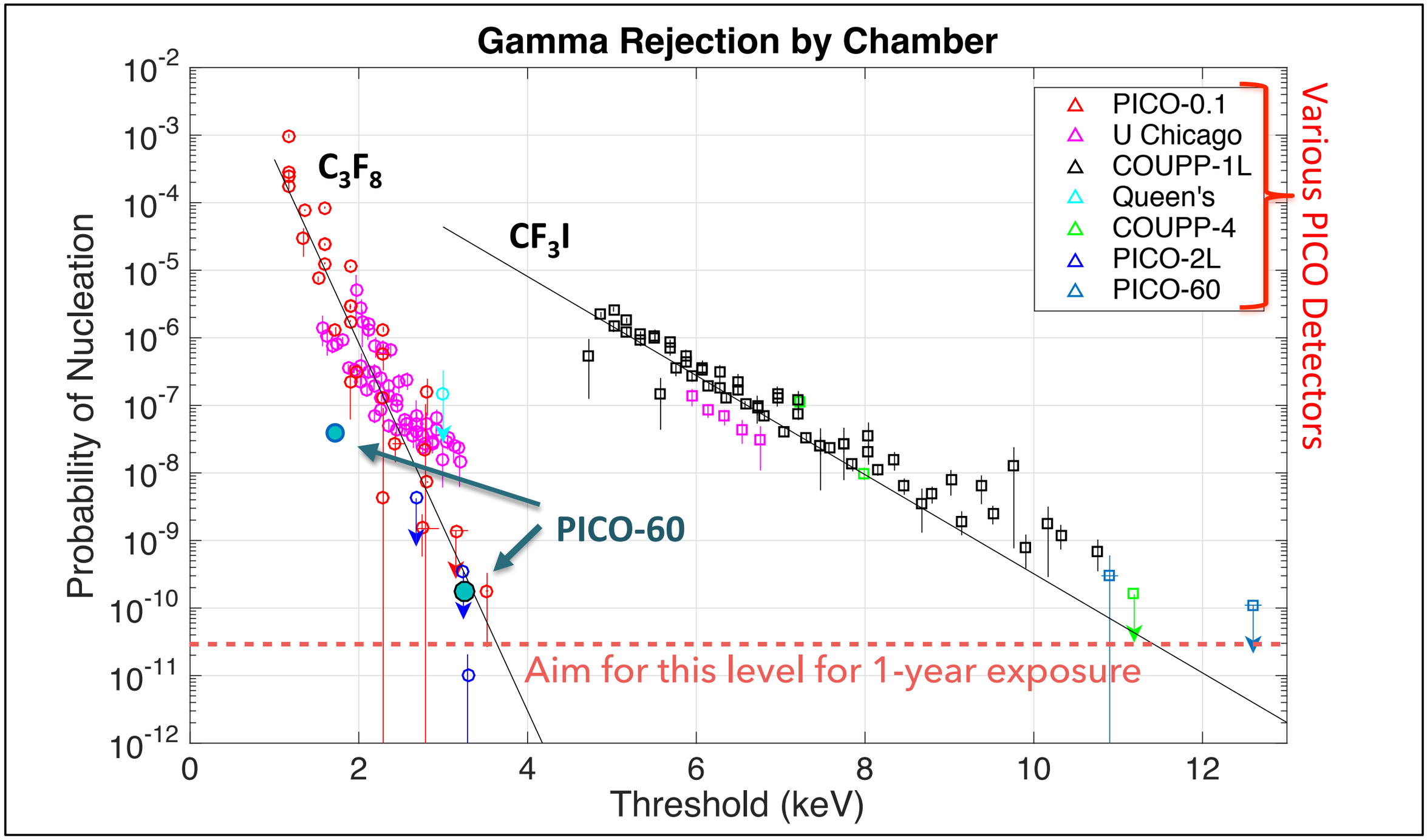
(plots by Eric Dahl)

Gamma rejection



Choose thermodynamic parameters for sensitivity to nuclear recoils, but **not** electron recoils

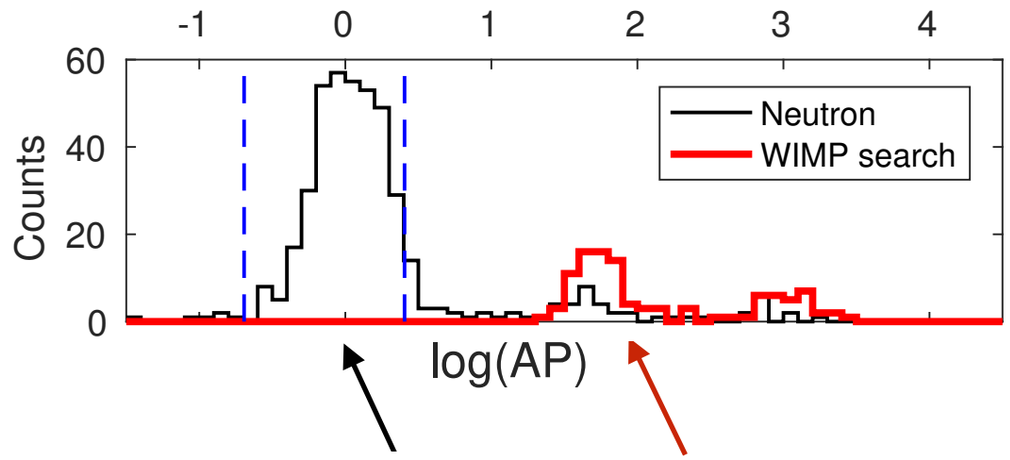
Gamma rejection

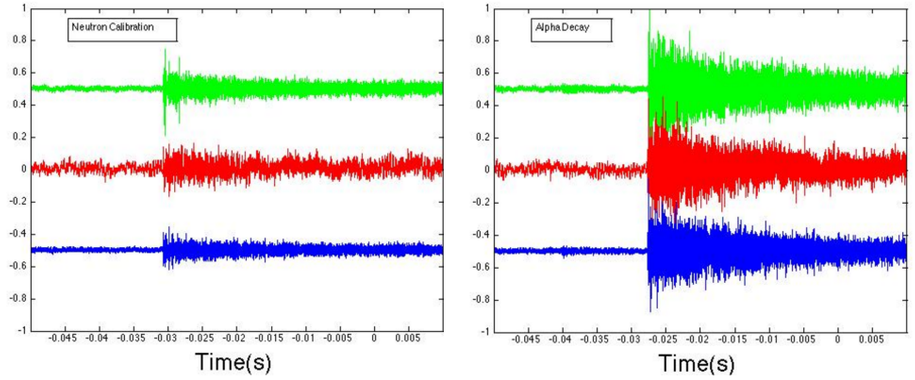


(Dan Baxter, Conference on Science at SURF, May 14, 2017)

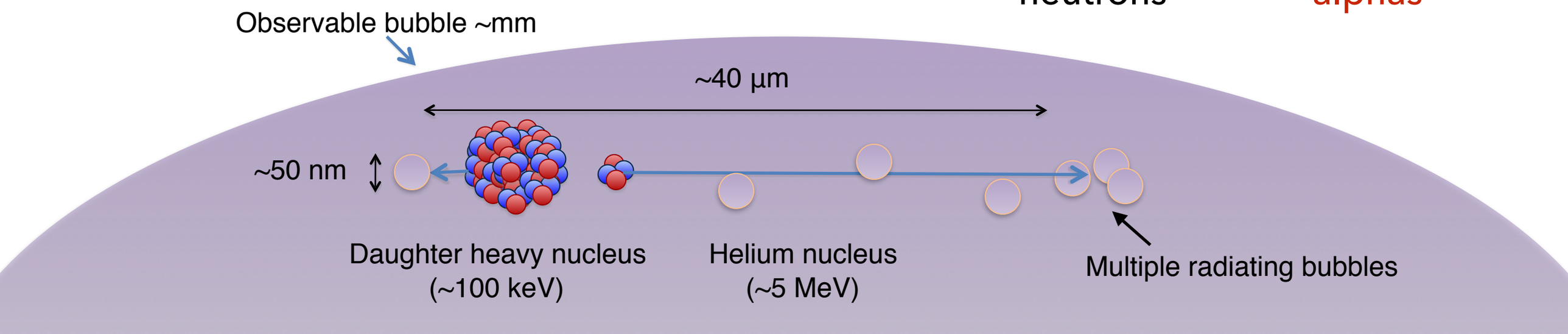
Acoustic discrimination

- Acoustic discrimination against alphas discovered by PICASSO
  (*Aubin et al., New J. Phys.10:103017, 2008*)
  - Alphas deposit their energy over **tens of μm**
  - Nuclear recoils deposit energy over **tens of nm**
- In PICO, **alphas** are several times **louder** than recoils
- For a WIMP-search run, the acoustic signals are blinded in order to set an unbiased cut on this "acoustic parameter" ("AP")





neutrons alphas



Backgrounds checklist

- Gammas/betas:
  - *dE/dx* threshold in superheated detectors affords “intrinsic” rejection ~10^{-11} for typical PICO energy thresholds
- Alpha decays:
  - large acoustic signals allow discrimination at >99.4% (stats. limited)
- Neutrons:
  - reject multiple scatters visually, veto detector-adjacent cosmogenics, minimize other sources (extensive material screening, shielding)

The PICO programme

- PICO was formed from merger of PICASSO and COUPP collaborations

- Small surface test chambers at UdeM, Queen's, Northwestern, Drexel, NEIU

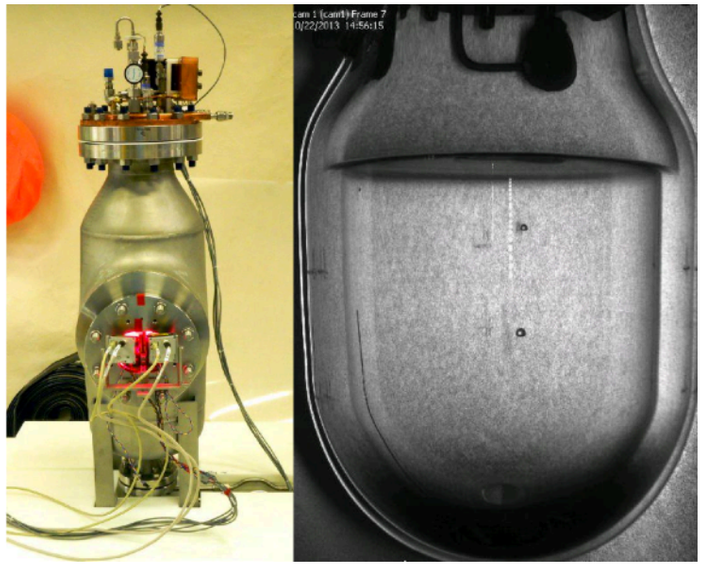
- PICO-2L C_3F_8 (2014-17)
  C. Amole *et al.*, Phys. Rev. Lett. **114**, 231302 **(2015)**
  C. Amole *et al.*, Phys. Rev. D **93**, 061101 **(2016)**

- PICO-60 CF_3I (2013)
  C. Amole *et al.*, Phys. Rev. D **93**, 061101 **(2016)**

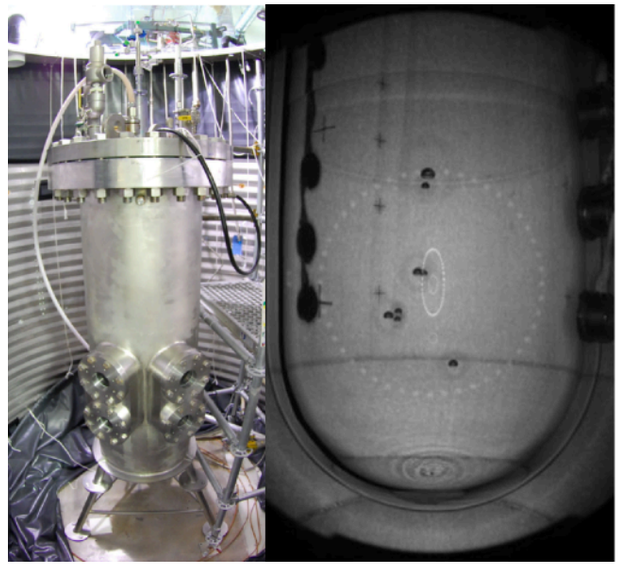
  PICO-60 C_3F_8 (2016-17)
  C. Amole *et al.*, Phys. Rev. Lett. **118**, 251301 **(2017)**

- PICO-40L (2017-18)

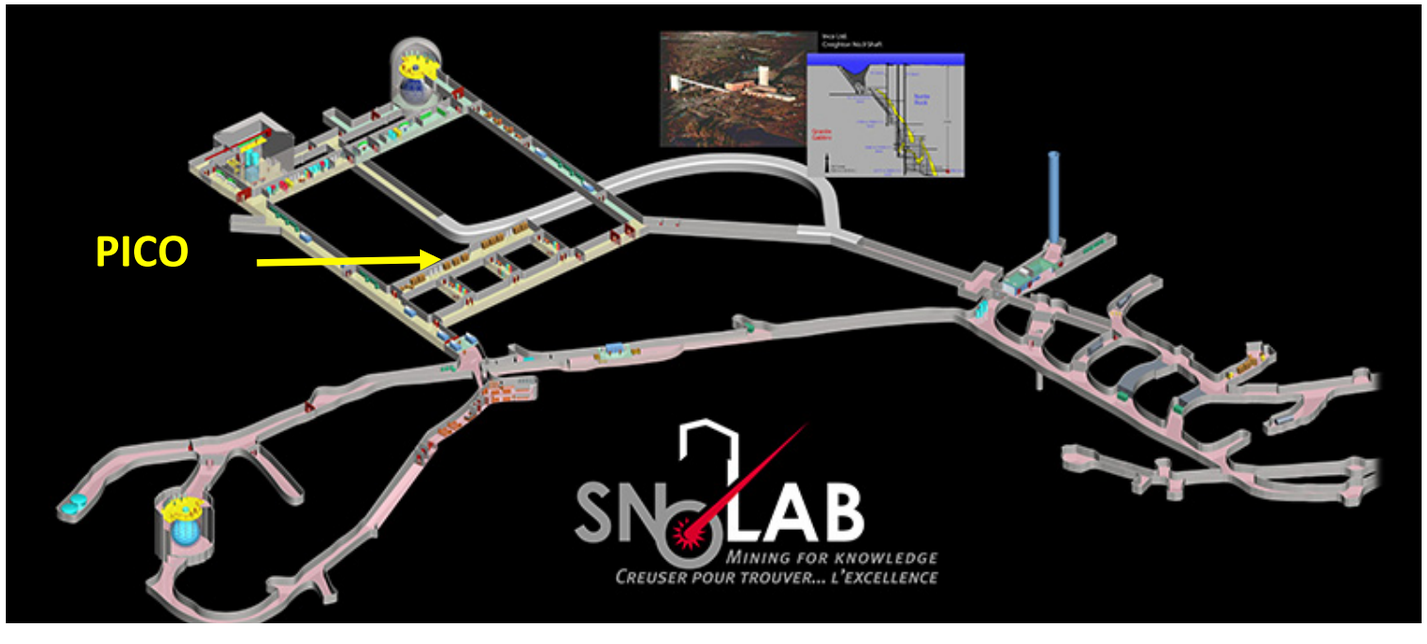
- PICO-500 (future)



PICO-2L
C_3F_8

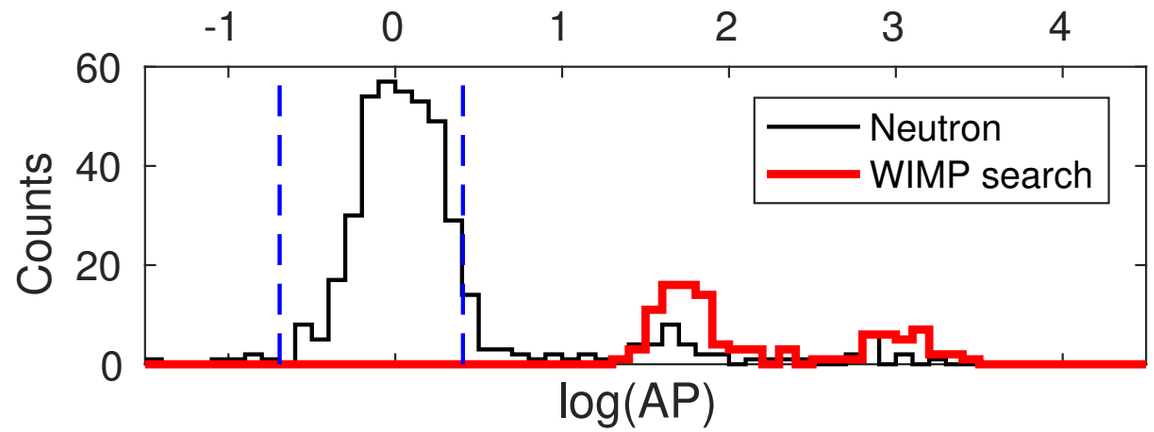


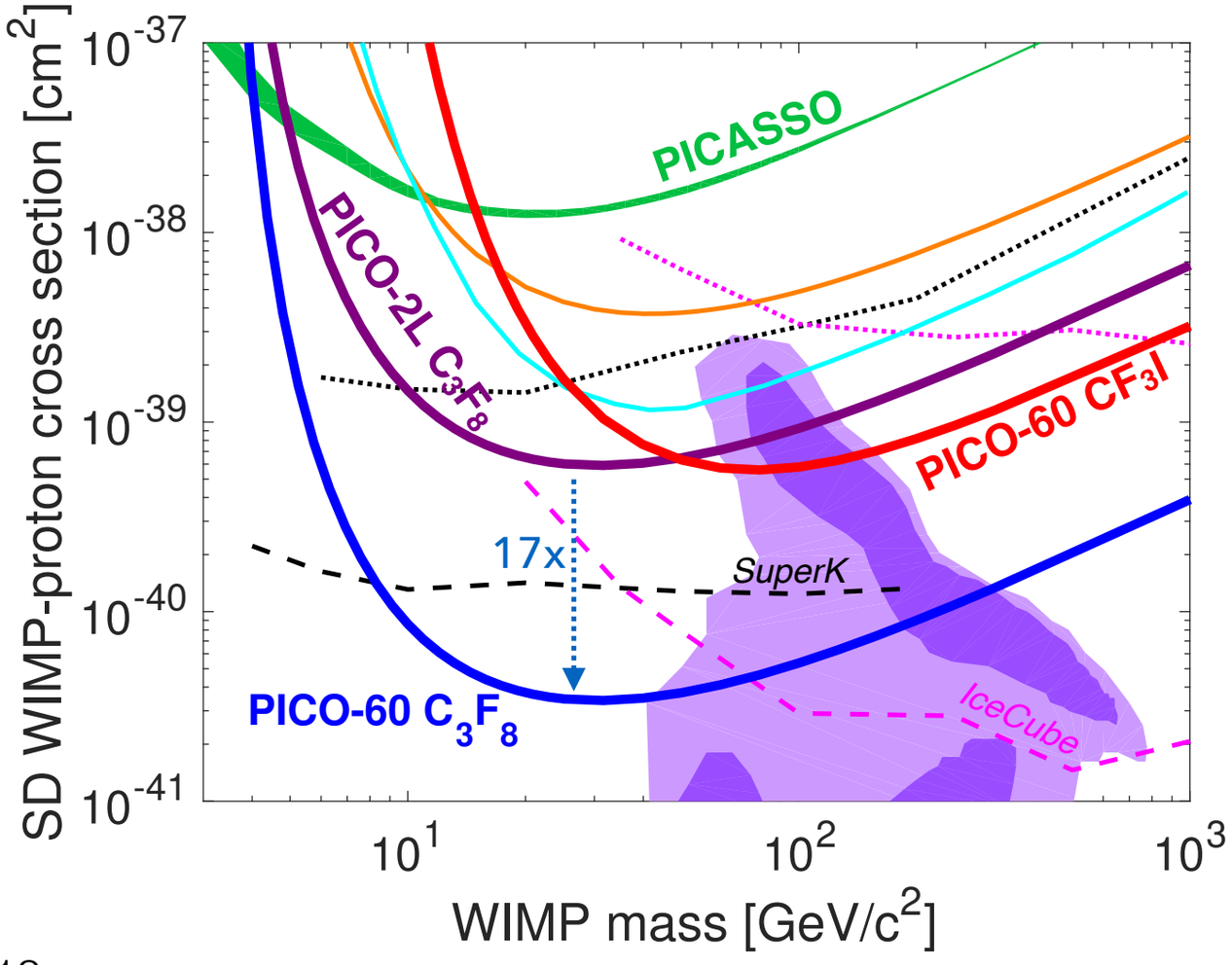
COUPP-60 → **PICO-60**
CF_3I, C_3F_8



First PICO-60 physics run

- See plenary talk Tuesday 9:50am (C. Krauss) for details
- **30 live-day run at 3.3 keV** threshold, published in PRL*: a *background-free* **1167 kg-day** WIMP-search exposure
- **Factor of 17** improvement in upper limit on spin-dependent WIMP-proton cross-section
- Additional blinded exposure acquired, expected to be **background limited**



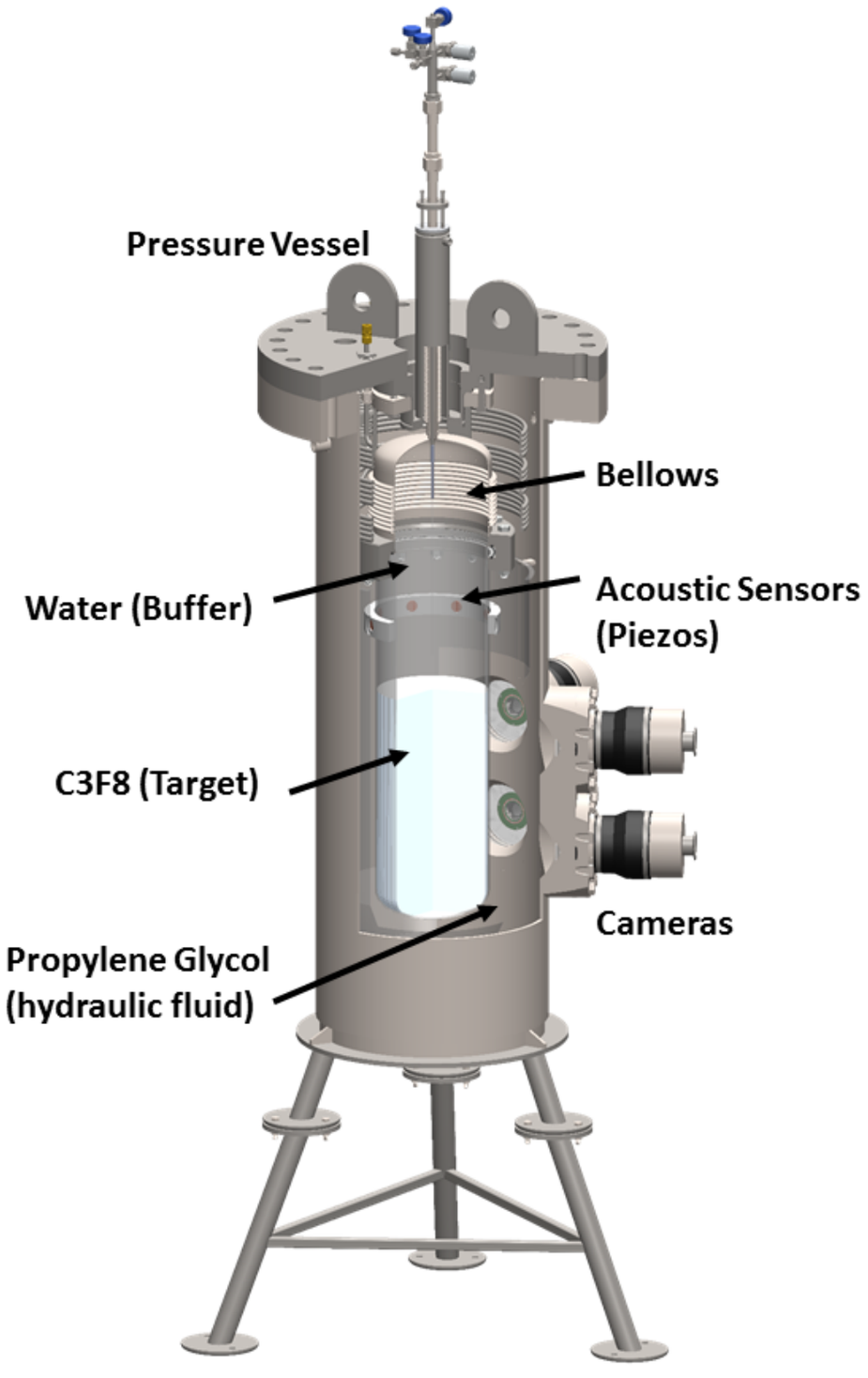


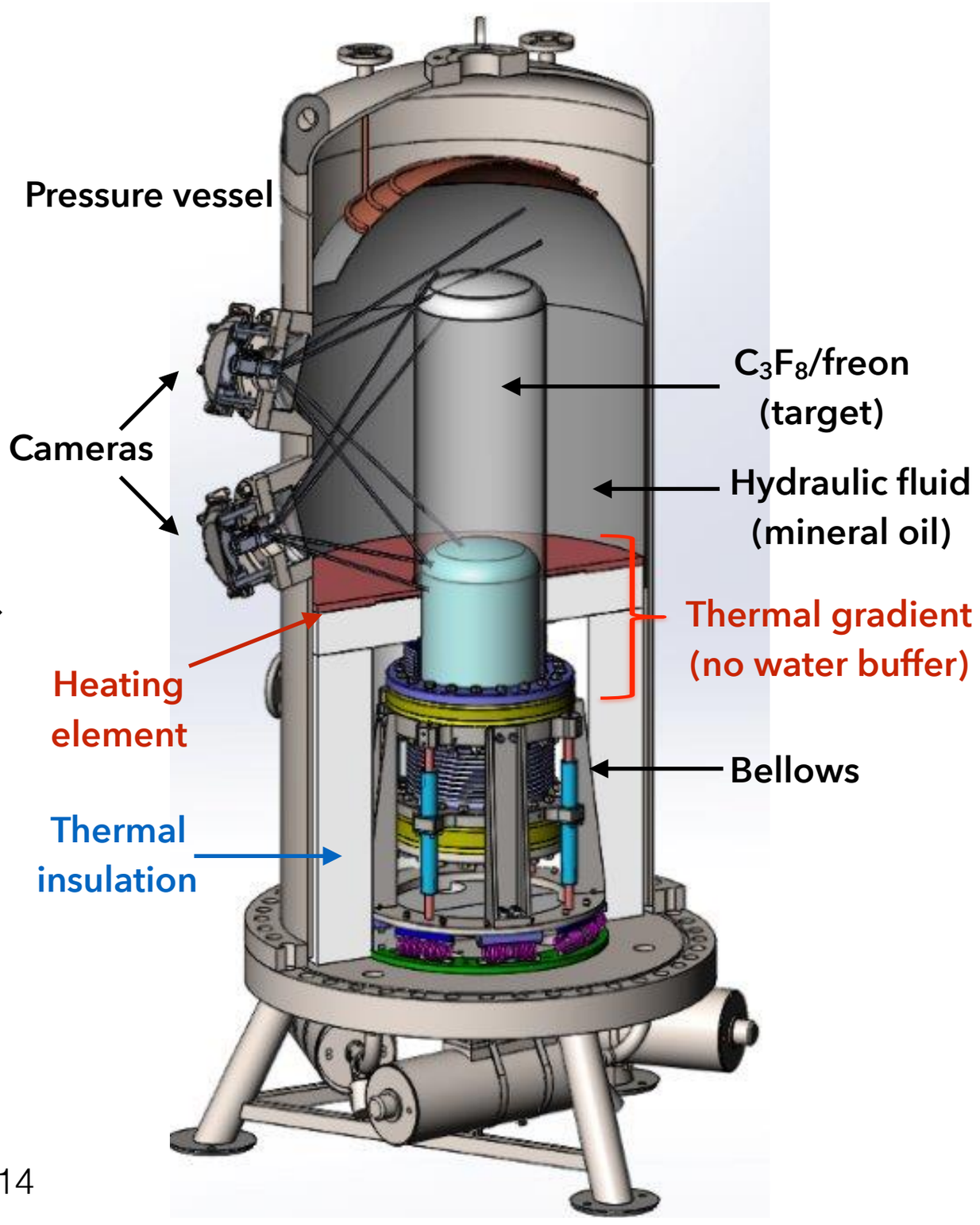
*C. Amole *et al.*, Phys. Rev. Lett. **118**, 251301 **(2017)**

PICO-40L Goals

- **Science:** acquire one-year background-free exposure
  - Order of magnitude improvement on PICO-60 limits
- **Engineering:** demonstrate background reduction and technology improvements for PICO-500
  - Focus on (neutron) background reduction
  - Confirm “RSU” design used in prototype chambers

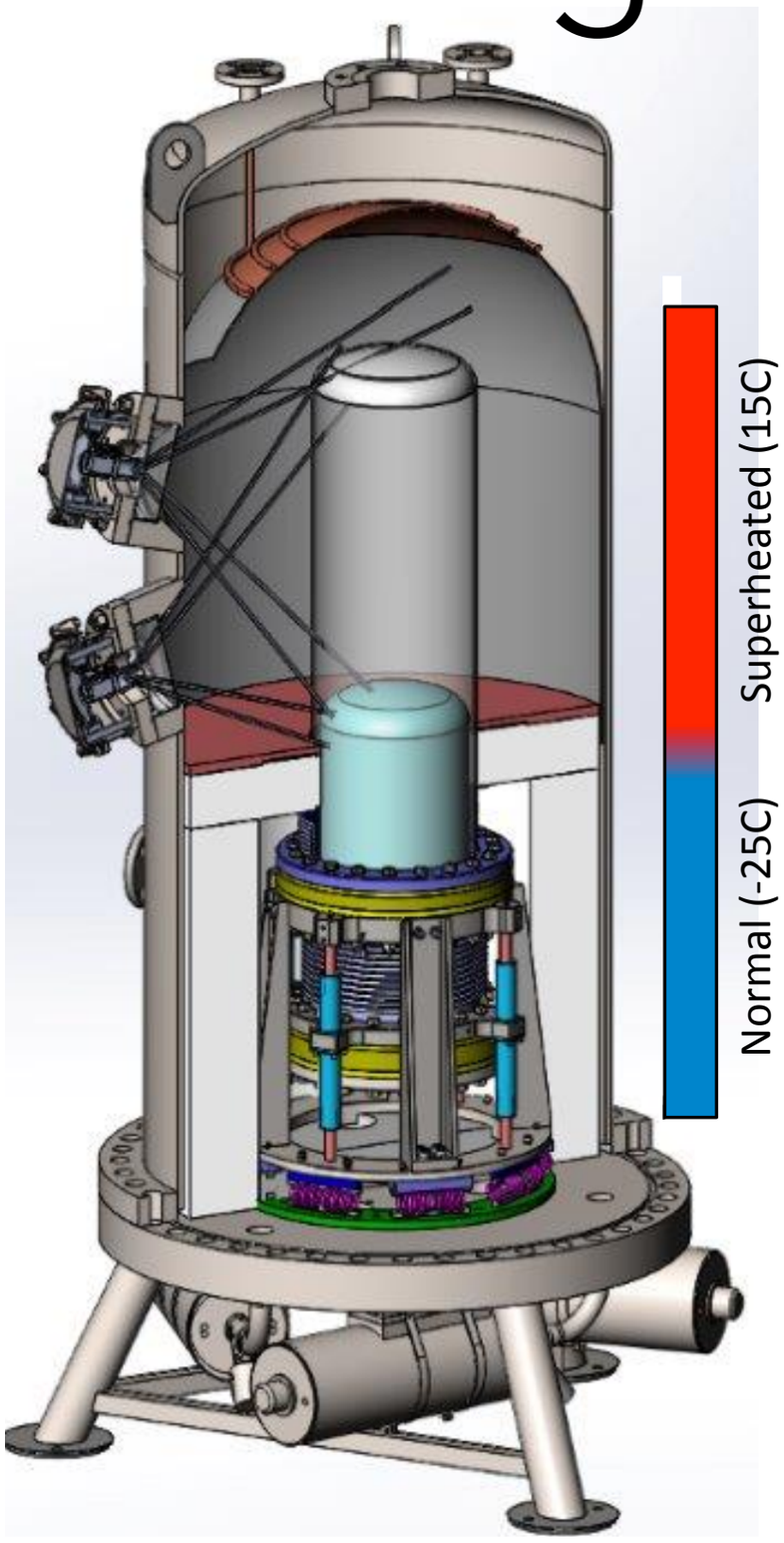
PICO-60 → PICO-40L





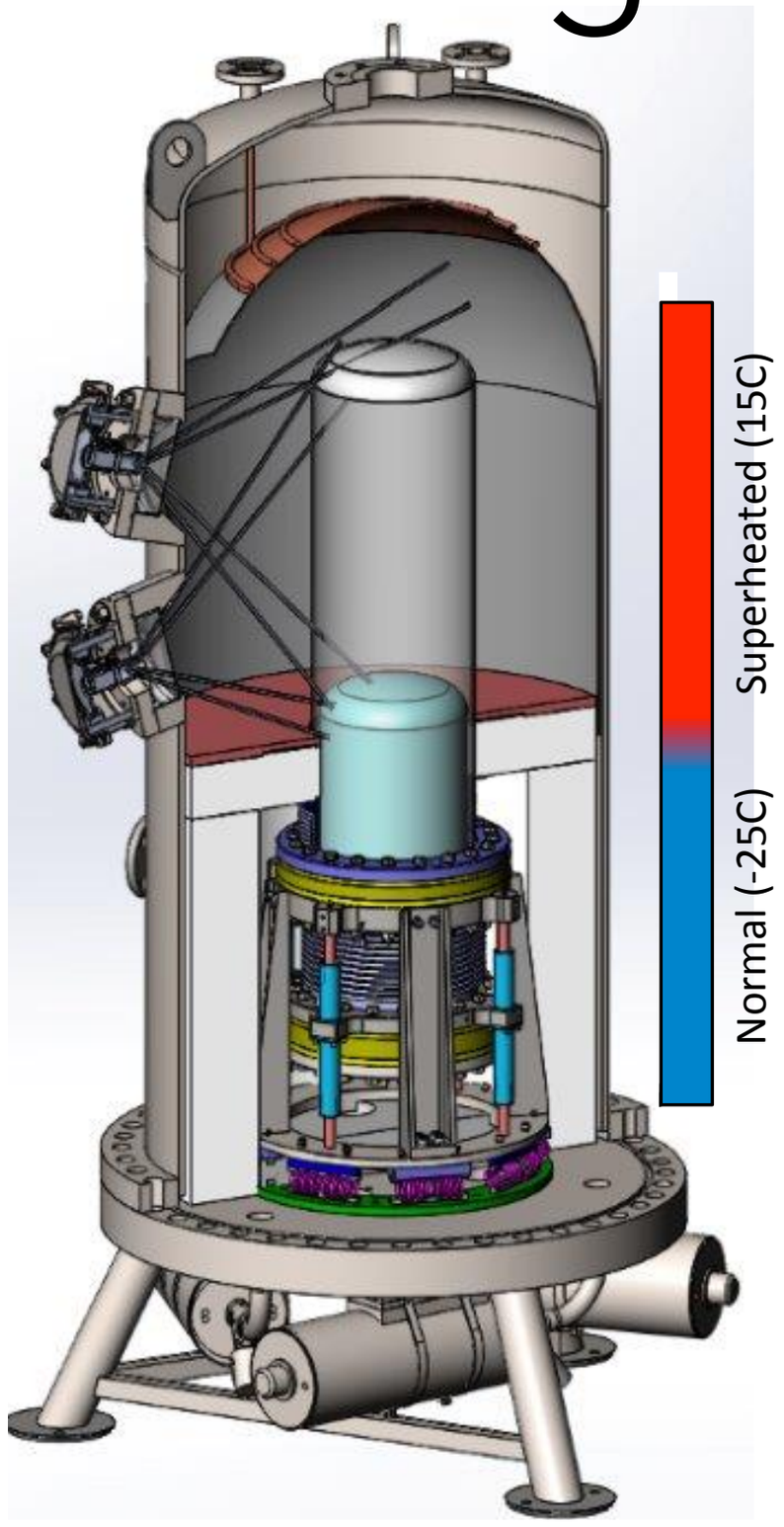
PICO-40L detector design

- To be deployed 2 km underground at SNOLAB (“ladder labs” area)
- Target: ~40L C_3F_8, (proj. >90% fiducial)
- Synthetic fused silica inner vessel and piston (no more “water piston”)
- **Larger** stainless steel pressure vessel, 20t water tank, muon veto – all minimize neutron backgrounds



PICO-40L detector design

- Inversion eliminates potential sources of background:
  - water droplets
  - surface tension effects
  - particulates – would now fall out of active region into cold annulus
- No buffer: allows wider choice of target fluid, wider range of operating temperatures; directly enables full target recirculation and purification



Many upgraded systems

- Optics/DAQ: much better Basler cameras using new Sony IMX174 CMOS sensor
  - running on newer USB3 Vision interface for more programming flexibility
  - better lenses (higher resolution, reduced barrel distortion, etc.)
  - better stereoscopic viewing angles and camera mounts
  - better retroreflector and improved LED lighting rings

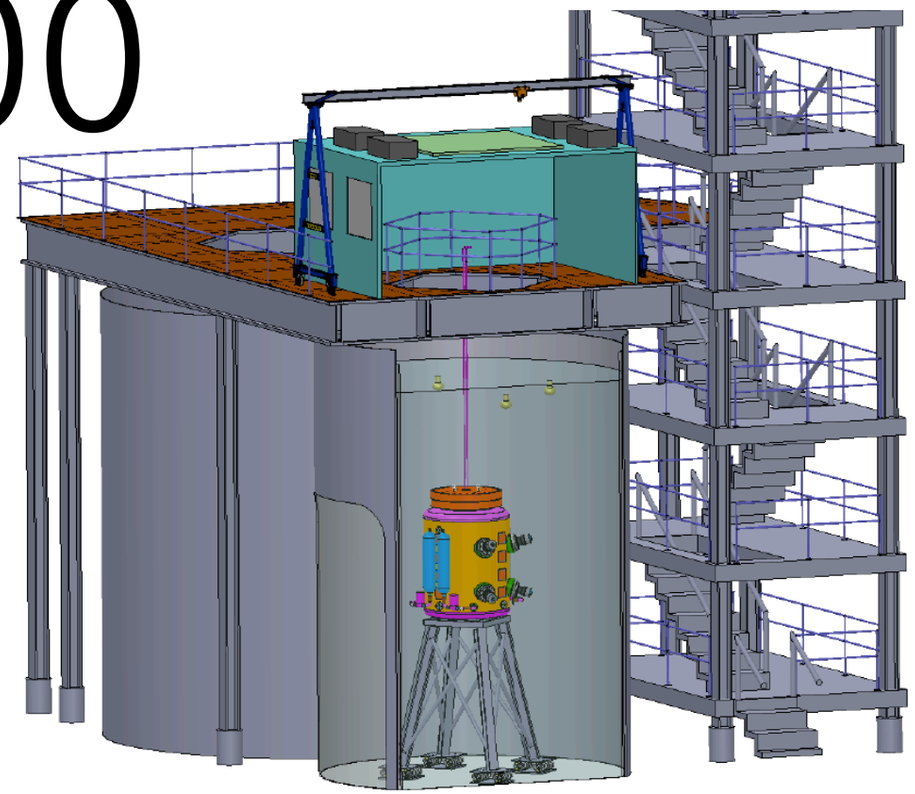
Basler CMOS camera with new IMX714 sensor

- Hydraulic system control: brought into alignment with new designs used on several test chambers; will enable continuous active recirculation/filtration
- Piezo acoustic sensors: better physical coupling, and improved longevity in different hydraulic fluid (mineral oil rather than propylene glycol)

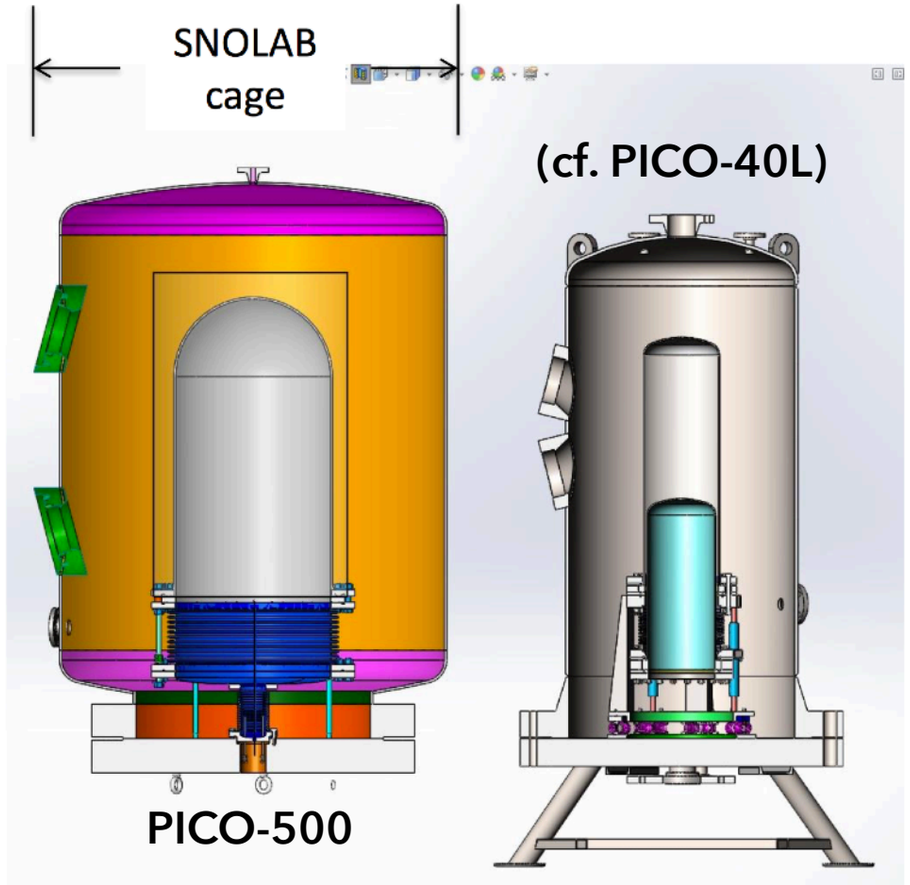
PICO-40L timeline

- Pressure vessel arrived to SNOLAB surface 18 May 2017
- Clean surface commissioning ongoing presently
- Full detector assembly to be shipped underground to SNOLAB Dec 2017
- First data January 2018
- End of physics data in 2019

PICO-500

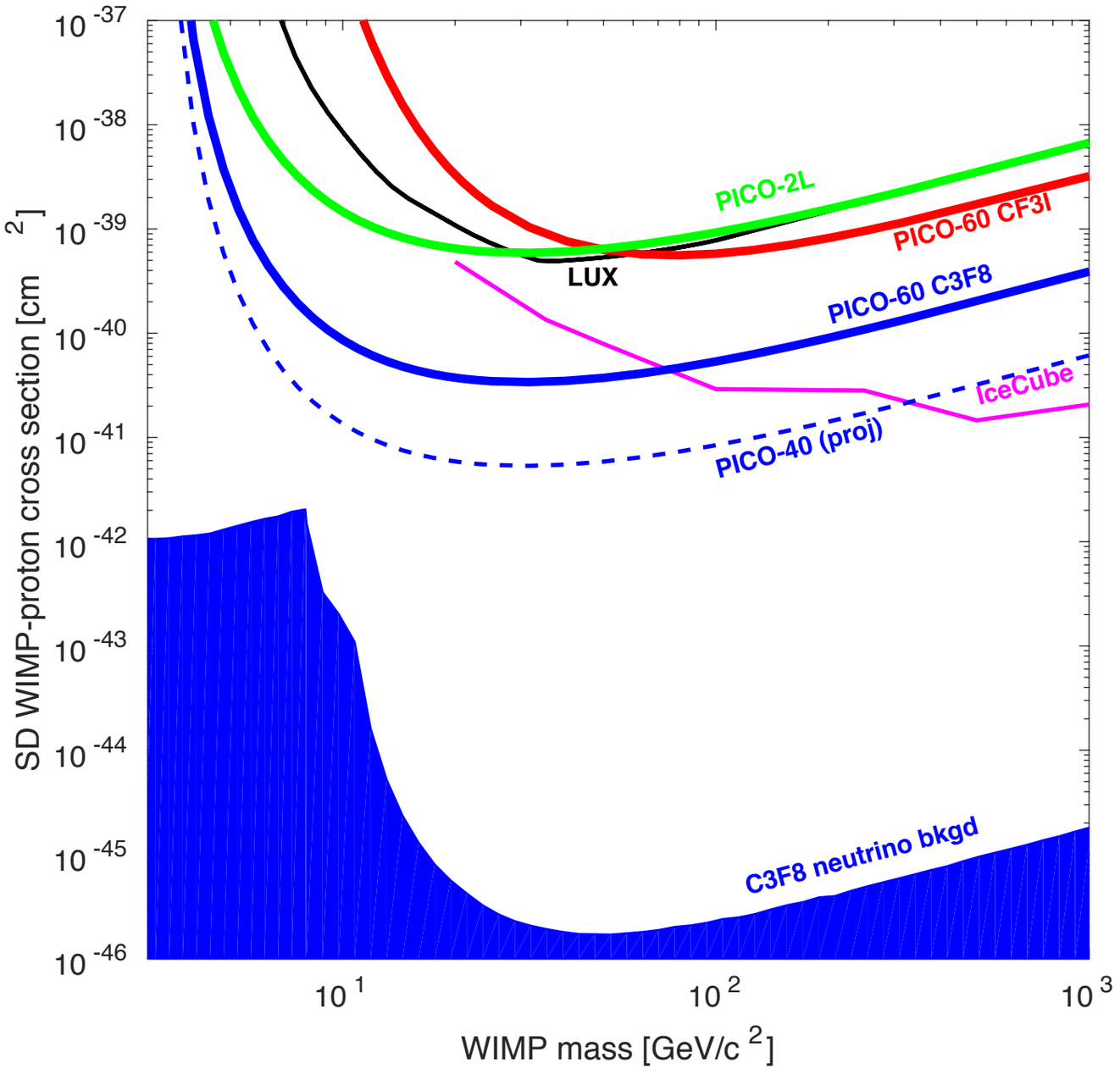


- Proposed tonne-scale detector
- See talk Tuesday 4:30pm (E. Vázquez Jáuregui) for details
- Could begin surface commissioning as soon as late 2018
- Goal is to begin data-taking in 2019



PICO-500

- Designed to have an additional order of magnitude sensitivity beyond PICO-40L
- Could run C_3F_8 and/or several other targets (i.e. CF_3I or hydrocarbons: $C_2H_2F_4$, etc.) to probe higher/lower mass or reduce a WIMP signal in a predictable way



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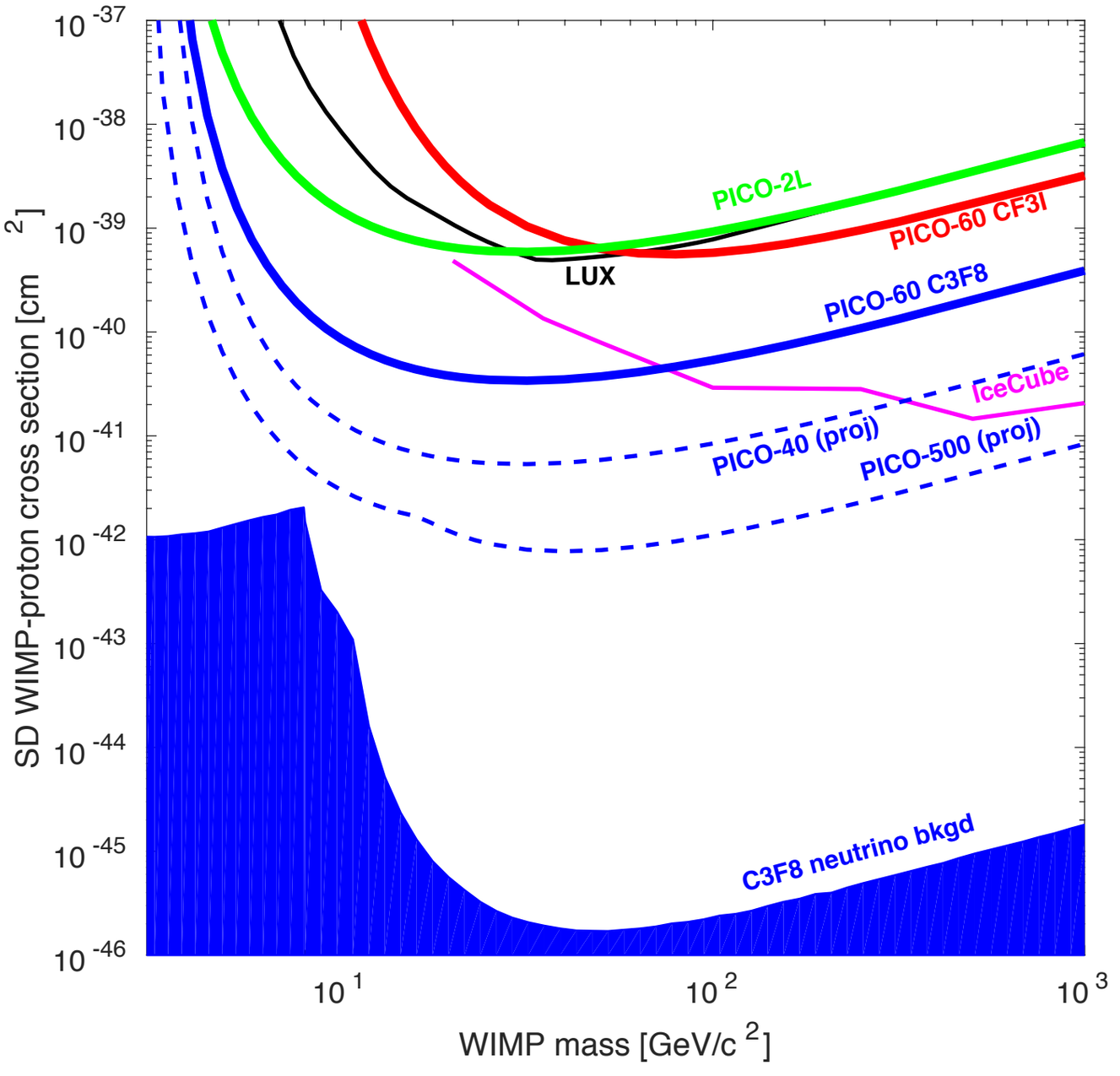


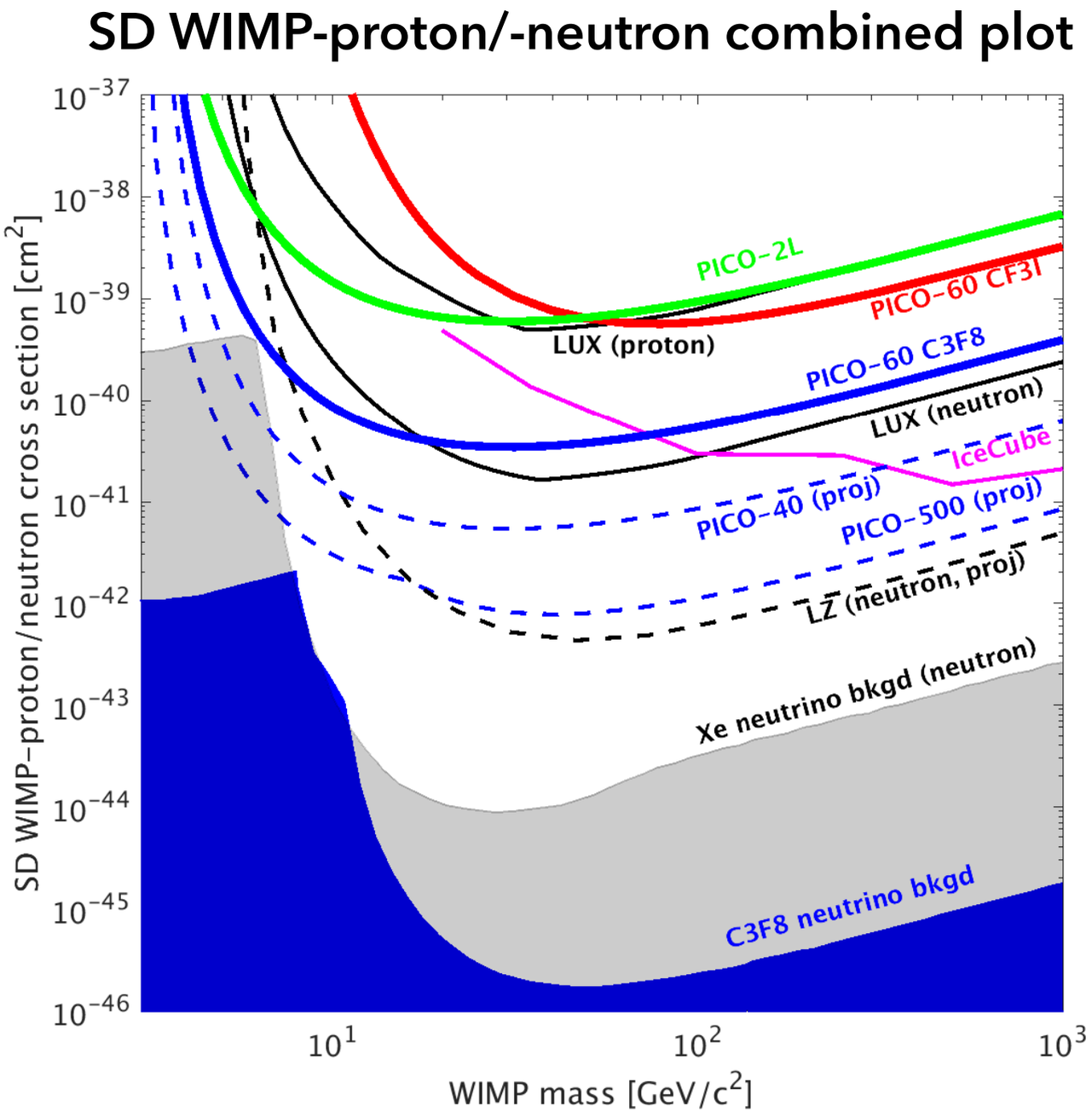
Summary and outlook

- PICO-40L commissioning now, data early 2018
  - Demonstrate background reduction advances enabling tonne-scale bubble chamber PICO-500
    - One year background-free running to produce order of magnitude improvement on PICO-60 result
- PICO-500 could begin data taking as early as 2019
  - Sensitivity to additional order of magnitude beyond PICO-40L, covering significant new well motivated parameter space
  - Could check itself/signals from other detectors with a target change

Extra slides

PICO-500

- Designed to have an additional order of magnitude sensitivity beyond PICO-40L
- Could run C_3F_8 and/or several other targets (i.e. CF_3I or hydrocarbons: $C_2H_2F_4$, etc.) to probe higher/lower mass or reduce a WIMP signal in a predictable way



PICO-500 projection assumptions

- 250L fiducial
- 6 live-months at 3.2 keV (expect 6 solar neutrinos/yr), and 12 live-months at 10 keV (0.15 solar neutrinos/yr)
- Neutron backgrounds:
  - alpha-n: 0.1 singles/yr
  - muon-induced rock: 0.65 singles/yr in a large enough tank
  - muon-induced on detector material assumed veto-able