WIMP Search at Low Energy Threshold with PICO-60 C_3F_8

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CAP Congress – Queen's University

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PICO

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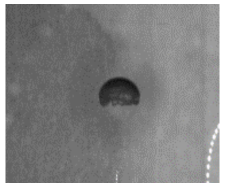
Overview

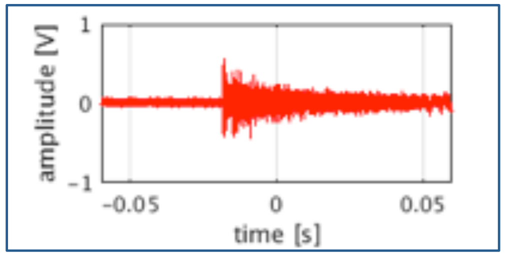
- The PICO-60 C_3F_8 detector
- Results from first physics run (28 Nov 2016 – 13 Jan 2017) accepted for publication in Phys. Rev. Lett. (arXiv:1702.07666)
- Energy threshold constraints and gamma background
- Second physics run, with lowered energy threshold
- Potential physics reach; impact on future chambers

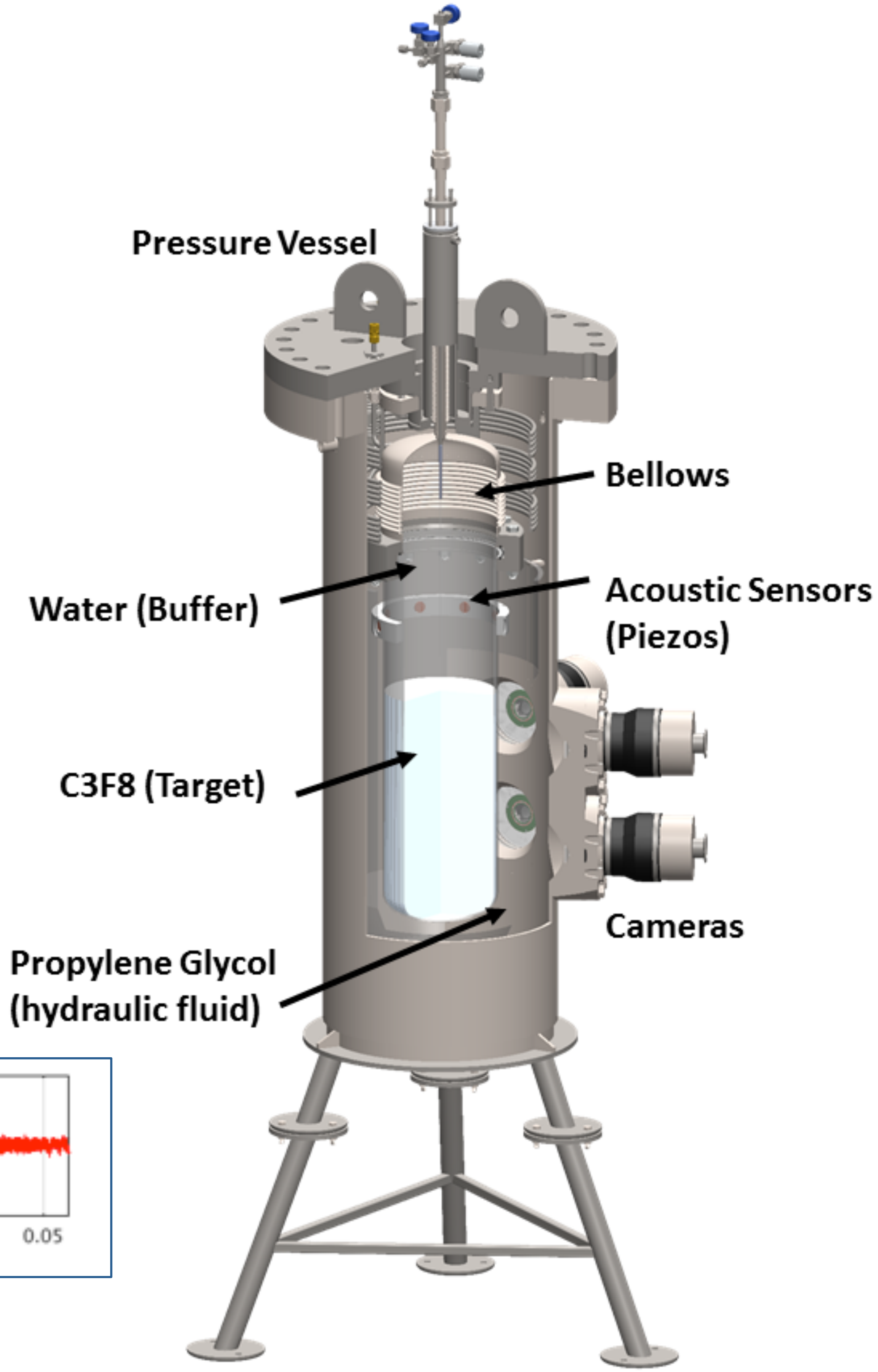
The PICO-60 detector

- Deployed 2 km underground at SNOLAB
- C_3F_8 target: 52 kg total
  (45.7 ± 0.5 kg fiducial, 87.7%)
- Synthetic fused silica inner vessel, stainless steel pressure vessel, water tank, muon veto
- Bellows allow expansion to superheated state with typical per-event cycle of 800s, >80% live-fraction
- Four cameras monitor for bubble nucleation using LED illumination



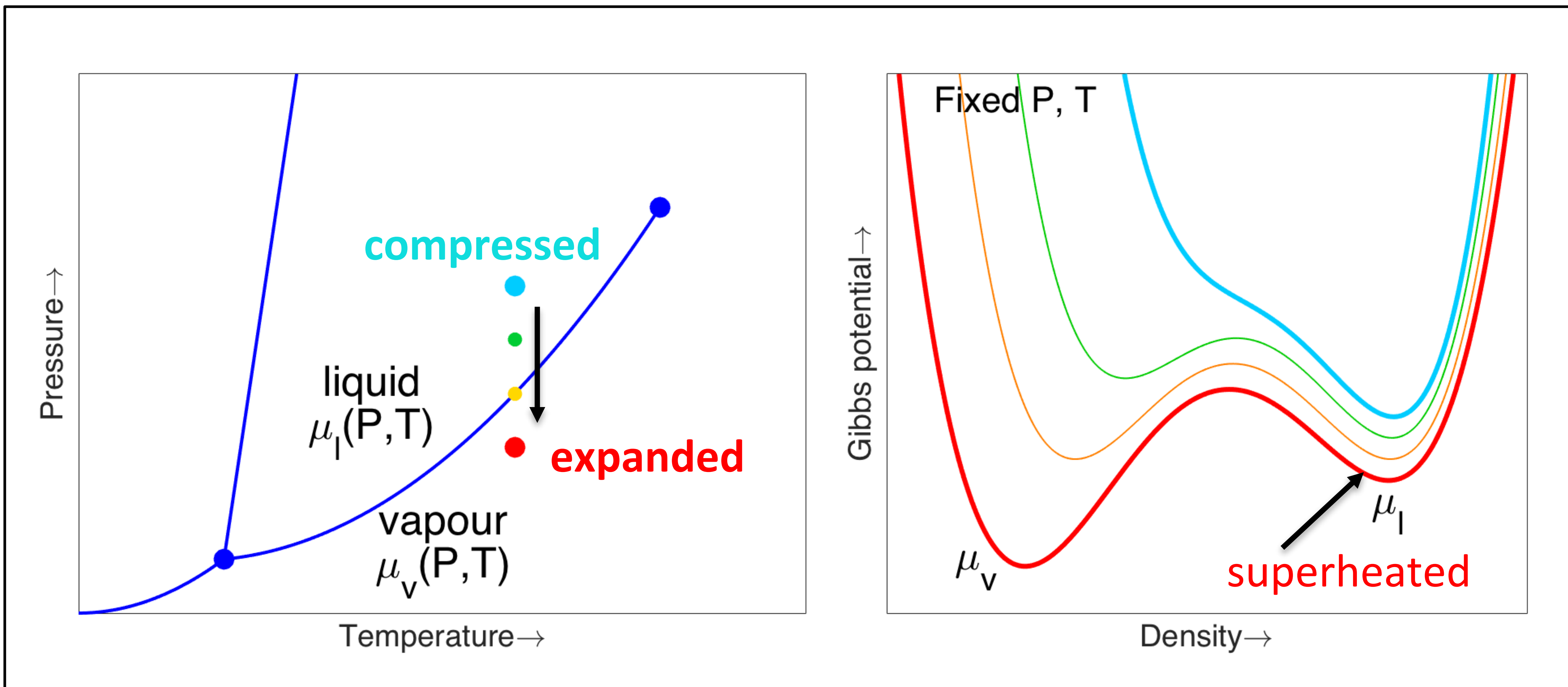
- Eight piezoelectric acoustic sensors monitor sound of bubble nucleation





Target: superheated liquid

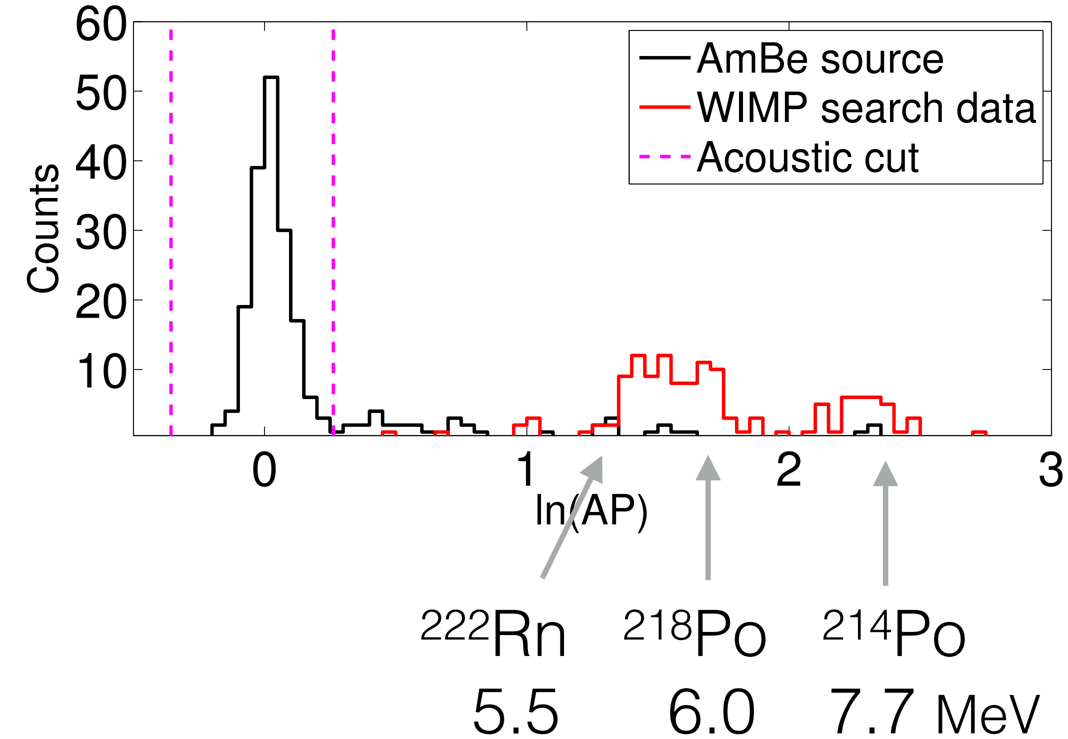
Lower pressure in the target liquid until it is in metastable superheated state
Energy deposition nucleates small bubble that grows to visible size
Cameras watch for visible bubble and issue the primary trigger



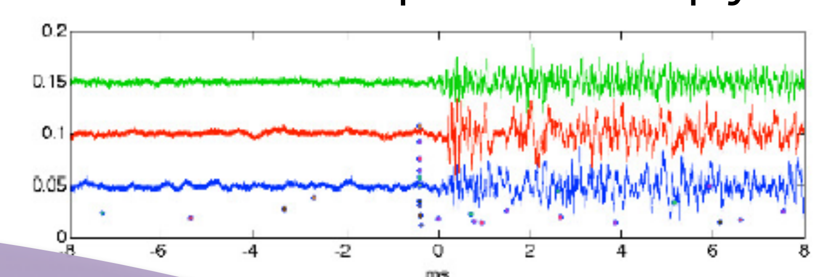
(plots by Eric Dahl)

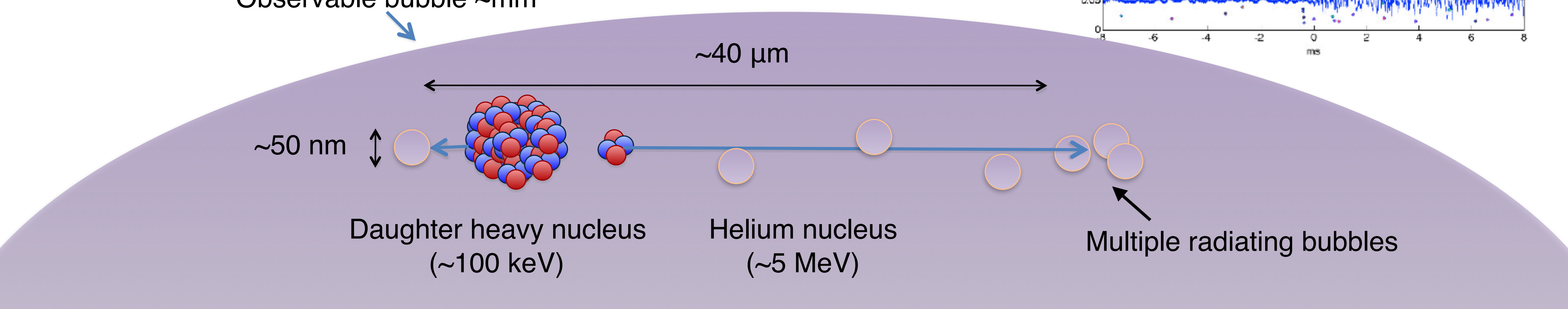
Acoustic discrimination

- 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”)



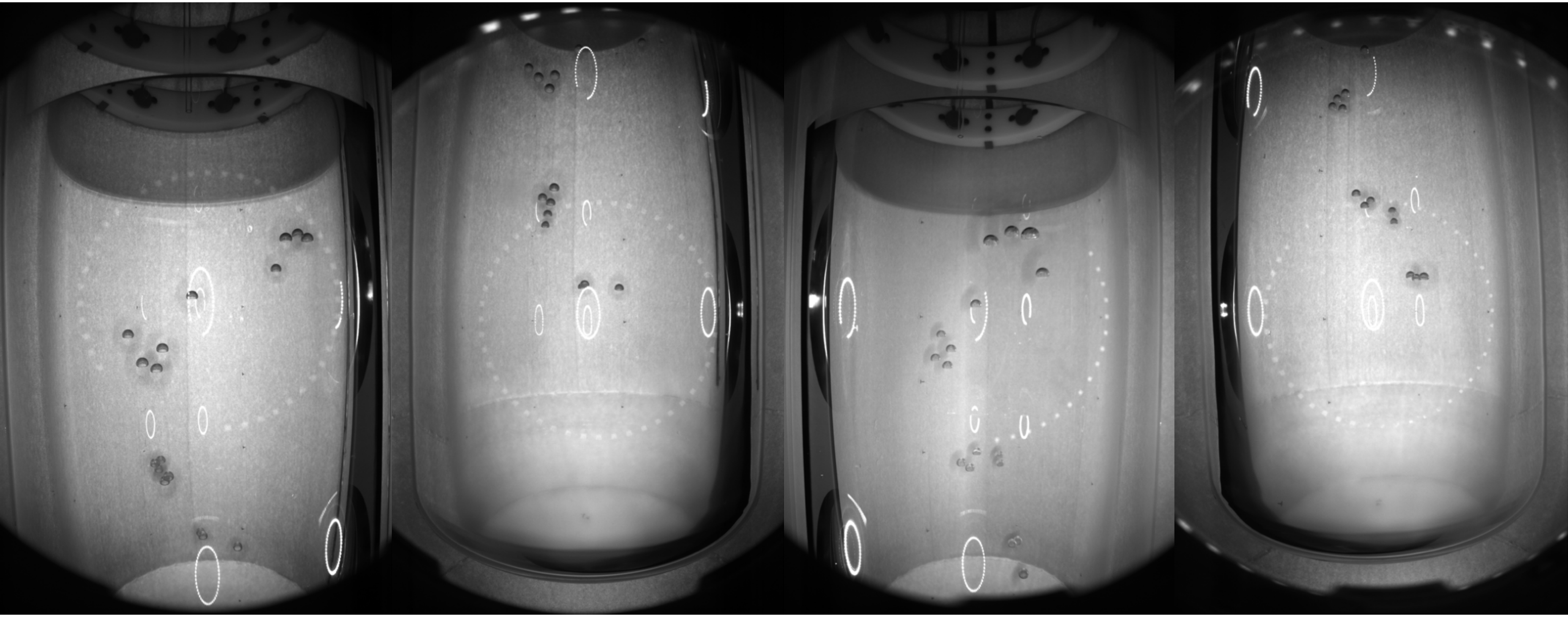
“acoustic spectroscopy”





Additional data stream: optics

Multiply-scattering neutrons won’t be mistaken for WIMPs either (3:1)



Four views of a neutron event from an AmBe source

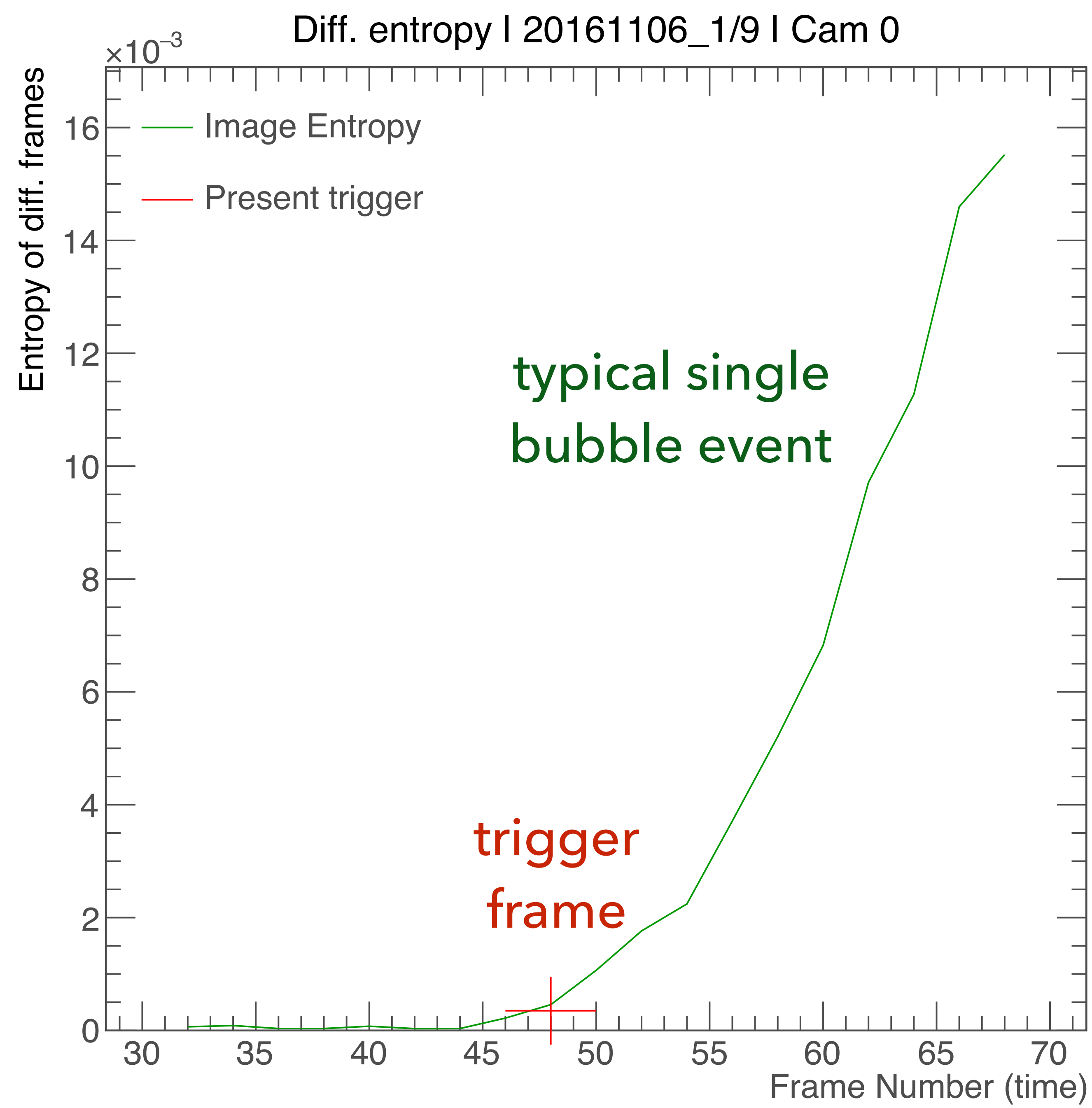
Fast camera trigger

- Primary trigger: “image entropy”

$$S_I = -\sum_i P_i \log_2 P_i$$

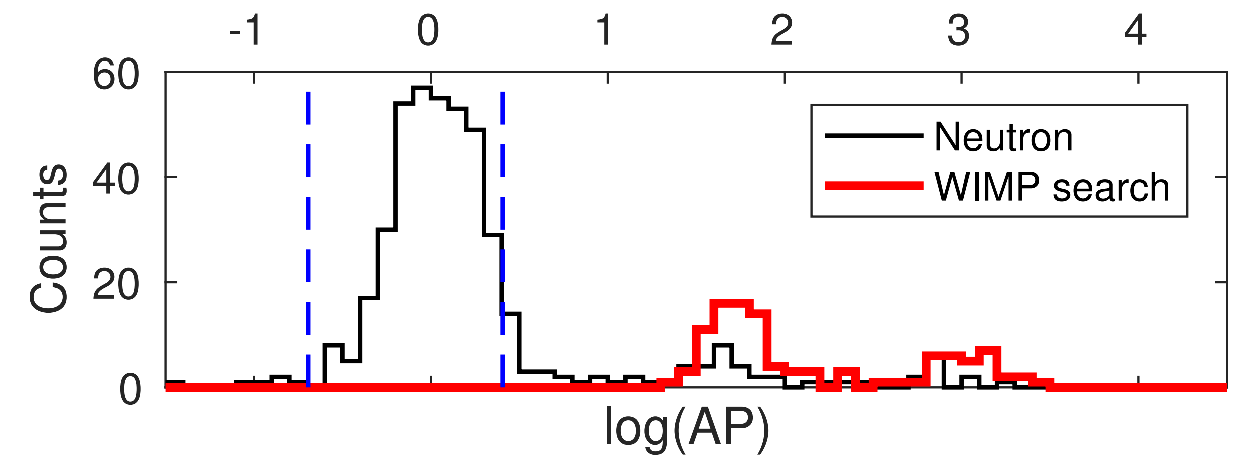
- Calculate absolute difference of successive frames, searching for changes in information content

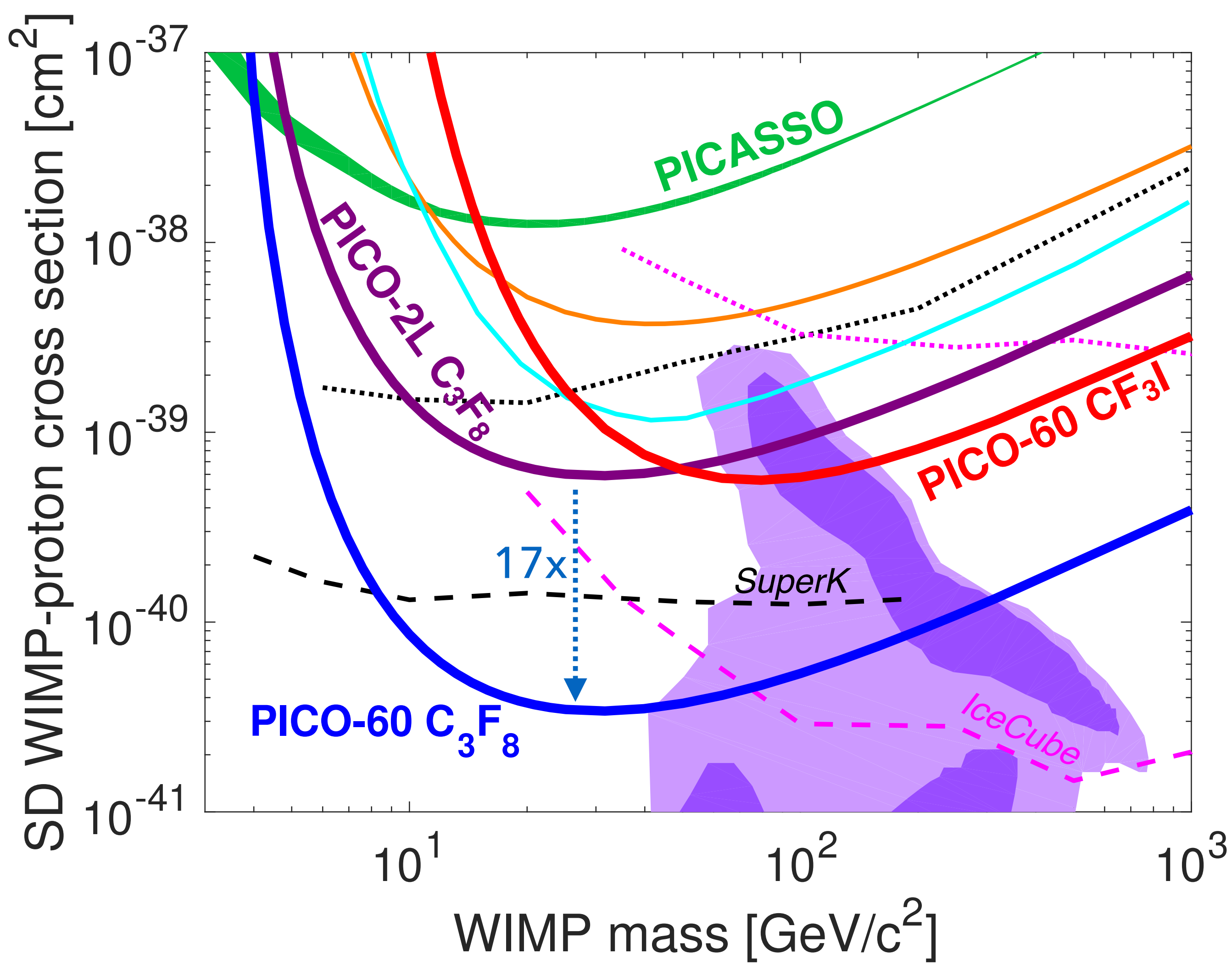
- Images initially acquired at 200 Hz – increased to hardware maximum 340 Hz for low threshold run – fast trigger ensures stable operations at very low pressures



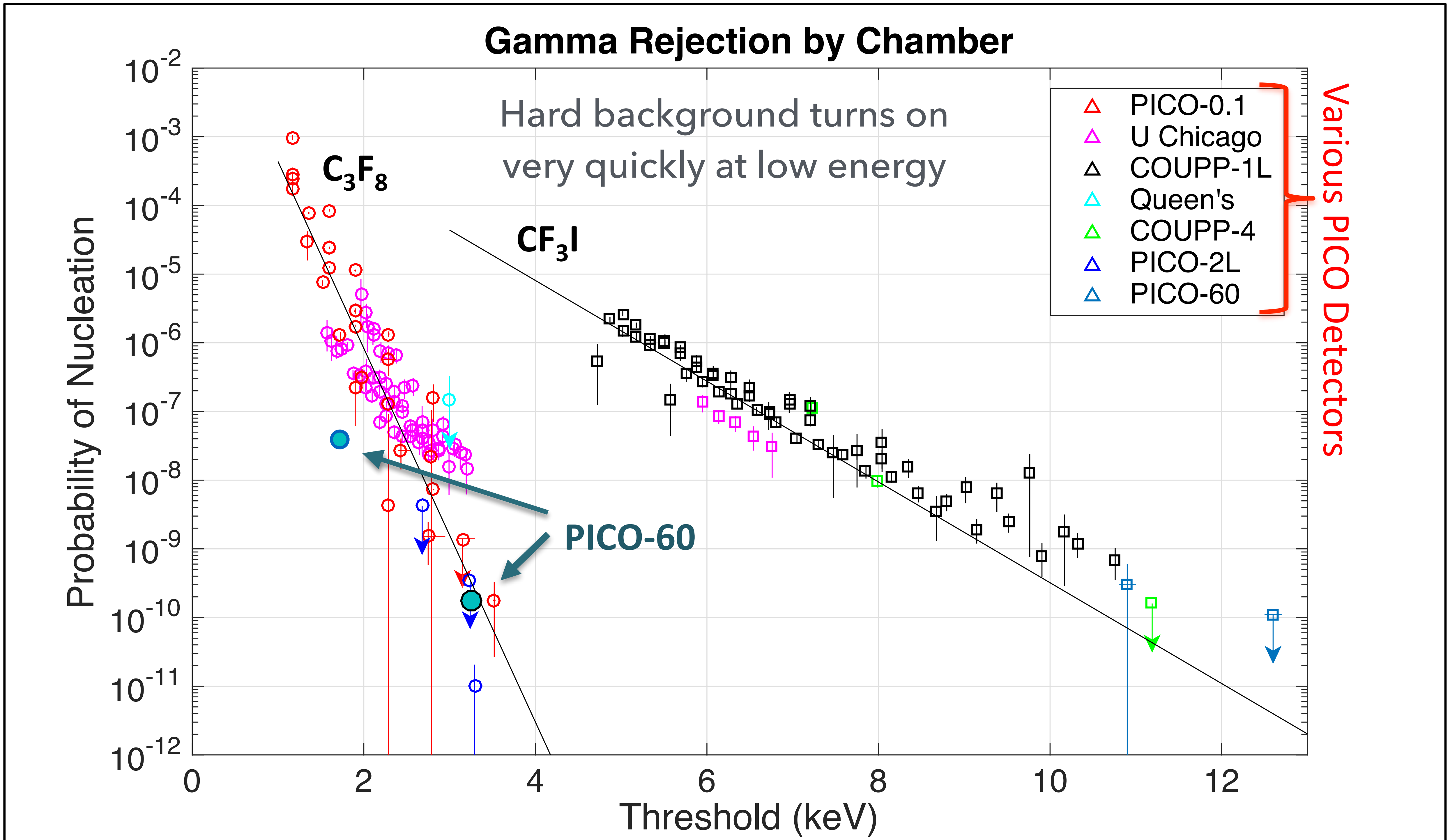
First physics run

- **30 live-day run at 3.3 keV** threshold, accepted for pub. in PRL: a *background-free* **1167 kg-day** WIMP-search exposure
- **Factor of 17** improvement in upper limit on spin-dep. WIMP-proton cross-section
- See session R3-3 (Thurs. 14:00), talk by G. Giroux, for details
- Can we probe lower masses?





Gamma rejection

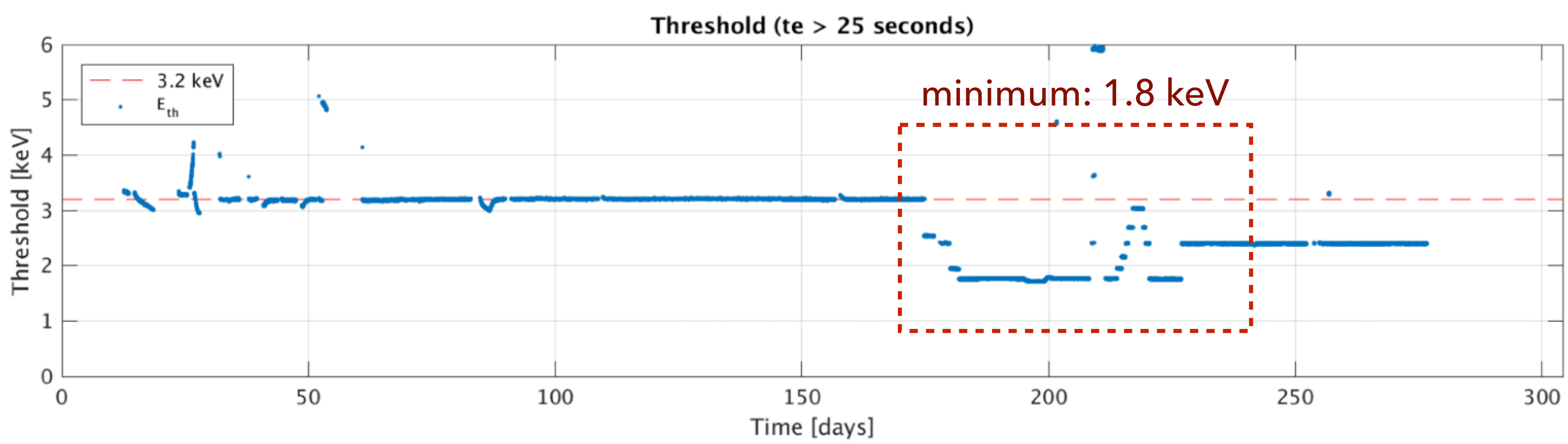


(Dan Baxter, Conference on Science at SURF, May 14, 2017)

Decreasing pressure scan

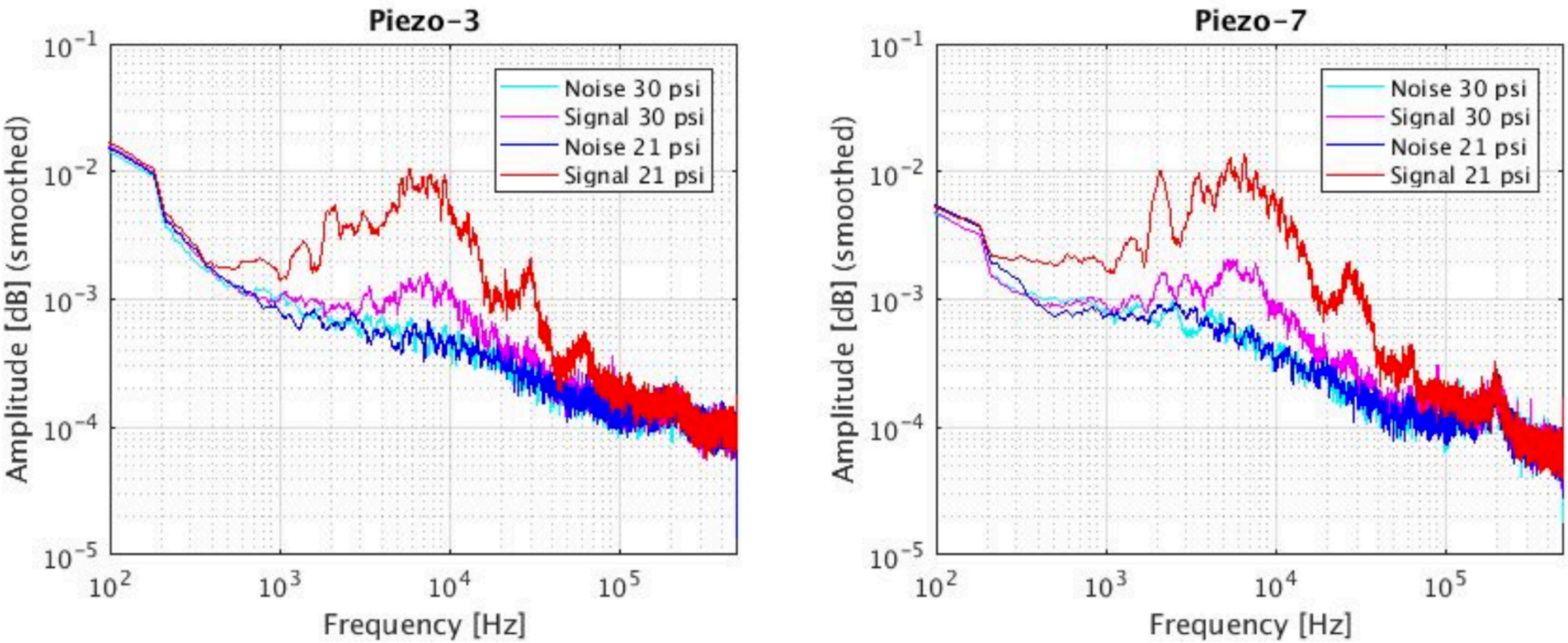
- Following the blind physics run at 3.3 keV (14°C, 30 psi), raised temperature to 16°C, scanned in pressure (to 21 psi)

- Goals:
  1. Measure background appearance at low threshold
  2. Test detector stability at much lower pressures



Decreasing pressure scan

Incidental benefit: improved acoustic signal-to-noise
→ potential for more powerful discrimination

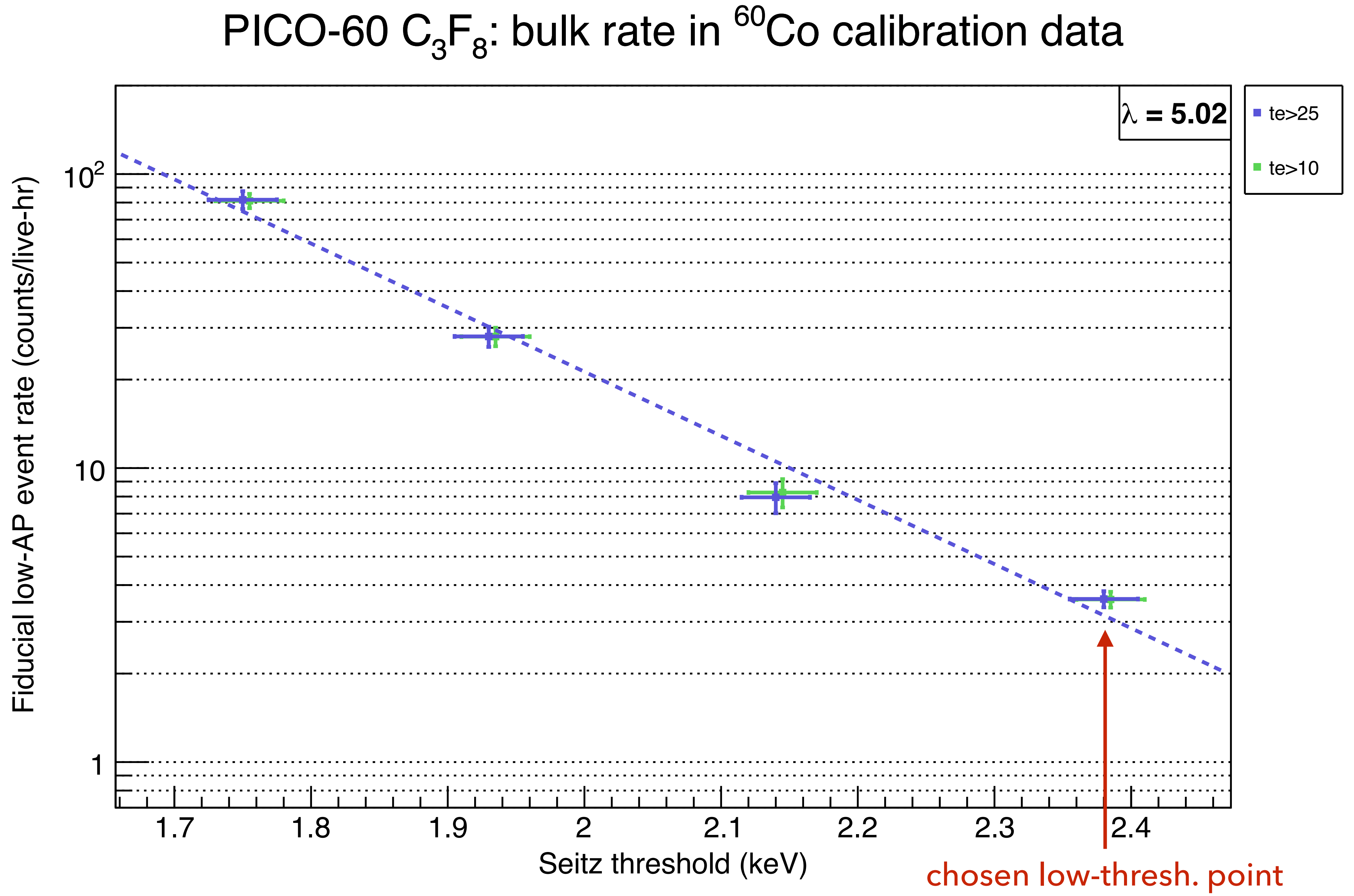


(plots by Guillaume Giroux)

Gamma rejection

- PICO-60 at 3.3 keV exposed to 1 mCi ^{133}Ba source + Geant4 Monte Carlo yields rejection factor: **(1.80 ± 0.38) x 10^{-10}**
- Combining MC with estimate of local gamma flux, expect **0.026** electron recoil events in Run-1 (90% CL upper limit)
- Extrapolating nucleation probability down to 1.8 keV
  expected: 27 gamma events per day
  observed: <5 per day (90% CL) over 7.5 live-days
- Revised estimate suggests physics reach available at thresholds below 3.3 keV

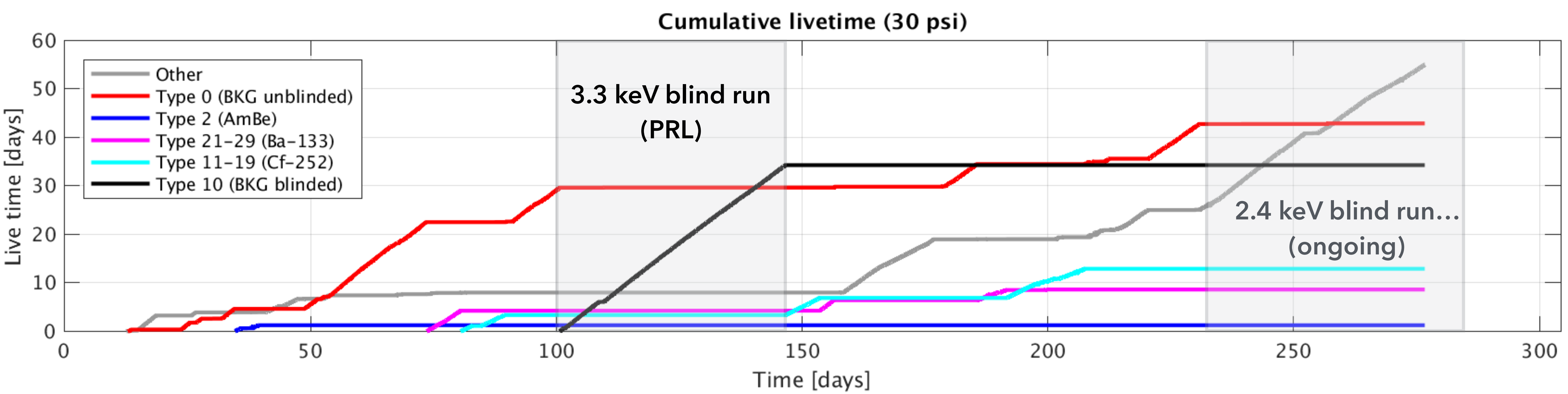
Gamma rejection



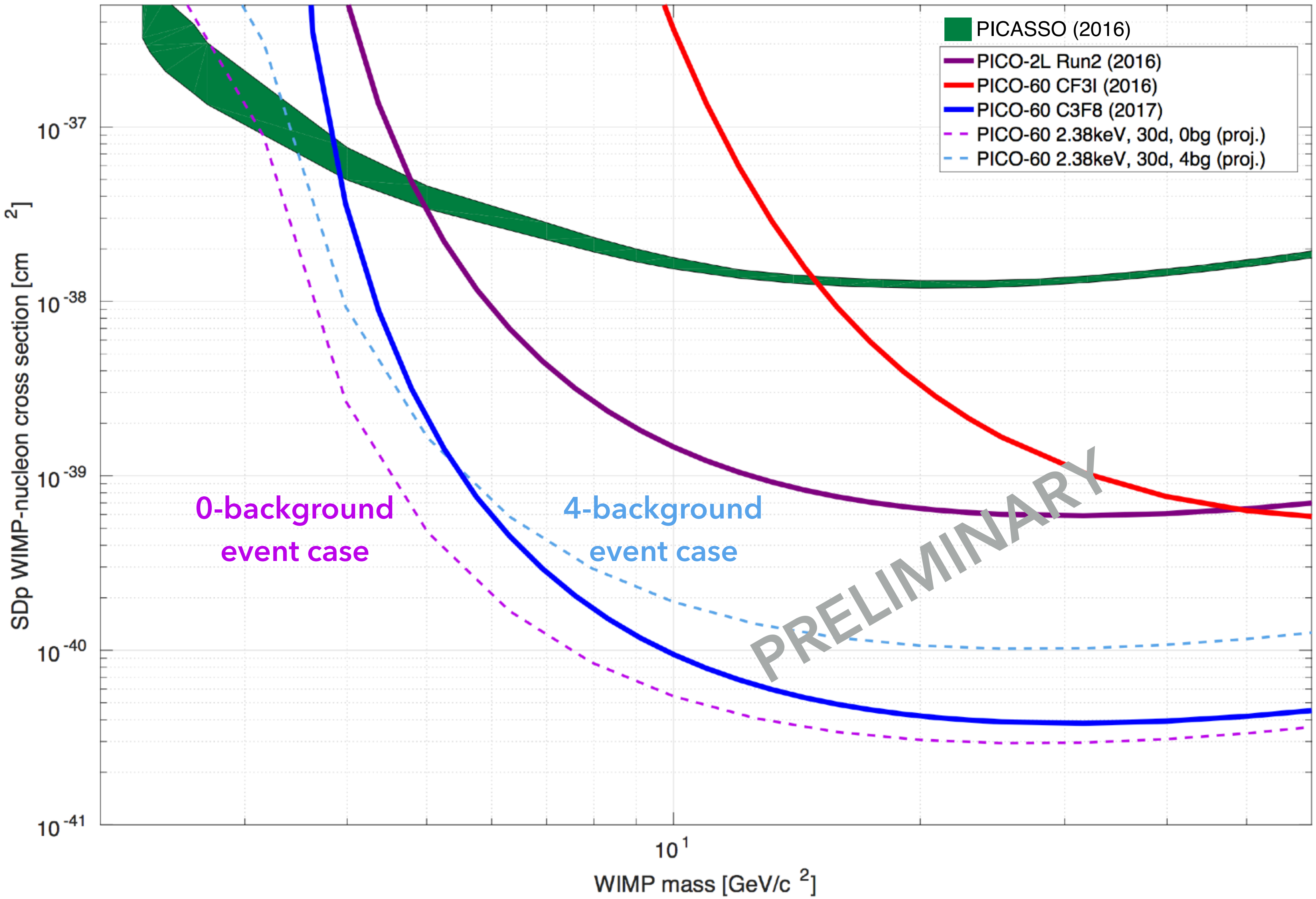
Measured event rates with ^{60}Co gamma source

Low threshold physics run

- Second physics run prompted by observation of far fewer recoil events than expected at lower thresholds
- Decided on a threshold of **2.4 keV**, where backgrounds are projected to produce <5 events over a 30 live-day exposure



Potential reach: spin-dep. p



Ultimate plan: use data at 1.8 keV, 2.4 keV, and 3.3 keV to produce combined limit

Outlook

- Next chamber already on the way: PICO-40L in early commissioning; tonne-scale PICO-500 proposed
- Ability to run stably at much lower pressures, thresholds now demonstrated
- Gamma backgrounds measured to be significantly lower than initially predicted
- Opens up possibility to run background-free at lower energy thresholds with PICO-40L and/or PICO-500, for significantly improved sensitivity to low-mass WIMPs

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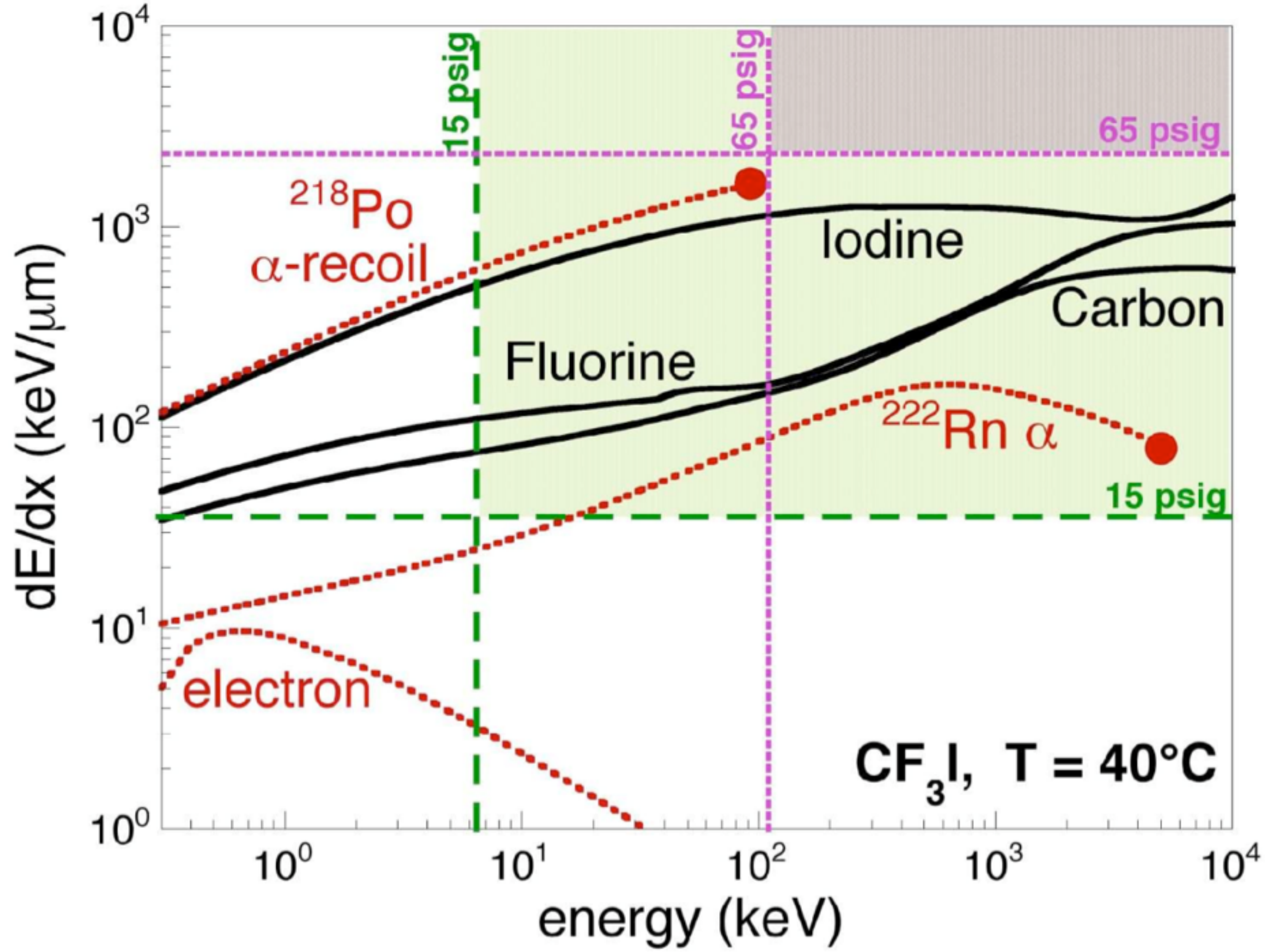
Extra slides

Setting the threshold

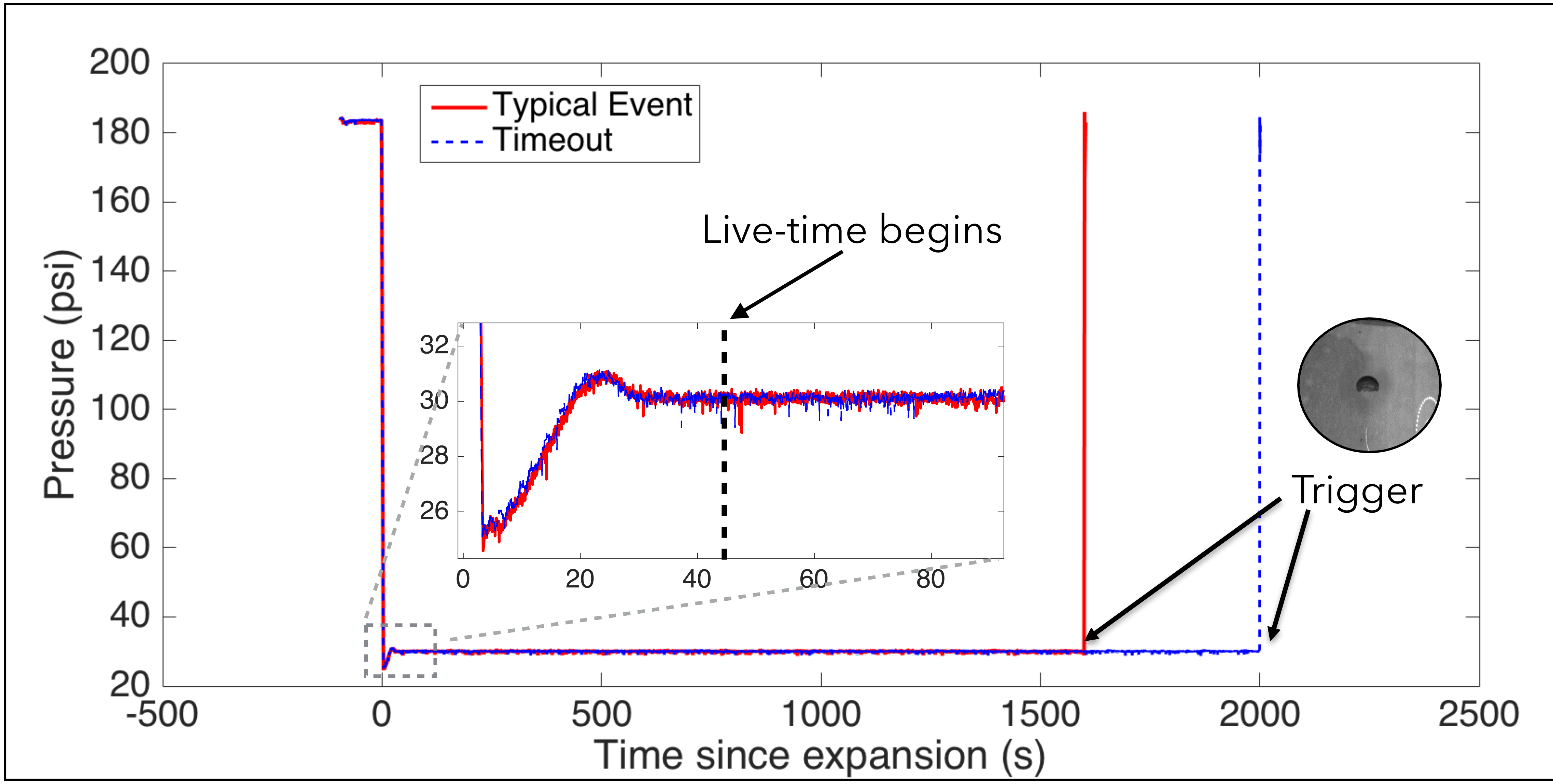


Choose thermodynamic parameters for sensitivity to nuclear recoils, and not electron recoils

Backgrounds: Neutrons

- Single-scatter neutrons are indistinguishable from WIMPs in these detectors
- Can't discriminate against them, so minimize them
- Two neutron sources for PICO-60:
  - **Cosmogenic:** spallation in rock near detector by high energy cosmic ray muons (veto present for C_3F_8 Run-1, saw no muons)
  - **Radiogenic:** natural radioactivity in rock and detector apparatus (alpha-n and spontaneous fission)
- Total neutron background estimate for C_3F_8 Run-1: **0.25 ± 0.09** (0.96 ± 0.34) **single-** (multiple)-bubble events

Event cycle



(plot by Dan Baxter)

Expand to target pressure, begin counting live-time after 25s stability

Primary trigger: changes in image information content (bubble appearance)

Time-out trigger set to 2000s – regular cycling improves detector stability