Acoustic response of nuclear recoils in bubble chambers

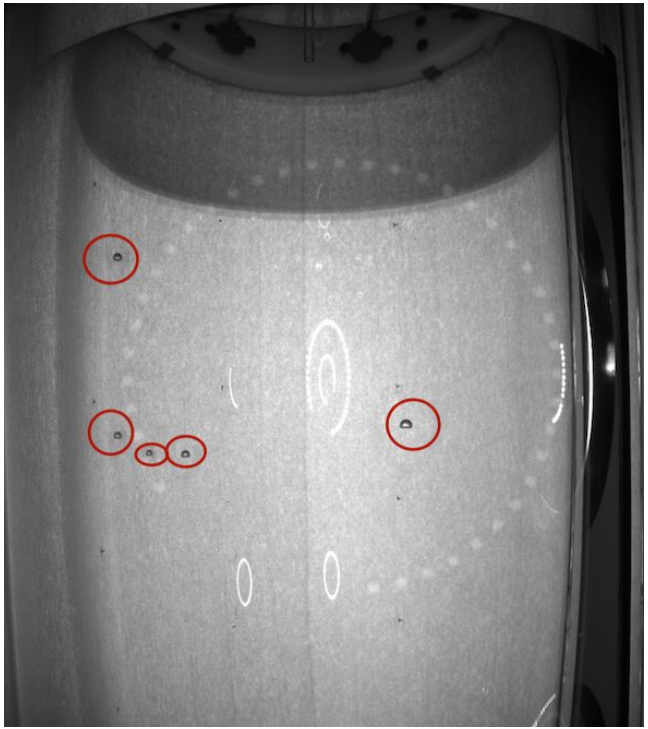
Ben Broerman
TAUP 2021

Outline

- Nucleation and acoustic signal generation
- PICO and Queen's University test chamber
- Acoustic response measurement
- Implications for PICO-500
- Conclusions

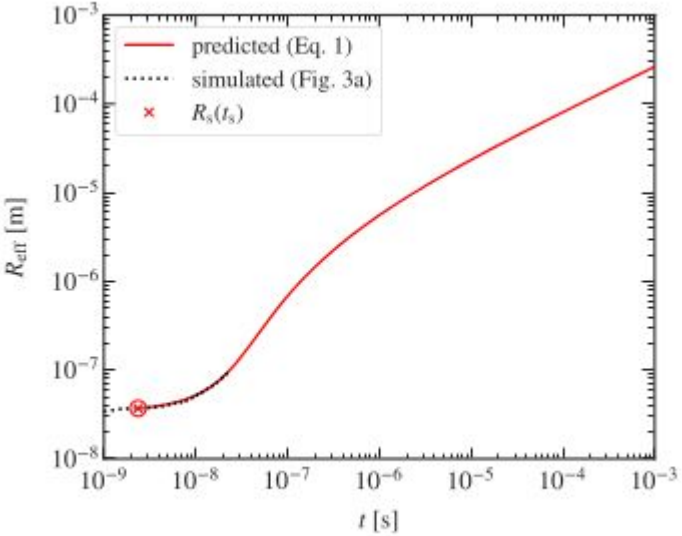
Bubble nucleation

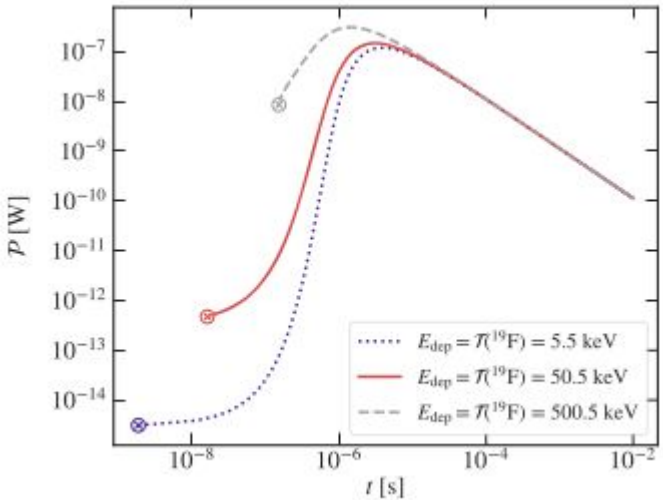
- Bubble chambers maintain target fluid in superheated state
- Ionizing radiation nucleates a bubble if $E_{dep} > E_{th}$ and within critical radius r_c
- E_{th} and r_c for n and $\boldsymbol{\alpha}$ described by Seitz model



Acoustic signal generation

- Emitted acoustic power can be predicted by solving for bubble radius vs. time



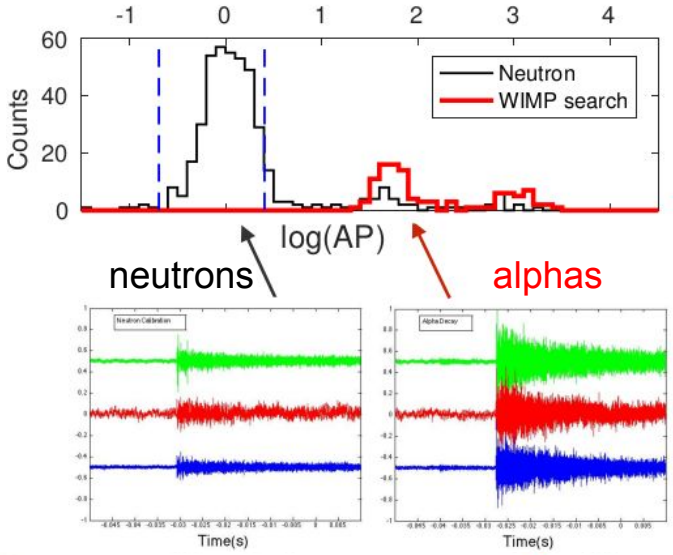


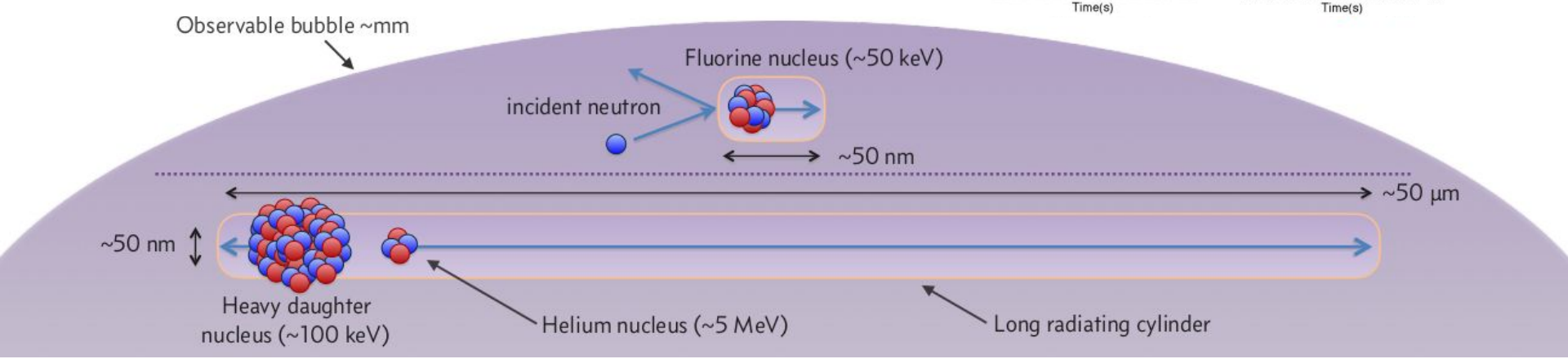
Kozynets et al. PRD 100, 052001 (2019)

- Intensity radiated: $\mathcal{P} \propto \left(\frac{d^2}{dt^2}\text{Volume}\right)^2$
- Most acoustic power generated within first ~10's μs (inertial growth phase)

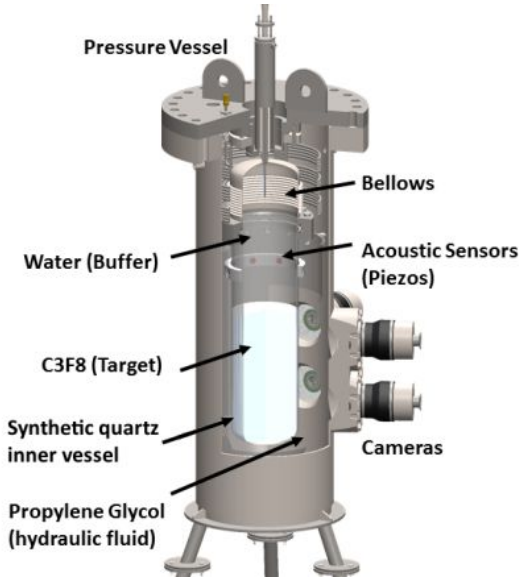
Usefulness of acoustics

- Different behaviour of nuclear recoils and alphas leads to an acoustic power (AP) discriminator
  (Aubin et al., New J. Phys. 10:103017, 2008)

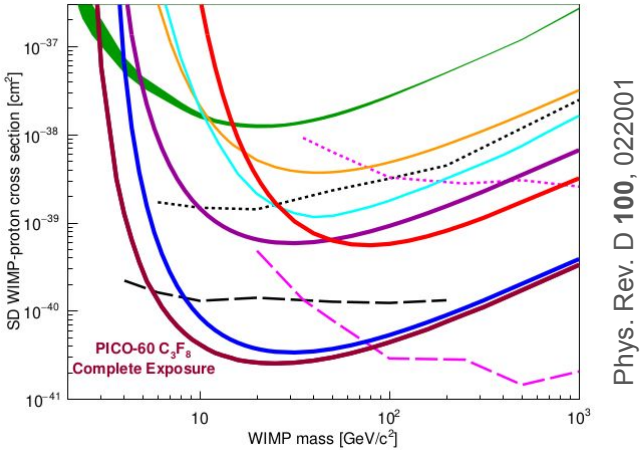




PICO experiments



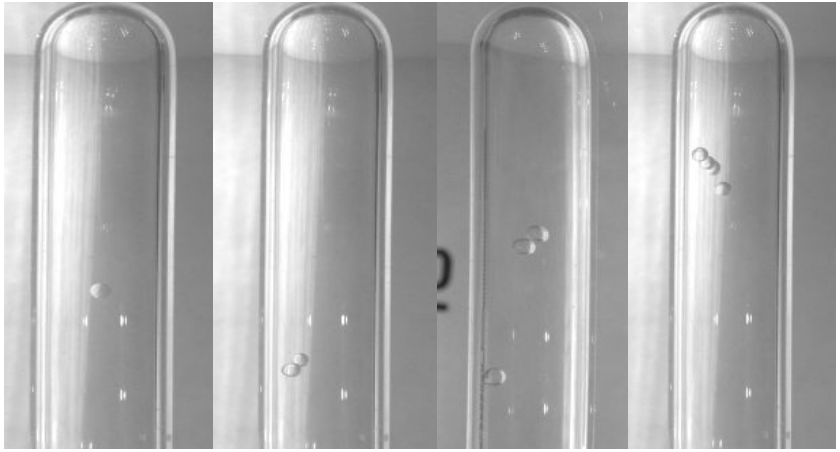
- Utilize low E_{th} and AP for dark matter searches with superheated CF_3I and C_3F_8
- Particular sensitivity to low mass spin-dependent WIMPs with ^{19}F

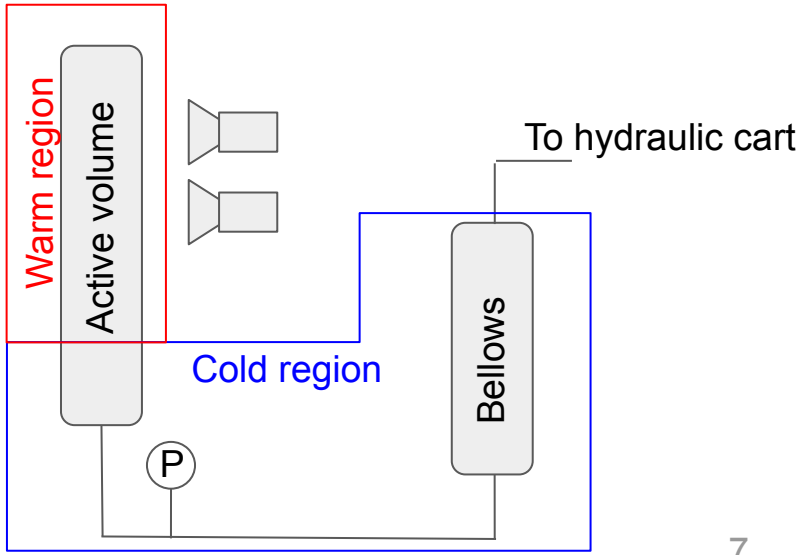


- PICO-40L under construction, PICO-500 planning phase (see Guillaume Giroux's talk)

Queen's Test Chamber (QTC)

- 14 mL right-side-up chamber for small scale testing of jar materials, fluids, contaminates
- 2x Basler cameras, piezo transducer, fast differential pressure gauge, LabView-controlled pressure system
- Active fluids: C_4F_{10} and (C_4F_{10} + C_3F_8) mixtures





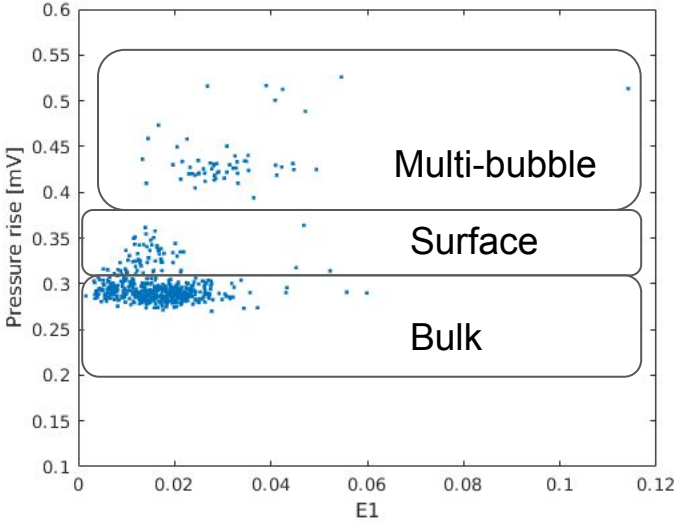
Acoustic response measurement

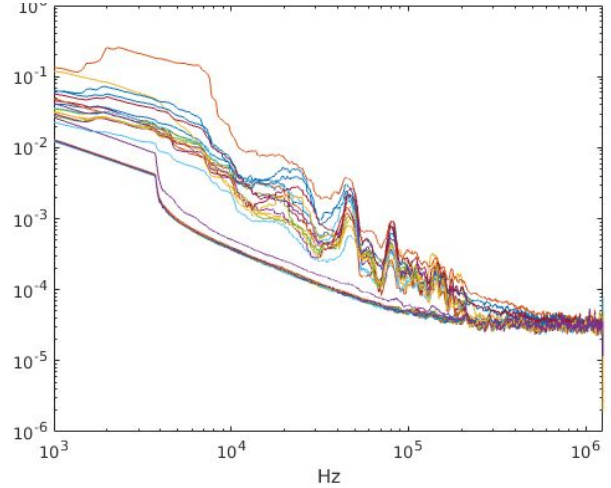
- ^{252}Cf neutron source data sets with different P,T conditions
- Event selection to isolate bulk events
  - Basic data quality cuts
  - Pressure rise cut removes surface and multi-bubble events

- Acoustic response *E* per event:

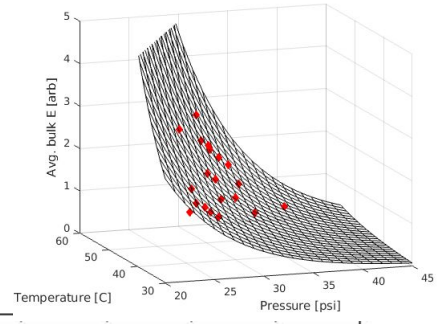
$$\sum_{\text{bins}} DFT(t > t_0) - \sum_{\text{bins}} DFT(t \ll t_0)$$

- Average E for all events in a P,T data set





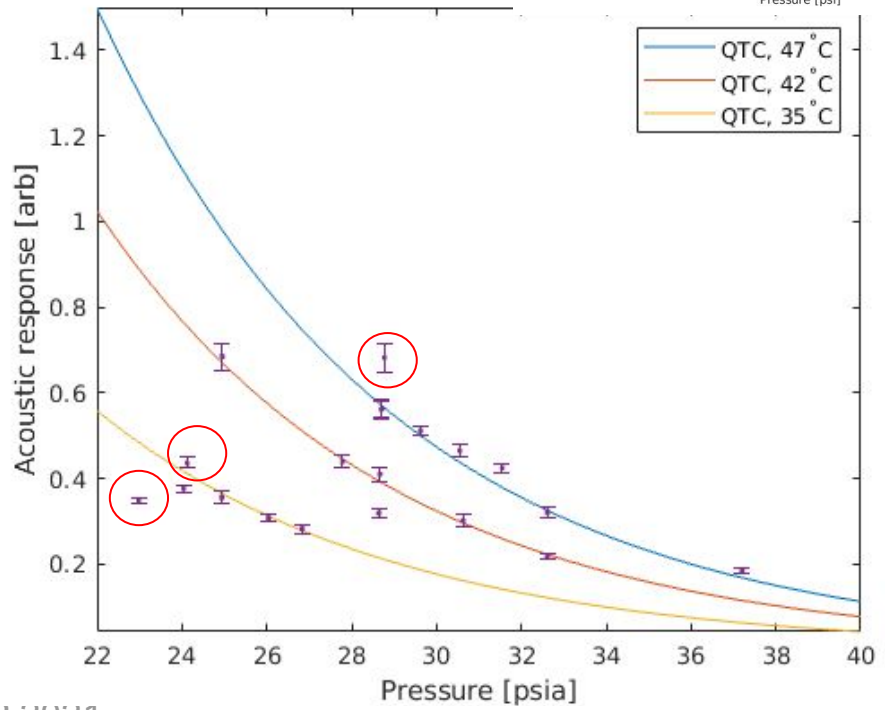
Pressure and temperature dependence



- Overall E response takes form:

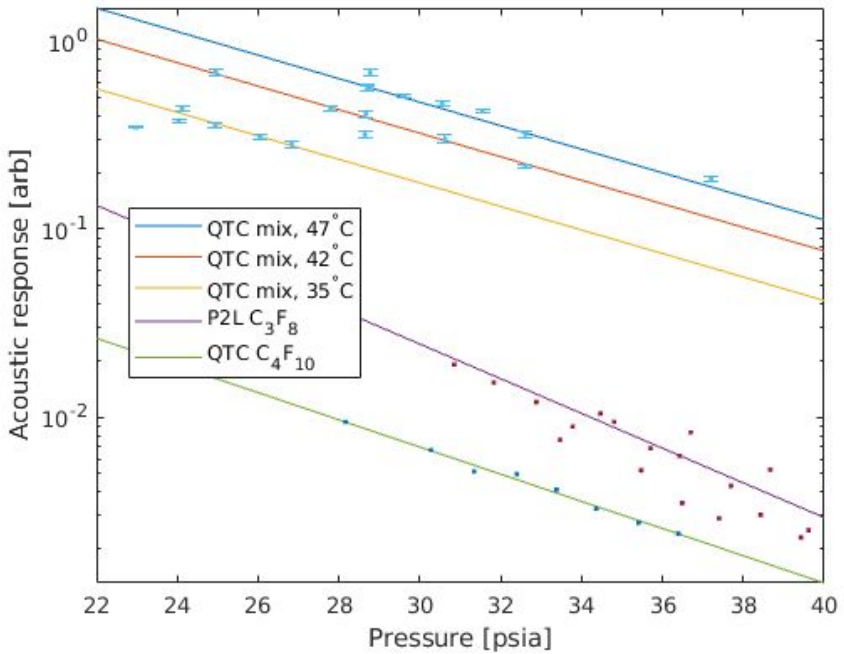
$$a_1 \exp(-a_2 P) \exp(a_3 T)$$

(a_1 has large dependence on piezo coupling)
- Predictive in off-isothermal scan data sets (◯)
- Similar response across frequency range from 70-170 kHz



Pressure and temperature dependence

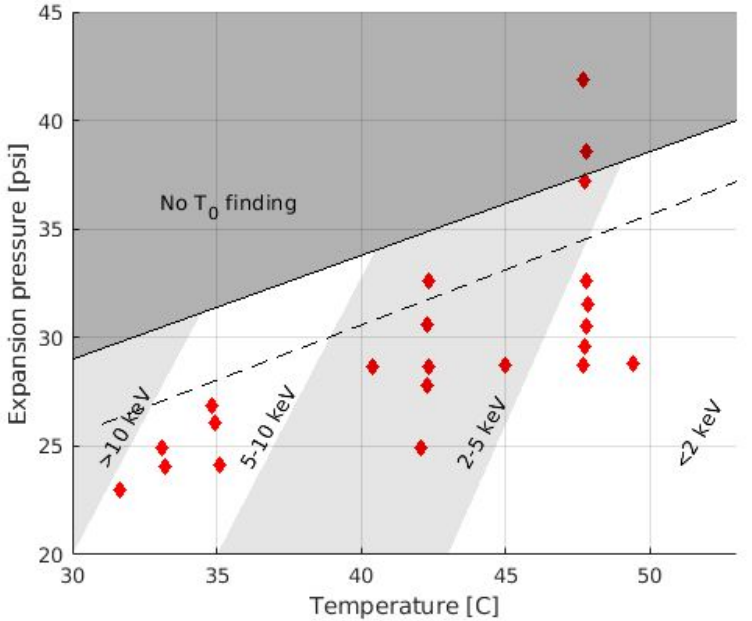
- Similar P,T dependence observed in existing PICO-2L and additional test chamber data (different a_1, a_2, and a_3)
- Nucleations still occur at higher pressure, but acoustic bubble finding and AP fail



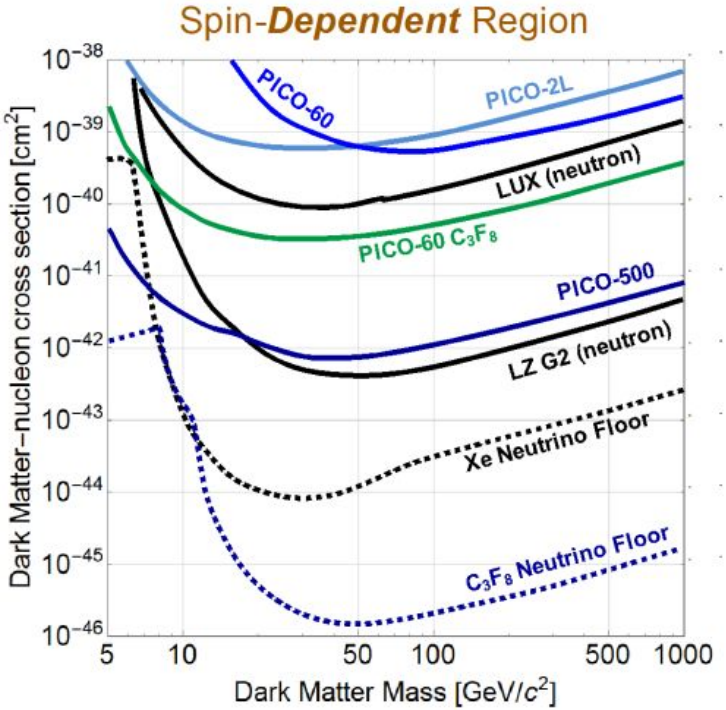
Effect on reaching high thresholds

QTC specific threshold boundaries
(red dots = different data sets)

- Low thresholds easily attained ($\lesssim$ 5 keV), while mid range thresholds can be harder to reach maintaining good acoustic data



Effect on reaching high thresholds



- E_{th} ≳10 keV needed for PICO-500 to avoid ^{8}B CEνENS background
- Operating conditions and thermal design in warm/cold regions need to be informed by predicted acoustic response

See G. Giroux's talk for more on PICO-500

Conclusions

- Data sets scanning pressure and temperature in a small test chamber were taken to measure the acoustic response of nuclear recoils

- The loudness of bulk nuclear recoil events has exponential dependence on pressure and temperature

- The acoustic response is useful to inform operation of high threshold running in PICO-500

Thank you.