Calibration of Scintillating Bubble Chambers

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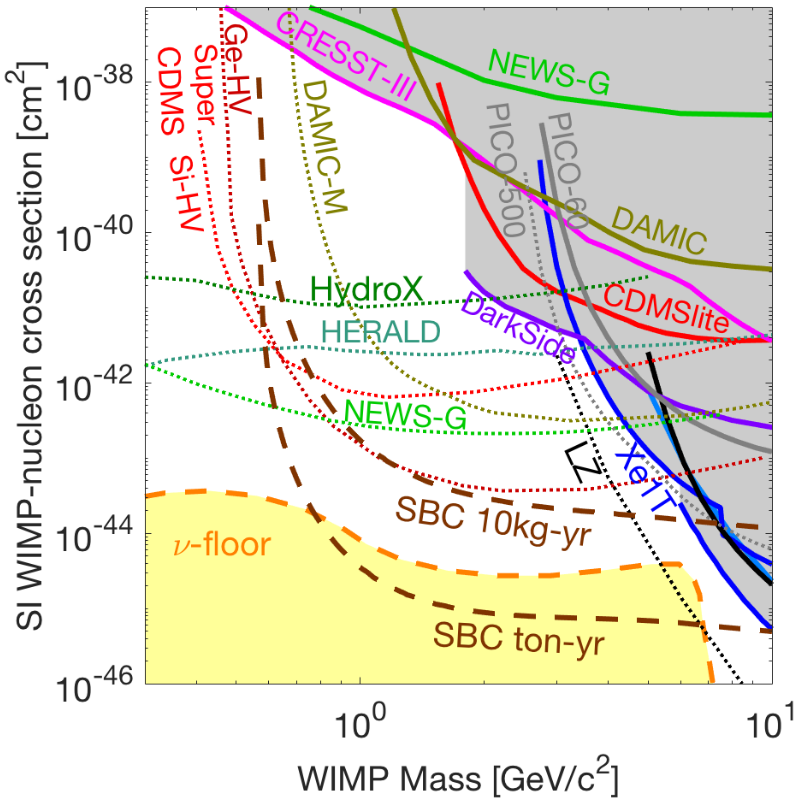
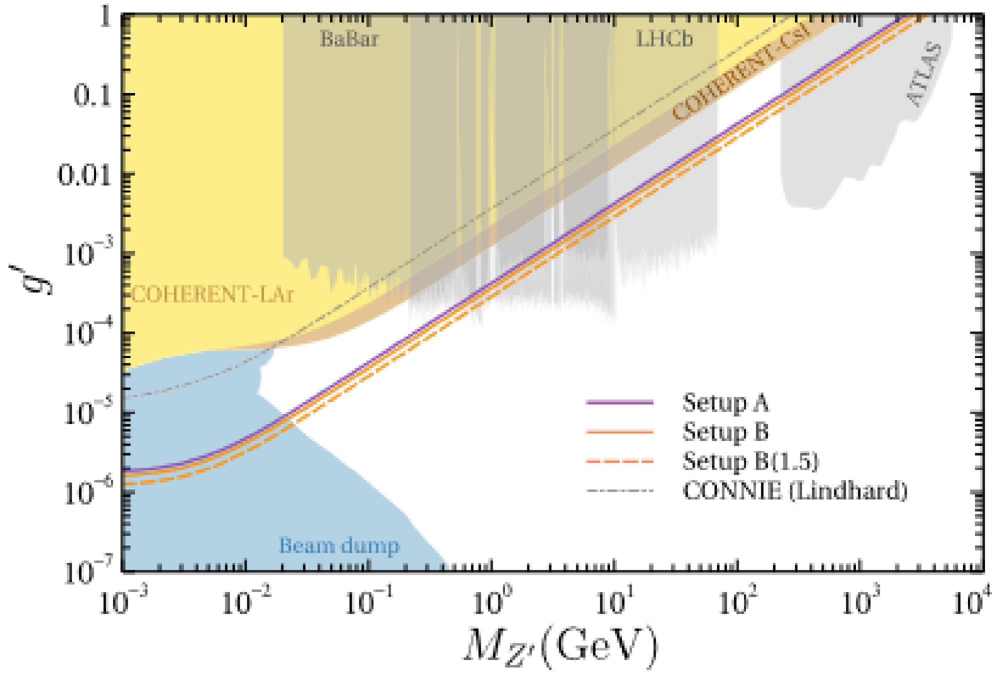
NEW PERSPECTIVES 2021

FERMILAB-SLIDES-21-065-PPD-V

Goals for Scintillating Bubble Chambers

- **Background-free 100 eV nuclear recoil detection** for dark matter and CEvNS experiments

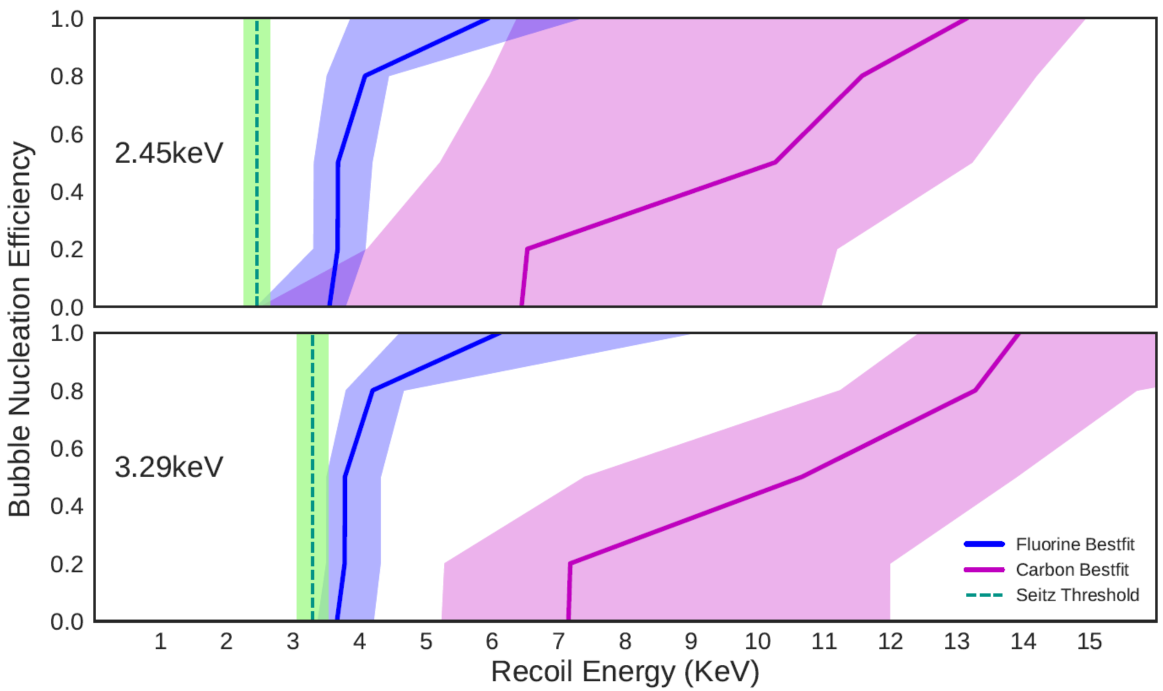




PRD **103**, L091301 (2021)

A Note on Thresholds

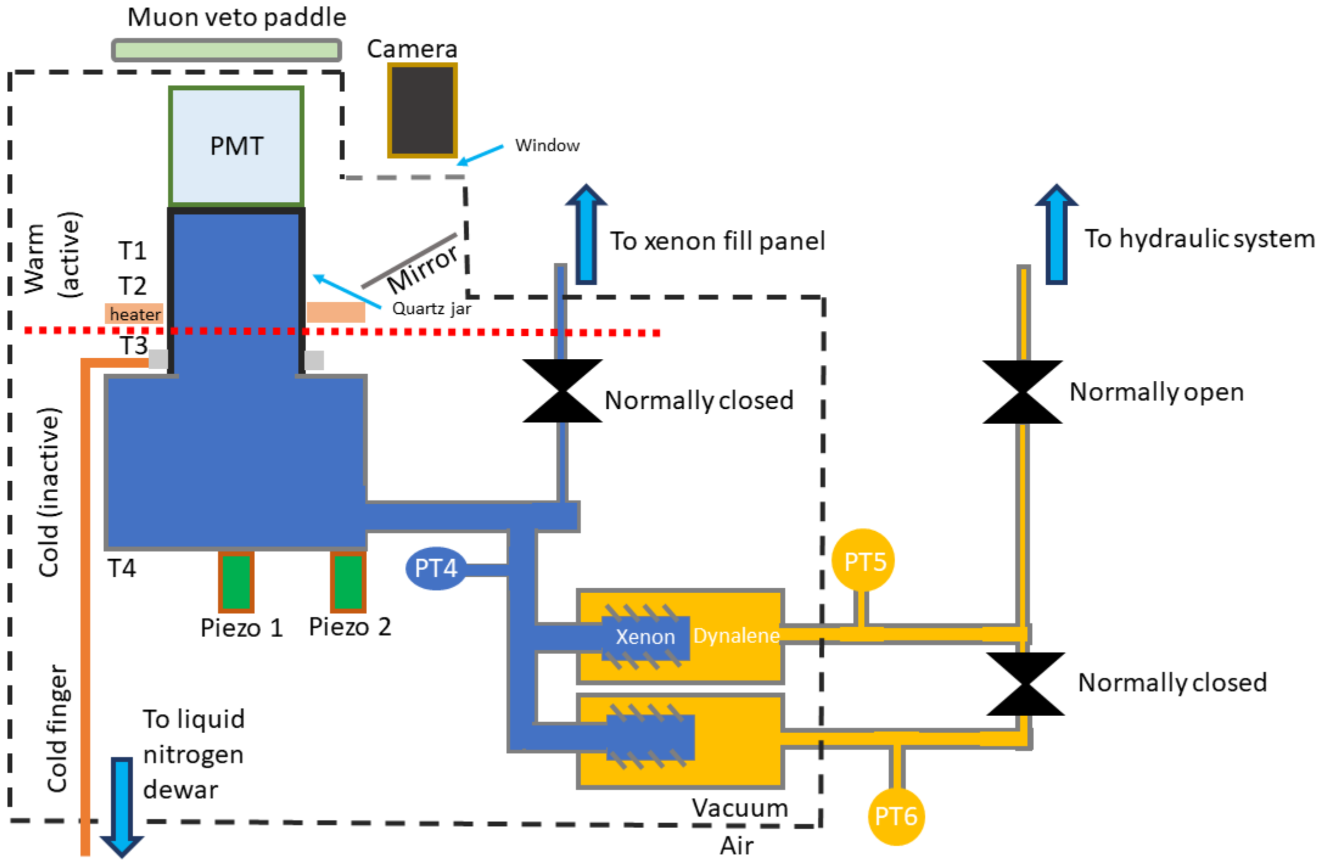
- We calculate the thermodynamic threshold $\boldsymbol{Q_{Seitz}}$: the amount of energy (heat) required to create a detectable bubble
- The truth is that NR detection efficiency is not a step function at Q_{Seitz}
- Finding the true efficiency curve is what we mean when we say “NR calibrations”



PICO (2019) PRD **100**:022001

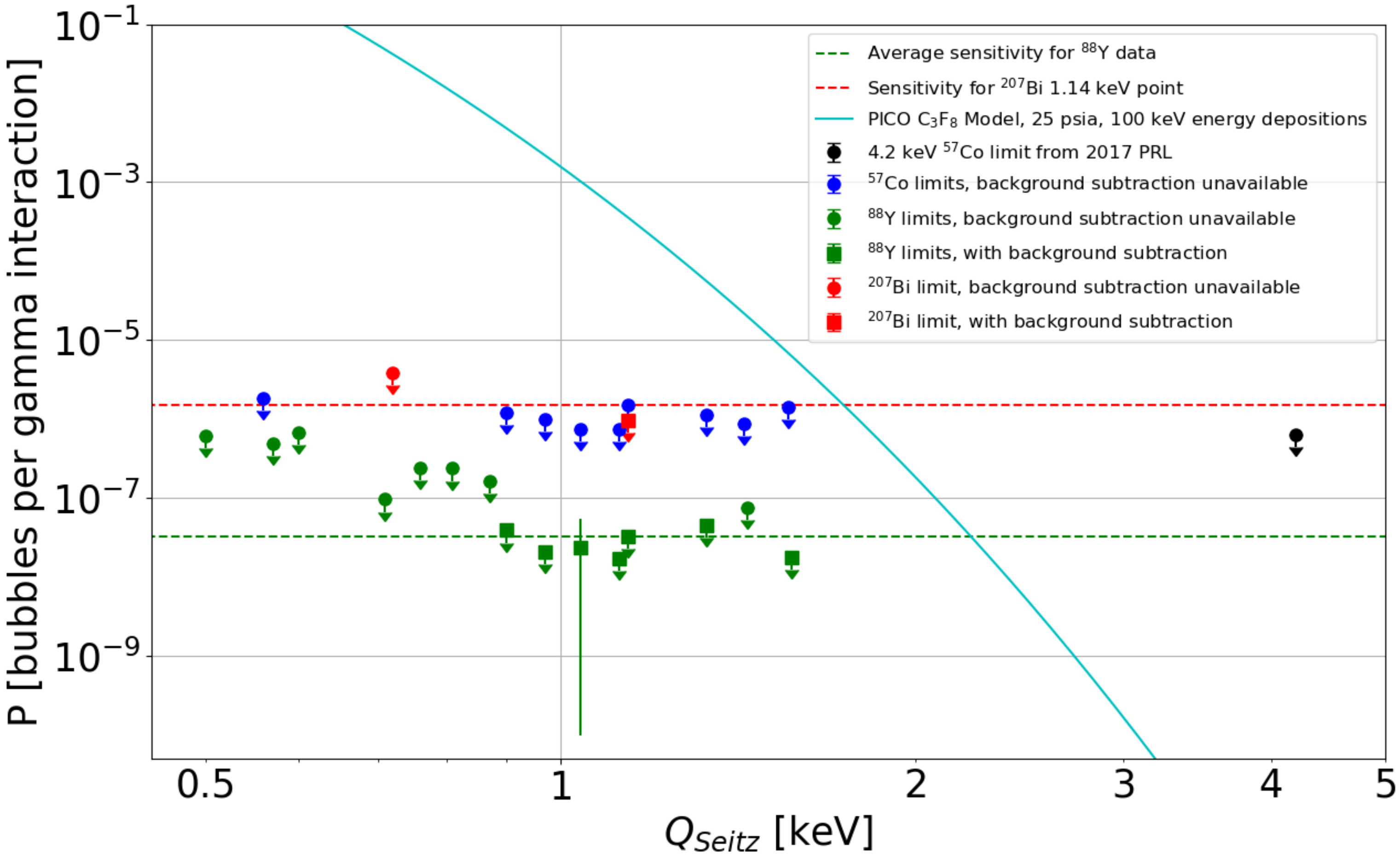
The Xenon Bubble Chamber

- A small (30 g) test chamber has been operated with LXe to demonstrate the principles of scintillating bubble chambers
- No electron-recoil bubble nucleation
- Bright scintillation in background events
- Little scintillation with SF neutrons
- <5 keV nuclear recoil bubbles



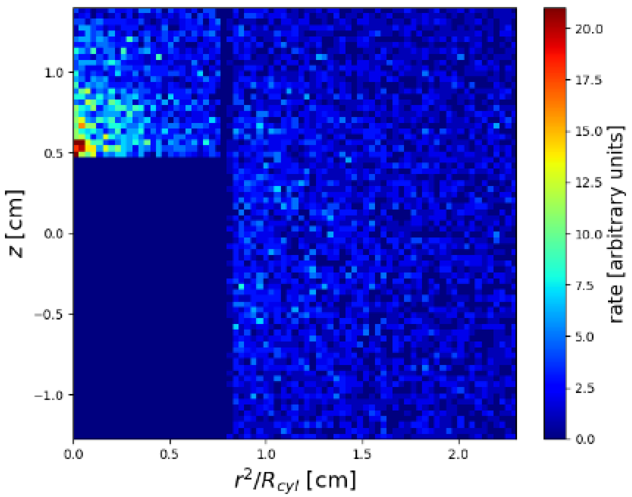
XeBC Calibrations

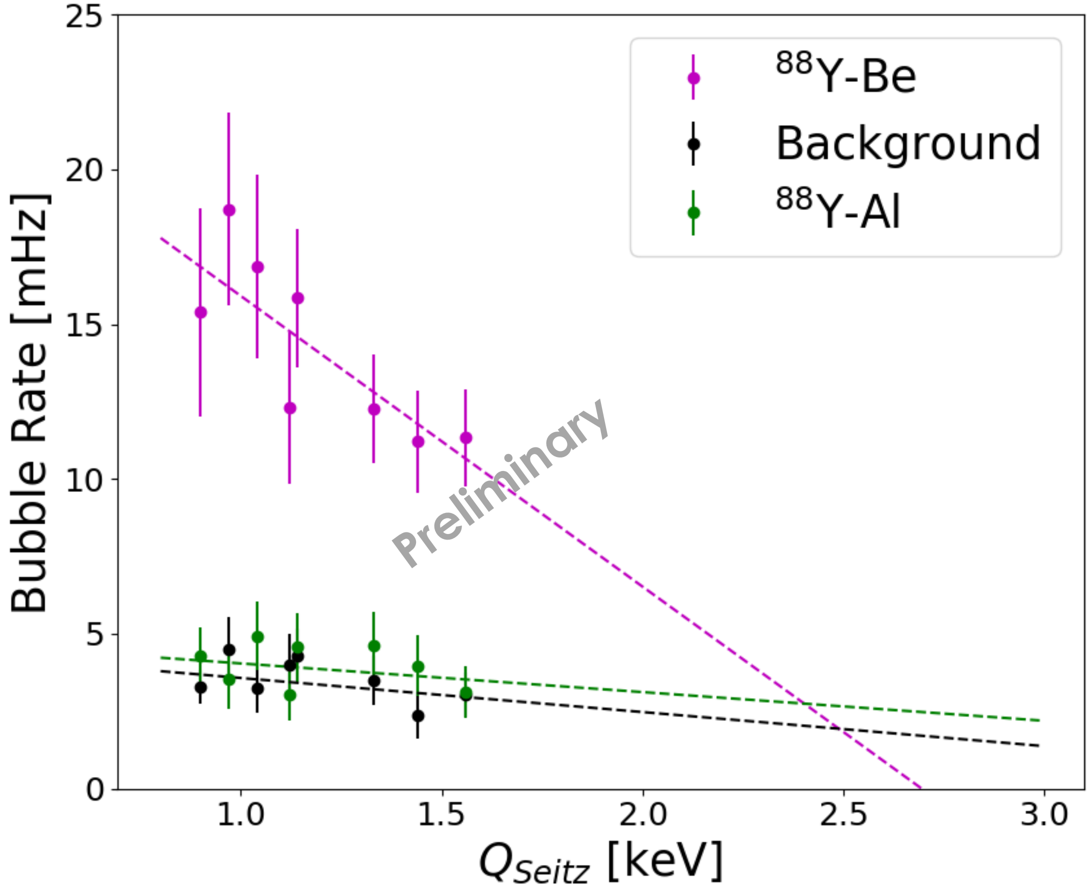
- $O(10^{-7})$ gamma nucleation probability at Seitz thresholds around 1 keV
  - 90% C.L. upper limits, we see no rate above background with the gamma sources



XeBC Calibrations

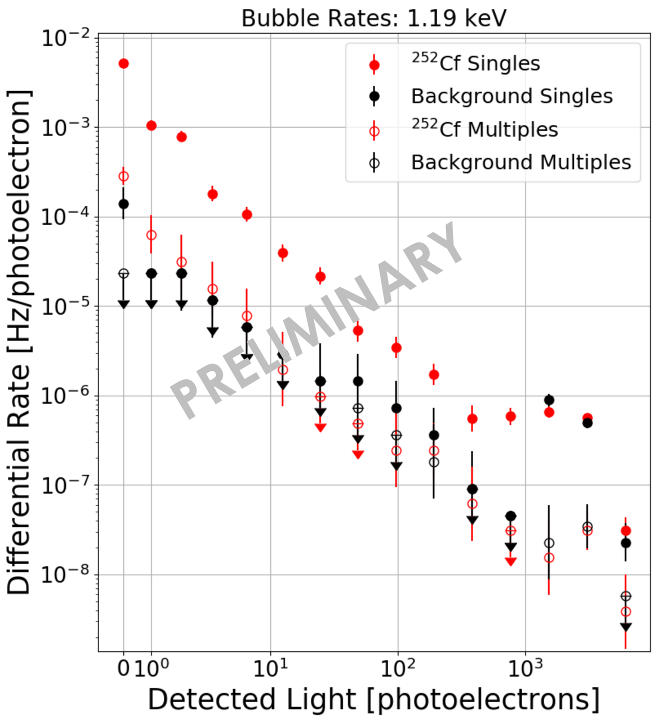
- ^{88}Y-Be source (~850 n/s) produces a rate above background
  - 4.9 keV endpoint for NRs from the dominant ~152 keV neutron; evidence of true threshold < 5 keV$_{nr}$

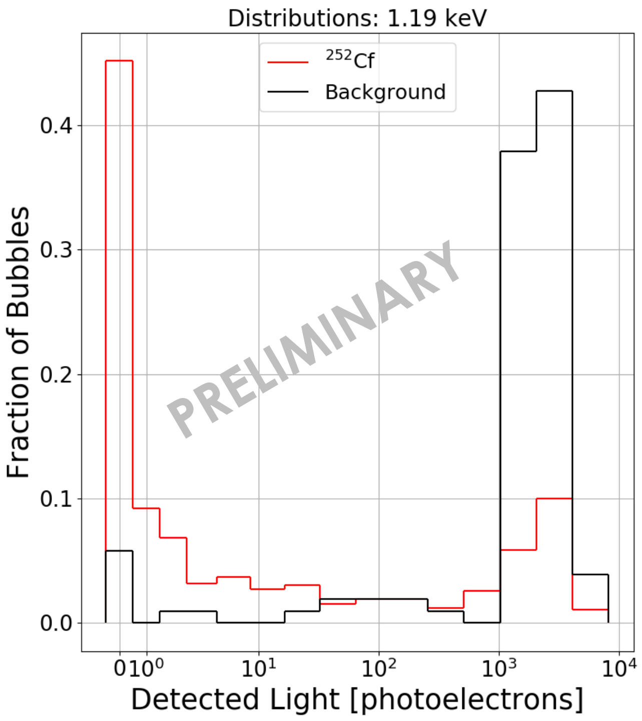




XeBC Calibrations

- Little scintillation from ^{252}Cf neutrons, while most of the background produces very bright events



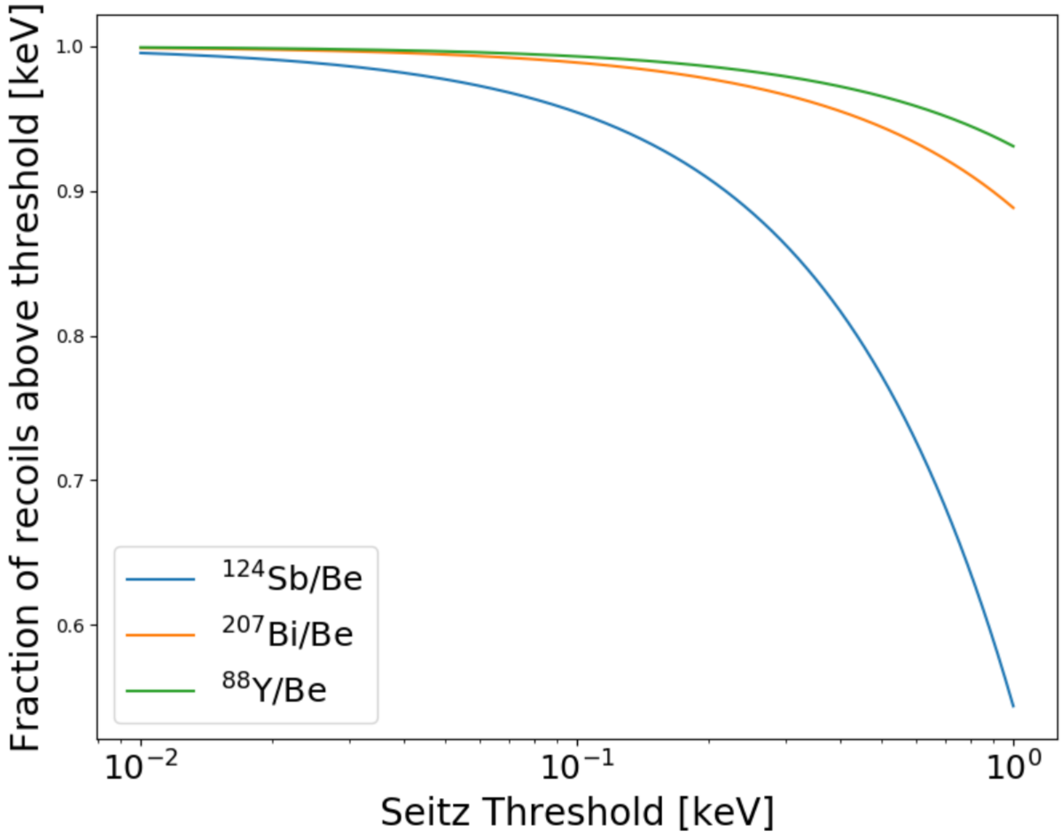


The Argon Bubble Chamber(s)

- 10 kg argon + O(100)ppm xenon chambers for dark matter and neutrino experiments
- Currently constructing SBC-Fermilab at FNAL to perform low threshold calibrations and as a prototype for SBC-SNOLAB
- Design minimum threshold is 40 eV
  - We want to verify the Seitz model at low thresholds, and find operating conditions for 100 eV_{nr} detection
  - We need to determine the electron recoil nucleation efficiency in LAr
    - This should be the simplest calibration; expose the chamber to gamma sources and check whether the rate of bubbles increases
    - If it does, map the sensitivity to ERs as a function of operating conditions

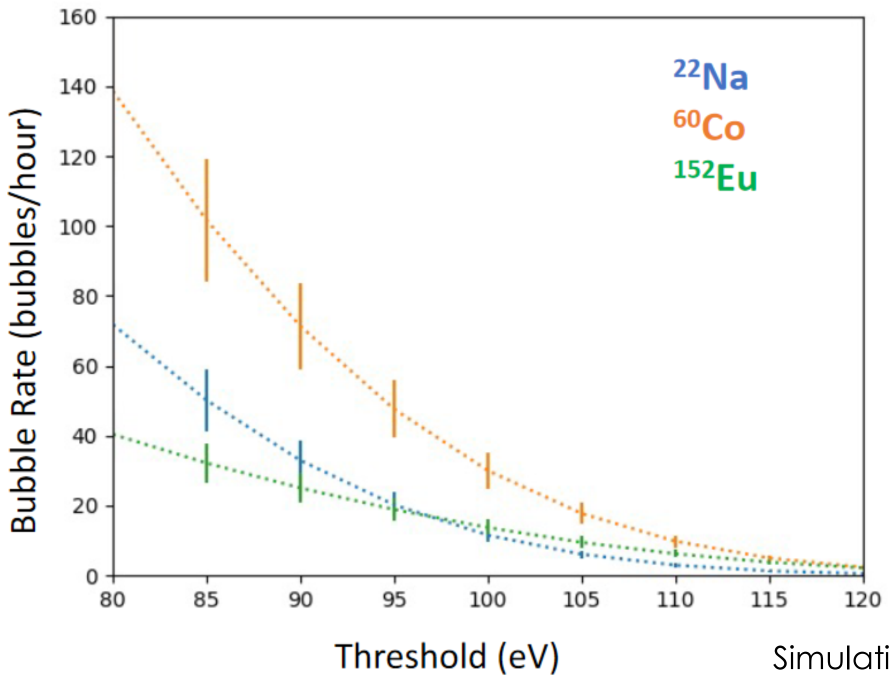
SBC-Fermilab Calibrations

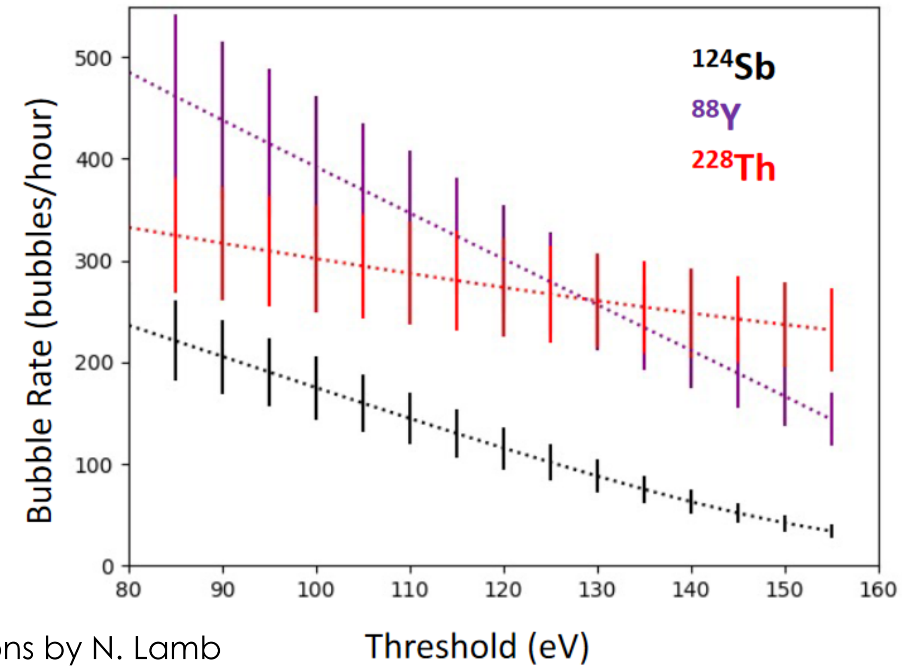
- Photoneutrons can provide ~keV nuclear recoils on argon
  - ~monoenergetic neutrons -> simple recoil spectrum
- $^{124}Sb/Be$:
  - 23 keV neutrons
  - $E_r < 2.2\ keV$
  - Expect no detected scintillation
- $^{207}Bi/Be$:
  - 94 keV neutrons
  - $E_r < 9\ keV$
  - Expect detectable scintillation from ~half of the recoils
- $^{88}Y/Be$:
  - Primarily 152 keV neutrons
  - $E_r < 14.5\ keV$
  - Expect detectable scintillation from >half of the recoils



SBC-Fermilab Calibrations

- If electron recoils do not cause significant bubble nucleation, high-energy gammas can nucleate bubbles by Thomson and Delbrück scattering

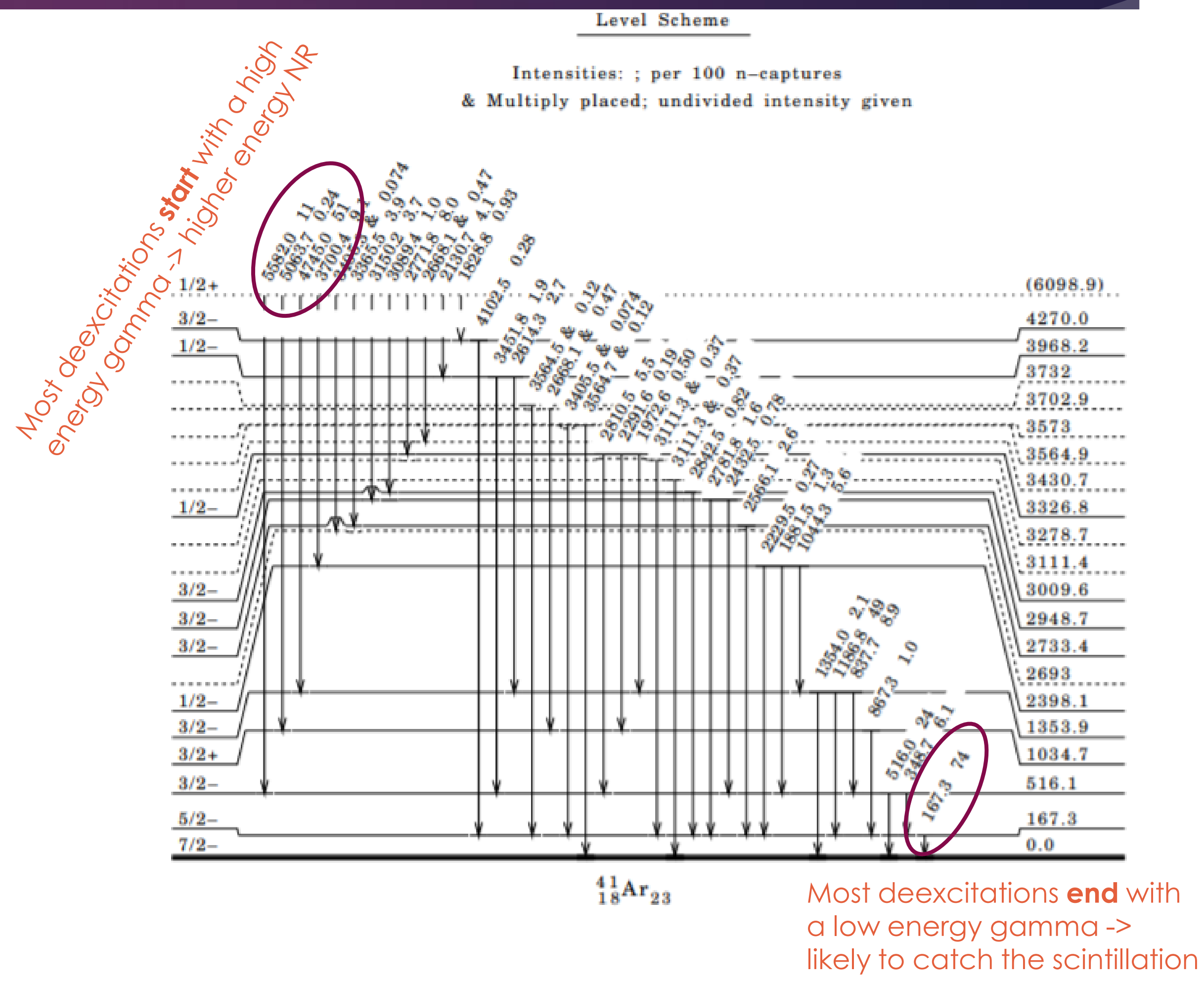




Simulations by N. Lamb

SBC-Fermilab Calibrations

- ^{40}Ar captures thermal neutrons with $\sigma = 673\, mb$
- Capture is followed by a gamma cascade (~ps) as the excited nucleus relaxes, resulting in a nuclear recoil of the ^{41}Ar nucleus of ~320 eV
- D-D generator neutrons from neighbors in MINOS area, but we need to ensure they are ~entirely thermalized
- Can find full efficiency point with threshold scan (in principle)



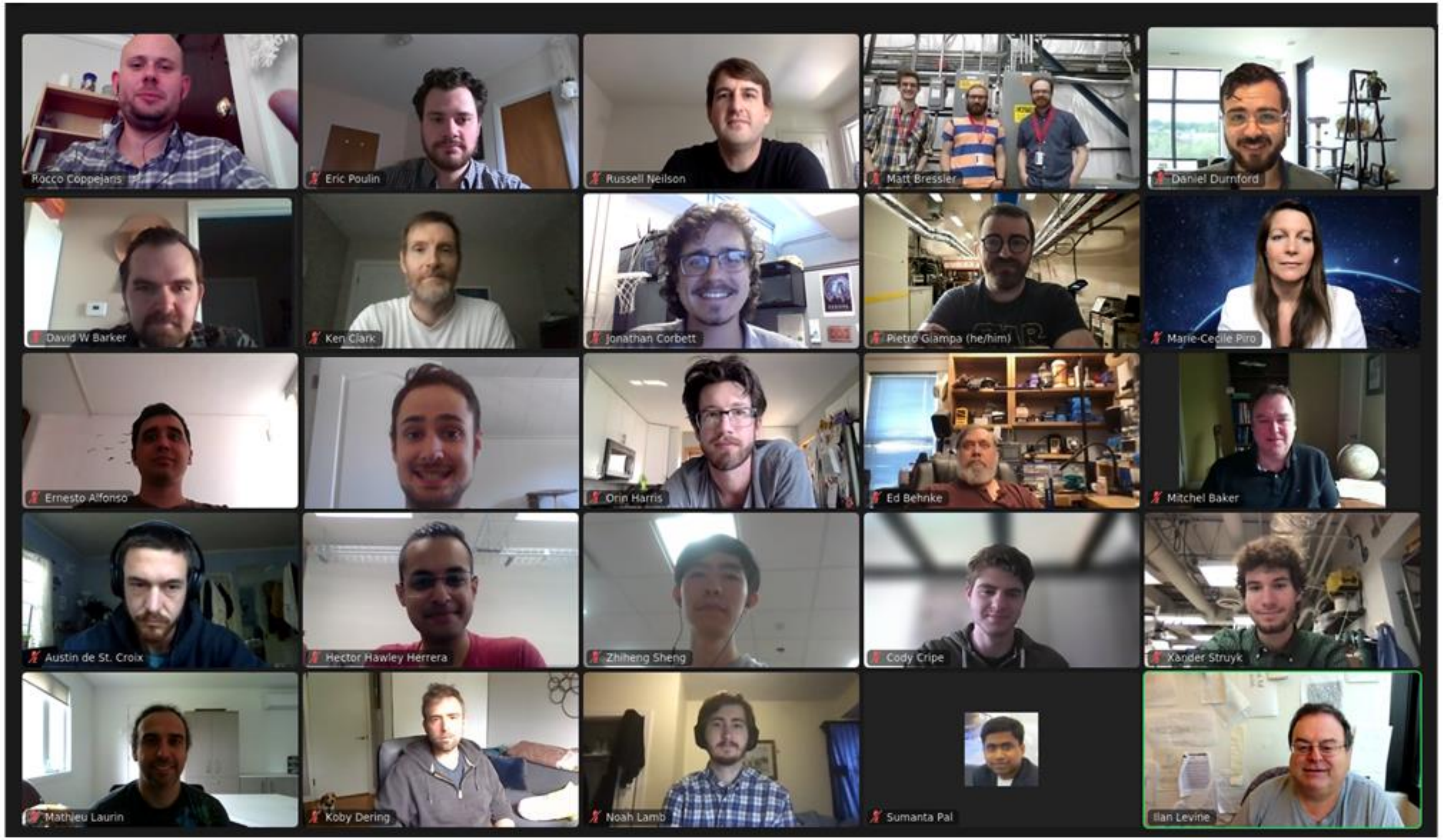
^{40}Ar(n,γ) E=res 1974Ke18

1974Ke18: E_n=15–70 keV and 58 keV produced from ^{7}Li(p,n)^{7}Be reaction. Measured Eγ, Iγ using Ge(Li).

Conclusions

- Scintillating bubble chambers combine bubble chamber ER rejection with noble liquid energy reconstruction
- We have calibrations in liquid xenon, showing insensitivity to gammas down to 0.5 keV, and sensitivity to ~keV nuclear recoils
  - With a great background veto in the scintillation channel
- We intend to run calibrations in the argon bubble chamber in the coming years, at O(100) eV Seitz thresholds

Thank You!



SBC Collaboration
Photo July 2021