FERMILAB-SLIDES-24-0225-PPD

Scintillating Bubble Chambers for Direct Dark Matter Detection, and an Update on SBC-LAr10

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On behalf of the SBC Collaboration

TeV Particle Astrophysics 2024

2024-08-27

Northwestern

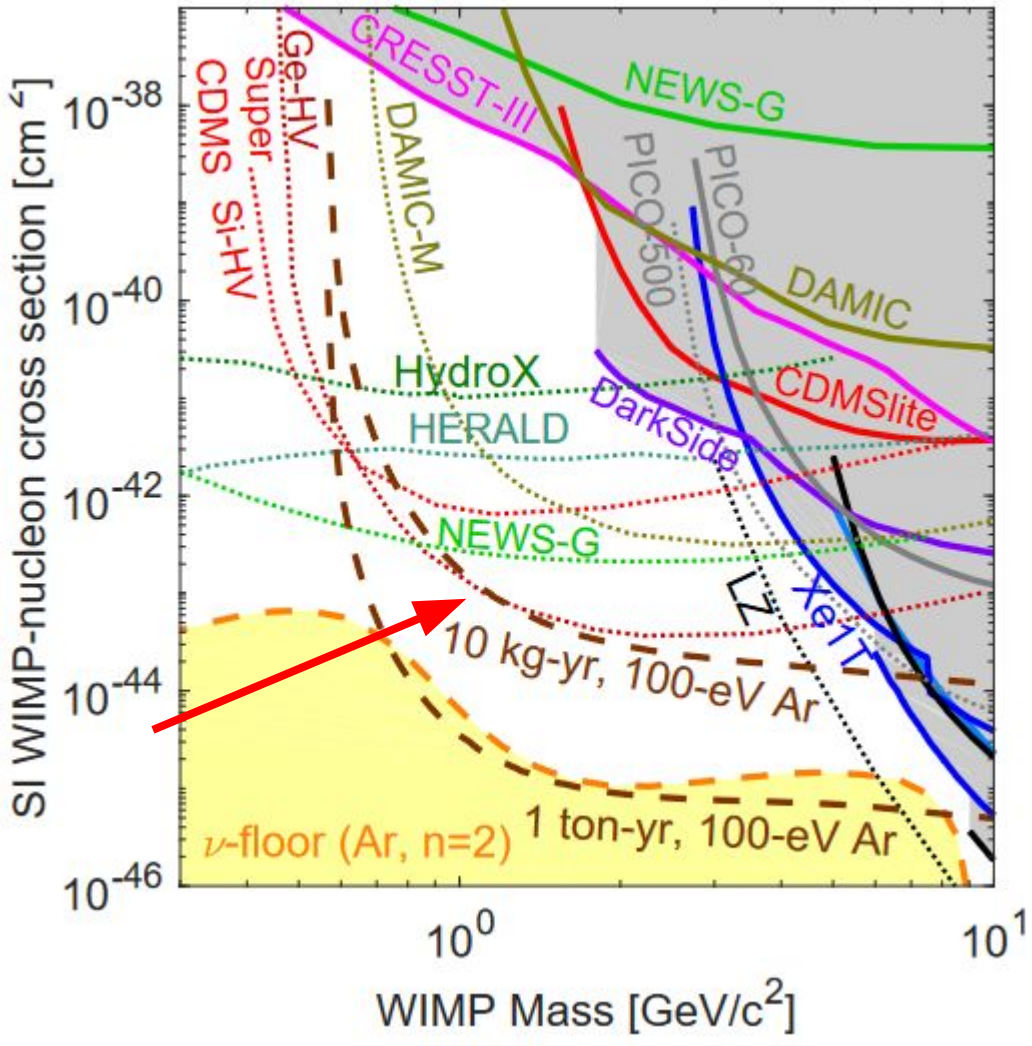
Department of
Physics and Astronomy

Overview

Status Update

Calibration Plan

Scintillating Bubble Chamber Technology



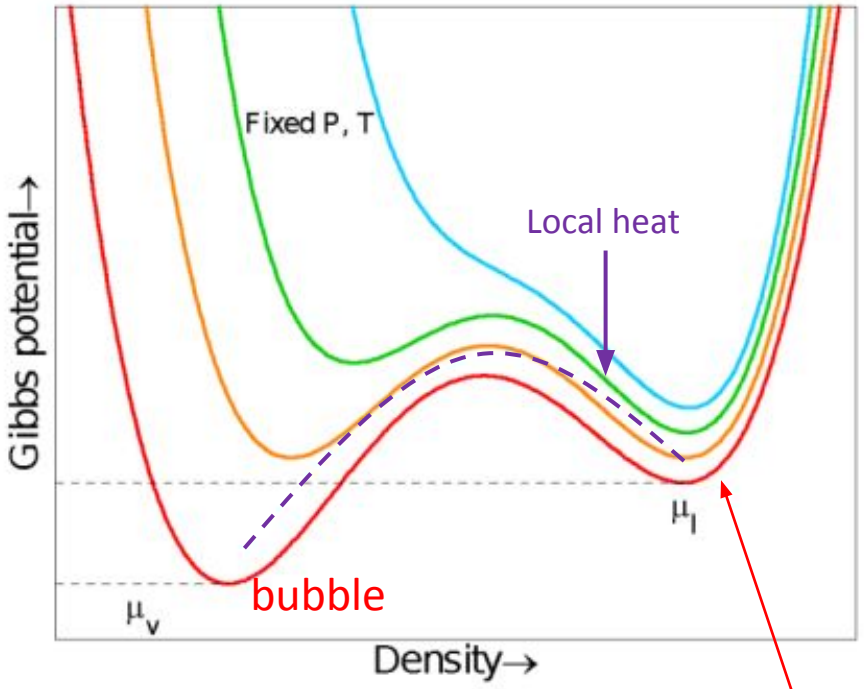
1. Scintillating Bubble Chamber (SBC) combines **powerful electron recoil (ER) discrimination** of the bubble chamber technique with **event-by-event energy resolution** of liquid-noble scintillators

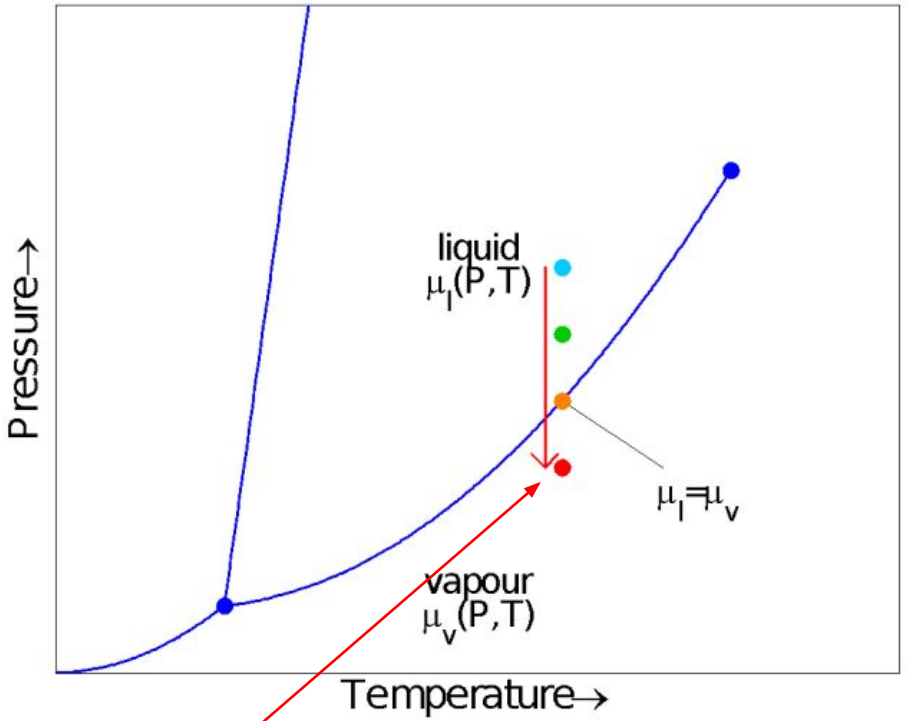
2. DM masses down to ~1 GeV, or ~100 eV nuclear recoil (NR) on argon nucleus

3. SBC is the only technology that can achieve the **discrimination** and **scalability** needed for a ton-year exposure at 1 GeV WIMP mass

SBC Snowmass White Paper, arXiv: 2207.12400v1

Superheated Fluid and Bubbles





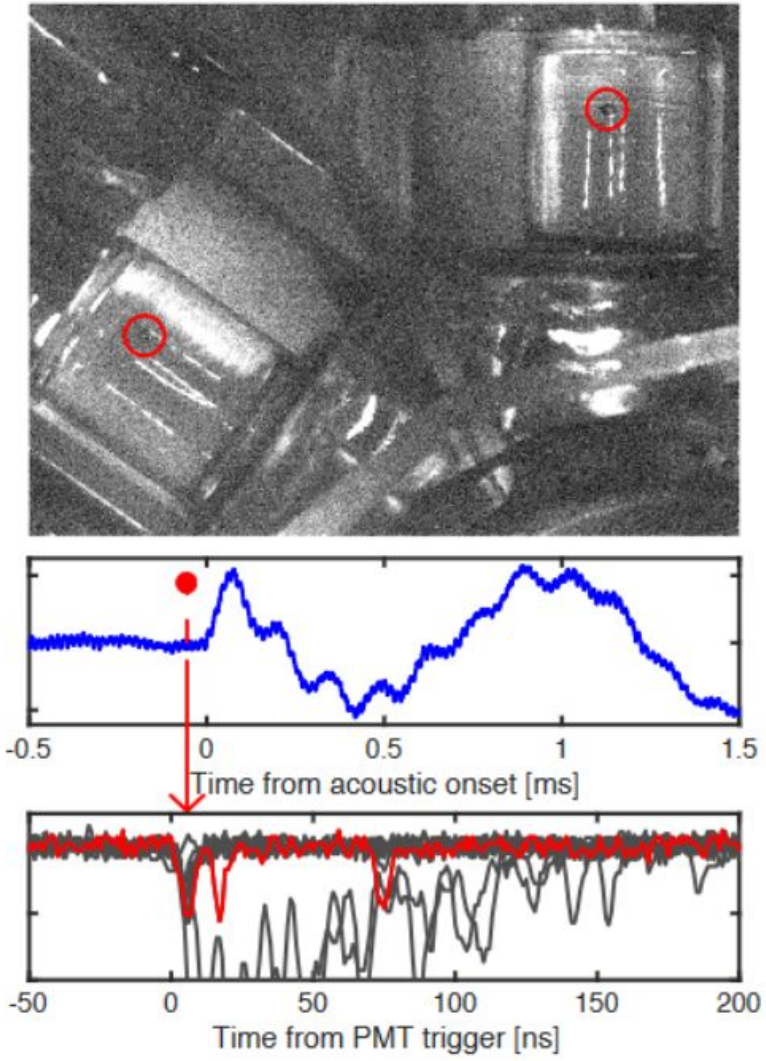
Superheated fluid

Fast Neutron / Dark Matter → Nuclear recoil → Large dE/dx → Heat deposited locally → Bubble

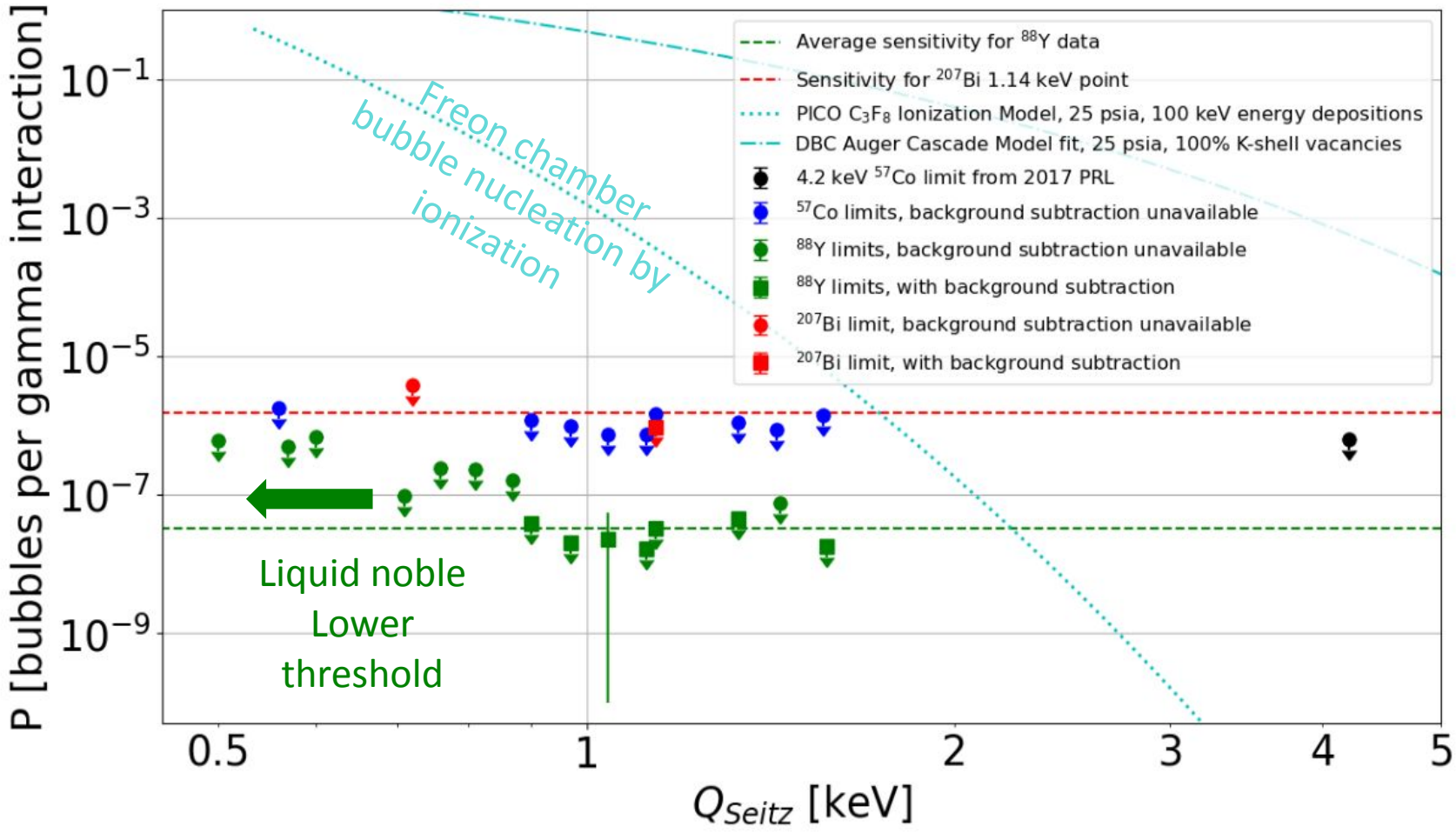
Beta / Gamma → Electron recoil → Small dE/dx → Heat deposited over long distance → No bubble

(In liquid noble) → No heat, only radiation → Less than no bubble

Electron Recoil Discrimination



Prototype Xenon bubble chamber



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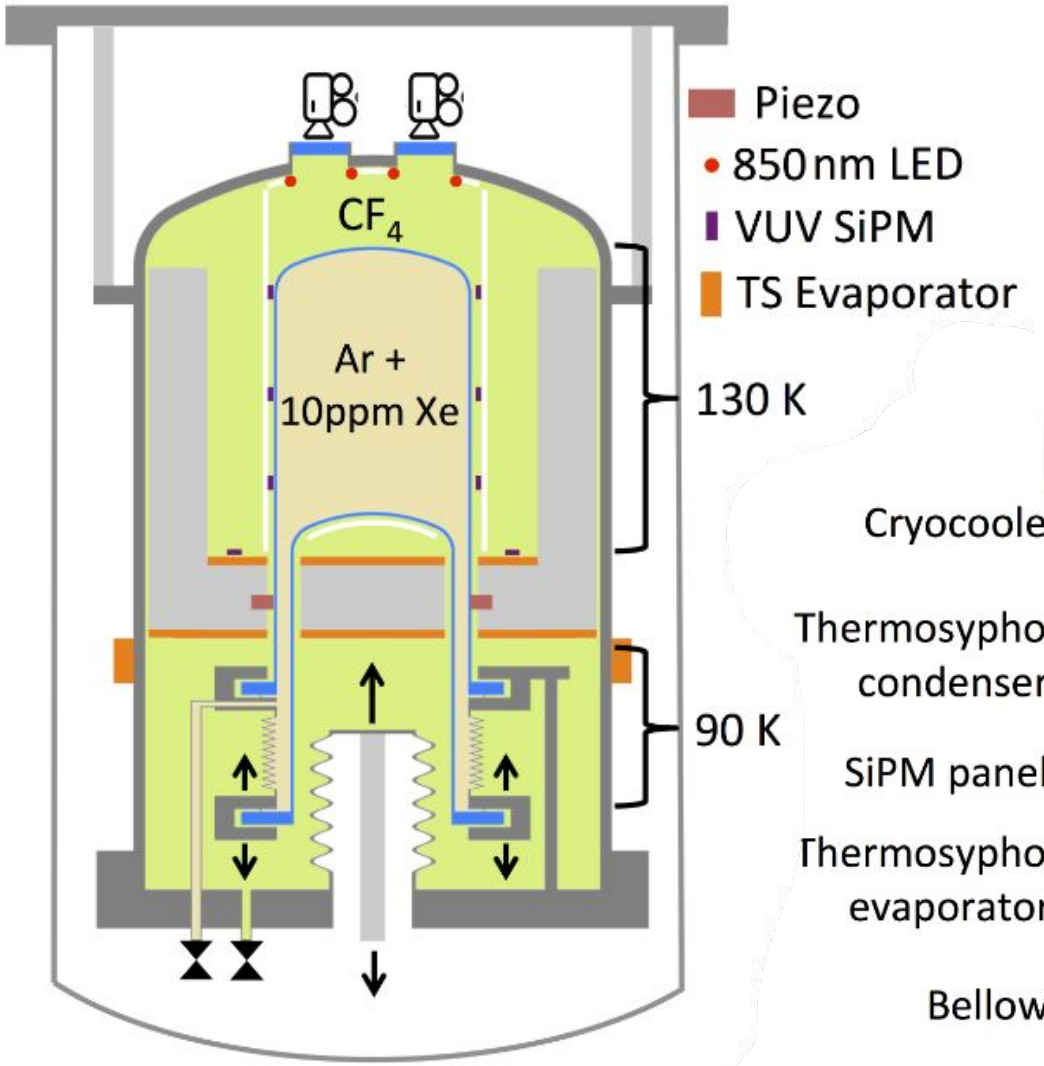


SBC-LAr10 Fermilab

10kg calibration chamber recently installed in MINOS underground tunnel

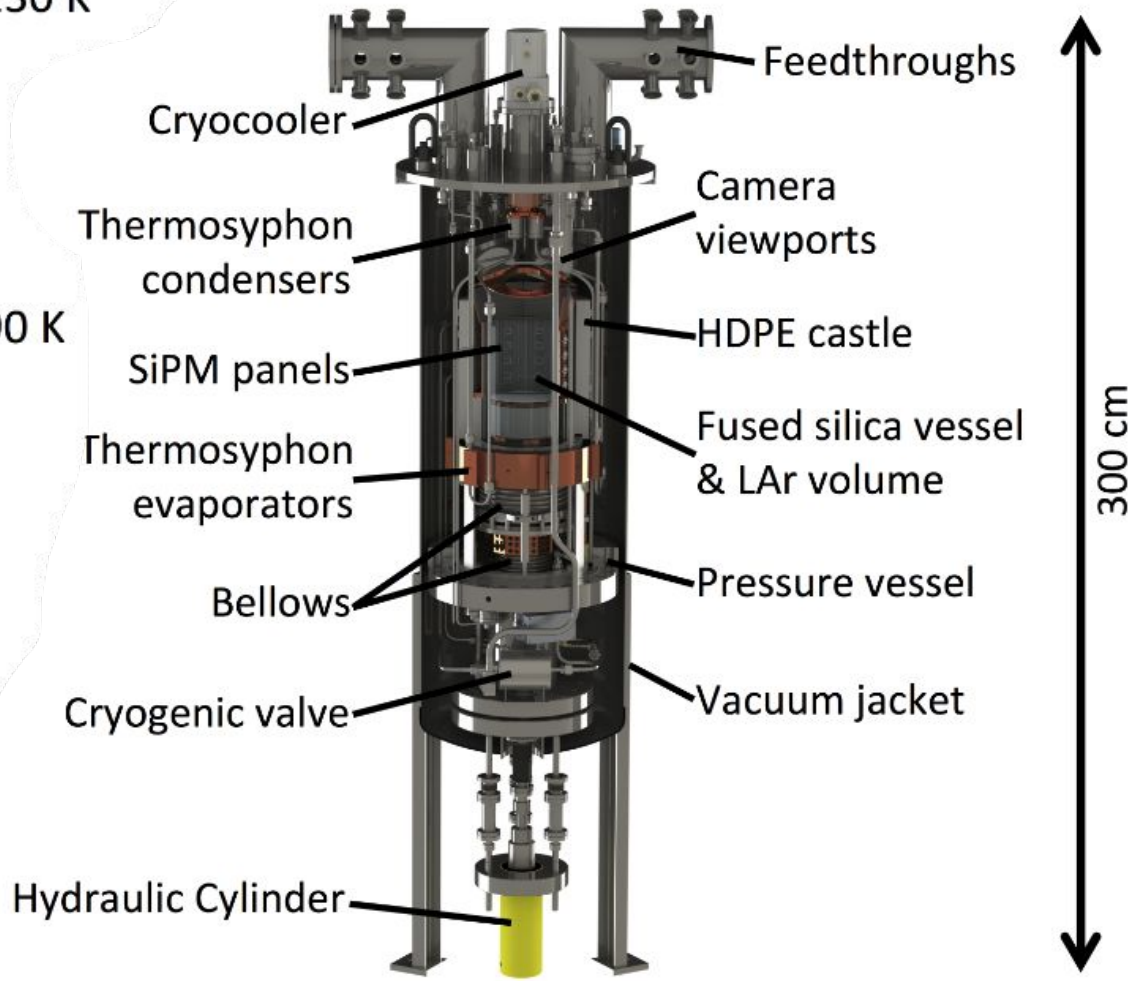
SBC-LAr10 SNOLAB

Functionally identical radiopure chamber

Dark matter search

Ton-year chamber

Explores solar CEvNS at 1 GeV



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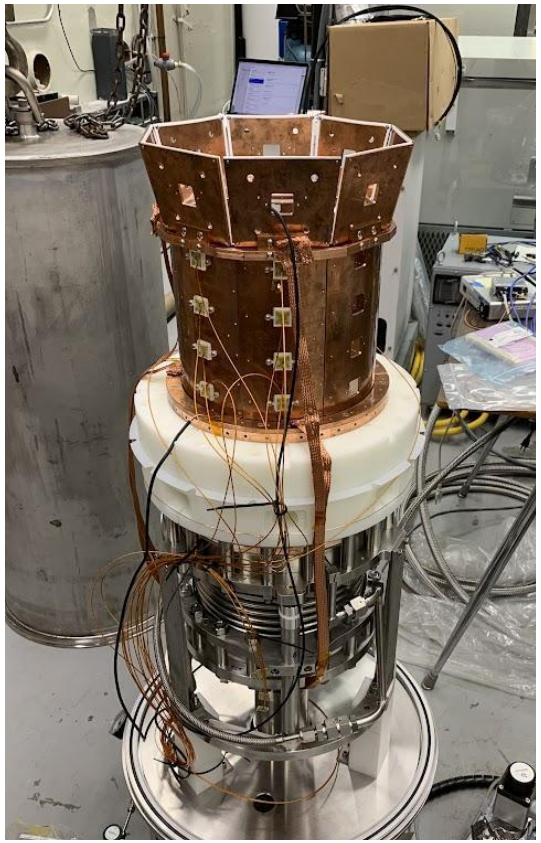
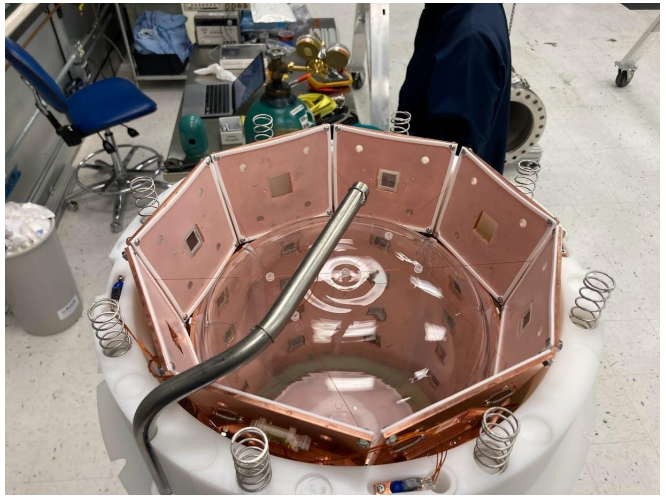
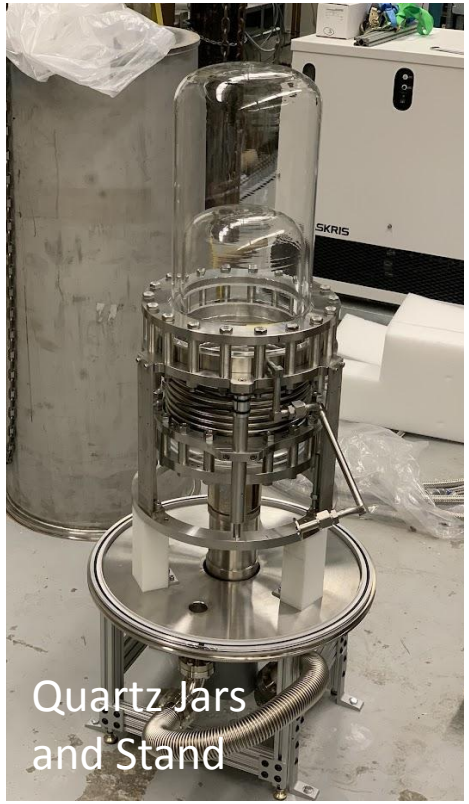
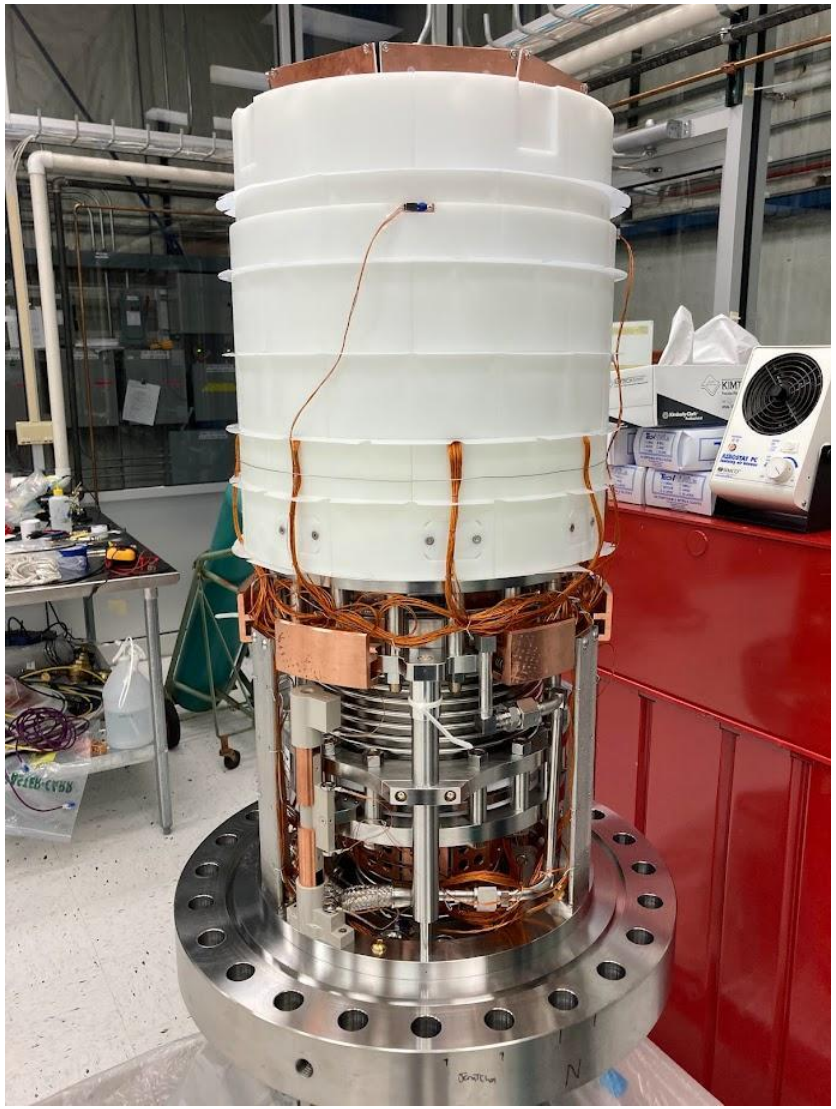
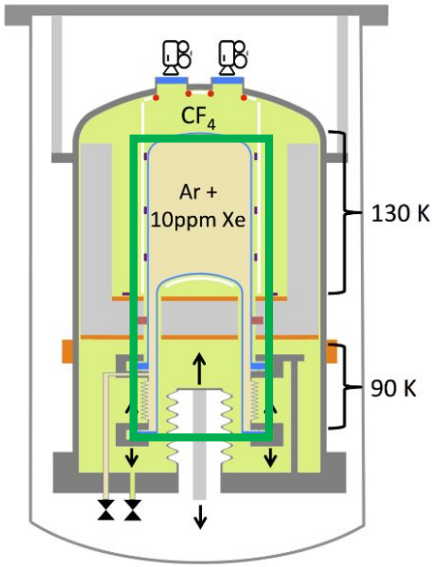




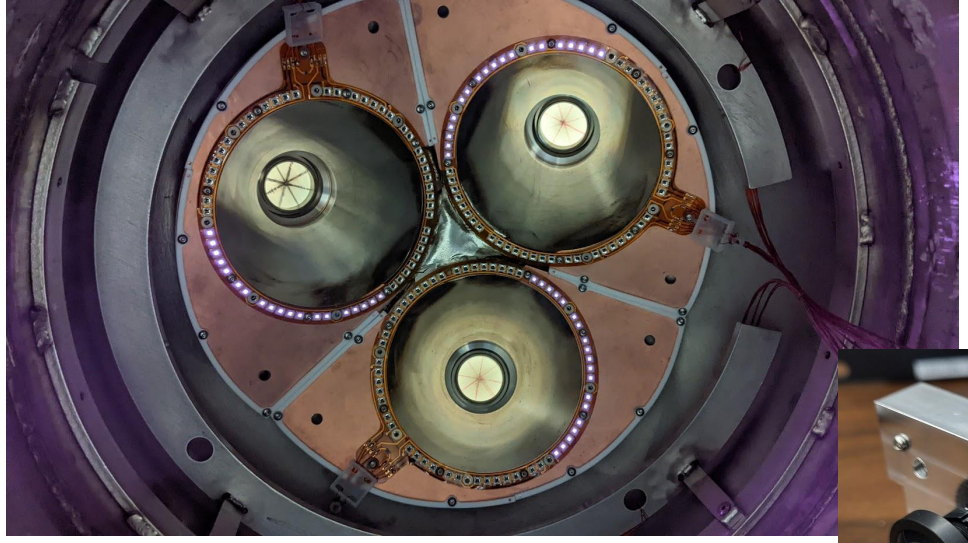


Quartz Jars
and Stand

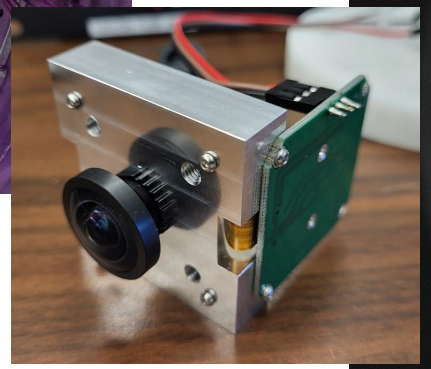




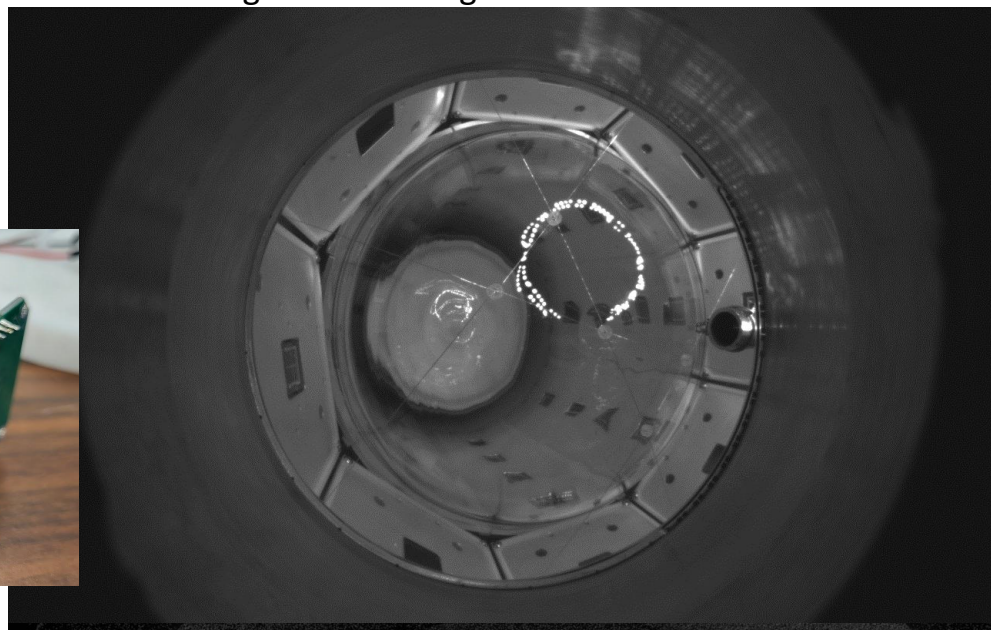
Inner Assembly

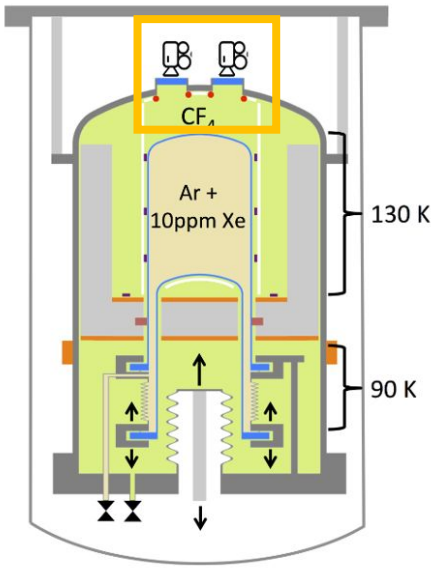


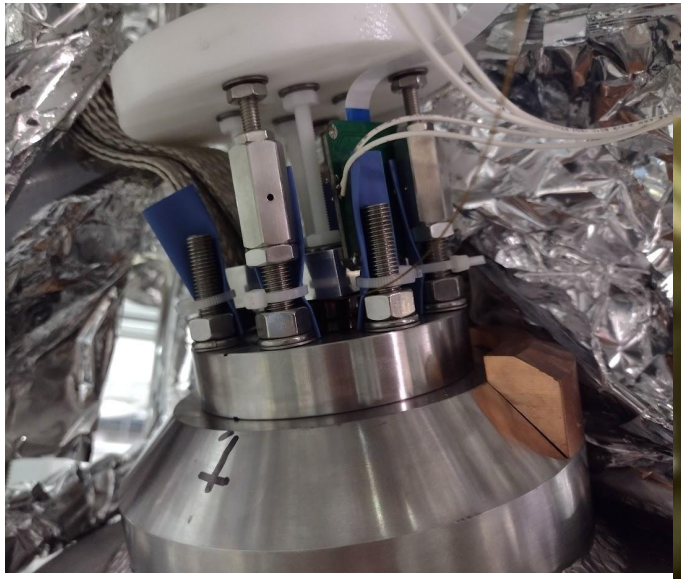
Three camera ports with LED rings



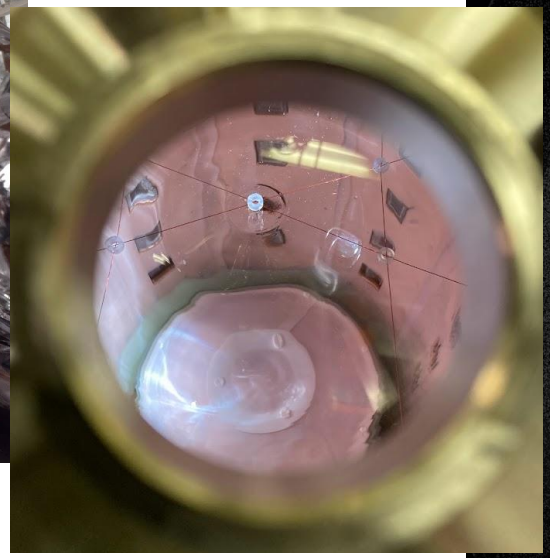
Real image taken during cold test run

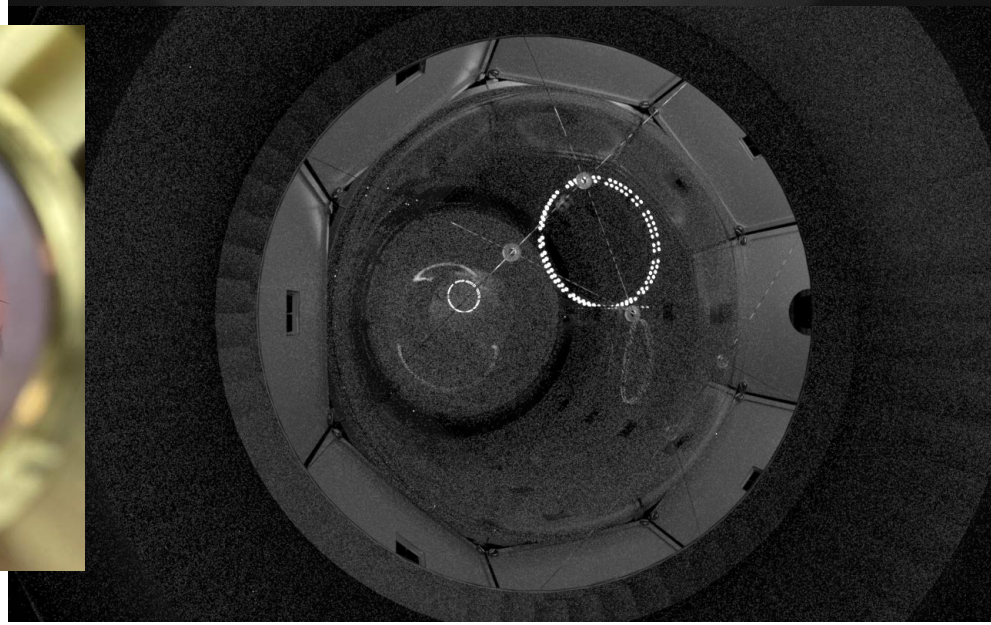






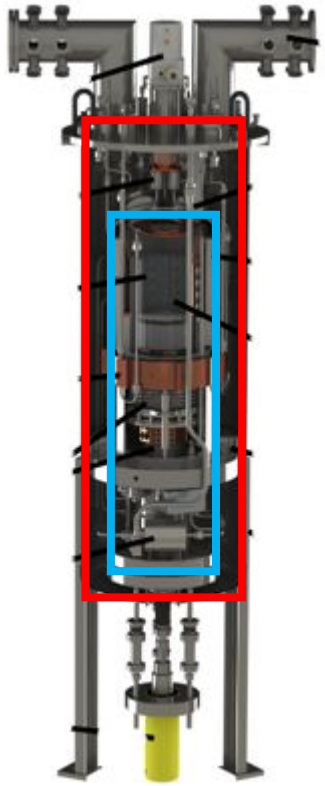
Camera mount on view port

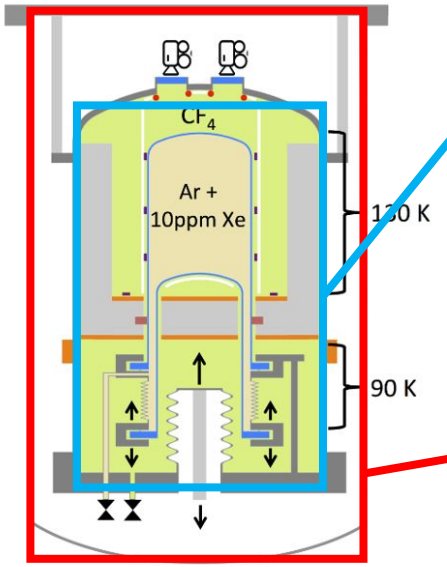


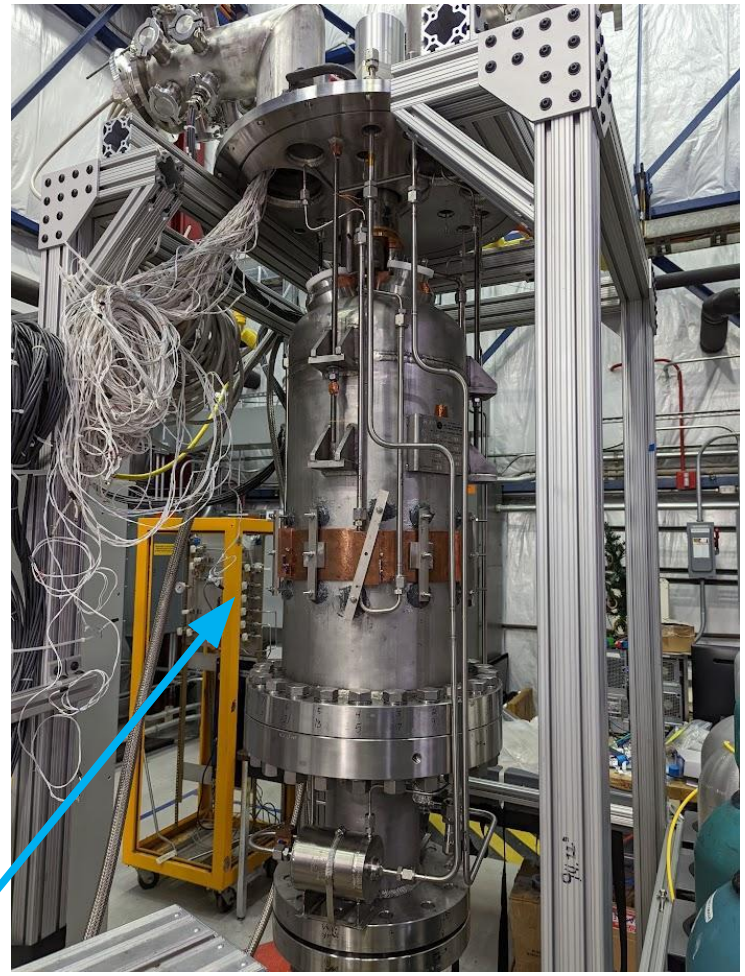


Rendering using Mitsuba 3

Bubble imaging (cameras)







Pressure vessel

Super-insulation

Vacuum jacket

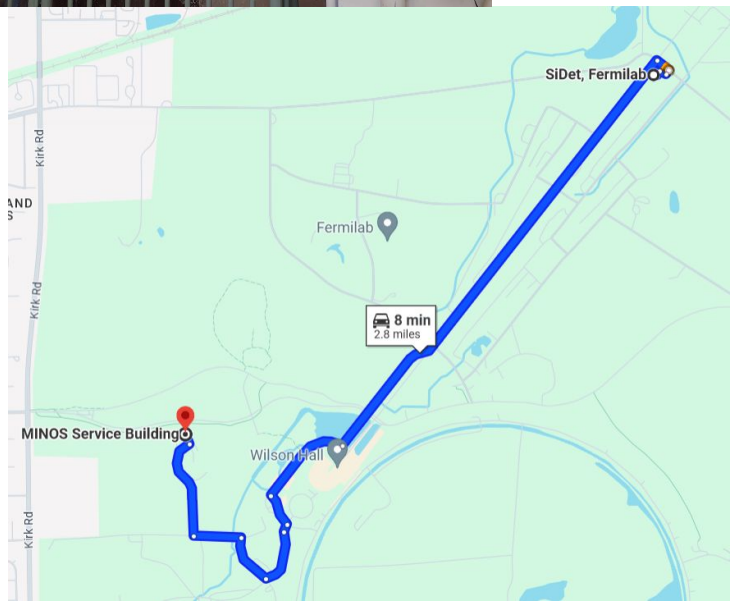
Vacuum jacket and pressure vessel

Moving Underground

May 15, 2024

Departing SiDet Lab B

Arriving at MINOS building



Moving Underground

May 15, 2024

Arriving at MINOS underground tunnel

Overview

Status Update

Calibration Plan

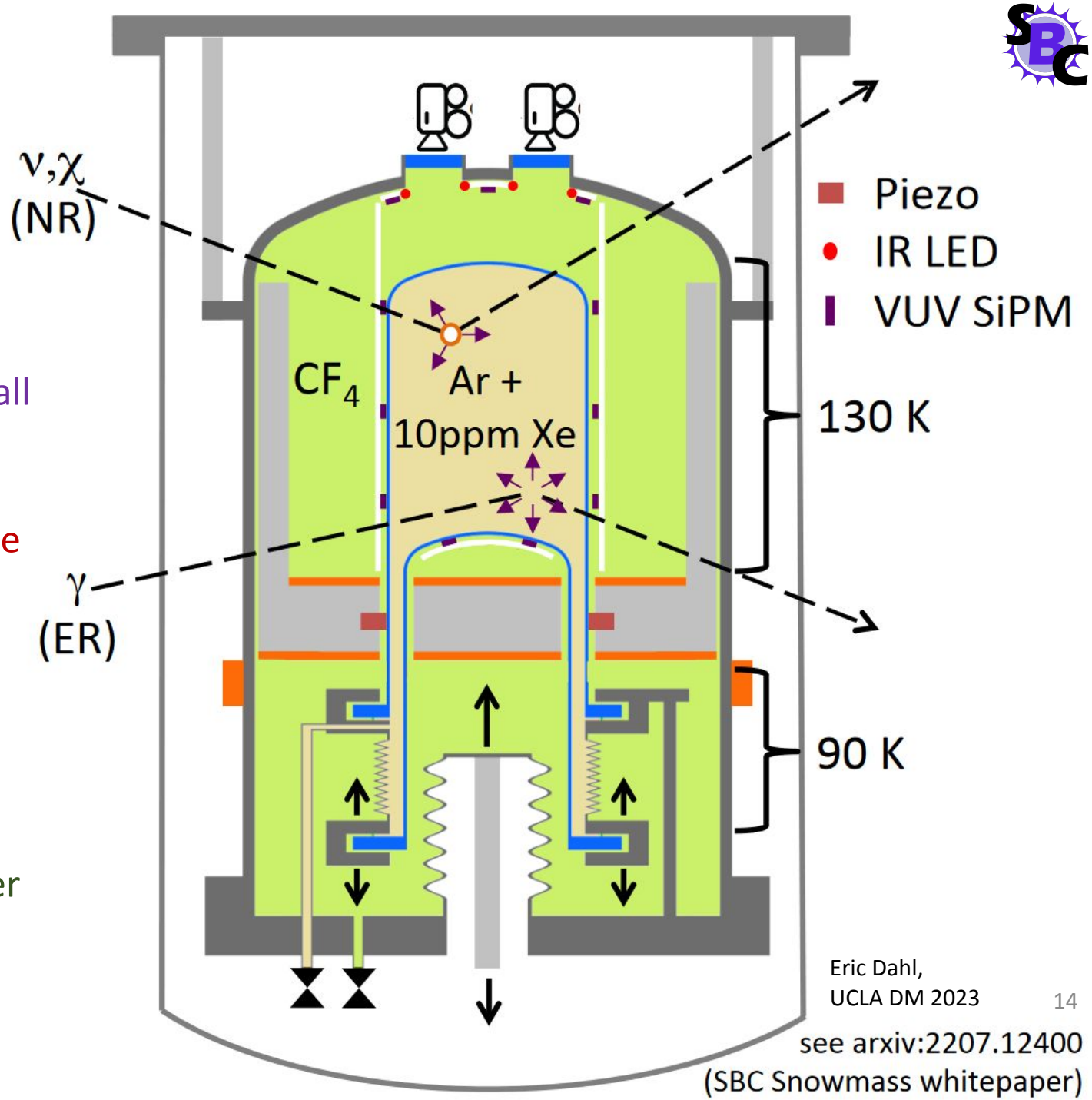
Questions to answer with the calibration chamber:

Can we operate the chamber as expected? Do all the data streams work together?

What's the lowest thermodynamic threshold we can operate the bubble chamber at while still being insensitive to ERs?

What's the lowest energy of NRs that can nucleate bubbles at that threshold?

Can we set a (even if not very good) dark matter limit with the background data collected?



see arxiv:2207.12400
(SBC Snowmass whitepaper)

Electron recoil (ER) calibration

- Operation of chamber at multiple thermodynamic thresholds
- Multiple gamma sources – explore limit of ER blindness
  - Consistent elevated bubble rate above background
- Used to determine ideal operating conditions
- Scintillation can also be used to study ER light yield in LAr and LCF4

How superheated can we get?

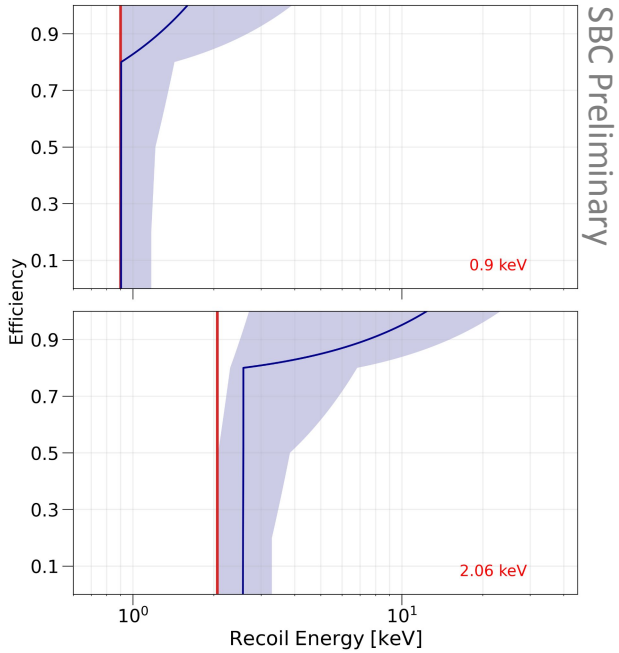
Liu 2023 – All metal argon bubble chamber

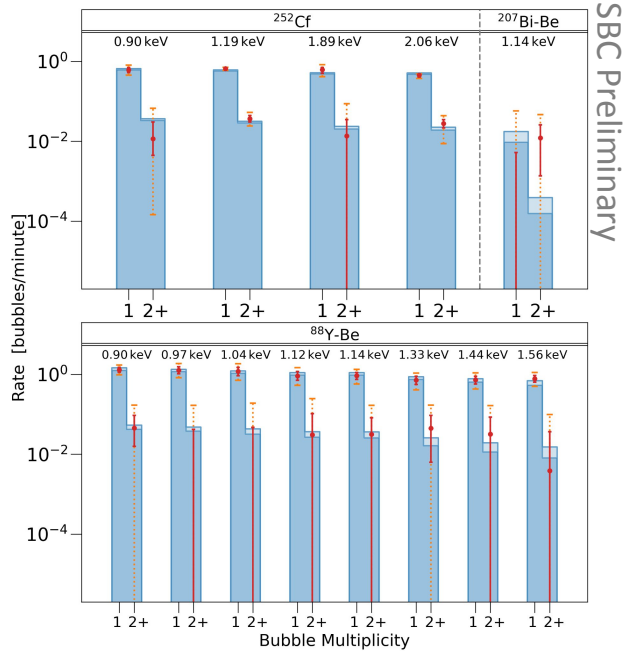
Nuclear recoil (NR) strategy

- Run the chamber at target (100 eV) thermodynamic threshold
- Using multiple sources with argon nuclear recoil energies spanning 100 eV to 3 keV range
- See which of the NR sources nucleate bubbles

Why this is necessary:

- calculated threshold is only accurate to a factor of 2 at best (red and blue lines not overlapping)
- The threshold calculation has never been tested below 1 keV





Red: calculated thermodynamic threshold

Blue: measured bubble nucleation efficiency from various sources (each at its NR energy)

XeBC nuclear efficiency plots (WIP)

NR calibration sources

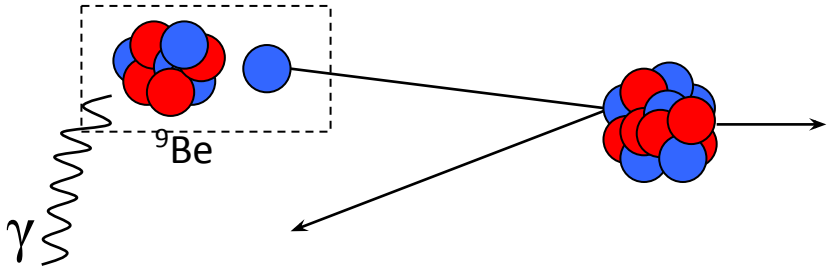
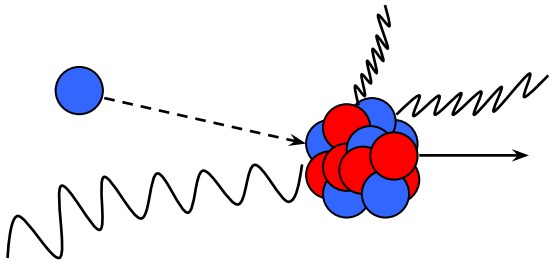
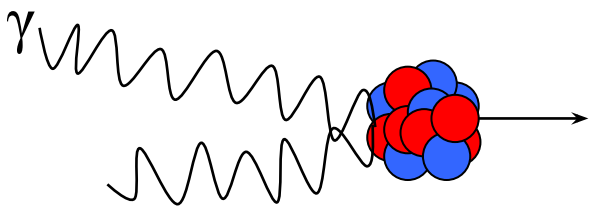


Photo-neutrons (> 500 eV E_r)
- Multi-bubble events
- Study bubble nucleation efficiency



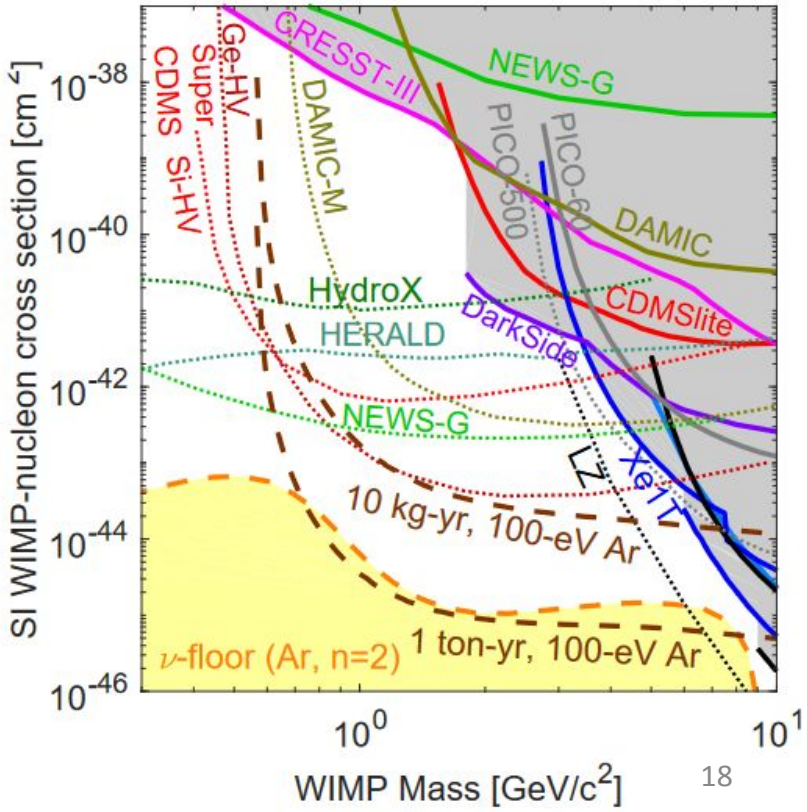
Thermal neutrons (200 – 500 eV E_r)
- With scintillation



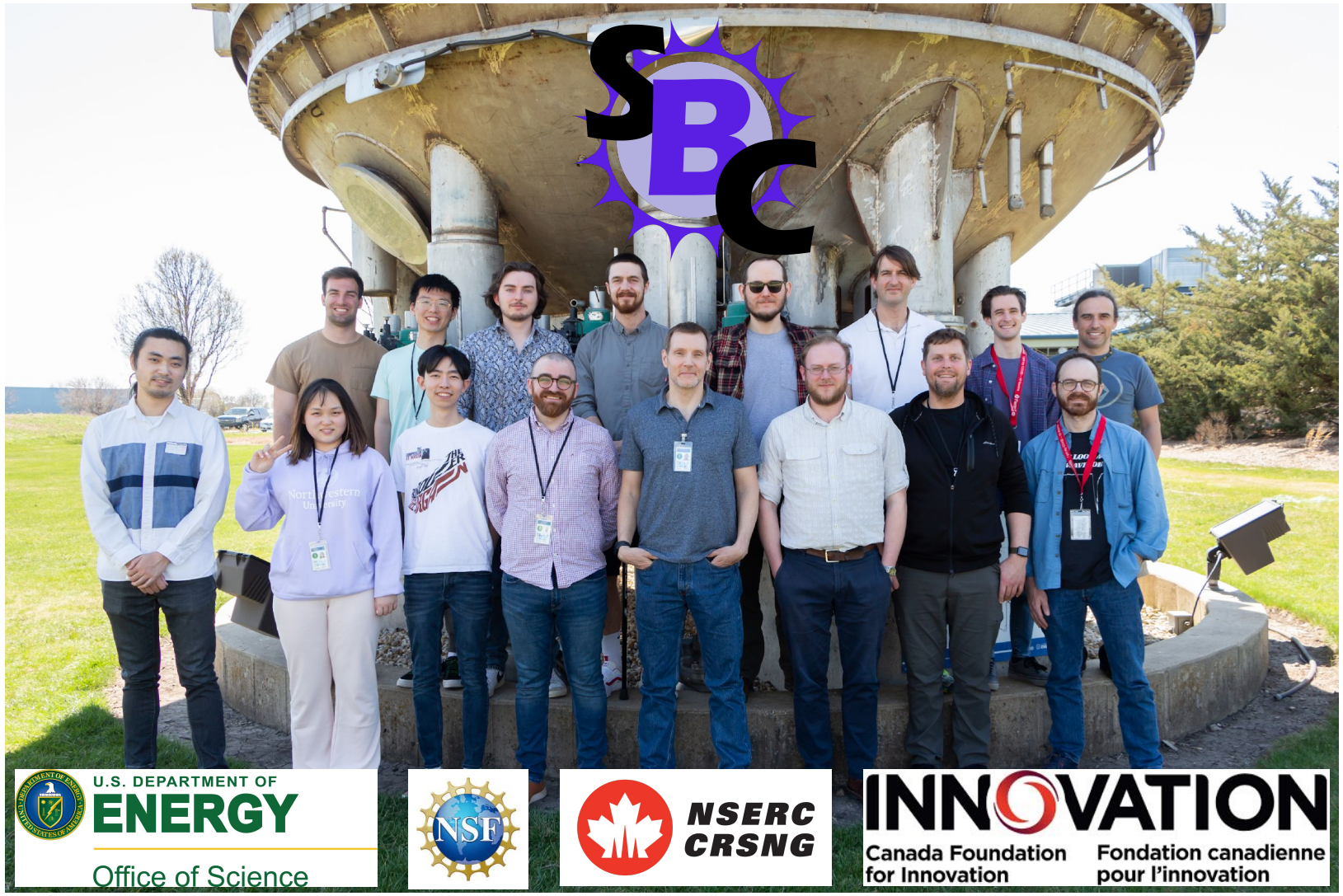
Gamma sources (< 300 eV E_r)
- Photo-nucleus Thomson scattering

Dark matter analysis

- Using background data during ER calibration
- Get upper limit using total number bubbles seen in data
- Compare to background model in MINOS
  - no background subtraction



This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education for the DOE under contract number DE-SC0014664.



Northwestern University
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- Jonathan Corbett
- Austin De St Croix
- Koby Dering
- Hector Hawley
- Gary Sweeney
- Ezri Wyman

University of Alberta
- Marie-Cécile Piro
- Carsten Krauss
- Mitchel Baker
- Daniel Durnford
- Youngtak Ko

SNOLAB
- Jeter Hall
- Alex Claveau

TRIUMF
- Pietro Giampa

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- Mathieu Laurin
- Pierre Frédérick

Northeastern University
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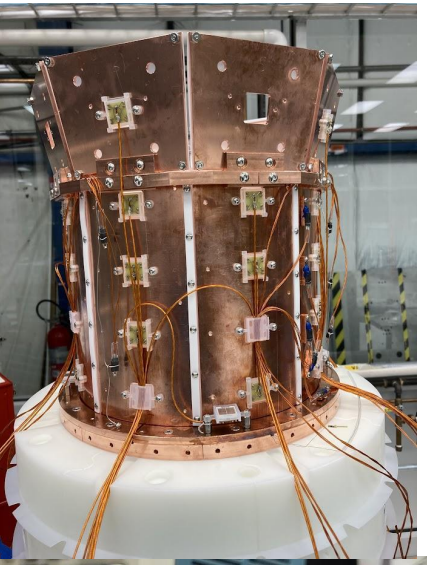
- Logan Joseph
- TJ Whitis
- Runze Zhang

Fermilab
- Gray Putnam
- Vrushank Patel

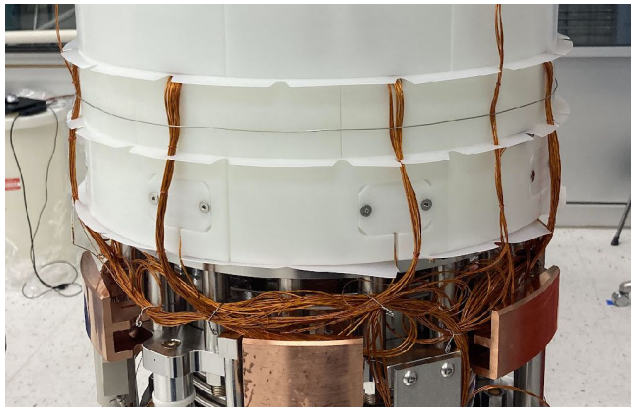
PennState
- Shashank Priya

Back Up Slides

Data Acquisition System

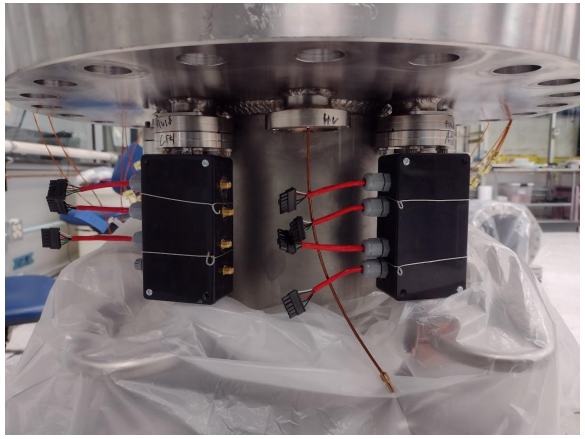


SiPM panel

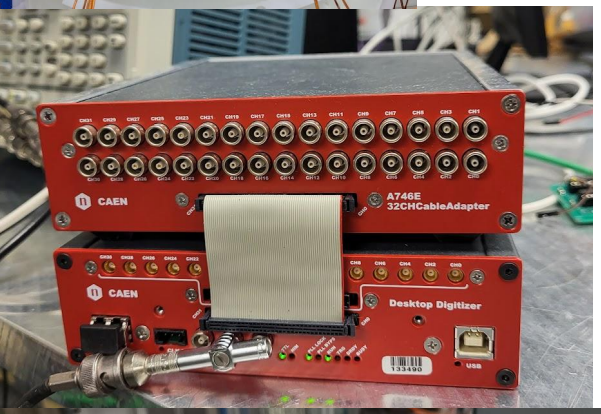


Piezo housing

Acoustic preamplifier



CAEN digitizer



SiPM amp

Back-Up: NR calibration sources

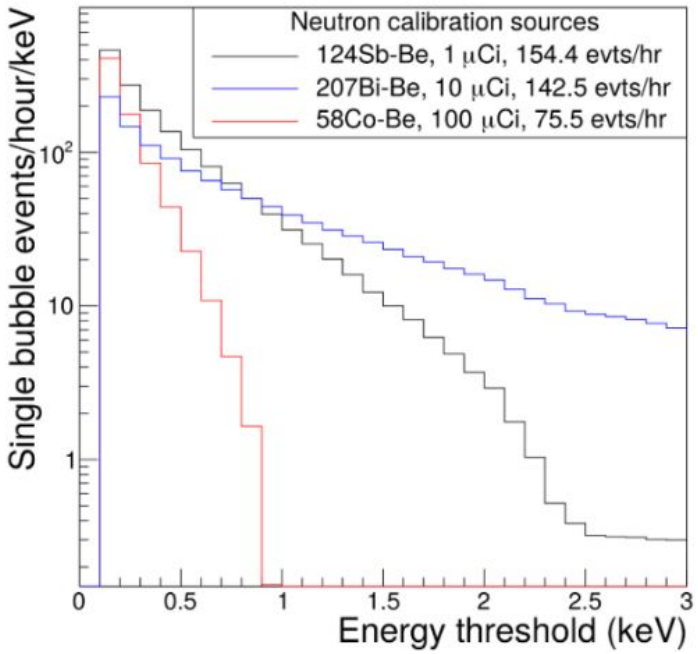
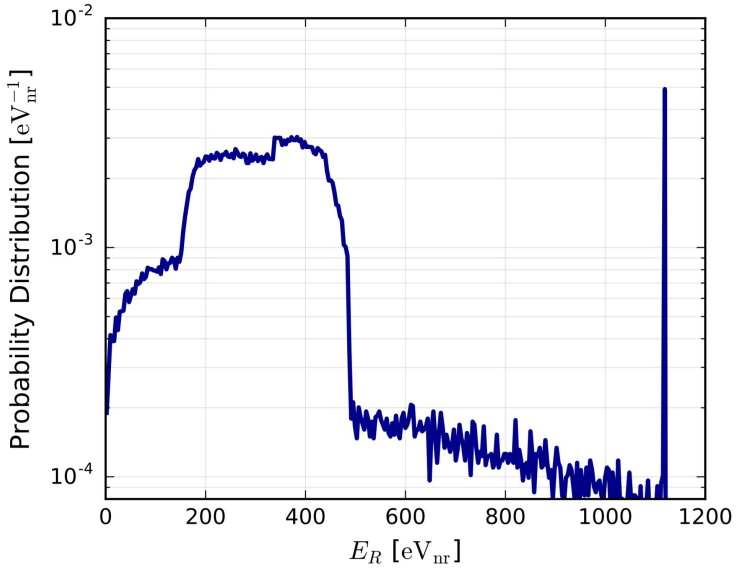
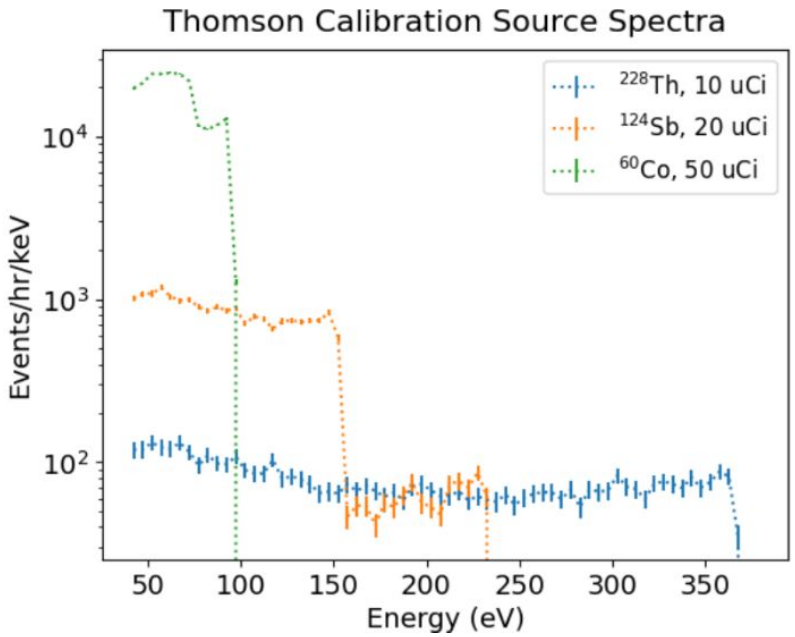


Photo-neutron scattering
(recoil > 500eV)



Neutron capture
(200eV < recoil < 500eV)



Photon-nucleus scattering
(recoil < 300eV)