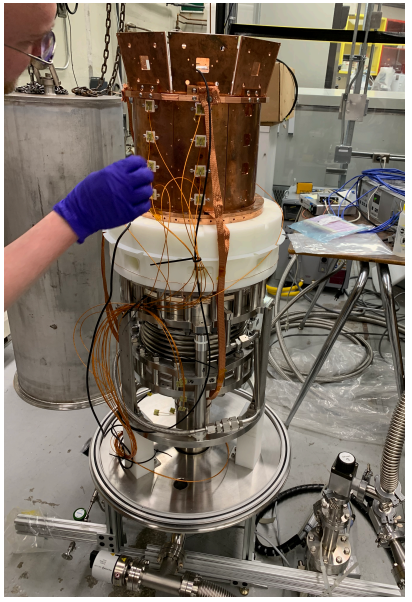
Updates from the Scintillating Bubble Chamber Collaboration



Eric Dahl
Northwestern / Fermilab

UCLA DM – March 31, 2023

Northwestern University

- **Eric Dahl**
- Xingxin Liu
- Zhiheng Sheng
- Ari Sloss
- Wei Zha

Queen's University

- **Ken Clark**
- Ben Broerman
- Jonathan Corbett
- Austin De St Croix
- Koby Dering
- Hector Hawley
- Gary Sweeny
- Ezri Wyman

University of Alberta

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

SNOLAB

- Jeter Hall
- Mike Hood

TRIUMF

- Pietro Giampa

Université de Montréal

- Mathieu Laurin
- Pierre Frédérick

Northeastern University

- Orin Harris

UC Riverside

- Shawn Westerdale

Universidad Nacional Autónoma de México

- Eric Vázquez-Jáuregui
- Ernesto Alfonso-Pita

Drexel University

- Russell Neilson
- Julian Fritz-Littman
- Noah Lamb
- Daniel Pyda

Indiana University South Bend

- Ilan Levine
- Ed Behnke
- Cody Cripe

UC Santa Barbara

- Hugh Lippincott
- Logan Joseph
- TJ Whitis
- Runze Zhang

Fermilab

- Mike Crisler
- Vrushank Patel

PennState

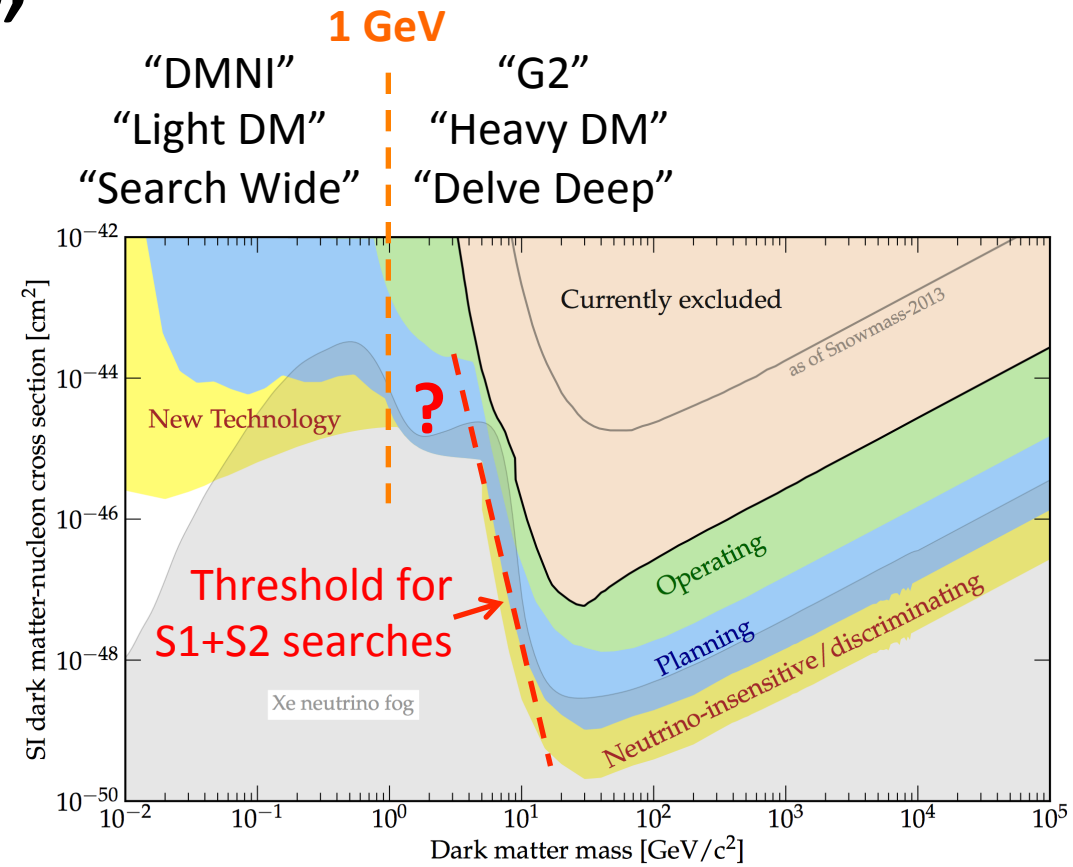
- Shashank Priya

“Mind the gap”

- We have built dichotomies:
  - in our language
  - in our technology

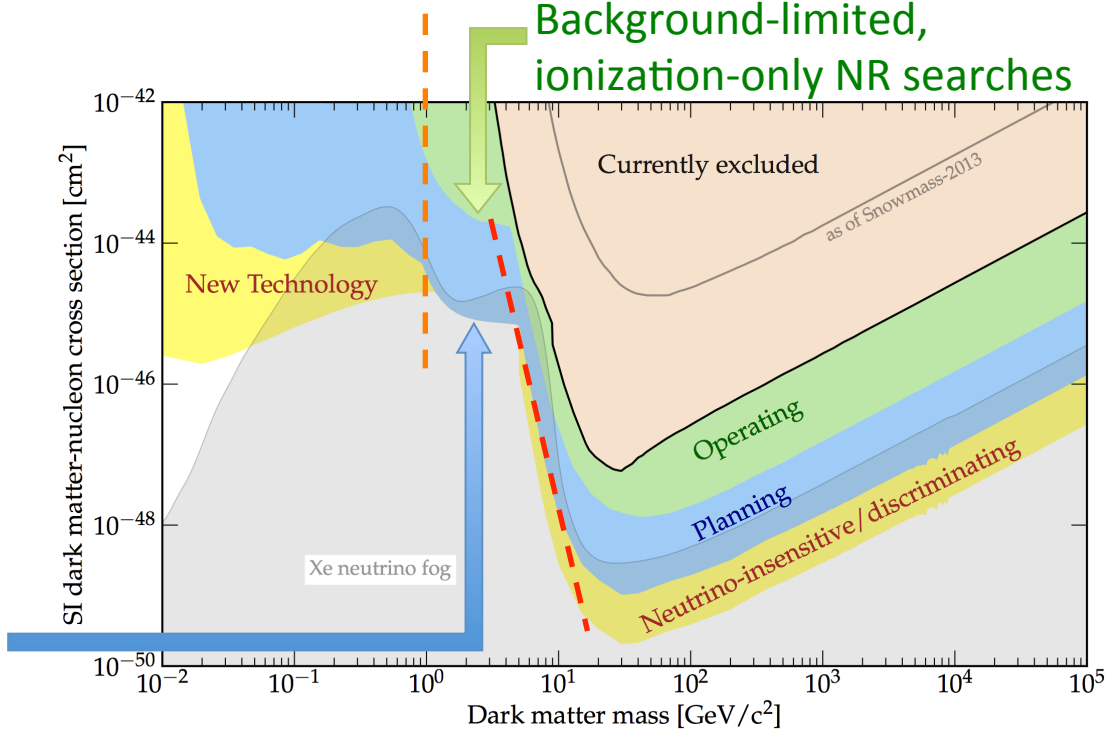
Both with good reason…

…but the two don’t match.



Exploring the ^{8}B CEvNS fog

- Requirements:
  - Scalability
    - O(1) ton-year
  - Threshold
    - ~3 MeV/c recoil momentum
  - Backgrounds
    - ER Discrimination
    - Fiducialization



Snowmass CF Report

E.g., n=2 in Ar fog @ 1 GeV requires

- 1 ton-year exposure
- 100 eV recoil energy threshold
- non-CEvNS bkg < 1 event / ton-year

No operating tech meets all three requirements!

Liquid Noble Bubble Chambers

Objective:

Quasi-background-free detection of sub-keV Nuclear Recoils

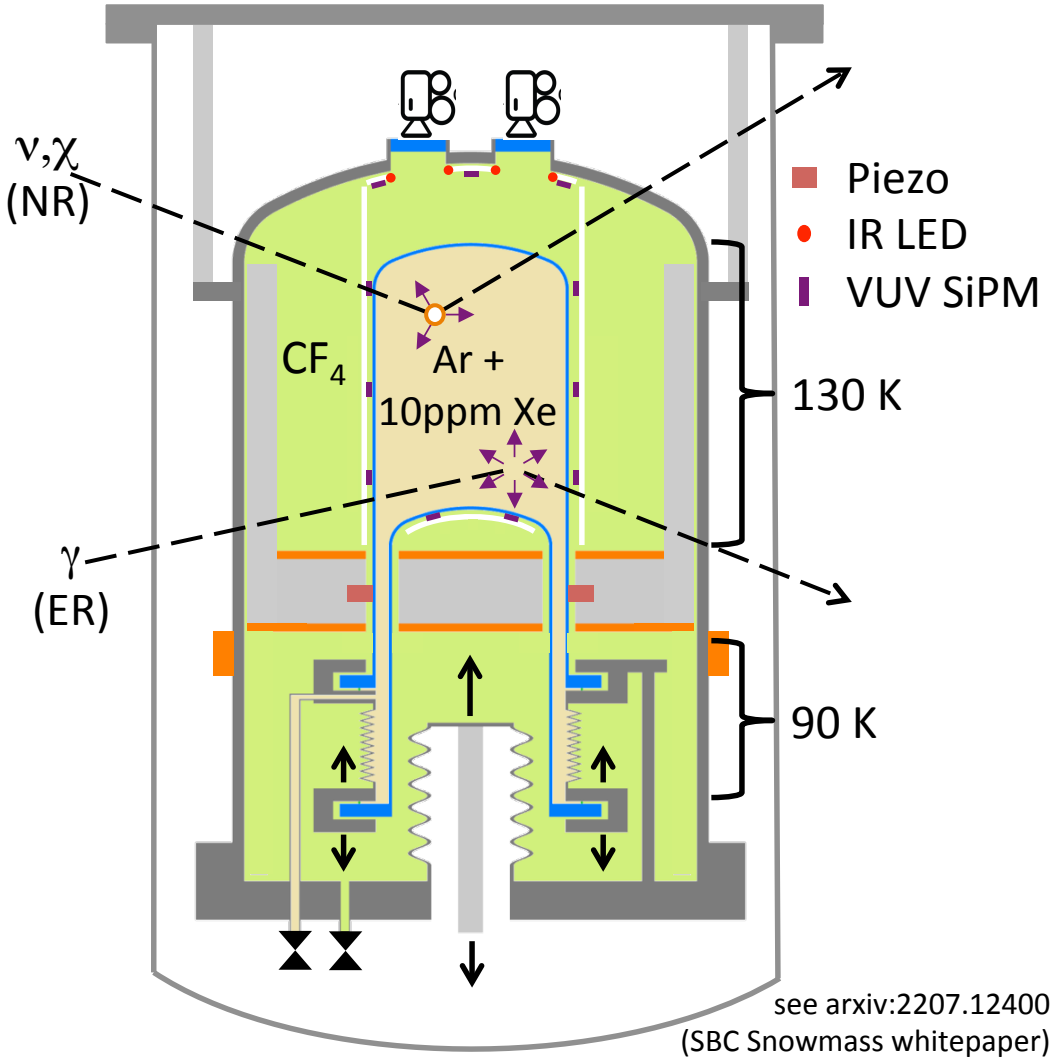
Signal:

Single bubble with little or no coincident scintillation

Backgrounds:

ER's (beta, gamma):
No bubbles

NR's (fast neutron):
Multiple bubbles
Strong coincident scintillation



see arxiv:2207.12400
(SBC Snowmass whitepaper)

Liquid N
Bubble

Objective:

Quasi-background-
of sub-keV Nuclear

Signal:

Single bubble with
coincident scintillat

Backgrounds:

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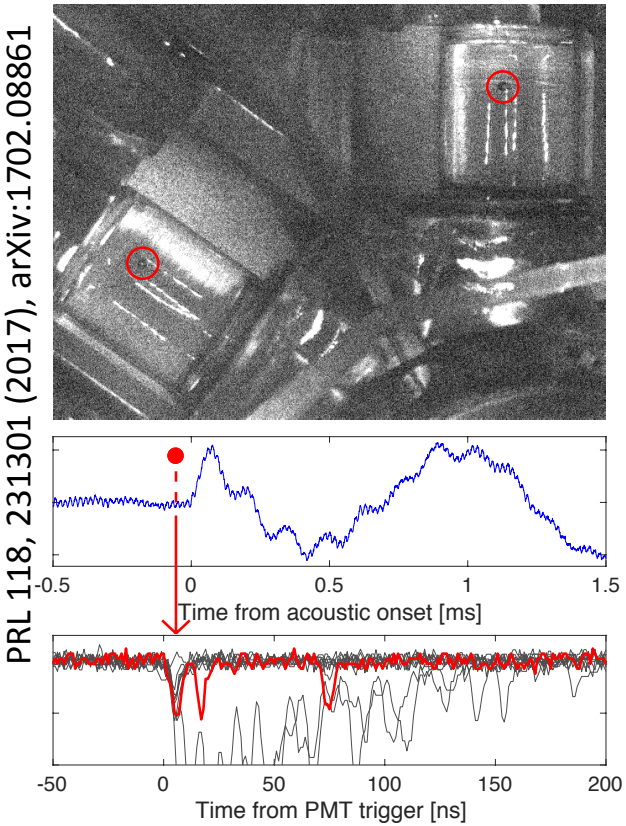
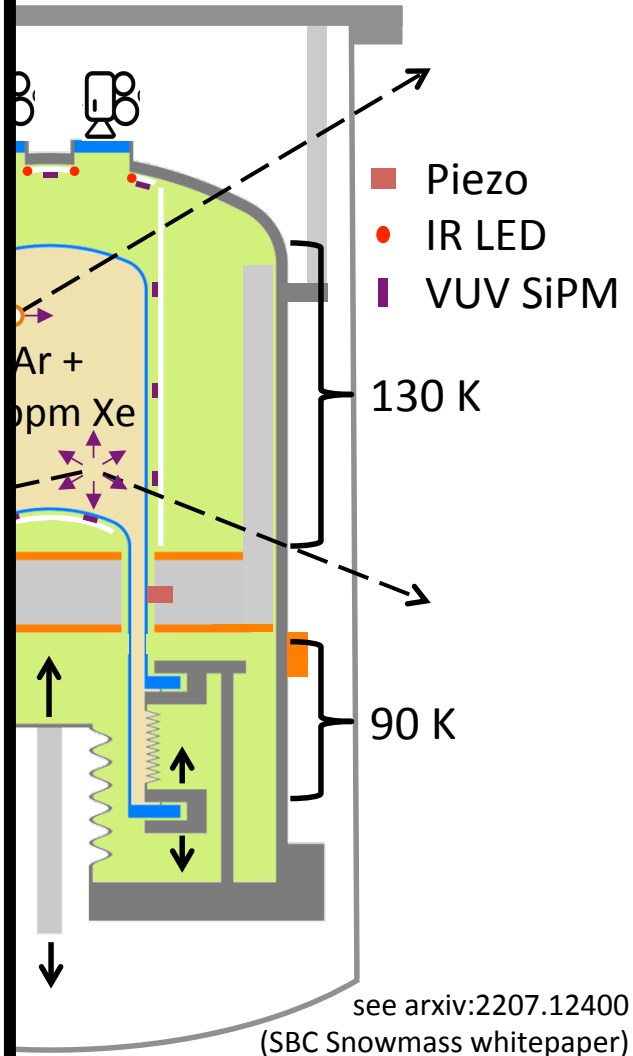
No bubbles

NR's (fast neutron)
Multiple bubbles
Strong coincident

2017

30-gram xenon prototype





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Liquid Noble Bubble Chambers

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Multiple bubbles
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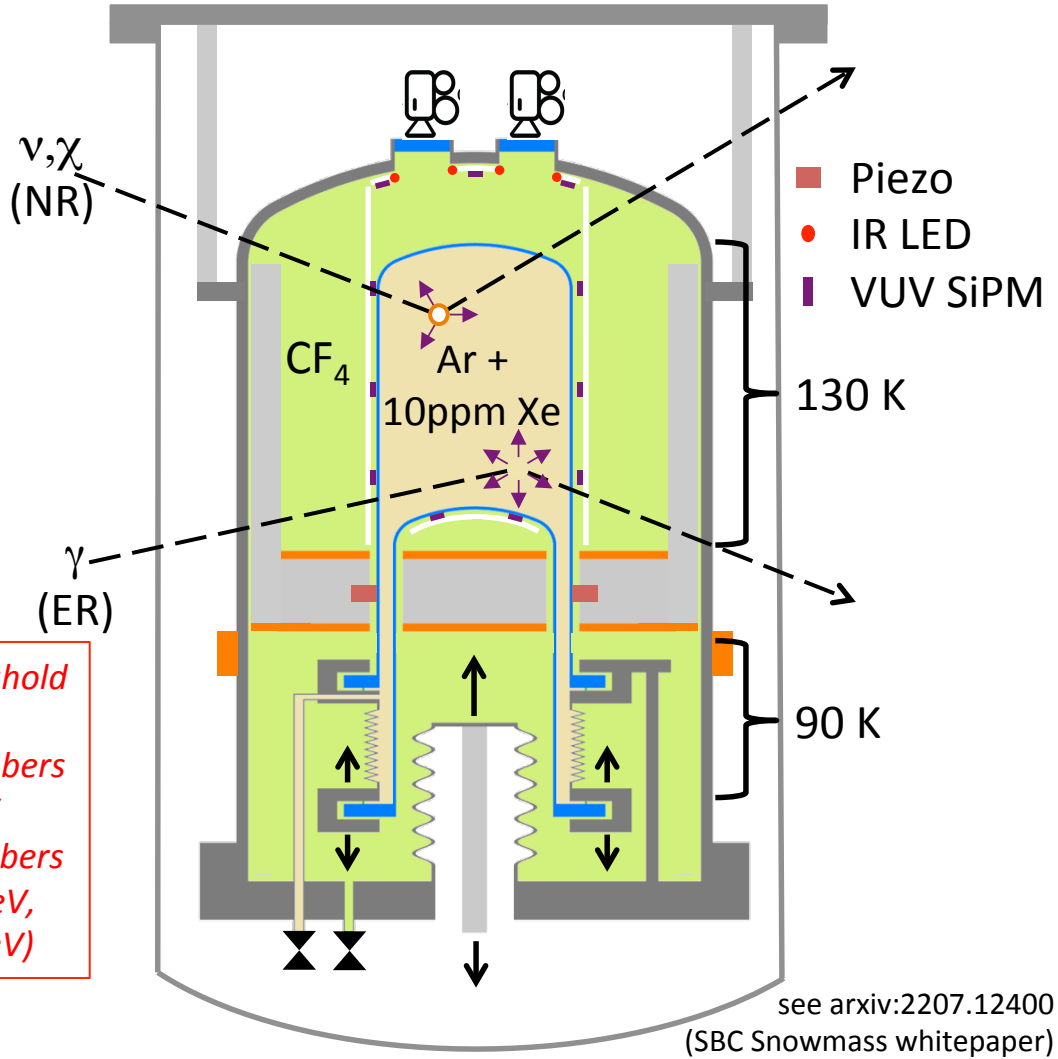
Depends on NR threshold and target fluid:
- *Freon-based chambers ER-blind @ ~3 keV*
- *Liquid-noble chambers ER-blind @ < 500 eV, (target 100 eV)*



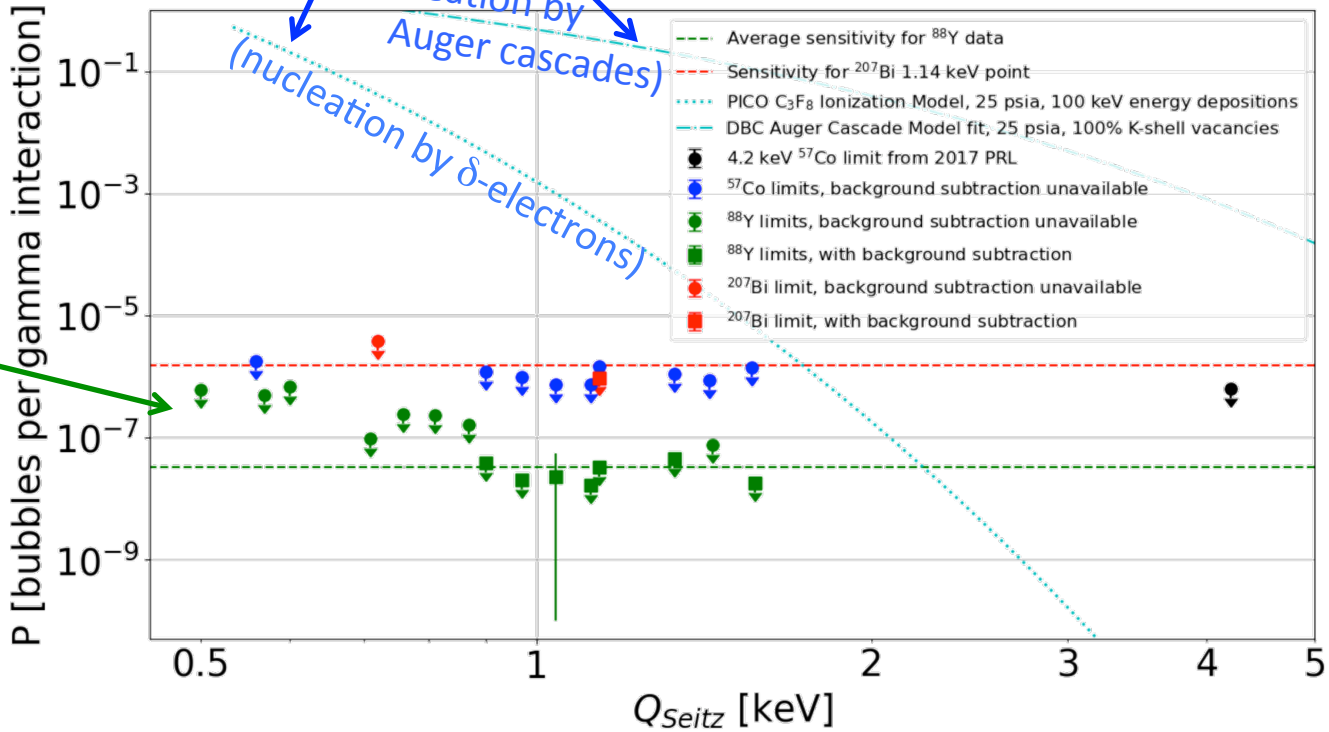
see arxiv:2207.12400
(SBC Snowmass whitepaper)

Performance at Low Threshold – ER's

ER's in PICO (nucleation suppressed by low dE/dx)

Lack of ER's in LXe

(nucleation suppressed by radiative losses)



M. Bressler, Drexel U, PhD Thesis (2022)

Performance at Low Threshold – ER's

No molecular degrees of freedom

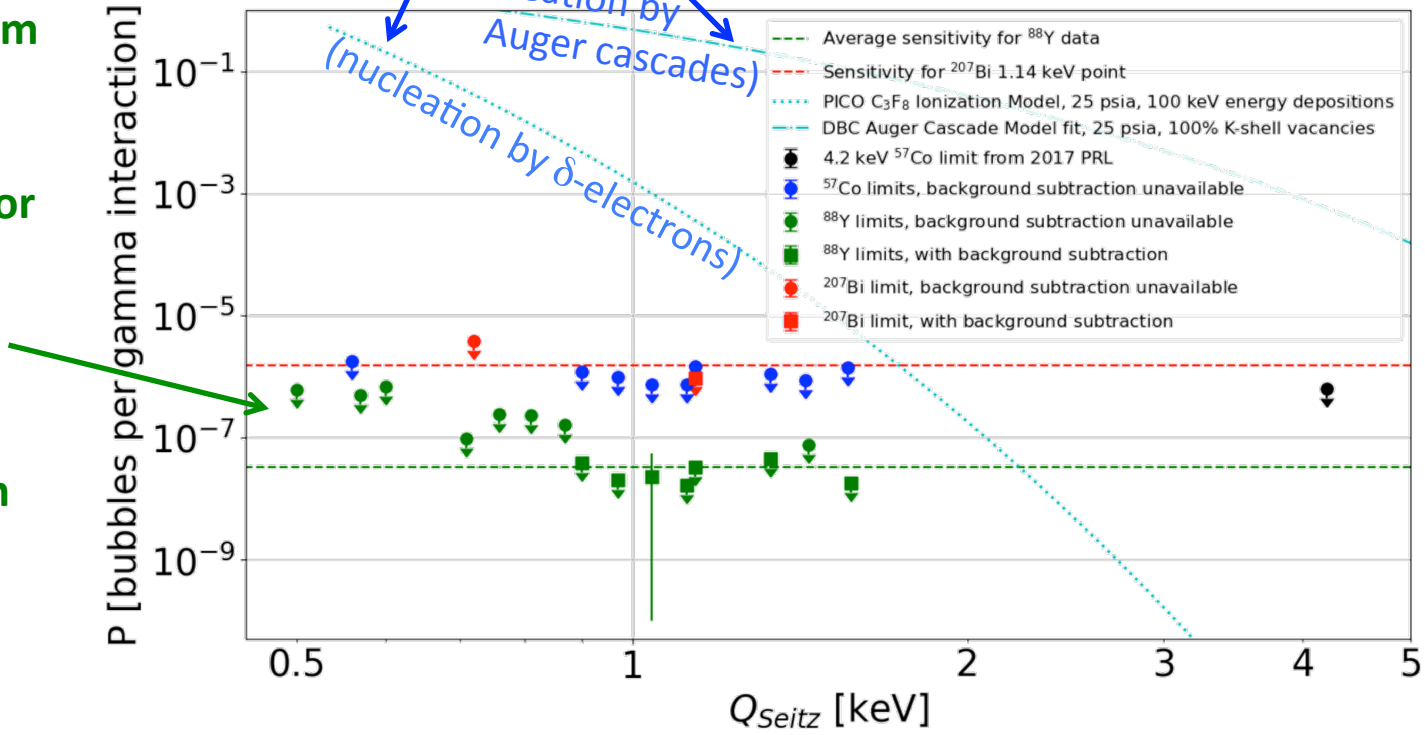
↓

No mechanisms for local heating by electrons

↓

No bubbles from ERs

ER's in PICO (nucleation suppressed by low dE/dx)



M. Bressler, Drexel U, PhD Thesis (2022)

Performance at Low Threshold – ER's

"Xenon, being predominantly a monatomic medium, has no rotational or vibration atomic oscillation modes, and as a result, it is effectively converting the energy of δ-electrons into light (scintillation). To convert the energy of scintillation into localised heat and enhance the formation of bubbles, molecular admixtures of ethylene or propane have been used in LXe bubble chambers."

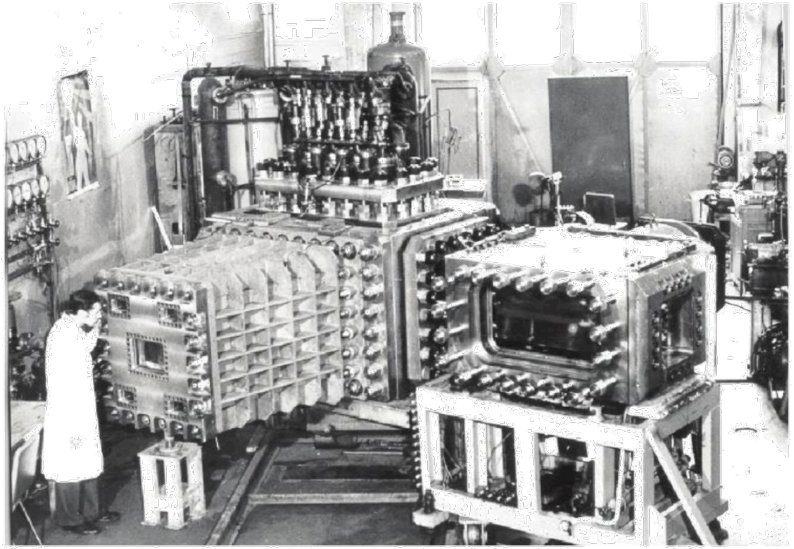
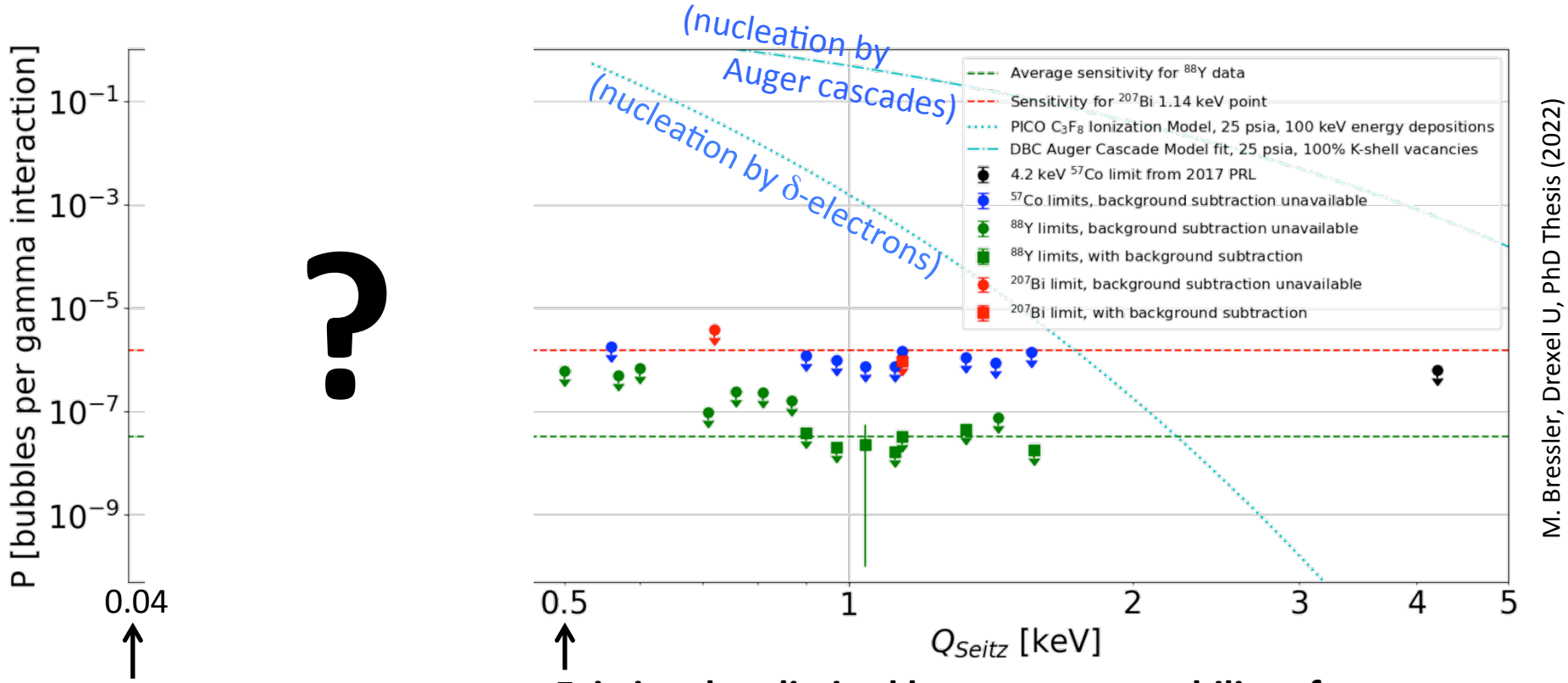


Figure 1.1 Liquid xenon bubble chamber DIANA with 1.5x0.7x 0.7 m^3 active volume constructed at ITEP in the 1970s. Courtesy of A.G. Dolgolenko.

Bolozdynya, Alexander I. Emission Detectors. Singapore: World Scientific, 2010.

M. Bressler, Drexel U, PhD Thesis (2022)

Performance at Low Threshold – ER's



Homogeneous nucleation (1 bubble / ton-yr in LAr)

Existing data limited by pressure capability of prototype

M. Bressler, Drexel U, PhD Thesis (2022)

Performance at Low Threshold – NR's

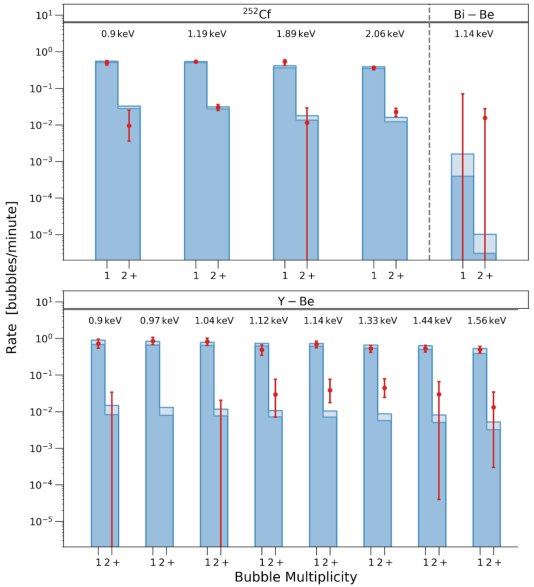
- Neutron Scattering
  - C_3F_8 @ 3 keV:
    $E_{NRthreshold} \approx 1.5 \times Q_{seitz}$

    [Ali *et al*. Phys Rev **D 106**, 122003, (2022)]

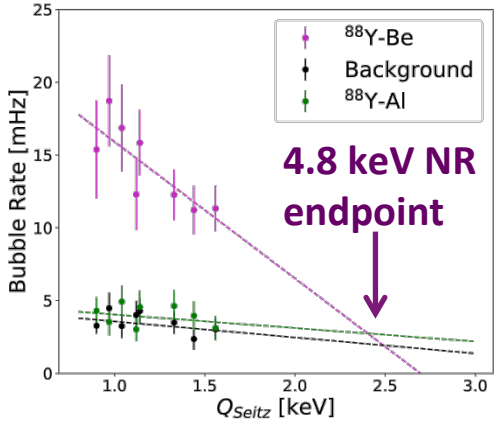
  - Xe @ 1.5 keV:
    $E_{NRthreshold} \approx 1.5 \times Q_{seitz}$ →

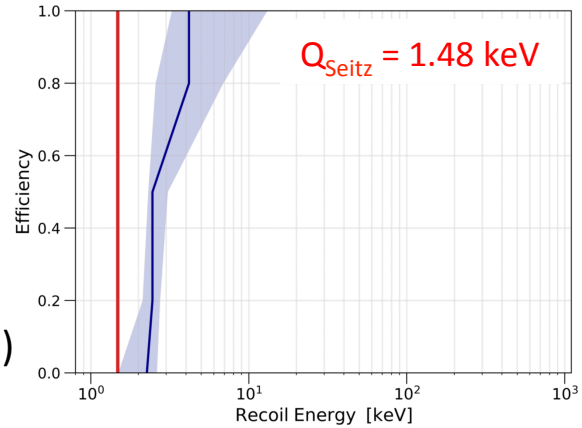
- MD Simulations
  - L-J Fluid @ 3,000 ε (Ar @ 40 eV):
    $E_{NRthreshold} \approx 1.5 \times Q_{seitz}$

    [Denzel, Diemand, Angélil. Phys Rev **E 93**, 013301 (2016)]



(Xe NR analysis by D. Durnford)





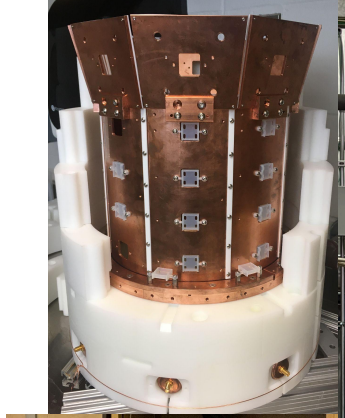
SBC-LAr10

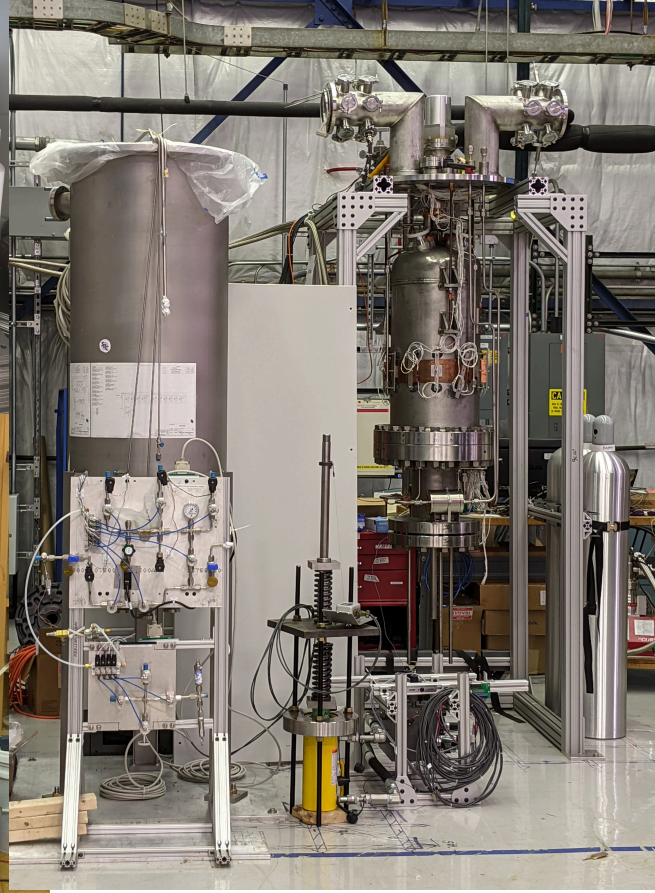
At a glance:

- 10kg LAr target
  - Xe, CF_4, N_2 also possible in same device
- Designed to operate @ Q = 40 eV
- Scintillation detection system:
  1 phd / 5 keVr ($g_1 \approx 0.02$) (simulated)

- Deploying in MINOS tunnel @ Fermilab
- Objectives:
  - Determine max ER-blind superheat in LAr
  - Calibrate NR response
    - down to 100 eV
    - with 10 eV resolution

Supported by Fermilab LDRD and Detector R&D





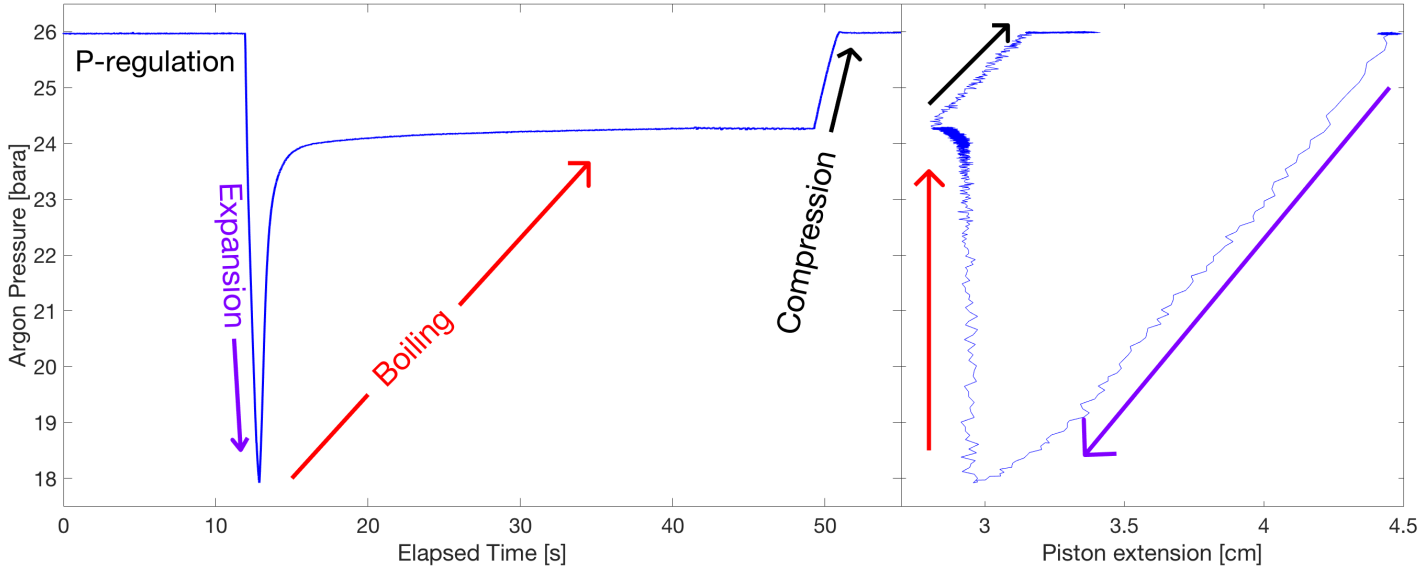
^SiDet Lab B (Fermilab)

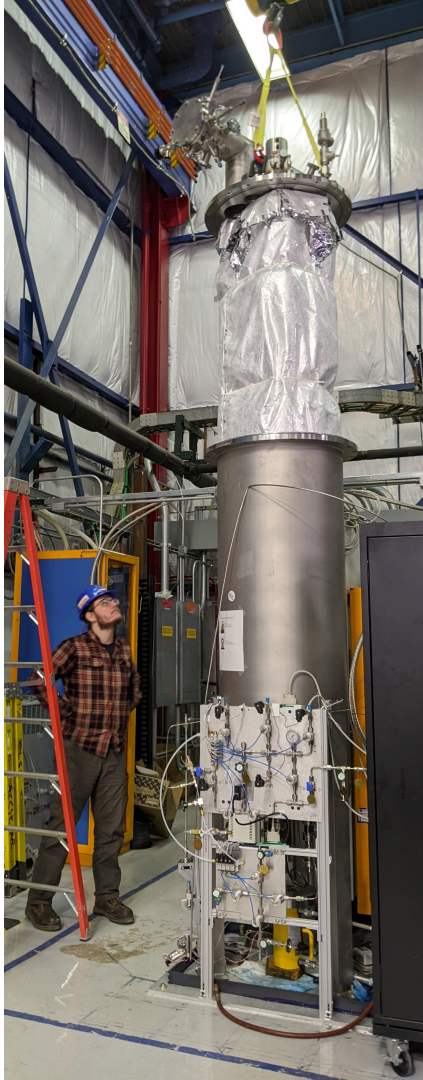
<- inner assembly @ Queen's (now @ SiDet)

SBC-LAr10 – Engineering Run

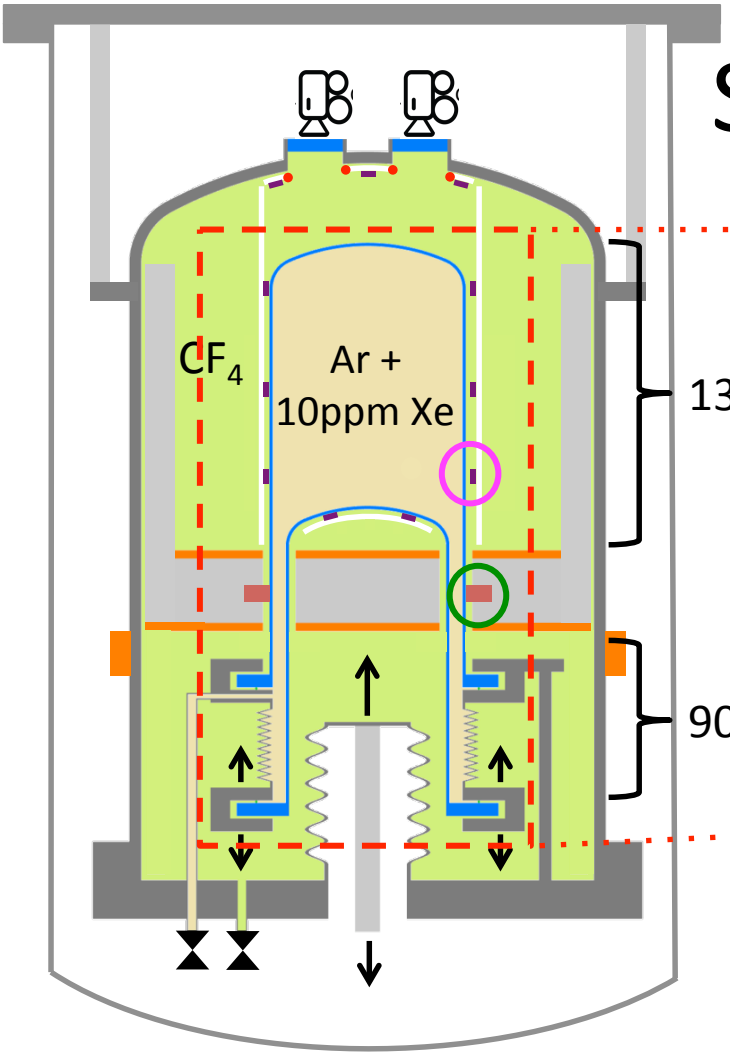
Dec 2022 – March 2023, @ SiDet (Fermilab)

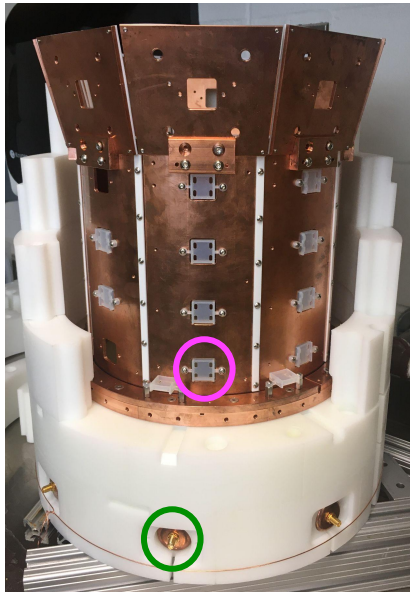
- 100kg LAr condensed in pressure vessel ; no inner assembly
- Demonstrated:
  - Thermal performance: cooling power, base temperature, thermal gradient
  - Pressure control: 0.01 bara precision in single-phase (liquid) state
  - Slow Controls and automation – pressure cycling!





SBC-LAr10: Inner Assembly

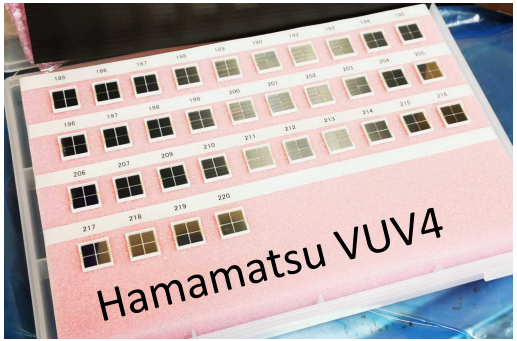


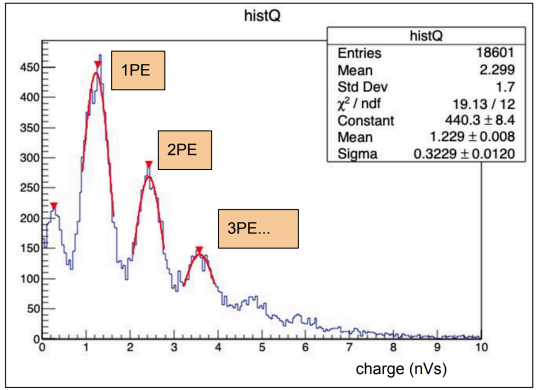


- Built and tested @ Queen's
  - Key test: cryogenic performance of jar seals
- Now @ Fermilab
  - Installation begins April 11

and much more …

- Electronics and DAQ
  - SiPM characterization
  - SiPM amplifiers and digitizers
  - Bubble chamber optics and illumination
  - Image acquisition
  - Acoustic sensors, amplifiers, and digitizers
  - ***Cryogenic QA of all of the above***
  - Trigger logic and Run Control
- Simulations and Backgrounds
  - Scintillation light collection
  - LCF_4 Scintillation light yield measurements
  - Surface nucleation studies
  - Backgrounds in MINOS tunnel





^ SiPM Performance in high-pressure LCF_4 with full electronics chain

Many students working many hours to bring this together!

Calibration Strategies
(for the ER-blind)

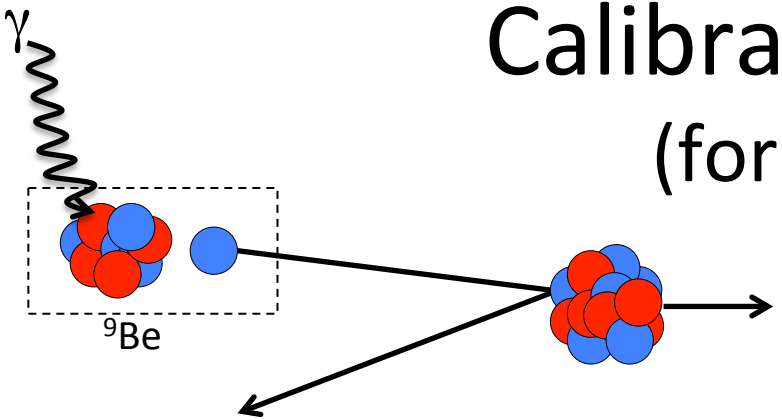
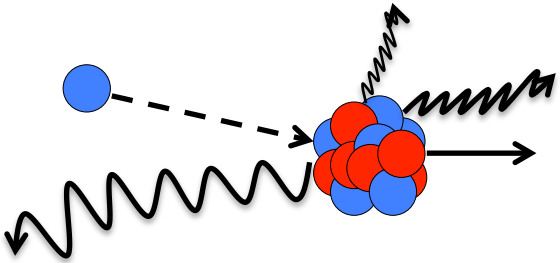
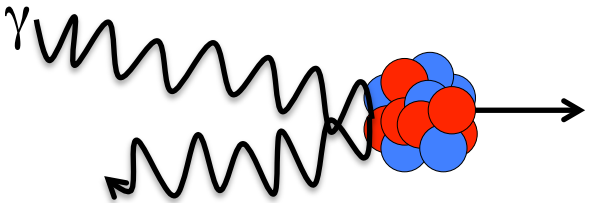


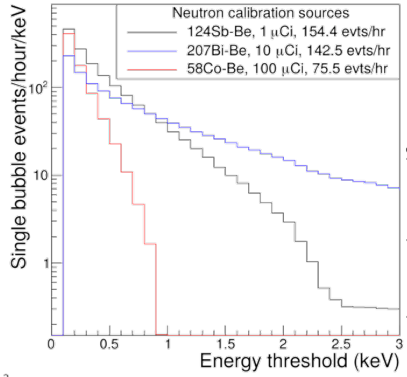
Photo-neutron Sources
(> 500 eV recoils)



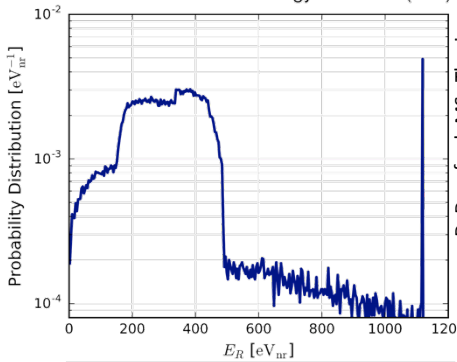
Thermal neutron Capture
(200 – 500 eV recoils)



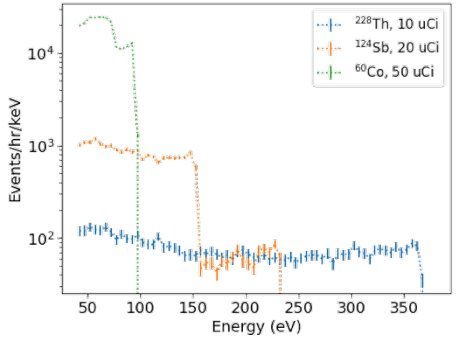
Photon-nucleus Scattering
(< 300 eV recoils)



Plot credit: E. Alfonso

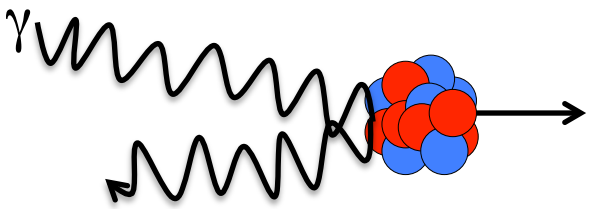


D. Durnford, MSc Thesis
http://hdl.handle.net/1974/24878

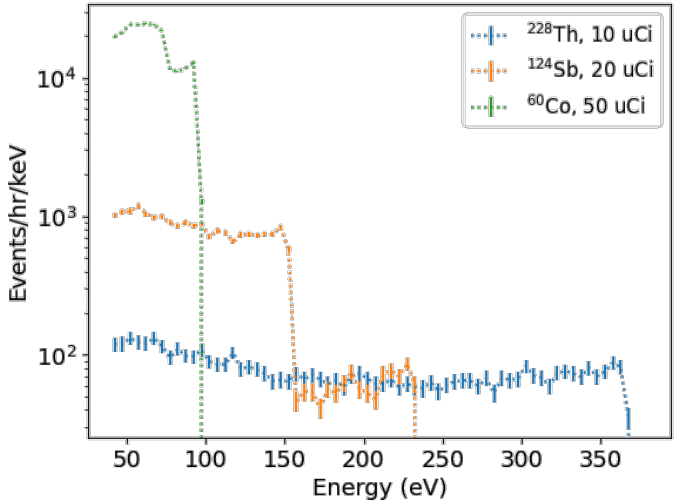


Plot credit: N. Lamb

Calibration Strategies

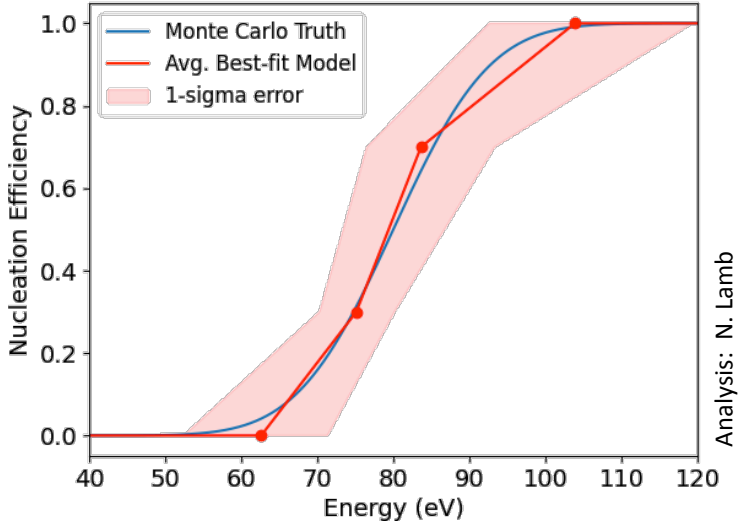


Photon-nucleus Scattering



Mock analysis based on observed bubble rates with a suite of three gamma sources

(assumes no nucleation by ER's)

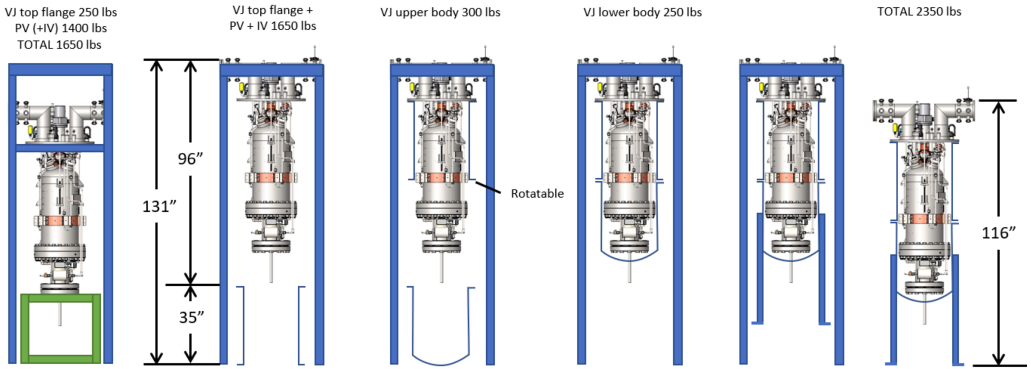


On to Dark Matter

SBC-LAr10: SNOLAB

CFI-supported, radiopure clone of SBC-LAr10

- Major procurements underway
  - With lessons learned from FNAL engineering run
- SNOLAB TDR planned for Fall 2023
  - Rapid progress towards critical TSSA approvals
  - Multiple shield options under consideration



Summary

- As a field, we don't (yet) know how to delve deep at 1 GeV
- Liquid Noble Bubble Chambers
  - Scale to ton-yr exposures
  - Discriminate @ low-threshold
- SBC-LAr10 @ Fermilab…
  - will tell us *how low* in threshold discrimination persists
  - will turn on in FY24
- SBC-LAr10 @ SNOLAB gearing up for our first DM search