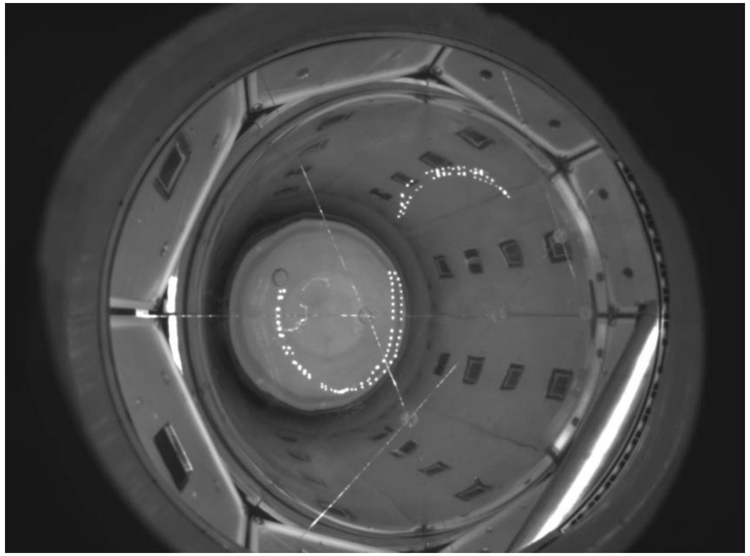
First Bubbles in the SBC-LAr10 Detector



Russell Neilson, Drexel University

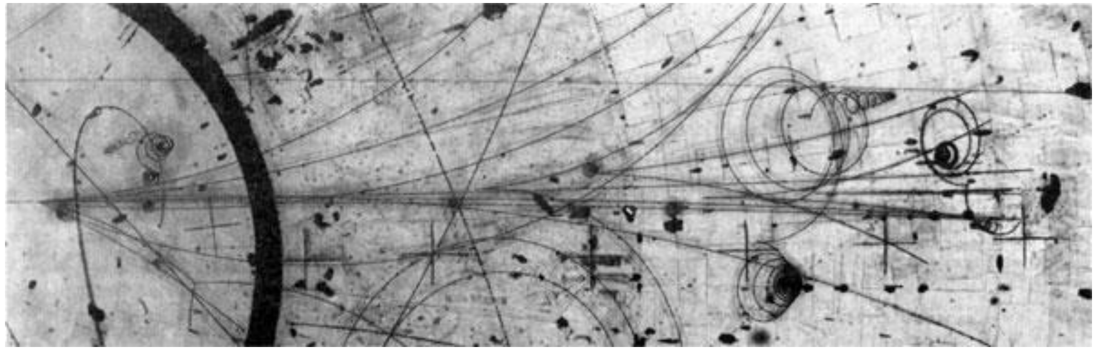
On Behalf of the SBC Collaboration

CosPA, University of Canterbury

July 8, 2026

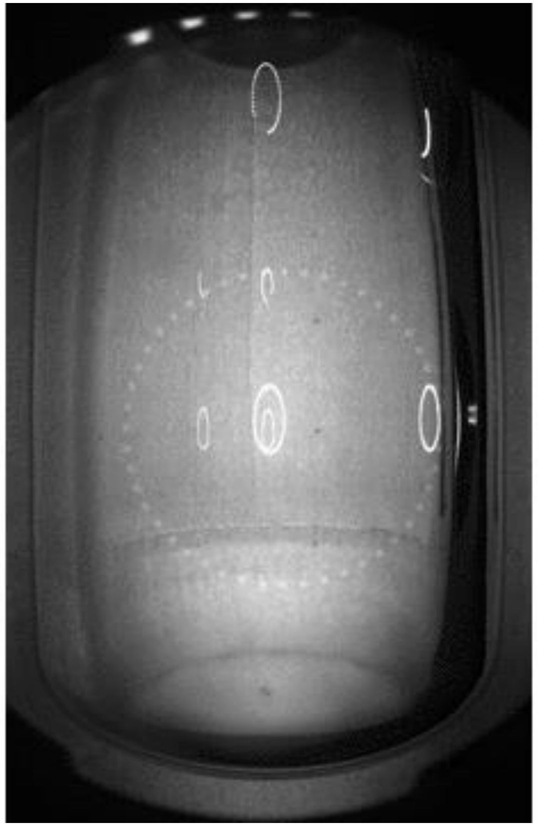
Physics with Bubble Chambers

- 1970s: Neutrino Beam Physics

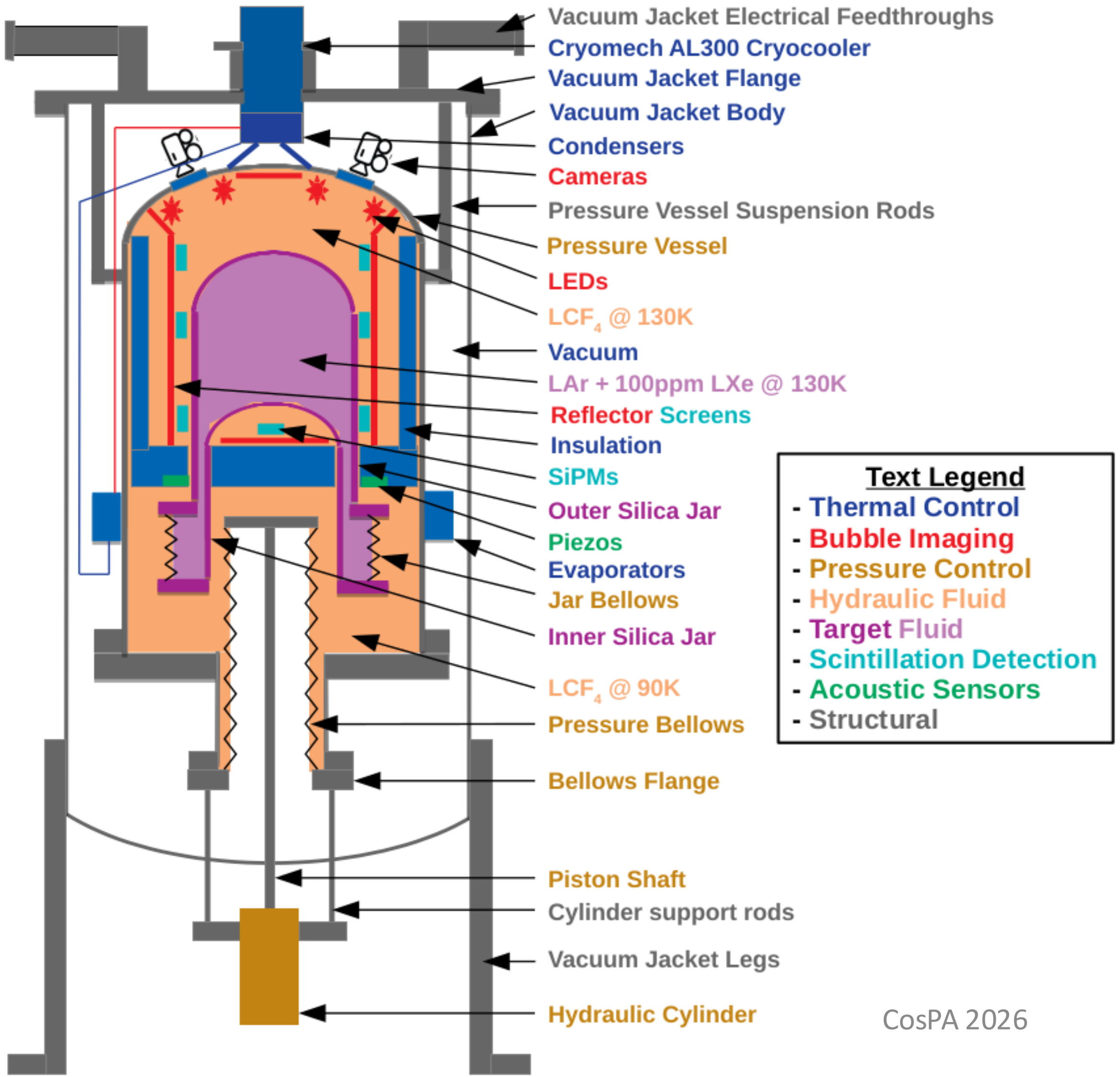


  - Sensitive to minimum ionizing particles
  - Particle tracks visible
  - Threshold <<1 keV
  - Multi-ton chambers, multiple fluids

- 2000-today: Nuclear Recoil Detectors
  - Dark matter searches with fluorocarbon bubble chambers
  - **Electron recoil blind**
  - Nuclear recoil threshold ~3keV
  - Scalable at modest cost



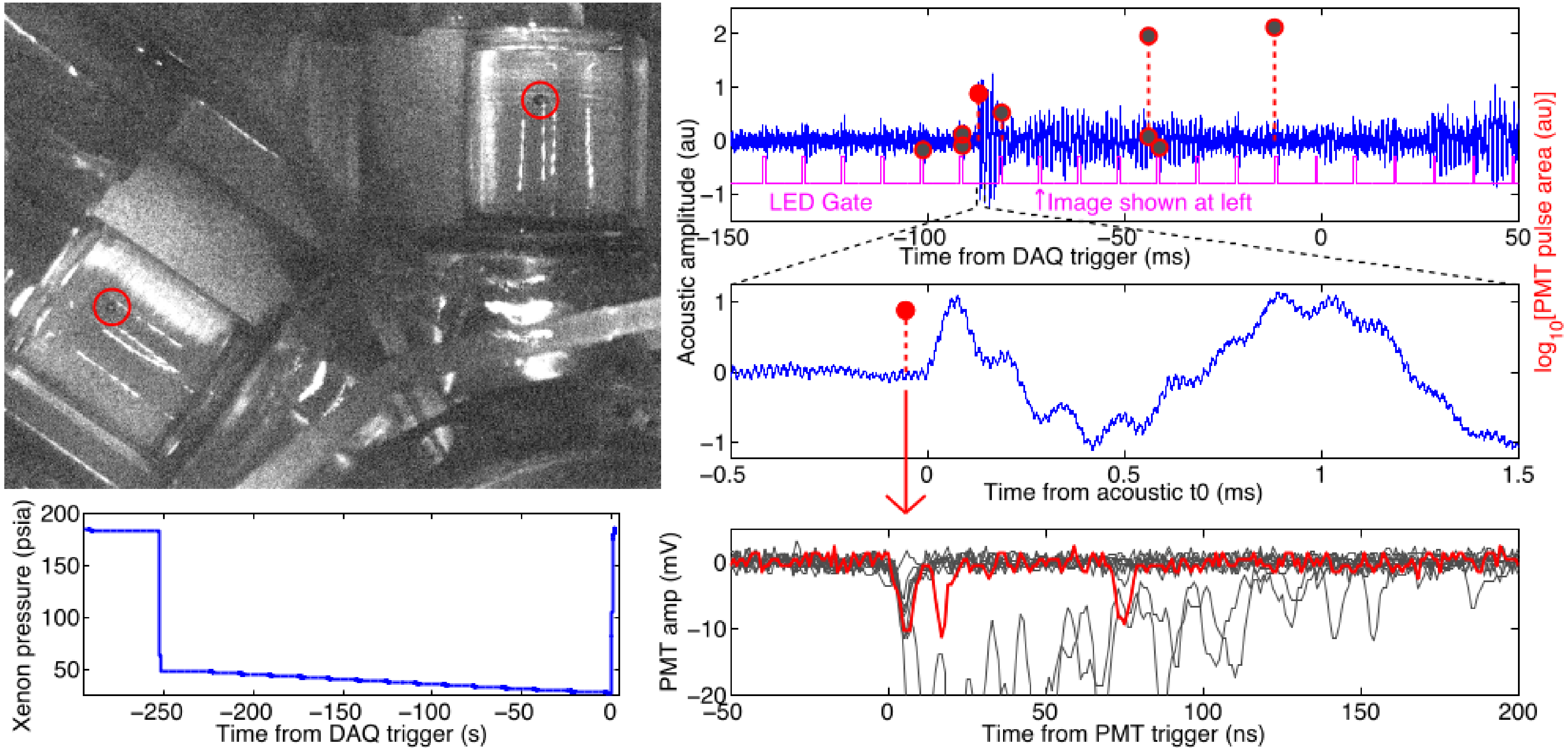
SBC
(Scintillating Bubble Chamber)



- 10kg liquid argon target with O(100) ppm Xe for wavelength shifting.
- Goal of 100eV nuclear recoil threshold while remaining electron recoil blind.
- Bubbles detected with cameras and pressure/acoustics.
- SiPMs for scintillation detection – scintillation threshold few keV.

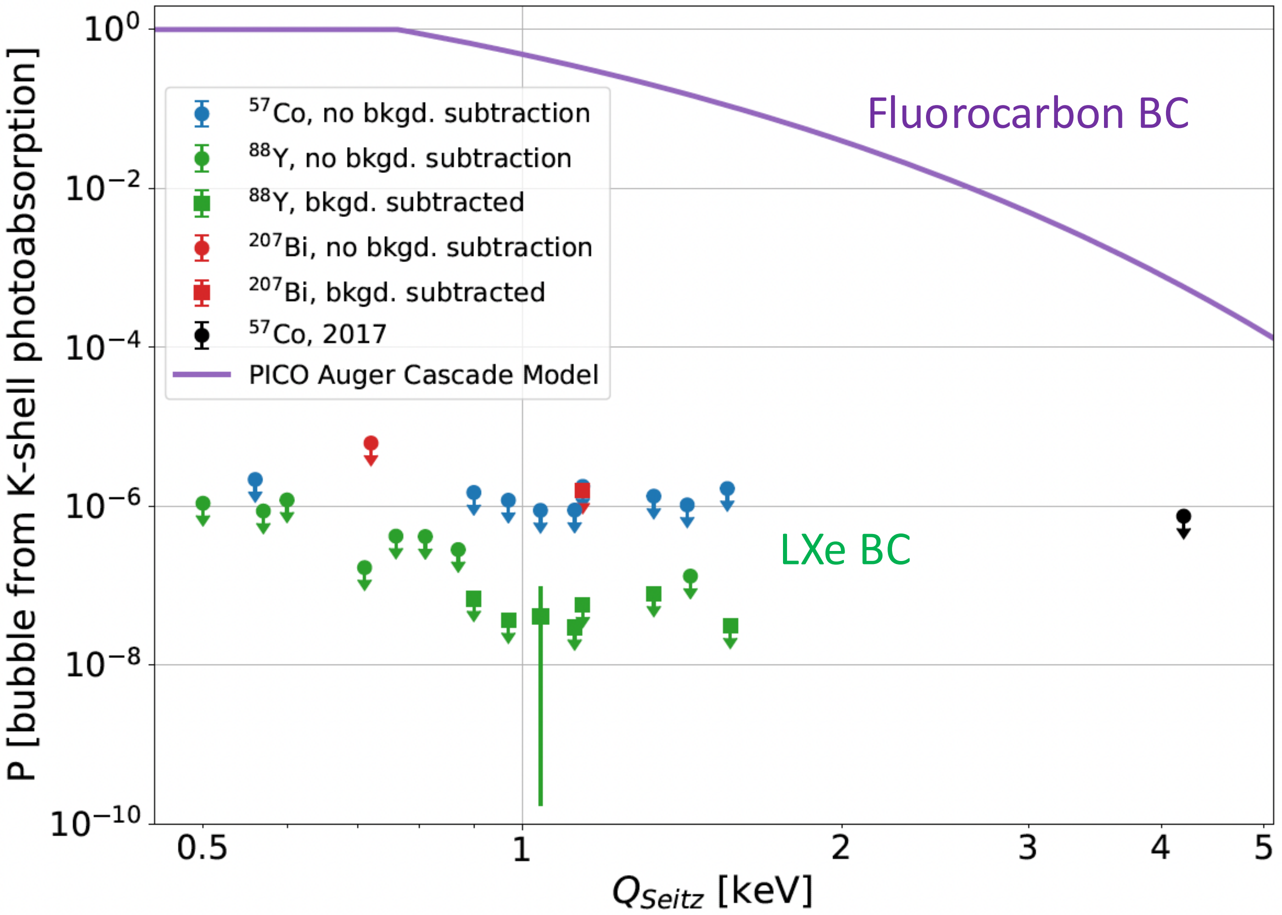
LXe Bubble Chamber

30g demonstration detector at Northwestern



Phys. Rev. Lett. 118, 231301 (2017)

Gamma Rejection in LXe Bubble Chamber



Phys. Rev. D 111, 032002 (2025)

Gamma rejection in LXe much better than fluorocarbon below 1keV, still sensitive to low energy NR.

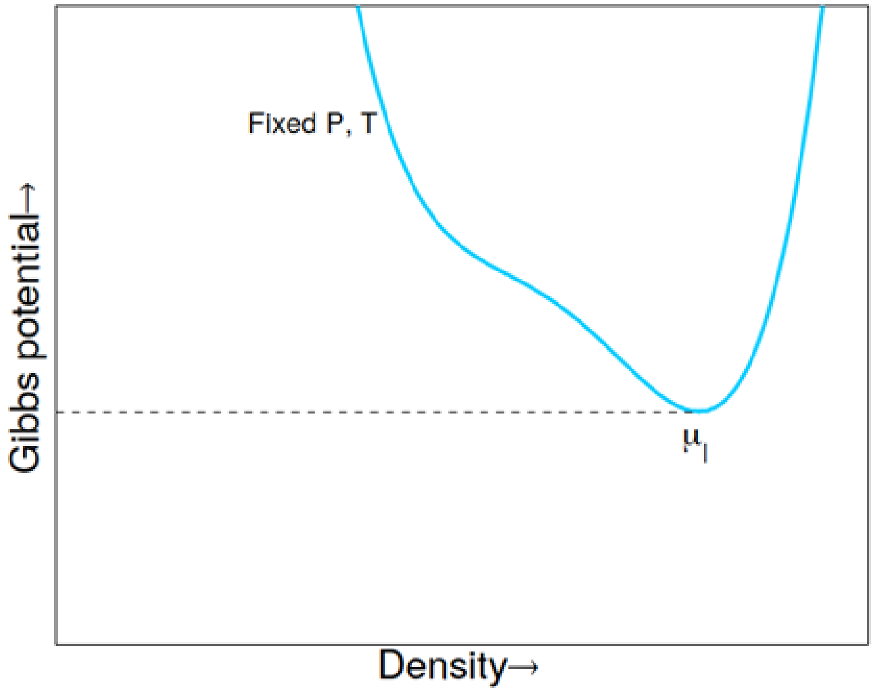
Known since 1956 that Xe bubble chambers don't work for tracks:

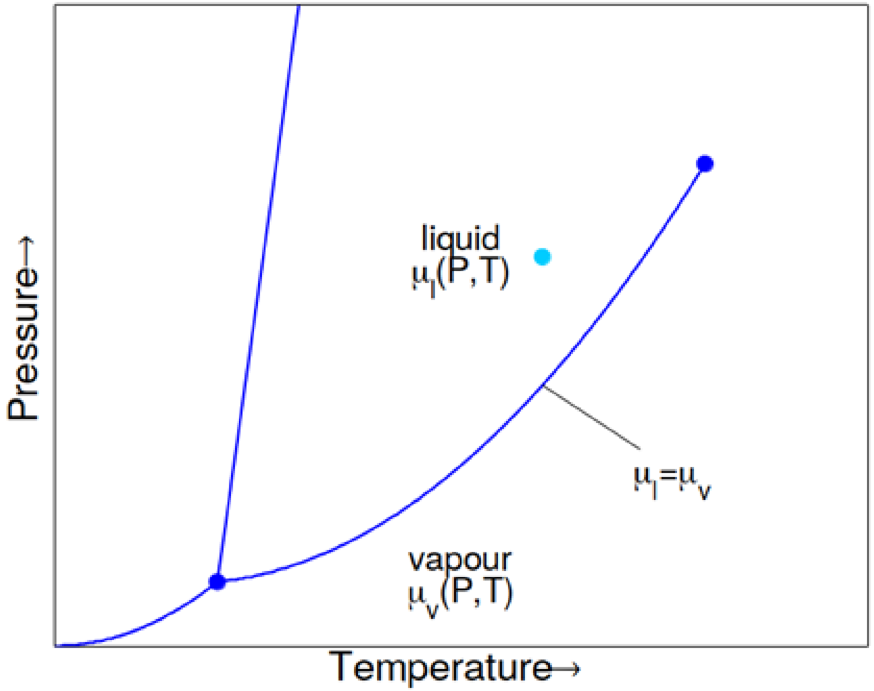
> Shortly after these failures to observe tracks, we learned[3] that gaseous xenon had been found to be an efficient scintillating material, so that some sizeable fraction of the energy lost by an ionizing particle in liquid xenon might escape in optical radiation instead of being deposited locally in the xenon itself. Other

J. L. Brown, D. A. Glaser, and M. L. Perl. Phys. Rev. 102 (1956)

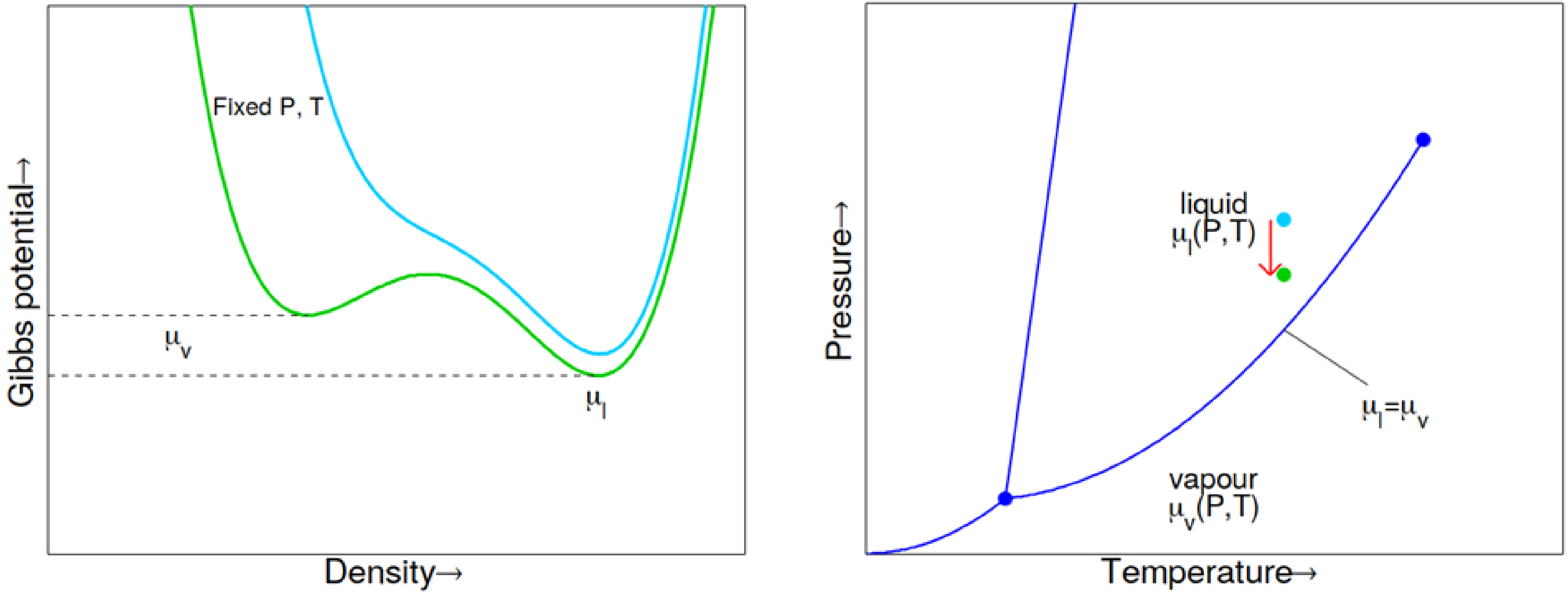
In that case, "solved" by adding 2% ethylene. The molecular species provides an efficient conversion from excitation/ionization to heat.

How Bubble Chambers Work

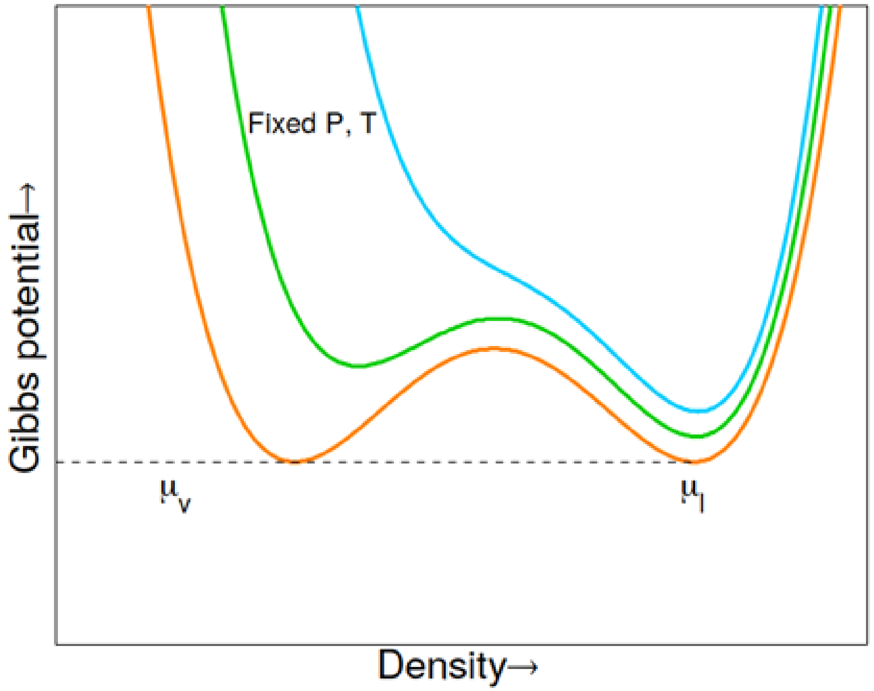


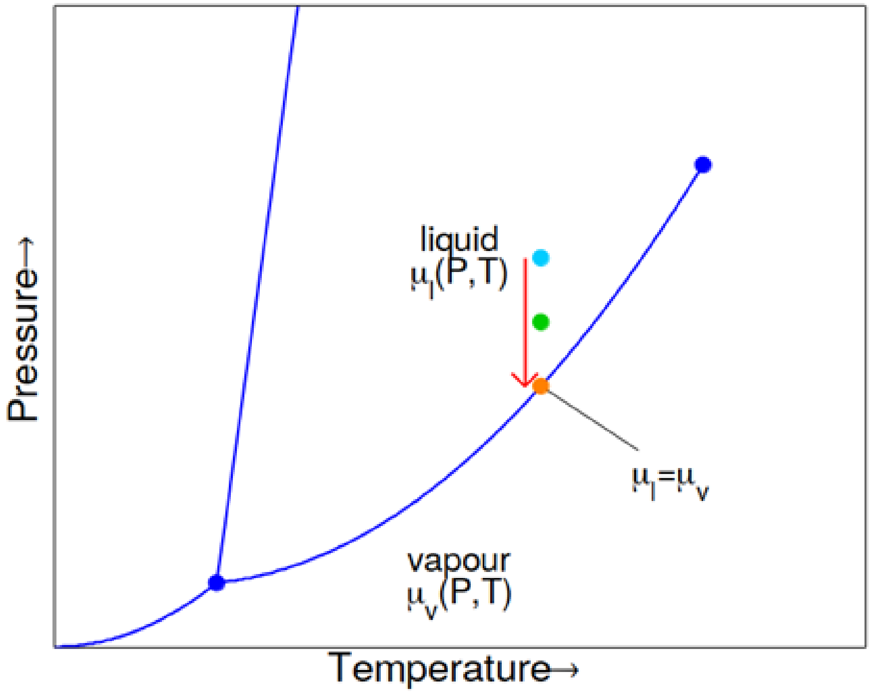


How Bubble Chambers Work

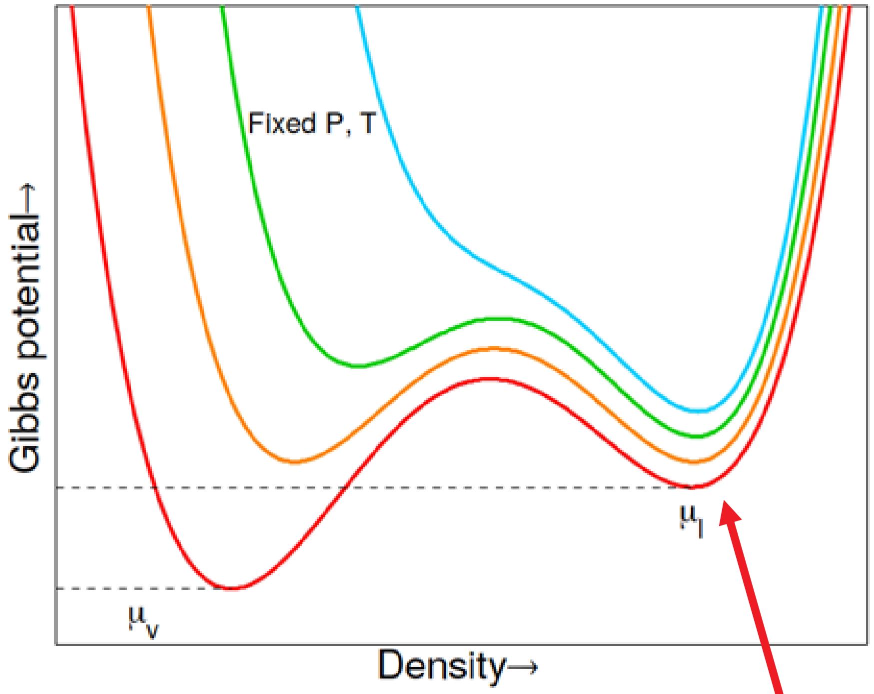


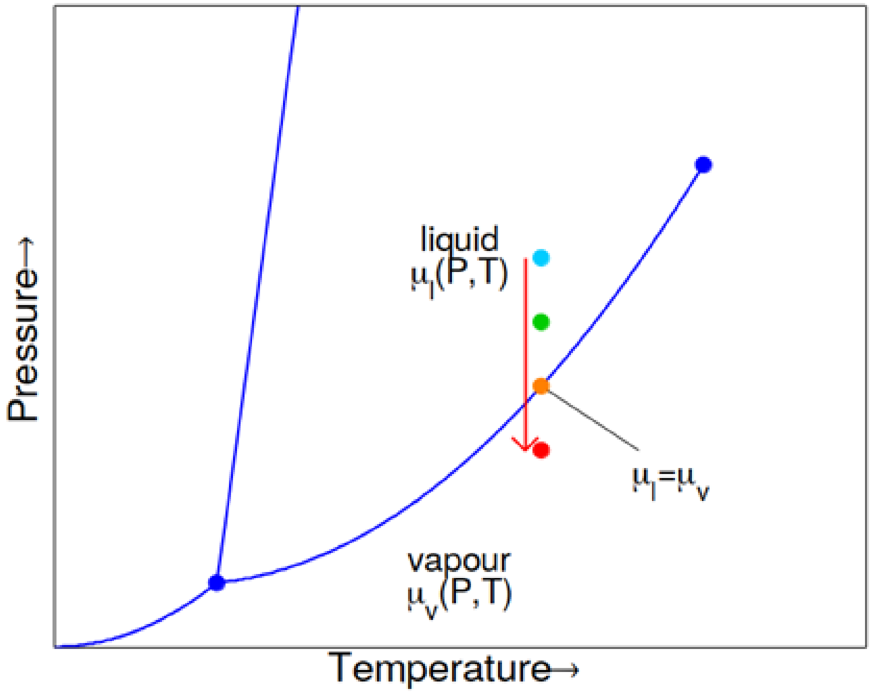
How Bubble Chambers Work





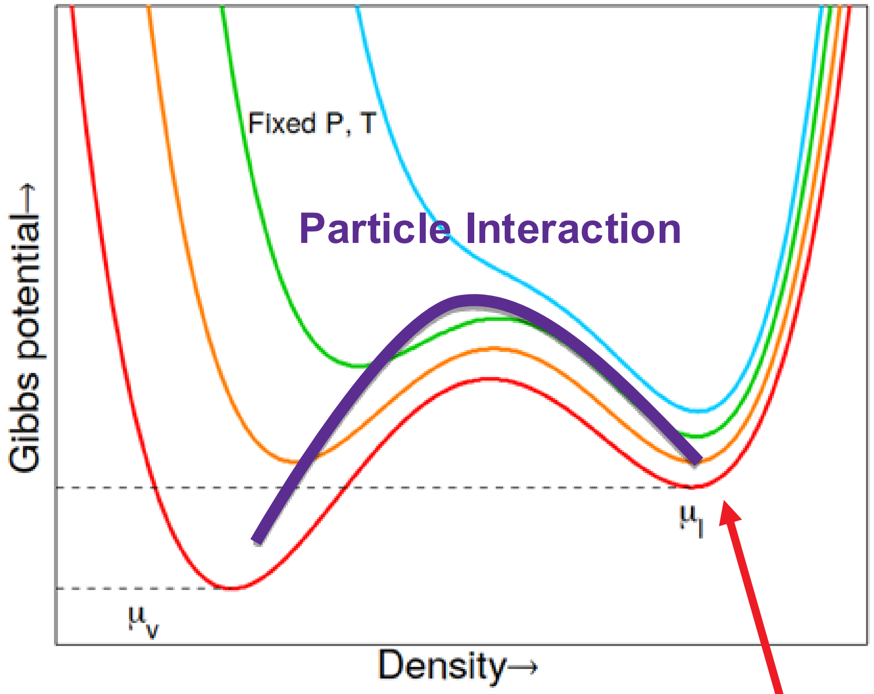
How Bubble Chambers Work

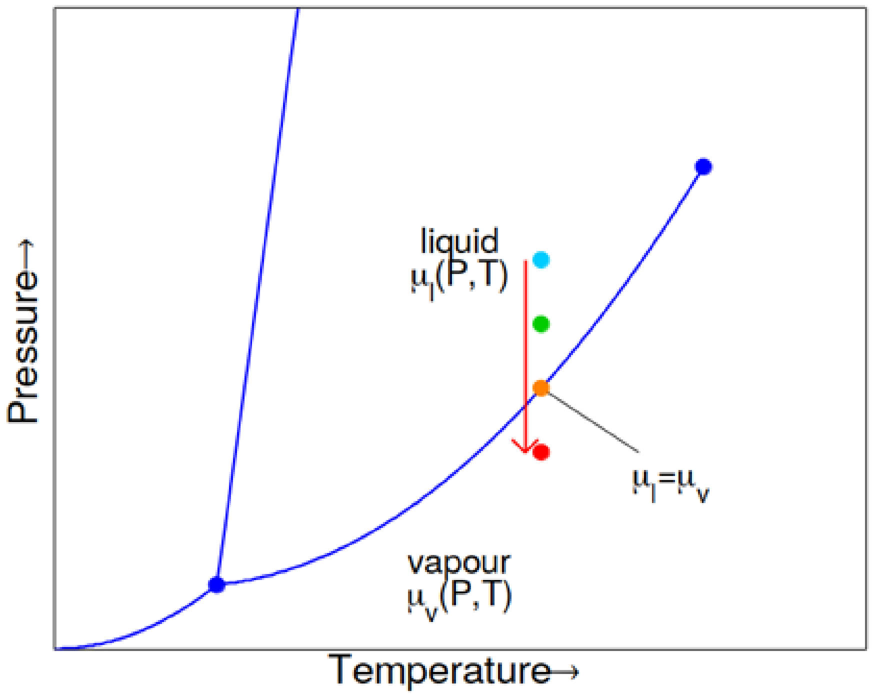




Superheated Liquid

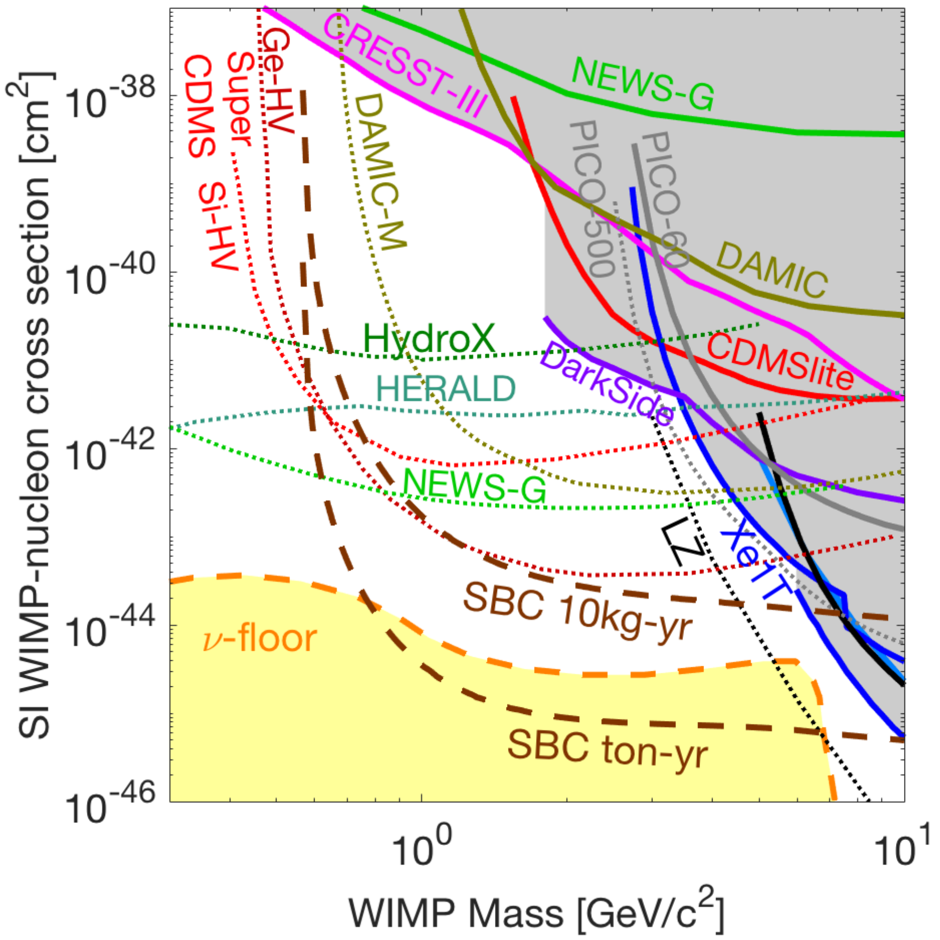
How Bubble Chambers Work



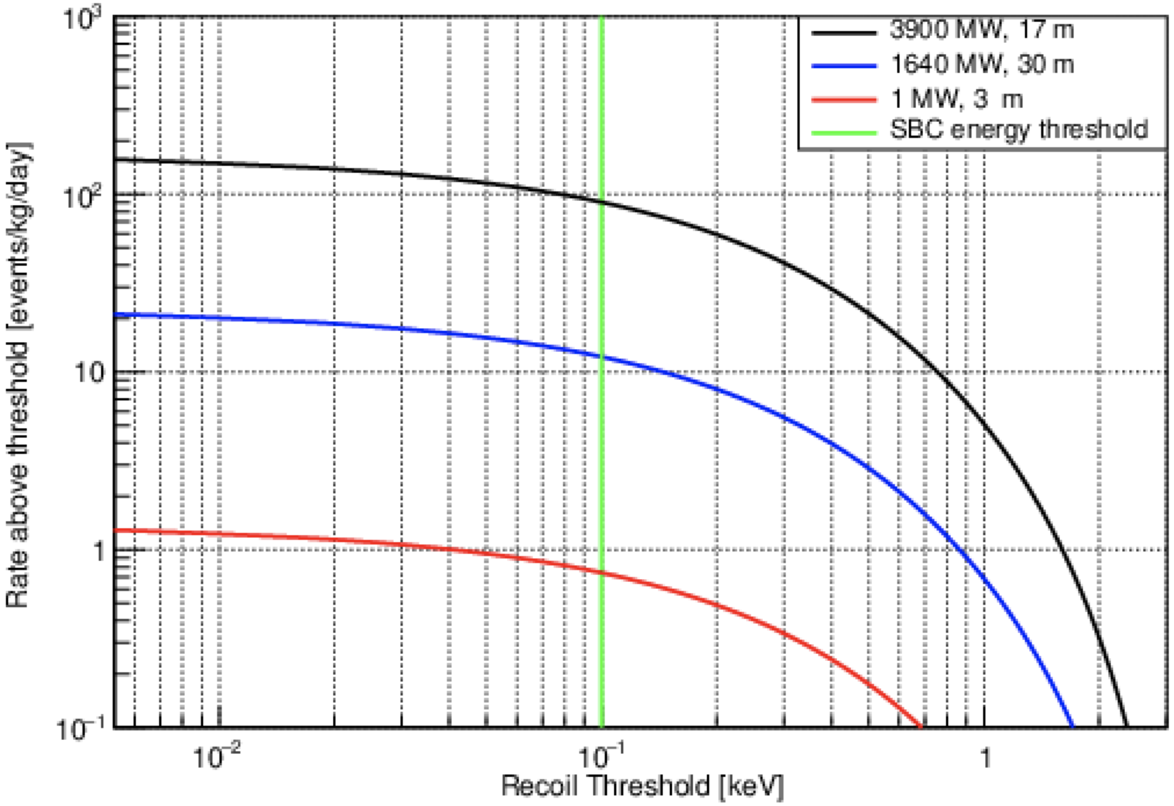


Superheated Liquid

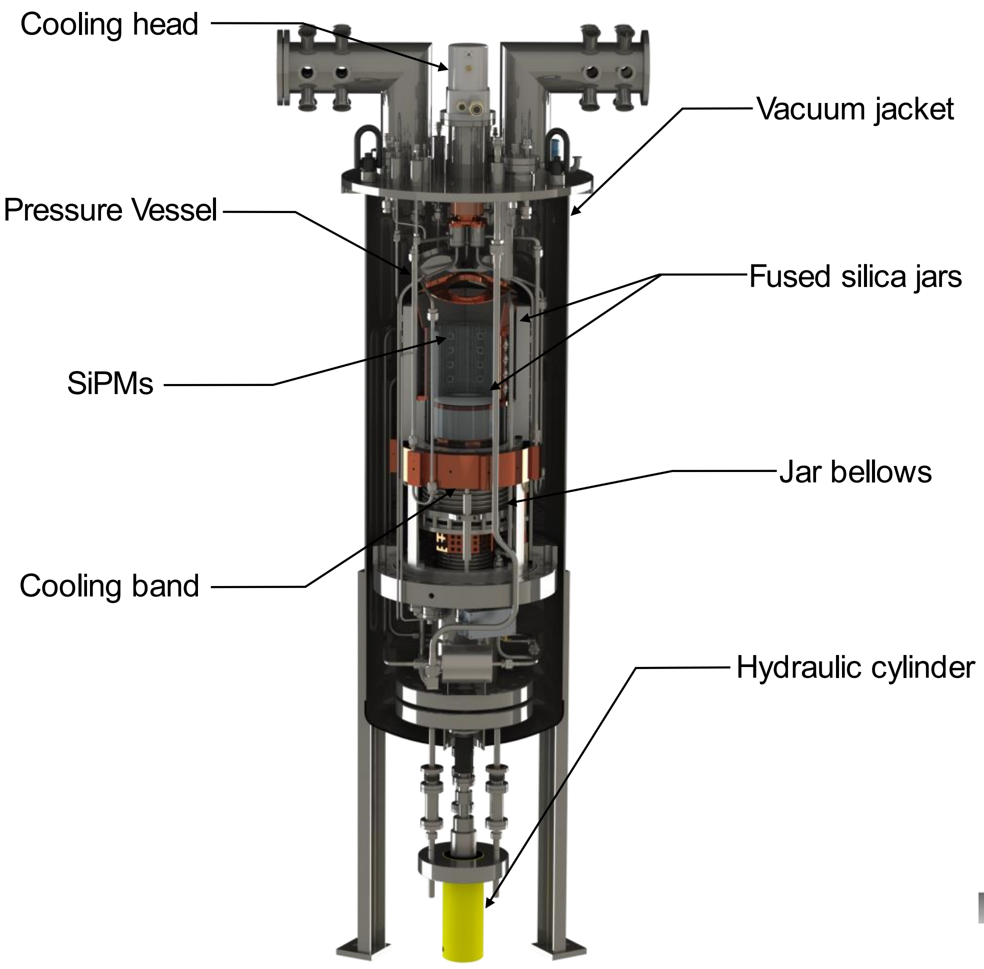
SBC Physics

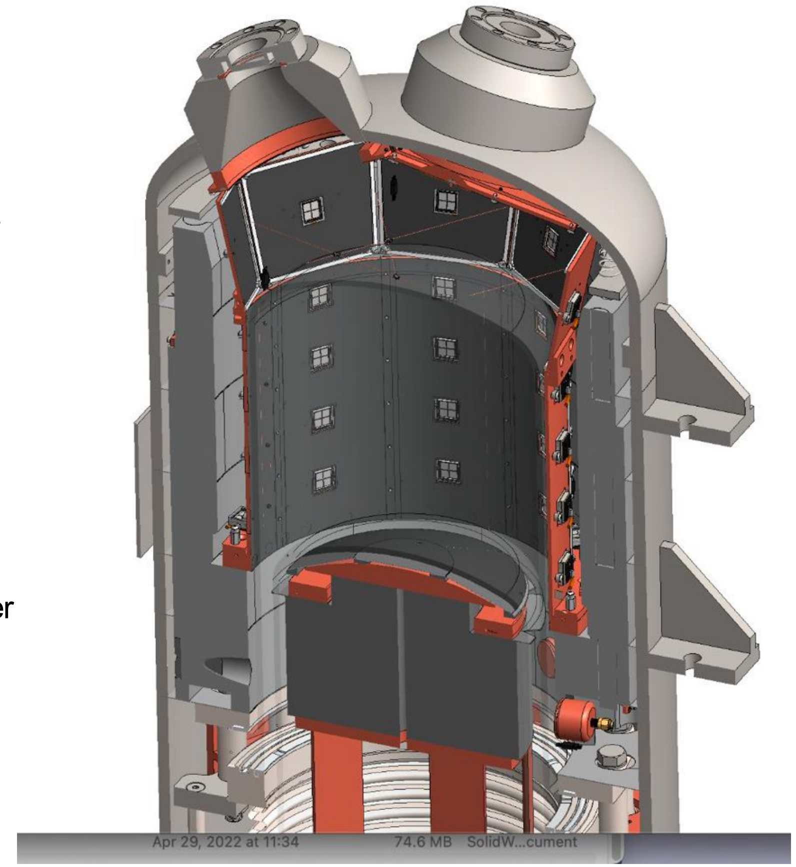


Reactor CEvNS Rates



Scintillating Bubble Chamber (SBC)



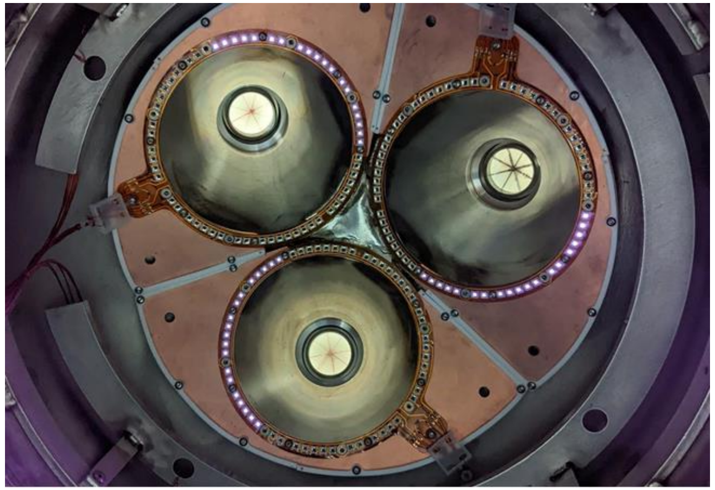


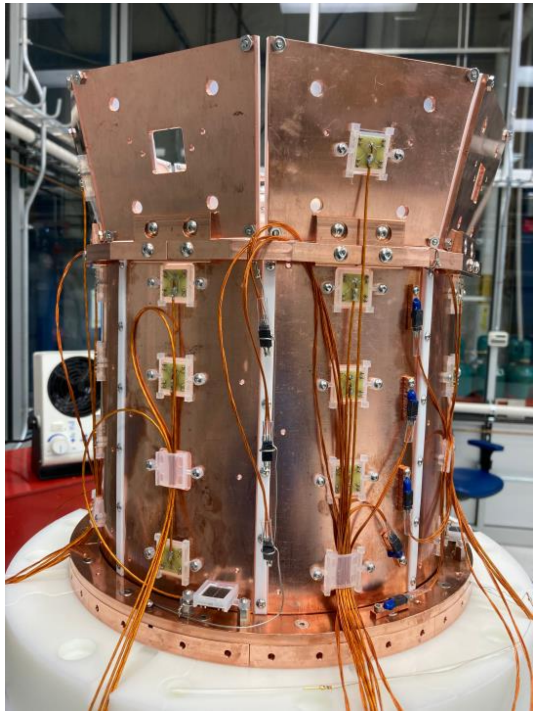
Two functionally identical detectors

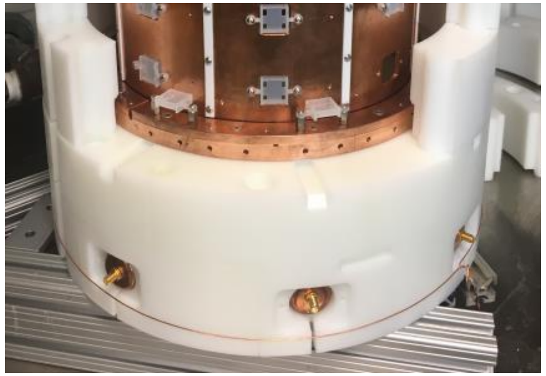
SBC-LAr10 at Fermilab – engineering, calibration, future CEvNS program

SBC-SNOLAB – low background dark matter search

SBC-LAr10 at Fermilab

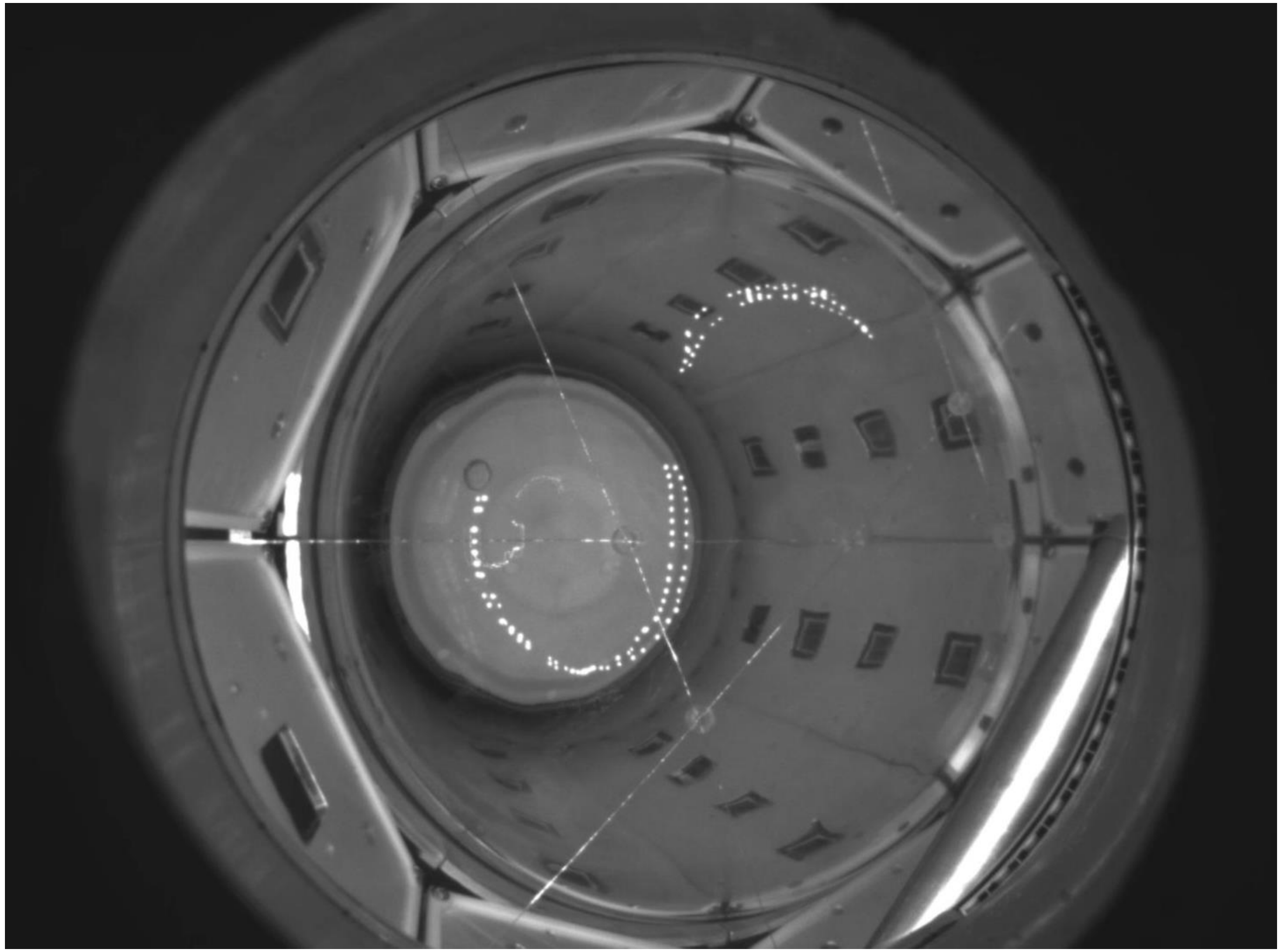




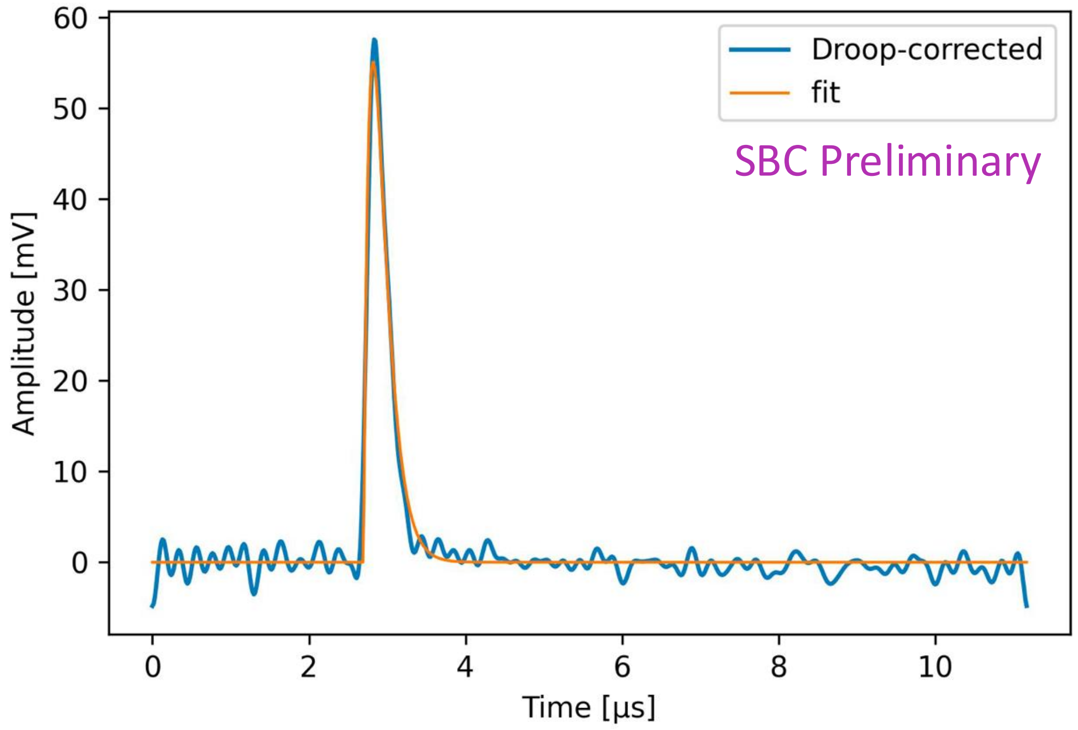


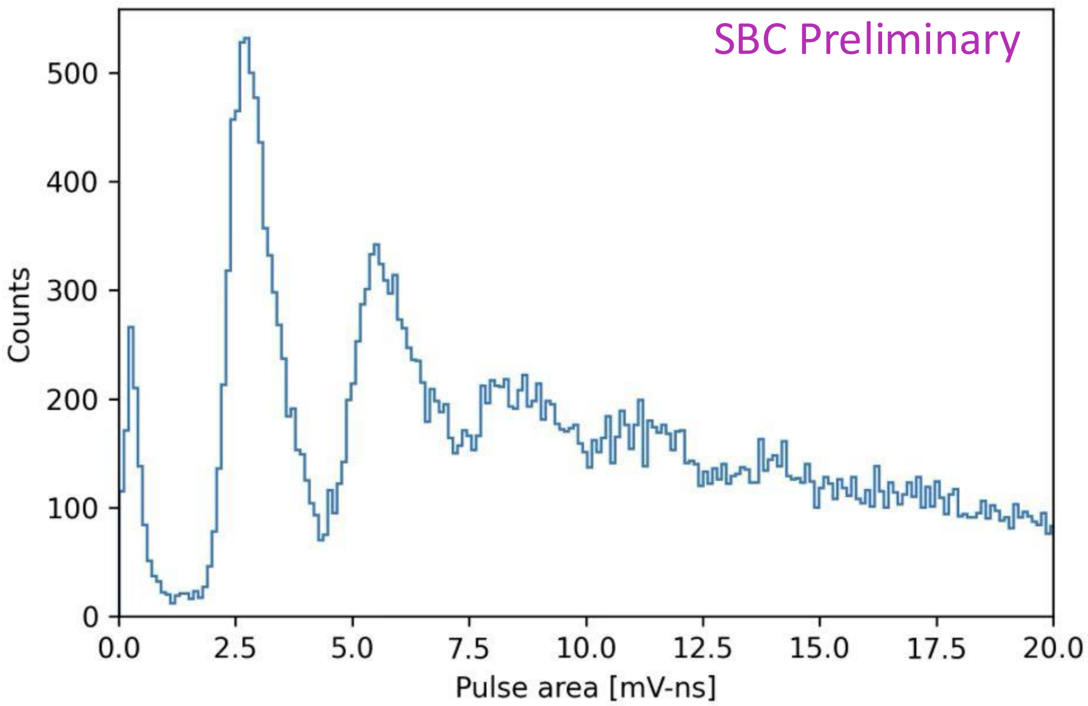
Operation at Fermilab

- 6 months of stable operation with nucleation thresholds from 0.46 – 3 keV
- Simultaneous measurement of scintillation and bubble nucleation observed



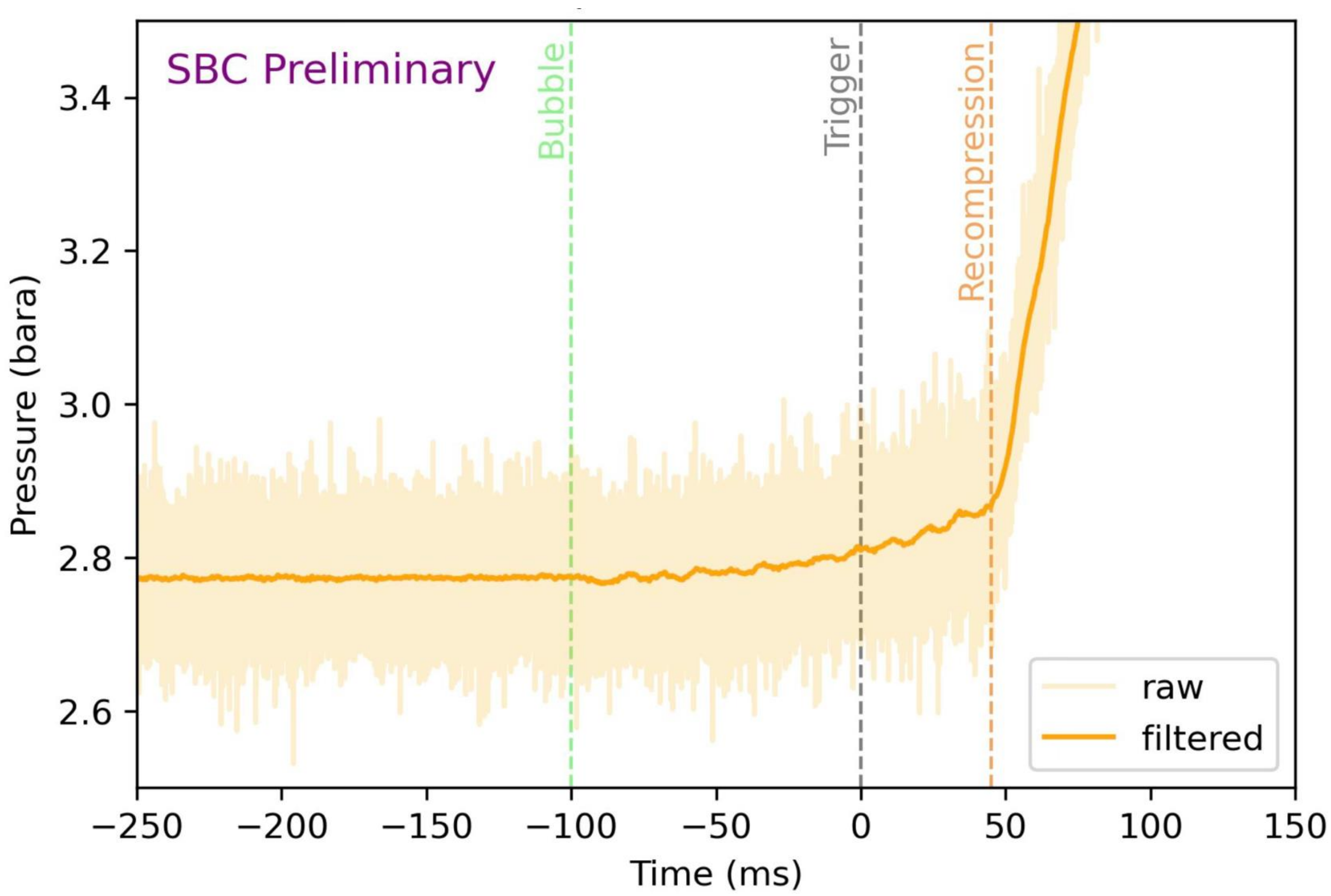
Example SiPM Signal



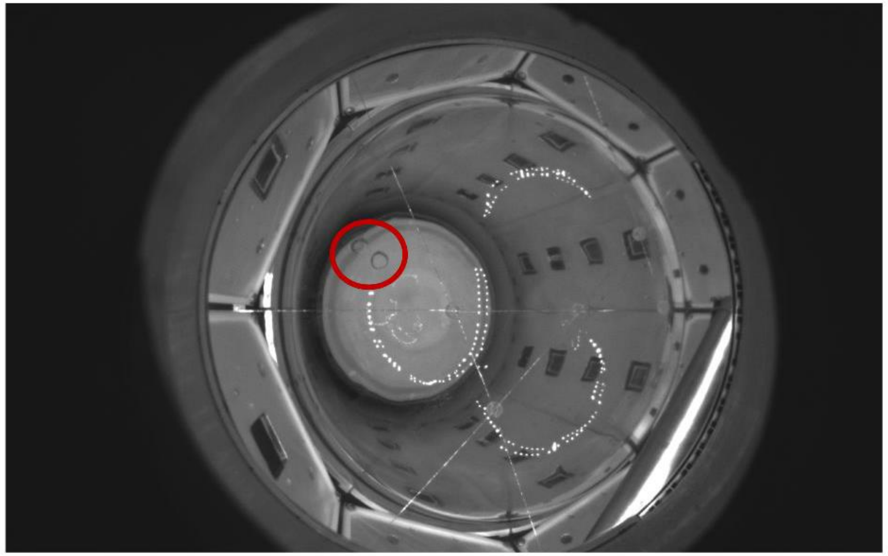


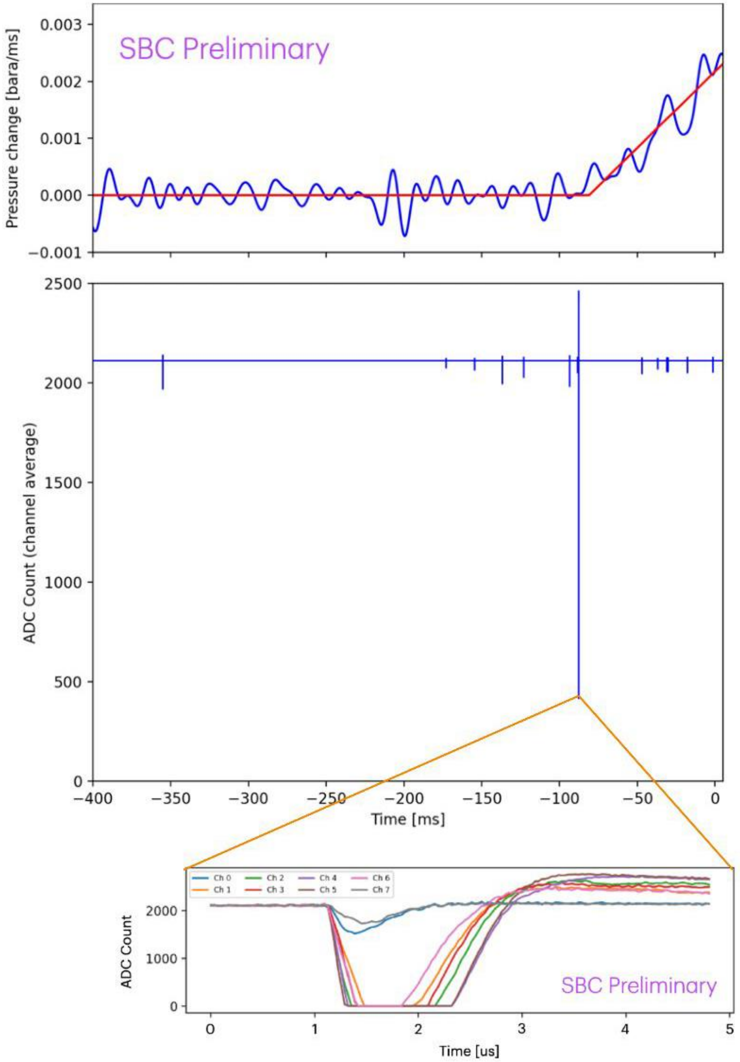
Pulse fitting to extract charge of the 32 SiPMs

Example Pressure Signal

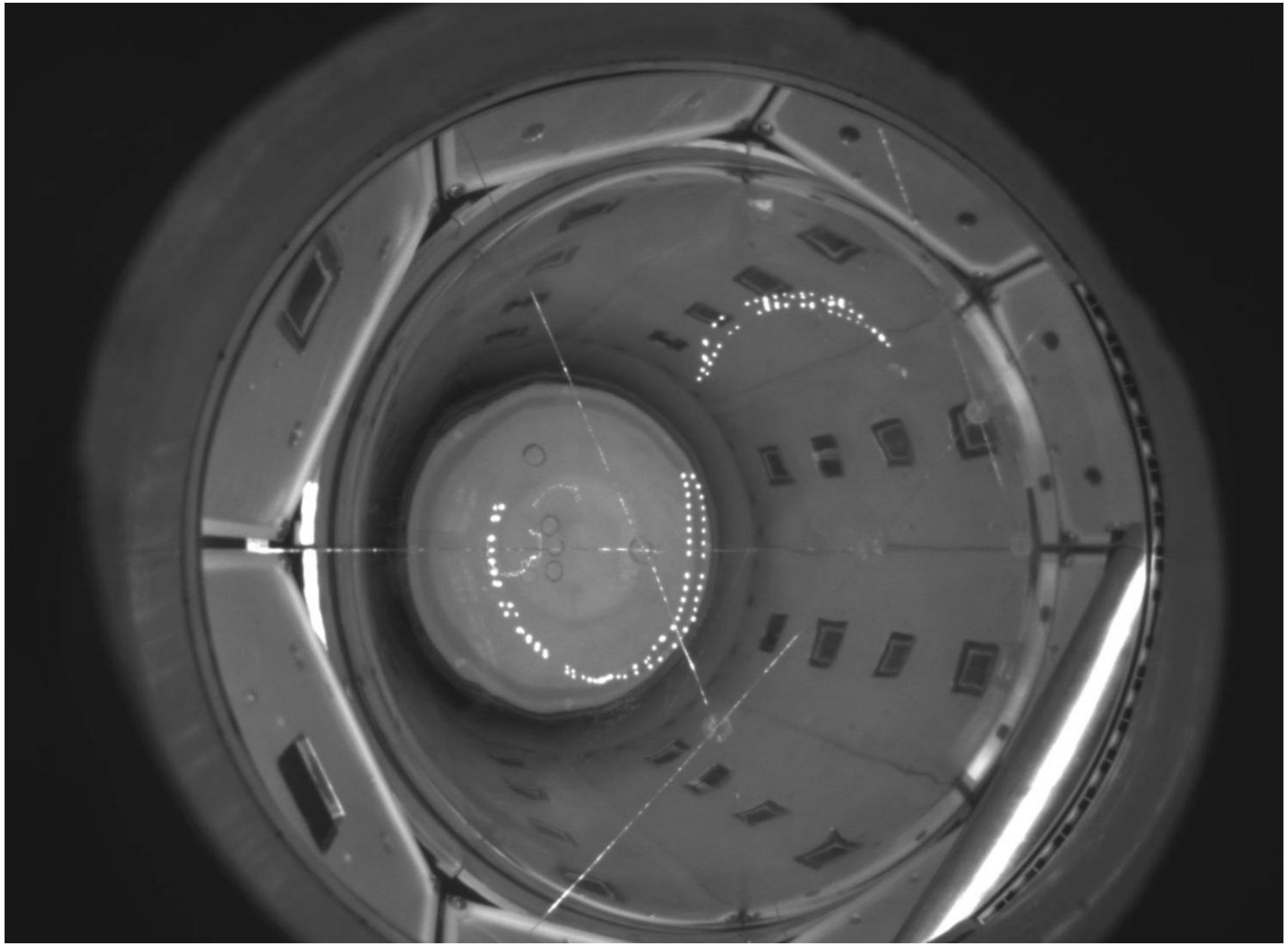


Coincidence: Bubble + Pressure + Scintillation





Multi-scatter Neutron Event



Component Arrival at SNOLAB

Main detector components are arriving on surface at SNOLAB

Pressure vessel

Vacuum Jacket

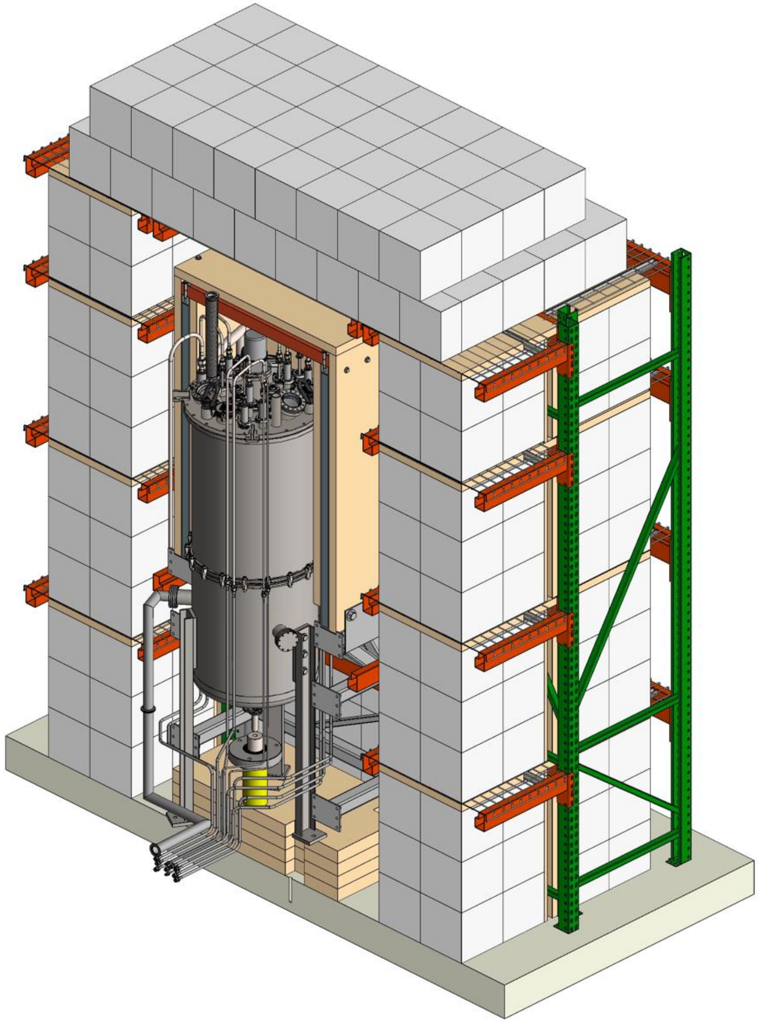
SNOLAB Backgrounds and Sheilding

- Main Backgrounds:
  - (α,n) in detector materials.
  - Muon-induced neutrons.
  - Nuclear Thomson scattering from external gammas.
  - Solar neutrinos.

- Water shield for fast neutrons.

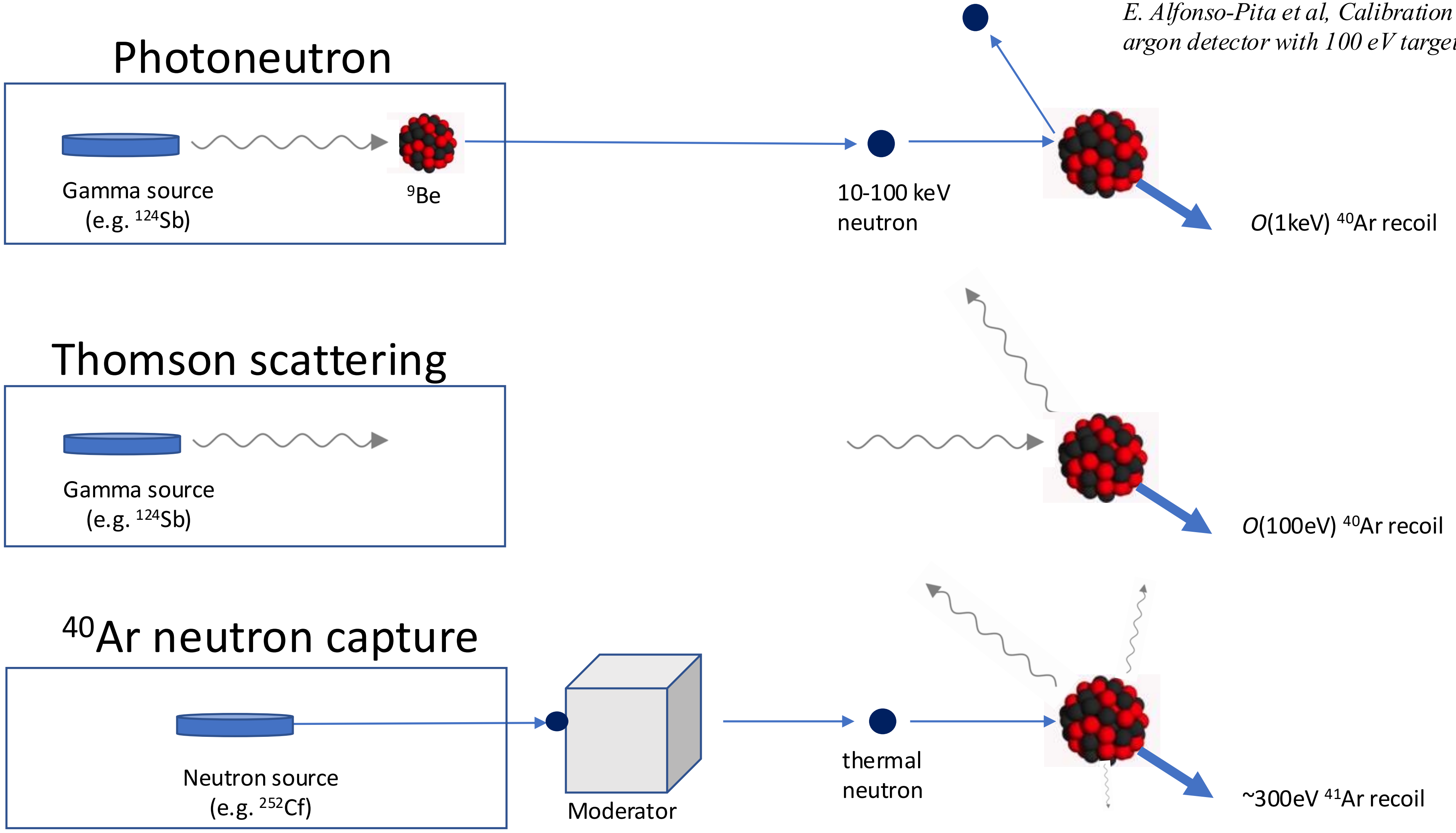
- Lead shield for gammas.

- Scintillation channel used for background rejection.



Three Nuclear-Recoil Calibration Techniques

E. Alfonso-Pita et al, Calibration plan for the SBC 10-kg liquid argon detector with 100 eV target threshold. 2026 JINST ***21*** *P03020*

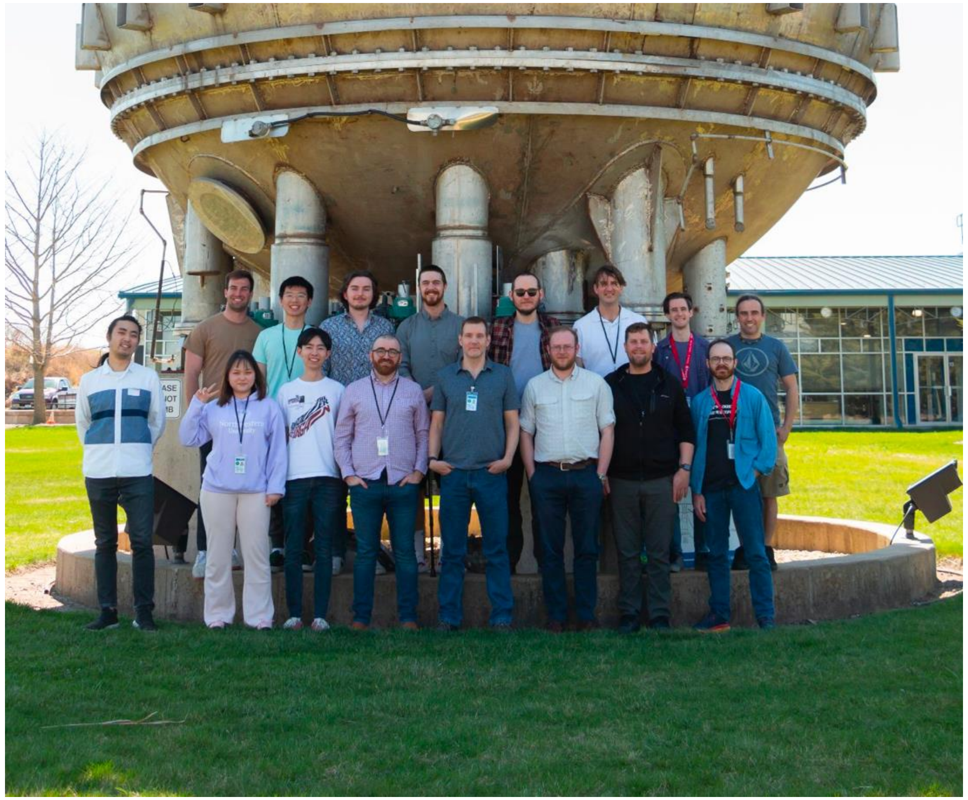


Conclusion

- Exciting time for SBC-SNOLAB.
  - Gateway 2 just passed
  - Parts arriving on surface for assembly to start in October.

- Publications:

[arXiv: 2207.12400]()
[Universe 9 (2023) 8, 346]()
[Phys. Rev. D 111 (2025) 3, 032002]()
[JINST 19 (2024) 08, T08003]()
[JINST 19 (2026) 03, P03020]()



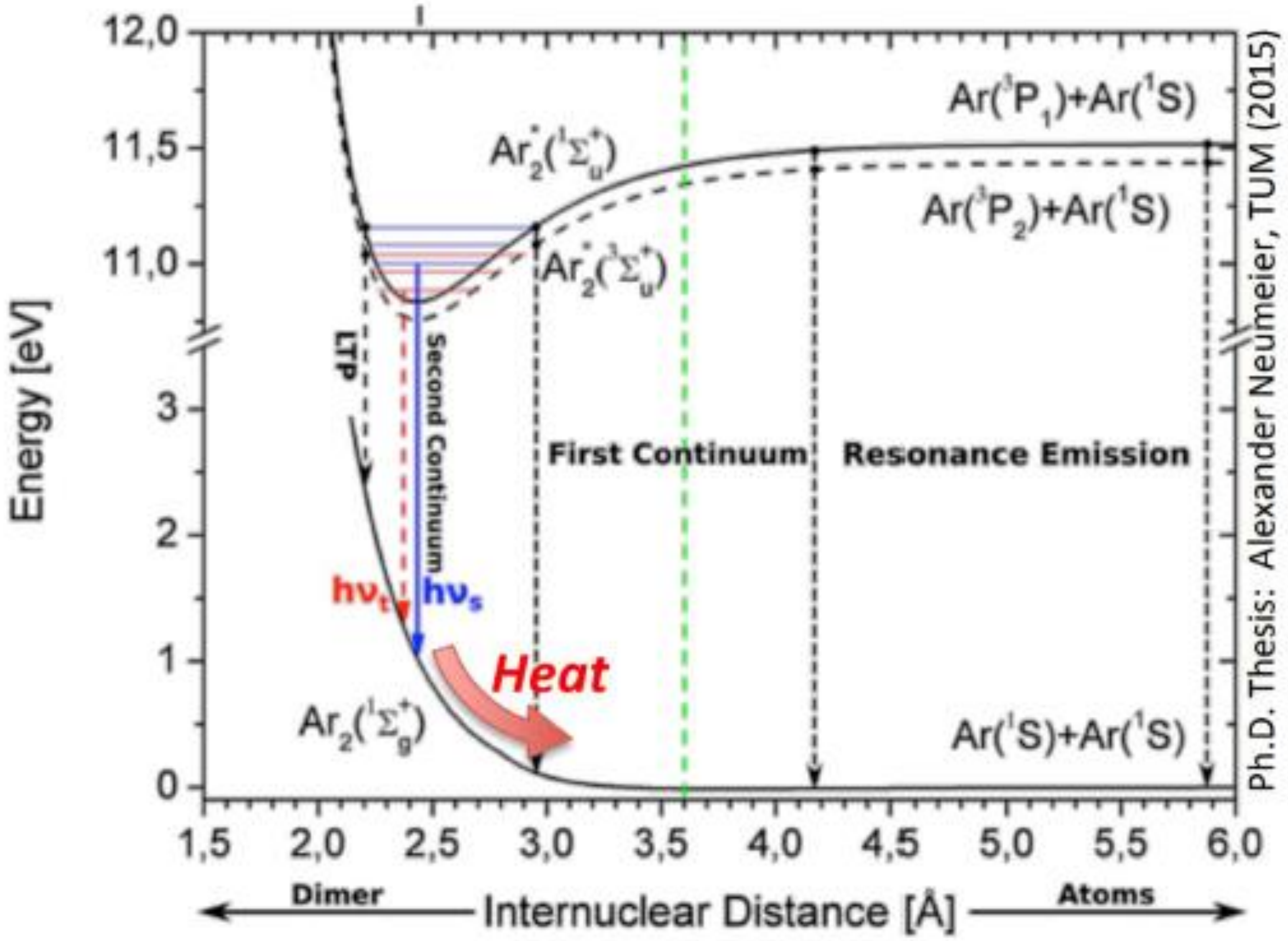
Backup slides

How low in threshold can we go?

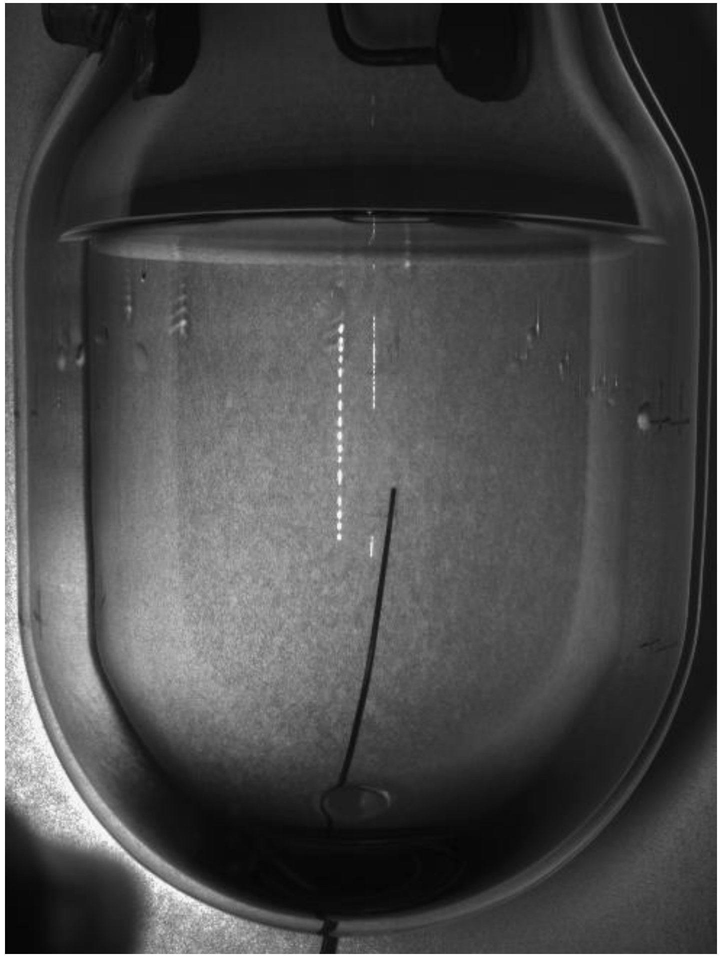
Liquid Argon bubble chambers have seen tracks with threshold O(10eV).

We also expect spontaneous nucleation from thermal fluctuations at a similar threshold, but not above 40eV.

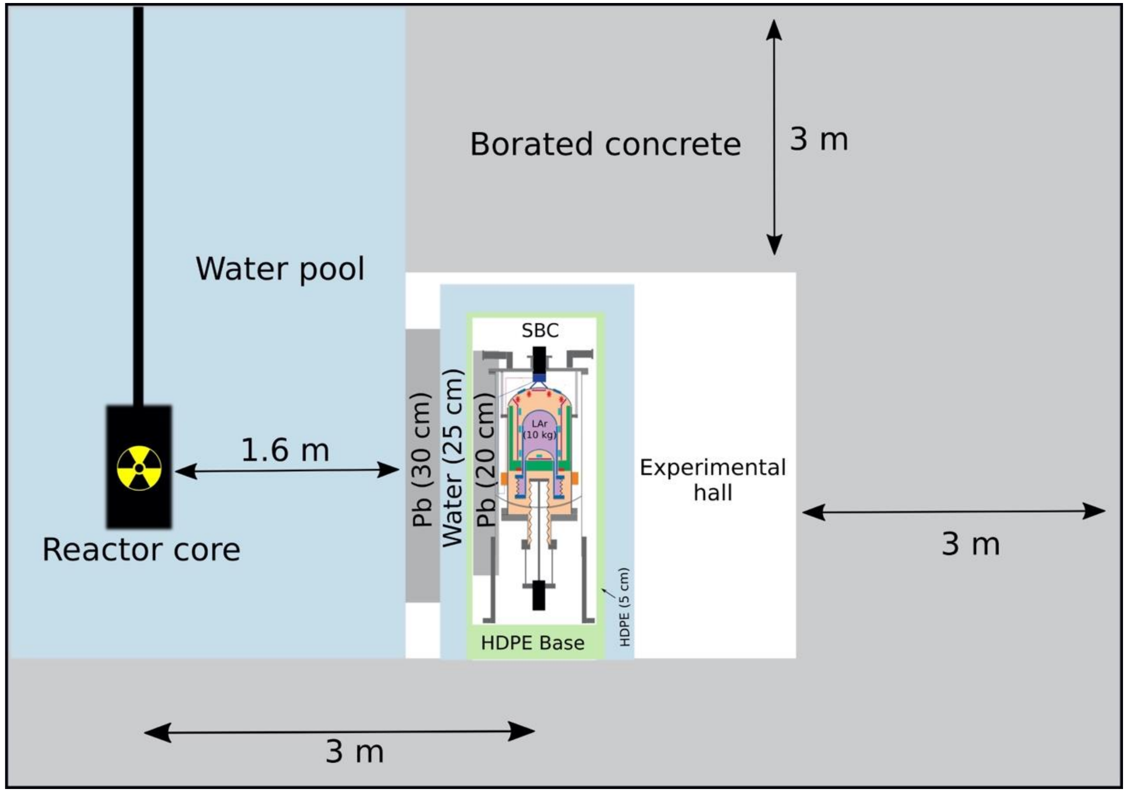
Design goal of SBC is 40eV Seitz threshold. Physics projections based on 100eVnr threshold.

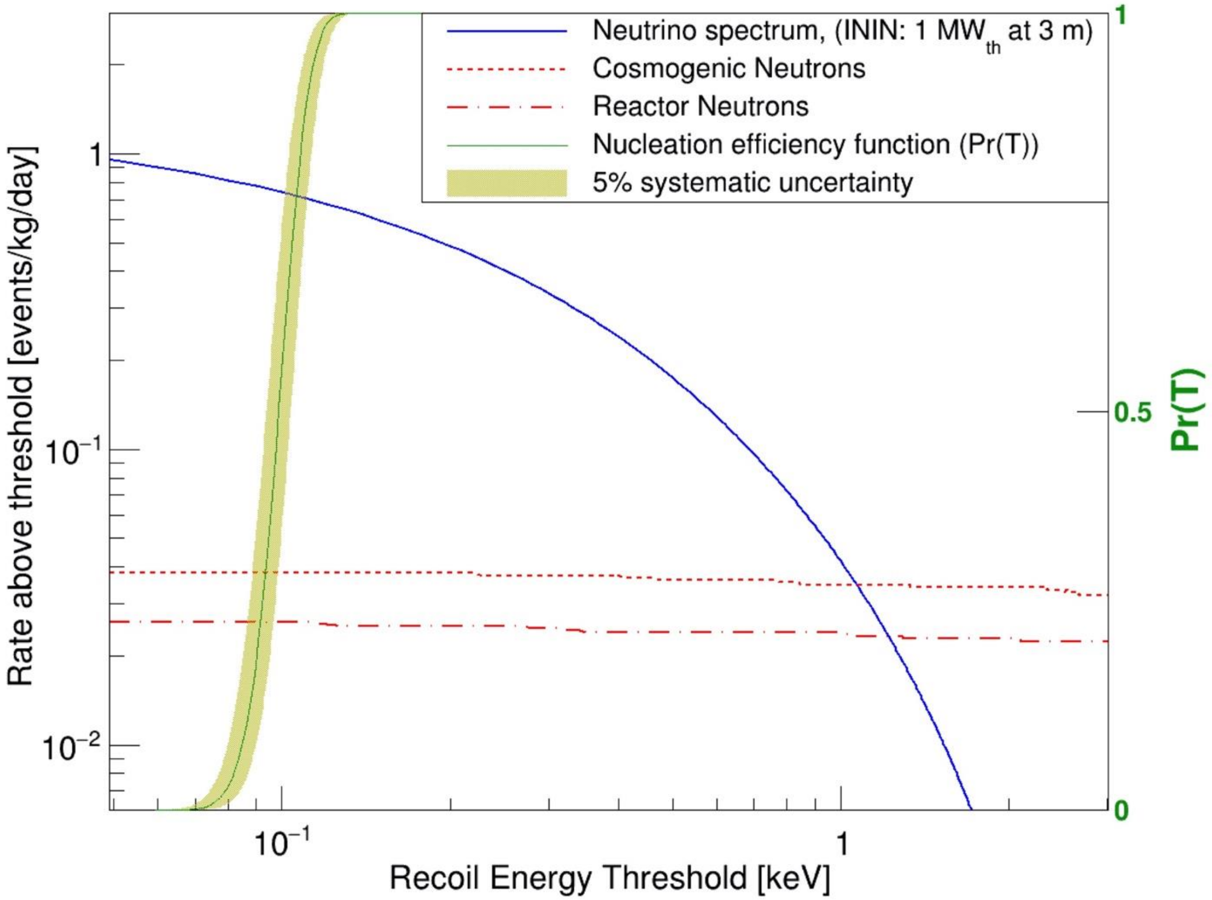


PICO bubble event (calibration)



CEνNS Backgrounds at ININ

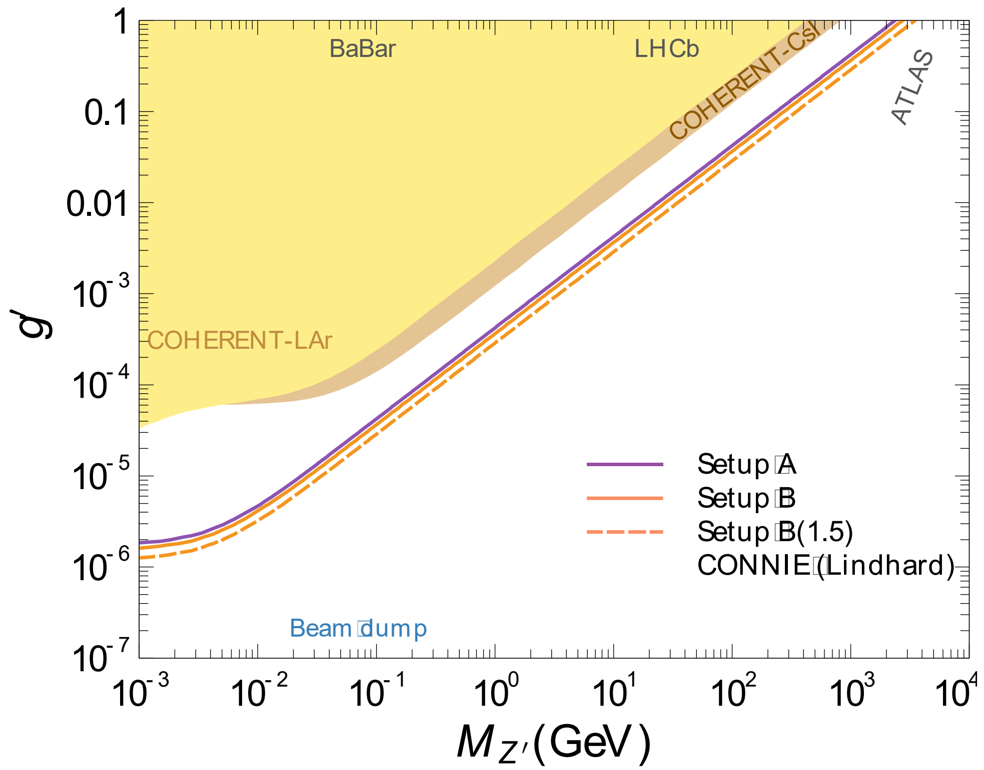




- 1MW TRIGA Mark-III reactor near Mexico City.
- Borated concrete shields from cosmogenics.
- Water shields from reactor neutrons, lead from reactor gammas (Thomson scattering).

Sensitivity to BSM Physics

Z’ (B-L gauge boson)



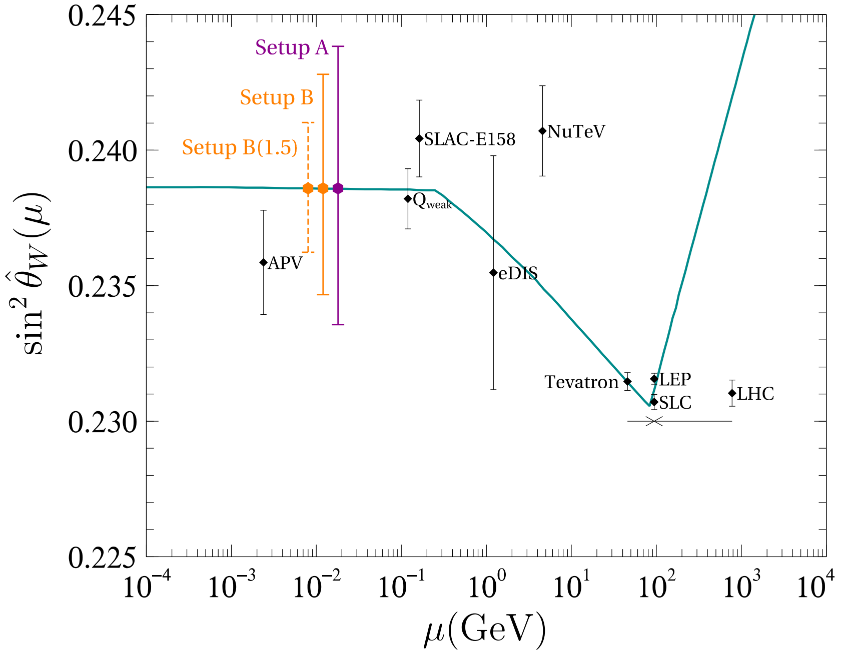
Physics reach in 1-year of reactor-on time.

Setup A: 10kg, 1MW$_{th}$, 2.4% flux uncertainty
Setup B: 100kg, 2GW$_{th}$, 2.4% flux uncertainty
Setup B(1.5): 100kg, 2GW$_{th}$, 1.5% flux uncertainty

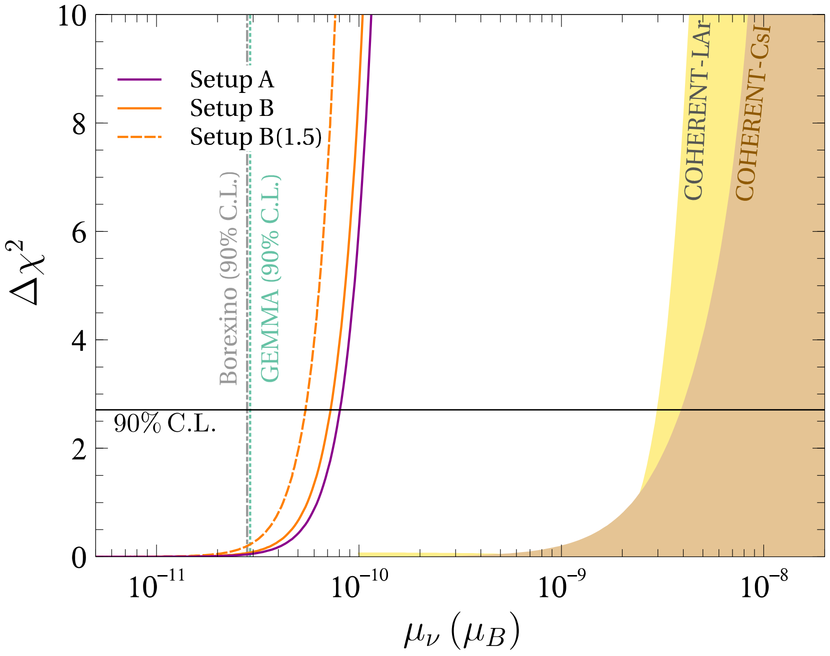
L. J. Flores, et. al , Phys. Rev. D 103 (2021)

Other Precision Studies

Weak mixing angle



Neutrino magnetic moment

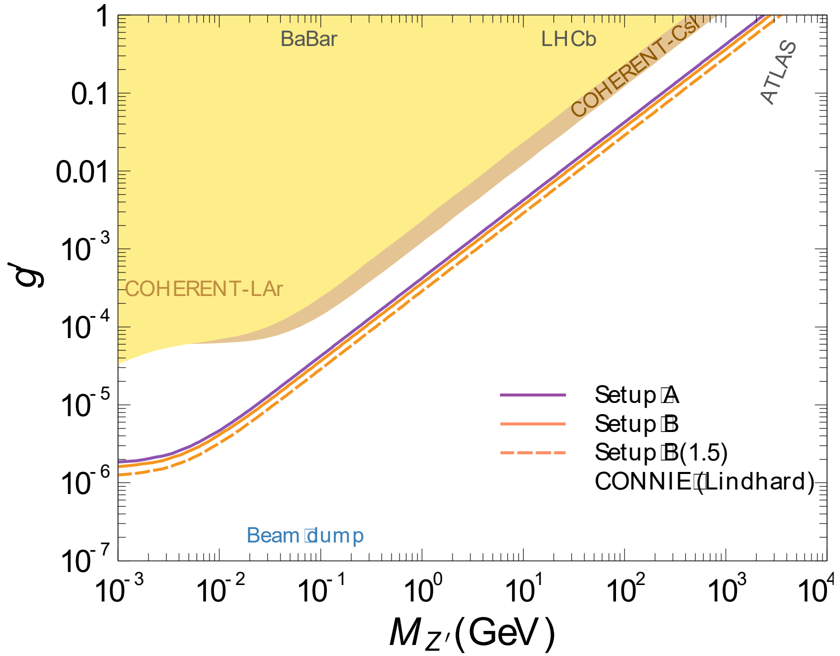


L. J. Flores, et. al , Phys. Rev. D 103 (2021)

- Physics can be done even with a 10-kg detector at a research reactor.
- Higher statistics and improved precision at a power reactor.

Sensitivity to BSM Physics

Z’ (B-L gauge boson)

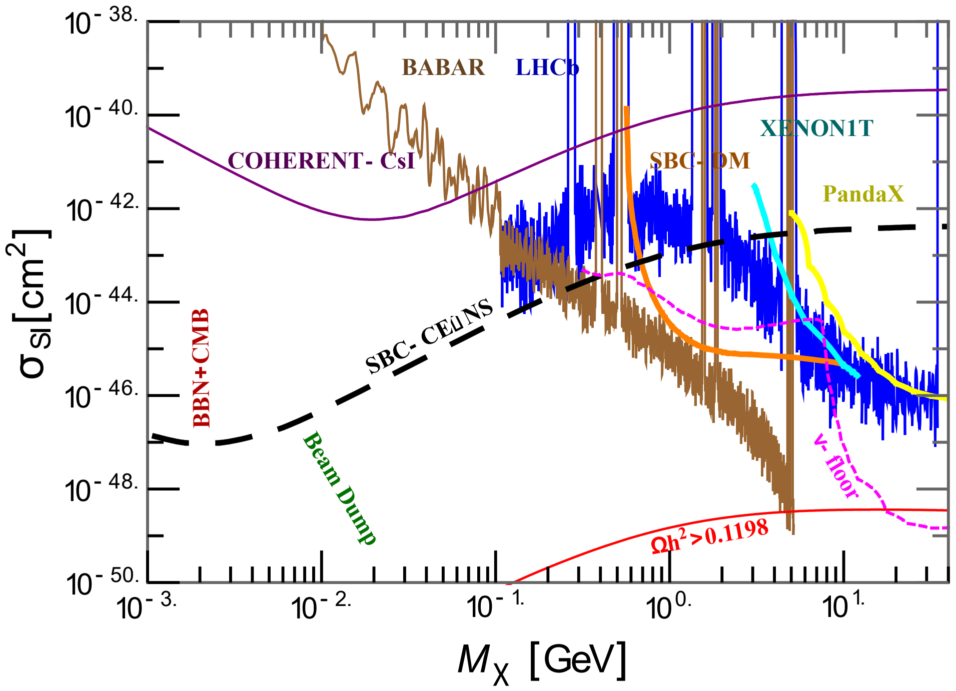


L. J. Flores, et. al , Phys. Rev. D 103 (2021)

Setup A: 10kg, 1MWth, 2.4% flux uncertainty

Setup B: 100kg, 2GWth, 2.4% flux uncertainty

Setup B(1.5): 100kg, 2GWth, 1.5% flux uncertainty



arXiv:2107.04037v1 [hep-ph]

Seitz Model for Bubble Nucleation

- A bubble chamber is filled a superheated fluid in meta-stable state.
- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble *(Seitz "Hot-Spike" Model).*
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses.
- Classical Thermodynamics says-

$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

Latent heat