Scintillating Bubble Chambers for Rare Event Searches

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for the SBC collaboration

CIPANP 2025

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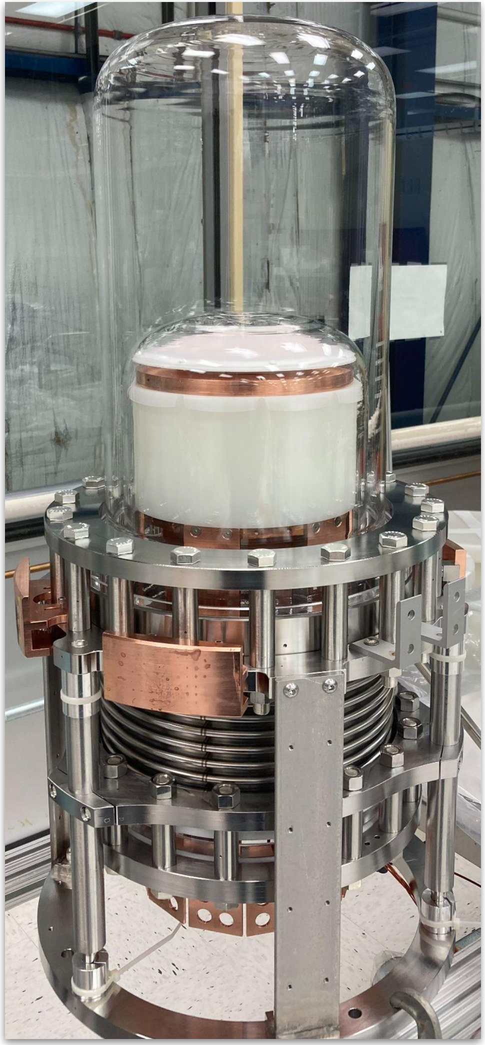
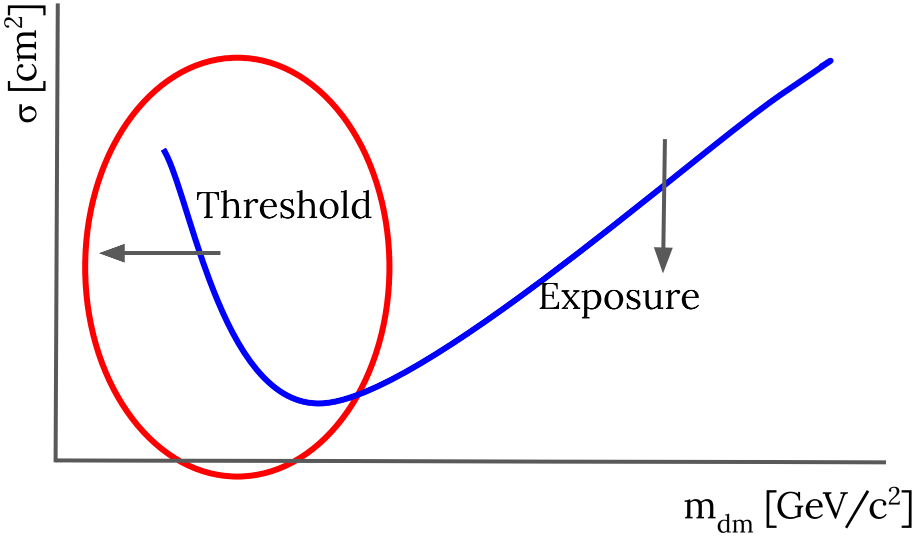


sub-keV nuclear recoils

- Difficult kinematics of GeV-scale DM-nucleon scattering require low thresholds ($\lesssim$ 1 keV)

    - Future success here needs background discrimination **and** scalability

- Similar challenge measuring CEνNS from MeV-scale ν's (see G. Putnam's talk, Wednesday)

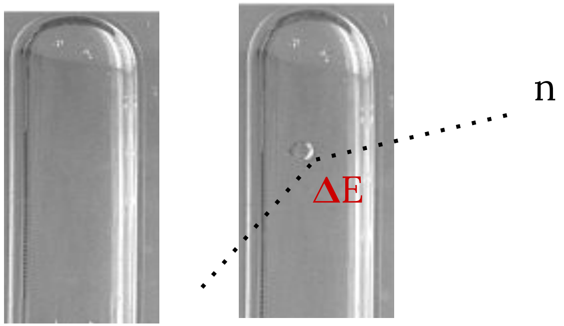


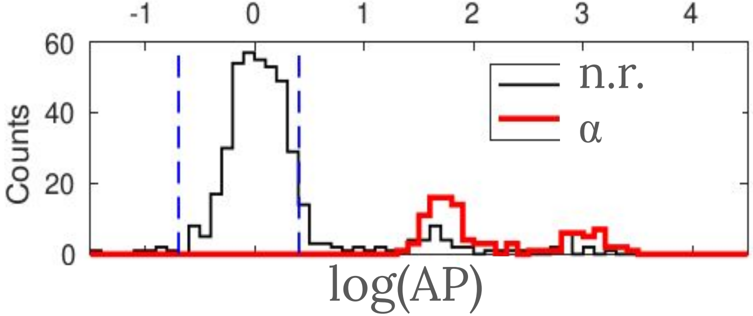
Bubble chambers for DM searches

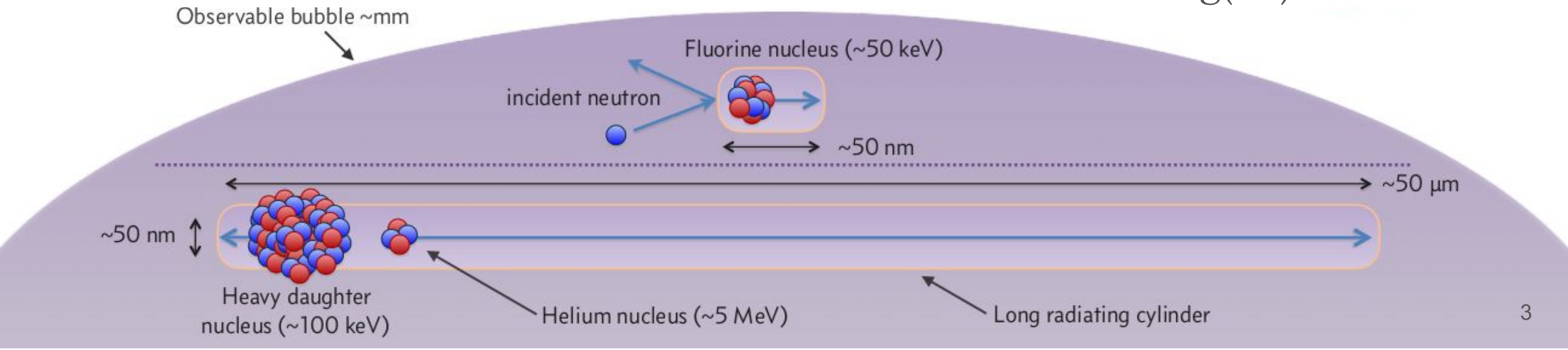
- Superheated liquids have efficient nucleation at low n.r. thresholds

- Highly β/γ insensitive

- n.r./α discrimination:





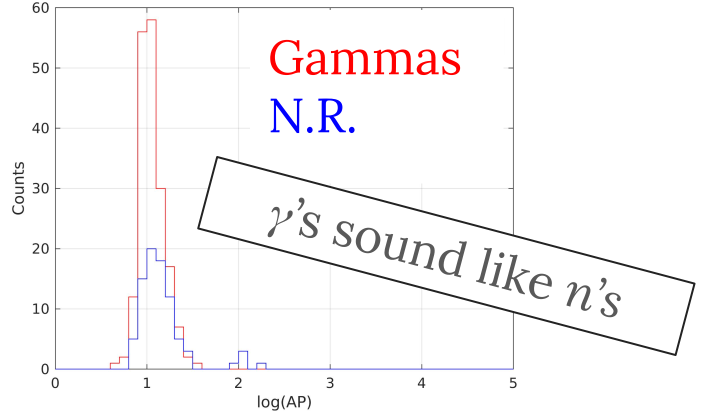


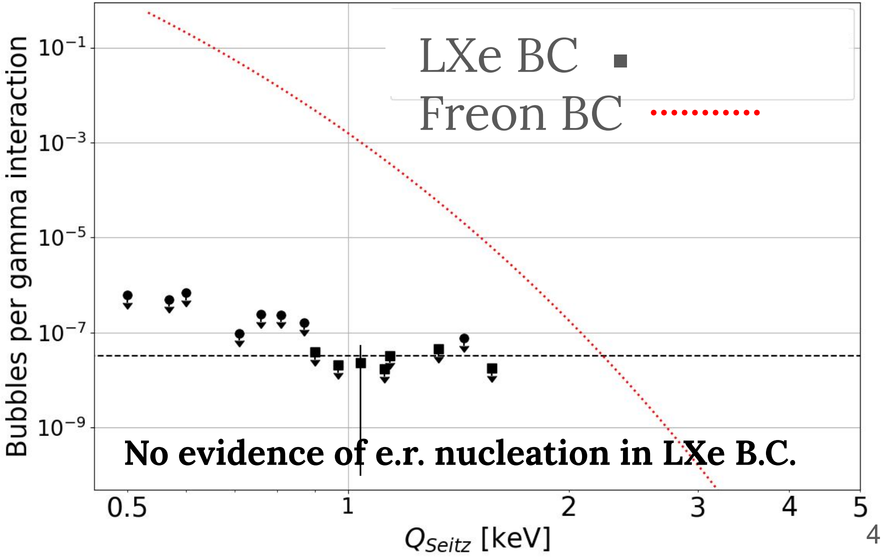
A liquid-noble bubble chamber

Adds in:

- Energy reconstruction

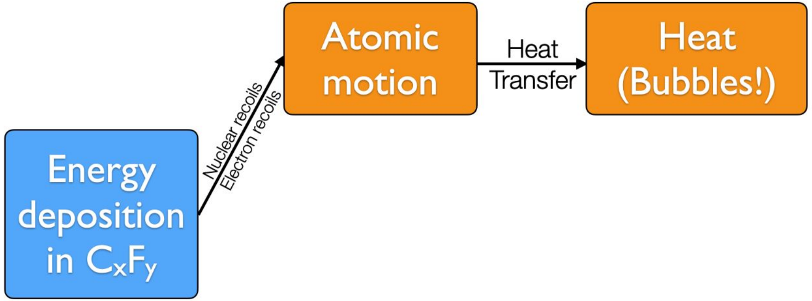
- Higher β/γ rejection than Freons
  - Lower threshold w/o e.r. backgrounds increases sensitivity to lower DM masses



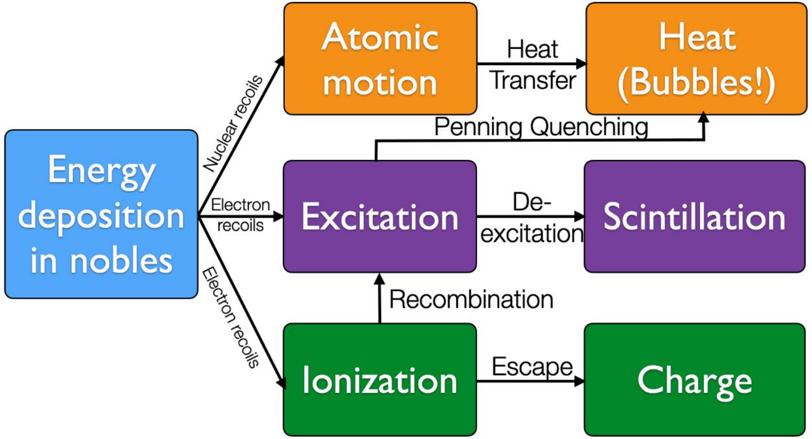


Why liquid-nobles work

Freon-based target fluid

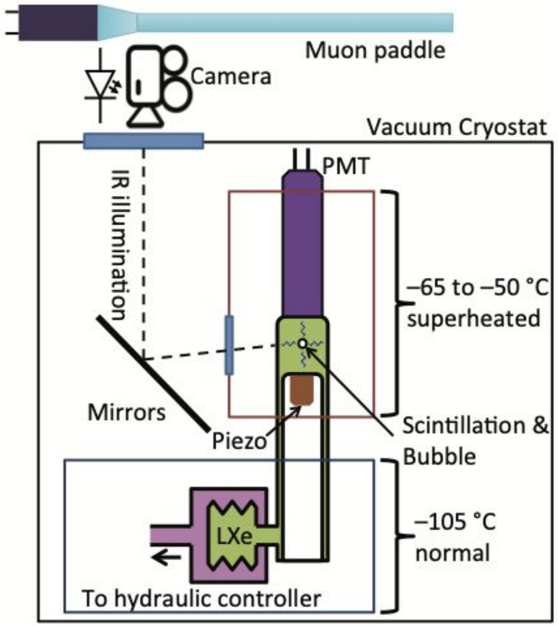


Liquid-noble target fluid



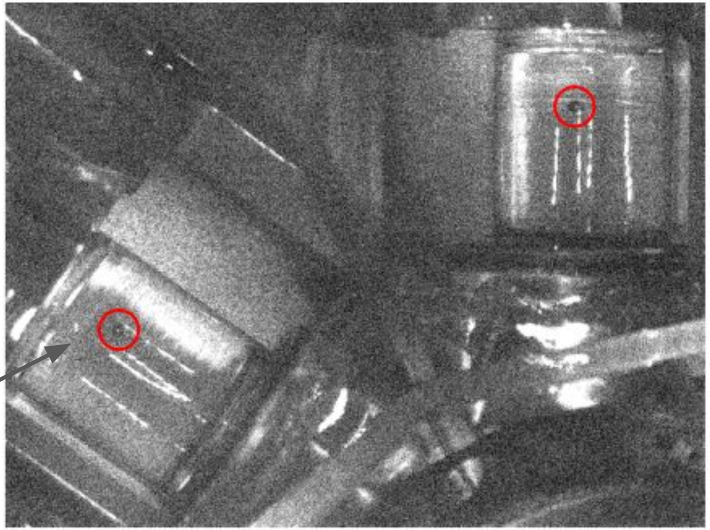
Main point: Liquid nobles remain β/γ blind in GeV-scale ROI
→ **sensitive to only nuclear recoils**

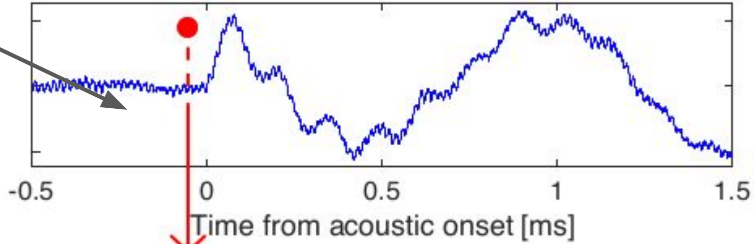
Prototype LXe bubble chamber

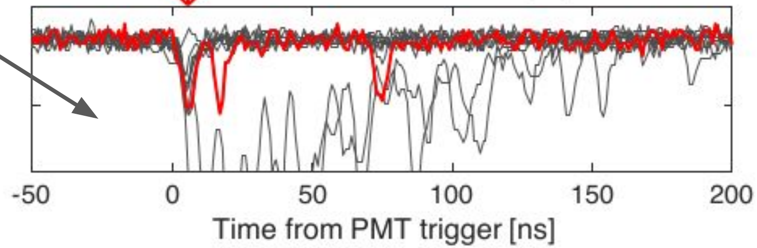


Simultaneous measurement of

- Bubble position (cameras)
- Acoustic emission (piezo transducer)
- Scintillation (UV-grade PMT)







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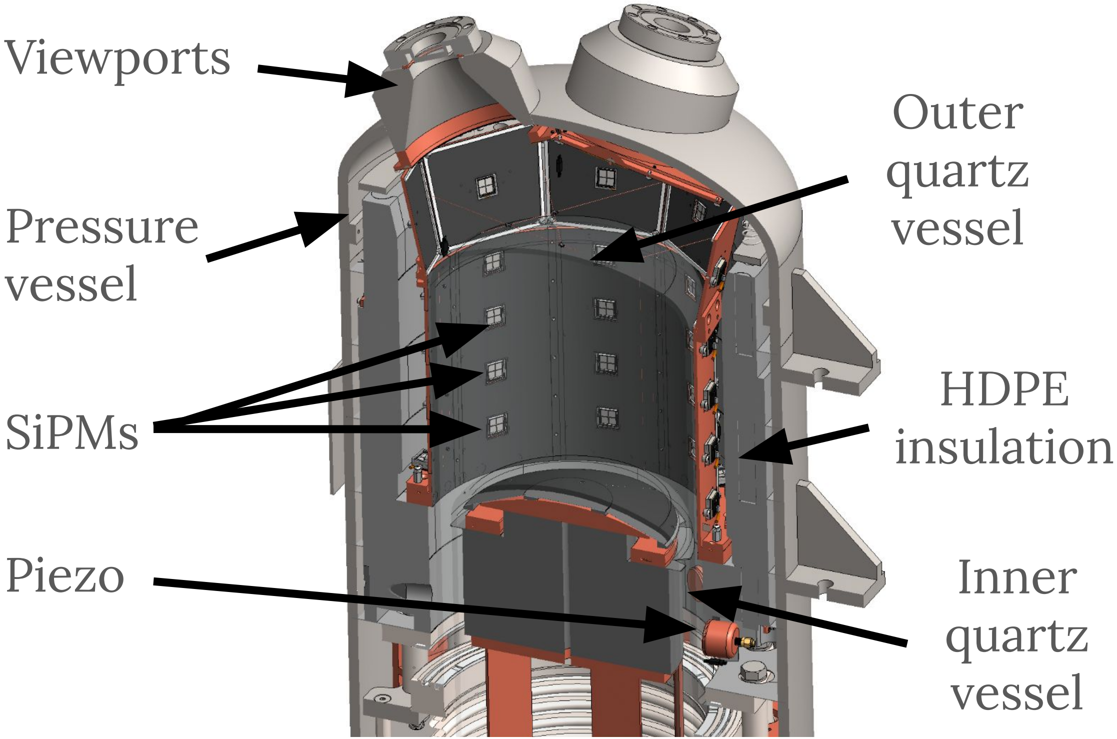
SBC's 10 kg detector design

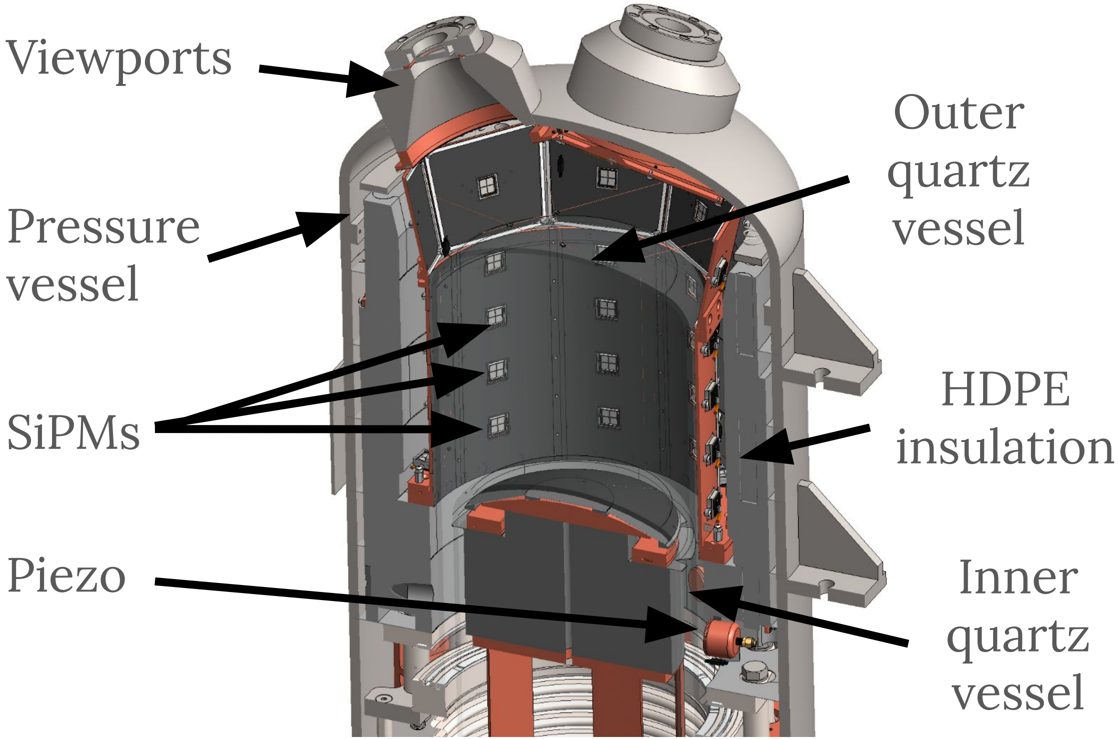


Building two functionally-identical detectors:

SBC-LAr10 @ Fermilab (engineering, calibration, future CEνNS program)

SBC-SNOLAB @ SNOLAB (low background dark matter search)

SBC's 10 kg detector design



Design Goals	
Target Volume	10 L (10 kg LAr @ 130 K)
Nucleation Threshold	100 eV (30 psi , 130 K)
Thermodynamic Regulation	±0.5 K, ±0.1 bar, (± 5 eV Seitz threshold)
Scintillation Detection	~2% collection, 1 photon/ 5 keV n.r.
Bubble Imaging	100 fps, mm resolution
Acoustic Reconstruction	Time-of-nucleation to ± 25 μs

SNOLAB internals & process controls

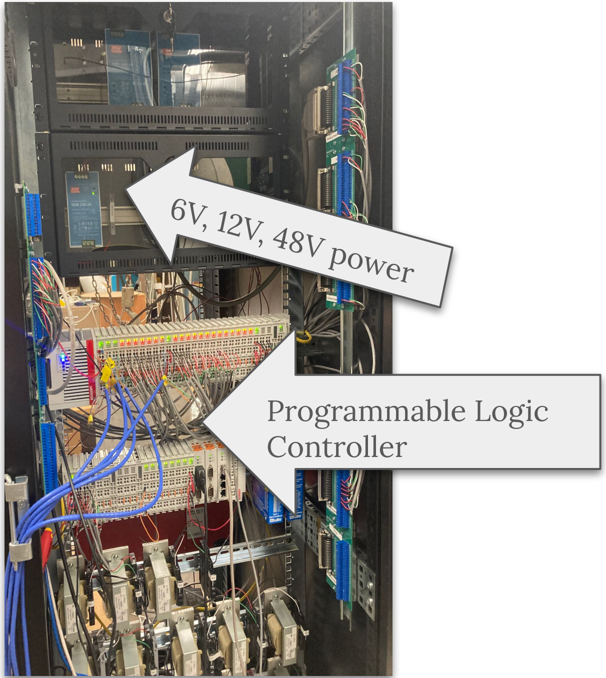
Internals components purchased/built and tested in parallel with Fermilab chamber

Fermilab, SNOLAB, and test vessels

Queen's test setup

PLC under construction at Queen's

(Carter Garrah, Queen's)



Component arrival at SNOLAB

Main detector components are arriving on surface at SNOLAB

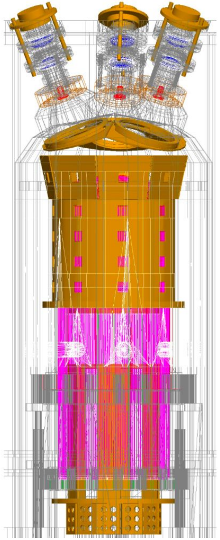
Starting assembly later this summer

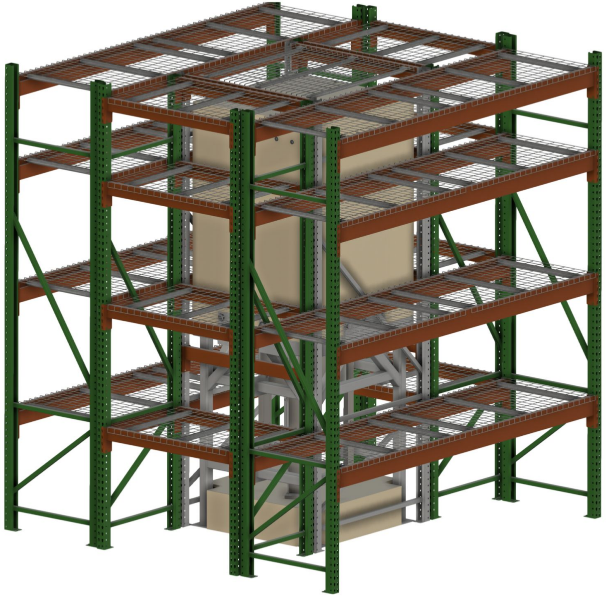
Pressure vessel

Vacuum jacket

Simulation and shield design

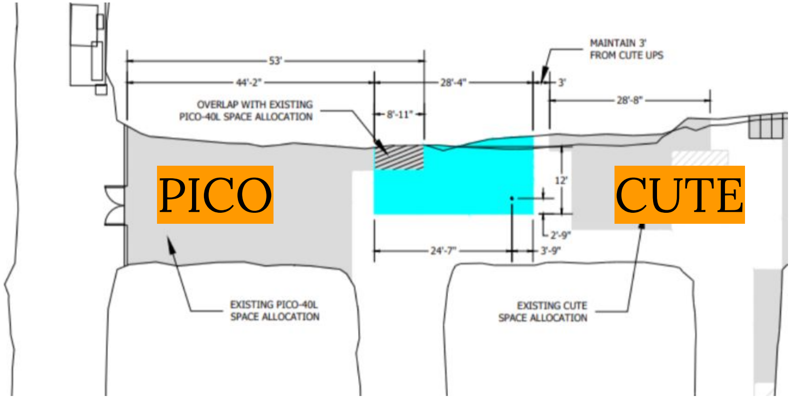
Full assay campaign and Geant4 simulation of internal and external backgrounds (led by Gary Sweeney, Queen's)





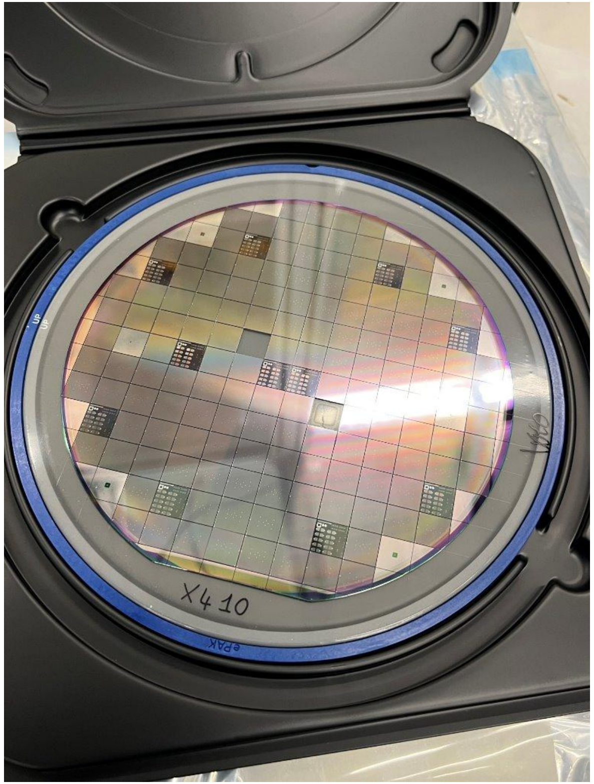
- Water shield for rock-wall neutrons (800x reduction in fast neutrons)

- Gamma shield (200x reduction in Thomson scattering $E\gamma \gtrsim 1.4$MeV)

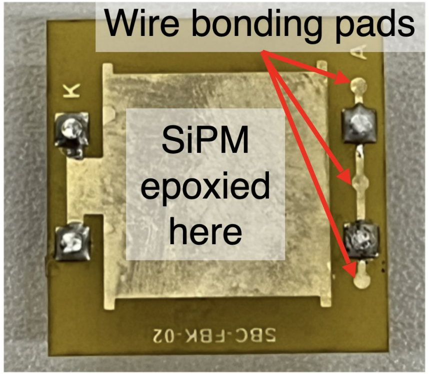


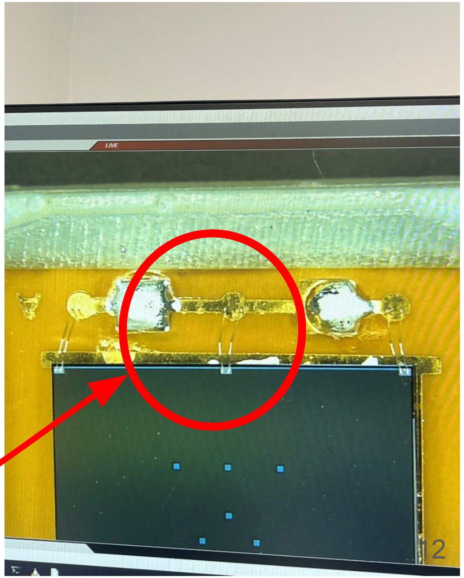
SiPM construction

- Simulations indicate high background rate from Hamamatsu VUV4 SiPMs
- Switch to FBK VUV HD3 (same as nEXO)
- Wire bonding in Atlas cleanroom at TRIUMF

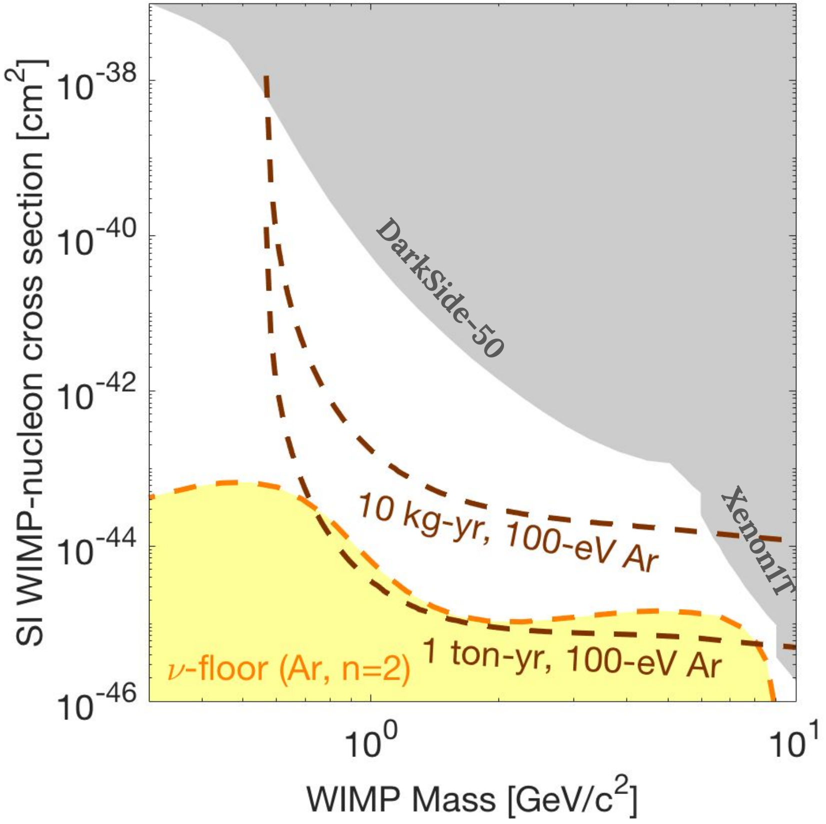


Raw silicon chips diced on wafer





Physics potential



- ROI: 0.1 keV - 10 keV n.r.
  - just bubble, no scintillation
- SNOLAB chamber, 10 kg-year exposure can reach 10^{-43} cm^2 @ 1 GeV/c^2
- Tonne-year can reach boundary of the Ar ν-fog
- Target fluid flexibility (Xe, Ar, N_2, etc.)

Conclusion

- SBC has great potential to probe GeV-scale dark matter

- Exciting time for SBC in 2025
  - Operation @ FNAL
  - SNOLAB TDR completed, construction late summer

Queen's University
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Indiana University South Bend
Northwestern University
University of Alberta
UC Santa Barbara
Fermilab
Northeastern Illinois University
Université de Montréal
Pacific Northwest National Laboratory
UC Riverside

Snowmass: **arXiv: 2207.12400.** ***Universe*** **9 (2023) 8, 346.**
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