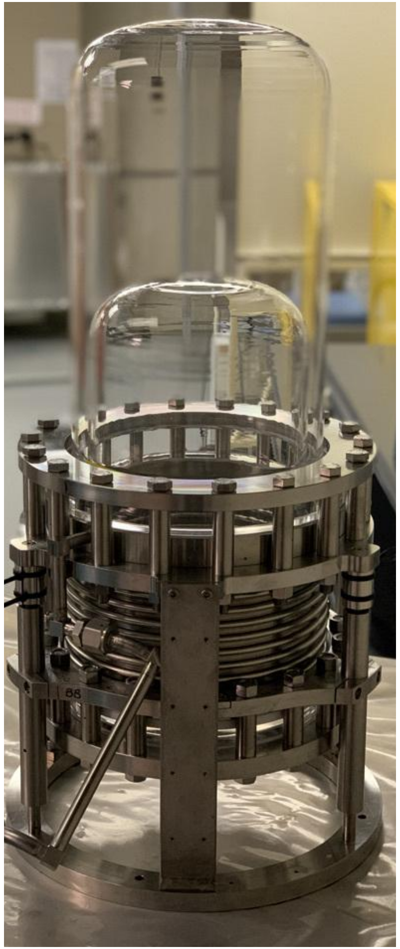
Scintillating Bubble Chambers for Rare Event Searches

Ben Broerman
for the SBC collaboration

CPAD 2022

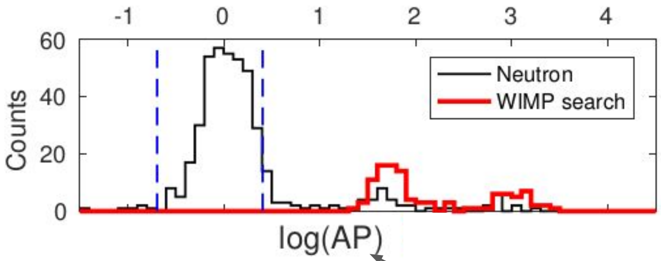


Queen's UNIVERSITY

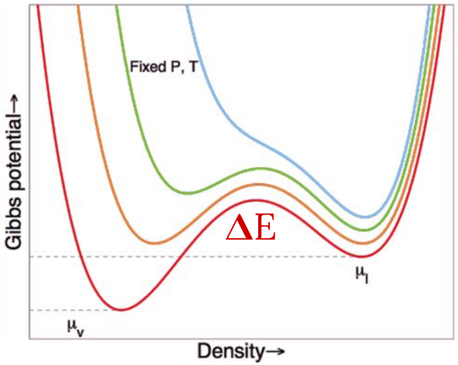
NSERC CRSNG

Bubble chambers

- Bubble chambers maintain target fluid in a superheated state
- High efficiency low n.r. threshold, β/γ insensitivity, n.r./α discrimination:

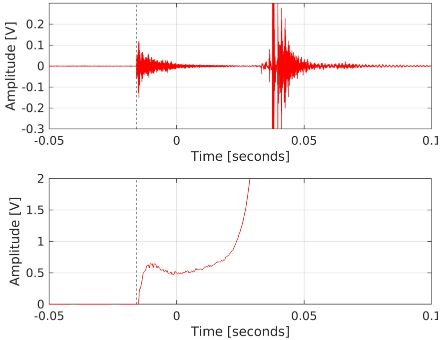


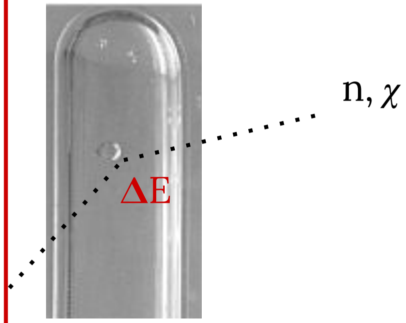
{x,y,z} + acoustics



Pressure ↓, 2 minima form

Further P ↓, Metastable superheated

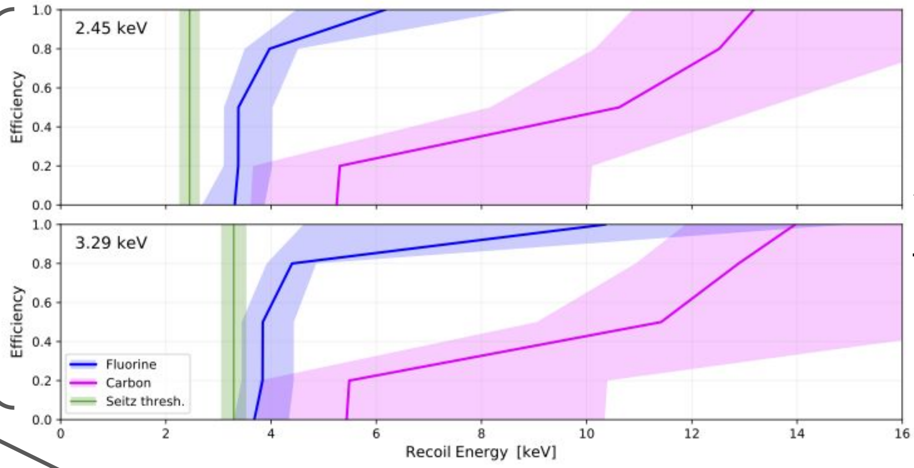




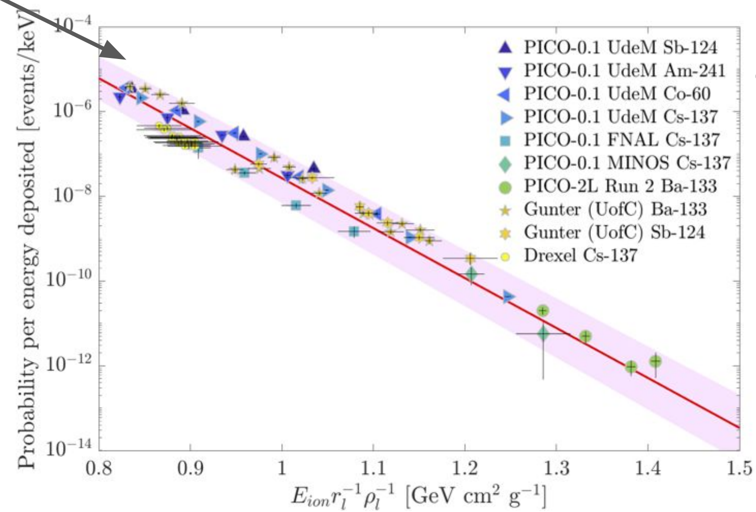
If ΔE deposited, local phase change

Bubble chambers

- Issues with freon B.C.'s
  - Threshold detectors: no energy information
  - β/γ rejection fails at low thresholds
- Liquid-noble B.C.'s
  - Scintillation provides energy information
  - Lack molecular vibrational modes to provide local heating (possible increase in β/γ suppression at low thresholds)
    - **No e.r. bubbles in pure Xe B.C., but nucleation in Xe + ethylene (quenched scintillation)**



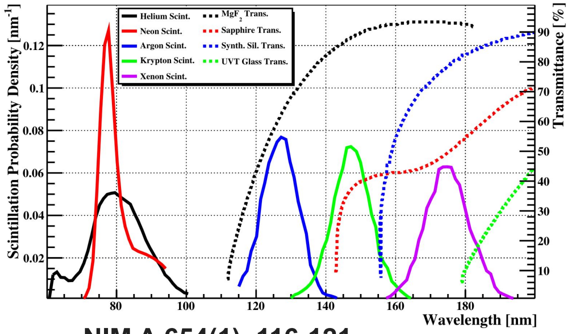
arXiv: 2205.05771, accepted to PRD



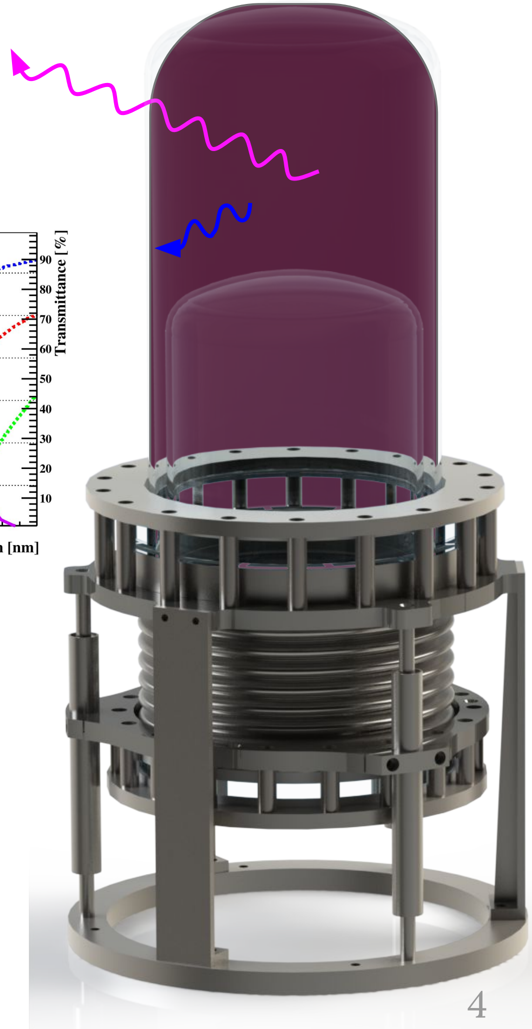
Phys. Rev. D 100, 082006

Liquid-noble bubble chambers

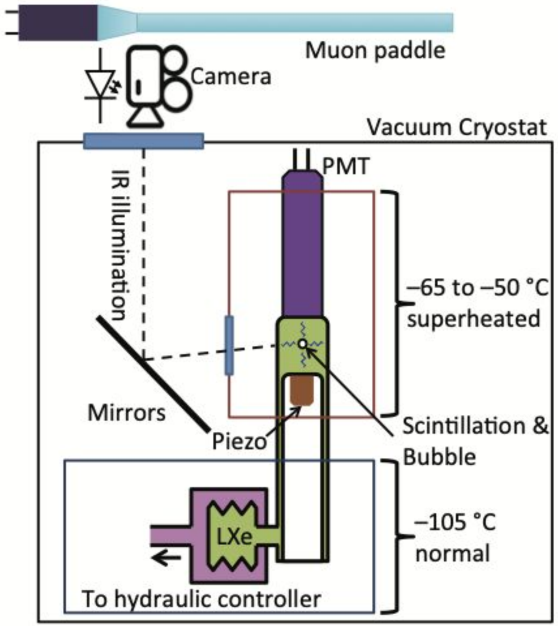
- Argon 3x lighter than Xe
  - Ar for low mass SI, Xe-doping to get the light out
- Cryogenic temperatures
  - Everything that moves, must move cold
- Signal timing difference
  - Scintillation $\mathcal{O}$(ns)
  - Bubble formation/acoustic emission $\mathcal{O}$(μs)
  - Recompression $\mathcal{O}$(ms)



NIM A 654(1), 116-121.

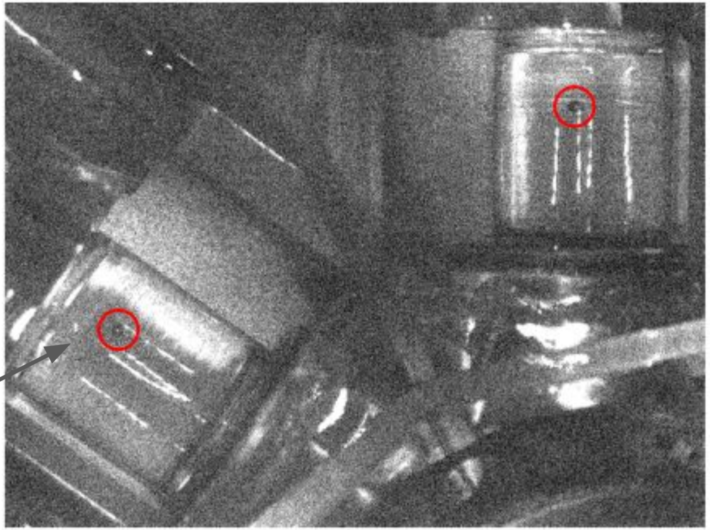


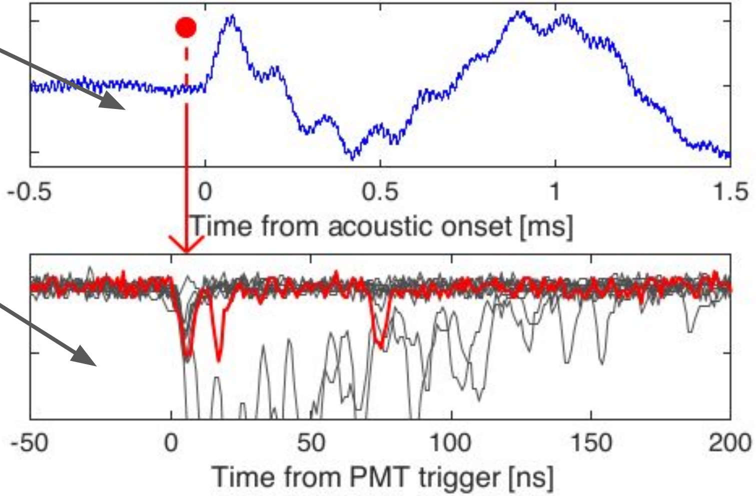
Prototype LXe bubble chamber



Simultaneous measurement of

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

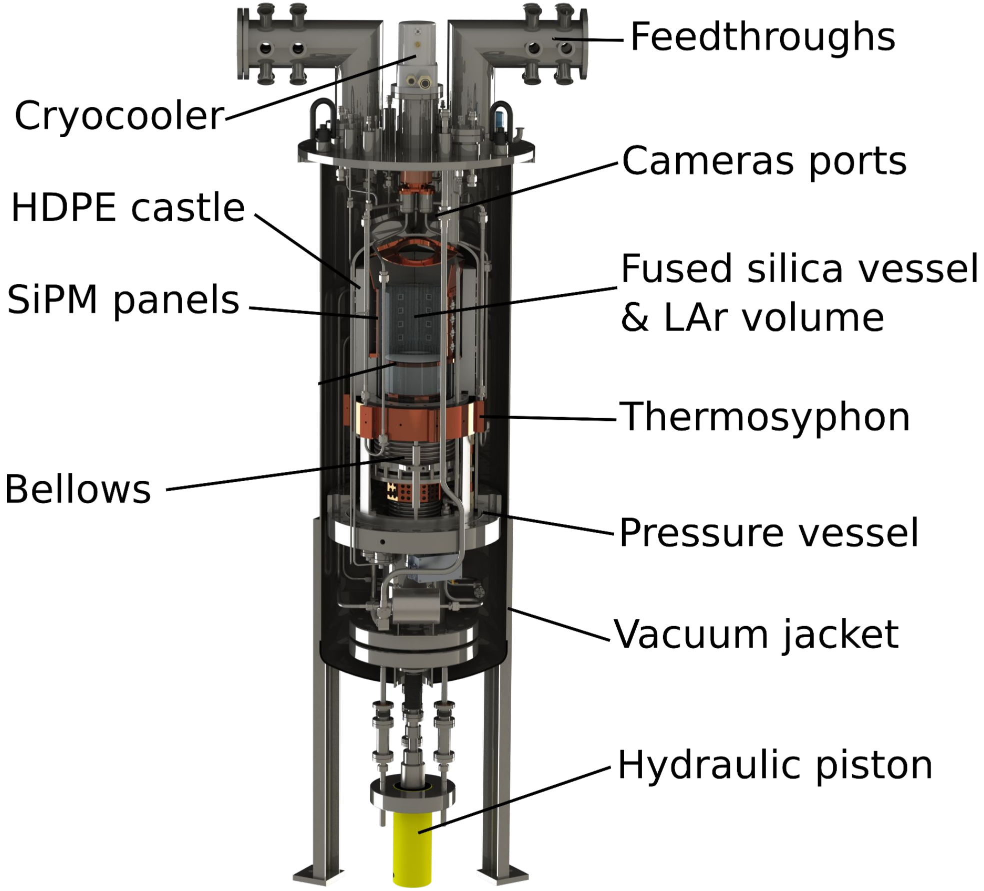




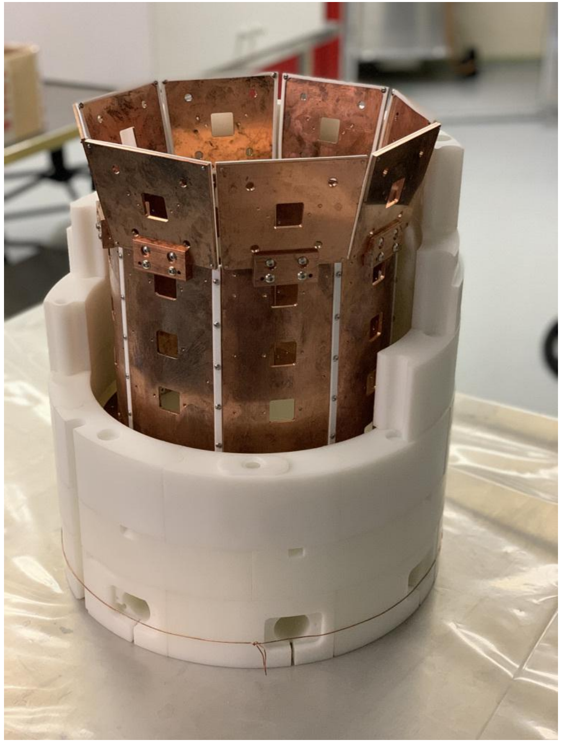
PRL 118.23 (2017) 231301

SBC detectors

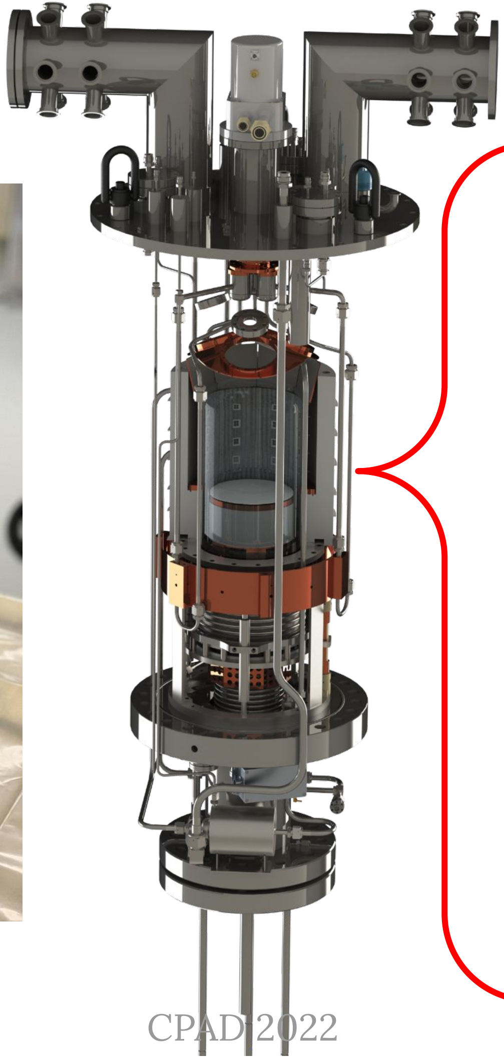
- Two functionally-identical detectors operated at:
  - SBC-LAr10 @ Fermilab (engineering, calibration, CEνNS)
  - SBC-SNOLAB @ SNOLAB (low bkg. dark matter)
- 10 kg LAr + Xe as a wavelength shifter targeting 100 eV n.r. threshold
- Cold region ~90 K, warm region ~130 K
- Expanded ~30 psi, compressed ~200 psi



Inner vessel

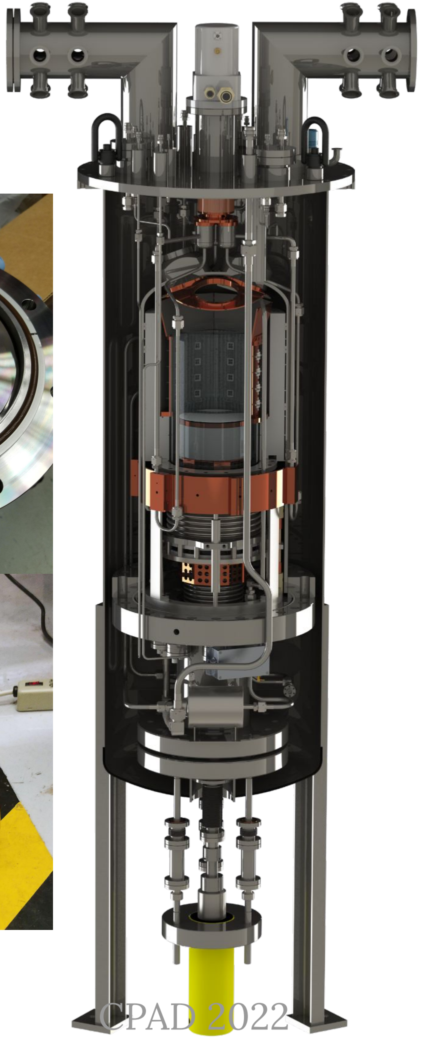


HDPE castle, Cu SiPM panel



Fused silica vessels and bellows

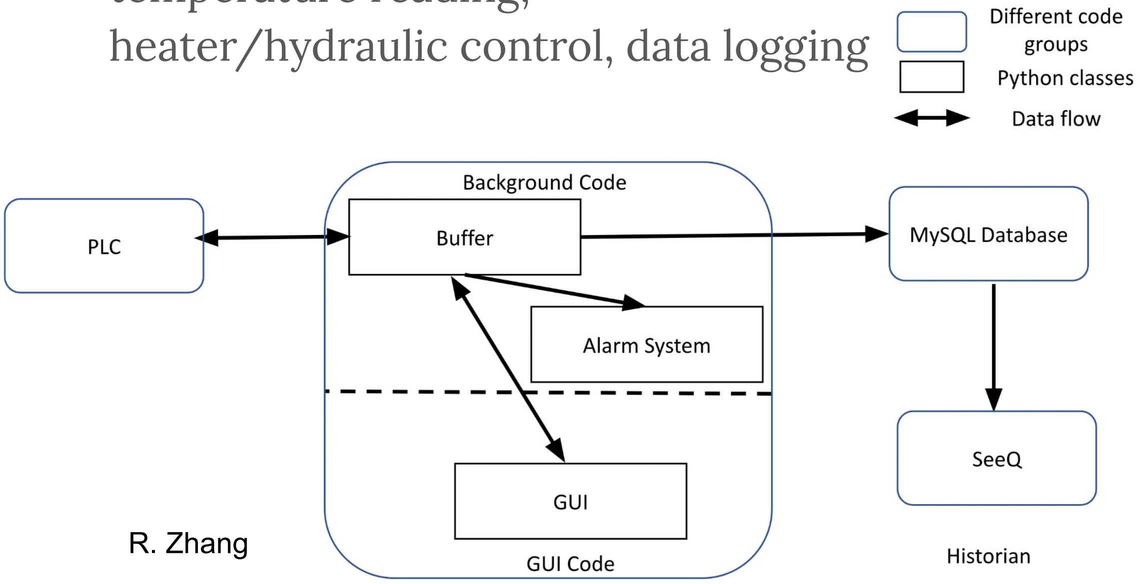
Outer vessel



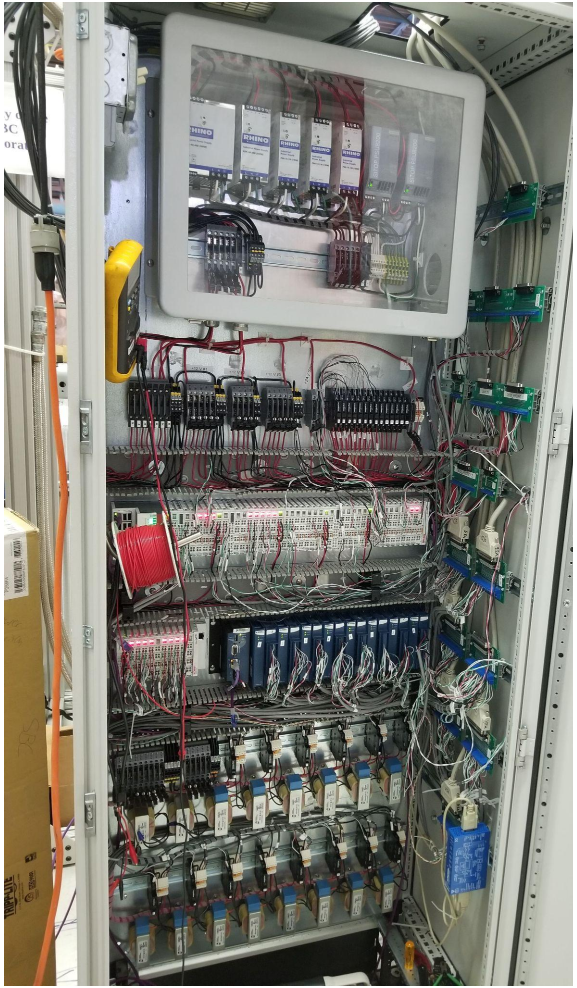
Vacuum jacket and pressure vessel

Pressure and temperature control

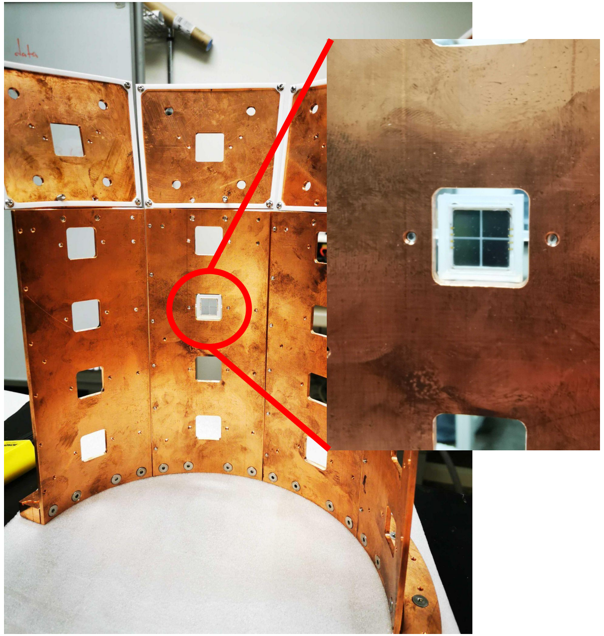
- Beckhoff-based system for pressure & temperature reading, heater/hydraulic control, data logging



R. Zhang

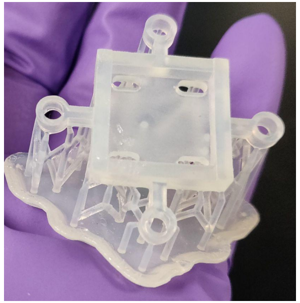


SiPMs, piezos, and cameras

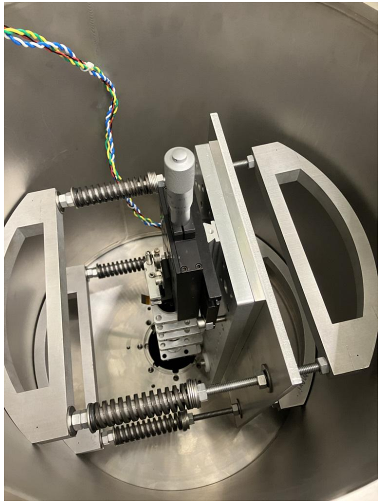


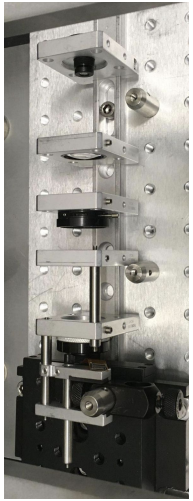
SNOLAB: FBK (25-30% QE)
Fermilab: Hamamatsu (20-25% QE)

Custom PZT piezo transducers



Camera and lens setup





Backgrounds

α-induced

Surface Po, bulk ^{222}Rn decays [purification/cleaning]

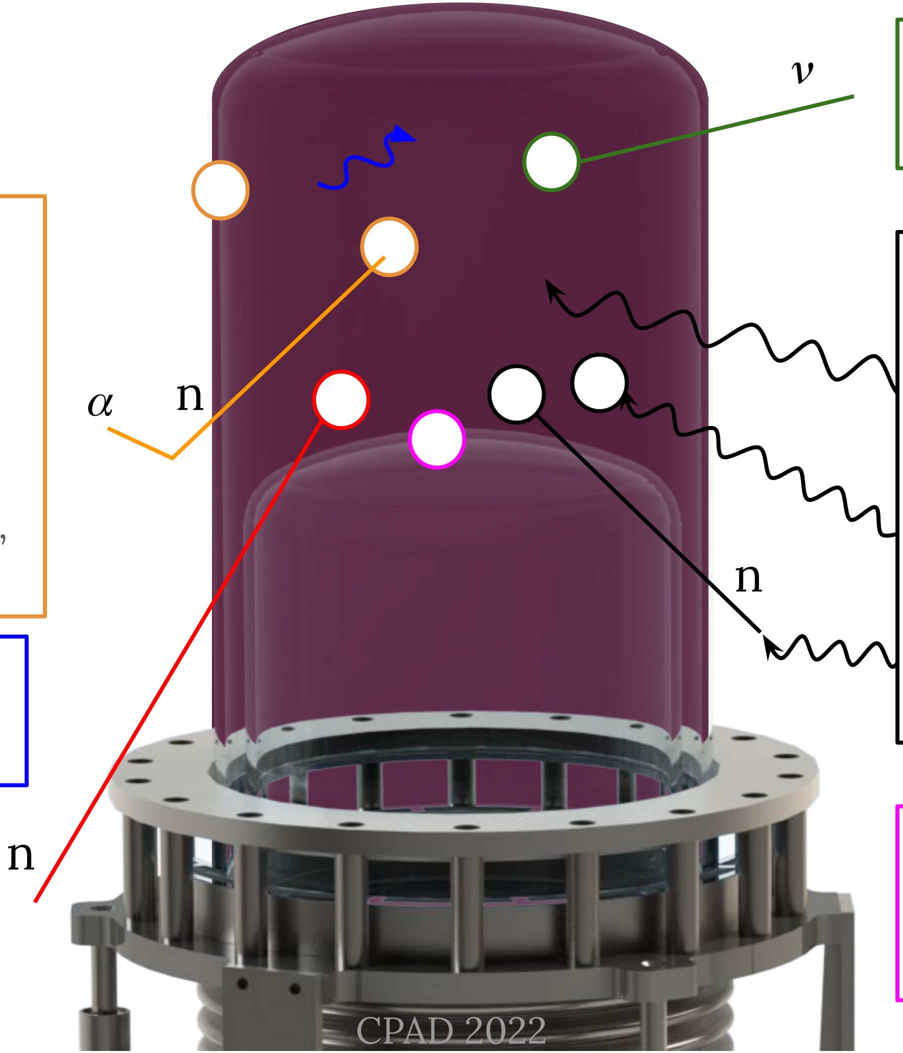
(α,n) in detector materials & LCF_4 [material selection, leaching]

β-induced

^{39}Ar [stray SiPM signals]

n-induced

Fast n [shielding/LCF_4 veto, multiple scatters]



ν-induced

^{8}B CEνNS [irreducible]

γ-induced

Compton [stray SiPM signals, material selection/shielding]

Thomson (^{40}K, ^{208}Tl) [shielding]

(γ,n) reactions in water tank [shielding]

Pathological

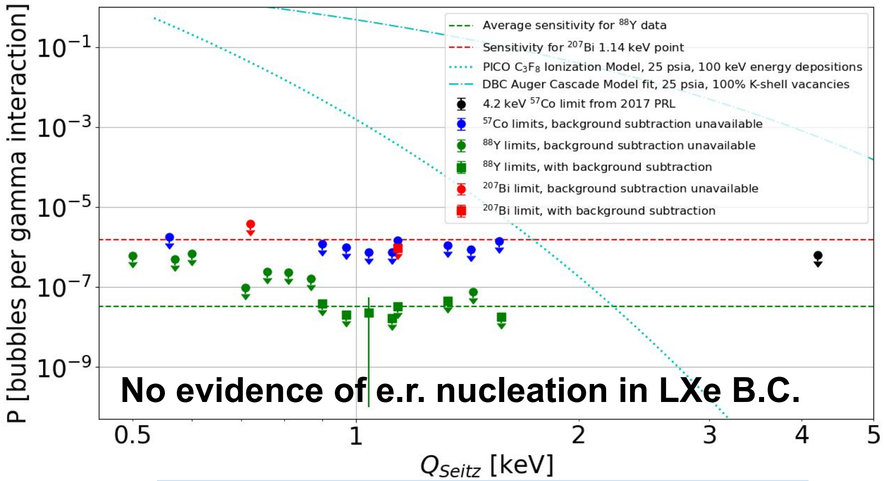
Surface roughness, thermal stability

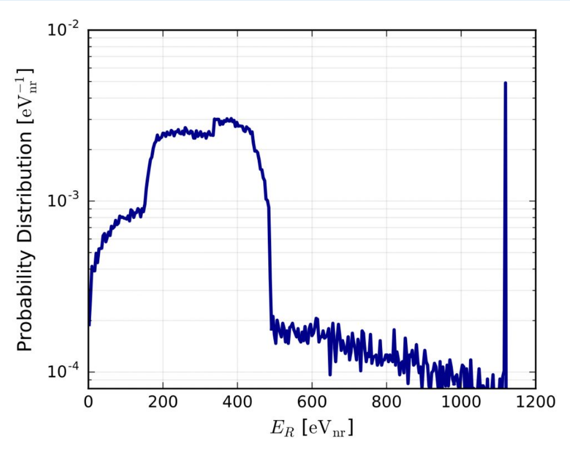
Initial calibration goals

1) Stable operation
   - Homogeneous response across sensitive volume

2) Gamma calibration
   - Confirming no e.r. nucleation at keV-scale
   - Investigate e.r. rejection at/below 100 eV

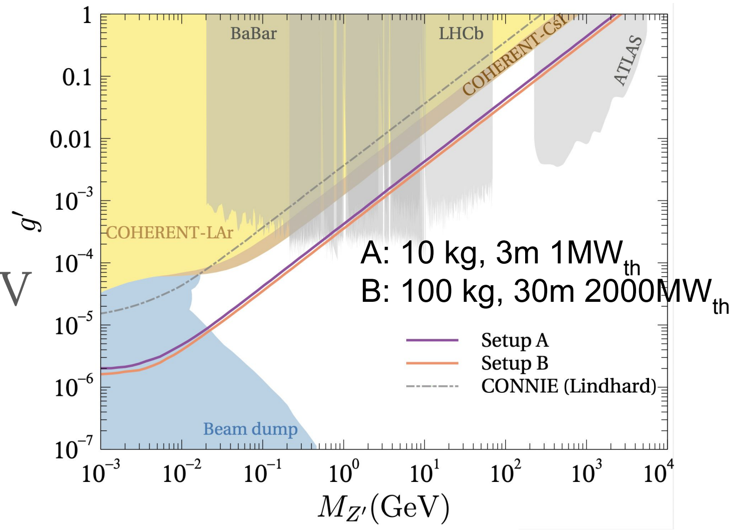
3) Nuclear recoil calibration
   - Photoneutron (keV), Thomson scattering (sub-keV), tagged neutron capture (< 100 eV)
   - See next talk from D. Durnford

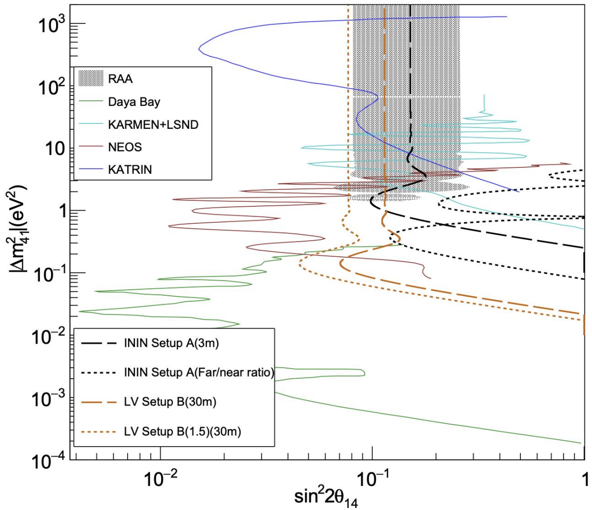




Physics potential: CEνNS

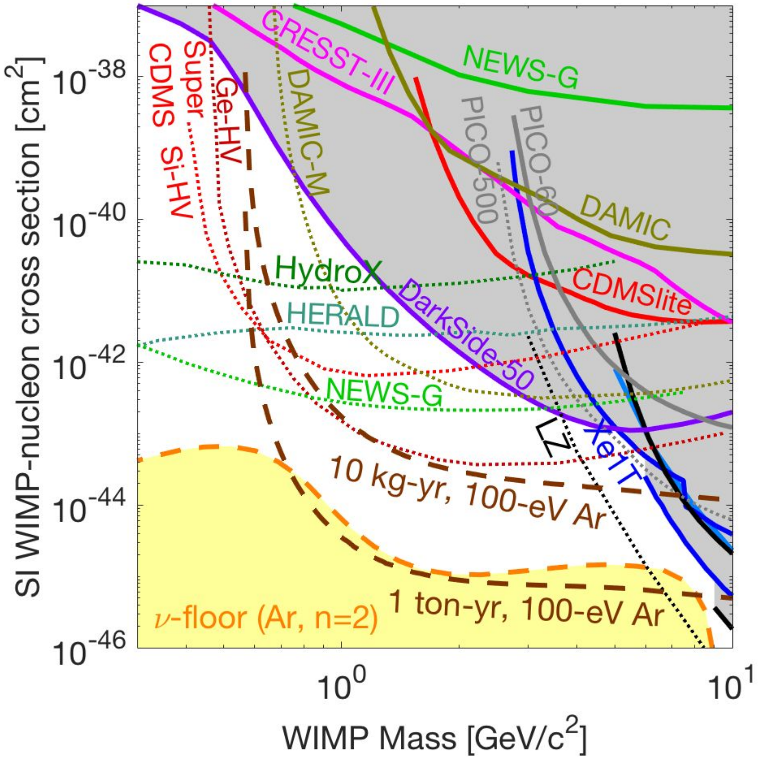
- MeV-scale reactor neutrinos produce sub-keV CEνNS scattering
- Harder to detect, but increase in flux over stopped-π sources
- Possible precision measurements of:
  - Weak mixing angle
  - NSI through Mz'
  - Neutrino magnetic moment
  - Sterile neutrinos





Check out: **PRD 103, L091301 (2021), arxiv 2203.05982**

Physics potential: dark matter



- ROI: 0.1 keV - 10 keV n.r.
- SNOLAB chamber, 10 kg-year can reach 10^{-43} cm^2 @ 1 GeV/c^2
- Ton-year can reach boundary of the Ar ν-fog
- Flexibility for other target fluids for SD searches

Conclusion

- Liquid-noble chamber will probe GeV-scale dark matter and CEνNS from MeV-scale reactor neutrinos
- Commissioning at Fermilab through 2022
  - 1st cooldown test happening now, IV components shipping in 2 weeks
- SNOLAB construction in 2023
  - Space allocated, TDR in preparation
- SBC collaboration consists of institutions from Canada, USA, Mexico (new collaborators always welcome)
- Check out our Snowmass white paper: **arxiv: 2207.12400**

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