The Scintillating Bubble Chamber Experiment, a 10 kg liquid noble bubble chamber

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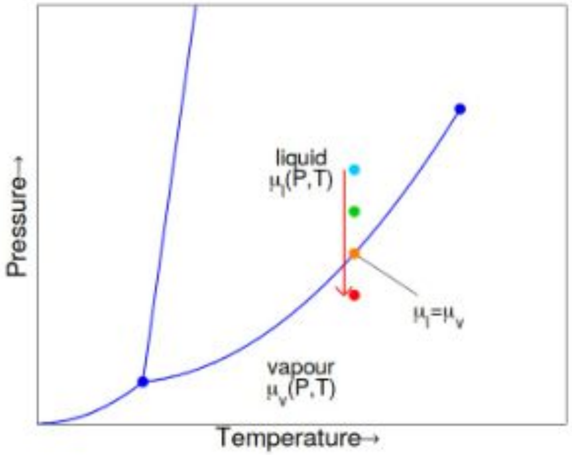
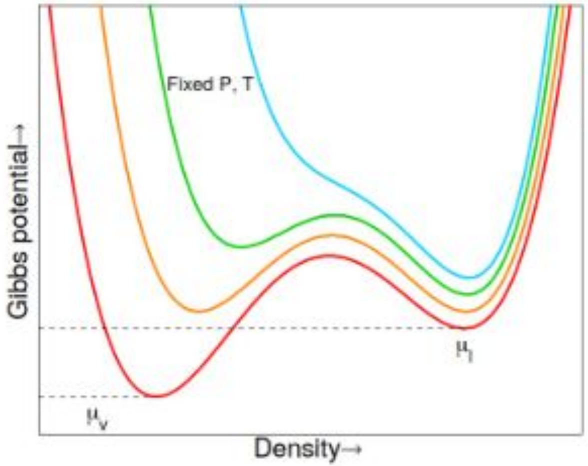
Motivations - Why make a scintillating bubble chamber?

- Liquid noble bubble chambers combine the advantages of a bubble chamber with a scintillation detector
- Useful properties for low mass dark matter and CEvNS detectors
  - Very good discrimination between nuclear and electron recoils
  - Low energy threshold
  - Position reconstruction
  - Scalability

Bubble Chamber Basics

- Bubble chambers exploit the thermodynamic properties of a superheated fluid
  - By reducing the pressure while holding the temperature constant a second lower minimum forms in the gibbs potential
- When a particle interacts with the target the heat deposited can bump a small region of the target from the higher to the lower potential, causing a bubble to form
  - This is then detected and the pressure is increased to condense the bubble again



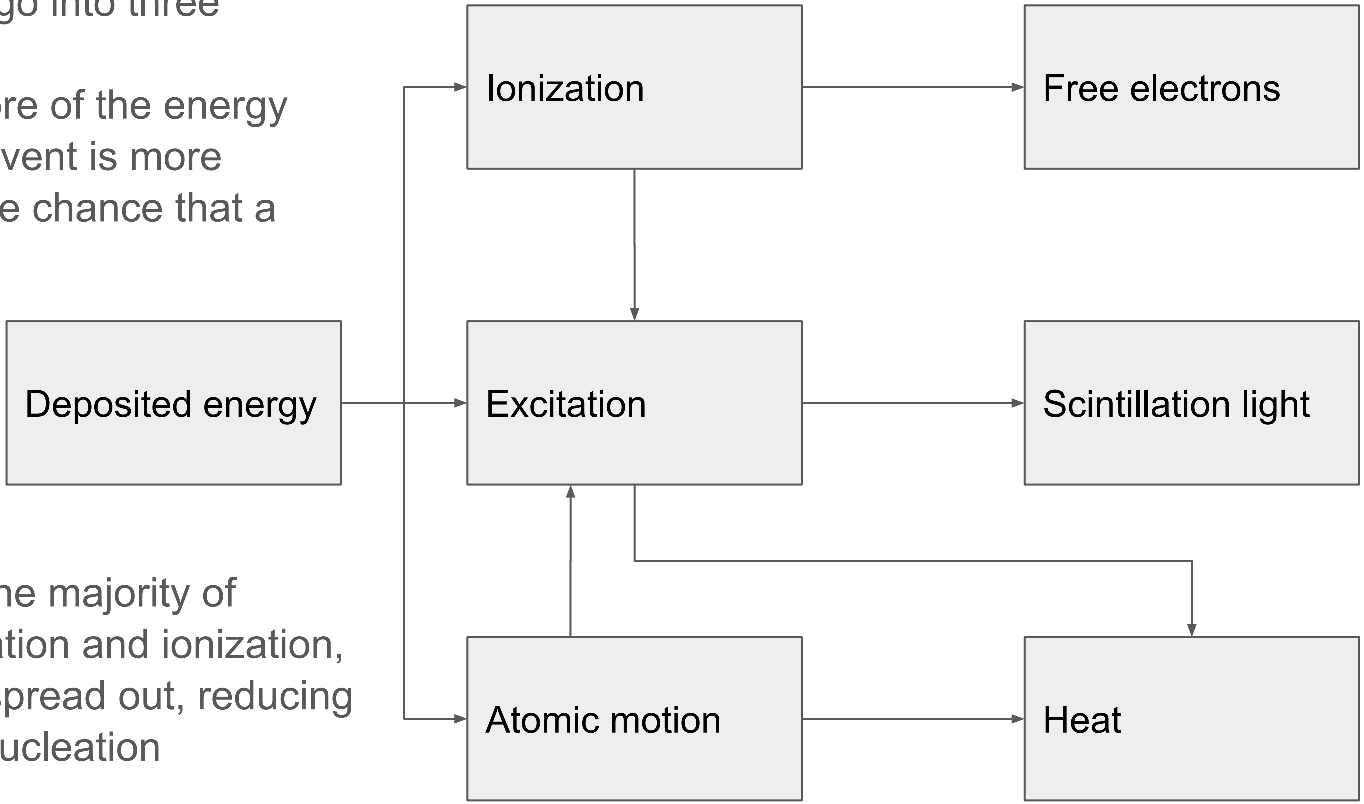


Using a Scintillating Target

- Using a target that also scintillates adds a second information channel apart from the bubble Generation
- More accurate measurements of interaction energy for higher energy events
  - Using just a picture of a bubble from a single scatter provides very little information on the energy of the event other then the fact that it crossed the threshold
- Can detect events below the bubble threshold
  - Calibrations of the NR bubble generation threshold vs the ER bubble generation threshold
- Split in energy deposition in liquid nobles allows for powerful Nuclear recoil discrimination

Energy deposition in Liquid Nobles

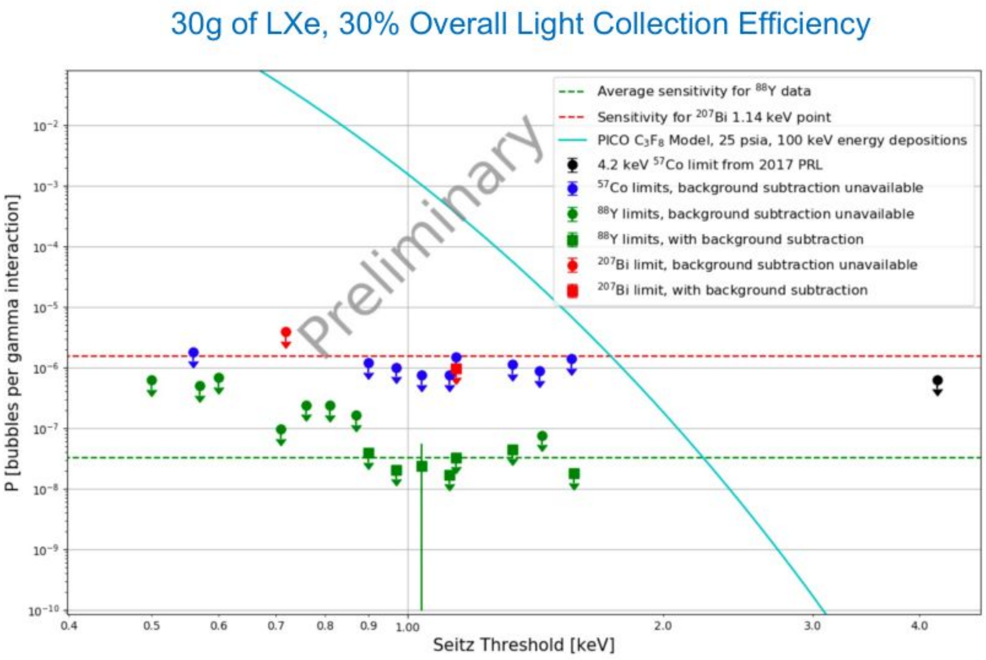
- Deposited energy can go into three different channels
- For a nuclear recoil more of the energy ends as heat and the event is more localized, increasing the chance that a bubble will nucleate



- For an electron recoil the majority of energy goes into excitation and ionization, and tends to be more spread out, reducing the chance of bubble nucleation

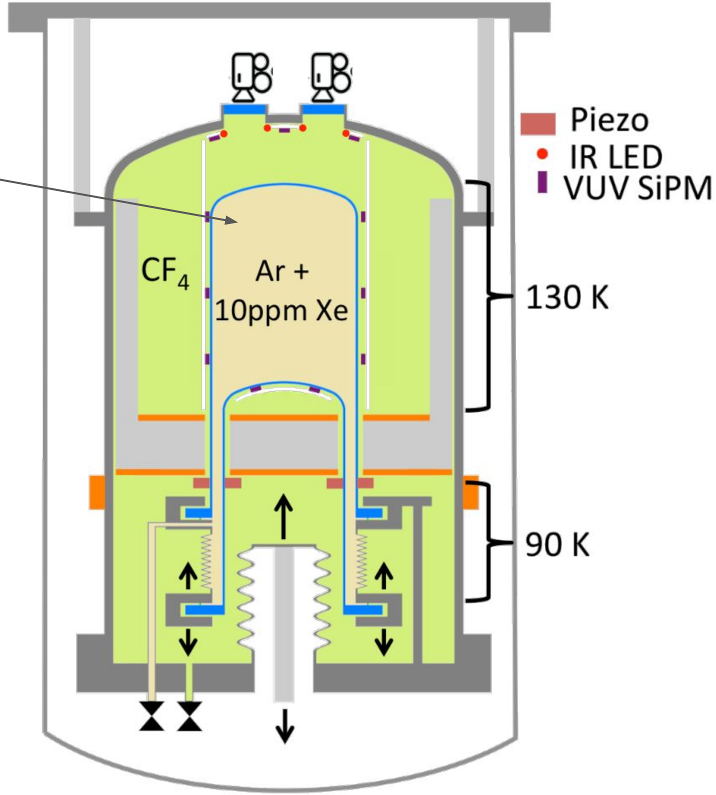
Nuclear recoil discrimination

- This difference in response to electron and nuclear recoils is what provides the discrimination we need
  - 10e-6 bubbles/ER in liquid xenon down to 500 eV NR threshold.
  - 100 eV NR threshold goal for the argon chamber



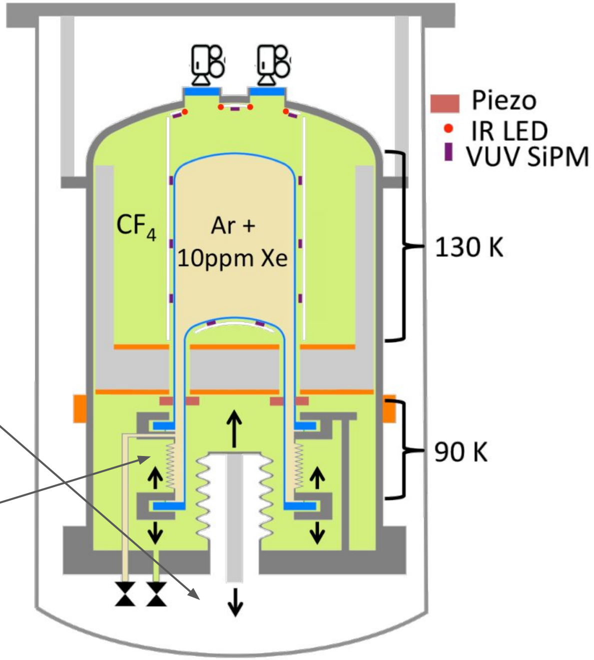
SBC Design

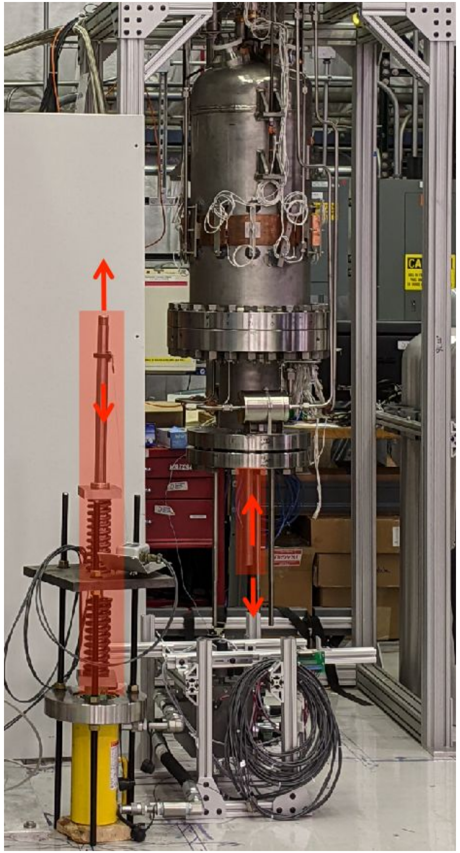
- 10 kg of Argon doped with Xenon as the target
  - The xenon shifts the scintillation wavelength to lower frequencies, allowing transmission through quartz jars, and higher SiPM efficiency
- Liquid CF4 bath
  - Thermal management
  - Hydraulic fluid
- Superheat is achieved using a hydraulic piston to change the volume of the chamber
- Three main data channels
  - Acoustic sensors - detect bubble formation
  - Cameras - locate bubble in volume
  - SiPM - readout scintillation light



Pressure control

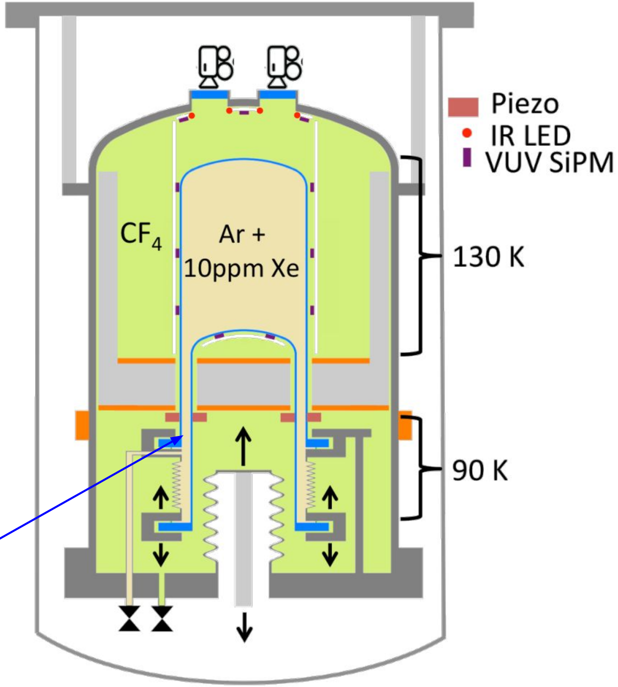
- A commercial hydraulic cylinder is connected to the bottom bellows to change the volume
- The two quartz jars are connected by a bellows allowing pressure changes in the CF4 space to be transmitted to the argon
- Testing is currently underway to validate our hydraulic system
  - Speed
  - Position control





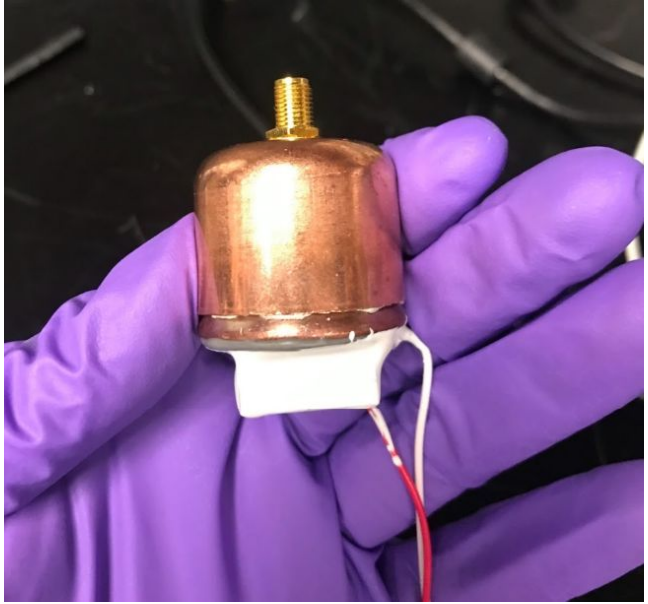
Thermal control

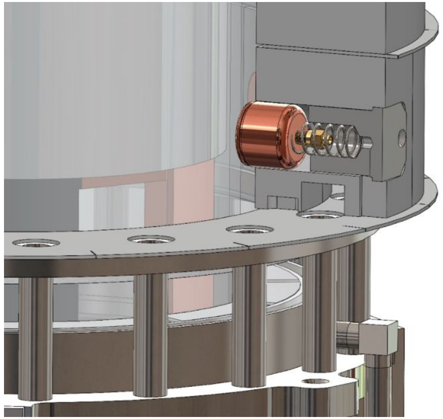
- Cooling source is a centrally mounted Cryocooler
  - This cooling power is distributed using 3 nitrogen Thermosiphons on a copper band
- The detector volume is split into two regions by the placement of the thermosiphon evaporators and the use of internal baffles and insulation
  - Lower region is kept at 90 K to prevent bubble formation in the annular space between the jars
  - Upper region is at 130 K to allow the argon to be superheated



Acoustic readout

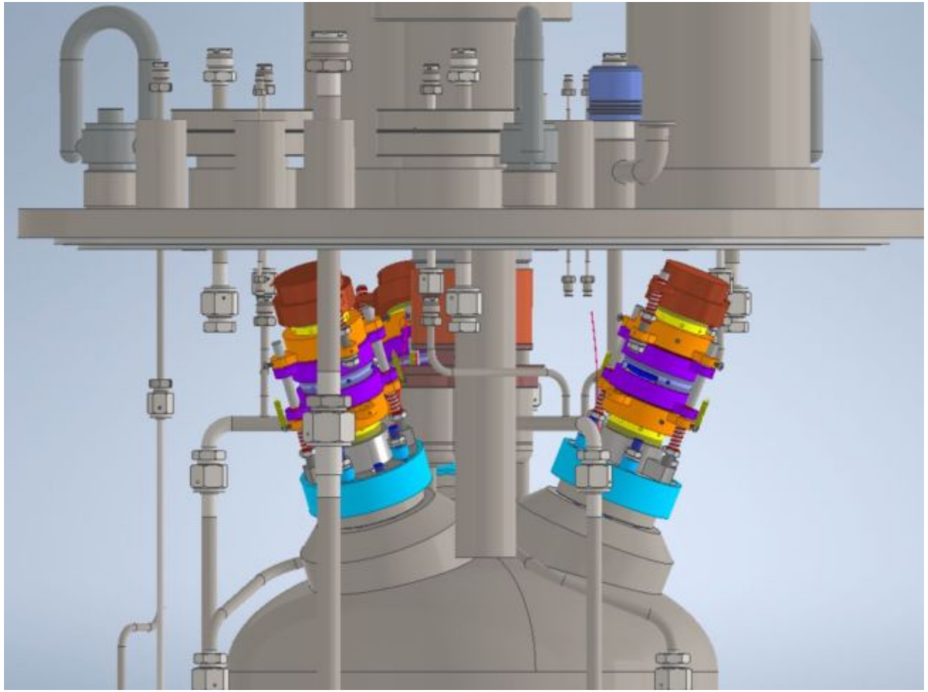
- Eight Piezoelectric sensors held in contact with the quartz jars
  - Using spring loaded mounts in the plastic insulation
- Used to trigger on bubble formation
  - Recompress and reset chamber
  - Record camera and SiPM data





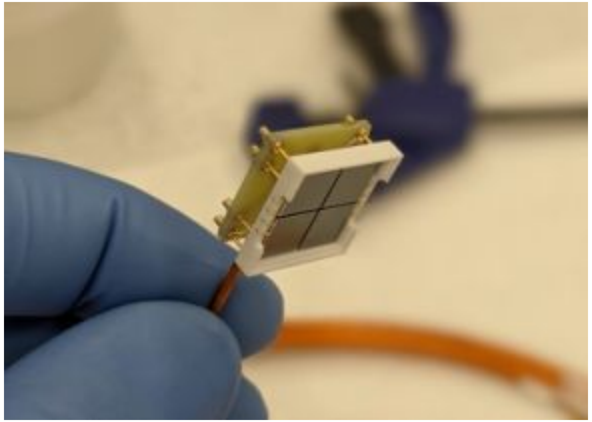
Cameras

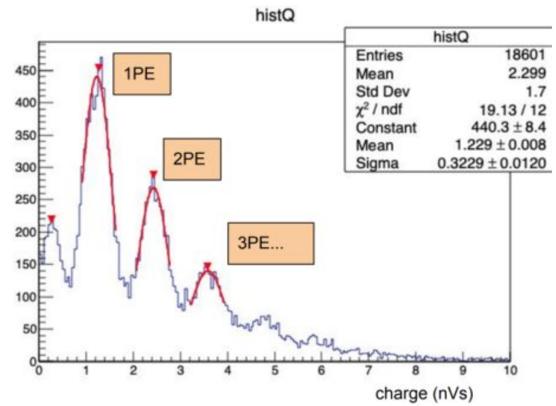
- Using 3 off the shelf Raspberry Pi camera sensors
  - Custom mount and optics
- Will operate in the vacuum space and look through sight glasses located on the top of the pressure vessel
  - Significantly reduces the complexity of the optical system
- Provides position reconstruction and veto of multiple scatters

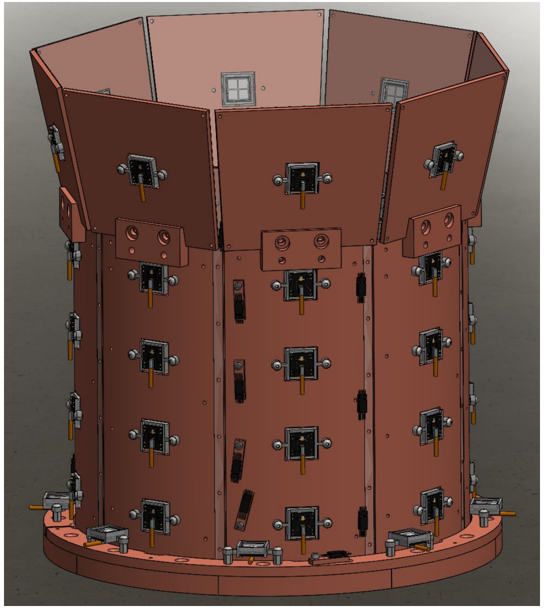


SiPM Array

- Using Hamamatsu VUV4 SiPMs
- 32 SiPM fully surround the jars
- We are also looking into scintillation in liquid CF4 as an additional veto

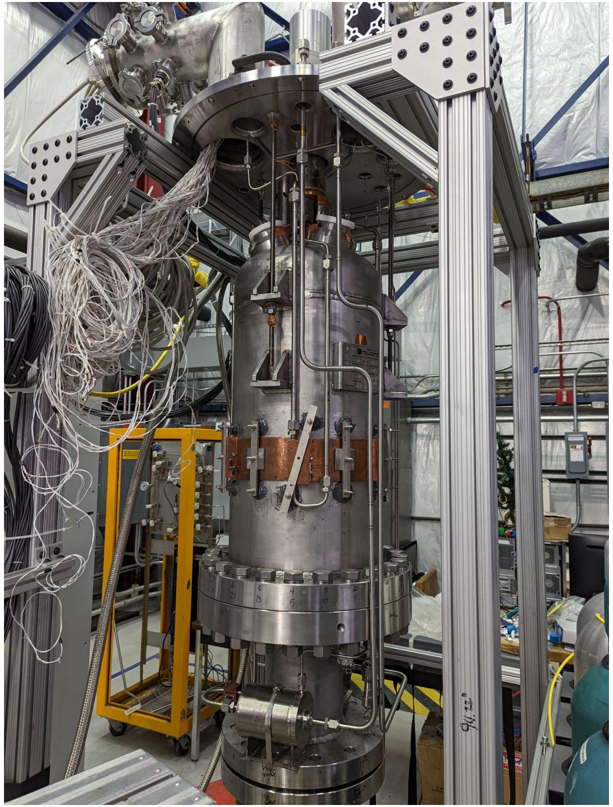






SBC-Fermilab Phase 1

- Build and commission the full size prototype
- Develop control procedures
- Explore thermodynamics
- Calibrate either underground or with shielding
  - Increase the amount of superheat until we begin to see ERs generate bubbles
  - Back off the superheat
  - Determine Nuclear recoil threshold at maximum superheat

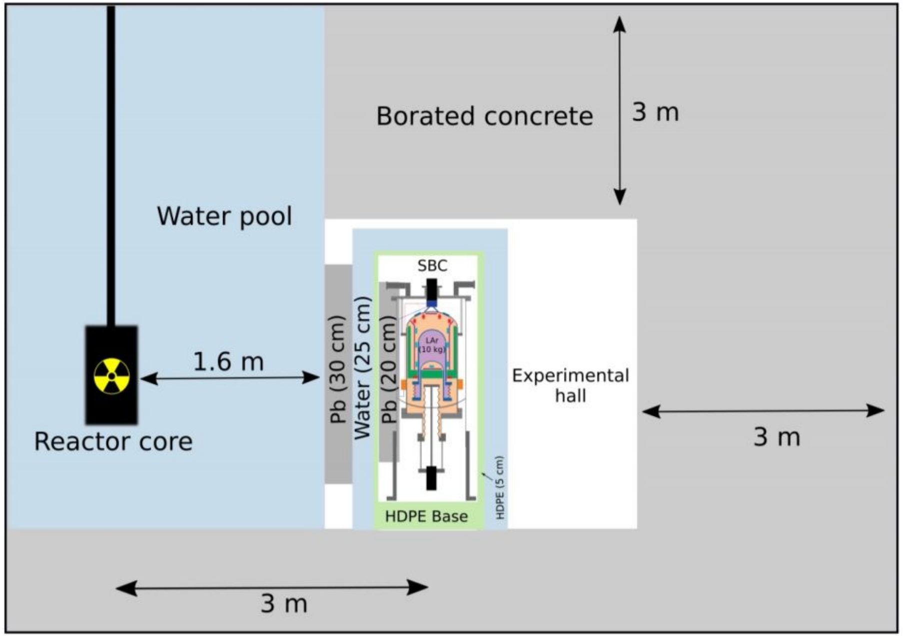


SBC-Snolab Phase 2

- Second mostly identical detector being constructed in canada for deployment at Snolab
- Intended for the actual dark matter search
- Using counted materials to reduce backgrounds
- Expect some lessons learned from the fermilab chamber

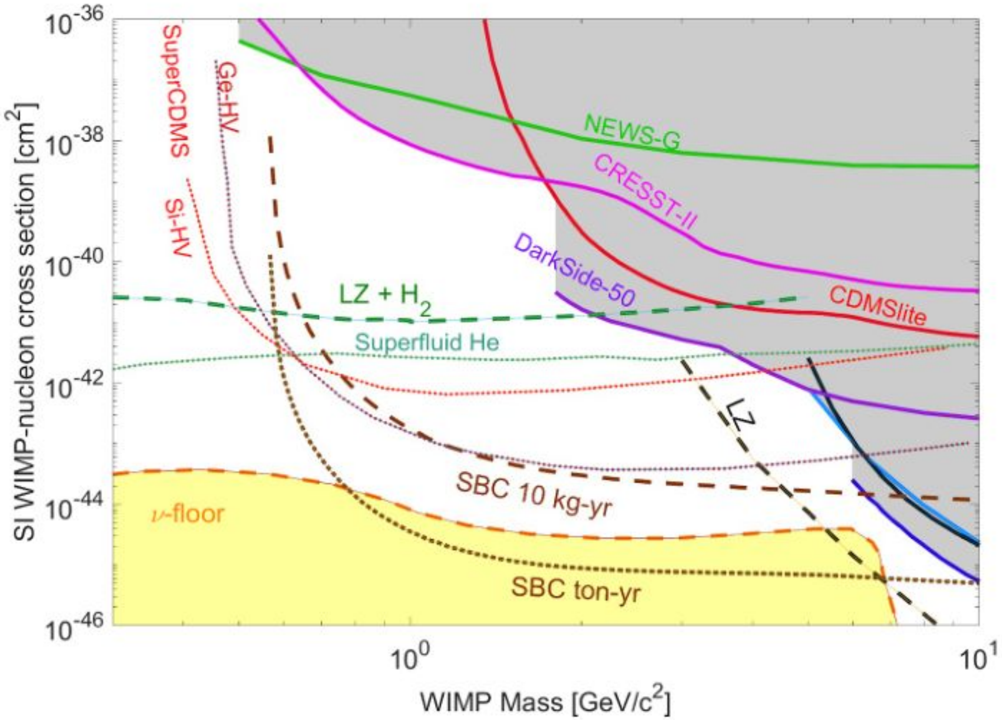
SBC-CEvNS

- Plan to reuse the SBC-Fermilab detector
- Looking at deployment at the ININ reactor in mexico
  - 1MW reactor
  - 3m distance from reactor core
  - We expect about 8 events/day above threshold from this setup
- We are also investigating the possibility of installing a larger detector at a power reactor



Dark matter sensitivity

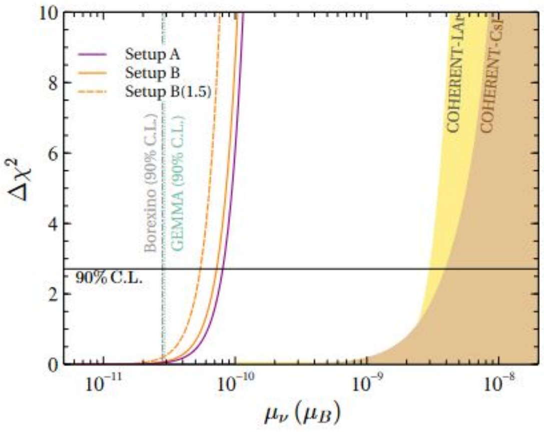
- Low threshold and high electron recoil discrimination allow us to be competative with other low mass dark matter detectors
- 10kg-yr exposure exceeds or is comparable to other low mass dark matter experiments above 1 GeV
- If scaled up a 1 ton-yr exposure reaches the neutrino floor/fog



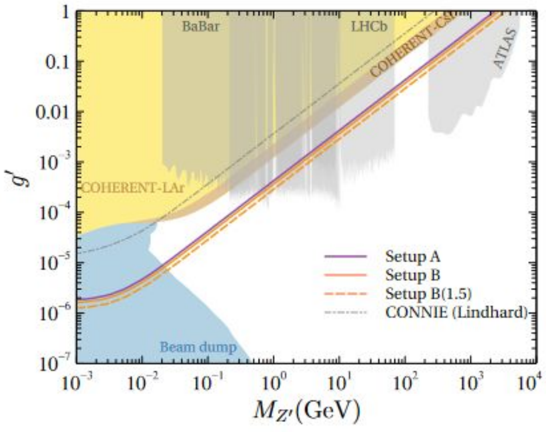
CEvNS sensitivity

- Simulations have been done for two cases a 10 kg detector running at a 1 MW research reactor (ININ) and a 100 kg detector running at a 2000 MW power reactor (Laguna Verde)
  - L. J. Flores et al. arXiv:2101.08785
- 1 year exposure provides competitive measurements or limits on multiple neutrino properties

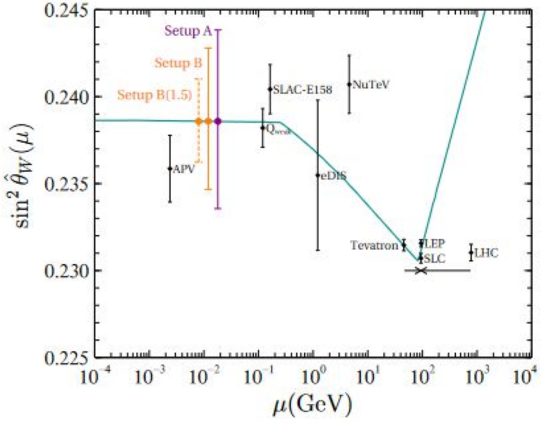
Neutrino Magnetic moment



Dark Mediator Z'



Weak Mixing Angle



Conclusions

- Construction is ongoing on SBC-Fermilab
- SBC-Snolab parts acquisition and counting continuing
- We expect to have calibration results in 2023 from the SBC-Fermilab detector
- Scintillating bubble chambers appear to be a good scalable option for low mass dark matter and CEvNS detectors
  - 10 kg scale detectors with a one year exposure provides competitive limits

The SBC Collaboration

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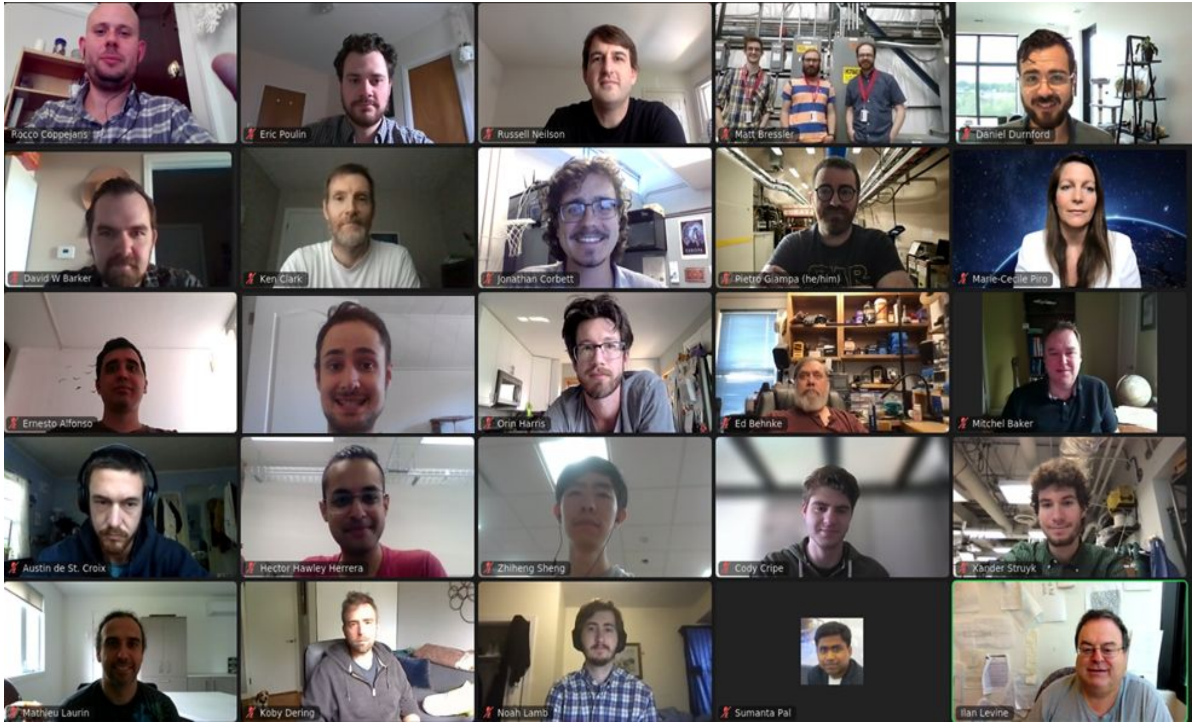

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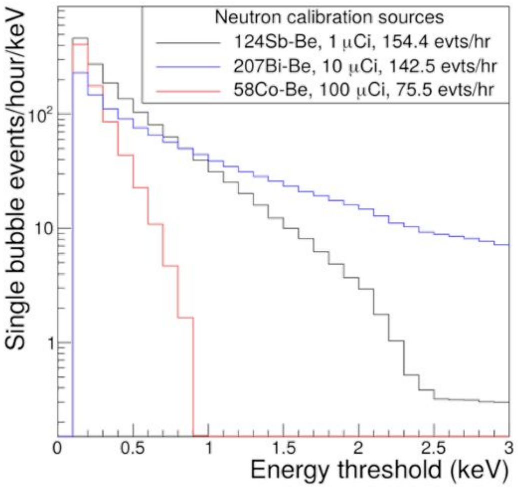
- Chris Jackson

Fermilab

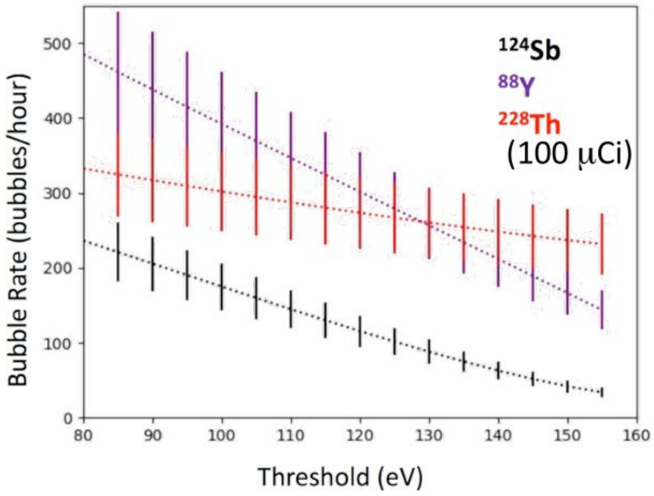
- Mike Crisler

Photo-Neutron sources



Plot credit: E. Alfonso

Thomson scattering



Plot credit: N. Lamb