External Background Event Suppression and Mitigation Techniques in SBC-SNOLAB

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CAP Congress, May 2024

The Scintillating Bubble Chamber

Bubble Chamber

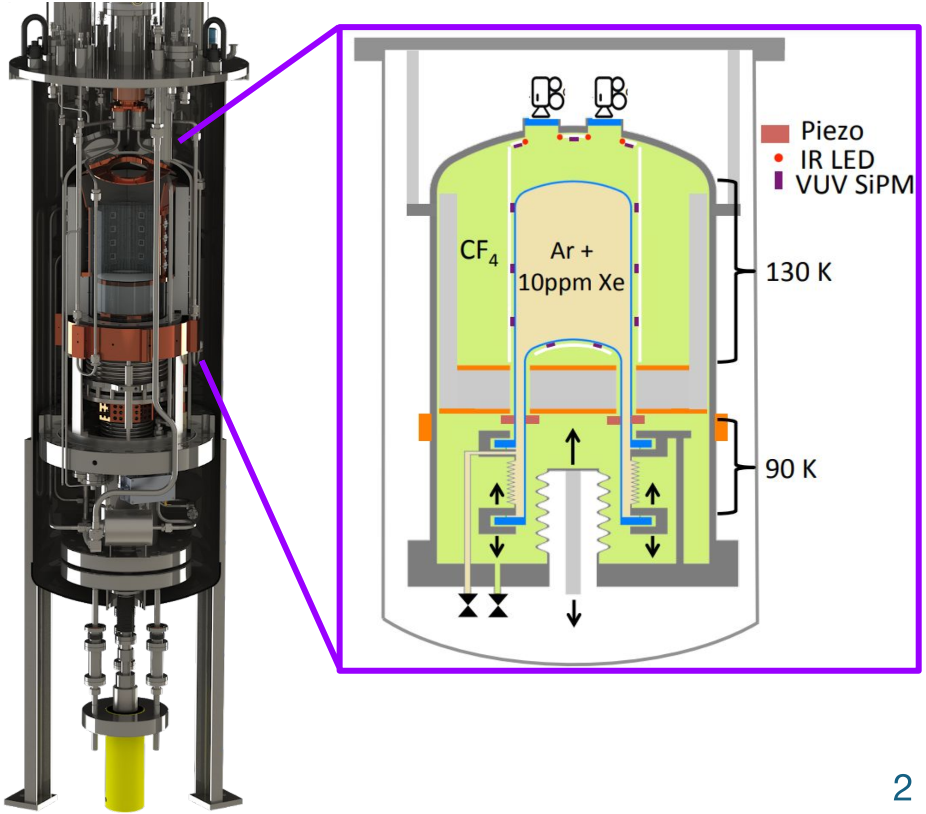
- Superheated fluid which nucleates, forming a bubble, when the energy deposit surpasses the threshold.

- Controlled nucleation threshold which can prevent lighter particles (e-/photon) from nucleation → electron recoil suppression.

Scintillating Target

- Target emits scintillation light when energy is deposited (175 nm → Xe-doped LAr).

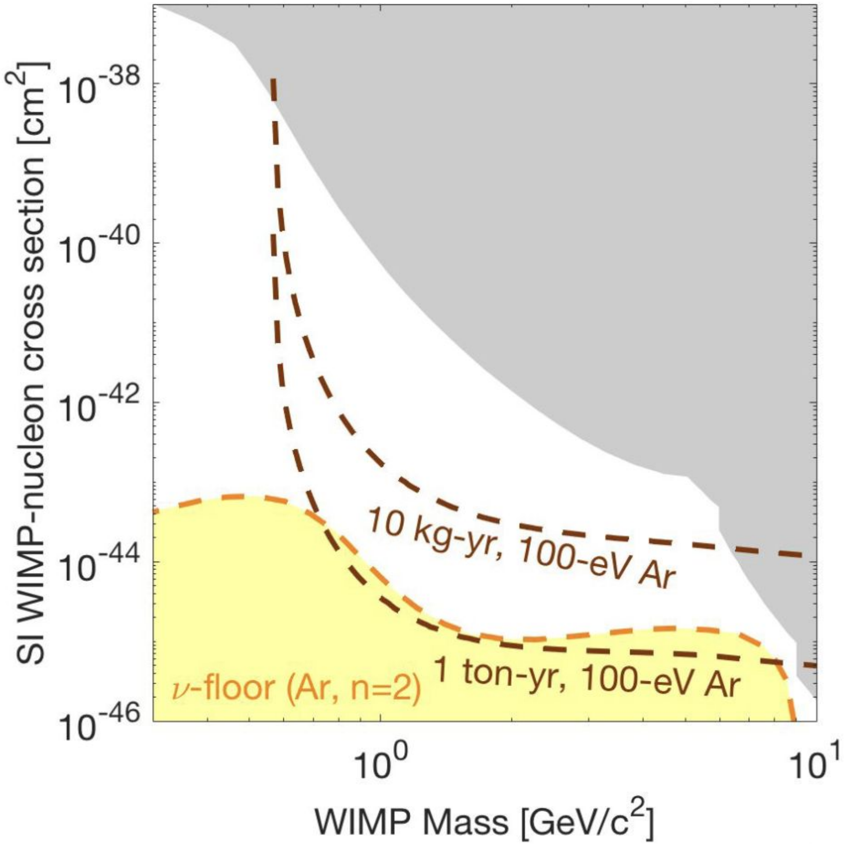
- Allows for event-by-event energy reconstruction.



Physics Goals at SNOLAB

GeV Scale Dark Matter

- Spin-independent search with argon as the target fluid.
- WIMP signal → single bubble with no scintillation light.
- Region of interest (ROI): 0.3 - 50 keV_{NR} for the first search at SNOLAB.
- Target ROI: 0.1 - 10 keV_{NR} depending on location and veto capabilities.
- SBC is capable of reaching 10^{-43} cm^2 at 1 GeV/c^2 for a 10-kg target.



Background Events in SBC

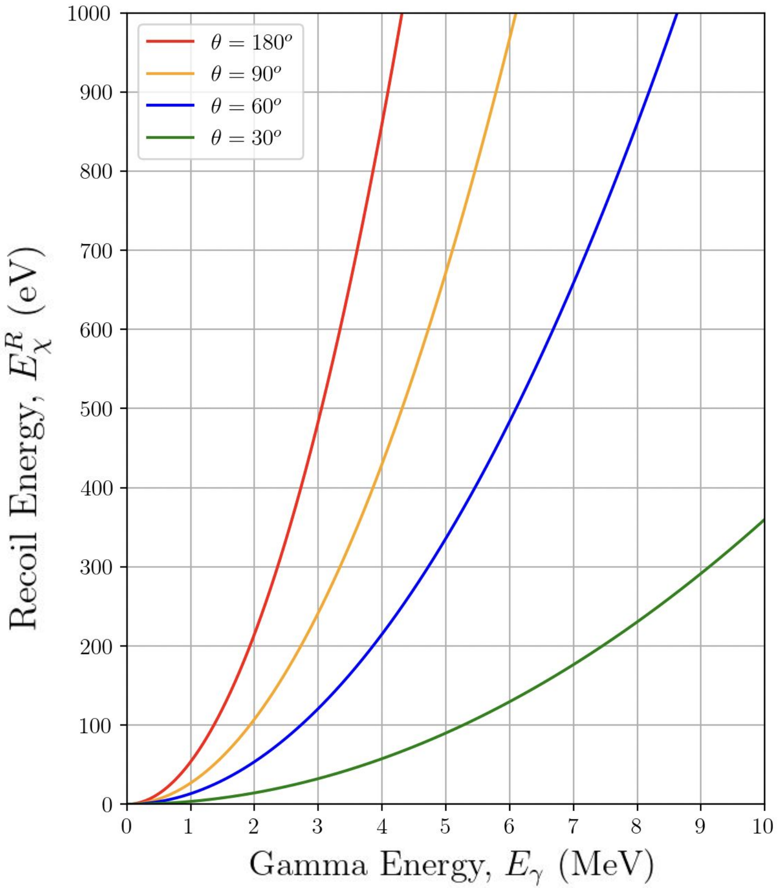
- High-energy **gamma-rays** can elastically scatter off the nucleus resulting in a recoil energy > 300 eV, given by:

$$\mathrm{E}_{\chi}^{\mathrm{R}} = \frac{2\mathrm{E}_{\gamma}^{2}\sin^{2}\left(\frac{\theta}{2}\right)}{\mathrm{m}_{\chi}}$$

- **Alphas** are highly ionizing and deposit large amounts of energy which can be vetoed by scintillation signals.

- **Neutrons** interact weakly and can produce single-scatter (SS) or multi-scatter (MS) events.
  - SS* and MS can be vetoed.

* SS can be vetoed if the E_{Recoil} > 50 keV.



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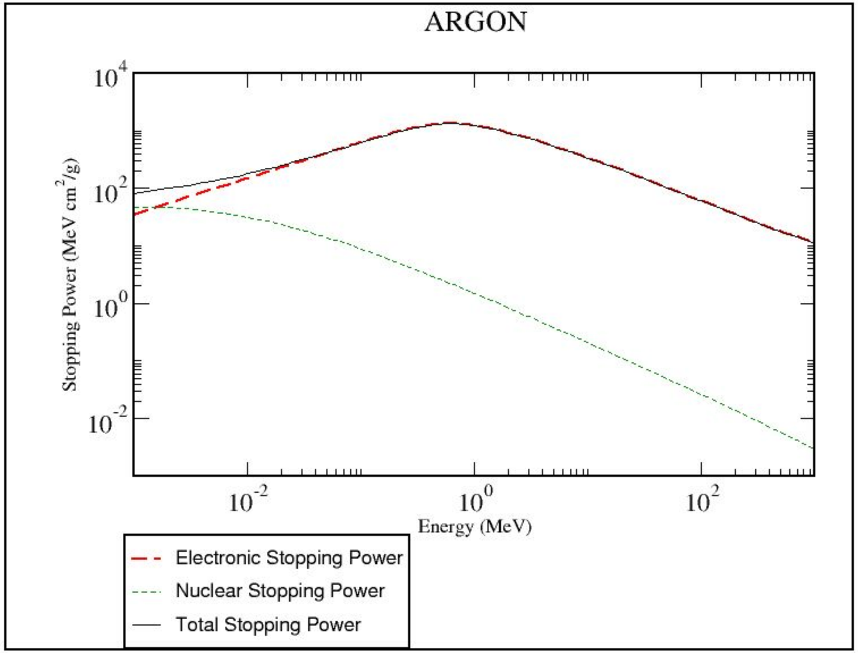

Stopping power obtained from ASTAR (NIST)

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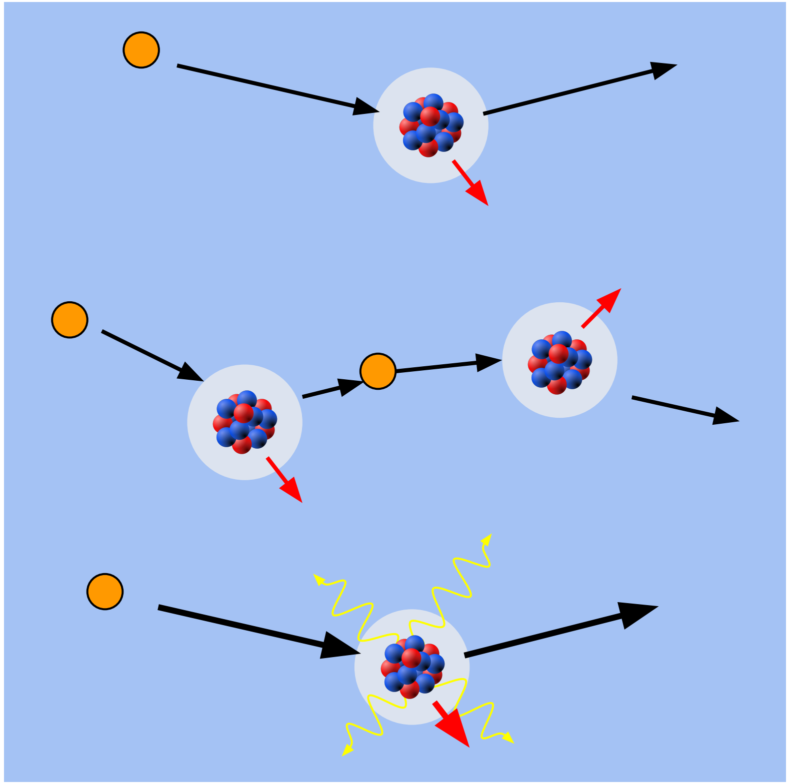

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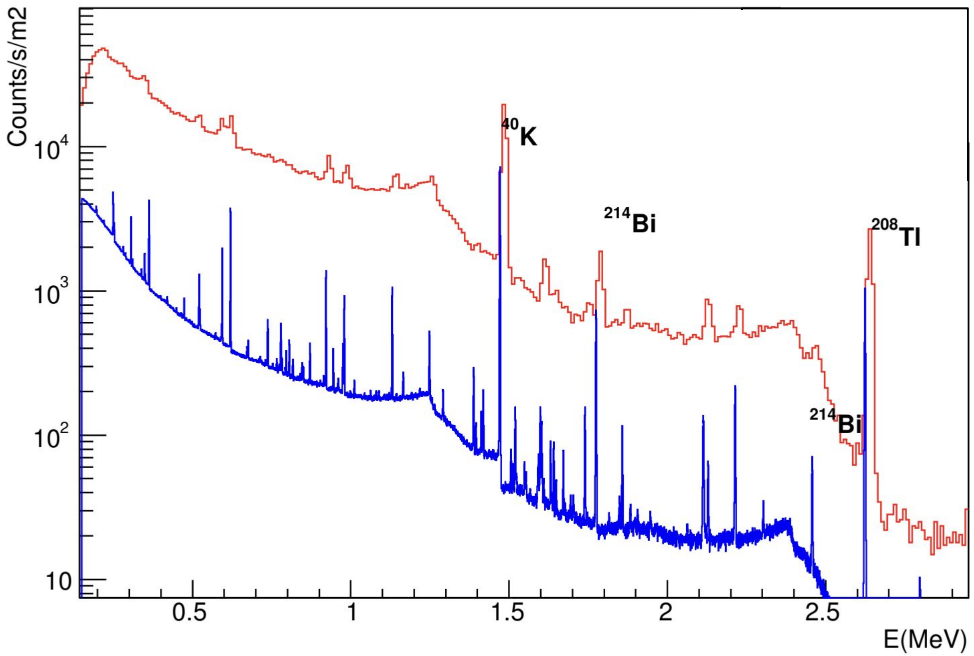
Ambient Gamma Flux at SNOLAB

- The gamma flux at SNOLAB has been recorded by PICO/PICASSO using large O(15-30)kg NaI detectors.

- Gamma emissions up to 3 MeV suspected to be from radio-isotopes present in the surrounding cavern (^{40}K, ^{60}Co, ^{244}Bi, ^{208}Tl, etc.).

- Beyond 3 MeV, gamma emissions from cosmic rays, (α,n) and (p,n) interactions in the rock → much smaller flux but still relevant.

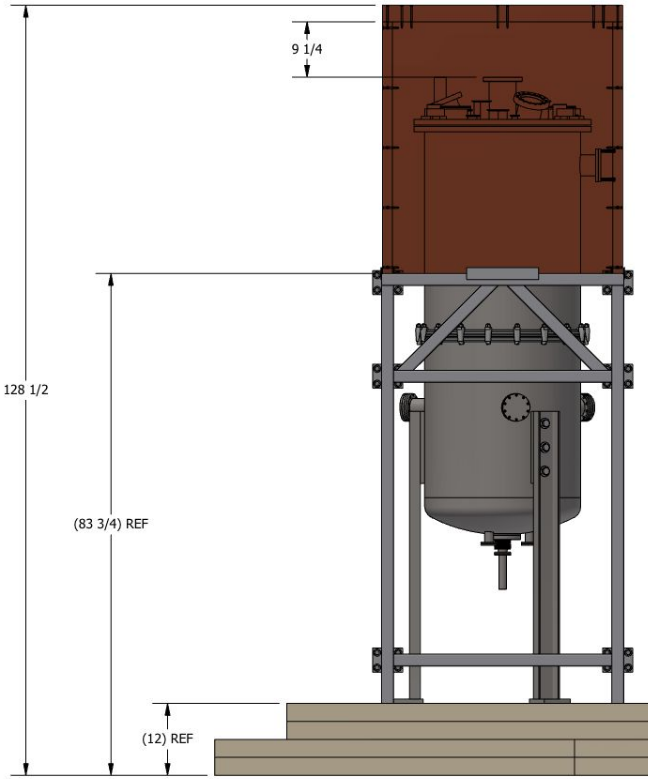
- Flux estimated at 42,500 γ/s/m^2



Flux obtained from SNOLAB User Manual

Gamma Shield

- To suppress background events imposed by the ambient gamma flux, a copper shield was developed.
- Large OFHC copper shield placed over the top of the active volume.
    - 1.625” thick side plates and 2.75” thick top plate.
- Seated on HSS tube support frame which is then bolted to the floor.
- Results in a reduction of the external gamma flux by three orders of magnitude!
- Drops the expected nucleation background rate from ≈ 200 nuc./yr to ≈ 10 nuc./yr at a threshold of 300 eV.



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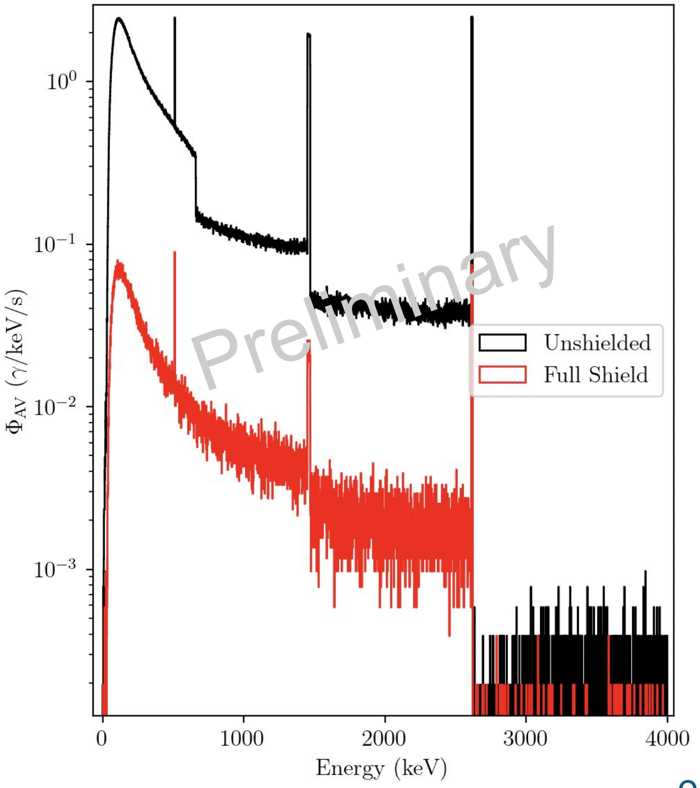
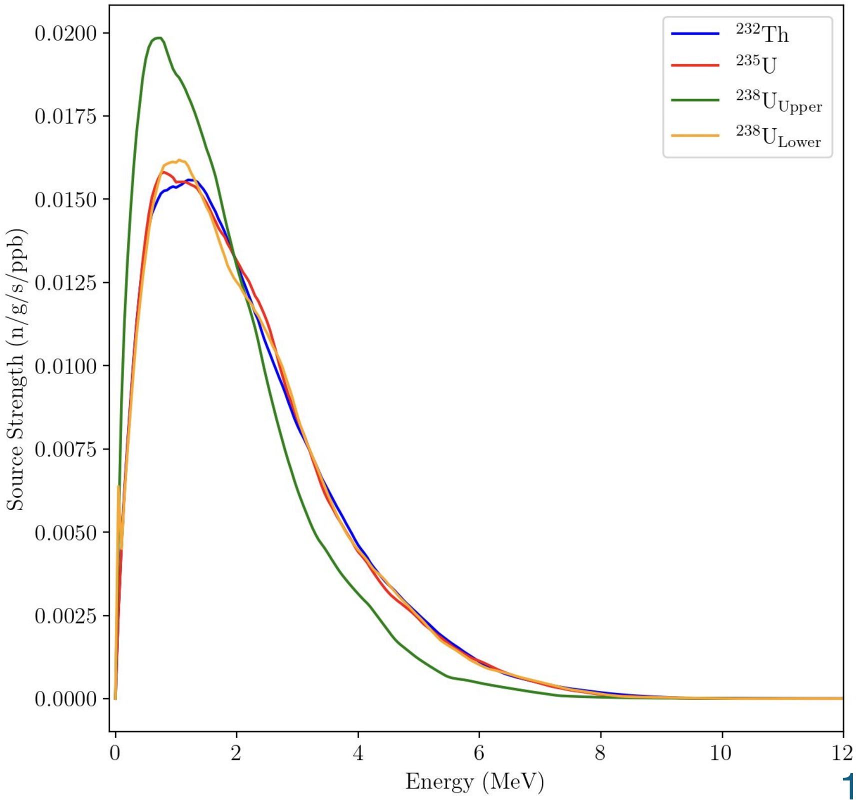
- Results in a reduction of the external gamma flux by an order of magnitude!
- Drops the expected nucleation background rate from ≈ 250 nuc./yr to ≈ 10 nuc./yr at a threshold of 300 eV.



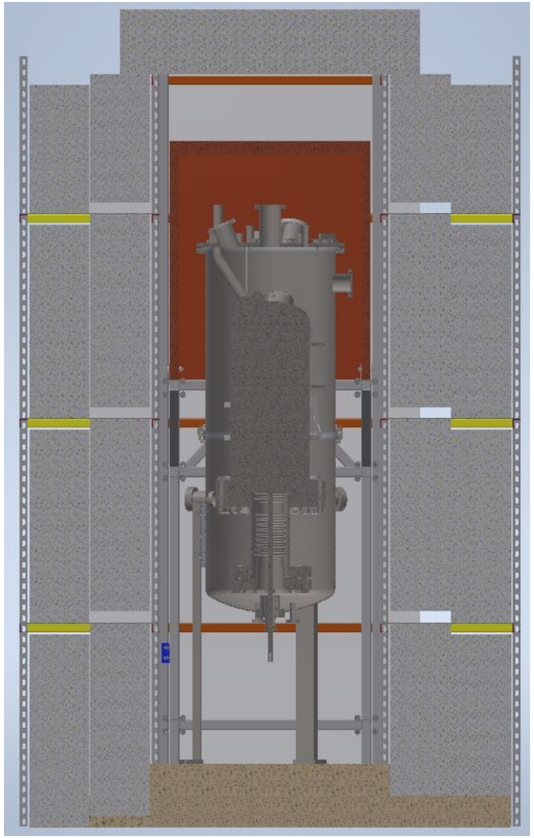
Ambient Neutron Flux at SNOLAB

- Neutrons are typically produced internally from the rock or through cosmic ray interactions in the rock.
    - Internal production is much more prevalent and the focus of this talk.
- Internal production through (α,n) reactions and spontaneous fission of larger isotopes.
- Need to consider the thorium (^{232}Th) and uranium ($^{235/238}$U) content in the rock to determine the emitted neutron flux.
- SOURCES-4C were used to compute the emitted neutron energy spectrum from norite rock and validated using NeuCBOT.



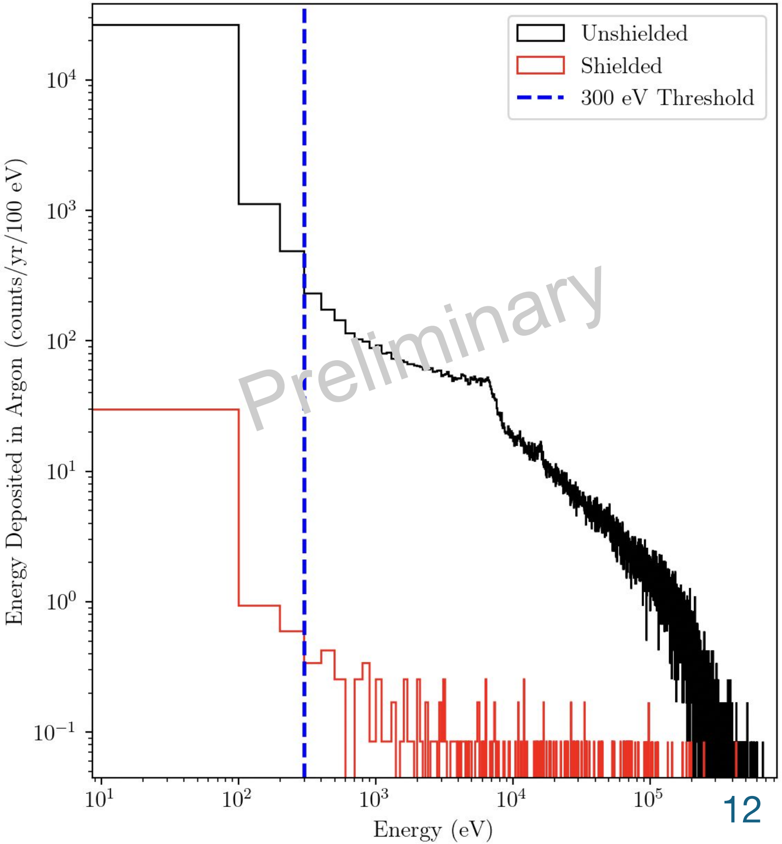
Neutron Shield

- Low Z materials are the best shield against neutrons → thermalize!
- Water boxes (1 ft^3) will be stacked around SBC to provide shielding.
    - Stacked in rows of two to provide 2 ft of exposure.
- SBC sits on a 1 ft thick sheet of HDPE to shield against neutron emanation from the floor.
- 2” thick HDPE sheets surround the copper gamma shield to catch straggling neutrons which make it through the water boxes shield.



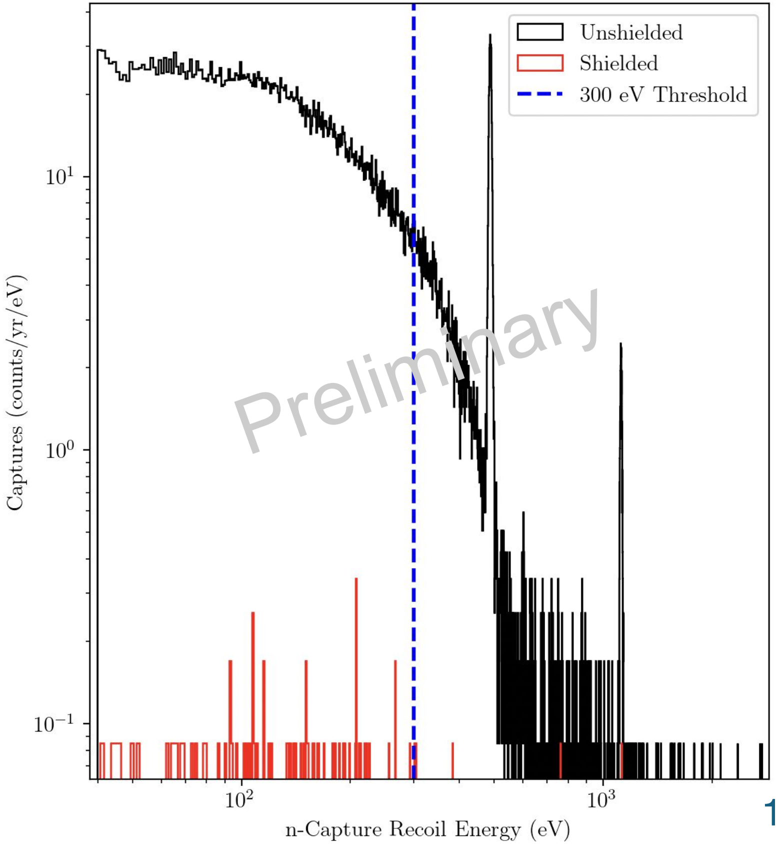
Neutron Shield – Fast Neutrons

- Fast neutrons are neutrons with high energies O(MeV) which are not expected to capture until thermalized.
- MC simulations show that the neutron shield is able to suppress the external neutron flux by three orders of magnitude.
- Unshielded, the SS background event rate was estimated to be ≈ 3200 nuc./yr with ≈ 2400 nuc./yr in the ROI.
    - The total background rate (SS + MS) is found to be ≈ 5600 nuc./yr.
- With the shield in place the background event rate drops to < 10 nuc./yr with ≈ 4 nuc./yr in the ROI.



Neutron Shield – Thermal Neutrons

- Thermal neutrons are assumed to capture on stable nuclei $\rightarrow n + {}^{36,38,40}Ar \rightarrow {}^{37,39,41}Ar$.
- The recoil nucleus can nucleate if the energy deposit is > 300 eV.
- MC simulation results assume the decay of the captured nuclei (${}^{37,39,41}Ar$) is missed to estimate worst case scenario.
- Without shielding in place ≈ 1000 nuc./yr are expected from thermal neutron capture.
  - All scatters are SS with energy deposits in the ROI → very concerning!
- With shielding rate is suppressed to < 1 nuc./yr



Conclusions

- External background events have been suppressed enough for a competitive low-mass WIMP search.
- Shielding design is well underway in terms of development along with the detector.
- Internal background control program is being finalized with a target of < 10 nuc./yr in the ROI.
- Studies into other veto methods through CF_4 scintillation also near completion.
- SBC-LAr10 at Fermilab (MINOS tunnel) nearing completion with engineering runs beginning soon!

Thank You!
Merci!

Queen's University

Universidad Nacional Autónoma de México

Drexel University

Indiana University South Bend

Northwestern University

University of Alberta

UC Santa Barbara

Fermilab

Northeastern Illinois University

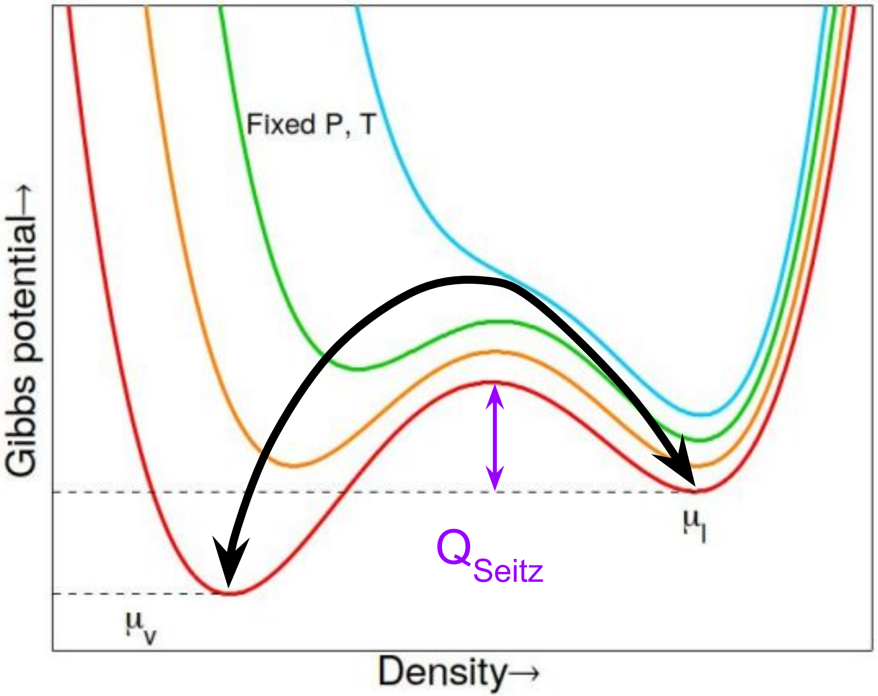
Université de Montréal

Pacific Northwest National Laboratory

UC Riverside

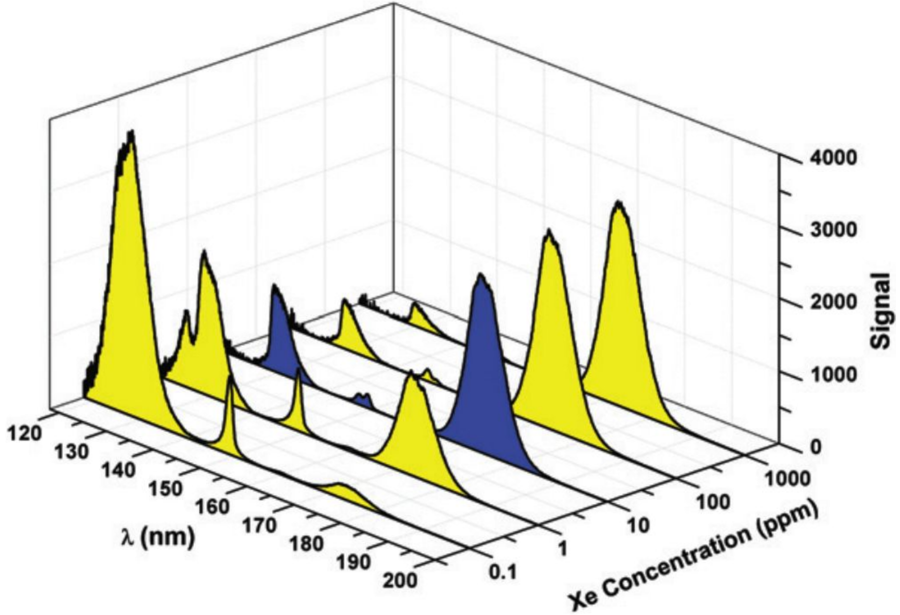
Bubble Formation

- Bubbles are expected to form based on the Seitz Hot Spike model.
- An energy deposit (nuclear recoil) of energy which surpasses the threshold drives the phase change from liquid to gas → proto-bubble.
- If the proto-bubble has a radius larger than the critical radius it will grow, if not it will collapse.
- Pressure changes trigger the chamber to recompress back to the stable liquid state.



Xenon Doping in Argon

- Argon scintillation light is really hard to see at 128 nm → doping with xenon shifts peak to 175 nm.
- FBK VUV-HD3 SiPMs have peak sensitivity at 175 nm.
- Also expected to slightly improve the scintillation light yield.
- SBC is aiming for a doping level of 10-100 ppm of xenon.
- Potential for PSD capabilities to add another method of veto.



Taken from: 10.48550/arXiv.2112.07427