A Cryogenic Witness Detector for Low-Energy Neutron Backgrounds

A.N. Villano

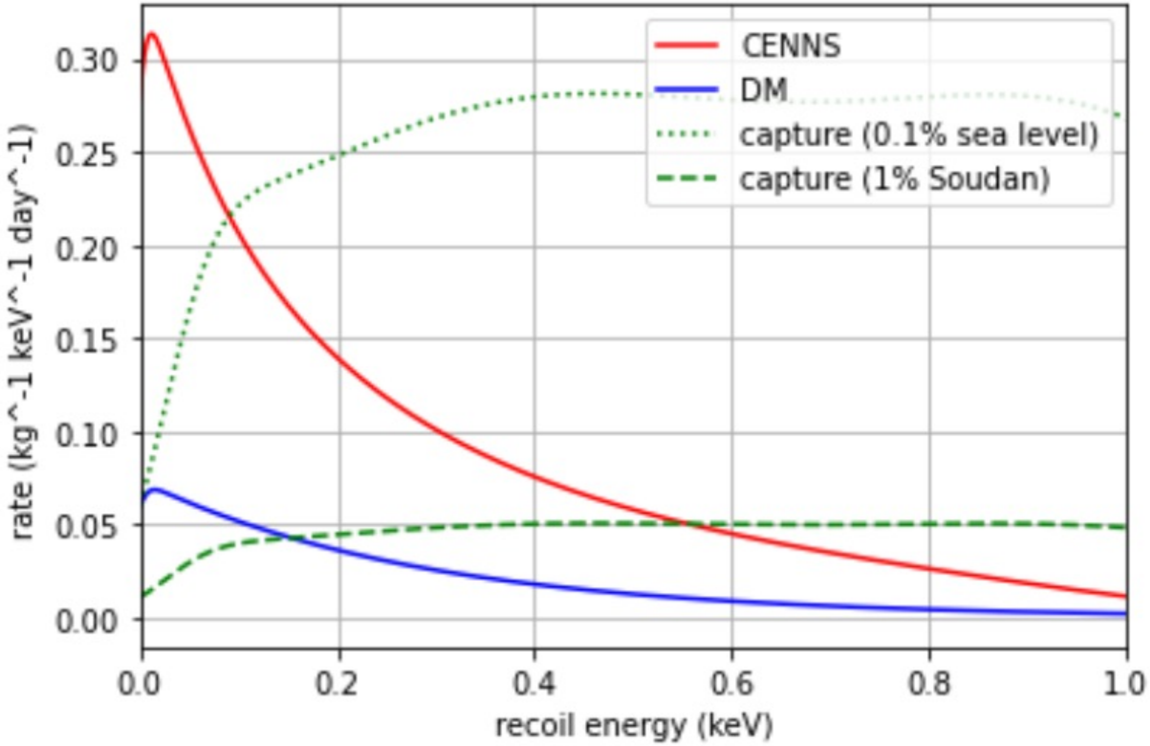
University of Colorado Denver

University of Colorado **Denver**

CU IN THE CITY

Neutrons are (still) DM Backgrounds

- **Thermal neutrons (which predominately create captures) have been traditionally not important** b/c their backgrounds are very low energy. Now, they are because of the low-energy reach of new detectors.



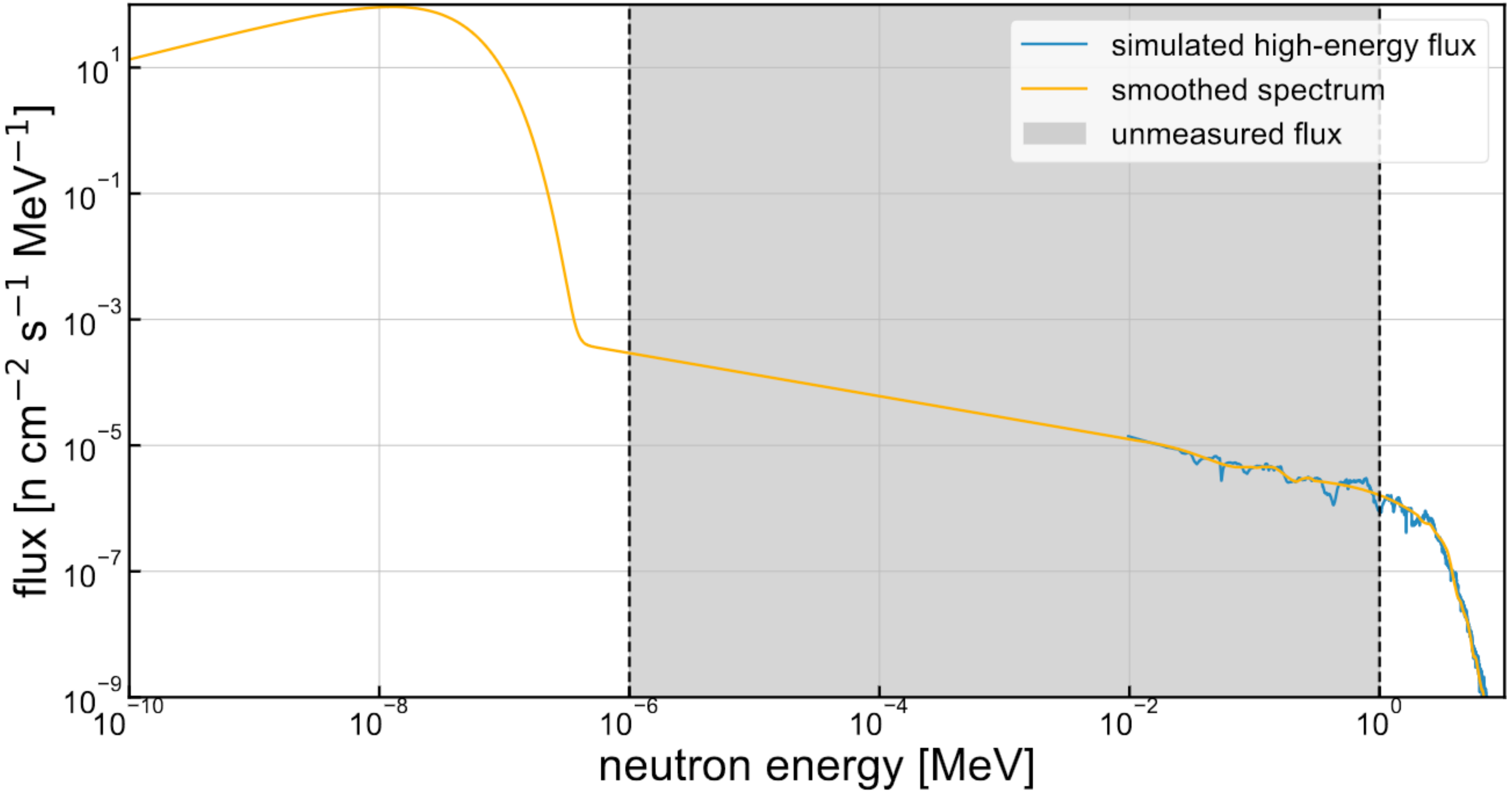
K. Harris; A. Gevorgian; A.J Biffl, A.N. Villano ; Physical Review D (PRD) **107** 076026 (2023)

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.107.076026

Also: neutrons in the energy range 1 keV – 1 MeV will quickly create thermal fluxes and have their own impact in this energy range via elastic scattering.

Neutron Backgrounds Underground: SNOLAB

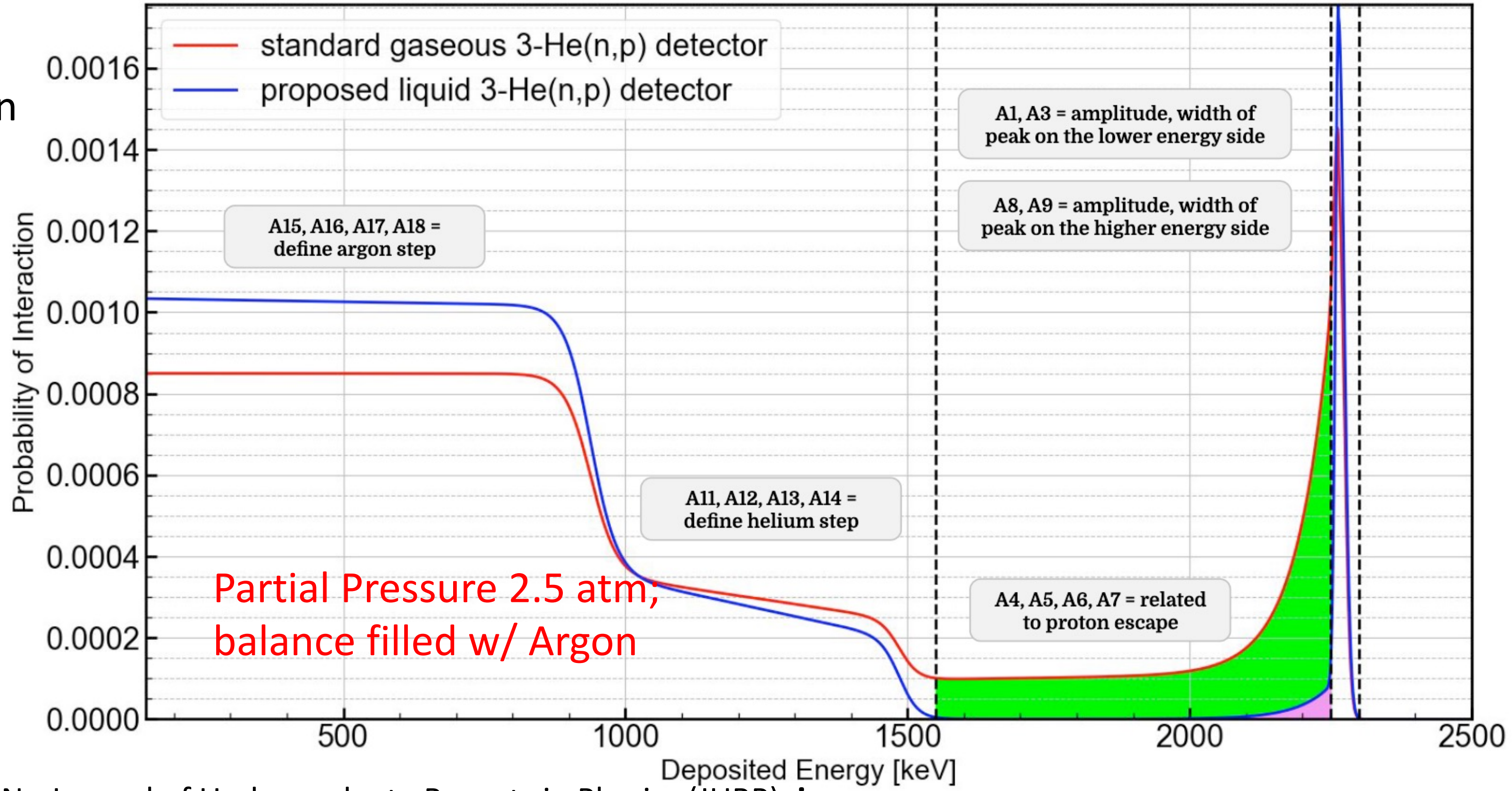
- One of the lowest-flux environments for neutrons is the SNOLAB underground lab
- Only the thermal neutron flux and “fast” neutron flux (> 1 MeV) are measured



Villano, A.N.; Journal of Low Temperature Physics (LTD20); **under review**

^{3}He Detectors: Used for Decades

- Gaseous ^{3}He detectors have been used for many years to detect neutrons for two main reasons:
- The process ^{3}He(n,p) has a high cross section and;
- Displays a mono-energetic peak that maps directly to the **incoming neutron energy**

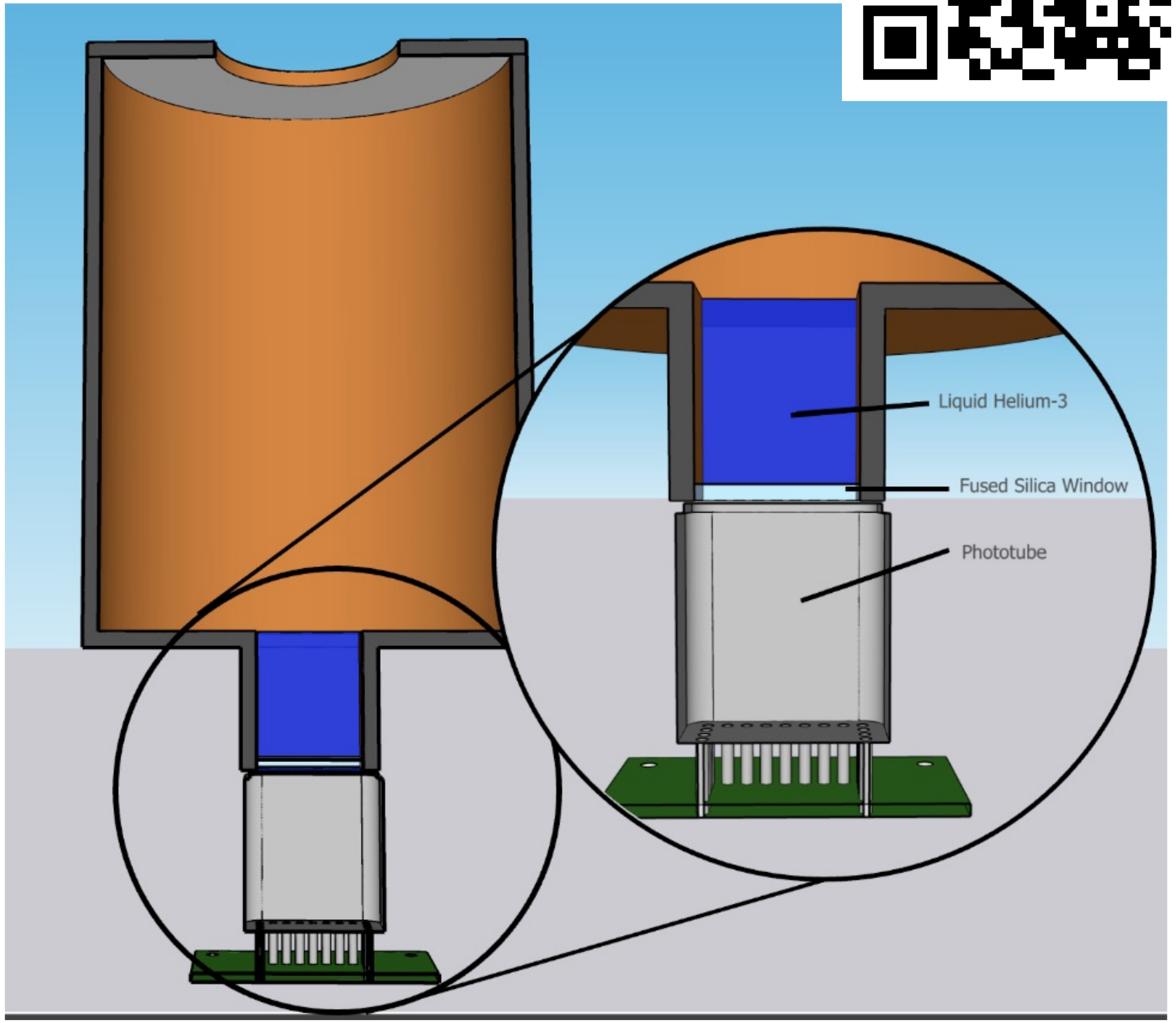


Sharbaugh, A.E., Jones, L., Villano, A.N.; Journal of Undergraduate Reports in Physics (JURP); **in press**

https://arxiv.org/abs/2305.00145

^{3}He Detectors: Liquid Design

- SPICE/HeRALD collaboration demonstrated phototube readout (see: Phys. Rev. D **105** 092005 (2022))
- Density boost of ^{3}He is between a factor of 64 – 107x compared to gas detectors of 4—10 atm partial pressure
- Hermetic design with copper vessel shown at right; copper is important for background mitigation (see later slides)



Sharbaugh, A.E., Jones, L., Villano, A.N.; Journal of Undergraduate Reports in Physics (JURP); **in press**

https://arxiv.org/abs/2305.00145

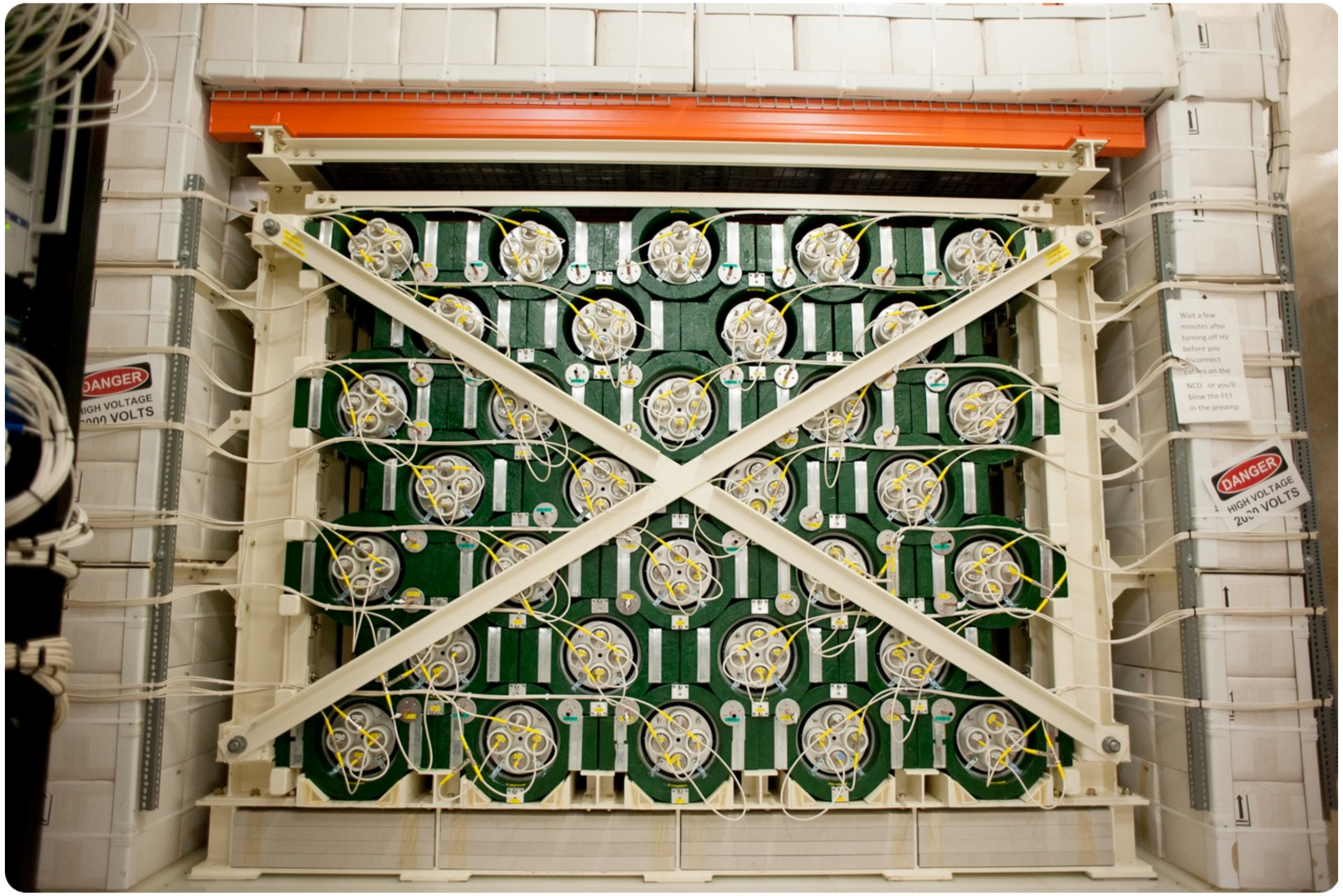
Gaseous ^{3}He Performance: HALO @ SNOLAB

- Compare to HALO detector at SNOLAB: 0.75 m^3 of ^{3}He gas at 2.5 atm partial pressure

- Very low neutron flux environment.

- In 1 year of running will reach 11,000 neutron counts in the 1 keV and above region but will also have **around 140,000 alpha background events from surfaces**

- These tubes are probably the lowest background available with **1 ppt thorium contamination** (see NIMA **449**(1) p 172 (2000))



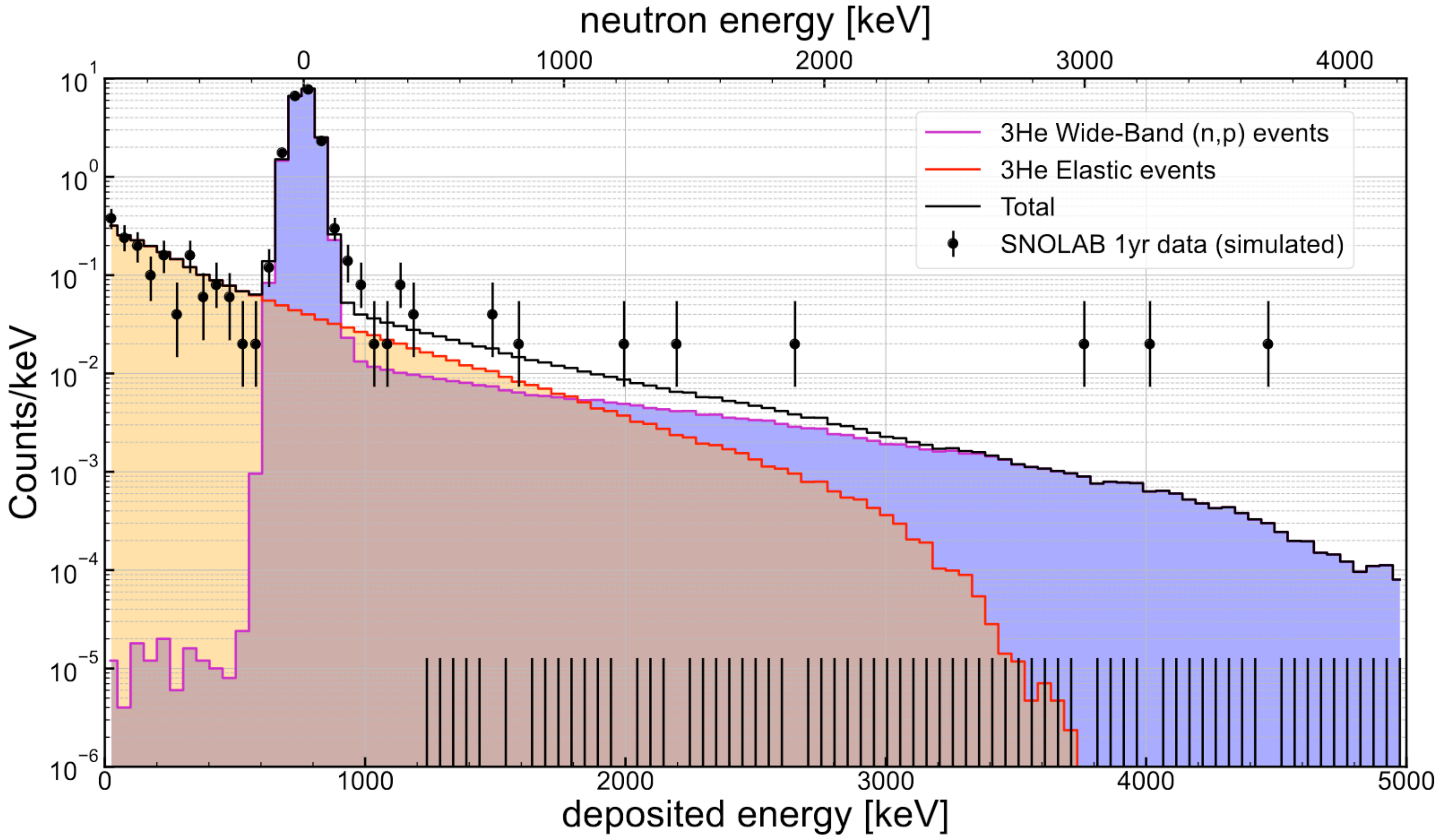
Villano, A.N.; Journal of Low Temperature Physics (LTD20); **under review**

Liquid ^{3}He: 8 cm^3 @ SNOLAB

- Same very low neutron flux environment as HALO
- Only 30 total neutron events over 1 yr of running in the region 1 keV—1 MeV compared to 11,000

…**BUT**…

- Small volume can be integrated into or near other detectors; including deep cryogenic ones as a witness
- Expect ~ 100 bknd alpha events dominated by PMT (might be able to remove)



Sharbaugh, A.E., Jones, L., Villano, A.N.; Journal of Undergraduate Reports in Physics (JURP); **in press**

https://arxiv.org/abs/2305.00145

Liquid ^{3}He Performance: Background Budget

- Alpha backgrounds from surface are dominant, other ambient gammas or (α,n) from detector less important
- Use low-background copper
- If modifications can be done to remove PMT readout (maybe with TES or MKID detector coupled to silicon substrate inside the hermetic volume), then we can have signal-to-noise of around 217 for this detector

Component	Contamination Level (ppt)	Background (α/yr)	Best signal-to-noise[1]
standard copper[2]	39	179	0.10
ultra clean copper[3]	0.03	0.138	0.26
quartz window[4]	2	1.9	0.26
TPB coating	120	112	0.26

Large, PMT-related backgrounds

[1] assuming all other components optimized for low background with photomultiplier readout

[2] Copper wire used in the Majorana project [13]

[3] as demonstrated by the Majorana project [13] using electroformed copper

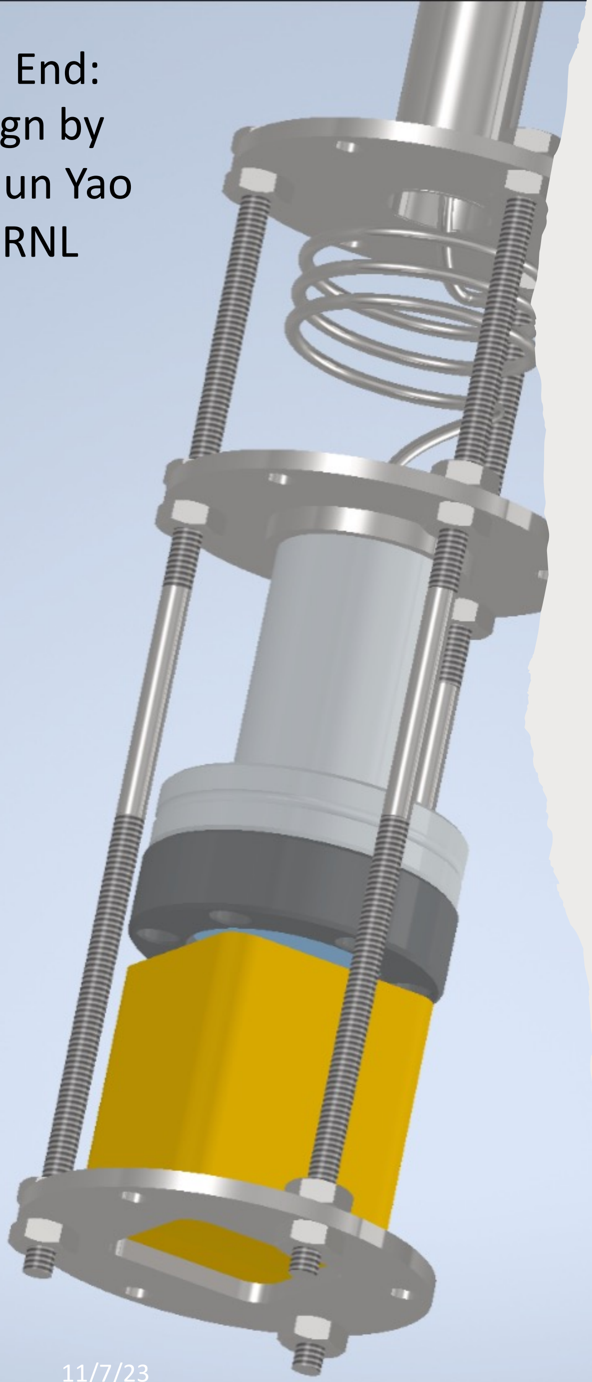
[4] as demonstrated by the EXO project [14]

Villano, A.N.; Journal of Low Temperature Physics (LTD20);
under review

Prototype Design:

1. Build a low-cost L^4He prototype on a 2” KF-50 dipstick and put into LHe Dewar
2. Test for scintillation yield with neutrons and gammas—
3. Design a ^3He system to keep detector volume on a closed cycle; can pump on Dewar volume to reach lower temperatures for ^3He liquification
4. Test with neutrons of reasonable between 10 keV and 1 MeV; can use neutron beam such as at Notre Dame
5. Re-design the detector volume with clean copper for deployment as a low-flux detector
6. Possible re-design without PMT

Cold End:
Design by
Weijun Yao
@ ORNL



Initial ^{4}He Design and Costs

- Simple initial design for liquid ^{4}He using mostly off-the-shelf parts and a capillary tube to a small LHe volume
- Read out with a Hamamatsu 2 cm x 2 cm square PMT through a quartz window
- TPB coating as a LHe wavelength shifter
- About $30k including 1 extra PMT and electronics and ~ $11k of LHe
- $11k of LHe is for 10 60L Dewars which last around 10—15 days of running each (unless include boiloff mitigation).

Warm End:
Design by
Weijun Yao
@ ORNL

Summary

- Backgrounds from neutron energies that have traditionally been overlooked are important now! All the way from 1 MeV to thermal energies
- It's hard to get a precise measurement of flux there; best bet is to use the ^{3}He(n,p) process
- Liquid ^{3}He detectors can offer advantages in compactness, and radiopurity
- Prototyping is underway
- **See QR code for talk slides**