SLoMo and APEX as Low Background Detectors

Eric Church

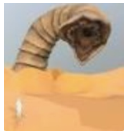
Stonybrook University APEX Workshop

28-June-2023

Pacific Northwest NATIONAL LABORATORY

DUNE

Outline

- SLoMo History
- Physics Sensitivity in 1 slide
- Radiopurity
- Simulation package -- sndwrm 
- Photon counting
- SLoMo => APEX
-

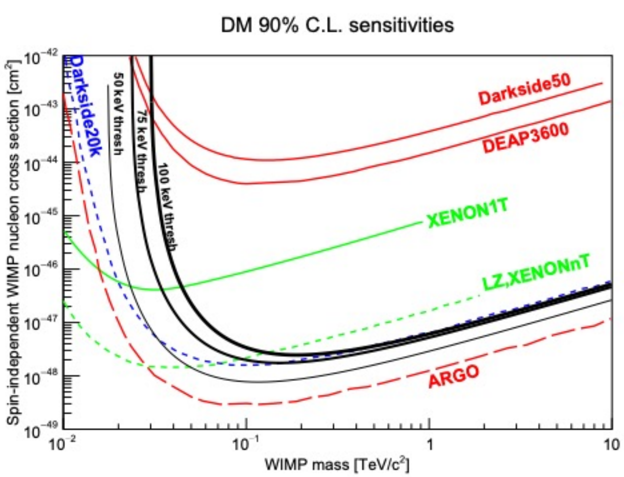
Physics in SLoMo

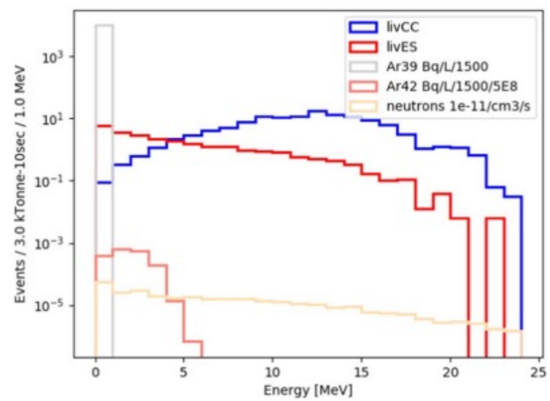
- JINST 2020
  - Church, Jackson, Saldanha

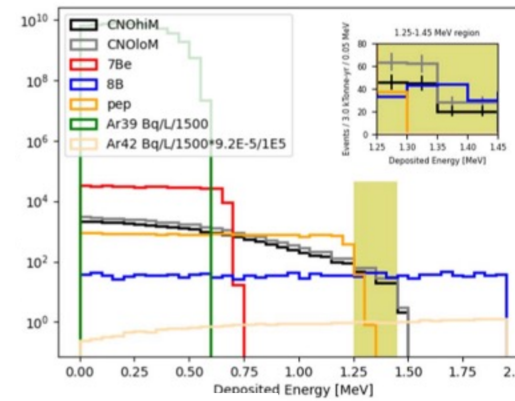
https://iopscience.iop.org/article/10.1088/1748-0221/15/09/P09026

- JPhysG 2023

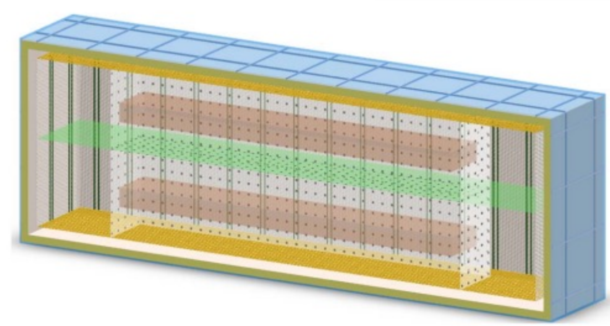
21-person proto-collaboration deeply integrated into Snowmass 2022.
https://iopscience.iop.org/article/10.1088/1361-6471/acc394



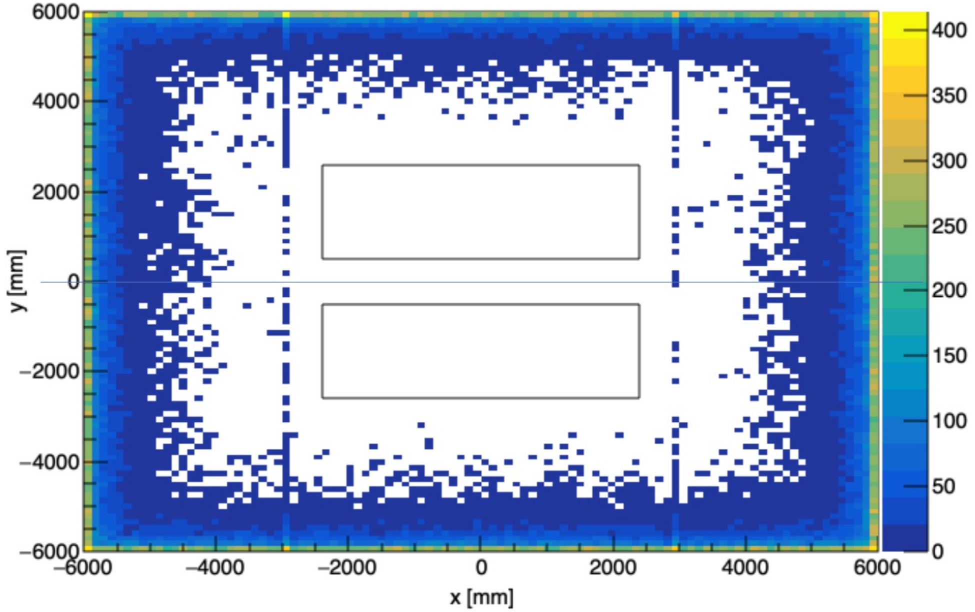




T Bezerra *et al*



Fiducialization



- 100 keV threshold for nuclear recoil
- 2E-10/cm3/sec from *cold cryostat steel* only (cleaner than default DUNE)
- 1.4 years, 3 kT fiducial volume shown

Distinction with APEX is that the PDS in SLoMo views an interior volume with a densely instrumented array of SiPM modules. And places radiopurity concerns foremost.

Radiopurity

- See Chris Jackson's talk at this workshop
- Juergen Reichenbacher's, 12-June-2023, Low Energy Physics Meeting and this workshop

Summary Table of External Backgrounds

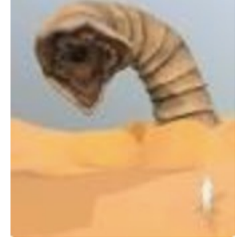
Modules 1 & 2

external background	4pi flux in cavern [cm^-2 s^-1]	reduction factor	attenuation factor	area factor	4pi flux at LAr [cm^-2 s^-1]	rate in full LAr (VD) [Hz]	rate in HD [Hz]	
cavern neutrons	2.94E-06	21.816	10.908	1.3687	2.70E-07	5.34E+00	4.63E+00	predicted and 4.6+/-1.1 Hz in HD from simulation of 1x2x6
n-capture gammas from cryostat	N/A	N/A	N/A	1.3687	1.68E-06	3.32E+01	1.50E+00	predicted rates [Hz] w/ approx. gamma-att. for 1.5 MeV
n-capture gammas from rock/shotcrete	3.75E-06	13.807	6.9035	1.3687	5.44E-07	1.08E+01	4.87E-01	predicted rates [Hz] w/ approx. gamma-att. for 1.5 MeV
cavern gammas from rock/shotcrete	12.60418	23.985	11.9925	1.3687	1.0510	2.08E+07	9.40E+05	predicted rates [Hz] w/ approx. gamma-att. for 1.5 MeV
foam gammas	N/A	N/A	N/A	1.0000	0.0441	8.72E+05	3.95E+04	predicted rates [Hz] w/ approx. gamma-att. for 1.5 MeV

SLoMo

- VD in all respects, including PoF!, **with following changes**
- Outer water shielding
- Radiopure steel, etc … (See Chris Jackson’s talk)
- UAr
- Heavily fiducialize events
- Interior structure
  - Optically hermetic acrylic box
    - Perhaps allows to confine UAr to smaller volume (2 Ar circulation systems)
  - Not necessary to be acrylic
  - Something to hold WLS panels w SiPM modules
  - **But … the same COMSOL studies that show the xArapucas do not distort the E-field between H-bars, will likely show the same for our Acrylic**
    - **And it can be grounded for charge-up concerns**
    - **Yes, there are buoyancy, etc., considerations**

sndwrm



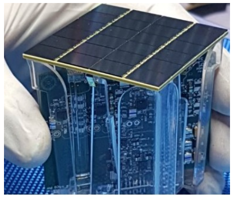
- Simulation of Neutrino Detector With Radiopure Module
  - (name adapted from clever colleague Richard Saldanha)
  - A “standalone” simulation, ala Laura’s talk.

github.com/echurch/sndwrm/liquid_deception/README

```
> emacs –nw opt_pbomb.mac
## SiPM SETTINGS ##
/sndwrm/det/setDetectorSiPMsOnAcrylic true
/sndwrm/det/setDetectorSiPMsOnCathode true
/sndwrm/det/setDetectorSiPMSize 20.0 cm
/sndwrm/det/setDetectorSiPMThickness 0.1 cm


/sndwrm/det/setDetectorSiPMPhotoCathodeCoverage 0.10 #SiPM Coverage
/sndwrm/det/setAcrylicRadius 4.5 m #Acrylic width/heigth (not larger than 6)
/sndwrm/det/setAcrylicLength 40. m #Acrylic length (not larger than 60)


/sndwrm/material/setG10SpecRef .44 #Anode planes reflectivity
/sndwrm/material/setAcrylicSpecRef .97 #Acrylic walls reflectivity
/sndwrm/material/setLArAbsLength 50 m #Max length photon travel in Argon


> ./sndwrm opt_pbomb.mac
```

Simple Geometry

- G10 reflectivity
- Acrylic reflectivity
- Darkside SiPM Modules
  - Can be swapped out for xArapucas and H-bars
- Limitations of geometry
  - No cathode
  - No internal structure
  - All in C++, not gdml

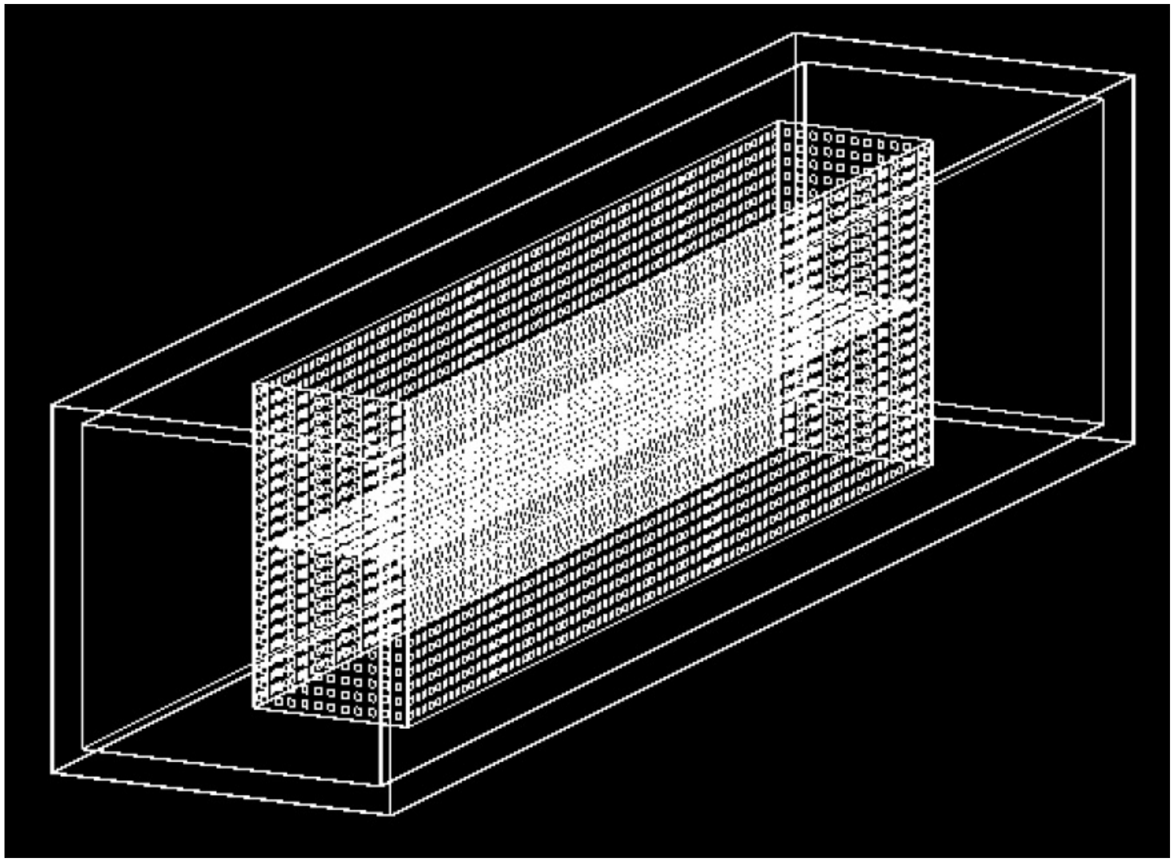


Prototype SiPM tile

16 of these make one 20x20cm2 module

- Engineering drawings for SLoMo would begin to be nice at this stage of development.

Darkside module coverage



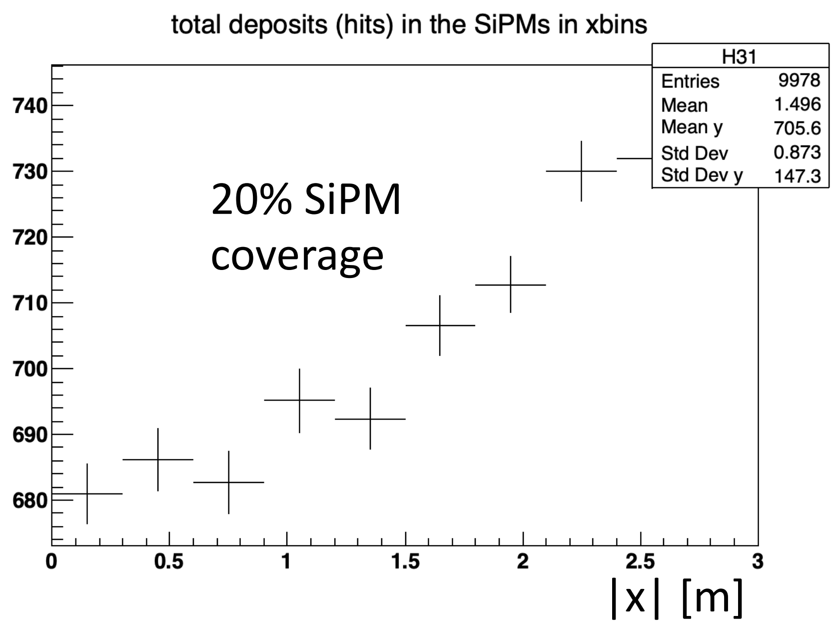
Example SiPM module coverage for illustration

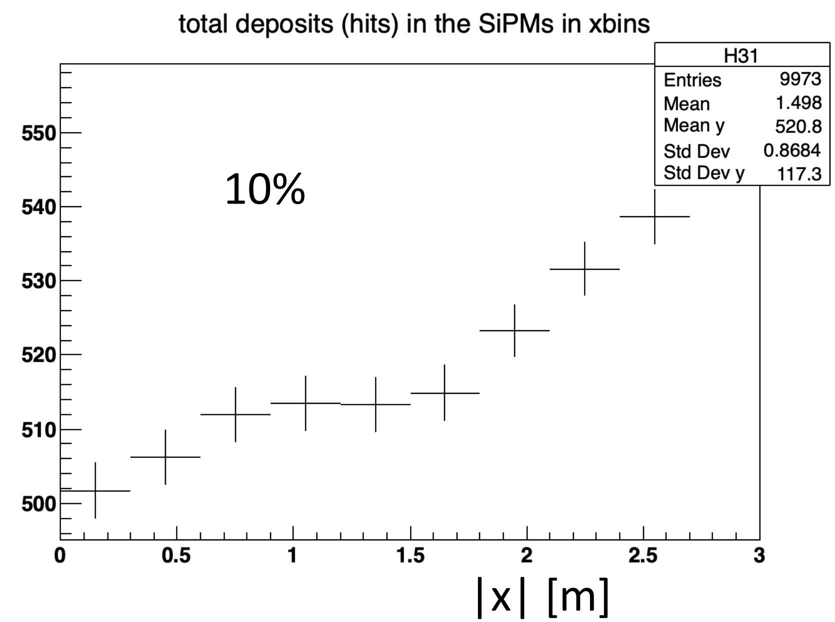
SLoMo photon detection

- Example: 10% coverage of DarkSide modules viewing inner ~4 kTonnes mounted on light-tight barrier
  - 25% detection efficiency imposed after the fact
    - 0.5 Q.E. * 0.5 WLS efficiency
  - 0.10* 0.5*0.5 = 2.5%
  - **~equivalent to 100% tiling all inner surfaces with xArapucas**
- Of course, the (x)Arapucas are presumed to remain on the outer walls at the modest VD1 coverage.

Photon counting

1250 photons/100 keV nuclear recoil
Based on iopscience.iop.org/article/10.1088/1748-0221/15/09/P09026





CRP reflectivity = 44%, acrylic reflec = 97%, λ_{attn} = 50m

Multiply by 0.25 efficiency for total detected photons

Photon counting

Previous plots are of response to 1250 photons/100 keV n.r. in SLoMo

- ~ 50 keV e.r.
- <photons> = 600*0.25 = 150
- 150ph/0.050MeV ee = **3000 ph/MeV ee**
  - *About 18x APEX's **full-volume** coverage*

Costs

- See JINST iopscience.iop.org/article/10.1088/1748-0221/15/09/P09026
- 20% DarkSide module coverage
  - 7400 modules ~ 50 M EUR
  - ~175 detected n.r. photons / 100 keV n.r. event
    - Allows to do PSD to reject all gamma activity and do a WIMP search
- 10% coverage
  - 3700 modules ~ 25 M EUR
  - ~130 n.r. photons/event
    - Can probably still do PSD for 100 keV n.r.
      - *Maybe even for a 50 keV n.r.*
- Let's stress: a Dk Matter search may make most sense if, say, LZ sees a signal, or GADMC/ARGO doesn't go forward …
- Our Darkside20k (and DS20k adjacent) SLoMo colleagues helping keep us in contact with developments and potential SiPM module tests

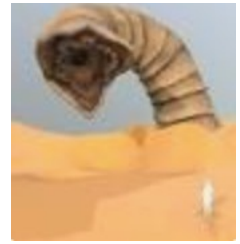
The limit SLoMo->APEX

- Keep all the radiopure materials and external shielding
  - … and QA/QC precautions!

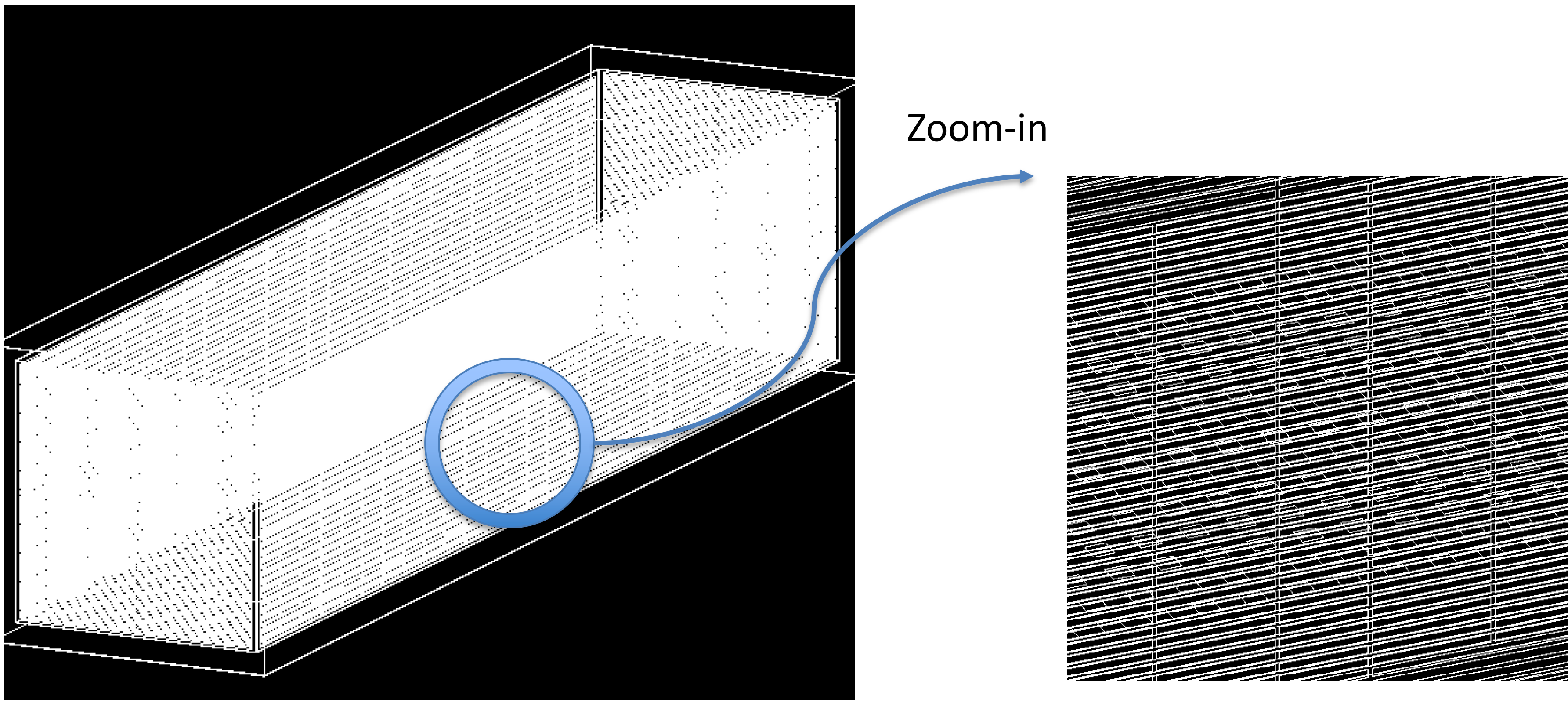
- Remove acrylic + PDMs
- Add xArapucas, structural framework: Al bars, etc
  - fSiPM = false; fArapuca = true;

- Count photon hits on xArapucas instead of SiPMs
  - Use the correct QE: 25% -> ~2%
    - (after the fact)

SLoMo->APEX

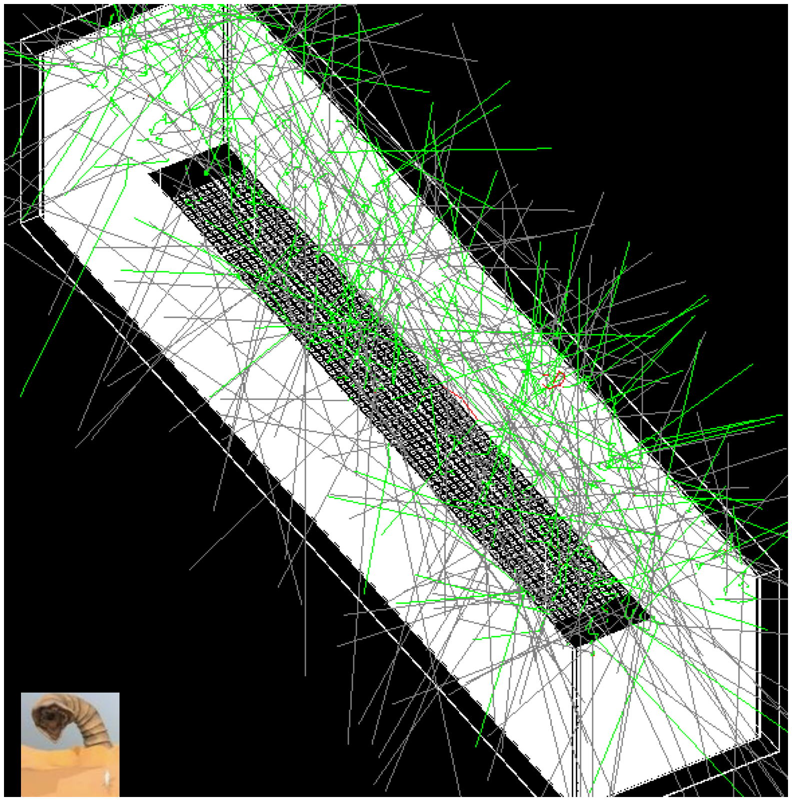


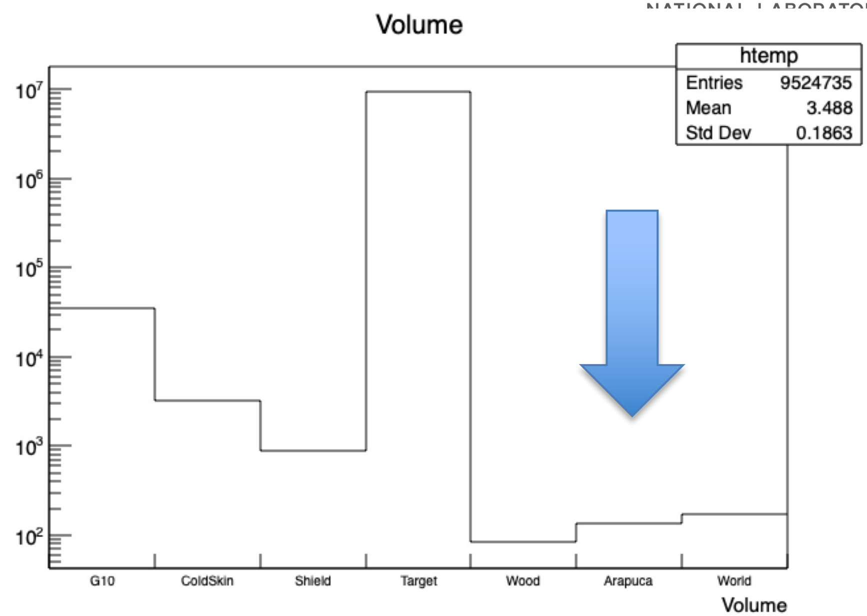
- Drop the Acrylic+SiPMs, add the xArapucas

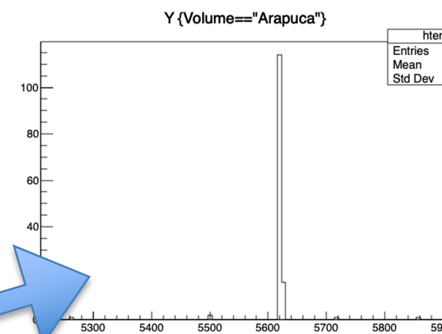


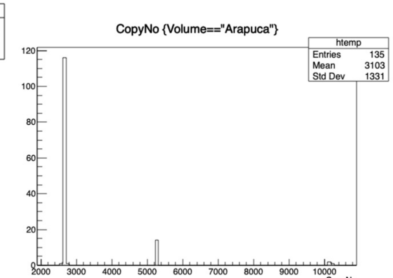
^{208}Tl from upper CRPs (G10)

β, then 2.6 MeV gammas









This also illustrates the effect of LAr self-shielding we exploit to shield against 21 MHz of rock/cement gammas.

Simulations for APEX

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- We have Carlos Moreno, a summer PNNL student to help run some APEX simulations in sndwrm
  - Gammas from xArapucas *detected by* xArapucas
  - neutrons from cryostat and rock seen by xArapuca
    - Perhaps see if we can see the 6 MeV capture peak with a simple detector response model
  - 21 MHz of gammas from outside!
    - Very little self-shielding in APEX
    - We'll explore this hit rate and spectrum

Conclusions

- Collaboration should decide which Low Energy physics we can and want to study -- in world-leading way
  - APEX can likely expand scope for supernova burst and solar neutrinos
  - radiopurity of materials, QA/QC are needed in all cases
- Low background module specifications follow from that.
- Such physics studies have at least initially been performed in a SLoMo detector where we aim for solar ns, SN physics expansion, and also more ambitiously, e.g., CNO, 0νββ, WIMP searches.
  - Elucidated in the two papers cited on slide 3
- Low-energy physics reach is yet to be demonstrated in APEX
  - We both look forward to, and can help with, those studies