Pacific Northwest
NATIONAL LABORATORY

A Low Background DUNE-like Module

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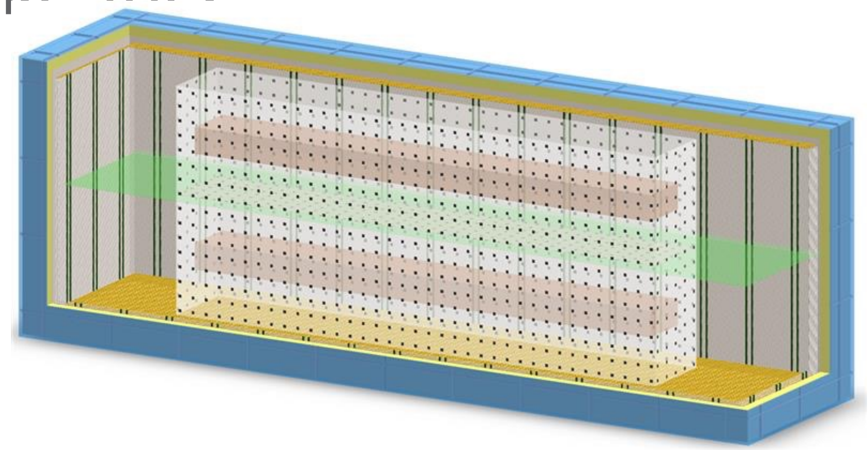
LIDINE 2021

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Expanding the DUNE Physics Scope

- There is significant interesting physics to be done in large LArTPCs below current thresholds of ~10MeV.
- physics
  - ✓ Solar neutrino measurements
  - ✓ $0\nu\beta\beta$ search
  - ✓ WIMP Dark Matter search
  - ✓ Supernovae detection
  - ✓ Supernovae Coherent ν-Nuclear elastic scattering (CEvNS) “glow”
- Might hope for module 3,4 for DUNE to look like this
  - “Do No Harm” to the main physics program



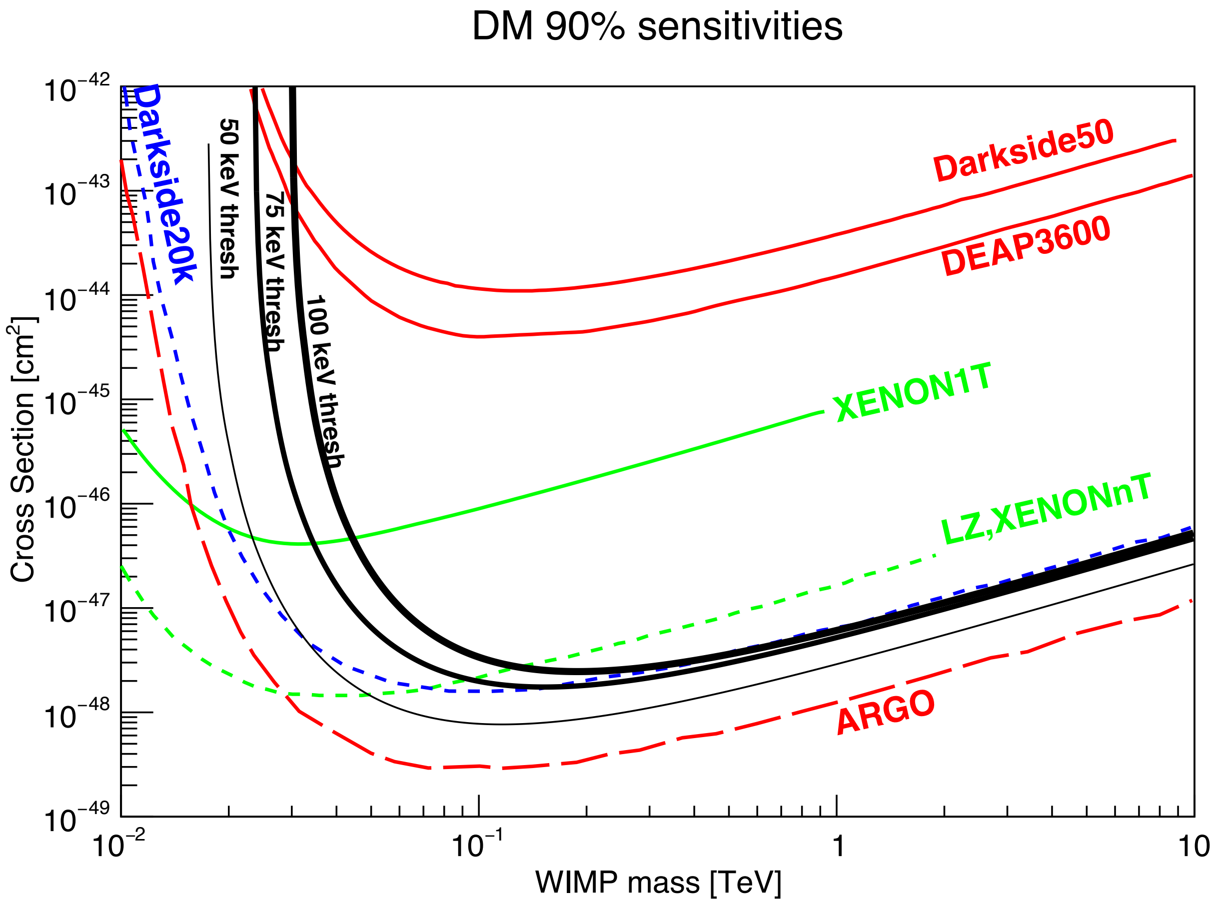
Detector Properties for Low-Energy Physics

- Vertical-Drift
  - ✓ Bulk argon, without many internal components: for radiopurity
  - ✓ Fiducialization and self-shielding
- Enhanced radiopurity
  - ✓ Low radioactivity underground argon
  - ✓ Increased detector materials radiopurity requirements
    - (do not require DM experiment levels!)
  - ✓ Improved radon control
- Additional shielding
  - ✓ 40cm water or plastic outside
- Low threshold readout
  - ✓ SiPM hits
- Enhanced Photon Detection System (PDS)
  - ✓ Reflectors, SiPMs, Increased coverage

WIMP Dark Matter Sensitivity

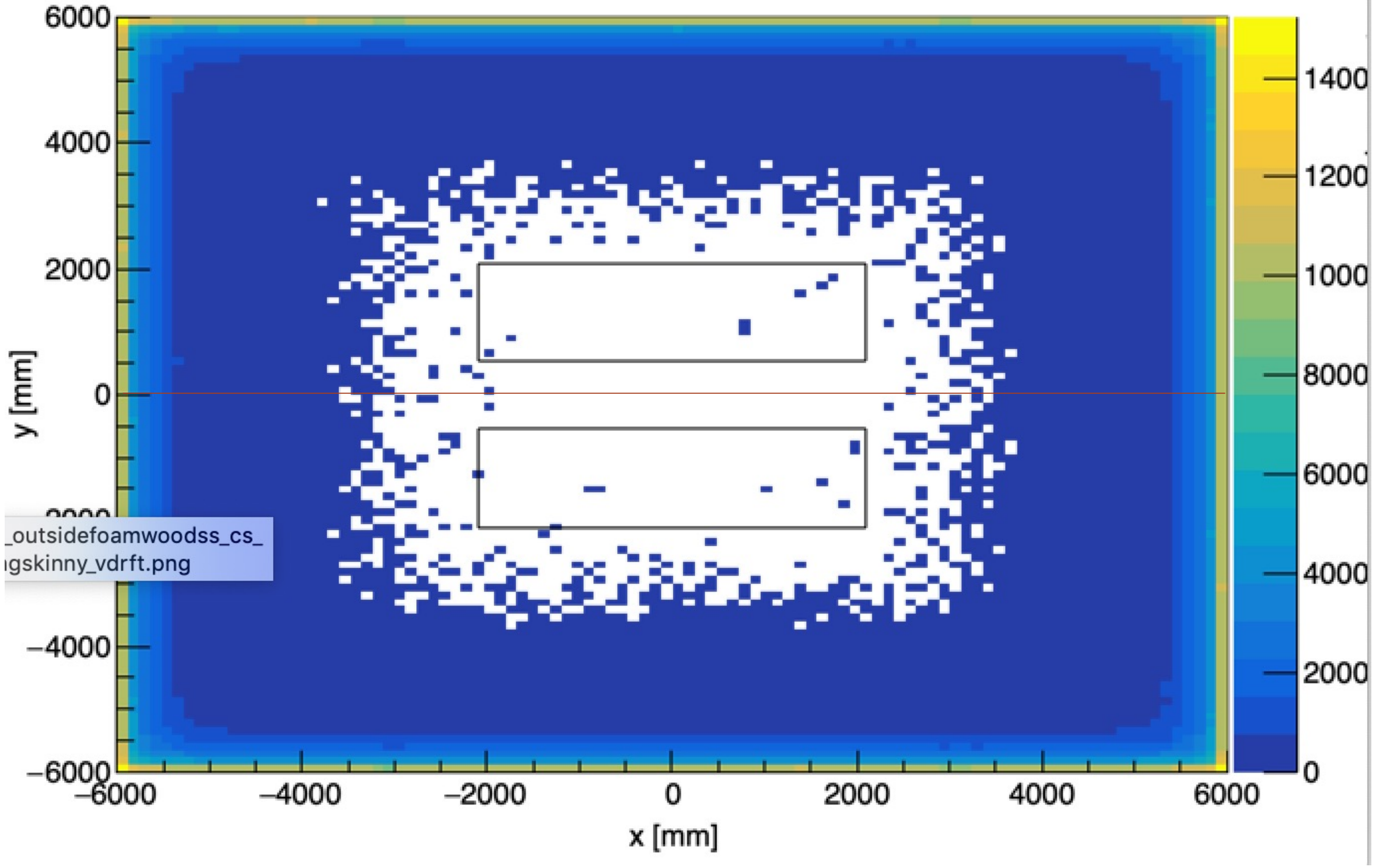
- A limiting case is WIMP Dark Matter Detection. Requires…
  - low backgrounds
  - Low Thresholds
  - Order (100) photons detected
    - ✓ for Pulse Shape Discrimination
      - To subtract all γ/β backgrounds

https://arxiv.org/abs/2005.04824
JINST 15 P092026 (2020)
--Church, Jackson, Saldanha



The DarkSide-20k exposure is 20 tons over a planned 10 years for a total of 200 ton-yrs, while the proposal for a DUNE-like module is 3 years of a 1 kt mass for a 3 kt-yr exposure.

Fiducialization Drops Neutron Background Significantly

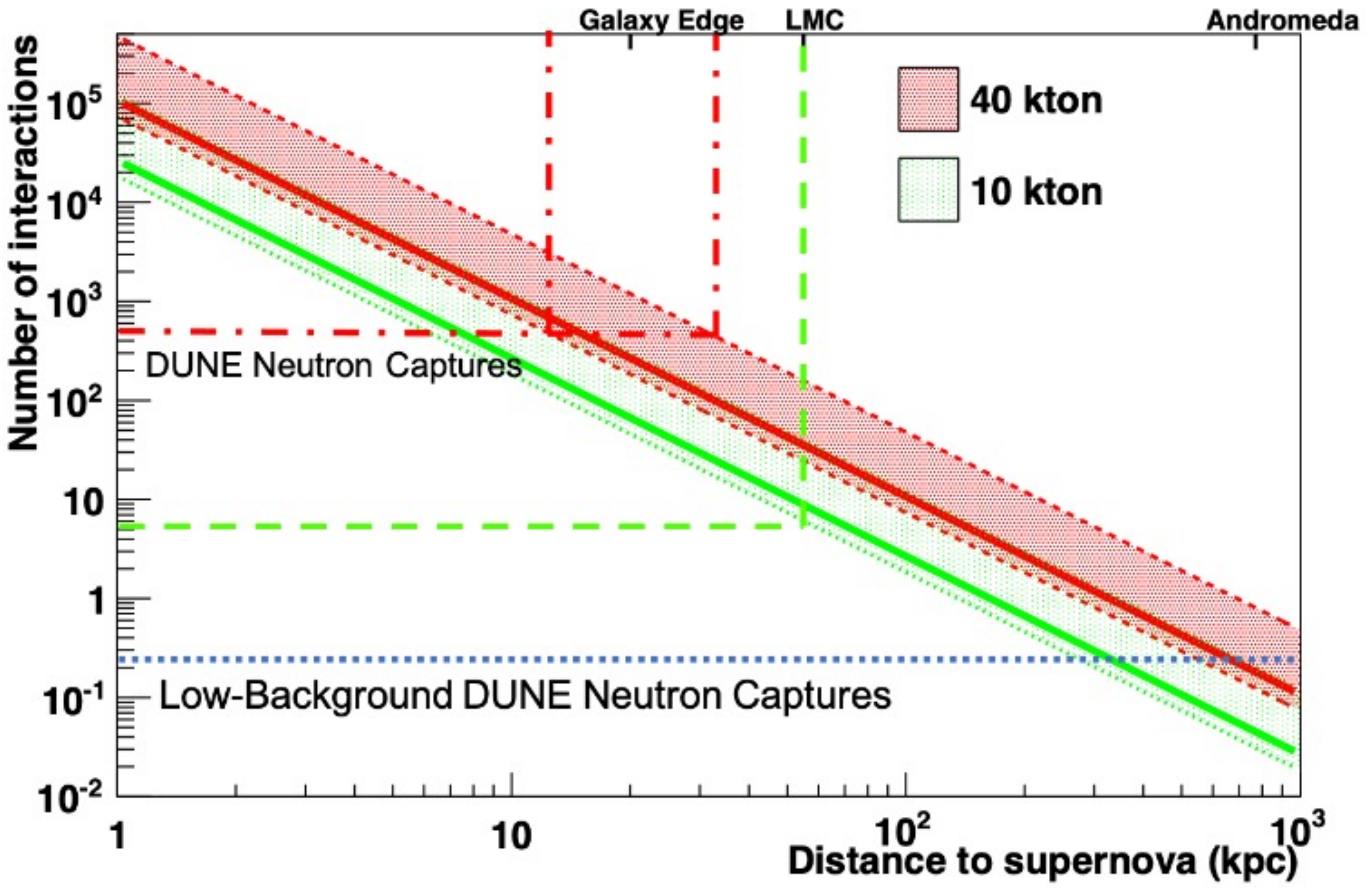


- 100 keV threshold for n.r.
- 2E-9/cm3/sec from cold cryostat steel only (cleaner than default DUNE)
- 9.4 neutrons -
- (2.6 multisite)
  - =>6.8 n's per kton/yr

Lower background => SNe Explosion Detection Sensitivity

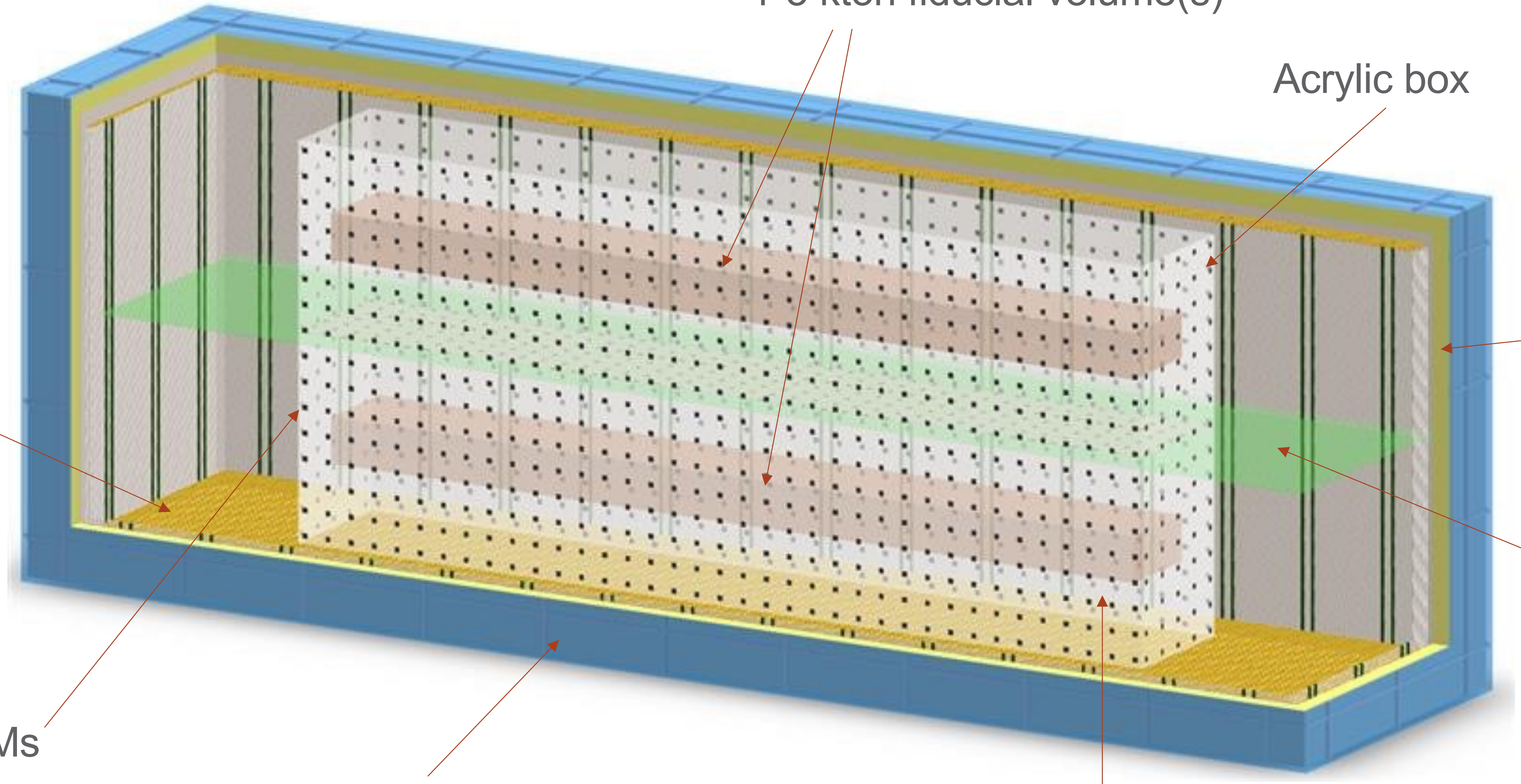
With a lower neutron capture rate, detection out to much greater distance is possible.

Even in just one module.

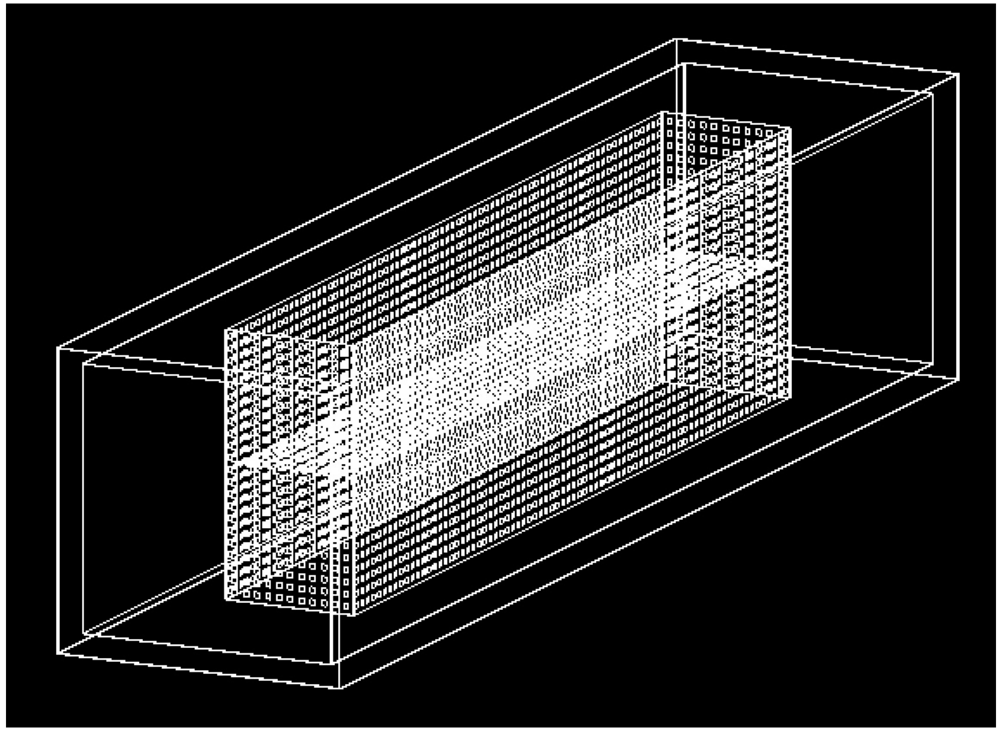


Adapted from arXiv:2008.06647

Vertical Drift Module -- Upgraded

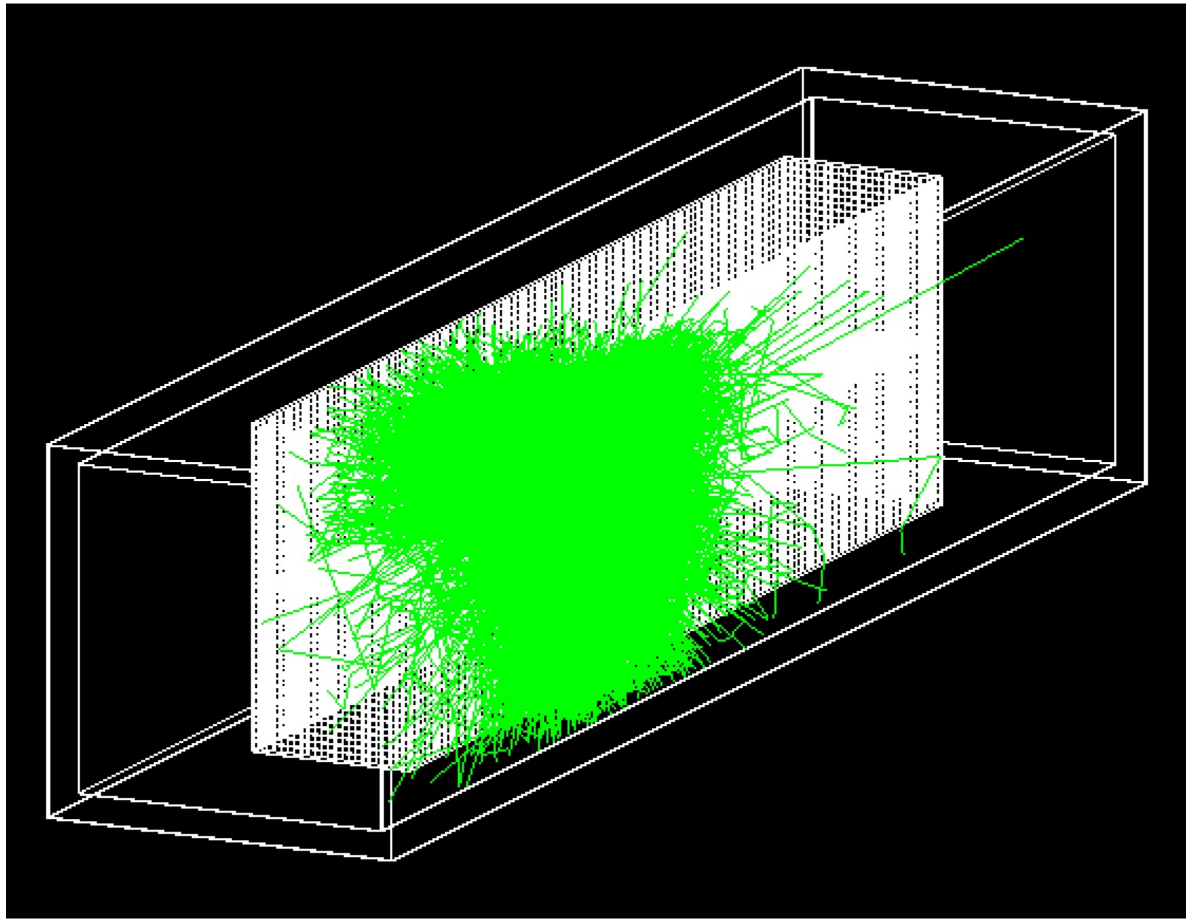


SiPMs and Optical Photons

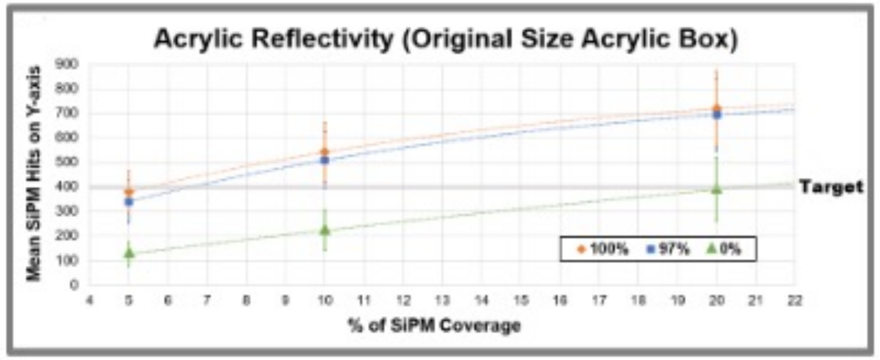


5x5 cm^2 DarkSide-like SiPM modules covering acrylic box walls and cathode

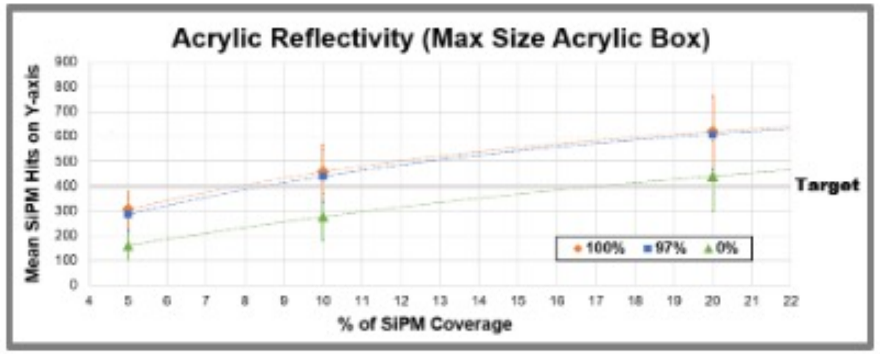
Optical Photons from a typical 100 MeV neutron



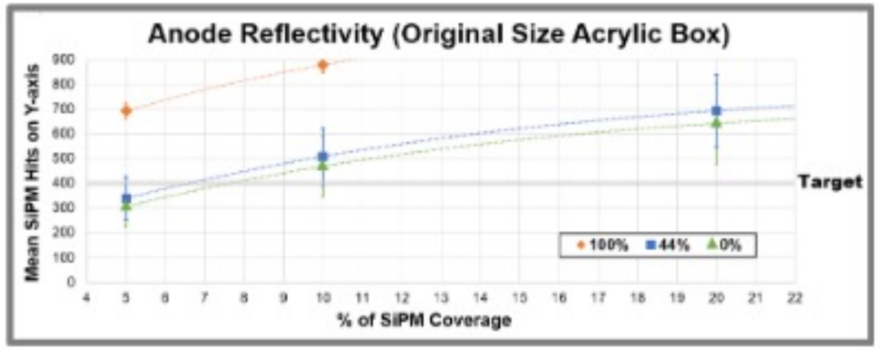
Optical Photon Detector Studies



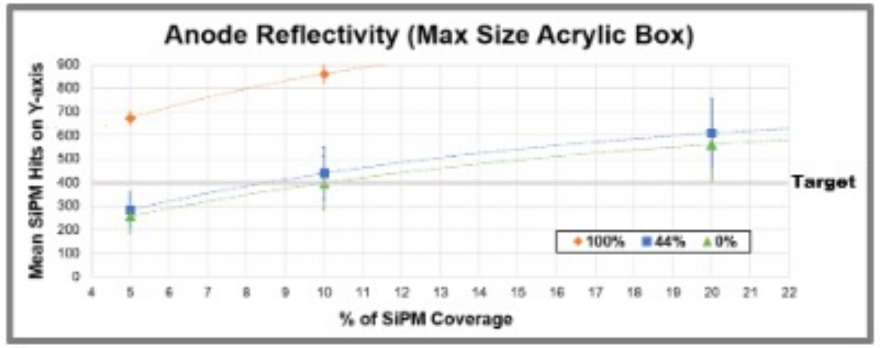
(a)



(b)



(c)



(d)

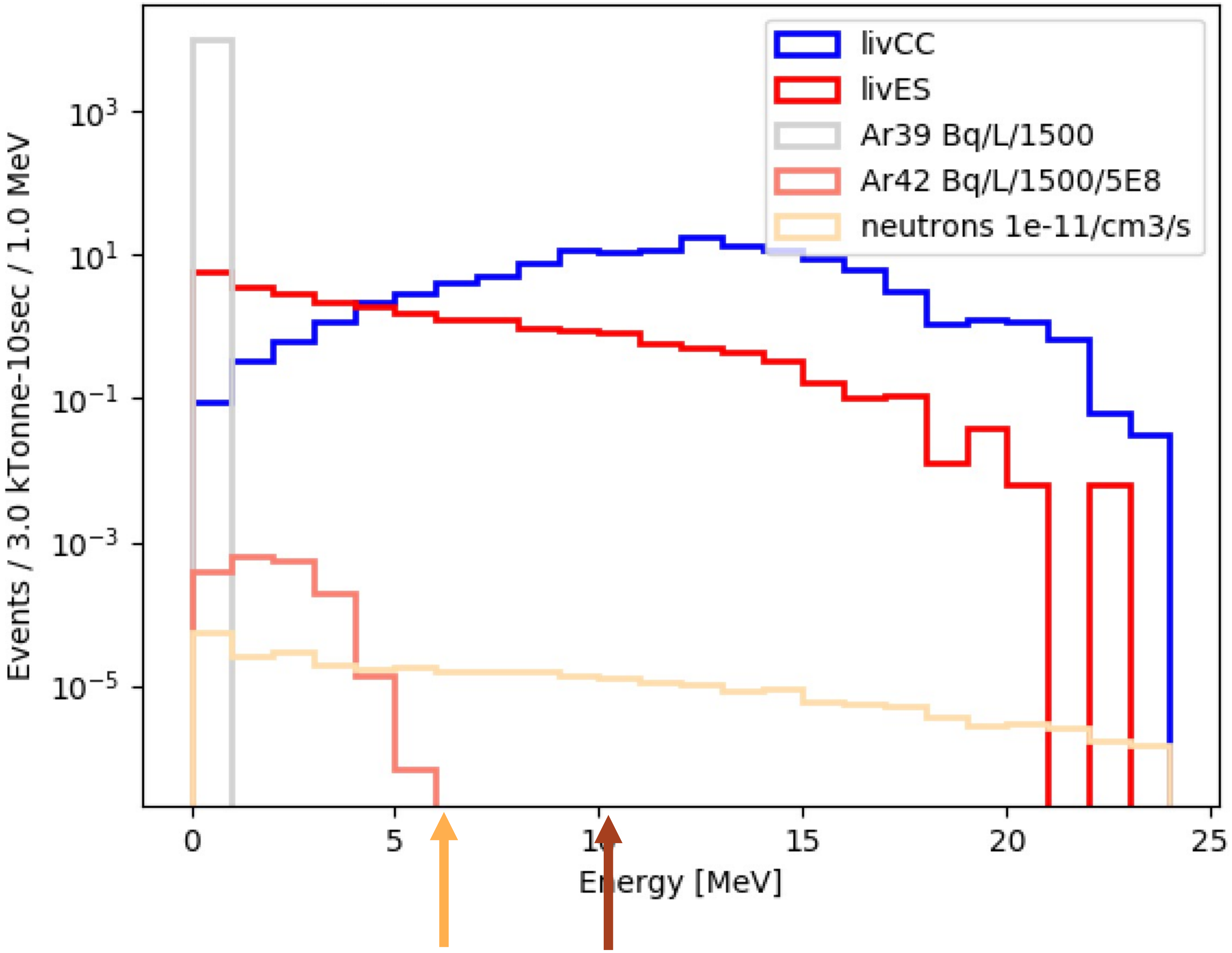
For q.e.=0.25 we need 400 hit SiPMs to get 100 detected photons, to allow PSD.
These plots show for 97% reflective acrylic walls and 44% reflective G10 we can achieve requirements at only 10% SiPM coverage either on Acrylic walls at Original Size or even all the way out at field cage (“Max Size”)

Supernovae at 10kpc

^{42}Ar /= 500 here beyond atmospheric Ar composition.

Clearly a detector of this type allows to see CC/ES spectrum to much lower thresholds.

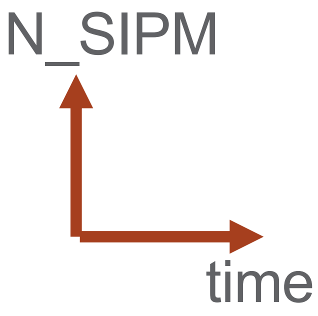
Radon neglected in this study. Presume will control via material selection, improved detector cleaning, argon recirculation and reconstructions techniques (e.g. alpha tagging)



Brown/Orange arrows show rough current DUNE module trigger and data thresholds (due to high n captures)

CEvNS in SuperNova Neutrinos

- A sufficient photon detection system in a low background detector can see the low energy but plentiful photons from CEvNS in a 2kT fiducial volume from a SN explosion



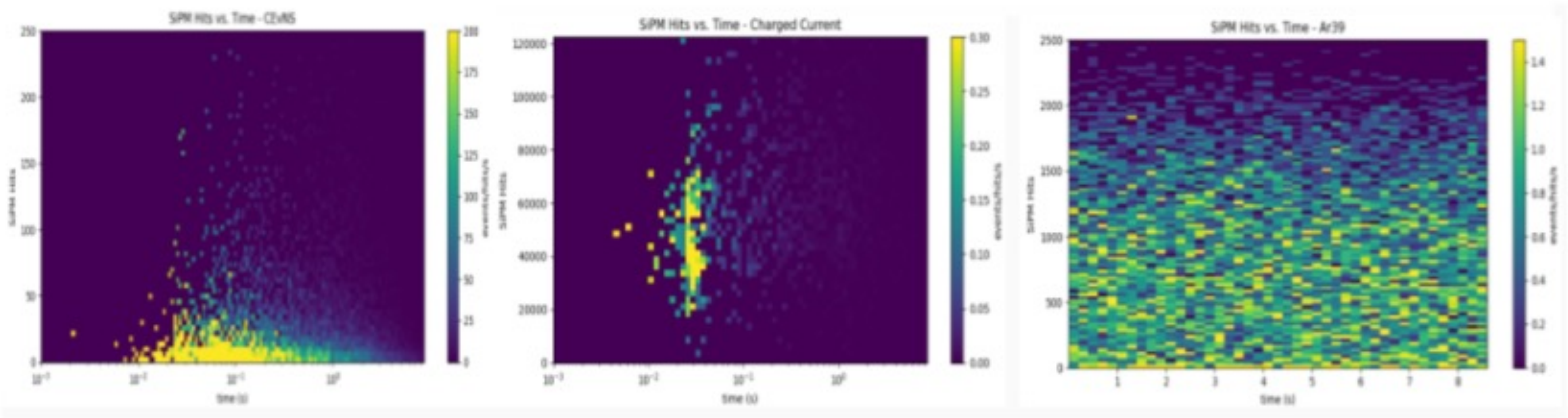


Figure 6: Figures from Carmelo Ortiz, DUNE low energy physics working group meeting,https://indico.fnal.gov/event/50302/

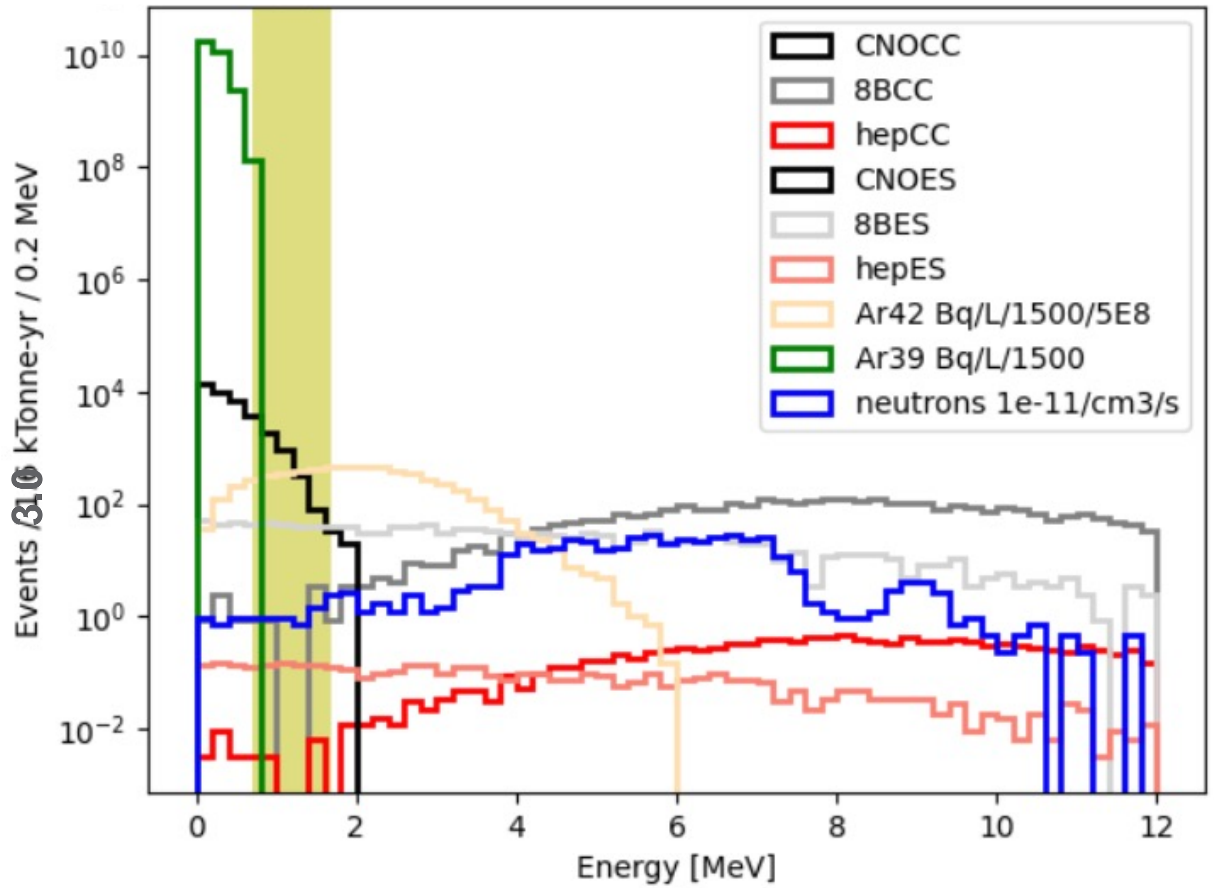
Carmelo Ortiz, Duke

CEvNS "glow" on left, triggered by CC observation center, sits above the steady ^{39}Ar on right **for UAr**, and fades over the 10 seconds of observation of this SN at 10 kpc.

CNO Solar

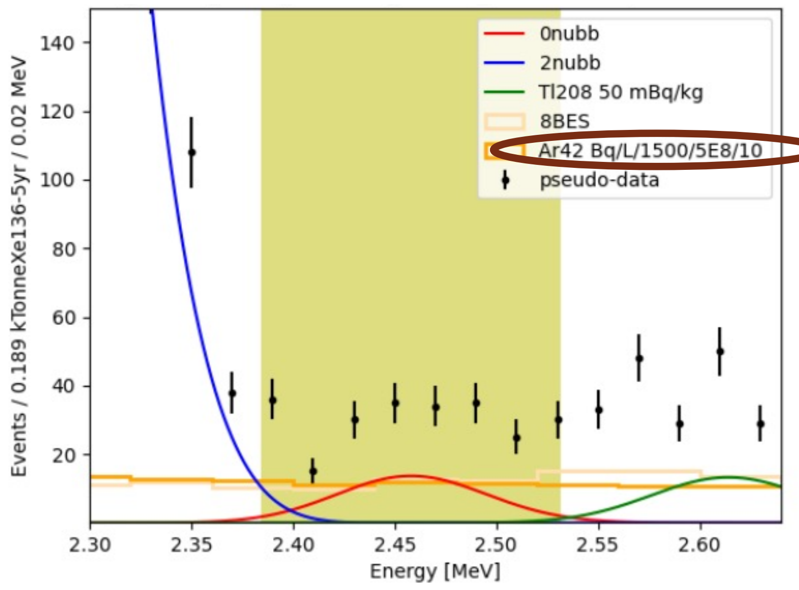
^{42}Ar /= 500 here beyond atmospheric Ar composition.

With UAr we expect very low ^{42}Ar rates. Among other implications, this leads to the ability for detecting CNO solar νs. Neutron rate is low due to requirement on cold cryoskin.



^{136}Xe $0\nu\beta\beta$

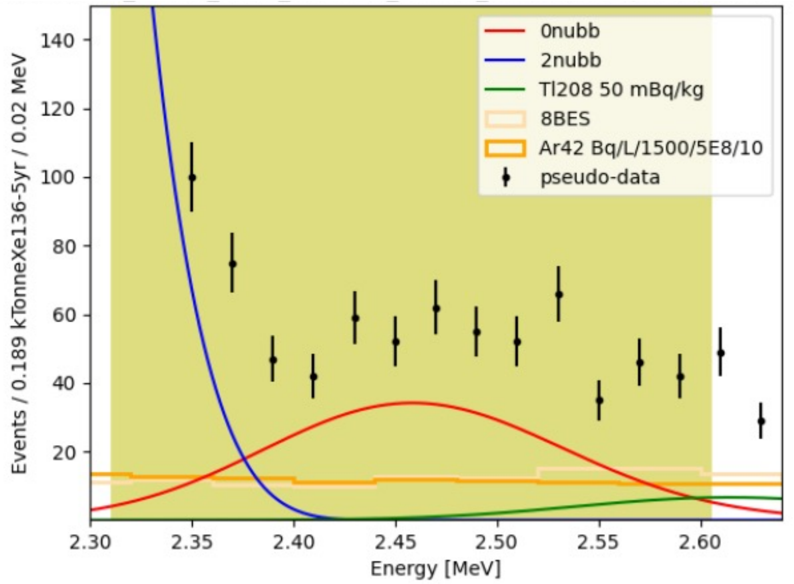
A 3% ^{136}Xe loading over 5 years in a 2 kT LAr box can allow a significant measurement of $0\nu\beta\beta$.



^{42}Ar /= 5000 here beyond atmospheric Ar composition.

σ/Q=1.5%, τ_{hl}=5E28 yrs

These half-lives are at limits and beyond that of nEXO sensitivity



σ/Q=3%, τ_{hl}=1E28 yrs

These plots are unique in that we need good energy resolution.

Curves assume a not-yet-demonstrated charge+light resolution of 1.5% and 3%.

Suggested also by:

J. Zennamo and F. Psihas and A. Mastbaum, Snowmass 2021 Letter of Interest:https://www.snowmass21.org/docs/files/summaries/NF/SNOWMASS21-NF5_NF10-IF8_IF0_Zennamo-175.pdf

Simulation Code – Standalone G4 code, with Optical Photons

- github.com/echurch/rdecay02
  - branch:liquid_deception

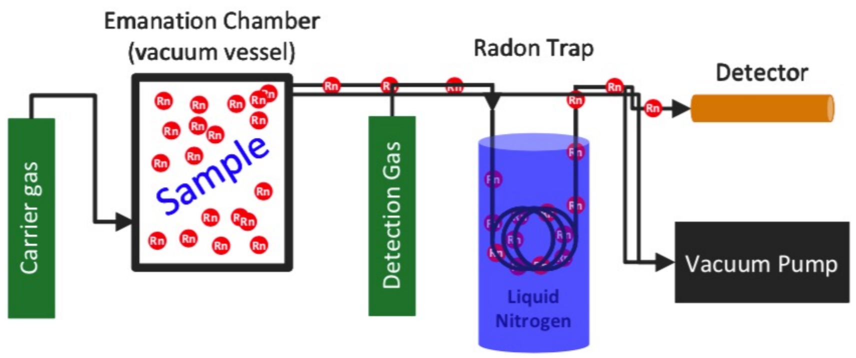
- There's a pretty simple, complete README
  - Start by installing ROOT, G4, marley on your machine
  - branch:liquid_deception

- Everything is controlled in config file, e.g. ../macros/marley_optphys.mac

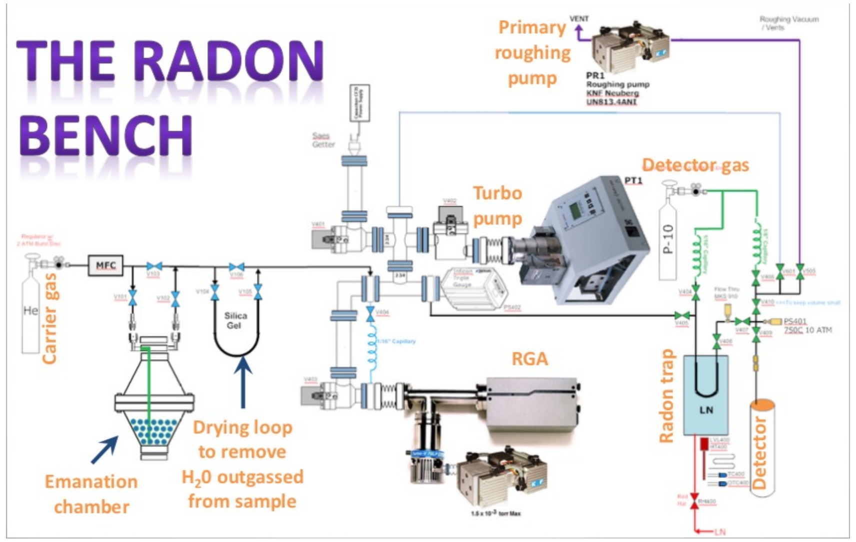
Radon

- A big caveat for all preceding plots is that the ^{222}Rn
  - swirling around in the Argon and emanating from materials is under control via filtering and recirculating.
  - and in some cases is further cut with use of a Bi-Po gamma-alpha coincidence

- This requires further study – at PNNL, other places



Step 1: "Rinse" sample with low-radon gas & evacuate to low pressure
Step 2: Emanate for ≈1 week until radon level nears equilibrium
Step 3: Transfer emanated radon to cryogenic trap
Step 4: Load radon into detector & detect decays



Underground Argon

- Low radioactivity underground argon has been demonstrated in DarkSide-50 [ds50], with a factor 1400 reduction in 39Ar and no observation of 42Ar.
  - We assume x1500 39Ar and x5000(0) 42Ar reduction for these studies

- Demonstration of large-scale sources capable of filling DUNE-like module have not been shown (DarkSide source is too small)
  - PNNL is in discussion with several commercial gas producers
  - Could be as low as 3x cost of atmospheric argon, 5kT/yr production rate

QA/QC in a Low Background Module

- Building a kTon-scale module radioactively clean will require significant quality control
- Brand new radiopurity.org for the wider low-background community
  - https://indico.ific.uv.es/event/6178/contributions/15934/
- Tools for managing assays and cleanliness are built
  - for modules 1 and 2
  - and then for subsequent modules
- bgexplorer, a Background model to show properties of radioactive contributions in the detector/cavern.
  - https://github.com/bloer/bgexplorer
  - Soon a DUNE instance at bgexplorer.pnnl.gov

The New radiopurity.org

radiopurity.org

radiopurity.org

documentation

GitHub

about | search | advanced search | insert | update | logout

Query Assistant

Email radiopurity@snolab.ca with contributions/questions.

1 Bq U-238/kg	=	81 ppb U	(80 x 10^{-9} gU/g)
1 Bq Th-232/kg	=	246 ppb Th	(246 x 10^{-9} gTh/g)
1 Bq K-40/kg	=	32300 ppb K	(32300 x 10^{-6} gK/g)
1 Bq U-235/kg	=	1.76 ppm U	(1.76 x 10^{-6} gU/g)

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Snowmass White Paper

- https://www.snowmass21.org/docs/files/summaries/NF/SNOWMASS21-NF10_NF4-CF1_CF0-IF8_IF0-UF1_UF3-137.pdf
  - LOI

- Snowmass Whitepapers due in 6 months.

  Still welcoming contributors.

  Meeting in next 4 weeks to discuss any outstanding studies to do.

Snowmass2021 - Letter of Interest

Low Background kTon-Scale Liquid Argon Time Projection Chambers

H. Back[1], J. F. Beacom[2], E. Church[1], Z. Djurcic[3], I. Gil-Botella[4], C. M. Jackson[1], S. J. M. Peeters[5], J. Reichenbacher[6], R. Saldanha[1], K. Scholberg[7], G. Sinev[6], M. Sorel[8], and S. Westerdale[9,10]

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NF Topical Groups:
- ■ (NF1) Neutrino oscillations
- ■ (NF3) Beyond the Standard Model
- ■ (NF4) Neutrinos from natural sources
- ■ (NF5) Neutrino properties
- ■ (NF6) Neutrino cross sections
- ■ (TF11) Theory of neutrino physics
- ■ (NF9) Artificial neutrino sources
- ■ (NF10) Neutrino detectors

Other Topical Groups:
- ■ (CF1) Dark Matter: Particle-like
- ■ (IF8) Noble Elements
- ■ (UF01) Underground Facilities for Neutrinos
- ■ (UF02) Underground Facilities for Cosmic Frontier
- ■ (UF03) Underground Detectors

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Abstract: With controls over radiopurity and some modifications to a detector similar to the DUNE Far Detector design we find that it is possible to increase sensitivity to low energy physics in a fourth 10 kt module. In particular, sensitivity to supernova and solar neutrinos can be enhanced with improved MeV-scale reach. Furthermore, sensitivity to Weakly-Interacting Massive Particle (WIMP) Dark Matter (DM) becomes competitive with the planned world program in such a detector.

1

Conclusion

- Opportunity to enhance DUNE physics program with a low background Far Detector module

- Concept being developed includes:
  - Fiducialized bulk argon module, Enhanced radiopurity, Increased shielding, Low radioactivity underground argon, Increased photon detection

- Physics enhancements include:
  - Increase supernova neutrino sensitivity, supernova CEvNS glow, precision solar neutrino measurements, neutrinoless double beta decay, WIMP dark matter detection
  - No detriment to current DUNE goals

- Snowmass White Paper in preparation – contact if interested