Pacific Northwest NATIONAL LABORATORY

Underground Argon and Other Low Background R&D

July 20th, 2022

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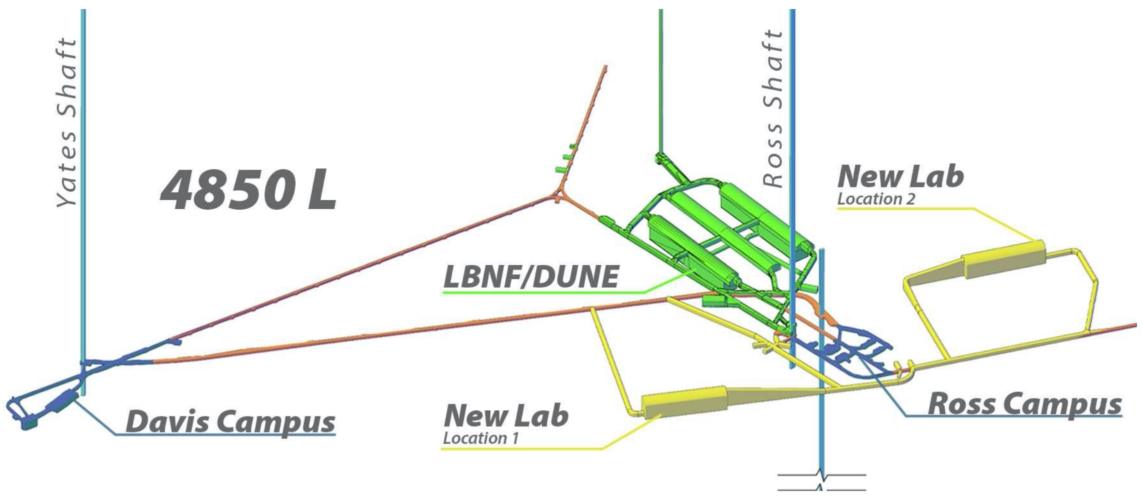
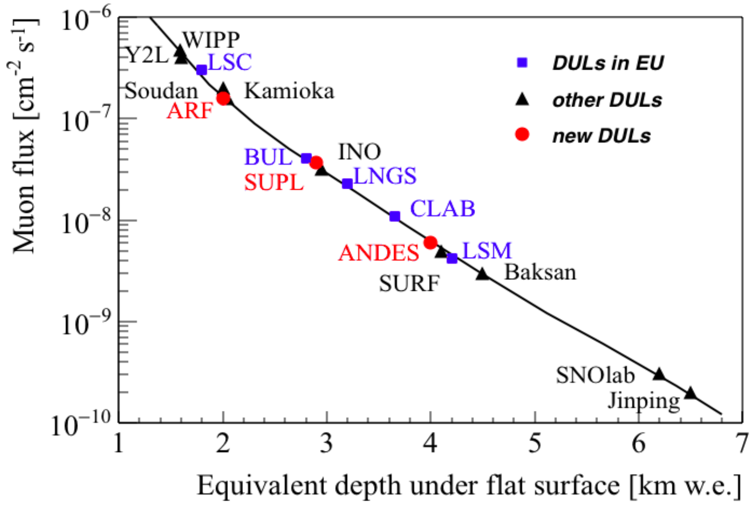
PNNL

U.S. DEPARTMENT OF ENERGY BATTELLE

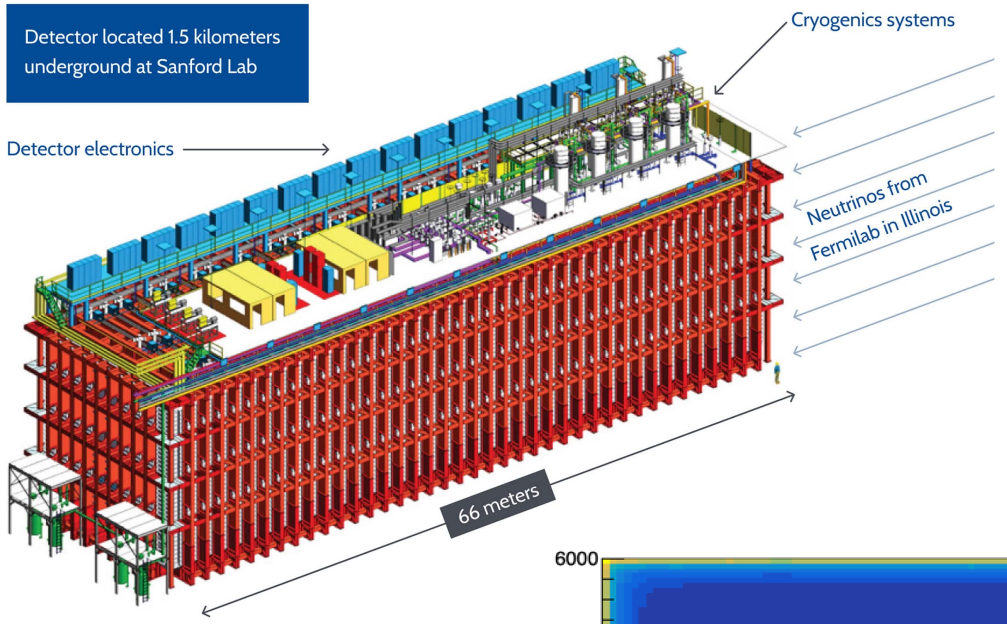
Dune has great low background potential…

… it is deep

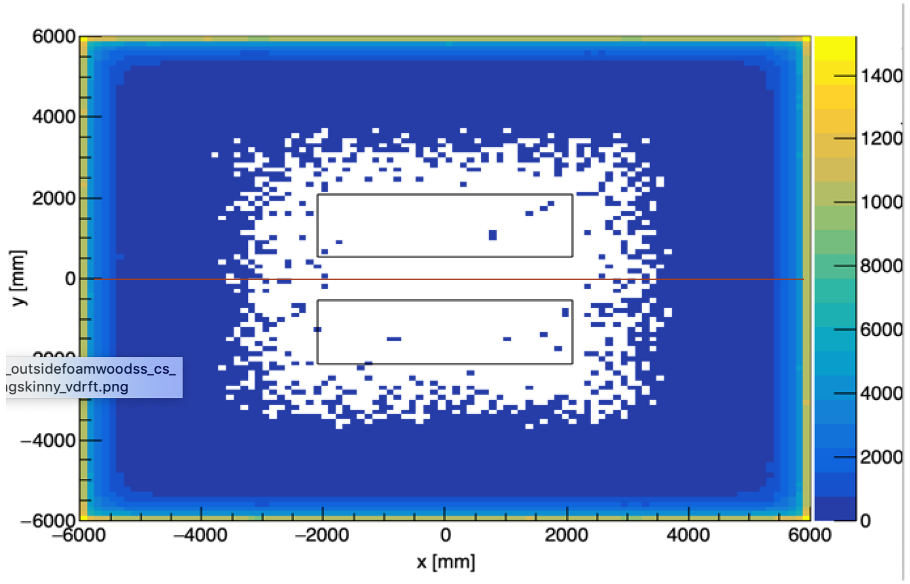




Ianni, TAUP 2017

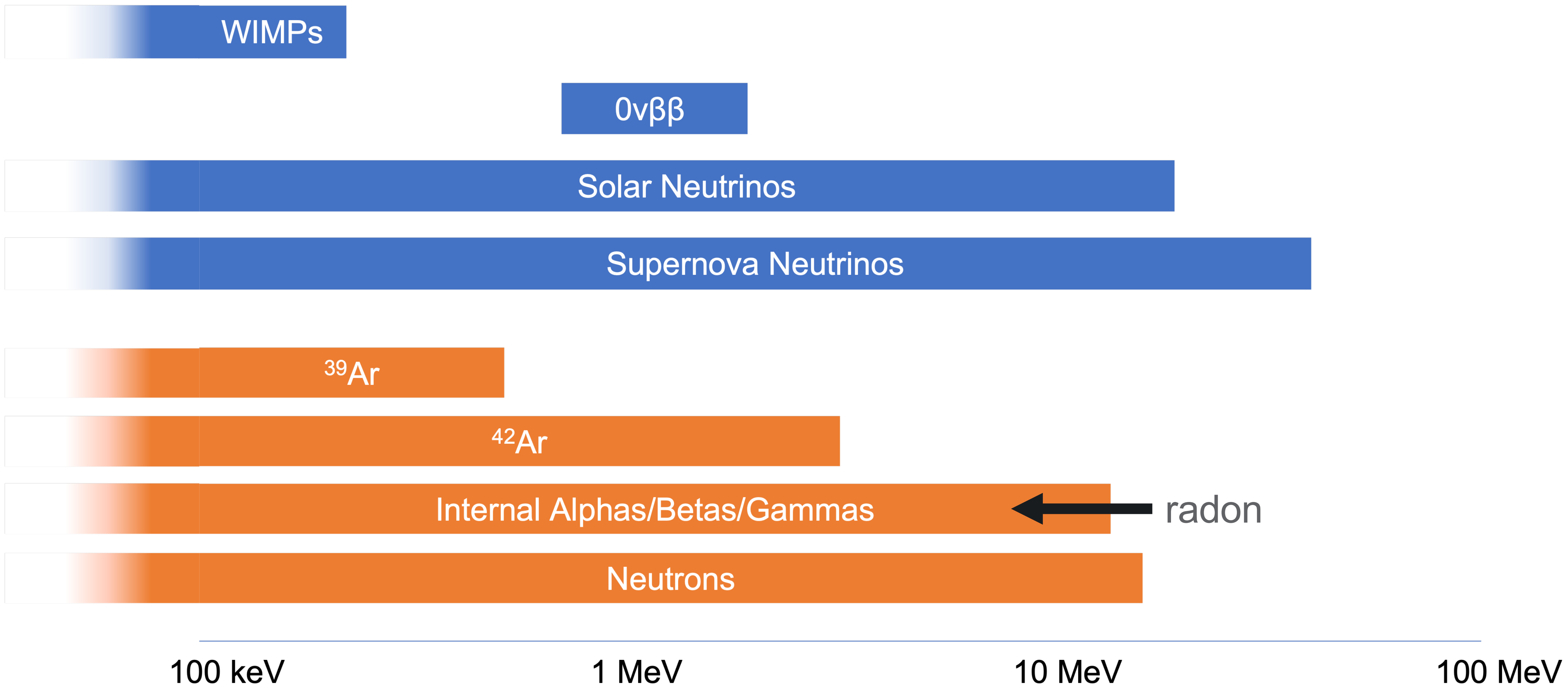


… it is big

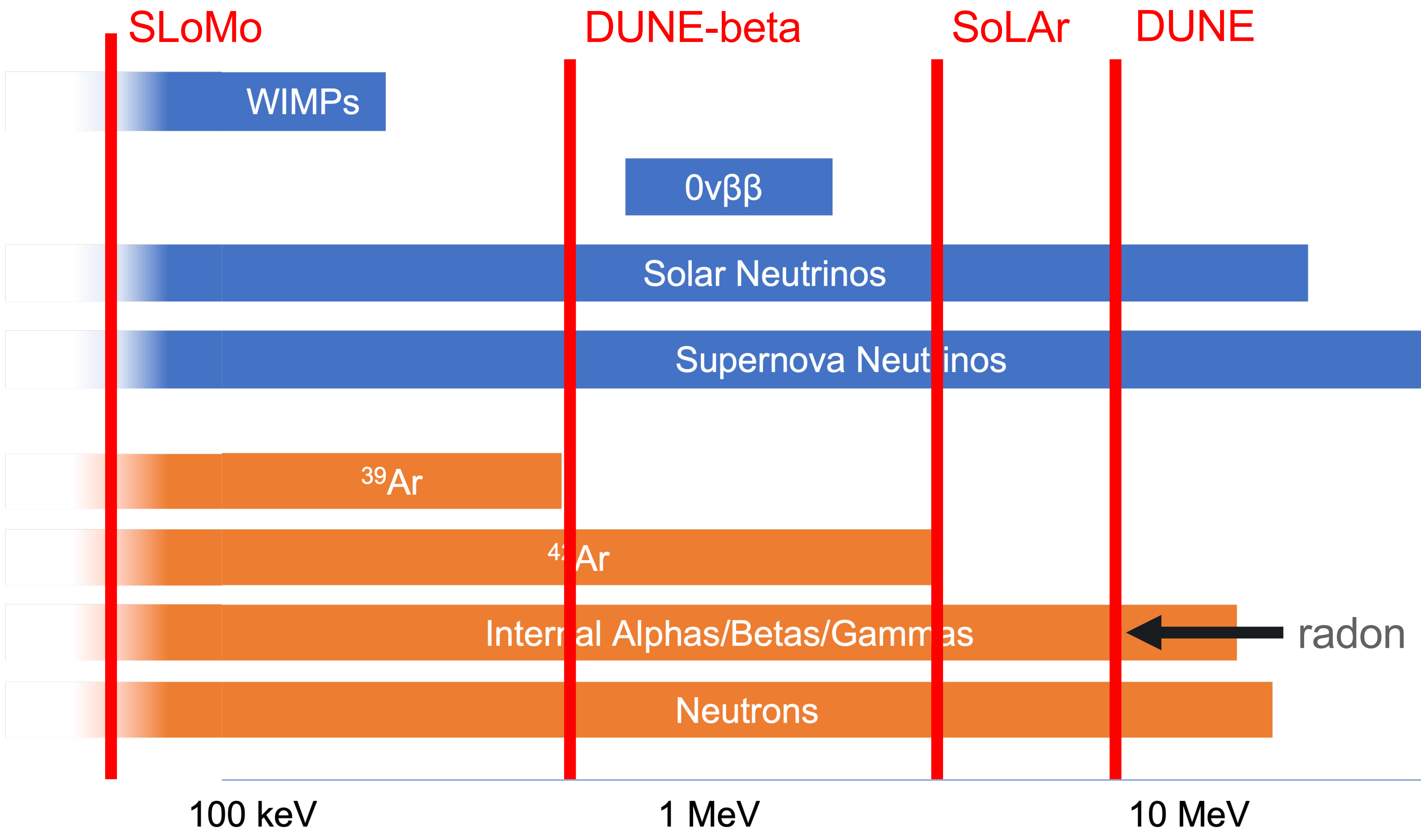


Neutron nuclear recoil events within a single DUNE module

Low Background Physics



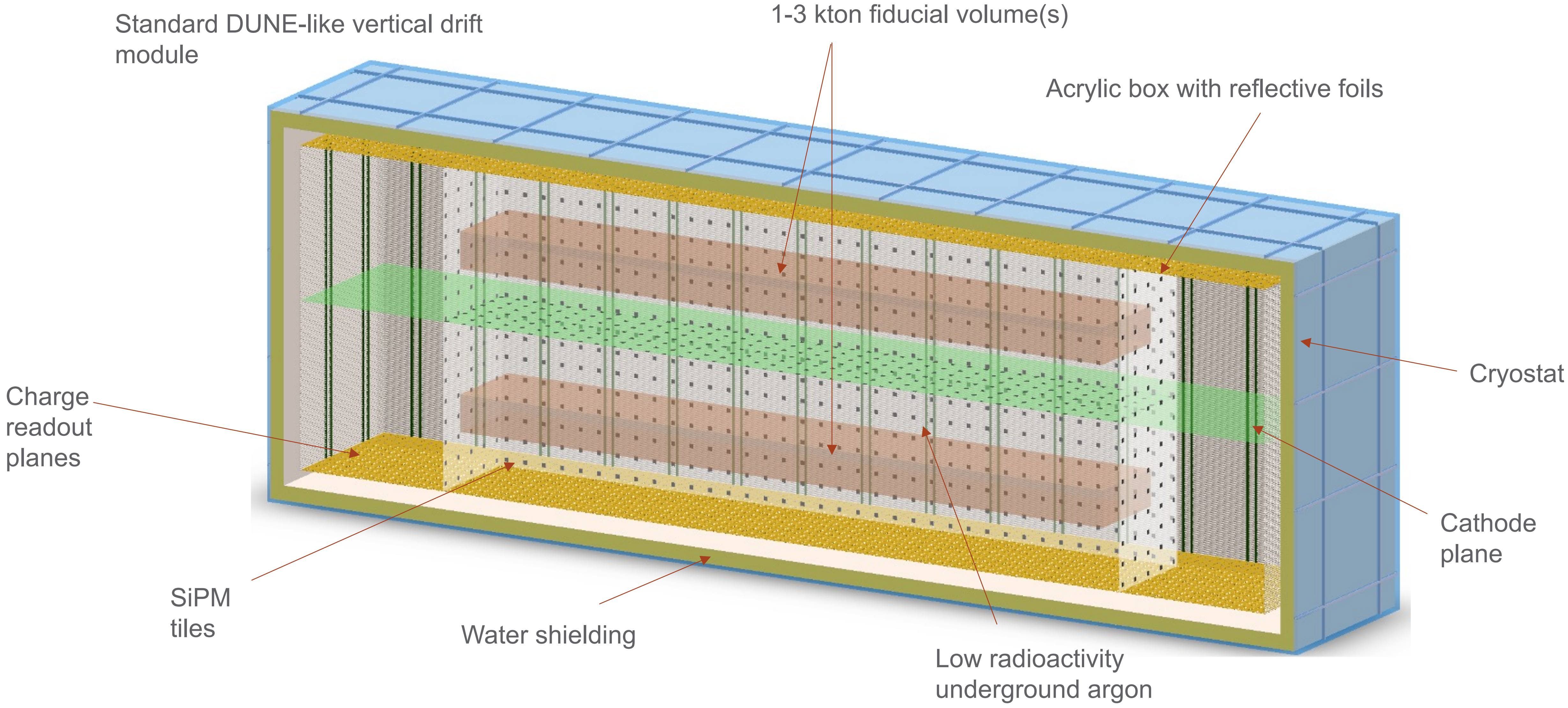
Low Background Physics



SLoMo: arxiv:2203.08821
DUNE-beta: arxiv:2203.14700
SoLAr: arxiv:2203.07501

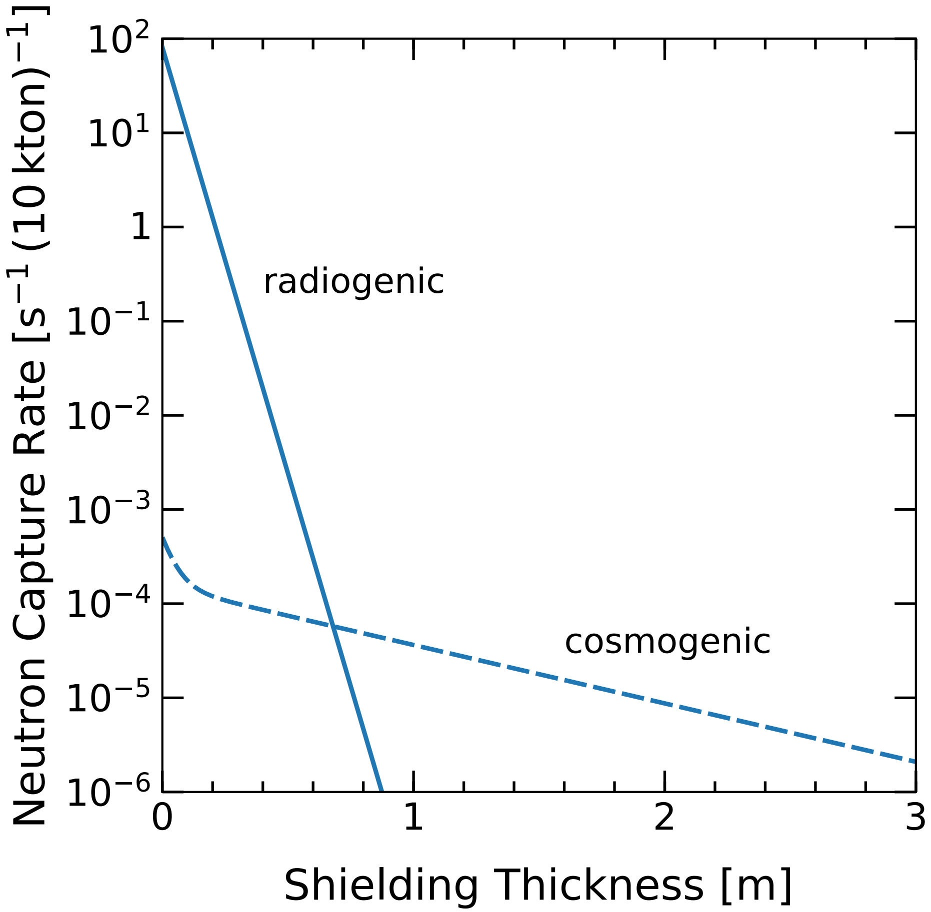
Also:
Low-Energy Physics in Neutrino LArTPCs: arxiv:2203.00740
DUNE as the Next-Generation Solar Neutrino Experiment
Phys. Rev. Lett. 123, 131803 (2019)

SURF Low Background Module (SLoMo) Concept

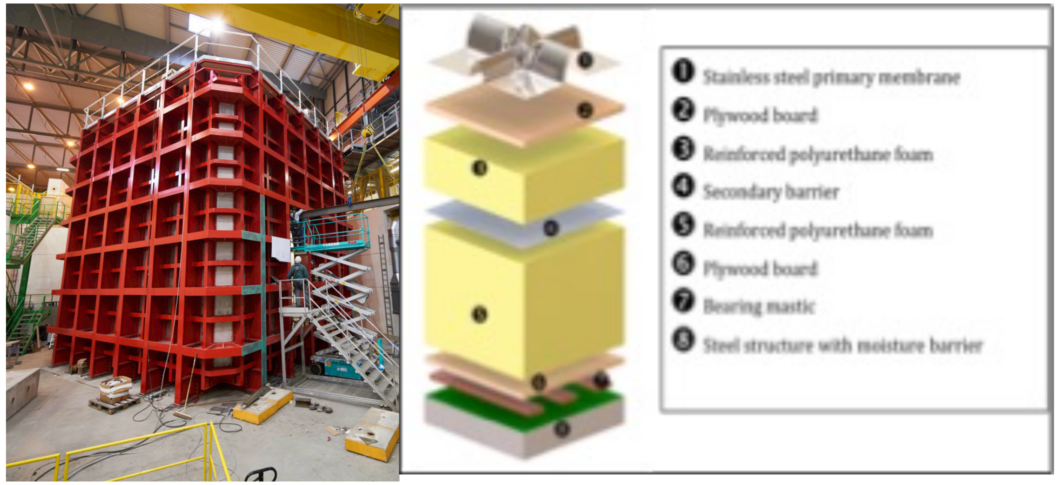


Neutron Backgrounds

- Neutron (n, γ) reactions in argon directly mimic low energy neutrinos
- Cavern rock likely primary source of neutrons (spontaneous fission and (α, n) from U/Th chains)
  - also from detector components
- Neutron shielding
  - No water shield in current DUNE design
  - 40 cm of water shielding around detector (proposed by Capozzi, Li, Zhu and Beacom)
    - ✓ ~3 order of magnitude reduction



Developing the MeV potential of DUNE: Detailed considerations of muon-induced spallation and other backgrounds, G. Zhu, S. W. Li, and J. F. Beacom, Phys. Rev. C **99**, 055810



- Other options
  - Exploring cryostat designs to increase shielding
    - ✓ e.g. Boron doped insulation
  - Planes of (doped) acrylic possible as shielding within the LAr

Internal Detector Backgrounds

- Neutrons from internal detector components:
  - For example, stainless steel in cryostat (1 kton!)

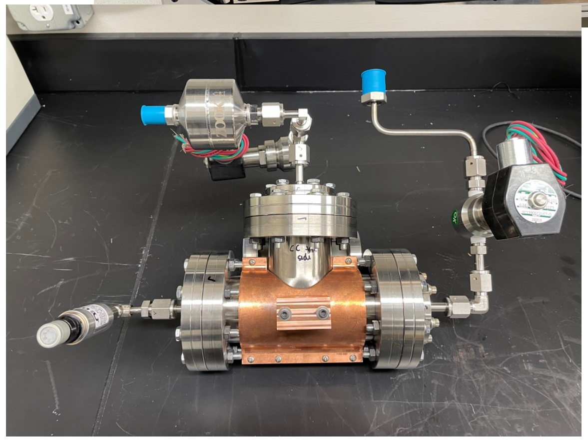
  - Need **~10^3** more radiopure than planned for baseline DUNE to match shielding
    - ✓ But LZ/DarkSide expect further 2 orders of magnitude, so is feasible

  - R&D required to develop large QA/QC program
  - Apply techniques used for dark matter experiments at kton-scale

Efforts to support continued database development

Radon Background

- Light from α’s or from (α, γ) (~15 MeV) in argon
- Radon levels
  - Target: 2 μBq/kg
  - This requirement is **~10^2-10^3** reduction beyond baseline DUNE
  - Exceeded by DarkSide-50, DEAP-3600: 0.2 μBq/kg
- Radon control ideas
  - Radon removal during purification via inline radon trap
    - ✓ MicroBoone filtration system (arXiv:2203.10147 **[physics.ins-det]**)
  - Emanation measurement materials campaign
    - ✓ New cryogenic systems, high throughput developments
  - Surface treatments
  - Dust control
  - Radon reduction system during installation and operation



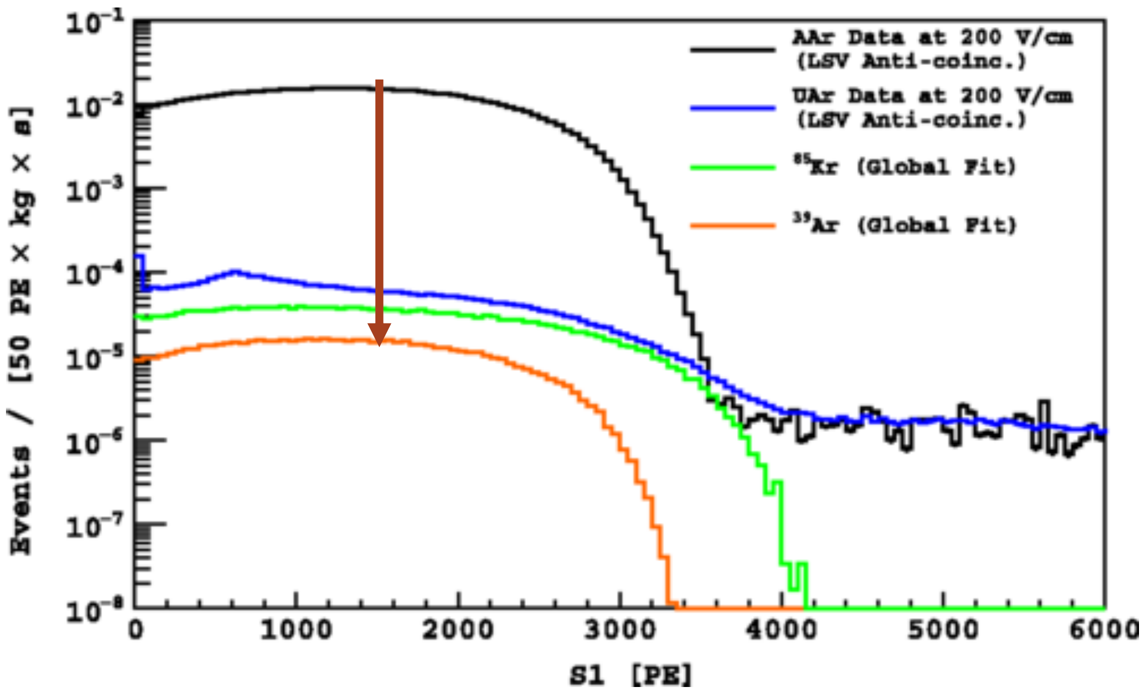
Prototype cryogenic radon emanation bench

What is Low-Radioactivity Underground Argon

- Atmospheric argon:
  - ^{39}Ar: 1 Bq/kg (10 MHz/module) – 0.57 MeV endpoint
  - ^{42}Ar: 0.1 mBq/kg – 0.6 MeV endpoint but…
  - Decays to ^{42}K with 3.5 MeV endpoint

- Underground sources of depleted argon exist
  - Demonstrated in DarkSide-50
    - ✓ 1400x reduction ^{39}Ar (air contamination = could be lower)
    - ✓ Larger reduction of ^{42}Ar likely
  - From CO_2 wells in Cortez, CO
  - Planned for DarkSide-20k and GADMC
  - Urania plant production target: 300 kg/day
  - Only vetted source but not large enough for a DUNE-like module

DarkSide 50: Phys. Rev. D 93, 081101(R)



^{39}Ar rate: x1400 reduction

^{39}Ar and ^{42}Ar Production

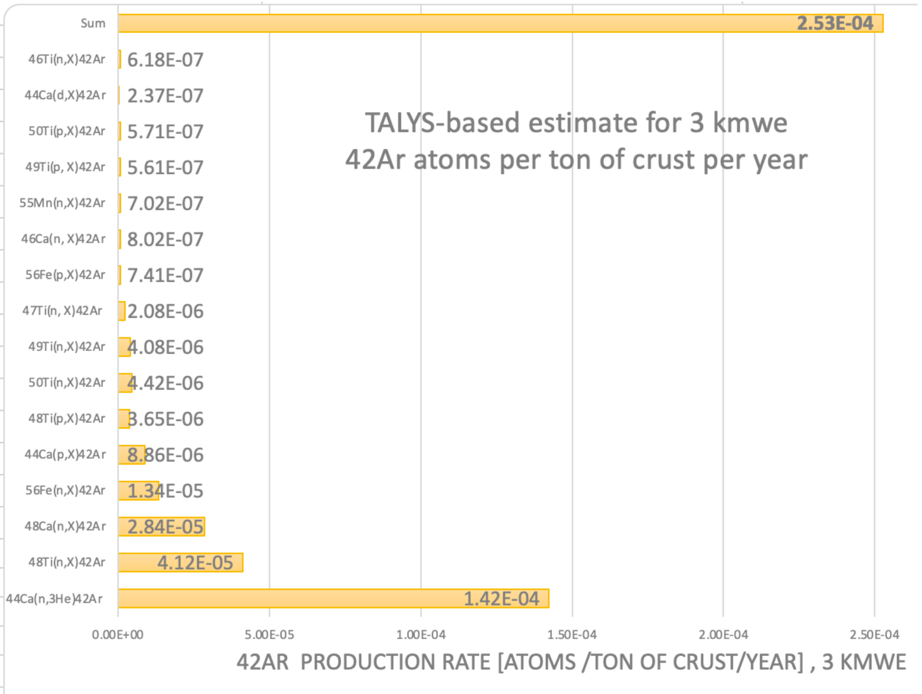
- Atmospheric production dominated by cosmogenic activation ^{40}Ar

Reaction	Estimated ^{39}Ar production rate [atoms/(kg$_{Ar}$day)]	Fraction of total AAr (%)
$^{40}Ar\ (n, 2n)^{39}Ar+$ $^{40}Ar(n, d)^{39}Cl$	759 ± 128	72.3
$^{40}Ar\ (\mu, n)^{39}Cl$	172 ± 26	16.4
$^{40}Ar\ (\gamma, n)^{39}Ar$	89 ± 19	8.5
$^{40}Ar\ (\gamma, p)^{39}Cl$	23.8 ± 8.7	2.3
$^{40}Ar\ (p, 2p)^{39}Cl$	<0.1	<0.01
$^{40}Ar\ (p, pn)^{39}Ar$	3.6 ± 2.2	0.3
$^{38}Ar(n, \gamma)^{39}Ar$	$\ll 0.1$ (UAr)	–
	1.1 ± 0.3 (AAr)	0.1
Total	1048 ± 133	100

Saldanha et al., Phys. Rev. C **100**, 024608

What is the ^{42}Ar level underground?

- Production calculation: 3 x 10^{-3} ^{42}Ar per ton of crust per year at 3 km w.e.
  - 7 orders of magnitude less than ^{39}Ar at this depth
- But many uncertainties:
  - Crust or mantle origin
  - How much argon diffuses into gas field
- Likely $>10^{10}$ suppression in rate compared to atmosphere



Sharma Poudel, LRT 2022, paper in preparation

Next Generation Production

- Need large-scale, cost-effective production
- This requires:
  - High concentration/chemically enriched underground source
  - Should be parasitic to major underground gas operation
  - Ideally commercial supplier produces argon
    - ✓ Could reuse existing Urania infrastructure

White paper:
A Facility for Low-Radioactivity Underground Argon
arXiv:2203.09734 **[physics.ins-det]**

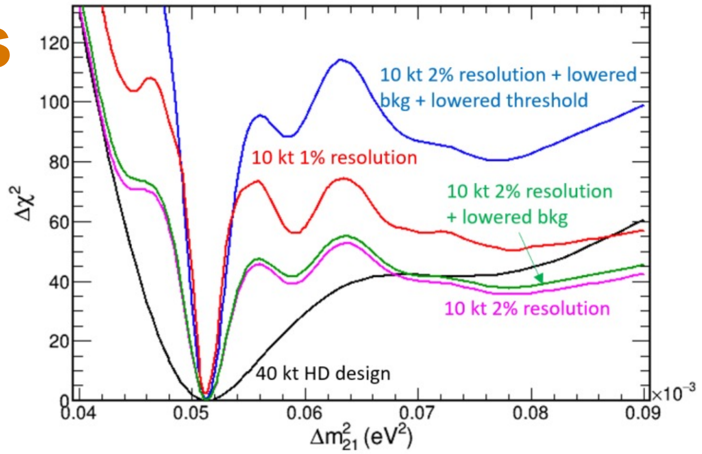
- PNNL working to explore large scale underground argon sources
  - Preliminary gas analysis indicates mantle origin.
  - **Supplier:** 3 major U.S. gas producers/suppliers *(not disclosed at company request)*
  - **Production rate:** ~5,000 tonnes/year
  - **Ballpark cost:** Could be as low as x3 regular argon for 10 kton+ scales

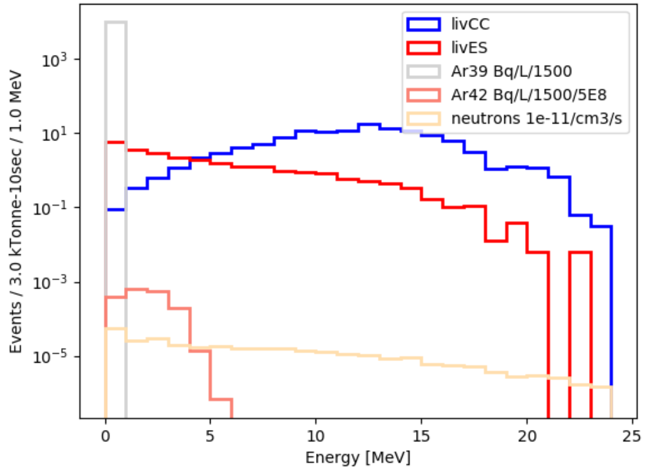
NOTE: These are very rough estimates.

Low Background Module Concept
SLoMo (SURF Low Background Module)

Solar Neutrinos

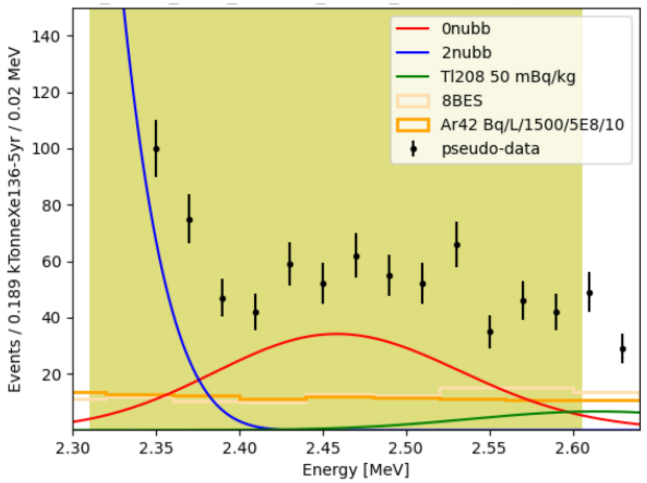
- Precision Δm^2_{21}
- NSI constraints
- Precision CNO, test solar metallicity





Supernova Neutrinos

- Lower threshold, elastic scatters
- Early- and late-time information
- Detection beyond Magellanic Cloud
- CEvNS glow

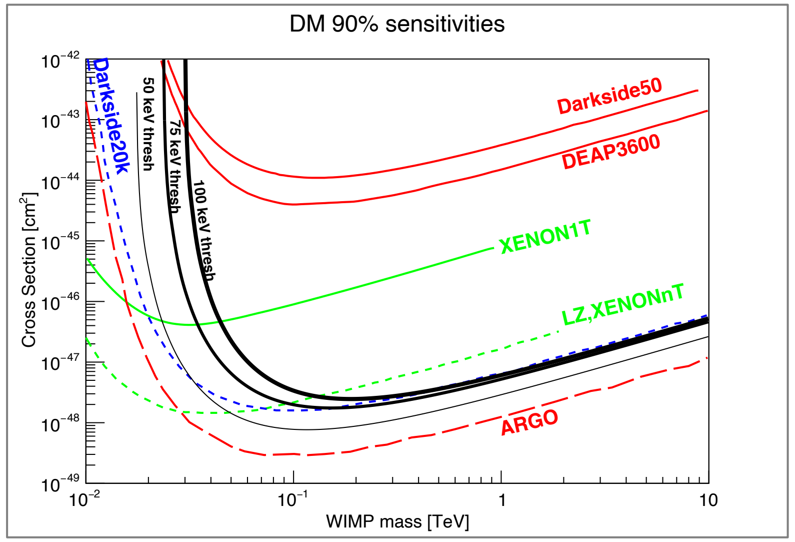


Snowmass White Paper:

Low Background kTon-Scale Liquid Argon Time Projection Chambers

A. Avasthi[1], T. Bezerra[2], A. Borkum[2], E. Church[3], J. Genovesi[4], J. Haiston[4], C. M. Jackson[3], I. Lazanu[5], B. Monreal[1], S. Munson[3], C. Ortiz[6], M. Parvu[5], S. J. M. Peeters[2], D. Pershey[6], S. S. Poudel[3], J. Reichenbacher[4], R. Saldanha[3], K. Scholberg[6], G. Sinev[4], J. Zennamo[7], H. O. Back[3], J. F. Beacom[8], F. Capozzi[9], C. Cuesta[10], Z. Djurcic[11], A. C. Ezeribe[12], I. Gil-Botella[10], S. W. Li[7], M. Mooney[13], M. Sorel[9], and S. Westerdale[14]

https://doi.org/10.48550/arXiv.2203.08821



Neutrinoless Double Beta Decay

- Confirm ton-scale signal
- Sensitivity beyond inverted hierarchy

WIMP Dark Matter

- Competitive high mass search on fast timescale
- Confirm G2 signal with annual modulation

Conclusions

- Growing interest in low background DUNE options:
  - SLoMo, DUNE-beta, SoLAr, *LEPLAr,…*
- Low background developments required to make this happen:
  - Shielding
  - Materials selection QA/QC
  - Radon reduction
  - Underground argon
    - ✓ Significant suppression of ^{42}Ar expected
    - ✓ Will require a new underground argon source
- Expanded physics program at DUNE possible:
  - Supernova neutrinos
  - Solar neutrinos
  - Neutrinoless double beta decay
  - WIMP dark matter

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Thank you