Underground Argon and Other Low Background R&D

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Dune has great low background potential...

... it is deep

... it is big

Neutron nuclear recoil events within a single DUNE module
Low Background Physics

- WIMPs
- $0\nu\beta\beta$
- Solar Neutrinos
- Supernova Neutrinos
- $^{39}\text{Ar}$
- $^{42}\text{Ar}$
- Internal Alphas/Betas/Gammas
- Neutrons
- radon

Energy range:
- 100 keV
- 1 MeV
- 10 MeV
- 100 MeV
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
SURF Low Background Module (SLoMo) Concept

- Standard DUNE-like vertical drift module
- 1-3 kton fiducial volume(s)
- Acrylic box with reflective foils
- Charge readout planes
- SiPM tiles
- Water shielding
- Low radioactivity underground argon
- Cryostat
- Cathode plane
Neutron Backgrounds

- Neutron \((n, \gamma)\) reactions in argon directly mimic low energy neutrinos
- Cavern rock likely primary source of neutrons (spontaneous fission and \((\alpha, n)\) 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)
  - \(\sim 3\) order of magnitude reduction

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

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
Internal Detector Backgrounds

- Neutrons from internal detector components:
  - For example, stainless steel in cryostat (1 kton!)
  - Need $\sim 10^3$ 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 $\alpha$’s or from $(\alpha, \gamma)$ (~15 MeV) in argon

• Radon levels
  ▪ Target: 2 µBq/kg
  ▪ This requirement is $\sim 10^2$-$10^3$ 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
  ▪ Emanation measurement materials campaign
    ✓ New cryogenic systems, high throughput developments
  ▪ Surface treatments
  ▪ Dust control
  ▪ Radon reduction system during installation and operation
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

$^{39}$Ar rate: x1400 reduction
39Ar and 42Ar Production

- Atmospheric production dominated by cosmogenic activation 40Ar

What is the 42Ar level underground?

- Production calculation: 3 x 10^{-3} 42Ar per ton of crust per year at 3 km w.e.
  - 7 orders of magnitude less than 39Ar 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
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

• 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 ×3 regular argon for 10 kton+ scales

**NOTE:** These are very rough estimates.

White paper:
A Facility for Low-Radioactivity Underground Argon
arXiv:2203.09734 [physics.ins-det]
Low Background Module Concept
SLoMo (SURF Low Background Module)

Solar Neutrinos
- Precision $\Delta m_{21}^2$
- 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

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

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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
Thank you