Underground Facilities for Neutrinos (UF1)

T. Bolton, M.P. Decowski, A. De Roeck∗, G. Orebi Gann∗, D. Speller
∗Liaisons from Neutrino Frontier.

with material provided by Snowmass session presenters (many thanks!)

Sanford Underground Research Facility

Underground Facilities for Neutrinos (UF1)

Part I

- Key topics in *underground-based* neutrino research
- UF1 Topical Report Summary
    - Drafts: https://snowmass21.org/underground/start
    - Long-baseline neutrino facilities
    - Neutrinoless double-beta decay facilities
    - Facilities for measurement of neutrinos from natural sources
- Status of UF1 Topical Report

Part II

- Discussion & Actions

Sanford Underground Research Facility

Key topics in *underground-based* neutrino research

- Long-baseline neutrino facilities
- Neutrinoless double beta decay facilities
- Facilities for measurement of neutrinos from natural sources

- These categories guide the development of the UF1 Topical Report

Long-baseline neutrino facilities

- **Capital “P” physics: neutrino CP violation and the neutrino mass hierarchy, plus a broad and rich supporting program:**
  - Precision tests on the PMNS model.
  - Supernovas and neutrino astrophysics.
  - Beyond SM probes: nucleon decay, new interactions,….
- **Challenges: interesting physics effects are small**
  - Full scope is required→ upgrades.
  - Systematic error control is critical→
    - Highly capable near detectors.
    - Qualitative improvements to far detectors.

Boulby Underground Laboratory

Long-baseline neutrino facilities

- **The coming decade is "ballistic"**
  - HyperK will begin its full program in ~2028.
  - Phase 1 of DUNE will start over 2028-2031.
  - Dynamite is exploding underground now in Lead and Kamiokande.
- **For the US program, what is the upgrade strategy? Optimize:**
  - More far detector mass AND better far detectors?
  - Near detector upgrades to control systematics?
  - Beam power?

Canfranc Underground Laboratory

Long-baseline neutrino facilities

- **Both HyperK and DUNE will likely seek to expand the scope of their physics program, mostly by pushing detection energy thresholds down and controlling radiological backgrounds..**
  - HyperK: Gd, more and better photodetector coverage,…
  - DUNE: 3D readout for LAr, better shielding, alternate target selection,…
- **Preserving the complementarity of DUNE and HyperK will produce the best science.**

Modane Underground Laboratory

Snowmass 2021

Long-baseline neutrino facilities

- **HyperK and Phase 1 of DUNE are pre-Snowmass 2022 projects that are under construction and on-track for physics by the end of the decade.**
- **The key questions for the US program relate to the timing and scope of DUNE upgrades.**
    - Plans and funding develop quickly (~2035 or earlier): DUNE rapidly builds its two final far detector modules. More mass may be prioritized over new detector technologies.
    - Plans and funding develop slowly (~2040 or later): there may be time to plan, build, execute, and decommission completely different experiments (dark matter, neutrinoless double beta decay) that use the vacant cavern space at SURF.
    - In between (most likely?): Hybrid detectors that both support DUNE physics and impact other science.

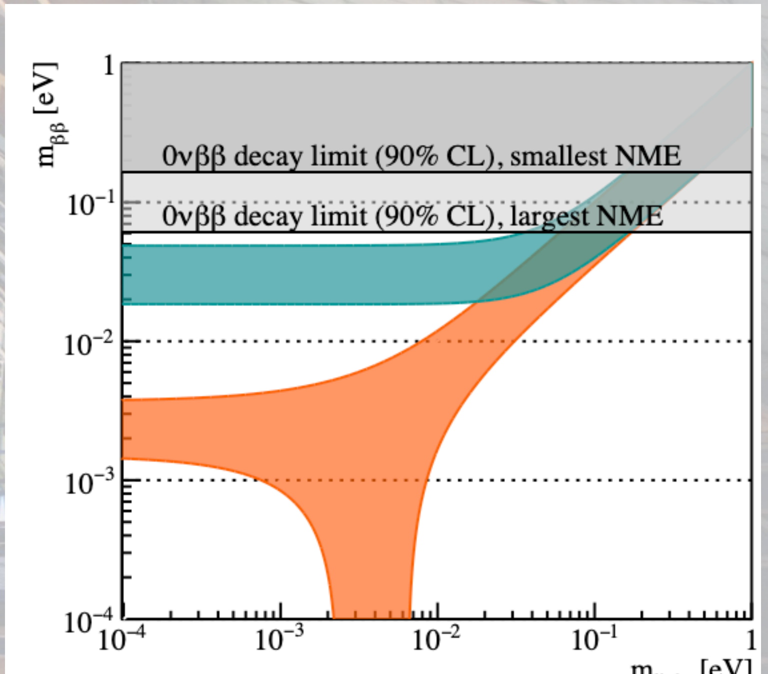
Neutrinoless double beta decay facilities

Science Drivers

- Are neutrinos their own antiparticles?
- What is the origin of the neutrino mass?
- How are the masses ordered?

Challenges for NDBD in Underground Facilities

- Space & Depth Requirements of future experiments
- Cleanliness Requirements
- Materials Assay & Environmental Monitoring
- Underground space for R&D



https://arxiv.org/pdf/2202.01787.pdf

China Jinping Underground Laboratory

Neutrinoless double beta decay facilities

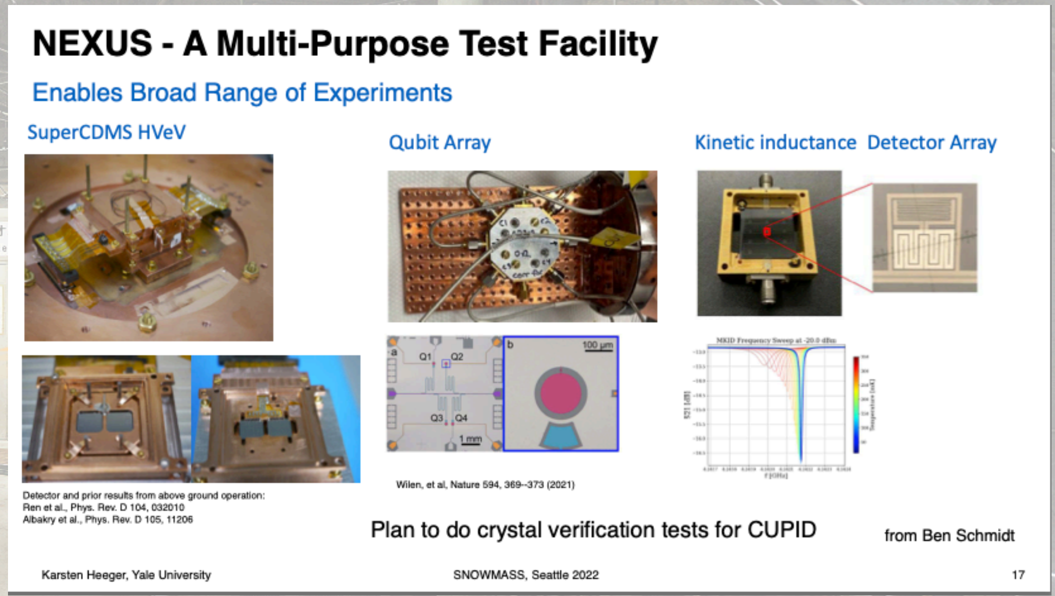
- **Space**
  - Currently there is space for the the generation of NDBD experiments.
  - Space needs must also be viewed in light of occupancy by DM experiments.
  - Support needed for local/domestic facilities key for training, testing, and prototyping
  - Beyond the horizon of Snowmass21:
    - Neutrino science does not end at the tonne-scale. Planning efforts for underground facilities needs at the next level of NDBD study (after ~2030) must begin now
- **Depth**
  - Gather existing NDBD and G2 results and perform simulations regarding the sufficiency of depth of existing laboratories to host NDBD experiments beyond the tonne-scale

Neutrinoless double beta decay facilities

Infrastructure & Facility needs

- Cleanrooms
- Muon veto systems
- Clean environments for materials
- Clean environments for detector construction
- Underground radio-assay and storage facilities
- Environmental monitoring and safety

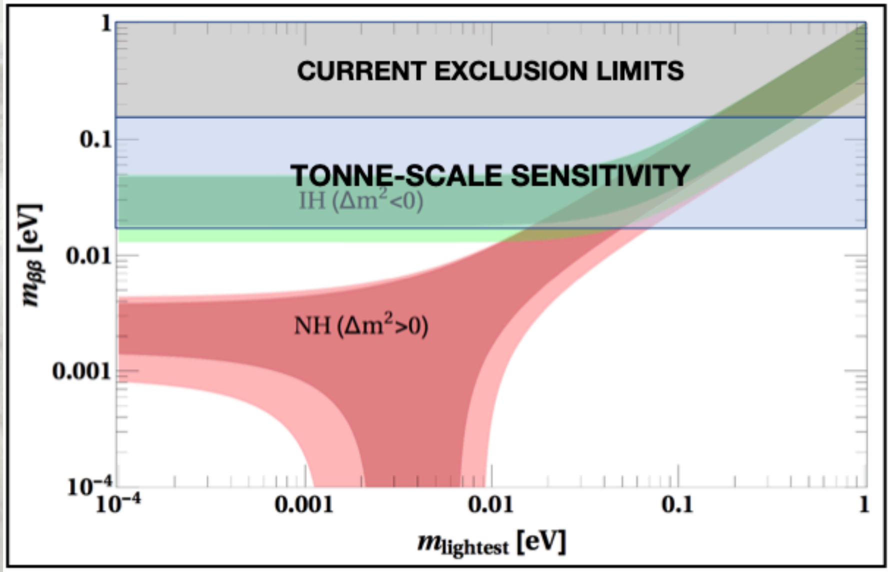
- Underground R&D facilities
- Experimental support considerations:
  - Space underground for detector + associated vessels and vetos/shields
  - Entry access for large components
  - Space for assembly of detectors (large clean room areas, cranes, vertical clearance)
  - Welding and fabrication facilities (e.g. electroforming facility)
  - Clean rooms (dust free, radon reduced air)
  - Xenon recovery and storage
  - Cryogenics
  - Shielding from neutrons
  - Low radioactive backgrounds
  - Large pressure vessels
  - Environmental monitoring (Radon; particle flux; dust, etc)



K. Heeger, 7/19/2022 “Bolometer Experiments, Underground Facilities, and Discovery Science”

Neutrinoless double beta decay facilities

- We need to understand the depth requirements for next-next-gen NDBD experiments
- Space is sufficient for now but will need to be addressed as future NDBD and DM experiments come online (prior to the next Snowmass period)
- Need for supporting facilities including clean, low radon space for storage and assembly
- Shielded underground R&D facilities needed, esp. near institutional home bases for training and preliminary work, prototyping



R. Saldhana (19 Jul 2022, “Beyond Ton Scale 0nBB and Future Xe Experiments”)

Neutrinos from Natural Sources

Science Drivers

- ***Probe far-reaching neutrino sources:***
  - cosmological,
  - stellar,
  - geological,
  - core-collapse supernova,
  - diffuse supernova background,
  - atmospheric,
  - extragalactic
- ***Address fundamental questions:***
  - Number of neutrinos,
  - sum of neutrino masses,
  - collective oscillations,
  - flavour physics,
  - new interactions,
  - sensitivity to non-standard physics

Neutrinos from Natural Sources

Underground Facilities Challenges for Natural-source Neutrinos

- Depth requirements
- Cleanliness requirements: *10^-19 g/g U/Th achieved by Borexino, sets a high bar for new projects to meet!*
- Space: large detectors needed for low-flux / high-precision measurements, plus:
  - *Additional space for utilities e.g. liquid handling, purifications, cryogenics etc*
  - *Additional space for R&D, testbeds, demonstrators, component testing in the same environment*
- Timeline: space needs to be planned well in advance of deployment schedule!
- Location requirements: opposite sides of the Earth (matter effects), diverse locations to probe geo-ν flux

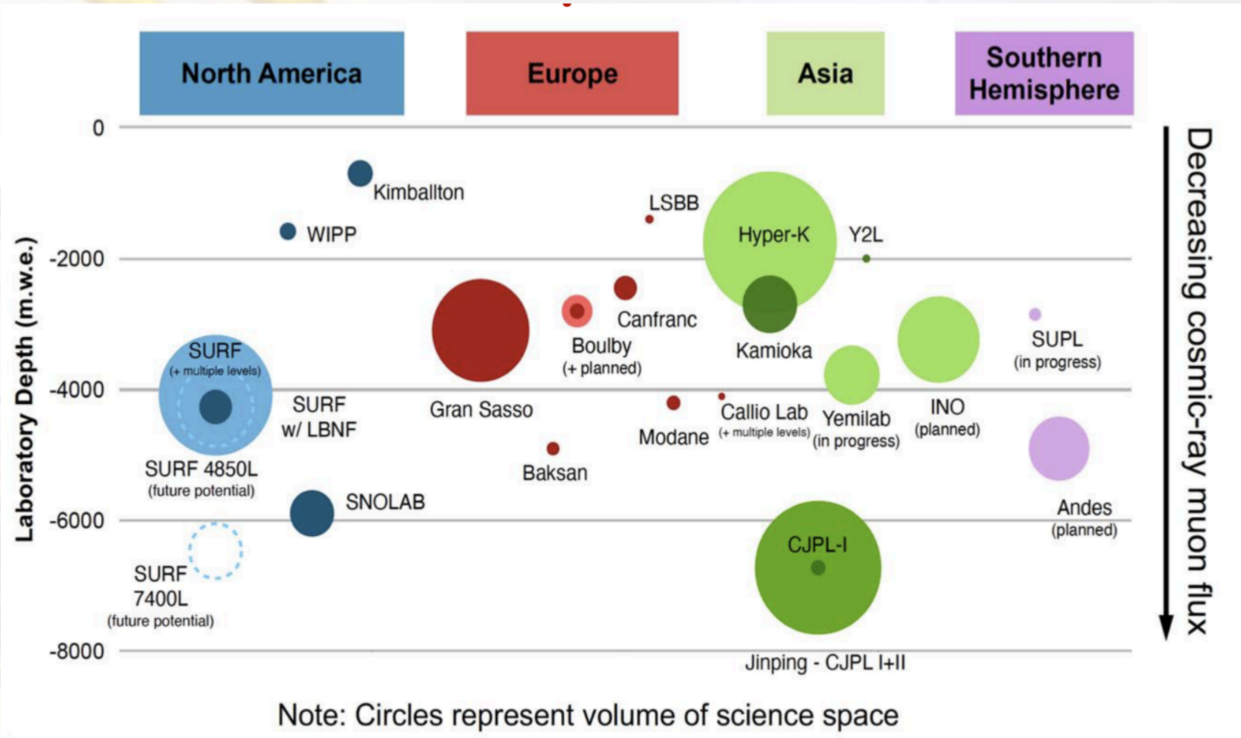
Neutrinos from Natural Sources

Needs and expectations for facilities

- Ongoing need for space for R&D, prototypes, demonstrators
- Need for new space for large detectors e.g.
    - THEIA's science program is substantially enhanced by accessing the LBNF neutrino beam at SURF—> Requires new space
- 35m GXe_{Nat} detector requires new space; about as big as super-K, + additional space for shielding and utilities
- R&D paths for the extraction, production and storage of Xe, and underground Ar, for large underground experiments is needed
- More location flexibility would enhance global geoneutrino programs
- Future development of techniques for measuring radio purity to improved levels
- Ongoing support for underground facilities for sample measurement
- Need for central coordinator of radio assay capabilities (most likely by a lab)
- Local support at the facility is often critical for success — many aspects of detector deployment are specific to a site, and require guidance and local expertise e.g. EH&S, fluid handling, shipping etc

Neutrinos from Natural Sources

- Greater precision requires larger / cleaner / more sophisticated detectors
- Each new discovery often opens up new pathways to explore: we can be confident in an ongoing need for access to clean UG lab space with good facility support
- International recognition of the need for these resources is illustrated by the breadth of international efforts to develop new facilities
- Must continue to support US efforts, as well as work with international partners



Snowmass 2021

Neutrinos from Natural Sources

- A broad range of cutting-edge science requires access to clean UG space
- Must plan space for the next decade+ of projects now
- Strong support for excavation of additional space at SURF for the next generation of physics discoveries
- Strong support for development of new, more sensitive radio assay techniques
- Suggestion for central coordination of radio assay facilities

Collective Needs

- Needs for data on activation databases (and radiopurity database)
  - Unified reference website for all labs
- Shared data and simulations
- Facilities for Radio-assays/Low-background counting
- Access for Equipment, Personnel
- Seismic safety requirements
- Supporting Facilities
- Lab accessibility

- Broadening participation/access to underground facilities for users from smaller/less-resourced institutions?
- Public and community engagement on underground science/public awareness and support of tax-funded facilities, emphasis on communication of the purpose?

Summary

- To maintain the full scientific potential of the complimentary HyperK and DUNE experiments, DOE, international partners, DUNE, SURF, and other stakeholders must develop a clear and transparent plan to optimize the total scientific return on the substantial US investment in SURF.
- The detection of neutrinoless double-beta decay remains one of the most sensitive probes of neutrino properties and the Majorana nature of the neutrino mass. The community must begin planning now to accommodate the depth, space, and infrastructure requirements for experiments beyond the tonne-scale.
- Neutrinos from natural and astrophysical sources are a rich source of information from otherwise inaccessible systems. Pursing the discovery potential requires access to clean underground space and planning now to address needs beyond the current Snowmass cycle.

Part II: Discussion

- Feedback on Topical Report Drafts
- Questions
- Input/Comments