Underground Facilities for Cosmic Frontier (UF1)

T. Bolton, P. Decowski, D. Speller

Liaisons from Neutrino Frontier: A. De Roeck, G. Gann

(S. Hertel presenting)

Topics covered by UF1

- Facility needs for future neutrino research performed in underground facilities
  - Long-baseline neutrino facilities (LBNF/DUNE, Hyper-K)
  - Neutrinoless double beta decay
  - Facilities for measurement of neutrinos from natural sources (supernova, solar, atmospheric, background)

Long-baseline neutrino facilities

- The coming decade strategy is 'ballistic':
  - HyperK will begin its full program in ~2028
  - DUNE Phase 1 will start over 2028-2031 (excavation well underway)

- For the US program, upgrade/future strategy after this stage is under discussion.
  - Neutrino frontier science and DUNE planning will drive UF requirements
  - Decisions during this Snowmass period will impact the late 2020's and beyond

Laboratori Nazionali del Gran Sasso

Neutrinoless double beta decay facilities

- 0vbb is funded via DOE Nuclear Physics
- Challenges/considerations for 0vbb facilities for future experiments:
  - Space & Depth
    - Space is sufficient for this snowmass period
    - Depth requirements for next-next-gen 0vbb experiments under discussion.
  - Other key concerns for this community:
    - Cryogenic support for experiments
    - Storage, and assembly space
    - Cleanliness, Environmental Monitoring
    - Materials Assay
    - Underground cryogenic test space specifically for R&D
- Significant synergies with dark matter direct detection; test facility synergy with QIS

Neutrinos from Natural Sources

- Science Drivers:
  - Probe neutrino sources (stellar, geological, atmospheric, extragalactic, …)
  - Probe fundamental physics (N_{eff}, masses, flavor physics, new interactions, …)

- Underground facilities challenges/considerations:
  - Depth
  - Space
    - Large experiment hall
    - Additional space for utilities (liquid handling, purification, cryogenics, etc.)
    - Additional space for underground cryogenic facilities for R&D
  - Geo-neutrinos benefit from diverse locations

- Must plan space now for the next decade+ of projects

UF1 Summary

- UF1 studies facility needs for neutrino science
  - Long-baseline
  - 0vbb
  - Natural sources

- US HEP is investing in long-baseline neutrino science
  - DUNE, located at SURF, will be occupying underground space for the next decade+

- Future neutrino experiments beyond the 2020’s will require advanced planning

Underground Facilities for Cosmic Frontier (UF2)

J. Cooley∗, S. Hertel, H. Lippincott∗, K. Ni, E. Pantic
∗Liaisons from Cosmic Frontier

Snowmass 2021

Snowmass CSS 2022

Topics covered by UF2

- Facility needs for future cosmic frontier research performed in underground facilities
- Primarily support direct detection dark matter
    - Noble Liquid Detector Experiments
    - Cryogenic Bolometer Experiments
    - ‘Other’ Dark Matter Detection Technologies

Facilities for noble liquid detector experiments

- Physics
  - Primary motivation: GeV-TeV mass DM via nuclear recoils
  - Sensitivity to *many* other other physics questions (sub-GeV DM via ionization-only, ER & migdal, solar neutrinos (both NR and ER), 0vbb, solar axions, hidden photons, etc.)

- Future Projects at planning stage
  - Liquid Xenon: a 50-100t observatory XLZD consortium (2028-2033, from CF1)
  - Liquid Underground Argon: a 300t observatory ARGO (2030-2035, from CF1)

- Future Projects at concept stage:
  - DarkSide-LowMass, (1.5t scale detector)
  - ALETHEIA (LHe TPC)

Facilities for noble liquid detector experiments

Challenges in moving to larger scales (I)

- Large Caverns
  - Experiment cavern
  - Underground staging caverns
    - e.g. large underground space for gas storage to avoid cosmogenic activation
- Experiment assembly underground
  - Current generation: Assembled in dedicated low-radon cleanroom, transported underground and installed in clean sealed state
  - Future larger experiments: increased underground assembly needs+efforts
    - Large underground low-radon clean room assembly/staging areas
    - Cranes and vertical space.
    - etc.

Facilities for noble liquid detector experiments

Challenges in moving to larger scales (II)

- Heat removal and vertical space for circulation/distillation
  - Heat output from experiment cooling and gas circulation loop
  - Online distillation column (for removal of Radon and other noble radioisotopes)

- Extreme cryogen safety/precautions
  - Human safety (asphyxiation etc.)
  - Enormous expense of target gas itself

- Handling of neutron-veto scintillators (Gd-doped LS or water, others)
  - Not all the underground labs are allowing usage of liquid scintillator,
  - Alternatives include Gd-doped water and liquid argon veto (neutron tagging efficiency to be demonstrated in the current generation experiments)

Related: Facilities for large bubble chambers

Three such experiments being planned:

- PICO-500
- PICO-5T
- Scintillating Bubble Chamber (ton-scale)

Target liquid at pressure and in a superheated metastable state

Similar to standard noble liquid experiments, in that pressure vessel and cryogenic safety topics require host lab input and interaction.

Snowmass 2021

Modane Underground Laboratory

Snowmass CSS 2022

Facilities for cryogenic bolometer experiments

- Low-mass DM (keV < m_{DM} <GeV) is growing in importance/visibility, we expect modest growth in the number of cryogenic bolometer experiments

- Change in philosophy: Some R&D requires an underground site
  - Traditional strategy: first complete R&D above ground, then deploy underground
  - Current/future considerations:
    - Low-rate 'heat-only events' from instrumental effects better constrained in quiet environment
    - Colder experiments can slower phonon timescales, pileup-limitations above ground
  - Two models for enabling this underground R&D:
    - Earlier deployment of experiment fridge for specific experiments
    - Shared shielded/underground User Facilities are one model to enable this R&D

- Shallow-underground facilities with QIS and CF synergies developing

Canfranc Underground Laboratory

Facilities for cryogenic bolometer experiments

- Comparatively small in facility footprint, but comparatively sensitive to facility environmental factors
  - Typically based around 3He/4He dilution fridge + shielding/veto
- Facility considerations:
  - Vertical Height: Ceiling height of >4m (for off-the-shelf DF geometries)
  - Depth/overburden: Highly experiment-specific
    - Depends on detector backgrounds (aka 'dark counts', aka 'heat-only excess', area of active R&D)
  - Floor vibration: Highly experiment-specific…
    - roughly <10^-7 g/sqrtHz at all frequencies
    - Some mitigations possible (e.g. seismic platform for SuperCDMS)
  - E&M environment: Highly experiment-specific …
    - Extreme sensitivity to both signals and background noise
    - Sources include facility utilities (power, air handling, lighting, etc.) and also neighboring experiments
    - Mitigation via filtering + faraday cage, again adds design complexity
    - DC magnetic field at <100μT (typical earth field, looser requirements after cooldown is complete)

Laboratori Nazionali del Gran Sasso

Facilities for other technologies

- Other DM detection technologies:
  - Skipper CCD (OSCURA)
  - Point-contact Ge (CDEX-100)
  - Low-pressure gas detectors (directional detectors, CYGNUS)
  - Scintillator (SABRE, COSINE-200, others)
  - Superheated water (SNOWBALL)
  - others!

- All of these technologies are (for now) relatively compact in footprint and relatively robust to lab environmental factors

Comments in common to all experiments (Both UF1 & UF2)

Robust onsite **computing** and network infrastructure

Robust **utilities** such as electrical power, cooling power, etc.

Lab **accessibility** for all scientists

Emphasizing **UF4**: Underground material assay facilities are essential. Underground material production, machining, purification, distillation, etc. *can* be essential for specific experiments.

Obvious, but needs mentioning: **facility personnel** are hugely important (Management, engineering, EH&S can all make or break an experiment)

Snowmass 2021

Snowmass CSS 2022

US HEP Cosmic Frontier Underground Program

Current Program:

G2: SuperCDMS , LZ

Dark Matter New Initiatives: TESSERACT , OSCURA

Cosmic Frontier science priorities will drive experiments beyond mid-2020s

Underground facility development is required prior to experimental construction

Kamioka

New Underground Spaces

Possible but *temporary* occupancy of LBNF cavern space (prior to full DUNE)

- Space: Detector caverns at SURF 4850 level (24m width, 28m height)
- Schedule: Outfitting ends May 2024 , subsequent DUNE occupancy date under discussion

SURF is advocating for additional excavation, starting immediately after LBNF excavation

- Cost savings due to already-deployed machinery, personnel, etc.
- Proposals at both 4850 and 7400 foot levels
- Schedule: Excavation could begin ~2027, completed by ~2030.
- See SURF Long-Term Vision Workshop, Sep. 2021 (https://indico.sanfordlab.org/event/26/)

SNOLAB also has proposals for significant expansion

- Proposals for both for gas storage space (e.g. for ARGUS project) and experimental space.
- Conceived as two expansions, requiring 5y timescale each.
- Intermediary storage for the fraction or all of ARGUS 400t of underground argon possible at the lesser depths.

UF2 Summary

- Multiple new DM experiments are expected and being planned, while facilities are currently 'full'. Clear need for additional underground space, tailored to needs beyond the late 2020s

- This underground space should specifically include
  - Both large spaces for large experiments (liquid noble) and small spaces for smaller experiments (cryogenic bolometer, 'other')
  - Large radon-free clean rooms for detector assembly and installation for the next generation experiments
  - Large areas for staging (e.g., gas storage) and experiment utilities (e.g. pumps, distillation)