The Sanford Underground Research Facility

Jaret Heise, Science Director
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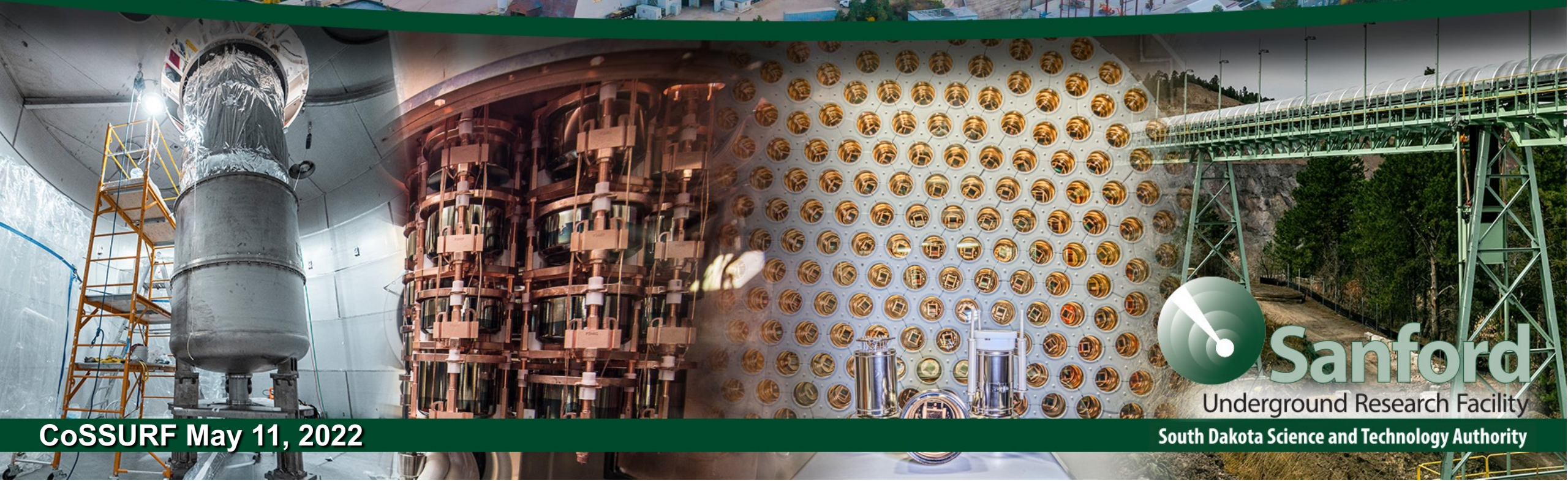


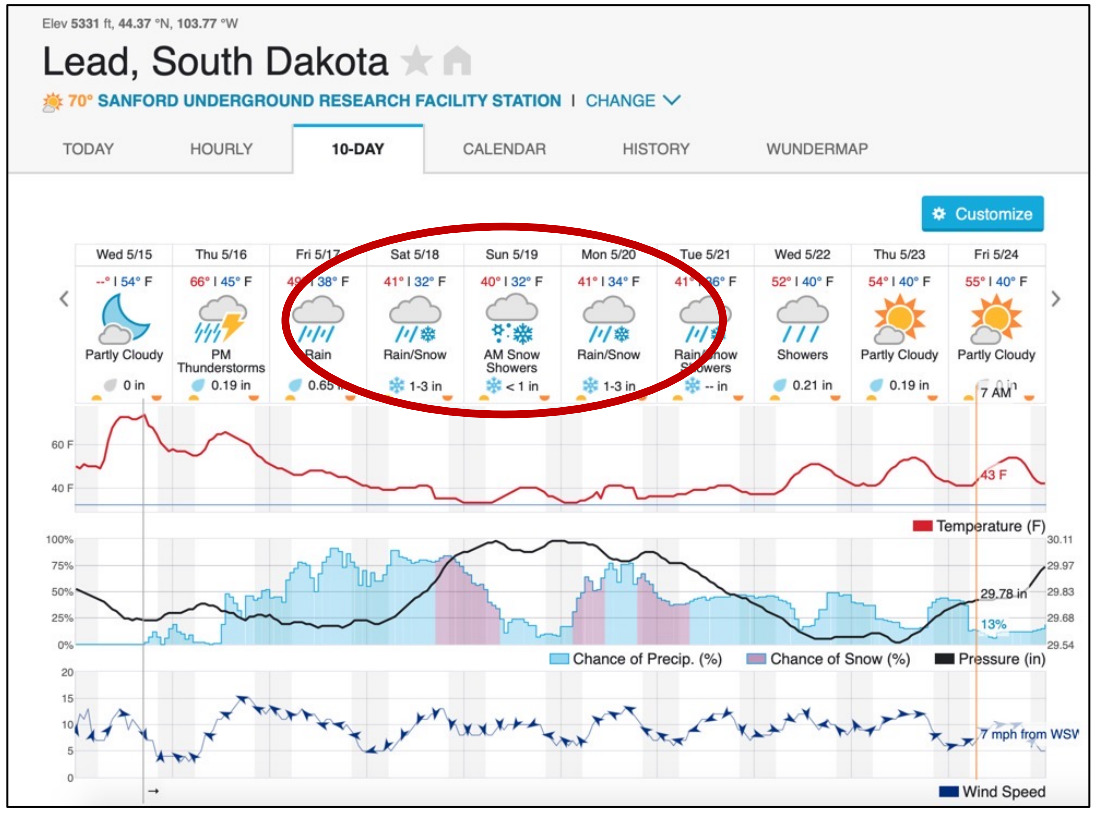
Sanford
Underground Research Facility
South Dakota Science and Technology Authority

CoSSURF May 11, 2022

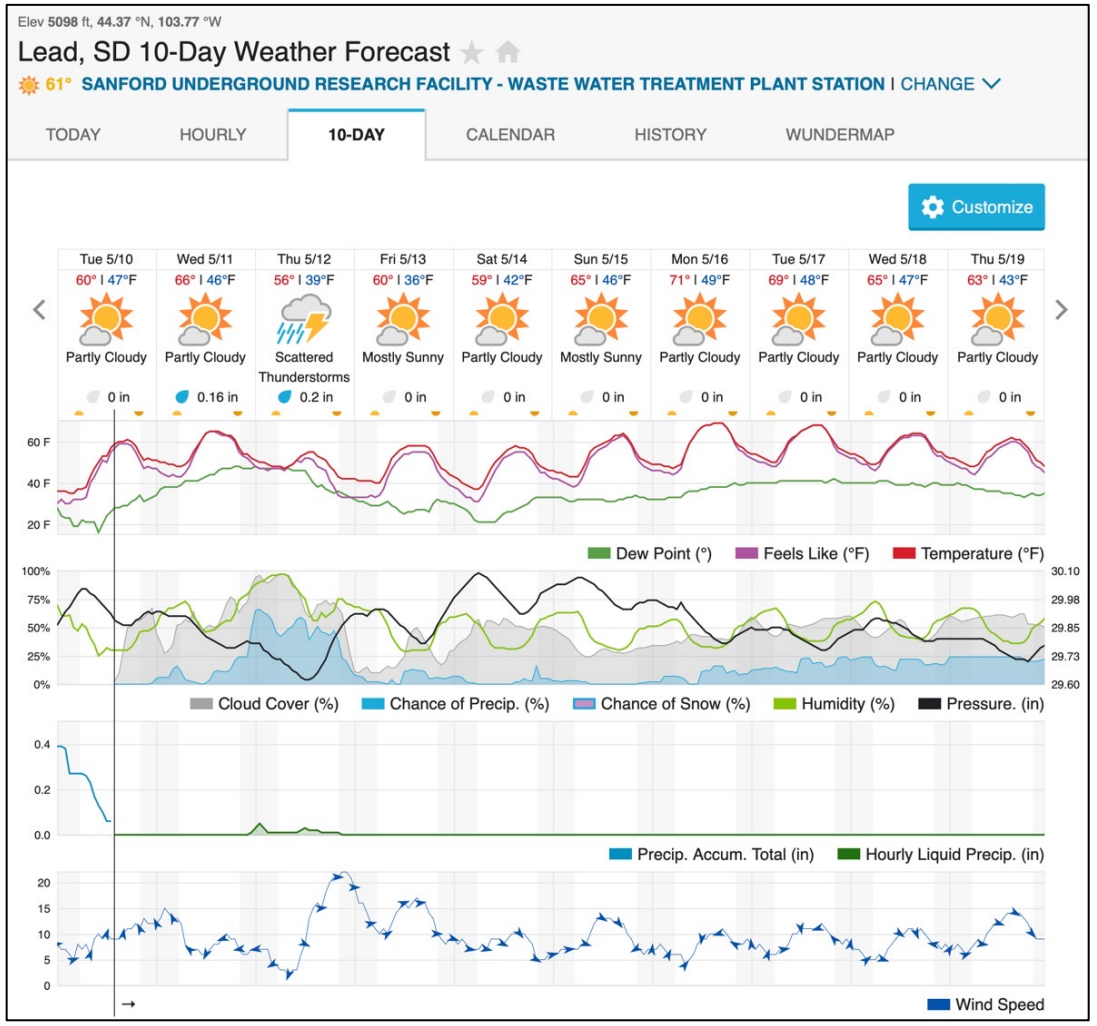
Sanford Underground Research Facility

Welcome to South Dakota!

CoSSURF 2019



CoSSURF 2022 – No snow!



Sanford Underground Research Facility

SURF Mission:

We advance world class science and inspire learning across generations.

SURF Vision:

The world's preferred location for underground science and education.

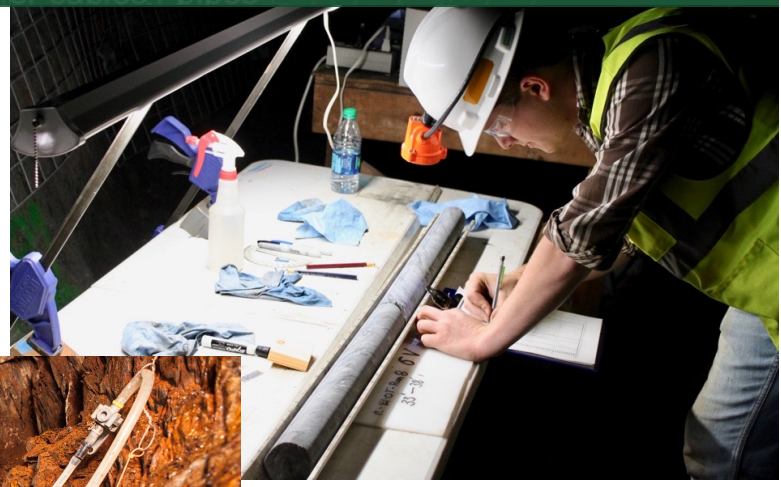
SURF serves the entire underground science community.

SURF welcomes and encourages research from all disciplines that are able to take advantage of the unique attributes of our laboratory.

Underground Facilities

UG Facilities serve a diverse community:

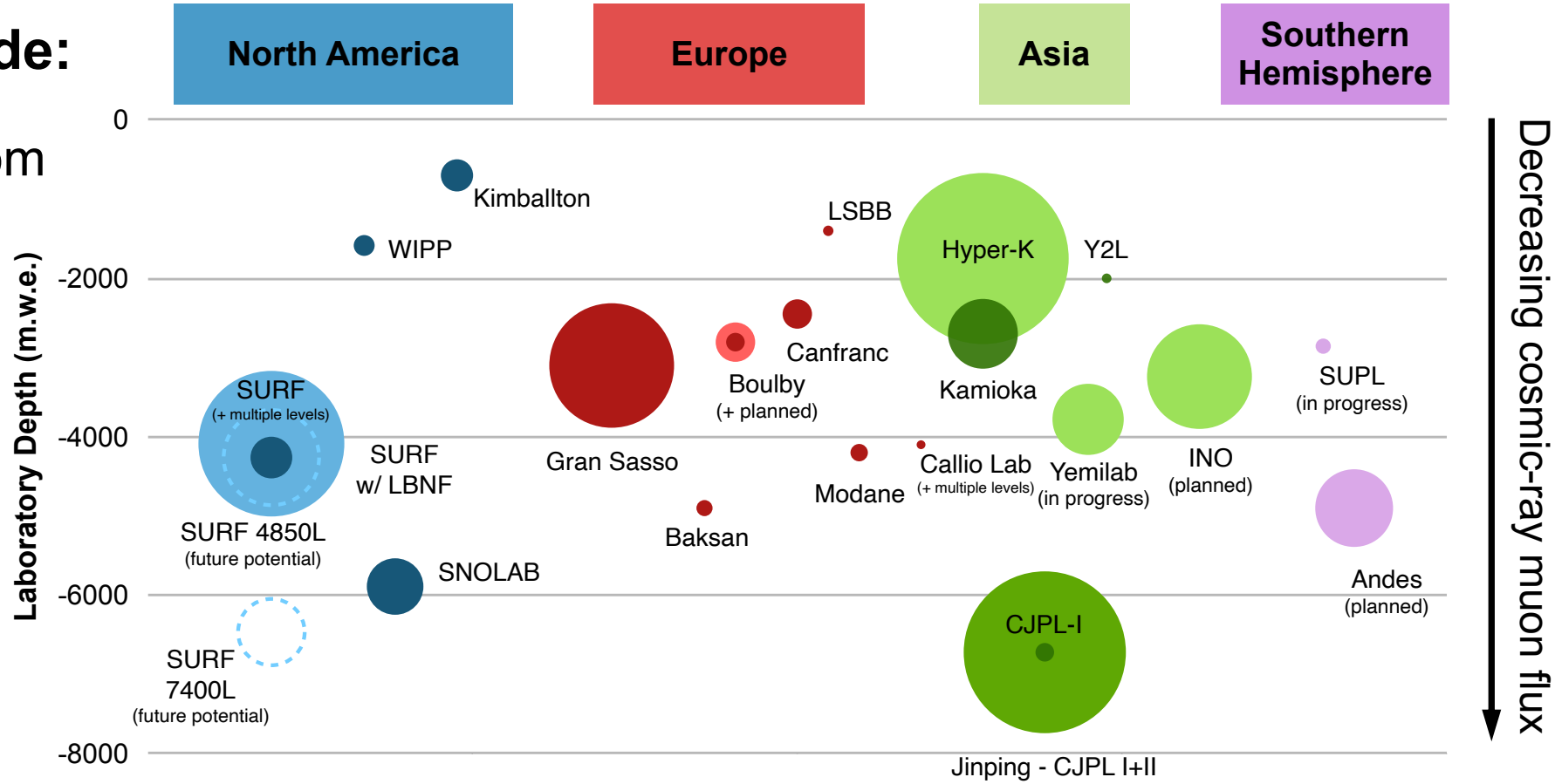
- Physics
  - Low-background environment to study rare processes
- Biology
  - Isolation from surface microorganisms
  - Variety of environmental conditions (temperature, humidity, etc)
  - Variety of niches (materials/rock geochemistry, water from different locations, trace gases, etc)
- Geology
  - Variety of geologic environments / rock formations (permeability, porosity, chemistry); also drill core archive
- Engineering
  - Real-world environments for technology development, mining, etc



Underground Facilities

UG Facilities can provide:

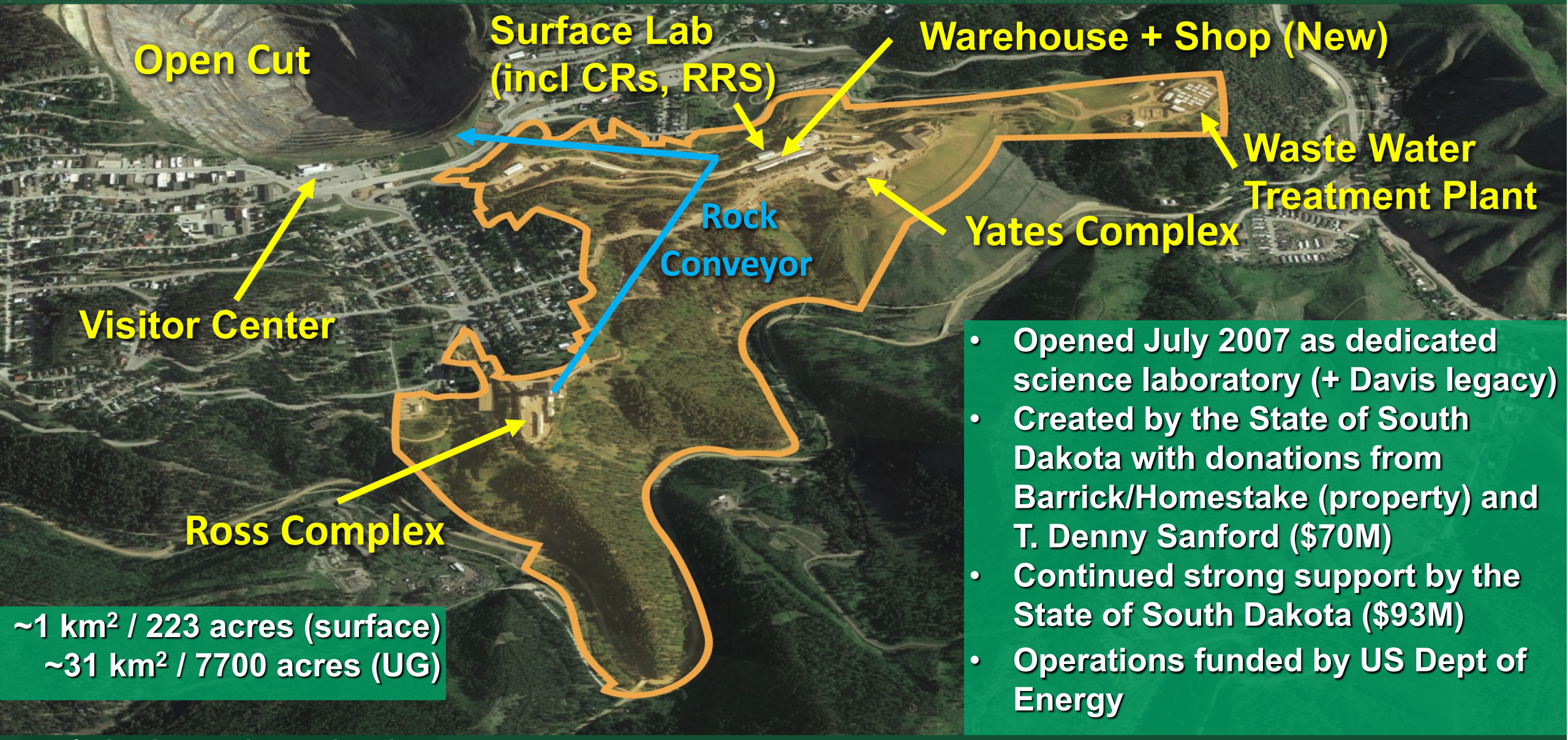
- Overburden protection from cosmic-ray muons
- Local radiation shielding
- Material screening
- UG material production or purification
- Environmental control
- Implementation and operations support



Note: Circles represent volume of science space

Sanford Underground Research Facility

Nation's underground lab to advance multi-disciplinary research

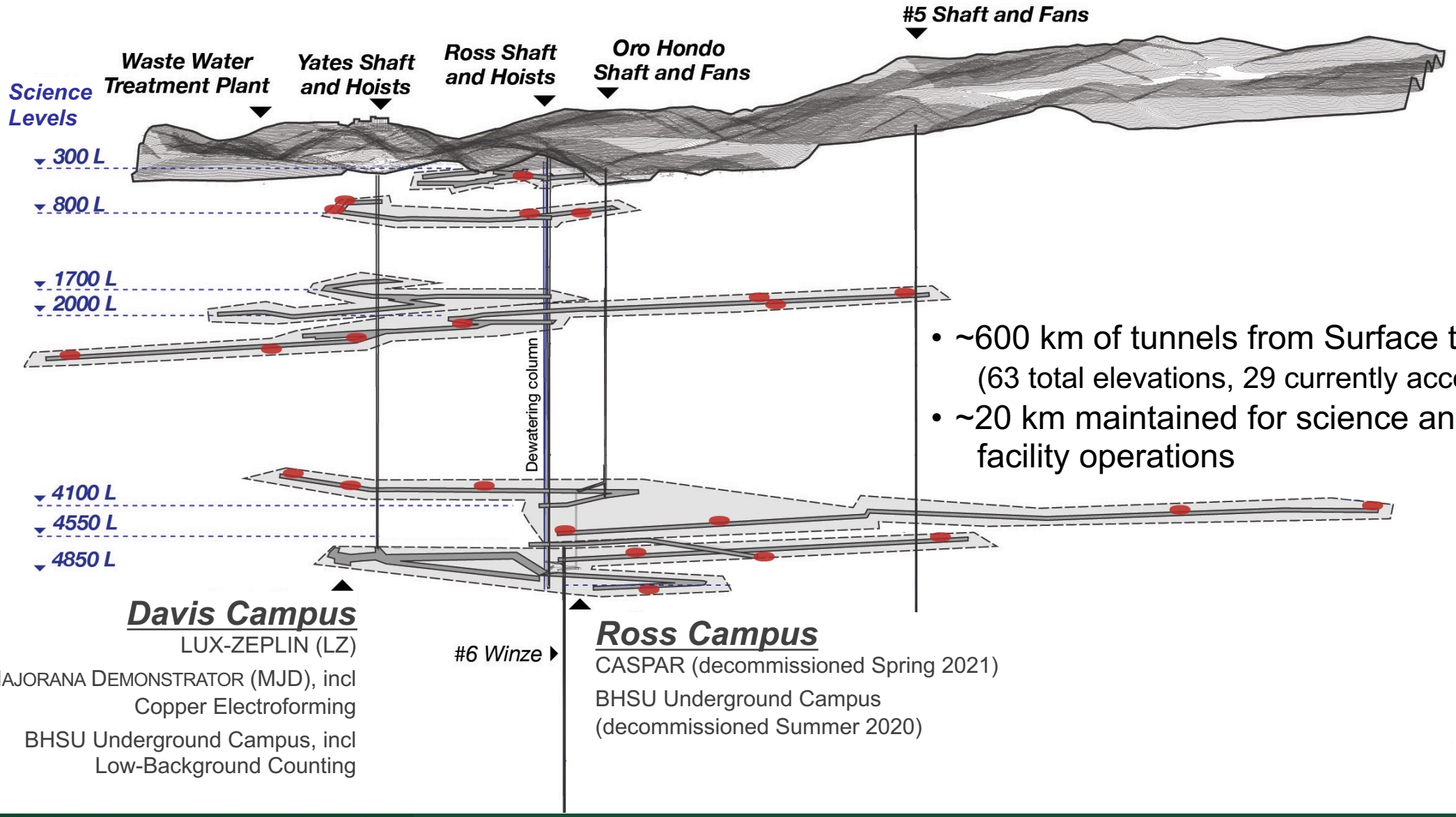


~1 km² / 223 acres (surface)
~31 km² / 7700 acres (UG)

- Opened July 2007 as dedicated science laboratory (+ Davis legacy)
- Created by the State of South Dakota with donations from Barrick/Homestake (property) and T. Denny Sanford ($70M)
- Continued strong support by the State of South Dakota ($93M)
- Operations funded by US Dept of Energy

SURF Underground Lab Geography

Yates & Ross + ventilation shafts, multiple levels for science



- ~600 km of tunnels from Surface to 2.4 km deep
  (63 total elevations, 29 currently accessible)
- ~20 km maintained for science and facility operations

Davis Campus

LUX-ZEPLIN (LZ)

MAJORANA DEMONSTRATOR (MJD), incl Copper Electroforming

BHSU Underground Campus, incl Low-Background Counting

Ross Campus

CASPAR (decommissioned Spring 2021)

BHSU Underground Campus (decommissioned Summer 2020)

SURF Overview

Expanding community of researchers from multiple disciplines

Facility Highlights

- **World-class services** and **unique attributes** attractive to physics, biology, geology and engineering
- **Deep** (1500 m, 4300 mwe) underground facility **dedicated** for science, with **capacity** & **expansion** possibilities (SURF strategic plan incl additional laboratories and deeper access to 2300 m, 6500 mwe)
- **Redundant** safe access with 2 principal shafts (incl redundant **power** and **network** utilities)
- **Robust Organization:** Resources to ensure safe and successful science: ~200 full/part-time staff, 11 departments such as Environment, Safety & Health (incl nurse, 24-hr emergency response), Engineering, Operations, Science + others
- **Mature Programs:** Experiment implementation, safety, operations; also monitoring
- **Community:** SURF **User Association** launched in 2020, SURF **Science Program Advisory Committee** established in 2021. Both groups support upcoming SURF application to become DOE Office of Science **User Facility**

SURF Supports Science

Robust organization and resources to ensure safe and successful science

Markus Horn (PhD)
Research Scientist
- Surface + UG Campuses

Charles Maupin (BSME, PE)
Expt Review Engineer
- Reviews, cryogen safety

Jaret Heise (PhD) – *Director*
- Manage dept and experiment implementation program

Mark Hanhardt (MS)
Expt Support Scientist
- Surface + UG Campuses

David Rynders (CHP, CSP)
Expt Health & Safety
- Health physics, radiation

T. Regan, G. Vandine
Safety, UG Coordination
- Biology/geology (no pic)

J. Connot, Others
UG Operations Eng,
UG Maintenance Crew
- Ventilation, prep (no pic)

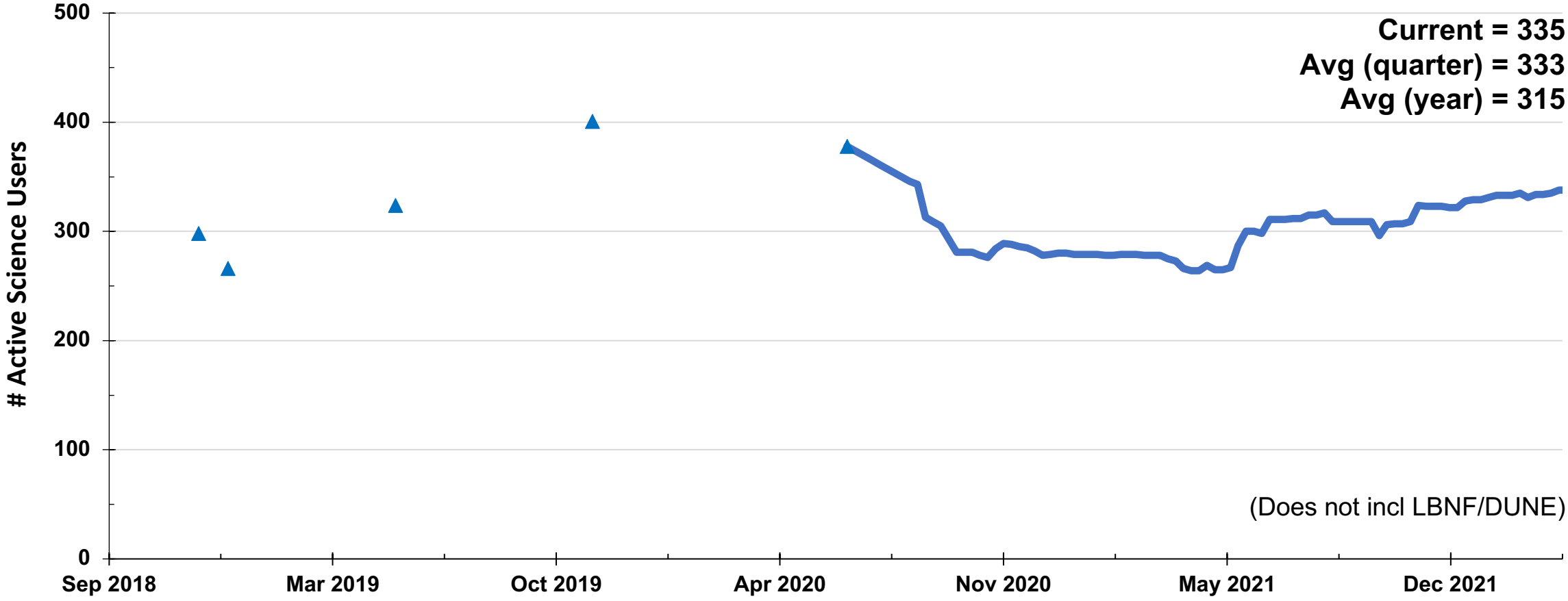
Robyn Varland - *Lab Custodians (Surface + UG)* - Melissa Johnston

Doug Tiedt (PhD)
Research Scientist
- Surface + UG Campuses

Sarah Wortman (+ Service Contracts)
Facilities Technician
- Surface + UG lab system maintenance

SURF Science – By the Numbers

29 Experiments with **569** Collaborators involving **87** Institutions in **9** Countries
335 Onsite Science Users [Current]
650-700 Onsite Science Users [2007-present]



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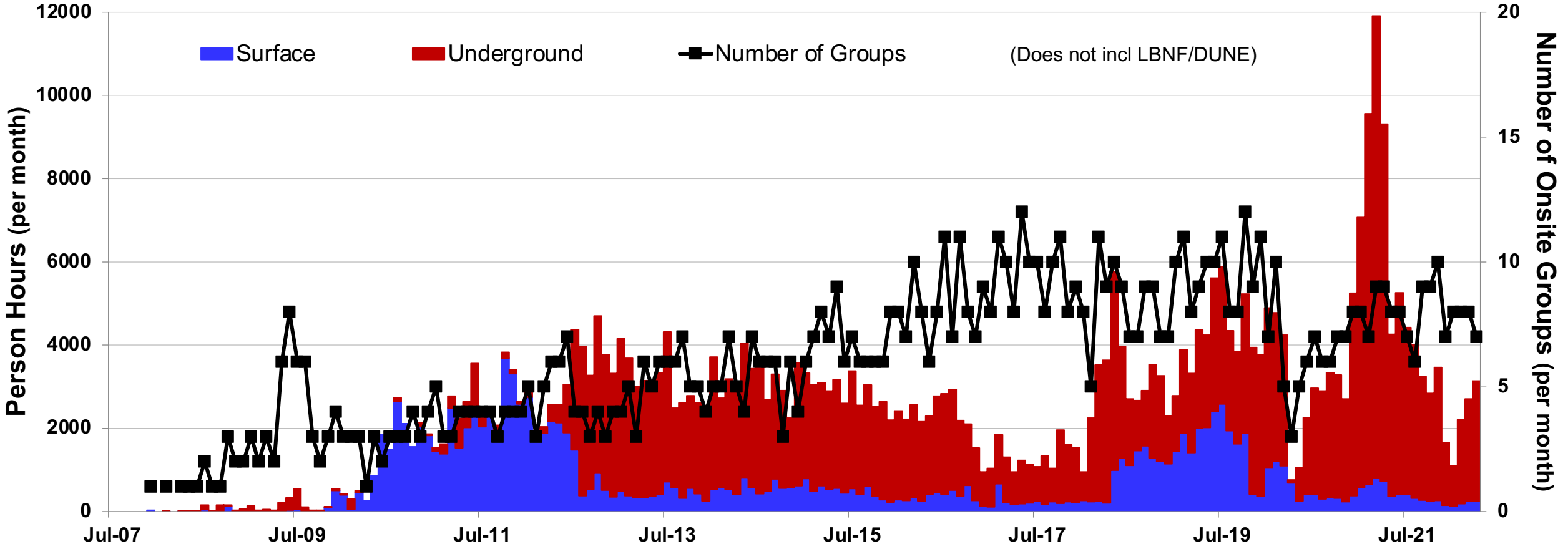


SURF Science Program

Research activities ranging from the surface to 1500+m underground

Physics

LZ – *Dark matter, 2-phase Xe TPC*

MAJORANA DEMONSTRATOR / LEGEND – *Neutrinoless double-beta decay, Ge-76, Ta-180m, also Cu e-forming*

CASPAR – *Nuclear astrophysics with 1 MV accelerator*

LBNF/DUNE – *Neutrino properties, etc*

BHUC – *BHSU Underground Campus, mainly material screening*

Berkeley LBF – *Low-bkgd counter (x3);* also CUBED – *Low-bkgd counter (x1)* *(possibly future Crystal Growth)*

nEXO – *Low-bkgd counter (x1)*

LLNL – *Low-bkgd counter (x1)*

SDSMT Bkgds – *Neutron bkgds*

Total = 29 groups

21 Active Projects

60 Total Groups Since 2007

Significant interest from others

(17 groups in 2021)

Biology

Astrobiology/DeMMO – *In-situ cultivation, DNA isolation*

2D Best – *Biofilms*

Biodiversity – *Microbial communities*

Biofuels – *Extremophile bioprospecting*

BuG ReMeDEE – *Methane oxidation*

Carbon Sequestration – *Biology in core*

Chemistry – *Env characterization*

Liberty BioSecurity* – *Extremophiles*

Geology

SIGMA-V – *Geothermal*

3D DAS – *Seismic monitoring using fiber*

Core Archive* – *Mainly gold deposits*

Hydro Gravity – *Gravity for water tables*

BH Seismic – *Global monitoring*

Transparent Earth – *Seismic arrays*

Engineering

Xilinx, Inc* – *Chip error testing*

Thermal Breakout – *In situ stress*

Shotcrete – *Mining safety*

GEOX™ – *Env monitoring*

Caterpillar* – *Mining processes*

Blast Monitoring – *LBNF-related*

* Denotes proprietary group

SURF Science Program – Current Highlights

Strong and diverse program with exciting future

- **LZ:** Direct search for **dark matter** using 10 tonnes xenon within ultra-pure water shield + Gd liquid scintillator veto

  Status: Liquid scintillator fill complete. All purified Xe UG, condensing and commissioning complete. WIMP search started in 2021, first results expected in 2022, run for 5 years.

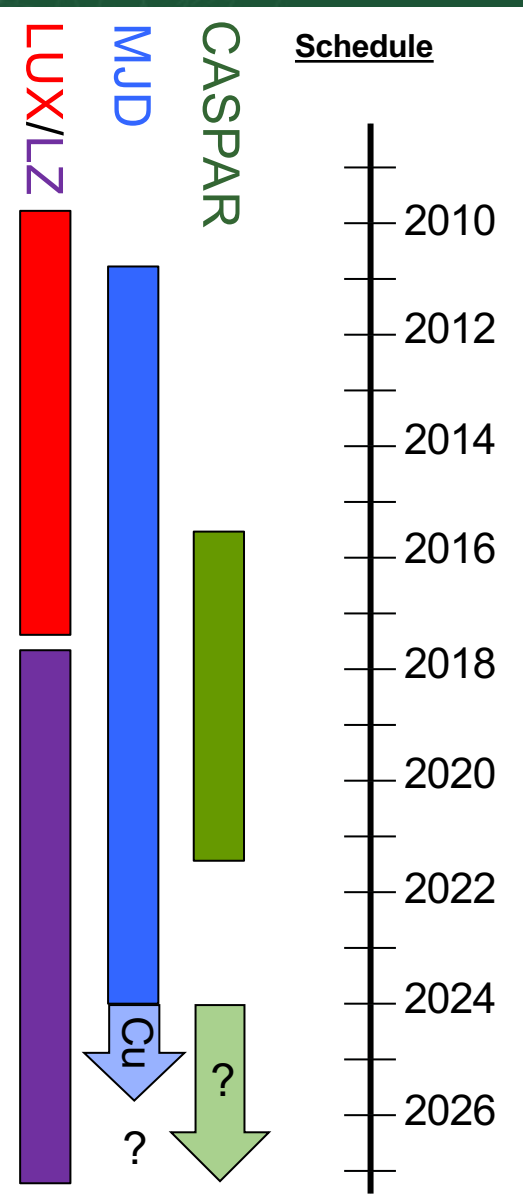
- **MAJORANA DEMONSTRATOR:** Investigate **neutrinoless double beta decay** using 44 kg Ge in two cryostats, 30 kg enriched ^{76}Ge inside multi-layer compact shield

  Status: Data 2015-2021 (exposure goal achieved). Bkgd studies underway with 23 natural Ge detectors. Ultra-pure electroformed Cu production continues, also LEGEND detector characterization and R&D. Rare decay search ^{180m}Ta underway, complete in 2023.

- **CASPAR:** Study of stellar nuclear fusion reactions, esp. neutron production for **slow neutron-capture nucleosynthesis** using 1-MV accelerator

  Status: Beam operation 2017-2021, targets incl ^{14}N, ^{11}B, ^{27}Al, ^{22}Ne (gas), ^{18}O, ^{7}Li, ^{20}Ne, ^{22}Ne (solid). Planning next phase.

- **BHUC:** 5x **low-bkgd assay** counters operating (~10s ppt sensitivity)



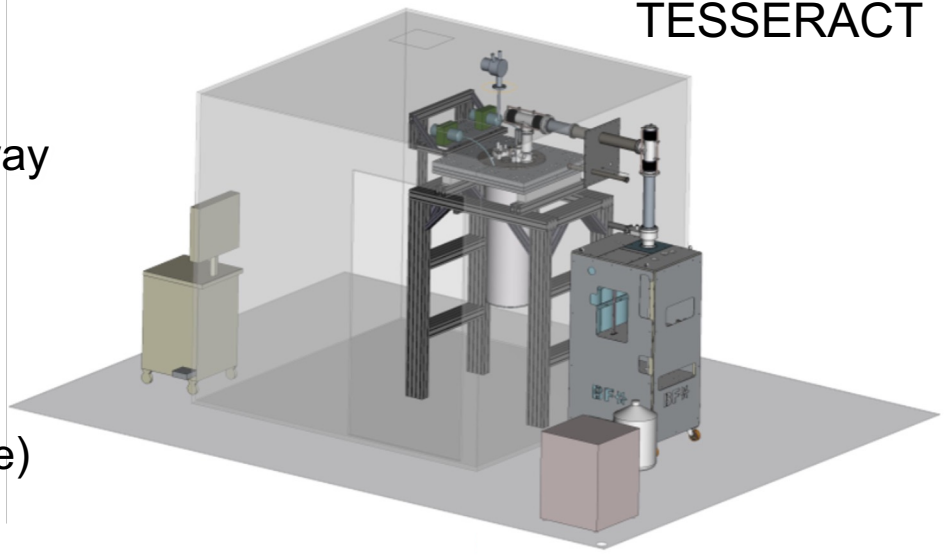
SURF Science Program – Planned / Future

Shorter term

- **CASPAR**
  - Optimize existing accelerator to compliment global UG accelerator program. Restart timeframe ~FY24

- **Low-Mass Dark Matter**
  - Transition Edge Sensors with Sub-EV Resolution And Cryogenic Targets (**TESSERACT**)
    - Targets proposed incl Al_2O_3, GaAs, LHe. Shielding design underway
    - Nominal space identified at Davis Campus
    - Annual DOE reviews (latest in Jun 2021), installation timeline ~FY24-25 (funding driven)
  - Other Dark Matter: Possibly using SDSTA Xe after LZ (e.g., **Hydro-X** using hydrogen dissolved in Xe or **CrystaLiZe** solid Xe)

TESSERACT



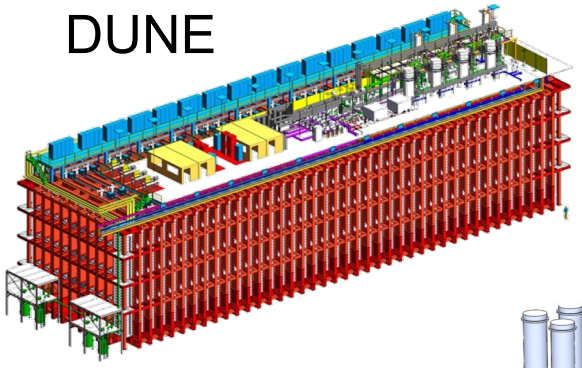
- **Others**
  - Geothermal proposals that take advantage of **EGS** investment (proposals submitted); recent visit by DOE Office of Science Basic Energy Science-Geosciences program manager.
  - *Quantum Information Systems (QIS)?*
  - *Industrial partnerships?*

SURF Science Program – Planned / Future

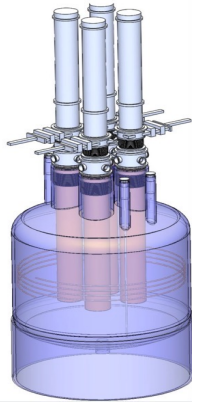
Longer term

- DUNE: 4x 10 kT LAr detectors with wire planes for **neutrinos** (**CPV, MH, SN, proton decay**, etc), excavation complete in 2024, science starts 2029; possible “module of opportunity”
- Neutrinoless Double-Beta Decay (100T-Scale): Investigate **neutrino properties** using ~100-tonne enriched isotope, inverted hierarchy coverage
- Dark Matter (Generation-3): Search for WIMP **dark matter** to neutrino background “floor/fog” using ~50-100 tonne Xe (or other target)
- THEIA: Water-based liquid scintillator using LBNF beam to investigate **neutrino** properties (**CPV, MH, CNO, DSNB**, etc)
- Others:
  - *Vertical facility? (atom interferometry, n-nbar, cloud formation, combustion, etc)*

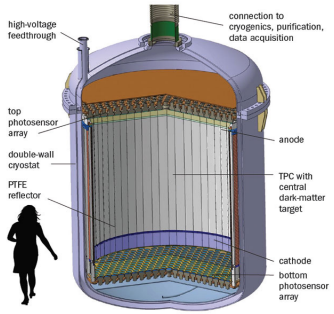
DUNE

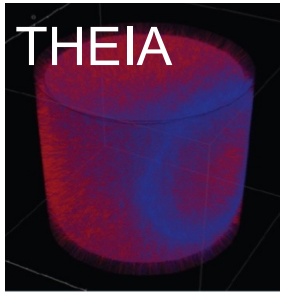


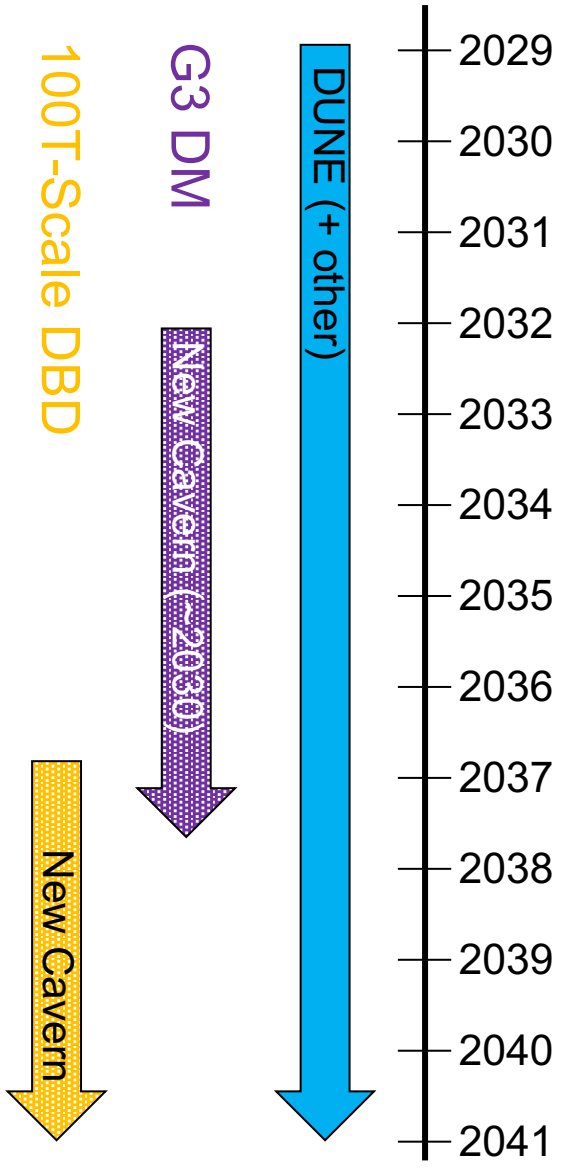
100T-Scale DBD



G3 DM

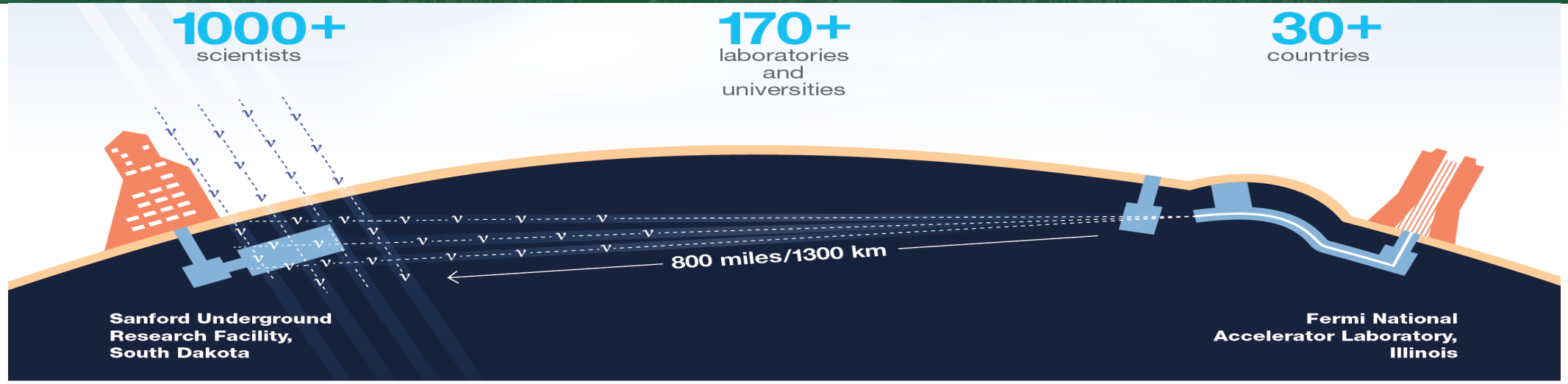






Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)



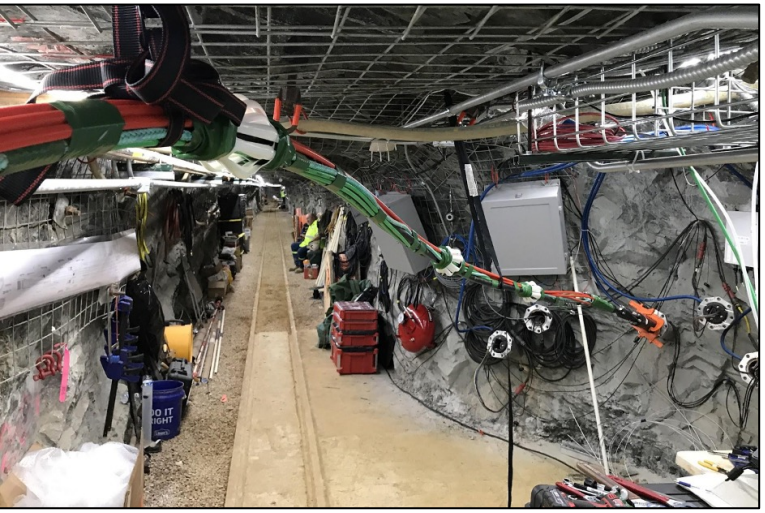
- First internationally conceived, constructed, and operated project hosted by the Department of Energy in the United States. Significant **international** contributions (incl CERN).
- Two detector caverns to host 4 detectors (total of 70 kT/50M liter liquid argon) + utility cavern.
- **Reliability projects** rehabilitated some key SURF infrastructure 2016 – 2020.
- **Pre-excavation construction** at SURF in Jan 2019 – Feb 2021. Transportation system for excavated rock operational (first rock to Open Cut May 2021).
- **Excavation** initial phase started Jun 2020, focused on ventilation. Main excavation phase (caverns, access) started Apr 2021 and will last ~3 years (drill & blast expected to complete by ~Oct 2023).
- **Infrastructure outfitting** and **cryostat construction** expected 2024-2027.

SURF Science Program

Biology / Geology / Engineering (Multiple Levels)

Life Science:

- Explorations into the diversity and extent of life, practical applications such as biofuels. Testing equipment for future Mars mission.
- **Status:** 800L, 1700L, 2000L, 4100L, 4850L.



Earth Science:

- Topics include seismic studies, UG monitoring, geothermal testing, mineral deposit studies
- **Status:** Surface, 800L, 1700L, 2000L, 4100L, 4850L.

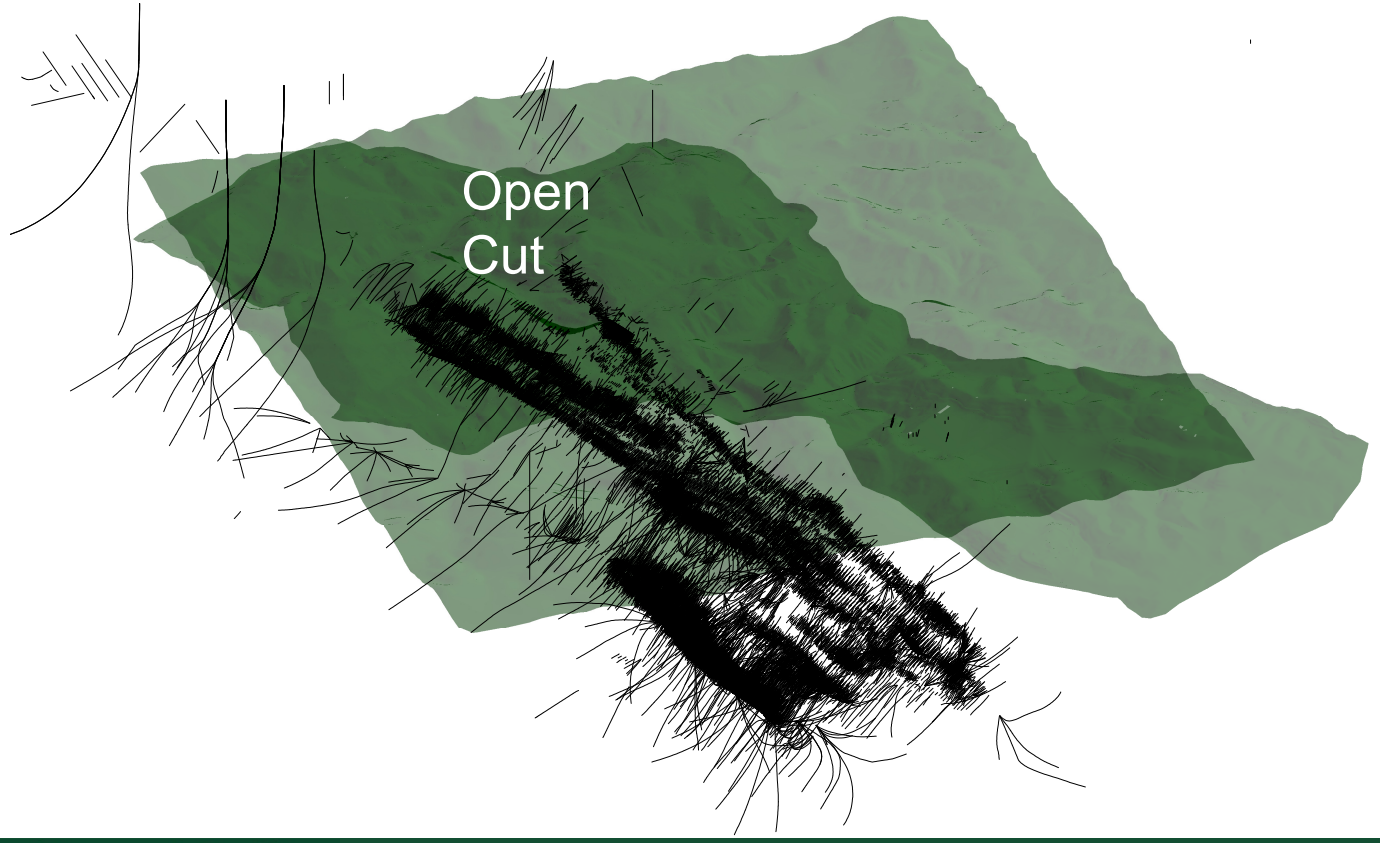
Engineering:

- Topics include soft error rate chip testing, thermal applications, UG hazard monitoring, reinforced shotcrete, technology R&D
- **Status:** Surface, 1700L, 4100L, 4850L.

SURF Science Opportunities – Drill Core

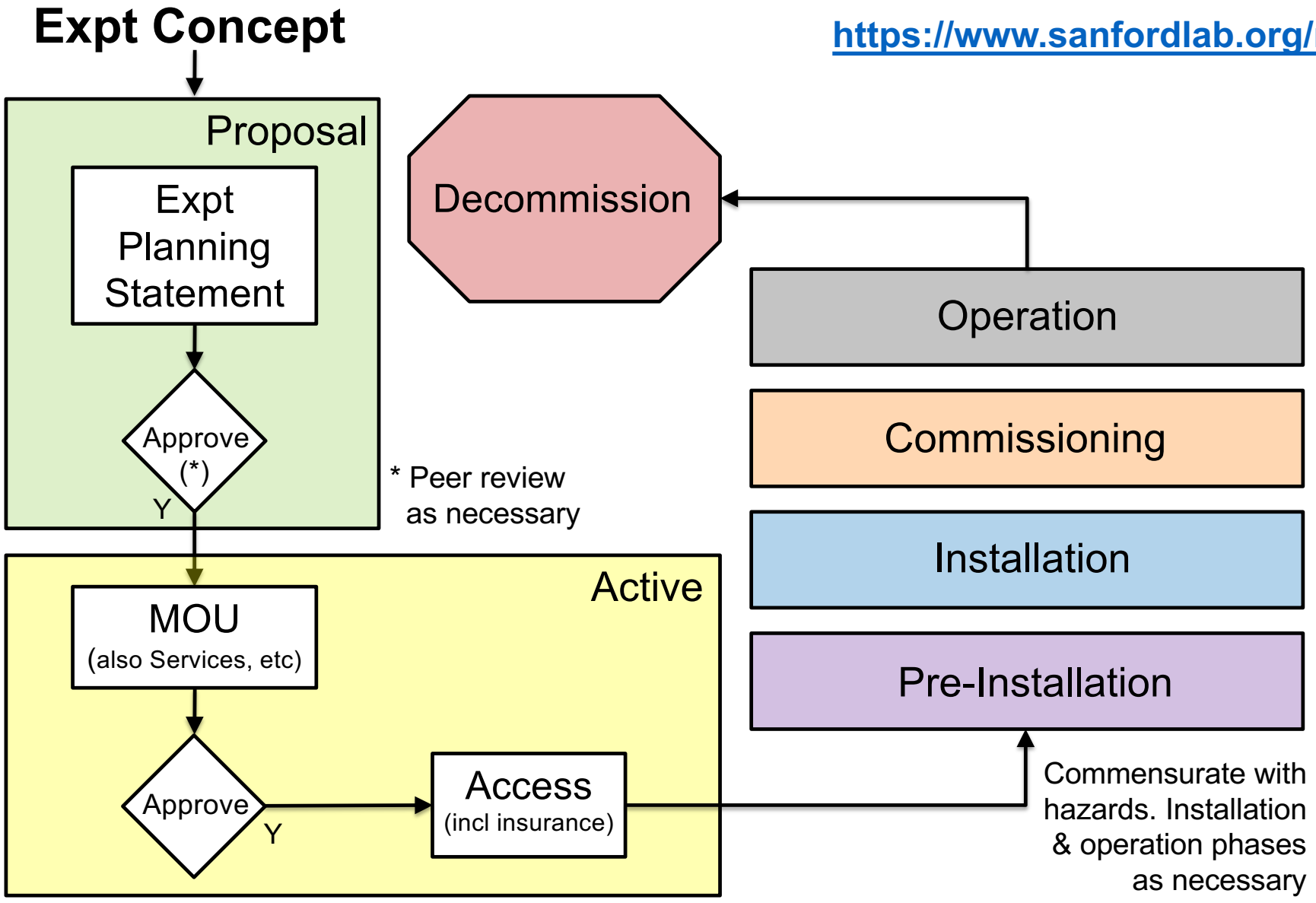
Core repository

- Total of 27,870 drill holes (+ others) on Homestake property
- Portion of core retained and donated to SDSTA: 39,760 boxes of core for 2,688 drill holes (91 km!), SDGS initial help with stewardship
- SDGS database with 58,000+ entries, representing 1,740 drill holes: http://cf.sddenr.net/homestake/

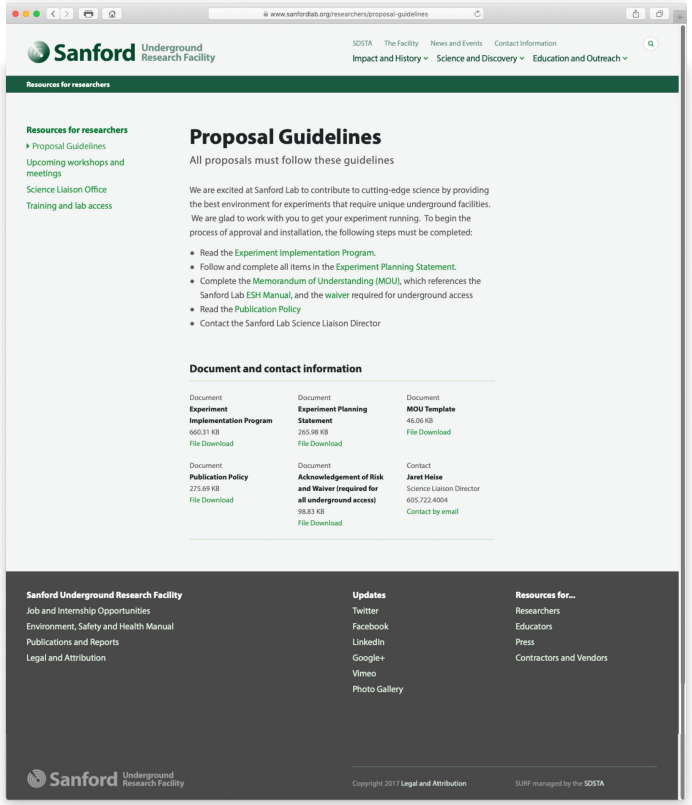


SURF Experiment Implementation Program

Identify interfaces and hazards within approval framework



https://www.sanfordlab.org/researchers/proposal-guidelines



SURF Science Guidance

SURF User Association

- Established Dec 2020: 9-10 members spanning breadth of SURF science: physics, biology, geology, engineering.
- Scope: reinforce two-way communication, foster sense of community, promote scientific case for UG science.
- SURF Long-Term Vision Workshop held mid-Sep 2021, very successful. Membership expansion underway.

1. Brittany Kruger (DRI/**Chair**)
2. Megan Smith (LLNL/**Secretary**)
3. Mark Hanhardt (SDSTA)
4. Kevin Lesko (LBNL)
5. Rachel Mannino (Wisconsin)
6. Ralph Massarczyk (LANL)
7. Sam Meijer (LANL)
8. Brianna Mount (BHSU)
9. Frank Streider (SD Mines)
10. Wenqin Xu (USD)

Also:

- SDSTA Board of Directors (SD Mines President *ex-officio*)
- SURF Strategic Advisory Committee
- SURF is looking to strengthen administrative and academic relationships with SD universities

Science Program Advisory Committee

- Established Sep 2021: 14 members, national & international experts spanning breadth of SURF science with strategic and synergistic influences.
- Scope: Review science program, support and facilities. Peer review per DOE User Facility.
- First meeting held Jan 2022, next meeting in 2022.

1. David MacFarlane (SLAC/**Chair**)
2. Ed Blucher (Chicago)
3. Derek Elsworth (Penn State)
4. Joseph Formaggio (MIT)
5. Hunter Knox (PNNL)
6. Magdalena Osburn (Northwestern)
7. Federica Petricca (Max Planck)
8. Lance Roberts (SD Mines)
9. Hamish Robertson (Washington)
10. William Roggenthen (SD Mines)
11. Kate Scholberg (Duke)
12. Barbara Szczerbinska (TAMU-CC)
13. Mary Voytek (NASA)
14. TBD

SURF Science Strategic Planning
Capabilities and future plans responsive to community's needs

- SURF 15-yr strategic plan addresses need for additional space
  - Several module options studied and designed over past decade+, 4850L well characterized (incl recent LBNF + other research efforts)
  - **4850L lab expansion** – Feasibility study completed Feb 2022, DOE-HEP briefed
  - **Surface assembly/staging** – Initial planning requirements complete

- SURF Long-Term Vision Workshop (User Association Sep 2021)
  - Very successful: 18 talks, 9 hours of presentations and discussions, 88 participants https://indico.sanfordlab.org/event/26/
  - Support for additional space for all disciplines, cavern dimensions appropriate for future experiments, possible new directions

- "Snowmass" (Physics HEP community planning/strategic planning)
  - Snowmass LOI submitted for Underground Facilities Frontier: https://www.snowmass21.org/docs/files/?dir=summaries/UF/
  - Snowmass whitepaper submitted for Underground Facilities Frontier: https://arxiv.org/abs/2203.08293

SURF Science Strategic Planning

SURF Snowmass whitepaper highlights

- SURF advocates for DOE panel recommendations:
  - Mission need for additional deep laboratory space (incl at depths > 6000 m.w.e.) in U.S. to support compelling future science
  - Mission need for a next-generation (~100 tonnes) dark matter and neutrino observatory in U.S.
  - Develop a process for allocating temporary use of a LBNF module ("module of opportunity")
  - Endorse value of multi-disciplinary underground science at a dedicated laboratory in U.S.
- SURF proposing additional underground space:
  - 4850L (1500 m, 4300 m.w.e), 7400L (2300 m, 6500 m.w.e.)
  - Initial engineering designs completed
  - Excavation for 1x 100-m cavern could begin as early as 2027 and take ~2.5 yrs (incl mobilization/de-mobilization)
- Other:
  - Operational details (incl conveyance specs, storage/staging, etc)
  - Ross Campus occupancy resuming FY24

The Sanford Underground Research Facility

J. Heise

630 East Summit Street, Lead, SD 57754 USA

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Executive Summary

The Sanford Underground Research Facility (SURF) has been operating since 2007 supporting underground research in rare-process physics, as well as offering research opportunities in other disciplines. SURF laboratory facilities include a Surface Campus as well as campuses at the 4850-foot level (1500 m, 4300 m.w.e.) that host a range of significant physics experiments, including those studying dark matter, neutrino properties, and nuclear astrophysics topics. SURF is also home to the Long-Baseline Neutrino Facility (LBNF) that will host the international Deep Underground Neutrino Experiment (DUNE). SURF offers an ultra-low background environment, low-background assay capabilities, and electroformed copper is produced at the facility. SURF is proposing additional underground space on the 4850L and 7400L (2300 m, 6500 m.w.e.), and initial engineering designs have been completed. SURF is a dedicated research facility with significant expansion capability, and applications from new experiments are welcome.

As the nation's primary underground laboratory and based on input from the underground science community, SURF advocates for the following Snowmass and P5 recommendations:

- Mission need for additional deep laboratory space (including at depths > 6000 m.w.e.) in the U.S. to support compelling future science
- Mission need for a next-generation (~100 tonnes) dark matter and neutrino observatory in the U.S.
- Develop a process for allocating temporary use of a LBNF module ("module of opportunity")
- Endorse the value of multi-disciplinary underground science at a dedicated laboratory in the U.S.

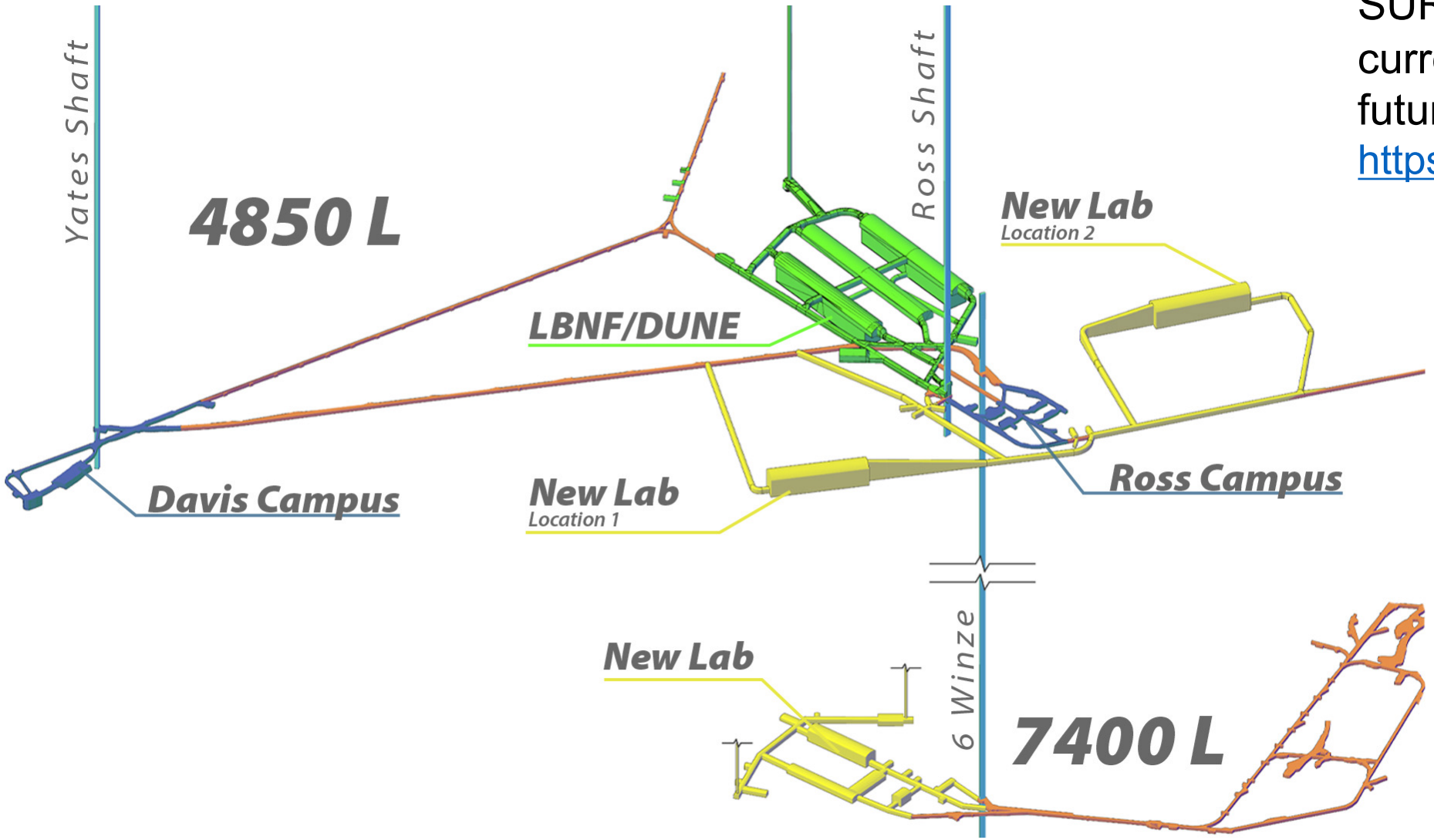
1 Introduction

The Sanford Underground Research Facility (SURF) is an international facility dedicated to advancing compelling multidisciplinary underground scientific research, including physics, biology, geology and engineering [1, 2, 3]. The unique underground environment at SURF allows researchers to explore an array of important questions regarding the origin of life and its diversity, mechanisms associated with geologic processes as well as a number of engineering topics such as mining innovations and technology developments. A deep underground laboratory is also where some of the most fundamental topics in physics can be investigated, including the nature of dark matter, the properties of neutrinos and topics

1

SURF Future

15-yr plan incl additional 4850L labs + deeper access



SURF whitepaper describing current status and proposed future facilities: https://arxiv.org/abs/2203.08293

Snowmass 2021

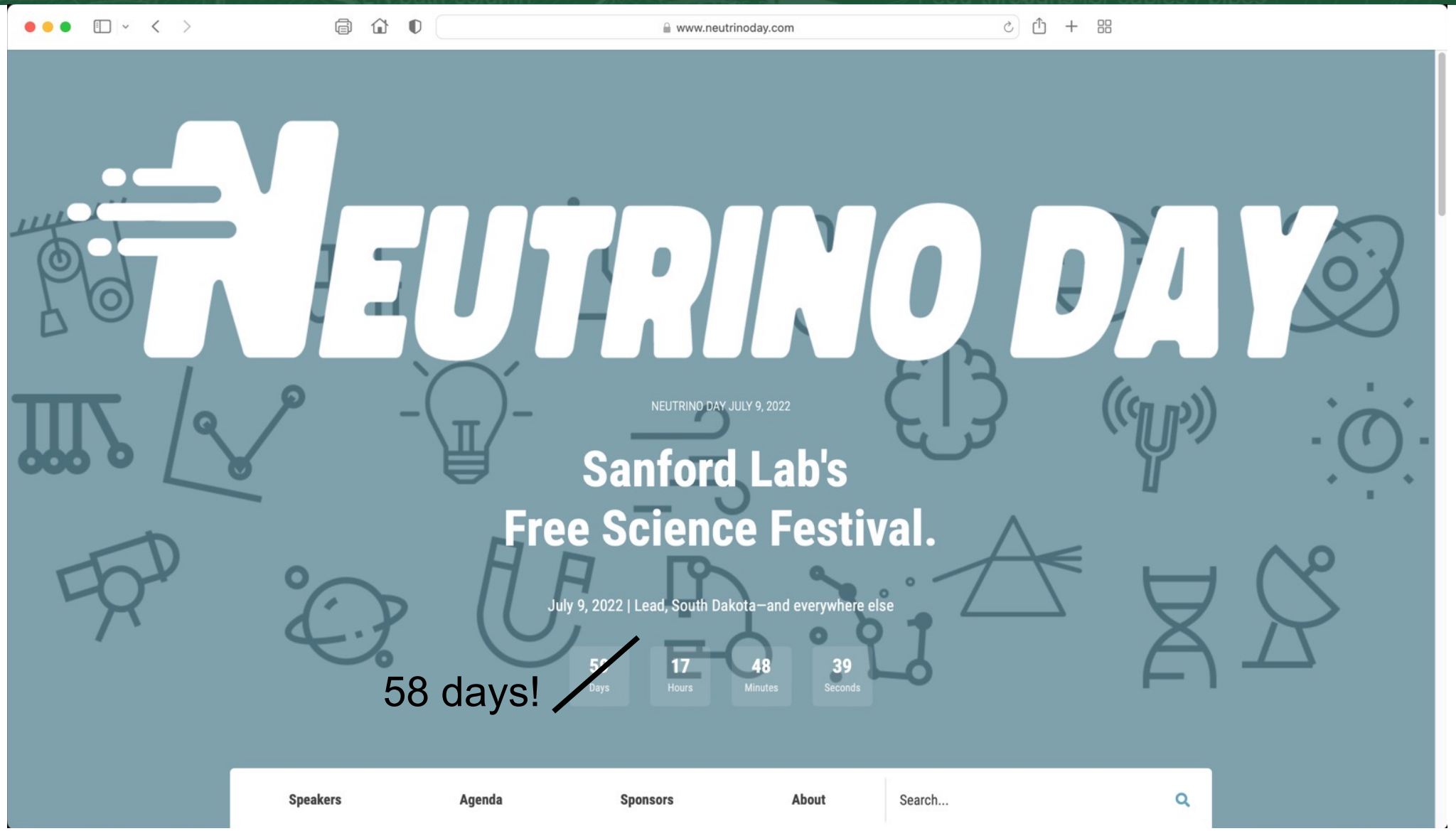
Upcoming Events – Conferences

May 11-13, 2022:
Conference on Science at SURF (SD Mines)
https://indico.sanfordlab.org/e/CoSSURF2022

Jun 14-17, 2022:
Low Radioactivity Techniques (SD Mines + SURF)
https://indico.sanfordlab.org/e/LRT2022

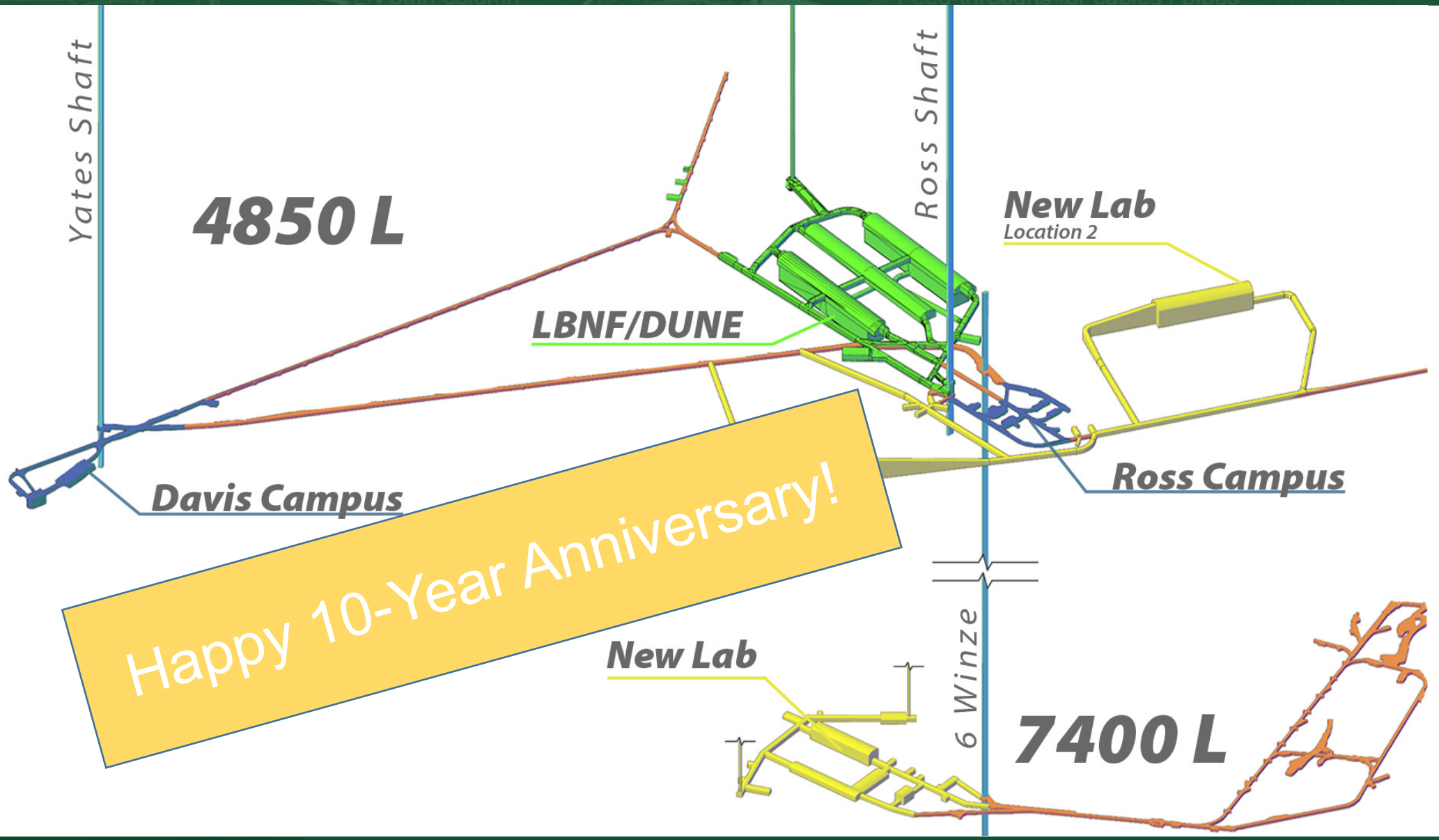
Upcoming Events – Neutrino Day

July 9, 2022, planning in-person (http://www.neutrinoday.com)



Upcoming Events – 10-Yr Anniversary

Davis Campus: The First 10 years 2012-2022



SURF Designated APS Historical Site

Announcement Sep 2020, Dedication May 2022

www.interactions.org/press-release/aps-designates-sanford-lab-morgan

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A communication resource from the **world's particle physics laboratories.**

APS designates Sanford Lab, Morgan State University as historic physics sites

14 September 2020 - Sanford Underground Research Facility

The pioneering neutrino research done by Ray Davis over nearly three decades forever changed our understanding of the Standard Model of Physics

The American Physical Society (APS) today announced it has designated SURF one of two Historic Sites in physics. The other, Morgan State University in Baltimore, Maryland, is recognized as the birthplace of the National Society of Black Physicists (NSBP).

DATE ISSUED:
September 14th, 2020

SOURCE:
Sanford Underground Research Facility

CONTENT:
Press Release

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Communications Director
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Sanford Underground Research Facility

Thank You!

Agency Acknowledgement: The Sanford Underground Research Facility (SURF) is a federally sponsored research facility under DOE-SC HEP Award Number DE-SC0020216 (cooperative agreement)

CoSSURF 2022 Tour Visits Ray's Café

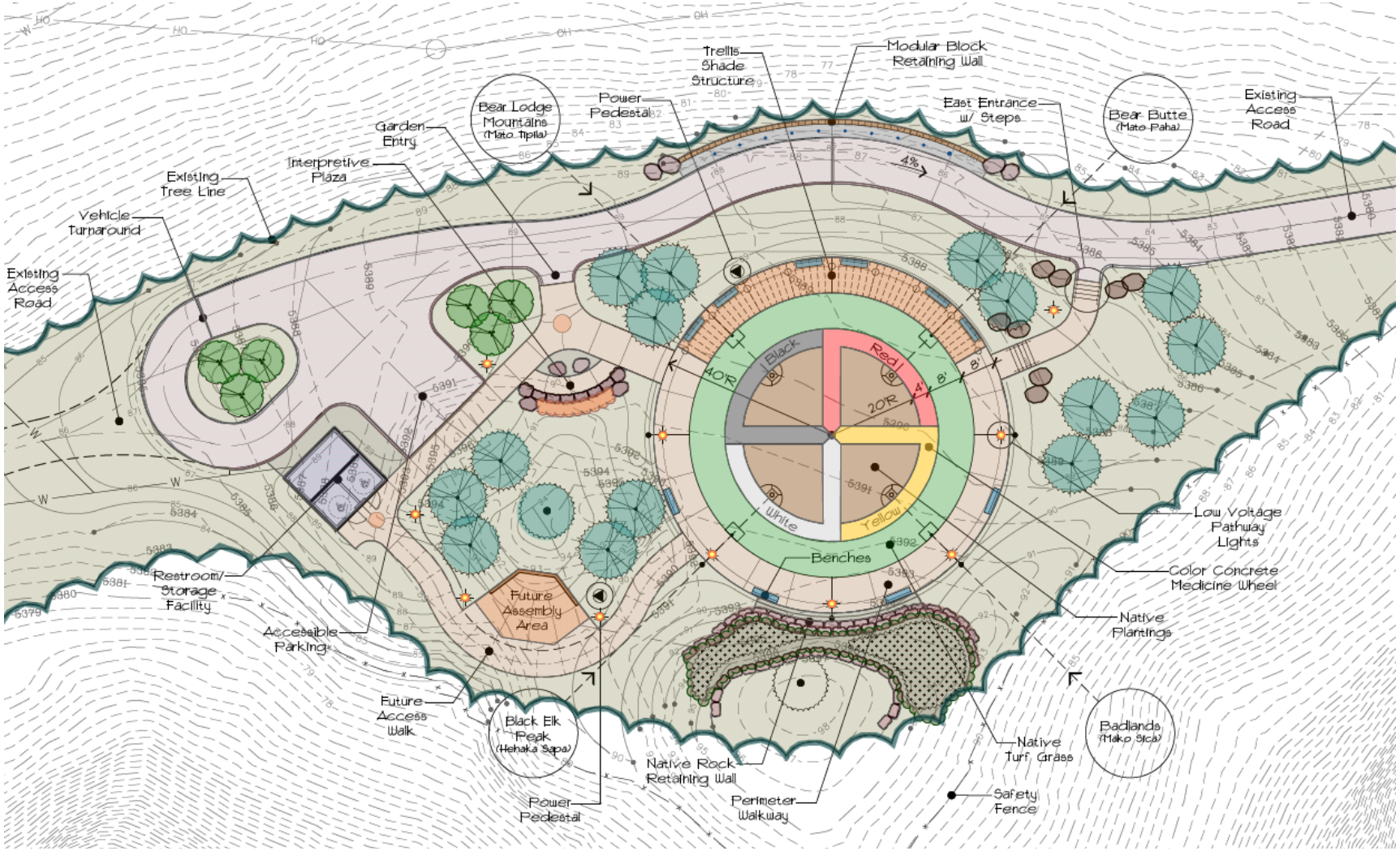
Sacred Circle Garden

Design is 75% completed. Fundraising is 56% complete.

We are creating an ethnobotanical garden, designed with native plant species with an aim to respect, protect and understand indigenous cultures of the Black Hills.

A place that protects our environment, our rich history and the values that connect us.

www.sanfordlab.org/garden



M. Michael Rounds Operations Center (ROC)

- $6.5M South Dakota commitment
- 26,000 sq.ft. (2415 m^2) total footprint
- Includes warehouse, machine shop, ops/engineering office space
- Dedicated Aug 20, 2021

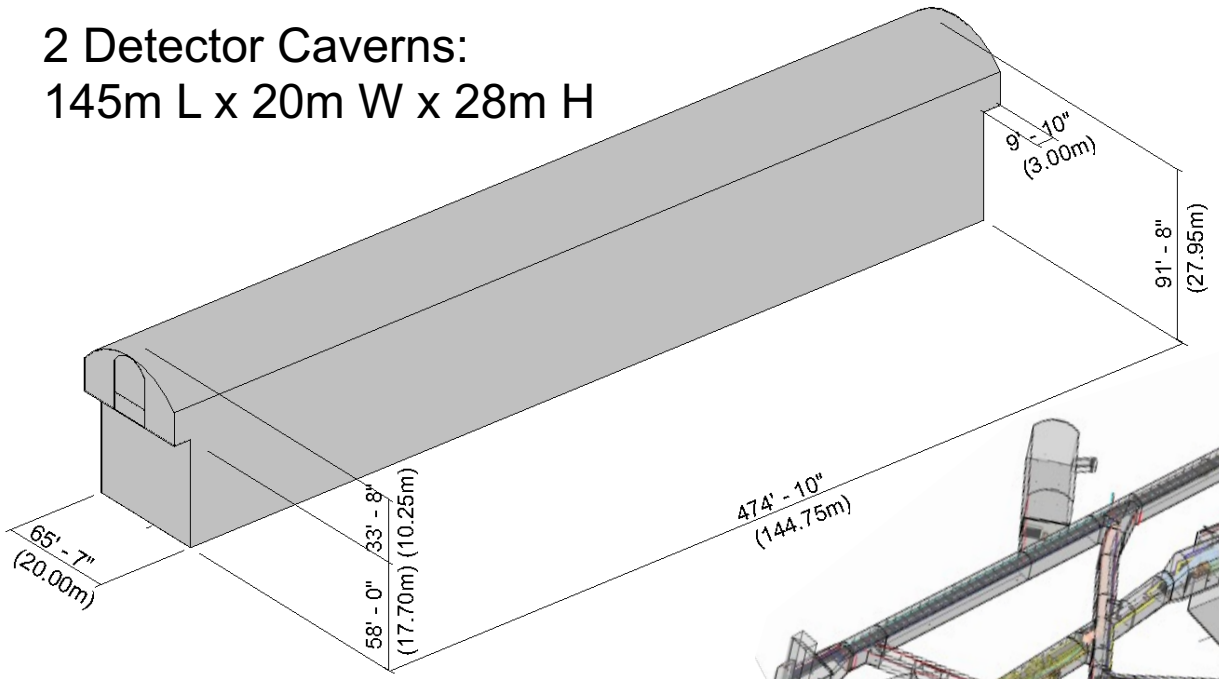
Sanford Lab Homestake Visitor Center

SDSTA acquired building and land on Jan 7, 2022. Acquisition and ops funded by SDSTA.

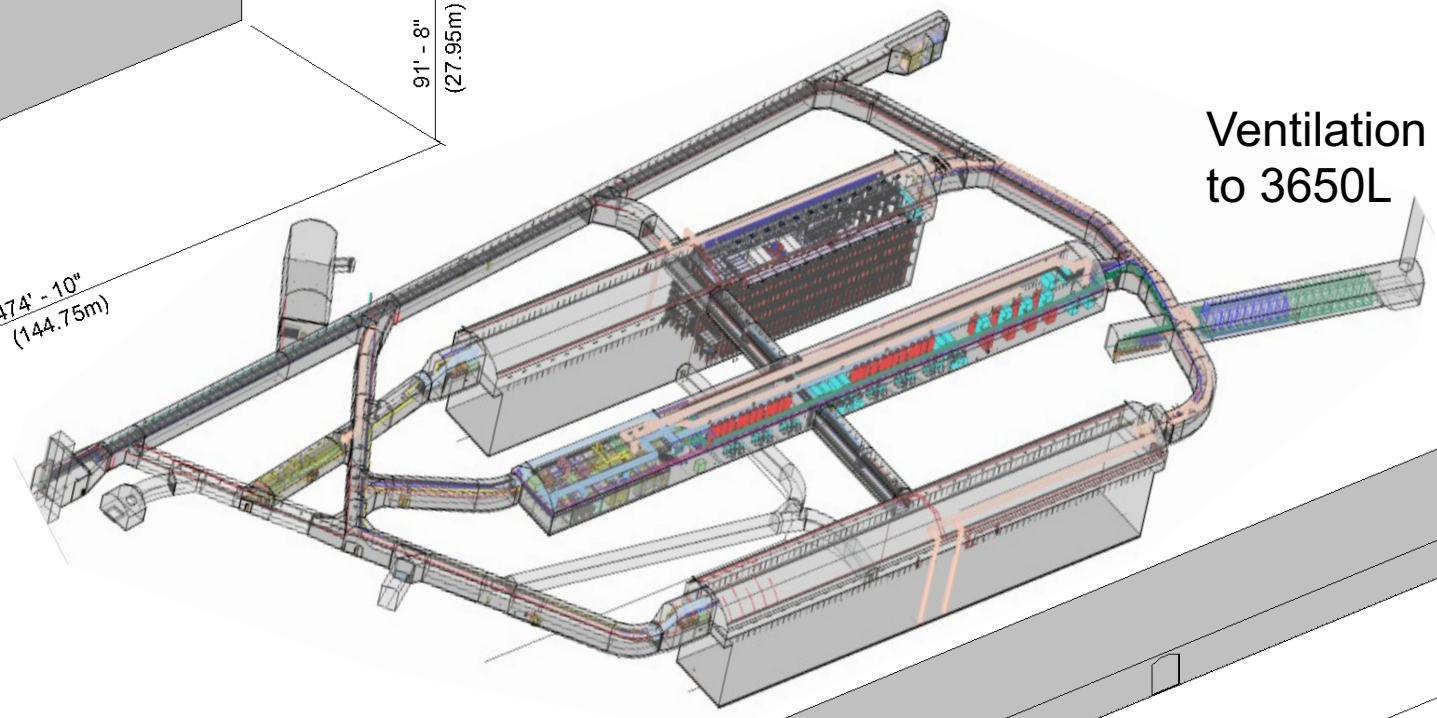
Long-Baseline Neutrino Facility (LBNF)

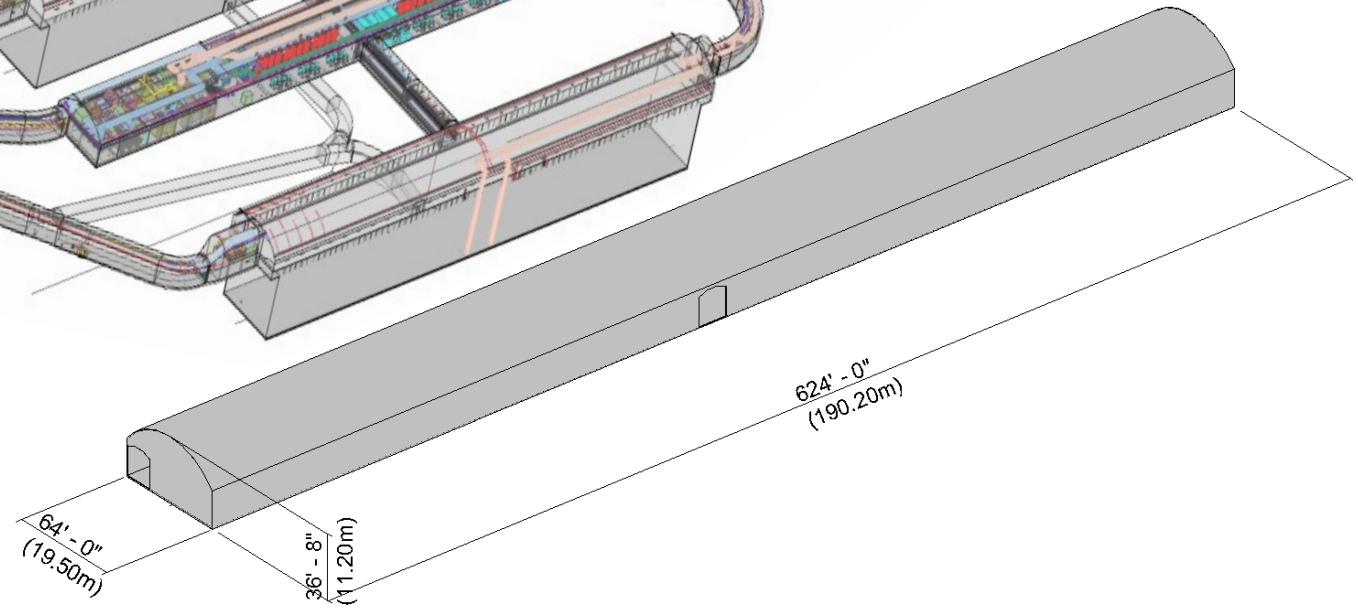
LBNF will host the Deep Underground Neutrino Experiment (DUNE)

2 Detector Caverns:
145m L x 20m W x 28m H



Ventilation Borehole
to 3650L



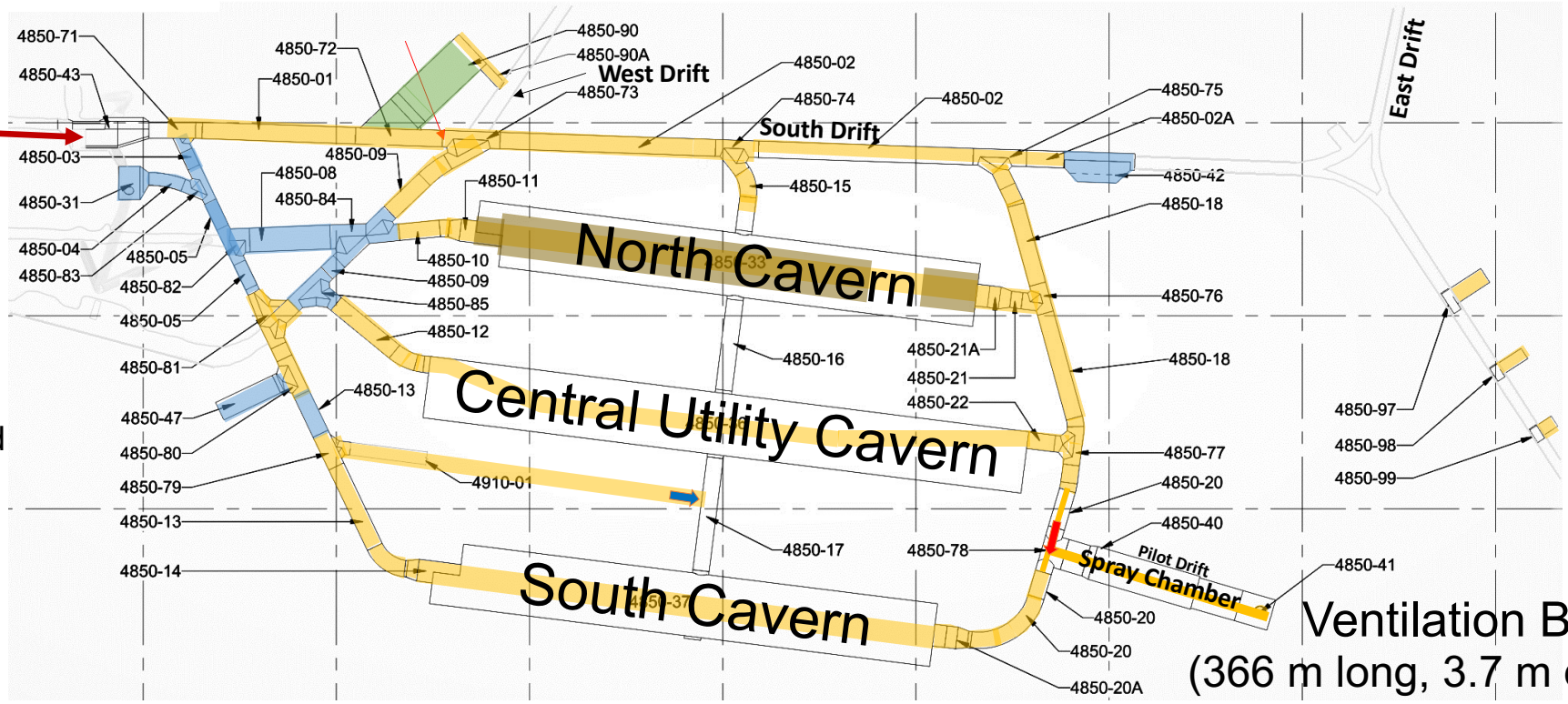


1 Utility Cavern:
190m L x 20m W x 11m H

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Excavation 27% complete



- Aug 2023: North Cavern excavation complete
- Mar 2023: Central Utility Cavern excavation complete
- Oct 2023: South Cavern excavation complete
- Mar 2024: All concrete complete
- May 2024: Infrastructure outfitting (~18 mths), cryostat construction starts (warm ~11 mths, cold ~12 mths)

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Rock conveyer to Open Cut

Borehole reamer

Excavation

Underground Facilities

SURF Science Program

Researchers from 87 institutions (Pre-DUNE), active in bold (61)

United States

- **Black Hills State University, Spearfish, SD**
- **Brandeis University, Waltham, MA**
- **Brookhaven National Laboratory, Upton, NY**
- **Brown University, Providence, RI**
- Caltech, Pasadena, CA
- **Caterpillar Global Mining, LLC, East Peoria, IL**
- Colorado School of Mines, Golden, CO
- **Department of Energy (EERE), Washington, DC**
- **Desert Research Institute, Las Vegas, NV**
- **DTRC, Lead, SD**
- **Duke University / TUNL, Durham, NC**
- **Fermi National Accelerator Lab, Batavia, IL**
- **Golder Associates, Inc., Redmond, WA**
- **Idaho National Laboratory, Idaho Falls, ID**
- **Indiana University, Bloomington, IN**
- Jet Propulsion Laboratory, Pasadena, CA
- **Lawrence Berkeley National Lab, Berkeley, CA**
- **Lawrence Livermore National Lab, Livermore, CA**
- Liberty BioSecurity, LLC, Arlington, VA
- **Los Alamos National Lab, Los Alamos, NM**
- **Mattson Hydrology LLC, Victor, ID**
- McClure Geomechanics, Palo Alto, CA
- **Montana State University, Bozeman, MT**
- National Energy Technology Lab, Albany, OR / Morgantown, WV
- National Renewable Energy Lab, Golden, CO
- **North Carolina State University, Raleigh, NC**
- **Northwestern University, Evanston, IL**
- **Oak Ridge National Lab, Oak Ridge, TN**
- **Pacific Northwest National Lab, Richland, WA**
- **Pennsylvania State University, State College, PA**
- **Primo, Lead, SD**
- **RE/SPEC, Rapid City, SD**
- Rensselaer Polytechnic Institute, Troy, NY
- **Rice University, Houston, TX**
- Rutgers University, Piscataway Township, NJ
- **Sandia National Laboratories, Albuquerque, NM**
- **South Dakota School of Mines & Technology, Rapid City, SD**
- **Spearfish School District, Spearfish, SD**
- **SLAC National Accelerator Lab, Menlo Park, CA**
- **Stanford University, Stanford, CA**
- Tennessee Tech University, Cookeville, TN
- Texas A&M University, College Station, TX
- US Geological Survey, Rapid City, SD / Tucson, AZ

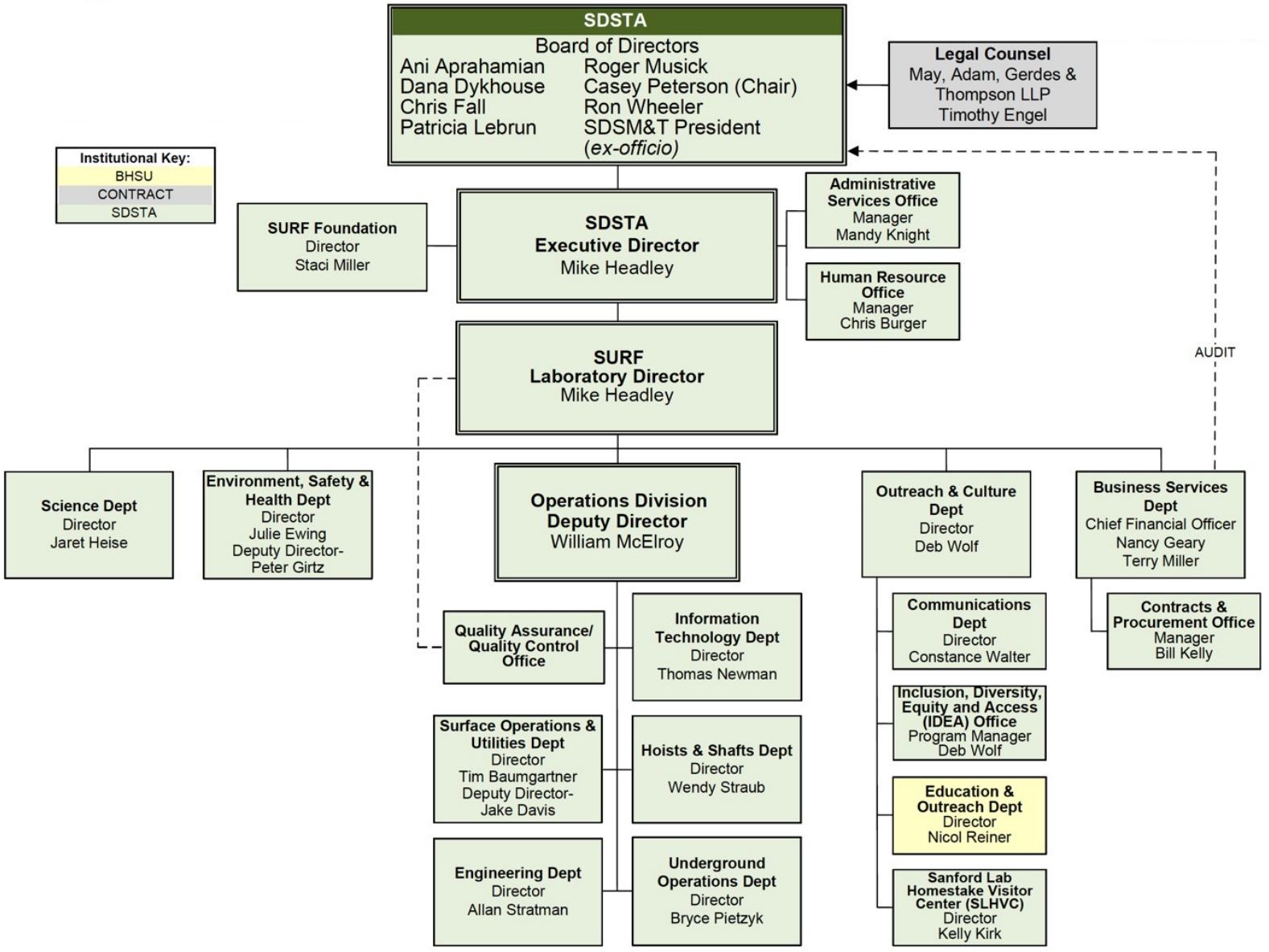
US – continued

- **University at Albany/SUNY, Albany, NY**
- **University of Alabama, Tuscaloosa, AL**
- **University of California Berkeley, Berkeley, CA**
- **University of California Davis, Davis, CA**
- **University of California Los Angeles, Los Angeles, CA**
- **University of California Santa Barbara, Santa Barbara, CA**
- **University of Kentucky, Lexington, KY**
- **University of Maryland, College Park, MD**
- **University of Massachusetts, Amherst, MA**
- **University of Michigan, Ann Arbor, MI**
- **University of North Carolina, Chapel Hill, NC**
- **University of Notre Dame, Notre Dame, IN**
- **University of Oklahoma, Norman, OK**
- **University of South Carolina, Columbia, SC**
- **University of South Dakota, Vermillion, SD**
- **University of Southern California, Los Angeles, CA**
- **University of Rochester, Rochester, NY**
- University of Tennessee, Knoxville, TN
- University of Utah, Salt Lake City, UT
- **University of Wisconsin – Madison / Physical Sciences Lab, Madison, WI**
- **University of Washington, Seattle, WA**
- USDA NCAUR, Peoria, IL
- WD Masonry, Rapid City, SD
- Williams College, Williamstown, MA
- Xilinx, Inc., San Jose, CA
- Yale University, New Haven, CT

World

- **Center for Underground Physics (IBS), Daejeon, Korea**
- Joint Institute for Nuclear Research, Dubna, Russia
- **Imperial College London, London, England**
- **LIP Coimbra, Coimbra, Portugal**
- NRC Institute for Theoretical and Experimental Physics, Moscow, Russia
- Osaka University, Osaka, Japan
- Queen's University, Kingston, Canada
- **Royal Holloway and Bedford New College, Egham, England**
- **Rutherford Appleton Laboratory, Didcot, England**
- Technische Universitat Munchen / Max Planck Institute, Munich, Germany
- **University College London, London, England**
- **University of Bristol, Bristol, England**
- **University of Edinburgh, Edinburgh, Scotland**
- **University of Liverpool, Liverpool, England**
- **University of Oxford, Oxford, England**
- **University of Sheffield, Sheffield, England**

SURF Organization



SURF High-Impact Science

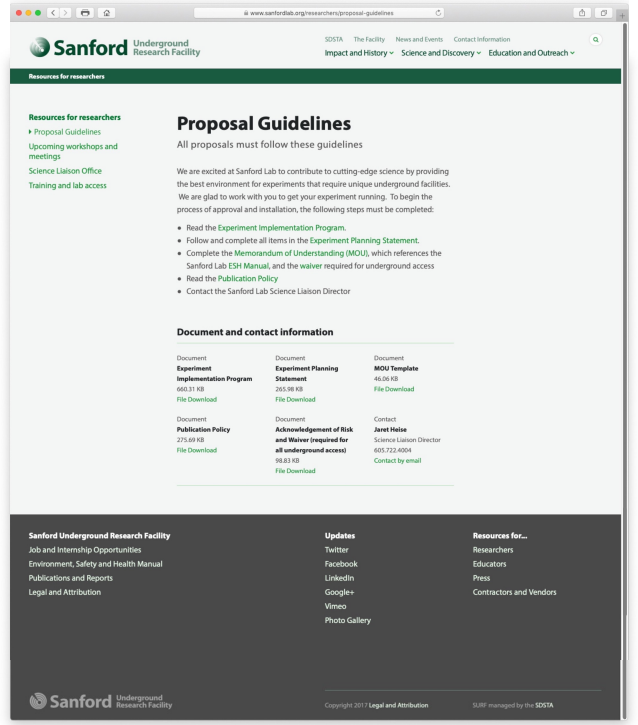
https://www.sanfordlab.org/publications-and-reports

- Insights into the phylogeny and coding potential of microbial dark matter, Rinke C, Schwientek P, Sczyrba A, Ivanova NN, Anderson IJ, Cheng JF, Darling A, Malfatti S, Swan BK, Gies EA, Dodsworth JA, Hedlund BP, Tsiamis G, Sievert SM, Liu WT, Eisen JA, Hallam SJ, Kyrpides NC, Stepanauskas R, Rubin EM, Hugenholtz P, Woyke T. *Nature* **499**:431-437 (2013) doi: 10.1038/nature12352.
- Obtaining genomes from uncultivated environmental microorganisms using FACS-based single-cell genomics, Rinke C, Lee J, Nath N, Goudeau D, Thompson B, Poulton N, Dmitrieff E, Malmstrom R, Stepanauskas R, Woyke T. *Nature Protocols* **9**:1038-1048 (2014) doi: 10.1038/nprot.2014.067.
- First Results from the LUX Dark Matter Experiment at the Sanford Underground Research Facility, D.S. Akerib *et al*. (LUX Collaboration) *Phys. Rev. Lett.* **112**, 091303 (2014) doi: 10.1103/PhysRevLett.112.091303.
- Results on the Spin-Dependent Scattering of Weakly Interacting Massive Particles on Nucleons from the Run 3 Data of the LUX Experiment, D.S. Akerib *et al.* (LUX Collaboration) *Phys. Rev. Lett.* **116**, 161302 (2016) doi: 10.1103/PhysRevLett.116.161302.
- Results from a Search for Dark Matter in the Complete LUX Exposure, D.S. Akerib *et al*. (LUX Collaboration) *Phys. Rev. Lett.* **118**, 021303 (2017) doi: 10.1103/PhysRevLett.118.021303.
- First Searches for Axions and Axionlike Particles with the LUX Experiment, D.S. Akerib *et al*. (LUX Collaboration) *Phys. Rev. Lett.* **118**, 261301 (2017) doi: 10.1103/PhysRevLett.118.261301.
- New limits on Bosonic Dark Matter, Solar Axions, Pauli Exclusion Principle Violation, and Electron Decay from the MAJORANA DEMONSTRATOR, N. Abgrall *et al*. (MAJORANA Collaboration) *Phys. Rev. Lett.* **118**, 161801 (2017) doi: 10.1103/PhysRevLett.118.161801.
- Search for Neutrinoless Double-ß Decay in ^{76}Ge with the MAJORANA DEMONSTRATOR, C. E. Aalseth *et al*. (MAJORANA Collaboration) *Phys. Rev. Lett.* **120**, 132502 (2018) doi: 10.1103/PhysRevLett.120.132502.
- Measurement of Low-Energy Resonance Strengths in the ^{18}O(α,γ)^{22}Ne Reaction, A.C. Dombos *et al*. (CASPAR Collaboration) *Phys. Rev. Lett.* **128**, 162701 (2022) doi: 10.1103/PhysRevLett.128.162701.

SURF Experiment Implementation Program

Identify interfaces and hazards within approval framework

- https://www.sanfordlab.org/researchers/proposal-guidelines
- **Project Documentation**
  - Expression of Interest, incl support letters
  - Experiment Planning Statement
  - Memorandum of Understanding (space commitment)
  - Access: Request form, risk waiver, insurance
  - Services Agreement(s), if applicable
    - General Services Agreement: Who provides what and who pays
    - Contract(s): Specific expenses, direct use of SURF staff
  - Experiment Decommissioning Plan
- **Environment, Safety & Health**
  - Hazard Analysis: Assessments/analyses, procedures, testing/certifications
  - Inventories: Chemical, electrical, hoisting & rigging, pressure vessel, radioactive materials
  - Training: Sanford Lab modules, Expt training plan (incl equivalences), recordkeeping
- **Reviews** (Commensurate with hazards)
  - Facility, walk-through inspections, monitoring, readiness reviews (safety, operation)
- **Authorization**
  - Work planning & controls (procedure reviews/approvals, release), Science/ESH + Subject Matter Experts
  - Authorization To Proceed for significant installation and associated significant hazards



SURF COVID-19 Response

Effective measures limiting COVID spread at SURF

- **Protocols**
  - SURF COVID-19 response and control requirements documented (currently version 10)
- **Initial**
  - Brief period of minimal essential operations:
    - Mar 25 – May 6, 2021: Access limited, critical monitoring/maintenance, consumable supplies (e.g., LN) still supported; some surface activities resumed in April
  - Monitored data in 100-mile region, scrutiny on travel
  - Controls developed based on CDC, OSHA:
    - Masks required in buildings/labs, respirators required on conveyances
    - Reduced #s on conveyances & meeting rooms, telework encouraged
    - Wellness checks at site entrances
  - Significant collaboration institutional travel restrictions
  - Large in-person events canceled or virtualized (e.g., Neutrino Day 2020 & 2021)
- **Current**
  - Masks optional in all areas at SURF per CDC based on county Community Levels (cases, hospitalizations)

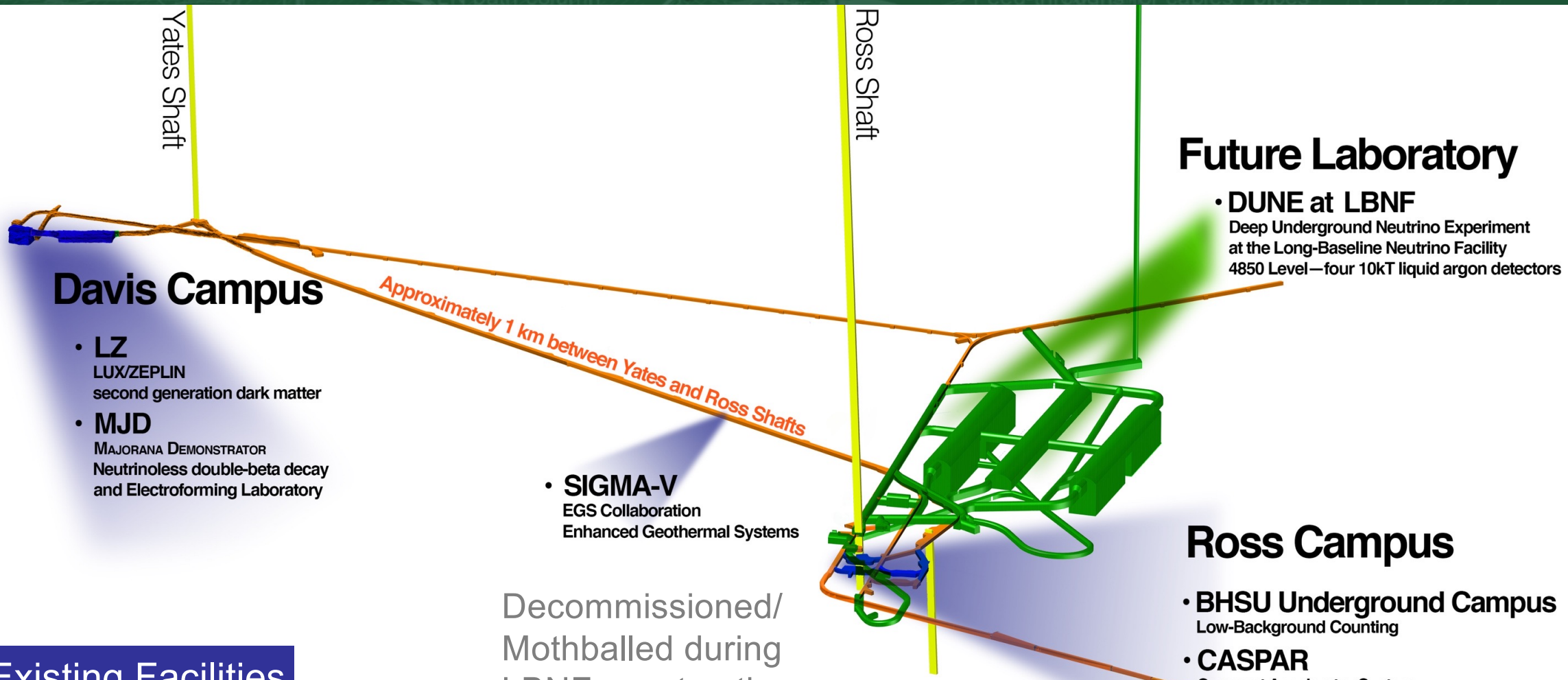
SURF Laboratory Space

Summary for various science campuses, including timelines

Location	Laboratory	Existing/*Planned* Space		Available (CY)	Comments
		Area (m^2)	Vol (m^3)		
Surface	Surface Lab (+ RRS)	210	600	2021	LZ use ~complete, allowing use by others
Davis Campus (4850L)	LZ Lab – Davis Cavern (2 levels)	372	1,956	~2027	LZ operations beginning 2021, complete by ~2026 + decommissioning
	MJD Lab – 2 Rms + BHUC share	300	1,279	~2024/2026	Initial scope completed 2021, Ta-180m data 2022-2023 + decommissioning; Cu e-forming through 2025
	Cutout Rms (4)	100	412	~2027	LZ timeframe for most spaces
Ross Campus (4850L)	Former E-forming	228	742	?	LBNF use + SURF UG WWTP
	BHUC (BHSU cleanroom)	266	773	~2024	Mothballed, most equipment and systems relocated to Davis Campus; re-occupy after LBNF construction
	CASPAR	395	1,130	~2024	Mothballed, equip remains, re-occupy after LBNF construction. (Also expanded Refuge Chamber)
	Refuge Chamber	258	866	?	Long-term use TBD
LBNF (4850L)	*LBNF*	*9,445*	*191,863*	*~2024*	*Excavation complete in 2024, "module of opportunity"?*
4100L	Geoscience lab	334	11 drill holes	Fall 2022	Leverage EGS/SIGMA-V infrastructure
4850L	*Propose 2 labs*	*2 x 2,011*	*2 x 47,304*	*Earliest: excavation 2027, complete ~2030*	*Each 20m (W) x 24m (H) x 100m (L)*
7400L	*Propose 2 labs*	*2 x 1,125*	*2 x 14,288*		*Each 15m (W) x 15m (H) x 75m (L)*

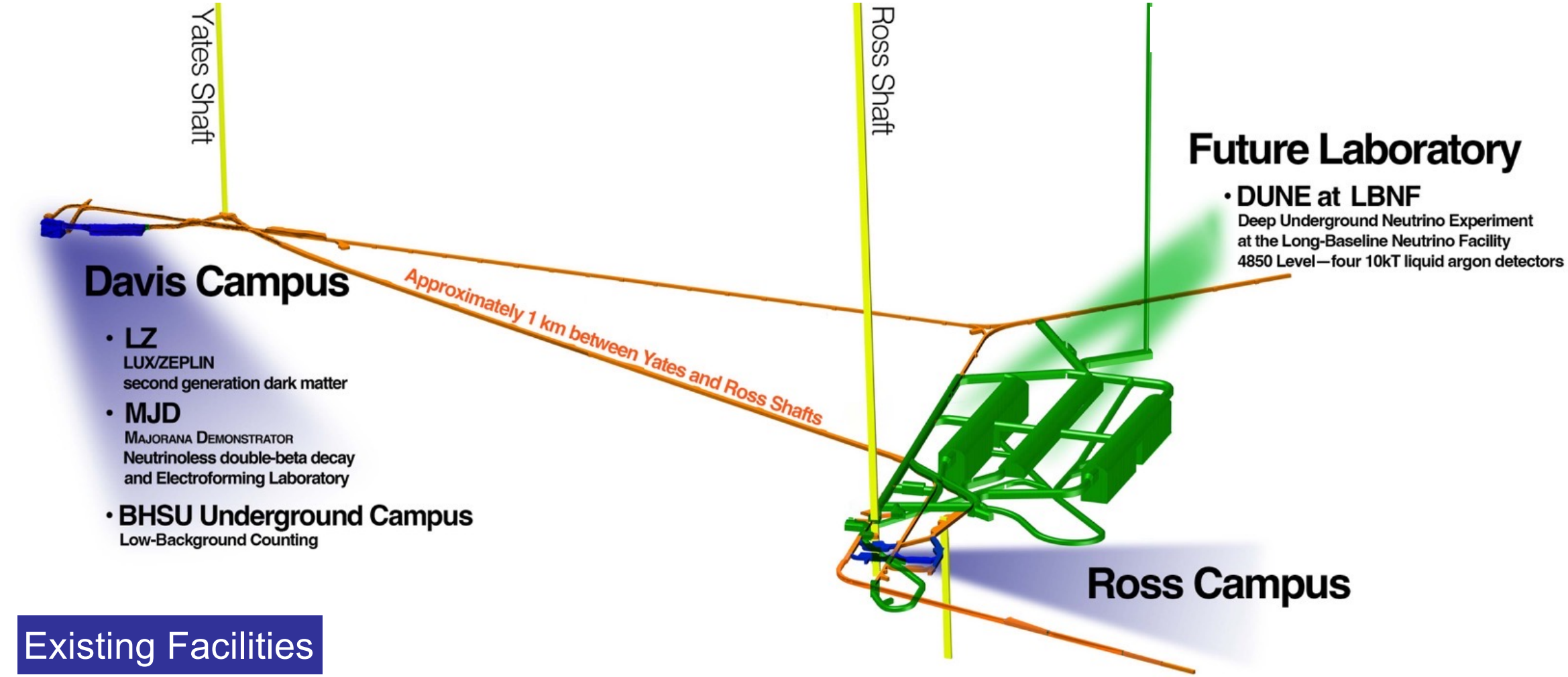
Current & Future Underground Facilities

SURF research through 2050 and beyond



Current & Future Underground Facilities

SURF research through 2050 and beyond

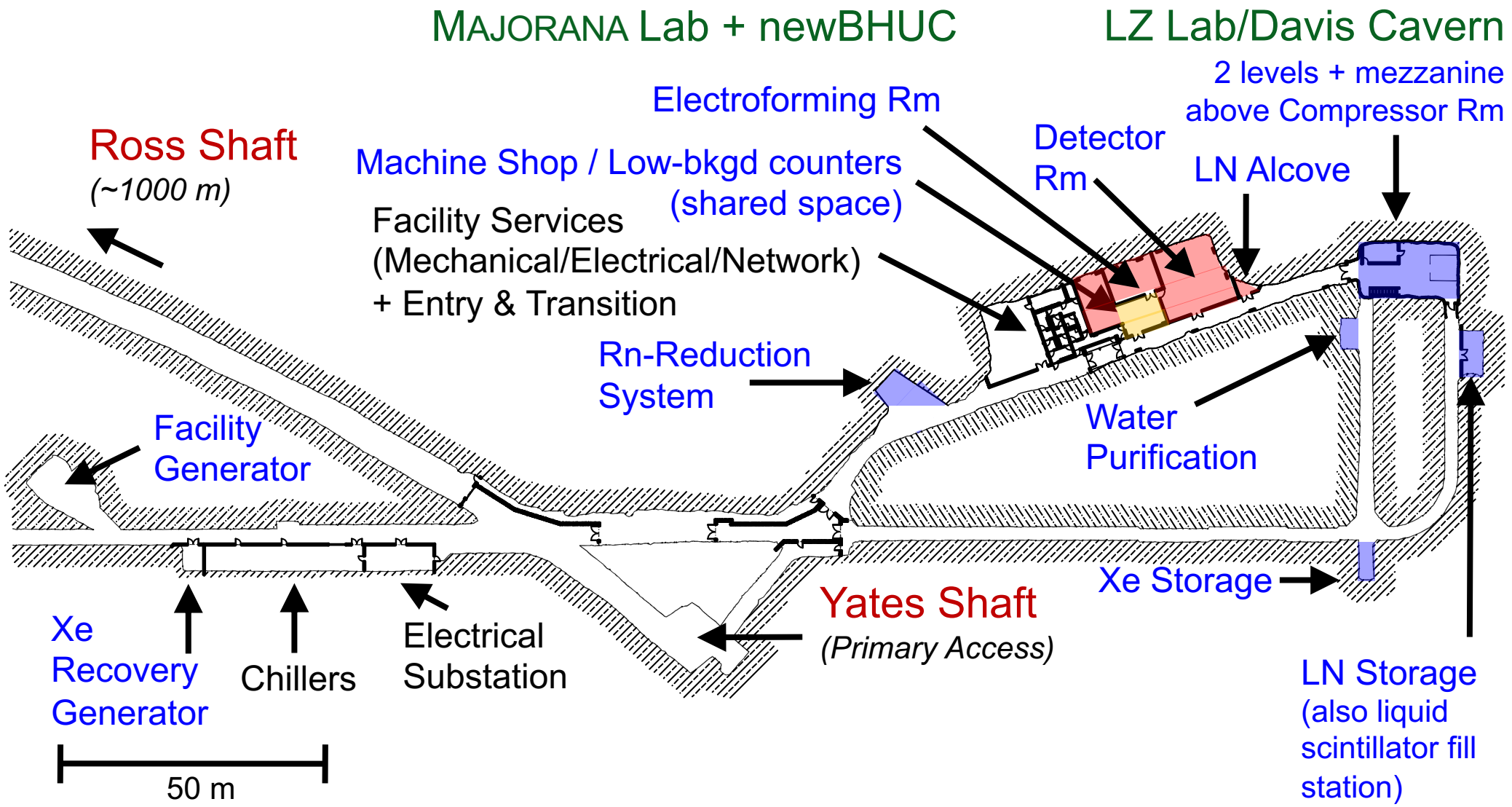


Existing Facilities

Future Facilities

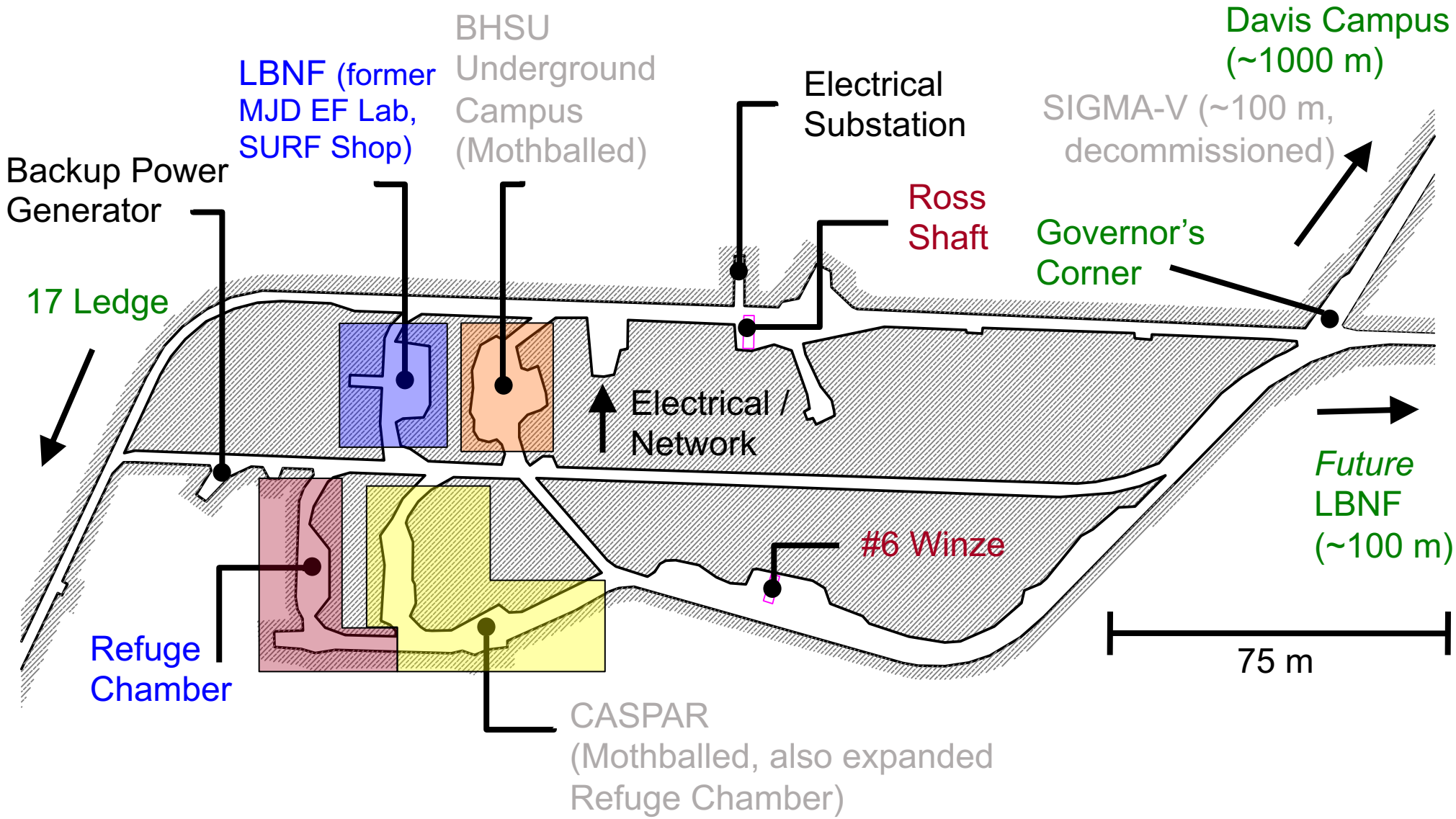
4850L Davis Campus

3,017 m² (Total) / 1,018 m² (Science), New Excavation+Davis Cavern



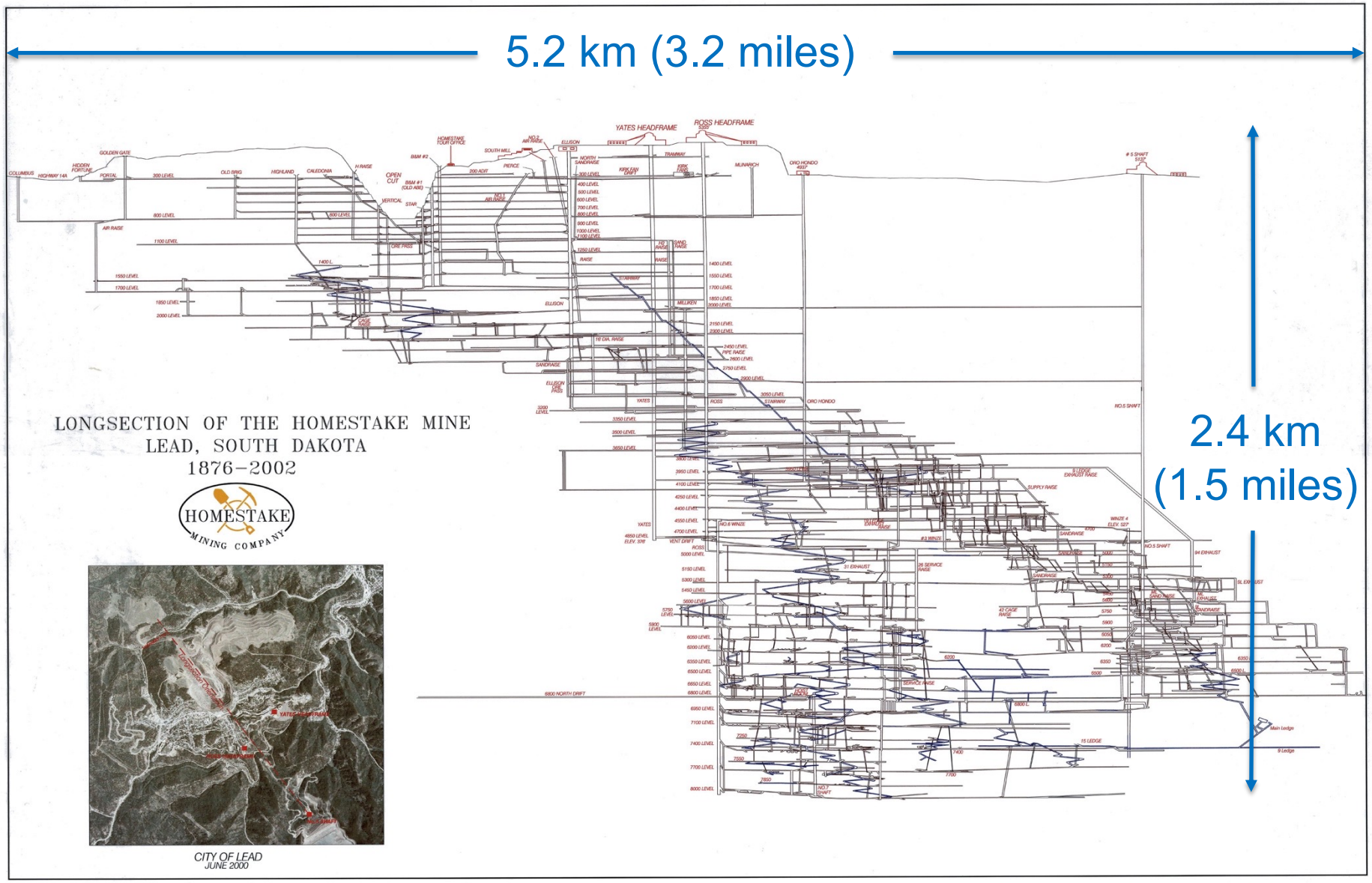
4850L Ross Campus

2,653 m² (Total) / 920 m² (Science), Existing Excavations Improved



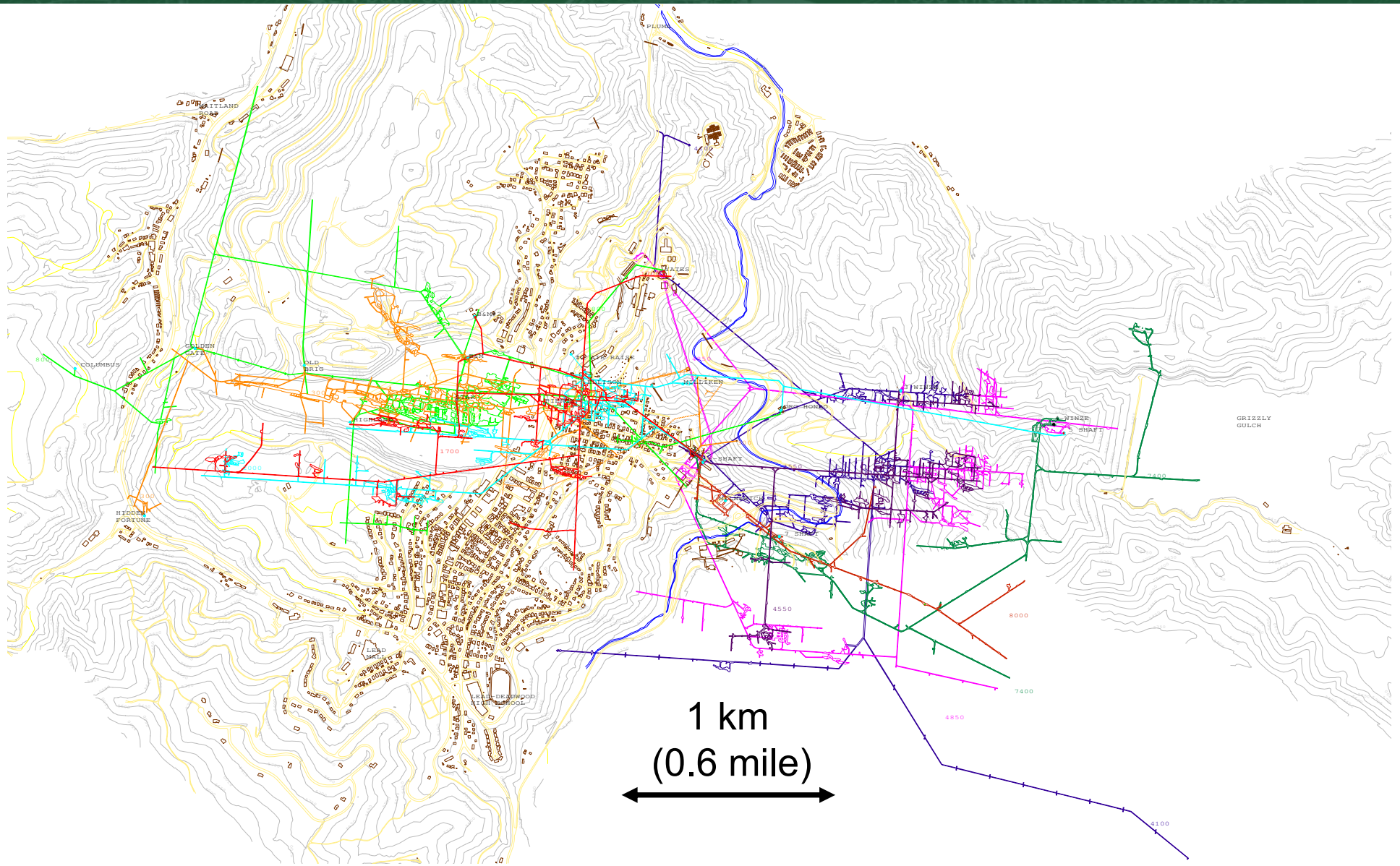
SURF Underground Lab Geography

Significant underground science footprint



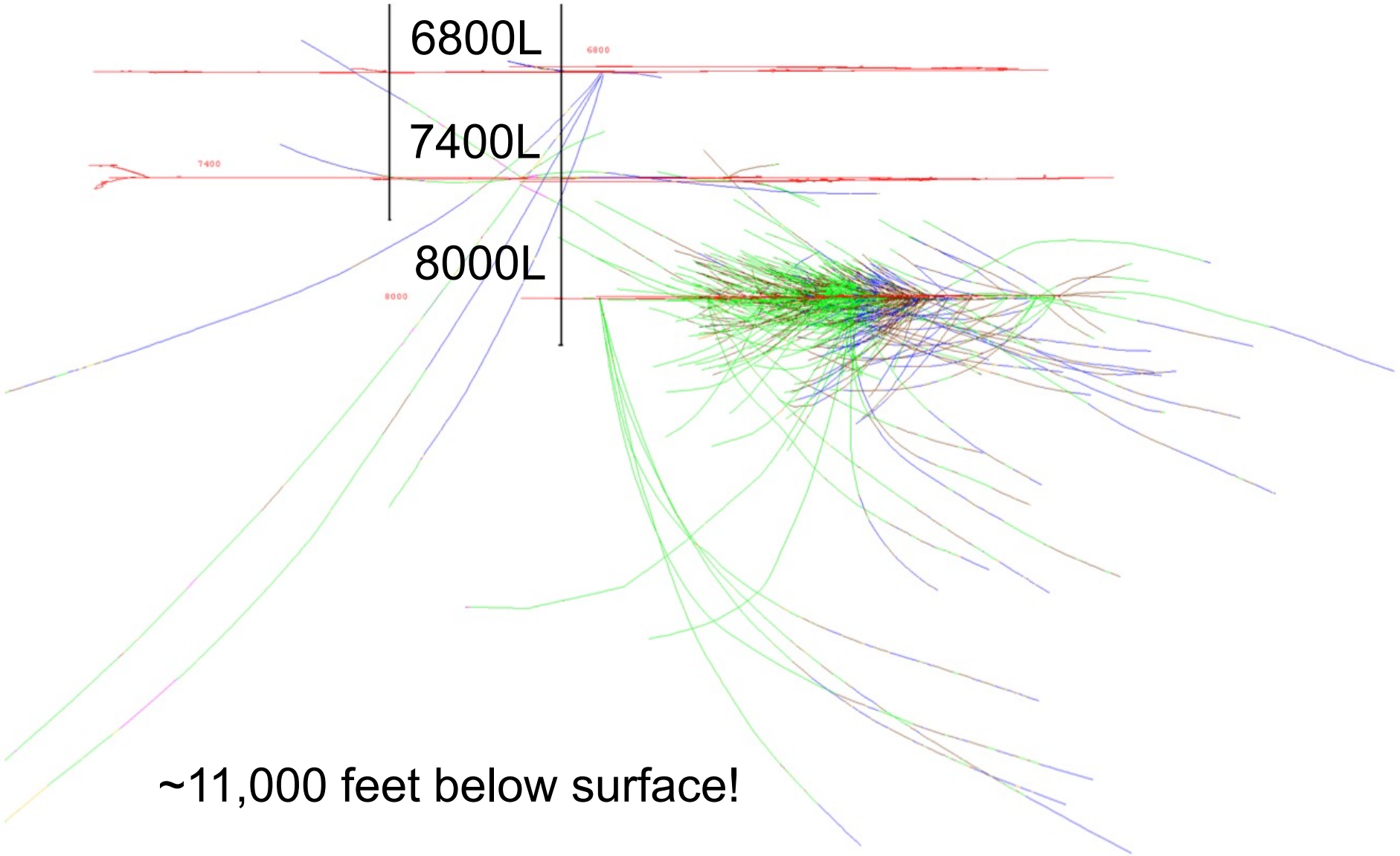
SURF Underground Lab Geography

Significant underground science footprint



SURF Underground Lab Geography

Future Possibilities to Access Existing Deep Holes?



~11,000 feet below surface!

BHUC
Black Hills State University Underground Campus (Low-Background Assays)

- **Operations**
  - BHSU and SDSTA personnel continue to perform sample swaps, data analysis and liquid nitrogen support at Davis Campus.
  - Recent samples incl IceCube, protoDUNE and CUPID.
  - Five of six counter systems currently operating, incl LLNL dual-crystal system recently finalized.
  - nEXO Ge-IV crystal offsite (still) at vendor for troubleshooting. Cooling system issue resolved at Univ Alabama. Re-designed lifting device for shield components. Expected online by Summer 2022.
  - New dirty-side LN storage supports 2 dewars at ODH class zero (higher capcity, easier logistics).

- **Future**
  - Operation of all six detector systems.
  - Limited space for expansion at Davis Campus. Return to Ross Campus in ~FY24 following LBNF construction.


LLNL detector commissioning

New LN storage

SURF Material Assay at BHUC

Establishing national & international-level low-bkgd capabilities

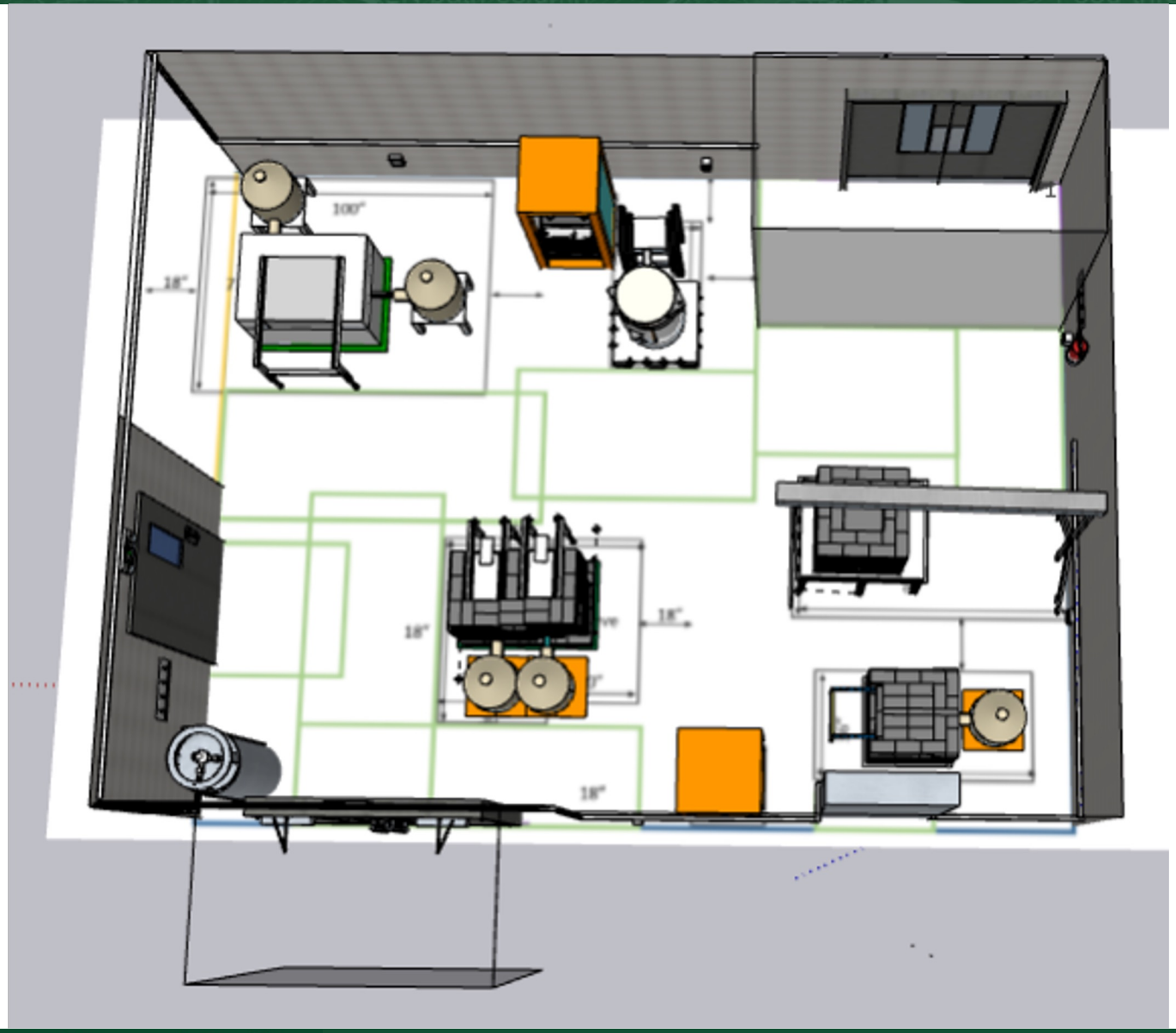
Detector	Crystal		[U] mBq/kg	[Th] mBq/kg	Install Date	Status	Comments
	Type	Size					
Maeve (BLBF)	p-type (85%)	2.2 kg	**0.1** (10 ppt)	**0.1** (25 ppt)	Davis Campus: Nov 2020 (Ross Campus: Nov 2015; Davis Campus: May 2014)	Production assays	Relocated from Oroville. Old Pb (200-yr old) inner shielding. Cooling system upgrade 2020.
Morgan (BLBF)	p-type (85%)	2.1 kg	**0.2** (20 ppt)	**0.2** (50 ppt)	Davis Campus: Nov 2020 (Ross Campus: Nov 2015; Davis Campus: May 2015)	Production assays	Low-bkgd upgrade 2015. Cooling system upgrades 2020.
Mordred (USD/CUBED, BLBF)	n-type (60%)	1.3 kg	**0.7** (60 ppt)	**0.7** (175 ppt)	Davis Campus: Nov 2020 (Ross Campus: Jul 2016; Davis Campus: Apr 2013)	Production assays	Low-bkgd upgrade 2015-2016, shield access upgrade. Cooling system upgrades 2020.
Dual HPGe ("Twins") (BLBF, BHSU, UCSB)	p-type (2x120%)	2x 2.1 kg	**~0.01** (~1 ppt)	**~0.01** (~1 ppt)	Davis Campus: Sep 2020 (Ross Campus: Mar 2018, Jul 2017 (initial))	Operating	Low-bkgd upgrades 2016-2017; flexible shield. Cooling system upgrades 2020.
Ge-IV *(Alabama, Kentucky)*	*p-type (111%)*	*2 kg*	***0.04*** *(3 ppt)*	***0.03*** *(8 ppt)*	*Davis Campus: Summer 2022?, Nov 2020 (initial) (Ross Campus: Jul 2018, Oct 2017 (initial))*	*Installation underway*	*Vertical design, requires gantry + hoist. Cooling system upgrades 2020.*
Dual HPGe ("RHYM+RESN") (LLNL)	p-type (2x65%)	2x 1.1 kg	**<0.1** (<10 ppt)	**<0.1** (<25 ppt)	Davis Campus: Feb 2022, Sep 2020 (initial)	Operating	Cryocooler, low-E ^{210}Pb (<2 mBq/kg).

Also see: LZ Assay Paper https://arxiv.org/pdf/2006.02506

Local universities have some additional material screening capabilities: **ICP-MS** (Black Hills State University) and **Rn emanation** characterization (SD Mines). Other: BetaCage (SDSMT prototype), XIA UltraLo-1800 (LZ, purchased)

BHUC

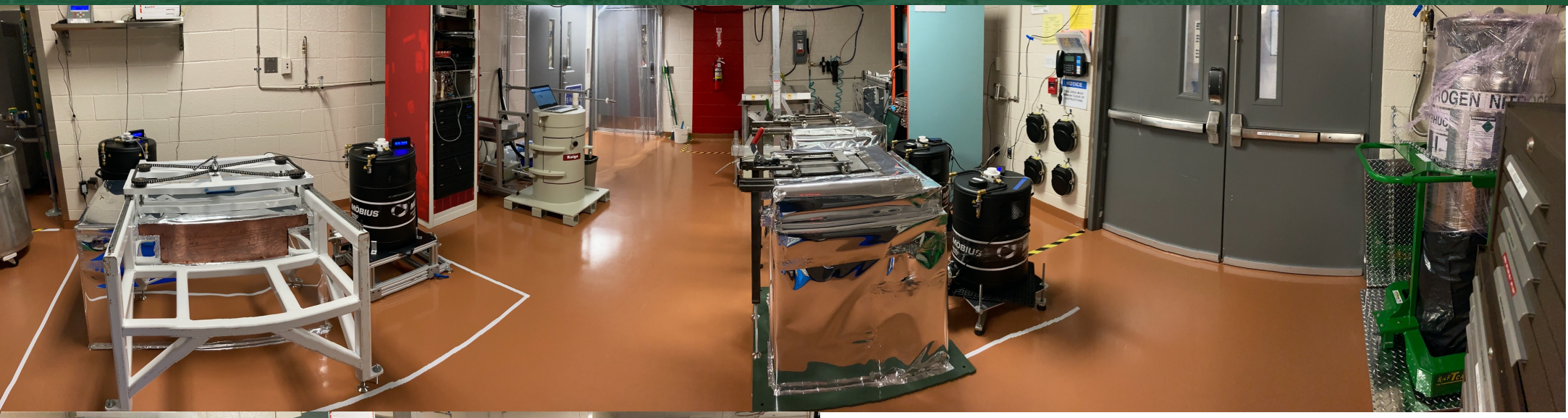
Black Hills State University Underground Campus (Low-Background Assays)



Relocated to Davis Campus in Fall 2020

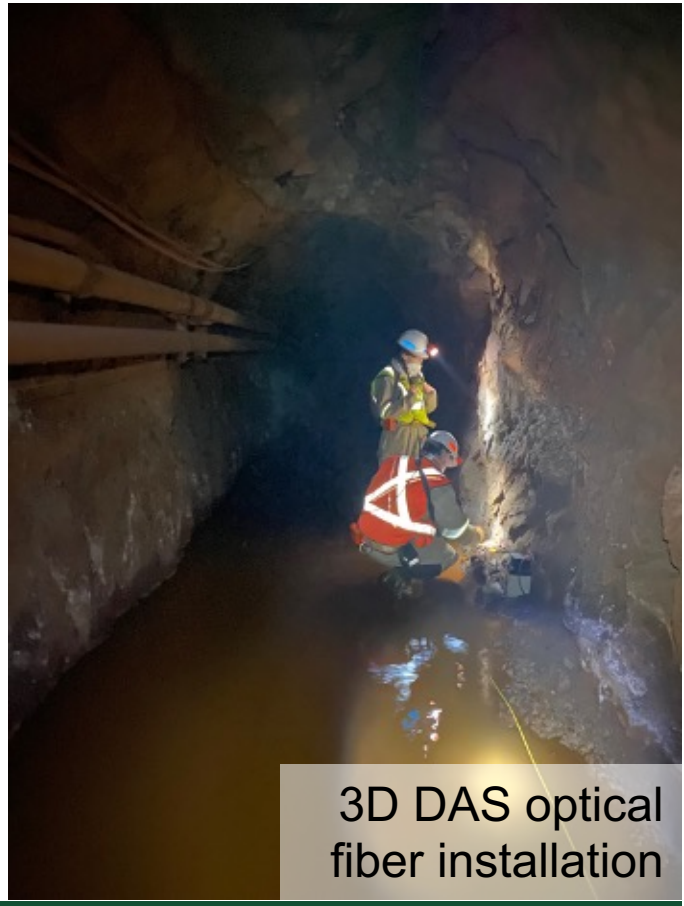
BHUC

Black Hills State University Underground Campus (Low-Background Assays)



Other Experiments

- **Physics**
  - TESSERACT: Discussions continue with low-mass dark matter project.
  - Expression of interest from LLNL WbLS group (50-100 tons).
  - Interest from USD-led group in UG crystal growth (300L).
- **Geology**
  - 3D DAS: 3100 m optical fiber deployed on 4550L and ramp between 4100L and 4850L for seismic monitoring.
  - BH Seismic: 4100L installation complete, data online: https://stationview.raspberryshake.org/#/?net=AM&sta=R2760&lat=44.08646&lon=-103.90414&zoom=10.000
  - Small teams of geologists accessing surface core archive.
  - Extensometer data collected by SURF personnel and shared with Univ of Utah experts.
  - Interest in core (Homestake archive or other) to validate stress measurement technique.
- **Biology**
  - Support for project producing drinking water for space flight.
- **Engineering**
  - Thermal Breakout: 4100L heater tests in new holes ~Summer, continue into 2023.
  - Post-Blast Monitoring: Data from LBNF collected for several months.
  - Autonomous UAV project completed in 2021.



3D DAS optical fiber installation

SURF Science & Education Opportunities

Summer Internships (Bozied/Bauer/Headley)

- Openings for science, engineering, operations, environmental science and communications, incl underrepresented groups
- https://www.sanfordlab.org/feature/internships

Davis Bahcall Scholars Program

- Multidisciplinary studies at U.S. & European labs, industry
- https://www.sanfordlab.org/feature/davis-bahcall-scholars

Local faculty and collaborators:

- SD Mines:
  - Christofferson, Martinez Caicedo, McCormick, Piper, Reichenbacher, Roberts, Roggenthen, Sani, Schnee, Shearer, Shende, Stetler, Strieder, Tukkaraja, Uzunlar, Wang
- BHSU:
  - Anderson, Babbitt, Bergmann, Domagall, Jensen, Keeter, Lamb, Mount, Reiner, Sarver, Sayler, Zehfus

Research Experiences for Undergraduates

- Multidisciplinary program through BHSU (physics, chemistry, biology)
- http://www.bhsu.edu/research/reu

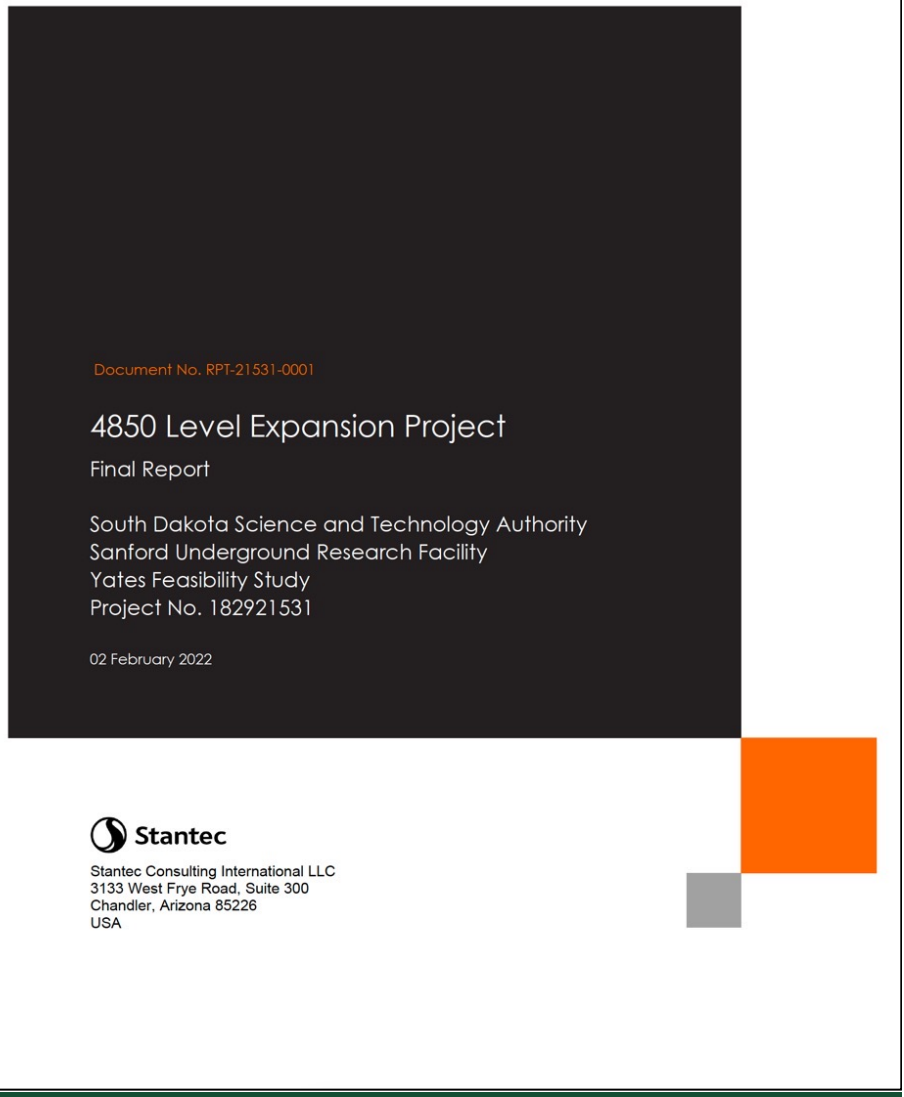
BHSU Underground Campus

- Promoting undergraduate research (multi-disciplinary efforts resume ~FY24)

SURF Underground Facility Expansion

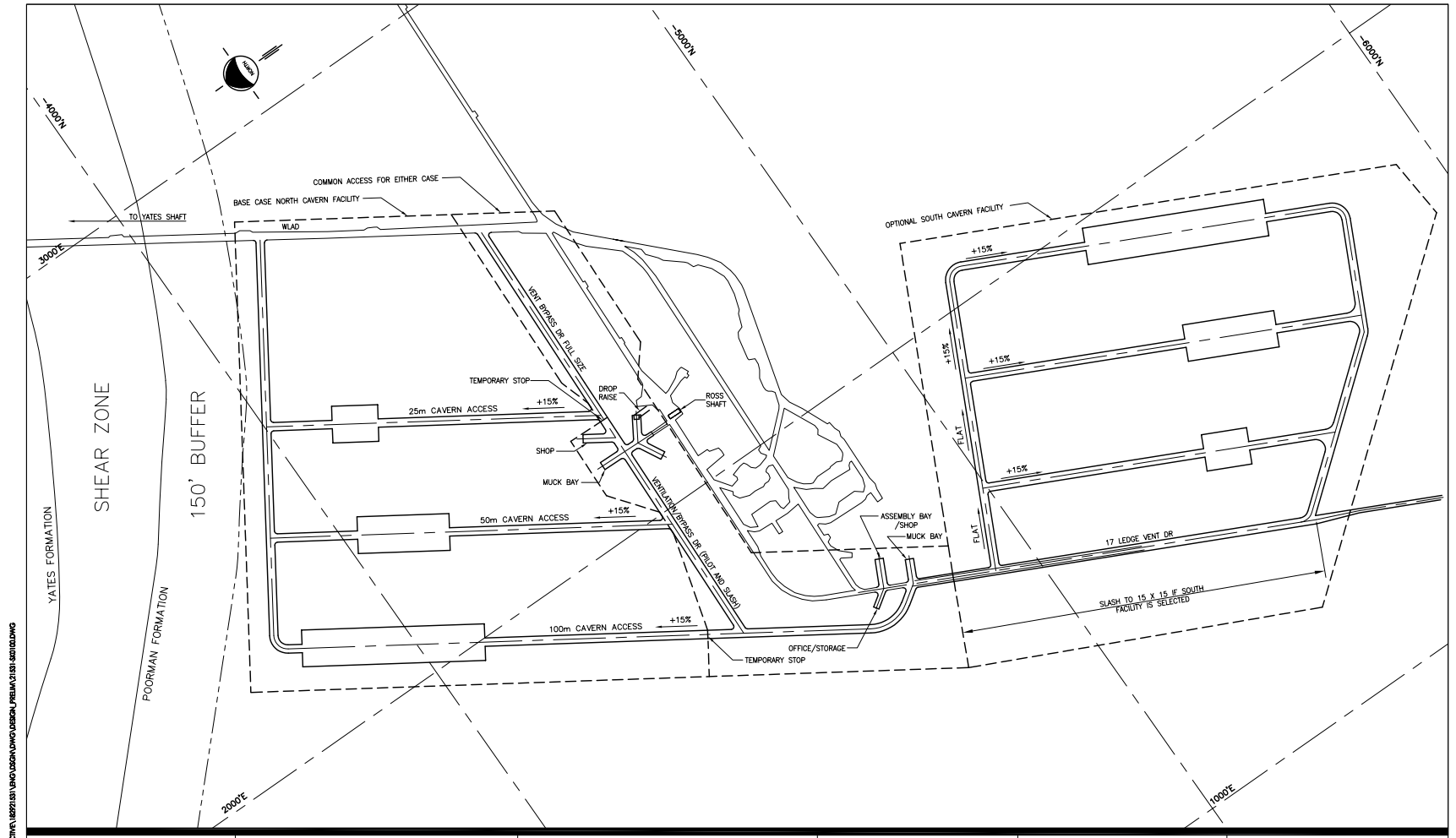
Feasibility design considerations for 4850L cavern(s)

- Geotechnical conditions
- Ventilation (intake and exhaust)
  - *Excavation, outfitting, operation*
- Access to existing operations
  - *Rock handling near Ross Shaft*
- Separation from existing facilities (LBNF, Ross Campus)
  - *Isolate researchers from construction (dust, equipment, etc)*
- Ability to excavate, construct, expand in phases
  - *Maximize flexibility at expense of efficiency (e.g., single heading only)*
- Adequate cavern space availability (25m, 50m, 100m lengths)
  - *15% grade to reach top of cavern*
  - *Room to install bridge crane/monorail*
- Misc alcoves, etc
  - *No rock in West Drift (!)*



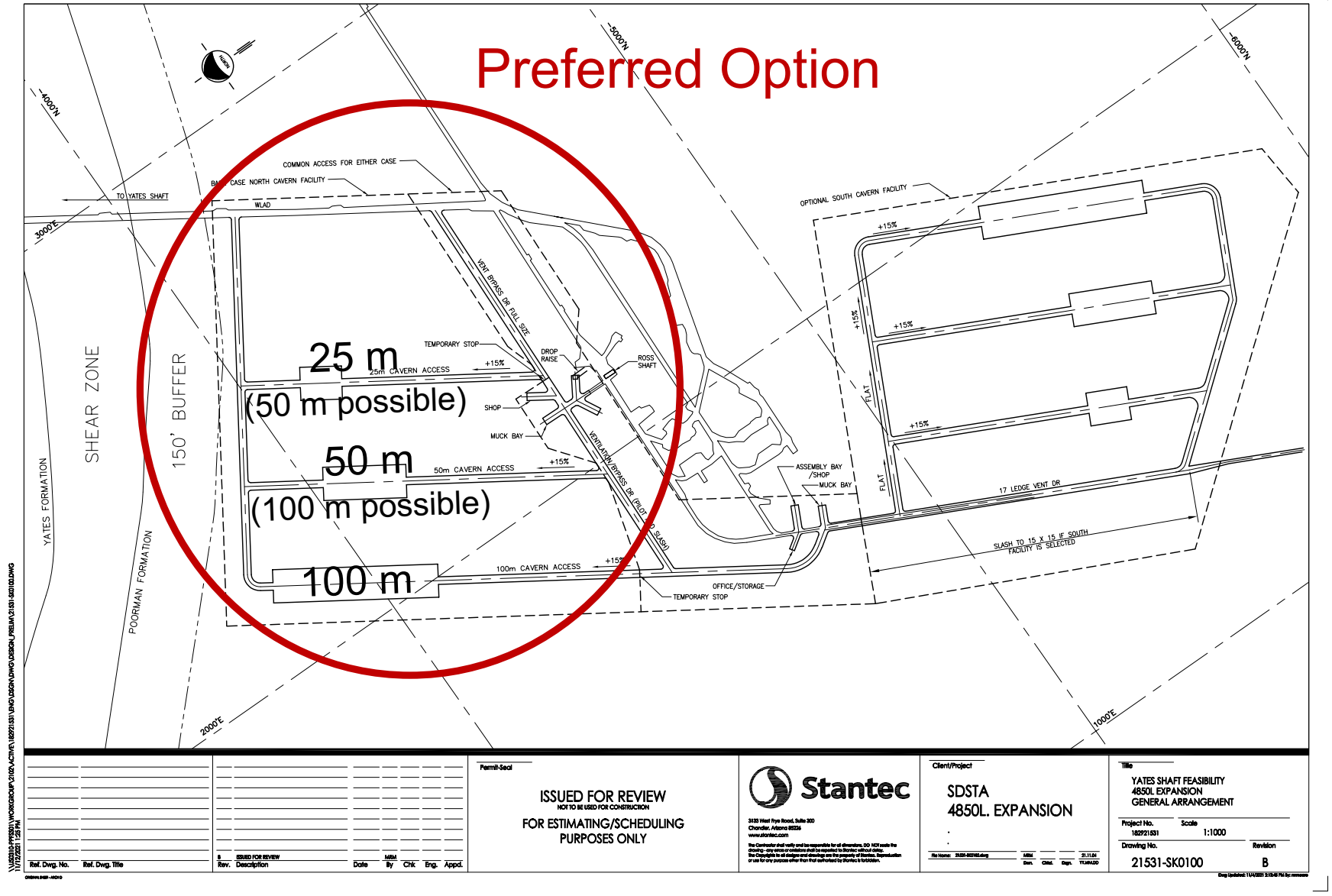
SURF Underground Facility Expansion

Feasibility concept



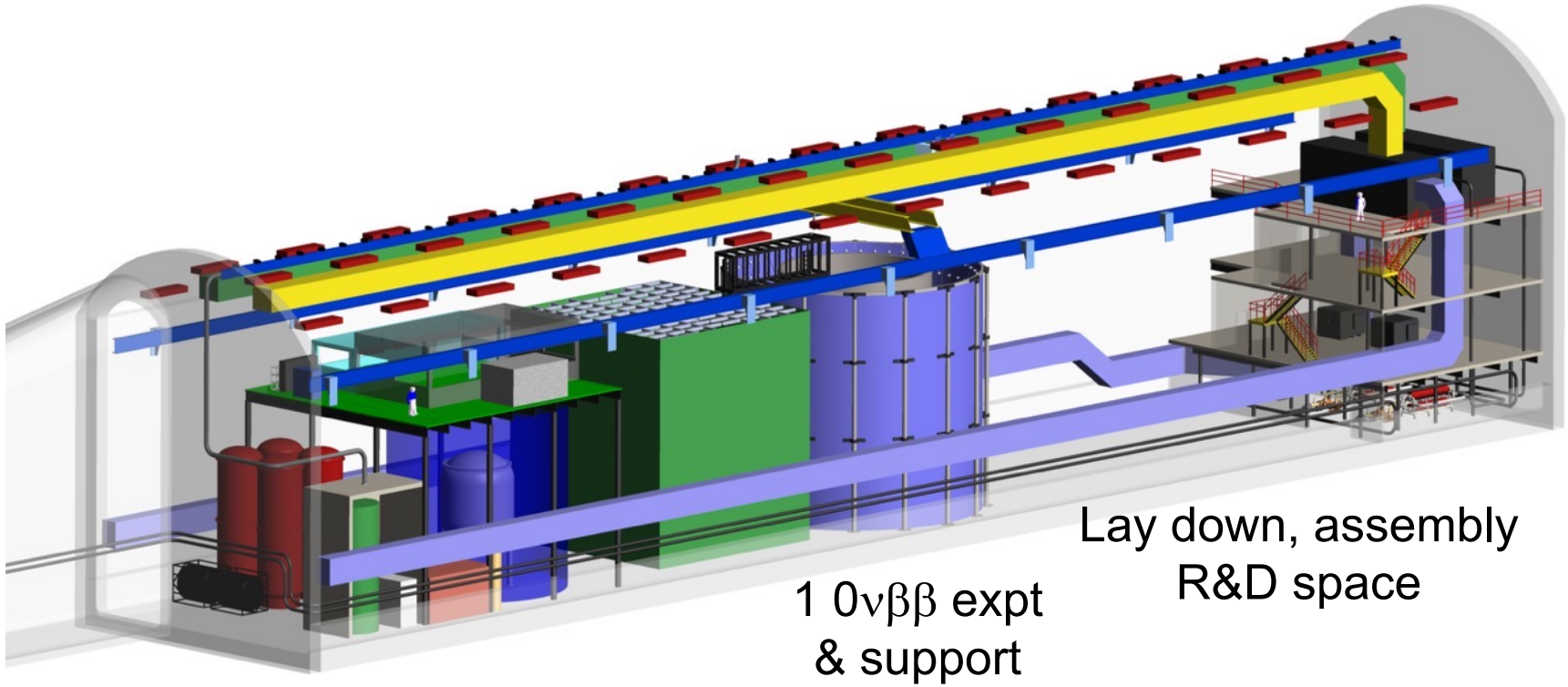
SURF Underground Facility Expansion

Feasibility concept



SURF Underground Facility Expansion

Example 4850L experiment hall layout

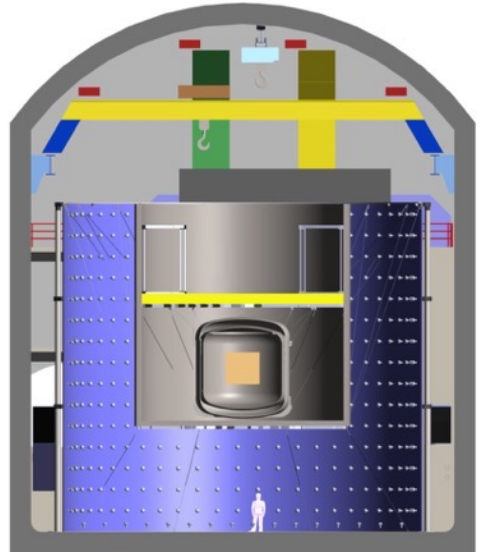


Mechanical
& electrical

Lay down, assembly
R&D space

1 $0\nu\beta\beta$ expt
& support

1 dark matter expt

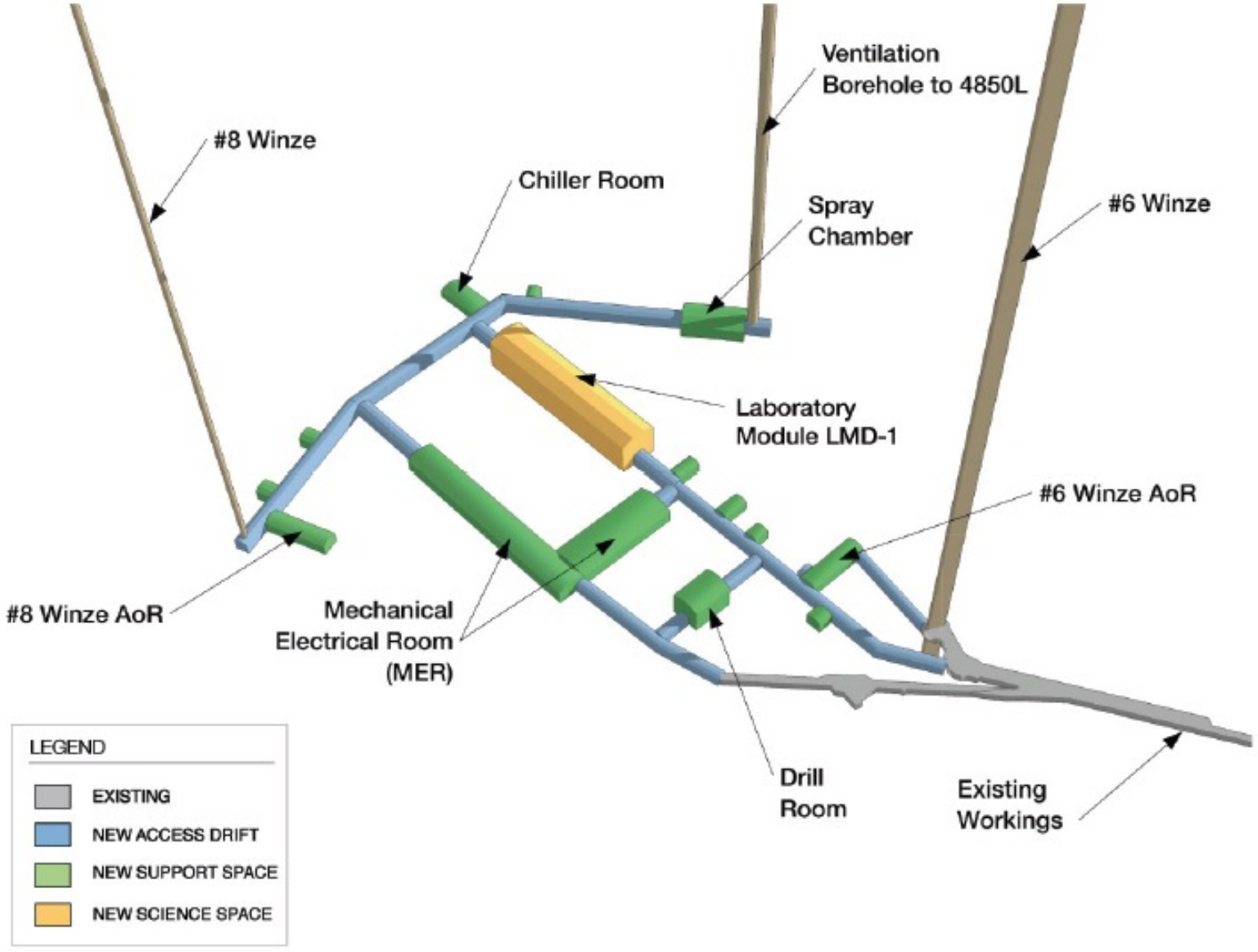


Cavern Size 20m (W) x 24m (H) x 115m (L)

(current design is 100m with additional space for utilities)

SURF Underground Facility Expansion

Example 7400L experiment hall layout



SURF Science Strategic Planning
SURF Long-Term Vision Workshop Summary

Science Space

- **All Science Disciplines:** Significant interest in additional underground space. Additional excavation both scientifically motivated and cost effective (if following LBNF/DUNE) even if precise details on which experiments not worked out yet
- **"Module of Opportunity":** Significant interest in temporary use of 4th LBNF cavern. Need (DOE?) process for engaging with community to identify potential suitable projects
- **Physics:**
  - ***LBNF/DUNE:*** *Other experiments may be able to take advantage of LBNF/DUNE neutrino beam at SURF (e.g., THEIA). Consider SURF physics focus to be neutrinos? Prediction of DUNE+ beyond 2040 (follow-on experiment to DUNE)*
  - ***Dark Matter:*** *Generation-3 detector footprint (incl shield) ~10-12 m high [20m W x 24m H lab module would work]. Also quantum sensors for low-mass dark matter (modest UG space required for some technologies)*
  - ***Neutrinoless Double Beta-Decay:*** *One more generation beyond ton-scale [20m W x 24m H lab module would work for ~100 ton, gaseous or natural Xe detector may need larger]*
  - ***Nuclear Astrophysics:*** *CASPAR at SURF still relevant even with other UG accelerators*
  - ***Atom Interferometry:*** *Vertical shaft ~1000-m length, 2.4-m diameter*
- **Quantum Computing:** Cosmic rays/radioactivity cause disruption across multiple qubits. Likely do not need deep site. Synergies could help other physics disciplines
- **Geology**: Interest in modest-scale alcoves and opportunities for scales beyond 10-100 m
- **Biology:** Interest in deep holes, diverse sites; important to access host rock
- **Engineering:** Opportunity to test new excavation techniques with new caverns at SURF

SURF Science Strategic Planning

SURF Long-Term Vision Workshop Summary

Science Support

- **Long-Term Access:** All research disciplines benefit from access afforded by dedicated science lab [DUNE will ensure longevity of SURF]
- **Low-Background Counting:** Assay capability important, consider pre-counting radiopure materials and/or maintain underground stockpile of cosmogenically-sensitive materials
- **Other Physics Support:** copper electroforming (already done at SURF, could do more), crystal growth and fabrication, long-term use of SURF's xenon (kilotonne quantities likely require new acquisition techniques)
- **Other Capabilities:** Onsite machine shop (surface and/or UG), underground GPS for timing

Misc

- UG labs can bring different research communities together to explore **synergies**
- Several (unprompted) recommendations for an **Institute** (suggestion for theme = climate change; may be significant funding opportunities)
- "No one has successfully created a true **multi-disciplinary UG lab**." SURF aspires to this goal
- "A robust Snowmass white paper on a **unified plan** for complementary strengths of underground labs worldwide would help SURF". Identify strengths so UG labs do not compete with each other on all fronts [Need input from funding agencies]
- "Focus on big projects or diverse smaller projects?" Some advocacy for **rich suite of smaller projects**

SURF User Association

Purpose

- **Two-way communication** on topics important to researchers.
- Promote a **sense of community** amongst SURF experiments and researchers.
- Articulate and promotes **scientific case for UG science** and significance to society, provides channel for **advocacy.**

Organization

- **Membership** open to Underground Science Community (initially was active SURF researchers). Annual meeting.
- **Executive Committee** consists of 9 individuals across scientific disciplines, incl early career. Two-year terms (except first year in order to provide overlap), limits per experiment and institution. Quarterly meetings.

1. Brittany Kruger (DRI/**Chair**)
2. Megan Smith (LLNL/**Secretary**)
3. Mark Hanhardt (SDSTA)
4. Kevin Lesko (LBNL)
5. Rachel Mannino (Wisconsin)
6. Ralph Massarczyk (LANL)
7. Sam Meijer (LANL)
8. Brianna Mount (BHSU)
9. Frank Streider (SD Mines)
10. Wenqin Xu (USD)

Status

- **Established** Dec 2020, operating well. Two rounds of **Executive Committee** elections conducted successfully (2020, 2021).
- **Charter** updated in Aug 2021 to broaden membership to **global underground science community**. Subcommittee ratified new registration process in Apr 2022 (need to post on SURF website, etc).
- **Charter** update in progress to reflect SPAC recommendations re: **minimum representation** from various disciplines (ratified by Executive Committee in Apr 2022, SURF to formally adopt).
- Association organized SURF **Vision Workshop** Sep 14-15, **General Meeting** Sep 28-29.

SURF Science Program Advisory Committee

Purpose

- **Science Program:** Provide guidance on overall SURF scientific program (incl current, planned/proposed experiments), as well as direction and breadth of program. Peer review per DOE User Facility
- **Science Support:** Advise on SURF experiment implementation program and organizational capacity to support experiments
- **Science Facilities:** Advise on capability and capacity of the SURF facility necessary to support the SURF scientific program

Organization

- SPAC consists of up to **14 members,** representing breadth of SURF research disciplines with strategic and synergistic influences (SDSTA Laboratory and Science Directors *ex-officio*)
- Members: **Two-year** terms (extendable). Chair: **One-year** term (extendable)
- Selection of new members made by SDSTA Laboratory + Science Directors in consultation with SDSTA IDEA Office

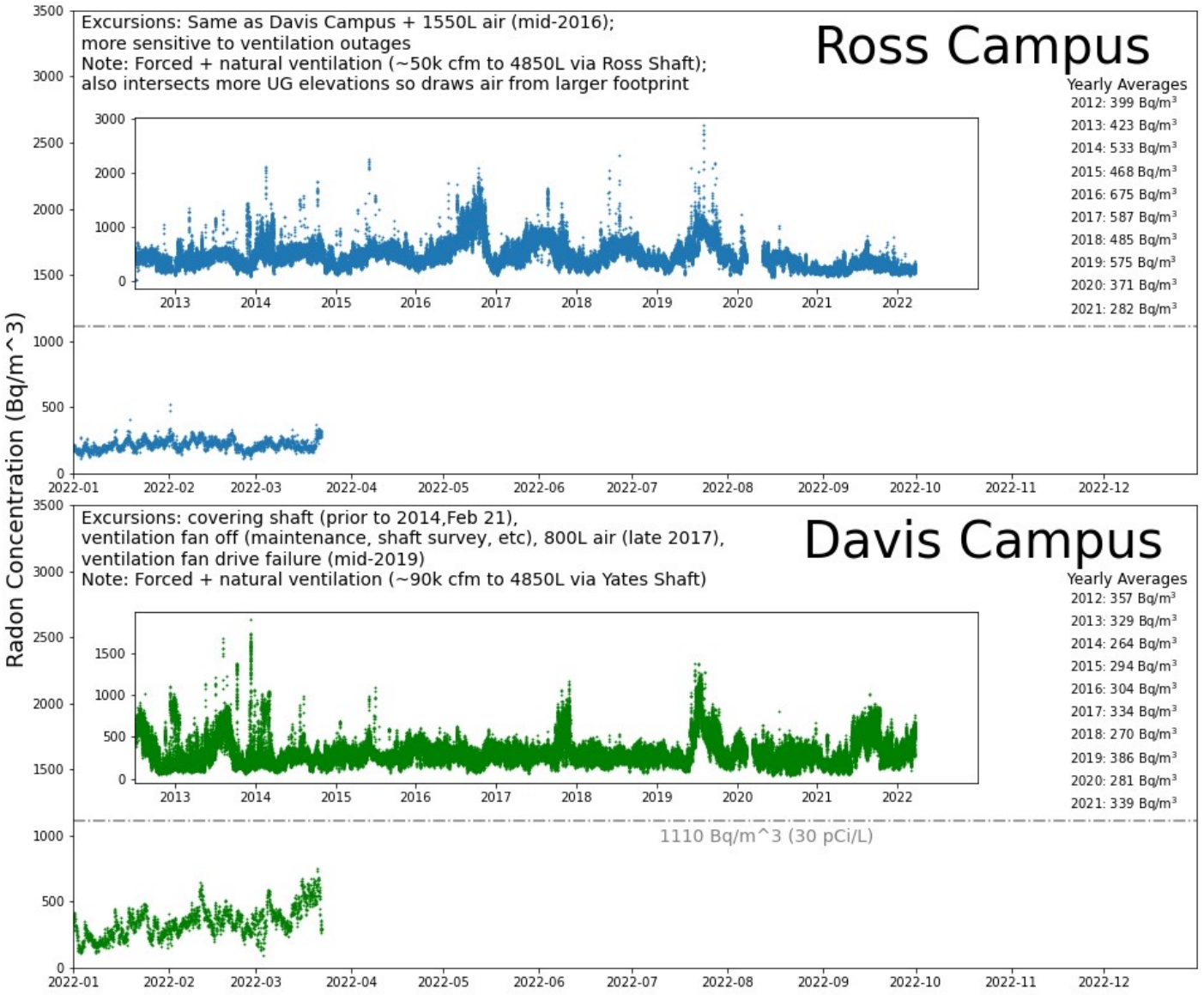
1. David MacFarlane (SLAC/**Chair**)
2. Ed Blucher (Chicago)
3. Derek Elsworth (Penn State)
4. Joseph Formaggio (MIT)
5. Hunter Knox (PNNL)
6. Magdalena Osburn (Northwestern)
7. Federica Petricca (Max Planck)
8. Lance Roberts (SD Mines)
9. Hamish Robertson (Washington)
10. William Roggenthen (SD Mines)
11. Kate Scholberg (Duke)
12. Barbara Szczerbinska (TAMU-CC)
13. Mary Voytek (NASA)
14. TBD

Status

- **Established** Sep 2021, operating well
- **First meeting held** (remotely) Jan 2022, tracking 16 recommendations (incl conducting planning workshops)
- Next meeting planned for 2022 (hopefully, in-person!)

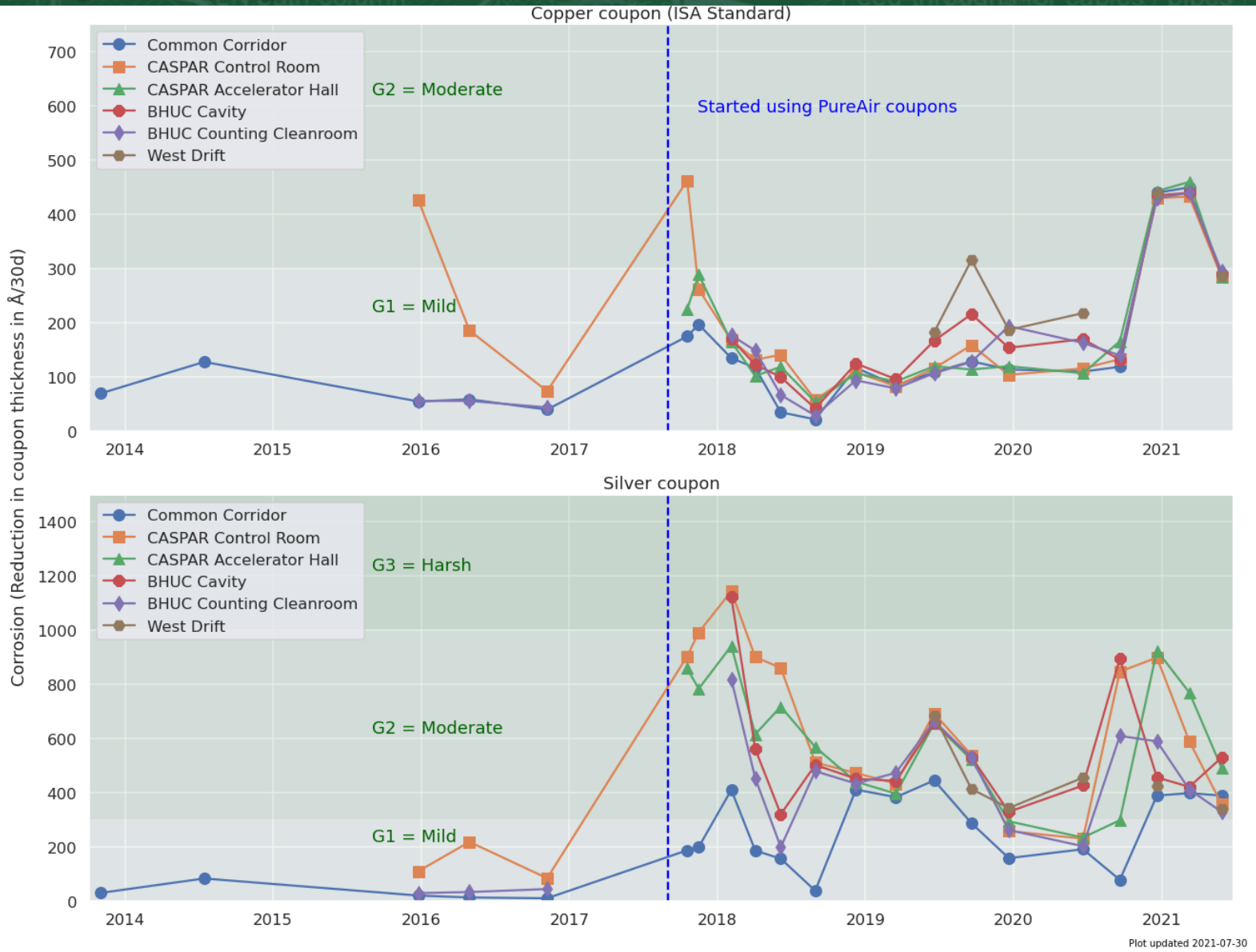
SURF Science Support – Monitoring

Radon concentrations in 4850L laboratories since 2012



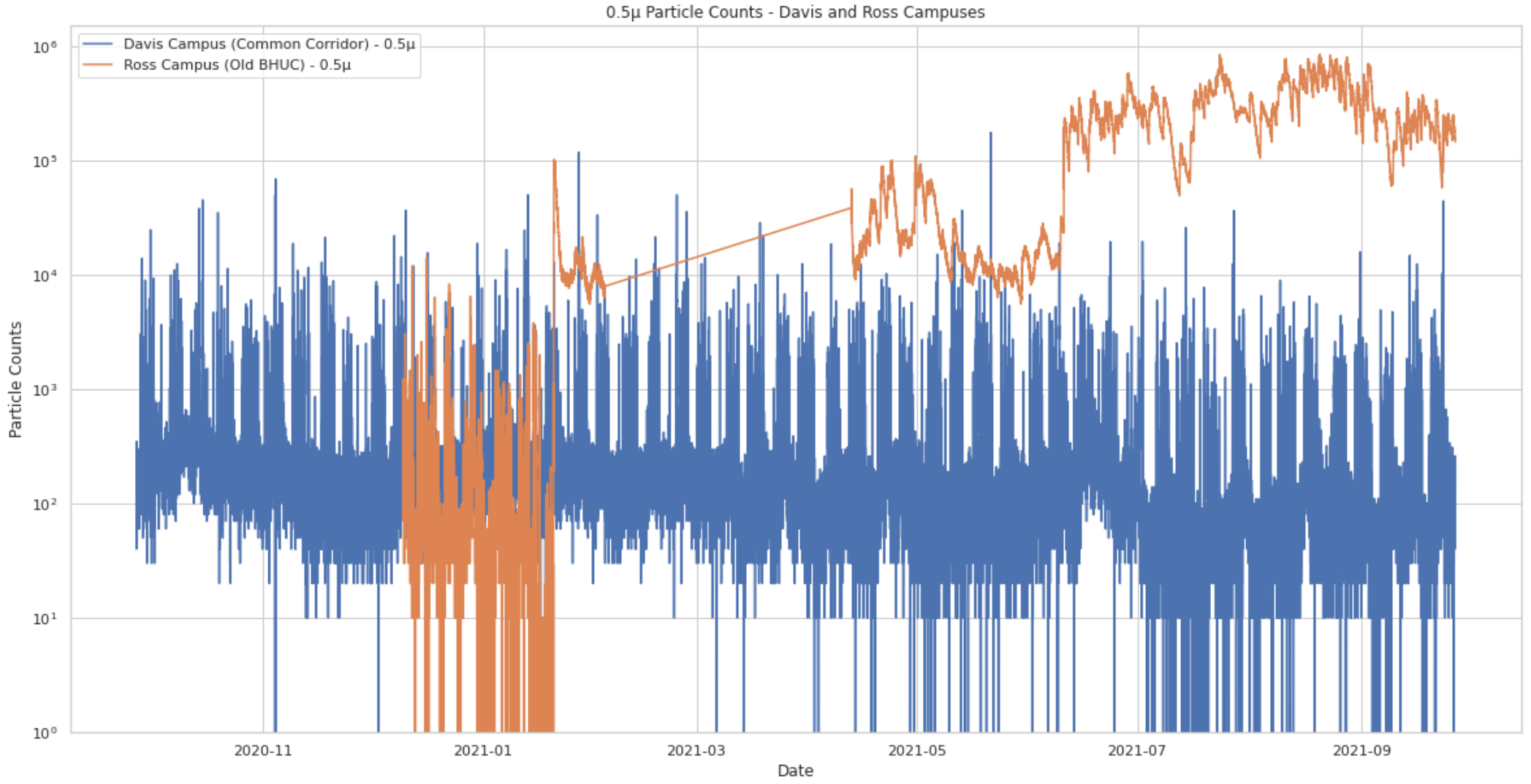
SURF Science Support – Monitoring

Corrosion/reactivity testing in 4850L laboratories since 2013



SURF Science Support – Monitoring

Particle counts in 4850L laboratories since 2013 (past year indicated)



SURF Core Values

Safety Focused: We do not compromise safety or endanger the environment. Period.

Care for Others: We embrace and honor the fundamental value and dignity of all individuals. We listen knowing everyone has something to offer and to learn.

Professional: What we do is important to our community and the world. We sweat the details to achieve big things. Our behavior and ethics exemplify our best.

Team Players: We provide unmatched service. We are respectful and deliver for our customers and partners. We build trust not barriers.