SANFORD UNDERGROUND RESEARCH FACILITY

SURF Science Overview

Jaret Heise, Science Director
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Higher Education Connections Workshop
Nov 2-4, 2025 (Pre-Record)

Jaret Heise – Science Director

- **17 years** SDSTA Science Director
- **22 years** science management experience
- **29 years** experience in underground science

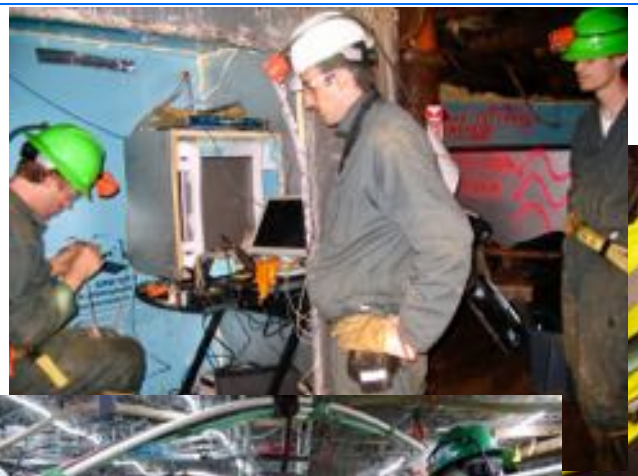
Participation in **Sudbury Neutrino Observatory** (SNO) experiment (6800-ft level of active nickel mine, now SNOLAB), which resolved Solar Neutrino Problem first posed by Ray Davis Homestake Chlorine Experiment

  - **University of British Columbia** PhD Student at SNO (detector construction, supernova neutrino search)
  - **Los Alamos National Lab** Postdoctoral Researcher at SNO (led neutron detector installation)
  - **Queen's University** SNO Detector Operations Manager (member of onsite management team)

SURF Science Program

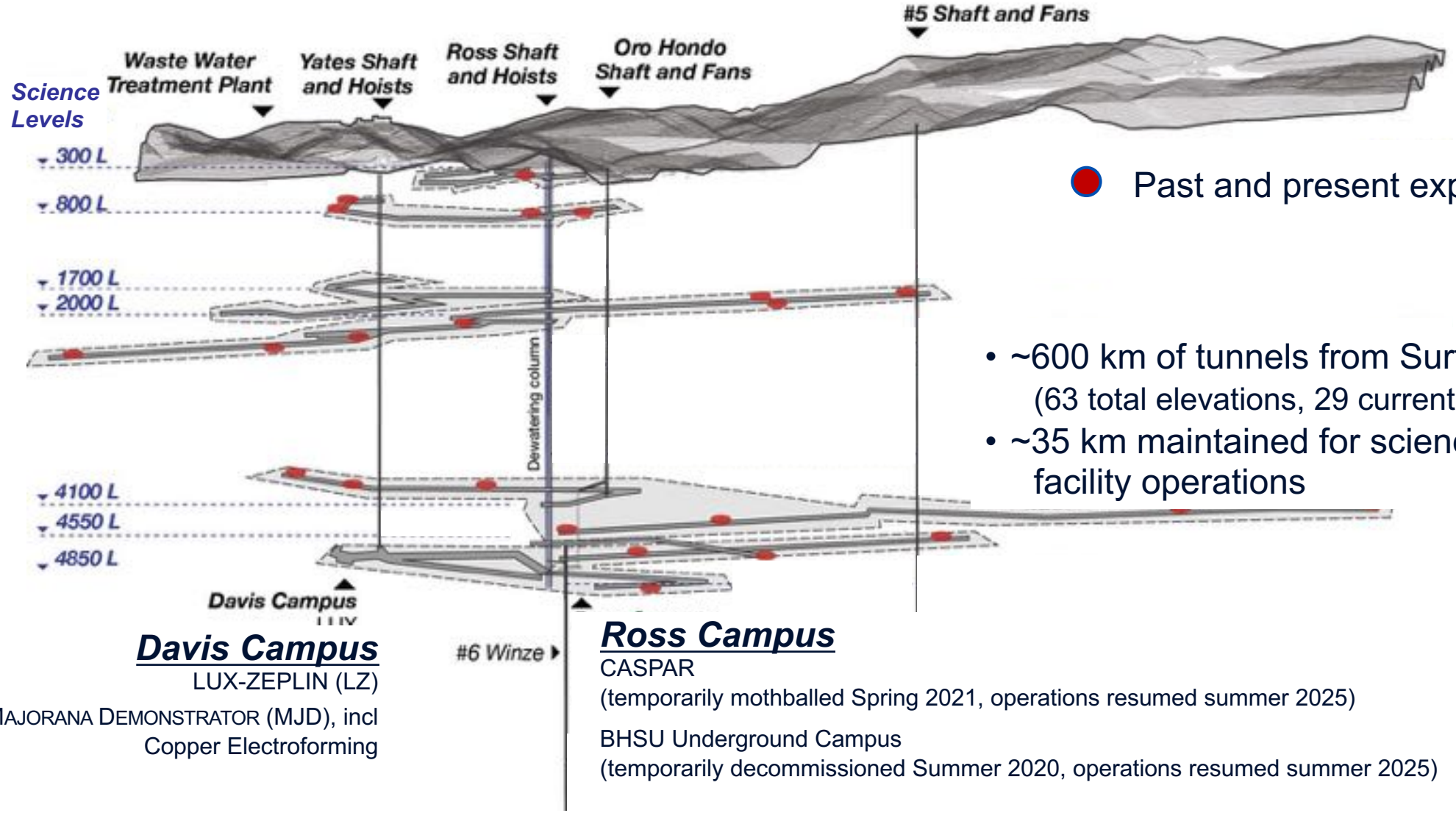
SURF serves a diverse community:

- Physics
  - Low-background environment to study rare processes (cosmic-ray muons, vibrational noise)
- 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



SURF Underground Lab Geography

Yates & Ross Shafts + ventilation shafts, multiple levels for science



Past and present experiment sites

- ~600 km of tunnels from Surface to 2.4 km deep
  (63 total elevations, 29 currently accessible)
- ~35 km maintained for science and facility operations

Davis Campus

LUX-ZEPLIN (LZ)

MAJORANA DEMONSTRATOR (MJD), incl Copper Electroforming

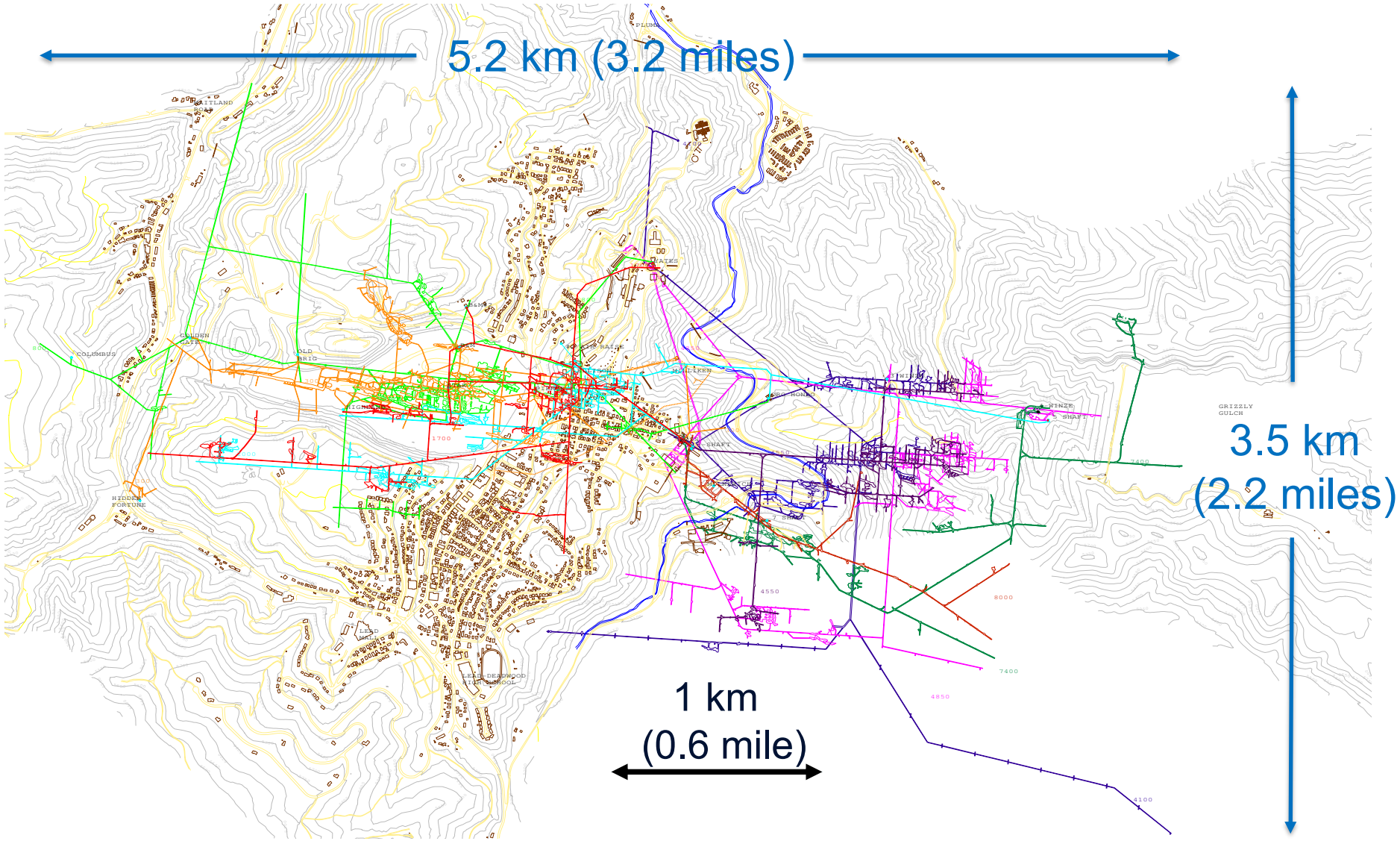
Ross Campus

CASPAR
(temporarily mothballed Spring 2021, operations resumed summer 2025)

BHSU Underground Campus
(temporarily decommissioned Summer 2020, operations resumed summer 2025)

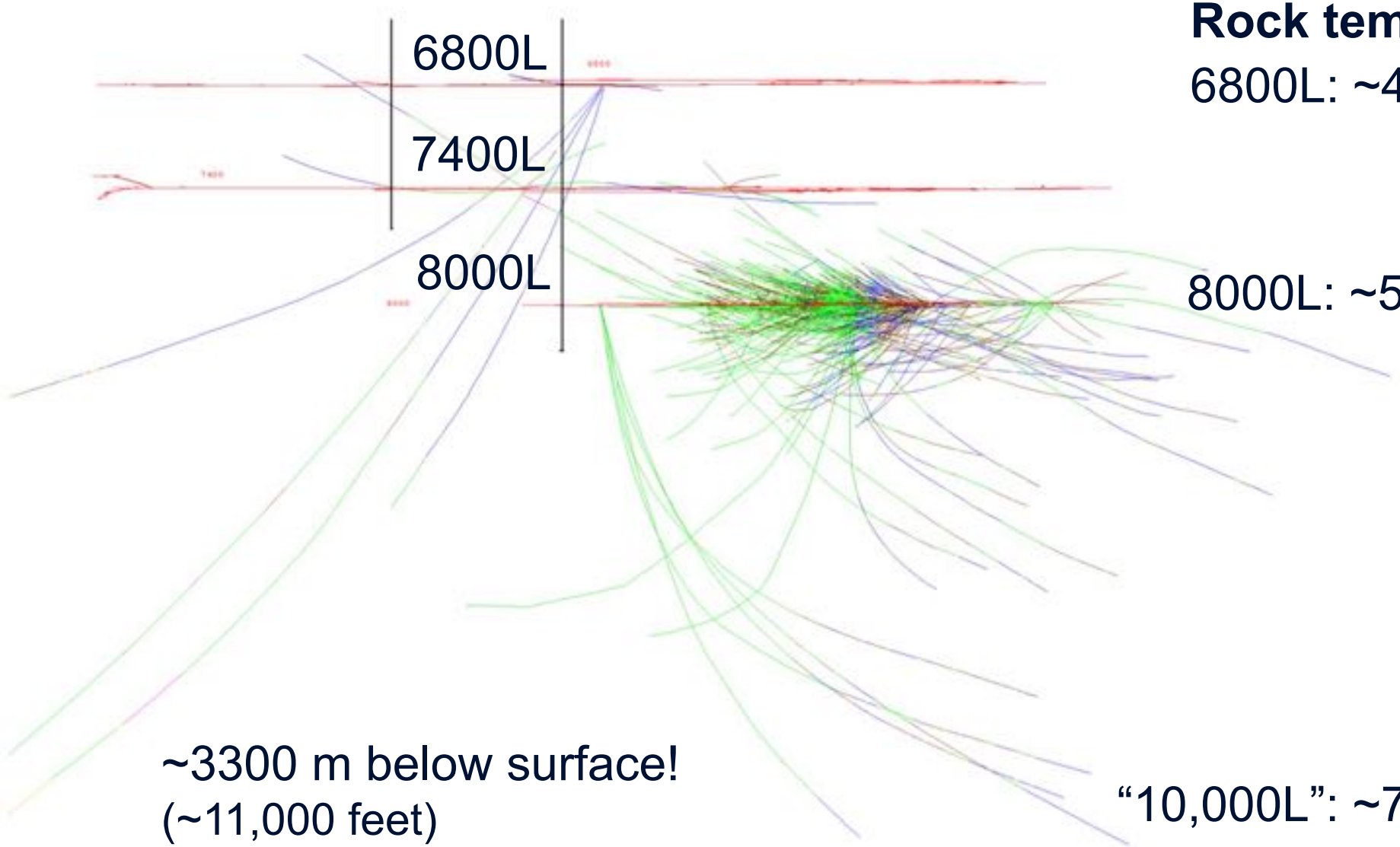
SURF Underground Lab Geography

Significant underground footprint for science



SURF Underground Lab Geography

Future possibilities to access existing deep holes?



Rock temperature

6800L: ~48 C / 119 F

8000L: ~56 C / 133 F

~3300 m below surface!
(~11,000 feet)

“10,000L”: ~74 C / 165 F


Geology and Engineering
Enhanced Geothermal Systems
Mining Technology
Biology
Extremophiles, Biodiversity
Science Program
30 Expts with 2,450 Collaborators,
319 Institutions in 55 Countries
Physics
Neutrinos, Dark Matter, and Astrophysics
Partnerships
Commercial, Technology,
Industrial, Workforce development

SURF Science Program

Research activities ranging from 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 – *Neutron bkgds*

Total = 30 groups
20 Active Projects
71 Total Groups Since 2007

Significant interest from others
(30 groups in 2025)

* Denotes proprietary group

Biology

- Astrobiology/DeMMO – *In-situ culture, isolate DNA*
- 2D Best – *Biofilms*
- Biodiversity – *Microbial communities*
- Biofuels – *Extremophile bioprospecting*
- m-sense – *Microbes and environment*
- Chemistry – *Env characterization*
- Delavie Sciences* – *Extremophiles*
- DULIA-Bio/REPAIR – *Yeast in low-radiation (multi-lab)*

Geology

- CUSSP – *Geothermal*
- DEMO-FTES – *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

- AMD (was Xilinx, Inc)* – *Chip error testing*
- Thermal Breakout – *In-situ stress*
- Shotcrete – *Mining safety*
- Enviro Monitoring – *Ventilation airflow*
- Caterpillar* – *Mining technology*
- MAP – *Microbe-assisted phytoremediation*

SURF Science Program – Current Physics Highlights

Strong and diverse program with exciting future

LUX-ZEPLIN (LZ)

- Direct search for **dark matter** using 10 tonnes xenon
- World-leading WIMP-search results announced July 2022 + Aug 2024

MAJORANA DEMONSTRATOR (MJD)

- Investigate **neutrinoless double-beta decay** using 44 kg Ge
- Ge-76 DBD and Ta-180 decay searches complete, decom underway

CASPAR

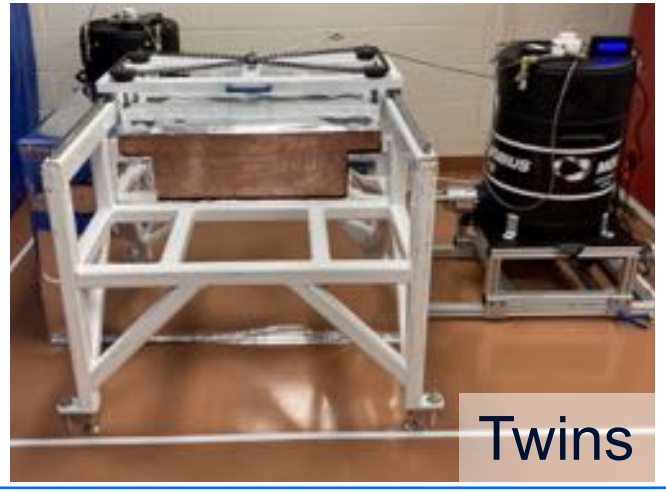
- Stellar fusion reactions to study **nucleosynthesis** using accelerator
- Initial phase 2015-2021, next phase started in 2025, last for 3+ years

SURF Material Assay at BHUC

Low-background counting capabilities serving national & international community


Mordred


Maeve & Morgan


Twins


RHYM/RESN


Ge-IV

Geology: DEMO-FTES

Demonstration of Fracture Thermal Energy Storage

- **Science Goal:** Study enhanced geothermal system (EGS) and fracture thermal energy storage (FTES) effects.
- **Collaboration:** DEMO-FTES (12 members, 4 institutions) [DOE EERE, Geothermal Technology Office (GTO)]
- **Status:**
  - Onsite starting Dec 2023 (other geothermal since Jun 2016).
  - Leveraging 4100L site: 11 drill holes (180-265 m long) and some existing instrumentation (no new drilling).
  - Electrical upgraded for water heater (source of stored heat).
- **Future:**
  - DEMO-FTES activities at SURF expected through 2025.
  - CUSSP geothermal project started in 2024, hoping for DOE funding ramp up.
  - Other community interest in geothermal at SURF with DOE calls for proposals summer 2025.

FTES 4100L

CUSSP meeting at SURF

Biology: DeMMO

Deep Mine Microbial Observatory

- **Science Goal:** Explore and understand rock-hosted microbial ecosystems by performing long-term water sampling.
- **Collaboration:** DeMMO (7 members, 2 institutions); lead = Northwestern [institutional funding]
- **Status:**
  - Onsite since 2014.
  - Initial NASA project w/ synergistic collaboration between biology, geology & physics (NASA funding 2014-2018).
  - Outfitted 6 holes for long-term monitoring, 1 site impacted by 4850L Expansion waste rock.
  - Drill core analysis incl JPL's *in situ* laser spectrometer SHERLOC, technology concept used on Mars Perseverance rover:
    - Recent news! https://www.jpl.nasa.gov/news/nasa-says-mars-rover-discovered-potential-biosignature-last-year/
- **Future:**
  - Continue sampling indefinitely (and somewhat infrequently).

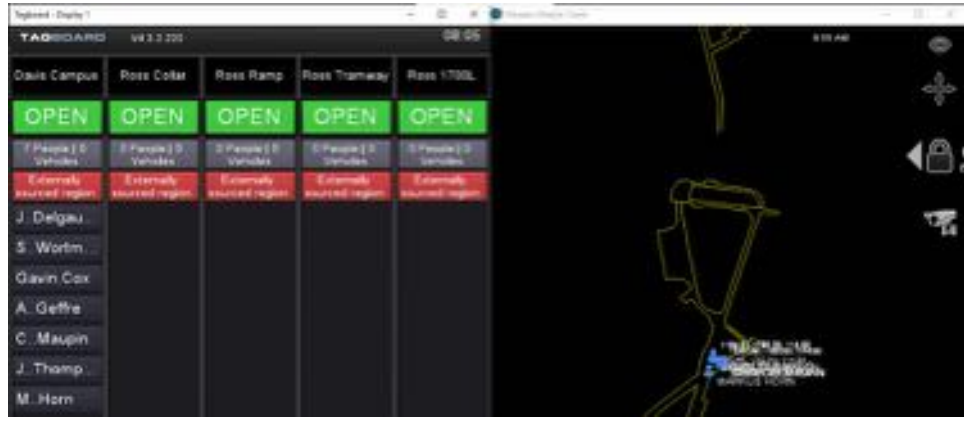
DeMMO water sampling

Life on Mars?!

CAT

Caterpillar Underground Research Center

- **Industrial Partnership Goal:** Provide real-world, interactive environment for customer experiences, training and new product implementation.
- **Collaboration:** 12 core members (total of 334 ppl, incl customer groups), 50 institutions, lead = Caterpillar [institutional funding]; proprietary group requires full DOE cost recovery
- **Status:**
  - Onsite since Aug 2020 (initial inspections Feb 2019).
  - Former motor & loader barns (~925 m^2), ~1000-m ramp. Total of 17,000+ rock bolts, 3000+ mesh panels, new rail.
  - Over 1.5 km of MineStar tracking technology distributed throughout 1700L and ramp to 1550L.
  - 6 utility vehicles currently UG at SURF using tracking technology.
  - Tracking system operating (4850L, 1700L, surface), system optimization and expansion continues.
- **Future:**
  - 10-year agreement through Sep 2030.



SURF High-Impact Science

Hundreds of papers have been published on science at SURF

- Characterization of thermostable cellulases produced by *Bacillus* and *Geobacillus* strains, G. Rastogi, A. Bhalla, A. Adhikari, K. M. Bischoff, S. R. Hughes, L. P. Christopher, R. K. Sani *Bioresource Technology* **101**, 8798 (2010) doi: 10.1016/j.biortech.2010.06.001.
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- First Limit on the Direct Detection of Lightly Ionizing Particles for Electric Charge as Low as e/1000 with the MAJORANA DEMONSTRATOR, S. I. Alvis *et al*. (MAJORANA Collaboration) *Phys. Rev. Lett.* **120**, 211804 (2018) doi: 10.1103/PhysRevLett.120.211804.
- 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.
- Geological activity shapes the microbiome in deep-subsurface aquifers by advection, Y. Zhang, R.N. Horne, A.J. Hawkins, J.C. Primo, O. Gorbatenko, A.E. Dekas, *PNAS* **119**, 2113985119 (2022) doi: 10.1073/pnas.2113985119.
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- Final Results of the MAJORANA DEMONSTRATOR's Search for Double-Beta Decay of ^{76}Ge to Excited States of ^{76}Se, I. J. Arnquist *et al*. (MAJORANA Collaboration) *Phys. Rev. Lett*. **134** 242501 (2025) doi: 10.1103/PhysRevLett.134.242501.
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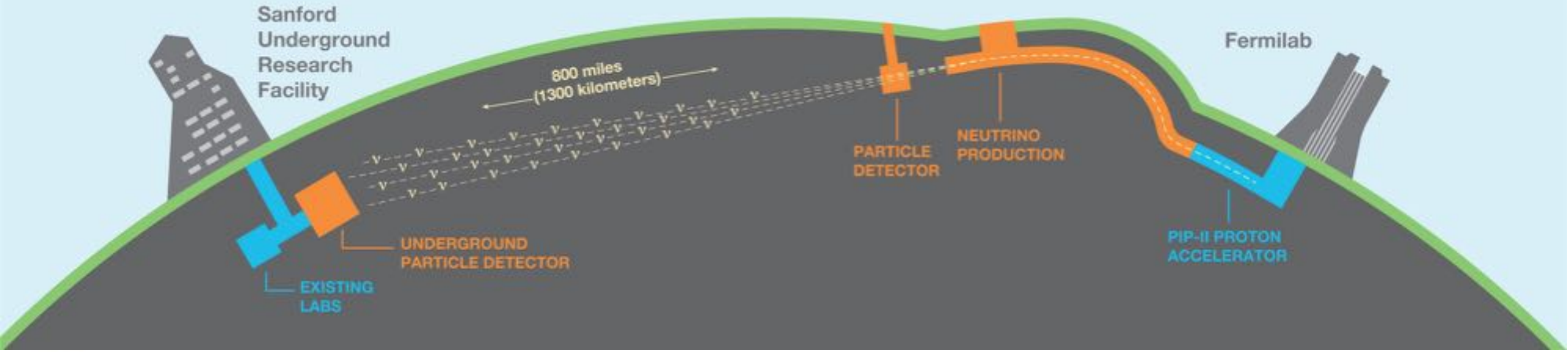
Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

U.S. DOE's Flagship Neutrino Experiment



Origin of matter: Investigate CP violation. Are neutrinos the reason the universe is made of matter?

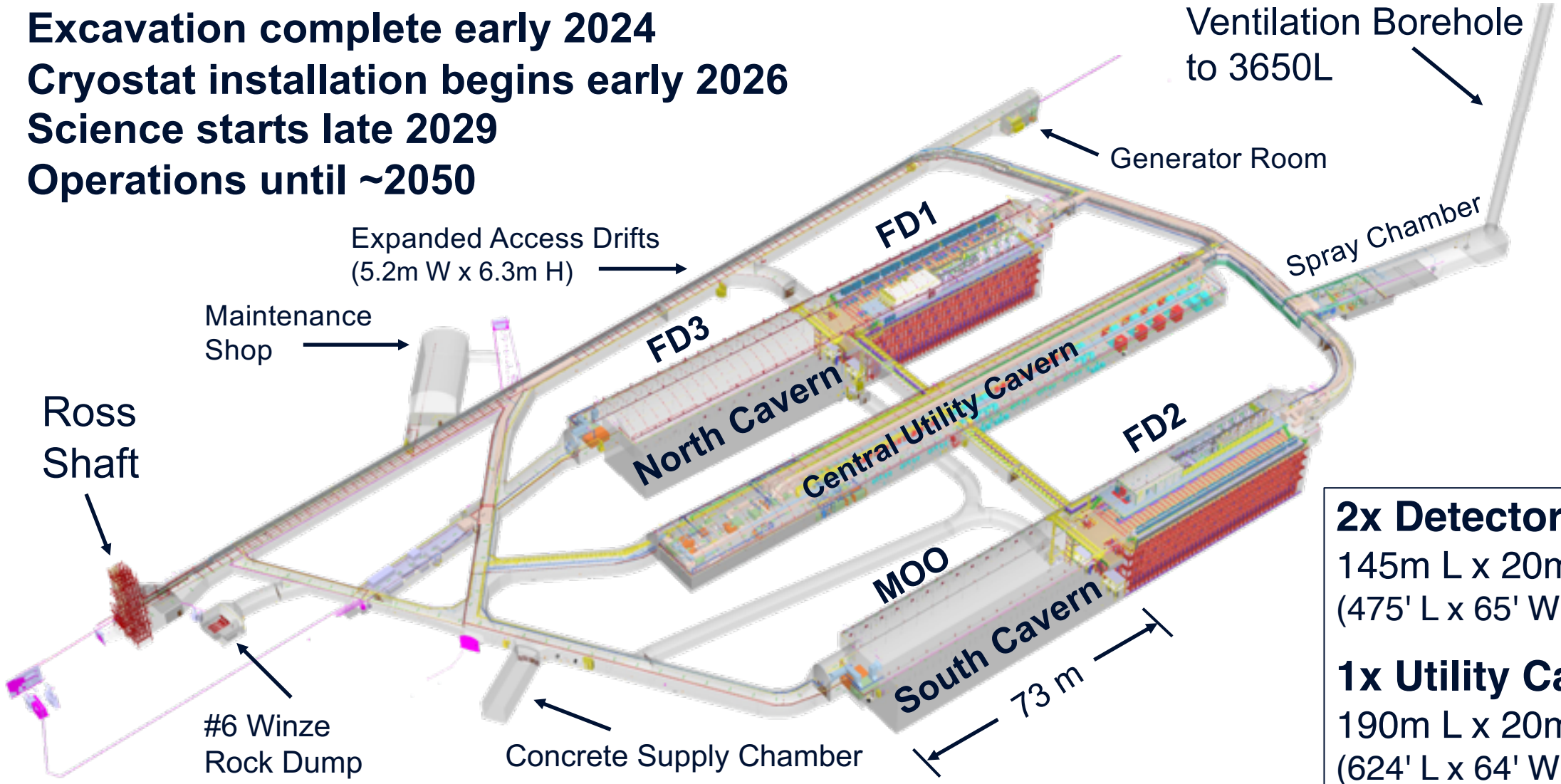
Supernova explosions and black hole formation: Ability to observe neutrinos from supernovae events and neutron star (or possibly black hole!) formation in real time.

Unification of forces: Investigate nucleon decay, advance unified theory of energy and matter.

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Excavation complete early 2024
Cryostat installation begins early 2026
Science starts late 2029
Operations until ~2050

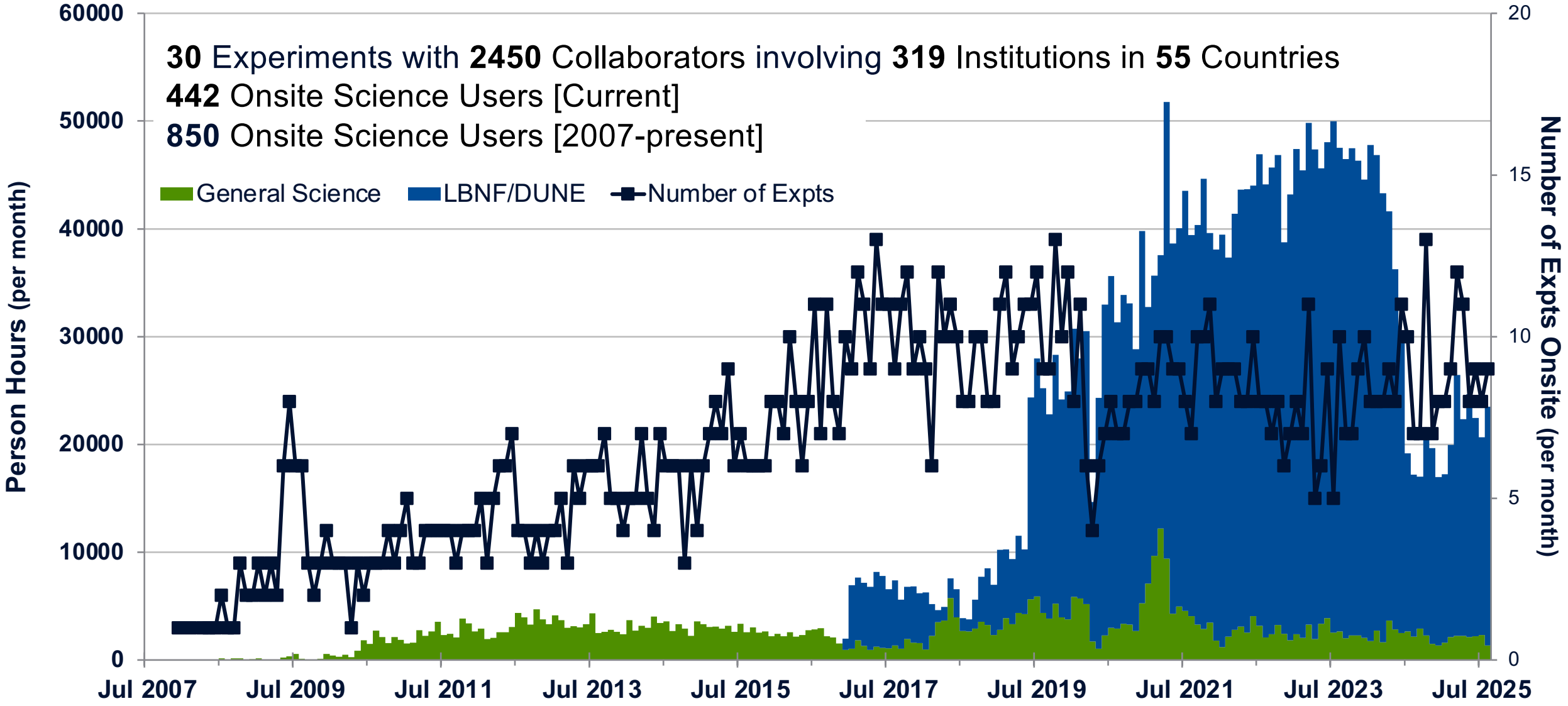


2x Detector Caverns:
145m L x 20m W x 28m H
(475' L x 65' W x 92' H)

1x Utility Cavern:
190m L x 20m W x 11m H
(624' L x 64' W x 37' H)

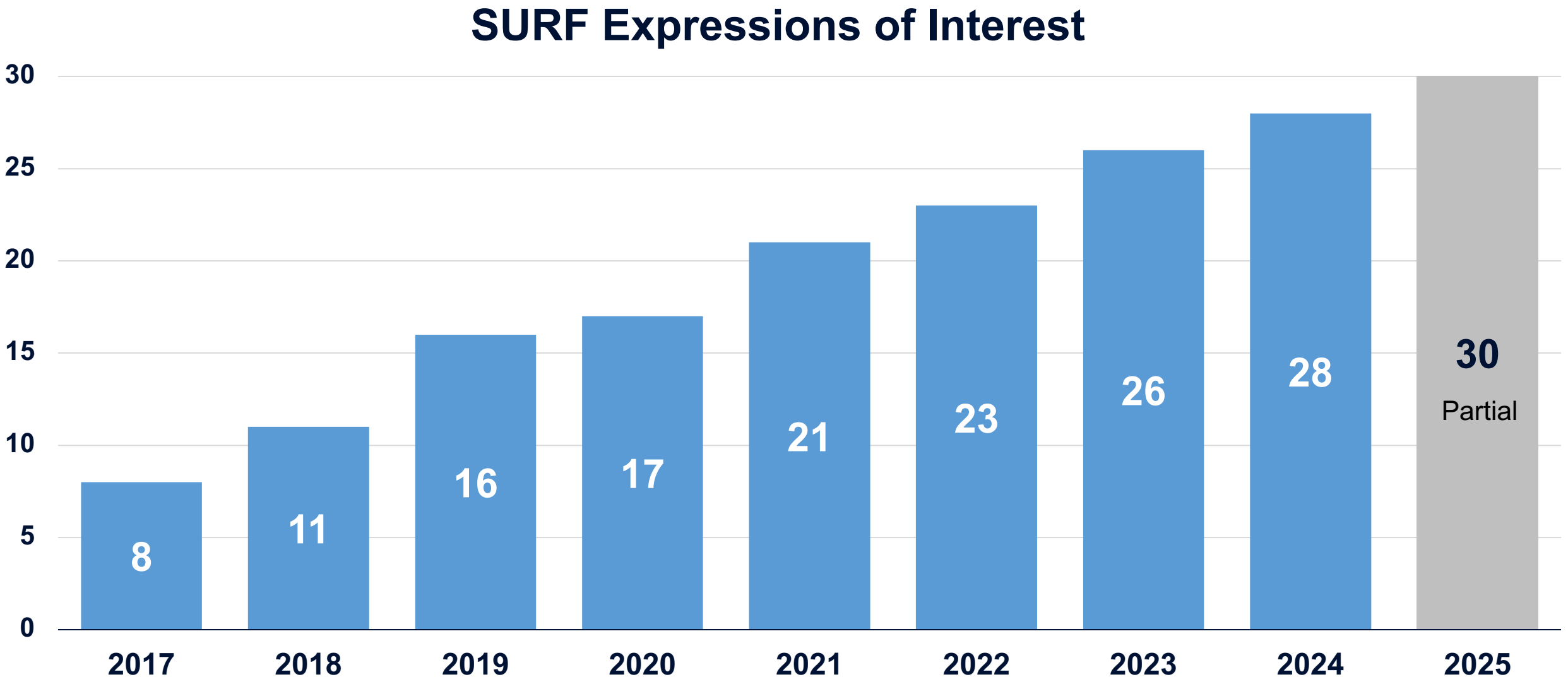
SURF Science Program

Hosting world-leading experiments and researchers from diverse scientific communities



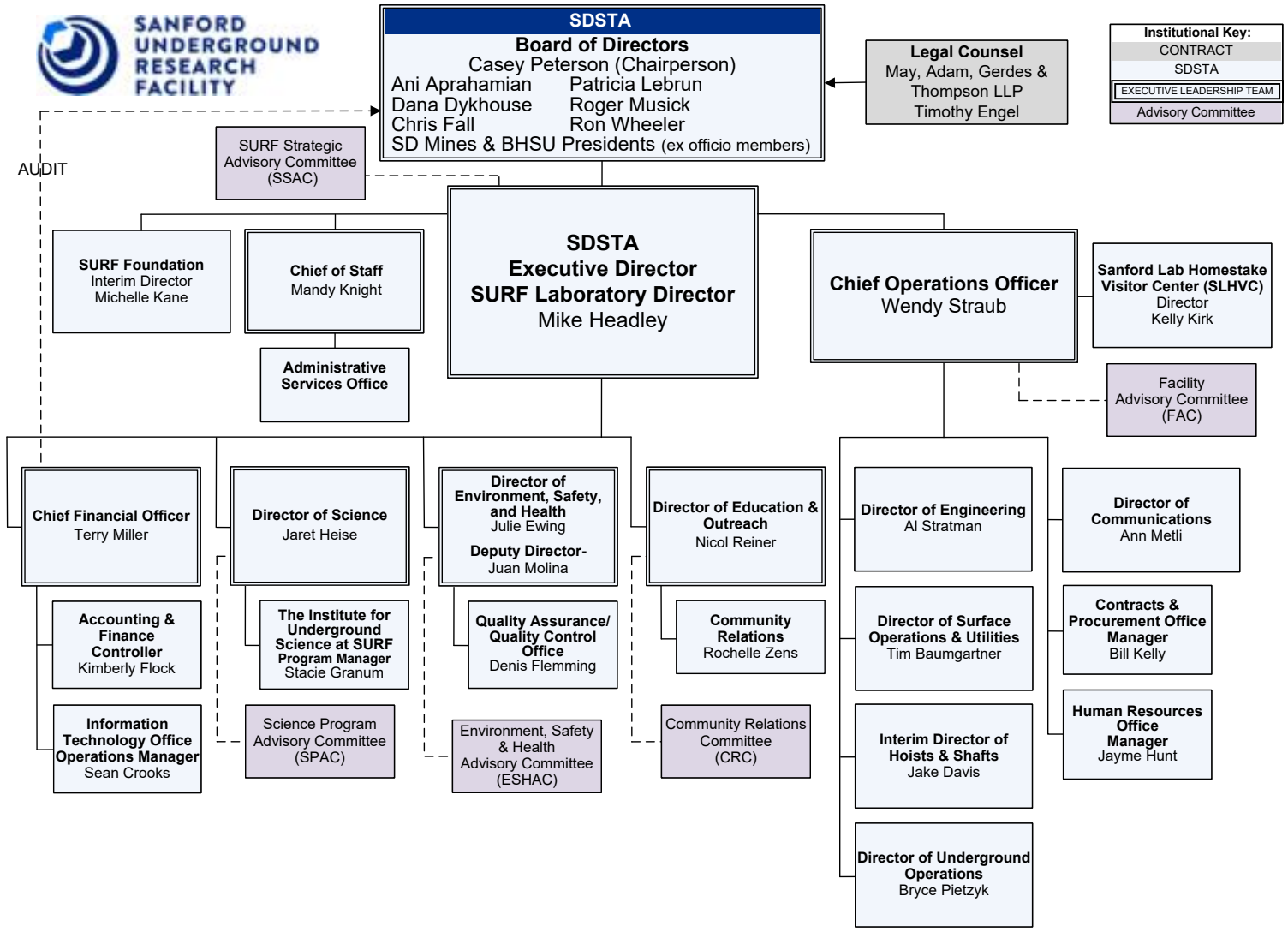
SURF Science Program

Growing interest from the underground science community



SDSTA Organization

Robust organization: 9 depts, 5 offices + Institute, Visitor Center and Foundation



Staffing Area	Current FTE (%)	FY29 FTE (%)
Admin / Mgmt	31 (15%)	31 (13%)
Engineering	12 (5%)	12 (5%)
ESH	21 (10%)	23 (10%)
Outreach	23 (11%)	24 (10%)
Scientific	5 (2%)	6 (3%)
Technical / Operations	128 (58%)	142 (60%)
TOTAL	**220**	**235**

Current Science Direct Support = ~19 ppl

SDSTA Organization – Science Staffing

Resources to enable safe and successful implementation of experiments

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

SURF has robust organization:
9 Depts + 5 Offices + Institute

Gavin Cox (MS)
Expt Support Scientist
- LZ Operations

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

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

Julia Delgaudio (BS)
Expt Support Scientist
- LZ Operations

Robyn Weis - *Lab Custodians (Surface + UG)* - Dee Espinosa

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

+ Many Others!
Engineering, ESH, OPS…

Christopher Kreitzinger
Support Associate
- Admin, User Association

SURF Experiment Implementation & Support

Main Science documents under IMS/ISO document control

Experiment Implementation Program

- Integral to the SDSTA institutional mission is advancement of compelling underground, multidisciplinary research
- EIP framework allows experiments to be implemented at SURF in effective and efficient manner
- References several key elements:
  - Experiment Planning Statement
  - User Agreement (was MOU)
  - Publication Policy
  - Experiment Decommissioning Statement

Experiment Integration & Support

- In partnership with research groups, SDSTA aims to maintain a robust organization with resources to promote safe and successful experiment operations at SURF
- References several key elements:
  - Several specific ESH Standards (incl Work Planning)
  - SURF Applications/Databases (TAP, SARF, etc)
  - Table of responsibilities (SDSTA and Experiment)
  - Perception Survey, Information for Researchers, etc

SURF User Association

https://sanfordlab.org/surf-user-association (incl registration)

Purpose

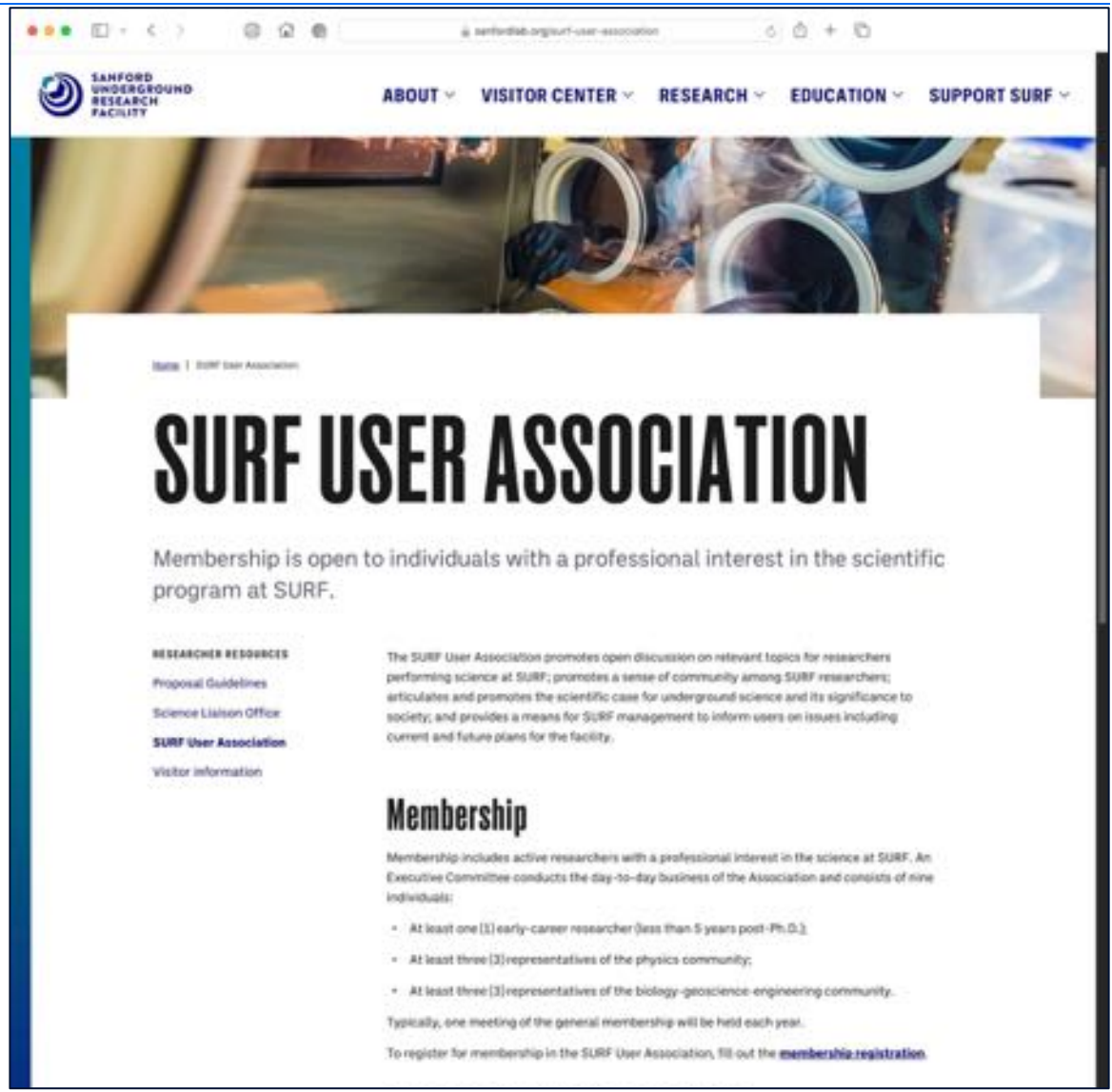
- **Two-way communication** on topics important to researchers.
- Promotes a **sense of community** amongst SURF experiments and researchers.
- Articulates and promotes **scientific case for UG science** and significance to society, provides channel for **advocacy**.

Organization

- **Membership** open to all UG science community.
- **Executive Committee** consists of 9 individuals across scientific disciplines, incl early career. Quarterly meetings with SURF Management.

Meetings

- **General meetings** typically held annually, last at CoSSURF 2024 (no CoSSURF 2026 planned).
- **Topical workshops**, incl community planning (e.g., Vision Workshop 2021). Next workshops in 2026.



South Dakota Science & Technology Plan

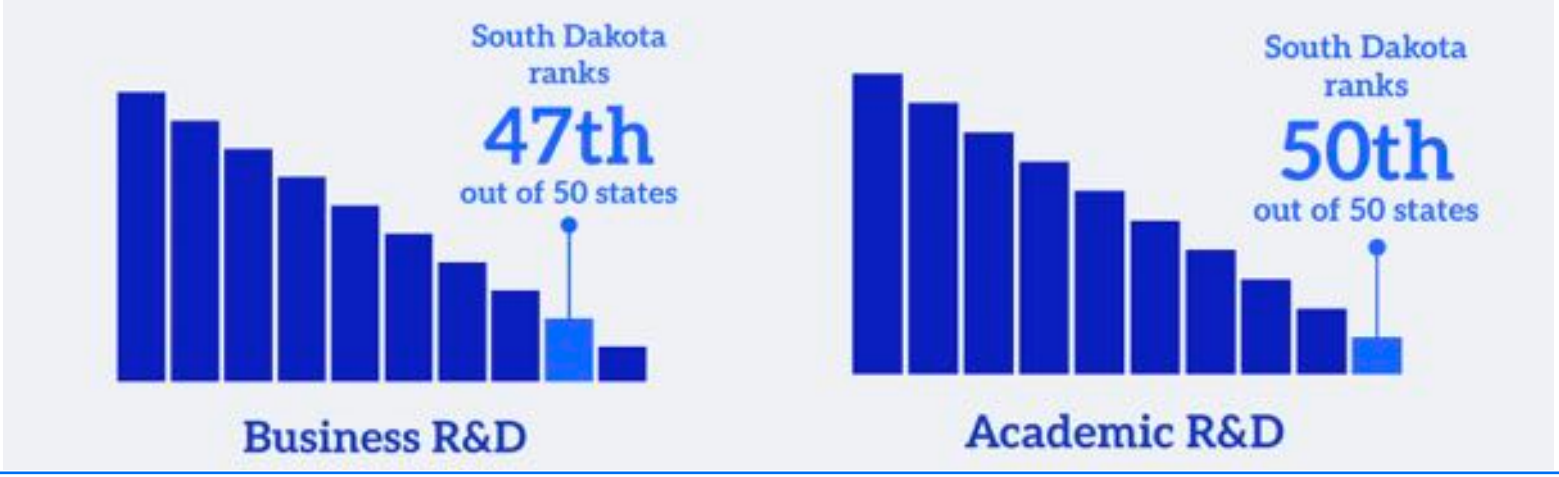
High-priority research areas have strong links to SURF

Vision:

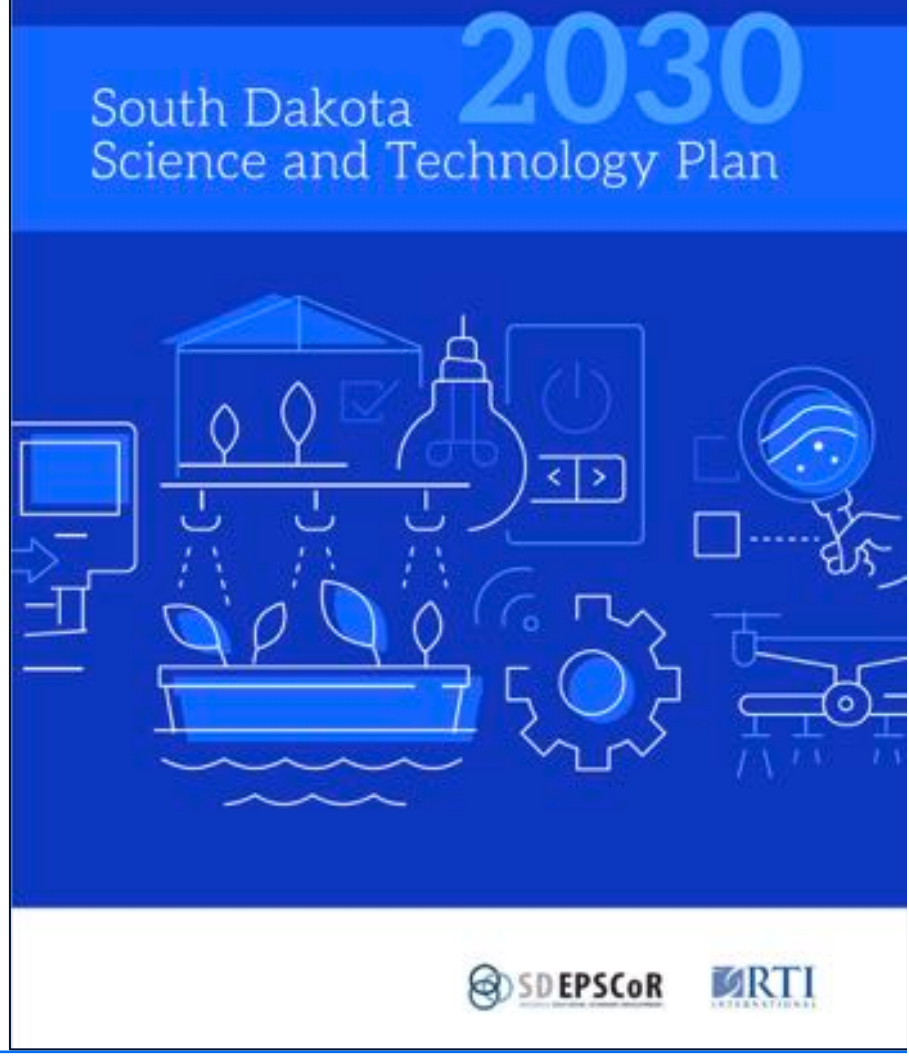
- South Dakota invests in research and commercialization to drive economic growth and diversification and to educate a highly prepared STEM workforce.

High-Priority Research Areas:

- Computational Science
- Cybersecurity
- Fermentation & Bioprocessing
- Health, Food & Nutrition
- Environmental & Biological Sciences
- Materials
- **Deep Underground Science**



https://sdepscor.org/sd-science-technology-plan



SURF Science Strategic Plan

Physics elements incorporated into organization long-term vision

Goals:

- **Program:** Attract world-leading scientists and experiments
- **Facilities:** Ensure SURF facilities support science program
- **Support:** Ensure organizational capabilities serve experiments
- **Engagement:** Establish strong SURF role in global UG science community

Scope:

- Organize science strategic plan in two parts: Physics and Non-Physics

Physics (closely aligned with top U.S. national priorities):

- DUNE support (Phase 1 and Phase 2)
- Generation 3 Dark Matter (XLZD and/or ARGO)
- 'Agile' Experiments / Low-Mass Dark Matter
- General R&D facility

} **Cryogenic User Facility w/ dilution refrigerator**

- Generation 2 Dark Matter upgrade (LZ → HydroX, CrystaLiZe, etc)

Non-Physics:

- Several expert panel discussions so far, aim for report in late 2025

4850L Space Needed for Future Experiments

U.S. strategic plan recognized need for more UG space, endorsed expansion

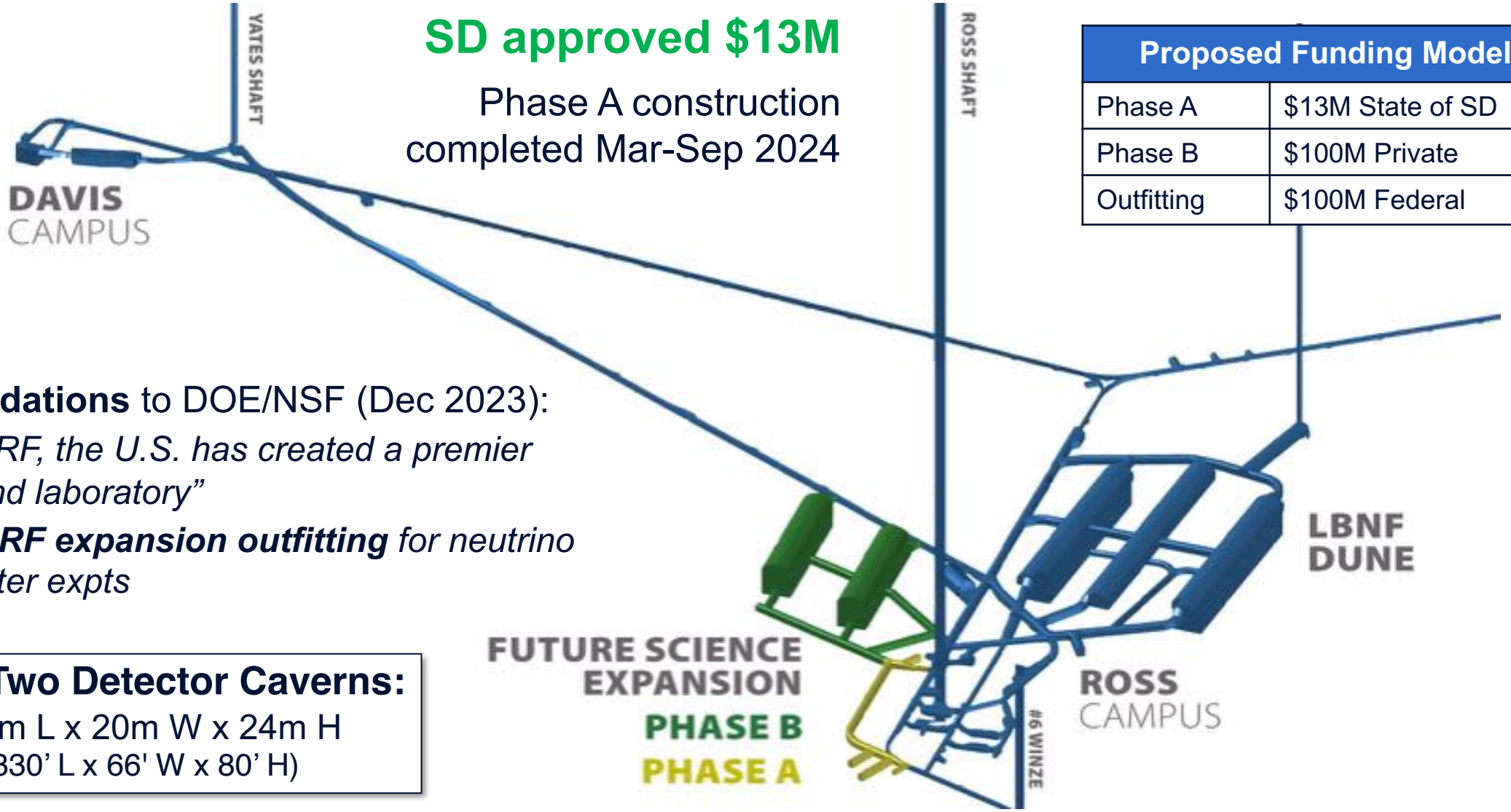
SD approved $13M

Phase A construction completed Mar-Sep 2024

Proposed Funding Model	
Phase A	$13M State of SD ✓
Phase B	$100M Private
Outfitting	$100M Federal

P5 recommendations to DOE/NSF (Dec 2023):

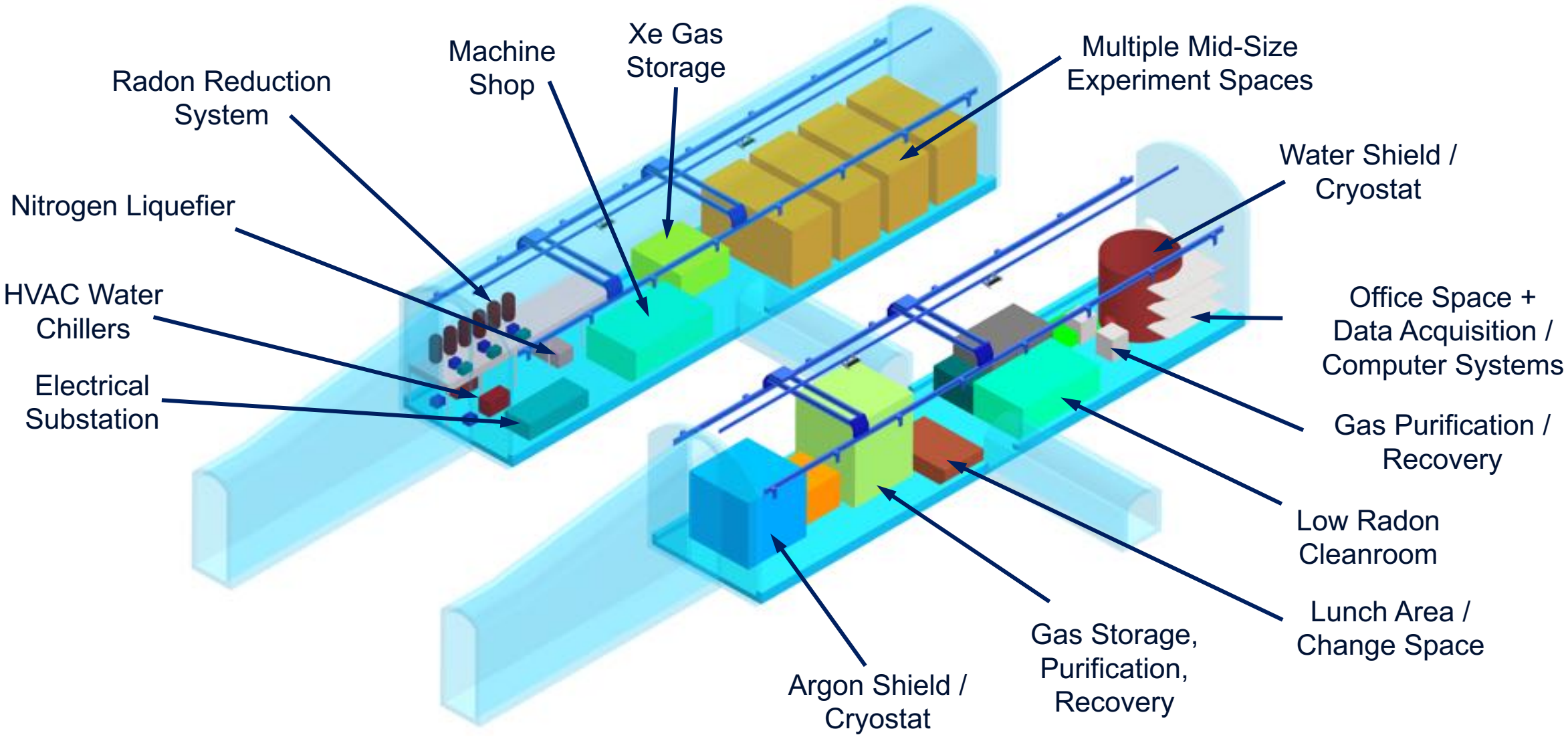
- *"With SURF, the U.S. has created a premier underground laboratory"*
- ***Fund SURF expansion outfitting*** *for neutrino & dark matter expts*



Up to Two Detector Caverns:
100m L x 20m W x 24m H
(330' L x 66' W x 80' H)

Big Science at SURF

Conceptual layout (2x 100m caverns), informed by DUSEL PDR, ARGO/XLZD, LZ



South Dakota Support for Quantum Initiatives

Notable state investment attracting interest, also federal congressional support

24.585.12 99th Legislative Session 45

2024 South Dakota Legislature

Senate Bill 45

ENROLLED

An Act

ENTITLED An Act to make an appropriation for the establishment of a Center for Quantum Information Science and Technology and to declare an emergency.

Be it enacted by the Legislature of the State of South Dakota:

Section 1. There is hereby appropriated from the general fund the sum of $3,034,444 to the Board of Regents, for the purpose of establishing a Center for Quantum Information Science and Technology.

Gov. Noem signs bill to fund Center for Quantum Information Science and Technology

Governor Kristi Noem signed SB 45, which funds the establishment of a Center for Quantum Information Science and Technology.

Quantum Partnership Workshop (2024, 2025)
https://indico.sanfordlab.org/e/QPW2024 / QPW2025

Growing community both within SD and beyond,
~50% increase in participation year-over-year

Save the Date for QPW2026: **Jul 22-24, 2026**

SURF Cryogenic User Facility Partners

Many more expected once facility available

South Dakota

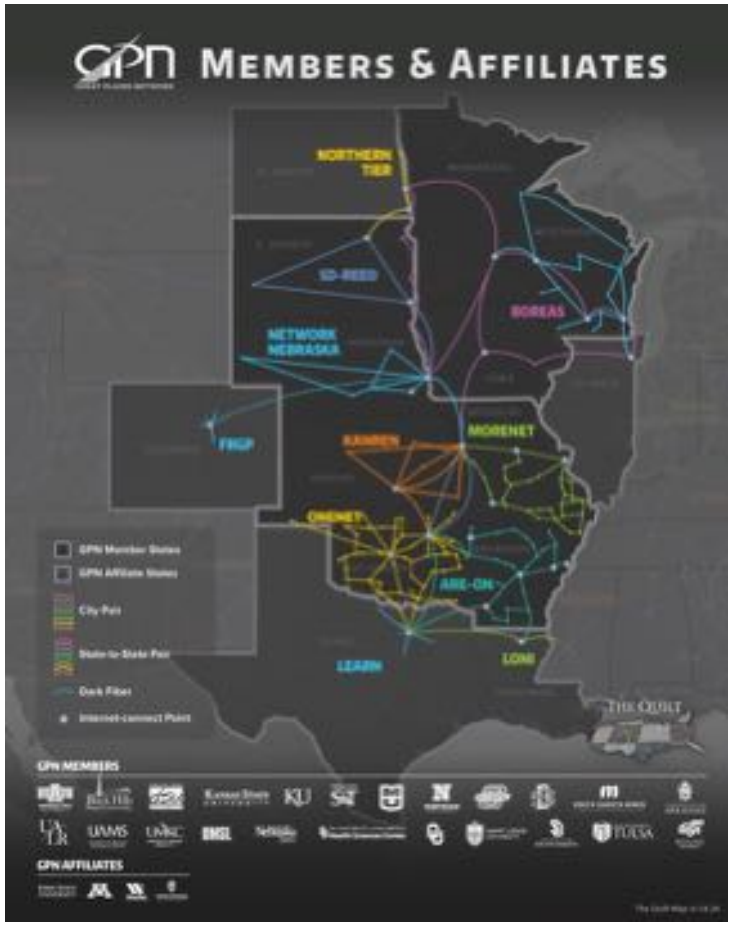
VIRGINIA TECH

Los Alamos NATIONAL LABORATORY

BERKELEY LAB

GREAT PLAINS NETWORK

6 States,
23 Members
(incl SD)

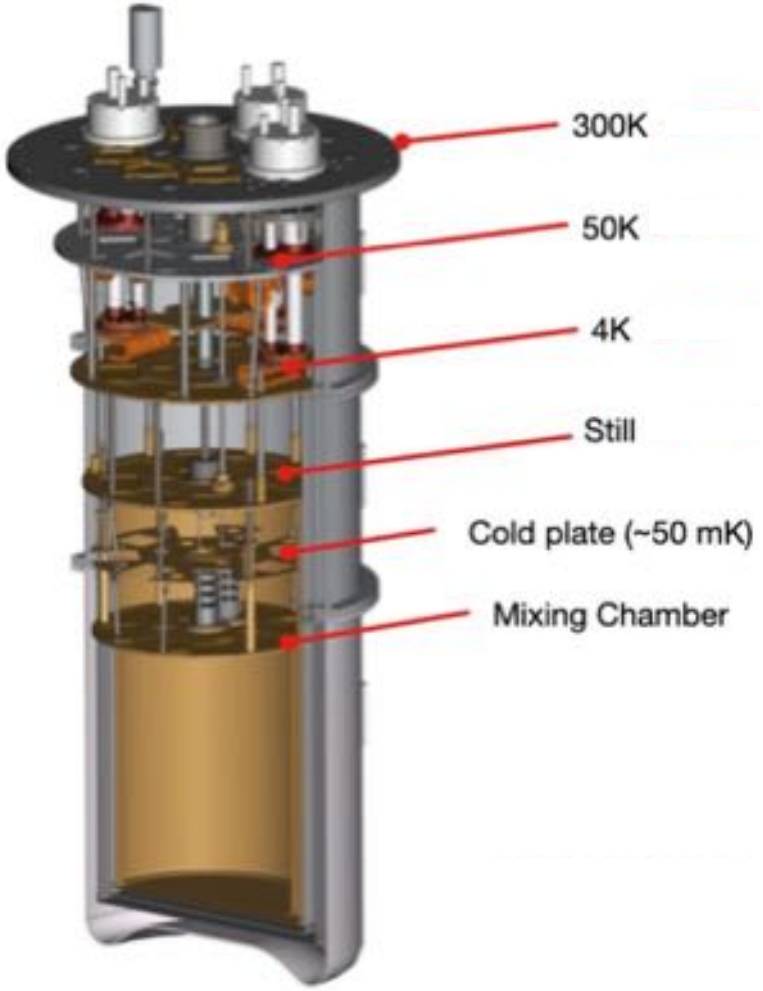


SURF Cryogenic User Facility

State investment to leverage federal funding and attract industry leaders

Multi-user, low-background, ultra-low temperature test facility

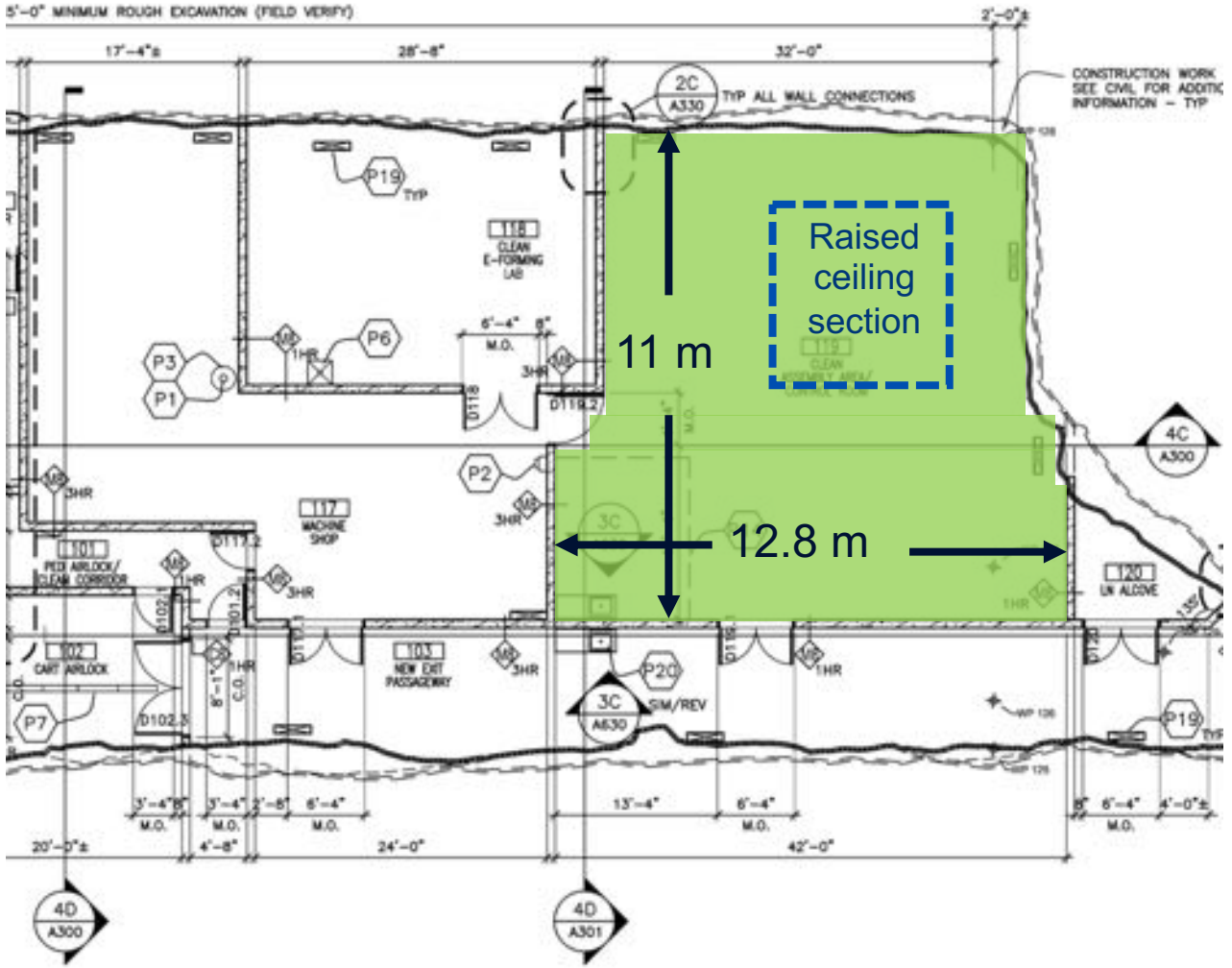
- Cryogenic User Facility at SURF will significantly bolster recent **South Dakota quantum initiative**
  - Center for Quantum Information Science & Technology incl DSU and SD Mines, interest from USD, SDSU and BHSU in facility at SURF
- Cryogenic User Facility at SURF will establish **internationally-competitive research resources** in South Dakota
  - New facility at SURF will bring scientific staff and support development of novel detectors to address questions in fundamental science
  - Significant interest from U.S.-based groups
  - New facility at SURF will attract industry leaders (Google, IBM)
- **No deep underground cryogenic facility** currently exists in the U.S.
  - Due to strategic value, many other countries operate cryo facilities (Europe, Canada) or are planning to build them (several countries in Asia; LBNL currently working with Japan on a facility like this)



Several options for commercial dilution refrigerator that would meet facility needs

4850L Davis Campus

MJD Detector Room space for Cryogenic User Facility



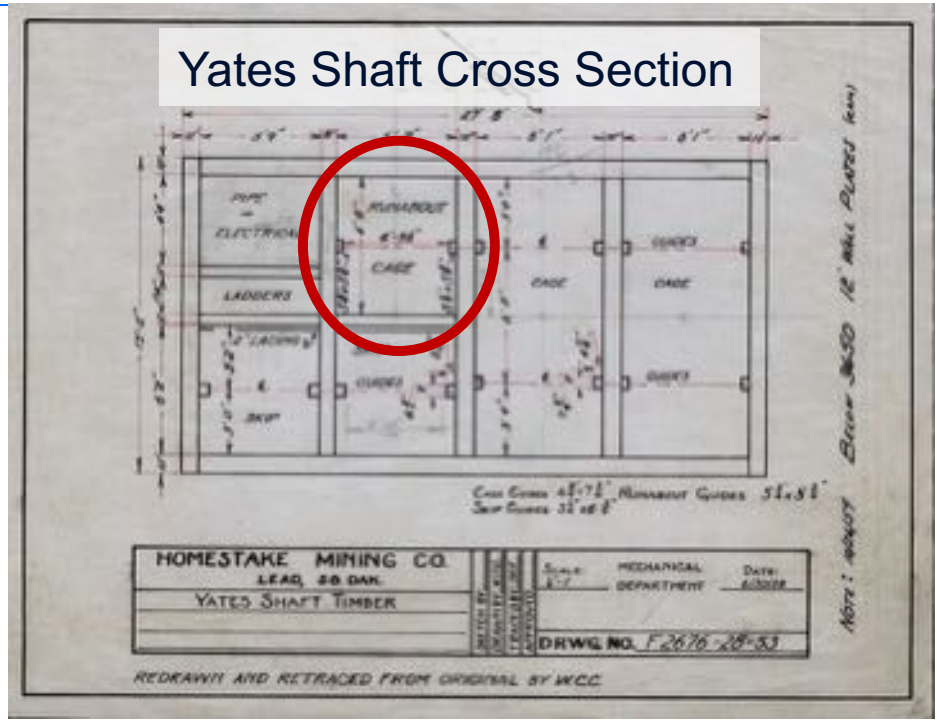
Area (total =**140 m²**): 11 m × 9.8-12.8 m × 2.7 m (H)
Area (raised section): 5.9 m × 5.8 m × 3.2 m (H)

Height (standard, drop ceiling) = 2.7 m
Height (raised section, 5.9 m × 5.8 m) = **3.2 m**

SURF Potential Vertical Facility

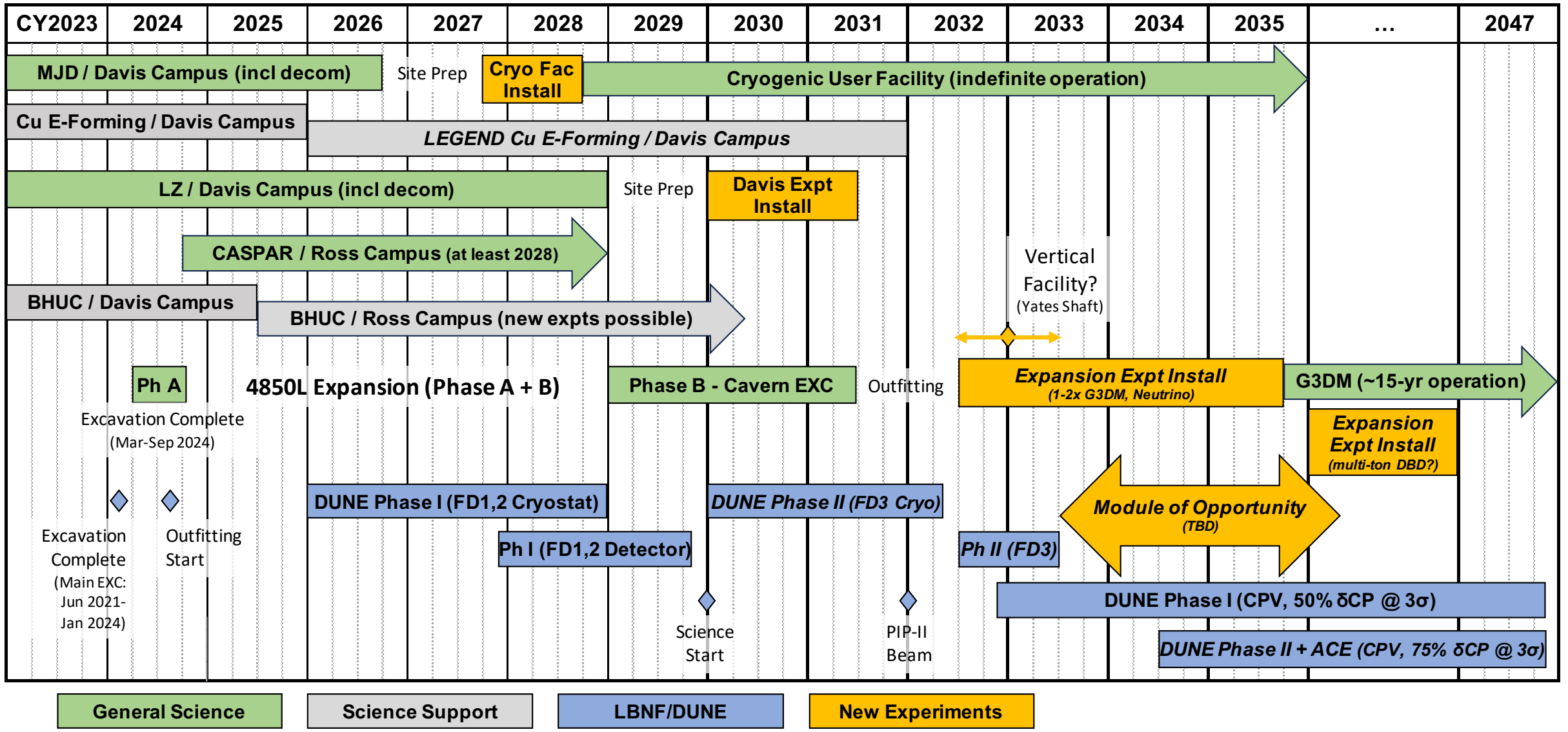
Unique facility would serve broad range of science communities

- **Science Goals:** Atom interferometry using quantum sensors (ultralight dark matter, gravitational waves), quantum network; also atmospheric cloud chamber, microgravity studies, isotope separation
- **Community Interest:**
  - Early interest at SURF related to vertical facility and atom interferometry (e.g., Vertical Facility workshop Fall 2008)
  - SURF Vision Workshop Sep 2021 incl atom interferometry
  - SURF Quantum Partnerships Workshop series incl interest in gravitational measurements and quantum networks/sensors
  - SURF joined TVLBAI collaboration in Oct 2025 (50+ institutions)
- **Expt Requirements** (TVLBAI https://arxiv.org/pdf/2503.21366):
  - TVLBAI: **1.5-m diameter** shaft (minimum), **15-cm diameter** pipe for ultra-high vacuum; separate pipe for quantum network?
  - Aiming for initial **technical discussions in 2026**
- **SURF Facility:**
  - Initial shaft study completed March 2022, six legacy shafts potentially feasible (but challenging)
  - **Yates Shaft refurbishment** – DOE recognizes investment necessary to ensure safe and redundant access at SURF (especially for LBNF/DUNE); schedule **~2030s** after related upgrades complete
  - Potential for Yates Shaft to accommodate Vertical Facility, “Runabout” compartment **1.75m x 2.0m**



SURF Science Strategic Planning

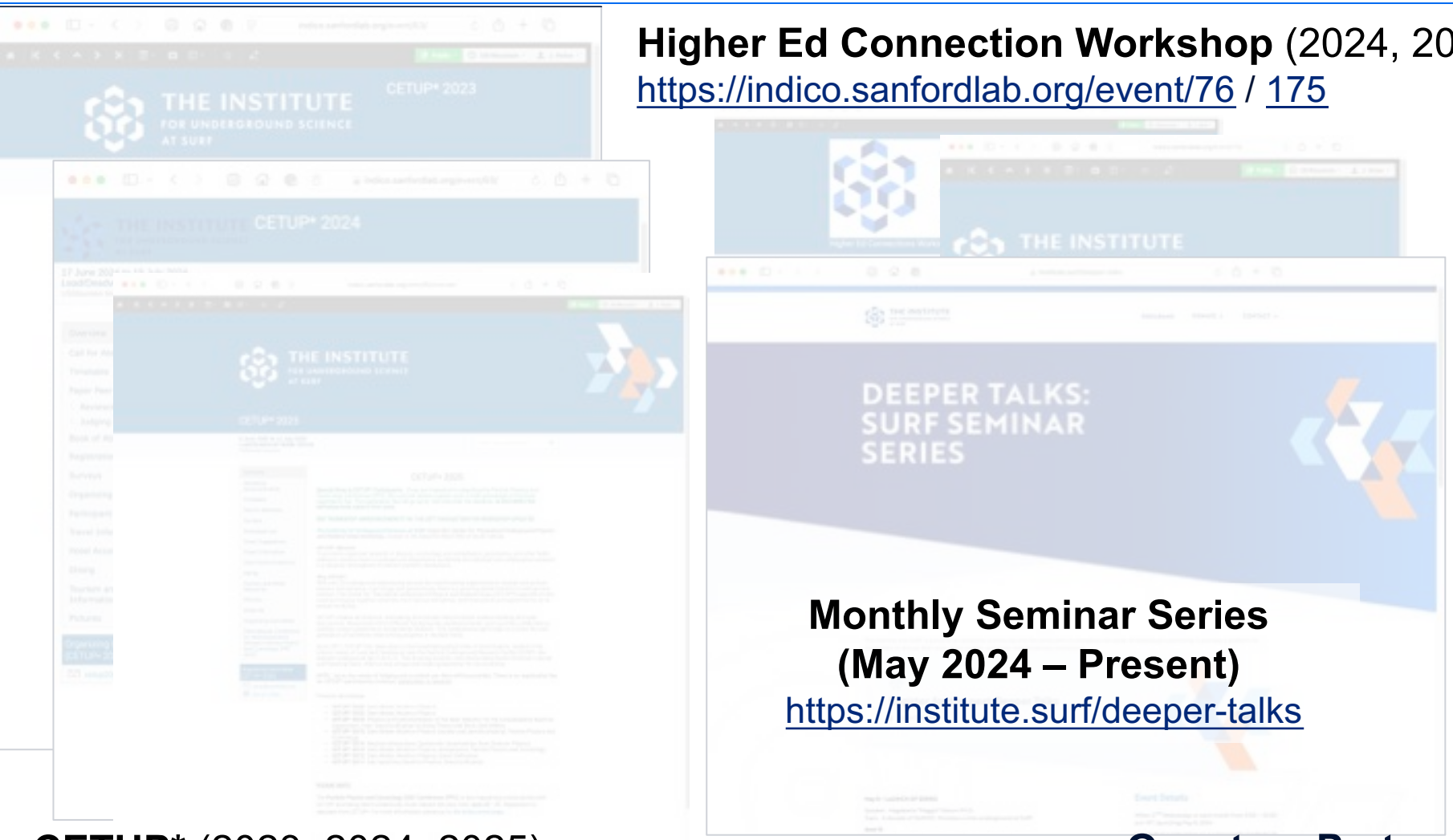
Timeline



Institute for Underground Science at SURF

Activities since June 2023, formally launched December 2023

Higher Ed Connection Workshop (2024, 2025)
https://indico.sanfordlab.org/event/76 / 175



Monthly Seminar Series
(May 2024 – Present)
https://institute.surf/deeper-talks

CETUP* (2023, 2024, 2025)
https://indico.sanfordlab.org/e/CETUP2023 / 2024 / 2025

Quantum Partnership Workshop (2024, 2025)
https://indico.sanfordlab.org/e/QPW2024 / QPW2025

SURF Science & Education Opportunities

SURF Programs

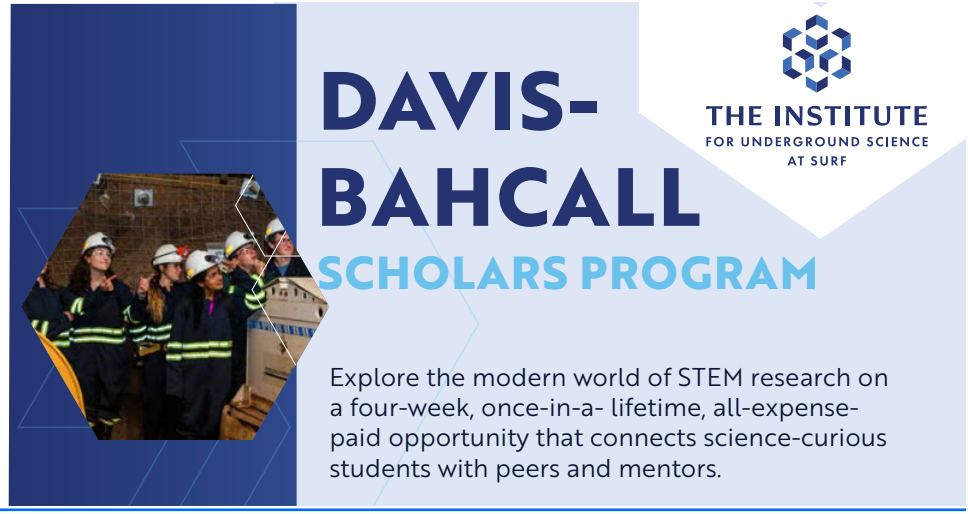
- **Summer Internships** (Bozied/Bauer/Headley)
  - Science, engineering, operations, environmental science and communications, incl underrepresented groups https://sanfordlab.org/internships
- **Davis-Bahcall Scholars Program**
  - Multidisciplinary studies at U.S. & European labs/industries https://sanfordlab.org/dbs

National Programs

- NSF Research Experiences for Undergraduates (REU):
  - **BHSU** multidisciplinary program since 2016 (physics, chemistry, biology) https://bhsu.edu/academics/programs/physics.html
  - **SD Mines Li-SMART** (Lithium, Mining, Recycling and Technology) started 2025 https://www.sdsmt.edu/news/releases/Li-SMART.html
- DOE Reaching a New Energy Sciences Workforce (RENEW):
  - **RENEW-Midwest:** From the Underground to the Cosmos, student diversity in STEM (BHSU, UMich, Benedictine) https://www.pathwaystoscience.org
  - **NuPUMAS**: Neutrino Physics for Undergraduate Minority Advancement in Science, student diversity in STEM (UHouston / Texas Physics Consortium) https://nupumas.physics.uh.edu

Other Opportunities

- **BHSU Underground Campus:** Promoting undergraduate research
- **Local Researchers:** SD Mines, BHSU, RESPEC; also USD, SDSU, DSU



SURF Summary

- SURF has strong relationship with DOE that benefits UG science community:
  - SURF has mandate to **support experiments** and ensure **safe and reliable access for decades**.
- SURF offers world-class service to the underground science community:
  - SURF attributes attract **world-leading** experiments and scientists from **diverse scientific communities**.
  - SURF has **proven track record** of enabling high-impact science by leveraging strong **institutional partnerships**.
- SURF is playing a strong role in the UG science community:
  - **User Association** serving as catalyst for community discussions: https://sanfordlab.org/surf-user-association.
  - **Institute** has had significant impact with initial programming, advancing intellectual community building.
- SURF wants to host future world-leading experiments:
  - LBNF excavation done, outfitting started in 2024. **DOE** "**Module of Opportunity**" expanded physics program.
  - Construction underway to **increase underground laboratory space**, plans advancing for new large caverns on 4850L on **timeframe of next-generation experiments (~2030)**.
  - Call for **Letters of Interest (LOIs)** re-affirmed prospective experiments and identified **new avenues**. New facilities in planning (Cryogenic User Facility) and consideration (Vertical Facility).
  - SURF is **deep laboratory** site and offers **largest footprint** in the world for scientific pursuits. **Many options to host future initiatives – big or small!**

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)

Sanford Underground Research Facility

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

Sanford Underground Research Facility

General summary

Site: Deepest underground lab in U.S., largest footprint for scientific pursuits (former Homestake Gold Mine). Operations funded directly by U.S. Department of Energy ($35M/yr). Robust org, total staff = 213 ppl.

Science Program:

- **Past:** Davis Solar Neutrino Experiment, LUX, MAJORANA DEMONSTRATOR ($0\nu\beta\beta$, ^{180m}Ta), others (incl Deep Underground Gravity Lab, affiliated with LIGO collaboration)
- **Current:** LZ, CASPAR, Low-bkgd counting (BHUC), Geoengineering (esp. geothermal, seismic), Geomicrobiology, Industry/engineering (Caterpillar)
- **Future** (no funding/site decisions yet):
  - Dark Matter: Low-mass (SPLENDOR, HydroX), next-generation WIMP (XLZD, Argo), other (CrystaLiZe)
  - Neutrino: Water-based liquid scintillator (Theia), Multi-ton-scale $0\nu\beta\beta$ (LEGEND 6000), etc
  - QIS, atom interferometry – gravitational waves, ultra-light dark matter (km-scale vertical or horizontal)

Facility:

- **4850L Existing:** Davis Campus operating well, Ross Campus re-opened following LBNF blasting
- **4850L Cryogenic User Facility:** Dilution fridge for QIS at Davis Campus (exploring SD funding)
- **4850L LBNF/DUNE:** Excavation complete, “Module of Opportunity” for expanded science program (DOE)
- **4850L Expansion:** Up to 2x caverns (100m L × 20m W × 24m H), complete in early 2030s (private/DOE?)
- **Vertical Facility:** Accommodate during Yates Shaft refurbishment, schedule TBD / ~2030s (DOE/other?)

Sanford Underground Research Facility

Physical characteristics

- **Property:** 1 km^2 (surface) with ~1600 m^2 storage (incl drill core) and 355 m^2 staging/assembly space; 31 km^2 (total underground) with ~600 km of tunnels extending to over 2450 m below ground.
- **Access:** Vertical; personnel and materials via one of two main shafts (Yates Shaft extensive maintenance campaign completed, DOE funding discussions for full refurbishment). Facility dedicated to science.
  - Yates Shaft: 1.39 × 3.77 × 2.58 m, 4.8 tonnes (lengths up to 7.3 m possible at reduced payload mass)
  - Ross Shaft: 1.40 × 3.70 × 3.62 m, 6.1 tonnes (lengths up to 8.2 m possible at reduced payload mass; new cage soon)
- **Depth:** Main UG level = 4850L (1480 m, 4300 mwe), muon flux = 5.31×10^{-5} $\mu/m^2/s$ (4.6 $\mu/m^2/d$). Several other UG elevations for science: 300L, 800L, 1700L, 2000L, 4100L, 4550L.
- **Space:**
  - Surface (science space, as low as class 10-100): 210 m^2 (cleanrooms = 92 m^2 / 914 m^3)
  - 4850L (science space, as low as class 100): Davis Campus (1018 m^2 / 4633 m^3), Ross Campus (920 m^2 /3144 m^3)
  - Radon-reduction: Surface = 2200x reduction @ 300 m^3/h (Ateko), Davis = 700x reduction @ 150 m^3/h (SD Mines)
- **Bkgds** (4850L): Radon* = 180-402 Bq/m^3, gamma = 1.9 $\gamma/cm^2/s$, neutron = 1.7×10^{-2} $n/m^2/s$.
- **Utilities:**
  - Power = 24,000 kW capacity (20,000 kW available now, 15,000 kW in FY27); Standby = 3 diesel generators (390 kW)
  - Chilled water (2x 246 kW), purified water (37.8 lpm), compressed air (up to 1100 scfm, 140 scfm at Davis Campus)
  - Network = 20 Gbps internally, 10 Gbps externally (100 Gbps planned), WiFi available surface + underground

* Studies conducted Summer 2024, expect to reduce Rn concentration

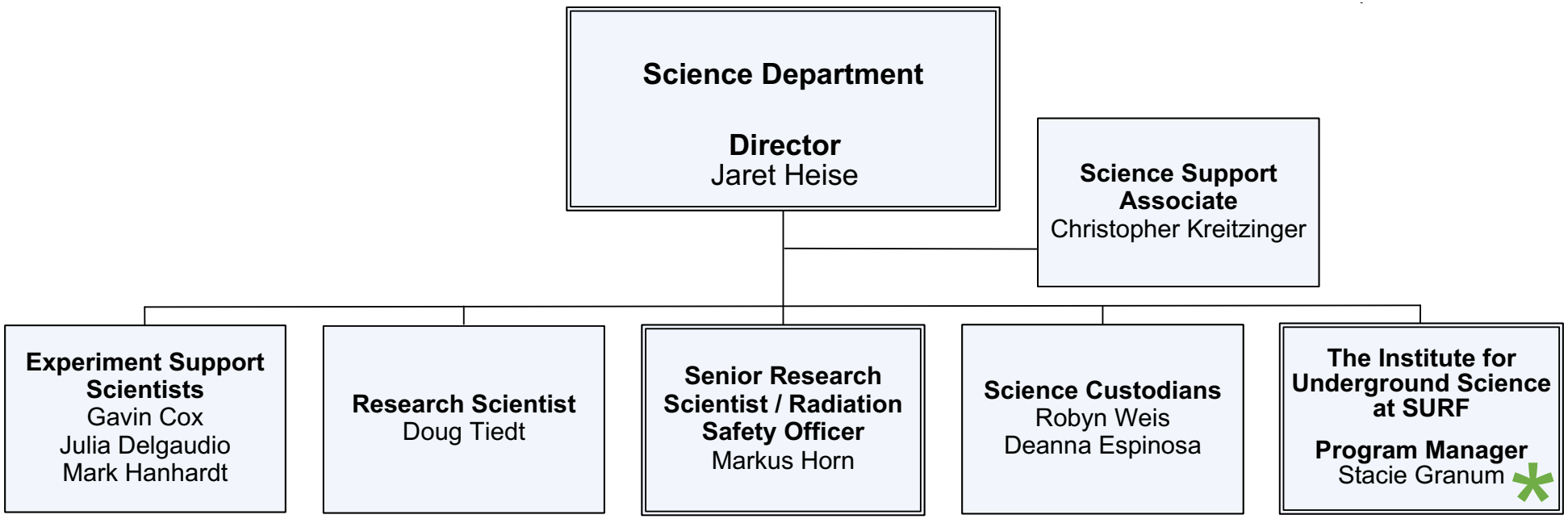
Sanford Underground Research Facility

Capabilities

- **Unique environments for multi-disciplinary research:** SURF has attracted world-leading experiments and scientists from diverse scientific communities.
  - **Overburden protection from cosmic-ray muons:** SURF is the deepest underground lab in U.S., one of deepest laboratories in the world (1500 m, 4300 mwe). SURF is expanding to meet the needs of next-generation experiments
- **Local radiation shielding:** Water tank and corresponding water purification system, steel shielding; also selection of low-activity facility construction materials/finishes (e.g., concrete, shotcrete)
- **Assay capabilities:** Low-bkgd counting serving national & international community (~10 μBq/kg U/Th)
- **Material production/purification:** One of only a few labs where UG Cu electroforming is performed (average U, Th decay chain ≤ 0.1 μBq/kg)
- **Environmental control:** Experience w/ HEPA filtration cleanrooms, dehumidifier, Rn-reduction systems
- **Implementation and operations support:** Robust organization with support for planning, execution and coordination of science program activities both planned and ongoing at facility. SURF has proven track record of delivering successful science.
- **Community catalyst:** User Association, incl Vision Workshop 2021. Science Program Advisory Cmttee. Both groups support upcoming SURF application to become **DOE Office of Science User Facility**

Science Organization & Scope

Resources to enable safe and successful implementation of experiments



- **Main point of contact** for experiments and researchers
- **Experiment implementation process** management, incl coordination of review and authorization processes
- **Scientific support,** incl participation as collaboration members and technical experiment support
- **Science facility support**, incl lab coordination and oversight, specialized custodial support
- **Represent SURF** (facility and science), incl public presentations, scientific conferences, etc
- **Build intellectual community** *

SURF's Road to Multi-Disciplinary Science

Broad science program right from the start

- South Dakota and Black Hills Roots:
  - **Agriculture** is largest economic sector in state, many universities have strong biology departments & faculty
  - Locally, Black Hills region has strong ties to **mining/geology**; leveraged some industrial connections, also some early biology sampling during Homestake operations
  - Geographically near other interesting sites (e.g., Yellowstone National Park, well-known to researchers)
- DUSEL Roots:
  - Funding strategy for national UG lab was via National Science Foundation with **broad science mandate**
  - Strong leadership from U.S. national laboratory, LBNL, with **multi-disciplinary science portfolio**
- SURF Opportunities:
  - Significant footprint with access to **variety of environments** (range of temperature and humidity, rock formations/materials, water, depth, etc)
  - Drill core **repository**, access to underground **drill holes** (and **expertise** to modify), areas of **isolated water**
- SURF Multi-Disciplinary Science:
  - Biologists on SURF User Association (incl recent chair) and Science Program Advisory Committee
  - Planning at least one biology/geology Research Scientist hire in next 2 years
  - SURF Vision Workshop 2021: "No one has successfully created a true multi-disciplinary underground lab." **SURF [and other laboratories] aspire to this goal!**

LUX-ZEPLIN (LZ)

Large Underground Xenon - ZonEd Proportional scintillation in Liquid Noble gases

- **Science Goal:** Direct dark matter search using 10 tonnes xenon.
- **Collaboration:** 197 members, 36 institutions, lead = LBNL [DOE HEP].
- **Status:**
  - Onsite since Jul 2017 (as LUX since Nov 2009).
  - Data taking started Dec 2021. Initial WIMP-search results 2022 (world-leading), latest 2024 results 10.1103/4dyc-z8zf (world-leading).
  - WIMP-search data taking continuing (~65% of run goal).
  - Nitrogen generator serving entire Davis Campus.
- **Future:**
  - Complete science data by early 2028, then decommission. SURF Xe inventory available through Sep 2028.
  - Meetings with next-generation XLZD experiment (up to ~100 tonnes). Site TBD; SURF wants to host!
  - Low-mass dark matter projects potential follow-ons to LZ.

LZ compressor work

LZ nitrogen generator

MAJORANA DEMONSTRATOR (MJD)

Also Large Enriched Ge Experiment for Neutrinoless ββ Decay (LEGEND)

- **Science Goal:** Neutrinoless double-beta decay using 44 kg Ge; also LEGEND R&D and rare decays (^{180m}Ta).
- **Collaboration:** 62 members, 20 institutions, lead = ORNL [DOE NP].
- **Status:**
  - Onsite at SURF since Nov 2010.
  - Ge campaign finished (2015-2021), final result published 2023. Enriched Ge detectors to Gran Sasso.
  - Ta-180m rare-decay search complete (2022-2025), world-leading results (2023).
  - Decommissioning underway (some materials shipped to France), Cu electroforming and machining to continue.
- **Future:**
  - Decommissioning complete by Oct 2026.
  - Cu e-forming expanding up to 8 baths (6 operating soon).
  - Ton-scale: DOE review fall 2025 for LEGEND-1000 (nEXO paused).
  - "Multi-ton-scale" experiment possible at SURF in 2040s.

MJD decommissioning

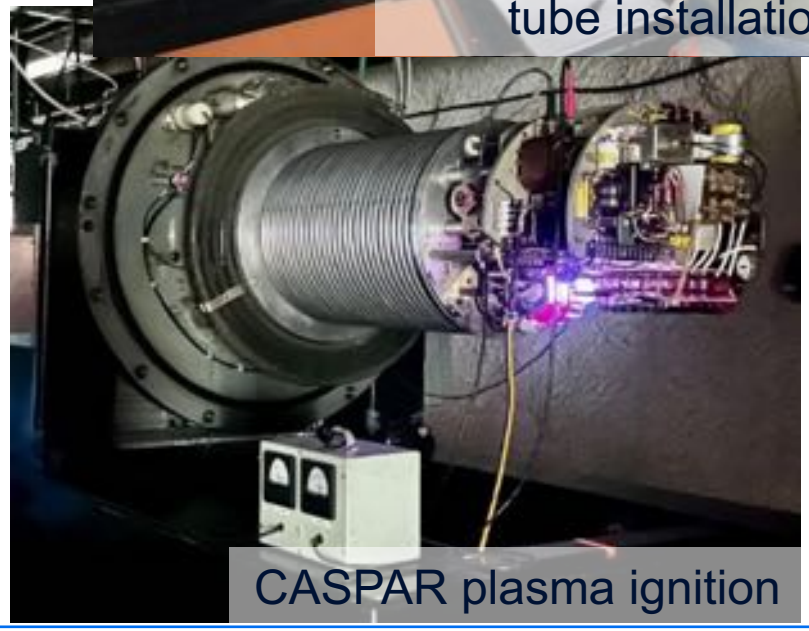
MJD Ge strings in glovebox

CASPAR

Compact Accelerator System for Performing Astrophysical Research

- **Science Goal:** Study of stellar nuclear fusion reactions using accelerator for protons or alpha particles.
- **Collaboration:** 26 members, 2 institutions, lead = SD Mines [NSF MPS/PHY].
- **Status:**
  - Onsite at SURF since mid-2015.
  - Phase 1 (2017-2021): 8 targets investigated, 6 PhD graduates (SD Mines, Notre Dame).
  - Laboratory shut down Apr 2021 due to LBNF construction.
  - Phase 2: Operations resumed Summer 2025.
- **Future:**
  - Phase 1: 4-5 papers and 1 PhD student in queue.
  - Phase 2 (2025-2028): First target data expected Fall 2025, incl ^{19}F (CNO solar neutrinos) and ^{7}Li, ^{10}B (complement JWST data).
  - Phase 3: Proposed continuation of nuclear astrophysics program, with electrical upgrade optimizing low-energy measurements.

CASPAR accelerator tube installation

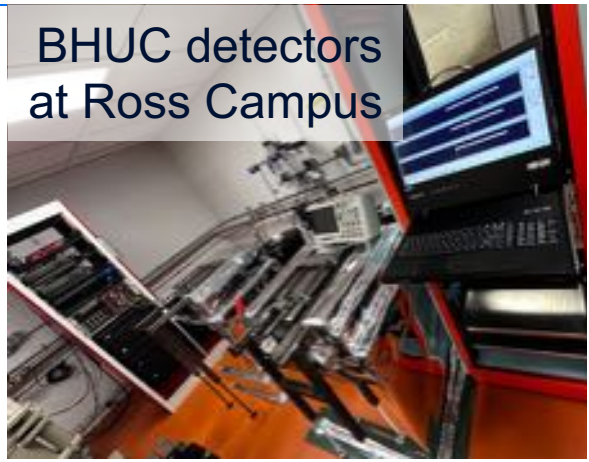


CASPAR plasma ignition

SURF Material Assay at BHUC

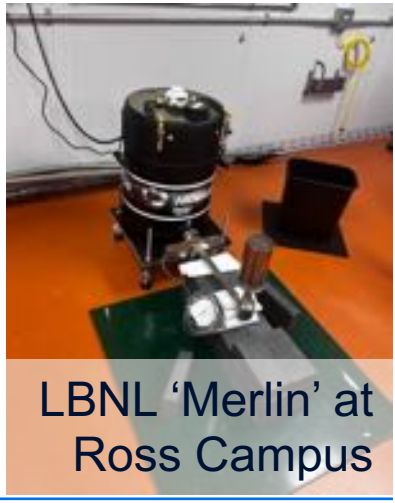
Black Hills State University Underground Campus

- **Science Support Goal:** Characterize radiopurity of experiment components; also multi-disciplinary science support at Ross Campus.
- **Collaboration:** 14 members, 7 institutions, lead = BHSU [institutional/expt funds
- **Status:**
  - Onsite starting Sep 2015 at Ross Campus (initial efforts 2013 at Davis Campus).
  - Ross Campus operations Sep 2015 – Jul 2020 (six detectors operating). Laboratory shut down Mar 2021 due to LBNF construction.
  - Davis Campus operations Nov 2020 – Jun 2025 (six detectors, five operating).
  - Ross Campus operations Aug 2025 – Present (six detectors, incl new LBNL detector; assays resumed!)
  - Sample counting for global community, incl XLZD and DUNE.
- **Future:**
  - Troubleshooting continues for Ge-IV at Davis Campus.
  - Additional detectors possible: 8th (UCLA) and 9th (AL/KY).
  - Interest from small-scale detector R&D groups.



BHUC detectors at Ross Campus

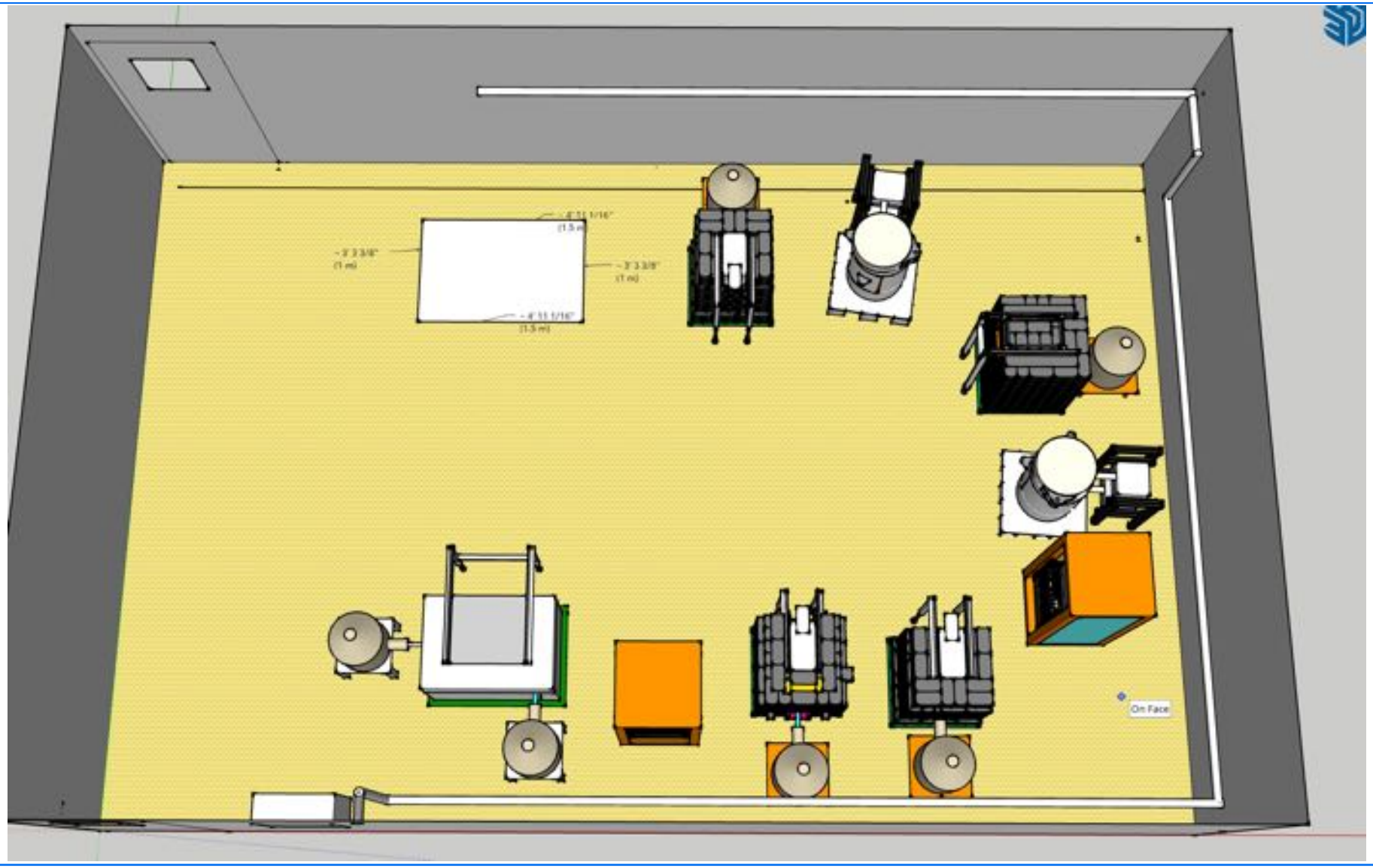
Ge-IV pumping at Davis Campus



LBNL 'Merlin' at Ross Campus

SURF Material Assay at BHUC – Back to Ross!

Black Hills State University Underground Campus

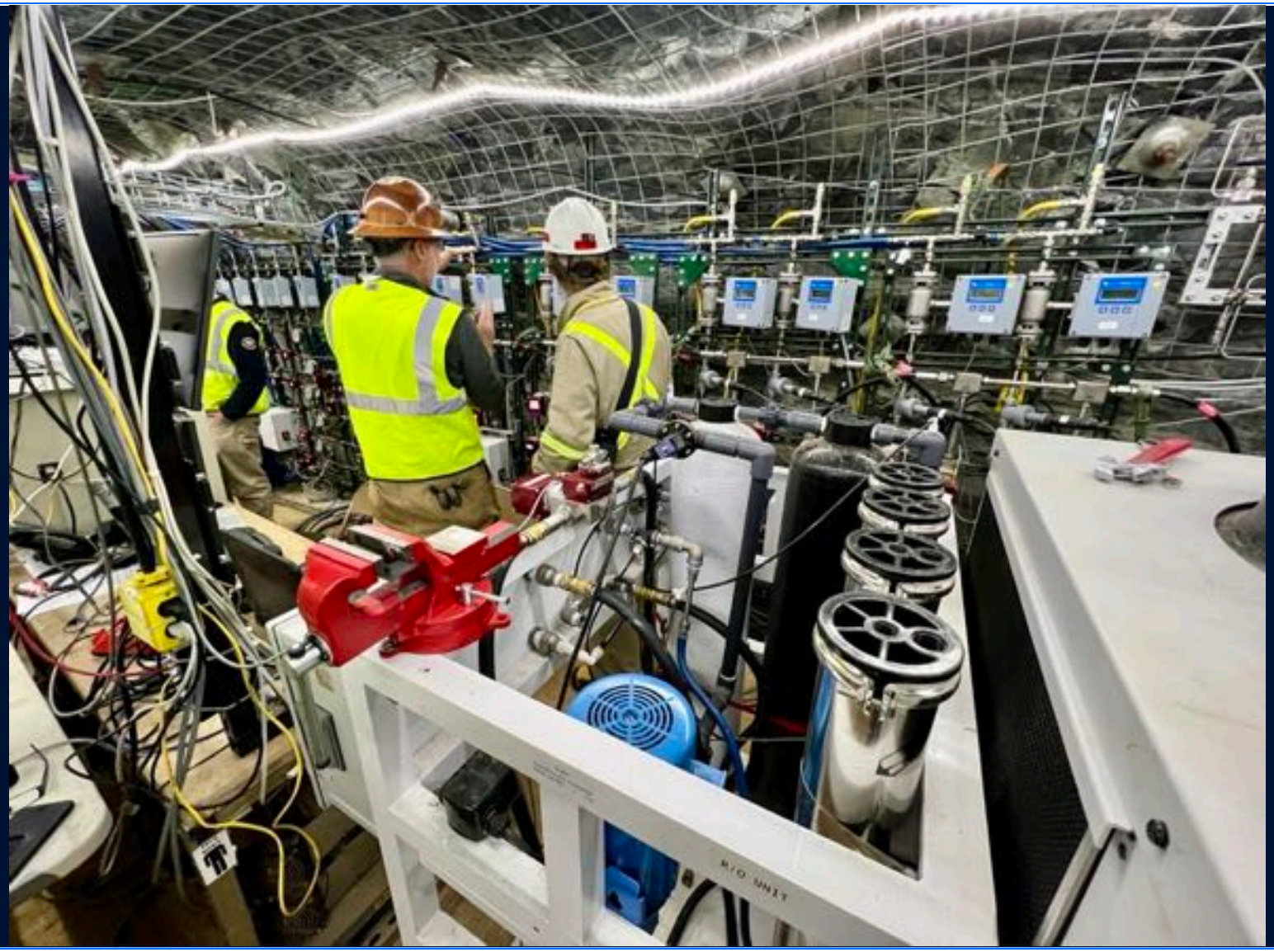


EGS Collab / SIGMA-V

Research activities on 4850L, West Drift

Geothermal Testbed

Research activities on 4100L, Yates area



SURF Past and Ongoing EGS-Related Projects

kISMET *(4850 Level)*

- permeability [k] and Induced Seismicity Management for Energy Technologies [EERE-GTO]

EGS Collab-SIGMA-V *(4850 and 4100 Levels)*

- Enhanced Geothermal Systems - Stimulation Investigations for Geothermal Modeling Analysis and Validation [EERE-GTO]
- 4850L: 8x holes drilled (each 60 m long), 4100L: 2x initial holes (50-m vertical, 10-m horizontal) plus 9x holes (180-265 m long). Stimulation and flow studies completed at both sites, decommissioning / mothballing to be complete in Nov 2022. 2x 4850L holes could be re-used; 4100L testbed for re-use.

DEMO-FTES *(4100 Level)*

- Demonstration of Fracture Thermal Energy Storage [Geothermica (Intl) -> EERE-GTO]
- Near-term re-use of some of EGS/SIGMA-V 4100L infrastructure, onsite starting summer/fall 2023

Thermal Breakout *(4850 and 4100 Levels)*

- Development of thermal wellbore breakout technology for determining the maximum principal stress magnitude and direction [DOE Fossil Energy & Carbon Mgmt]
- 4850L: Tests performed in 2019 and 2020 using DUSEL geotechnical overcore holes. 4100L: Testing in existing EGS/SIGMA-V holes in 2021. Two new long 4100L holes drilled (15-cm diameter x 23 m long) and imaged in 2021, SURF completed 6 shallow holes (6-cm diameter x 4.5 m long). Heater testing in 2025.

SD Mines Biologists in Action

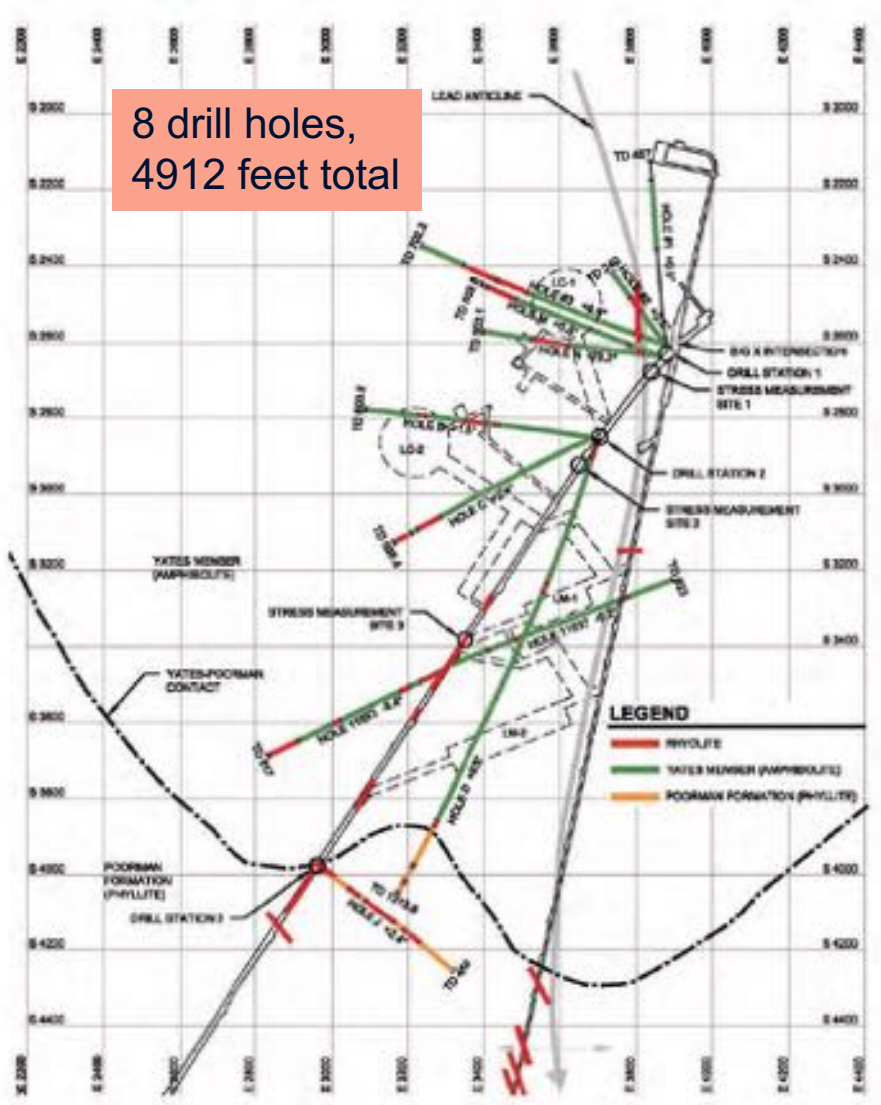
Biology / Geology / Engineering (Multiple Levels)

BHSU Biologists in Action

Biology / Geology / Engineering (Multiple Levels)

SURF Science Opportunities – Core Holes

Example: DUSEL Preliminary Design Core Holes

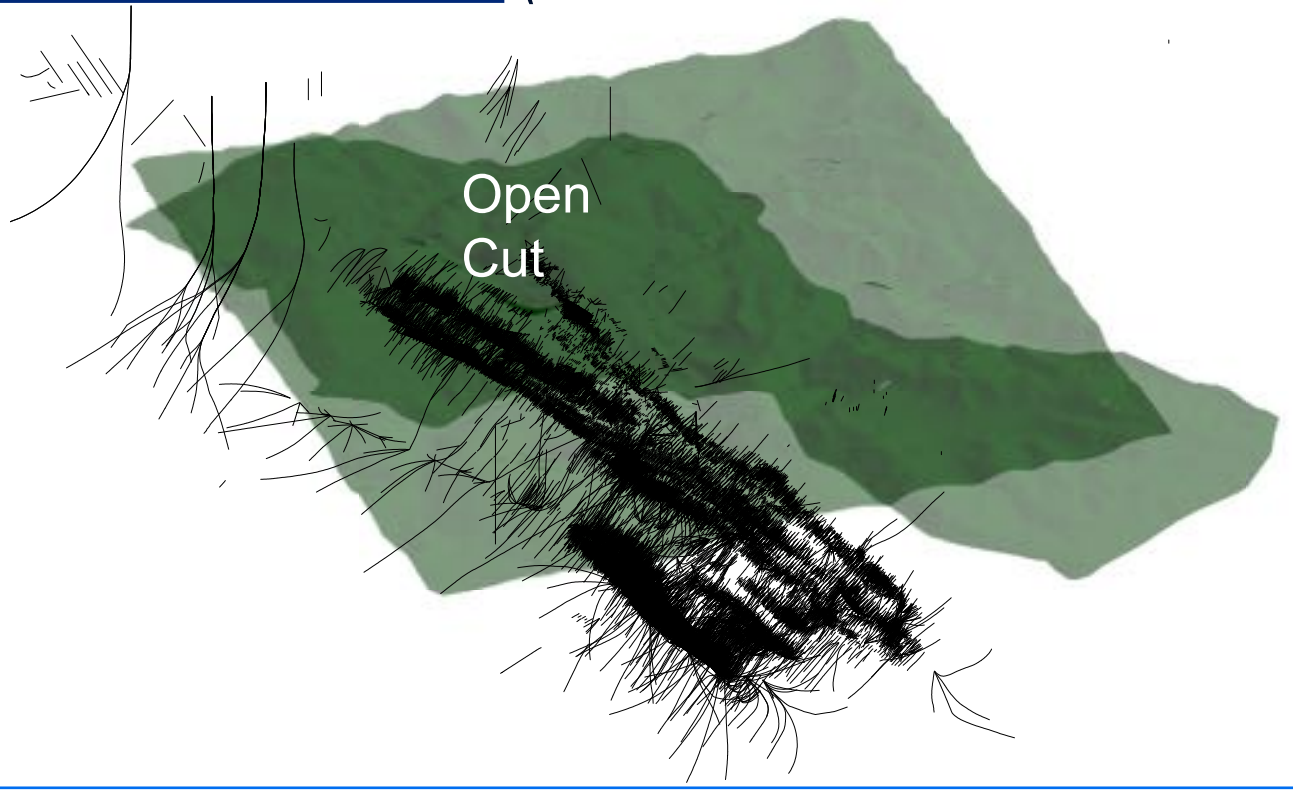


See DUSEL PDR:
https://arxiv.org/abs/1108.0959

SURF Science Opportunities – Drill Core

Core repository

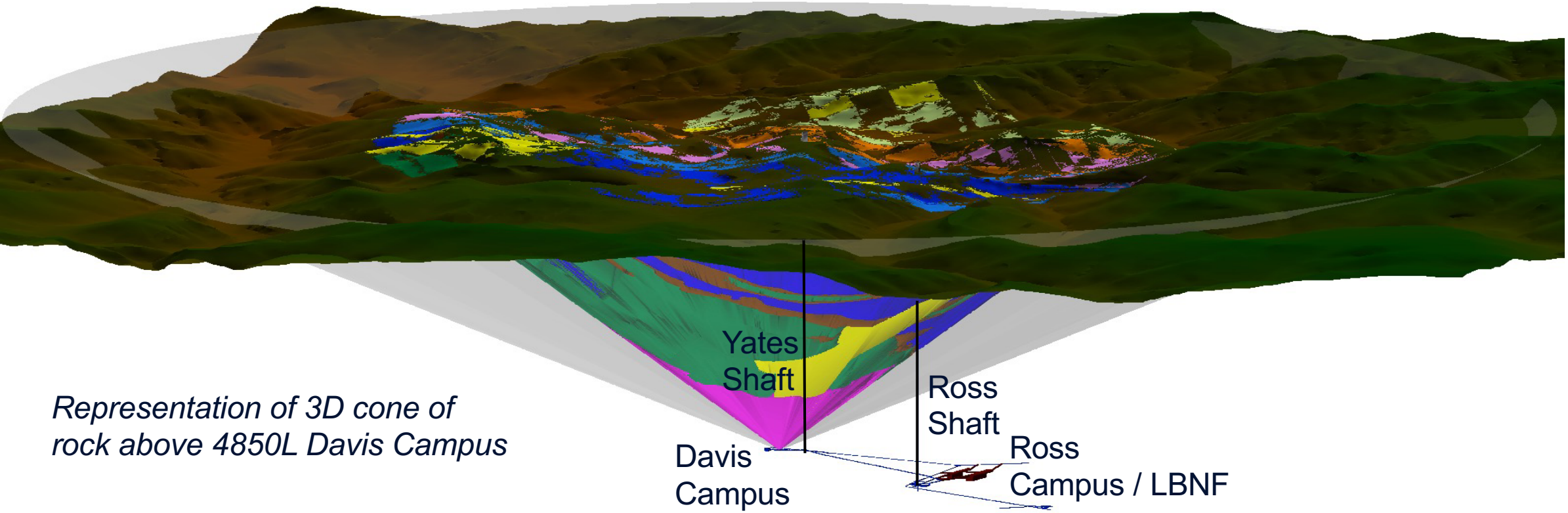
- Total of 27,870 drill holes (+ others) on Homestake property
- Portion of core retained and donated to SDSTA: 39,760 boxes of core for 2,688 drill holes (91 km!), SDGS initial help with stewardship
- SDGS database with 58,000+ entries, representing 1,740 drill holes: http://cf.sddenr.net/homestake/ *(not sure if still available via DANR)*



SURF Science Support – Geology Model

Site well understood, including drill core & logs

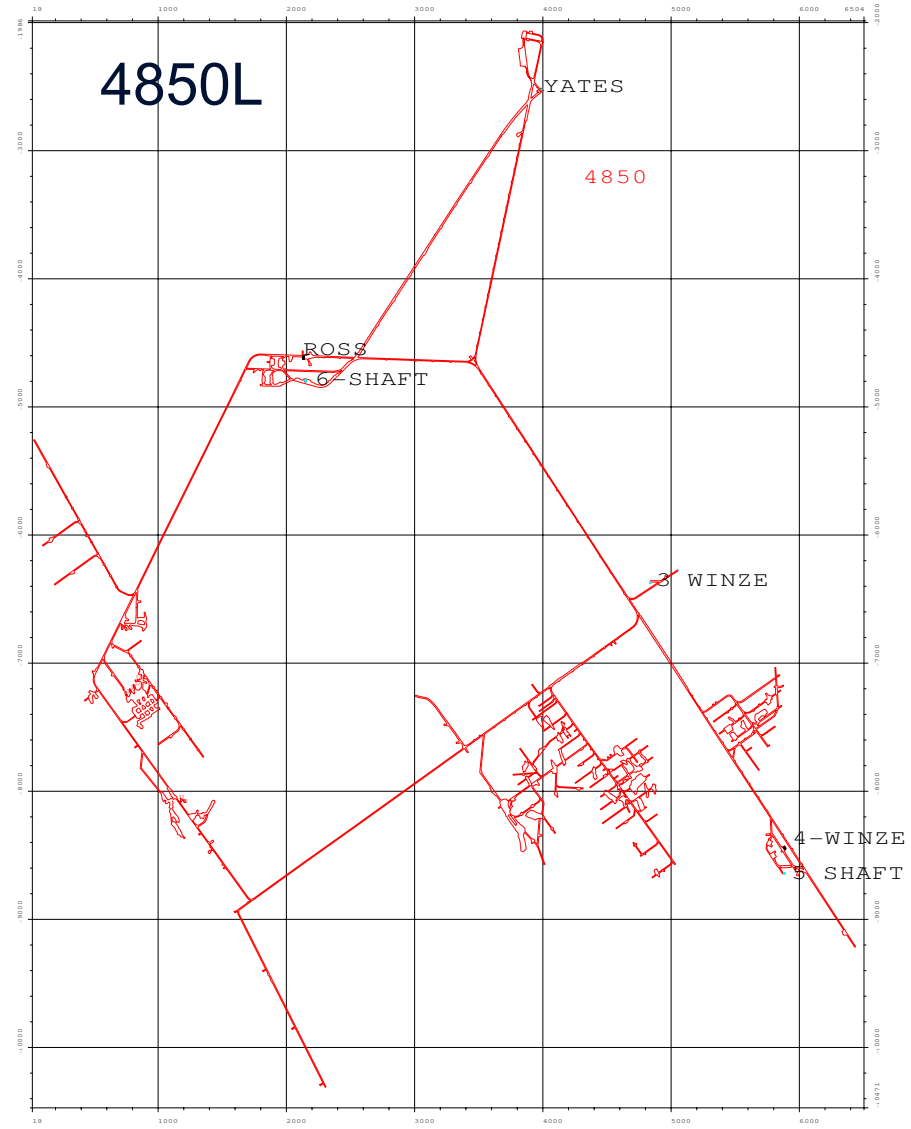
- 3D model of seven main rock formations + Rhyolite intrusives
- Detailed surface topology: Aerial survey for site performed 2011 (1’ contours)
- Global coordinates: Survey performed summer 2016 (incl world’s longest plumb bob)
- Rock density data: Hart, Trancynger, Roggenthen, Heise, SD Acad Sci **93**, 33 (2014)

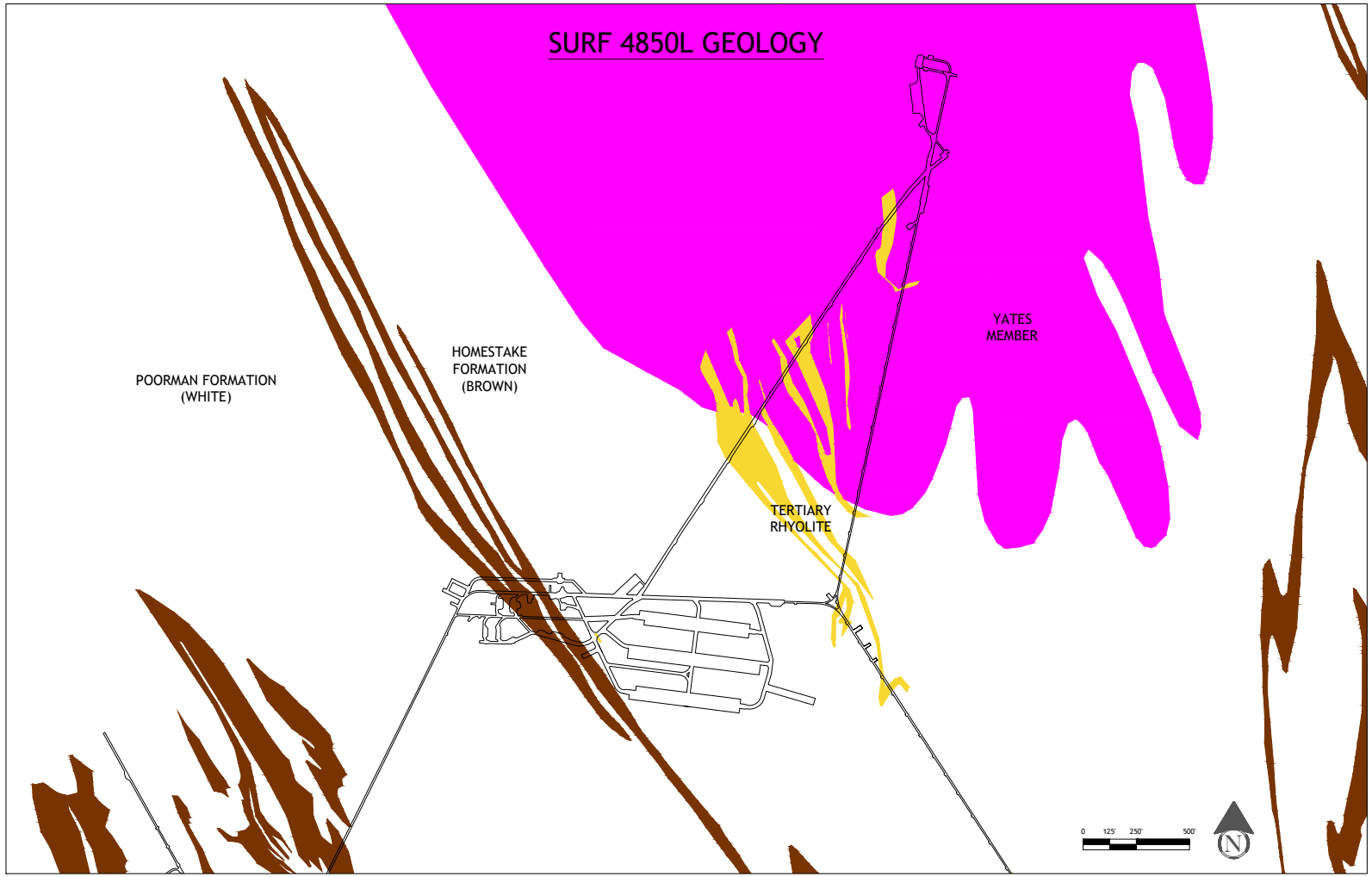


Representation of 3D cone of rock above 4850L Davis Campus

SURF Underground Lab Geography

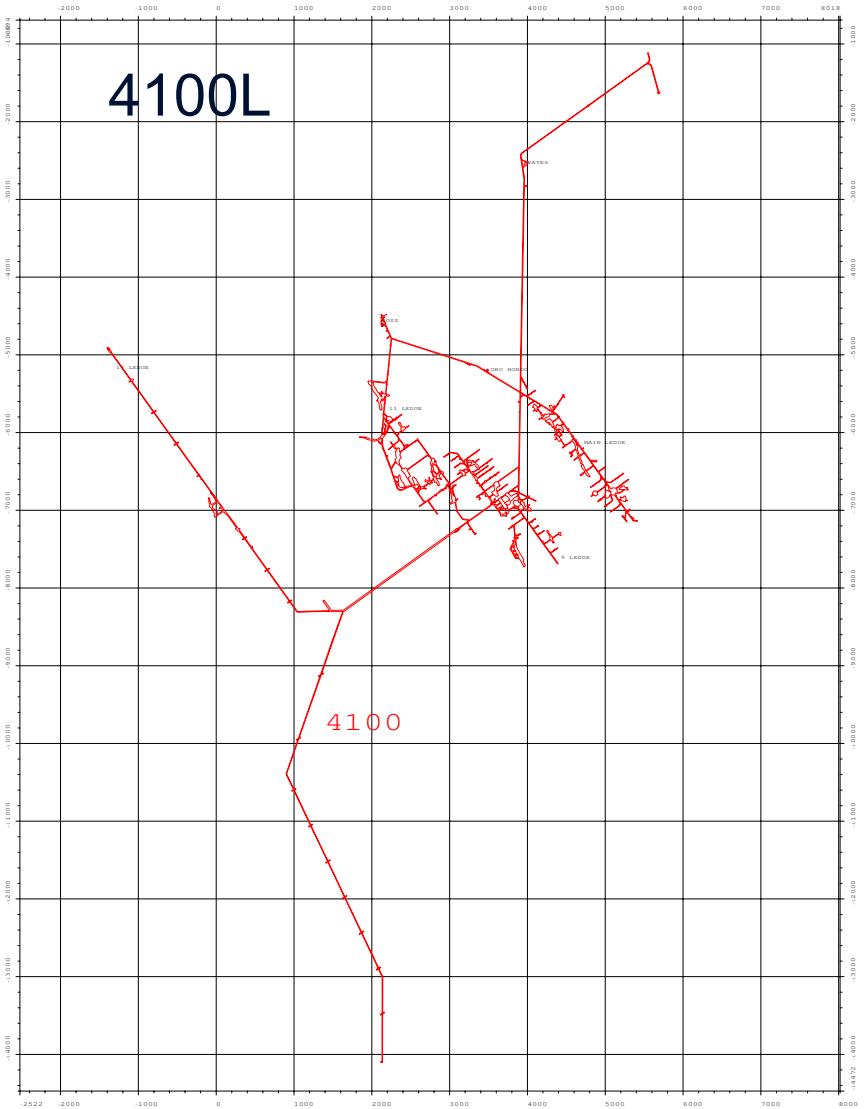
Generalized geology model – 4850L

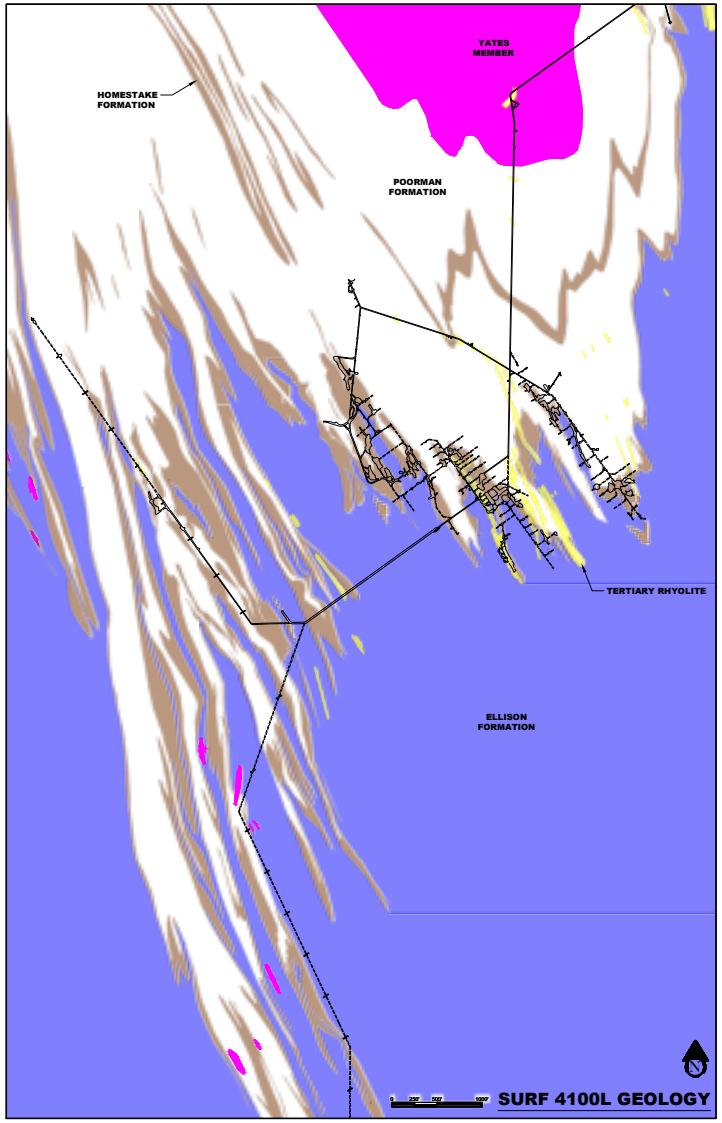




SURF Underground Lab Geography

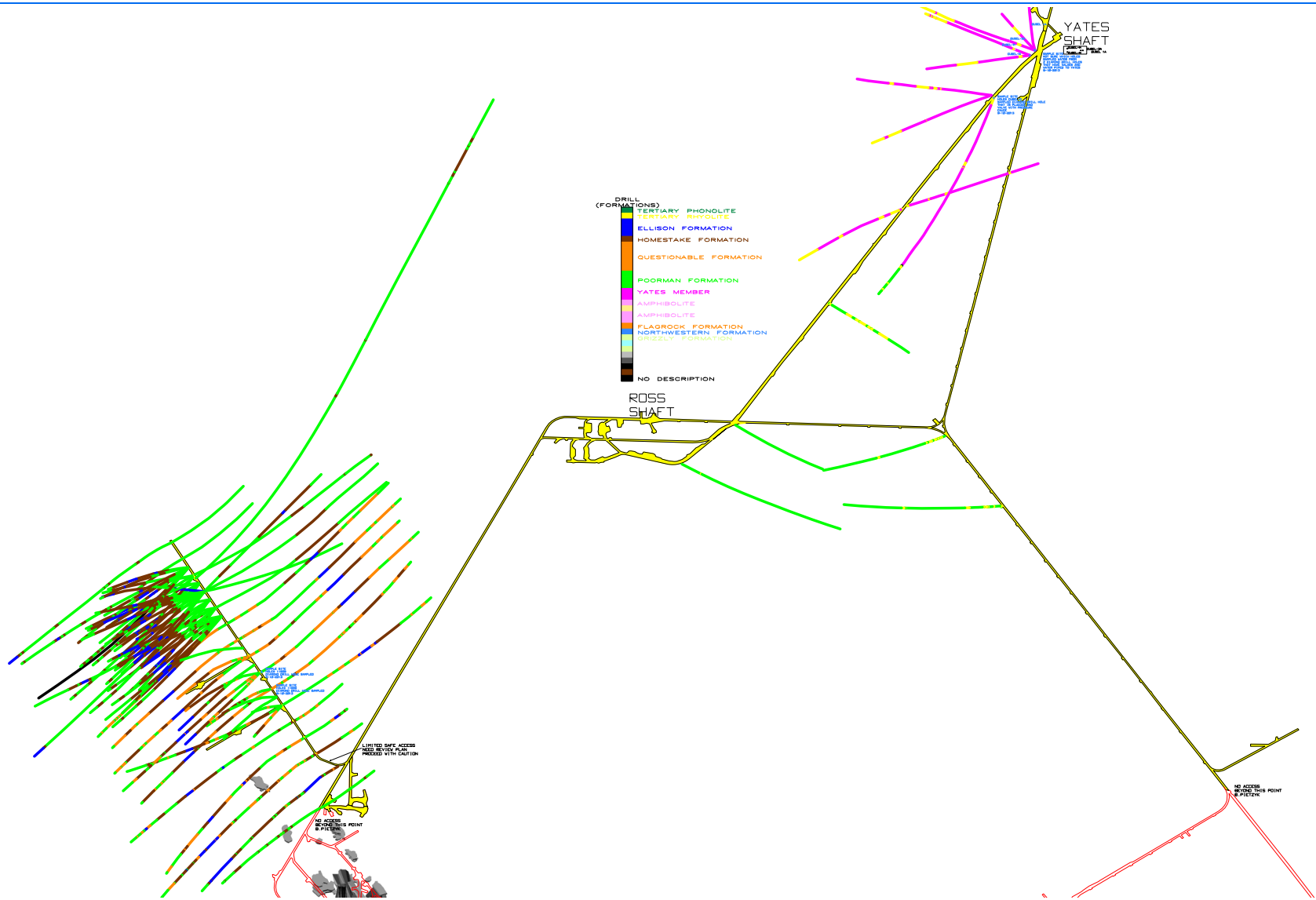
Generalized geology model – 4100L





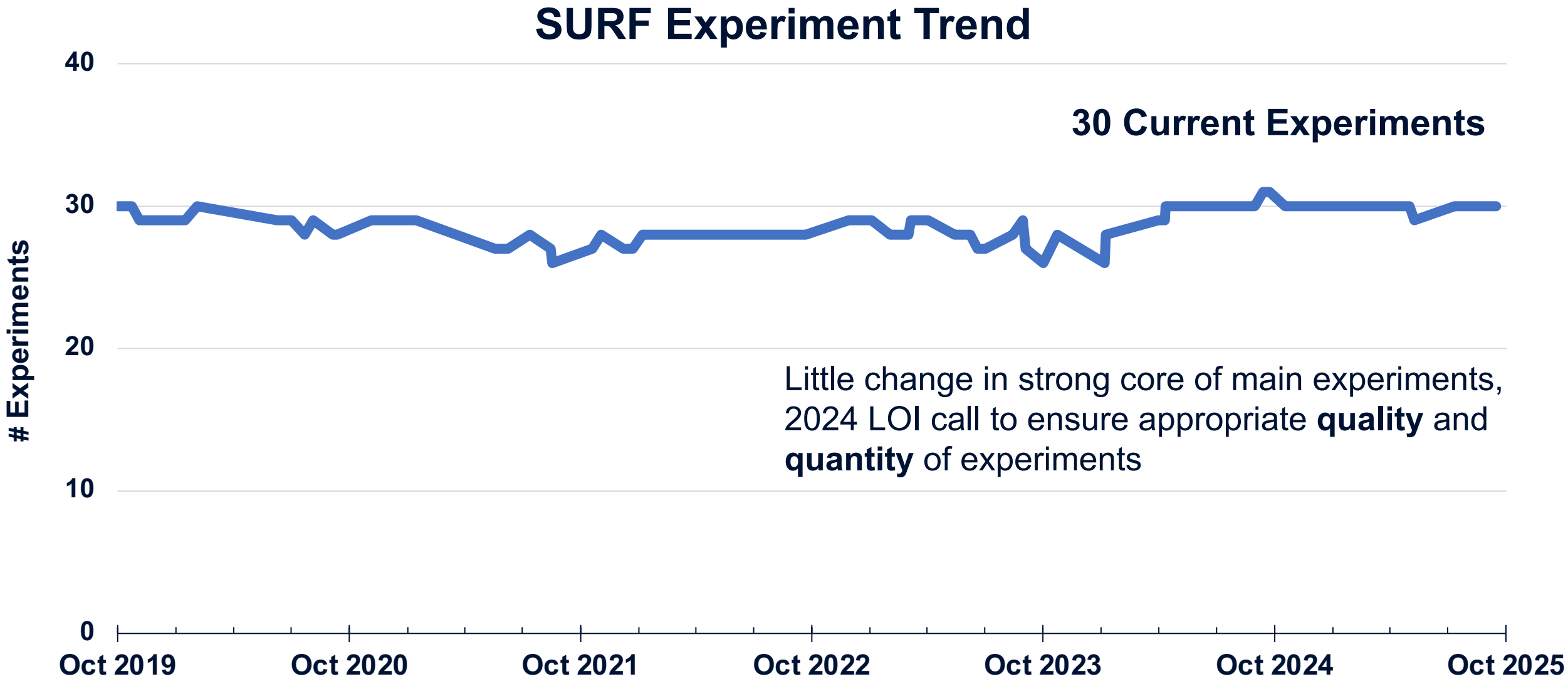
SURF Underground Lab Geography

Other resources: Example: 4850L drill holes with geology and stopes



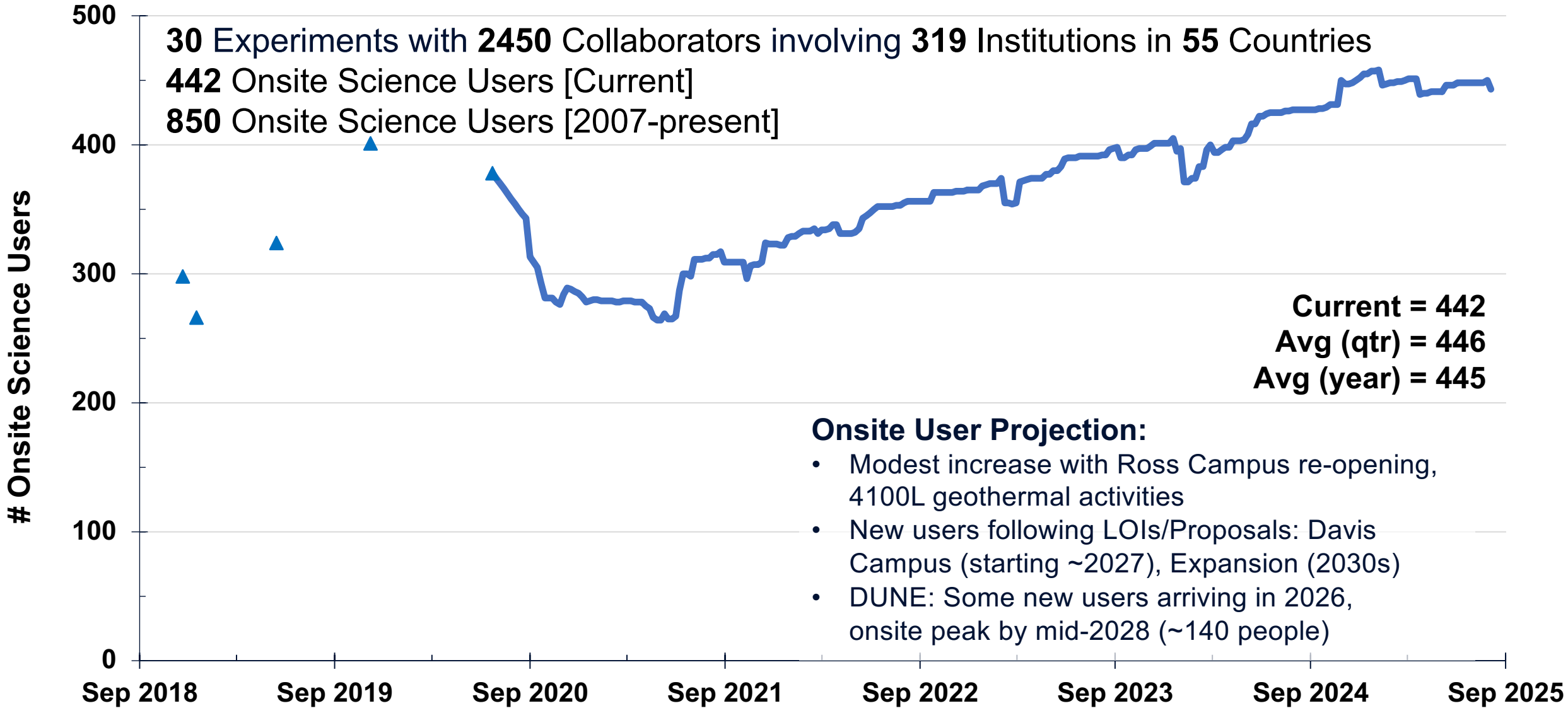
SURF Science Program

Hosting world-leading experiments and researchers from diverse scientific communities



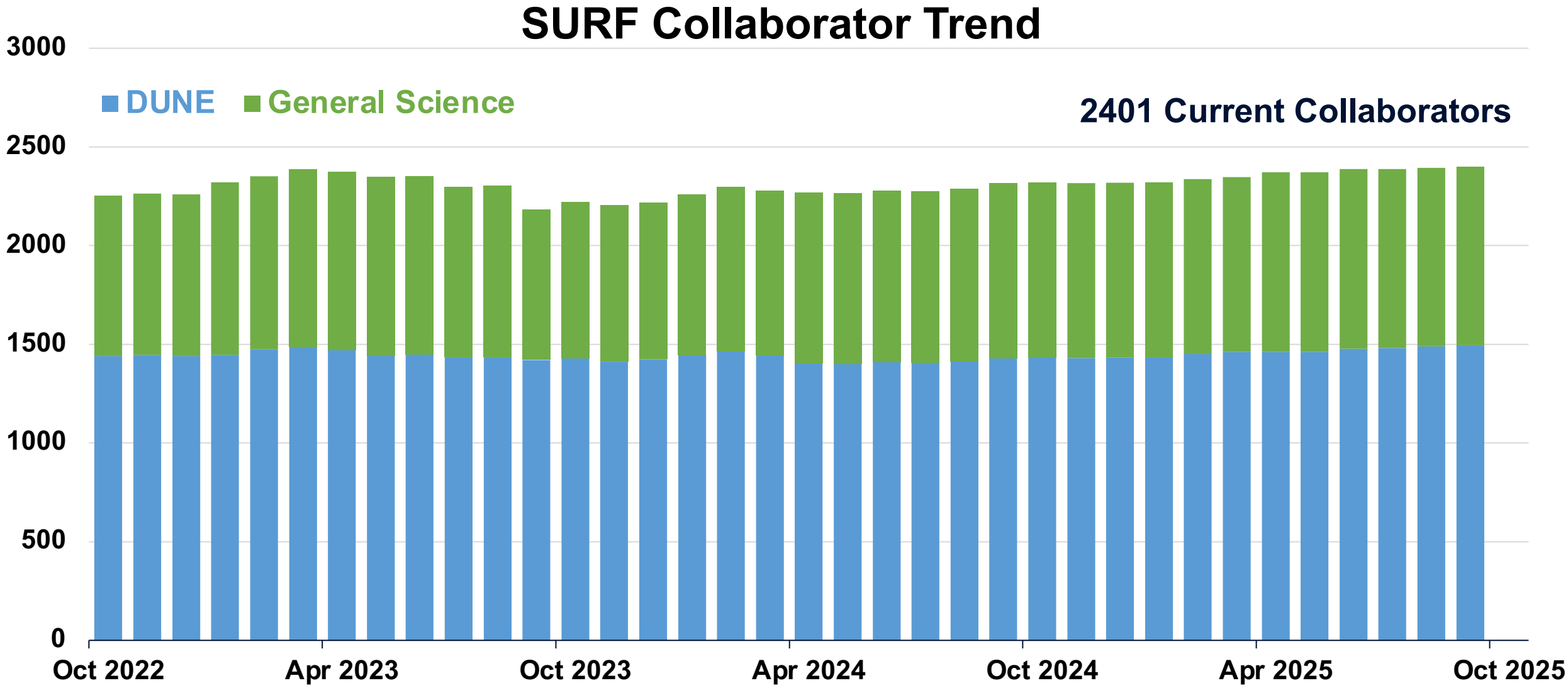
SURF Onsite Users

Significant user base, expect more engagement with UG science community



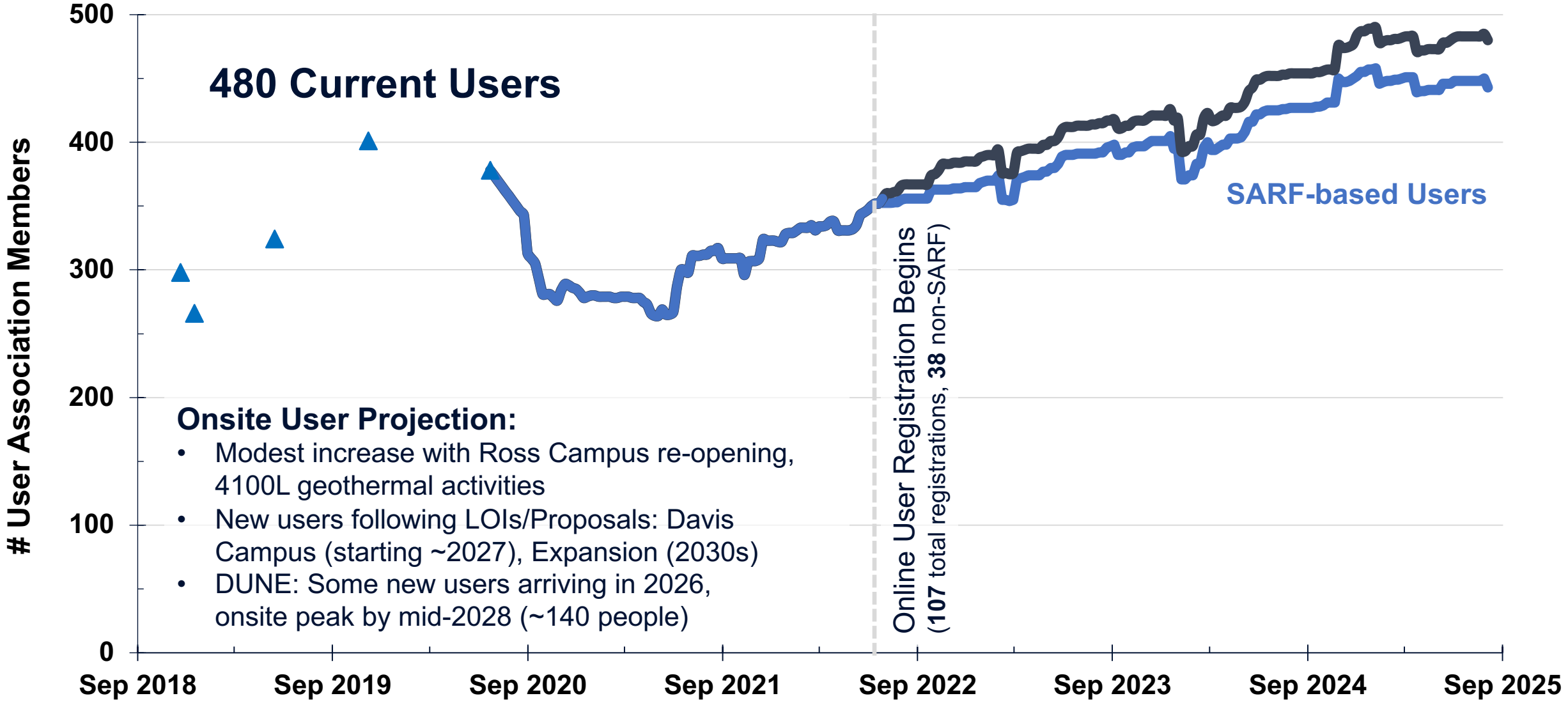
SURF Science Program

Hosting world-leading experiments and researchers from diverse scientific communities



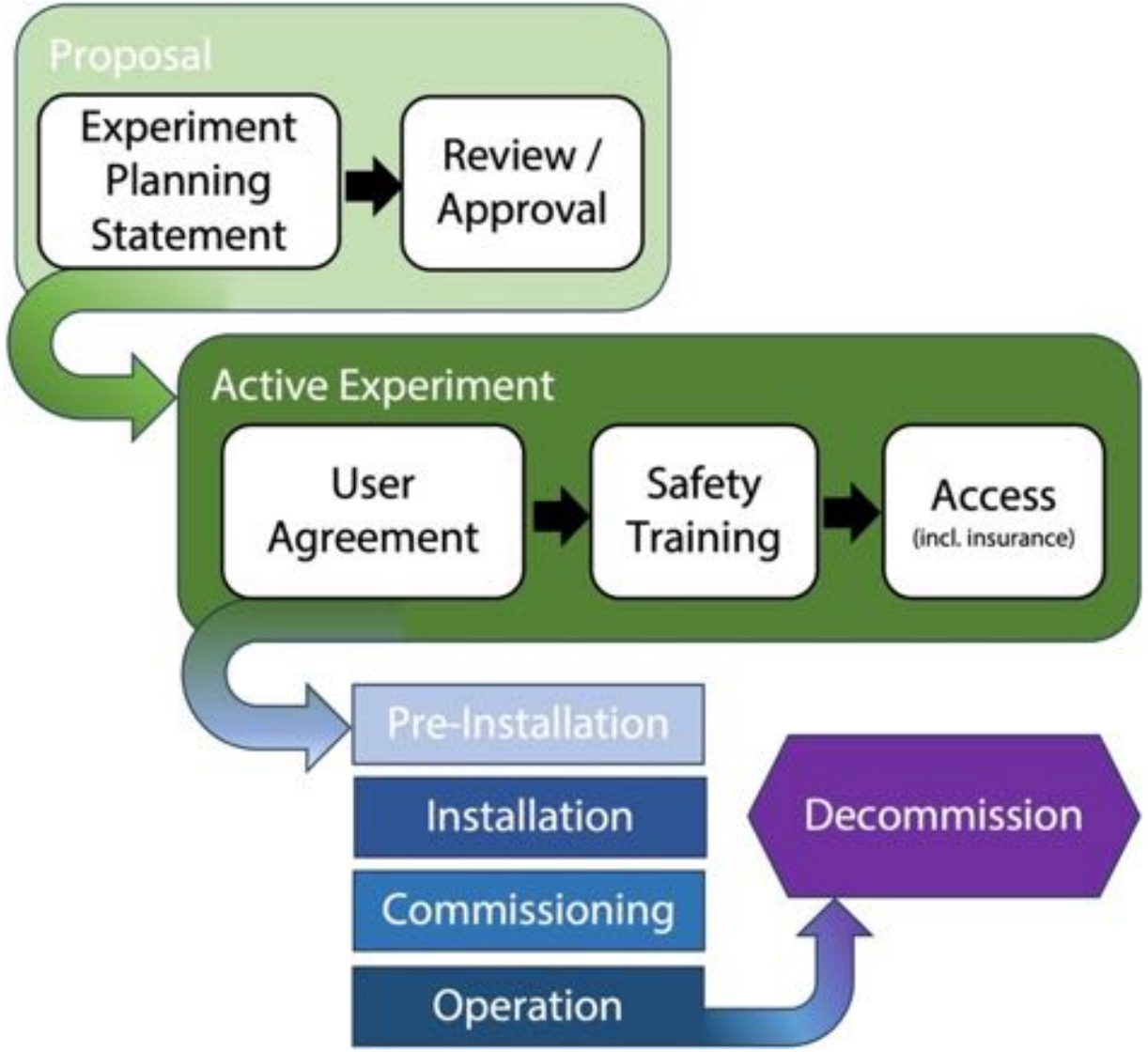
SURF User Association Members

Significant user base, expect more engagement with UG science community



SURF Experiment Implementation Program

Identify interfaces and hazards within approval framework



https://sanfordlab.org/proposal-guidelines

SURF Experiment Implementation Program

Identify interfaces and hazards within approval framework

Rev. 04
SCI-(1000-F)-34460
Experiment Planning Statement

Project Name

Date Submitted: **mm/dd/yyyy**

Status: ☐ Preliminary (Expression of interest, Support letter request) ☐ Formal implementation request ☐ Update

1. Project Summary

Discipline: ☐ Physics ☐ Biology ☐ Geology ☐ Engineering ☐ Other: _____

Project Description
Provide a brief project description, including purpose, scientific merit and scope. Add relevant citations or references as appropriate. If necessary, add additional space to this form.

Community
SDSTA is committed to creating a welcoming and collaborative
SURF's core values (Safety Focus, Care for Others, Professio
considerations in these areas.

South Dakota Science and Technology Author

Rev. 04
SCI-(1000-F)-34460
Experiment Planning Statement

9. SDSTA Review Section – to be completed by SDSTA personnel

Research Category (SDSTA determination based on user input)		☐ Non-proprietary	☐ Proprietary	
Experiment Implementation Program Requirements Additional documentation requirements.				
Required for all Experiments:	☐ User Agreement (UA)	☐ Insurance (General Liability, Workers' Compensation)		
Services Agreements:	☐ General Services Agreement (GSA)	☐ Contract		
Environment, Safety & Health Requirements Based on the information provided in the Experiment Planning Statement, the following training, documentation, and reviews are warranted.				
Hazard Analysis:	☐ (JHA/SOP required for most activities)			
Minimum Training:	☐ Orientation (surface and/or underground)	☐ General Safety – Basic (and subsequent Annual Refresher Training (ART))		
Other Training:	☐ SDSTA: _____	☐ Non-SDSTA: _____		
Inventories:	☐ Chemicals ☐ Electrical	☐ Hoisting & Rigging	☐ Pressure Vessels	☐ Radioactive Materials
Assessment Documents:	☐ Experiment Hazard Assessment Summary (EHAS), incl additional training	☐ Quantitative Analysis – Mechanical	☐ Quantitative Analysis – ODH	☐ Quantitative Analysis – Pressure
Reviews:	☐ Walk-through Inspection(s)	☐ Readiness Review(s)	☐ Merit Review	

SDSTA Review	*Name*	*Date*	*Signature*
SCIENCE			
ENVIRONMENT, SAFETY & HEALTH			
ENGINEERING			
INFORMATION TECHNOLOGY			
HOISTS AND SHAFTS			
SURFACE OPERATIONS & UTILITIES			
UNDERGROUND OPERATIONS			
Other Review (If applicable)	*Name*	*Date*	*Signature*
_____			
_____			
SDSTA Acceptance	*Name*	*Date*	*Signature*
SURF LABORATORY DIRECTOR			

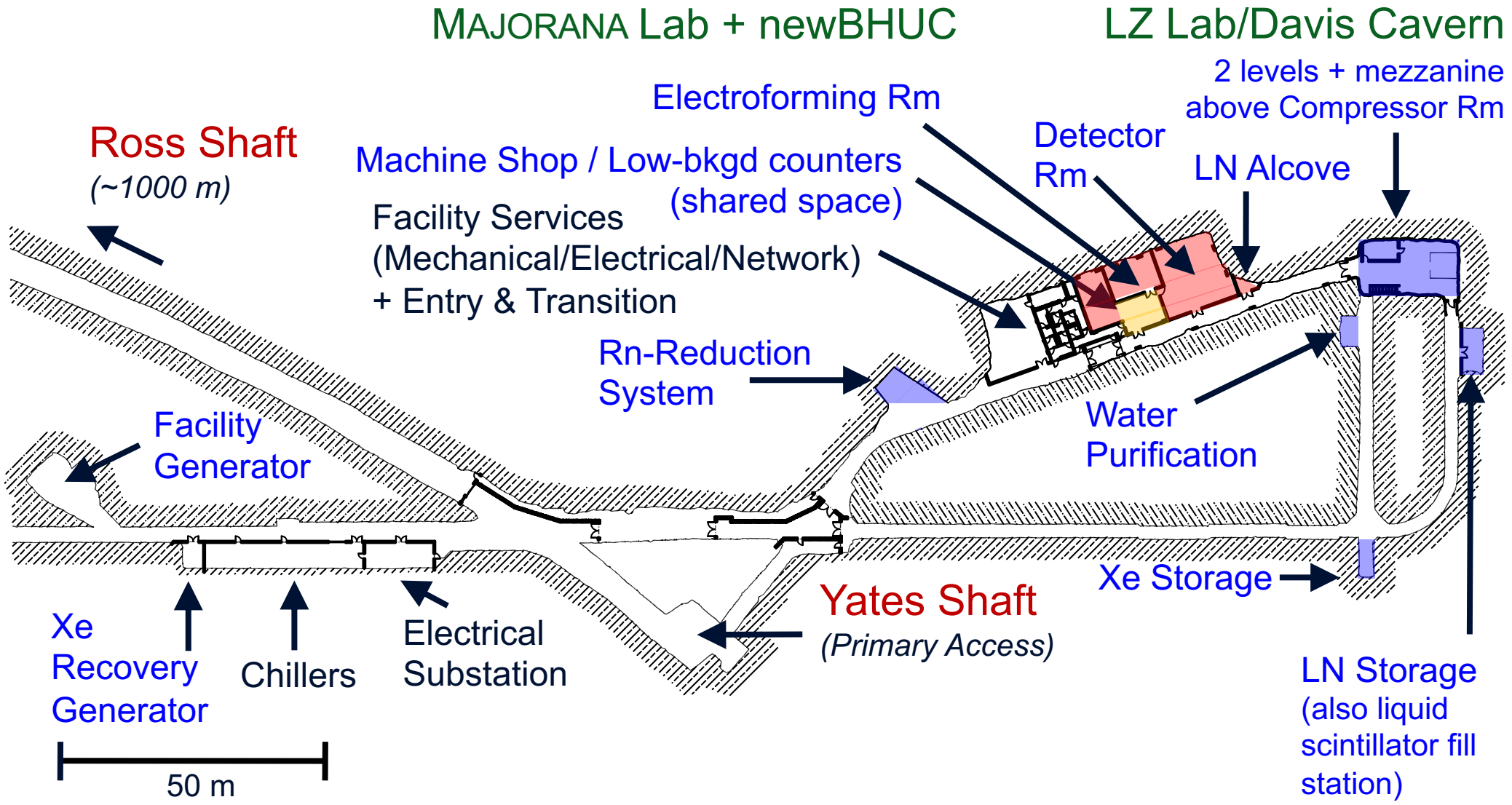
South Dakota Science and Technology Authority Page **11** of **12** Form

Expt Planning Statement (EPS)

https://sanfordlab.org/proposal-guidelines

4850L Davis Campus

3,017 m² (Total) / 1,018 m² (Science)



SURF 4850L Davis Campus

Examples of laboratory space

Detector Room (MJD):
Area =140 m^2, 11 m × 9.8-12.8 m × 2.7 m (H)
(raised section: 5.9 m × 5.8 m × 3.2 m (H))

Davis Cavern, Lower (LZ):
Area =142 m^2, 13.7 m × 9.1 m × 6.4 m (H)
(incl tank: 7.6 m dia. × 6.4 m H). Total Cavern H = 10.8 m

SURF Designated APS Historical Site

Announcement Sep 2020, Dedication May 2022

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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

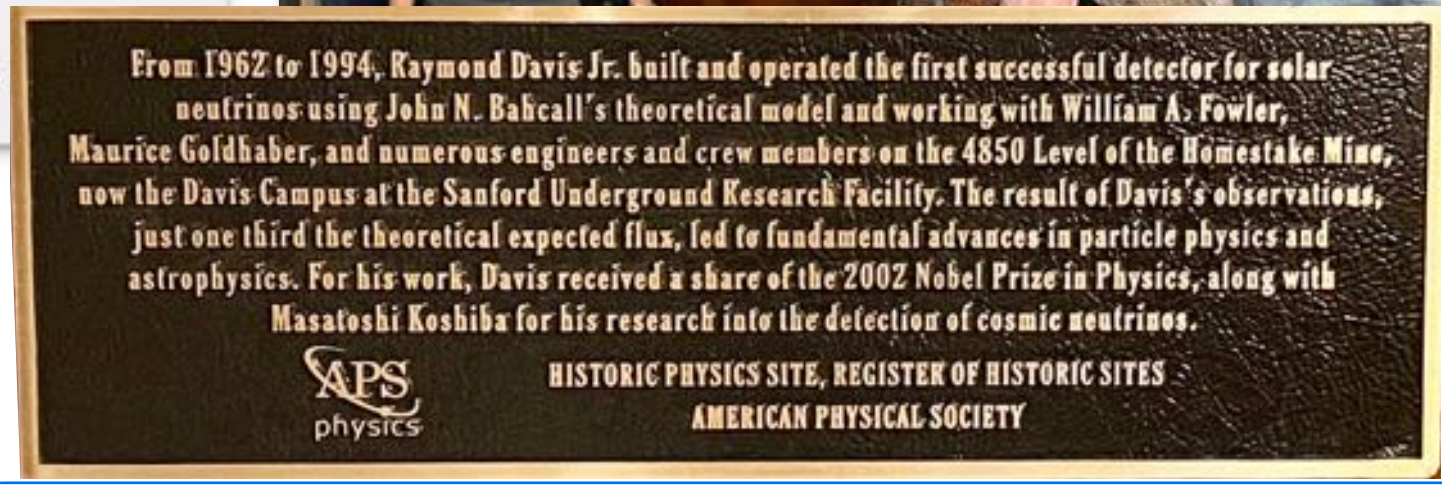
The American Physical Society (APS) today announced it has designated SURF one of two Historic Sites in physics. The other, Morgan State University in Baltimore, Maryland, is recognized as the birthplace of the National Society of Black Physicists (NSBP).

DATE ISSUED:
September 14th, 2020

SOURCE:
Sanford Underground Research Facility

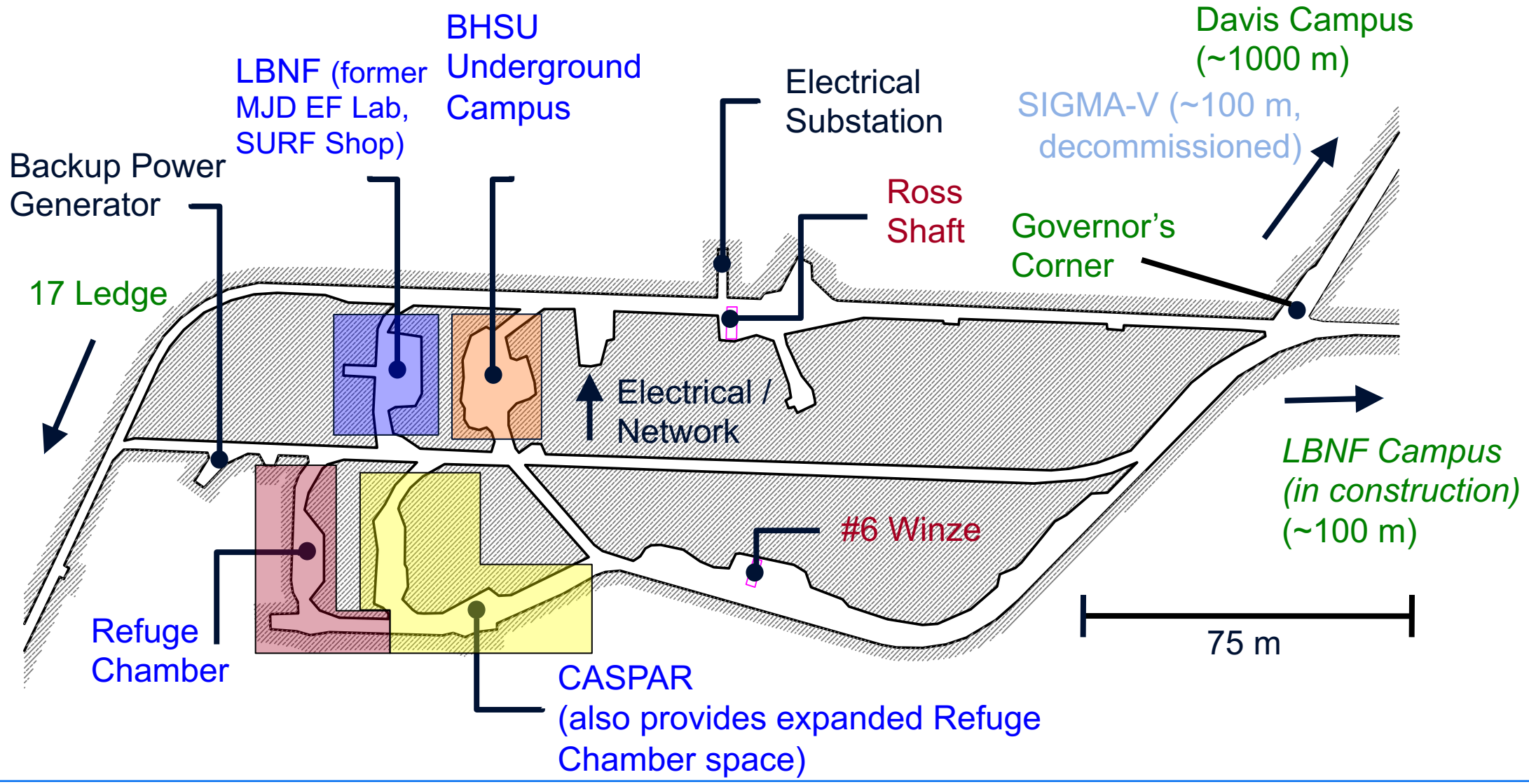
CONTENT:
Press Release

CONTACT:
Constance Walter
Communications Director
cwalter@sanfordlab.org



4850L Ross Campus

2,653 m² (Total) / 920 m² (Science)



SURF 4850L Ross Campus

Examples of laboratory space

2010-2017

Copper Electroforming

2015-2020, resumed 2025

Former MJD Electroforming:
Area = 228 m^2
(Cleanroom removed,
current construction office)

2015-2021, resumed 2025

BHUC Cleanroom:
Cavern Area = 268 m^2,
Cleanroom = 12.1 m × 6.1 m ×
2.4 m (H)

CASPAR Hall:
Area = 236 m^2,
30 m × 3 m (min) × 2.8 m (H)

SURF Plans to Become DOE User Facility

Benefits:

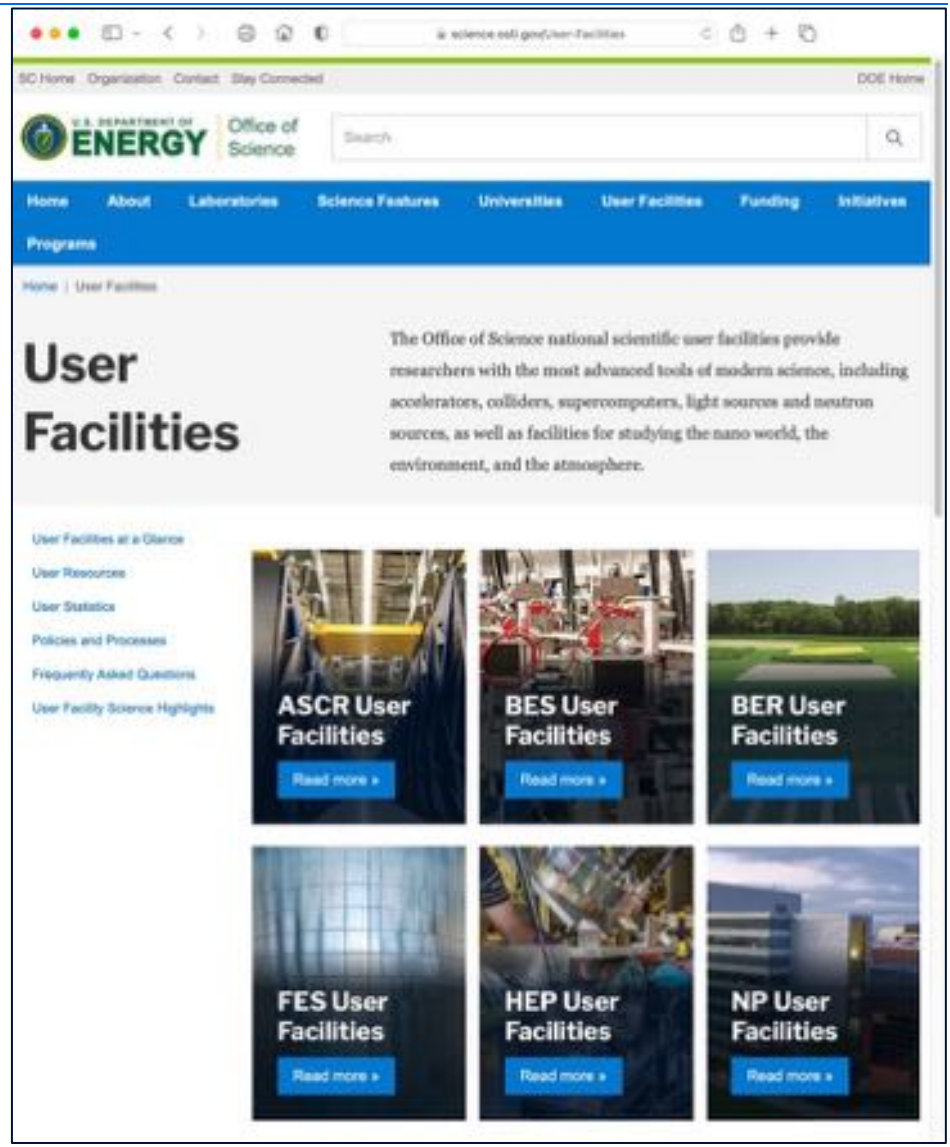
- Expands DOE User Facility portfolio to incl underground lab, raises SURF's stature within DOE community.
- Promotes underground science in U.S., increases funding opportunities.
- Enhances SURF's role in global science community.
- Communicates SURF is open to a broad range of science and users and that we have a standard process, accepted by DOE, for hosting science.

Main Requirements:

- Facility open to users regardless of nationality or institution.
- Allocation of facility resources determined by merit review.
- Facility resources for users to conduct work safely and efficiently.
- The facility supports a formal user organization.

Status:

- User Association and Science Program Advisory Cttee established.
- Application draft near final, expect DOE invitation to submit soon.



SURF Call for Letters of Interest

Ensuring SURF used to its fullest scientific potential

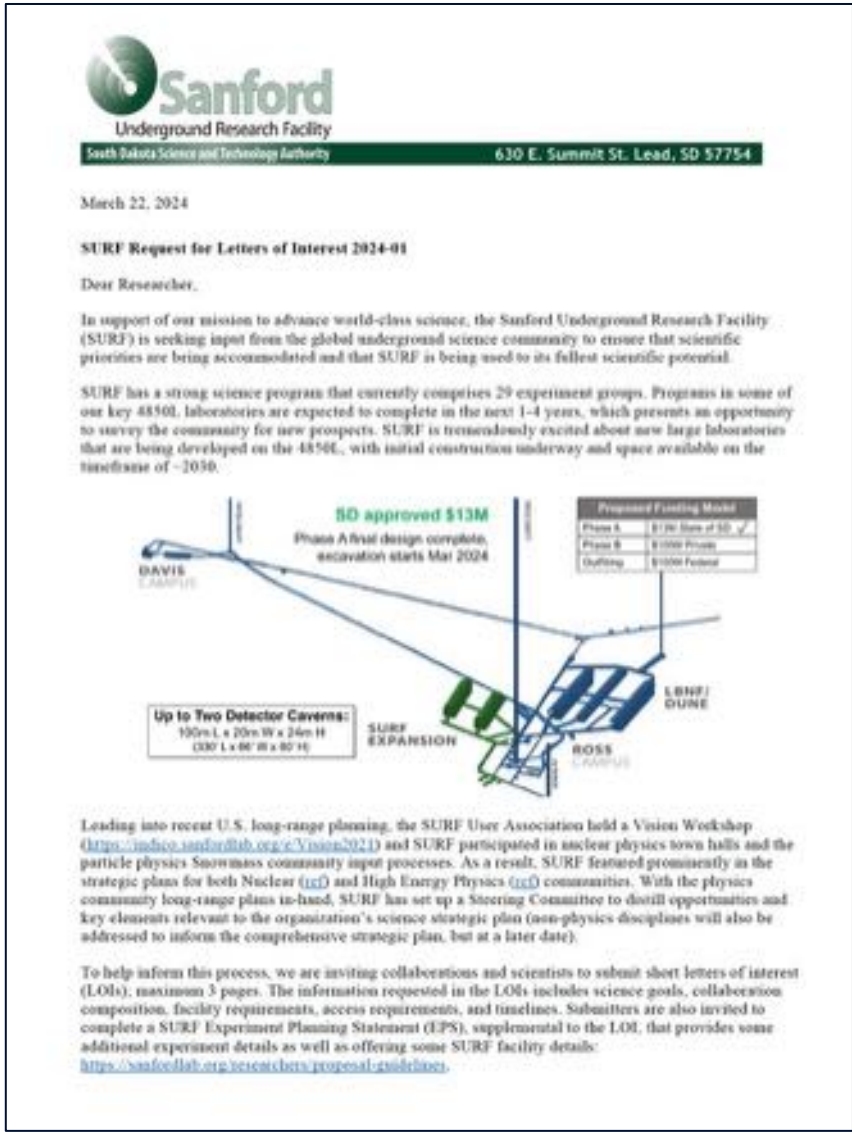
Significance of 2024 LOI Call:

- SURF's first formal call to UG science community since 2005!
- Initial calls selected strong physics anchors for Davis Campus: MJD and LUX (which led to current LZ)
- 2024 call is opportunity for SURF to advance scientific strategic plan goals, ensure strong science program continues

Overview of 2024 LOI Call:

- Open to all disciplines: Physics, Geology, Biology, Engineering
- Identifies specific existing space on 4850L and 4100L, other undeveloped areas may be available now
- 4850L Expansion started Mar 17, 2024, space available ~2030 (nominally two detector caverns: 100 m L x 20 m W x 24 m H, LOIs and subsequent discussions will inform final design)
- LOIs reviewed by SURF Science Program Advisory Committee
- Nominal deadline May 17, 2024, **LOIs still being accepted**

15 responses received, initial SPAC review complete



Sanford
Underground Research Facility
South Dakota Science and Technology Authority 630 E. Summit St. Lead, SD 57754

March 22, 2024

SURF Request for Letters of Interest 2024-01

Dear Researcher,

In support of our mission to advance world-class science, the Sanford Underground Research Facility (SURF) is seeking input from the global underground science community to ensure that scientific priorities are being accommodated and that SURF is being used to its fullest scientific potential.

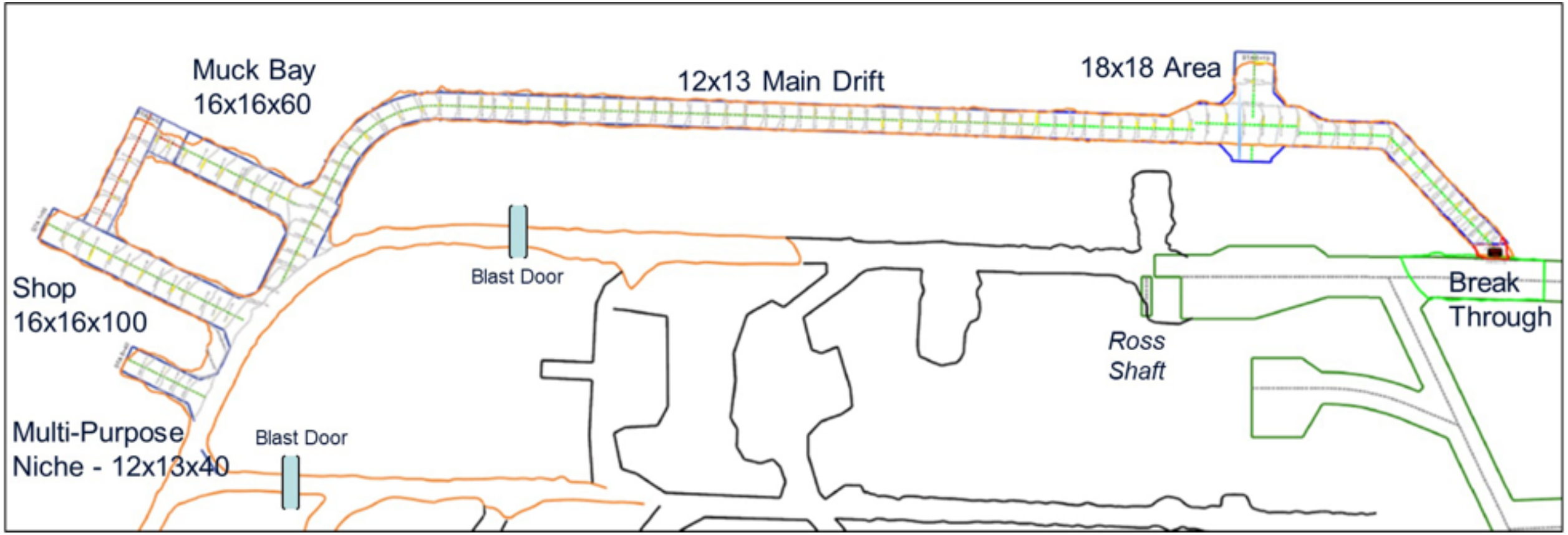
SURF has a strong science program that currently comprises 29 experiment groups. Programs in some of our key 4850L laboratories are expected to complete in the next 1-4 years, which presents an opportunity to survey the community for new prospects. SURF is tremendously excited about new large laboratories that are being developed on the 4850L, with initial construction underway and space available on the timeframe of ~2030.

Leading into recent U.S. long-range planning, the SURF User Association held a Vision Workshop (https://indico.sanfordlab.org/e/Vision2021) and SURF participated in nuclear physics town halls and the particle physics Snowmass community input processes. As a result, SURF featured prominently in the strategic plans for both Nuclear (nrd) and High Energy Physics (hrd) communities. With the physics community long-range plans in-hand, SURF has set up a Steering Committee to distill opportunities and key elements relevant to the organization's science strategic plan (non-physics disciplines will also be addressed to inform the comprehensive strategic plan, but at a later date).

To help inform this process, we are inviting collaborations and scientists to submit short letters of interest (LOIs); maximum 3 pages. The information requested in the LOIs includes science goals, collaboration composition, facility requirements, access requirements, and timelines. Submitters are also invited to complete a SURF Experiment Planning Statement (EPS), supplemental to the LOI, that provides some additional experiment details as well as offering some SURF facility details: https://sanfordlab.org/researchers/proposal-guidelines.

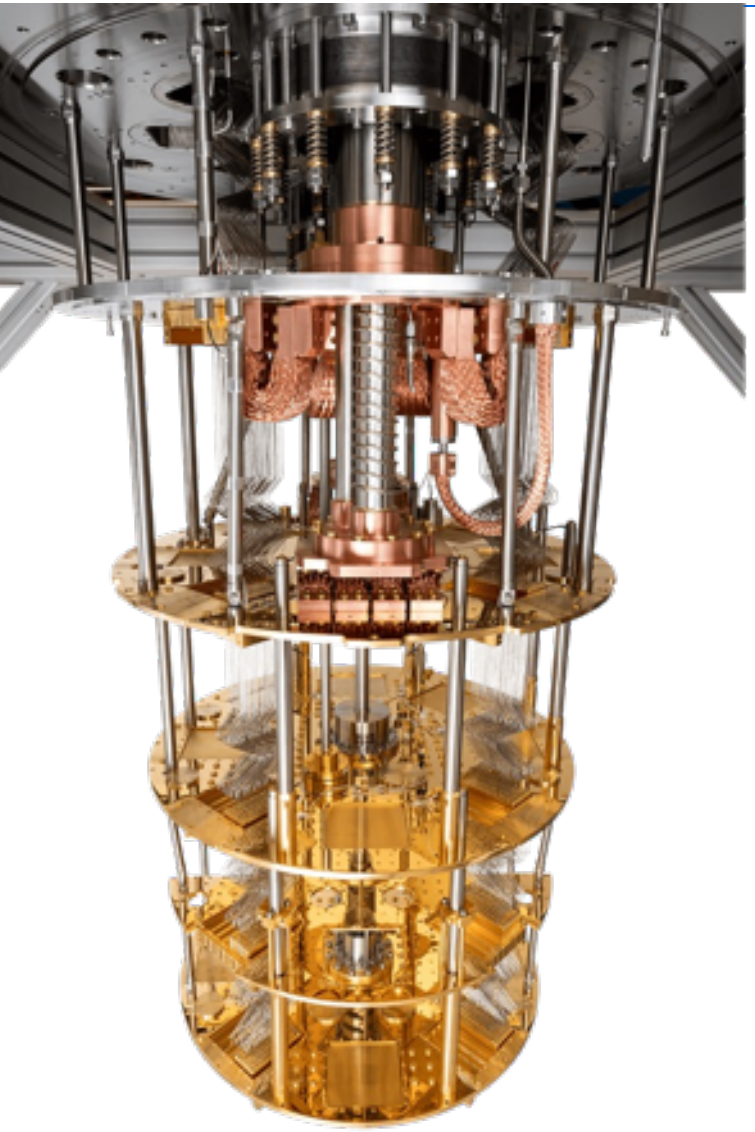
4850L Laboratory Expansion – Phase A Complete

Bypass Drift layout



SURF Cryogenic User Facility

State investment to leverage federal funding and attract industry leaders

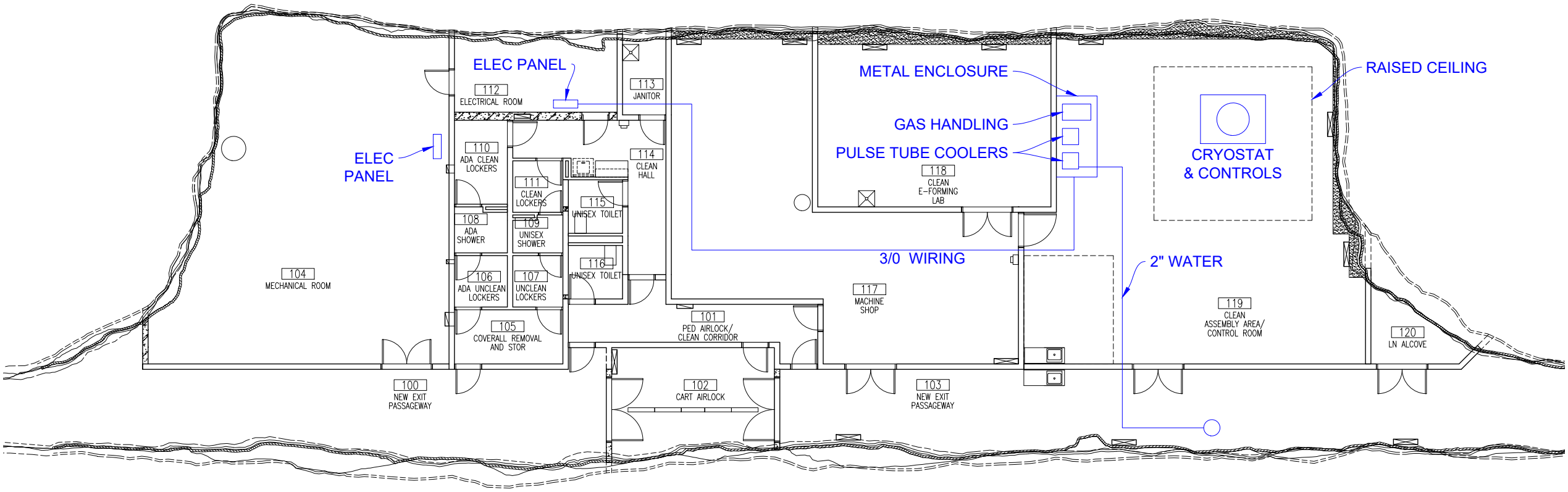


- **Bluefors XLD1000SL** dilution refrigerator, accommodates science detector/shielding; also appropriate for industry/quantum computing
- **Cryogenic/Quantum Center** strengthens case for becoming DOE scientific User Facility, with potential for increased funding for scientific infrastructure

XLD1000sl	Guaranteed	Expected
Base temperature	10 mK	8 mK
Cooling power at 20 mK	>30 µW	34 µW
Cooling power at 100 mK	>1000 µW	1100 µW
Cooling power at 120 mK	>1400 µW	1600 µW
MXC Flange Diameter	500 mm	

4850L Davis Campus

Conceptual layout for Cryogenic User Facility



SURF Current & Future Facilities

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	~2028	LZ data complete early ~2028 + decommissioning
	MJD Lab – 3 Rooms *(1 Rm for Cryo Facility)*	300	1,279	2027 / ~2032	Ge-76 DBD + Ta-180m completed, decommissioning complete in 2026; Cu e-forming through ~2031
	Cutout Rooms (4)	100	412	~2028	LZ timeframe for most spaces
Ross Campus (4850L)	Former E-forming	228	742	?	LBNF use currently, likely unavailable for several yrs
	BHUC (BHSU cleanroom)	266	773	N/A	Low-bkgd counting operations resumed summer 2025. Indefinite use.
	CASPAR	395	1,130	2027+	Phase II program underway until at least 2028. Proposals for Phase III (Also expanded Refuge)
	Refuge Chamber	258	866	?	Long-term use TBD
LBNF (4850L)	LBNF	9,445	191,863	?	Excavation complete early 2024; MOO/FD4 available
4100L	Geoscience Lab	334	11 drill holes	2028	DEMO-FTES use 2023-2025, CUSSP 2025-2027
4850L	*Expansion (2 proposed)*	*4,022*	*94,608*	*Earliest new: excavation 2029, complete ~2031*	*Each 20m (W) x 24m (H) x 100m (L)*
7400L	*New Labs (2 proposed)*	*4,178*	*42,440*		*Each 15m (W) x 15m (H) x 75m (L) + other supporting*

SURF Electrical and Standby Power

Current SDSTA + LBNF	Total Capacity	Available Capacity
Electrical Power [kW]	24,000	20,000
Standby Power [kW]	390	80

Future (FY27) SDSTA + LBNF	Total Capacity	Available Capacity
Electrical Power [kW]	24,000	15,000

LBNF/DUNE Operations = 5-6 MW

(4 detectors)

- Nitrogen generators ~3 MW
- Chillers/cooling ~1.6 MW
- Detector power ~1.4 MW