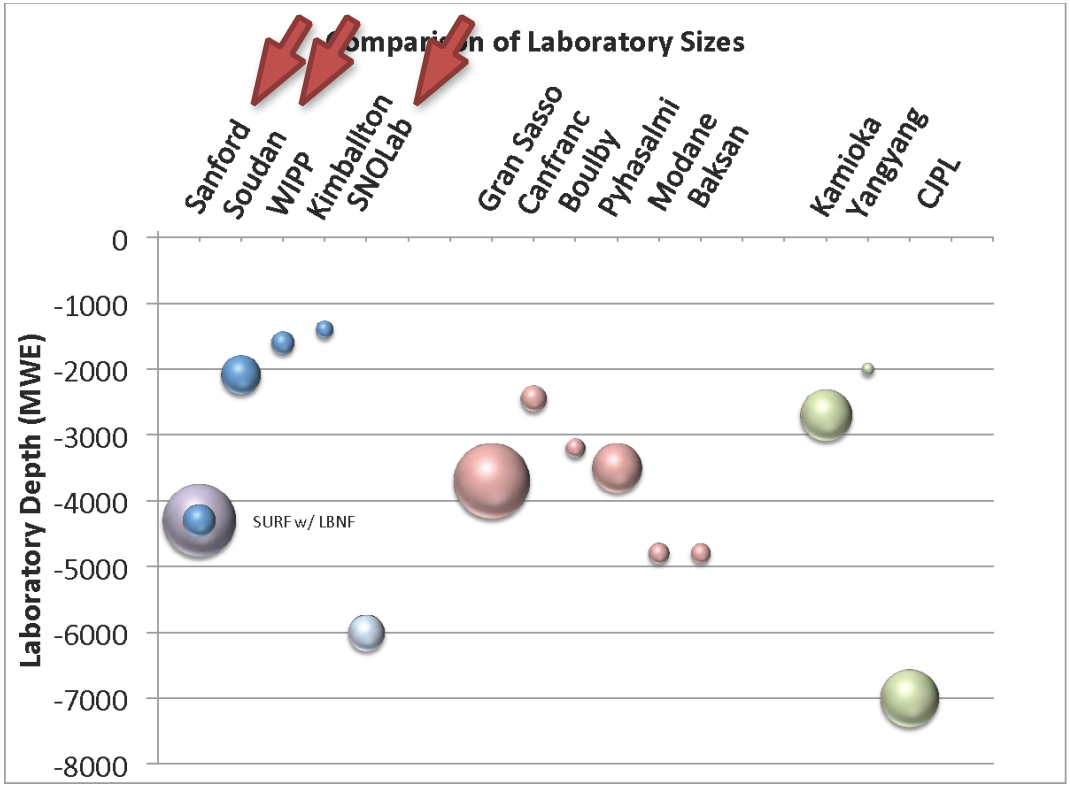
North American Deep Underground Laboratories:

Soudan, SNOLab, & Sanford Underground Research Facility



Kevin T. Lesko

LBNL

18 March 2015

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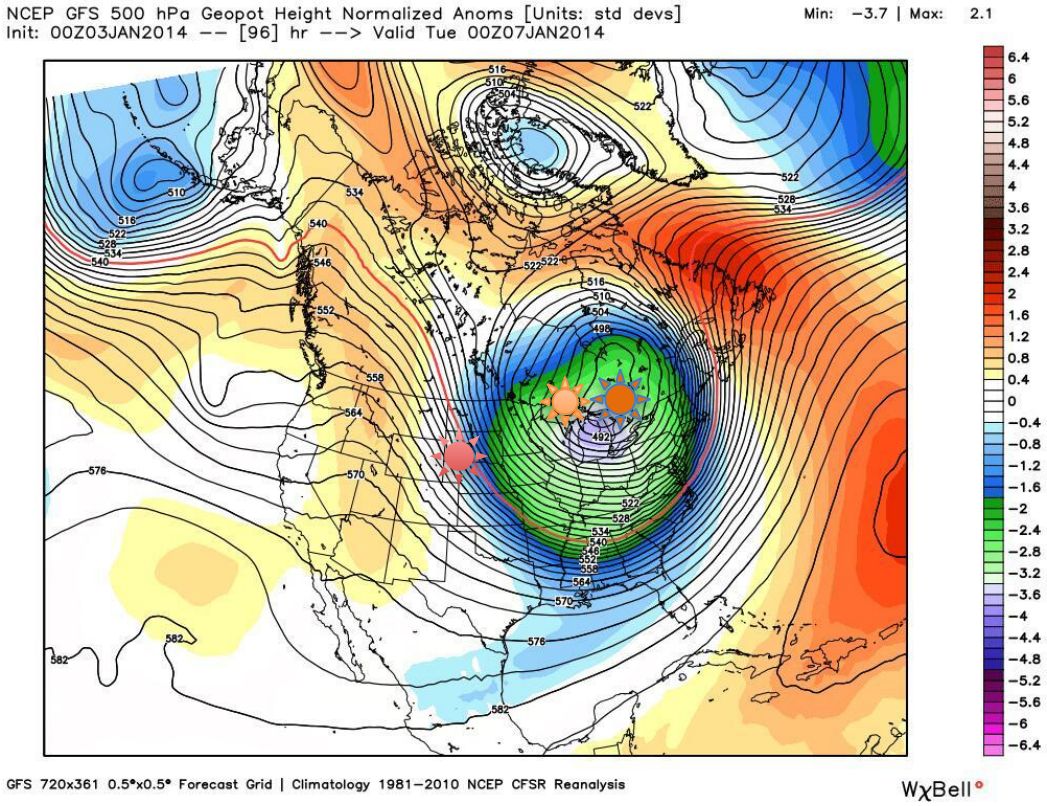

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SNOLab's science programme

Experiment	Solar ν	0νββ	Dark Matter	S/Nova ν	Geo ν	Other	Space allocated	Status
CEMI						Mining Data Centre	Surface Facility	In Construction
COUPP-4			√				"J"-Drift	Completed
COUPP-60			√				Ladder Labs	Operational
DAMIC			√				"J"-Drift	Operational
DEAP-1			√				"J"-Drift	Completed
DEAP-3600			√				Cube Hall	In Construction
DEAP-50T/CLEAN			√				Cube Hall	Letter of Intent
Ge-1T		√					Cryopit	Letter of Intent
nEXO		√					Cryopit	Request
HALO				√			Halo Stub	Operational
MiniCLEAN			√				Cube Hall	In Construction
PICASSO-III			√				Ladders Labs	Completed
PICO-2L			√				"J"-Drift	Operational
PICO-500			√				Ladder Labs	Letter of Intent
PUPS						Seismicity	Various	Completed
SNO+	√	√		√	√		SNO Cavern	In Construction
SuperCDMS			√				Ladder Labs	Commitment
U-Laurentian						Genomics	External Drifts	Operational

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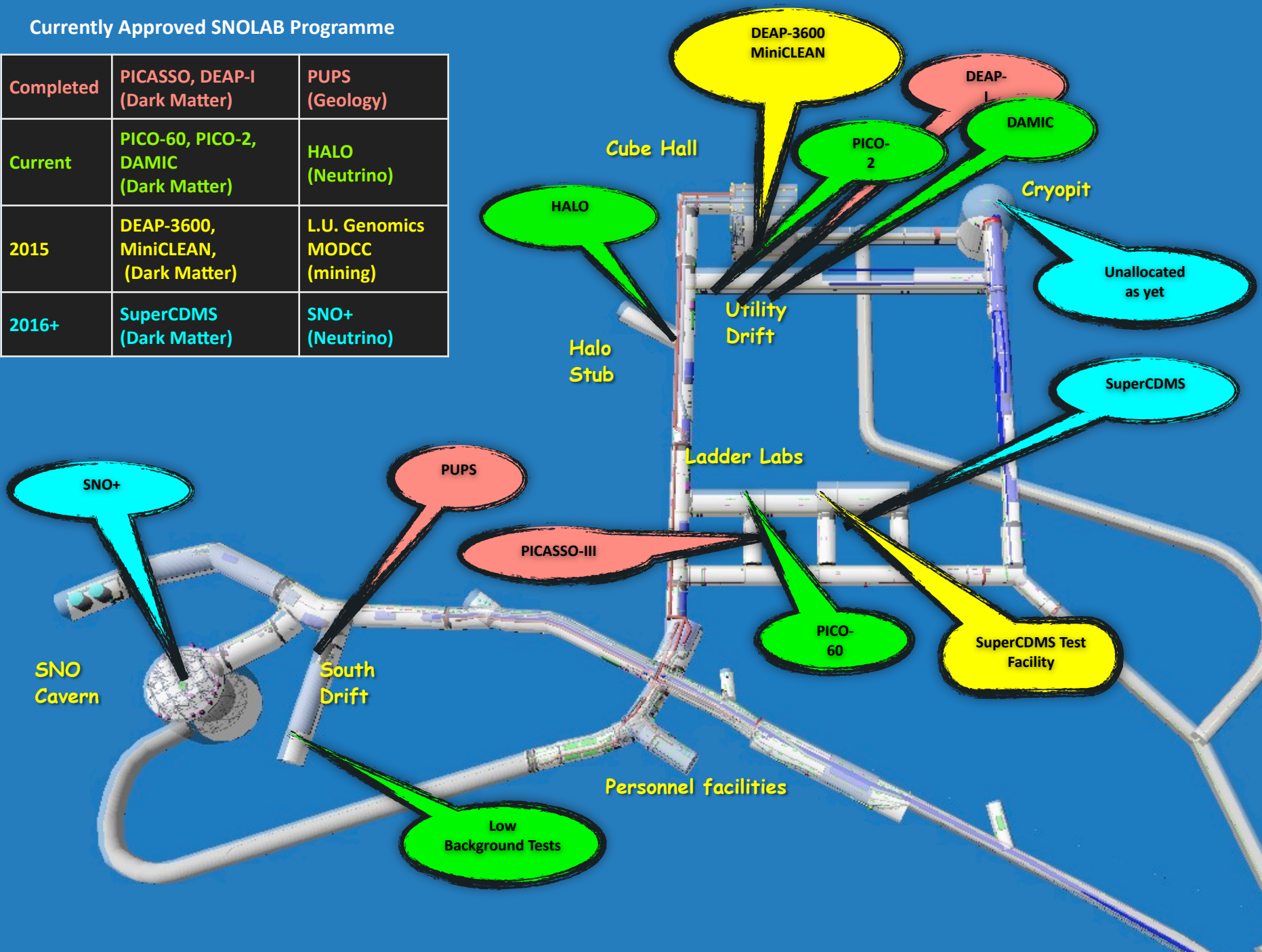
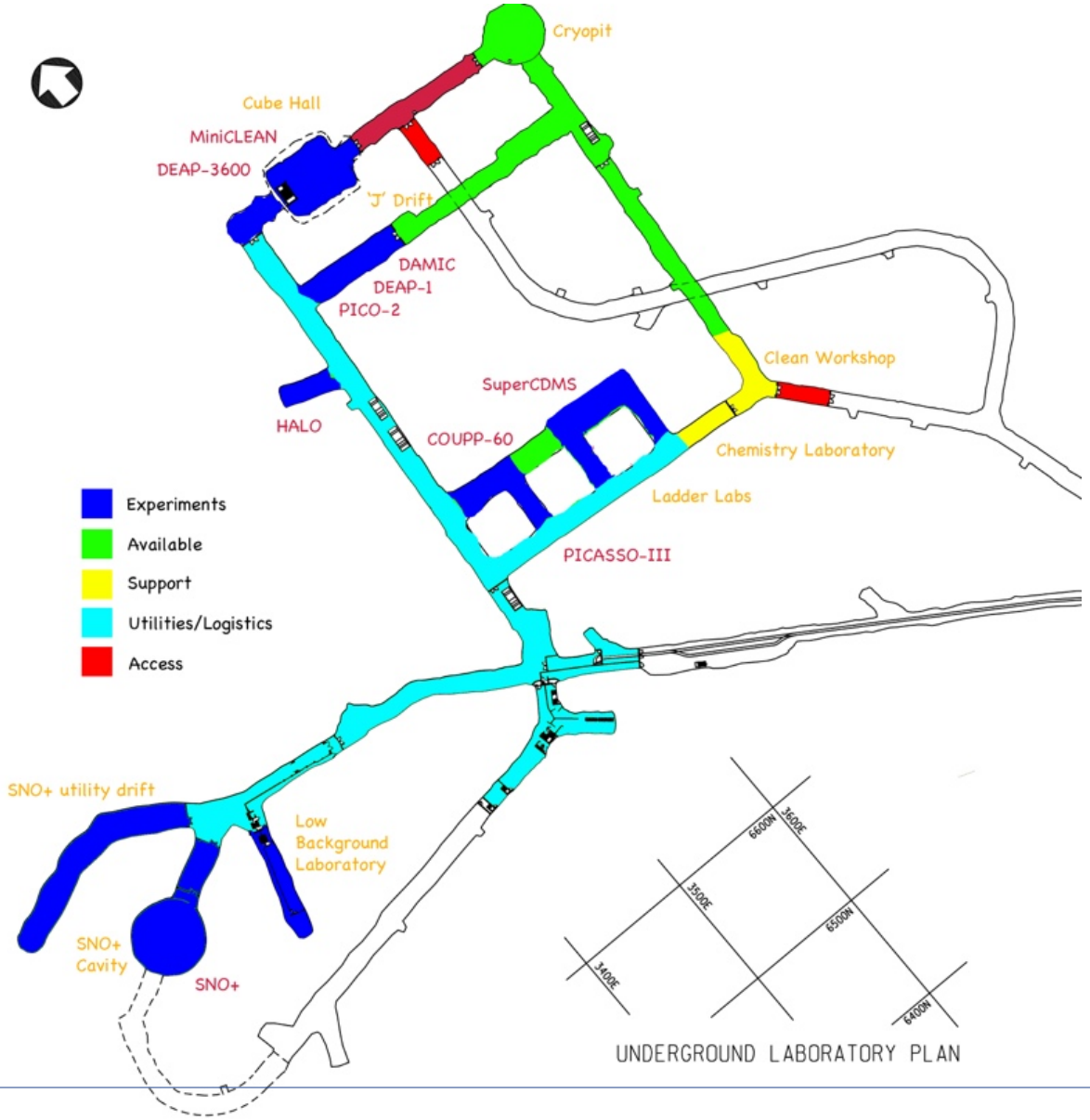
Currently Approved SNOLAB Programme

Completed	PICASSO, DEAP-I (Dark Matter)	PUPS (Geology)
Current	PICO-60, PICO-2, DAMIC (Dark Matter)	HALO (Neutrino)
2015	DEAP-3600, MiniCLEAN, (Dark Matter)	L.U. Genomics MODCC (mining)
2016+	SuperCDMS (Dark Matter)	SNO+ (Neutrino)



Underground Space Allocation



Dark Matter at SNOLAB

- Noble Liquids: DEAP-I, MiniCLEAN, & DEAP-3600
  - Single Phase Liquid Argon using pulse shape discrimination
  - Prototype DEAP-I completed operation. Demonstration of PSD at 10^8.
  - Construction for DEAP-3600 and MiniCLEAN well advanced.
  - Will measure Spin Independent cross-section.
- Superheated Liquid / Bubble chamber: PICASSO, COUPP & PICO
  - Superheated droplet detectors and bubble chambers. Insensitive to MIPS radioactive background at operating temperature, threshold devices; alpha discrimination demonstrated;
  - COUPP-4 (CF_3I) and PICASSO-III (C_4F_{10}) operation completed; COUPP-60 (CF_3I) and PICO-2l (C_3F_8) in data taking;
  - Measure Spin Dependent cross-section primarily, COUPP has SI sensitivity on iodine;
  - World leading spin-dependent sensitivity published in 2012.
- Solid State: DAMIC, SuperCDMS
  - State of the art CCD (DAMIC) Si / Ge crystals with ionisation / phonon readout (SuperCDMS).
  - DAMIC operational since 2012, 10g CCD; Upgrade planned to 100g
  - CDMS Currently operational in Soudan facility, MN. Next phase will benefit from SNOLAB depth to reach desired sensitivity. Approved in recent G2 decision.
  - Mostly sensitive to Spin Independent cross-section.

$0\nu\beta\beta$ and neutrinos at SNOLAB

- SNO+ : $^{130}Te \rightarrow {}^{130}Xe + e^- + e^-$
  - Uses existing SNO detector. Heavy water replaced by scintillator loaded with ^{130}Te. Modest resolution compensated by high statistical accuracy.
  - Requires engineering for acrylic vessel hold down and purification plant. Technologies already developed.
  - Will also measure
    - solar neutrino pep line (low E-threshold)
    - geo-neutrinos (study of fission processes in crust)
    - supernovae bursts (as part of SNEWS)
    - reactor neutrinos (integrated flux from Canadian reactors)
- EXO : $^{136}Xe \rightarrow {}^{136}Ba^{++} + e^- + e^-$
  - Engineering work for nEXO next generation liquid xenon double beta decay target, assessing potential for location at SNOLAB
  - Development work at SNOLAB surface facility on Ba daughter tagging for EXO-gas. Potential option to develop zero (non-double beta) background gas phase targets.
- HALO: Dedicated Supernova watch experiment
  - Charged/neutral current interactions in lead
  - Re-use of detectors (NCDs) and material (Pb) from other systems
  - Operational since May 2012
  - Will form part of SNEWS array

Soudan Underground Laboratory (SUL)

Operated by the University of Minnesota
Located in the Soudan Mine State Park (DNR)

Located 220 miles north of Minneapolis
60 miles south of the NOVA Lab
730 km from FNAL (On-axis NuMI ν-beam)

710 m deep (2090 mwe)
40,000 sq m of underground volume

Primary Experiments

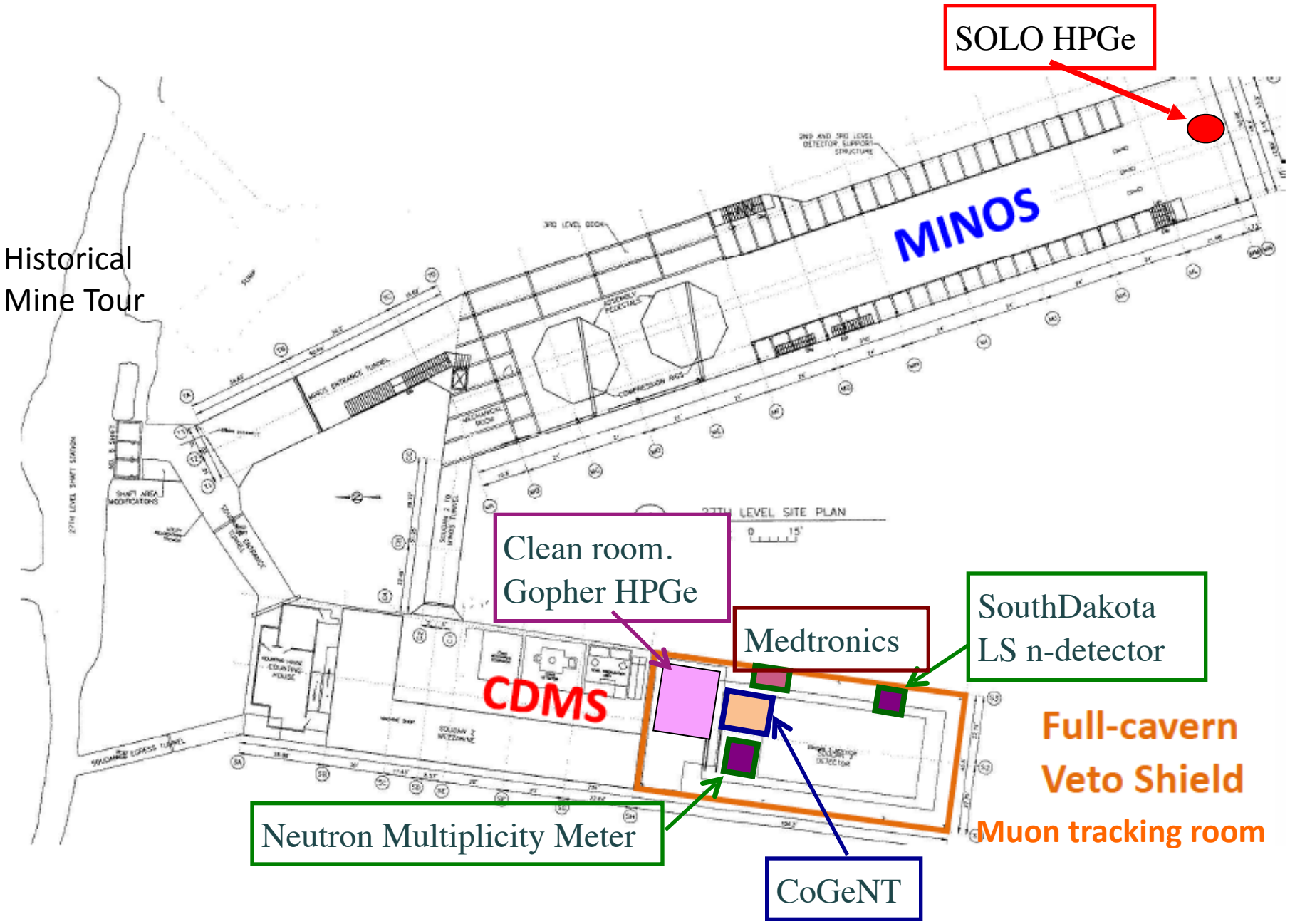
MINOS: Neutrino Oscillations
CDMS: Dark Matter
CoGeNT: Dark Matter

Low Background Counting Facility

Muon Tracking Room (11 m x 12 m x 30 m)
Gamma Screeners
Neutron Detectors

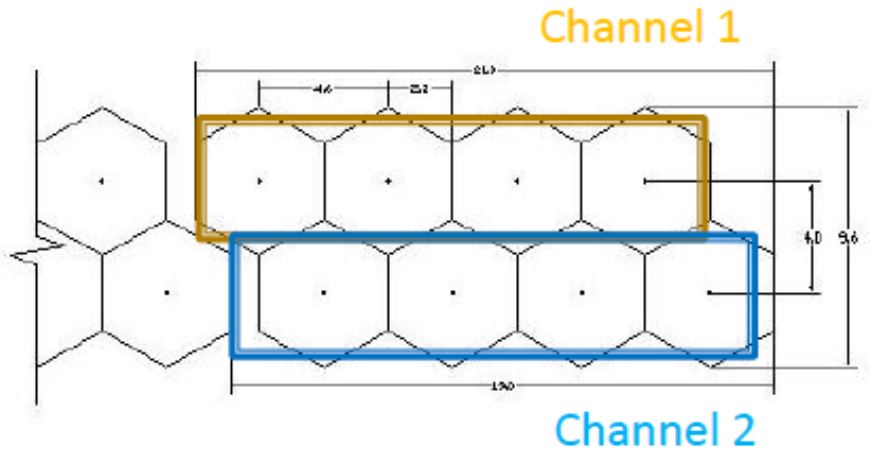
University of Minnesota committed to operation for at least until 2020. (Prisca Cushman)
Bio/Geo/Hydro Studies to continue.

Soudan Lab Plan View

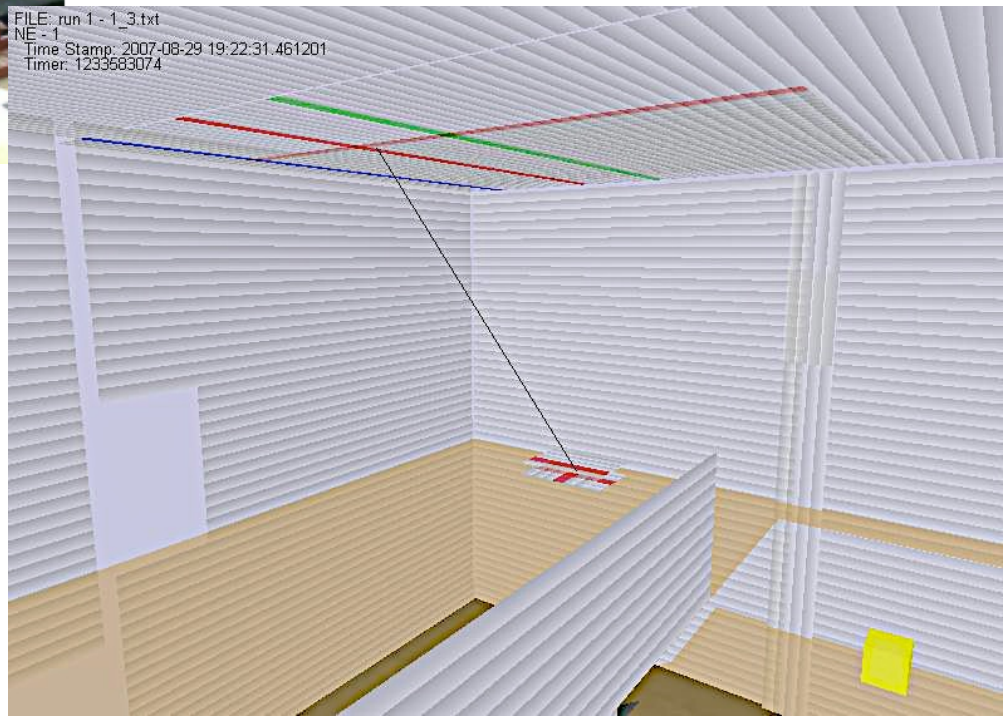


Muon Shielded Experimental Hall (35’ x 40’ x 100’)

Proportional Tube Muon Veto from old Soudan2 Proton decay experiment



- Running for 2 years as Muon Tracker
- DAQ sends to SQL Database
- Data with coincident tracks (via GPS) in
  - Neutron Multiplicity Meter
  - CDMS Muon Veto
  - NUMI beam window
- Reconfigurable trigger with CPLDs
- Provides a Muon Veto for experiments



High Purity Germanium Screeners

Cryogens, maintenance, and sample handling by Soudan crew,
Analysis and queue management by Universities

Gopher: University of Minnesota. Primarily for SuperCDMS

2.0kg of Ge

Canberra Ge detector w/ thin 1.6 mm Al window
- 2" inner OFHC copper
- surrounded by 2" low-activity Pb (<3 Bq/kg 210Pb)
- surrounded by >10" of normal Pb
- plus some outer polyethylene

Housed in clean room with very robust Rn shield

SOLO: Brown University. Primarily for LUX and LZ

0.6 kg of Ge

"Diode M" from Soudan Mo-100 double beta decay exp.

Low-activity lead shielding:
- >12" of Doe Run Pb (50 Bq/kg ^{210}Pb)
- Inner 2" German Pb (50 mBq/kg ^{210}Pb)

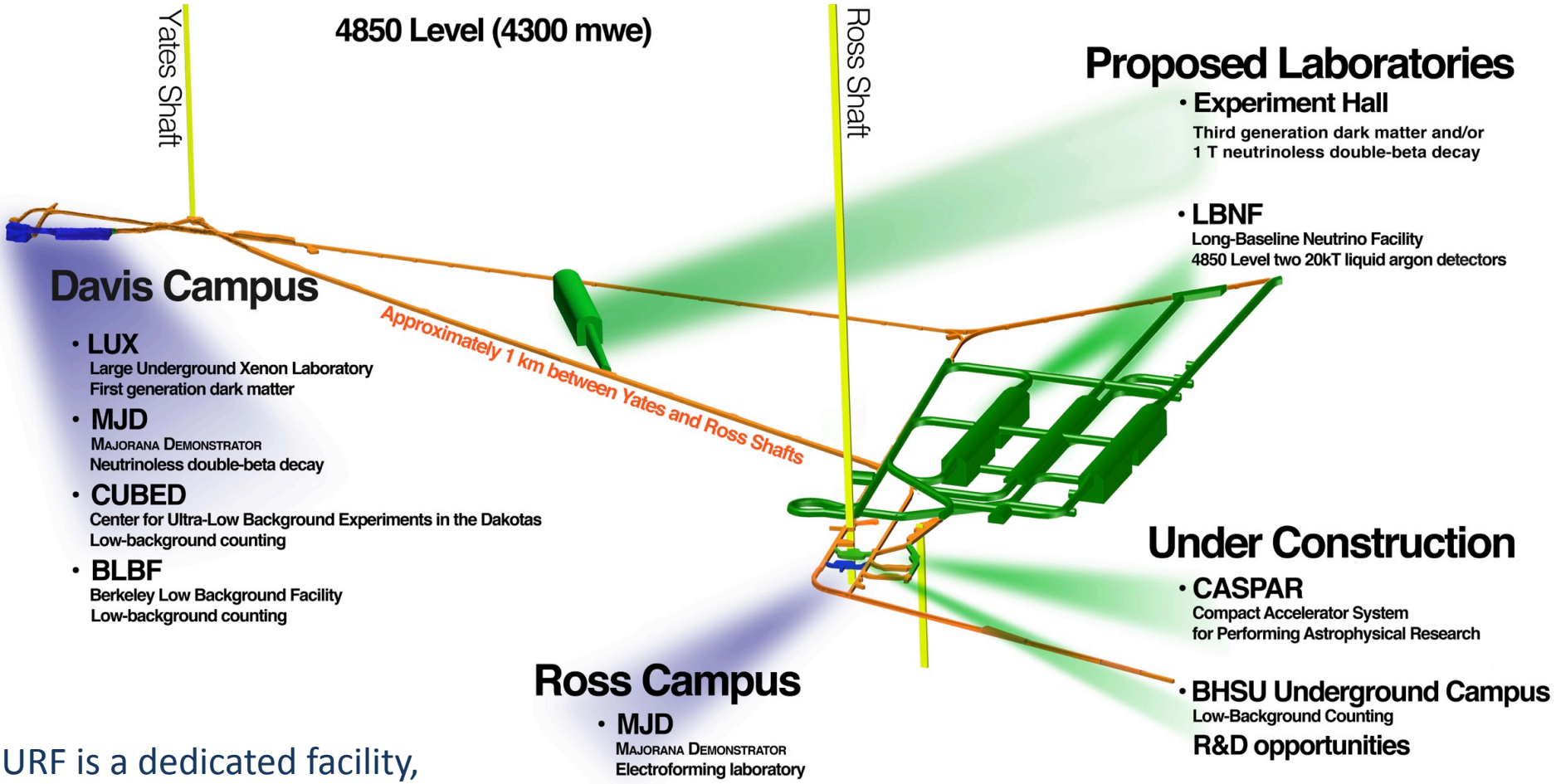
Radon seal & N_2 purge

Sanford Underground Research Facility

Sanford
Underground Research Facility

March 18, 2015

SURF 4850L Physics Laboratories

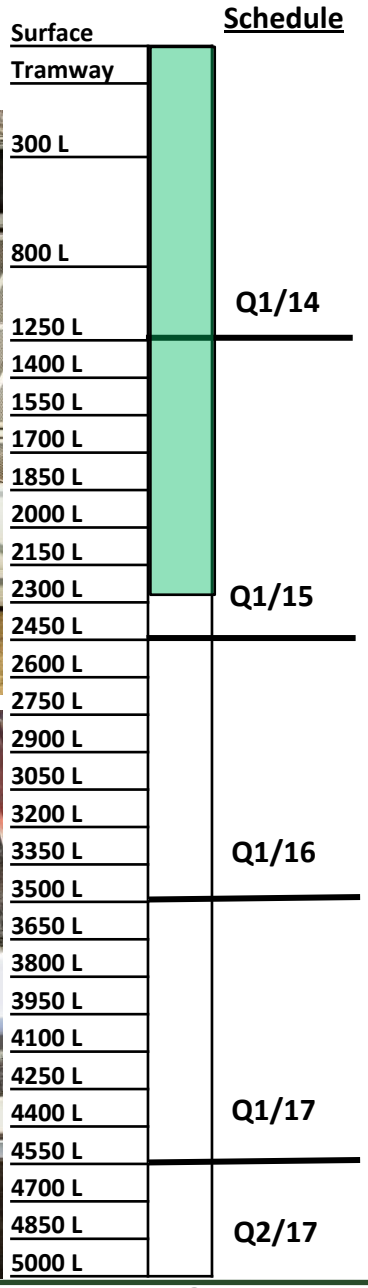


SURF is a dedicated facility, created originally with the support of the NSF, UCB, South Dakota, and Private Donations and since 2010 supported by the DOE-HEP and continued exceptional strong support by South Dakota

also arXiv:1401.0861v1 (2014)
Lesko, Euro Phys J Plus **127**, 107 (2012)

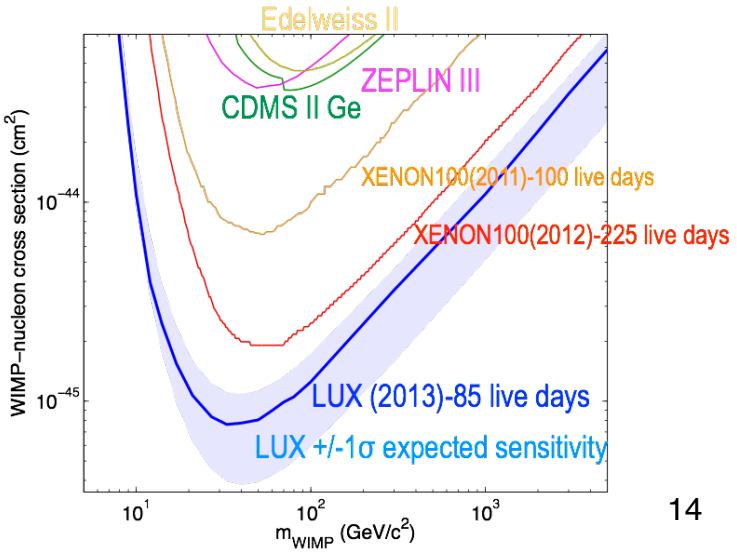
SURF Facility Status

- Facility Highlights
  - Deep (4300 mwe) underground facility dedicated for science with expansion possibilities
  - Redundant safe access with 2 principal shafts (including redundant power and network utilities)
- Ross Shaft Rehabilitation
  - Strip and re-equip underway, new installation of steel and ground support ~ 50% complete
  - Expected completion in Summer 2017 to support LBNF/DUNE
- Yates Shaft Upgrades
  - Provides main access for personnel and materials
  - Maintenance ongoing, full rehabilitation expected to occur after Ross completed
- Dewatering
  - Maintaining water level ~5700’ below surface
- Laboratories
  - Underground (Ross and Davis Campuses), Surface Lab (including cleanroom) and other surface facilities
  - Major near-term expansion plans for Ross Campus
  - Underground space for research & development



Science Road Map

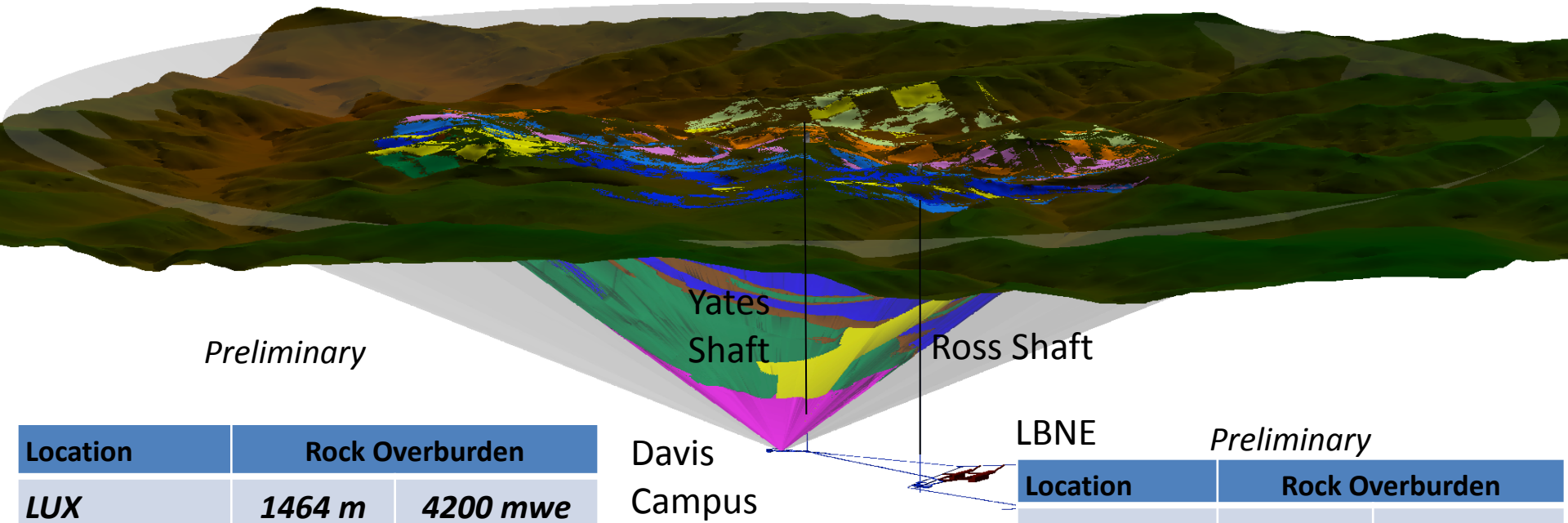
- Current Science Program
  - Majorana Demonstrator ($0\nu\beta\beta$)
  - LUX Dark Matter
  - Small scale BioGeoEng efforts
- Near-Term Expansions
  - CASPAR - Nuclear Astrophysics
  - Black Hills Underground Campus – Low Background Counting Facility
- (Slightly) Longer Term
  - LZ Generation-2 Dark Matter
  - LBNF/DUNE Long Baseline Neutrinos



SURF Geology Model

Host rock well characterized

- 3D model of seven main rock formations, detailed surface topology
- Compiling rock geo-chemistry and density data from variety of sources, paper submitted for publication
- Radioactivity well understood in host rock and intrusions



Preliminary

Location	Rock Overburden	
LUX	*1464 m*	*4200 mwe*
MJD	*1478 m*	*4300 mwe*
R&D Space	*1561 m*	*4500 mwe*

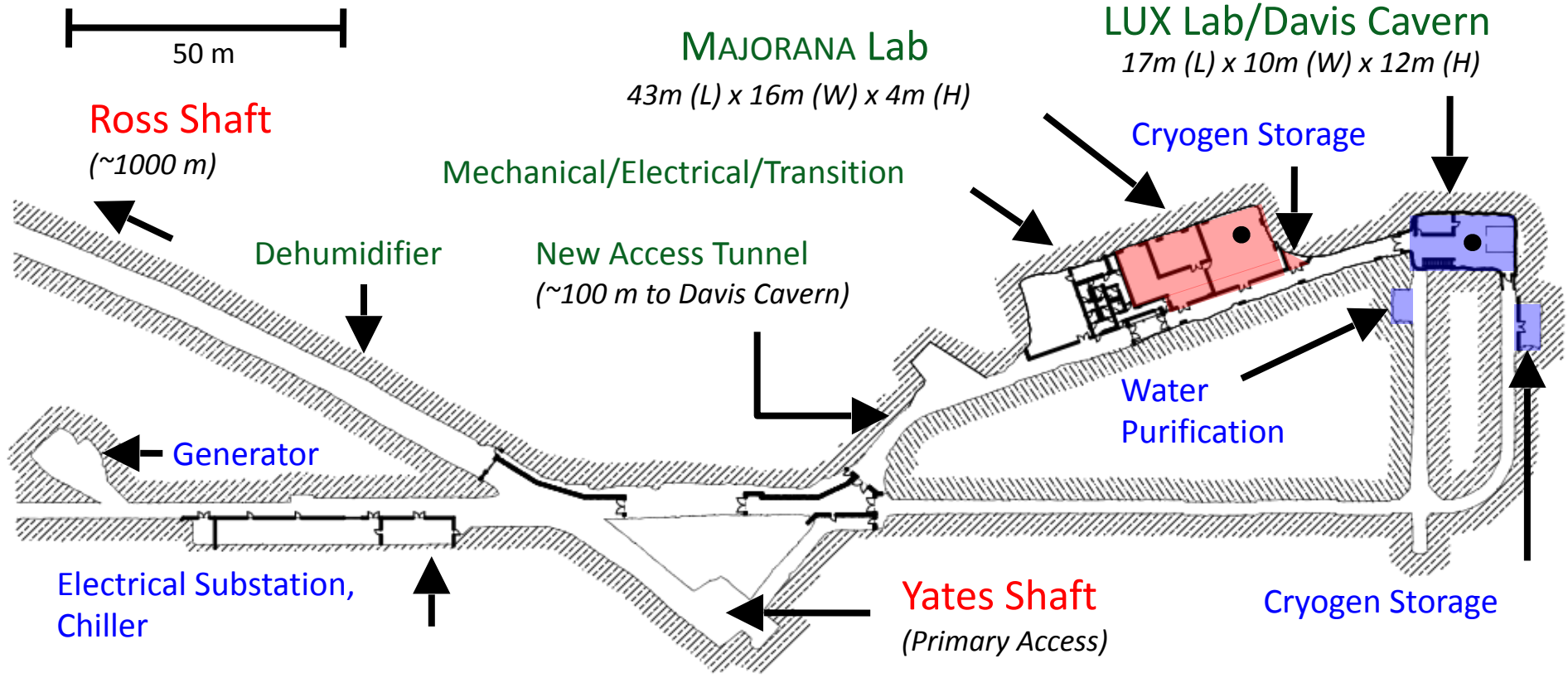
Representation of 3D cone of rock above 4850L Davis Campus

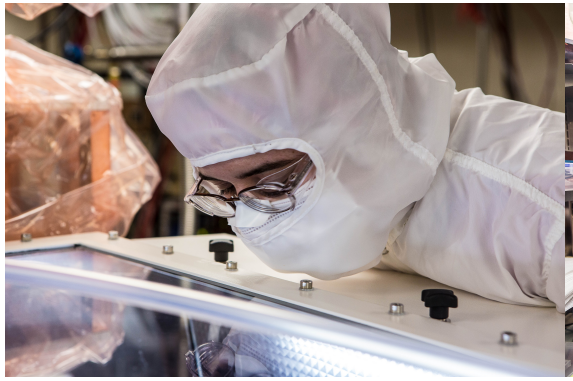
Preliminary

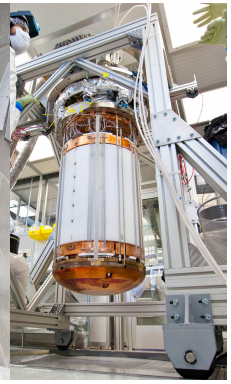
Location	Rock Overburden	
MJD Eform	*1503 m*	*4300 mwe*
LBNE 10 kt	*1391 m*	*3900 mwe*
LBNE 24 kt	*1374 m*	*3800 mwe*

4850L Davis Campus

2,732 m^2 (Total) / 1,074 m^2 (Science)



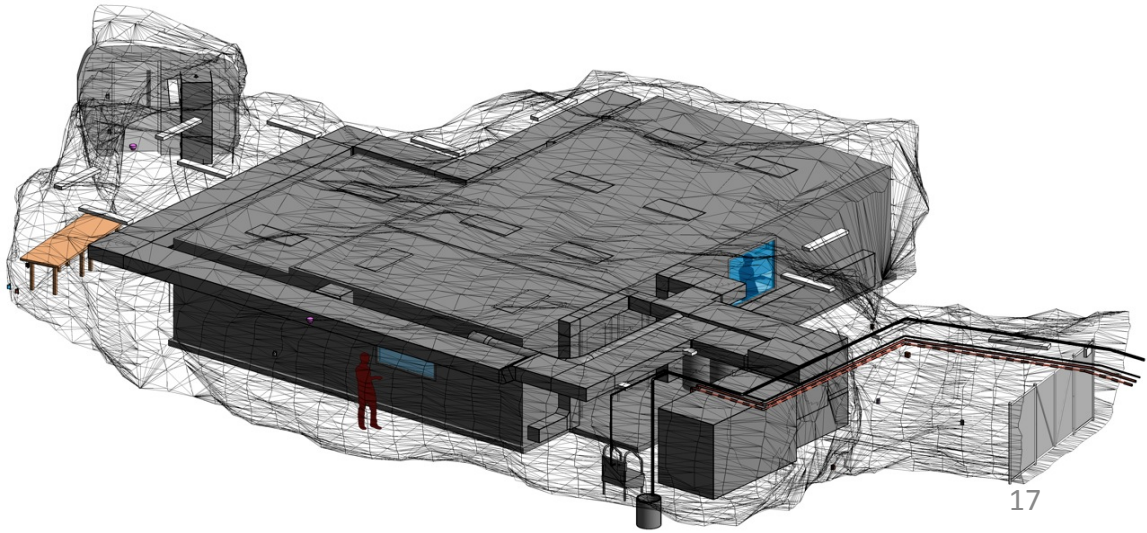




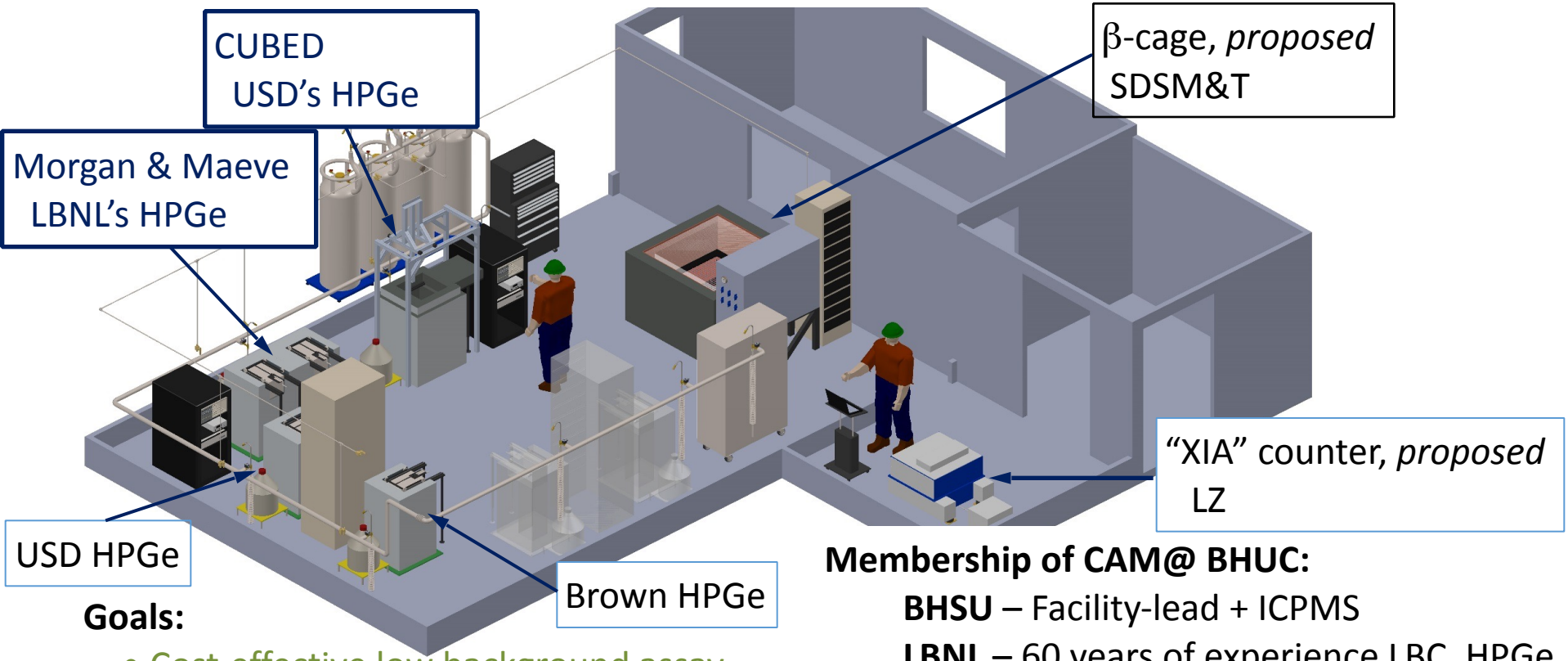
BHSU Underground Campus (new) – BHUC

Low-Background Counting Facility + R&D

- Facility supporting multidisciplinary research from multiple institutions
- Class 1000 cleanroom: 20’ x 30’, room for 8 low-background counters (or similar equipment)
  - Essential to characterize radio-purity of experiment materials and lab environment
  - 3 LBCs will relocate from Davis Campus, exploring additional capabilities
- Class 10,000 cleanroom: 20’ x 10’, mainly for biology and geology and other small projects
- Potential R&D space outside cleanroom
- Rehabilitation completed (bolting, shotcrete, paint), outfitting design awarded
- Beneficial occupancy August 2015



Consortium for **A**ssay and **M**easurement at the **B**lack **H**ills **U**nderground **C**ampus: **CAM@BHUC**



Goals:

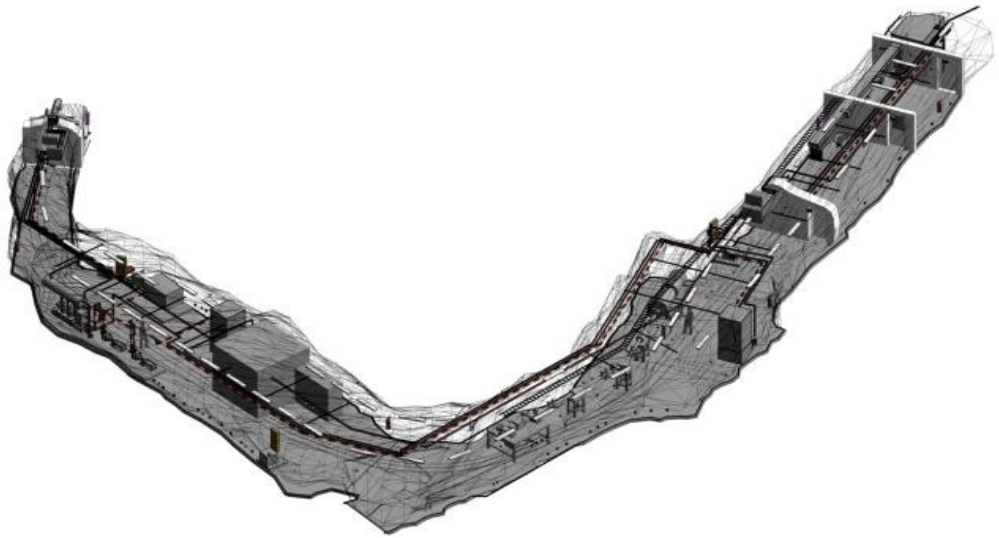
- Cost-effective low background assay
- High accuracy and cross-calibrated
- Ultra-low level sensitivity
- Simple operational model
- Develop and deploy new capabilities and higher sensitivity levels
- Develop strong connection to SD students

Membership of CAM@ BHUC:

BHSU – Facility-lead + ICPMS
LBNL – 60 years of experience LBC, HPGe
SDSTA – SURF Facility Operations
USD – HPGe, Radon, Surface Contam.
Brown - HPGe, Surface Contamination
UCL – ICPMS, Radon, HPGe
Boulby – HPGe
SDSM&T – Radon, β-cage, Si
Seeking additional members & devices

Future Experiments: CASPAR

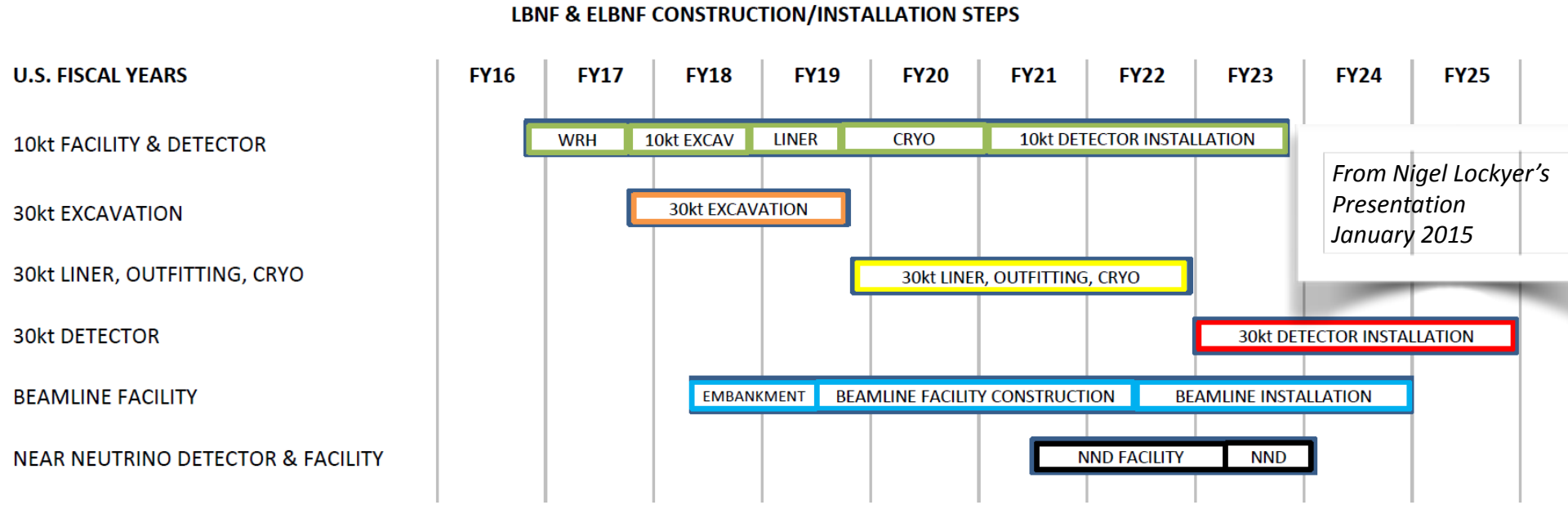
Compact Accelerator System for Performing Astrophysical Research



- Study of stellar nuclear fusion reactions responsible for production of half the elements in nature, esp. slow neutron-capture nucleosynthesis (s-process)
- Accelerator:
  - Electrostatic (best energy resolution)
  - Proton and He beams: ~200 keV to 1 MeV
  - High intensity ~150 μA
- Specialized target system, including ^{22}Ne, ^{13}C
- Detectors sensitivities including neutron, gamma, charged particles
- CASPAR will operate 10+ years
- Collaboration includes University of Notre Dame, SDSM&T, and Colorado School of Mines; SDSM&T will operate
- Initial preparations complete, including ground control, shotcreting and painting
- Laboratory outfitting started Mar 2015
- Beneficial occupancy Aug 2015

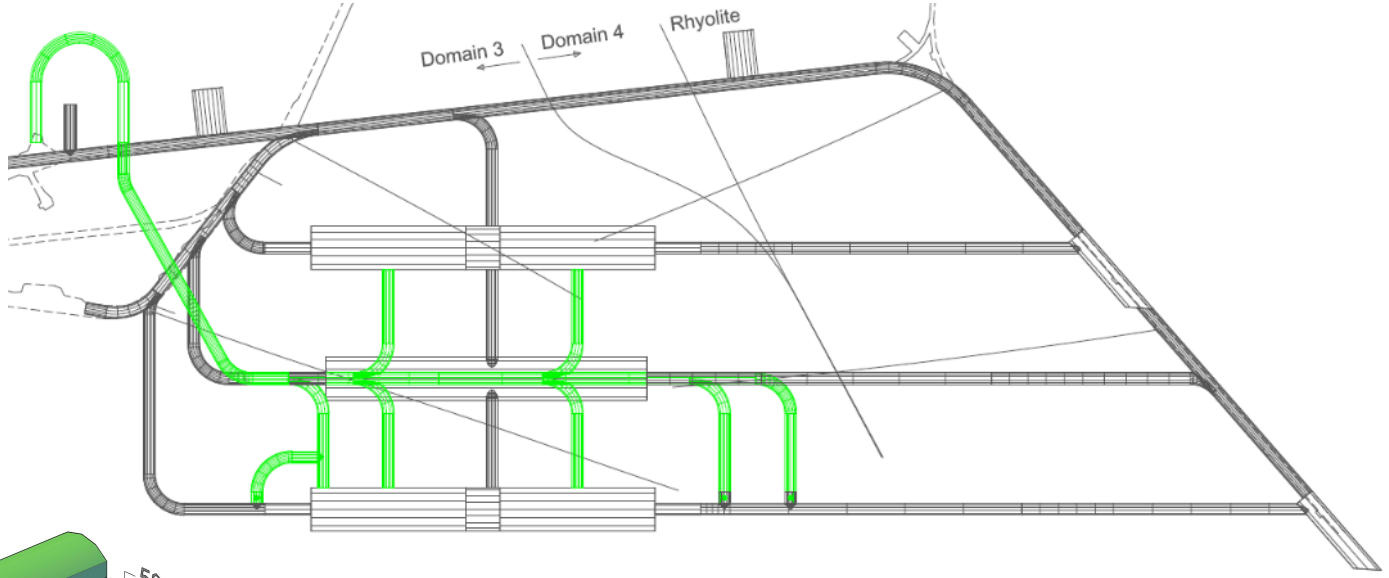
LBNF & DUNE (ELBNF) STEPS

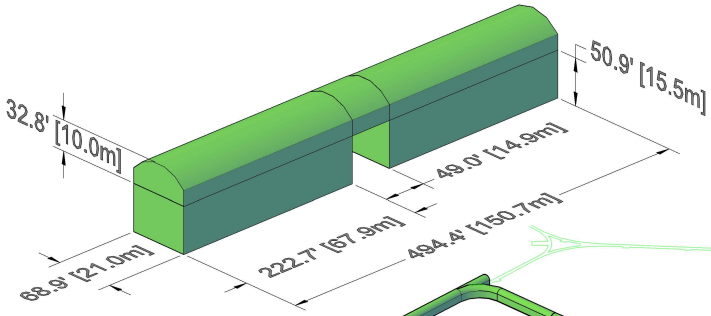
- US is aggressively developing plans to host a world-class neutrino program
- Aligned with US P5 Report, the CERN/European Strategy, and Japan/T2K-HK
- Collaboration and leadership re-formed to reflect unification with the international partners – following LHC management model
- Key goal to develop 10kt by 2021
- Ultimately to develop 40kt
- CD1-refresh, CD2a/3a in summer/fall 2015
- Goal to begin underground construction 2017

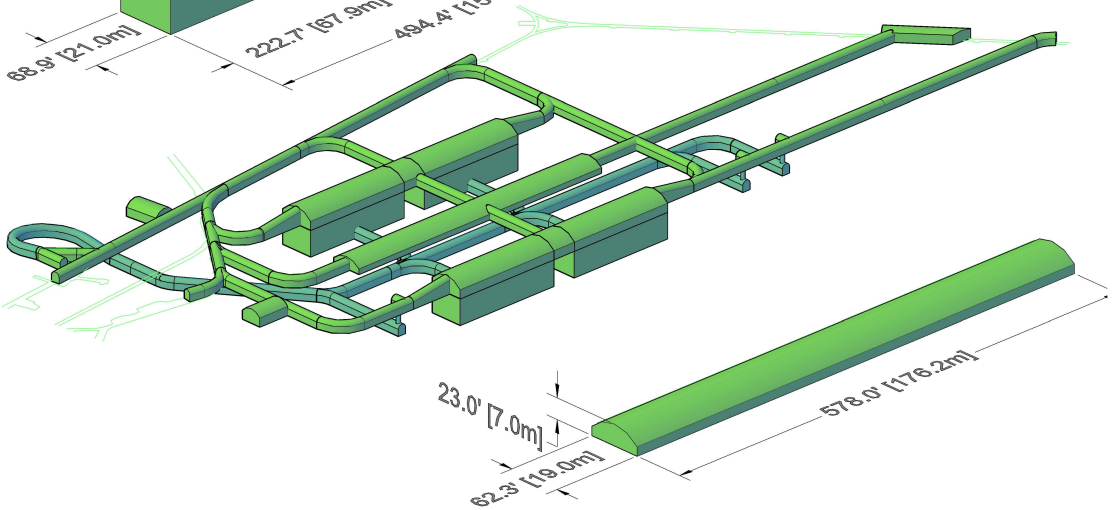


Summary and critical path durations only, could be moved in time

LBNF/DUNE's Excavations 40-ktonne Experiment







Summary
Sanford Underground Research Facility

- Site is well characterized and science programs functioning smoothly in the facility
  - LUX – Dark Matter in 300 day long run
  - MAJORANA DEMONSTRATOR – 0νββ preparing for first physics runs
  - BioGeoEng on going investigations
- Expansions to accommodate additional science progressing well
  - CAM @ BHUC (Low Background Assay) near the Ross (2015)
  - Caspar Nuclear Astrophysics near the Ross (2015)
  - LZ G2 Dark Matter in the Davis Campus (2017)
  - LBNF/DUNE on the 4850L near the Ross Shaft (2017)
- Additional space available on the surface and underground for other experiments and collaborations