XXIX INTERNATIONAL CONFERENCE ON NEUTRINO PHYSICS

Worldwide Underground Facilities

Jaret Heise, Science Director

(on behalf of many!)

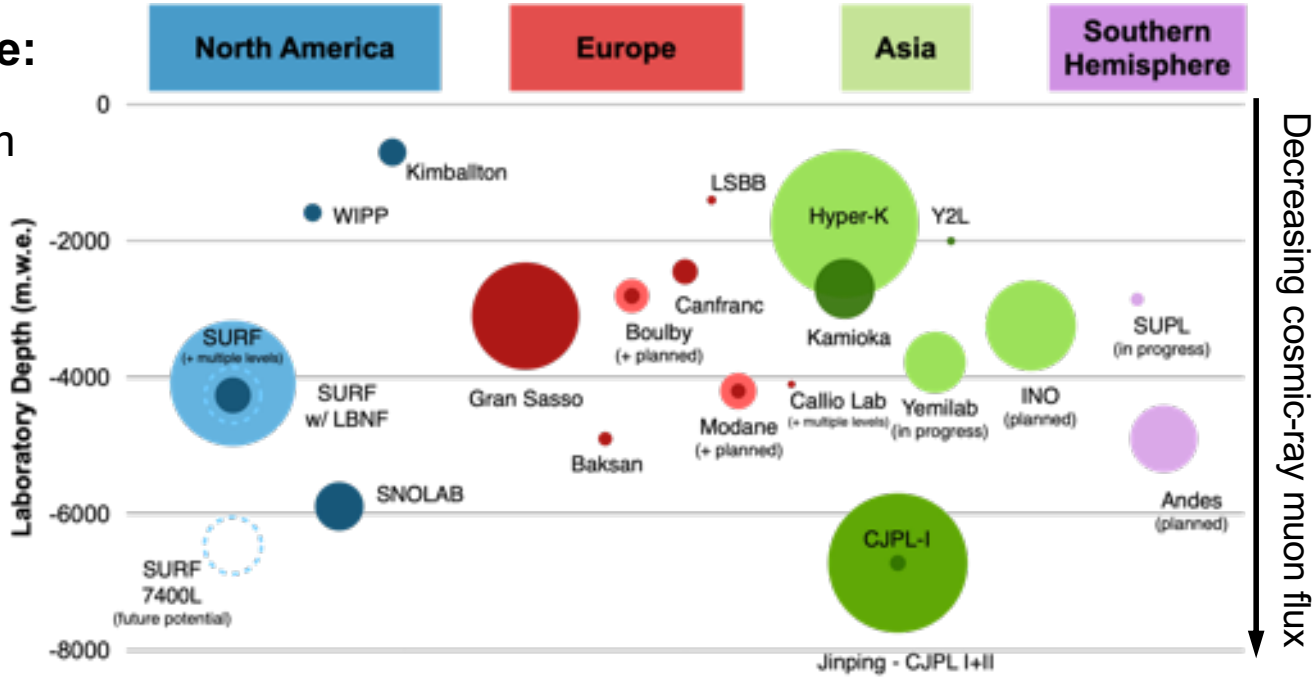
Sanford Underground Research Facility

Underground Facilities

UG Facilities serve a diverse community

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

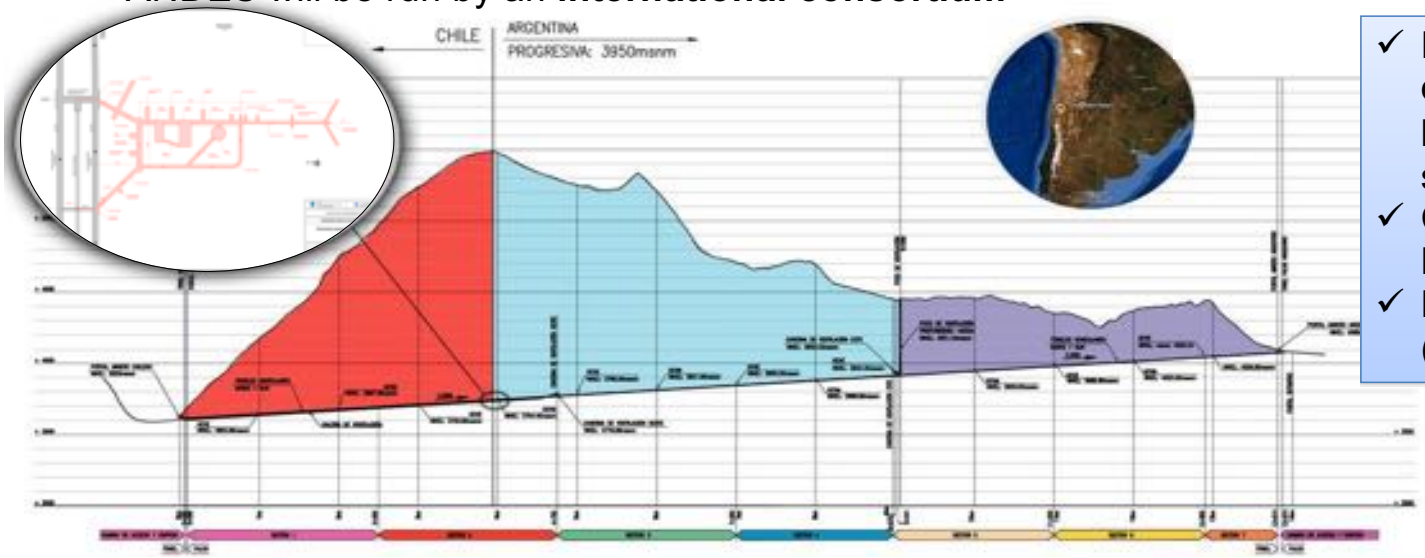
Underground Facilities – Worldwide

Underground Facilities – Worldwide

ANDES: Agua Negra Deep Experiment Site

- General:
  - **Agua Negra** tunnel between Argentina and Chile. Vertical depth = **1775m** (1675m omnidirectional)
  - Size: ~4000 m^2 and ~70000 m^3, horizontal access
  - Tunnel financed by Inter-American Development Bank; **construction 2021-2029**
  - ANDES will be run by an **international consortium**

- Laboratory
  - **Main Hall:** 50m L x 21m x 23m
  - **Secondary Hall:** 40m L x 16m x 14m
  - **Experiment Pit:** 30m diameter x 30m tall
  - Geosciences + biology areas
  - Offices and small labs, incl cleanrooms



- ✓ Final exact location to be determined once geology is better known (initial geology studies already performed)
- ✓ Conceptual study finished by Lombardi in January 2015
- ✓ Detailed engineering design ($0.5 M) finished May 2019

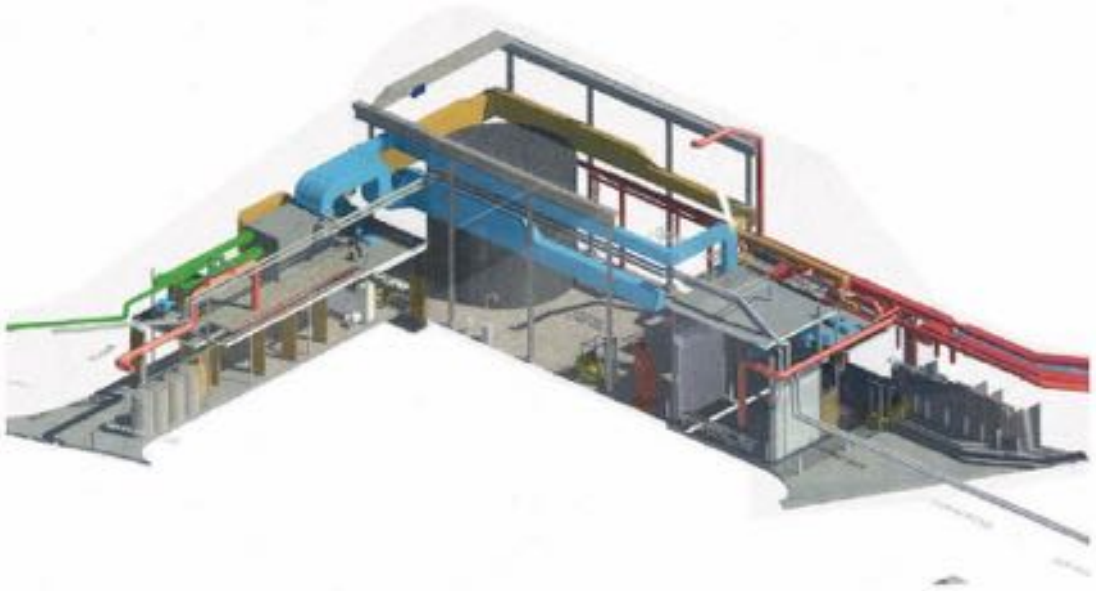
More information at http://andeslab.org

SUPL: Stawell Underground Physics Lab

- **Laboratory:**
  - Location: Hosted in active Stawell Gold Mine in Western Victoria (250 km from Melbourne); drive-in access via decline
  - Depth: 1050 m (~2900 m.w.e.), flat overburden
  - Footprint: 30m L x 10m W x 10m H
  - Gamma counting performed at 729-m depth to select low-bkgd materials for facility construction (e.g., concrete, rock bolts)
- **Status:**
  - Fully funded by federal ($5M) and Victoria ($5M) governments
  - Excavation completed April 2020, incl shotcreting cavern walls, ceiling
  - Outfitting design completed, start delayed until ~Sep 2020 due to COVID
  - Lab completion late 2021

Temporary underground materials test lab

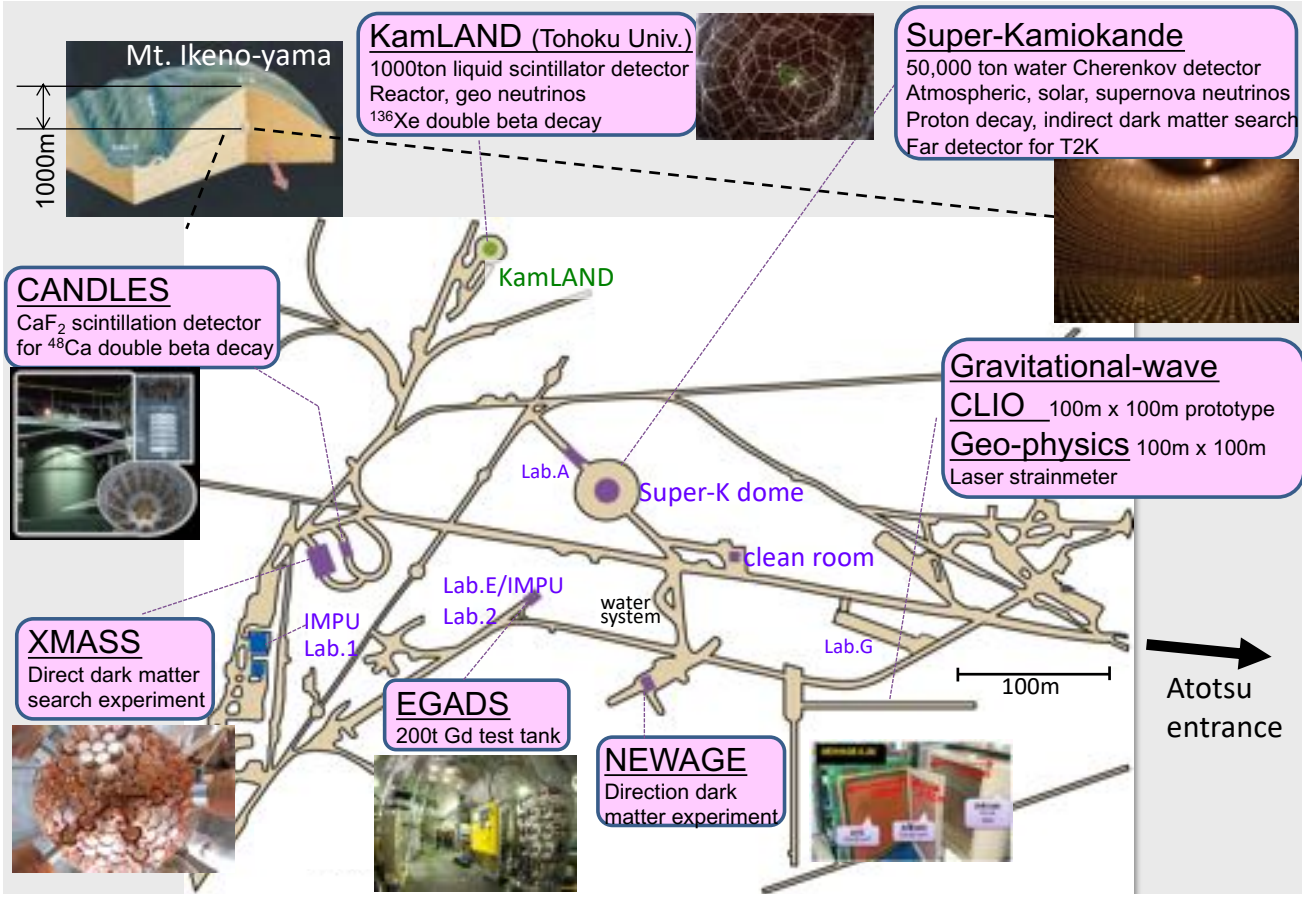
SUPL: Stawell Underground Physics Lab



Kamioka Observatory

Mozumi

Kamioka Observatory Underground Labs

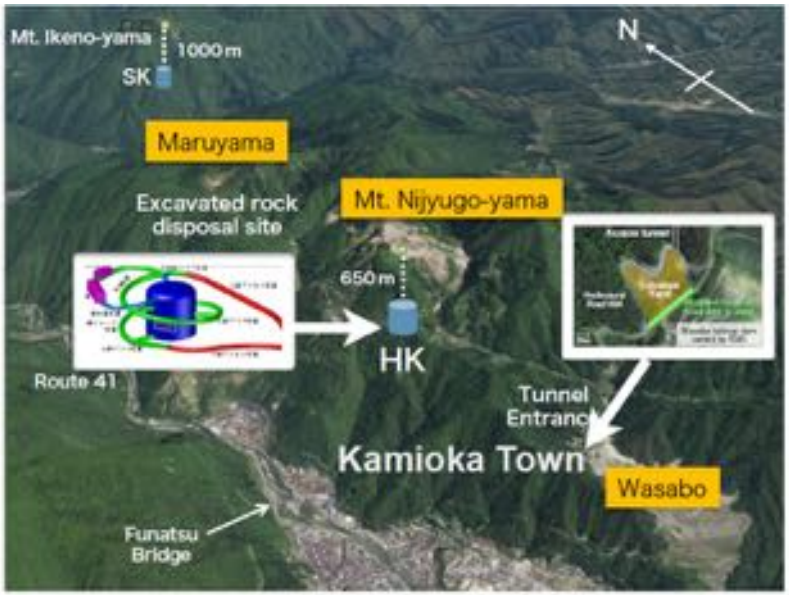


Kamioka Observatory: Hyper-Kamiokande

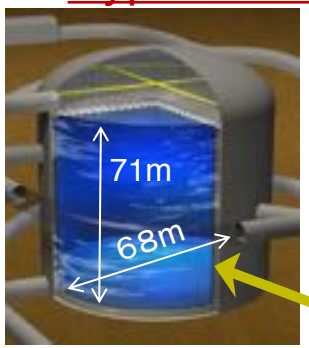
In the beginning of 2020 the Hyper-Kamiokande project officially started. Construction schedule includes 5 years of cavern excavation and 2 years of instrumentation. Data taking is scheduled to commence in 2027.

Detector location

- 8 km south of Super-K, 295 km from J-PARC
- 650 m rock overburden

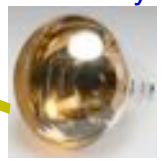


Hyper-K detector



Total mass: 260 kton
Fid. mass: 187 kton (8.4x SK)

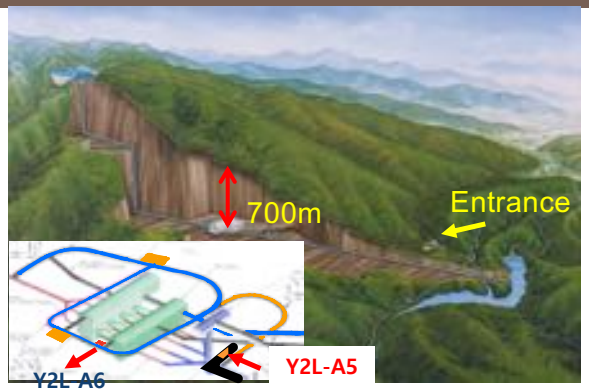
PMTs with high sensitivity



2020.5 The Univ Tokyo president Makoto [R] Gonokami and KEK Director General Masanori Yamauchi [L] signed the MoU to advance Hyper-K.

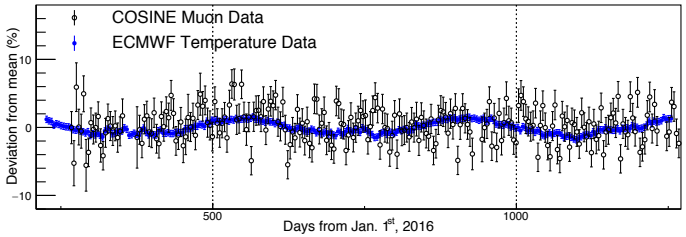
2020.5 Entrance yard is under construction.

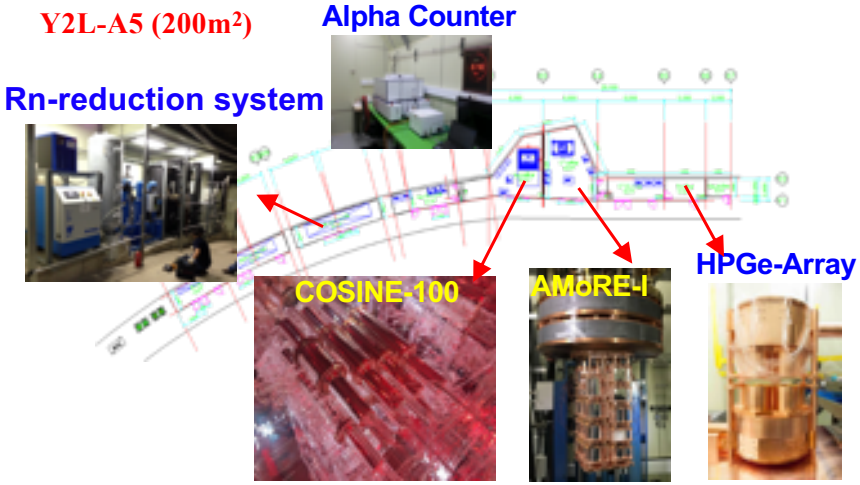
Y2L: YangYang Underground Lab in Korea



1. **Muons : 327.9±9.5 muons/day/m^2**
2. **Rocks : U = 3.9±1.4 ppm, Th = 10.5±6.5 ppm**
3. **Rn level : ~ 50 Bq/m^3 at Tunnel.**
4. **Thermal neutrons : 2.4x10^{-5} /cm^2/sec**
   ~ an order higher than Gran Sasso lab.

Muon modulation amplitude = 0.6%



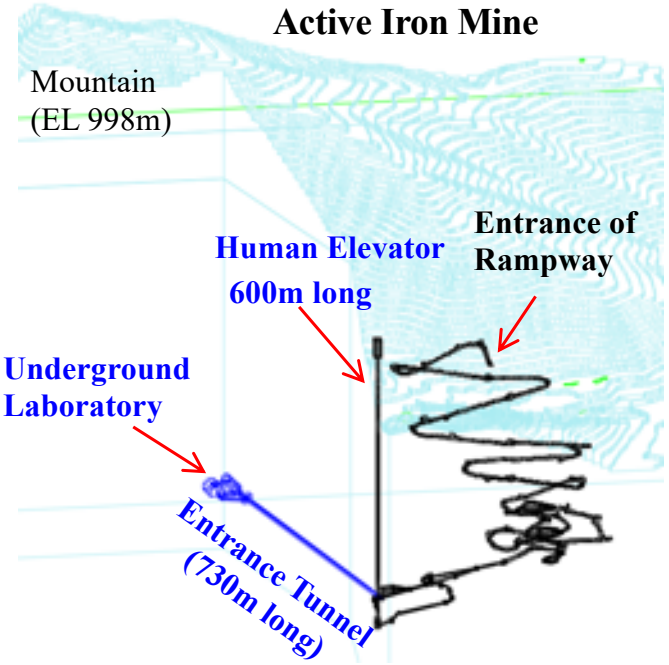


- COSINE-100 & AMoRE-I currently running.
- Radon Reduction system, HPGe detectors, alpha counters will be moved to Yemilab in **2022**.
- We plan to run COSINE-200 at Y2L until **2025** if crystal development is done until 2021.

Yemilab – New Underground Lab in Korea

- **A new underground lab, deeper and larger than Y2L, is constructed.**
- **~ 1000-meter deep space at an active mine.**
- **An independent access (vertical lift for human) from mine activity.**

Bird's eye view of Handuk Iron Mine

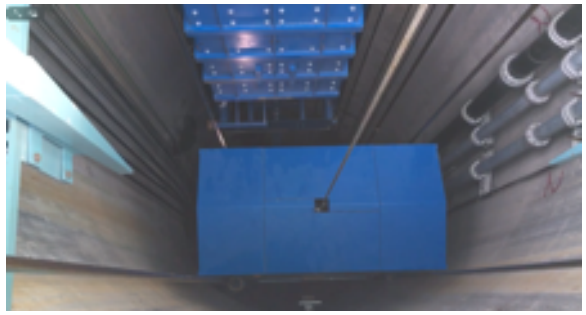


Large (>2000m^2), deeper (1100m depth)

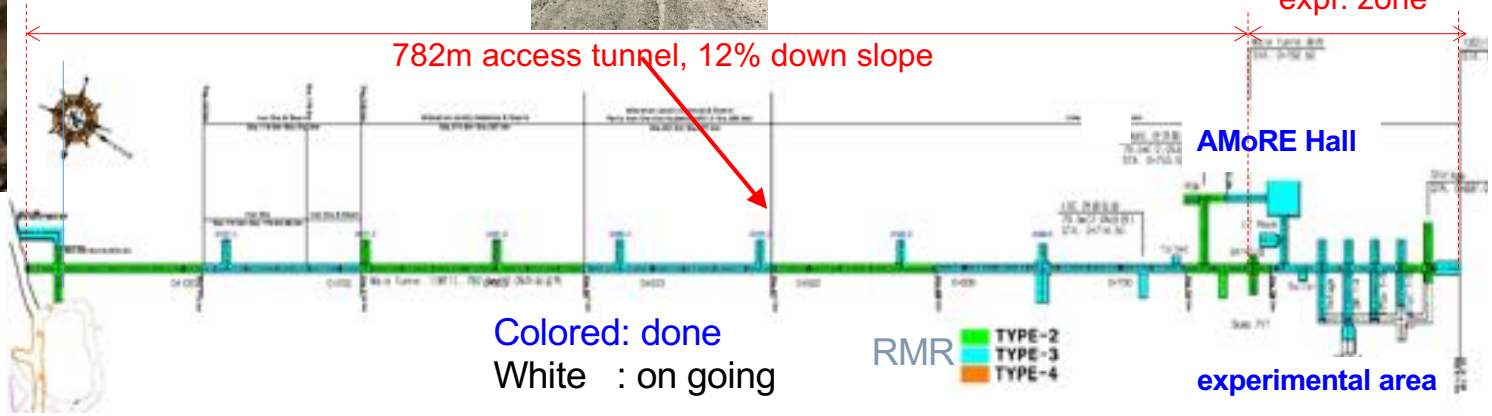
Yemilab – Construction Step 1

Center for Underground Physics (ibs)

- Human elevator is installed.



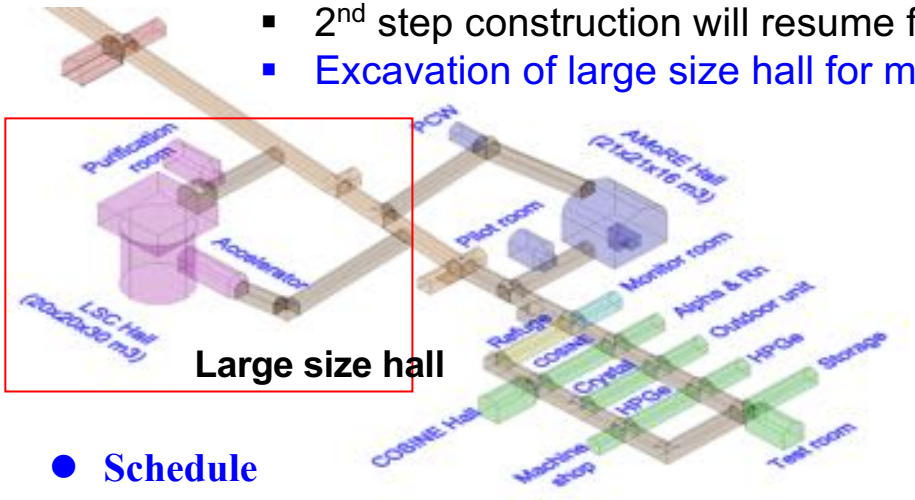
- 95% of excavation is completed.



Yemilab – Construction Step 2, Expts

Center for Underground Physics

- 2nd step construction will resume from Jan. 2021 to Mar. 2022 (incl excavation, outfitting).
- Excavation of large size hall for multi-purpose experiments.



Large size hall

- Lab operation begins **2022**
- Operation team of 15-20 people
- Rock = Limestone, U: 2ppm, Th: 8.5ppm, K: 2.2%

Science Program:

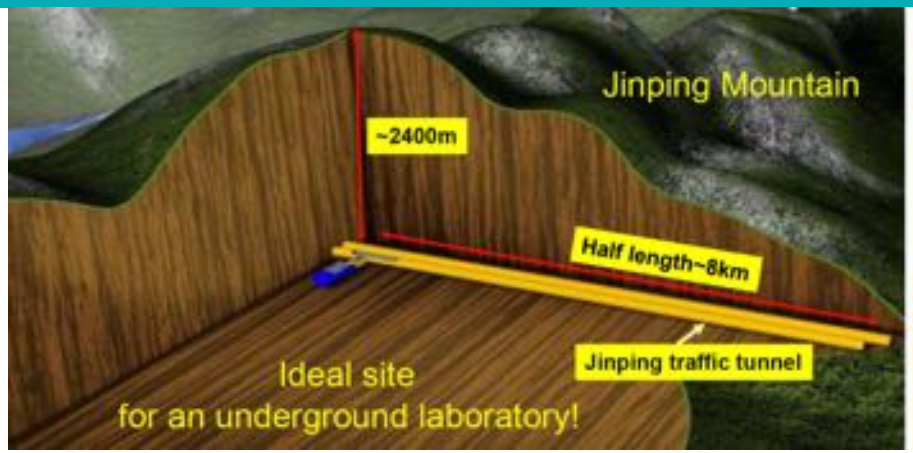
- **AMoRE-II –** neutrinoless double beta decay expt.
- **Large NaI crystal array -** dark matter search.
- **Large liquid scintillator -** dark photon, solar neutrinos, etc.

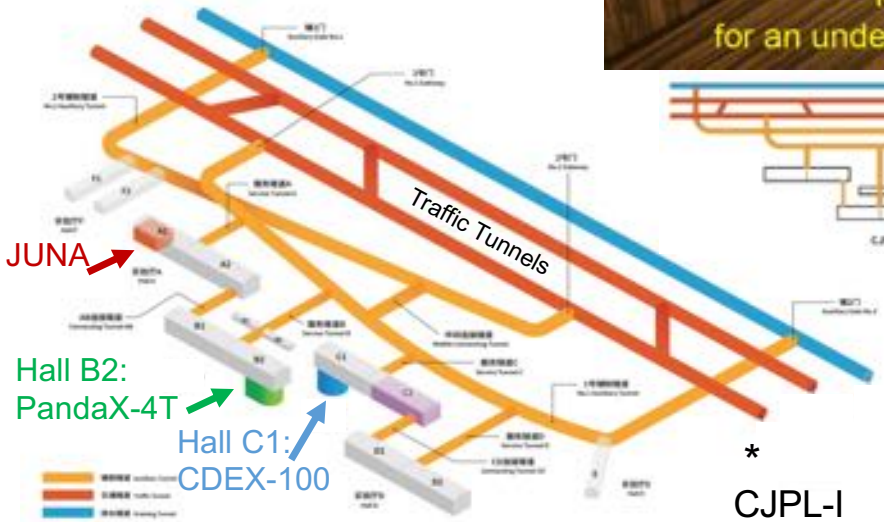
- **Schedule**

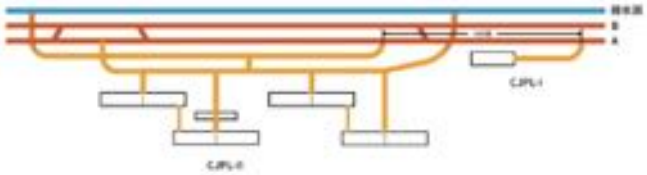
	2020				2021				2022			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1st Construction												
2nd Construction	Large hall excavation Elec. & equip.											
HPGe, Alpha, Radon	Screening, Monitoring											
AMoRE-II Commissioning												

CJPL: China Jinping Underground Laboratory

- **Yalong River Jinping Hydropower Plant** (highest dam in world at 305 m)
- **World's deepest and largest underground lab:**
  - 2400 m rock overburden
  - 300,000 m³ volume
  - Annu. Rev. Nucl. Part. Sci. 2017.67:231-251







* CJPL-I

- **CJPL-I (opened 2010):**
  - Panda-X, CDEX, Jinping Neutrino Expt) + 3 low-bkgd counters
- **CJPL-II (excavation and civil engineering completed May 2016):**
  - 4 halls, each 14m W x 14m H x 130m L; 2 halls with pits
  - Experiments will incl larger versions of Panda-X and CDEX
- **National Major Scientific and Technology infrastructure award**

CJPL-II Status

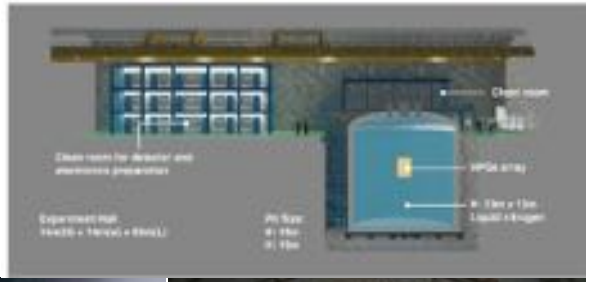
Pure Water Shield

- Hall B2, LXe/Ar Dark Matter Experiment
- 4500m^3 pure water (L27m x W15m x D13m)
- Inner gamma bkg level: 10^{-5} cpkkd @ 2MeV

9 km ventilation system
(Rn < 20 Bq/m^3)

Liquid Nitrogen Shield

- Hall C1, HPGe Dark Matter/DBD Experiment
- Vessel Size: ϕ 16.4m x H 20m (outer), ϕ 13m x H 13m (inner) -> 1725m^3 liquid nitrogen
- Inner gamma bkg level: 10^{-6} cpkkd @ 2MeV



CJPL DURF

National Major Scientific and Technology infrastructure award

- **D**eep **U**nderground and ultra-low **R**adiation background **F**acility (DURF) for frontier physics experiments
- Feasibility proposal approved Dec 2018, preliminary design completed in summer 2019
- Construction in existing CJPL-II space was to begin in late 2019 (now 2020)

DURF

- Shielding:
  - Liquid nitrogen, pure water, solid (e.g., polyethylene)
- Low bkgd counting
  - Additional instruments incl alpha, liquid scintillator, ICP-MS
- High-purity material production:
  - UG electroformed Cu
- Surface laboratory in Xichang city
- Schedule: Complete by the end of 2023

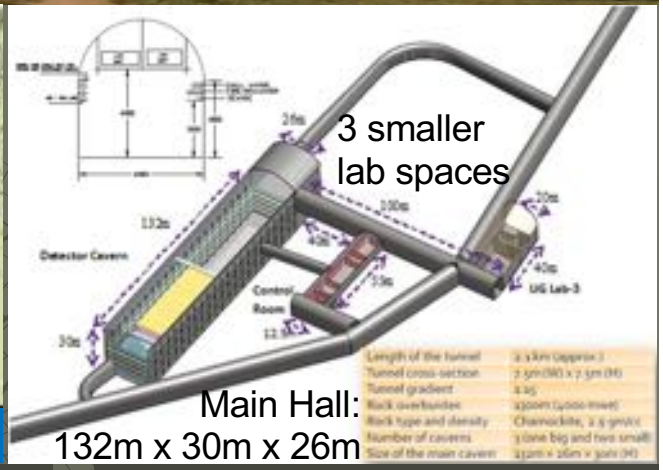
Hall

Service tunnel

INO: India Neutrino Observatory

INO salient features

9°58′ N; 77°16′ E, 110 km from Madurai (South India)



Physics Programmes

- 51-kt magnetized Iron CALorimeter (ICAL) for measurements on atmospheric neutrinos and mass hierarchy.
- Cryogenic bolometer of tin (^{124}Sn) (TIN.TIN) to search for neutrino- less double beta decay.
- Cryogenic Scintillator based dark matter experiment @INO (DINO).
- Facility for other studies in physics, biology, geology, material research etc.

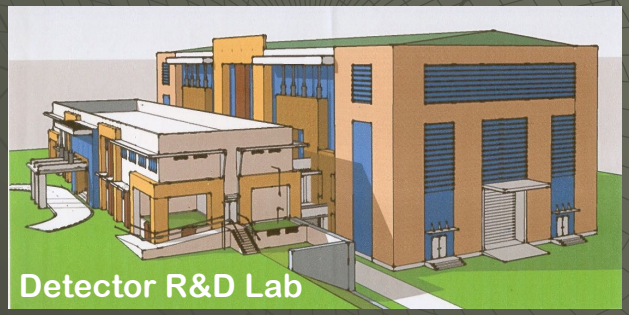
Approvals and Status

- Environmental Clearance obtained second time in March 2018.
- Wildlife Clearance from Central Government awaited.
- Building and final construction Clearances awaited from Tamil Nadu State Government.
- We are hoping to get these in the next 12 months.

IICHEP

Inter-Institutional Centre for High Energy Physics

- To be setup on a 12.2 hectares land close to Madurai Kamaraj University.
- Will be the nodal centre for all activities and will operate and maintain the INO laboratory.
- INO Graduate Training programme since 2008.
- Human resource development in basic experimental science.
- Will be a particle detector R&D laboratory for basic and applied sciences & technology.
- A 700-ton ICAL prototype will be built in the next 2.5 years, for which all the requisite clearances obtained.



Baksan Neutrino Observatory

BUST (Baksan Underground Scintillation Telescope)
- study of cosmic rays with surface and underground detectors
- gravitational collapse supernova (e.g., SN1987A)

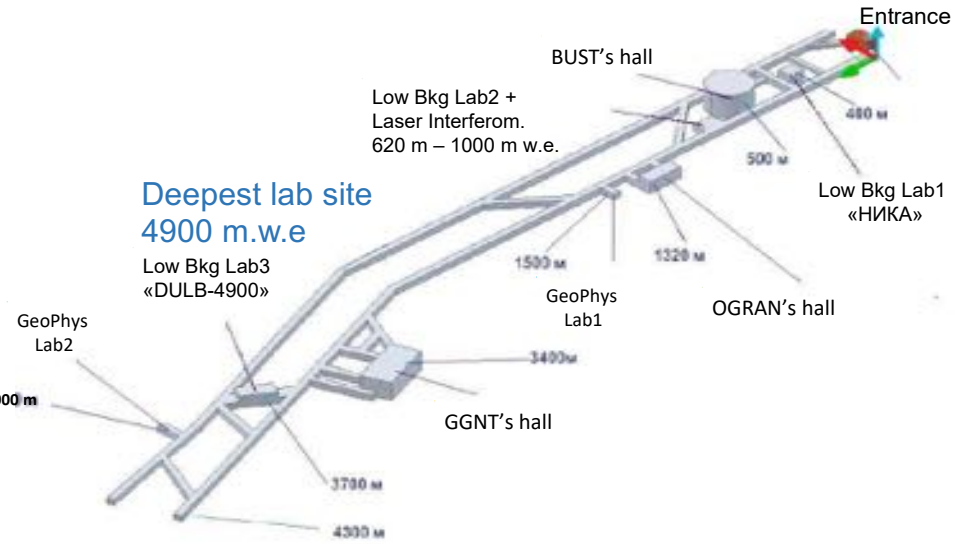
GGNT (Gallium-Germanium Neutrino Telescope)
- solar neutrino observatory
- **BEST** (Baksan Experiment on Sterile Transitions) with ^{51}Cr neutrino source (3.4 MCi) and Ga (see Gavrin update this conf)

LBR (Low Background Researches)
- Investigation of rare decay processes (DBD and DM)

LGG (Laboratory for Geophysics)
- Geophysics and gravitational waves

Also **CARPET** (surface array for PeV gamma rays)

Future:
- Cryogenic laboratory for bolometers (Mo-based DBD)
- **NBNT** (New Baksan Neutrino Telescope), 5kt scale Borexino-like detector, CNO + geoneutrinos + DSNB



CALLIO LAB

LAB

- Callio Lab is a unique underground research environment in Pyhäsalmi, Finland
- Accessibility: only two-hour drive away from five airports, railway connection to the site. Installations in sea containers (up to 20') transportable via incline
- Flat overburden, deepest level 1440 m (4100 m.w.e), main level at 1410 m
- Multidisciplinary steering group established 2020
- Underground mining ends in 6/2021. Agreement between the mining company and Callio allows activities at least until 2025 (/2030)

ACTIVITIES

- **EMMA:** Experiment with a MultiMuon Array, cosmic-ray induced bkgds using drift chambers
- **NEMESIS:** New Emma MEasurement with neutronS In cosmic Showers, study neutron bursts in shielding materials (also performed at other Eurpoean labs)
- **C14:** Measure 14C isotope in oil-based liquid scintillators (goal of 10e-20 or lower)
- **BSUIN:** Member of the Baltic Sea Underground Innovation Network (13 partners from 8 countries), incl bkgd measurements, develop best practices, etc
- **Goldeneye:** Test site for remote sensing technology (safety and environmental monitoring)
- **Occupational Health:** Intelligent, adaptive lighting studies for UG workers
- Biology & food production, geology & hydrogeology
- UG Rescue & mining training

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CALLIO LAB

FACILITIES

LAB 1

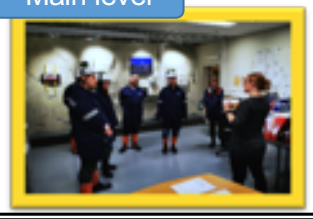
LAB 2

LAB 3

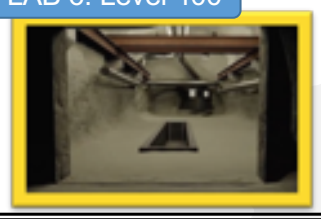
LAB 4

LAB 5

Main level

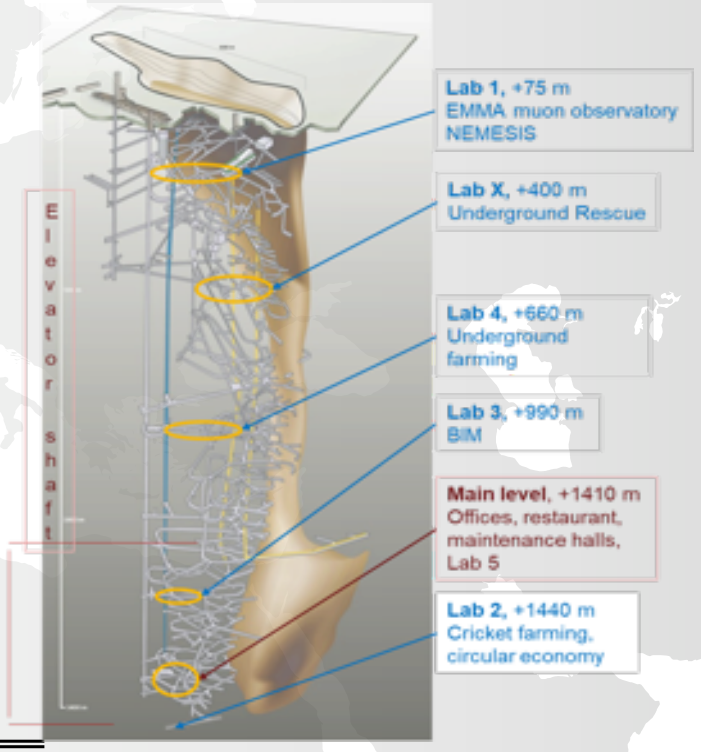


LAB 6: Level 400



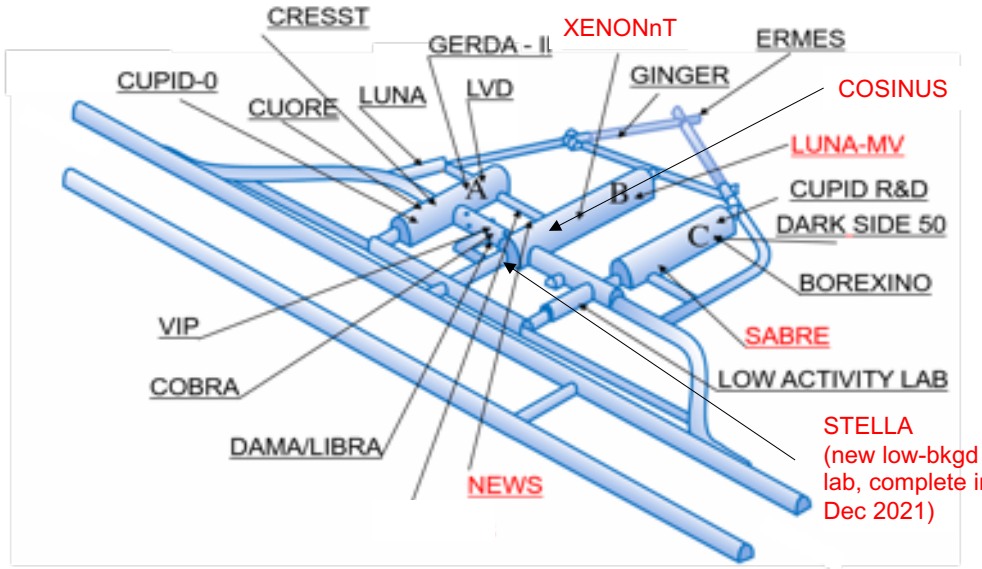
Additional R&D

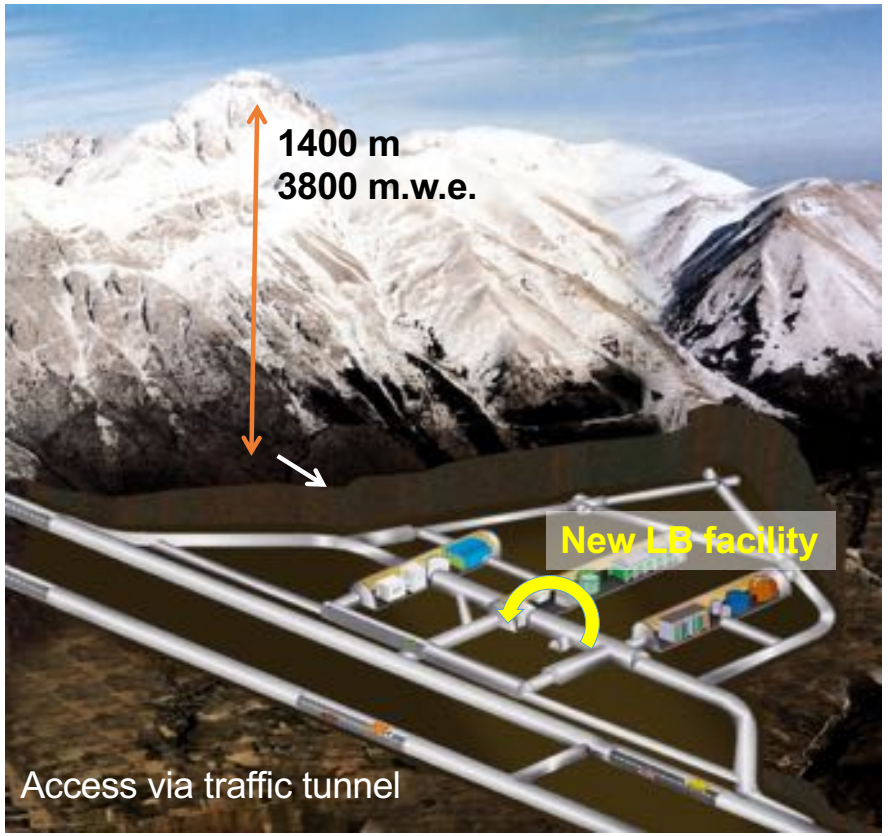
Geopolymers
Underground Rescue
Geothermal
Environmental data monitoring
Microseismic monitoring
EM data



Laboratori Nazionali del Gran Sasso

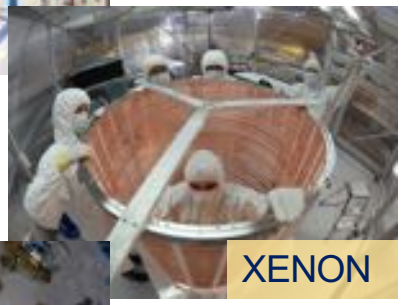
- **Vertical Depth:** 1400 m / 3800 m.w.e. (under mountain profile)
- **Underground Space:** 17,800 m^2 / 180,000 m^3
- Surface and underground facilities
- Radon in underground ~100 Bq/m^3 with 5-8 air changes/day





Laboratori Nazionali del Gran Sasso

- **Neutrino astrophysics**
  - Borexino (solar neutrinos incl CNO + pp, geo-neutrinos, and supernova neutrinos)
  - LVD (supernova neutrinos)
- **Nuclear astrophysics**
  - LUNA (nuclear processes of interest for astrophysics)
- **Neutrinoless Double Beta Decay (DBD): (A,Z)→ (A,Z+2) + $2e^-$ + ~~2ν~~**
  - GERDA with ^{76}Ge (35.8 kg of 88% enriched Ge) →LEGEND-200 (>2021)
  - CUORE with ^{130}Te (206 kg of ^{130}Te)
  - CUPID (R&D with bolometer with particle identification, ^{100}Mo(LSC,LSM), ^{82}Se(LNGS), ^{130}Te)
- **Dark Matter (DM): χ + N → χ + N**
  - XENON-nT with xenon TPC in 2020 (+ 5ton wrt previous set-up)
  - DarkSide-50 (DarkSide-20k after 2023) with underground argon TPC
  - CRESST with tungsten-based bolometers
  - COSINUS with NaI bolometer (after 2021)
  - DAMA/LIBRA and SABRE (prototype stage)
  - DARWIN: LoI to be deployed inside Borexino Water Tank
- **R&D for rare events search and biology in low radiation environments**
  - Recent workshop on biology in DULs (Nov 2019): DULIAbio https://agenda.infn.it/event/19116/

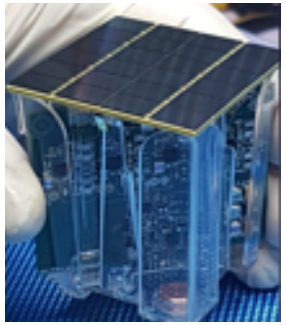


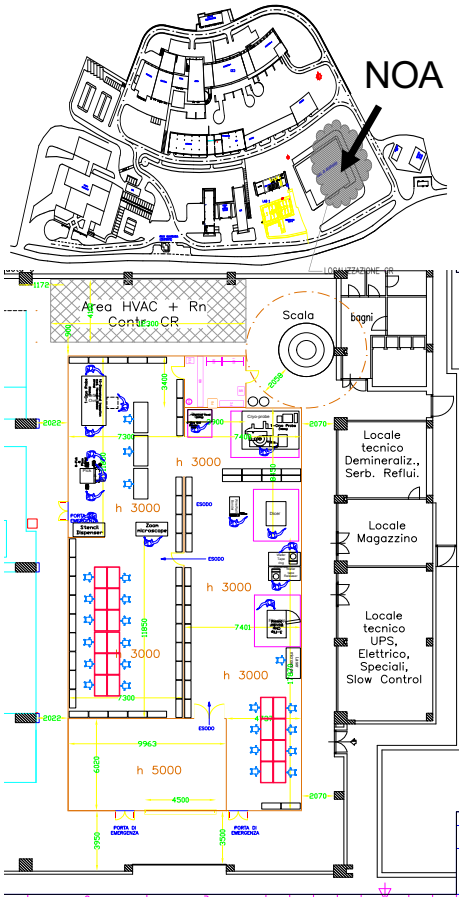
Laboratori Nazionali del Gran Sasso

NOA at LNGS

- The European Union established a program to improve the economy of "poor" regional areas by supporting new technologies and advanced training
- In this framework, NOA was born in 2018 with an initial budget of 10 M€ (equipment) and 3M€ (personnel – MasterPlan)
- Mission
  - Make a new and innovative infrastructure for photosensors based on SiPM
    - SiPM wafer produced by LFoundry
    - Users: DarkSide, CTA, NUSES
    - Possible interests from CMS and JUNO
  - Develop Advanced Machining at LNGS
  - Enhance the ICP-MS facility (sub-ppt level sensitivity)
- Status of NOA radon-free cleanroom:
  - A 400 m^2 radon-free clean room being built on surface at LNGS, construction to start in August 2020, complete in June 2021
  - Clean room will host equipment to make SiPM based photosensors
  - Clean room will offer space for detector assembly in a radon-free environment

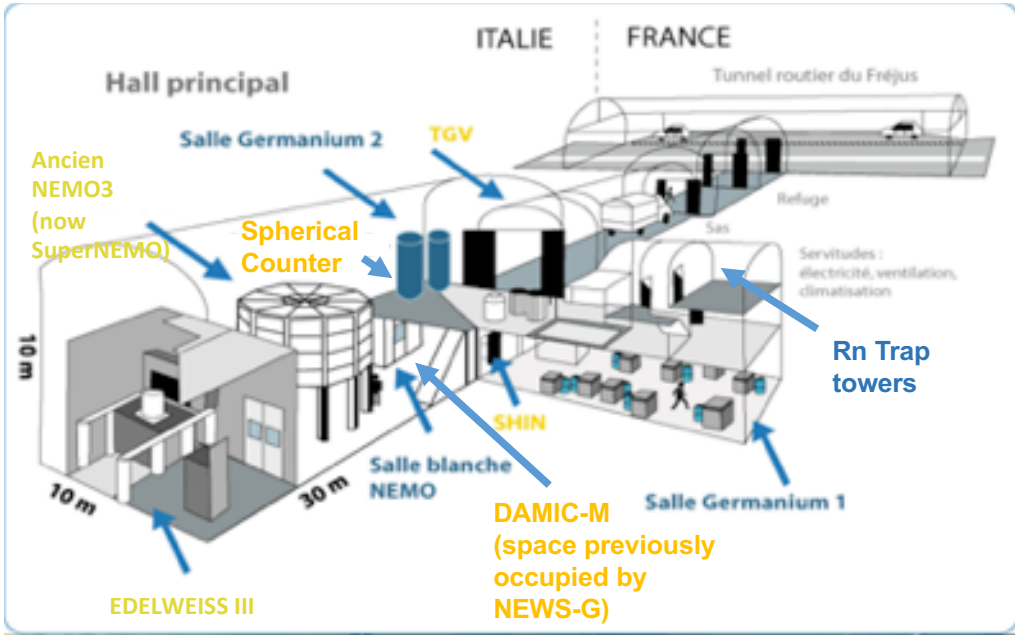
PDM for DS-20k





Laboratoire Souterrain de Modane

- **Underground laboratory**
  - Depth : 1700m (4800 m.w.e.)
  - Volume of 3500 m^3, 400m^2 available for experiments
  - Rock temperature : 28°C
- **Infrastructure provided by Frejus tunnel**
  - Ventilation : 5000m^3/h
  - Electricity, Water, Ethernet link (high-speed link to IN2P3 hub in Lyon)
- **Organization**
  - Since 2019, LSM operated as IN2P3 national platform, attached to Grenoble LPSC laboratory (CNRS/Grenoble University)
  - Scientific Director (J. Gascon), Director of Operations (C. Vescovi); also strategic/scientific steering at national level
  - Administrative, Safety, and Personnel managed by LPSC: access to resources of this larger laboratory (>200 people)
  - Staff: 4 engineers, 5 technicians, 1 onsite administrative support
- **LSM technical elements**
  - Cooling (cold water for air conditioning, expt cooling)
  - Radon extraction plant
  - ISO5 Clean room (Class 100)
  - HPGe detectors hosting (14 detectors in operation)



- **Planned investments**
  - Upgrade of the germanium platform (already started)
  - Refurbishing the radon trapping facility: increase of capacity from 80 m^3/h to 250 m^3/h
  - Increase of floor area by 180 m^2: mezzanine level above main hall for computing/DAQ rooms and “light” experiments
  - Cryogenic facility

Laboratoire Souterrain de Modane

Running

CUPID-Mo

- Joint cool-down of cryogenic detectors in EDELWEISS cryostat since 12/2018
- New $2\beta0\nu$ limits at Neutrino 2020 (see B. Smith poster #419)

EDELWEISS: see Arxiv:2003.01046

- First Ge cryogenic detector with sub-electron resolution
- Sensitivity to sub-MeV DM particle interaction with electrons
- Dark Photon limits down to 1 eV

NEWS-G

- First commissioning of ϕ 1.4m spherical detector in autumn 2019
- Runs with CH_4 target, before expedition to SNOLAB

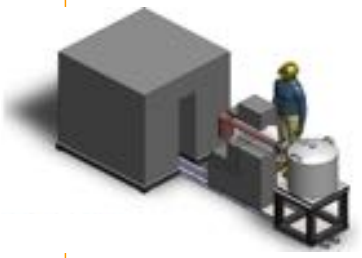
Installation

SuperNEMO demonstrator **($2\beta0\nu$)**

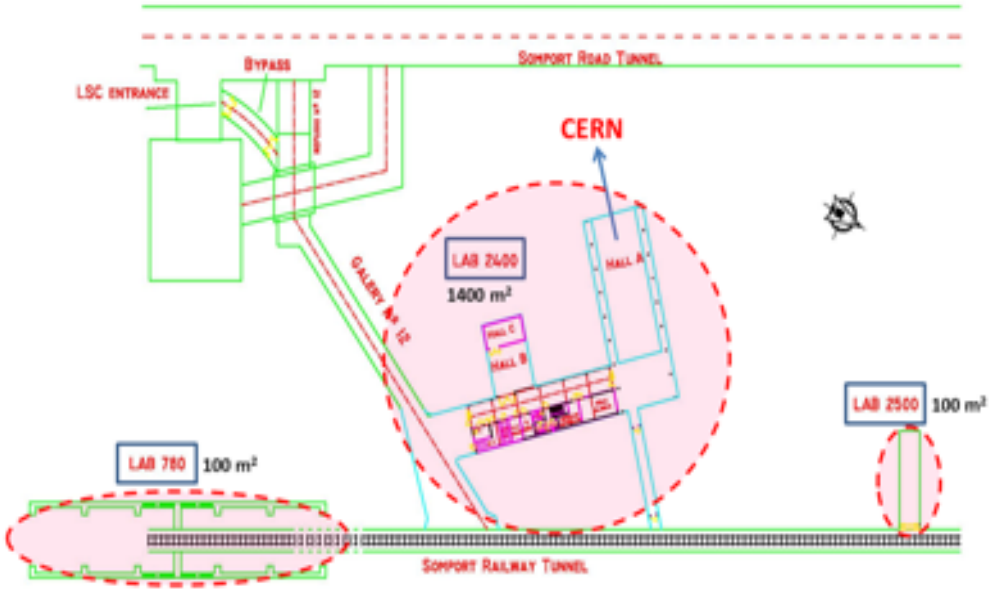
- 7 kg ^{82}Se target in modular design, extensible to 100 kg target in a larger underground lab
- Construction started at LSM in 2015
- Calorimeter commissioning data taking started in 2019
- *Tracker cabling completed*
- *Coming in 2020-2021: coil, anti-Rn tent, final shielding.*

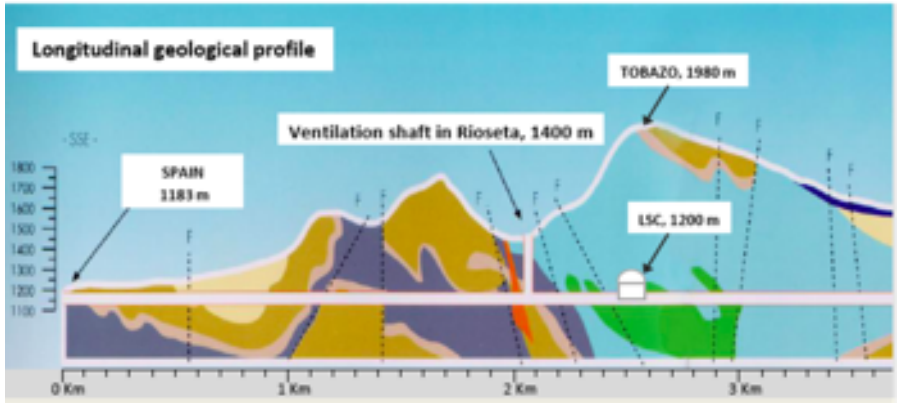
DAMIC-M **(low-mass DM search)**

- 1 kg Si (50 skipper CCDs x 20g)
- Installation work started in 2019
- Installation of a first, smaller 2-CCD chamber foreseen in 2020



Laboratorio Subterráneo de Canfranc





1986-2002 - first experiments: IGEX, …
2003-2006 - new lab built 1600m^2
2007-2010 - refurbishment works in main Hall
Since 2010 - start experimental activities
National Research Installation Staff: 15

Inlet air flux: 20,000 m^3/h
Radon: 50-80 Bq/m^3 -> 1 mBq/m^3
Muon Flux: (5.3 ± 0.2) x 10^{-3} m^{-2}s^{-1}
Neutron Flux (<10 MeV): ~3.5 x 10^{-6} cm^{2}s^{-1}
Gamma Flux: ~2 cm^{-2}s^{-1}

arXiv:1902.00868v4

Laboratorio Subterráneo de Canfranc

Experiments

Neutrino physics (see other talks & posters)
- **NEXT –** ^{136}Xe high-pressure gas TPC (data and construction)
- **CROSS –** Cryogenic Observatory with Surface Sensitivity for CUPID
- **SK-Gd & Hyper-K –** Screening and R&D (e.g., PMT covers)

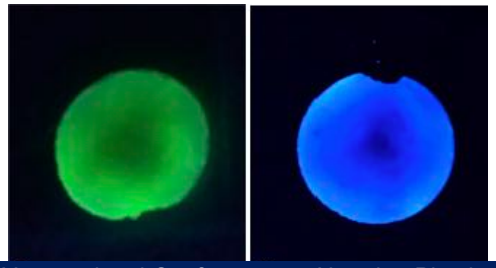
Dark matter searches
- **ANAIS –** 112 kg NaI crystals (3-yrs data) to verify DAMA-LIBRA
- **DaRT –** Argon activation detector for DarkSide (GADMC)
- **TREX –** Nobel gas (Ne,Ar) high-pressure TPC

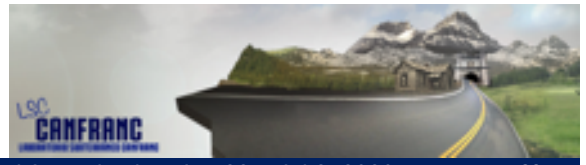
Lab Services

HP Ge detectors
Electroformed Cu facilities
Rn reduction (220 m^3/h)
Rn monitoring (1 mBq/m^3)
Rn-emanation detector (<1 mBq/m^2)

R&D 2019-2020

RITA – Ra screening (10^{-18} g/g) by single-molecule imaging with with new fluorescent bicolor indicator
UHP Ge – New Ge detectors with G. Zuzel & Mirion
EF-Cu – >100 kg mass production (3D LNGS Cu printer)





Boulby Underground Laboratory

UK's deep UG science facility operating in working polyhalite & salt mine

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by UK Science & Technology Facilities Council (STFC) in partnership with mine operator ICL

10 projects, 40+ institutions, 170+ scientists and students

Operations, H&S, science programme managed by 8 (+2) onsite staff and supported by Rutherford Appleton Lab

BUGS+ Material screening

New Lab open since 2017

> 4000m^3 class 1k & 10k cleanroom lab space, 5T & 10T lifting, LN generation, fume hood, clean prep

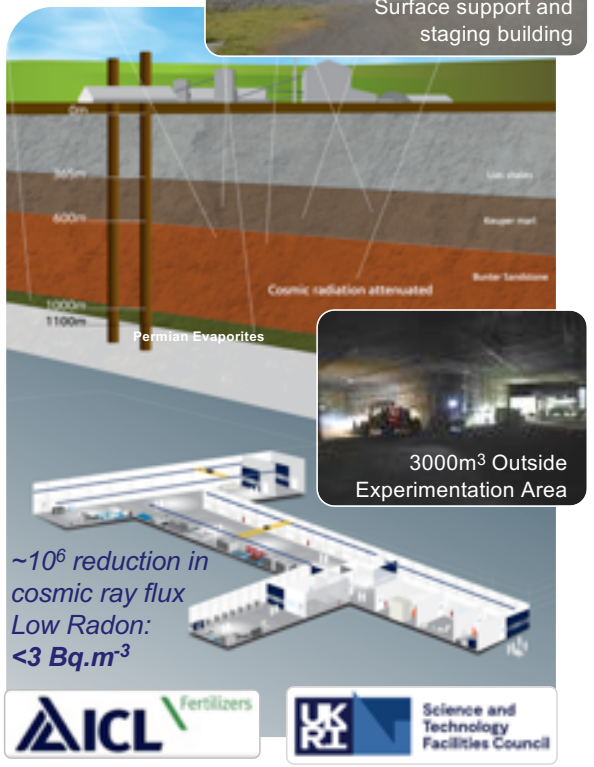
Sensitivity down to <50ppt U/Th per sample, & improving

Current Detectors:

- ORETC 1.8 kg (72%) p-type (ULB)
- Canberra 2.0 kg (112%) & 3.2 kg (171%) p-type (S-ULB)
- 2x Canberra BEGe detectors (5030 ULB, 6530 S-ULB)
- Canberra SAGe Well-type (S-ULB)

Contact: sean.paling@stfc.ac.uk

Surface support and staging building



3000m^3 Outside Experimentation Area

~10^6 reduction in cosmic ray flux
Low Radon:
<3 Bq.m^{-3}

Boulby Science Programme

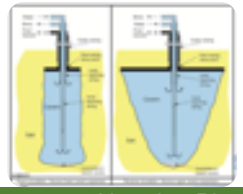
Current

- **DRIFT/CYGNUS:** Directional Dark Matter
- **Spherical Proportional Counter R&D** (NEWS-G)
- **BUGS:** Ultra-low background material screening (LZ, SK-Gd)
- **AWE(Ge):** Atmospheric gamma spectroscopy
- **RESOURCE:** Salt cavity energy storage study
- **BISAL:** Geo-microbiology / Astrobiology studies
- **MINAR:** Space Exploration Tech. Development
- Misc. Low Background & Geoscience…

Busy & growing multi-disciplinary science programme: Astrophysics and Low Background science, Earth and Environmental Science, Astrobiology and Planetary Exploration. Continue / increase hosting **core STFC science projects** & **wider multidisciplinary** studies addressing RCUK (UKRI) priority themes

Future

- **BUGS:** Expand ULB material screening and environmental gamma spectroscopy
- Expanding **Astrobiology, MINAR** & wider **Robotics**
- **RESOURCE study (NERC)**: Salt cavity test facility for studies of compressed gas energy storage
- Misc Others… Incl supporting **NEWS-G, DAMIC, AION**, etc
- '**BOULBY-FS**': STFC funded feasibility study for Boulby hosting **next generation Dark Matter, Neutrino and 0νββ** studies
- **AIT-NEO (WATCHMAN)**: 6kT water-based neutrino detector for nuclear non-proliferation purposes & more…

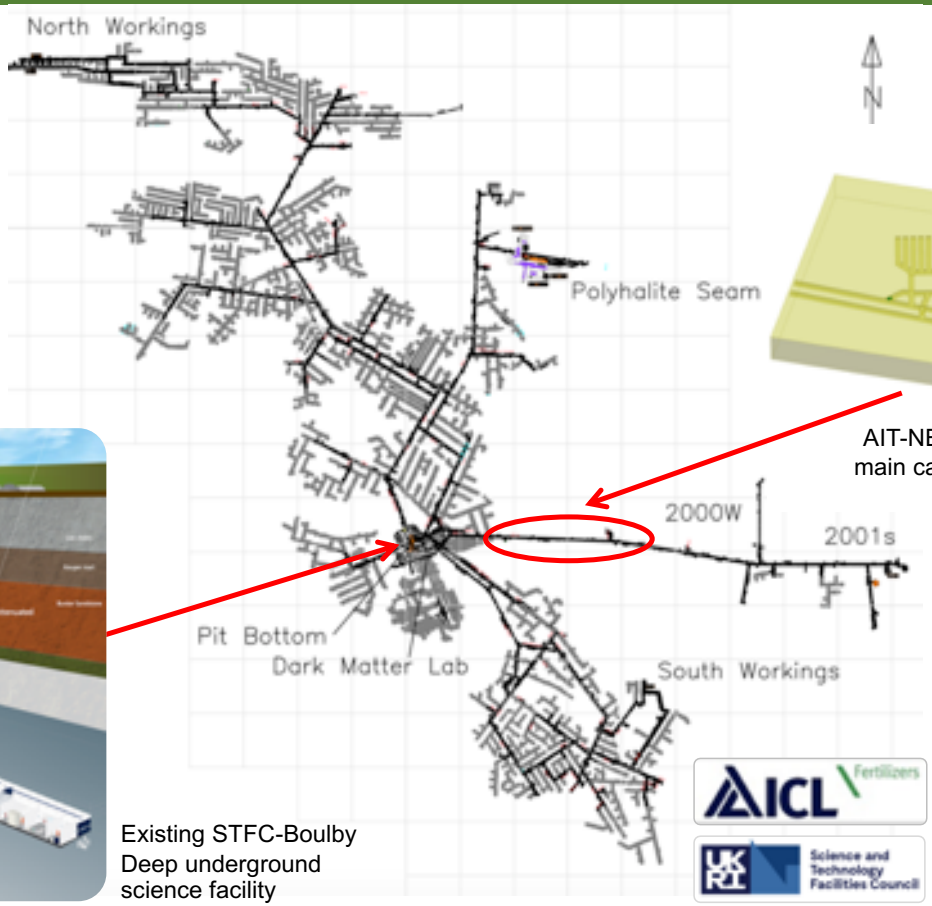


RESOURCE: Salt cavity energy storage

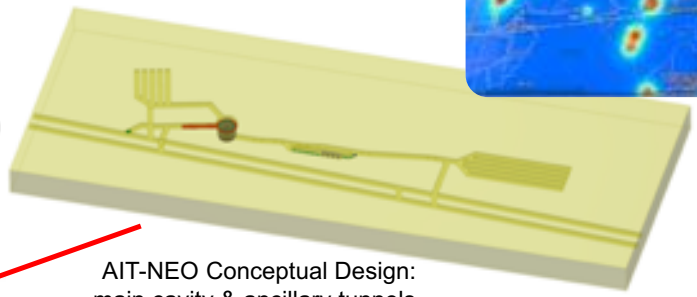
Robotics

Boulby Laboratory Expansion For AIT-NEO

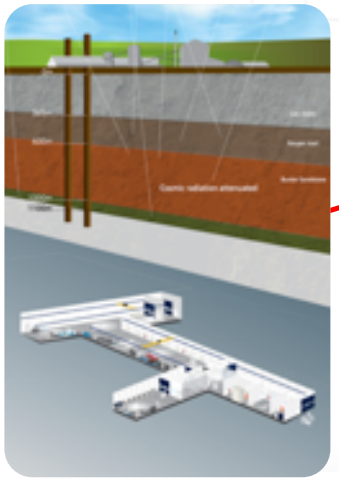
Design, excavation, installation & operation 2019 to 2026(+)



World antineutrino flux levels

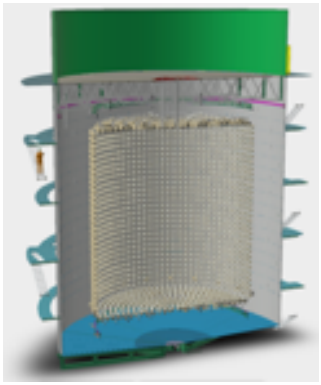


AIT-NEO Conceptual Design: main cavity & ancillary tunnels (total > 40,000 m^3)



Existing STFC-Boulby Deep underground science facility

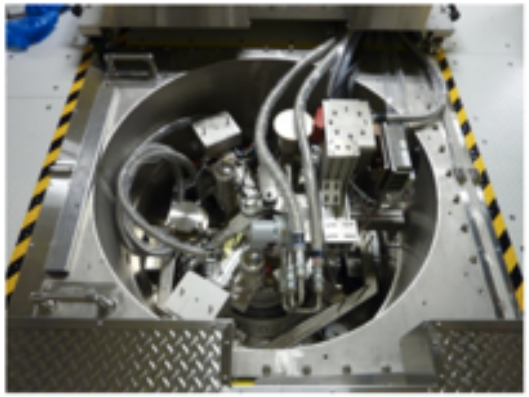
~20 m



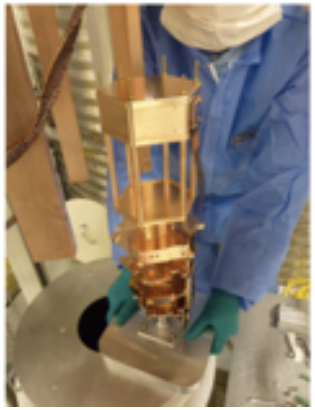
A 6kT WBLS or Gd-H2O detector looking at anti-neutrinos from Hartlepool nuclear reactor (25 km distance)

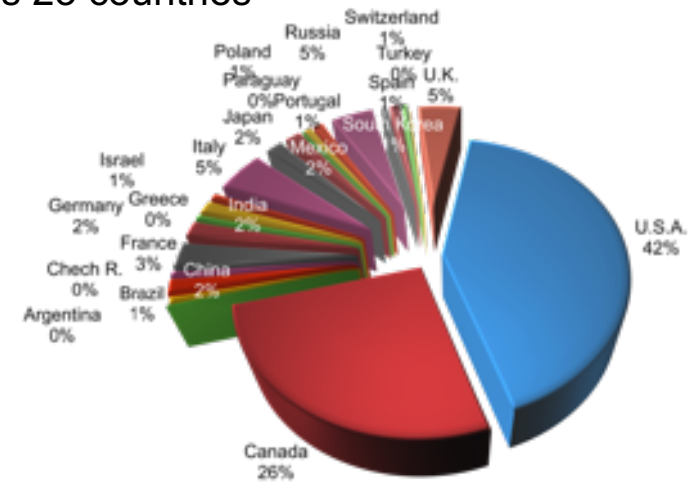
The SNOLAB Facility

- Operated in Vale Ltd Creighton nickel mine, near Sudbury, Ontario, Canada
- Deep site (2092 m / 5890 m.w.e.), laboratory operated as cleanroom (5,000 m^2 / 37,000 m^3)
- Operations CFI funding secured through April 2023
- Construction underway for SuperCDMS/CUTE, NEWS-G, PICO-40/500, etc
- Community has grown to >850 users from 130 institutes across 23 countries

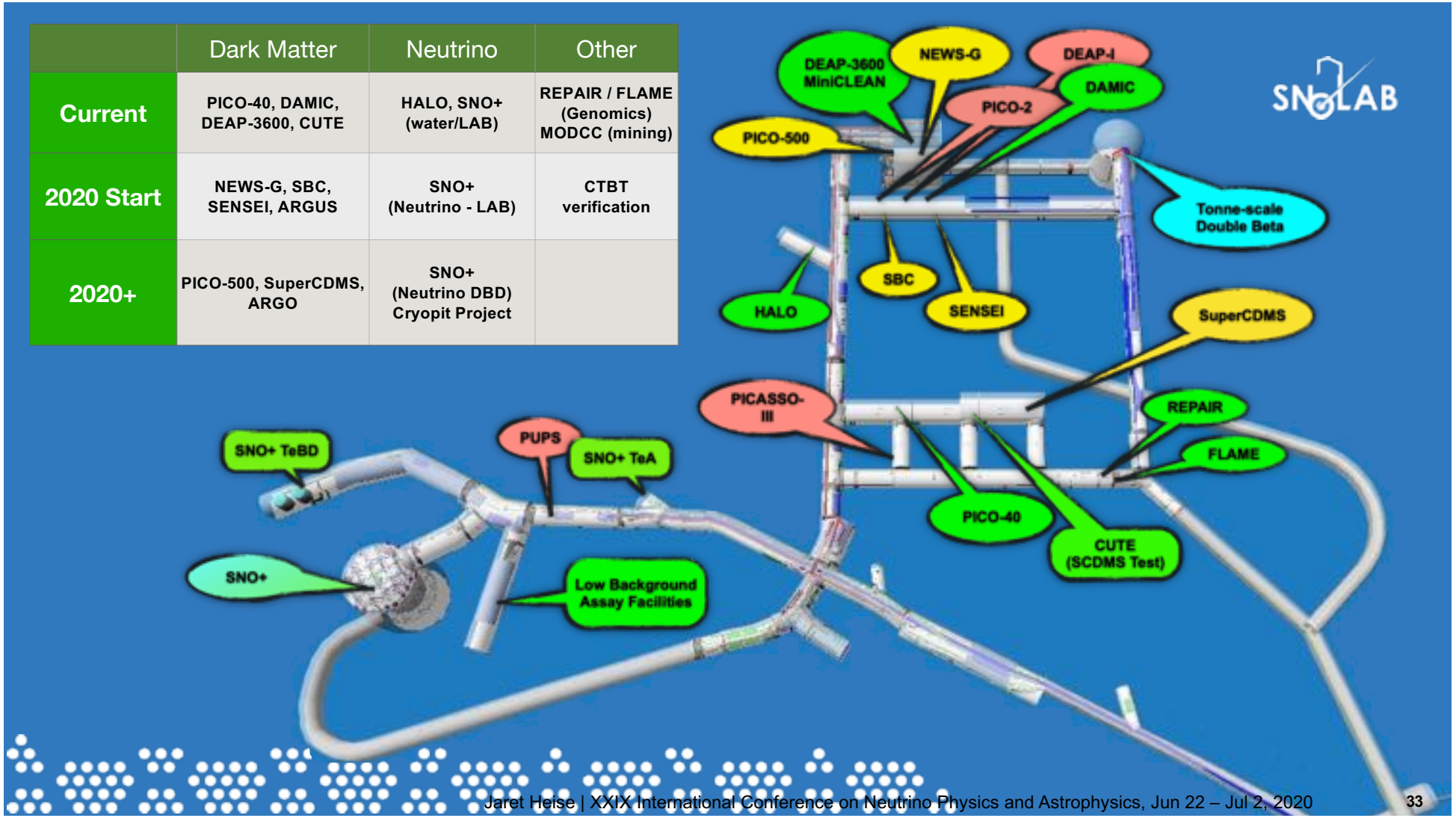


CUTE (**C**ryogenic **U**nderground **TE**st) Facility at SNOLAB used for SuperCDMS pathfinder tests



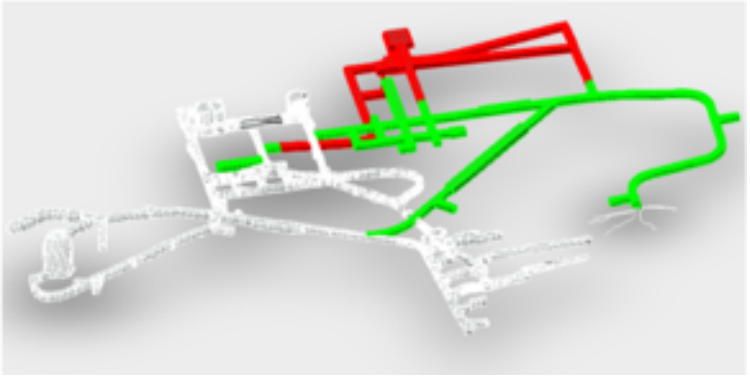


	Dark Matter	Neutrino	Other
Current	PICO-40, DAMIC, DEAP-3600, CUTE	HALO, SNO+ (water/LAB)	REPAIR / FLAME (Genomics) MODCC (mining)
2020 Start	NEWS-G, SBC, SENSEI, ARGUS	SNO+ (Neutrino - LAB)	CTBT verification
2020+	PICO-500, SuperCDMS, ARGO	SNO+ (Neutrino DBD) Cryopit Project	

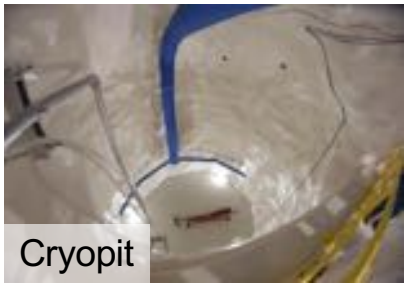


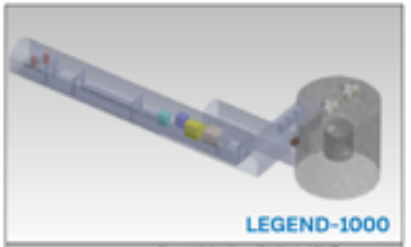
SNOLAB Future

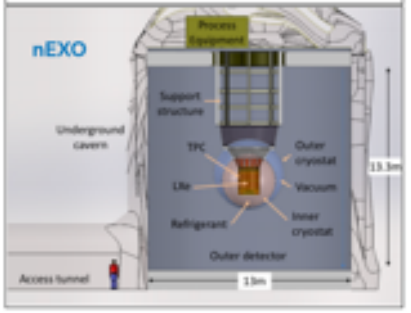
- Future large-scale programme strategy based around dark matter and 0νββ, strong engagement with U.S. DOE regarding site selection (later this year?)
- Evaluation of expansion possibilities completed
  - Included current (ambitious) plans as communicated by community
  - Additional drift space (e.g., storage of depleted Ar). New cavity (similar to Cryopit)
  - Cost estimate O(US$90M)
- Development requires substantial ROI and support from community (e.g., LEGEND-1000 at O(US$300M)
- SNOLAB space fixed for foreseeable future
  - May impact ability to host development projects (and clearly large-scale projects)



Tonne-Scale 0νββ

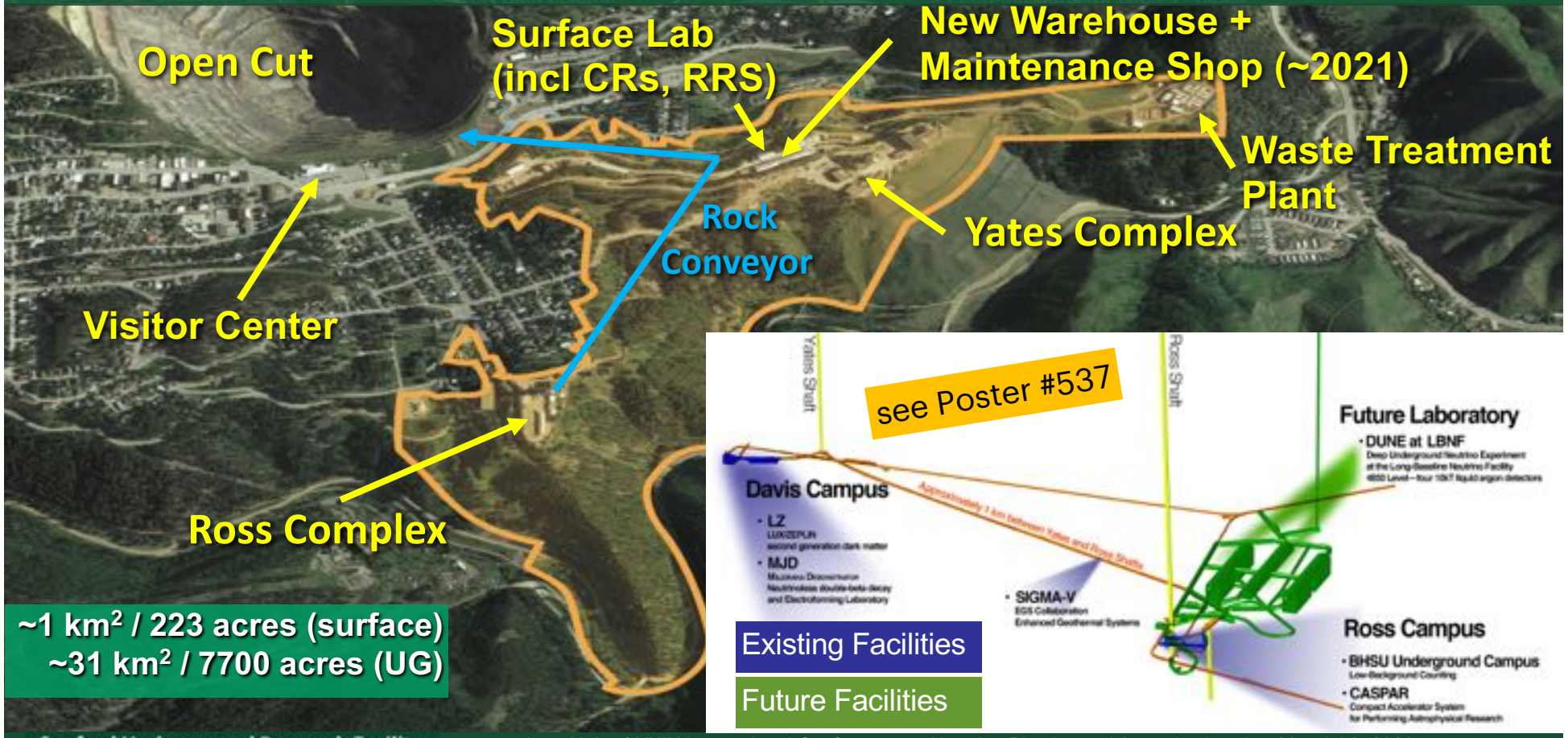






SURF: Sanford Underground Research Facility

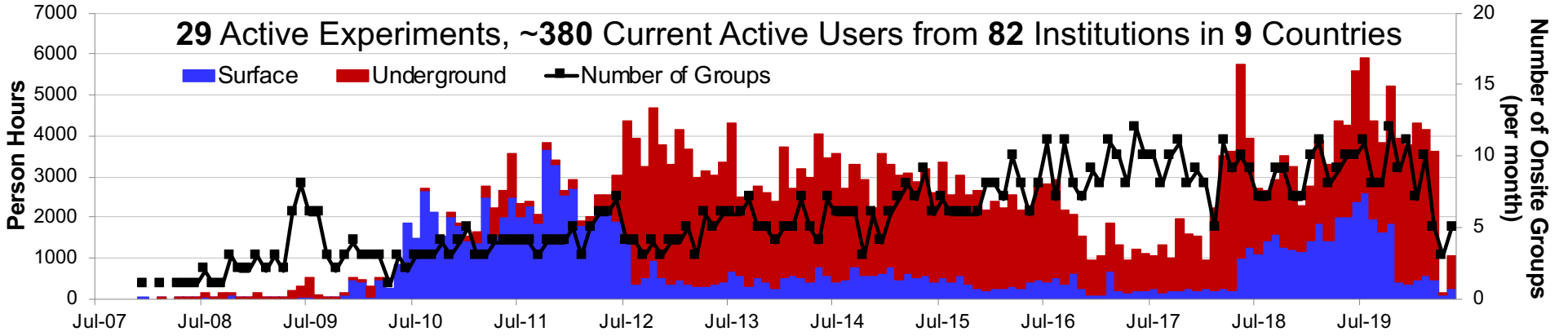
Nation's underground lab to advance multi-disciplinary research



SURF Overview

Expanding community of researchers from multiple disciplines

- Facility Highlights
  - **Deep** (1500 m, 4300 mwe) underground facility dedicated for science, with significant **capacity** & **expansion** possibilities (**additional** laboratories and **deeper** laboratories part of new **strategic plan**)
  - **Redundant** safe access with 2 principal shafts (incl redundant **power** and **network** utilities)
- Science Support
  - **Robust** organization with resources to ensure safe and successful science (163 full-time staff, incl occupational nurse and full-time 24-hr ERT; organization has 11 departments, incl Engineering, ESH, Operations + Science personnel)
  - **Mature** experiment implementation & safety programs
  - **Experience** in underground operations/logistics; also cryogen/pressure, cleanroom operations and maintenance, assays, etc
  - **SURF User Association** launching this year; initial planning underway for **SURF STEM Institute**



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: TPC assembly complete at Surface Lab, inner cryostat successfully transported to Davis Campus, data in 2020, 100x more sensitive than LUX

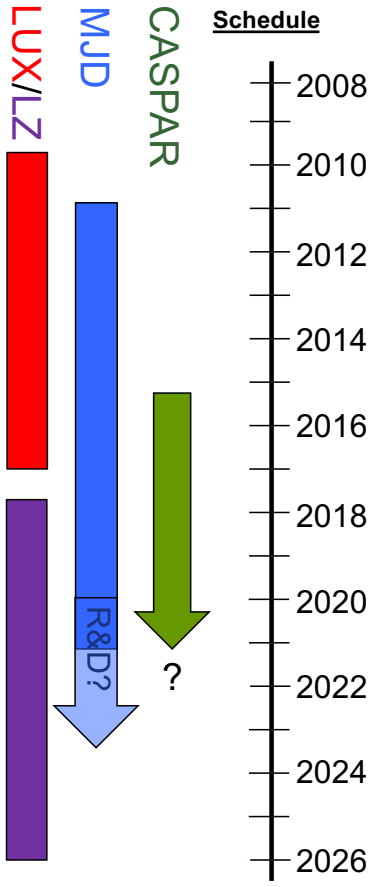
- **MAJORANA DEMONSTRATOR:** Investigate **neutrinoless double beta decay** using 44 kg Ge in two cryostats, 30 kg enriched ^{76}Ge inside multi-layer compact shield

  Status: Data since mid-2015, cable & connector upgrade performed, aiming for 65 kg-yr exposure, ultra-pure electroformed Cu production continues (avg U, Th decay chain $\leq$ 0.1 μBq/kg); LEGEND R&D

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

  Status: Beam operation since 2017, targets so far incl N-14, B-11, Ne-22 (gas), O-18/16; Li-7 soon + more Ne-22

BHUC: 6x **low-bkgd assay** counters operating (~10s ppt sensitivity)



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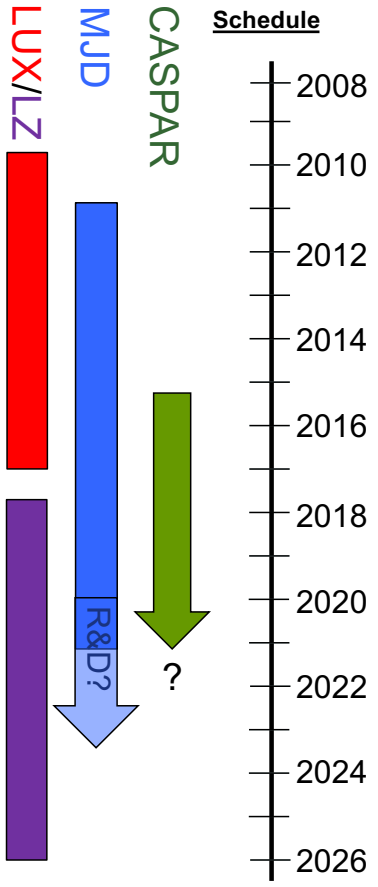


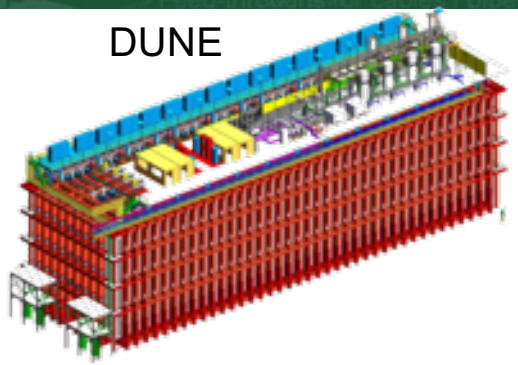
SURF Science Program – Planned & Potential

Strong and diverse program with exciting future

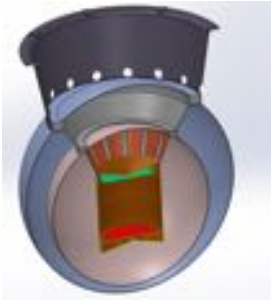
DUNE: 4x 10 kT LAr detectors with wire planes for **neutrinos** (**CPV, MH, SN, proton decay**, etc), excavation 2021-2024; possible "module of opportunity"

- **BHUC:** 10-12 **low-bkgd assay** instruments
- **DIANA:** Measure **stellar burning reactions, incl ^{12}C beam for ^{16}O production**, using 2.5-MV accelerator
- **Ton-scale DBD:** Investigate **neutrinoless double beta decay** using 1000 kg enriched isotope, inverted hierarchy coverage
- **G3 DM (also Low-Mass):** **Dark matter** ~100 ton Xe (or other); modest-scale low-mass designs, possibly mods to LZ
- **THEIA:** Water-based liquid scintillator using LBNF beam (**CPV, MH, CNO, DSNB**, etc)

DUNE

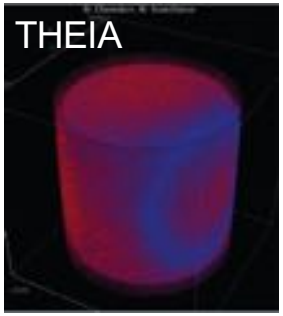


Ton-Scale DBD



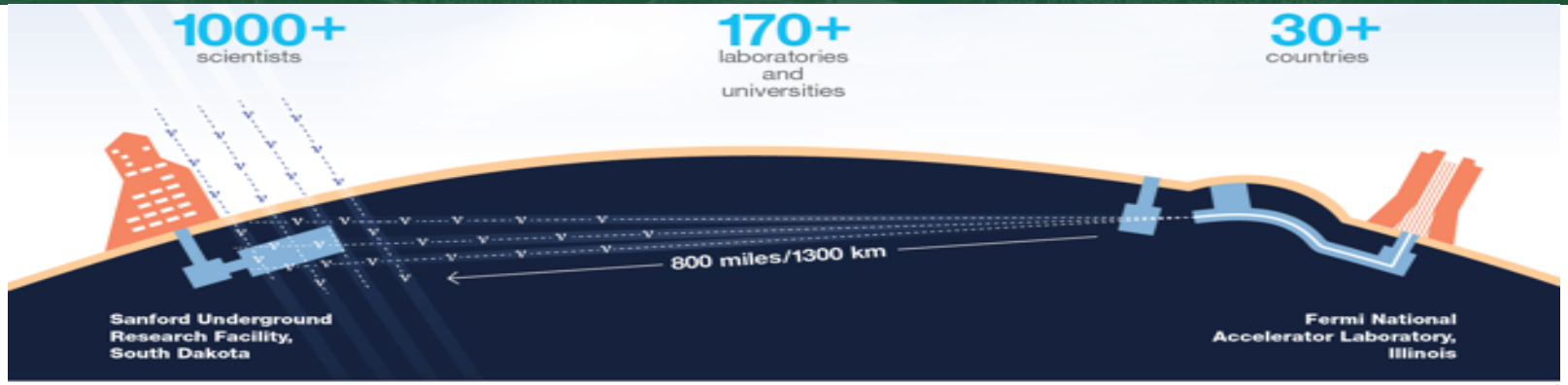
DIANA

THEIA



Long Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

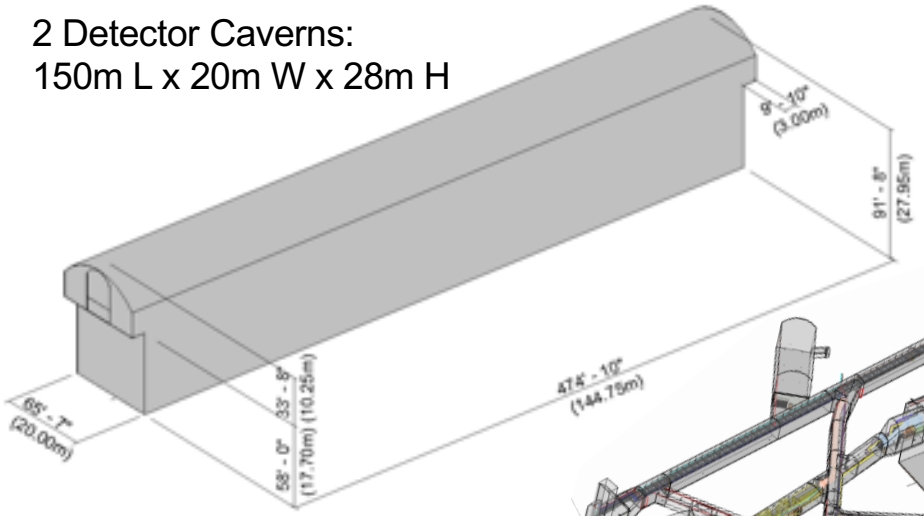


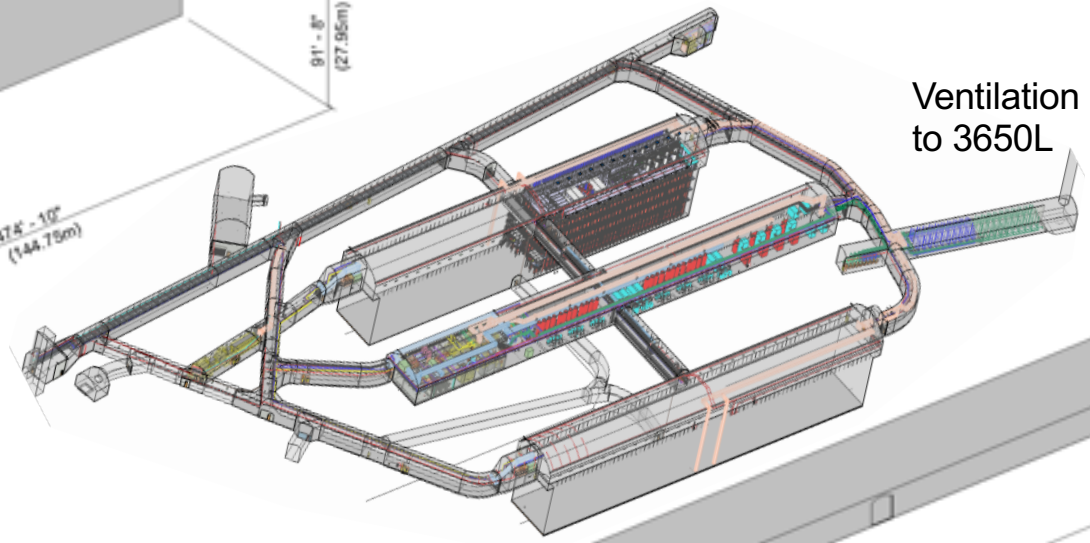
- First internationally conceived, constructed, and operated **mega-science project** hosted by the Department of Energy in the United States. Significant **international** contributions (incl CERN).
- Two detector caverns to host 4 detectors + utility cavern.
- **Reliability projects** to rehabilitate some key SURF infrastructure (incl main ventilation fan, Ross Shaft and hoisting systems, UG Refuge Chamber, etc). In progress since 2016, complete in 2020.
- **Pre-excavation construction** started at SURF in Jan 2019, grown to ~100 people onsite daily. Main goal is to install systems to transport excavated rock. To be complete end of Feb 2021.
- **Excavation** started Jun 2020, with initial focus on ventilation. Main excavation (caverns, access) starting early 2021 and lasting ~3 years.

Long Baseline Neutrino Facility (LBNF)

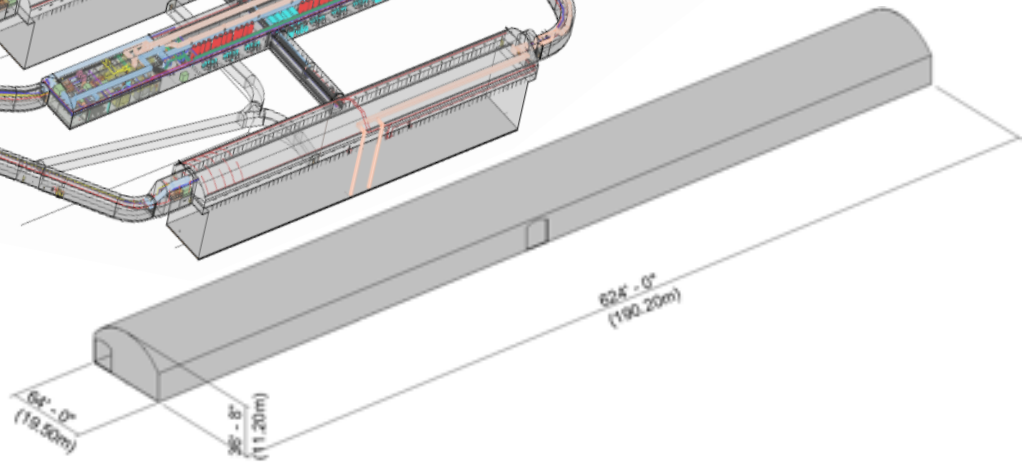
LBNF will host the Deep Underground Neutrino Experiment (DUNE)

2 Detector Caverns:
150m 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)

Rock conveyer for ~800,000 tons of rock to the Open Cut

Tramway rehabilitation to support UG portion of rock conveyer (~45m below Ross headframe)

Surface portion of rock conveyer extending into the Open Cut

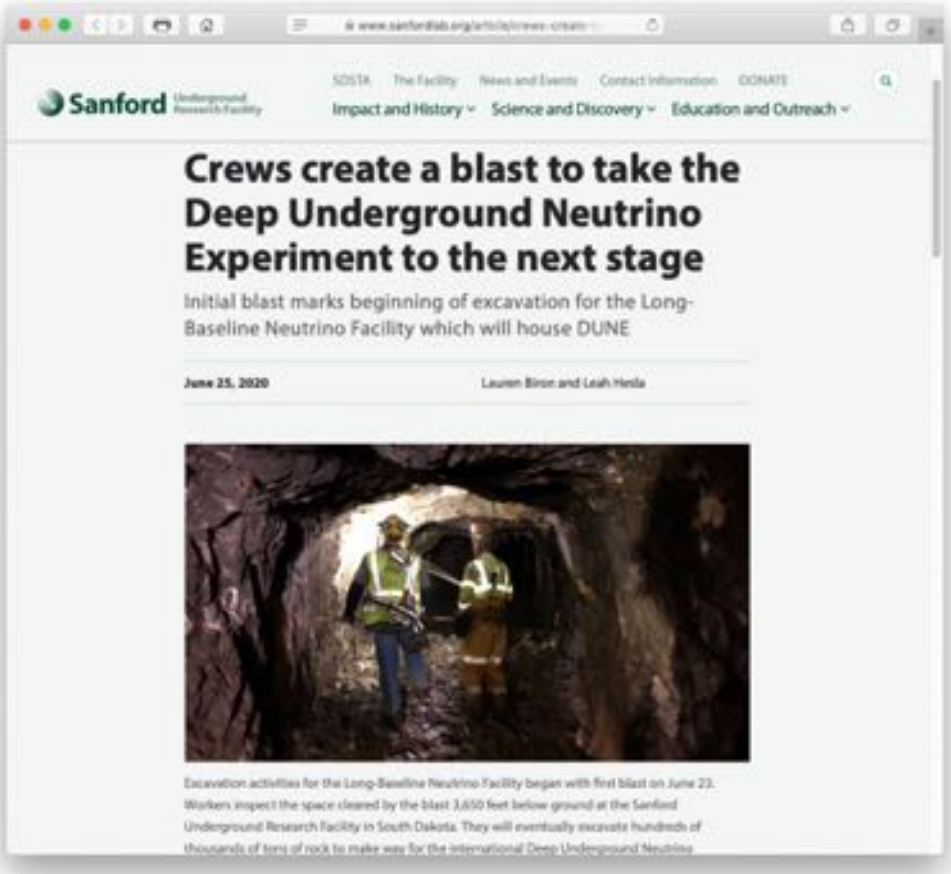
Long Baseline Neutrino Facility (LBNF)

Completing the upgrade of the Ross Shaft

Preparing to install final steel set
in the Ross Shaft (Set 305)

Long Baseline Neutrino Facility (LBNF)

First blast June 23, 2020



Sanford Underground Research Facility

SDSTA The Facility News and Events Contact Information DONATE

Impact and History Science and Discovery Education and Outreach

Crews create a blast to take the Deep Underground Neutrino Experiment to the next stage

Initial blast marks beginning of excavation for the Long-Baseline Neutrino Facility which will house DUNE

June 25, 2020 Lauren Biron and Leah Hesla

Excavation activities for the Long-Baseline Neutrino Facility began with first blast on June 23. Workers inspect the space cleared by the blast 3,650 feet below ground at the Sanford Underground Research Facility in South Dakota. They will eventually excavate hundreds of thousands of tons of rock to make way for the international Deep Underground Neutrino

Summary of Main Existing UG Facilities

		SURF	SNOLAB	LNGS	LSC	Boulby	LSM	Callio Lab	Baksan	CJPL	Kamioka	Y2L
Creation Date		2007 (1965)	2003 (1991)	1987	2010	1989	1982	1995	1967	2009/ 2014	1983	2003 A6 2014 A5
Vertical Depth [m]		1500	2092	1400	780	1100	1700	1440	1700	2400	1000	700
Volume [m^3]		7800*	37000	180000	10000	4000	3500	700*	23000	I: 4000 II: 300000	56500	5000
Personnel	**Total**	163	120	106	15	10 + RAL	10 + CNRS/ Grenoble	2 + mining company	240	20	102	26
	Scientist	*4*	*~17*								*73*	*20*
	Engineer/Tech	*15*	*~8*				*9*				*11*	*6*

* Deepest Level

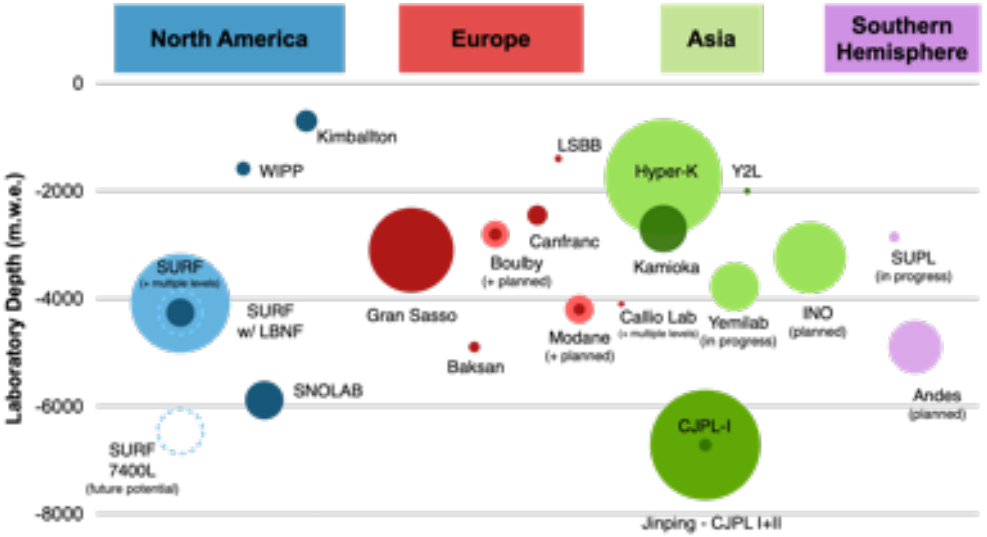
After A. Ianni, TAUP2017, NNN19

COVID-19 and UG Facility Operations

- All facilities affected
- Many in essential-personnel mode since March 2020 (support critical monitoring, LN, etc), operating experiments affected less than those in installation phase
- Collaboration institutional travel restrictions
- Some are on road to ‘normal’ (e.g., SURF step 3 of 4, SNOLAB step 2 of 5)
- CJPL back to ‘normal’ operations

Underground Facilities – Worldwide

- Underground facilities provide infrastructure to support a wide range of efforts (incl rare-process physics topics)
- Rich suite of facility options currently exists
- Many facilities are crowded. While there are exciting developments in the near term, they are largely earmarked for specific projects
  - Important decisions regarding 0νββ soon?
- Growing number of networks and good examples of cooperation between UG facilities
- Science programs range from specific to broadly multi-disciplinary
- Strategic planning is active in many jurisdictions (e.g., Snowmass->P5) and include a strong facilities component



Underground Facilities – Worldwide

CJPL: Jul 2018

Canfranc: May 2019

Thank You / Merci
(Happy Canada Day!)

SNOLAB: Jul 2017

Boulby: Jul 2016

Y2L & Yemilab: Oct 2016

Agency Acknowledgement: The Sanford Underground Research Facility (SURF) is a federally sponsored research facility under DOE-SC HEP Award Number DE-SC0020216 (5-year cooperative agreement)

Underground Facilities – Worldwide

CJPL: Jul 2018

Canfranc: May 2019

Thank You / Merci
(Happy Canada Day!)

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Boulby: Jul 2016

Y2L & Yemilab: Oct 2016

Contributor Acknowledgements: M. Nakahata (Kamioka), S. Gaffet (LSBB), X. Bertou (ANDES), C. Mariani (KURF), Y. Kim (Y2L/Yemilab), N. Smith (SNOLAB), J. Gascon (LSM), B. Monreal (salt caverns), S. Paling (Boulby), S. Troitsky (Baksan), Q. Yue (CJPL), C. Peña Garay (LSC), R. Garrett (SUPL), J. Joutsenvaara (Callio Lab), B. Dozier (WIPP), B. Satyanarayana (INO), A. Ianni (LNGS + others), SURF staff + discussions with others!

SURF Neutrino Day – July 6-11, 2020

Participation incl other labs: FNAL (2018), CERN (2019) and SNOLAB (2020)

http://www.neutrinoday.com

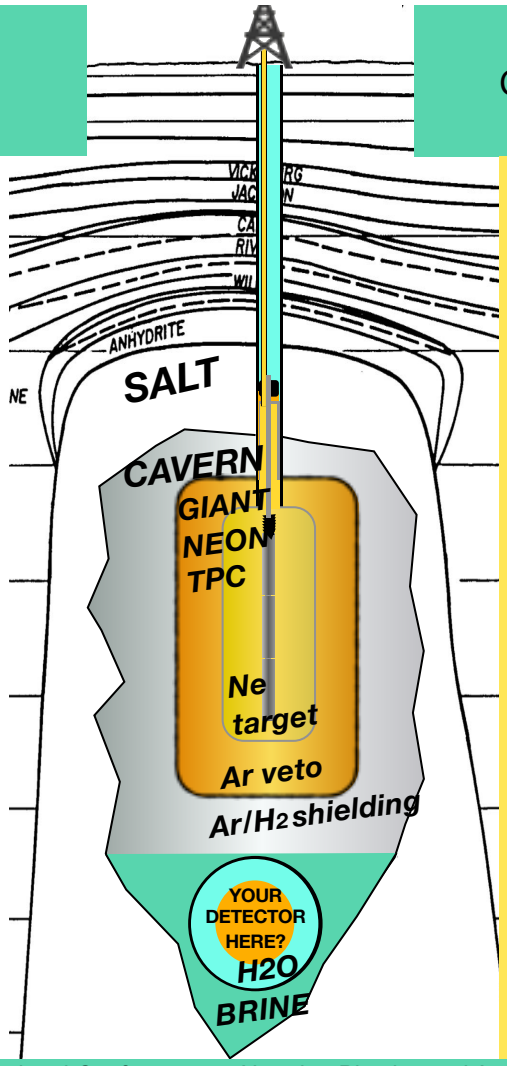
Neutrino observatories in high-pressure salt caverns

Ben Monreal
Case Western Reserve University
benjamin.monreal@case.edu

- Ultra-low-cost underground space can be made in solution mined salt caverns
  - Costs ~ $20/m^3
  - Volumes to 2x10^6 m^3
  - Depths 500-3000m

see Poster #509

- Can we do experiments in them?
  - Pros: vast space, low U/Th/K, no explosion hazards, many sites
  - Cons: Experiment has to fit down a narrow well
  - Pro or con?: normally flooded and pressurized
- Current focus: spherical and cylindrical gas TPCs
  - Detector, veto, and shielding balloons are lowered into the cavern and inflated
  - Seeking collaborators & funding



Case Underground Salt Observatory (CUSO)

Proposal:
- 10-15m cavern
- 12" well bore
- 600m depth (60 bar)
- same salt as IMB

CUSO physics:
- Ton-scale He/H_2 spherical TPC for light dark matter
- R&D, radioassay

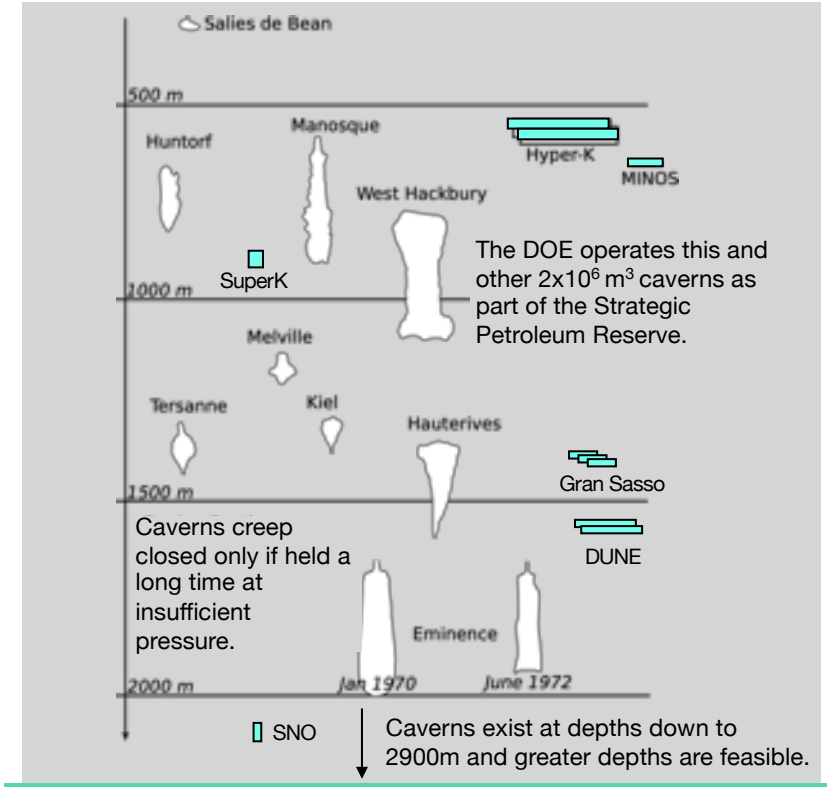
Larger-cavern physics:
- kT-scale Ne (solar ν)
- kT-scale H_2 ($\bar{\nu}$, DM)
- 10t-scale Xe gas
- Low pressure TPCs?
- Water Cerenkov?

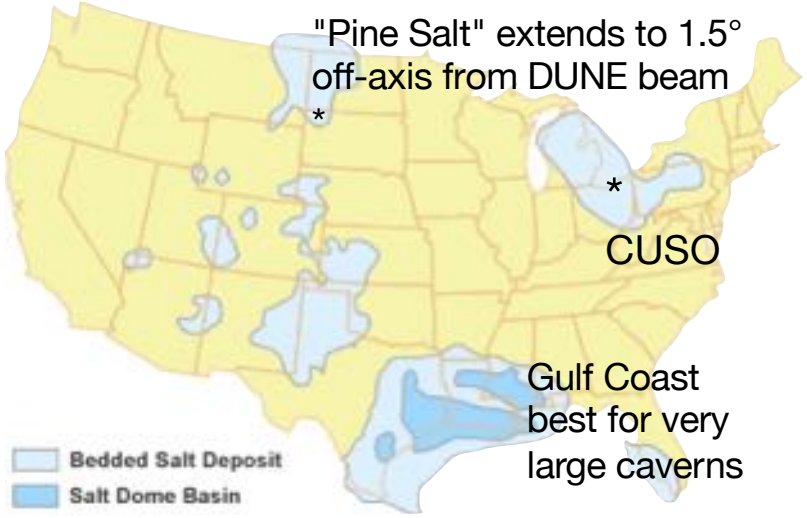
Neutrino observatories in high-pressure salt caverns

see Poster #509

Ben Monreal
Case Western Reserve University
benjamin.monreal@case.edu

50 years of industry & DOE experience with solution mining; 100% standard processes





Wellhead of a solution-mined cavern producing industrial salt in Seville, OH

KURF: Kimballton Underground Research Facility

- Active limestone mine < 1 hour from Virginia Tech Blacksburg campus
- Horizontal drive-in access
- R&D-appropriate space available at various overburdens ~300 m.w.e to ~1400 m.w.e

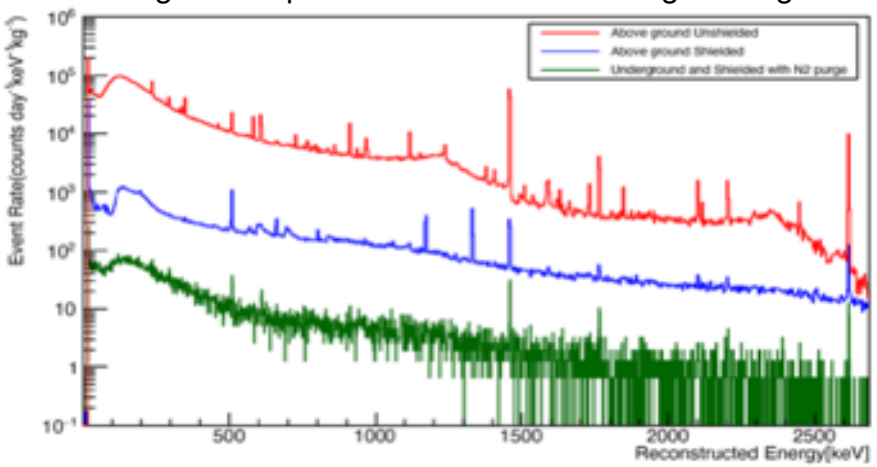
Expansion to 700 m.w.e Level

- Currently developing space at 700 m.w.e.
- Will host Bluefors LD-400 dilution refrigerator for cryogenic detector R&D
- Quiet cavern, isolated from mine activity 100m x 12m x 10m (LxWxH)

Low Background Counting on 300 m.w.e Level

- ORTEC HPGe installed in mobile research trailer
- Sensitivity: ^{238}U ~4 mBq/kg
  ^{232}Th ~10 mBq/kg
  ^{40}K ~10 mBq/kg

Background Spectrum Before/After Going Underground



Facility Director and Point of Contact:
Prof. Camillo Mariani camillo@vt.edu

MULTIDISCIPLINARY AND OPEN TO WELCOME NEW USERS

Resources	Environment/ fluid interactions	Life	Instrumentation and metrology	Human science & society	Geophysics, physics, astrophysics, instrumentation
• Karst • Underground Water Resources • Carbonated platform	• THMBC couplings • Poroelasticity • Geomechanics	• Geobiology • Brain imaging	• Magnetometry • Gravimetry • Densitometry • Seismometry • Rotation • Clinometry • Optic fiber • Electronics charact. • New tools development	• Cold war contemporary History • Anthropization vs Global Changes	• Seismology • Magnetism • Gamma • Neutrons • Muons • WIMPs (DM) • Atmospheric EM phenomenology

Carrière et al. (2020) doi: 10.1016/j.scitotenv.2019.134247
Felizardo M. (2020) doi: 10.1142/S0217751X20300057
Lázaro Roche et al. (2020) doi:10.1088/1742-6596/1498/1/012048

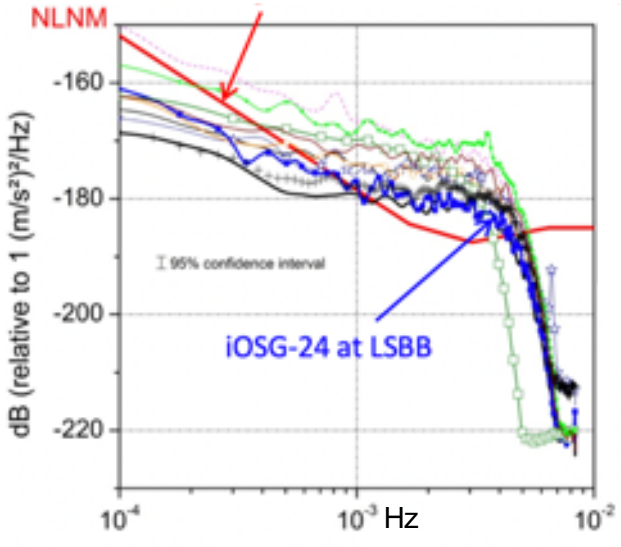
Sabulsky et al. (2020) doi: 10.1038/s41598-020-59971-8
Bernard et al. (2019) doi: 10.1785/0220190049
Hamzei et al. (2019) doi: 10.1051/e3sconf/20198802002
Rosat et al. (2018) doi: 10.1016/j.jog.2018.05.009
Santolik et al. (2017) doi:10.1038/s41598-017-13849-4

The LSBB counts with 54 ha of surface and 4 km of underground galleries with depths ranging from 0 to 518 m

LSBB facility https://lsbb.cnrs.fr

- Accommodation of large experiments in controlled environments
- Underground operation
- Potential for multi-scales & multi-depths projects
- Permanent staff to ensure the experiment survey
- Fine monitoring of environmental parameters
- Boreholes at different depths and locations
- Easy access for materials and water, electricity and network availability
- Surface and underground facilities in a low-background noise environment
- Underground vaults, clean room, electromagnetically shielded spaces

OUTSTANDING LOW NOISE ENVIRONMENT

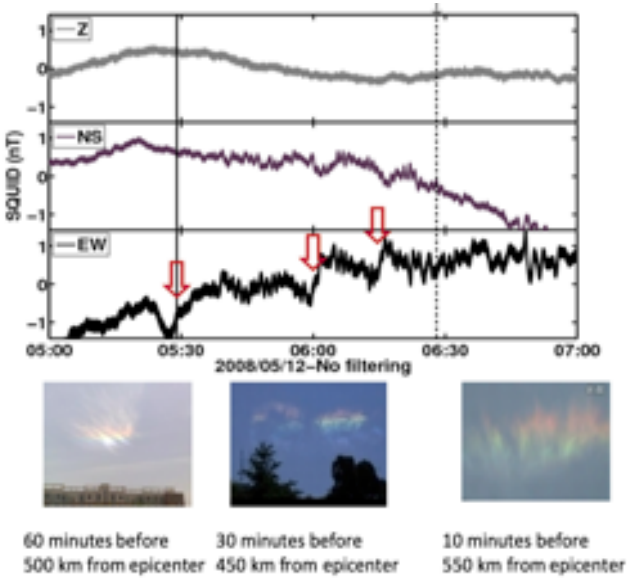


Superconducting gravimetry

One of the quietest sites in the world

Canuel et al. (2019) arXiv:1911.03701v1

Sichuan 2008/05/11-06:28 Mw 7.9

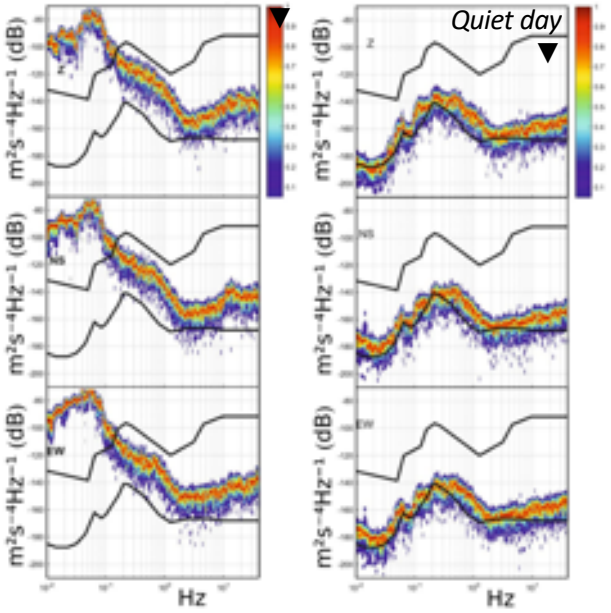


Ultra-sensitive magnetometry, Earth/ionosphere couplings

Jumps of magnetic field in time coincidence with "rainbow clouds" observed at different locations before Sichuan earthquake

Waysand et al. (2011) EDP 02004

Tohoku-Oki 2011/03/11-05:46 Mw 9.1

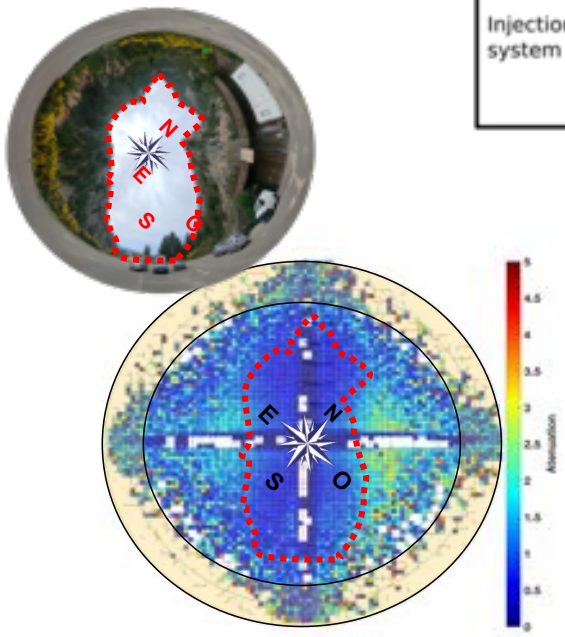


Low-noise seismic properties

Seismic noise PSD for three components (top, Z; middle, NS; bottom, EW) vs Peterson's high and low noise models (black lines)

Rosat S. et al. (2018) J. of Dynamics 119

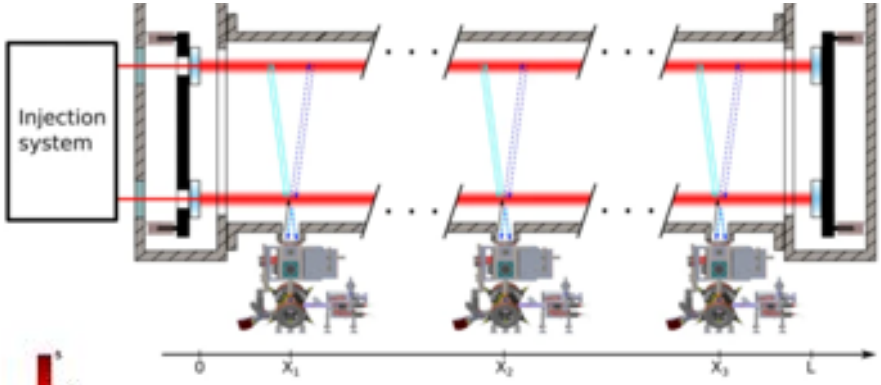
SAMPLE OF PROJECTS



Muon tomography

Inhouse technology and largest network of muon cameras in the world

Lazaro, I. (2020) Journal of Physics 1498



Gravitational waves

The MIGA project involves 15 French laboratories and 3 companies, experts in atomic physics, optics, geophysics, hydrology and instrumentation.

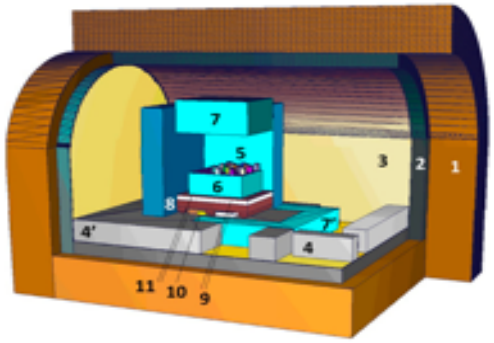
The instrument is a demonstrator for gravitational wave detection in a frequency band (0.01Hz–100 Hz) not explored by existing and future GW observatories

Canuel B. et al. (2018) Scientific Reports 8

Neutron spectrometry

HERMEIS type detector for background characterization

Cheminet A. et al. (2012) J Instrum 7



WIMPs search

Host the SIMPLE experiment phases I & II

Felizardo M. (2012) EDP 03002

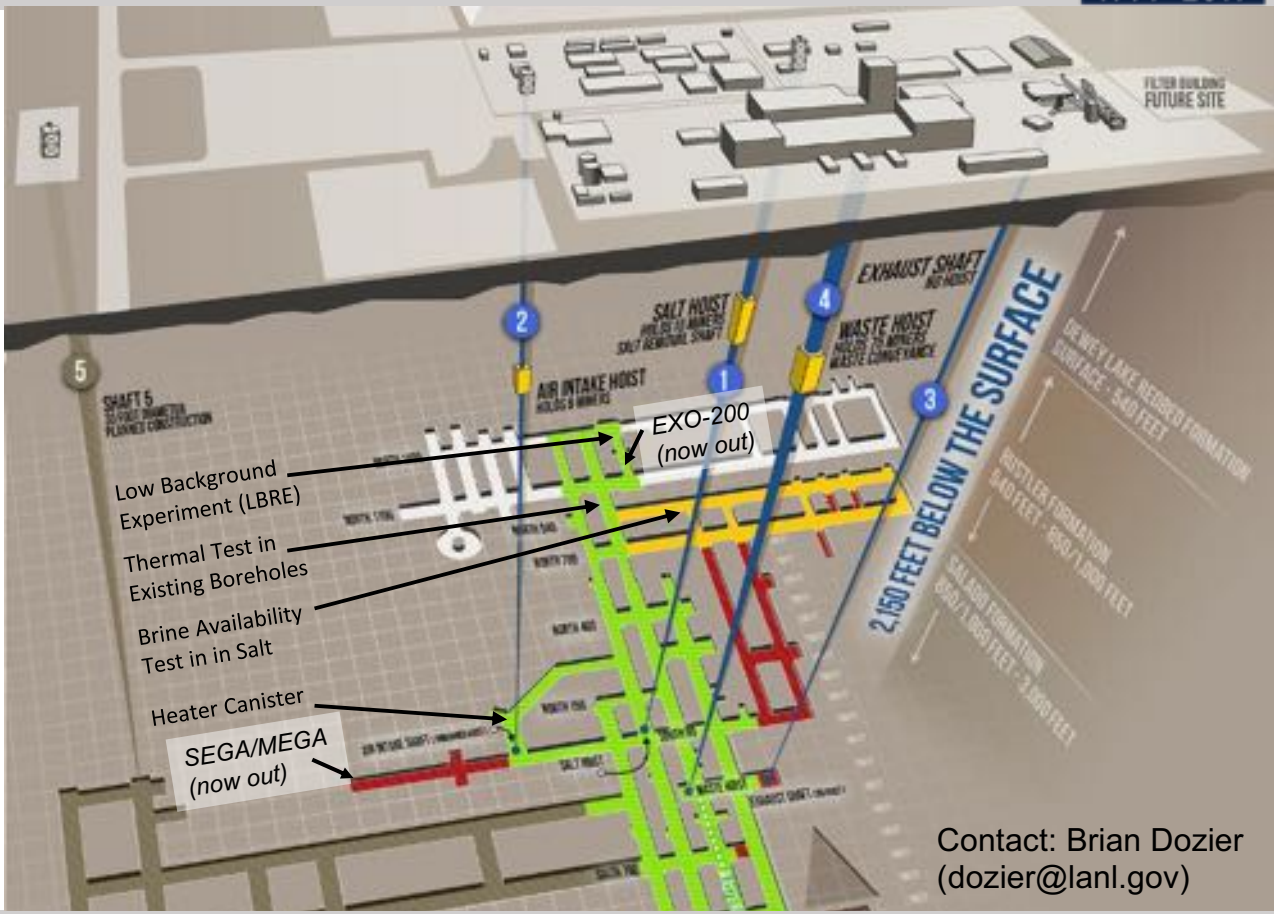
WIPP: Waste Isolation Pilot Plant

Lab Characteristics

- Low Rn: 7.4 Bq/m^3
- Low-activity "rock":
  ^{238}U: 29 ppb, ^{232}Th: 78 ppb
  ^{40}K: 169 ppb

Experiments

- **LBRE** (Low Bkgd Experiment)
  Study life in low-bkgd environment
- Various engineering projects involving heating salt
- Currently no physics experiments

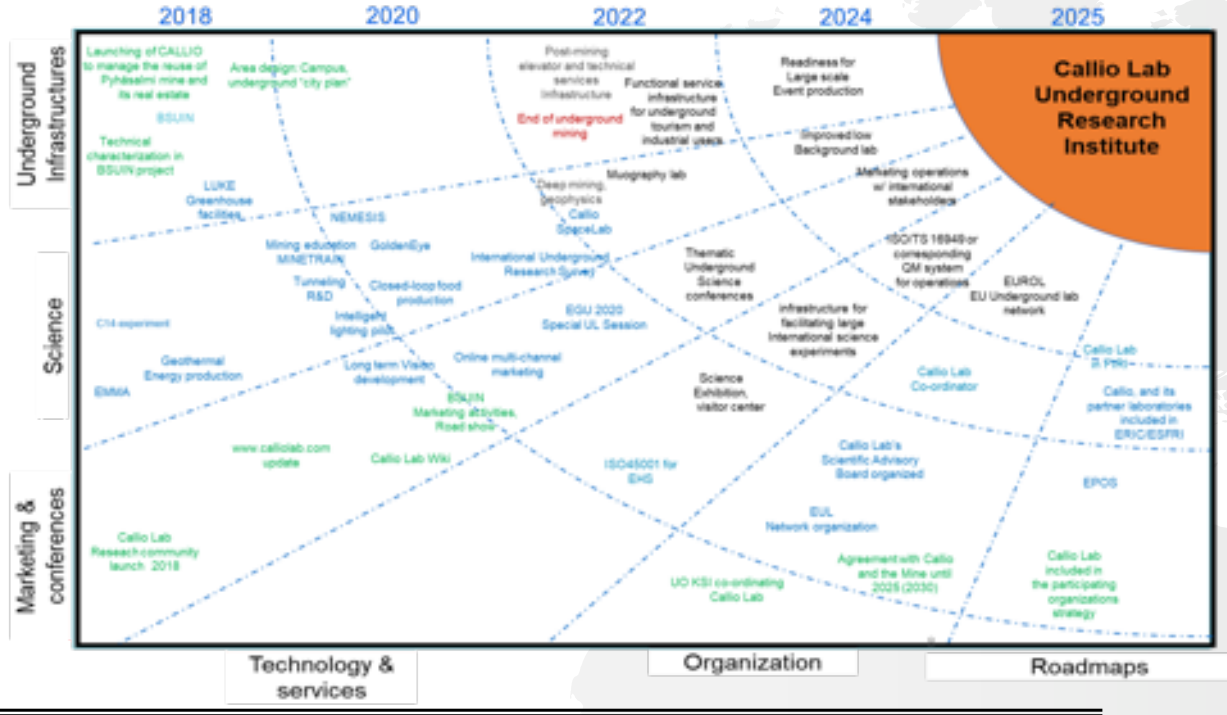


Contact: Brian Dozier
(dozier@lanl.gov)

CALLIO LAB

VISION 2025

- DONE
- In-Progress
- To be started



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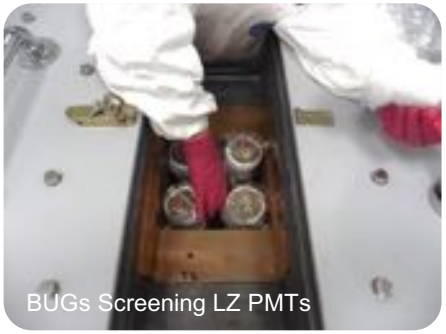
Boulby BUGS(+) Material Screening

Growing suite ('BUGS': Boulby Underground Germanium Suite) of Ultra-Low-Background (ULB) germanium detector systems to support Dark Matter & misc 'rare-event' studies…


BUGs Screening LZ PMTs

ULB counting studies supporting UK DM (**LZ**) and neutrino communities.

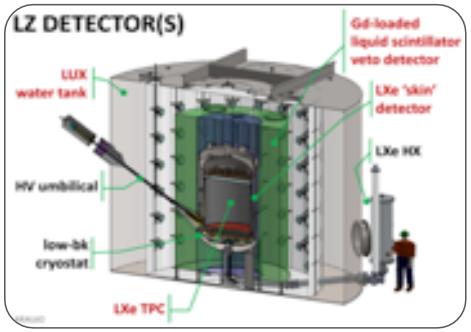
Now **EXPANDING** ULB counting capabilities. Inc. **XIA surface alpha counting**

In collaboration with UCL, DMUK, Sheffield & others.

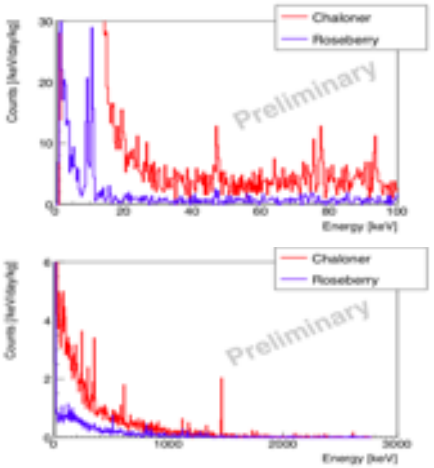
Boulby undertaking material selection for **LUX-ZEPLIN** and **SK-Gd/T2K** and more…

Sensitivity down to <50ppt U/Th per sample, & improving

Our Current Detectors;
- Ortec 1.8 kg (72%) p-type (ULB)
- Canberra 2.0 kg (112%) & 3.2 kg (171%) p-types (S-ULB)
- 2x Canberra BEGe detectors (5030 ULB, 6530 S-ULB)
- Canberra SAGe Well-type (S-ULB)



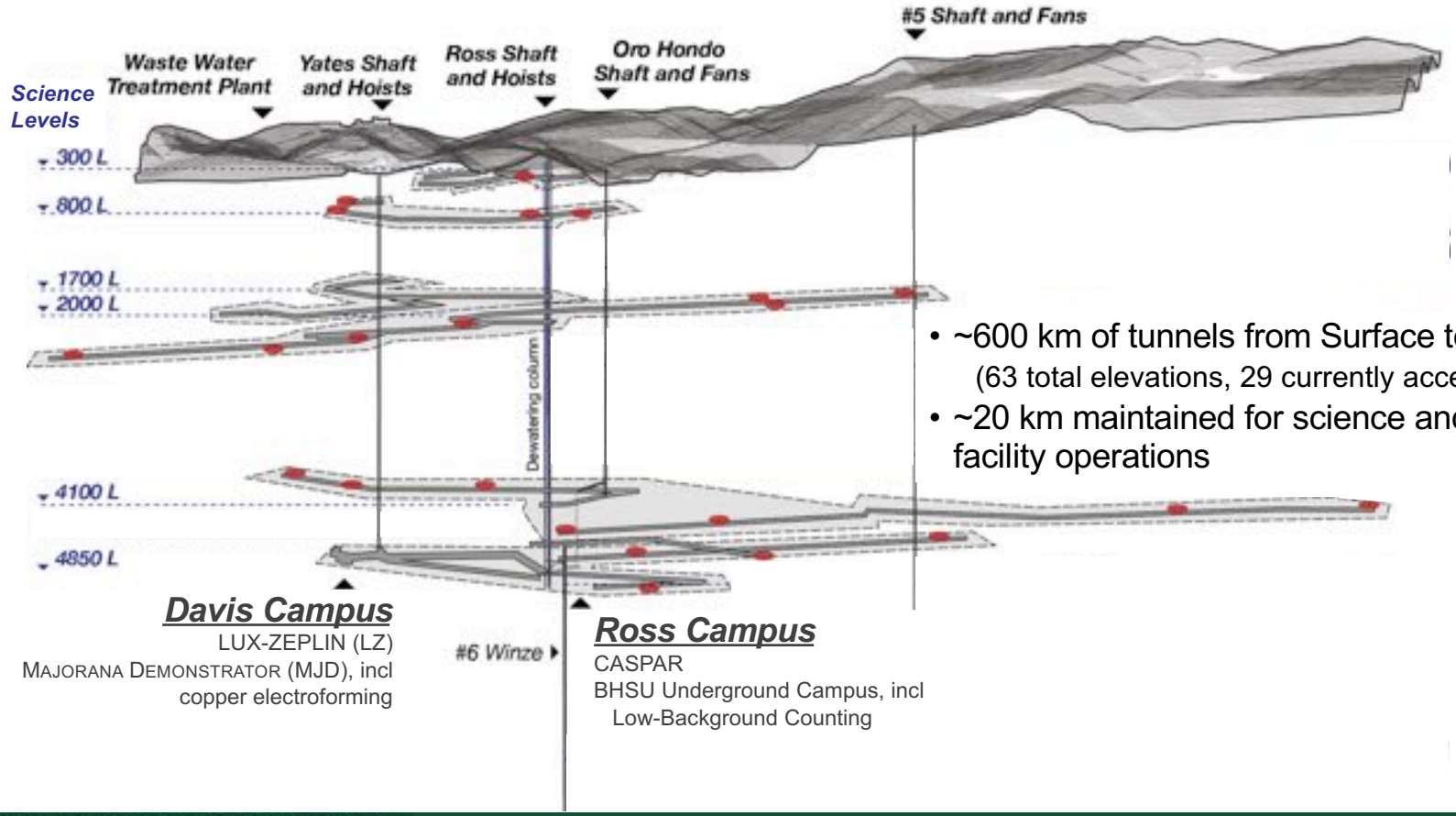
LUX-ZEPLIN



BUGS Germanium Suite

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

Ross Campus

CASPAR
BHSU Underground Campus, incl Low-Background Counting

Long Baseline Neutrino Facility (LBNF)

Rock conveyer for ~800,000 tons of rock to the Open Cut

SURF Science Program

Research activities ranging from the surface to the 5000L

Physics

- LZ – *Dark matter, 2-phase Xe TPC*
- MAJORANA DEMONSTRATOR / LEGEND – *Neutrinoless double-beta decay, Ge, also Cu e-forming*
- CASPAR – *Nuclear astrophysics with 1 MV accelerator*
- BHUC – *BHSU Underground Campus, incl biology & physics labs*
  - Berkeley LBF – *Low-bkgd counter (x3)*
  - CUBED – *Low-bkgd counter (x1); also past bkgd characterization (possibly future Crystal Growth)*
  - LZ SOLO – *Low-bkgd counter (x1)*
  - Alabama/USD – *Low-bkgd counter (x1)*
  - USD/UNC/SDSMT – *Low-bkgd counter (x1)*
  - SDSMT – *Neutron bkgds*
- Dust Monitoring – *ICPMS*
- LBNF/DUNE – *Neutrino properties, etc*

Total Active = 29 groups

48 Total Groups Since 2007 (+ interest from others)

Biology

- Astrobiology/DeMMO – *NWU/DRI*
- Biodiversity + Chemistry – *BHSU*
- Biofuels – *SDSMT*
- BuG ReMeDEE – *SDSMT, Mont, Okla*
- Extremophiles – *Liberty BioSecurity*
- GoLife – *Bigelow Lab/DRI*

Geology

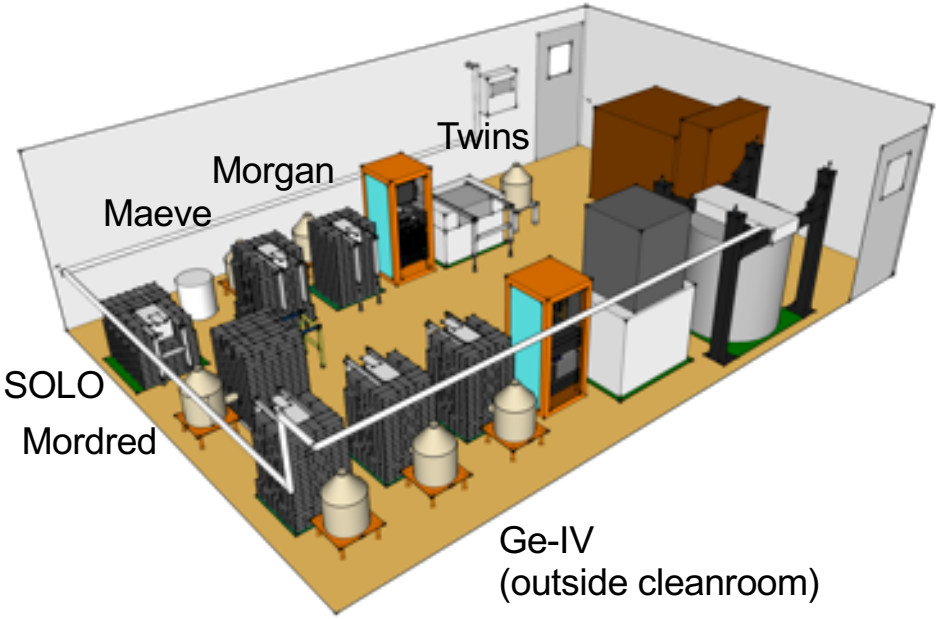
- SIGMA-V – *Geothermal*
- Core Archive – *Mainly gold deposits*
- GEOX™ – *Optical fiber applications, environmental monitoring*
- Hydro Gravity – *Local gravity for water tables, densities*
- Transparent Earth – *Seismic arrays*
- Geothermal Applications – *Modeling*

Engineering

- Xilinx, Inc – *Chip error testing*
- Luna – *In situ rock stress*
- Thermal Breakout – *In situ stress*
- Shotcrete – *Mining safety*

SURF Material Assay at BHUC

Establishing national & international-level capability for low-background assays



Relocating many instruments to Davis Campus in 2020, also cooling system upgrades in progress for 5 systems

Other Planned/Proposed instruments: BetaCage (SDSMT prototype + future proposal), XIA UltraLo 1800 (LZ, purchased)

SURF Material Assay at BHUC

Establishing national & international-level capability for low-background assays

Detector	Crystal		[U] mBq/kg	[Th] mBq/kg	Install Date	Status	Comments
	Type	Size					
Maeve (BLBF)	p-type (85%)	2.0 kg	**0.1** (~10 ppt)	**0.1** (~25 ppt)	Nov 2015 (from Oroville, Davis Campus May 2014)	Production assays	Old Pb (200-yr old) inner shielding
Morgan (BLBF)	p-type (85%)	2.0 kg	**0.2** (~20 ppt)	**0.2** (~50 ppt)	Nov 2015 (Davis Campus May 2015)	Production assays	Low-bkgd upgrade 2015
Mordred (USD/CUBED, BLBF)	n-type (60%)	1.3 kg	**0.7** (~60 ppt)	**0.7** (~175 ppt)	Jul 2016 (Davis Campus Apr 2013)	Production assays	Low-bkgd upgrade 2015-2016, shield access upgrade
SOLO (LZ/Brown)	p-type (35%)	0.6 kg	**0.6** (~50 ppt)	**0.3** (~75 ppt)	Feb 2016 (from Soudan)	Production assays	Shield reconfigured and optimized
Dual HPGe ("Twins") (BLBF, BHSU, UCSB)	p-type (120%)	2x 2.1 kg	**~0.01** (~1 ppt)	**~0.01** (~3 ppt)	Jul 2017 (initial), Mar 2018	Production assays	Low-bkgd upgrades 2016-2017; flexible shield
Ge-IV (Alabama, Kentucky)	p-type (111%)	2 kg	**~0.04** (~3 ppt)	**~0.03** (~8 ppt)	Oct 2017 (initial), Jul 2018	Production assays	Located outside cleanroom due to vertical design
MALBEK *(USD, UNC, TUNL,SDSMT)*	*p-type PPC (10%)*	*0.47 kg*	***~10-100*** *(1-10 ppb)*	***~4-40*** *(1-10 ppb)*	*~2020?* (from KURF Jul 2016)	*Detector + Pb at SURF, install 2020?*	*Ancient Pb inner shielding (<0.01 Bq/kg ^{210}Pb)*
Dual HPGe *(LLNL)*	*p-type (>100%)*	*2x ~1.1 kg*	***<0.1*** *(<10 ppt)*	***<0.04*** *(<10 ppt)*	*Summer 2020*	*Implementation process underway*	*Cryocooler, low-E ^{210}Pb (<2 mBq/kg)*

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

Relocating many instruments to Davis Campus in 2020, also cooling system upgrades in progress for 5 systems

Other Planned/Proposed instruments: BetaCage (SDSMT prototype + future proposal), XIA UltraLo 1800 (LZ, purchased)

SURF Radon Reduction System – Surface

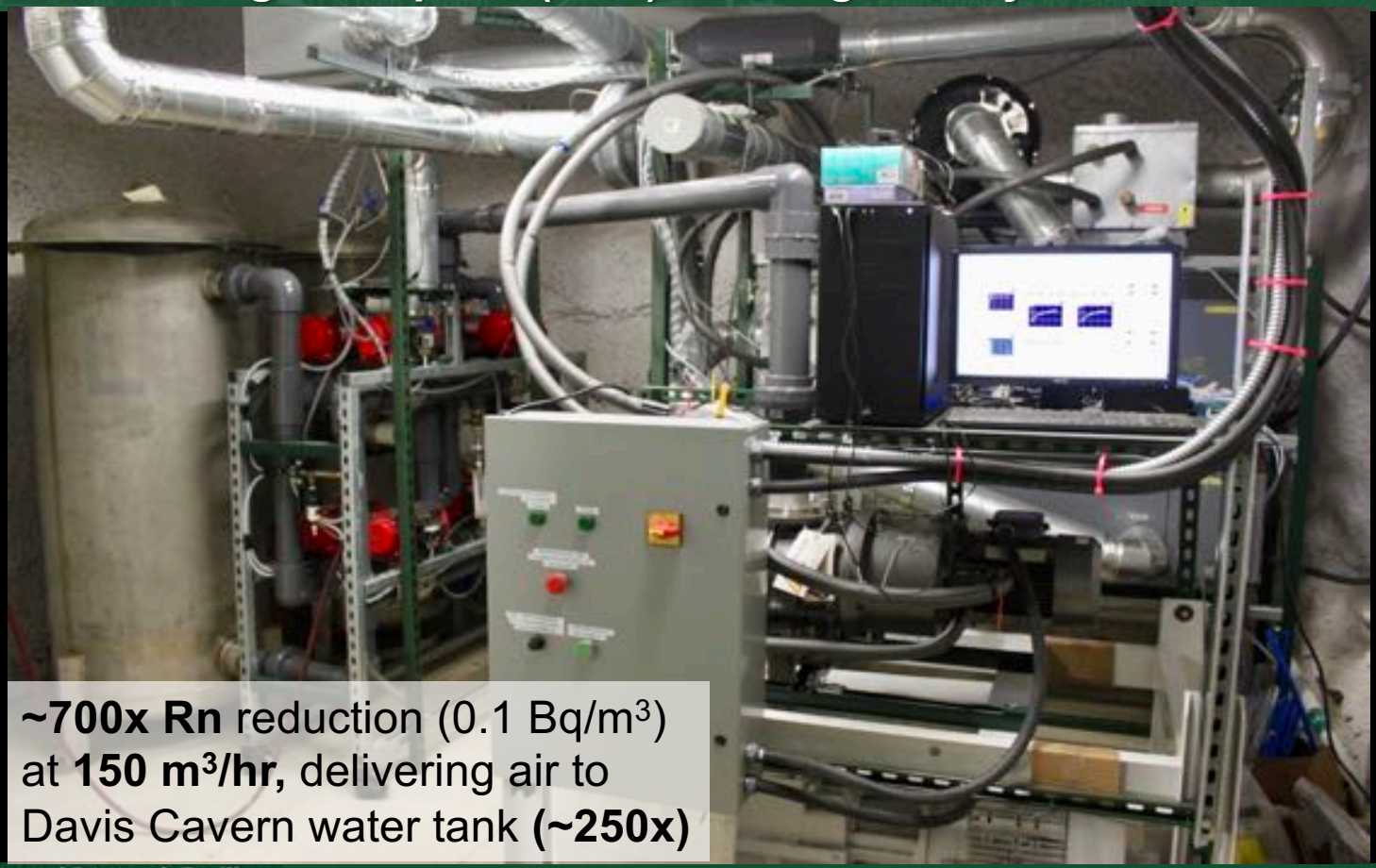
Commercial continuous-cooled Rn mitigation system

- **Specs:** 1000x Rn reduction, 300 m^3/hr
- **Supplier:** Ateko, Czech Republic (same as Y2L, Gran Sasso, etc)
- **Design:** Compress air to 9 bar, cool to -60C dew point, flow air through carbon adsorption columns, reduce pressure, reheat as desired
- **Space:** Dedicated bldg, 74 m^2
- **Status:** Operating, 2200x Rn output reduction

- **Specs:** Design/protocols support Class 100
- **Supplier:** SBB Inc., Syracuse, NY
- **Design:** Metal panels (Al) with careful sealing, balancing differential pressures, special entry ports (air shower, soft-wall for materials, etc)
- **Space:** 54 m^2, 240 m^3
- **Status:** Operating as Class 100, 770x Rn reduction inside cleanroom

SURF Radon Reduction System – Underground

SDSMT vacuum-swing adsorption (VSA) Rn mitigation system



~700x Rn reduction (0.1 Bq/m^3) at **150 m^3/hr,** delivering air to Davis Cavern water tank **(~250x)**

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 rock formations (also drill core archive), rock properties (fractures, stress, etc), geology logs
- Engineering
  - Real-world environments (especially mining)