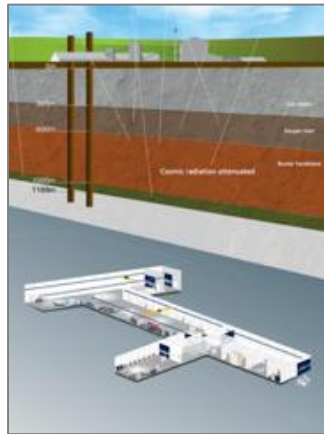


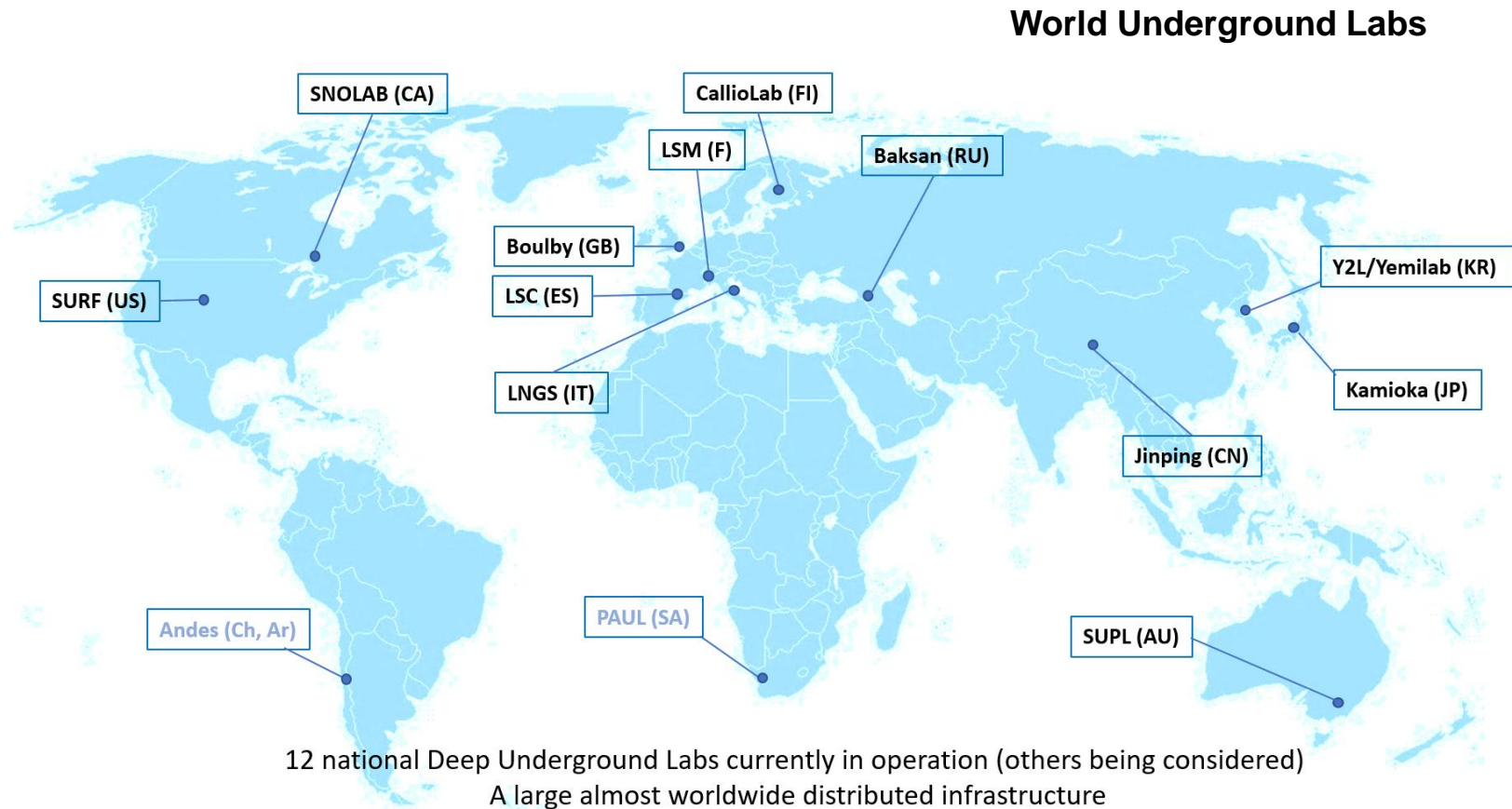
Overview of World Deep Underground Science Facilities



Jinping Underground Laboratory (China)



Boulby Underground Laboratory (UK)



Sean Paling
STFC Boulby Underground Laboratory

Why go underground?

Deep Underground Science Themes

Low Background Particle / Astroparticle Physics

- Direct dark matter searches
- Atmospheric, solar & supernova neutrinos
- Reactor and accelerator neutrinos
- Neutrino-less double beta decay
- Nuclear astrophysics / stellar reactions
- Misc. rare-decay processes

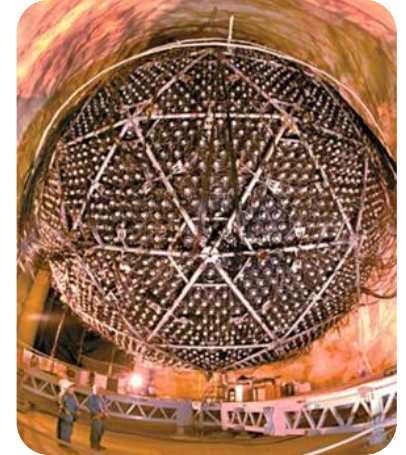
Other 'Multi-disciplinary' studies

- Pure and applied cosmic ray studies,
- Gravitational waves studies
- Misc. Earth and Environmental Sciences
- Geo-microbiology & life in extreme environs
- Astrobiology and planetary exploration
- Quantum sensors, quantum computing
- Etc...

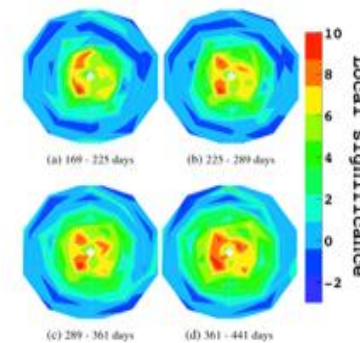
Dark Matter
Studies



Neutrino
Studies

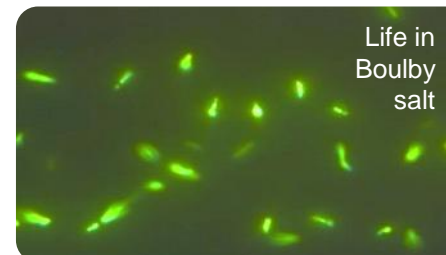


Geology &
geophysics



ULB Gamma
spectroscopy

Biology,
astrobiology and
more.



What's needed from an underground lab? (1)

Experimental Space with... **Low Backgrounds...**

Cosmic ray Muons...

- Deep underground facilities provide rock overburden & commensurate reduction in c.r. flux & spallation induced products (neutrons)

Go underground...

Neutrons...

Production from

- c.r. muon spallation
- U/Th fission
- α , n reactions

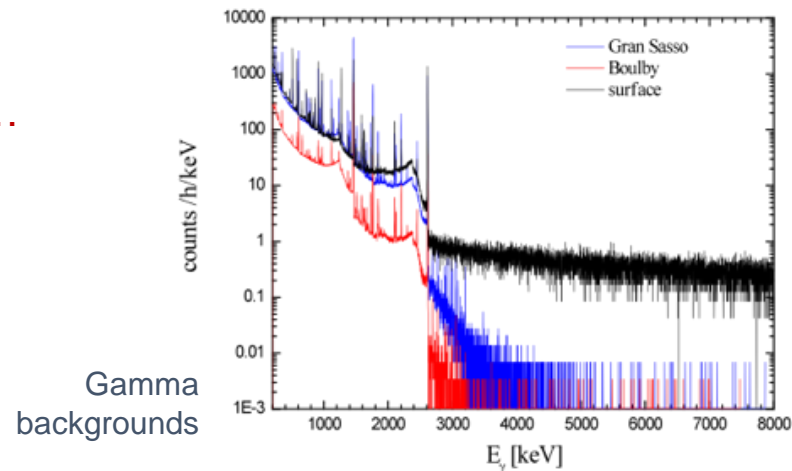
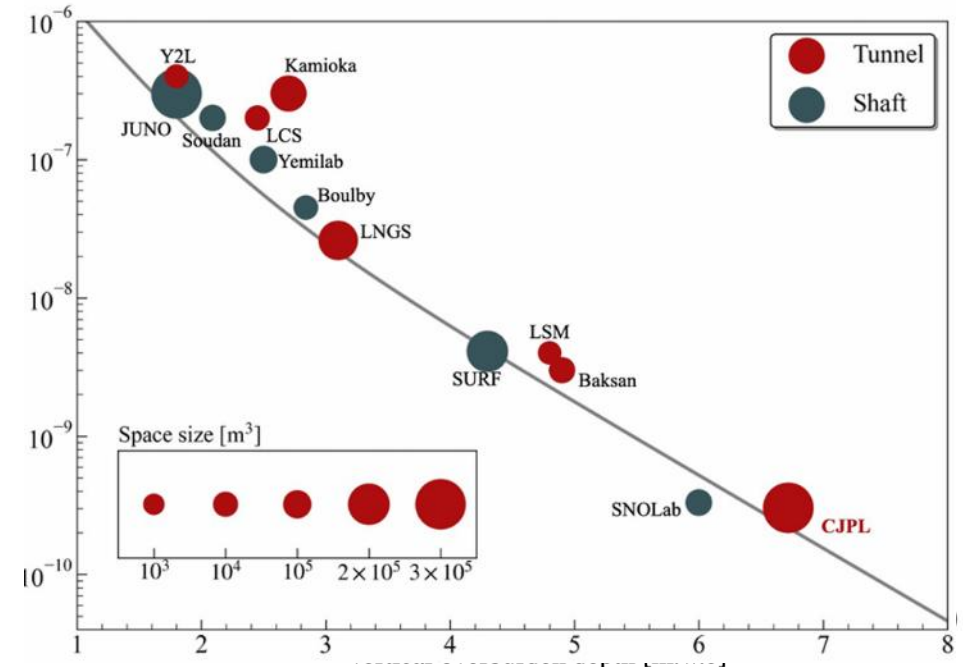
Radon....

- Dependent on local geology & ventilation

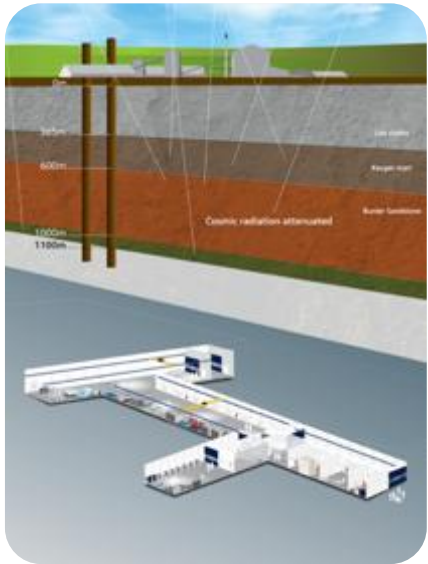
Choose low background rock...

Gammas....

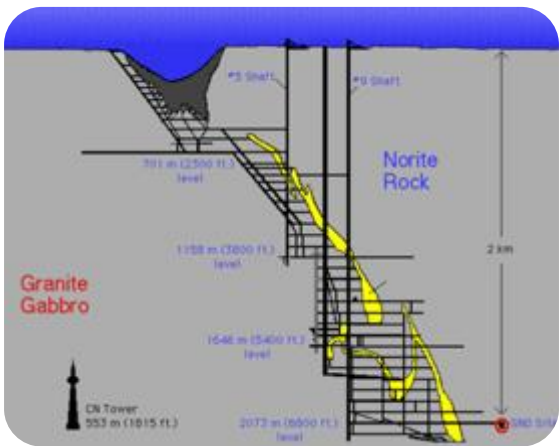
- Reduction in γ -ray background at higher energies from c.r. and neutron reduction
- Below 3.5MeV dependent on local geology



Underground Labs around the world....

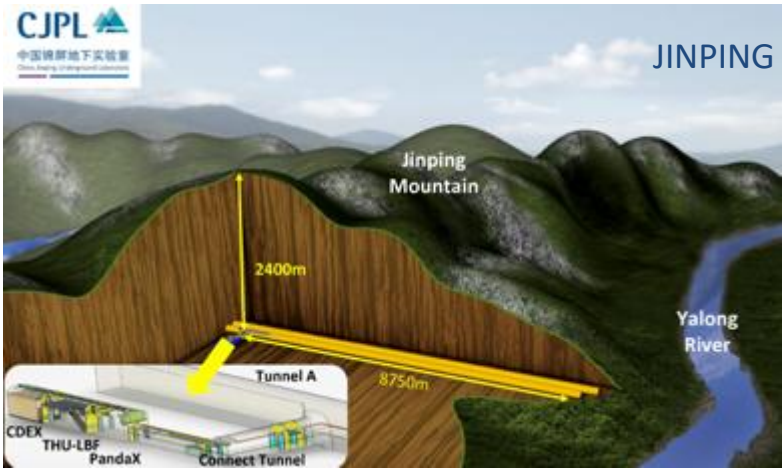


Boulby

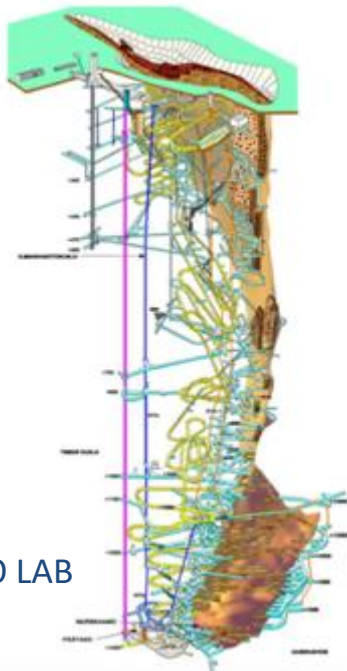


SNOLAB

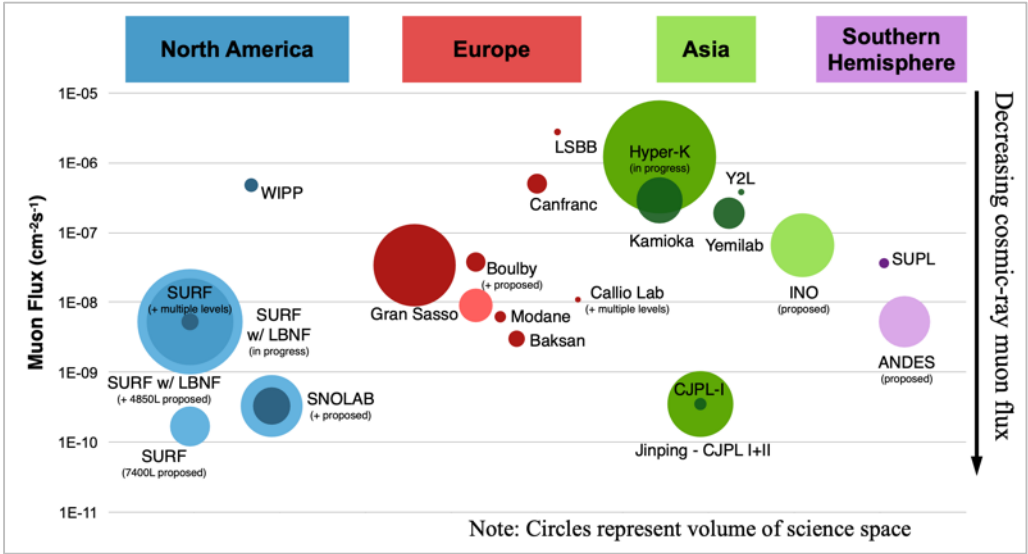
In mines and under mountains



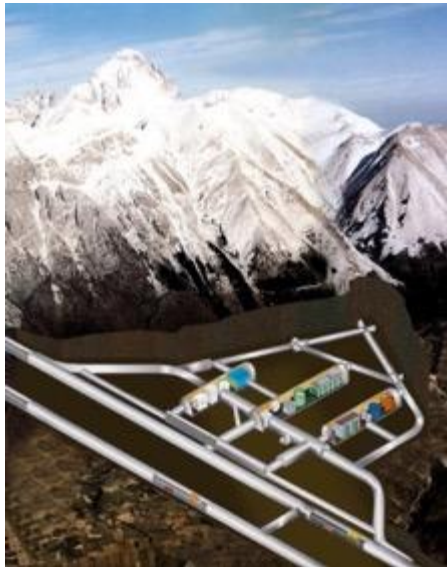
JINPING



CALLIO LAB



LNGS



SURF

What's needed from an underground lab? (2)

Other Factors:

Facility Infrastructure, operations and support factors:

- Good surface & underground infrastructure & support facilities
- Reliable utilities: power, ventilation, heat management, water, gases/liquids
- Good Health & Safety and security systems
- Scientific and technical support personnel: design, construction, operation/analysis
- Ancillary science support facilities: low background assay systems, clean rooms workshops etc, etc ...

'A hole in the ground is not a facility!'



Various other site characteristics that matter to science teams:

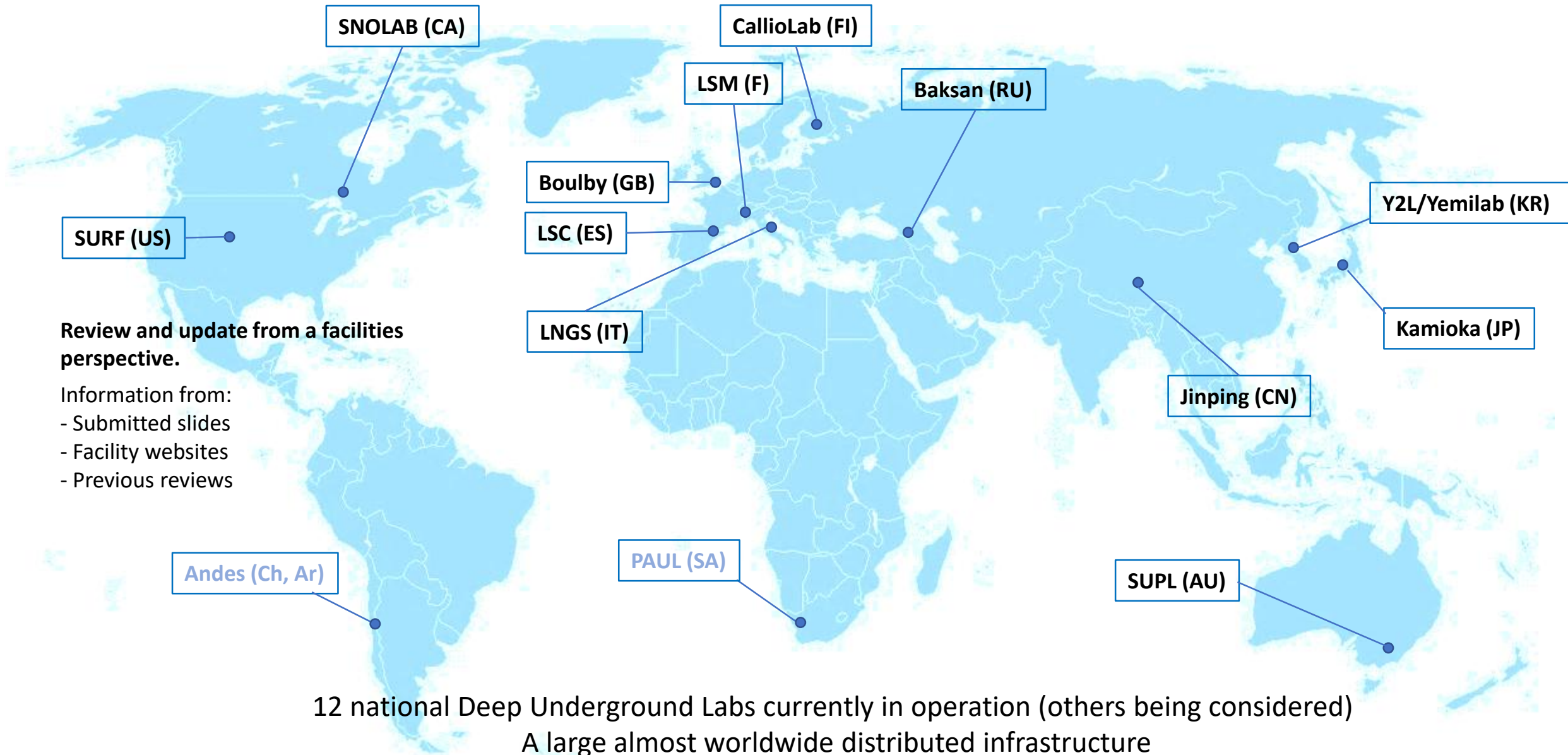
- Ease of Access (vertical or horizontal); Max installation size limitations
- Location (neutrino flux from beam/reactor, ease of travel, quality of life)
- Cleanliness, vibration and other interferences
- **Suitable geology / environmental characteristics**



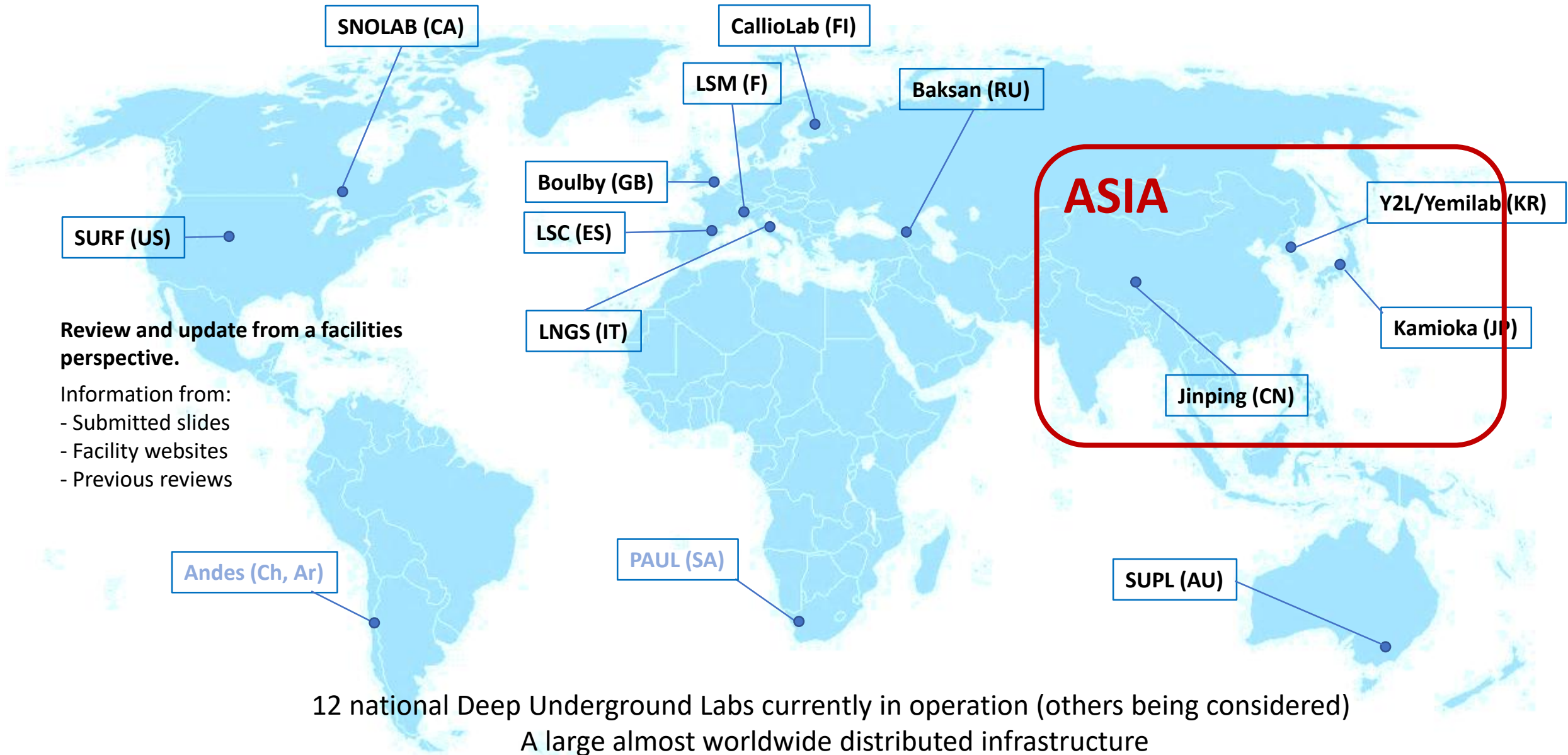
Other non infrastructure-based things can be important too

Local politics & science community: Solid host nation political and financial support, strong local science community involvement and support.

World Deep Underground Science Labs



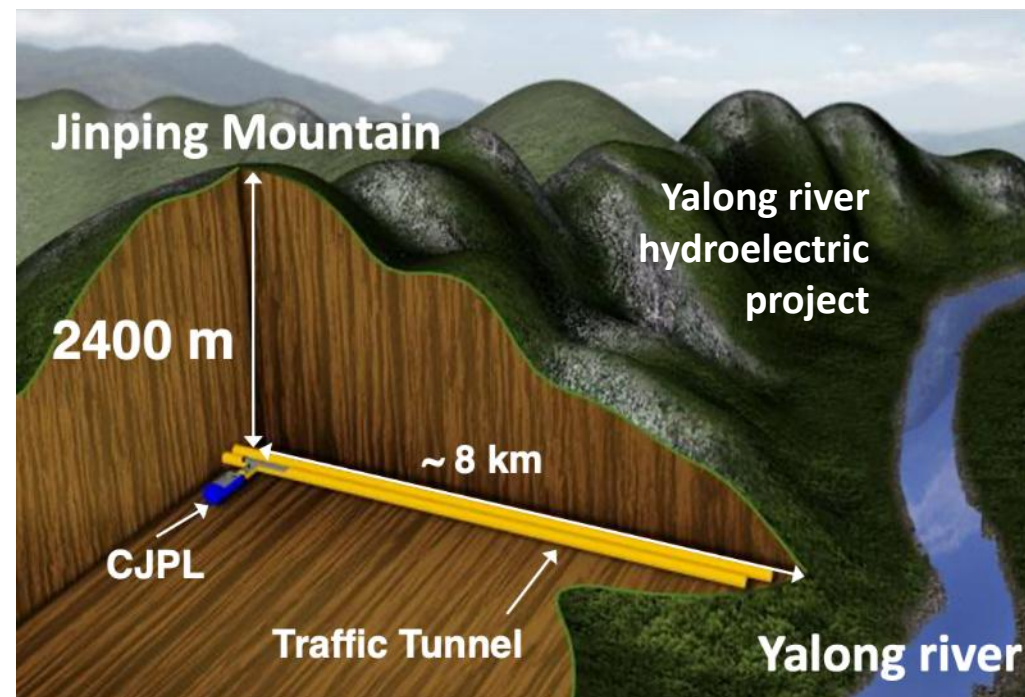
World Deep Underground Science Labs



China Jinping Underground Laboratory (CJPL)

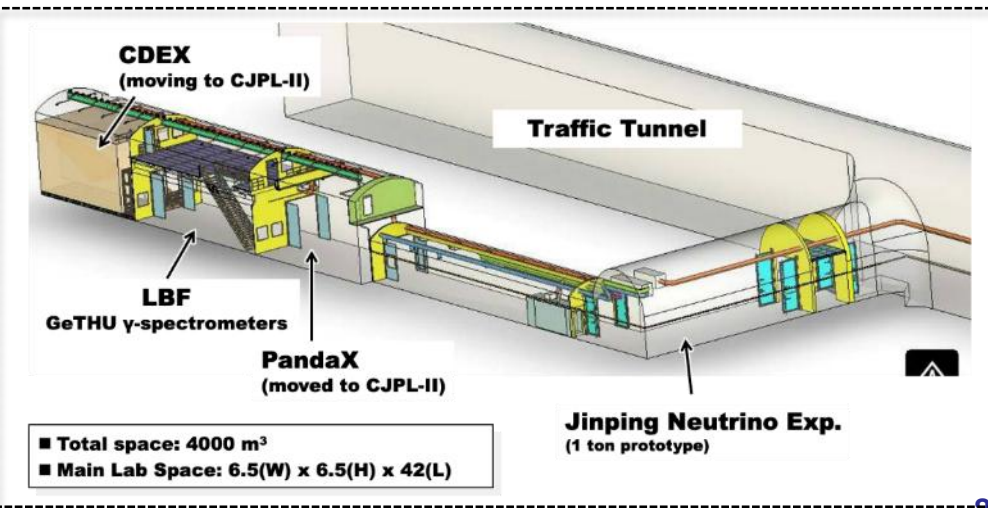
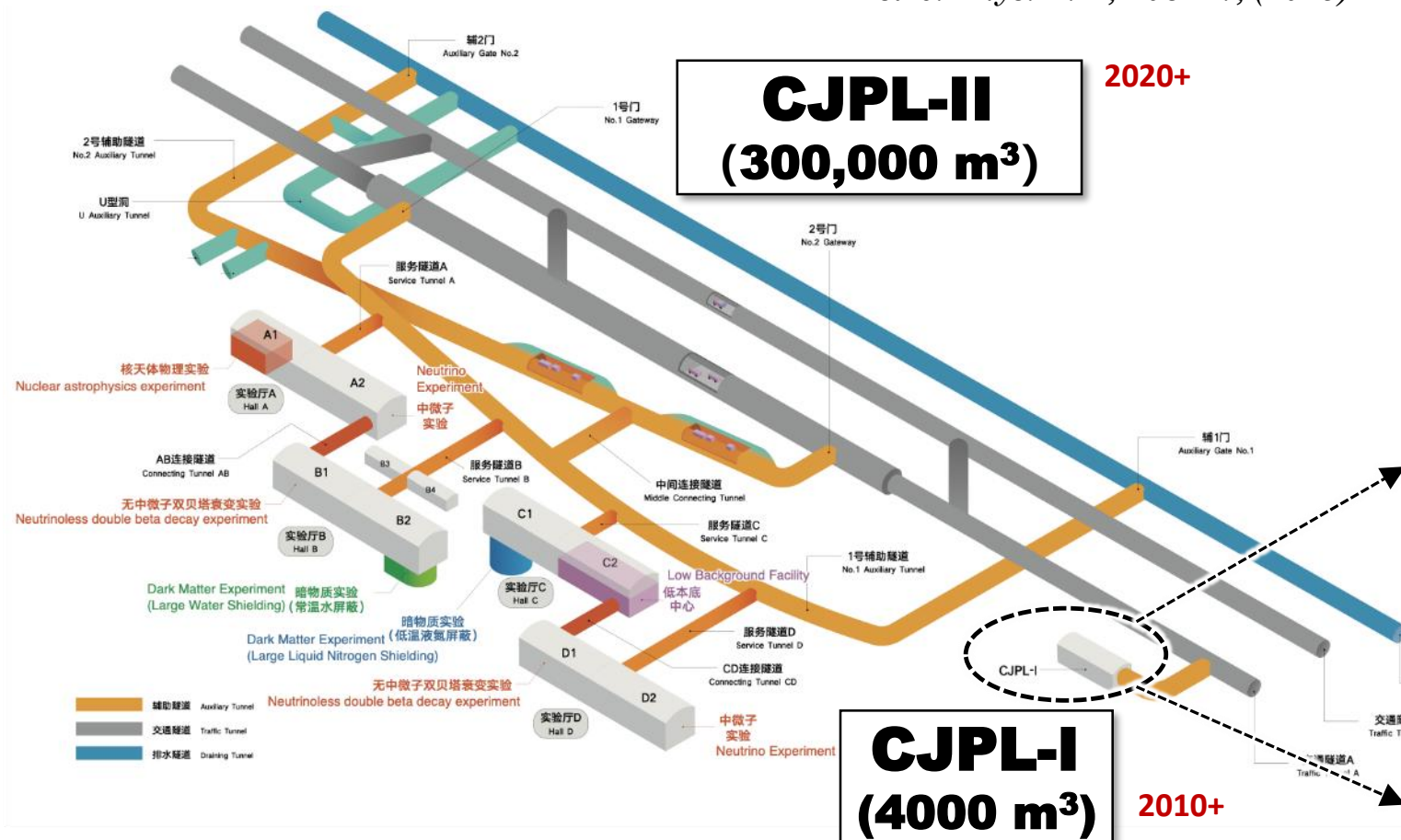
- ❑ Rock overburden 2400 m
- ❑ Muon flux $3.03 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$
- ❑ Experimental space $>330,000 \text{ m}^3$

Astro. Phys. 172, 103147, (2025)



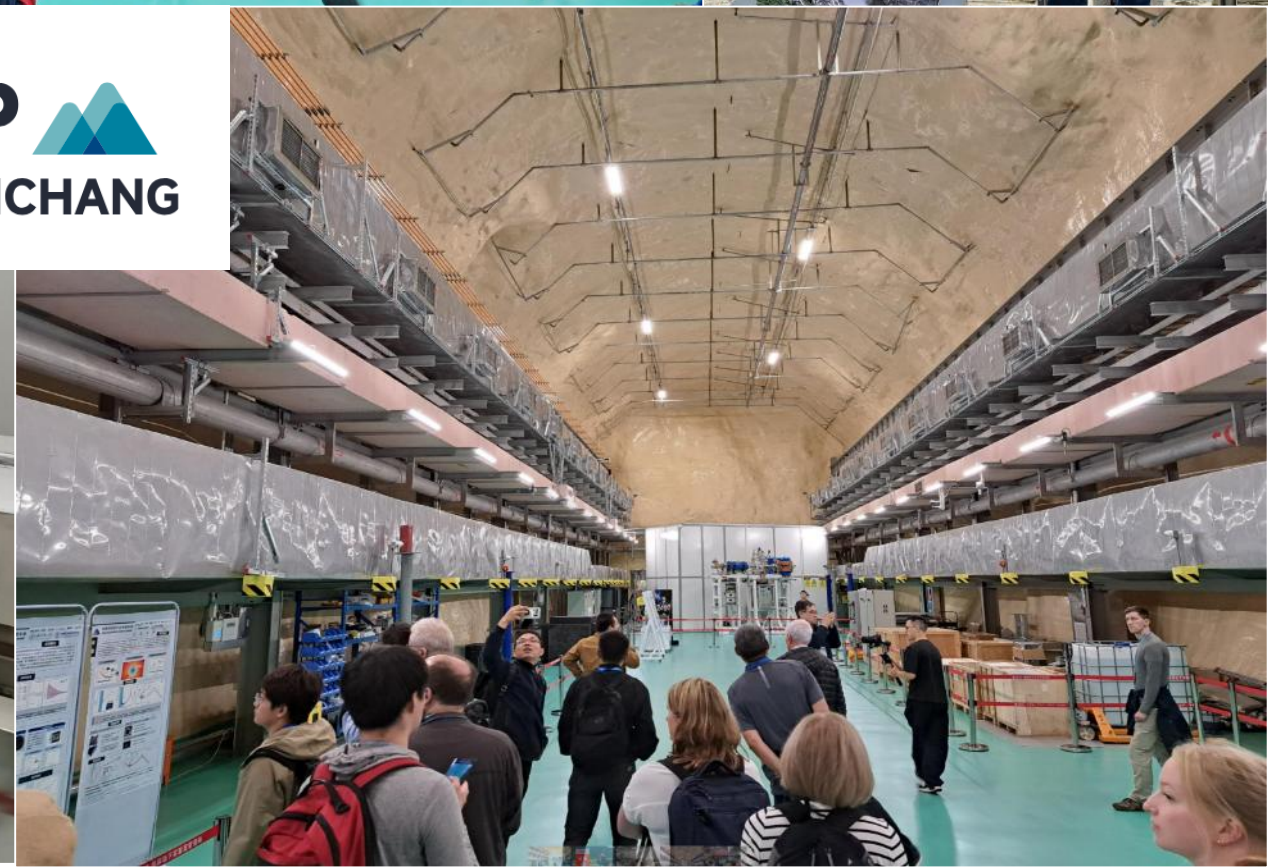
CJPL-II
(300,000 m³)

2020+



live.com - To exit full screen, press **Esc**

锦屏大设施大型液氮恒温器
CJPL Large Scale Liquid Nitrogen Cryostat



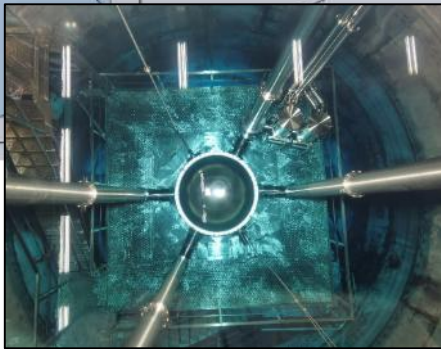
Large Shielding Facilities at CJPL-II

- ❑ **Large Water Shielding in B2-Hall**
- ❑ **For PandaX LXe-TPC experiment**

5500 m³ Water

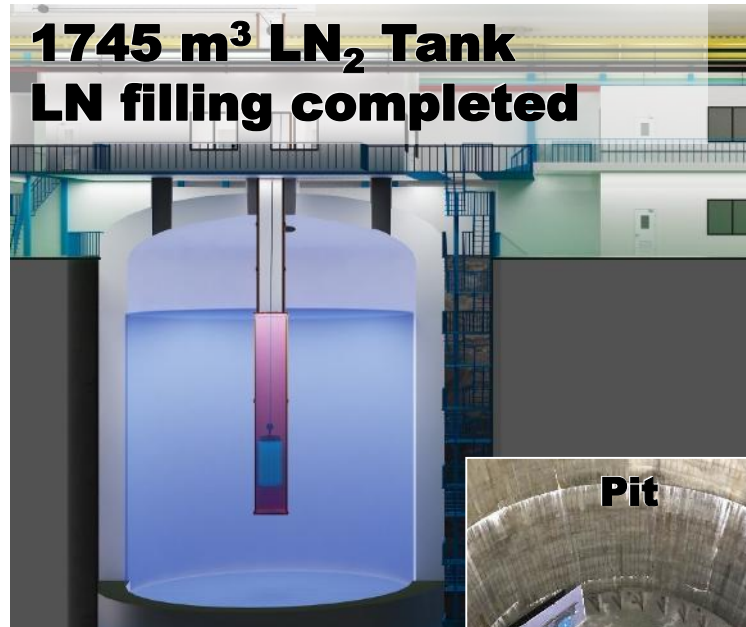


Look at the PandaX det.



- ❑ **Large LN₂ Shielding in C1-Hall**
- ❑ **For CDEX HPGe DM & 0νββ experiment**

**1745 m³ LN₂ Tank
LN filling completed**



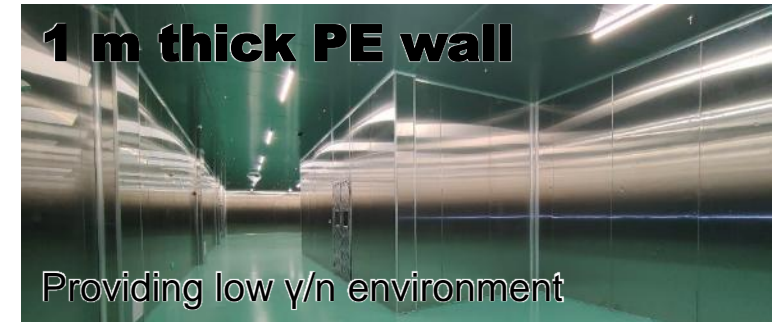
Top view of the Tank



Pit

- ❑ **Large PE Shielding Room in C2-Hall**
- ❑ **Total 16 low-BG HPGe γ spectrometers**

1 m thick PE wall



Providing low γ/n environment

GeTHU



ARGUS



GeTHU

➤ **15 low-BG γ spectrometers**

ARGUS

➤ **Ultralow-BG γ spectrometer**

Research Activities at CJPL-II

JUNA

Jinping Underground Nuclear
Astrophysics experiment

PandaX

DM & $0\nu\beta\beta$ via LXe-TPC

*PandaX-4T since 2020
PandaX-20T to come soon*

CDEX – 300/1T to come soon

CDEX

DM & $0\nu\beta\beta$ via HPGe

GeoDEX

Deep underground geologic time
variation in-situ detector experiment

JNE

Jinping Neutrino Program

And more: CUPID-CJPL

Mo-100 $0\nu\beta\beta$

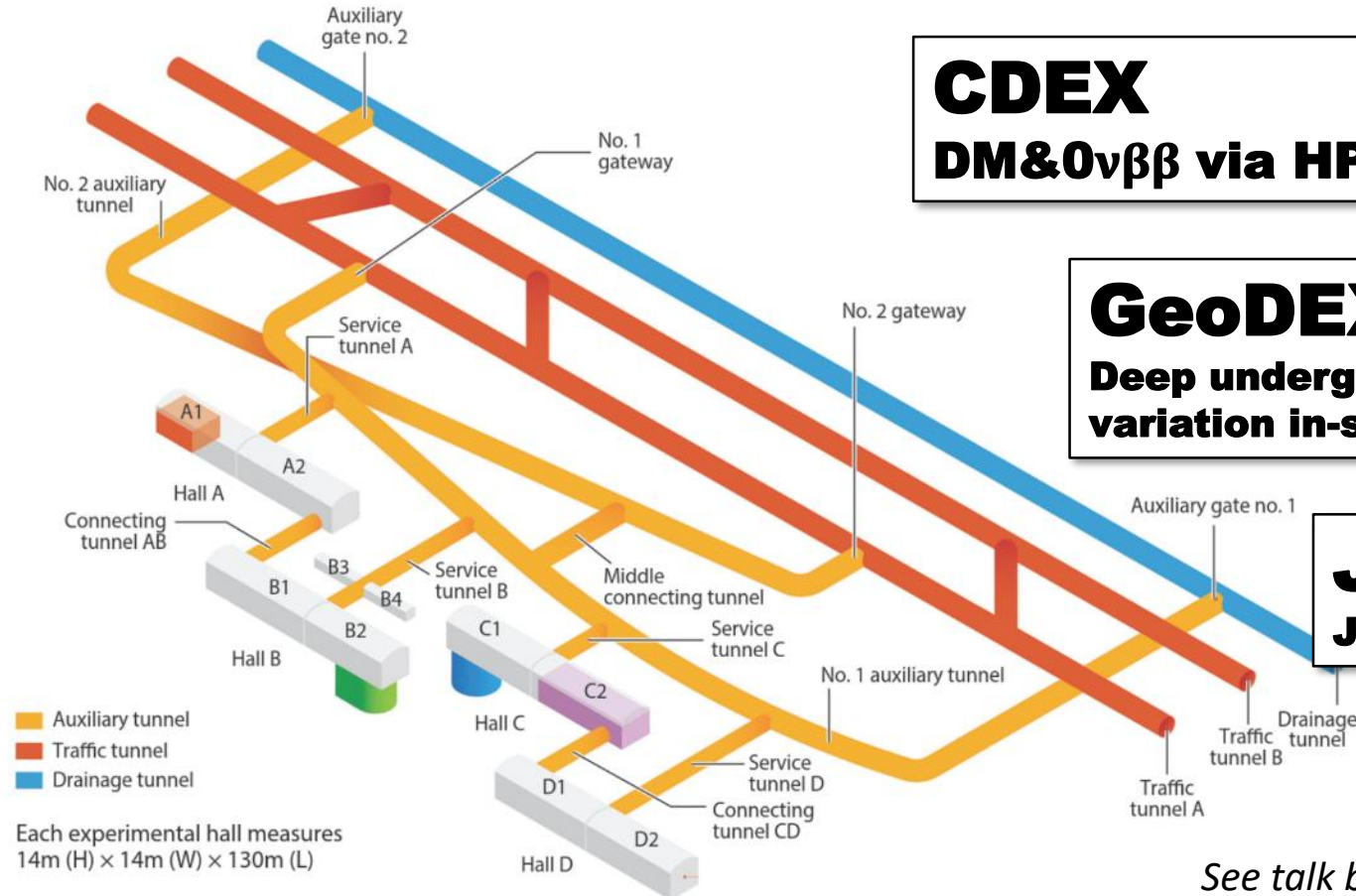
NvDEX

Se-86 $0\nu\beta\beta$

ICSER

Integrated Circuit Soft
Error Research

■■■



See talk by Zeng Zhi – Monday TAUP 25

CJPL welcomes researchers worldwide to submit proposals!



Underground labs in Japan

Mt. Ikeno-yama
(Mozumi mine)

1000 m

Mt. Nijugo-yama
(Tochibora mine)

8 km

600 m

Hyper-K

Rail Mountain Bicycle
Gattan Go!! Mt. Urushi
レールマウンテンバイク
Gattan Go!! 平台コース

Suimu Shrine
水無神社

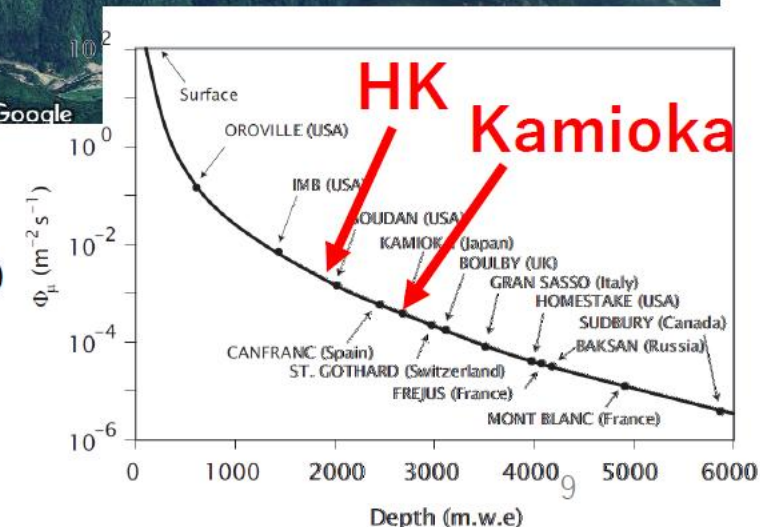
ニッ屋トンネル

Google



- Kamioka underground (Mozumi mine)
 - 1000 m overburden
 - Super-K, KamLAND, EGADS, CADLES, NEWAGE, XMASS, KAGRA, CLIO
- Tochibora mine
 - 600 m overburden
 - 8 km far from Mozumi mine.
 - It is now being excavated.

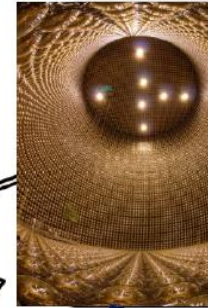
From Takeda, LRT-24



Kamioka underground facilities (Mozumi mine)

KamLAND (Tohoku Univ.)

- 1 kton liquid scintillator detector.
- Reactor, geo, low-energy astrophysical neutrinos, ^{136}Xe $0\nu\beta\beta$ decay.



Super-Kamiokande

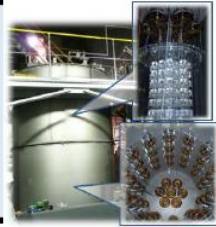
- 50 kton Gd-water Cherenkov detector.
- Atmospheric, solar, SN neutrinos, DSNB, proton decay, indirect DM searches, far detector for T2K.

Super-K 2025:

- Running with Gd doping since 2020

CANDLES (Oosaka Univ.)

- CaF_2 scintillator.
- ^{48}Ca $0\nu\beta\beta$ decay.
- Low BG HPGe in Lab-D



XMASS

- 1 ton single-phase LXe detector.
- Direct DM searches.
- Data taking was completed.



Others in Lab-C

- Two ultra-low BG HPGe

Lab-I

- Three HPGe
- Low-BG α counter
- ICP-MS

AICHAM

Clean room in storage

- ICP-MS (Agilent7900)

EGADS

- 200 ton Gd-water test tank

Lab-E

Lab-C

Lab-I

Lab-B

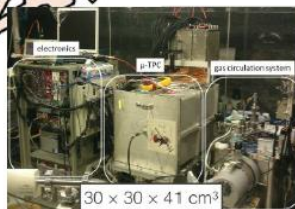
Lab-G

Atotsu entrance

100 m

NEWAGE (Kobe Univ.)

- Low pressure TPC+MPGD
- Direction-sensitive direct DM searches.



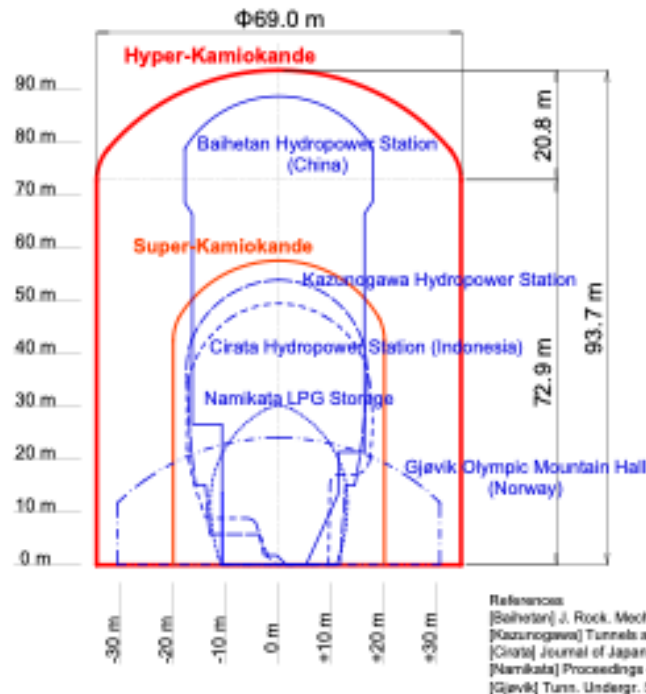
CLIO (Gravitational-wave)

- 100 m \times 100 m prototype.
- Geophysics
- 100 m \times 2 laser strain meter.

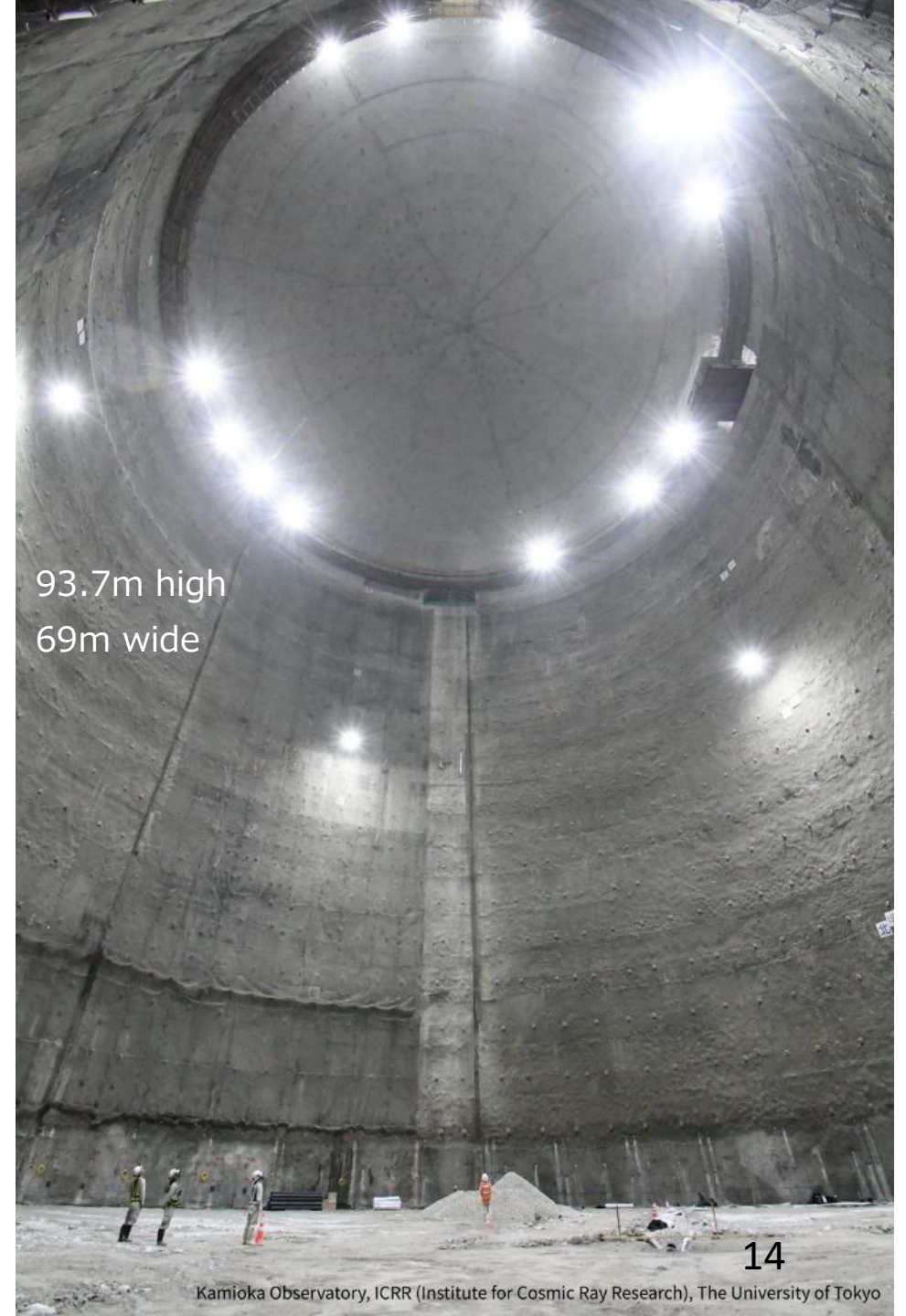
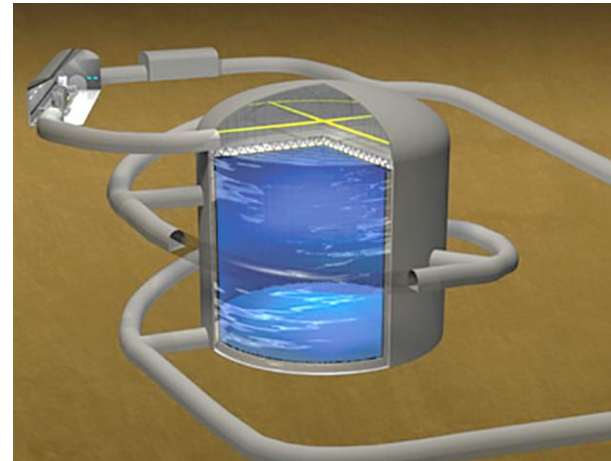
Excavation of the Massive Cavern for Hyper-Kamiokande

Completed on July 31, 2025

- <https://www.icrr.u-tokyo.ac.jp/en/news/16770/>
- The project reached a major milestone!
- Full-scale operations are scheduled to begin in 2028.



Cross-sectional comparison of major underground rock caverns in Japan and abroad

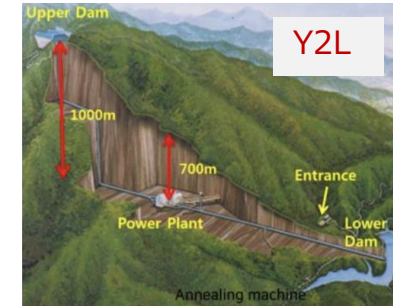


Underground labs in Korea



● Yangyang Underground Laboratory (Y2L): (2003+)

- Yangyang Pumped Storage Power plant
- 700 m overburden
- ~150 km from Seoul

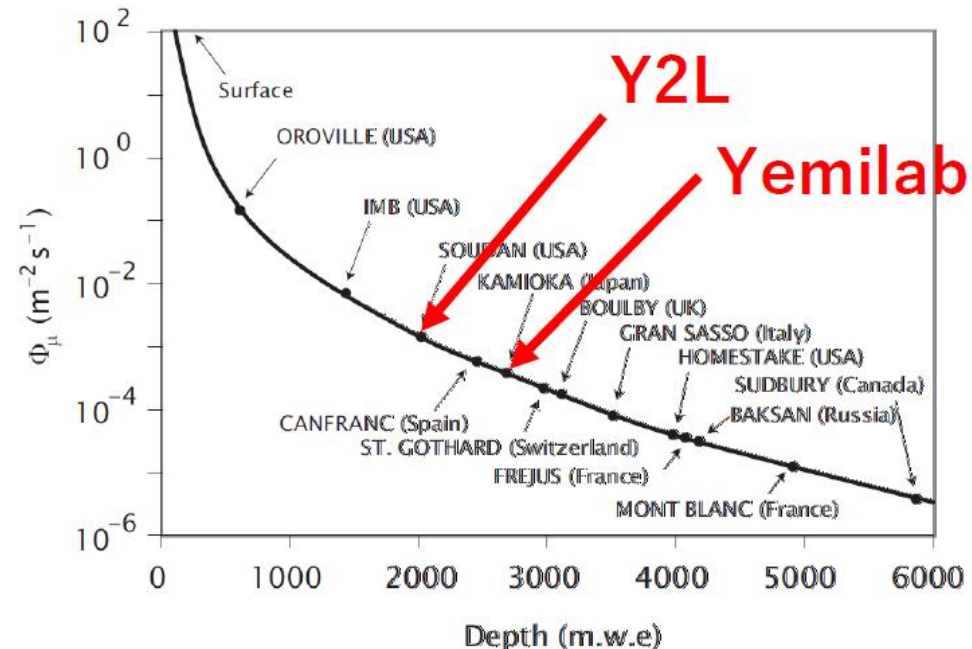


Since 2003

- KIMS (DM)
- COSINE (DM)
- AMoRE (0vBB)
- HPGe

● Yemilab: (2022+)

- Handeok mine
- 1,000 m overburden
- ~150 km from IBS-HQ



Mu-on flux

Yemilab

AMoRE-II @
Yemilab

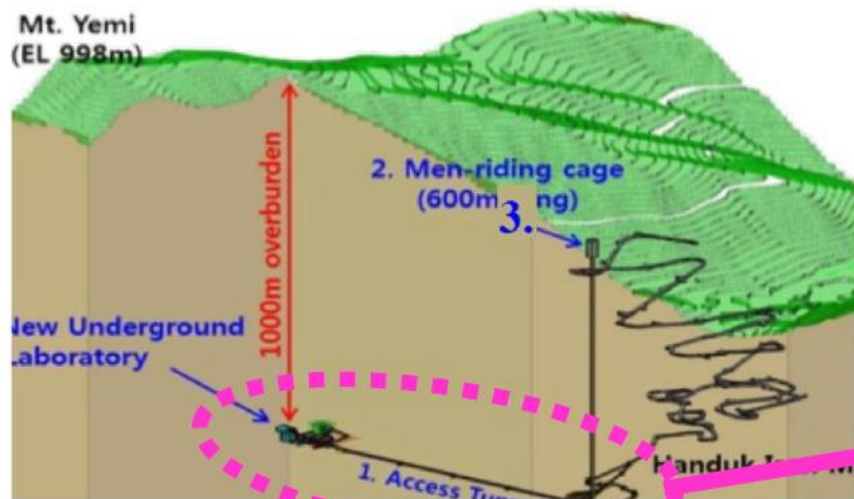


- Completed in September 2022.
- 1,000 m depth and 3,000 m³ exclusive experimental area
- Y2L facilities are being relocated to YemiLab.
- Large halls for **AMoRE-II**, LSC w/cyclotron/accelerator and purification.
- Ladder halls for **COSINE**, HPGe/Alpha, Refuge, etc.

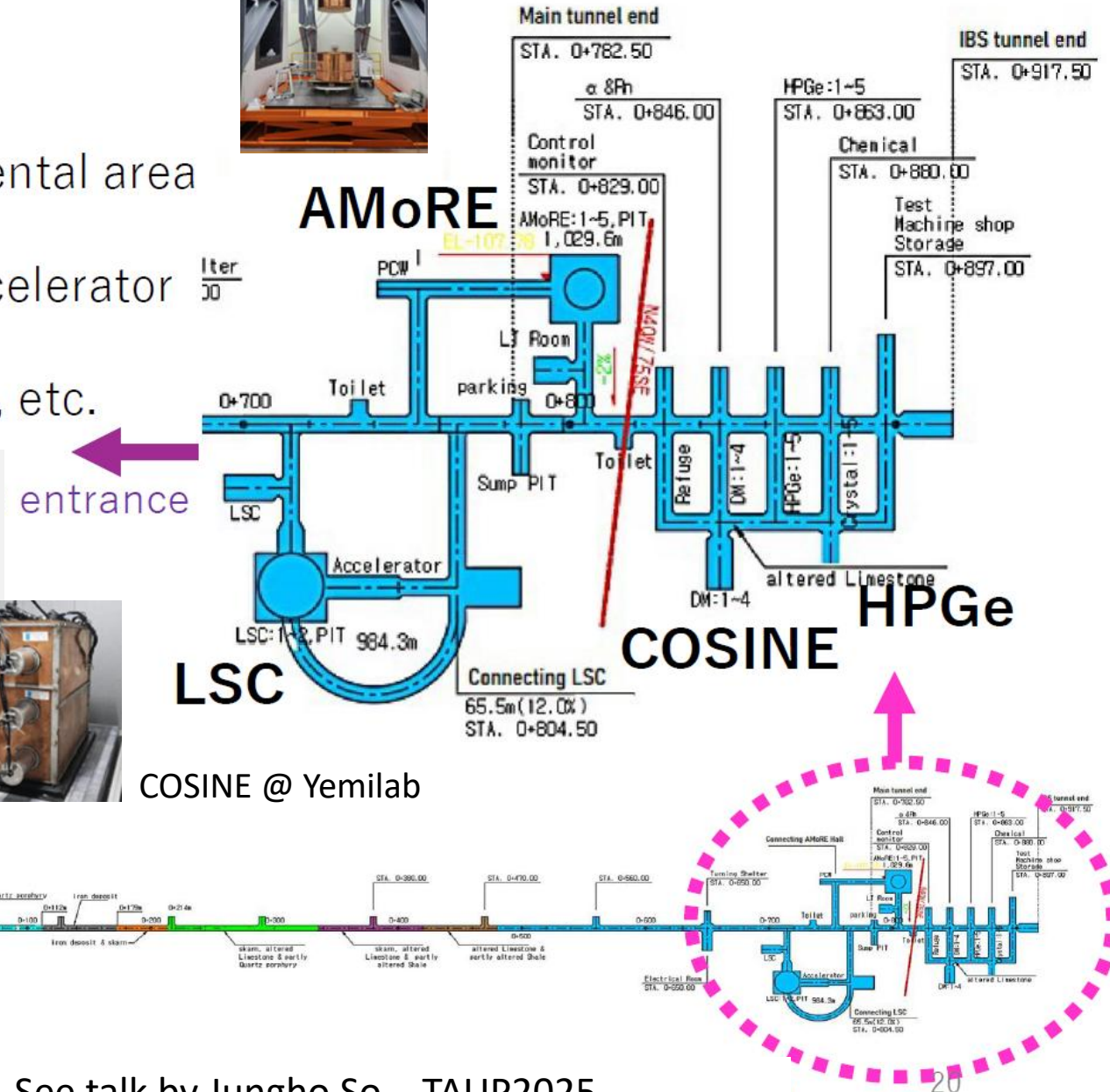
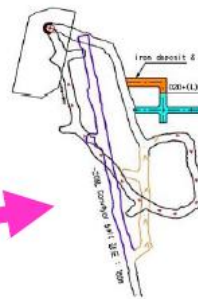
2025: Yemilab now fully operational.

AMoRE-II & COSINE-100 installed & preparing for operation.

Other science to come (Neutrinos, Geology, Biology ++)



COSINE @ Yemilab



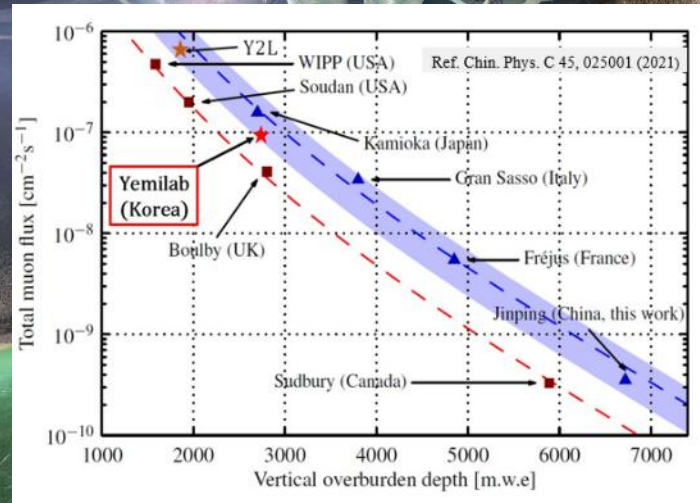
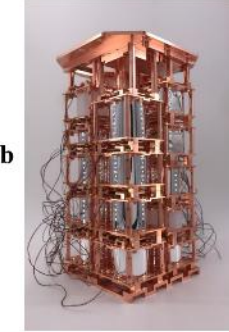
See talk by Jungho So – TAUP2025

Yemilab

CENTER FOR
UNDERGROUND PHYSICS

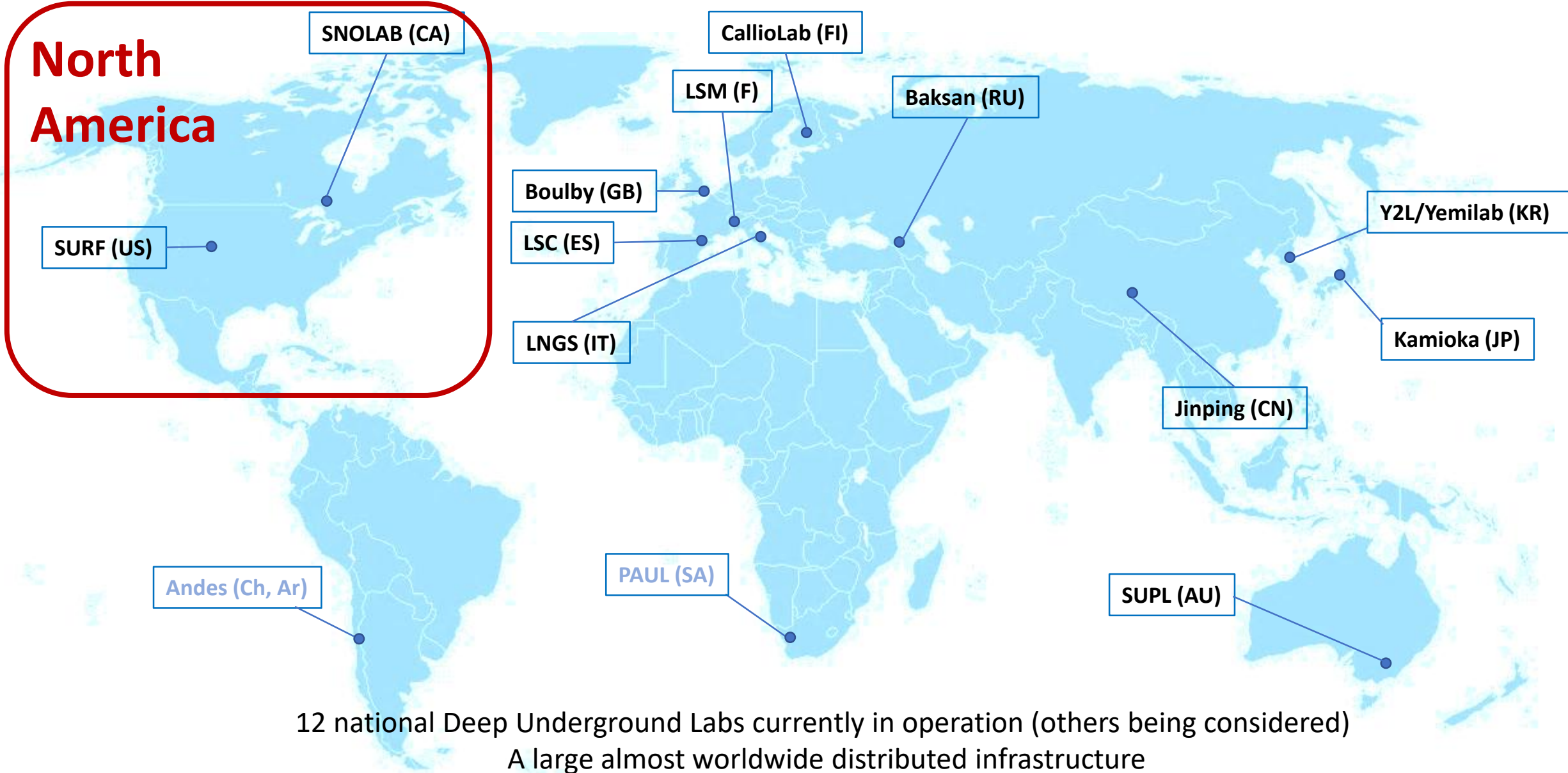
Nuclear and Particle Physics:

- **WIMP: COSINE-100U @ Yemilab**
 - Lower temperature (-30°C)
 - Experiment will begin in 2025.
- **$0\nu\text{DBD}$: AMoRE-II @ Yemilab**
 - Large cryostat is under testing.
 - Experiment will begin in 2026.



AMoRE Hall

World Deep Underground Science Labs

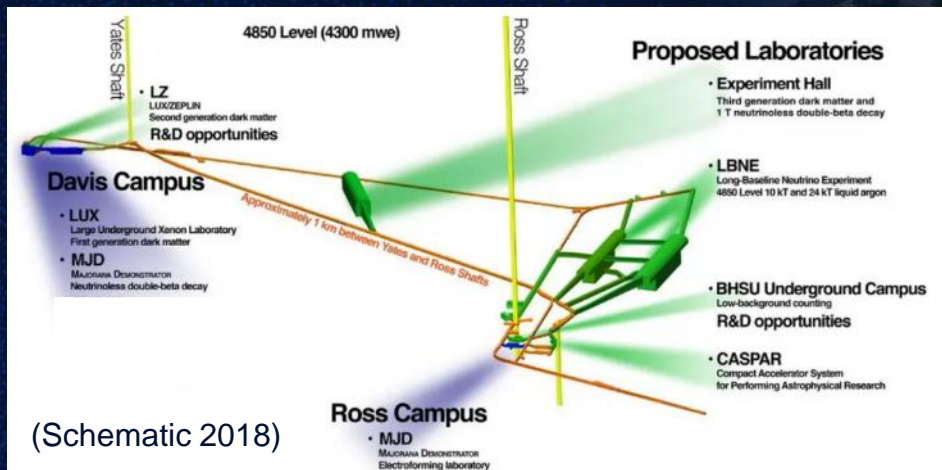




SANFORD UNDERGROUND RESEARCH FACILITY

Sanford Underground
Research Facility (SURF)
Homestake mine, Lead, South
Dakota, USA

SURF Overview



Depth - 4850L (1480 m, 4300 mwe)

Davis Campus (1018 m² / 4633 m³)

Ross Campus (920 m² / 3144 m³)

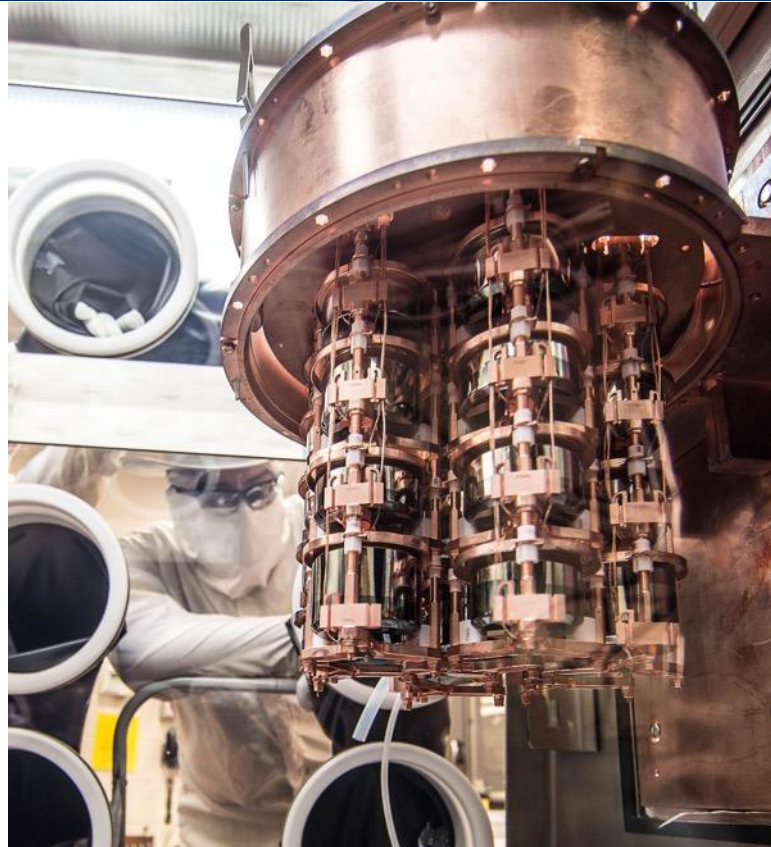
SURF Science Program – Current Physics Highlights

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
- Final Ge result July 2022, Ta-180 decay search first results June 2023



CASPAR

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

Long-Baseline Neutrino Facility (LBNF)

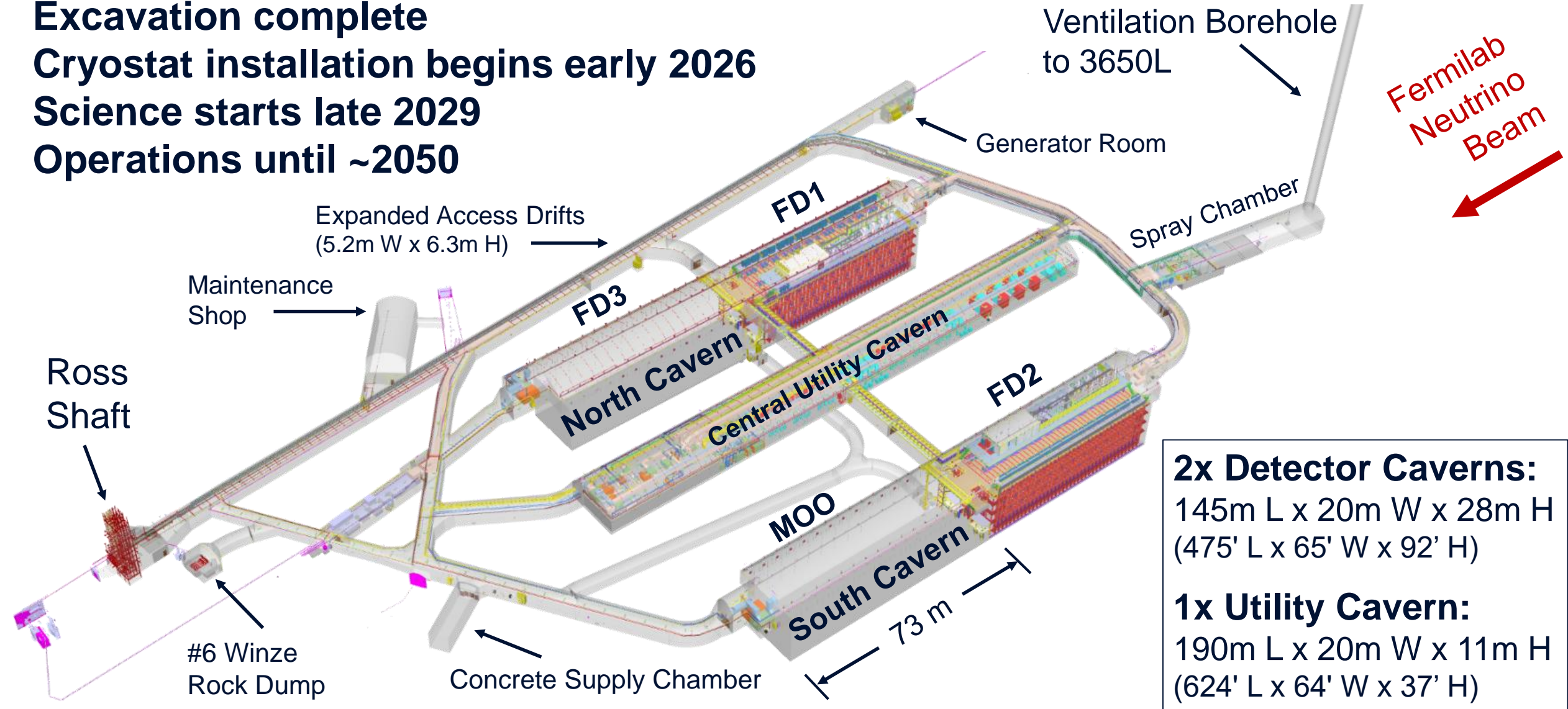
LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Excavation complete

Cryostat installation begins early 2026

Science starts late 2029

Operations until ~2050



LBNF North Cavern



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

Proposed expanded
area 'on a timeframe
of next generation
experiments
(~2030)'

P5 recommendations to DOE/NSF (Dec 2023):

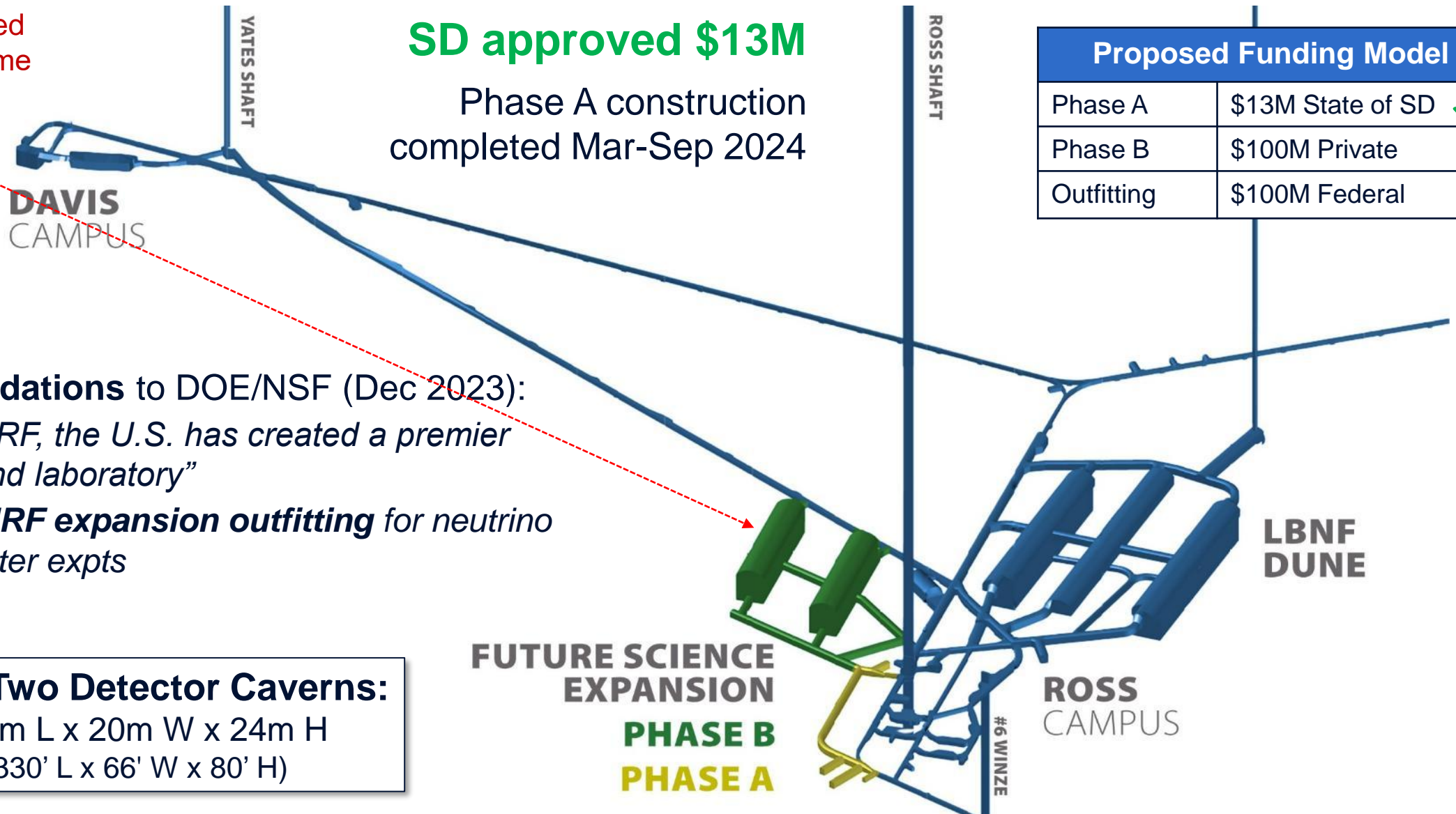
- “With SURF, the U.S. has created a premier underground laboratory”
- **Fund SURF expansion outfitting** for neutrino & dark matter expts

Up to Two Detector Caverns:

100m L x 20m W x 24m H
(330' L x 66' W x 80' H)

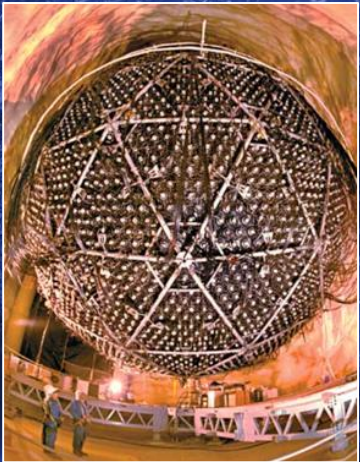
**FUTURE SCIENCE
EXPANSION**

PHASE B
PHASE A



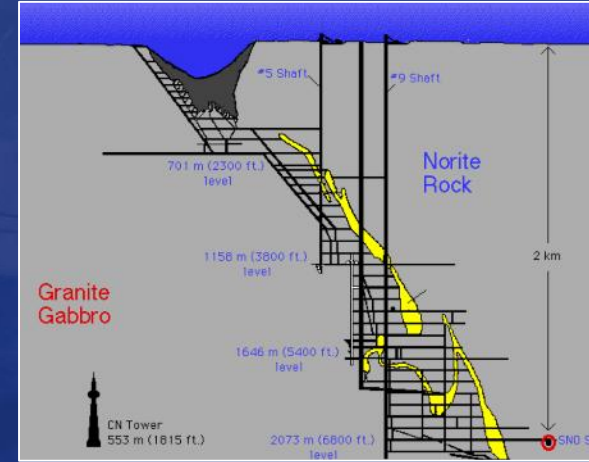


Creighton mine, Sudbury
Ontario



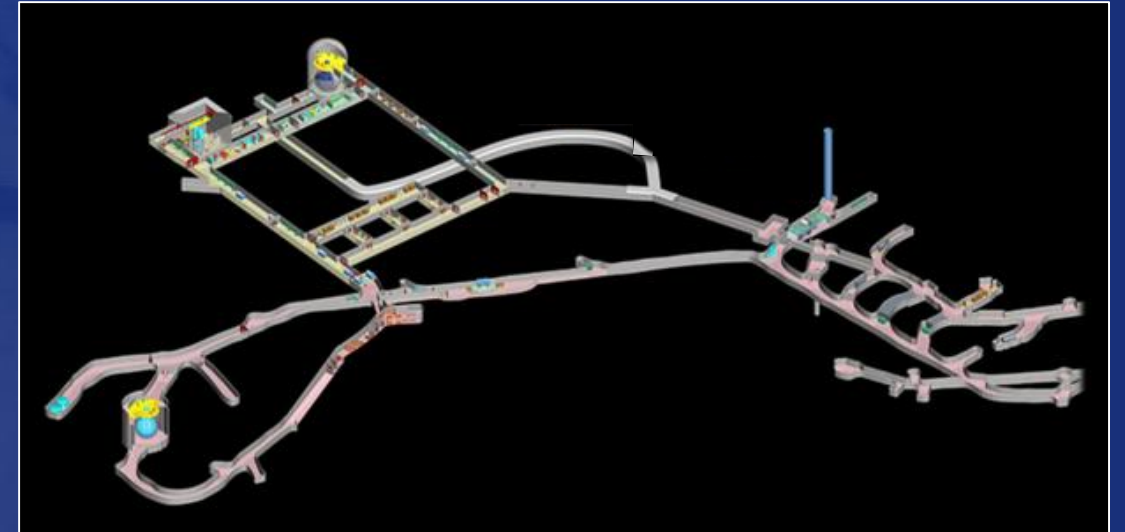
SNO, SNO+
and more...

Depth 2070m (6800mwe)
Volume 37,241m³



SNOLAB Status Update

Deep Underground Science Laboratory
Vale's Creighton mine, Sudbury
Northern Ontario, Canada



SNOLAB Science Program Broad & Multidisciplinary

Science programme goals:

1) Increase our understanding of the particles and forces that have shaped the universe.

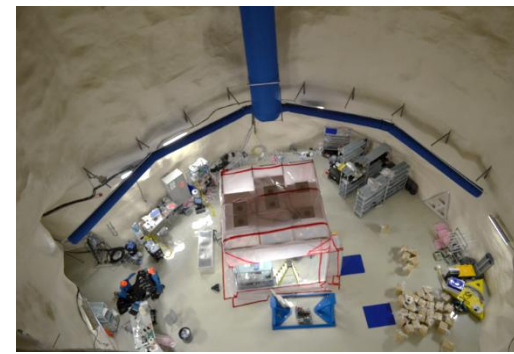
- What is the nature of dark matter?
- What is the nature of the neutrino?

2) Collaborate in scientific research requiring deep underground facilities.

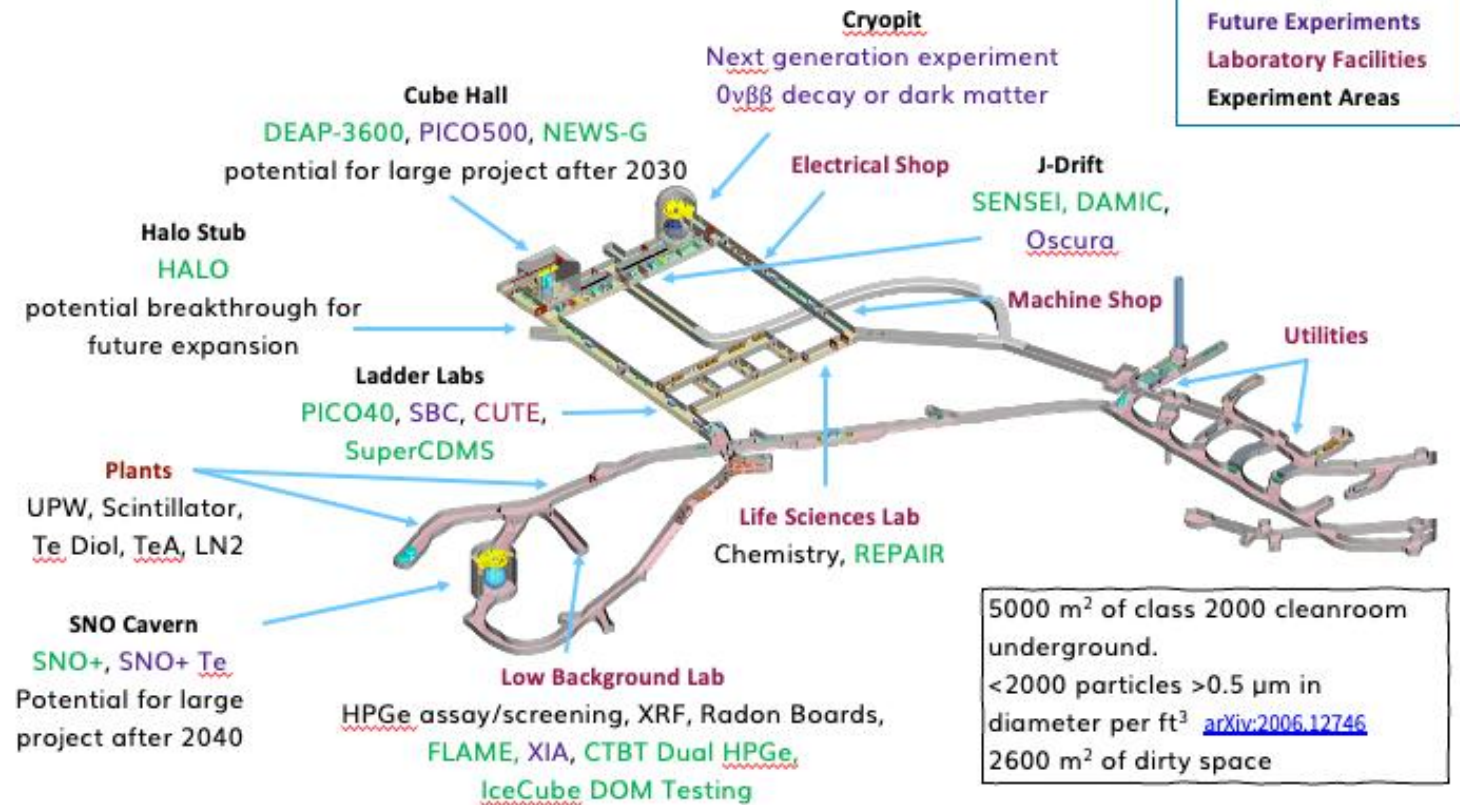
- Neutrino observatories (solar, supernovae, geo, reactor, etc.)
- Effects of radiation on biological systems
- Environmental monitoring (nuclear non-proliferation, etc.)

3) Pursue opportunities in emerging areas of underground science.

- Quantum technologies (quantum computing, sensors, and materials)



Free space
in Cryopit



4) Become an intellectual hub that fosters collaboration and connection.

(Jodie Cooley 2025)

Background Characterization Capabilities



Assay Capabilities

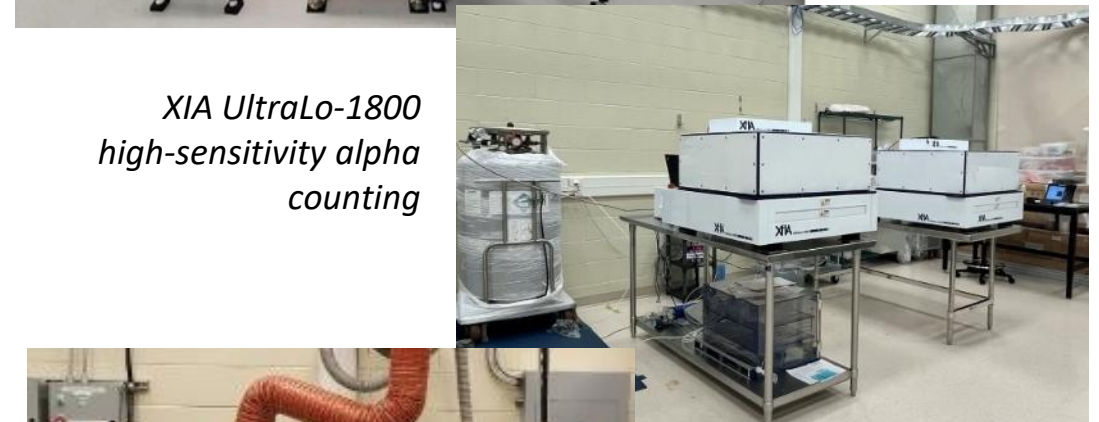
- **HPGe gamma counters**
 - Dual-detector system, well detector, multiple coaxial
- **Radon measurement systems**
 - Analysis of water, gases, and emanation from materials
 - Radon measured with Lucas cells (produced in house)
- **Alpha counting:**
 - XIA UltraLo-1800 and ORTEC Alpha Duo spectrometers
- **Inductively Coupled Plasma Mass Spectrometry**
 - ICP-MS instrument: Agilent 8900 ICP-QQQ
- **Radium assay of water/leachate**
 - HTiO and beta/alpha coincidence counting

Underground Background Measurements

- **Continuous radon monitoring:** DurrIDGE RAD7s
- **Neutrons:** Bubble Technology BDS System
- **Gammas:** NaI detectors
- **EMI:** RIGOL spectrum analyzer (9 kHz to 7.5 GHz)



*HPGe
gamma
counting*



*XIA UltraLo-1800
high-sensitivity alpha
counting*



*ICP-MS low-level
elemental analysis*

SNOLAB 15-Year Plan: Highlights



- New decision-making framework introduced in the 2024 Canadian federal budget to support Canadian Major Research Facilities (MRF). SNOLAB was named one of six research facilities included in the framework.
- CFI is assessing long-term capital and operational needs of each MRF.
- SNOLAB asked to provide detailed and reliable budget estimates for the next 15 years under three budget scenarios.
 1. Maintain current levels of operation
 2. Fully support the needs of the Canadian research community
 3. Increase global competitiveness.

Also considering expansion UNDERGROUND

New Building Feature	Scenario 1	Scenario 2	Scenario 3
Outside the Vale control zone	✓	✓	✓
Large auditorium ¹	✓	✓	✓
Training space	✓	✓	✓
Additional surface lab space	Addition equivalent to size of current space	Addition 50% larger than current space	Addition 50% larger than current space
Additional office and collaboration space	Addition equivalent to size of current space (3 floors)	Expansion to 5 floors of such space	Expansion to 5 floors of such space
Warehouse	✗	✓	✓
Visitor Centre	✗	✓	✓
Food preparation space (kitchenette)	✗	✓	✓
Hostel	✗	✗	✓
Day Care (on-site)	✗	✗	✓
Cafeteria (on-site)	✗	✗	✓

Underground expansion?

X

✓

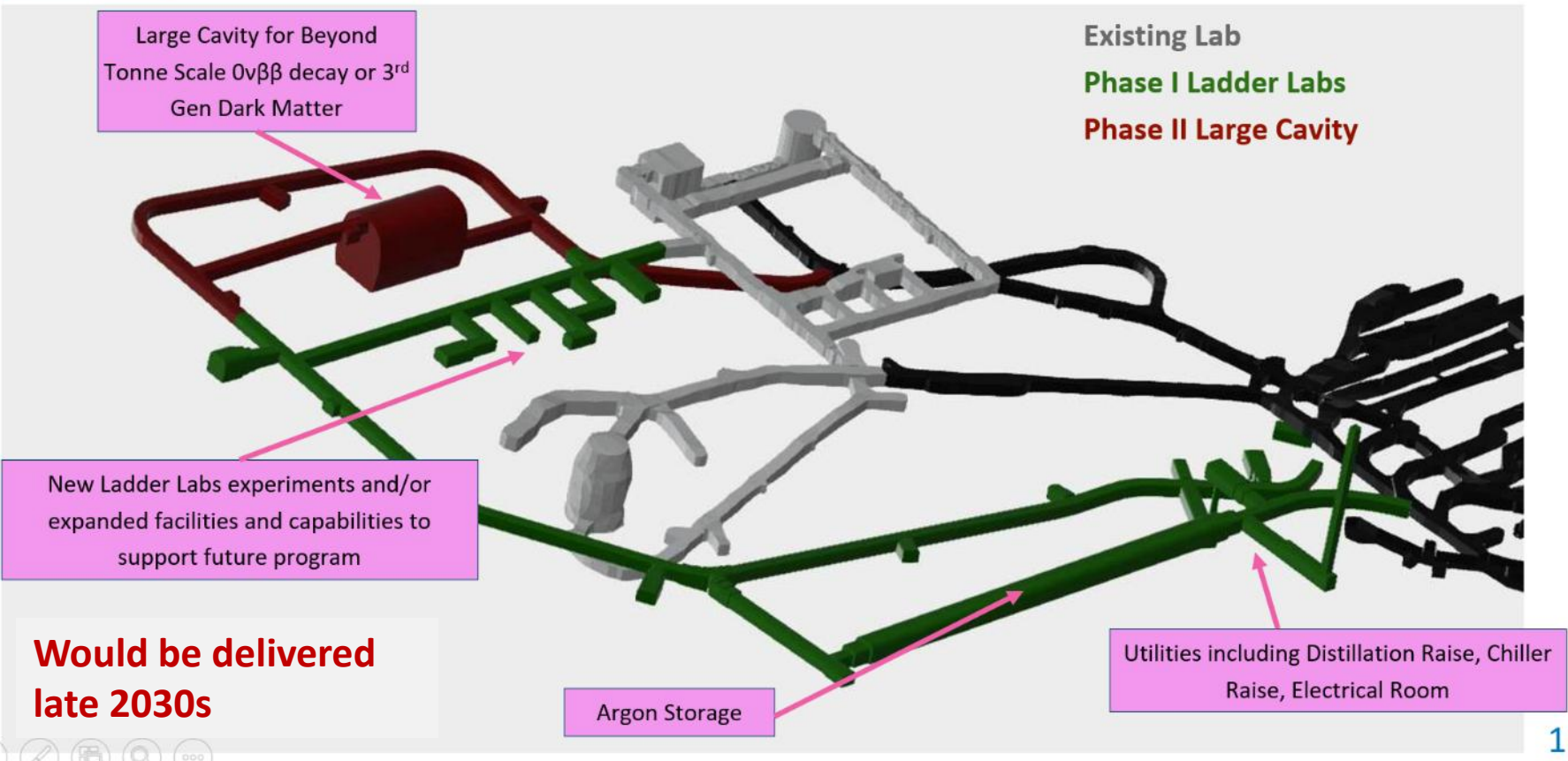
✓

SNOLAB 15-Year Plan: Highlights



- New decision framework for 2024 Canada Major Research named on decision framework.
- CFI is assessing needs of each research program.
- SNOLAB asking for budget estimates for budget scenarios:
 1. Main research program
 2. Full research program
 3. Increased research program

Scenario 2 & 3: New Underground Lab Space



Scenario 3



Addition 50% larger than current space

Expansion to 5 floors of such space



1

Also considering expansion UNDERGROUND

Criteria (on-site)

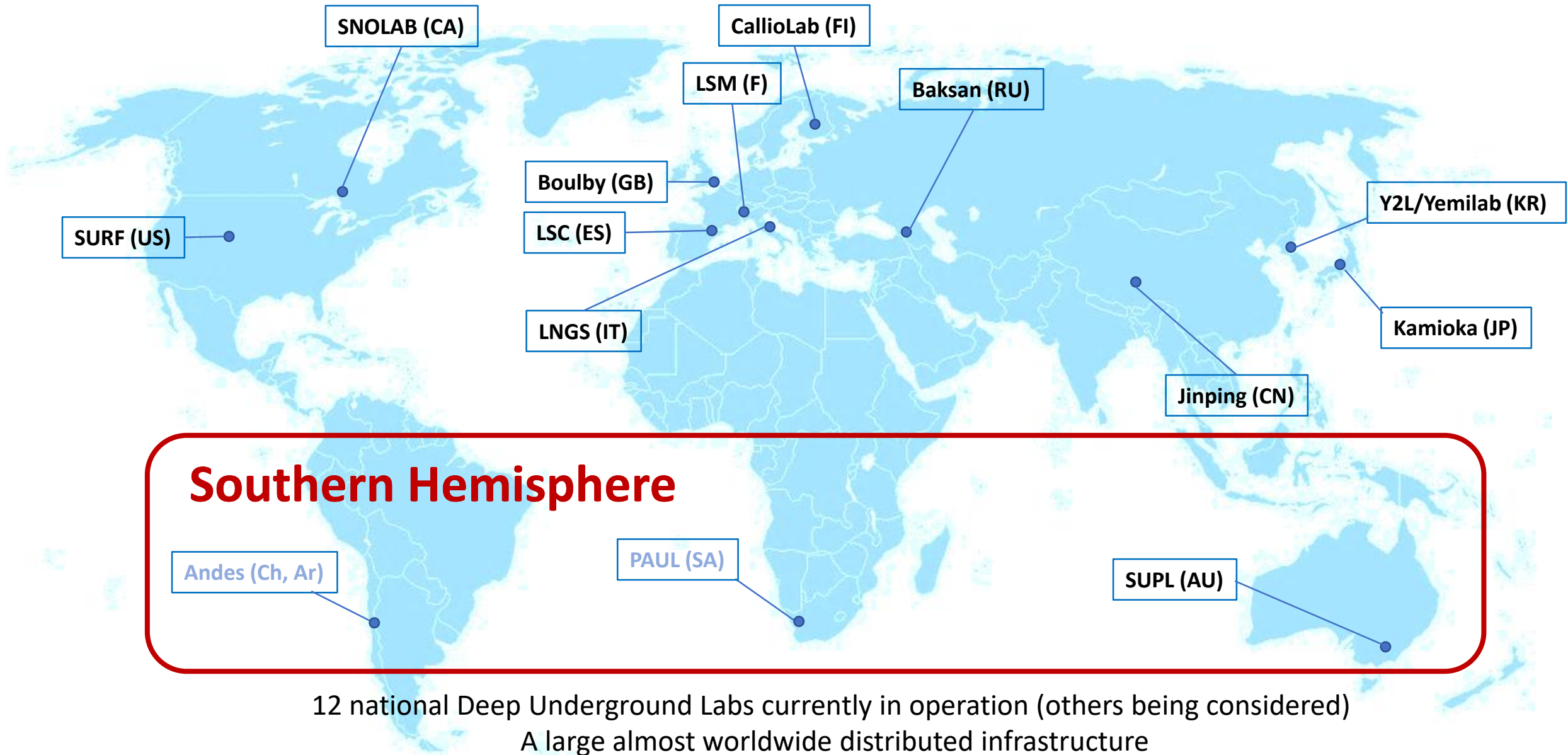
Underground expansion?

X

✓

✓

World Deep Underground Science Labs



Stawell Underground Physics Laboratory

- **Operational** since October 2023.
- **Located** within Stawell Gold Mines, operational mine ~2.5 hours west of Melbourne, Victoria, Australia.
- **Research Space:** 260m² / 2500m³
- **Radon:** Limited access to 10 Bq/m³ from a surface air line.

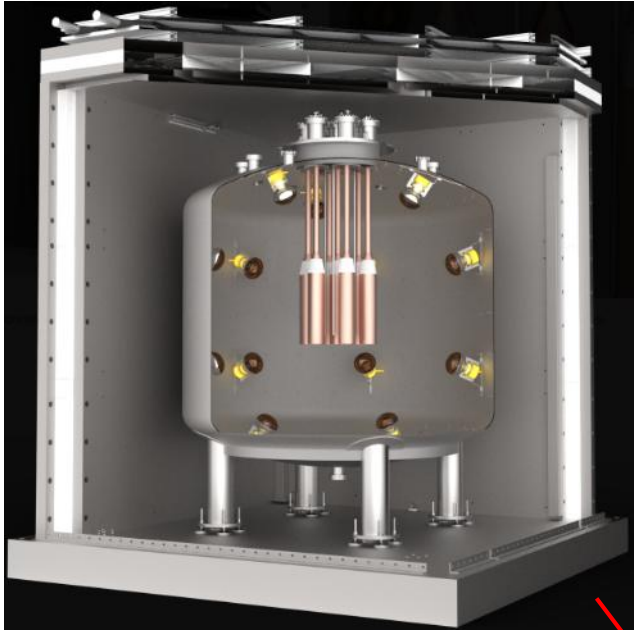
↓	Depth 1025m rock over burden	☀	M.W.E. 2900
💧	Relative Humidity 40-70%	🌡	Temperature 21°C +/- 2
⚛	Average radon concentration 450 Bq/m ³	🎯	Total muon flux 3.6x10 ⁻⁸ /cm ² /s
🔑	Type of access Helical drive-in via operational mine		



Figure 1 – Stawell's location relative to key capital cities



Stawell Underground Physics Laboratory



SABRE South

Direct detection dark matter experiment.
Installation and construction phase underway.
Commissioned 2026.



CELLAR

Cryogenic Facility
Proteox MX dilution fridge
Operational 2026.

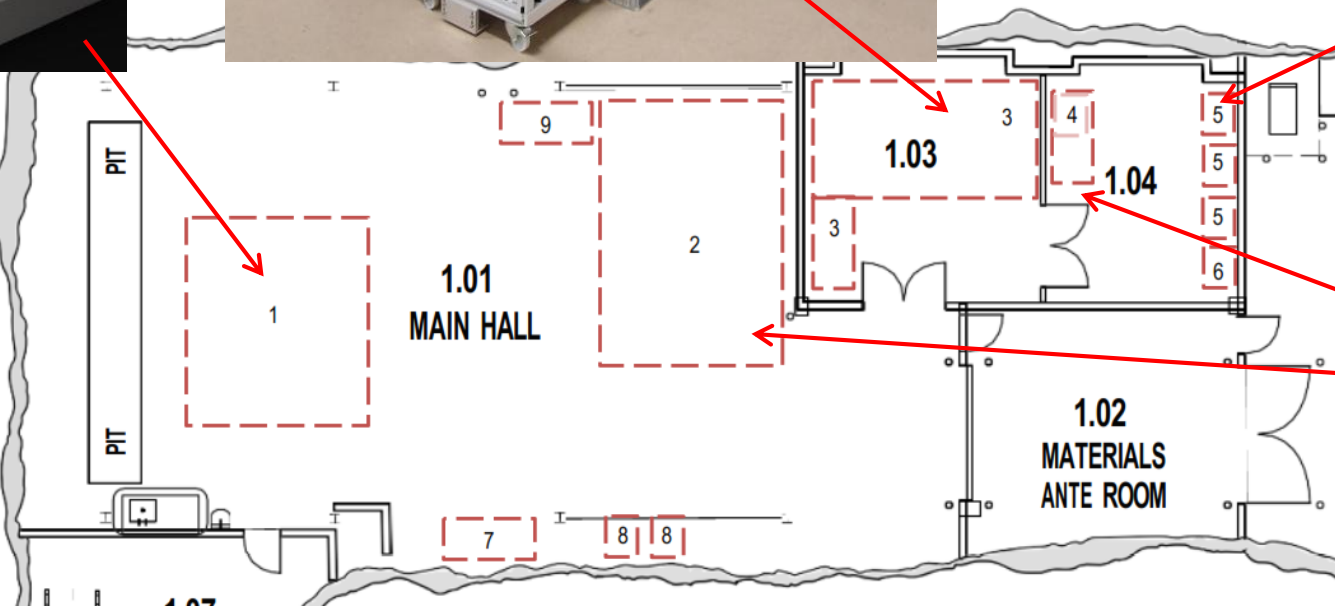
Research Program:

- Quantum technologies
- Low mass dark matter
- Gravitational waves



Materials Screening

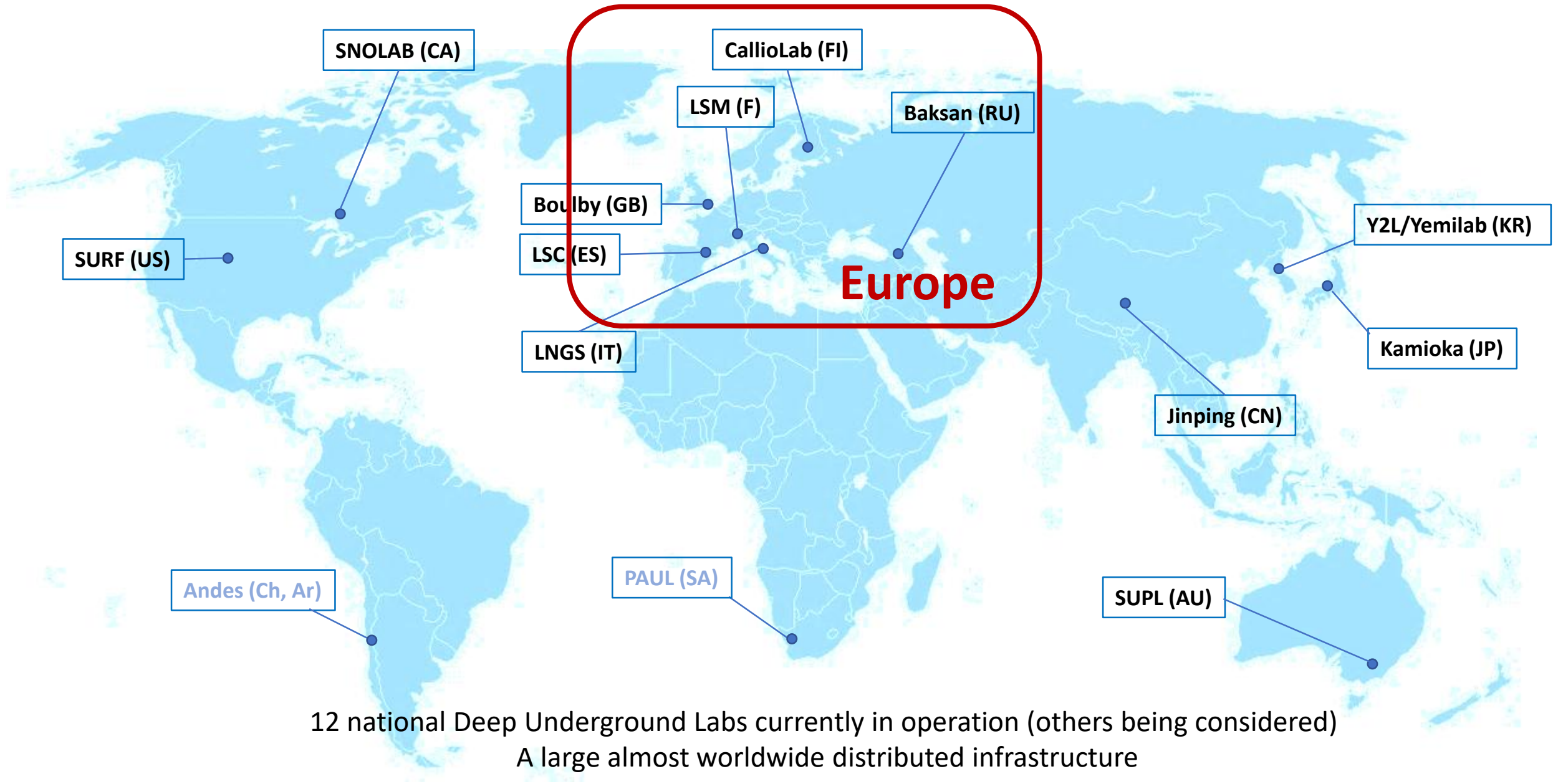
Future proposed capability.



Future Proposals

Radiation biology facilities.
Clean room 20m².

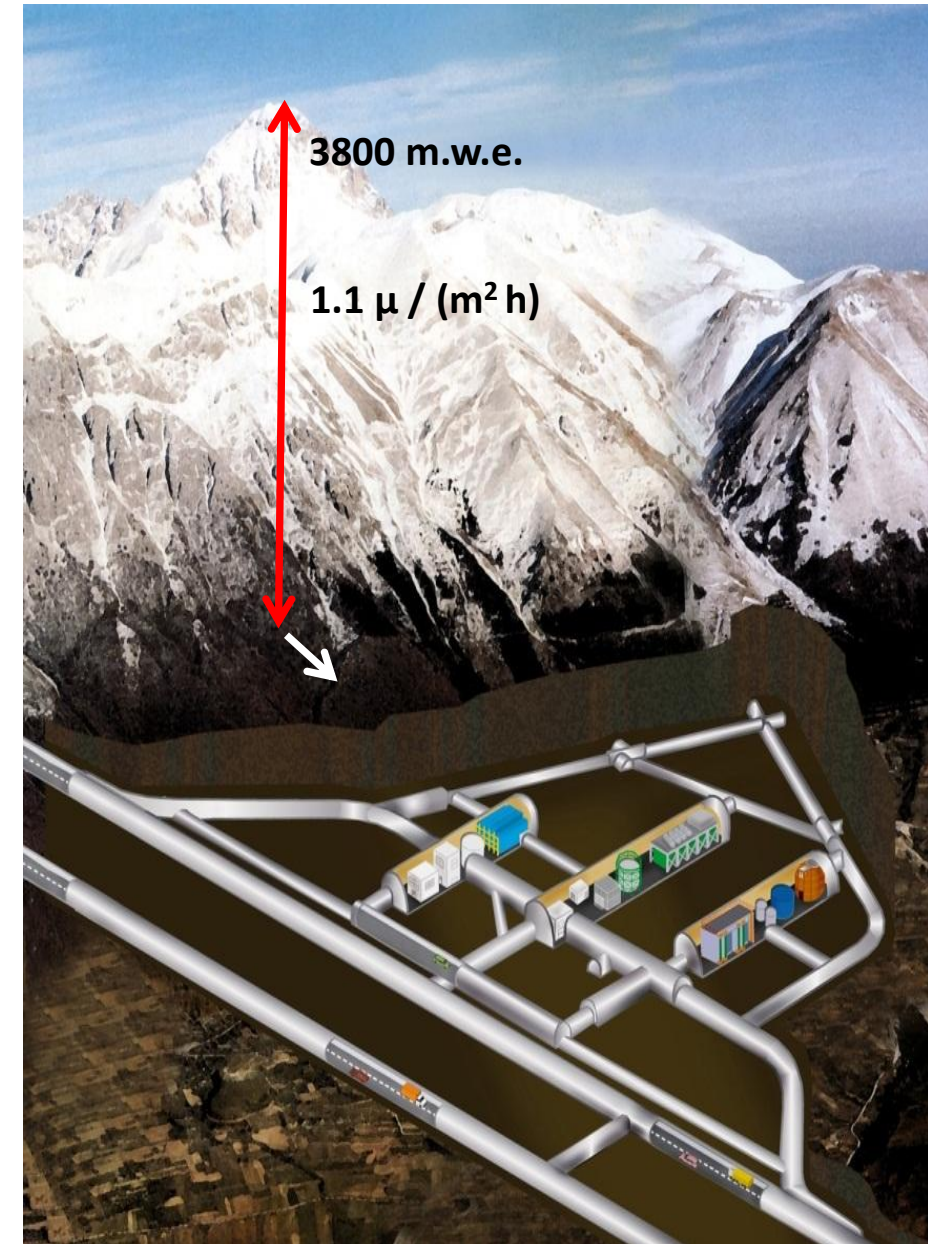
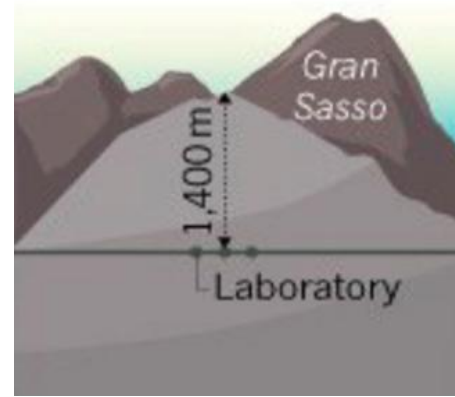
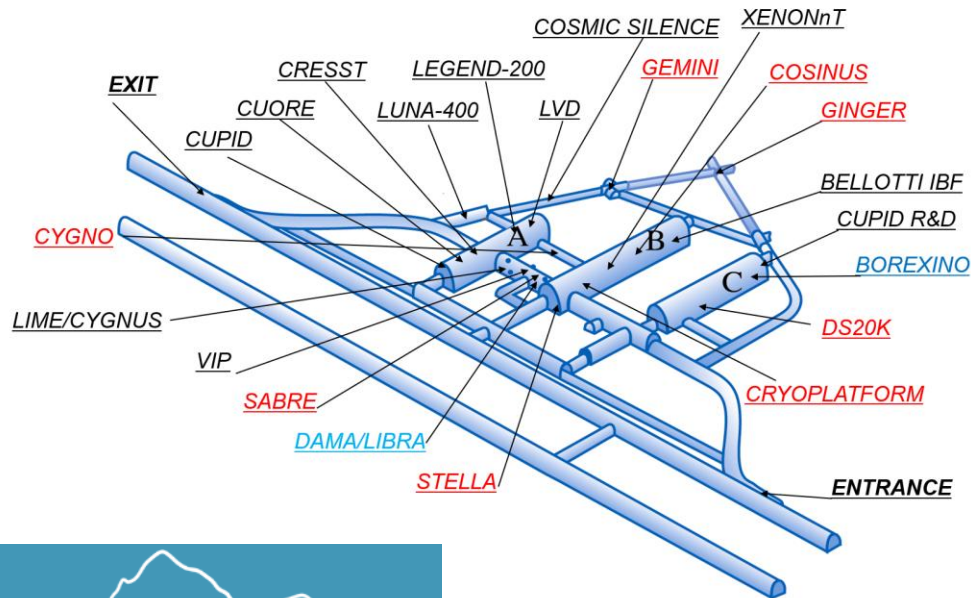
World Deep Underground Science Labs



Gran Sasso National Laboratory - LNGS

Italy. Under Gran Sasso Mountains (<2hr frm Rome)
Shielded by 1400 m (3800 m.w.e.) of rock
Total Muon flux $3 \cdot 10^{-8} \text{ cm}^{-2} \text{ s}^{-1}$
Radon $\sim 100 \text{ Bq/m}^3$ with 5-8 air changes/day
Largest lab in Europe
3 main experimental halls:
~100 m long, 20 m width and 18 m height
Established 1980s

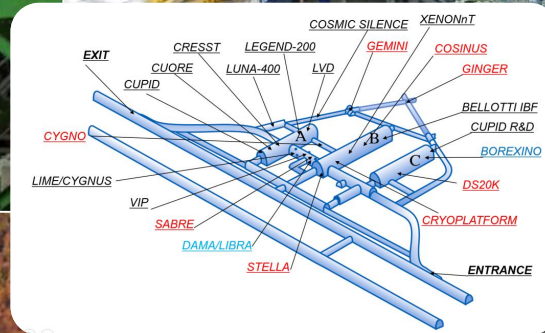
Area: 17.800 m^2
Volume: 180.000 m^3



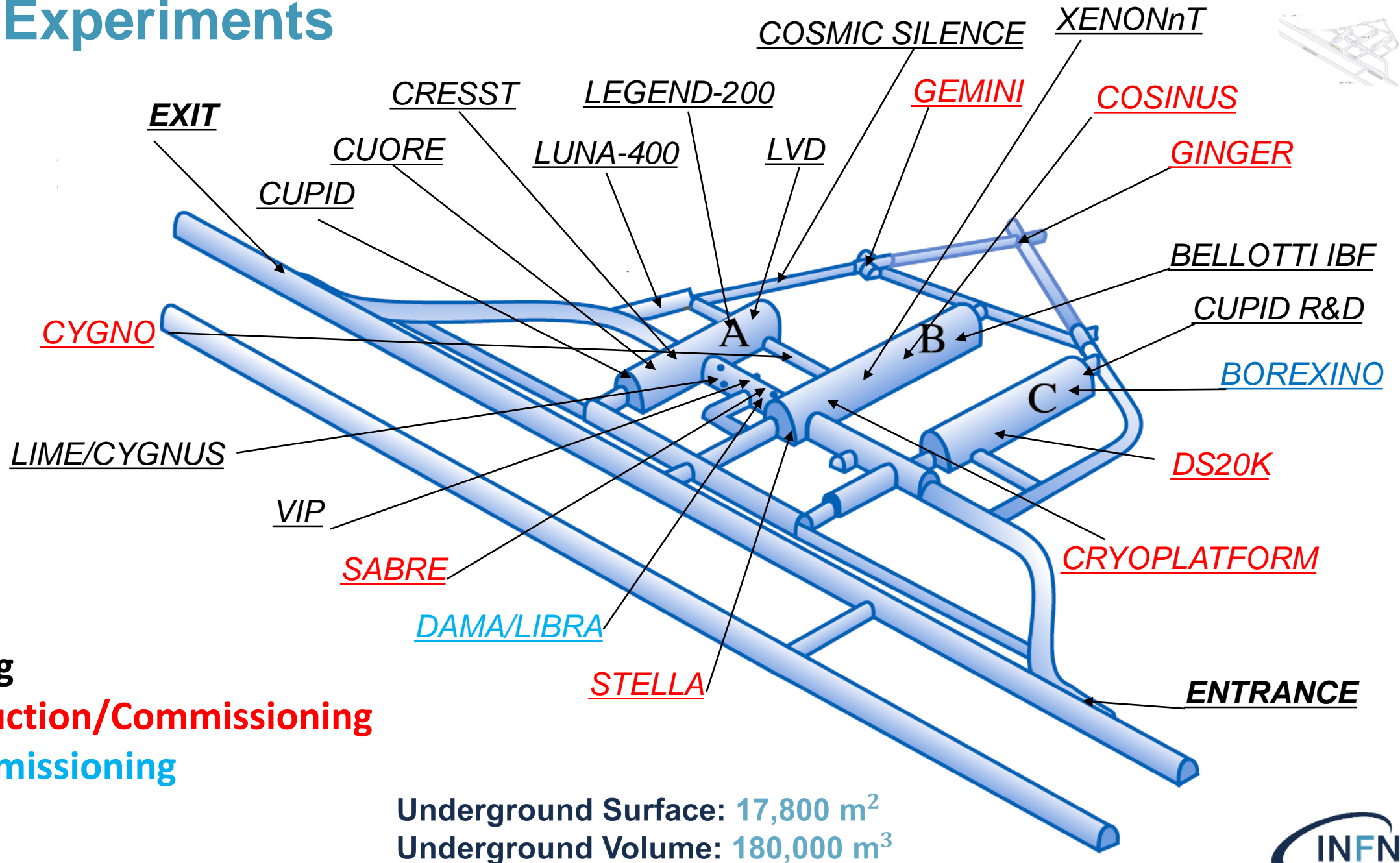
Gran Sasso National Laboratory - LNGS



Area: 17.800 m^2
Volume: 180.000 m^3



LNGS Experiments



- Running
- Construction/Commissioning
- Decommissioning

Decommissioning of Borexino and re-arrangement of LNGS Hall C

LEGEND-200 (operational)

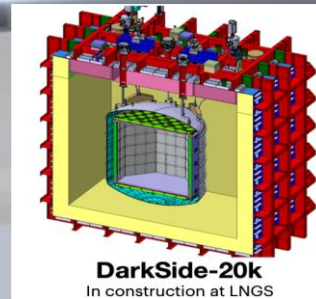
Hall A

Hall B

LEGEND-1000 (planned)

Free space

Hall C



Decommissioning of Borexino

North

Hall C

South

Borexino Water Tank

Technological Infrastructures

CTF Water Tank

Storage Area

DS20k Area

Water and scintillator removal from Borexino and CTF completed

The dismant program for Borexino

- Dismount activities will be organized to minimize interferences
- Many plants will not be available in hall C
- Reconfiguration of safety infrastructures will be necessary
- Dismounting will start before the end of the year

The new design for the hall C imply:

- LEGEND-1000 in the North part
- Discussion ongoing to install a new experiment in central part
- New infrastructures to support experiments

A new big cryogenic plant for LN production will be realized

- Located south of hall C just outside the hall
- Design completed
- Construction will start soon

The LSM Underground Laboratory

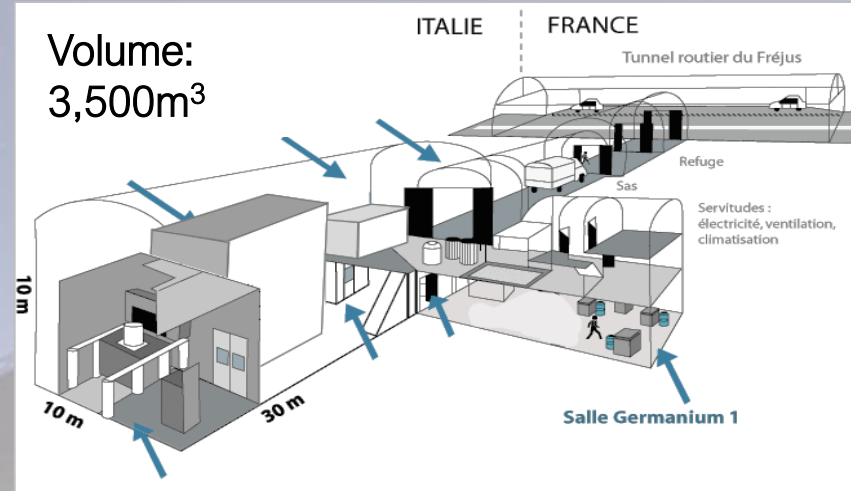


Deepest Underground Lab in Europe

4800 m.w.e: muon flux reduced by $>10^6$

Radon $\sim 10\text{-}15 \text{ Bq/m}^3$

Experiment	Focus	Technology	Description
SuperNEMO	$0\nu\beta\beta$	Tracking-calorimeter	$0\nu\beta\beta$ demonstrator tracking-calorimetry technique, aiming at improving the sensitivity on the $0\nu\beta\beta$ ($T_{1/2} > 6 \times 10^{24} \text{ yr}$ with 6.3 kg of ^{82}Se). Its scientific scope includes detailed studies of the $2\nu\beta\beta$, single-state vs higher-state dominance discrimination, and the constraining of gA.
BINGO	$0\nu\beta\beta$	Cryogenic	$0\nu\beta\beta$ R&D focusing on developing innovative technologies to achieve a very low background index, of the order of $10^{-5} \text{ counts/(keV kg yr)}$ in the region of interest.
Obelix ^{82}Se	ECEC 2ν	Ge ionisation	Counting of 6kg enriched ^{82}Se sample from LNGS started in January 2022: ECEC 2ν to excited states.
DAMIC-M	DM	Si CCD	DARk Matter In CCDs at Modane experiment employs thick, fully depleted silicon charged-coupled devices (CCDs) to search for dark matter particles with a target exposure of 1 kg-year.
MIMAC	DM	TPC	An original prototype detector based on the direct coupling of a large pixelated micromegas with a special developed fast self-triggered electronics showing the feasibility of a new generation of directional detectors.
RAMURE	Bio		Bio experiment on the long-term impact of natural radioactivity on living organisms, in particular those inhabiting aquatic ecosystems.
CELL STEM	Bio		Cryopreservation of stem cell in absence of radioactivity background.
AQURA	Quantum Clocks		Study on the impact of natural radioactivity on modern atomic quantum clocks.
PARTAGE	Low Background Counting	HPGe	LSM is developing a low background centre of excellence, which will incorporate the local expertise and capitalises on the low background HPGe detectors currently a LSM while adding additional hardware to this suite.



Surface lab (office, garage, museum)

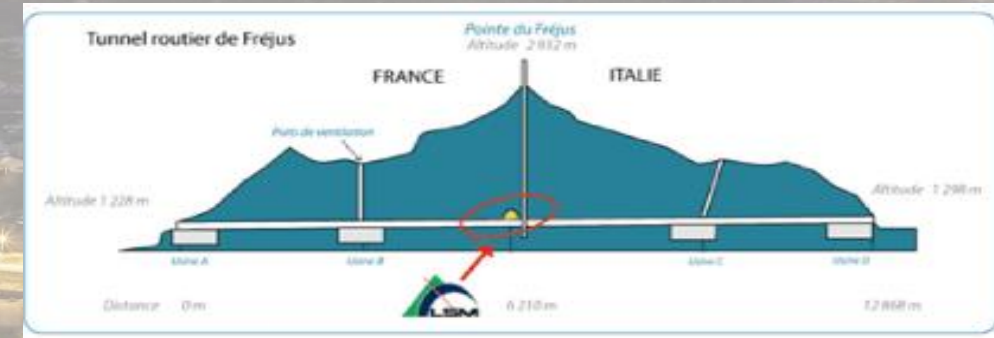
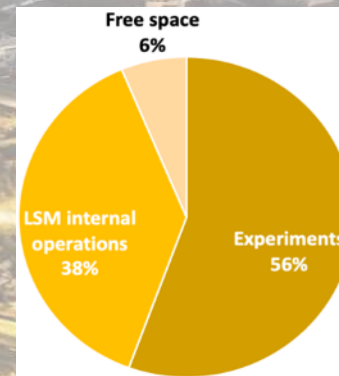
Science prog adapted to lab size:

- Low-mass DM Experiments
- $0\nu\beta\beta$ technologies
- HPGe array for ULB activities

TESSERACT (DM) to follow SuperNEMO.

Space is now tight.

Plans being developed to install a new mezzanine level



LSM Lab midway in the 13km France/Italy highway road tunnel

Straight-forward access (trucks up to 9m)

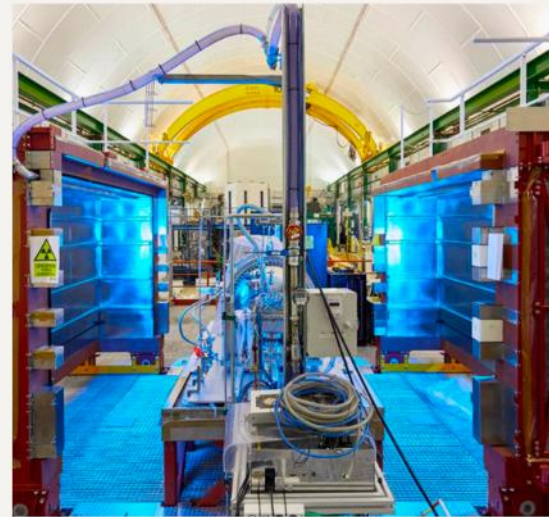
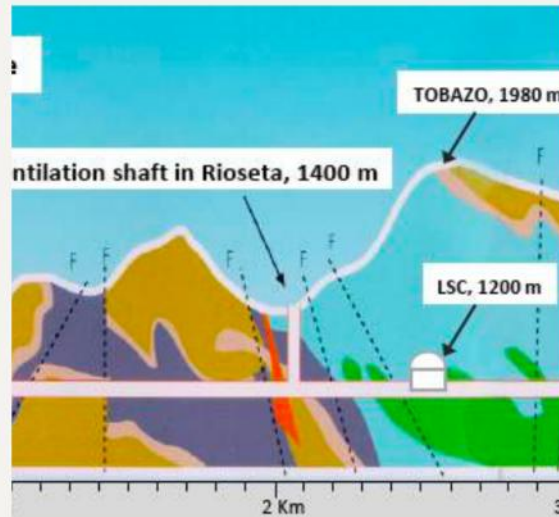
Canfranc Underground Lab

Located in Spanish-French Pyrenees border. Two-way access tunnels: abandoned train tunnel and operative road tunnel.

First experiments (IGEX, ...) since 1986. Modern lab, 1600 m², operative since 2010. 260 scientists from 50 institutions.

800 meters (v) of rock - muon flux is $5 \times 10^{-7} \text{ cm}^{-2}\text{s}^{-1}$; neutron flux ($E < 10 \text{ MeV}$) is $3.5 \times 10^{-6} \text{ cm}^{-2}\text{s}^{-1}$; gamma flux is $2 \text{ cm}^{-2}\text{s}^{-1}$

Radon abatement system: 220 m³/h radon-reduced air at 1 mBq/m³



Canfranc Underground Laboratory, SPAIN

Depth = 800m

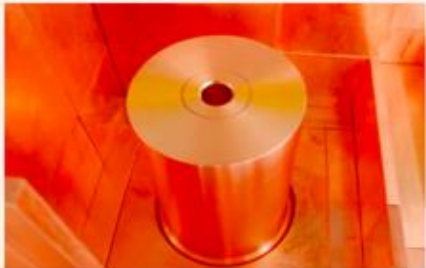
Volume = 10,000m³



NEXT-100 experiment -TPC with 100 kg of Xe-136 at high pressure - installed @LSC to search for neutrinoless double beta decay. In operation since December 2023.



NEXT-HD - TPC with 1 ton of Xe-136 at high pressure will start construction plans in 2025. Already working on LRT for the ton-scale experiment: higher purity copper shielding, light extraction with fibers,...



HPGe detector GeRysy



ICPMS-QQQ underground



EFCu: DAMIC lids



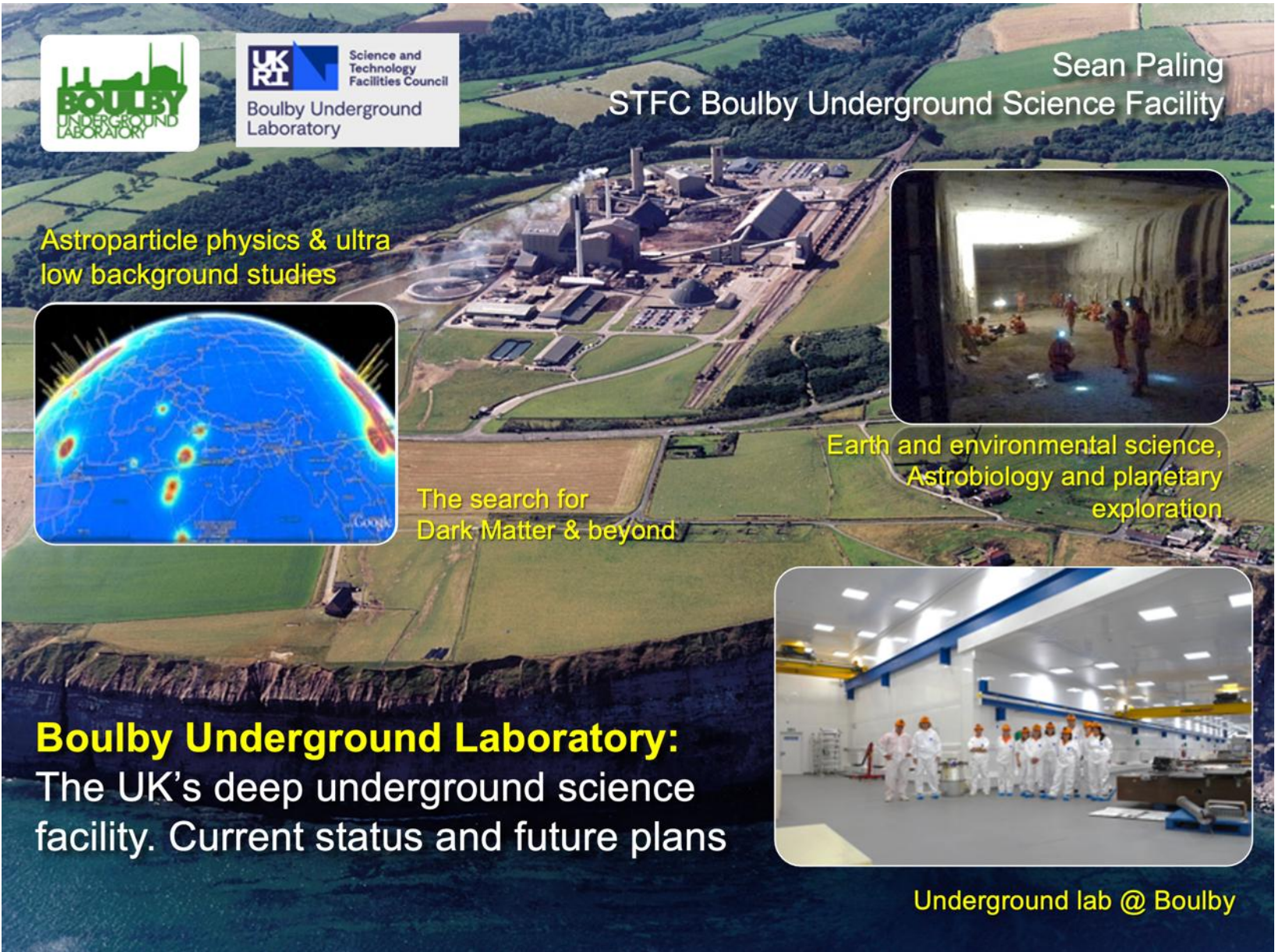
AN AIS Experiment



Science and
Technology
Facilities Council

Boulby Underground Laboratory: Status and plans for the UK's deep underground science facility.

Sean Paling
Boulby Underground
Laboratory, UK



UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

Sean Paling
STFC Boulby Underground Science Facility

Astroparticle physics & ultra low background studies

The search for Dark Matter & beyond

Earth and environmental science, Astrobiology and planetary exploration

Boulby Underground Laboratory:
The UK's deep underground science facility. Current status and future plans

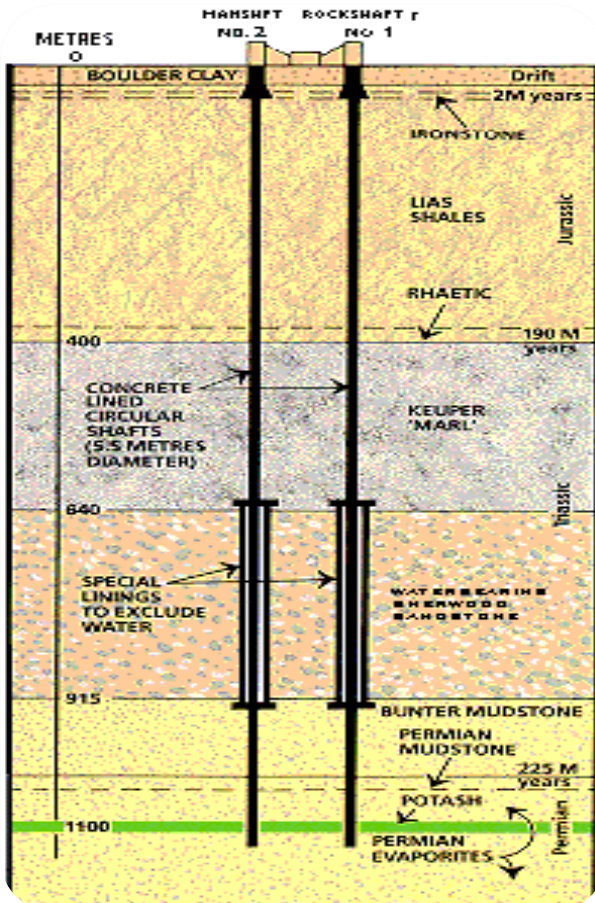
Underground lab @ Boulby

Boulby Geology & Mining

Excavations are in Salt (NaCl), Potash (KCl) and Polyhalite ($K_2Ca_2Mg(SO_4)$). Permian evaporite layers left over from the Zechstein Sea (250m.yrs past).

Over 40 kms of tunnel mined each year (now >1,000kms), the long-lived roadways being cut in the lower NaCl layer.

Britain's
deepest mine.
1.1 to 1.3km
deep.
>1000kms
tunnel



Polyhalite



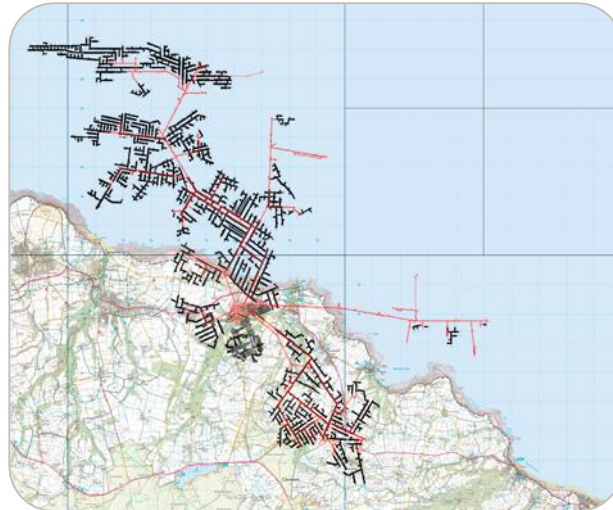
Potash



Rock-Salt



Low activity salt
U ~67 ppb,
Th ~125 ppb



Typical Boulby
Salt Roadway



Zechstein Sea





Surface support and staging building



Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

Supported access to surrounding geology & UG environs. Power, wifi/internet.



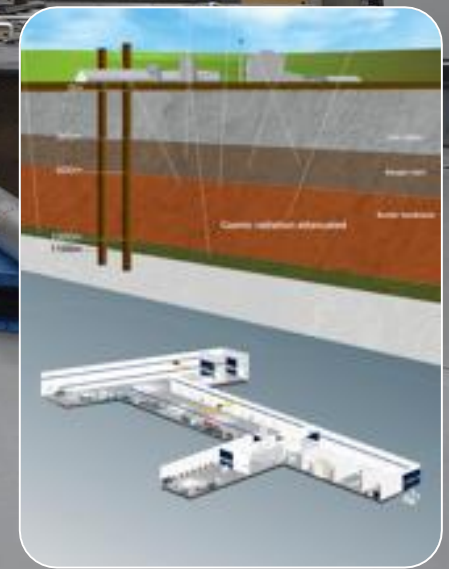
3000m³ Outside Experimentation Area

Volume 4000m³
Depth 1,100m
(>2800 m.w.e.)
Radon <3Bq/m³



BUGS Material screening

Boulby Underground Lab Facilities 2024: >4000m³ class 1k & 10k (ISO 6 & 7) clean room lab space. 10Gb Internet. AC, air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep space. 3000m³ Outside Experimentation Area (OEA) with power & internet. Supported access to wider mine environs.



Boulby Science Now & Future

Particle physics and ultra-low background studies

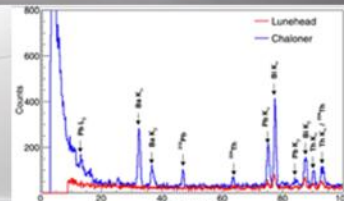
BUGS



XIA alpha particle counters



8 ULB Ge detector systems, 2 XIA alpha counters, Rn emanation (2), ICPMS-QQQ



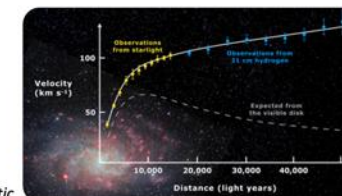
BUGS (Boulby UnderGround Screening). World-class material screening for current and future ULB experiments. Towards PPT sensitivity for G3 DM and Neutrino experiments



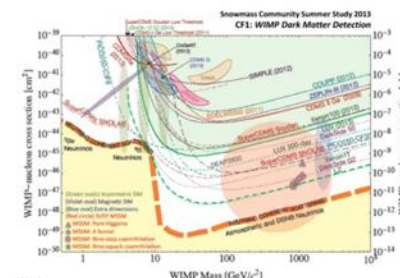
Boulby Dark Matter Studies...

Boulby has hosted **Dark Matter search** studies for over two decades. Including the **NAIAD**, **DRIFT** & **ZEPLIN** experiment programmes.

Boulby now hosts **CYGNUS** directional DM programme, **NEWS-G**/Dark-Sphere R&D and providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**



Galactic rotation curves



World DM particle search limits and future projections

ZEPLIN-II & III:
The world's first 2-phase Xenon dark matter detectors (Finished 2011)

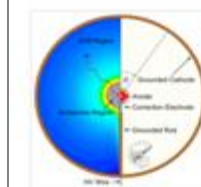


ZEPLIN-III @ Boulby

NEWS-G

Spherical Proportional Counter (SPC) studies @ Boulby

k. Nikolopoulos,
I. Katsioulas, P. Knights, T. Need, R. Ward
University of Birmingham
And wider NEWS-G Collab.



SPC concept: Variable target Low Eₑₑ, Low mass sensitivity

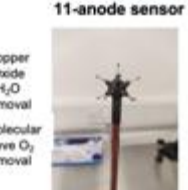
Simulation study of neutron interactions in the S30 at Boulby



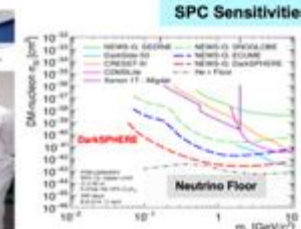
Purpose-made gas filter



Neutron Beam 4 MeV



Simulation study of neutron interactions in the S30 at Boulby



Direction of R&D at Boulby

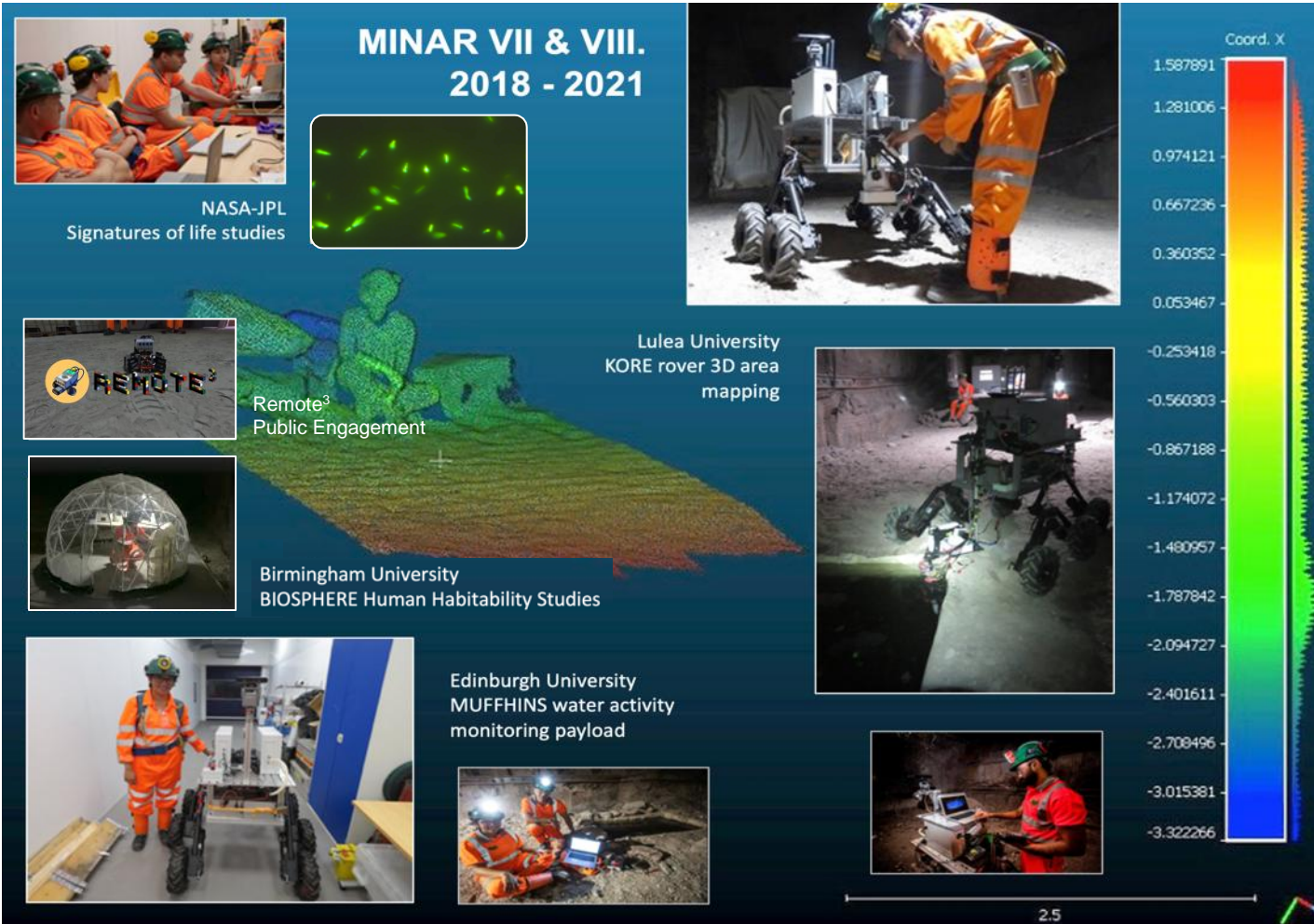
- Instrumentation development alongside NEWS-G at SNOLAB
 - Multi-anode sensor
 - Gas mixtures & filtration
- Working towards scaled-up detector at Boulby, 3m diam. **DarkSPHERE**
- Establishing Electro-forming Capability at Boulby for Dark SPHERE and beyond (I. Katsioulas, This conf.)

Multidisciplinary Science

Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.

BUTTON:
Neutrino
technology
testbed

MINAR:
Astrobiology and planetary exploration technology development

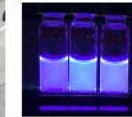


BUTTON-30: a technology testbed for future (anti)neutrino detection

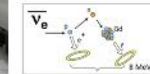
A US-UK proof of concept project for a non-proliferation implementation

BUTTON-30 is a proof of concept for a future 1-kT detector providing 100-tonne fiducial volume

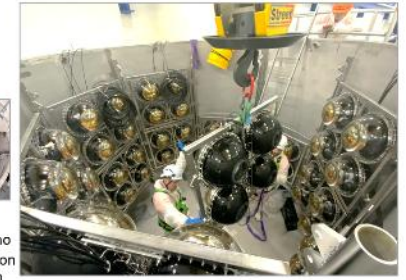
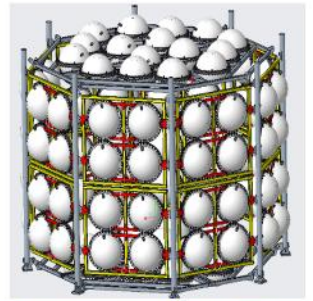
Part of a worldwide effort to develop WbLS detector technology. Other experiments include EOS at LBNL and the Brookhaven 30-ton at BNL.



PMT structure installation completed July 2025

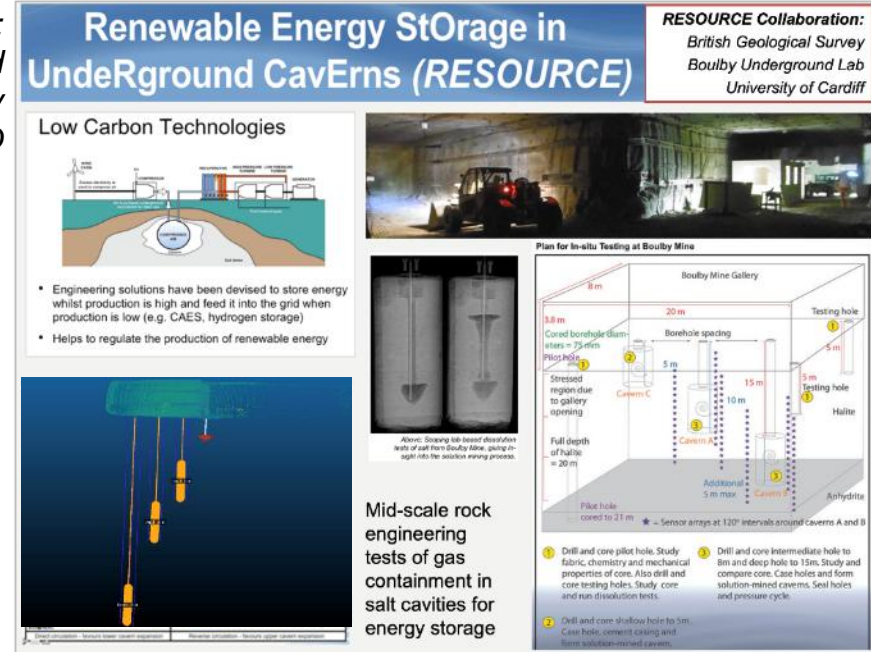


Anti-neutrino discrimination with Gd-H₂O



Button @ Boulby Feb 25

RESOURCE:
Compressed
gas energy
storage R&D



Future facilities & science @ Boulby...

2030-2040+

Boulby Activities Now and in the Future

Now

	Current Projects	Status
Particle Physics & Low Background	CYGNUS - DM R&D	E/P
	News-G - DM R&D	A
	BUGS: Ge, XIA, RnEm - Material Screening	A
	RECON - Nuclear Security R&D	A
	BUTTON - Nuclear security R&D	A
Earth & Environmental	Muon Tomog – CCS & undersea Geoimaging R&D	A
	RESOURCE – Energy store R&D	A
	Seismology/AION R&D	A
Astrobiology & Planetary Exploration	BISAL – Biology/Astrobiology	A
	MINAR – Planetary Exploration Tech development	A
	Misc. Other. SELLR, C14, Adrok, BIO-SPHERE...	A/P
	Outreach/ Education - Misc events, progs, Remote3...	A

Status: A = Active, P = Paused, E = End, I = Interest confirmed

2023-2030

Medium Term (Current Lab + mods)	Status
BUGS: Ge, XIA, RnEm, ICPMS - Material Screening	A
BUTTON-30 – Nuclear security R&D	A
RECON+ - Nuclear Security R&D	A/I
DarkSPHERE, SDMS, SOLAIRE, UltraDark, MechQSDM – DM Search	I
DATUM – Neutrino Tech R&D	I
SoLAR – Neutrino R&D	I
Seismology Array – Geosurvey R&D	I
RESOURCE+ – Energy store R&D	A/I
Muon Tomog – CCS & undersea Geoimaging R&D	A/I
BISAL+ – Biology/Astrobiology	A/I
MINAR+ – Planetary Exploration Tech development	A/I
Misc. Other. AION R&D – Atomic Interferometry Quantum Computing Tech R&D?	A I
Outreach/ Education: General Public, Schools +	A

Long Term (Current lab plus major new lab)

Particle Physics and Low Background Science:

Dark Matter: Major Next Gen Experiments:

- Xenon (XLZD)
- Argon (SOLAIRE+)
- Gas (DarkSPHERE+)
- ULT technologies for DM
- Quantum Technologies for DM

Target projects for a major new UK underground facility / campus

Neutrinos:

- BUTTON-100+
- DATUM (LEGEND Support),
- SoLAR +....

Mat screening & LB Techniques: A world's best facility:

- Ge, XIA, RnEm, ICPMS, Cleanliness & Engineering R&D
- RECON+ - Nuclear Security Gamma spec

Earth & Environmental Science:

- Sustainable Energy R&D (Gas Storage, Geotherm, CCS)
- Local/Global Seismology Observatory
- Geological Repositories R&D
- Misc geology / Geophysics R&D

Astrobiology & Planetary Exploration:

- Extremophile R&D
- Astrobiology / life beyond Earth R&D
- Human habitation R&D
- Planetary exploration technology development
- Mining and industry application development.

Quantum Sensors and Computing:

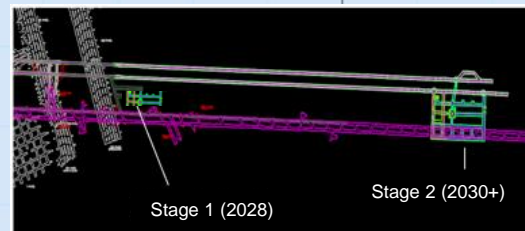
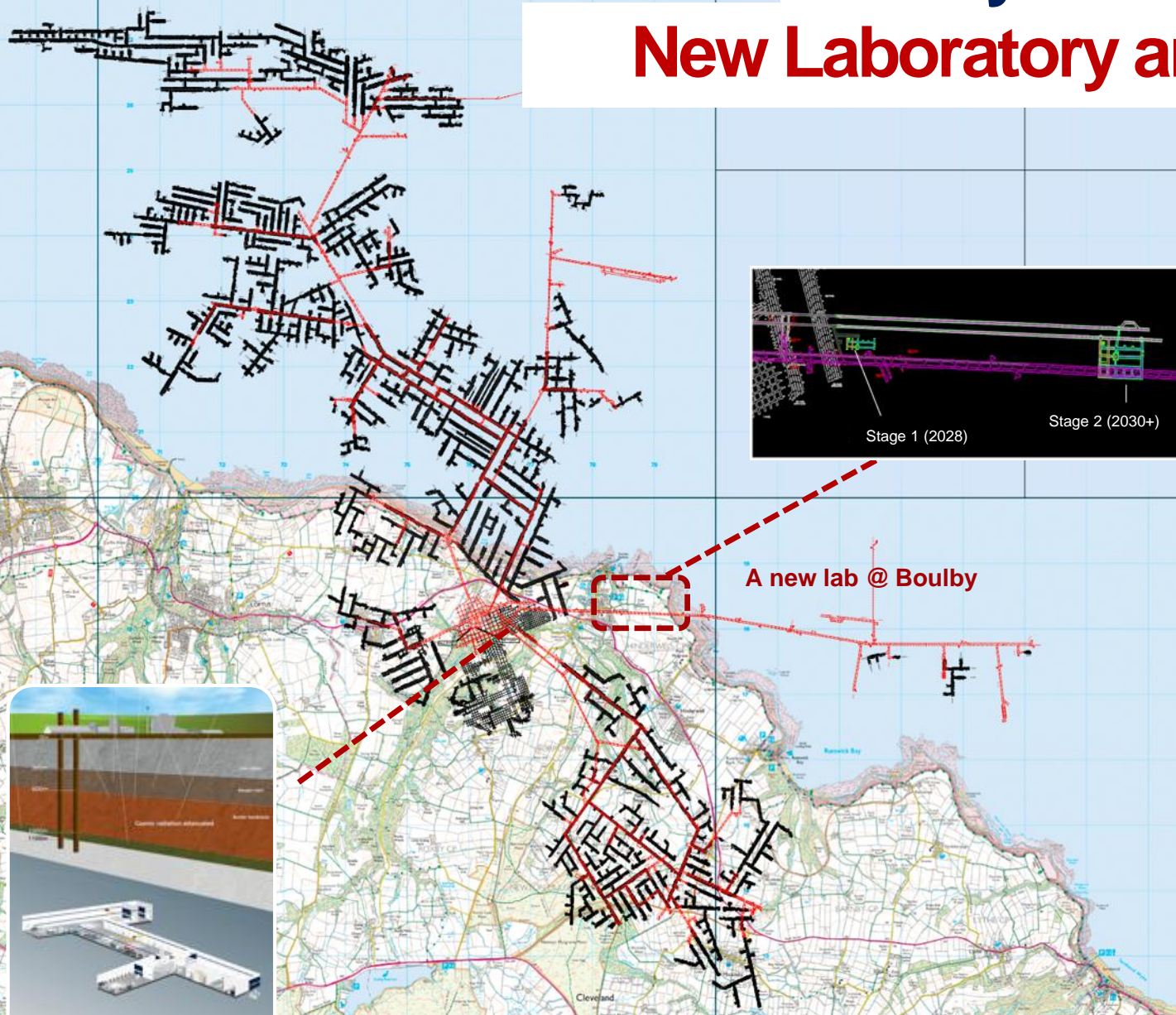
- AION-20/100/100 – Atomic Interferometry
- Quantum Sensor and Computing Technology R&D

Outreach and Education:

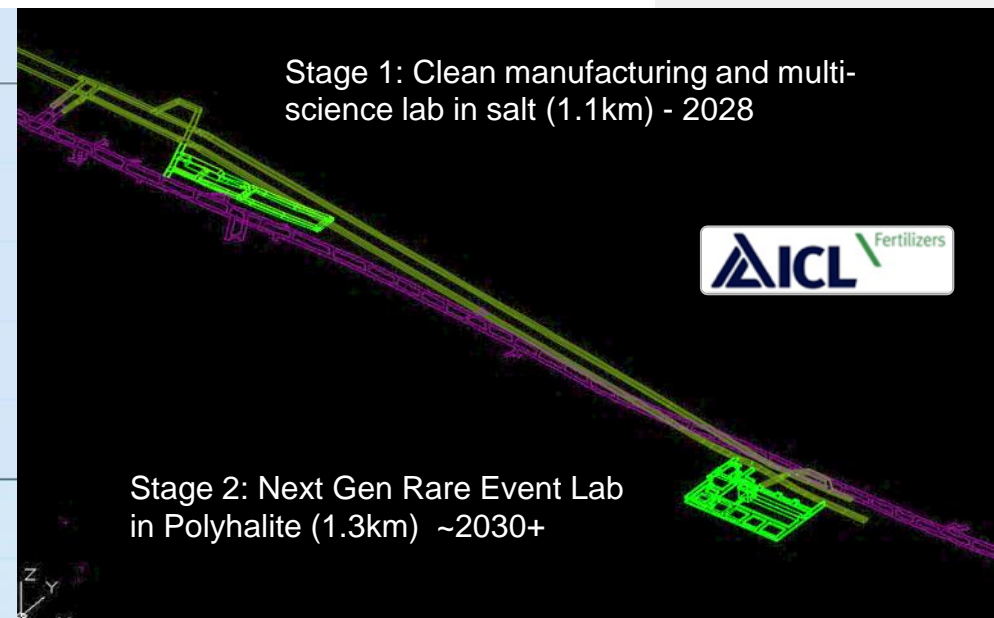
- A National Centre for Science and technology outreach and education.

Boulby Development Project

New Laboratory and New Science.

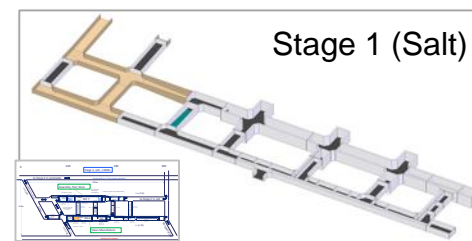


A new lab @ Boulby



Stage 1: Clean manufacturing and multi-science lab in salt (1.1km) - 2028

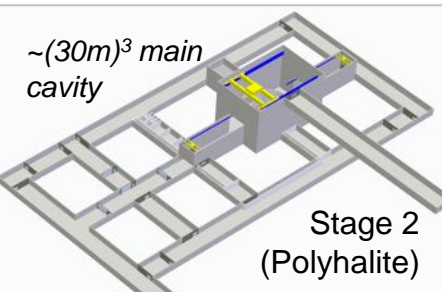
Stage 2: Next Gen Rare Event Lab in Polyhalite (1.3km) ~2030+



Stage 1 (Salt)

Total volume
(Stage 1 + stage 2)
~120,000m³

DRAFT: 2-stage Designs



Stage 2
(Polyhalite)

Boulby now EXPANDING to host expanding science

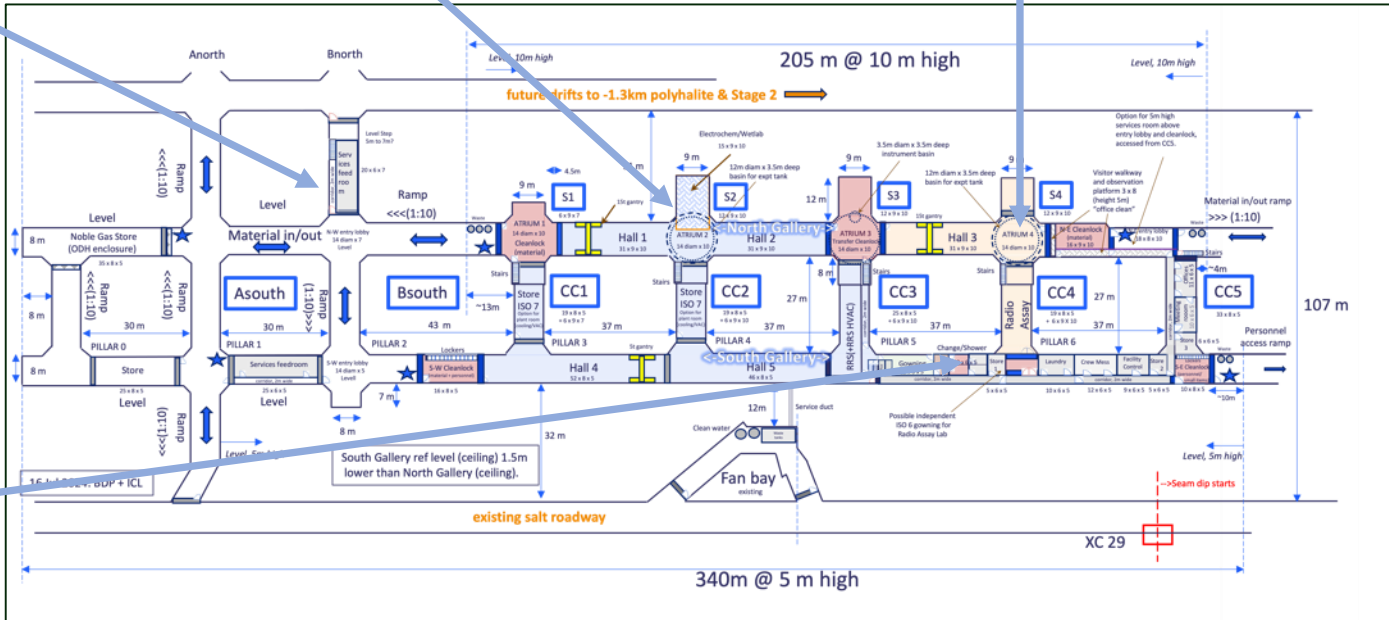
Excavations for stage 1 now underway

Boulby Development Project: Stage 1 Excavation

Work in
progress
2024/25



North Hall will be 10m high with
additional 14m (dia) 5m (h) pits
(15m height in total)



Stage 1
Functional
Design

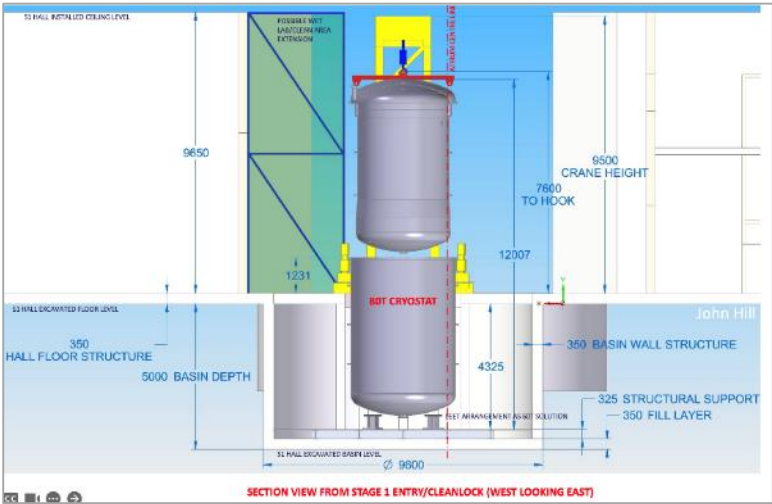
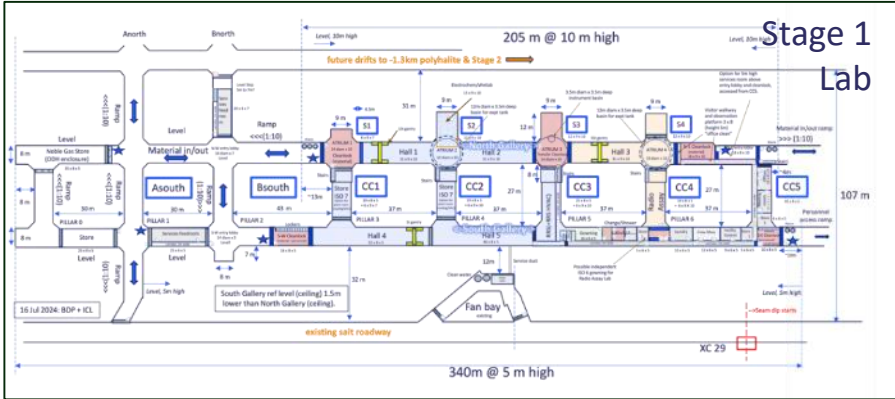
Depth:
1.1km
Volume:
~60,000m³



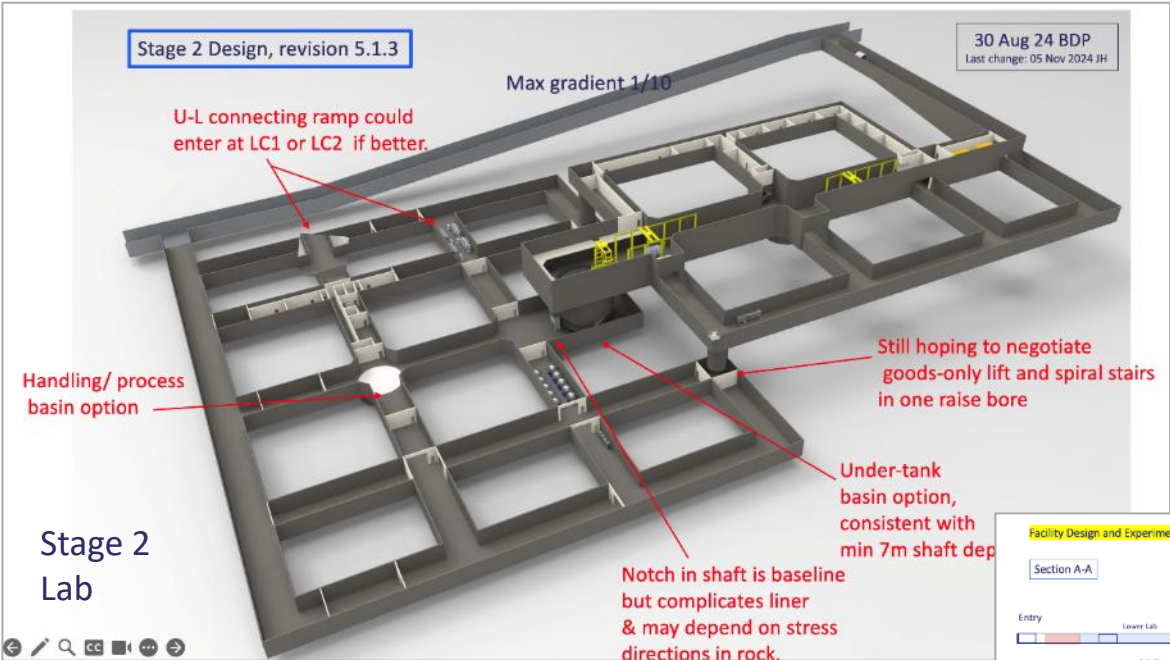
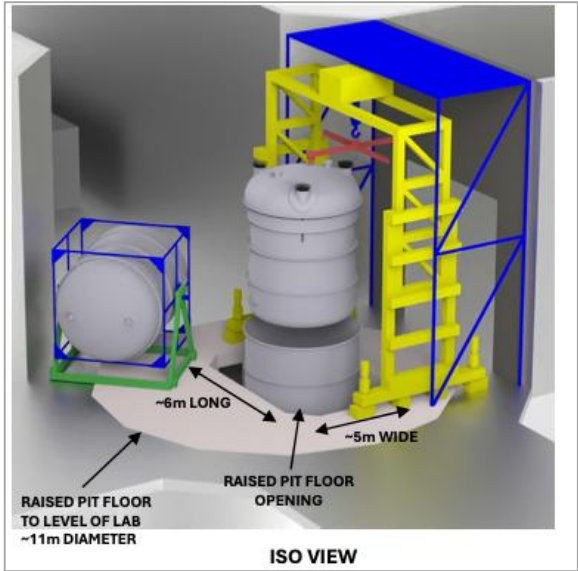
Stage 1 lab will give >5 x increase in clean
multi-disciplinary experimental space

Excavation almost complete. Expected Oct 2025. (Outfitting ~2028)

New Lab(s) Design



Stage 1 XLZD Pre-Construction



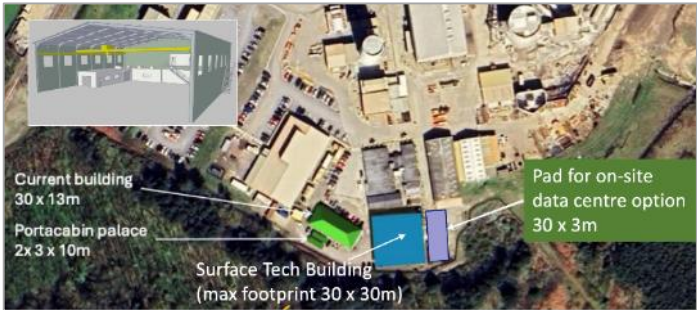
XLZD in Stage 2



Stage 1 Ventilation

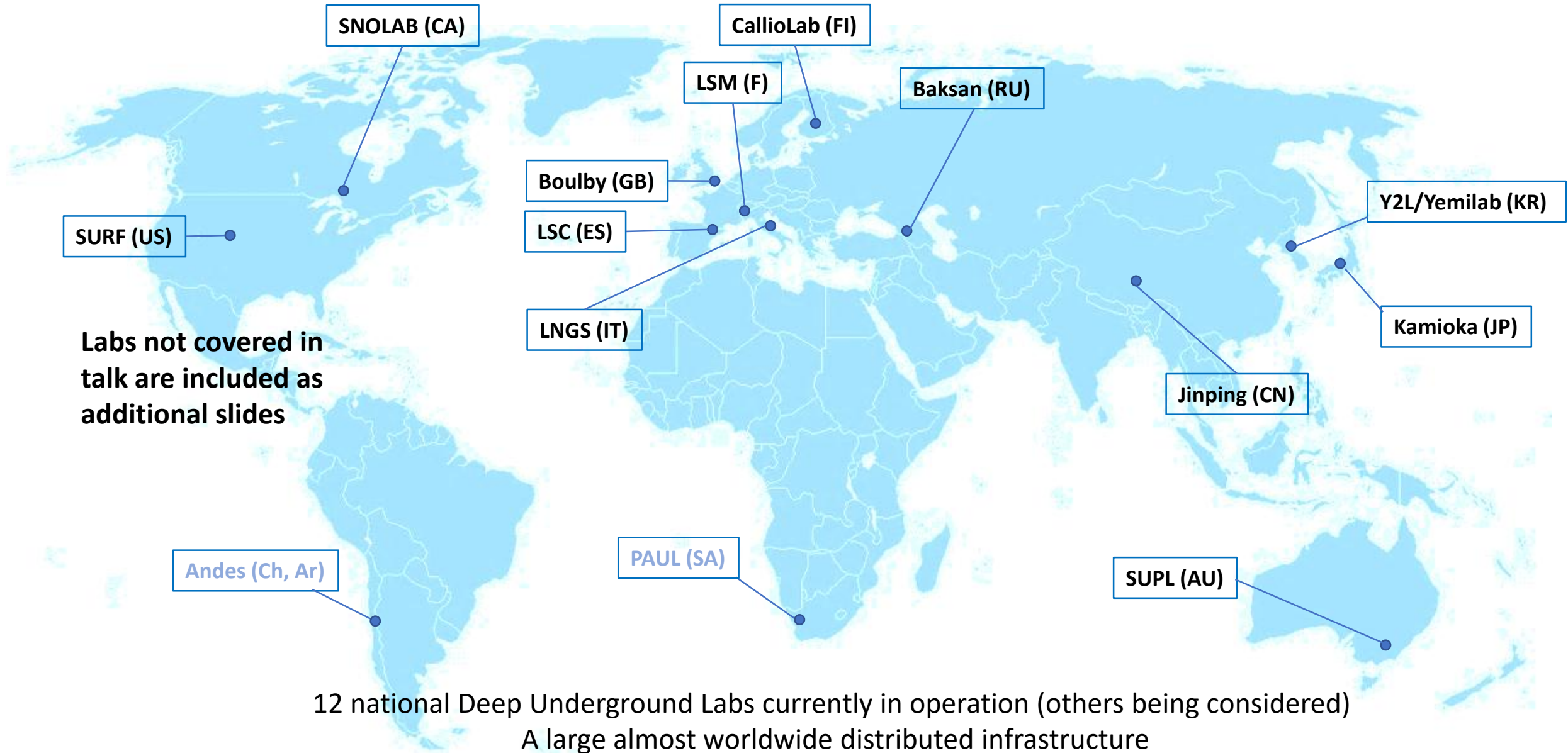


Stage 1 Lining Options



Surface Building Plans

World Deep Underground Science Labs



Overview of World Deep Underground Science Facilities - **SUMMARY**

Globally there is wide variety of excellent deep underground science facilities operating. (I believe) the underground science communities are well served by the facilities that have emerged to meet their various needs.

In the future:

- Science projects (and demands on facilities) will grow:
- Some large spaces needed, more stringent cleanliness and low background requirements, more severe engineering and technology challenges, and more.
- The underground labs will be (and are) looking to meet these needs.

International Underground Lab cooperation.

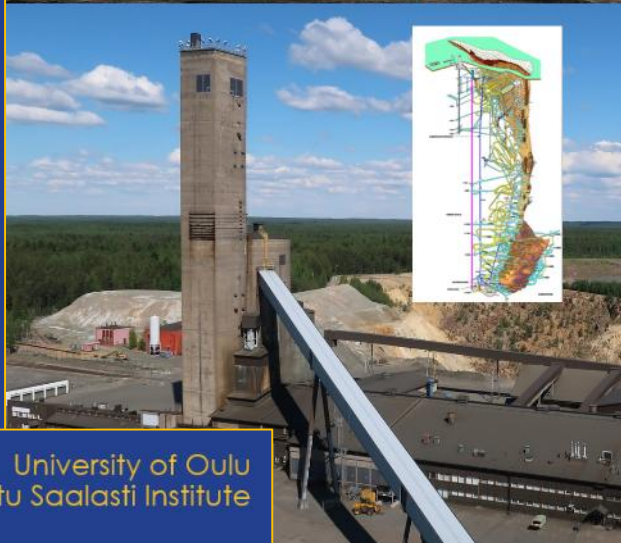
- Benefit to be had from sharing of operational practices and possibly international coordination of use of space and support systems (low background counting etc)... **Discussions to be had.**

Sean Paling
STFC Boulby Underground Laboratory

Additional Slides



CALLIO LAB at the Pyhäsalmi Mine, in Pyhäjärvi Finland



About the Pyhäsalmi mine:

- Underground mining since 1967 (Cu, Zn & pyrite)
- 1.4 km (~4100 mwe) flat overburden
- Access via incline (12 km) or elevator
- Mining ceased in 2022
- Transitioning from mine to repurposing
- **Owned by** Pyhäsalmi Mine Oy
- **Post-mining activities** coordinated by the Pyhäjärvi town-owned Callio- Mine for Business
- Science activities coordinated by the University of Oulu Callio Lab



University of Oulu
Kerttu Saalasti Institute

CALLIO LAB

Underground Center for Science and R & D

and above ground

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For more information, please visit:
www.calliolab.com
www.oulu.fi/en/callio-lab



CALLIO LAB

Multidisciplinary research and experiments
since 2015

Basic information:

- Benefits From The Whole Mine Site And Infrastructure
- **Project-based Operations – Low Operational Costs**
- Research Activities At Callio Lab Coordinated By The Kerttu Saalasti Institute, University Of Oulu
- An EPOS Research Infrastructure (ESFRI, 2020)
- A FIN-EPOS Infrastructure (FIRI, 2020)
- Member of DULIA network and collaborating with CELLAR network
- Founding member of European Underground Laboratories Association (EUL, BSUIN projects) Undergroundlabs.network

We offer coordination, cooperation,
networking and facilitation



Education and training



Mining & tunnelling



Mine reuse



Geothermal research



Working environment



Underground H&S



Future food &
Underground farming



SpaceLab



Earth Observation
and remote sensing



Deep underground low
background facility



Particle physics &
muography



Something new?

BAKSAN Neutrino Observatory (Russia)





Biological researches at the deep underground low radiation background laboratory (DULB-4900) and tunnel of Baksan Neutrino Observatory: biophysics and microbiology

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Baksan Large Neutrino Telescope Project: Prototypes and Perspectives

Show affiliations

Lukanov, A. D. ; Budzinskaya, A. A. ; Gangapshv, A. N. ; Gavrin, V. N. ; Fazliakhmetov, A. N. ; Ibragimova, T. V. ; Kazalov, V. V. ; Kuzminov, V. V. ; Lubsandorzhiev, B. K. ; Malyshev, Yu. M. ; Nanzanov, D. A. ; Novikova, G. Ya. ; Petkov, V. B. ; Shikhin, A. A. ; Sidorenkov, A. Yu. ; Smirnov, O. Yu. ; Ushakov, N. A. ; Veretenkin, E. P. ; Voronin, D. M. ; Yanovich, E. A.

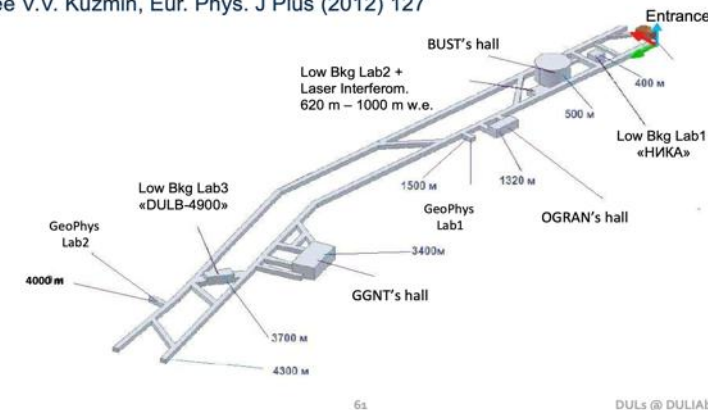
The article reports on the current status of the Baksan Large Neutrino Telescope project and describes some selective results of the first stage of the project, a detector prototype with a liquid scintillator mass of 0.5 tons. The results of the second stage of the project, a prototype with liquid scintillator mass of 5 tons, and project prospects also presented.

Publication: Physics of Atomic Nuclei, Volume 86, Issue 6, p.1380-1384
 Pub Date: February 2024
 DOI: [10.1134/S1063778823060182](https://doi.org/10.1134/S1063778823060182)
 Bibcode: 2024PAN....86.1380L

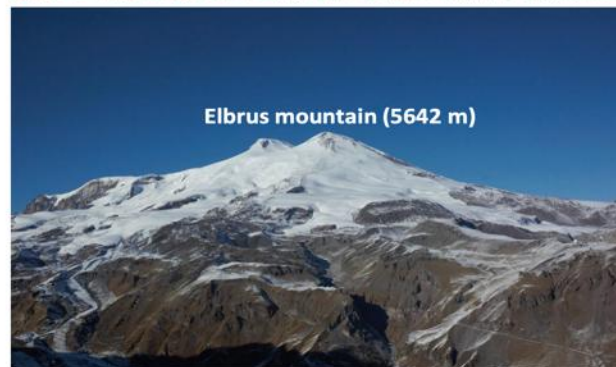
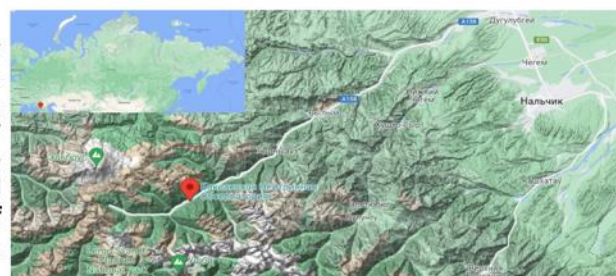
<https://indico.stfc.ac.uk/event/1058/>

Laboratory structure at Baksan

See V.V. Kuzmin, Eur. Phys. J Plus (2012) 127



Baksan Neutrino Observatory
 BNO (INR RAS) was founded in the late 60-80th in the Neutrino Village (1700 m.a.s.l.) located 22 km from the highest european mountain Elbrus (5642 m, dormant volcano) under the peak of Andyrchy mountain (3937 m). Main scientific goals of BNO are related to fields of astrophysics, particle physics and nuclear physics. Moreover newer topics of interdisciplinary research are linked to geophysics, geology and biology (since 2019)



Scientific program at Baksan: highlights

- + BUST (Baksan Underground Scintillation Telescope)
 - study of cosmic rays with surface and underground detectors
 - gravitational collapse supernova rate < 0.07/year (90% CL)
- + GGNT (Gallium-Germanium Neutrino Telescope)
 - Solar neutrinos observatory
 - BEST (Baksan Experiment on Sterile Transitions) with ⁵¹Cr source (3.4 Mci) and 0.6-1m baseline
- + LBR (Low Background Researches)
 - Investigation of rare decay processes (DBD and DM)
- + LGG (Laboratory for Geophysics)
 - Geophysics and gravitational waves
- + New:
 - cryogenic laboratory for bolometers (Mo-based DBD)
 - long term: 5kt scale Borexino-like detector (prototype stage)

The ANDES Laboratory project design is ready to be included in the Agua Negra tunnel call for tenders

Towards a new lab in South America?



Andeslab.org

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Manuel Platino –
manuel.platino@iteda.gob.ar

Argentina and Chile collaborators designed, built, and tested two innovative (3-x/y planes) muon veto telescopes ready to be installed, (see poster 517)

Advanced research in MMCs and digital SiPMs in conjunction between ITeDA and KIT (Germany)

Engineering Design **ANDES**

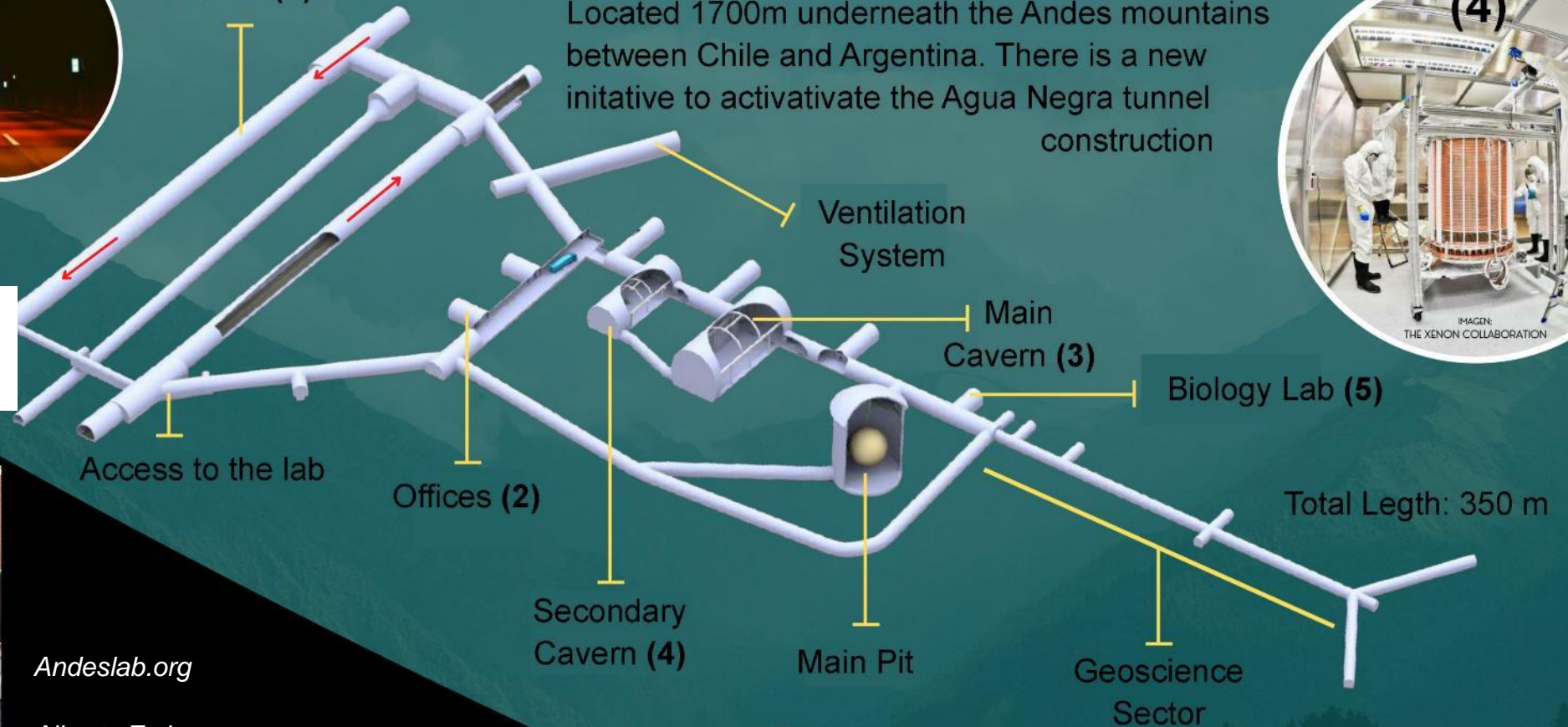


Agua Negra tunnel (1)

Located 1700m underneath the Andes mountains between Chile and Argentina. There is a new initiative to activate the Agua Negra tunnel construction



IMAGEN: THE XENON COLLABORATION



(3)

IMAGEN: SNOILAB



(5)



(2)

Paarl Africa Underground Laboratory



Symposium on Science at PAUL

14–18 Jan 2024
Du Kloof Lodge, Du Toitskloof Mountains
Africa/Lehavesburg timezone

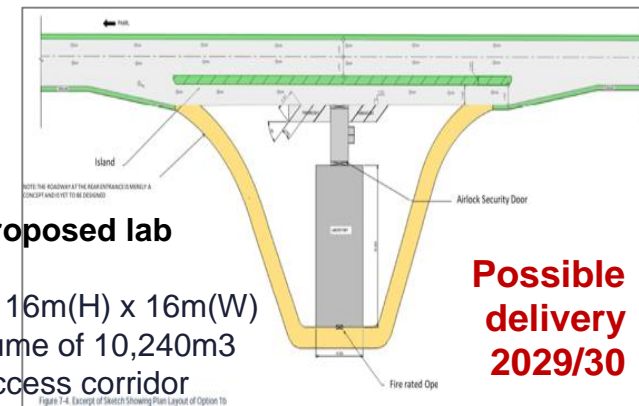
Du Toitskloof Tunnel
Du Toits Kloof tunnel view point

Plans for a new lab in South Africa

North Bore

South Bore

F Malek (CNRS, France)
RT Newman (Stellenbosch University, South Africa)



One of 3 proposed lab designs. ~

- 40m(L) x 16m(H) x 16m(W)
- Total volume of 10,240m³ inc an access corridor

Muography of tunnel: 1,5 years of measurements in- and outside of tunnel

Muon tracker from J.Marteau (IP2I Lyon, FR)

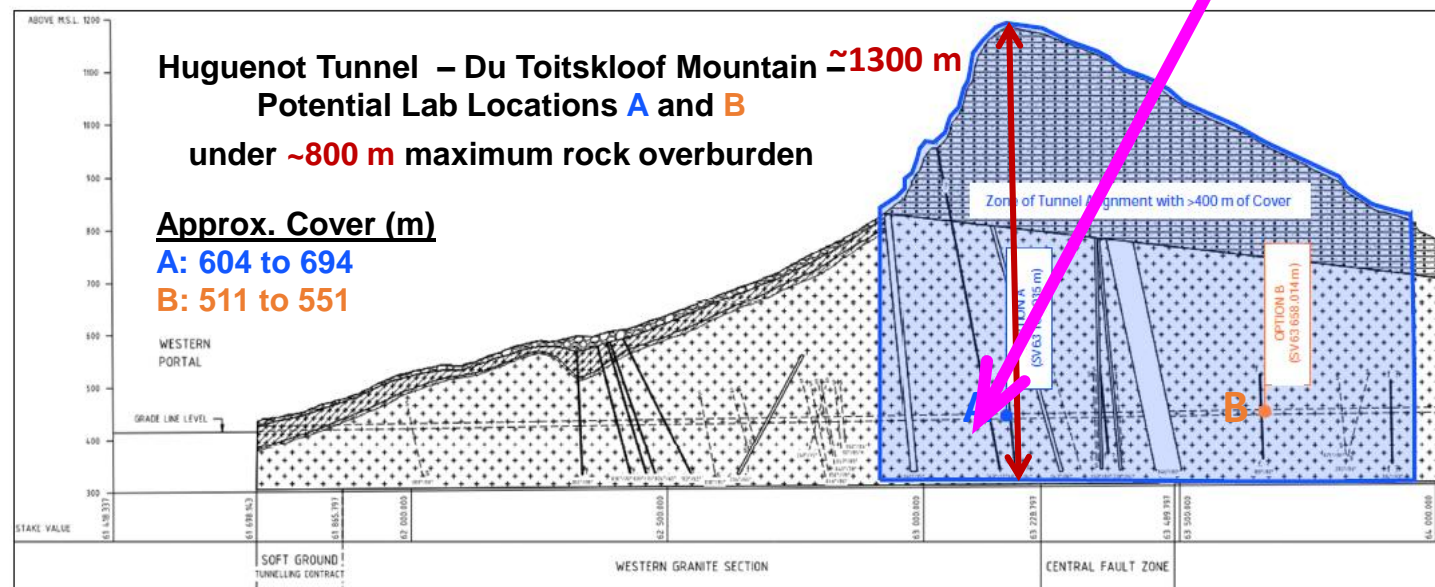


Figure 6-1. Proposed PAUL locations are shown on an excerpt of the geological longitudinal section (drawing no. C1870-0300-DRG-STN-233011)