(Deep) Underground Laboratories: a brief review

DULIAbio 2024

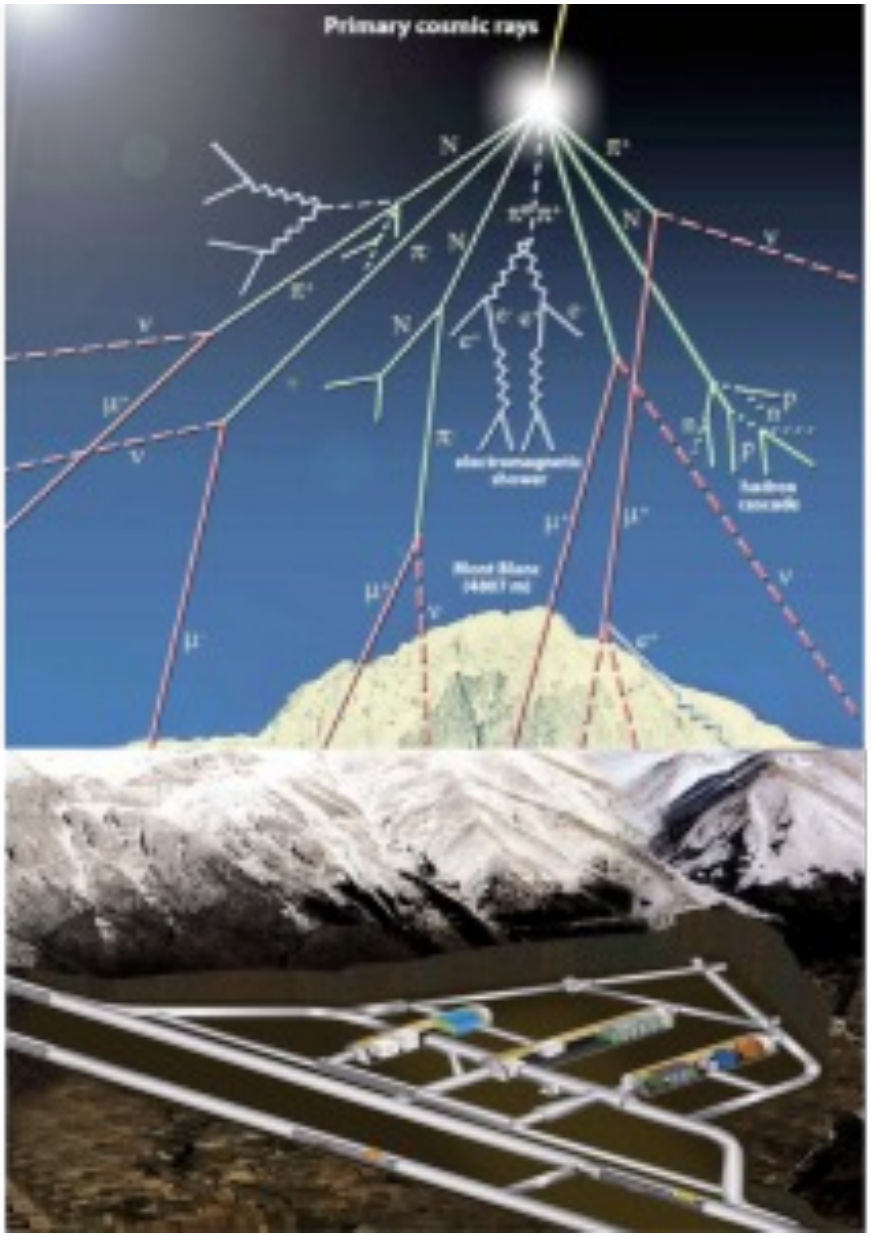
York, UK 19-22 Aug 2024

Aldo Ianni, I.N.F.N. Laboratori Nazionali del Gran Sasso

Why are we interested in DULs?

Reduction of muons from primary comic rays opens the possibility to search for **exceptionally rare events** such as low energy neutrino interactions, dark matter interactions, proton decay, double beta decay, …

Muons reduction has a great impact on biology as well, this meeting topic.



The science in DULs

- The original and main research topics in DULs are **proton decay and neutrino physics (atmospheric, solar neutrinos, and DBD).** About 30 years ago **direct detection of Dark Matter** became another crucial topic.
  - ✓ **1965: Observation of upgoing muons from neutrino interactions at 3200m depth in South Africa**
  - ✓ **1968: First detection of solar neutrinos**
  - ✓ **Early 1980s: Kamiokande, IMB, and NUSEX proton decay experiments proposed**
  - ✓ **1987: Observation of neutrinos from a core collapse supernova**
  - ✓ **1998: Discovery of neutrino oscillations in Super-Kamiokande**
  - ✓ **2002 and 2015 Noble Price in Physics**

- In the **last decade** DULs have expanded the research interest to neighboring sectors that can benefit of underground facilities and infrastructures
  - At SURF (South Dakota) an **Institute for Underground Science** is being established

- **Multi-disciplinary** is becoming a key feature for DULs
  - Precision measurement in high-energy particle physics
  - Technology sharing for gravitational waves search
  - Technology to support quantum computing
  - **Biology** in extreme environments and low radiation biophysics (**this meeting topic!**)
  - Geophysics
    - ➢ Groundwater characterization
    - ➢ Deployment of seismic arrays underground
    - ➢ Rotational seismology
    - ➢ Geo-neutrinos

Where are they?

operational

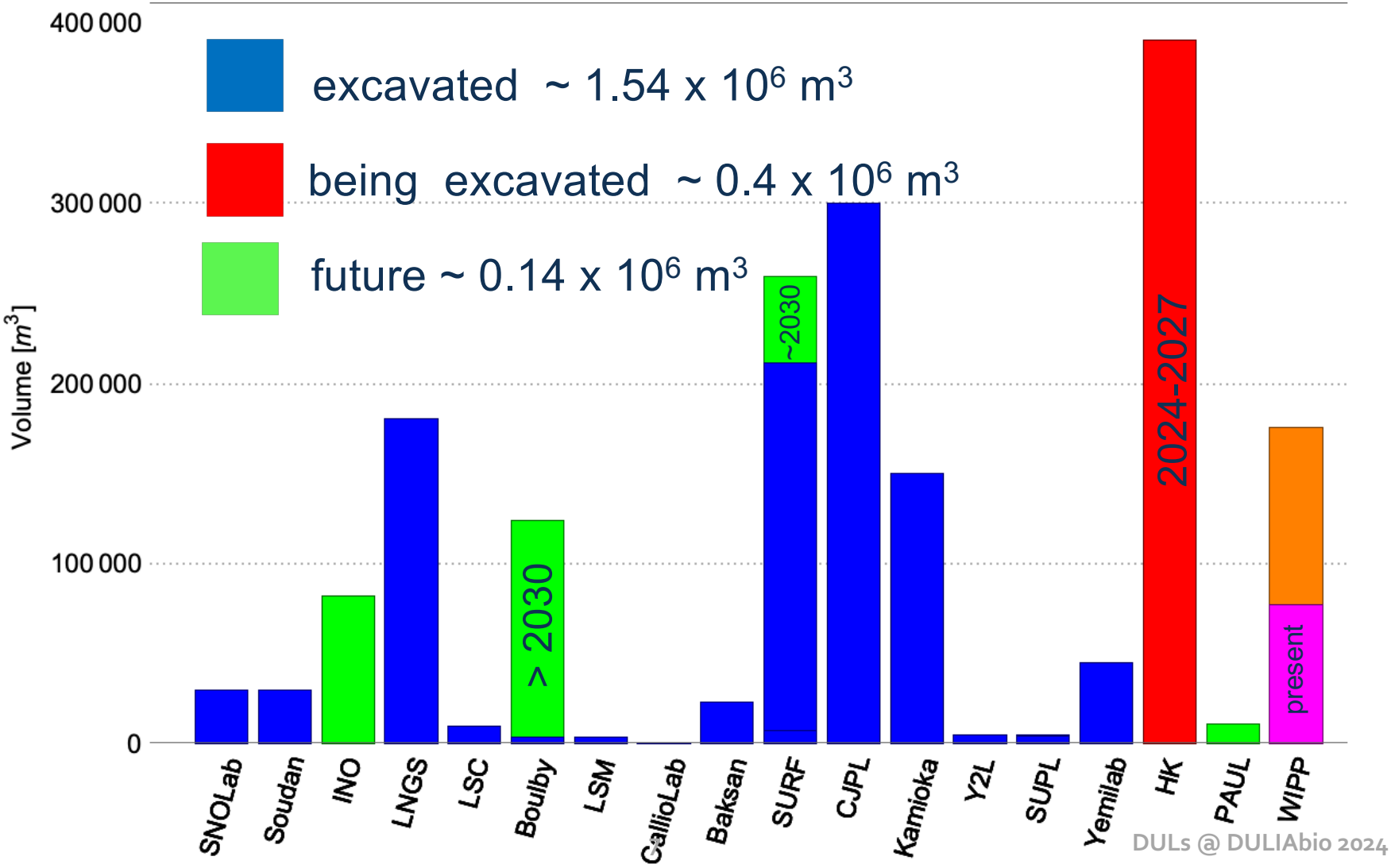
new proposal/ expansion

not operational

shallow

Main features

How large are DULs ?



Structure and access

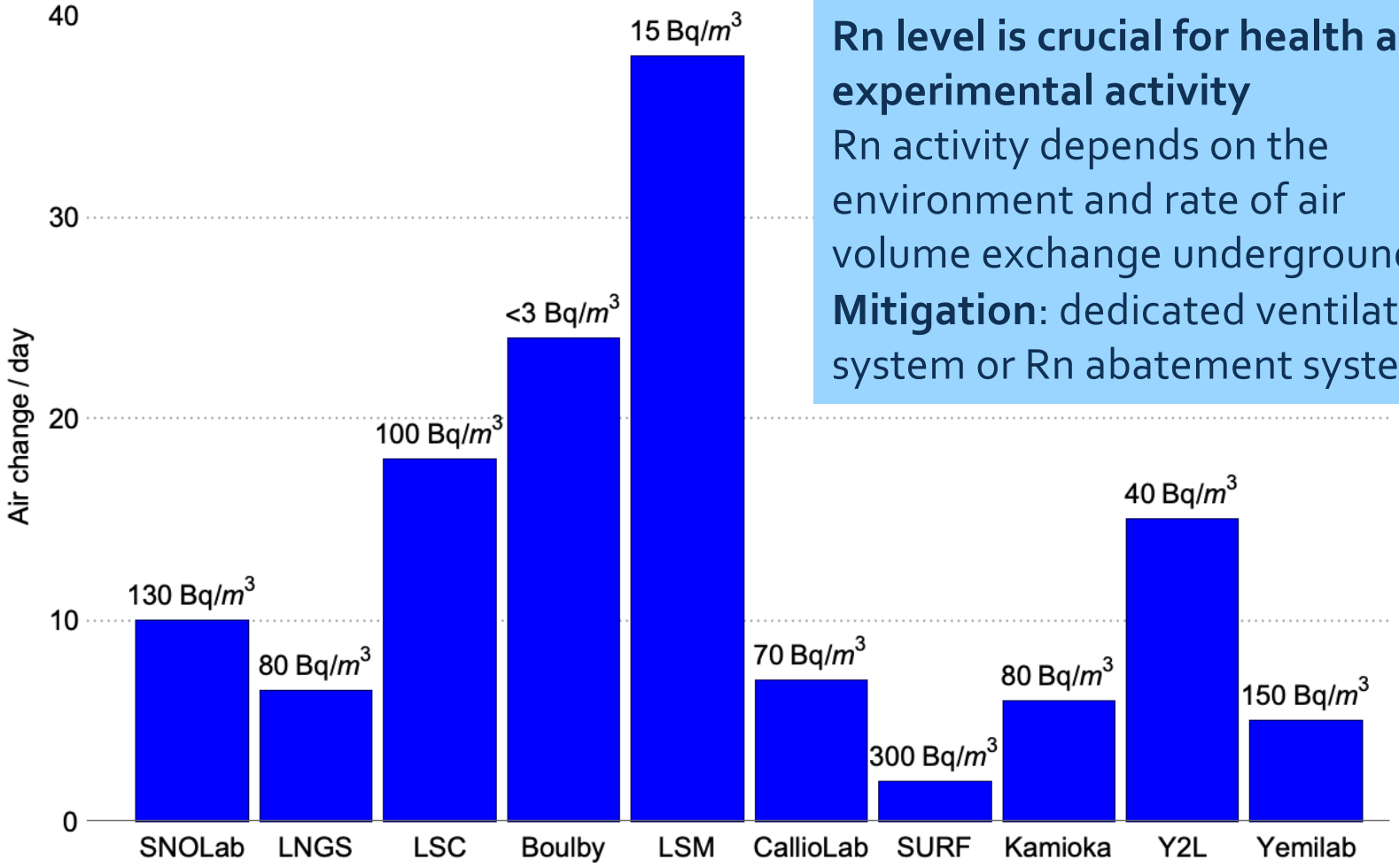
Structure

- **Single-site** (SNOLAB, LNGS, LSM, Yemilab, SUPL)
- **Multi-site** (LSC, SURF, Boulby, Kamioka, CJPL, CLAB)

Access

- **Vertical** by means of a cage system (SNOLAB, Boulby, SURF)
  - + Need special manpower and maintenance
  - + Interaction with mining Company
  - + Limited loading volume for equipment to be taken underground
- **Horizontal** (Baksan, LNGS, CJPL, LSM, LSC)
  - + Easy access, not special maintenance
  - + Loading volumes only limited by tunnel cross-section
  - + Interaction protocol with Company keeping control of the road tunnel (LNGS, LSC, LSM)
- **Helical drive access** (SUPL, Yemilab, CLAB)
- **Multiple** (CLAB, Yemilab)
  - + Cage system and drive-in possibility

Radon, ventilation and environment



Rn level is crucial for health and for experimental activity

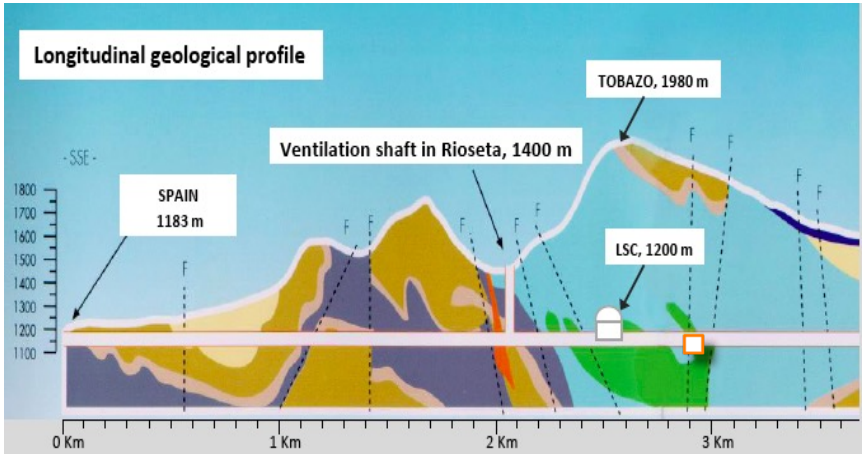
Rn activity depends on the environment and rate of air volume exchange underground.

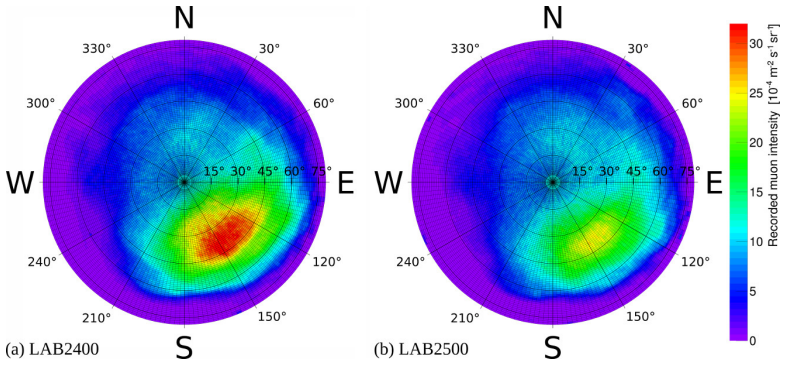
Mitigation: dedicated ventilation system or Rn abatement system

Muon flux vs rock overburden

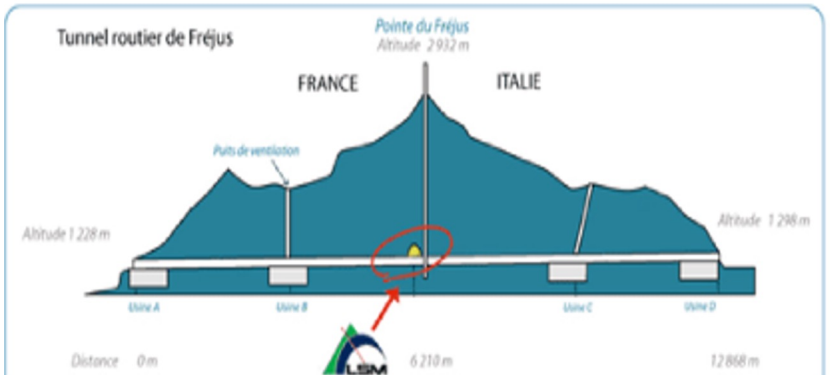
The mountain profile affects the muon flux underground

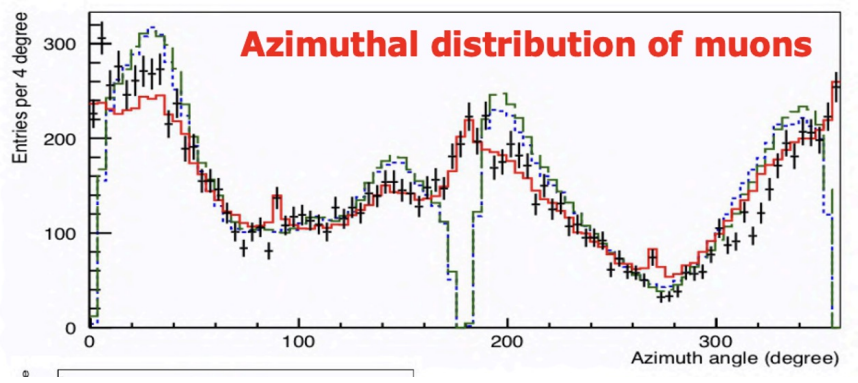
The case of LSC



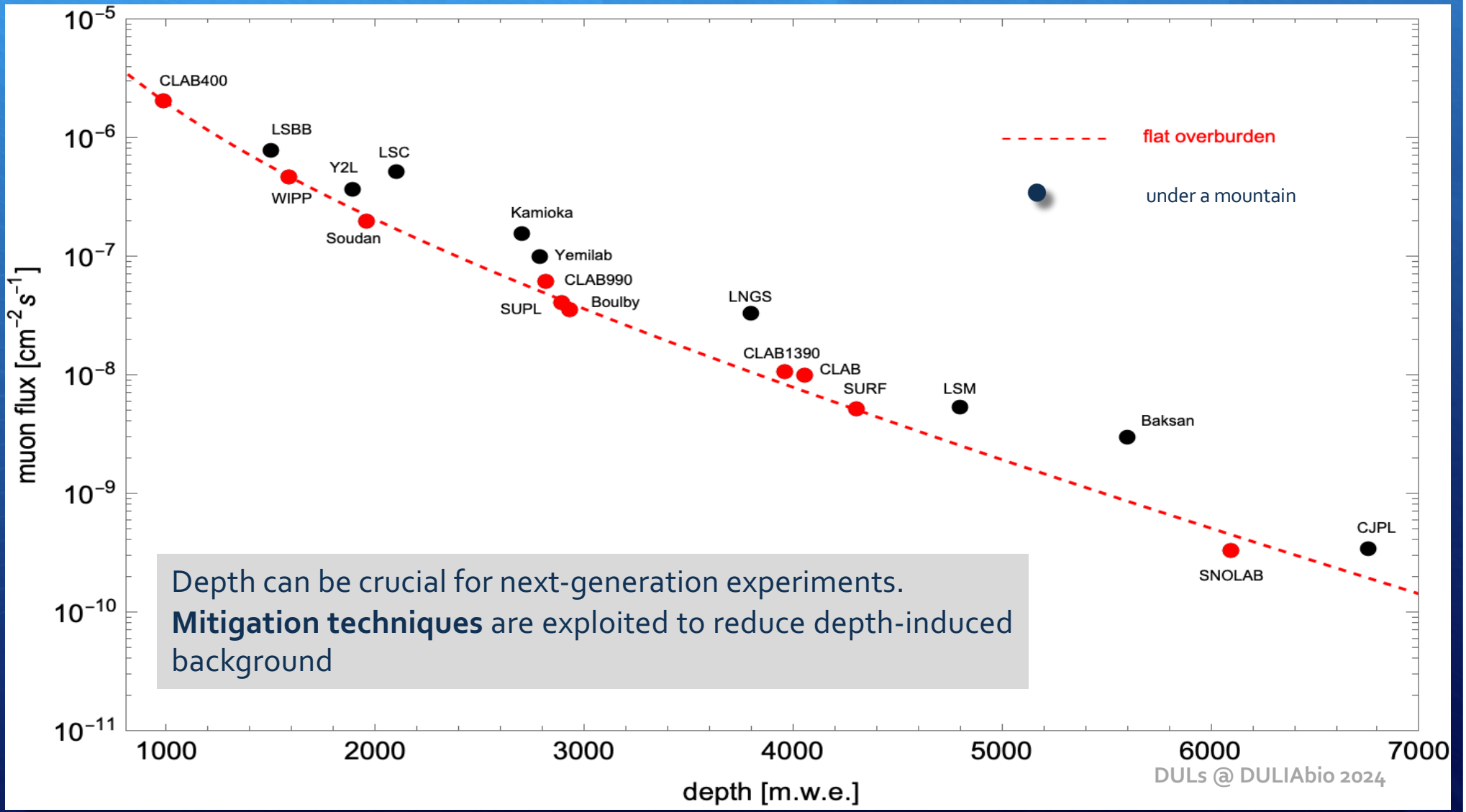


The case of LSM





Muon flux vs depth



Key technologies developed in DULs

DULs can develop new technology

Not an exhaustive list

- Innovative technology in radio-purity assay
- Innovative technology for Rn-free environments
- New advanced technologies for cryogenic infrastructures
- Additive manufacturing for rare events research
- SiPM based innovative photo-detectors
- Superconducting sensors in ultra-low background environments for quantum computing
- Muon tomography
- Safety and engineering in deep underground research infrastructures
- …

DULs worldwide collaboration

- EU DULs have a long history of collaboration that has intensified in recent years
- **Global collaboration required** for next-generation experiments
  - ✓Working Group established during TAUP 2023
- Representatives
  - Boulby (UK): Sean Paling
  - CLAB (Finland): Julia Puputti
  - CLPL (China): Qian Yue
  - LNGS (Italy): Aldo Ianni
  - LSBB (France): Gilles Micolau
  - LSC (Spain): Carlos Peña-Garay
  - LSM (France): Silvia Scorza
  - SNOLAB (Canada): Jeter Hall
  - SUPL (Australia): Kim Mintern-Lane
  - SURF (USA): Jaret Heise
  - Yemilab (South Korea): Kang-Soon Park
  - ANDES (Argentina): Xavier Bertou

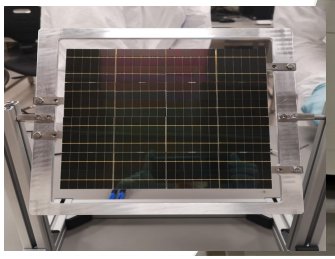
DULs cooperation: main goals

Foster	Foster coordination and synergy between DULs
Coordinate	Coordinate global strategy for future investments
Establish	Establish a transnational access (TA) policy
Reinforce	Reinforce cooperation and coordination in key services to support next-generation experiments
Connect	Connect existing facilities through a Virtual Coordination Office to support research and optimize synergy

Highlights from DULs

New infrastructure @ LNGS: NOA

- ISO6 400 m^2 CR built on surface to be operated in Rn-free mode (1000 m^3/h)
- Outfitted with equipment for SiPM-based photodetectors packging
- In no radon-free operation mode: 7800 m^3/h
- Standard (Rn) operation mode with all equipments: 400 kW (660 kW)
- **Use**:
  - ✓Assembly of detector parts
  - ✓Development of SiPM-based photodetectors to be operated in LAr /LXe
  - ✓**Production of photosensors for DarkSide-20k underway**



DS-20k photo detection unit

Bellotti Ion Beam Facility

LABORATORI NAZIONALI DEL GRAN SASSO

LNGS user facility open to external proposals

Start of Scientific data taking: **19 June 2023**

First Scientific results presented at at the International Symposium "Nuclei in the Cosmos XII" (17-22 September 2023)

A new underground measurement of $^{14}N(p,\gamma)^{15}O$ reaction at the LNGS Bellotti Ion Beam Facility

Alessandro Compagnucci[1]
on behalf the LUNA collaboration

(1) Gran Sasso Science Institute and INFN, Laboratori Nazionali del Gran Sasso
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Preliminary results

- During the first beam time in **June 2023**, cross section data have been collected in the energy range **0.25-1.3 MeV** with one HPGe detector at 55° and 5 cm from the target, for a total of 38 C of charge collected on 4 different targets.

Specifications of the 3.5 MV Accelerator

Ion specie	Terminal Voltage 0.3 MV – 0.5 MV	Terminal Voltage 0.5 MV - 3.5 MV
$^{1}H^{+}$	500 µA	1000 µA
$^{4}He^{+}$	300 µA	500 µA
$^{12}C^{+}$	100 µA	150 µA
$^{12}C^{+2}$	60 µA	100 µA

Terminal Voltage Ripple (max):	± 0.01 %
Reproducibility of Terminal Voltage (max):	± 0.01 %
Variation of beam energy after 1h:	< 0.001 %
Variation of beam intensity after 1h:	10 %
Intervention free operation time	> 24 h
Interruption free operation	> 24 h
Service Interval	> 29 d
Beam time / year	> 308 d
Beamlines available for scientific users	2

Call for proposals of experiments

https://l.infn.it/Bellotti

PI: Matthias Junker

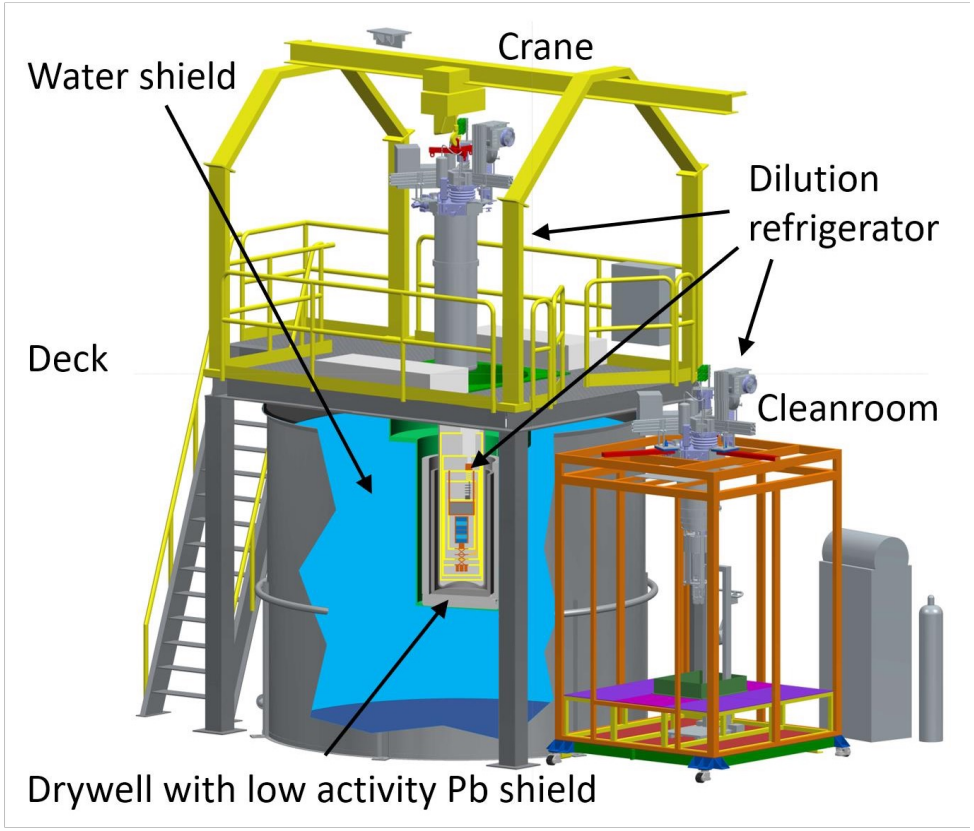
New radiopurity assay facility @ LNGS: STELLA

Detector space shielded by PE, water, and 5 cm of steel
3-floor building
New area for samples handling
Status: outfitting completed, detectors being installted

PI: Matthias Laubenstein

CUTE at SNOLAB: a facility to support new developments

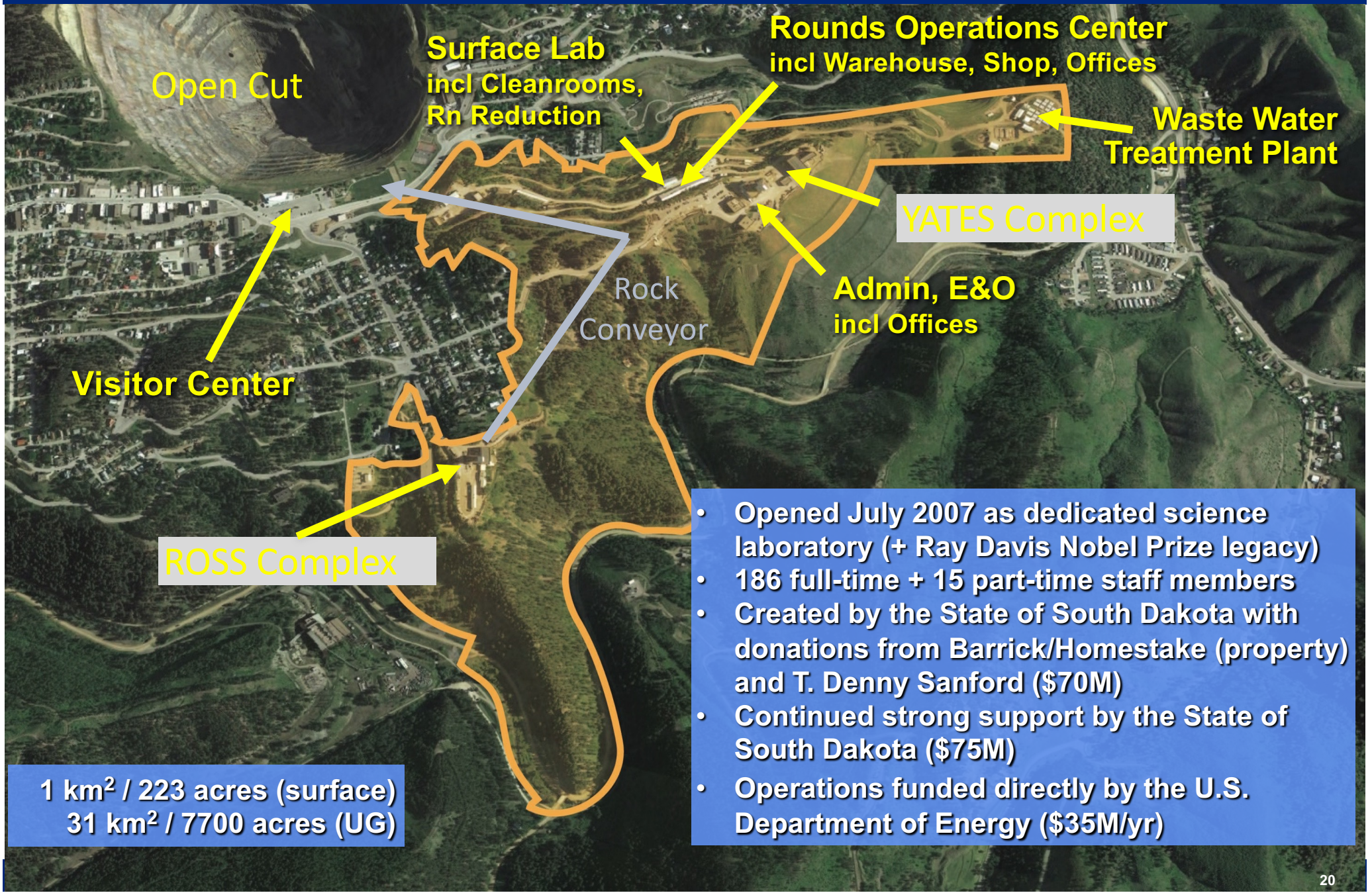
- CUTE, the **cryogenic underground test facility** built to test components of dark matter experiments. It is well shielded from background radiation, can operate at very low temperatures, and is designed to prevent micro-vibrations that could interfere with testing.
- Lead, water and PE used as shielding at SNOLAB depth
- Carrying out tests for SuperCDMS



SNOLAB: a unique class 2000 clean laboratory deep underground

Sanford Underground Research Facility

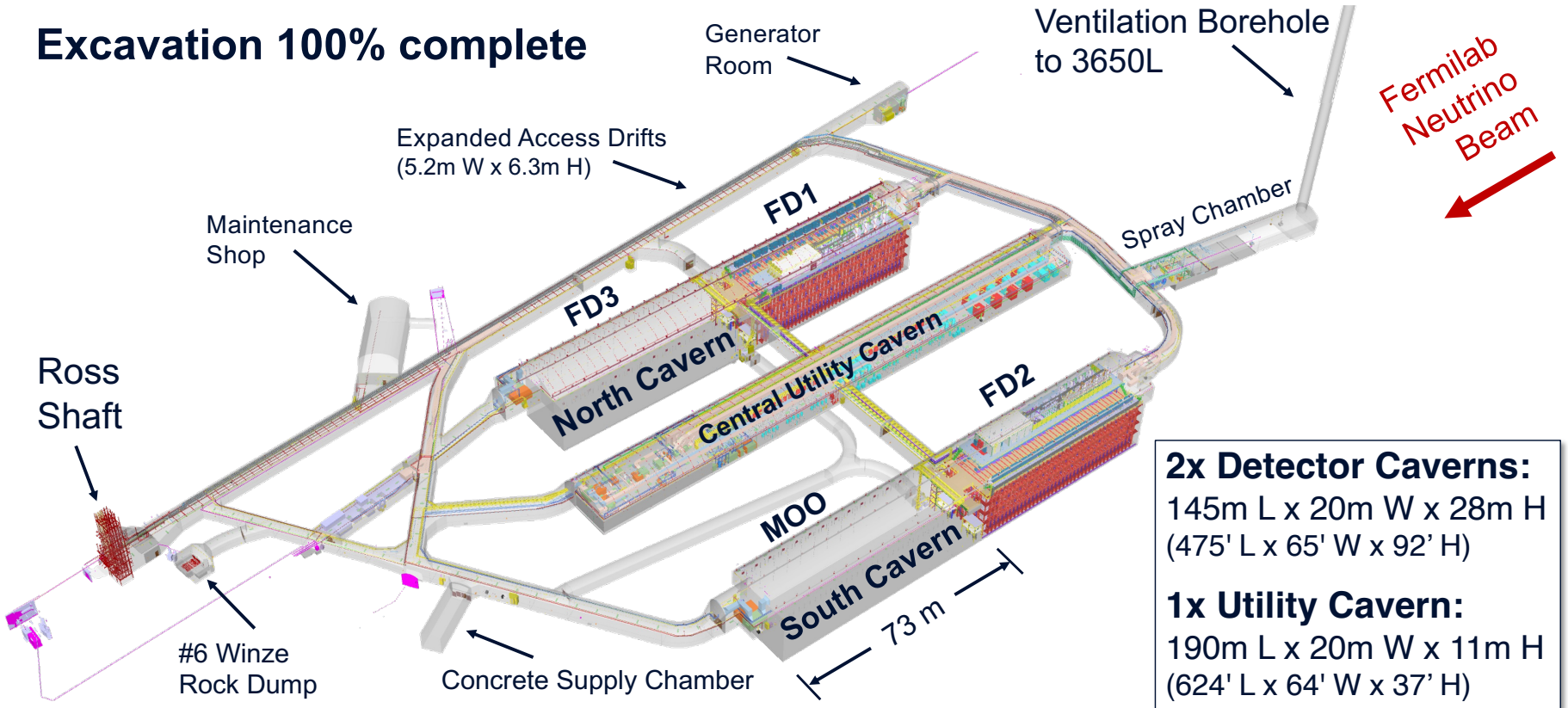
Nation's deepest underground lab, advancing multi-disciplinary research



- Opened July 2007 as dedicated science laboratory (+ Ray Davis Nobel Prize legacy)
- 186 full-time + 15 part-time staff members
- Created by the State of South Dakota with donations from Barrick/Homestake (property) and T. Denny Sanford ($70M)
- Continued strong support by the State of South Dakota ($75M)
- Operations funded directly by the U.S. Department of Energy ($35M/yr)

1 km^2 / 223 acres (surface)
31 km^2 / 7700 acres (UG)

DUNE, long-baseline neutrino FD



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

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

4850L new expansion @ SURF

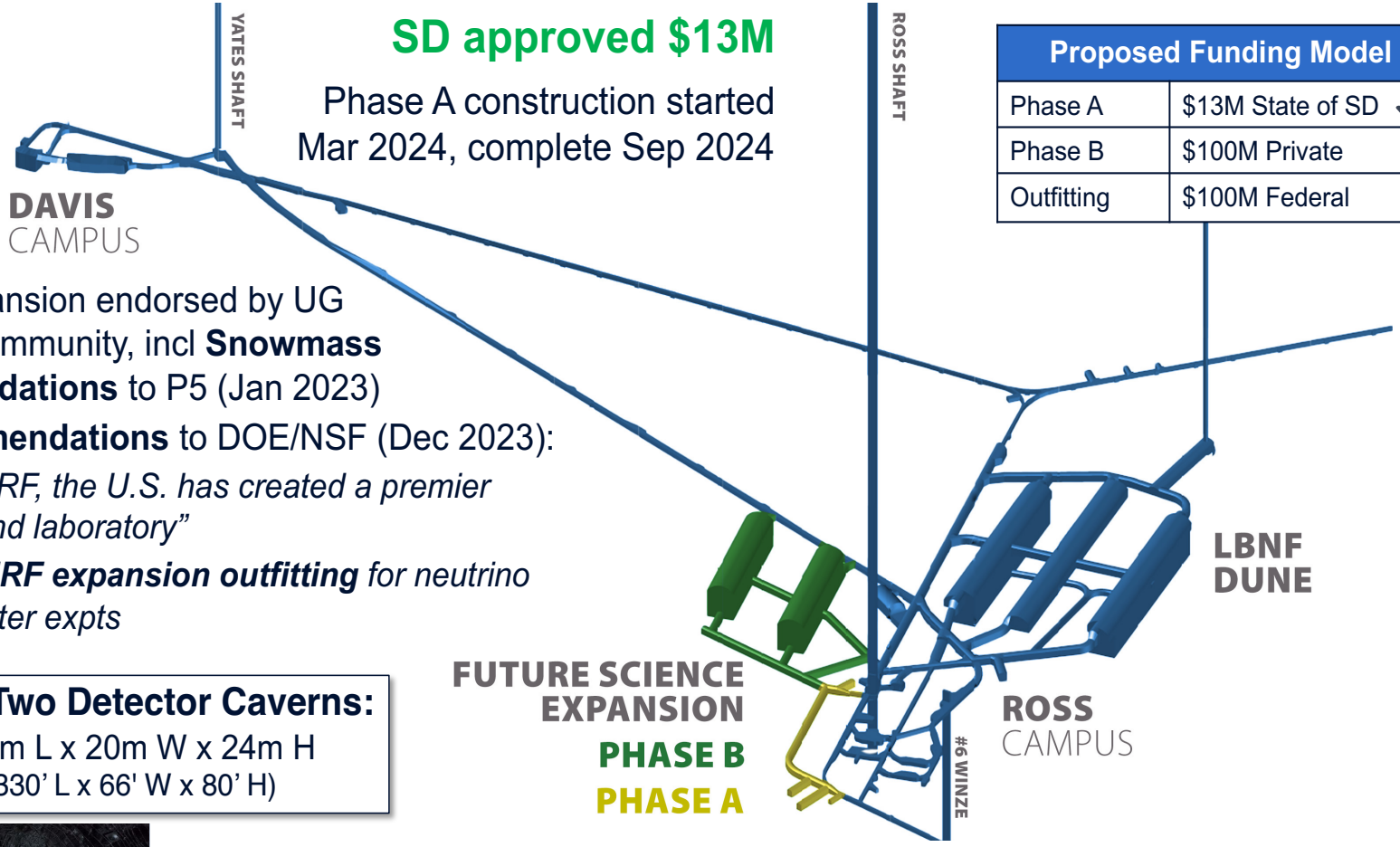
SD approved $13M

Phase A construction started
Mar 2024, complete Sep 2024

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

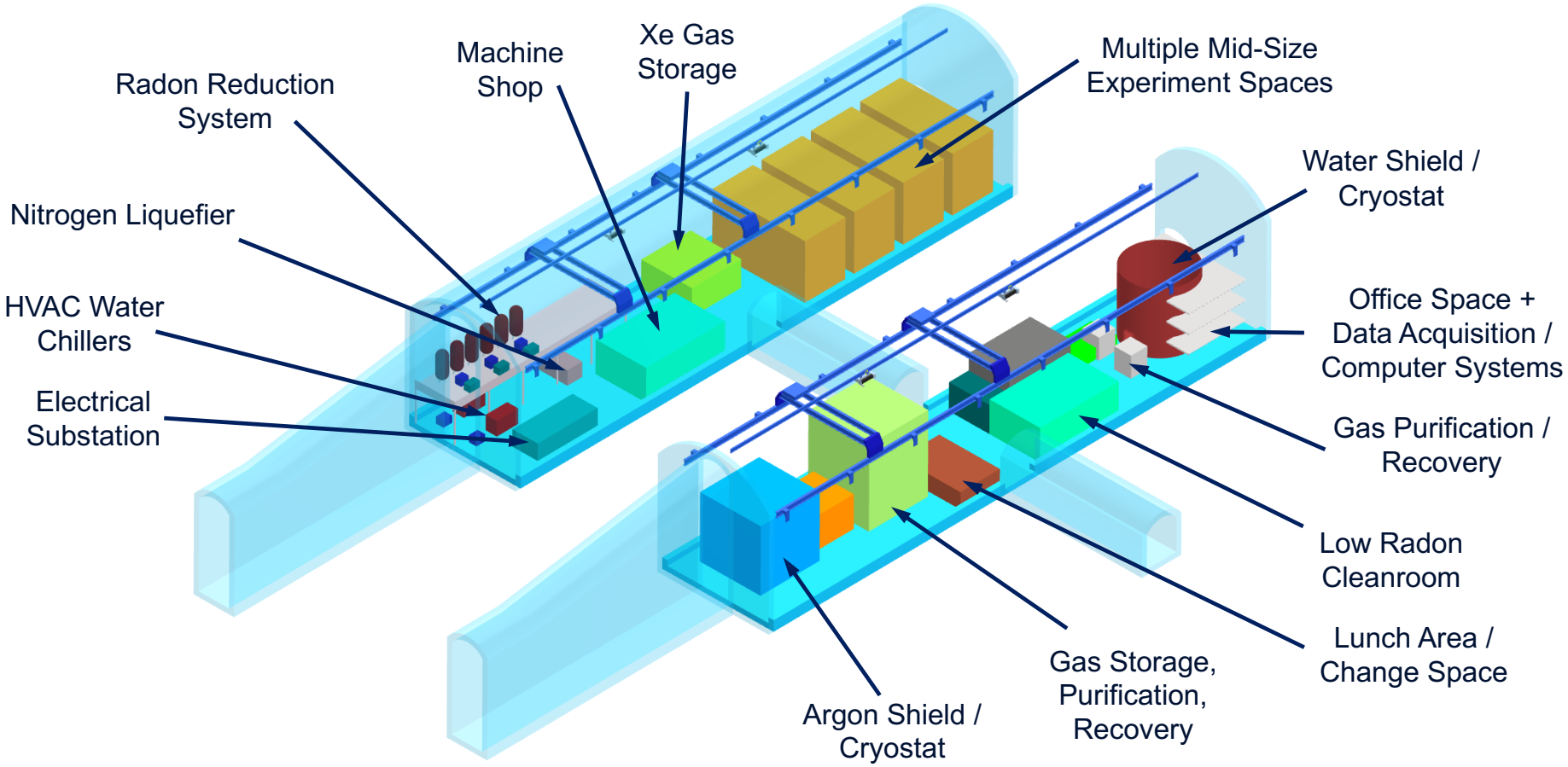
- SURF Expansion endorsed by UG Science Community, incl **Snowmass recommendations** to P5 (Jan 2023)
- **P5 recommendations** to DOE/NSF (Dec 2023):
  - *"With SURF, the U.S. has created a premier underground laboratory"*
  - ***Fund SURF expansion outfitting*** *for neutrino & dark matter expts*

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



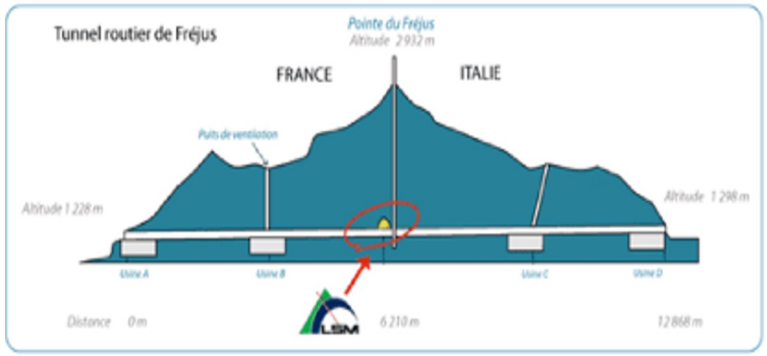
Phase A underway
Phase B and outfitting, 2028-2031

Conceptual layout for the new expansion (towards G3DM)



Modane UL (LSM)

A French National RI



Location (Modane):

- 130 km from Grenoble
- 200 km from Lyon
- 100 km from Torino

Surface building

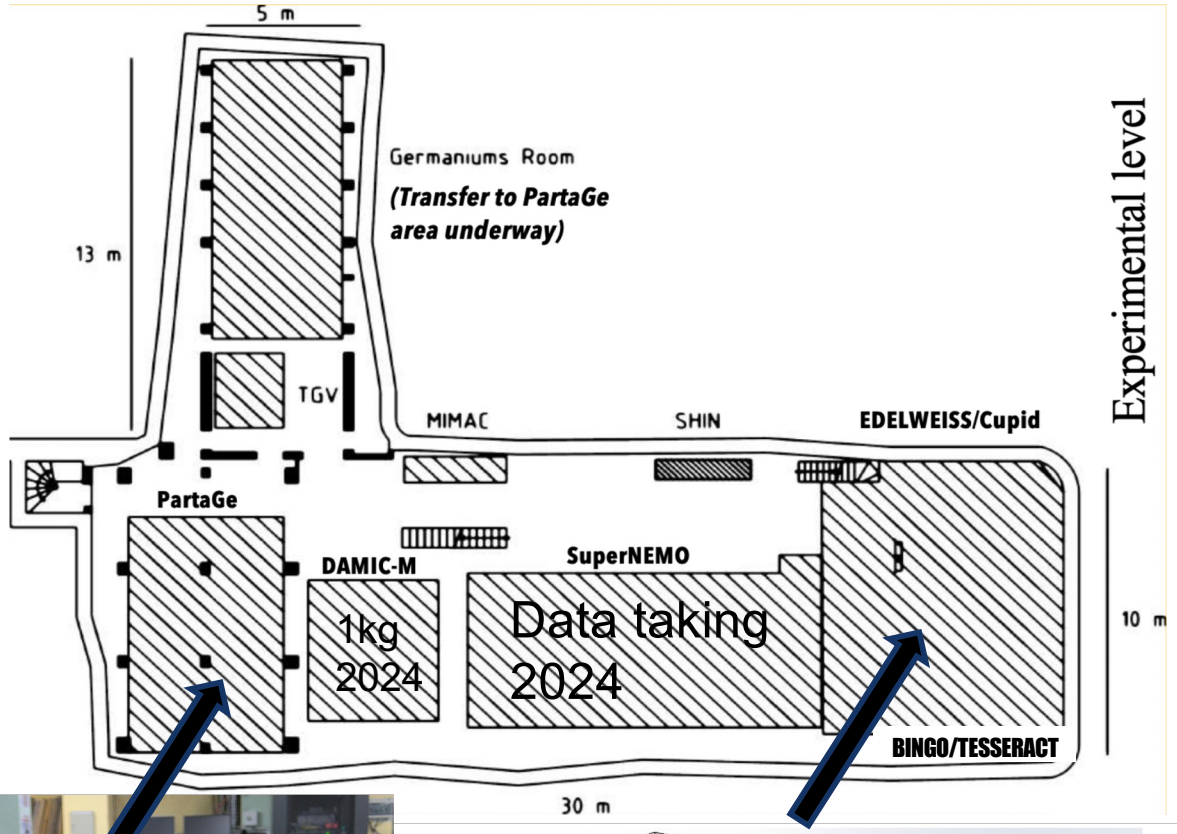
Deepest site in Europe with 4.5μ/m²/day
Since 1979
Easy access
3500 m³ and 400 m²
Radon ~ 15 Bq/m³

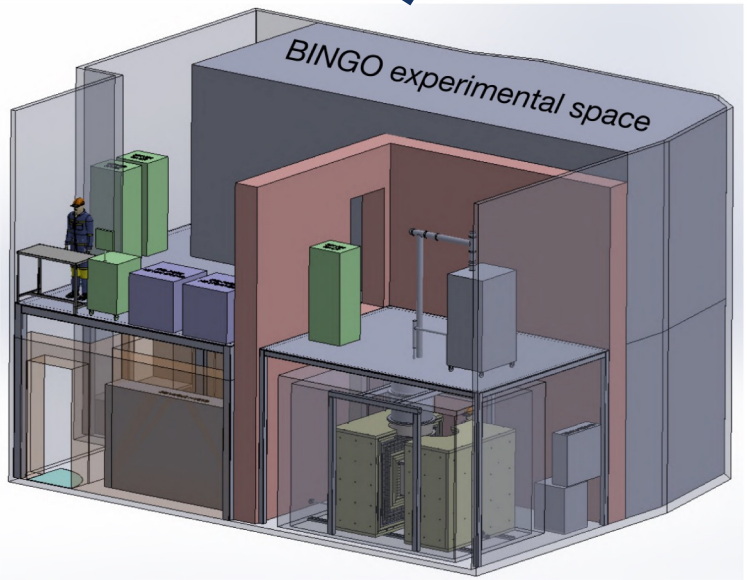

6
Grenoble 130 km
E70
Torino 100 km

LSM occupancy and future plan

Tight occupation of the available 400m²

Design study to possibly install ***180m² mezzanine level*** *(over the crane access) above the experimental level*

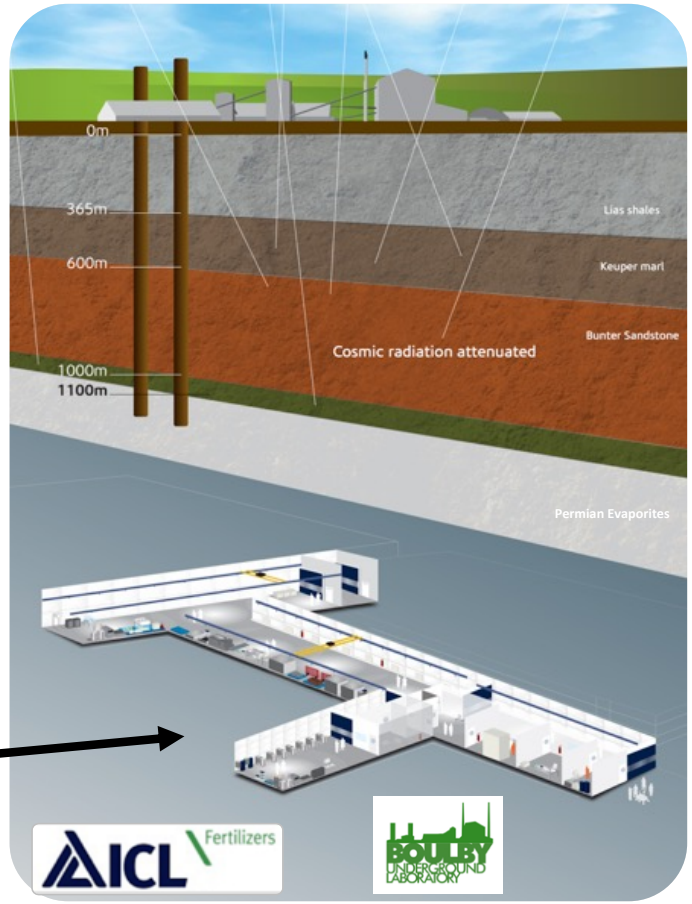


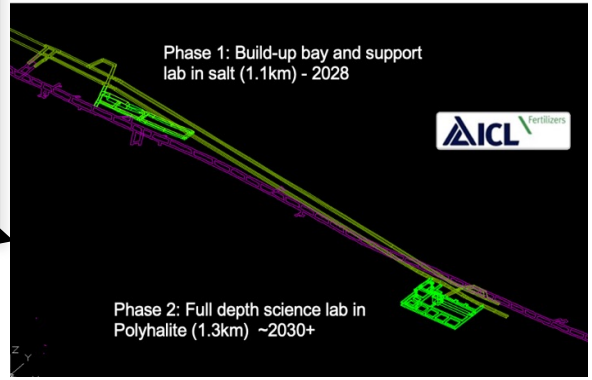


25 HPGe detectors
15 in **PartaGe**
Upgraded to reduce the background level
~1000 samples/year
Wide-range program
for Astroparticles,
Earth Sciences
(sediment and ice core sample datation),
environmental safety (CEA), biology, etc...

STFC Boulby Underground Science Facility

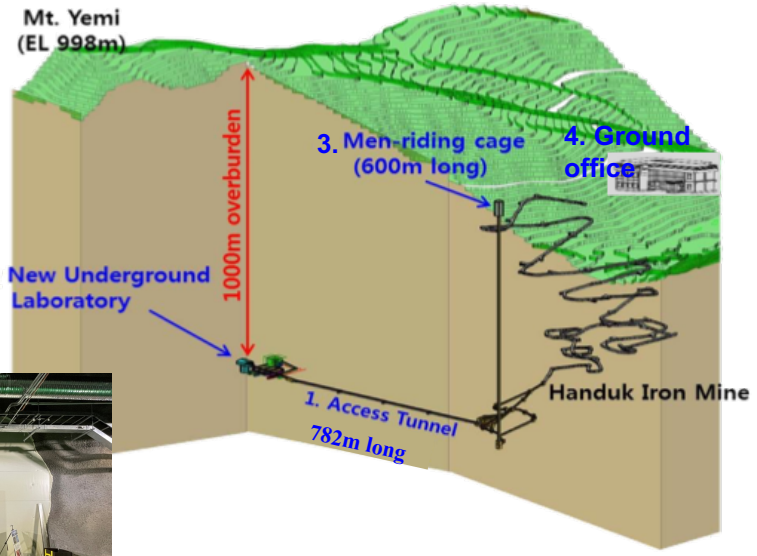
- Located in a polyhalite and rock-salt mine
- Deepest mine in Britain
- 1.1 km deep with low background surrounding rock-salt with 10^6 reduction
- **4000 m³ class 10k and 1k clean laboratory (ISO 7 and 6)**
- **3000 m³ outside underground experimentation area available**
- Surface support building
- **world's first 2-phase Xe detector**
- **Medium-to long term**: build a major new DUL to host next-generation world-leading projects
  - ✓ **Boulby development project**
  - ✓ Expansion feasibility study completed in 2021
  - ✓ **Phase 1 (2028) and 2 (>2030) with large cavity**



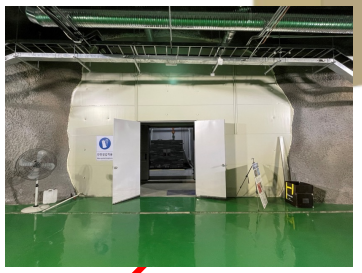


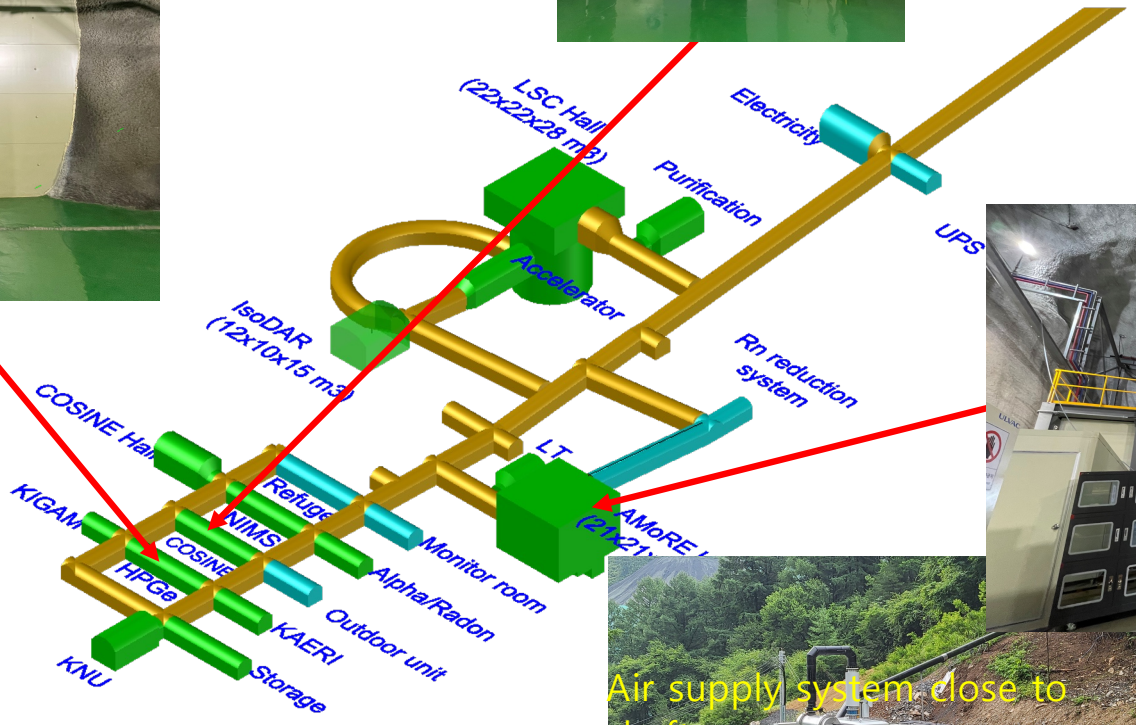
YEMILAB

Surface building



❖Relocated Y2L equipment to Yemilab





30,101 m^3 and 2,946 m^2
Air supply: 12,000 m^3/h
- 6,000 m^3/h from surface
- 6,000 m^3/h from re-circulation

Rn level currently 150 Bq/m^3


MINEARC SYSTEMS
ETS400
enviroLAV
mineARC
Toilet


国家重大科技基础设施
极深地下极低辐射本底前沿物理实验设施
CJPL: China Jinping Laboratory
Outfitting of CJPL-II being completed
垂直岩石覆盖厚度2400米
距离西出口9km
距离东出口9km
排水隧道
Draining Tunnel
1号门
No.1 Gateway
2号门
No.2 Gateway
2号辅助隧道
No.2 Auxiliary Tunnel
交通隧道B
Traffic Tunnel B
交通隧道A
Traffic Tunnel A
辅助隧道 Auxiliary Tunnel
交通隧道 Traffic Tunnel
排水隧道 Draining Tunnel
核天体物理实验
中微子实验
实验厅A
Hall A
A1
A2
无中微子双贝塔衰变实验
B1
B2
实验厅B
Hall B
暗物质实验（常温水屏蔽）
C1
C2
低本底中心
实验厅C
Hall C
暗物质实验
（低温液氖屏蔽）
D1
D2
中微子实验
无中微子双贝塔衰变实验
实验厅D
Hall D
1号辅助隧道
No.1 Auxiliary Tunnel
国际上宇宙射线通量最少、岩石覆盖厚度最深、可用空间最大、综合条件最好的极深地下实验设施，能提供极低辐射本底实验条件，满足暗物质、中微子、无中微子双贝塔衰变、核天体物理等实验极端辐射本底实验需求。

LSC

Canfranc Underground Lab

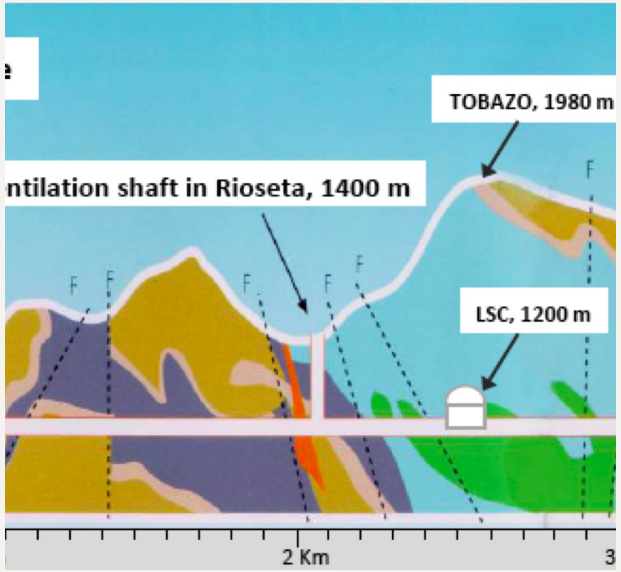
Located in Spanish-French Pyrenees border.

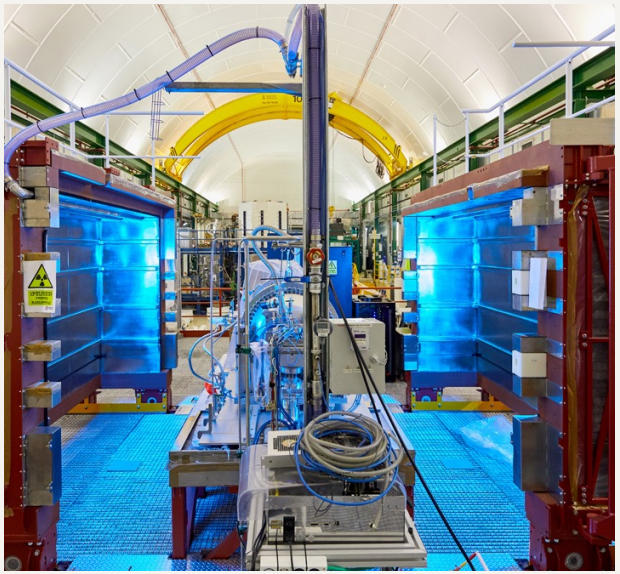
Two-way access tunnels: abandoned train tunnel and operative road tunnel.

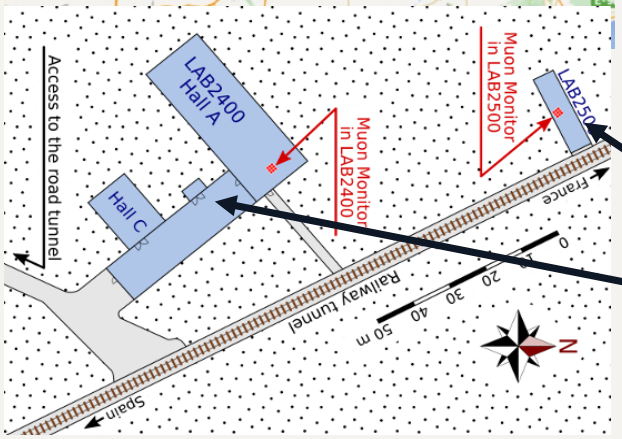
First experiments (IGEX, …) since 1986. Modern lab, 1600 m^2, operative since 2010. 260 scientists from 50 institutions.

800 meters (v) of rock - muon flux is $5x10^{-7}$ $cm^{-2}s^{-1}$; neutron flux (E<10MeV) is $3.5x10^{-6}$ $cm^{-2}s^{-1}$; gamma flux is 2 $cm^{-2}s^{-1}$

Radon abatement system: 220 m^3/h radon-reduced air at 1mBq/m^3





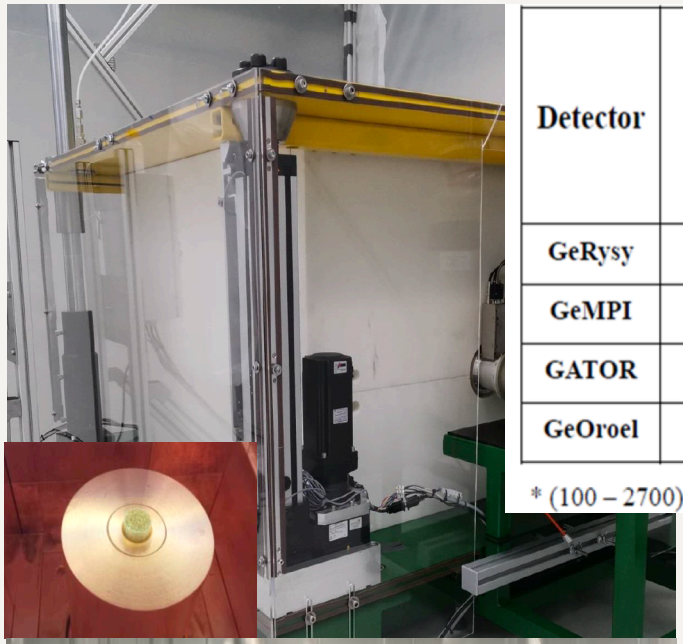


Two underground sites:

LAB2500

LAB2400

Improved low radioactivity techniques @ LSC with GeRysy



Detector	M_{act} [kg]	V_{cham} [L]	Lab	Counting rates in the full energy range [cts/d/kg] and for various peaks [cts/yr/kg]						
				40 - 2700 keV	609 keV [^{226}Ra]	662 keV [^{137}Cs]	583 keV [^{228}Th]	1332 keV [^{60}Co]	1461 keV [^{40}K]	2614 keV [^{228}Th]
GeRysy	2.27	15	LSC	50 ± 1	74 ± 19	< 27	27 ± 17	< 37	60 ± 16	25 ± 9
GeMPI	2.21	15	LNGS	66 ± 1	< 30	57 ± 27	< 21	35 ± 8	86 ± 12	18 ± 5
GATOR	2.20	15	LNGS	103 ± 1*	99 ± 33	50 ± 17	--	83 ± 17	83 ± 17	33 ± 16
GeOroel	2.31	40	LSC	142	190	--	182	91	66	--

* (100 – 2700) keV

Preliminary results

New lowest background HPGe for screening (collaboration UJ-LSC, led by G. Zuzel). Another two HPGe in preparation.

	^{238}U				^{232}Th			
Modo	LOD, ppt	LOQ, ppt	BEC, ppt	Sensibilidad (cps/ppt U)	LOD, ppt	LOQ, ppt	BEC, ppt	Sensibilidad (cps/ppt Th)
No gas	0.002	0.006	0.04	790	0.04	0.12	0.2	632
He	0.01	0.03	0.04	833	0.02	0.06	0.3	650

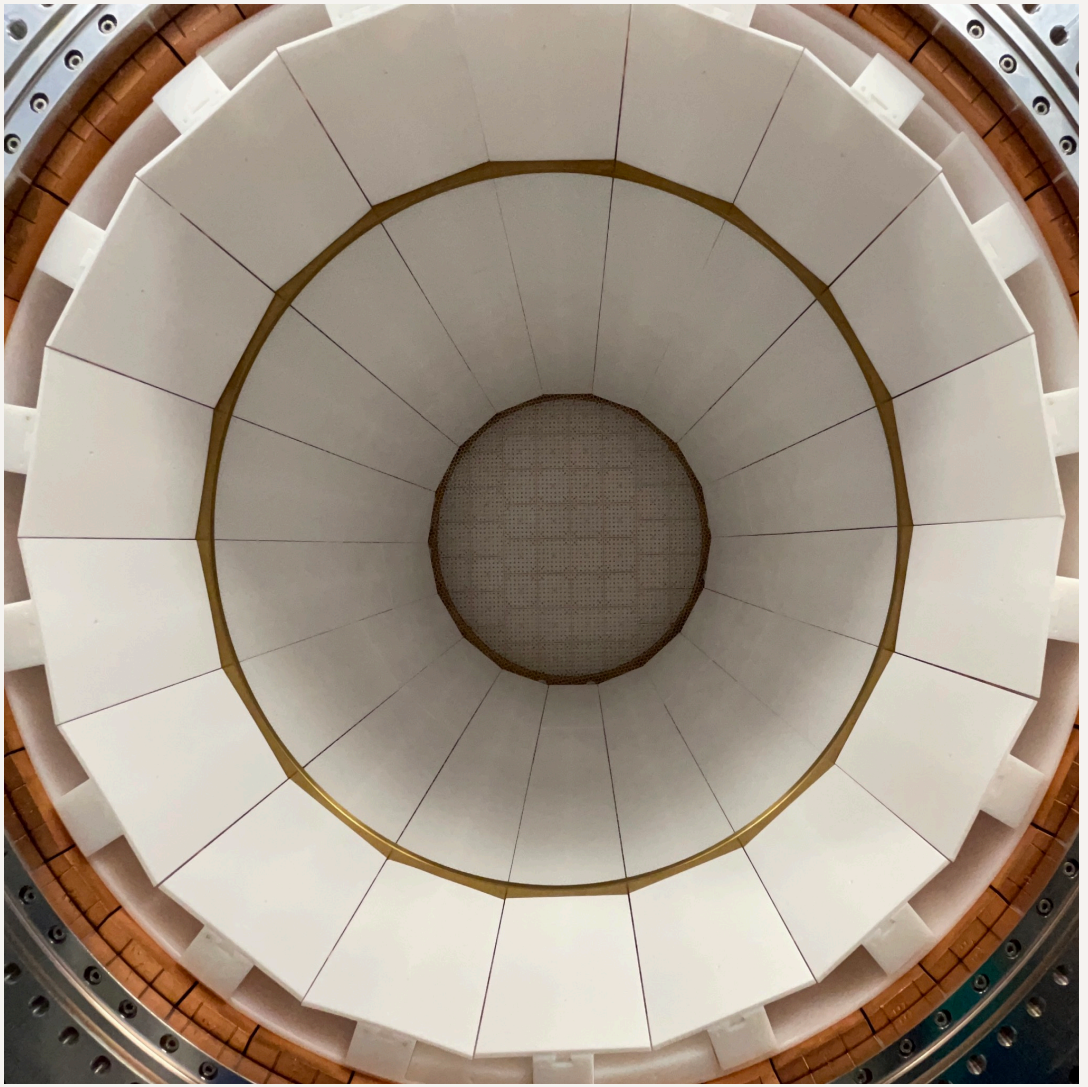
New ICPMS-QQQ, chemistry and automatization -> ppq limit of detection.

NEXT-100 @ LSC

Flagship experiment at LSC:

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 October 2023.

NEXT-HD - TPC with 1 ton of Xe-136 at high pressure will start construction plans in 2025. Already working in various directions: reduce backgrounds, heat dissipation, extract light by

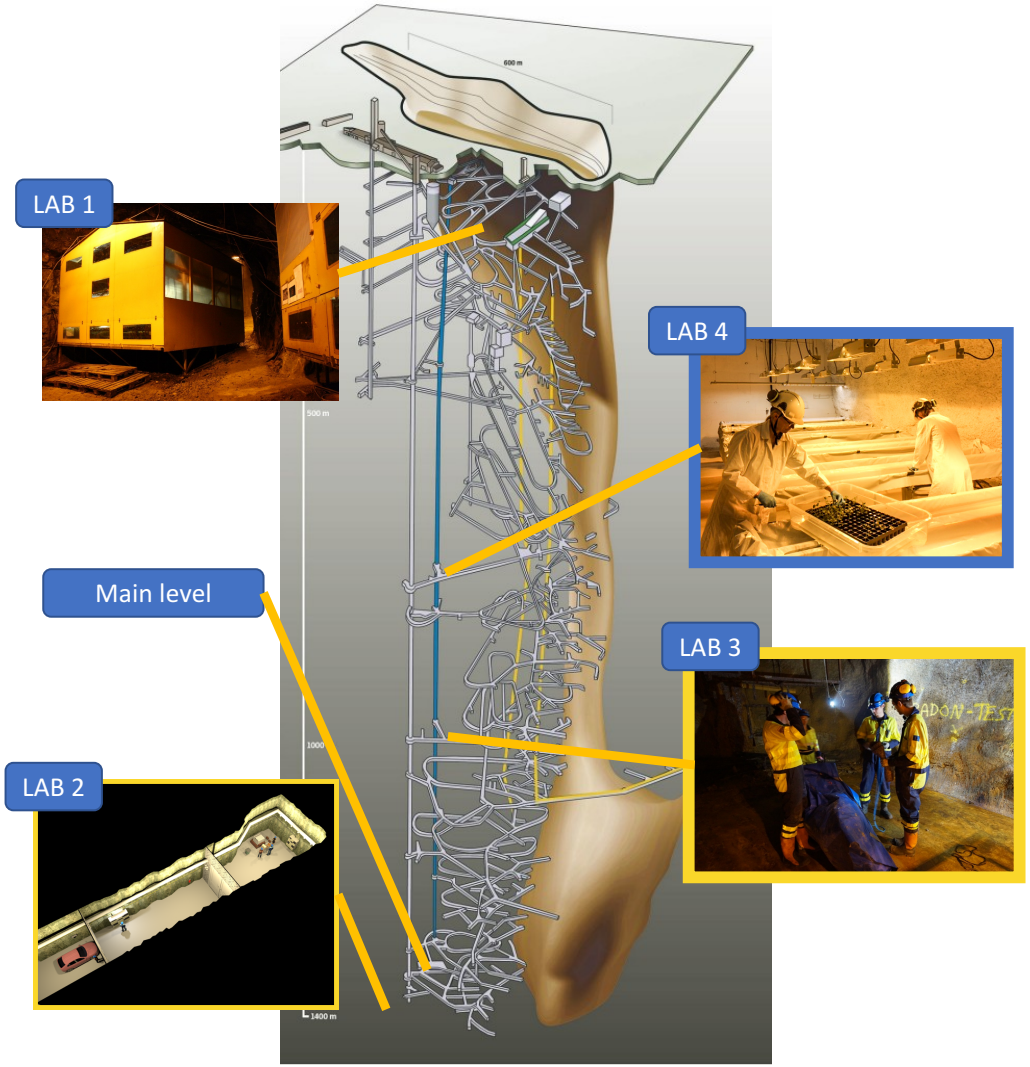


CALLIO LAB

Existing underground multidisciplinary research environments

- Physics: LAB 1, Main level
- Biology and food production: LAB 2, LAB 4
- Underground information modelling: LAB 3
- Occupational health (iLighting): Main Level
- Geology and hydrogeology studies: LAB 2
- Microseismic network: all over the mine
- MINETRAIN: all over the mine

www.calliolab.com

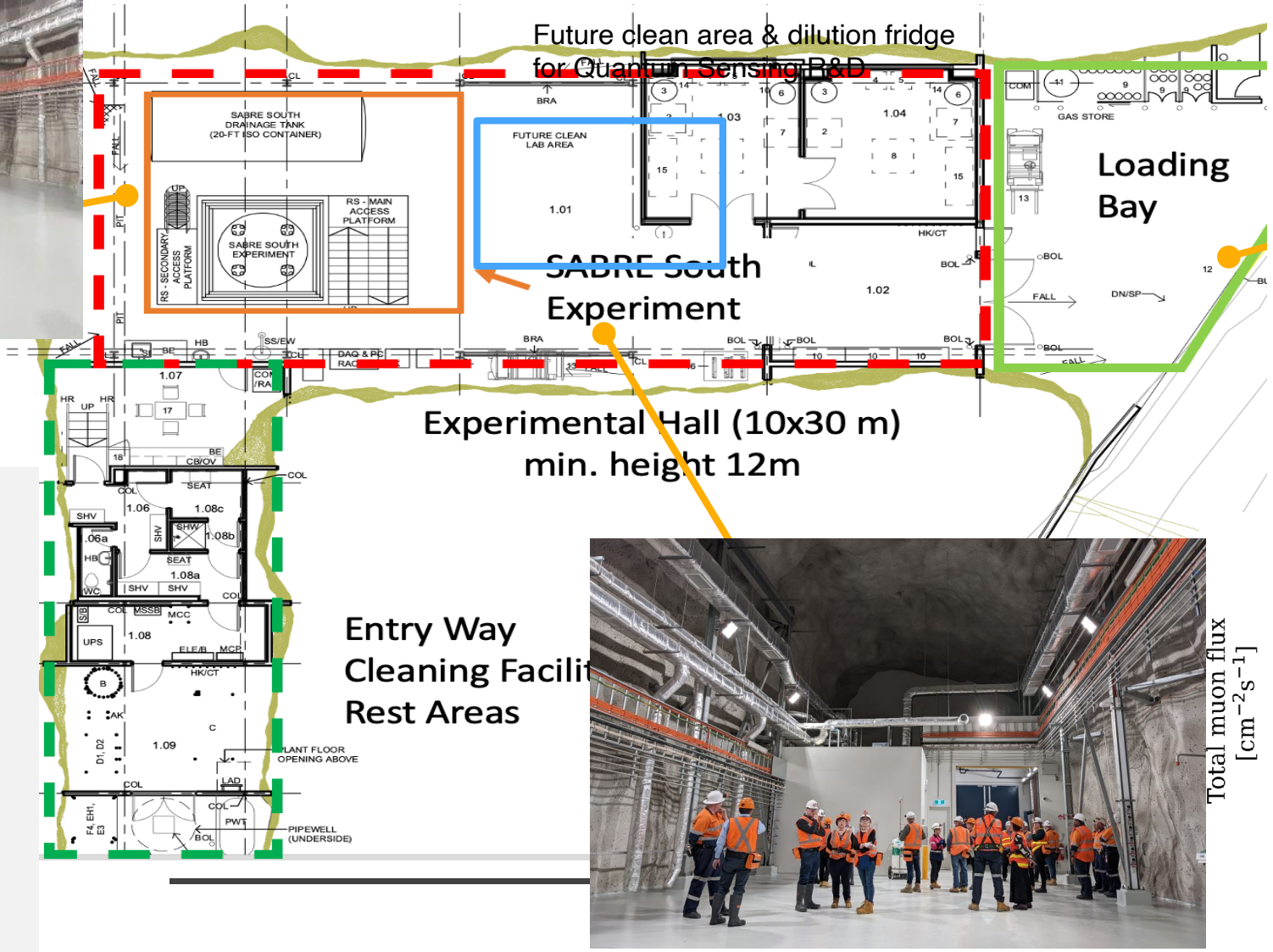


Callio Lab is a unique underground research environment in Pyhäsalmi, Finland.

- Flat overburden, vertical depth 1440 m (~4100 m.w.e)
- Access via incline (30min), shaft (<3 min)

See Jari Joutsenvaara at this meeting

STAWELL Underground Physics Lab (SUPL)

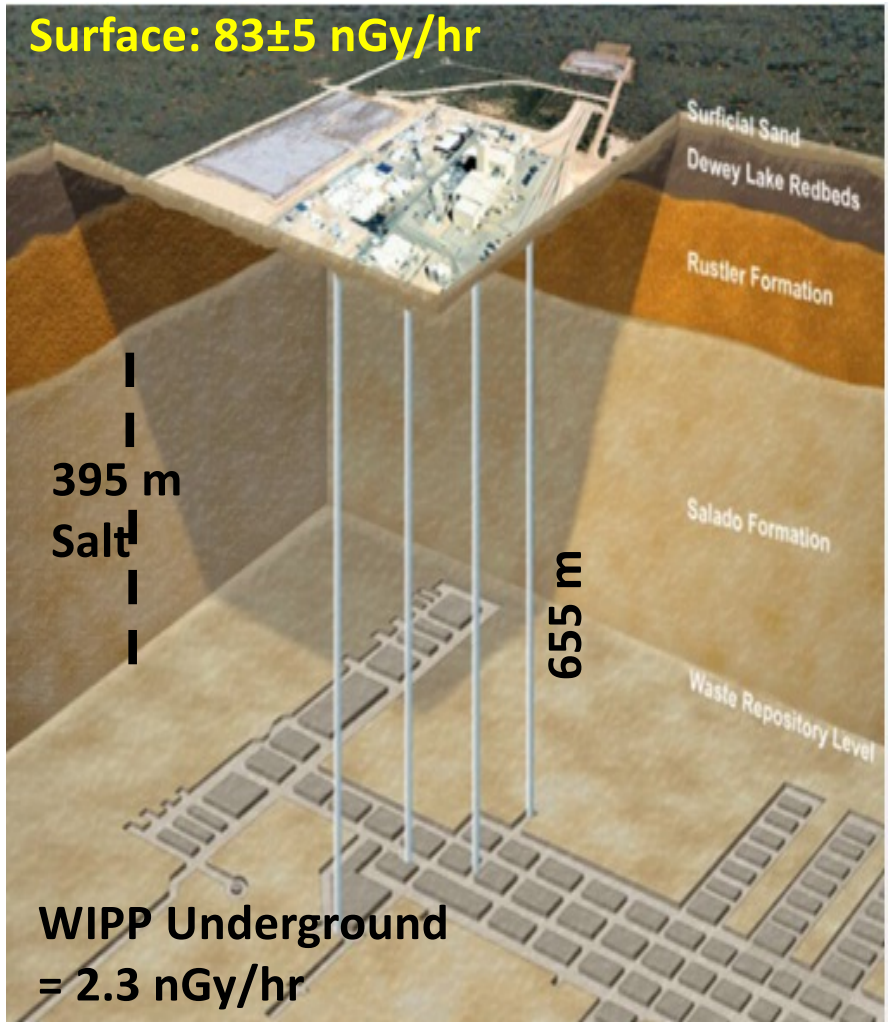


2014 proposed
2019 construction start
2022 outfitting start
1025 m deep
240 km from Melbourne
Helical drive access
Outfitting ends 2023
Muon flux meas. ongoing
SABRE South deployment
in 2025

WIPP

Thanks to Geoffrey Smith, NMSU

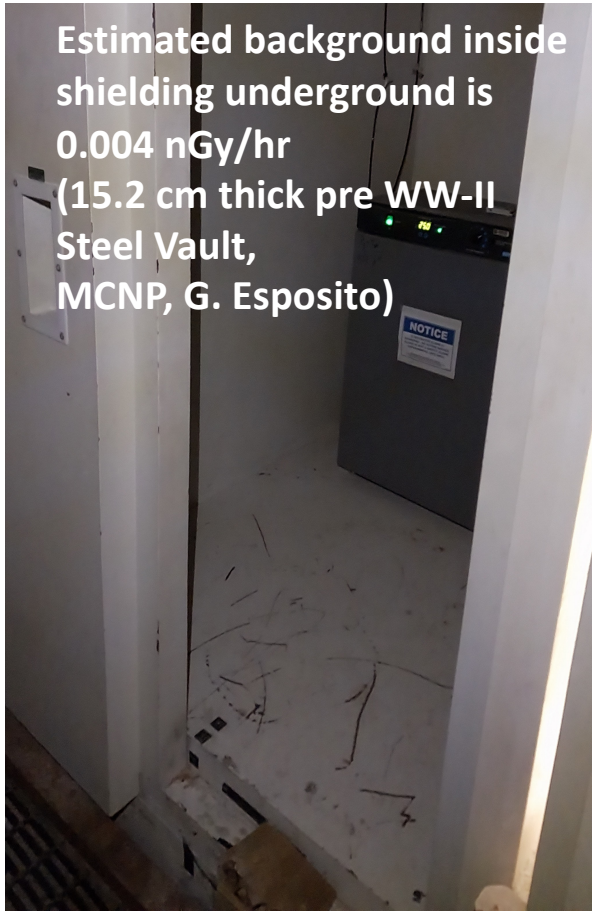
Gamma Dose Rates at WIPP.



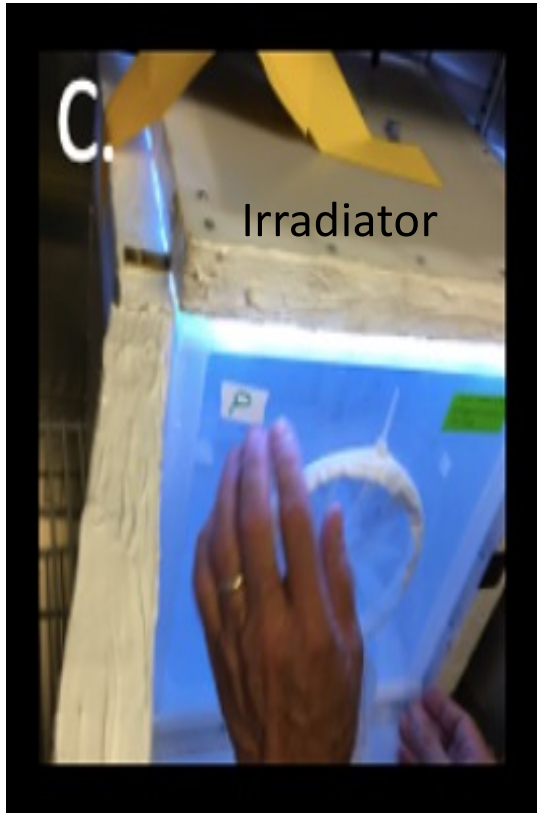
WIPP is 655 m deep, with 395 m salt over-burden

Low Radiation Experimental Design.

Cells at Surface vs. Underground in Vault

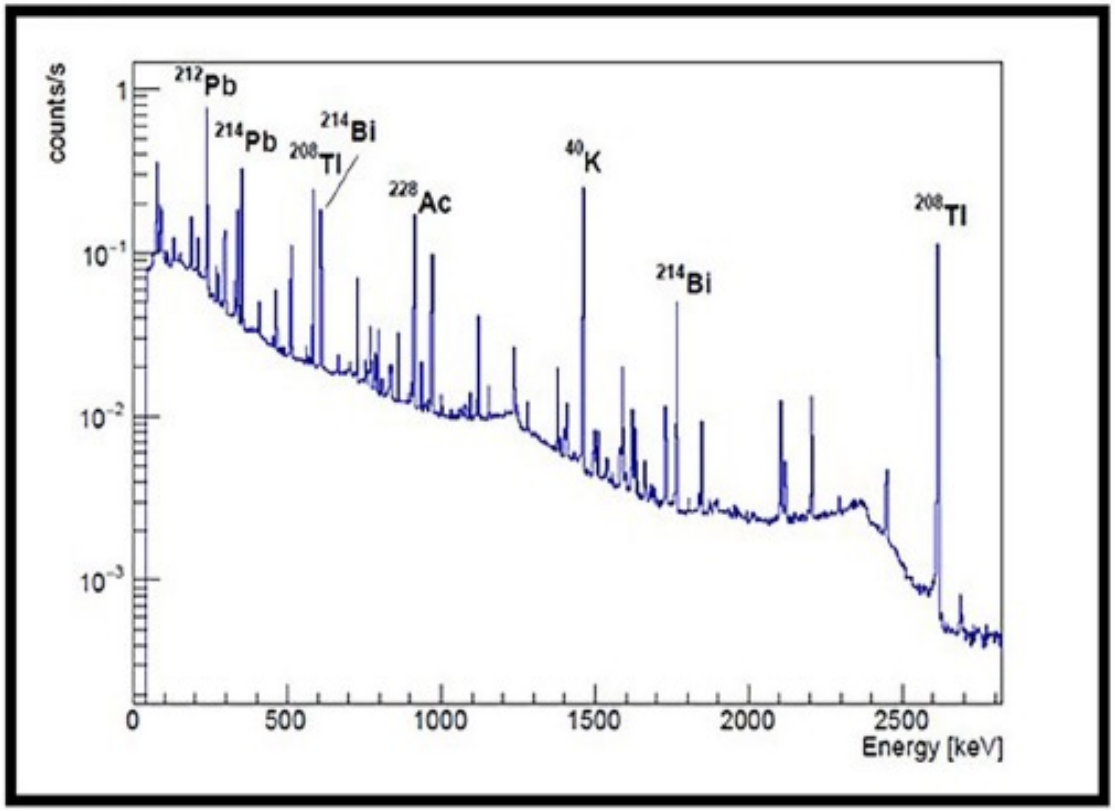


14 kg of Pozzolana or KCl gives an underground "Add-back" Control
Irradiator w/ ~ 140 nGy/hr

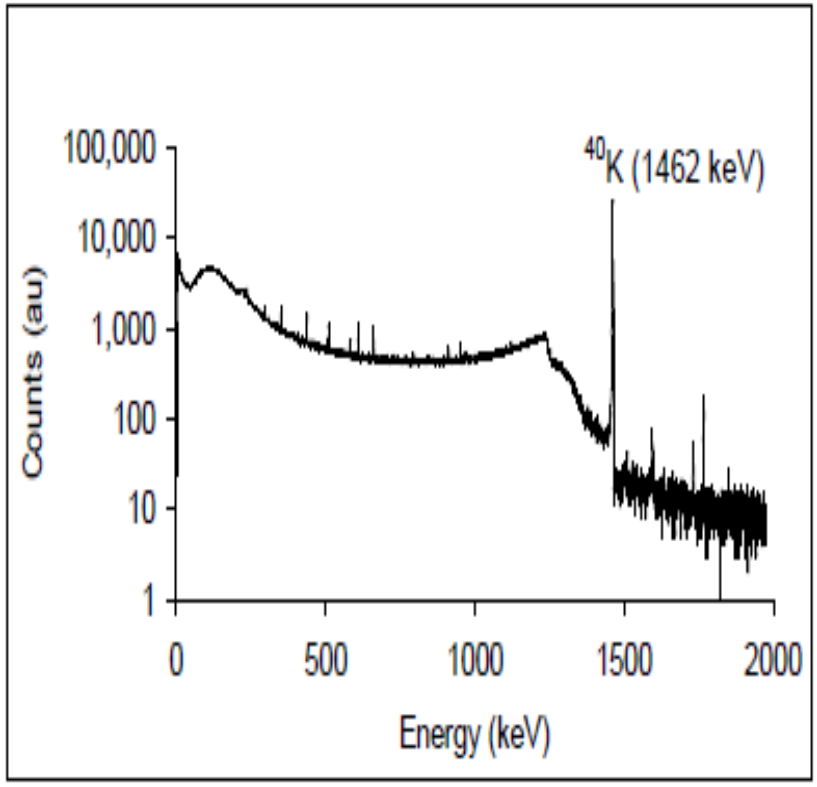


Expansion underway. Foreseen a 50-year operation plan.
Current site can be operated till 2033. Only 44% so far excavated of allowed volume.

Rad Quality We know organisms respond to different quantities of radiation.
We now ask: Can organisms sense and respond to different qualities of radiation?



HPGe spectrum of Tufo+Pozollana, ~ 122 nGy/hr
(Esposito et al.2021)

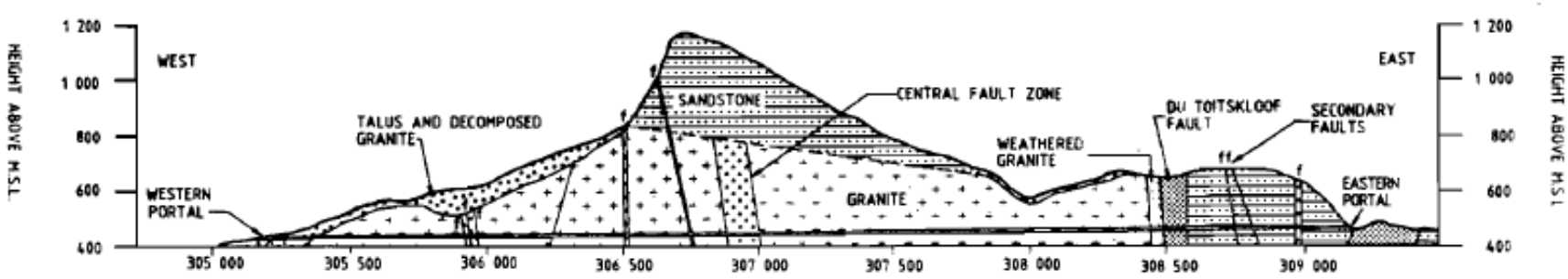


Spectrum of 40K,
(Espinosa et al. 2009)

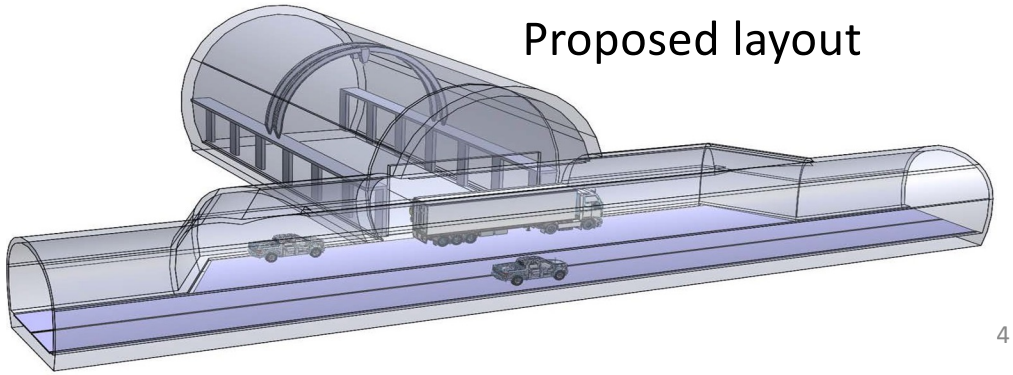
Thanks to Geoffrey Smith, NMSU

New DUL: PAUL South Africa

- Using an existing road tunnel (Huguenot tunnel close to Paarl town)
- 60 km from Cape Town
- Close to Stellenbosch University, University of Cape Town, University of the Western Cape
- Status: Conceptual Design Study ongoing
- Excavation expected in 2026



Proposed layout



10,240 m^3 laboratory (40x16x16)
640 m^2
~ 800 m rock overburden

Conclusions

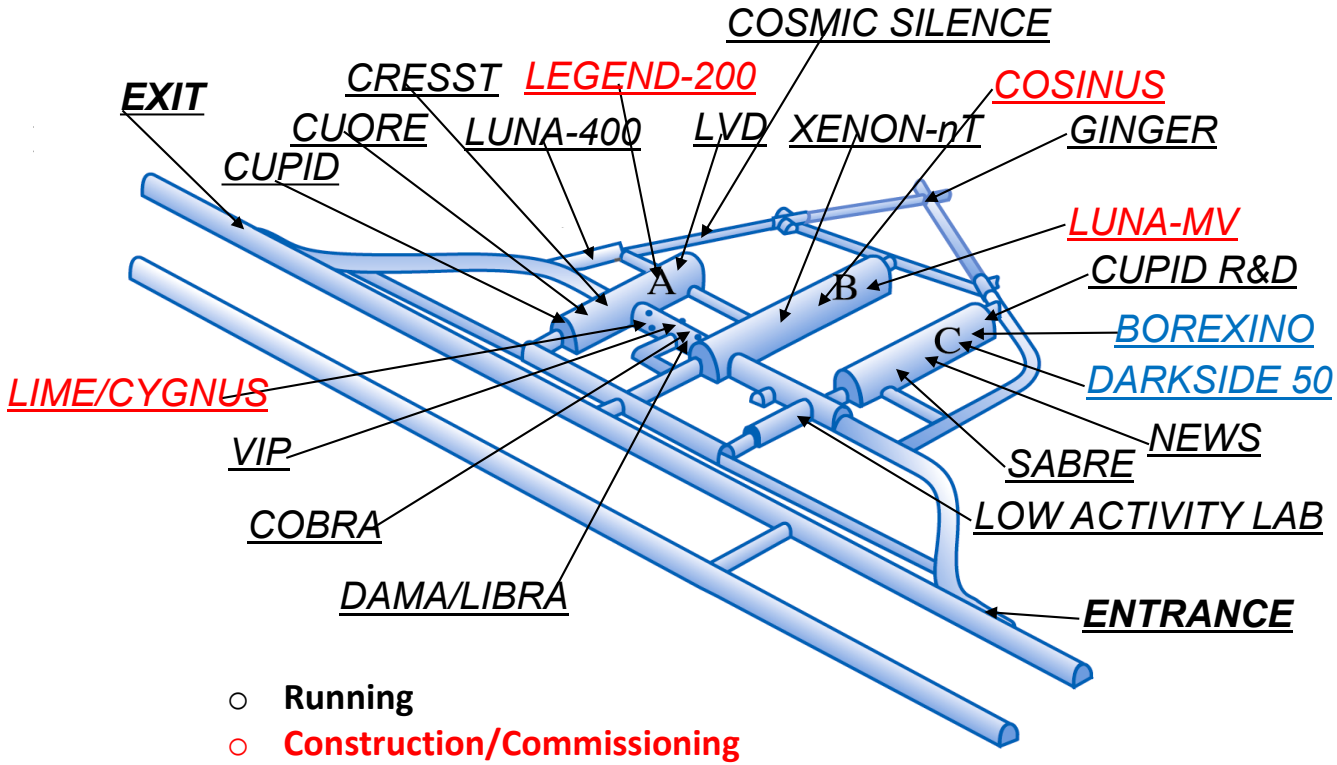
- At present **12 DULs in operation**
- Underground laboratories continue to expand:
  - Hyper-K and SURF ongoing; new proposal for Boulby and PAUL
- Science in Underground laboratories is pushing forward the limits of knowledge
- Several next-generation experiments under discussion for more sensitive results
- Order of 100 experiments running or under construction
- **Building the future**:
  - Enhance collaboration and coordinate strategy for future developments
  - Reinforce Advance Training and Transnational Access
  - Enlarge the science horizon. DULIAbio 2024 is an example

Thank you for your attention!

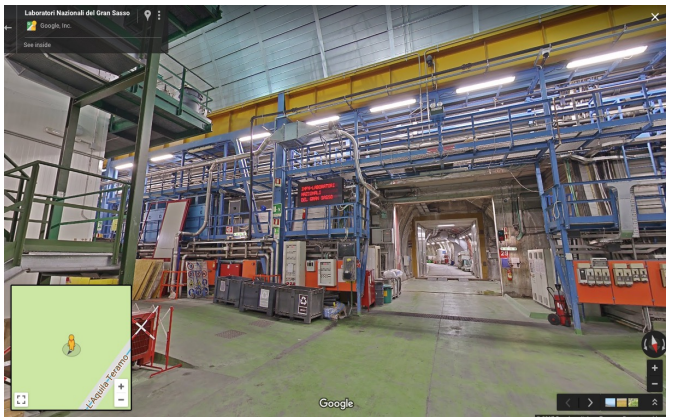
Acknowledgements for contributions to:
Qian Yue (CJPL), Carlos Peña-Garay (LSC), Jaret Heise (SURF), Julia Puputti (CLAB), Geoffrey Smith (NMSU), Silvia Scorza (LSM), Sean Paling (Boulby), Jodi Cooley/Jeter Hall (SNOLAB), Kang-Soon Park (Yemilab), Richard Newman (PAUL), Elisabetta Barberio (SUPL)

Laboratori Nazionali del Gran Sasso (LNGS)

- Shielded by **1400 m (3800 m.w.e.)** of rock (Gran Sasso Mountains)
- Total Muon **flux 3 10^{-8} cm^{-2} s^{-1}**
- Easy access directly from the **A24 highway**
- **3 main experimental halls** 100 m long, 20 m width and 18 m hight
- Many small tunnels for lab facilities and small experiments
- There are **20 experiments in data taking or under construction**



- **Running**
- **Construction/Commissioning**
- **Decommissioning**



SNOLAB –
At a Glance

Current Experiments
Future Experiments
Laboratory Facilities
Experiment Areas

Cube Hall
DEAP-3600, PICO500, NEWS-G
potential for large project after 2026

Cryopit
nEXO/LEGEND

Electrical Shop

J-Drift
SENSEI, DAMIC, OSCURA

Halo Stub
HALO
potential breakthrough for future expansion

Machine Shop

Utilities

Ladder Labs
PICO40, SBC, CUTE, SuperCDMS

Plants
UPW, LN2, Scintillator, Te Diol, TeA

Life Sciences Lab
Chemistry, REPAIR

SNO Cavern
SNO+, SNO+ Te
Potential for large project after 2035

Low Background Lab
HPGe assay/screening, XRF, Radon Boards, FLAME
XIA, CTBT Dual HPGe

5000 m^2 of class 2000 cleanroom underground.
<2000 particles >0.5 µm in diameter per ft^3

3 MWe diesel generator backup on surface

Infrastructure: Surface Spaces & Support

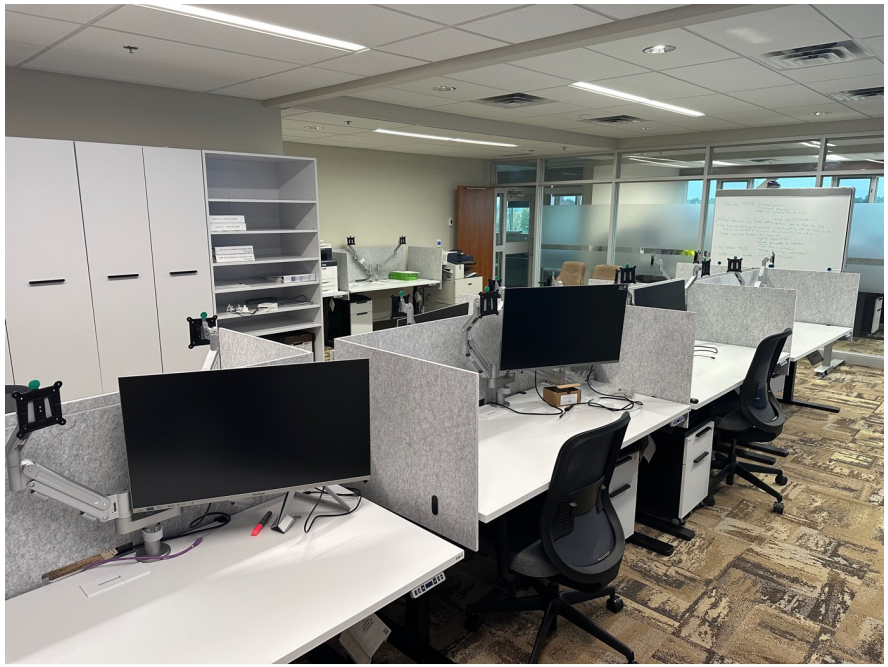
Offices, Clean Labs, Shipping/Receiving on Surface

- Dedicated office space for users.
- Clean room laboratories for surface work and final checks before shipping underground.
- Multiple meeting rooms (10-20 people) and auditorium seating 150.

Create Welcoming Environment - SNOLAB Summer of Science

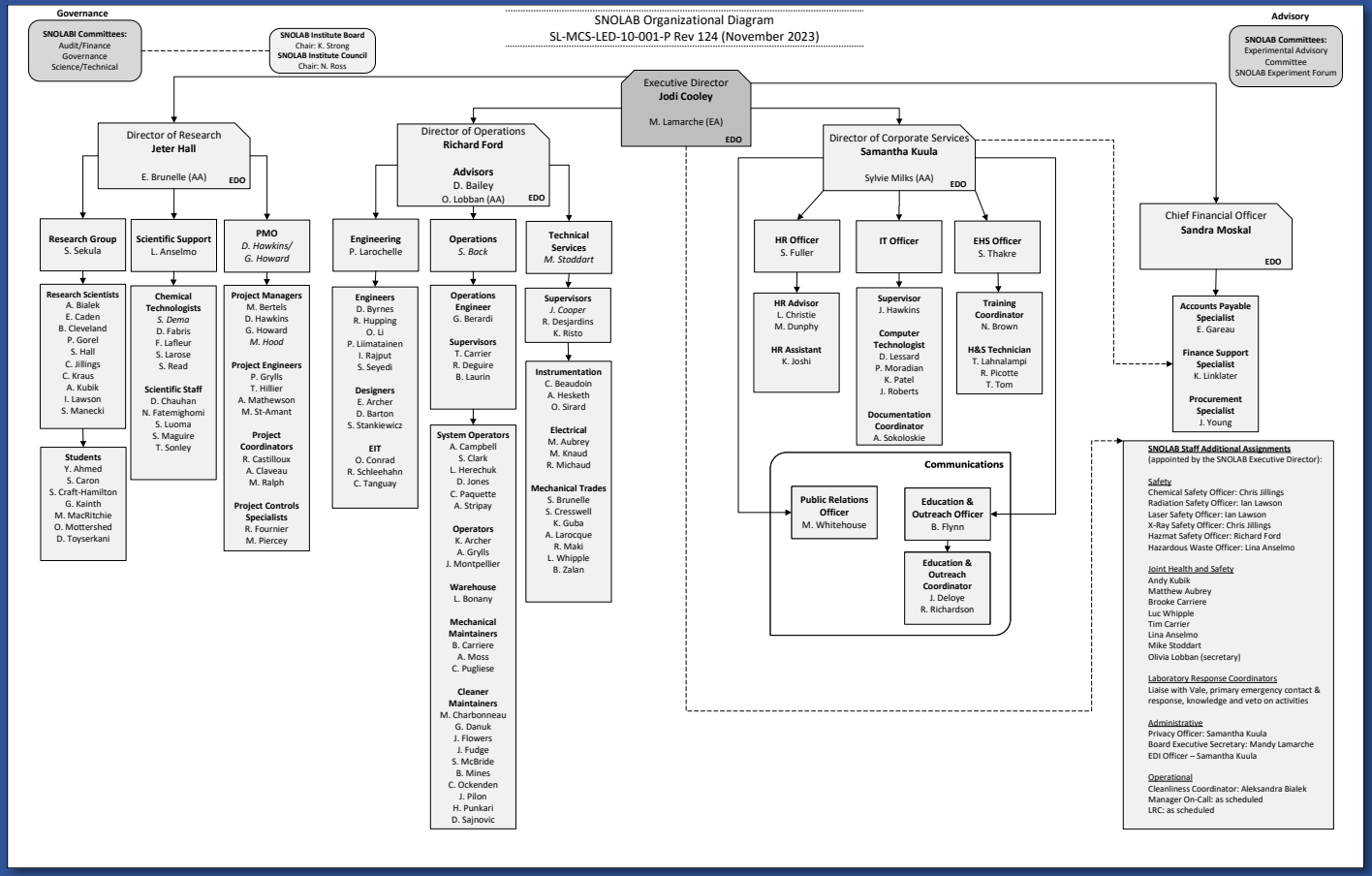
SNOLAB will host a series of meetings and workshops in Summer 2024:

- Invited senior scientists in-residence will give/lead topical and relevant lectures and discussions in weeks between.
- Goal of increasing the interactions between scientific collaborations while accomplishing the experimental goals.



SNOLAB by Organization

- ~150 employees
- Dedicated to operating the laboratory space and experiments
- Scientists, Project Managers/Coordinators, Project Engineers, Design Engineers, Operators, Millwrights, Electricians, Instrumentation, Chemical Support
- Human resources, IT support, Environment Health and Safety, Communications, Finance



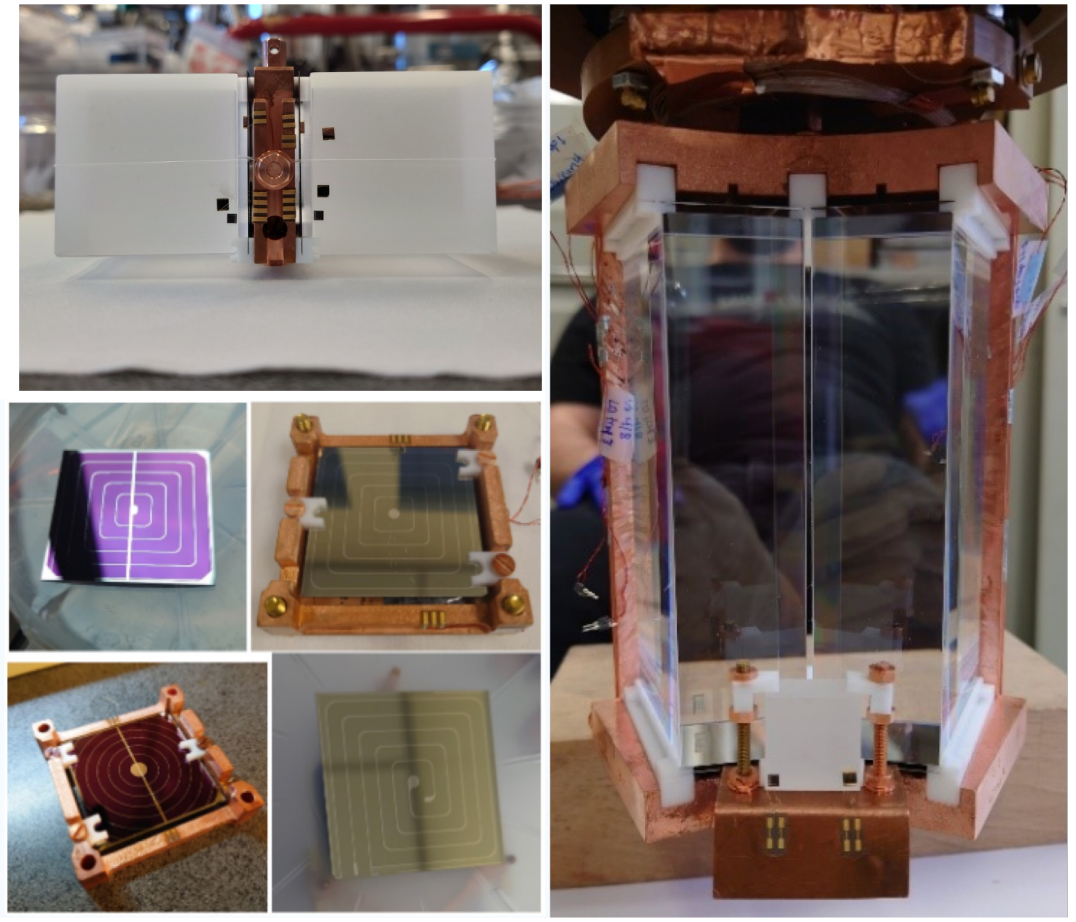
BINGO

R&D program for 0nDBD with ^{100}Mo

Reduction of surface and external radioactive background with:

- Compact assembly with fewer materials
- Rejection of events coincident with a veto in BGO or $ZnWO_4$
- Light detector with signal-to-noise amplification using the Luke-Neganov technique
- New technologies will allow $<10^{-5}$ events/(keV kg year)

The technologies offered by BINGO are likely candidates for the next generation of detectors



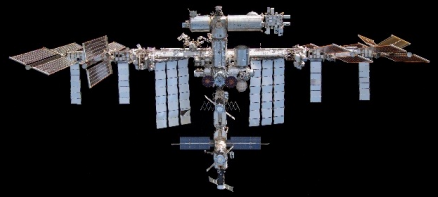
Space Medicine

Dealing with conditions in space

+

Leveraging space environment for

- research
- development
- manufacturing



SpaceTiinTech

Drop Tower

SLT drop tower makes use of mine shafts for vertical movement.

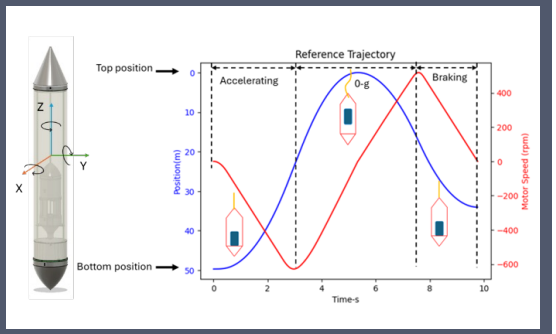
1.62m/sec^2

3.71m/sec^2

Drop tower is capable of not only generating microgravity but also lunar or Martian gravity.

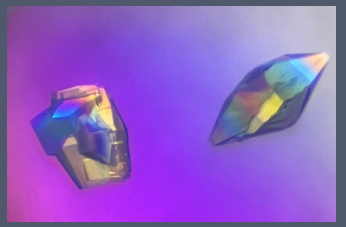
Microgravity

Generation of microgravity



Testing on the ground level

Leveraging microgravity in space



Higher quality protein crystallization

LNGS science program

- Direct DM search with LXe with XENONnT (**record in background level**)
- Direct DM search with LAr with DarkSide-20k
- Direct DM search with $CaWO_4$ with CRESST (bolometer)
- Direct DM search with NaI with DAMA/LIBRA, COSINUS and SABRE
- 0νDBD with ^{76}Ge with LEGEND-200
- 0νDBD with ^{130}Te with CUORE (ending 2025)
- Supernova neutrinos with LVD
- Nuclear Astrophysics with the Bellotti's facility
- **Biology** (see Patrizia Morciano, Anna Bianchi, Umberto Galderisi at this meeting)
- Geophysics
  - ✓GINGER - Gyroscopes IN GEneral Relativity, ring laser gyroscope (3.6m side) for Lens-Thirring effect (measurement of Earth's rotation rate at $1/10^{10}$)

LSM science program

- 0νDBD with ^{82}Se with SuperNEMO (**data taking start in 2024**)
- 0νDBD with ^{100}Mo with CUPID-Mo and BINGO (bolometer)
  - ✓ERC grant, commissioning 2024
- Direct DM search with Si-CCD with DAMIC-M
  - ✓Installation of kg stage in 2024
- Direct DM search with gas detector with SEDINE
- Direct DM search with Ge/Si cryogenic detector with TESSERACT
- Directional DM with MIMAC
  - ✓Commissioning 2025
- Environmental research
  - ✓Radioactivity in the atmosphere
  - ✓Retro-observation (impact of human activity on environment)
  - ✓Oceanography
  - ✓Marine and continental geochemistry (dating of carots)
  - ✓Geographic food origin
- Biology (see Vincent Breton, Guillaume Warot at this meeting)

Sanford Underground Research Facility

Nation's deepest underground lab, advancing multi-disciplinary research

SURF science program

- Direct DM search with LXe with LZ
- Neutrino physics with LAr with DUNE (**long-baseline neutrino program**)
  - ✓ FD1,2 installation 2027-2028
  - ✓ FD3 installation 2031-2032
  - ✓ DUNE Phase 1 >2031
- 0νDBD with ^{76}Ge with Majorana, convering into LEGEND
  - ✓ Cu e-forming facility for LEGEND-1000
- Nuclear Astrophysics with CASPAR
  - ✓Next phase starting in 2024
  - ✓Lasting at least till 2027
- **Biology** (see Markus Horn at this meeting)
- Quantum computing
- Geology & engineering
  - ✓Seismic monitoring using fibers
  - ✓Geothermal
  - ✓Seismic global monitoring
  - ✓Mining technology

SNOLAB science program

- Direct DM search with LAr with DEAP-3600
- Direct DM search with Ge/Si with SuperCDMS (bolometer)
- Direct DM search with with C_3F_8 target PICO40 (bubble chamber)
- Direct DM search with CH_4 , Ar+CH_4 , Ne+CH_4 NEWS-G (spherical proportional counter)
- Direct DM search with Si-CCDs with DAMIC
- 0νDBD with ^{130}Te with SNO+ (>2025)
- Solar/reactor/geo neutrinos with SNO+
- Supernova neutrinos with HALO and SNO+
- 0νDBD with ^{76}Ge/^{136}Xe with LEGEND/nEXO
- **Biology** (see Shaun Hall, Chris Thome at this meeting)
- Nuclear monitoring and quantum computing

LSC science program

- 0νDBD with ^{136}Xe with NEXT (high pressure gas TPC)
- 0νDBD with ^{100}Mo with CROSS (bolometer)
- Direct DM search with NaI with ANAIS
- Neutrino physics with Hyper-Kamiokande
- Biology (see Carlos Peña-Garay at this meeting)

CJPL science program

- 0νDBD with ^{76}Ge with CDEX
- 0νDBD with ^{100}Mo with CUPID-CJPL (bolometer)
- 0νDBD with ^{82}Se with NνDEX (high pressure SeF_6 TPC)
- Direct DM search with LXe with PANDAX
- Nuclear Astrophysics with JUNA
- Neutrino physics with a kton scale detector

Yemilab science program

- 0νDBD with ^{100}Mo with AMoRE (bolometer)
- Direct DM search with NaI(Tl) with COSINE-100U,200
- Neutrino physics (beyond the SM and sterile ν) with a kton scale detector
  - ✓ status: proposal under development
  - ✓ IsoDAR (Isotope Decay-at-Rest Experiment) electron antineutrino beam from 60 MeV protons
- space biology (by SpaceLintech co LTD)
- human life underground on the moon(by KIGAM, Korean In stitute for Geology and Mineral Resources)

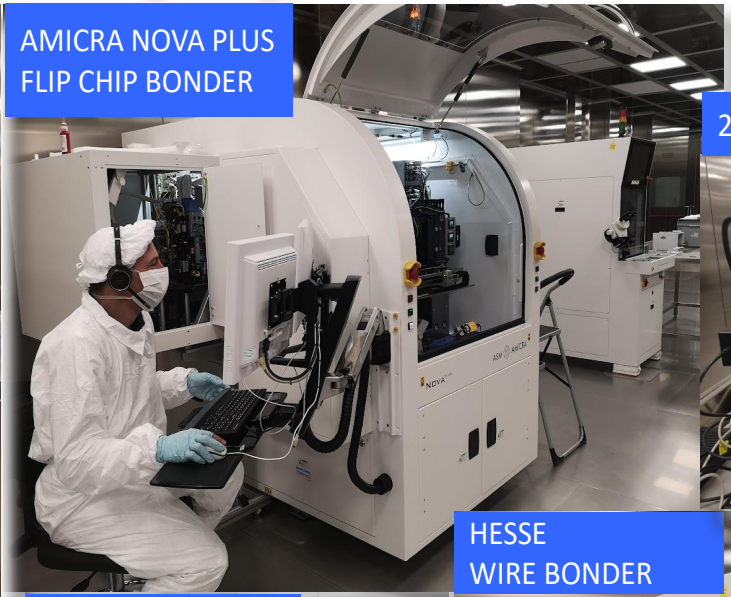
Boulby science program

- Hosted direct DM search with NaIAD, DRIFT and ZEPELIN (**world's first 2-phase Xe detector**)
- Direct DM search with gas detector with NEWS-G
- Direct DM search with LXe with LZ
- Directional DM with CYGNUS
- Material screening (x8 HPGe, XIA, ICP-MS, Rn emanation)
- Muon tomography for geological surveying
- Nuclear test monitoring (**collaboration with CTBTO**)
- Renewable energy storage in underground caverns with RESOURCE
- Astrobiology/Biology (see Jens Holtvoeth, Scott Perl, Jonathan Gutteridge at this meeting)

NOA packaging area

FORM FACTOR PAC200
CRYOPROBE

AMICRA NOVA PLUS
FLIP CHIP BONDER



2 LEICA MICROSCOPES

HESSE
WIRE BONDER

ADT 7122 DICER

MANUAL
PACKAGING TOOLS:
FRAME MOUNTER
DIE EXPANDER
UV CURING

28/08/2023

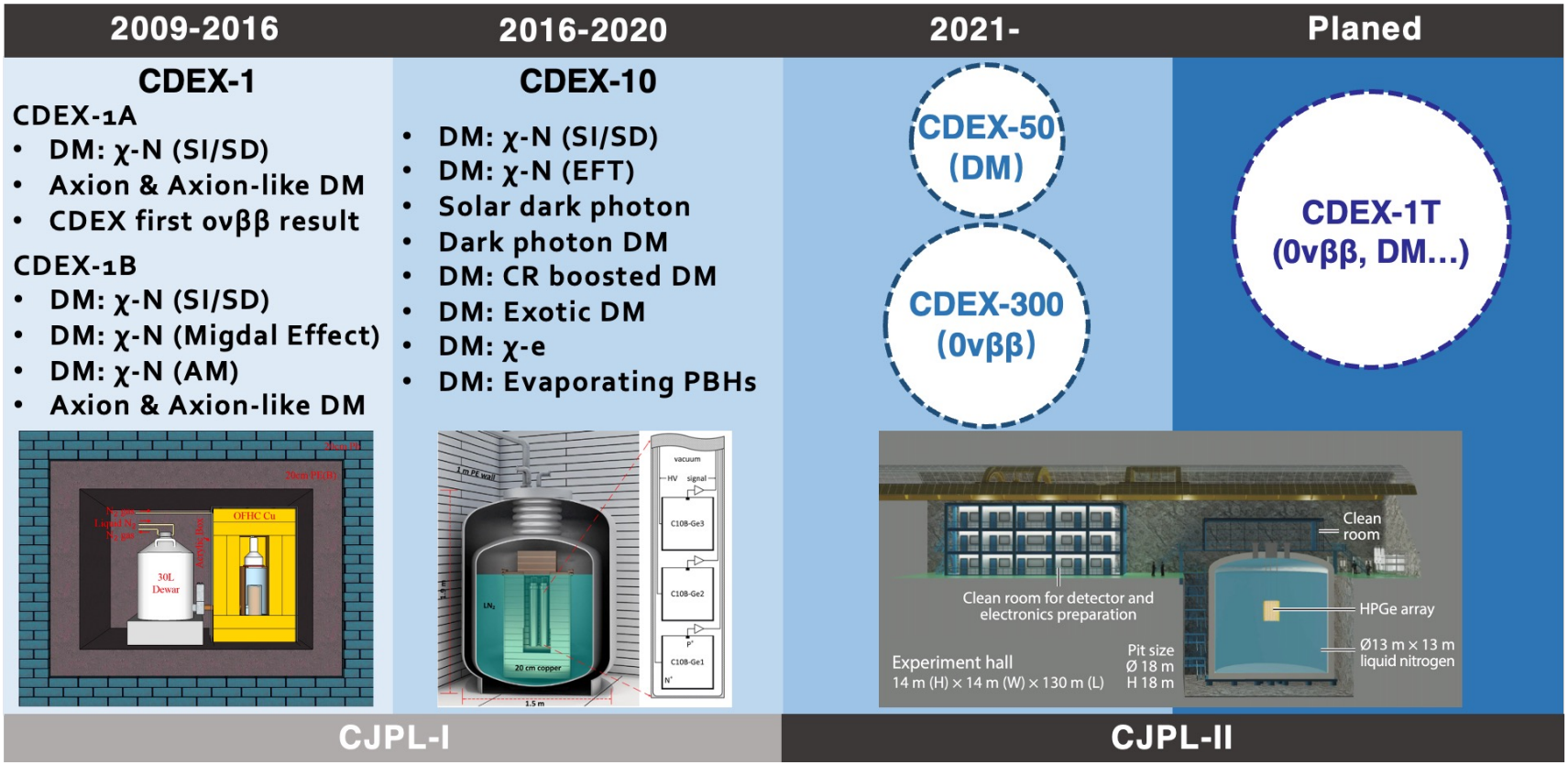
Courtesy: Lucia Consiglio

Advance machining

- Strong request for light, low radioactivity, and complex geometry detectors components
- At LNGS (**3DIab**) and LSC an R&D in progress to develop high radio-purity copper components by e-forming production and 3D printing
  - e-formed copper produced at LSC underground
  - copper atomized and 3D printing at LNGS
  - screening to assay radio-purity level both at LNGS and LSC

CDEX Collaboration

- Founded in 2009, 11 institutions, more than 100 people now
- Focused on Dark Matter detection and Ge-76 0νββ search using HPGe technology



PandaX

- Starting in 2009, consists of dozens of Universities and research Institutions
- Goals: Increase LXe detector mass for DM and neutrino studies

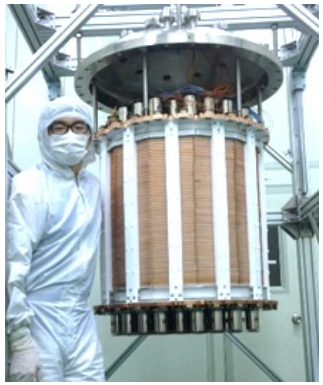
PandaX

2009

Phase-I
120 kg

2010-2014

Phase-II
580 kg



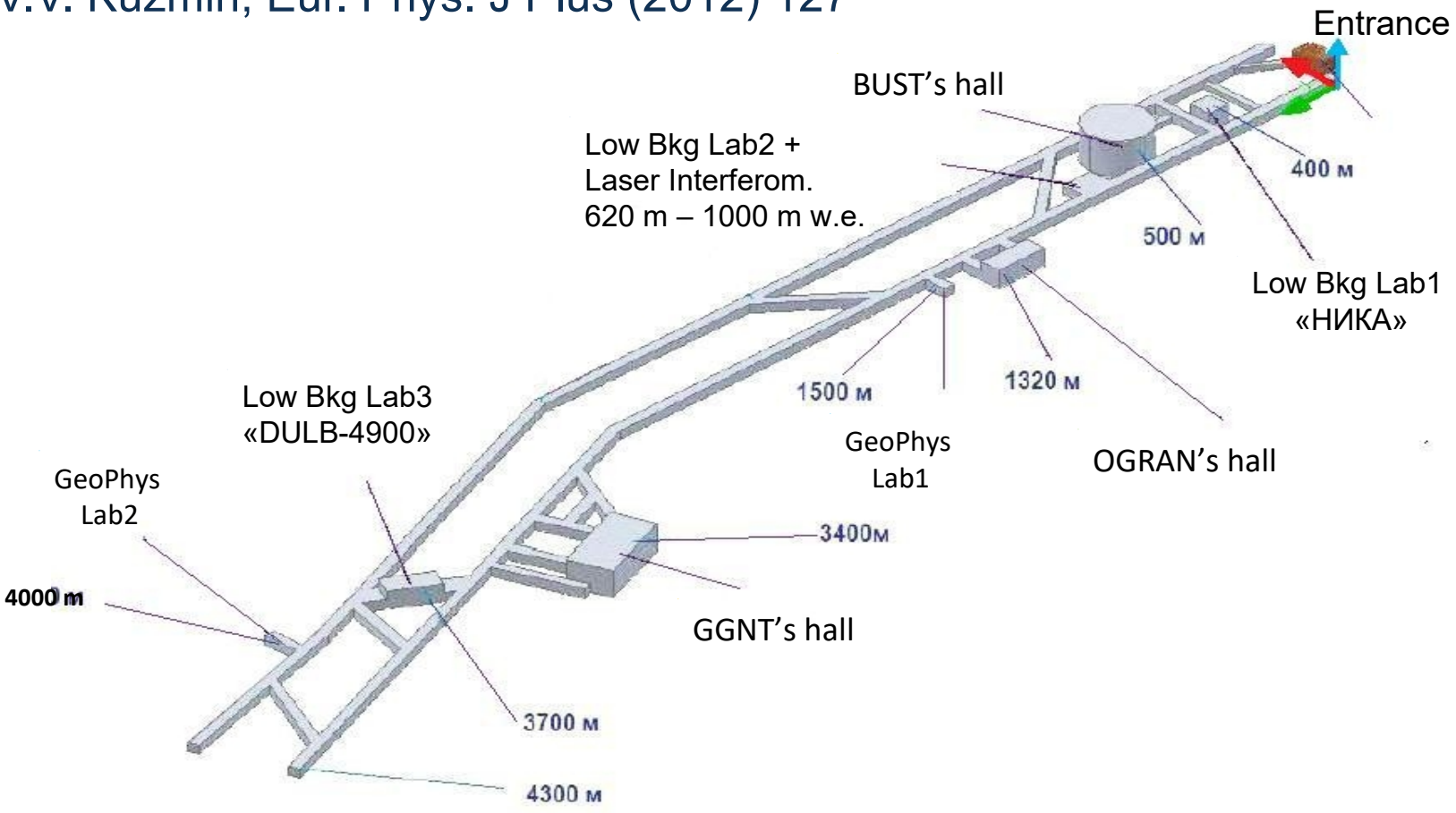
2015-2019

PandaX-4T
3.7 ton

2020-

Laboratory structure at Baksan

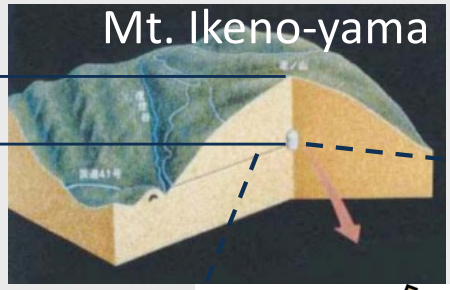
See V.V. Kuzmin, Eur. Phys. J Plus (2012) 127



Scientific program at Baksan: highlights

- BUST (Baksan Underground Scintillation Telescope)
  - study of cosmic rays with surface and underground detectors
  - gravitational ollapse supernova rate < 0.07/year (90% CL)
- GGNT (Gallium-Germanium Neutrino Telescope)
  - Solar neutrinos observatory
  - BEST (Baksan Experiment on Sterile Transitions) with ^{51}Cr 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)

Kamioka: underground facilities

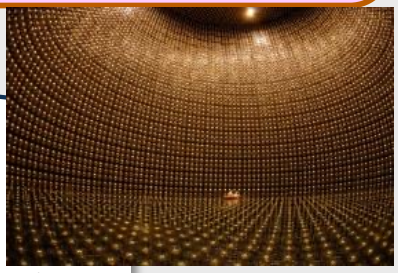


KamLAND (Tohoku Univ.)

1000ton liquid scintillator detector
Reactor, geo neutrinos
^{136}Xe double beta decay

Super-Kamiokande

50,000 ton water Cherenkov detector
Atmospheric, solar, supernova neutrinos
Proton decay, indirect dark matter search
Far detector for T2K



CANDLES

CaF_2 scintillation detector
for ^{48}Ca double beta decay

KamLAND

Lab.A

Super-K dome

clean room

Lab.E/IMPU
Lab.2

water
system

IMPU
Lab.1

Lab.G

100m

Gravitational-wave

CLIO 100m x 100m prototype
Geo-physics 100m x 100m
Laser strainmeter

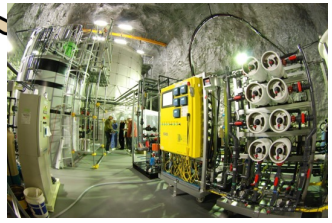
Atotsu
entrance

XMASS

Direct dark matter
search experiment

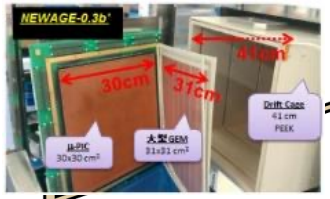
EGADS

200t Gd test tank



NEWAGE

Direction dark
matter experiment



Environmental backgrounds

- ✓ $\langle\rho\rangle \sim 2.7 - 2.9$ g/cm^3, $\langle Z^2/A\rangle \sim 5.7\text{-}5.9$, $\langle Z\rangle \sim 11$
- ✓ **gamma-rays** from rocks: order of a few cm^{-2} s^{-1}
  - Mitigation: passive shielding (Pb, Cu, steel)
- ✓ **radiogenic neutrons**: order of a few 10^{-6} cm^{-2} s^{-1}
  - Mitigation: passive shielding (polyethylene …), active veto with water, Gd-loaded water, scintillators
- ✓ **muon-induced neutrons**: ~10^{-7} cm^{-2} s^{-1}
  - Mitigation: large active and passive shielding with water, Gd-loaded water, scintillators
- ✓ **Radon**
  - Mitigation: high ventilation, radon suppressed environment, leak tightness (see Ivan Stekl this meeting)
- ✓ **Dust**
  - Mitigation: cleanliness protocol