Overview on Deep Underground Laboratories

Symposium on Science at PAUL (Paarl Africa Underground Laboratory),
Paarl, South Africa 14-18 Jan 2024

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Outline

DULs (>600m) main features and science

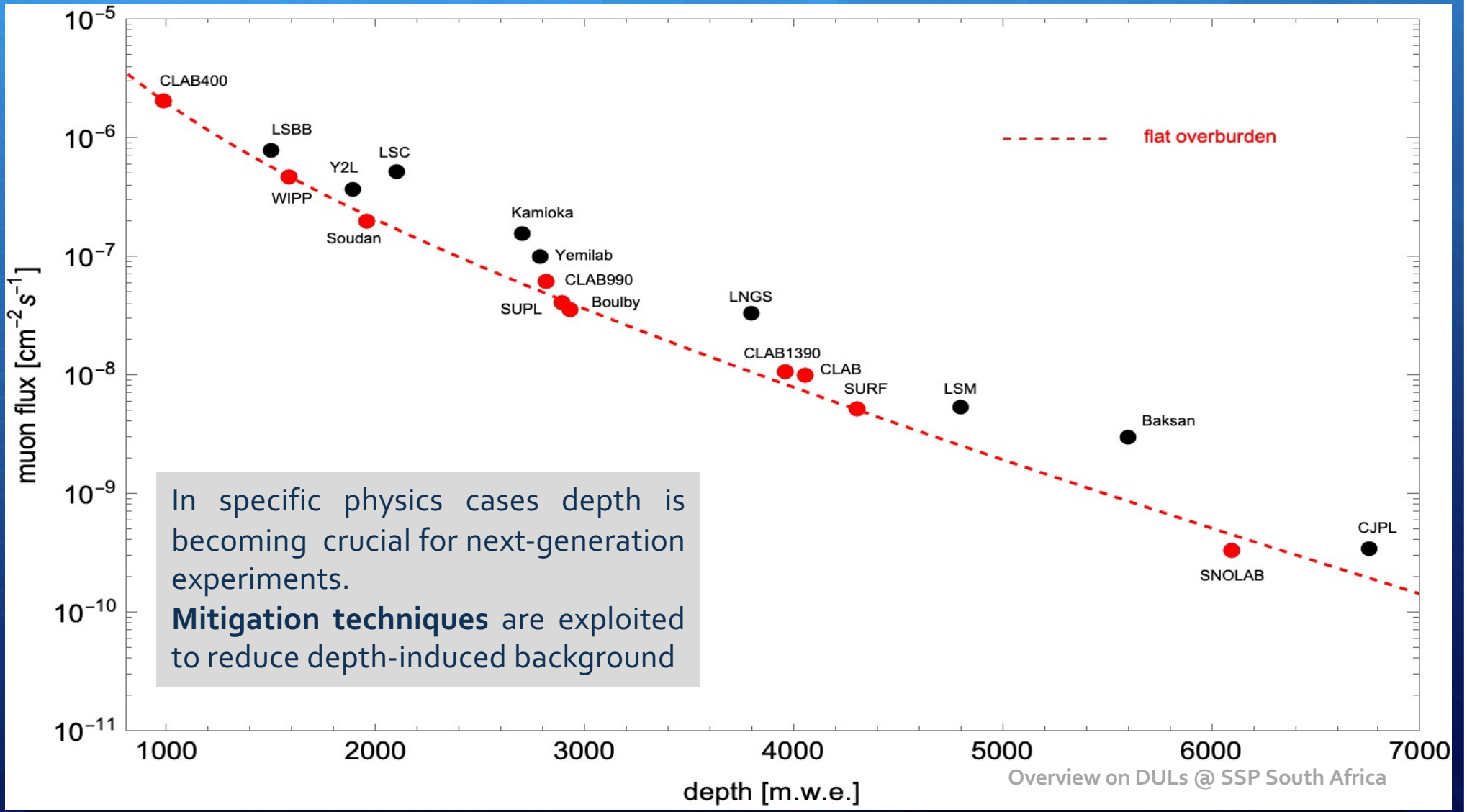
DULs network and cooperation

A few highlights from DULs (not covered in other talks)

DULs around the world

operational new proposal not operational

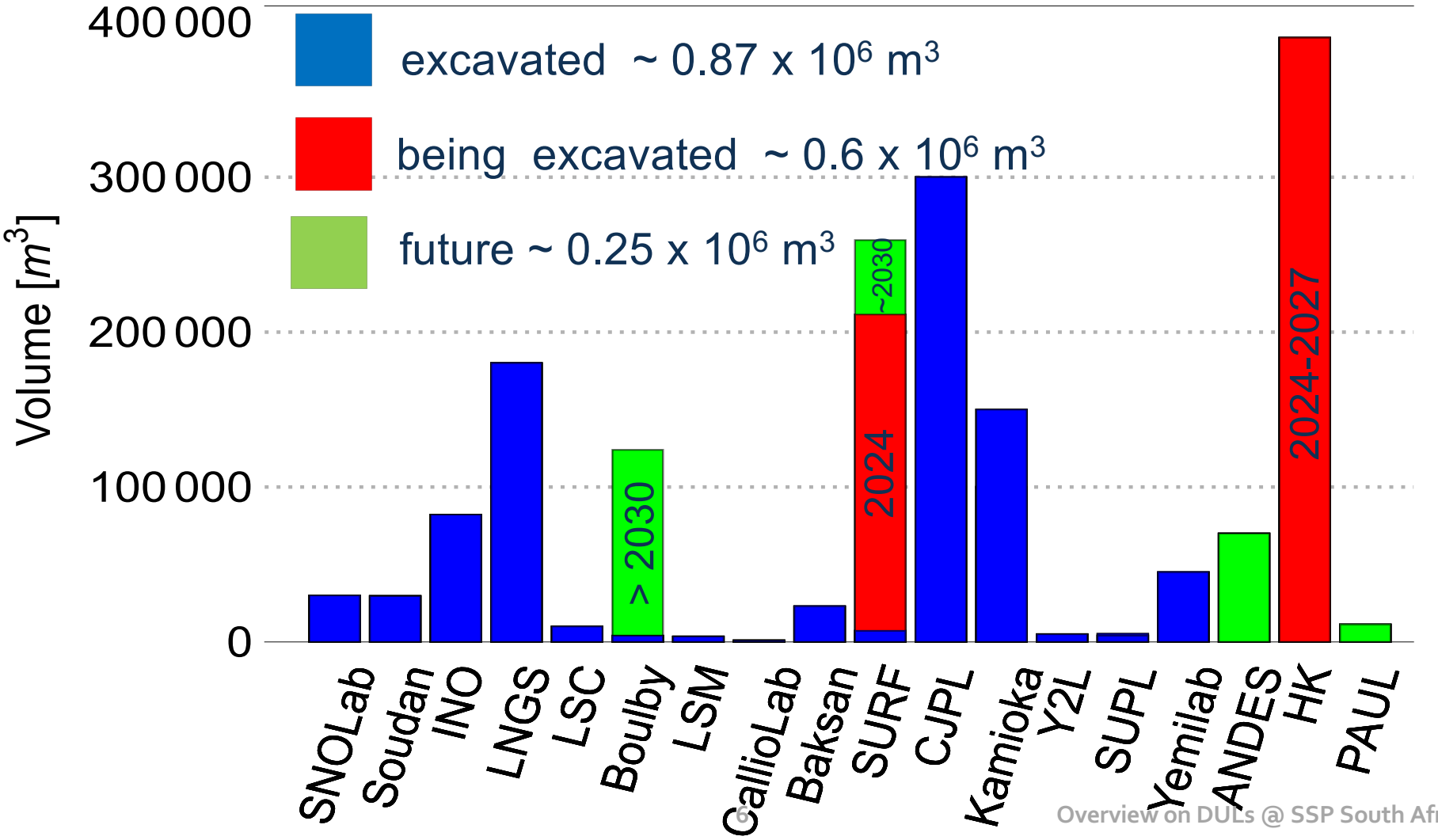
DULs features: depth and muon flux



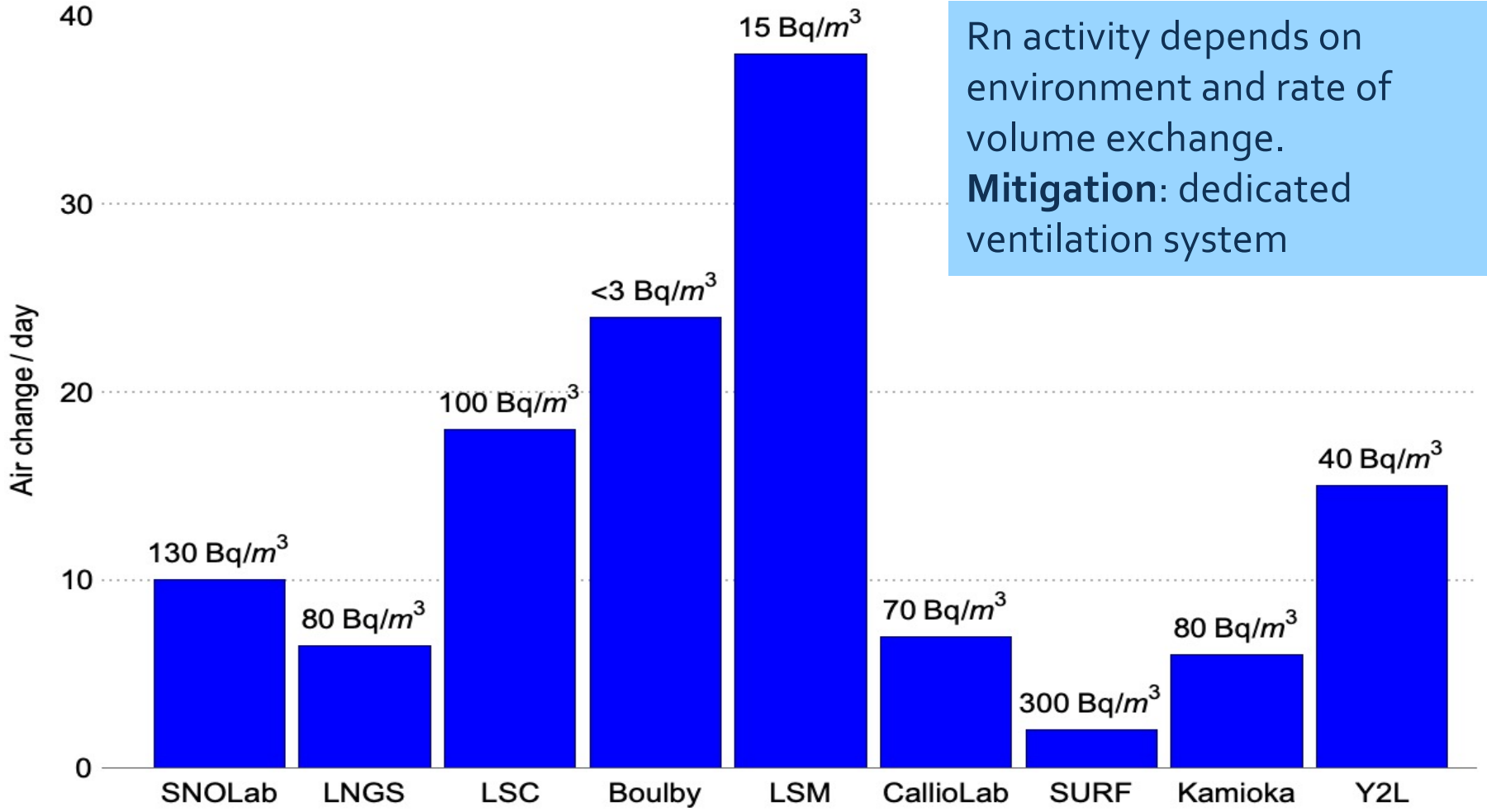
In specific physics cases depth is becoming crucial for next-generation experiments.

Mitigation techniques are exploited to reduce depth-induced background

DULs features: volume



DULs features: ventilation and Rn



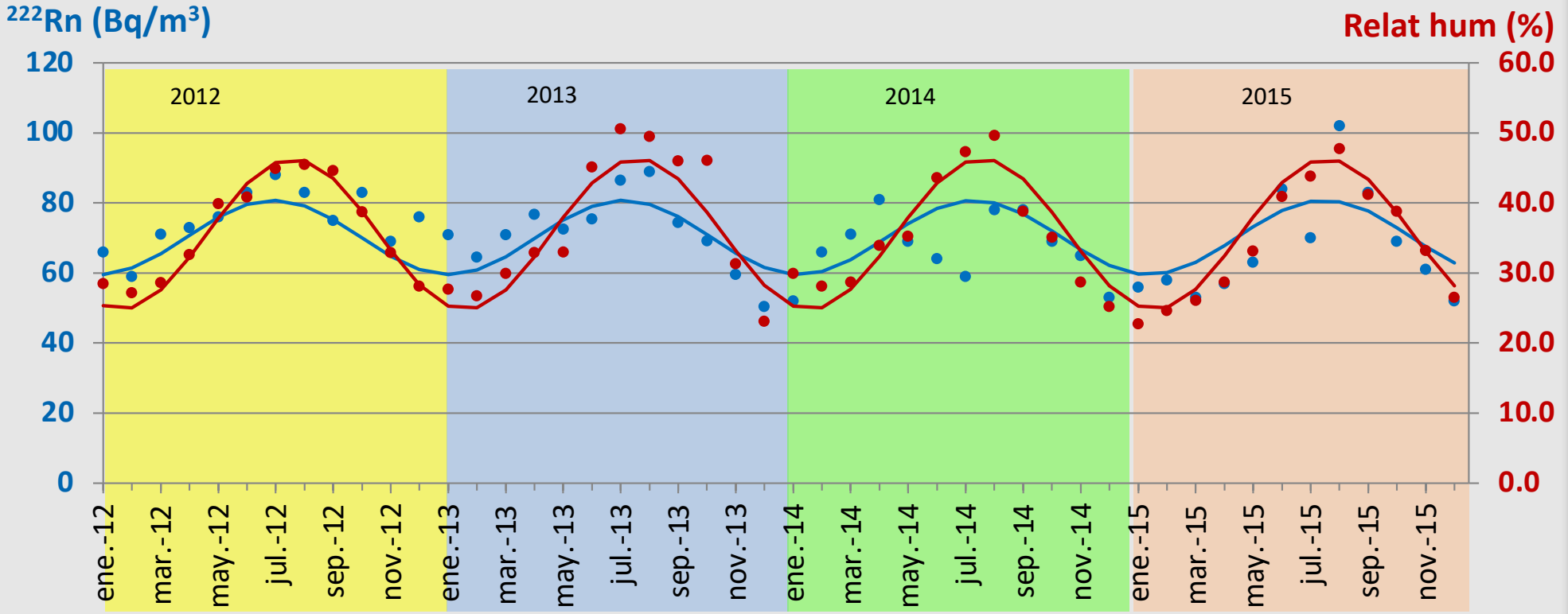
Rn activity depends on environment and rate of volume exchange.
Mitigation: dedicated ventilation system

Temporal periodicity for the concentration of ^{222}Rn in air (Bq / m^3) and Relative humidity (%) at LSC

$$Y = A + B\cos\left(\frac{2\pi}{T}(t - t_M)\right)$$

$Y \rightarrow$ ^{222}Rn concentration or Relative humidity

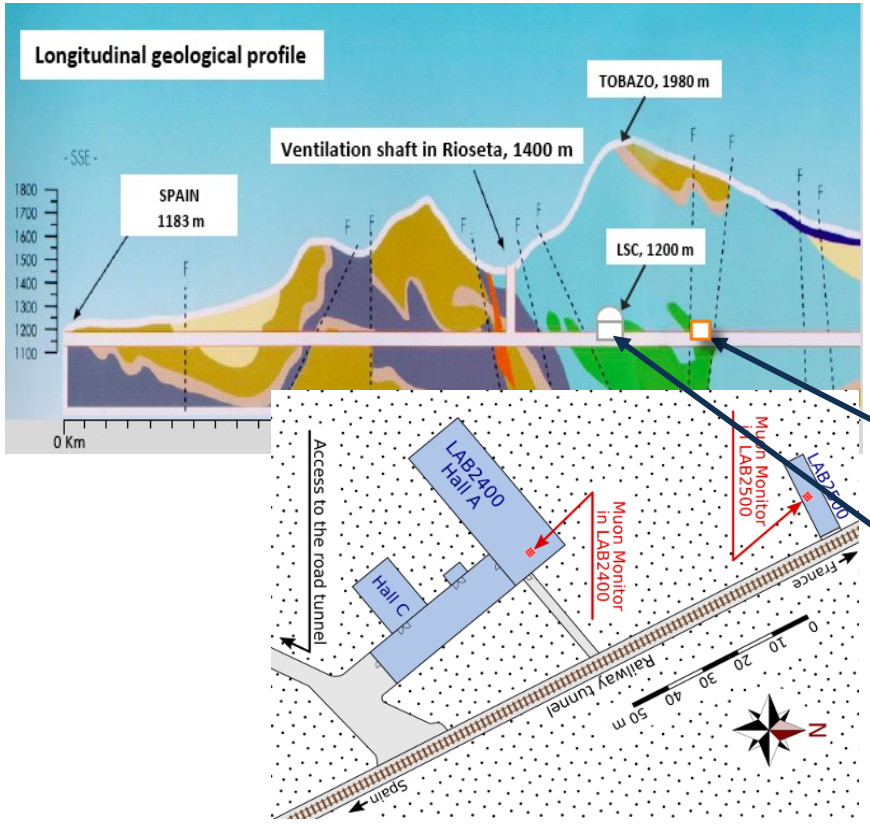
$t \rightarrow$ time, in month.



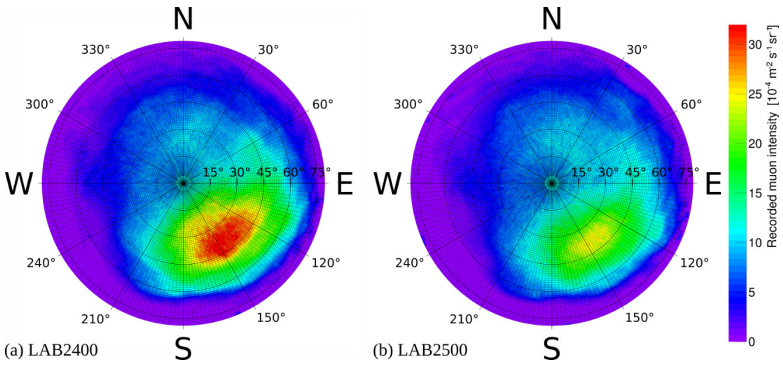
DULs features: rock overburden

Mountain profile affects muon flux underground

- LNGS, Baksan, LSC have measured a significant angular dependece for the muon flux



The case of LSC



LAB2500

LAB2400

Environmental backgrounds

- ✓ $<\rho> \sim 2.7 - 2.9$ g/cm^3, $<Z^2/A> \sim 5.7\text{-}5.9$, $<Z> \sim 11$
- ✓ **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

DULs as Research Infrastructures

Underground facilities can provide:

+ Unique environments for **multi-disciplinary research**
+ Local radiation shielding
+ Assay capabilities
  - mainly radio-purity (gamma-rays spectrometry, mass spectrometry, radon emanation measurements)
+ Material production/purification
  - copper e-forming, advance machining, crystal production
+ Environmental control
+ Implementation and operations support
+ Above-ground and underground support facilities (CR, Rn-free CR, ….)
+ **Advance training** (inspire next-generation of scientists)
+ **International working environment with TA agreements between DULs**

DULs features: structure of underground facilities

- **Monolithic**:
  - LNGS
  - Boulby
  - LSM
  - SNOLAB
  - SUPL
  - Yemilab
- **Distributed**:
  - LSC with LAB2400 and LAB2500 + train tunnel
  - Baksan
  - CallioLab (multi-level structure inside the mine)
  - Kamioka
  - SURF
  - CJPL (CJPL-I and CJPL-II)

DULs features: access to underground area

- **Vertical** by means of a cage system (SNOLAB, Boulby, SURF)
  - Need special manpower and maintenance
  - Limited loading volume for equipment to be taken underground
- **Horizontal** (Baksan, LNGS, CJPL, Y2L, 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)
- **Multiple** (CLAB, Yemilab)
  - Cage system and drive-in possibility

DULs science

Astroparticle phyiscs

- Dark Matter direct detection
- Solar and Supernova neutrinos

Neutrino physics

- Neutrinoless double beta decay
- Neutrino oscillations
- Neutrinos from reactors

Rare events

- Rare decays and nuclear processes, nuclear astrophysics

Geophysics

- Study of seismic events at local and global scale
- Water effects underground, solid earth tides, human activities
- geoneutrinos

Biology

- Cells behaviour in low dose environments

New technologies

- Cryogenic systems
- Quantum computing
- Radio-purity assay techniques
- Low background detector developments
- ...

Main research supporting facilities in DULs

- **HPGe screening facilities** (in all labs) + alpha counting + ICP-MS (M. Laubenstein)
- **Cu electro-forming production** (SURF, LSC, CJPL,SNOLAB,Yemilab)
- **Clean rooms** (ISO5, ISO6, ISO7, …) (S. Scorza)
- **Radon abatement systems** (x 1000 Rn reduction)
  - In operation at LNGS, LSC, Y2L, LSM, Yemilab, SURF (make-up air: 100 – 300 m^3/h)
  - To be installed at CJPL, SUPL
- **Radon-free clean rooms** (Present at LNGS, SURF (on surface), LSM
  - More discussions at this meeting on Radon
- Sensitive **radon detectors** (<mBq/m^3) for emanation and monitoring
- Cryogenic test facilities
- Crystal growing facility (planned in LSC, Yemilab, CJPL)

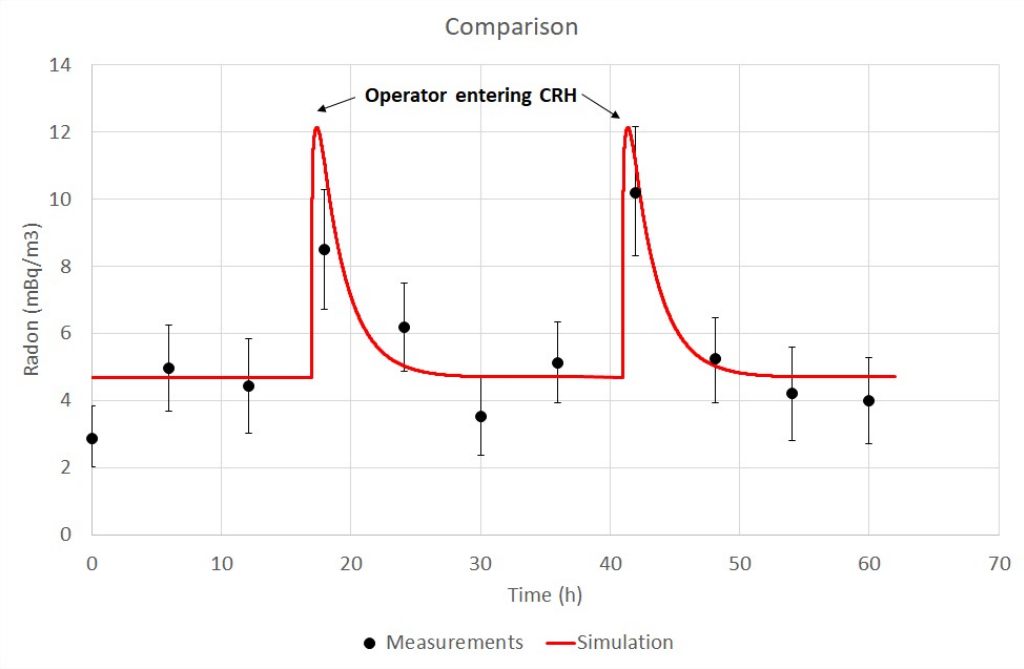
Radon-free clean room for DarkSide-50 @ LNGS

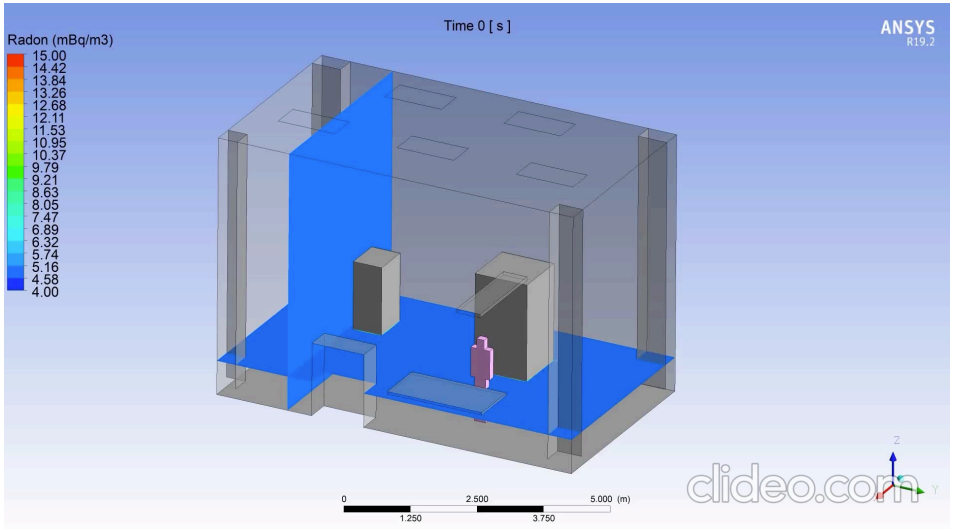
DarkSide-50 use of radon-free clean rooms:

1. Cleaning and conditioning of TPC components
2. Assembling and deploying of TPC into the neutron veto
3. Radon delivered to clean room at ~ mBq/m^3
4. Radon level in equipped clean rooms 100-500 mBq/m^3

Study effects from operators on Rn concentration

- We have used data from DS-50 Rn-free clean room
- This CR has 166 m^3 and a make-up of 100 m^3/h





Condition	Measured	Calculated
No operators	5.8 mBq/m^3	6.24 mBq/m^3
1 operator	8.5 ÷ 10.2 mBq/m^3	12.0 mBq/m^3

See: K. Pelczar et al., EPJ C 81 (2021) 86 and
V. Di Marcello et al. *JINST* 17 (2022) 06, P06033

Radio-purity assay in DULs

- **A key technology in DULs see M. Laubenstein this meeting**
- DULs have highly specialized facilities for radio-purity assay (best ~10μBq/kg in U,Th with HPGe and ~1μBq/kg with ICP-MS)
  - Only in EU labs there are 48 HPGe detectors
  - Other 28 from CJPL-I, SURF, Y2L, SNOLAB, Baksan
- **DULs are already networking to support requests from Collaborations**. More coordination effort underway.
  - examples
    - Gd salt screening for SuperKamiokande (Kamioka, LSC, Boulby, HADES)
    - DarkSide-20k (LNGS, LSC, SNOlab, Boulby)
    - LZ (Soudan, SURF, Boulby) …
    - Qualified support from other labs, Institutions, and Companies (e.g. PNNL, Jagiellonian Univ., Seastar, …)
- Efforts being made between ULs to improve present sensitivity/synergy to face next-generation experiments

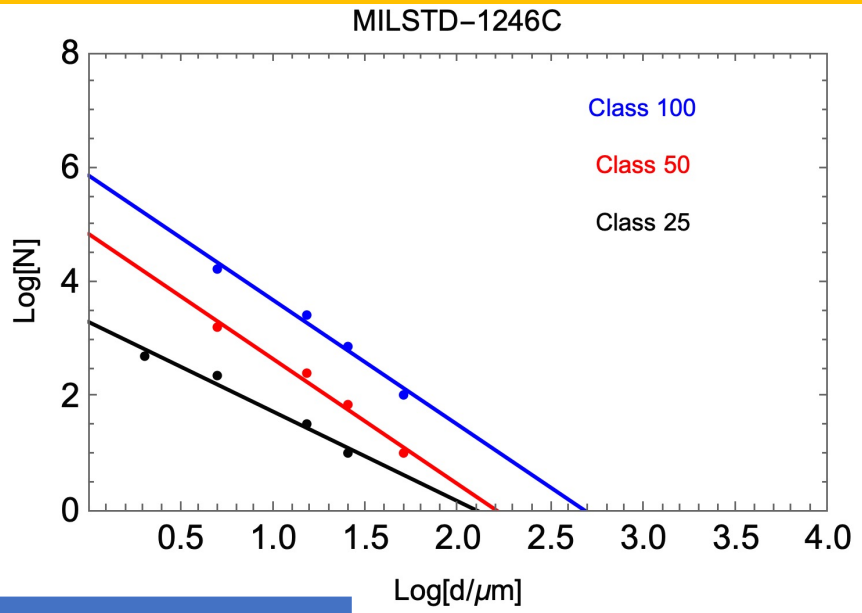
Cleanliness [1]

- Different strategies depending on the main DUL features
- Main goal: reduce contamination due to particulate
- Dedicated facilities:
  - Access to inner detector through clean room
  - Turn inner detector during installation in a clean room (ISO6, ISO7 depending on dimensions)
  - Custom facility for advanced cleaning of large as-built equipment

	SNOLab	LNGS	LSC	Boulby	LSM	Callio Lab	Baksan	SURF	CJPL-I/II	Kamioka	Y2L
Cleanliness	CR class 2000 or better	Only in sectors	Only in sector	CR ISO7 and ISO6	Only in sectors	Only in sectors	Only in sectors	Access restrictions class 3000	Only in sectors	Only in sectors	Only in sectors

Cleanliness level classification: large as-built fluid handling system - Borexino

- Use MILSTD-1246C to define cleanliness level
- **Requirement < class 50**
- After purification rely on 0.05 μm filtration
  - ✓99.9% efficiency above 0.1 μm



CL	Particulate mass [g/g_{LS}]	^{238}U background [cpd/ton]	^{238}U background with filtration [cpd/ton]
25	3.6×10^{-10}	0.4	10^{-4}
50	4.1×10^{-9}	4.4	**0.01**
100	4.4×10^{-8}	47	0.1

1 cpd/100ton

Cleanliness [2]

- **Mine environment or small volume underground area**
  - Specific protocol to enter lab area (SNOLAB, Boulby, SURF,SUPL)
  - With some basic protocol it is possible to achieve good conditions
    - SNOLAB class 2000 or better throughout the whole volume with a more demanding protocol
    - SURF class ~3000
    - Boulby main area ISO7
    - All: dedicated personnel for regularly cleaning activity
- **Large volume, not mine environment** (LNGS, CJPG)
  - Specific protocol in sectors (clean rooms)
- **Medium size volume, not mine environment** (LSC,LSM)
  - Specific protocol (cleaning shoes, regular floor cleaning …)
  - Example: at the LSC particulate counting in different areas ~ ISO7

Multi-disciplinary in DULs

- In the last decade DULs are expanding research to neighboring sectors that can benefit of Underground Facilities technologies and infrastructures
  - At SURF planned to establish an **Institute for Underground Science**

- **Diversify** is becoming a key parameter for DULs
  - Technology sharing for gravitational waves search
  - Technology to support quantum computing
  - Biology in extreme environments and low radiation biophysics
    - Effect of radiation on cells (underground vs surface)
  - Geophysics
    - Groundwater characterization
    - Deployment of seismic arrays underground
    - Rotational seismology (high frequency rotation parameters)

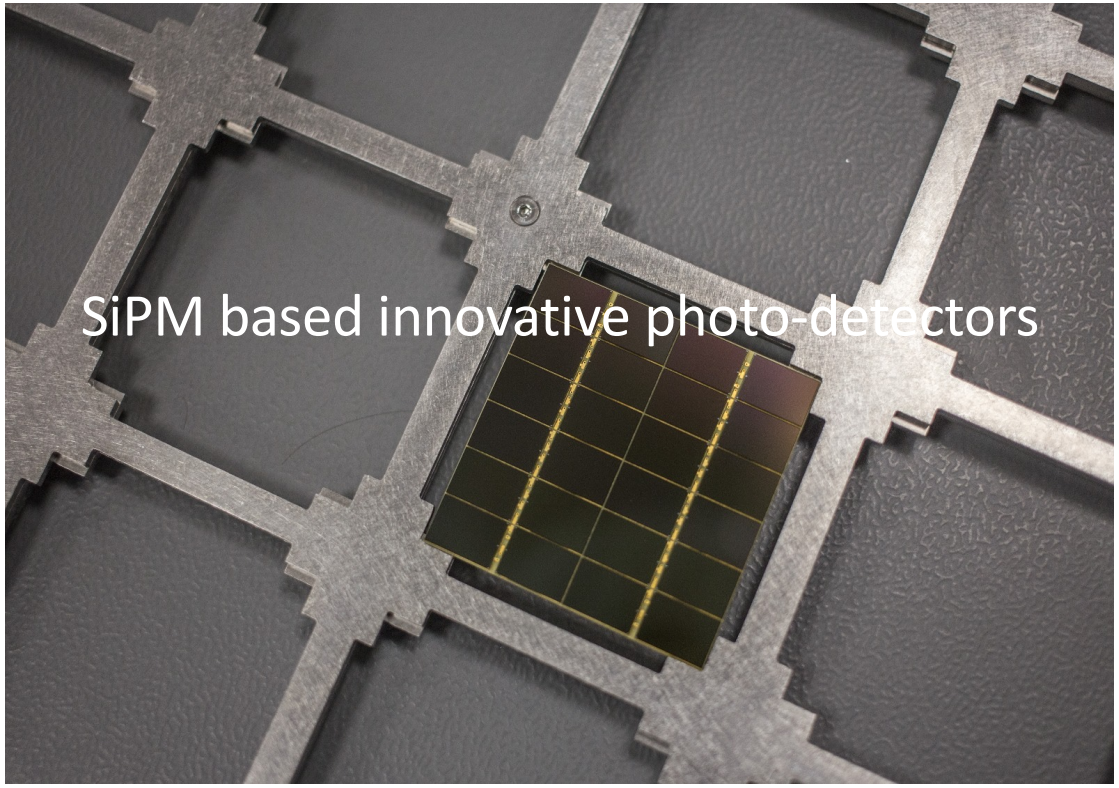
Key technologies to support research

Identified tasks after discussions within EU DULs

- T1: SiPM based innovative photo-detectors
- T2: Superconducting sensors in ultra-low background environments for quantum computing
- T3: Innovative technology in radio-purity assay
- T4: New technology for Rn-free environments
- T5: New advanced technologies for cryogenic infrastructures
- T6: Additive manufacturing for rare events searches
- T7: Biology in ULs
- T8: Safety and engineering in ULs


New advanced technologies for cryogenic infrastructures
New technology for Rn-free environments


Superconducting sensors in ultra-low background environments for quantum computing


SiPM based innovative photo-detectors


Safety and engineering in DULs

DULs cooperation: main goals

Foster	Foster coordination and synergy between DULs
Coordinate	Coordinate DULs 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

Outreach, training, and community

DULs outreach activities includes engagement in Dark Matter Day, Cosmic Rays Day, Neutrino Day (SURF), dissemination of science, production of «small» detectors for demonstrations

Often an outreach center is built with specific exhibits

Open day activities

Training

in collaboration with close by Universities DULs can offer training programs for next-generation of scientists, engineers and technicians

Opportunities for PhD thesis, stage programs

Community

involvement of the local community to raise awareness of environmental respect and science appreciation

Established Working Group for DULs collaboration

- Established during TAUP 2023
- Current activity: survey of main characteristics, organization, and facilities
- Representative
  - Boulby (UK): Sean Paling
  - CLAB (Finland): Julia Puputti
  - CLPL (China): Qian Yue
  - LNGS (Italy): Aldo Ianni
  - LSBB (France): Gilles Micolau
  - LSC (Spain): Carlos Pena-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

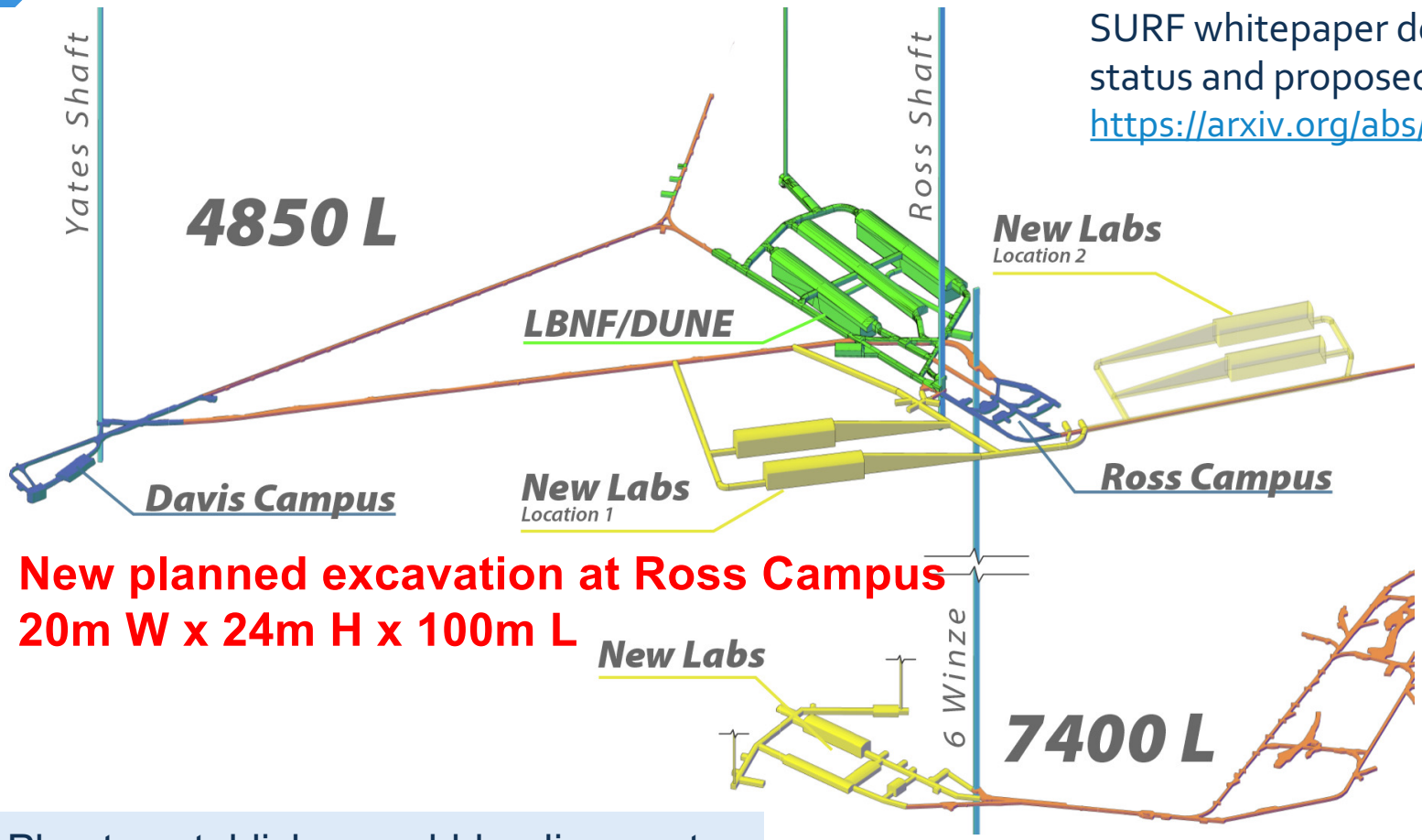
New DULs

- In proposing a new DULs the following (order 0) considerations should be made
  - ✓ next-generation experiments ask for
    - a robust international collaboration due to scientific, technological and costs **challenges**
    - a strong share of workload at international level (>1000 samples for assay)
    - sharing of facilities for R&D activities
  - ✓ next-generation experiments could be driven by depth and size
  - ✓ **large vs small size experiments**
  - ✓ optimize strategy for deployment of new facilities
  - ✓ new opportunity for increasing **international collaboration and for training**
  - ✓ open **new frontiers** in science providing new ideas to face big challenges (dark matter, DBD, …)
  - ✓**Location and logistic**
    - nearby Universities, access from international airport, nearby suppliers and industry
  - ✓ **more to be discussed at this meeting …**

A few highlights from DULs
(not covered in other talks)

Highlights from SURF
Current & Future Underground Facilities

15-yr plan incl additional 4850L labs + deeper access



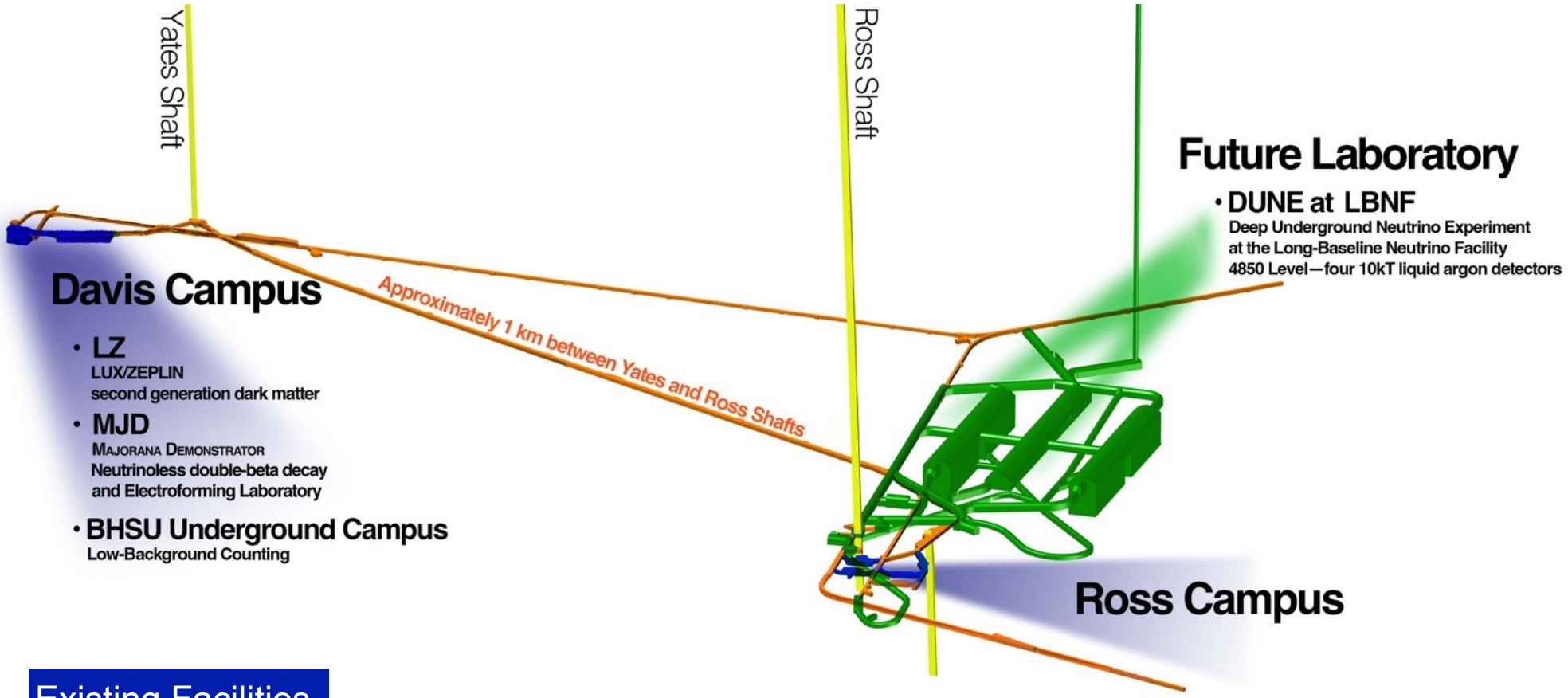
SURF whitepaper describing current status and proposed future facilities: https://arxiv.org/abs/2203.08293

New planned excavation at Ross Campus
20m W x 24m H x 100m L

Plan to establish a world-leading center through the **Institute for Underground Science at SURF**

Expansion at deeper level under investigation
Timeline ~ 15yr

4850L Science Facilities (present undergroundlayout)

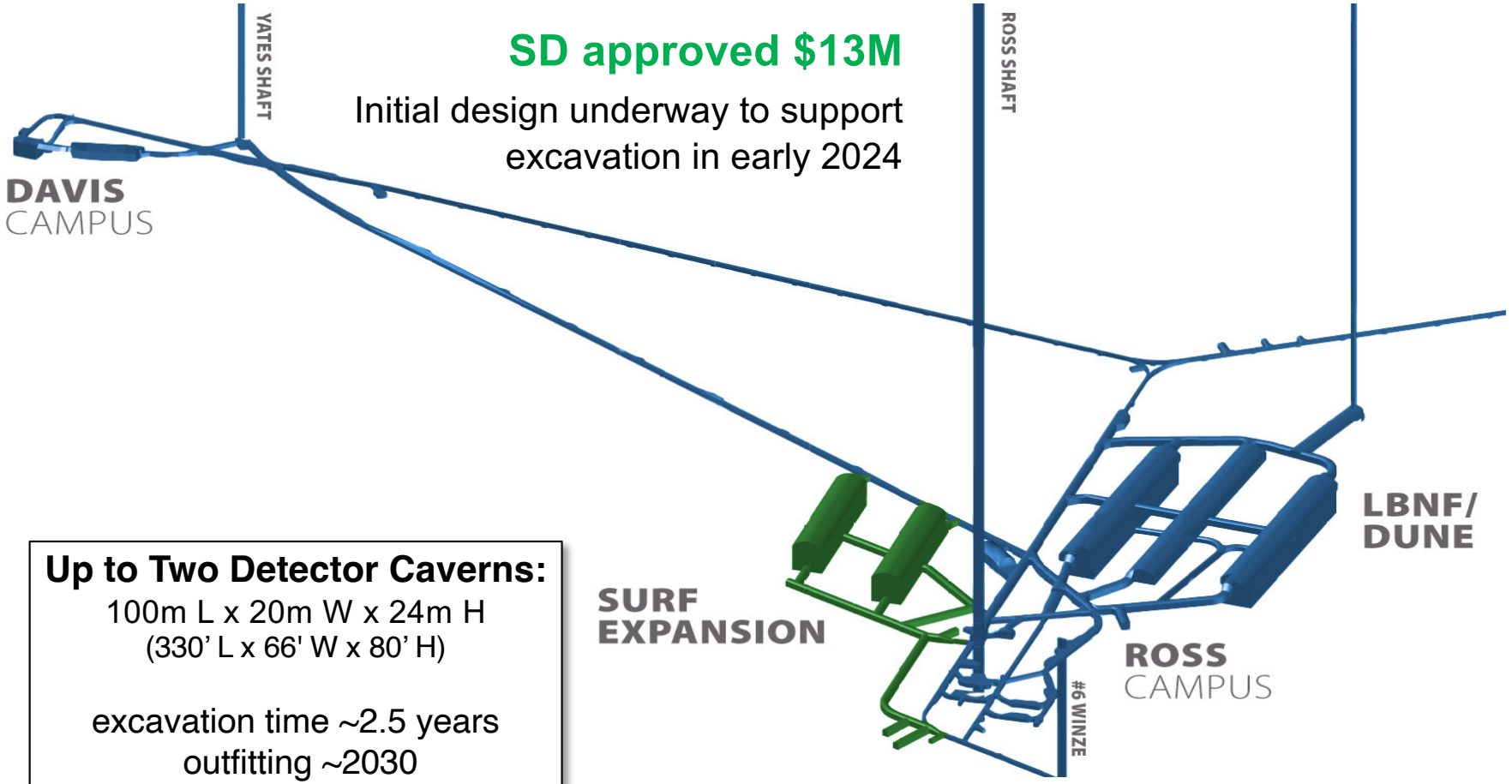


Existing Facilities

Facilities in Development

4850L Space Needed for Future Experiments

U.S. strategic plan requires more space, community has endorsed expansion



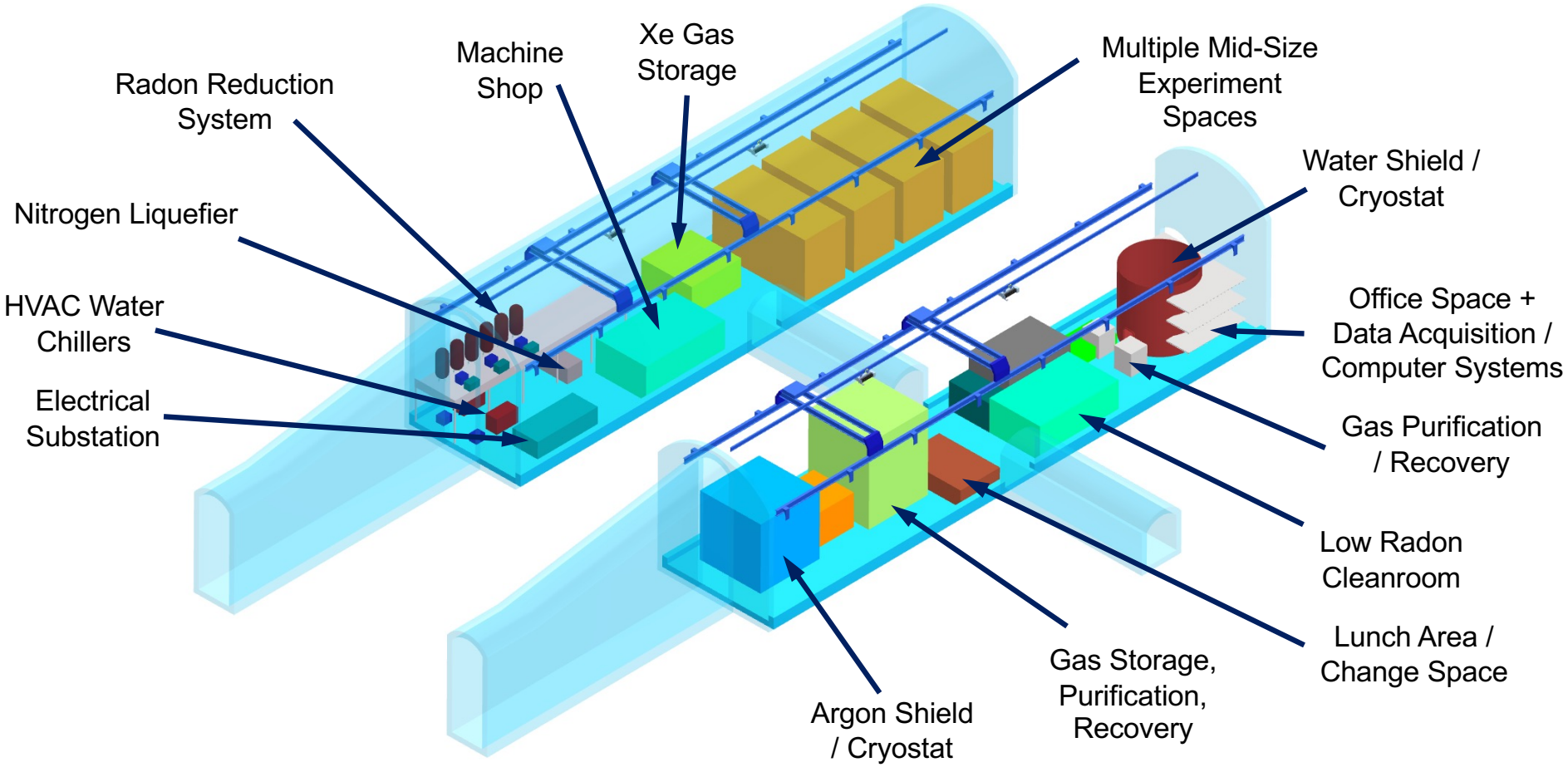
Up to Two Detector Caverns:

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

excavation time ~2.5 years
outfitting ~2030

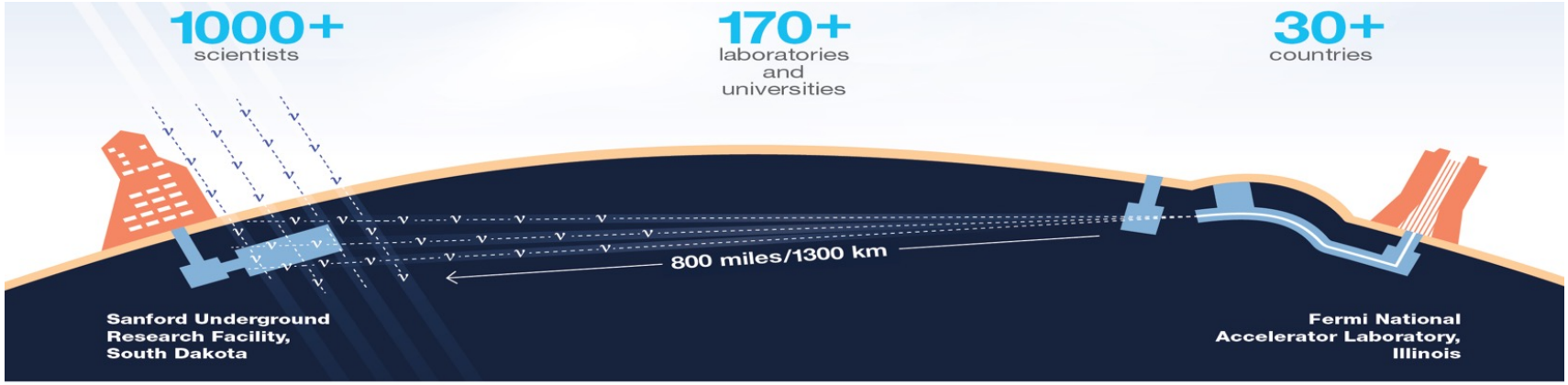
4850L Space Needed for Future Experiments

Conceptual laboratory layout (2x 100m caverns)



Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

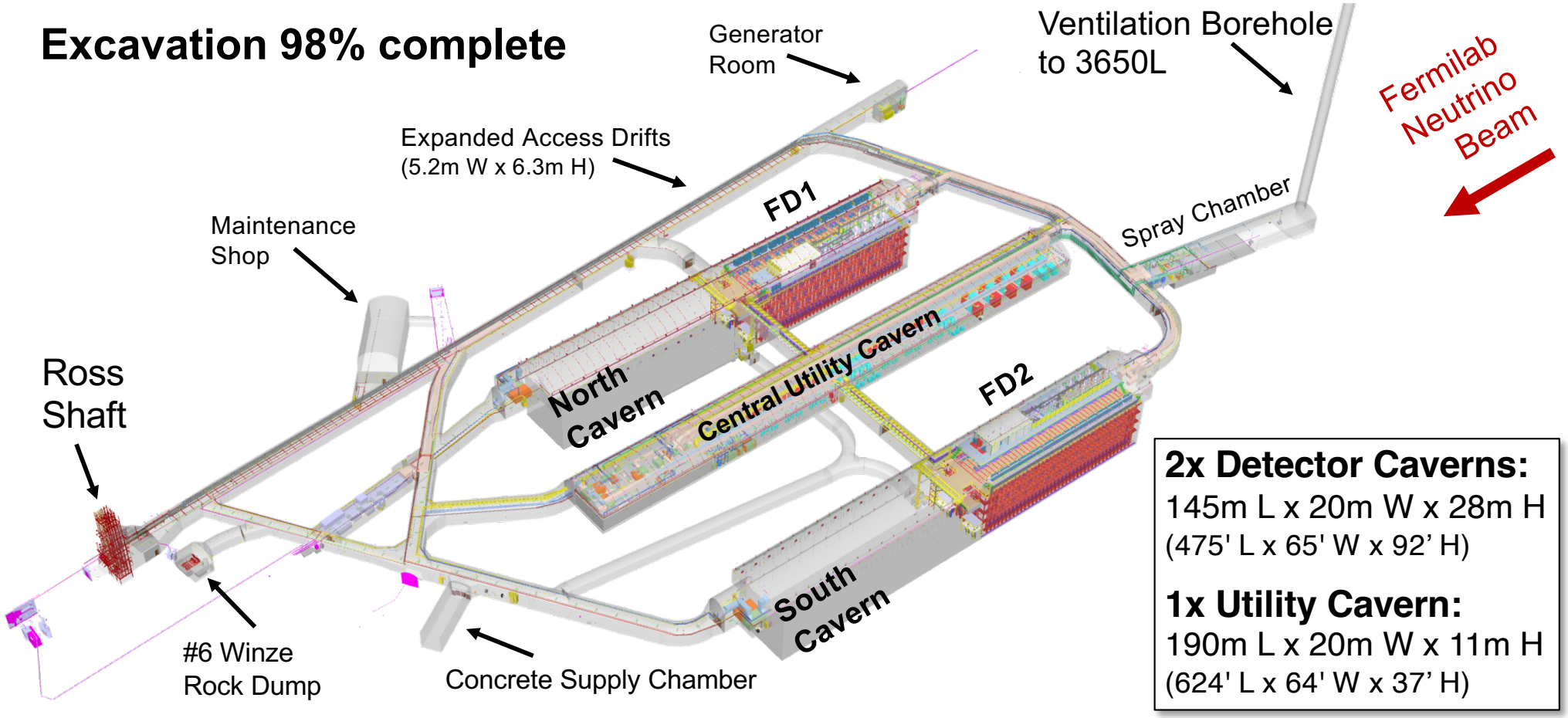


- Two detector caverns to host 4 detectors (total of 70 kT/50M liter liquid argon) + utility cavern.
- **Excavation** initial phase started June 2020, focused on ventilation.
- **Infrastructure outfitting** and **cryostat construction** expected 2024-2027, **science starts 2028**.
  - Aug 2023: north cavern excavation complete
  - Mar 2023: central utility cavern excavation complete
  - Jan 2024: south cavern excavation complete
  - Sep 2024: all concrete complete
  - Cryostat 1 and 2 installation + detector 1 complete: Jun 2027
  - Detector 2 complete: Jun 2028

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Excavation 98% complete



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)

Highlights from Yemilab

Most of facilities are done

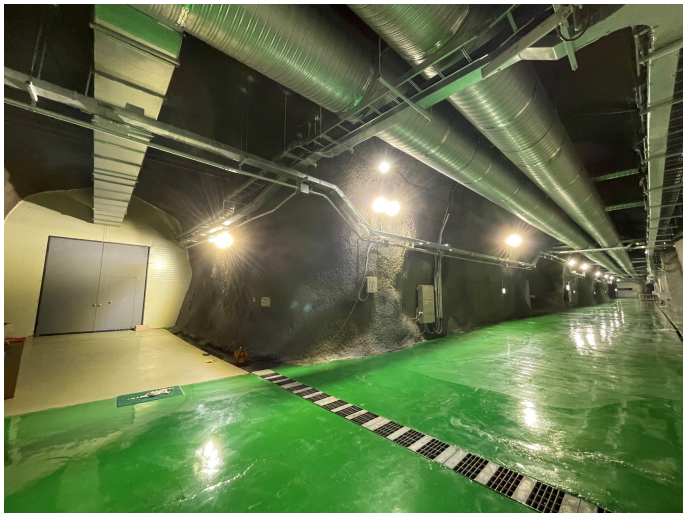
- Electricity : power cable line completed for 2,500kW
- Dust-proof doors, painting expr. wall, epoxying floor etc…
- Rn-less air supply system to reduce underground Rn level less than 150Bq/m^3

AMoRE-II preparation

- Moving Dilution Refrigerator from Deajeon(HQ)
- Commissioning starts late 2024

Y2L move to Yemilab (2023 ~ early 2025)

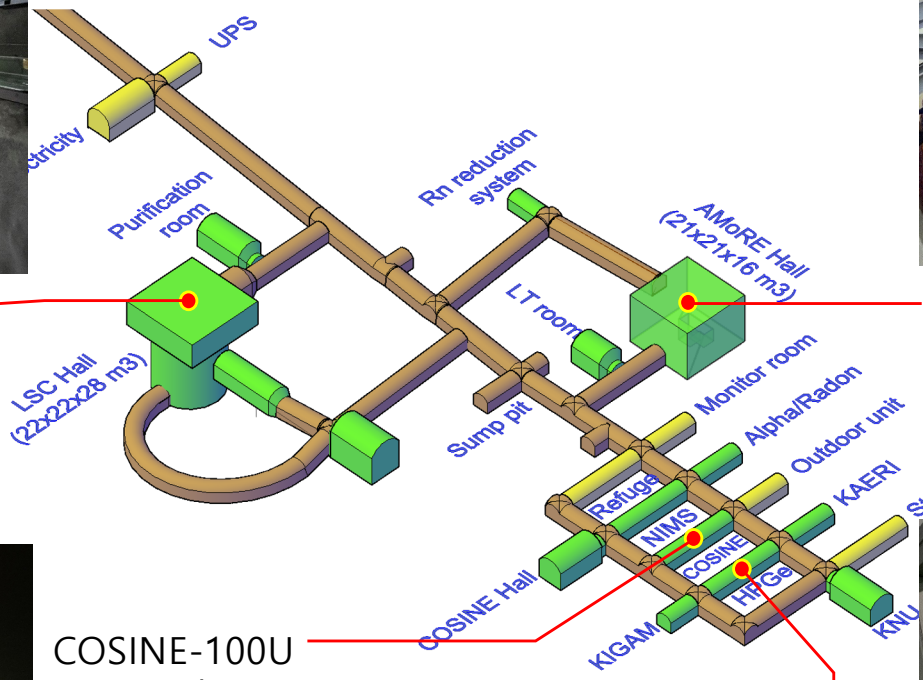
- COSINE-100U
- AMoRE-1
- HPGes'
- And so on…



Rn-less air supply system

Layout of Yemilab

LSC Hall 10-ton crane
- Completion June 2023



AMoRE-II
- Shield structure done
- Late 2024, commissioning

COSINE-100U
- -30℃ low-temp. room
- Moving Y2L detector to the room
- Early 2024, commissioning

HPGe
- Moving from Y2L
- Feb. 2024, start

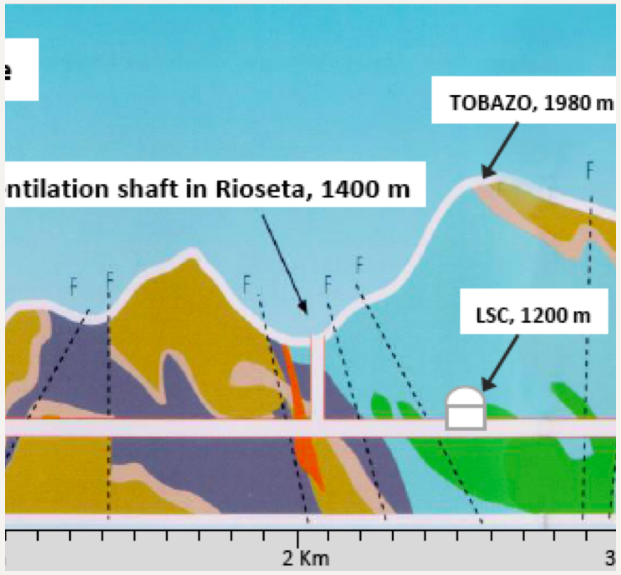
Canfranc Underground Lab

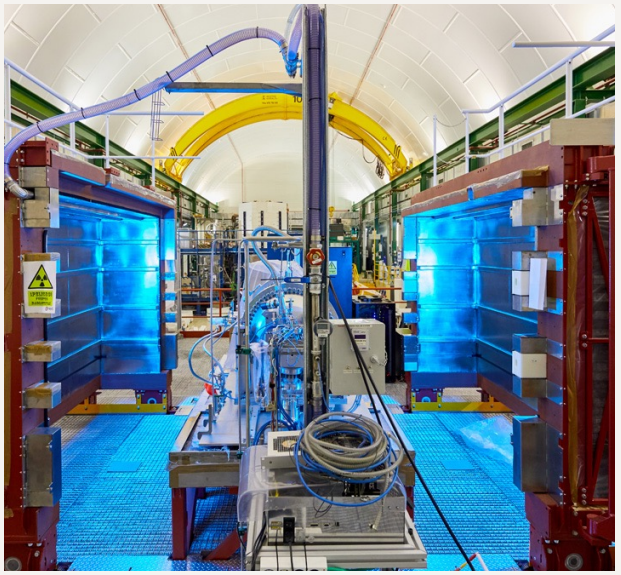
Located in Spanish-French Pyrenees border. Two-way access tunnels: abandoned train tunnel and operative road tunnel.

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 $cm^{-2}s^{-1}$

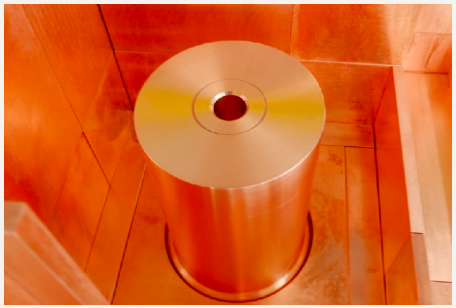
Radon abatement system: 220 m^3/h radon-reduced air at 1mBq/m^3





Example of Underground Science Trend: Budget, staff and experiments (institutions involved) increased twofold since 2018.

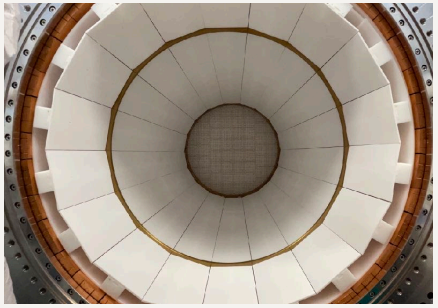
Hub of Cosmic Silence Science in Spain



HPGe detector GeRysy

ICPMS-QQQ

ANAIS Experiment



NEXT-100 interior

GeRysy: **New** lowest background world **record** in **HPGe** gamma screening with ***μ*Bq/kg sensitivity** (led by **G. Zuzel**).

New ICPMS-QQQ placed in Class ISO5 clean room underground: **2 (20) ppq** sensitivity in ^{238}**U(**^{232}**Th) and ppb** on ^{40}**K.**

ANAIS experiment: Modulation excluded at 3 sigma. Started **last (7th) year** of data taking **to reach 5 sigma** exclusion.

NEXT-100 experiment: Xe-136 gas TPC installation completed. Detector in operation since **December 2023**.

HyperKamiokande: Coordination of the Spanish contribution to the construction of HK (PMT covers, ventilation and geomagnetic compensation systems, electronic components, calibration sources, …).

Biology Platform: Two biolabs hosting cosmic silence experiments on viral infection, human cells aging, multicellularity, …

LNGS & LSC agreement: Research Collab and Transnational Access

AGREEMENT BETWEEN

Laboratorio Subterráneo de Canfranc (Huesca, SPAIN)

and

Laboratori Nazionali del Gran Sasso, Istituto Nazionale di Fisica Nucleare, (Assergi, ITALY)

In the framework of an international collaboration among research underground laboratories and in the framework of the international effort on searches for rare events, this Agreement defines the terms of Research Collaboration (RC) and Transnational Access (TA) between the Laboratori Nazionali del Gran Sasso (INFN-LNGS) and the Laboratorio Subterráneo de Canfranc (LSC) to reflect the rapid increase of collaboration and synergy between the two research infrastructures. Users at LNGS and LSC will benefit from a dedicated agreement to access experimental surface and underground areas, ultra-low background instrumentation, and facilities to support research in both sites.

Deep Underground and ultra-low Radiation background Facility for frontier physics experiments(DURF) in CJPL-II

- Internal Construction started at 2020/12
- Civil engineering will be finished in Oct. 2023
- All constructions will be completed by 2024
- 4 experiment halls (A-D), total space of >300,000 m^3
- Will be the deepest and largest underground lab worldwide

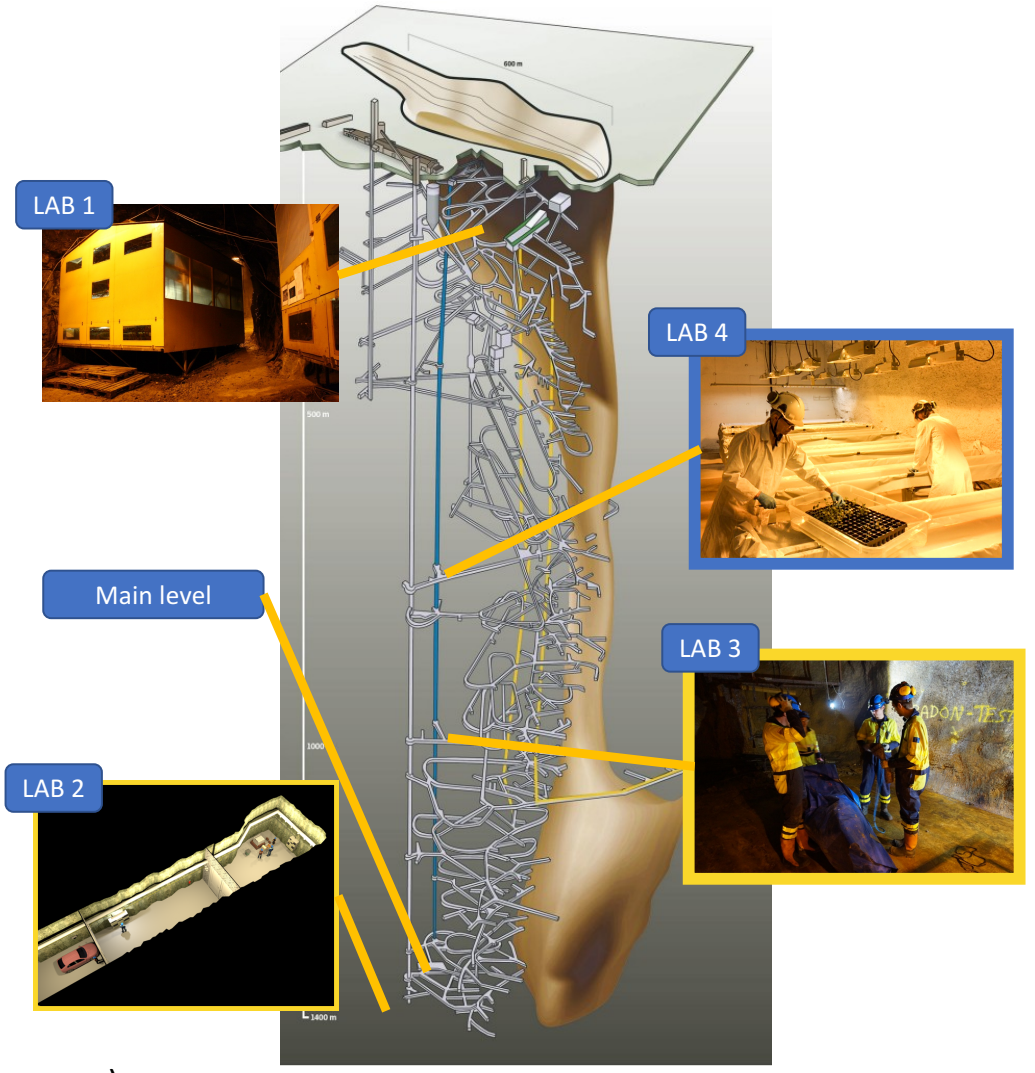
Experiments in CJPL-II

- CDEX (DM+0vββ)
- PandaX (DM+0vββ)
- JUNA (Nuclear Astroparticle)
- Jinping Neutrino Program (Solar and Geoneutrino)
- SER (integrated circuit Soft Error Research)
- GeoDEX (Deep underground geologic experiment)
- CUPID-CJPL (0vββ)
- NvDEx (0vββ)
- More coming……

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)

Conclusions

- At present **13 DULs in operation** and one new proposal
- Some 100 experiments running or under construction
- Some 6000 involved researchers
- Getting ready to **face the future**:
  - Workload sharing + optimization of facilities use + investments optimization
  - Coordinate strategy for future developments
  - Inventory of existing facilities
  - **Support new DUL** proposals to reinforce science/connections/sharing
  - Advance Training and Transnational Access

Thank you for your attention!

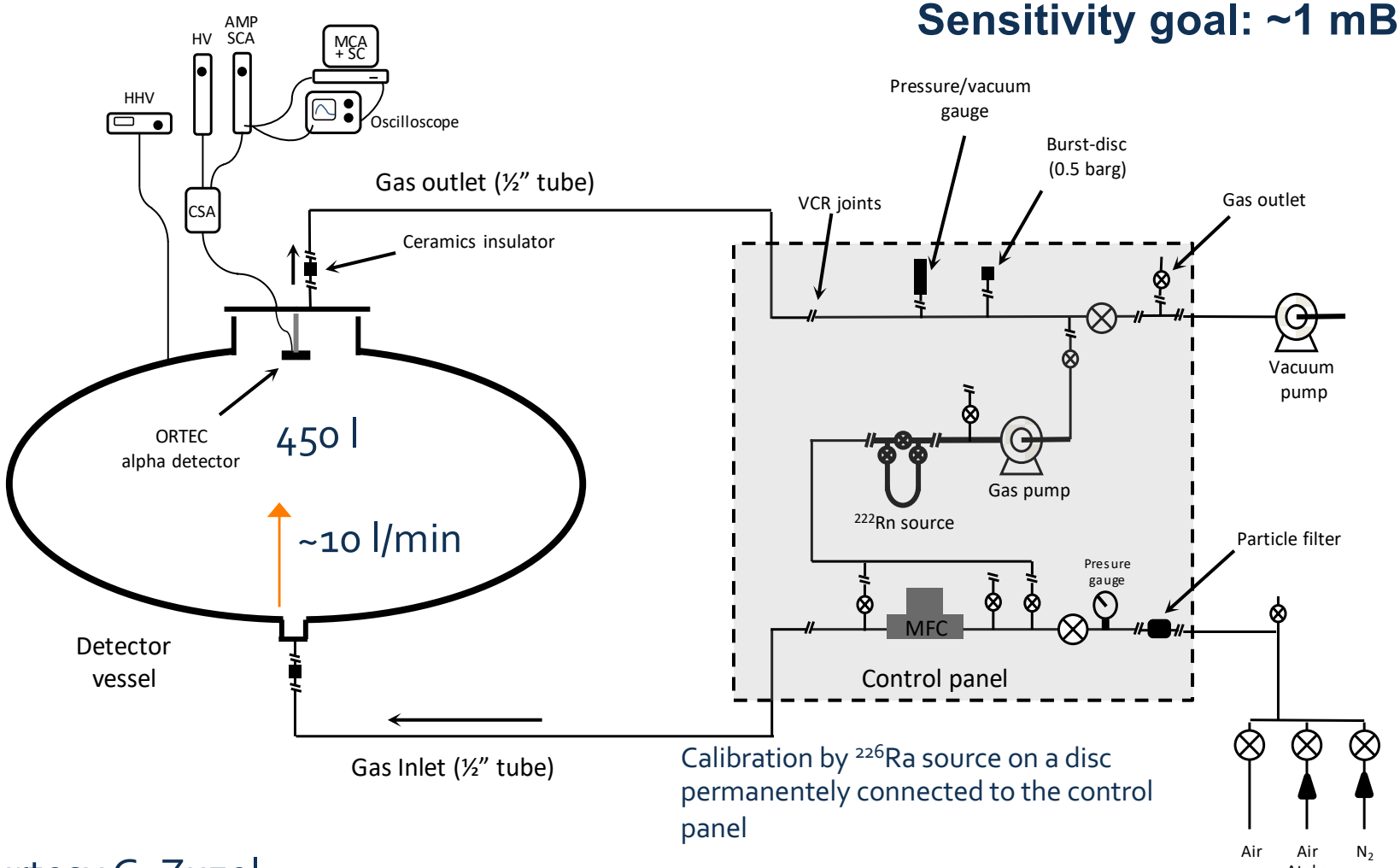
Acknowledgements for contributions to:
Qian Yue (CJPL), Carlos Pena-Garay (LSC), Jaret Heise (SURF), Yeongduk Kim (Yemilab), Julia Puputti (CLAB)

Advance machining

- Strong request for light, low radioactivity, and complex geometry detectors components
- At LNGS (**3Dlab**) 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

Electrostatic ^{222}Rn detector - concept

Sensitivity goal: ~1 mBq/m^3

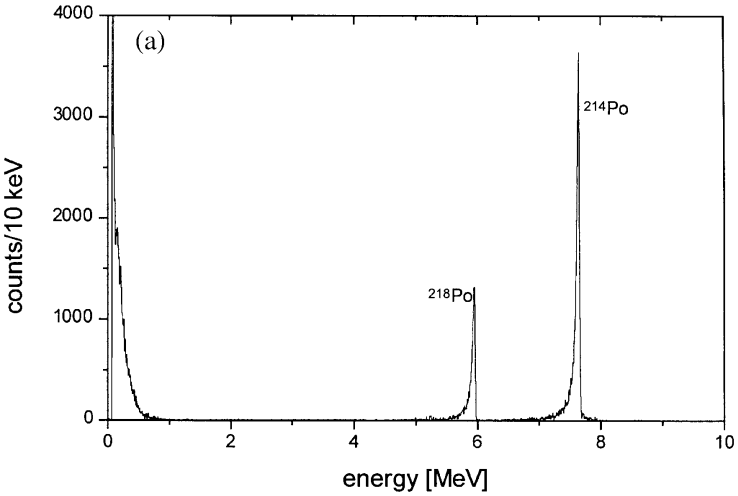


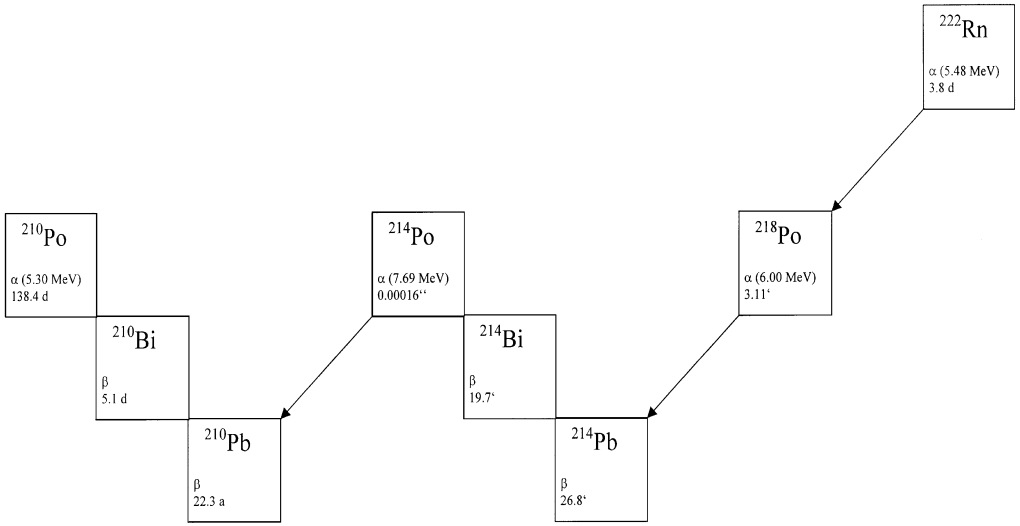
Calibration by ^{226}Ra source on a disc permanentely connected to the control panel

Courtesy G. Zuzel

Determine Rn activity

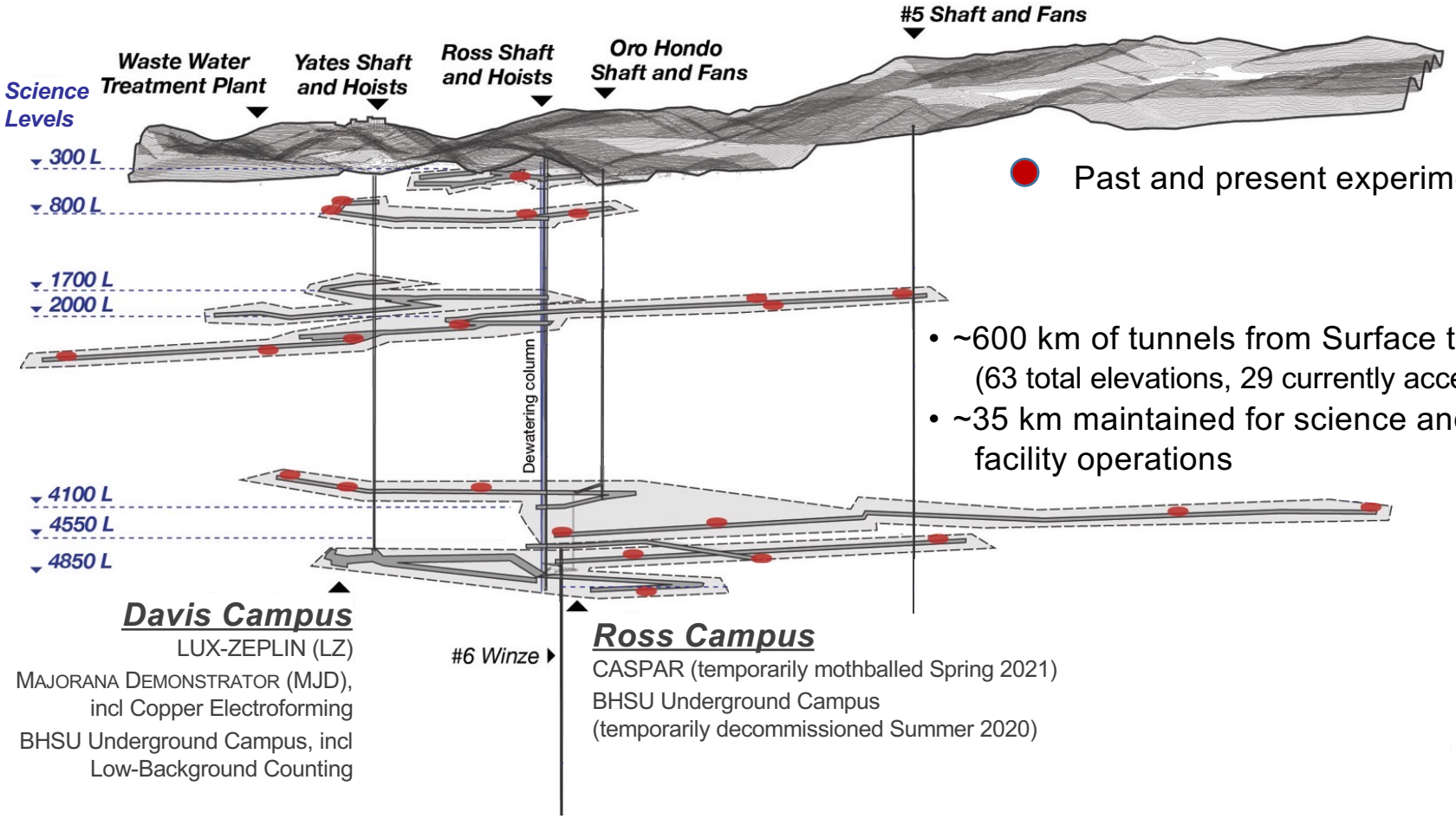
- $R_{218} = \varepsilon_{\alpha}\varepsilon_{C218} A_{Rn} V$
- $R_{214} = R_{218} + \varepsilon_{\alpha} \varepsilon_{C214} (1-\varepsilon_{C218}) A_{Rn} V$
- $R_{214} / R_{218} = 1$ if $\varepsilon_{C218} = 1$





SURF Underground Lab Geography

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



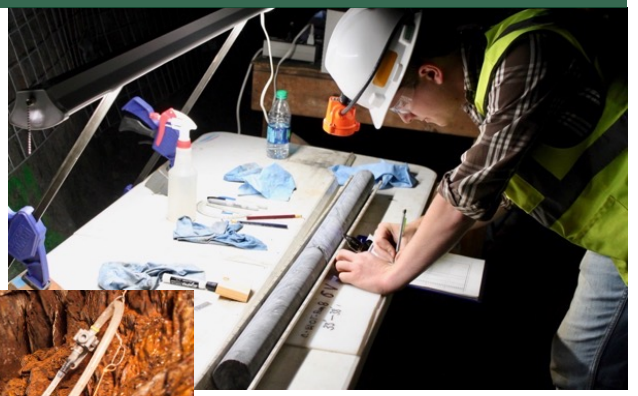
Past and present experiment sites

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

SURF Science Program

SURF serves a diverse community:

- Physics
  - Low-background environment to study rare processes
- Biology
  - Isolation from surface microorganisms
  - Variety of environmental conditions (temperature, humidity, etc)
  - Variety of niches (materials/rock geochemistry, water from different locations, trace gases, etc)
- Geology
  - Variety of geologic environments / rock formations (permeability, porosity, chemistry); also drill core archive
- Engineering
  - Real-world environments for technology development, mining, etc



SURF Science Program

Research activities ranging from the surface to 1500+m underground

Physics

- LZ – *Dark matter, 2-phase Xe TPC*
- MAJORANA DEMONSTRATOR / LEGEND – *Neutrinoless double-beta decay, Ge-76, Ta-180m, also Cu e-forming*
- CASPAR – *Nuclear astrophysics with 1 MV accelerator*
- LBNF/DUNE – *Neutrino properties, etc*
- BHUC – *BHSU Underground Campus, mainly material screening*
- Berkeley LBF – *Low-bkgd counter (x3);* also CUBED – *Low-bkgd counter (x1) (possibly future Crystal Growth)*
- nEXO – *Low-bkgd counter (x1)*
- LLNL – *Low-bkgd counter (x1)*
- SDSMT – *Neutron bkgds*

Total = 29 groups
20 Active Projects
65 Total Groups Since 2007

* Denotes proprietary group

Significant interest from others
(26 groups so far in 2023)

Also Science Programs for Students: 2x DOE RENEW, 1x NSF REU

Biology

- Astrobiology/DeMMO – *In-situ culture, isolate DNA*
- 2D Best – *Biofilms*
- Biodiversity – *Microbial communities*
- Biofuels – *Extremophile bioprospecting*
- BuG ReMeDEE – *Methane oxidation*
- Chemistry – *Env characterization*
- Liberty BioSecurity* – *Extremophiles*
- Plant Growth – *Low EM, cosmic ray muons*

Geology

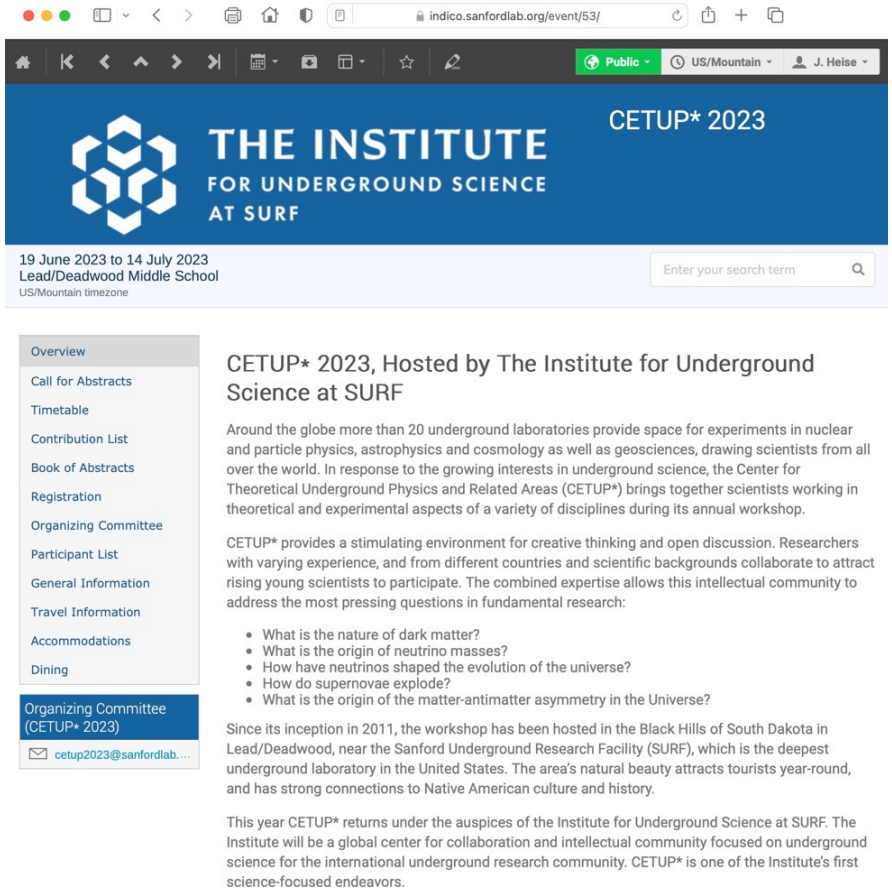
- DEMO-FTES – *Geothermal*
- 3D DAS – *Seismic monitoring using fiber*
- Core Archive* – *Mainly gold deposits*
- Hydro Gravity – *Gravity for water tables*
- BH Seismic – *Global monitoring*
- BH Geochemistry – *Exobiology*
- Transparent Earth – *Seismic arrays*

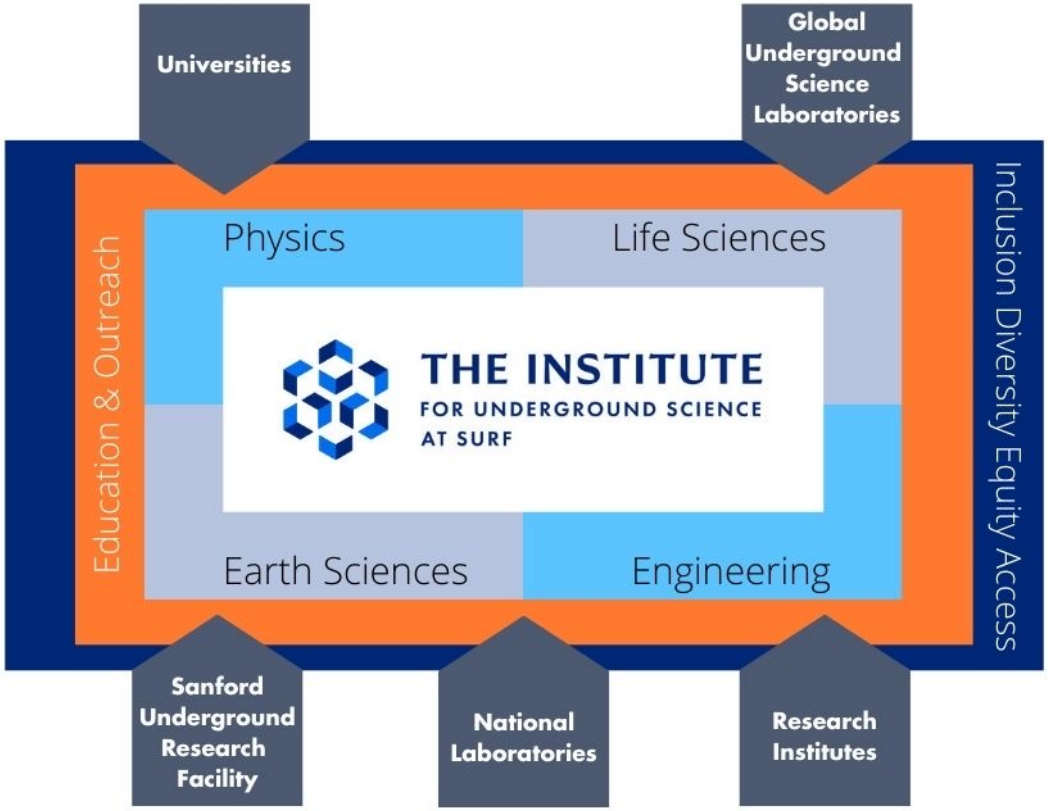
Engineering

- Xilinx, Inc* – *Chip error testing*
- Thermal Breakout – *In-situ stress*
- Shotcrete – *Mining safety*
- Enviro Monitoring – *Ventilation airflow*
- Caterpillar* – *Mining technology*

Institute for Underground Science at SURF

CETUP* Topical Workshop held summer 2023! Registration underway for 2024





Advanced Machining and ultra-pure copper

- **E-formed copper made at LSC**
  - Make copper powder
  - Use advanced machining Service

  to make components for experiments

Contamination level of radio impurities, expected at sub-ppt level (<= 1μBq/kg)

Cu	U [ppt]	Th [ppt]
OFHC	0.2±0.01	1±0.06
E-formed	< 0.05	0.040±0.002

CALLIO LAB

Research activities coordinated by the Kerttu Saalasti Institute, University of Oulu

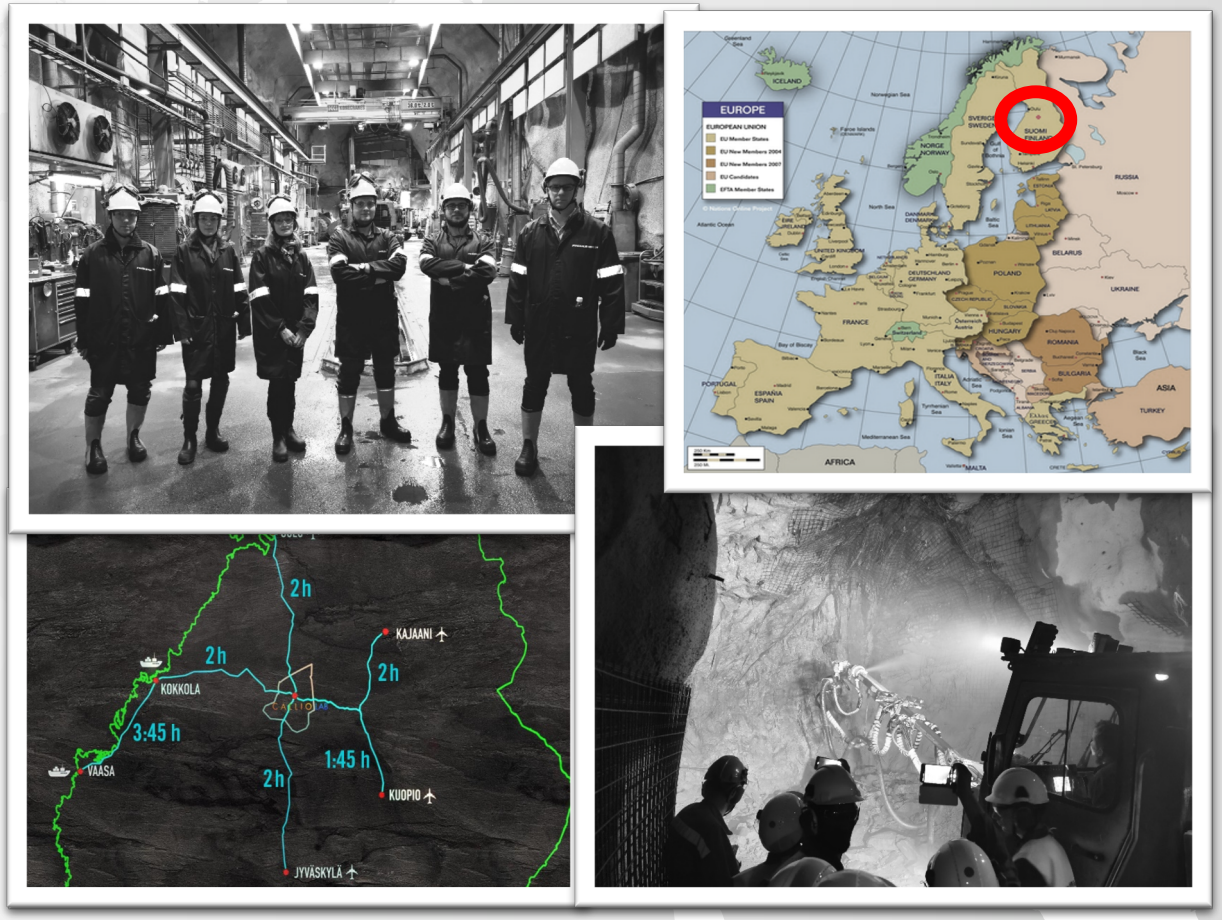
UNIQUE UNDERGROUND RESEARCH NETWORK AND INFRASTRUCTURE LOCATED AT THE 1.4 KM DEEP PYHÄSALMI MINE, PYHÄJÄRVI, FINLAND

POSTI-MINING ACTIVITIES COORDINATED BY CALLIO PYHÄJÄRVI

CURRENTLY SIX UNDERGROUND HALLS OR TUNNEL NETWORKS HAVE BEEN TURNED INTO MINE RE-USE FACILITIES: LABS

RESEARCH TOPICS INCLUDE:

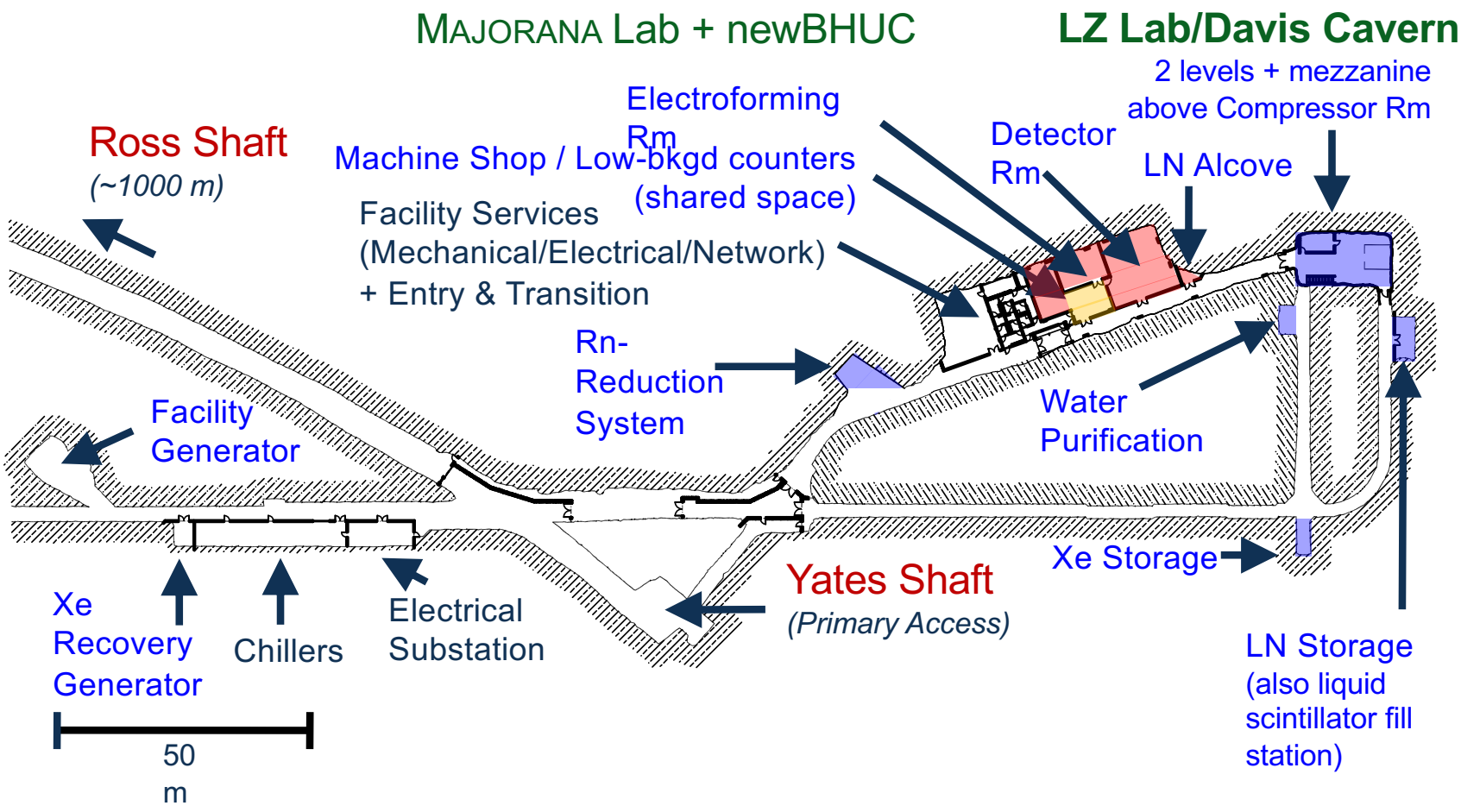
- PARTICLE PHYSICS
- GEOTHERMAL ENERGY
- MINING & TUNNELLING
- UNDERGROUND OCCUPATIONAL SAFETY
- REMOTE SENSING AND MANY MORE



UNIVERSITY OF OULU

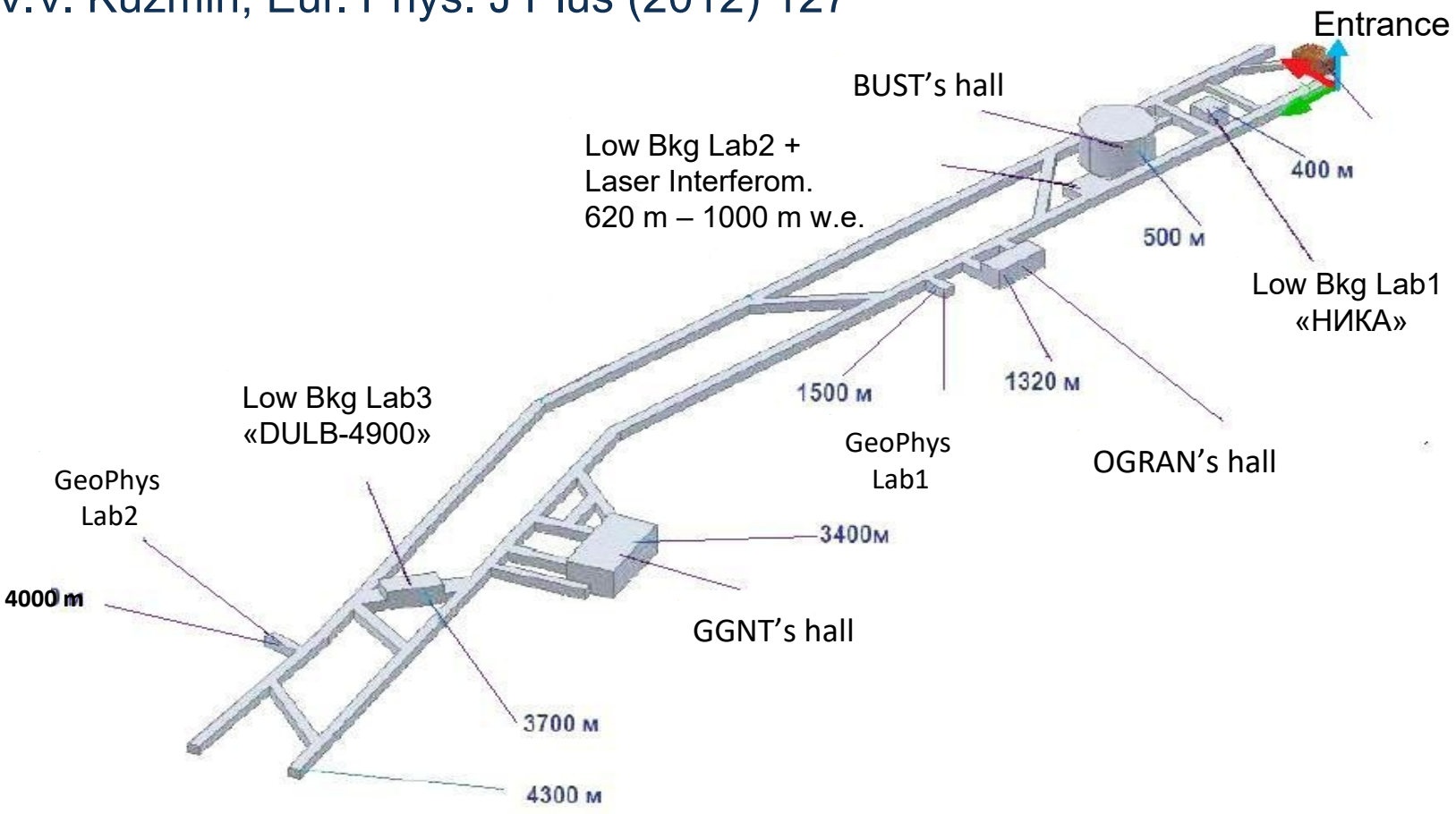
4850L Davis Campus

3,017 m^2 (Total) / 1,018 m^2 (Science)



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)