Future facilities: underground laboratories

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Outline

- **D**eep **U**nderground **L**aboratorie**s** (**DULs**):

  main characteristics

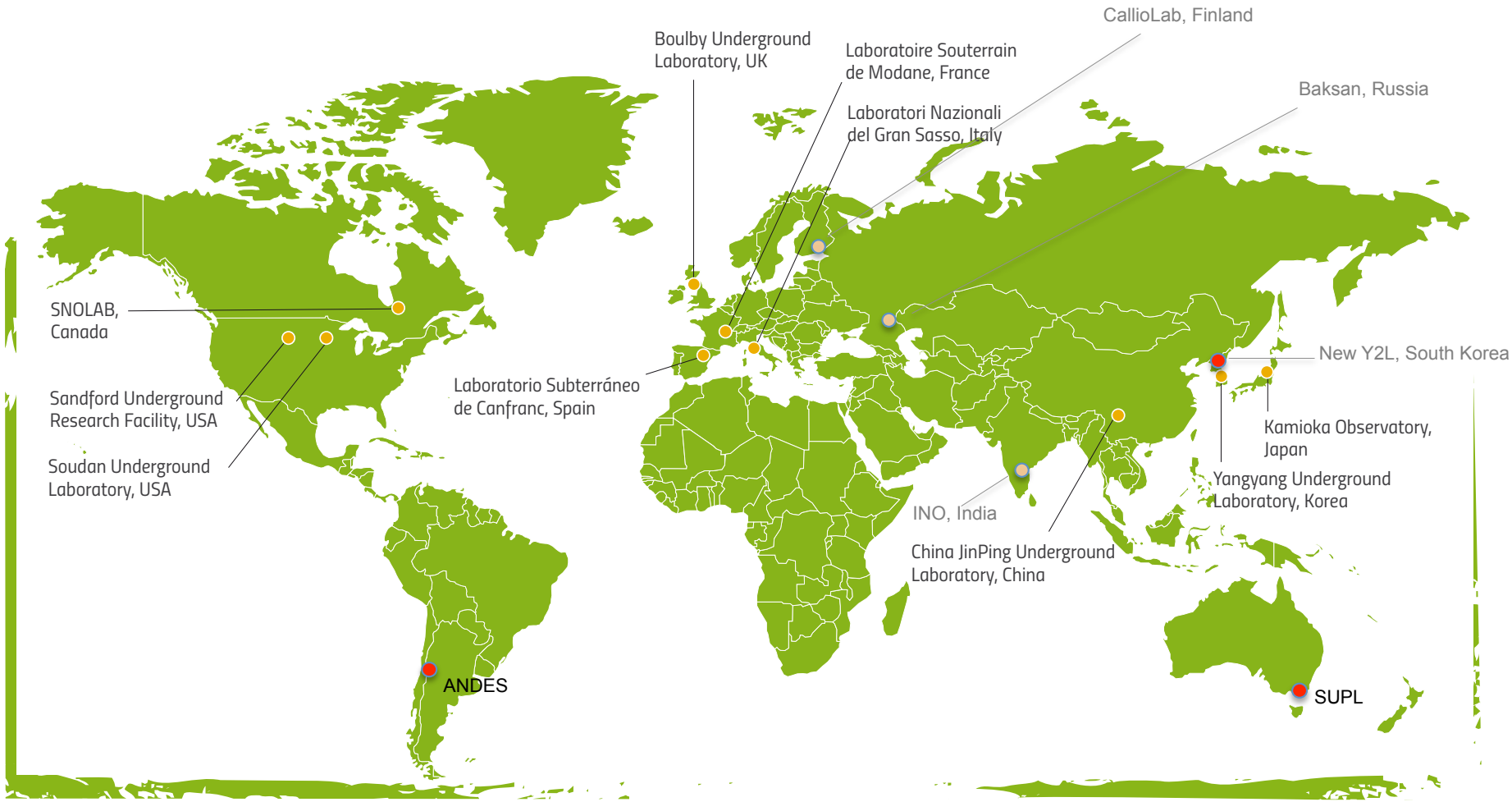
- Science and technology in DULs

- Future facilities

DULs worldwide

- DULs: more than 1000 m.w.e. overburden
- **13** infrastructures (**DULs**) in operation
  - all in the north hemisphere
- One soon under major expansion (SURF)
- Three upcoming DULs (two in the south hemisphere). Time scale: 2019-2027

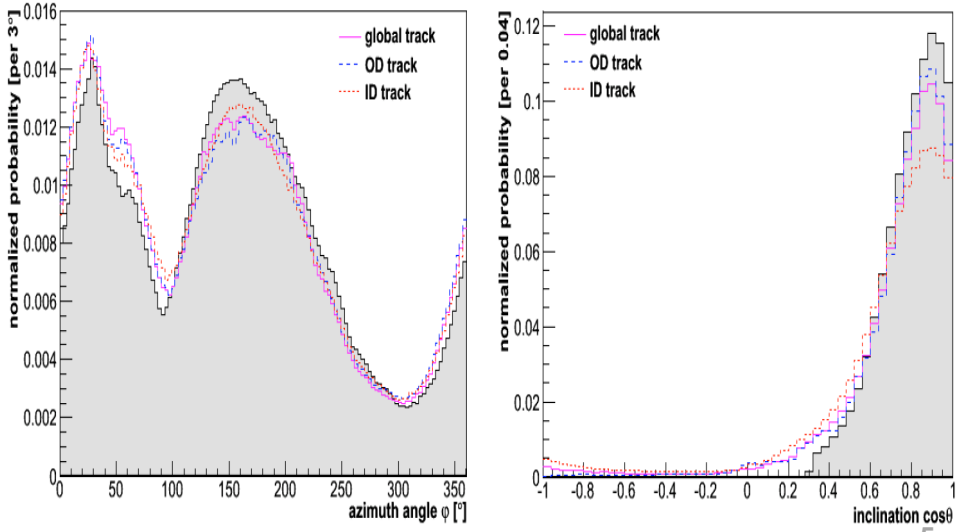
Map of DULs

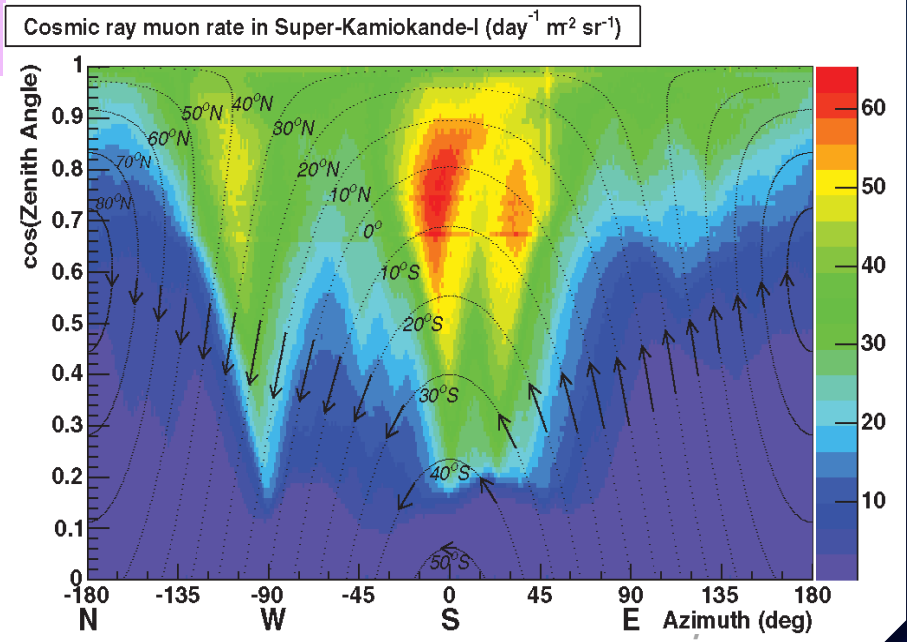

CallioLab, Finland
Boulby Underground Laboratory, UK
Laboratoire Souterrain de Modane, France
Baksan, Russia
Laboratori Nazionali del Gran Sasso, Italy
SNOLAB, Canada
New Y2L, South Korea
Laboratorio Subterráneo de Canfranc, Spain
Sandford Underground Research Facility, USA
Kamioka Observatory, Japan
Soudan Underground Laboratory, USA
Yangyang Underground Laboratory, Korea
INO, India
China JinPing Underground Laboratory, China
ANDES
SUPL

Overburden characteristic [1]

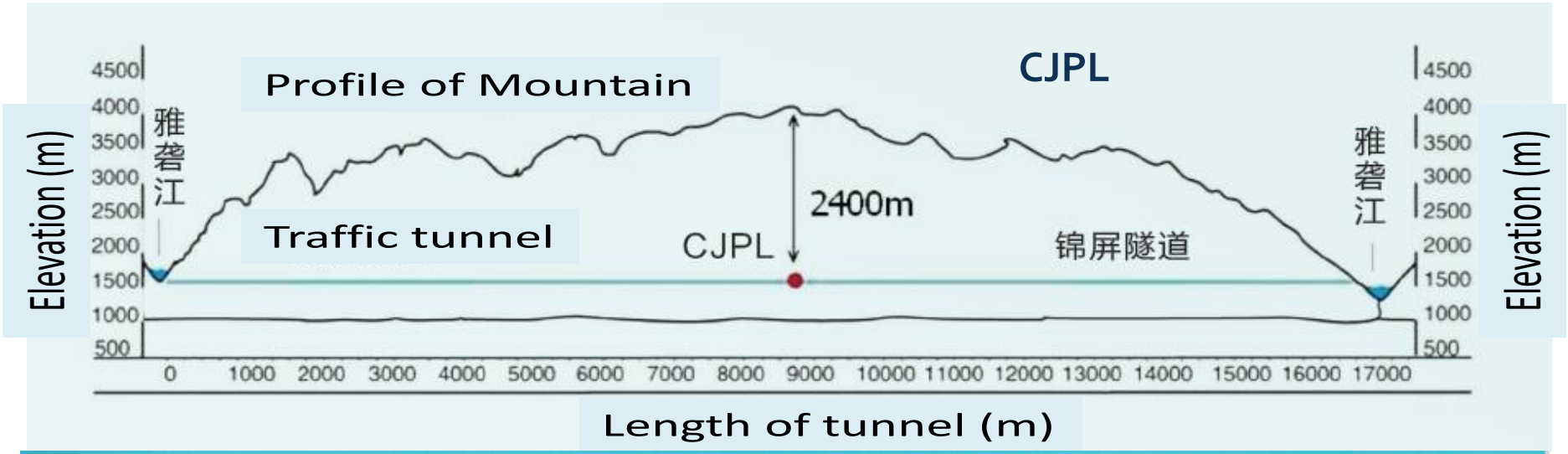
- Under a flat surface (SNOLab, CallioLab,SURF,Soudan)
- Under a mountain (Baksan, LNGS, LSC, LSM, CJPL)
  - Important cosmic-rays angular dependence

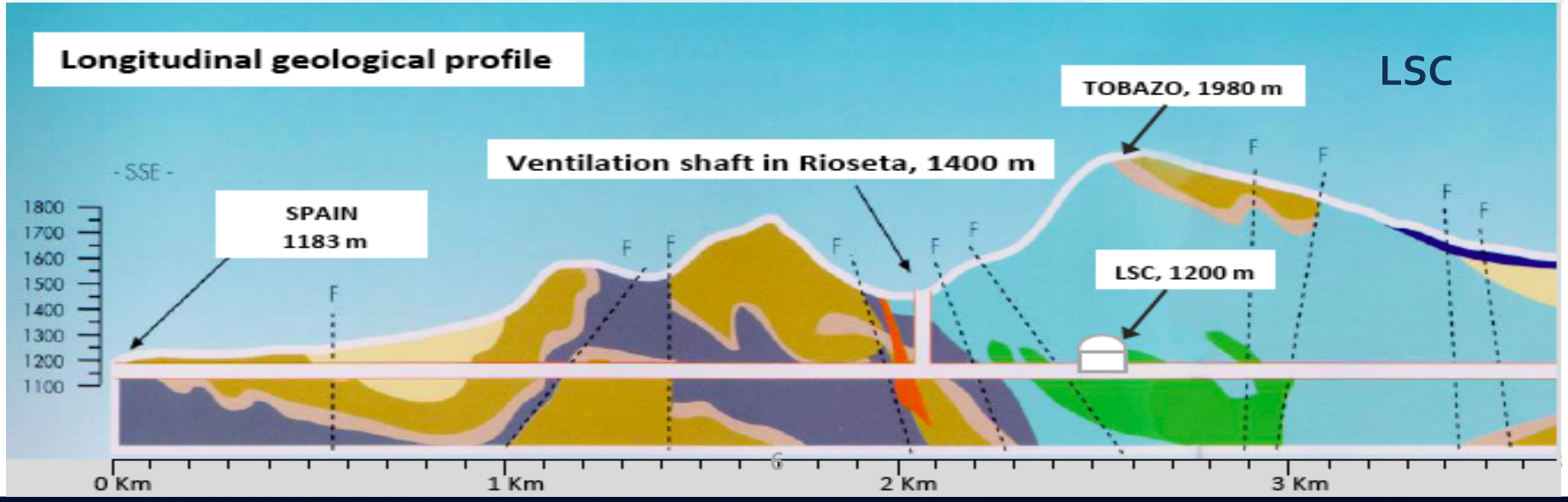
Muon data for LNGS: MACRO and Borexino



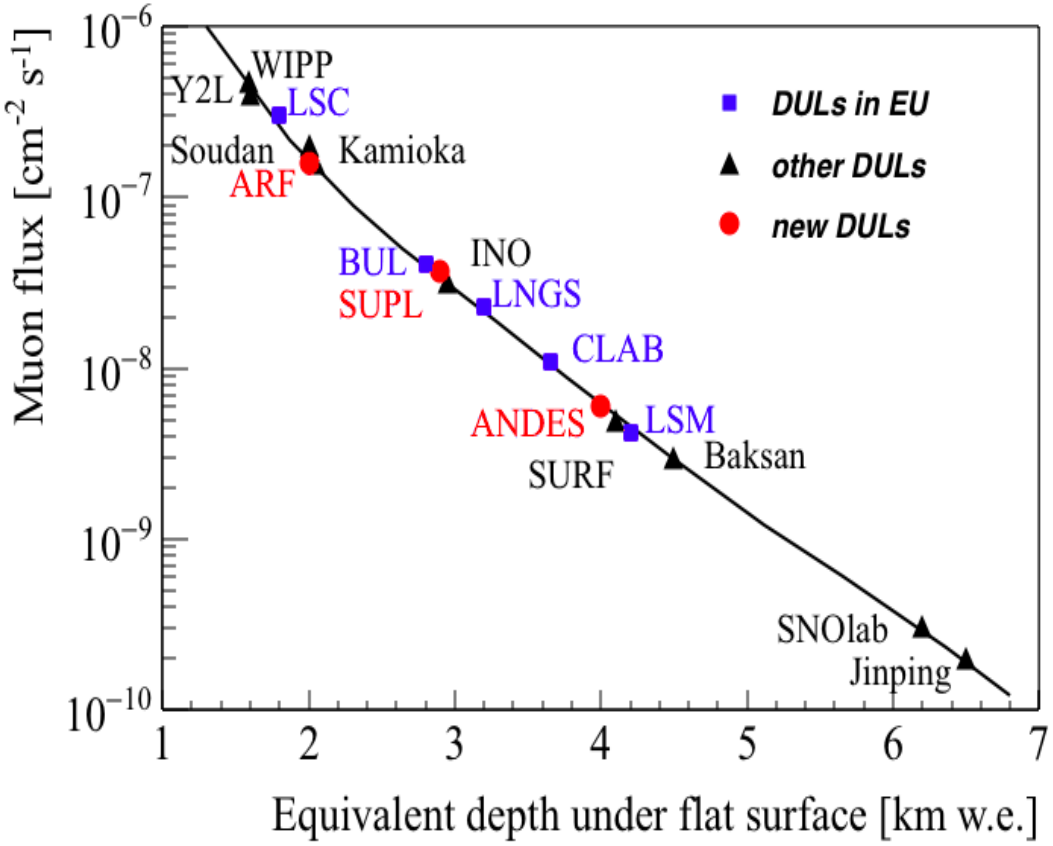


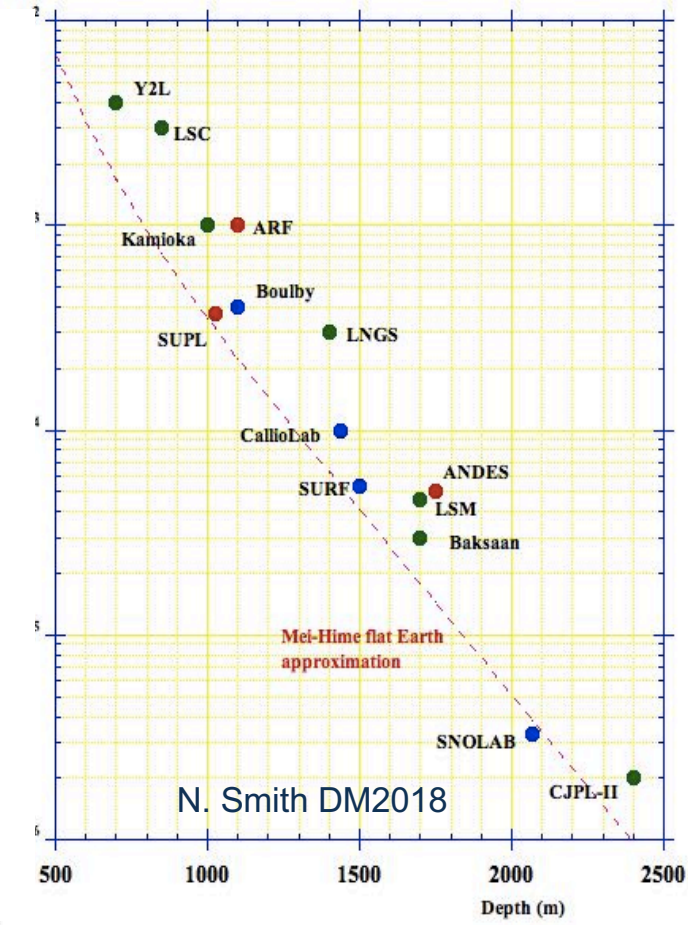
Overburden characteristic [2]





Muon Flux in DULs





DULs provide

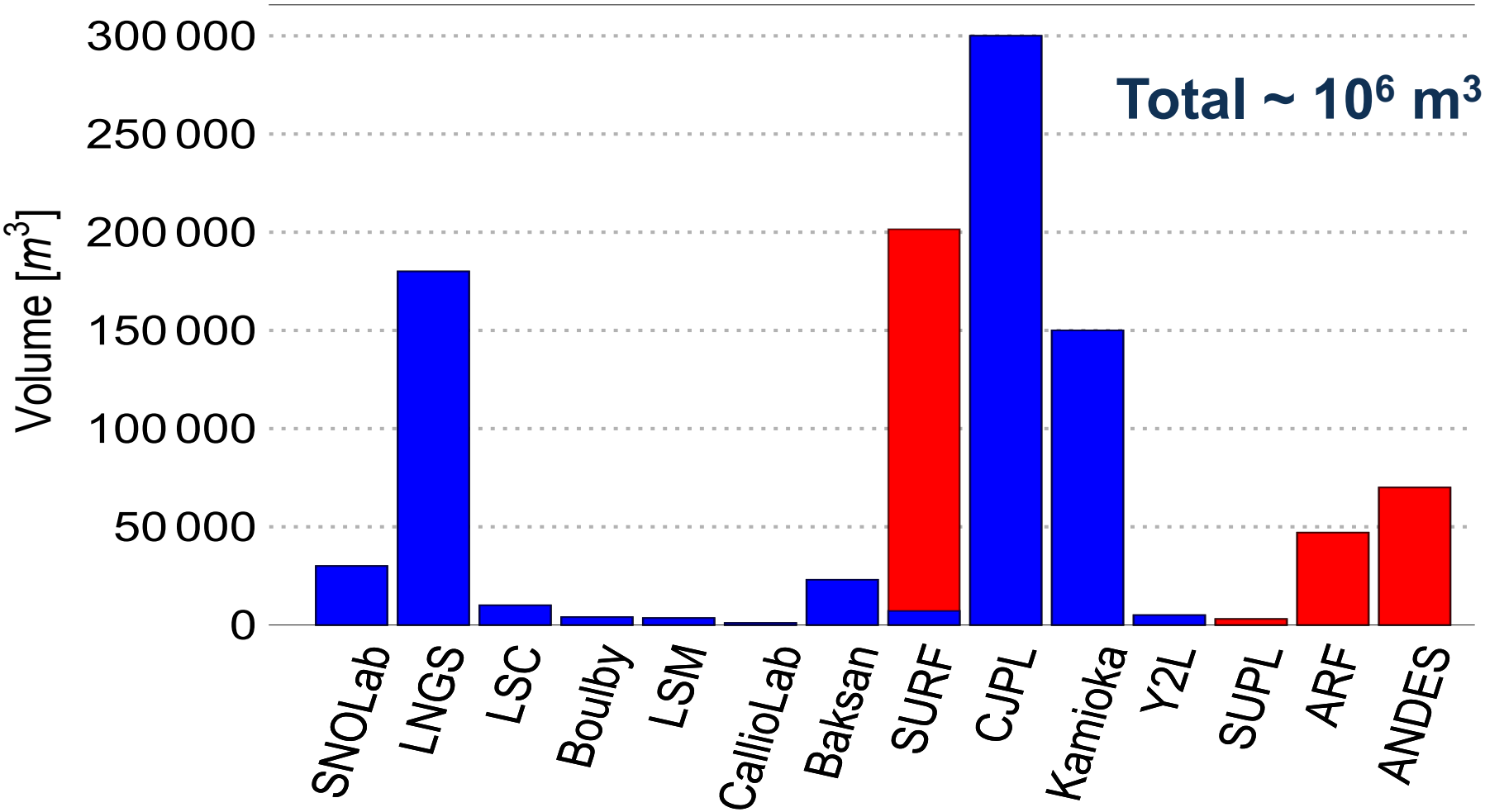
- Monolithic or distributed space underground
- Support for construction, operation and design for experimental activities
- Safety assessment protocols
- Overburden, neutrino flux from a beam, neutrino flux from reactors, horizontal/vertical access
- Surface and underground facilities: offices, workshop, chemistry lab, electronics lab, metting rooms, computing
- Utilities: power, ventilation, water, …
- Cleanliness standard
- Ancillary facilities: radio-purity assay lab, free radon air, clean rooms, …

DULs classification

- **Depth**: shallow, deep, very deep
  - The physics program depends on the depth
- **Location**: close to reactors, close to oceanic crust, in a mine, in beam line, possibility for expansion
  - The physics case depends on the location
  - The access and cleanliness depend on the location
- **Size**: large, medium, small
  - The physics program depends on the size
  - The cleanliness standard depends on the size

Hall A at LSC
example of medium size

Excavated volume in DULs

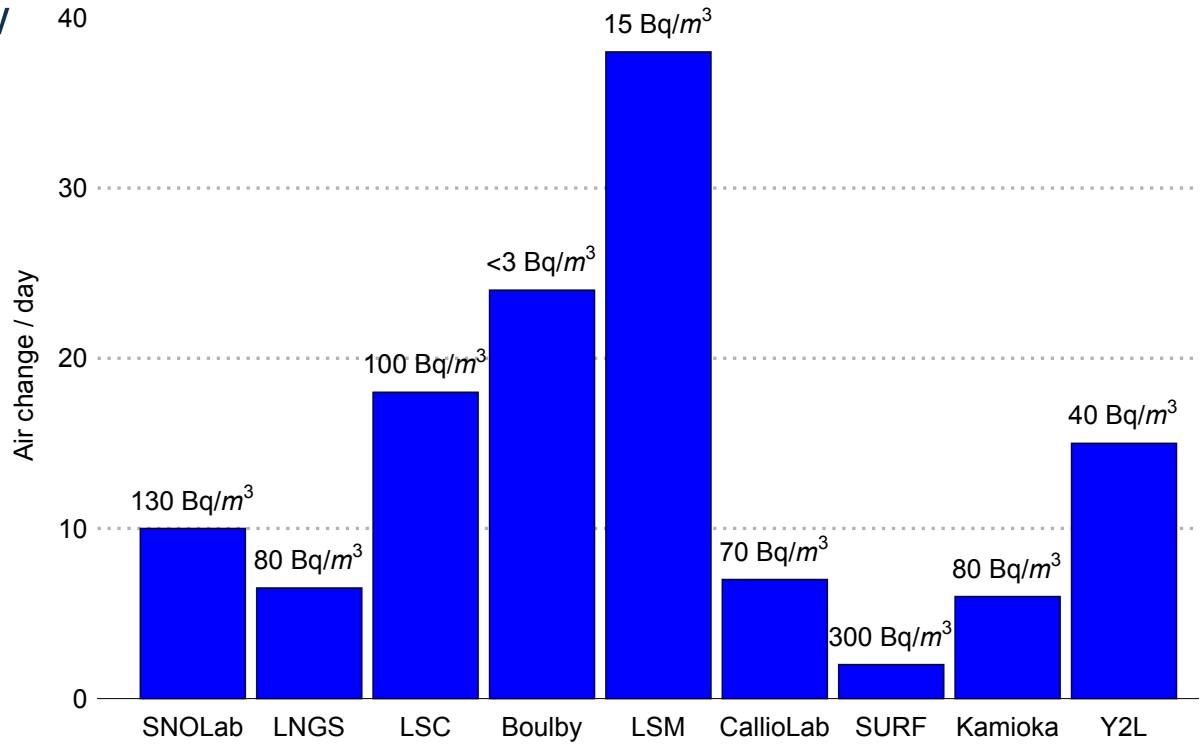


Radon level in DULs

Air ventilation reduces the natural radon level to comply with restrictions by the Law

Two exeptions in salt and potash mines:

1) Boulby (UK)
2) WIPP (NM, USA)



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)
  - Easy access, not special maintenance
  - Interaction protocol with Company keeping control of the road tunnel (LNGS, LSC)
- **Multiple** (CallioLab, ARF)
  - Cage system and drive-in possibility

Cleanliness in DULs

- **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, CJPL)
  - Make use of 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

Boulby new laboratory ISO7

Sean Paling

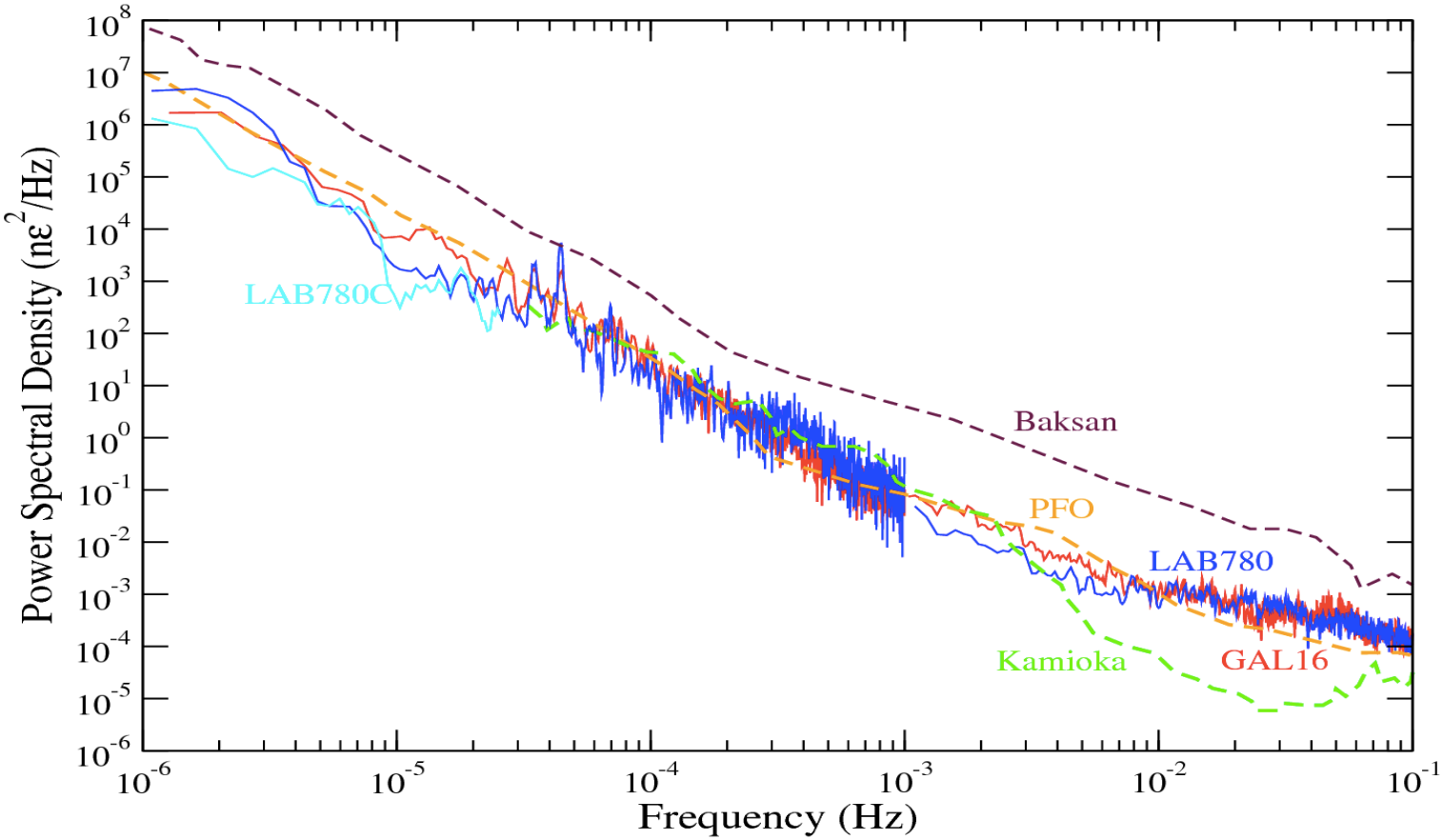
Synergy and coordination efforts between DULs

- SNOLab and LNGS initiated an effort to put forward an idea about a **Global Underground Research Infrastructure**
  - Supported by LSC, Boulby, LSM and, CallioLab
- **Coordination on outreach programs**
  - LNGS, SNOLab and LSC
- **Sharing work load**
  - Radiopurity assay for SuperKamiokande-Gd
    - Kamioka, LSC, Boulby
  - Global argon program
    - SNOLab, LNGS, LSC
- **APPEC**: meant to drive the science program in DULs at international level (downselection program)
- **IUPAP WG9** (international cooperation in nuclear physics)

Science in DULs

- In DULs we mainly carry out research for
  - **Neutrino physics** (solar, reactor, atmospheric, accelerator, geo and, supernova)
  - **Neutrinoless double beta decay**
  - Direct detection of **Dark matter**
  - **Rare processes** (proton decay …)
  - **Nuclear astrophysics**
- **Multidisciplinary research**
  - Geophysics
  - Gravitational waves
    (KAGRA in Kamioka, feasibility studies at LSC)
  - Biology

An example on multidisciplinary in DULs: geophysics underground with laser strainmeters



Physics done and to be done in DULs
(astroparticle and neutrino physics only)

Observations and meausurements already done in DULs

+ Neutrino oscillations and Matter effect in neutrino propagation (MSW)
+ Neutrino from a collapse supernova (in Feb 1987)
+ Spectroscopy of solar neutrinos + nuclear astrophysics
+ Geo-neutrinos (neutrinos from the uranium and thorium radioactivity within the Earth)

Next future main goals

+ Precision of neutrino physics (mixing matrix determination, mass ordering)
+ Direct dark matter
+ Neutrinoless double beta decay
+ Neutrinos from relic supernovae

Science driving new technologies from DULs

A few selected examples to address the issue: **science driving new developments from DULs**

- Classification of cleanliness for large as-built facilities
- **Radon abatement system and radon monitoring**
- Radon-free clean rooms to suppress background from radon daugthers
- Reduction of ^{210}Pb and ^{210}Po in water
- **Measurements at sub ppt levels of U and Th with ICP-MS**
- **Advancement in gamma spectroscopy with HPGe detectors**
- Active neutron veto with boron-loaded liquid scintillator
- **Extreme purification levels achieved for scintillators**
- Calibration with ^{83}Kr for dark matter and double beta decay experiments using xenon and argon
- **Underground argon for dark matter search**
- **Development of low background photo-detectors based on SiPM**
- Copper electroforming
- …

Future facilities: new DULs

- **SURF**: new excavation for DUNE (long baseline neutrino program)
  - Excavation begins in 2019 and last 3 yr
- **Handuk Mine**: new laboratory in South Korea
  - Ready by mid-end 2019
- **SUPL**: new laboratory in Australia
  - Ready by end of 2019
- **ANDES**: new laboratory Chile-Argentina
  - ready by 2027

Some features for the existing DULs

	SNOLab	LNGS	LSC	Boulby	LSM	Callio Lab	Baksan	SURF	CJPL-I/II	Kamioka	Y2L
Date of creation	2003 (1991)	1987	2010	1989	1982	1995	1967	2007 (1967)	2009/ 2014	1983	2003 A6 2014 A5
Personnel	100	106	12	6	12	13	227	125	20	94	4
Surface U/S [m^2]	5350/ 3100	17000/ 95000	1600/ 2550	1700/ 400	400	220	1600/ 10000	1900/ 190	8000	15000/ 3000	300/ 60
Volume [m^3]	30000	**180000**	10000	7200	3500	1000*	23000	7160	4000/ **300000**	150000	5000
Depth [m]	2070	1400	850	1100	1700	1440	1700	1500	2400	1000	700
Access [V or H]	V	H	H	V	H	V / drive in	H	H	H	H	Drive in
Makeup Air [m^3/h]	12000	35000-60000	20000	300	5500	3600	1440	510000	_	6000	3300
Air change/day	10	5-8	48	24	38	7	_	144 (LUX)	_	6	15
Muon flux [$m/m^2/s$]	$3.1\ 10^{-6}$	$3\ 10^{-4}$	$3\ 10^{-3}$	$4\ 10^{-4}$	$4.6\ 10^{-5}$	$1\ 10^{-4}$	$3\ 10^{-5}$	$5.3\ 10^{-5}$	$2\ 10^{-6}$	10^{-3}	$4\ 10^{-3}$
Radon [Bq/m^3]	130	80	100	**<3**	15	70	40	300	40	80	40
Cleanliness	2000 or better	Only in sector	Only in sector	10000	ISO9	Only in sector	Only in sectors	3000	Only in sectors	Only in sectors	Only in sectors

* Only for deepest level

Feature for the new DULs

	SUPL	ARF	ANDES
Expected to be in operation	2019	mid-end of 2019	2027
Personnel	3	20	–
Access	Drive in	V / drive in	H
Volume [m^3]	3025	~16000	70000
Surface [m^2]	350	~2000	2800
Outside surface [m^2]	100	1000	Foreseen building
Depth [m]	1025	1100	1750
Muon Flux [$\mu/m^2/s$]	$3.7\ 10^{-4}$	$\sim 10^{-3}$	$\sim 5\ 10^{-5}$
Makeup air [m^3/h]	From the mine through Rn purification	7840	-
Air change/day	96	6	-
Cleanliness requirement	Yes (SNOLab style)	Only in sectors	–

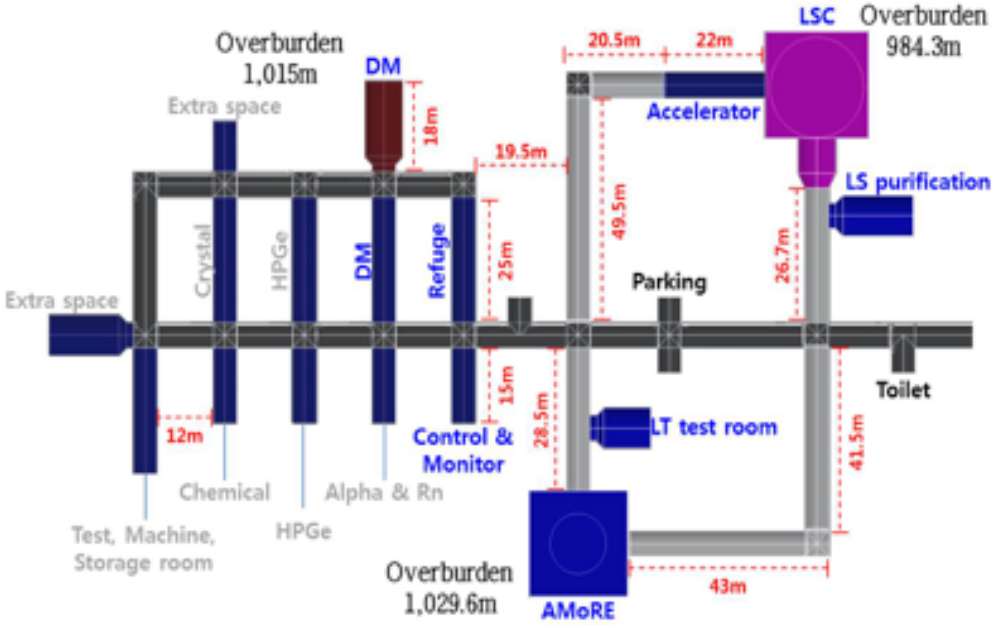
Main research supporting facilities in DULs

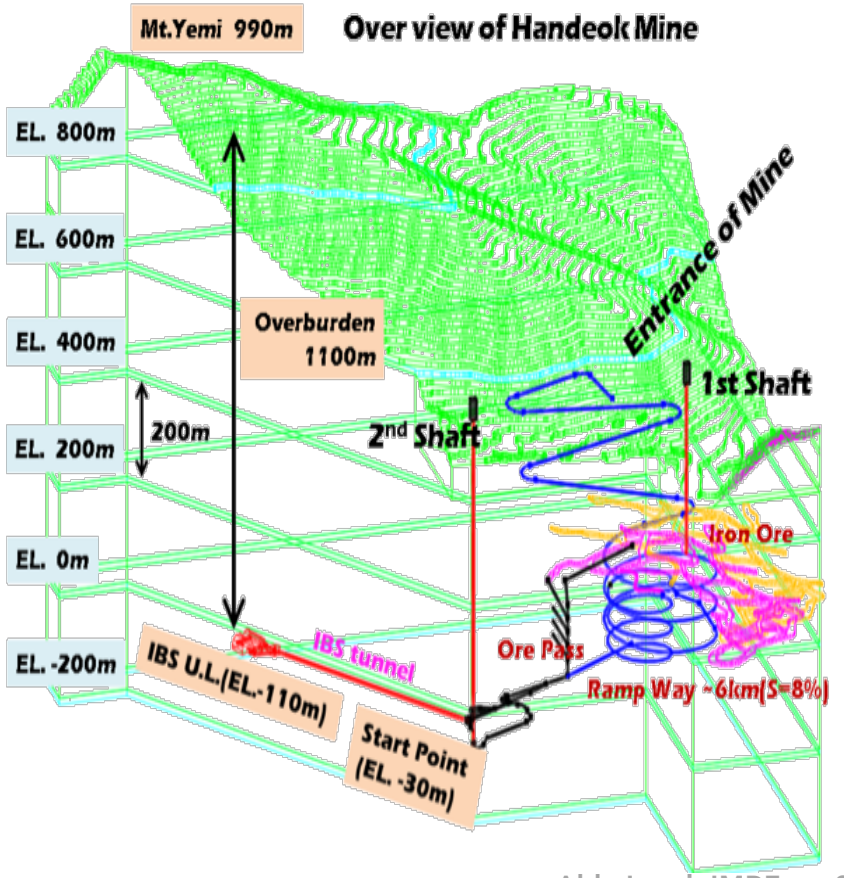
- **HPGe screening facilities** (in all labs) + alpha counting + ICP-MS
  - Some 80 detectors deployed in DULs
- **Cu electro-forming production** (SURF, LSC, CJPL,SNOLab,ARF)
- **Clean rooms** (ISO5, ISO6, ISO7)
- **Radon abatement systems** (1000x Rn reduction)
  - In operation at LNGS, LSC, Y2L, LSM (100 – 300 m^3/h)
  - To be installed at SURF, SNOLab,CJPL, SUPL, ARF
- **Radon-free clean rooms**
  - Present at LNGS
  - To be installed at SURF, SNOLab …
- Sensitive **radon detectors** (<mBq/m^3) for emanation and monitoring
  - Monitoring blanket N2 gas in the Borexino-CTF, Xenon1t water tanks …
- Crystal growing facility (ARF,CJPL)

Future facility: Status

Future facility: Handuk Mine Laboratory in South Korea ARF (Astroparticle Research Facility)

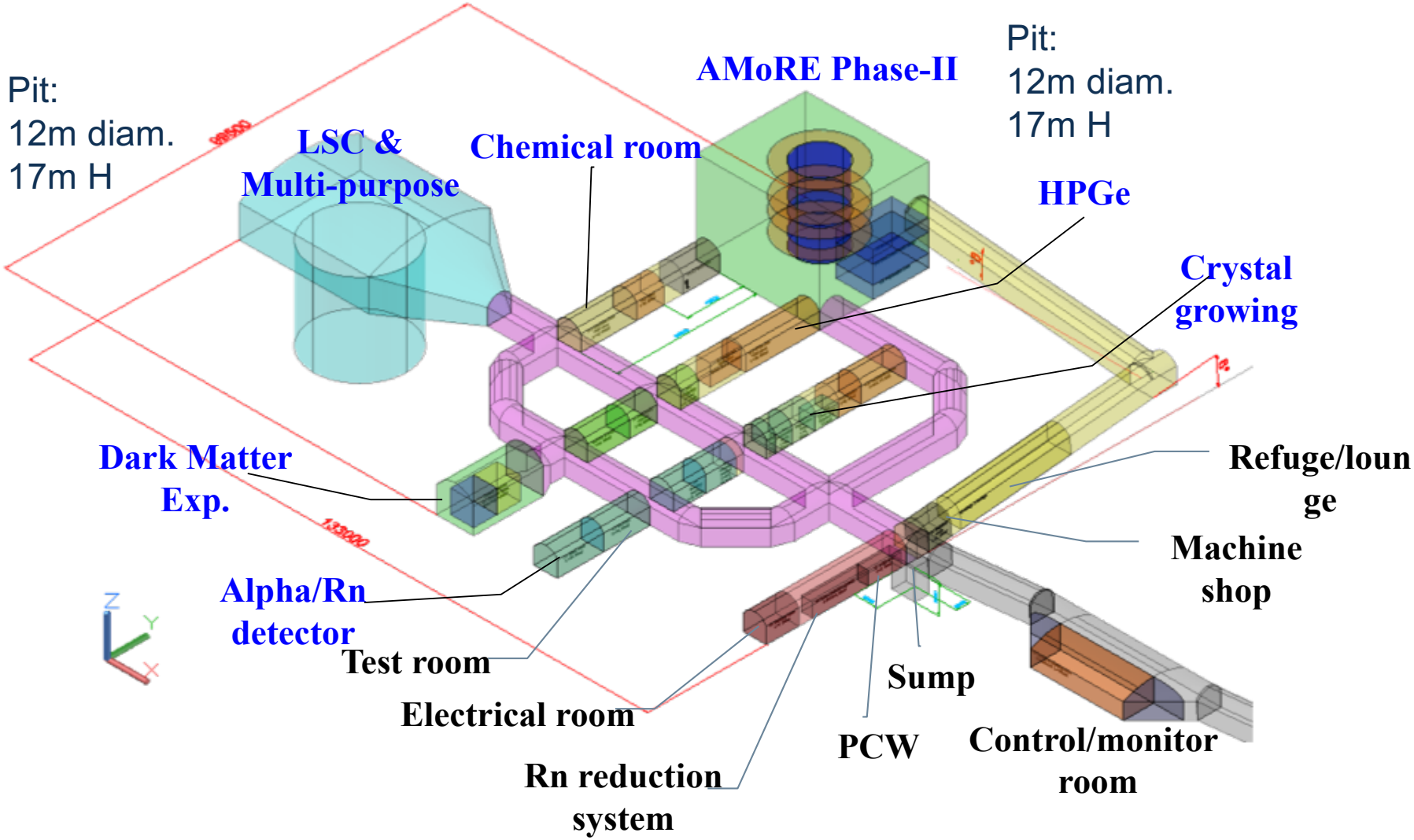
- Two experimental halls (total area ~2000 m²)
- 1100 m below surface.
- Access: cage + driveway (through running iron mine)





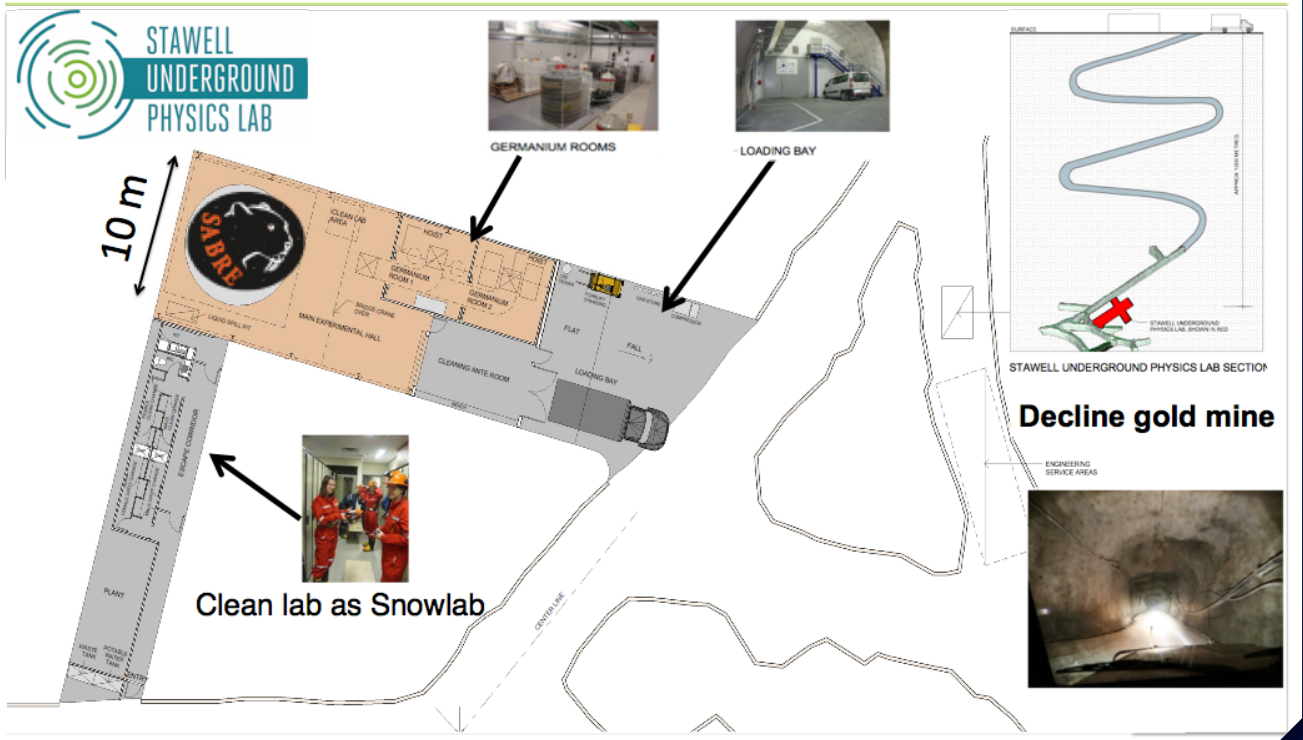
Future facility: Handuk Mine Laboratory in South Korea

- 8 experiments with 25 spaces
- 10 utility rooms
- Began construction and will finish by end of next year, 2019

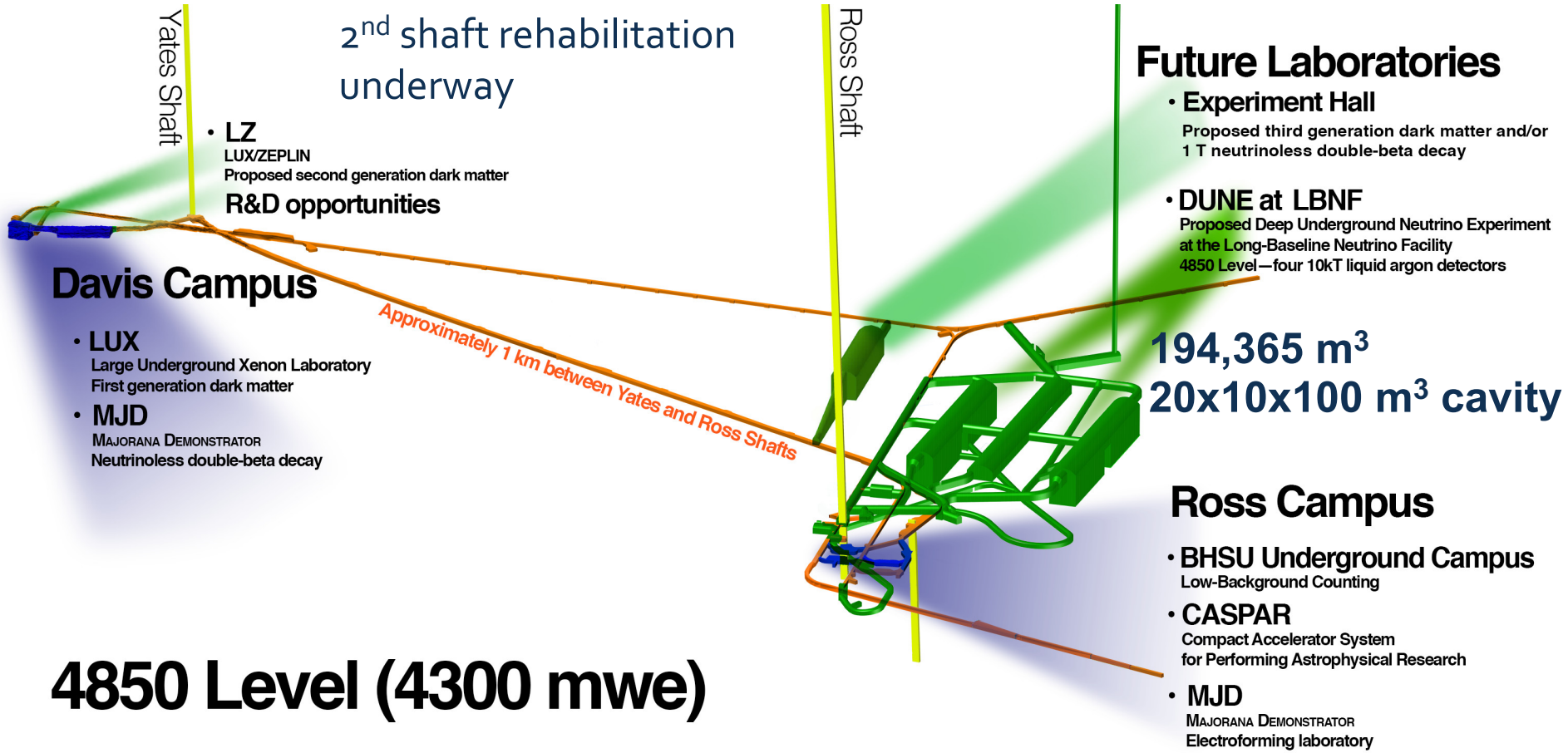


Future facility: SUPL Australia

- Underground Laboratory being excavated this year (~2000 m^2)
- Depth: 1100 m below surface.
- Radioactivity measurement carried out in the area give ~250 Bq/m^3 for radon
- Underground lab ventilated thorugh a radon abatement system producing ~850 m^3/h of radon-free air
- Inside excavated area install a surface coating to inhibit radon emanation
- Cleanliness level similar to SNOLab

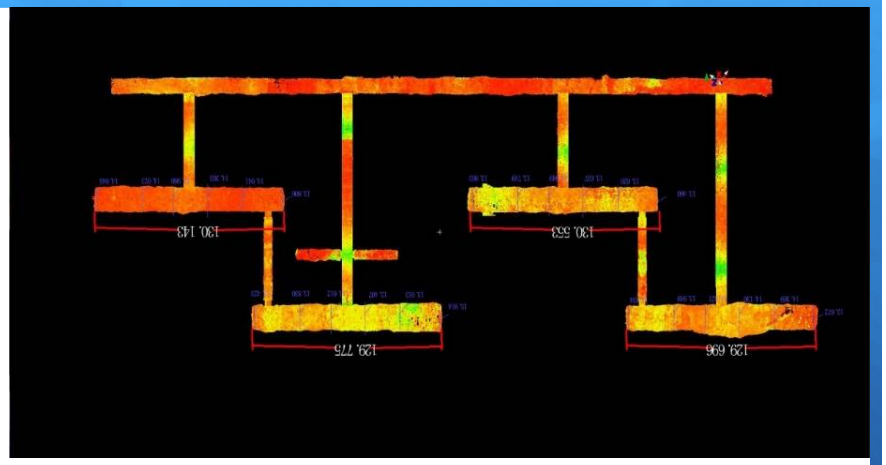


Future facility: SURF Ross Campus



Aldo Ianni, TAUP 2017

CJPL-II Layout



Four 14m*14m*130m main halls
Total Volume ： ~300K m³

Future facilities: upgrades @ SNOLab

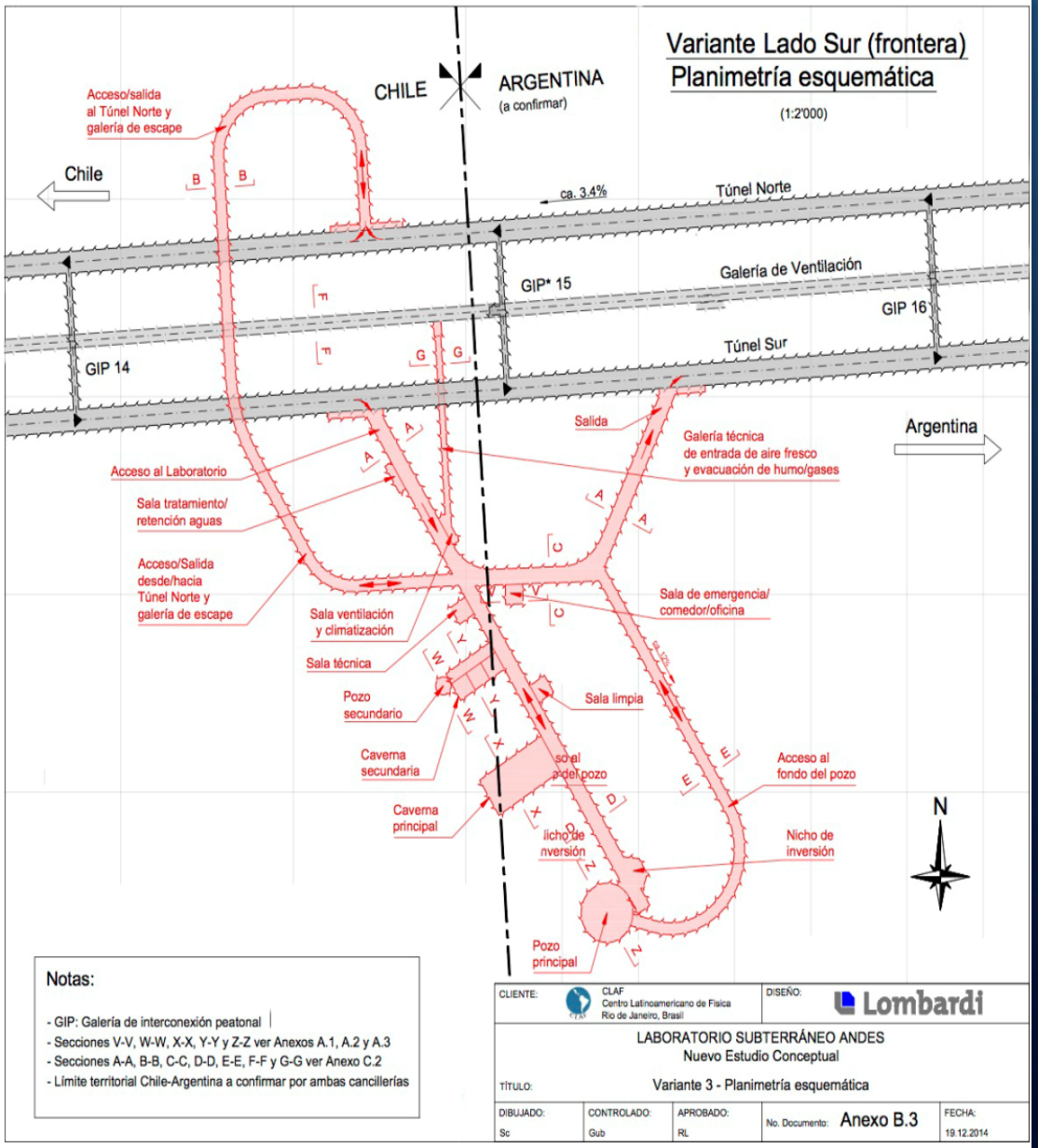
- Surface diesel generator 3 MW
- Low radon air supply system and low radon air assembly room
- Liquid nitrogen generator plant underground
- Water system under construction

Future facilities: status of CJPL

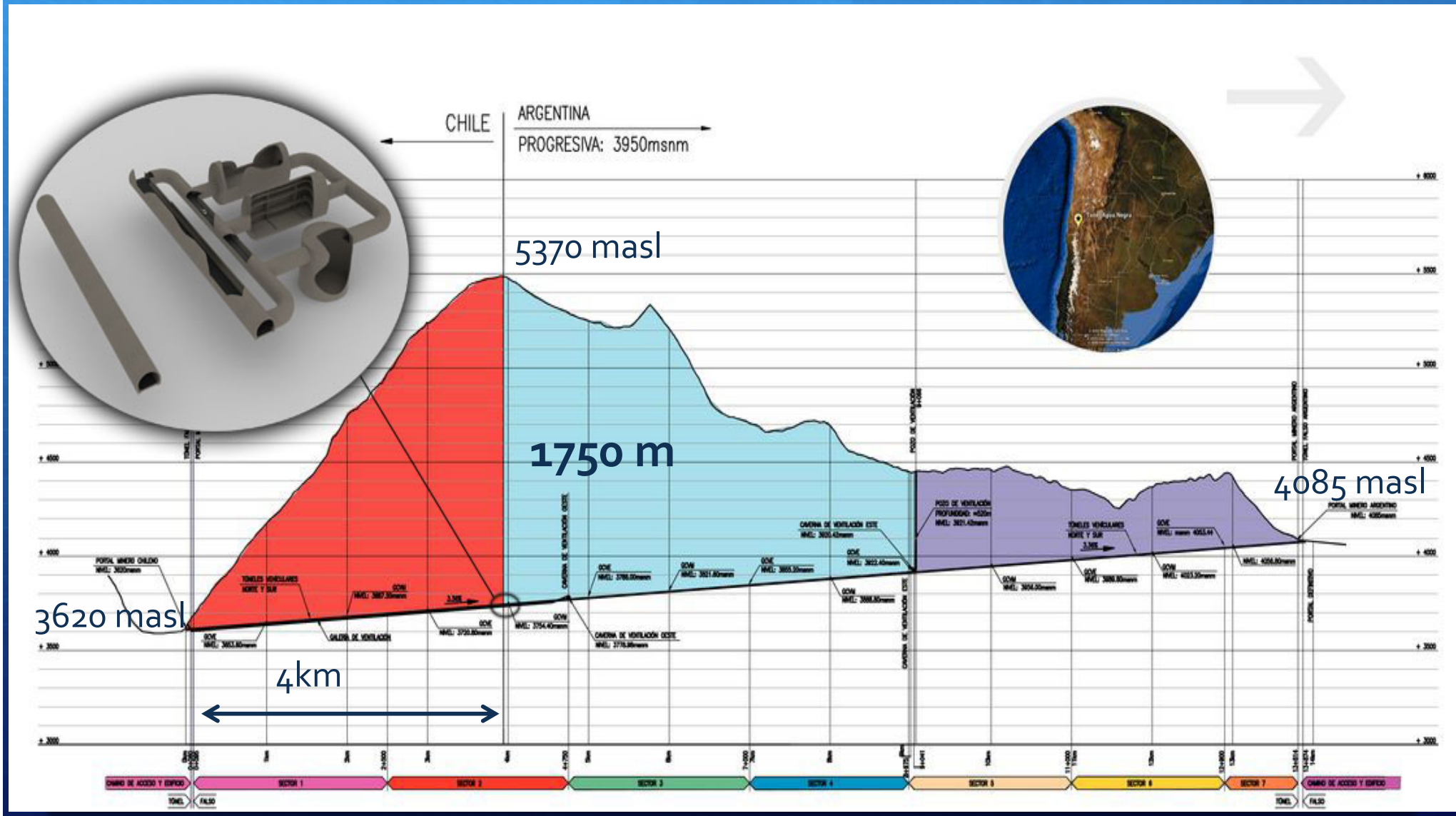
- Rock excavation competed in 2017 (300k m^3)
- Ventilation system completed
  - 10km pipeline
- Power supply system completed
- Water system under construction
- External buildings completed

Future facility: ANDES

- **Main hall**
  (21 m x 23 m x 50 m)
- **Secondary hall**
  (16 m x 14 m x 40 m)
- Offices and small labs
- **Low radiation pit**
- **Large single experiment pit**
  (~ ø 30 m, 30 m tall)
- Vertical depth: 1775 m,
  omnidirectional: 1675 m
- Total: 70 000 m^3 laboratory volume
  (+ 35 000 m^3 access tunnels)



ANDES mountain profile



Future facilities: experimental program

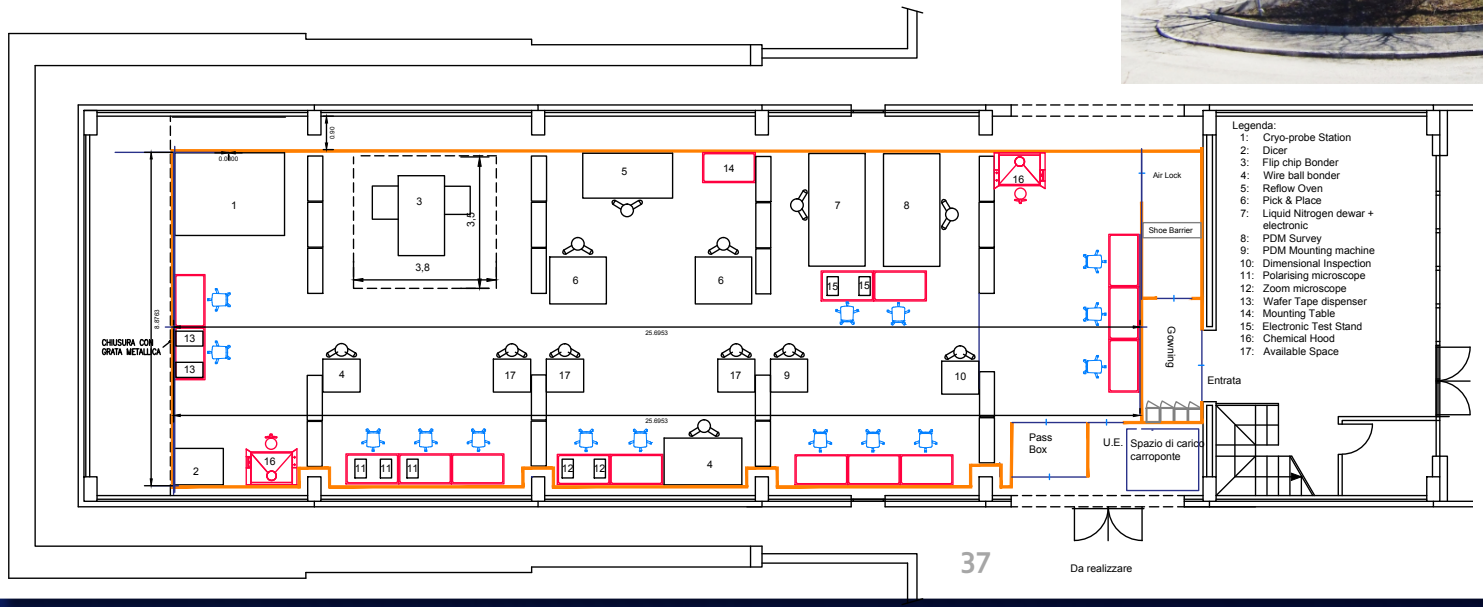
In the following slides I report a (not exhaustive) list of highlights about the experimental program in DULs in the next ~5-6 years from my personal perspective

Future facilities: experimental program (2019-2025) [2]

- **LNGS**
  - Complete Borexino (solar neutrinos)
  - Complete CUORE (DBD with ^{130}Te)
  - Complete Xe-nton (DM with LXe TPC)
  - Installation and running LUNA-MeV (nuclear astrophysics)
  - Complete GERDA phase2 and start/run LEGEND (DBD with ^{76}Ge)
  - Complete CUPID (DBD with bolometers)
  - Complete present phase for CRESST (DM with bolometers)
  - SABRE-North (DM annual modulation)
  - Complete and run NOA (infrastructure for characterization and assembling photo detectors based on SiPMs)
  - Installation and running DarkSide-20k (DM with underground LAr)

NOA @ LNGS

- A new infrastructure for testing and packaging photo-detectors based on SiPM in a 250 m^2 radon-free clean room
- Ready by end of 2019. First user: DarkSide-20k
- Budget 10 M€ from RESTART program



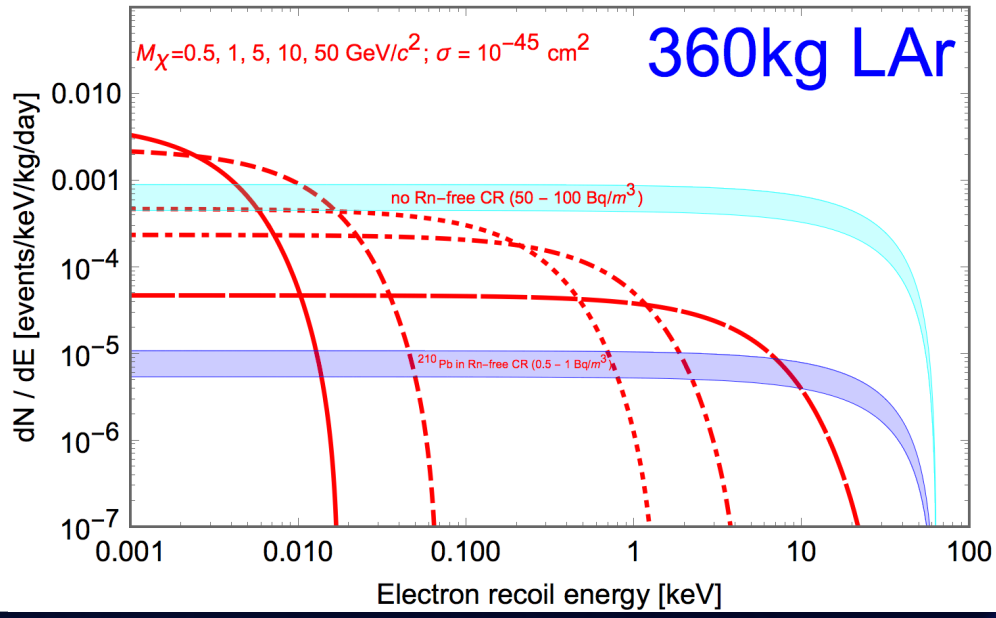
Radon-free clean room for DarkSide-50 at the LNGS

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

Use of radon-free clean room

- Motivation for use: avoid leaching out of radon daughters
- Being done for the construction of
  - Borexino nylon vessels
  - Cleaning and assembling of DS-50 TPC
  - Cleaning and assembling of LZ TPC
  - CUORE towers installation



Future facilities: experimental program (2019-2025) [1]

- **SNOLab**
  - Complete DEAP-3600 using underground argon (DM with LAr)
  - Run SNO+ (DBD with ^{130}Te in liquid scintillator)
  - Installation/run NEWS (DM with light gases)
  - Installation and run of SuperCDMS (DM with bolometers)
  - Evaluation / starting for new projects: nEXO, Ge-1ton (DBD program)

Future facilities: experimental program (2019-2025) [3]

- **LSC**
  - Complete characterization of NEXT demonstrator (DBD with gas ^{136}Xe)
  - Installation and running NEXT-100
  - Installation and running the present phase for TREX-DM (DM with gas Ar/Ne TPC), if necessary move to next phase
  - Installation and running CROSS (DBD bolometers)
  - Complete present phase of ANAIS (DM annual modulation)
  - Running new phase for ArDM (testing UAr, more …)
  - Long term running for strainmeters (geophysics)
  - Complete work on feasibility study for gravitational wave detectors
  - New excavation … ?

Future facilities: experimental program (2019-2025) [4]

- **SURF**
  - Installation and running of LZ (DM search with LXe TPC)
  - Complete excavation and start construction for DUNE
  - Running CASPAR (nuclear astrophysics)

Future facilities: experimental program (2019-2025) [5]

- **Kamioka**
  - Complete refurbishment of Super-Kamiokande and running with Gd (neutrino physics)
  - Complete KamLAND program (DBD with ^{136}Xe in liquid scintillator / geo-neutrinos)
  - Running KAGRA (gravitational waves underground)
  - Toward Hyper-K

Future facilities: experimental program (2019-2025) [6]

- **CJPL**
  - Complete infrastructures installation in CJPL-II
  - Running PandaXII (DM search with LXe)
  - Complete present phase CDEX and start next phase (DM search with HPGe)
  - Complete 1-ton prototype with Liquid Scintillator (LS)
  - Start new physics program in CJPL-II
    - 10 ton LS prototype
    - 2kton LS detector planned for solar and geo neutrinos
      - Location ideal for geo-neutrinos
    - PandaX-xT next phase (4 ton sensitive mass for DM with LXe)
    - PandaX-III (DBD with gas ^{136}Xe TPC)
    - JUNA (Jinping Underground Nuclear Astrophysics)
    - CUPID-China (bolometer for DBD)

Future facilities: experimental program (2019-2025) [7]

- **Y2L and Handuk Laboratory**
  - Complete data taking with COSINE in Y2L
  - Complete AMoRE present phase in Y2L (DBD with bolometer based on ^{100}Mo)
  - COSINE and AMoRE 2nd phase in new lab
- **SUPL**
  - SABRE-South (high purity NaI array for DM annual modulation)

Conclusions

- 13+3(new) underground multidisciplinary research infrastructures equipped with high technology detectors
- Main discoveries with two Nobel Price in Physics in 2002 and 2015
- Main research goals (and lots of work) for the next future are:
  - Neutrino physics, Dark Matter and, Neutrinoless Double Beta Decay
- Several technological breakthroughs developed in the framework of detectors deployed in different DULs worldwide

Thank you for your attention