# Considerations on Underground Laboratories

Aldo Ianni, Laboratorio Subterraneo de Canfranc and LNGS

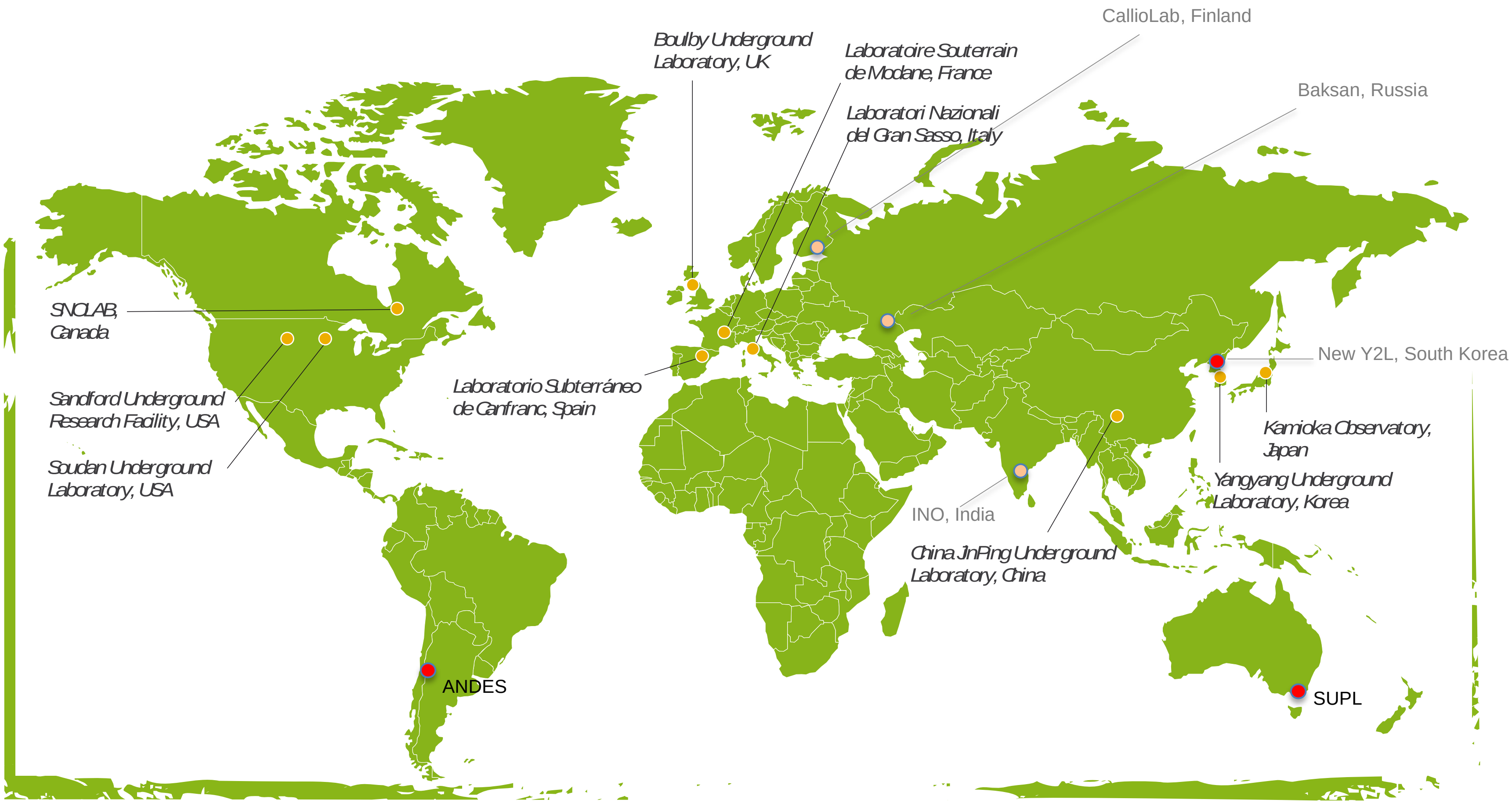
# Outline

- Main features of **D**eep **U**nderground **L**aboratorie**s** worldwide
  - Main experimental activities being reviewed in this meeting
  - Main ideas and programs in physics being reviewed in this meeting
  - Some complementary information being reviewed in this talk
- Expansions and new excavations
- Synergy and networks for DULs
- DULs as multidisciplinary research infrastructures

# DULs worldwide

- DULs: more than 1000 m.w.e. overburden
- **13** infrastructures (**DULs**) in operation at present (north hemisphere!)
- One soon under major expansion (SURF)
- Three upcoming DULs (two in the south hemisphere)

# Map of DULs worldwide




Aldo Ianni, TAUP 2017

# Some features for the existing DULs

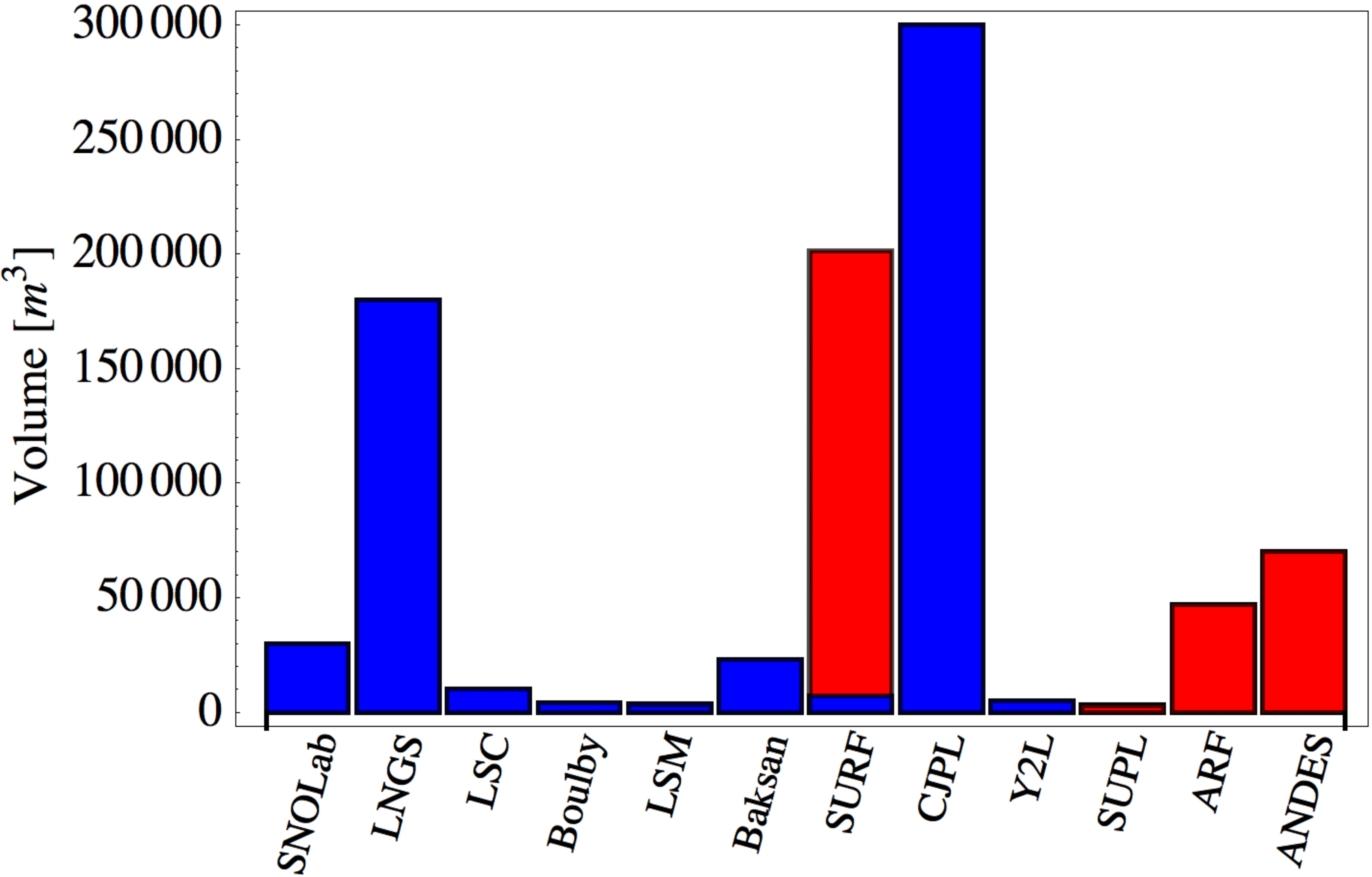
| | SNOLab | LNGS | LSC | Boulby | LSM | Callio Lab | Baksan | SURF | CJPL-I/II | Kamioka | Y2L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of creation | 2003 (1991) | 1987 | 2010 | 1989 | 1982 | 1995 | 1967 | 2007 (1967) | 2009/ 2014 | 1983 | 2003 A6 2014 A5 |
| **Personnel** | 100 | 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** | end of 2018 | mid-end of 2019 | 2027 |
| Personnel | 3 | 20 | _ |
| Access | Drive in | V / drive in | H |
| Volume [$m^3$] | 3025 | 47000 | 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 | _ |

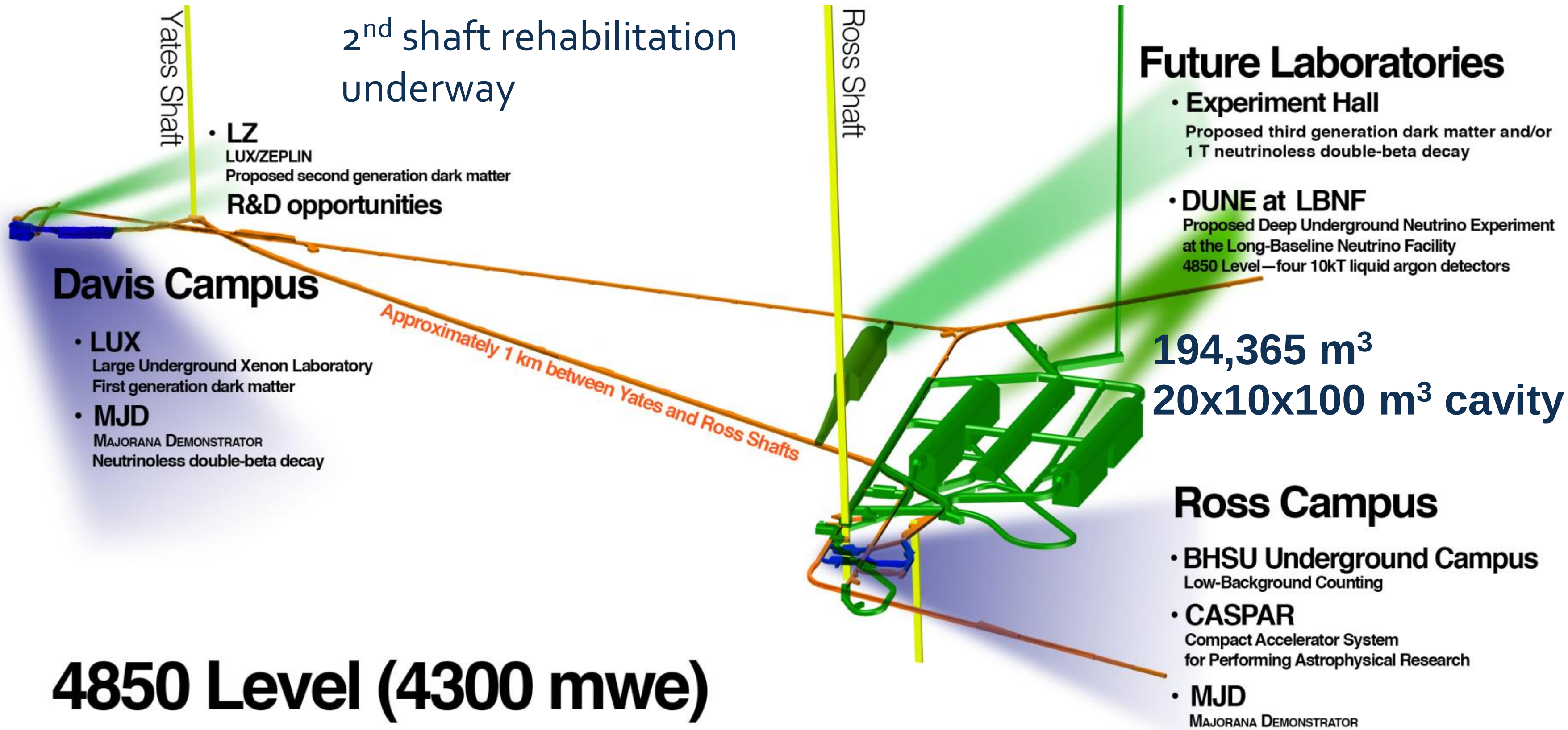
# Underground volume in DULs



# Expansion and new excavations underway

- **SURF**: new excavation for DUNE
  - Excavation begins in 2019 and last 3 yr
    - see J. Heise this meeting
- **ARF**: new laboratory in South Korea
  - Ready by mid-end 2019
- **SUPL**: new laboratory in Australia
  - Ready by end of 2018
- **ANDES**: new laboratory Chile-Argentina
  - ready by 2027

# Excavation for DUNE at SURF

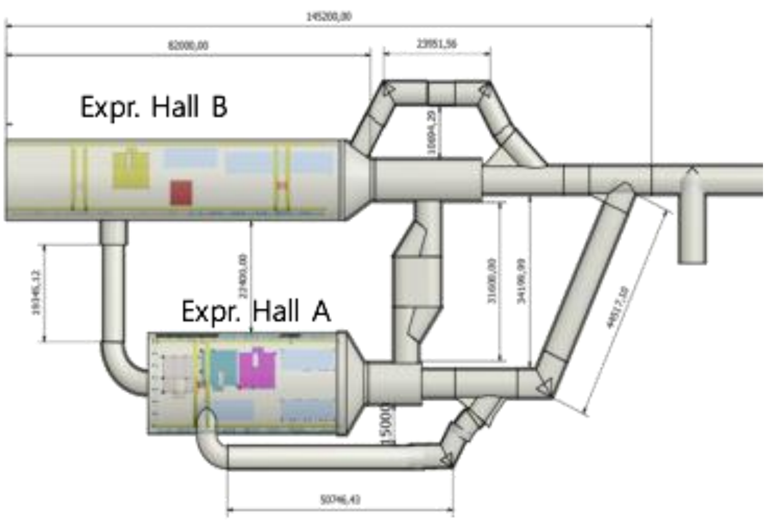


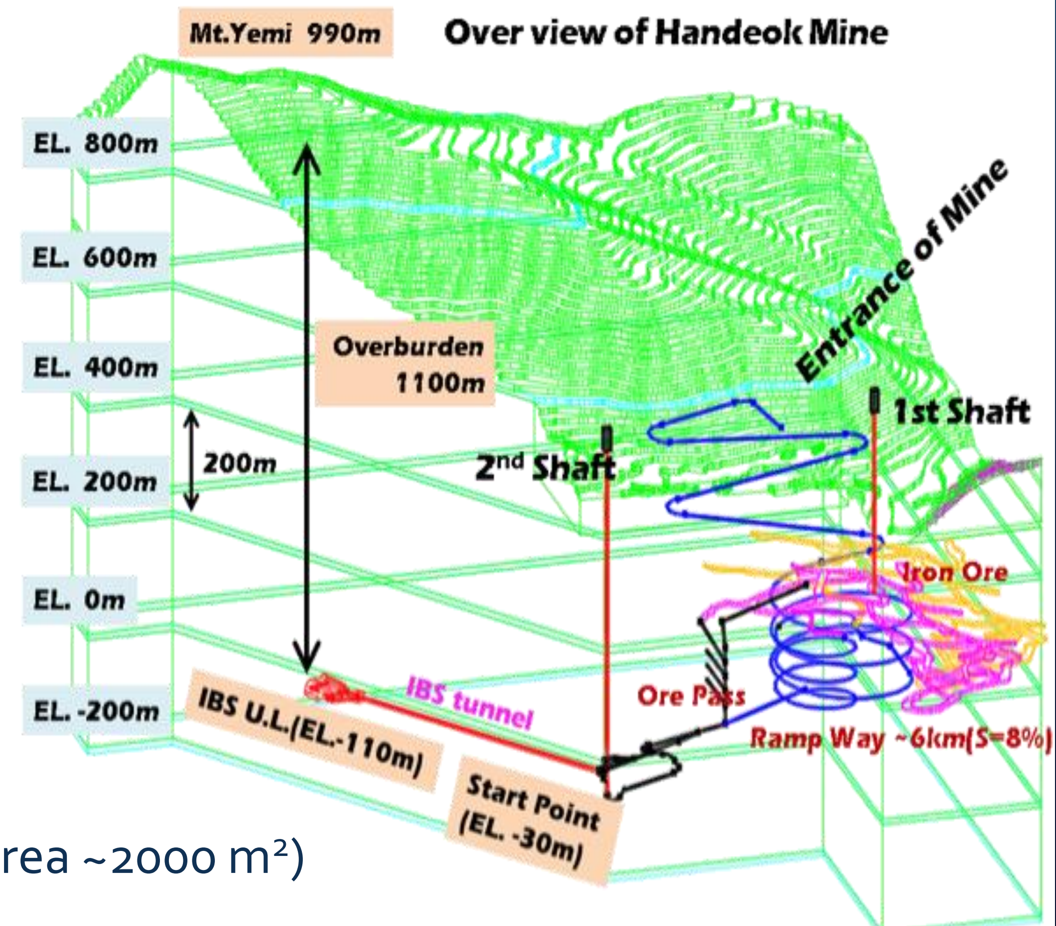

Future Facilities

Existing Facilities

# Astroparticle Research Laboratory (ARF) – South Korea

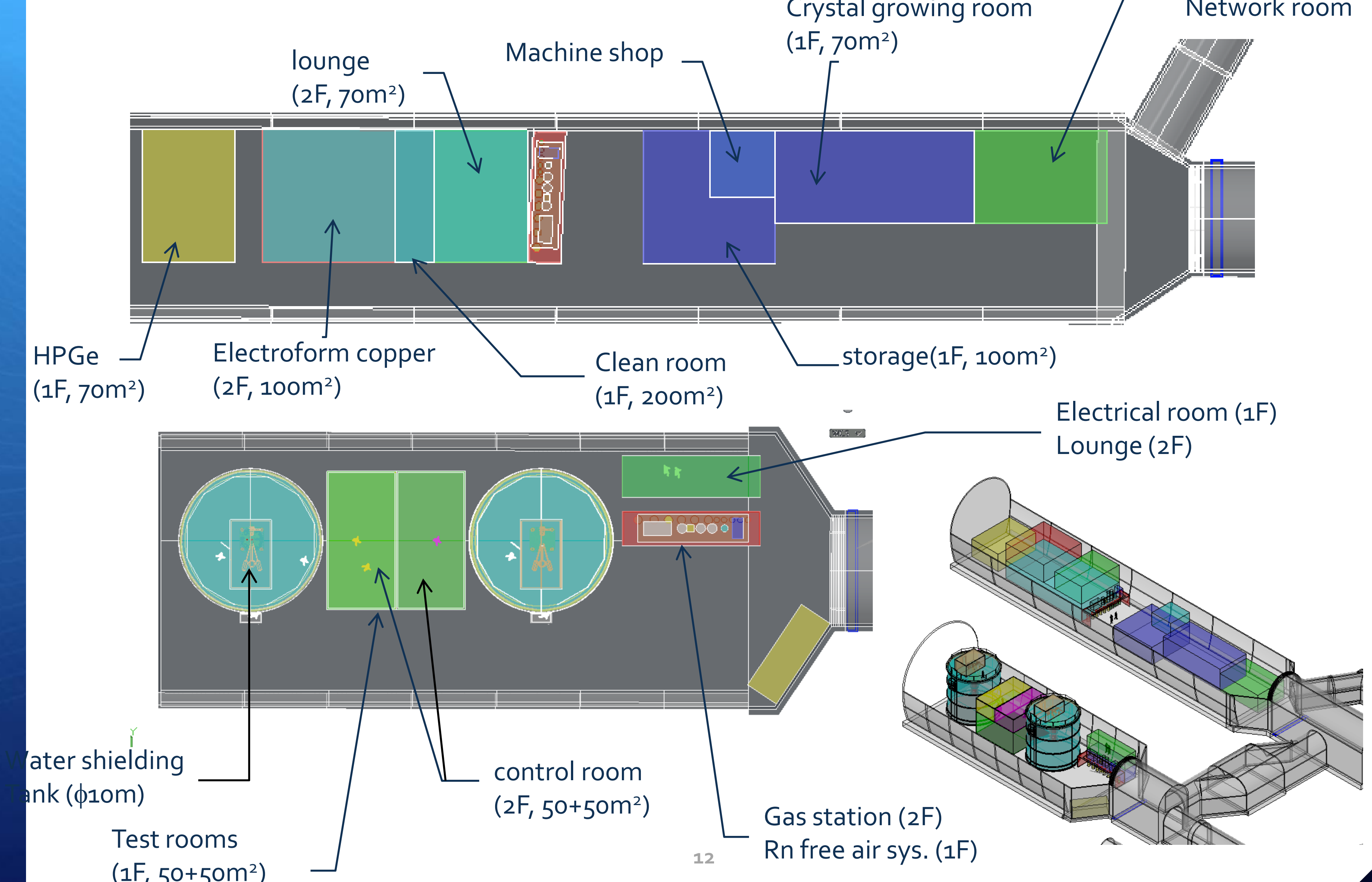
Preliminary design of
Underground Laboratory




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

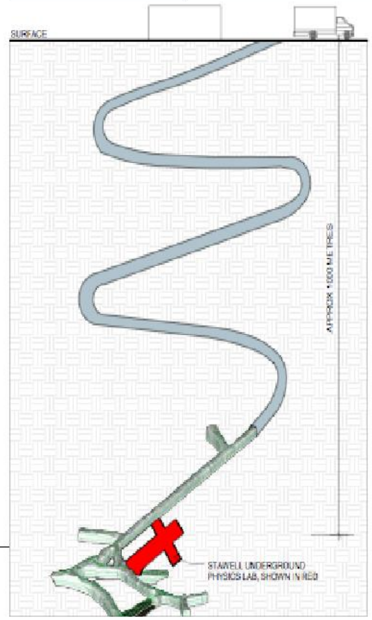
- Features of two main expr. halls



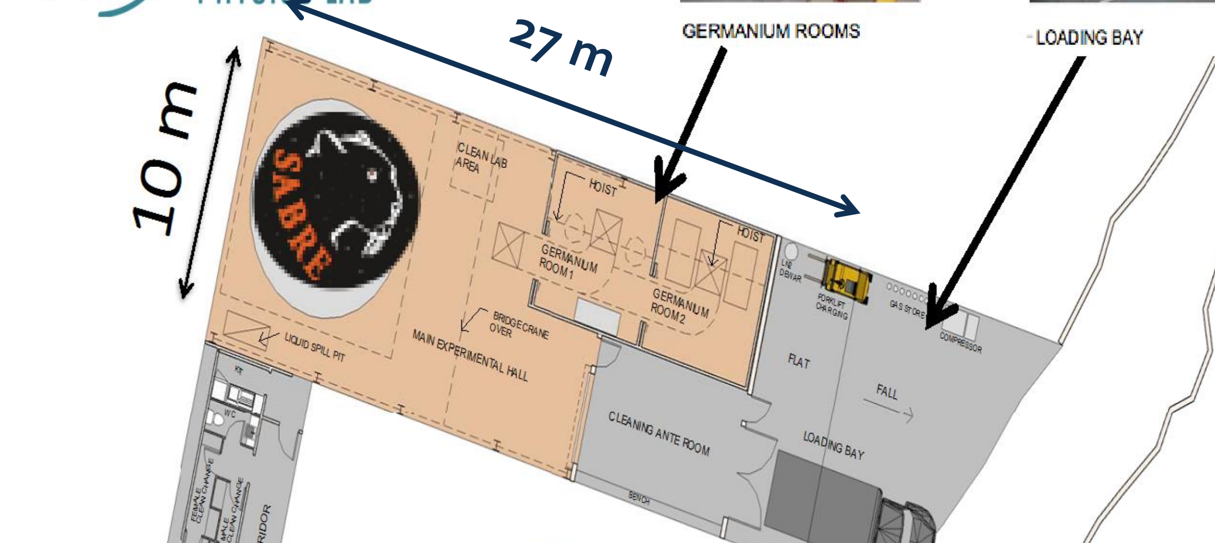
STAWELL UNDERGROUND PHYSICS LAB

GERMANIUM ROOMS

LOADING BAY




STAWELL UNDERGROUND PHYSICS LAB SECTION




Clean lab as Snowlab

## Decline gold mine

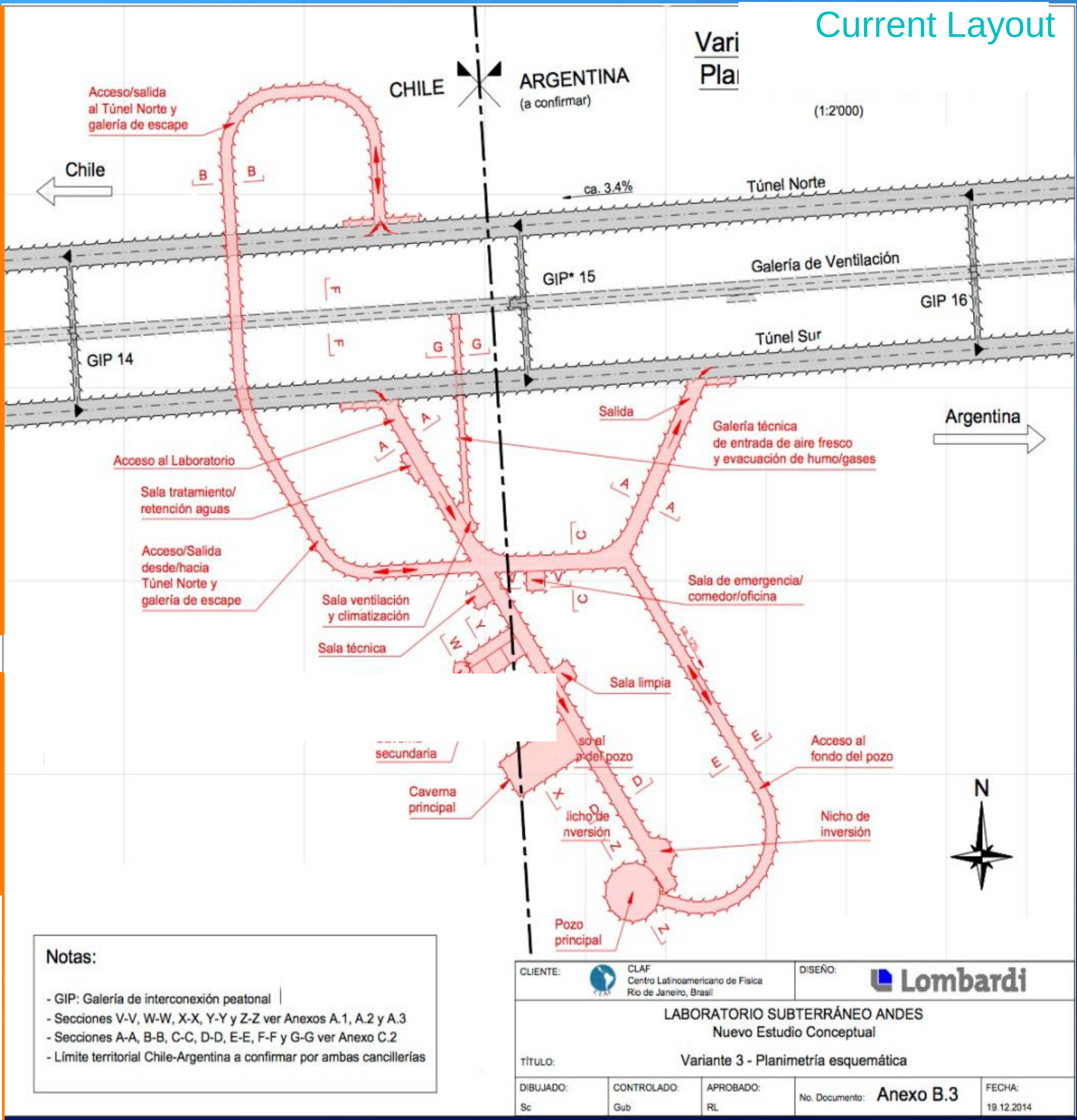
ENGINEERING SERVICE AREAS

- Active decline mine - accessed by car/truck
- Rock primarily basalt $\rho \sim 2.9\ g/cm^3$
- Laboratory @ 1025 m, flat overburden

# ANDES: Agua Negra Deep Experiment Site

- **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)

Current Layout




Rock Studies
(from test samples
~ 600 m deep)

Preliminary data (Bq/kg)

| | Basalt | Andesite | Rhyolite 1 | Rhyolite 2 |
|---|---|---|---|---|
| $^{238}$U | $2.6 \pm 0.5$ | $9.2 \pm 0.9$ | $14.7 \pm 2.0$ | $11.5 \pm 1.3$ |
| $^{232}$Th | $0.94 \pm 0.09$ | $5.2 \pm 0.5$ | $4.5 \pm 0.4$ | $4.8 \pm 0.5$ |
| $^{40}$K | $50 \pm 3$ | $47 \pm 3$ | $57 \pm 3$ | $52 \pm 3$ |

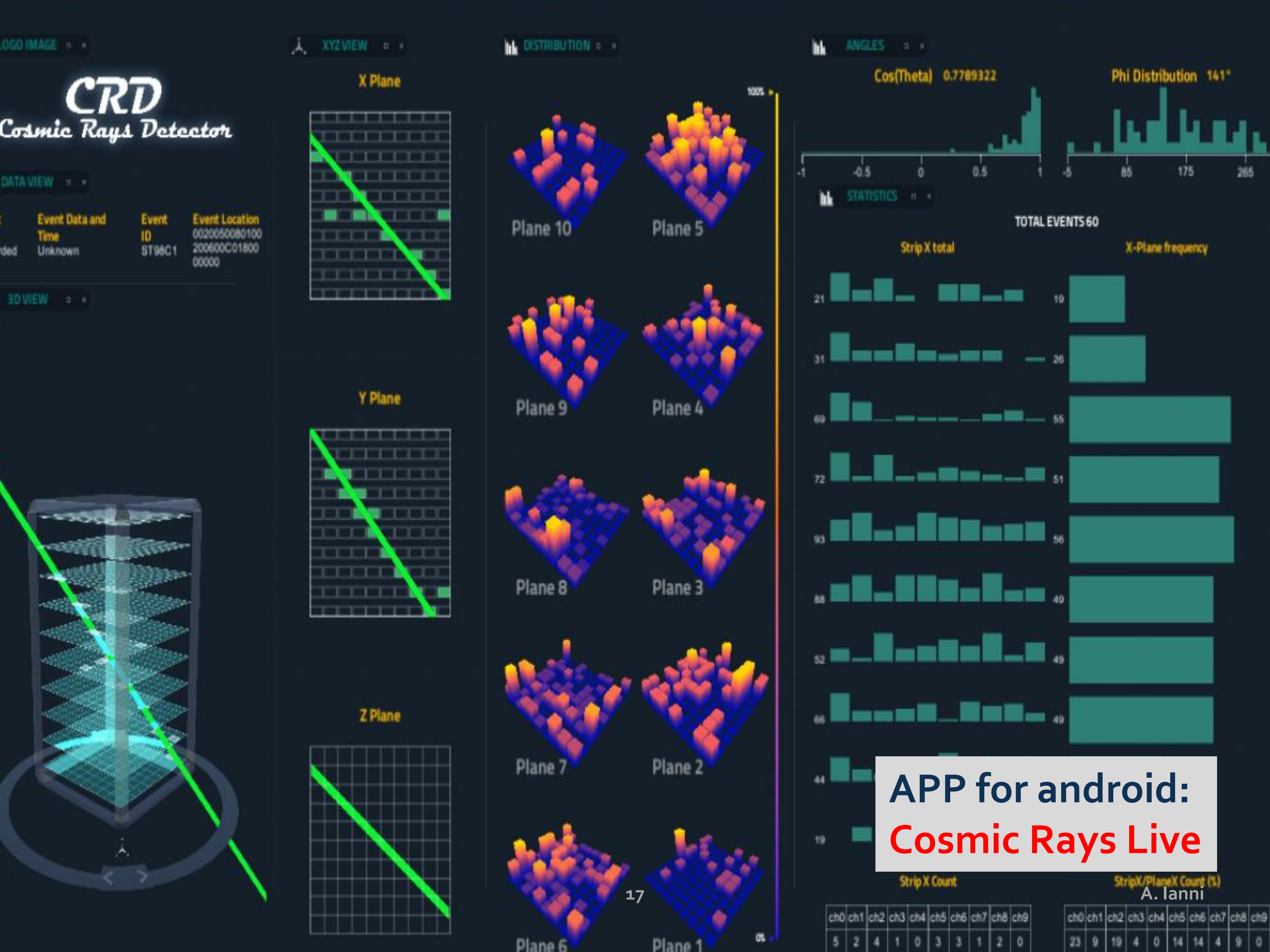
More information at http://andeslab.org/

# Network between DULs [1]

- **DULIA**: attempt to establish a network between LNGS, LSC, LSM, Boulby and CallioLab. Purpose:
  - to enhance collaboration between infrastructures
  - to standardize procedures (experiment safety assesment, experimental approval, environmental policy ...)
- SNOLab + LNGS: put forward a proposal for an **Underground Global Research Infrastructure** (under evaluation)
- Share load of work for international collaborations
  - an example: screening of gadolinium salt for SuperKamiokande-Gd
    - At work Kamioka, LSC, Boulby
    - Under discussion LNGS

# Network between DULs [2]

- Some physics case can profit of a network between DULs
  - ✓ Deploy in DULs similar detectors to enhance the sensitivity for a specific research
    - An example: CYGNUS(TPC) global network
- Network for outreach activities in DULs
  - ✓ An example
    - LNGS and LSC have developed and deployed muon telescopes in both sites




APP for android:

Cosmic Rays Live

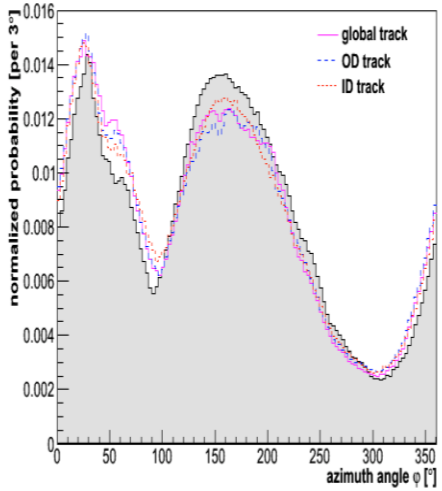


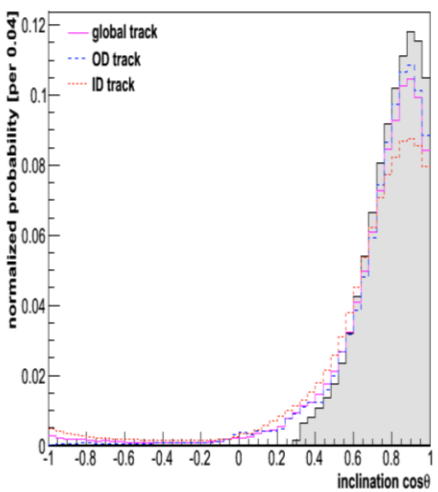
A. Ianni

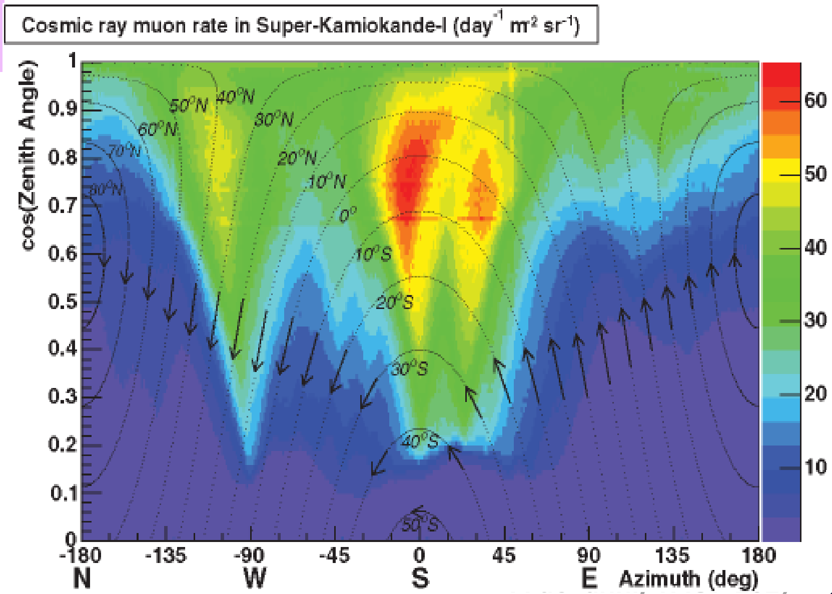
# Overburden characteristic [1]

- Under a flat surface (SNOLab, CallioLab,SURF)
- Under a mountain (Baksan, LNGS, LSC, LSM, CJPL)
  - Underground cosmic-ray muons angular dependence can be important

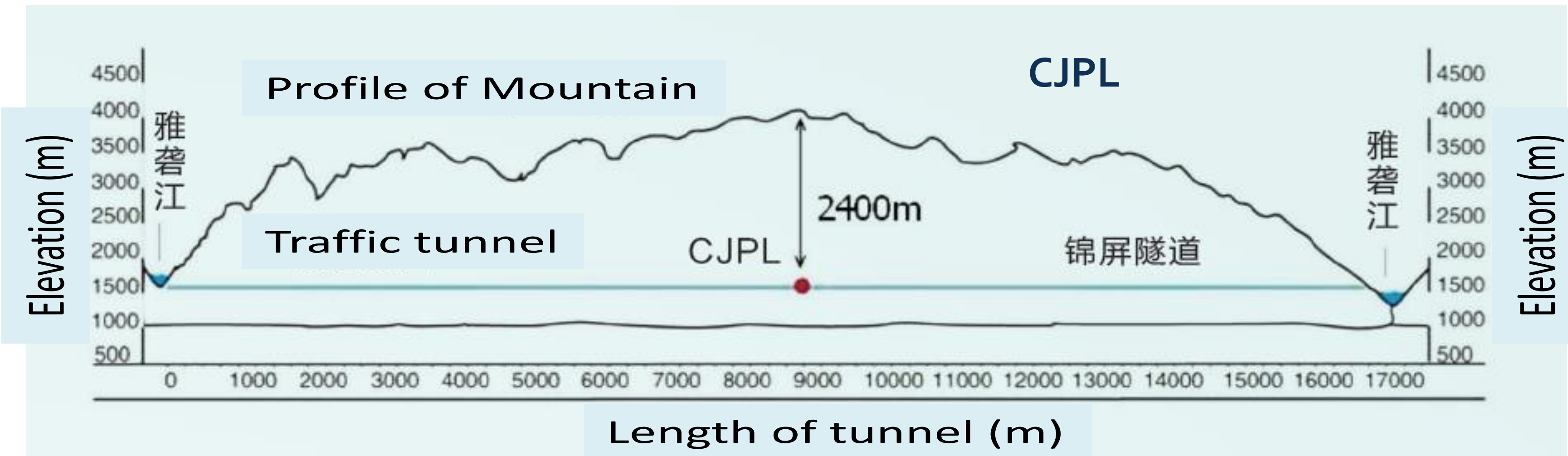
**Muon data for LNGS: MACRO and Borexino**

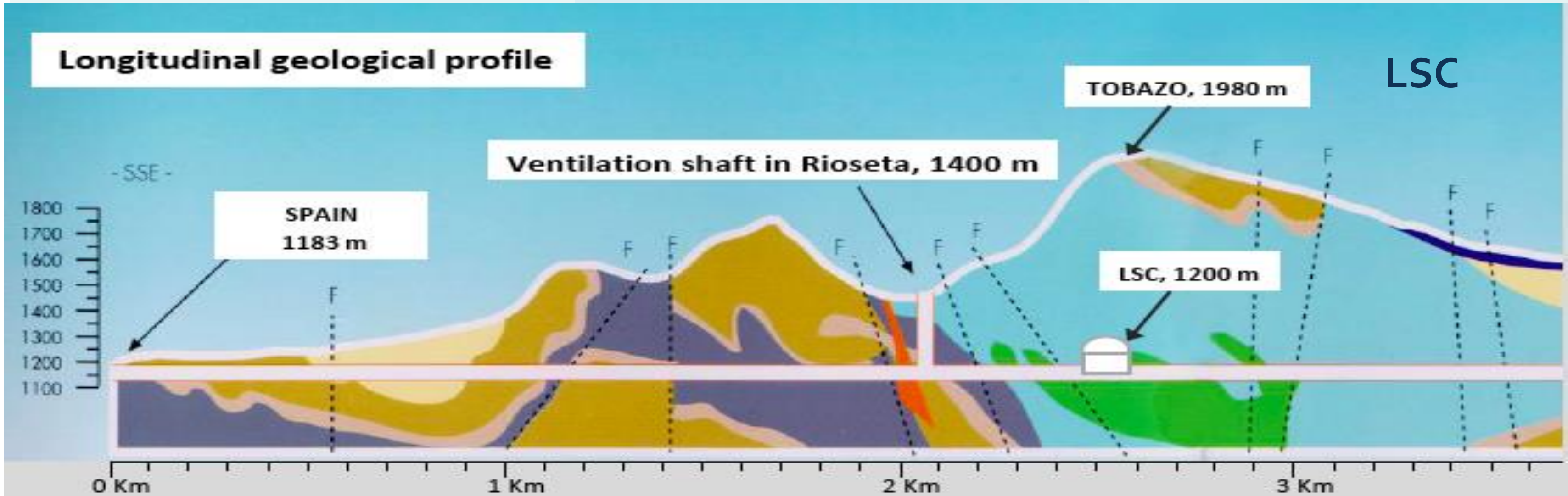


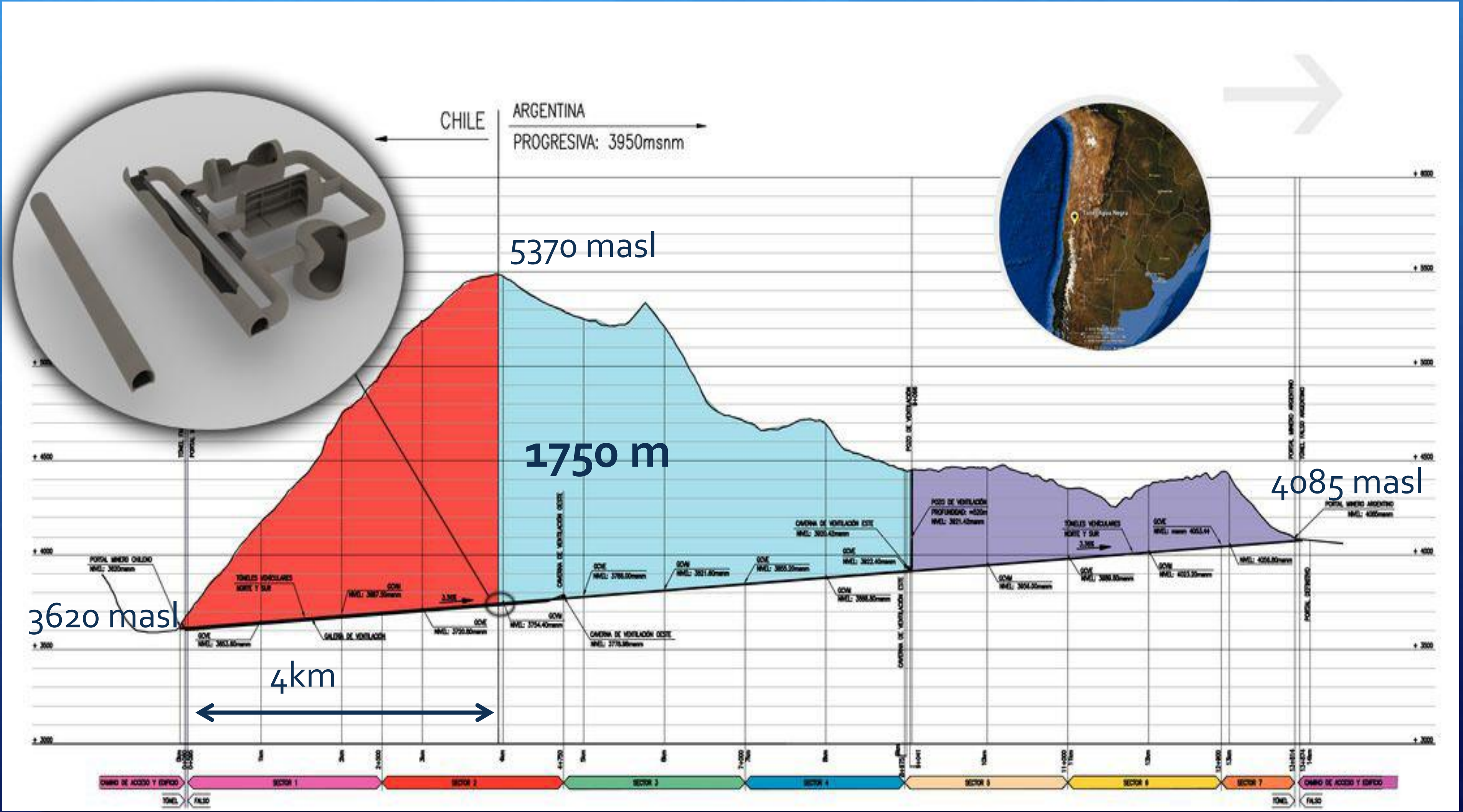



# Overburden characteristic [2]

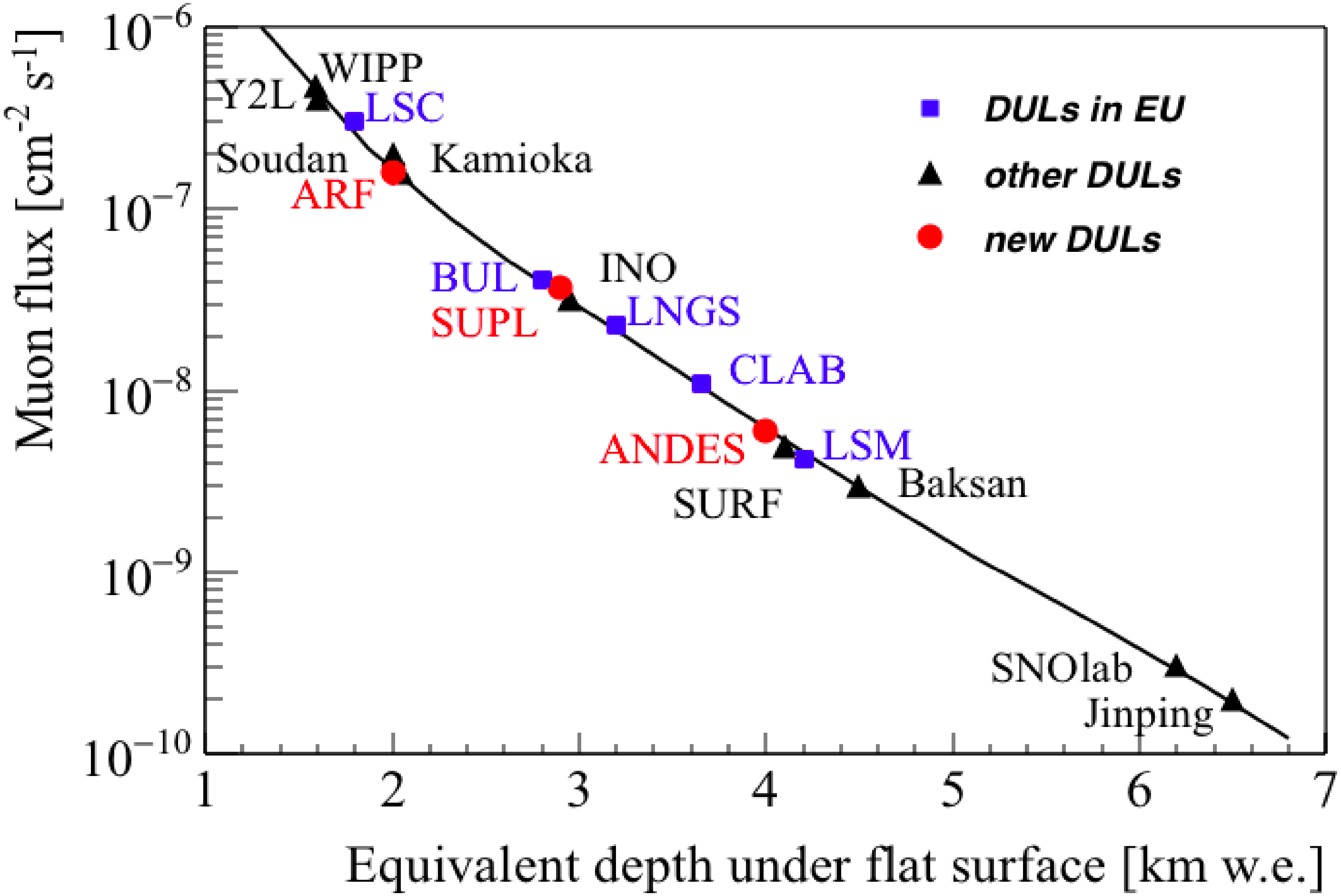


# ANDES mountain profile



# Muon Flux in DULs



# Cleanliness

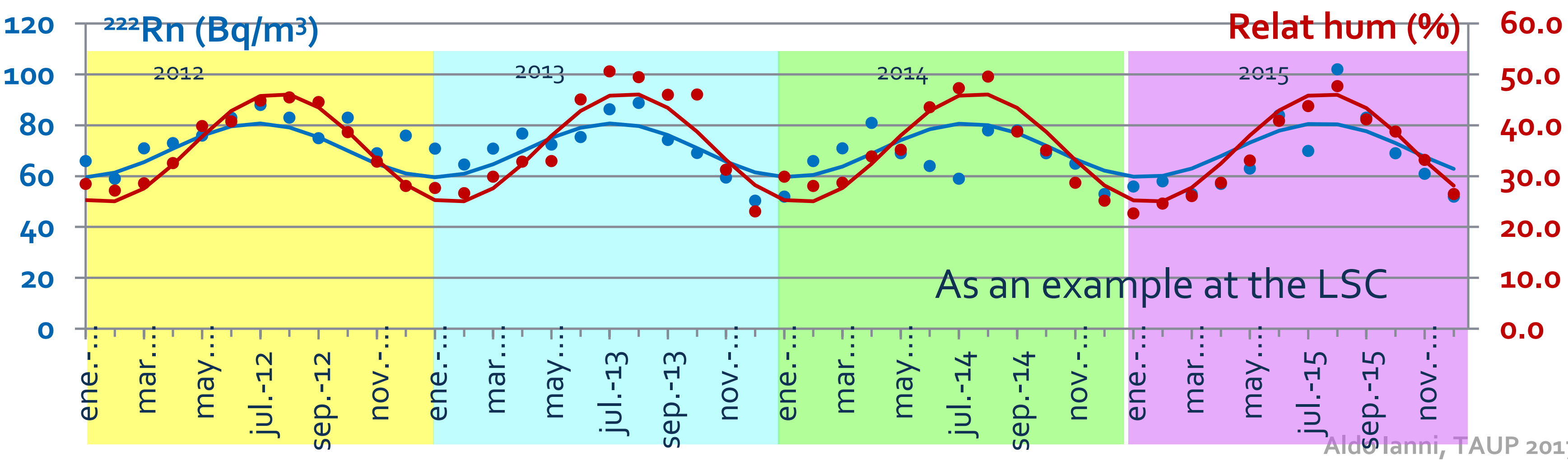
- **Mine environment or small volume underground area**
  - Specific protocol to enter lab area (SNOLab, Boulby, SURF,SUPL)
  - With some basic protocol it is possible to achieve good conditions
    - SNOLab class 2000 or better throughout the whole volume with a more demanding protocol
    - SURF class ~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

# Boulby new laboratory ISO7


Access protocols for cleanliness in Boulby and SURF are similar

# Monitoring environmental changes

- Seasonal cosmic-ray muons change
- Radiation and seasonal variation of neutron background underground
  - Need to put more effort into this task
- Seasonal dependence of radon in air
- Other parameters such as humidity, particulate counting, rock stability …



# Main research supporting facilities in DULs

- **HPGe screening facilities** (in all labs) + alpha counting + ICP-MS
- **Cu electro-forming production** (SURF, LSC, CJPL,SNOLab,ARF)
- **Clean rooms** (ISO5, ISO6)
- **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 $N_2$ gas in the Borexino-CTF, Xenon1t water tanks …
- Crystal growing facility (ARF,CJPL)

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

DarkSide-50 protocol:

1. Cleaning and conditioning of TPC components in 500 mBq/m$^3$ CR
2. Assembling and deploying of TPC in 10 mBq/m$^3$ CR

# HPGe screening facilities in DULs

| | SNOLab | LNGS | LSC | SURF | LSM | Boulby | Baksan | Kamioka | CJPL |
|---|---|---|---|---|---|---|---|---|---|
| Number of HPGe detectors | 5 | 12(+1) | 7 | 4+1 | 18+6 | 4+3 | 2+2 | 6 | 10 |

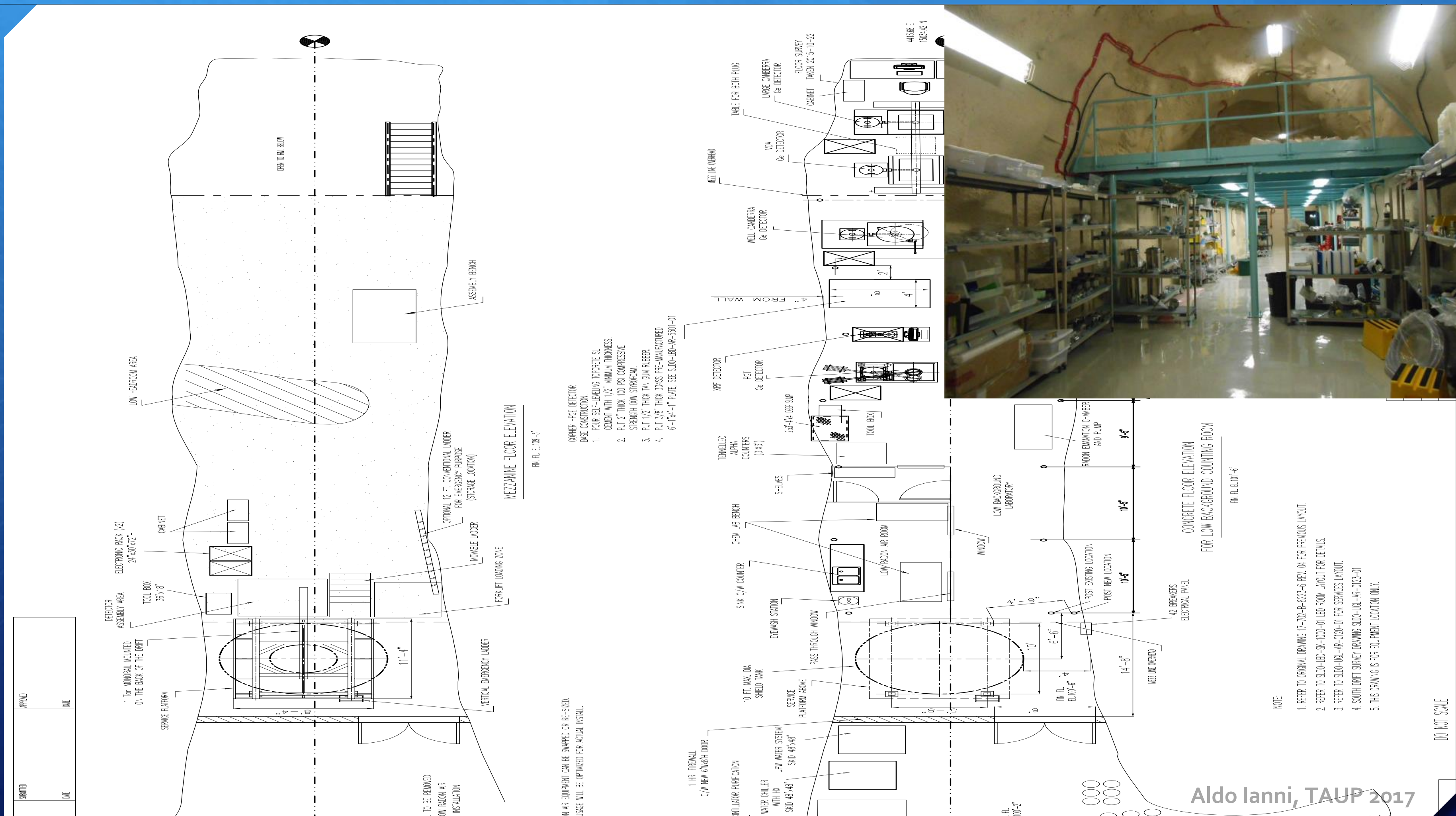
- ✓ Sensitivities
  - Commercial detectors 0.5 – 1 mBq/kg in U, Th
  - Custom 10-50 μBq/kg

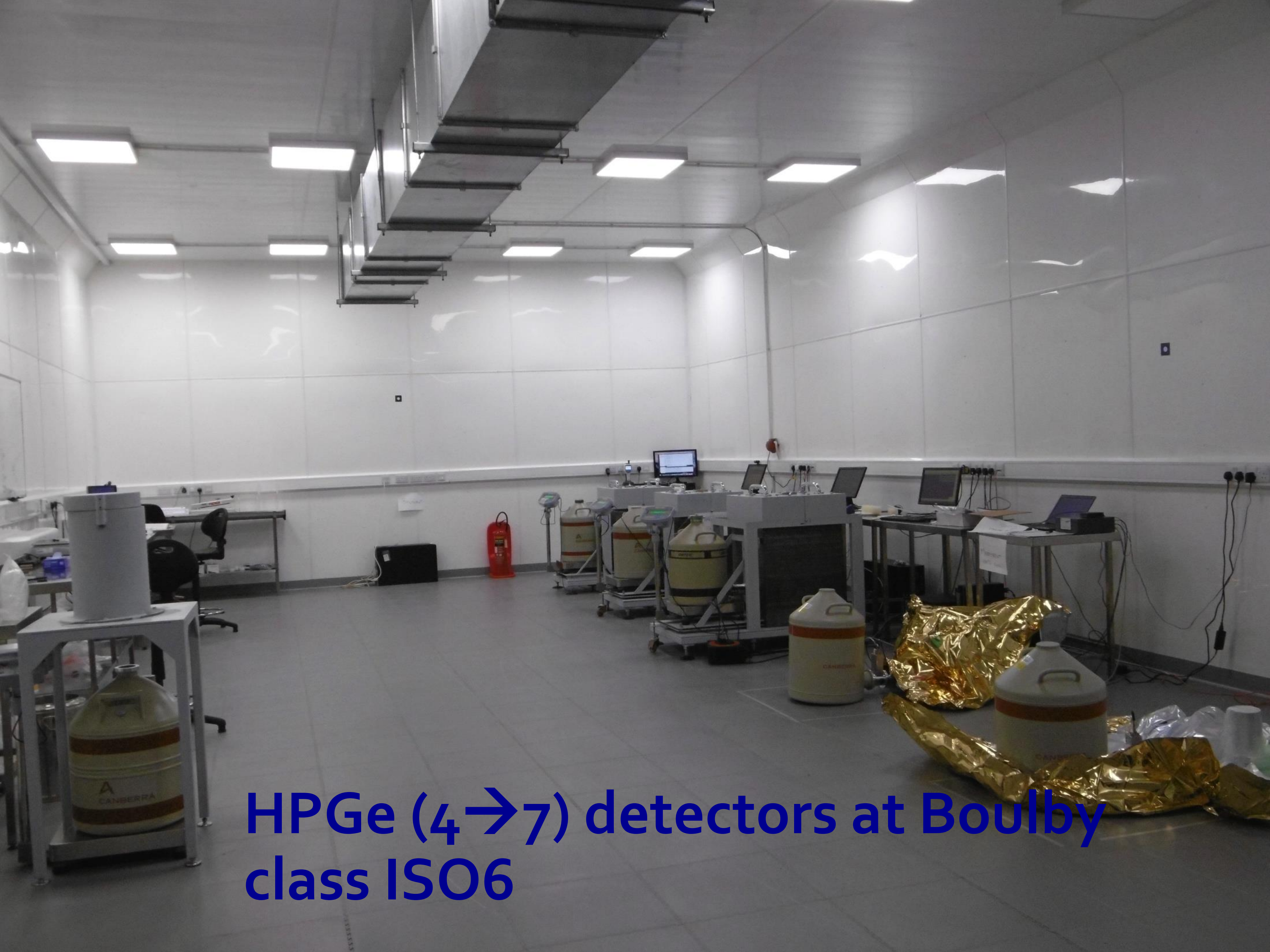
- ✓ Overall DULs have collected some 81 HPGe which corresponds to about 8 M€

- ✓ These detectors used to support screening for experiments and environmental research and other requests from Research Institutions not directly related to DULs

- ✓ Build a global radioactivity database

# Low Background Facility @ SNOLab






HPGe (4→7) detectors at Boulby class ISO6


# HPGe detectors at LNGS


HPGe detectors at SURF, ISO6

# Cu e-forming facility

Used at SURF, LSC, CJPL,SNOLab

An example from the LSC

| sample | $^{238}U$ [ppt] | $^{232}Th$ [ppt] |
|---|---|---|
| OFHC stored underground at the LSC | 0.20±0.01 | 1.00±0.06 |
| e-formed Cu at the LSC | <0.05 | 0.040±0.002 |

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# DULs as multidisciplinary Research Infrastructures

- **Geophysics**
  - Underground environment enhance the sensitivity to local and global phenomena using data from strain meters and seismometers
    - ✓ Local: slow earthquakes, hydrogeologically-induced deformations, sesonal charge and discharge of aquifiers, ocean loading tides
    - ✓ Global: free oscillations of the Earth induced by large quakes, background free oscillations due to atmospheric environment, free core nutation …
  - Ring laser in underground for Lense-Thirring effect measurement (see A. di Virgilio this meeting)
  - DULs could provide data from different locations worldwide
  - Muon tomography for deep geological mapping applications (Boulby)

- **Biology**
  - See: DULIA-bio Workshop held at the LSC in Oct 2015 (*https://indico.cern.ch/event/436589/*)


# Strain meters coupled with seismometers

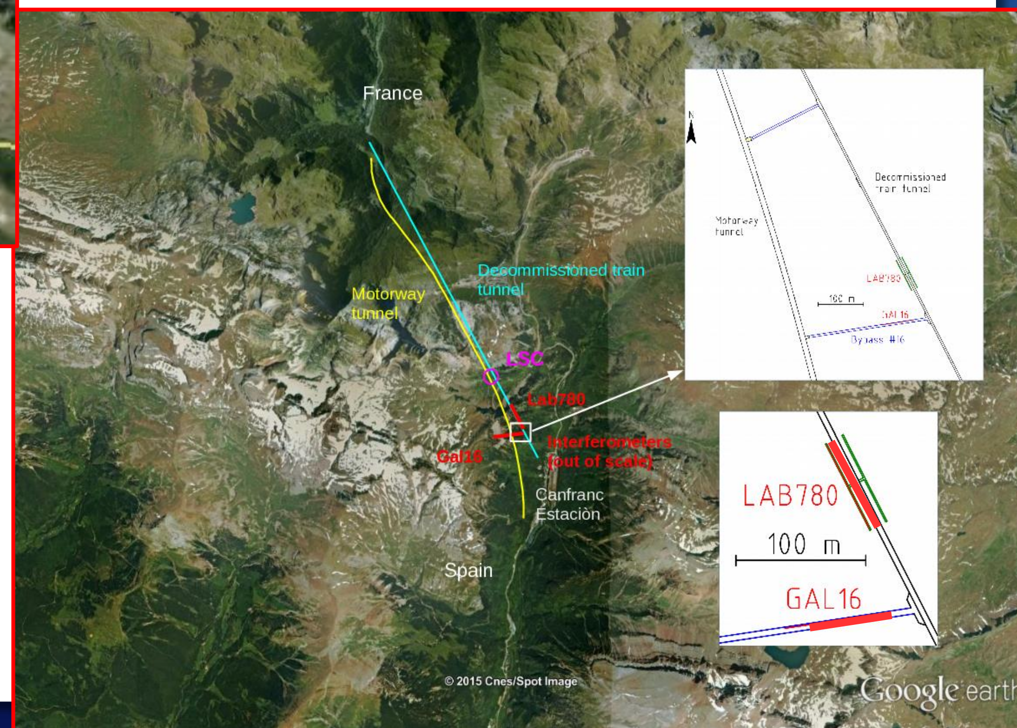
Gran Sasso interferometers
**(LNGS, Italy, 1994-2013)**

Baseline length: 90 m

Canfranc interferometers
**(LSC, Spain, 2011-present)**

Baseline length: 70 m

Nominal resolution $\Delta l/l < 10^{-12}$
Maximum $\Delta l/l$ nominally unlimited
Nominal bandwidth $\approx$ 200 Hz to 0 Hz
Maximum strain rate few $10^{-7}$ $s^{-1}$
1ne $\Longleftrightarrow$ $\Delta l/l = 10^{-9}$



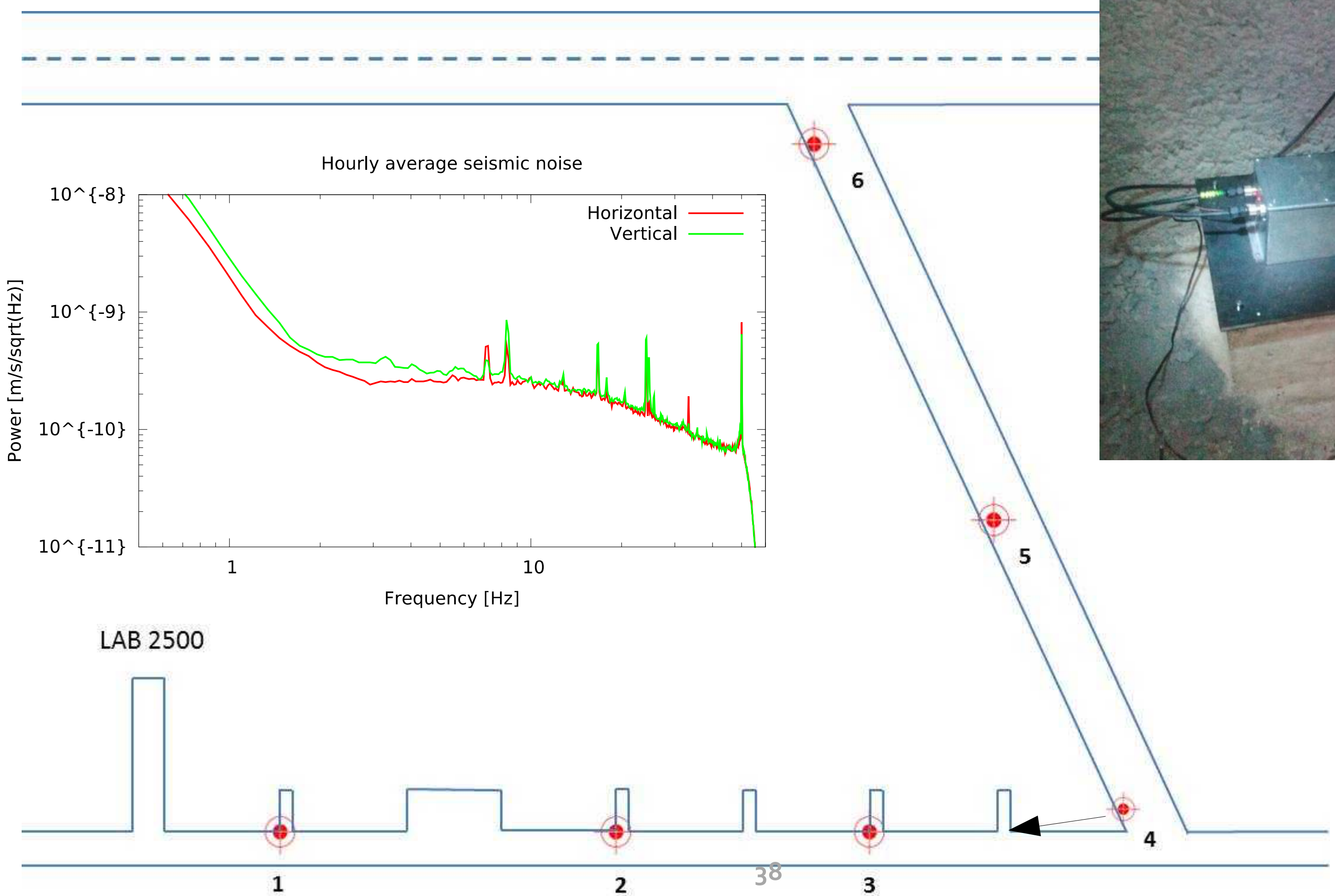
# GINGERino: deep underground ring laser

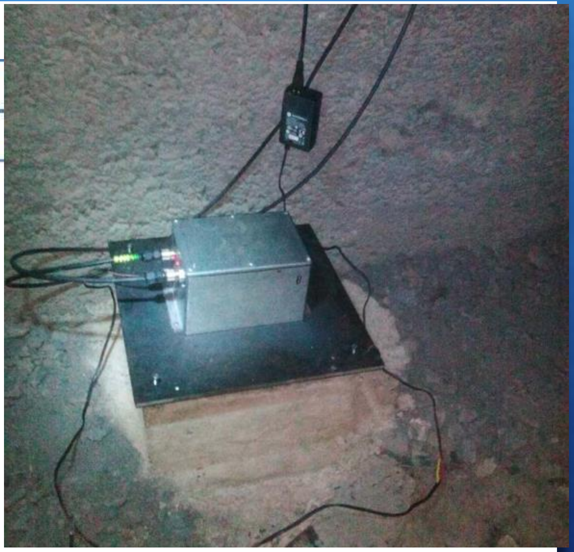
**GINGER-ino (INFN-LNGS)+ Seismometers (INGV)**

See A. D Virgilio this meeting

He-Ne laser at 633 nm
Square cavity, L=3.6 m
Mirrors r.o.c= 4 m
Earth rotation Sagnac bias: **fs=280.4 Hz**

# Seismometers network at the LSC





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# Conclusions

- 11+3 underground multidisciplinary research infrastructures equipped with high technology detectors
- ~720 on-site staff to support activities in DULs worldwide
- Impressive global radio-purity screening power
- Unique opportunity to exploit new technologies
- Great scientific program (see this meeting)
- Opportunity to develop a global network to enhance and spread out our work and achievements

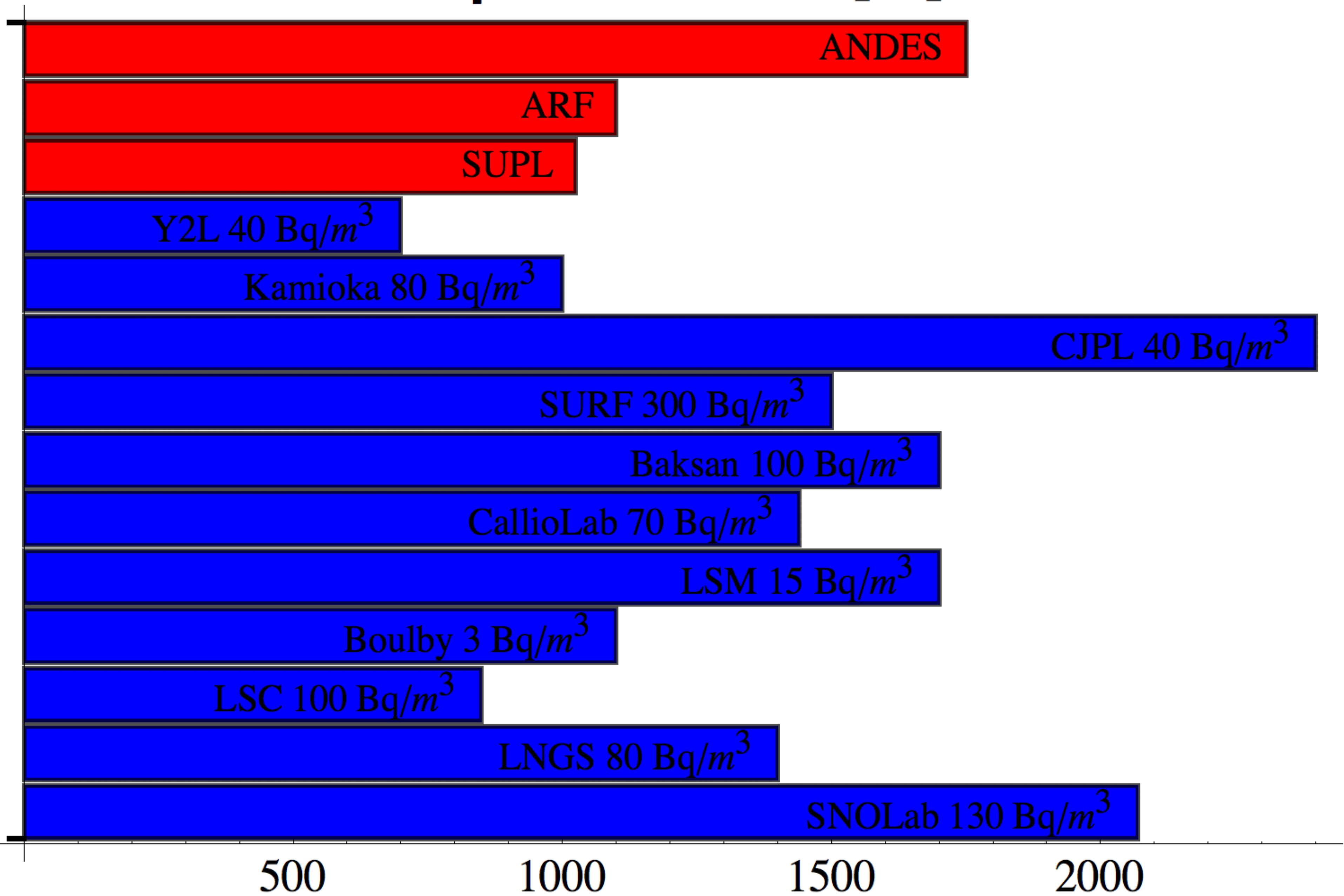
# Acknowledgment


- Nigel Smith (SNOLab), Richard Ford (SNOLab), Ian Lawson (SNOLab)
- Sean Paling (Boulby),
- Fabrice Piquemal (LSM), Masayuki Nakahata (Kamioka),
- Stefano Ragazzi (LNGS), Alba Formicola (LNGS), Matthias Laubenstein (LNGS), Massimiliano de Deo (LNGS), Attanasio Candela (LNGS)
- Alberto Bayo (LSC), Sergio Fernandez (LSC)
- Jaret Heise (SURF), Valery Kuzminov (Baksan),
- Moo Hyun Lee (Y2L, ARF),
- Jari Joutsenvaara (CallioLab), Ville Isoherranen (CallioLab),
- Qian Yue (CJPL)
- Xavier Bertou (ANDES), Elisabetta Barberio (SUPL)
- Luca Crescentini, Angela di Virgilio

# More on background comparison

| | SNOLab | LNGS | LSC | SURF | LSM | Boulby | Baksan | CJPL |
|---|---|---|---|---|---|---|---|---|
| Gamma-rays flux [$cm^{-2}$ $s^{-1}$] | | 0.3-1 | 1 | | 4 | 1 | 1 | |
| Thermal neutrons [$cm^{-2}$ $s^{-1}$] | $5\ 10^{-6}$ | $4\ 10^{-6}$ | $3.5\ 10^{-6}$ | $8\ 10^{-6}$ | $1\ 10^{-6}$ | $<1.5\ 10^{-6}$ | $6\ 10^{-6}$ | $4\ 10^{-6}$ |

# Depth for DULs [m]



# An example: radon abatement system and radon monitoring detector at the LSC