



**Universidad  
de Medellín**  
Ciencia y Libertad

**NNN19**  
Nov 7-9 2019  
University of Medellín, Colombia

# Underground Facilities: Europe

NNN19, 7-9 Nov. 2019

Aldo Ianni, Laboratori Nazionali del Gran Sasso

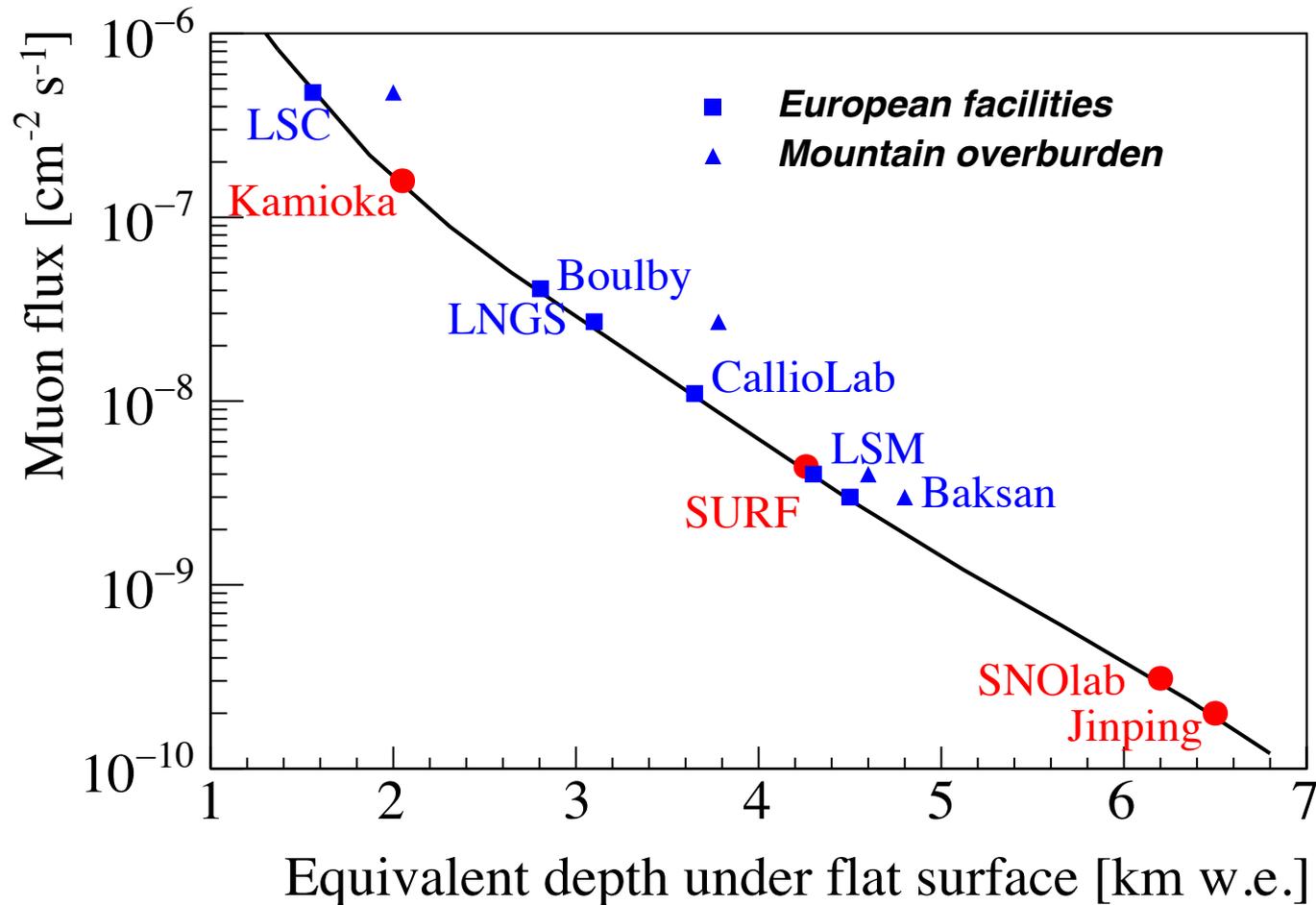


Aldo Ianni, NNN19

# European Facilities (>1km w.e.)

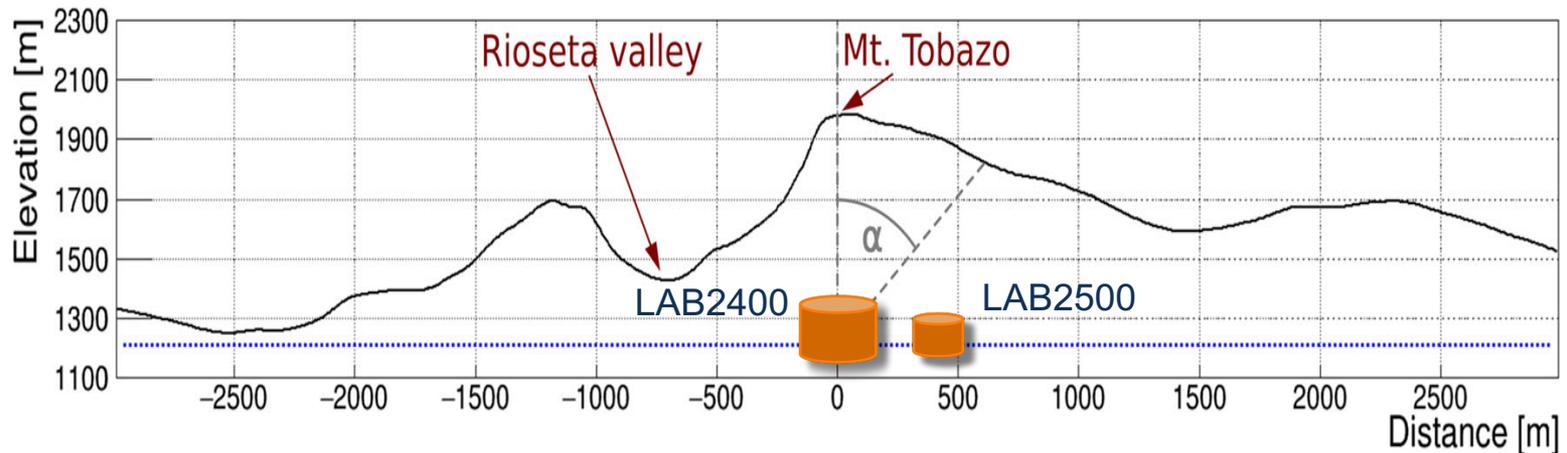


# Effective depth and muon flux in eDULs



# Overburden characteristic

## LSC: mountain profile



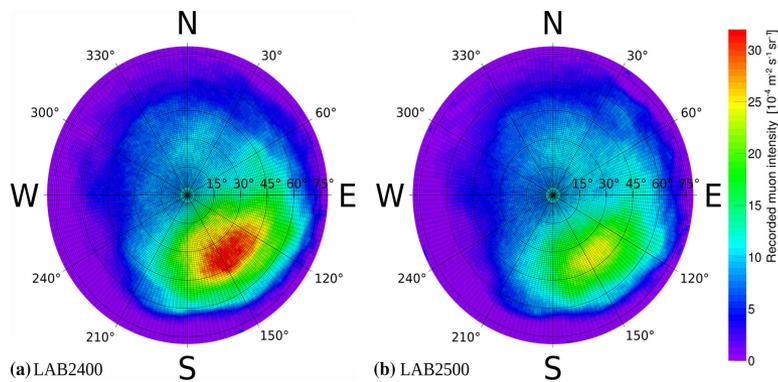
Rock overburden = 750 m, about 2 km w.e.

Effective overburden from muon flux measurement (Eur. Phys. J C, 79, 2019) is about 1.5 km w.e.

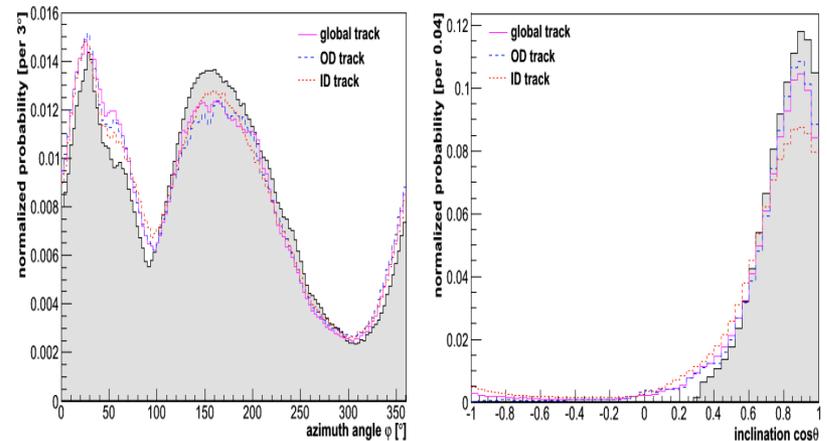
Effective overburden can be optimized against the mountain profile

# Muon flux angular dependence

Angular dependence measured at **LSC** vs zenith and azimuth angles



Cosmic muons data for **LNGS**:  
MACRO and Borexino



Maximum intensity points towards  
Riosetta valley

# Some features for eDULs

	LNGS	LSC	Boulby	LSM	Callio Lab	Baksan
Date of creation	1987	2010	1989	1982	1995	1967
<b>Personnel</b>	106	15	8	13	13	240
Surface U/S [m <sup>2</sup> ]	17000/ 95000	1600/ 2550	1700/ 400	400	220	1600/ 10000
<b>Volume [m<sup>3</sup>]</b>	180000	10000	7200	3500	1000 lower level	23000
Rock overburden [m]	1400	750	1100	1700	1440	1700
<b>Access [V or H]</b>	H	H	V	H	V / drive on incline	H
Makeup Air [m <sup>3</sup> /h]	35000- 60000	20000	300	5500	3600	1440
Air change/day	5-8	48	24	38	7	–
Muon flux [m/m <sup>2</sup> /s]	2.8 10 <sup>-4</sup>	4.8 10 <sup>-3</sup>	4 10 <sup>-4</sup>	4 10 <sup>-5</sup>	1 10 <sup>-4</sup>	3 10 <sup>-5</sup>
Radon [Bq/m <sup>3</sup> ]	80	100	~3	15	70	40
<b>Cleanliness</b>	Only in sectors	Only in sectors	10000	ISO9	Only in sectors	Only in sectors

# Structure of underground facilities

## + **Monolithic:**

- + LNGS with multiple Halls (3 x 36,000 m<sup>3</sup>)
- + Boulby
- + LSM

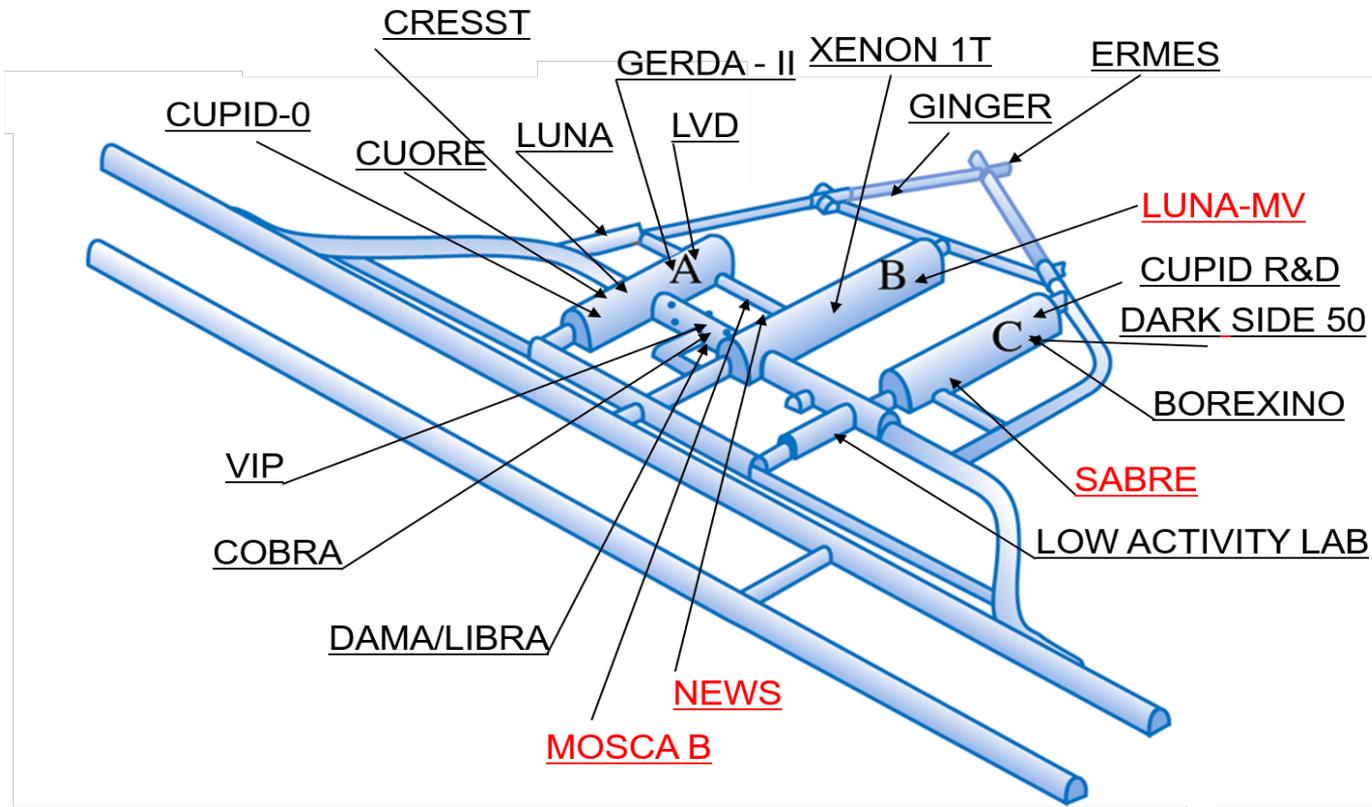
## + **Distributed:**

- + LSC with LAB2400 and LAB2500 + train tunnel
- + Baksan
- + CallioLab (multi-level structure inside the mine)

## + **Smaller and shallower facilities**

- + A number of underground installations are spread in Europe
- + Interactions with main DULs activities

# Layout and research projects at LNGS



# The LNGS Laboratory

- 1400 m (3800 m.w.e. vertical depth) under mountain profile
- Und. surface: 17,800 m<sup>2</sup>
- Und. volume: 180,000 m<sup>3</sup>
- Surface and underground facilities
- Radon in underground ~100 Bq/m<sup>3</sup> with 5-8 air change/day
- **Easy access to underground through highway tunnel**



# Science at LNGS

## + Neutrino astrophysics

- Borexino (solar neutrinos, geo-neutrinos, and supernova neutrinos)
- LVD (supernova neutrinos)

## + Nuclear astrophysics

- LUNA (nuclear processes of interest for astrophysics)

## + Neutrinoless Double Beta Decay (DBD): $(A,Z) \rightarrow (A,Z+2) + 2e^-$ ~~+ $2\nu$~~

- GERDA with  $^{76}\text{Ge}$  (35.8 kg of 88% enriched Ge)  $\rightarrow$  LEGEND-200 (>2021)
- CUORE with  $^{130}\text{Te}$  (206 kg of  $^{130}\text{Te}$ )
- CUPID (R&D with bolometer with particle identification,  $^{100}\text{Mo}$ (LSC,LSM),  $^{82}\text{Se}$ (LNGS),  $^{130}\text{Te}$ )

## + Dark Matter (DM): $\chi + N \rightarrow \chi + N$

- Xenon-Nt with xenon TPC in 2020 (+ 5ton wrt previous set-up)
- DarkSide-50 (DarkSide-20k after 2023) with underground argon TPC
- CRESST with tungsten-based bolometers
- COSINUS with NaI bolometer (after 2021)
- DAMA/LIBRA and SABRE (prototype stage)
- DARWIN: Lol to be deployed inside Borexino Water Tank

## + R&D for rare events search and biology in low radiation environments

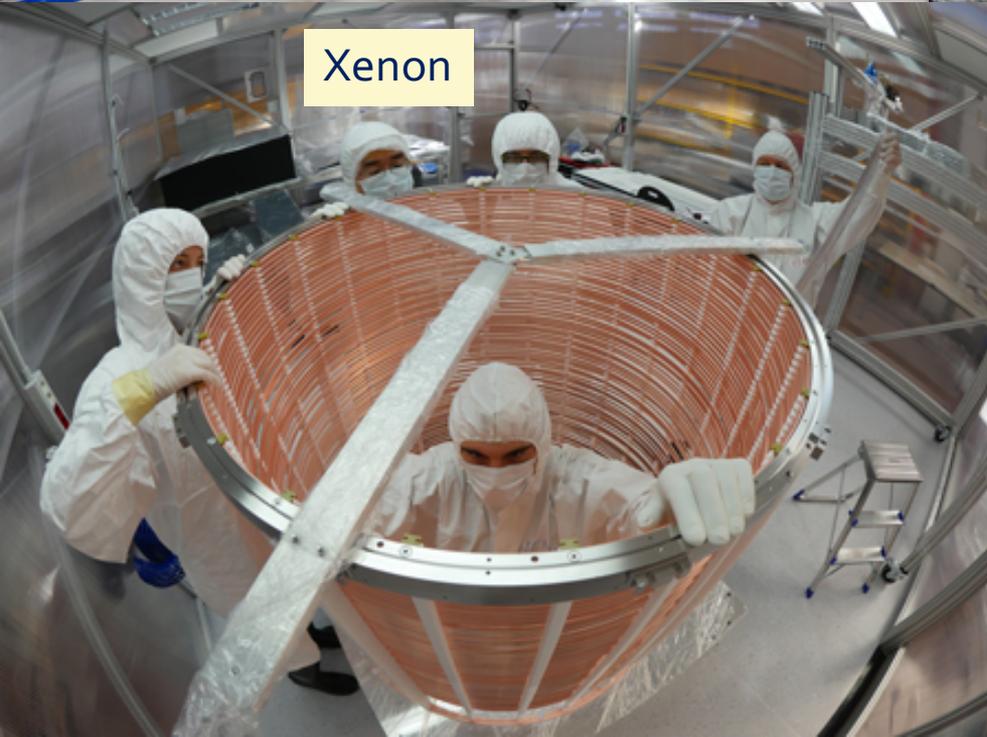
- we just finished a Workshop on biology in DULs: DULIAbio <https://agenda.infn.it/event/19116/>



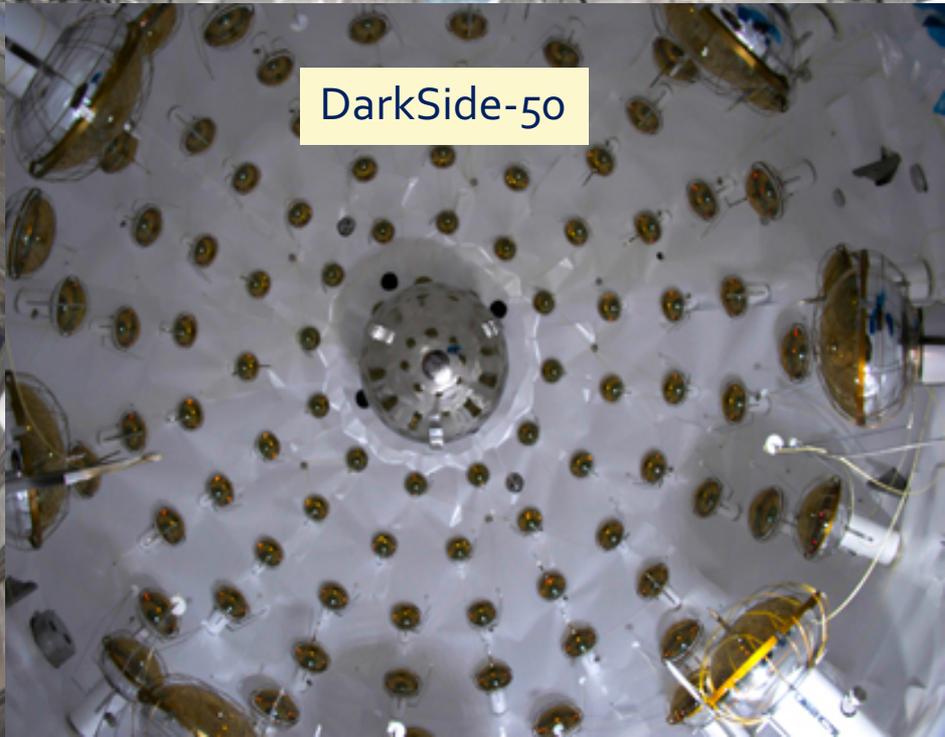
CUORE



GERDA



Xenon



DarkSide-50

# NOA @ LNGS

- The European Union has established a program to improve the economy of “poor” regional areas by supporting new technologies and advanced training
- In this framework, NOA was born in 2018 with an initial budget of 10 M€ (equipment) and 3M€ (personnel – MasterPlan)
- Mission
  - Make a new and innovative infrastructure for photosensors based on SiPM
    - SiPM wafer produced by LFoundry
    - Users: DarkSide, CTA, NUSES
    - Possible interests from CMS and JUNO
- Reinforce the ICP-MS facility and Advance Machining at LNGS

# NOA packaging and assembling radon-free clean room

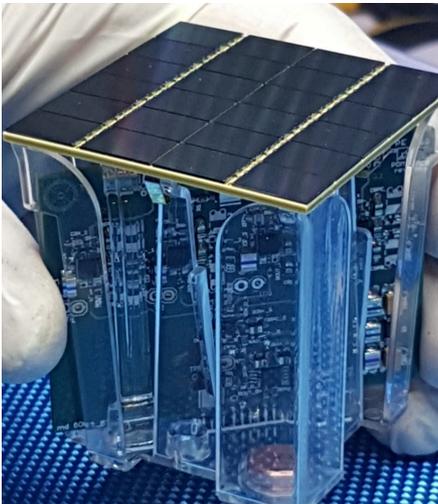
- + A 400 m<sup>2</sup> radon-free clean room being built on surface at LNGS in 2020
- + The clean room will host equipment to make SiPM based photosensors
- + The clean room will offer space for detector assembling in a radon-free environment



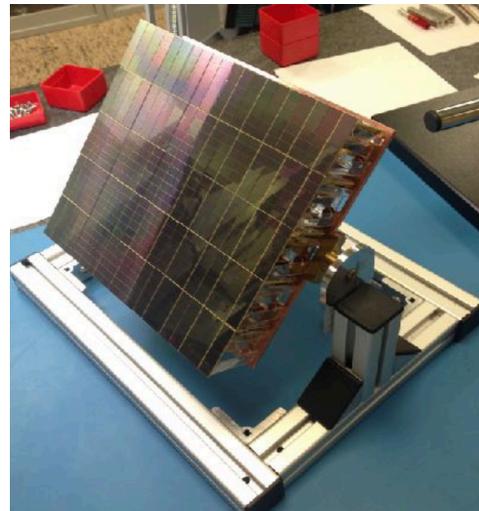
# Photosensors for DarkSide-20k

- + One Photo Detector Module is made with 24 SiPMs
- + 25 PDM makes a Mother Board unit
- + DarkSide needs  $\sim 20 \text{ m}^2$  equipped with SiPM produced by NOA

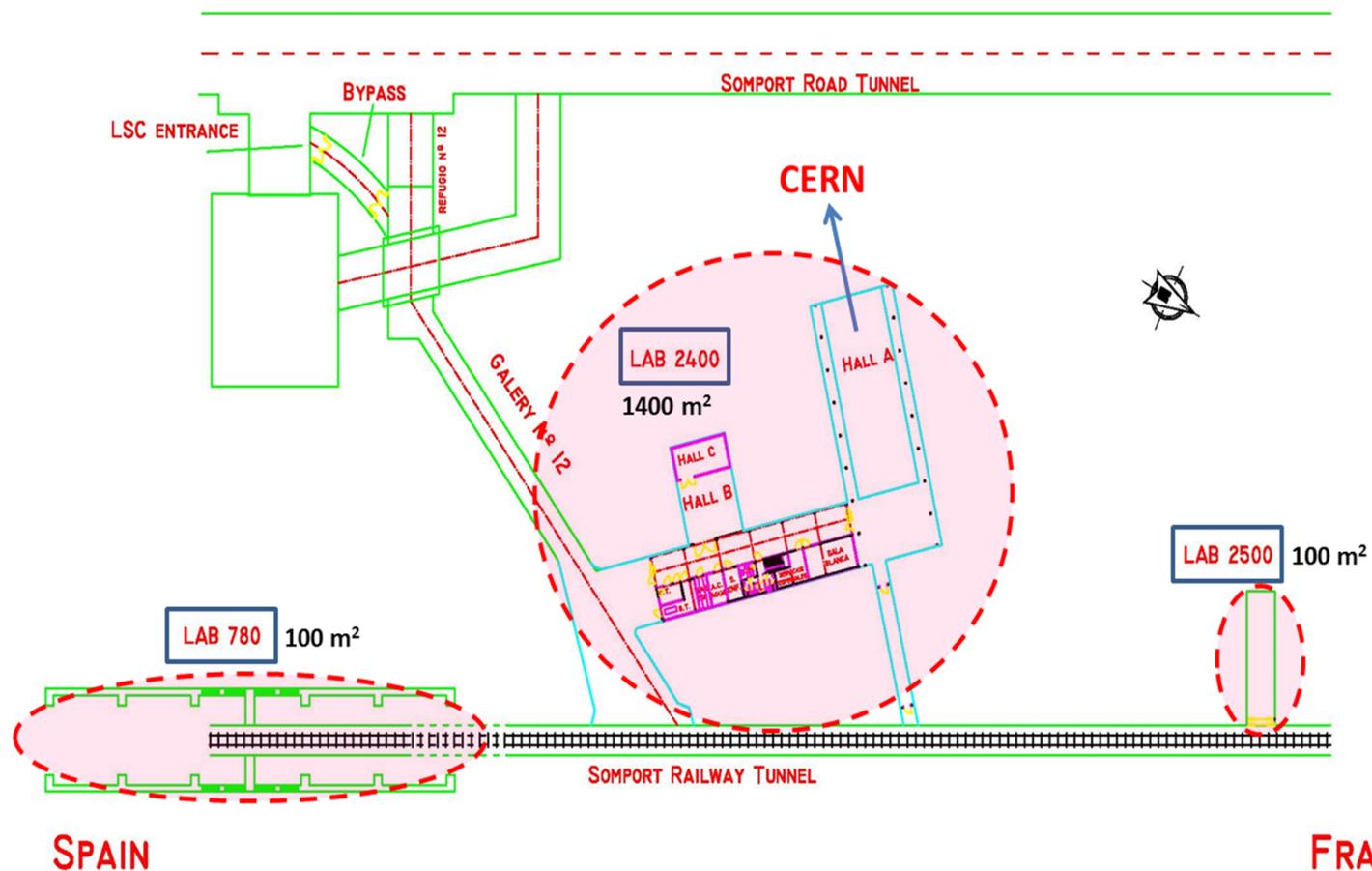
PDM



MB



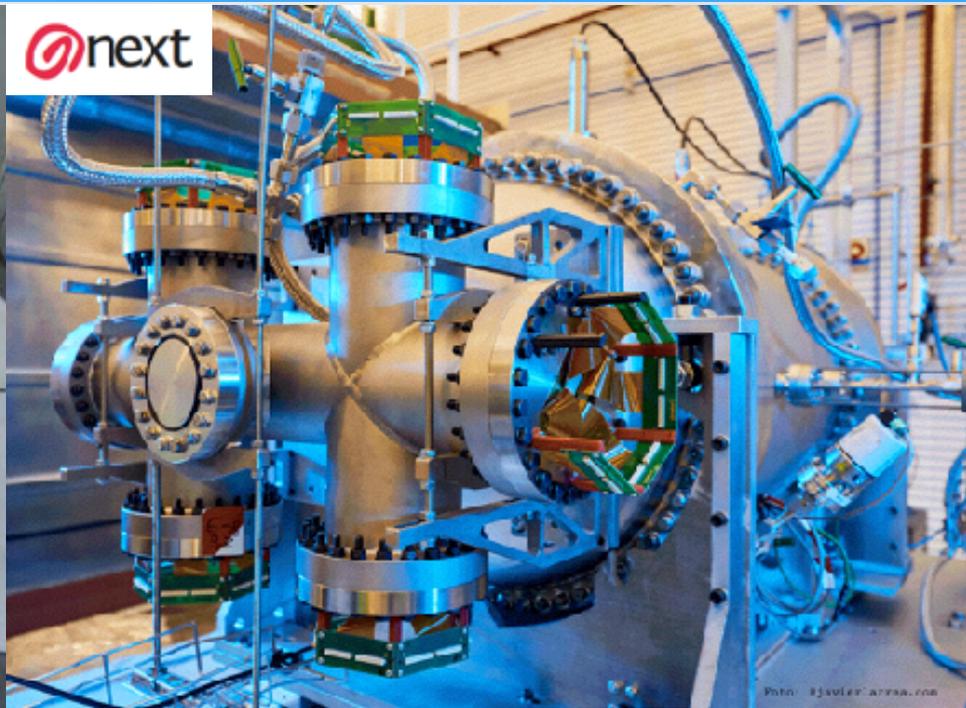
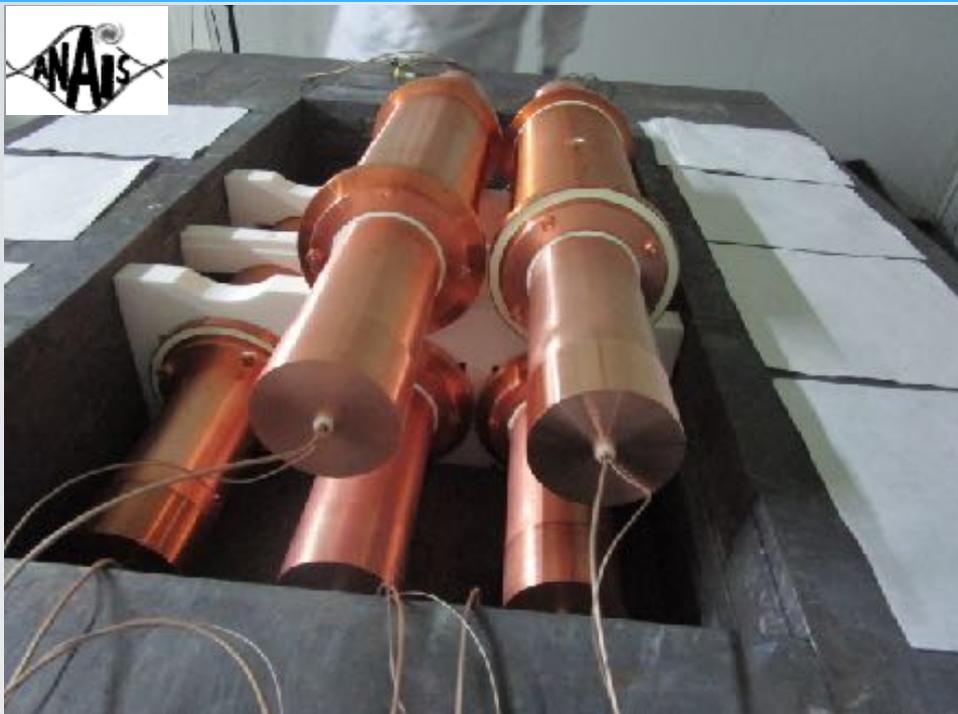
# Laboratory structure at LSC



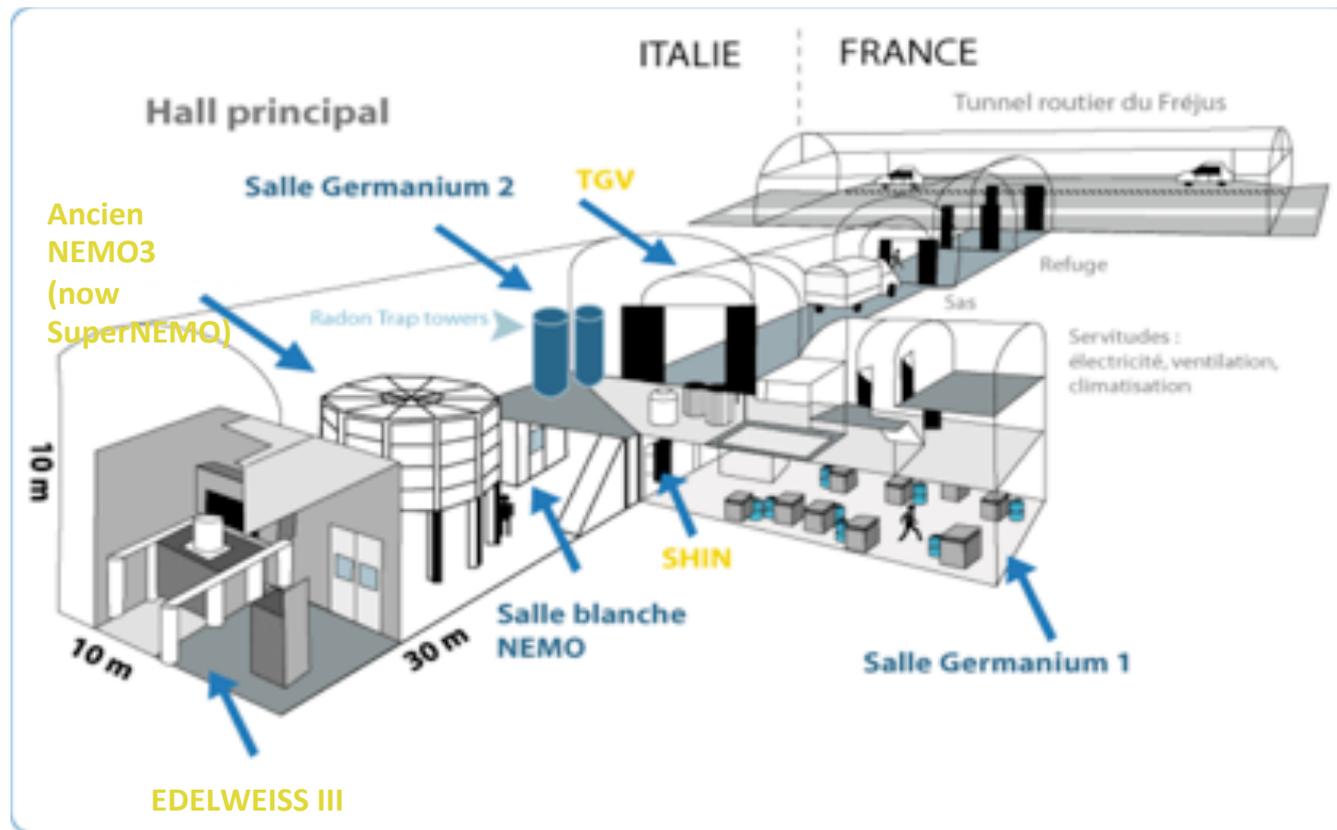


# Scientific program at LSC: highlights

- + NEXT: DBD with  $^{136}\text{Xe}$  in high pressure TPC
  - 10kg prototype under measurement
  - 100kg detector expected by the end of 2020
- + CROSS: DBD bolometer with  $^{100}\text{Mo}$  (demonstrator)
- + ANAIS: DM annual modulation search with NaI in data taking with 112kg
- + ArDM into DArT: LAr TPC as support facility for DarkSide-20k to measure  $^{39}\text{Ar}$  depletion down to  $10^{-5}$
- + Geophysics (70m laser strainmeter) and biology



# Laboratory structure at Modane



# Scientific program at LSM: highlights

- + SuperNEMO: DBD with  $^{82}\text{Se}$  7kg in final commissioning, data taking in 2020
- + CUPID-Mo: DBD bolometer with  $^{100}\text{Mo}$  (20 x 0.2 kg  $\text{Li}_2\text{MoO}_4$ )
  - demonstrator for CUPID in data taking
  - data taking till summer 2020 to improve NEMO-3 limit ( $10^{24}$  yr)
- + EDELWEISS-III: DM subGeV WIMPs search in demonstrating phase since early 2019
- + NEWS-G: gas spherical proportional counter for low mass WIMPs 1.4m diameter Cu sphere
  - just completed data taking phase at LSC, moving to SNOlab
- + DAMIC-M: after DAMIC at SNOlab with 50 10g CCDs
  - deployment start late 2019
- + R&D and biology



# Boulby Underground Laboratory

The UK's deep underground science facility operating in a working polyhalite & salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL

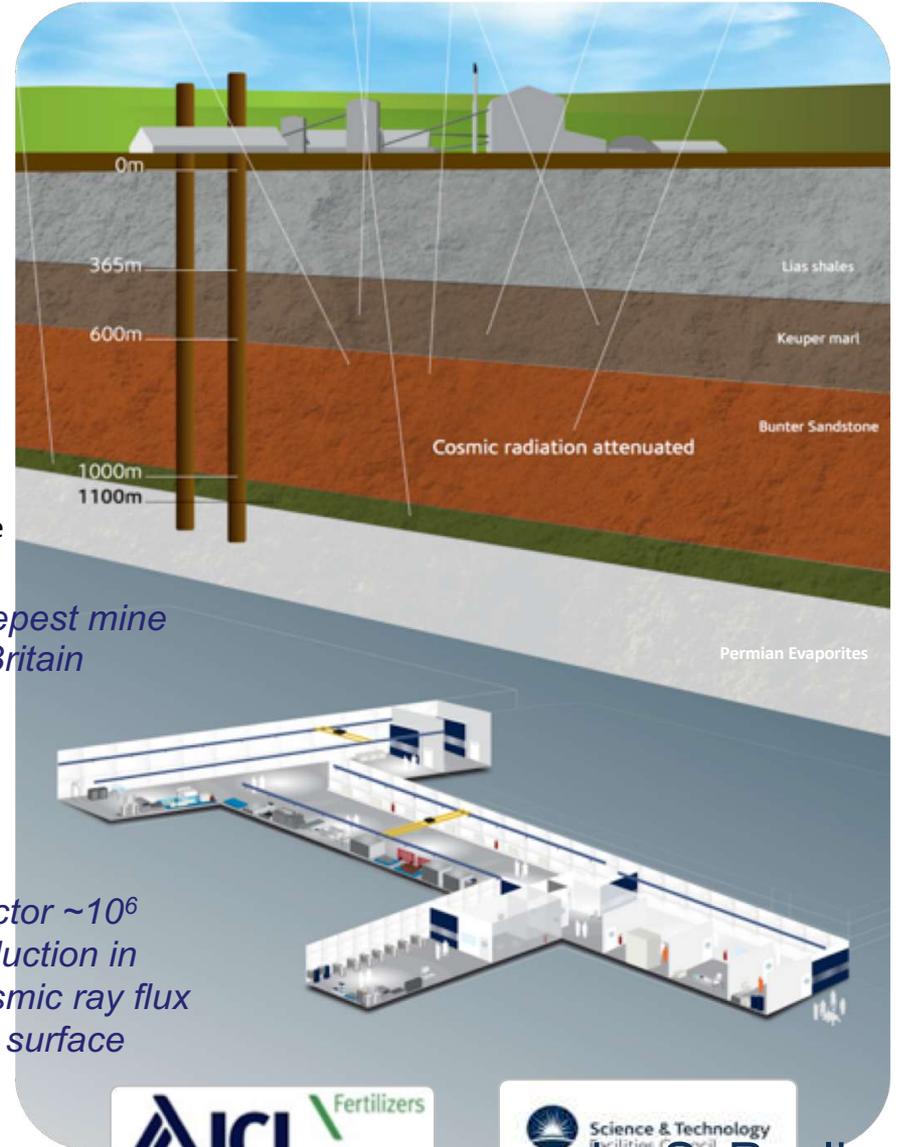


Polyhalite



*Deepest mine in Britain*

*Factor ~10<sup>6</sup> reduction in cosmic ray flux vs. surface*



A **QUIET** place in the Universe



by S. Pauling

# Boulby laboratory ISO7



Access protocols for cleanliness in Boulby and SURF are similar

# Scientific program at Boulby: highlights

- + DRIFT/CYGNUS: DM directional search
- + BUGs: ultra-low background facility in support of LZ, SuperK, and DarkSide-20k
- + ERSaB: environmental gamma spectroscopy
- + Deep Carbon: muon tomography
- + SELLR: life in low background radiation environment
- + BISAL: geomicrobiology and astrobiology studies
- + MINAR: space exploration technology development
- + WATCHMAN (WATER Cherenkov Monitor of Antineutrinos)
  - + 6kt Gd-loaded detector expected in operation in 2024

# CALLIO LAB

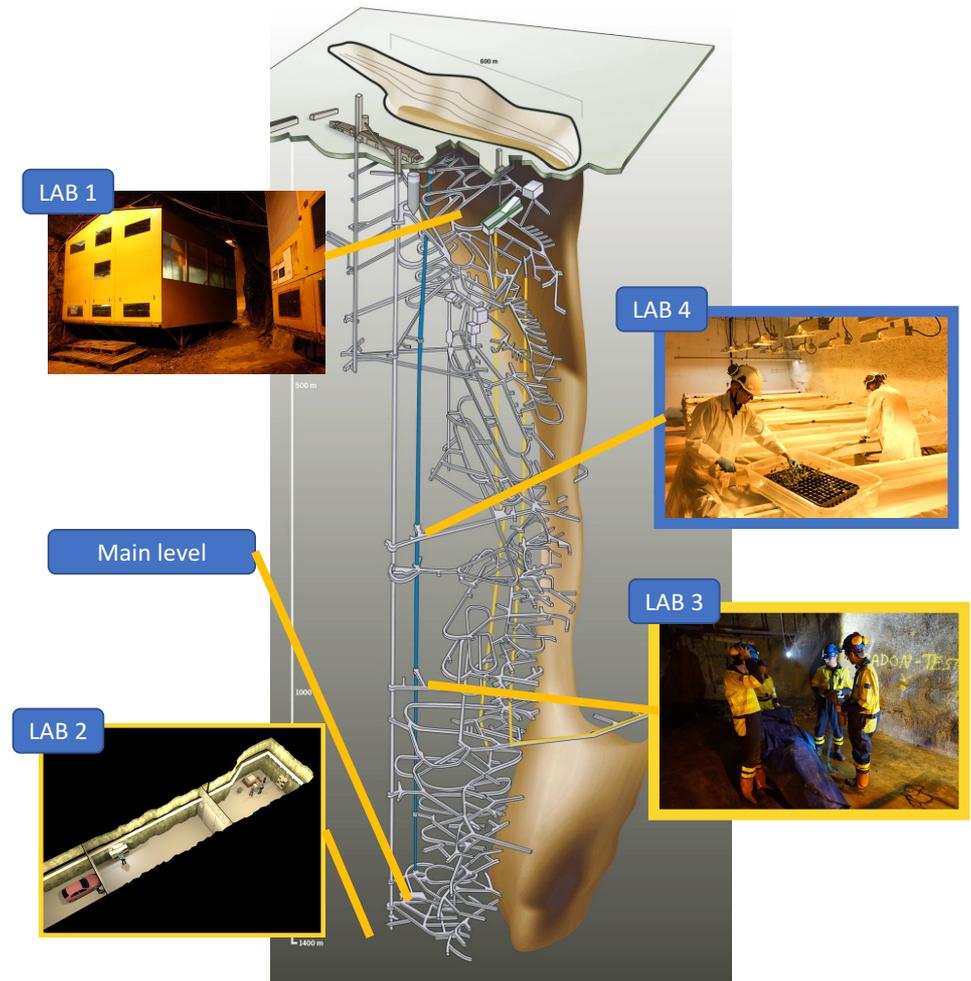
Existing underground multidisciplinary research environments

- 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
- MINETRAN: all over the mine

[www.calliolab.com](http://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)



## Baltic Sea Underground Innovation Network

- aims to make the underground laboratories in the Baltic Sea region more accessible for innovation, business development and science by improving the information about the underground laboratories, the operation, user experiences and safety.
- helps underutilised underground laboratories to develop their operations, risk identification and management, marketing and administration.
- Lead by Kerttu Saalasti Institute at the University of Oulu, Finland
- 2017-2020, a 3 M€, 3-year Interreg Baltic Sea Region project
- 13 partners from 8 countries

[www.bsuin.eu](http://www.bsuin.eu)

## Underground Labs



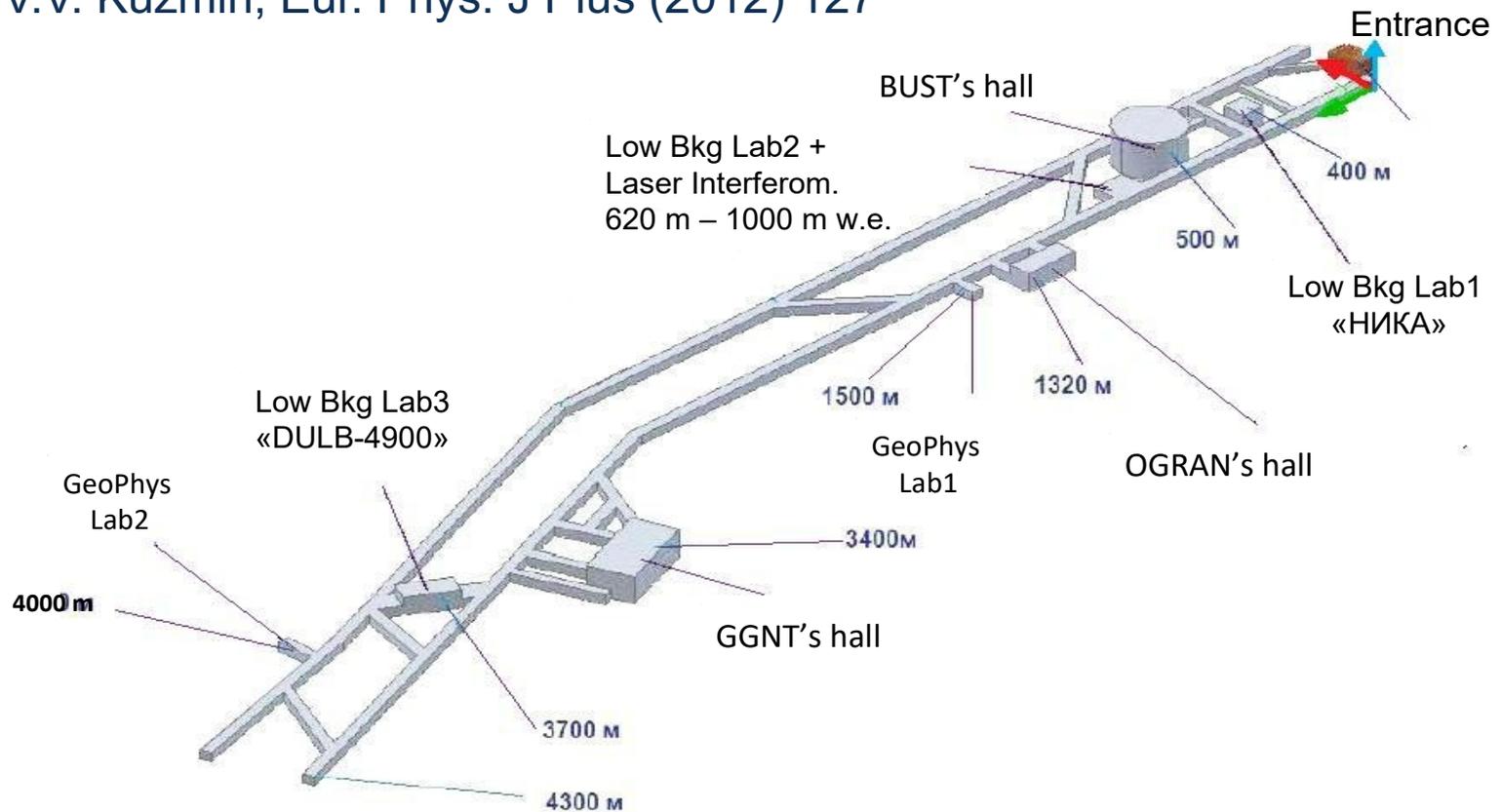
### UNDERGROUND LABORATORIES INVOLVED IN THE BSUIN PROJECT:

- Callio Lab, Pyhäsalmi mine, Finland
- Äspö Hard Rock Laboratory, Oskarshamn, Sweden
- Reiche Zeche, TU Freiberg Research and Education mine, Germany
- Conceptual Lab development co-ordinated by KGHM Cuprum R&D centre, Poland
- Khlopin Institute Underground Laboratory, Russia
- Ruskeala, Russia

## BSUIN -NETWORK

# Laboratory structure at Baksan

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

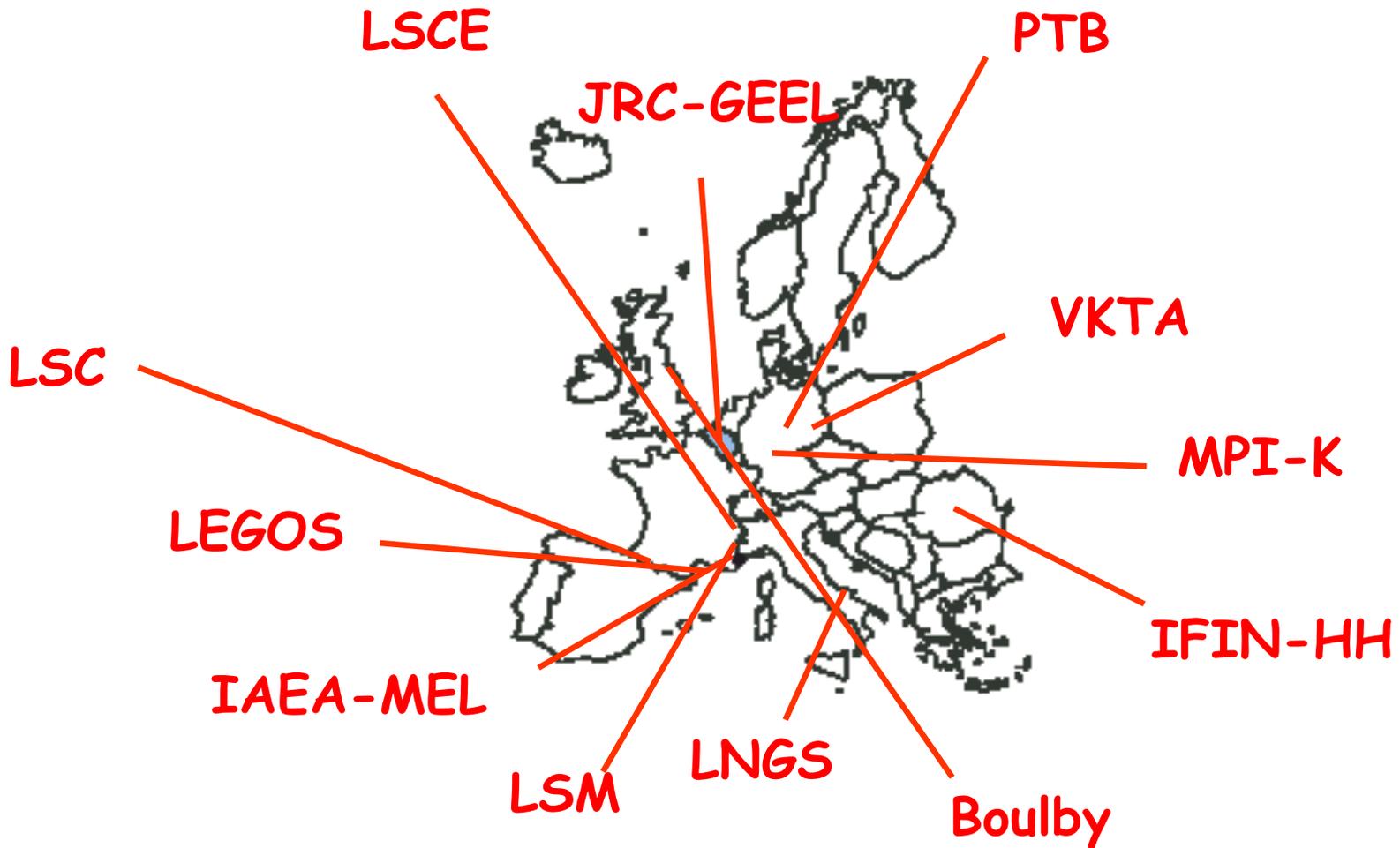


# Scientific program at Baksan: highlights

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

# CELLAR (Collaboration of European Low-level underground LABoRatories)

- + Goal: combine expertise and equipment for ultra low-level radio-purity assay
  - Gamma spectroscopy
  - ICP-MS
  - radon emanation measurement
- + Members: eDULs and shallow depth facilities equipped with instruments for radio-purity assay for rare events search and environmental monitoring

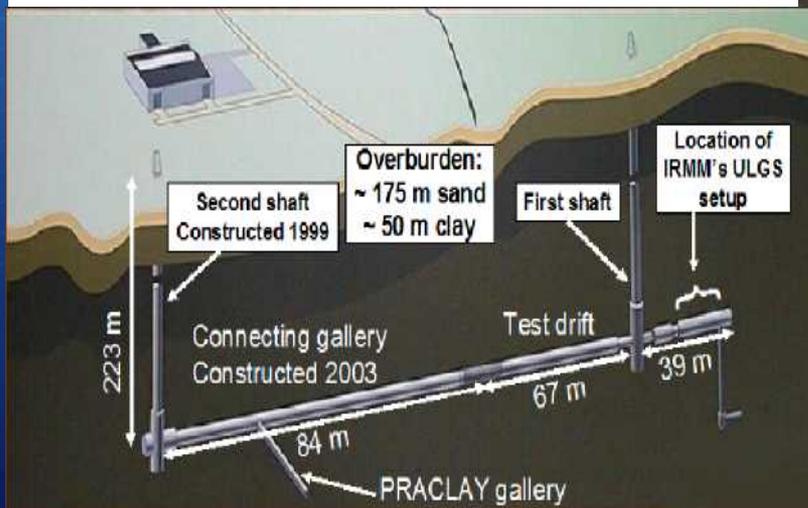


Courtesy M. Laubenstein

# JRC-Geel HADES

Underground Lab for ultra-low gamma spectroscopy

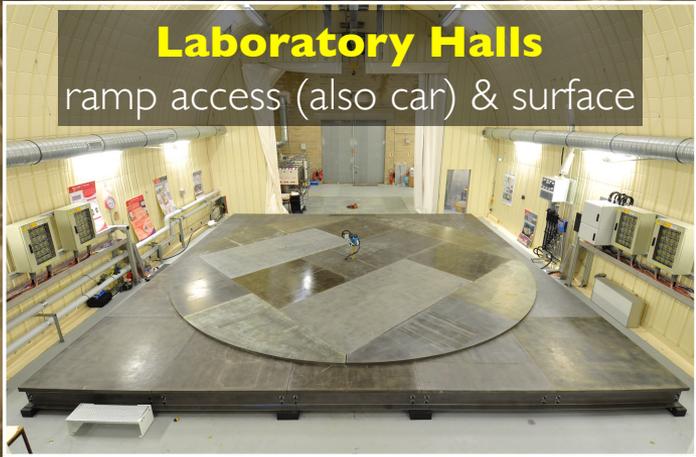
Depth 225m





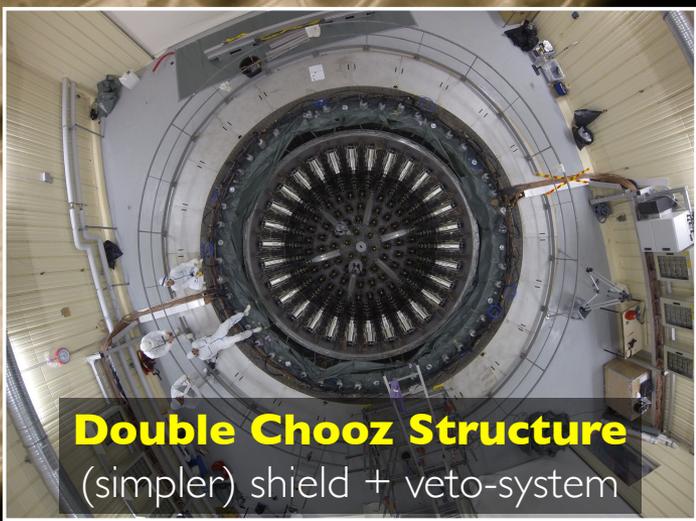
# LNCA laboratory (Chooz)...

**Chooz-B Experimental Hall**  
~120mwe overburden  
~30v day<sup>-1</sup> ton<sup>-1</sup> @ <410m>



**Laboratory Halls**  
ramp access (also car) & surface

**Chooz: 2x N4 Reactors**  
~8.4GW<sub>thermal</sub> ⇒ ~10<sup>21</sup>v/s



**Double Chooz Structure**  
(simpler) shield + veto-system



Available experimental space  
close to powerful reactor  
For any query contact  
Anatael Cabrera

**Chooz-A Experimental Hall**  
~300mwe overburden  
~6v day<sup>-1</sup> ton<sup>-1</sup> @ <1050m>

# eDULs network and collaboration

- + DULIA: Deep Underground Laboratory Integrated Activity
  - Collaboration program in the framework of EU and with APPEC sponsorship between LNGS, LSC, LSM, Boulby, CallioLab
- + Work load sharing for radiopurity assay
  - Global argon program (DarkSide): LNGS, LSC, Boulby
  - SuperKamiokande with Gd: LSC, Boulby
- + Low background technology
  - Sharing expertise and equipments
  - Collaboration on new developments
- + Baltic Sea Network

# LNGS + LSC

Advanced Machining and ultra-pure copper

## + E-formed copper made at LSC

- Make copper powder
- Use Advanced Machining at LNGS to make components for experiments (PI: D. Orlandi)



GOAL:

e-formed Cu

production at LSC

100 kg/year in 2020

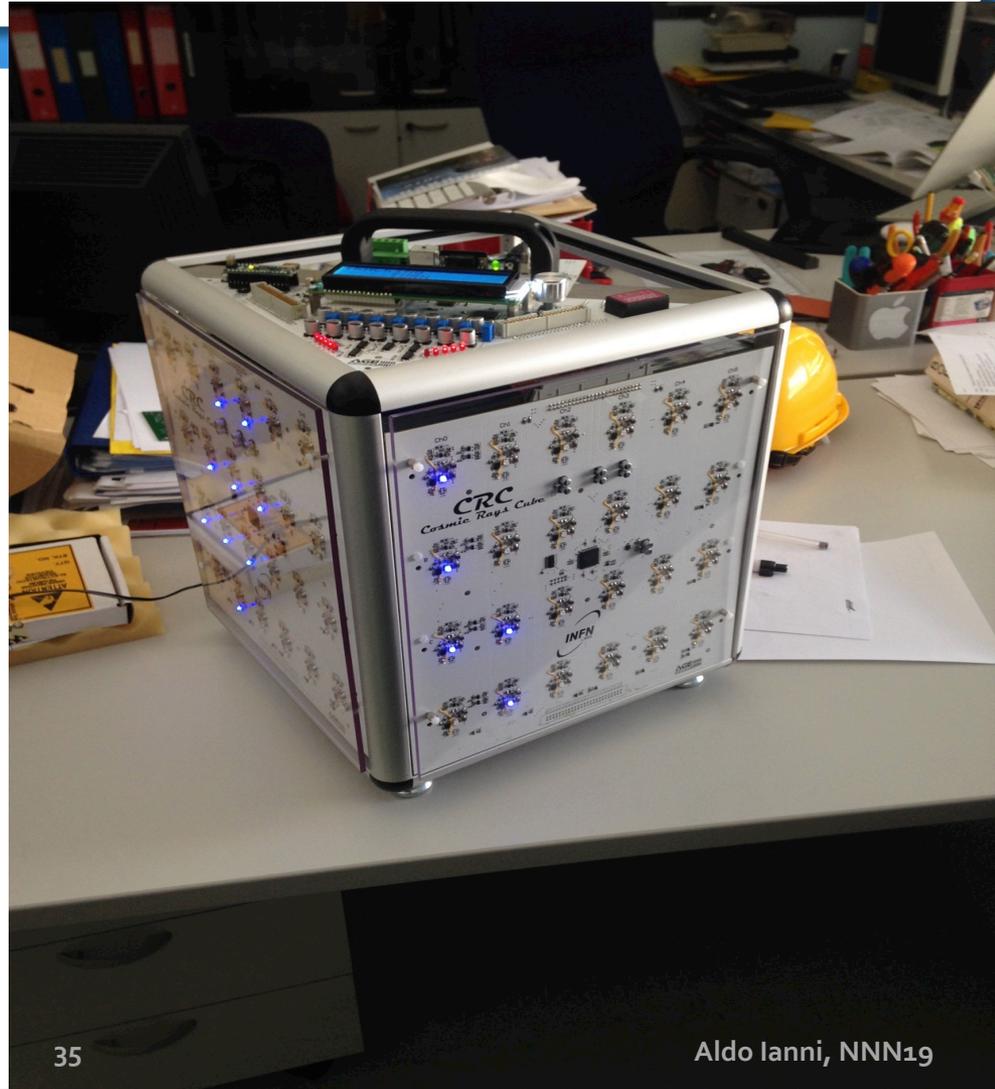
Cu	U [ppt]	Th [ppt]
OFHC	$0.2 \pm 0.01$	$1 \pm 0.06$
E-formed	$< 0.05$	$0.040 \pm 0.002$

# Outreach activities

LNGS and LSC in collaboration have made large and portable muon telescopes for outreach activities

We have developed an App for Android and iPhone to share collected data worldwide (Cosmic Rays Live)

New collaboration underway including SNOlab and Kamioka



LOGO IMAGE

XYZVIEW

DISTRIBUTION

ANGLES

# CRD Cosmic Rays Detector

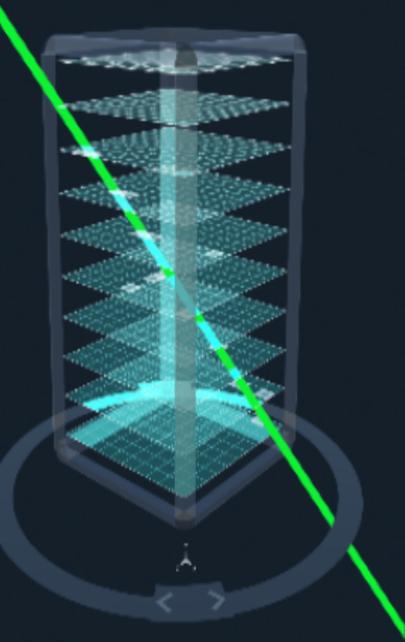
DATA VIEW

Event Data and Time  
Unknown

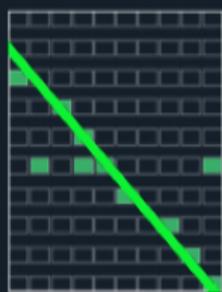
Event ID  
ST98C1

Event Location  
0020050080100  
200600C01800  
00000

3D VIEW



X Plane



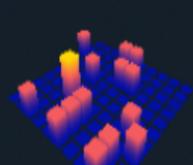
Y Plane



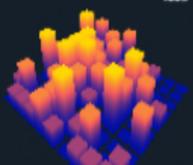
Z Plane



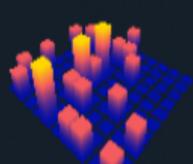
Plane 10



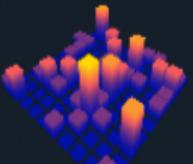
Plane 5



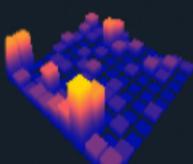
Plane 9



Plane 4



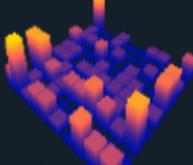
Plane 8



Plane 3



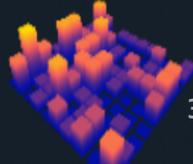
Plane 7



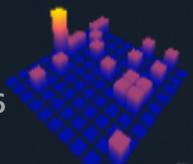
Plane 2



Plane 6



Plane 1



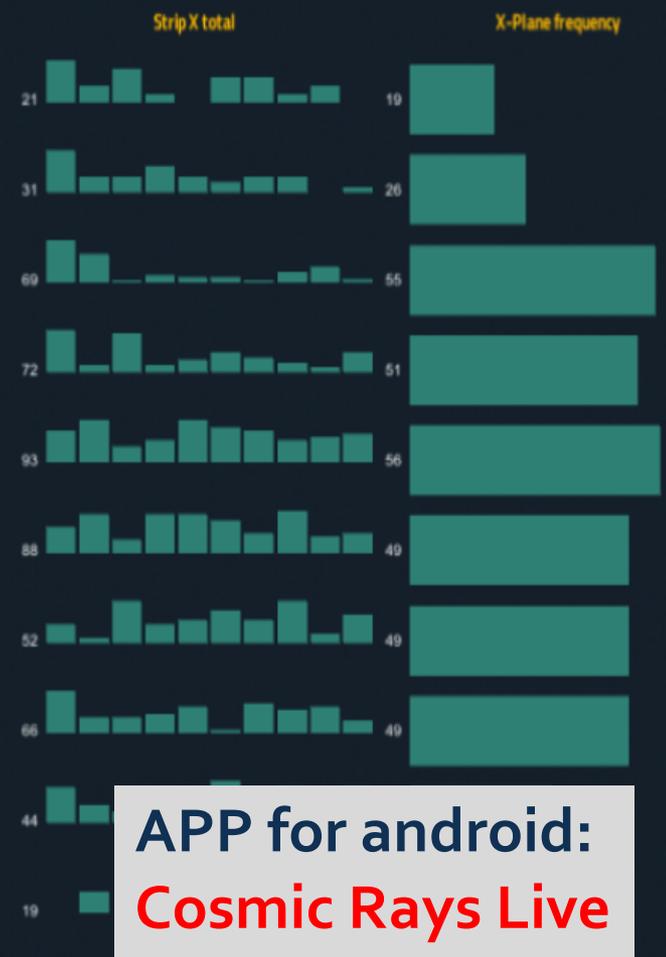
Cos(Theta) 0.7789322

Phi Distribution 141°



STATISTICS

TOTAL EVENTS 60



**APP for android:  
Cosmic Rays Live**

Strip X Count										StripX/PlaneX Count (%)									
ch0	ch1	ch2	ch3	ch4	ch5	ch6	ch7	ch8	ch9	ch0	ch1	ch2	ch3	ch4	ch5	ch6	ch7	ch8	ch9
5	2	4	1	0	3	3	1	2	0	23	9	19	4	0	14	14	4	9	0

# Management and operating costs for eDULs

1. ~2000 users and ~2500 visitors all together
2. ~300 Staff
  - Direction Service + Safety Service + External funding Office + Research Division + Technical Division + Administration Service
3. Scientific Advisory Committees to steer scientific activities (LNGS, LSC, Boulby, LSM (from 2020))
4. Annual operating budget (no hosted experiments budget)
  - LNGS: ~13 M€
  - LSC: ~ 1.7 M€
  - LSM: ~ 0.2 M€ + personnel
  - Boulby: ~ 1.2 M€

# Conclusions

- + 6 large DULs and a number of shallow labs
- + Multidisciplinarity (physics, geophysics, biology) research program
- + Improving connections and collaborations within and outside Europe
  - DarkSide-20k is the present example
- + Move toward reinforcing work load and sharing of facilities for next generation large experiments
- + outreach

Thank you for your attention

# Acknowledgments:

S. Pauling (Boulby), C. Pena-Garay (LSC), J. Gascon(LSM),  
S. Troitsky (Baksan), Jari Joutsenvaara (CallioLab), S.  
Ragazzi (LNGS)