FUTURE LARGE FACILITIES: (DEEP) UNDERGROUND

Carlos Peña Garay
Laboratorio Subterráneo de Canfranc

Sep 8, 2021

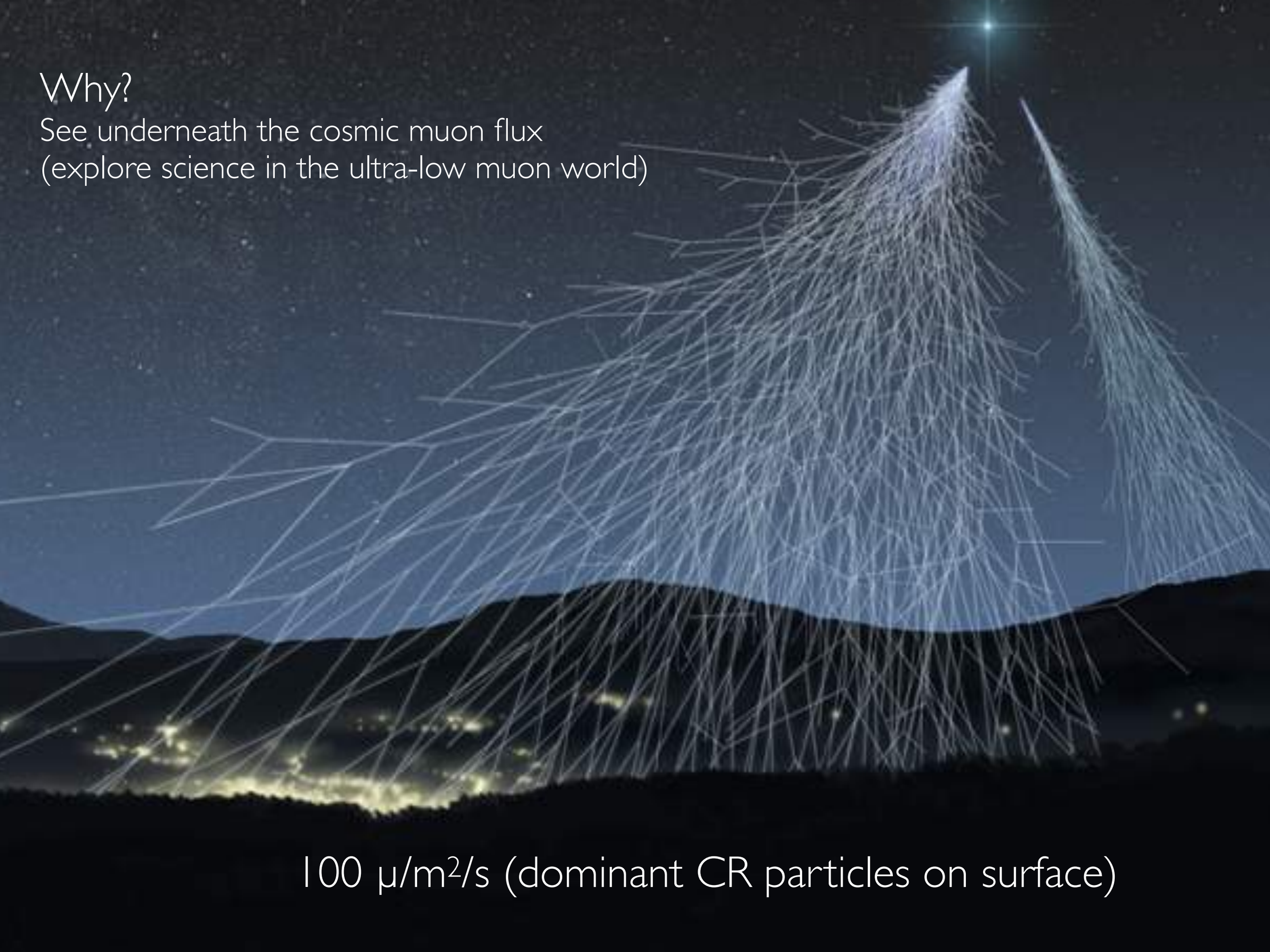
XLVIII IMFP, Benasque

LSC
Laboratorio Subterráneo de Canfranc

The Five W for Deep Underground Laboratories

Why?

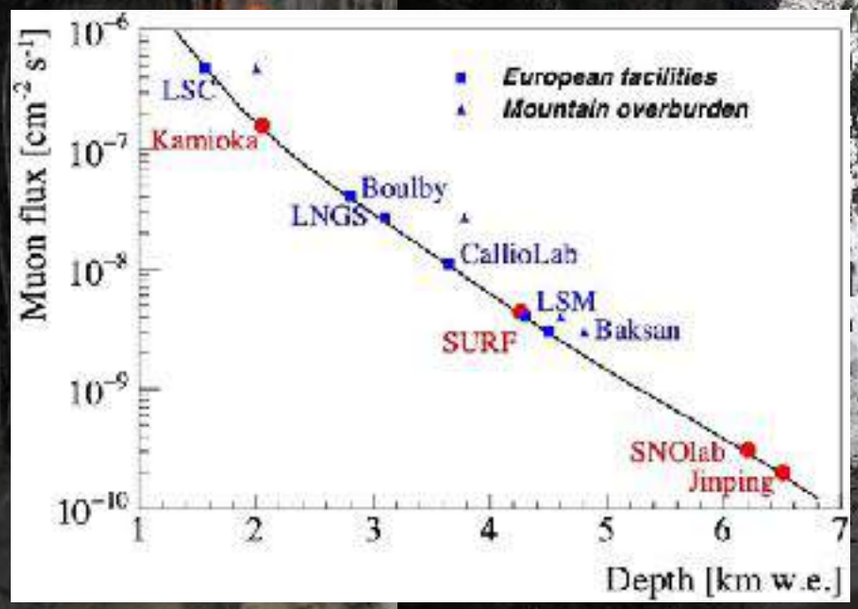
See underneath the cosmic muon flux
(explore science in the ultra-low muon world)



100 μ/m^2/s (dominant CR particles on surface)

Where?

Spaces next to mines or tunnels



When?
Since 1901
Growth in number
in 1960s & 1980s &
Nowadays!

Neithpad Train tunnel: Used by CTR Wilson to explore whether penetrating radiation was extraterrestrial

Who?

Start by one group
Become a national
& international hub

Angel Morales, Julio Morales, José Ángel Villar, Rafael Nuñez-Lagos
Canfranc-Estación, c. 1986

Imagen cedida por GIFNA, Universidad de Zaragoza

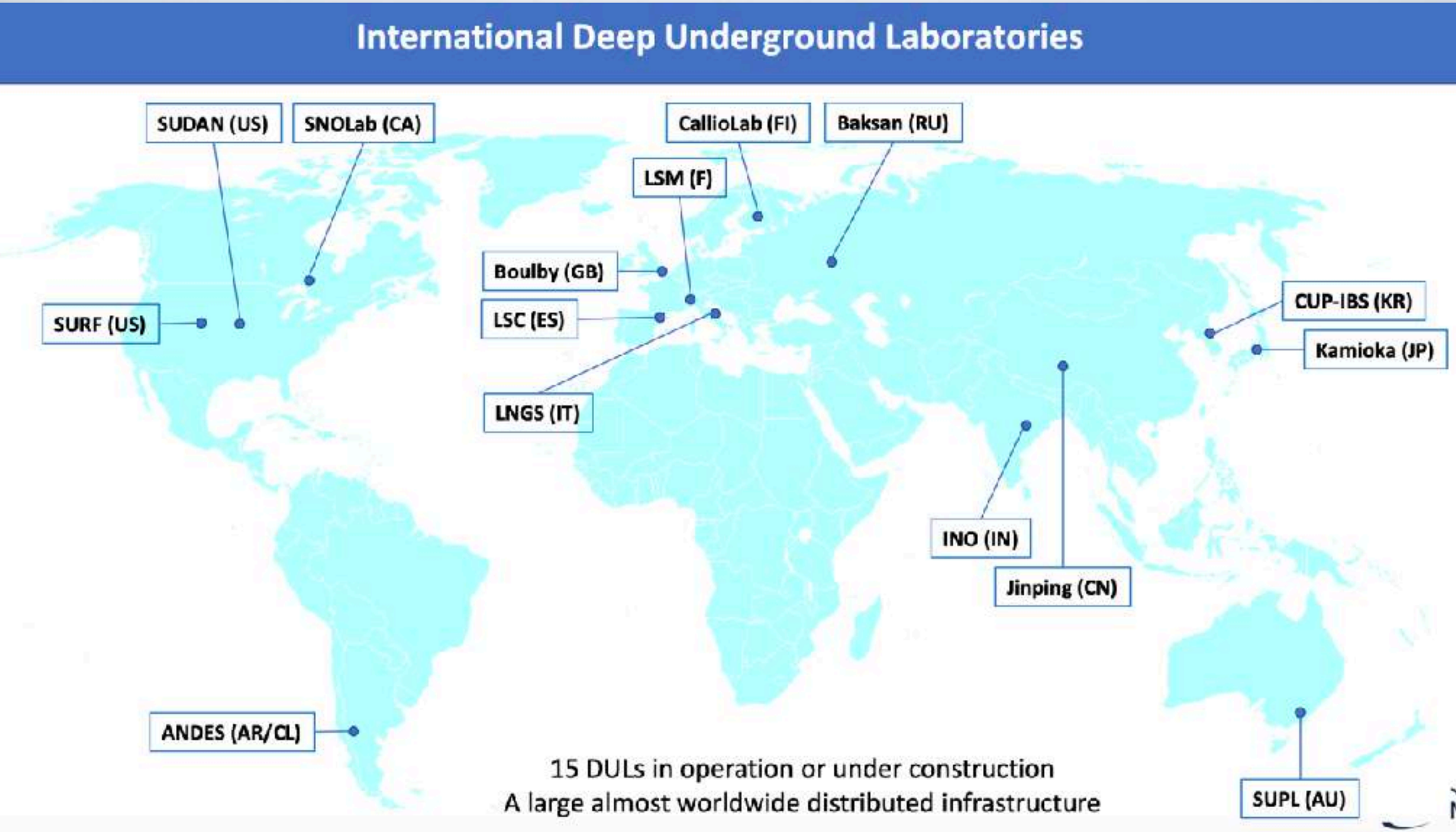
What?

Hub for experiments and Low Radioactive Techniques

Laboratorio Subterráneo de Canfranc

DUL : Global Numbers

15+ DUL WORLDWIDE



DUL GLOBAL NUMBERS

DULs Research Community

Trying to collect some number we could find:

- 15 (probably more) DULs in the world
- Many Lab infrastructures and facilities
- Something around 100 experiments running or under construction (R&D not considered)
- A rough estimate of more than 6000 involved researchers worldwide
- Important increase of manpower requests for the DUL staffs
- A growing needs of funds for DUL operations and maintenances
- A careful approaches to safety and environmental impacts needed

DUL research community became a large and important community

I believe that more coordinated actions could be extremely helpful

- Sharing information on various aspects: infrastructures, safety, measurements database, ...
- Optimizing the investments in new approaches and in designing new facilities
- Defining a common strategy for future developments
- Having a more substantial role in the definition of the real needs for DULs
- .....

NATIONAL HUBS WITH INTERNATIONAL CONTRIBUTIONS

Best example: LNGS started in 1987 as an INFN National Lab (almost all INFN Sections in the contribute to LNGS activities).
SNOLab (2003) was build with the same strategy. Multiple institutions contribute.

Not always the case.

LSC: Started by GIFNA(UZ), since 2010 is a National Lab (ICTS), currently with 14 Spanish institutions with experiments/activities underground:
CIEMAT, UAM, UCM, IFAE, UPC, UB, IFIC, UPV, UPV/EHU, DIPC, UO, USC, IFCA, CAPA

and growing: UPN, UPCT, CAB, CBM, I2SysBio, UPF (20 at the end of 2021)

National labs useful to find support to develop technology with interest for low background

If you are interested, please contact LSC

The kton+ neutrino detectors and the multi-ton dark matter and ton double beta decay require international partners

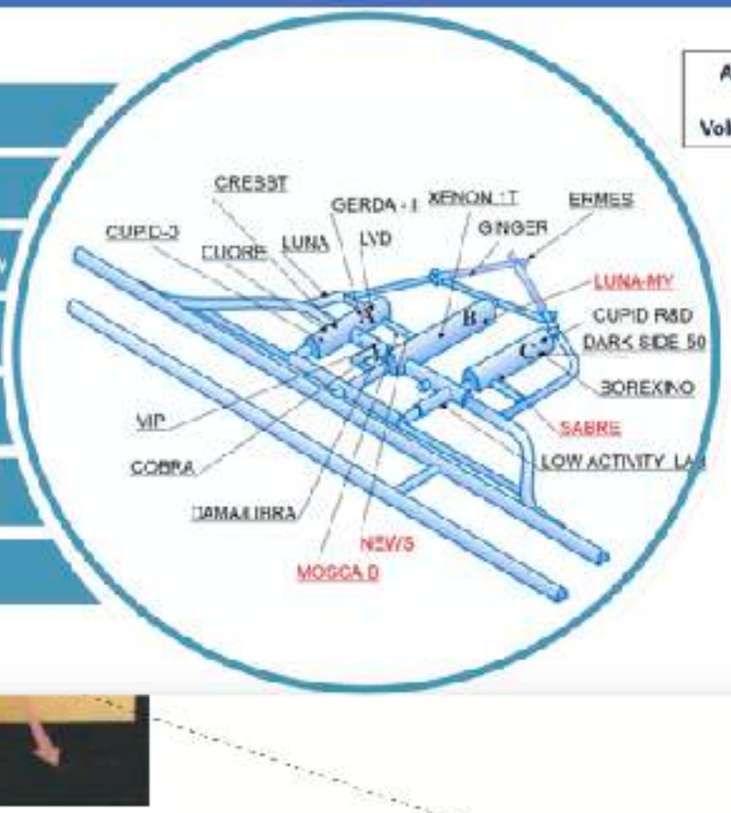
Laboratorio Subterráneo de Canfranc

4 (+1) XL-SIZE DUL

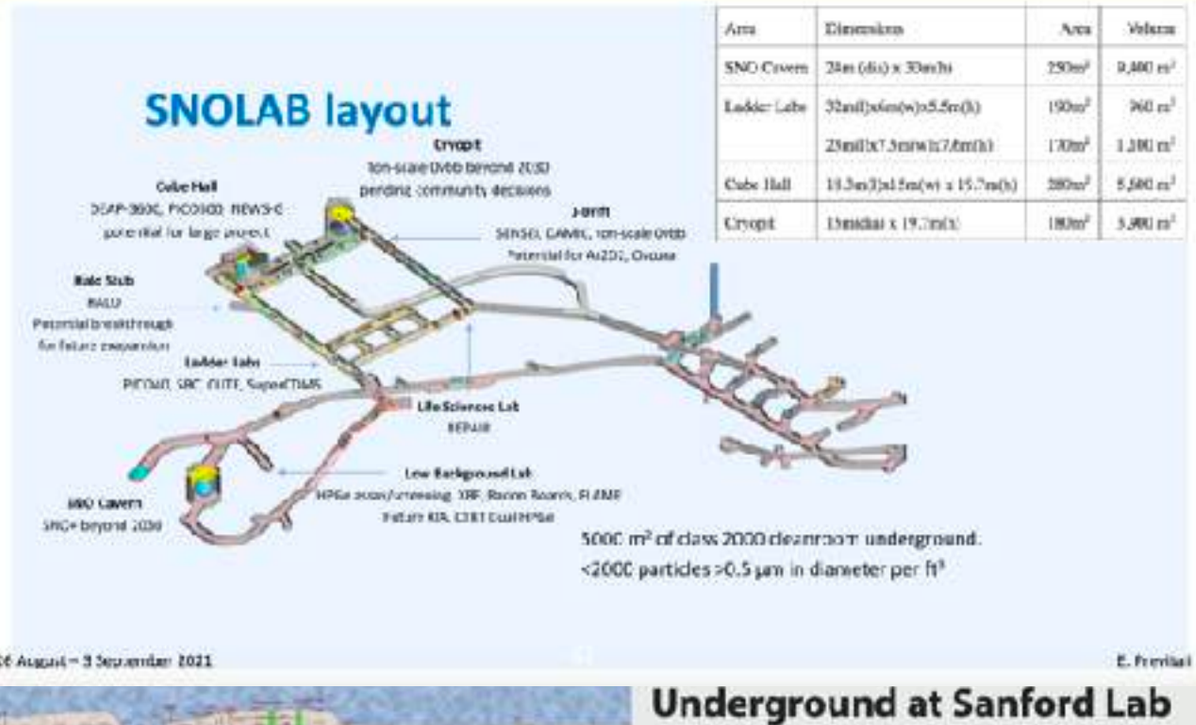
CURRENTLY ACTIVE BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

Gran Sasso DUL

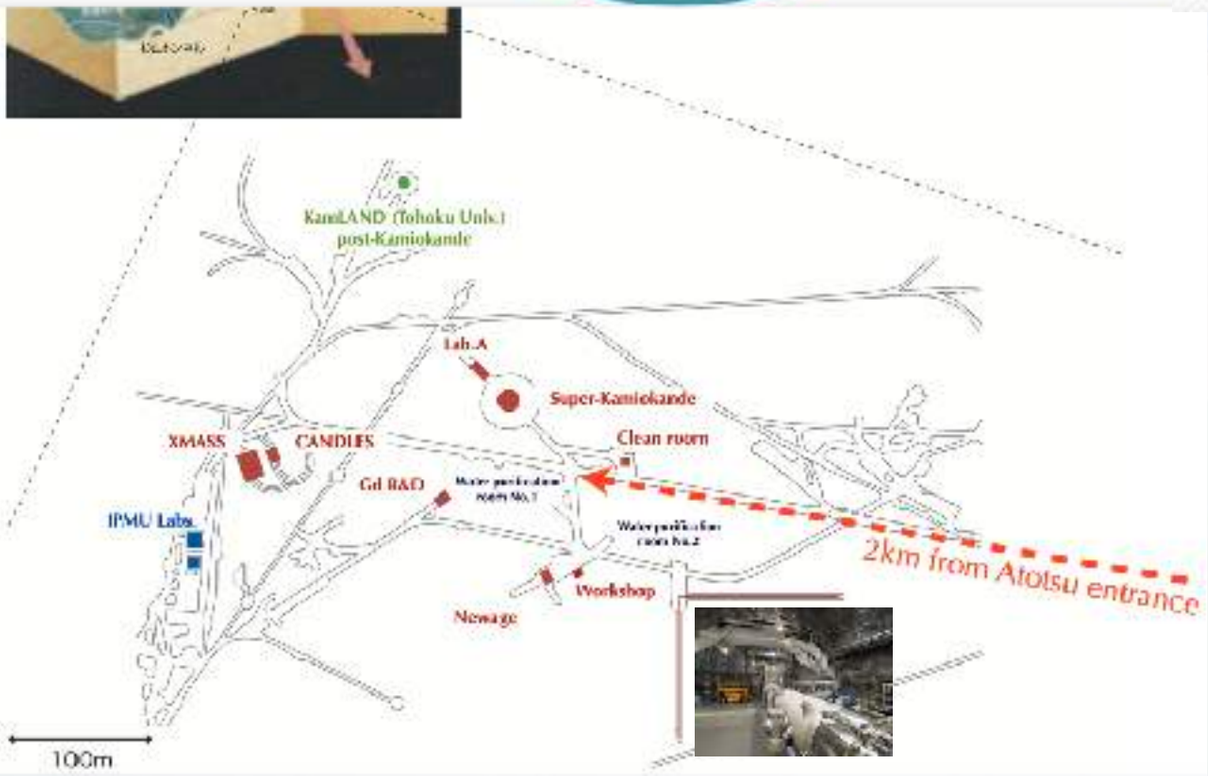
- Shielded by 3400 m (3800 m.w.e.) of rock (Gran Sasso Mountains)
- Total Muon flux 3 10⁻⁸ cm⁻² s⁻¹
- Easy access directly from the A24 highway
- 3 main experimental halls 100 m long, 20 m width and 18 m height
- Many small tunnels for lab facilities and small experiments
- Actually there are 22 experiments in data taking or under construction
- Very sensitive laboratory for very low radioactivity measurements

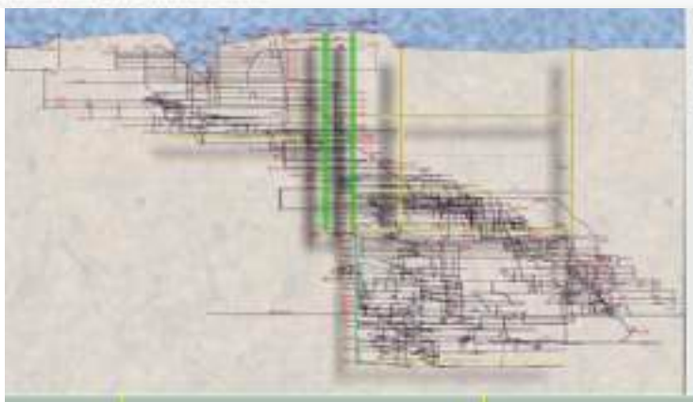


SNOLab DULs



Area	Dimensions	Area	Volume
SNO Cavern	28m (dia) x 30m(h)	650m²	9,400 m³
Ladder Labs	32m(l)x6m(w)x5.5m(h)	190m²	960 m³
	23m(l)x7.5m(w)x7.6m(h)	170m²	1,200 m³
Cube Hall	18.3m(l)x15.5m(w) x 15.7m(h)	280m²	5,600 m³
Cryopt	13m(dia) x 19.7m(h)	180m²	3,900 m³





Underground at Sanford Lab

The main level for science is the 4850 Level, which can be accessed by the Yates Shafts. But Homestake carved out over 370 miles of shafts, drifts, and ramps. SanfordLab maintains about 12 miles for science activities.

kton+ DETECTORS IN CURRENTLY ACTIVE IN BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

Also SK-Gd & KamLAND-Zen

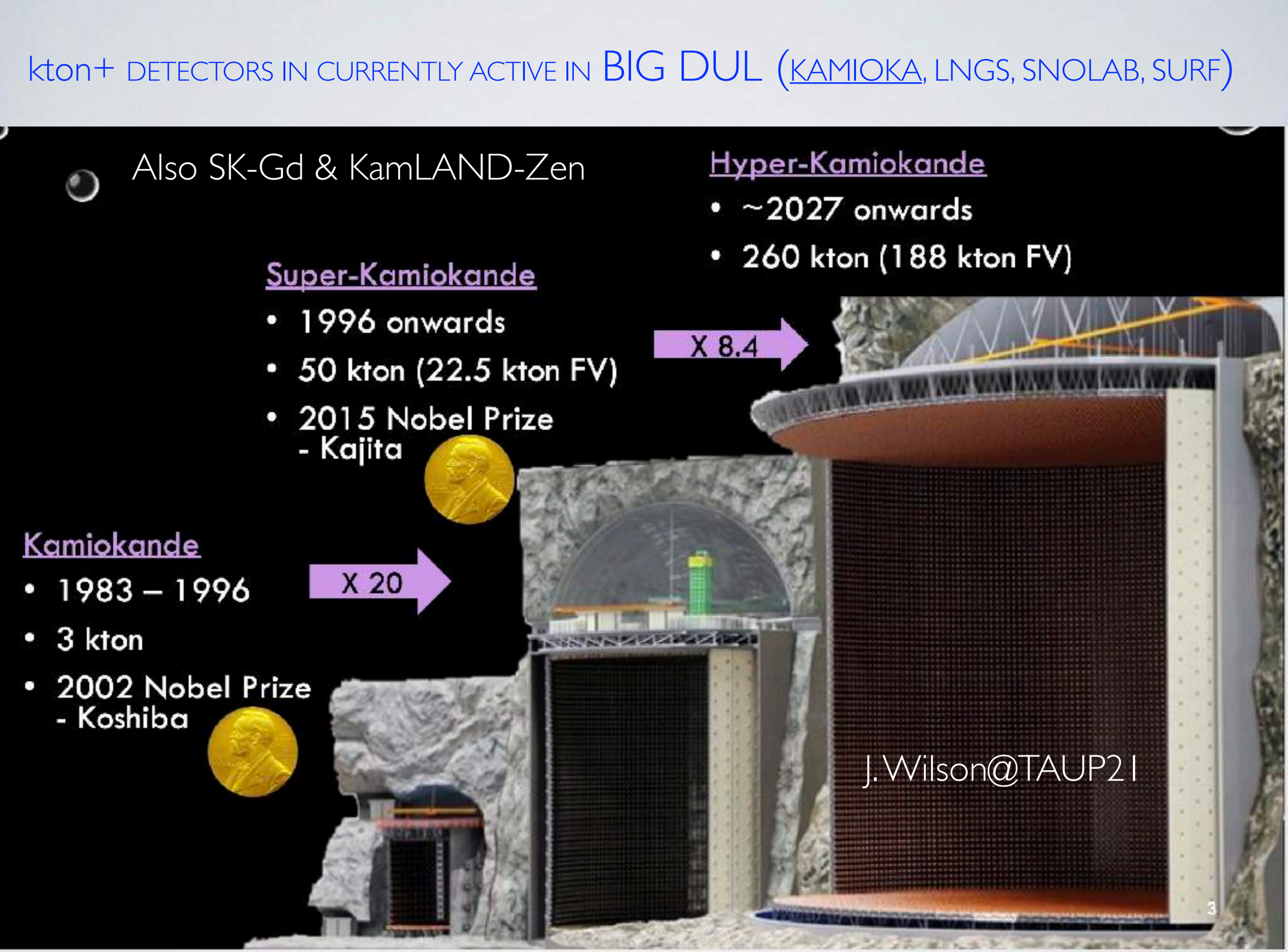
Hyper-Kamiokande
- ~2027 onwards
- 260 kton (188 kton FV)

Super-Kamiokande
- 1996 onwards
- 50 kton (22.5 kton FV)
- 2015 Nobel Prize - Kajita

X 8.4

Kamiokande
- 1983 – 1996
- 3 kton
- 2002 Nobel Prize - Koshiba

X 20

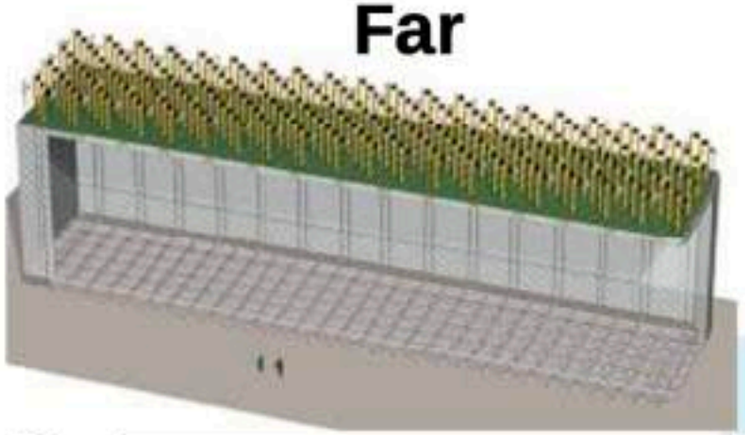


J. Wilson@TAUP21

kton+ DETECTORS IN CURRENTLY ACTIVE IN BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

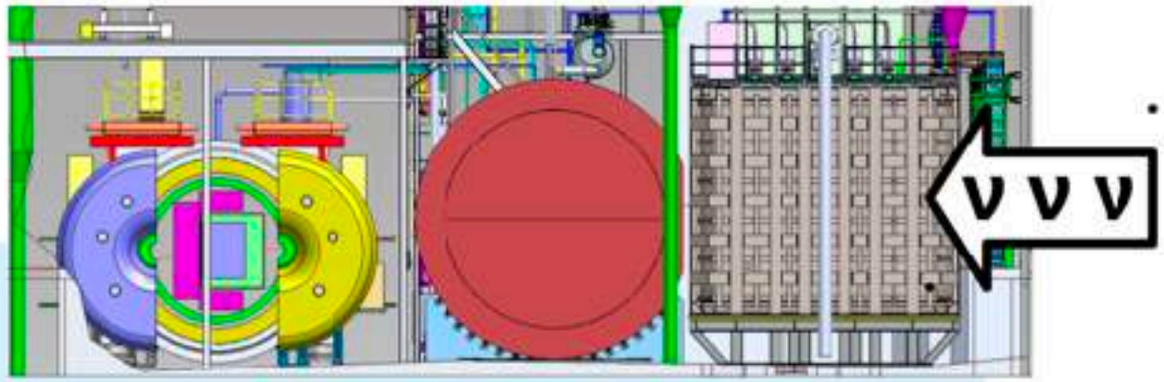
DUNE

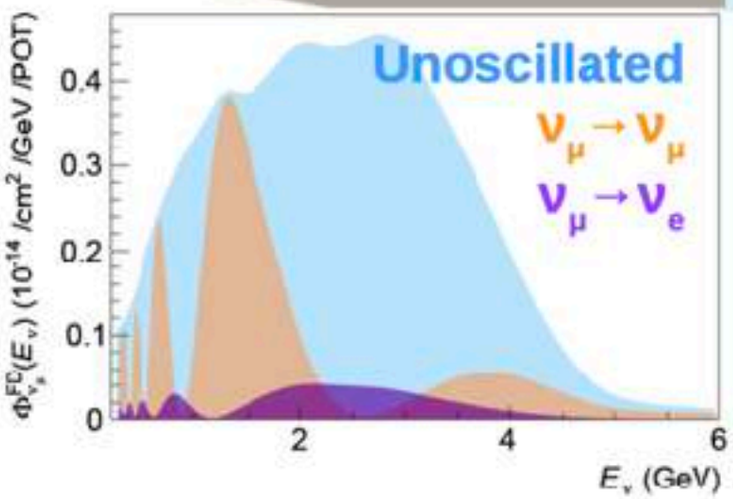
Far

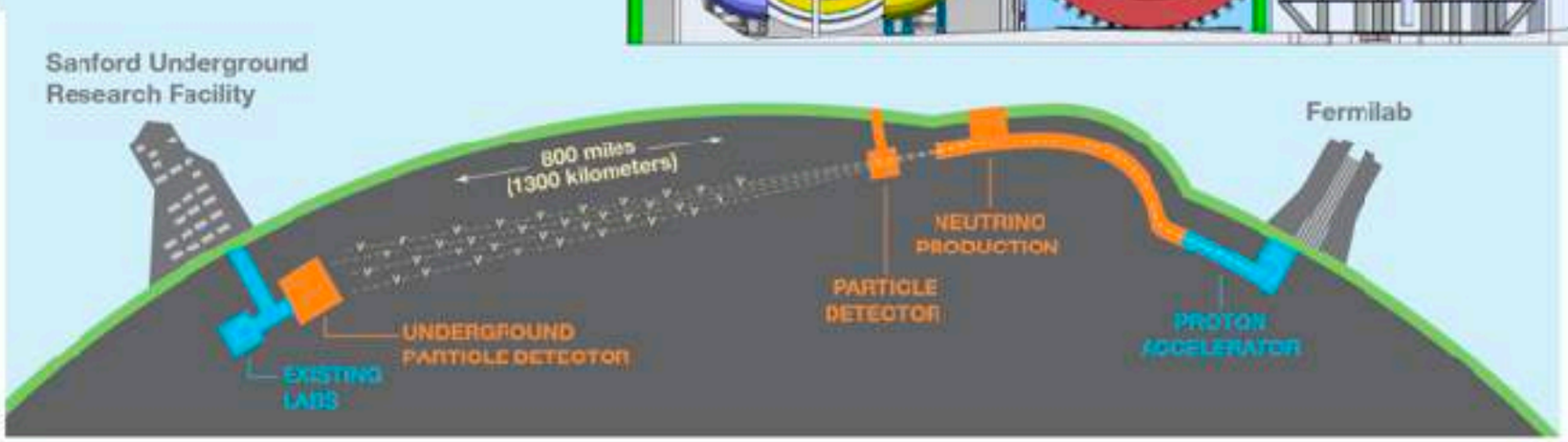


4 x 17 kt

Near







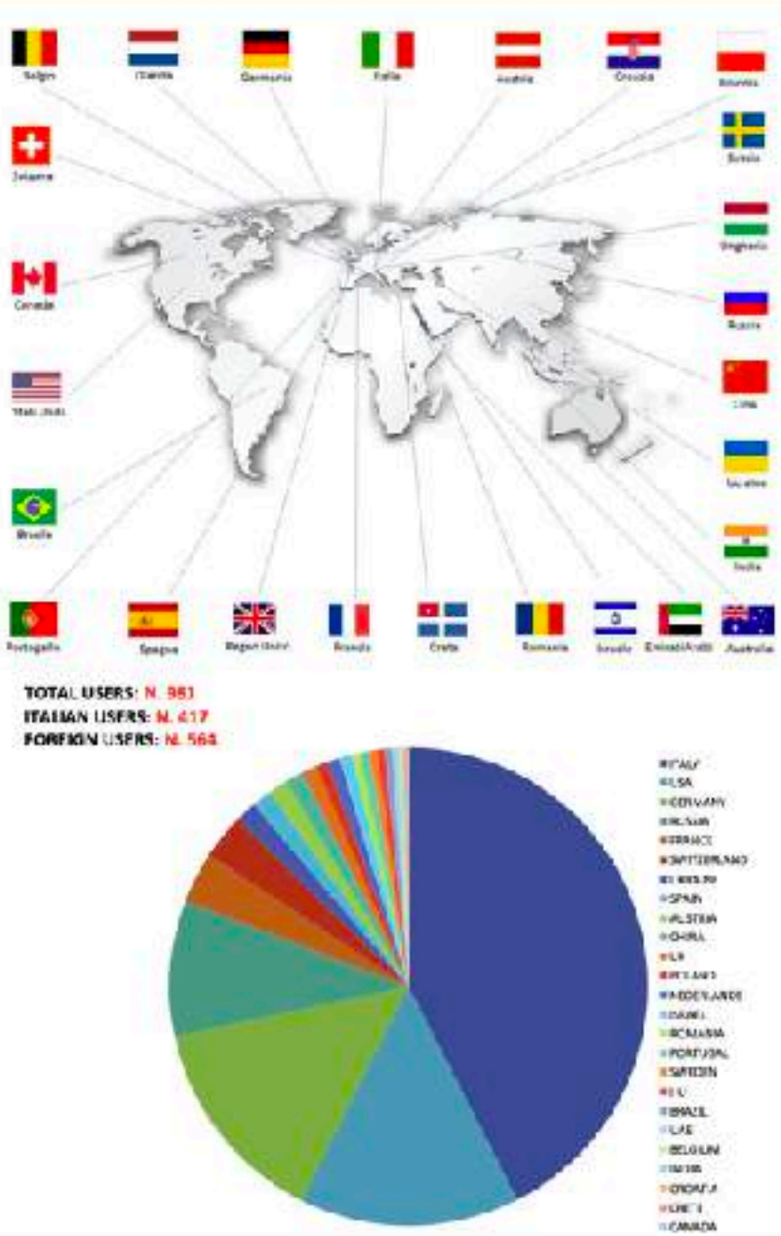
C. Wilkinson@TAUP21

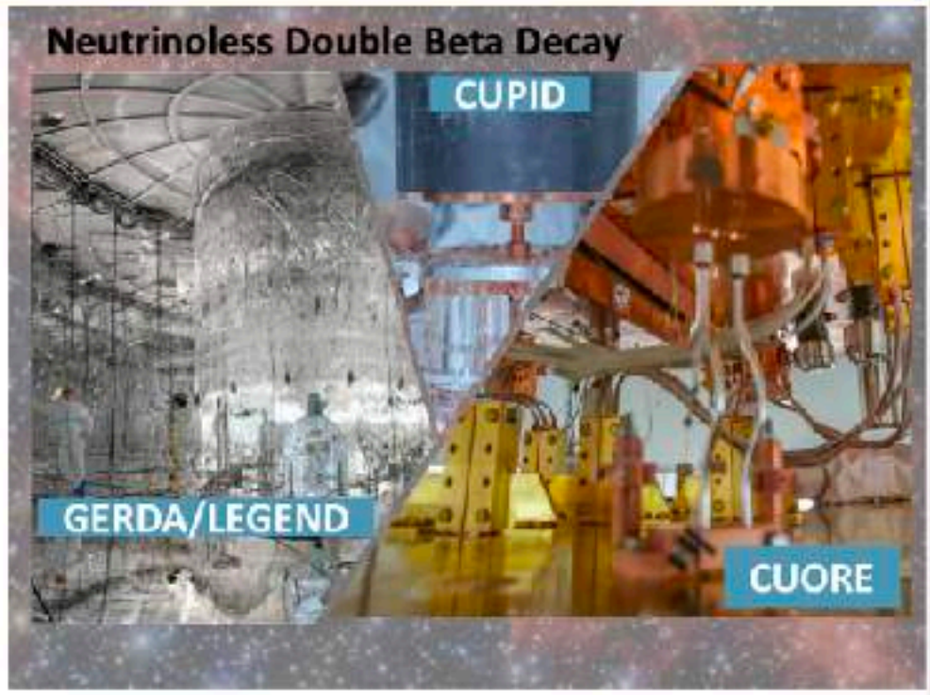
- Unprecedented intensity neutrino beam (1.2→2.4 MW)
- Near detector system at Fermilab
- 4 x 17 kt LAr far detector modules, 1285 km baseline
- **Rich physics program:** BSM studies; supernovae; solar neutrinos; three-flavor oscillation measurements

kton+ DETECTORS IN CURRENTLY ACTIVE IN BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

CURRENTLY ACTIVE BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

Gran Sasso Science





..... but also

- Test on quantum mechanics
  - Study on Planck invariance
  - Electron decay
- Radiobiology
  - Biological effects of low radioactive environment
- Geophysics
  - Earthquacke monitoring and study
  - Analysis of water resources
- Ultra Trace elemental analysis
  - Low radioactivity tests and measurements
  - Cultural Heritage analysis
  - Advanced additive manufacturing

E. Previtali INFN

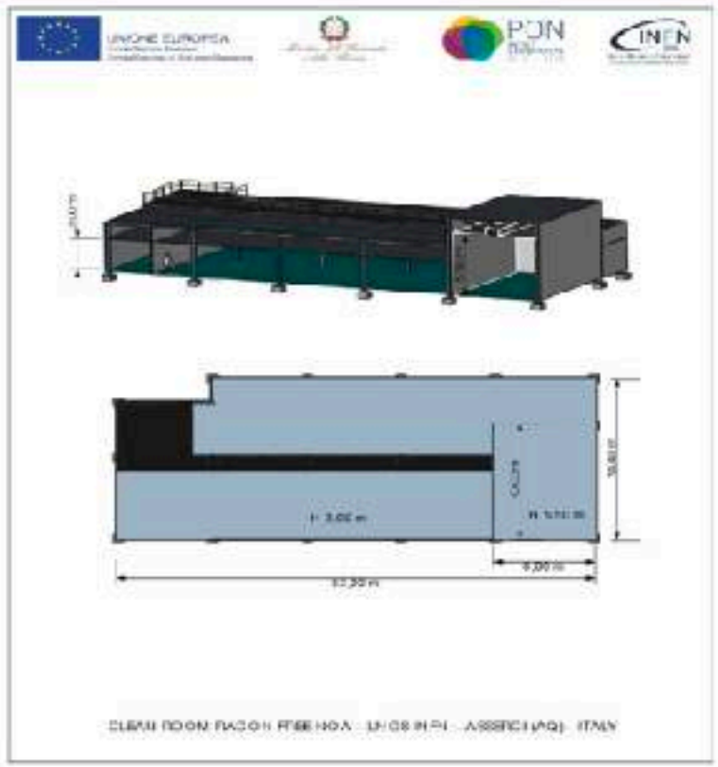
E. Previtali @TAUP21

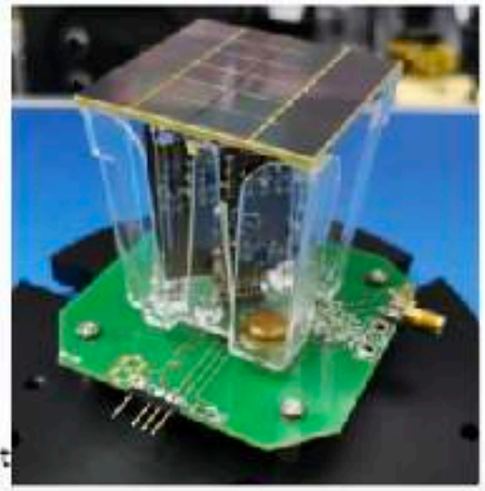
CURRENTLY ACTIVE BIG DUL (KAMIOKA, LNGS, SNOLAB, SURF)

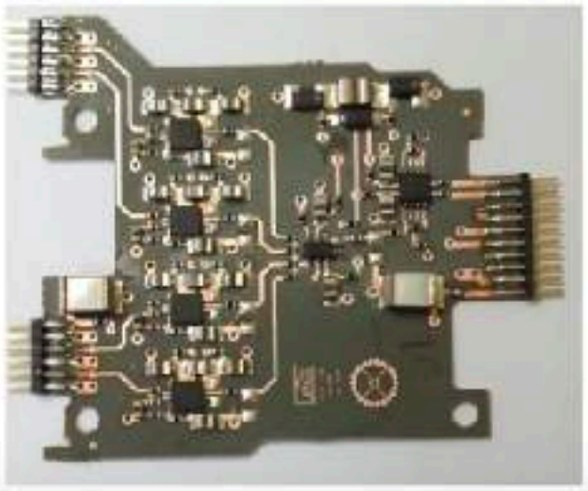
Nuova Officina Assergi (NOA) Clean Room

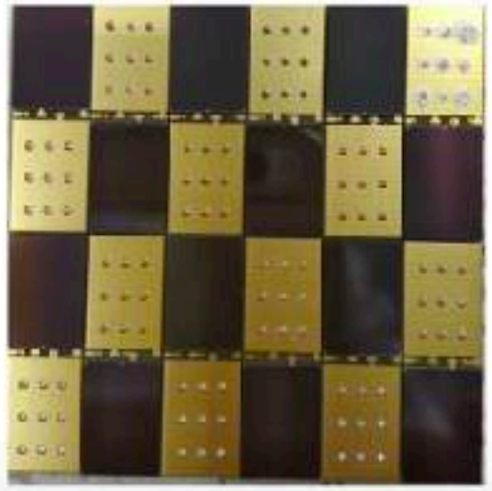
NOA will be an advanced packaging facility for

- 450 m² Clean Room suitable for Radon Free operation
- Bonding
  - Dicing
  - Thermo-compression/epoxy bonding
  - Wire bonding
- PCB
  - Advanced and radio-clean reflow system
- Testing capabilities
  - Performances characterization at cryogenic temperature
- Production
  - Main 1st production starting in 2022 for DarkSide-20k: ~ 20 m² SiPM







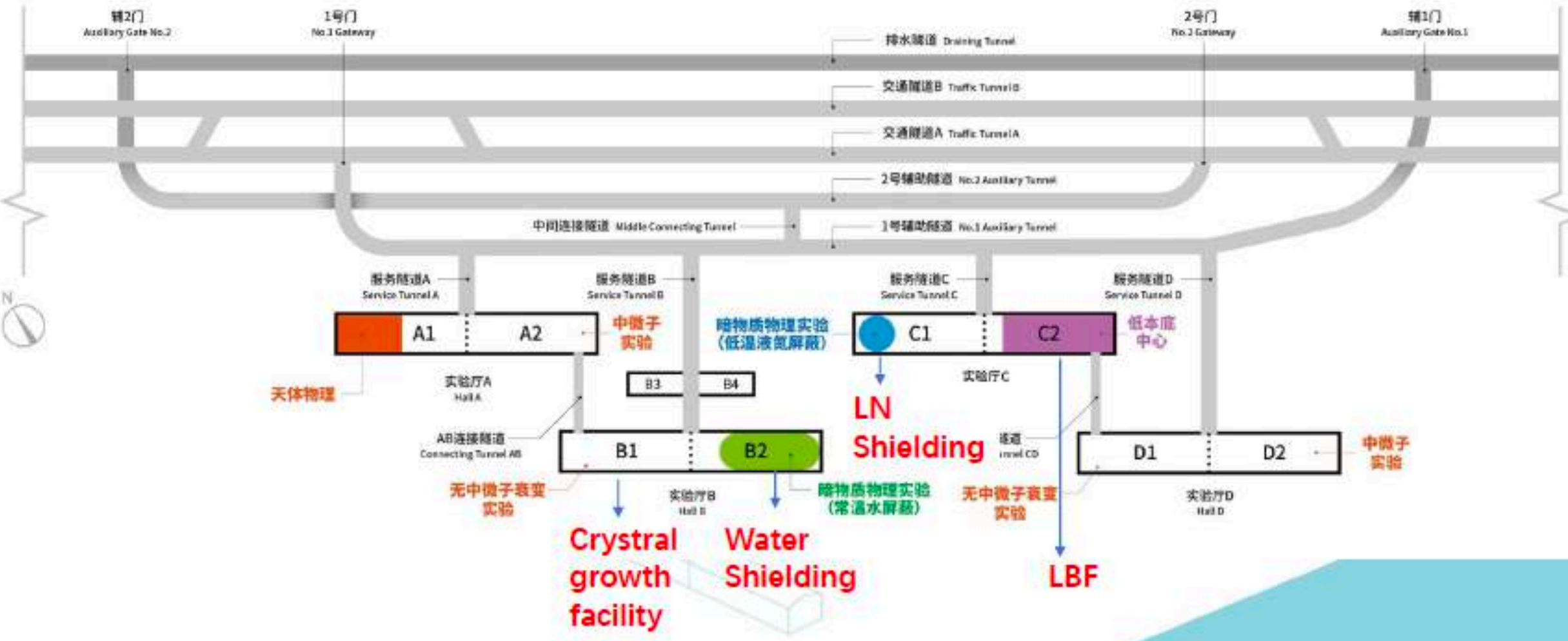


E. Previtali @TAUP21

LSC
Laboratorio Subterráneo de Canfranc

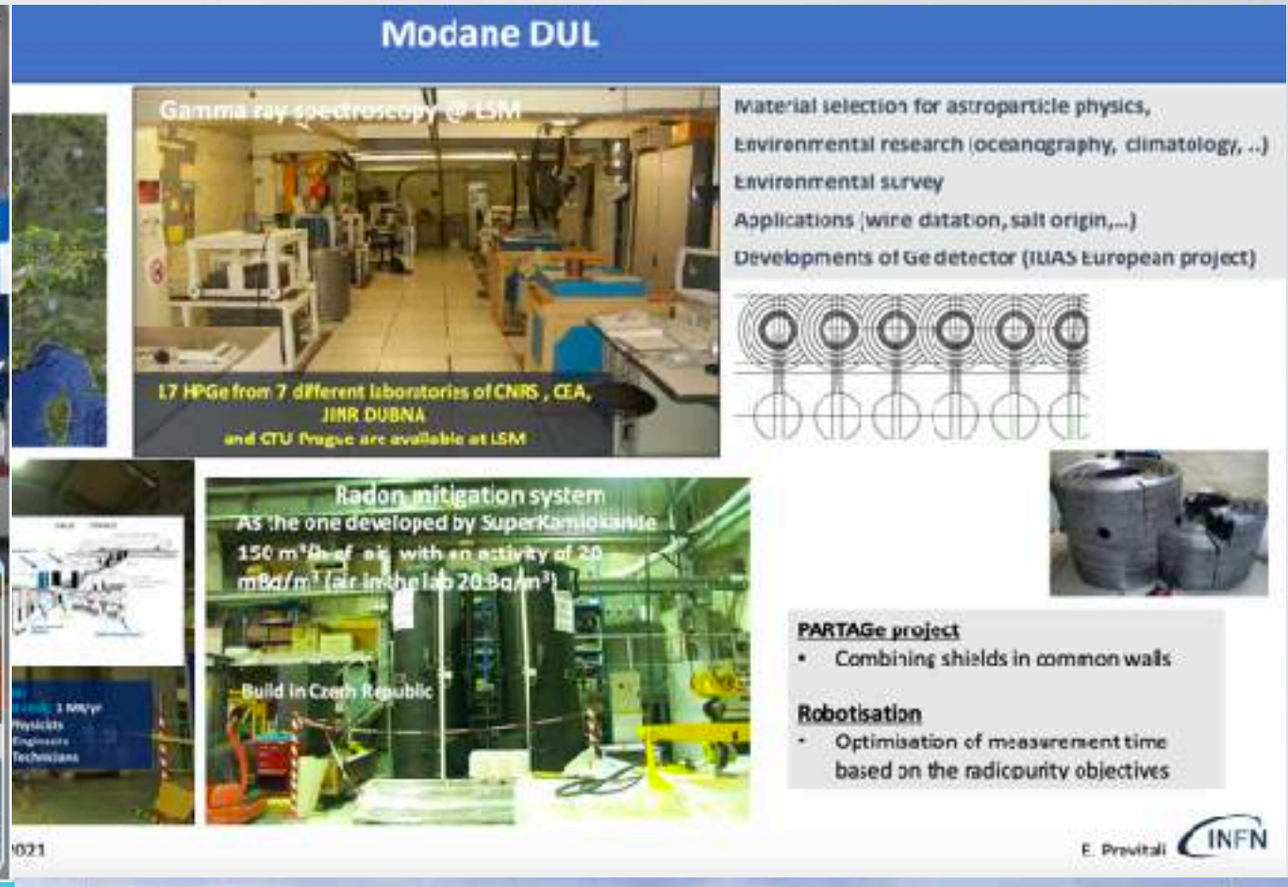
NEXT BIG DUL IN CHINA (2025-)

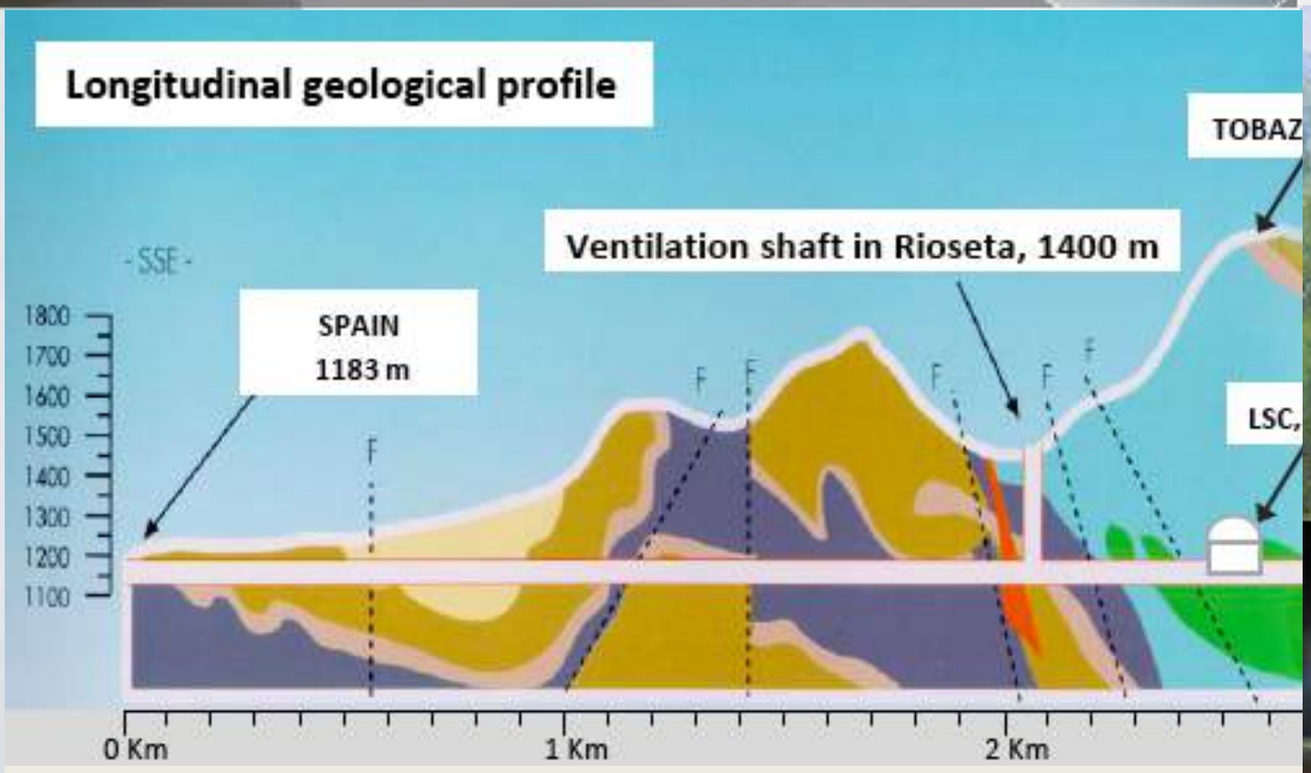
DURF in CJPL-II



L-SIZE DUL (Mainly LSC)

MEDIUM DUL (LSC,LSM, BOULBY,Y2L,…)

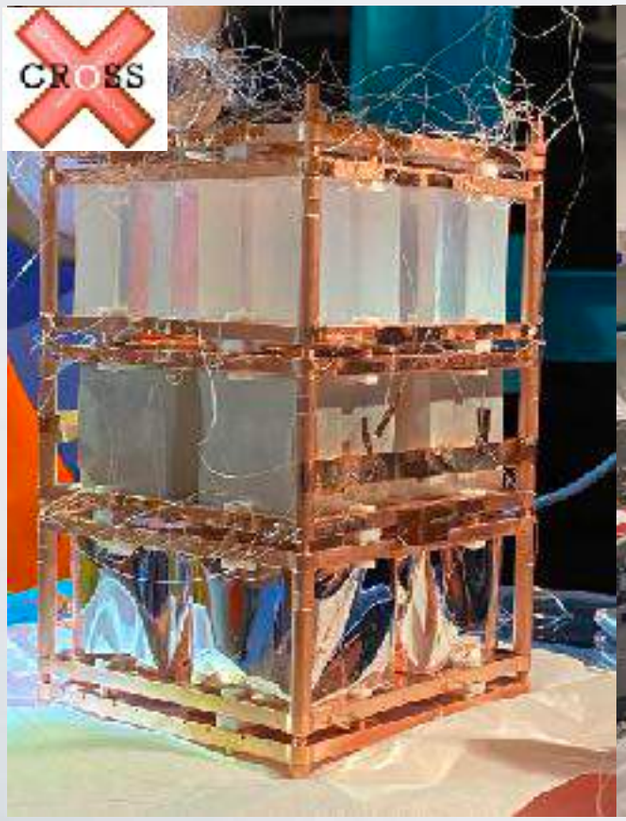


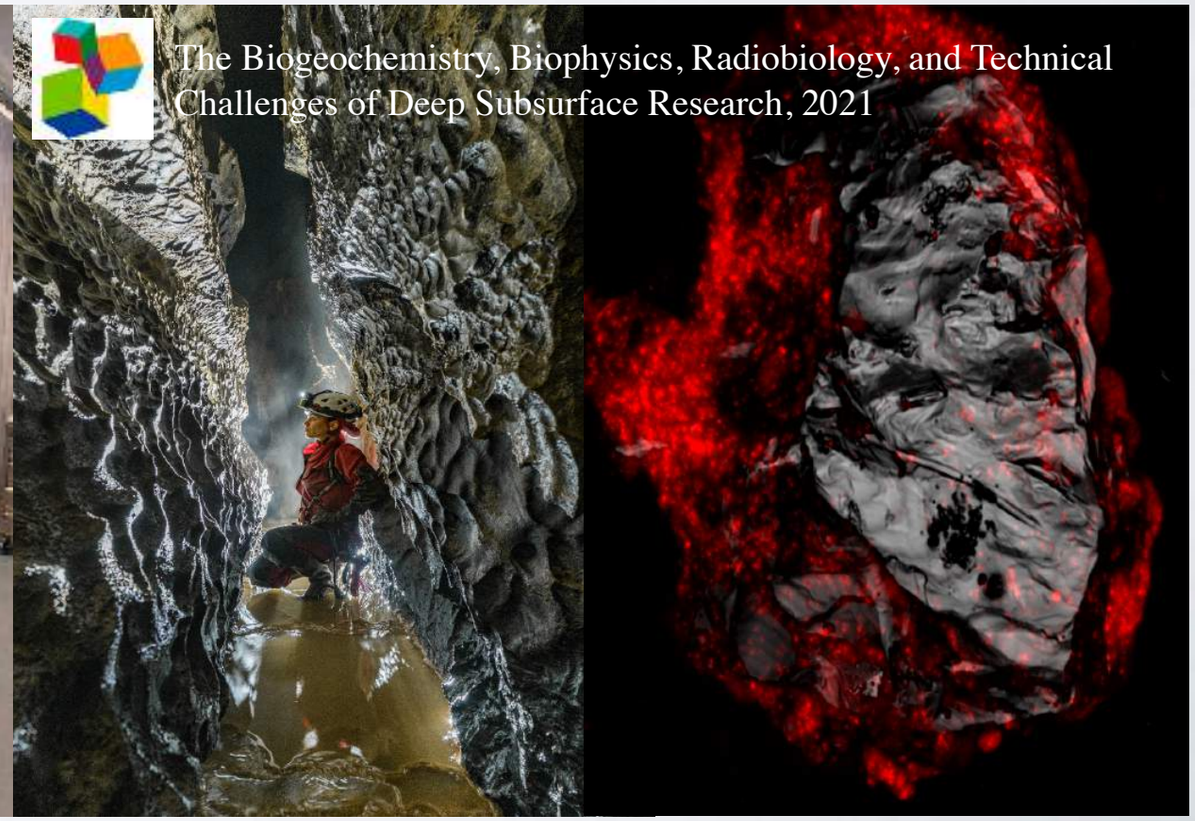


800 m bajo el Tobazo (~ 2500 m.w.e)

CANFRANC UNDERGROUND LAB SINCE LAST TAUP

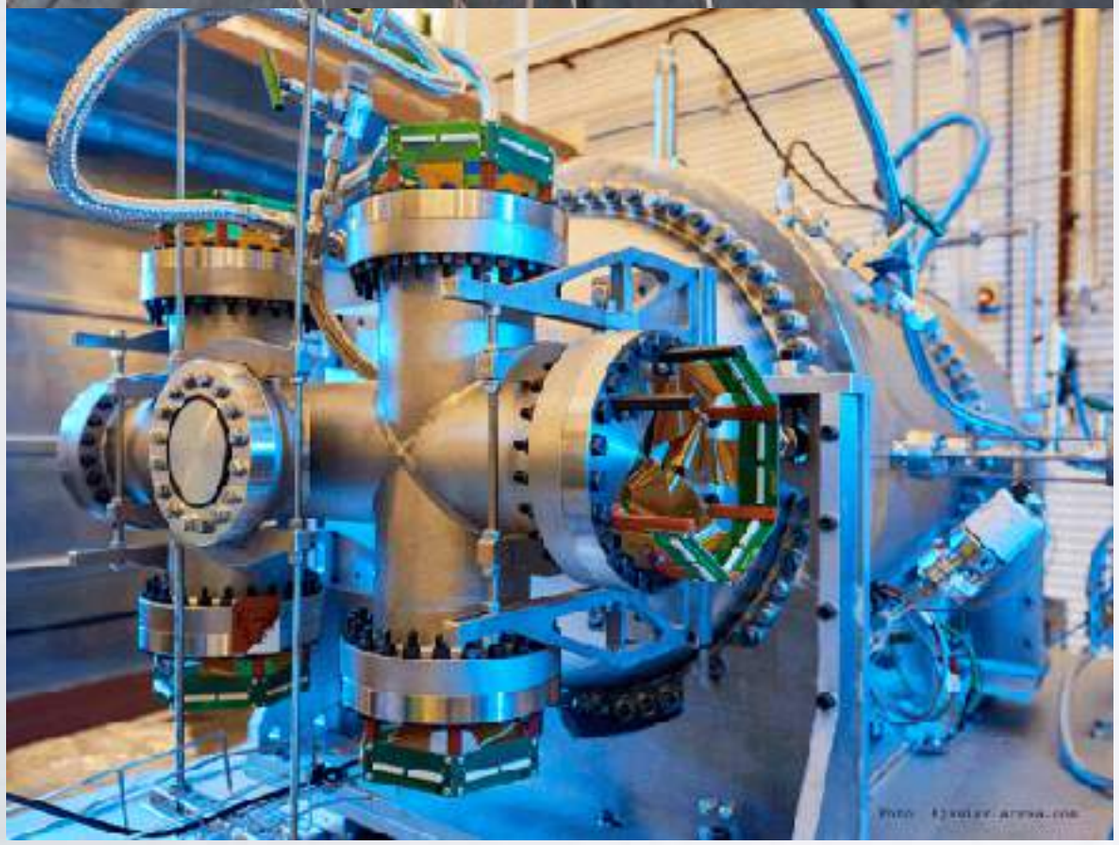
- **Long-term stability**: Budget plan approved by the LSC patronage for 2022-2031.
- **Growing Lab**: doubled people on site since 2019 (20 people now, more in 2022).
- **Two big projects** in the LSC approved Strategic Plan: Double beta ^{136}Xe 1ton detector, Spanish contribution to the HyperKamiokande construction.
- **New Strategic Lines** at LSC: Biology (labs on surface & underground), Cryogenics (qubits, axion searches,…), RITA Lab (radium by Single Molecule Fluorescence Imaging).
- **Collaboration** with Deep Underground Labs on LSC experiments relevant for large experiments (CROSS Panel Nu 3, DArT Panel DM 1,…) and on Low Radioactivity Techniques: new Electroformed Copper installation (in operation at the clean room underground), ultrapure NaI crystal growth installation underground, CLYC neutron detectors, …

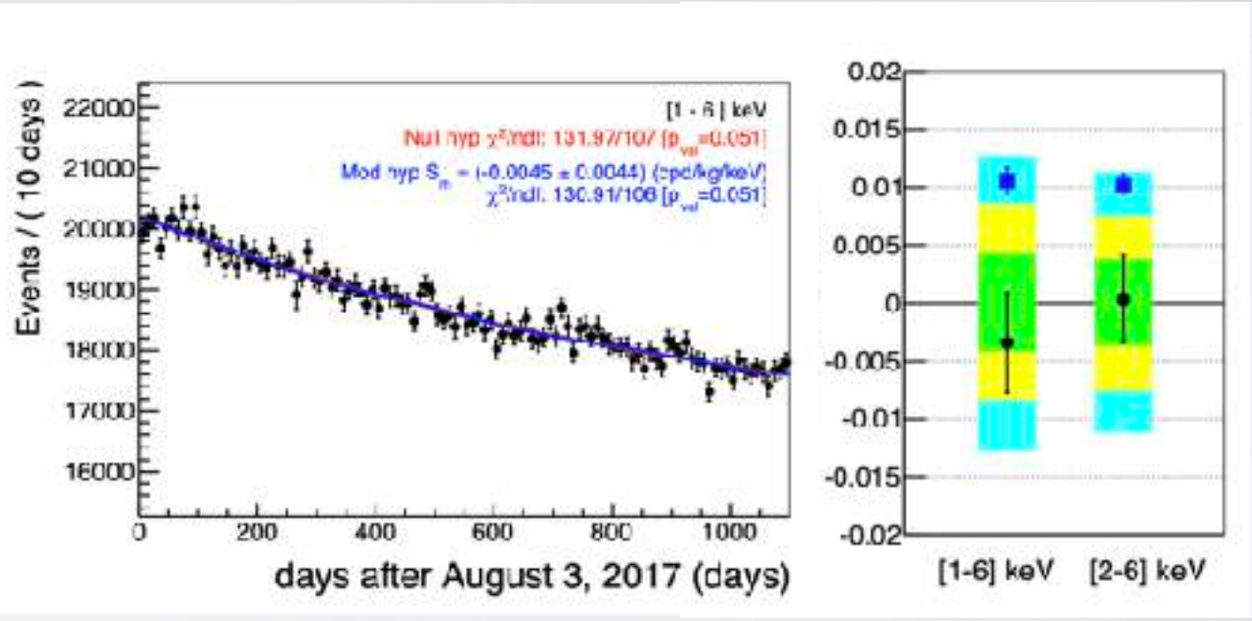




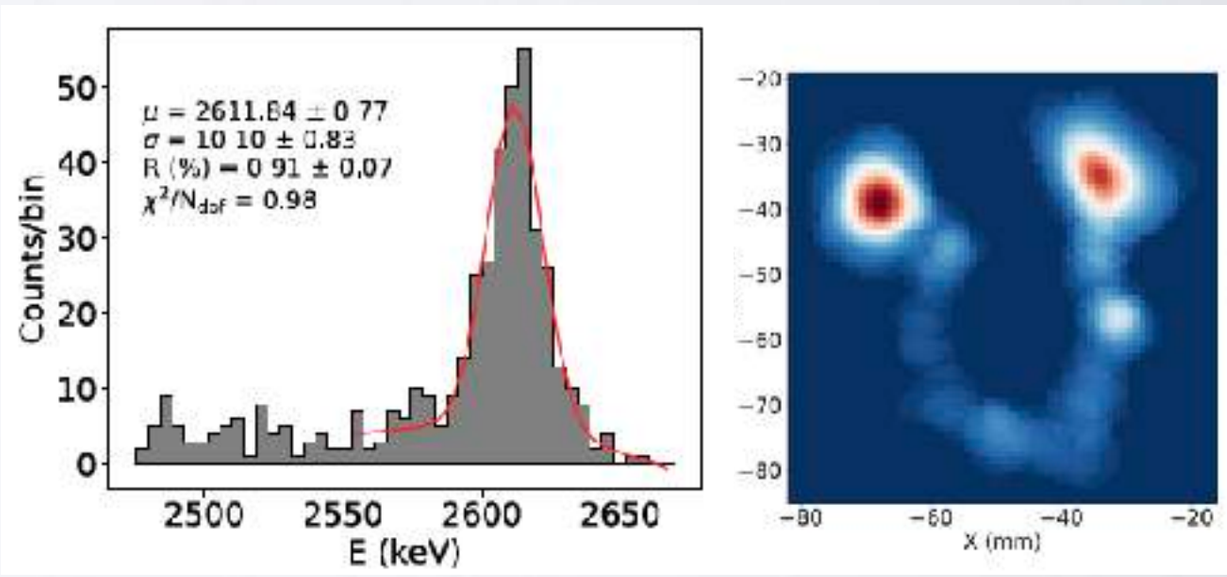
LSC EXPERIMENTS: PHYSICS HIGHLIGHTS 2021

Laboratorio Subterráneo de Canfranc





ANAIS: 4 years of data taking (published 3-yrs). No modulation observed so far! See Marisa's talk

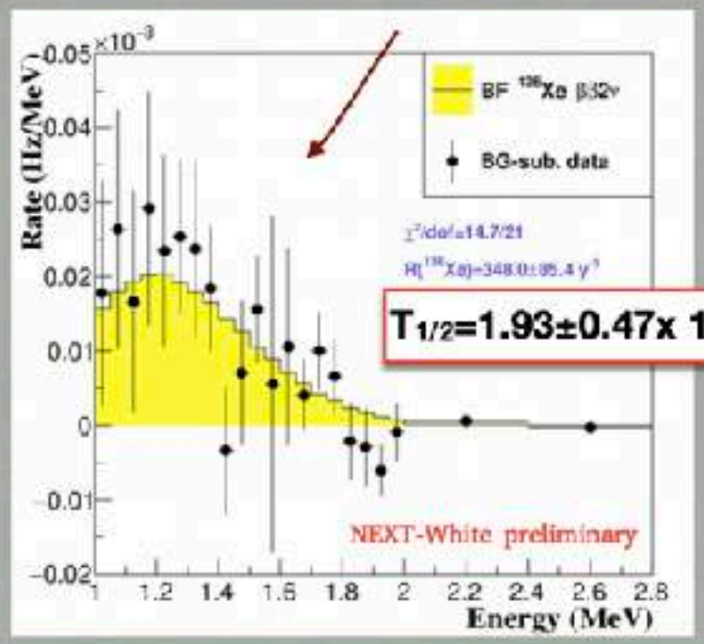


NEXT- ßß-decay of ^{136}Xe with best resolution in energy and e-track reconstruction. Assembling of NEXT-100 and starting of NEXT-1ton!

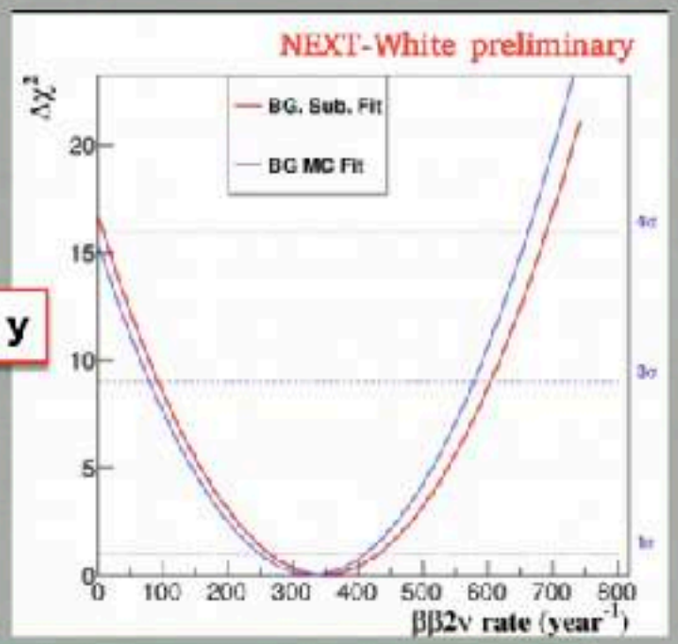
NEXT-WHITE COMPLETED

ββ2ν analysis: Background-subtraction fit

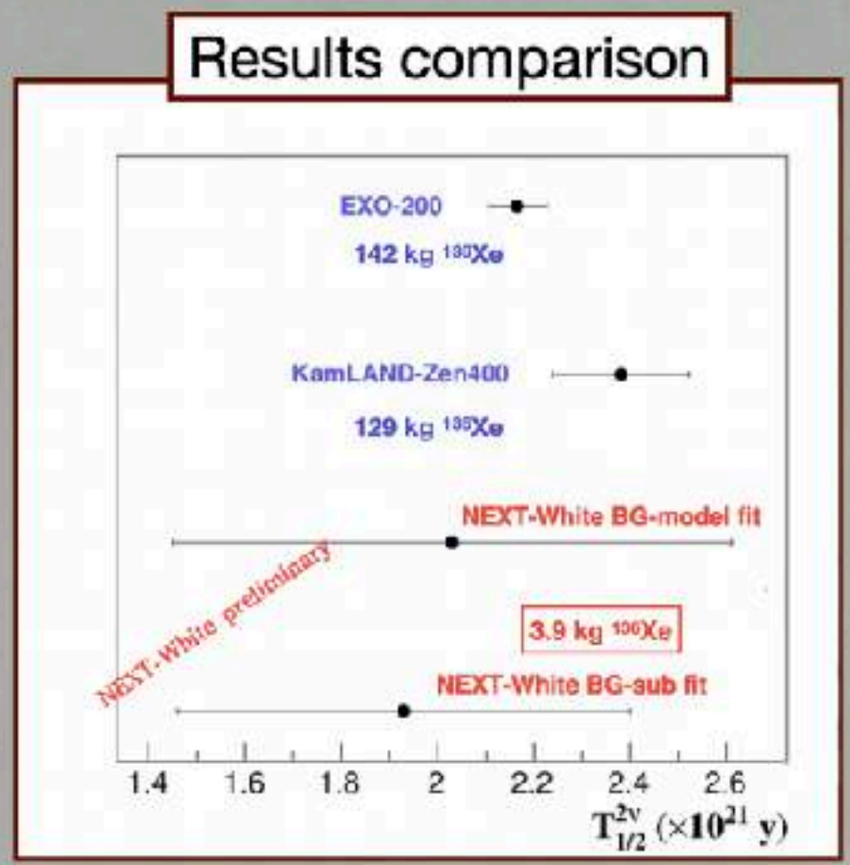
- Do not lean on Bkg-Model → **Independent approach**
- $T^{2\nu}_{1/2}$ subtracting ^{136}**Xe-enr. - ^{136}Xe-dep.** data samples
- Subtracted distribution fitted to ββ2ν expectation



$T_{1/2}$=1.93±0.47x 10^{21} y



- 4.1σ measurement (3.8σ expected)
- χ^2/ndf = 14.6/21 (much **better** goodness-of-fit)
- **1st $T^{2\nu}_{1/2}$ measurement** using direct bkg. subtraction



- Good agreement between independent fit strategies
- Consistency with other experiments
- Much less amount of ββ source

A. Uson @TAUP21

Laboratorio Subterráneo de Canfranc

DUL for Multi-ton and Ton Experiments

COMPETITION/COLLABORATION TO HOST MULTI-TON DARK MATTER EXP.

A. Kopec, J. Pienaar @ TAUP 2021

XENONnT @ LNGS

- 5.9 t LXe target
- Rn activity (goal): 1 μBq/kg
- in data taking phase

B. Penning @ EPS-HEP 2021

LZ @ SURF

- 7.0 t LXe target
- Rn activity (goal): 2 μBq/kg
- in commissioning phase
- expect first data later this year

M. Schumann @TAUP21

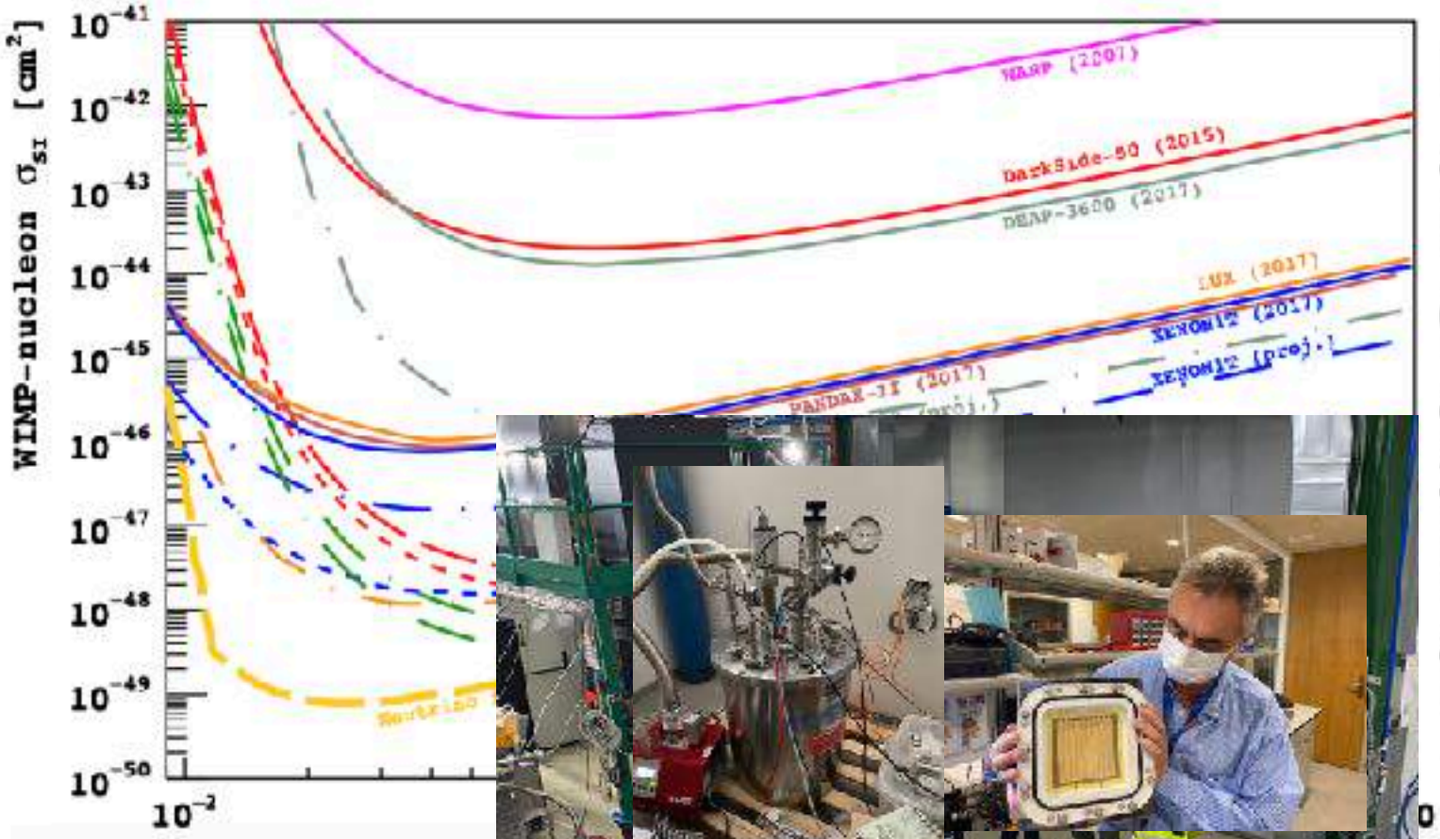
Laboratorio Subterráneo de Canfranc

COMPETITION/COLLABORATION TO HOST MULTI-TON DARK MATTER EXP.

The Global Argon Dark Matter Collaboration

ArDM
DarkSide
DEAP
MiniCLEAN

A Single Global Program for Direct Dark Matter Searches
Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
Next step: DarkSide-20k at LNGS (2021-)
Last Step: **300 tonnes detector**, location t.b.d **(2027-)**



DarkSide-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017
Officially supported by LNGS, LSC, and SNOLab
30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon
14 m^2 of SiPM coverage

COMPETITION TO HOST TON BB DECAY EXP.

Next generation and beyond

I will focus now **on 7 research lines / experiments**:

- 4 fluid embedded
- 3 crystal embedded

In my view, **these experiments are in the best position for actual construction and data taking** on a-few-year time scale, for several reasons:

- Technology maturity
- Solid collaboration
- Funding prospects

Fluid embedded source — Large source mass, Easily scalable

① KamLAND-Zen 400 → KamLAND-Zen 800 → KamLAND2-Zen

② EXO-200 → nEXO

③ NEXT-White → **NEXT-100** → NEXT-HD / NEXT-BOLD

④ SNO+ → **SNO+-phase II**

Crystal embedded source — High energy resolution / efficiency

⑤ GERDA, MAJORANA dem. → LEGEND-200 → **LEGEND-1000**

⑥ CUPID-Mo, CUPID-0, CUORE → **CUPID** → CUPID Reach / CUPID 1t

⑦ AMORE-I → **AMORE-II**

Completed
Data taking
Construction / Commissioning
Advanced R&D
R&D

18

A. Guiliani @TAUP21

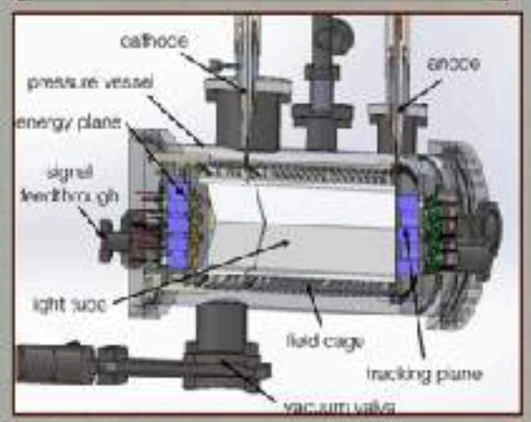
NEXT-100 AND NEXT-1ton

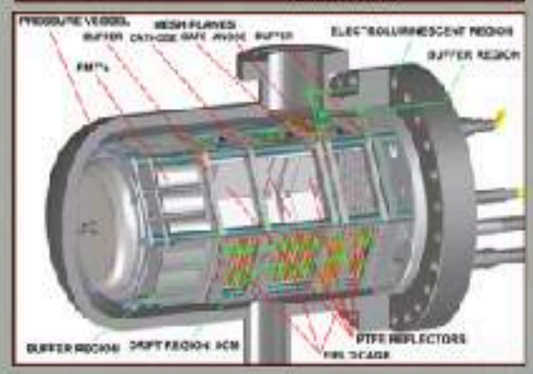
The NEXT Program

2009 — 2014 2015 — 2021 2022 — 2025 — 2028

Prototypes | **~1kg**

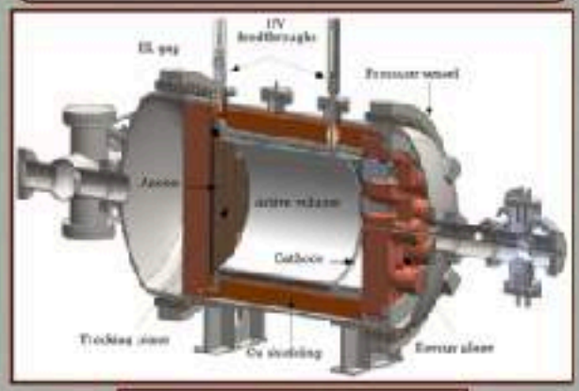
- Proof of concept





NEXT-White | **~5kg**

- Background model assessment
- Two neutrino double beta decay searches

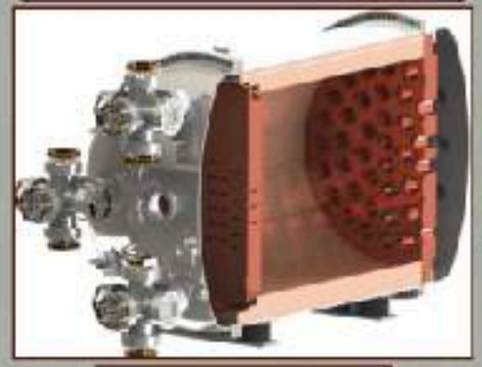


LSC Laboratorio Subterráneo de Canfranc

This talk

NEXT-100 | **~100kg**

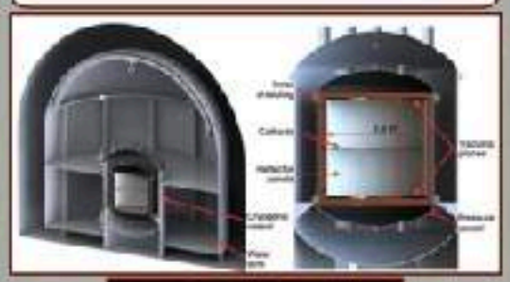
- Neutrinoless double beta decay searches

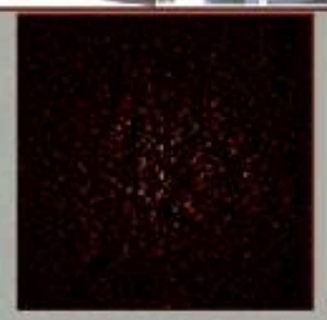


LSC Laboratorio Subterráneo de Canfranc

Ton-scale + Ba tagging | **~1t**

- ββ0ν in the inverted ordering ν-mass scale





Laboratorio Subterráneo de Canfranc

Low Radioactivity Techniques

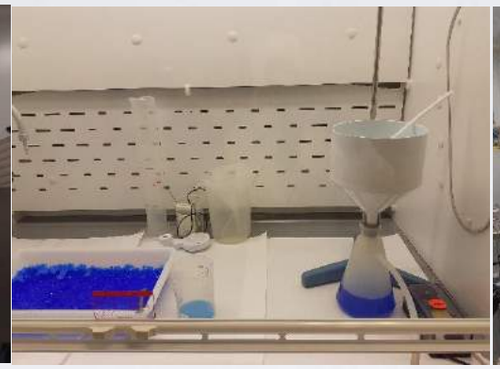
SERVICES: MULTI-SITE GERMANIUM DETECTORS

…and more. Highly demanded, used as an international service.

SERVICES: ELECTROFORMING COPPER

EF-Cu PIECE – DAMIC Collaboration

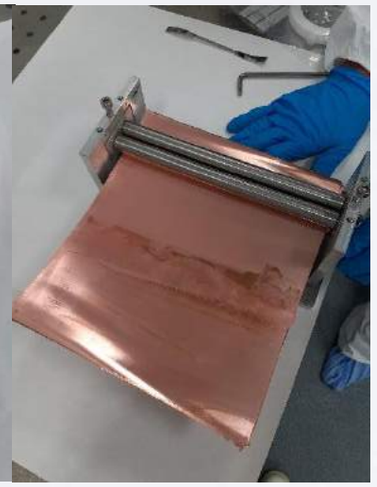
Setup installed in the LSC Clean Room (Class 10.000, underground). Preparation done in the Clean Room: copper sulphate recristallization (purification), electrolyte, OFHC copper bars (anodes) cleaning…


2022: ICPMS in clean room underground

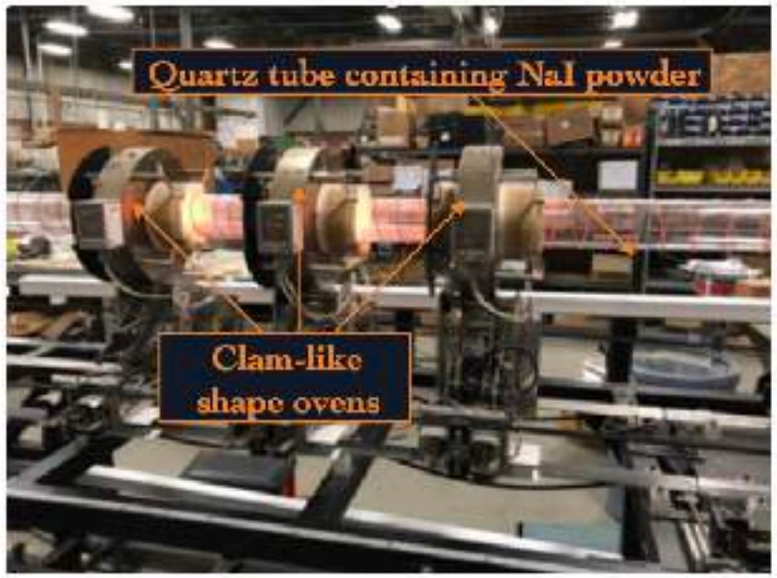
1st STEP: Electroforming, EF-Cu hole cylinder preparation (0.3-0.5 mm tickness, 82mm diameter, 205mm height)	**2nd STEP**: cut, open and flatten the EF-Cu cylinder	**3rd STEP**: plastic support setup	**4th STEP**: Electroforming, EF-Cu plane (in progress)



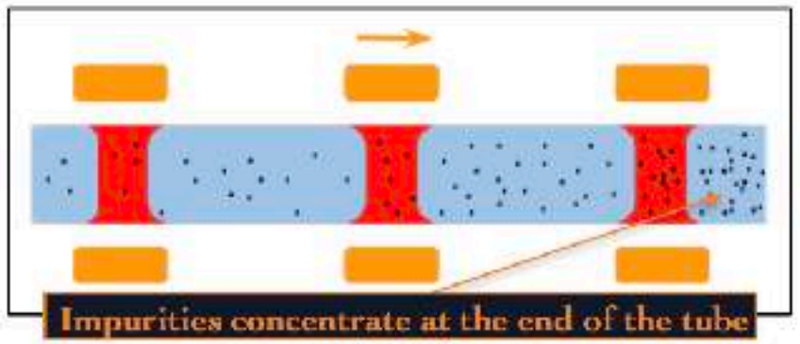



Fall 2021 (LSC-LNGS):
From EFCu to additive manufacturing

SERVICES: NaI CRYSTALS FACILITY UNDERGROUND



Zone refining system developed in collaboration with the Mellen Company.



B. Suerfu, *PhD thesis*, Princeton University, 2018.

Further improvements on crystals radio-purity are under investigation: Zone Refining (ZR) purification tests on NaI powder

- ZR is a purification process in which impurities in the powder are moved, together with the molten material, in the same direction as the ovens move.
- Test operation made in 2019: samples taken from five successive sectors along the tube to perform ICP-MS measurements and estimate the purification factors.

Ovens motion direction →

Isotope	Powder [ppm]	S_1 [ppm]	S_2 [ppm]	S_3 [ppm]	S_4 [ppm]	S_5 [ppm]
^{39}K	0.0085	< 0.0008	< 0.0008	0.001	0.016	0.46
^{208}Pb	0.0012	0.0004	0.0004	0.0004	0.0005	0.0005
^{85}Rb	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0007

ZR reduces ^{40}K and ^{87}Rb (from ^{39}K and ^{85}Rb measurements) to negligible levels, and ^{208}Pb by at least a factor of three

B. Suerfu et al., *Phys. Rev. Applied* 16, 014060, 2021.

Assuming NaI-33 contamination after scaling for the reduction factors observed in ZR tests and using a clean PTFE reflector:

SABRE crystals could reach a background level in the ROI ≤ 0.3 cpd/kg/keV

↓

Mostly due to ^{210}Pb contamination in the crystal

A. Mariani@TAUP21

SERVICE: Radlum TAgging (RITA) BASED ON SMFI

(installation in 2022)

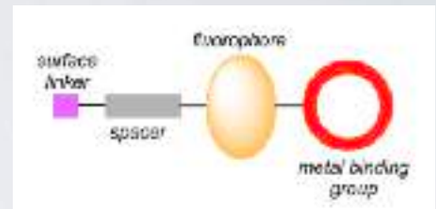
New detection method of Ra with $<10^3$ atoms sensitivity

Goal: Screening of UltraLow background materials for DM&bb

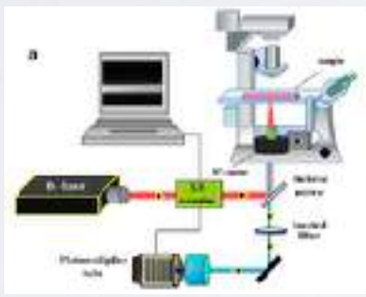
Makes use of single molecule fluorescence imaging techniques

Molecule with unchelated/chelated fluorescence bicolor

Scheme (budget approved at LSC):

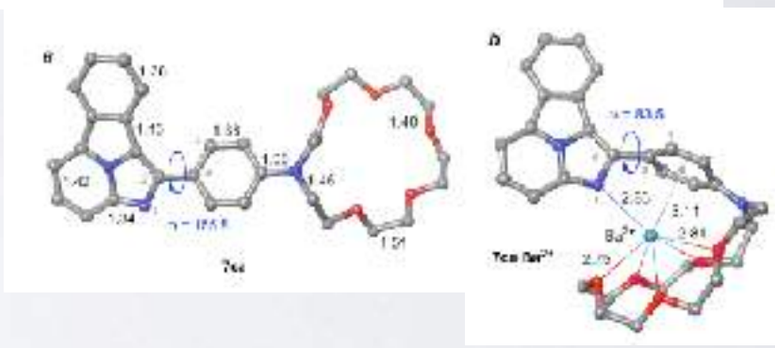


Ra^{++} beam preparation from sample droplets **Mass Spectrometry** → Deceleration **ion trapping** → Capture by molecules on gold plate and SMFI induce by strong laser **Ion capture and counting**



Towards a background-free neutrinoless double beta decay experiment based on a fluorescent bicolor sensor

Iván Rivilla,[a] Borja Aparicio,[b] Juan M. Bueno,[c] David Casanova,[c,d] Claire Tonnelé,[a] Zoraida Freixa,[d,e] Pablo Herrero,[a] José I. Miranda,[f] Rosa M. Martínez-Ojeda,[c] Francesc Monrabal,[a,d] Beñat Olave,[g] Thomas Schäfer,[a,d] Pablo Artal,[c] David Nygren,[b] Fernando P. Cossío,[a,d,1] Juan J. Gómez-Cadenas[a,d,1]

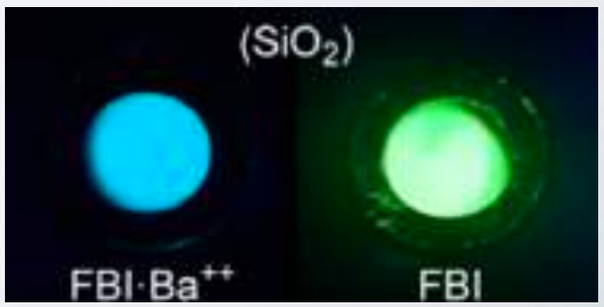


Built Molecular bisensor with optimal separation Nature 583, 48-54 (2020)

Screening: Measure ^{226}Ra with best sensitivity

Industry: New detector for multichannel MS

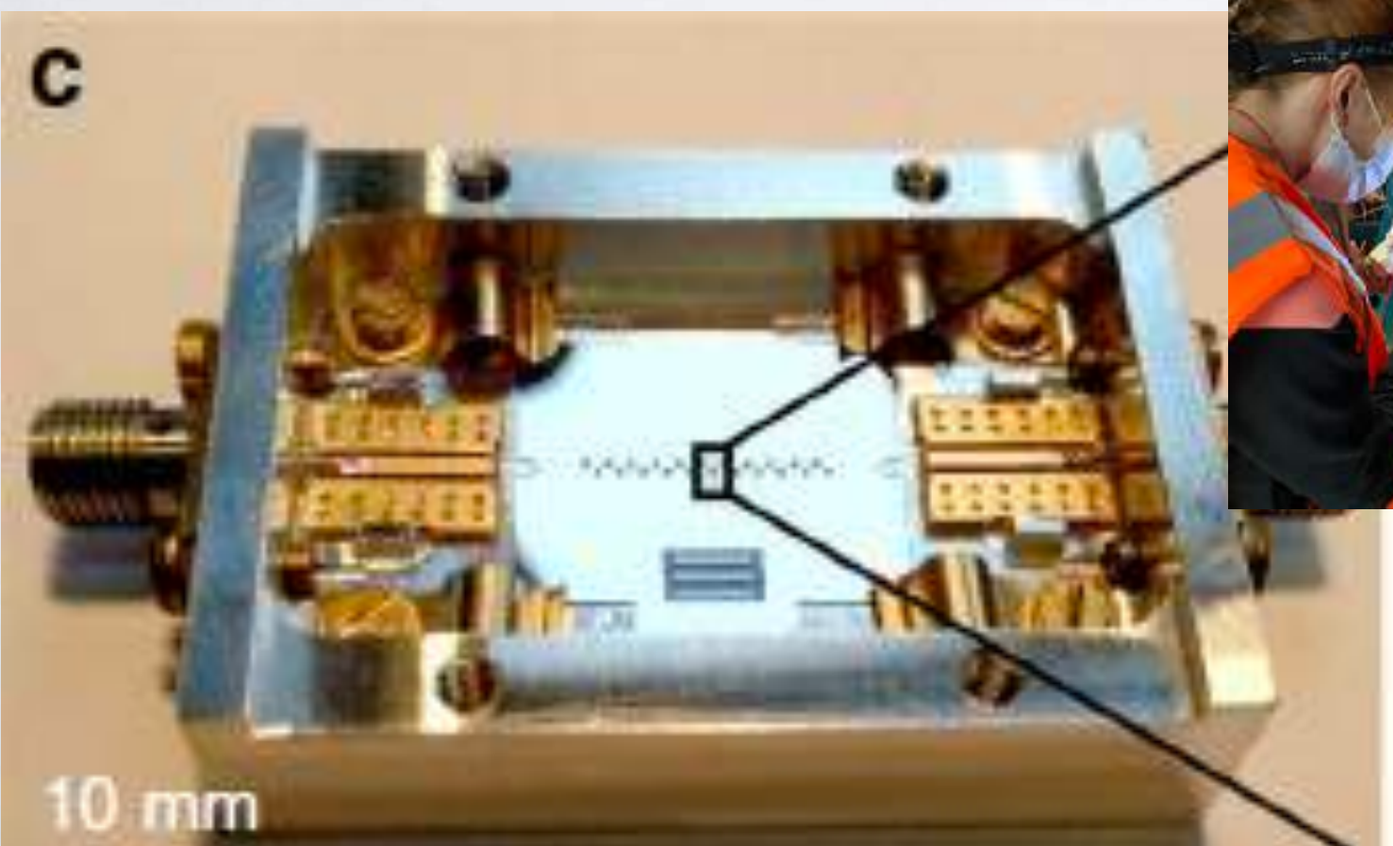
Science: Prototype for single atom Ba++ detection



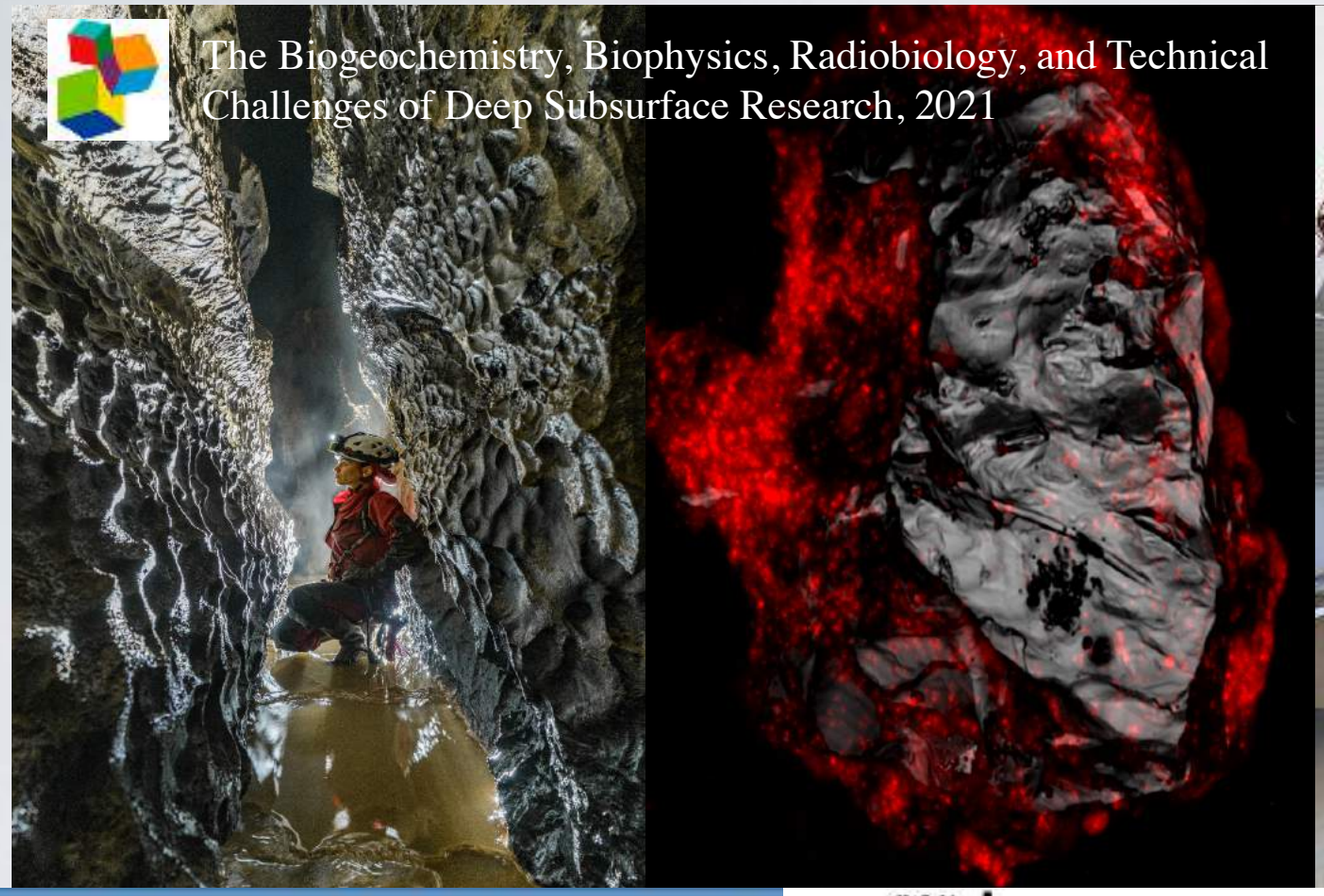
NEW STRATEGIC AREA: CRYOGENICS

CROSS (2018-) and LSC (2022-) dilution refrigerators:

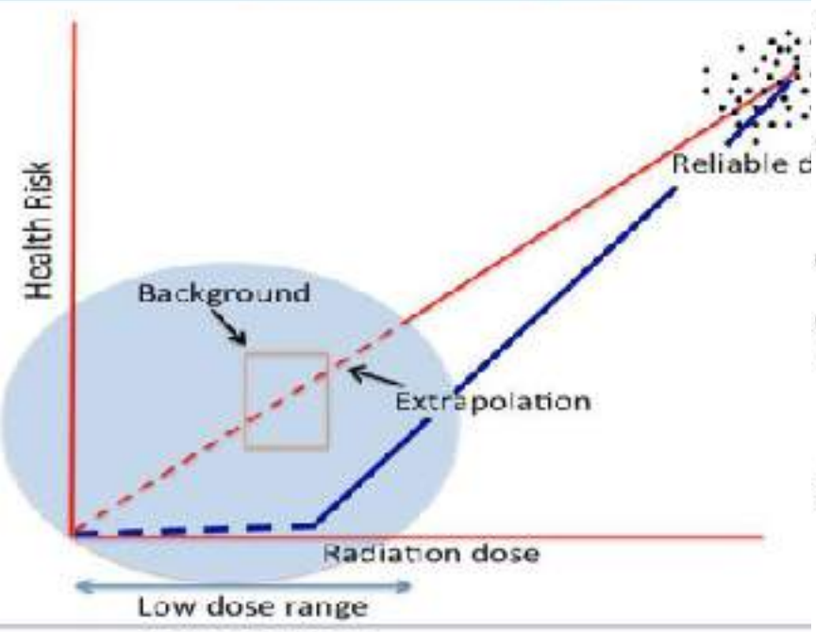
- ARQ/MIRQ- Mitigating Radiation in Qubits
IFAE, LSC, UZ and CROSS team placed underground). First experiment (2021) with qubits underground to demonstrate the impact of cosmic muons on coherence time.
- WRADES: Axion haloscope based on microwave filters, antenas and KIDs at 10 mK.
- Test new detectors based on qubits and KIDs
- Materials characterization

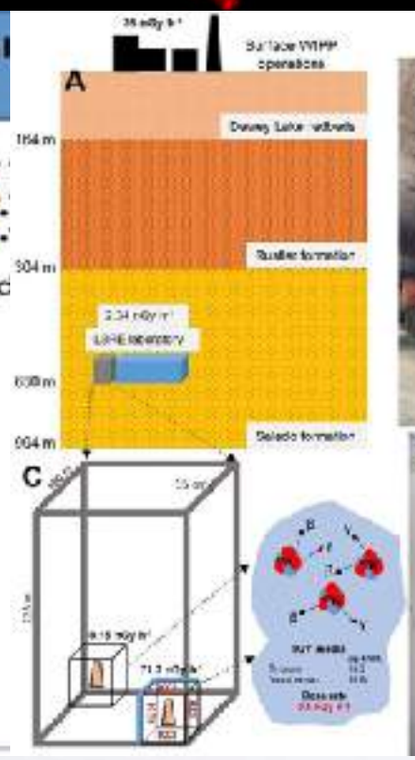


NEW STRATEGIC AREA: BIOLOGY

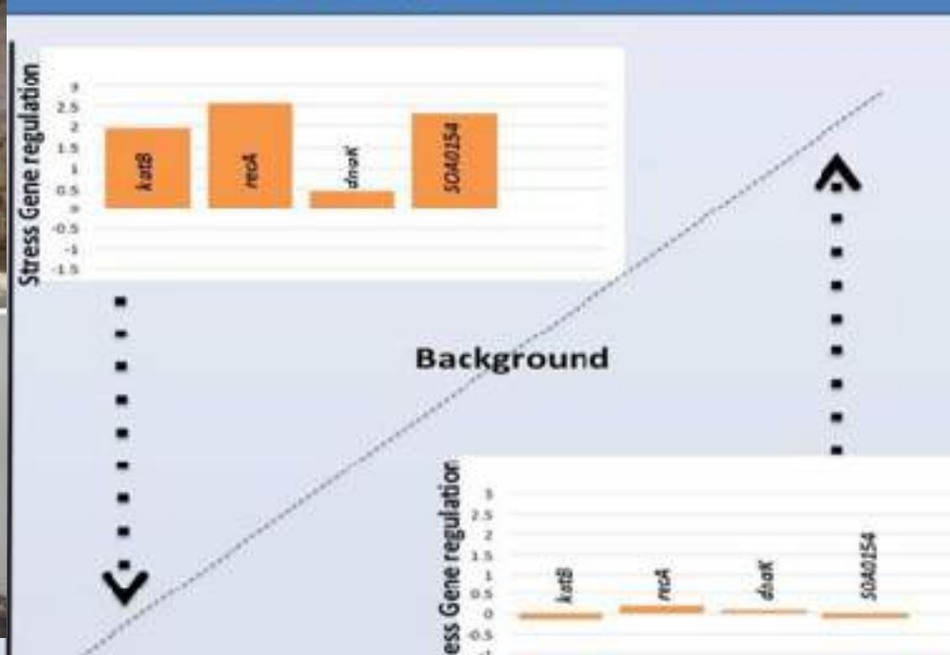


Linear no-threshold model (LNT) not biological predictive at low doses





Stress-related genes are turned on at below but not a above background radiation doses



SEE YOU SOON @LSC

Carlos Peña Garay
Laboratorio Subterráneo de Canfranc

Sep 8, 2021

LSC, Canfranc