

# EU Underground Laboratories



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LRT 2015  
Seattle



Stefano Ragazzi – INFN LNGS & UNIMIB

# Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.

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

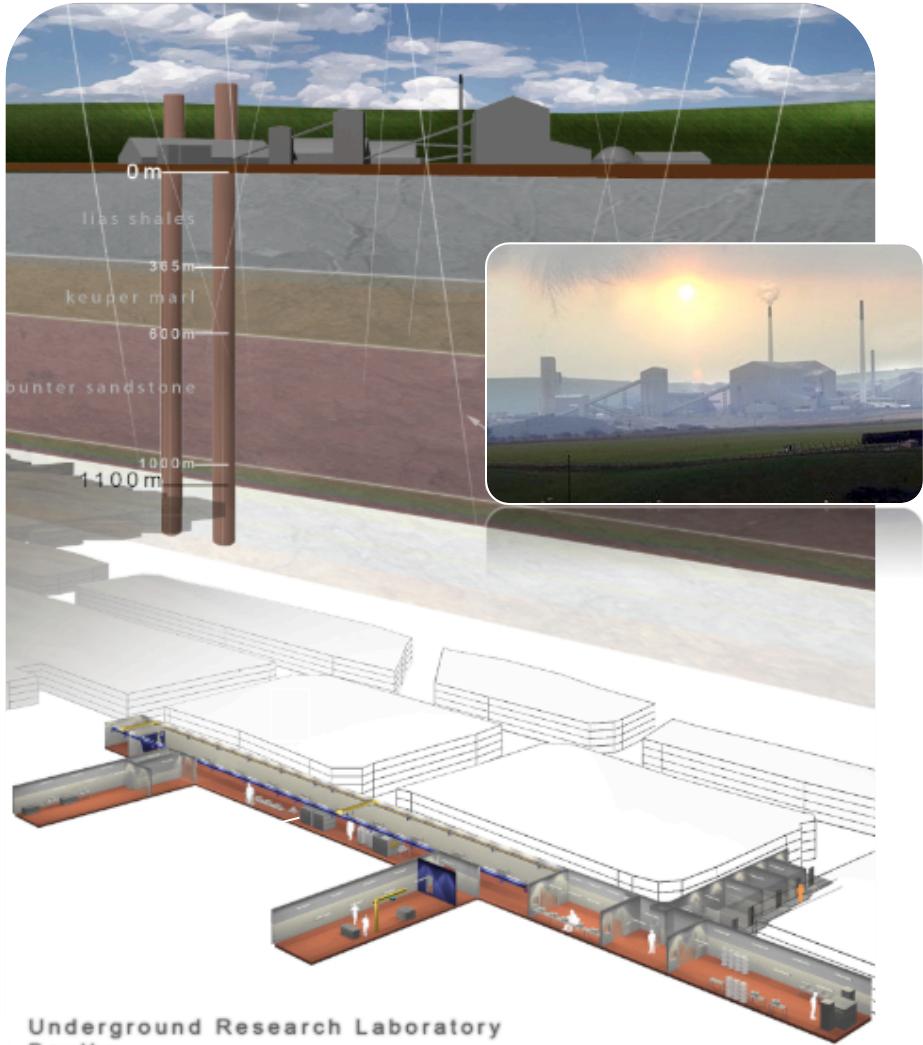
Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL

**VERY low ambient Radon background: <3 Bq/m<sup>3</sup>**

**Low ambient gamma backgrounds**



Boulby Palmer lab. >800m<sup>2</sup> floor space.  
Operating since 2001



# Underground Science @ Boulby Mine

- DRIFT: Directional Dark Matter Search
- DM Ice: NaI(Tl) Dark Matter detector
- Ultra-low background material screening
- Deep Carbon: Muon Tomography for CCS (etc)
- ERSaB: Environmental gamma spectroscopy
- BISAL: Geomicrobiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Misc. Geology / Geoscience
- Misc. Low-background support projects
- Etc... (More to come).



A growing **multi-disciplinary** science programme:  
from astro-particle physics to studies of geology,  
climate, the environment, life on Earth & beyond.

# Boulby Dark Matter Studies

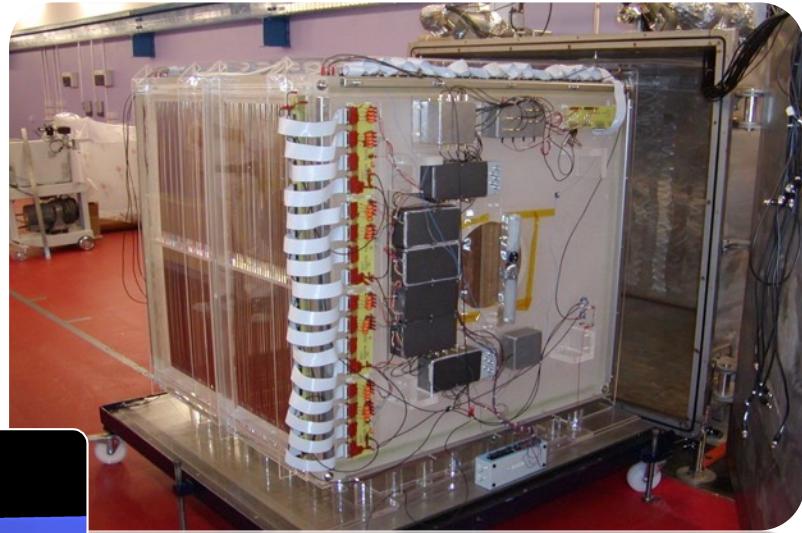
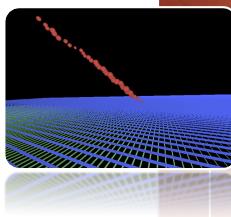
## DRIFT-II: A DIRECTIONAL Dark Matter Detector...

*Participants: Occidental College, New Mexico, Colorado State, Hawaii, Wesley Coll. Sheffield, Edinburgh, Boulby*

**STATUS:** Programme operating at Boulby since 2001. Currently limit-setting and conducting system performance and scale-up R&D



~18kg ULB NaI(Tl) detector units



1m<sup>3</sup> (Fiducial) Low-pressure gas TPC with MWPC readout

## DM-Ice: NaI(Tl) array for studying WIMP wind annual modulation

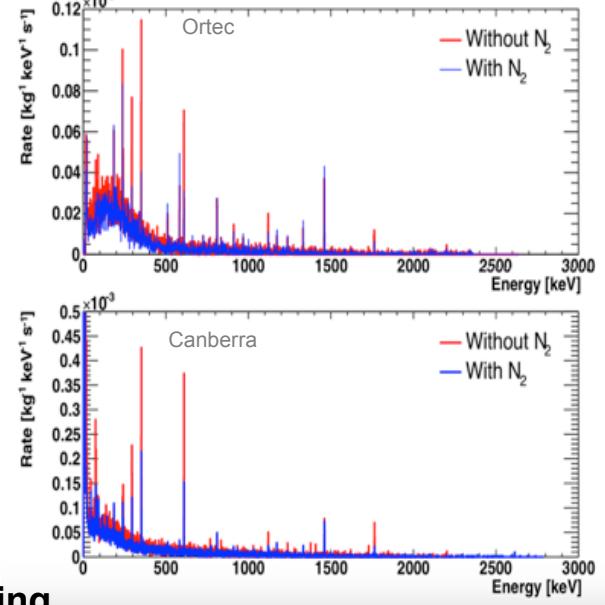
*Participants: Wisconsin, Yale, Fermi Nat. Accel. Lab, Illinois, Alberta, Sheffield, Boulby*



**STATUS:** ULB NaI (Tl) detector array assembly, characterisation & operation prior to installation at the South Pole.

# ULB Material Screening

Growing suite of ultra-low-background germanium detector systems to support astro-physics & misc 'rare-event' studies



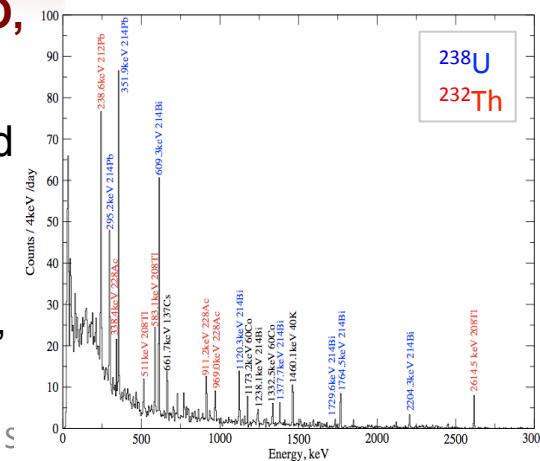
- Ortec 2kg Coax (90% eff).
- Canberra BEGe detector
- Canberra SAGe Well-type

Sensitivity down to **50ppt**  
U/Th per sample, & improving

Various low BG counting studies underway supporting **SuperNEMO**, **DRIFT**, **DM-Ice**, **LZ** and more.

Now **EXPANDING** low background counting capabilities to meet international demand.

Working in collaboration with UCL, Oxford, STFC-RAL



# Expanding Multi-Disciplinary Studies



**ERSaB:** Gamma spectroscopy & low BG counting environmental radioactivity studies

Boulby, Scottish Universities Env.  
Research Ctr (SUERC)



**From astrophysics to climate,  
geology, the environment,  
life on Earth & beyond...**

**MINAR:** Space Technology  
Development

Boulby,  
Edinburgh, NASA,  
DLR, CPL etc.

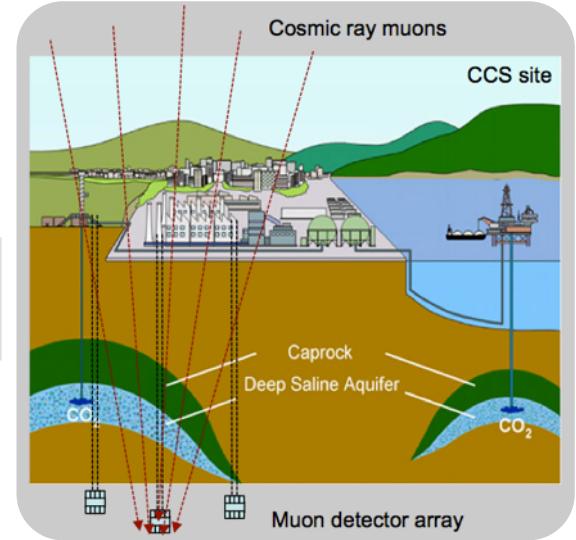
Plus Misc. Geology &  
Geoscience (& more to  
come)...

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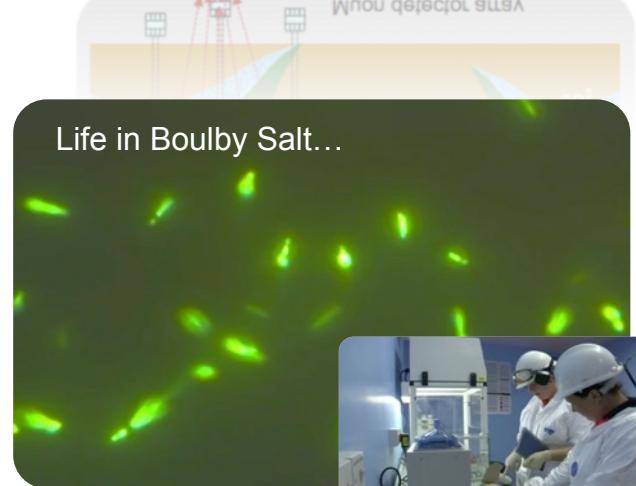


**DEEP-Carbon:** Muon Tomography for  
deep geological mapping applications  
including CCS

Boulby, Durham,  
Sheffield, Bath,  
Premier Oil, CPL.



Life in Boulby Salt...



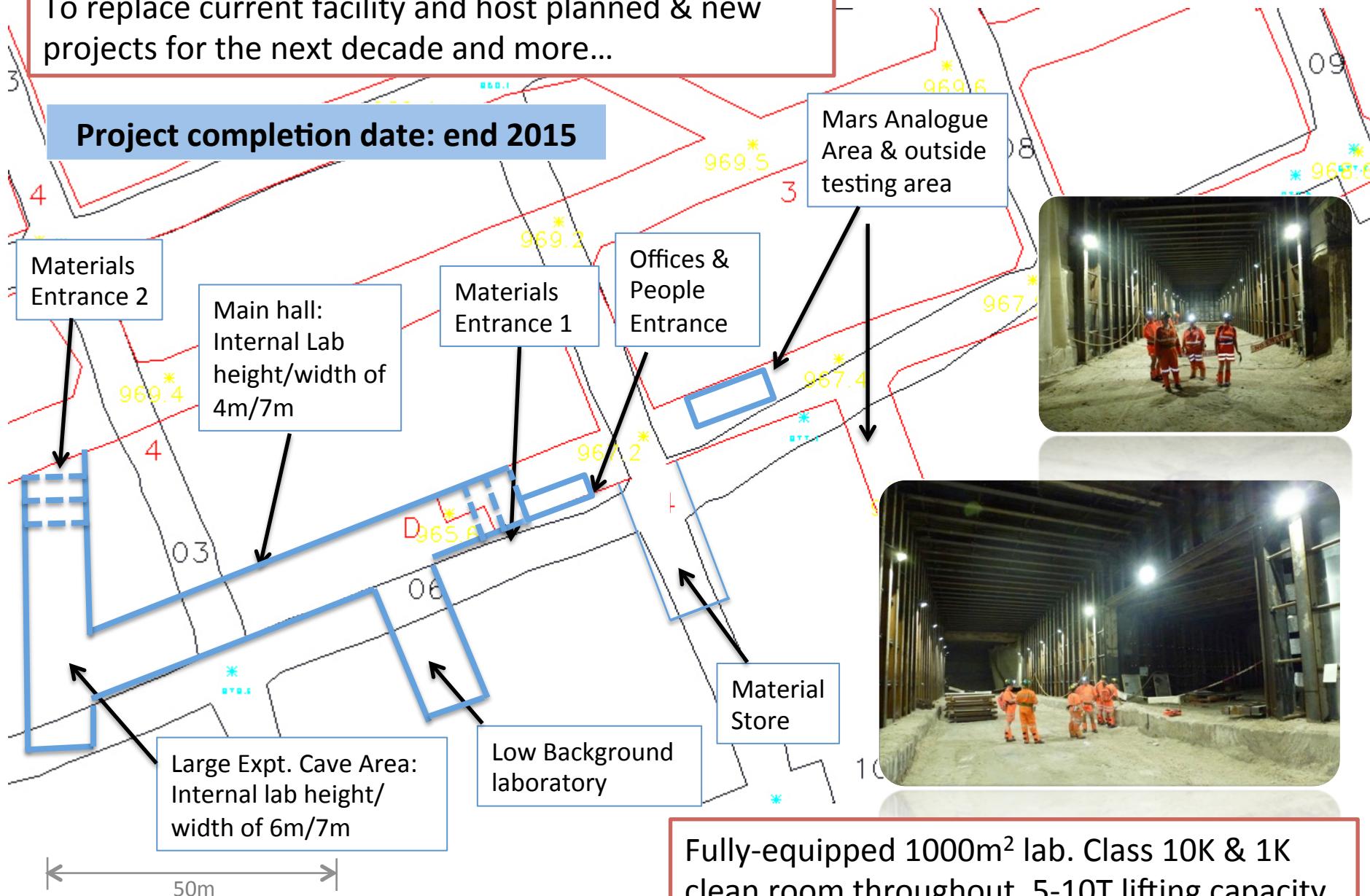
**BISAL:** Astrobiology / Geo-microbiology. Studies  
of life in salt, life on Earth & beyond



# A NEW LABORATORY now being built at Boulby

To replace current facility and host planned & new projects for the next decade and more...

Project completion date: end 2015



# Laboratoire Souterrain de Modane

Depth: 4800 m.w.e.

Surface: 400 m<sup>2</sup>

Volume : 3500 m<sup>3</sup>

Muon flux:  $4 \cdot 10^{-5} \mu\text{m}^{-2}.\text{s}^{-1}$

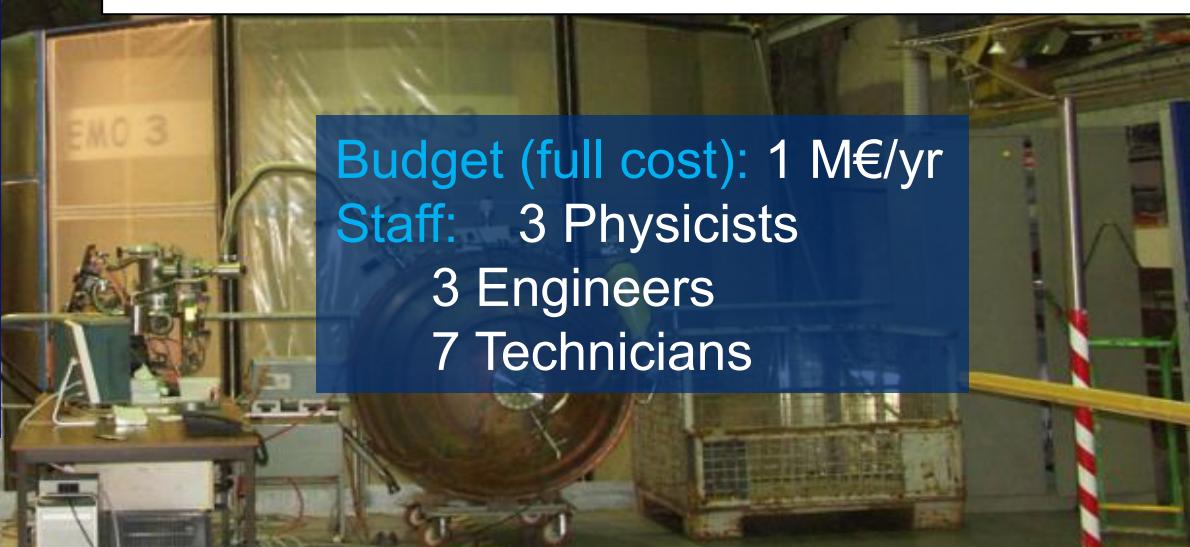
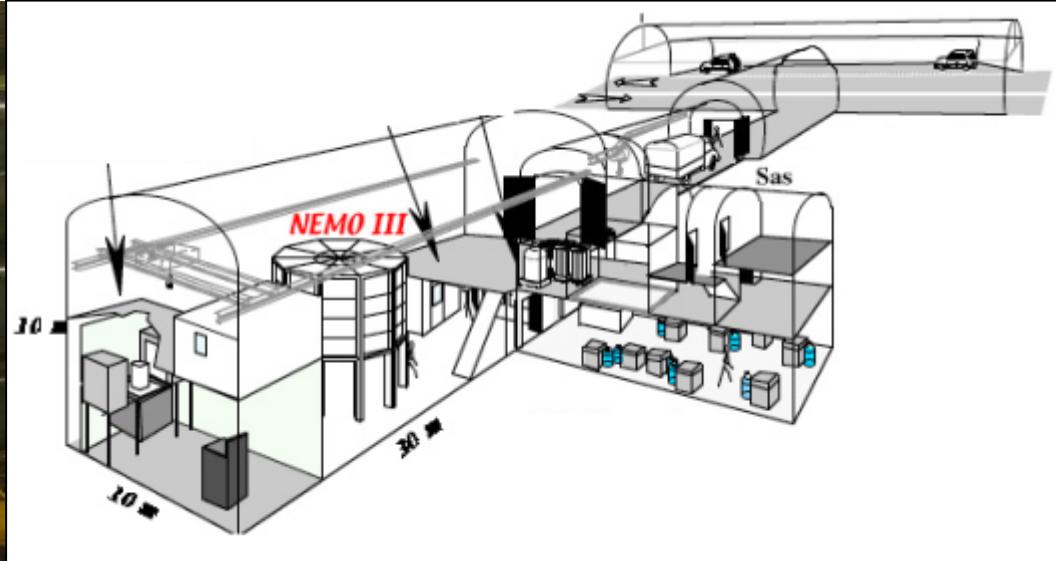
Neutrons:

Fast flux:  $4 \cdot 10^{-2} \text{n.m}^{-2}.\text{s}^{-1}$

Thermal flux:  $1.6 \cdot 10^{-2} \text{n.m}^{-2}.\text{s}^{-1}$

Radon: 15 Bq/m<sup>3</sup>

Access : horizontal

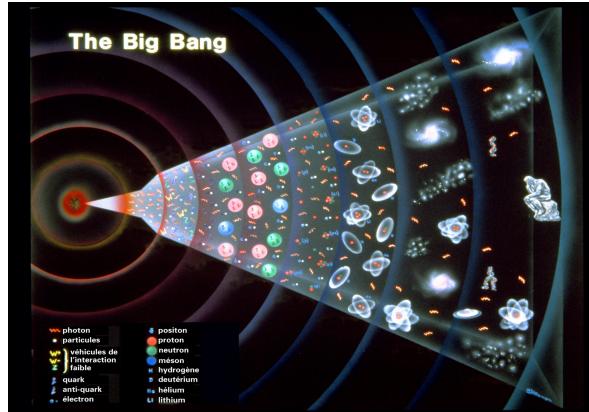


Budget (full cost): 1 M€/yr

Staff: 3 Physicists  
3 Engineers  
7 Technicians

International associated laboratory agreement with JINR Dubna (Russia) and CTU Prague (Czech Republic)

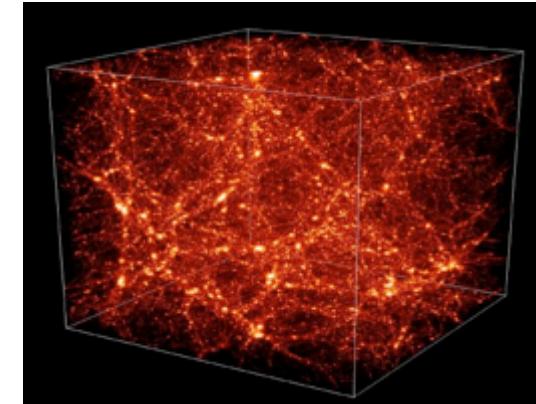
# Science at LSM



Creation of the matter



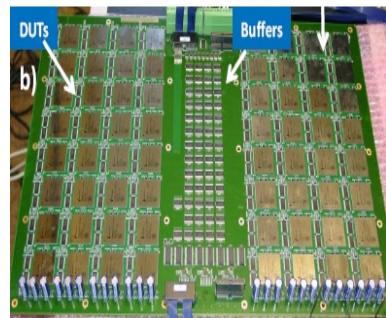
Search for Dark Matter



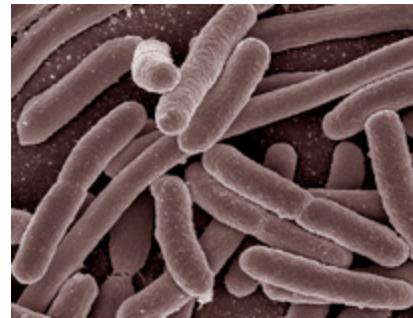
Evolution of Universe



Environment



Nano-electronics



Biology



Datation Bordeaux wine

And also :climatology, oceanography, Human effects on the environment, effets de l'homme sur l'environnement, glaciology, archeology,....

# Modane UG Laboratory

From a particle physics experiment to a multi-science platform

1979 - 1981

1982- 1990

1990- 2000

2000 - ....



Construction

$\tau_p$  Experiment

Prototypes

Experiments

## Fundamental physics:

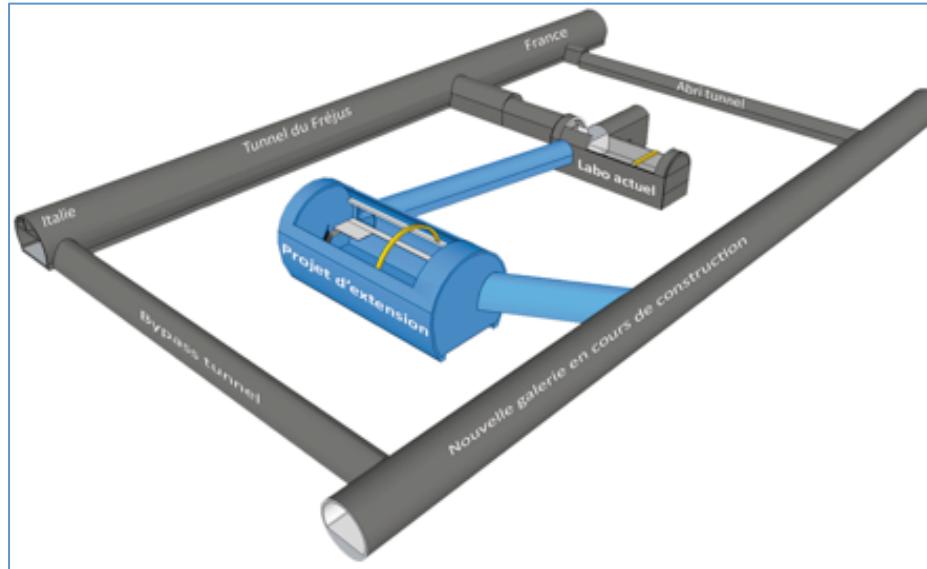
- Neutrino: double beta decay  
(SuperNEMO)
- Dark matter (EDELWEISS,  
SEDINE, MIMAC)
- Nuclear structure (TGV, SHIN)

## Multidisciplinary activities

- Ultra low radioactivity measurements  
Environmental sciences, applications, expertises
- Logical test failures in nano/micro-électronics
- Biology

# LSM Extension Project: Domus

DOMUS extension project 14 000 m<sup>3</sup> (X4 present LSM)



Cavity: Length 40 m, width 18 m, height 16 m

# Laboratorio Subterráneo de Canfranc

Headquarters & Administration

Safety and Quality Assurance

16 offices for scientific users

7 offices for LSC personnel

4 specialised laboratories

Mechanical workshop & storage room

Meeting room & Library

Conference room& Exhibitions room

2 apartments

Personnel: 10 units

Budget: $\approx$  1.6 M€/yr

Users: 275 (19 countries)

Visits (2014): 966

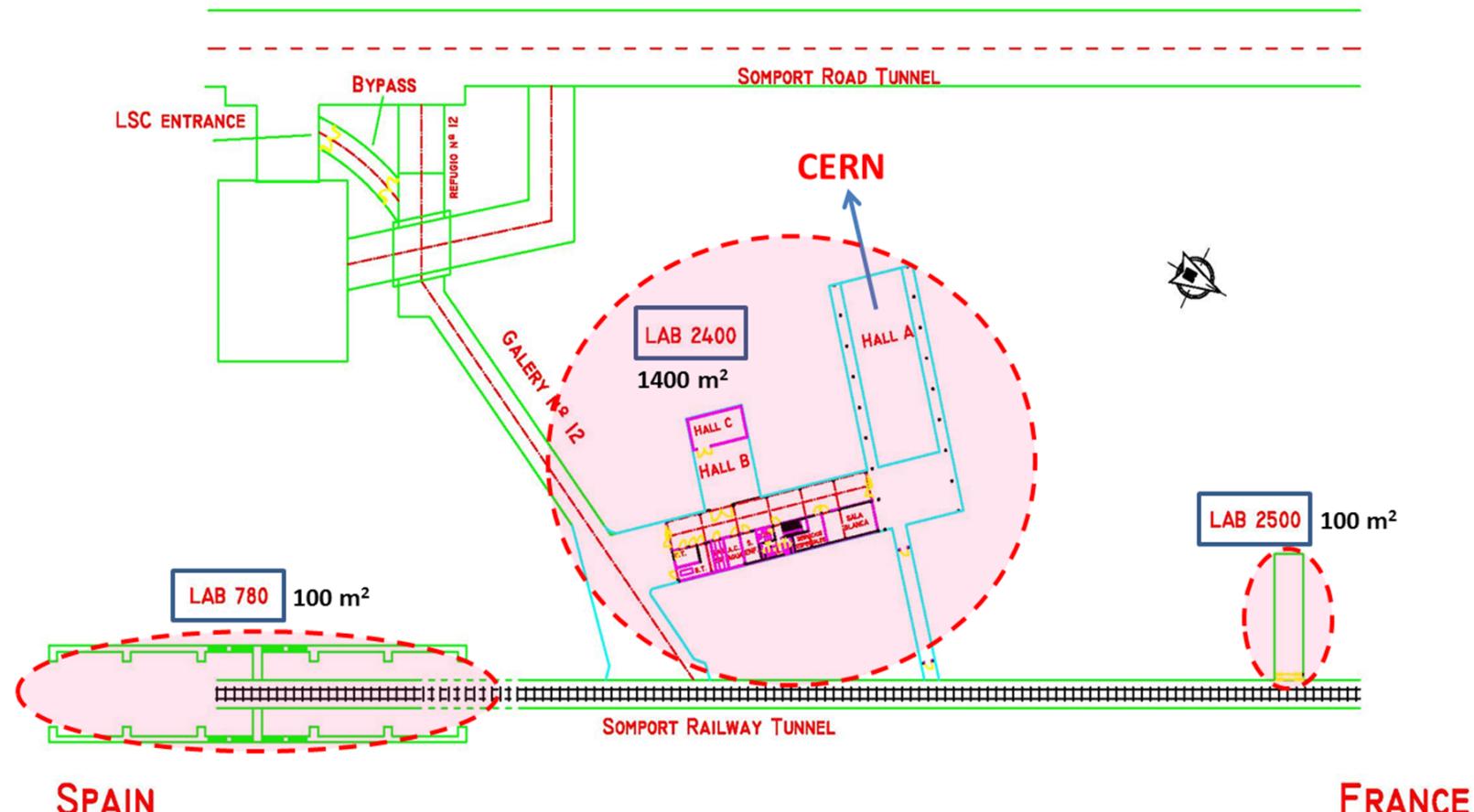


LSC external building

# LSC Underground

Two main Halls

- Hall A (length: 40 m, width 15 m, height: 12 m)
- Hall B (length: 15 m, width 10 m, height: 8 m, Figure 7)



# LSC services

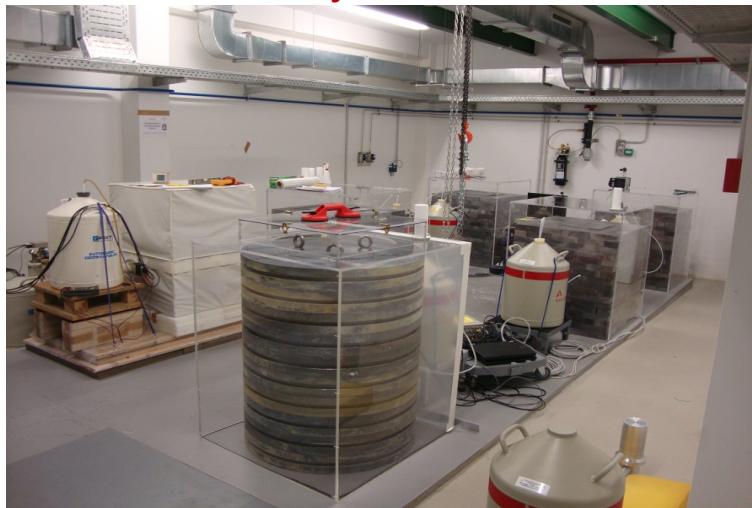
## - On surface

- ✓ Chemistry      Electroforming
- ✓                  Environmental analyses
- ✓ Mechanics
- ✓ Electronics
- ✓ Computers&Network

## -Underground

- ✓ Low activity 7 HP Ge counters and related analysis software
- ✓ Clean room ISO 7 and 6 & mechanical shop
- ✓ Continuous convergence monitoring

Low activity 7 HP Ge



Clean room



# LSC Experiments

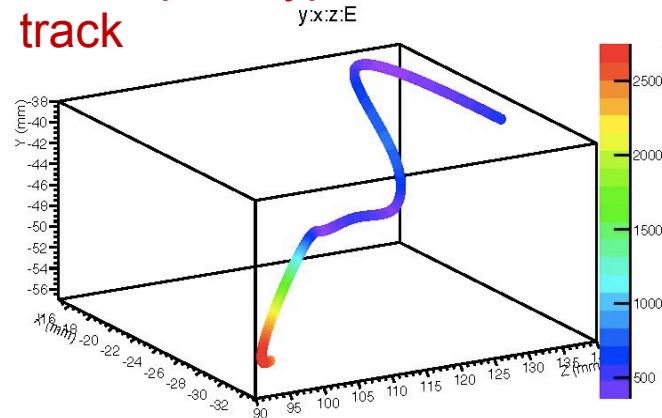
## - Experiments under construction

- ✓ **ANAINS** DM (NaI, Annual modul.)
- ✓ **ROSEBUD** DM (Scintill. bolometers)
- ✓ **ArDM** DM (2phase Ar TPC) 800 kg
- ✓ **NEXT**  $0\nu 2\beta$  (Enr  $^{136}\text{Xe}$  gas TPC)
- ✓ **BiPo**  $0\nu 2\beta$  (screening for S-NEMO)
- ✓ **SuperK-Gd** screening for Super-K-Gd
- ✓ **GEODYN** Geodynamics

## - Expressions of Interest

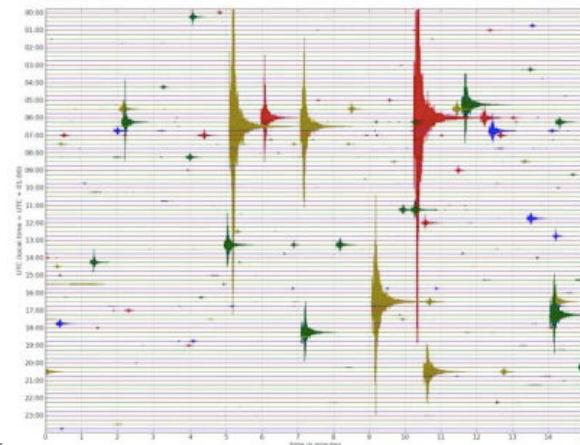
- ✓ **CUNA** Nuclear astrophysics
  - ✓ New 300 m<sup>2</sup> facility in project
- ✓ **GOLLUM** Characterising subterranean bacterial

NEXT prototype. Cs electron track

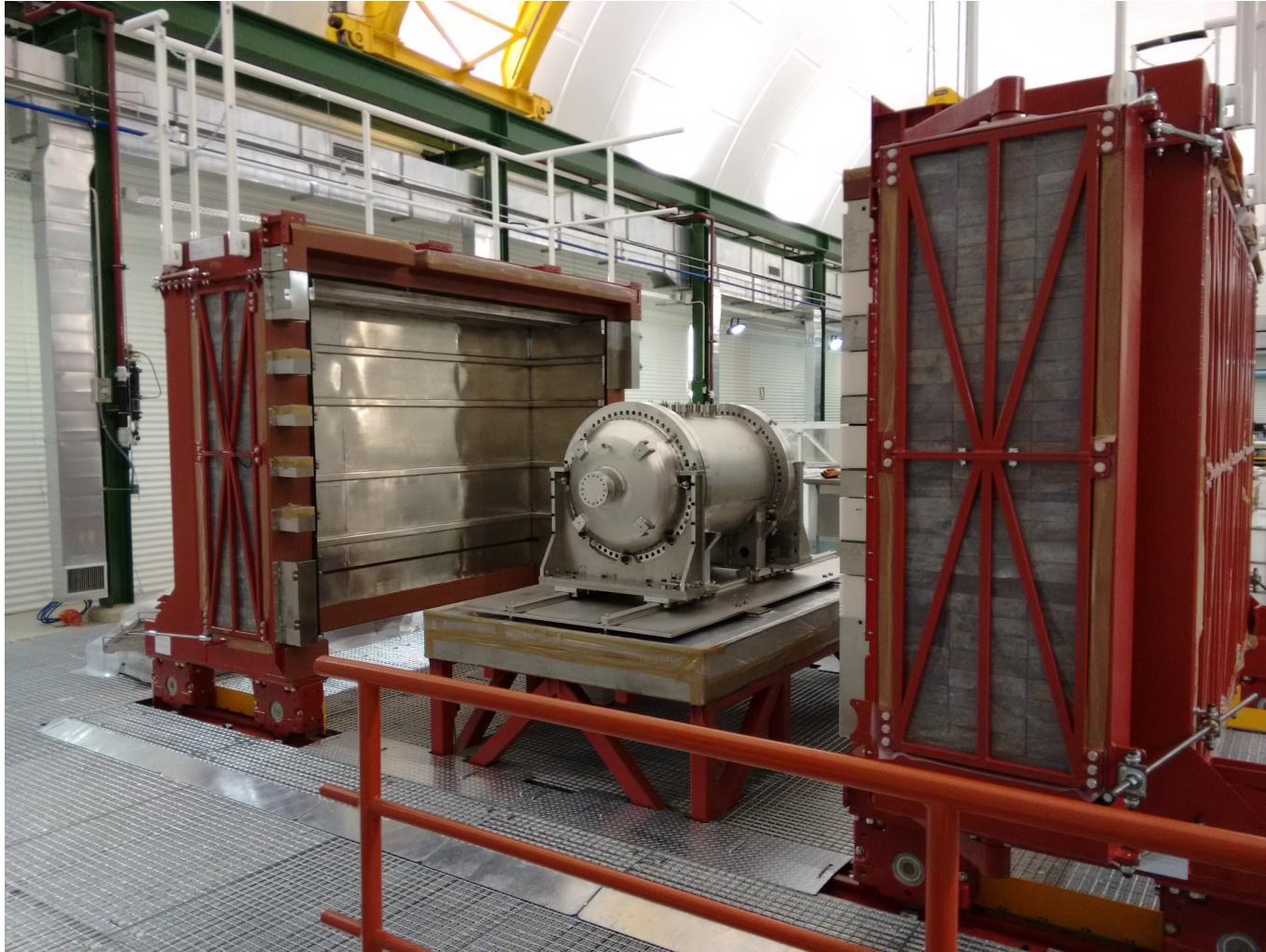


GEODYN small magnitude aftershocks, in low background underground environment

01/01/2013



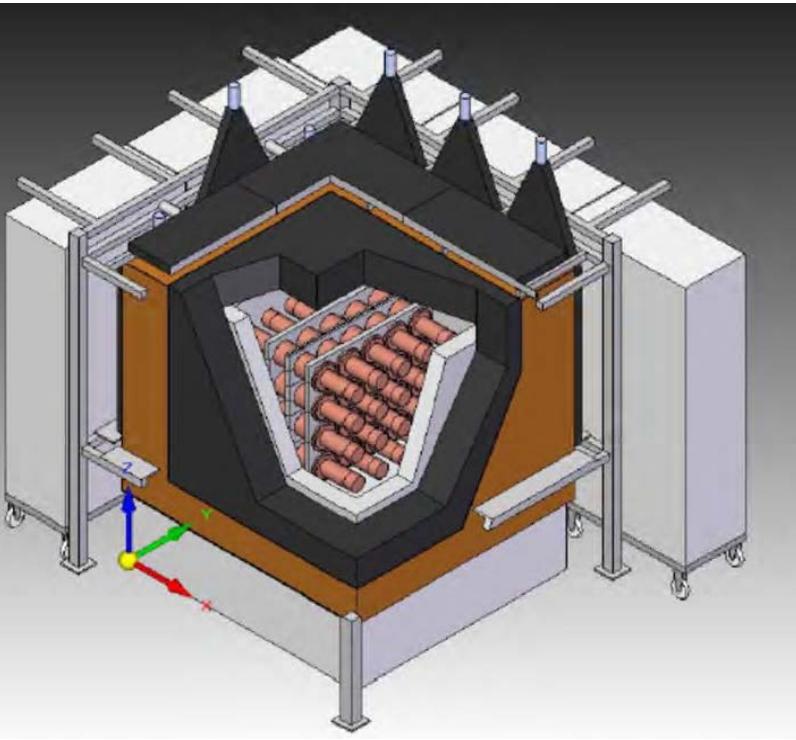
# NEXT – Double beta decay



Enriched  $^{136}\text{Xe}$  (100 kg) High Pressure Time Projection Chamber  
NEXT-NEW prototype (10 kg Xe) being installed in its Pb shield

# LSC Dark Matter

ANAlS-NaI(Tl) 250 kg



ARDM-Lar TPC 800 kg



Now filled with  
LAr



LSC ordered to Alpha Spectra a NaI(Tl) prototype aiming to 20 ppb or less of  $^{40}\text{K}$  Traveling (on surface) to LSC.

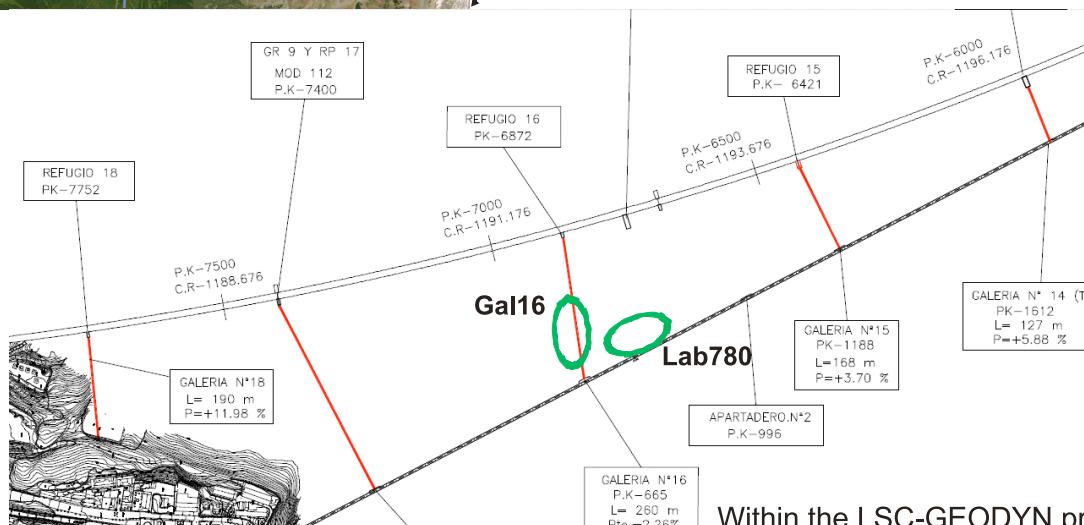
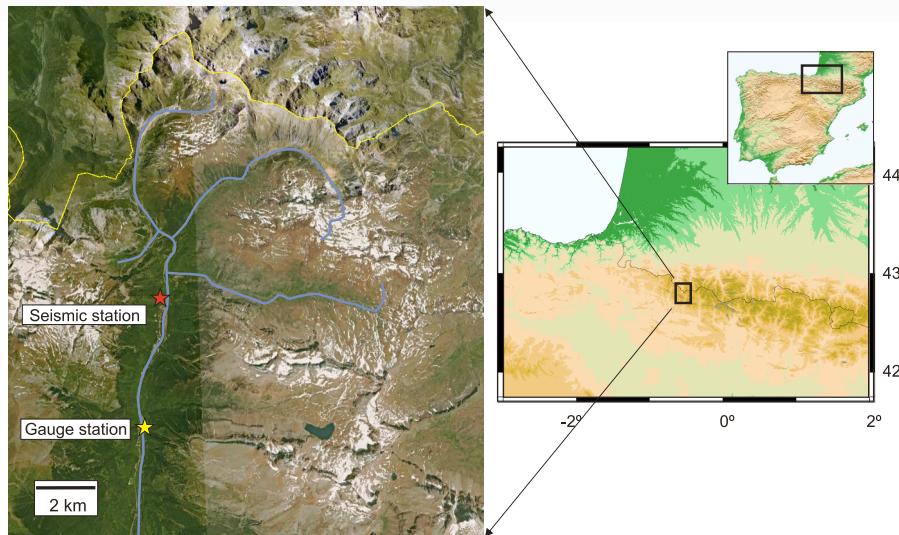


## GeoDyn Facility - Canfranc Underground Laboratory (Central Pyrenees).

J. Diaz<sup>(1)</sup>, L. Crescentini<sup>(2)</sup>, M. Ruiz<sup>(1)</sup>, A. Amoruso<sup>(2)</sup> and J. Gallart<sup>(1)</sup>

<sup>(1)</sup> ICTJA-CSIC, Barcelona, Spain,

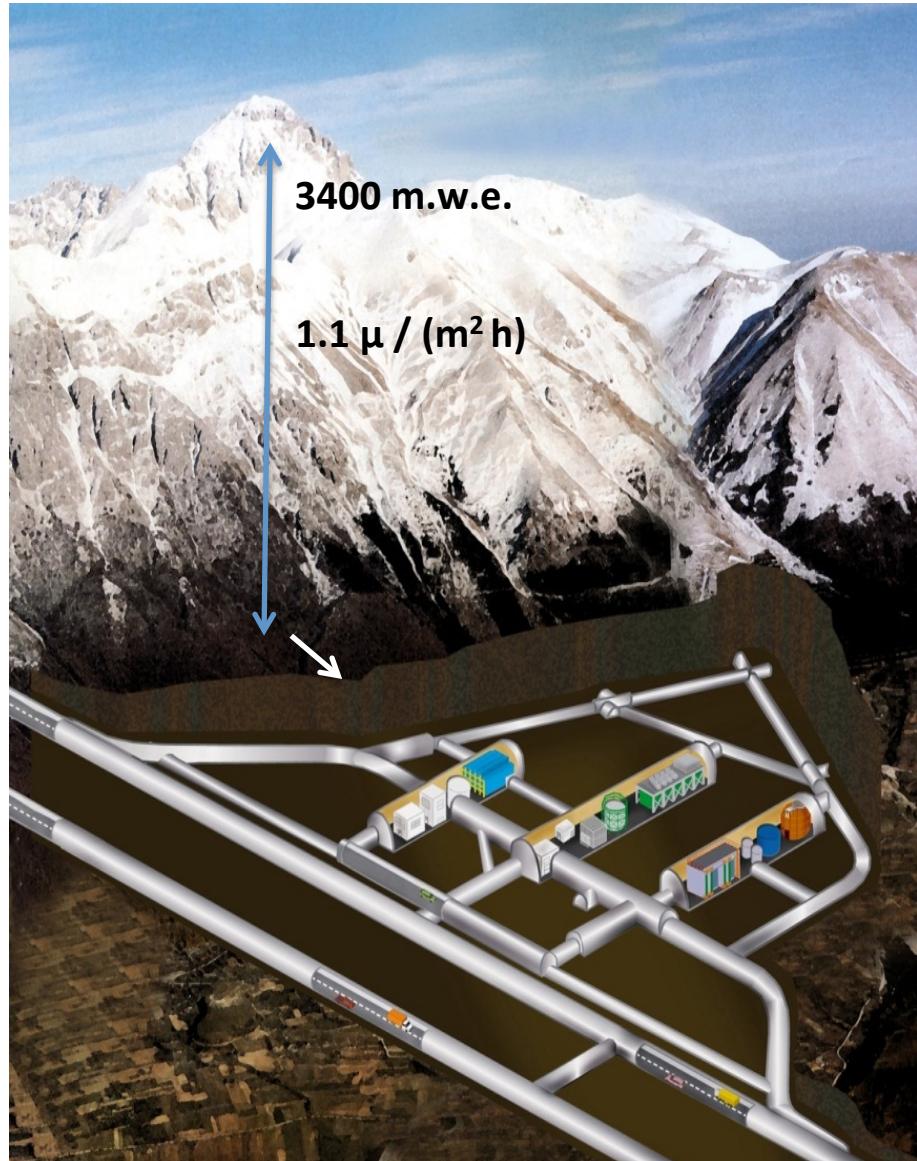
<sup>(2)</sup> Dipartimento di Fisica, Università di Salerno, Italy



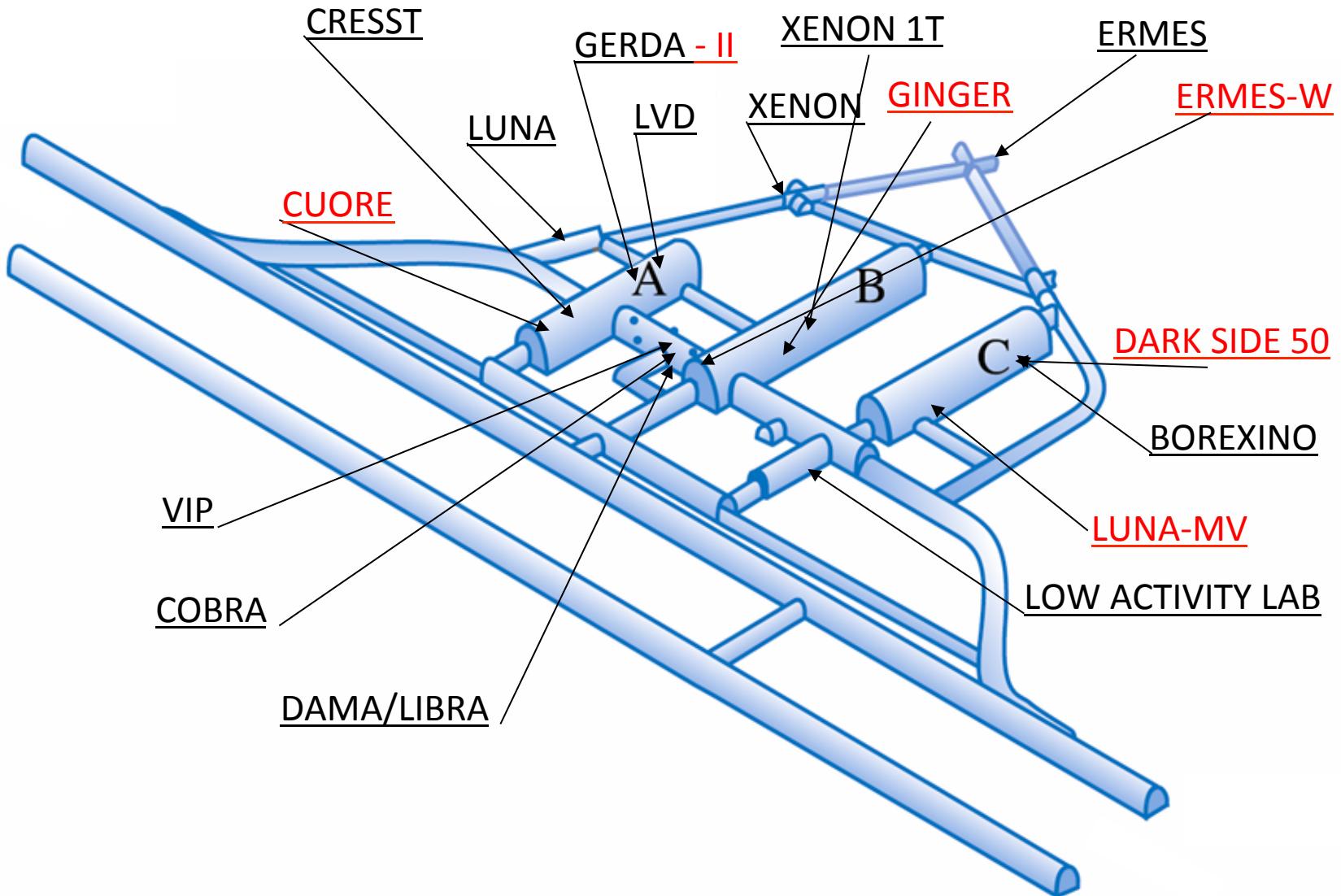
Within the | SC-GEODYN proje

# Laboratori Nazionali del Gran Sasso

- Muon flux:  $3.0 \cdot 10^{-4} \text{ m}^{-2}\text{s}^{-1}$
- Neutron flux:
  - $2.92 \cdot 10^{-6} \text{ cm}^{-2}\text{s}^{-1}$  (0-1 keV)
  - $0.86 \cdot 10^{-6} \text{ cm}^{-2}\text{s}^{-1}$  ( $> 1 \text{ keV}$ )
- Rn in air: 20-80 Bq m<sup>-3</sup>
- Surface: 17 800 m<sup>2</sup>
- Volume: 180 000 m<sup>3</sup>
- Ventilation: 1 vol / 3.5 hours
- Mechanical Design and Workshop
- Electronics Lab & Service
- Chemistry Lab & Service
- ULB Lab & Service
- > 900 users from 29 countries
- ~ 100 Staff
- 225 avg. daily presence in 2014
- ~ 8000 visitors/y
- Virtual tour via Street View

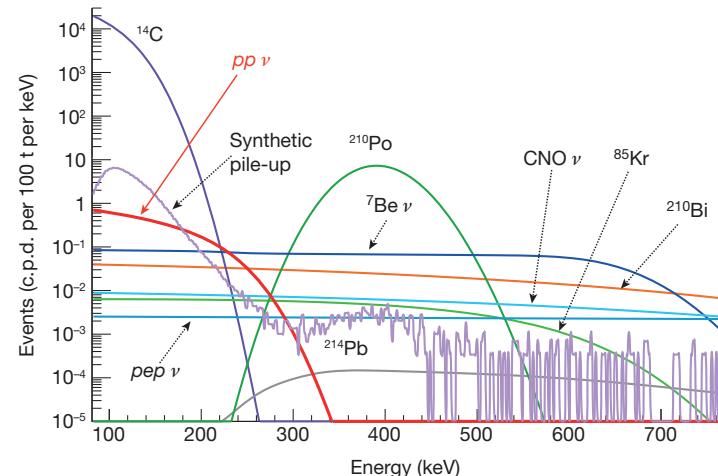


# LNGS Activities



# LNGS Neutrino

- SN neutrino:
  - LVD 1 kton liquid scint. Waiting for SN since 1992
- Solar Neutrino:
  - Borexino: real-time measurement of pp neutrino, ..., Geo-neutrinos
- Double Beta Decay
  - Gerda / Gerda-II:  $^{76}\text{Ge}$
  - CUORE – *the coldest m<sup>3</sup> in the world :*  $^{130}\text{Te}$
  - Cobra:  $^{116}\text{Cd}$
  - LUCIFER: R&D phase on crystals
- Sterile Neutrino
  - Borexino-SOX (CeSOX first)



# LNGS Dark Matter

- DAMA/Libra: NaI
  - Reports annual modulation
- NaI
  - INFN-LNGS is going to support independent test of DAMA result
- CRESST
  - CaWO<sub>4</sub> scint with bolometric r/o
- XENON family
  - Double phase liquid Xe TPC
- DarkSide
  - Liquid Ar TPC double phase



# LNGS Nuclear Astrophysics

- LUNA-400 – LUNA-MV

- Measurement of small x-section relevant to Nucleosynthesis
- LUNA-MV upgraded with intense C-beam

- Solar neutrinos:

- ${}^3\text{He}({}^3\text{He}, 2\text{p}) {}^4\text{He}$ ,  ${}^3\text{He}({}^4\text{He}, \gamma) {}^7\text{Be}$ ,  
 ${}^{14}\text{N}(\text{p}, \gamma) {}^{15}\text{O}$

- Age of globular cluster:

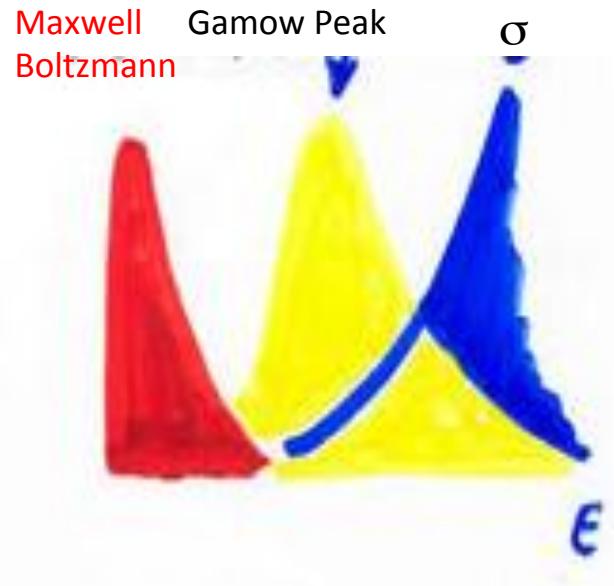
- ${}^{14}\text{N}(\text{p}, \gamma) {}^{15}\text{O}$

- Light nuclei nucleosynthesis

- ${}^{15}\text{N}(\text{p}, \gamma) {}^{16}\text{O}$ ,  ${}^{17}\text{N}(\text{p}, \gamma) {}^{18}\text{O}$ ,  ${}^{25}\text{Mg}(\text{p}, \gamma) {}^{26}\text{Al}$

- Big Bang Nucleosynthesis:

- ${}^2\text{H}(\alpha, \gamma) {}^6\text{Li}$ ,  ${}^3\text{He}({}^4\text{He}, \gamma) {}^7\text{Be}$ ,  ${}^2\text{H}(\text{p}, \gamma) {}^3\text{He}$



- Next:

- Light nuclei nucleosynthesis:

- ${}^{17}\text{O}(\text{p}, \alpha) {}^{14}\text{N}$ ,  ${}^{22}\text{Ne}(\text{p}, \gamma) {}^{23}\text{Na}$ ,  
 ${}^{23}\text{Na}(\text{p}, \gamma) {}^{24}\text{Mg}$ ,  ${}^{18}\text{O}(\text{p}, \gamma) {}^{19}\text{F}$ ,  
 ${}^{18}\text{O}(\text{p}, \alpha) {}^{15}\text{N}$

- He burning and stellar evolution:

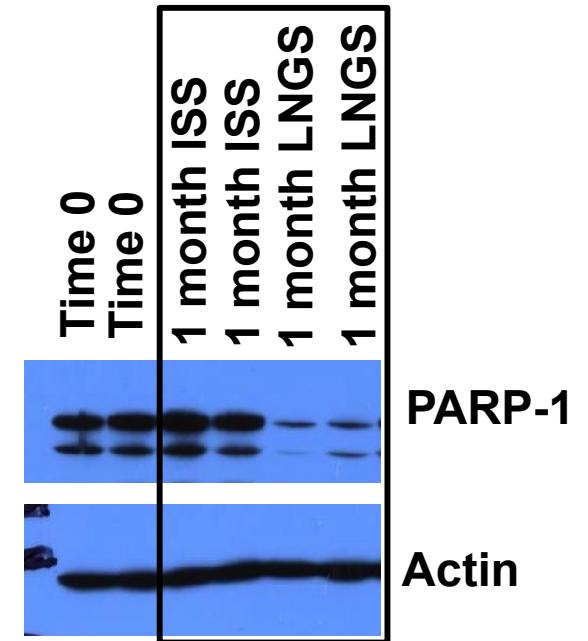
- ${}^{12}\text{C}(\alpha, \gamma) {}^{16}\text{O}$

- s process nucleosynthesis:

- ${}^{13}\text{C}(\alpha, \text{n}) {}^{16}\text{O}$ ,  ${}^{22}\text{Ne}(\alpha, \text{n}) {}^{25}\text{Mg}$

# LNGS General, Multidisciplinary

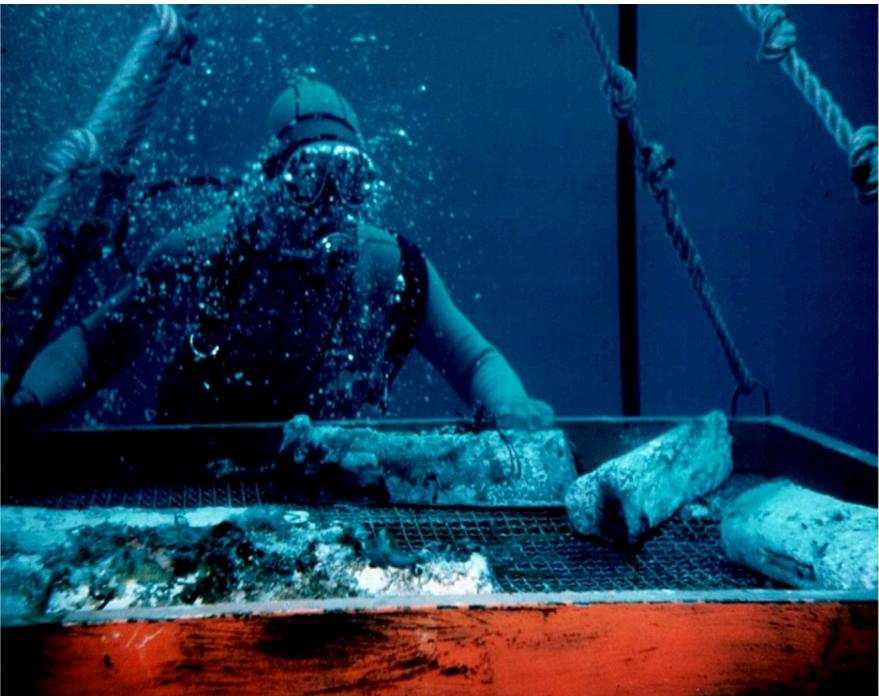
- **GINGER**
  - Ring-laser to probe Lense-Thirring effect
- **Cosmic Silence**
  - Study effect of very low radiation doses on cells, fleas, ...
  - Test Linear No Threshold model
- **ERMES-W**
  - Primary resources, global geodynamic...
- **VIP**
  - Test Pauli Exclusion Principle



# Four labs main characteristics

	LNGS	LSM	LSC	BUL
Date of Creation	1987	1982	2010	1989
Surface m <sup>2</sup>	18 000	500	1600	500 + 1000
Volume m <sup>3</sup>	180 000	3 500	10 000	3 000
Personnel	51 (A-T) + 16 eng + 12 phys + 27 postdocs	11 + 1 postdoc	10	5
No of users	950	150	275	70
Depth meter water equivalent (mwe)	3 700	4 800	2 450	2 800
Altitude	1 000	1 240	1 195	-1000
Temperature (base) in Celsius	10°	28°	12°	30°
Humidity (base) in %	90	30%	60%Wint - 80%Sum	30-35%
Available electrical power kW	1500	60 → 300	692	
Air renewal flux m <sup>3</sup> /h	50 000	4 800	11 000	24 000
Muon flux/(m <sup>2</sup> .s <sup>-1</sup> )	2.87 x 10 <sup>-4</sup>	4,6 10 <sup>-5</sup>	2-4x10 <sup>-3</sup>	4.1 10 <sup>-4</sup>
Air renewal/total vol/h	0.3	1.5	1.2	10
[Radon] Bq/m <sup>3</sup>	20-120	10-15	70	<5
Gamma flux/ (m <sup>2</sup> .s <sup>-1</sup> )	0.3 – 1 x 10 <sup>4</sup>	3.8 x 10 <sup>4</sup>	1.23±0.17 10 <sup>4</sup>	~1.3 x 10 <sup>4</sup>
Neutron flux (>1MeV)/(m <sup>2</sup> .s <sup>-1</sup> )	~3.78x10 <sup>-2</sup>	(1.06±0.1±0.6) x 10 <sup>-2</sup>	3.47±0.35 10 <sup>-2</sup>	<1.5x10 <sup>-2</sup>
Main Physics Activities	DM, 0NBB, neutrinos, NP, LR measurement	DM, 0NBB, neutrinos, NP, LR measurement	DM, 0NBB, neutrinos, LR measurements	DM, LR measurements
Access	Horizontal	Horizontal	Horizontal	Vertical
Travel time between surface building + lab access	20 min	20 min	15 min	25 min
γ spectroscopy LR Ge's	12 units	15 units 200cc: 6 / 400cc: 4 / 800 cc :1 1000 cc: 2	7 units: 400 cc	1 unit: 400 cc
Additional low background measurements radioactivity Ge's	Radon water mon, liq scint setup	Rn monitor @ few mBq/m <sup>3</sup>	Low background alpha-beta counting system	Rn monitor @ few mBq/m <sup>3</sup>
Background reduction equipment	Radon purify in LN2: @ μBq/m <sup>3</sup>	Radon-free air system: 150 m <sup>3</sup> /h @ 0.10 Bq/m <sup>3</sup>	Clean room	Clean room

# 2000 Years Old LRT



$^{210}\text{Pb}$  free (22.3 y half-life)

2000 y shielded by sea water

A couple of hundred ingots  
for the CUORE shielding

