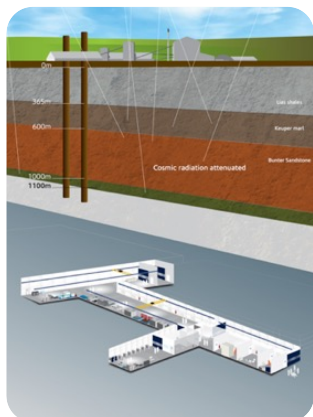# Overview of Deep Underground Science Facilities
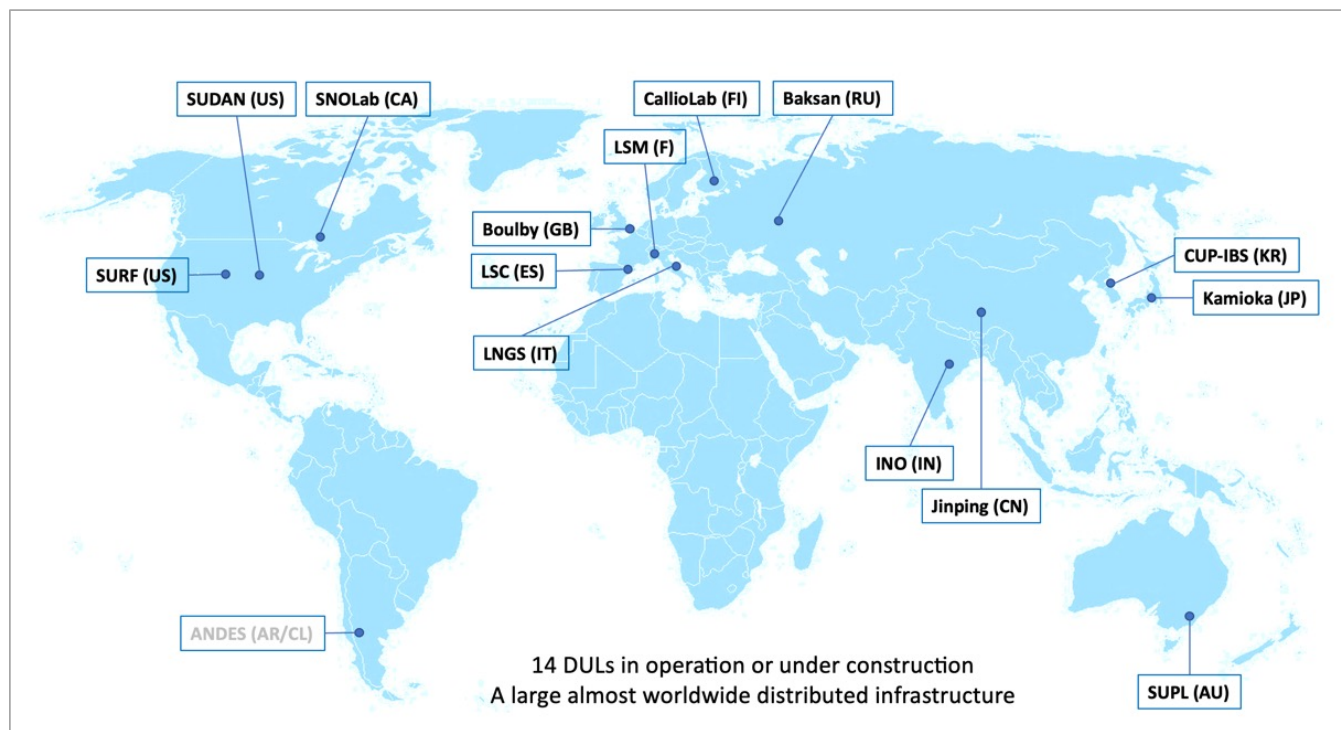
World Underground Labs

Boulby Underground Laboratory (UK)

Gran Sasso National Laboratory LNGS (Italy)

SUDAN (US) · SNOLab (CA) · CallioLab (FI) · Baksan (RU) · LSM (F) · Boulby (GB) · CUP-IBS (KR) · Kamioka (JP) · SURF (US) · LSC (ES) · LNGS (IT) · INO (IN) · Jinping (CN) · ANDES (AR/CL) · SUPL (AU)

14 DULs in operation or under construction
A large almost worldwide distributed infrastructure

Sean Paling – STFC Boulby Underground Laboratory
European Laboratory Directors Group Meeting – July 2023

UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

Why go underground?

Deep Underground Science Themes

Low Background Particle / Astroparticle Physics
- Direct dark matter searches
- Atmospheric, solar & supernova neutrinos
- Reactor and accelerator neutrinos
- Neutrino-less double beta decay
- Nuclear astrophysics / stellar reactions
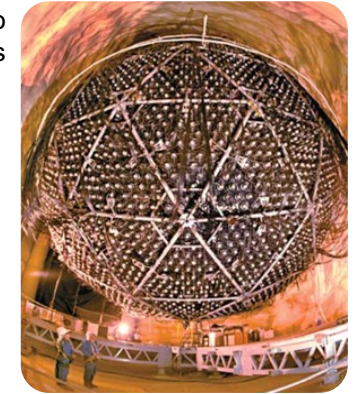- Misc. rare-decay processes

Other 'Multi-disciplinary' studies
- Pure and applied cosmic ray studies,
- Misc. low background studies, Gamma spectroscopy
- Misc. Earth and Environmental Sciences
- Geo-microbiology & life in extreme environs
- Astrobiology and planetary exploration
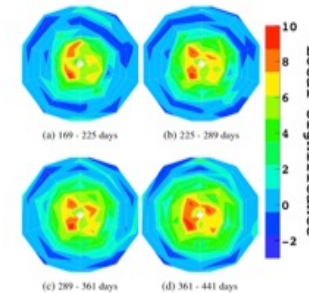- Quantum sensors, quantum computing
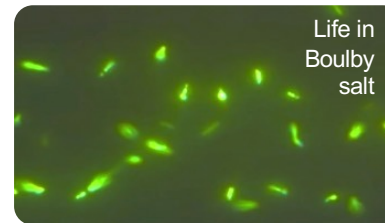- Etc…

Dark Matter Studies

Neutrino Studies

Geology & geophysics

ULB Gamma spectroscopy

Life in Boulby salt

Biology, astrobiology and more.

UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

What's needed from an underground lab? (1)

Experimental Space with… **Low Backgrounds…**

Cosmic ray Muons…

- Deep underground facilities provide rock overburden & commensurate reduction in c.r. flux & spallation induced products (neutrons)

Neutrons…

Production from

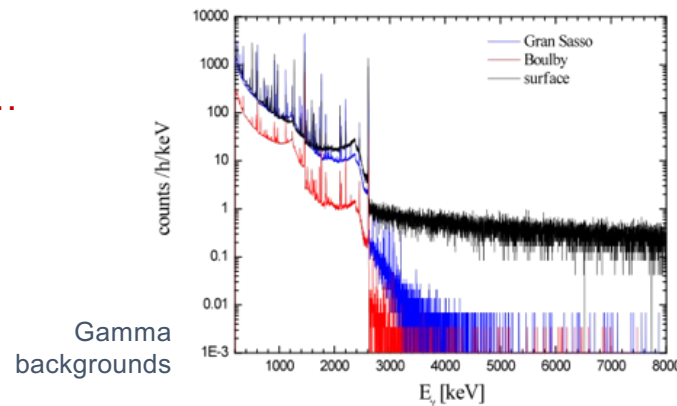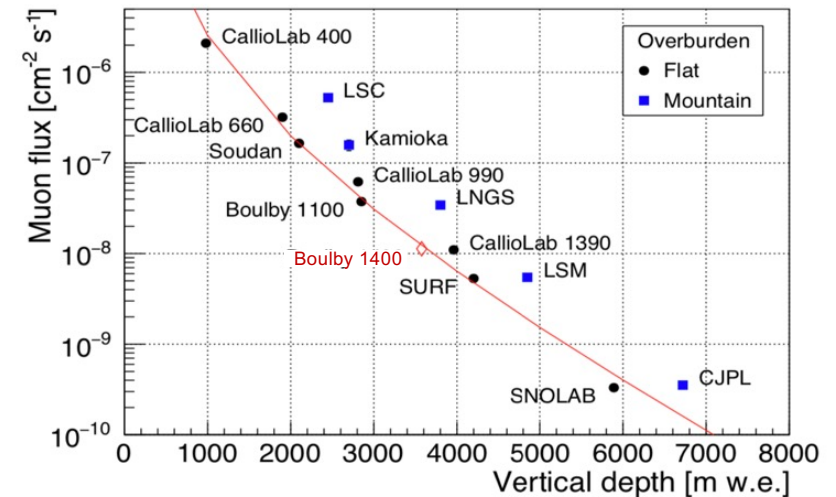- c.r. muon spallation
- U/Th fission
- α, n reactions

Radon….
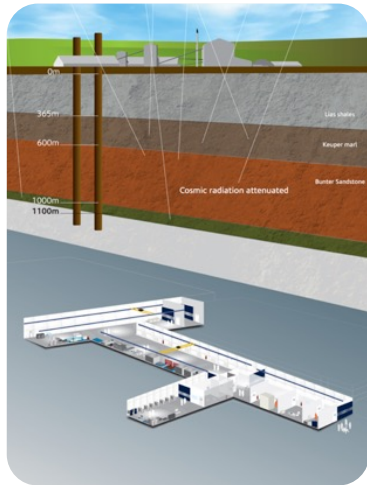
- Dependent on local geology & ventilation

Go underground…

Choose low background rock…

Gammas….

- Reduction in γ-ray background at higher energies from c.r. and neutron reduction
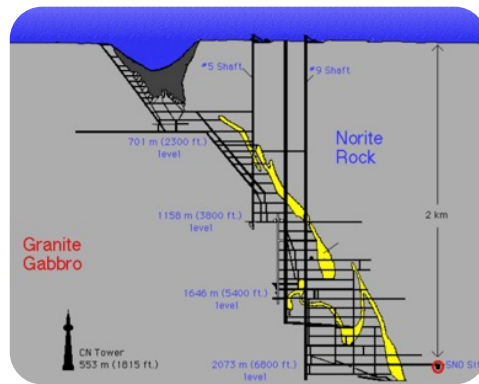- Below 3.5MeV dependent on local geology
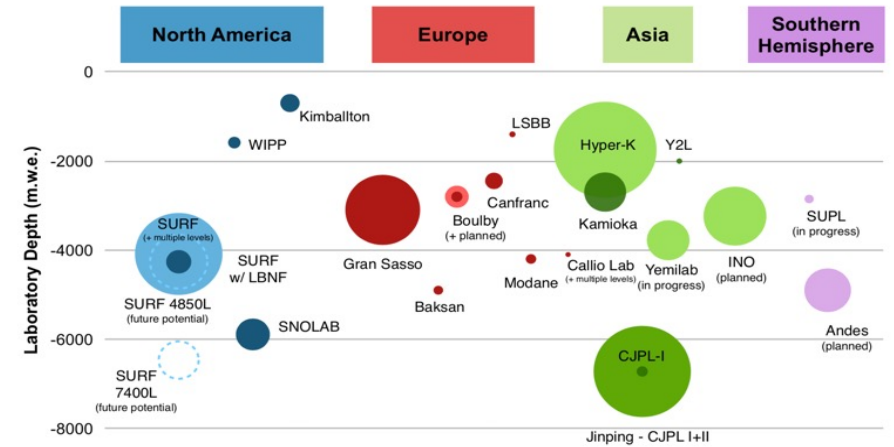
Muon Flux vs. Depth

Gamma backgrounds

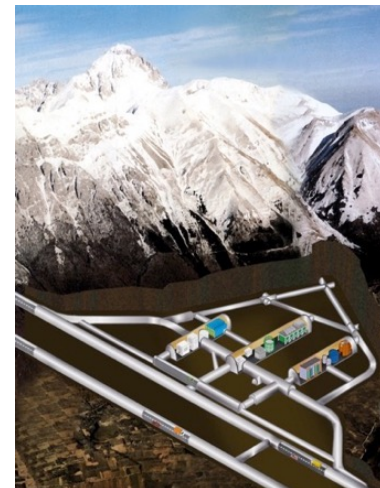UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

Underground Labs around the world....

Boulby

In mines and under mountains

SNOLAB

JINPING

CALLIOLAB

LNGS

SURF

UK RI Science and Technology Facilities Council

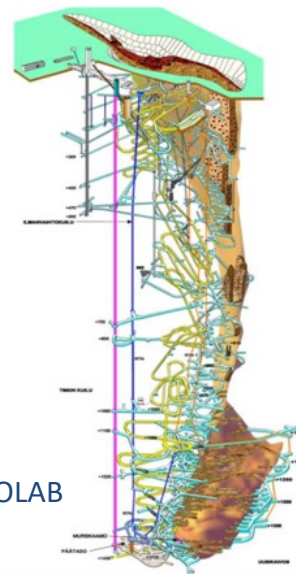Boulby Underground Laboratory
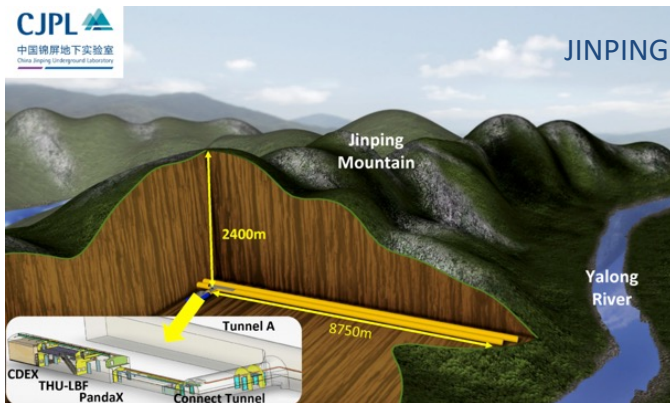
What's needed from an underground lab? (2)

Other Factors:

Science and operations support:

- Good surface & underground infrastructure & support facilities
- Reliable utilities: power, ventilation, heat management, water, gases/liquids
- Good Health & Safety and security systems for underground use
- Scientific support personnel: design, construction, operation/analysis
- Infrastructure support and personnel: workshops, chemical labs, IT etc.
- Good ancillary science support facilities: low background assay, clean rooms etc…

Other Facility Characteristics:

- Size (monolithic or distributed; Space available)
- Ease of Access (vertical or horizontal); Max installation size limitations
- Location (neutrino flux from beam/reactor, Earth, ease of access, quality of life)
- Cleanliness and radiological interference
- Suitable geology

'A hole in the ground is not a facility!'

Non lab-based things are very important too.

Local Politics & funding: multi-year budgets, solid host nation support, local support /engagement in the facility and the science. Science community networking.
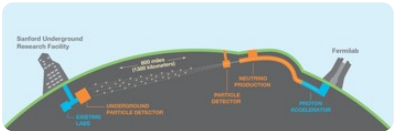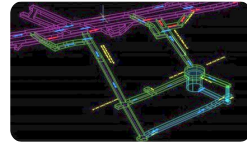
UK RI Science and Technology Facilities Council

Boulby Underground Laboratory

World deep underground laboratories…

Boulby Underground Laboratory (UK)
Working Mine, 2850 mwe
Current vol: 7,200m^3
ZEPLIN+ (past), BUGs, News-G,
RECON, Multi- sci, BUTTON (to come)

**SNOLAB (Canada)**
Active Mine, 5890 mwe
Current vol: 30,000m^3
SNO+, SuperCDMS, Deep3600,
PICO, Next Gen 0vBB (to come?)

World Underground Labs
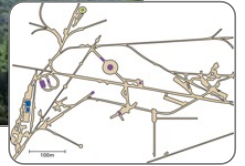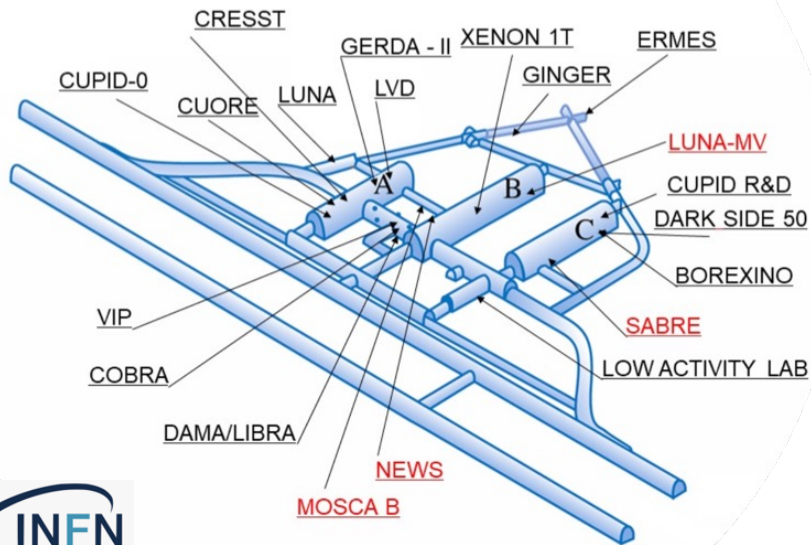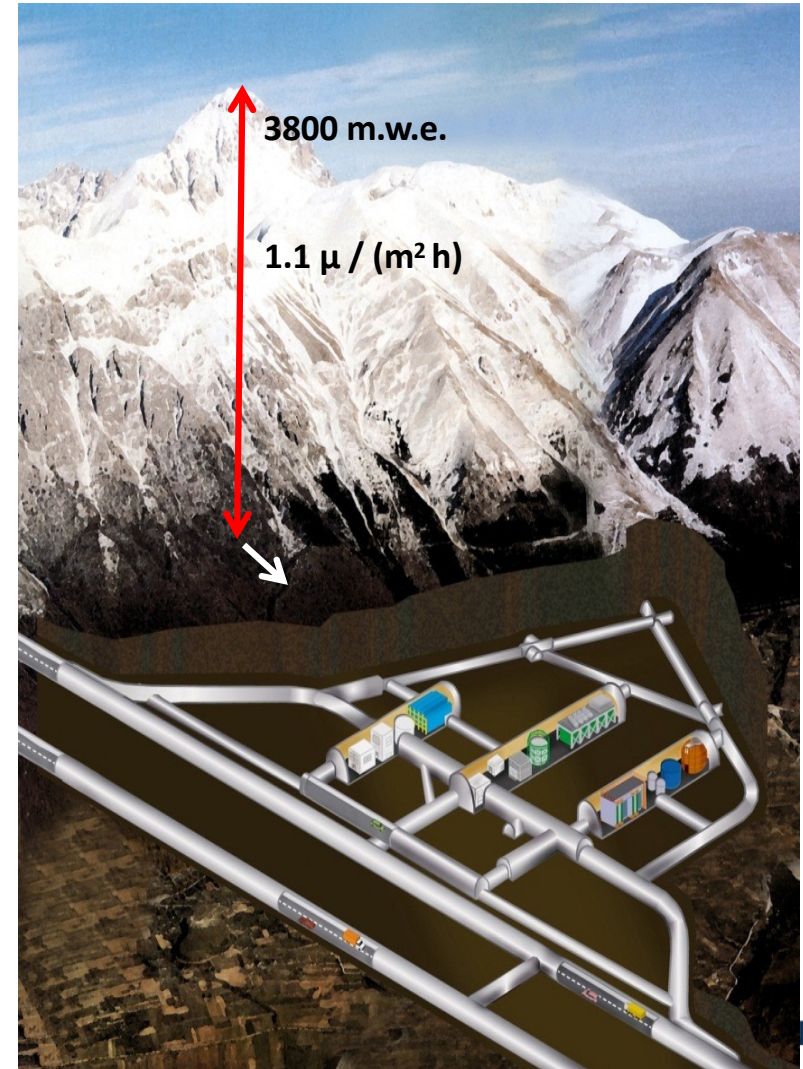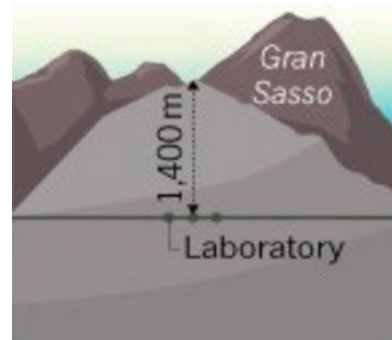

SUDAN (US) SNOLab (CA) CallioLab (FI) Baksan (RU)
LSM (F)
Boulby (GB)
SURF (US) LSC (ES) CUP-IBS (KR)
Kamioka (JP)
LNGS (IT)
INO (IN)
Jinping (CN)
ANDES (AR/CL)
SUPL (AU)

14 DULs in operation or under construction
A large almost worldwide distributed infrastructure

Kamioka (Japan)
Active Mine, 2700 mwe
Current vol: 150,000m^3
Super-K, XMAS, Kamland-Zen +.
Hyper-K (nearby, to come)

SURF Laboratory (USA)
Disused Mine, 4200 mwe
Current vol: 7,100m^3
LZ, MJD, DUNE (to come)
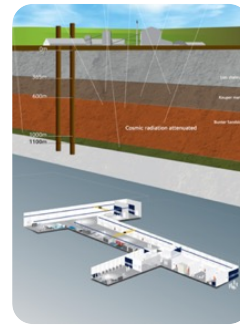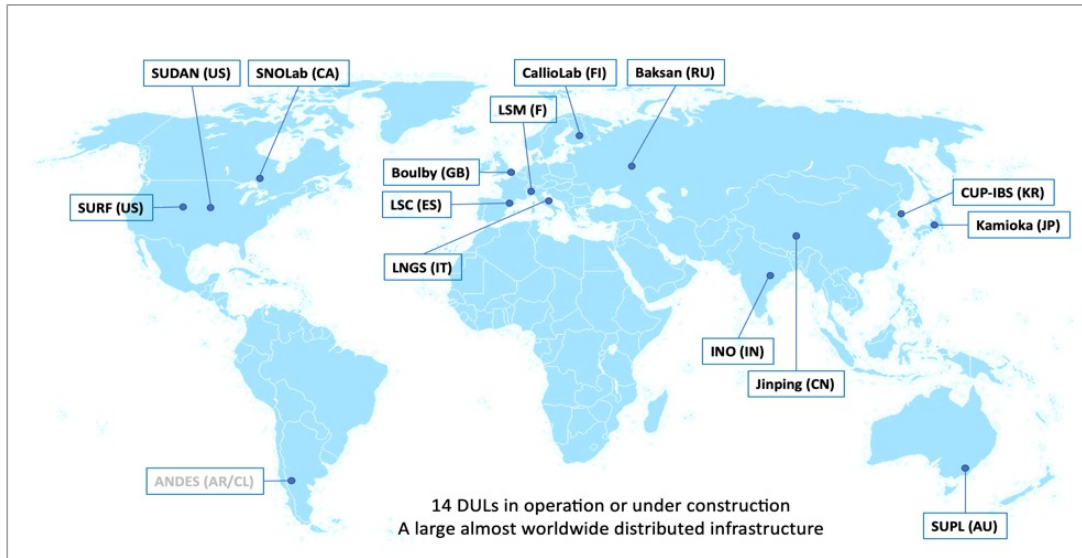
Gran Sasso National Laboratory
LNGS (Italy)
Under mountain, 3800 mwe
Current vol: 180,000m^3
Borexino, Xenon, DarkSide +

LNGS / Gran Sasso Deep Underground Lab

- Shielded by 1400 m (3800 m.w.e.) of rock (<u>Gran Sasso Mountains</u>)
- Total Muon flux 3 10^{-8} cm^{-2} s^{-1}
- Radon i~100 Bq/m3 with 5-8 air changes/day
- 3 main experimental halls:
  100 m long, 20 m width and 18 m height
- 22 experiments data taking or under construction
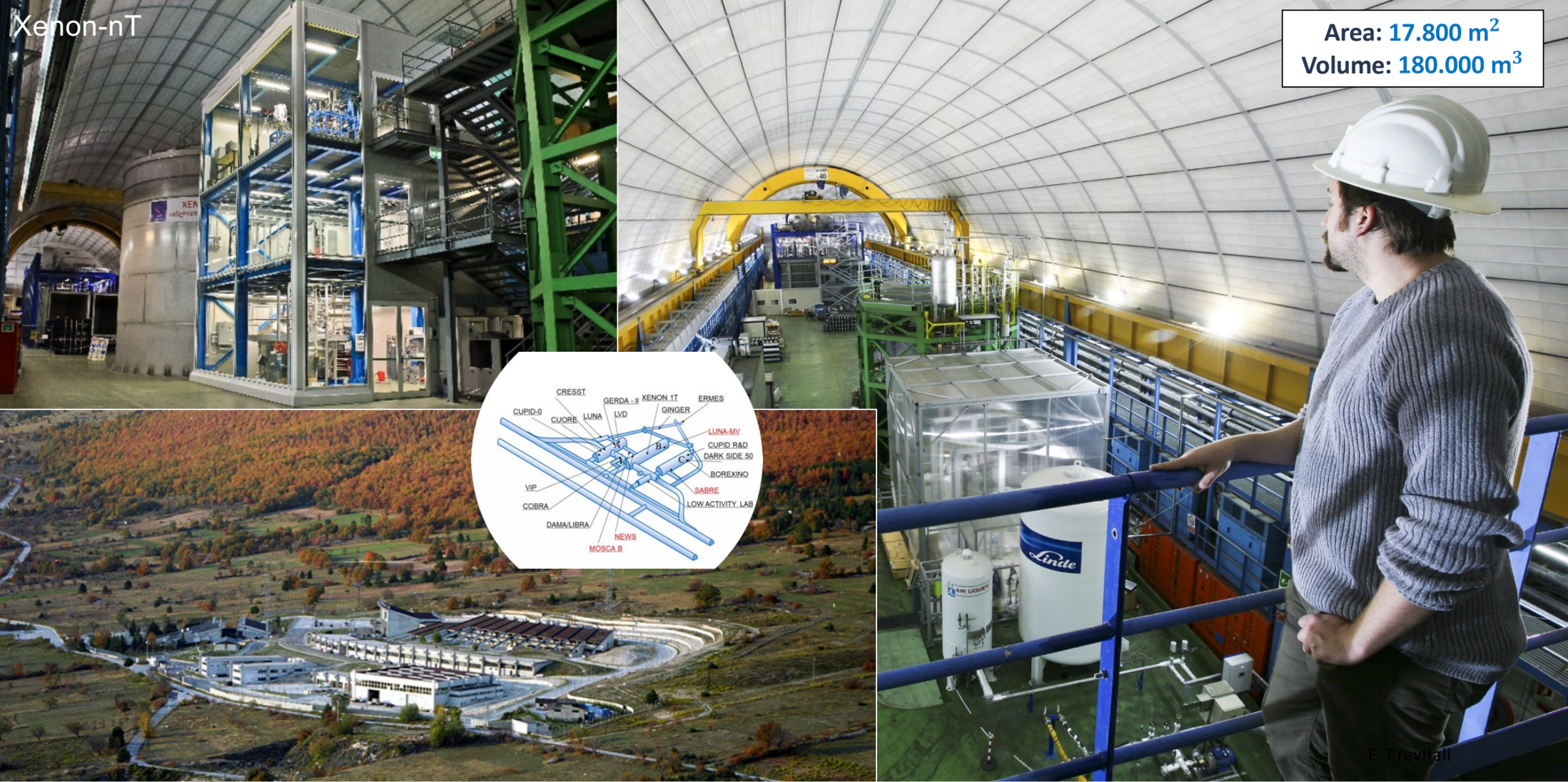- Laboratory for very low radioactivity measurements

Area: 17.800 m^2
Volume: 180.000 m^3

3800 m.w.e.

1.1 μ / (m² h)

LNGS / Gran Sasso Deep Underground Lab

Xenon-nT

Area: 17.800 m^2
Volume: 180.000 m^3

CRESST
CUPID-0   GERDA - II   XENON 1T   ERMES
CUORE   LUNA   LVD   GINGER
LUNA-MV
CUPID R&D
DARK SIDE 50
BOREXINO
VIP
SABRE
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA
NEWS
MOSCA B

E. Previtali

Gran Sasso Science

Neutrino Astrophysics

LVD

BOREXINO

LUNA
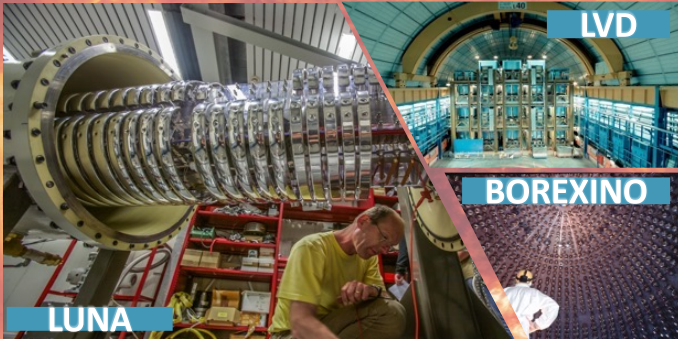
Nuclear Astrophysics

Dark Matter Search

CRESST

DAMA

DarkSide

XENON

TOTAL USERS: N. 981
ITALIAN USERS: N. 417
FOREIGN USERS: N. 564

Belgio · Olanda · Germania · Italia · Austria · Croazia · Polonia
Svizzera · Svezia · Ungheria · Canada · Russia · Cina · Stati Uniti · Ucraina · Brasile · India
Portogallo · Spagna · Regno Unito · Francia · Creta · Romania · Israele · Emirati Arabi · Australia

- ITALY
- USA
- GERMANY
- RUSSIA
- FRANCE
- SWITZERLAND
- UKRAINE
- SPAIN
- AUSTRIA
- CHINA
- UK
- POLAND
- NEDERLANDS
- ISRAEL
- ROMANIA
- PORTUGAL
- SWEDEN
- HU
- BRAZIL
- UAE
- BELGIUM
- INDIA
- CROATIA
- CRETE
- CANADA

Neutrinoless Double Beta Decay

CUPID

GERDA/LEGEND

CUORE

...... 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

Boulby Underground Laboratory (UK)

Boulby Science Now & Future

Particle physics and ultra-low background studies

Multidisciplinary Science

Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.
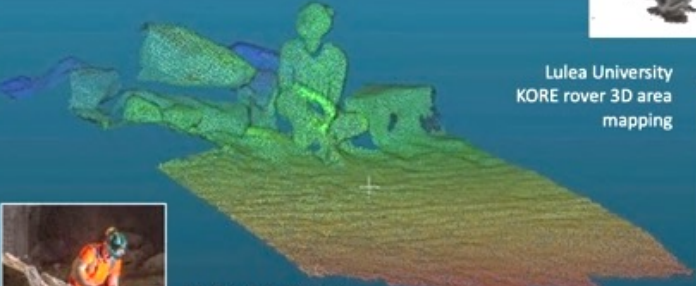
Boulby Activities Now and Potential Future

Now

Current Projects	Status
CYGNUS - DM R&D	E/P
News-G - DM R&D	A
BUGS: Ge, XIA, RnEm - Material Screening	A
RECON - Nuclear Security R&D	A
BUTTON – Nuclear security R&D	A
Muon Tomog – CCS & undersea Geoimaging R&D	A
RESOURCE – Energy store R&D	A
Seismology/AION R&D	A
BISAL – Biology/Astrobiology	A
MINAR – Planetary Exploration Tech development	A
Misc. Other. SELLR, C14, Adrok, BIO-SPHERE…	A/P
Outreach/ Education - Misc events, progs, Remote3…	A

Particle Physics & Low Background
Earth & Environmental
Astrobiology & Planetary Exploration

Status: A = Active, P = Paused, E = End,
I = Interest confirmed

2023-2030

Medium Term (Current Lab + mods)	Status
BUGS: Ge, XIA, RnEm, ICPMS - Material Screening	A/P
BUTTON-30 – Nuclear security R&D	P
RECON+ - Nuclear Security R&D	A/P
DarkSPHERE – DM Search	I
DATUM – Neutrino Tech R&D	I
SoLAr, SOLAIRE – DM/Neutrino R&D	I
AION-100 & 1000 R&D	I
Seismology Array – Geosurvey R&D	I
RESOURCE+ – Energy store R&D	A/I
Muon Tomog – CCS & undersea Geoimaging R&D	A/I
BISAL+ – Biology/Astrobiology	A/I
MINAR+ – Planetary Exploration Tech development	A/I
Misc. Other. Quantum Computing Tech R&D	-
Outreach/ Education: General Public, Schools +	A

2030-2040+

Long Term (Current lab plus major new lab)

Particle Physics and Low Background Science:
Dark Matter: Major Next Gen Experiments:
- Xenon (XLZD)
- Argon (DarkSideLM+)
- Gas (DarkSPHERE+)

Neutrinos:
- BUTTON-100+
- DATUM (LEGEND Support),
- SoLAr / SOLAIRE+

Mat screening & LB Techniques: A world's best facility:
- Ge, XIA, RnEm, ICPMS, Cleanliness & Engineering R&D

Misc Other:
- AION-100
- AION 1000
- Nuclear Security Gamma spec
- Quantum Computing Tech R&D & Operation

Earth & Environmental Science:
- Sustainable Energy R&D
- Seismology Observatory
- Geological Repositories R&D
- Misc geology / Geophysics R&D

Astrobiology & Planetary Exploration:
- Extremophile R&D
- Astrobiology / life beyond Earth R&D
- Human habitation R&D
- Planetary exploration technology development
- Robotics and AI
- Mining and industry application development.

Outreach and Education:
- A National Centre for Science and technology outreach and education.

Target projects for a major new UK underground facility / campus

Boulby Facility Expansion Plans

Boulby-FS (2020-21) Overview:

- **Community-led study of motivation, context and practicalities of creating a major new deep underground science facility in UK**

- Infrastructure specifications for potential projects (Dark Matter, Neutrinos & more).

- Conceptual designs for excavations and outfitting laboratories in 1.1km (Salt) and 1.4km (Polyhalite) layers

- Staffing and surface facility needs.

- Detailed costs and schedules.

LZ @ SURF. Next generation in the UK?
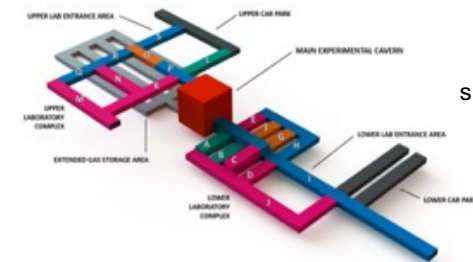
New lab specifications & designs
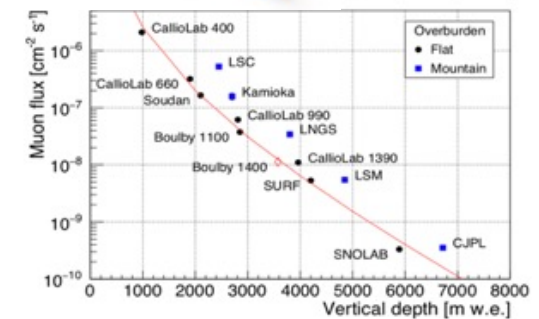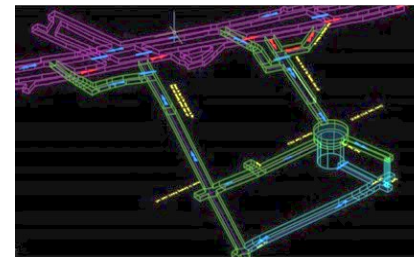
Government 'fit': Levelling Up, Strength in Places, Build Back Better, UK Science Superpower…

Boulby Now looking to EXPLAND to host next generation astro-particle physics projects from 2030+

World deep underground laboratories…

Boulby Underground Laboratory (UK)
Working Mine, 2850 mwe
Current vol: 7,200m^3
ZEPLIN+ (past), BUGs, News-G,
RECON, Multi- sci, BUTTON (to come)

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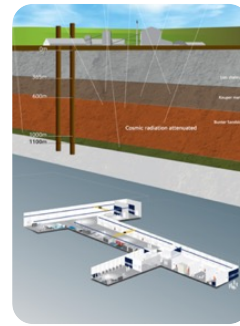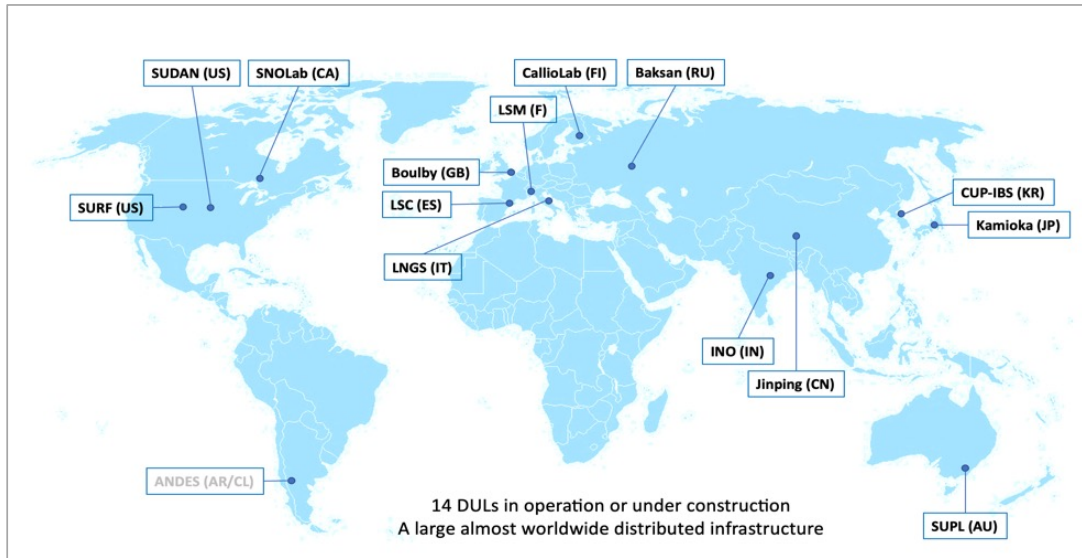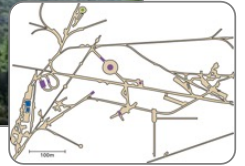
Gran Sasso National Laboratory
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Upcoming and Future Underground Science Projects

Particle / Astroparticle Physics
- Direct dark matter searches
- Atmospheric, solar and supernova neutrinos
- Reactor and accelerator neutrinos
- Neutrino-less double beta decay
- Nuclear astrophysics / stellar reactions
- Misc. rare-decay processes

Other 'Multi-disciplinary' studies
- Pure and applied cosmic ray studies,
- ULB Gamma spectroscopy
- Earth & Environmental Sciences
- Biology / Geo-microbiology
- Astrobiology and planetary exploration
- Quantum sensors, quantum computing
- Etc…

Projects are varied, technologically innovative, challenging, impactful, exciting & GROWING.

Super-Kamiokande
Kamioka, Japan
50kT $_{Gd-H20}$
Solar, Atmospheric &
SN Neutrinos
1996 – now.

Lux-ZEPLIN (LZ)
SURF, USA
10T (7T) LXe
Dark Matter search
2022 - now

Upcoming and Future Underground Science Projects

Selected Astroparticle Physics Projects…

Operating:
LZ: DM, LXe - SURF, USA.
Super-K: Neutrinos, Gd-$H_2$0 - Kamioka, Japan
KamLAND: Neutrinos, LS - Kamioka, Japan
CUORE: 0vBB, HPGe – LNGS, Italy
PandaX: DM, LXe – CJPL, China
CDEX: DM, HPGe – CJPL, China
LEGEND-200: 0vBB, HPGe – LNGS, Italy
XENON-nT: DM, LXe – LNGS, Italy
SNO+: 0vBB, Te-LS – SNOLAB, Canada

Under construction:
DarkSide-20k: DM, Lar – LNGS, Italy
SuperCDMS: DM, HPGe - SNOLAB, Canada
NEXT-100: 0vBB, Xe – LSC, Spain
JUNO: Neutrinos, LS – Jiangmen, China
DUNE: Neutrinos, LAr, SURF, USA
HyperK: Neutrinos, Gd-$H_2$0 - Kamioka, Japan

Selected Nuclear astrophysics Projects

LUNA: 400kV Accelerator – LNGS, Italy
JUNA: 400kV Accelerator – CJPL, China
CASPAR: 1MV Accelerator – SURF, USA

Selected Future Projects
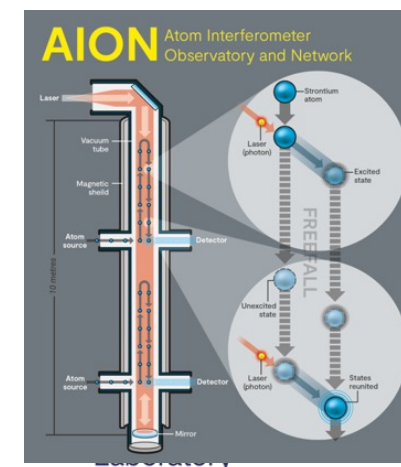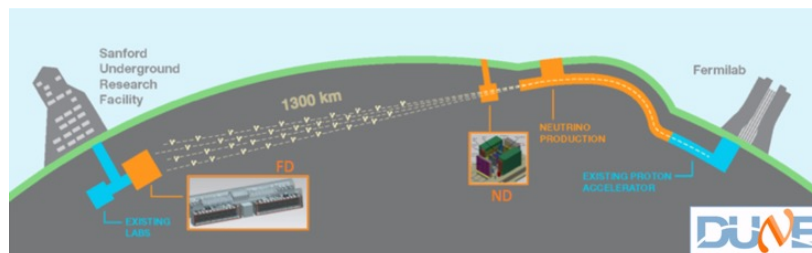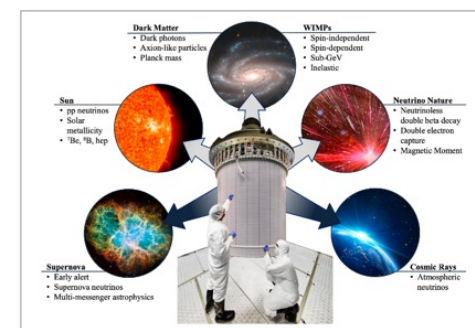
LEGEND-1000: 0vBB, 1000kg HPGe
nEXO: DBD, 0vBB, 5000kg Xe
CUPID: 0vBB, 250kg Li_2MoO_4
XLZD: DM, 40-100T Lxe
ARGO: DM, 300T, LAr
AION 100 & 1000: DM & Grav. Waves,
                          Atomic Interferometer.

Summary & Some QUESTIONS...

Summary:

The world's underground laboratories are numerous and varied. These are special places for pure and applied science, innovation, outreach and education.

The underground science projects hosted by these laboratories are varied, technologically innovative, challenging, impactful, exciting, busy - and <u>GROWING</u>

QUESTIONS:

1) How can we make best use of the current underground science facilities – to serve the world science communities most effectively:
- Inter-laboratory communication and cooperation -> sharing practices?
- Some central coordination of facilities?
  - Available facility experimental space?
  - Available facility support services? E.g: Low background material screening.

2) Are underground science laboratories interacting sufficiently with national or international SURFACE facilities:
- Are they getting support they need from surface labs?
- Are their services being effectively/widely exploited by surface lab or wider community?
- Are underground facilities sufficiently visible?