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Underground Laboratories

A rapid expansion of the numbers // explosion of interest in underground science

- Motivations

Status of the various facilities

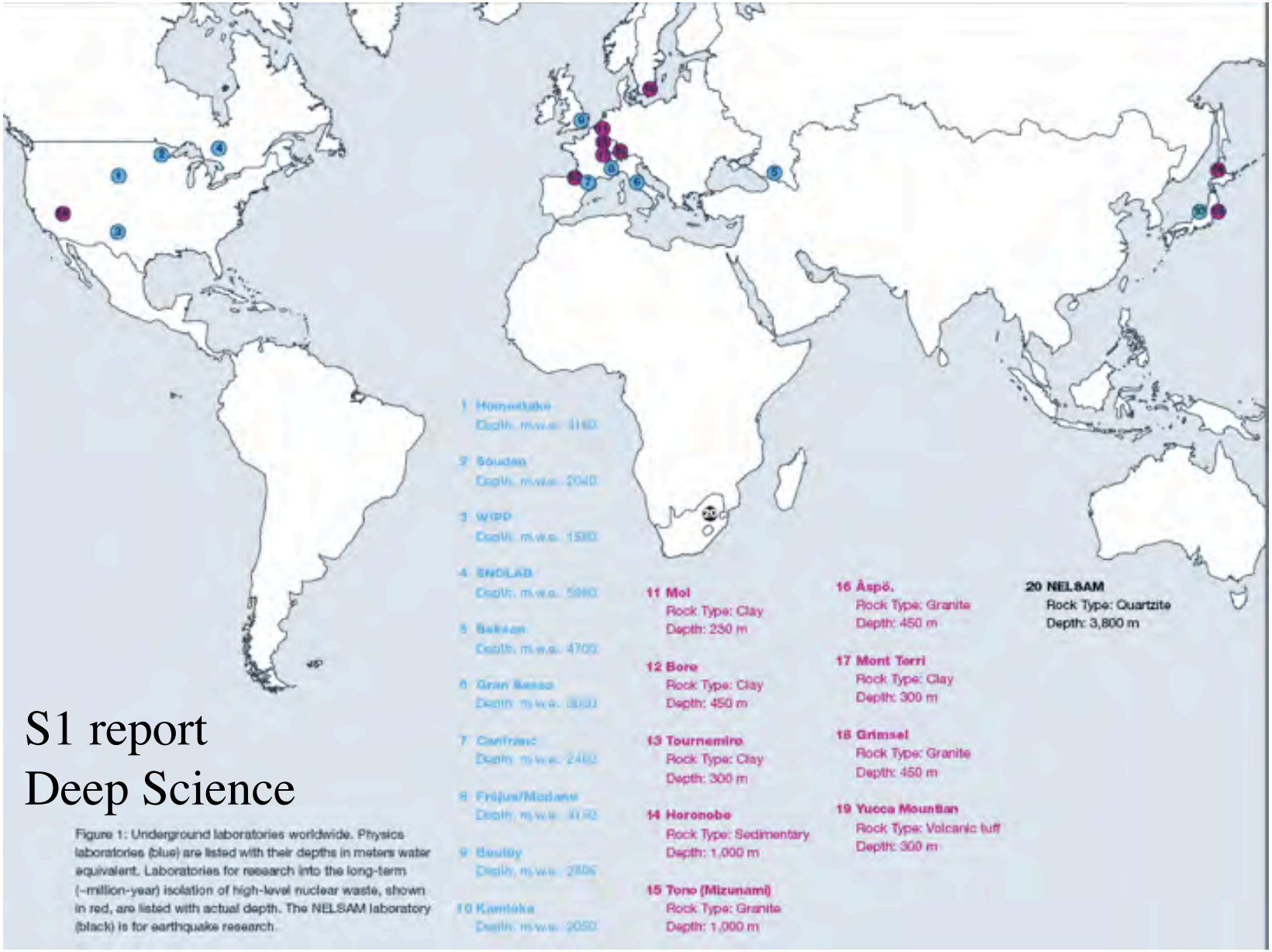
- Established laboratories
- New comers

The US project: DUSEL

- Status in decision process
- Plans

cf Eugenio Coccia talk at TAUP 09:
http://taup2009.lngs.infn.it/slides/jul5/coccia.pdf

Main Underground Science Laboratories



S1 report
Deep Science

Figure 1: Underground laboratories worldwide. Physics laboratories (blue) are listed with their depths in meters water equivalent. Laboratories for research into the long-term (~million-year) isolation of high-level nuclear waste, shown in red, are listed with actual depth. The NELSAM laboratory (black) is for earthquake research.

Fast increase of facilities

Explosion of interest in underground science

- Physics
  - Dark Matter
  - Double beta decay
  - Nuclear astrophysics
  - Proton decay
  - Long base line neutrino
- Biology
- Geology
- Engineering

Convenience of proximity

- R&D
- Less travel away from lab, teaching and family

Local/regional support

- Interest of funding agencies
- Regional economic development agencies
- Mining or hydroelectricity industry

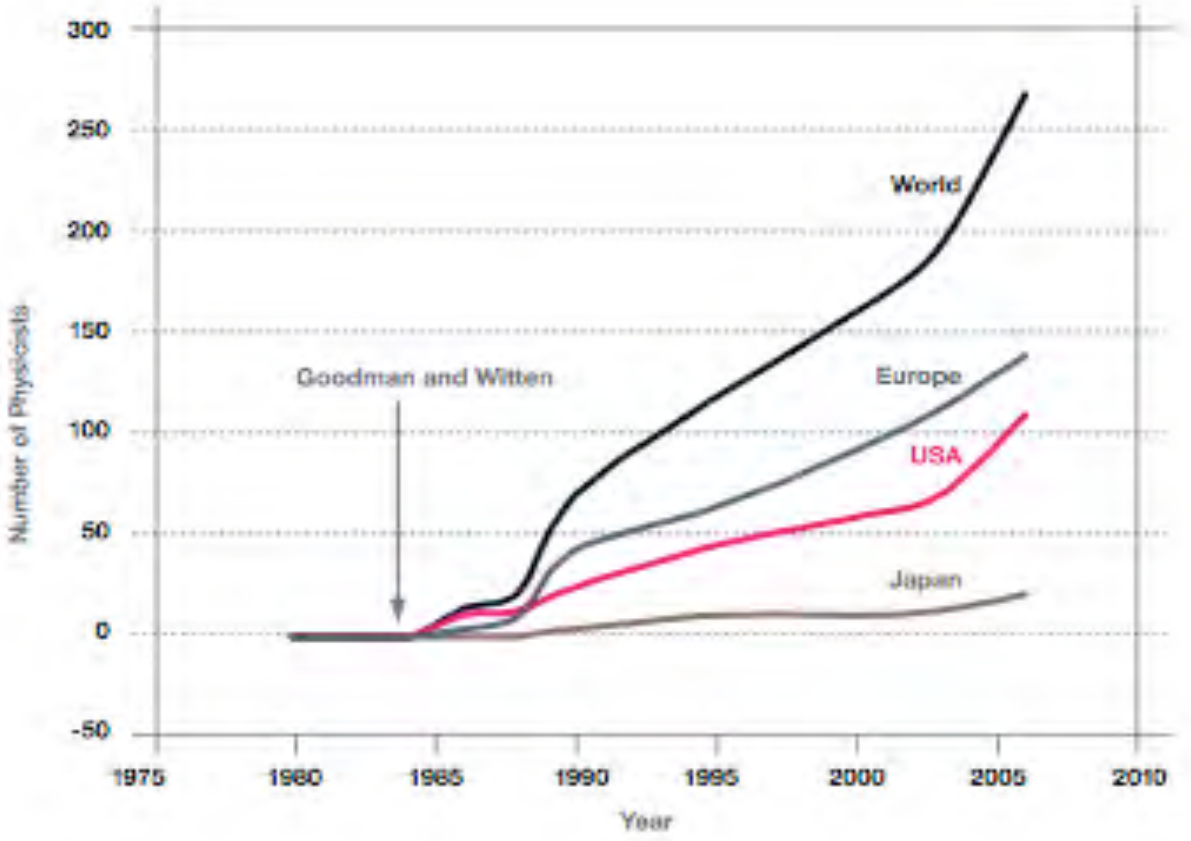
Some pleasant (and less pleasant) places...

- Unfortunately not Hawaii

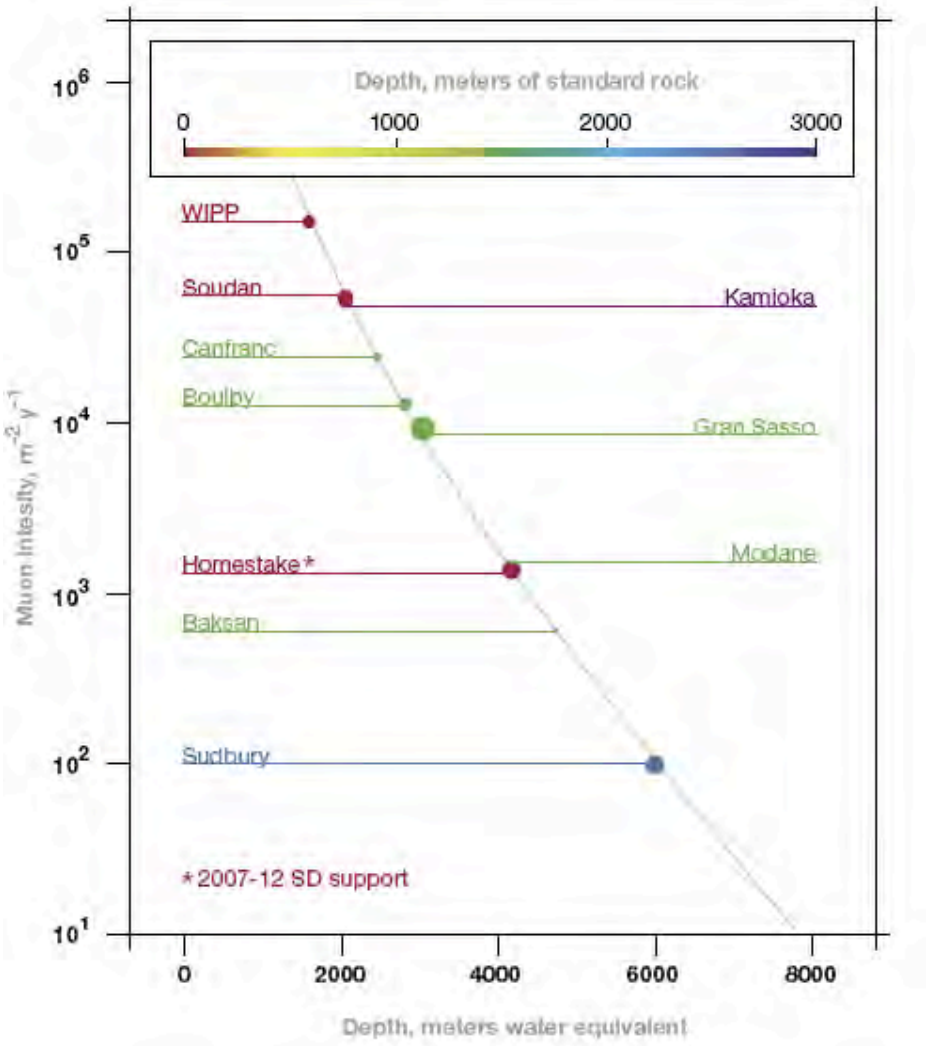
Increase of Underground Community

Importance/interest of the science: neutrinos, cosmology
Shift from accelerator based experiments
Fast progress at boundaries between fields

Example: Dark Matter

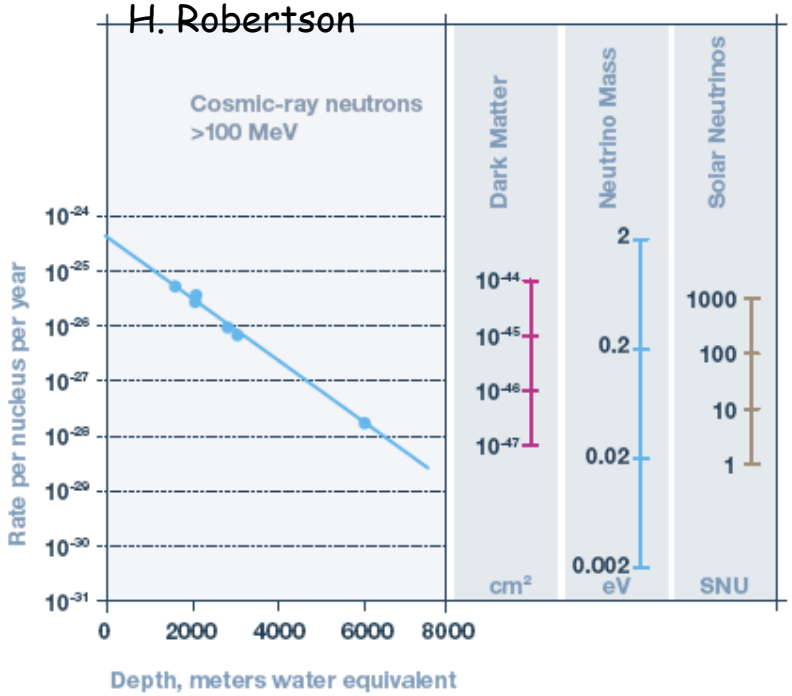


Why deep?

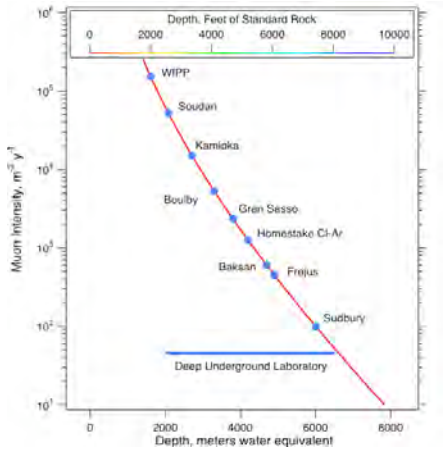


Before additional tricks

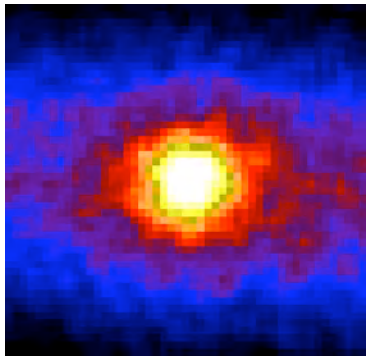
H. Robertson



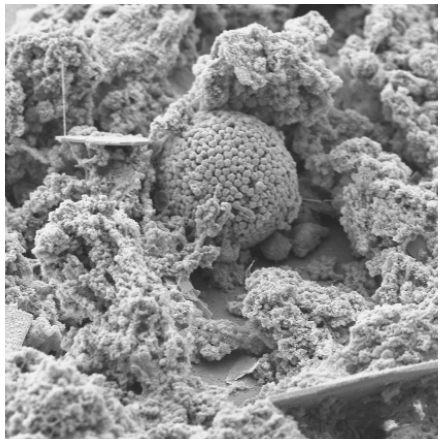
Why deep?



Neutrino picture of the Sun

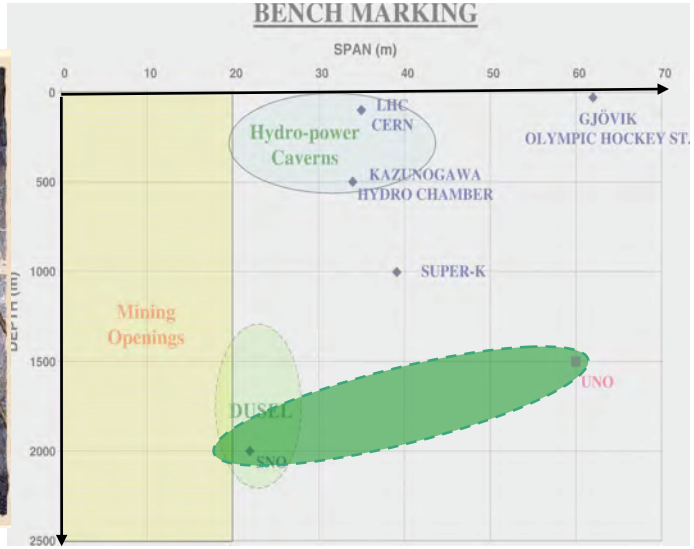


Geo-microbes



Ground Truth

Large Block Geo Experiment
Coupled Processes



Size of cavity vs depth

Undergraduates in South Africa mine

Scientific Motivation

Extraordinary increase of interest in underground science and engineering

3 Fundamental Questions that uniquely require a deep laboratory

- What is the universe made of?
  What is the nature of dark matter?
  What happened to the antimatter?
  What are neutrinos telling us?
  - Particle/Nuclear Physics: Neutrinos, Proton decay
  - Astrophysics: Dark Matter, Solar/Supernovae neutrinos

- How deeply in the earth does life extend?
  What makes life successful at extreme depth and temperature?
  What can life underground teach us about how life evolved on earth and about life on other planets?
  - Unprecedented opportunity for long term in situ observations

- How rock mass strength depends on length and time scales?
  Can we understand slippage mechanisms in high stress environment, in conditions as close as possible to tectonic faults/earthquakes?
  - Earth Sciences: Mechanisms behind the constant earth evolution
  - Engineering: rock mechanics at large scales, interplay with hydrology/chemistry/biology

The Frontier is at Large Depth!

Physics

Neutron and activation of materials
- Neutrinoless double beta decay
- Dark Matter
- Neutral current/ elastic scattering solar neutrino
- New ideas

Neutron active shielding (300MeV) is difficult and risky
Rejection of cosmogenic activity is challenging

Biology

DUSEL = aseptic environment at depth
Study microbes in situ (at constant pressure, microbial activity at low respiration rate)
Deep campus: Platform to drill deeper -> 12000ft (120°C)

Earth science/ Engineering

Get closer to conditions of earthquakes
Behavior of rock on large scale

Other Motivations

Exciting potential for cross disciplinary synergies

Pushing the rock mechanics envelope <-> physicists needs for large span cavities at great depth

"Transparent earth" Improvement of standard methods + new technologies

Geoneutrinos, Neutrino tomography of the earth?

Sensors, low radioactivity, education etc…

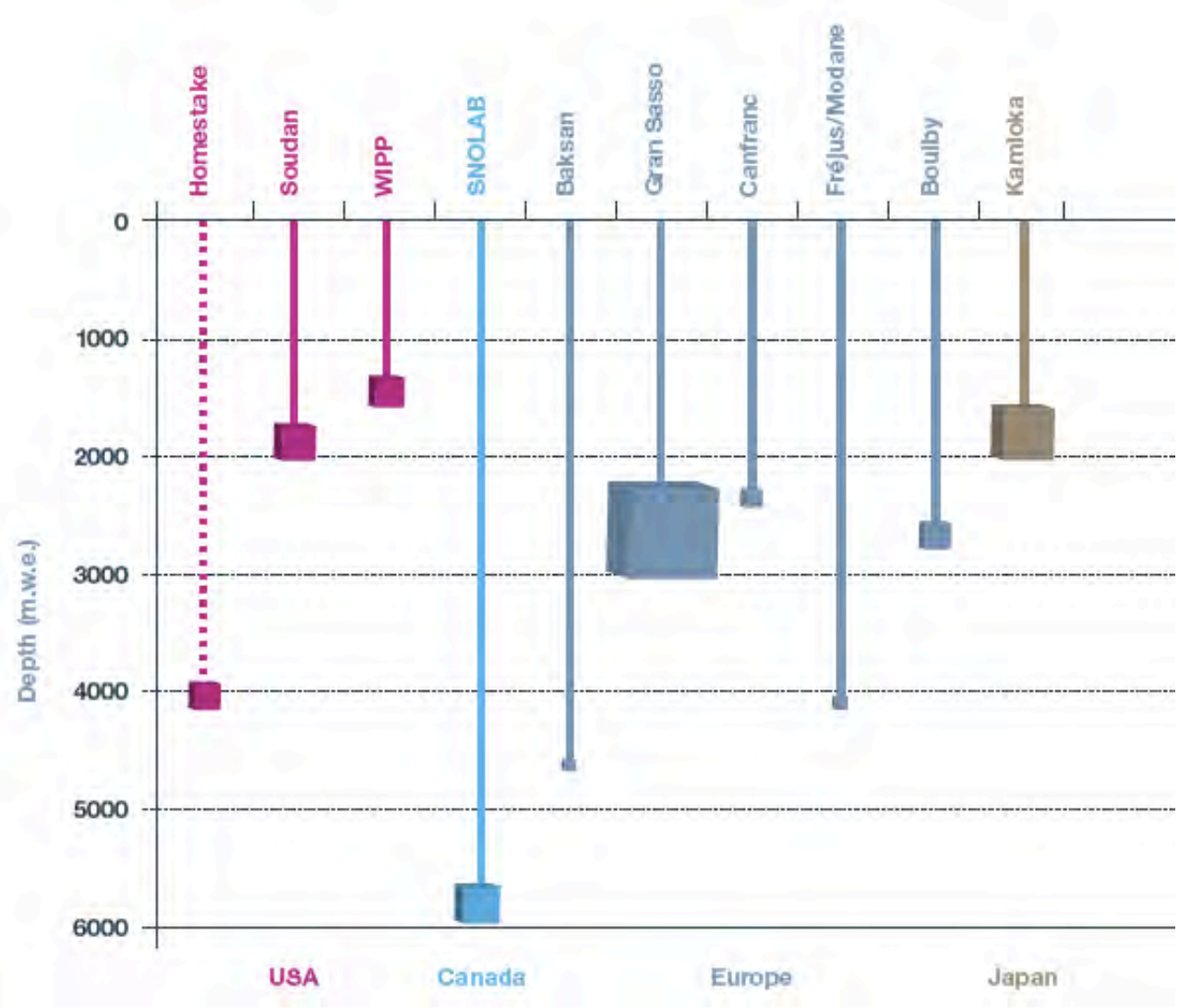
Relevance to Society

- **Underground construction**: the new frontier (urban, mining,fuel storage)
- **Resource extraction**: Critical need for recovery efficiency improvement
- Water resources:
- **Environmental stewardship**
  - Remediation (e.g. with micro-organisms)
  - Waste isolation and carbon dioxide sequestration.
- **Risk prevention and safety**
  - Making progress in understanding rock failure in structures and earthquakes
- **National security**
  - Ultra sensitive detection methods based on radioactivity

Training next generation of scientists and engineers

+ public outreach: better understanding of science

Major Facilities Situation 2006

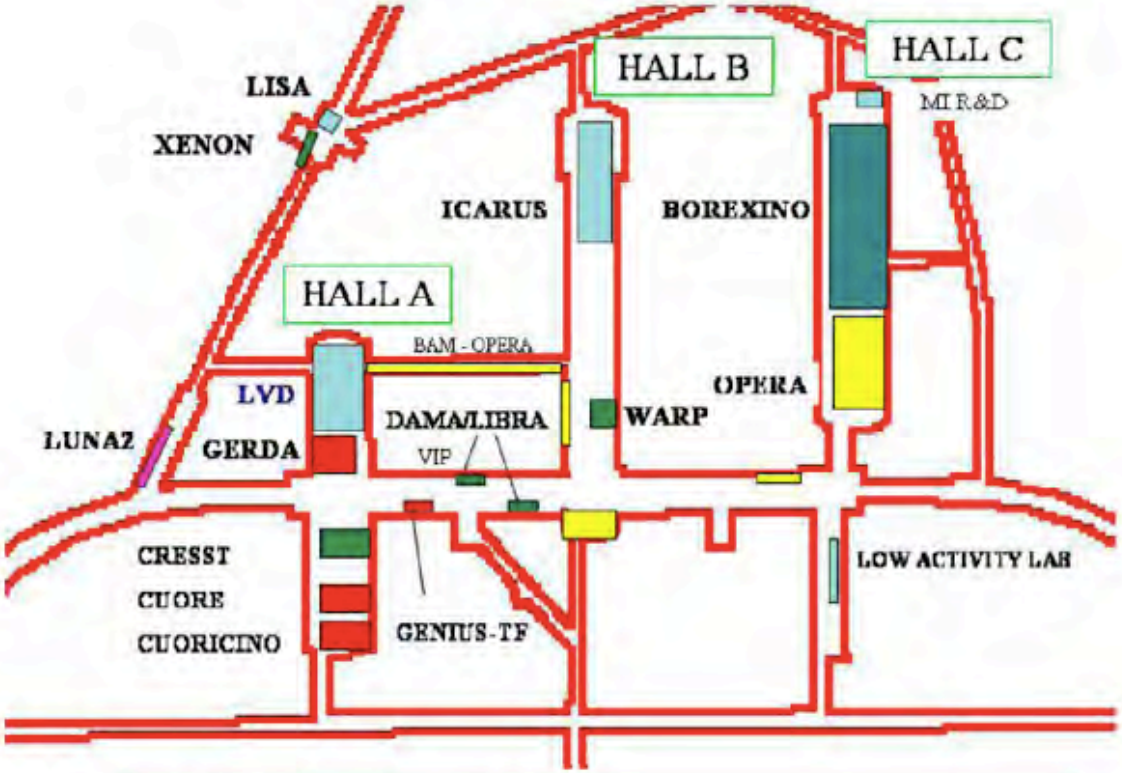


Baksan

Unfortunately

Largest hall, 40 000 m3, construction stopped in 1992, when SU collapsed

Gran Sasso



MODULAr perspective

- LAr TPC - ICARUS @ 20 kt scale
- new facility at shallow depth (1.2 km w.e.)
- 10 km off axis the CNGS beam line
- new neutrino source at CERN 1.6 MW beam power

28-Aug-09

L'Aquila Earthquake

6 April 2009

300 dead; 15 000 injured;
60 000 homeless

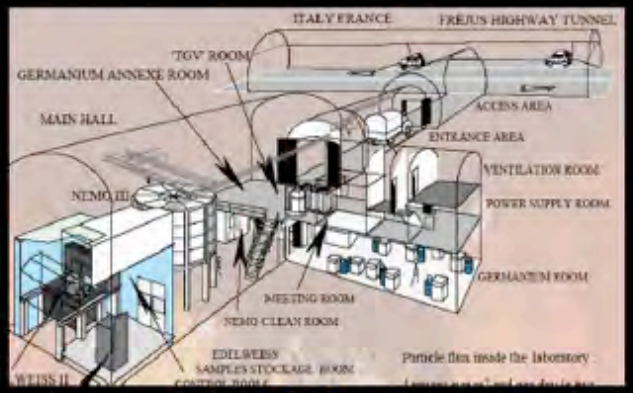
Lab not affected

0.03 g instead of 0.64g in L'Aquila (0.15g in external lab)

Operation restarted 29 April

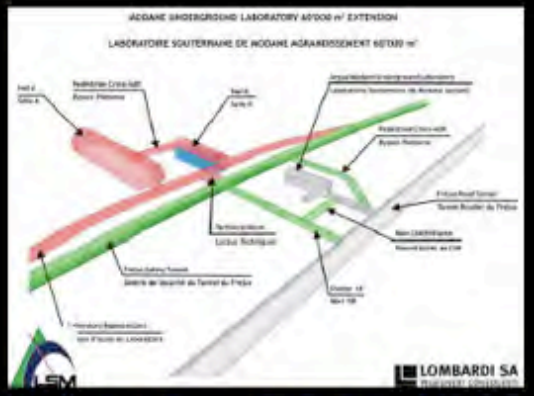
Laboratoire Souterrain de Modane

IN2P3 (CNRS) and DAPNIA (CEA) run the Modane Underground Laboratory (LSM)
The Lab Facilities are composed by:

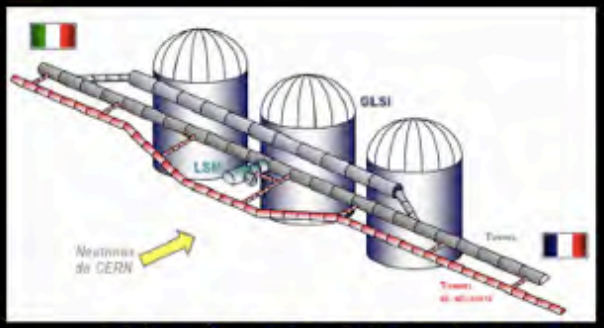


A cavity of about 3'500 m3 at middle of Fréjus Road Tunnel in French Territory

External LSM buildings (construction 2008)



LSM Project for a 60'000 m3 extension to be constructed according to on-going projects (safety tunnel)

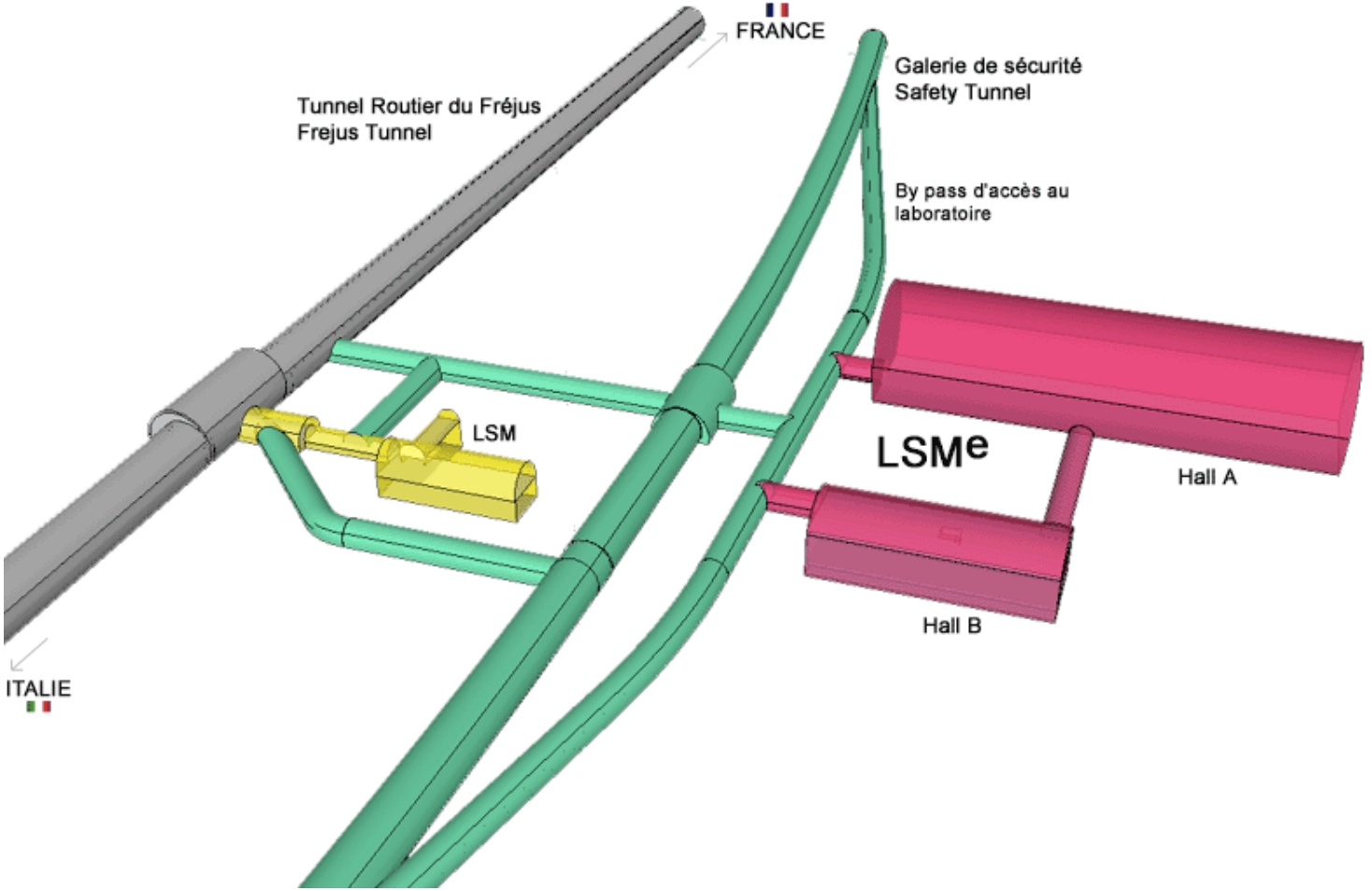


Project for Large scale underground laboratory (1'000'000 m3)

Extension of Modane (Frejus)

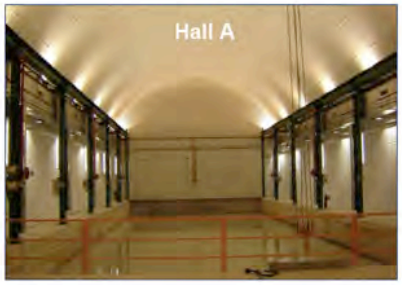
Access: early 2013

20x15x100 m^3 and 20x15x50 m^3 plus smaller dependencies with a total available volume of 60 000 m^3 = 20 times existing facility



Canfranc

Experimental halls A, B and C



Depth: 800 m

Muons: 0.47 μ x 10^{-2} m m^{-2} s^{-1}

Ventilation: 11.000 m^3/h

RECONSTRUCTION/REINFORCEMENT CIVIL WORKS STARTED IN JUNE. FORESEEN DURATION = 10 MONTHS

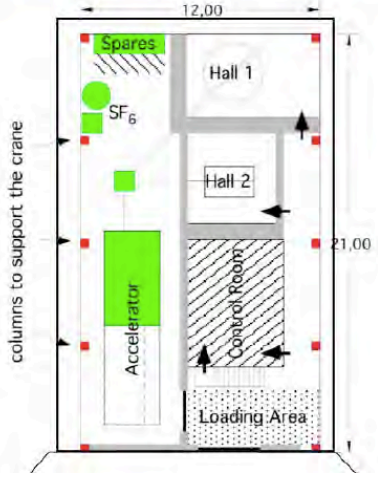
- ✓ EXP-01-2008 (ANAIS) — Dark Matter (NaI, Annual modulation) — Direct check of DAMA/LIBRA result
- ✓ EXP-02-2008 (ROSEBUD) — Dark Matter (Scintillating bolometers) — Integrated in the European EURECA project
- ✓ EXP-03-2008 (BiPo) — $0\nu2\beta$ decay (extra-low surface background) — Ancillary to Super-NEMO
- ✓ EXP-04-2008 (ULTIMA) — Super-fluid ^{3}He physics — To be screened by muon background
- ✓ EXP-05-2008 (NEXT) — $0\nu2\beta$ decay (Enriched ^{136}Xe TPC)) — Majorana vs Dirac neutrinos; CUP Consolider
- ✓EoI-02-2005 (ArDM) — EoI on Dark Matter (Liquid Argon TPC) — In risk analysis phase

GEODYN Facility

- Two LASER interferometers
- Broad-band and strong-motion seismometers
- GPS surface stations
- Integrate in the TOPO-IBERIA Consolider

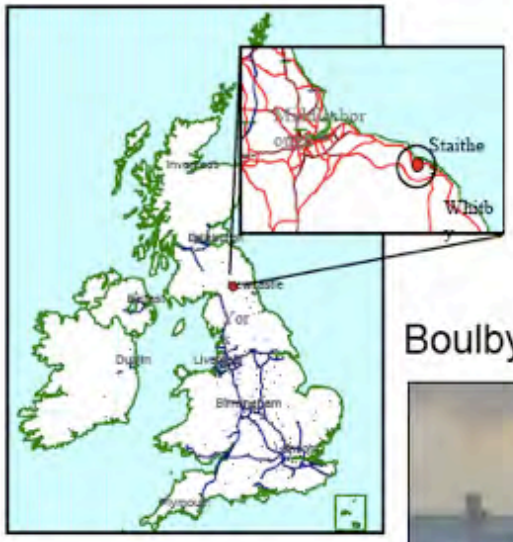
CUNA, Canfranc Nuclear Asrtophysics facility

- New dedicated hall & Accelerator (about 3 MeV)
- Develop synergic program with LNGS
- Dedicated scientific Workshop in Barcelona 19-20 Feb 2009



Boulby

- Boulby is **a working potash mine** in the North East of England. Operated by Cleveland Potash Ltd – a major local employer.
- **1100m deep** (2805 mwe giving ~10^6 reduction in CR muons).
- Surrounding **rock-salt = low activity** giving low gamma and radon backgrounds.

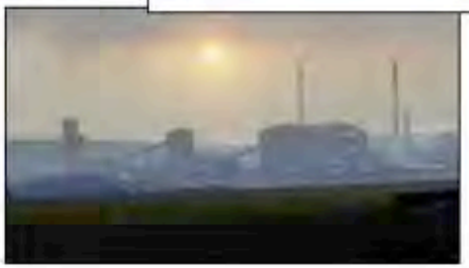


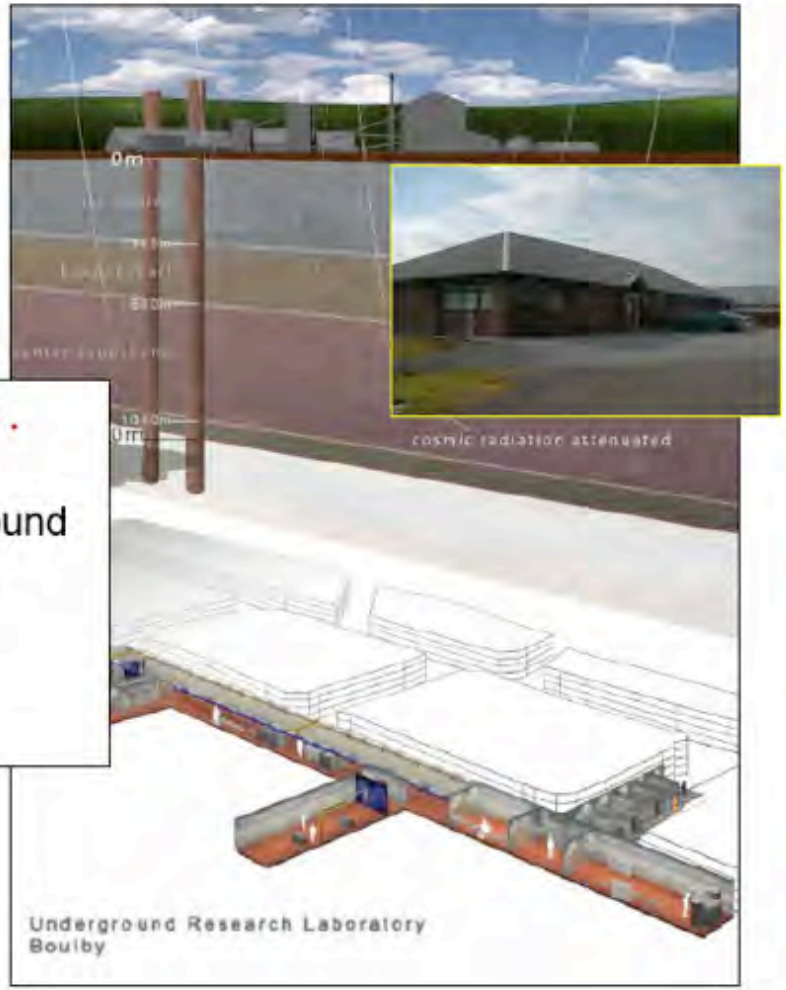
JIF facilities - 2003 .

> 1000 m^2, fully equipped underground 'Palmer lab'

> Surface support facility.

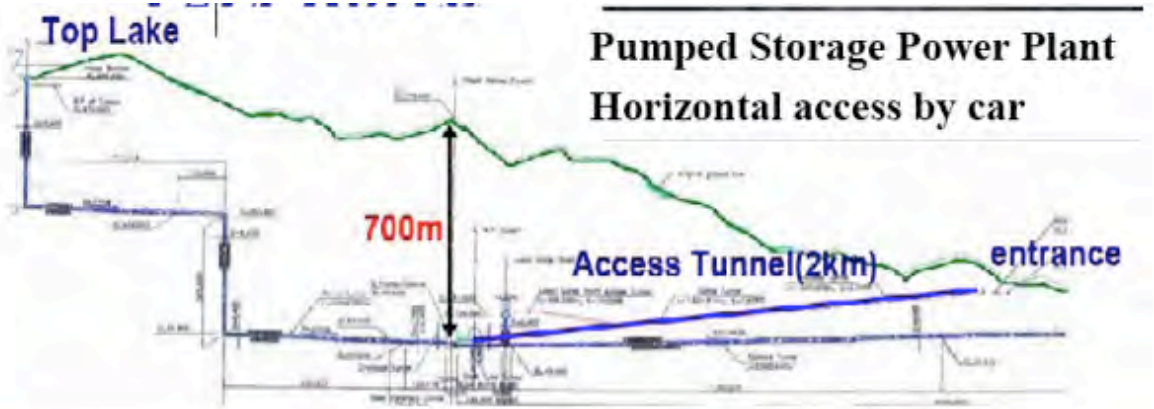
Boulby Mine





Y2L Korea

Operated by Dark Matter Research Center of Seoul University in the YangYang



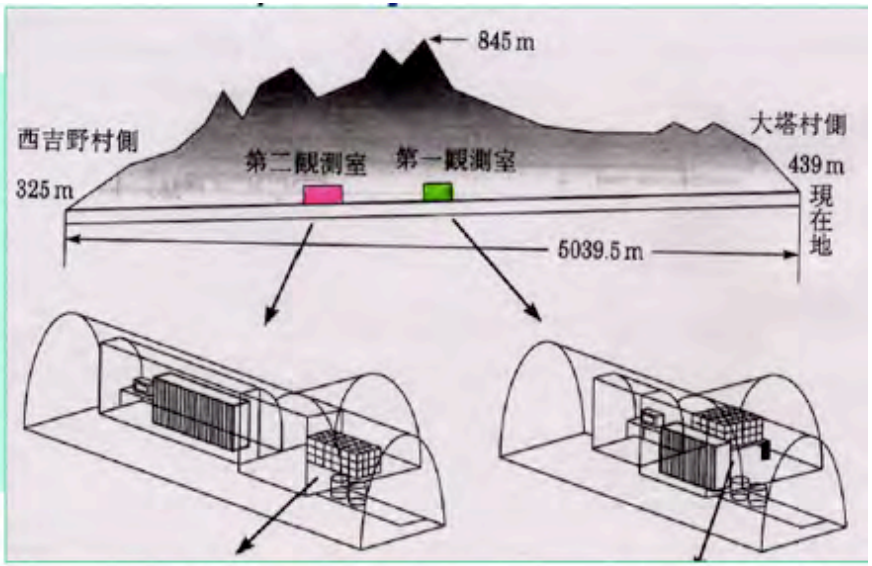
Pumped Storage Power Plant
Horizontal access by car

- Overburden: 700 m, ≈ 2 km w.e.
- Available area≈100 m^2 (possibly 800 m^2 if funded)
- Muon flux: $\phi_\mu = 2.7 \times 10^{-3}\ m^{-2}s^{-1}$
- Radon: 40-80 Bq/m^3
- Neutrons: $\phi_n = 8 \times 10^{-3}\ m^{-2}\ s^{-1}$ $1.5<E<6.0$ MeV

Science
KIMS, WIMP search with CsI(Tl) crystal detectors. Data taking ⇒ 100 kg in 2007
R&D for ββ
HP Ge detectors

Oto Cosmo Laboratory,Japan

- Horizontal access (unused railway tunnel)
- Overburden ≈ 470 m (1.4 km w.e.)
- Available area (Labs I, II, III)≈ 100 m^2
- μ flux: $\phi_\mu = 4 \times 10^{-3}\ m^{-2}s^{-1}$
- Radon: 10 Bq/m^3 (in "Rn-free" containers)
- Neutrons: $\phi_n = 4 \times 10^{-2}\ m^{-2}\ s^{-1}$
- Users 20



Users ≈ 20
DBD
ELEGANT V (^{100}Mo)
DM
MOON-1 NaI
DBD+DM
ELEGANT VI (^{48}Ca)(CaF_2)

28-Aug-09

Kamioka, Japan

≈2000m.w.e.

Tohoku University
KamLAND

Ge

Hall A: 21x15x15m³
Hall B: 11x6x11m³

New Experimental Halls
XMASS, CANDLES

Super-Kamiokande

T2K
April 09

Clean room
ICP-MS
XMASS R&D

To Atotsu entrance

GAZOOKS! Test tank
Under construction

IPMU lab.
API-MS, Ge

NewAGE (DM)
Super-Conductive Gravity meter

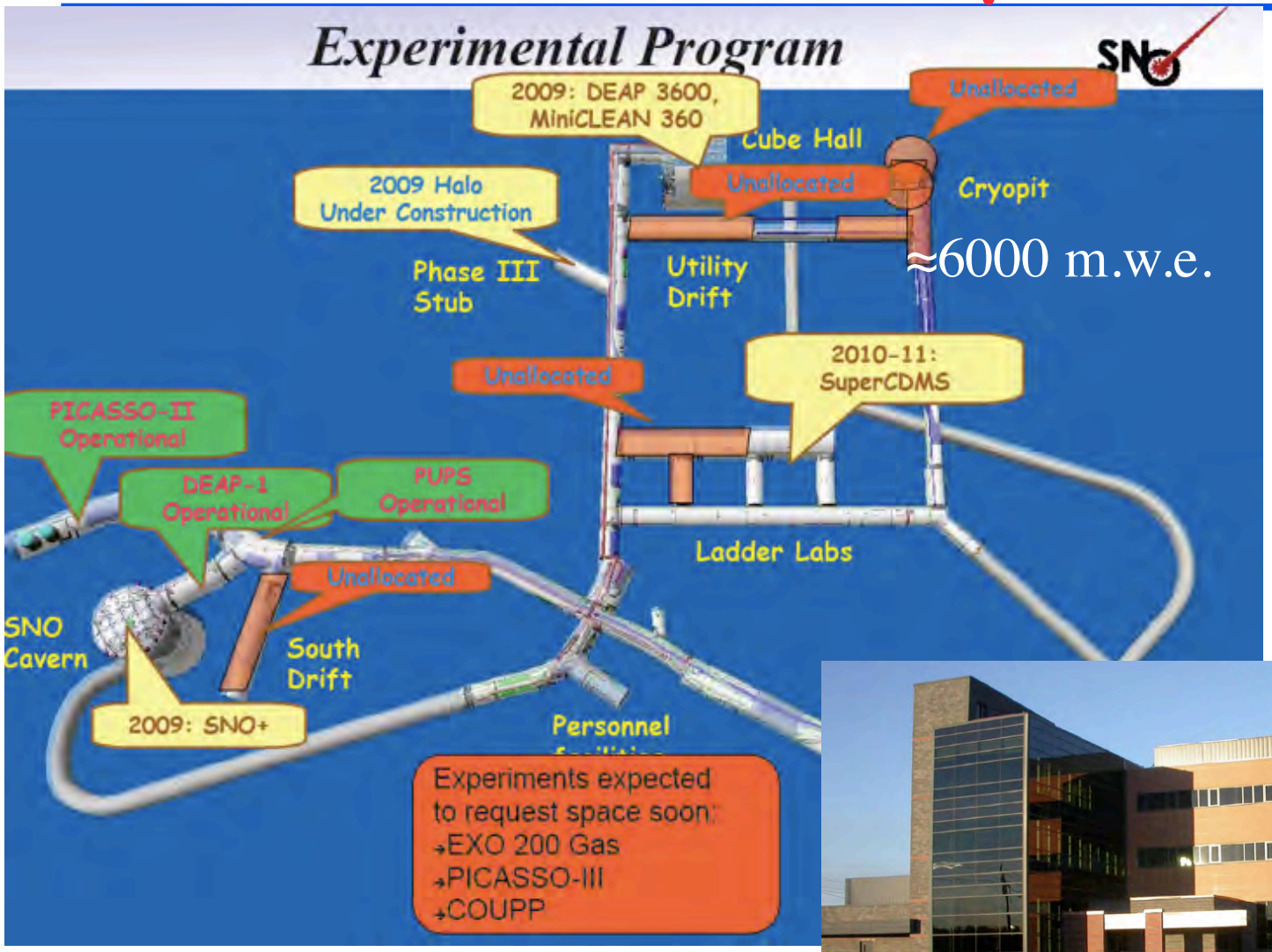
CLIO (GW) 100m prototype
Laser strain meter

200m

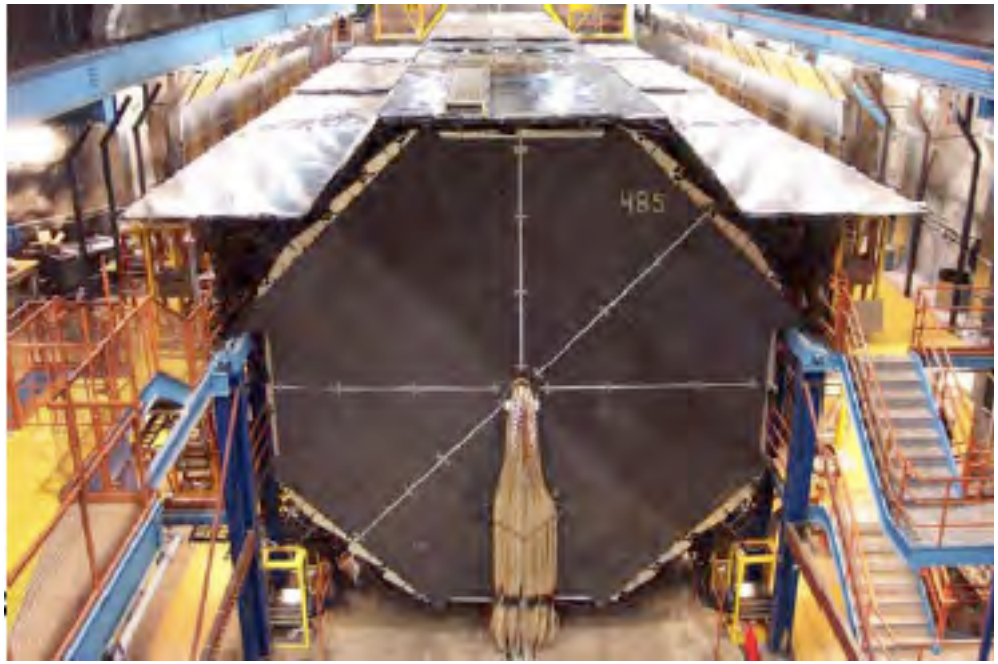
Proprietary area

2009/7/1 Kamioka Observatory (Y. Suzuki) 3

SNOLAB, Sudbury, Canada



Soudan, MN, USA



MINOS

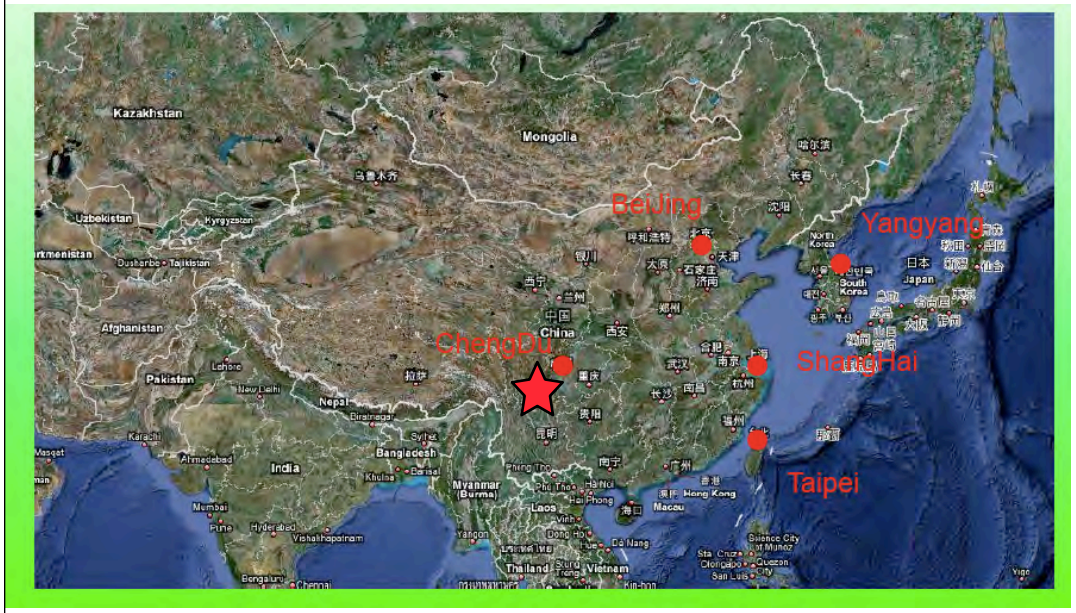
CDMS

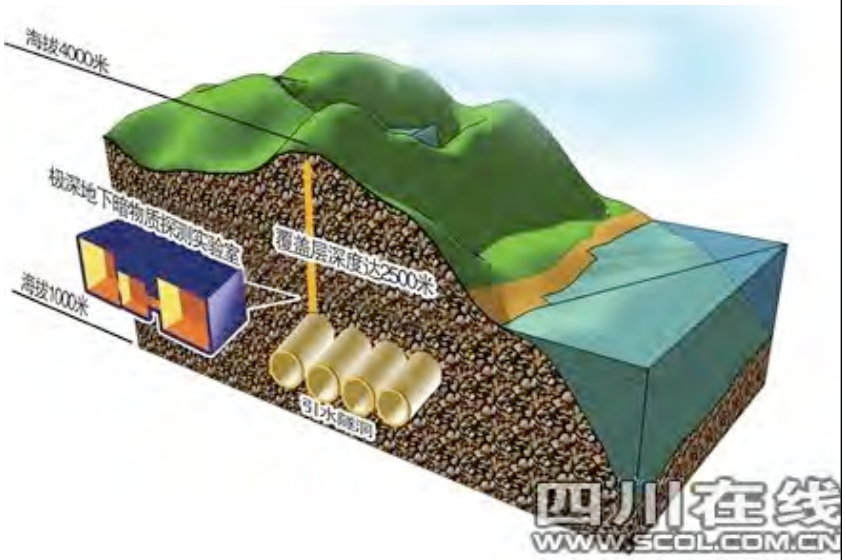
≈ 2000 m.w.e.
+ Low background counting facility
Operation at least to 2012

WIPP

≈ 1500mwe salt nuclear material repository
EXO 200kg

JinPing China Deep Underground Lab.

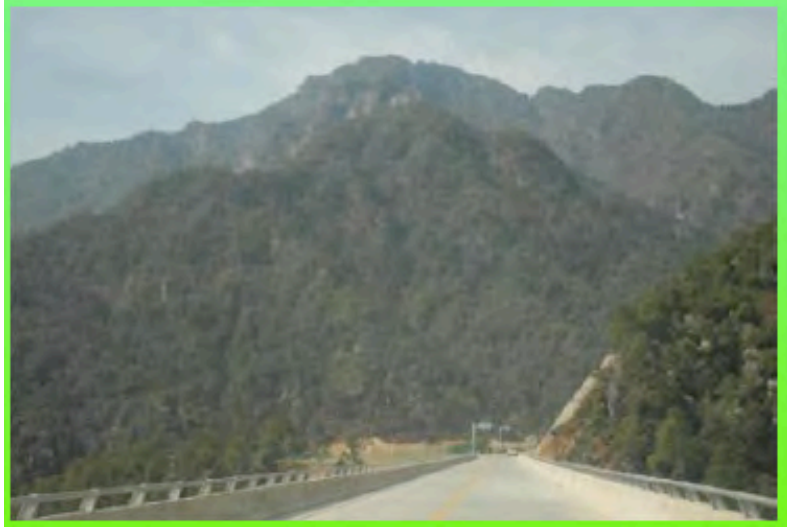




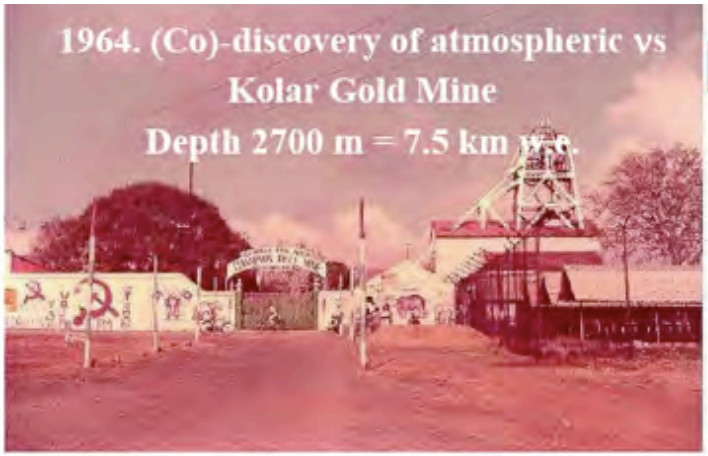
2500m rock ≈7500 m.w.e
Horizontal access
Agreement signed

Between Tsinghua University and Ertan Hydropower Development Co., Ltd

JingPing



India based Neutrino Observatory

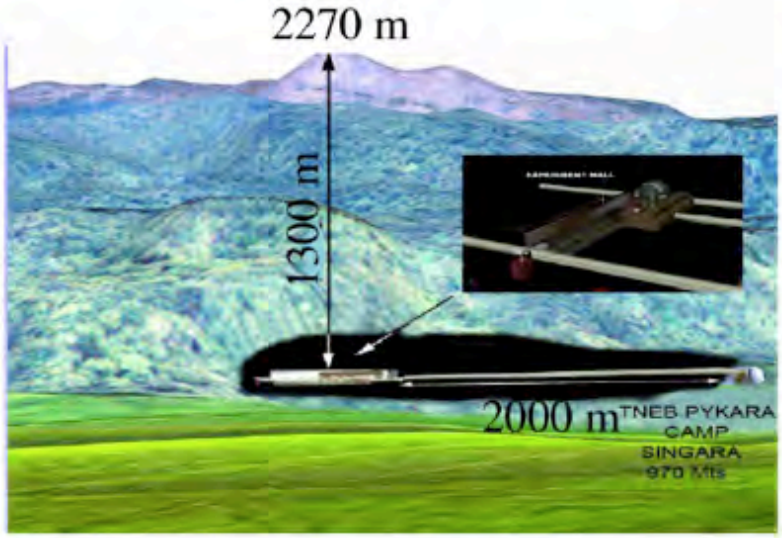


2000

Create a world class underground lab

Selected site

Singara in Southern India

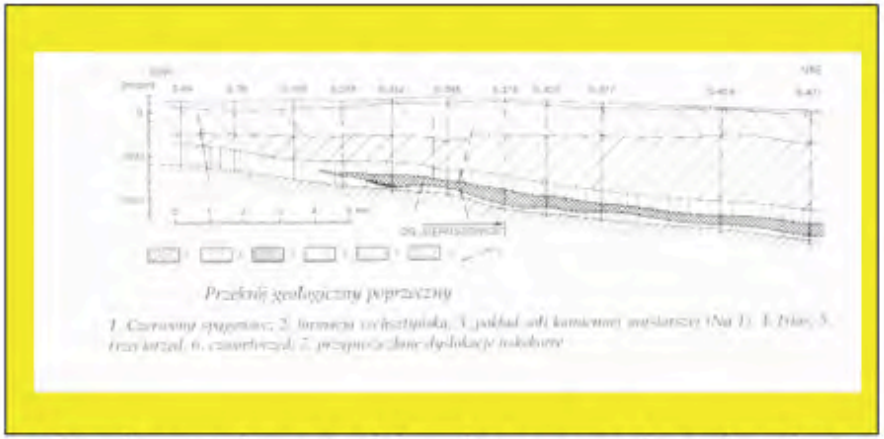


The southernmost Underground Laboratory

Near PUSHEP hydroelectric pumping station station, with several useful infrastructures

The Polkowice-Sieroszowice mine in Poland

One of the sites for LAGUNA and ArDM

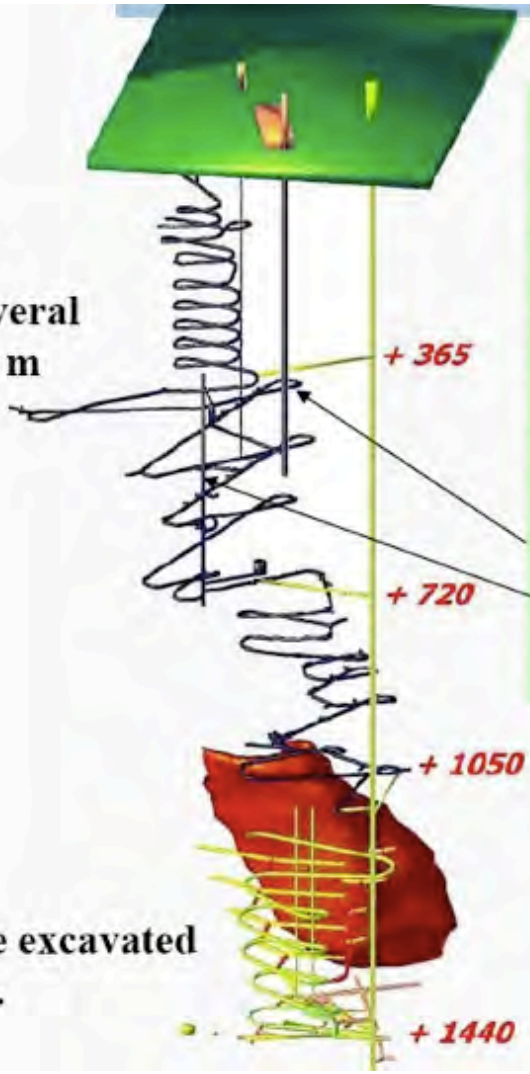


Geological cutoff – layers of anhydrite, dolomite and salt rocks at depths from 600 till >1400 m below the surface

Near Wrocław, south-west of Poland - easily accessible from the Wroclaw airport and from the A4 motor-way, 950 km from CERN

The Sieroszowice mine (178 km² of underground excavation area), belongs to the KGHM holding of copper mines and metallurgic plants - 6th position in the world's copper production and 2nd position for silver.

Centre for Underground Physics in Pyhäsalmi CUPP. Finland



Old mine

Operational 1962-2001

Cavities available at several levels from 95 m to 980 m

EMMA experiment at shallow depth with about 20 users

Composition of atmospheric μ @ knee

Neutron flux being measured

Personnel: 3 on site + 3 @ Oulu

Offices, labs and guest rooms on surface

Access via

lifts or

inclined road tunnel

New mine

Lab facilities may be excavated @ 1440 m, 4 km w.e.

28-Aug-09

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U.S. : DUSEL

A National Deep Underground Science and Engineering Laboratory in the US

- Support technically and scientifically the U.S. research and international institutions engaged in underground science and engineering
  Not only design and operate DUSEL but also:
  Technical support: Critical mass
  Long term R&D (instrumentation, low background, new approaches)
  Theory, workshops -> vibrant interdisciplinary intellectual vitality

- Focus the national underground effort (critical mass, excellence)
  + coordinate it with other national initiatives (accelerators, Earth Scope, SecureEarth)
  and other underground labs nationally and internationally (e.g. SNOLab, Kamioka, Gran Sasso,Modane)

- Maximize societal benefits
  Interagency, multidisciplinary collaborations
  Involvement of industry
  Education of the next generation of scientists and engineers
  A better general understanding of frontier science by the public

DUSEL Plans

A series of studies since 2000

- including S1 study => "Deep Science" report
- U.S. National Science Foundation =lead agency

Homestake chosen as site for DUSEL

Sanford Underground Laboratory

- 4850 ft level
- South Dakota + private money (≈$110M)
- Water brought down to below 4850ft
- Beneficial occupancy August 2010
  - LUX
  - MAJORANA Demonstrator

Study money for DUSEL approved

- $15M+$3M + $29M approved by National Science Board (Sept 2009

DOE + NSF Coordination

- Transmittal letter signed by NSF director and DOE Under Secretary for Science(August 3, 2009)=

DUSEL Plans

MREFC proposal in Dec 2010

Major Research Equipment and Facility Construction

= Line item in NSF budget: = new money!

Preliminary design of the facility

Generic experimental program with strict budgetary envelope

Hopefully decision by National Science Board Spring 2011

=> Construction would start 2013

Beneficial occupancy of 4850 ft ≈2016

7400 ft ≈2018

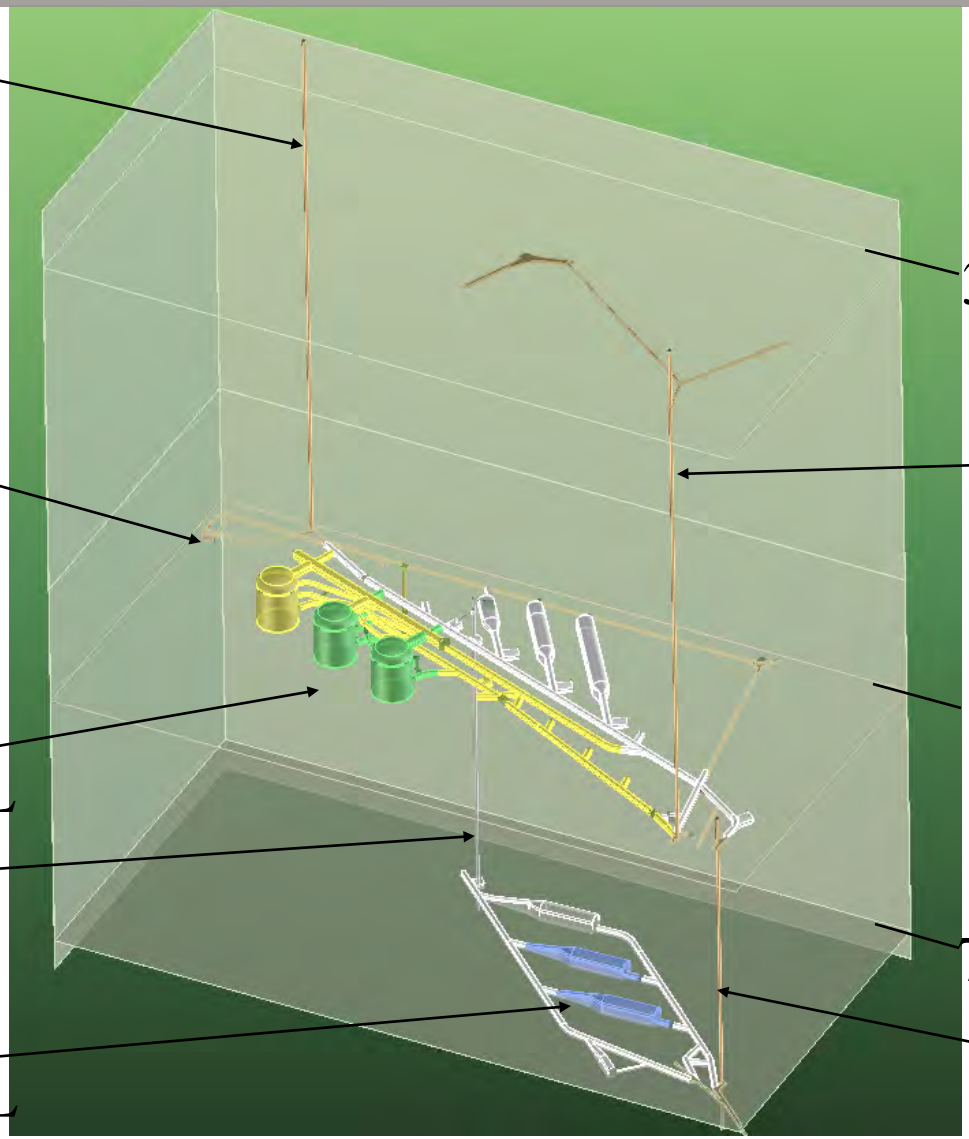
Study under way to see whether can be brought earlier

+ keep access to 4850 ft Sanford Laboratory

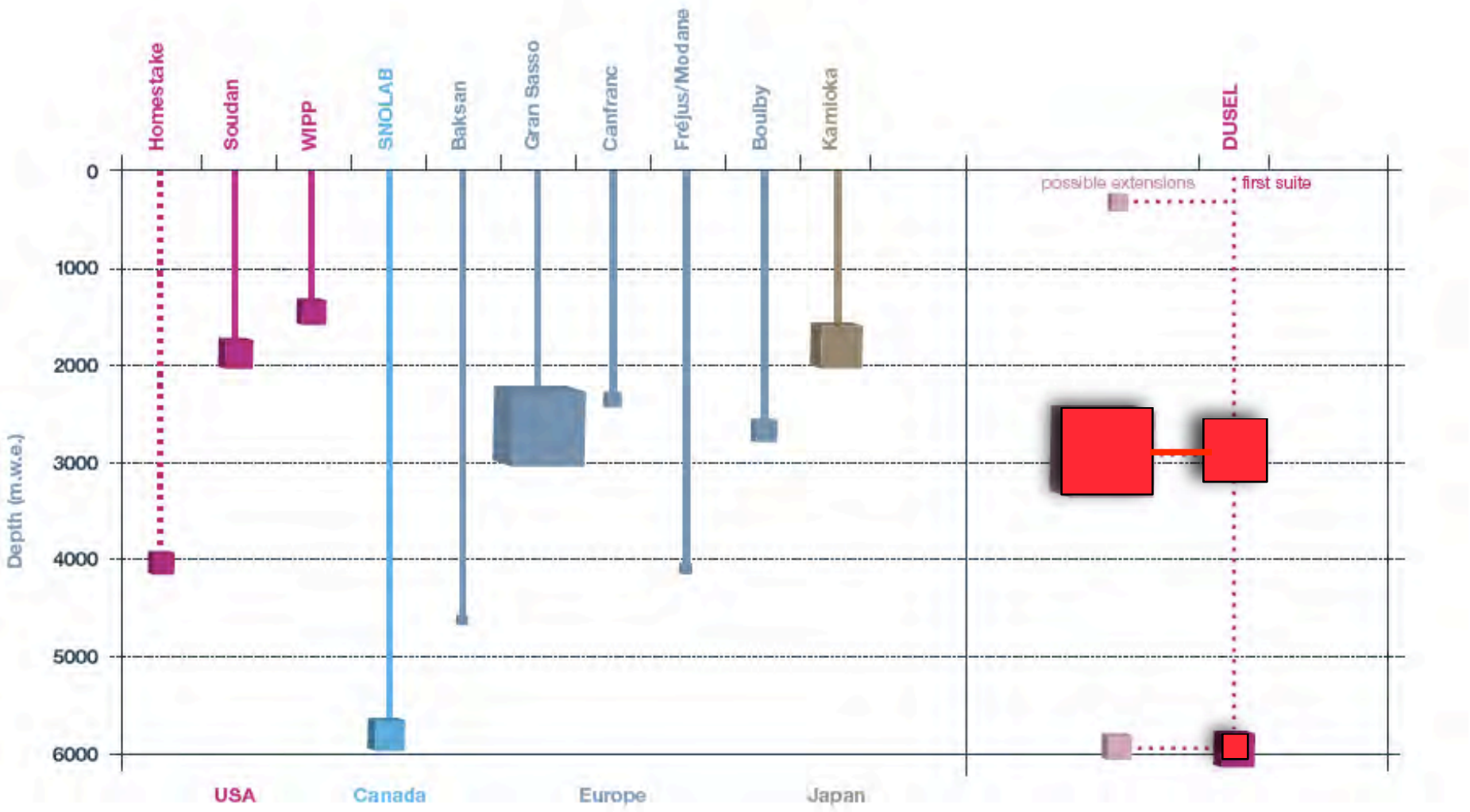
Possibility of 300 ft campus

e.g. underground fabrication facilities, Ge growing etc.

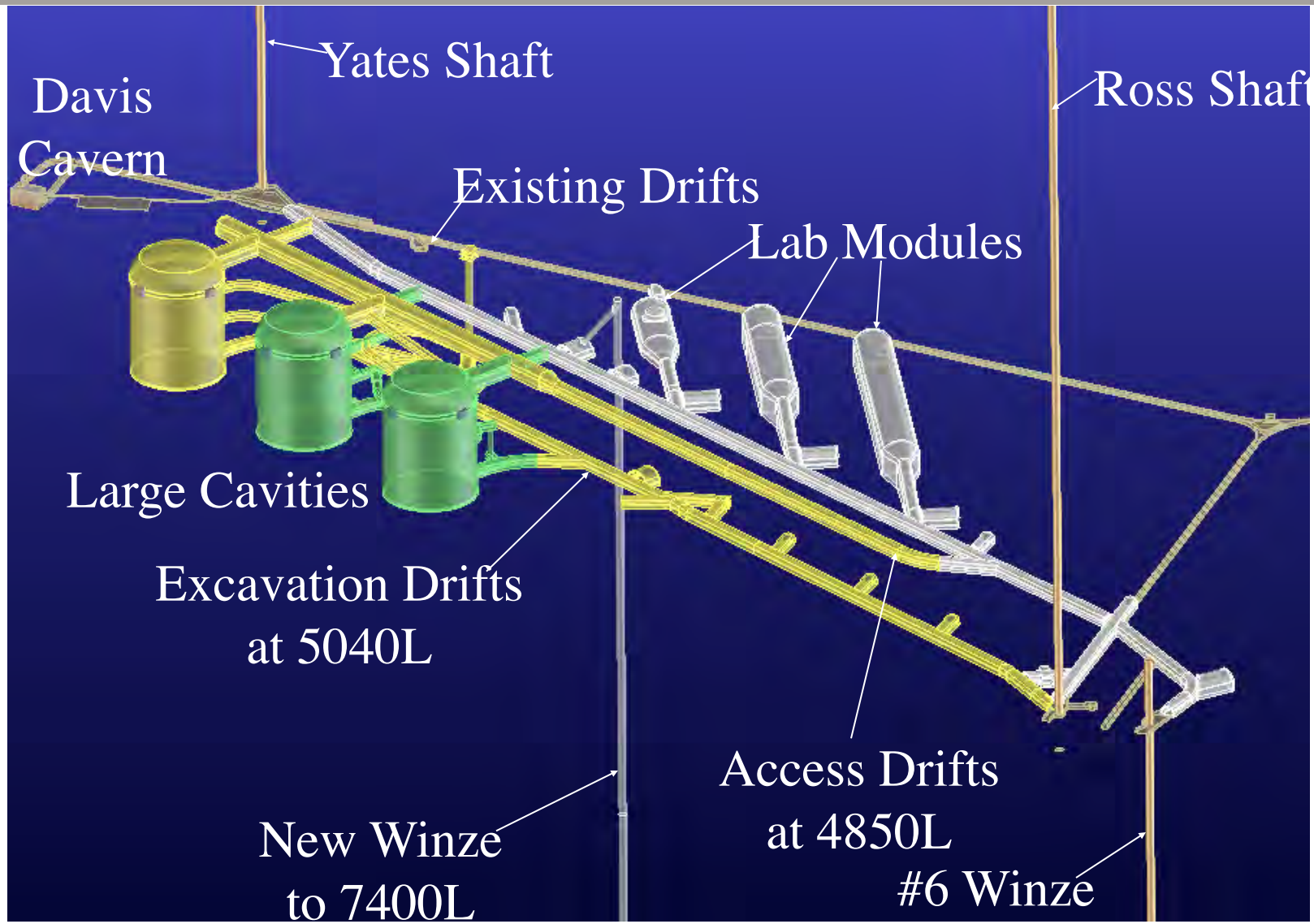
DUSEL Future Underground Campus Development at 4850L and 7400L



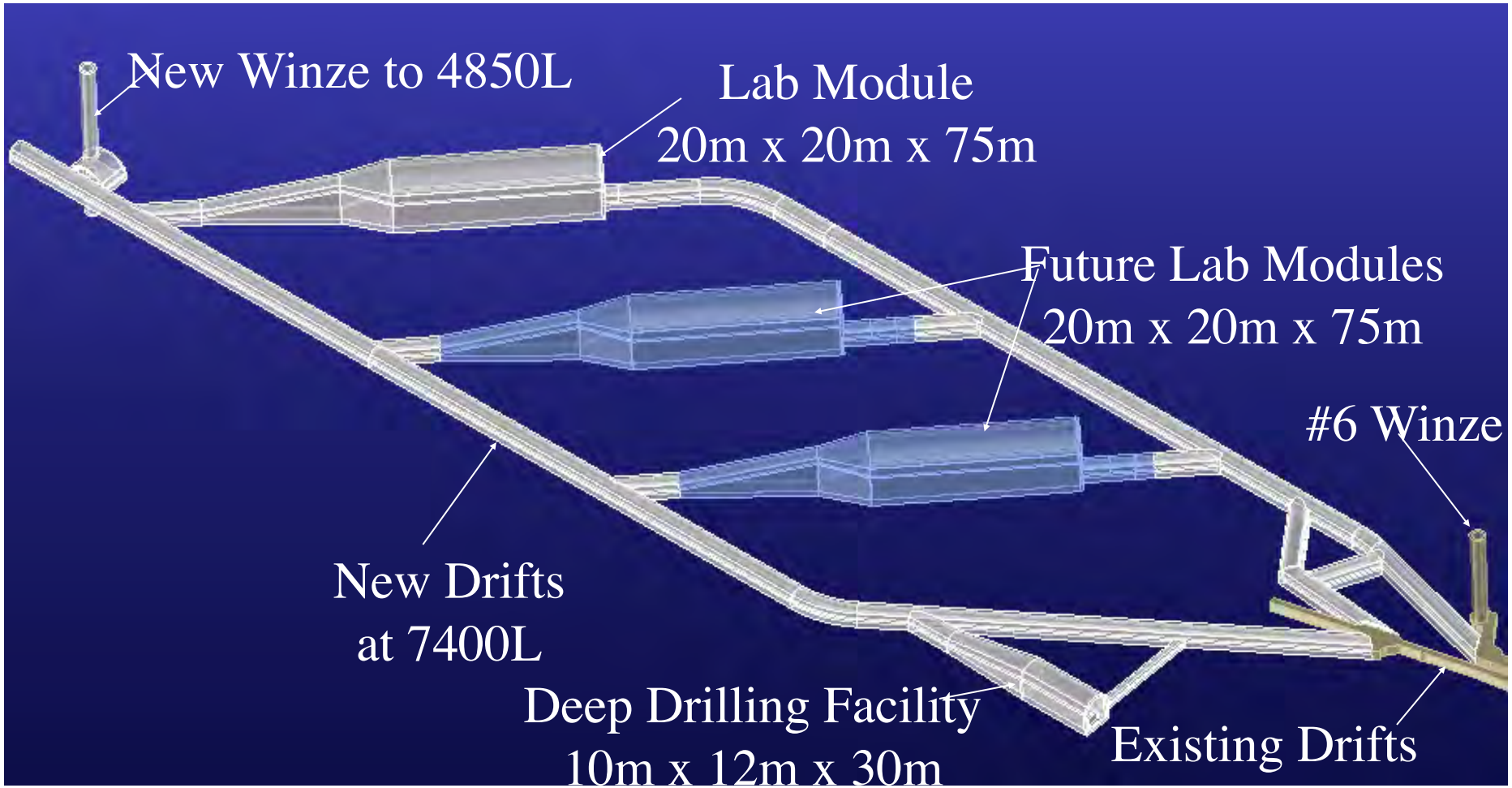
Main Underground Laboratories



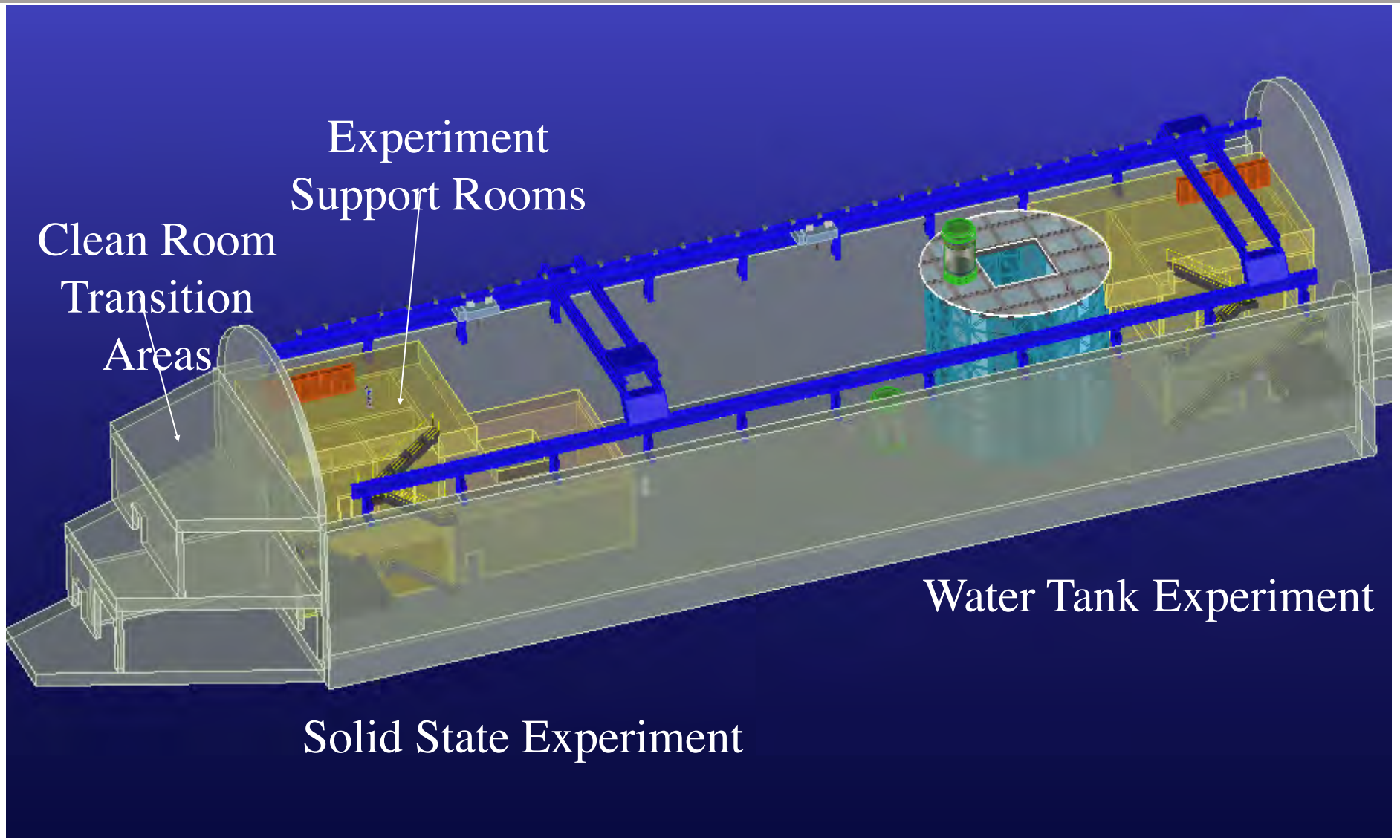
4850 Level Preliminary Layout



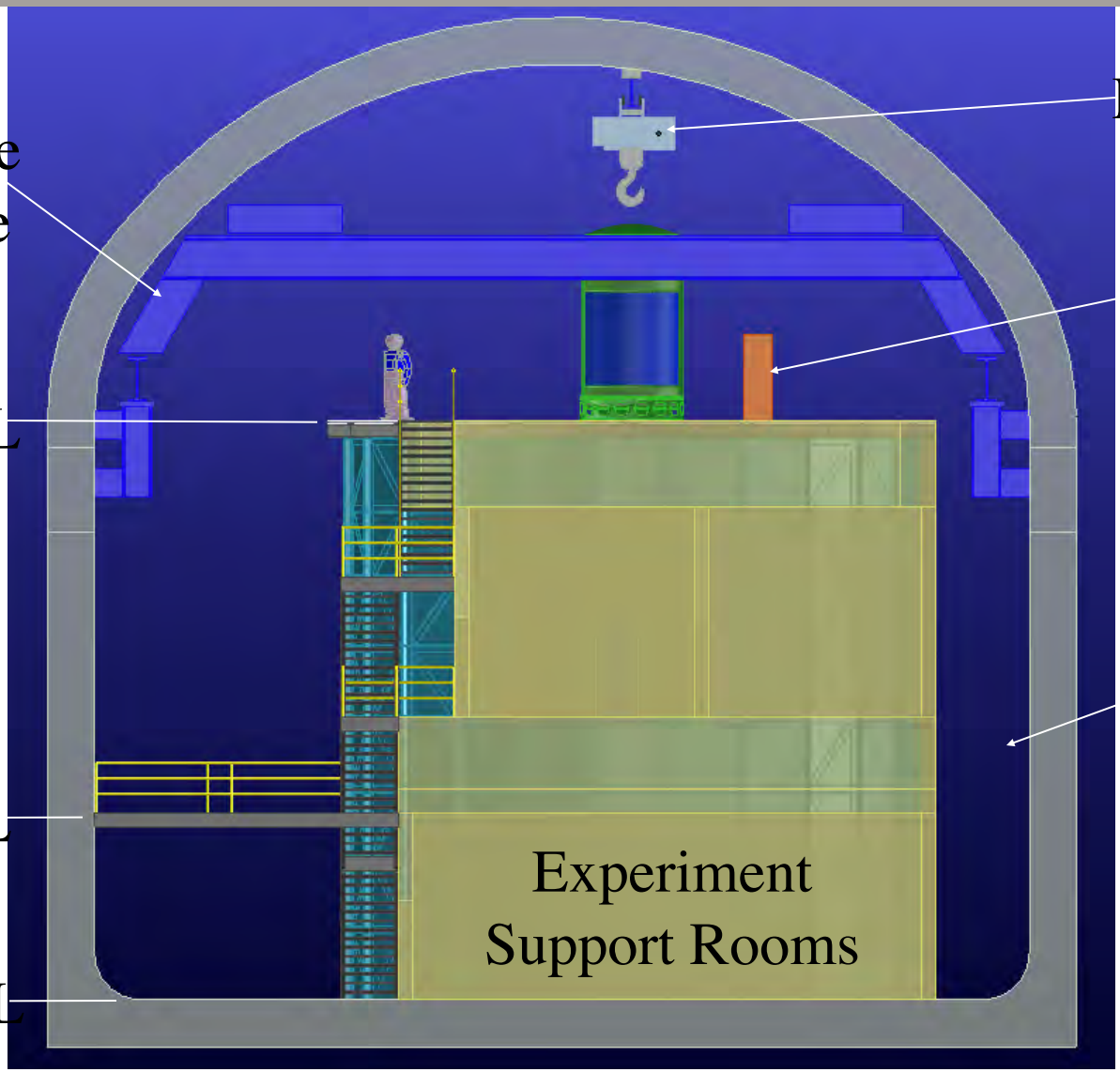
7400 Level Preliminary Layout



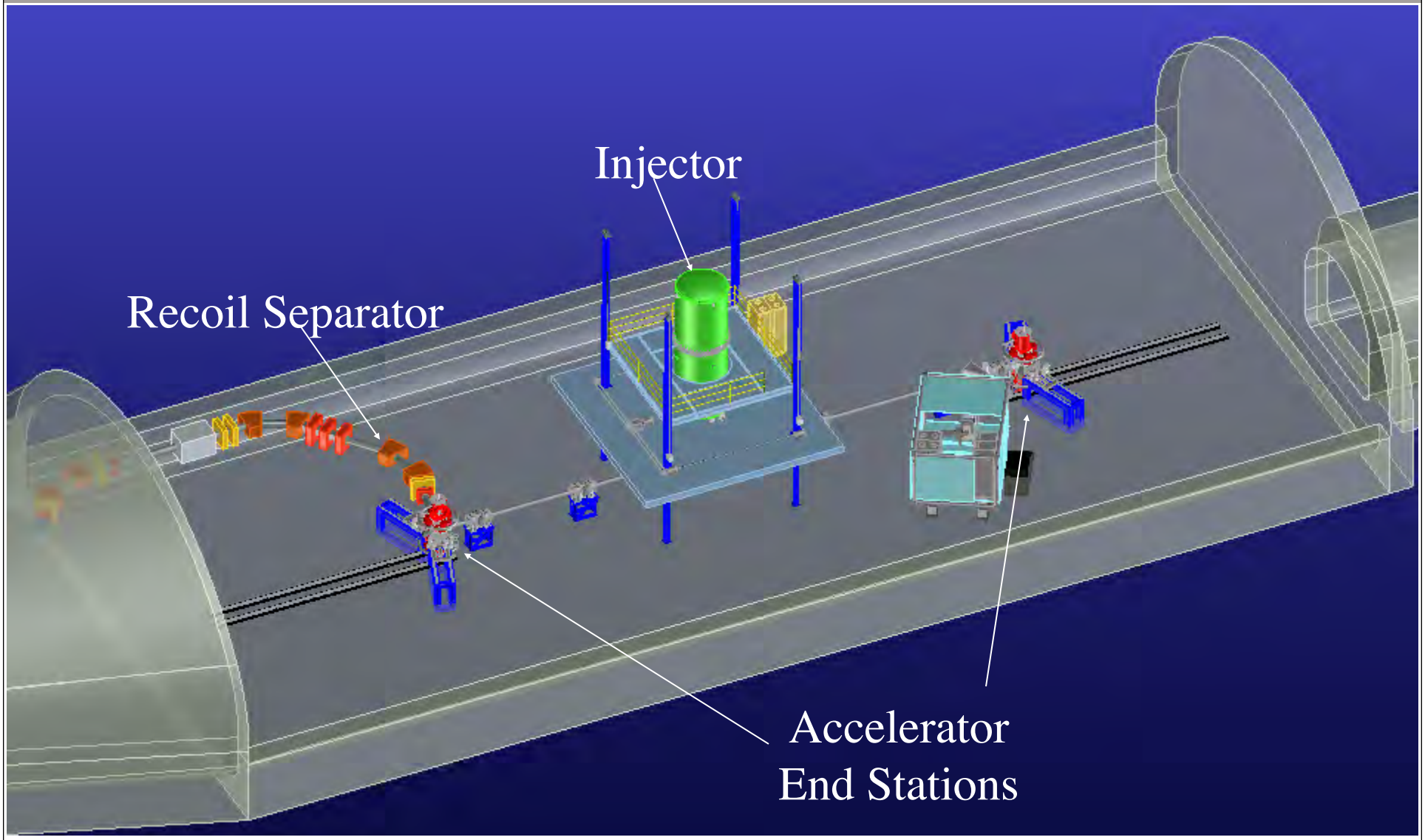
Lab Module with 1 Water Shield Experiment and 1 Solid State Experiment, (20m x 20m x 75m)



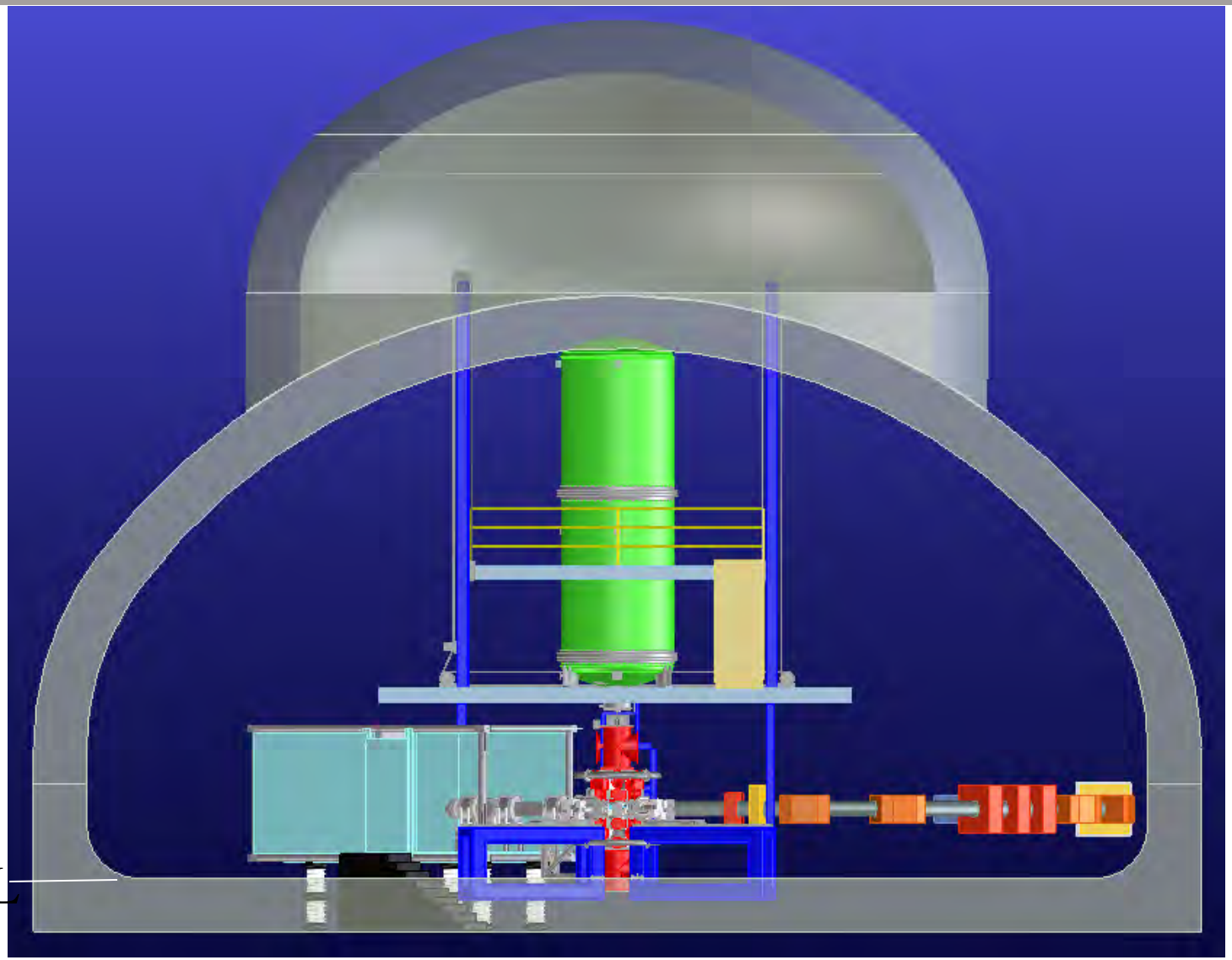
Lab Module with 1 Water Shield Experiment and 1 Solid State Experiment, End View (20m x 20m x 75m)



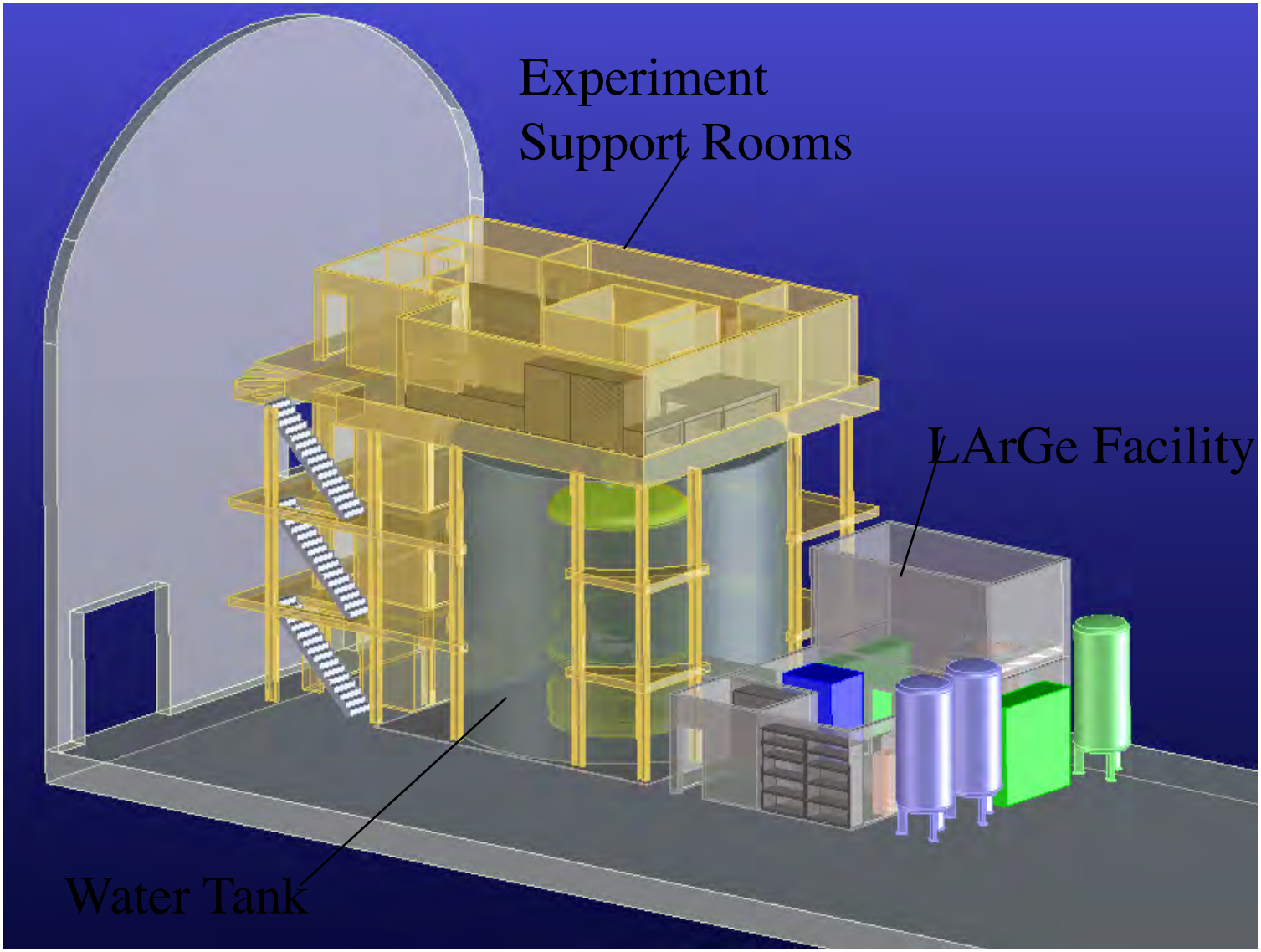
Lab Module with Accelerator Experiment (20m x 10m x 50m)



Lab Module with Accelerator Experiment, End View (20m x 10m x 50m)



How to have a liquid Ar shield?



Conclusions

A lot of enthusiasm for new underground facilities

Are we going too far?

Not necessarily: chronic oversubscription of the science

Variety of the science

- Physics
  - including
- Biology
- Earth science and engineering

Definite need for local R&D facilities

Danger of dispersion?

Definitely: need to focus most resources on few well equipped facilities

- critical mass of facility and technical support
- intellectual vitality
- interdisciplinary collaboration

Probably mix of

- large regional laboratories
- small facilities with local support

Coordination between agencies

- e.g. in Europe: ILIAS, ASPERA

ILIAS= Scientists

Integrated Large Infrastructures for Astroparticle Science in EU

- EU contribution (6th Framework Programme): 7.5 M€ in 5 years from April 2004
- Participants: ~800 scientists, 140 institutes, 23 countries
- Gravitational Waves, Dark Matter, Double Beta Decay
- Infrastructures: Underground Laboratories, Gravitational Waves observatories
- **"Networking" activities ⇒ *Fostering links within and between communities***
  - Underground Science Laboratories
    - *Safety: exchange of experience, protocols, visits*
    - *Outreach: common open days, production of media, etc.*
  - Direct Dark Matter Search
    - *Improve collaboration: DM cryogenic collaboration EURECA*
  - Neutrino-less Double Beta Decay
  - Gravitational Waves
  - Collaboration in theoretical Astroparticle Physics
- **Joint Research Activities (R&D projects) ⇒ *R&D for best service to users***
  - Low background techniques underground
  - Double beta decay European observatory
  - Noise in gravitational wave detectors
- **"Transnational" Access to Underground Laboratories**
  - **Helping foreign scientists in their work at the Laboratories** (only from EU)

ASPERA: Agencies

About ASPERA

ASPERA AStroParticle ERAnet

ASPERA is a network of national government agencies responsible for coordinating and funding national research efforts in Astroparticle Physics

ASPERA IN EUROPE

Participating to ASPERA

Within the **ERA-NET 6th Framework Programme of the EU**, ASPERA started in July 2006 and is funded by the **European Commission** at the level of 2.5 Million € over a three year period.

ASPERA has come about through the existence of **ApPEC**, an interest grouping of national funding agencies, which was founded in 2001 when six European scientific agencies took the initiative to coordinate and encourage Astroparticle Physics in Europe.

http://www.aspera-eu.org/