Review of underground physics

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27 May - 4 June 2019 - Otranto (LE) , Italy

Additional material

IDPASC

Otranto School

Outline

- Motivations
- Rare event physics
- Underground laboratories

Astro-particle:

- Neutrino physics
- Rare Nuclear decays
- Dark matter
- …

Other:

- Nuclear reactions
- Gravitational waves
- Fundamental physics
- Technology
- Biology
- …

No mention to:

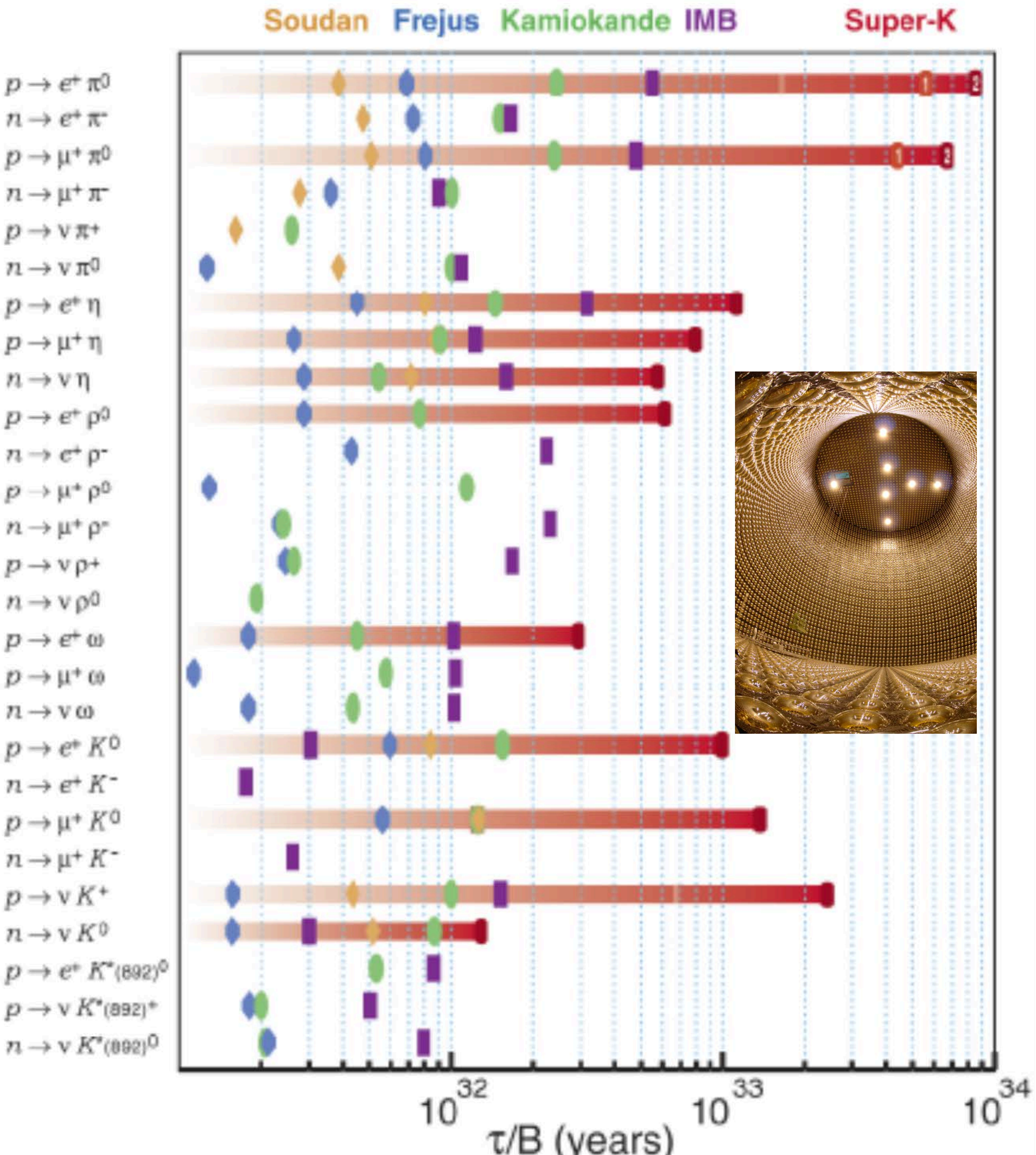
- Under-water
- Under-ice

Other

Nucleon stability

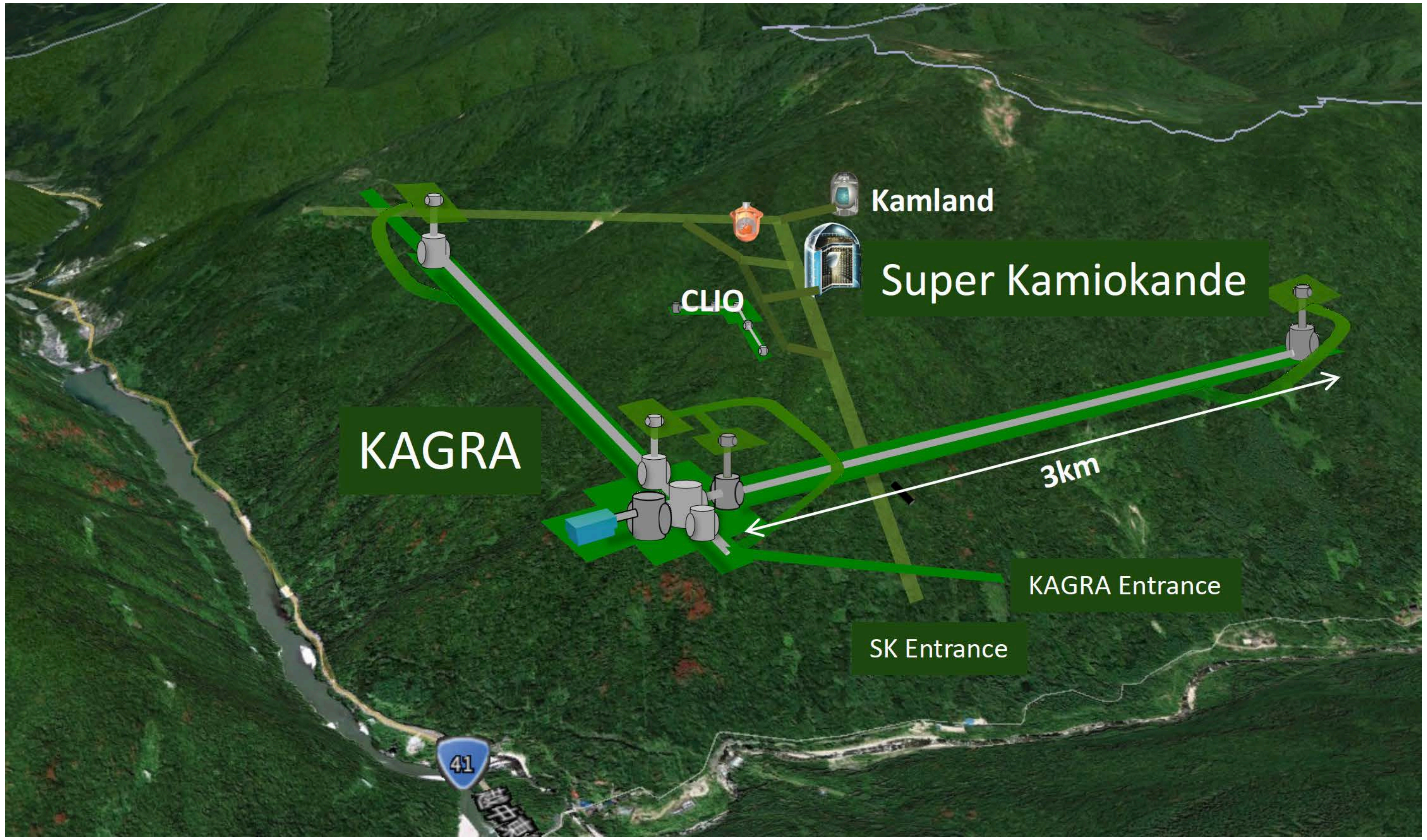
GUTs consider various conservation violations: B, L, B+L, B-L, etc.

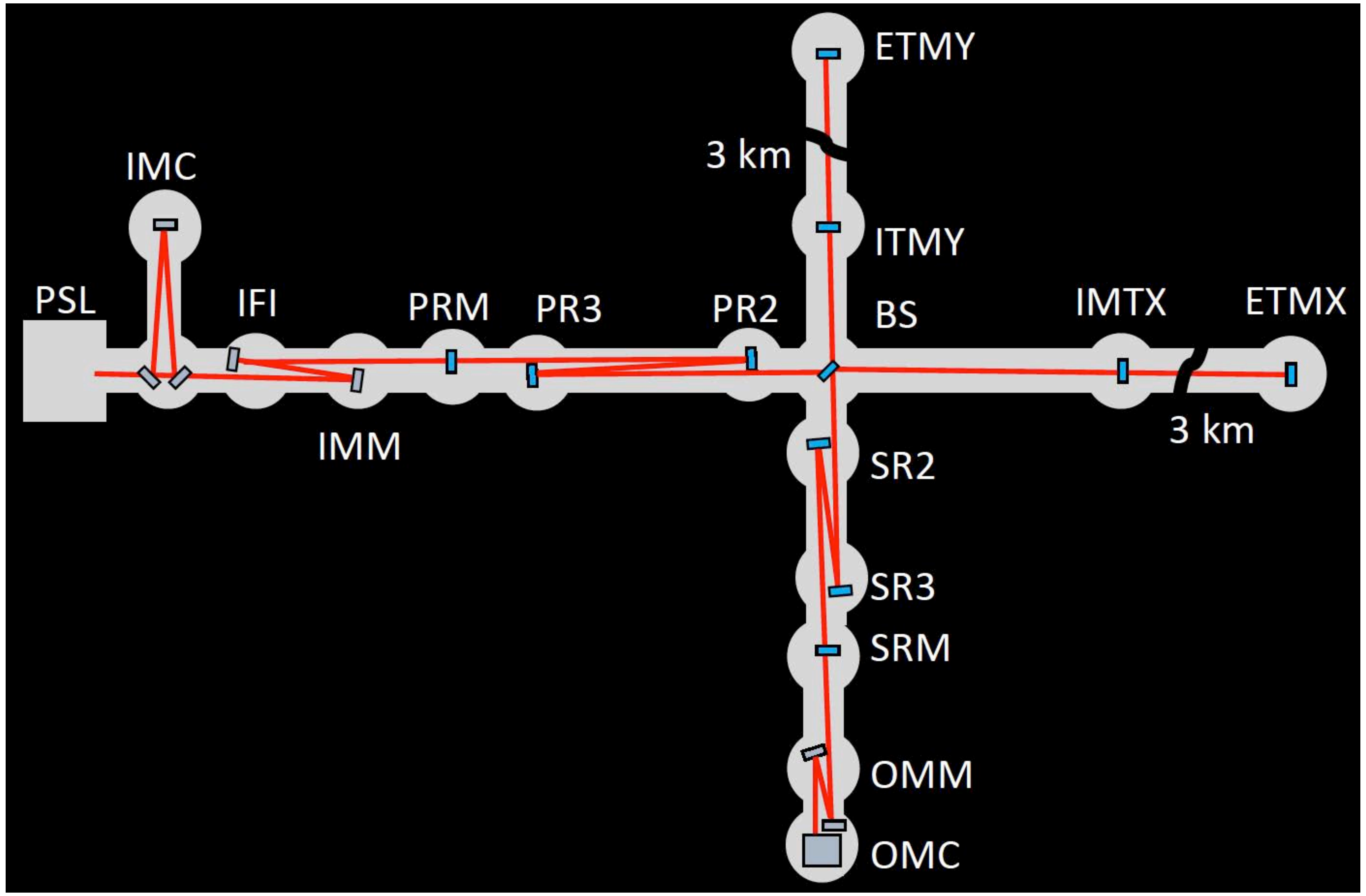
- Limits set on various processess
- Experiments: Cerenkov detectors, Sampling calorimeters
  - relativistic particles products of cosmic muons
  - muon secondaries
  - neutrino interaction products
- Past and current: See chart
- Future: HyperK, UNO, Memphys
- Backgrounds: atmospheric neutrinos



Gravitational waves: KAGRA

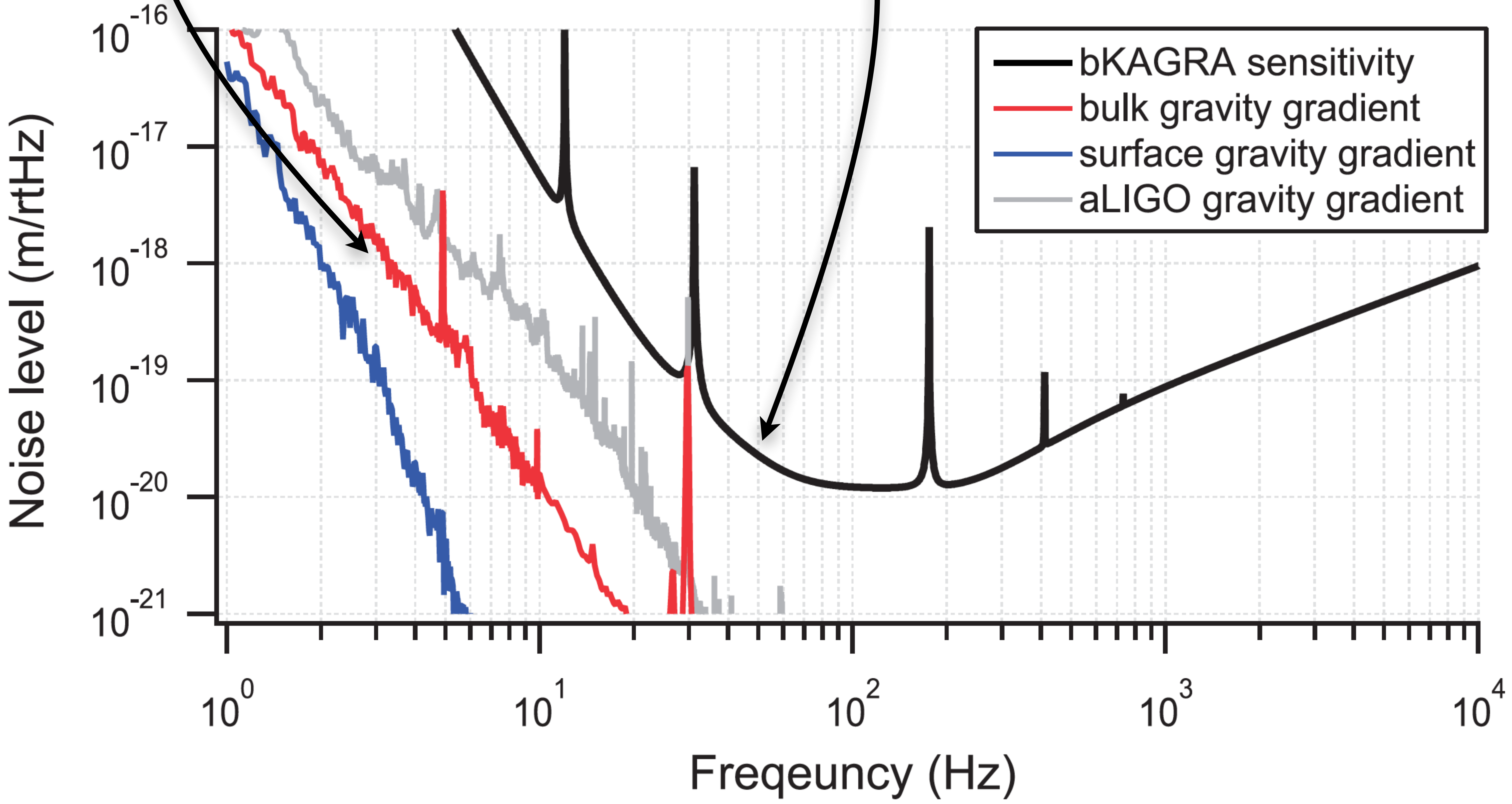
- second-generation gravitational-wave interferometer (3 km arms)
- started in 2010, funded by MEXT, Japan
- international collaboration (97 institutions, 470 members)
- installed underground in the Kamioka mine
- isolation from background seismic vibrations on the surface
- good sensitivity at low frequencies and high stability

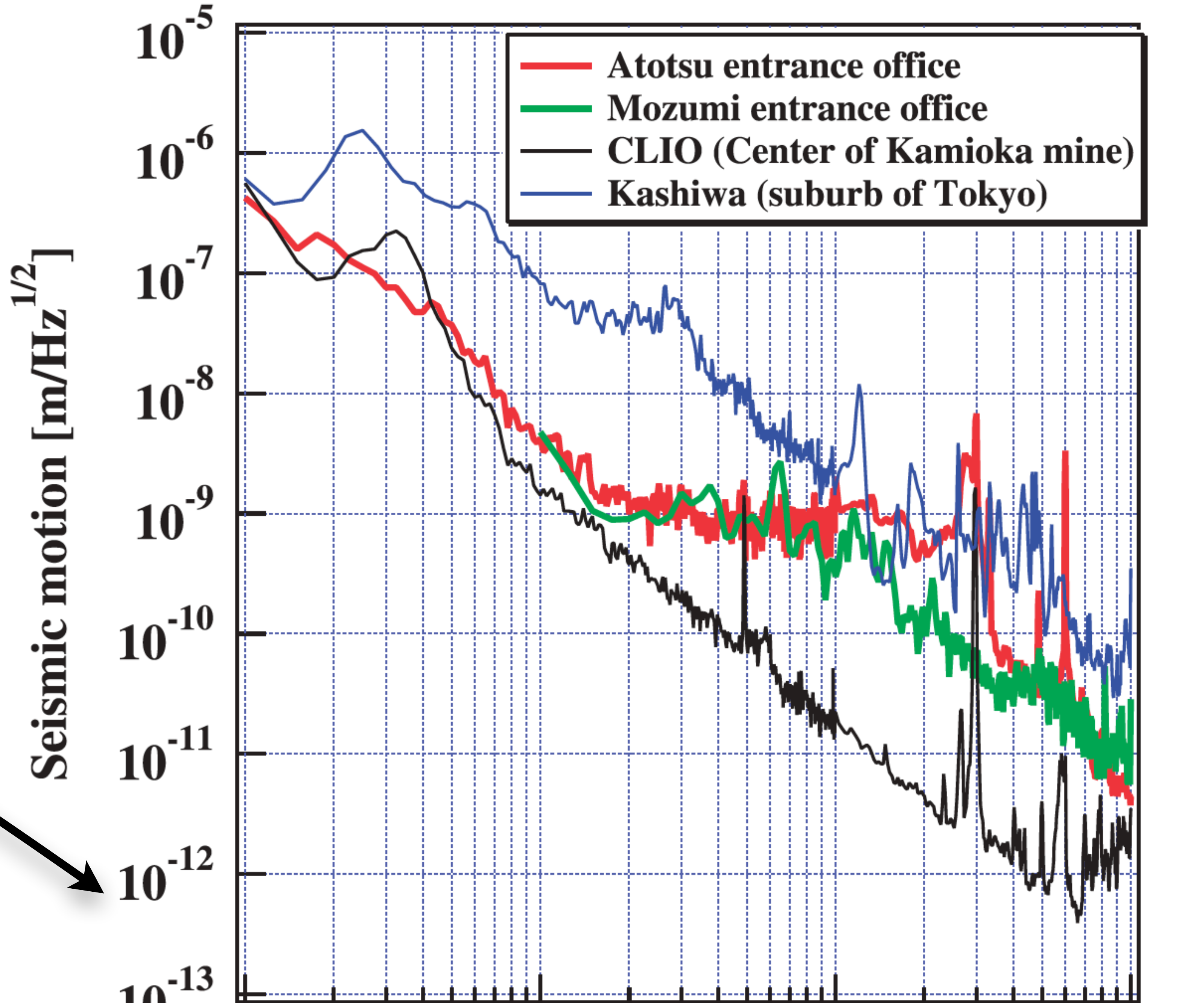


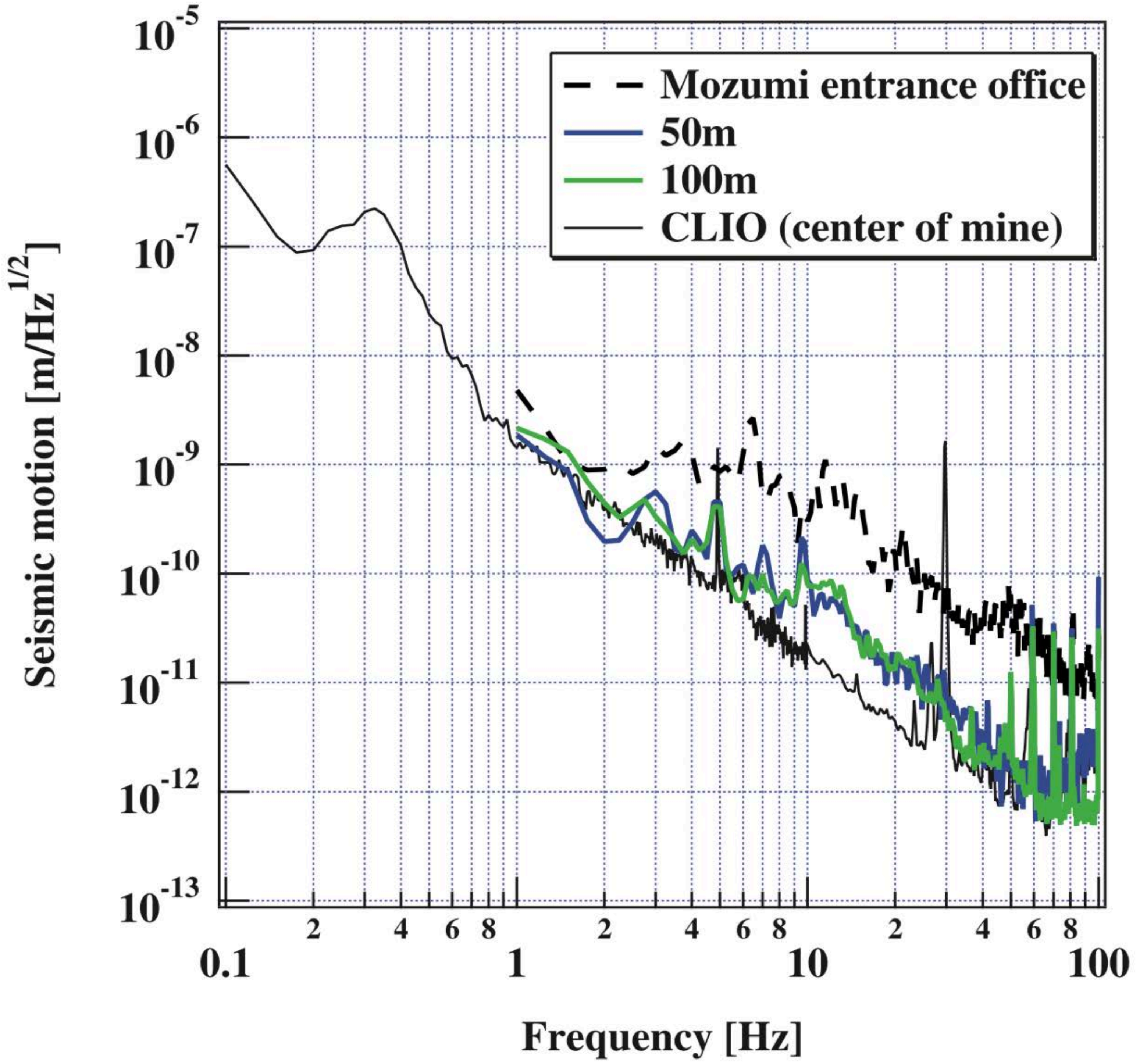


KAGRA noise

- lower seismic noise
- lower gravity gradient noise
- improved sensitivity







LUNA

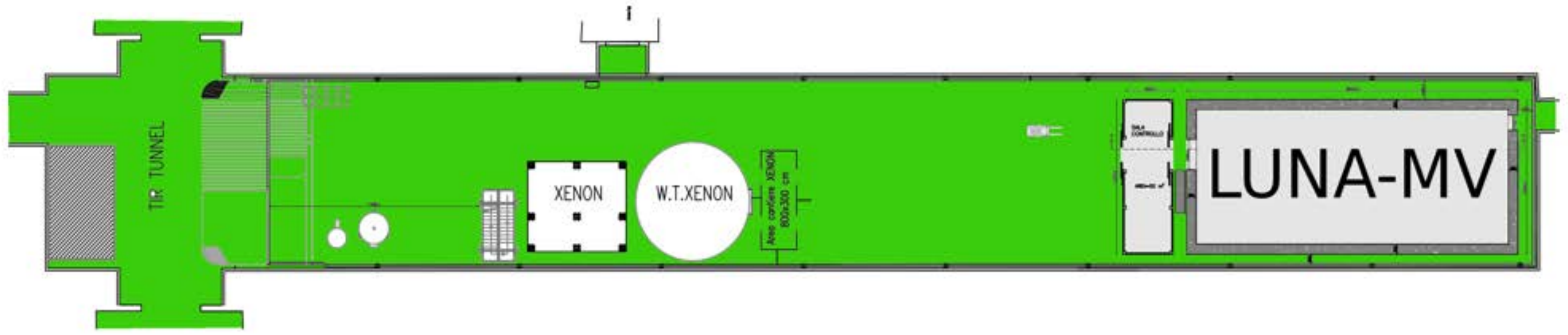
LUNA (Laboratory for Underground Nuclear Astrophysics)

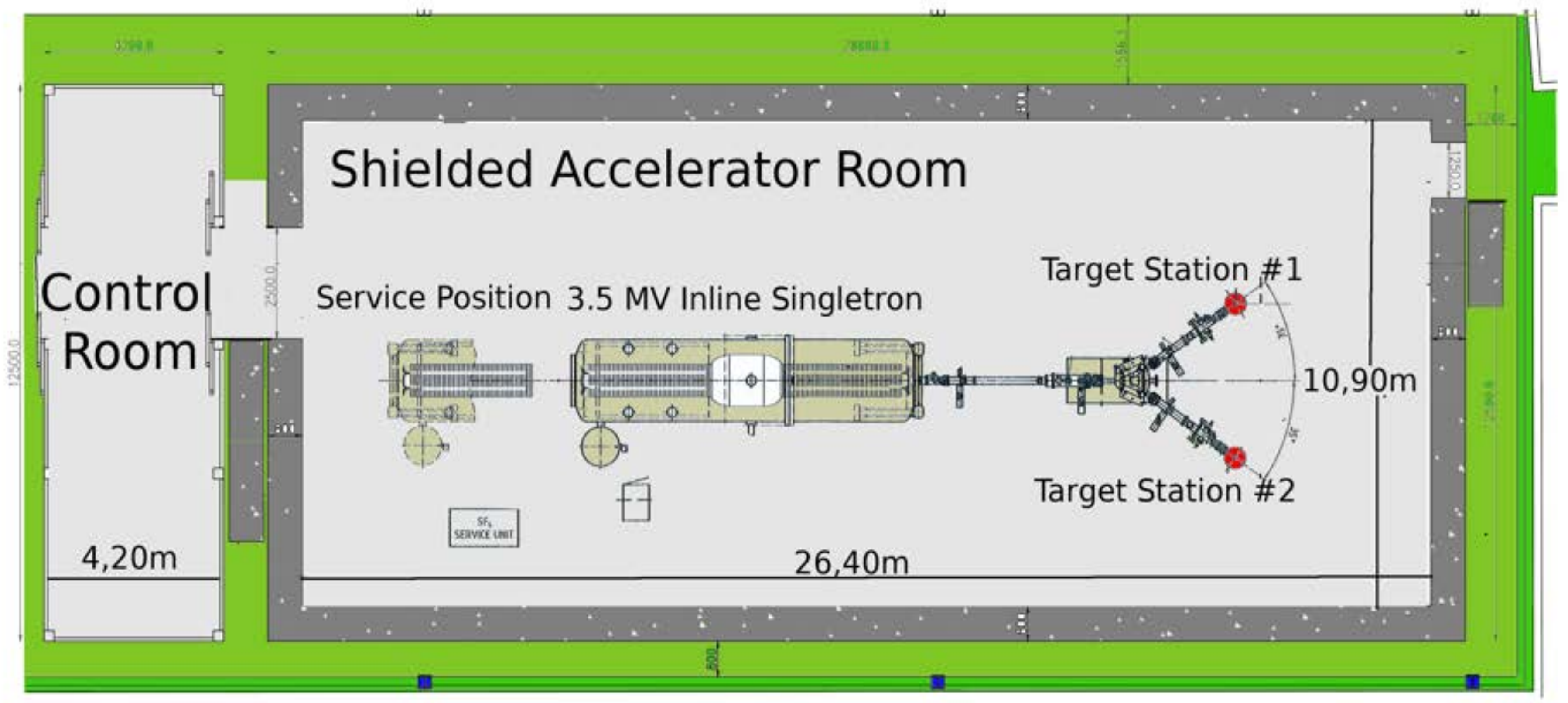
- Experimental approach to the study of nuclear fusion reactions based on an underground accelerator laboratory.
- In 25 years of activity, the cross sections of the Hydrogen burning and Primordial nucleosynthesis reactions have been precisely measured

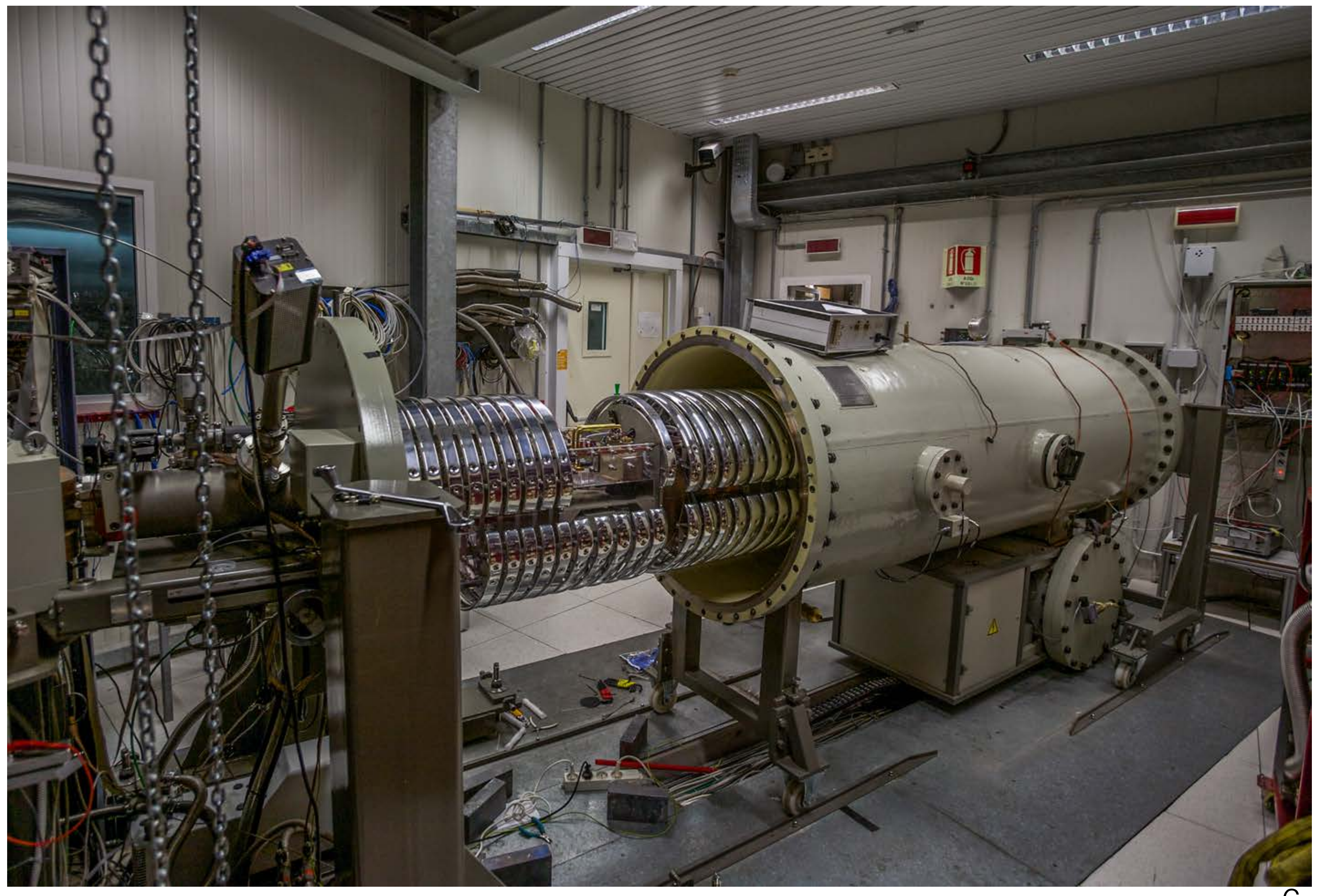
  - $^{3}He(^{3}He,2p)^{4}He$ at Gamow peak
  - $^{3}He(^{4}He,\gamma)^{7}Be$
  - $^{14}N(p,\gamma)^{15}O$, which was found a factor of two smaller than previous measurements
  - $^{25}Mg(p,\gamma)^{26}Al$ and $^{17}O(p,\gamma)^{17}F$ for stellar nucleosynthesis

3 generation of accelerators to study the formation of heavy elements in stars and primordial Universe

LUNA-50 → LUNA-400 → **LUNA-MV**



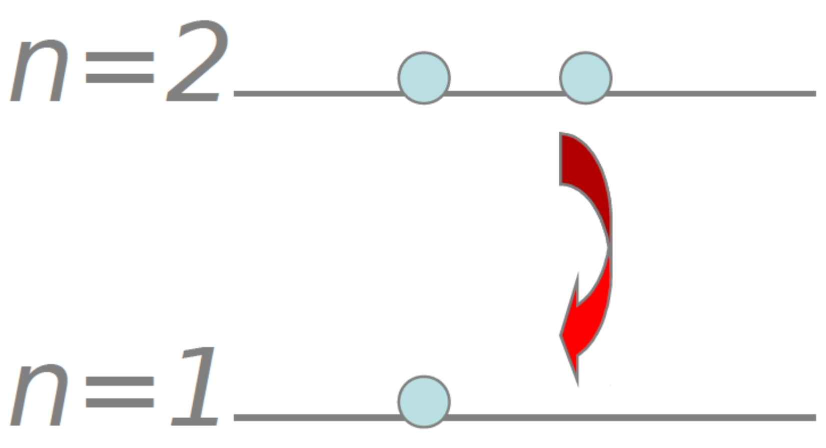




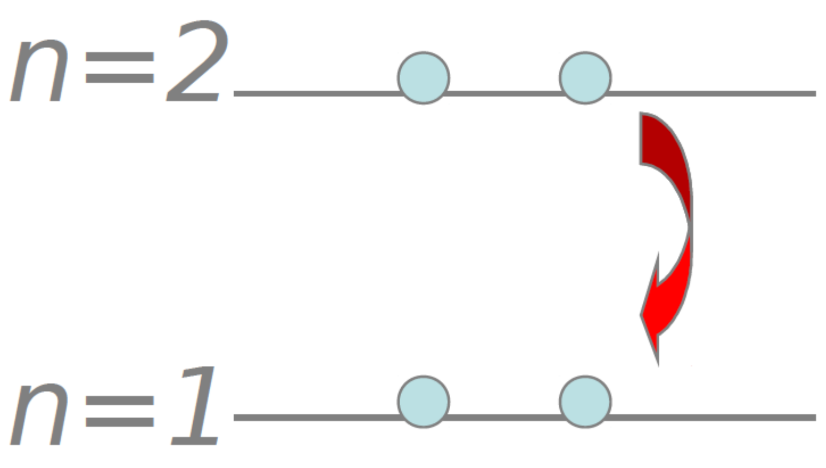
VIP

- VIP-2 **tests the Pauli Exclusion Principle** (spin-statistics) for electrons in a clean environment (LNGS)

- Search for anomalous X-ray transitions performed by electrons introduced in a target trough a DC current (open system)

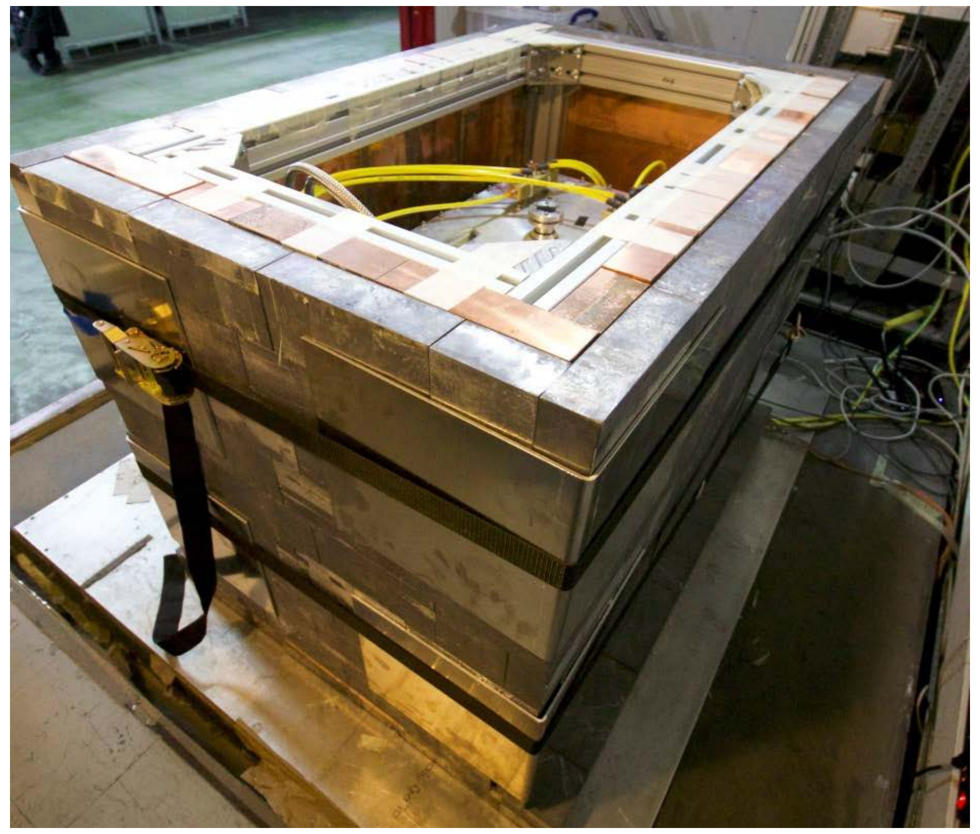


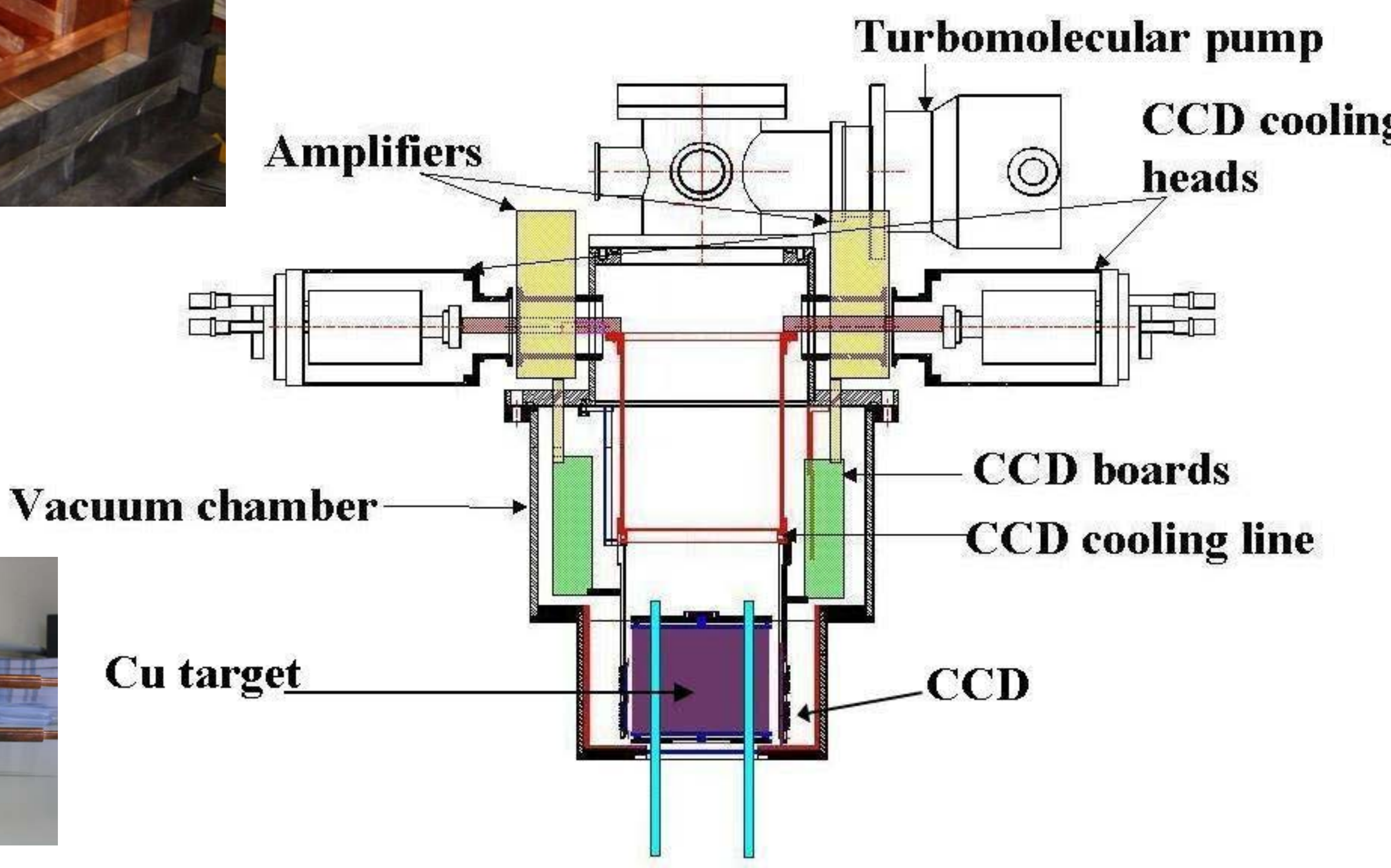
Normal 2p→1s transition
~ 8.05 keV in Cu

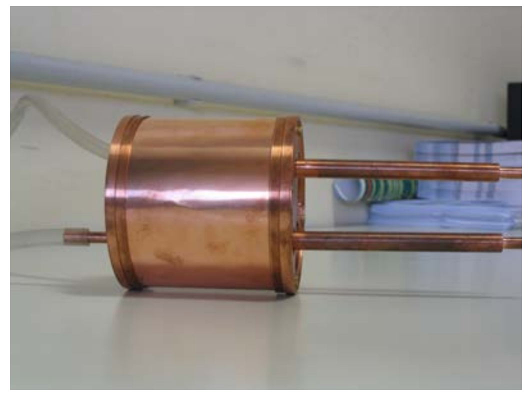


2p→1s transition
violating Pauli principle
~ 7.7 keV in Cu

Experimental setup
- copper ultrapure cylindrical foil surrounded by 16 Charge Coupled Devices (CCD) res. at 8 keV 320 eV (FWHM)
- inside a vacuum chamber: CCDs cooled to 168K by a cryogenic system amplifiers + read out ADC boards.







Biology: cosmic silence

The low dose-dose rate issue in radiation protection: linear no-threshold model (LNT) used for cancer risk extrapolation

- Experimental evidence for deviations from linearity in two opposite directions:
  - sub-linear extrapolation (adaptive response, threshold or hormetic effects)
  - supra- linear extrapolation (bystander effects and genomic instability)
- In this context:
  - Systematic investigation of biological response at increasing dose/dose rate exposure
  - Underground experiments complement above-ground studies at increasing dose rate

Underground laboratories

Directly ionizing cosmic rays: 10^{-3} - 10^{-6} nSv/h
Neutrons: 10^{-1} - 10^{-3} nSv/h
Radon: units - hundreds Bq/m^3
Gamma rays: 10 - 100 nSv/h

Environmental background

Directly ionizing cosmic rays: tens of nSv/h
Neutrons:~ 10 nSv/h (at 1 km above sea level)
Radon: tens - hundreds Bq/m^3
Gamma rays: tens - hundreds nSv/h

Low dose/dose rate facilities

Increase of the gamma dose rate ***above some μSv/h up to 20 mSv/h***

- Shape of the dose-response relationship for human health risk at low dose/dose rate
  - Are there different thresholds for different biological systems and/or end points?
  - Which is the role of qualitative differences in the radiation exposure scenarios?
  - Is the triggering of the biological responses dependent on radiation quality?

- **LNGS:** largest data set showing that the reduction in background radiation is perceived as a significant stress by eukaryotic cellular systems

Underground Laboratories

Features

Deep underground laboratories (DULs) differ from many points of view

- **Depth**
  - μ flux and the fluence of the μ-induced spallation neutrons decrease with increasing depth.
  - however μ do not contribute substantially to the background budget below about 1500 m of rock overburden
  - on the other hand μ are useful for calibration purposes.
- **Size**
  - 15–20 m diameters and heights are needed for water shields and for large liquid scintillator detectors
  - significant heights require thick enough layers of good quality rock.
- **Horizontal access**
  - allows drive-in to the experiments
  - installation of large setups
  - reduced operation costs
  - with the only exception of BNO, the access tunnels are provided by a road tunnel
    - … but unique window of opportunity during the construction of the tunnel, before it is opened to the traffic
- **Support facilities on the surface**
  - differ widely between the DULs (both in quantity and skills of personnel)
- **Underground space** (main mission of all the DULs)
  - allocation policies differ (international vs national)
  - general purpose vs. "on demand"
- **Internationalization**
- **Multidisciplinarity**
- **Management**
- **Funding regulations**
- **Safety and security**
- **Technology transfer**
- **Accountability policies**
- **Outreach and education**

Costs

- Site dependent factors can be sizeable, but, in general, the costs are
  - proportional to the volume for th excavation
  - proportional to the area of the surfaces for the rocks stabilization
- Some example:
  - the cost of the service equipped LNGS (volume ~190,000 m3) is ~57 Me (300 €/m^3)
  - an independent access tunnel, 6 m diameter, 5 km length, would cost 55 M€ (220 €/m^3)
  - LSM DOMUS project (excavation of a second road tunnel for building a new experimental hall of about 14,000 m3) has been evaluated on the basis of a unitary cost of 300 e/m^3.
  - SNOLab cryopit (40,000 m3 and an area of 3500 m2) costed 15 M$Can, corresponding to about 300 €/m^3
- The unitary cost is substantially lower for larger cavities
- Only a fraction of the total volume is directly available to experiments (corridors can reach a substantial fraction of the total)
- compact structures are cheaper (but require the availability of a large enough volume of good rock)
- Refurbishing an existing mine tunnel is substantially more expensive than drilling a new one

Radon

- Radon (^{222}Rn) is a radioactive, volatile gas that is always present in the atmosphere, being continuously produced by the decay of ^{226}Ra present in the rocks
- An important source of Rn is ground water.
- Rn activity is typically
  - 10–20 Bq/m^3 in the open air
  - larger by two orders of magnitude or more in closed underground cavities
  - it is reduced by ventilation.
- The equilibrium activity depends on the emanation rate and on the ventilation speed.
- Radon in the air is a source of background both direct and through the long life daughters it brings to the experimental sur- faces.
- Rn activity in the air must be constantly monitored in a few locations in the laboratory
- Strong seasonal dependence has been observed
  - Rn activity is minimum in winter and an order of magnitude larger in summer, in phase with the external temperature and, in opposite phase, with humidity
- Rn can be reduced by orders of magnitude in limited regions by fluxing pure N2 or ‘‘Rn free’’ air produced by dedicated structures

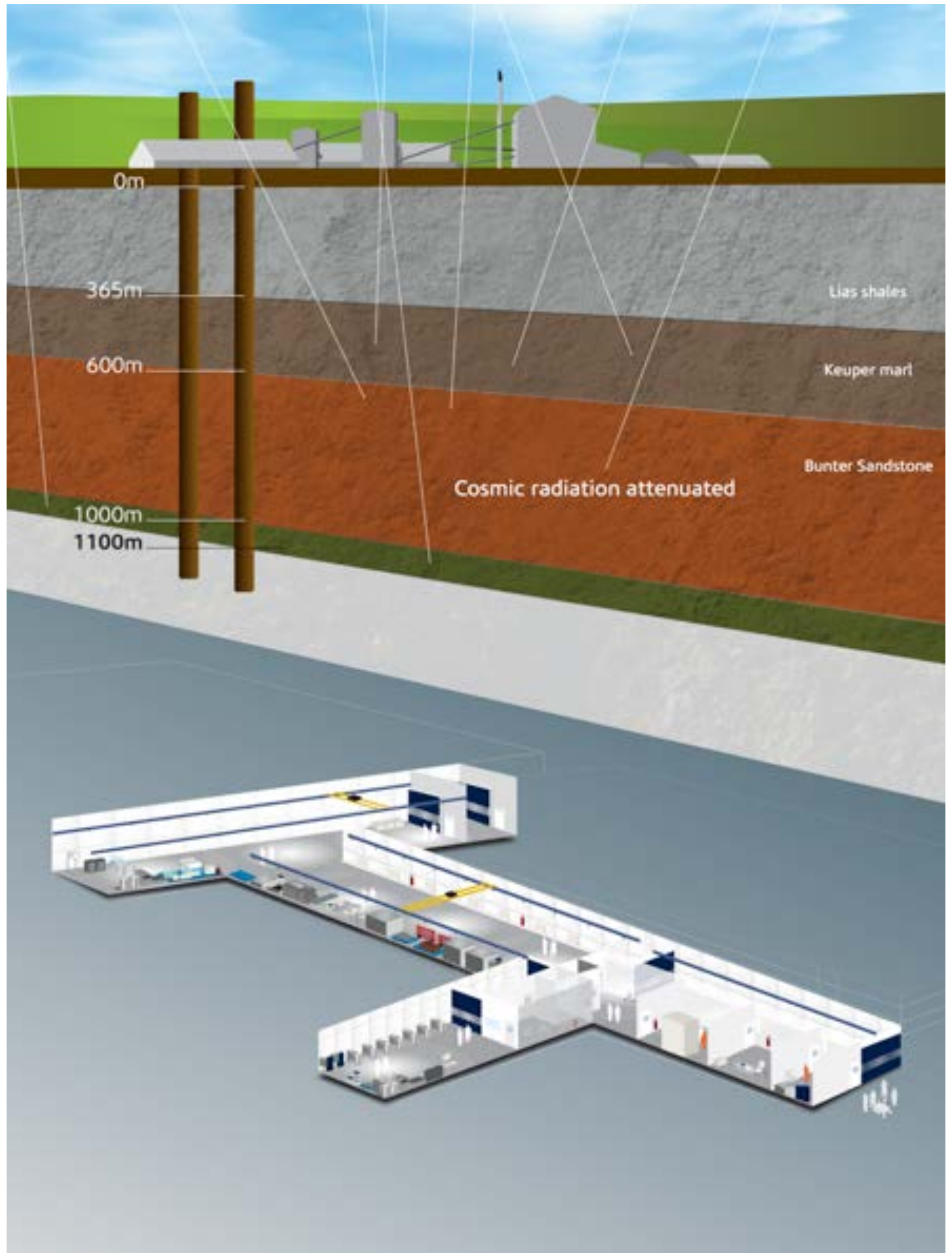
History in brief

- **The first experiments underground date back to the 60s. They were performed very deeply in mines**
- 1965: discovery of the first cosmic ray neutrinos interactions by two groups working in the Kolar Gold Mine in South India at a depth of 2700 m and in the East Rand Property Gold Mine in South-Africa at a depth of 3200 m
- 1968: R. Davis installs the first solar neutrino experiment in a cavity in the Homestake Mine in S. Dakota (USA): birth date of the “Solar Neutrino Puzzle”
- 1966: the first full-fledged underground laboratory (Baksan Neutrino Observatory or BNO) is built (horizontal access tunnel included) under the Caucasian mountains
- 1979: a double tunnel is under construction for a freeway under the Gran Sasso Mountain in central Italy. A. Zichichi proposes the construction of a world-class underground laboratory (LNGS) approved n 1982 by the italian. The laboratory was completed in 1987, at a very low cost.
- 1983 M. Koshiba established the Kamioka Underground Observatory, in a modern working mine with horizontal access, to host the KamiokaNDE water Cherenkov detector
- 1984-85 Slovotvina and LSC (the elder).

BUL - Boulby Palmer Laboratory (UK)

http://astro.ic.ac.uk/Research/ZEPLIN-III/boulby.htm

- 1988: start by N. Spooner and collaborators from RAL.
- **Location:** active potash mine
- **Depth:** 1000 m under a flat surface
- **Access:** vertical through a shaft.
- **Size:** salt environment → cavities ø < 5 m.
  - Volume: clean area of approximately 1500 m^3 available to experiments.
- **Cosmic rays**:
  - ϕ_n(E>0.5 MeV) = $1.710^{-2}\ s^{-1} m^{-2}$
  - $\phi_\mu = 4.5\ 10^{-4}\ m^{-2}\ s^{-1}$
- **Facilities:** building on the surface (200 m^2) with laboratories for computing, electronics and chemistry, offices, a conference room, changing rooms, mess rooms, a mechanical workshop, storage and construction rooms.
- **Scientific program:** focused on dark matter (ZEPLIN II and III [completed], DRIFT II)
- **Personnel:** about 30 scientists



LSC - Laboratorio Subterráneo de Canfranc (Spain)

https://lsc-canfranc.es/en/home-2

- **Location**: Pyrenees, close to a dismissed railway tunnel
- **1980**: A. Morales and the Nuclear and High-Energy Physics Department of the Zaragoza University (taking advantage of the excavation of a parallel road tunnel). Completed in 2005. Started operation in 2010.
- **Overburden:** 850 m of rock
- **Dimensions**: Hall A (40×15×12) and B (15×10×8). Total area 1560 m^2, volume 10500 m^3.
- **Safety**: located between two parallel tunnels, one for road traffic and one for safety, connected by by-pass galleries
- **Access**: horizontal by car
- **Radon**: average activity in the air 60 Bq/m^3 (November–December, 80 Bq/m^3 (June–August). Air ventilation: 1V/40'
- **Cosmic rays:** $\phi_\mu = 5 \cdot 10^{-3}$ m^{-2} s^{-1}, $\phi_n = 3.47 \cdot 10^{-2}$ m^{-2} s^{-1} $\phi_\gamma = 1.23 \cdot 10^{4}$ m^{-2} s^{-1}
- **Scientific program:** double beta decay (NEXT, CROSS,SuperNEMO), dark matter (ANAIS, ROSEBUD, ArDM). Proposal for an extension to build a nuclear astrophysics facility with a 3 MV ion accelerator

LSC
Laboratorio Subterráneo Canfranc

LSM - Laboratoire Subterrain de Modane (France)

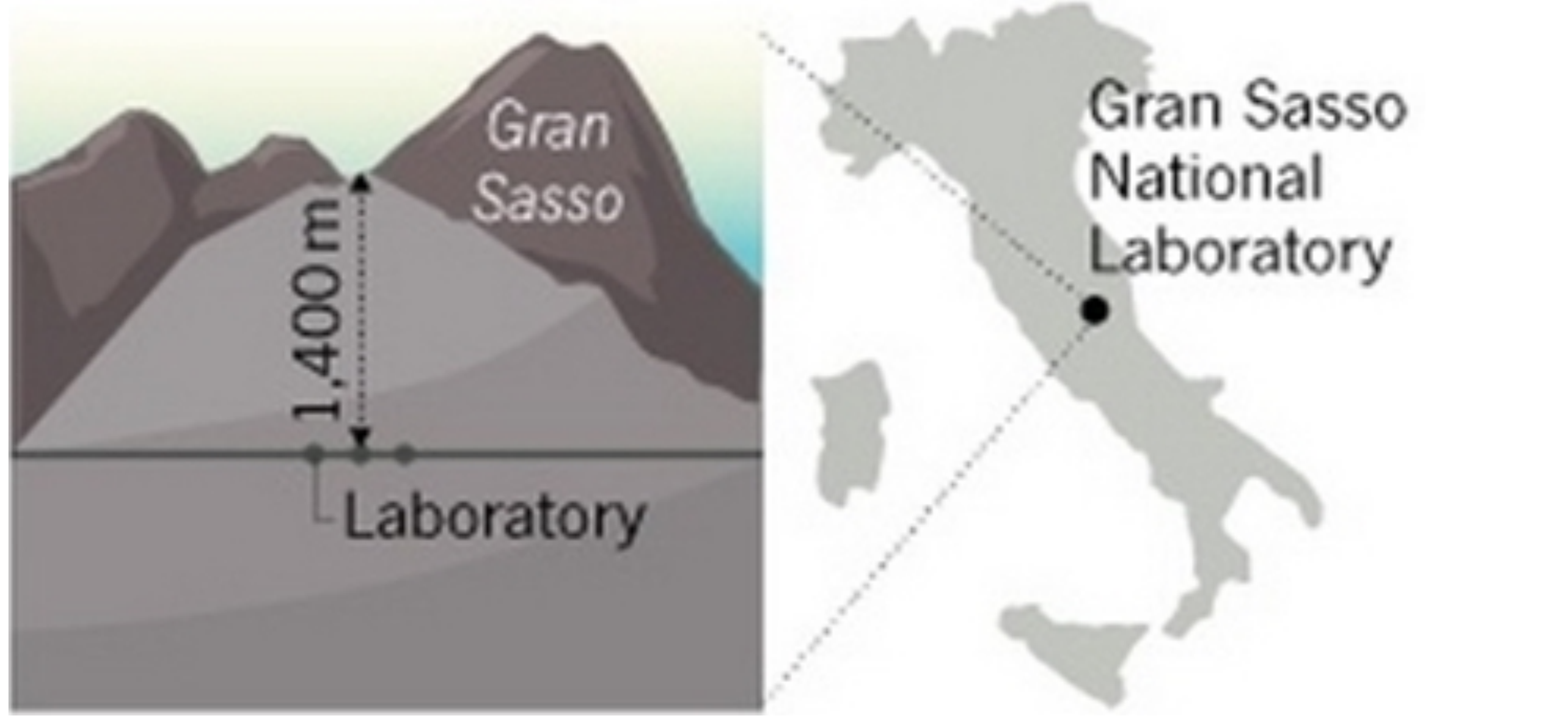
http://www-lsm.in2p3.fr/

- Operated jointly by CNRS/IN2P3 and CEA/DSM
- **1979**: start of excavation. Completed by 1982, to host the 900 t iron tracking “Frejus ” experiment
- **Overburden**: 1700 m.
- **Cosmic rays:** ϕ_{μ}=4.7 10^{-5} $m^{-2}s^{-1}$, ϕ_n=5.6 10^{-2} $m^{-2}s^{-1}$.
- **Access**: horizontal (Frejus roadway tunnel). Traffic control (stop) needed for entrance/exit
- **Dimensions**: Main Hall A=300 m^2,(30×10×11m^3) Gamma Hall A=70 m^2, two smaller halls A_1=18 m^2 and A_2=21 m^2 areas
- **Facilities**: surface building with offices (100 m^2), a warehouse and workshop (150 m^2) and a flat.
- **Personnel**: 8 technicians and engineers
- **Radon**: 15 Bq/m^3 obtained by in taking fresh air at a rate of 1.5 lab volumes/hour.
- **Scientific program**: double beta decay (SuperNEMOD-D), dark matter (EDELWEISS) and a low-radioactivity counting facility
- **Personnel**: about 100 scientists
- **Extensions**: Ulisse project → new tunnel to increase the safety conditions of the traffic. DOMUS project → new hall of 40–50 × 18.2 × 15.6 H m^3 .The scientific program under definition

LNGS. Laboratorio Nazionale del Gran Sasso (Italy) (1/2)

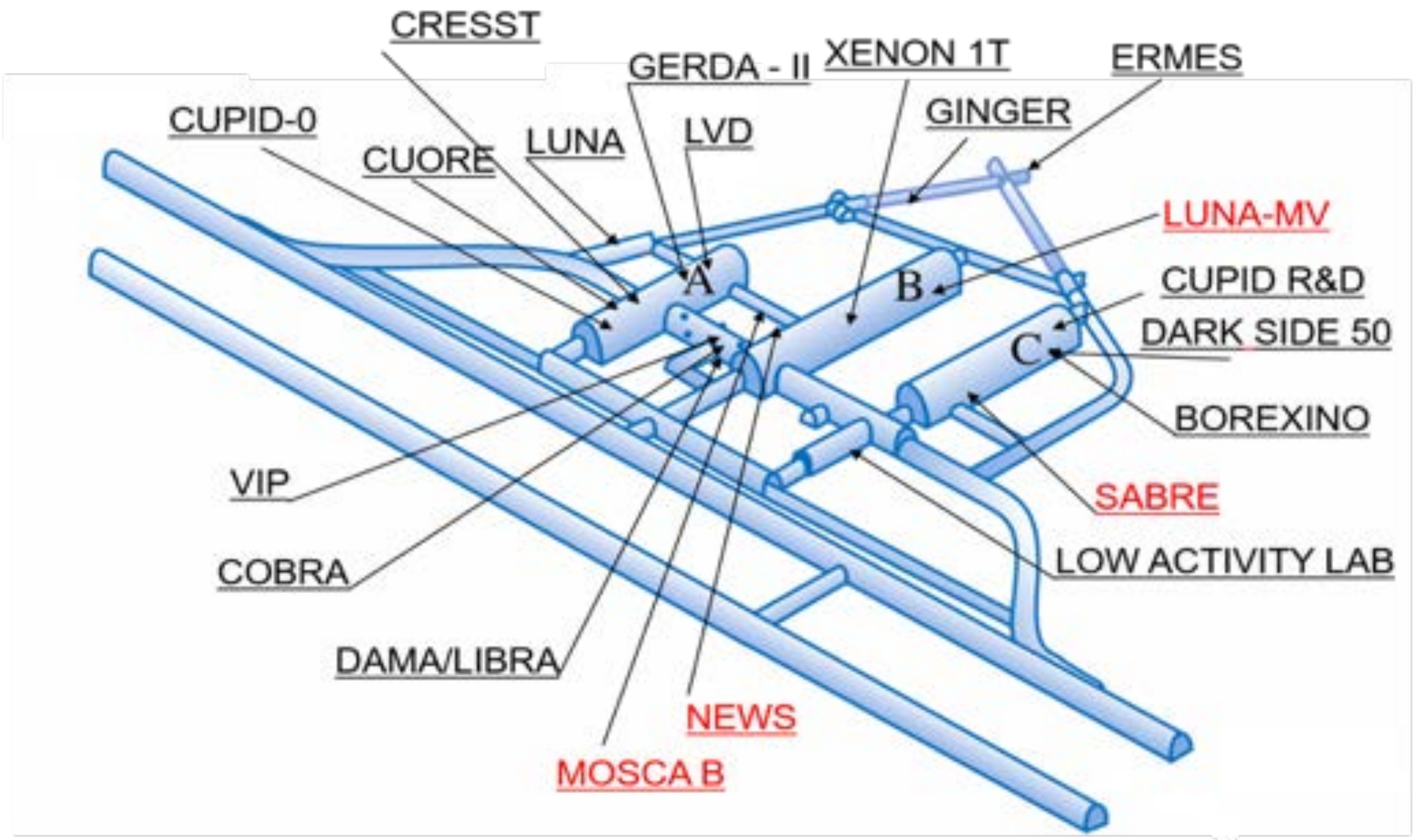
http://www.lngs.infn.it/

- LNGS is a national laboratory of the INFN. It is the largest in the world, serving the largest and most international scientific community.
- **1979**: A. Zichichi, INFN President, proposer the excavation of a large underground laboratory close to the Gran Sasso freeway tunnel then under construction. 1982: approval. 1987: lab is complete
- **Access**: horizontal, through the freeway.
- **Size**: three main halls (called A, B and C), about 100x20x18(h) m^3 plus ancillary tunnels, providing space for services and small-scale experiments. Total area: 17 300 m^2, total volume: 180 000 m^3.
- **Facilities**: campus on the surface with offices, a mechanical workshop, storage facilities, a chemical lab, an electronic workshop, an assembly hall, computers and networking, a library, a canteen, sleeping rooms, conference rooms, headquarters, administration.
- **Safety**: structures, procedures and training activities
- **Outreach and education**: visits to the lab,virtual tour
- **Personnel** (physicists, engineers, technicians, administration): about 100, 2/3 of which are permanent staff
- **Overburden**: 1400 m.
- **Cosmic rays**: $\phi_\mu=3\times10^{-4}$ m^{-2} s^{-1}. $\phi_n=3.78\times10^{-2}$ $s^{-1}m^{-2}$.
- **Radon**: 50-120 Bq/m^3 with a ventilation system providing one lab volume of fresh air in 3.5 hr.



LNGS. Laboratorio Nazionale del Gran Sasso (2/2)

- Operated as an international laboratory. International Scientific Committee, appointed by INFN, advises the Director.
- Underground space and other resources are allocated for a definite amount of time, in order to guarantee turnover.
- Experimental program: dark matter searches (DAMA/ LIBRA, CRESSTIII, XENON1t, DarkSide), double Beta Decay (COBRA, CUORE, GERDA
- solar/geo neutrinos(BOREXINO), supernova neutrinos (LVD), nuclear astrophysics (LUNA), fundamental physics (VIP). LNGS hosted the far detectors (OPERA and ICARUS) of the CNGS program.. A special facility is dedicated to low-radioactivity measurements.
- The laboratory also supports several experiments on geology, biology and environmental issues.
- Almost all of the experiments are second-generation ones and have been approved for several years of data taking.
- Scientific user community involve 981 scientists from 26 countries (418 talian, 564 foreign).
- Status: space is available both in Hall B and Hall C

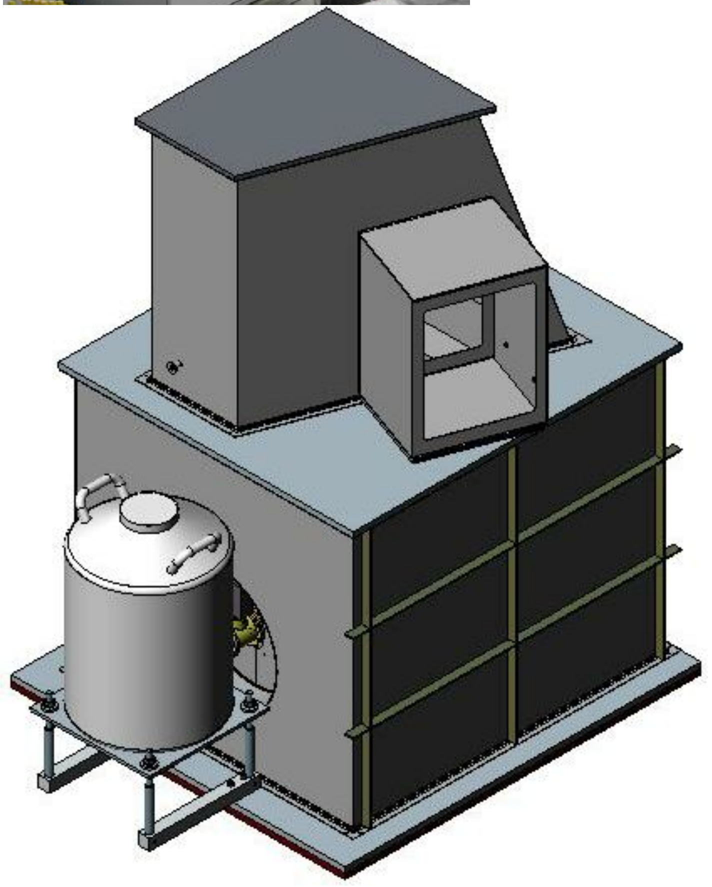


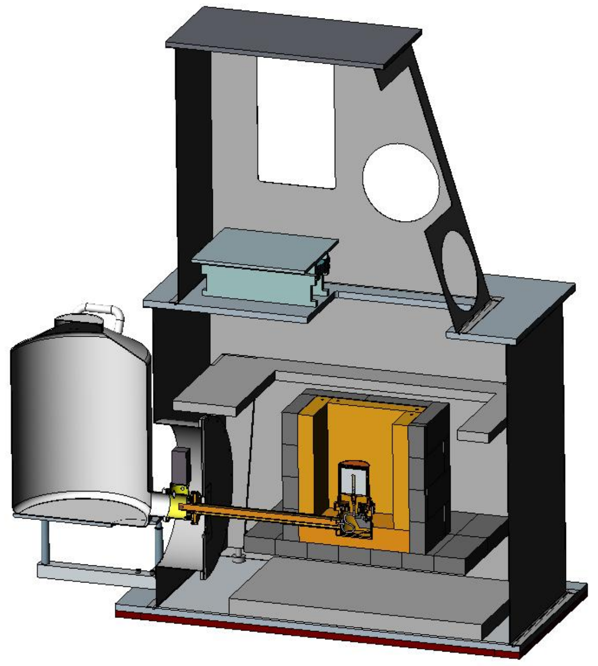
Ultra-low level radioactivity counting facilities at LNGS

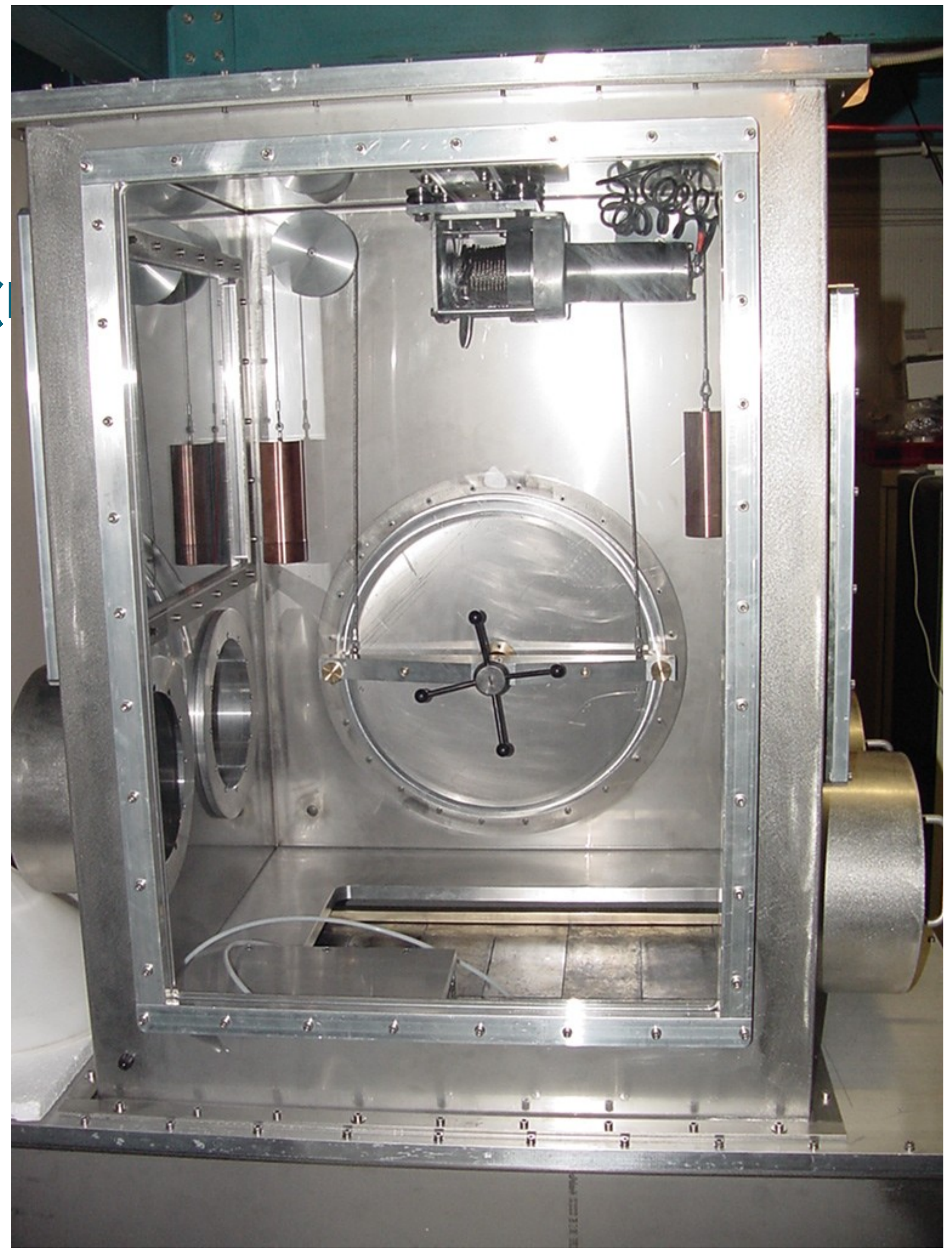
STELLA (SubTErranean Low Level Assay)
- γ spectrometry (High-Purity Ge Detectors, HPGe) – 10 detectors
- Sensitivity
•from 1 mBq/kg to 50 mBq/kg
- α spectrometry
- liquid scintillation counters

Inductively coupled plasma mass spectrometry (

- 7500a Agilent quadrupole ICP-MS
- TIMS (isotopic ratios)
- Class ISO6 clean room
- Sensitivity
• from 1 to 10 mBq/kg







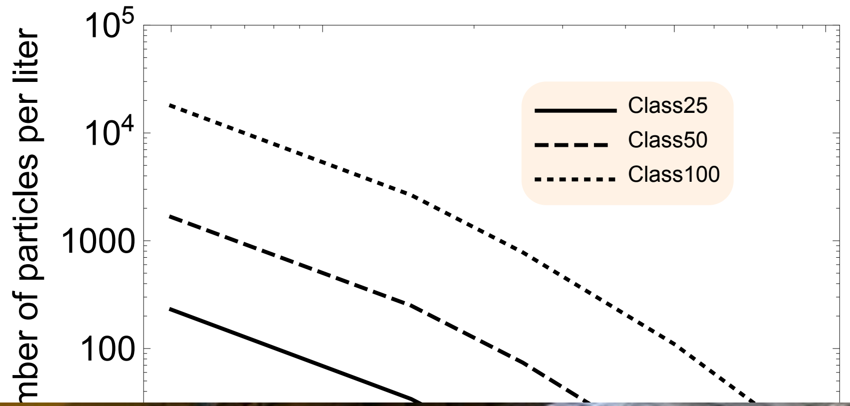
GeMPI type

MPI-K detector operated at LNGS
Custom made and ultra sensitive
4 systems

LNGS: cleanliness

- At LNGS world record on cleanliness level for large as-built fluid handling plant (framework Borexino and DarkSide-50)
- Use MILSTD-1246C
  - Class 50 implies for 2g/cm^3 particulate density a mass of 3.6 mg/l
  - Considering ~ ppm of U and Th contamination in particulate (for soil but conservative for steel) the residual radio impurity level is at 0.05-0.02 mBq/kg (~10^{-15}g/g)
- For class <= 50 after filtration <**10^{-16} g/g**
  - reached class 25 for 100 m^3 vessel
- Dedicated cleaning plant

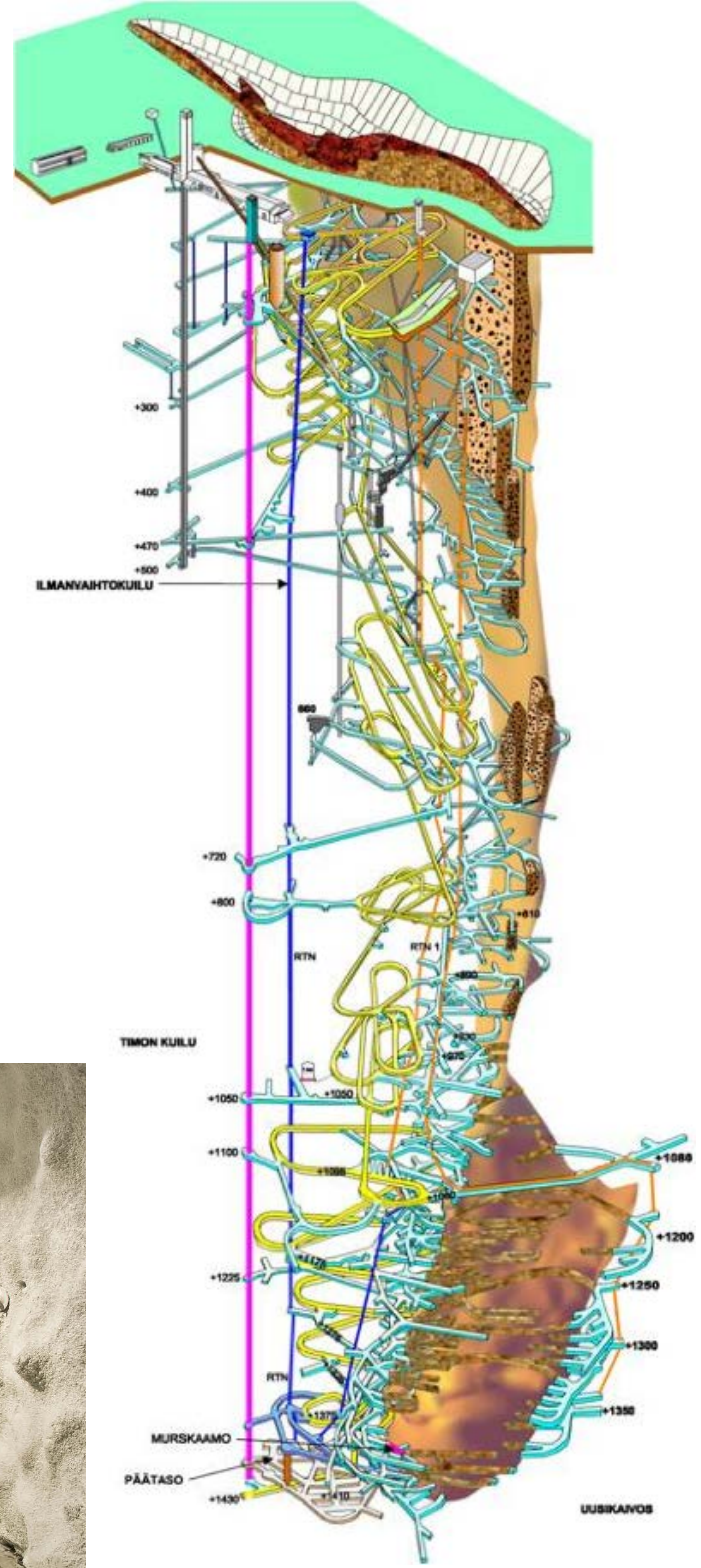
Interior of CR1 completed



CUPP - Centre for Underground Physics in Pyhäsalmi (Finland)

http://www.cupp.fi/

- Hosted in a working mine. Several cavities, dismissed by the mine, are available at different depths down to 980 m. Presently, the mine works at between 1000 m and 1440 m depth.
- Dimensions: Total area > 1000 m^2.
- Access: both via a shaft and an inclined tunnel.
- Facilities: small lab and office space in a surface building, a guest-house
- Personnel: 3 people on site and 3 at Oulu University
- Scientific program: atmospheric muons (EMMA). Proposed for the far detector of the LAGUNA-LBNO.
- New experimental hall (4100 mwe) avalilable since 2016

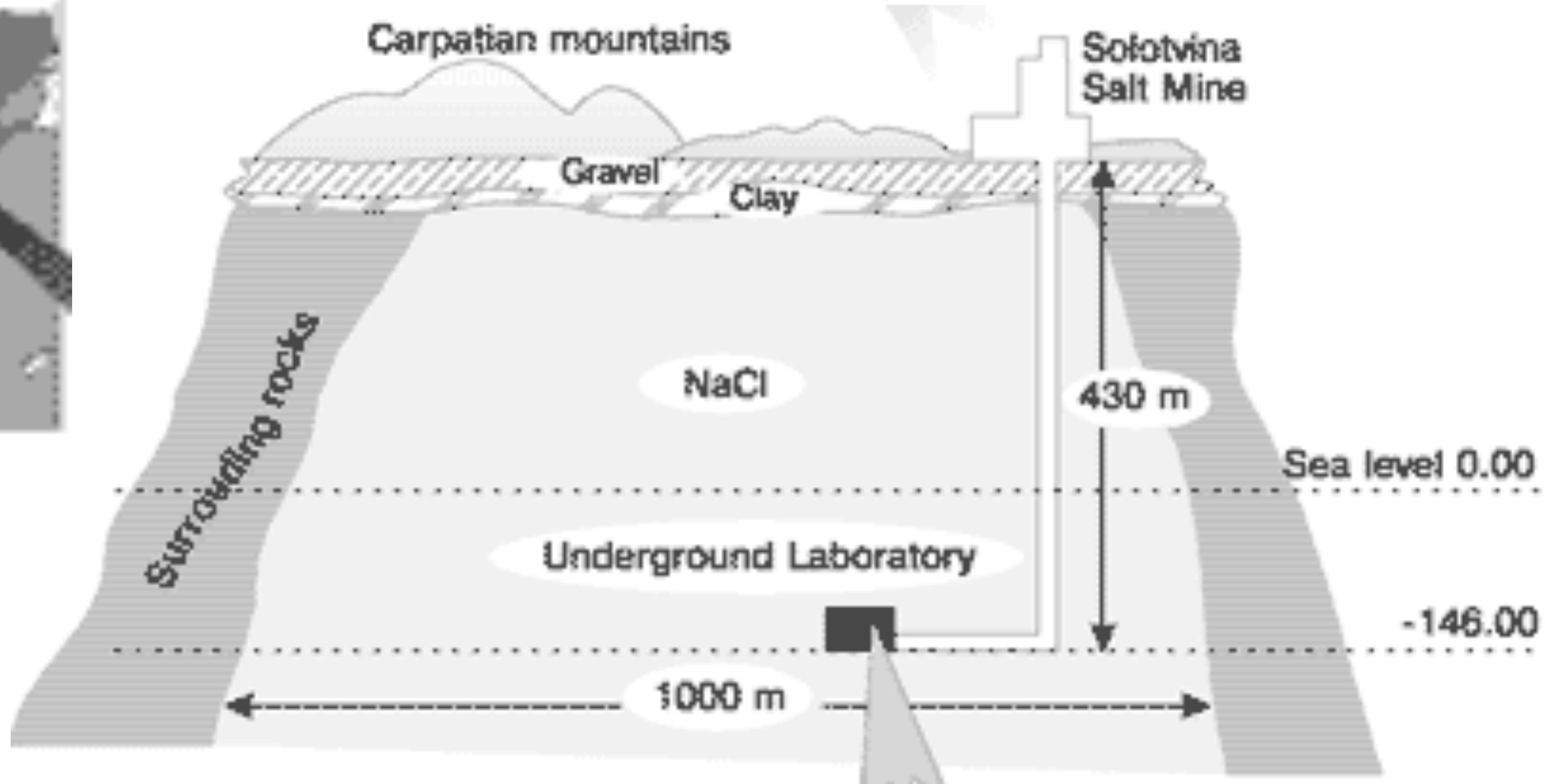


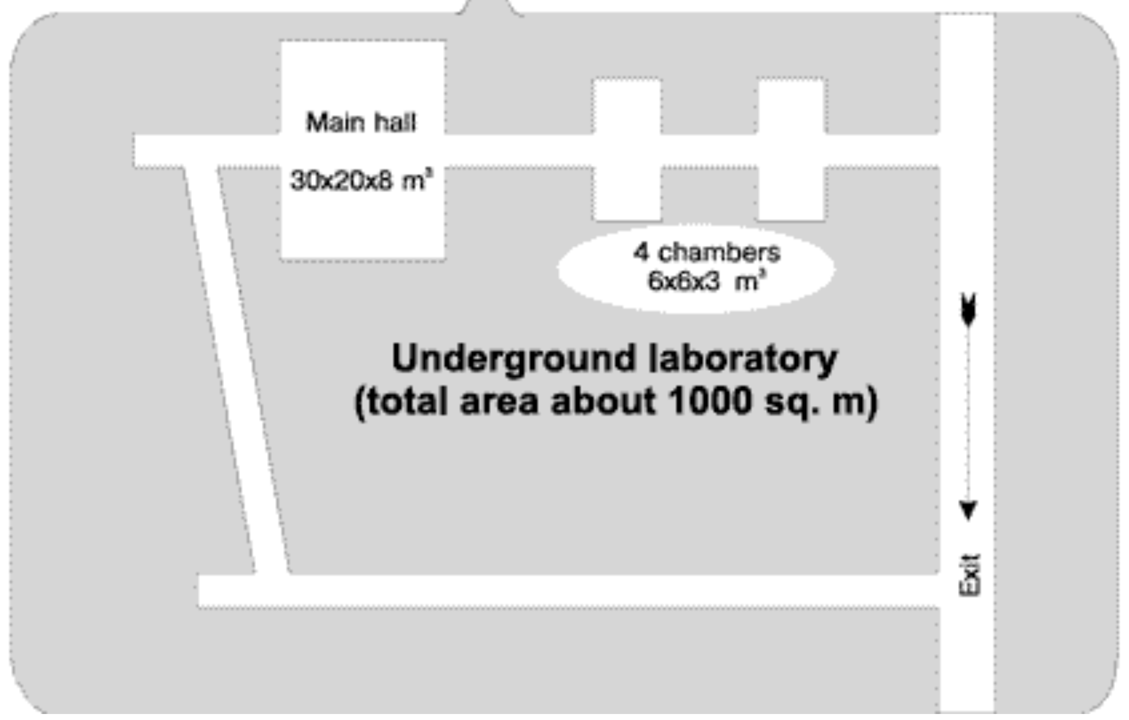
CUPP
Centre for Underground Physics in Pyhäsalmi

SUL - Solotvina Underground Laboratory (Ukraine)

http://lpd.kinr.kiev.ua/LPD_SUL.htm

- **1984**:excavated in a salt mine in 1984 under the leadership of Yuri Georgievich Zdesenko (Lepton Physics Department - Ukrainian National Academy of Sciences)
- **Dimensions**: Main Hall: 25×18×8 m^3 and four chambers 663(h) m^3. Total area ~1000 m^2.
- **On the surface**: three living rooms.
- **Personnel**: 14 technicians and engineers.
- **Access**: vertical by the mine cage (time-table of the mine)
- **Depth**: 430 m deep in salt (1 km w.e.).
- **Cosmic rays**: $\phi_\mu = 1.7\times10^{-2}$ m^{-2} s^{-1}, $\phi_n = 2.7\times10^{-2}$ m^{-2} s^{-1}
- **Radon**: 33 Bq m^{-3}.
- **Scientific program**: double beta decay ($^{116}CdWO_4$ scintillators, SuperNEMO R&D)





BNO - Baksan Neutrino Observatory (Russia)

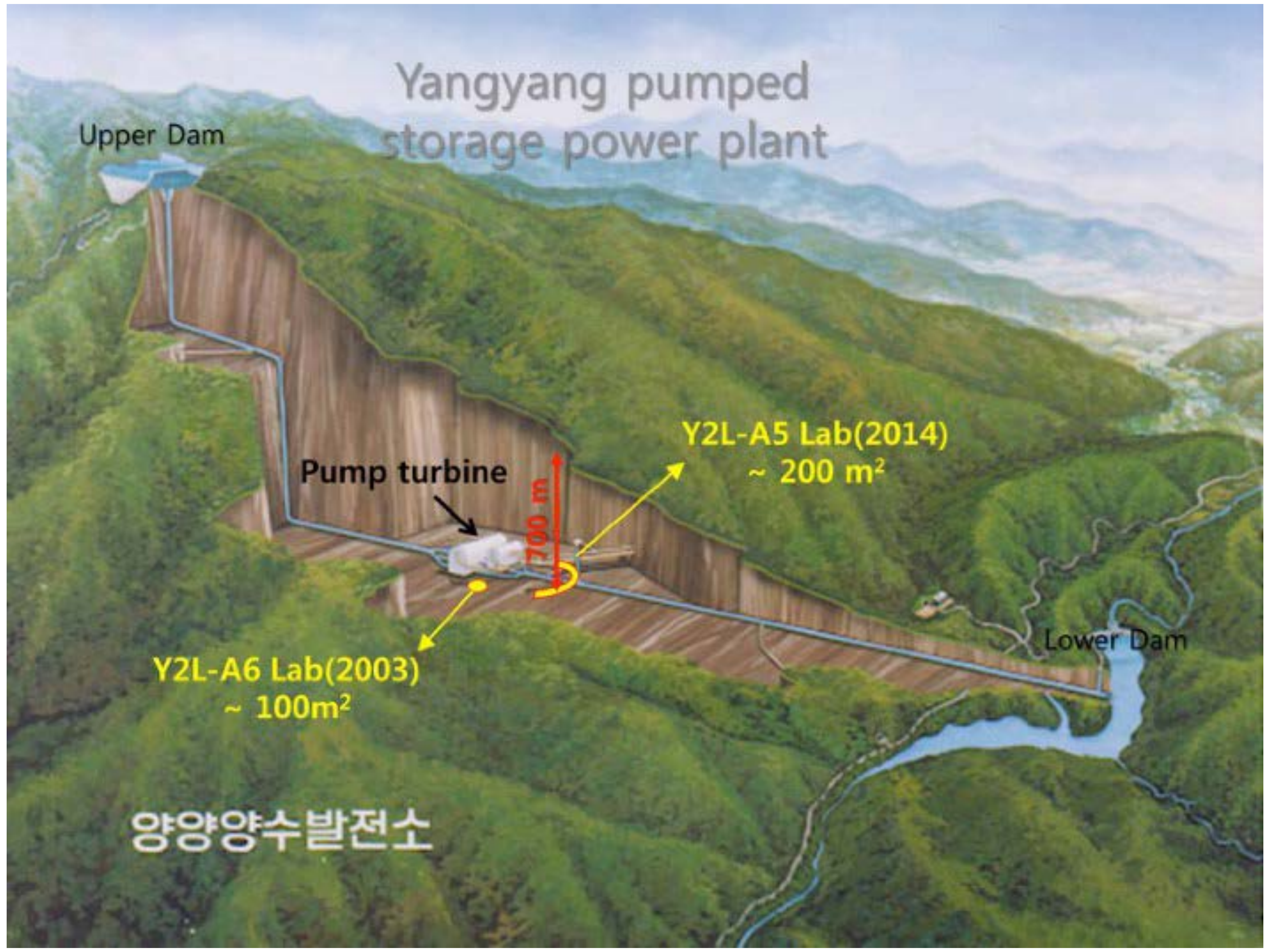
http://www.inr.ac.ru/INR/

- Operated by the INR (Russian Academy of Sciences) as an observatory, with very long-duration experiments.
- 1966: oldest facility in the world built specifically for scientific research (M. Markov), under Mount Andyrchi in the Caucasus.
- On the surface: a new village, called ‘Neutrino’, was built as a part of the original project, with necessary services (heating station, water-supply system, first medical help, transportation, safety, etc.).
- Personnel: 50-60 staff people.
- The scientific activity started under the leadership of Alexander Chudakov and George Zatsepin.
- Access: horizontal via two dedicated tunnels, with train transportation.
- Underground: BUST → 24×24×16 m^3 in volume, 300 m deep; SAGE → 60×10×12 m^3 at a vertical depth of 2 100 m.
- Cosmic rays: ϕ_μ=3.03±0.19×10^{-5} $m^{-2}s^{-1}$; ϕ_n(E>1 MeV)=1.4×10^{-3} $m^{-2}s^{-1}$
- Radon: 40 Bq/m^3 with a fresh air input of 60 000 m^3/h.
- Larger and deeper hall, about 40 000 m^3 in volume, was started in 1990, and stopped in 1992. Present fate under discussion.
- Users: 30-35.

Y2L - YangYang Laboratory (Korea)

http://dmrc.snu.ac.kr/

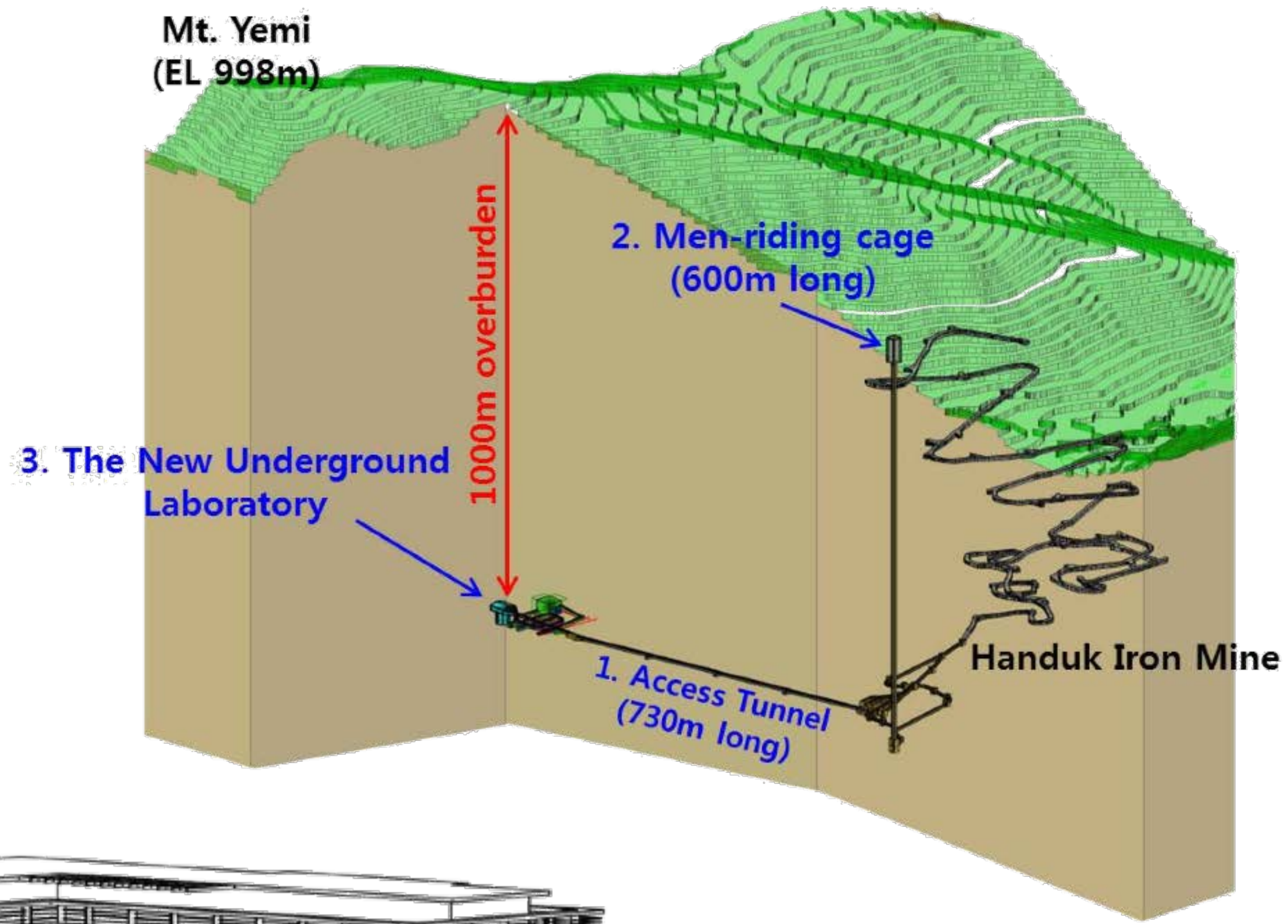
- Operated by the Dark Matter Research Centre (DMRC) of Seoul National University. in the tunnel of the YangYang Pumped Storage Power Plant
- Dimensions: total area ~200 m^2. 8 rooms, 3 experiments
- Access is horizontal by car.
- Safety: regulation of the Plant.
- Rock overburden: 700 m
- Cosmic rays: $\phi_\mu=2.7\times10^{-3}\ m^{-2}s^{-1}$, $\phi_n(1.5\ MeV < E_n < 6.0\ MeV)=8\times10^{-3}\ m^{-2}s^{-1}$
- Radon: 40-80 Bq/m^3.
- Scientific program: dark matter (KIMS)
- Users: ~30.

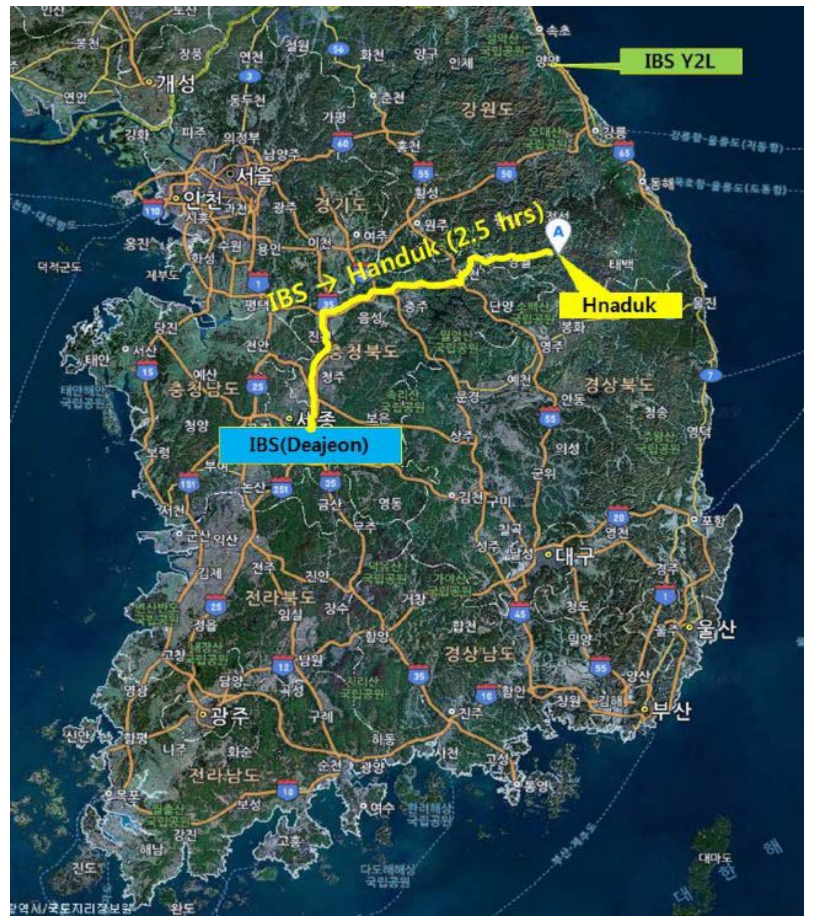


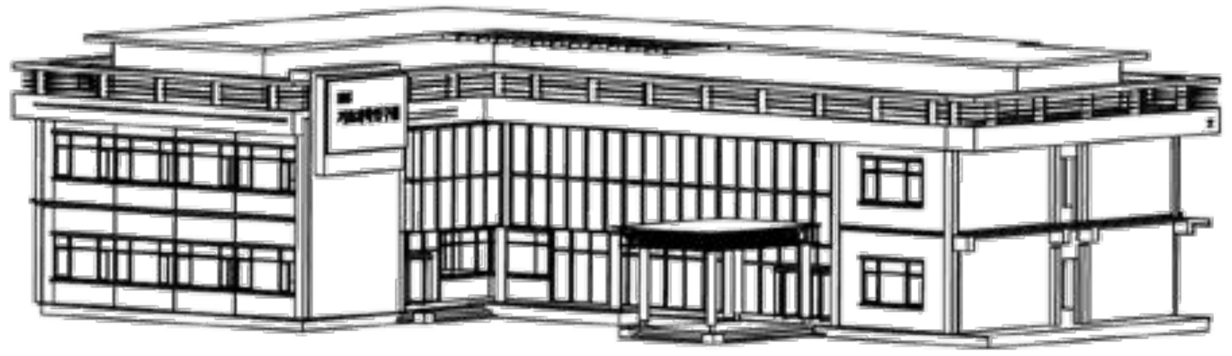
CUNPA - Centre for Underground Nuclear & Particle Astrophysics (Korea)

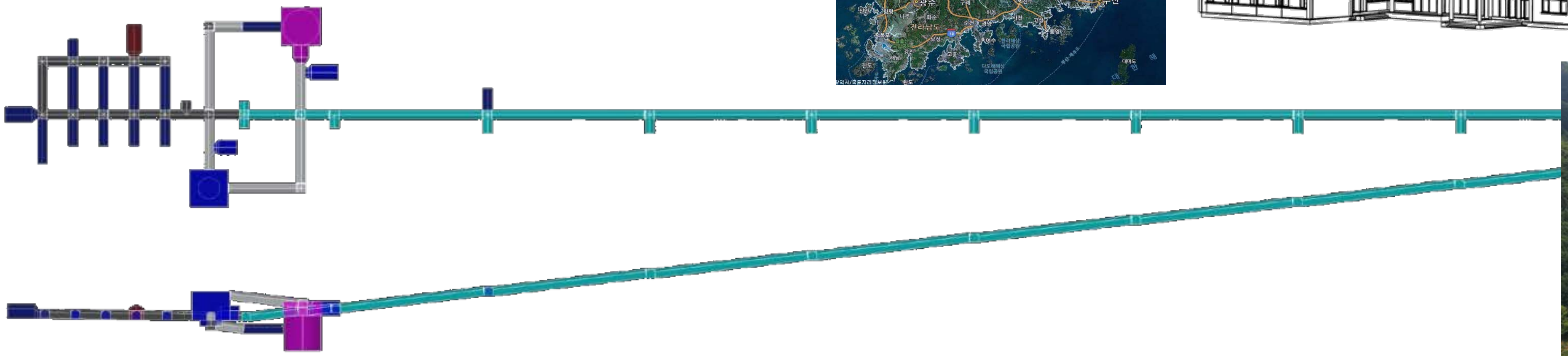
https://www.ibs.re.kr/en/research/astrophysics/astrophysics.jsp

- Started Institute by Basic Science (IBS) in 2012
- Various alternatives. Handeok mine, only operating iron ore mine in Korea (0.7 Mt/y of ore).
- Access: vertical (600 m long 2nd shaft constructed)
- 4 major sub-constructions: Tunnel excavation, Men-riding cage, Underground lab, Surface office/lab
- Dimensions: 58188 m^3 , 2648 m^2
- Depth: ~ 1000 m
- Excavation completed by 2019.
- Scientific program: double beta decay (AMORE)





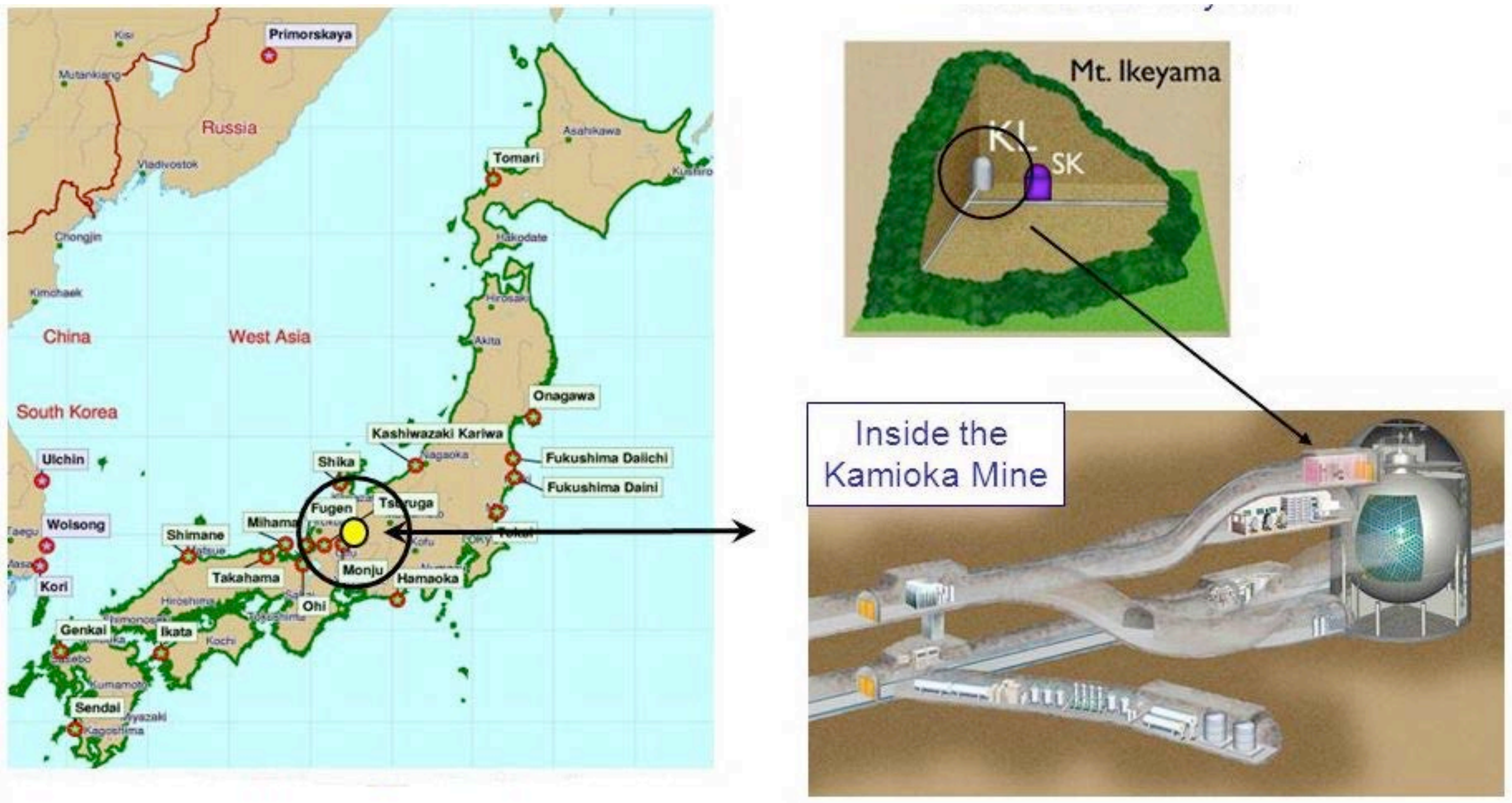


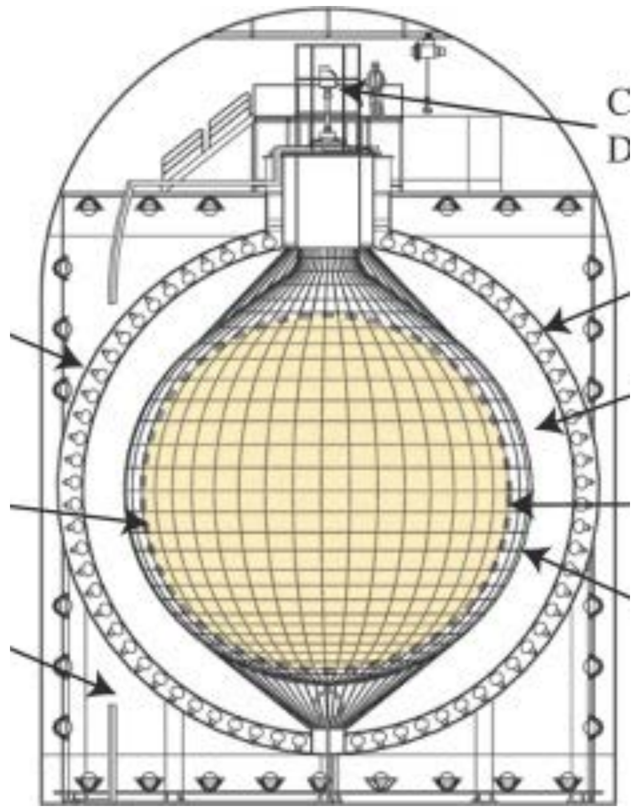


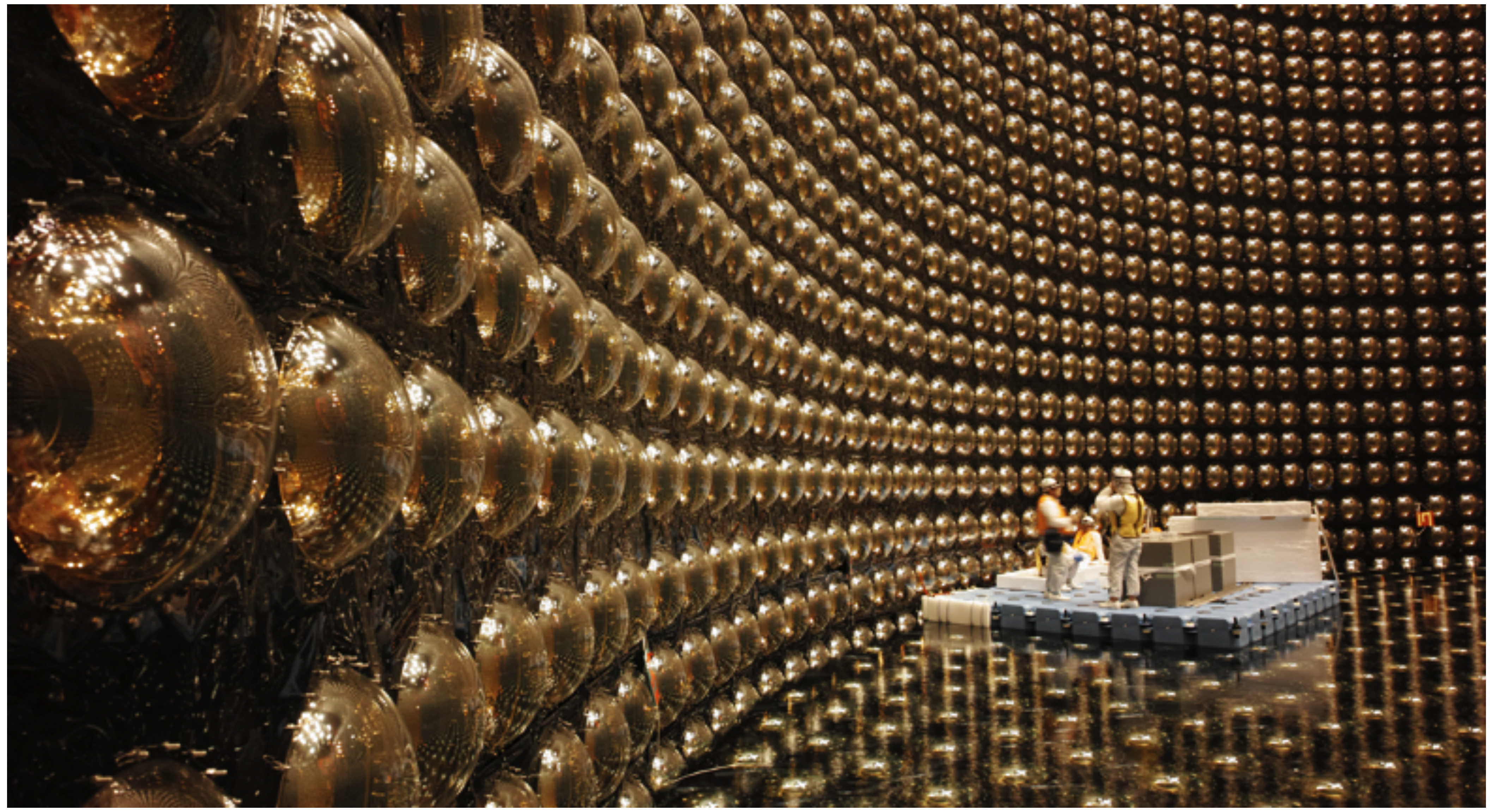
Kamioka Observatory (Japan)

http://www-sk.icrr.u-tokyo.ac.jp/index_e.html

- Operated by the Institute for Cosmic Ray Research, University of Tokyo.
- Established in **1983** by M. Koshiba as Kamioka Underground Observatory for the KamiokaNDE experiment
- **Personnel**: 13 scientists, 2 technical support units, one for administration.
- **Rock overburden**: 1000 m
- **Cosmic rays**: $\phi_\mu=3\times10^{-3}$ m^{-2}s^{-1}, ϕ_n(thermal)$=8.25\pm0.58\times10^{-2}$ m^{-2}s^{-1}, ϕ_n(fast)$11.5\pm1.2\times10^{-2}$ m^{-2}s^{-1}.
- **Ventilation**: 3000 m^3/h.
- **Access**: horizontal by car (no interference with the mining activity)
- **Underground structures**: Hall SK (50 m diameter), Clean room (105 m^2), Hall 40 (L-shape, 40m× 4m arm) , Hall 100 (L- shape, 100 m4 m arm), Hall A (1521 m^2), Hall B (611 m^2), KamLAND hall. Small areas are available in the dismissed mine.
- **Users**: > 200
- Cryogenic gravitational interferometer under construction.



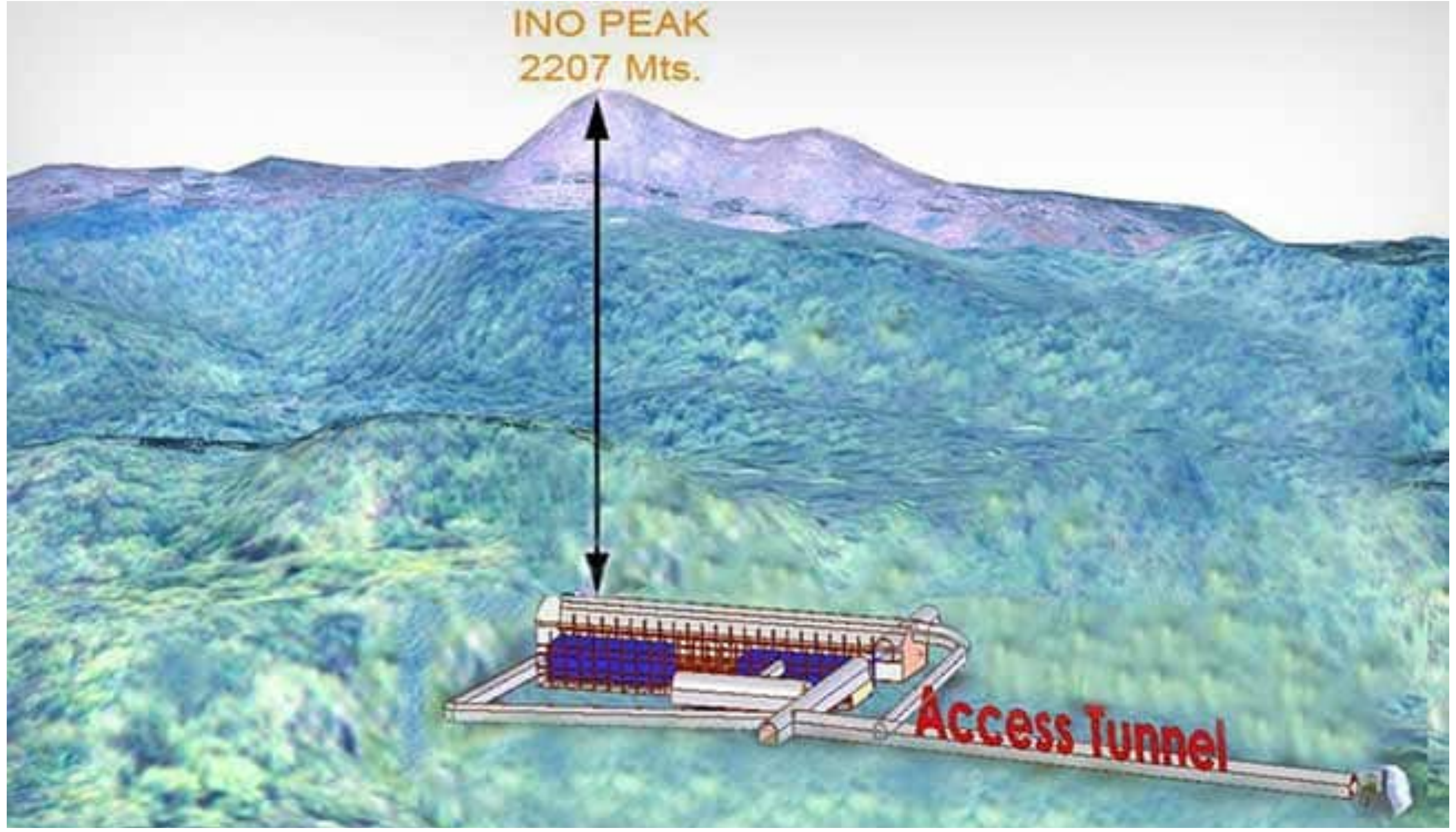


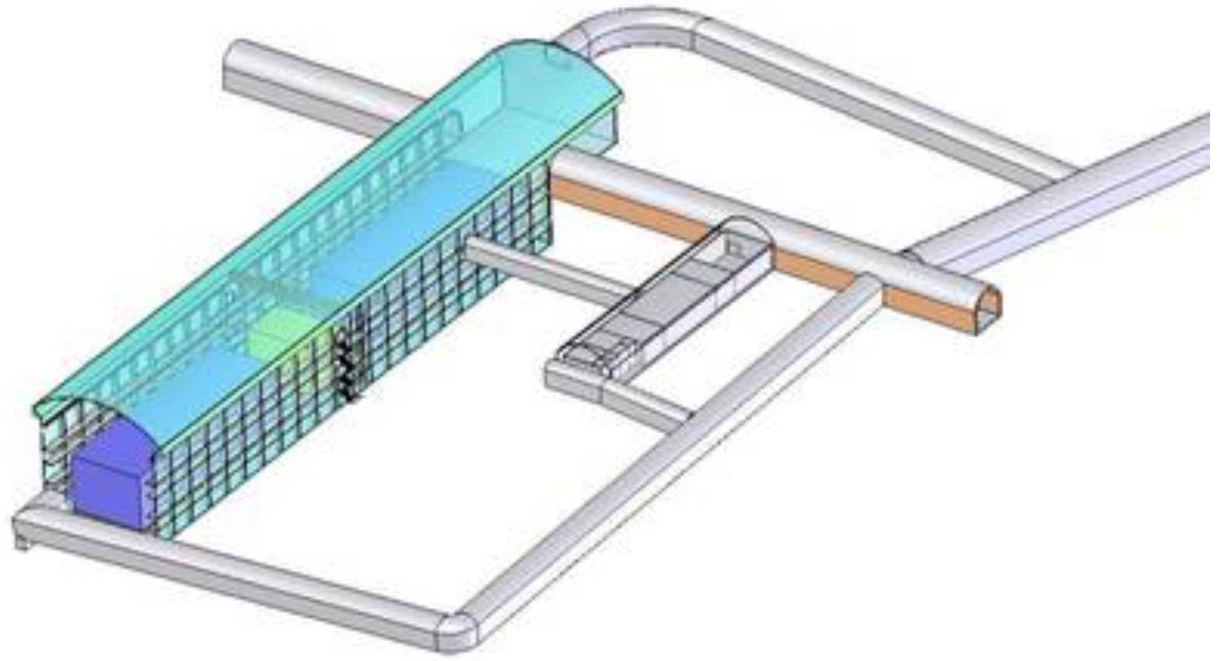


INO - India based Neutrino Observatory (India)

http://www.imsc.res.in/~ino/

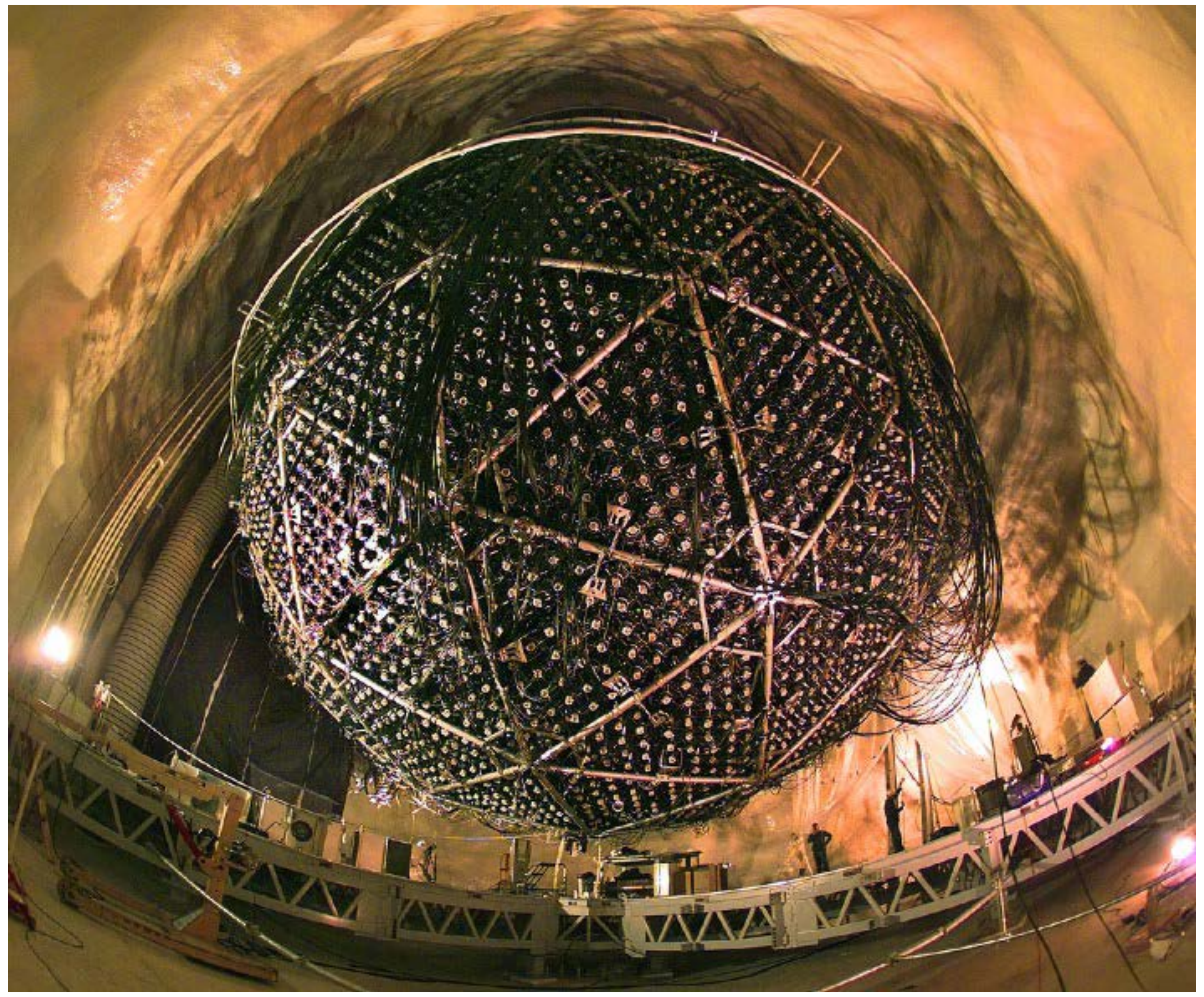
- One of the two experiments that first observed atmospheric neutrinos in 1964 was located at 2700 m depth in the Kolar Gold Mine in India.
- Foreseen to be built 115 km west of Mandurai in Tamil Nadu
- **Rock overburden**: 1200 m rock
- **Access**: horizontal: 1.9 km tunnel
- The project is waiting for the final approval of the Federal Government.
- **Planned underground structures**: a large hall $132 \times 26 \times 30(h) m^3$, smaller halls of $55 \times 12.5 m^2$ and $40 \times 20 m^2$ plus connecting tunnels.
- **Scientific program**: 100 kt mass ICAL detector for neutrino physics.





SNO-Lab (Canada)

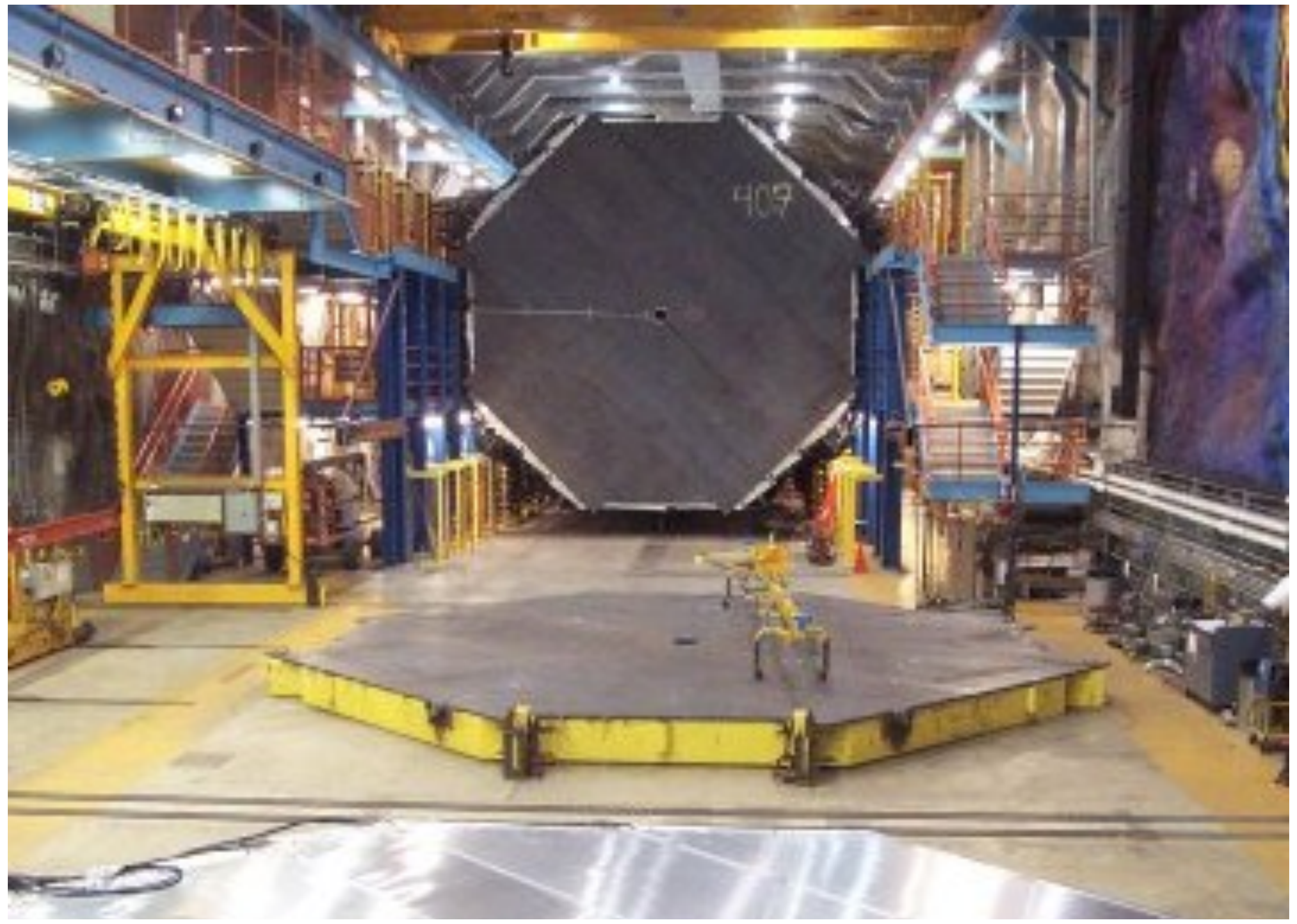
- http://www.snolab.ca/ also http://www.sno.phy.queensu.ca/
  The third largest and second (after CJPL) deepest of the working laboratories
- Hosted in the working Creighton nickel mine operated by Vale Ltd.
- All of class 1500 clean room characteristics
- Depth: 2070 m under flat surface
- Underground structures: a main hall (V=18×15×(15 to 19.5 height) m^3, a service hall ~ 180 m^2 and a number of narrow (6-7 m) volumes, called "ladder labs", and a large structure, called cryopit. Total area [volume]: 7215 m^2 [46 648 m^3], of which 3055 m^2 [29555 m^3] is available for the experiments
- Safety: use of cryogenic fluids.
- Access: vertical through the Vale maintained shaft and conveyances. Strict integration of the mine safety procedures and timetable (max size on the shaft 3.7 × 1.5 × 2.6 m^3)
- Procedures to separate the "dirty" mine environment from the clean one of the laboratory.
- Radon: 130 Bq/m^3 with ventilation providing 10[5] air changes/hour in smaller [larger] rooms
- Cosmic rays: $\phi_\mu=3\times10^{-6}\ m^{-2}\ s^{-1}$, $\phi_n=9.3\times10^{-2}\ m^{-2}\ s^{-1}$.
- On the surface: a 3159 m^2 building with clean room, laboratories, staging and assembly areas, office space (60 users), meeting rooms, control rooms,
- Personnel: 30 full-time people.
- Scientific program (reviewed by the Experimental Advisory Committee): dark matter search (DEAP, CLEAN, COUPP, PICASSO, SuperCDMS); double beta decay and neutrino physics (SNO+, EXOgas R&D); supernova neutrinos (HALO)
- Space for more experiments is still available

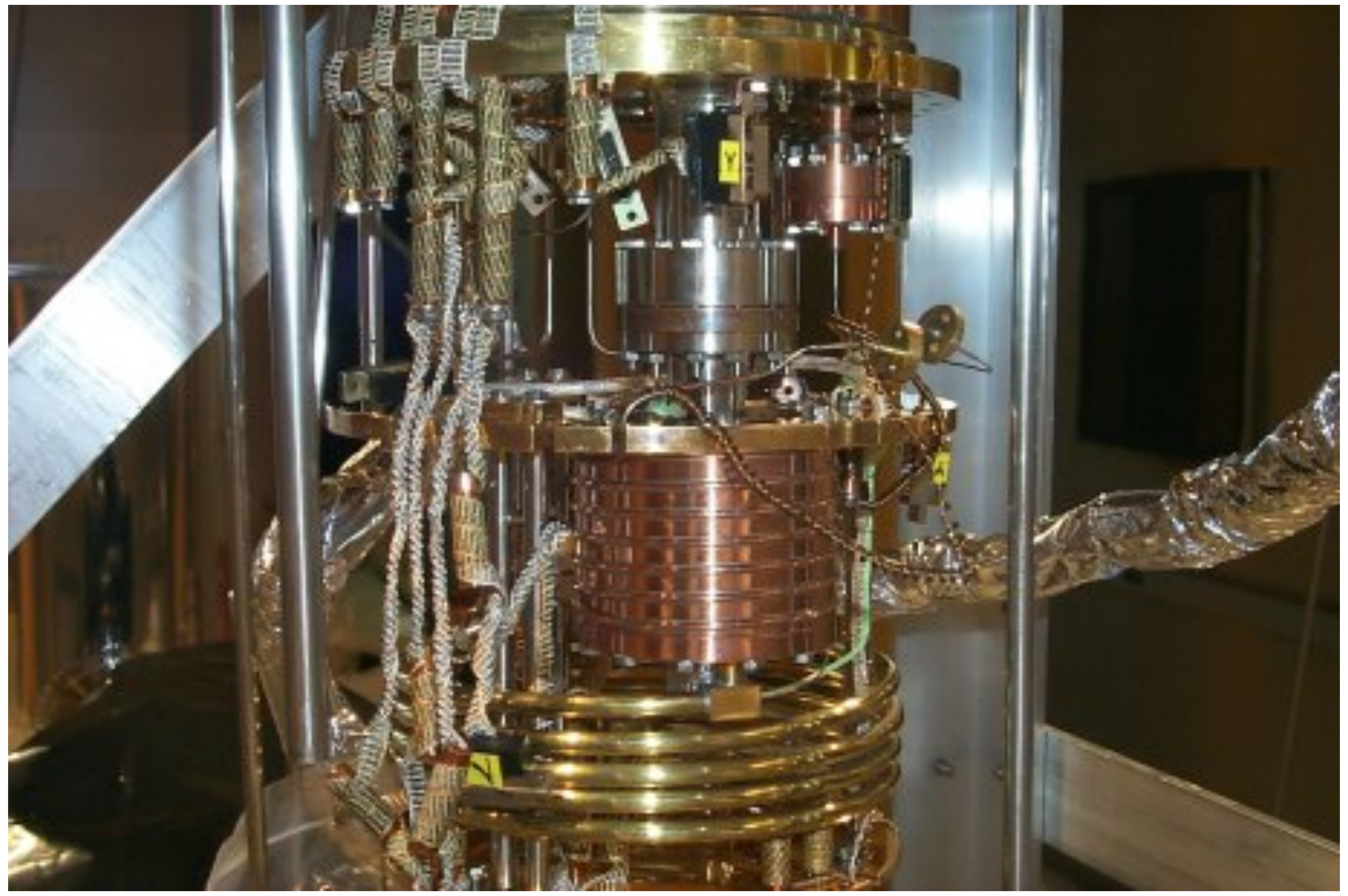


SUL - Soudan Underground Laboratory (USA)

http://www.soudan.umn.edu/

- Underground structures: Soudan lab 20×7×10(h) m^3 (which will expand to 25×14×14(h) m^3, if funded); MINOS lab 35×16×14(h) m^3
- Users: 265
- Access: vertical via a two-compartment slightly angled shaft. Diameters in excess of 1m and lengths in excess of 10m pose a problem. Access outside normal operating hours is possible.
- The laboratory coexists with an historic State Park, which offers mine tours during the summer months to the public, and winter tours to school groups. Some tours utilize a visitor's gallery available in the MINOS laboratory.
- No active mining activity.
- Depth: 700 m of rock.
- Cosmic rays: $\phi_\mu = 2\times10^{-3}\ m^{-2}\ s^{-1}$. $R_n = 10\ kg^{-1}\ d^{-1}$ (from U/TH, low energy) or 0.01 $kg^{-1}\ d^{-1}$ (muon generated in the rock)
- Radon: 300-700 Bq/m^3 in the summer.
- Ventilation: natural with ~550 m^3/h for the level of the laboratories (a complete air change every 110')
- On the surface: a building of approximately 650 m^2 with offices, a kitchen and sanitary facilities.
- Personnel: 9 staff, including secretarial and accounting assistance (10 hours/day, 5 days per week)





SURF Sanford Underground Research Facility(USA)

Sanford Underground Research Facility

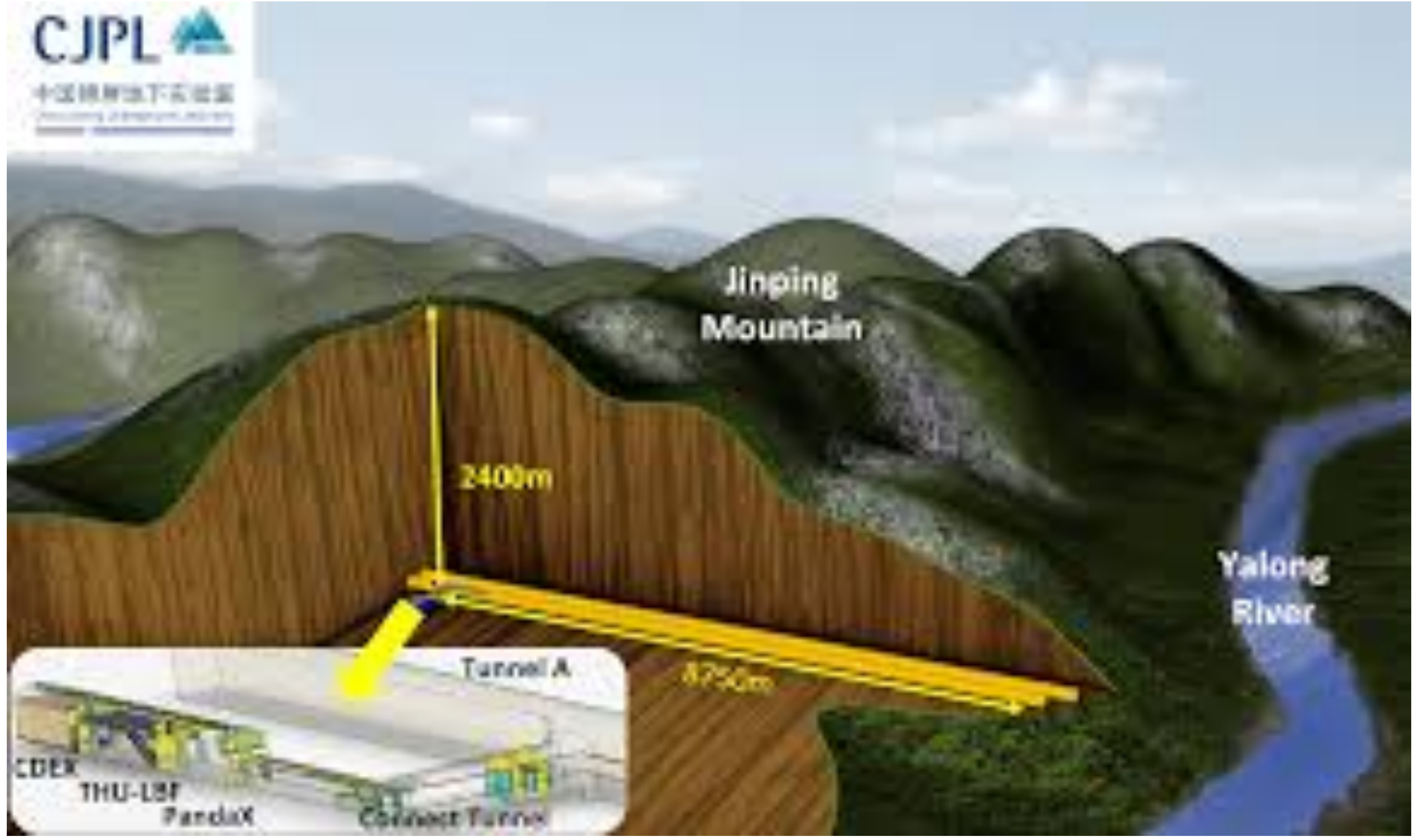
http://www.sanfordlab.org

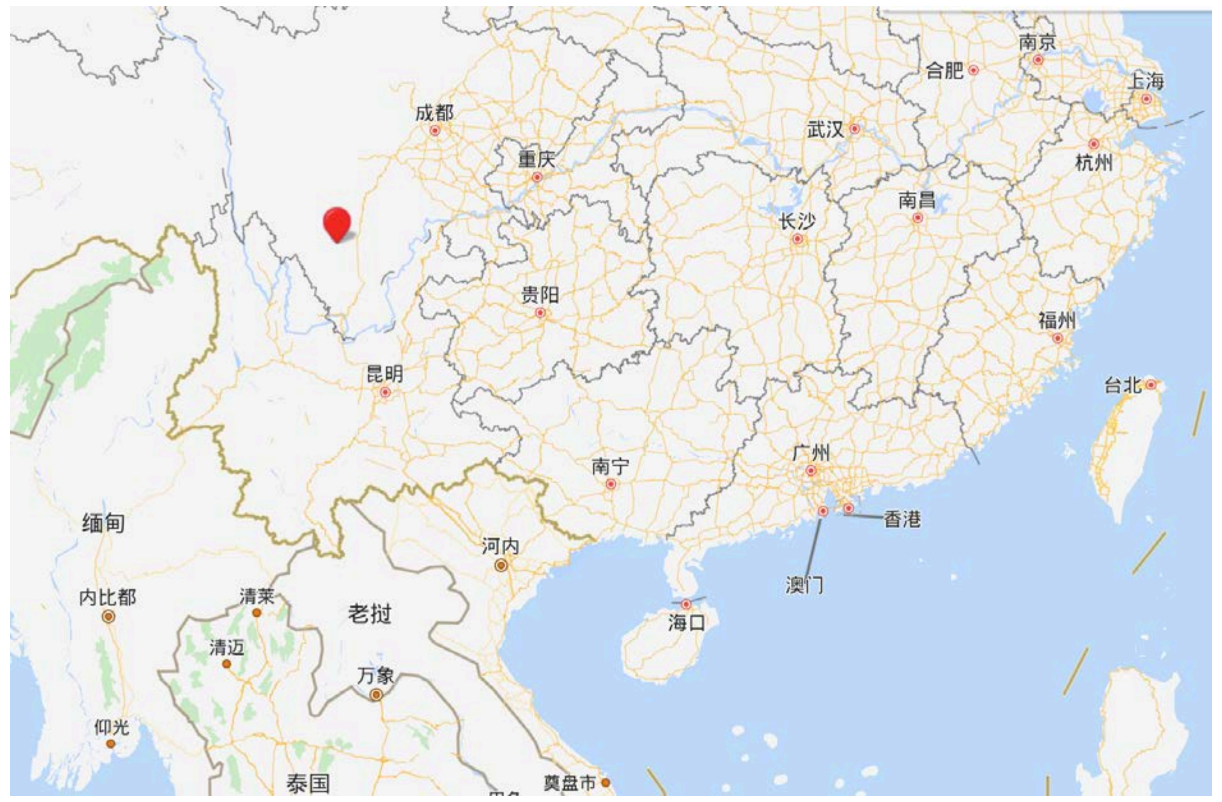
- Hosted in the Homestake Gold Mine, in Lead, South Dakota
- No mining activity
- 2003: the site is donated to the State of South Dakota. Supported by T. Denny Sanford. More funds were provided by the State of SD and by NSF.
- 2007: selected by US National Science Foundation (NSF) as the site for the Deep Underground Science and Engineering Laboratory (DUSEL)
- 2012: NSF discontinues support. Sanford Laboratory, or SURF, shifts to the DoE
- Lab refurbishment follows: underground water is pumped out, and the two vertical accesses to 4840L rehabilitated. The Davis Cavity was enlarged (18 × 11 × 13 m^3) and brought to laboratory standards. A new laboratory (43×16×5 m^3) has been excavated nearby (LUX, MJD)
- Pretty long tunnels connect the labs to the shafts.
- Underground structures: total area 2730 m^2, of which 930 m^2 are used for science.
- The site has been proposed as the host for the DUNE far detector

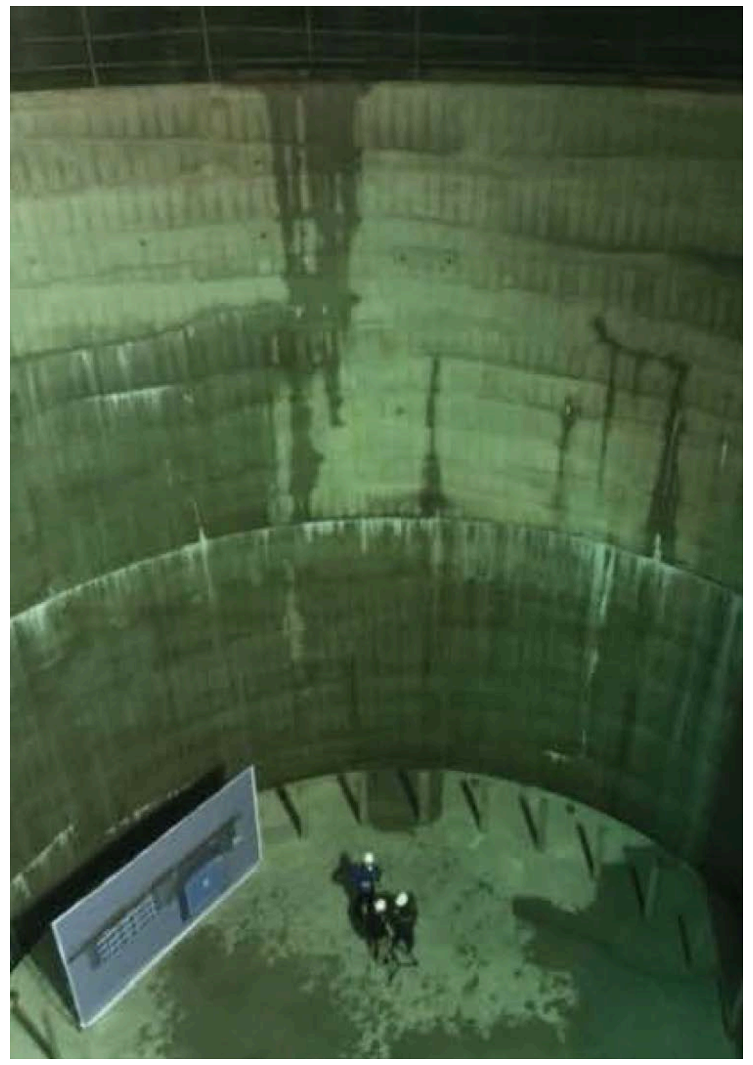
CJPL - China JinPing underground Laboratory

jinping.hep.tsinghua.edu.cn

- The Yalong river in China makes a large U-turn while descending from the 4000 m high JinPing mountain.
- A hydroelectric power stations system consisting of five parallel, 17 km long tunnels have been constructed.
- Service tunnels run parallel to the water ducts at about 1500 m elevation.
- The site for the new CJPL is in the middle of a service tunnel
- Rock overburden: 2400 m (the deepest world wide)
- Cosmic rays: $\phi_\mu = 2\times10^{-6}\ m^{-2}\ s^{-1}$.
- A hall of $40\times6\times6\ m^2$ (CJPL-I)has been completed in 2011.
- CJPL-II expansion has added 151,000 m3: interconnecting access tunnels, four large experimental halls (each 14×14×130 m and two pits for shielding tanks below the halls' floors.
- Scientific program is rapidly developing: dark matter (CDEX, PANDA-X)



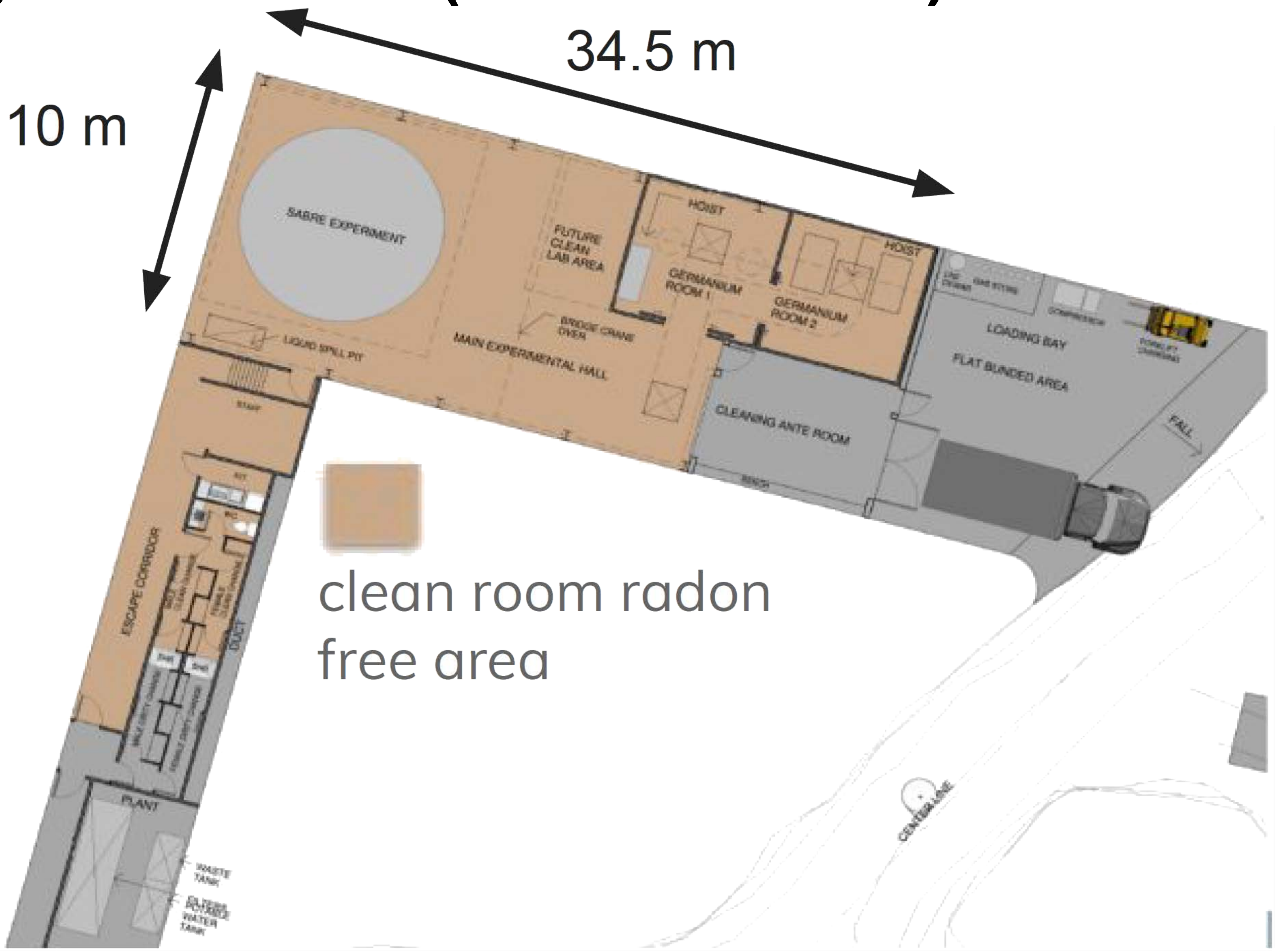




SUPL - Stawell Underground Phys. Lab. (Australia)

http://labdpr.cab.cnea.gov.ar/andes.php

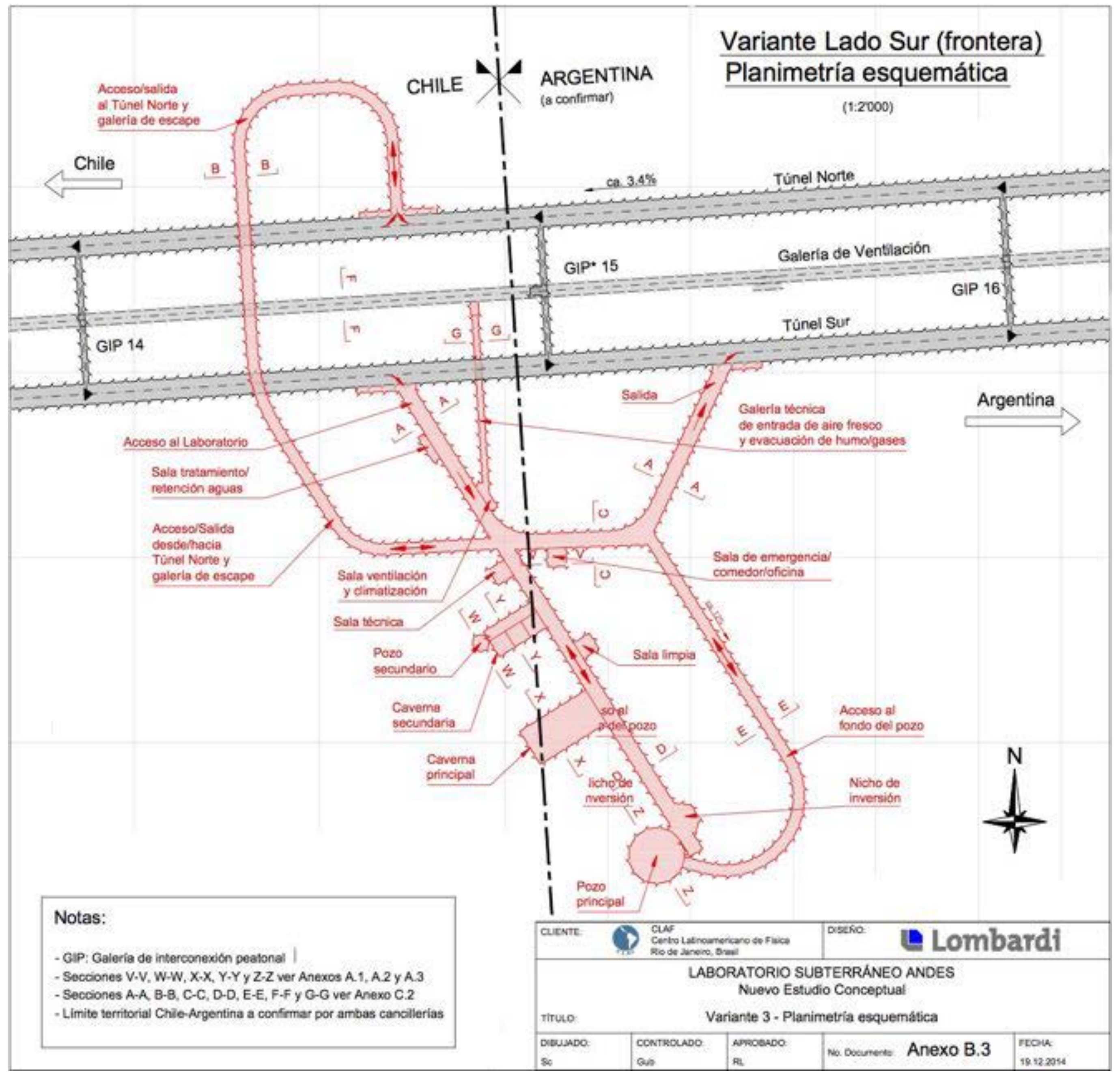
- Proposed in the Stawell Goldmine, located in Stawell, Shire of Northern Grampians, Victoria, Australia.Argentine entrance 4085 m, Chilean3620 m.
- Depth: ~1000 m.
- 2019: start construction.
- Access: by car through a decline (ramp)
- Underground structures: single cylindrical hall (ø=~10m) divided into 25 m for experiments, and 15 m (50 ft) of "dirty" loading area. A side tunnel (ø=5 m and 20 m long) for physical plant and personnel facilities
- Scientific program: dark matter (SABRE)

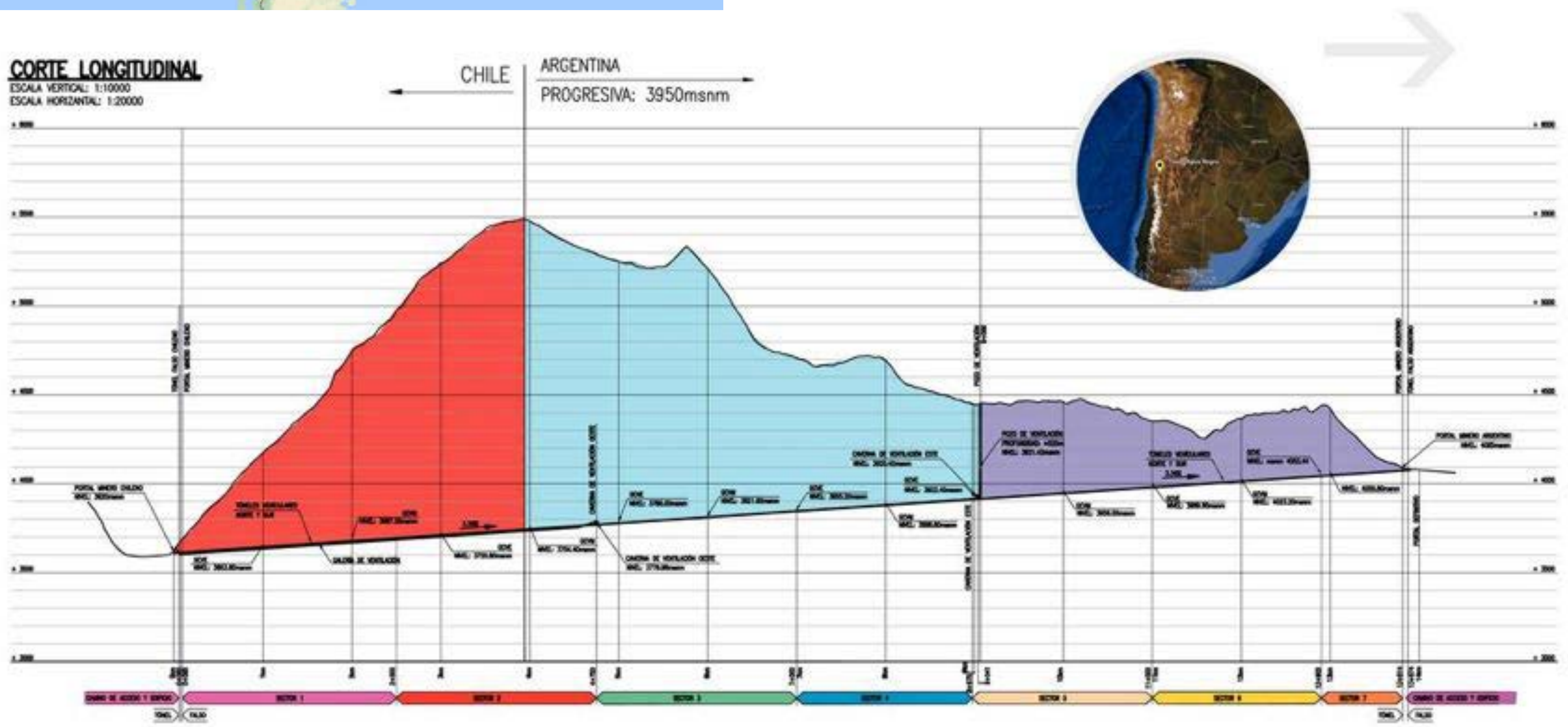


ANDES: Agua Negra Deep Experiments Site (Argentina)

http://labdpr.cab.cnea.gov.ar/andes.php

- Two parallel tunnels (ø 12m each, 60m one from another, 13.9 km in length) will cross the Andes. Tunnels completion of the tunnel is expected for 2021
- Argentine entrance 4085 m, Chilean3620 m.
- Deepest rock overburden 1750 m.
- 2013: call for expressions of interest published..
- The construction of the Agua Negra tunnel offers a unique opportunity to build a international facility for multidisciplinary underground science in the southern hemisphere.
- The lab volume and cost are around 2% of those of the tunnels.
- Expected underground facilities: main hall 21 × 23 × 50 m^3, a secondary hall of 16 × 14 × 40 m^3, a large pit 30(ø)x30 m, a low activity pit 9(ø)x9 m and a few smaller halls.
- On the surface: 2 laboratories at lower altitudes are foreseen (Rodeo in Argentina and Vicuña in Chile).
- The scientific programme is under development: neutrino physics, astrophysics and geology.. Other chapters will be on geophysics (the site is on the Nazca plate), biology underground, low activity and nuclear astrophysics





SAUPL - South African Und. Phys. Lab (South Afrika)

http://labdpr.cab.cnea.gov.ar/andes.php

- Discussions about an underground research facility in SA started in 2011 @ iThemba (Cape Town).
- South Africa has a number of the worlds deepest gold mines (TauTona Gold Mine ~3.9 km)
- Initial focus was on establishing an underground facility in one of South Africa's deep gold mines.
- The alternative is to develop such an underground laboratory inside the Huguenot Tunnel.
- The range mostly consists of Table Mountain sandstone, an erosion-resistant quatzitic sandstone