DuRA 2012 Meeting

Fermi National Accelerator Laboratory

Batavia, Illinois – USA

January 19-2- 2012

The World Underground Physics Laboratories

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INFN. Padua

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Canfranc Underground Laboratory

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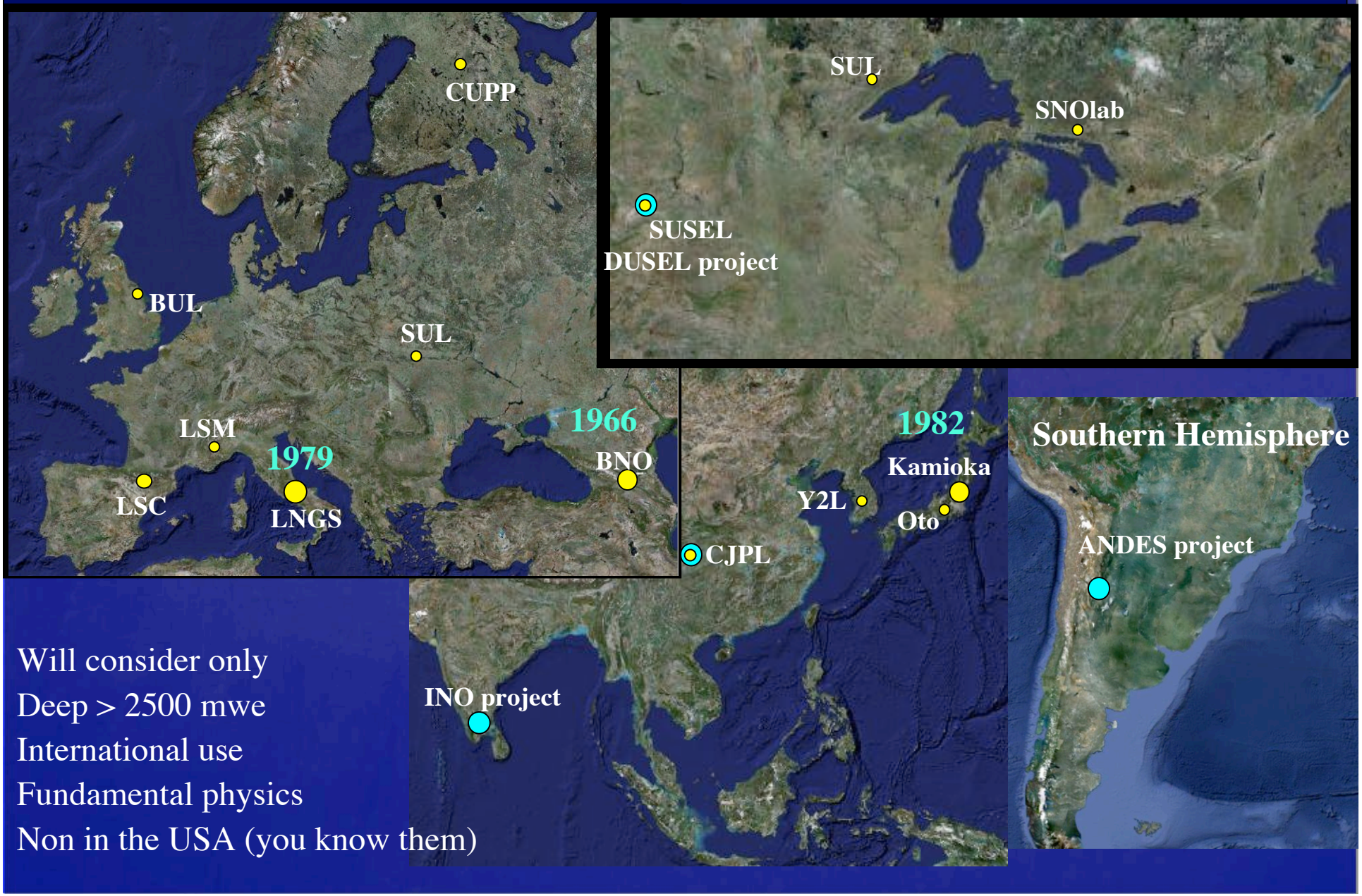
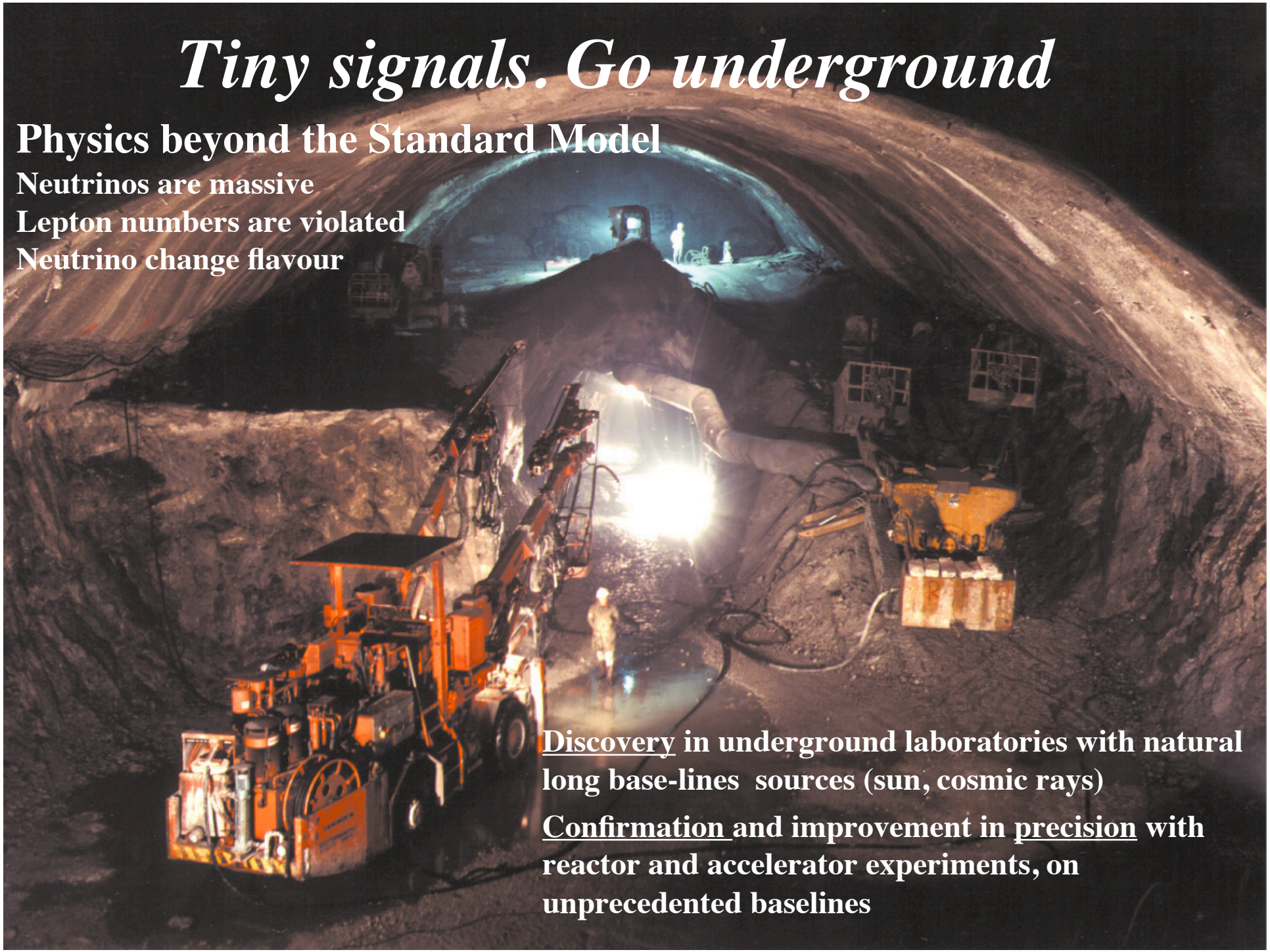
The sites



Will consider only
Deep > 2500 mwe
International use
Fundamental physics
Non in the USA (you know them)

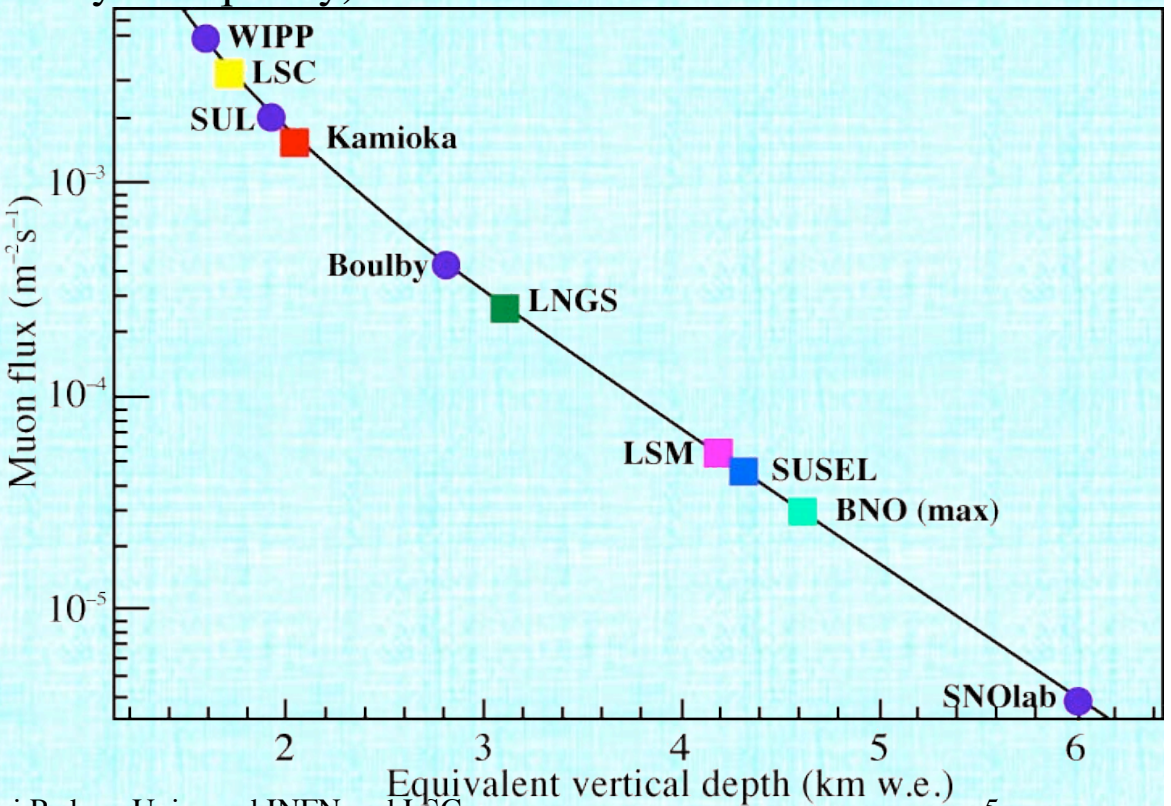

Tiny signals. Go underground
Physics beyond the Standard Model
Neutrinos are massive
Lepton numbers are violated
Neutrino change flavour
Discovery in underground laboratories with natural long base-lines sources (sun, cosmic rays)
Confirmation and improvement in precision with reactor and accelerator experiments, on unprecedented baselines

Physics in Underground Laboratories

- **Proton decay**
- **Atmospheric neutrinos**
  - **Oscillations (neutrinos have a mass, neutrinos change family)**
- **Solar neutrinos**
  - **Oscillations and matter effects (neutrinos have a mass, neutrinos change family)**
  - **Solar physics**
- **Are neutrinos and antineutrinos the same particle?(double beta decay)**
- **Masses of neutrinos**
- **Neutrinos from accelerators**
  - **Oscillations, CP violation in the lepton sector**
- **Neutrinos from nuclear reactors**
  - **Oscillations**
- **Neutrinos from Earth (what powers the Earth heat?≈ 30 TW)**
- **Neutrinos from supernova explosions**
- **Relic supernovae neutrinos**
- **Dark matter - Direct search of WIMPs**
- **Nuclear astrophysics**

Characteristics of Underground Laboratories

- Depth (μ flux, spallation n flux)
  - Determines only a fraction of the background sources
  - Maximum cavity size decreases with increasing depth, costs increase, rock bursts risk increases
- Diameter & height of the halls
  - May limit the thickness of the shields (water tanks)
  - Depends on rock quality and depth
- Horizontal vs. vertical access (vertical more expensive and risky)
- Support infrastructures, personnel (quantity and quality)
- Underground area allocation policy, turnover of experiments
  - Scientific Committee: international vs. local (or national)
- Degree of internationality of the community
- Other science (geology, biology, engineering, etc.)

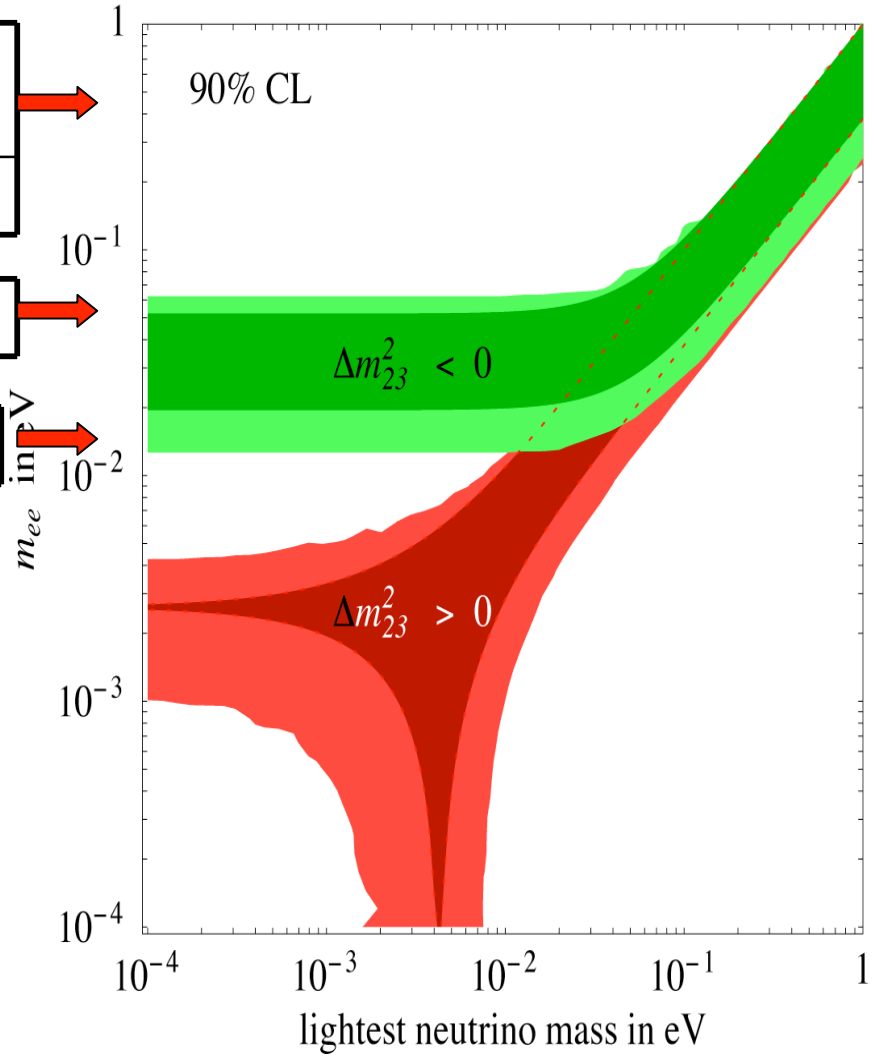


The experimental challenge. DBD

Events per ton per year

	Ge enrich. (85%)	TeO_2 natural	Xe enrich. (85%)
KDKC claim M_{ee}=500 meV	360	250	350
M_{ee}=50 meV	3.6	2.5	3.5
M_{ee}=15 meV	0.4	0.25	0.4

Reaching 50 meV requires reducing background index by 2 or 3 orders of magnitudes



Shielding ambient radioactivity with H2O

γ flux from U, Th, K = 0.5 $m^{-2}s^{-1}$ @ LNGS, almost depth independent

n flux from U, Th, K = 3.8×10^{-2} $m^{-2}s^{-1}$ @ LNGS, almost depth independent

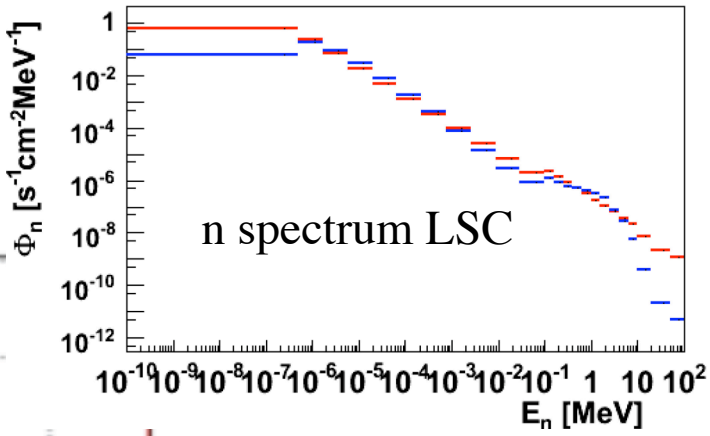
n flux μ-induced in rocks $\approx 8 \times 10^{-6}$ $m^{-2}s^{-1}$ @ LNGS, depth **dependent** ($\approx \times 10$ @ LSC)

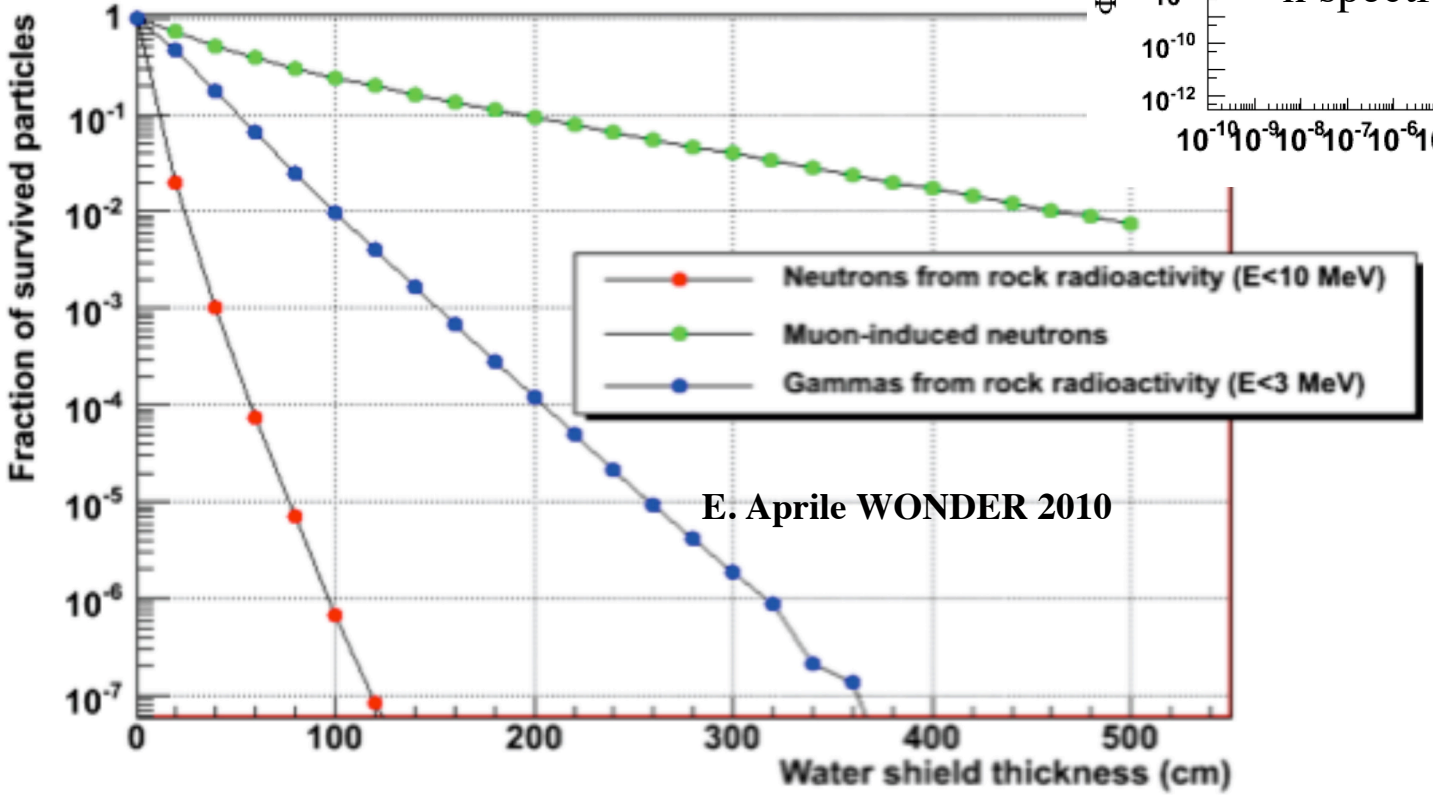
H. Wulandri et al. CRESST hep-ex0401032v1

Shielding materials must be sufficiently radio-pure

Consider radioactivity of the inner wall (if any)

Water shields thickness ⇒ 3-4 m





Designed for external
γ,n,μ background
~10^{-4} cts/(keV kg y)

∅ 10 m

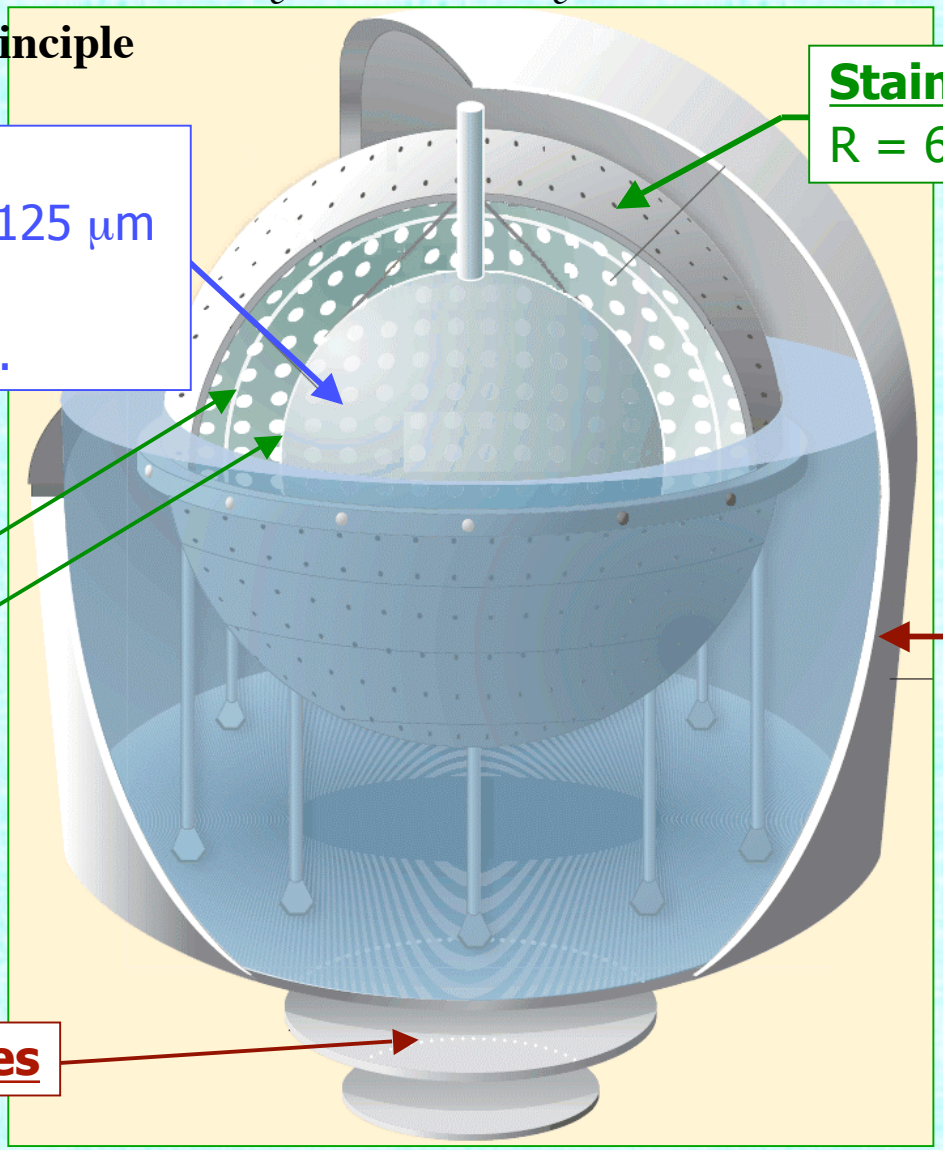
H = 9.5 m

V = 650 m^3

BOREXINO - Detector layout

$\nu_e + e^- \rightarrow \nu_e + e^-$

Graded shielding principle



Stainless Steel Sphere:
R = 6.9 m V=1350 m^3

Scintillator:
270 t PC+PPO in a 125 μm thick nylon vessel
Inner 100 t: fid. vol.

Nylon vessels:
Inner: R=4.25 m
Outer: R=5.50 m

Water Tank:
γ and *n* shield
μ water Ch detector
R=9 m
2100 m^3

Carbon steel plates

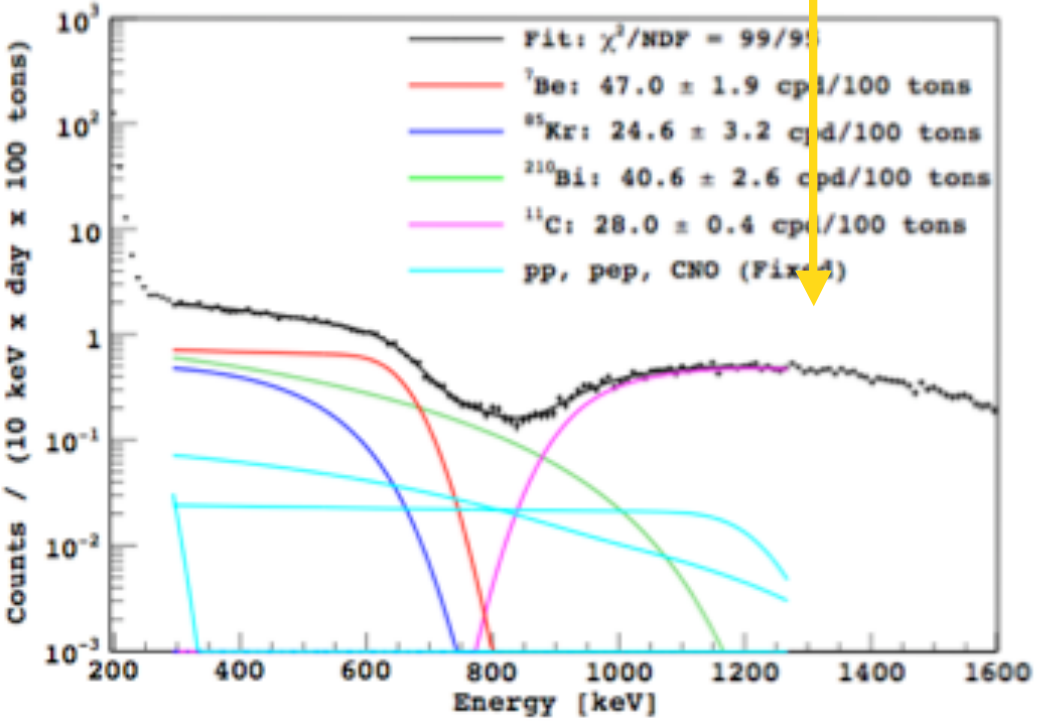
BOREXINO

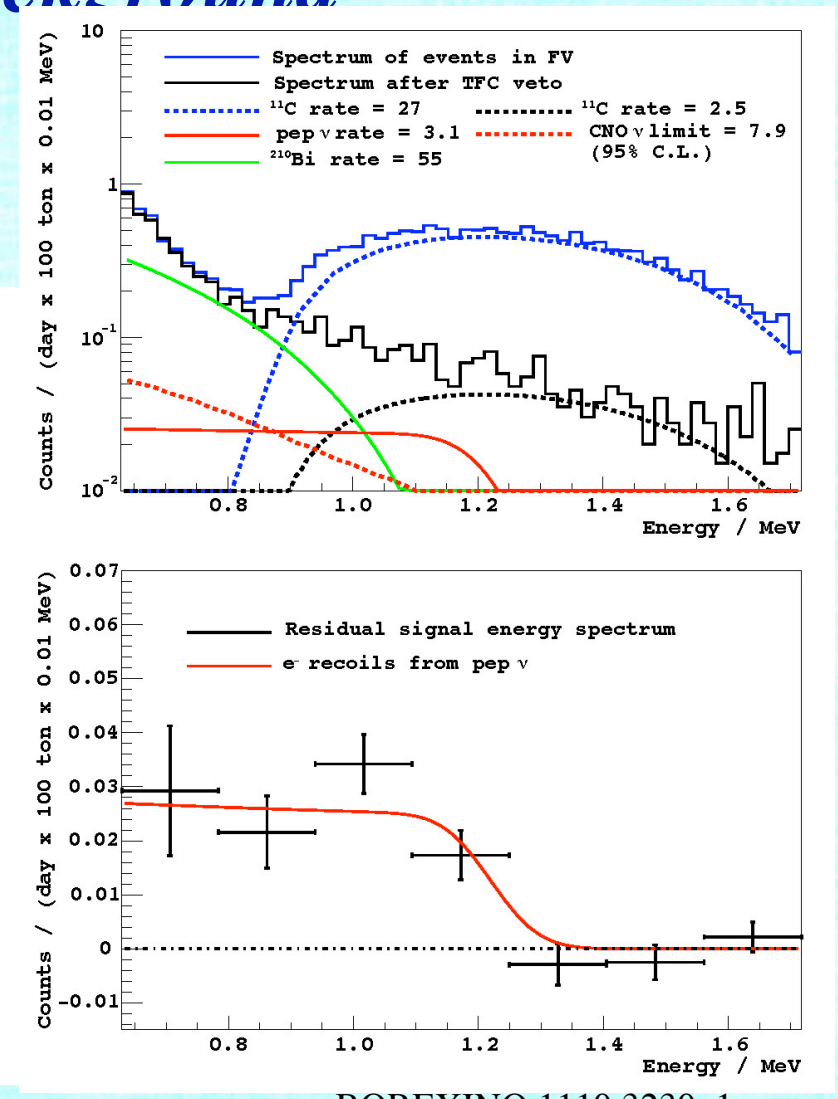
$$\nu_e + e^- \rightarrow \nu_e + e^-$$

a cosmogenic background

Cosmogenic in situ ^{11}C

@ LNGS depth suppression by off-line analysis needed





BOREXINO 1110.3230v1

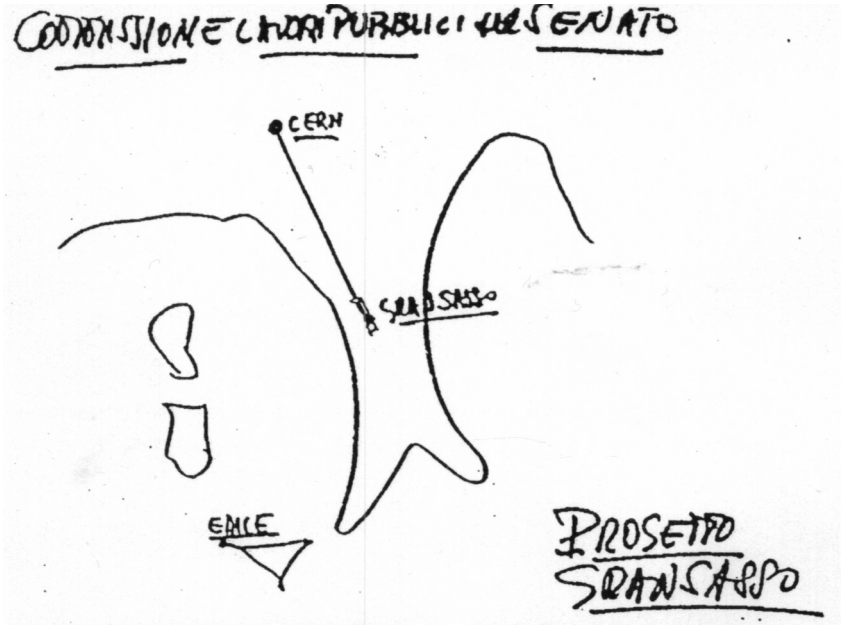
Gran Sasso Laboratory. Italy

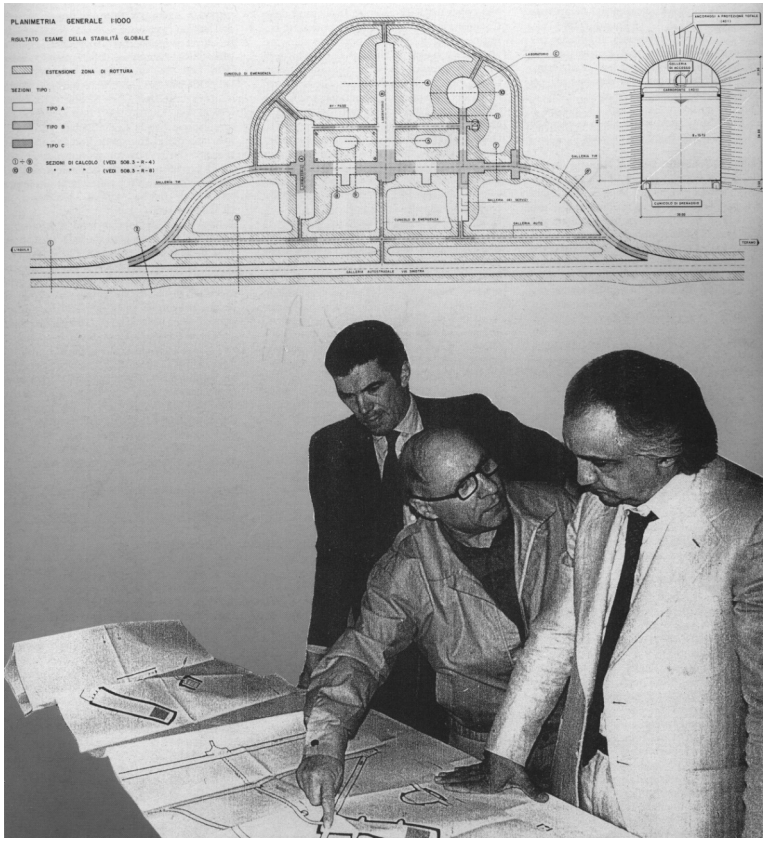
The largest underground laboratory
The largest scientific community

INFN Gran Sasso National Laboratory

1979 A. Zichichi proposes to the Parliament to build a large underground laboratory close to the Gran Sasso freeway tunnel, under construction

1982 the Parliament approves the construction, finished in **1987**



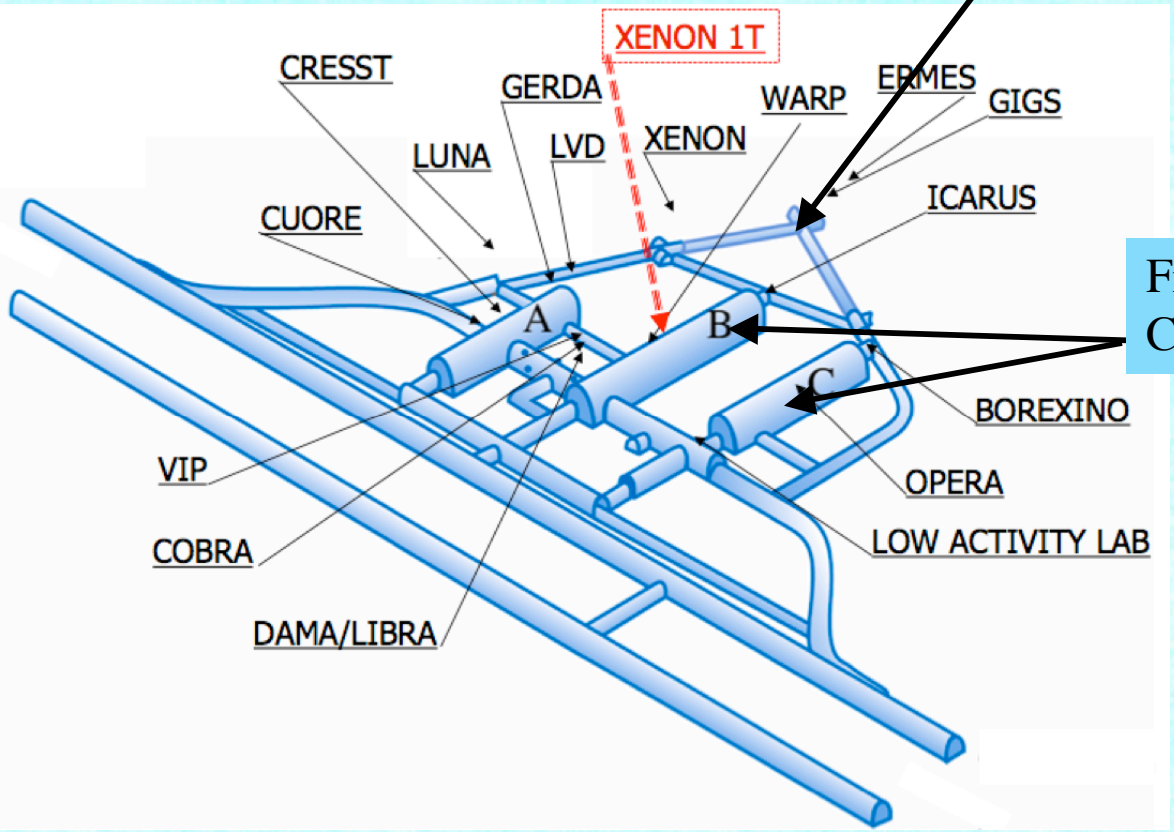


INFN-LNGS

- 1400 m rock overburden (3.2 km w.e.)
- n flux = 3.8±0.3 10^{-2} $m^{-2}s^{-1}$ (spectrum measured)
- μ flux = 3 x 10^{-4} $m^{-2}s^{-1}$ (angular dependence measured)
- γ flux= 1× 10^{-4} $m^{-2}s^{-1}$
- Volume 180 000 m^3, area 17 300 m^2
- Radon in air 50-80 Bq/m^3
- Drive in to the experiments
- Staff = 82 permanent +19. Users=960

LNGS Experiments

Possible location of LUNA MeV



Free space after CNGS ends (2012)

Experiments are approved with a defined duration to allow turnover of the underground space

Large pieces of apparatus can be moved in (ICARUS module 4x4x20 m^3). [Only one entrance]

Cost ≈ 96 M€ 2011 + surface structures (Access tunnel L=5km, D=6.5 m; cost ≈ 70 M€ 2011)

Running costs= 15 M € /y.

LSC. Surface Laboratories

Headquarters & Administration
Safety and Quality Assurance
16 offices for scientific users
7 offices for LSC personnel
4 specialised laboratories

Useful area = 1800 m^2

Cost =3 M €

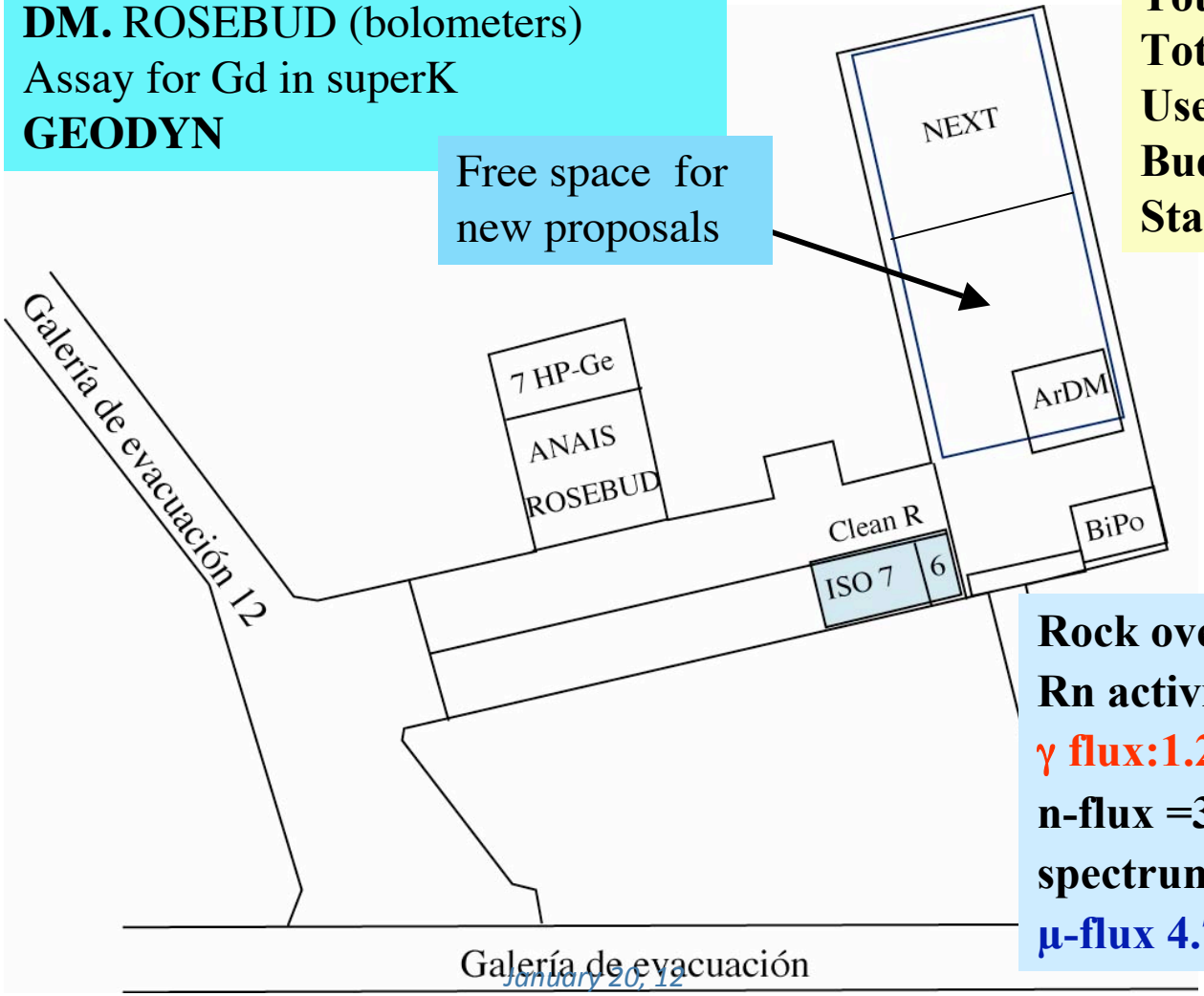
Mechanical workshop
Storage room
Meeting room
Library
Conference room
Exhibitions room
2 apartments

LSC. Spain. Underground structures

DBD. NEXT (Xe gas TPC)
DBD. BiPo, ancillary to SNemo
DM. ArDM (LAr TPC)
DM. ANAIS (NaI modulation)
DM. ROSEBUD (bolometers)
Assay for Gd in superK
GEODYN

Free space for new proposals

Not in this map:
"old" LSC 120 m^2 **(Lab 2500)**
two halls of about 18 m^2 **(Lab 780)**
Total area 1560 m^2
Total volume 10500 m^3
Users 214
Budget 1.6 M€/year
Staff=12



Rock overburden = 850 m (2.5 km we)
Rn activity: 80-90 Bq/m^3
γ flux:1.23±0.17 x 10^{-4} m^{-2}s^{-1}
n-flux =3.60±0.08 x 10^{-2} s^{-1} m^{-2}
spectrum measured
μ-flux 4.7 x 10^{-3} s^{-1} m^{-2}

ANAIS @ LSC

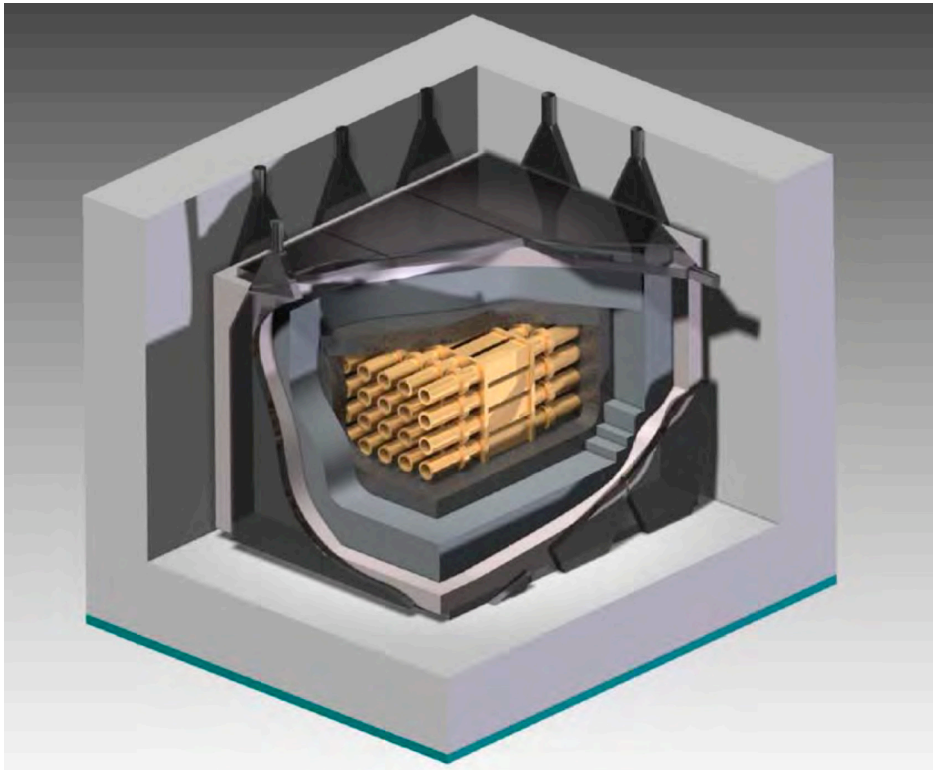
DAMA/LIBRA result is very important. It must be checked by an independent experiment

Comparison with experiments not looking for modulation is model dependent

Do not discriminate electromagnetic signal

Use NaI (same nuclei) crystals

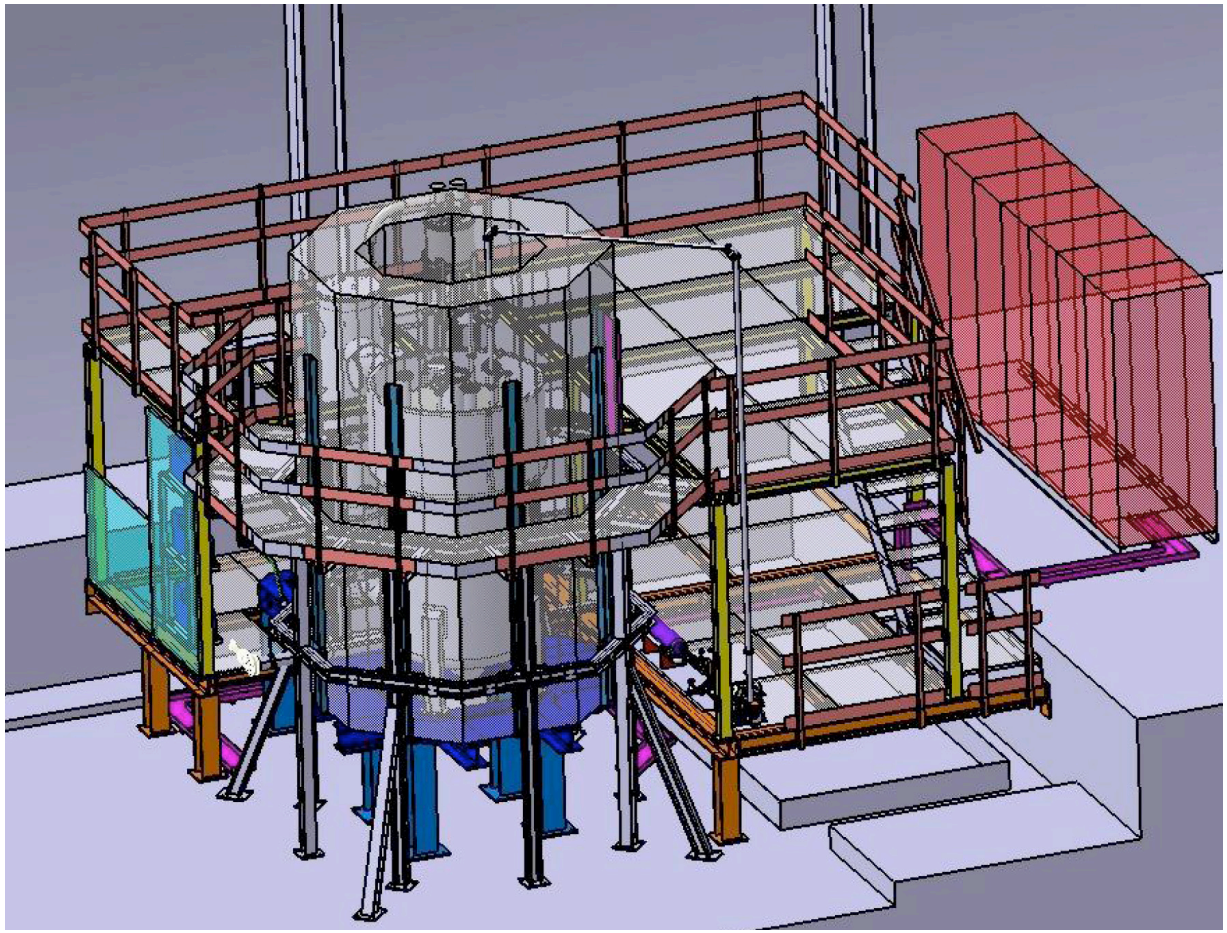
Look for annual modulation

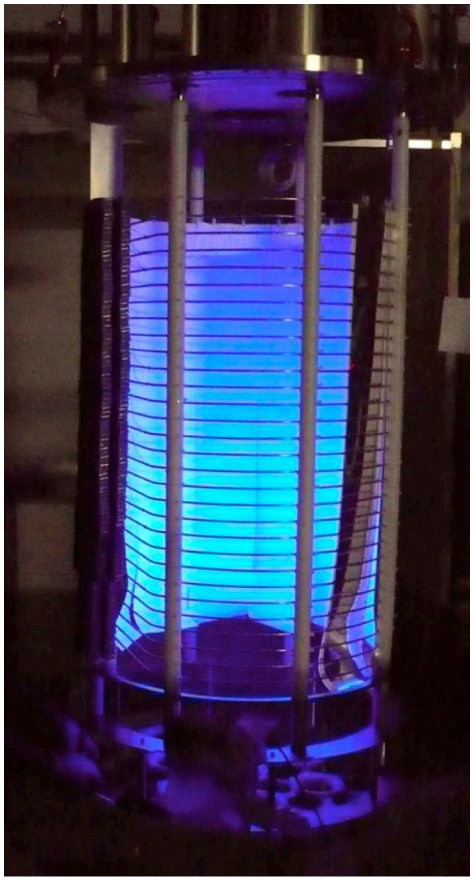


ANAIS

- Develop technique for **250 kg** NaI(Tl) crystals
- ^{40}K DAMA **< 100 ppb** in powder.
  - **< 90 ppb** obtained
- **< 20 ppb** in crystal
  - Ingot produced. Detectors being cut
- Aim: assemble in 2012

ArDM 1 ton @ LSC

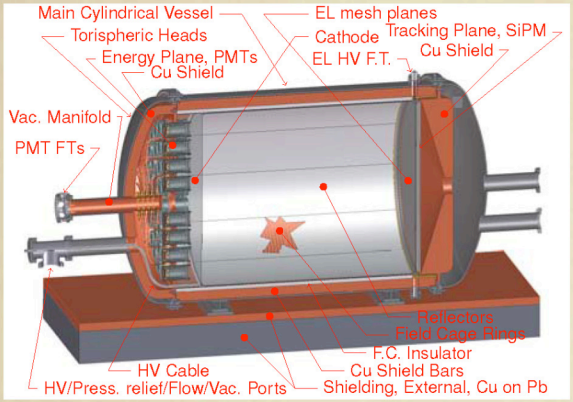




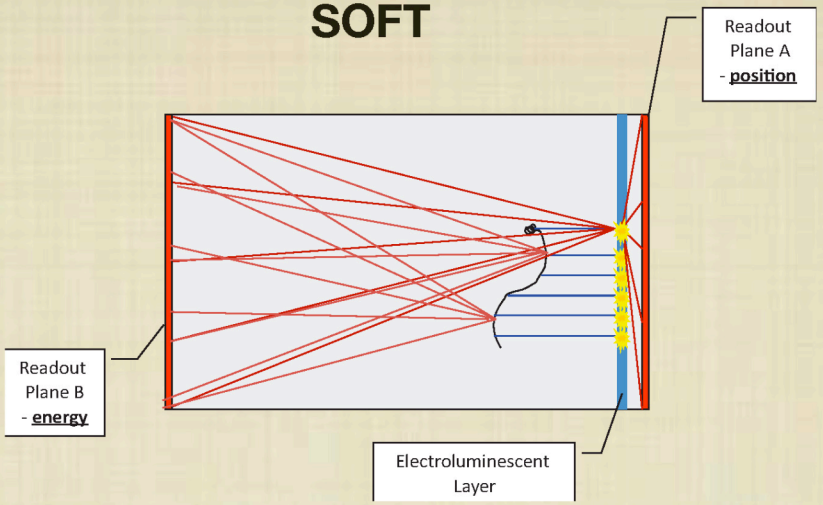
To be installed in Hall A LSC in 2012

NEXT DBD @ LSC

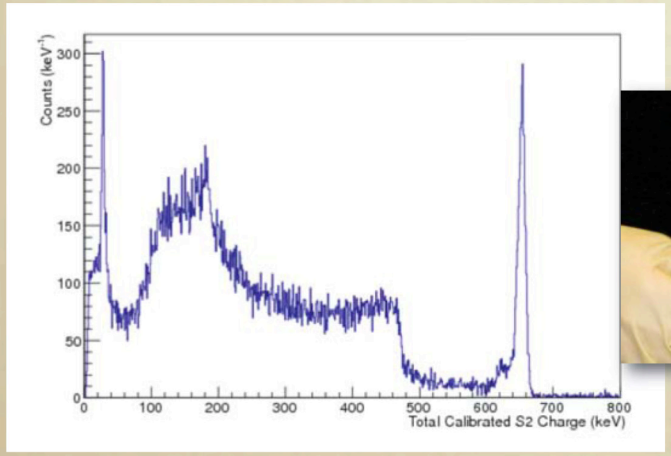
HPGXe



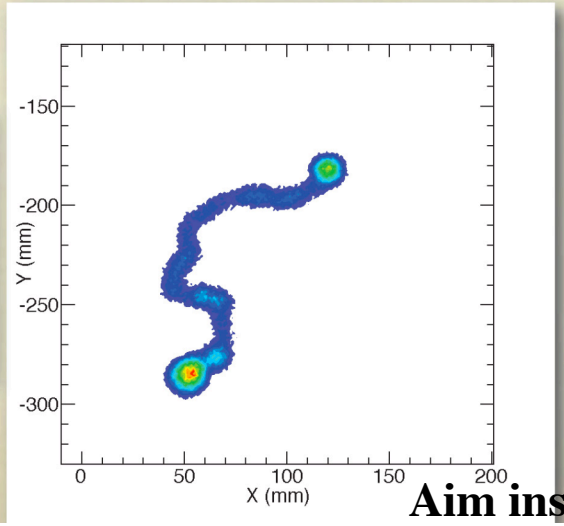
SOFT

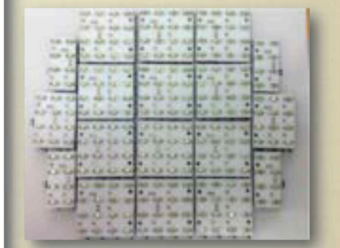


Energy resolution



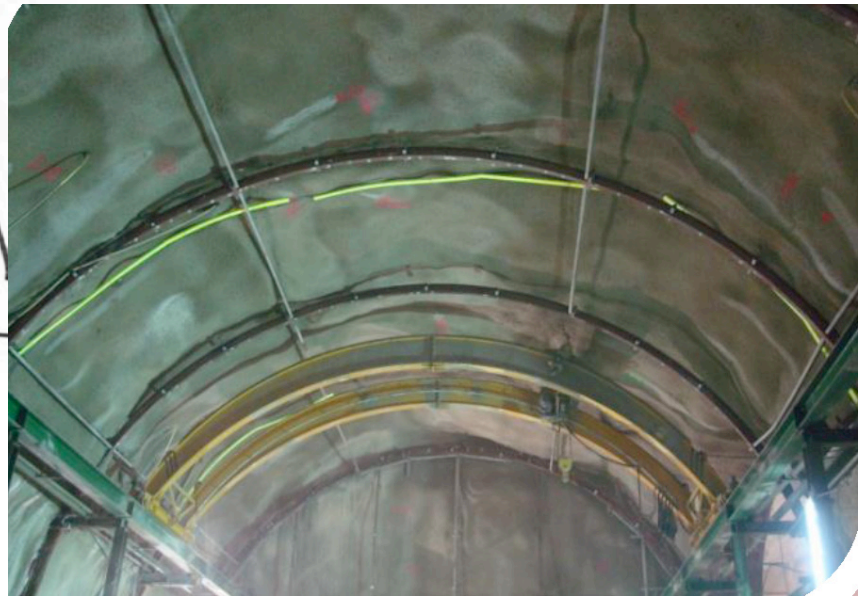
Topological signature



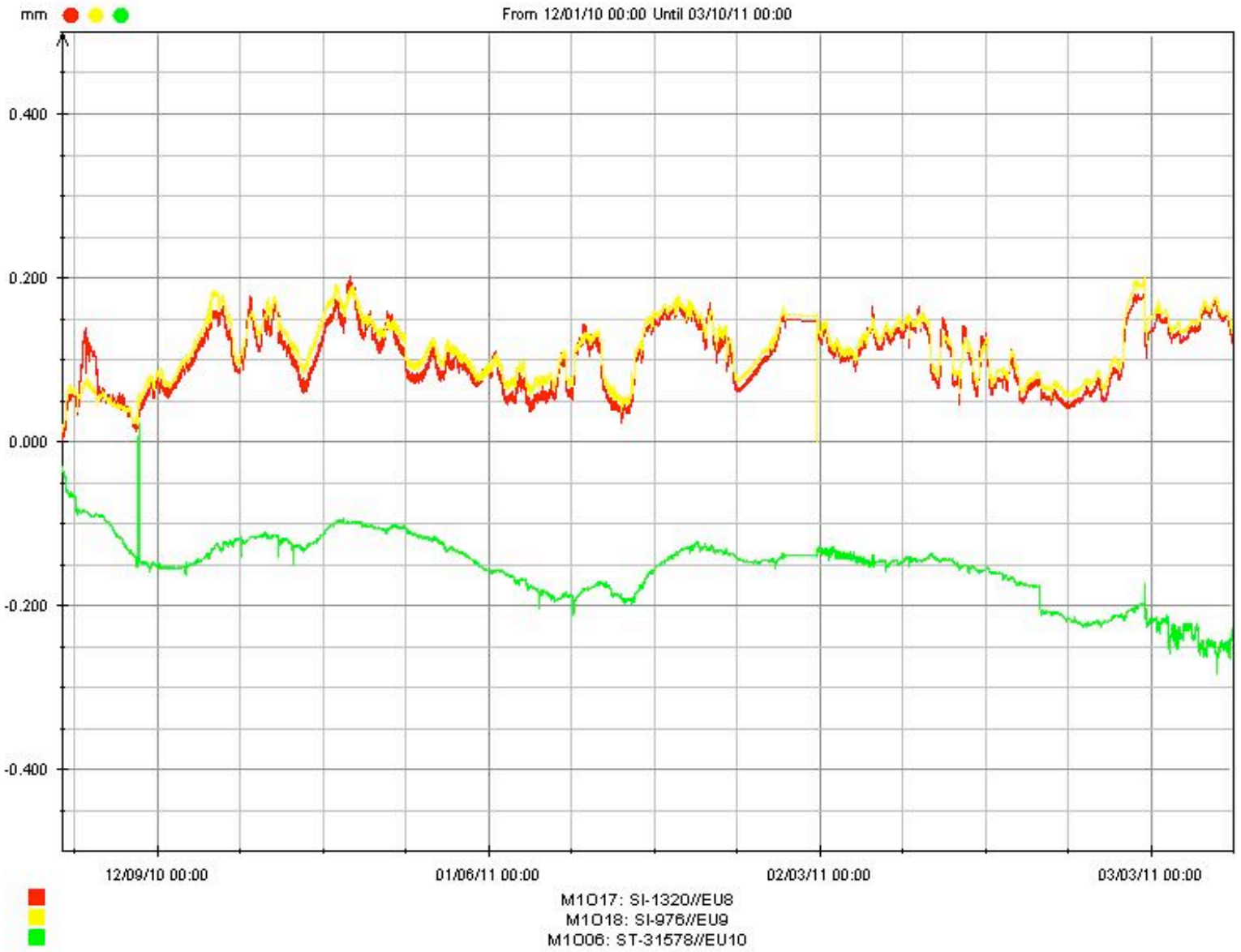


Aim installing in 2013

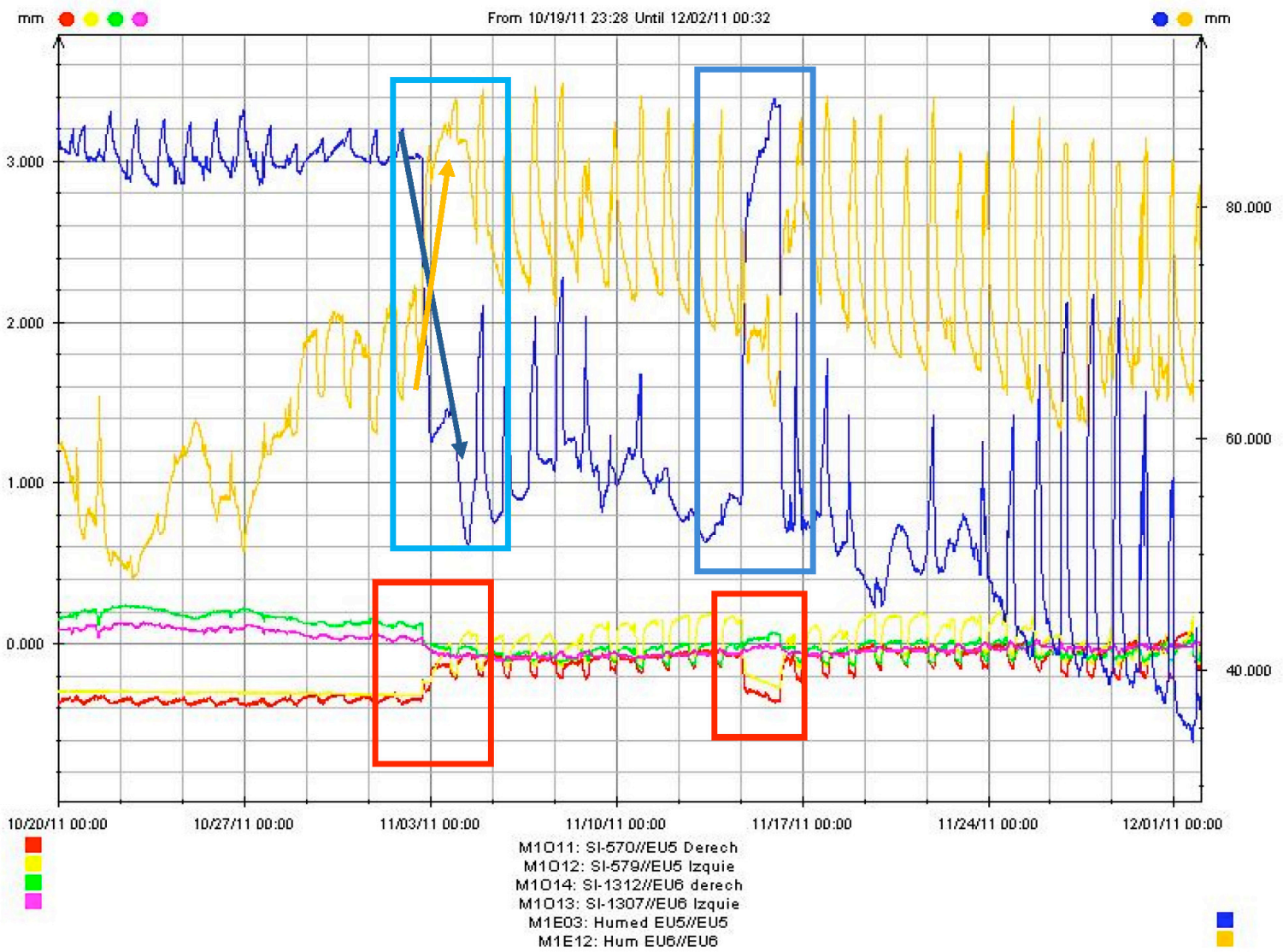
LSC. Optical fibres monitoring system



Continuous convergence monitoring

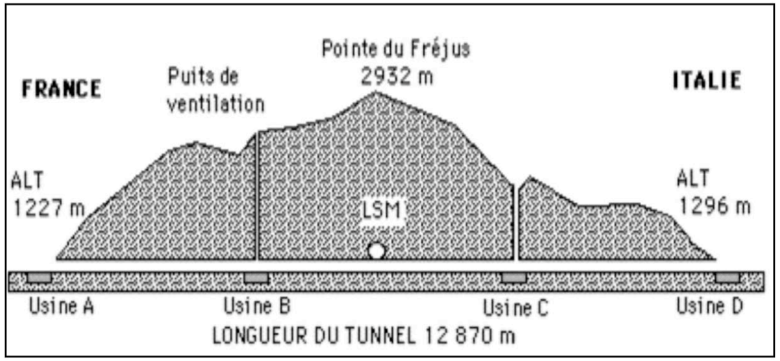


Sensitivity to humidity

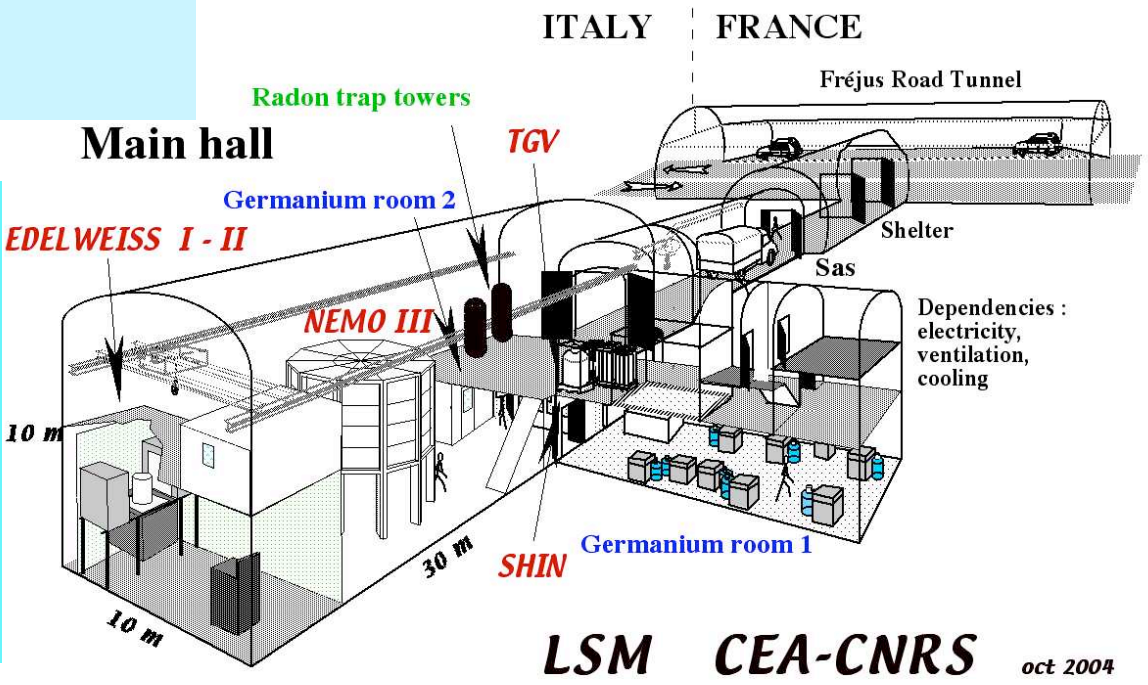


Laboratoire Subterrain de Modane (LSM). France

- 1700 m rock overburden (4.8 km w.e.)
- Ventilation: one volume/40'
- Neutron flux = 5.6×10^{-2} $m^{-2}s^{-1}$
- μ flux = 4.7×10^{-5} $m^{-2}s^{-1}$
- Radon 15 Bq/m^3
- Underground area 400 m^2
- Support facilities on the surface (250 m^2)
- Horizontal access (freeway traffic)
- Staff = 11
- **Budget 1.3 M€/year**



Science
DBD. NEMO III (tracking+calo)
DM EDELWEISS II (Ge cryo)
Double electron capture TGV II
Heavy elements SHIN
TPC sphere
BiPo 1 and 2
Low radioactivity measurements



Underground Laboratories. Extension Projects

LSM. ULISSE one 100x20x20 m^3 & services (15 M€)

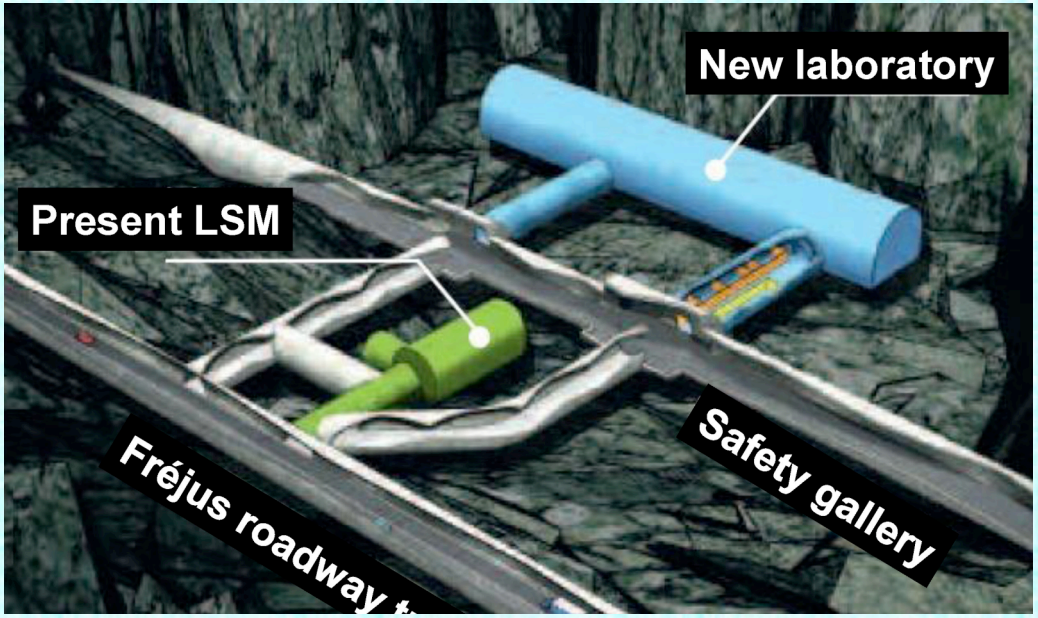
Foreseen experiments

SuperNEMO

EURECA

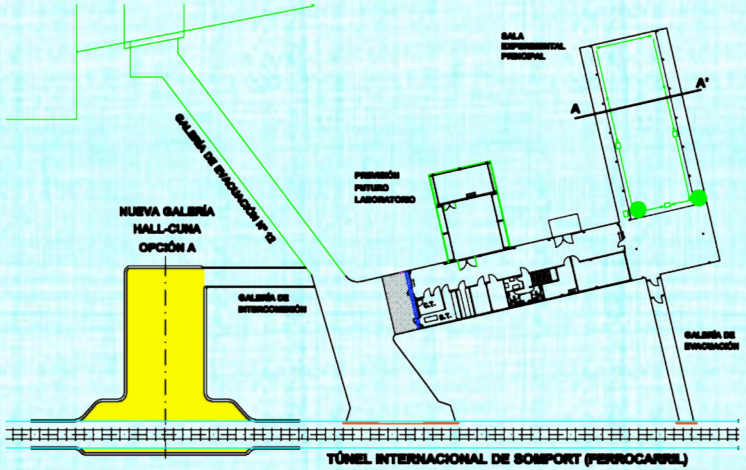
First funding request not approved

To be resubmitted

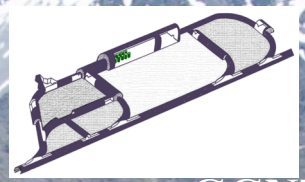


LSC. CUNA dedicated to nuclear astrophysics facility complementary to LNGS (3 M€)

Not completely funded



Baksan Valley and Mt. Andyrchi



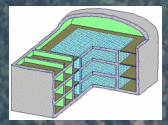
GGNT

The oldest underground laboratory

"Andyrchy" EAS array

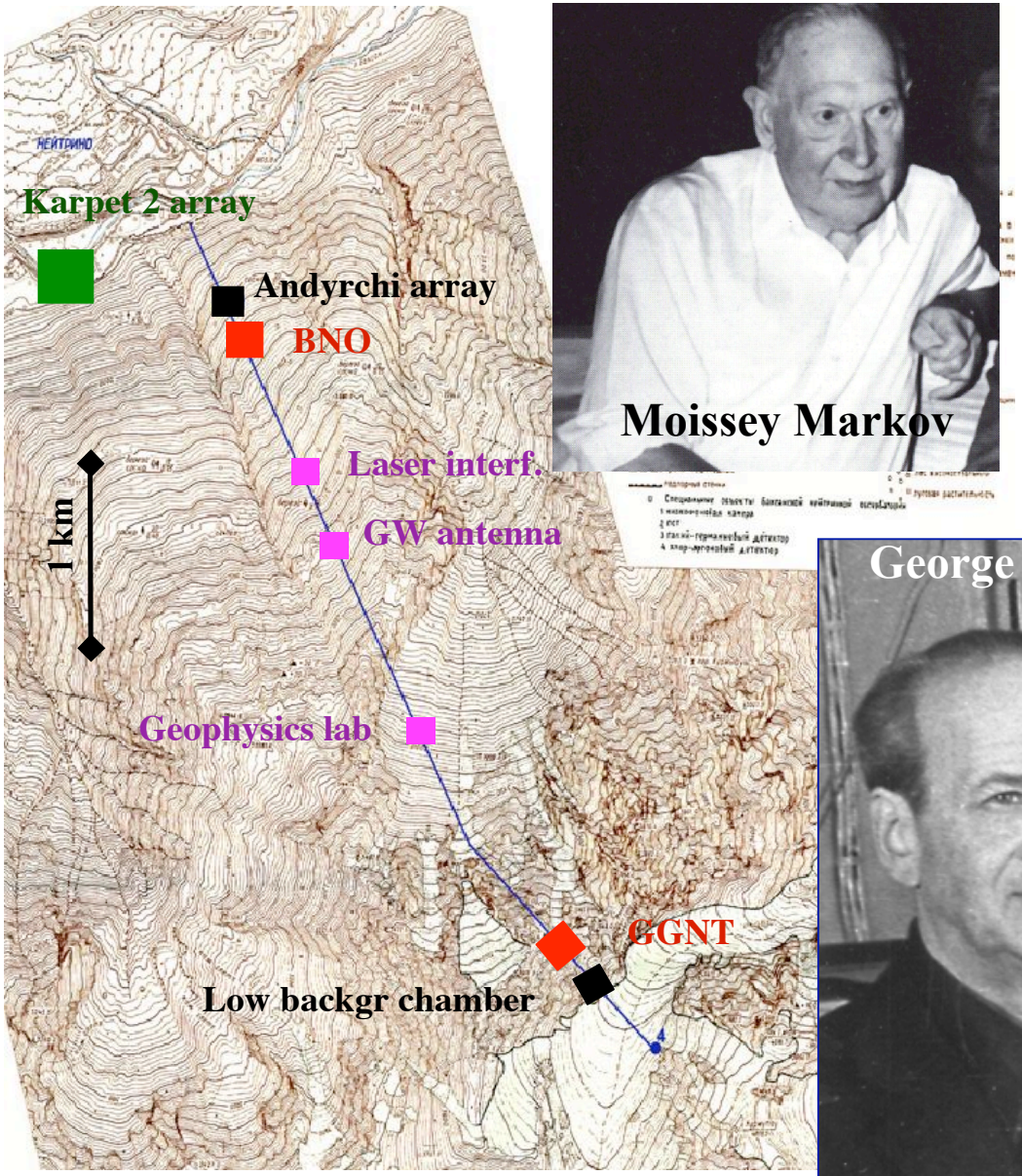
"Karpet-2" EAS array

BUST



Tunnel entrance

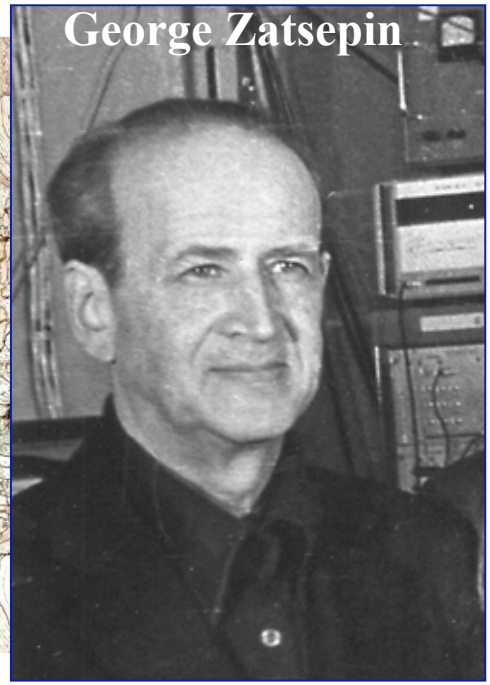
Baksan Neutrino Observatory. The oldest



Moissey Markov

1966. Under the action of M. Markov, Head of the Physics Division, the Academy of Sciences of the USSR obtains a Decree of the Soviet Government for the construction of the underground and surface facilities (Neutrino village)

Scientific activity started under the leadership of


George Zatsepin

and


Alexander Chudakov

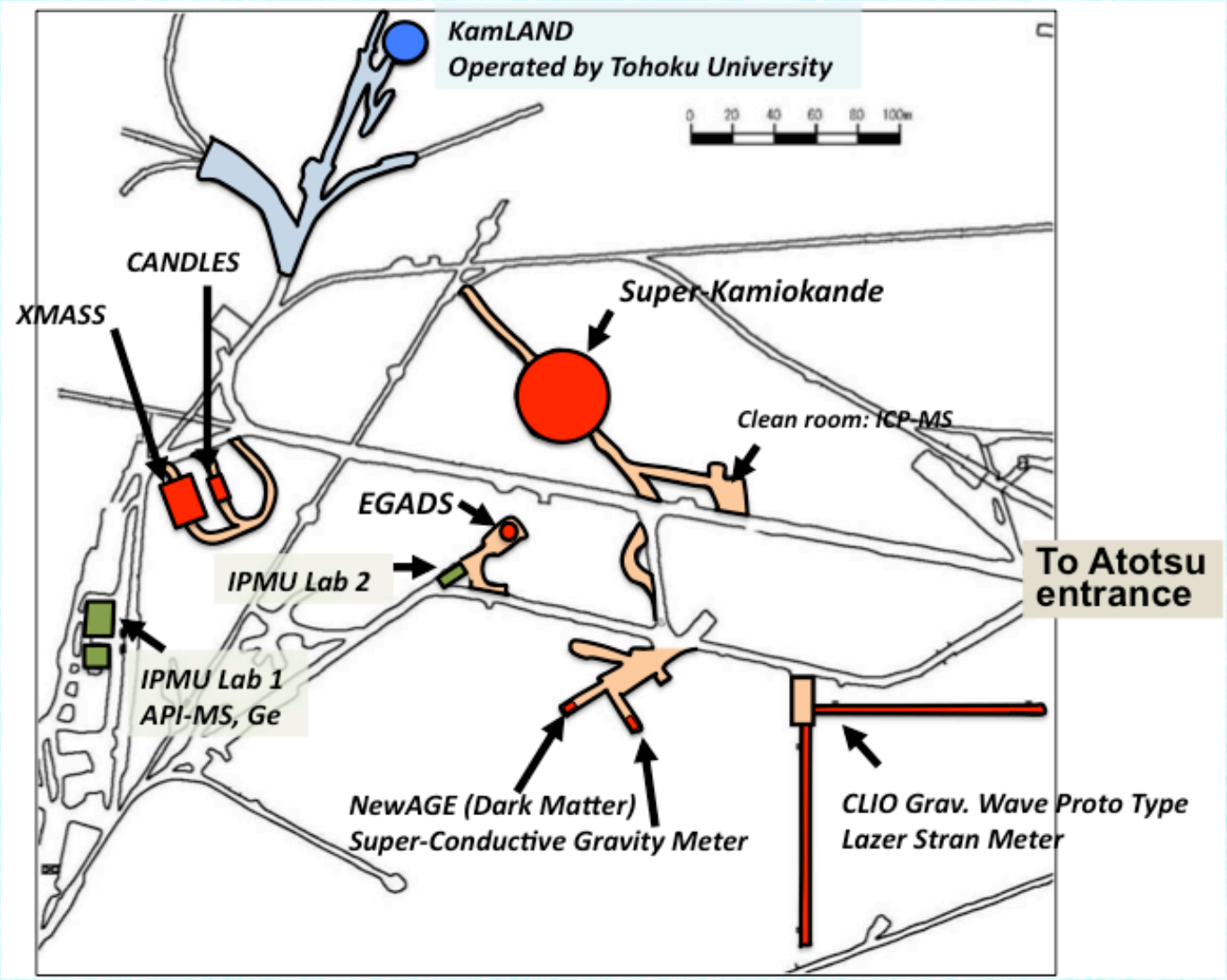
Kamioka Observatory. The largest detector

In 1983 M. Koshiba established the Kamioka Underground Observatory to host KamiokaNDE (**NDE=Nucleon Decay Experiment later = Neutrino Detection Experiment**)

- Overburden 1000 m ≈ 2.7 km w.e.
- Horizontal access. Free h24
- μ flux: $\phi_\mu = 3 \times 10^{-3}$ m^{-2}s^{-1}
- Radon: few Bq/m^3 (with ventilation)
- Neutrons: thermal $= 8.25 \pm 0.58 \times 10^{-2}$ m^{-2} s^{-1}
  non thermal $= 11.5 \pm 1.2 \times 10^{-2}$ m^{-2} s^{-1}

- Users >200+KAMland
- Building for offices and computer facilities on the surface
- Personnel: 13 scientists, 2 technical support
- Strategy: build new cavities when new experiments require so

Kamioka Obseravtory



New experimental halls built as a function of the needs of new experiments

Interference with ongoing experiments minimised by distance between halls

INO. India based Neutrino Observatory

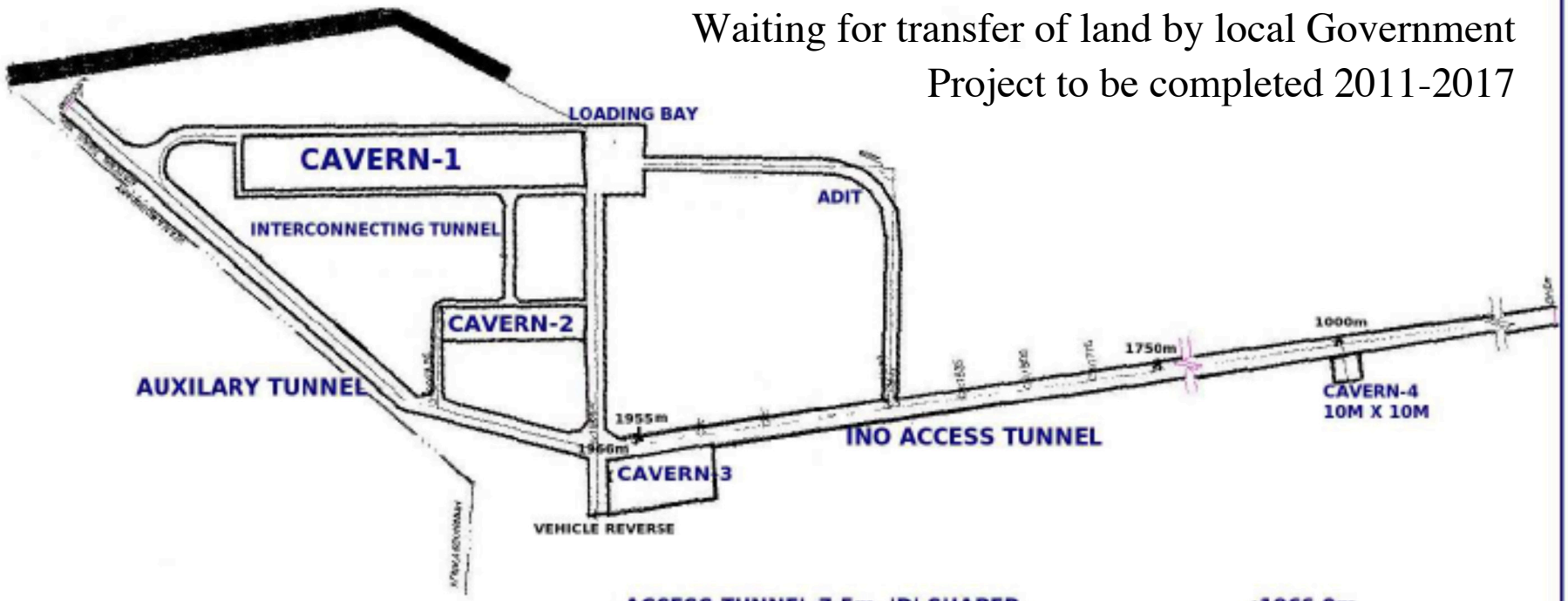
Build Underground and Surface structures

ICAL= 50 kt Magnetised Fe Calorimeter for atmospheric neutrinos

Environment and Forest clearances obtained

Waiting for transfer of land by local Government

Project to be completed 2011-2017

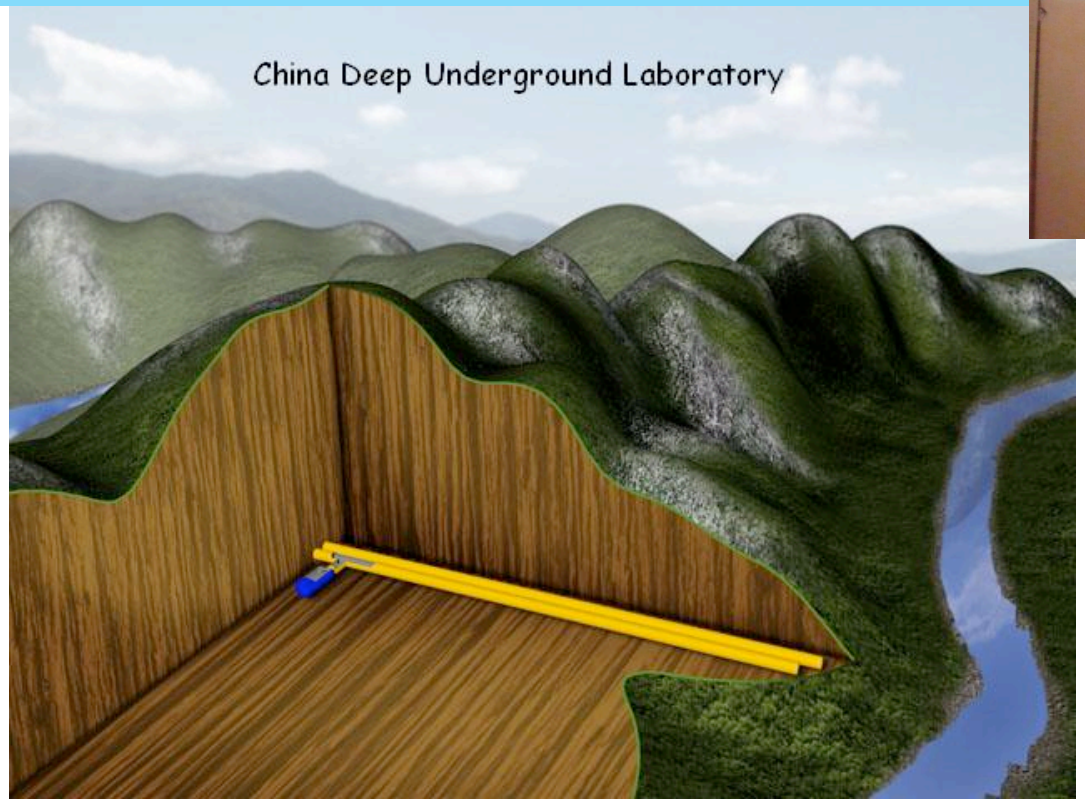


ACCESS TUNNEL 7.5m, 'D' SHAPED	:1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPED	: 175.4m
AUXILARY TUNNEL 7.5m 'D' SHAPED	: 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPED	: 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPED (future expn)	: 50.0m

CAVERN -1 : 132m x 26M x 32.5m
CAVERN -2 : 55m x 12.5m x 8.6m
CAVERN -3 : 40m x 10m x 10m
CAVERN -4 : 10m x 10m x 10m

CJPL. China Deep Underground Laboratory
The deepest

- Peak：4193m
- Maximum rock overburden: ~2500m
- Horizontal access via two tunnels (17.5 km)
- μ flux = 7×10^{-7} $m^{-2}s^{-1}$



The first experimental hall

Proposal for the full laboratory did not pass the first vote

Resubmit proposal for nest five-year plan

Rockburst risk?

SNOLAB. Sudbury. Canada

- **3000 m² building**
- **Administration, operation, IT, quality assurance, offices, laboratories, clean room, chemistry lab., conference room, etc.**

SNOLab

Construction cost (not SNO hall): 65 M$

Staff: 57 FTE

Budget: 8 M$/yr

+VALE services 6.6 M$/yr

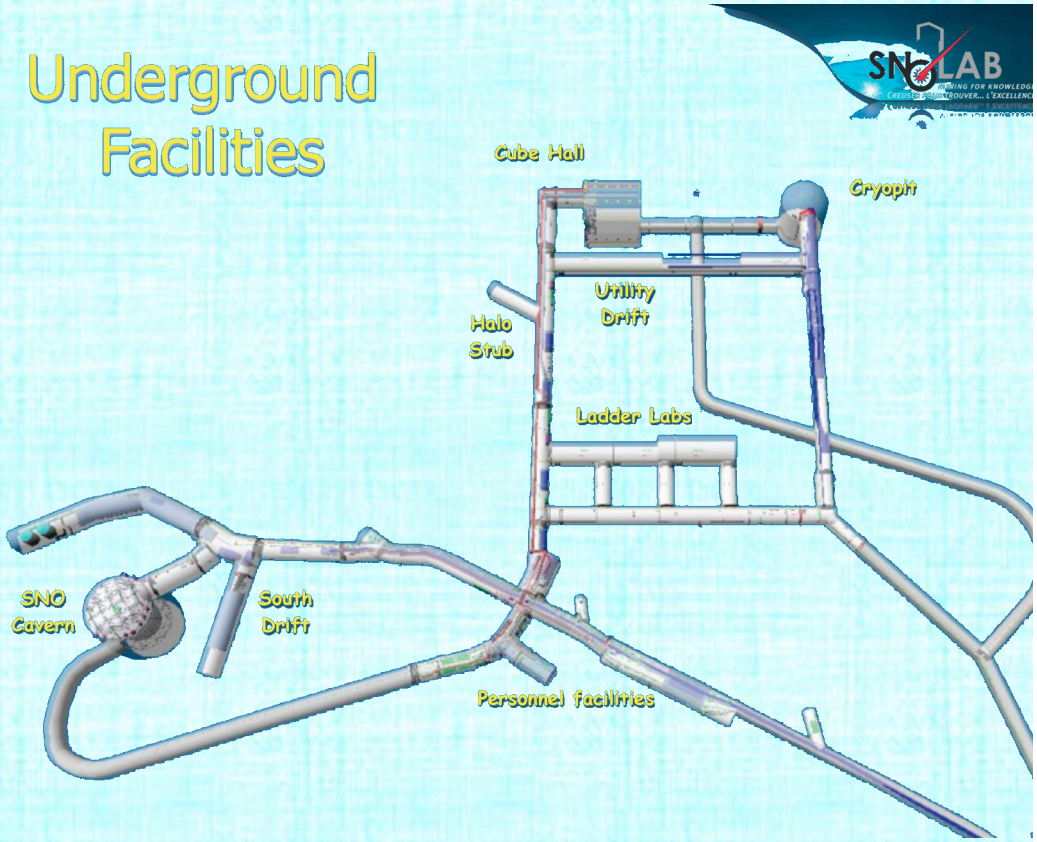
Space underground: 5000 m^2

"Clean room" class 2000

Neutron flux = 9.3×10^{-2} $m^{-2}s^{-1}$.

Rn specific activity in air: 120 Bq/m^3

(no dedicated air pipe from the surface)



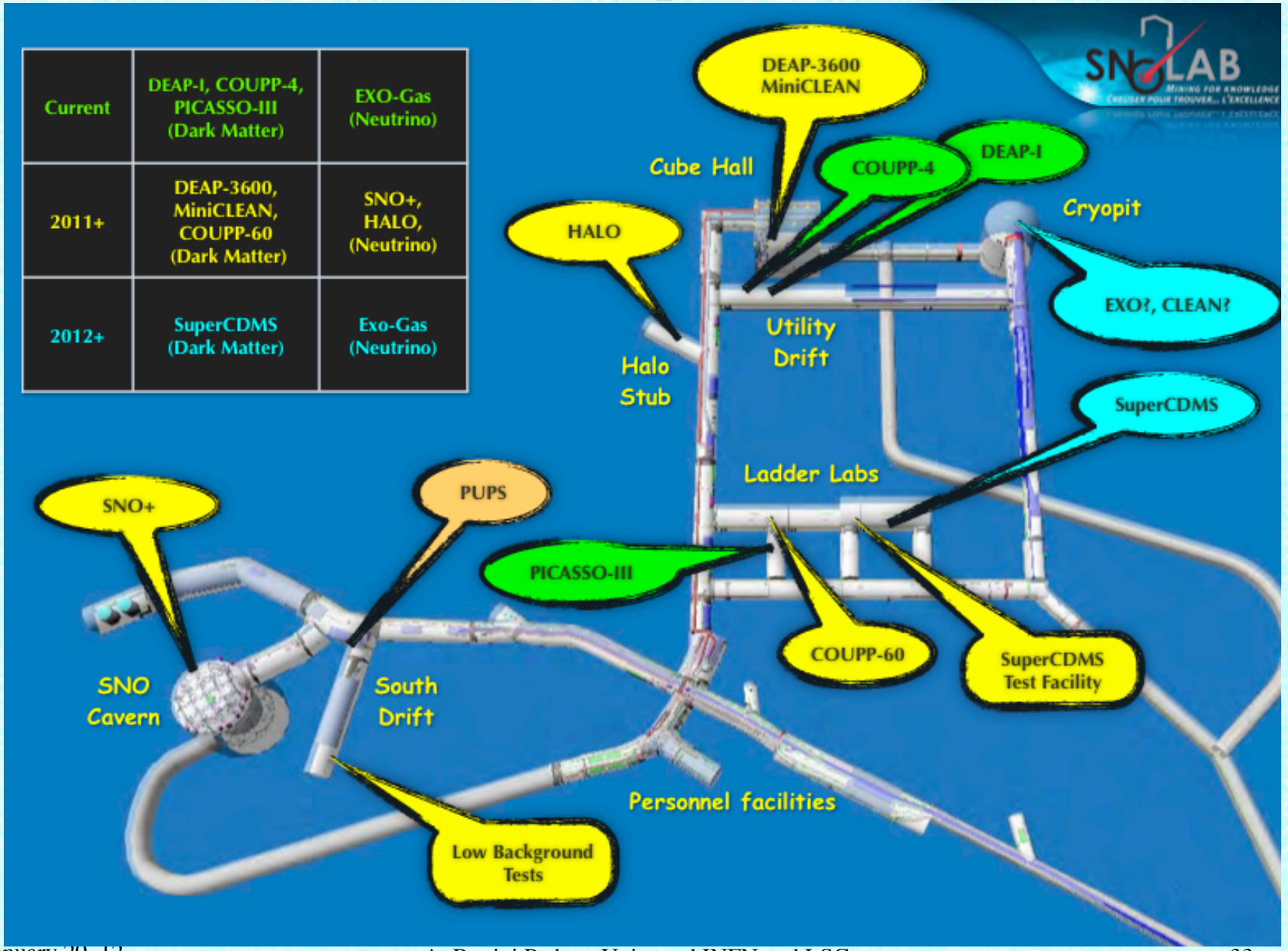
Building a lab in a mine implies a reduced ratio useful/total volume (about 50%)

Halls for experiments need good quality rock of sufficient thickness

Long drifts between halls are expensive but make use of the halls more flexible

SNOLab Experiments

Current	DEAP-I, COUPP-4, PICASSO-III (Dark Matter)	EXO-Gas (Neutrino)
2011+	DEAP-3600, MiniCLEAN, COUPP-60 (Dark Matter)	SNO+, HALO, (Neutrino)
2012+	SuperCDMS (Dark Matter)	Exo-Gas (Neutrino)

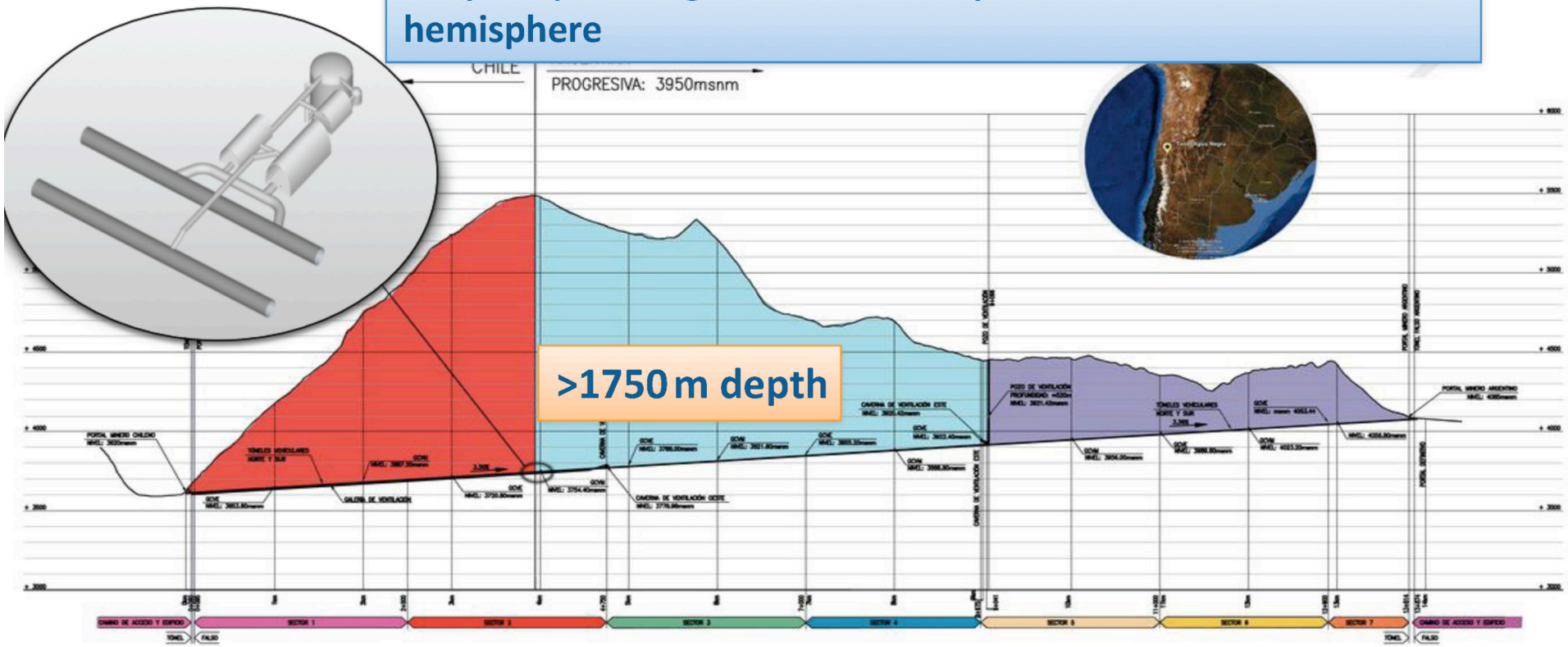


ANDES

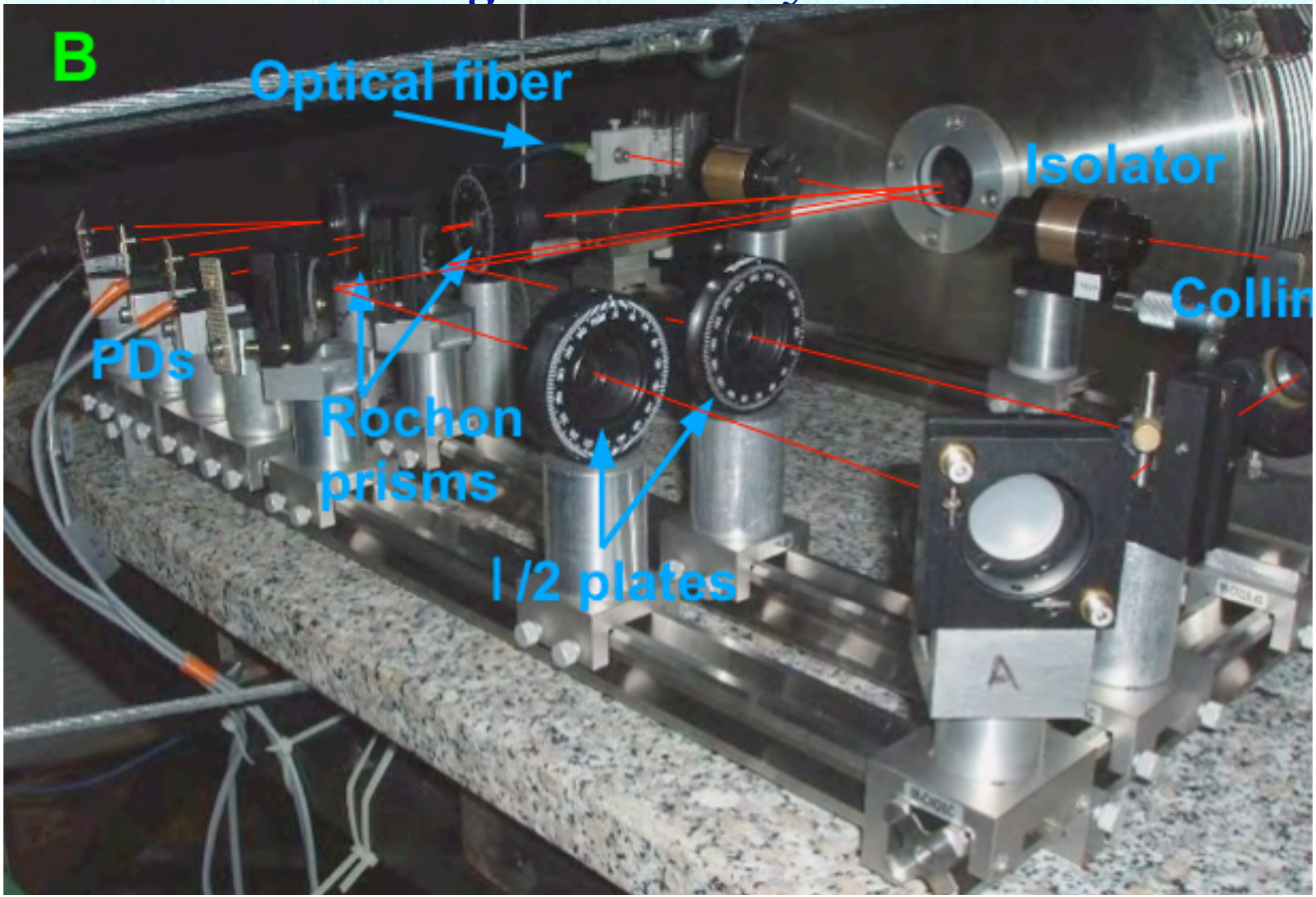
Joint venture of Argentina, Brazil, Chile and Mexico

- Agua Negra tunnel between Argentina and Chile, linking MERCOSUR to Asia
- Possible laboratory location as deep (or deeper) than Modane
- Construction planned 2012-2018 (tunnel opening)
- Horizontal access, size of ~4 000 m^2 and ~65 000 m^3 in 5 halls and pits

Only deep underground laboratory in the southern hemisphere



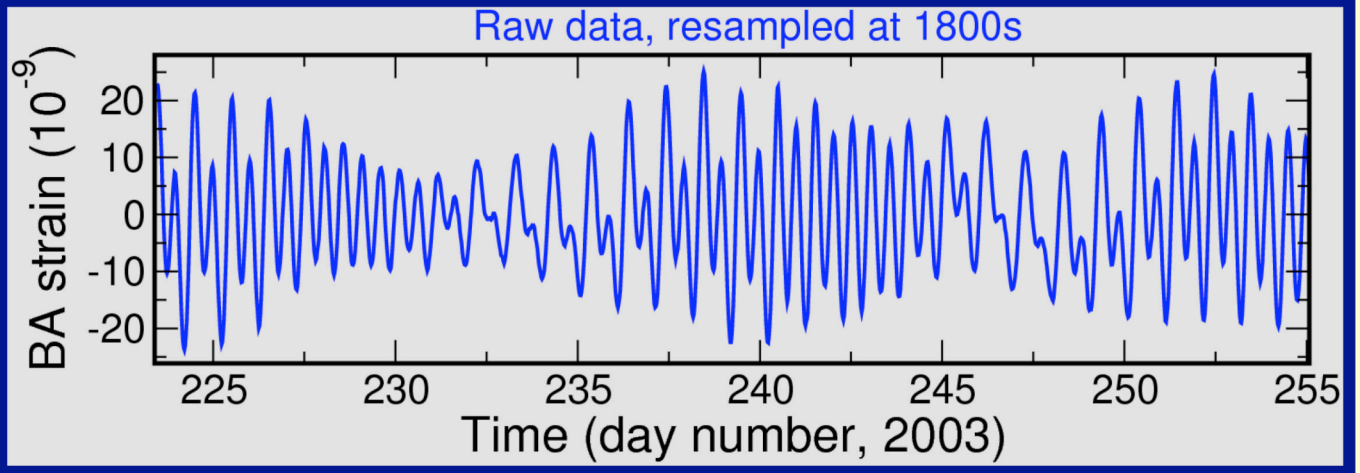
Underground Geodynamics

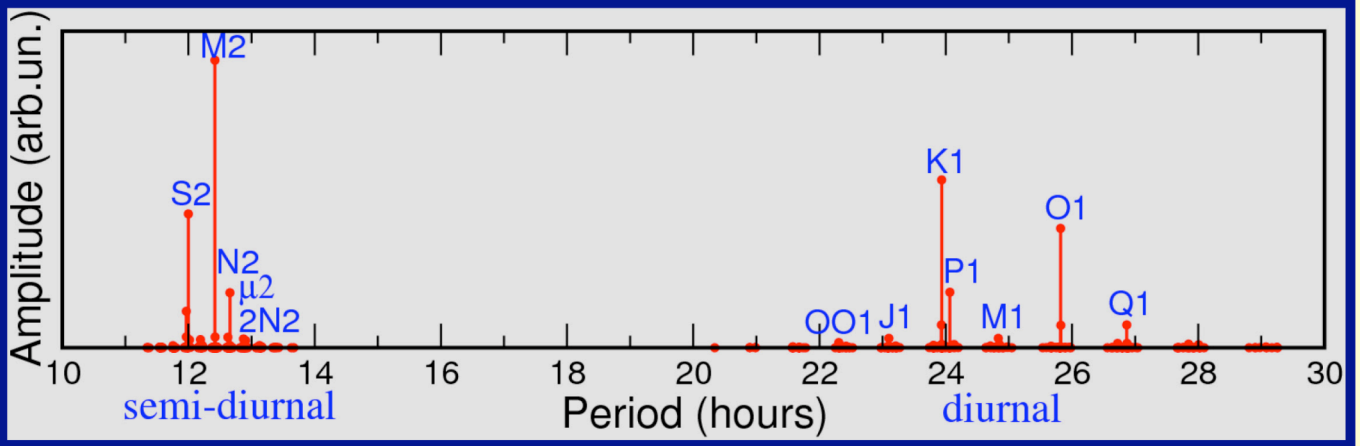


GIGS @ LNGS. Earth Tides

What about current activities?

Earth tides (Free Core Resonance)





By earth tides, we understand all phenomena related to the variation of the Earth's gravity field and to the deformation of the Earth's body induced by the tide generating forces, i.e. the forces acting on the Earth due to differential gravitation of the celestial bodies as the Moon, the Sun and the nearby planets.

GEODYN
Underground Geodynamic Observatory at LSC

Integrated in the Spanish TOPO-IBERIA and TOPO-EUROPE, the principal pan-European Earth Science Programme

BB seismometer and accelerometer

Two GPS stations on surface

Two perpendicular LASER strain-metres (interferometers)

GEODYN
Underground Geodynamic Observatory at LSC

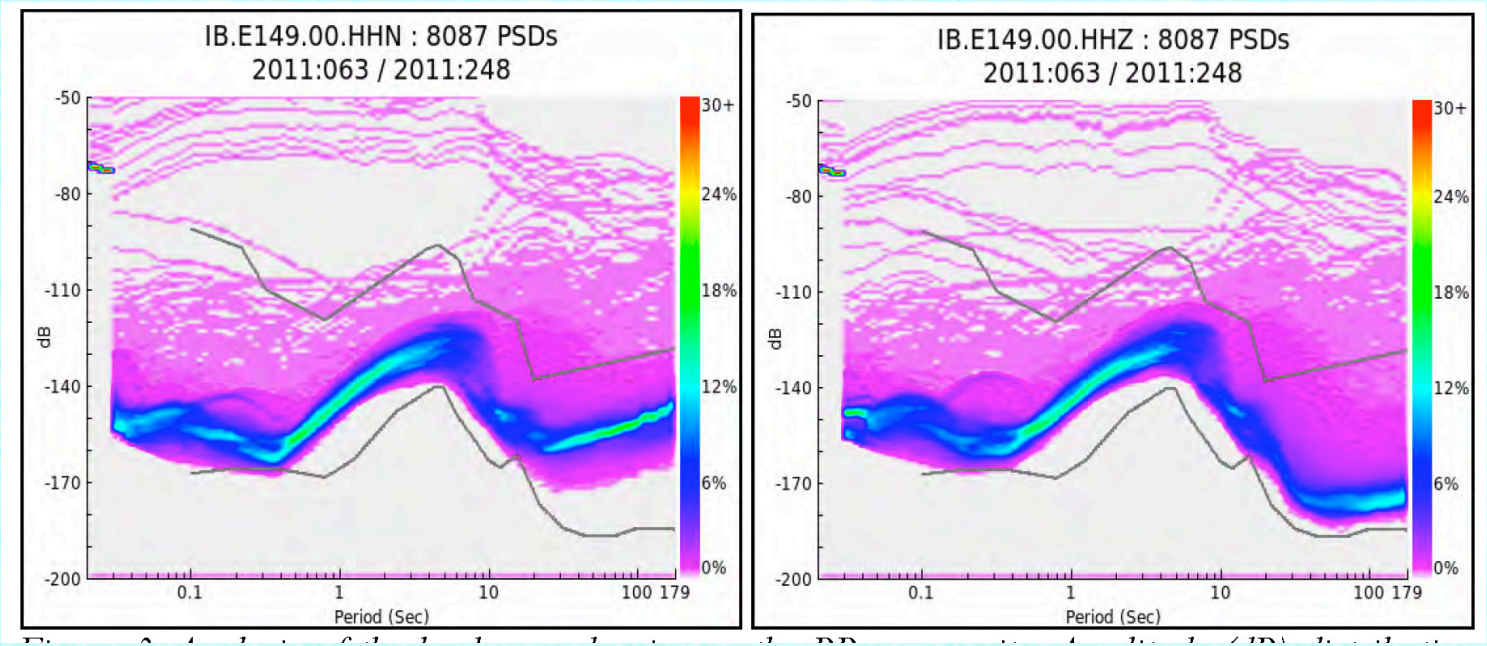
Checking the BB sensor

the ambient noise signals (blue colors) are within the theoretical minimum/maximum theoretical threshold (black curves)

Peak at several seconds: micro-tremors due to waves in the Atlantic Ocean

pink curves on the upper part of the panels correspond to relevant regional or teleseismic events

Horizontal **Vertical**

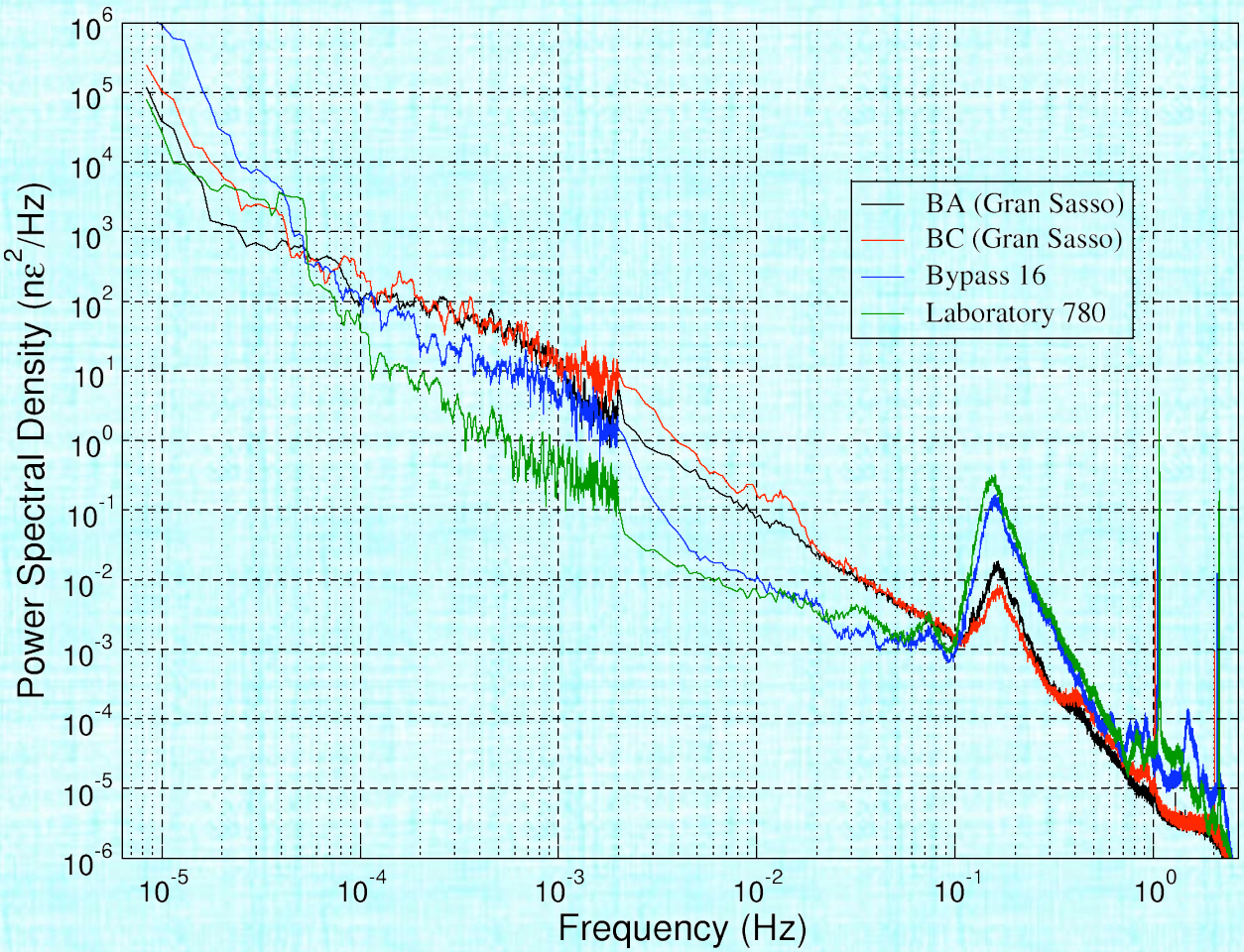


GEODYN and GIGS

Checking the intereferometers.

Region 10^{-4} -- 10^{-2} Hz, important for: long period seismic waves, free Earth oscillations and slow quakes. “Background index” @ LSC is smaller (1/10) than @ LNGS

Peak @ 10^{-1} Hz. Oceanic micro-tremors events. In Atlantic >> in Mediterranean



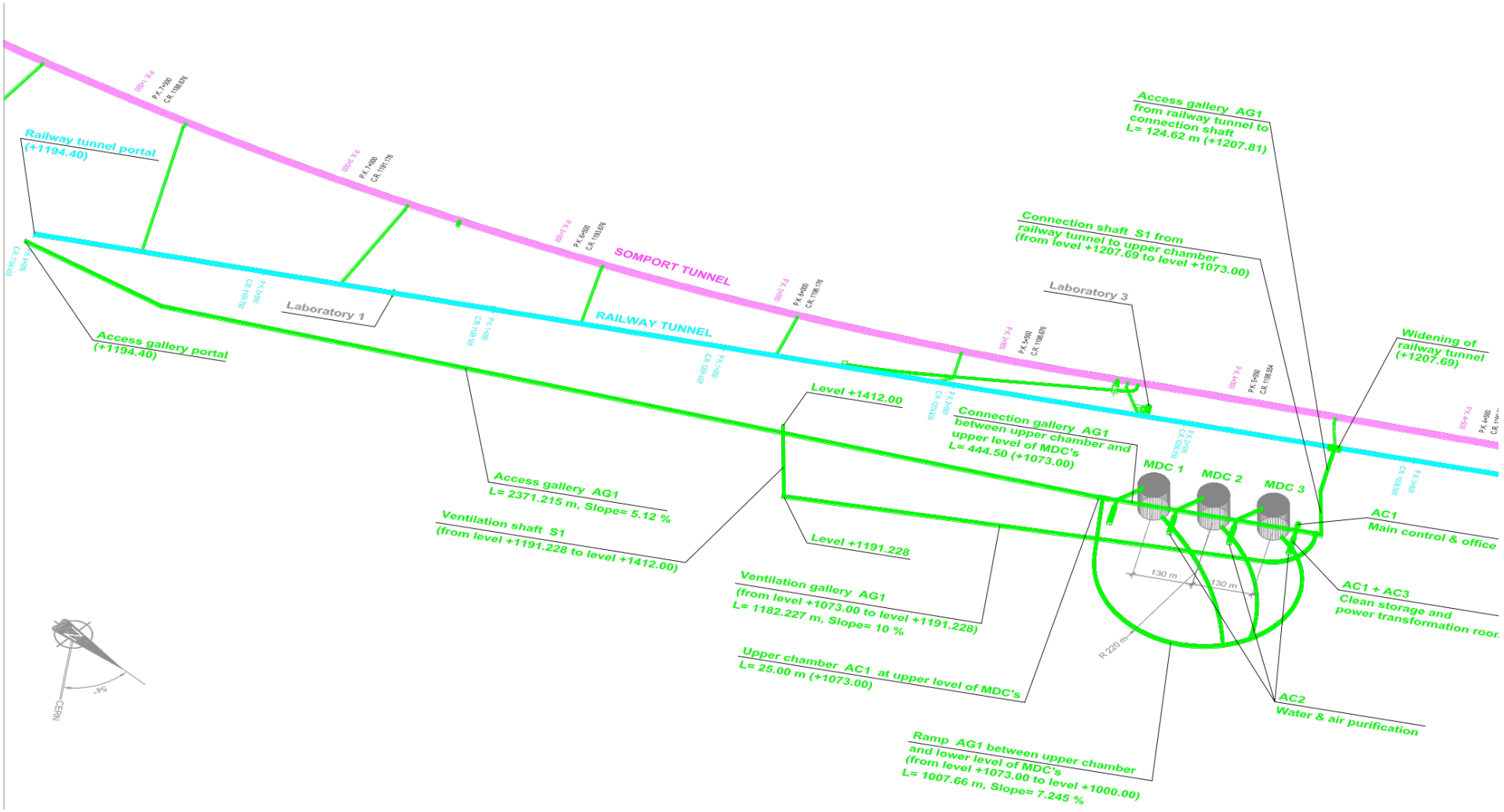
LAGUNA-LSC-MEMPHYIS

Three 200 kt water Cherenkov detectors

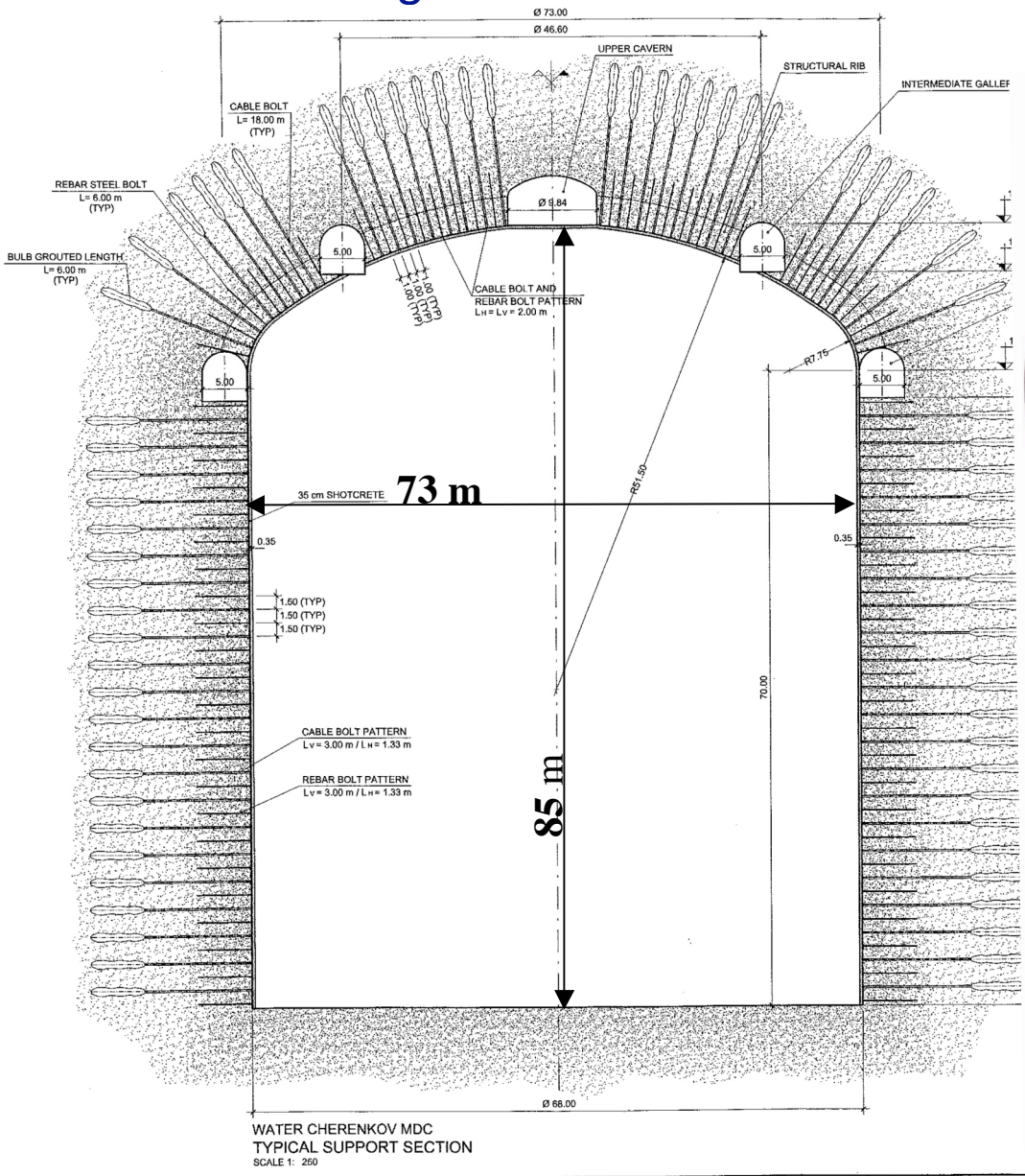
Access and services

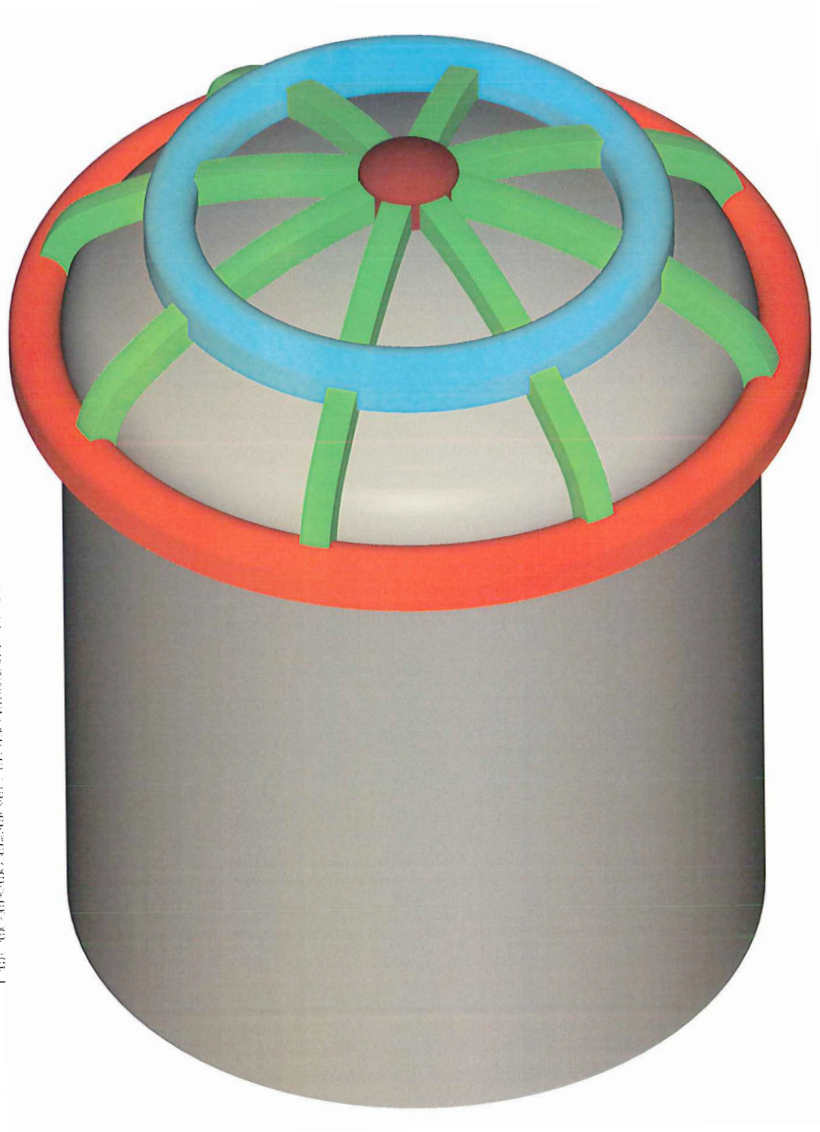
Excavated volume = 1 650 000 m^3

Cost to tender 230 M€



Pre-design of one of the three cavities for MEMPHYS @ LSC





LSC Laboratorio Subterráneo de Canfranc

STMR Manuel Romana Ruiz

IBERINSA Clemente Sáenz Sanz

FEASIBILITY STUDY FOR THE CONSTRUCTION OF LARGE UNDERGROUND OPENINGS AND AUXILIARY INFRASTRUCTURE OF THE LAGUNA PROJECT AT CANFRANC (HUESCA, SPAIN)

DATE:

SCALE: 1:250

Original DIN A1

Costs & uncertainties

Excavation costs proportional to the volume

Rock stabilisation costs proportional to the surface (increasing with depth)

Costs of services are not a large fraction of the total

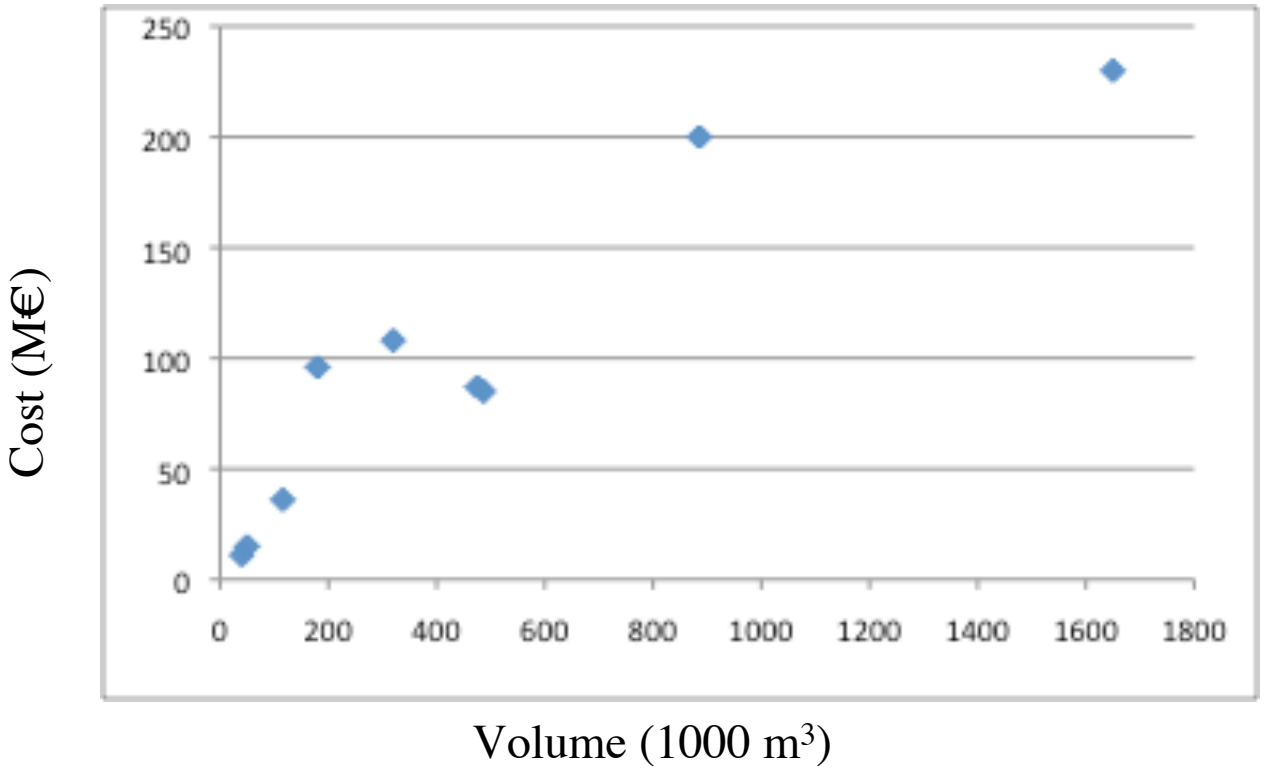
Other factors contribute, but within a factor of π comparisons possible

LNGS. 190 000 m^3, no access expenses, fully equipped	96 M€ 2011
Access to LNGS. Tunnel: 5 km, 6 m diameter, with services	70 M€ 2011
2nd safety tunnel would cost about 1/2	

LAGUNA Design Study: Construction costs evaluation in 7 locations for three detector technologies in each: Water Cherenkov, LAr TPC, Scintillator. Access and services included

Three Water Cherenkov		
@LSC	1 650 000 m^3	230 M€
@LSM	886 000 m^3	200 M€
@Pyasalmy	1 079 000 m^3	75 M€
Liquid Ar		
@LSC	487 000 m^3	85 M€
Liquid scintillator		
@LSC	475 000 m^3	87 M€
@LSM	116 000 m^3	36 M€

Costs vs volume



DUSEL	
Refurbish shafts and general structures	311 M$
Halls for two experiments (1/3 LNGS Hall or Ulisse [15 M€])	159 M$
Infrastructure for **one** water Cherenkov	not found
Costs quoted with large uncertainty.	

General issues

- BNO built with a private access tunnel
  - In general 2nd (smaller) one advisable for safety
- LNGS, LSC, LSM, ANDES project: close to and in phase with free way construction
  - Reduce construction & running costs. Drive-in to experiments
- Kamioka: similar, drive-in in a working mine, no interference
- Hydroelectric power station infrastructures may offer similar opportunities (CDUL)
- SNOLab, SUL and BUL built in working mines
  - – need to find good rock, possibly far from shaft: useful/total volume smaller
  - – limits in the size of the detector elements to bring in
  - – scheduling of access necessary (as a function of mine programme)
  - + integrate in the safety structures of the mine
- LNGS, LSC, ….built general purpose experimental halls, turnover of experiments
- Kamioka, SNOLab: build experiment specific halls
- DUSEL/SUSEL to be built in an abandoned mine


Thank you