New Underground Laboratories

A. Bettini

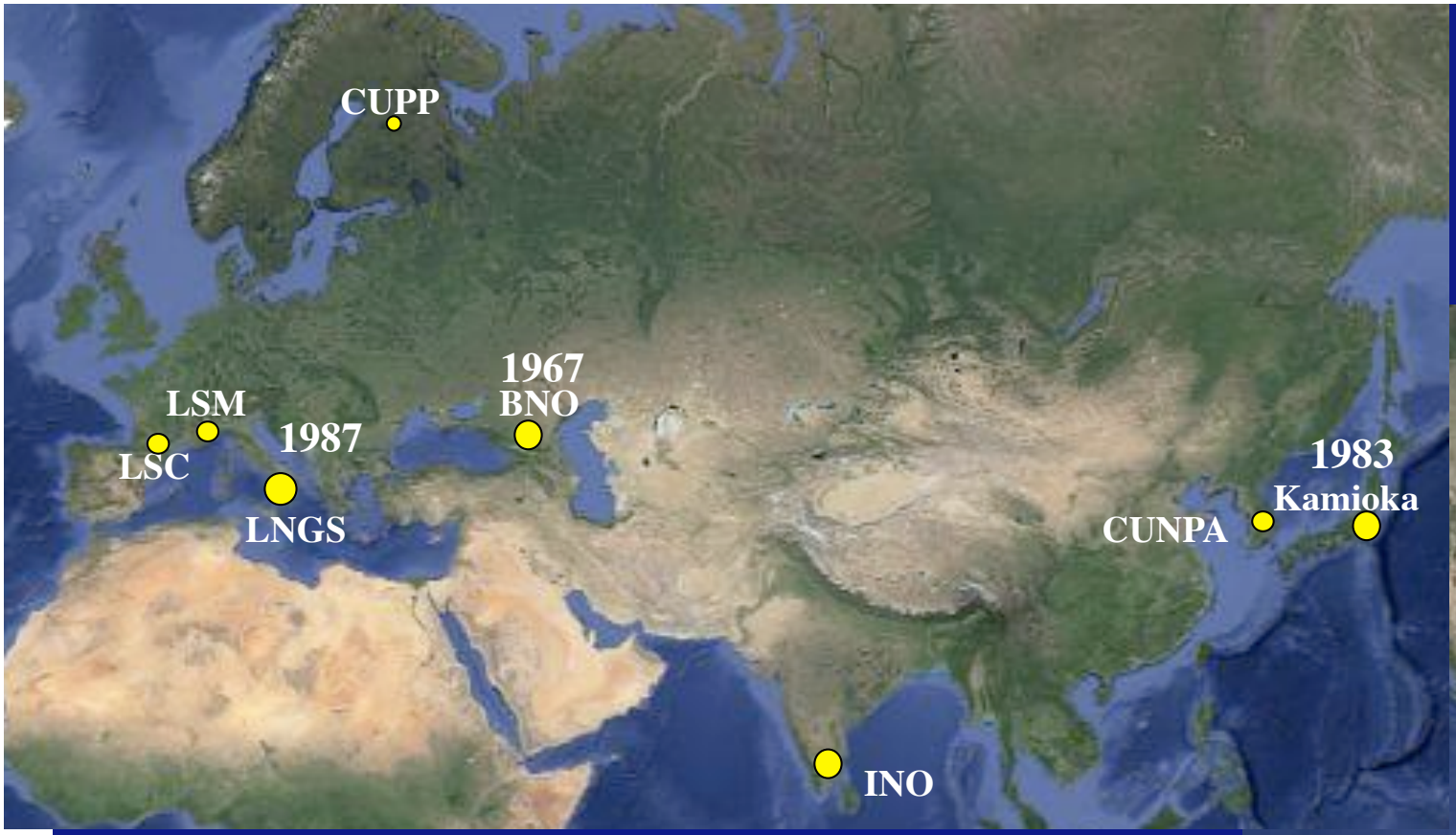
Laboratorio Subterráneo de Canfranc (Spain)

Padova University and INFN (Italy)

Thanks to:

X. Bertou, H. Chen, T. Enquist, K. Lesko, N. Mondal, F.Piquemal, S. Ragazzi, N. Smith, K. Yeongduk

The sites



Will consider projects for new sites and expansions of old ones.

Not included

- **laboratories for long base line neutrinos and for gravitational waves**
- **shallow facilities**

A. Bettini (2012) EPJ-p 127:114

Characteristics

- **A laboratory is not a mine**
  - Excavation technique different
  - Services to experiments needed
- **Depth (μ flux, spallation *n* fluence)**
  - Determines only a fraction of the background sources
  - μs are useful or calibration
- **Diameter & height of the halls**
  - May limit the thickness of the shields (e. g. water shield 5-6 m each side)
  - Maximum diameter depends on rock quality and depth
- **Horizontal vs. vertical access** (life much easier if H access)
- **Distance from accelerator**
- **Support infrastructures, personnel** (quantity and quality)
- **Underground area allocation policy, turnover of experiments**
  - Laboratory vs. observatory
  - Scientific Committee: international vs. local (or national)
- **Degree of internationality of the community**
- **Other science** (geology, biology, engineering, etc.)
- **Management issues**
  - Budget, funding of the experiments, accountability policy
  - Safety and security policy
  - Environmental policy

Costs

Excavation costs proportional to the volume

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

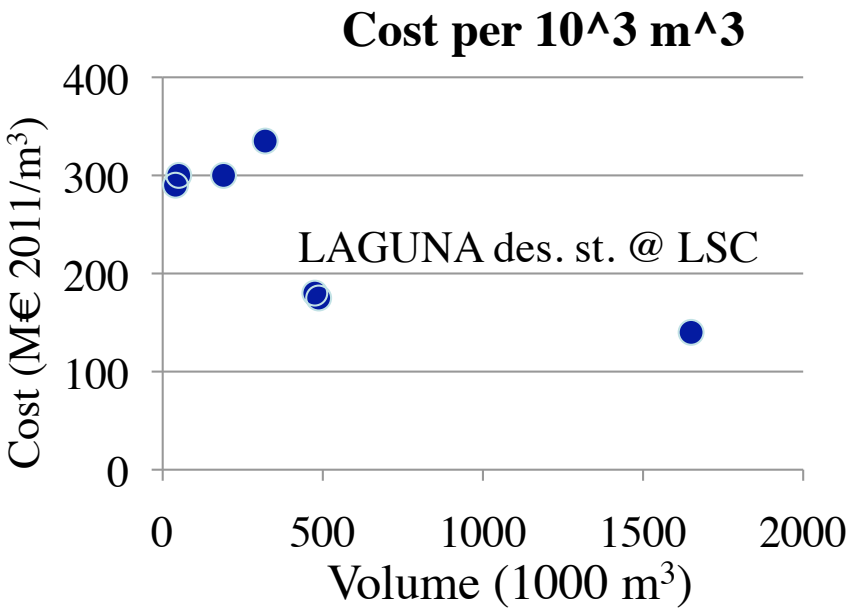
Costs of services are not a large fraction of the total

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

LNGS. 190 000 m^3, no access expenses, fully equipped	57 M€ 2011
Access to LNGS. Tunnel: 5 km, 6 m diameter, with services	55 M€ 2011 = 220 €/m^3
2nd safety tunnel would cost about 1/2	

LNGS, SNOLab-Cryopit, CO2 sq. in USA costs are the actual ones extrapolated to 2011 €, taking inflation into account
ULISSE is proposal estimation

Laboratory-stile underground structures V> 50 000 m^3 cost 300-350 € (2011)/m^3
Large cavities unitary cost is substantially smaller



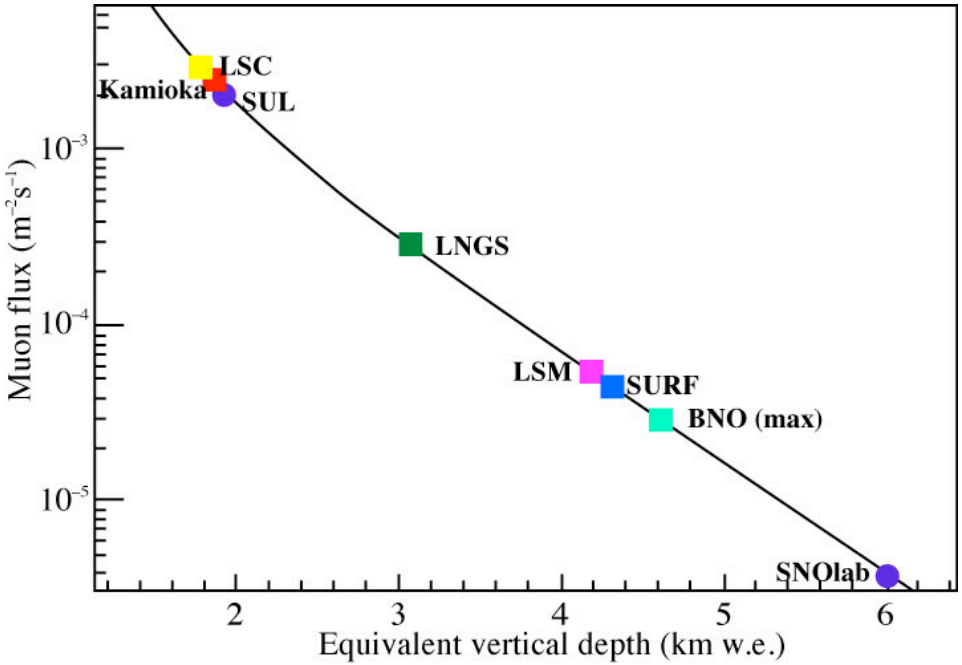
Different decisions

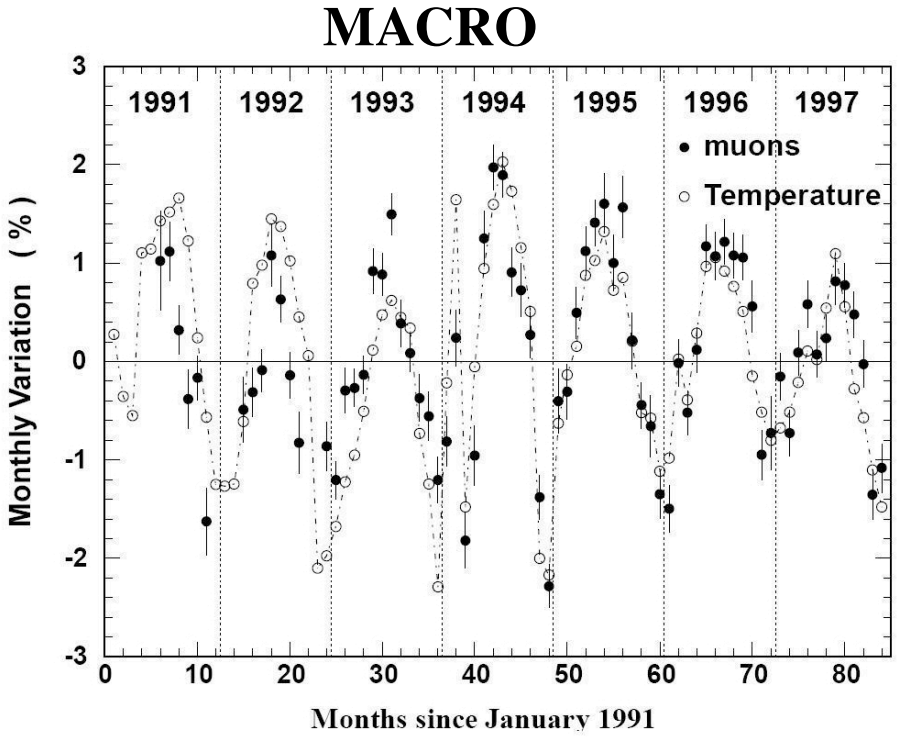
- BNO built (1966) with a dedicated access tunnel
  - In general 2nd (smaller) one advisable for safety
- LNGS (the largest), LSC, LSM, ANDES: close to and in phase with free way construction
  - Reduce construction & running costs. Drive-in to experiments
- Kamioka: similar, drive-in in a working mine, no interference
- CJPL, CUNPA. Hydroelectric power station infrastructures offer similar opportunities
- LNGS, LSC, ….built general purpose experimental halls, turnover of experiments
- SNOLab (the deepest), built in a working mine (we discussed pros and cons)
- Kamioka, SNOLab: build experiment specific halls
- SURF in an abandoned mine. Rehabilitation costs are high

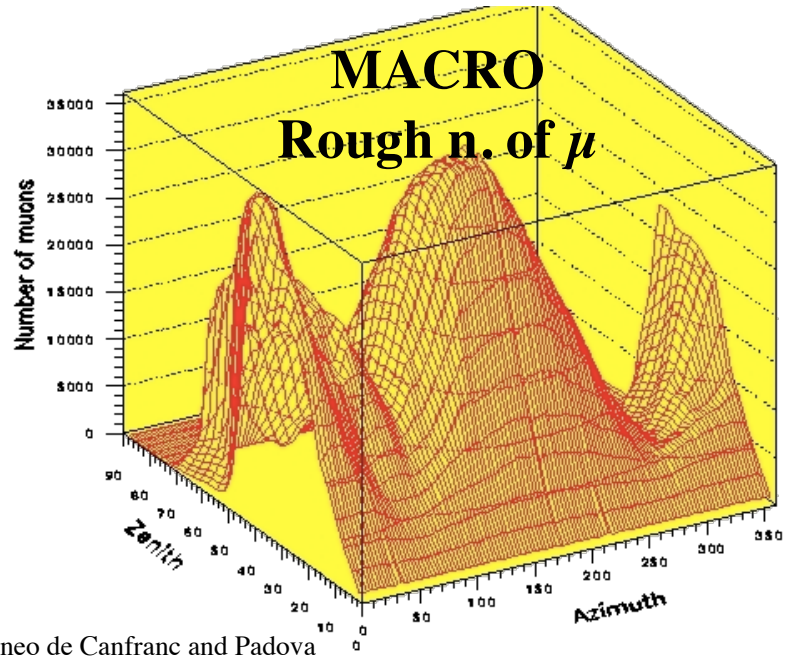
Muons

Equivalent vertical depth = depth for the same μ flux under horizontal surface

- μ flux decreases with increasing overburden
  - can be suppressed by anticoincidence
- cosmogenic background does not contribute substantially to the budget at depth > 1500 m
- with a few exceptions (^{11}C in scintillator detectors
- angular dependence of the μ flux
- seasonal variations of the μ flux and of their spallation neutrons





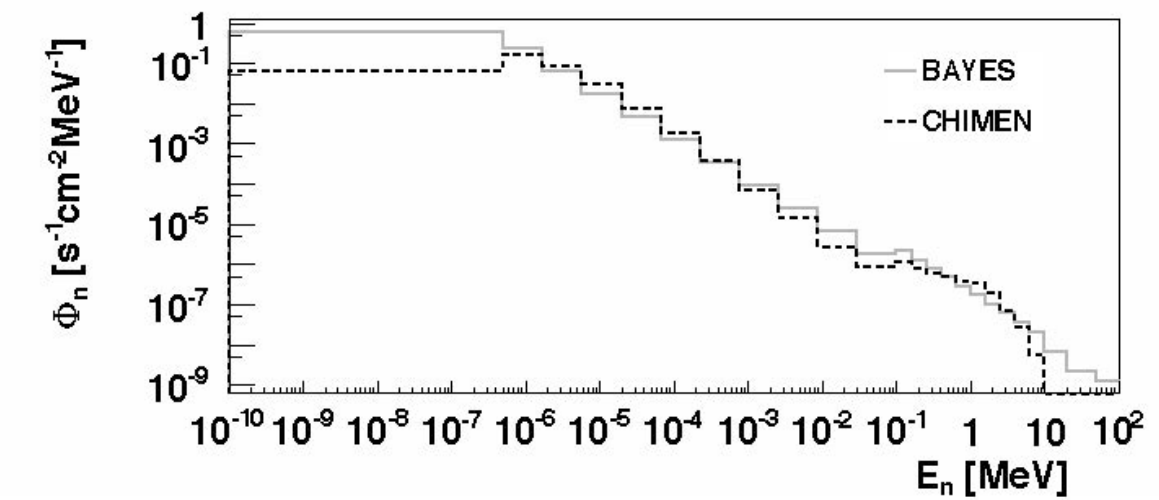


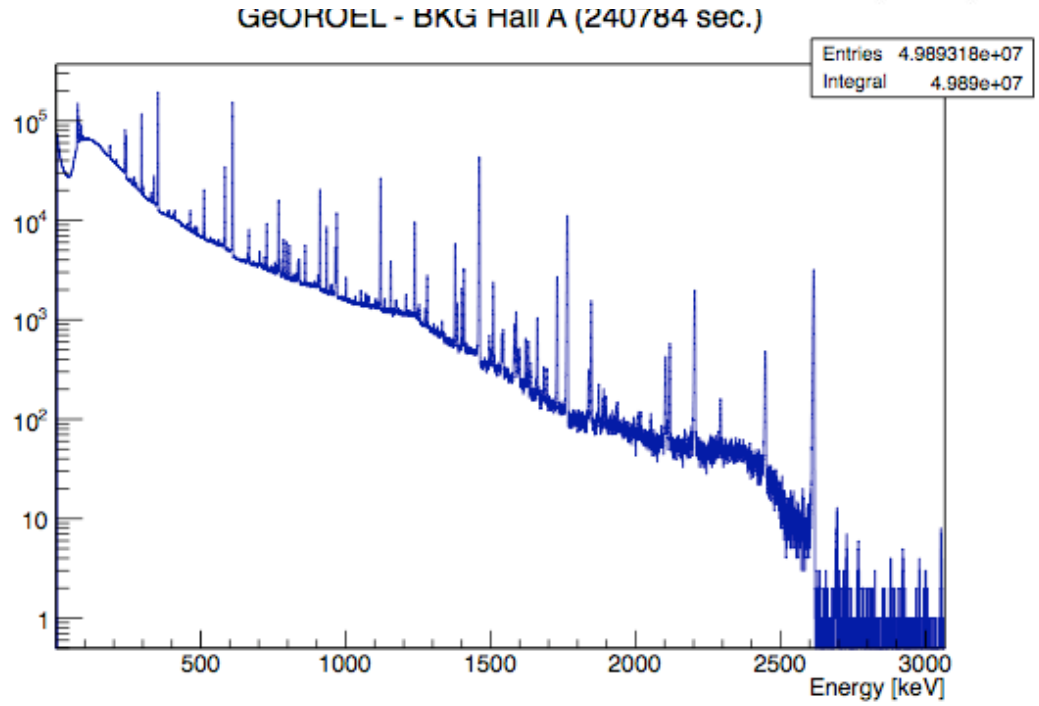
Neutrons

- **From (α,n) and fission** (U/Th) in the rocks and concrete at lower energies (< 8 MeV)
  - not difficult to shield, energy spectrum must be known
  - dependent on geology and on the concrete (few-several $10^{-2}m^{-2}s^{-1}$)
    - Reduced to $2.3 \cdot 10^{-3}$ $m^{-2}s^{-1}$ at BNO
  - independent of depth @> 100 m's
- **Interactions of μs in the rocks**
  - higher neutron energies (several GeV), thicker shields needed
  - flux is time dependent (seasonal variations)
  - flux depends on depth
  - flux 3-4 orders of magnitude smaller than thermal
- **Interactions of μs in the shields & in the detector**
  - cannot be shielded
  - decreases with increasing depth
  - **induced <u>fast</u> background can be reduced by anticoincidence**
    - 4 orders of magnitude in BOREXINO
  - **metastable nuclides more difficult, can be reduced by depth**
    - **experiment dependent, more severe for high-Z materials**

Energy spectra n and γ

Largely independent on depth, dependent on geology and construction materials (n)





LSC as an example

$\Phi_{\text{Hall-A}} = (3.47\pm0.35)\times10^{-2}$ m^{-2}s^{-1}

Hall A

^{40}K: 0.17±0.03 cm^{-2}s^{-1}

^{232}Th: 0.38 ±0.02 cm^{-2}s^{-1}

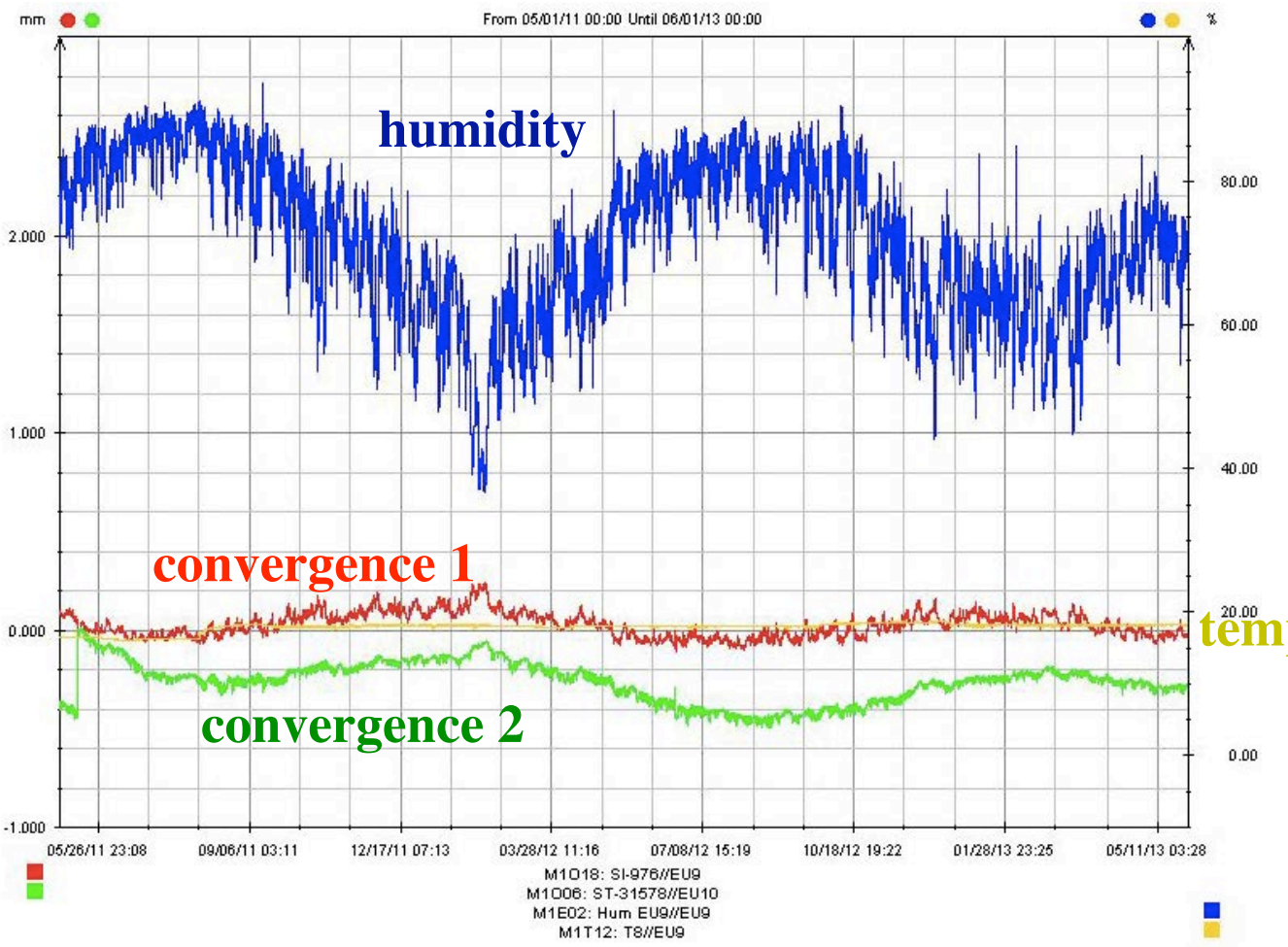
^{238}U: 0.68 ±0.17 cm^{-2}s^{-1}

Tot: 1.23±0.17 cm^{-2}s^{-1}

Monitoring environment changes

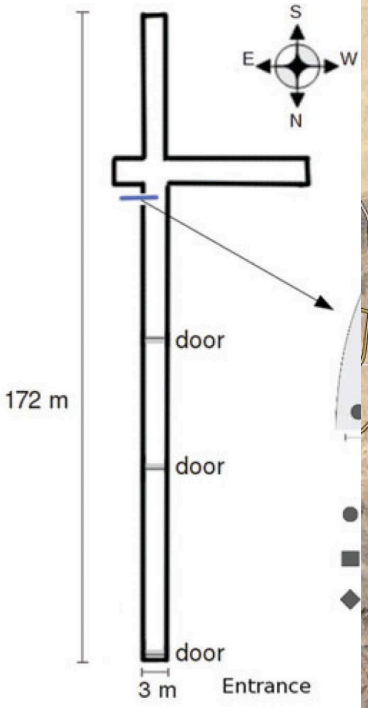
- convergence of the caves
- seasonal variations of the μ flux
- seasonal variations of the n flux
- seasonal dependence of humidity (temperature is about constant)
- seasonal and aperiodic variation of the Rn activity in the air
- ……..

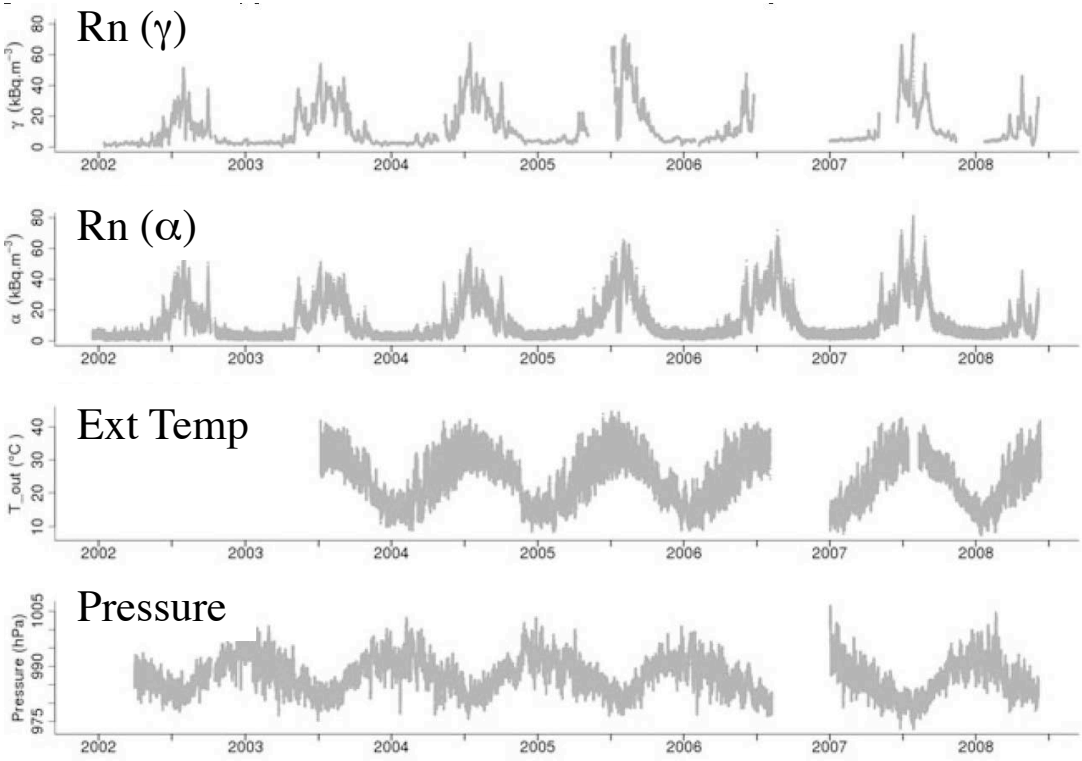
LSC optical fibres monitor



Rn seasonal variations in Amran tunnel

S. M. Barbosa et al. Geoph Journ. Internaz. **182** (2010) 829





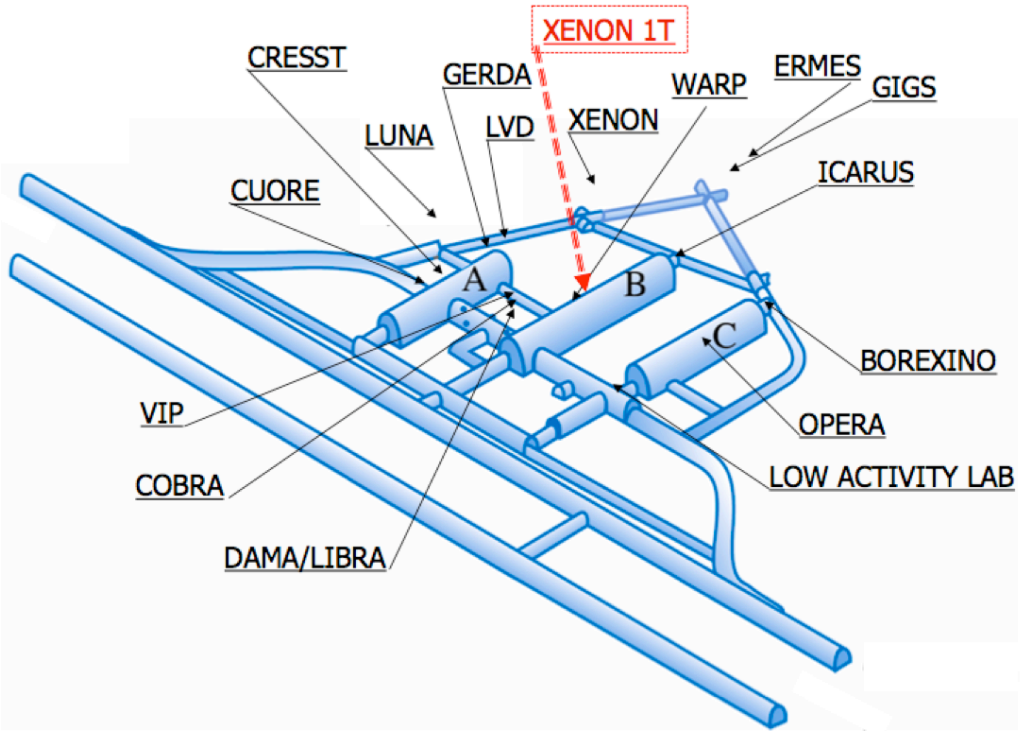
Originally escavated for Gravitational Waves antenna
Now used as underground geophysics observatory

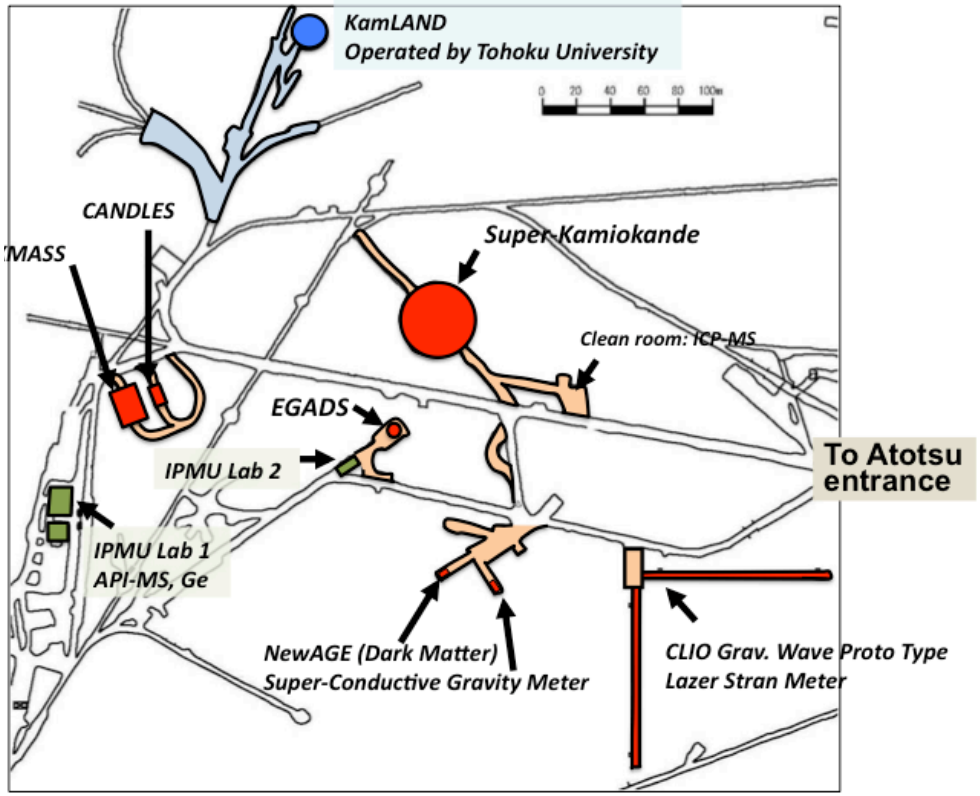
At LSC much smaller modulation observed

Different design concepts

Gran Sasso Laboratory designed with general purpose large halls. Majority of experiments approved for a number of years

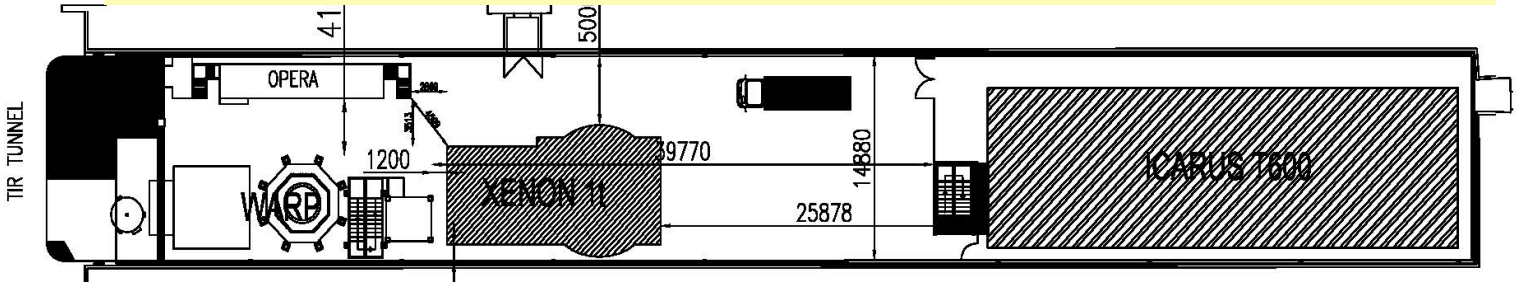
Kamioka Observatory in a mine with easy horizontal access. Many existing tunnels allow building new halls for new approved experiments



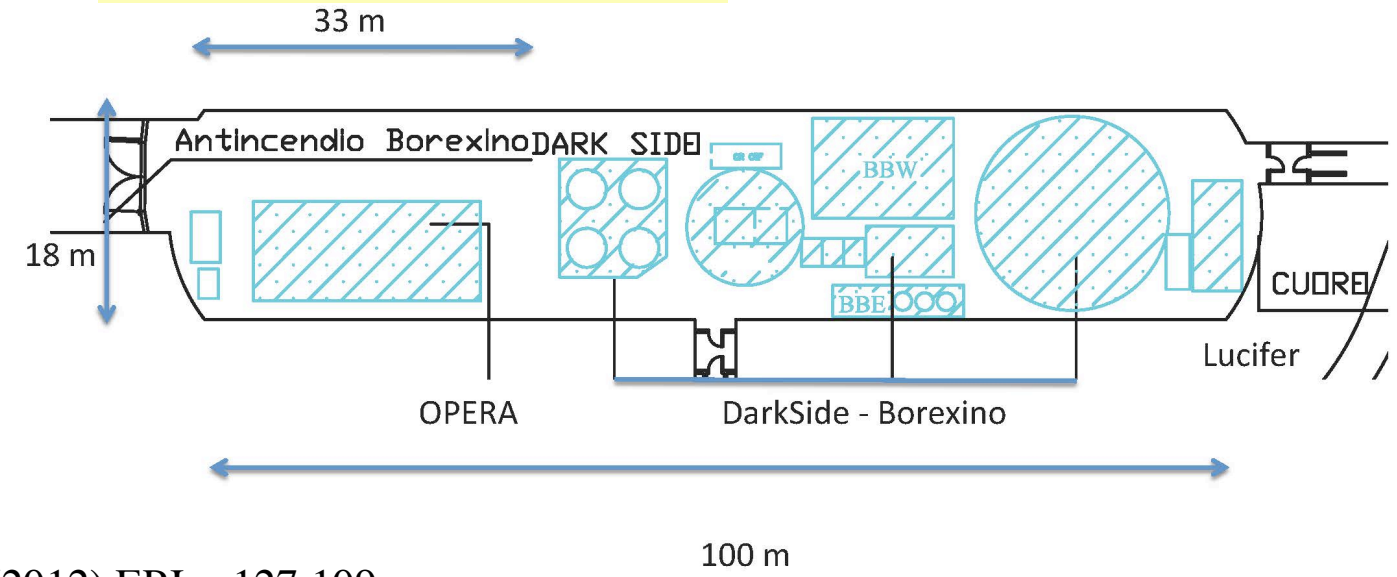


End of the CNGS programme + termination of WARP , and corresponding decommissioning will make space available for future programmes

Hall B. Available in 2015, 100 m minus XENON 1 t space



Hall C. Available in 2017



L. Votano (2012) EPJ-p 127:109

LSC

Total area 1560 m²
Total volume 10500 m³
Max coverage 850 m

A. Bettini (2012) EPJ-p 127:112

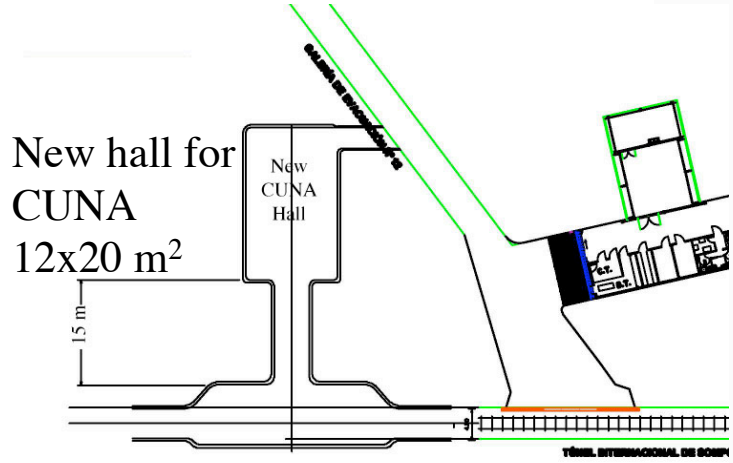
http://www.lsc-canfranc.es/en/

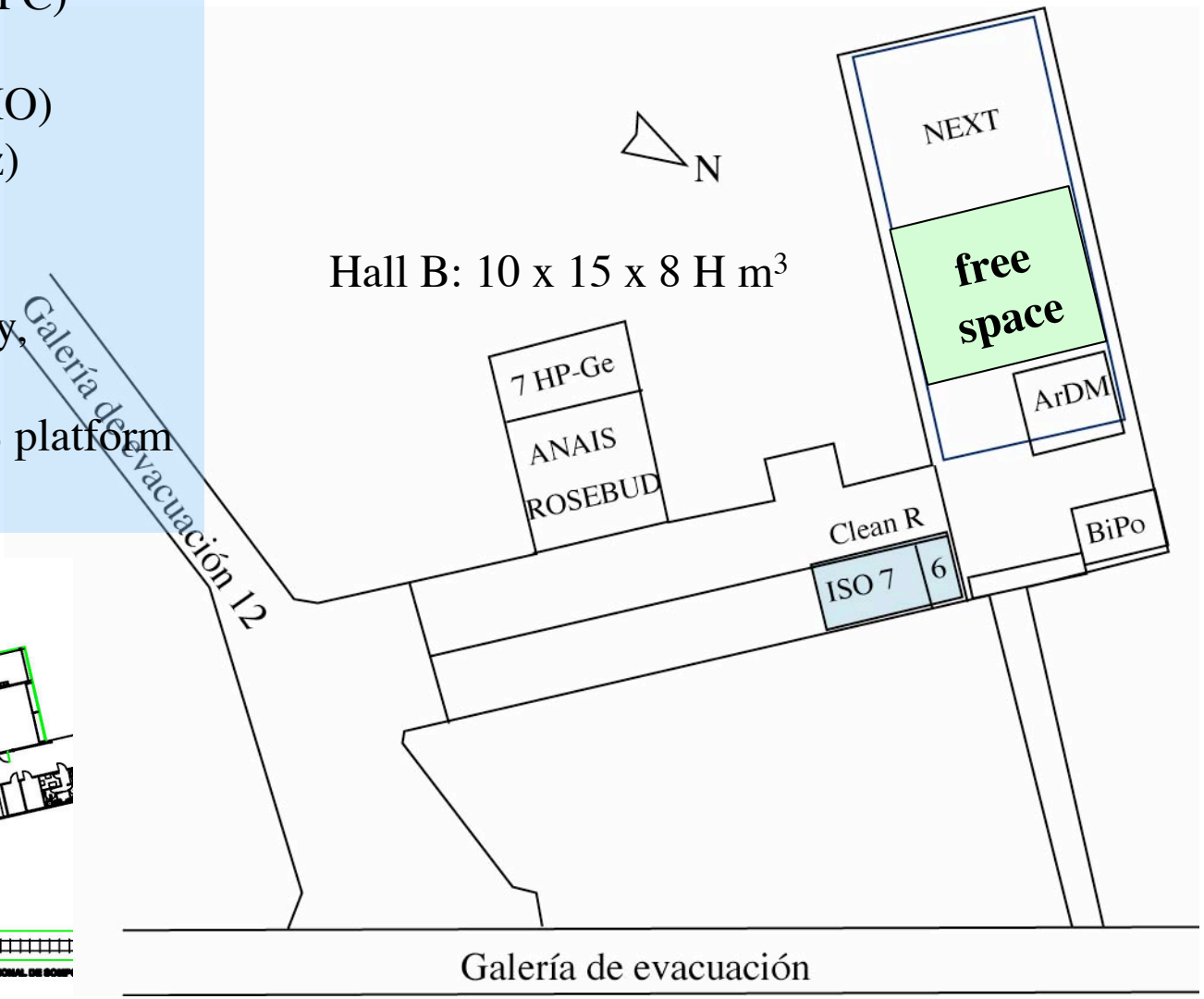
- **Dark matter**
  - ANAIS (NaI annual modulation)
  - ArDM (LAr two phase TPC)
  - ROSEBUD (R&D bolometers)
- **Double beta**
  - NEXT (High pressure Xe TPC)
- **Neutrino physics**
  - BiPo (support to superNEMO)
  - SK-Gd (support to Gadzooz)
- **Geology**
  - GEODYN
    - measure strain, velocity, acceleration
      - integrate in EPOS platform
- **Nuclear astrophysics** (CUNA)

LSC

LSC and the Spanish Government look forward for more experimental proposals

Hall A: 14.5 x 40 x 10 H m^3





Geology under-surface

Geodynamic observatories underground provide complementary information to surface

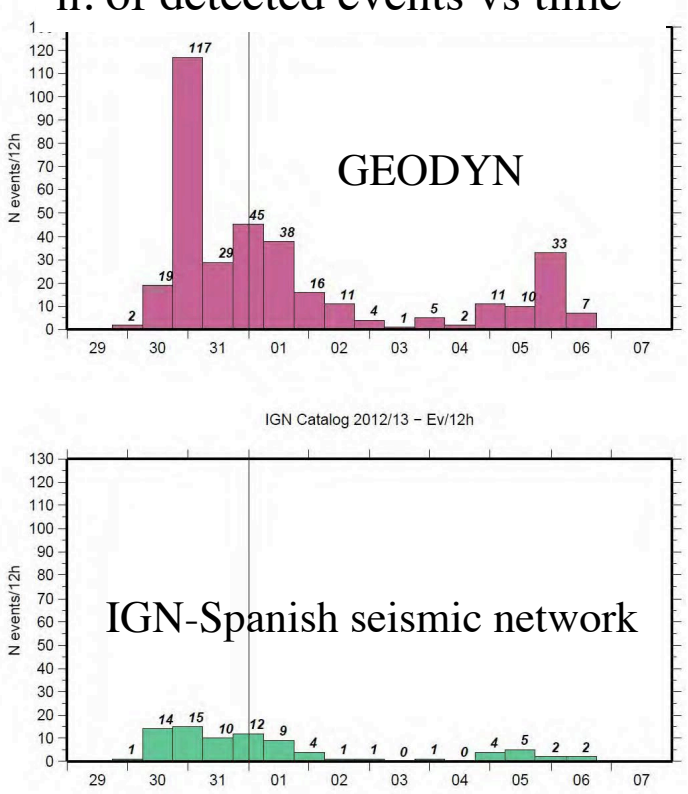
"Background" to seismic signals on surface due to natural and, mainly, anthropic phenomena

Geo-neutrinos

•Examples

- •Discovery of a "slow" quakes sequence at LNGS
- •Small magnitude events in a seismic sequence at LSC
- •Correlation between seismic noise and water flow in the valley at LSC

n. of detected events vs time



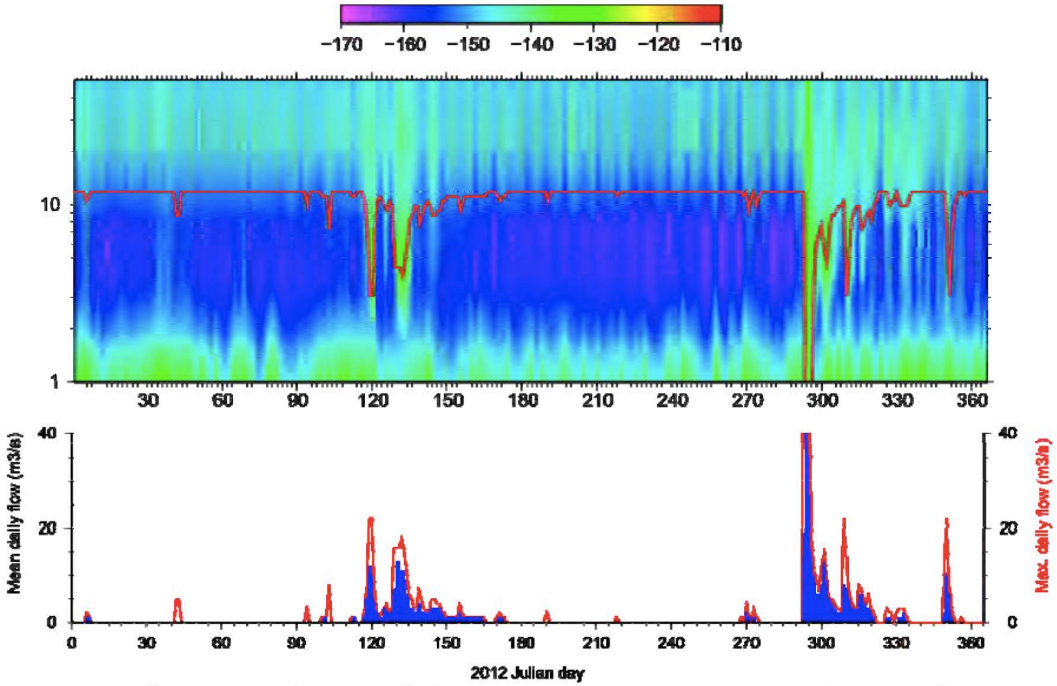
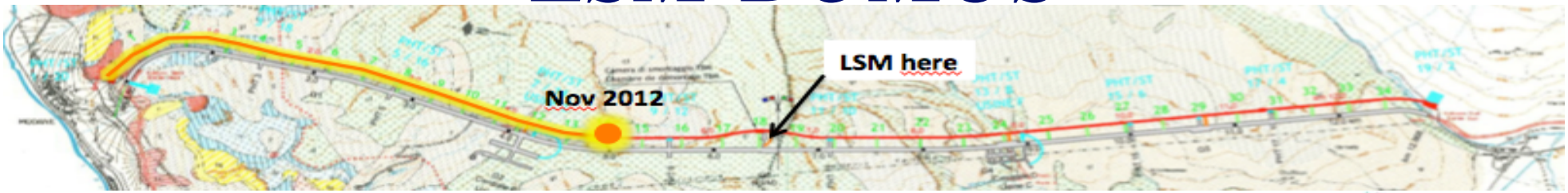


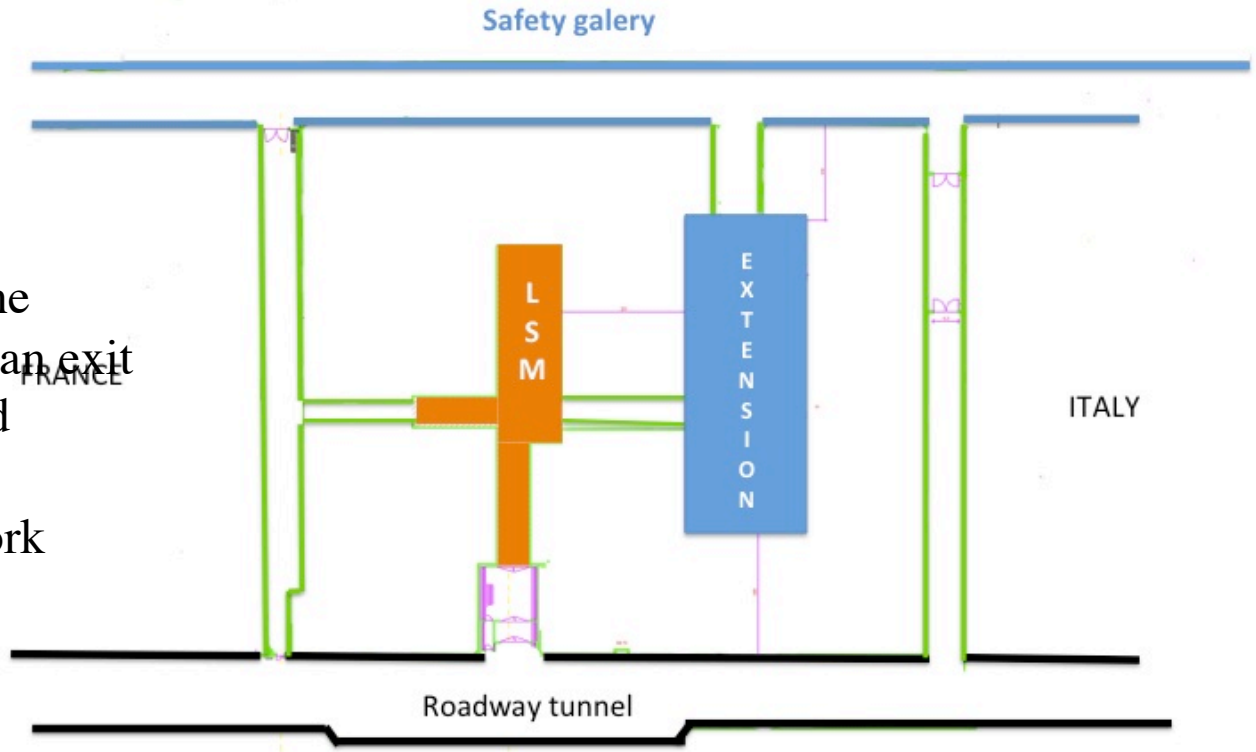
Figure 12. Comparison between daily variations in seismic noise and in river flow.

LSM-DOMUS

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



Unique opportunity
Safety tunnel -> traffic tunnel
Being excavated with TBM from the French side, continuing till the Italian exit
Progressive of LSM almost reached
Start DOMUS excavation 2014-15
Possible to blast during TBM at work
Duration 6-8 months



40-50 x 18.2 x 15.6 H m^3 + access
Estimated cost = 7 M€ (assuming = 300 €/m^3)
Contract being defined

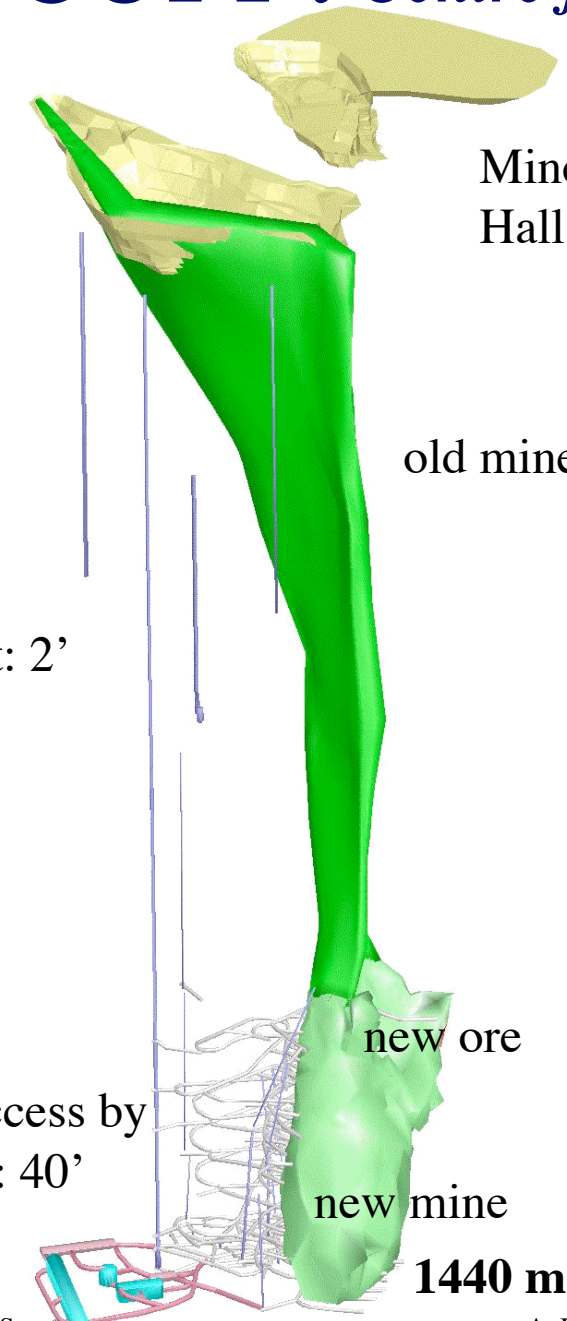
F. Piquemal (2012) EPJ-p 127:110

LSM-DOMUS
defining the programme

- **12 LoI and 1 EoI received**
- **Dark matter**
  - EURECA (Bolometers)
  - DARWIN EoI (Noble liquids)
  - MIMAC (TPC)
  - ULTIMA (3He)
- **Double beta**
  - SuperNEMO (Tracking+calorimete)
  - COBRA
- **Double EC**
  - TGVIII (pixel detector)
  - Double ECv(Ge)
- **R&D for p-decay and neutrinos**
  - MEMPHINO
- **SN neutrinos**
  - TPC sphere
- **Geology**
- **Environmental studies**

CUPP. *Centre for Underground Physics in Pyhäsalmi*

http://www.cupp.fi/

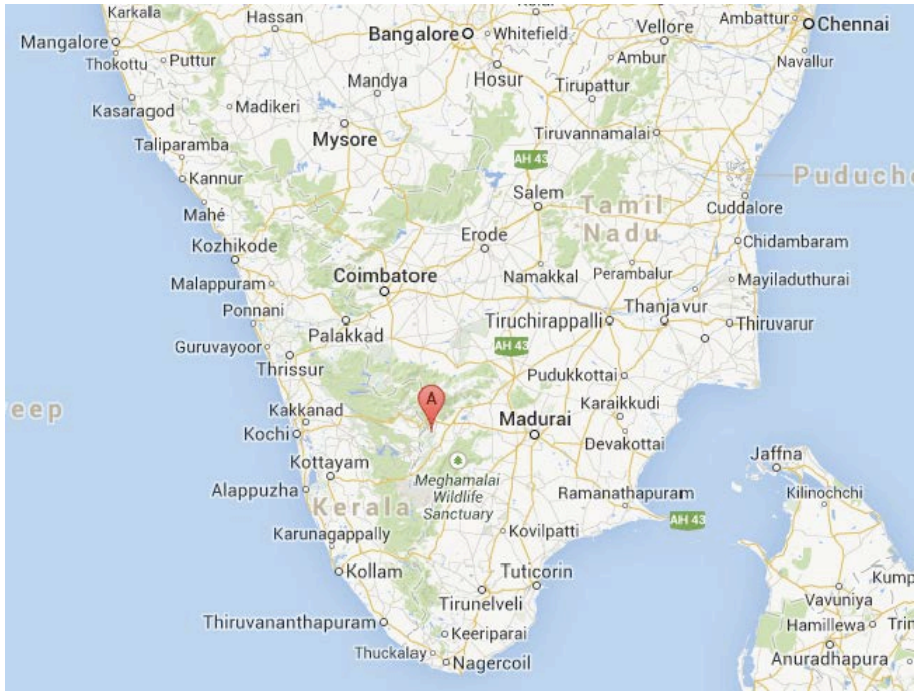


Mine is expected to close around 2019
Halls, with infrastructures, may be available then for experiments.


Mine maintenance hall 1400 m depth

Site Investigation Project (for very large caverns)
Funded for 1.5 M€ by Finland
Site proposed for LAGUNA-LBNO

INO. *India based Neutrino Observatory*



115 km west of Mandurai (int. airport)
Tamil Nadu (near border with Kerala)
Rock coverage: 1200 m
Horizontal access: 1.9 km

Obtained forest and environmental clearances. Civil construction will start soon.

TN govt. has handed over 66 acres of land for the construction of INO facilities at site

Additional 33 acres of land acquired at Madurai for the INO centre.

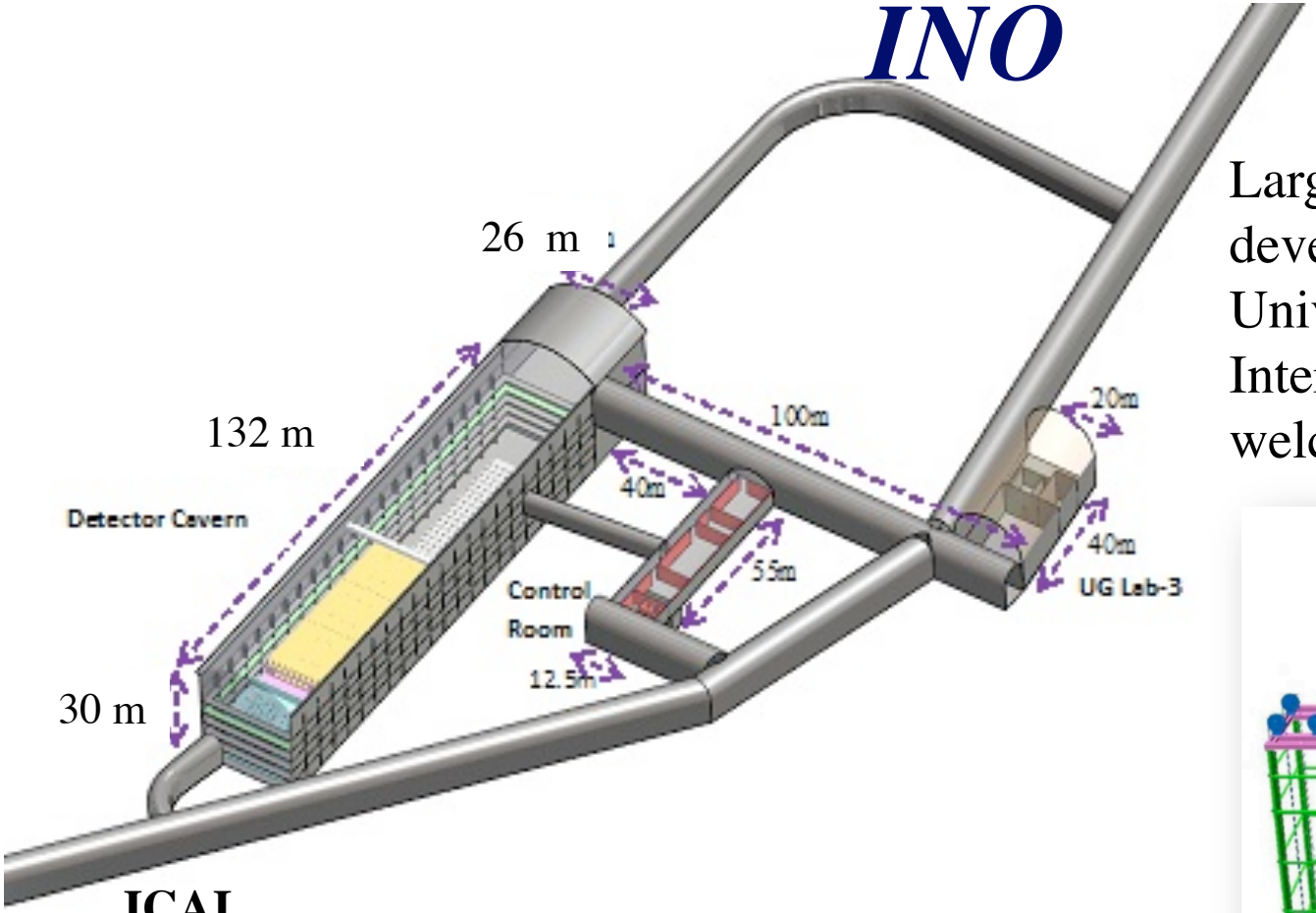
Graduate training program with emphasis on hands for detector development running since 5 yr

Waiting for the final approval of the Federal Gvt

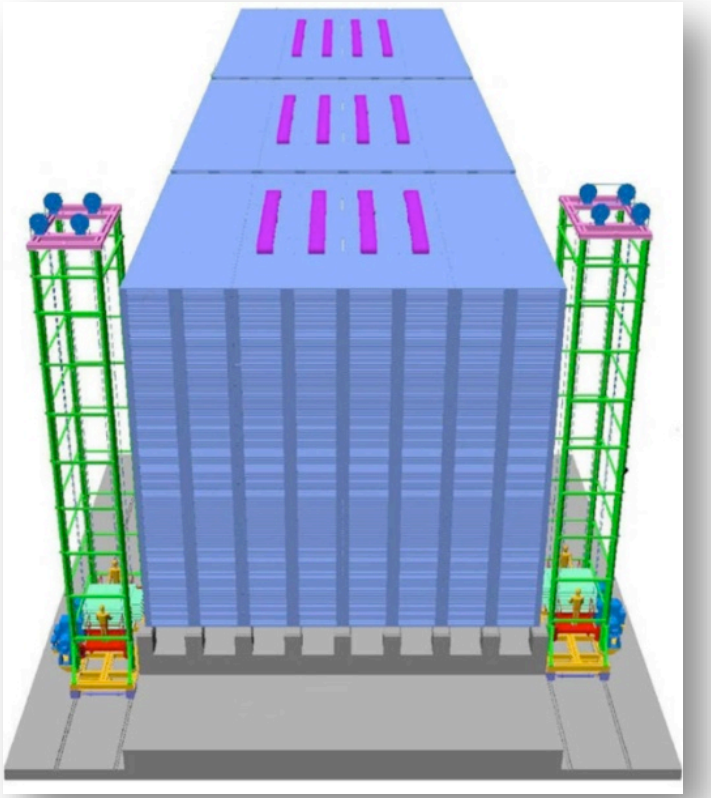
N. K. Mondal (2012) EPJ-p 127:106

http://www.ino.tifr.res.in/ino/

INO



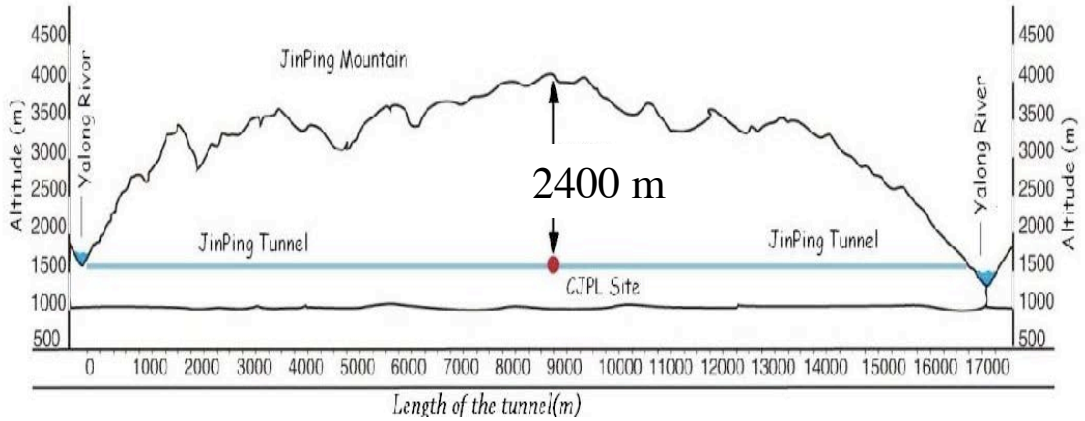
Large collaboration developed with 20+ Indian Universities and Institutions
International collaboration welcome



ICAL

50 kt magnetized tracking calorimeter
Neutrino physics
"Large" θ_{13} allows determining mass order at 3 σ with 750 kg yr exposure
Space for 100 kt in main hall
Smaller halls for smaller experiments

CJPL



Deepest underground lab: 2400 m

μ flux = 60/(m^2 yr)=2 x 10^{-6}/(m^2 s)

Drive in to the halls

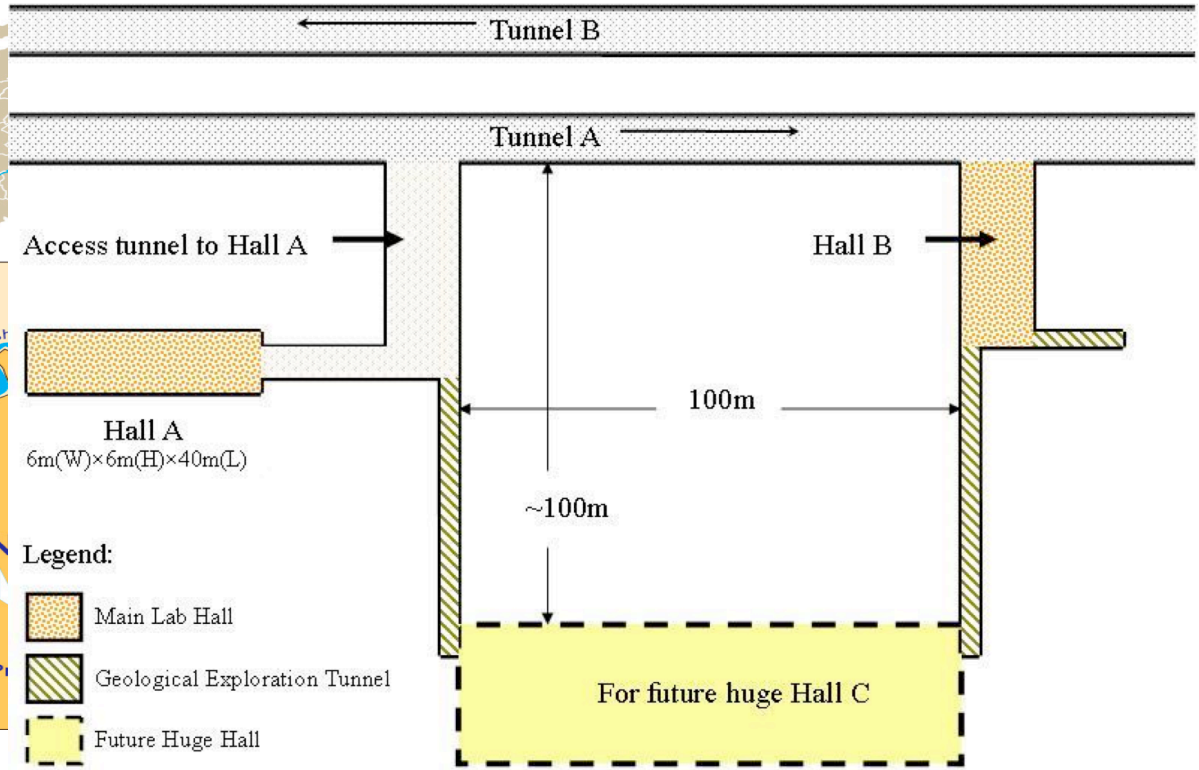
Tunnels (17km) for hydropower stations

Hall A 40x6x6 m^3 ready (2011)

Hall B excavated for rock mechanics

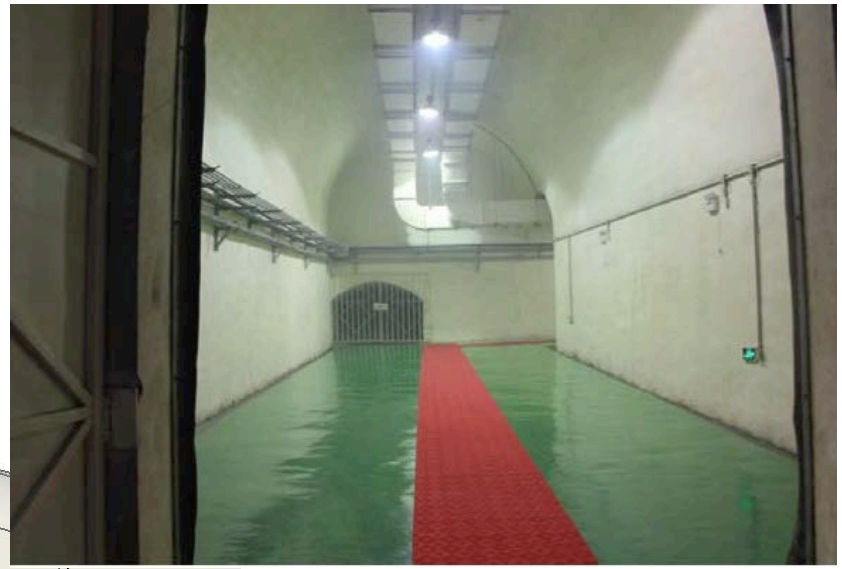
Designing expansion to 20 times larger

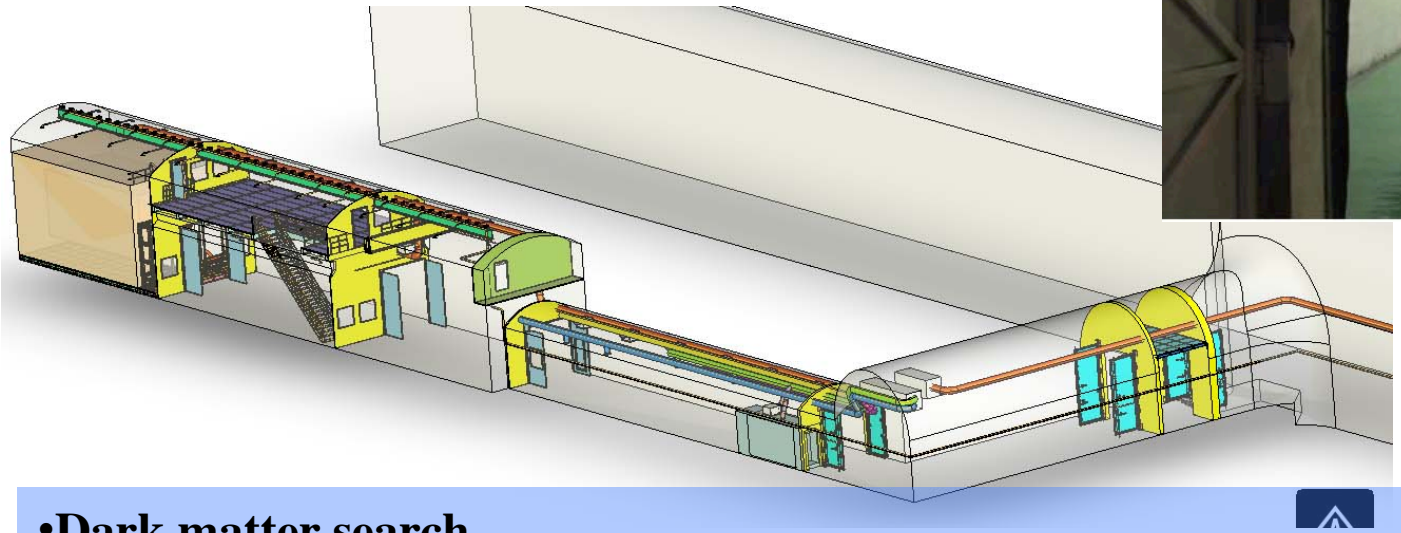
Including Halls 50x12x12 m^3



H. Cheng (2012) EPJ-p 127:105

CJPL

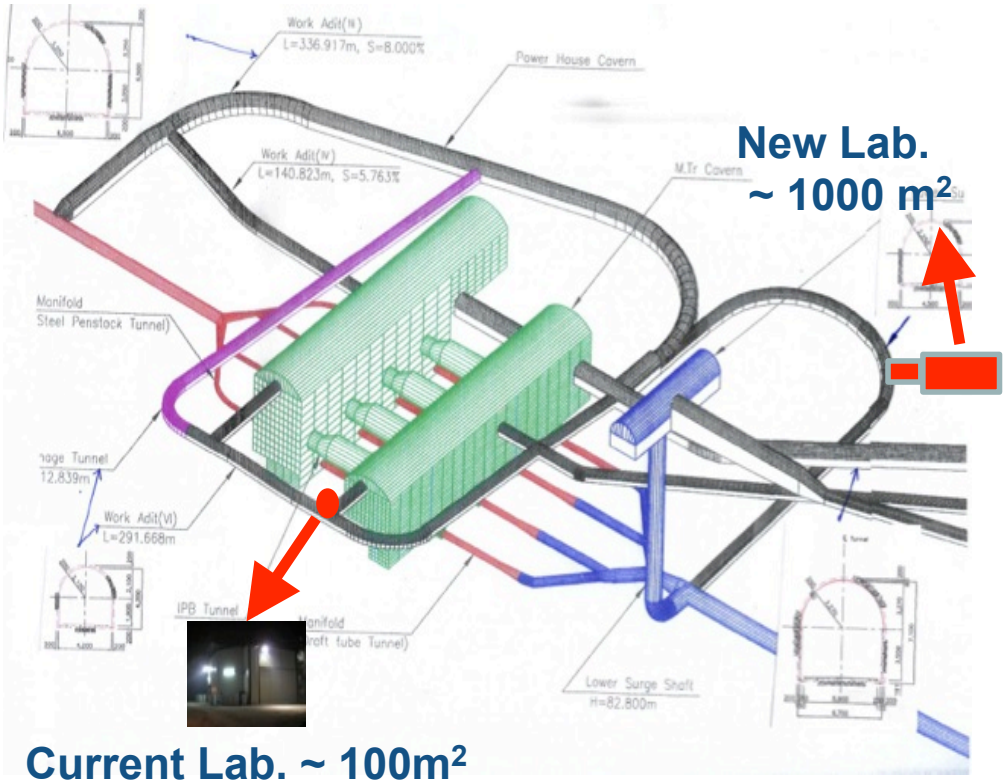




- **Dark matter search**
  - PANDA-X. Liquid Xe TPC. Develope modules of increasing mass (now 400 kg)
  - R&D of CsI(Na) at IHEP (Beijing)

- **Medium term scientific programme under development, including**
  - Physics research laboratory
  - Laboratory for rock mechanics and engineering studies
  - Laboratory for geophysics studies
- **The laboratory will open to international community**

CUNPA *CENTRE for Underground Nuclear & Particle Astrophysics*



Proposal 1. New lab at the Y2L site
Near power station structures
Depth ≈700 m
Area ≈1000 m^2 / Volume ≈7000 m^3
Cost ≈ 5 M$
Proposal 2.
Other location Depth ≈1050 m
Area ≈1000 m^2 / Volume ≈7000 m^3
Access tunnel: 1600x4.5x4.5 m^3
Cost of the tunnel ≈ 10-15 M$
Proposal 3
Near operational mine

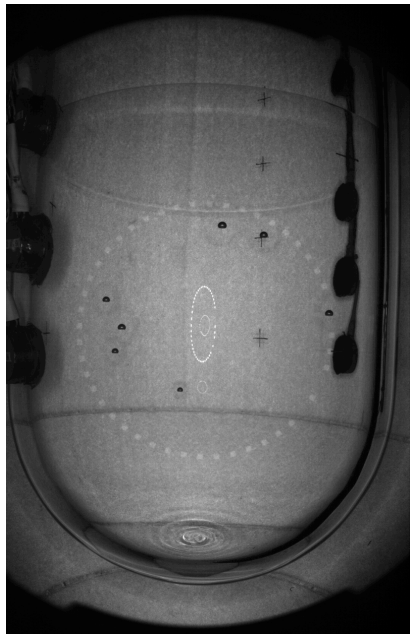
- **TDR for experiments in preparation**
  - **Dark matter (KIMS+)**
  - **Double beta AMoRE**
  - **Nuclear Astrophysics**
  - **Low temperature detectors R&D**

- Approved and funded in May 2013 by the new Institute for Basic Science in Korea
- 10 M$/yr for 10 years from year 2013
- construction of new lab.
- Aim finishing construction by end 2014.

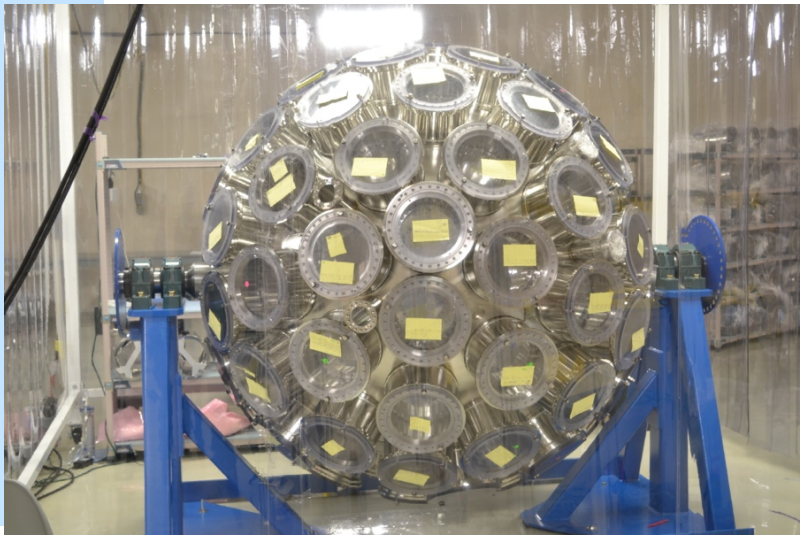
N. Smith (2012) EPJ-p 127:108

SNOLab

- Surface facility 3 500 m^2
- Depth: 2070 m under flat surface in the working Creighton nickel mine operated by Vale Ltd.
- Access: vertical through the Vale maintained shaft and conveyances
  - Significant operation savings (+)
  - Integrate safety procedures with mine ones (+)
  - Need synchronize access with mine works (–)
  - Maximum size: 3.7 x 1.5 x 2.6 m^3 (–)



- **Rich programme ongoing and under development**
- **Dark matter** (in particular Spin dependent)
  - DEAP (Noble liquids)
  - CLEAN (Noble liquids0
  - COUPP (Bubble Chamber)
  - PICASSO (Superheated spheres)
  - Super CDMS (Ge bolometers)
  - DAMIC (10 g CCD)
- **Double beta and neutrinos**
  - SNO+ (^{130}Te in Liquid Scintillator)
  - EXOgas R&D
- **SN neutrinos**
  - HALO (ν_e CC in Pb)

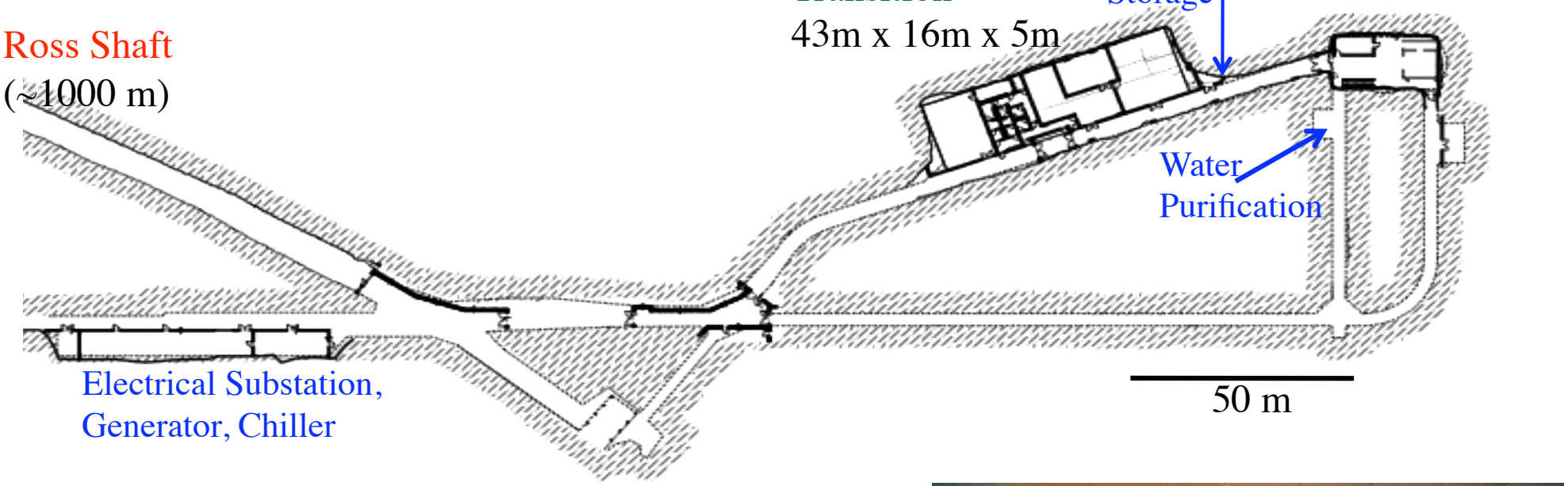


SURF

http://www.sanfordlab.org/

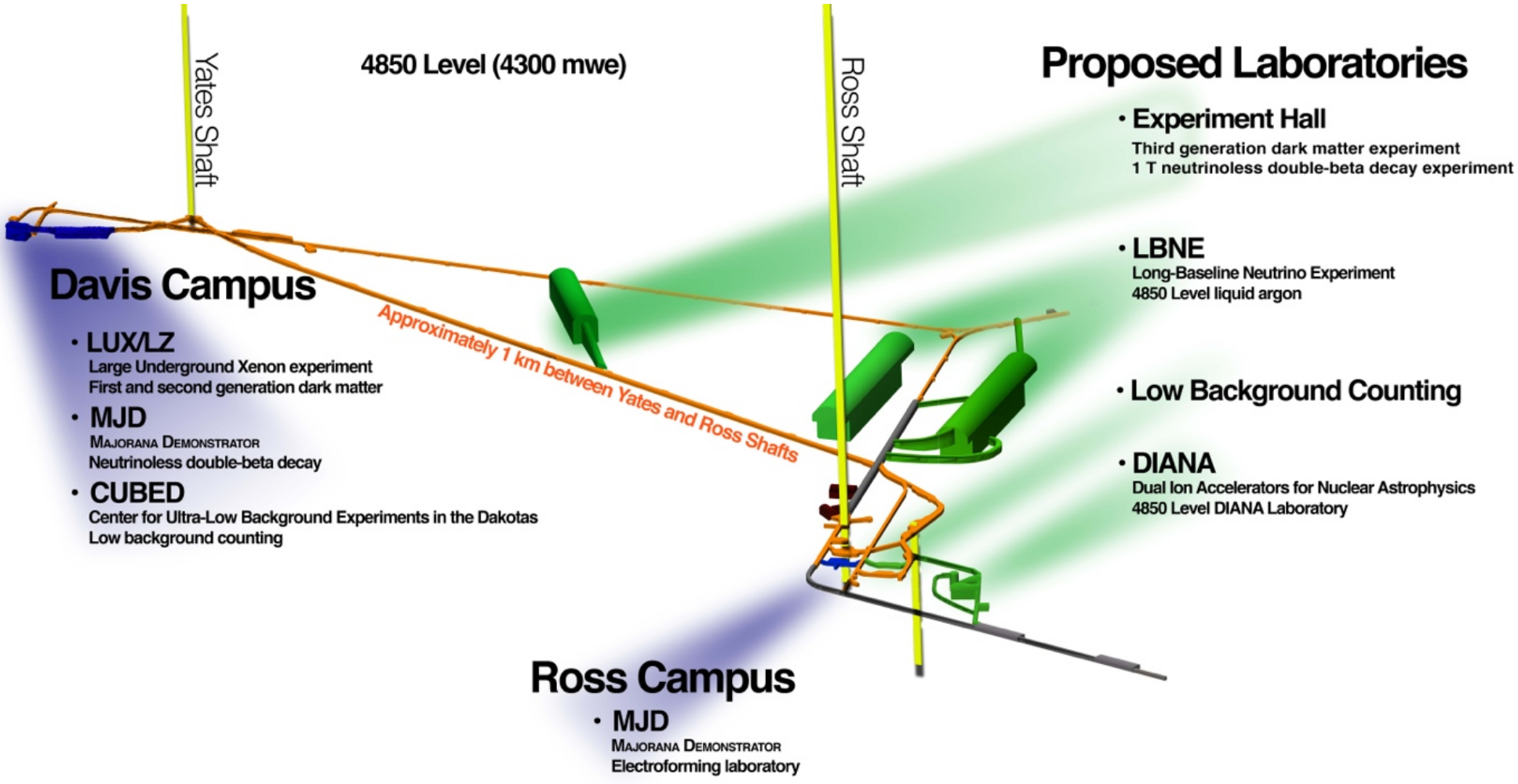
K/Lesko (2012) EPJ-p 127:107

Davis Campus
Depth 1480 m
2730 m² (Total) / 930 m² (Science)



Dewatered below the 6000 foot level. Complete
Yates promoted to primary access. Complete
Davis Laboratory Outfitting. Complete
Ross Shaft Rehab - design completed and reviewed – rehabilitation in progress
Yates Shaft Inspections and Rehab. Initiated
On surface. Office space, R&D Space, Warehouse and Prototyping Facilities, Meeting Space, Conference

SURF



Existing galleries allow excavation of new halls if needed (and if funded)

X. Bertou (2012) EPJ-p 127:104

Agua Negra Tunnel

Unique opportunity: large freeway infrastructure joining Pacific and Atlantic Oceans between Chile and Argentina, connected to Brazil and Paraguay

Two parallel tunnels, one for each direction:13.9 km in length. The Argentine entrance will be on altitude of 4,085 m, and the Chilean entrance is on 3,620 m

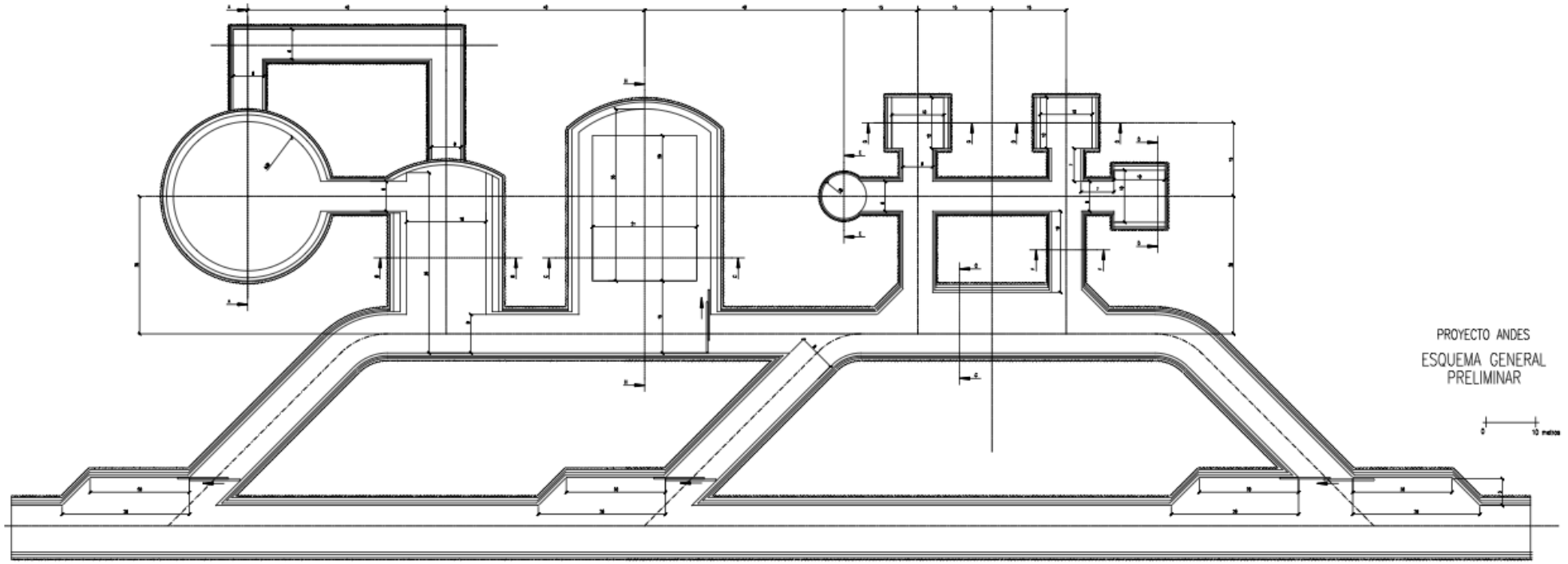
Deepest point ≈ 1750 m

Call for expression of interest published in July 2013

Tendering + construction ≈ 8-10 years (my guess)

ANDES. *Agua Negra Deep Experiment Site*

International facility for multidisciplinary underground science
Exploit the unique geo-political location
The CLES Latin American Consortium for Underground Experiments has been created (Argentina, Brazil, Chile and Mexico). Open to international partners
Status: Design, to be completed by October 2013. Civil works will be part of the tender for the tunnel. Need final approval by Government (volume and cost is around 2% of the tunnel)
Depth: 1700 m. Design under development
Main hall 21x23x50 m^3; Secondary hall: 16x14x40 m^3; Large pit 30 m diam 30 m H, small halls
Two surface laboratories at lower altitudes
Rodeo in Argentina and Vicuña in Chile.



ANDES. Science

The only UL in Southern Hemisphere
Located in unique tectonic region and environment

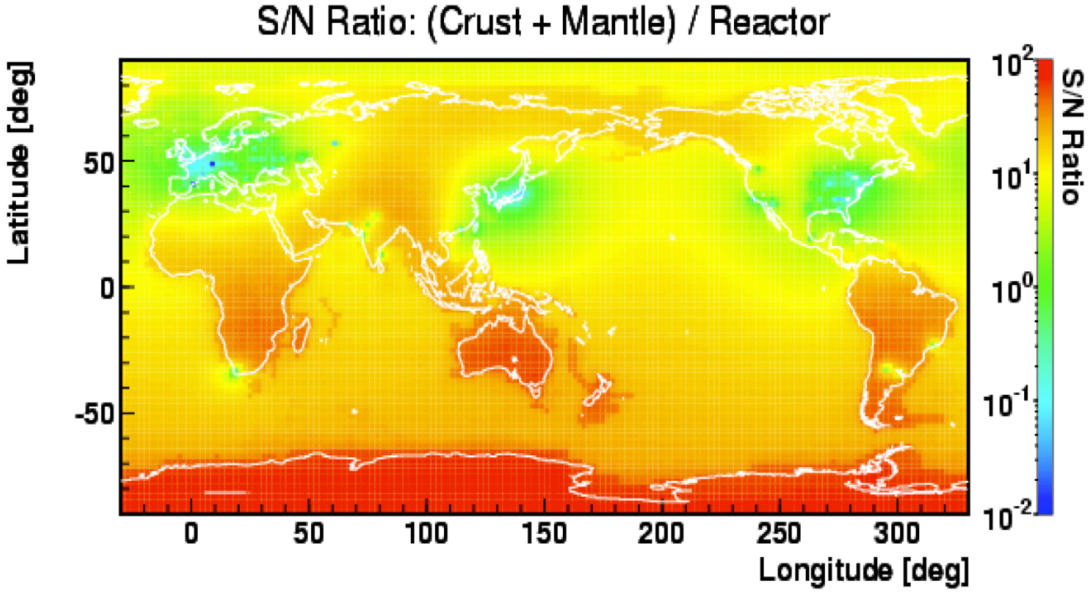
Neutrino physics, astrophysics, geology

- Large Latin America Neutrino Detector (BOREXINO technology)
- Supernova neutrinos (triangulation with Northern detectors)
- Double beta decay

Dark matter

- Exploit modulation (different environmental phases)
- New technologies

- Geophysics (Nazca plate, subduction)
  - Integrate underground nodes into Argentina and Chile surface seismic networks
  - NB. Be far from traffic
- Biology underground
- Low background measurements
- Nuclear astrophysics



Conclusions

- **Underground laboratories have discovered physics beyond the Standard Model**
  - almost 50 years ago in Homestake
- **The field is progressing staidly**
- **Underground space is already available in several laboratories**
  - More in this decennium
- **Cost for ton-scale DBD or 10 ton-scale DM > cost of a lab to host them**
- **Large detectors using liquid scintillator and cryogenic liquids may require dedicated underground infrastructures (see Cryo-pit)**
- **Decisions in the different countries are sensitive to geo-political arguments**
  - should we, the community, stress more the scientific side?
  - SN neutrino network?
  - …..
- **Geology may become an important (but limited) element of the programme**
  - see GIGS, Geodyn,…
  - Global geo-neutrinos network?