Status update on deep underground neutrino facilities

Nigel Smith
SNOLAB

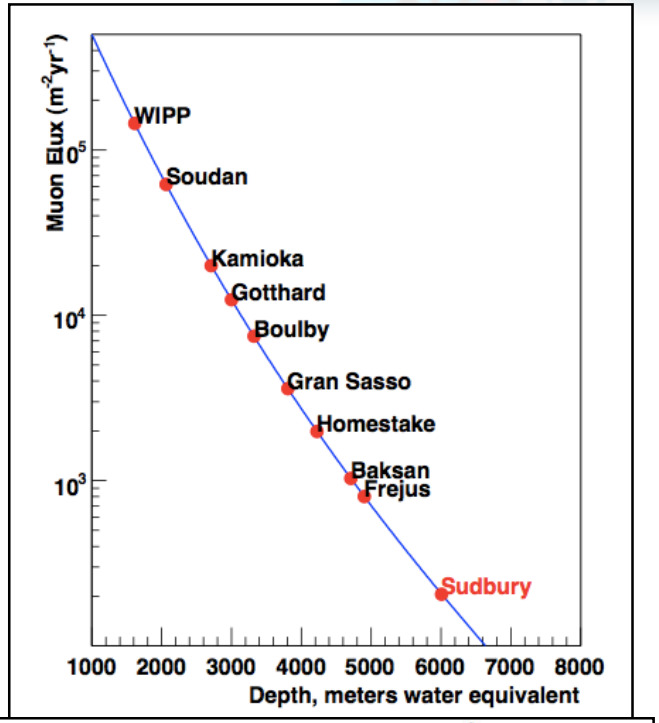
with thanks to X. Bertou, A. Bettini, A. Habig, K. Lesko, N. Mondal, S. Paling, F. Piquemal, Y. Suzuki, L. Votano, Y. Qian
...and many others

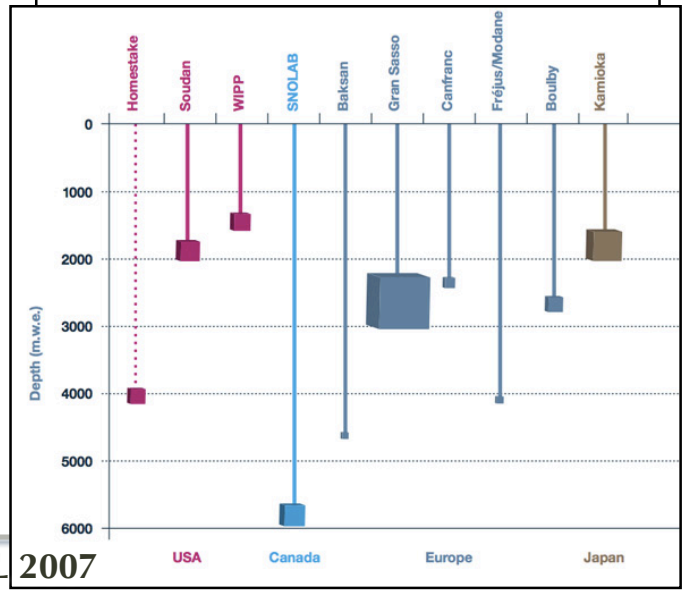
Outline

- Scope of talk:
  - Deep underground neutrino facilities
  - Focus on new/planned expansions to facilities
  - Detailed reviews of experiments and techniques in other talks this week....
- Why go underground?
  - Background suppression
  - Science capabilities of underground facilities
- Status update on underground facilities
  - Asia
  - Europe
  - America
- Review of expansion potential

Why go underground?

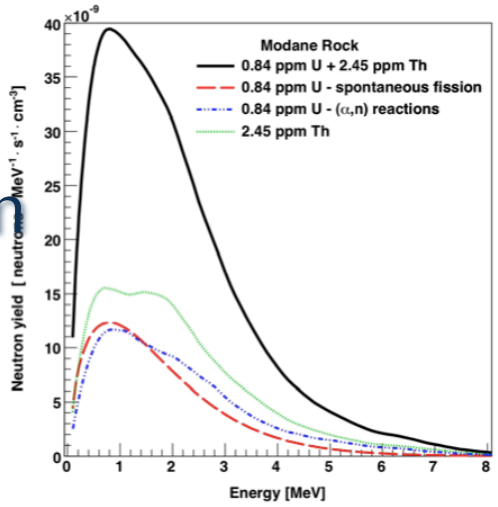
- Studies for rare events, either decays (eg proton or $0\nu\beta\beta$) or weak interactions (dark matter, natural or generated neutrino), require very radio-quiet environments to undertake searches
- Deep underground facilities provide significant rock overburden and commensurate reduction in c.r. flux, and c.r.-spallation induced neutrons
  - Additional science programmes possible with such infrastructure - nuclear astrophysics, extreme biosystems, geology, geophysics, ...

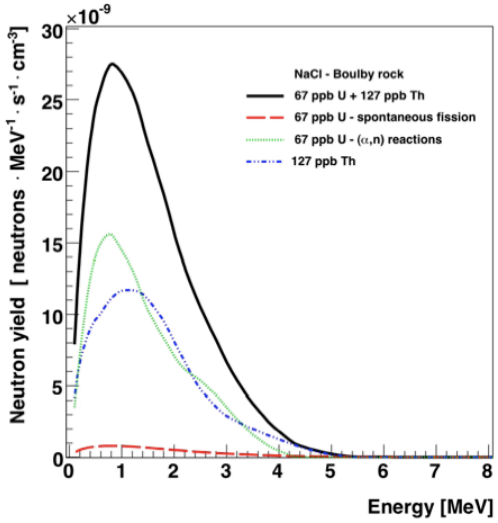




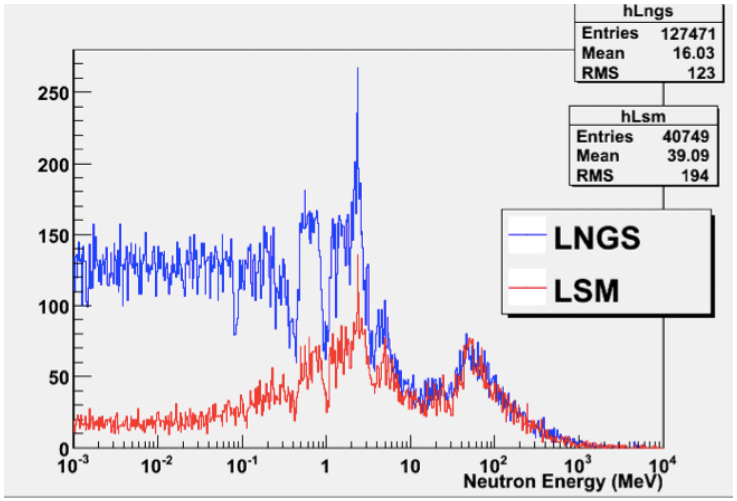
Neutron backgrounds

- Neutron production from
  - c.r. muon spallation
  - U/Th fission
  - α, n reactions
- Spectrum in laboratory depends on local geology (rock composition)
  - both for fast and thermal neutrons
  - U/Th + moderators
  - muons + moderators
  - small levels of high neutron cross-section make a big difference





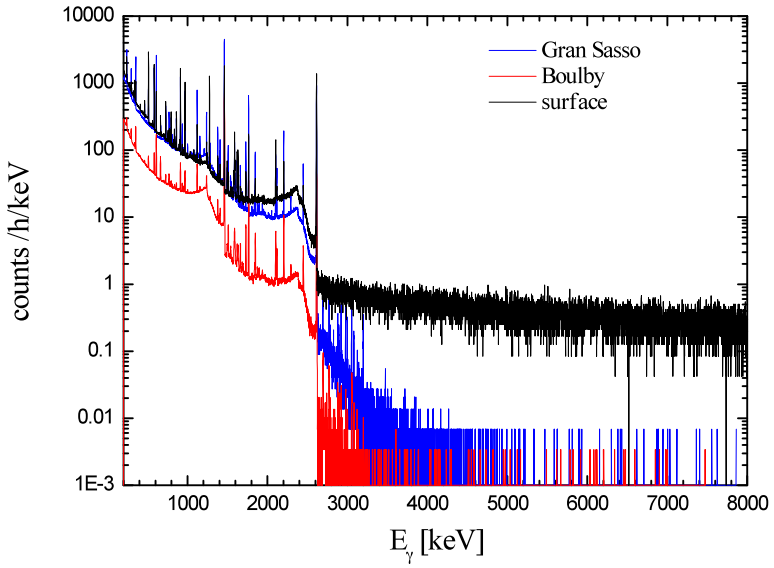
Kudryavtsev

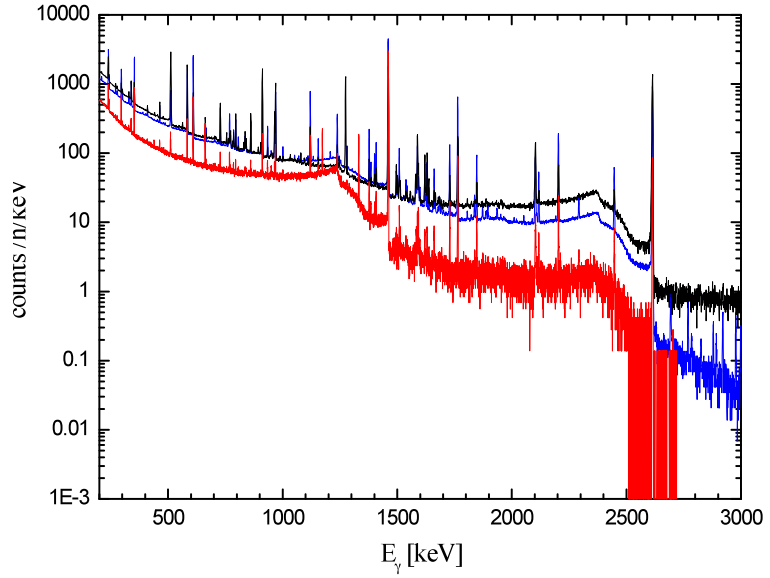


Persiani / Selvi

Gamma Backgrounds

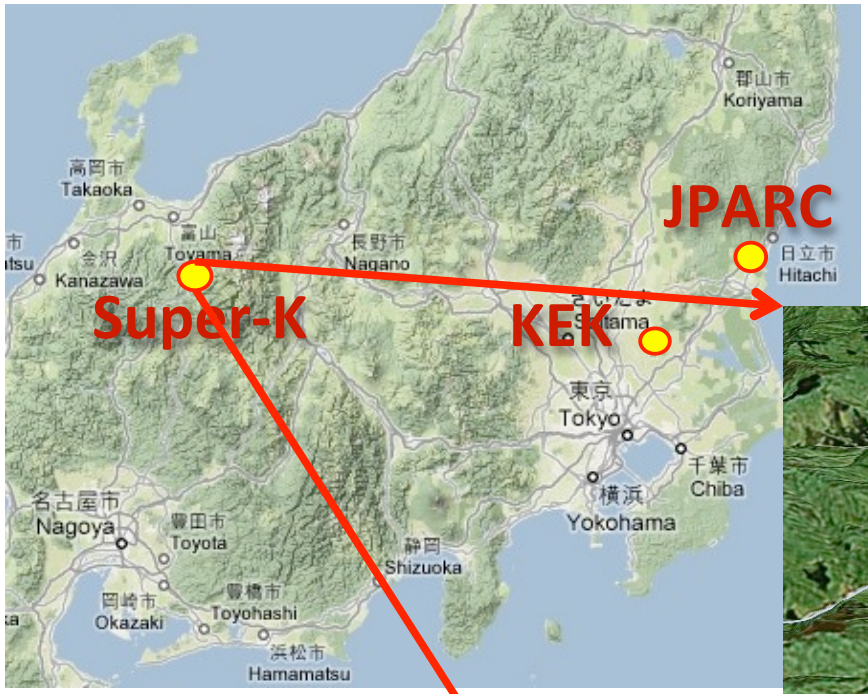
- Reduction in gamma background at higher energies from c.r. and neutron reduction
- Below 3.5MeV dependent on local geology and rock material
  - Boulby (red)
  - Gran Sasso (blue)
  - surface (black)





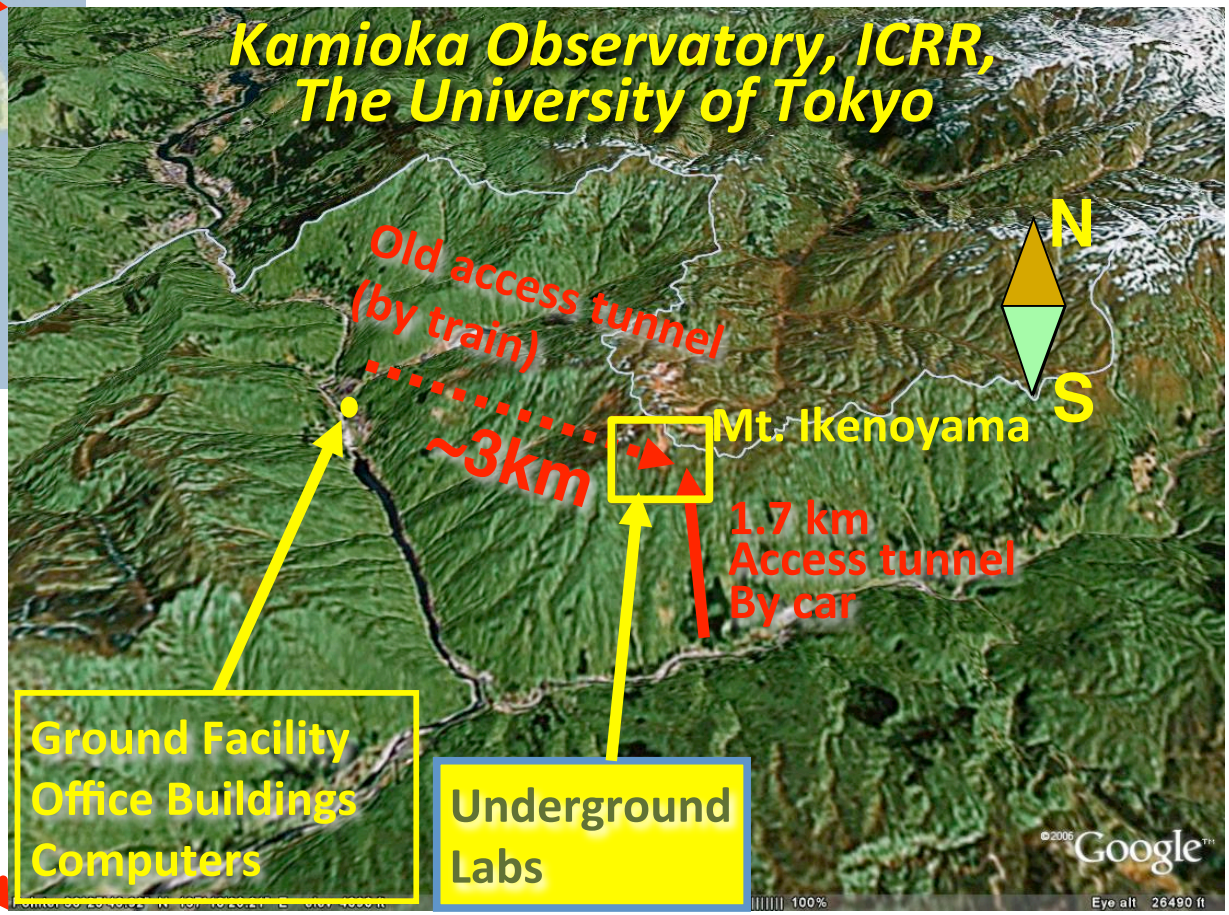
Underground Facilities

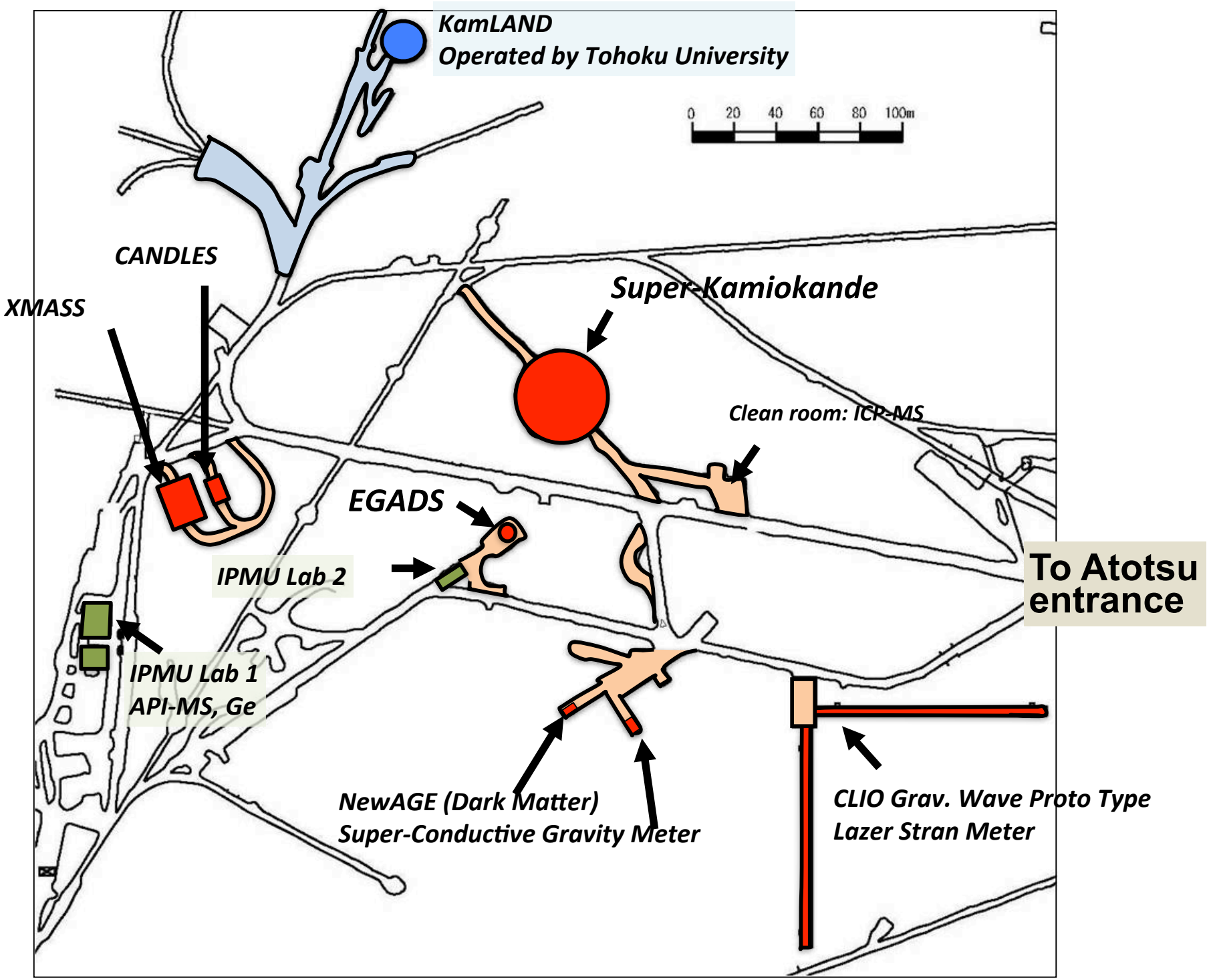
Kamioka Observatory



- **Location**
  - Northan part of Gifu pref.
  - 40 minutes drive from Toyama airport, where is 1 hour flight from Tokyo Airport

- 1000 m underground
- 24 hours access by car
- Holizontal access
- 10 minutes from the ground facility




KamLAND
Operated by Tohoku University
0 20 40 60 80 100m
CANDLES
XMASS
Super-Kamiokande
Clean room: ICP-MS
EGADS
IPMU Lab 2
To Atotsu entrance
IPMU Lab 1
API-MS, Ge
NewAGE (Dark Matter)
Super-Conductive Gravity Meter
CLIO Grav. Wave Proto Type
Lazer Stran Meter

Current Experiments in Kamioka (topics by red colored)

- LCGT (Large Cryogenic Gravitational Antenna)
  - **Funded in 2010, ~$100M**
  - Construction till 2015
  - To be operated by diferent reserch center
- CLIO (prototype of LCGT)
- Geo physics
  - Laser strainmeter
  - Superconductive gravity meter
- NewAGE (Dark Matter: Direction)
- XMASS (Dark Matter: liq. Xenon)
  - Detector completed
  - **Commissioning in 2011**
- CANDLES (Double beta)

  Detector completed

  Commissioning
- Super-K

  Indication of electon appearance (by T2K)

  GAZOOKS

  Feasibility test by 200 ton test tank
- KamLAND (not under the kamioka Observatory, but operated by Tohoku University)

  KamLAND-ZEN (double beta decay of 136Xe)

  Under construction

Yangyang Underground Laboratory

Yangyang Pumped Storage Power Plant

(Upper Dam)

Korea Middleland Power Co.
→ Korea Hydro and Nuclear Power Co.

700m

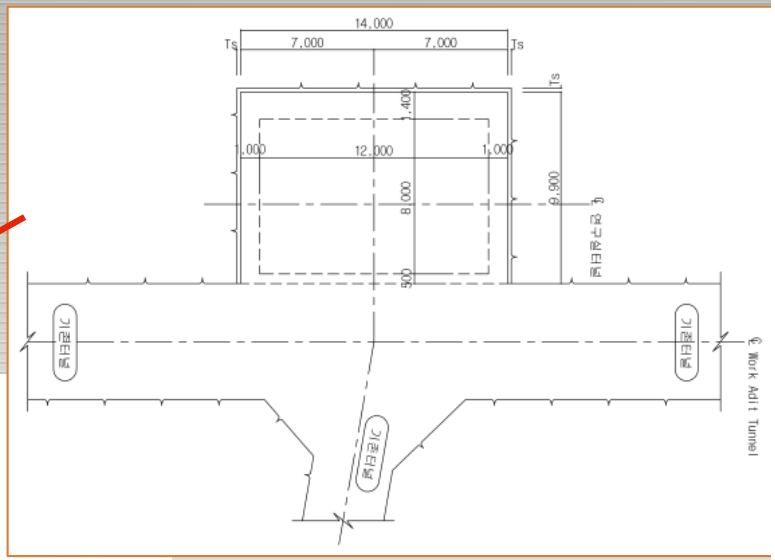
(Power Plant)

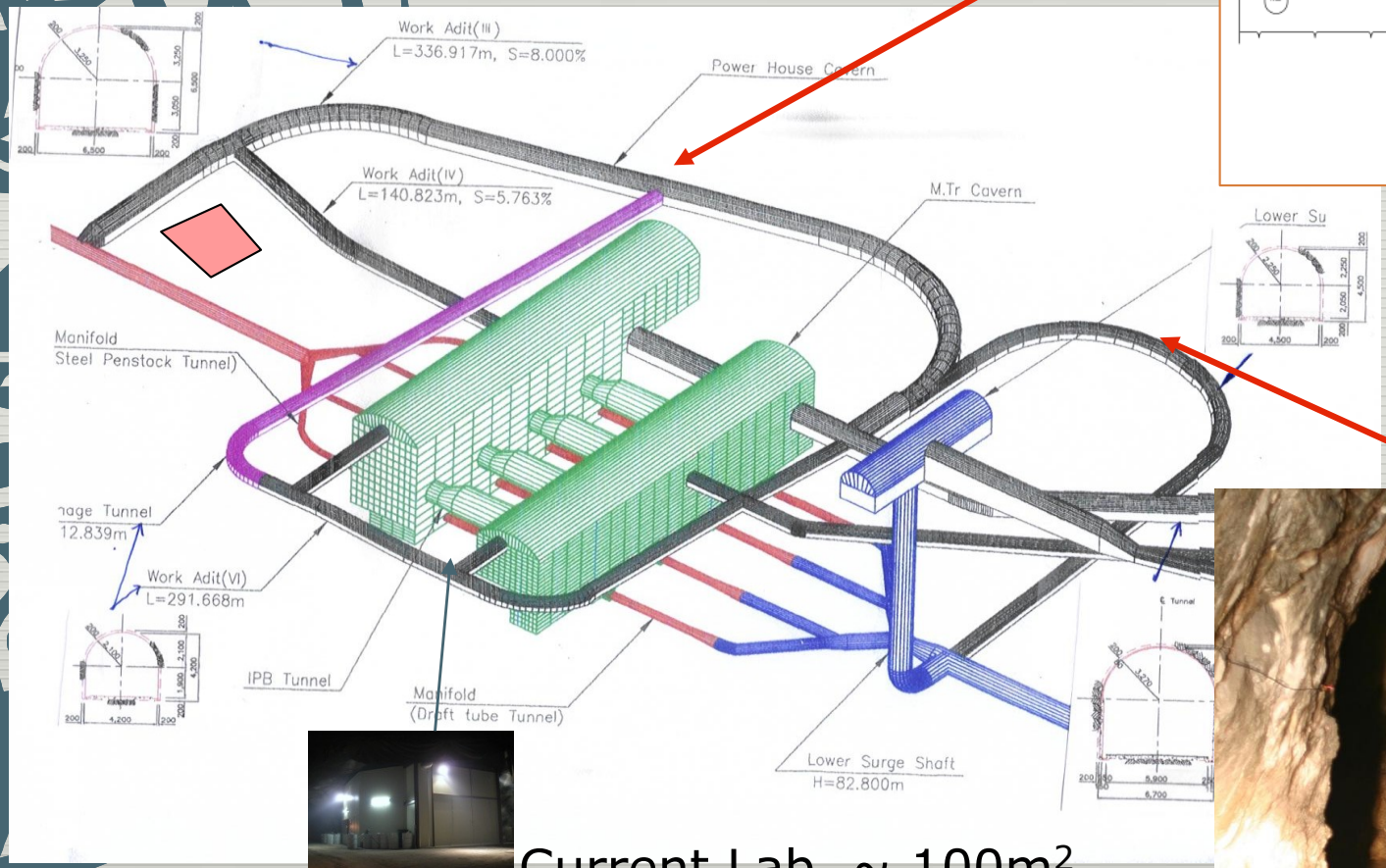
(Lower Dam)

양양양수발전소

Vertical depth : 700 m / Access to the lab by car (~2km)
Constructed in 2003

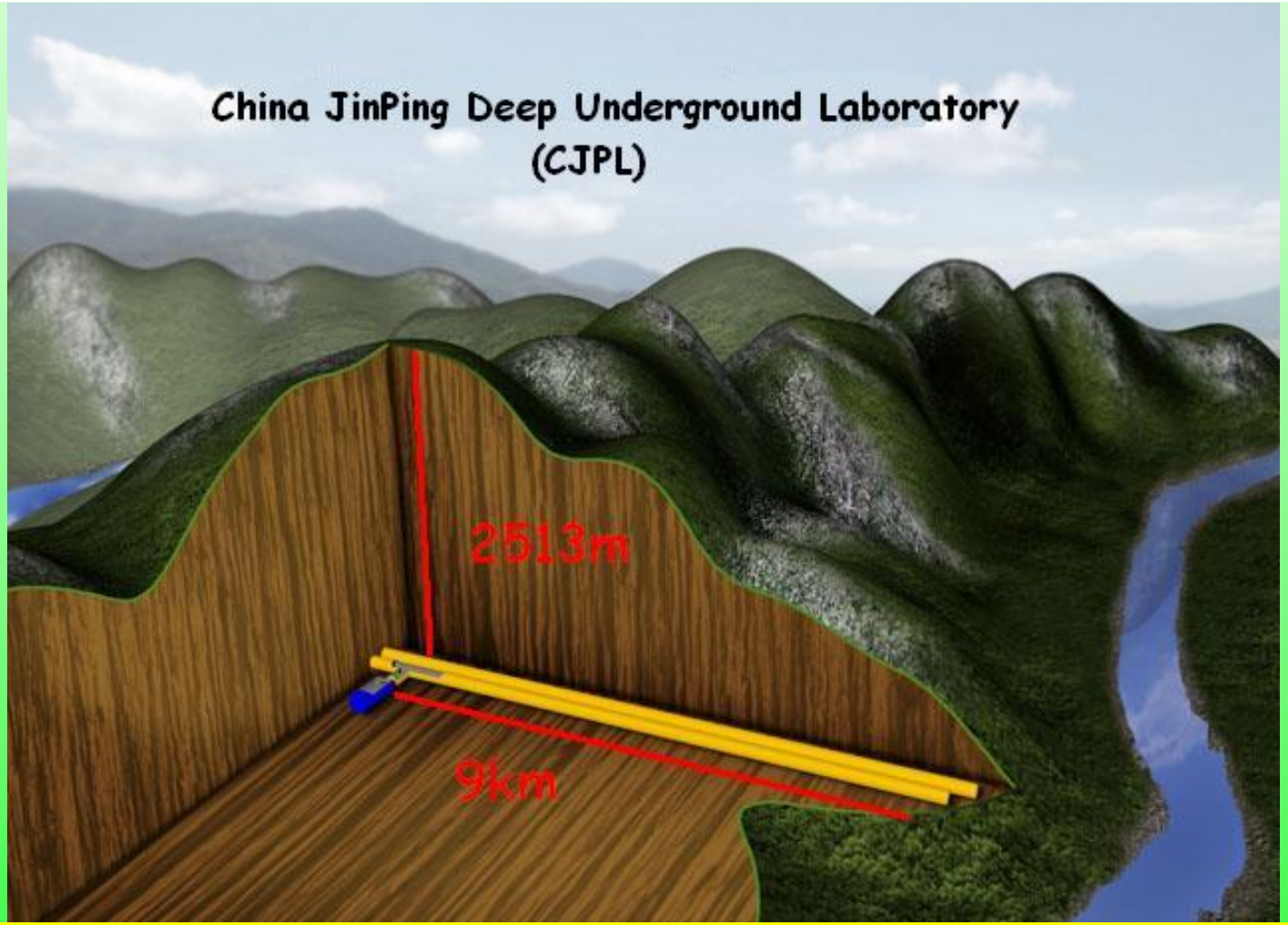
Underground Lab. Space





New Lab. Space under discussion with KHNPC

Current Lab. ~ 100m^2



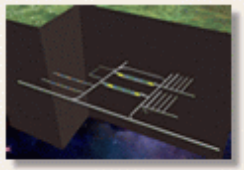
- Jinping Mountain Peak：4193m
- Maximum rock overburden: ~2500m
- Length of Jinping transportation tunnel: 17.5km
- Rock cover larger than 1500m:>70%

国家深地实验室
National Deep Underground Laboratory

Visit of CJPL

Hallway to Exp. Hall

View of Experimental Hall



国家深地实验室
National Deep Underground Laboratory

Brief history about NLAB in CAS

- 2006-2008, Propose for a National underground lab.
- Nov. 2008, CAS organized for deep underground laboratory discussion
- Feb.-Mar, 2009, support the funding application for Dark matter and Dark energy studies from government.
- Oct. 29-30, 2009 organized XiangShan workshop
- Mar. 2010, Developed underground laboratory proposal for the 12th 5 year planning, it didn't pass the last round of voting.

5 Institutions from CAS are included in the proposal:

Institute of Geodesy and Geophysics, Institute of High Energy Physics, Institute of Modern Physics, Institute of Physics and Mathematics, Institute of Rock and Soil Mechanics

India-based Neutrino Observatory (INO)

- ***Underground laboratory with ~1 km all-round rock cover accessed through a 2 km long tunnel. A large and several smaller caverns to facilitate many experimental programmes.***

- ***A 50 Kton magnetised iron tracking calorimeter will be the first detector to come up. Frontline neutrino issues e.g., mass parameters and other properties, will be explored in a manner complementary to ongoing efforts worldwide.***

- ***Distance from CERN (Switzerland) and JPARC (Japan) ~ 7000 km, close to "magic baseline" for experiments with neutrino beams in a few decade from now***

- ***Will support several other experiments when operational. Neutrino-less Double Beta Decay and Dark Matter Search experiments foreseen in the immediate future.***

- ***INO facility will be available for international community for setting up experiments.***

INO Project

- ***Construction of the underground laboratory and surface facilities.***
- ***Construction of the 50 kton magnetised Iron calorimeter (ICAL) detector to study properties of neutrinos.***

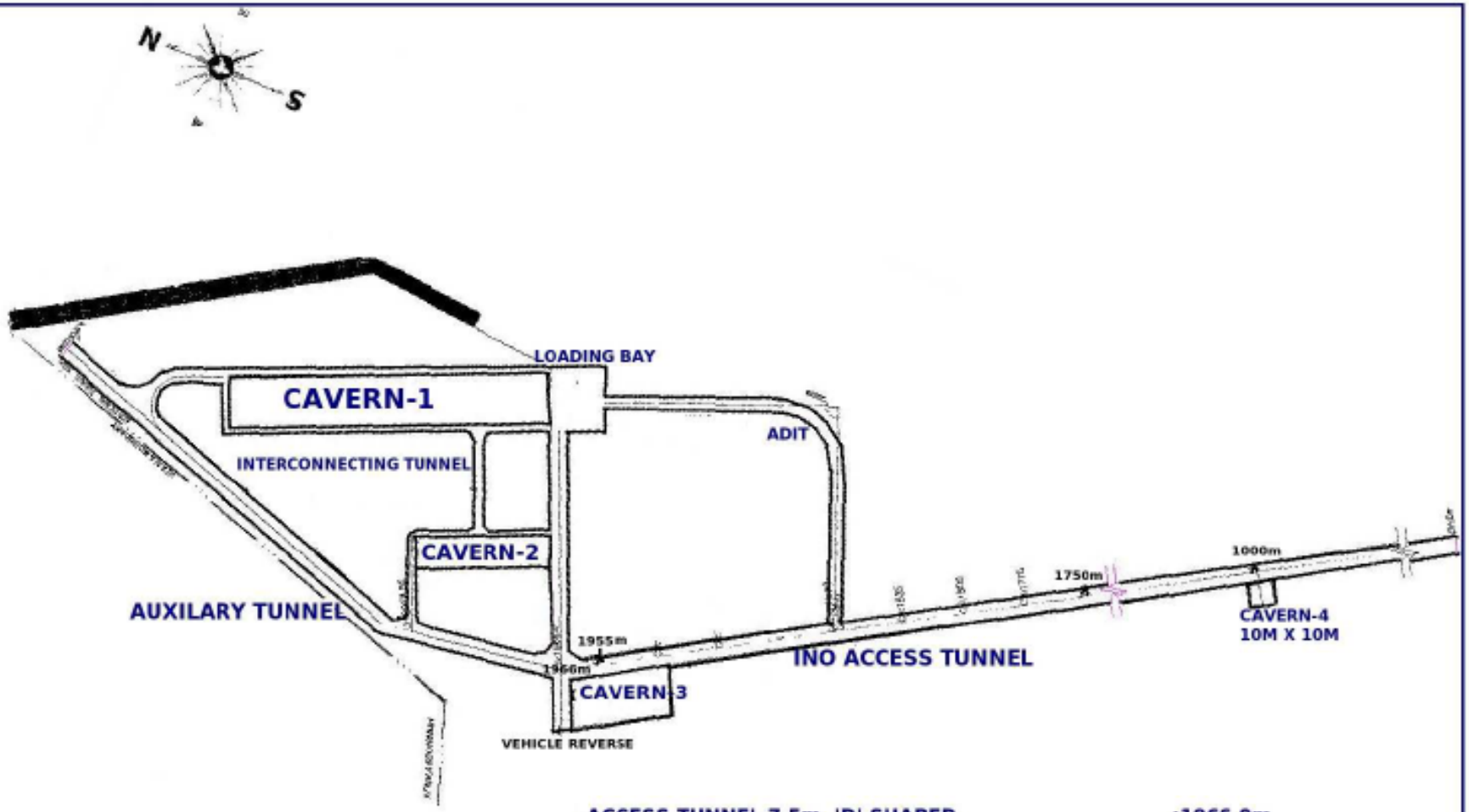
- ***Construction of the INO centre- The National Centre for High Physics (NCHEP) at Madurai, India***

Status

Environment & Forest clearances obtained.
Administrative formalities for transfer of land completed. Waiting for the transfer of land by local Government.

Projected to be completed within Six Years (2011-2017)

INO Underground Laboratory Layout

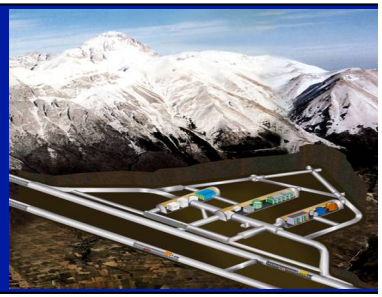


ACCESS TUNNEL 7.5m, 'D' SHAPED :1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPED: 175.4m
AUXILARY TUNNEL 7.5m 'D' SHAPED : 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPED : 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPED (future expn) : 50.0m

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

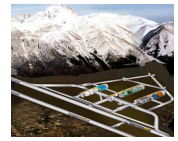
INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

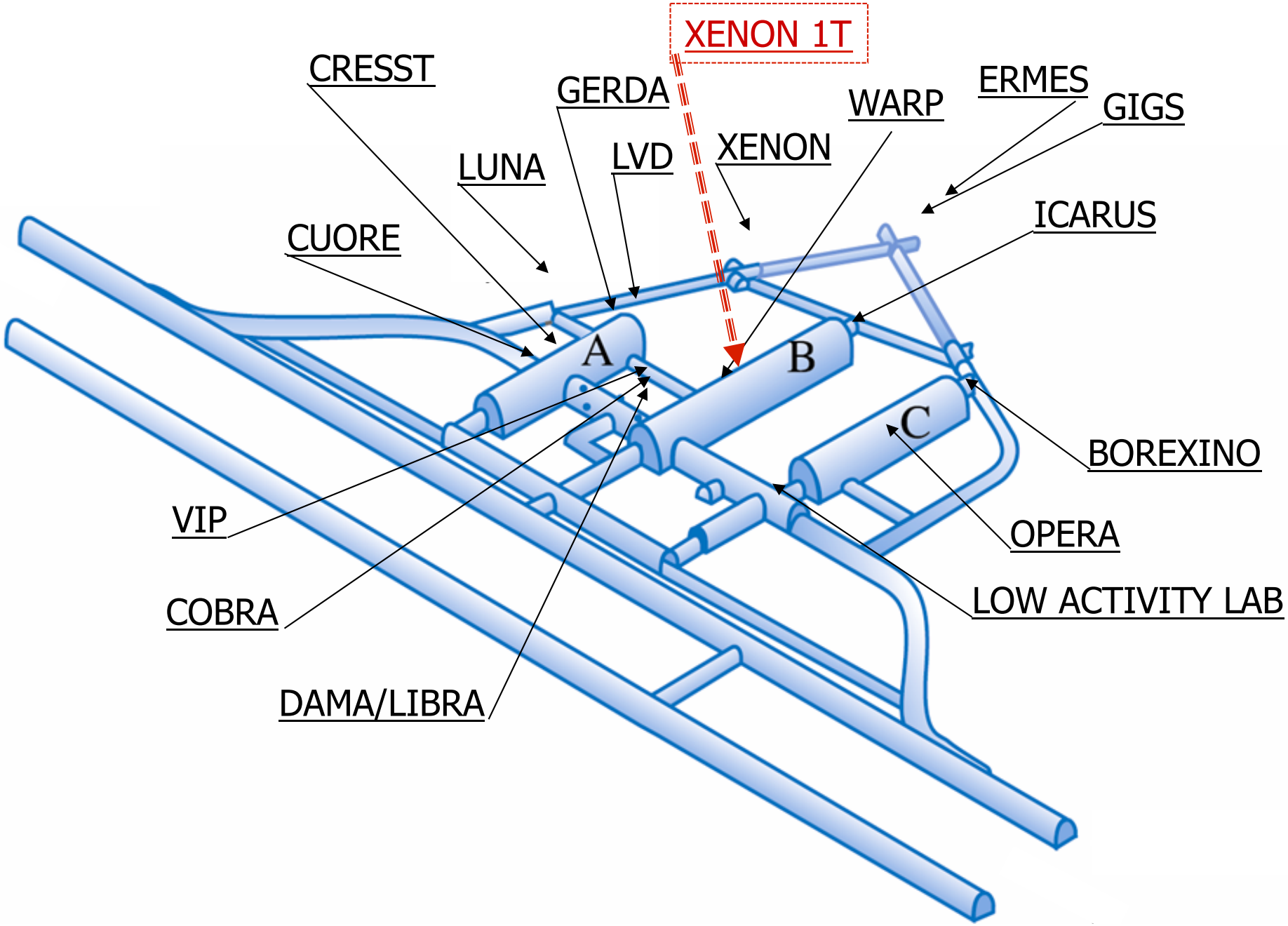
Highlights from Gran Sasso Laboratory



- **Largest** underground laboratory in the world
  - Run by **INFN** under the Gran Sasso Mountain, Italy
  - 120 km far from Rome, completed 1987
  - International scientific community (1000 users per year)
  - Permanent staff: 82 + 19 temporary positions
- **Neutrino physics**
  - Neutrinoless double beta decay
  - Solar, geo and supernova neutrinos
  - CNGS neutrinos
- **Dark matter searches**
- **Nuclear Astrophysics**
- Geophysics and environmental physics
- Biology

OCCUPANCY




XENON 1T
CRESST
GERDA
WARP
ERMES
GIGS
LUNA
LVD
XENON
ICARUS
CUORE
A
B
C
BOREXINO
VIP
OPERA
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA

Laboratoire Souterrain de Modane

Depth: 4800 m.w.e.

Surface:: 400 m2

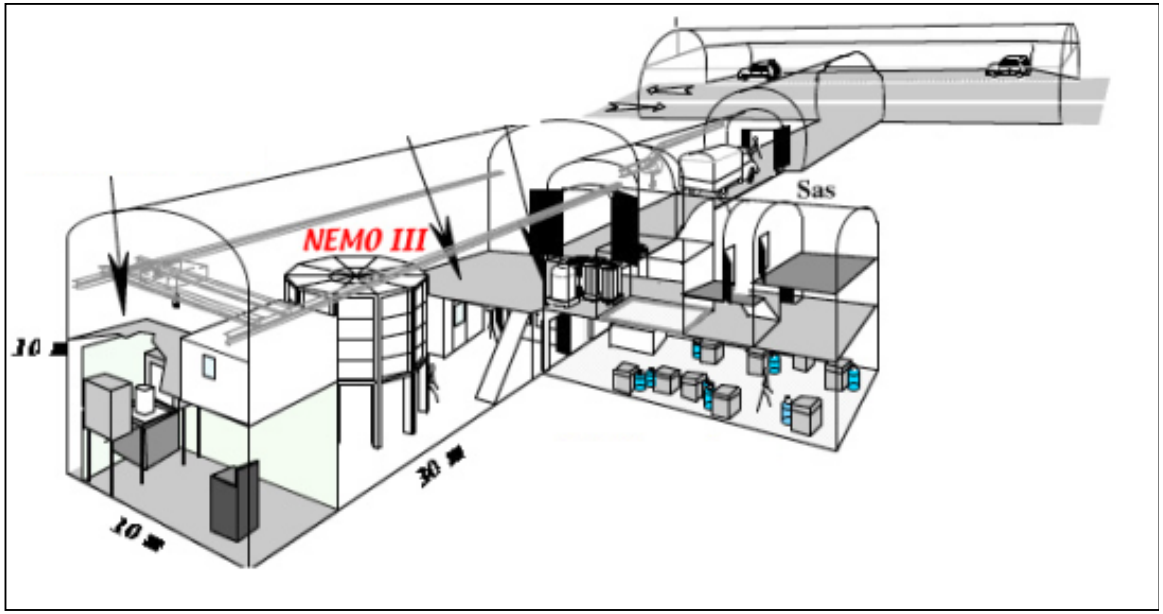
Volume : 3500 m^3

Muon flux: 4 10^{-5} $\mu.m^{-2}.s^{-1}$

Neutrons:
Fast flux: 4 10^{-2} $n.m^{-2}.s^{-1}$
Thermal flux: 1.6 10^{-2} $n.m^{-2}.s^{-1}$

Radon: 15 Bq/m^3

Access : horizontal



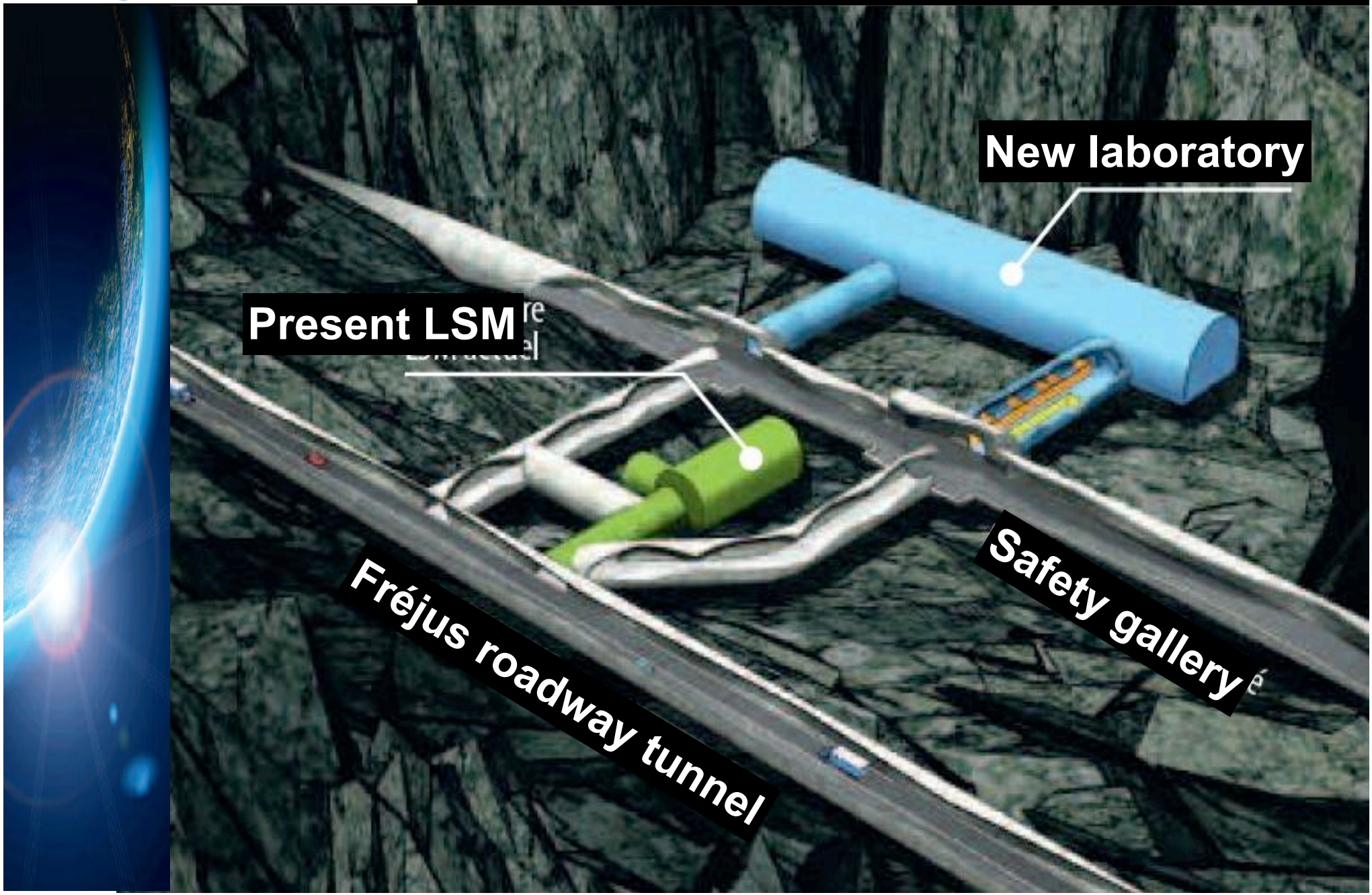
Budget (full cost): 1 M€/yr
Staff: 3 Physicists
3 Engineers
7 Technicians

~100 users

International associated laboratory agreement with
JINR Dubna (Russia) and CTU Prague (Czech Republic)

LSM ULISSE
Un autre regard sur l'Univers

LSM Extension project



LSM ULISSE
Un autre regard sur l'Univers

LSM Extension

- Safety gallery work started in October 2010

- 600 m excavated, TBM start September

- Laboratory digging end 2012

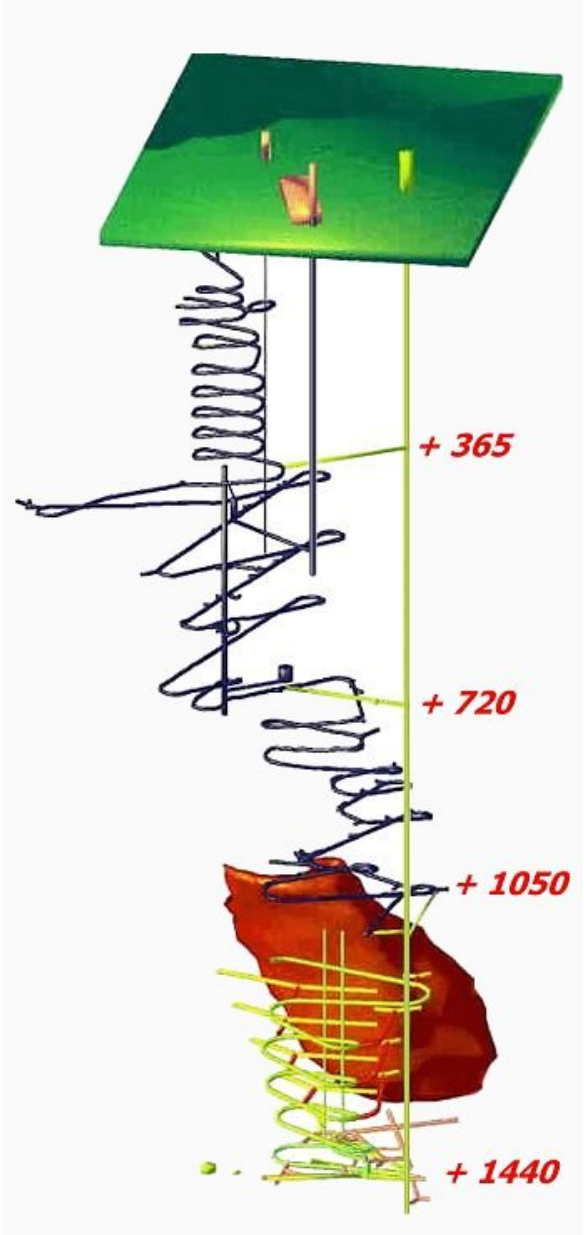
New LSM in operation mid-2014

Centre for Underground Physics in Pyhäsalmi CUPP. Finland

Old mine - Operational 1962-2001
Cavities available at several levels from 95 m to 980 m
Lab facilities may be excavated @ 1440 m, 4 km w.e.

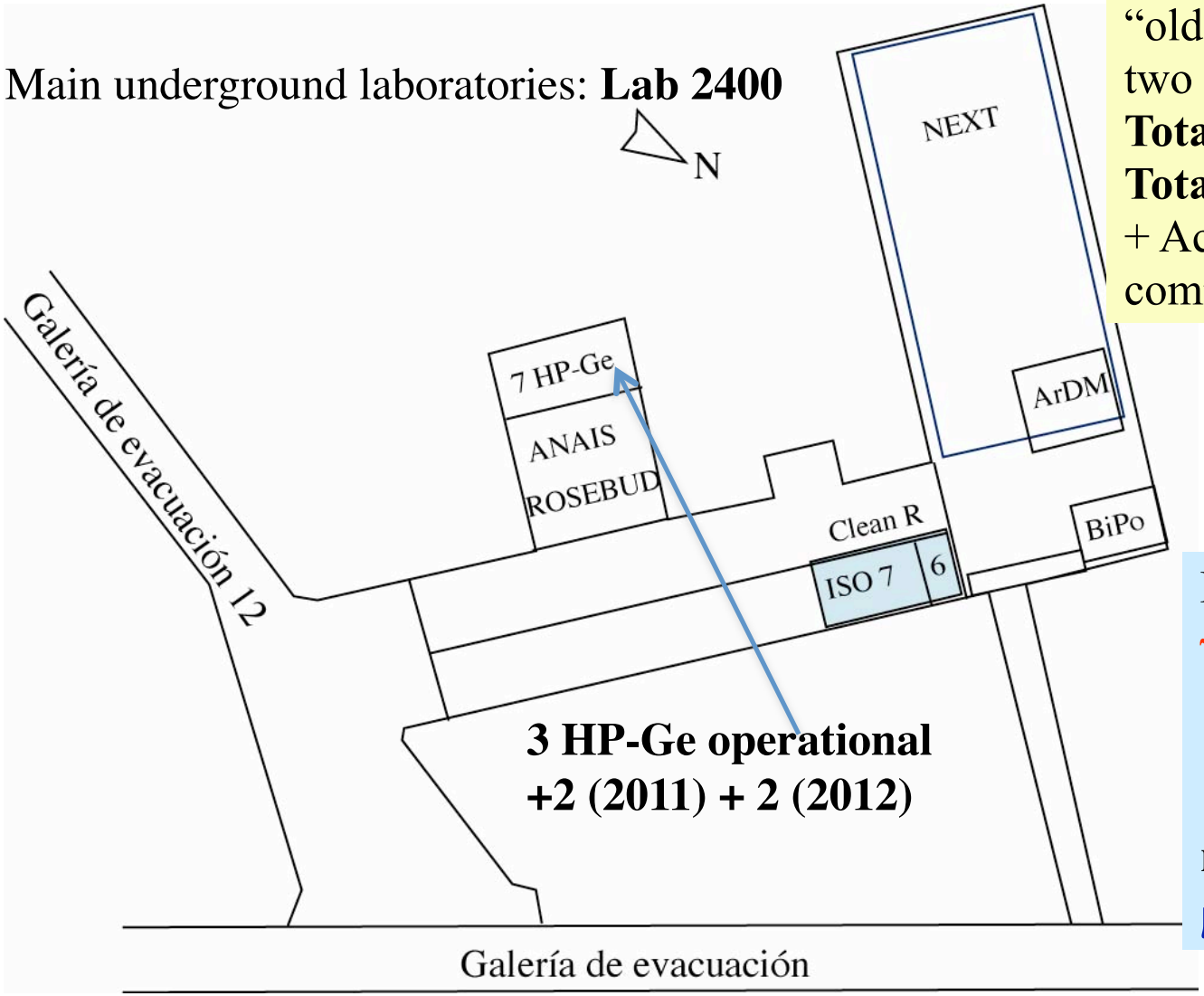
Neutron flux being measured
Personnel: 3 on site + 3 @ Oulu
Offices, labs and guest rooms on surface
Access via lifts or inclined road tunnel

EMMA experiment at 75m depth
Composition of atmospheric μ @ knee
Drift chamber and plastic scintillators



LSC. Underground structures

Main underground laboratories: **Lab 2400**



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
+ Access structures partially in common with Canfranc Tunnel

Rn activity: 80-100 Bq/m^3
γ flux:1.23±0.17 cm^{-2}s^{-1}
^{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}
n-flux & spectr. measured
μ-flux 0.47 x 10^{-2} s^{-1} m^{-2}

LSC. External building and Hall A

Headquarters & Administration
Safety and Quality Assurance
16 offices for scientific users
7 offices for LSC personnel
4 specialised laboratories
Mechanical workshop & storage room
Meeting room & Library
Conference room& Exhibitions room
2 apartments

Radio-link (64 MB/s) to RIA (Red de Investigación de Aragón)
Support personnel: 12 (+1 in 2012)
Users: 214
Visits (2011): 170

Experiments: approved and proposed

- Approved experiments (3 years running)

✓ EXP-01-2008;LoI-2009 (ANAIS)	Dark Matter (NaI, Annual modulation)
✓ EXP-02-2008;LoI-2009 (ROSEBUD)	Dark Matter (Scintillating bolometers)
✓ EXP-03-2008;LoI-2009 (BiPo)	$0\nu2\beta$ decay (Ancillary to Super-NEMO)
✓ EXP-05-2008;LoI-2009 (NEXT)	$0\nu2\beta$ decay (Enriched ^{136}Xe TPC)
✓ EXP-06-2009 (SuperK-Gd)	Material screening for SuperK Gd
✓EXP-08-2010 (ArDM)	Dark Matter (Liquid Argon TPC)

- Approved observatory

✓ EXP-07-2009 (GEODYN)	Geodynamics (Underground & surface)

-Expressions of Interest

✓EoI-12-2009 (CUNA)	Nuclear astrophysics
	New 300 m^2 facility in project

✓Part of LAGUNA project

Baksan Neutrino Observatory

Mt. Andyrchi

EAS array "Andyrchy"

"Karpet-2" EAS array

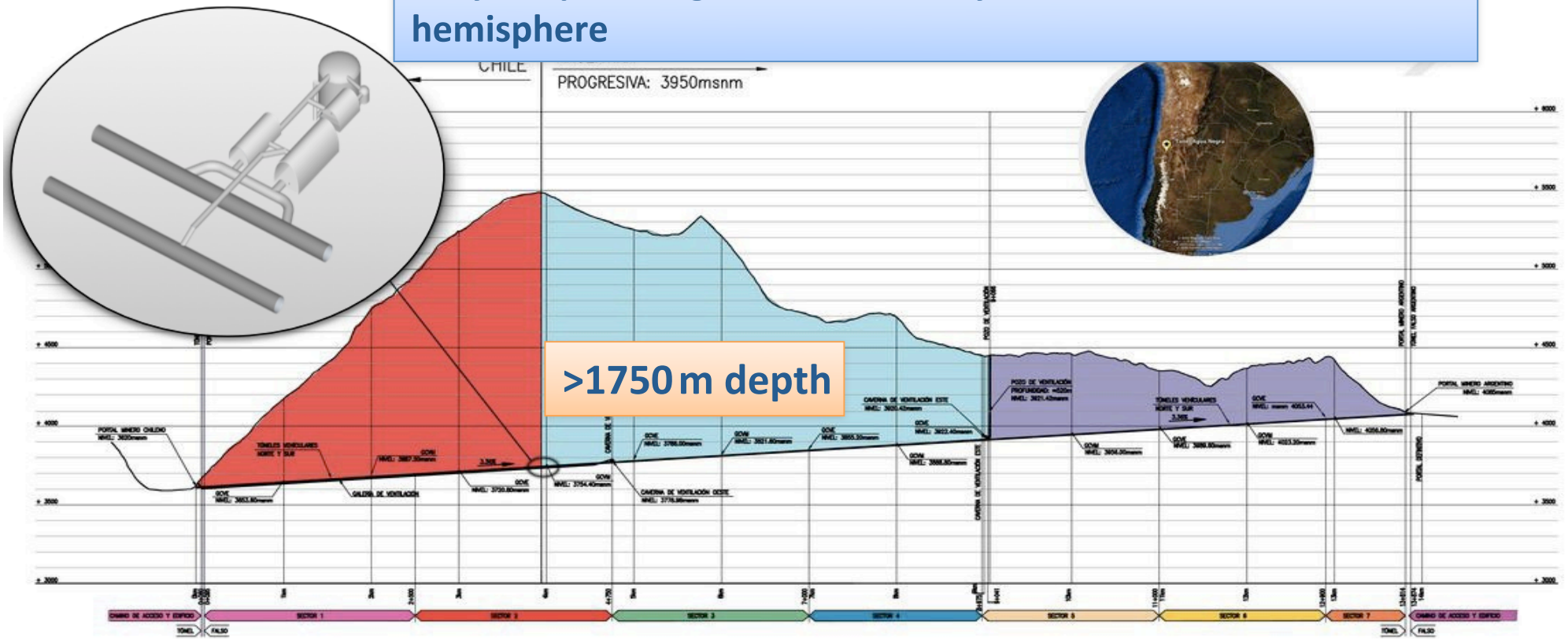
Tunnel entrance

Neutrino village

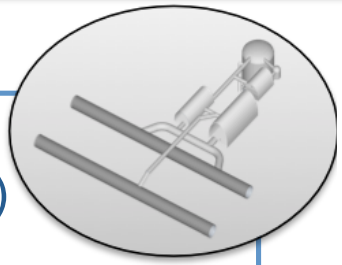
ANDES
The Agua Negra deep underground laboratory

- 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

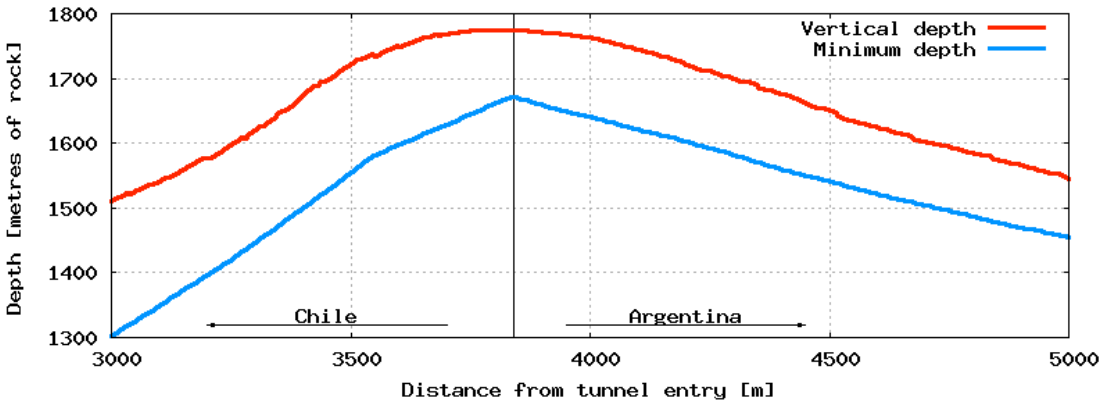
Only deep underground laboratory in the southern hemisphere



ANDES: Agua Negra Deep Experiment Site



- Main hall (21 m x 23 m x 50 m)
- Secondary hall (16 m x 14 m x 50 m)
- Offices and small lab hall
- Low radiation pit
- Large single experiment pit (~ ø 30 m, 30 m tall)



Vertical depth: 1775 m, omnidirectional: 1675 m

Rock Studies (from test samples ~600 m deep)

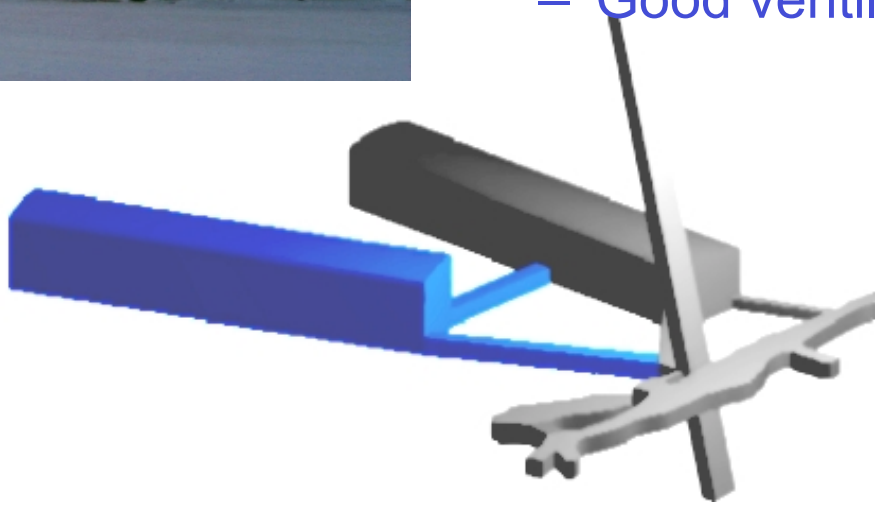
Preliminary data (Bq/kg)

	Basalt	Andesite	Rhyolite 1	Rhyolite 2
^{238}U	2.6 ± 0.5	9.2 ± 0.9	14.7 ± 2.0	11.5 ± 1.3
^{232}Th	0.94 ± 0.09	5.2 ± 0.5	4.5 ± 0.4	4.8 ± 0.5
^{40}K	50 ± 3	47 ± 3	57 ± 3	52 ± 3

- ✓ Final location to be determined once geology is known (ventilation tunnel)
- ✓ Work on White papers (lab, science)
- ✓ Proposed as a Latin American laboratory (CLES: Argentina, Brazil, Chile, Mexico)
- ✓ Open to host international experiments
- ✓ Final approval of tunnel and lab expected for within a few months

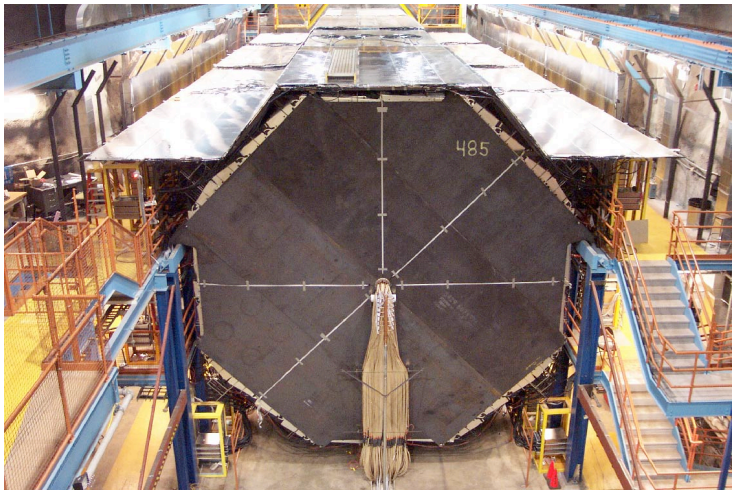
Soudan Mine Underground Lab

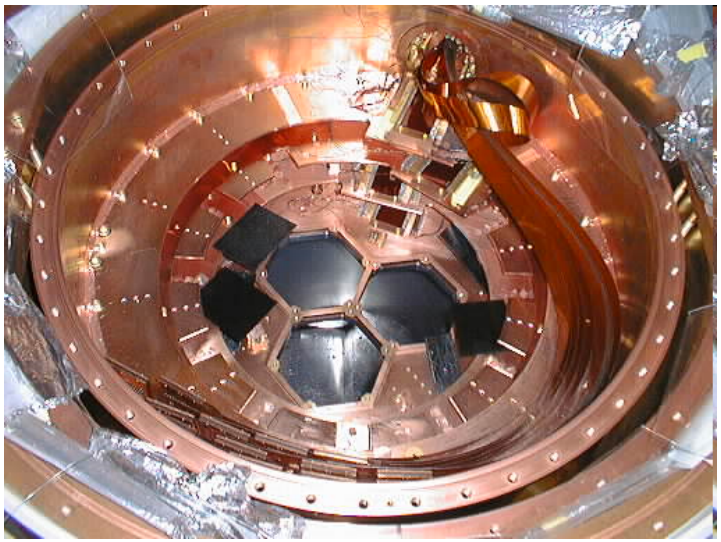
- Soudan Iron Mine has been a state historical park since the 1960's
- Soudan I proton decay experiments started the science in the 1980's
  - Soudan II, MINOS excavated new caverns
- Operated by Univ. of Minnesota, main funding from DoE via Fermilab
- 700 m (2070 mwe) deep
  - Vertical access
  - Good ventilation, low radon, strong old rock



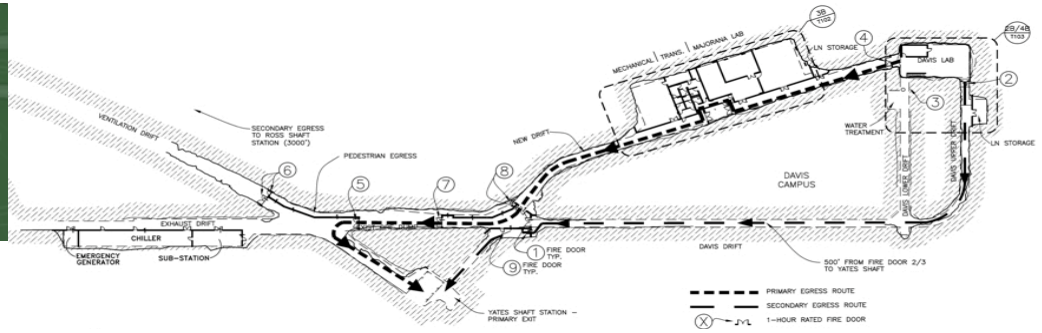
Large Experiments

- Fermilab operates the Lab's main tenants
  - So pays the vast bulk of the ~$1.2M/yr budget
- MINOS will run through March 2012
  - Plans for "MINOS+" extension well received (~2016?)
- CDMS will run through 2013
- Lab is active, open for business, and fills a need complementary to DUSEL

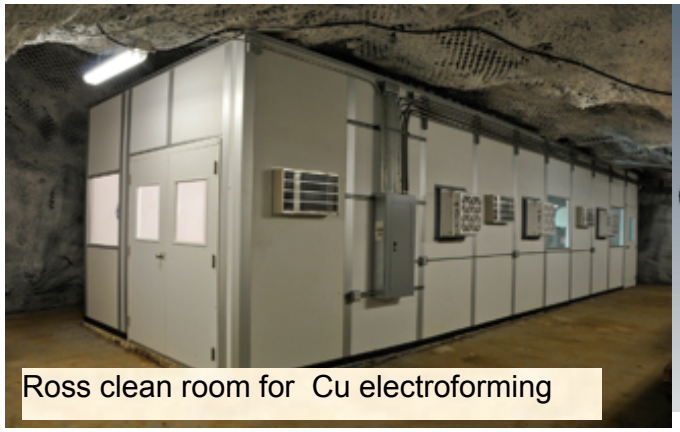




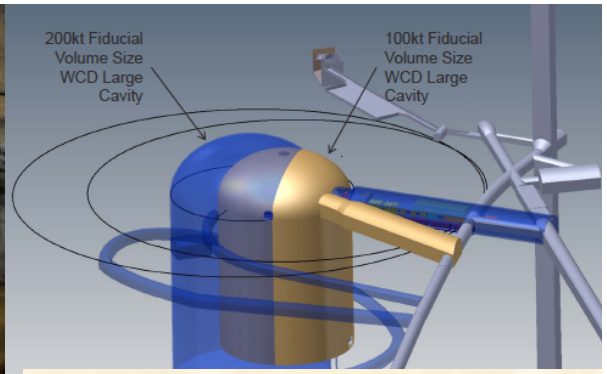
Sanford Underground Research Facility



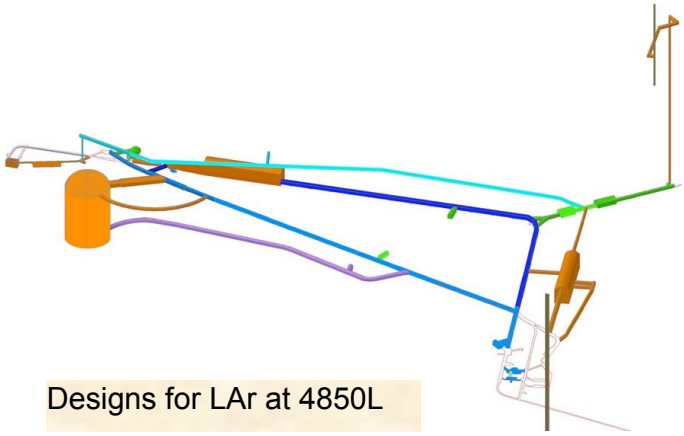
- Davis Campus will begin installing experiments in winter 2011/2012
- Director William Brinkman at the DPF Conference directed US's efforts in Dark Matter and Neutrinoless Double Beta Decay to stay focused on Homestake (LUX and Majorana Demonstrator)
- Geotechnical site investigations and Conceptual design of 200kt Large Cavities advancing well - confidence in constructability of 65m dia. cavity
- Siting of LAr at 4850L advancing well - cost and schedule neutral to a shallower site which would enhance the LBNE physics program



Ross clean room for Cu electroforming



Designs for 200kt WCD at 4850L



Designs for LAr at 4850L

DUSEL Deep Underground Science and Engineering Laboratory

Plans B (and C) at the Sanford Lab (reduced scope options for DOE Physics Experiments)

- Reduce Facility Scope to safely support:

– LBNE 4850L (or 800L)

– Early Science in the Davis Campus (DLM, DTA) (LUX, MAJORANA DEMONSTRATOR, and perhaps a G2 Dark Matter Experiment, some Low Background Counting (CUBED))

– A single Laboratory Module (LM) at 4850L or 7400L supporting either/both

  - a single G3 Dark Matter experiment
  - a 1 tonne-scale neutrinoless double beta decay experiment

- Facility Design

– Single Laboratory Module & LBNE

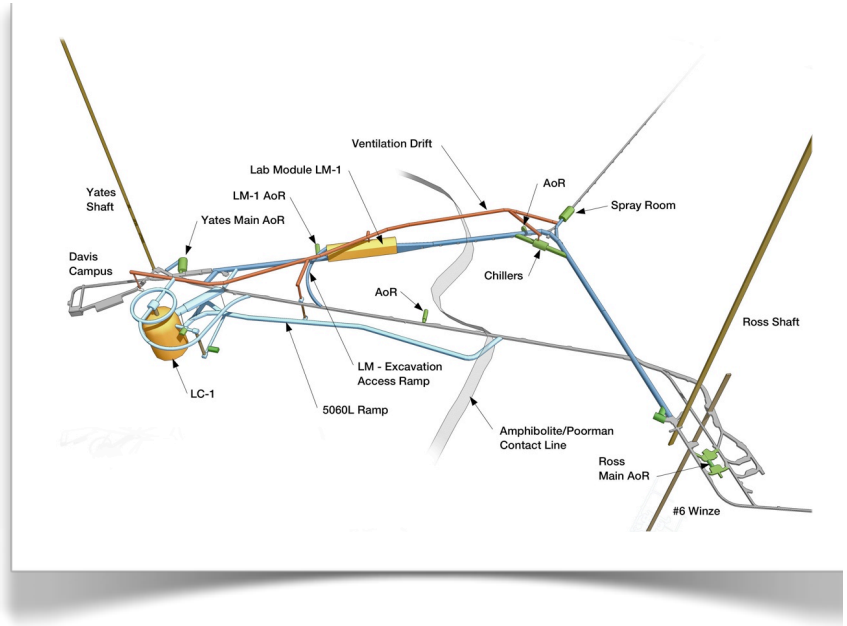
– Safe, redundant, but not-significantly modified, access

– Preserves options for deeper LMs, additional LMs, and facility improvements

– Sanford supported Education & Outreach on the surface

– Preserves option for NSF participation in the science

  - 2nd DM experiment
  - Nuclear Astrophysics Facility and LM
  - participation in Long Baseline Neutrinos and/or Proton Decay, Neutrinoless Double Beta Decay
  - Biology, Geology, & Engineering program as self-sufficient efforts



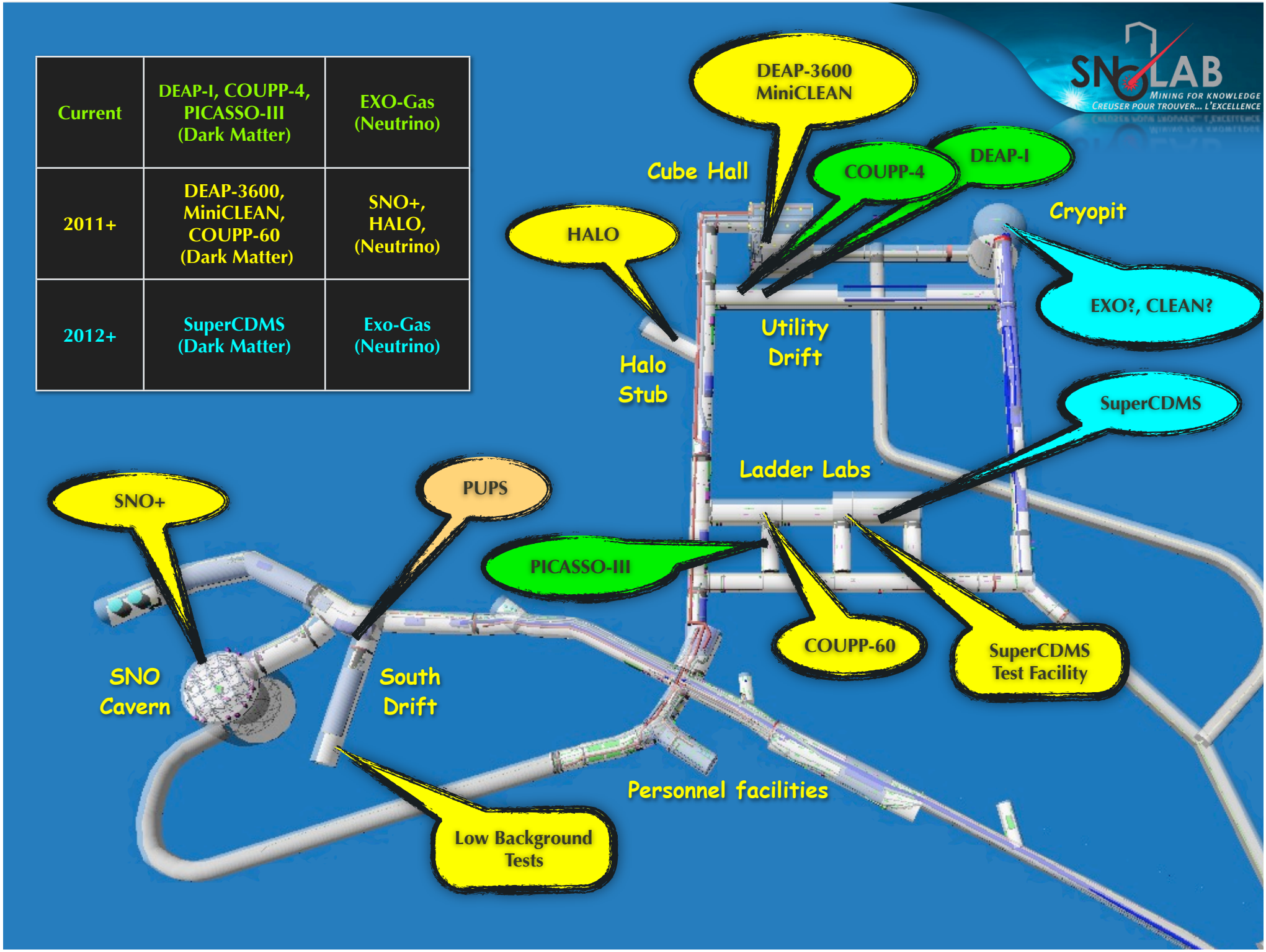
DUSEL Deep Underground Science and Engineering Laboratory

SNOLAB Overall Status

- Surface Facility (3100 m^2)
  - Operational from 2005 - Provides offices, conference room, dry, warehousing, IT servers, clean-room labs, detector construction labs, chemical + assay lab
  - 440m^2 class 1000 clean room for expt setup
- Underground Construction (Cube Hall, Cryopit, Ladder Labs)
  - Phase I excavation complete and outfitting began June 2007.
  - General outfitting in Phase I areas complete 2009, final clean 2010.
  - Phase-II excavation complete June 2008
  - Phase-II integration complete March 2011, final clean completed.
  - SNO cavity, Cube Hall and Ladder Labs hosting and developing experiments.
- Experimental Programme
  - Relocation / continued operation of DEAP-1 & PICASSO-III (and EXO-gas R&D).
  - New experiment deployed: COUPP-4
  - Construction support for HALO, SNO+, DEAP-3600, MiniCLEAN
  - Current allocations to: PICASSO-III, DEAP-I, SNO+, DEAP-3600, MiniCLEAN, SuperCDMS TF, SuperCDMS, COUPP, HALO.
- Operational funding currently secured to 2013


DENKA-LIFT
United Rentals

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)

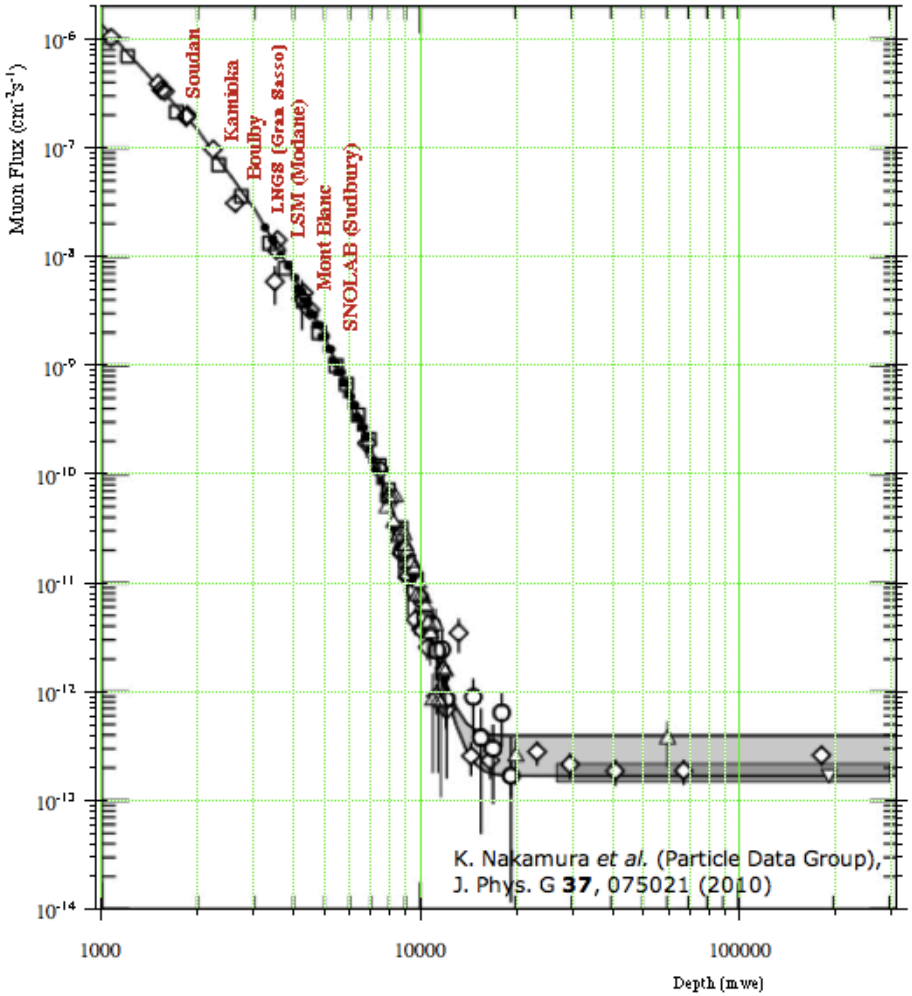


Facility Programme Summary

Site	Depth (kmwe)	Scale	Status	Access	DM	0νββ	LBL	Other ν	BGE	Nuclear Astro	Gravity
ANDES	4.5	**	Planned	H	√		√				
Baksan	4.8	*	Operational	H	√	√		√			
Boulby	2.8	**	Operational	V	√				√		
CJPL	7.0	*	Op/Planned	H	√						
CUPP	4.0	*	Planned	V*			√				
DUSEL/SUSEL	4.8/7.4	***	Op/Planned	V	√	√	√	√	√	√	
INO		**	Planned	H				√			
Kamioka	3.3	***	Operational	H	√	√	√	√	√	√	√
LNGS	3.5	***	Operational	H	√	√	√	√	√	√	
LSC (Canfranc)	2.4	**	Operational	H	√	√			√		
LSM (Modane)	4.8	**	Operational	H	√	√					
SNOLAB	6.0	***	Operational	V	√	√		√	√		
Soudan	2.3	**	Operational	V	√		√	√			
Y2L	2.3	*	Operational	H	√						

When is 'deep enough'?

- Current generation experiments well served by current facilities and backgrounds achievable
- Additional shielding available from c.r's
  - Three orders magnitude suppression from current deepest labs
  - Limited by upward-going muons from neutrino prod.
- If 3G++ systems require greater depth then challenge for facilities
  - But not unsurmountable



Facility developments

- Several expansions of deep underground facilities completed, in construction or well progressed in planning

Site	Size	Status	Available
Kamioka	+ $5.5 \times 10^3 m^3$	Complete	2008
SNOLAB	$3 \times 10^4 m^3$	Complete	2009
LSC	$8 \times 10^3 m^3$	In Construction	2010
SUSEL	$>3 \times 10^4 m^3$	In Construction	2010
CJPL	$1.7 \times 10^3 m^3$	In Construction	2011
Yangyang	$1.6 \times 10^4 m^3$	In Construction	2011+
LSM	$4 \times 10^4 m^3$	Planned	2013
DUSEL	$>10^5 m^3$	Planned	2015
ANDES	$7.5 \times 10^4 m^3$	Planned	2017
Baksan	$4 \times 10^4 m^3$	Planned	Under Discussion

Outlook

- Deep underground sites provide the required infrastructure for low background dark matter, neutrino and additional science programmes
- These physics programmes provide rich fields of study over the next decades
  - Complementary to other search/study techniques
  - Breadth of scale in detectors and infrastructures provides a wide portfolio of projects for physics and training
- Expansion of several deep underground facilities world-wide is completed, underway or well advanced in planning
  - Providing significant additional space world-wide in near to long term
- Exciting discoveries lay ahead!