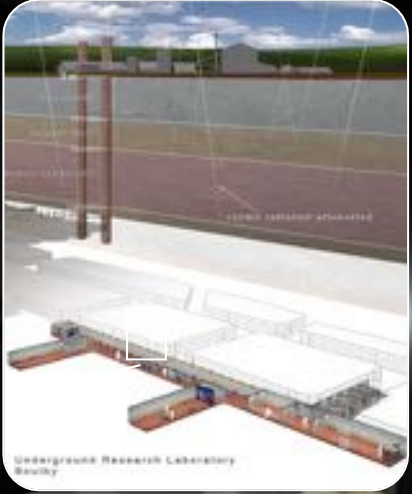


Developments in the World's Deep Underground Laboratories



Sean Paling
STFC Boulby Underground Science Facility



Developments in the World's Deep Underground Laboratories

Overview of status & future plans of (some of) the world's underground facilities...



Europe

- Gran Sasso
- Modane
- Canfranc
- Boulby

Asia

- Kamioka
- Jinping
- Yangyang
- INO
- JUNO

North America

- SNOLAB
- SURF
- Soudan
- WIPP

Southern Hemisphere

- Andes
- Stawell

Lots going on. Many and varied science projects and laboratories progressing and emerging.



Deep Underground Science

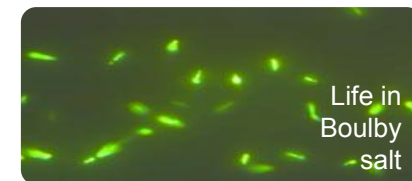
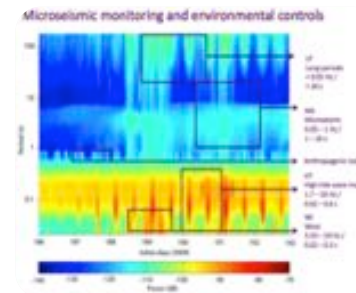
Low Background Particle / Astroparticle Physics

- Atmospheric, solar & supernova neutrinos
- Reactor and accelerator neutrinos
- Neutrino-less double beta decay
- Direct dark matter searches
- Nuclear astrophysics / stellar reactions
- Misc. rare-decay processes



Other 'Multi-disciplinary' studies

- Cosmic rays studies
- ULB Gamma counting & spectroscopy
- Misc. Geology/geophysics
- Geo-microbiology & life in extreme environments
- Astrobiology
- Etc...





What Makes a Good Underground Laboratory?

Low Backgrounds...

Cosmic ray Muons...

- Deep underground facilities provide rock overburden & commensurate reduction in c.r. flux, & c.r.-spallation induced products (neutrons)

Neutrons...

Production from

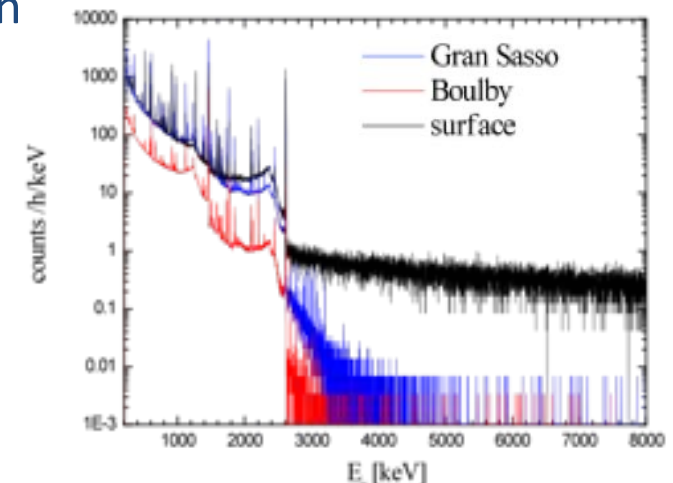
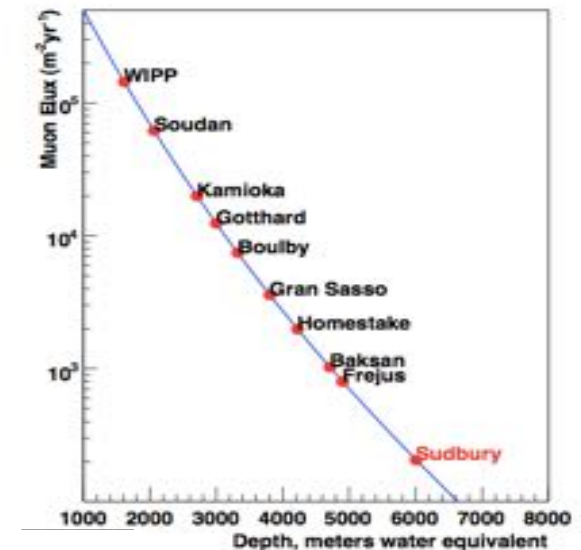
- c.r. muon spallation
- U/Th fission
- α , n reactions

Radon....

- Dependent on local geology & ventilation

Gammas....

- Reduction in γ -ray background at higher energies from c.r. and neutron reduction
- Below 3.5MeV dependent on local geology





What Makes a Good Underground Laboratory?

Other Factors

Science and operations support:

- Good surface & underground infrastructure & support facilities
- Good Health & Safety and security systems for underground use
- Scientific support personnel: design, construction, operation/analysis
- Ancillary science support facilities: low background assay
- Infrastructure support and personnel: workshops, chemical labs, IT etc.
- Reliable utilities: power, ventilation, heat management, water, gases/liquids

‘A hole in the ground is not a facility’

Other Facility Characteristics:

- Size (monolithic or distributed; Space available)
- Ease of Access (vertical or horizontal); Max installation size limitations
- Location (neutrino flux from beam, reactor, Earth, ease of access, quality of life)
- Cleanliness and radiological interference
- Suitability of geology etc

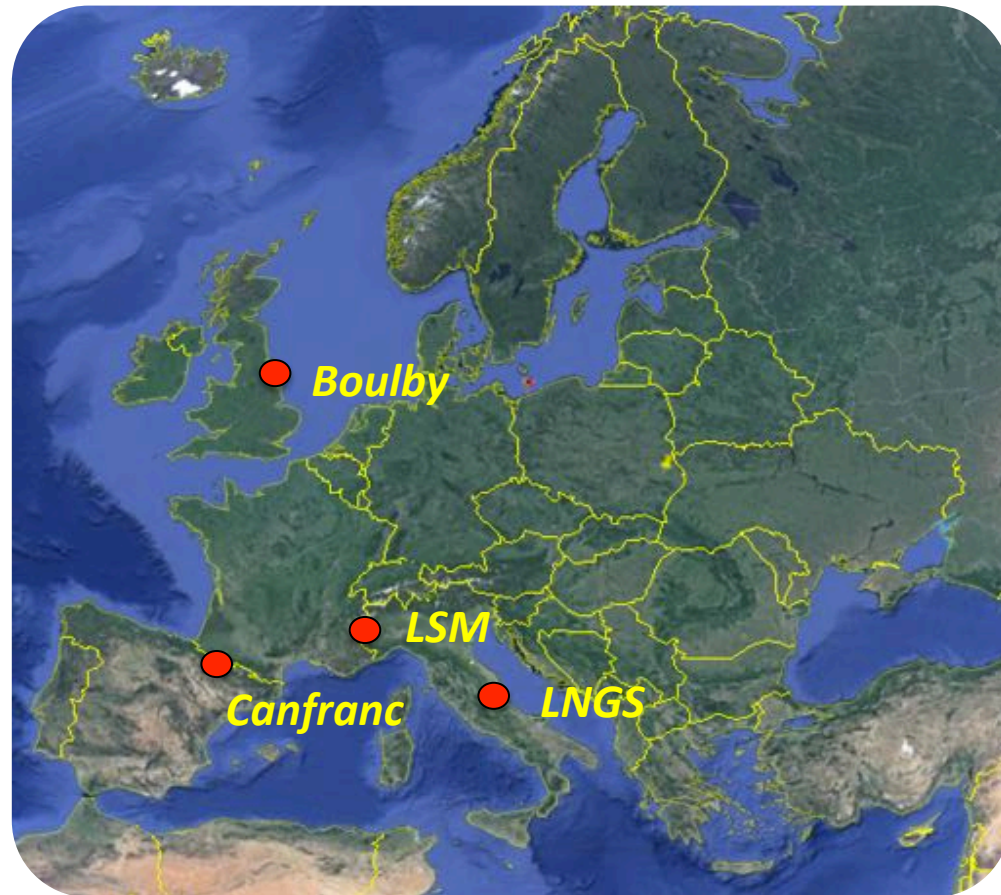
Local Politics & funding: multi-year budgets, solid host nation support, local support/engagement in the facility and the science.



РЯВКЯМКА

European Labs

- *Boulby*
- *Modane (LSM)*
- *Canfranc*
- *Gran Sasso (LNGS)*



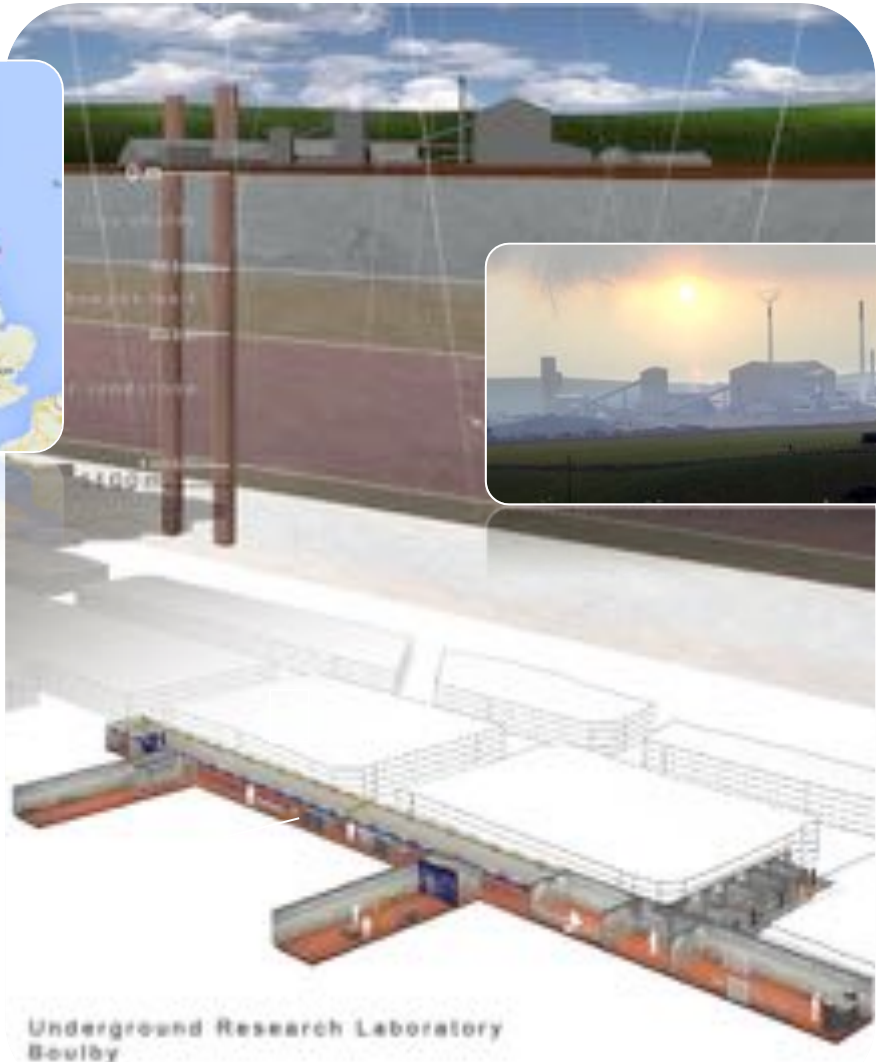


Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL

1.1km depth (2805 mwe).
Cosmic ray muon flux reduced by factor ~1 Million



Boulby Palmer lab. >1000m² floor space.
Operating since 2001

S.M.Paling - Boulby@stfc.ac.uk

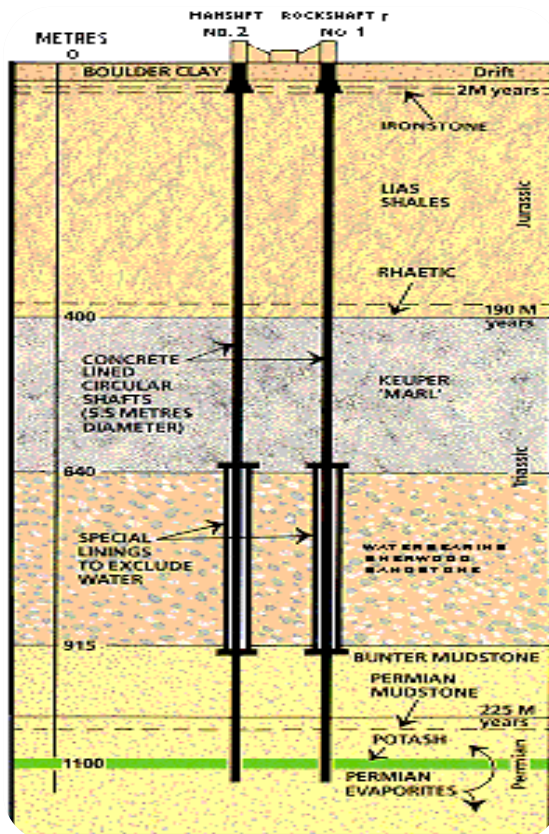




Boulby Geology & Mining

Excavations are in Salt (NaCl) & Potash (KCl) Permian evaporite layers left over from the Zechstein Sea.

Over 40 kms of tunnel mined each year (now >1,000kms in total), the long-lived roadways being cut in the lower NaCl layer.



Boulby Geology

U: 67 ± 6 ppb
 Th: 125 ± 10 ppb
 Low γ & n backgrounds
 Low Rn (<3 Bqm⁻³)

Rock-Salt



Potash

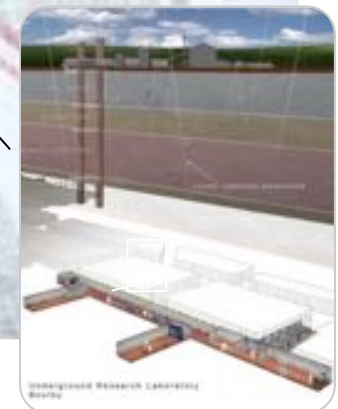


Typical Boulby Salt Roadway



Boulby Mine

Mine Shafts



Palmer Lab



Underground Science @ Boulby Mine

- DRIFT: Directional Dark Matter Search
- DM Ice: NaI(Tl) Dark Matter detector
- Ultra-low background material screening
- Deep Carbon: Muon Tomography for CCS (etc)
- ERSaB: Environmental gamma spectroscopy
- BISAL: Geomicrobiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Misc. Geology / Geoscience
- Misc. Low-background support projects
- Etc... (More to come).

A growing **multi-disciplinary** science programme:
from astro-particle physics to studies of geology,
climate, the environment, life on Earth & beyond.

S.M.Paling - Boulby@stfc.ac.uk



Science & Technology
Facilities Council





Boulby Dark Matter Studies

Boulby has hosted Dark Matter search studies for two decades. Including the NAIAD, DRIFT & ZEPLIN experiment programmes.

Boulby now hosts two on-site dark matter studies (**DRIFT & DM-Ice**) & provides ULB material screening for other studies, inc **LUX-ZEPLIN**

ZEPLIN: *The world's first 2-phase Xenon dark matter detector (Finished 2011)*



ZEPLIN-III @ Boulby

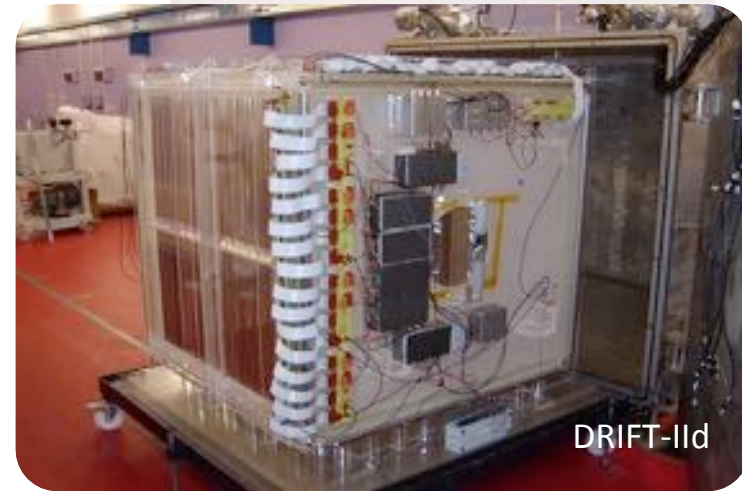


DM-Ice



DM-Ice

Wisconsin, Yale, FNAL, Illinois, Alberta, Sheffield, Boulby



DRIFT-II d

DM-Ice: 250kg NaI(Tl) array for studying WIMP annual modulation

DRIFT: Negative Ion drift low pressure TPC **directional** dark matter detector

Occidental College, New Mexico, Colorado State, Hawaii, Wesley Coll. Sheffield, Edinburgh, Boulby



Expanding Multi-Disciplinary Studies



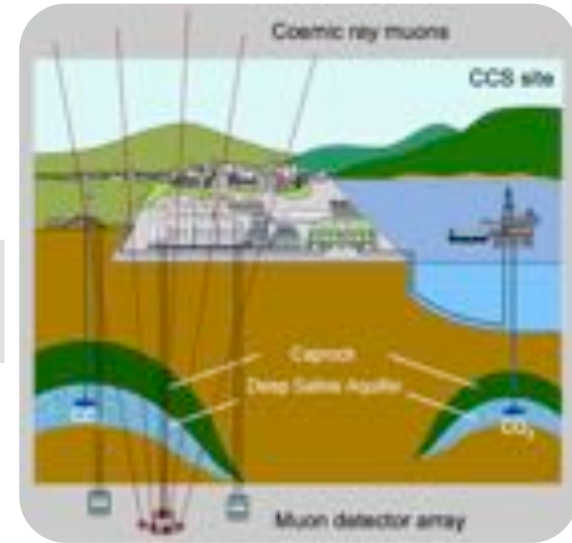
ERSaB: Gamma spectroscopy & low background counting environmental radioactivity studies

Boulby, Scottish Universities Env. Research Ctr (SUERC)



DEEP-Carbon: Muon Tomography for deep geological mapping applications including CCS

Boulby, Durham, Sheffield, Bath, Premier Oil, CPL.



From astrophysics to climate, geology, the environment, life on Earth & beyond...



S.M.Paling - Boulby@stfc.ac.uk

MINAR: Space Technology Development

Boulby, Edinburgh, NASA, DLR, CPL etc.

Plus Misc. Geology & Geoscience (& more to come)...



BISAL: Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond



How does Boulby compare?

“A hole in the ground does not make a science facility”

What Makes Boulby Special?

Requirements for an underground laboratory... 1.1 km deep (2.850±0.20 mwe)
CR muons attenuated by $\sim 10^6$
(3.79 ± 0.15) $\times 10^{-8}$ cm⁻² s⁻¹

- Low Backgrounds**
 - Deep (to shield from cosmic rays)
 - Low background rock/lab (and/or adequate shielding)

Salt = low in U/Th (67±5/125±10ppb)
→ Low gamma & neutron backgrounds
→ Low Radon (<3Bq/m³)
- Plenty of Laboratory space**

>1000 m² existing lab space & excellent potential for expansion.
- Easy access for equipment**

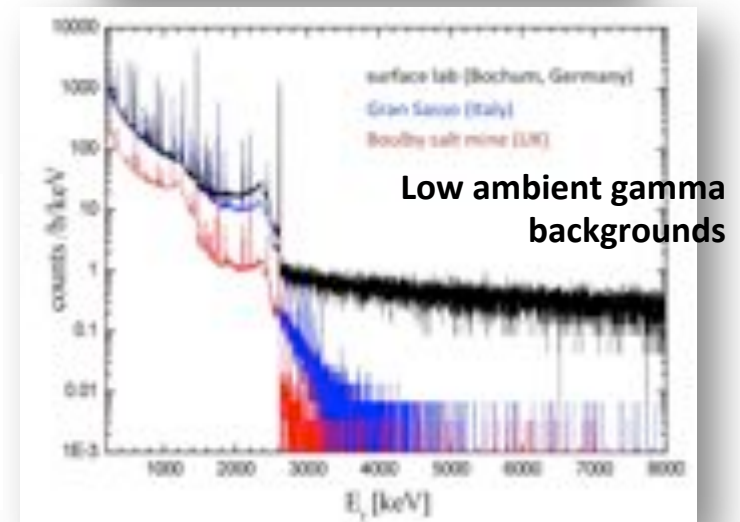
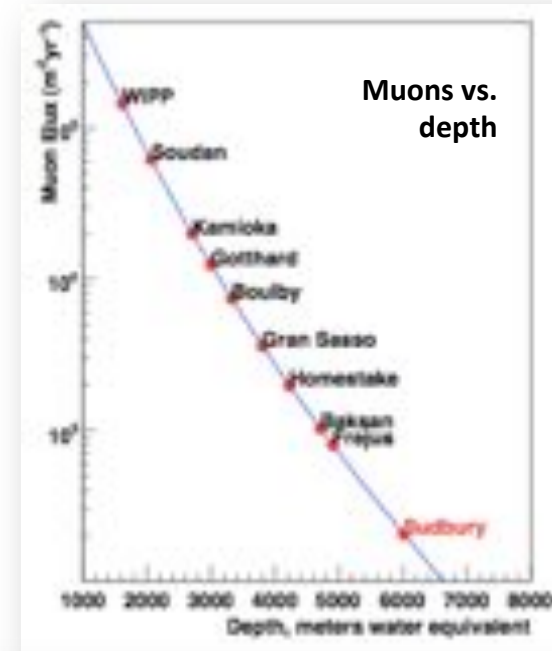
Via mine shaft (5m diam. – 2×2×2m cage)
+ Transport underground
- Proximity of services / civilisation**

20 min → Whitby, Saltburn
1 hr → York, Leeds, Middleborough
< 5 hrs → London, Manchester etc.
- Good infrastructure + support**
 - JIF Underground & surface facilities
 - Wide-ranging support from mine operators (Cleveland Potash Ltd)

A unique science / industry partnership

- VERY low ambient Radon background: <3 Bq/m³
- Good location (close to cities / services)
- Interesting geology: diverse science programme
- Good potential for expansion...

S.M.Paling - Boulby@stfc.ac.uk

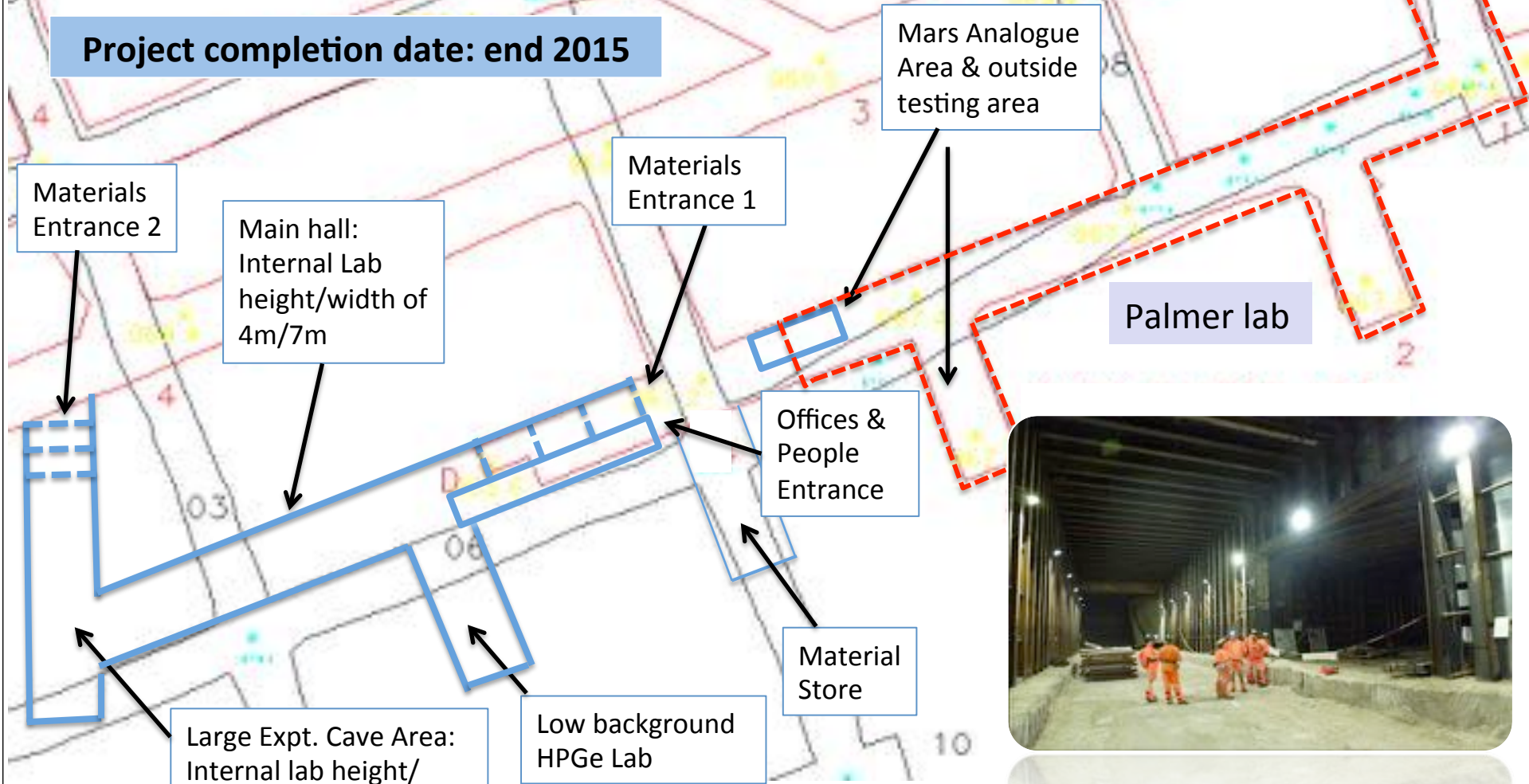


A NEW LABORATORY now being built at Boulby

To replace current facility and host **planned & new projects** for the next decade and more...



Project completion date: end 2015



Fully-equipped >5000m³ lab. Class 10K & 1K clean room throughout. 5-10T lifting capacity.



Main Hall



'BUGS' ULB Germanium Facility



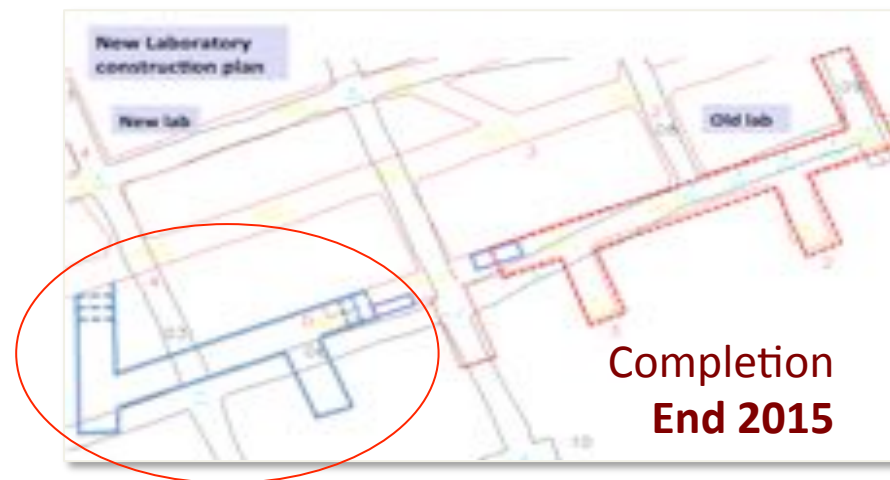
Boulby New Lab Construction
Aug 2015



Large Experimental Cavern (LEC)

Air conditioning HEPA filtration, 10 & 5 T lifting capacity.

> 5000m³ well supported class 1,000 & class 10,000 clean room experimental space



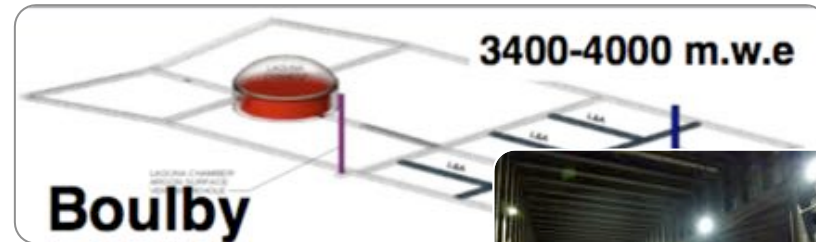
Seeking expressions of interest from new projects early 2016



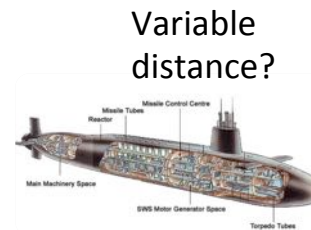
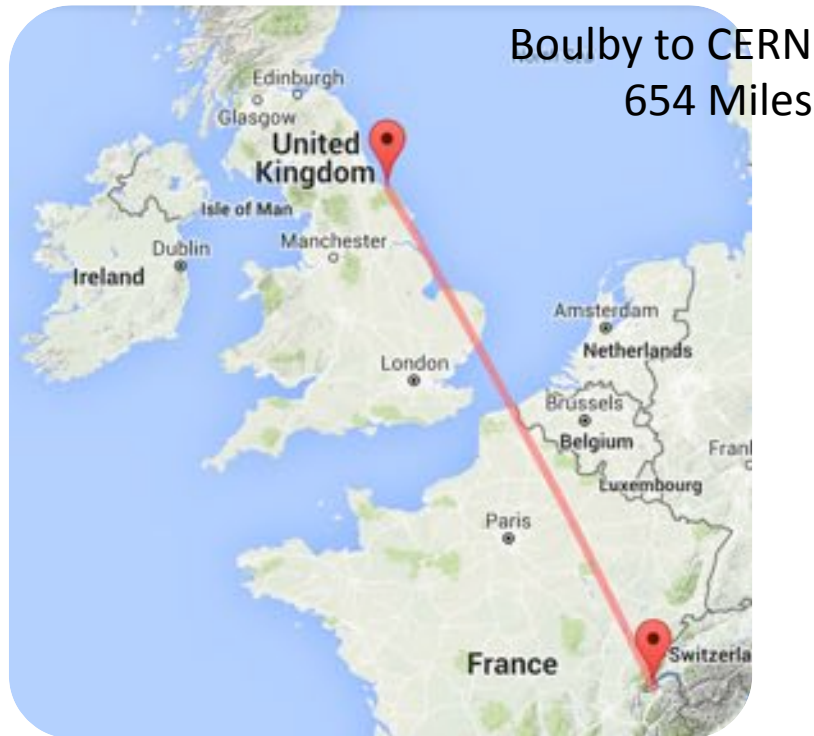
Boulby & Neutrino Studies?

Potential for futures studies....

- **0νBB decay?**
- **Atmospheric, Solar and SN neutrinos?**
- **Long baseline neutrinos?**
- **Reactor neutrinos?**
- **Variable baseline?**



Large Caverns
Possible (in misc. layers)



Hartlepool power station – 18miles from Boulby
AGR reactor 2x660MW generators
Expected upgrade to 2x1.8GW





Laboratoire Souterrain de Modane

Road tunnel under Alps
between France & Italy

Access: **Horizontal**. Drive

Depth: **4800 m.w.e.**

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

Neutrons:

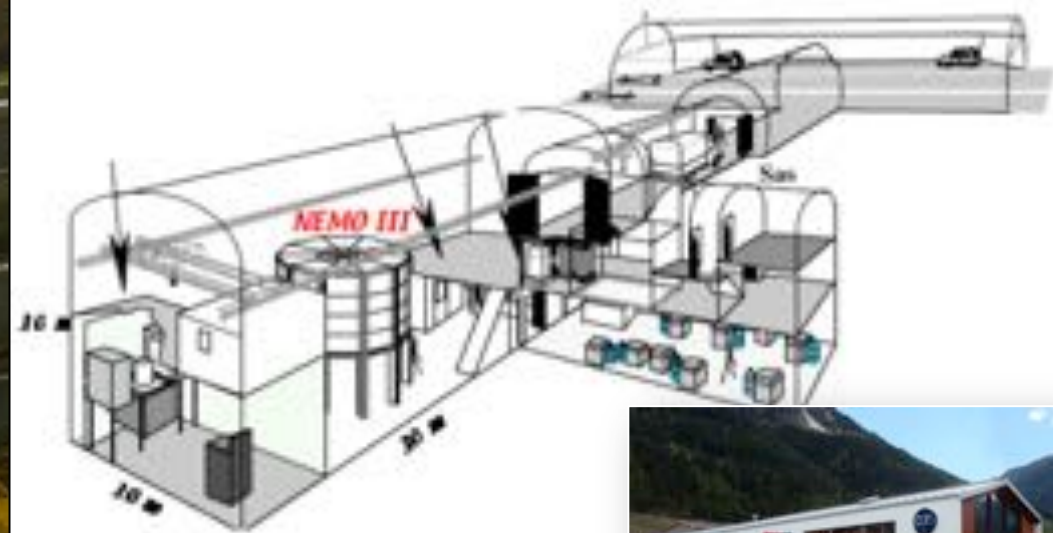
Fast flux: $4 \cdot 10^{-2} n.m^{-2}.s^{-1}$

Thermal flux: $1.6 \cdot 10^{-2} n.m^{-2}.s^{-1}$

Radon: **15 Bq/m³**

UG Lab Volume : **3500 m³**

Surface: **400 m²**



Budget (full cost): 1 M€/yr

Staff: 3 Physicists

3 Engineers

7 Technicians

150 Users, 10 countries

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



Modane UG Laboratory

From a particle physics experiment to a multi-science platform

1979 - 1981

1982- 1990

1990- 2000

2000 -



Construction

τ_p Experiment

Prototypes

Experiments

Fundamental physics:

- Neutrino: double beta decay (NEMO3->SuperNEMO)
- Dark matter (EDELWEISS, SEDINE, MIMAC)
- Nuclear structure (TGV, SHIN)

Multidisciplinary activities

- Ultra low radioactivity measurements
Environmental sciences, applications, expertises
- Logical test failures in nano/micro-électronics
- Biology



LSM Extension Project: DOMUS

DOMUS extension project 14 000 m³ (X4 present LSM)



Proposed New Cavity:
Length 40 m, width 18 m,
height 16 m . 12,000m³
(4x current lab)

Proposed work to be undertaken in
conjunction with funded (nearly complete)
excavation of new roadway

Detailed studies funded by Savoie departement
and Rhone-Alpes Region
Agreement from Ministry and CNRS for the
project
Funding almost secured (85% already obtained
CNRS, Region Rhone-Alpes, FEDER funds)





Laboratorio Subterráneo de Canfranc

Horizontal access
laboratory in road and rail
tunnel between Spain &
France

Overburden: ~ 2450 mwe
Muon Flux: $2 \times 10^{-3} \text{ m}^2\text{s}^{-1}$
Neutrons (>1 MeV): $3.5 \times 10^{-3} \text{ m}^2\text{s}^{-1}$
Radon: 50-100 Bq.m⁻³

UG Lab vol: 10,000m³
Personnel: 10
Budget: ≈ 1.6 M€/yr
Users: 275 (19 countries)





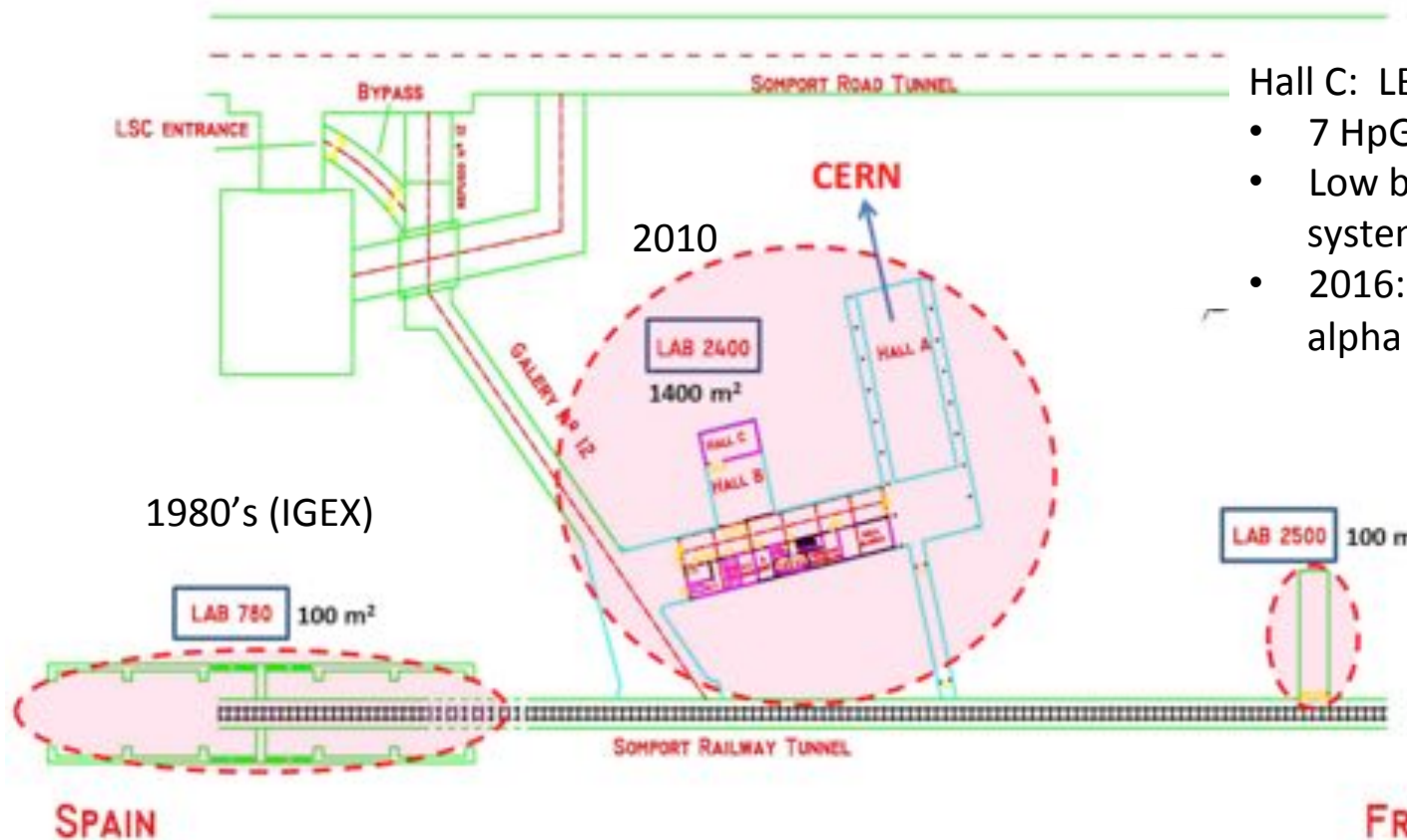
LSC Underground

Two main Halls

- Hall A (length: 40 m, width 15 m, height: 12 m)
- Hall B (length: 15 m, width 10 m, height: 8 m)

Total Volume: 10,000 m³

Hall A



Hall C: LB Screening facility:

- 7 HpGe with a few mBq/kg
- Low background α/β counting system
- 2016: SAGe well detector & an alpha spectrometer





LSC Experiments

- Experiments:

- ✓ **ANAIS** DM (NaI, Annual modul.)
- ✓ **ArDM** DM (2phase Ar TPC) 800 kg
- ✓ **NEXT** $0\nu 2\beta$ (Enr ^{136}Xe gas TPC)
- ✓ **BiPo** $0\nu 2\beta$ (screening for S-NEMO)
- ✓ **SuperK-Gd** Ge screening for Super-K-Gd
- ✓ **GEODYN** Geodynamics, seismic studies

-Expressions of Interest

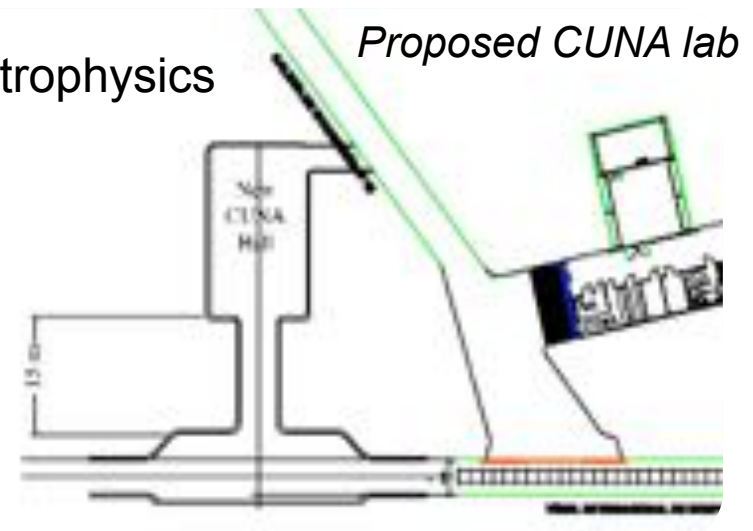
- ✓ **CUNA** 3MeV accelerator for nuclear astrophysics
- ✓ **GOLLUM** Subterranean bacteria studies

Lab Space available....

1/3 of Hall A, 1/2 of Hall B

New 2300m³ lab proposed for CUNA
(2016-2020?)

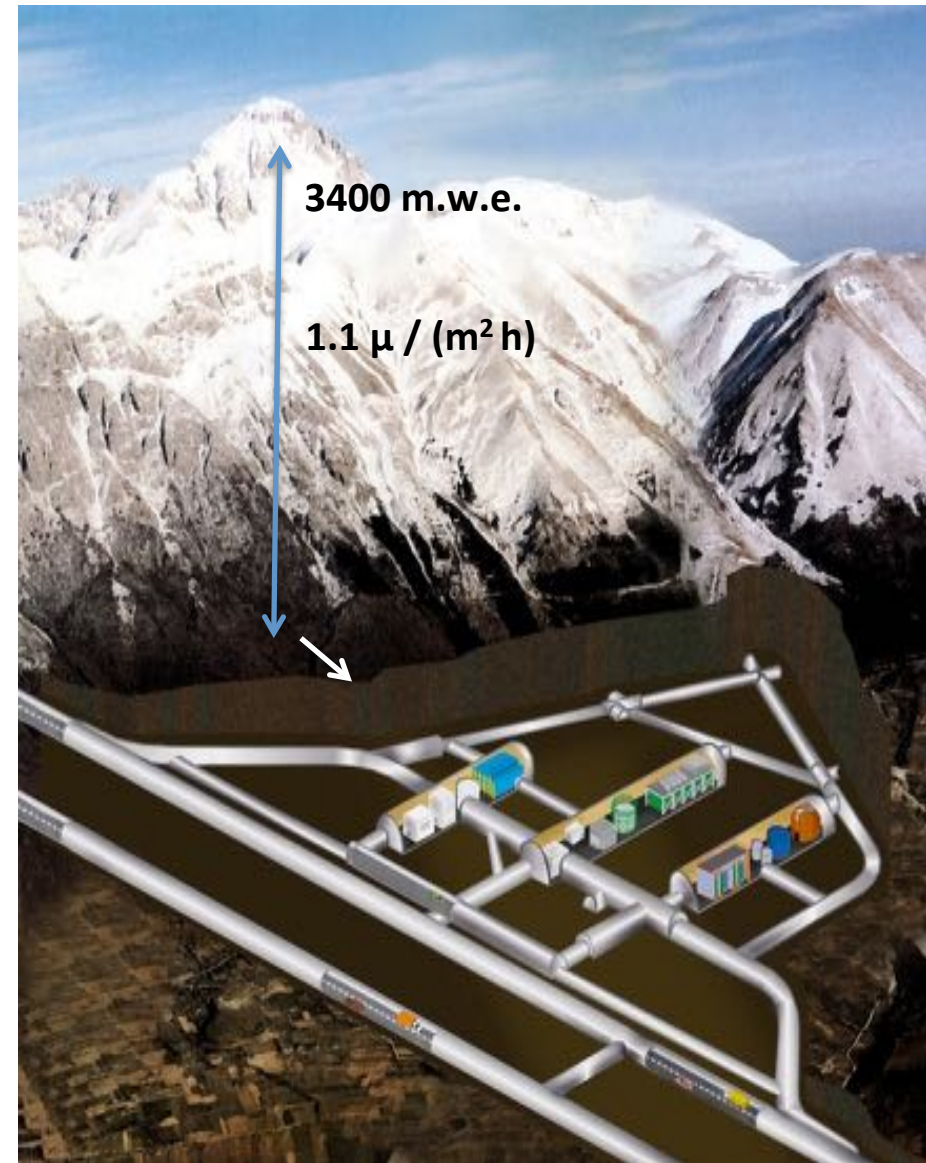
NEXT-NEW: 10kg Enr ^{136}Xe gas TPC





Laboratori Nazionali del Gran Sasso

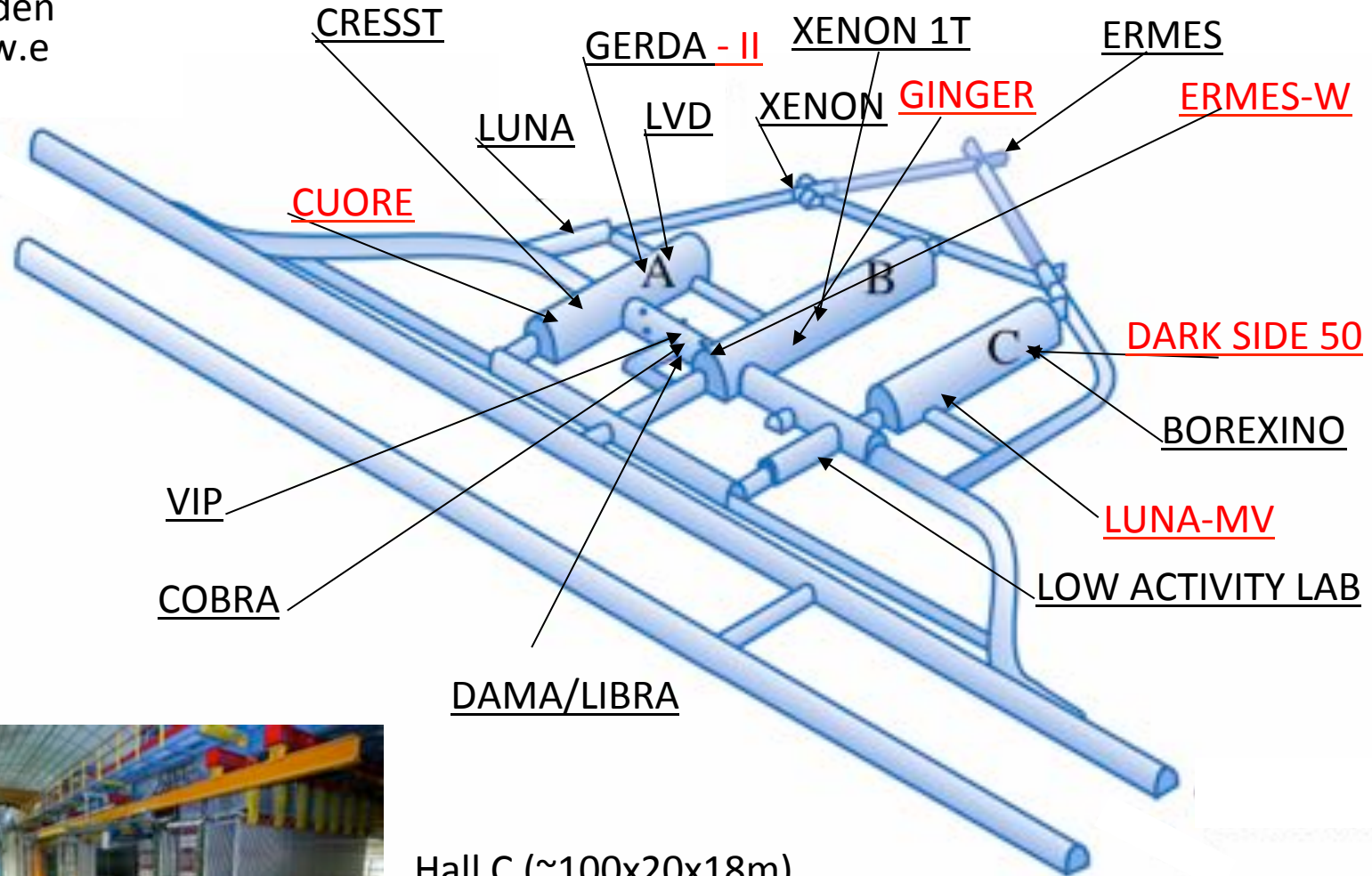
- Surface: 17 800 m²
- **Volume: 180 000 m³**
- **Overburden 3400 m.w.e**
- Muon flux: 3.0 10⁻⁴ m⁻²s⁻¹
- Neutron flux:
 - 2.92 10⁻⁶ cm⁻²s⁻¹ (0-1 keV)
 - 0.86 10⁻⁶ cm⁻²s⁻¹ (> 1 keV)
- Rn in air: 20-80 Bq m⁻³
- Ventilation: 1 vol / 3.5 hours
- Mechanical Design and Workshop
- Electronics Lab & Service
- **Chemistry Lab & Service**
- **ULB Lab & Service**
- **> 900 users from 29 countries**
- **~ 100 Staff**
- 225 avg. daily presence in 2014
- **~ 8000 visitors/yr**
- **[Virtual tour via Street View](#)**





LNGS Activities

Overburden
3400 m.w.e



Hall C (~100x20x18m)

Total Lab Volume: 180 000 m³

Stefano Ragazzi – INFN LNGS & UNIMIB

LNGS Plans...

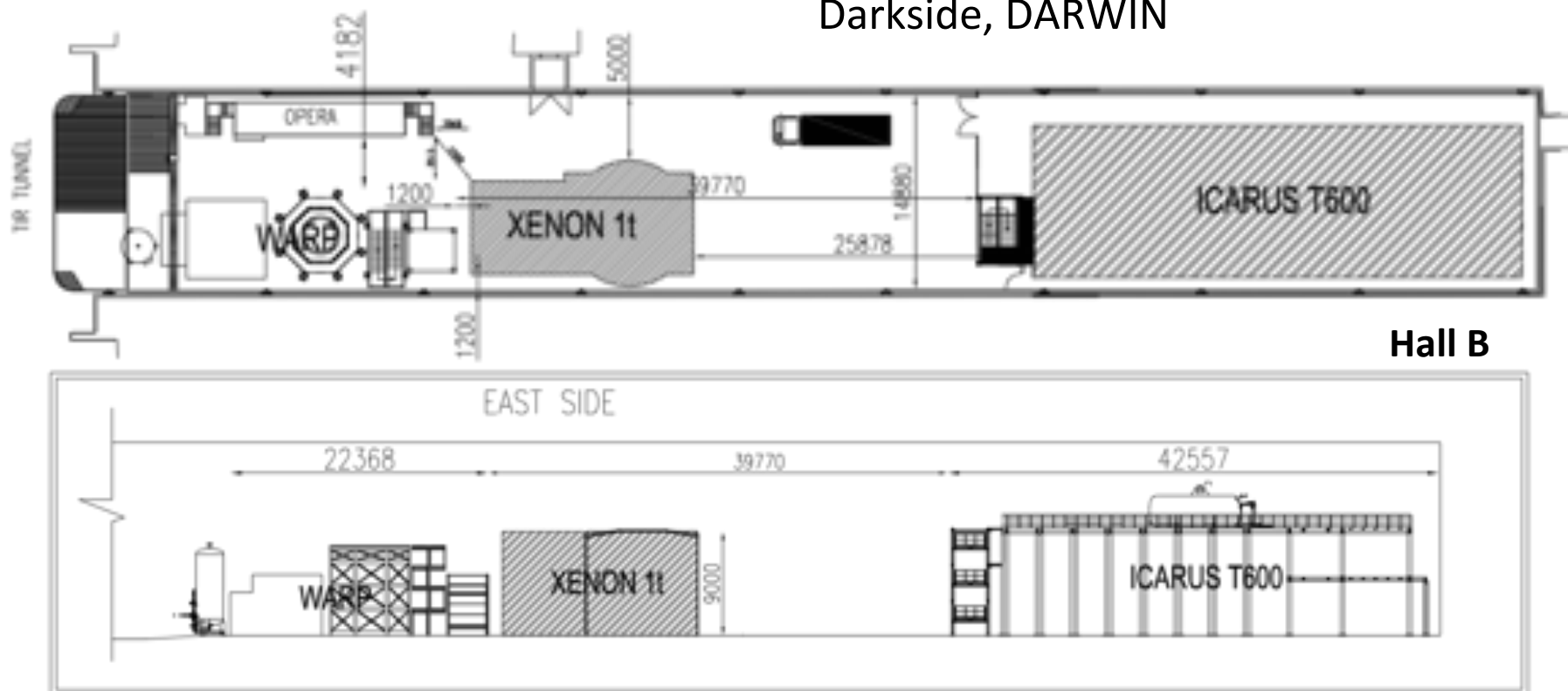
No facility expansion plans for LNGS

Space available?

- Icarus, Warp, Opera gone
- Two free areas in Hall-B
 - “Icarus” 65 m x 15 m
 - “Warp” 22 m x 10 m

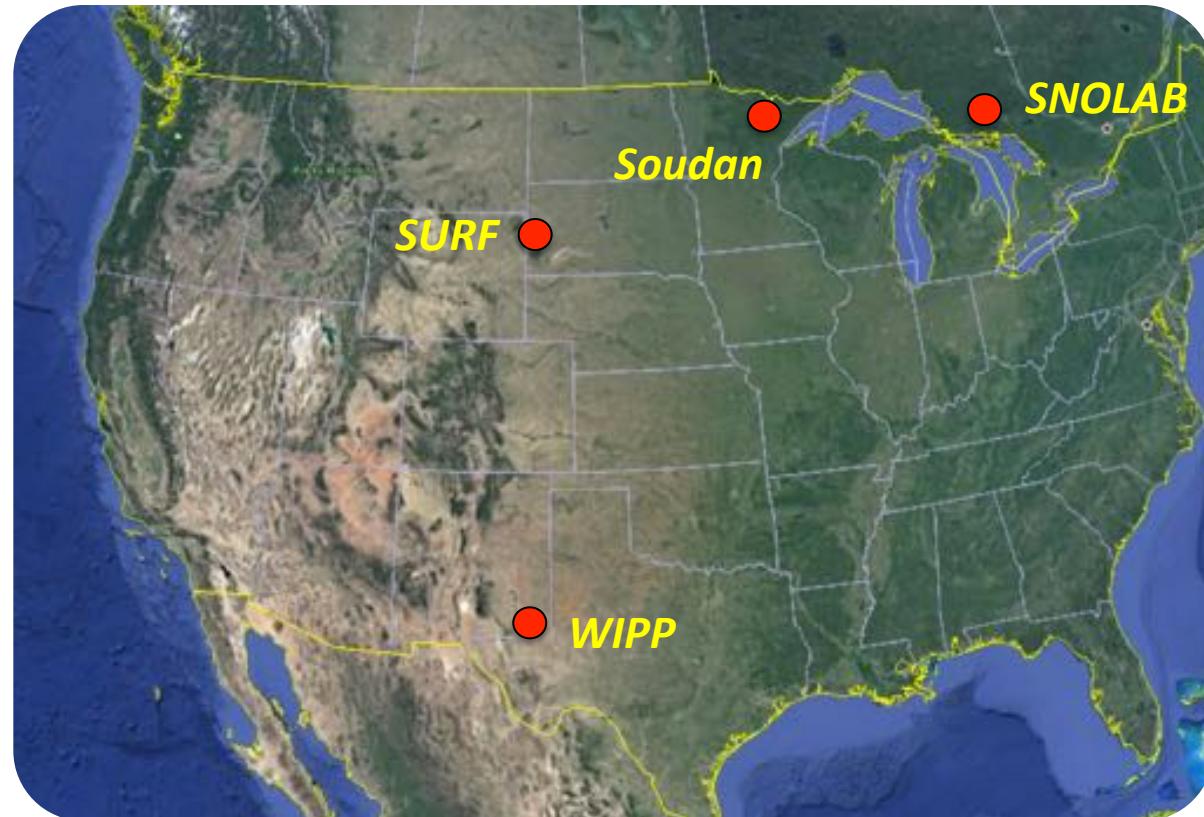
Upcoming activity

- Sabre (DM annual Modulation Expt) going in to North end of hall B
- Planned extension of screening facilities
- **Active Shielding in part of hall B?**
- Considering locations of Xenon-nT, Darkside, DARWIN



North America Labs

- SNOLAB
- SURF
- Soudan
- WIPP





SNOLAB Status Update

Nigel J.T. Smith
Director, SNOLAB



Deep Underground Science Laboratory
Vale's Creighton mine, Sudbury
Northern Ontario, Canada
2070m (6010mwe)



Currently Approved SNOLAB Programme

| | | |
|----------|--|--------------------------------------|
| Complete | PICASSO, DEAP-I (Dark Matter) | PUPS (Geology) |
| Current | PICO-60, PICO-2, DAMIC (Dark Matter) | HALO (Neutrino) MODCC (mining) |
| 2015 | DEAP-3600, MiniCLEAN, (Dark Matter) | L.U. Genomics |
| 2016+ | SuperCDMS (Dark Matter) | SNO+ (Neutrino) |

60/50ft(l/5)
50/65ft (h)

50ft(r)
50/65ft (h)



Cube Hall

Cryopit

HALO

PICO-2

DAMIC

Unallocated as yet

Utility Drift

Halo Stub

SuperCDMS

Ladder Labs

SNO+

PUPS

PICASSO-III

PICO-60

SNO Cavern

South Drift

Low Background Tests

Personnel facilities

Lab Volume >30,000m³
2070m (6010 mwe)

72ft(r)
85ft (h)

Our programme is expanding



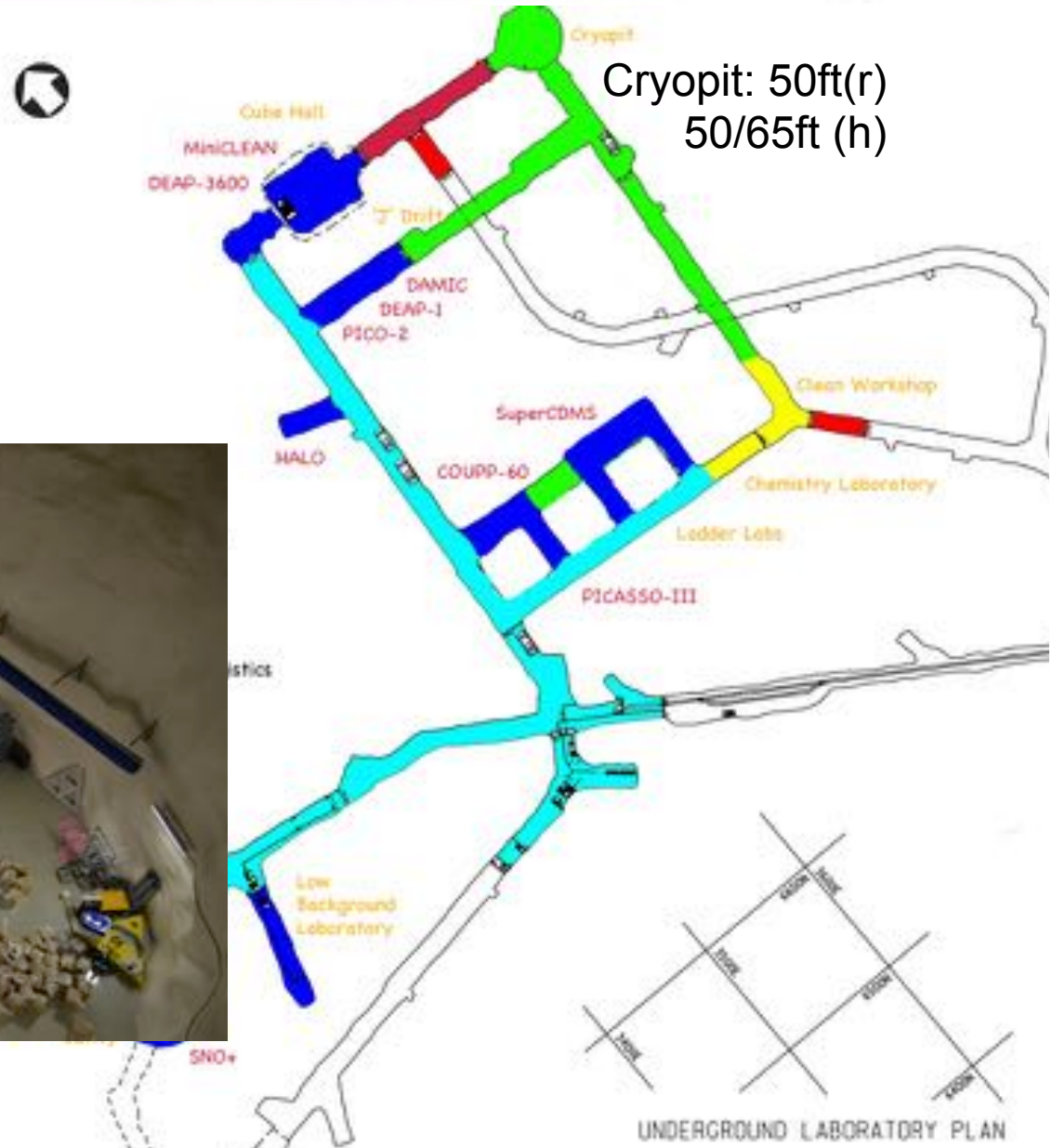
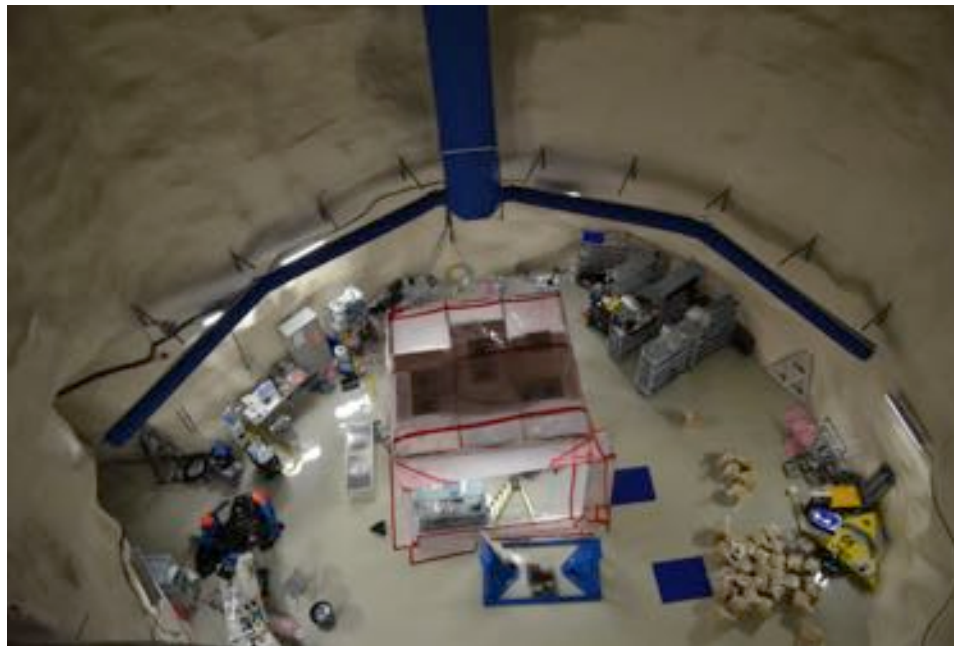
| Experiment | Neutrino | Dark Matter | Other | Space allocated | Status |
|----------------|----------|-------------|--------------------|------------------|------------------|
| CEMI | | | Mining Data Centre | Surface Facility | In Construction |
| COUPP-4 | | √ | | *J'-Drift | Completed |
| DAMIC | | √ | | *J'-Drift | Operational |
| DEAP-1 | | √ | | *J'-Drift | Completed |
| DEAP-3600 | | √ | | Cube Hall | In Construction |
| DEAP-50T/CLEAN | | √ | | Cube Hall | Letter of Intent |
| DMTPC | | √ | | Ladder Labs | Letter of Intent |
| Ge-1T | √ | | | Cryopit | Letter of Intent |
| nEXO | √ | | | Cryopit | Concept Phase |
| HALO | √ | | | Halo Stub | Operational |
| MiniCLEAN | | √ | | Cube Hall | In Construction |
| NEWS | | √ | | Cryopit? | Letter of Intent |
| PICASSO-III | | √ | | Ladders Labs | Completed |
| PICO-2L | | √ | | *J'-Drift | Operational |
| PICO-60 | | √ | | Ladder Labs | Operational |
| PICO-250 | | √ | | Ladder Labs | Letter of Intent |
| PINGU | | | Test facility | Ladder Labs | Letter of Intent |
| PUPS | | | Seismicity | Various | Completed |
| SNO+ | √ | | | SNO Cavern | In Construction |
| SuperCDMS | | √ | | Ladder Labs | In Preparation |
| U-Laurentian | | | Genomics | External Drifts | Operational |

Space is still available



- Cryopit

- Currently unallocated
- Potential short term site for NEWS
- Future Projects Meeting held in August



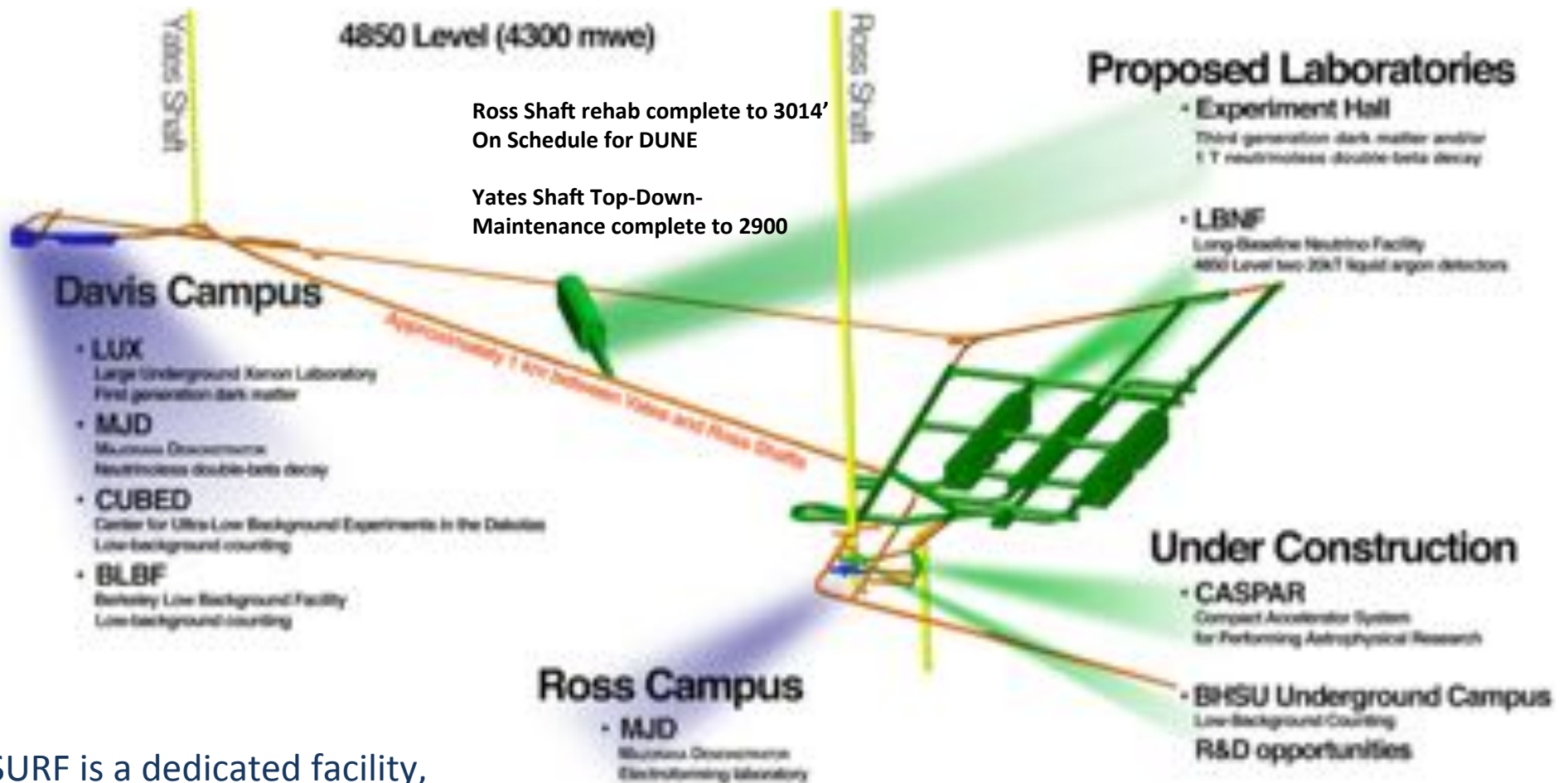
Sanford Underground Research Facility



Homestake Gold Mine
Lead, South Dakota
4850ft (4300 m.w.e)



SURF 4850L Physics Laboratories

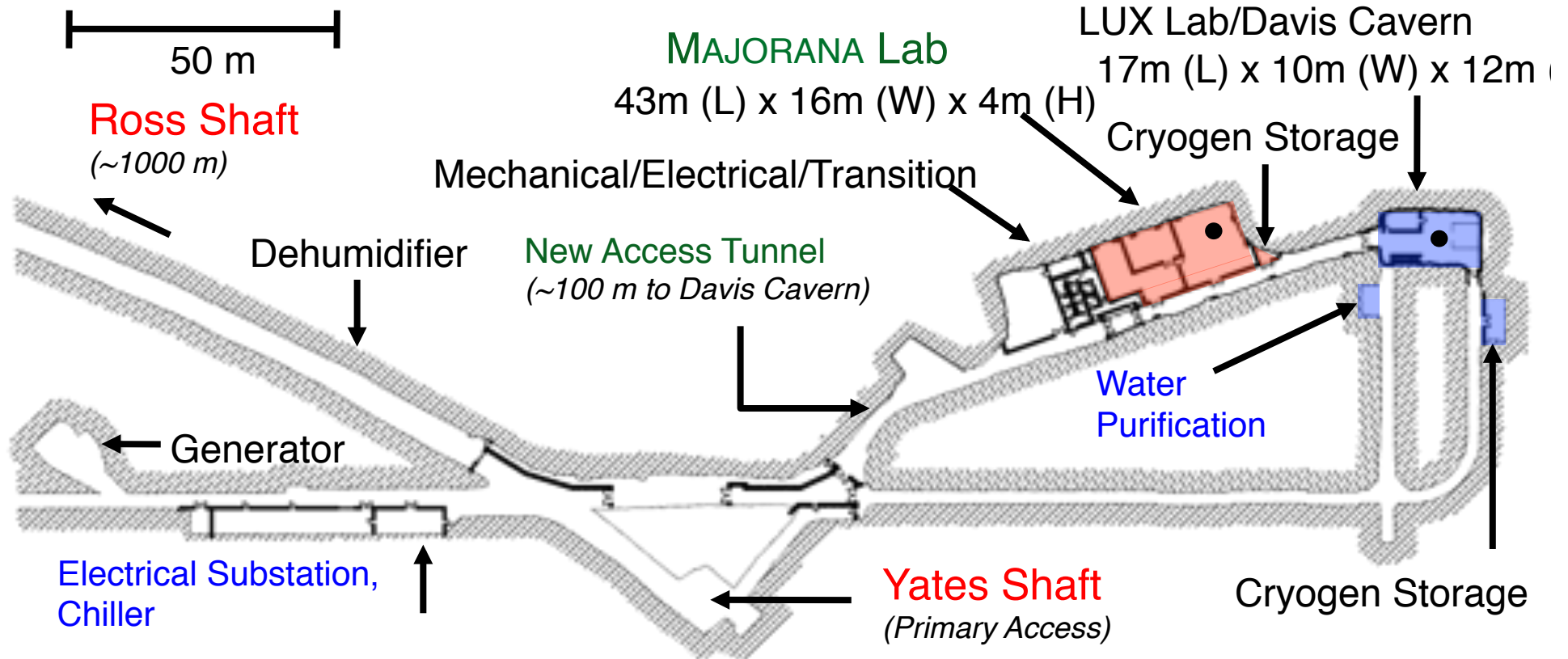


SURF is a dedicated facility, created originally with the support of the NSF, UCB, South Dakota, and Private Donations and since 2010 supported by the DOE-HEP and continued exceptional strong support by South Dakota

Heise, AIP Conf. Proc. **1604** 331 (2014);
also arXiv:1401.0861v1 (2014)
Lesko, Euro Phys J Plus **127**, 107 (2012)

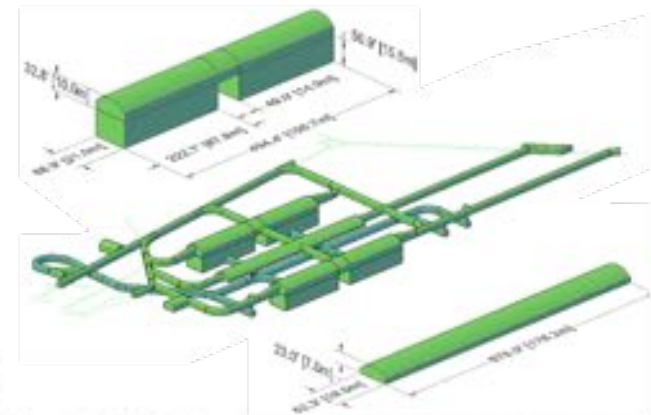
4850L Davis Campus

2,732 m² (Total) / 1,074 m² (Science)



LBNF & DUNE STEPS

- US is aggressively developing plans to host a world-class neutrino program
- Aligned with US P5 Report, the CERN/European Strategy, and Japan/T2K-HK
- Collaboration and leadership re-formed to reflect unification with the international partners – following LHC management model
- Key goal to develop 10kt by 2021
- Ultimately to develop 40kt
- CD1-refresh completed July 2015, CD2a/3a Dec 2015
- Goal to begin underground construction 2017
- Test blasts scheduled for Nov/Dec 2015



LBNF & ELBNF CONSTRUCTION/INSTALLATION STEPS

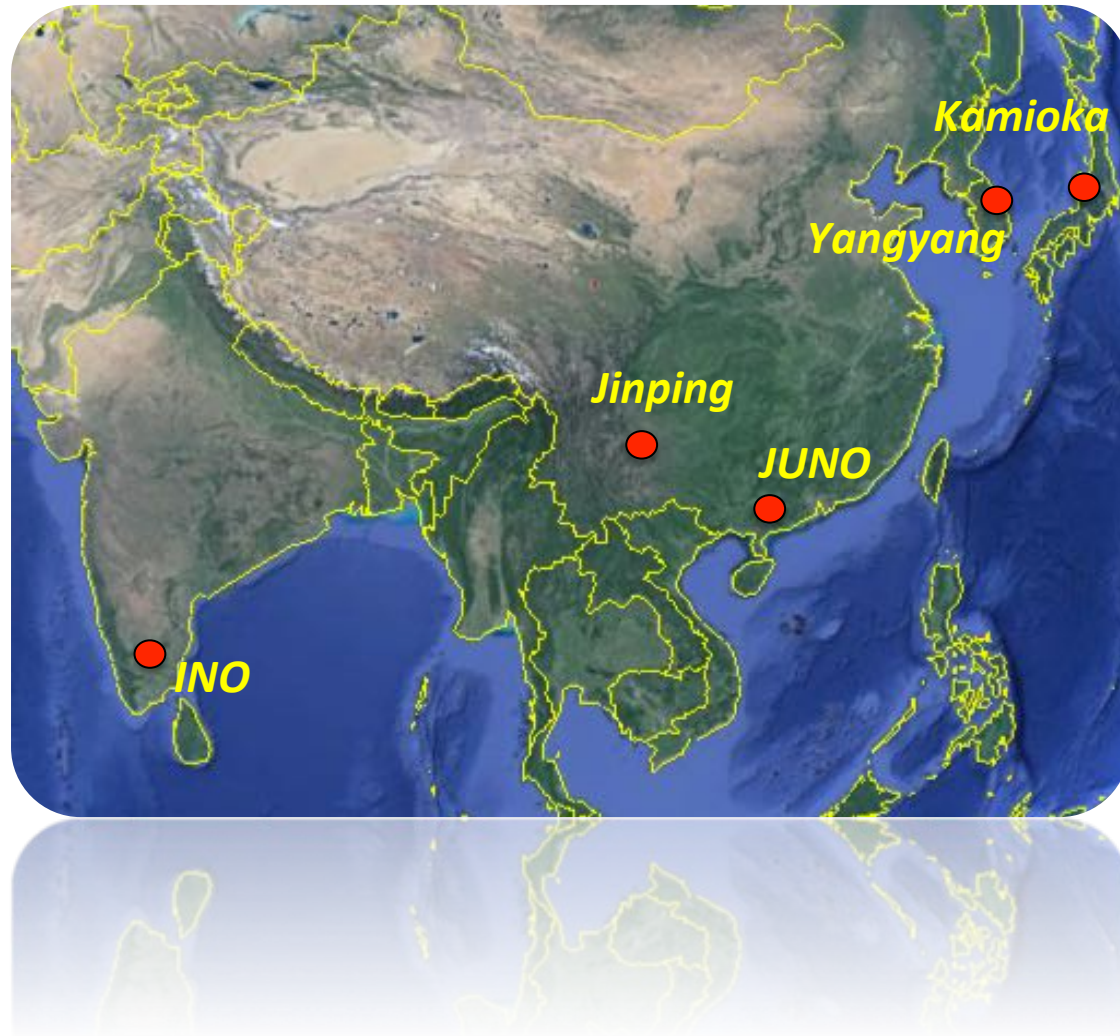


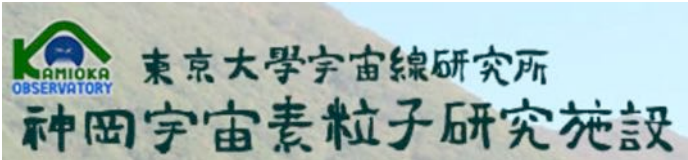
From Nigel
Lockyer's
Presentation

Summary and critical path durations only, could be moved in time

Asia Labs

- *Kamioka*
- *Jinping*
- *Yangyang (Y2L)*
- *INO*
- *JUNO*

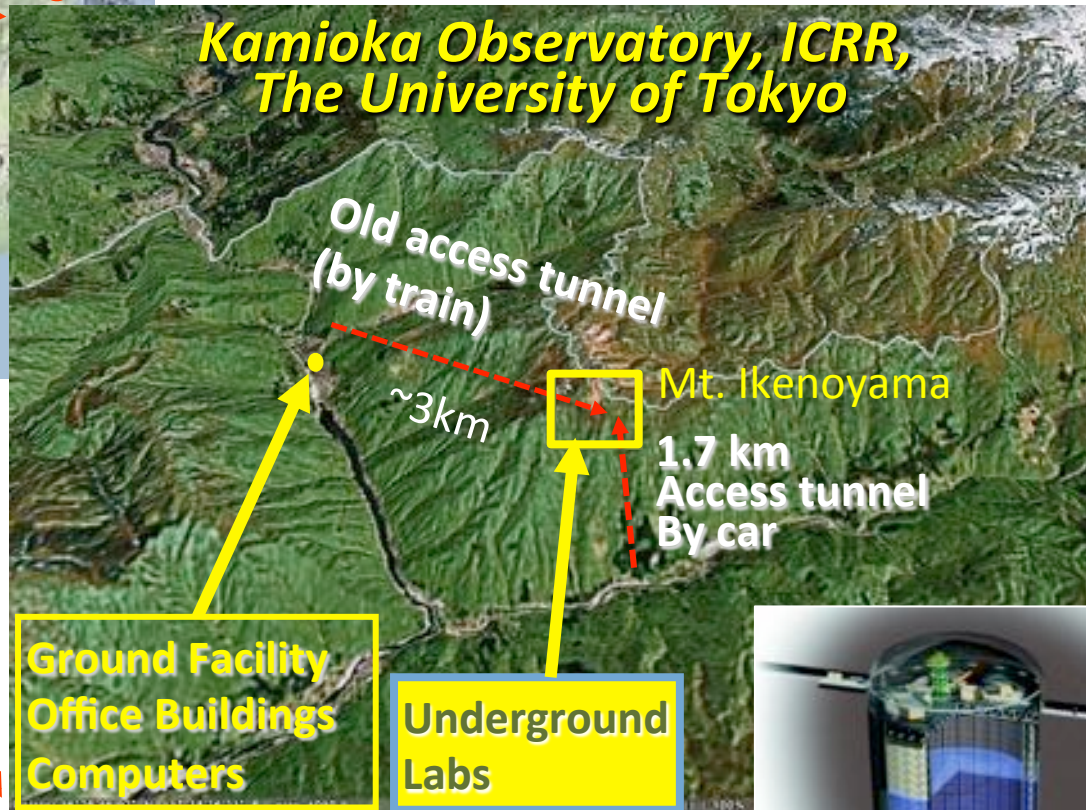
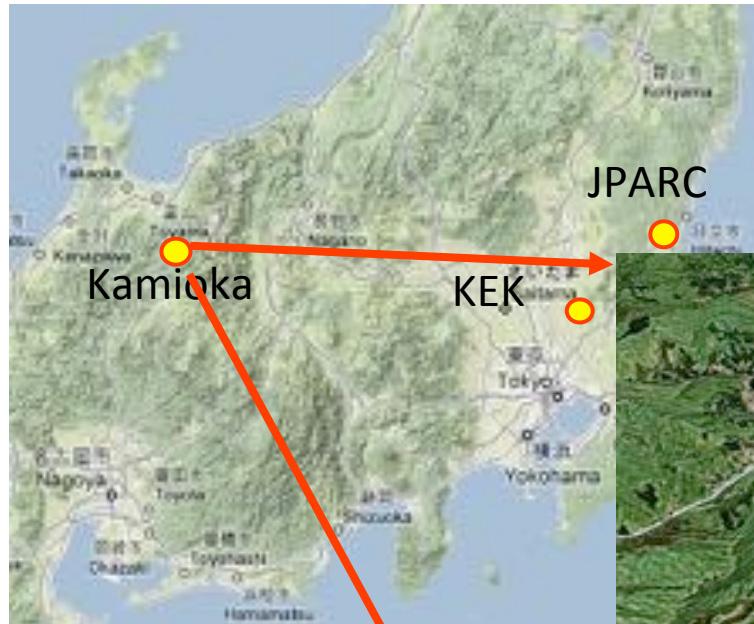




Kamioka Observatory

Location

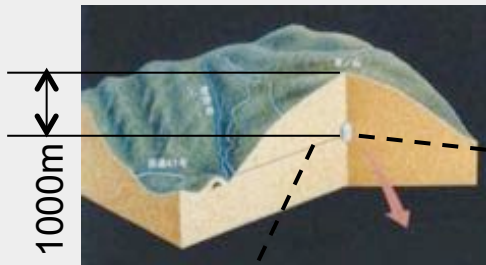
- Mozumi Zinc Mine
- Northan part of Gifu pref. in Japan
- 40 minutes drive from Toyama airport, where is 1 hour flight from Tokyo Airport



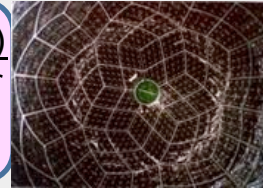
- 1000 m underground
- 2700 m.w.e
- Horizontal access
- 24 hours access by car
- 10 minutes from ground facility



Kamioka Underground Laboratories

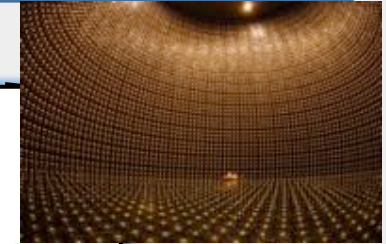


KamLAND (Tohoku Univ.)
 1000ton liquid scintillator detector
 Reactor, geo neutrinos
 ^{136}Xe double beta decay



Super-Kamiokande

50,000 ton water Cherenkov detector
 Atmospheric, solar, supernova neutrinos
 Proton decay, indirect dark matter search
 Far detector for T2K



CANDLES

CaF_2 scintillation detector
 for ^{48}Ca double beta decay



KamLAND
 (old Kamiokande site)

Gravitational-wave

CLIO 100m x 100m prototype
KAGRA 3km x 3km cryogenic
 laser interferometer under
 construction.



Lab.A Super-K dome

clean room

Gd test
 water
 system

XMASS

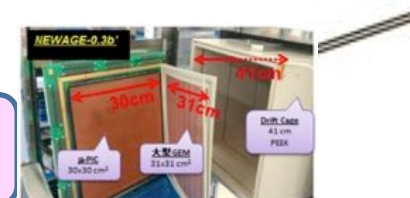
Direct dark matter search
 experiment



100m

NEWAGE

Direction dark matter experiment





Current Experiments in Kamioka

Center for Gravitational Wave (Op. by Univ. of Tokyo)

- KAGRA (Large Cryogenic Gravitational-wave Telescope)
 - **Under construction.**
 - Commissioning will start in 2015.
 - Cryogenic run from 2017.

Neutrino Science Center (Op by Tohoku Univ.)

- KamLAND (reactor & geo ν)
- KamLAND-ZEN (double beta decay of ^{136}Xe)
- **Increasing Xe136 content**

Kamioka Observatory (Op. by Univ. of Tokyo)

- Super-Kamiokande
 - Precise oscillation studies by atmospheric and solar neutrinos.
 - Evidence for ν_e appearance (T2K)
 - **Dissolve 0.1% Gd for anti-neutrino physics in future.**
- XMASS (Dark Matter: liq. Xenon)
 - 1st phase detector completed
 - **Improvement of the detector**
- CANDLES (Double beta)
 - Detector completed
 - Commissioning
- NewAGE (Dark Matter)
 - Directionality
- CLIO (prototype of KAGRA)
- Geo-physics
 - Laser strain meter
 - Superconductive gravity meter

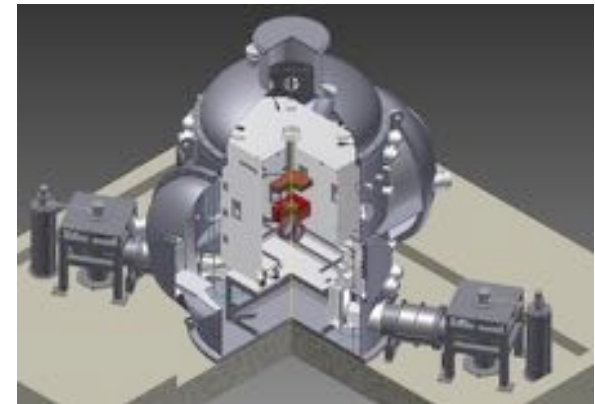
KAGRA



Photo of center area



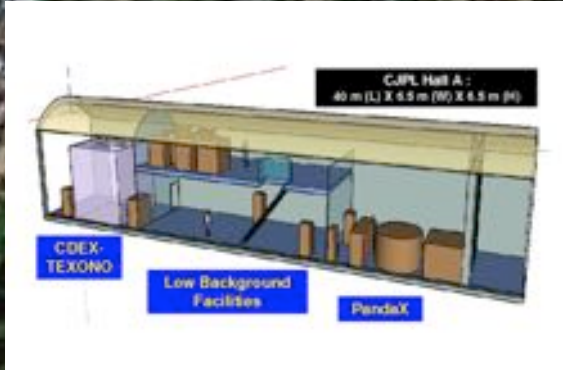
Outline of cryostat



Schedule

- Installation of the major equipment completed by March 2015.
- Normal temperature operation will start in 2015.
- Cryogenic operation from 2017.

China Jin-Ping Underground Laboratory (CJPL) Site



Current laboratory volume = 1700m³

Tunnel

World's deepest underground facility

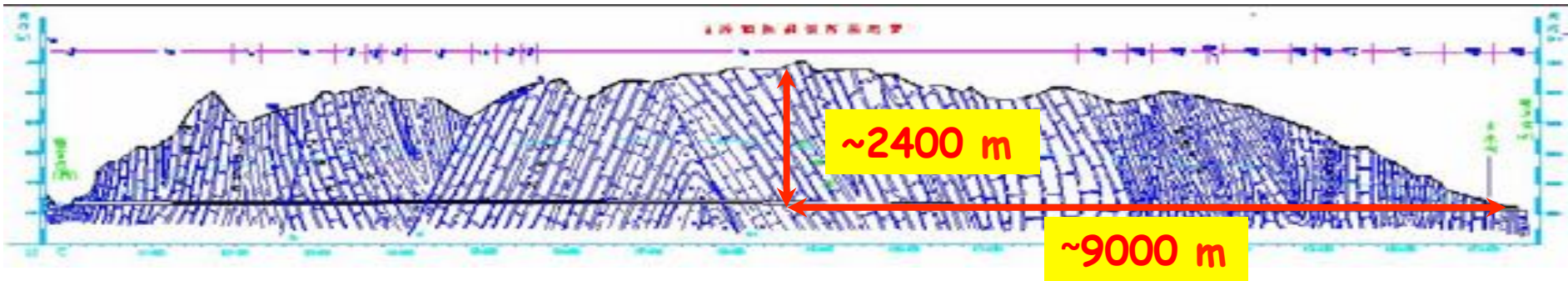
50min from Chengdu By Air

Established 2010
 Within Jinping-II Dam hydro-electric facility.
 Sichuan Province in China
 Under Jinping mountain 4193m
 2400m of rock overburden (6720m.w.e)

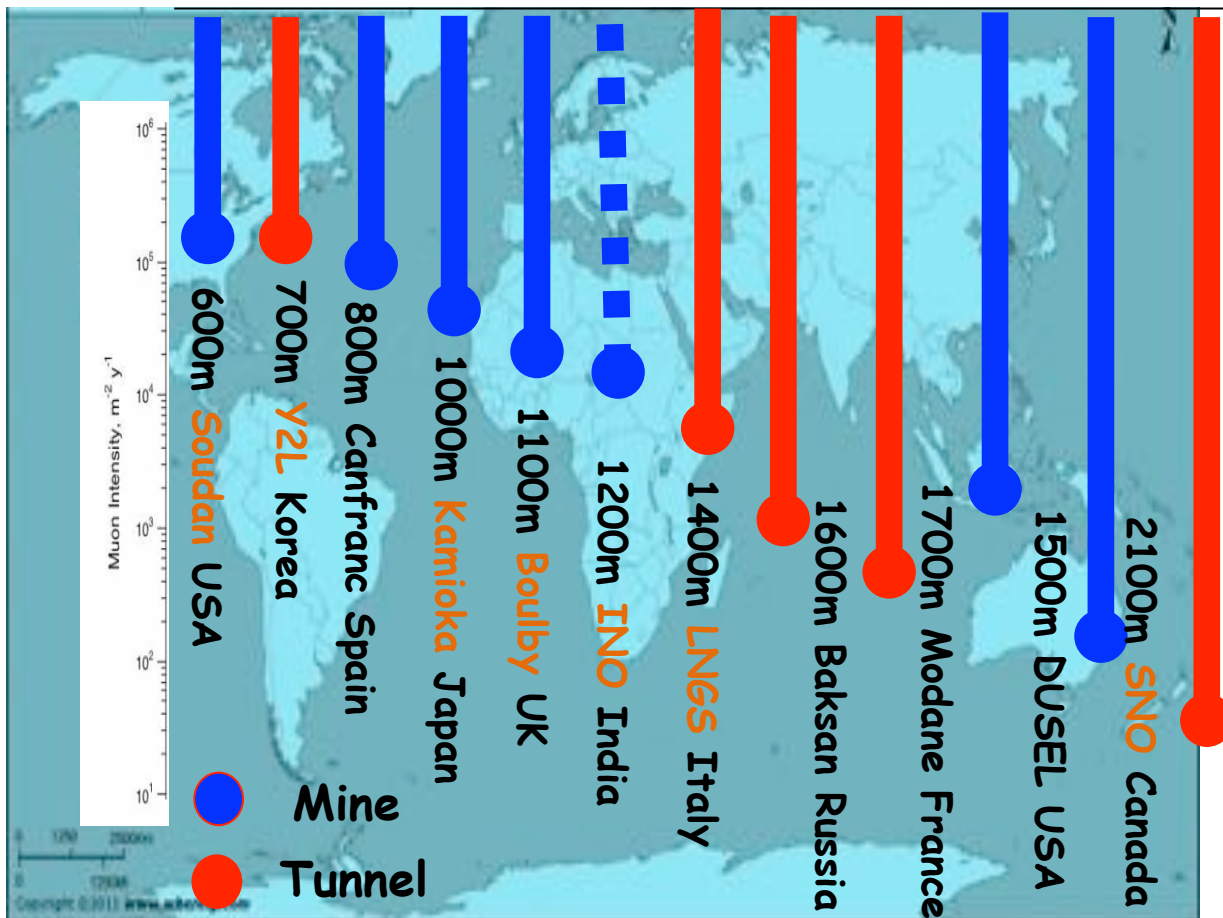
120km



XiChang



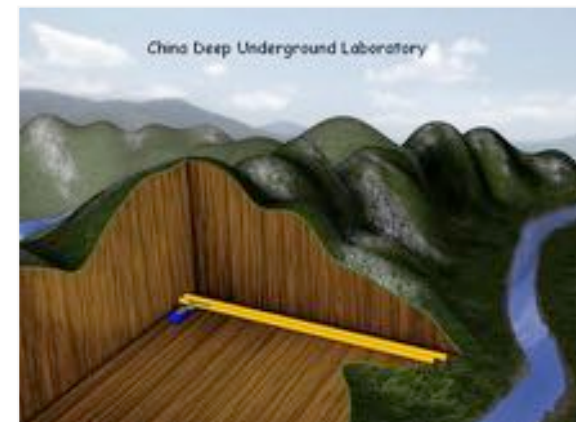
⊙ 2400+ m rock overburden, drive-in road tunnel access



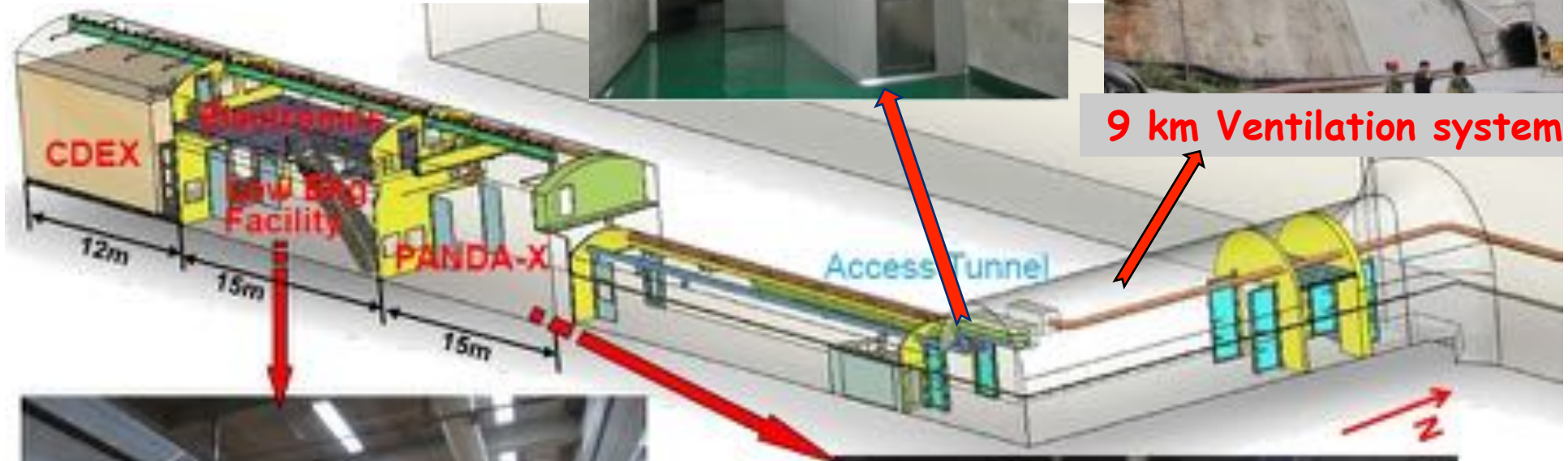
World's deepest underground facility @2400m (6720 m.w.e)

Under Jinping mountain 4193m

Current laboratory volume = 1700m³



Internal layout of CJPL-1 (6m x 6m x 40m)



9 km Ventilation system



Currently supported studies...

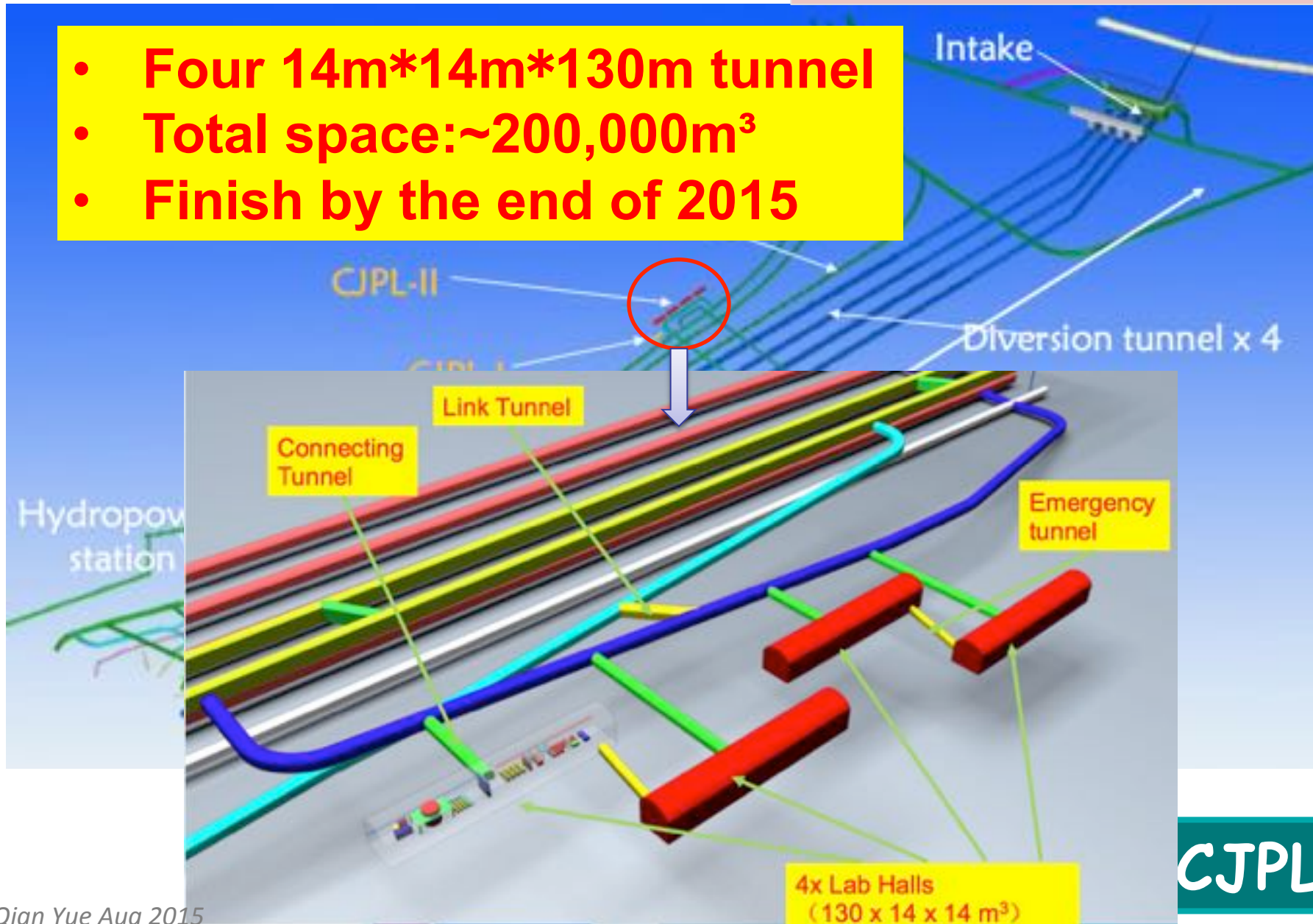
- Dark matter/Double beta: Panda-X, CDEX
- Cs(I) and Ge crystal studies
- Geological studies

Shin-Ted Lin Aug 2015

Plan of CJPL-II

The Deepest and BIGGEST(?)
underground Lab in the World

- Four 14m*14m*130m tunnel
- Total space:~200,000m³
- Finish by the end of 2015



CJPL

CJPL-II possible users

- CDEX-1T (Ge DM+DBD Exp.)
- PandaX-1T (Xe DM Exp.)
- LAr DM experiment led by IHEP
- Nuclear astroparticle physics-JUNA
- Solar neutrino experiment
-



RYBOKYIOKA

Southern Hemisphere Labs

- *Andes*
- *Stawell*



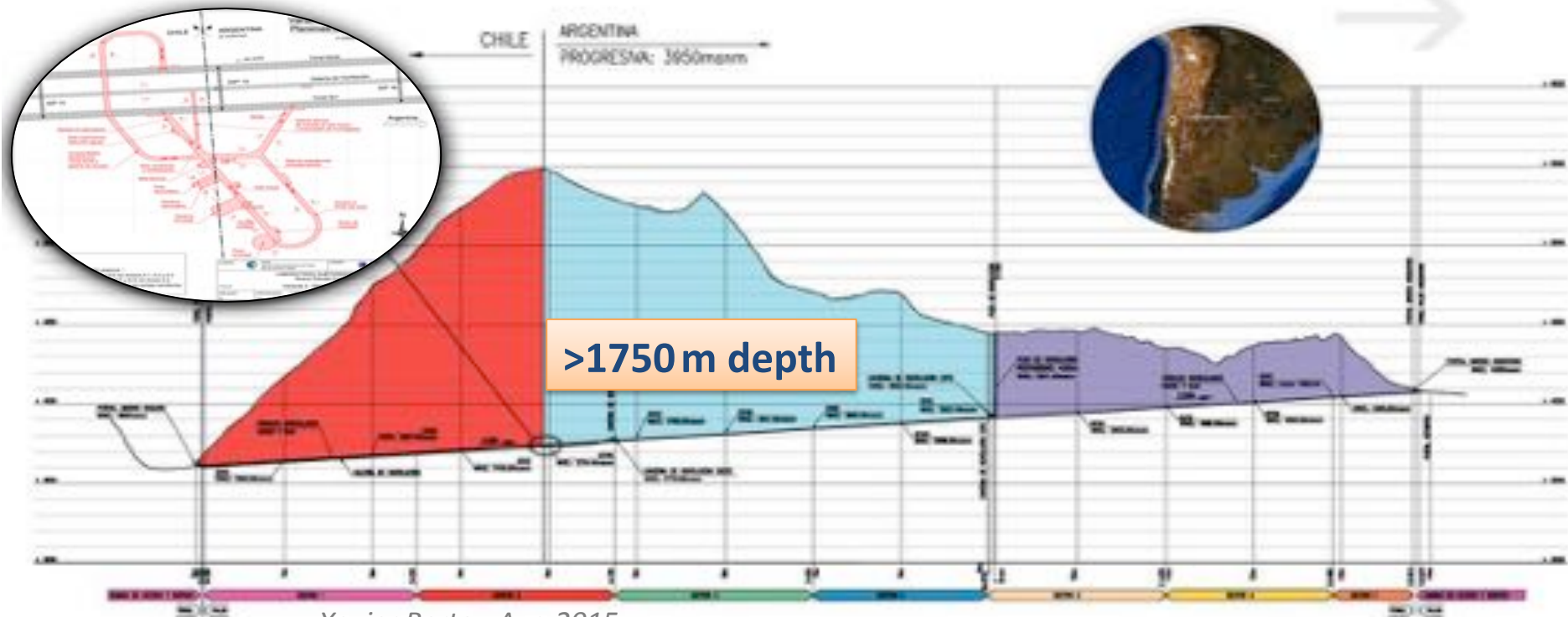
ANDES

The Agua Negra deep underground laboratory



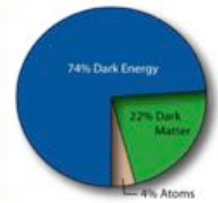
- Agua Negra tunnel between Argentina and Chile, linking MERCOSUR to Asia
- Laboratory location as deep as Modane
- Tunnel construction approved in August 2015; construction period 2016-2024
- Horizontal access, size of $\sim 4\,000\text{ m}^2$ and $\sim 70\,000\text{ m}^3$ in 8 halls and pits

Large and deep underground laboratory in the southern hemisphere

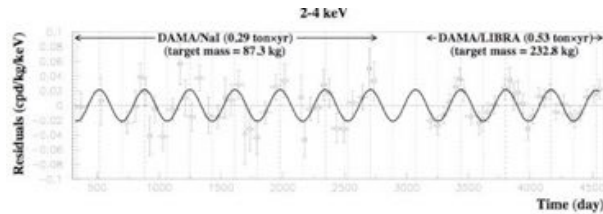


Xavier Bertou Aug 2015

ANDES: Agua Negra Deep Experiment Site



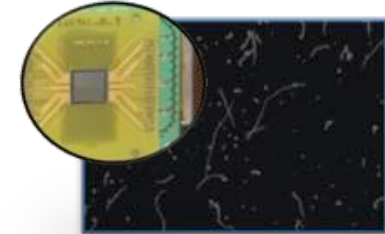
Dark Matter



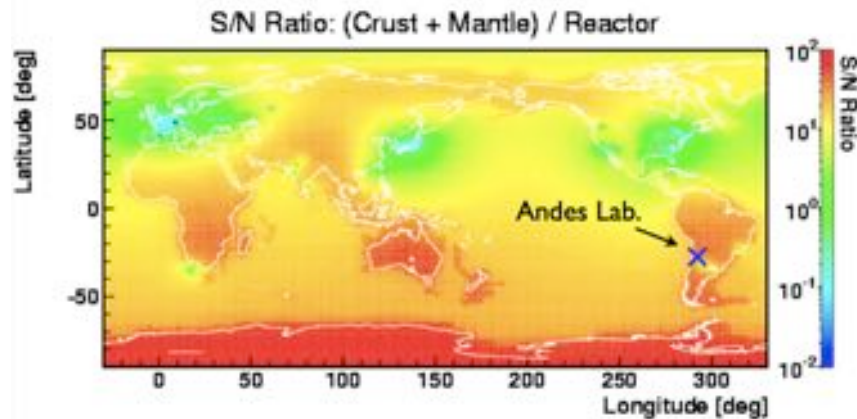
DAMA/LIBRA yearly modulation, to investigate in Southern hemisphere



Host 3rd generation DM experiment

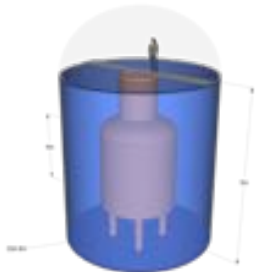


Study new particle detection techniques, ex: CCD



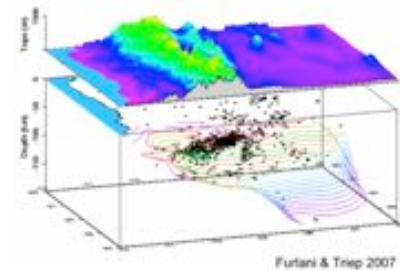
Neutrinos

- Geo-neutrinos (benefit from unique location)
- Build a low energy Latin American neutrino detector
- Host experiments for Mass & Nature (ex: host part of SuperNEMO?)



Ultra low radiation pit

Environmental measurements, material selection...

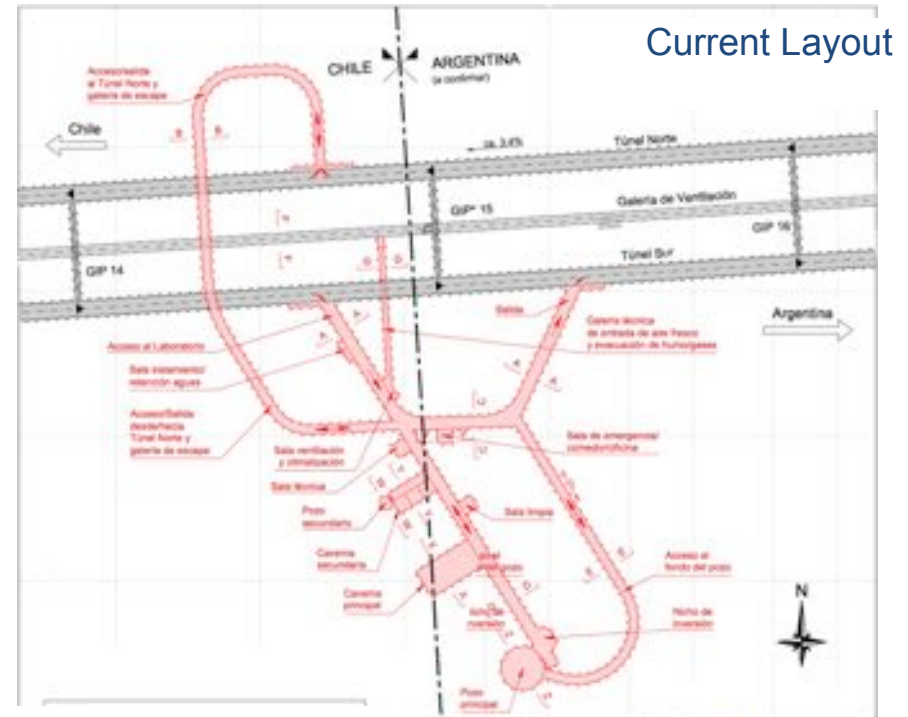


Geophysics laboratory

Local active region, Seismograph network junction (Argentina+Chile), Magnetic and Gravimetric studies

ANDES: Agua Negra Deep Experiment Site

- Main hall
(21 m x 23 m x 50 m)
- Secondary hall
(16 m x 14 m x 40 m)
- Offices and small labs
- Low radiation pit
- Large single experiment pit
(~ \varnothing 30 m, 30 m tall)
- Vertical depth: 1775 m,
omnidirectional: 1675 m
- Total: 70 000 m³ laboratory volume
(+ 35 000 m³ access tunnels)



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 exact location to be determined once geology is better known
- ✓ Proposed as an International laboratory within Latin America
- ✓ Conceptual study finished by Lombardi in January 2015
- ✓ Detailed engineering ongoing
- ✓ **Tunnel fully approved Aug 2015**

SUPL: Stawell Underground Physics Laboratory

Stawell gold mine ~240 km west of Melbourne... In 2017 will host the first ready to be used underground laboratory in the Southern hemisphere.



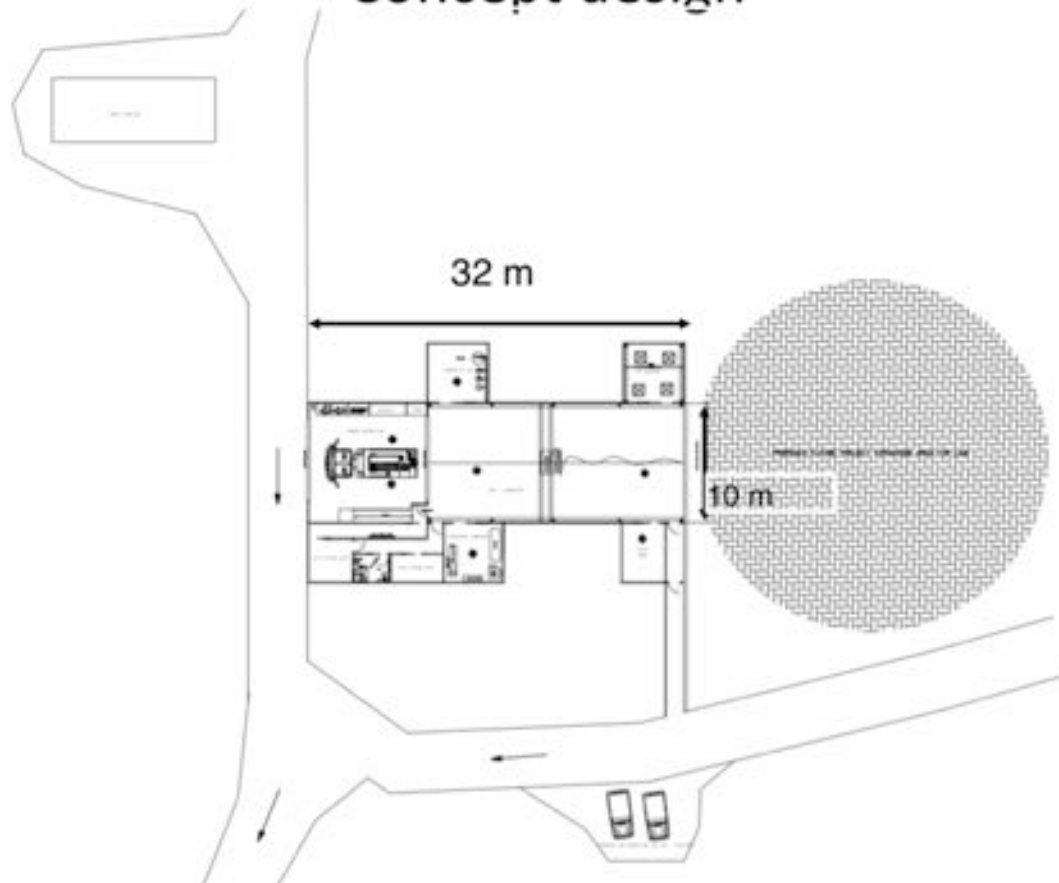
Chose a site at 1.02 km underground, ~3 km water equivalent

Decline gold mine mine, 1.6 km deep, with all caverns served with electricity, optical fibre, reached by car/truck. The mine is operational.

SUPL: Stawell Underground Physics Laboratory

In 2017 will host the first ready-to-be-used underground laboratory in the Southern hemisphere.

Concept design



Time line



Developments in the World's Deep Underground Laboratories

Overview of status & future plans of (some of) the world's underground facilities...



Europe

- Gran Sasso
- Modane
- Canfranc
- Boulby

Asia

- Kamioka
- Jinping
- Yangyang
- INO
- JUNO

North America

- SNOLAB
- SURF
- Soudan
- WIPP

Southern Hemisphere

- Andes
- Stawell

Lots going on. Many and varied science projects and laboratories progressing and emerging.



Boulby Underground Laboratory Review of expressions of interest Coming Soon (early 2016)



Sean Paling
STFC Boulby Underground Science Facility