Status update on non-US deep underground facilities

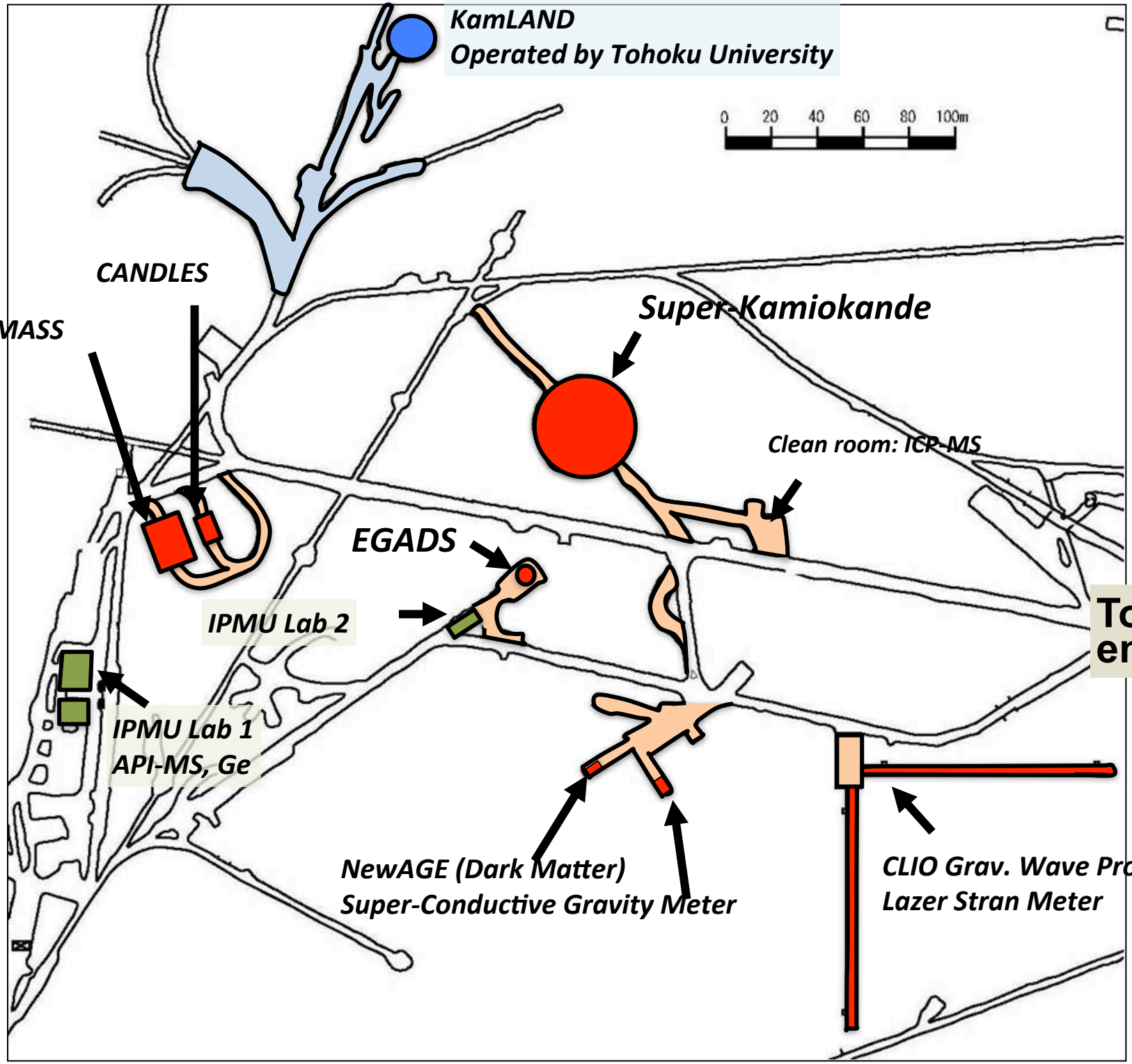
Nigel Smith

SNOLAB

with thanks to the deep underground lab directors for contributions

(also see EJPS **127** 9 (2012))

Underground Facilities


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 different research centre
- 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

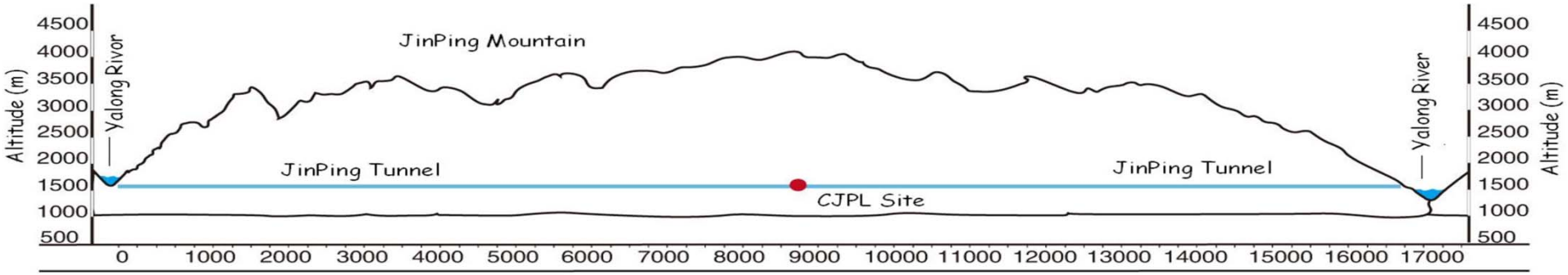
  Feasibility test by 200 ton test tank
- KamLAND (not under the kamioka Observatory, but operated by Tohoku University)

  KamLAND-ZEN (double beta decay of 136Xe)

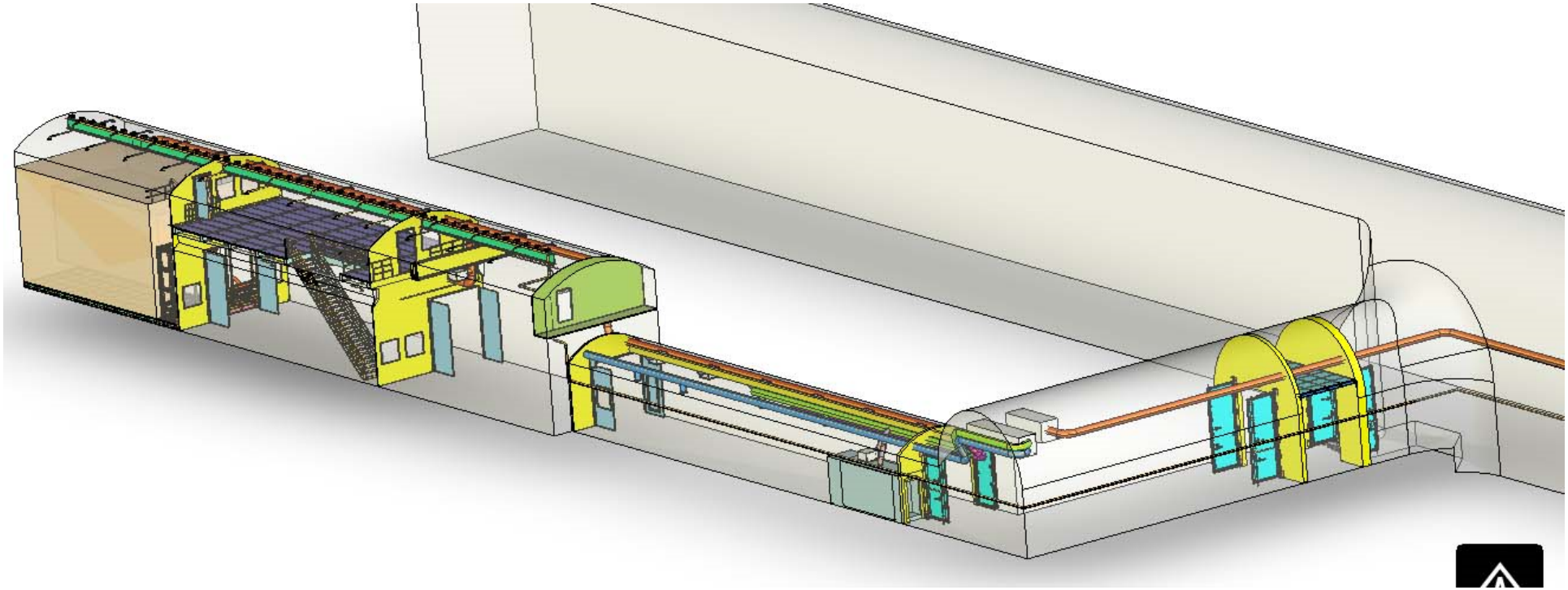
  recent results published

CJPL site

CHINA
Sichuan Province
Jinsha River
Jinping tunnels
YaLong River
YaLong River
Jinsha River
Jinsha River
N
Yunnan Province


Altitude (m)
4500
4000
3500
3000
2500
2000
1500
1000
500
Yalong River
JinPing Mountain
JinPing Tunnel
CJPL Site
JinPing Tunnel
Yalong River
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000

CJPL recent status(~4000m^3)



CJPL

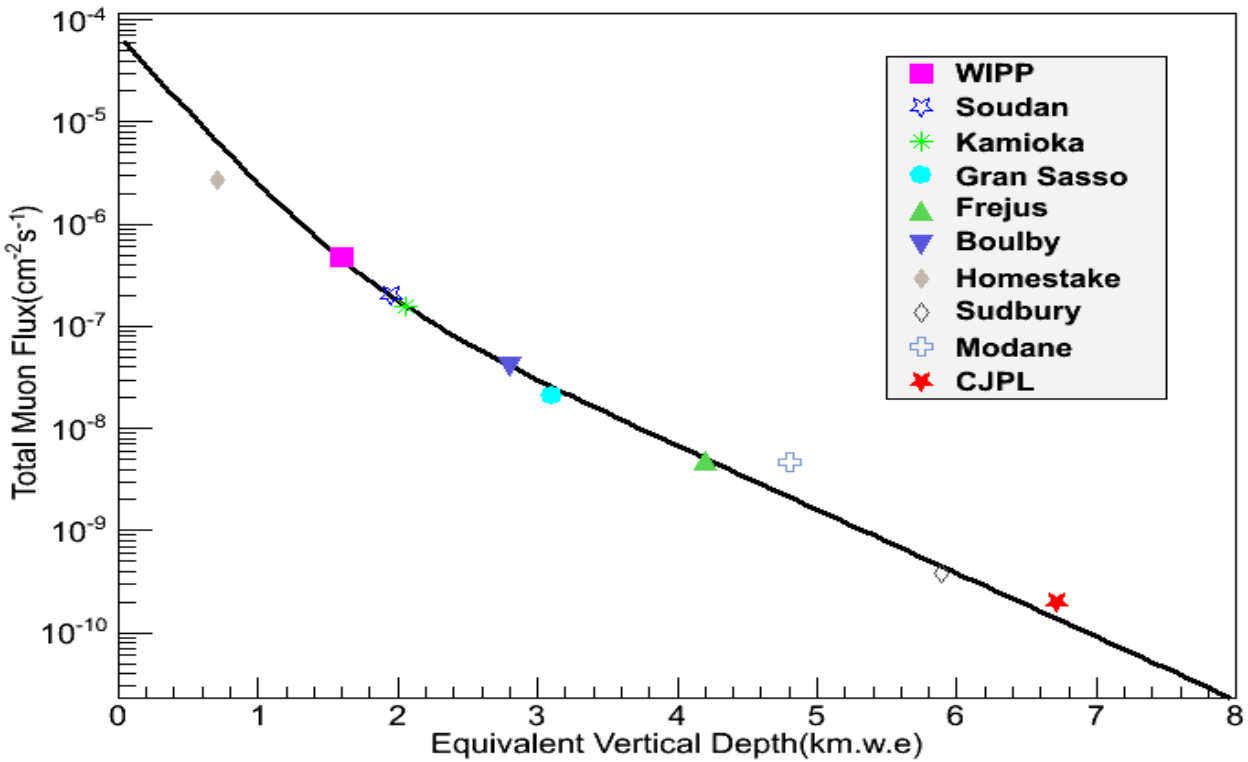
国家深地实验室
National Deep Underground Laboratory

Visit of CJPL

Hallway to Exp. Hall

View of Experimental Hall

Muon flux at CJPL



- Muon flux measured result: ~60 muons/year/m^2

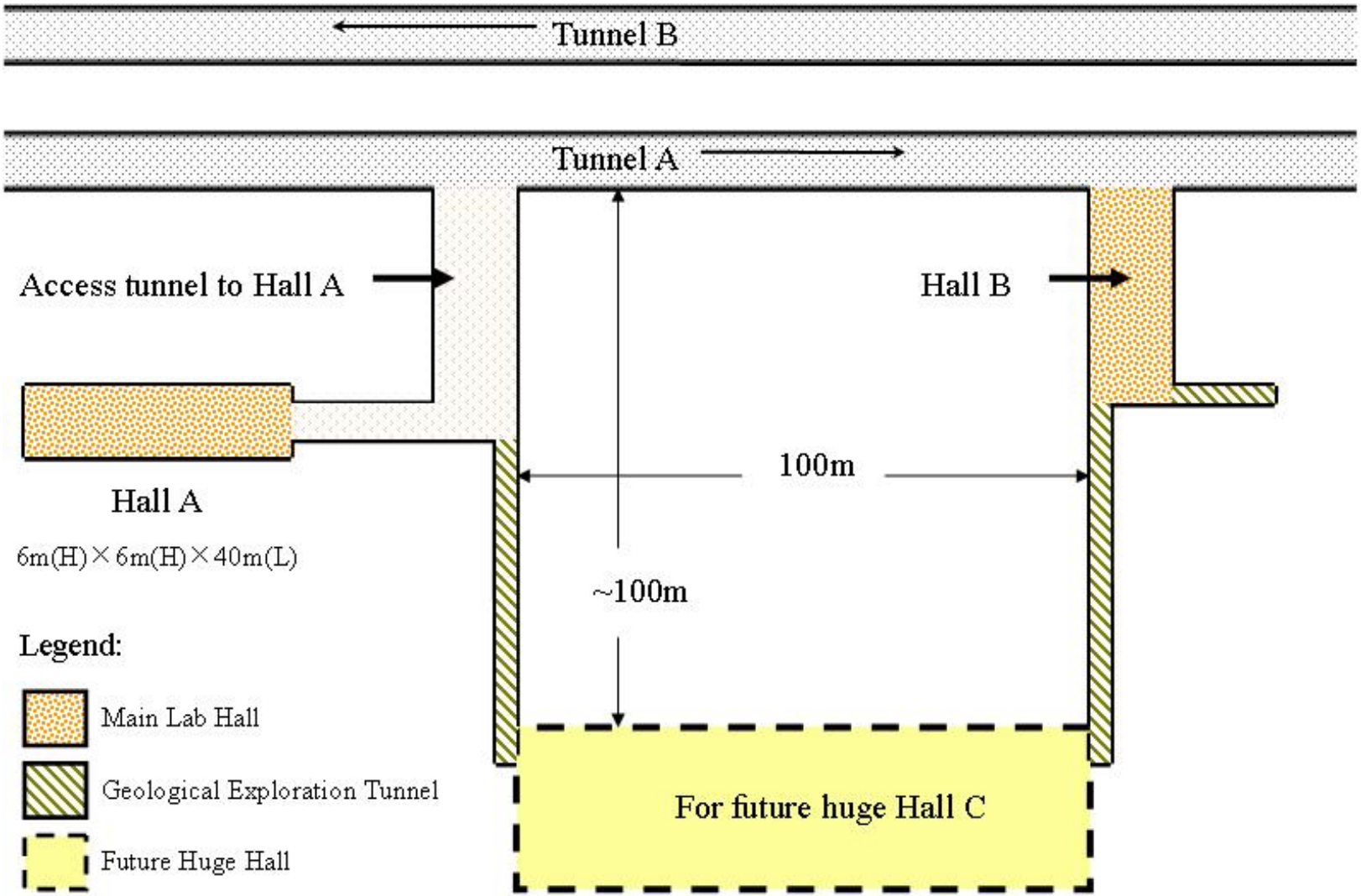
CJPL

China Jinping Underground Laboratory (CJPL)

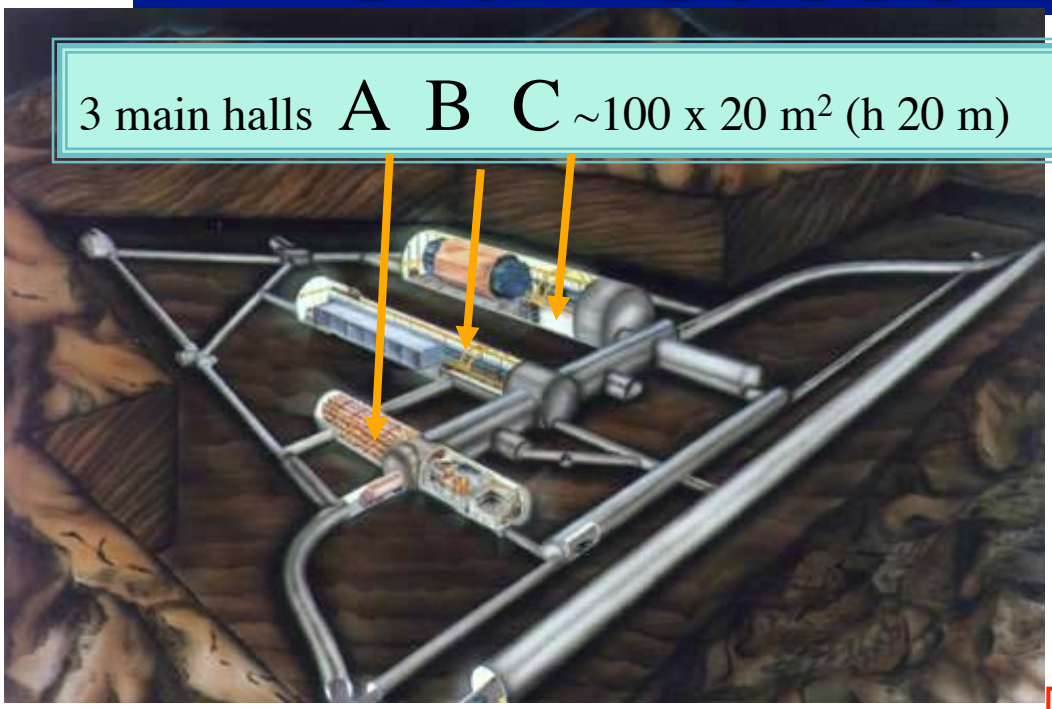
- Tsinghua University, have collaborated with Yalong River company to construct and run CJPL. It is the deepest underground formally run now in the world.
- CDEX has done many measurement of its main parameters including muon flux, thermal neutron background, gamma background. These parameters are very important for dark matter experiments.

CJPL

CJPL Future Plan



Gran Sasso Laboratory



Muon Flux
$3.0\ 10^{-4}\ \mu\ m^{-2}\ s^{-1}$

Neutron Flux	
$2.92\ 10^{-6}$ n $cm^{-2}\ s^{-1}$	(0-1 keV)
$0.86\ 10^{-6}$ n $cm^{-2}\ s^{-1}$	(> 1 keV)

Depth: 1400 m (**3800 m w.e.**)

Surface: 17800 m^2

Volume: **180000** m^3

Rn in air: 20-80 Bq/m^3

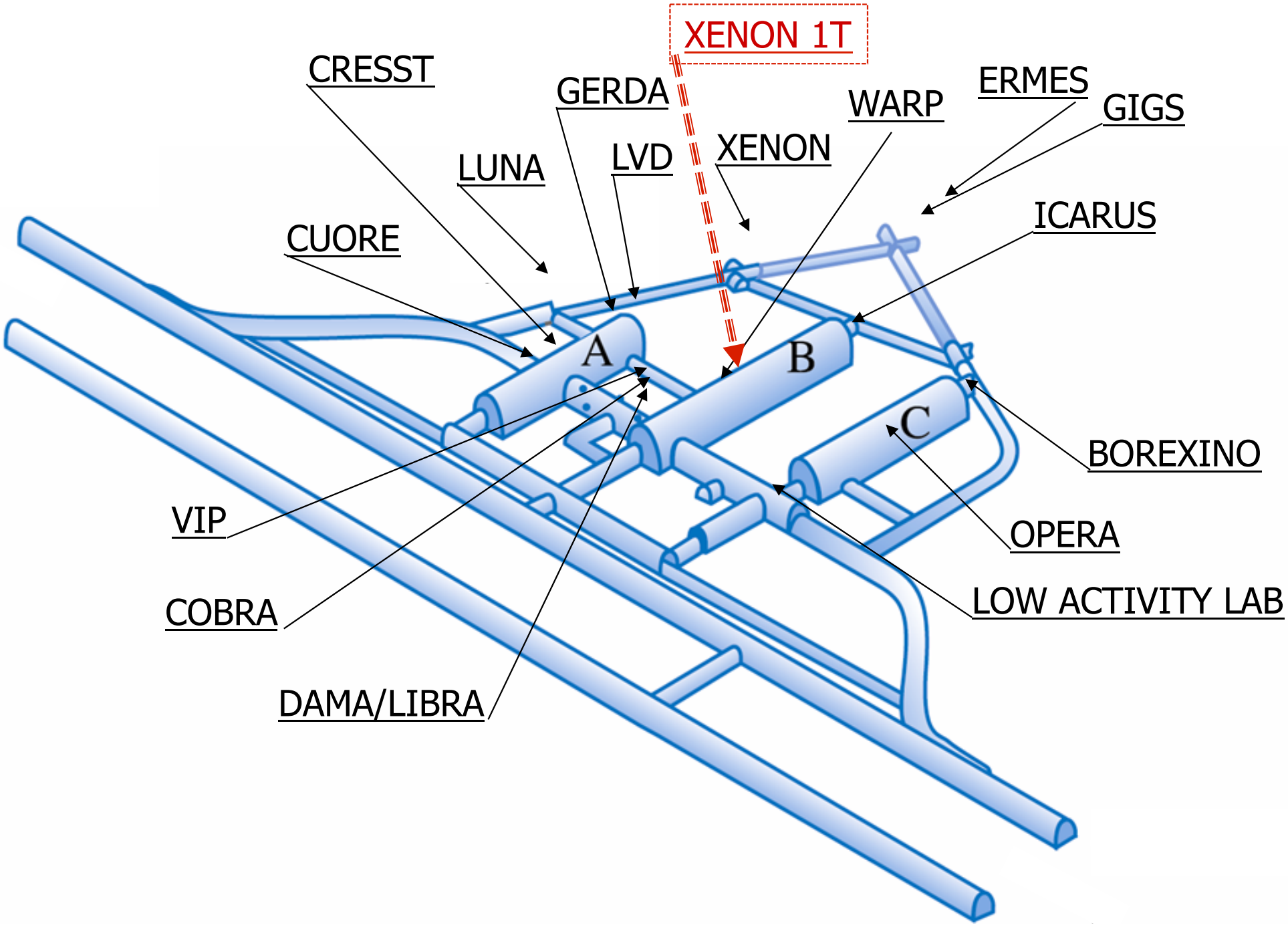
ISO 14001

Ventilation: 1 Lab volume/3 h

Electrical power: 1300 kW

Access: horizontal

OCCUPANCY


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

Laboratoire Souterrain de Modane

Depth: 4800 m.w.e.

Surface: 400 m2

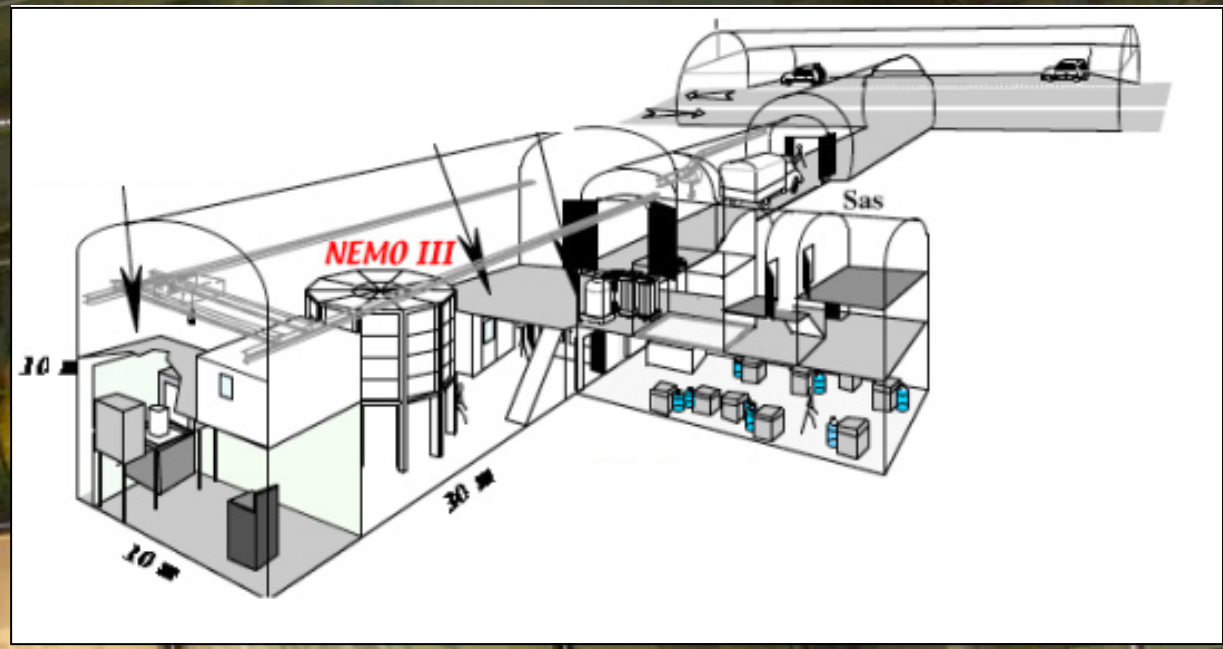
Volume : 3500 m^3

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

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

Laboratoire Souterrain de Modane

From a particle physics experiment to a multi-science plateform

1979 - 1981	1982- 1990	1990- 2000	2000 - ….

Construction	τ_p Experiment	Prototypes →	Experiments

Fundamental physics:

- Proton decay
- Neutrino: double beta decay, double EC
- Dark matter
- Nuclear structure

Multidisciplinary activities

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

DOMUS: LSM extension

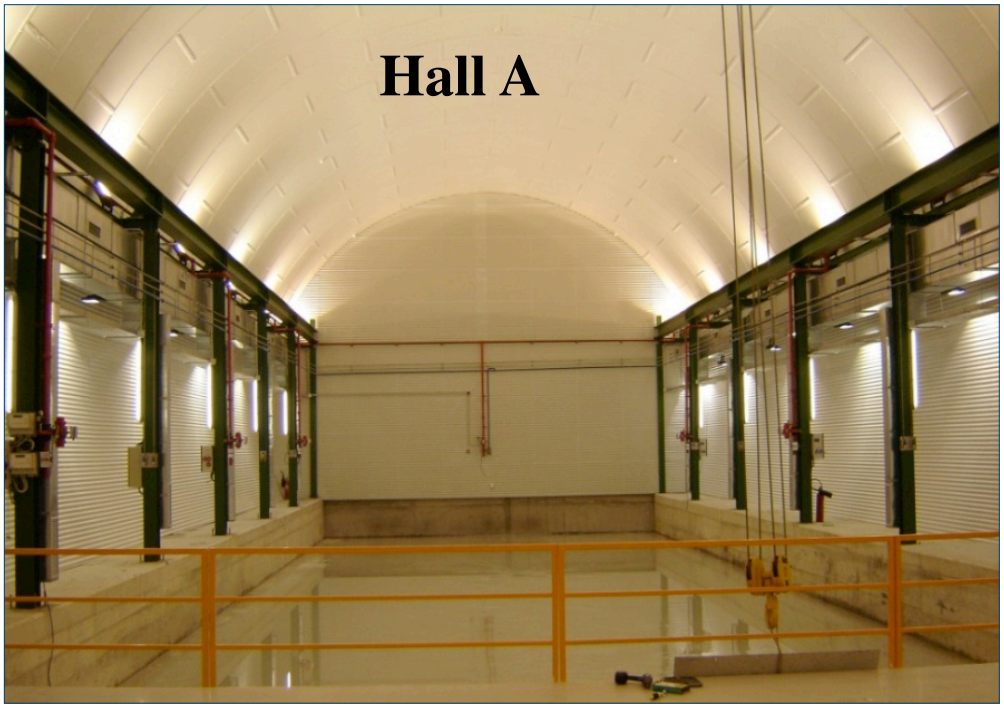
LSM Extension project

- Safety galery work started in September 2009
- Excavation of the extension : 2015.
- In operation in 2016.
- Detailed studies funded by Savoie departement and Rhone-Alpes Region
- Agreement from Ministery and CNRS for the project
- Funding almost secured (85% already obtained CNRS, Region Rhone-Alpes, FEDER funds)
- Technical discussion in progress

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

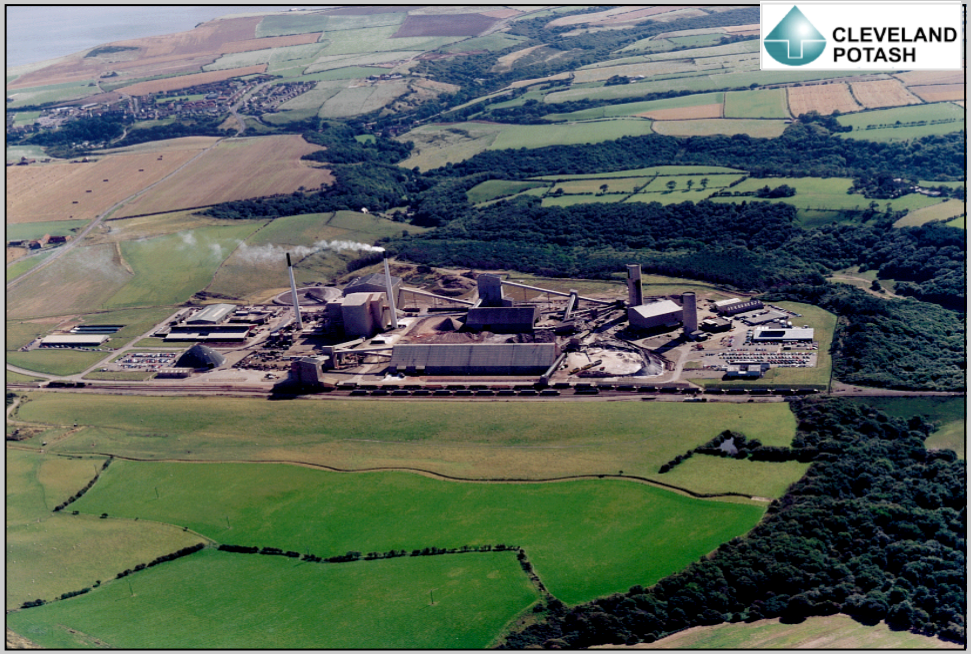
- Approved experiments (3 years running)
  - ✓ EXP-01-2008;LoI-2009 (ANAIS) — Dark Matter (NaI, Annual modulation)
  - ✓ EXP-02-2008;LoI-2009 (ROSEBUD) — Dark Matter (Scintillating bolometers)
  - ✓ EXP-03-2008;LoI-2009 (BiPo) — $0\nu2\beta$ decay (Ancillary to Super-NEMO)
  - ✓ EXP-05-2008;LoI-2009 (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

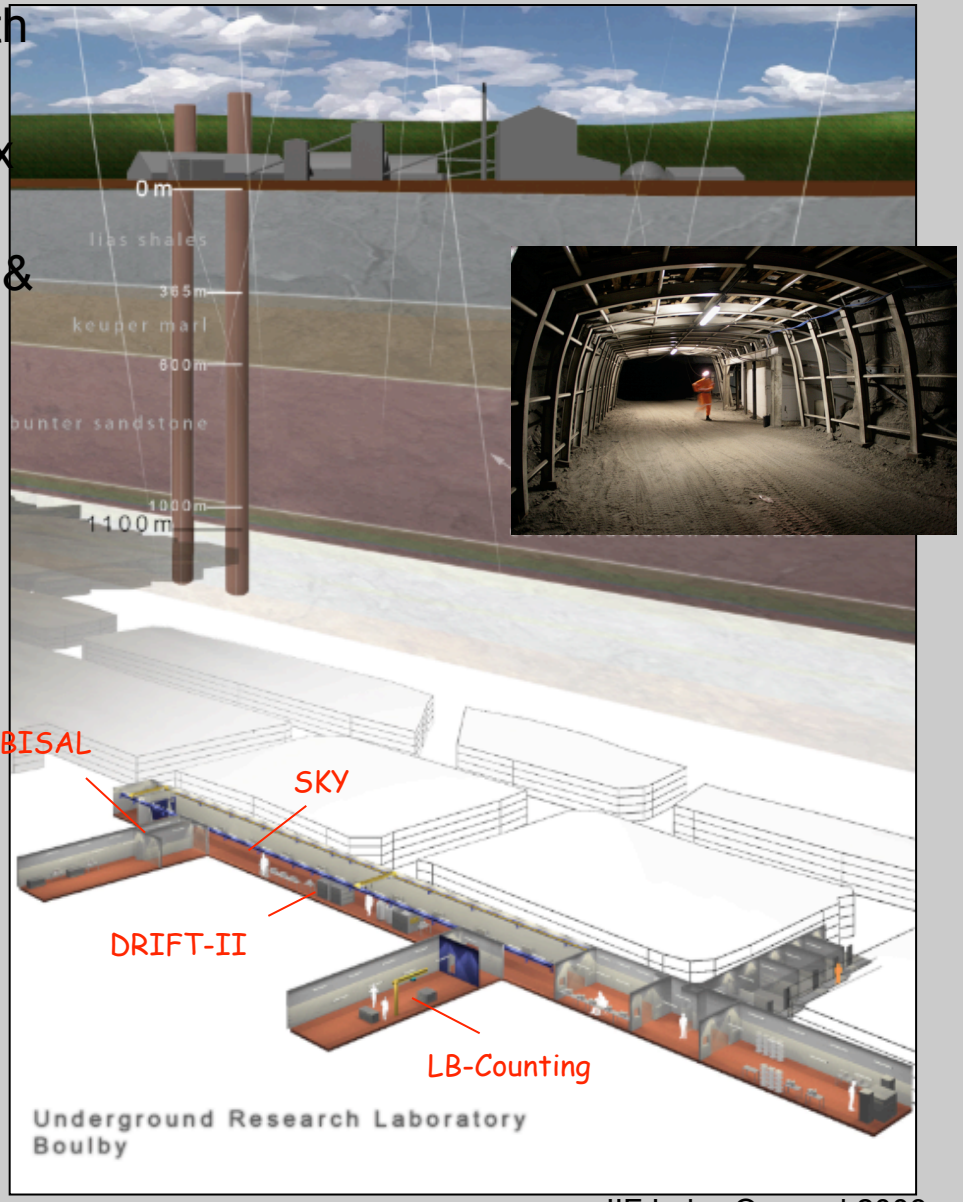
Boulby Underground Laboratory

A working potash and rock-salt mine on the North East coast of England

1100m deep (2805mwe) – Cosmic ray muon flux reduced by 10^6

Surrounding Rock Salt naturally low in Uranium & Thorium giving low gamma, neutron and Radon backgrounds.





JIF Lab - Opened 2003

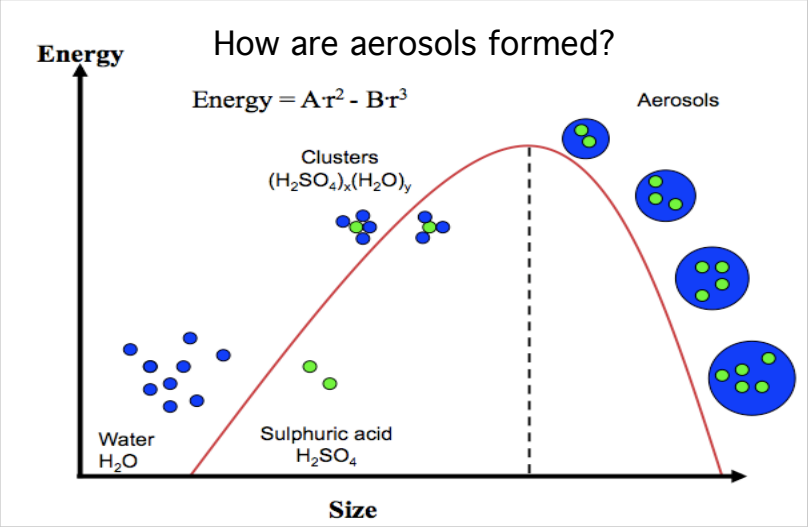
The SKY Project

An Danish/UK (EPSRC) study of the effect of ions on aerosol nucleation in the atmosphere - the 1st study in an ultra-low background environment.

'Cosmo-climatology': Ionisation from cosmic rays may have an influence on cloud production and mean cloud clover

SKY @ Boulby

Do Cosmic Rays play a role in aerosol formation & climate?



SKY-ZERO: Primary science runs @ Boulby completed 2008-2010. Next-generation detector 'SKY-II' now in preparation... Expected operation at Boulby 2013-2014

Participants: Boulby, Manchester, Oxford, Birmingham, Danish National Space Institute.

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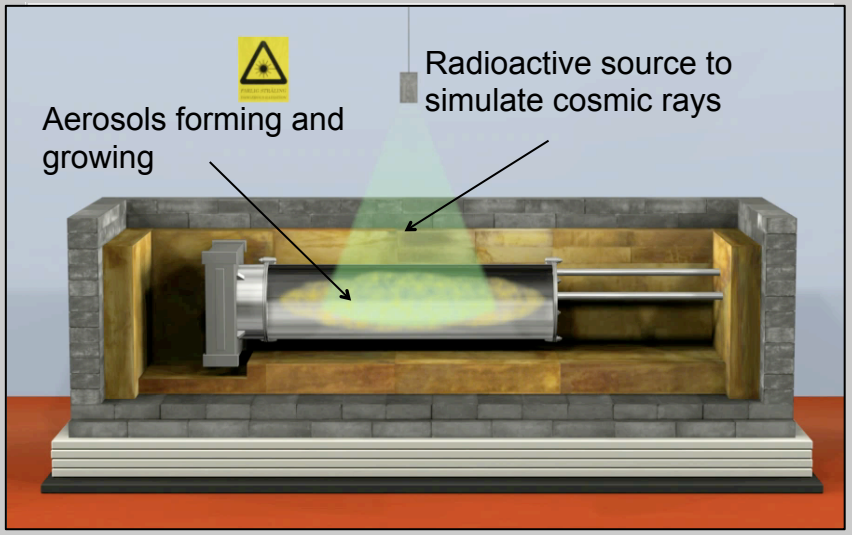

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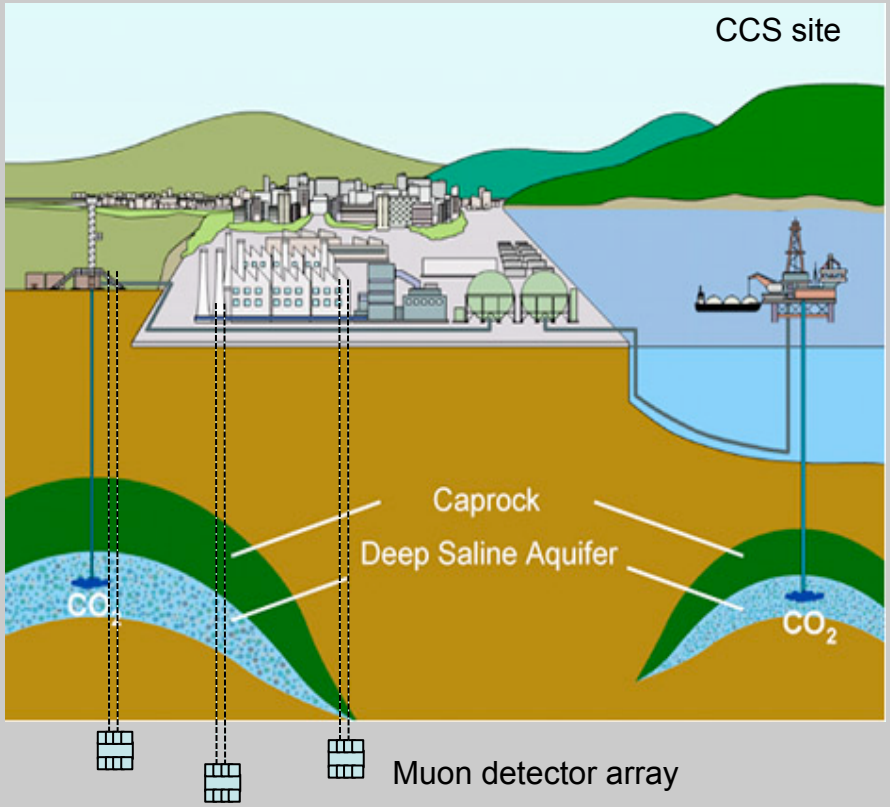
Muon Tomography @ Boulby

Development of a powerful new techniques for deep 3D geological surveying - using cosmic ray muons...

STFC-Boulby, Durham, Sheffield, Bath, NASA

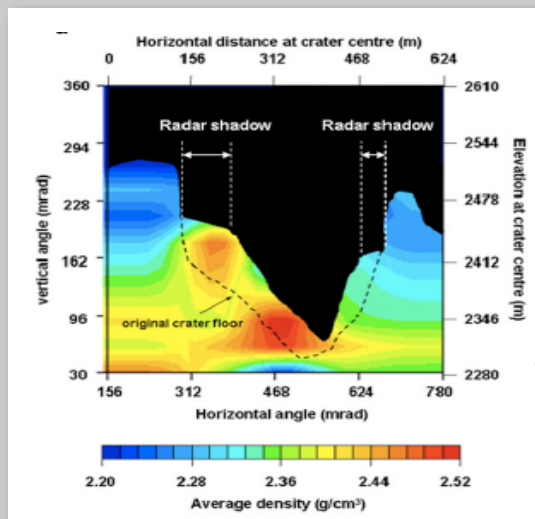


Muon Tomography: potentially of significant value for various deep geological mapping appls, inc CCS

Technique already proven for volcano interiors

Applications?
- Deep geological repository monitoring.
- Monitoring in Carbon Capture & Storage (CCS)

Why Muon tomography? Why Boulby?
- Potential for cheap, reliable, practical, real-time long-term monitoring of deep structures
-- Boulby site & skills uniquely well suited for development & testing: appropriate depths, ease of access, infrastructure & experstise, known geology



Already proven for shallower uses:
- Volacanos & pyramids interiors

Image from Mt Asama volcano study:
Earth & planetary Science Letters. 263 (2007) 104-113

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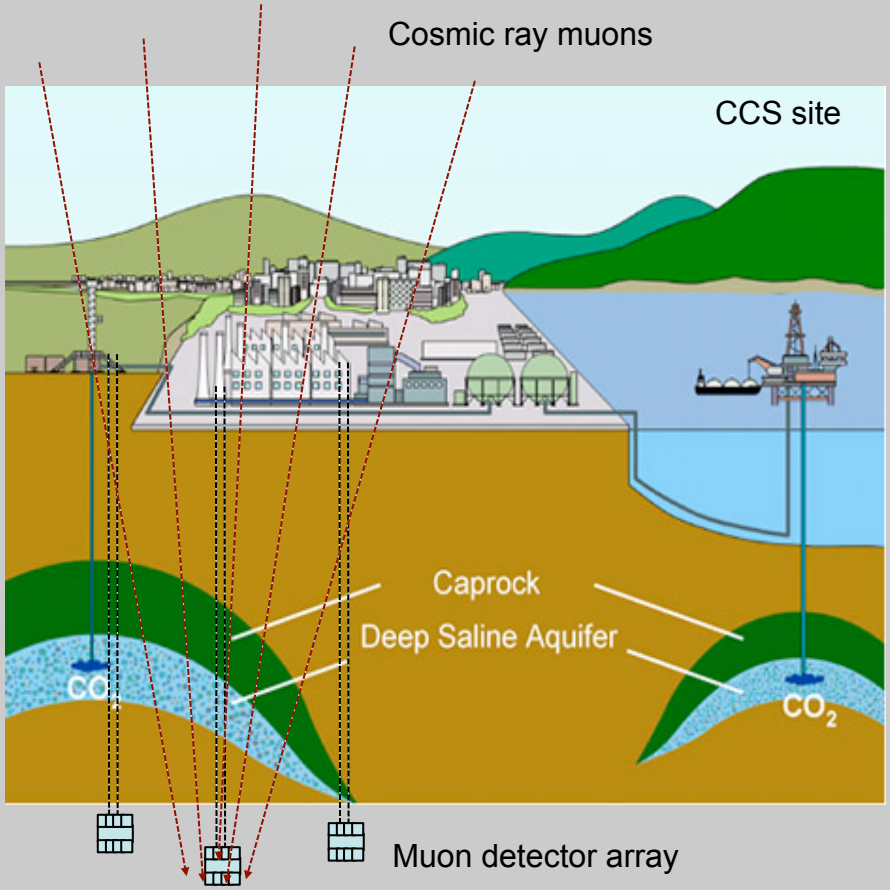

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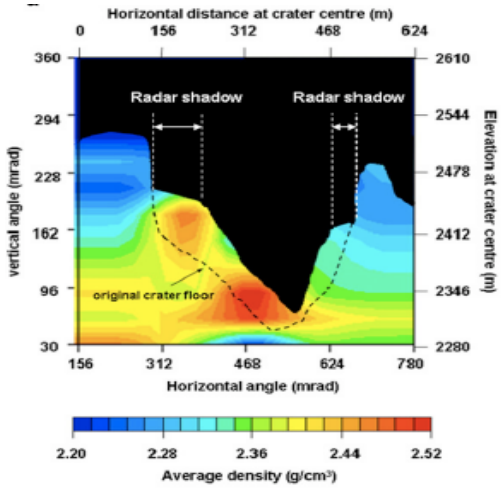

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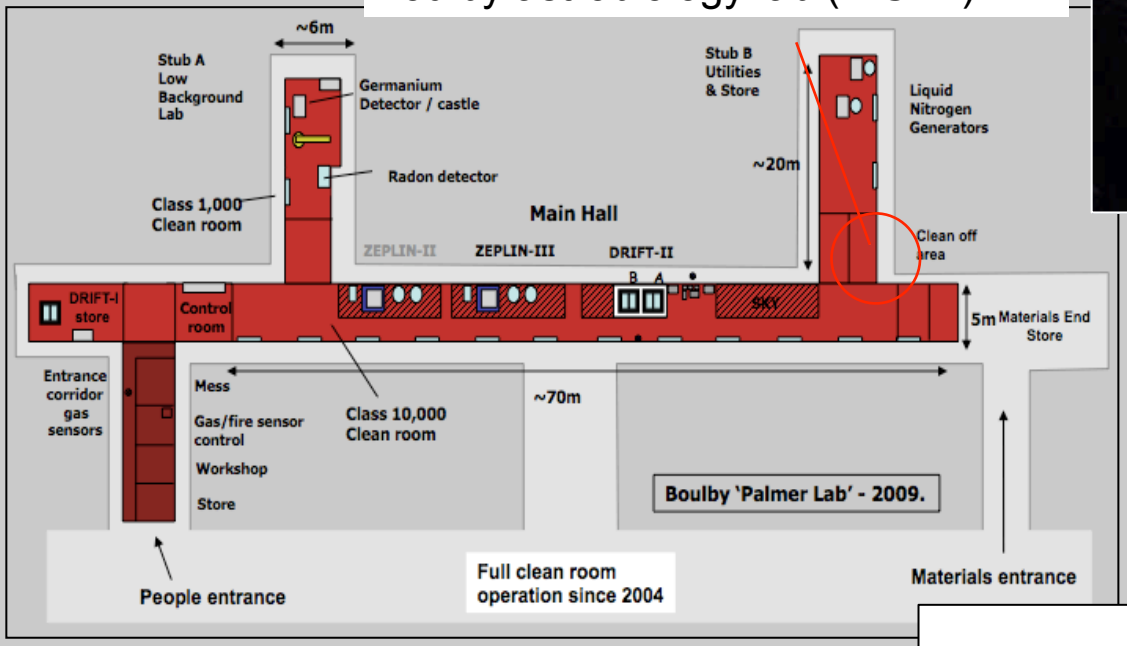
Image from Mt Asama volcano study:
Earth & planetary Science Letters. 263 (2007) 104-113

Geomicrobiology / Astrobiology

Development of an International Subsurface Astrobiology Facility – linked to Palmer Lab

Boulby facility provides:
- Clean, contamination-free labspace
- Supervised access to interesting geology
- Technology and physics expertise

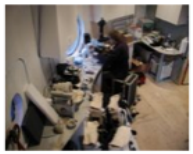
Boulby astrobiology lab (BISAL)



Key BISAL studies...
- Life in low background radiation
- Life salt and misc Boulby environs
- Exploitation as Mars analogue site.
- Application of astrobiology techniques to industrial challenges

Upcoming workshop: *From Outer Space to Mining.* Boulby 24th April 2013....

Boulby and Instrumentation for Earth and Space Exploration



From Outer Space to Mining

24th April 2013 at
Boulby Mine

A workshop for establishing a discourse between the mining and space industries to foster collaborations and promote technology sharing.

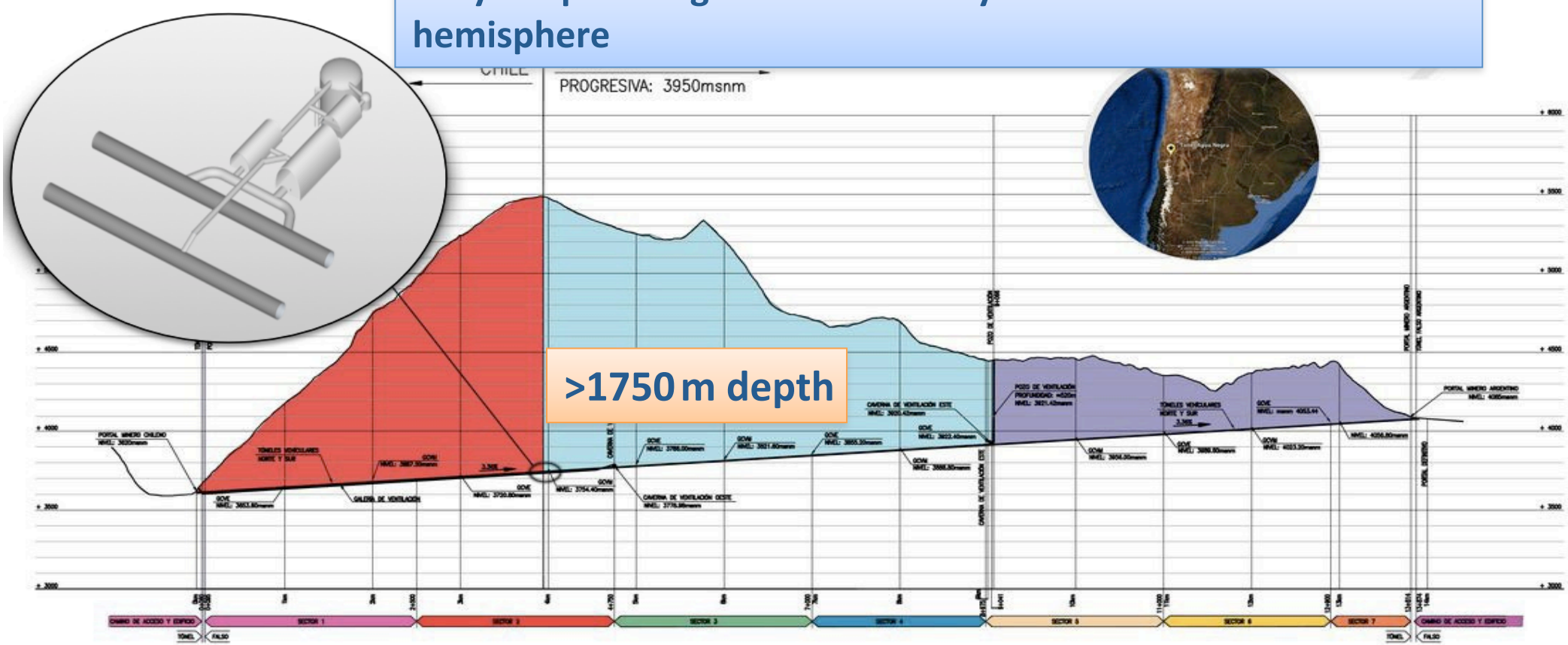
Attendees include personnel from:

CLEVELAND POTASH · NASA · esa · UK SPACE AGENCY · ANGLO AMERICAN · DLR · EADS astrium

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

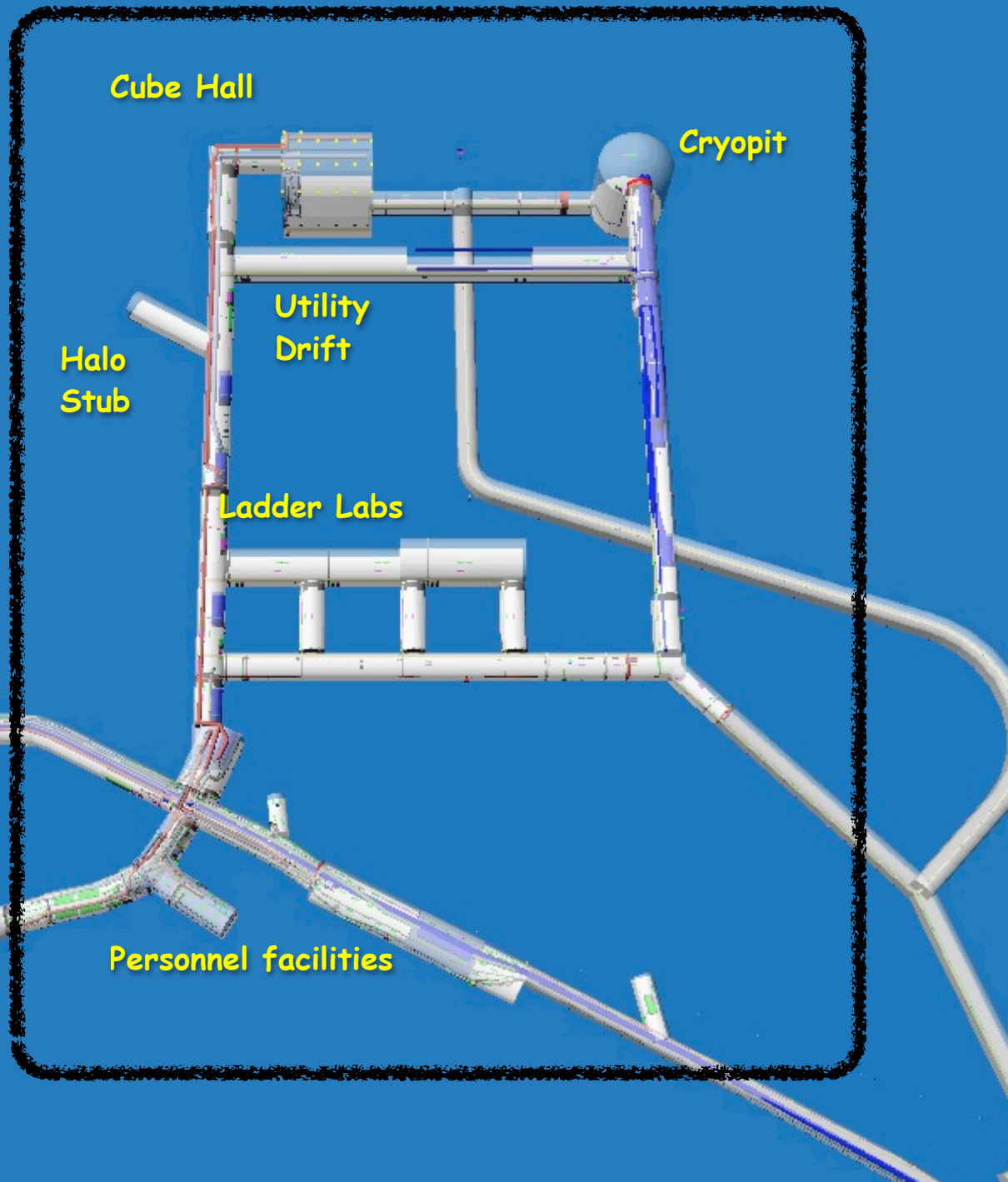


SNOLAB Facility

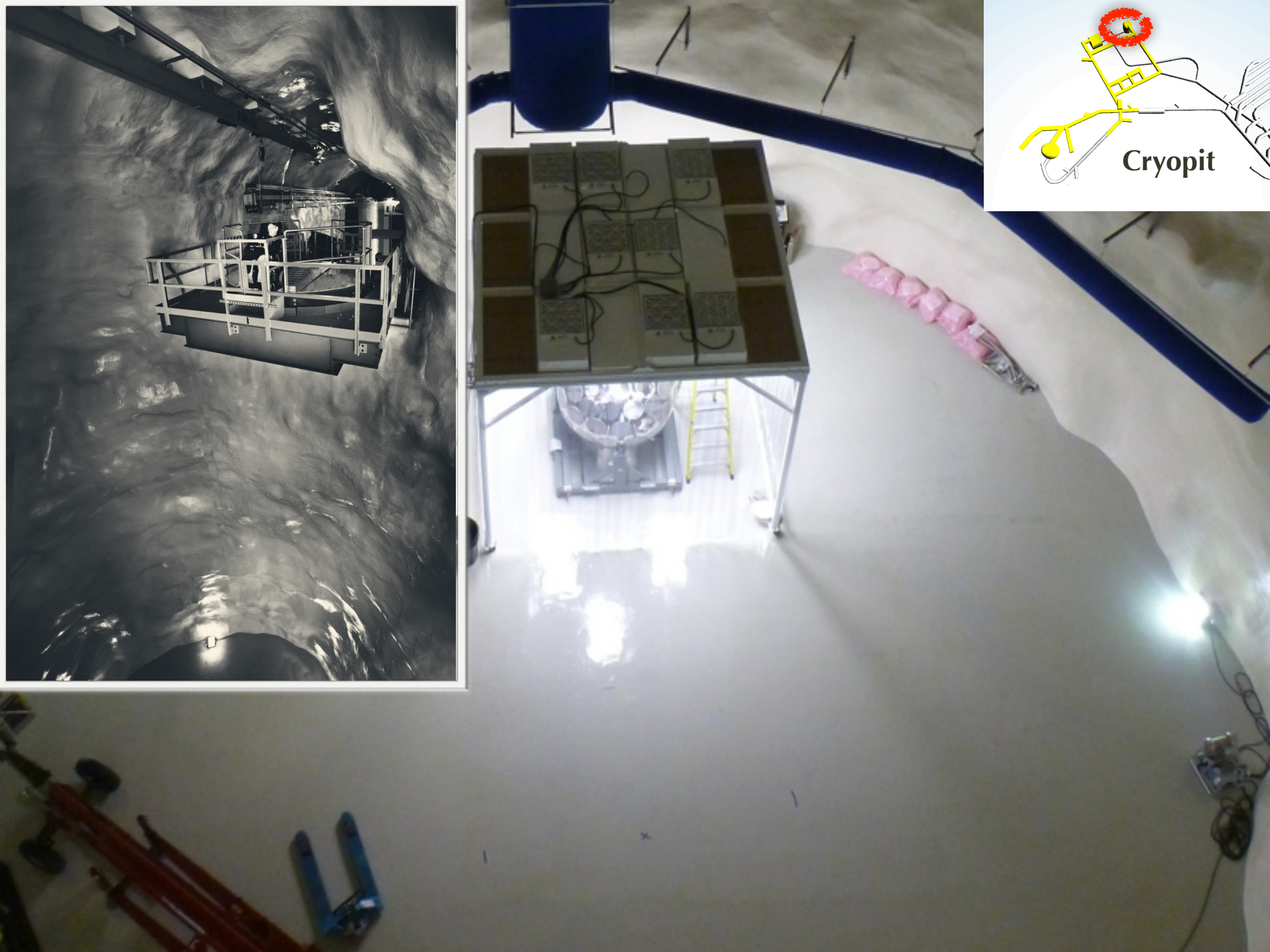
- Operated in the Creighton nickel mine, near Sudbury, Ontario, hosted by Vale.
- Underground campus at 6800' level, 0.27μ/m^2/day
- Entire lab at class-2000, or better, to mitigate against background contamination of experiments.
- Focus on ktonne dark matter, double beta decay, solar & SN neutrino experiments requiring depth and cleanliness.
  - Also provide space for prototyping of future experiments.
- Goal has been to progressively create a significant amount of space for an active programme as early as possible.
- 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 experiment setup and tests
- Underground Construction (5360 m^2)
  - Two additional large cavities (Cube Hall, Cryopit) and support drifts
  - Additional linear drifts for smaller scale experiments
  - Materials handling and cleaning areas; tram transportation
  - Personnel areas: refuge/galley, change areas/showers, offices, meeting room
- We are open! (Formal opening May, 2012)

Underground Facilities

SNOLAB Area: 5360 m^2



SNO Area: 1860 m^2

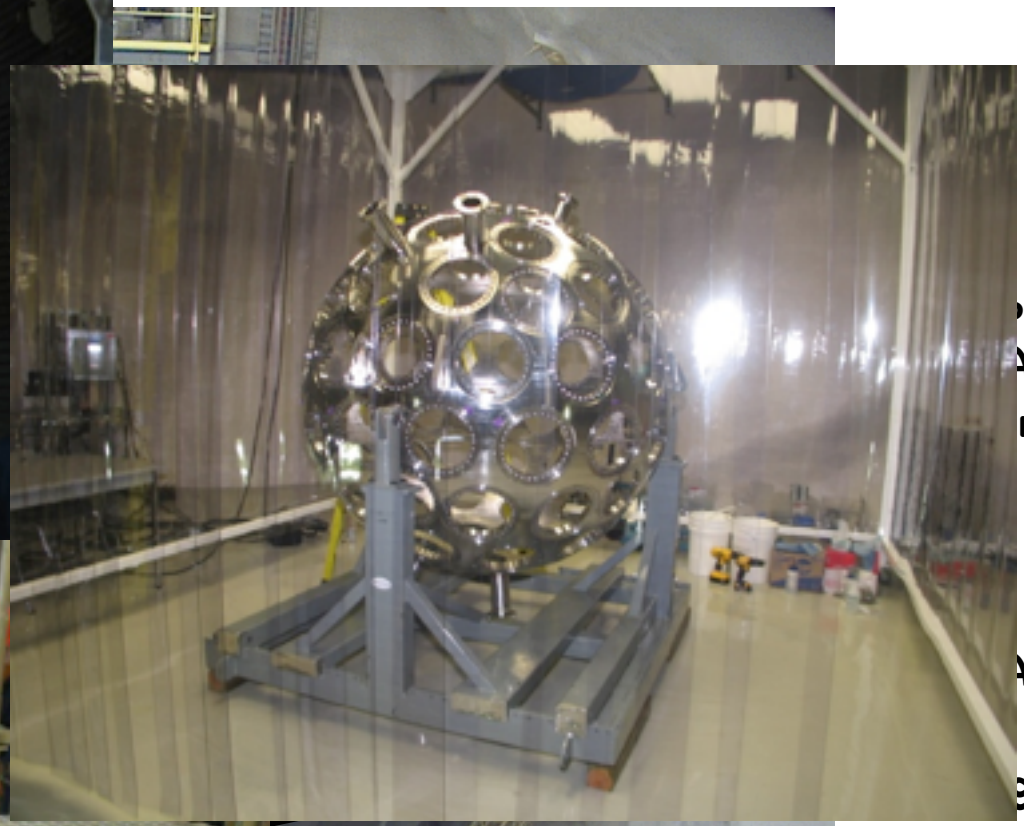

Cryopit

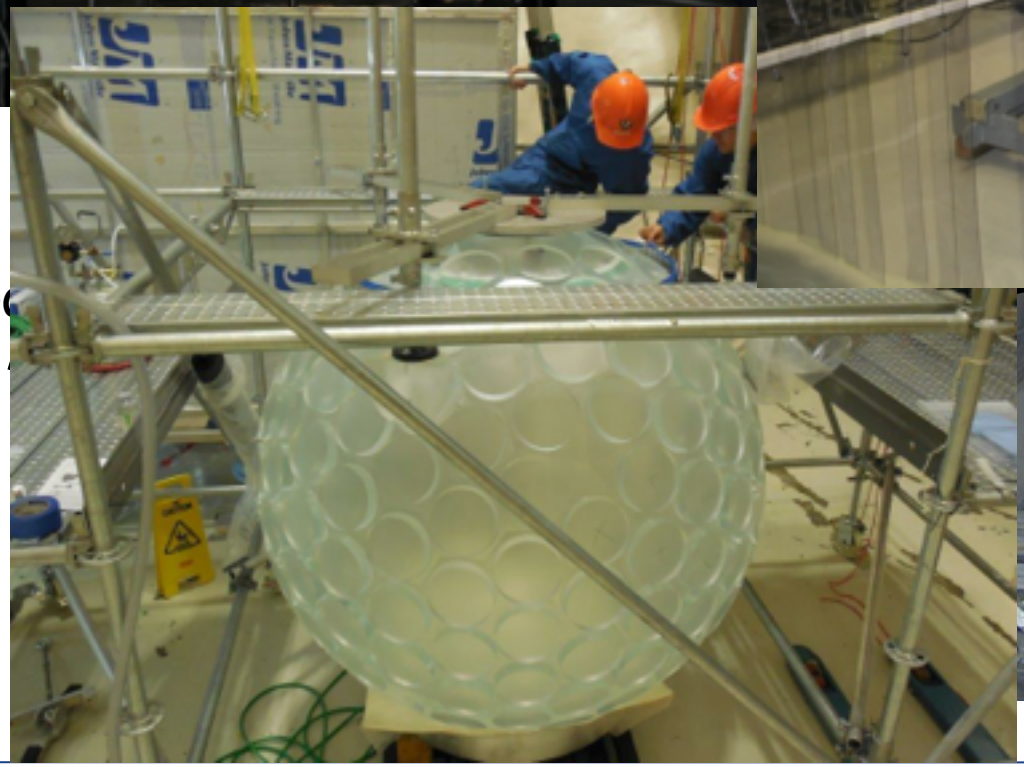
Current programme: Dark Matter at SNOLAB

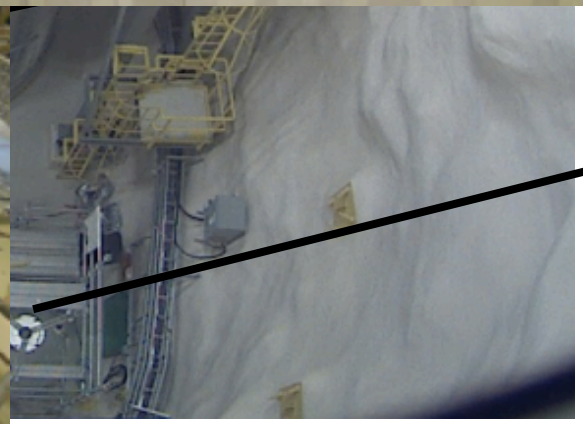
- Noble Liquids: DEAP-I, MiniCLEAN, & DEAP-3600
  - Single Phase Liquid Argon using pulse shape discrimination
  - Prototype DEAP-I operational in SNOLAB now. Successful demonstration of PSD and test bench for DEAP/CLEAN design/operations and background assessment.
  - Construction for DEAP-3600 and MiniCLEAN underway.
  - Will measure Spin Independent cross-section.
- Superheated Liquid / Bubble chamber: PICASSO, COUPP
  - Superheated droplet detectors and bubble chambers. Insensitive to MIPS radioactive background at operating temperature, threshold devices; alpha discrimination demonstrated;
  - PICASSO-III and COUPP-4 currently operational in SNOLAB, COUPP-60 construction underway.
  - Measure Spin Dependent cross-section primarily, COUPP has SI sensitivity
  - New world leading sensitivity published in 2012
- Solid State: DAMIC, SuperCDMS
  - State of the art CCD Si / Ge crystals with ionisation and phonon readout.
  - CDMS Currently operational in Soudan facility, MN. Next phase will benefit from SNOLAB depth to reach desired sensitivity.
  - Mostly sensitive to Spin Independent cross-section.

Cube Hall - DEAP/miniCLEAN

Cube Hall - DEAP/miniCLEAN







DE
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DEAP-360
AV
annealing
oven

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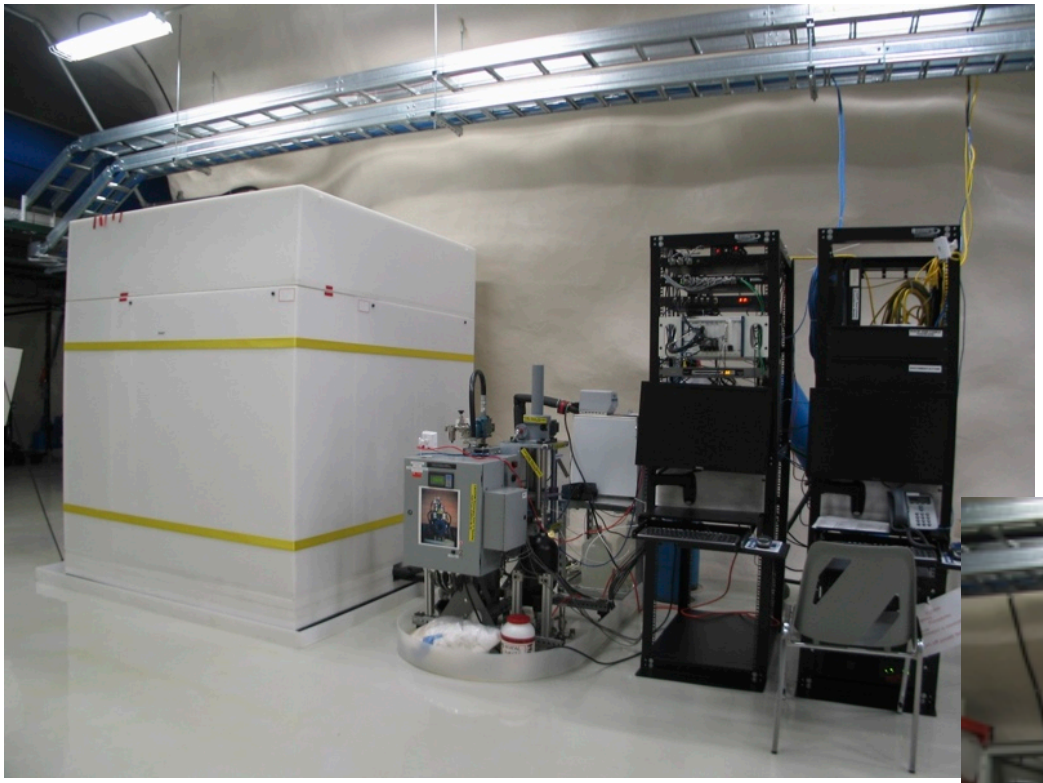
DEAP-36000
AV bonding

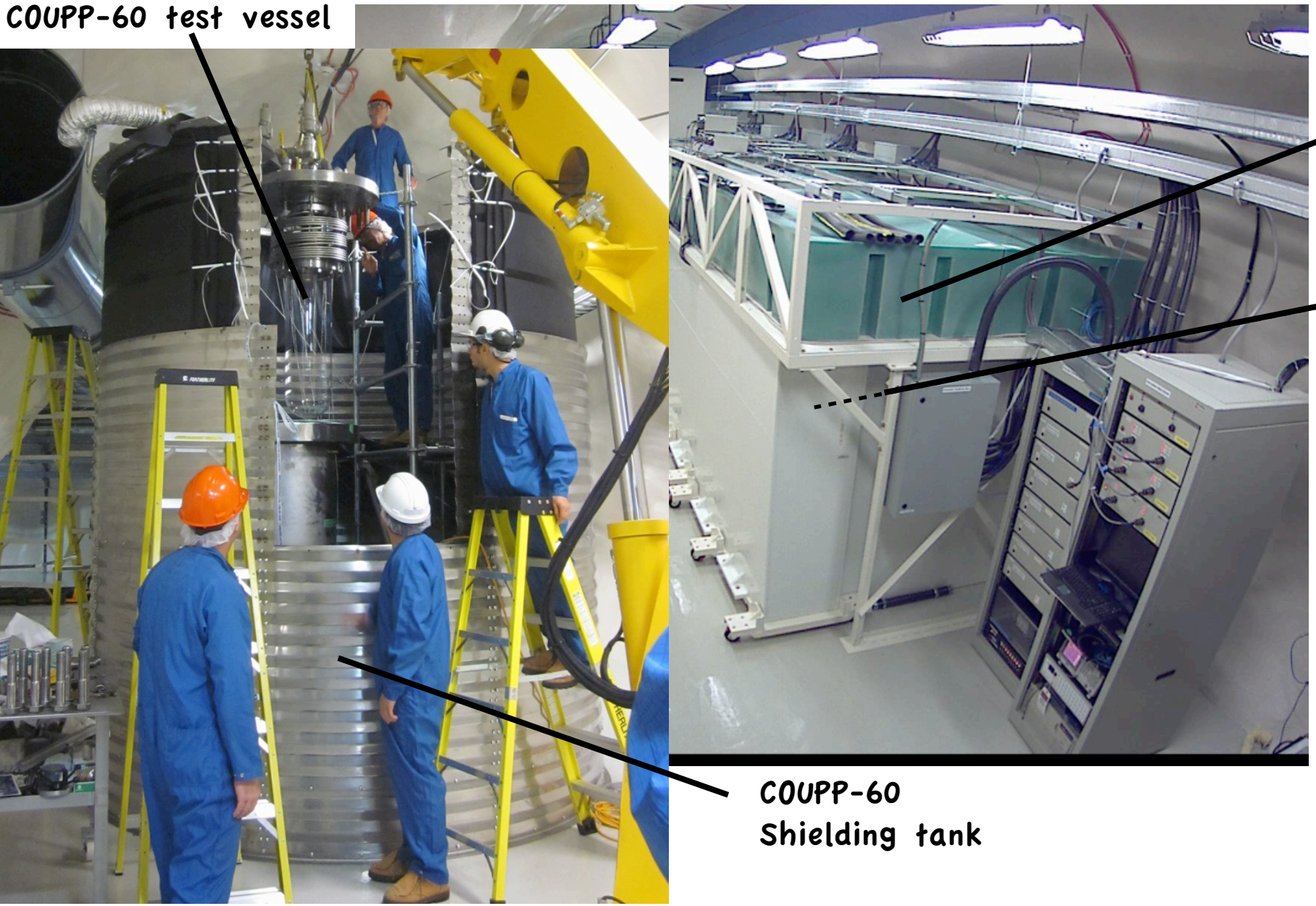
‘J’-Drift: R&D + rapid deployment



COUPP-4 bubble chamber, showing water tank shielding stack, pressure carts, DAQ racks

DAMIC CCD-based dark matter detector, focus on low mass WIMPS. (Currently 10g target, increase to 100g expected)

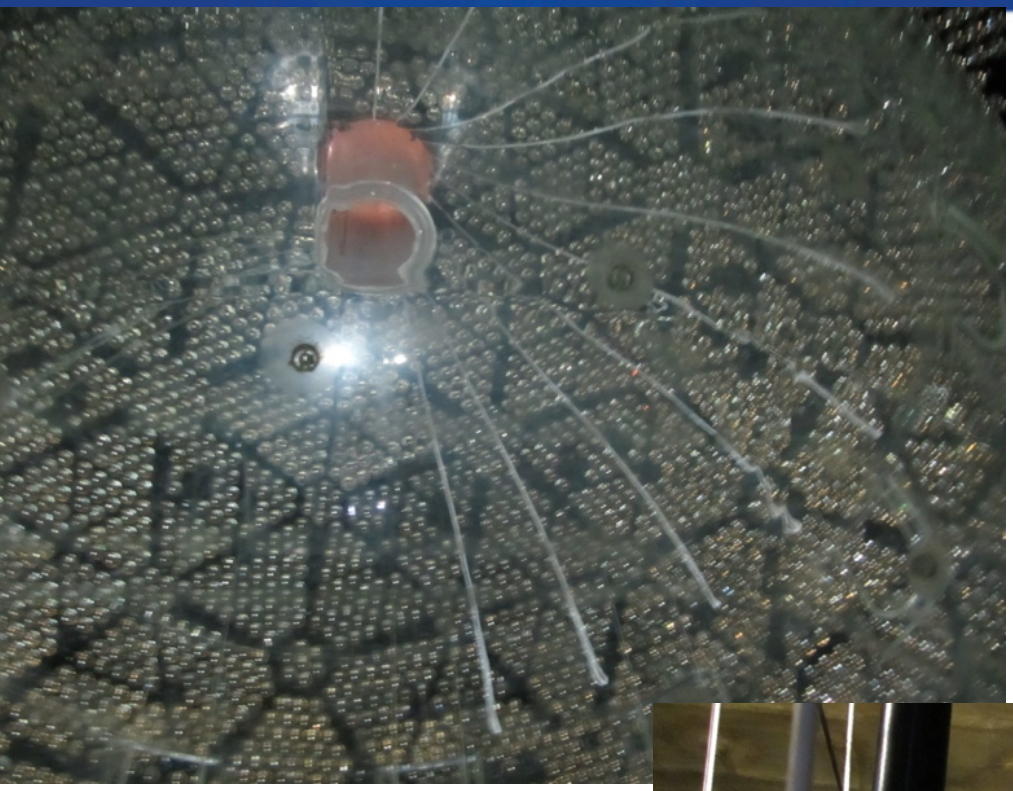
PICASSO and COUPP-60



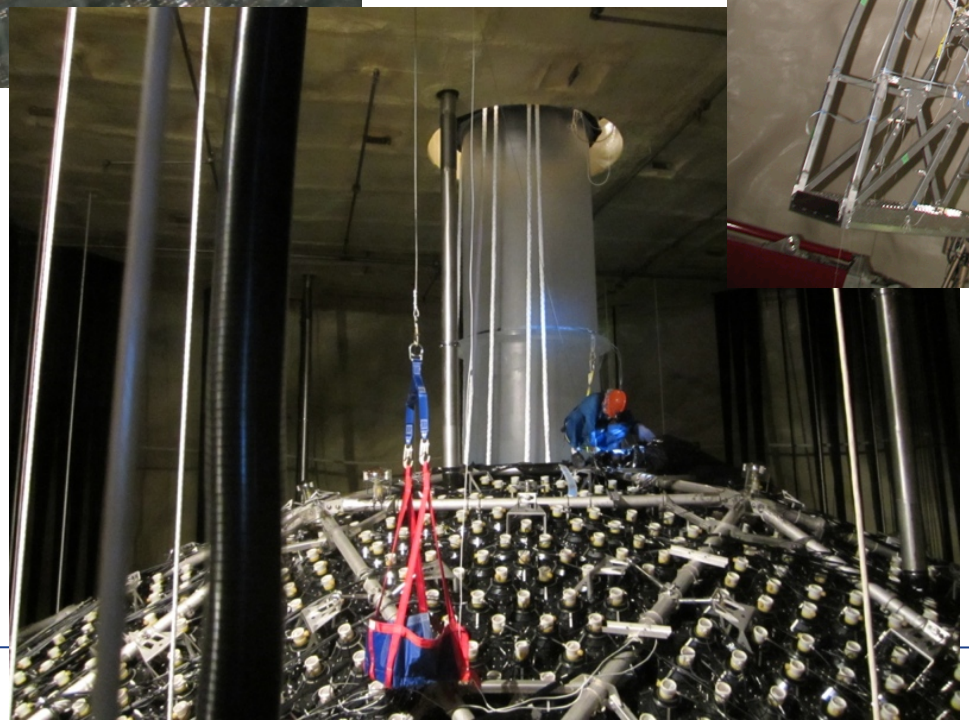
Current programme: $0\nu\beta\beta$ and neutrino at SNOLAB

- SNO+ : $^{150}Nd \rightarrow {}^{150}Sm + e^- + e^-$
  - Uses existing SNO detector. Heavy water replaced by scintillator loaded with ^{150}Nd. Modest resolution compensated by high statistical accuracy.
  - Requires engineering for acrylic vessel hold down and purification plant. Technologies already developed.
  - Will also measure
    - solar neutrino pep line (low E-threshold)
    - geo-neutrinos (study of fission processes in crust)
    - supernovae bursts (as part of SNEWS)
    - reactor neutrinos (integrated flux from Canadian reactors)
- EXO-gas : $^{136}Xe \rightarrow {}^{136}Ba^{++} + e^- + e^-$
  - Ultimate detector aim = large volume Xe Gas TPC
  - Developing technique to tag Ba daughter. Electron tracking capability.
  - Development work at SNOLAB surface facility
- HALO: Dedicated Supernova watch experiment
  - Charged/neutral current interactions in lead
  - Re-use of detectors (NCDs) and material (Pb) from other systems
  - Operational May 2012
  - Will form part of SNEWS array

SNO+ Developments



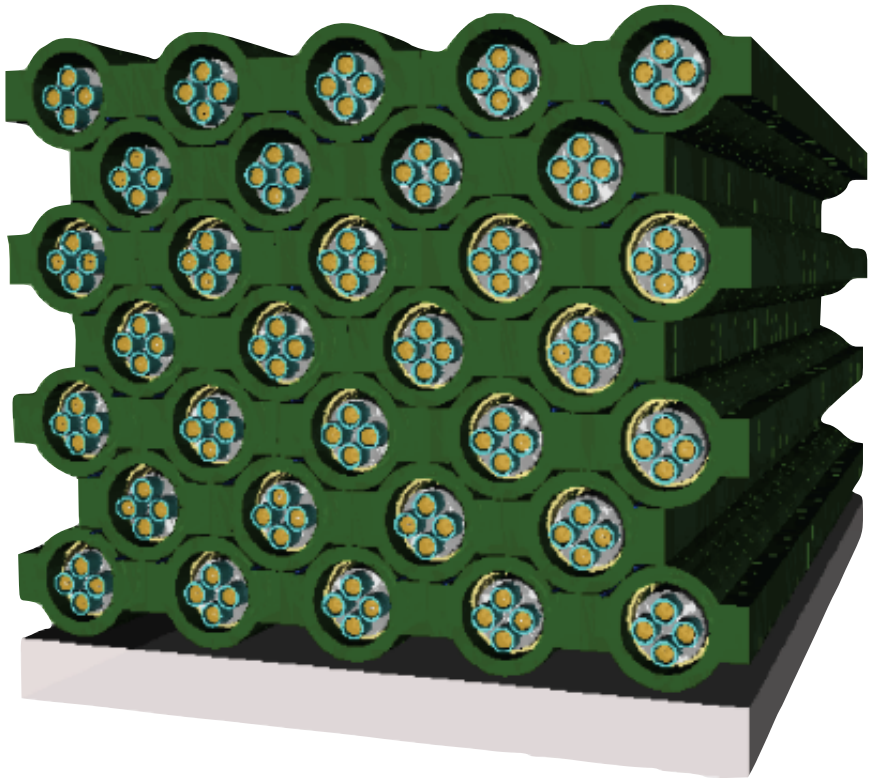
Deployment of the new hold-down rope net, and replacing hold-up ropes with lower activity ones.



Development of a scaffold for lapping radon off the acrylic vessel

HALO - a Helium and Lead Observatory

A "SN detector of opportunity" / An evolution of LAND – the Lead Astronomical Neutrino Detector, C.K. Hargrove et al., Astropart. Phys. 5 183, 1996.



"Helium" – because of the availability of the ^{3}He neutron detectors from the final phase of SNO

+

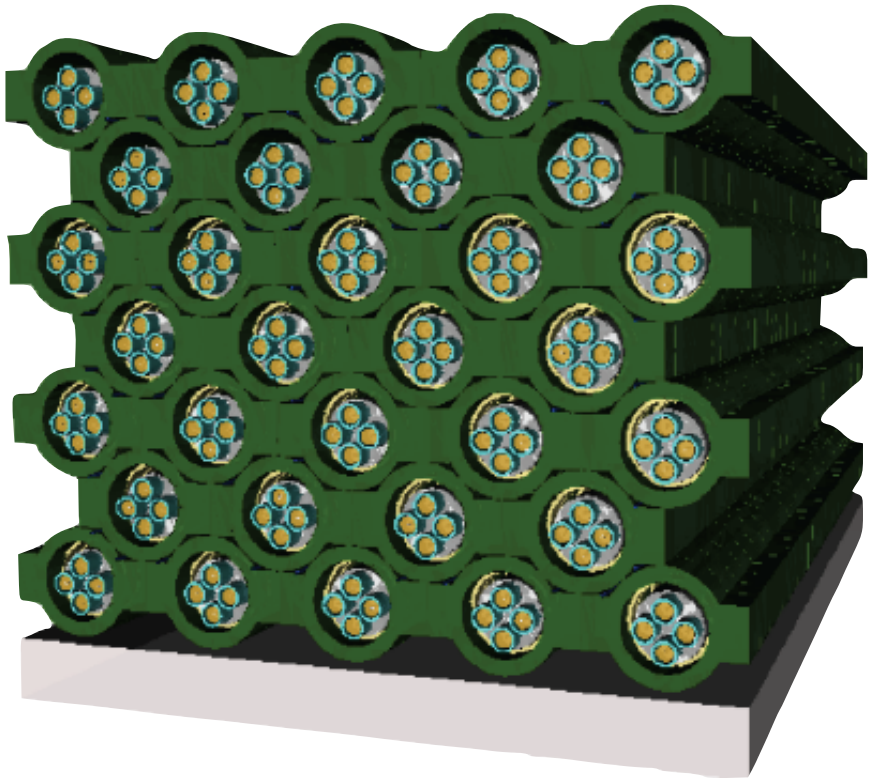
"Lead" – because of high ν-Pb cross-sections, low n-capture cross-sections, complementary sensitivity to water Cerenkov and liquid scintillator SN detectors

HALO is using lead blocks from a decommissioned cosmic ray monitoring station

Slide courtesy of C.Virtue, HALO

HALO - a Helium and Lead Observatory

A "SN detector of opportunity" / An evolution of LAND – the Lead Astronomical Neutrino Detector



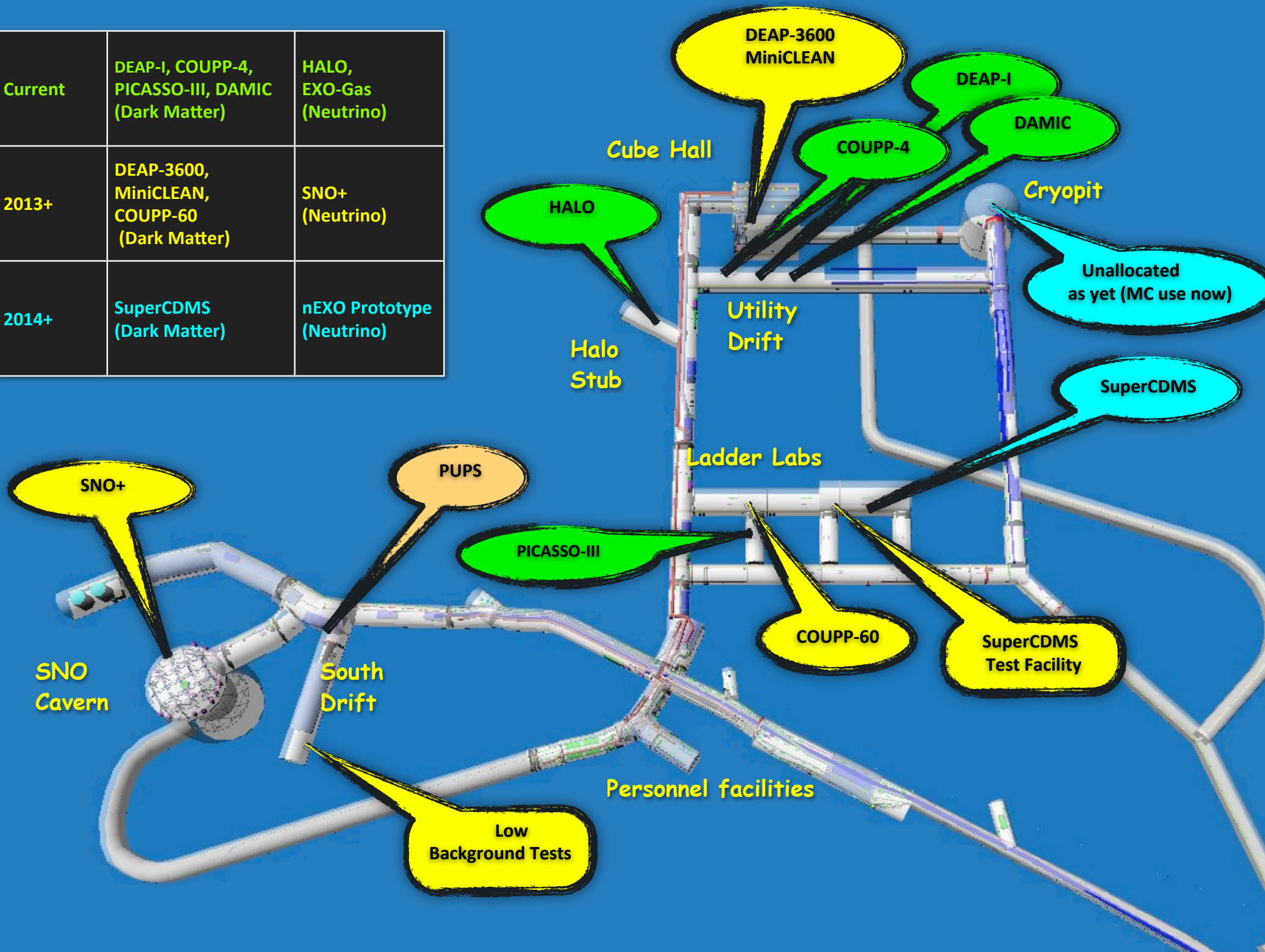
HALO is using lead blocks from a decommissioned cosmic ray monitoring station

Slide courtesy of C.Virtue, HALO

SNOLAB Programme

Experiment	Solar nu	$0\nu\beta\beta$	Dark Matter	SuperNovae	Geo nu	Other	Space allocated	Status
COBRA		√					Ladder Labs	Request
COUPP-4			√				Ladder Labs	Operational
COUPP-60			√				Ladder Labs	In Construction
DAMIC			√				Ladder Labs	In Construction
DEAP-1			√				J'-Drift	Operational
DEAP-3600			√				Cube Hall	In Construction
EXO-gas		√					Ladder Labs	Request
HALO				√			Halo Stub	Operational
MiniCLEAN			√				Cube Hall	In Construction
PICASSO-III			√				Ladders Labs	Operational
PUPS						Seismicity	Various	Completed
SNO+	√	√		√	√		SNO Cavern	In Construction
SuperCDMS			√				Ladder Labs	Approved

Current	DEAP-I, COUPP-4, PICASSO-III, DAMIC (Dark Matter)	HALO, EXO-Gas (Neutrino)
2013+	DEAP-3600, MiniCLEAN, COUPP-60 (Dark Matter)	SNO+ (Neutrino)
2014+	SuperCDMS (Dark Matter)	nEXO Prototype (Neutrino)



Facility developments

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

Site	Size	Status	Available
Kamioka	+ 5.5 $x10^3 m^3$	Complete	2008
SNOLAB	3 $x10^4 m^3$	Complete	2009
LSC	8 $x10^3 m^3$	Complete	2010
CJPL	1.7 $x10^3 m^3$	Complete	2011
SURF	>3 $x10^4 m^3$	Complete	2012
Yangyang	1.6 $x10^4 m^3$	In Construction	2012+
LSM	4 $x10^4 m^3$	Planned	2013+
LBNE/SURF	>$10^5 m^3$	Planned	2015+
ANDES	7.5 $x10^4 m^3$	Planned	2017
Baksan	4 $x10^4 m^3$	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 term
- SNOLAB is formally open for business!
  - Initial science programme operational
  - Large scale detectors being installed at the moment