Review

Astroparticle Physics Research at Underground Facilities

Tony Noble
Queen's University
Canada

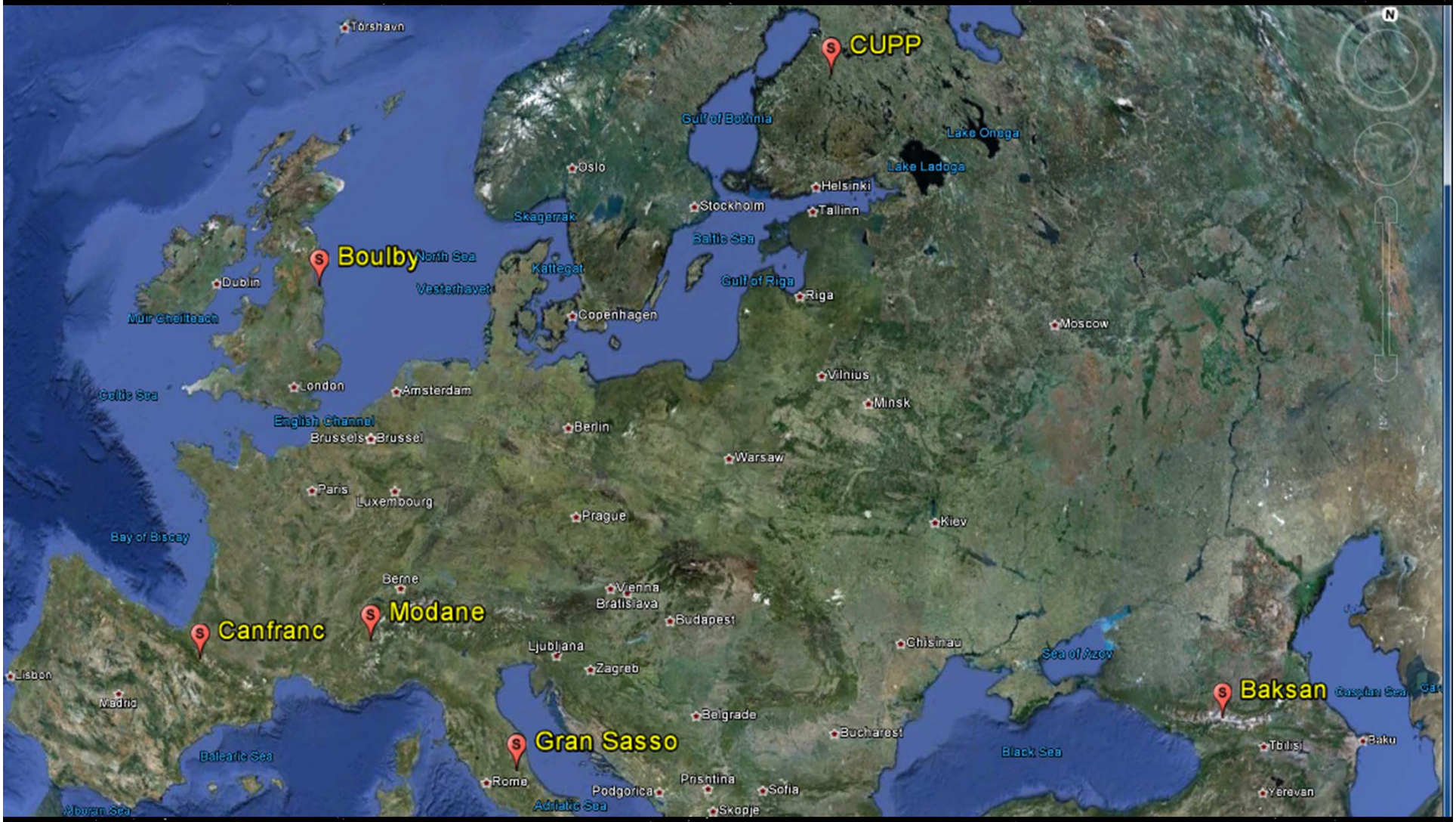
Outline

- A Tour of the International Labs
- Scientific Program Overview
- Facility Status & Plans
- Low Background Capacity
- Summary

Caveat Lector:

- Many thanks to the overwhelming response I had when contacting the directors of the various underground labs… when asked for a couple of slides, they provided dozens… 180 in all. I have tried to distill this down into a manageable size for this talk, so necessarily left out some information.
- I have focused on the large deap underground facilities dedicated to a program of particle astrophysics … leaving out entirely labs with a very specialized mandate, such as isolated facilities for low background counting…. We will hear about those independently.

6 Facilities on the European Continent



Canfranc

Located in the Spanish Pyrenees near the border with France

Access is horizontal.

Thanks to A. Bettini for providing updated information

LSC: Laboratorio Subterráneo de Canfranc

Current Status:

- Operational. Experiments under construction.

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

Surface Facility

Chemistry — Electroforming, Environmental analyses

Mechanics

Electronics

Computers & Network

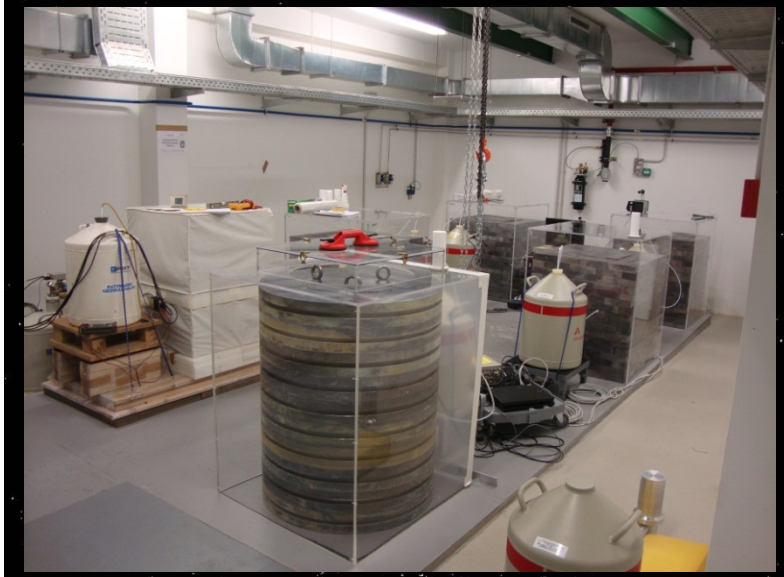
LSC: Laboratorio Subterraneo Canfranc

Current Status:

- Operational. Experiments under construction.
- **Support personnel: 12**
- **Users: 645**
- **Visits (2011): 239**

- Low activity: 7 HP Ge counters and related analysis software

- Clean room ISO 7 and 6 & mechanical shop

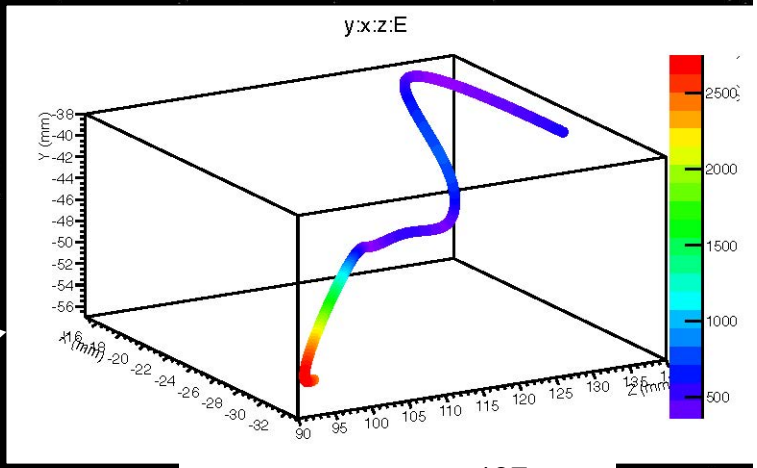


Experimental Program

	Active Program			Future Considerations
	Dark Matter	0νββ	Other	
Canfranc	ANAIS ROSEBUD ArDM	NEXT	Geodyn	CUNA LAGUNA

Experiments under construction

ANAIS	DM (NaI, Annual modul.)
ROSEBUD	DM (Scintillating Bolometers)
ArDM	DM (2phase Ar TPC)
NEXT	$0\nu2\beta$ (Enr ^{136}Xe gas TPC)
GEODYN	Geodynamics



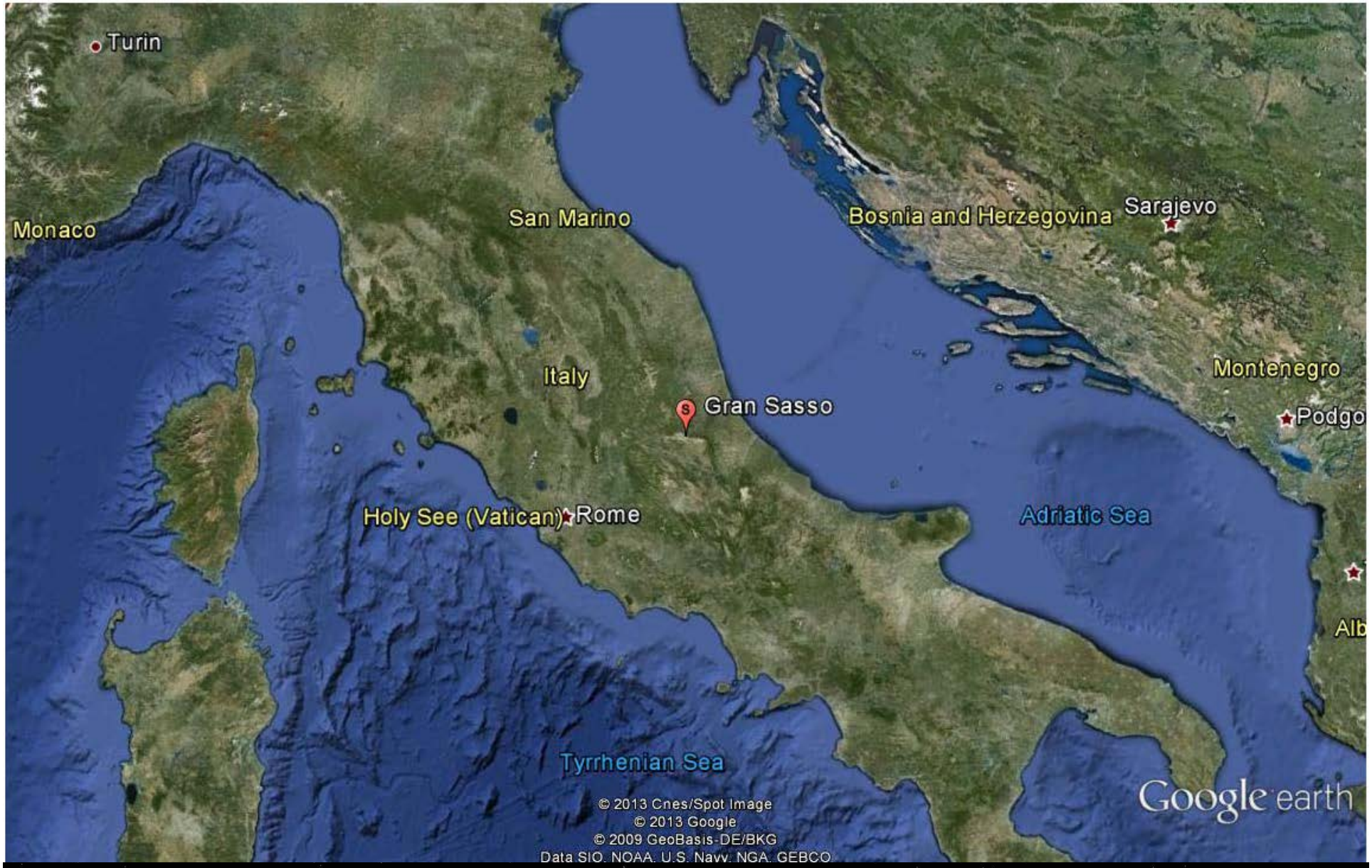
e$^-$ track from ^{137}Cs

Future Possibilities

CUNA	Accelerator for Nuclear astrophysics: 300 m^2 facility in planning
LAGUNA	

Plus

BiPo	$0\nu2\beta$ (screening for S-NEMO)
SuperK-Gd	screening for Super-K-Gd



Thanks to S. Ragazzi for providing updated information

LNGS Gran Sasso

LSNG: Laboratori Nazionali del Gran Sasso

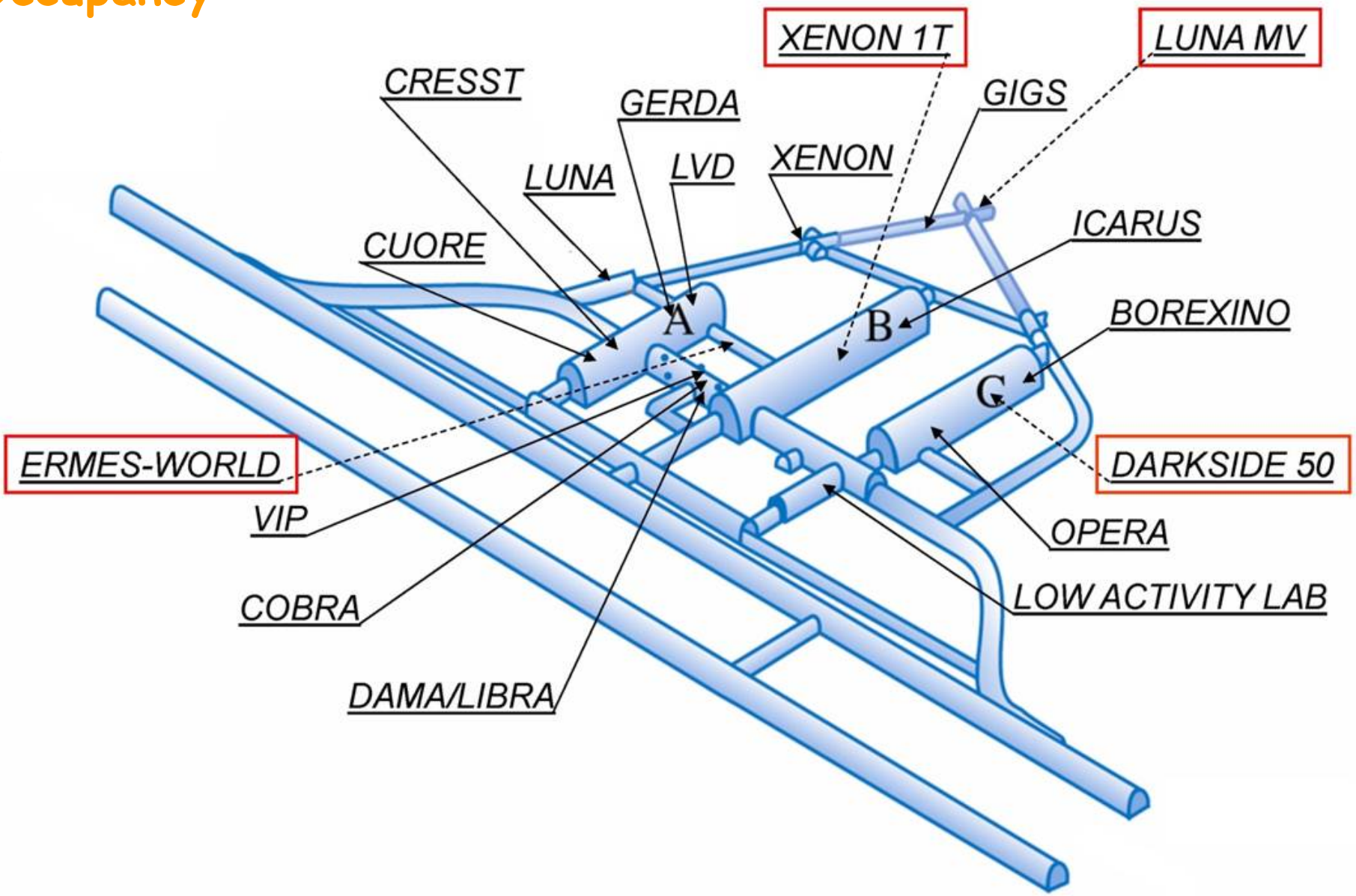
Largest underground laboratory in the world

- 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

Broad Physics Program:

- 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
LUNA MV
CRESST
GERDA
GIGS
LUNA
LVD
XENON
ICARUS
CUORE
BOREXINO
A
B
G
ERMES-WORLD
DARKSIDE 50
VIP
OPERA
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA

Experimental Program

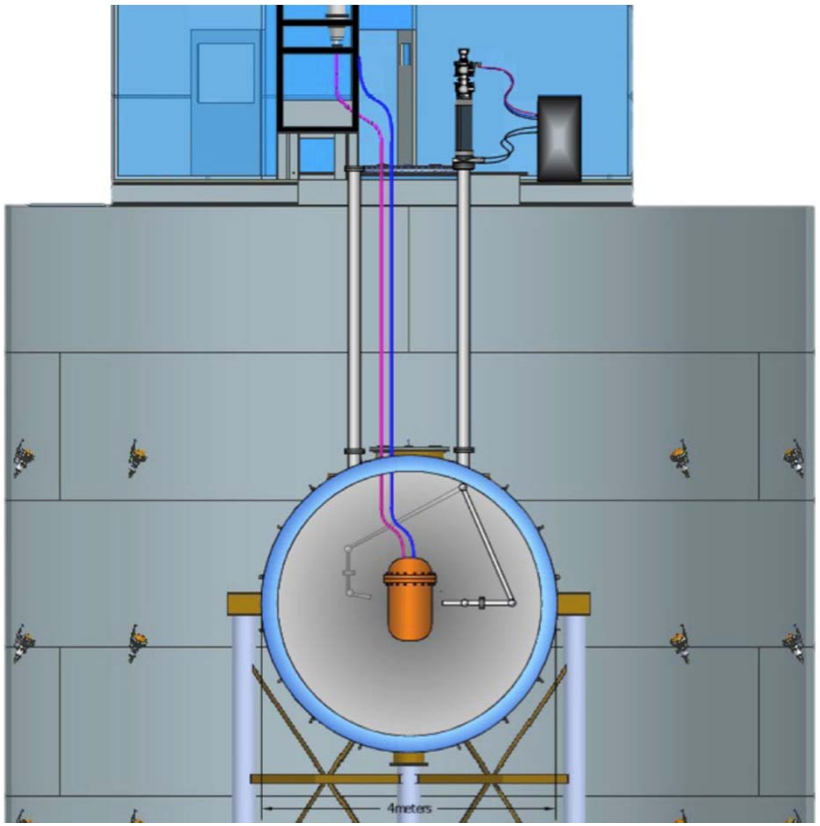
	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Gran Sasso	Dama/Libra CRESST Xenon Darkside	Gerda Cobra Cuore Opera Icarus Borexino LVD	Luna/Luna MV VIP GIGS	Xenon 1000

Active Experiments		Active Experiments	
Dama/Libra	DM (NaI, Annual modul.)	Opera	CNGS neutrino
Cresst	DM (Cryogenic detectors)	Icarus	CNGS neutrino
Xenon 100/1T	DM (2phase Xe)	LVD	Neutrino
Darkside 50	DM (2 phase Ar)	VIP	Violation of PEP
Gerda	$0\nu2\beta$	GIGS	Geo-seismisity
Cobra	$0\nu2\beta$	Luna/Luna MV	Accel. Nucl Astrop
Cuore	$0\nu2\beta$	Plus	
Borexino	Solar neutrino	Ermes-World	Low Back Counting

DarkSide

- Two-phase depleted (in ^{39}Ar) Lar TPC
- LAr technology earlier developed at LNGS in the past (WArP)
- Prototype with 10 kg of Lar in operation underground since one year
- 50kg detector in construction

DarkSide50



Thanks to F. Piquemal for providing updated information

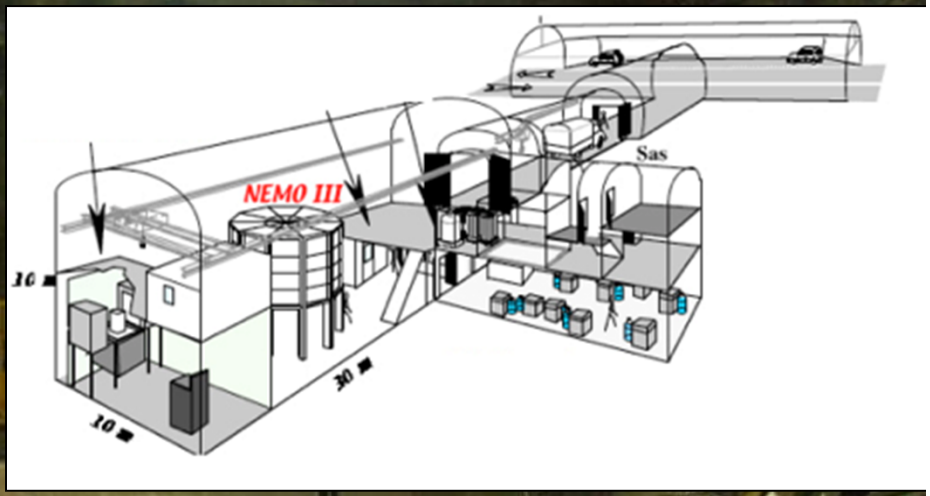
LSM Modane

Laboratoire Souterrain de Modane

Depth: 1700 m
4800 m.w.e.

Surface: 400 m2

Volume : 3500 m^3



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)

Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Modane	Edelweiss II	SuperNemo Sedine	TGV SHIN	Eureca DM Mimac DM

Active Experiments

Edelweiss II	DM (Ge cryogenic)
SuperNemo	$0\nu2\beta$ (various targets)
Sedine	SuperNova neutrino detector
TGV	Nucl Structure: Double electron capture
SHIN	Nucl Structure: Super Heavy Elements

Future:

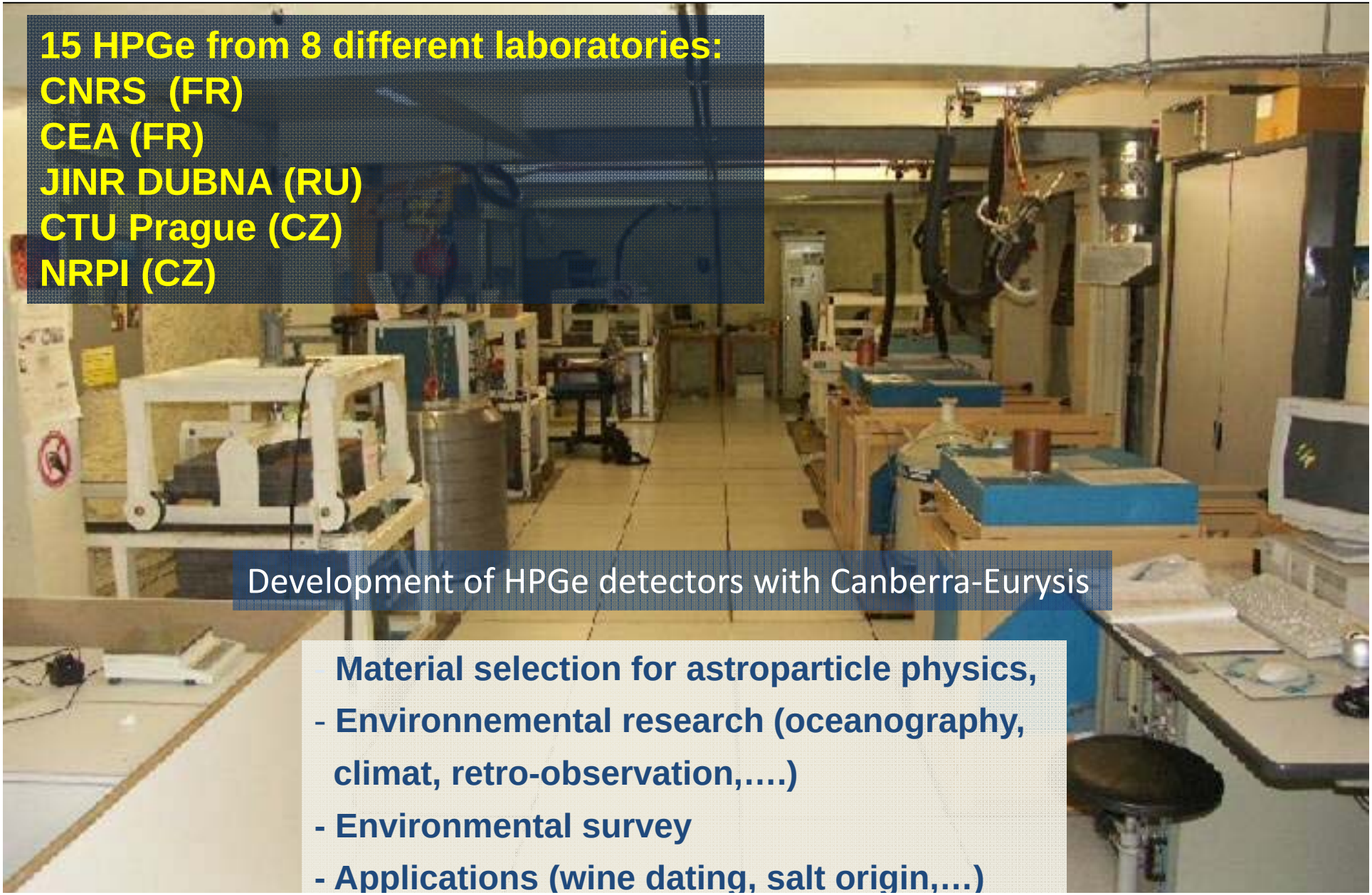
R&D towards Eureca (DM) and Mimac (DM with directional sensitivity)

Plus:

Low Background expertise: HPGe, Radon detectors, neutron detectors…

Biology

Gamma ray spectroscopy @ LSM

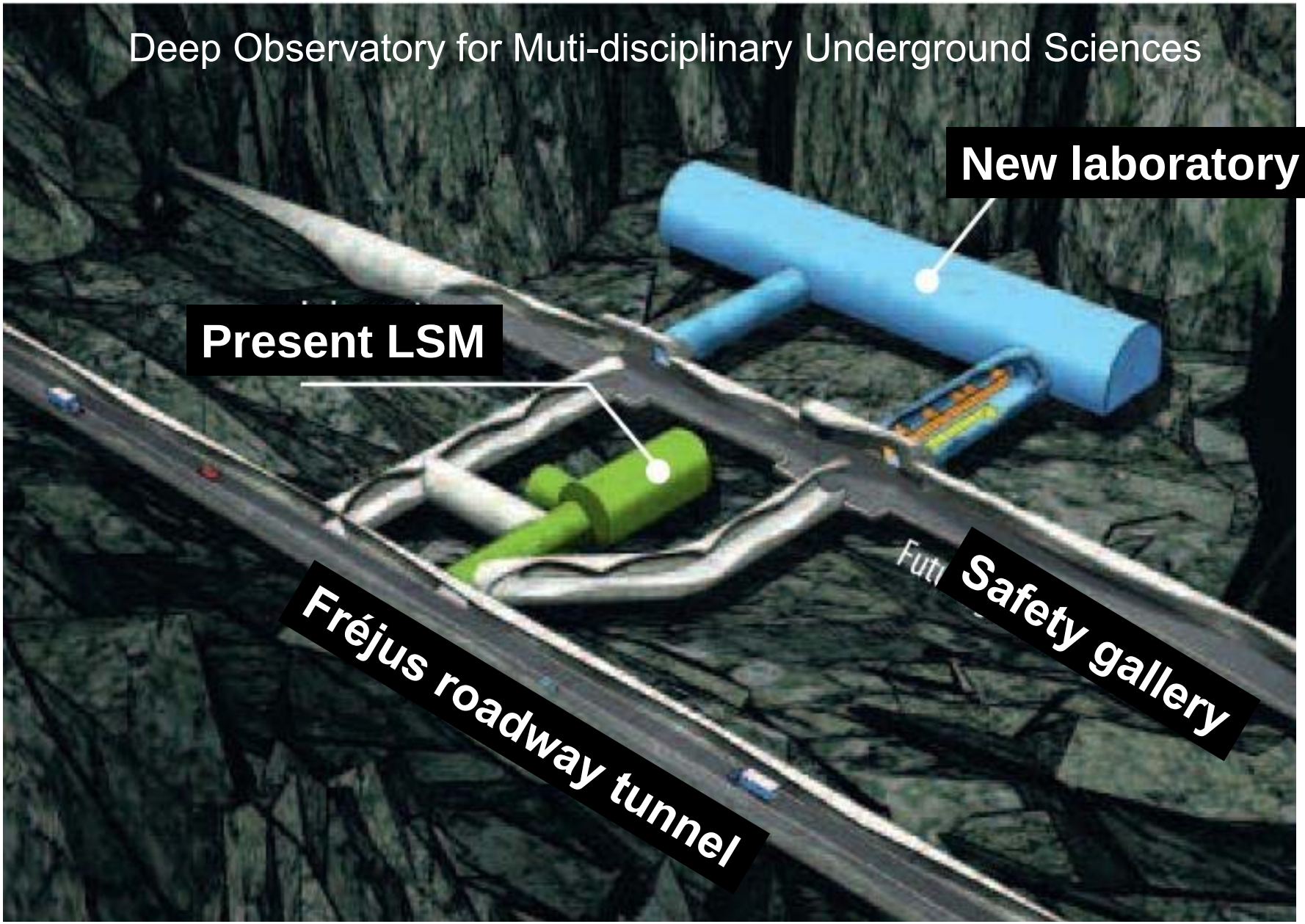


15 HPGe from 8 different laboratories:
CNRS (FR)
CEA (FR)
JINR DUBNA (RU)
CTU Prague (CZ)
NRPI (CZ)

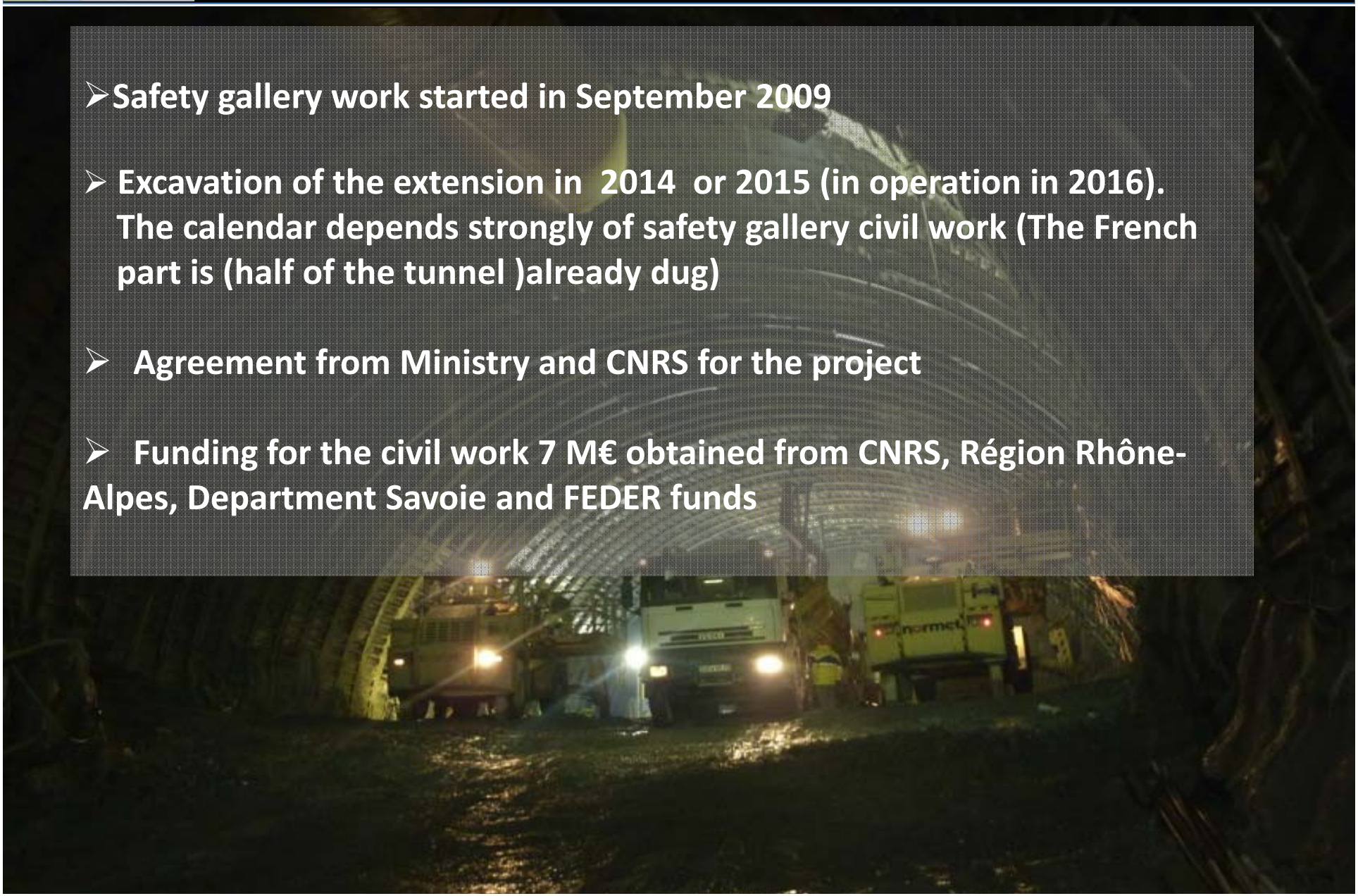
Development of HPGe detectors with Canberra-Eurysis

- **Material selection for astroparticle physics,**
- **Environnemental research (oceanography, climat, retro-observation,….)**
- **Environmental survey**
- **Applications (wine dating, salt origin,…)**

DOMUS: LSM extension



LSM Extension project



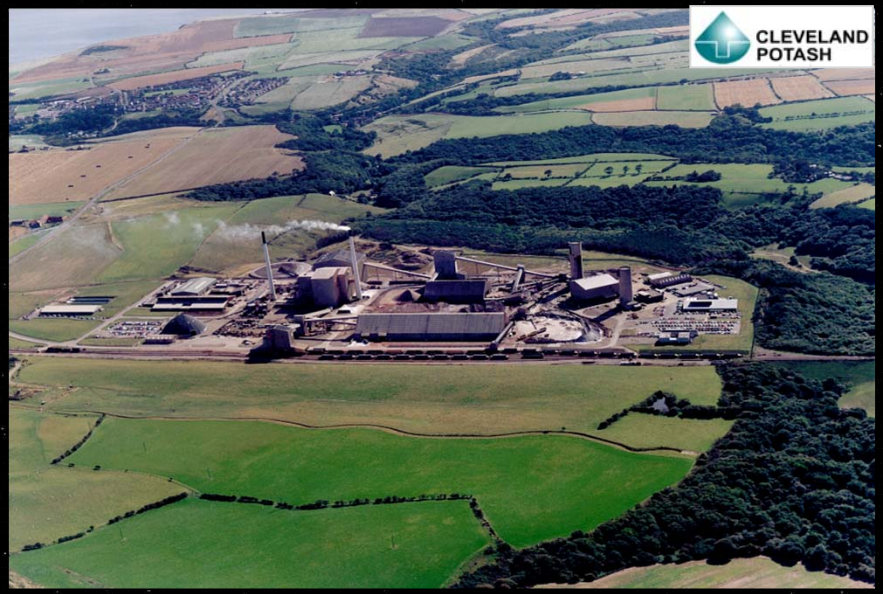
- Safety gallery work started in September 2009
- Excavation of the extension in 2014 or 2015 (in operation in 2016). The calendar depends strongly of safety gallery civil work (The French part is (half of the tunnel)already dug)
- Agreement from Ministry and CNRS for the project
- Funding for the civil work 7 M€ obtained from CNRS, Région Rhône-Alpes, Department Savoie and FEDER funds

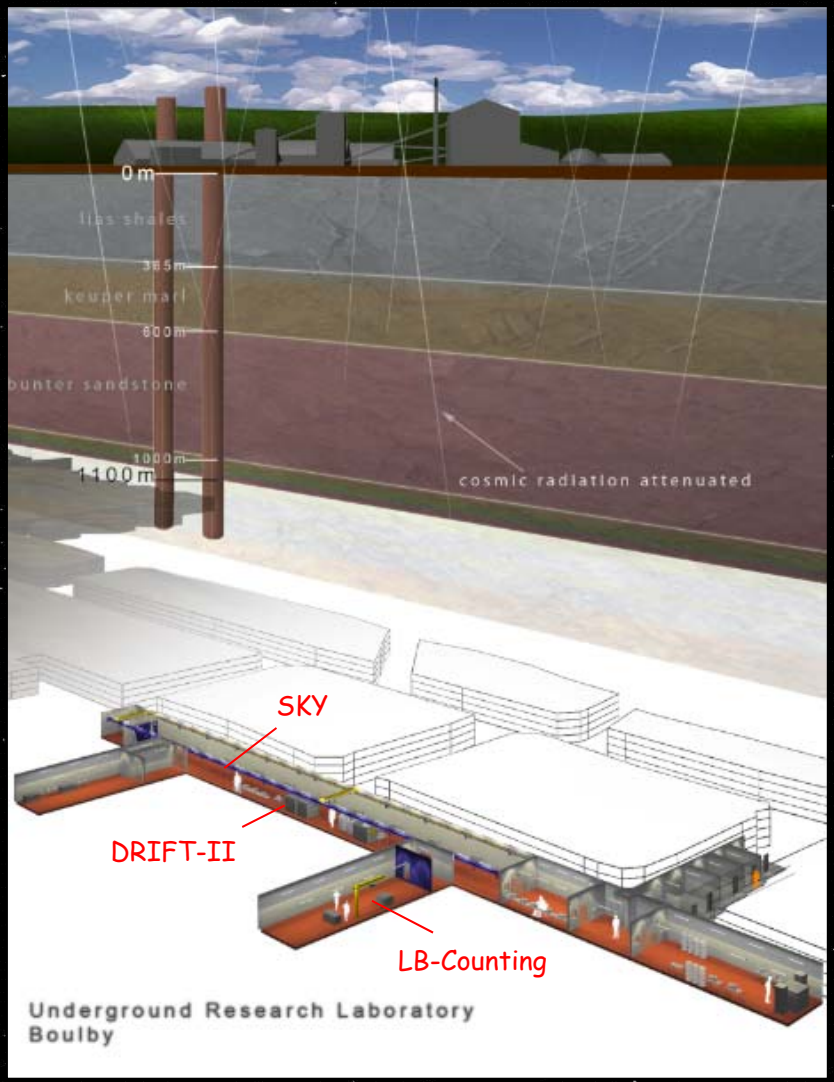
Thanks to S. Paling for providing updated information

Boulby

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.





Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Boulby	Drift		Tomography SKY	Laguna

Active Astroparticle Physics Experiments

Drift Directional DM

Diverse multi-disciplinary science programme under-development:

Funded projects underway include:

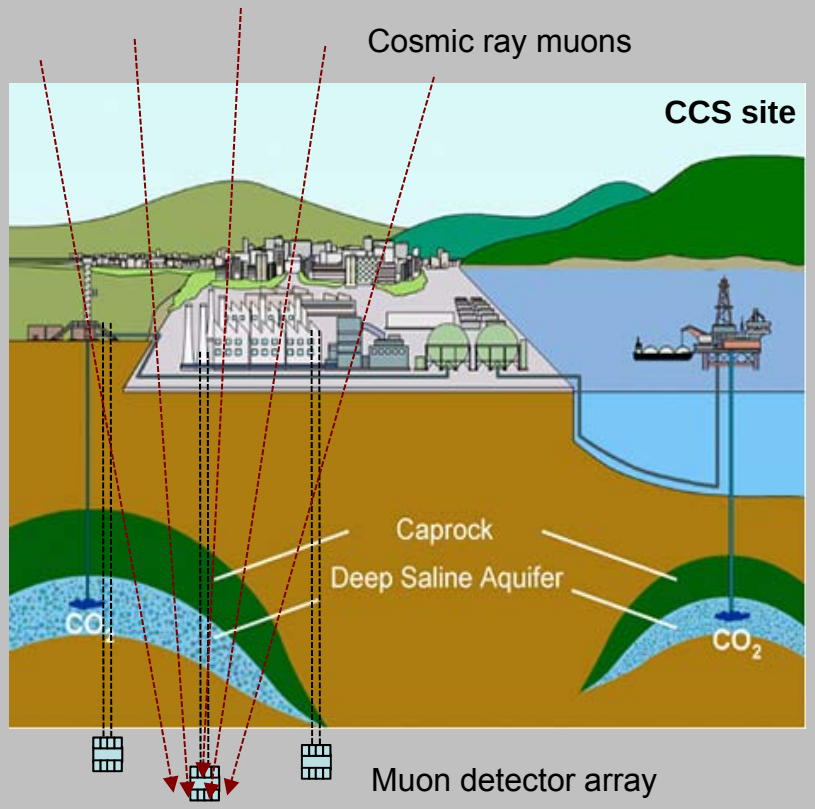
- SKY: Cosmoclimatology,
- Muon Tomography / Carbon Capture,
- Environmental Low Background Counting,
- Geo/AstroBiology & Misc Geology studies.

SP5

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

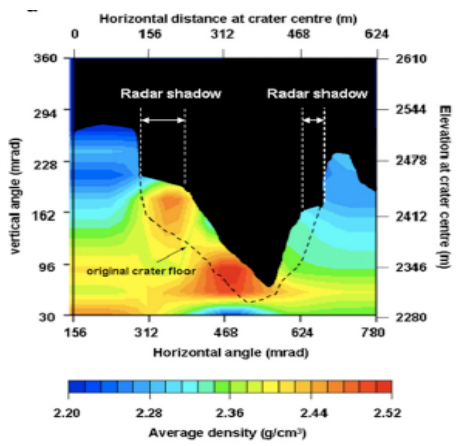
Applications?

- 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

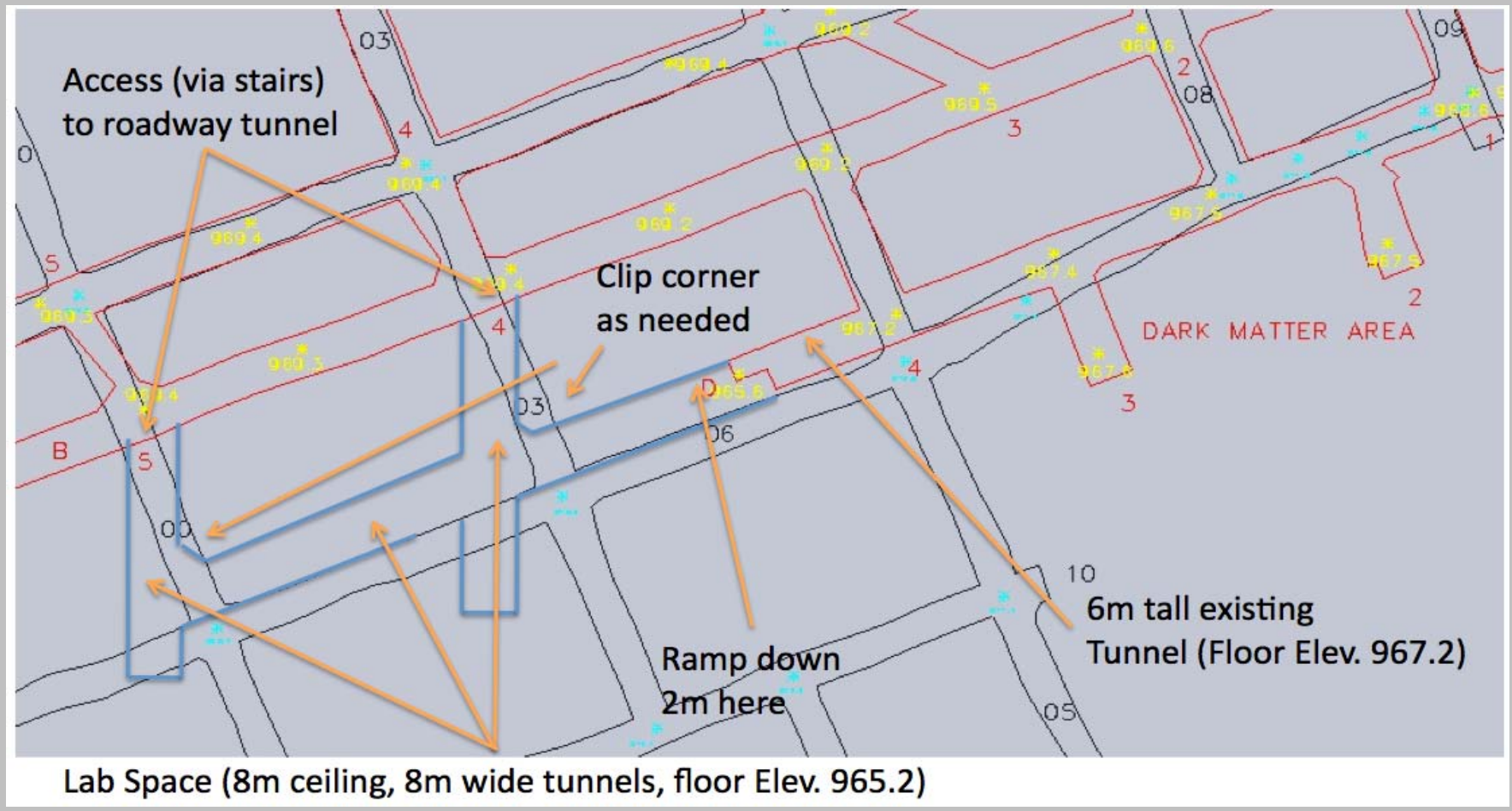


Already proven for shallower uses:
- Volacanos & pyramids interiors

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

Facility Expansion Plans...

Proposed excavations to allow a new lab >1000m^2.



Excavations offered **free** by mine operators CPL

Thanks to T. Enqvist for providing updated information

Centre for Underground Physics in Pyhäsalmi (CUPP)

Experimental Program

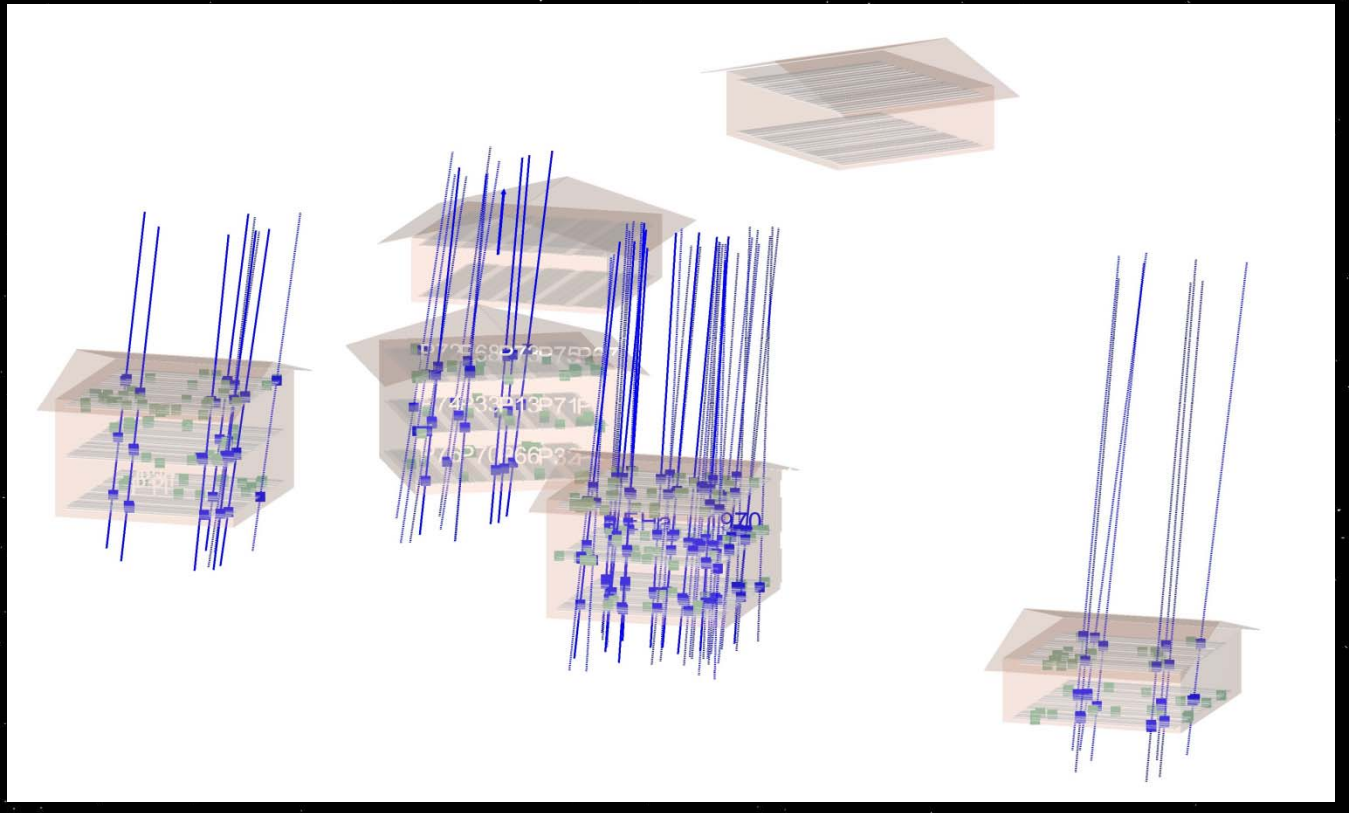
	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
CUPP			Emma	Laguna

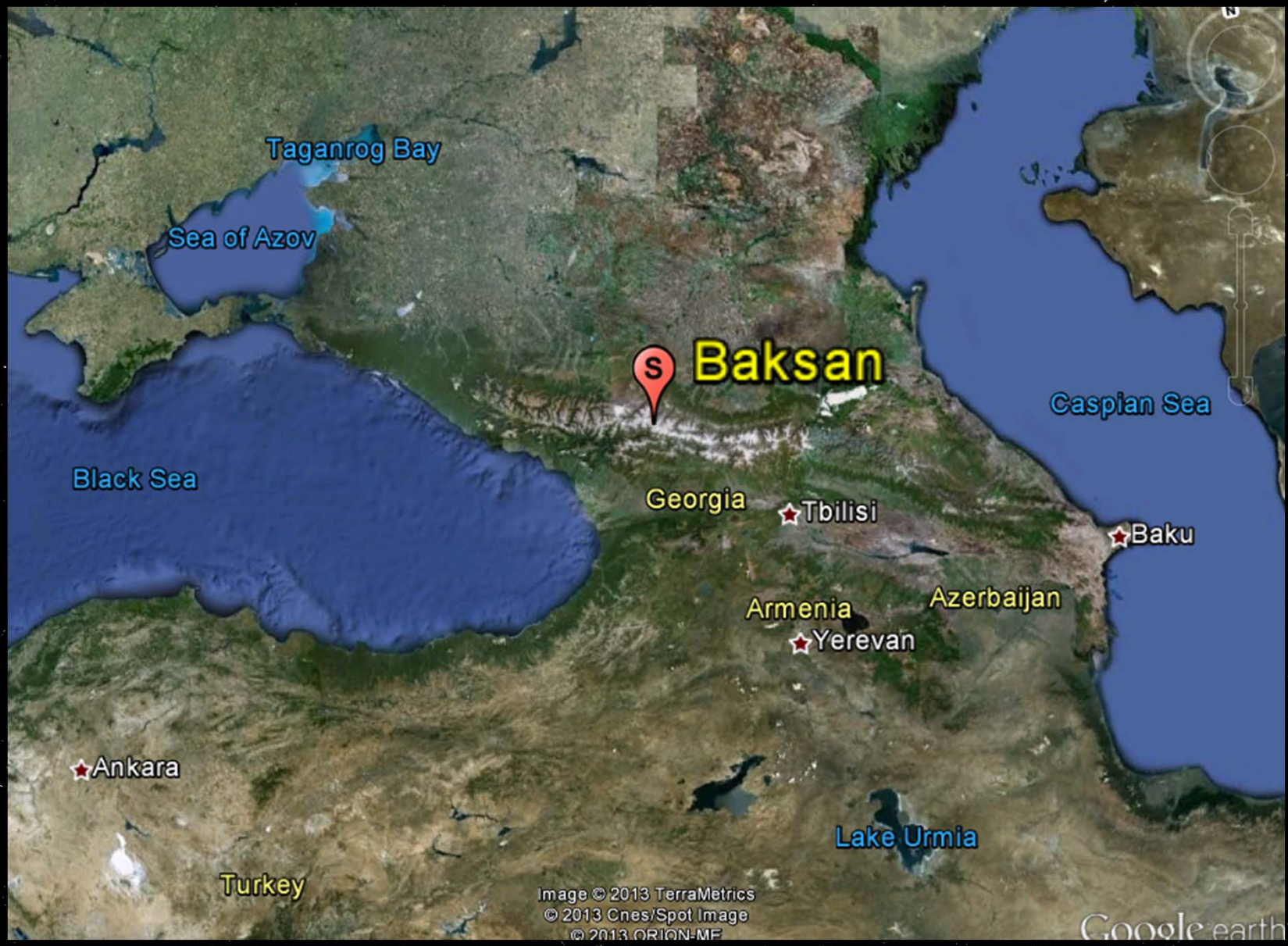
Active Astroparticle Physics Experiments

EMMA Comic Ray Observatory that can measure lateral extent of shower.

Potential site for Laguna

Currently occupy shallow site (75 m) but are looking at options to extend deeper into mine. (Currently mine is at ~1400 m)





Thanks to V. Kuzminov for providing updated information

Baksan Neutrino Observatory

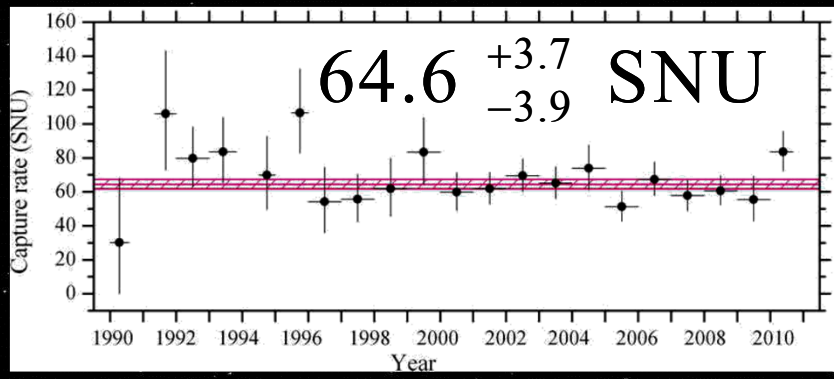
Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Baksan		SAGE	BUST 2β	

Active Physics Experiments

BUST Comic Ray Observatory / Gravitational Collapse

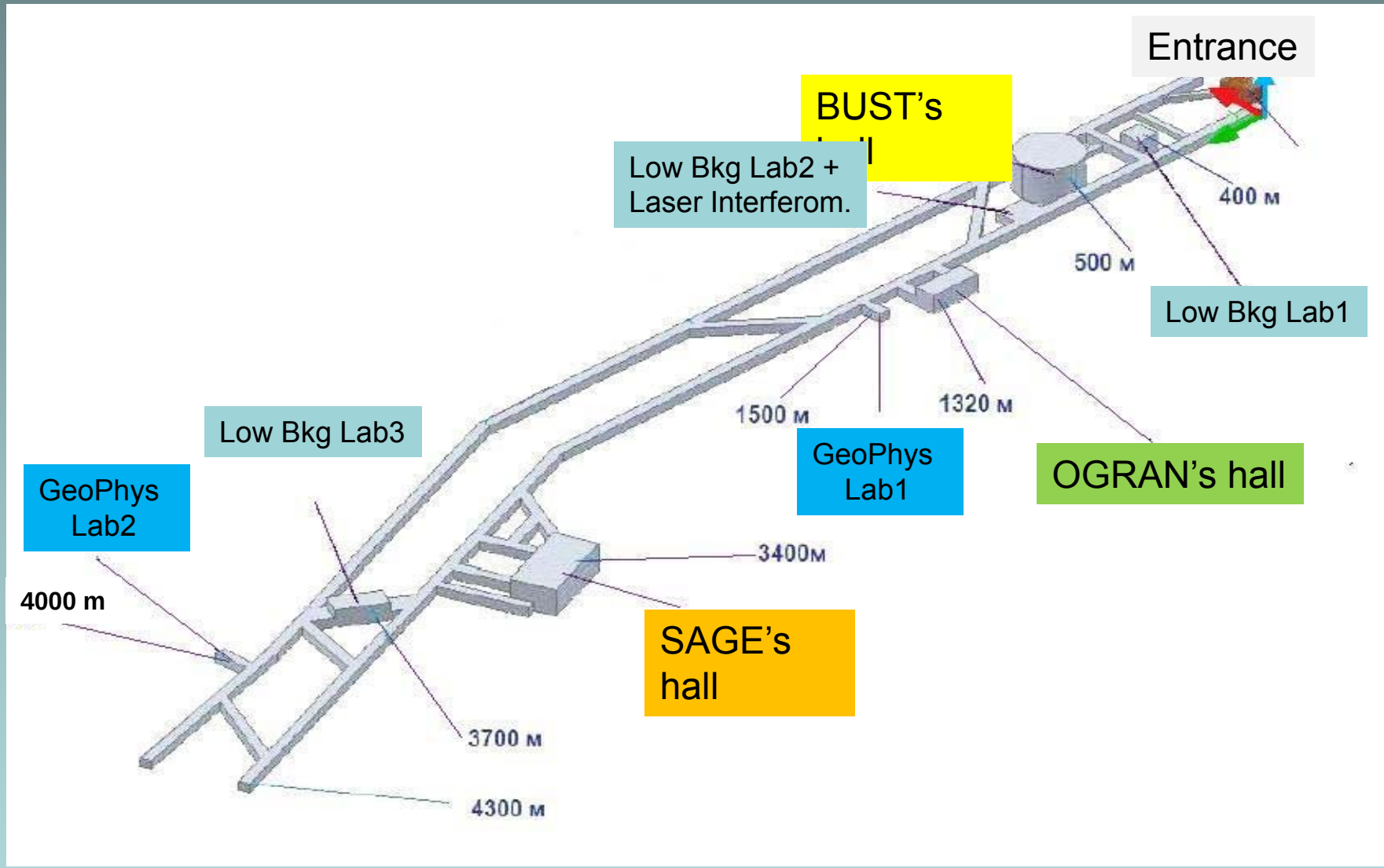
SAGE Solar Neutrino Observatory. 20 years of data!



Low Background / Rare Decay processes (2β)

- **Nd-150:** $T_{1/2}(2\nu)=(1.9^{+0.7}_{-0.4})*10^{20}$ y, $T_{1/2}(0\nu)\geq 1.7*10^{21}$ y
- **Ge-76:** $T_{1/2}(2\nu)=(9.0\pm1.0)*10^{20}$ y, $T_{1/2}(0\nu)\geq 1.6*10^{25}$ y
- **Xe-136:** $T_{1/2}(2\nu)= (5.5^{+4.6}_{-1.7}) \cdot 10^{21}$ y (new)
- **Kr-78 (2K-capture):** $T_{1/2}(2K, 2\nu+0\nu)=(1.4^{+2.2}_{-0.7}) \cdot 10^{22}$ y (90% c.l.) (new)

Geophysics and Gravity



Underground Laboratories of the BNO INR RAS

4 Facilities in India/Asia

Thanks to N. Mondal for providing updated information

Indian Neutrino Observatory

Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
INO				ICAL TBD

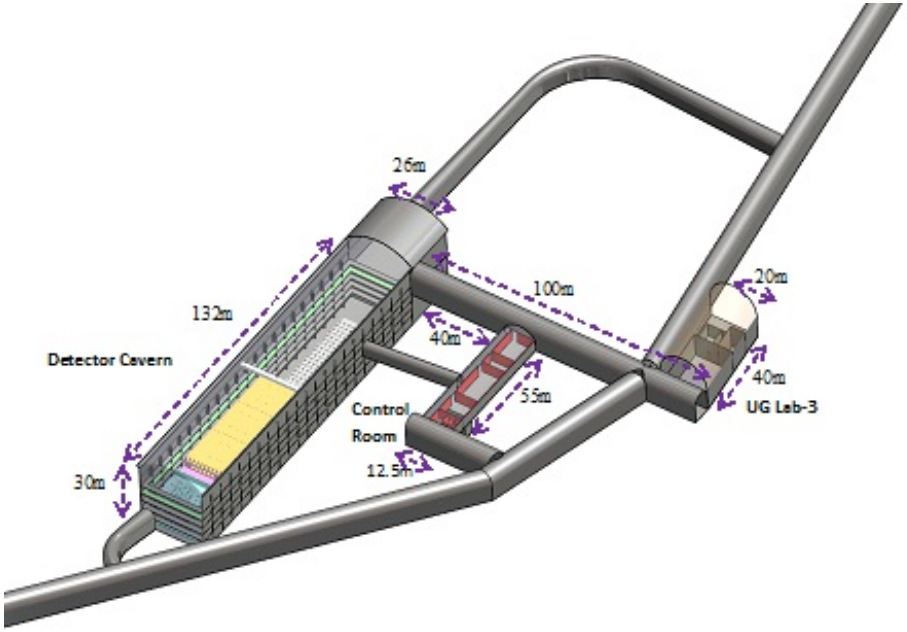
Planned Physics Experiments…Lab in design stage.

ICAL Neutrino studies, neutrino mixing

TBD Space available for DM, Neutrinoless Double Beta Decay

- Environmental and Forest Clearance for the site obtained.
- 26 hectars of land provided free by local state government for setting up surface facilities near portal location.
- 13 hectars of land acquired at Madurai for a INO centre.
- Local Govt. agencies will start laying water pipeline and approach road construction soon. Funds for both transferred to the respective Govt. agencies.
- Fencing work at both sites will start soon. Preparation for master plan for Madurai site has started. Tender documents for the master plan and structural design for the underground lab and surface facilities at Pottipuram is under preparation.
- Underground laboratory is expected to be ready by 2017.

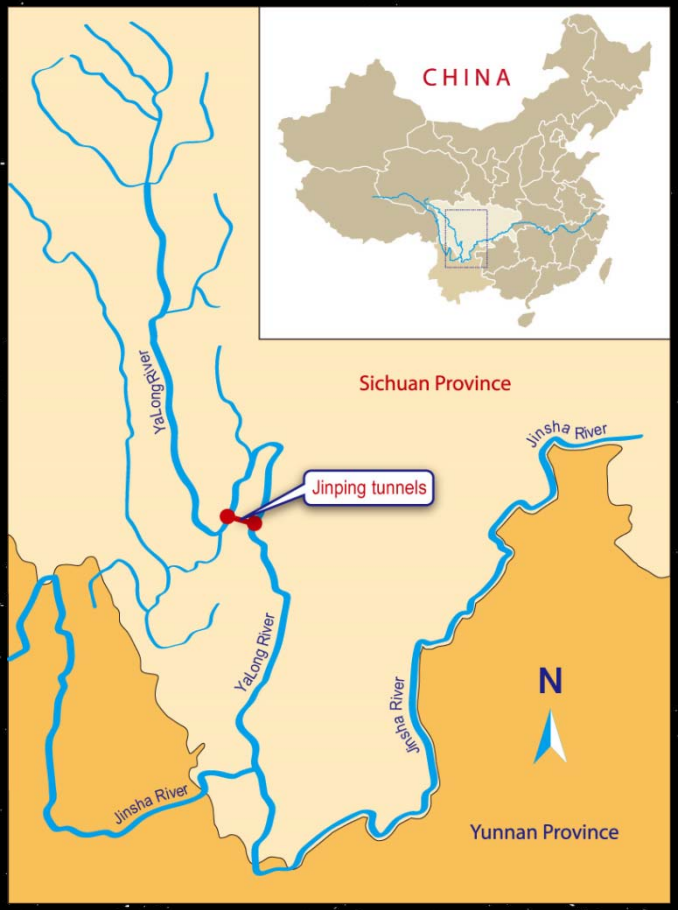
INO site is located 115 km west of the temple city of Madurai

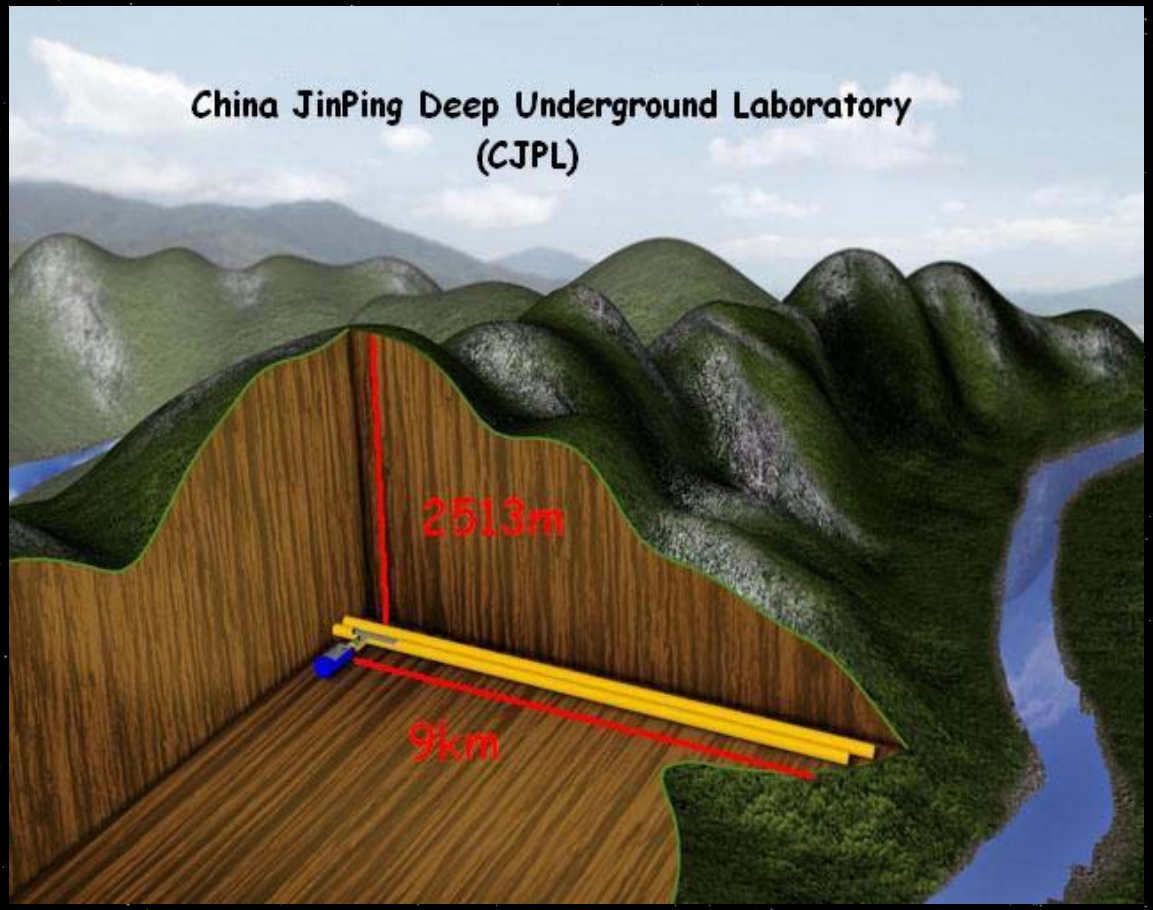


- The cavern-I is set under 1589 m peak with vertical rock cover of 1289 m.
- Accessible through a 1.9 km long tunnel
- Cavern -1 (size: 132m x 26m x 30m) will host 50 kt ICAL detector. Space available for additional 50 kt.
- Cavern-2 (size: 55m x 12.5 m x 8.6 m) & Cavern-3 (20m x10m x 10m) available for other experiments (NDBD, Dark Matter ….).

Thanks to Q. Yue for providing updated information

China JinPing underground Laboratory (CJPL)





CJPL is the deepest underground lab in the world.

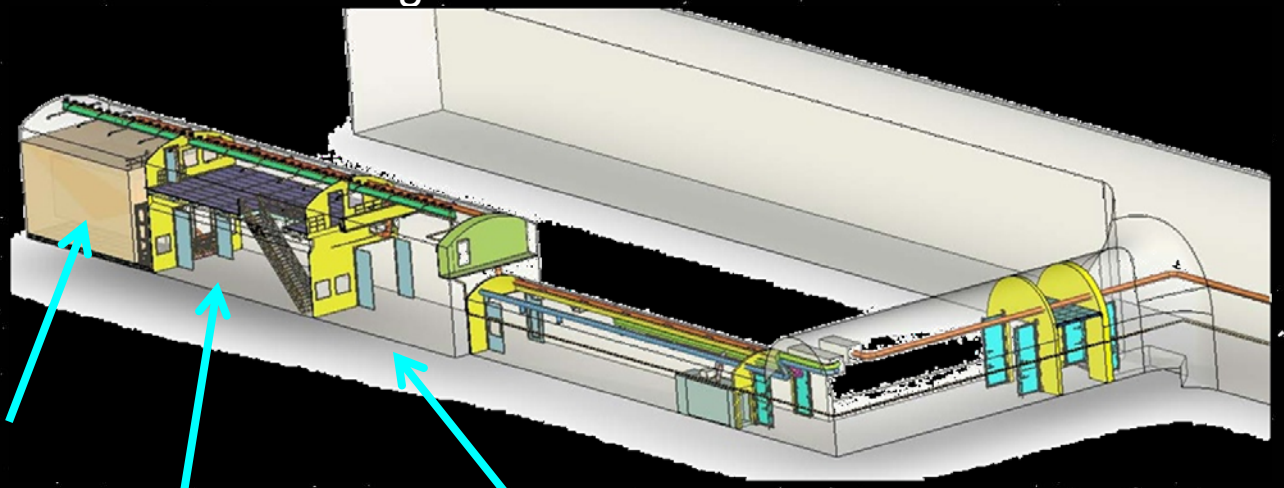
Experimental Program

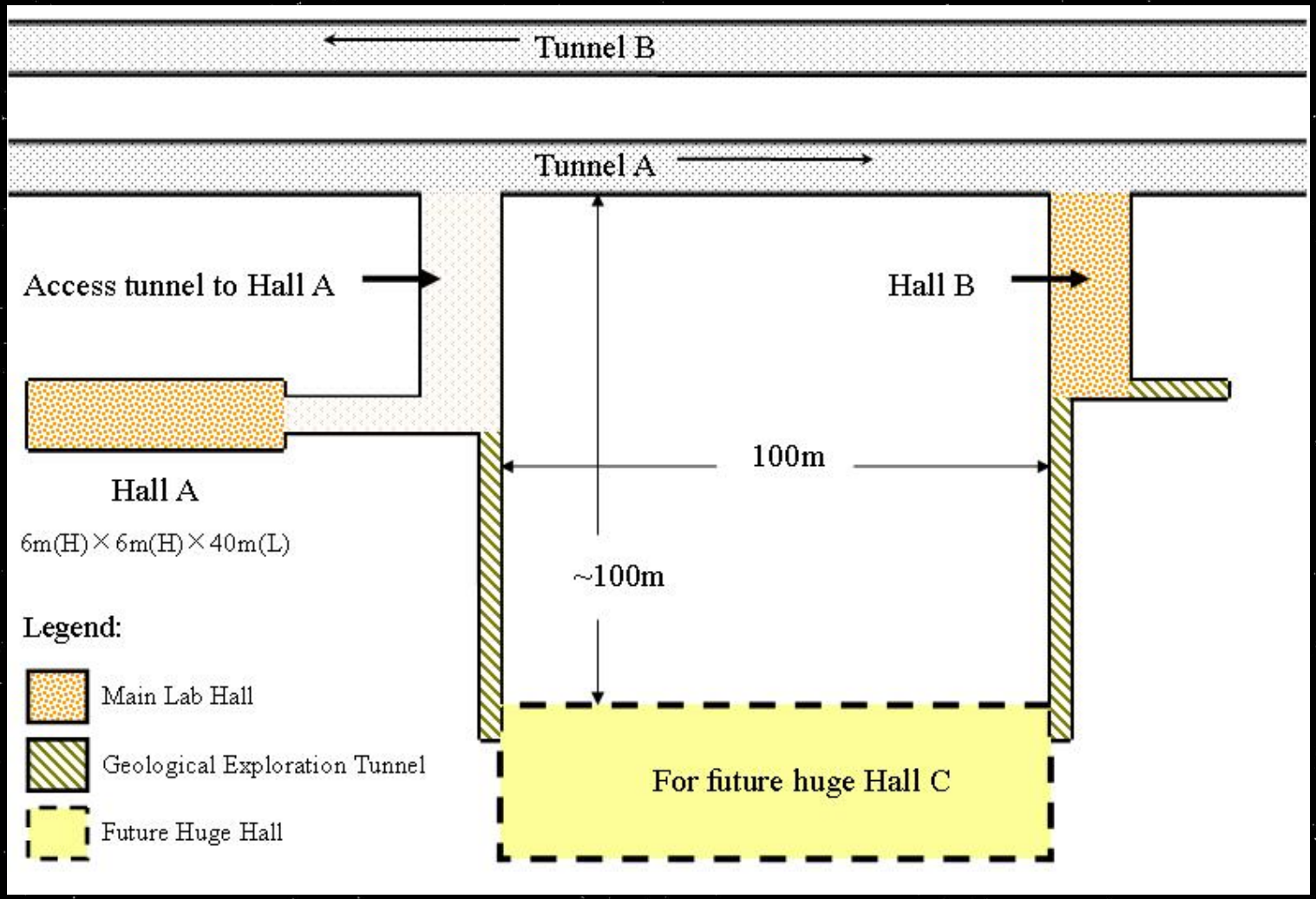
	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
CJPL	CDEX Panda-X		Low Bgnd	

Physics Program

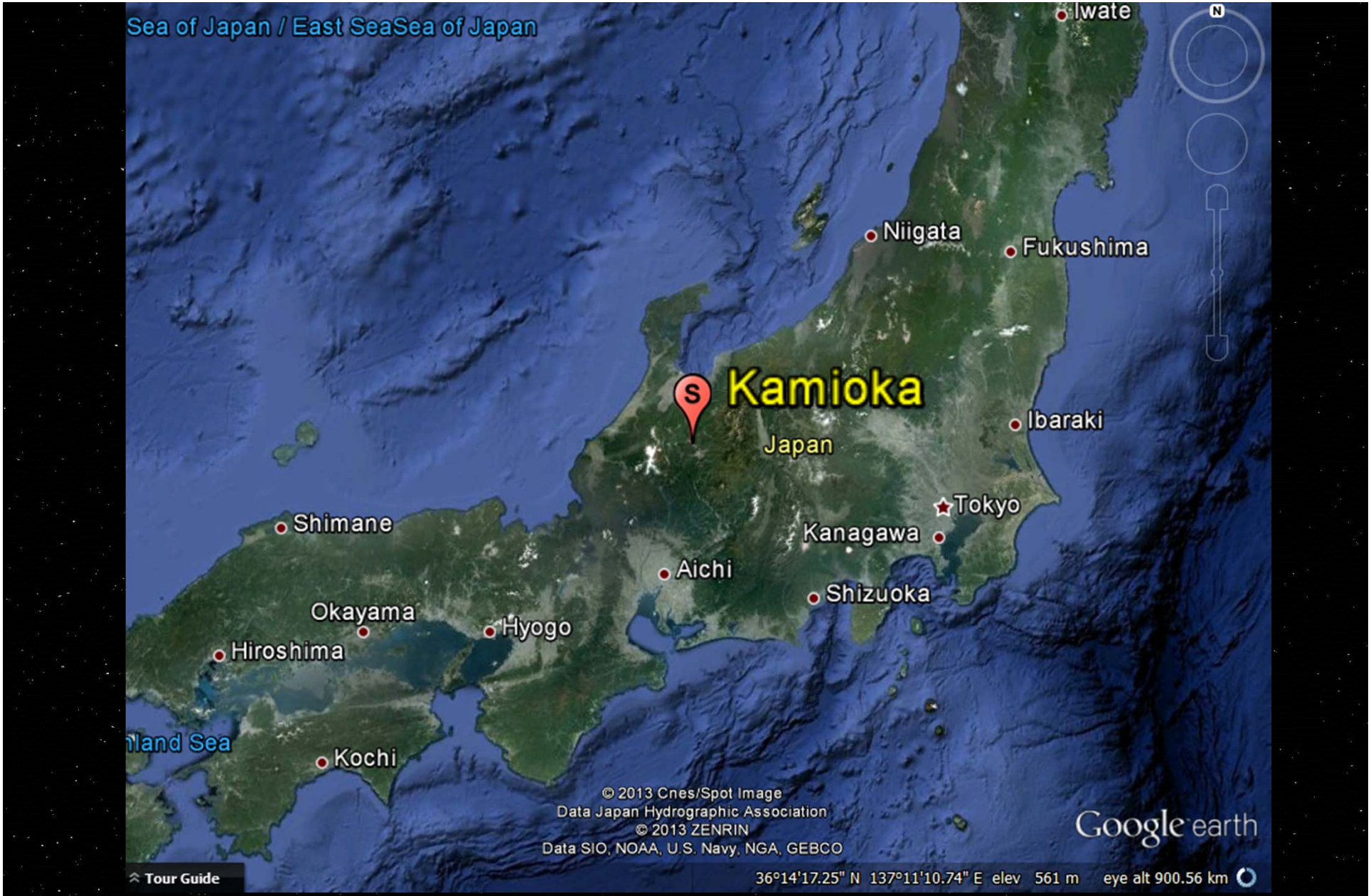
CDEX Low threshold HPGe detectors for low mass WIMP searches

PANDA-X Liquid Xenon detector for dark matter search. Current version, 30 Kg fiducial. Aiming at Tonne Scale





Expansion plans at CJPL

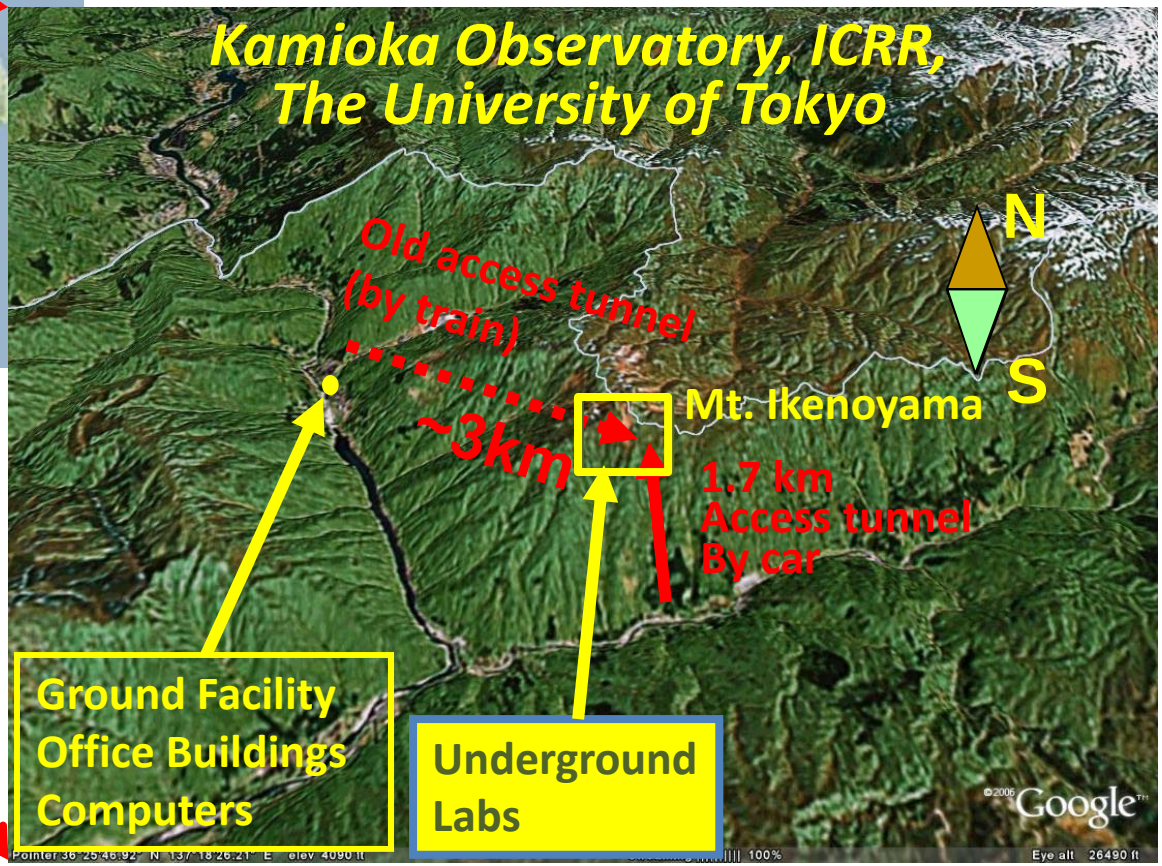


Thanks to Y. Suzuki for providing updated information

Kamioka Observatory

Kamioka Observatory

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



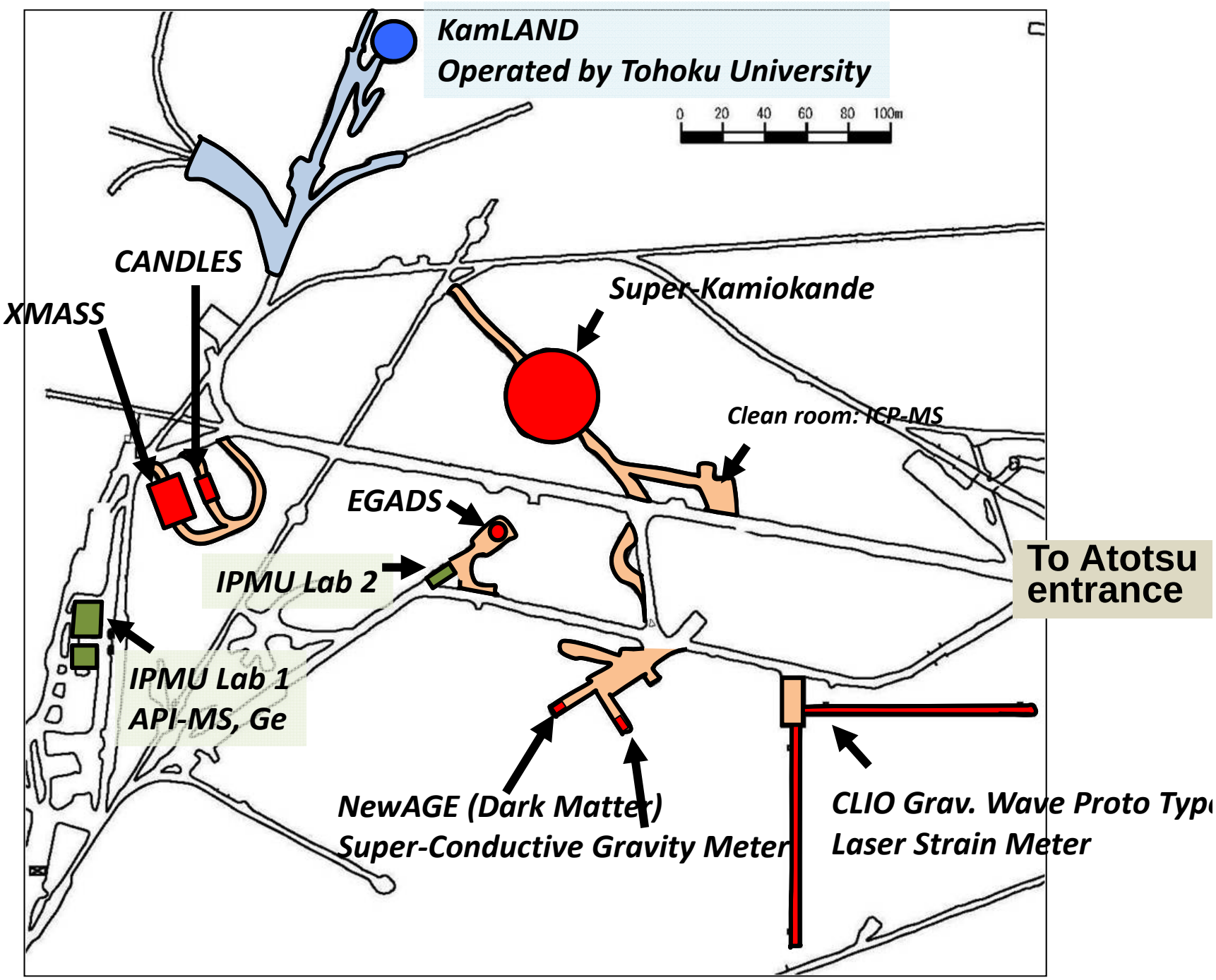
- **1000 m underground**
- **24 hours access by car**
- **Horizontal access**
- **10 minutes from the ground facility**

Experimental Program

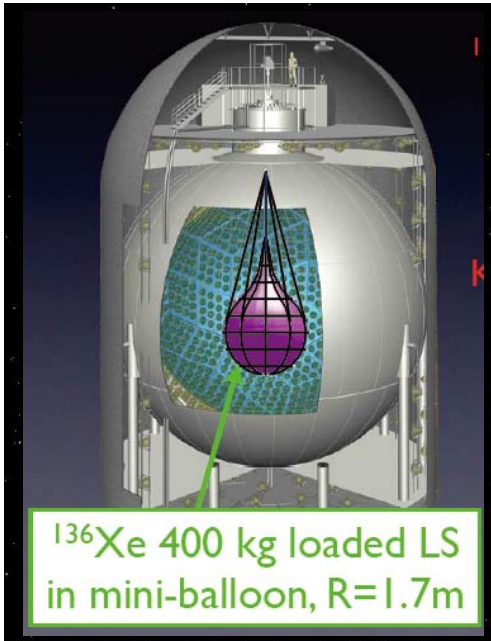
	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Kamioka	Xmass NewAge	SuperK/T2K Gadzook/Egad Candles Kamland-Zen	KAGRA/CLIO	HyperK

Physics Program

XMASS	DM with Xe
NewAge	Directional Dark Matter with CF_4
SuperK	Solar neutrinos
SuperK plus T2K	Long base line neutrino oscillations
SuperK plus Gadzooks	Neutron tag – relic Supernova neutrinos, proton decay, reactor neutrino …
EGADS	Prototype for Gadzooks
Candles	$0\nu\beta\beta$ with ^{48}Ca
KAGRA/CLIO	Gravitational Waves (Funded)
HyperK	Even bigger than SuperK Precision neutrino oscillations, CP…

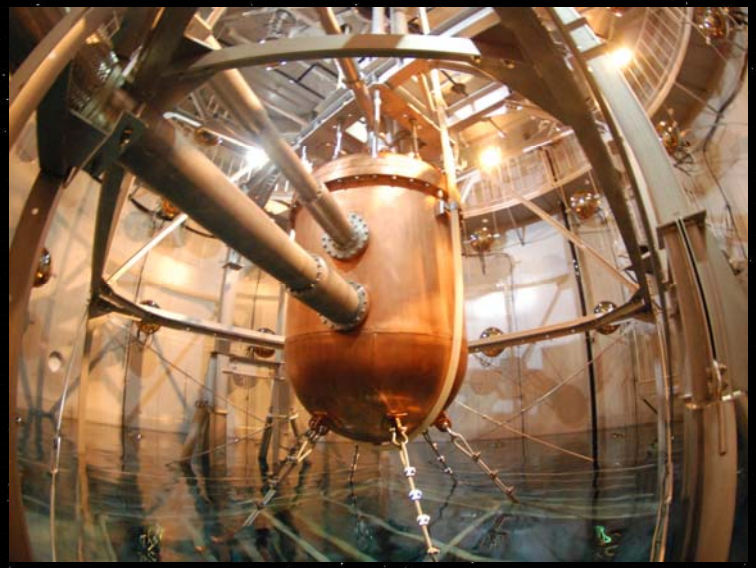

KamLAND
Operated by Tohoku University
0 20 40 60 80 100m
CANDLES
XMASS
Super-Kamiokande
Clean room: ICP-MS
EGADS
IPMU Lab 2
To Atotsu entrance
IPMU Lab 1
API-MS, Ge
NewAGE (Dark Matter)
Super-Conductive Gravity Meter
CLIO Grav. Wave Proto Type
Laser Strain Meter

Experimental Progress

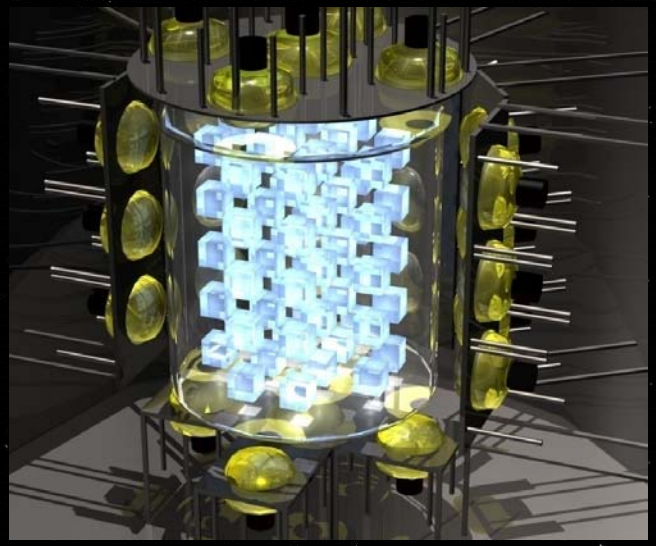


Kamland Zen

EGADS (Feasibility study for Gadzooks)



XMASS (operational)



Candles (commissioning)

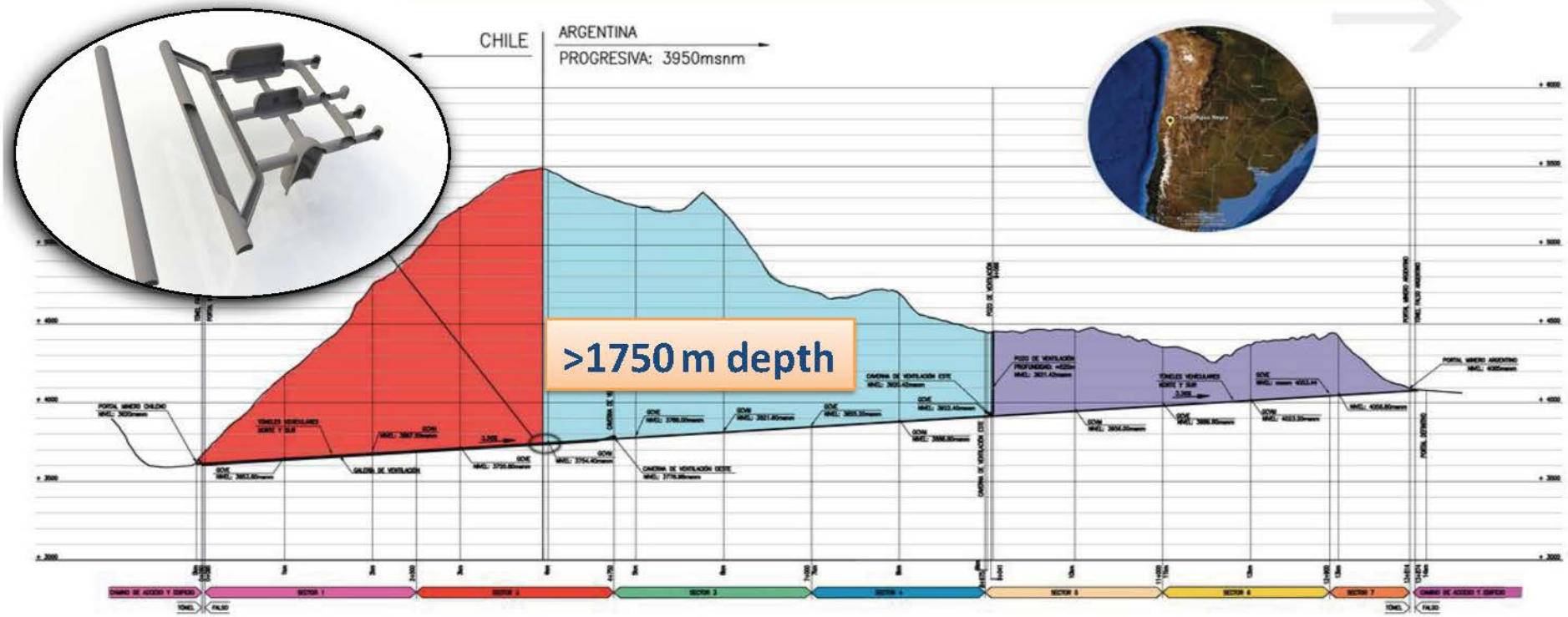
Thanks to X. Bertou for providing updated information

Planned Andes Lab

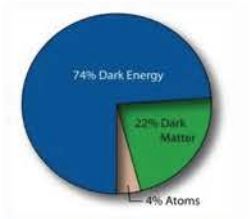
ANDES
The Agua Negra deep underground laboratory

- Agua Negra tunnel between Argentina and Chile, linking MERCOSUR to Asia
- Possible laboratory location as deep (or deeper) than Modane
- Tunnel tender started in January 2013, opening expected 2019-2020
- Horizontal access, size of ~4 000 m^2 and ~65 000 m^3 in 7 halls and pits

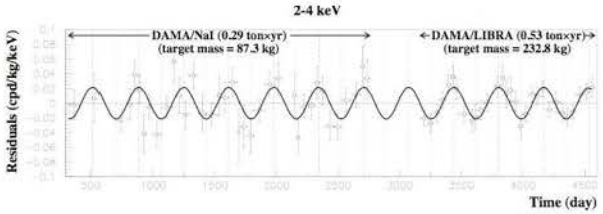
Only deep underground laboratory in the southern hemisphere



ANDES: Agua Negra Deep Experiment Site

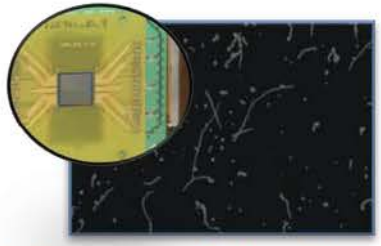


Dark Matter

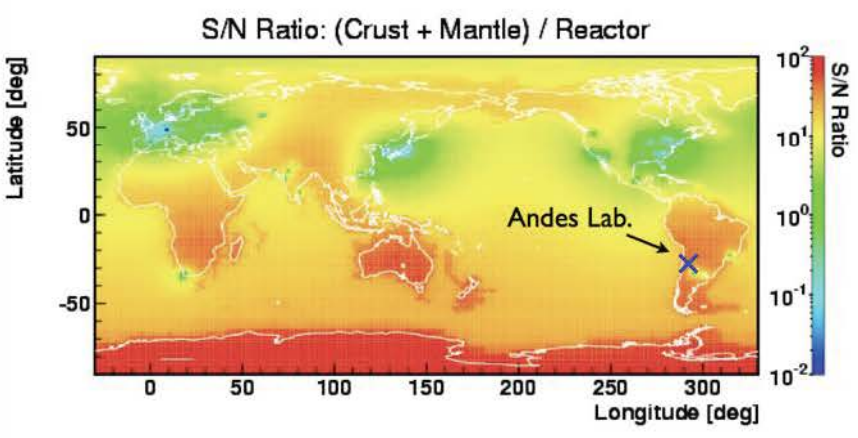


DAMA/LIBRA yearly modulation, to investigate in Southern hemisphere

Host 3rd generation DM experiment

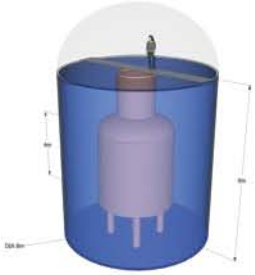


Study new particle detection techniques, ex: CCD



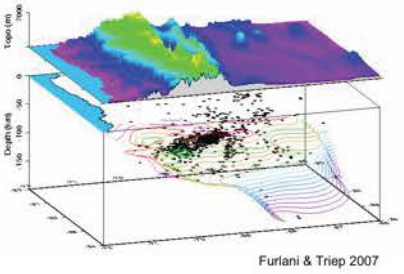
Neutrinos

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



Possible Ultra low radiation room

Environmental measurements, material selection…



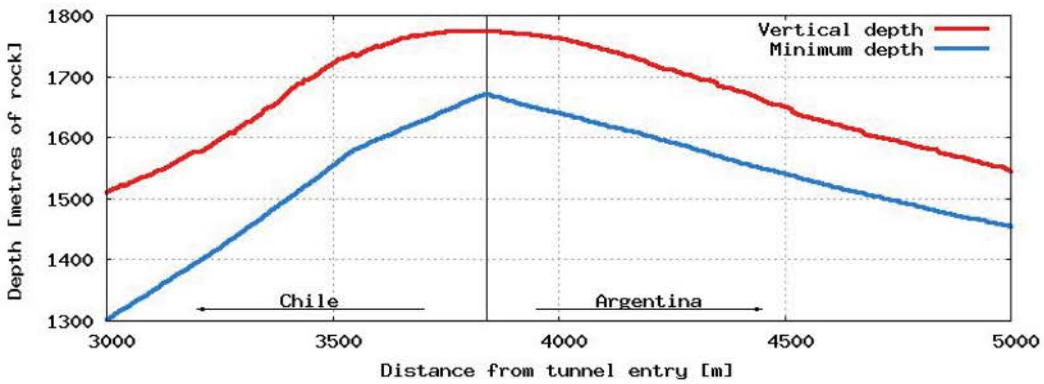
Geophysics laboratory

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

+ accelerator science, interdisciplinary science…

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 labs
- 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)

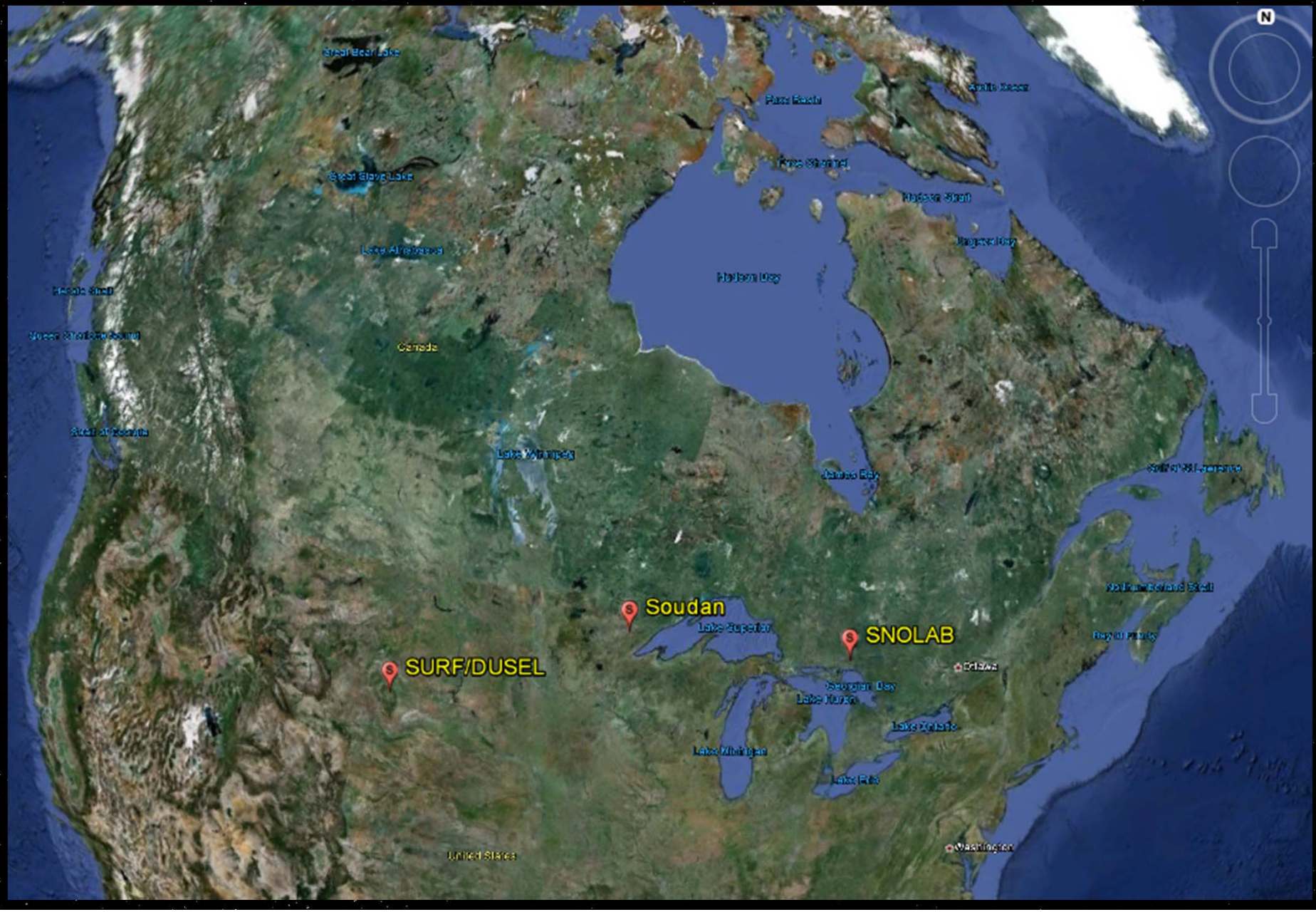
Preliminary data (Bq/kg)

	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
- ✓ Tunnel tender during 2013
- ✓ Lab to be introduced as additional civil work end of 2013

http://andeslab.org/

3 Facilities in North America



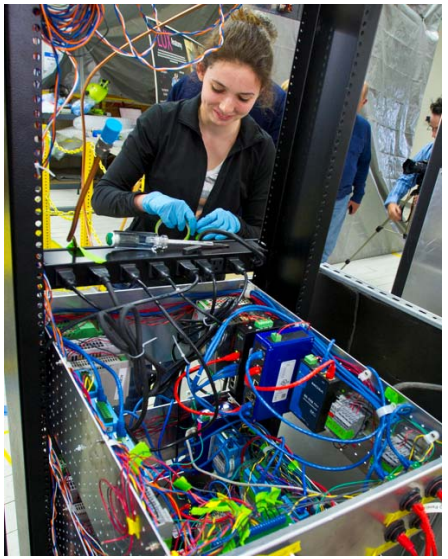
Thanks to K. Lesko for providing updated information

Sanford Underground Research Facility (SURF)

What is the current status of SURF?

- FY 2012
  - Facility
    - Facility 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 Initiated (still provides secondary egress)

  - Science
    - LUX Dark Matter, Majorana Demonstrator Neutrinoless Double Beta Decay, & CUBED - Installing ✓
    - LBNE 10 kt surface-deployment Conceptual Design Completed ✓
    - Proposals for DIANA, LZ, LBC under review, some funding announced
- FY 2013 - 15
  - Facility
    - Ross Shaft Rehab continues, first ~ 400 feet done.
  - Science
    - LUX and MJD commissioning, 1st results expected in 2013
    - LZ R&D funded in the US and Great Britain ✓
    - LBNE - CD1 approved December 2012 ✓
    - Site-visit by DIANA Project ✓



Thanks to K. Lesko for providing updated information

Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Surf	LUX	Majorana	Cubed	LZ LBNE Diana

Active Physics Program

LUX	DM detection with Xe. Operational (Commissioning)
Majorana Demonstrator	$0\nu\beta\beta$ with Ge. Being assembled.
Cubed	Low Background counting facility. To be installed soon.

Future Program under Consideration:

LZ	Large DM with Xe, R&D funded
LBNE	Long Base line Neutrino Oscillations. Phased approach to be considered for funding. Updated cost estimate nearing completion.
DIANA	Accelerator for Nuclear Astrophysics.

Thanks to A. Habig for providing updated information

Soudan (700 m, 2070 mwe deep)

Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Soudan	CDMS Cogeant	Minos+	Low Bgnd	Cogeant 4 Diana

Active Physics Program

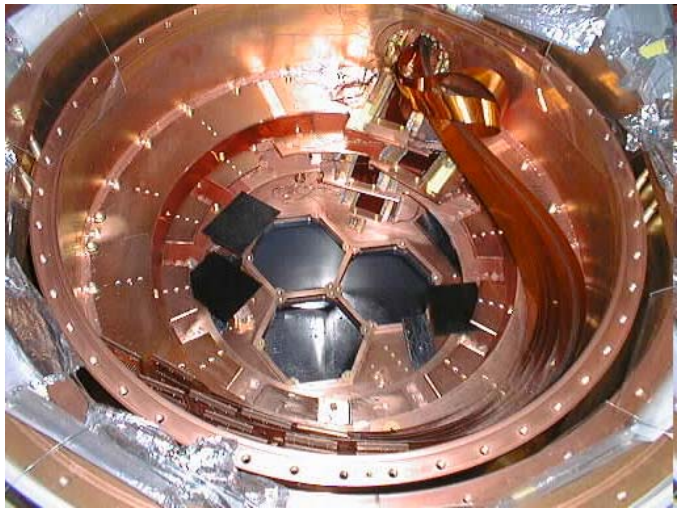
CDMS	DM detection with Ge. Operational, evolving into SuperCDMS
Gogeant	DM with low threshold Ge. Operational
Minos+	Neutrino Oscillations. Beam from Fermi lab. On axis Nova beam.

Future Program under Consideration:

DIANA	Accelerator for Nuclear Astrophysics.

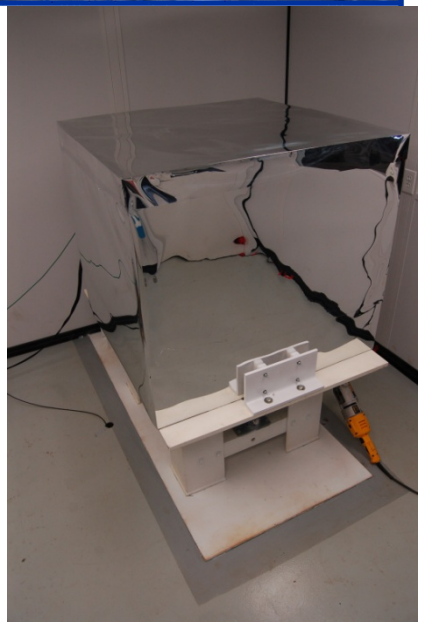
Large Experiments

- Fermilab operates the Lab's current main tenants
  - So pays the vast bulk of the ~$1.3M/yr operational budget
- MINOS changed into MINOS+ in 2013
  - Will observe NOvA's upgraded neutrino beam from an on-axis position through at least 2015
- CDMS taking data with new towers (*through 2015*)
- CoGeNT taking data, CoGeNT-4 upgrade planned



Low Background Counting facility

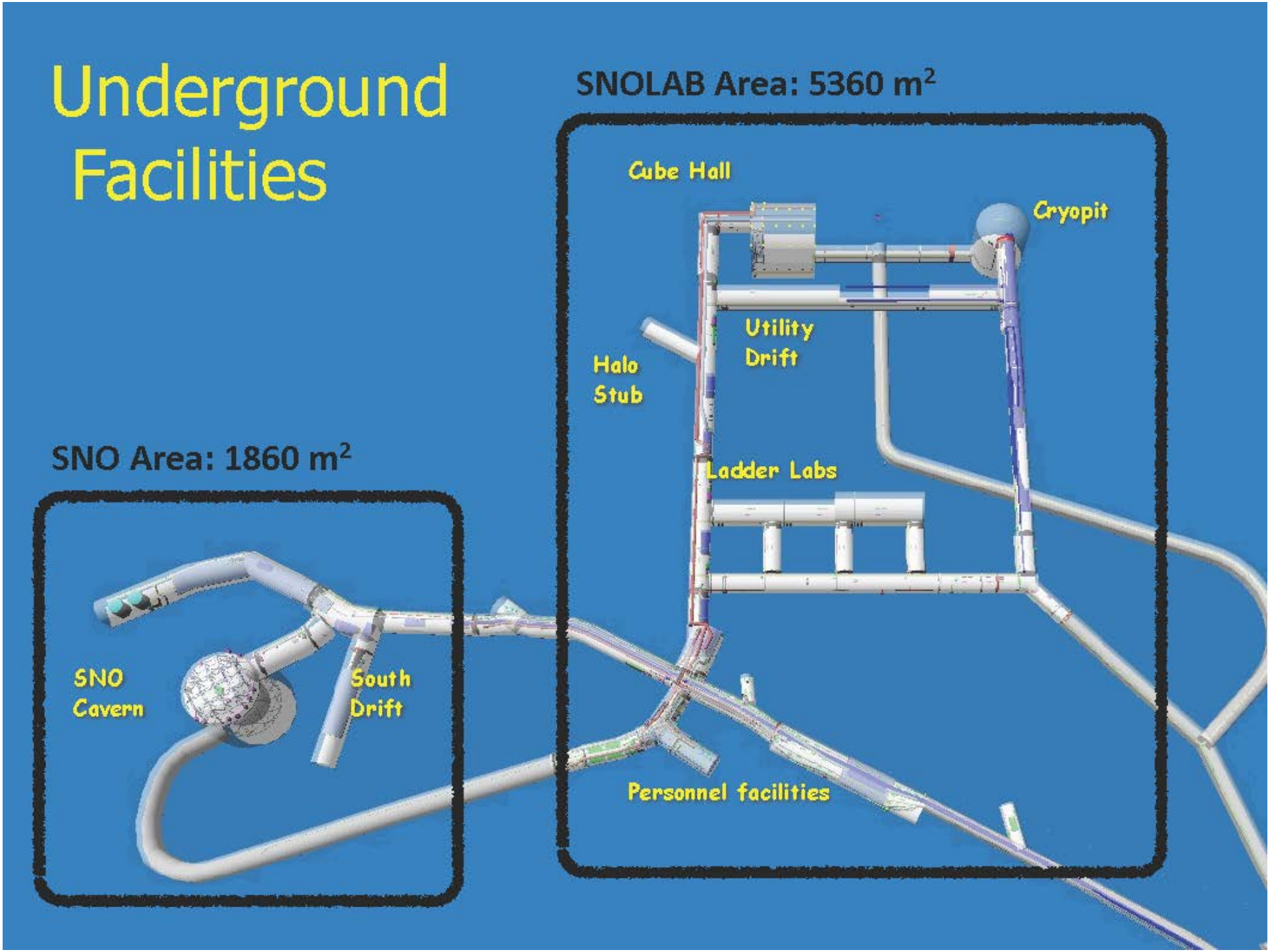
- Inside refurbished Soudan-II muon veto shield
  - 35 ft x 40 ft x 100 ft volume
  - Plenty of floor space available for new projects
- Facilities:
  - Multipurpose clean room
  - Two HP Ge detectors for γ screening
  - Two novel beta screening devices
    - neon gas drift chamber w/ multi-wire proportional readout
    - resistive parallel plate chamber
  - Surface facilities for receiving, storage, assembly, remote computer access
- Related projects:
  - Neutron Multiplicity Meter (UCSB)
    - Additional recent neutron counting from DIANA, USD
  - Various chip error counting test stands
  - XIA Alpha counter testing



Thanks to N. Smith for providing updated information

SNOLAB (6000 mwe deep)

Underground Facilities



Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
SNOLAB	DEAP 3600 Mini Clean Picasso Coupp Damic	SNO+ HALO	PUPS Low Bgnd	COUPP- PICASSO 500 Cobra SuperCDMS NEXO

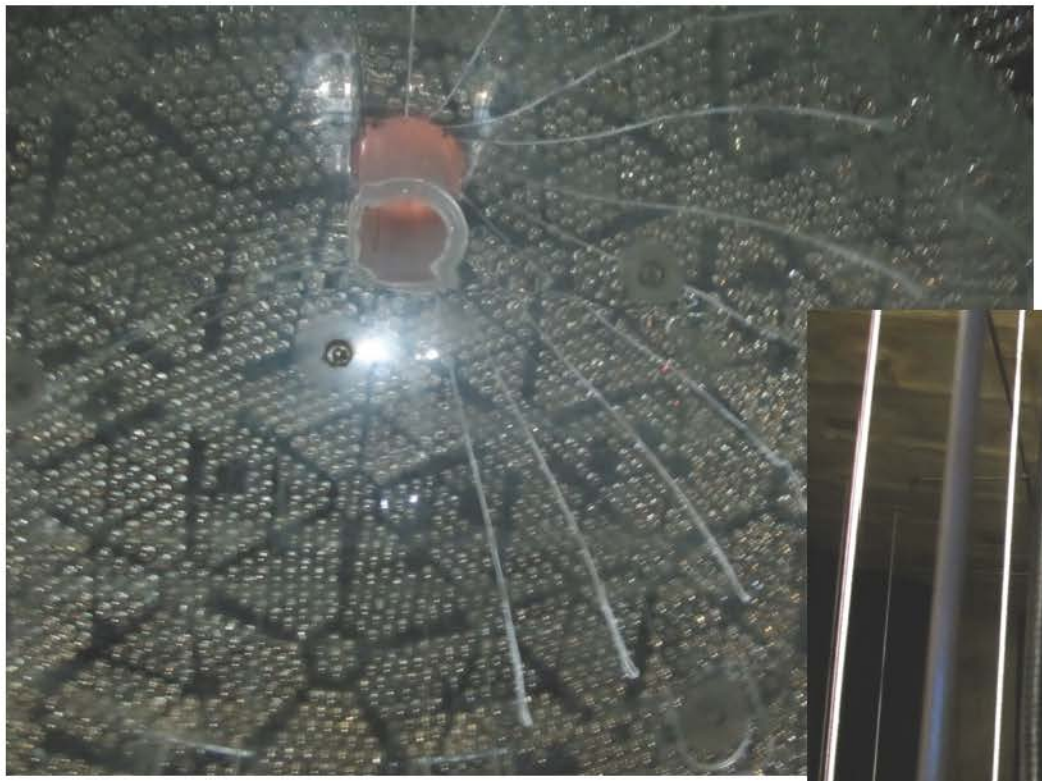
Active Physics Program

Deap-3600	Dark Matter detection with single phase Lar
MiniClean	DM with LAr and Lne
PICASSO	DM with ^{19}F in superheated droplet detector
COUPP	DM with bubble chamber
DAMIC	DM feasibility study with CCD readout
SNO+	Multipurpose neutrino detector. $0\nu\beta\beta$ with Te
Halo	SuperNova watch experiment

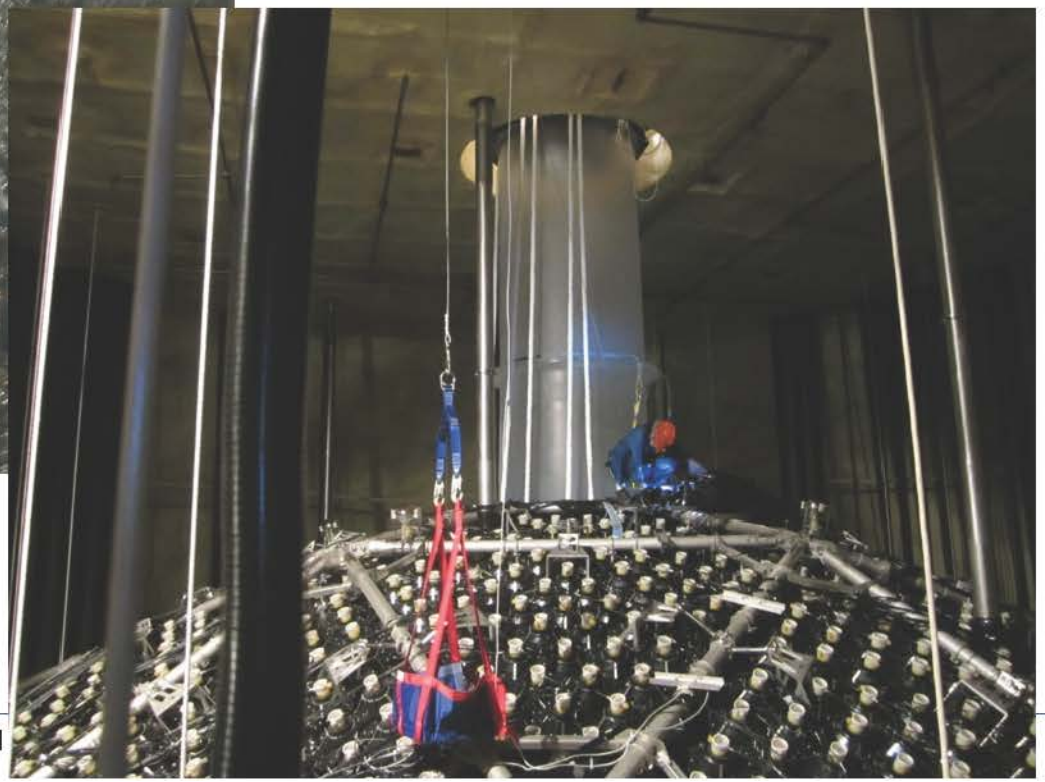
Future Program under Consideration:

SuperCDMS	If funded in US. Conditional funding in Canada
NEXO	Large scale version of EXO $0\nu\beta\beta$ with Xe

SNO+ Developments

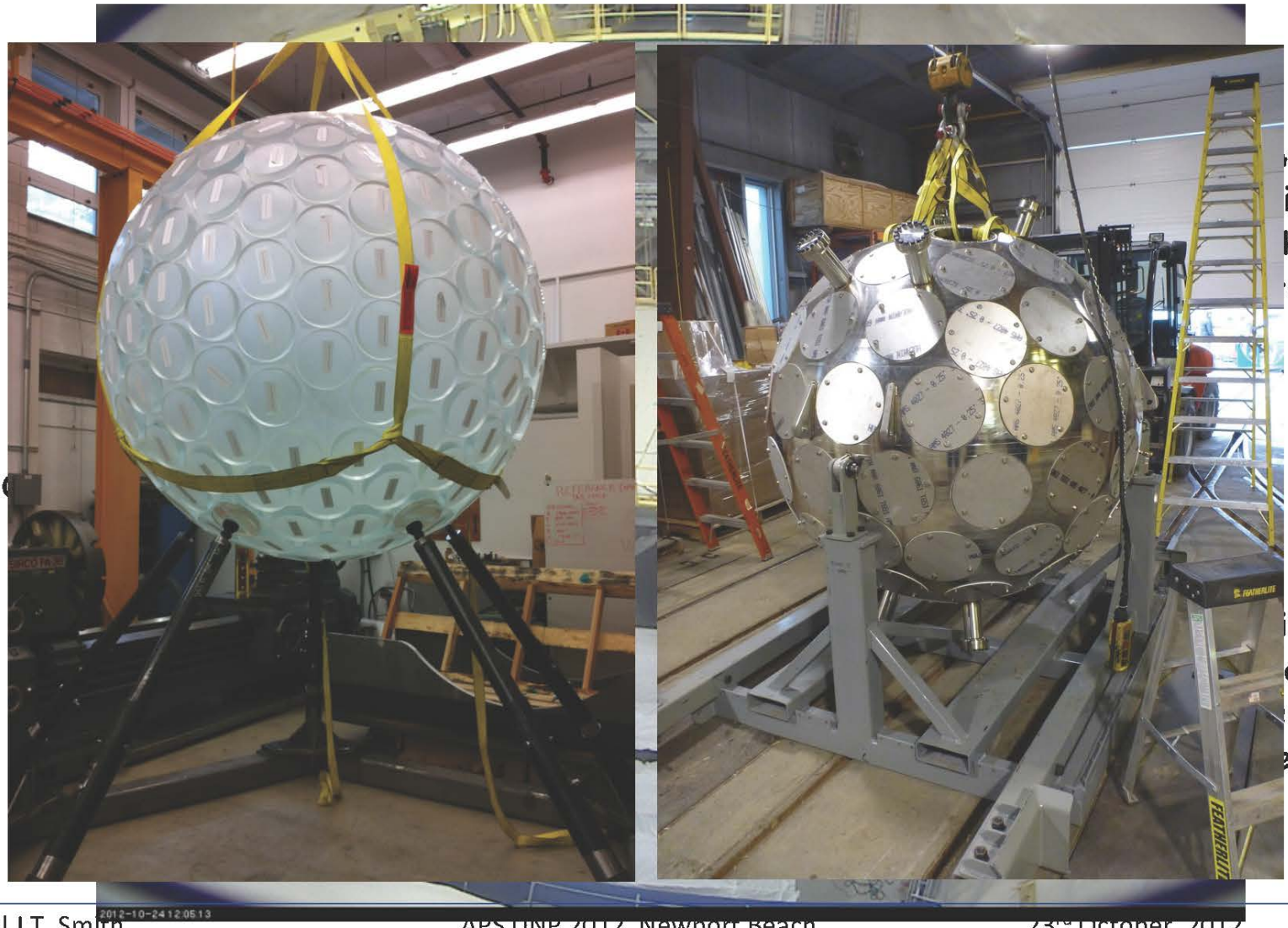


Deployment of the new hold-down rope net, and replacing hold-up ropes with lower activity ones



Cube Hall - DEAP/miniCLEAN

Cube Hall - DEAP/miniCLEAN



DEAP-360
water
shielding
tank

P-3600
iCLEAN
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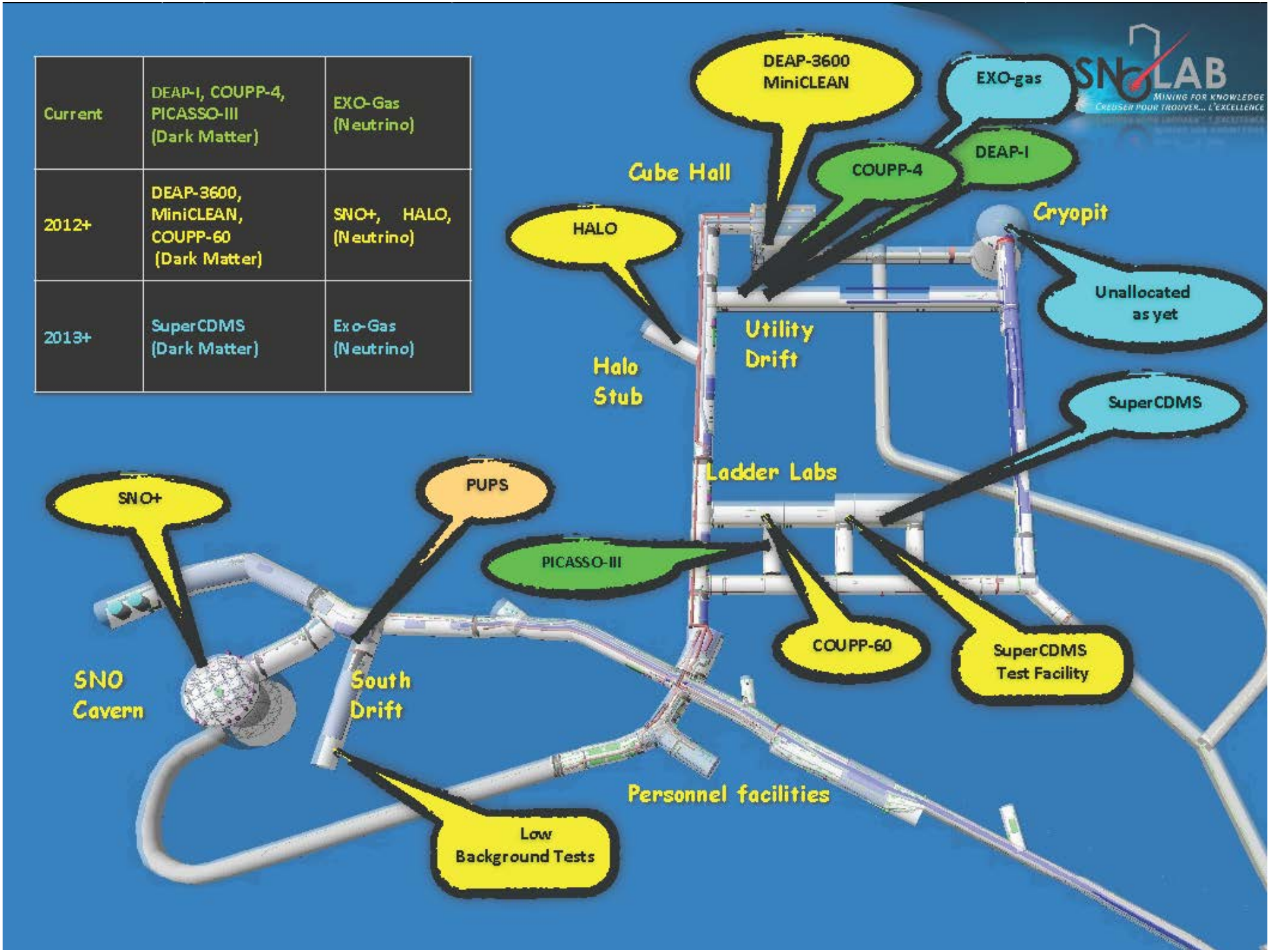
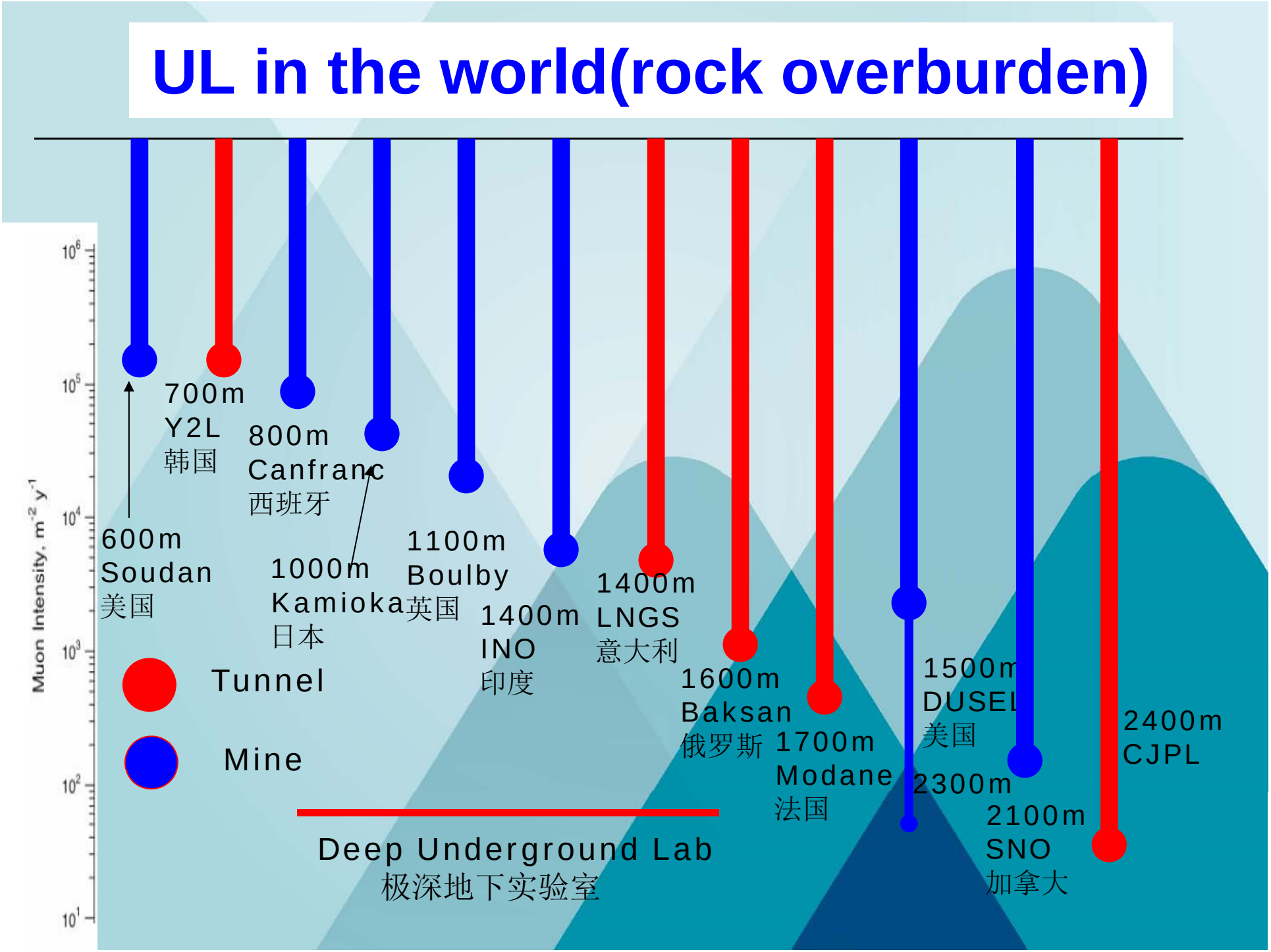

Current
DEAP-I, COUPP-4, PICASSO-III (Dark Matter)
EXO-Gas (Neutrino)
2012+
DEAP-3600, MiniCLEAN, COUPP-60 (Dark Matter)
SNO+, HALO, (Neutrino)
2013+
SuperCDMS (Dark Matter)
Exo-Gas (Neutrino)
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE
DEAP-3600 MiniCLEAN
EXO-gas
DEAP-I
COUPP-4
Cube Hall
Cryopit
HALO
Unallocated as yet
Utility Drift
Halo Stub
SuperCDMS
Ladder Labs
SNO+
PUPS
PICASSO-III
COUPP-60
SuperCDMS Test Facility
SNO Cavern
South Drift
Personnel facilities
Low Background Tests

Conclusions: Experimental Program

	Active Program			Future Considerations
	Dark Matter	Neutrino	Other	
Canfranc	ANAIS ROSEBUD ArDM	NEXT	Geodyn	CUNA LAGUNA
Gran Sasso	Dama/Libra CRESST Xenon Darkside	Gerda Cobra Cuore Opera Icarus Borexino LVD	Luna/Luna MV VIP GIGS	Xenon 1T
Modane	Edelweiss II	SuperNemo Sedine	TGV SHIN	Eureca DM Mimac DM
Boulby	Drift		Tomography SKY	Laguna
CUPP			Emma	Laguna
Baksan		SAGE	BUST 2β	
INO				ICAL
CJPL	CDEX Panda-X		Low Bgnd	
C2J	KIMS			
Kamioka	Xmass NewAge	SuperK/T2K Gadzook/Egad Candles Kamland-Zen	KAGRA/CLIO	HyperK
Surf	LUX	Majorana	Cubed	LZ LBNE Diana
Soudan	CDMS Cogeant	Minos+	Low Bgnd	Cogeant 4 Diana
SNOLAB	DEAP 3600 Mini Clean Picasso Coupp Damic	SNO+ HALO	PUPS Low Bgnd	COUPP-PICASSO 500 Cobra SuperCDMS NEXO

UL in the world(rock overburden)



A lot of work being done:

To perform world class experiments:

In state of the art underground facilities

And although there is healthy competition, there are also great synergies where the community works collaboratively on common issues…. such as Low Radioactivity Techniques …. Why we are here today