Underground Laboratories

a quick tour

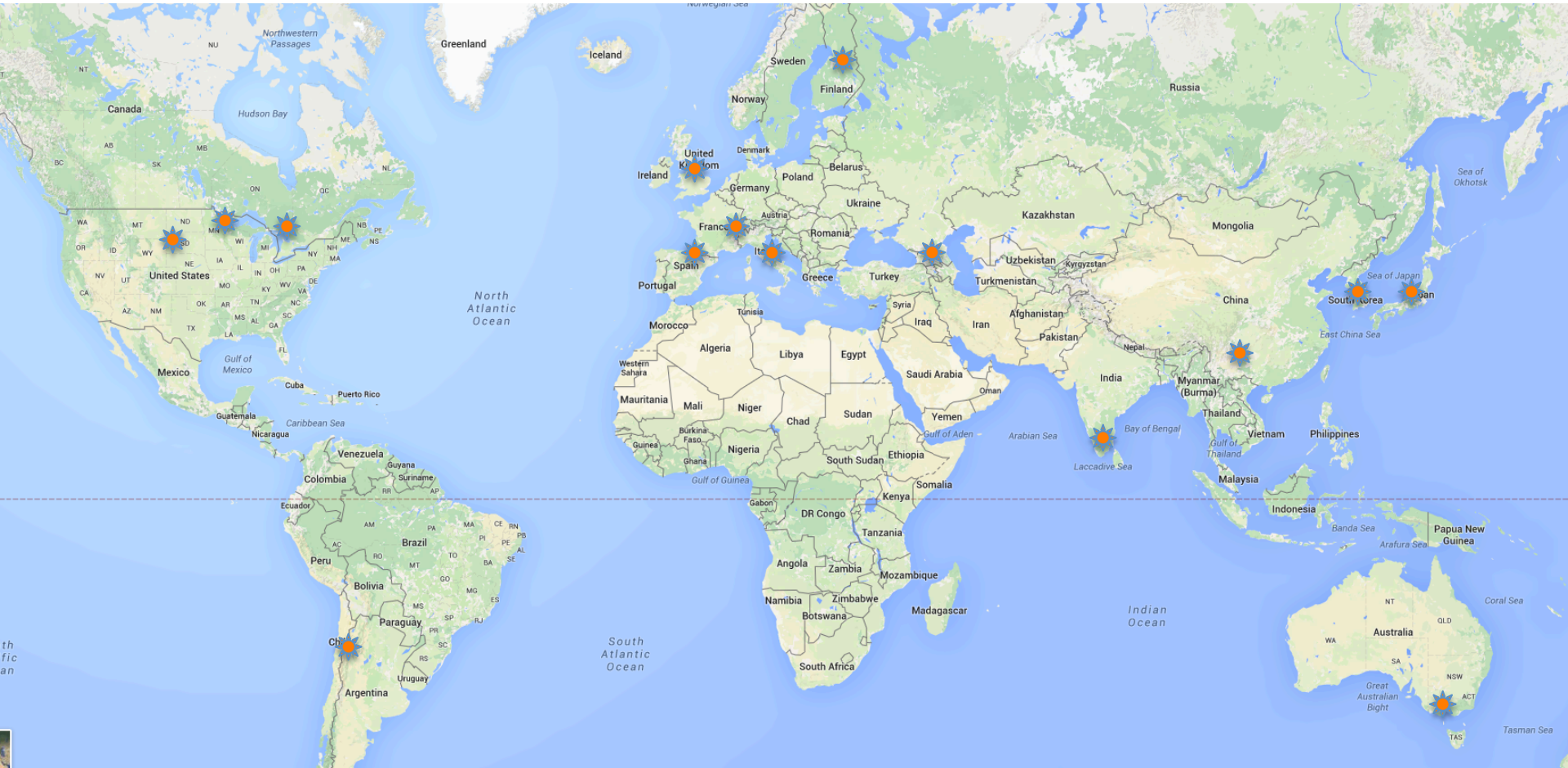
SR

München, April 2016

Outline

- A **very quick** tour (3 slides/min) around the world of **deep** UG laboratories
  - NOT a review
- General considerations
- Evolution
- Final remarks

A Broad Family



Europe

Phyasalmi

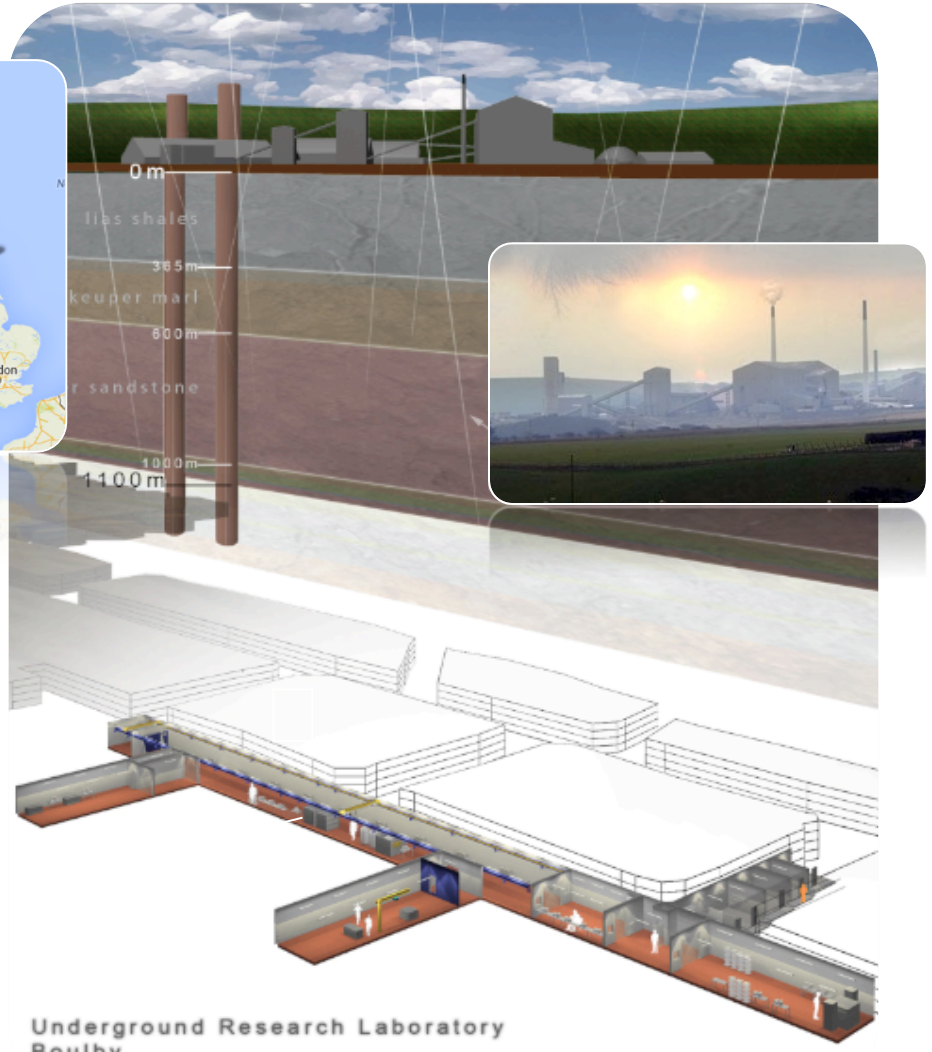
- New lab space in Phyasalmi mine, Finland
- 120 m^2
- 1430 m depth
- ideal location for tests and prototype detectors.

Boulby Underground Laboratory

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

1.1km depth (2805 mwe). With low background surrounding rock-salt

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



Boulby Palmer lab. >800m^2 floor space. Operating since 2001

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

Underground Science @ Boulby Mine

- DRIFT: Directional Dark Matter Search
- DM Ice: NaI(TI) 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).

Science & Technology Facilities Council

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

BOULBY UNDERGROUND LABORATORY

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

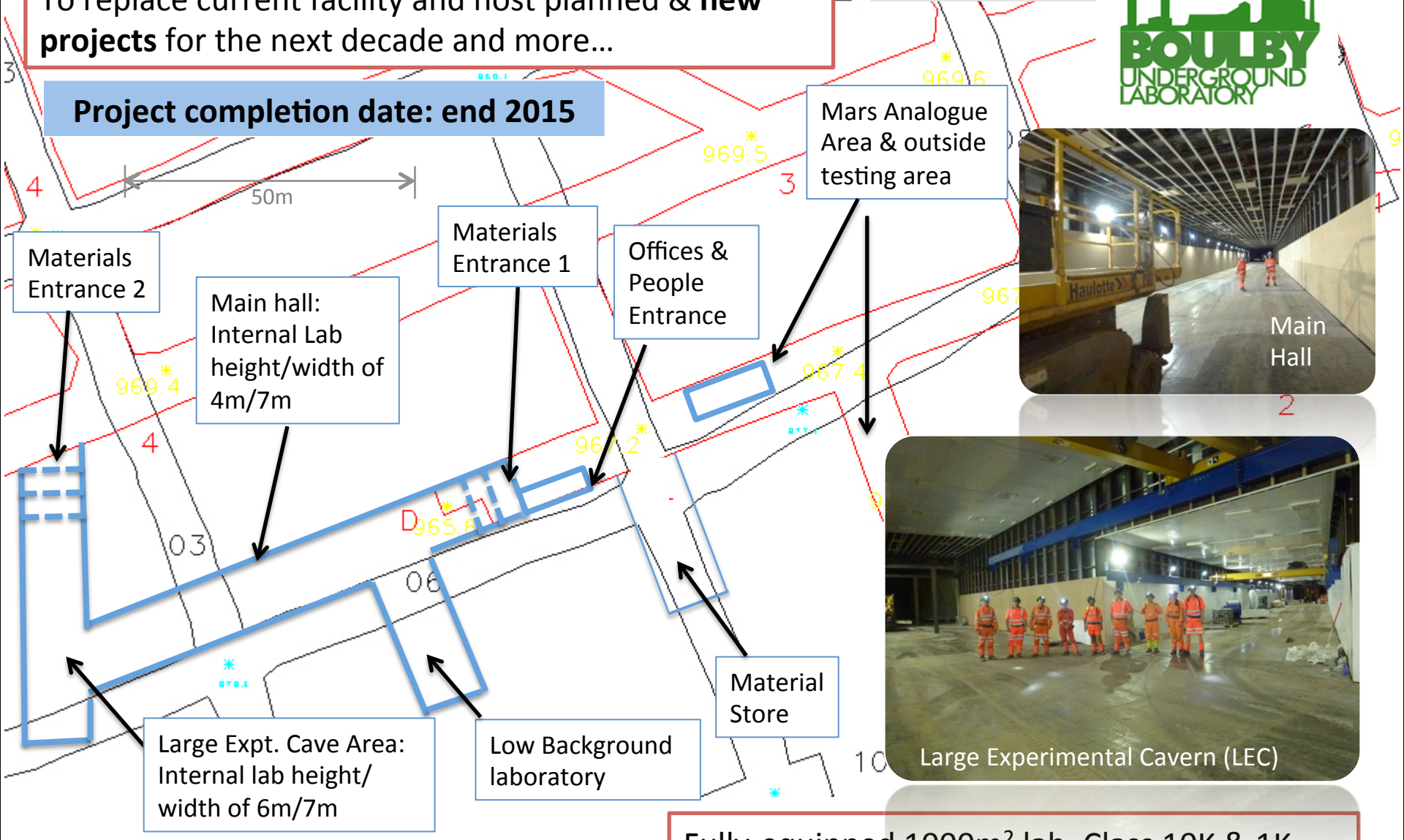
A NEW LABORATORY now being built at Boulby

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

Science & Technology Facilities Council

BOULBY UNDERGROUND LABORATORY

Project completion date: end 2015

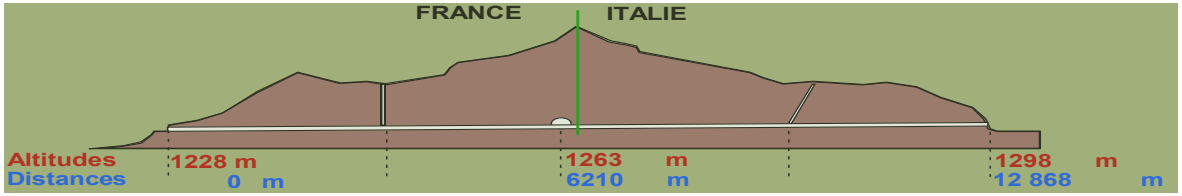


Fully-equipped 1000m^2 lab. Class 10K & 1K clean room throughout. 5-10T lifting capacity.

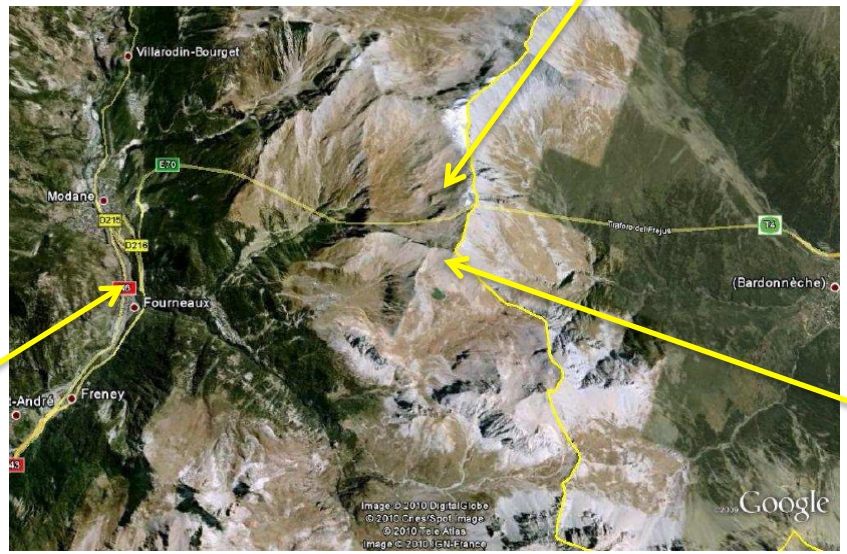
New project proposals invited

Modane Underground Laboratory

Fréjus roadway tunnel



Surface facility @ Modane

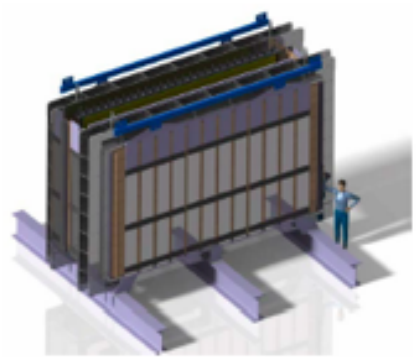


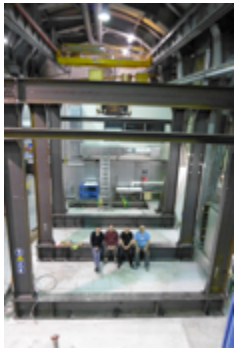
Underground site

Modane Underground Laboratory

Fundamental physics:

- Neutrino: double beta decay (SuperNEMO), EcHo (ν mass)
- Dark matter (EDELWEISS, LUMINEU, SEDINE, MIMAC)
- Nuclear structure (TGV, SHIN)
- General Relativity test with
- Optical atomic clock





SupernEMO demonstrator installation in progress

Sedine

Gamma spectrometer (16)

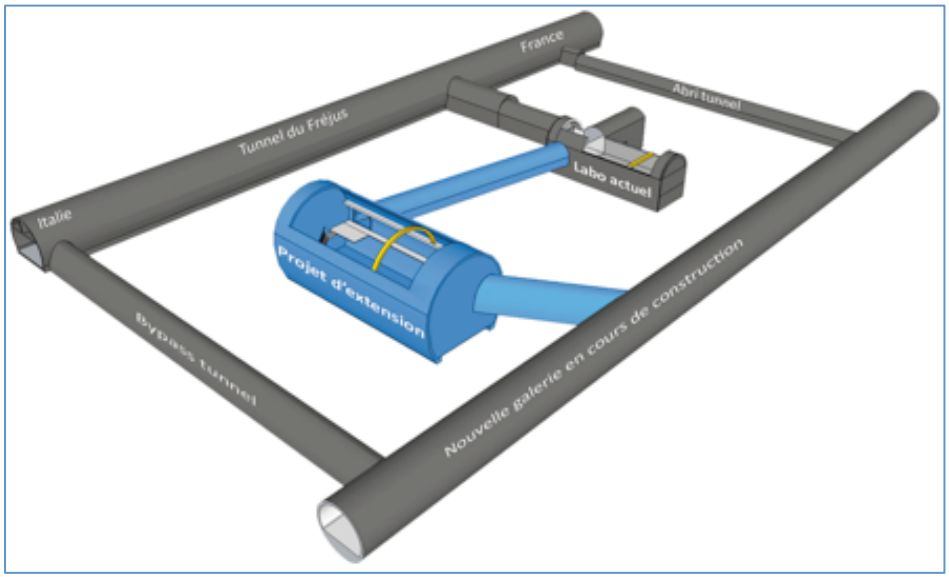
Multidisciplinary activities

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

LSM extension project:DOMUS

Next generation of underground astroparticle physics requires more space

DOMUS extension project 14 000 m^3 (X4 present LSM)



Cavity: Length 40 m,width18 m, height 16 m

Laboratorio Subterráneo de Canfranc

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

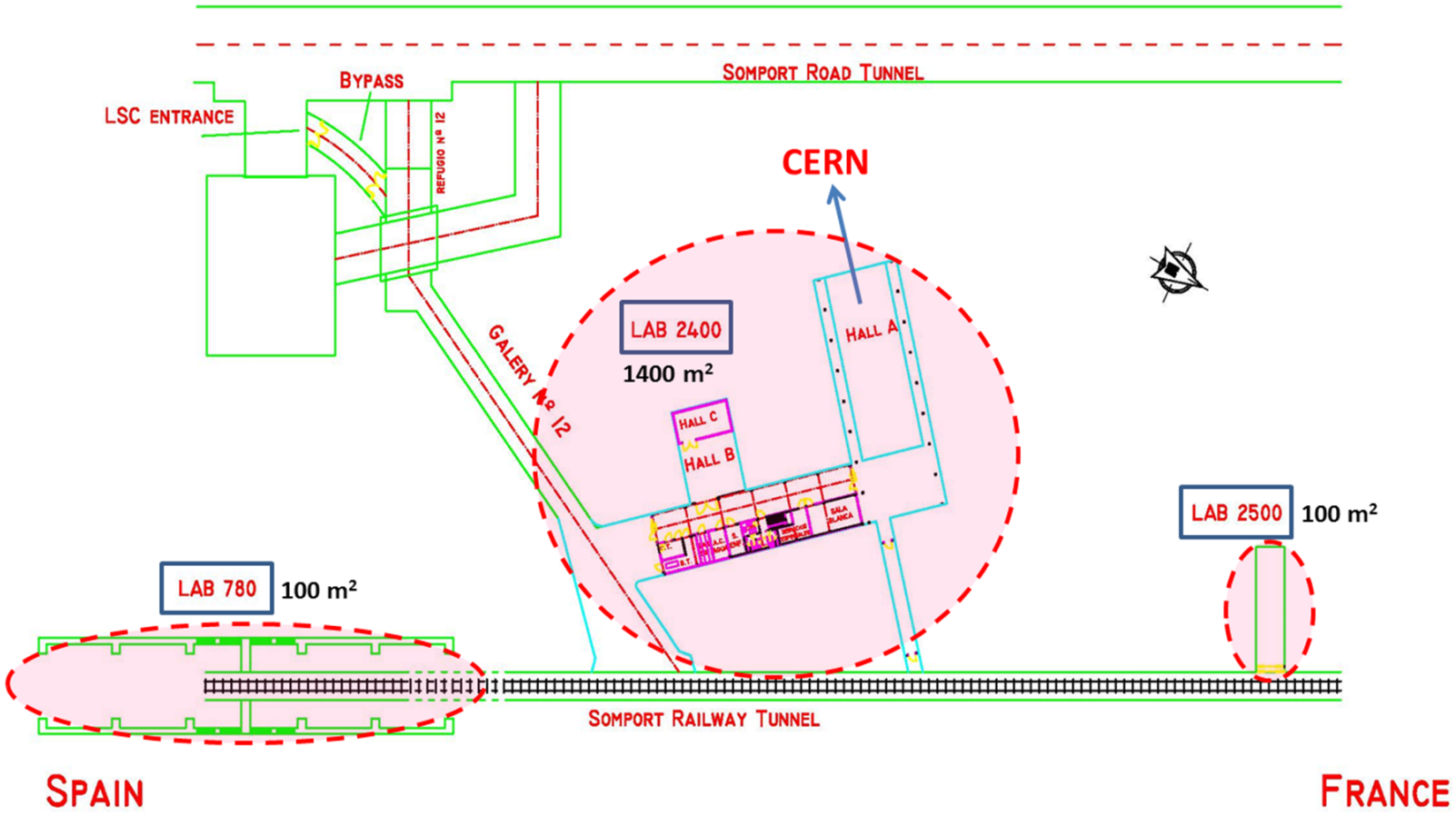
Personnel: 10 units
Budget:≈ 1.6 M€/yr
Users: 275 (19 countries)
Visits (2014): 966

LSC external building

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, Figure 7)



LSC Underground Facility

- LSC underground total volume ~10000 m^3 for a total surface of 1600 m^2.
- Underground space divided as:
  - **LAB780**(L and R) since 1985:
    - two small halls 12 m^2 each and two 70 m long small tunnels
    - early installation in service space for railway tunnel
  - **LAB2500**:
    - 118 m^2 hall in operation since 1994
  - **LAB2400**:
    - Hall A has dimensions 40×15×12(h) m^3 and Hall B has dimensions 15×10×8(h) m^3
    - 45 m^2 clean room and 215 m^2 service space
    - In operation since 2006
- Protocol to enter underground area:
  - Entrance through road tunnel
  - Independent exit through the railway tunnel

LSC Experiments

- **Experiments under construction**

✓ ANAIS DM (NaI, Annual modul.)

✓ ROSEBUD DM (Scintill. bolometers)

✓ ArDM DM (2phase Ar TPC) 800 kg

✓NEXT $0\nu2\beta$ (Enr ^{136}Xe gas TPC)

✓BiPo $0\nu2\beta$ (screening for S-NEMO)

✓SuperK-Gd screening for Super-K-Gd

✓**GEODYN** **Geodynamics**

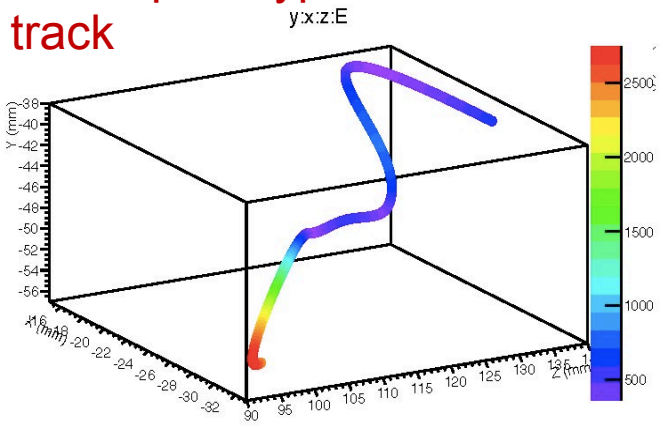
-Expressions of Interest

✓CUNA Nuclear astrophysics

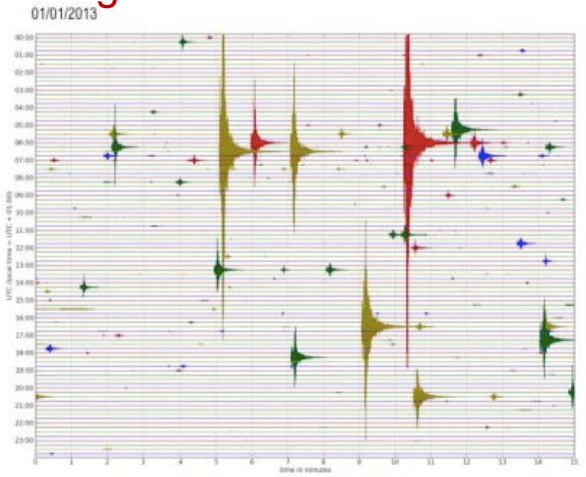
✓New 300 m^2 facility in project

✓**GOLLUM** **Characterising subterranean bacterial**

NEXT prototype. Cs electron track

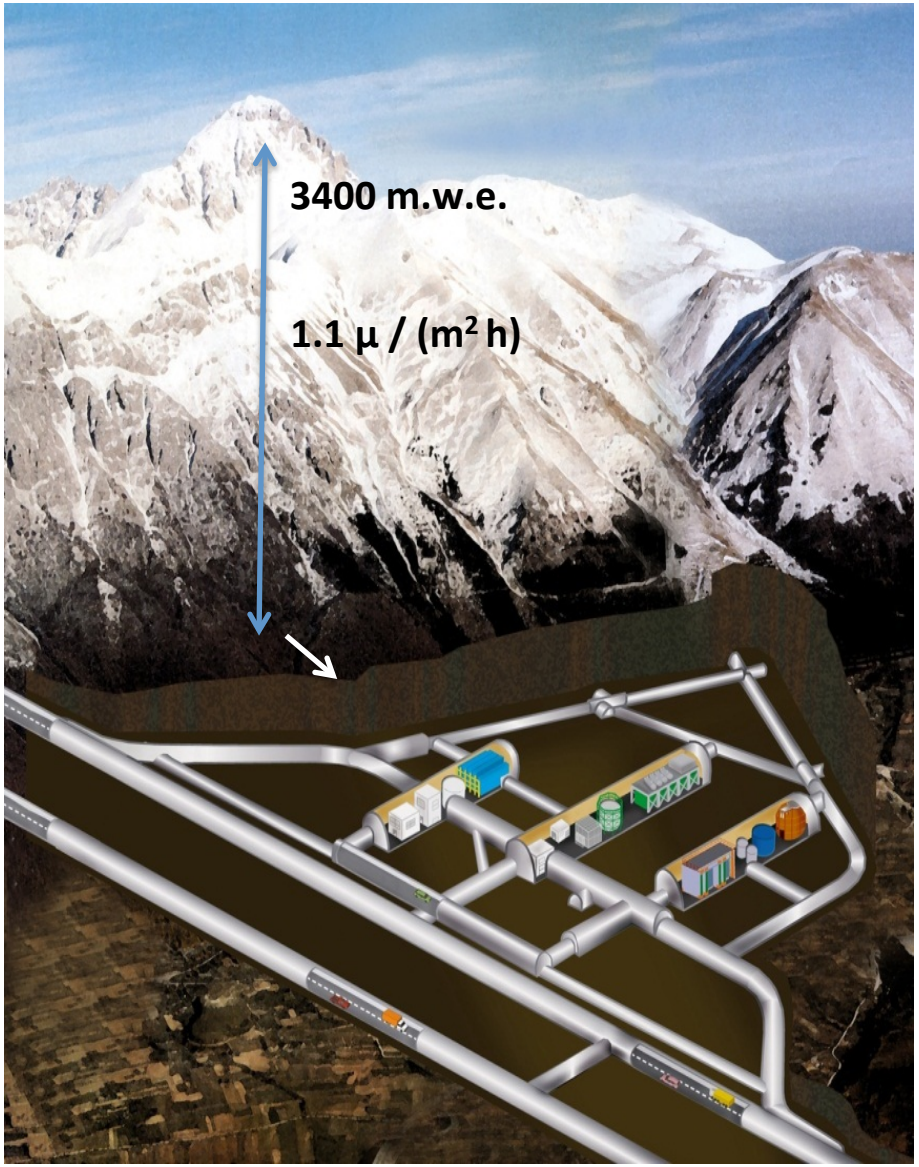


GEODYN small magnitude aftershocks, in low background underground environment



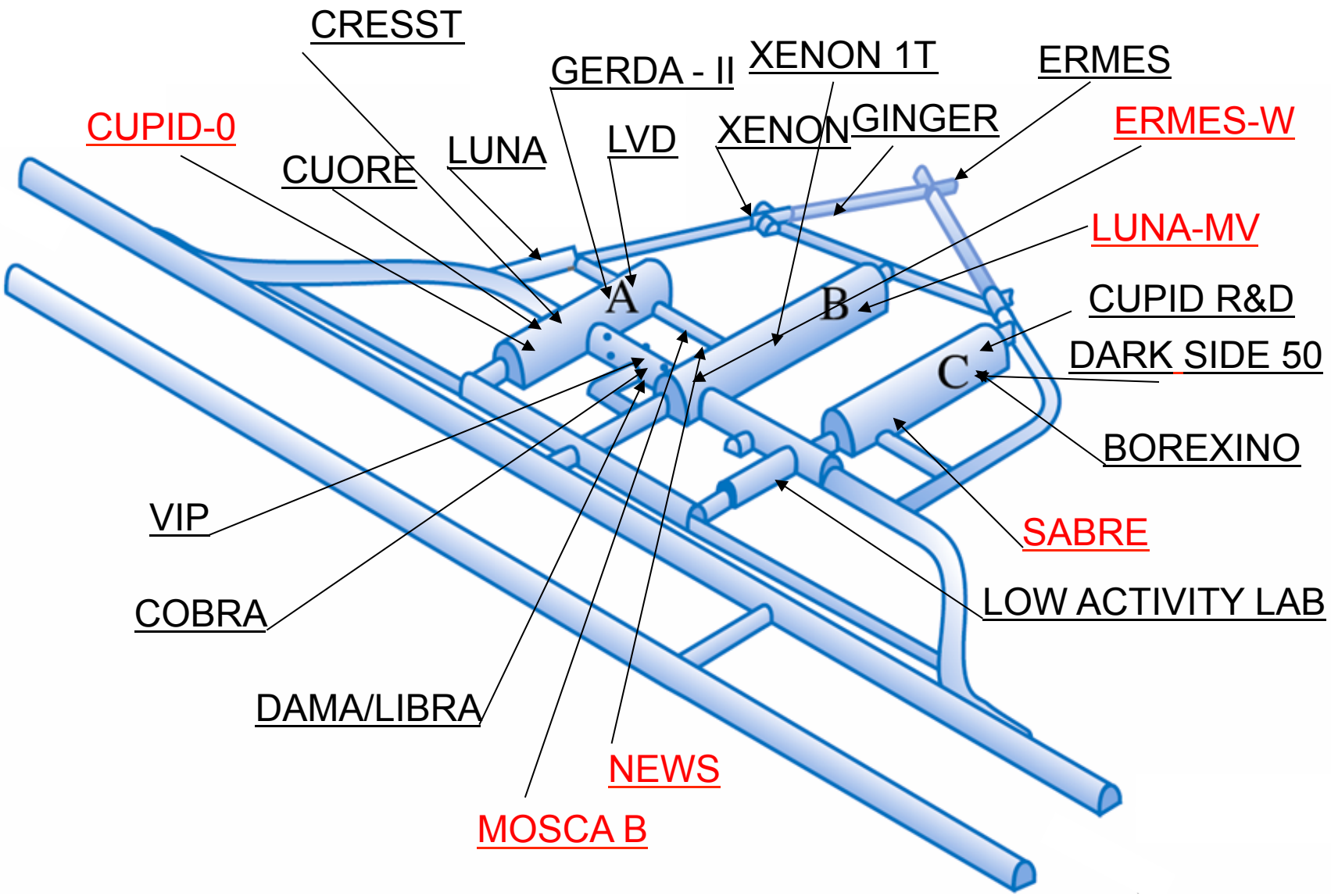
Laboratori Nazionali del Gran Sasso

- Muon flux: 3.0 10^{-4} $m^{-2}s^{-1}$
- Neutron flux:
  2.92 10^{-6} $cm^{-2}s^{-1}$ (0-1 keV)
  0.86 10^{-6} $cm^{-2}s^{-1}$ (> 1 keV)
- Rn in air: 20-80 Bq m^{-3}
- **Surface: 17 800 m^2**
- **Volume: 180 000 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/y
- Virtual tour via Street View



LNGS Activities

UG site



LNGS – 2020 and Beyond

A lively one-day meeting on April 28

- https://agenda.infn.it/conferenceDisplay.py?confId=9608

➢ Strong, challenging, engaging program for

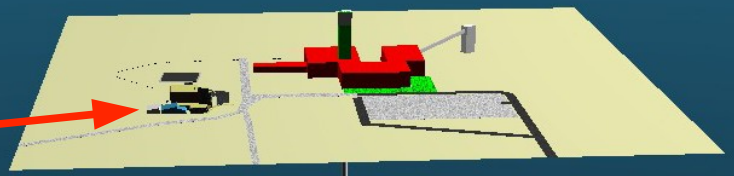
- Direct DM (WIMPs) searches - Experimental program of 3rd generation DM
- Experiments will include precision measurements of solar neutrinos
- Neutrino-less Double Beta Decay

➢ LUNA-MV program, which extends beyond 2030

➢ DarkSide20k proposal is currently (March 2016) being reviewed by NSF

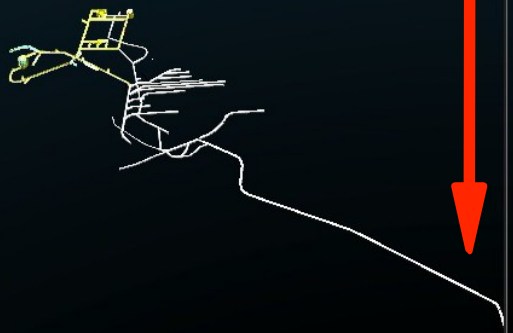
North America

Surface Facility

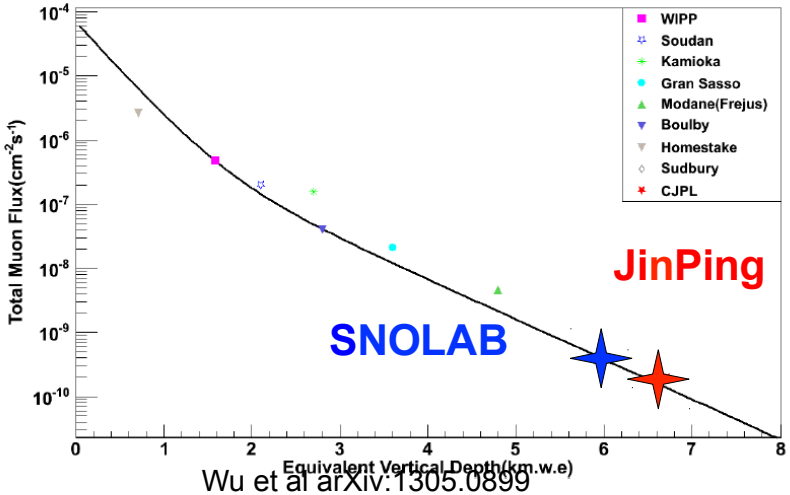


2km overburden (6000mwe)

Underground Laboratory



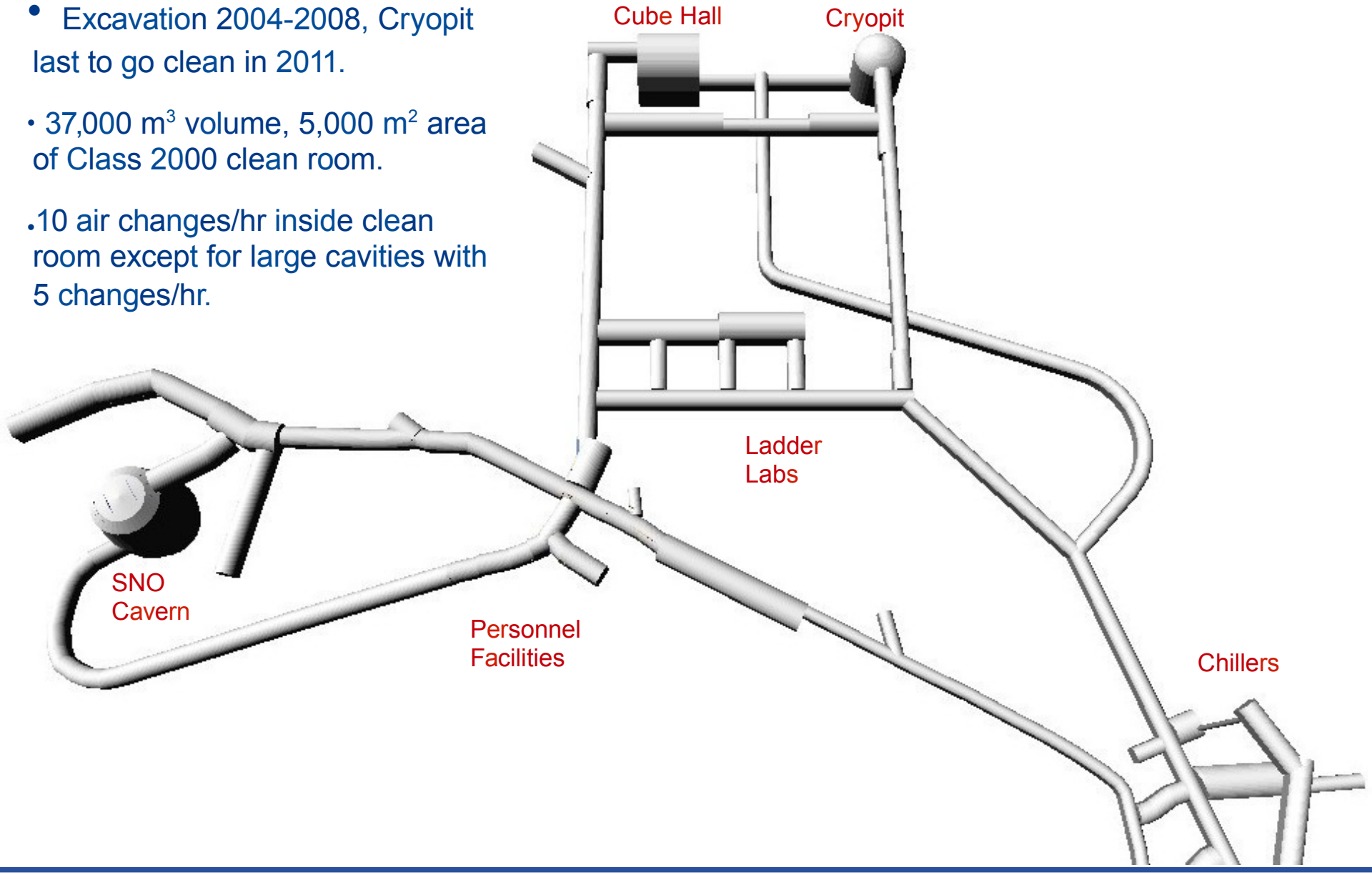
Muon Flux = 0.27/m^2/day



Wu et al arXiv:1305.0899

SNOLAB

- Excavation 2004-2008, Cryopit last to go clean in 2011.
- 37,000 m^3 volume, 5,000 m^2 area of Class 2000 clean room.
- 10 air changes/hr inside clean room except for large cavities with 5 changes/hr.



Current Science Program

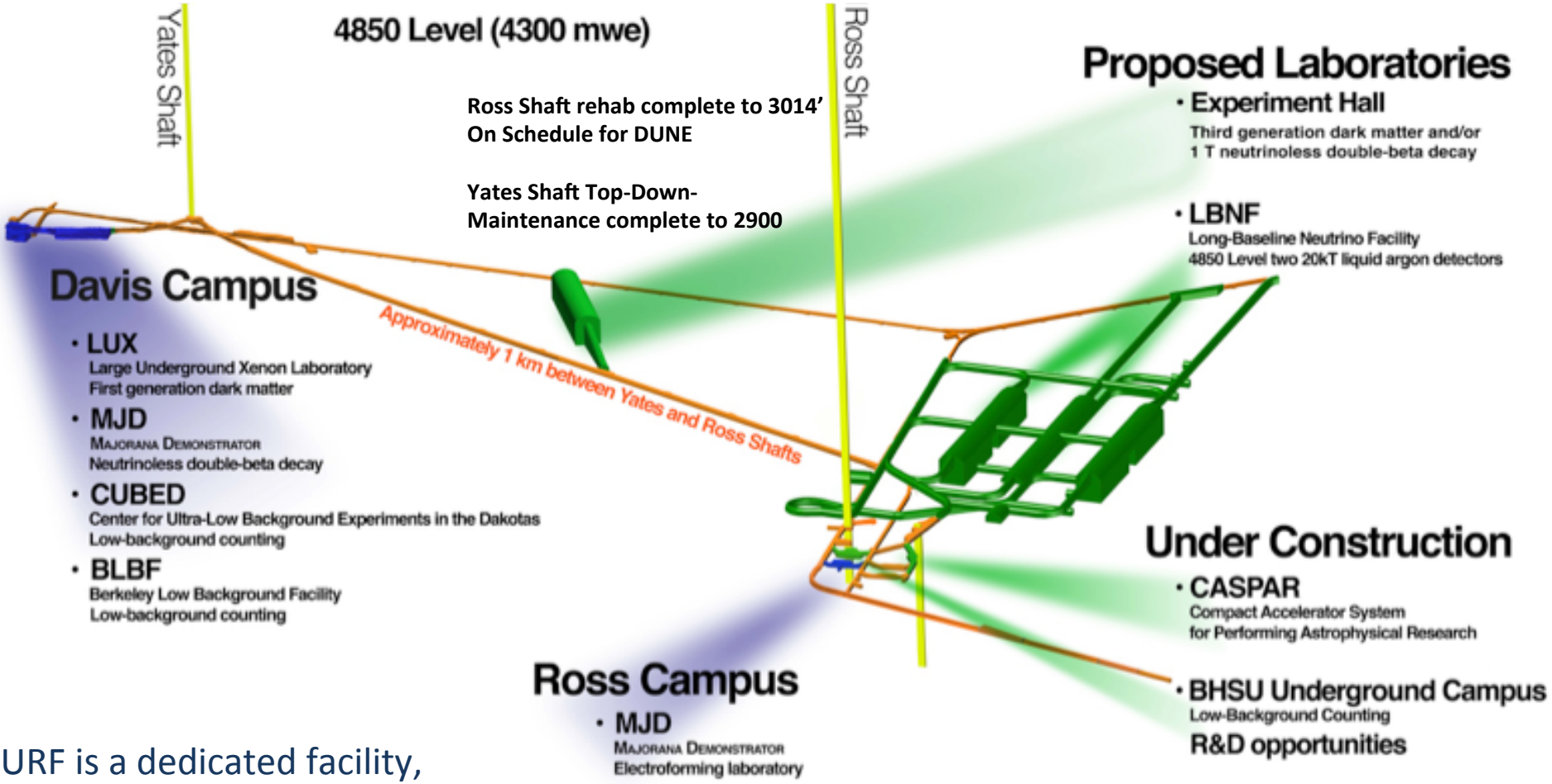
Experiment	Neutrino	Dark Matter	Other	Space Allocated	Satus
CEMI			Mining Data Centre	Surface Facility	In Construction
COUPP-4		X		J-Drift	Completed
DAMIC		X		J-Drift	Operational
DEAP-1		X		J-Drift	Completed
DEAP-3600		X		Cube Hall	In Construction
DEAP- 50T/CLEAN		X		Cube Hall	Expression of Interest
DMTPC		X		Ladder Labs	Expression of Interest
Ge-1T	X			Cryopit	Expression of Interest
nEXO	X			Cryopit	Feasibility Phase
HALO	X			HALO Stub	Operational
MiniCLEAN		X		Cube Hall	In Construction
NEWS		X		Cryopit?	Expression of Interest
PICASSO-III		X		Ladder Labs	Completed
PICO-2L		X		J-Drift	Operational
PICO-60		X		Ladder Labs	Operational
PICO-250		X		Ladder Labs	Expression of Interest
PINGU			Test Facility	Ladder Labs	Expression of Interest
PUPS			Seismicity	Various	Completed
SNO+	X			SNO Cavern	In Construction
SuperCDMS		X		Ladder Labs	In Preparation
U-Laurentian			Genomics	External Drifts	Operational

Space allocation

Sanford Underground Research Facility

Sanford
Underground Research Facility

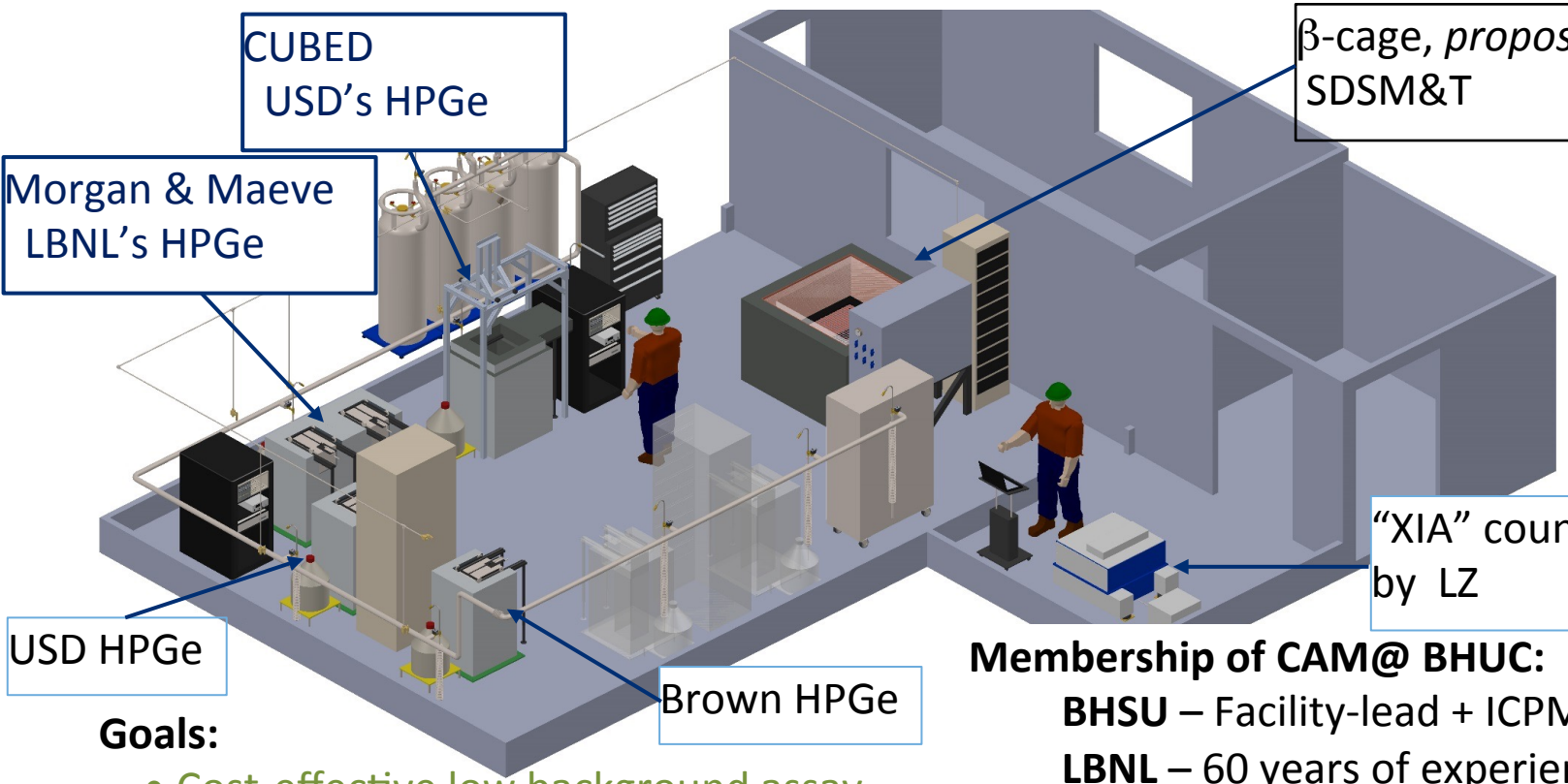
SURF 4850L Physics Laboratories



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)

Consortium for Assay and Measurement at the Black Hills Underground Campus: CAM@BHUC



Goals:

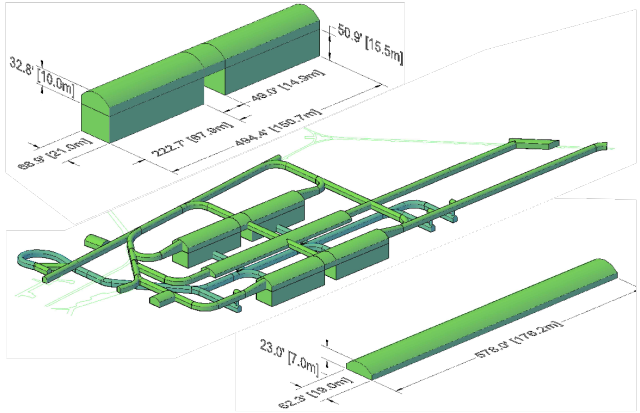
- Cost-effective low background assay
- High accuracy and cross-calibrated
- Ultra-low level sensitivity
- Simple operational model
- Develop and deploy new capabilities and higher sensitivity levels
- Develop strong connection to SD students

Membership of CAM@ BHUC:

BHSU – Facility-lead + ICPMS
LBNL – 60 years of experience LBC, HPGe
SDSTA – SURF Facility Operations
USD – HPGe, Radon, Surface Contam.
Brown - HPGe, Surface Contamination
UCL – ICPMS, Radon, HPGe
Boulby – HPGe
SDSM&T – Radon, β-cage, Si
Seeking additional members & devices

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 Fall 2015
- Goal to begin underground construction 2017



LBNF & ELBNF CONSTRUCTION/INSTALLATION STEPS

U.S. FISCAL YEARS	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
10kt FACILITY & DETECTOR		WRH	10kt EXCAV	LINER	CRYO	10kt DETECTOR INSTALLATION				
30kt EXCAVATION			30kt EXCAVATION							
30kt LINER, OUTFITTING, CRYO					30kt LINER, OUTFITTING, CRYO					
30kt DETECTOR								30kt DETECTOR INSTALLATION		
BEAMLINE FACILITY			EMBANKMENT	BEAMLINE FACILITY CONSTRUCTION			BEAMLINE INSTALLATION			
NEAR NEUTRINO DETECTOR & FACILITY						NND FACILITY	NND			

From Nigel Lockyer's Presentation January 2015

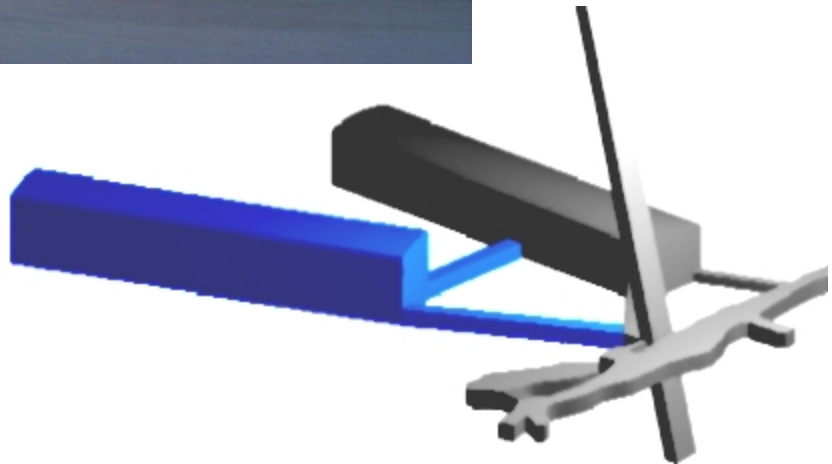
Summary and critical path durations only, could be moved in time

Summary
Sanford Underground Research Facility

- Site is well characterized and science programs functioning smoothly in the facility
  - LUX – Dark Matter – well into 300 day long run
  - MAJORANA DEMONSTRATOR – 0νββ preparing for first physics runs
  - BioGeoEng on going investigations
- Expansions to accommodate additional science progressing well
  - CAM @ BHUC (Low Background Assay) near Ross (2015) - outfitting
  - Caspar Nuclear Astrophysics near Ross (2015) – installation begun
  - LZ G2 Dark Matter in the Davis Campus (2017) – preparing CD2
  - LBNF/DUNE on the 4850L near Ross Shaft (2017) – completed CD1R
- Additional space available on the surface and underground for other experiments and collaborations

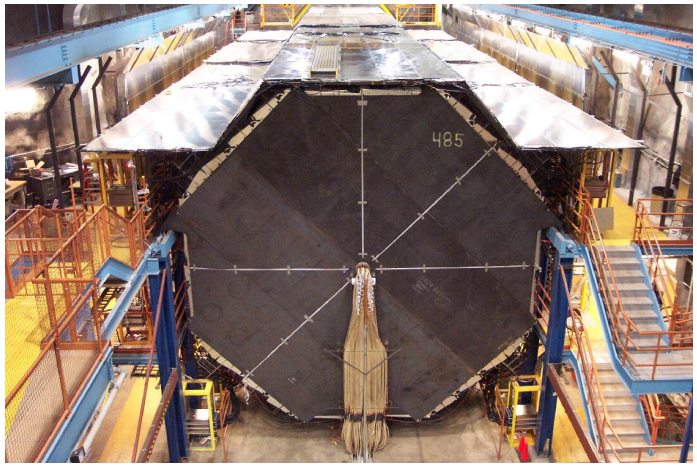
Soudan Mine Underground Lab

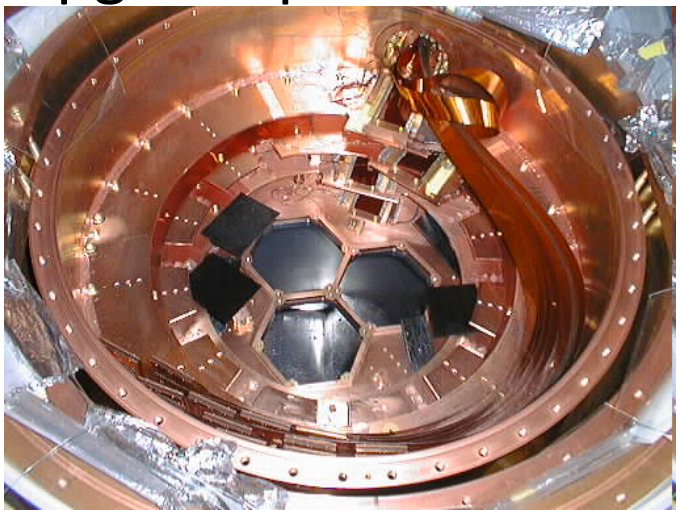
- Soudan Iron Mine has been a state historical park since the 1960's
- Soudan I proton decay experiments started the science in the 1980's
  - Soudan II, MINOS excavated new caverns, ~2,200 m^2 of climate-controlled, networked space with 13-14 m ceilings
- Operated by Univ. of Minnesota, main funding from DoE via Fermilab
- 700 m (2070 mwe) deep
  - Vertical access
  - Good ventilation, low radon, strong old rock, built in outreach in cooperation with the park



Large Experiments

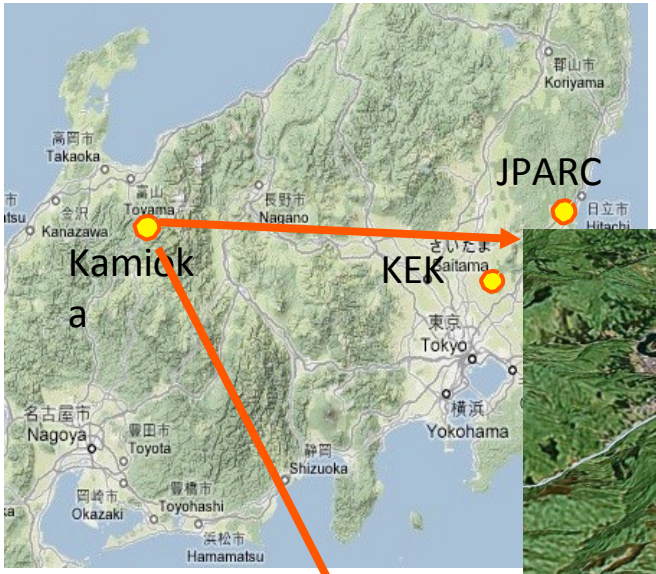
- Fermilab operates the Lab's current main tenants
  - So pays the vast bulk of the ~$1.2M/yr operational budget
- MINOS changed into MINOS+ in 2013
  - Observes NOvA's upgraded neutrino beam from on-axis
- CDMS taking final calibration data
- CoGeNT taking data, CoGeNT-4 upgrade planned



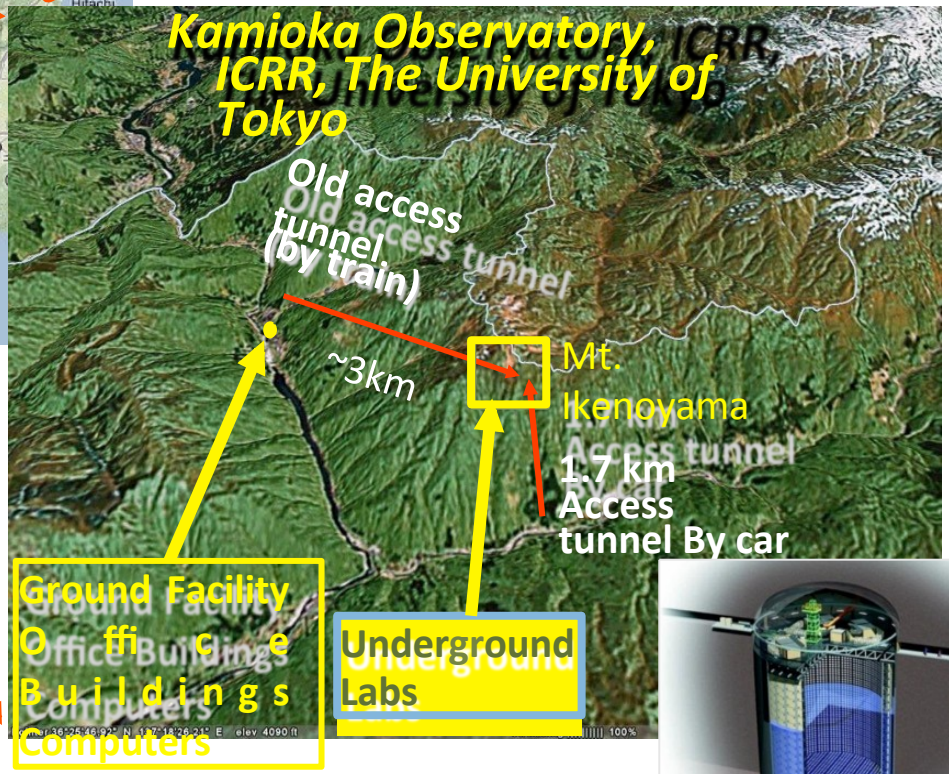


Asia

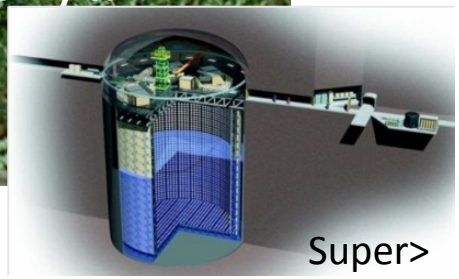
Kamioka Observatory



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

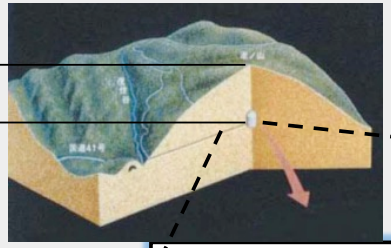


- Horizontal access
- 24 hours access by car
- 10 minutes from ground facility
- 1000 m underground
- 2700 m.w.e

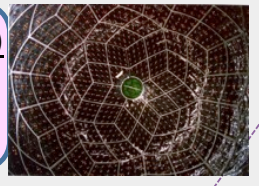


Super> K

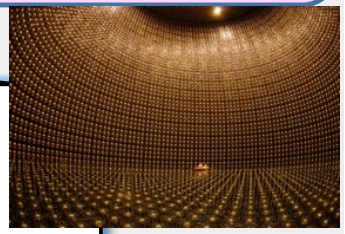
Kamioka Underground Laboratories



KamLAND (Tohoku Univ.)
1000ton liquid scintillator detector
Rector, 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)

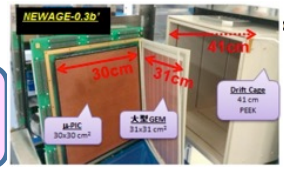
Lab.A
Super-K dome
clean room
Gd test
water
system

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

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
- 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)
  - **June 2015 - 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

New lab space at Y2L for KIMS-NaI & AMoRE-I

YangYang Underground Laboratory (Y2L)

YangYang Pumped
Storage Power Plant

- Minimum depth : 700 m
- Access to the lab by car (~2km)
- Lab area is only ~ 300m^2.

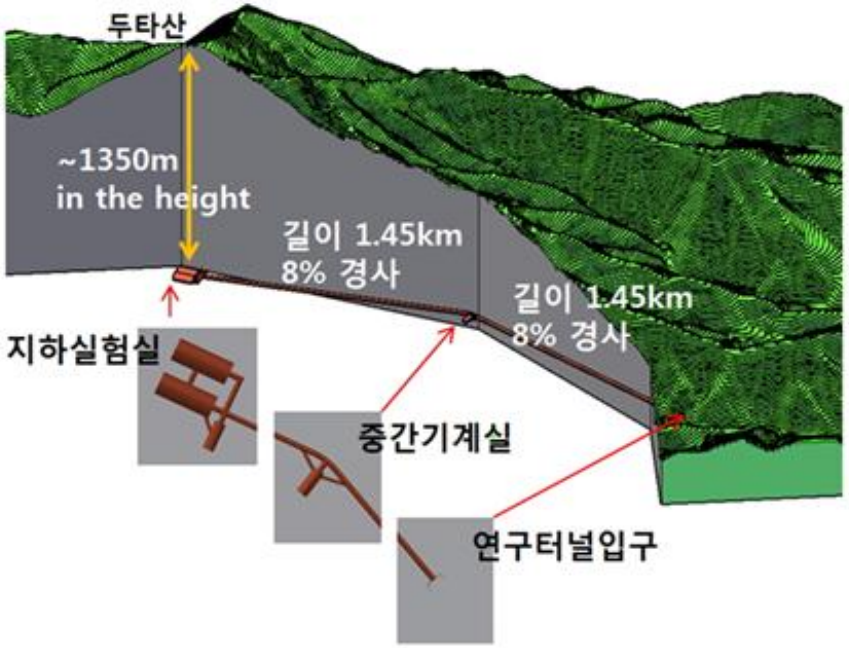
1000m

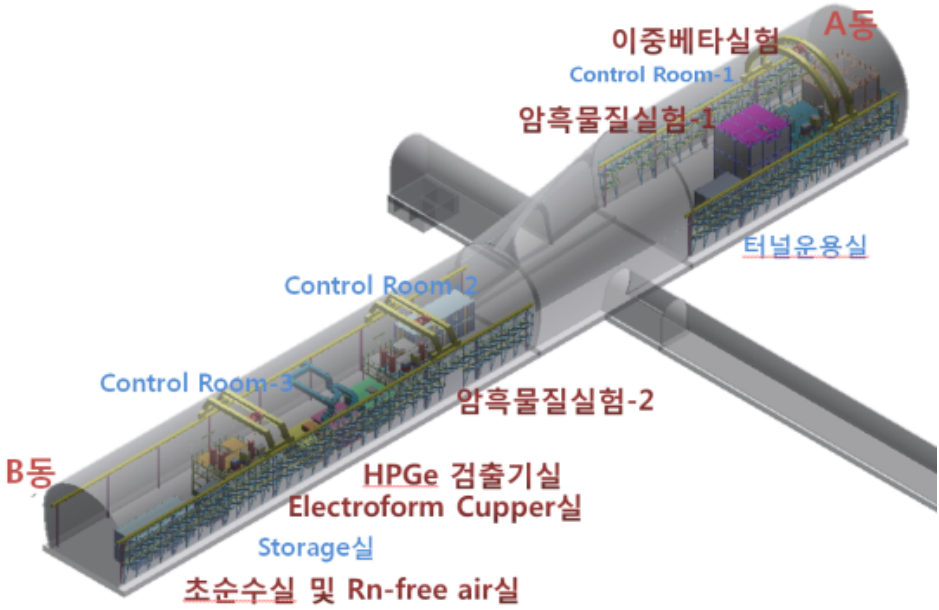
700m

New Rooms for KIMS-NaI & AMORE-I Constructed.

New Underground Laboratory – Proposal

- A new underground laboratory is under consideration at 1400m depth.
- since the expansion at Y2L seems to be not attractive compared to the new laboratory. – **Still need government approval.**





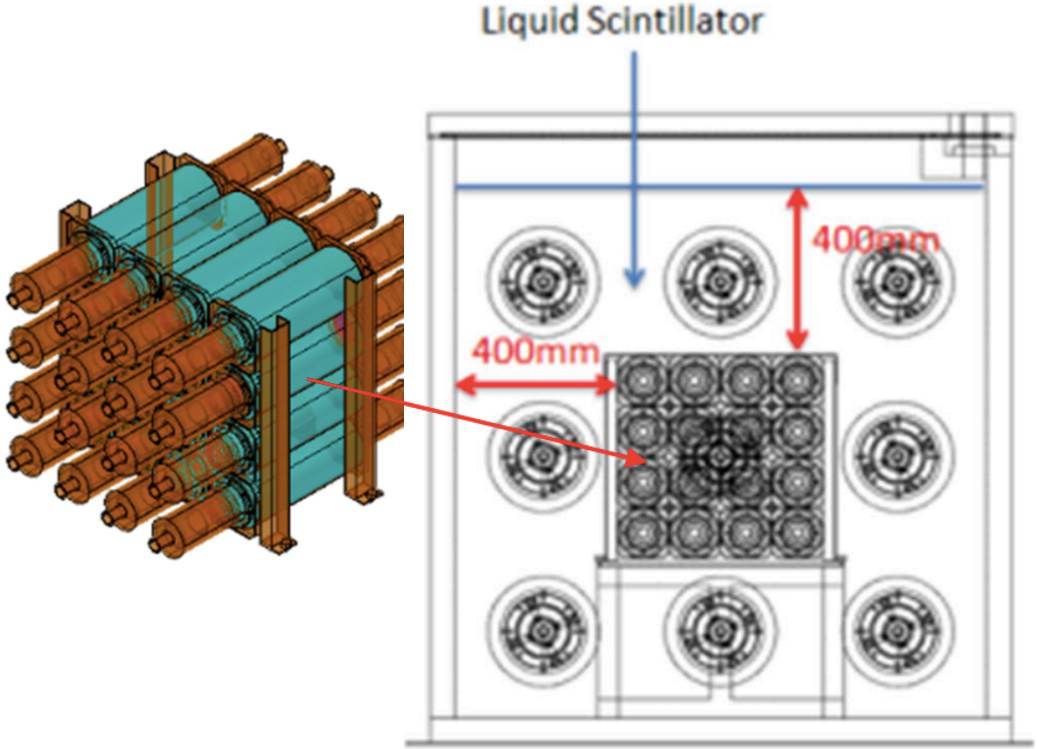
- 2000 m^2 lab area.
- 1400 m depth is similar to Gran Sasso Lab.
- Plan to finish until 2019.

Projects at Center for Underground Physics (CUP)

- CUP was approved as a research center of Institute for Basic Science (IBS) in Korea in 2013.
- Projects : Dark Matter (KIMS+), Double Beta Decay (AMoRE), Low temperature Detectors.
- Will construct a new underground Lab. until the end of 2018.

KIMS-NaI

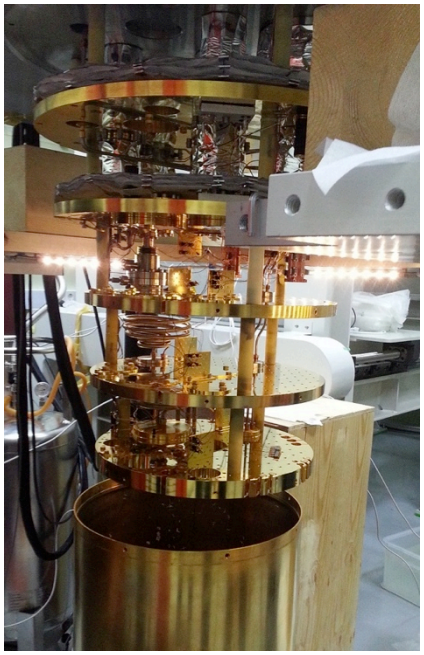
200 kg NaI(Tl) crystals inside liquid scintillator.



AMoRE ββ experiment

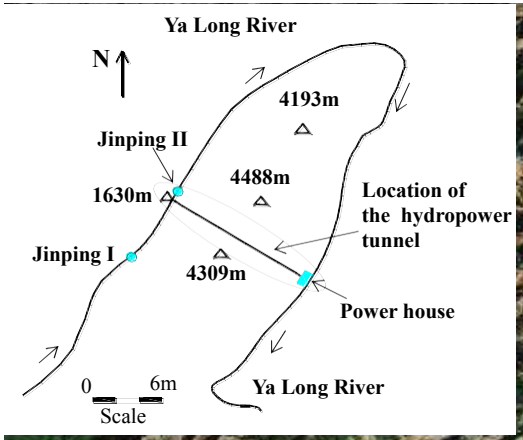
AMoRE-II

200 kg of $^{40}Ca^{100}MoO_4$



AMoRE-Pilot at Y2L, 2015
1.5 kg crystals installed.
Data taking.

China Jin-Ping Underground Laboratory(CJPL) Site



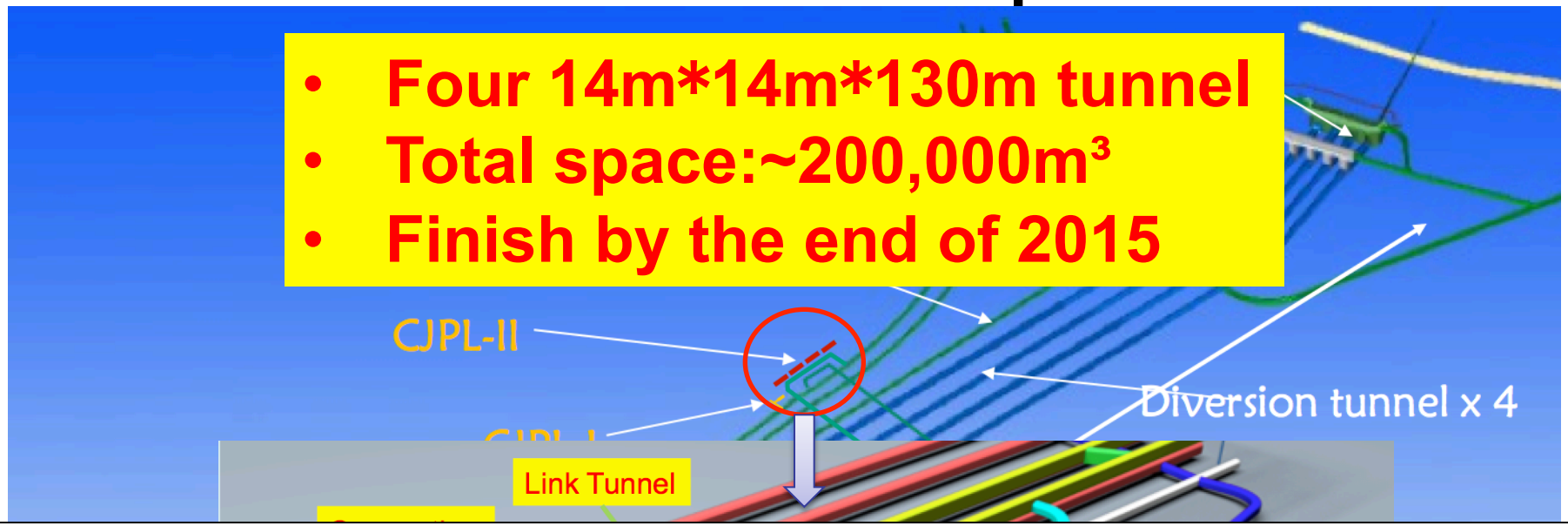
Tunnel

120km

50min from Chengdu By Air

XiChang

CJPL-II development



PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

By **Dennis Normile**

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese

WIMPs exist, they should occasionally travel unmolested through the mountain and collide with a xenon nucleus, producing a flash of light. In the other experimental hall, the China Dark Matter Experiment (CDEX) aims to catch the electrical signal produced if a WIMP bumps into a nucleus within a germanium crystal. "There is complementarity" between the two approaches,

a physicist at Academia S

Physics in Taipei and member of the CDEX

other labs indicating that WIMPs are likely to have very little mass.

For an initial effort, the results are "pretty decent," says Wick Haxton, a theorist at the University of California, Berkeley. To boost its chances of sighting WIMPs and determining their mass, CJPL needs a larger volume of xenon, more germanium crystals, and better

over the next couple years," Haxton says,

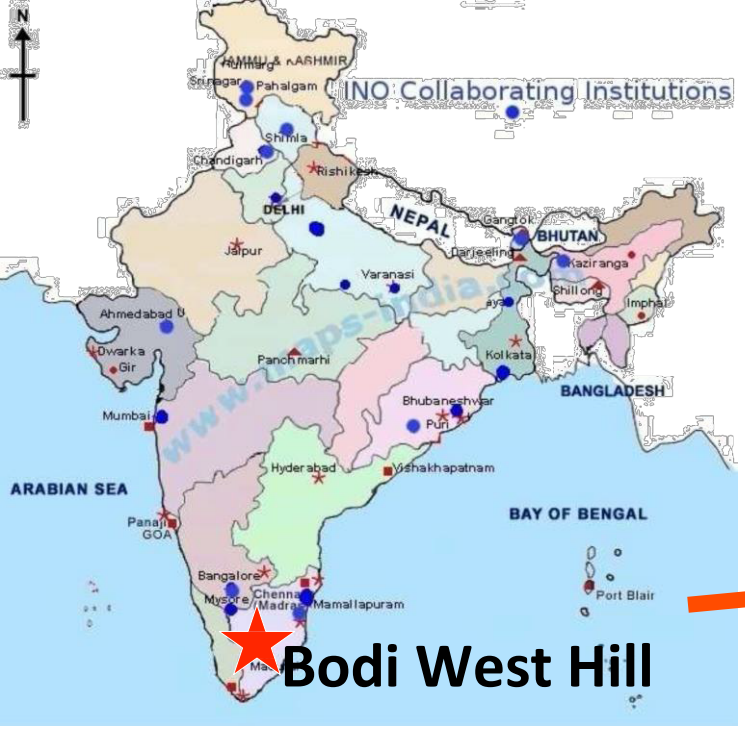
Science, Nov. 30, 2014

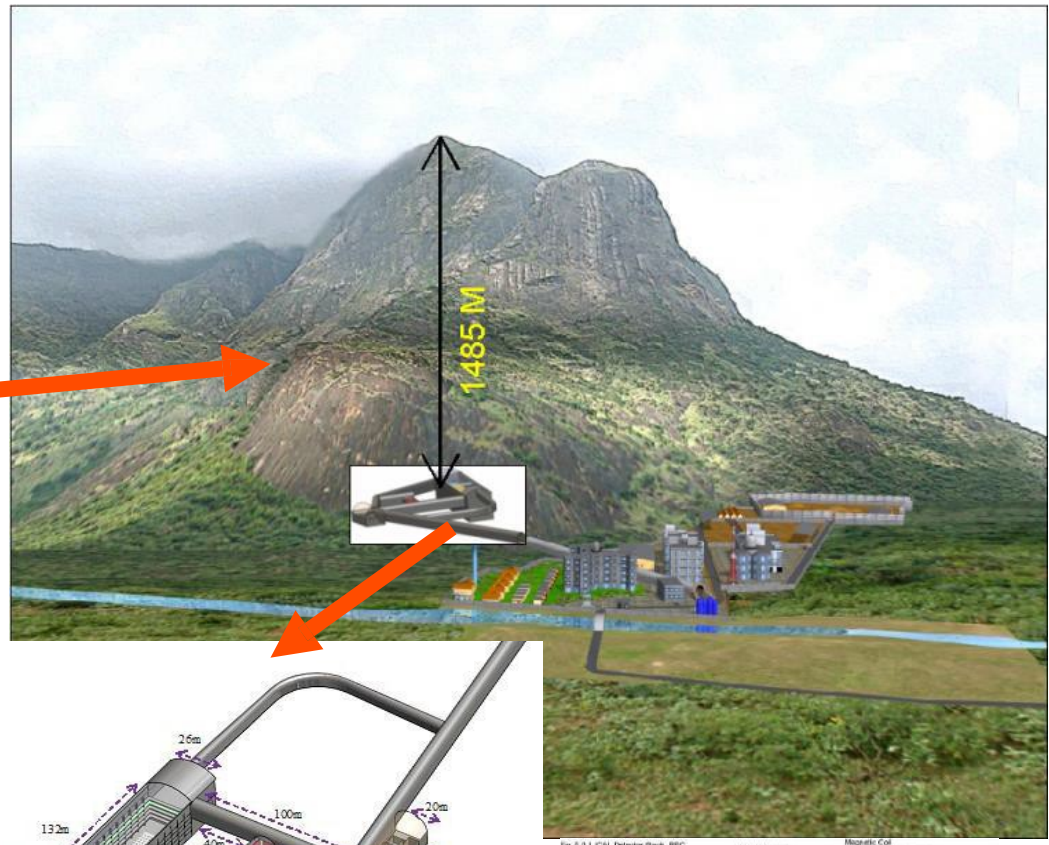
CJPL-II possible users

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

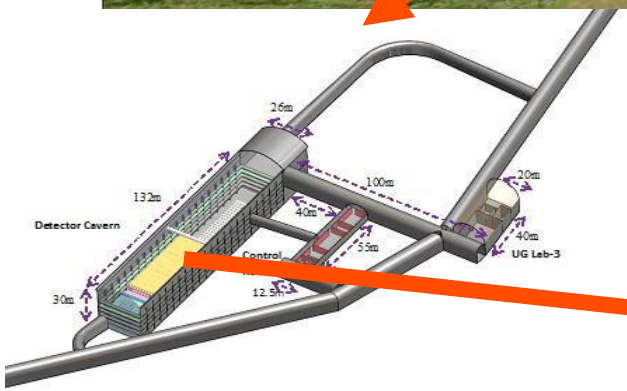
CJPL ground site

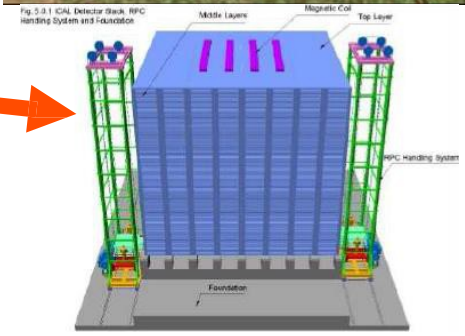
INO





Location : Pottipuram Village, Theni District Tamil Nadu State





- **INO Collaboration:**

~100 scientists from 23 research institutes & Universities in India.

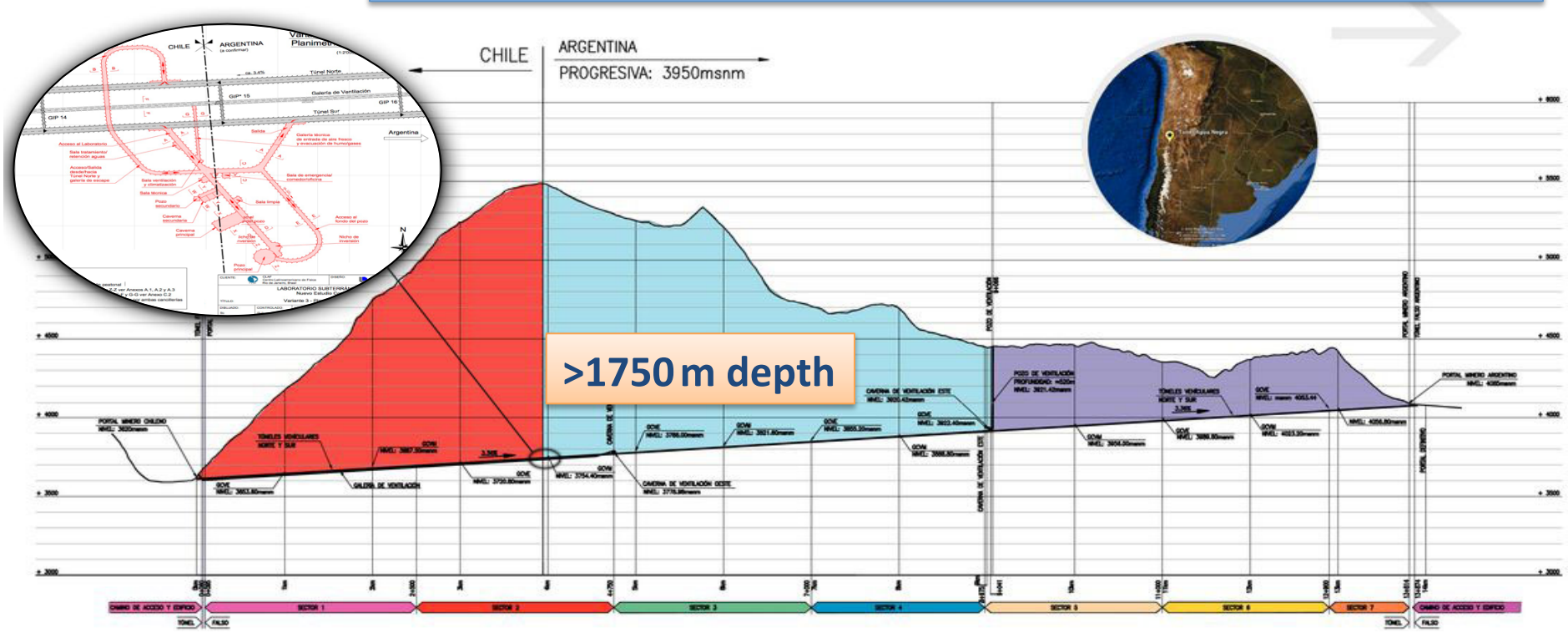
~1km rock overburden access through 2 km long tunnel

Southern Hemisphere

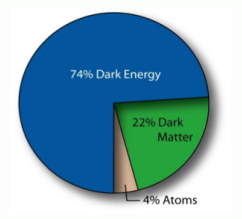
ANDES
The Agua Negra deep underground laboratory

- 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 ~4 000 m^2 and ~70 000 m^3 in 8 halls and pits

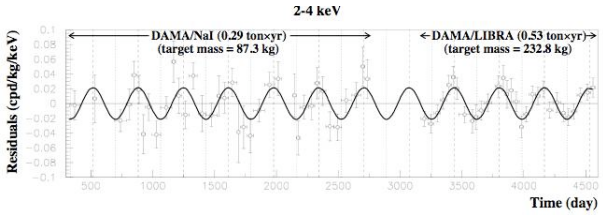
Large and deep underground laboratory in the southern hemisphere



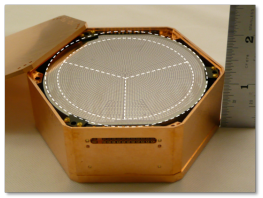
ANDES: Agua Negra Deep Experiment Site



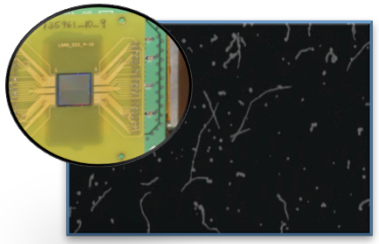
Dark Matter



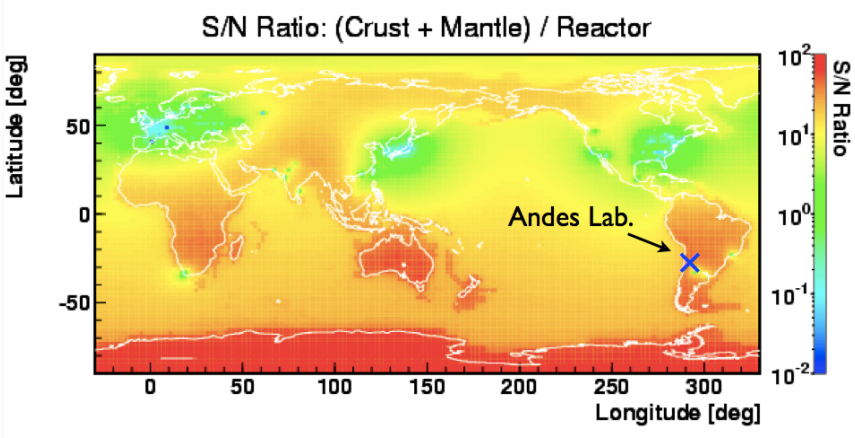
DAMA/LIBRA yearly modulation, to investigate in Southern hemisphere



Host 3rd generation DM experiment

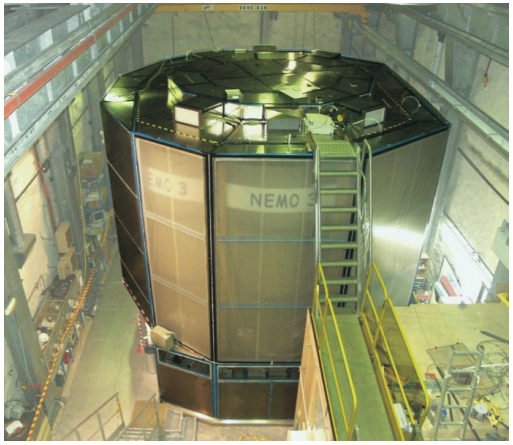


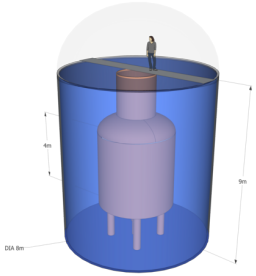
Study new particle detection techniques, ex: CCD



Neutrinos

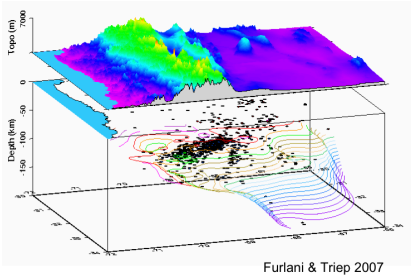
- Geo-neutrinos (benefit from unique location)
- Build a low energy Latin American neutrino detector
- Host experiments for Mass & Nature (ex: host part of SuperNEMO?)





Ultra low radiation pit

Environmental measurements, material selection…



Furlani & Triep 2007

Geophysics laboratory

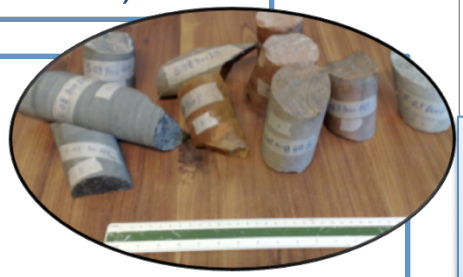
Local active region, Seismograph network junction (Argentina+Chile), Magnetic and Gravimetric studies

+ accelerator science, interdisciplinary science…

ANDES: Agua Negra Deep Experiment Site

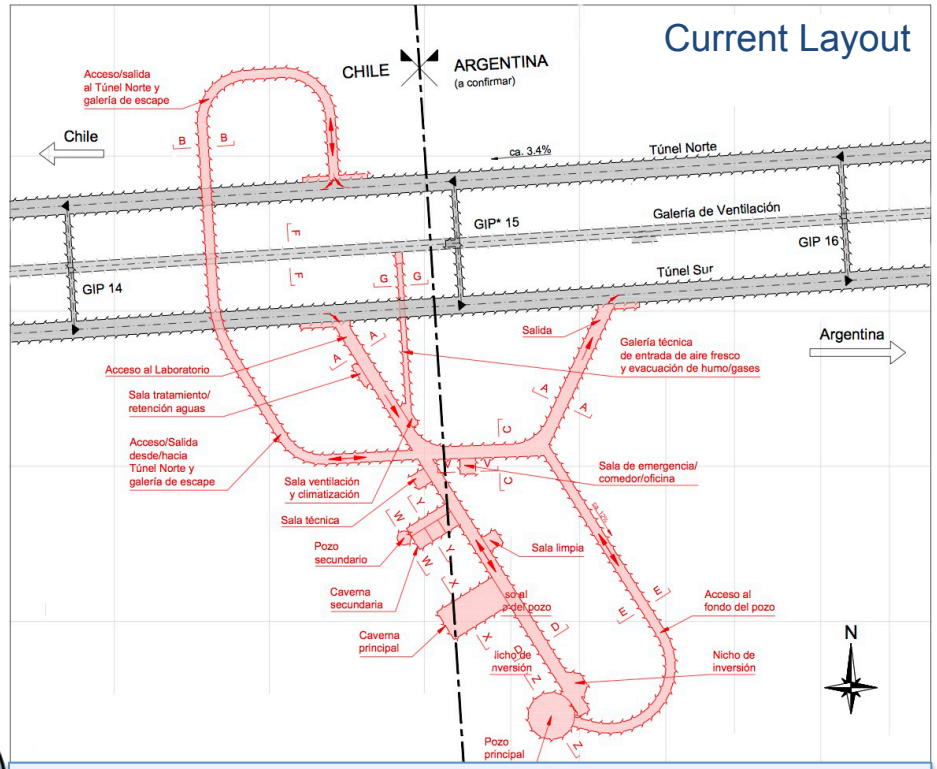
- Main hall (21 m x 23 m x 50 m)
- Secondary hall (16 m x 14 m x 40 m)
- Offices and small labs
- Low radiation pit
- Large single experiment pit (~ ø 30 m, 30 m tall)
- Vertical depth: 1775 m, omnidirectional: 1675 m
- Total: 70 000 m^3 laboratory volume (+ 35 000 m^3 access tunnels)

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



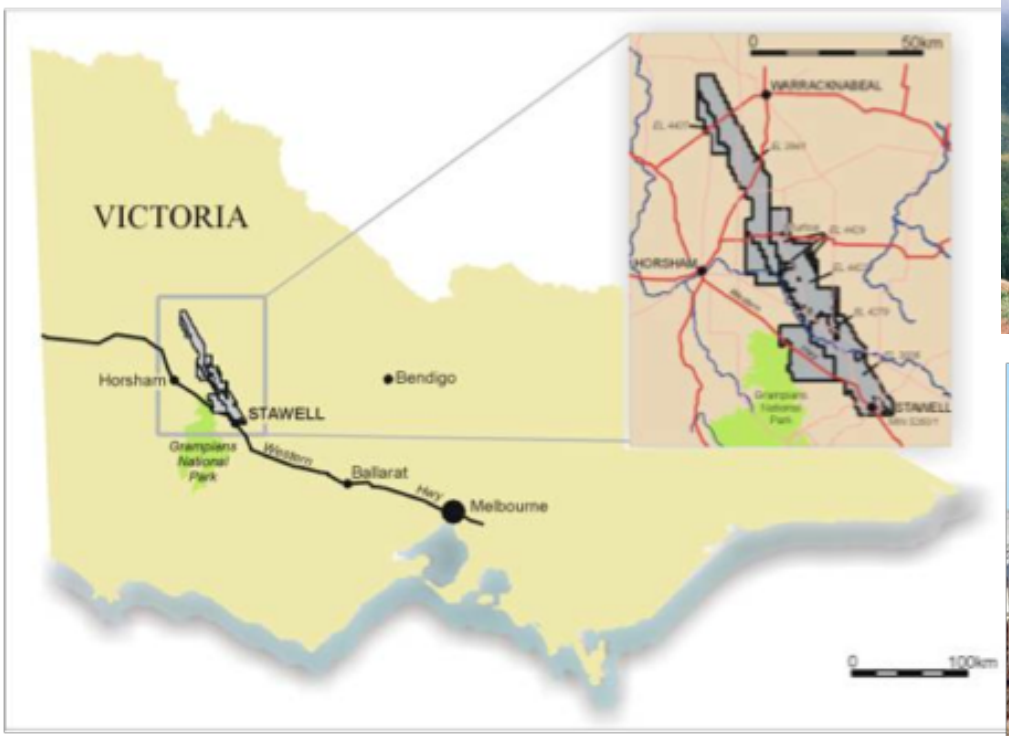
- ✓ Final exact location to be determined once geology is better known
- ✓ Proposed as an International laboratory within Latin America
- ✓ Conceptual study finished by Lombardi in January 2015
- ✓ Detailed engineering ongoing

More information at http://andeslab.org/

Stawell

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

SUPL: Stawell Underground Physics Laboratory



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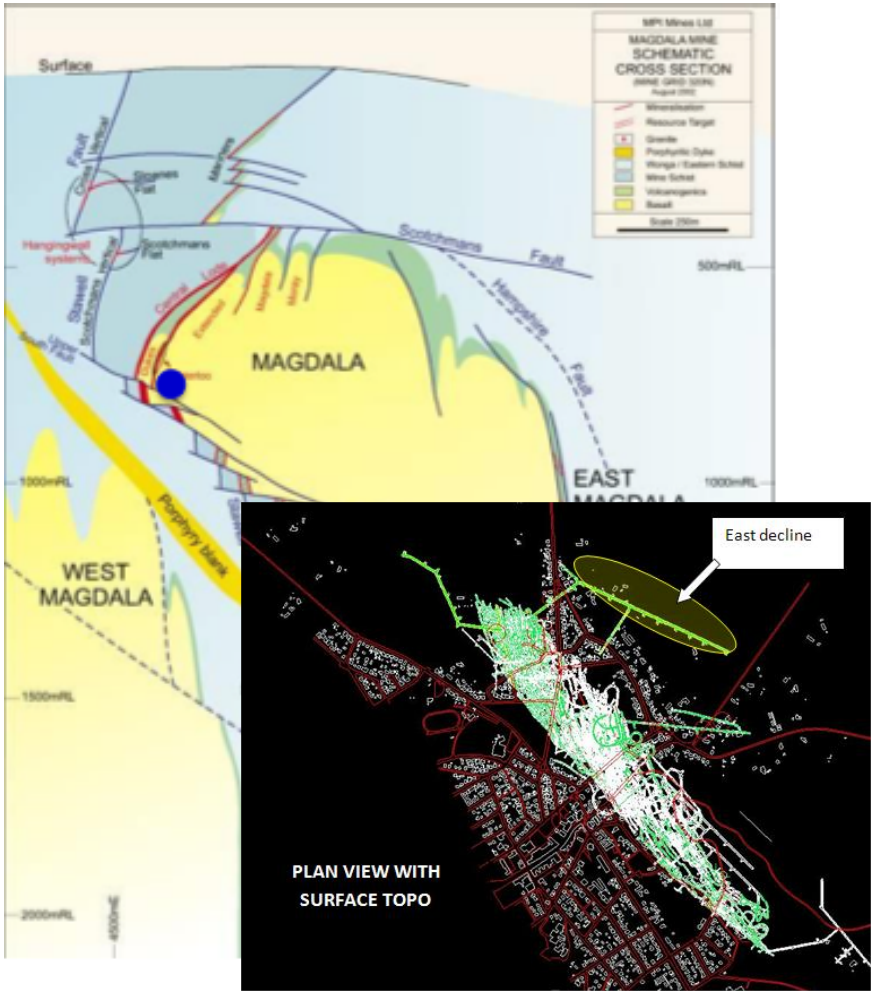
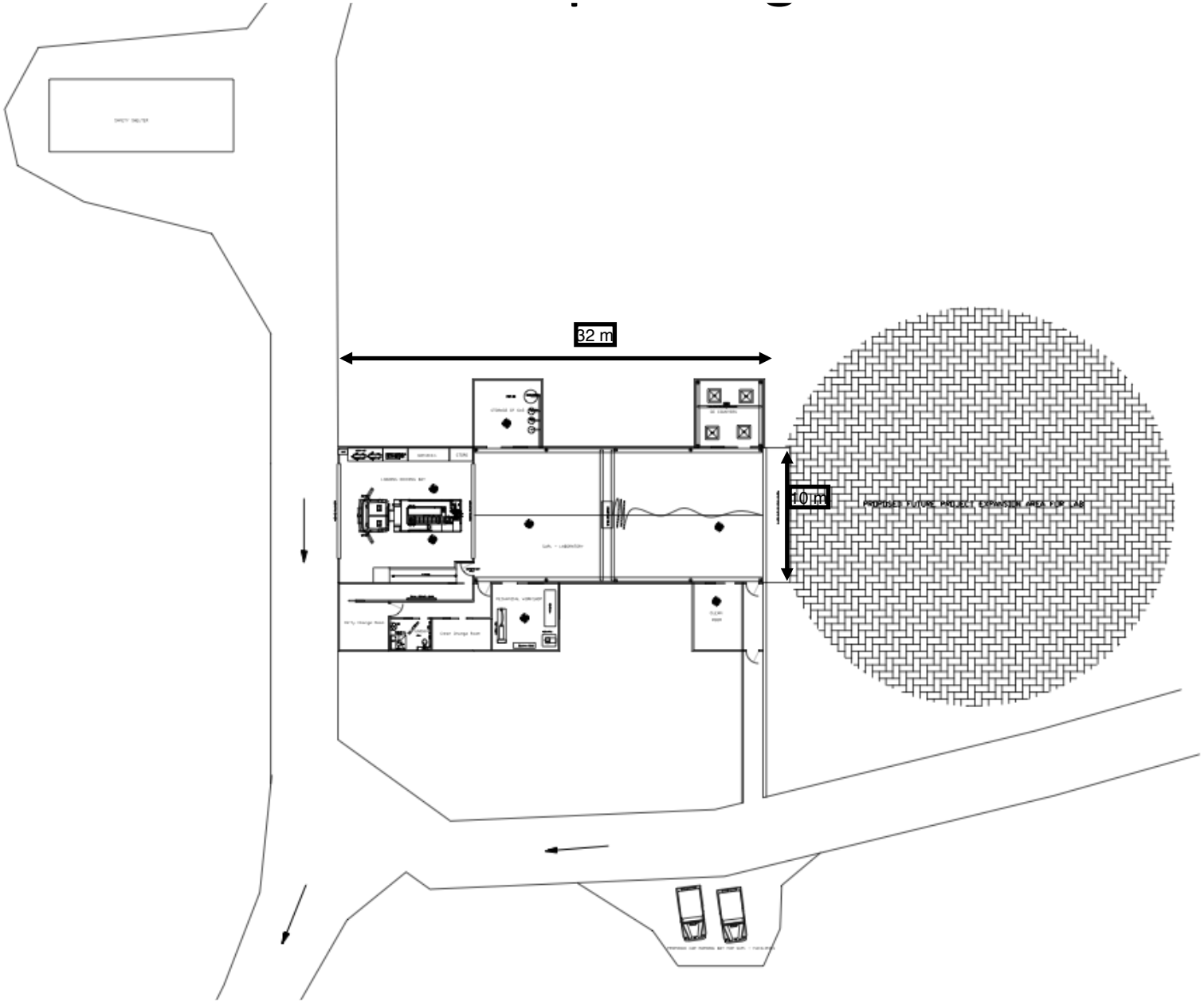
SUPL

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

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



Concept design



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Time line

2014

Lab proposed (Sep)

2015

Funding secured (May)

Call for tenders for final design (Aug)

Complete design (Nov)

Design Review (Dec/Jan)

2016

Start construction (Jan/Feb)

Facility ready (Dec)

2017

Lab ready to be use (Jan/Feb)

Planned experiments:

SABRE (~2017) – to check DAMA results, paired with Gran Sasso

Directional Dark Matter (later date)

Non HEP: Astrobiology

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General Remarks

- UG Physics is exciting since > 50 years
  - Physics BSM found un UG lab before SM assessed
- Several deep UG science labs worldwide
- Space availability is not going to be a major issue
- New labs in the southern hemisphere are a welcome addition

Lab Characteristics - Physical

- Depth -> muon flux
- Neutron flux
- Rn
- Size (min. dimension more important than total volume)
- Access: horizontal/drive-in vs vertical
  - (full spectrum of flavours available)
- Accelerator beams / nearby reactors

Lab Characteristics & Management

- Laboratories vs. Observatories
- Access by collaboration agreements
- Access by scientific quality selection

- Safety management
- Infrastructures
- Support
- Expertise
- Scientific life (community, seminars, etc.)

Critical Remarks

- High fragmentation
- Much of the expertise owned by users
- International?
  - Access by excellence, best practices898z -> yes
  - International governance -> no

Something is moving

- EU: application to INFRAIA call by 5 EU laboratories (starting community)

- Global: initiative for a distributed GRI led by LNGS & SNOLAB

Upgrades

- Major upgrade plans for LNGS & SNOLAB

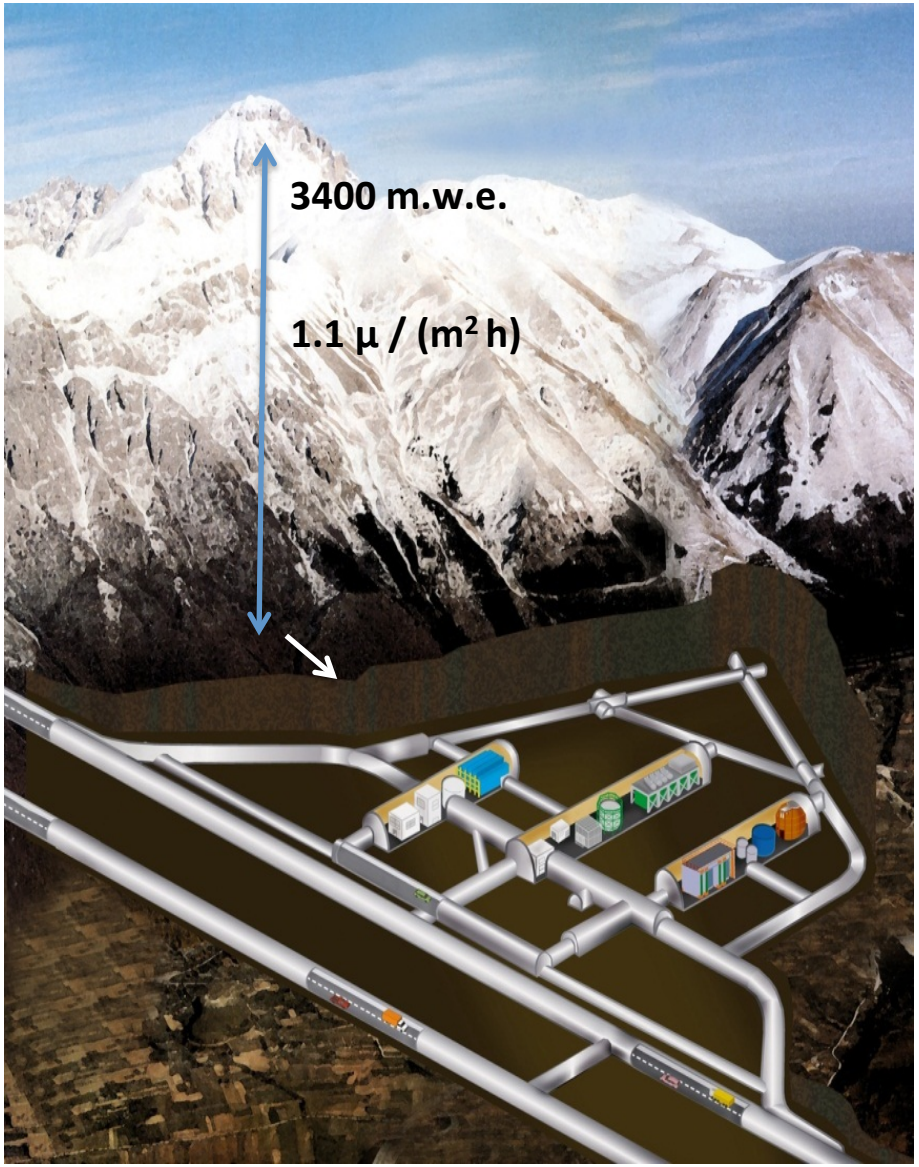
Recommendations

- Acquire, consolidate, develop, transmit unique expertise
- De-fragment – *How?*
- Remarks:
  - International scientific committees are there
  - No lab or network of labs has international governance yet

Laboratori Nazionali del Gran Sasso

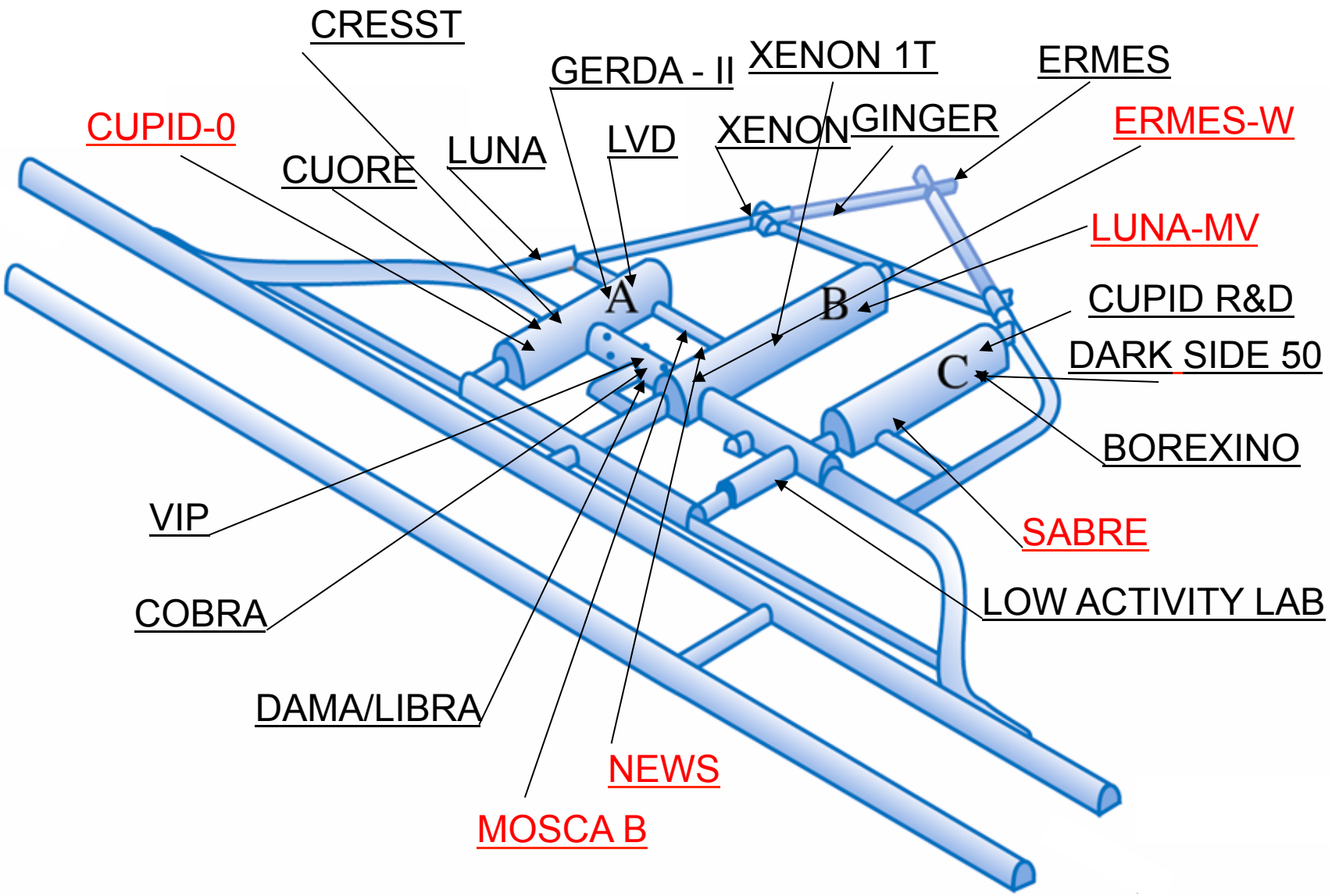
- Muon flux: 3.0 10^{-4} $m^{-2}s^{-1}$
- Neutron flux:
  2.92 10^{-6} $cm^{-2}s^{-1}$ (0-1 keV)
  0.86 10^{-6} $cm^{-2}s^{-1}$ (> 1 keV)
- Rn in air: 20-80 Bq m^{-3}
- Surface: 17 800 m^2
- Volume: 180 000 m^3
- Ventilation: 1 vol / 3.5 hours

- Users by 29 countries (Affiliation)
- 225 avg. daily presence in 2015



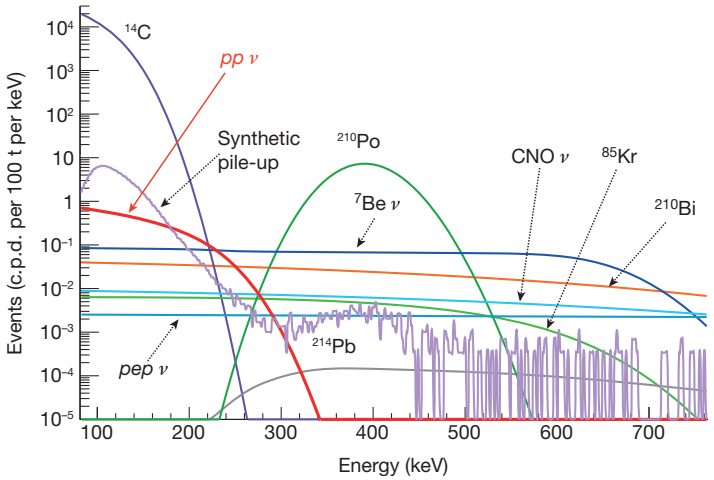
Laboratori Nazionali del Gran Sasso

Underground laboratory



LNGS Neutrino

- SN neutrino:
  - LVD 1 kton liquid scint. Waiting for SN since 1992
- Solar Neutrino:
  - Borexino: real-time measurement of pp neutrino, …, Geo-neutrinos
- Double Beta Decay
  - Gerda / Gerda-II: ^{76}Ge
  - CUORE – *the coldest m^3 in the world* : ^{130}Te
  - Cobra: ^{116}Cd
  - CUPID-0 95% enriched Zn^{82}Se scintillating crystal bolometers
- Sterile Neutrino
  - Borexino-SOX (CeSOX first)



LNGS Dark Matter

- DAMA/Libra: NaI
  - Reports annual modulation
- Sabre
  - INFN-LNGS is going to support independent test of DAMA result
- CRESST
  - $CaWO_4$ scint with bolometric r/o
- XENON family
  - Double phase liquid Xe TPC
- DarkSide
  - Liquid Ar TPC double phase

Core activities in the LNGS program

Neutrino

- SN neutrino:
  - LVD 1 kton liquid scint. Waiting for SN since 1992
- Solar Neutrino:
  - Borexino: real-time measurement of pp neutrino, …, Geo-neutrinos
- Double Beta Decay
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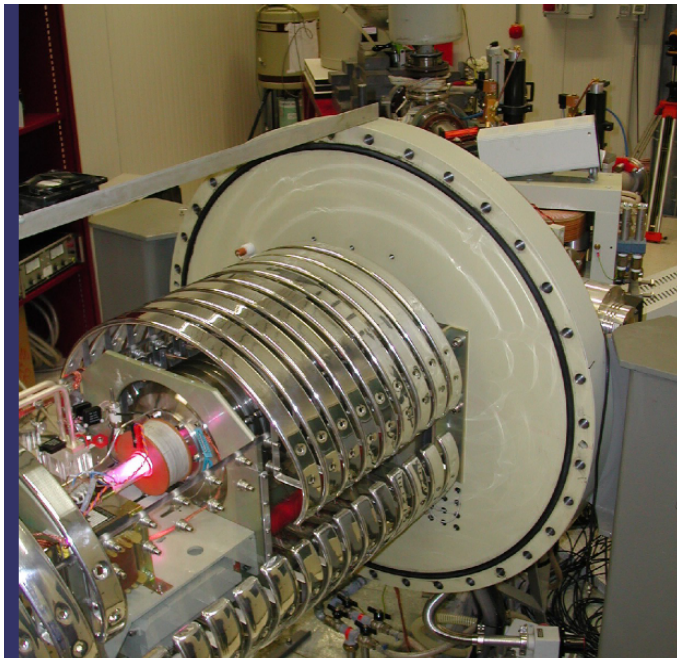
  Double phase liquid Xe TPC
- DarkSide
  Liquid Ar TPC double phase

Nuclear Astrophysics

LUNA-400 – LUNA-MV

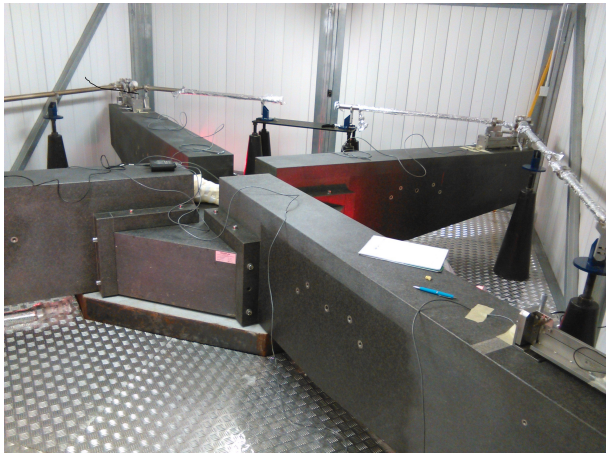
Measurement of small cross-section relevant to Nucleosynthesis

LUNA-MV upgraded with intense C-beam



General and Multidisciplinary activities

- GINGER
  - Ring-laser to probe Lense-Thirring effect
- Cosmic Silence
  - Study effect of very low radiation doses on cells, fleas, …
  - Test Linear No Threshold model
- ERMES-W
  - Primary resources, global geodynamic…
- VIP
  - Test Pauli Exclusion Principle



LNGS Users Support and Facilities

- Ultra low background techniques
- Chemistry lab and service
- Electronics lab
- Computing service
- Mechanics design
- Mechanics worksh
- Civil engineering