Title: Deep Underground Physics: Developments at SNOLAB

Date: Jan 24, 2012 01:00 PM

URL: http://pirsa.org/12010122

Abstract:


An overview of SNOLAB:
Facilities and Science
Nigel Smith
Director, SNOLAB

Weighing a Galaxy

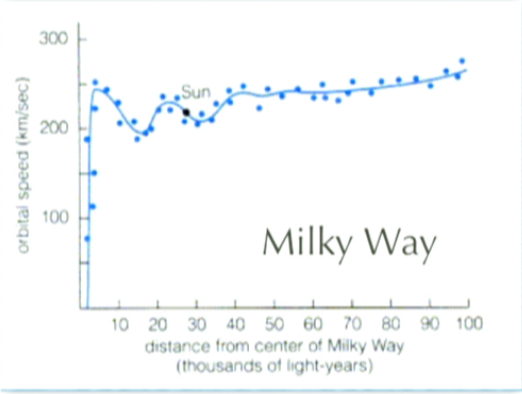
- Scale 10kPc (30 000 light years)
- Uses Doppler shift of light from star in spiral galaxy to give velocity (red shift)
- Expect velocity to fall off with distance from centre

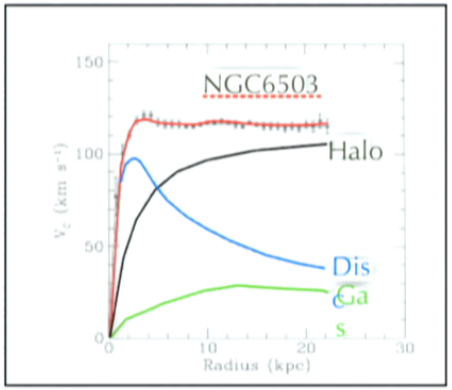
$$v_c^2 = G_N M_{vis}/r$$

$$M_{tot}(r) = v_c^2 r/G_N$$

...but it doesn't

... $\rho_{dm} \approx 0.3$ GeV/cc





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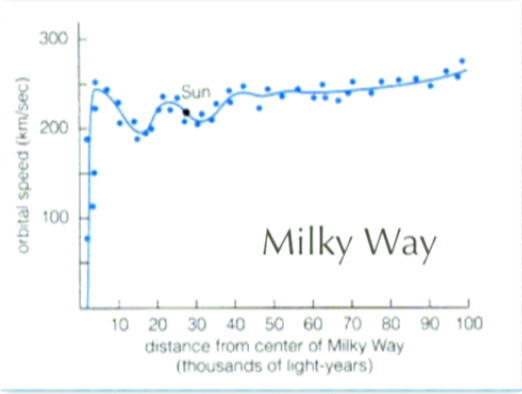
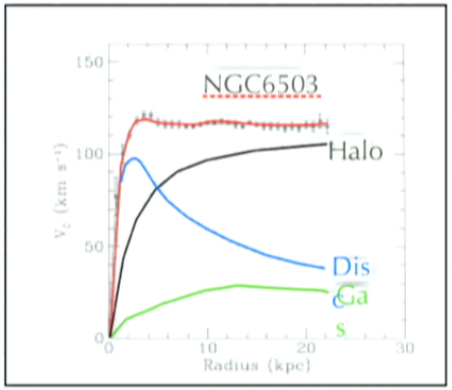
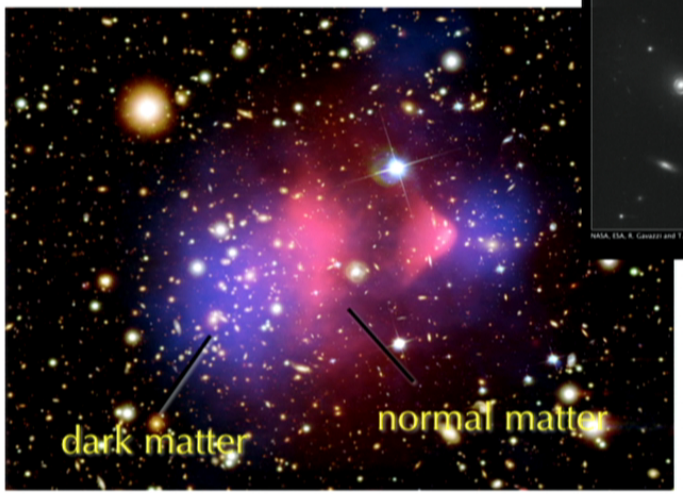
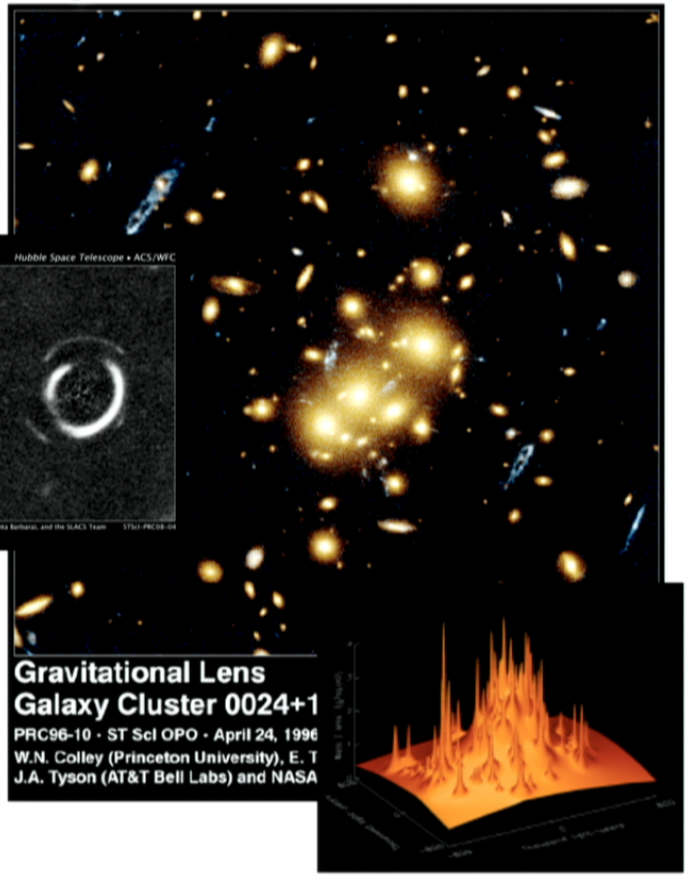




Weighing Galaxy Clusters

- Scale 1 Mpc (3M l.y.)
- Use gravitational lensing of quasars or galaxies by galaxy clusters.





Bullet cluster (interacting galaxies)
gravitational lensing compared to Xray images

Wise: Kavli Institute

Mass of the Universe

Describe with a cosmological mass density:

$$-\Omega_{m}(\Omega_{cdm}+\Omega_{hdm}+\Omega_{b})+\Omega_{\lambda}+\Omega_{\kappa}$$

Total density: $\Omega_T = 1.02 \pm 0.02$

(which is what we want for BB inflation)

Energy density: $\Omega_\Lambda = 0.73 \pm 0.04$

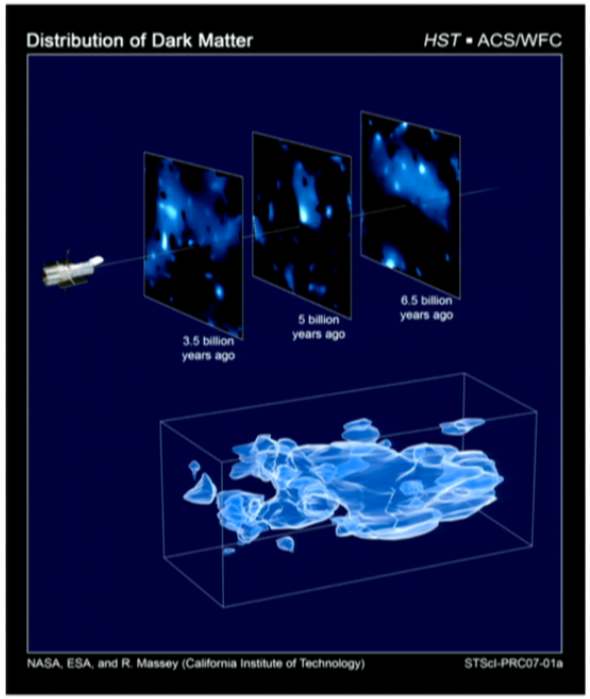
Matter density: $\Omega_m = 0.27 \pm 0.04$

Baryon density: $\Omega_b = 0.044 \pm 0.004$

Neutrinos (HDM): $\Omega_\nu < \sim 0.015$

Non-baryonic Cold Dark Matter

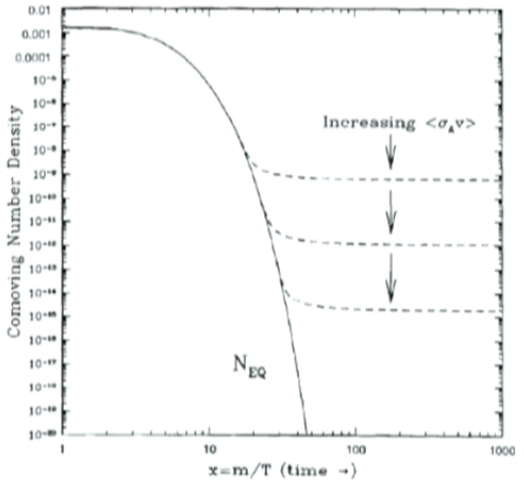
$\Omega_d = \Omega_m - \Omega_b = 0.22$



95% of what makes up the Universe is unknown — the concordance…

The WIMP solution

- SUSY models
  - Hierarchy problem $M_W << M_P$
  - CMSSM parameters
    - Higgs vacuum expectation value ratio: tan β
    - Gaugino masses: $m_{1/2}$ (assume same @ GUT scale)
    - Scalar masses: m_0 (assume same @ GUT scale)
    - Higgs mixing: μ
- Produced in early Universe
  - In thermal equilibrium $T > m_\chi$
  - Production stalled when $T < m_\chi$
  - Freeze out if expansion>annihilation
- Four neutralinos: WIMPs
  - χ, lightest SUSY particle (LSP)
  - 50 GeV < m_χ < 300 TeV (expt.)
  - 10^{-12}pb < σ_χ < 10^{-8}pb (theory)

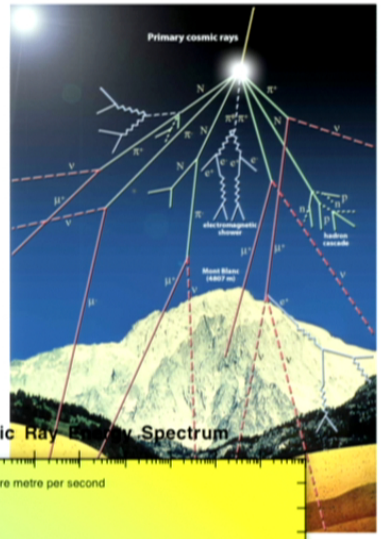


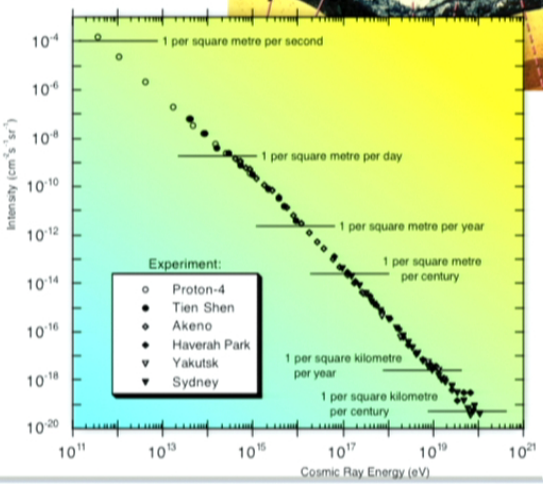
Experimental Challenge

- WIMP nuclear recoil signal is:
  - Low rate (1 - 10^{-5} events/kg/day)
  - Small energy (1-100keV actual: observed is less)
  - Similar observed exponential spectrum to many background signals (PMT, γ, etc.)
- Detection technique must be:
  - Low background
    - Gamma, beta: from U/Th/Co/Pb/etc radio-impurities
    - Neutron: from U/Th radio-impurities and c.r. μ spallation
  - Low threshold
    - To minimise form factor, maximise spectrum
  - Discriminating - Position sensitivity
    - Difference between WIMPs/n and γ/β, background rejection, directionality
  - Large mass (ultimately to reach 10^{-10} pb)

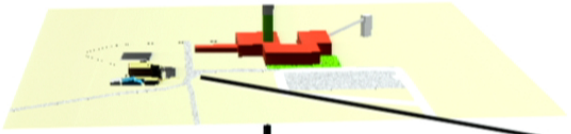
Go underground!

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



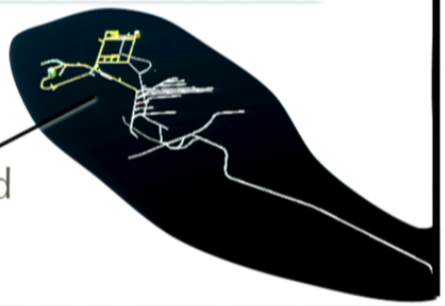


Muon backgrounds



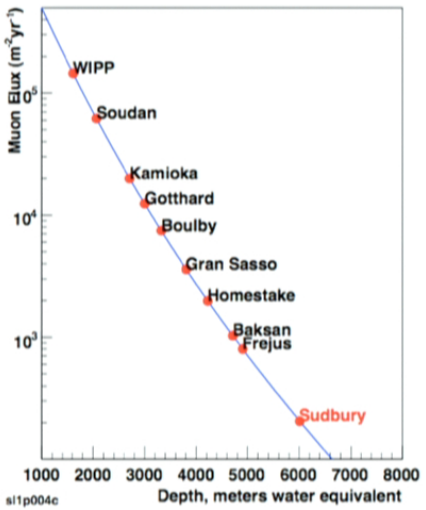
2km rock overburden (6000mwe)

Surface Facility



Underground Laboratory

Muon Flux = 0.27/m^2/day



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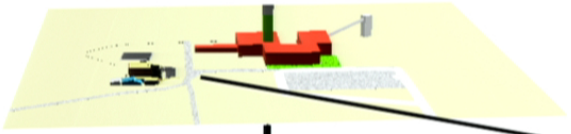

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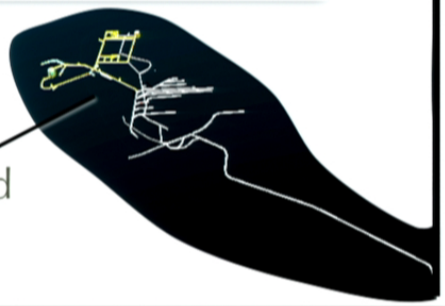

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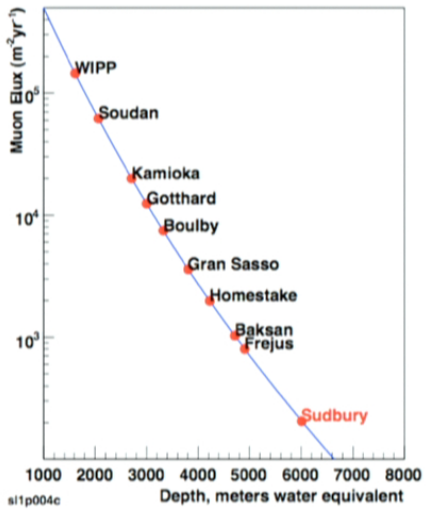
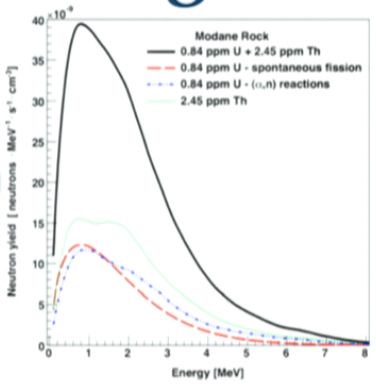
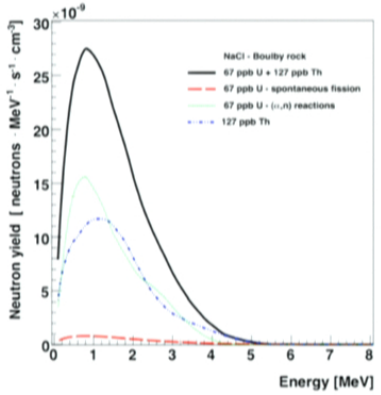


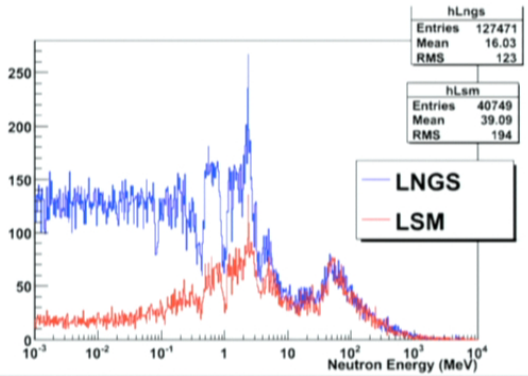
Neutron backgrounds

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





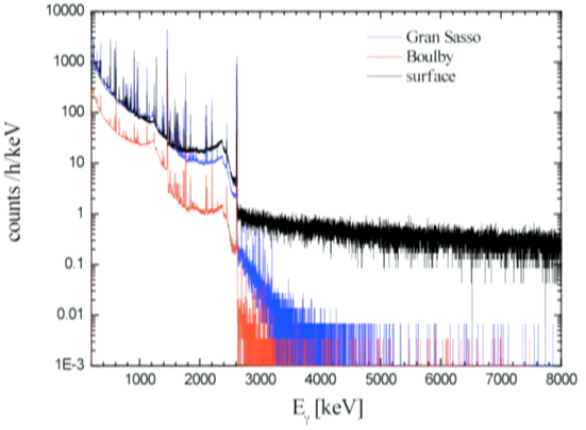
Kudryavtsev

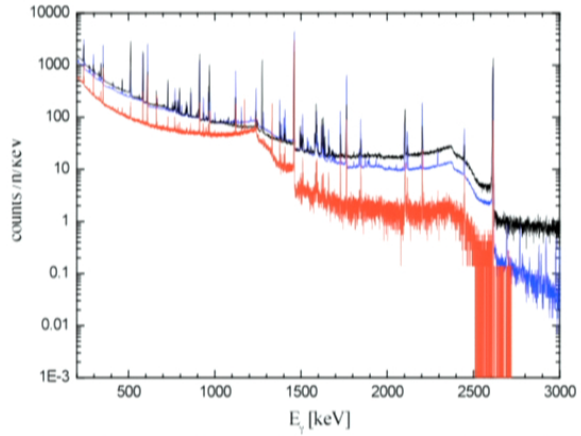


Persiani / Selvi

Gamma Backgrounds

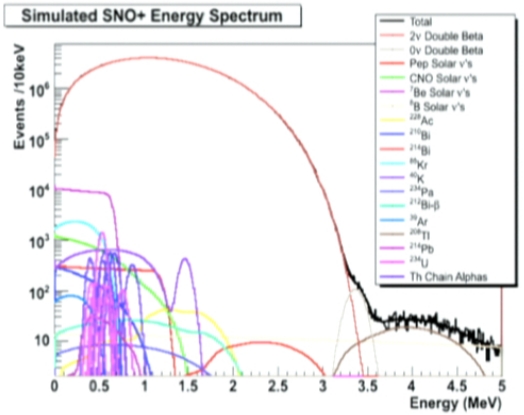
- Reduction in gamma background at higher energies from c.r. and neutron reduction
- Below 3.5MeV dependent on local geology and rock material
  - Boulby (red)
  - Gran Sasso (blue)
  - surface (black)



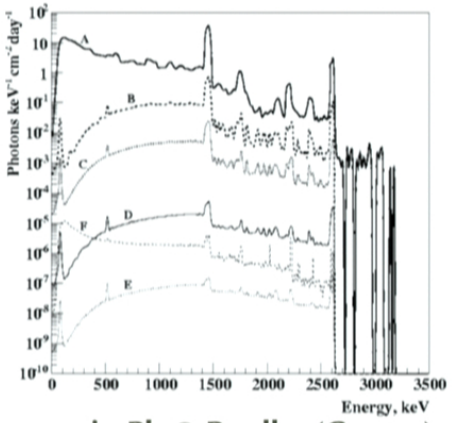


Background Suppression

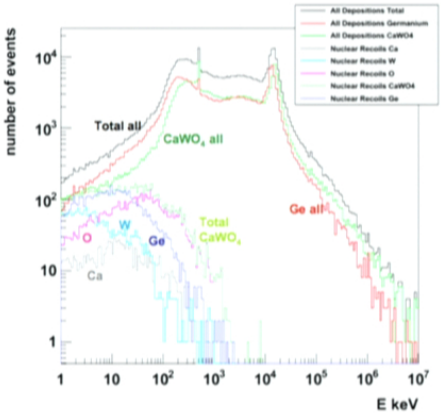
- c.r. μ and n spallation (depth, μ veto, self veto)
- γ,β (traditional gamma shielding or gamma blind)
- radon (clean room operations, atmospheric and material selection and radon suppression)
- U/Th (α,n) in rock and detector materials (shield, veto)
- Cosmogenics (underground fabrication)
- gravitational gradient (massive rock bed, away from surface)



SNO+ @ SNOLAB



γ in Pb @ Boulby (Carson)



EURECA @ LSM (Kudryavtsev)

Underground Facilities

Laboratoire Souterrain de Modane

Depth: 4800 m.w.e.

Surface:: 400 m2

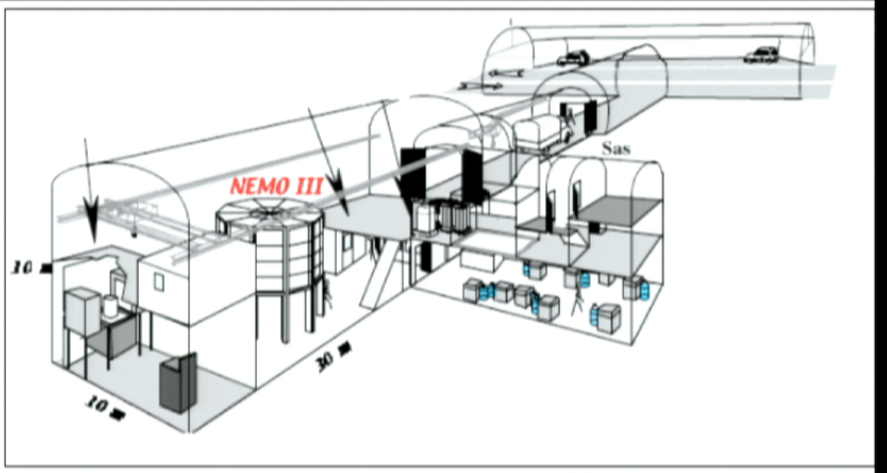
Volume : 3500 m^3

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

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

Radon: 15 Bq/m^3

Access : horizontal

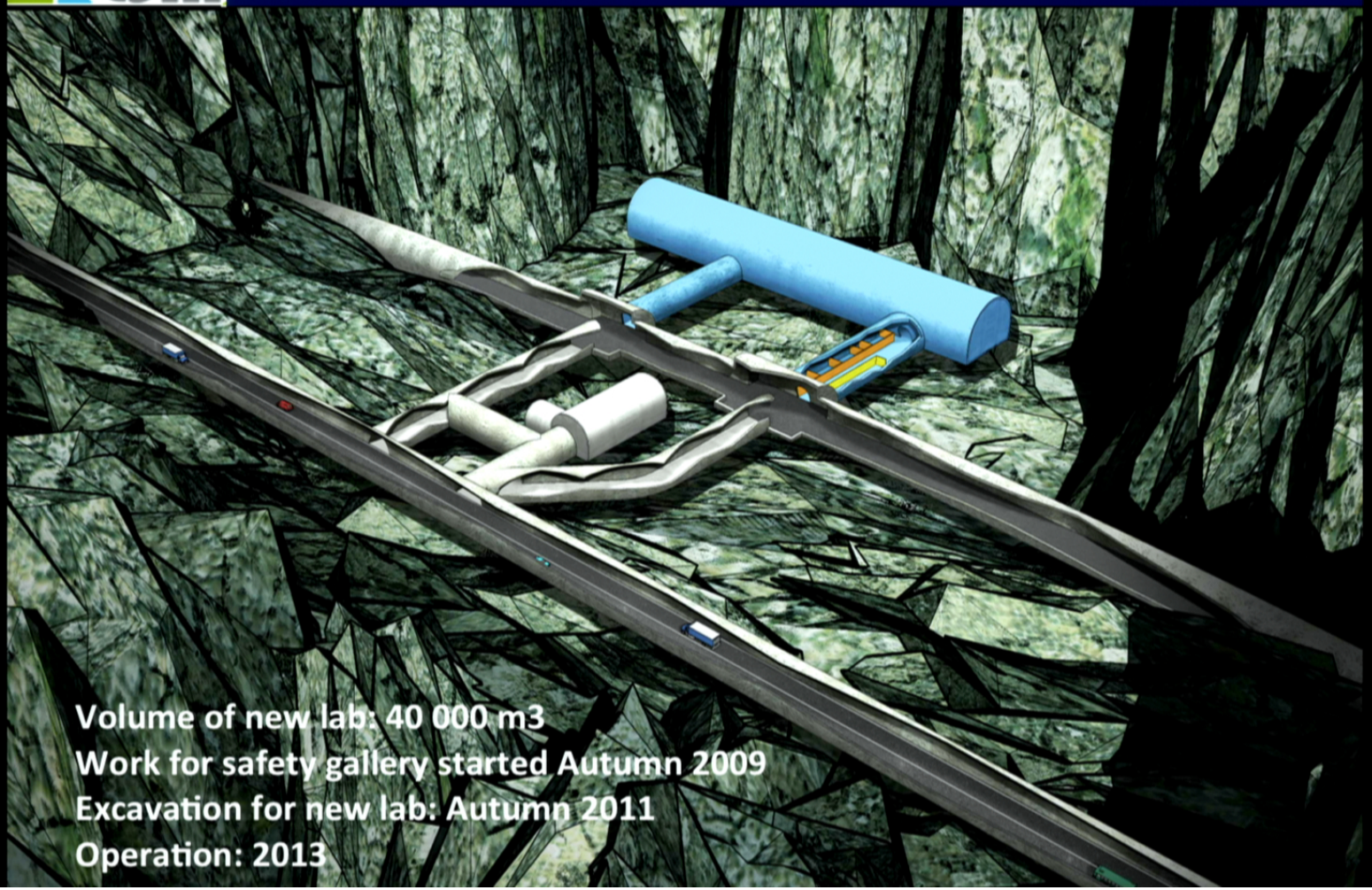


Budget (full cost): 1 M€/yr
Staff: 3 Physicists
3 Engineers
7 Technicians

~100 users

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

LSM and Extension

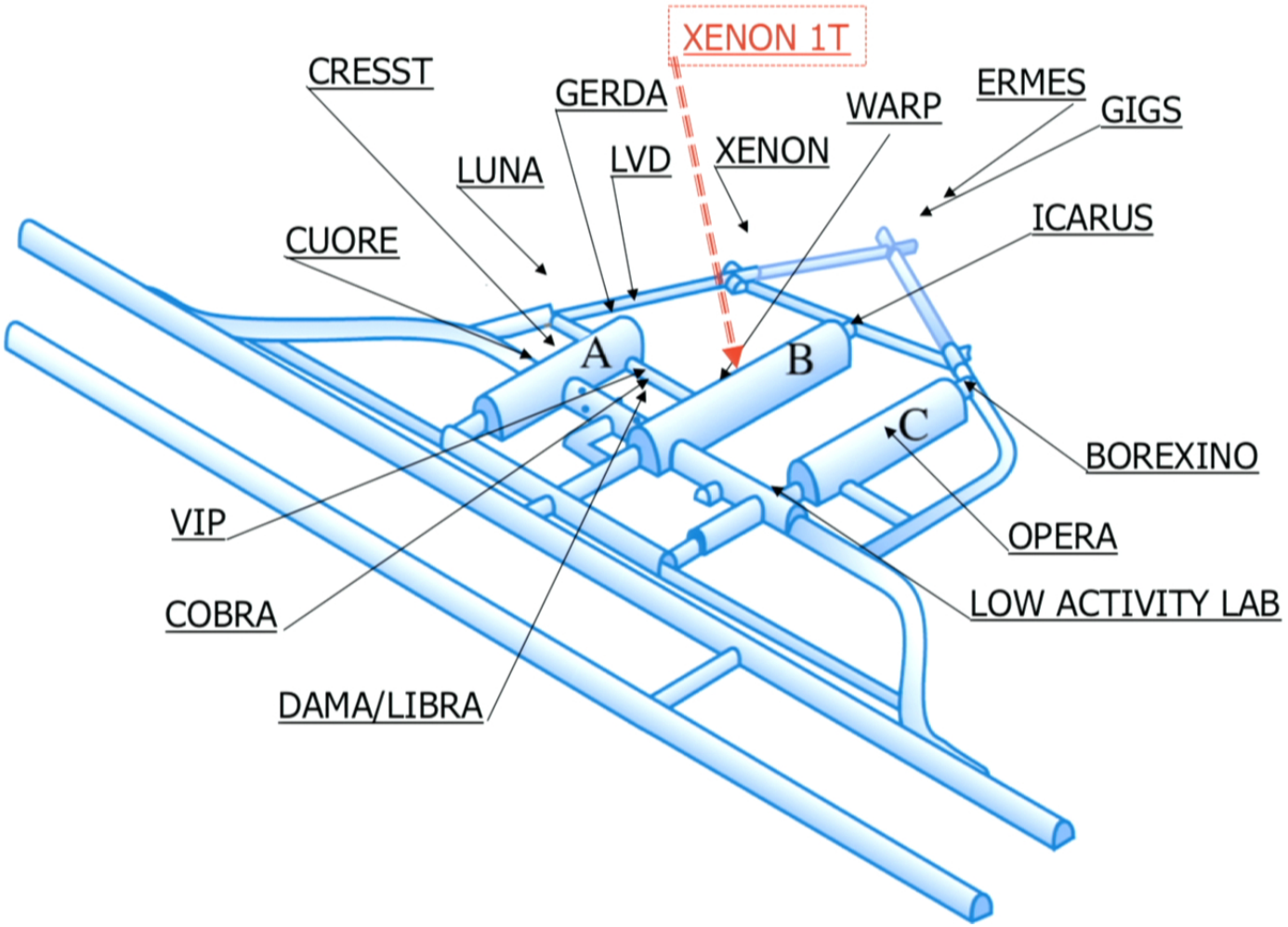


INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

Highlights from Gran Sasso Laboratory

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

OCCUPANCY


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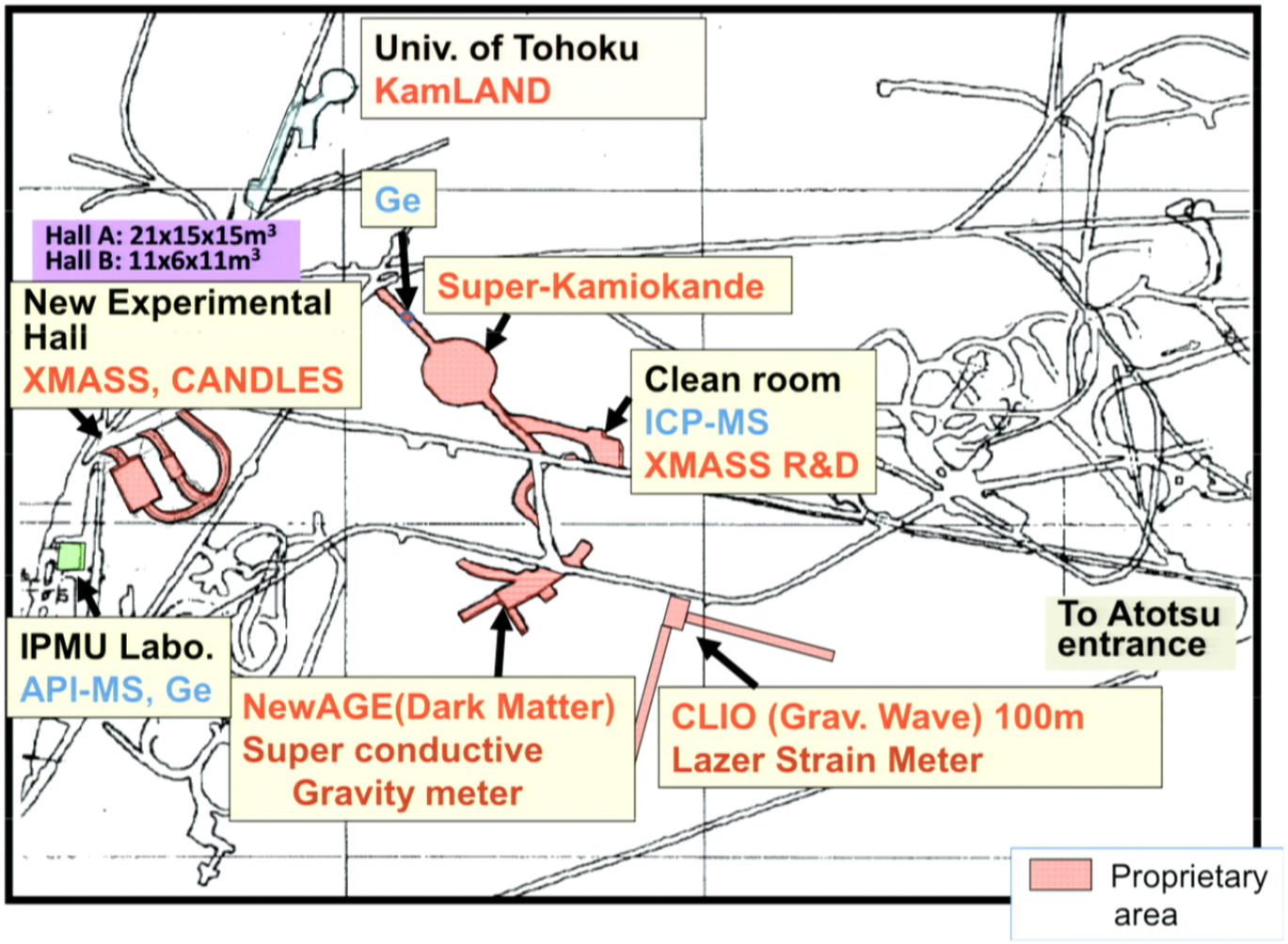
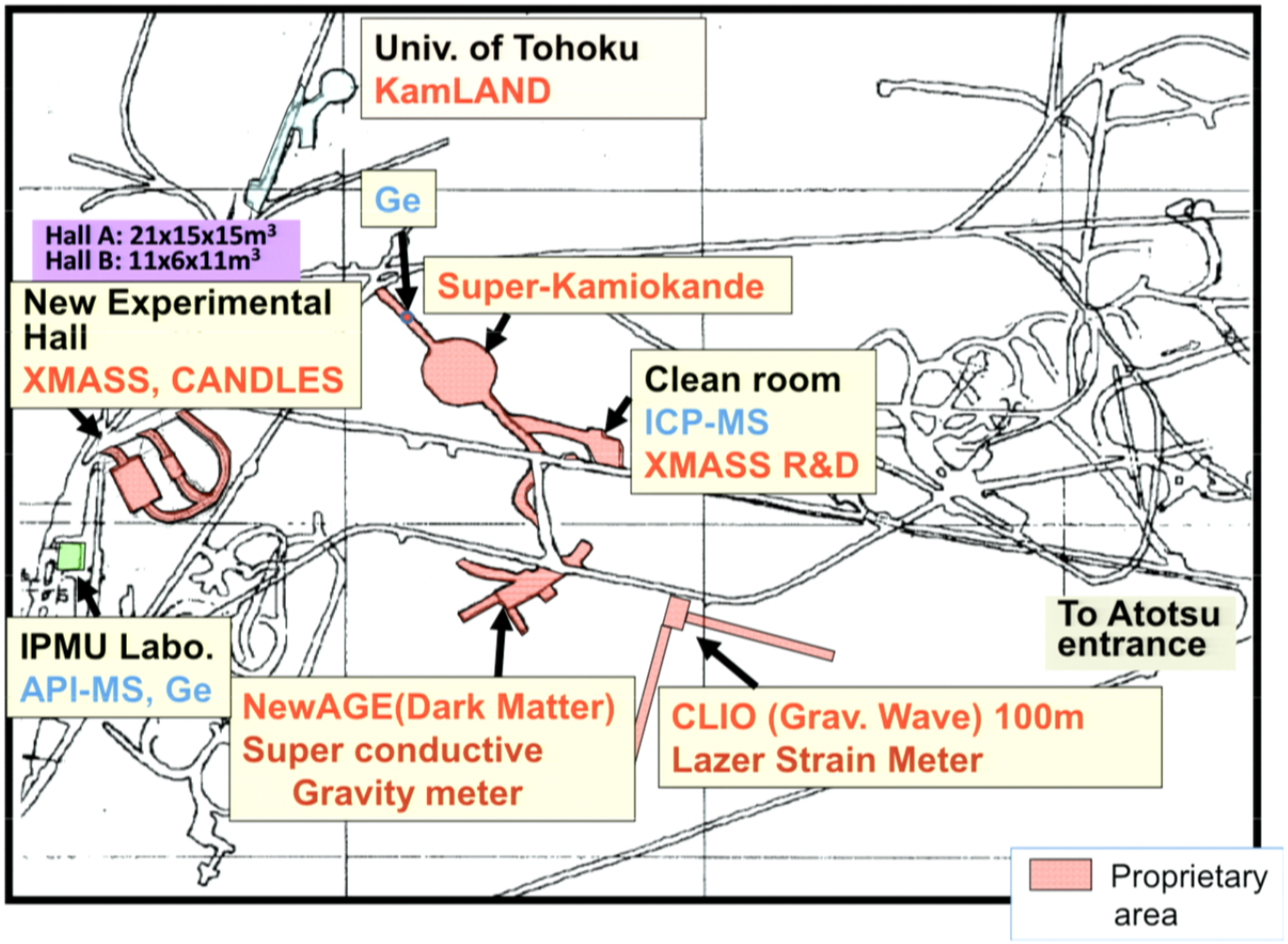
BOREXINO
VIP
OPERA
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA


Univ. of Tohoku
KamLAND
Ge
Hall A: 21x15x15m³
Hall B: 11x6x11m³
New Experimental Hall
XMASS, CANDLES
Super-Kamiokande
Clean room
ICP-MS
XMASS R&D
IPMU Labo.
API-MS, Ge
NewAGE(Dark Matter)
Super conductive
Gravity meter
CLIO (Grav. Wave) 100m
Lazer Strain Meter
To Atotsu entrance
Proprietary area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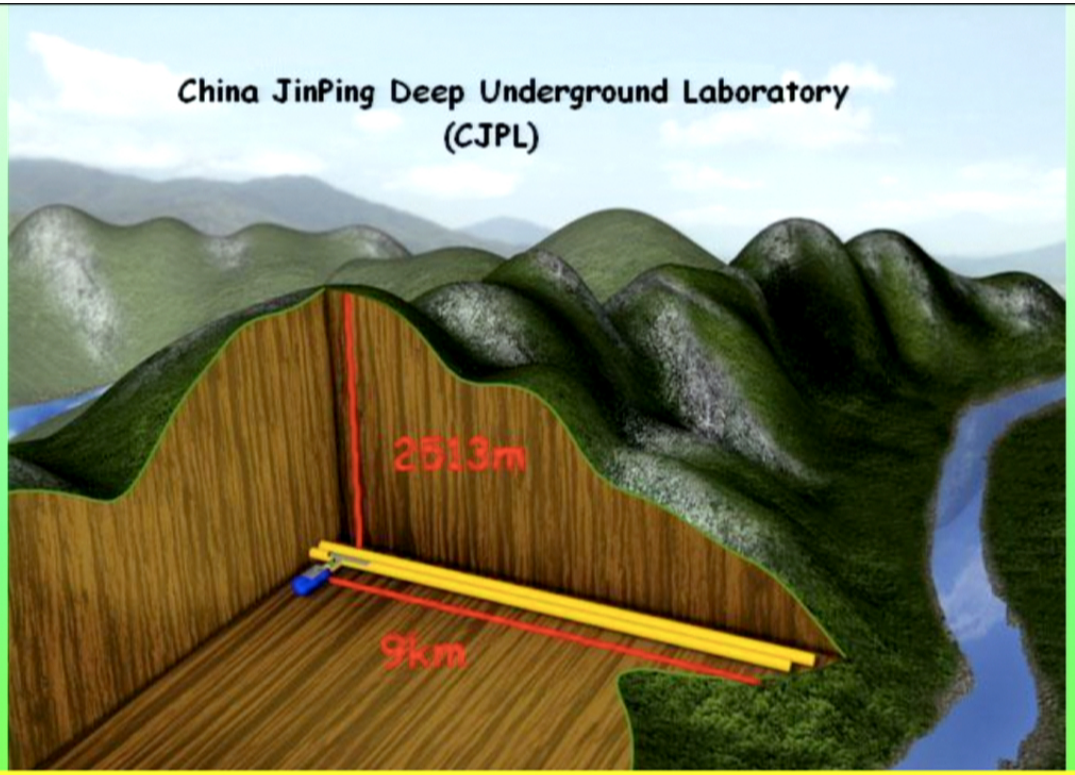


- Jinping Mountain Peak：4193m
- Maximum rock overburden: ~2500m
- Length of Jinping transportation tunnel: 17.5km
- Rock cover larger than 1500m:>70%

国家深地实验室
National Deep Underground Laboratory

Visit of CJPL

Hallway to Exp. Hall

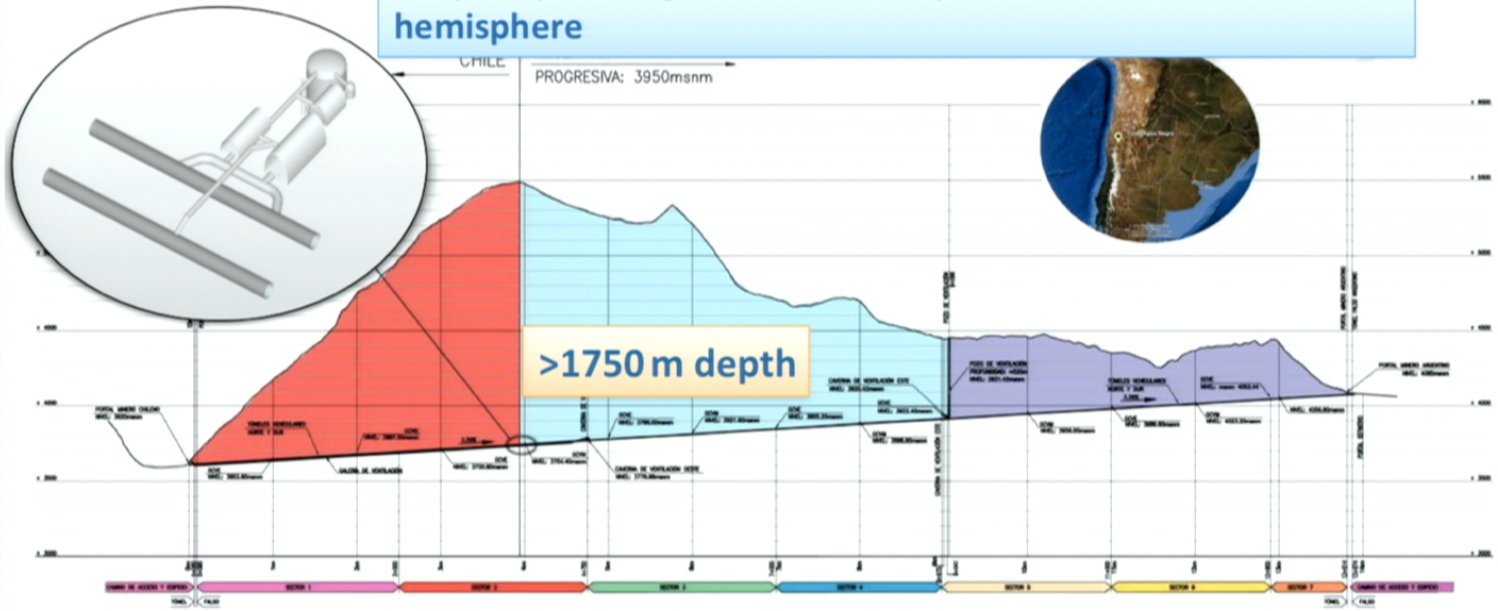
View of Experimental Hall

ANDES

The Agua Negra deep underground laboratory

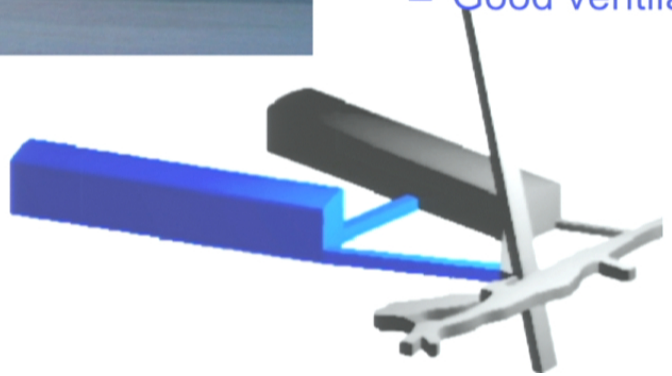
- Agua Negra tunnel between Argentina and Chile, linking MERCOSUR to Asia
- Possible laboratory location as deep (or deeper) than Modane
- Construction planned 2012-2018 (tunnel opening)
- Horizontal access, size of ~4 000 m^2 and ~65 000 m^3 in 5 halls and pits

Only deep underground laboratory in the southern hemisphere

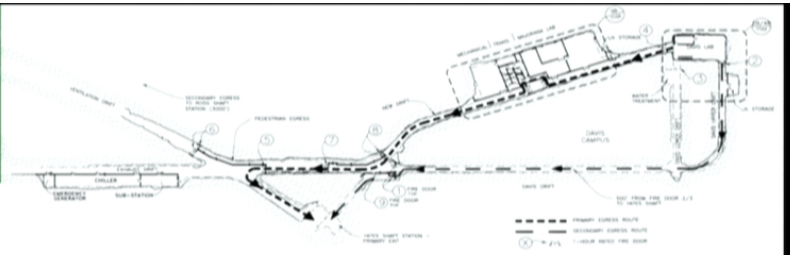


Soudan Mine Underground Lab

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

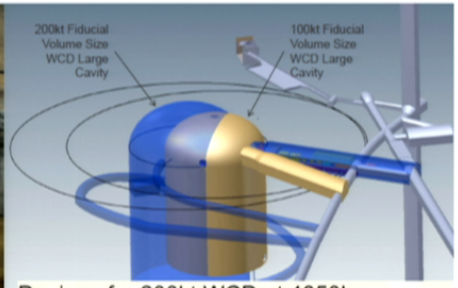


Sanford Underground Research Facility

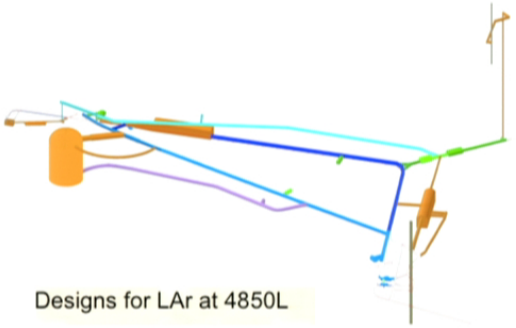


- Davis Campus will begin installing experiments in winter 2011/2012
- Director William Brinkman at the DPF Conference directed US's efforts in Dark Matter and Neutrinoless Double Beta Decay to stay focused on Homestake (LUX and Majorana Demonstrator)
- Geotechnical site investigations and Conceptual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

Ross clean room for Cu electroforming



Designs for 200kt WCD at 4850L

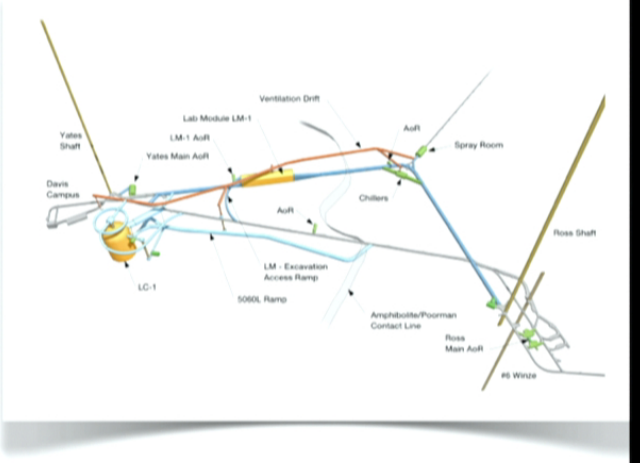


Designs for LAr at 4850L

DUSEL Deep Underground Science and Engineering Laboratory

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

- Reduce Facility Scope to safely support:
  - LBNE 4850L (or 800L)
  - Early Science in the Davis Campus (DLM, DTA) (LUX, MAJORANA DEMONSTRATOR, and perhaps a G2 Dark Matter Experiment, some Low Background Counting (CUBED))
  - A single Laboratory Module (LM) at 4850L or 7400L supporting either/both
    - a single G3 Dark Matter experiment
    - a 1 tonne-scale neutrinoless double beta decay experiment
- Facility Design
  - Single Laboratory Module & LBNE
  - Safe, redundant, but not-significantly modified, access
  - Preserves options for deeper LMs, additional LMs, and facility improvements
  - Sanford supported Education & Outreach on the surface
  - Preserves option for NSF participation in the science
    - 2nd DM experiment
    - Nuclear Astrophysics Facility and LM
    - participation in Long Baseline Neutrinos and/or Proton Decay, Neutrinoless Double Beta Decay
    - Biology, Geology, & Engineering program as self-sufficient efforts



DUSEL Deep Underground Science and Engineering Laboratory

Facility developments

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

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

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Yangyang	$1.6 \times 10^4 m^3$	In Construction	2011+
LSM	$4 \times 10^4 m^3$	Planned	2013
DUSEL	$>10^5 m^3$	Planned	2015

The SNOLAB Facility

- Operated in the Creighton nickel mine, near Sudbury, Ontario, hosted by Vale.
- Developed from the existing SNO detector
- 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 dark matter, double beta decay, solar & SN neutrino experiments requiring depth and cleanliness.
  - Also provide space for prototyping of future experiments.
- Large scale expt's (ktonne)
- Goal has been to progressively create a significant amount of space for an active programme as early as possible.

SNOLAB Funding Status

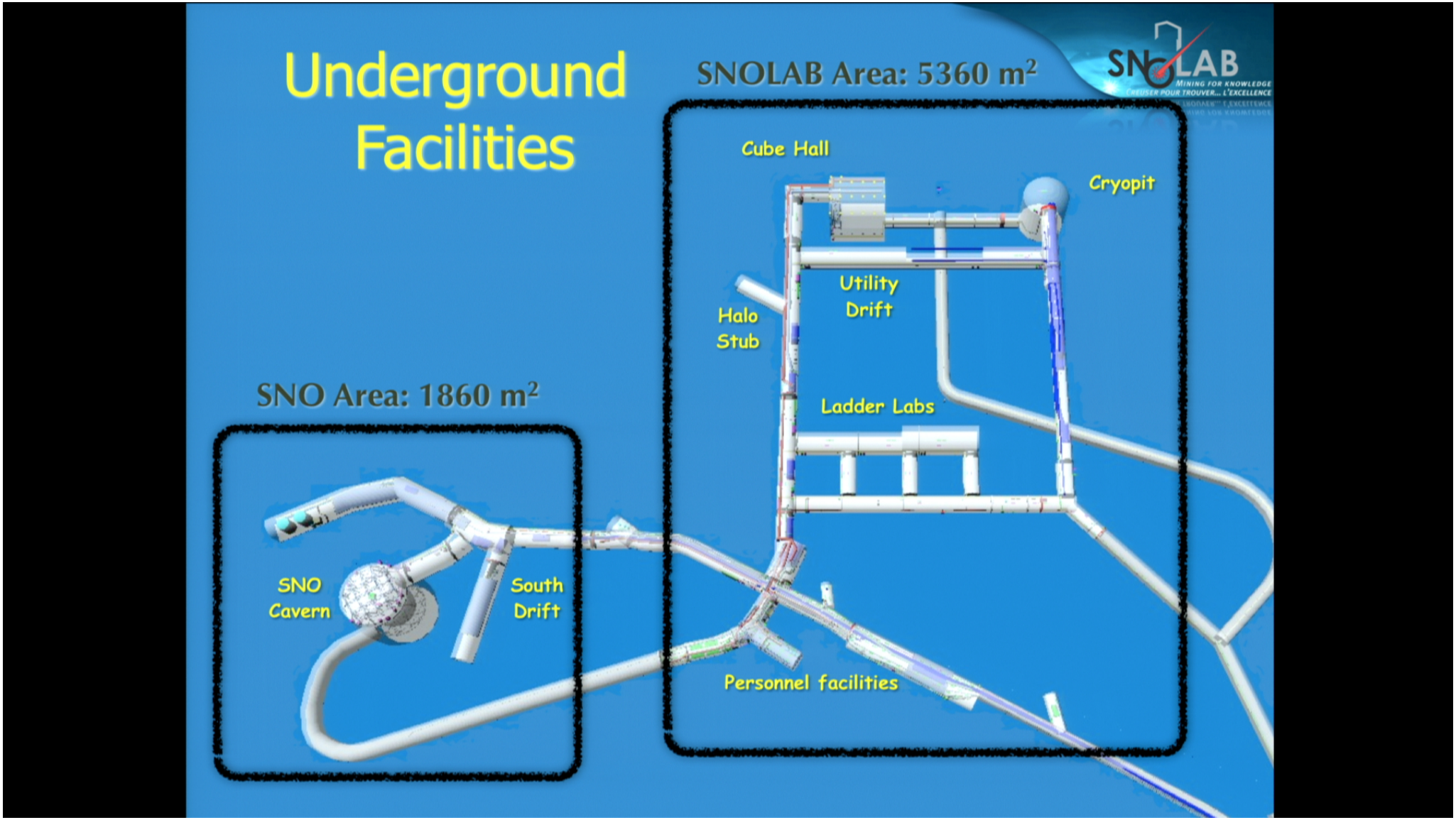
- $65M construction cost, $7-8M operations cost
  - ~60 operational support staff
- Development funds primarily through CFI as part of a competition to develop international facilities within Canada
- Additional construction funding from Federal: NSERC, and Provincial: OIT, FedNOR, NOHF
- Operational funding through NSERC, CFI, MRI (Ontario)
  - Currently secured to 2013
  - New federal programme created to support five Major Science Infrastructures
    - $180M over five years in total, from April 2012
  - Provincial support from 2013 under active discussion
  - Vale fully supportive: >20 year plan for Creighton

SNOLAB Current Status

- Surface Facility (3100 m^2)
  - Operational from 2005 - Provides offices, conference room, dry, warehousing, IT servers, clean-room labs, detector construction labs, chemical + assay lab
  - 440m2 class 1000 clean room for expt setup
- 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
  - Excavation started 2007, complete June 2008
  - Integration of Phase-I 2009/10
  - Integration of Phase-II 2011
  - Air handling/conditioning complete
  - Power delivery completed
  - Service delivery as required
  - Life-safety systems throughout

Area	Dimensions	Area	Volume
SNO Cavern	24m (dia) x 30m(h)	250m^2	9,400 m^3
Ladder Labs	32m(l)x6m(w)x5.5m(h)	190m^2	960 m^3
	23m(l)x7.5m(w)x7.6m(h)	170m^2	1,100 m^3
Cube Hall	18.3m(l)x15m(w) x 19.7m(h)	280m^2	5,600 m^3
Cryopit	15m(dia) x 19.7m(h)	180m^2	3,900 m^3

Surface Facilities


Underground Facilities
SNOLAB Area: 5360 m²
SNO Area: 1860 m²
Cube Hall
Cryopit
Utility Drift
Halo Stub
Ladder Labs
SNO Cavern
South Drift
Personnel facilities


Chiller


Chiller


Lab Entry
6800


Lab Entry


Lab
Entrance


Personnel
Facility


Galley/
Refuge


Meeting
Room


Cryopit


Cube
Hall


R&D 'J'
Drift

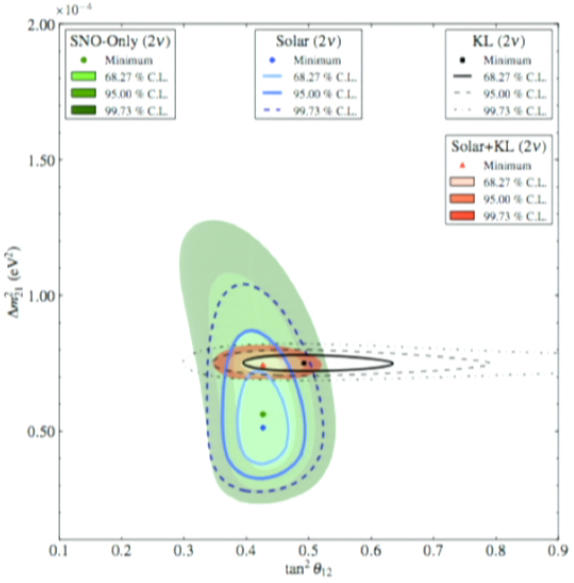

Ladder
Labs

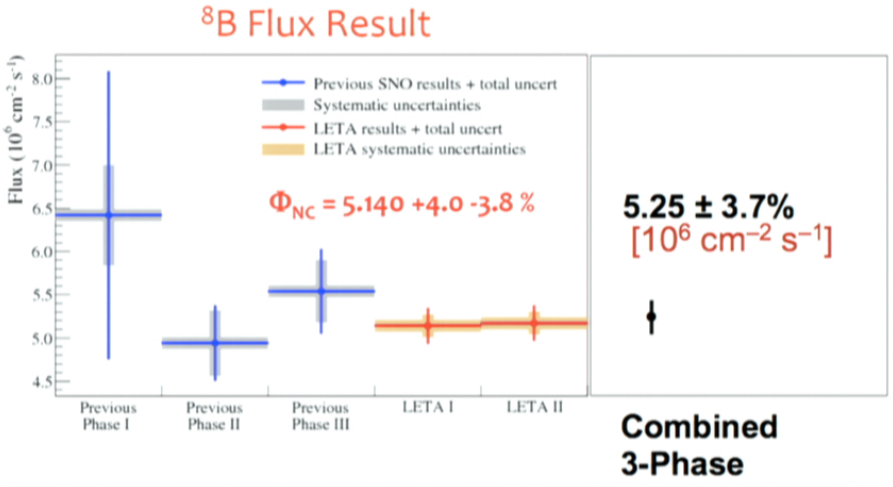
SNOLAB Programme

Experiment	Solar nu	0nuBB	Dark Matter	SuperNovae	Geo nu	Other	Space allocated	Status
SNO+	√	√		√	√		SNO Cavern	Underway
PICASSO-III			√				Ladders Labs	Underway
DEAP-1			√				J'-Drift	Underway
DEAP-3600			√				Cube Hall	Underway
MiniCLEAN			√				Cube Hall	Underway
HALO				√			Halo Stub	Underway
PUPS						Seismicity	Various	Completed
SuperCDMS			√				Ladder Labs	Request
EXO-gas		√					Ladder Labs	Request
COUPP			√				Ladder Labs	Underway
DarkSide			√				Ladder Labs	Request
COBRA		√					Ladder Labs	Request

Final SNO Results

- Detected ν_x ES, ν_e CC and ν_x NC interactions in heavy water
- NC neutrons detected three ways: D, Cl, NCD
- Final combined analysis of all three phases - arXiv:1109.0763
  - includes pulse shape particle ID in NCD (alpha / n rejection)
  - improved ^{8}B and ν_e survival probability (by 20%)





Current programme: 0νββ 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.
    - SNO Cavity: repairs to cavity liner and modification of detector support to hold down the Acrylic Vessel for liquid scintillator.
    - SNO Utility Room: Development of liquid scintillator purification system.
  - Capital funding turn on fall 2010.
- 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.

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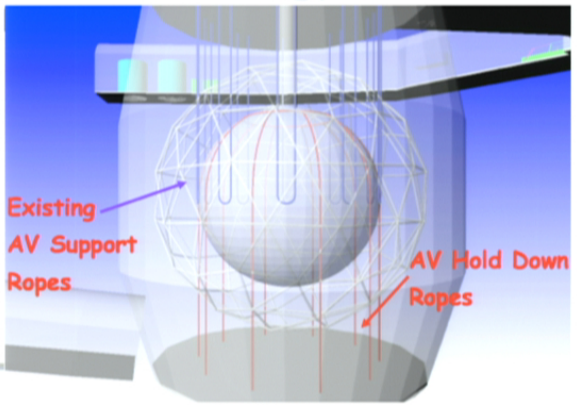
  - Developing technique to tag Ba daughter. Electron tracking capability.

Current programme: Natural neutrino sources

- SNO+ :
  - Will also measure
    - solar neutrino pep line (low E-threshold)
    - geo-neutrinos (study of fission processes in crust/mantle)
    - supernovae bursts (as part of SNEWS)
    - reactor neutrinos (integrated flux from Canadian reactors)
- HALO: Dedicated Supernova watch experiment
  - Charged/neutral current interactions in lead
  - Re-use of detectors (NCDs) and material (Pb) from other systems
  - DAQ refurbishment complete, NCD installation complete, partial ops underway, full ops by end 2011
  - Will form part of SNEWS array

SNO+ Developments

- Clean and lap AV interior
  - Cleaning completed; lapping process designed
- Hold-down rope net procured, now at site
  - Anchor points installed, new liner sprayed
- Scintillator process plant
  - Design completed; large vessels procured;EH&S (fire) under review
  - Scintillator to be bought at appropriate time (for 2013)
- Upgrade electronics for high rate, lower energy
  - Completed
- Aim for water-fill tests mid-2012
  - Scintillator fill early 2013



SNO+ Developments

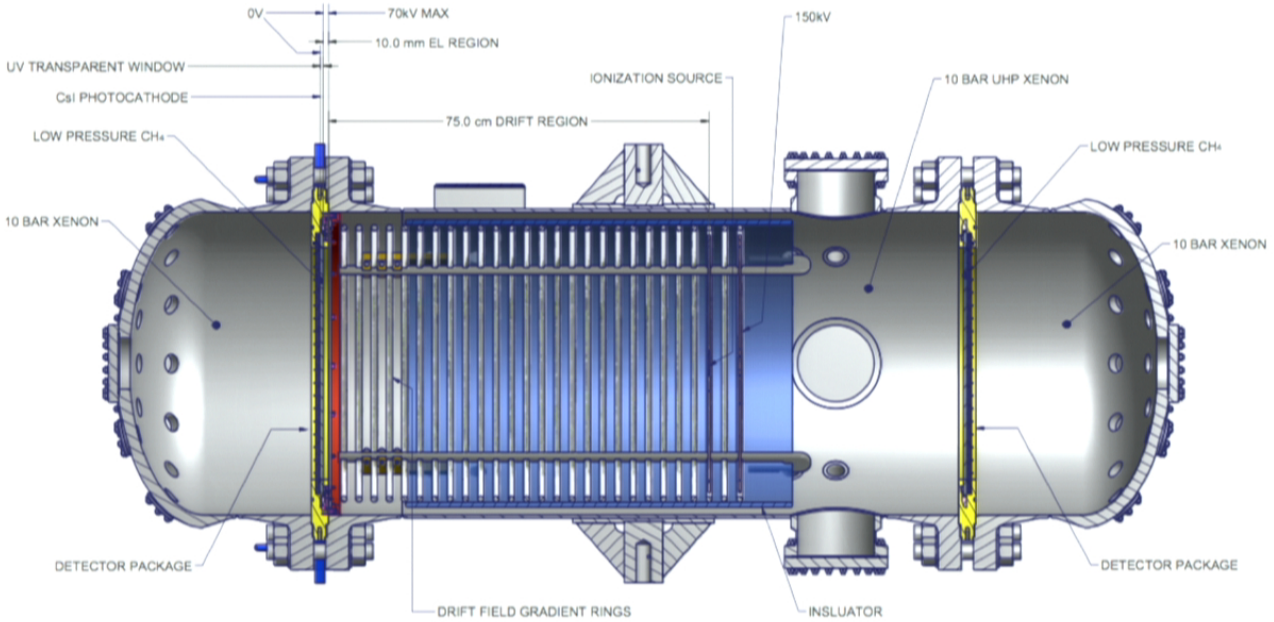
Process system design advanced, inc. EH&S
Cavity work completed - construction of 'umbrella', hold-down ropes, anchor points, AV cleaning completed, lapping underway, ..

Protection umbrella constructed underneath SNO+ AV and PSUP for floor repair and anchor point installation

Excavating a larger space in the SNO+ Utility room to accommodate the liquid scintillator process systems.

EXO-Gas

- ^{136}Ba laser-tagging tests completed at SNOLAB
- Development of electroluminescence test chamber underway at Carleton before deployment to SNOLAB
  - Extract Ba ion from high pressure region into laser fluorescence region

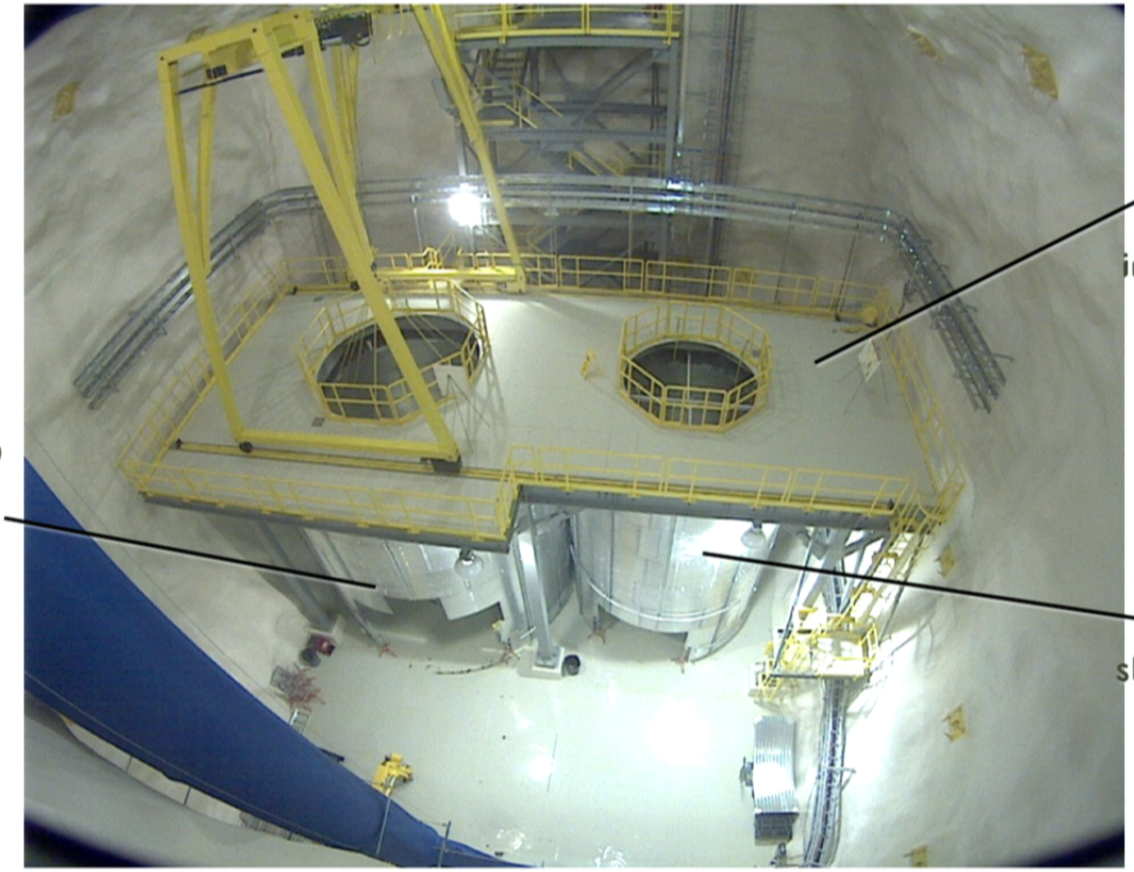


HALO this morning

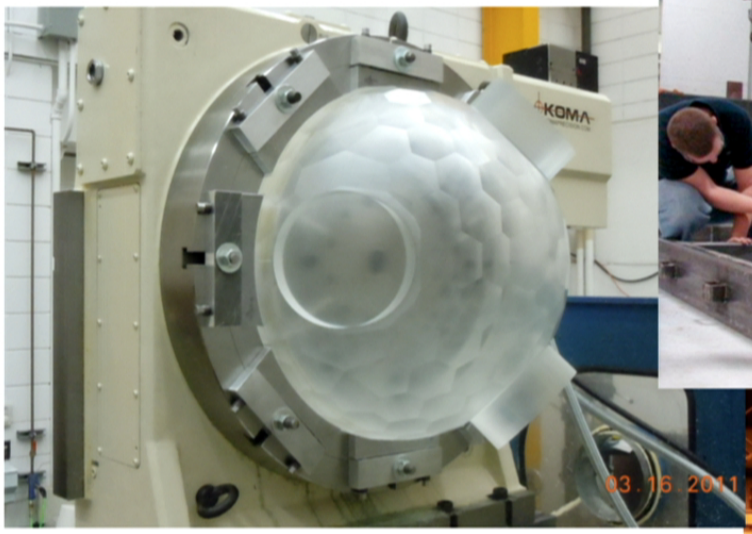
Current programme: Dark Matter at SNOLAB

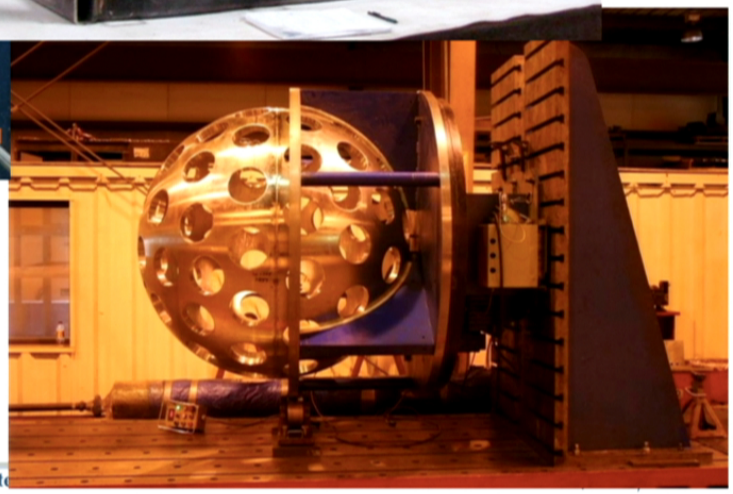
- Noble Liquids: DEAP-I, MiniCLEAN, & DEAP-3600
  - Single Phase Liquid Argon uses pulse shape discrimination.
  - Prototype DEAP-I operational in SNOLAB now, relocated to 'J' Drift. Successful demonstration of PSD and test bench for DEAP/CLEAN design/operations and background assessment.
  - Construction for DEAP-3600 and MiniCLEAN underway. Full DEAP-3600 capital funding granted
  - Will measure Spin Independent cross-section, reach anticipated 10^{-46} cm^2
- Superheated Liquid / Bubble chamber: PICASSO, COUPP
  - Superheated droplet detectors and bubble chambers. Insensitive to MIPS radioactive background at operating temperature, threshold devices
  - PICASSO currently operational, reworking of electronics and backgrounds, demonstration of alpha rejection and test bench for scale-up of detector volumes.
  - COUPP-4kg currently operational in 'J' Drift, 60kg Spring this year.
  - Will measure Spin Dependent cross-section primarily, COUPP has SI sensitivity
- Solid State: SuperCDMS
  - State of the art Ge crystals with ionisation and phonon readout.
  - Currently operational in Soudan. Next phase will benefit from SNOLAB depth to reach desired sensitivity. Test facility in Ladder Labs under development, expect installation later this year.
  - Mostly sensitive to Spin Independent cross-section.

Cube Hall - DEAP/miniCLEAN



MiniCLEAN / DEAP-3600 Construction

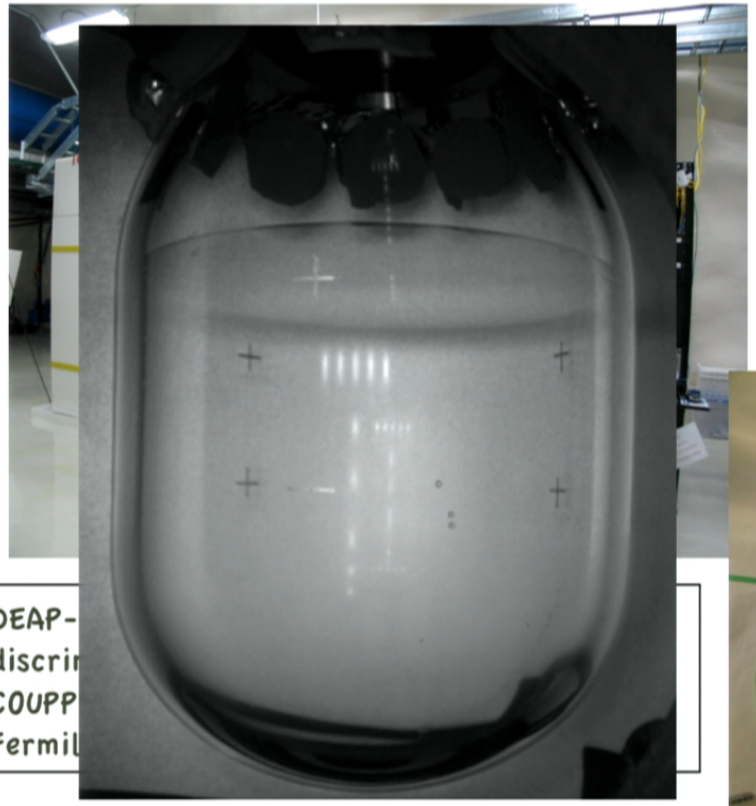




DEAP-3600 20" test-vessel machining at Alberta: bonding test.
Main vessel panels bonding and formed at RPT, CO

MiniCLEAN inner vessel final machining; PMT cassettes under construction

'J'-Drift: R&D + rapid deployment

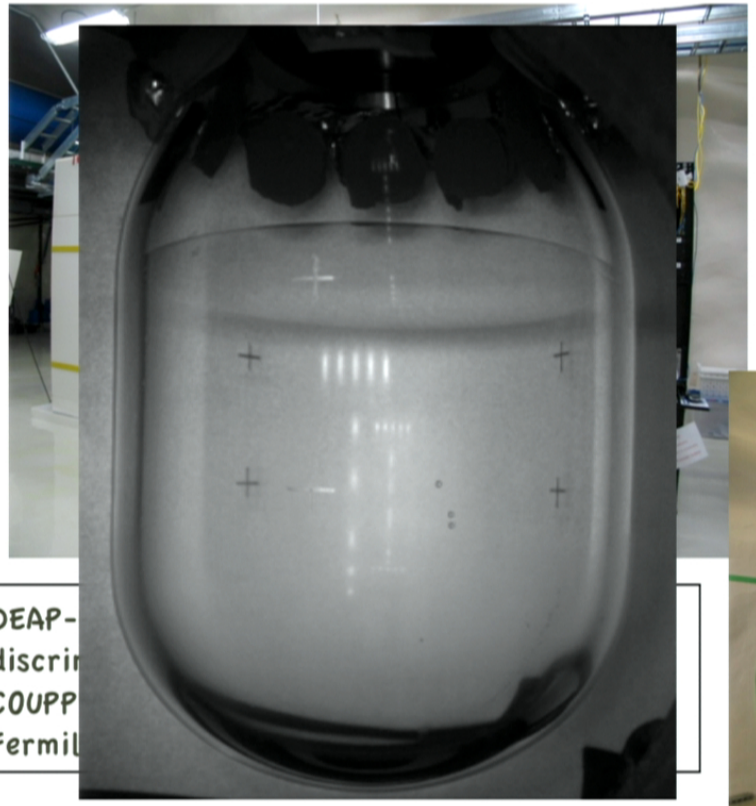


COUPP-4 bubble chamber, showing water tank shielding stack, pressure carts, DAQ racks

DEAP-
discri
COUPP
Fermil

DEAP-I in the 'J'-Drift, showing water cube shielding and purifier stack

'J'-Drift: R&D + rapid deployment



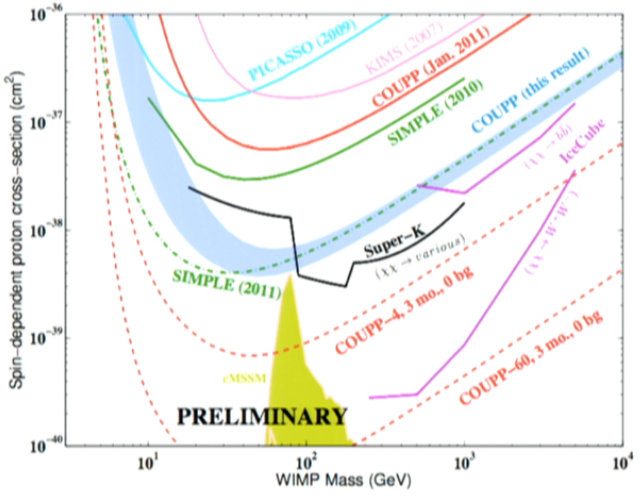
COUPP-4 bubble chamber, showing water tank shielding stack, pressure carts, DAQ racks

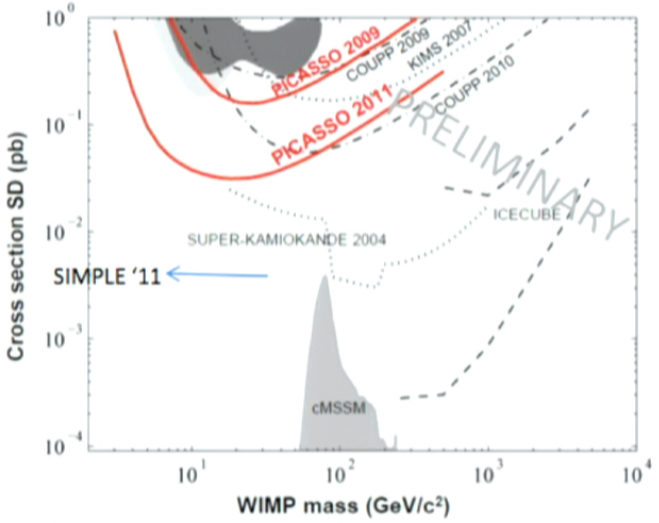
DEAP-
discri
COUPP
Fermil

DEAP-I in the 'J'-Drift, showing water cube shielding and purifier stack

Recent Results

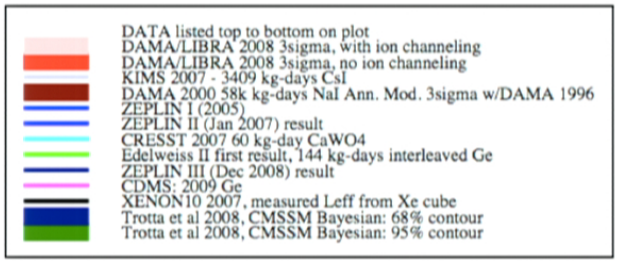
- Both PICASSO and COUPP presented new results at TAUP 2011 (Munich)
- World-leading spin-dependent (on the proton) limits set
- New result from SIMPLE: reanalysis of existing data

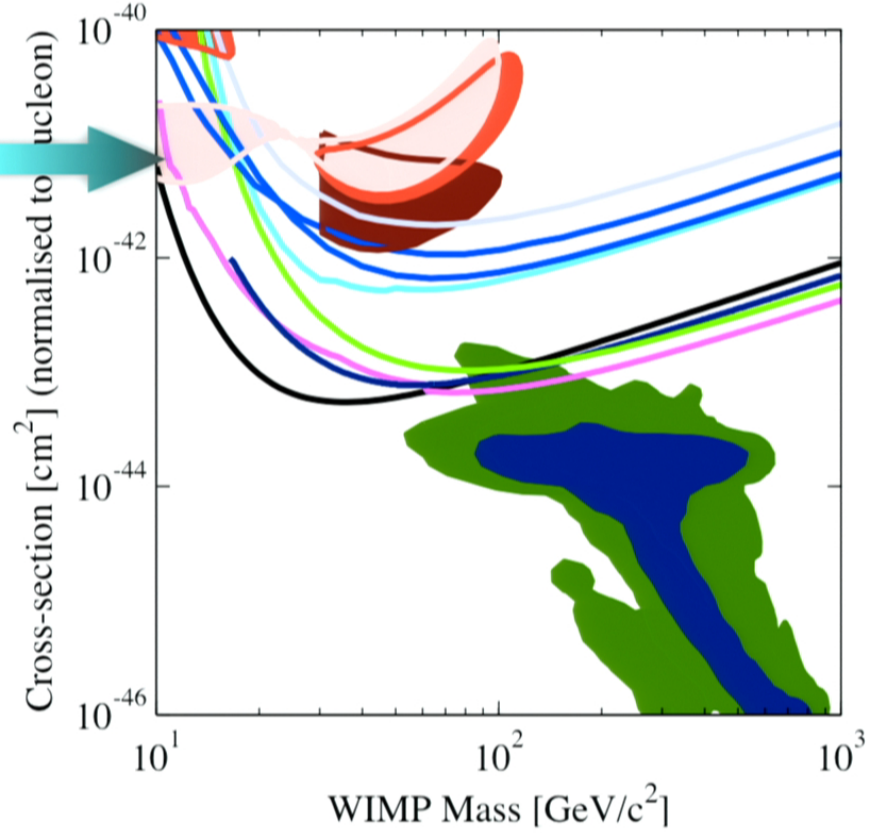




Current S.I. Limits

- Much activity at the moment in the low mass blogosphere
  - DAMA modulation
  - CRESST Oxygen
  - CDMS 2-events
  - Cogent modulated exponential recoils

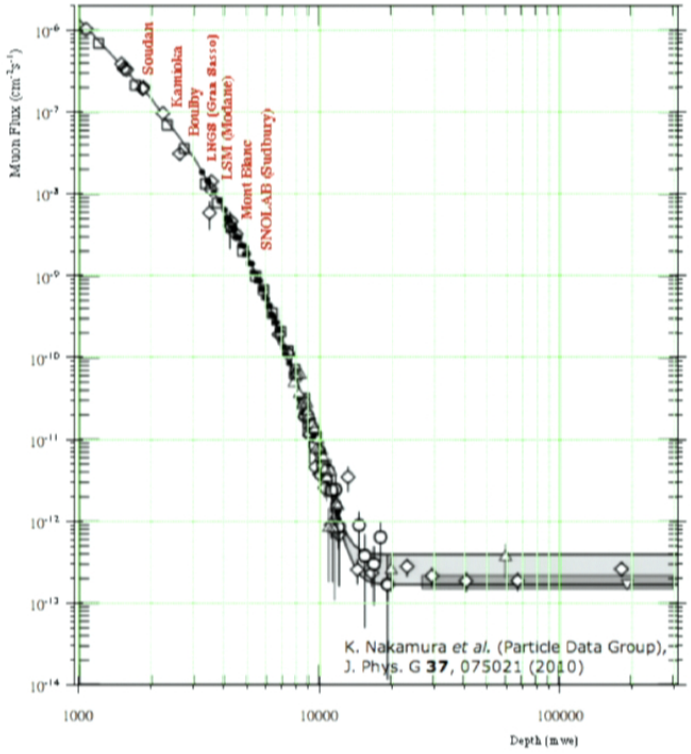


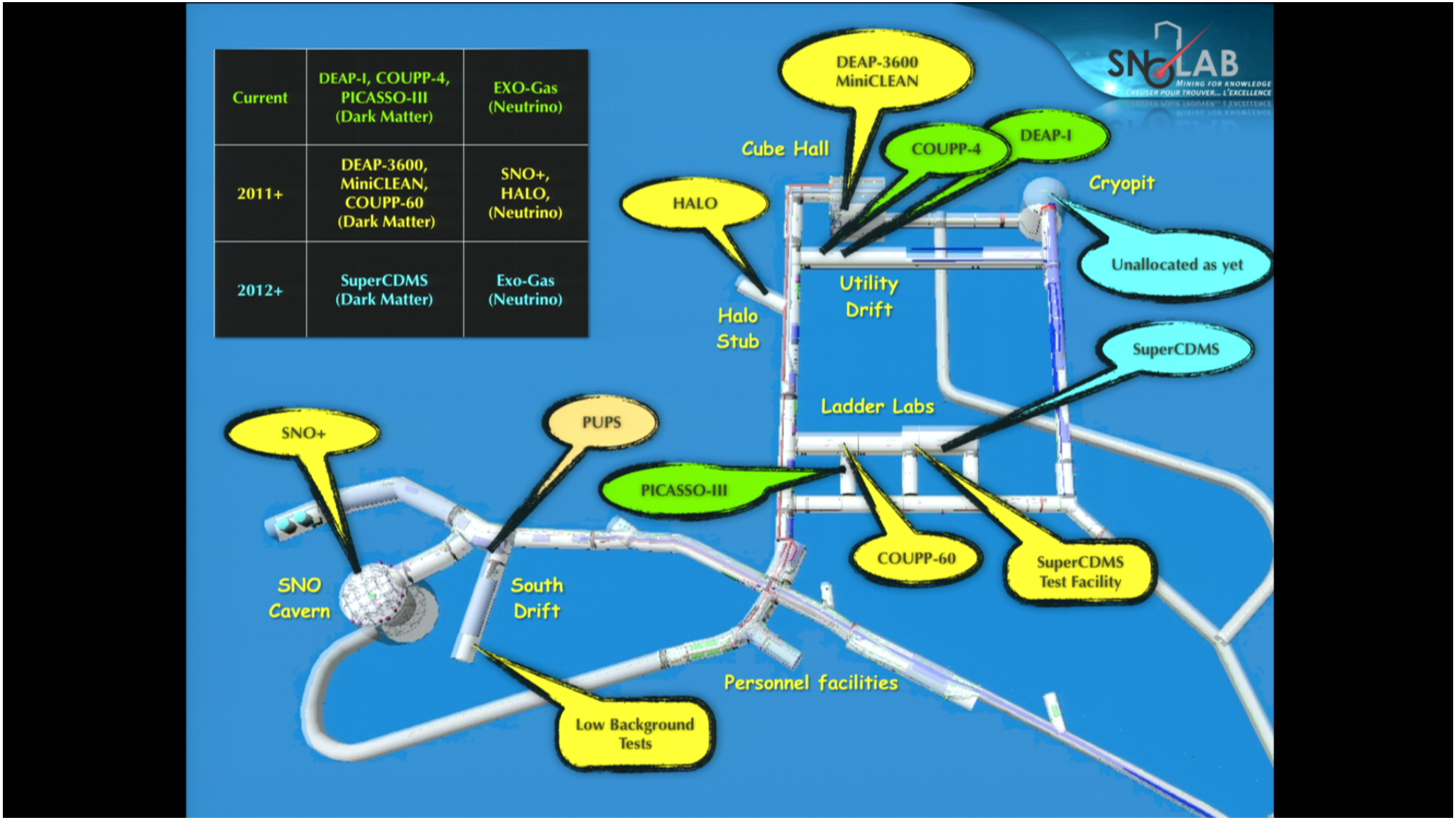


http://dmtools.berkeley.edu/limitplots/ Gaitskell/Mandic

When is 'deep enough'?

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




Current
DEAP-I, COUPP-4, PICASSO-III (Dark Matter)
EXO-Gas (Neutrino)
2011+
DEAP-3600, MiniCLEAN, COUPP-60 (Dark Matter)
SNO+, HALO, (Neutrino)
2012+
SuperCDMS (Dark Matter)
Exo-Gas (Neutrino)
SNOLAB
Mining for knowledge
Creuser pour trouver... l'excellence
DEAP-3600 MiniCLEAN
Cube Hall
COUPP-4
DEAP-I
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