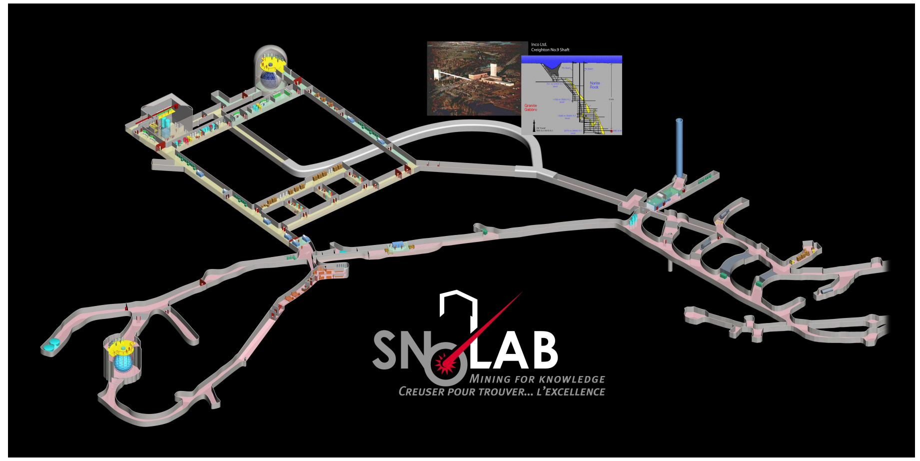
Facility and experiment developments at SNOLAB



Eric Vázquez Jáuregui

SNOLAB

Fourth International Workshop for the Design of the ANDES Underground Laboratory

México City, México; January 30, 2014

Outline

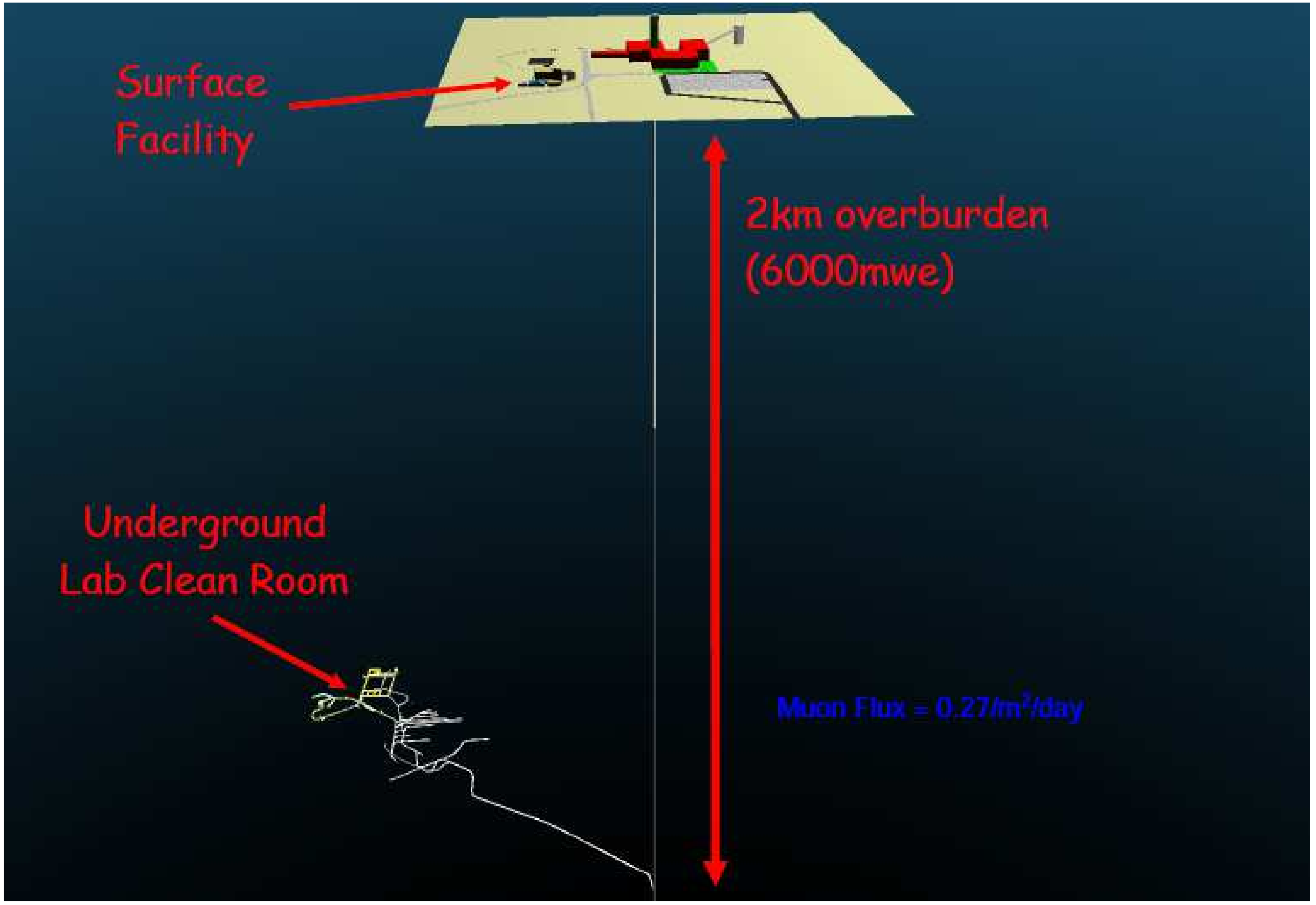
- **SNOLAB facility**
  - **design, services, operations, experiment support**

- **SNOLAB and its science programme**
  - **Dark Matter (see talk tomorrow by Tony Noble)**
  - **Neutrino Physics**

- **Final remarks**

SNOLAB: a world class facility

SNOLAB



2 km underground near Sudbury, Ontario

SNOLAB Objectives

- To promote an International programme of Astroparticle Physics
- To provide a deep experimental laboratory to shield sensitive experiments from penetrating Cosmic Rays
- To provide a clean laboratory
  - Entire lab at class 2000, or better, to mitigate against background contamination of experiments
- To provide infrastructure for, and support to, experiments

SNOLAB Objectives

- **Focus on dark matter, double beta decay, solar & SN experiments requiring depth and cleanliness**
  - **Also provide space for prototyping of future experiments**
- **Large scale expt's (ktonne, not Mtonne)**
- **Goal has been to progressively create a significant amount of space for an active programme as early as possible.**

SNOLAB Facility

- **Operated in the Creighton nickel mine, near Sudbury, Ontario, hosted by Vale Ltd**
- **Developed from the existing SNO detector**
- **Underground campus at 6800' level, $0.27\mu/m^2$/day**
- **Development funds primarily through CFI as part of a competition to develop international facilities within Canada**

SNOLAB Facility

- **Additional construction funding from NSERC, FedNOR, NOHF for surface facility**
- **Operational funding through NSERC, CFI, MRI/MEDI (Ontario)**
- **Managed as a joint trust between five Universities (Alberta, Carleton,Queen's, Laurentian, Montréal)**
  - **Carleton led SNOLAB construction and facility development**
  - **SNOLAB formally a Queen's Institute to provide legal entity (for Vale)**
  - **SNOLAB Institute Board of Directors has overall governance responsibility**

Facility design philosophy

- Initial underground design concept was single monolithic cavity
- Workshops held with community to determine experiment requirements
- Switched to multiple target cavities
  - Isolate experiments for background and noise control
  - Safety of large cryogenic liquid volumes: connection to raise
  - Logistics not limited by break-out into several cavities

Facility design philosophy

- Utility drifts separated from target volumes (a la SNO)
- Entire facility to be maintained as a C2000 clean-room
  - Minimise potential for cross-contamination of experiments from dust introduced into lab
  - Minimise burden on experiments, trained crew for materials
  - Controlled single point access for materials and personnel, including personnel showers and change area
  - Provide prototyping and rapid deployment capability for medium scale projects

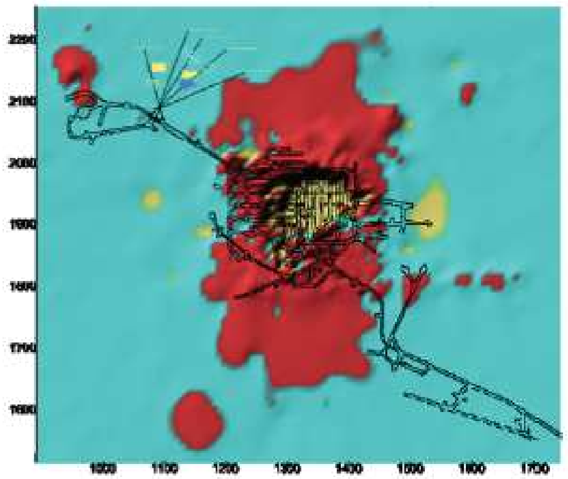
Facility design considerations

- **Background minimisation**
  - **Norite rock: 1.00 ± 0.13 % K, 1.11 ± 0.13 ppm U and 5.56 ± 0.52 ppm Th**
  - **Dust suppression required - all experimental areas shotcreted and painted to capture dust and contamination**
- **Seismic activity**
  - **Mining induced seismic activity - quasi-random**
  - **SNO and SNOLAB designed to 4.1 Nuttli, such event seen (after completion of SNO)**
  - **Maximum event now taken as 4.3 Nuttli**

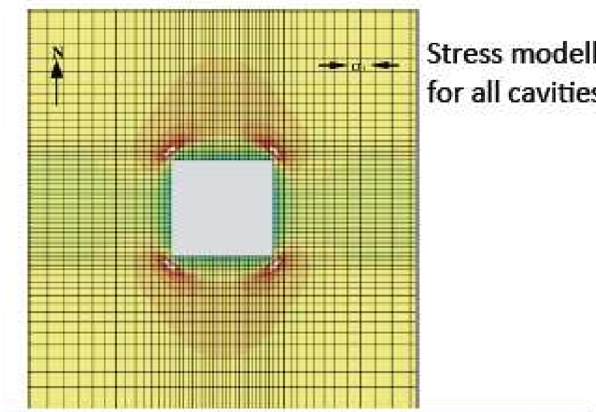
Facility design considerations

- **Design criteria - seismic**
  - **SNO and SNOLAB in the stable hanging wall of norite**
  - **Exploratory core drilling performed over lab area**
  - **Detailed analysis of cavity and lab design stress from ITASCA**
  - **Lab placed outside the lifetime 5% stress boundary from mining activity**
  - **Orientation to give cavities along line of maximum stress**
  - **Secondary support: 2m rockbolts, 7/10m cables, mesh and shotcrete**

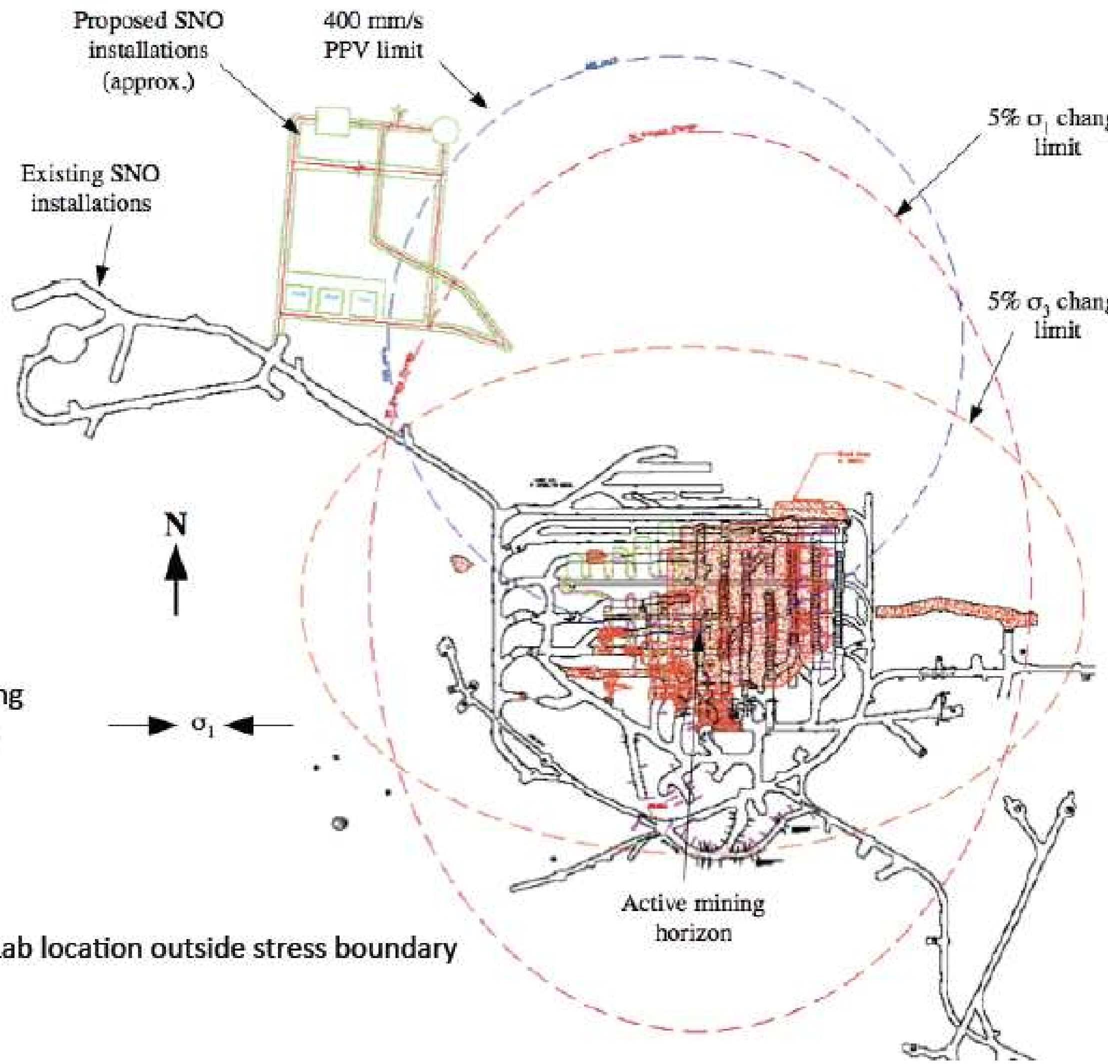
Seismic design criteria



5% stress contour



Stress modelling for all cavities



Lab location outside stress boundary

Facility services

- Ventilation
  - 100,000 cfm mine air flow to laboratory, mainly used for cooling of chillers
  - 10% make-up air fed in lab - 13 air handling units in lab
  - Maintains pressure differentials for cleanliness
  - 10 air changes/hour nominal;
    5 air changes/hour in cavities
- Cooling
  - 1 MW cooling capability from 5 cooled water units delivering 10C water to the laboratory.
    100kW from rock in steady state (42C base)
  - 20% utilised at present with minimal expt. load

Facility services

- **Power distribution**
  - **3-phase 13.8 kV fed to facility**
  - **Stepped to 3-phase 600V (total 2000 kVA); upgrade underway to 3000 kVA**
  - **150kW (++) Generator planned + switch-over infrastructure**
- **Water**
  - **Utility water derived from mine water**
  - **UPW as a general capability for experiments (150l/min, 183 kΩm)**
  - **Waste disposal through mine systems (except sewage - STP)**

Facility services

- Gases/Liquids
  - Bottle transport used for gases; dewar transport for LN2
  - Discussion on liquefaction underground (but purity issue for cover gas systems)
- Networking
  - Switching to single mode fibers underway
  - 100 Mbit through shaft; upgrade to Gbit once fibers switched
- Low Background Assay and calibrations
  - Co-ax and well Ge detectors available
  - X-ray fluorescence for cleanliness assay

Facility services

- Workshops
  - Surface machine shop; surface chem labs; surface electronics shop
  - Underground clean room workshop and chem labs in construction
- 'Hot' Lab
  - Dedicated surface lab at Laurentian University for 'hot' work
  - Encapsulation of sources; production of radiological spikes
- Other services
  - GPS timing

Consideration for experiments

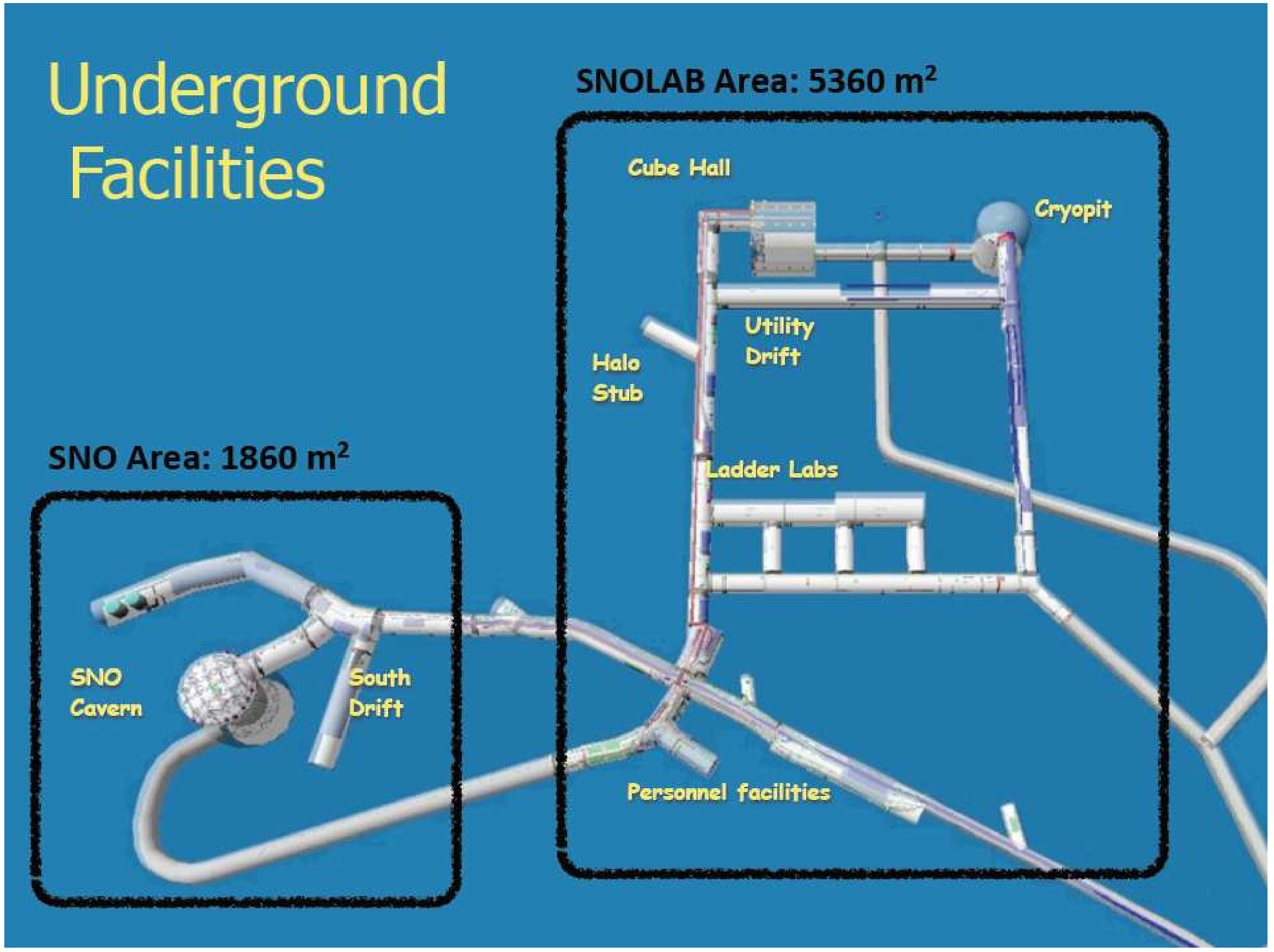
- **Transport**
  - **Cage size: 3.7 m x 1.5 m x 2.6 m, slinging for larger objects**
- **Seismic mitigation**
  - **Design criteria now 4.3 Nuttli, following 4.1 event in SNO**
  - **Forcing function applied to experiment designs maximum velocity 800 mm/s at 5 Hz**
- **H2S**
  - **Long term exposure to mine air showed deposition of CuS on SNO electronics**
  - **Suppression is now installed in the air handling units**

Consideration for experiments

- Pressure
  - Air pressure is 25% higher than atmospheric
  - Excursions during ventilation changes and crown blasts (up to 3% seen)
    - managed through baffling and blast doors
    - design pressure for experiments up to 20 psi
- Radon (130 Bq/m^3)
  - No direct radon suppression in main air intakes
  - Surface (compressed) air used to provide low(er) radon air to specific areas
  - Cover gas used (LN2 boil-off) on detector systems
  - Ventilation (make-up vs recirculation) minimises radon emission from walls

Surface Facility

Underground Layout



Deepest and cleanest large-space international facility
Ultra-low radioactivity background environment Class 2000

Underground Laboratory

Underground Laboratory

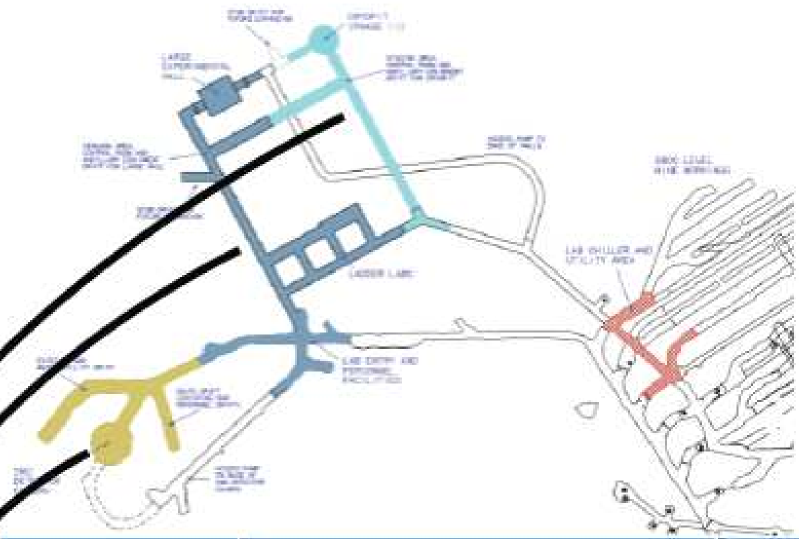
- Ultrapure water from the SNO water purification plant
- LN_2 supplied by transport dewar from surface

- 3 HPGe Gamma Counters
- Rn/Ra Emanation (electrostatic counters, radon emanation chambers)

Underground Laboratory

Stephen Hawking at SNOLAB

SNOLAB space summary



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)	$180m^2$	$3{,}900\ m^3$

	Excavation		Clean Room		Laboratory	
	Area (m2)	Volume (m3)	Area (m2)	Volume (m3)	Area (m2)	Volume (m3)
Original SNO Areas	1860	16500	1130	13300	750	11700
+Phase I	6070	38750	3900	29750	2430	23700
+Phase II	7220	46650	4940	37250	3060	29550

Support for experiments

- Through a staff of ∼55, SNOLAB provides technical and administrative support to SNOLAB experiments:
  - design, construction, operations
  - background assay, science support
  - materials transport, cleaning, EH&S, training, procurement
- The Research team members can act as collaborators on experiments, providing operational and scientific support
- Infrastructure support is provided through development of shielding systems, mechanical supports, access, EH&S, etc.

Support for experiments

- **Services provided as standard to experiments includes life safety, power, ventilation, compressed air, ultra-pure water, liquid nitrogen, IT and networking**
- **Vale provide materials transport through the shaft, maintain the safety of the infrastructure, regulatory checks, etc.**
  - **SNOLAB currently has 50-80 people underground regularly, 3 dedicated cages**
  - **Cages integrated into Vale operations effectively (eg SNO D2O movement)**
  - **Double shifts maintained regularly**

SNOLAB operations costs

- Staff complement ∼60
  - Cost ∼$4M/yr
    Note: additional support from University partners so NOT full project staff costs
  - 24hr/day operations not assumed
- Non-staff
  - Cost currently ∼$3M/yr
  - Includes Vale charges ∼$1M

SNOLAB operations costs

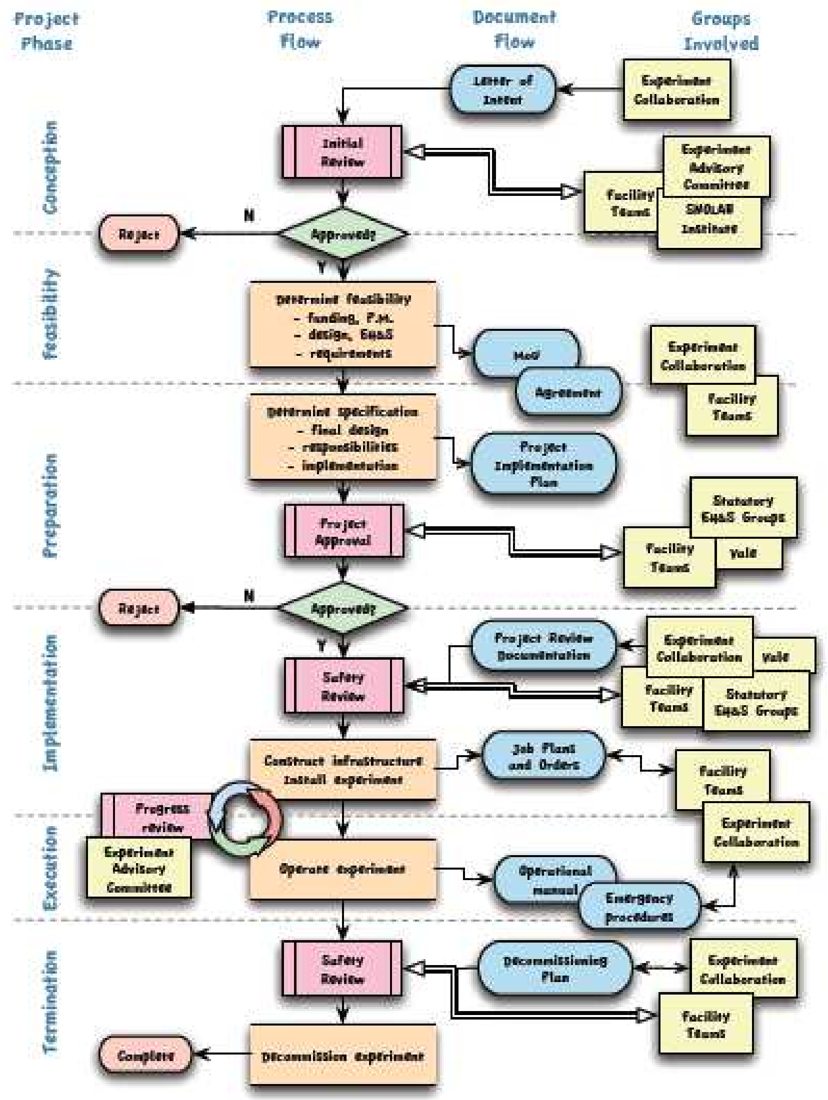
- **Project cash costs currently ∼\$7M/yr**
- **"In-kind"**
  - **If mining operations ceased, the equivalent contribution from Vale estimated ∼\$7-10M/yr:**
    - **Hoist, materials, service infrastructure, EH&S, drift maintenance, collar services, water+ventilation**
  - **University support ∼\$1M/yr**

SNOLAB operational model

- **For current facilities**
  - Traditional NP "free-at-the-point-of-access" model
  - Canadian support for baseline operations of the facility, including life safety, power, ventilation, materials handling, compressed air, UPW, IT and networking
  - Experiments charged for additional "non-standard" costs: significant transport, high power usage, significant gas/nitrogen
  - Experiments responsible for clean-room beyond C2000
  - Infrastructure negotiated: capital expected from experiments
- **Based on current planned programme**
  - If additional experiments incorporated immediately then additional installation and construction support would be required through the experiment for infrastructure

Project Lifecycle Planning

- Project lifecycle and interaction with facility well-defined
  - Structures and agreements under development
  - Q.A. under development
- International Experiment Advisory Committee helps to define programme
- H&S reviews integral to development and deployment
  - SNOLAB
  - Vale (if req'd)
- Workshop based approach to updated programme needs



Dark Matter programme

Dark Matter at SNOLAB

- **Noble Liquids:**
  - **DEAP-I, MiniCLEAN, & DEAP-3600: Single Phase Liquid Argon using pulse shape discrimination, prototype DEAP-I completed operation, demonstration of PSD at 10^8, construction for DEAP-3600 and MiniCLEAN well advanced, will measure Spin Independent cross-section**

- **Superheated Liquid / Bubble chamber:**
  - **PICASSO, COUPP & PICO: Superheated droplet detectors and bubble chambers, insensitive to MIPS radioactive background at operating temperature, threshold devices; alpha discrimination demonstrated, COUPP-4 operation completed; PICASSO-III currently operational, COUPP-60 construction completed, and running; measure Spin Dependent cross-section primarily, COUPP has SI sensitivity; new world leading sensitivity published in 2012; PICO-2L running, suitable for low WIMP masses; PICO-250 coming quickly**

- **Solid State:**
  - **DAMIC & SuperCDMS: State of the art CCD Si / Ge crystals with ionisation / phonon readout, DAMIC operational ; CDMS Currently operational in Soudan facility, MN., next phase will benefit from SNOLAB depth to reach desired sensitivity, mostly sensitive to Spin Independent cross-section.**

see talk tomorrow by Tony Noble

Neutrino Physics programme

Neutrino Physics at SNOLAB

- **SNO+ : $^{130}Te \rightarrow^{130} Xe + e^- + e^-$, uses existing SNO detector, heavy water replaced by scintillator loaded with 130^Te, modest resolution compensated by high statistical accuracy, requires engineering for acrylic vessel hold down and purification plant, technologies already developed, will also measure: solar neutrino pep line (low E-threshold), geo-neutrinos (study of fission processes in crust), supernovae bursts (as part of SNEWS), reactor neutrinos (integrated flux from Canadian reactors).**

- **EXO-gas : $^{136}Xe \rightarrow^{136} Ba^{++} + e^- + e^-$, ultimate detector aim = large volume Xe Gas TPC, developing technique to tag Ba daughter, electron tracking capability, development work at SNOLAB surface facility**

- **HALO: Dedicated Supernova watch experiment, charged/neutral current interactions in lead, re-use of detectors (NCDs) and material (Pb) from other systems, operational May 2012, will form part of SNEWS array**

SNO+ detector

- Acrylic vessel
  $\phi = 12$ m
- Liquid scintillator
  (LAB+PPO)
  780 tonnes
- 1700 tons H_2O inner
- 5700 tons H_2O outer
- 9500 PMTs
- Urylon liner

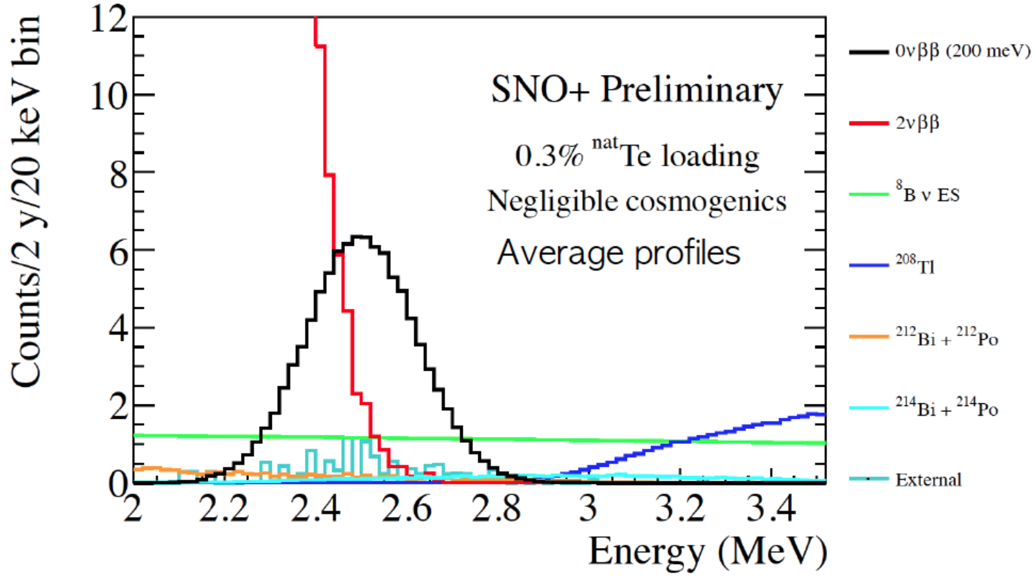
SNO+ Physics Goals

- Double beta decay with ^{130}Te
- Low energy solar neutrinos
- Geo-neutrinos
- Reactor neutrinos oscillation
- Supernova neutrinos
- Nucleon decay (water phase)

Double Beta Decay Phase

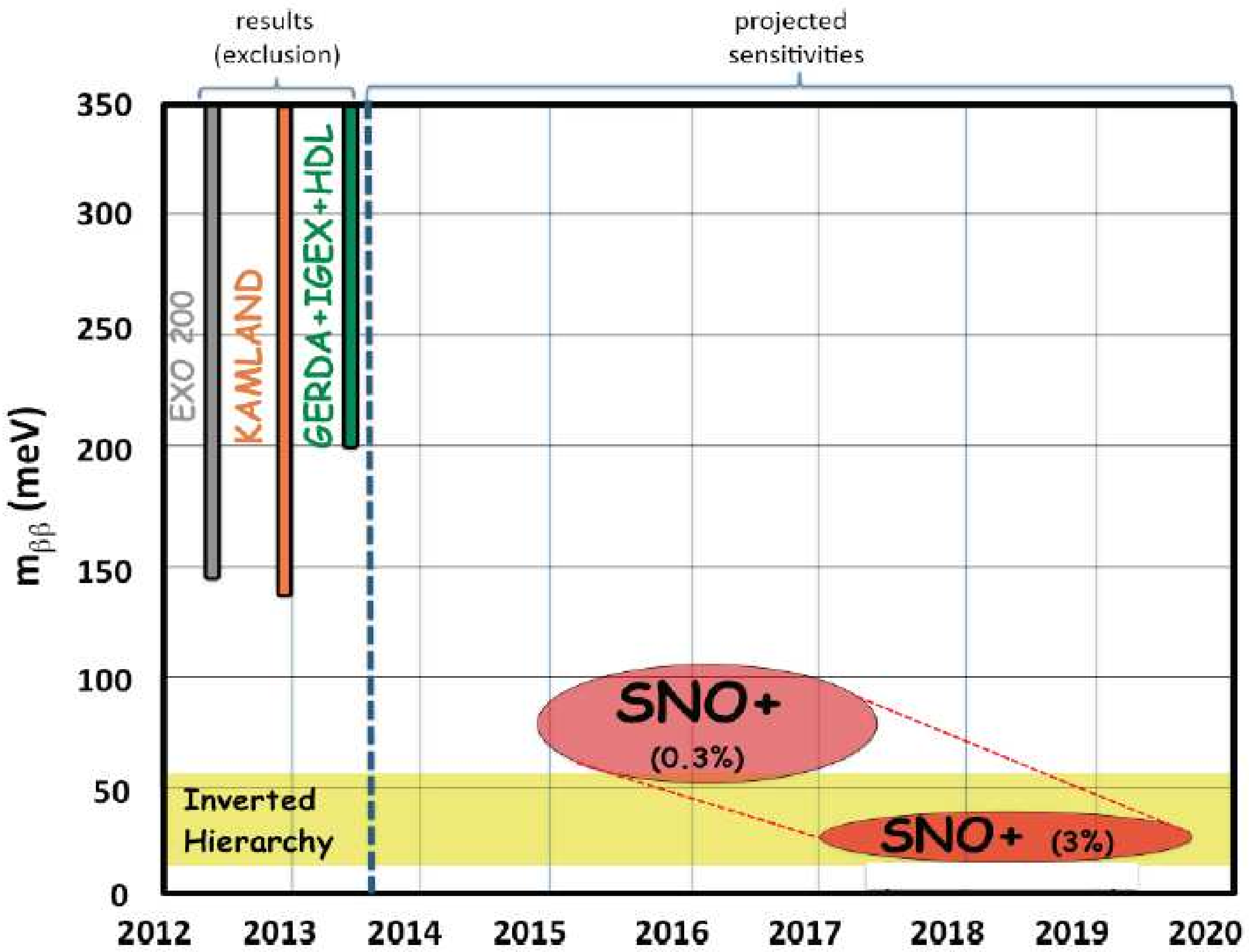
Energy spectrum simulation

- 3.5m (20%) fiducial volume cut
- 2 years livetime
- $>$ 99.99% efficient ^{214}Bi tag
- 97% efficient internal ^{208}Tl tag
- Factor 50 reduction ^{212}BiPo
- Negligible cosmogenics
- $< m_\nu >$=200meV



^{8}B: 440 events/year $_{(0,5)MeV}$
^{214}Bi: 2.3 events/year (3%)
^{208}Tl: 52.9 events/year (3%)

SNO+ sensitivity

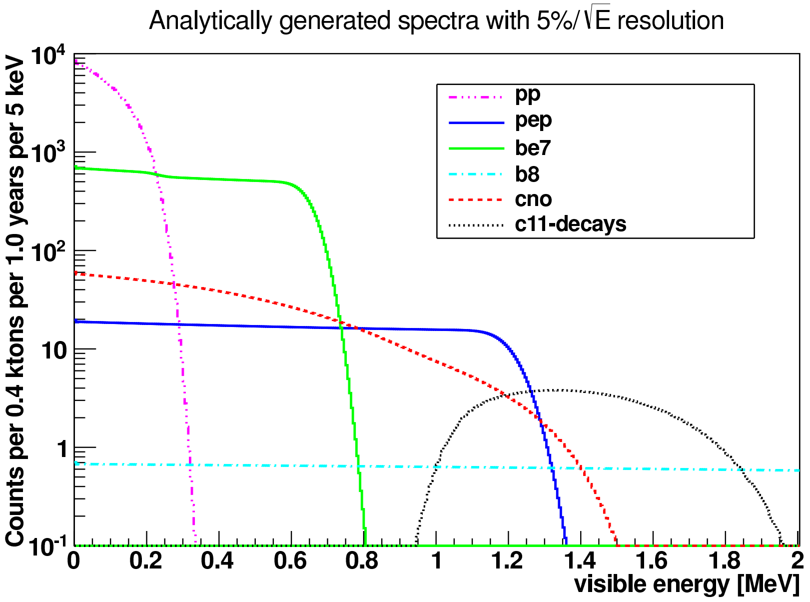


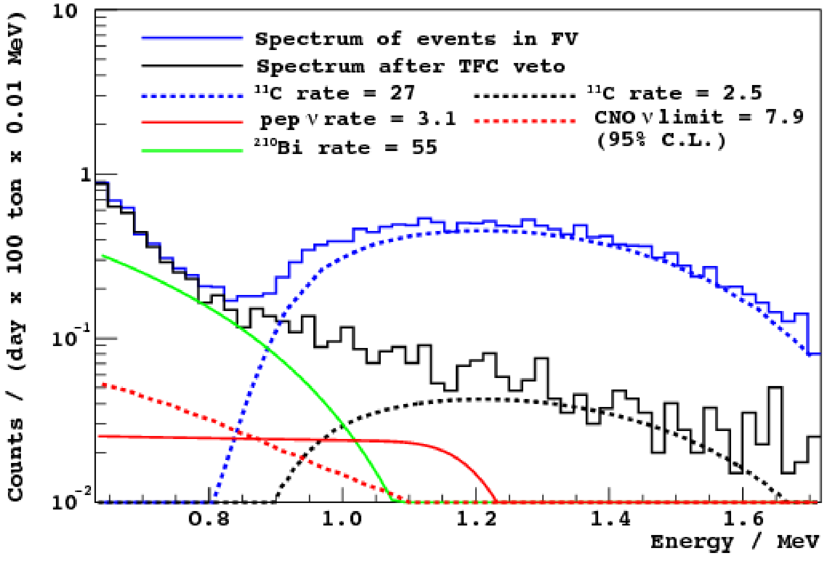
Low Energy Solar Neutrinos

pep and CNO neutrinos

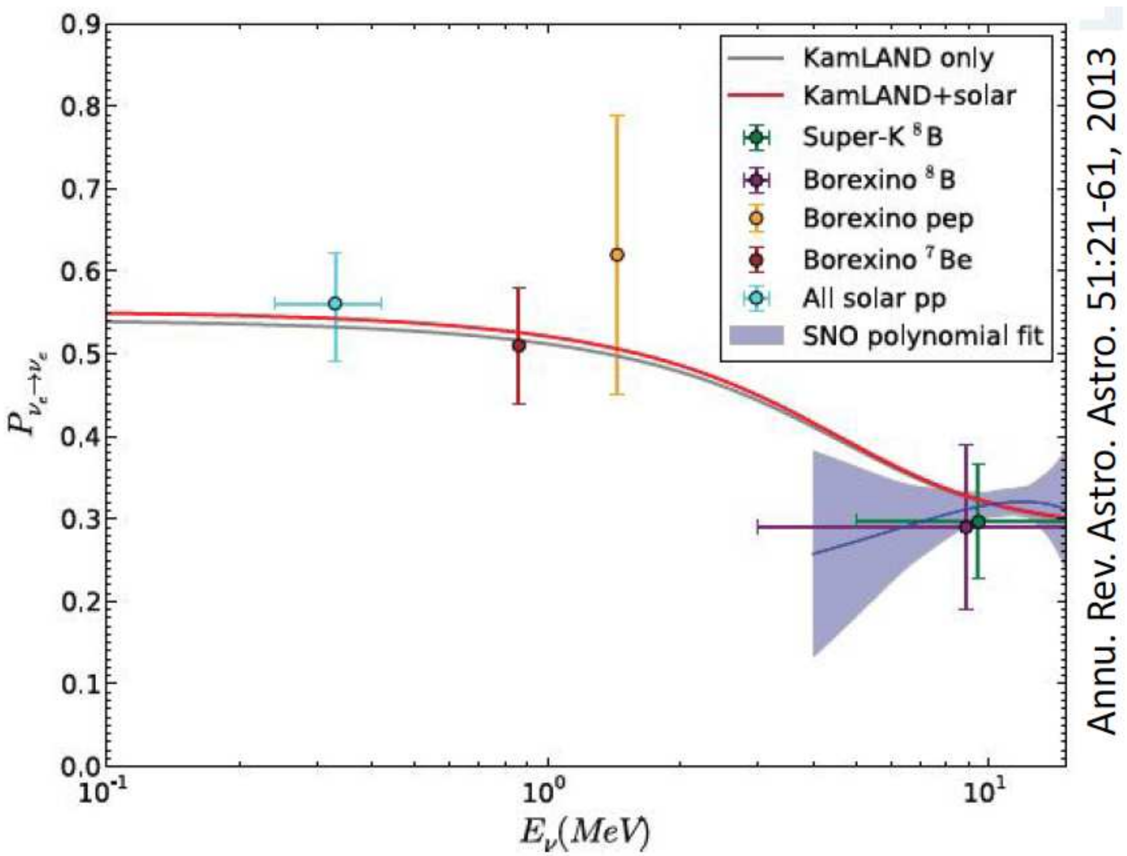
- Depth and size for precised pep measurement: 3600 pep events/(kton-year), for electron recoils > 0.8 MeV ±5% (stat, syst) after 3 years

- Reduction of ^{11}C for CNO measurement: ±7% (stat) after 3 years





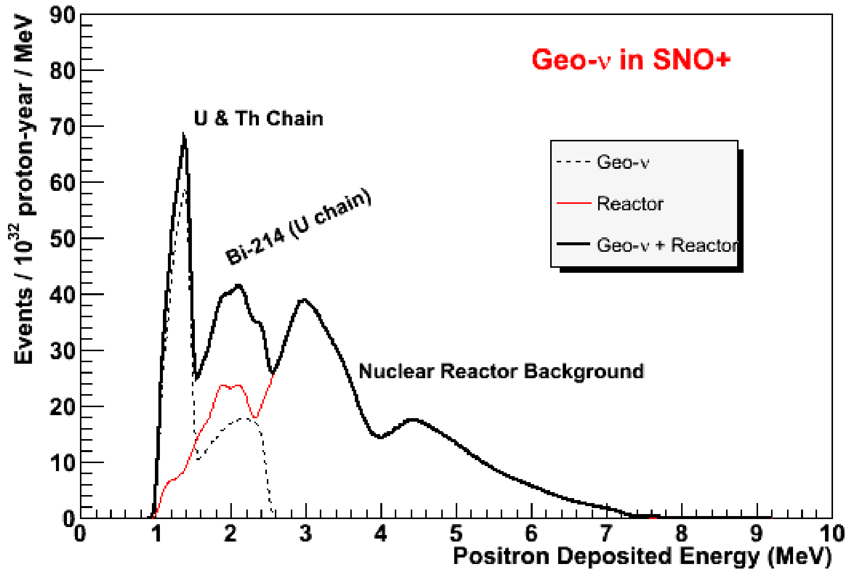
Confirm MSW-LMA behavior at lower energies: probe the solution in vacuum-matter transition region with pep neutrinos (1.2% error on predicted solar model flux)

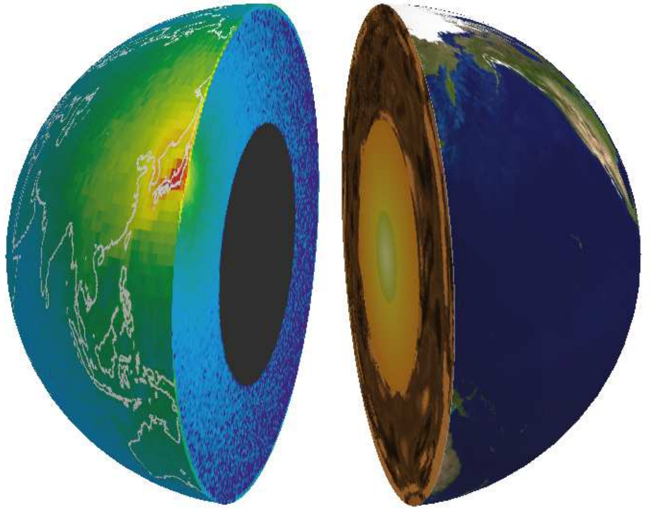


Geo-neutrinos

anti-ν_e from β^- decays (U, Th) to explore chemical composition of Earth's crust & mantle

- Check models of Earth heat production
- Low reactor background in SNO+: Reactor/Geo ~1.1
- Geo-ν in SNO+ mainly from two reservoirs:
  - mantle
  - old, thick continental crust (very local region well-studied

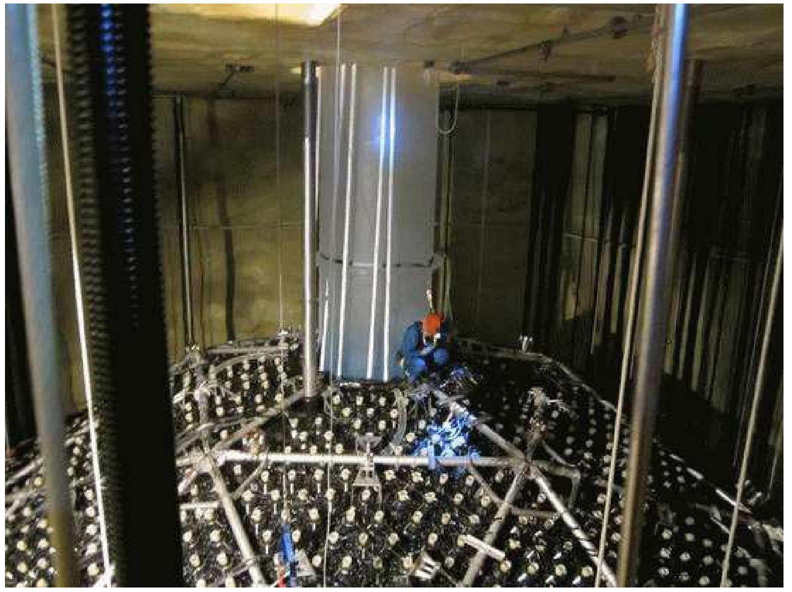


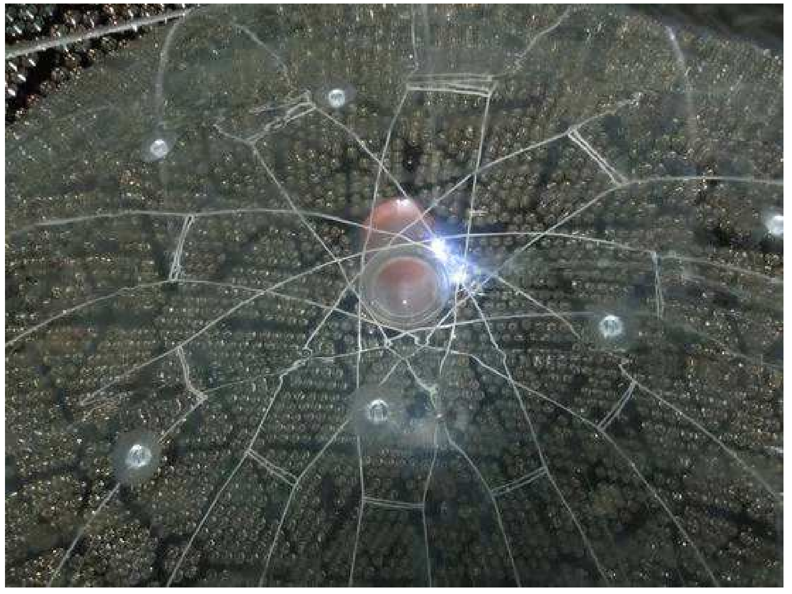


SNO+ Supernova Signal

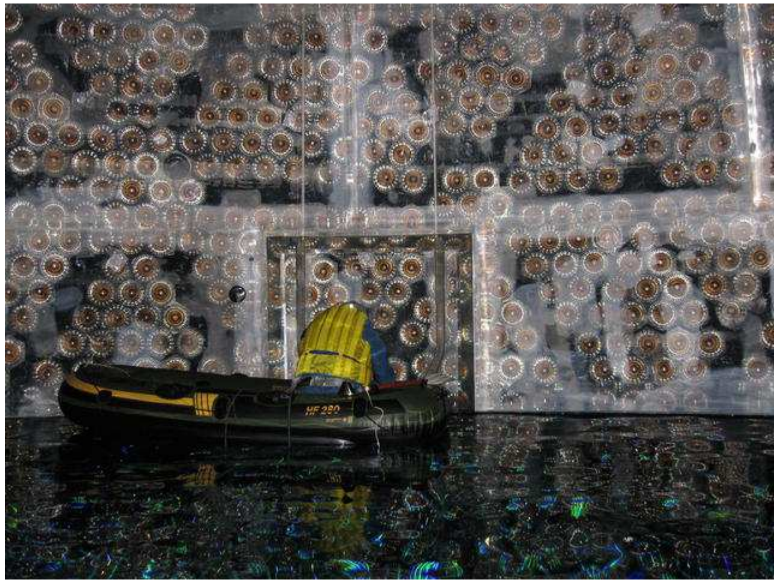
- **Elastic scattering:**
  - 8 evts: $\nu_e + e^- \rightarrow \nu_e + e^-$
  - 3 evts: anti-$\nu_e + e^- \rightarrow$ anti-$\nu_e + e^-$
  - 4 evts: $\nu_{\mu,\tau} + e^- \rightarrow \nu_{\mu,\tau} + e^-$
  - 2 evts: anti-$\nu_{\mu,\tau} + e^- \rightarrow$ anti-$\nu_{\mu,\tau} + e^-$
- **Charged Current:**
  - 263 evts: anti-$\nu_e + p \rightarrow n + e^+$
  - 27 evts: $\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$
  - 7 evts: anti-$\nu_e + {}^{12}C \rightarrow {}^{12}B + e^+$
- **Neutral Current:**
  - 58 evts: $\nu_x + {}^{12}C \rightarrow {}^{12}C^*(15.11\text{MeV}) + \nu_x$
  - 273 evts: $\nu_x + p \rightarrow \nu_x + p$

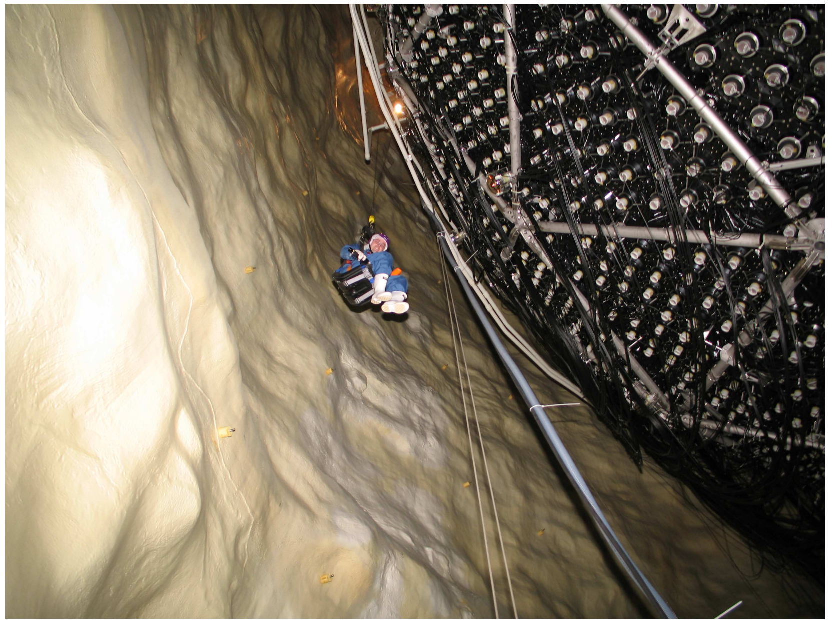
SNO+ detector

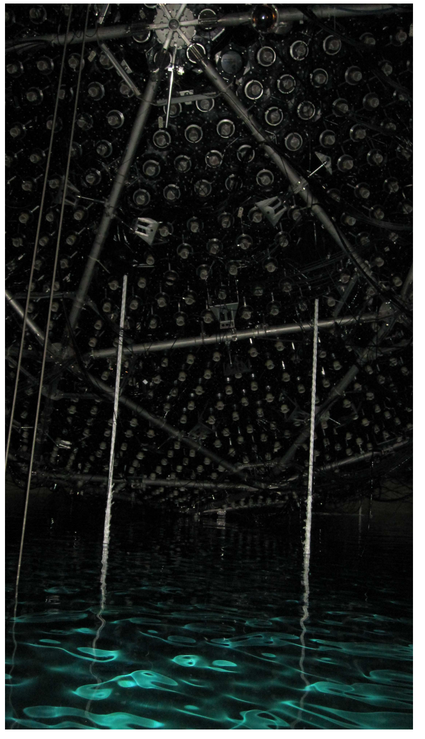





SNO+ detector

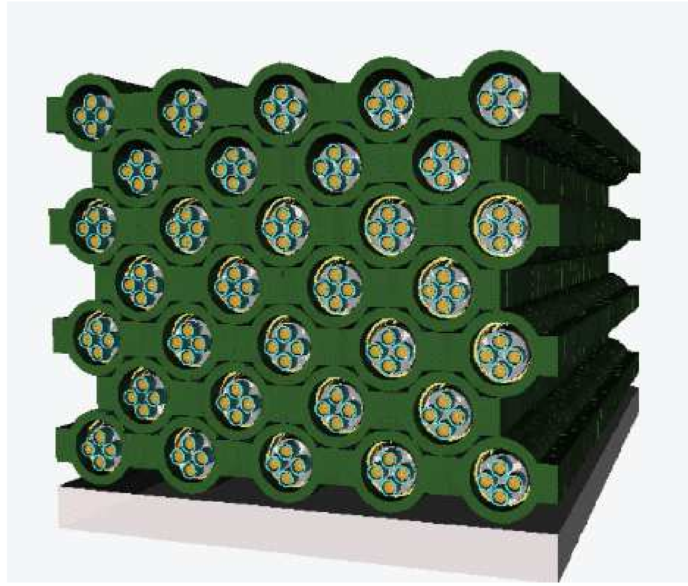






Helium And Lead Observatory

- **Helium:**
  available ^{3}He neutron detectors from the final phase of SNO
- **Lead:**
  lead blocks from a decommissioned cosmic ray monitoring station
  - high ν-Pb cross-sections
  - low n-capture cross-sections
  - complementary sensitivity to water Cerenkov and liquid scintillator SN detectors



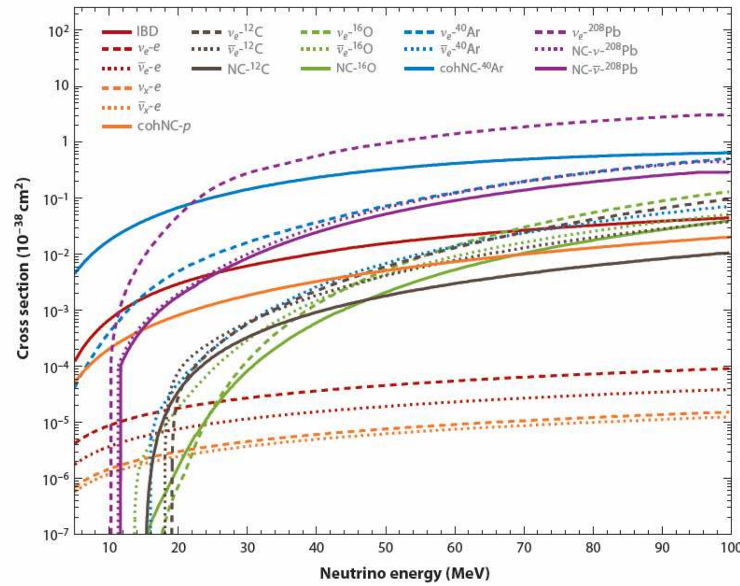


Figure 2
Cross sections per target for relevant interactions. See **http://www.phy.duke.edu/~schol/snowglobes** for references for each cross section plotted. Abbreviations: IBD, inverse β decay; NC, neutral current.

HALO Supernova Signal

- **Charged Current:**
  - $\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + \mathrm{n} + \mathrm{e}^-$
  - $\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2\mathrm{n} + \mathrm{e}^-$

- **Neutral Current:**
  - $\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + \mathrm{n}$
  - $\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2\mathrm{n}$

HALO is operational

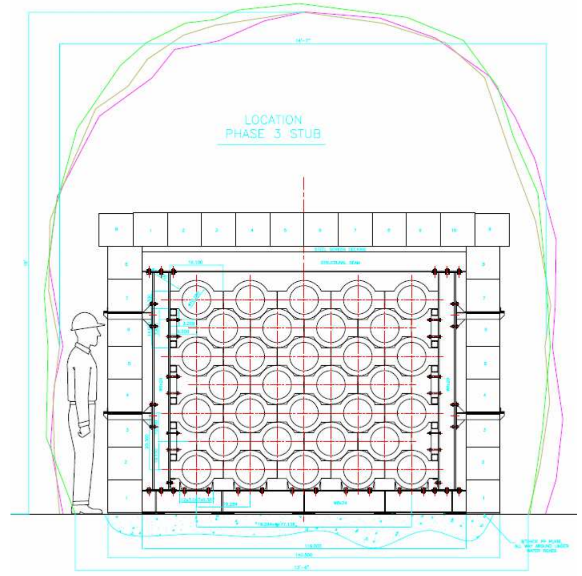
Part of SNEWS once the behaviour of the detector is well understood

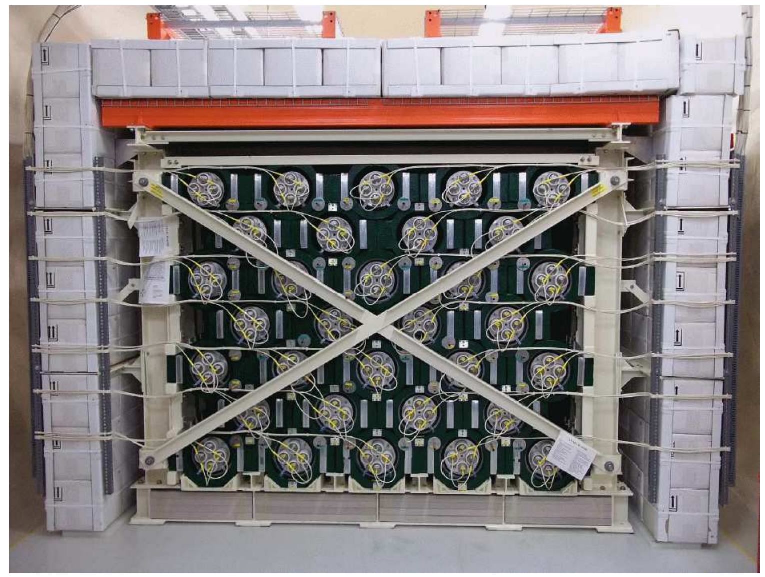
HALO Supernova Signal

79 tons of Pb for a SN at 10 kpc:
(FD distribution with T=8 MeV for ν_μ's and ν_τ's)

- **68 neutrons through ν_e charged current channels**
  - **30 single neutrons**
  - **19 double neutrons**
- **20 neutrons through ν_x neutral current channels**
  - **8 single neutrons**
  - **6 double neutrons**

∼88 neutrons liberated
∼1.1 n/tonne of Pb

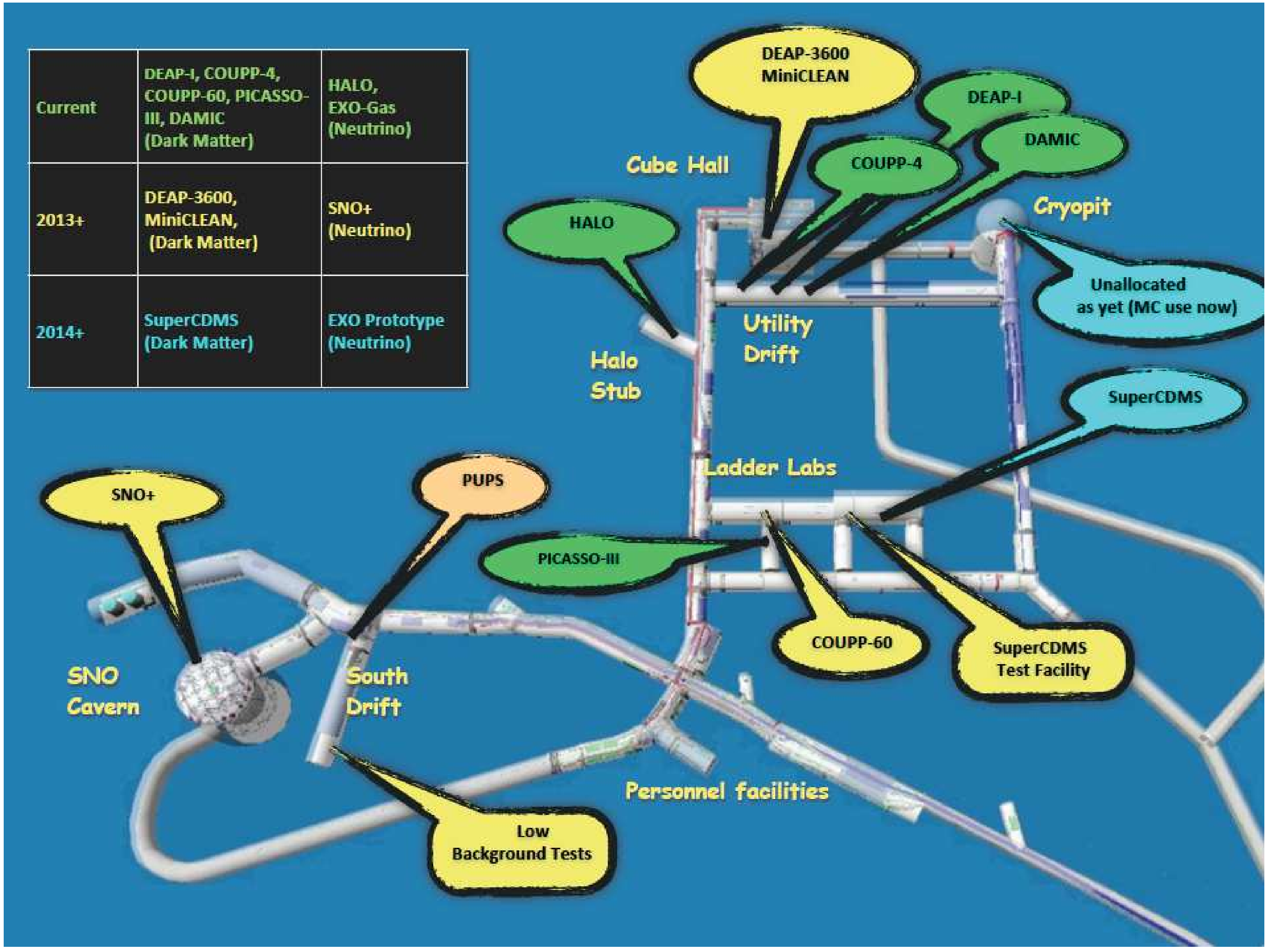




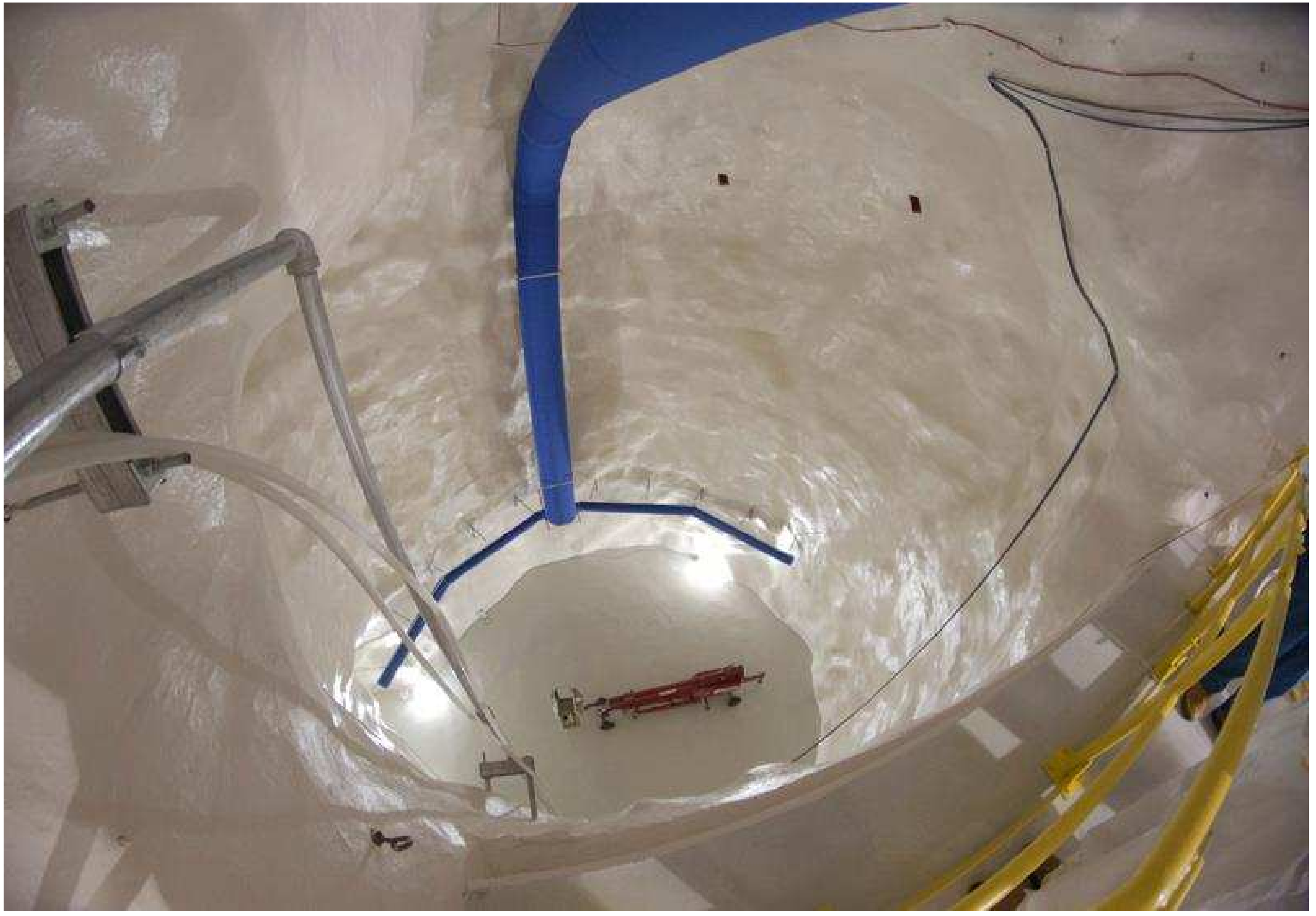
The SNOLAB science programme

Experiment	Solar ν	0νββ	Dark Matter	Supernova ν	Geo ν	Other	Space allocated	Status
CEMI						Mining Data Centre	Surface Facility	Proposal
COBRA		√					Ladder Labs	Request
COUPP-4			√				J'-Drift	Operational
COUPP-60			√				Ladder Labs	Construction
DAMIC			√				J'-Drift	Operational
DEAP-1			√				J'-Drift	Operational
DEAP-3600			√				Cube Hall	Construction
EXO-gas		√					Ladder Labs	Request
HALO				√			Halo Stub	Operational
MiniCLEAN			√				Cube Hall	Construction
PICASSO-III			√				Ladders Labs	Operational
PUPS						Seismicity	Various	Completed
SNO+	√	√		√	√		SNO Cavern	Construction
SuperCDMS			√				Ladder Labs	Request
U-Toronto						Deep Subsurface Life	External Drifts	Completed

Experiments layout



Still more space at SNOLAB



Final remarks

- **The physics program at SNOLAB is making important contributions to experimental research in Astroparticle Physics**
- **Detectors for supernovae and double beta decay, for solar neutrinos, geo-neutrinos and reactor neutrino oscillations are being built**
- **Dark matter research experiments at SNOLAB sensitive to spin dependent and/or independent using noble gases, superheated liquids and solid state detectors**
- **SNOLAB is becoming one of the leading facilities in experimental research in Astroparticle Physics**

Final remarks

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- **Dark matter research experiments at SNOLAB sensitive to spin dependent and/or independent using noble gases, superheated liquids and solid state detectors**
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Even in the deepest darkness
there is a physicist understanding the universe!