The SNOLAB Science Programme

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(on behalf of SNOLAB)

SNOLAB Objectives

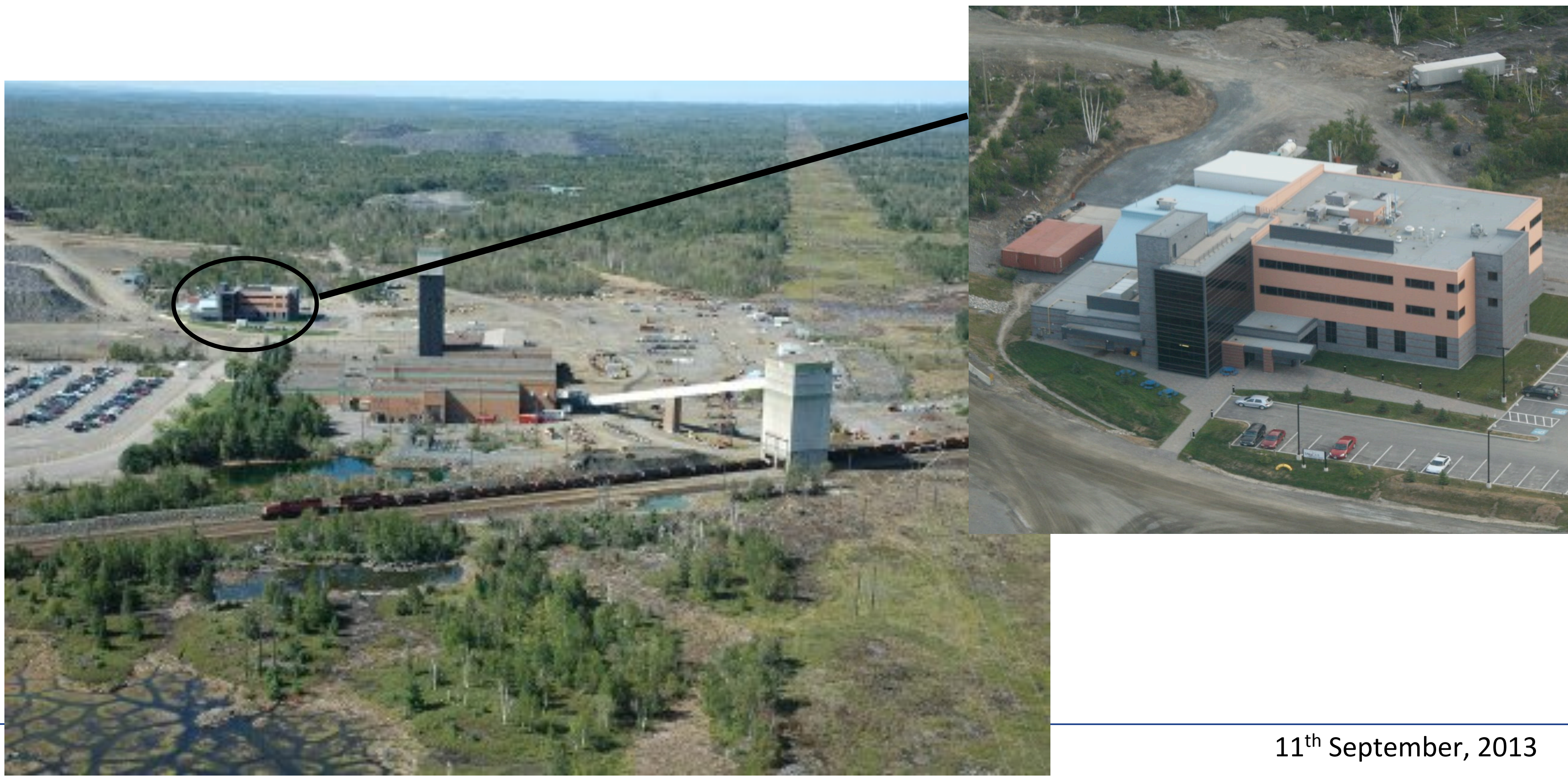
- To promote an International programme of Astroparticle Physics
- To provide a deep experimental laboratory to shield sensitive experiments from penetrating Cosmic Rays (2070m depth)
- To provide a clean laboratory
  - Entire lab at class 2000, or better, to mitigate against background contamination of experiments.
- To provide infrastructure for, and support to, the experiments
- 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.

The SNOLAB facility

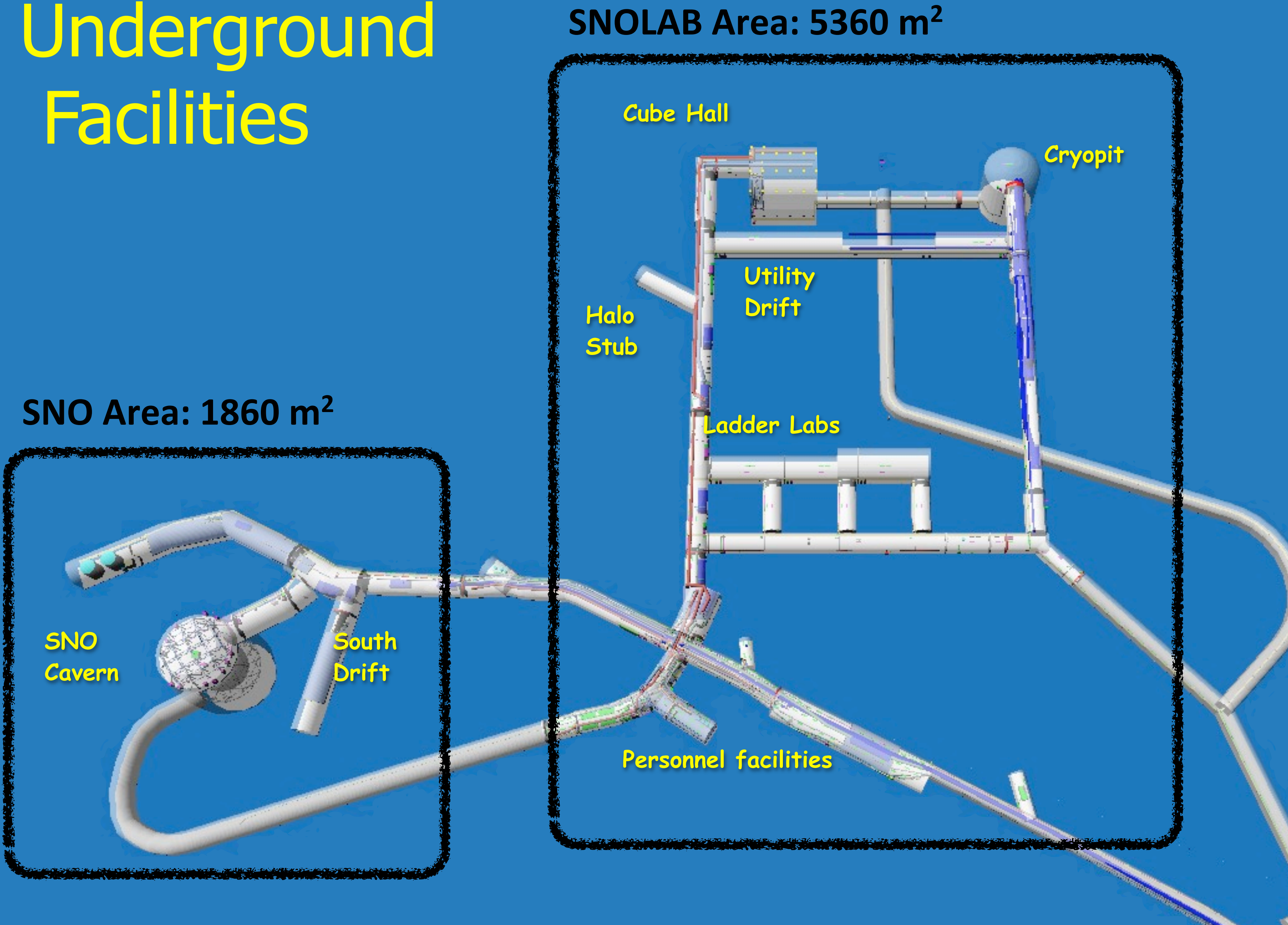
- Operated in the Creighton nickel mine, near Sudbury, Ontario, hosted by Vale Ltd.
- Developed from the existing SNO detector
- Underground campus at 6800’ level, 0.27μ/m2/day
- Development funds primarily through CFI as part of a competition to develop international facilities within Canada
- Additional 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

Vale Creighton Mine

- Surface Facility (3100 m2)
  - 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 experiment setup and tests



Underground Facilities



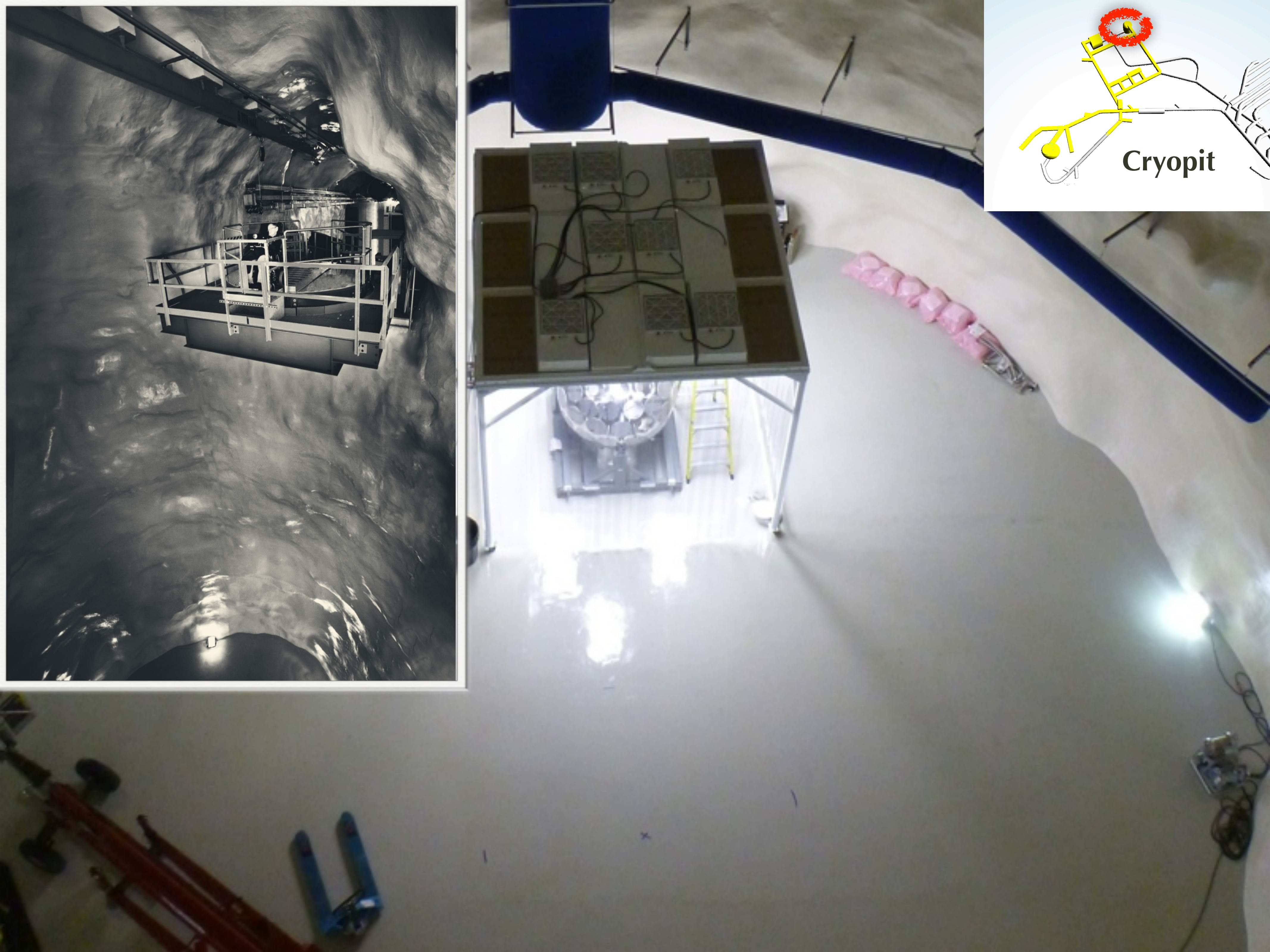

Chiller


6800
Lab Entry


Lab Entry


Lab
Entrance

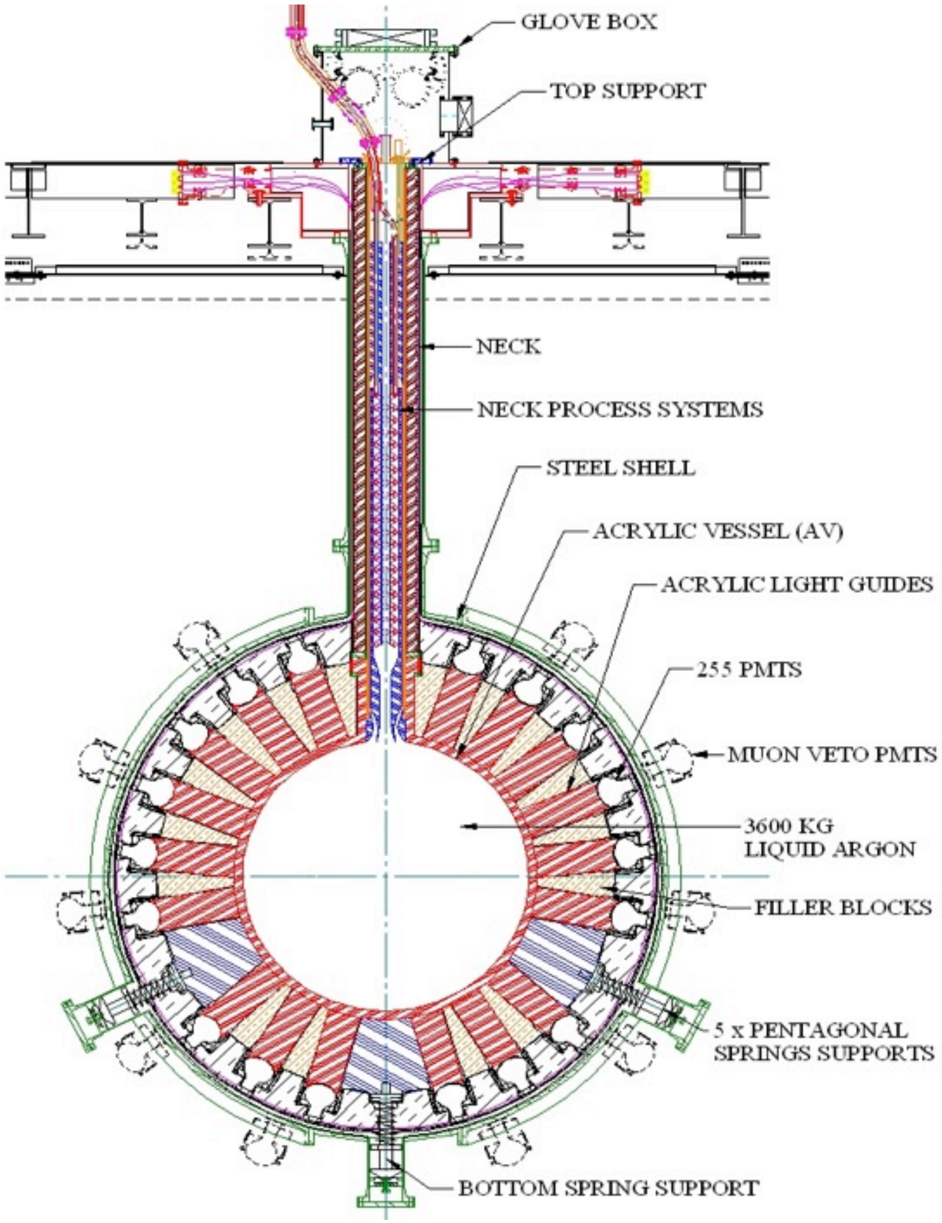

Personnel
Facility


Cryopit

Current programme: Dark Matter at SNOLAB

- Noble Liquids: DEAP-I, MiniCLEAN, & DEAP-3600
  - Single Phase Liquid Argon using pulse shape discrimination
  - Prototype DEAP-I 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 (CF_3I) operation completed; PICASSO-III (C_4F_{10}) currently operational, COUPP-60 (CF_3I) in data taking; PICO-2l (C_3F_8) under construction;
  - Measure Spin Dependent cross-section primarily, COUPP has SI sensitivity on iodine;
  - World leading spin-dependent sensitivity published in 2012.
- Solid State: DAMIC, SuperCDMS
  - State of the art CCD (DAMIC) Si / Ge crystals with ionisation / phonon readout (SuperCDMS).
  - DAMIC operational since 2012, 10g CCD;
  - 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.

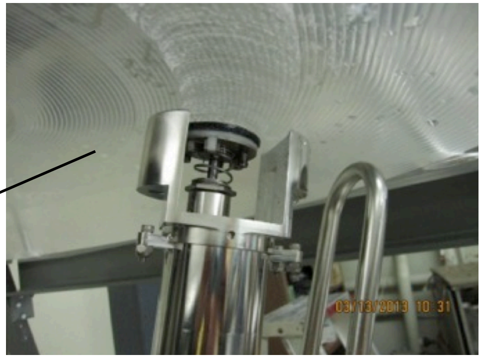
DEAP-3600



DEAP-3600 Detector

3600 kg argon target
(1000 kg fiducial)
in sealed ultraclean
Acrylic Vessel

Vessel is "resurfaced"
in-situ to remove
deposited Rn daughters
after construction

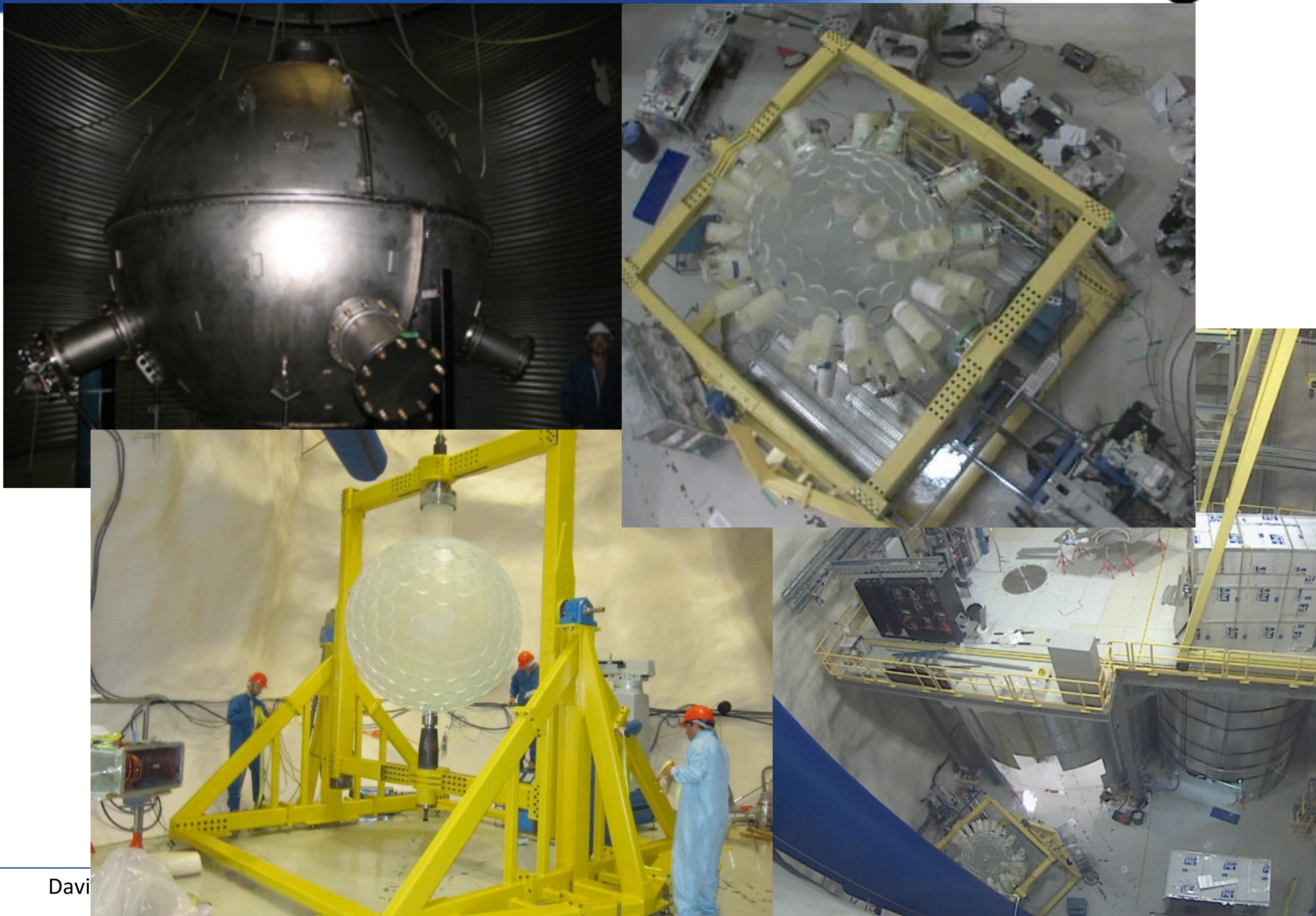


255 Hamamatsu
R5912 HQE PMTs 8-inch
(32% QE, 75% coverage)

50 cm light guides +
PE shielding provide
neutron moderation

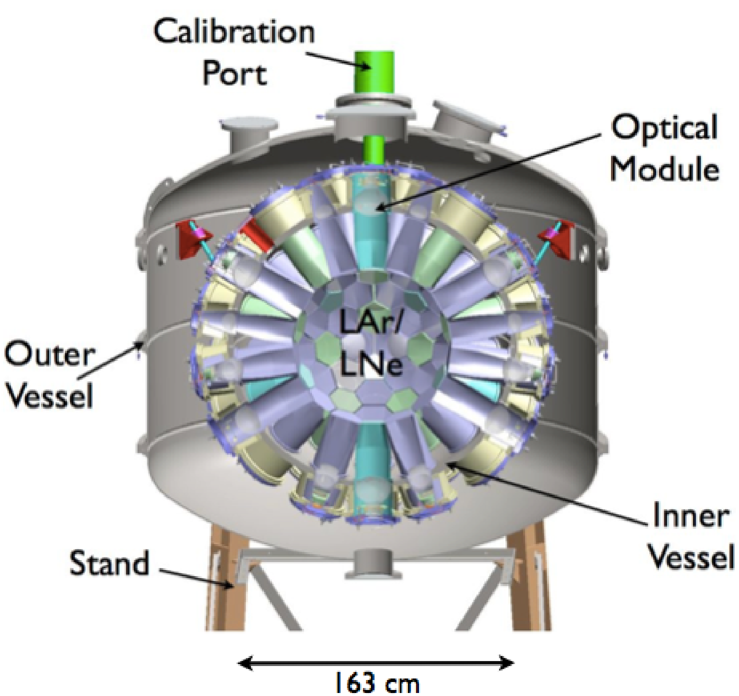
Detector in 8 m water
shield at SNOLAB

DEAP-3600 Construction



MiniCLEAN Detector

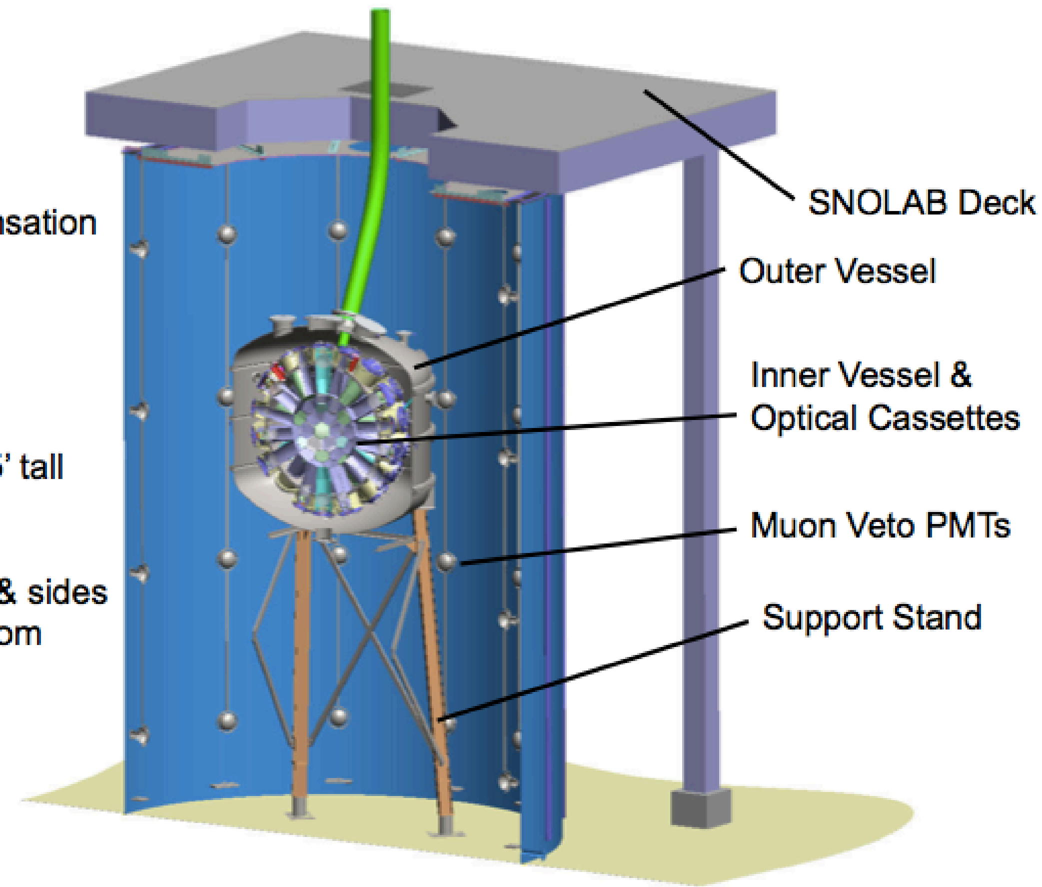
- Single phase LAr/LNe (solar neutrino capability)
- 180kg fiducial volume; PSD discrimination for background rejection
- Wavelength shifter on acrylic plugs
- PMT Cassette into steel vessel



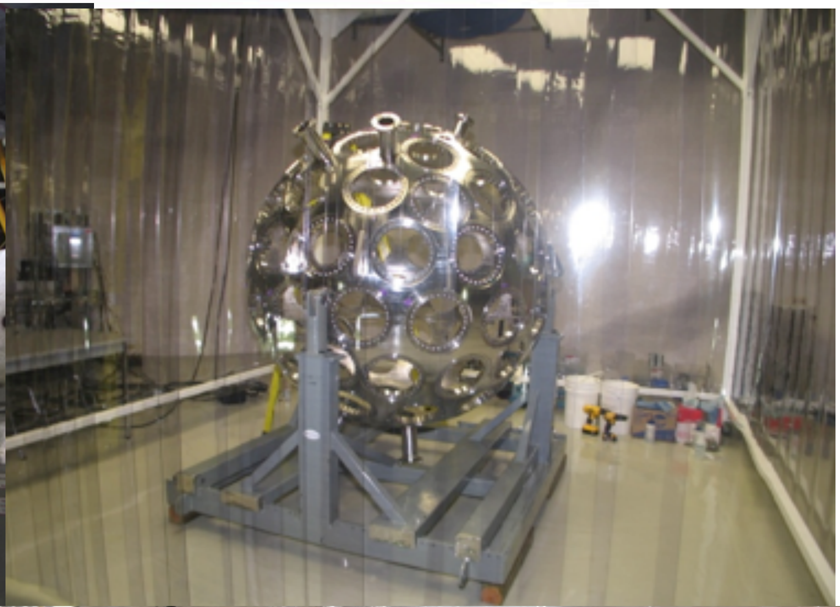
Not Shown:
Magnetic Compensation
Process Systems
Cable Bundles

Tank 18' dia. x 25' tall
47,600 gallons

~1.5m water top & sides
~3.5m water bottom



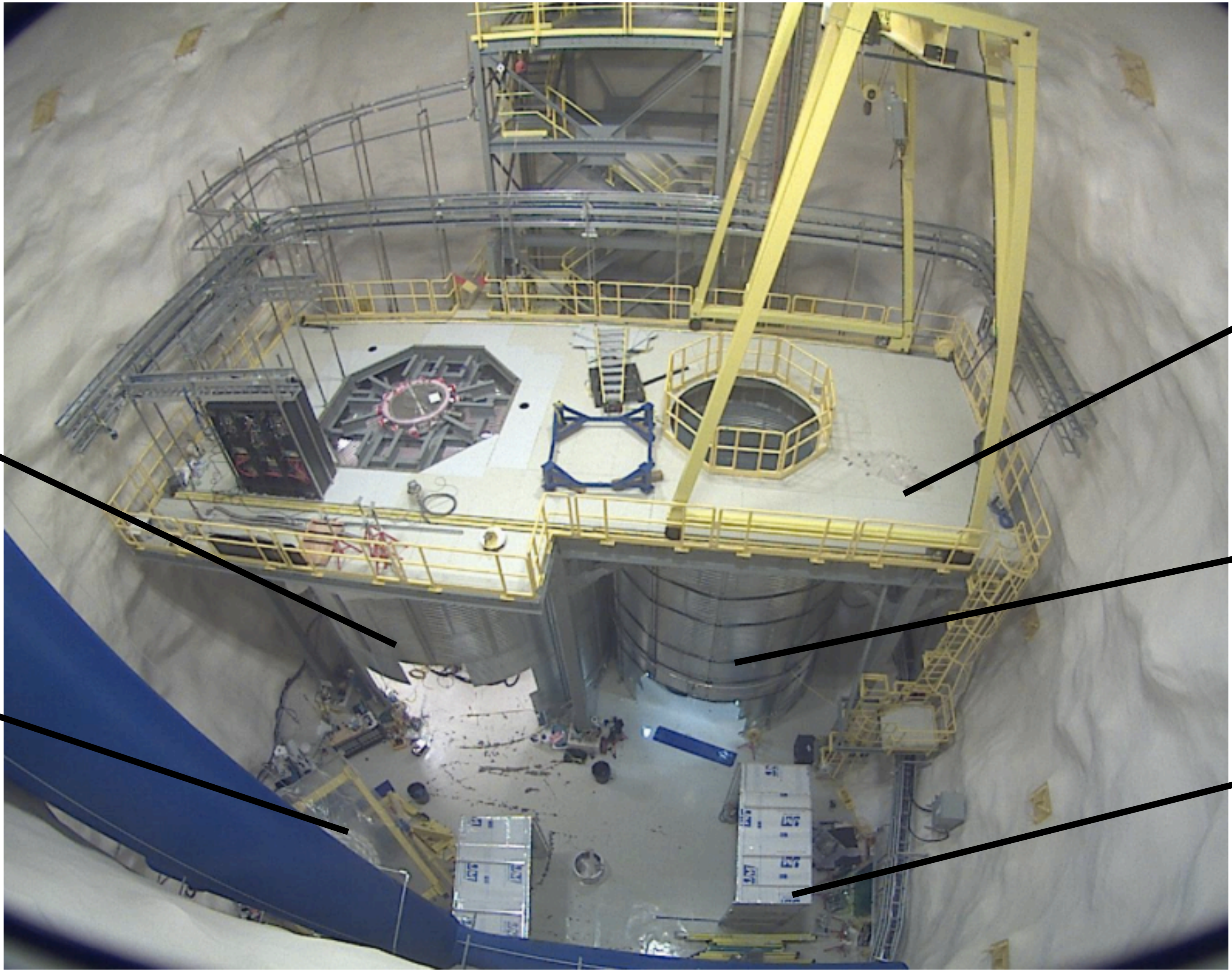
MiniCLEAN Construction



Cube Hall - DEAP/miniCLEAN

DEAP-36000 water shielding tank + outer vessel

DEAP-36000 AV machining

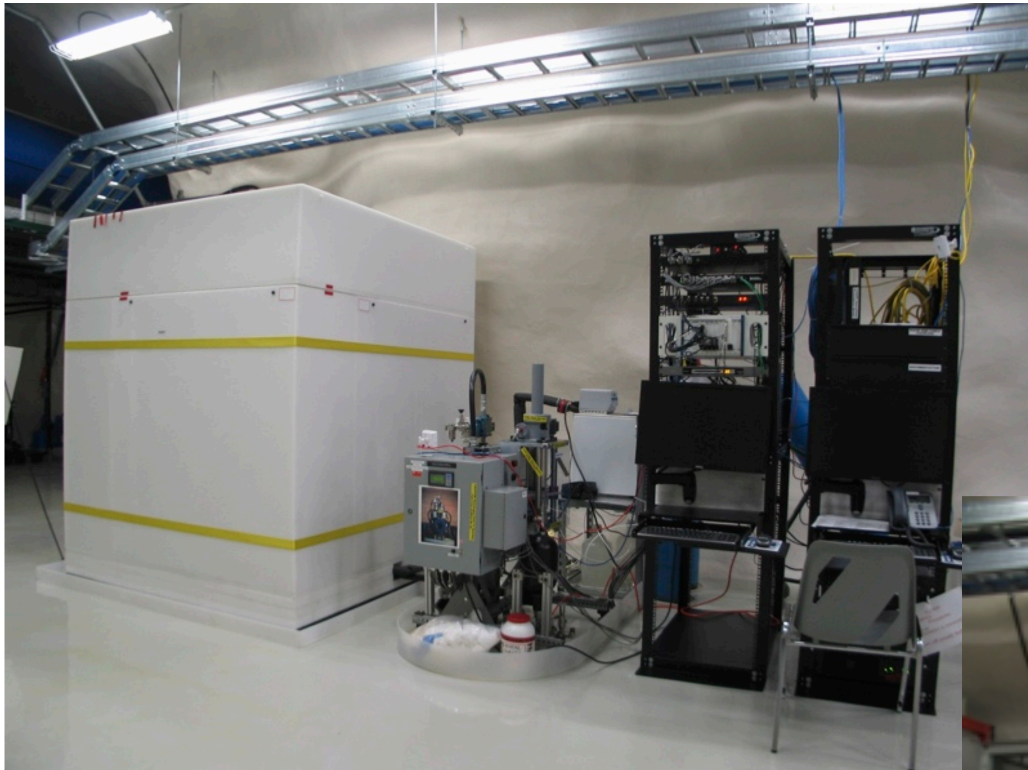


DEAP-3600 MiniCLEAN mezzanine

MiniCLEAN water shielding tank + outer vessel

DEAP-36000 AV annealing oven

‘J’-Drift: R&D + rapid deployment



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

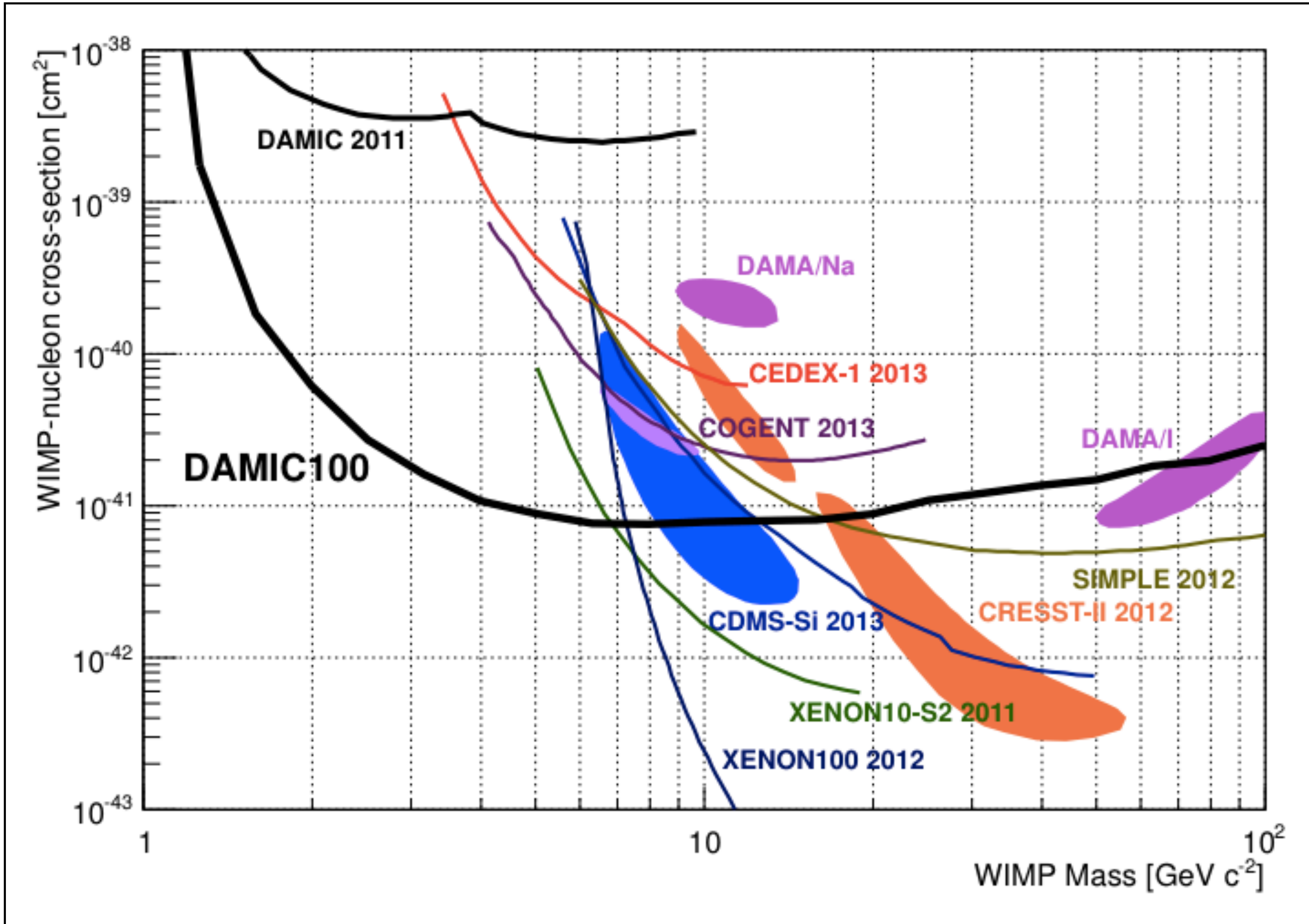
DAMIC CCD-based dark matter detector, focus on low mass WIMPS. (Currently 10g target, increase to 100g expected)

PICASSO

PICASSO-III
Water shield

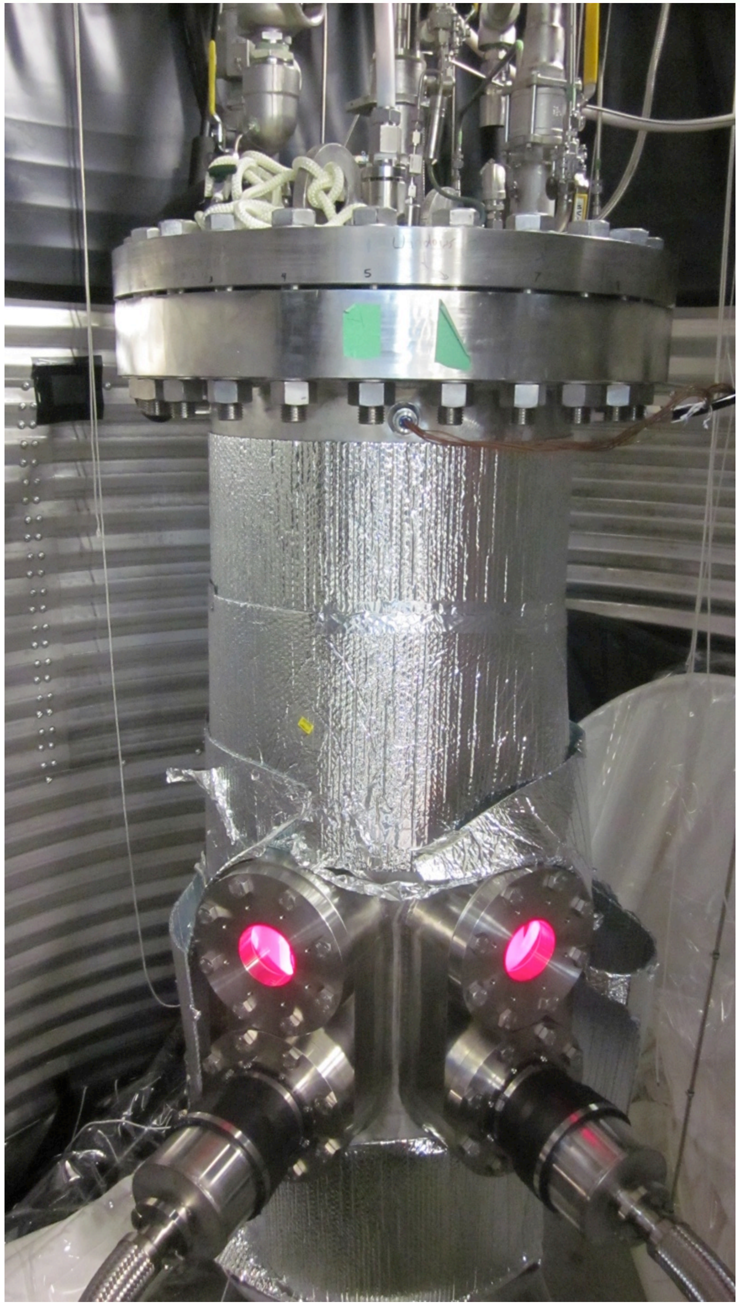
PICASSO-III
TPCS Boxes
and target

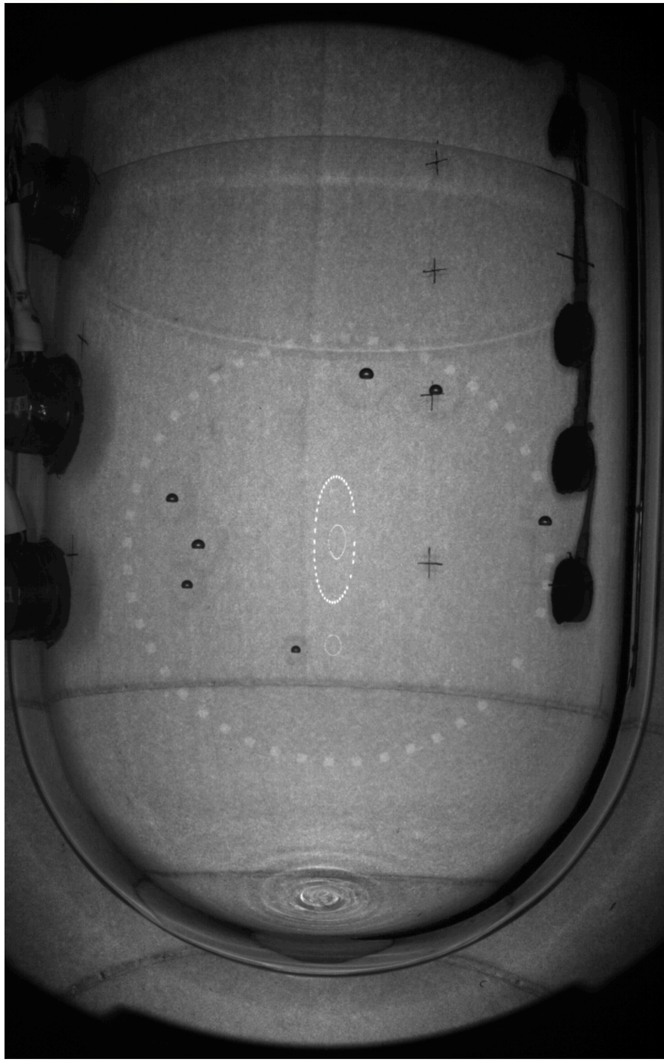
Low Mass WIMPs



Tiffenberg

COUPP-60 Deployment



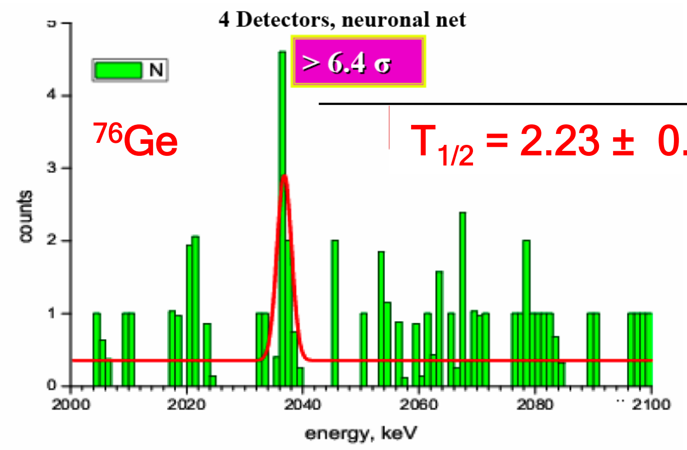


Neutron calibration showing multiple scatter

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

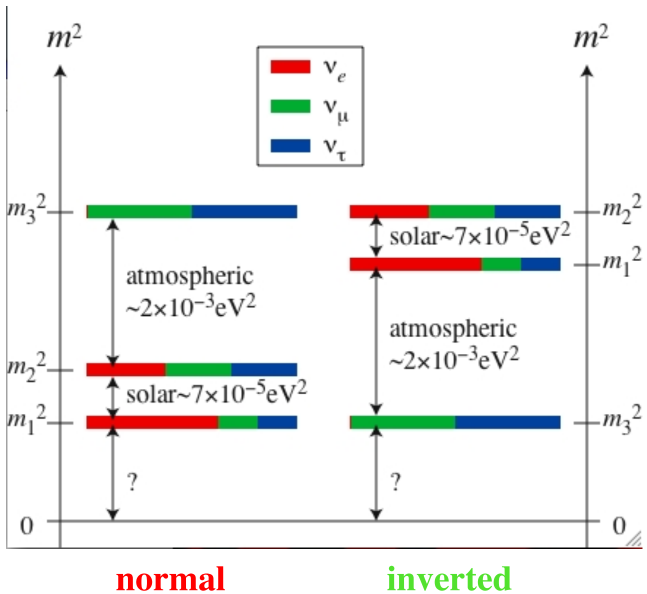
- SNO+ : $^{130}Te \rightarrow {}^{130}Xe + e^- + e^-$
  - Uses existing SNO detector. Heavy water replaced by scintillator loaded with ^{130}Te. Modest resolution compensated by high statistical accuracy.
  - Requires engineering for acrylic vessel hold down and purification plant. Technologies already 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 : $^{136}Xe \rightarrow {}^{136}Ba^{++} + e^- + e^-$
  - Engineering work for nEXO next generation liquid xenon double beta decay target, assessing potential for location at SNOLAB
  - Development work at SNOLAB surface facility on Ba daughter tagging for EXO-gas. Potential option to develop zero (non-double beta) background gas phase targets.
- 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

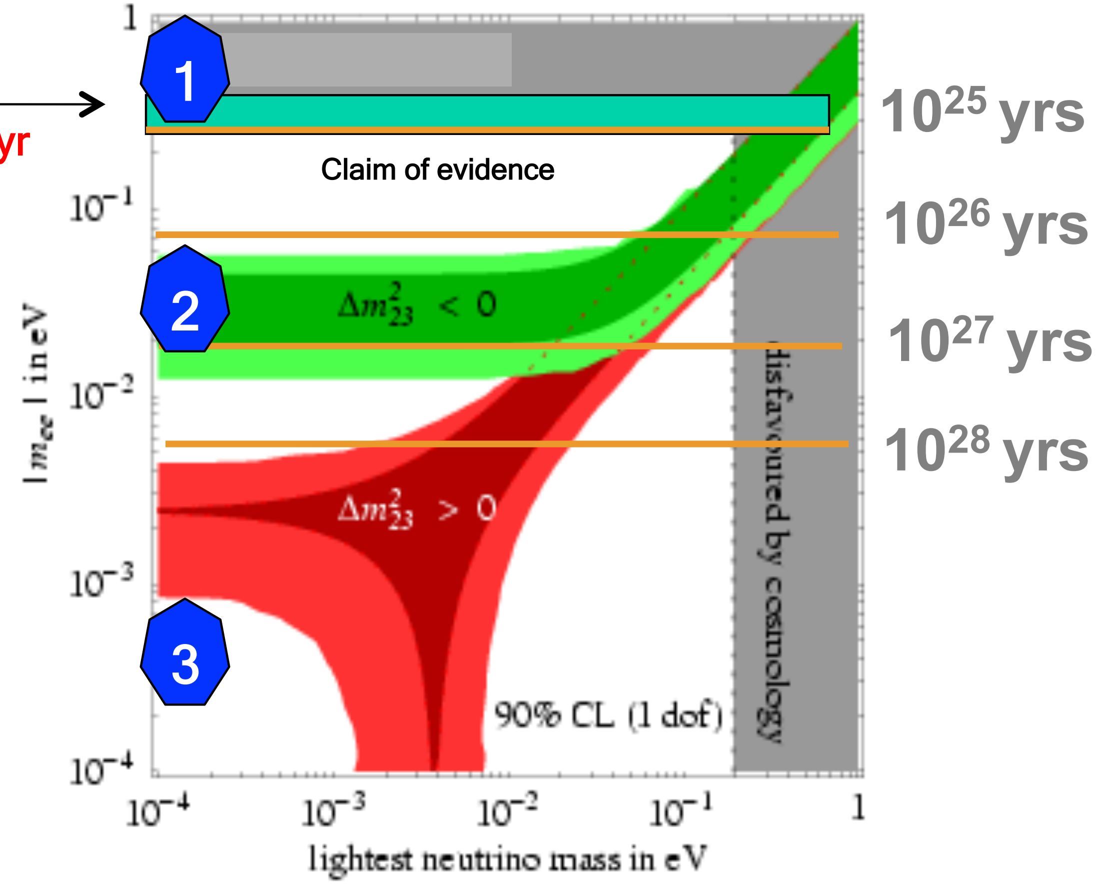
Mass hierarchies and DBD



$T_{1/2}$ = 2.23 ± 0.4 x 10^{25} yr

H.V. Klapdor-Kleingrothaus, I. Krivosheina,
Mod.Phys.Lett.A21:1547-1566 (2006)



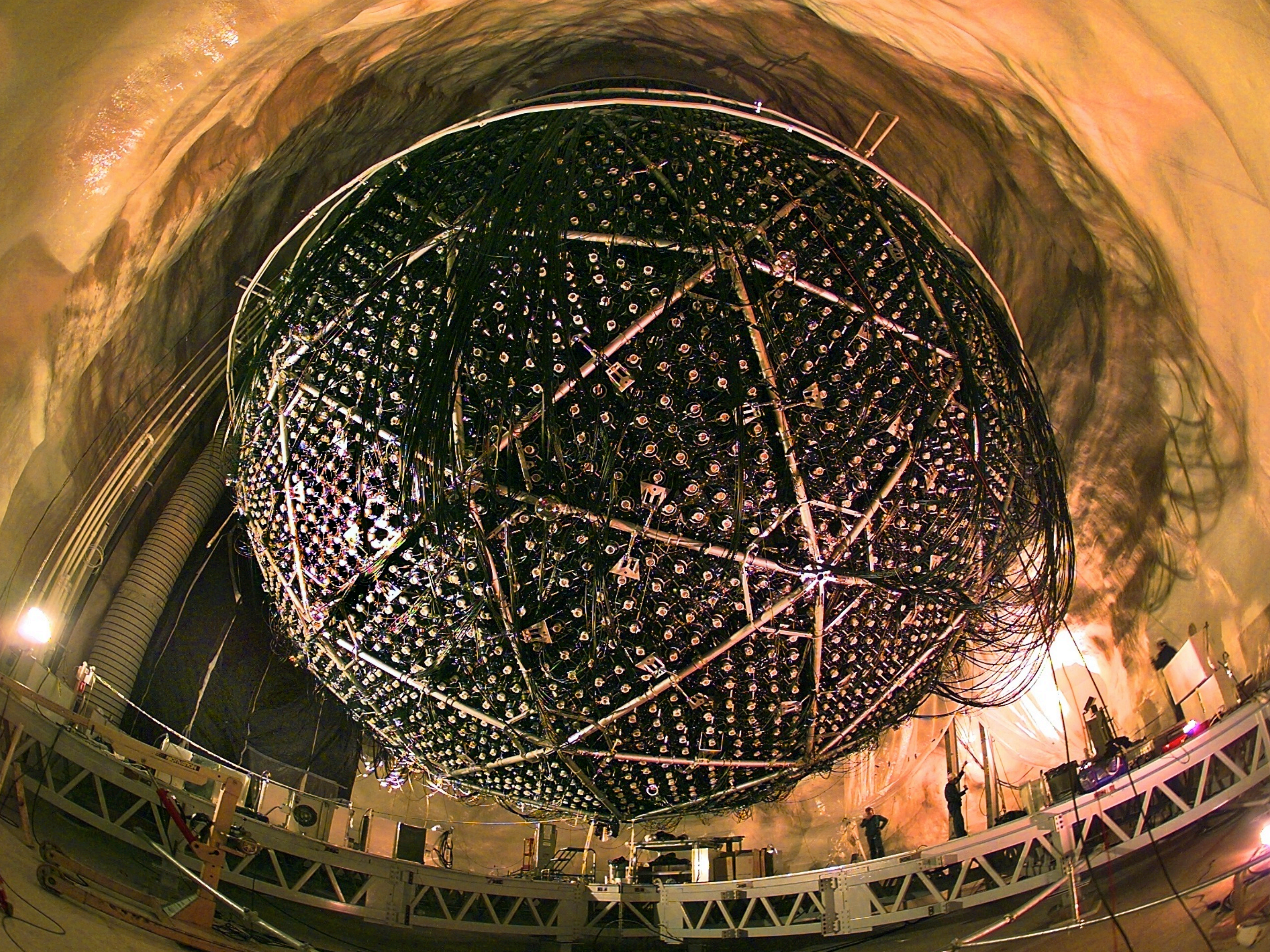


1.) Is the claimed evidence correct?

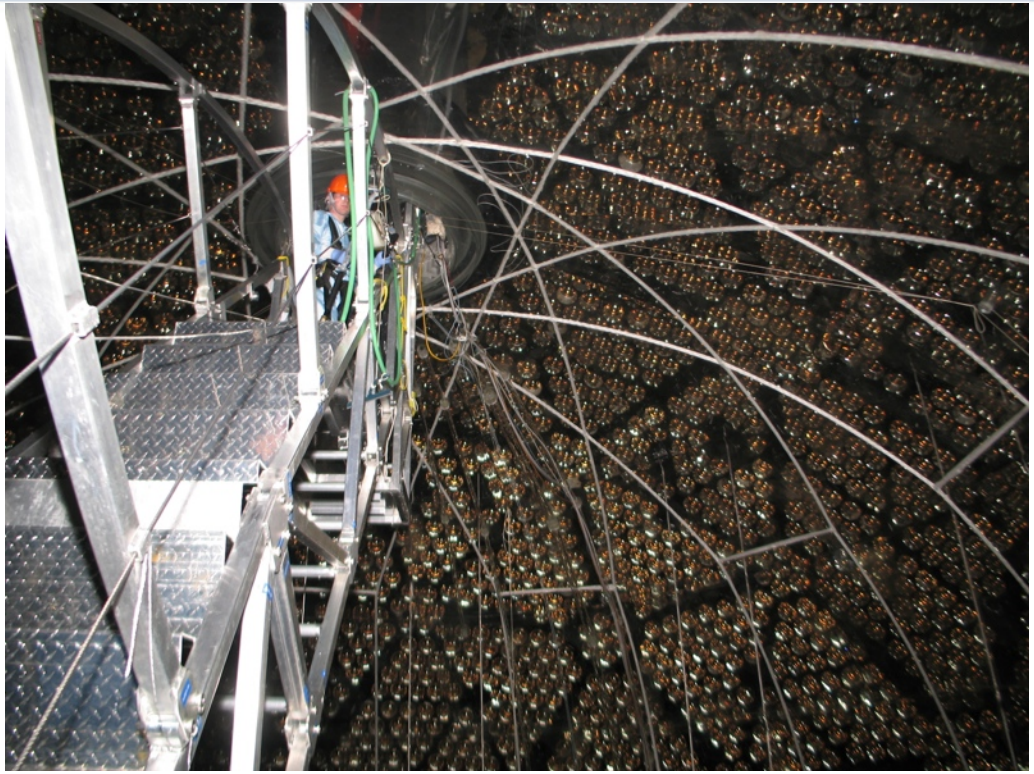
2.) Can we probe the inverted hierarchy?

3.) What about the normal hierarchy?

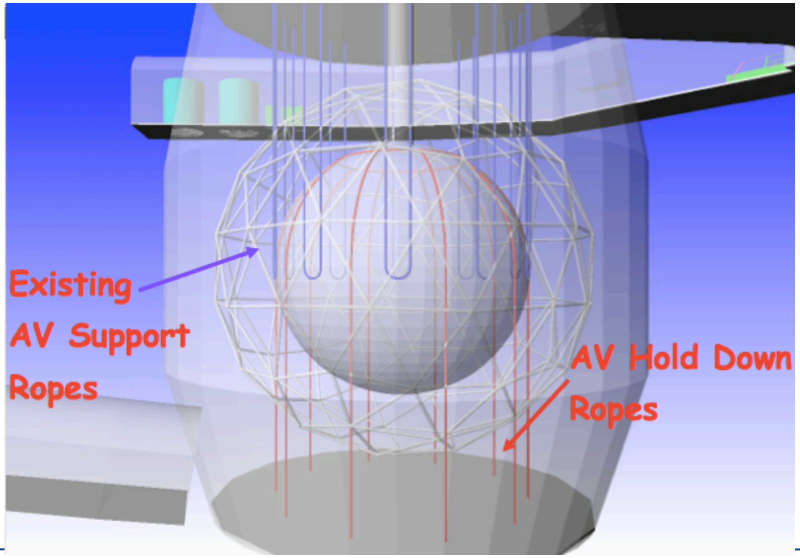
Slide courtesy of K. Zuber



SNO+ Developments



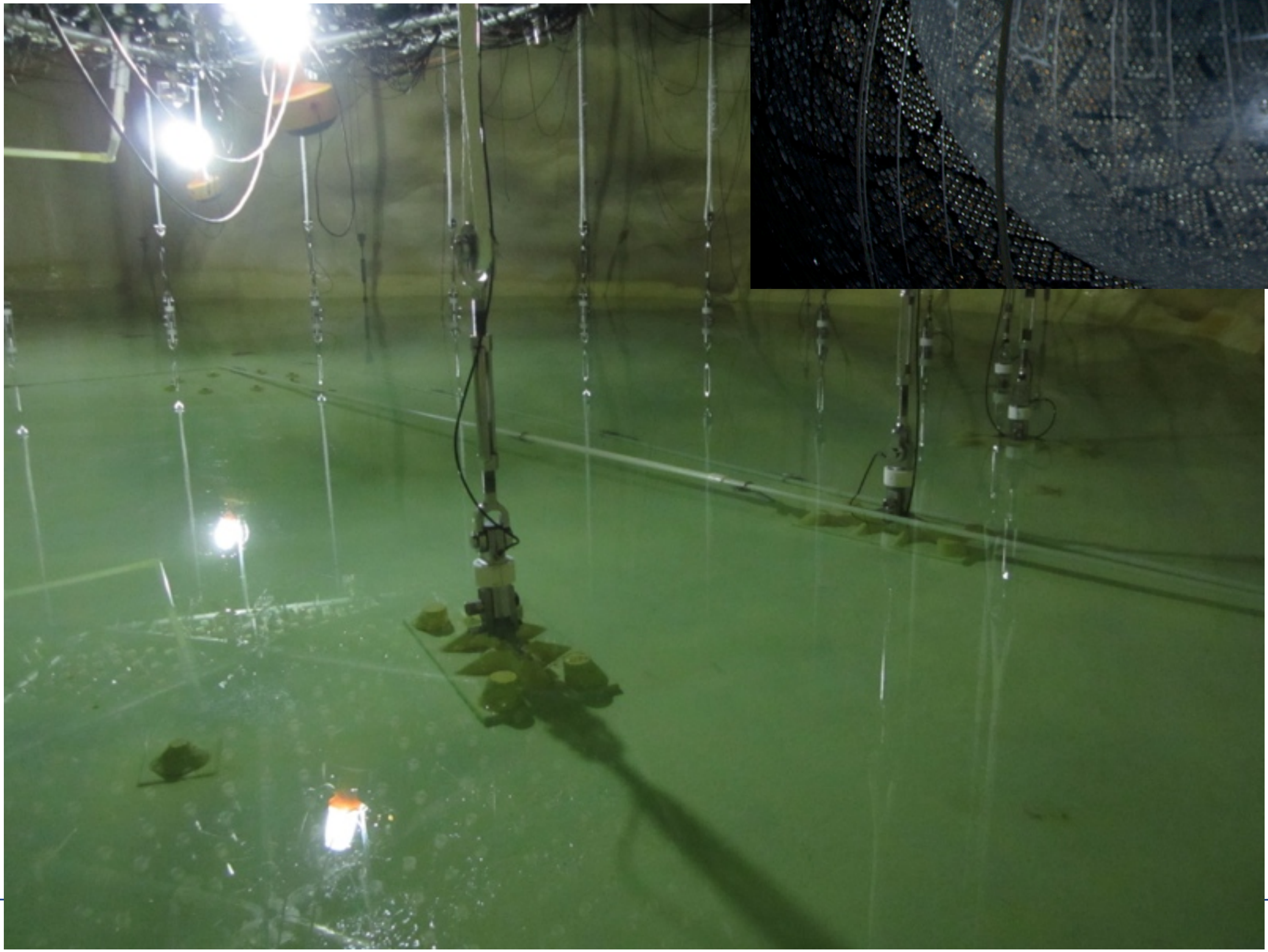
Development of a scaffold for cleaning internal surface of the acrylic vessel



First LAB plant vessel being installed into utility drift (prior to completion of steelwork)

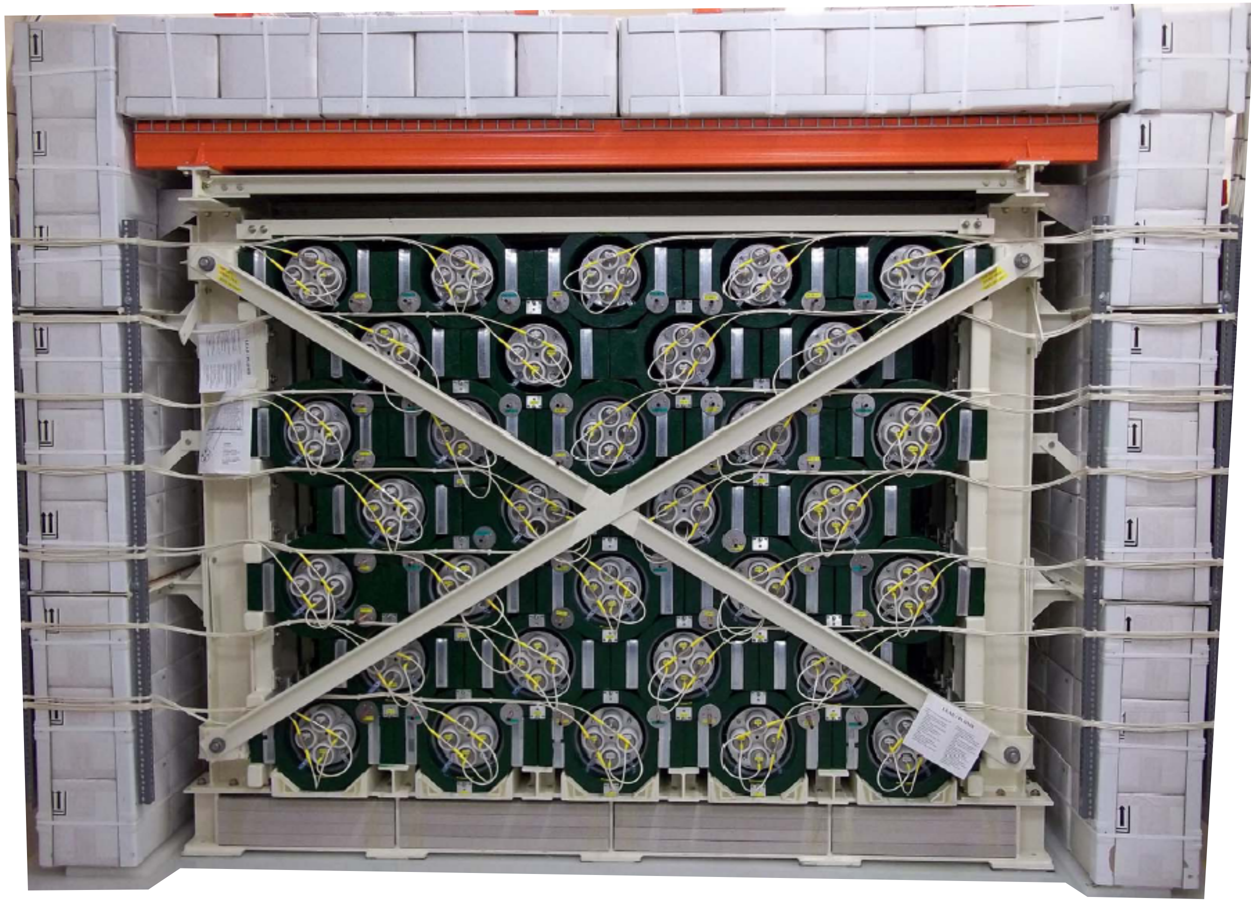
Cavity now being filled with UPW....

SNO+ Status



HALO - a Helium and Lead Observatory

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



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

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

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

Slide courtesy of C.Virtue, HALO

Supernova signal

- In 79 tonnes of lead for a SN @ 10kpc†,
  - Assuming FD distribution with T=8 MeV for ν_μ's, ν_τ's.
  - 68 neutrons through ν_e charged current channels
    - 30 single neutrons
    - 19 double neutrons (38 total)
  - 20 neutrons through ν_x neutral current channels
    - 8 single neutrons
    - 6 double neutrons (12 total)
- ~ 88 neutrons liberated; ie. ~1.1 n/tonne of Pb

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

NC:
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$$
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$$

†- cross-sections from Engel, McLaughlin, Volpe, Phys. Rev. D 67, 013005 (2003)

- For HALO neutron detection efficiencies of 50% have been obtained in MC studies optimising the detector geometry, the mass and location of neutron moderator, and enveloping the detector in a neutron reflector.

Slide courtesy of C.Virtue, HALO

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		√						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
nEXO		√						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

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