The SNOLAB Science Programme

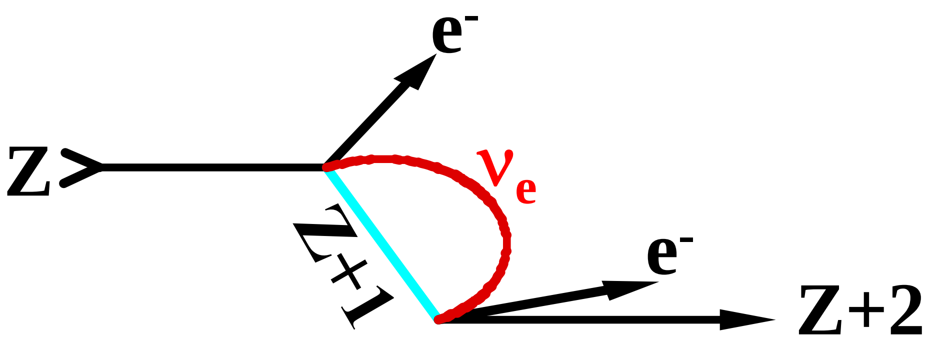
Clarence Virtue

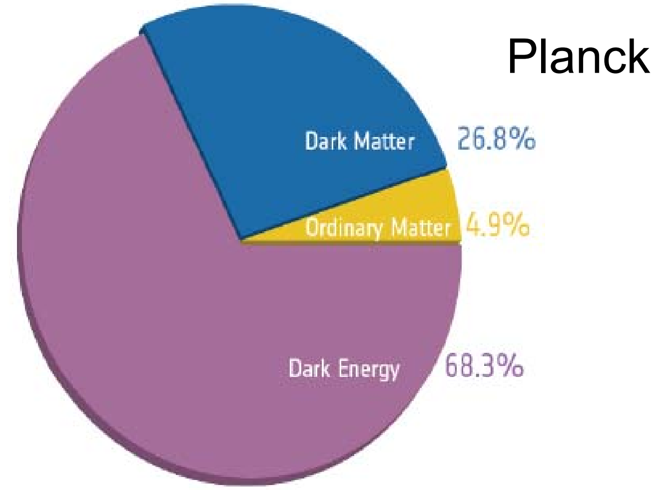
Laurentian University / Université Laurentienne

(on behalf of SNOLAB)

Elements of the Science Programme

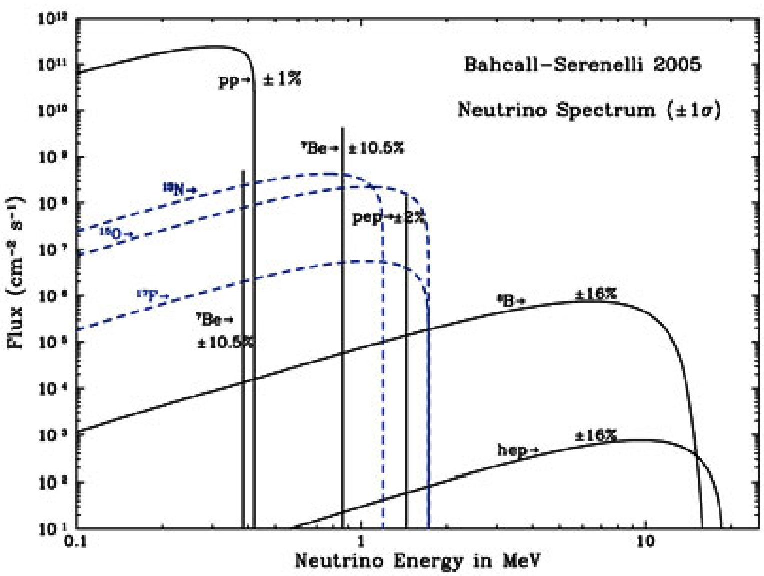
Neutrinoless Double Beta Decay

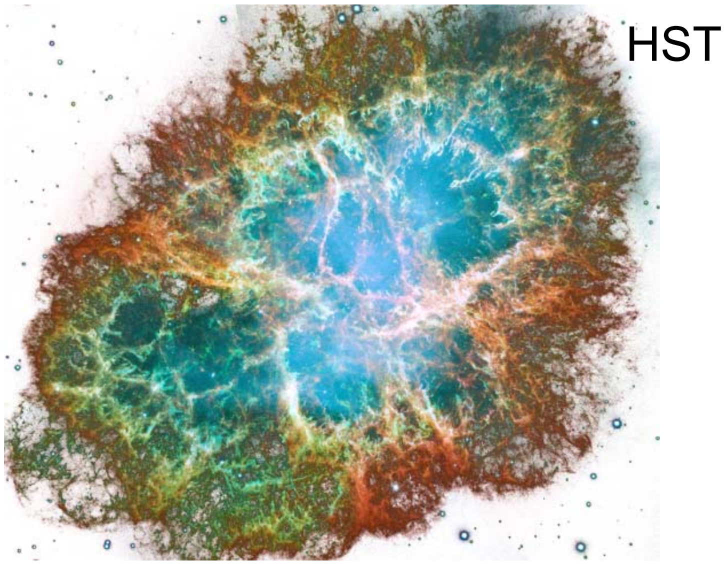




Direct dark Matter Detection

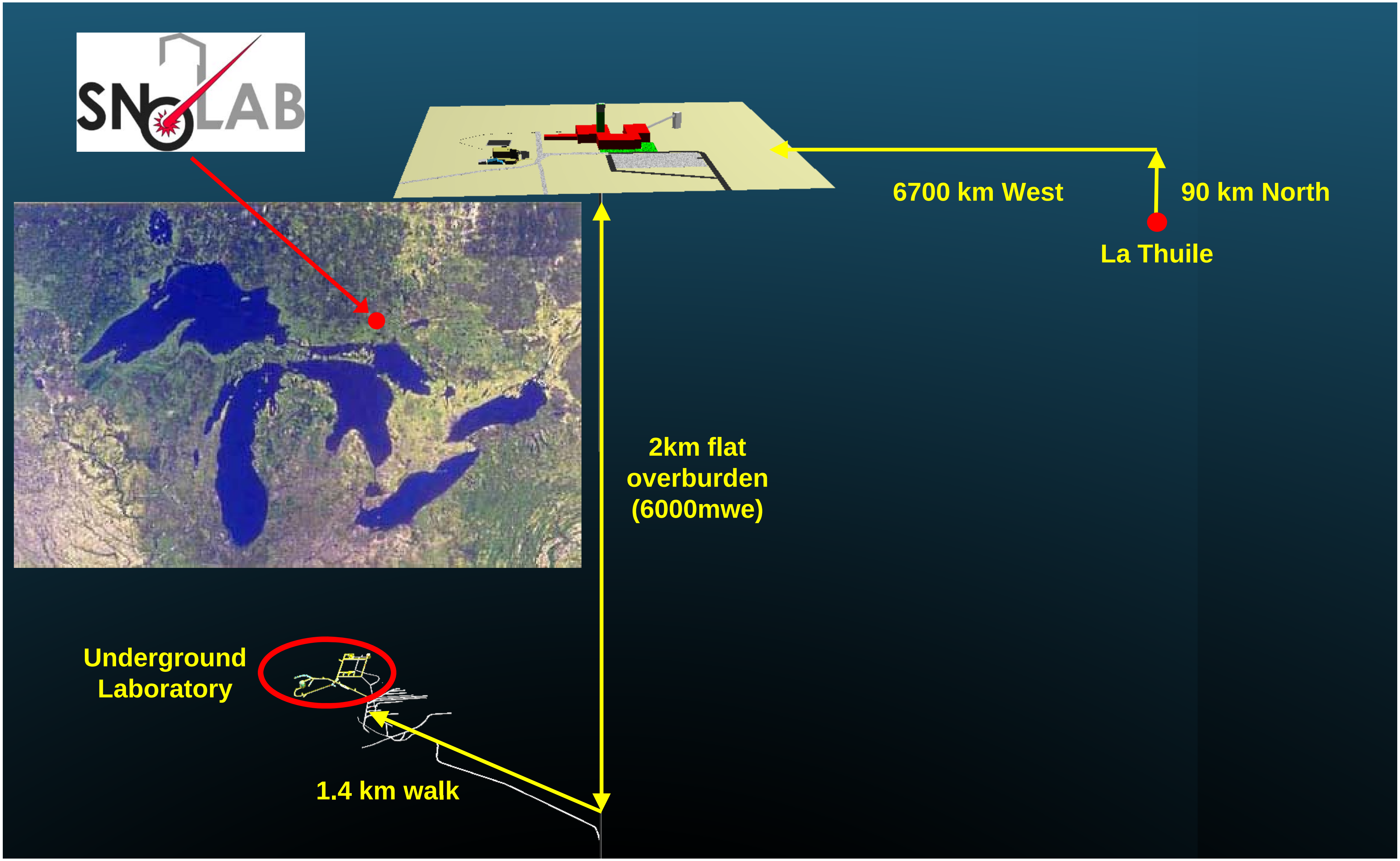
Low Energy Solar Neutrino Physics





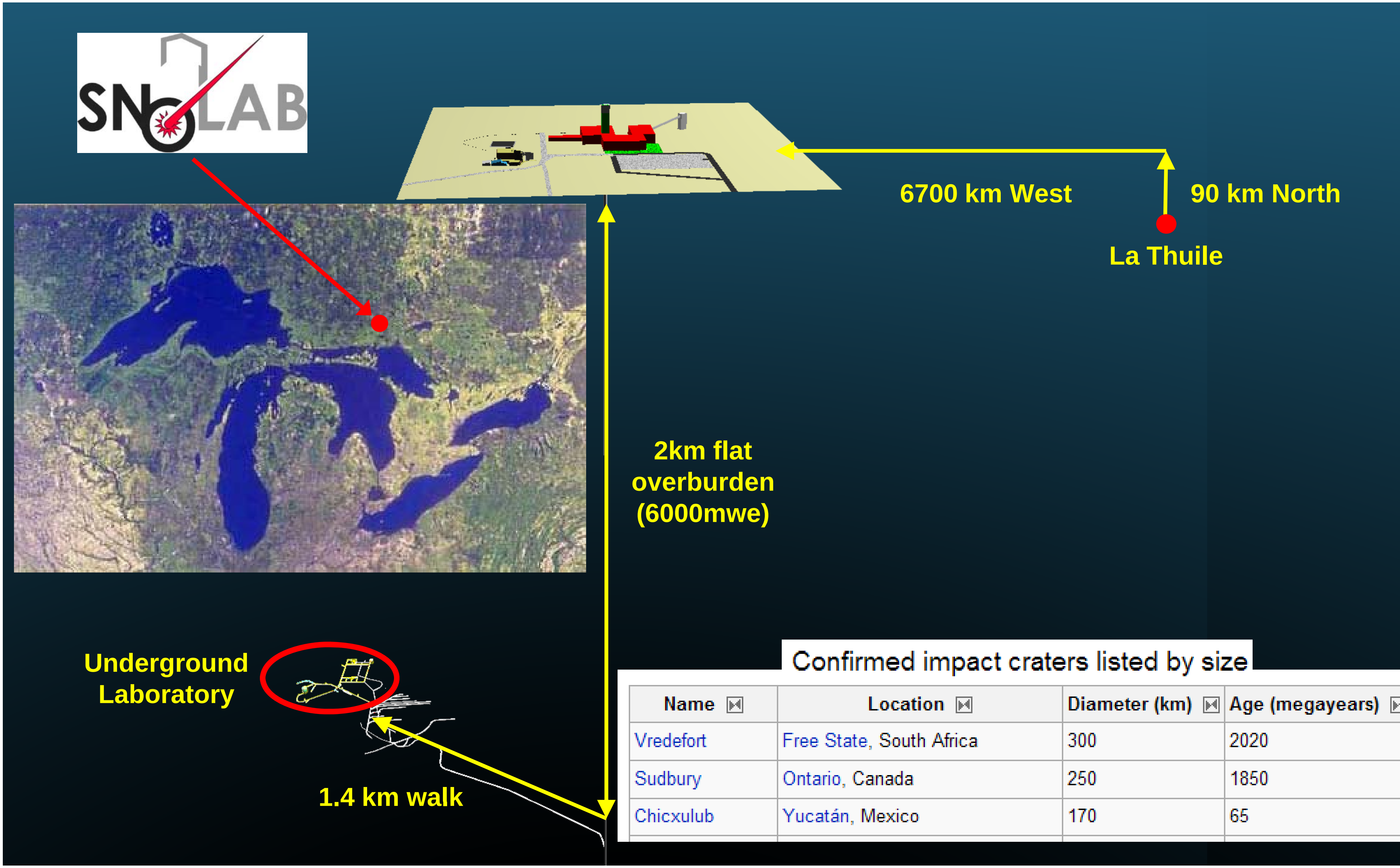
Supernova Neutrino Detection

Location



SNOLAB
6700 km West
90 km North
La Thuile
2km flat
overburden
(6000mwe)
Underground
Laboratory
1.4 km walk

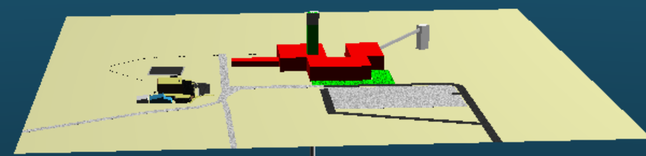
Location



Confirmed impact craters listed by size

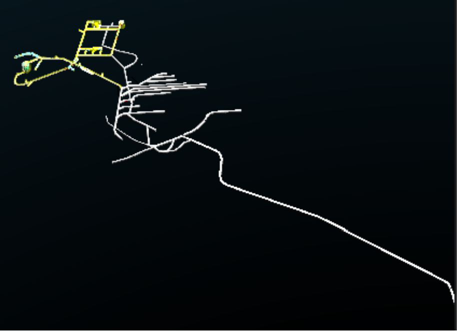
Name	Location	Diameter (km)	Age (megayears)
Vredefort	Free State, South Africa	300	2020
Sudbury	Ontario, Canada	250	1850
Chicxulub	Yucatán, Mexico	170	65

A Brief History



- Outgrowth of the highly successful SNO project
- Proposal in 2001
- Funding in 2002

- Surface facility
  - Groundbreaking 2004
  - Occupancy 2005
- Underground
  - excavation commenced Nov 2004
  - Experiment installation 2009



2 km deep!

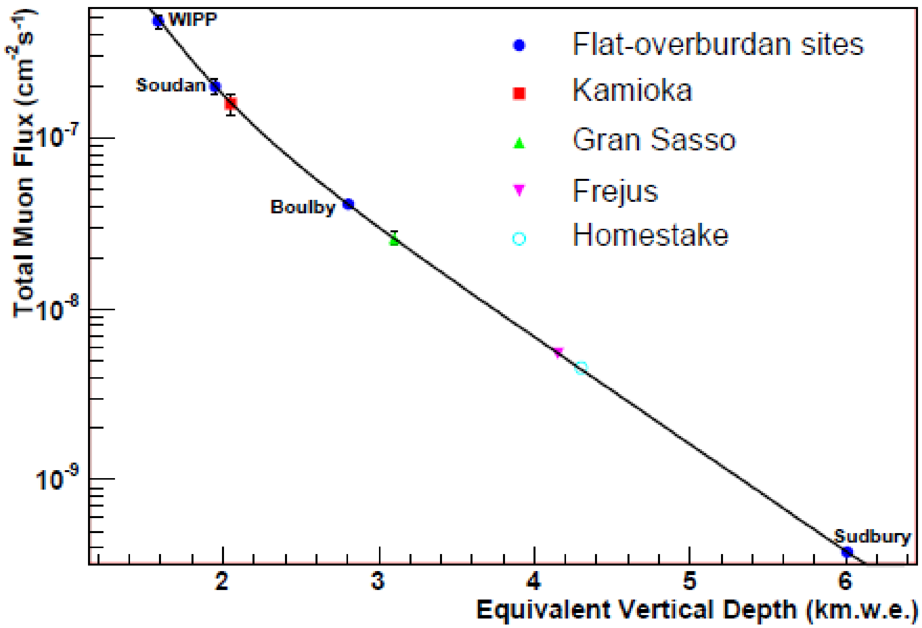


FIG. 3: The total muon flux measured for the various underground sites summarized in Table I as a function of the equivalent vertical depth relative to a flat overburden. The

Phys. Rev. D 73, 053004
D.-M. Mei and A. Hime

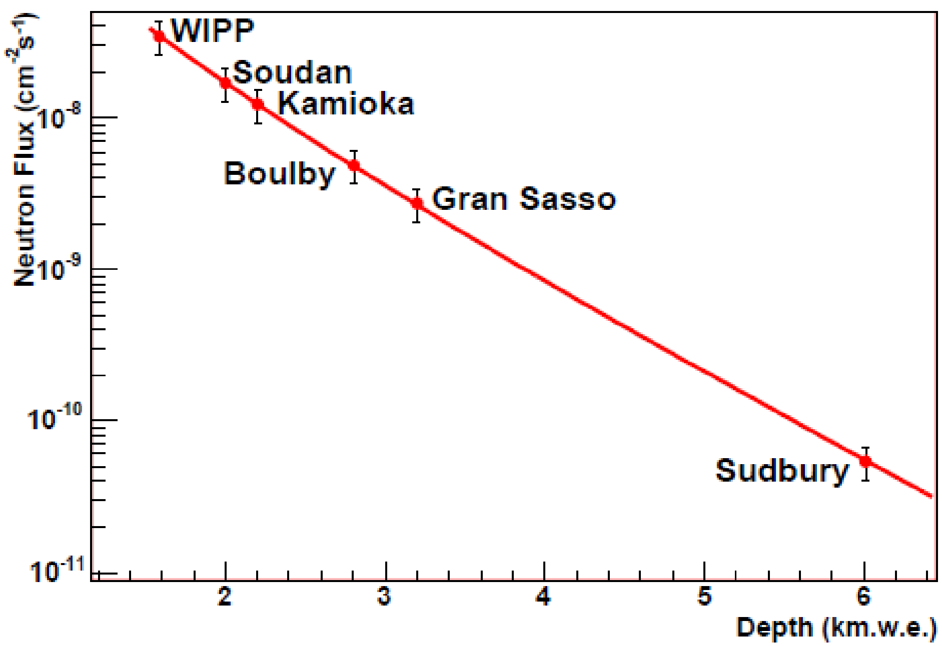


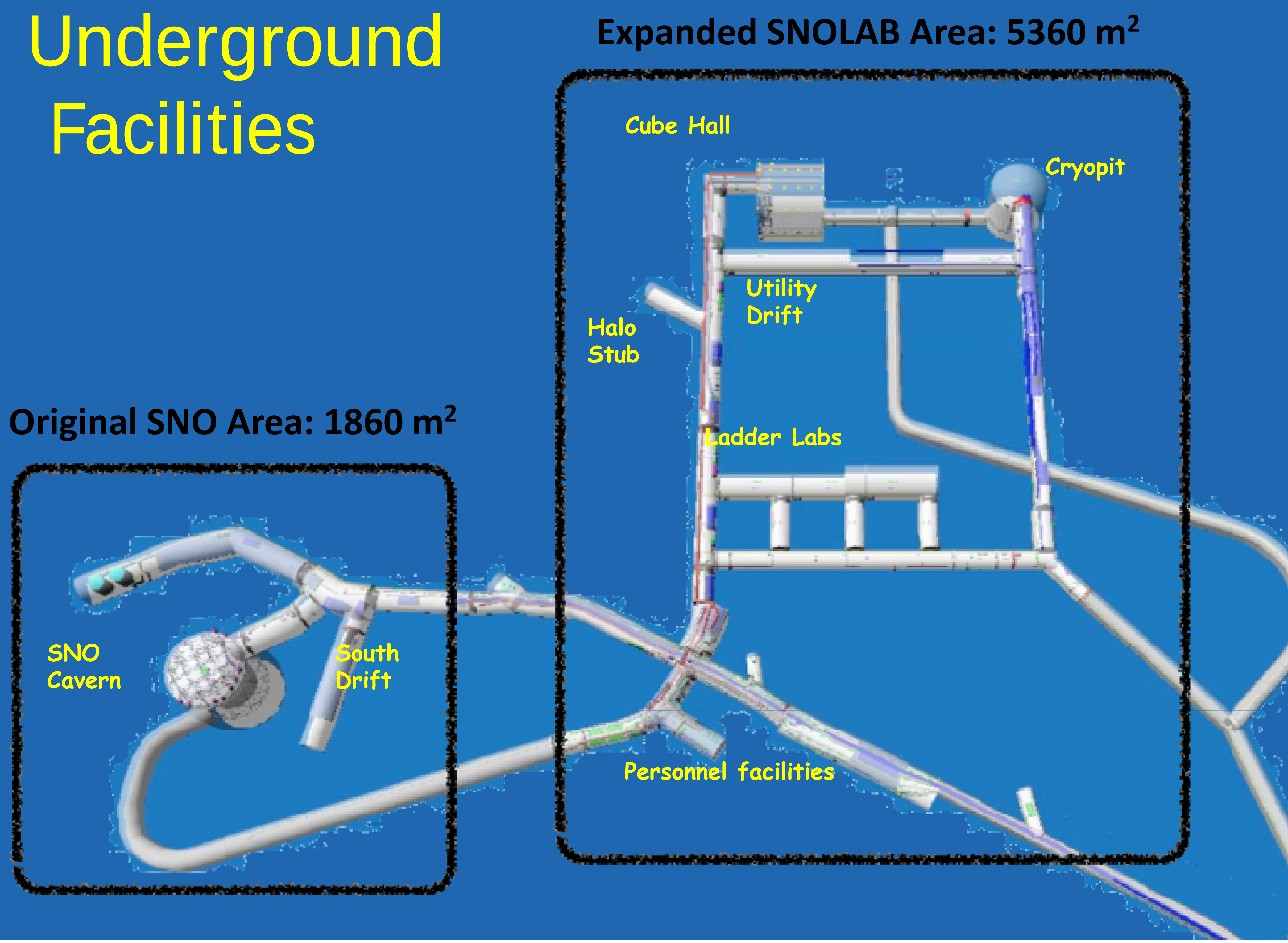
FIG. 14: The total muon-induced neutron flux deduced for the various underground sites displayed. Uncertainties on

Cosmogenics likewise reduced.
0.27 muons/m^2/day at SNOLAB.
70 /day in SNO+ vs 26,000 /day in KamLAND.

Vale Creighton Mine

- Surface Facility (3100 m^2)
  - Operational from 2005 - Provides offices, conference room, dry, warehousing, data center, clean-room labs, detector construction labs, chemical + assay lab
  - 440m^2 class-1000 clean rooms for experiment setup and tests

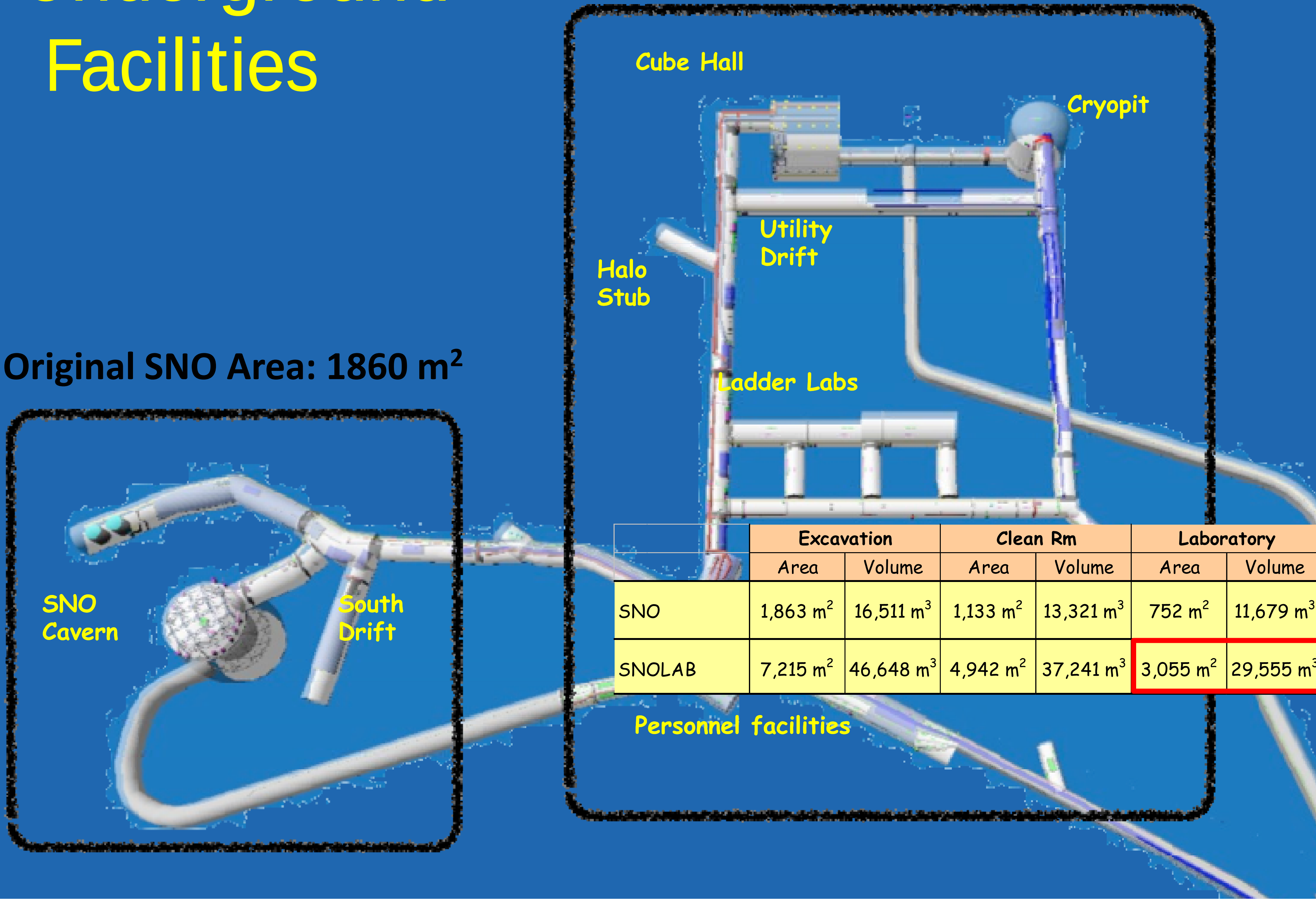
Underground Facilities



Underground Facilities

Expanded SNOLAB Area: 5360 m²

Original SNO Area: 1860 m²



	Excavation		Clean Rm		Laboratory	
	Area	Volume	Area	Volume	Area	Volume
SNO	1,863 m^2	16,511 m^3	1,133 m^2	13,321 m^3	752 m^2	11,679 m^3
SNOLAB	7,215 m^2	46,648 m^3	4,942 m^2	37,241 m^3	3,055 m^2	29,555 m^3


Chiller
JLG


Lab Entry


Lab
Entrance


Personnel
Facility


Refuge

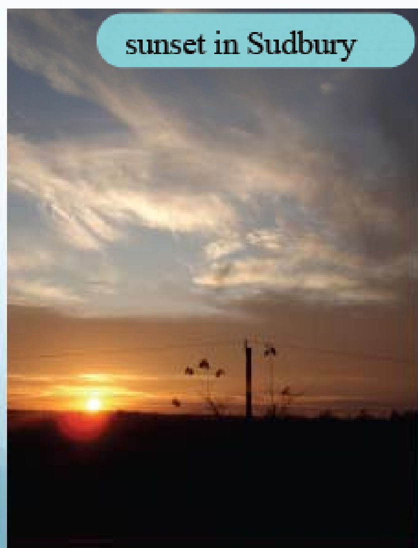
Current programme: $0\nu\beta\beta$ and neutrino at SNOLAB

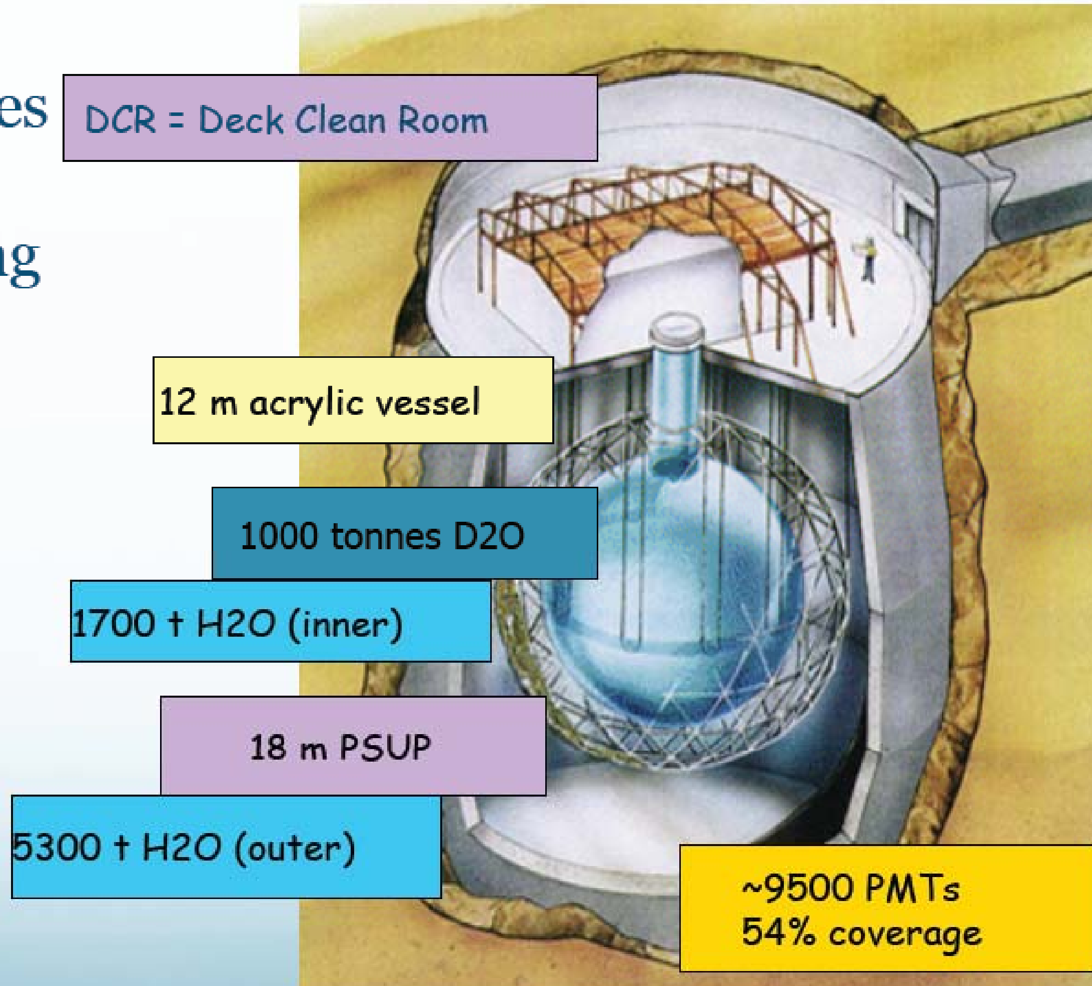
- SNO+ : $^{130}Te \rightarrow {}^{130}Xe + e^- + e^-$
  - Uses existing SNO detector. Heavy water replaced by scintillator loaded with ^{130}Te. Modest resolution compensated by high statistical accuracy.
  - Requires engineering for acrylic vessel hold down and purification plant. Technologies already 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)
- 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

SNO detector (inherited)

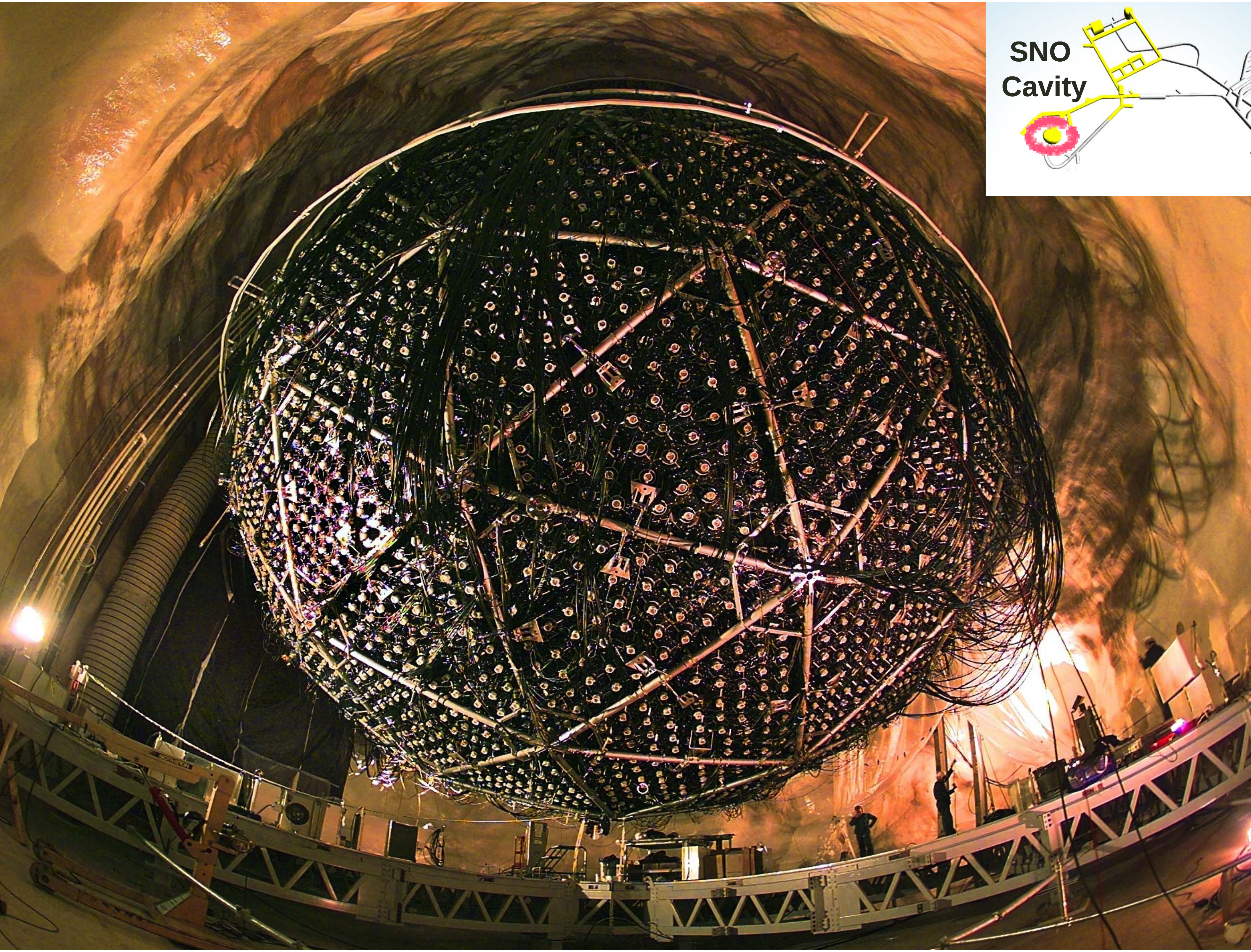
Acrylic vessel AV,
filled with 1000 tonnes
of heavy water:
1999-2006 data taking
in 3 phases
(different n detection methods)





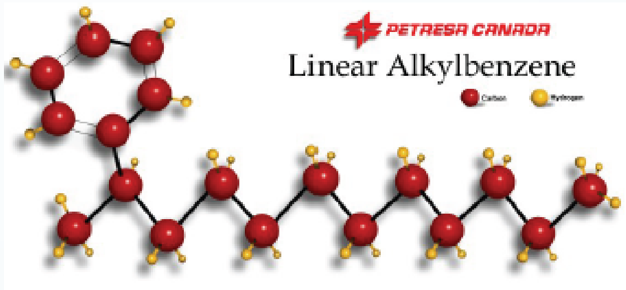
Erice September 2013, Christine Kraus, Laurentian University

4

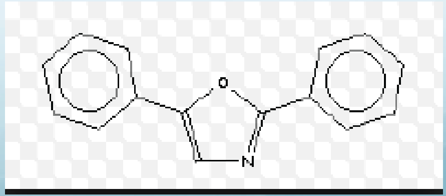

SNO
Cavity

Liquid scintillator

- Detector to be filled with 780 tonnes of organic liquid scintillator (LS)
- More light yield than Čerenkov , around 400 p.e./MeV, enabling lower energy threshold
- Linear alkylbenzene (LAB)
  - High light yield
  - Long attenuation length
  - Safe: high flash point and low toxicity
  - More affordable than other scintillators



- Add wavelength shifter
  - Initial plan: 2g/L PPO fluor

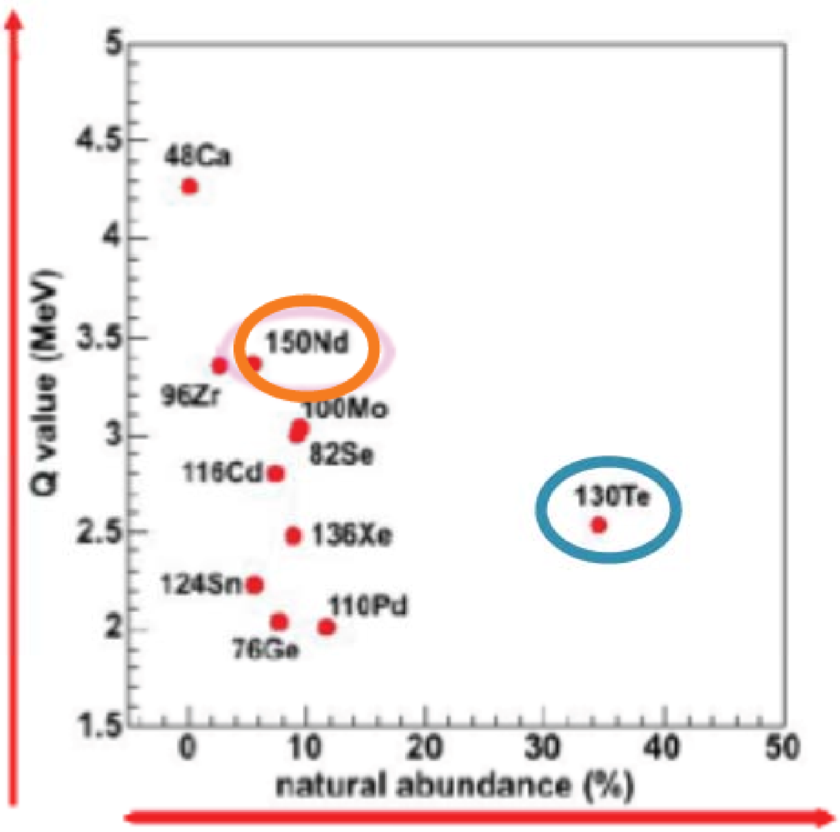


5

Erice September 2013, Christine Kraus, Laurentian University

Double beta isotopes

35 known isotopes



Decay candidate	Q-value (MeV)	% natural abundance
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Ca \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.1
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

Erice September 2013, Christine Kraus, Laurentian University

8

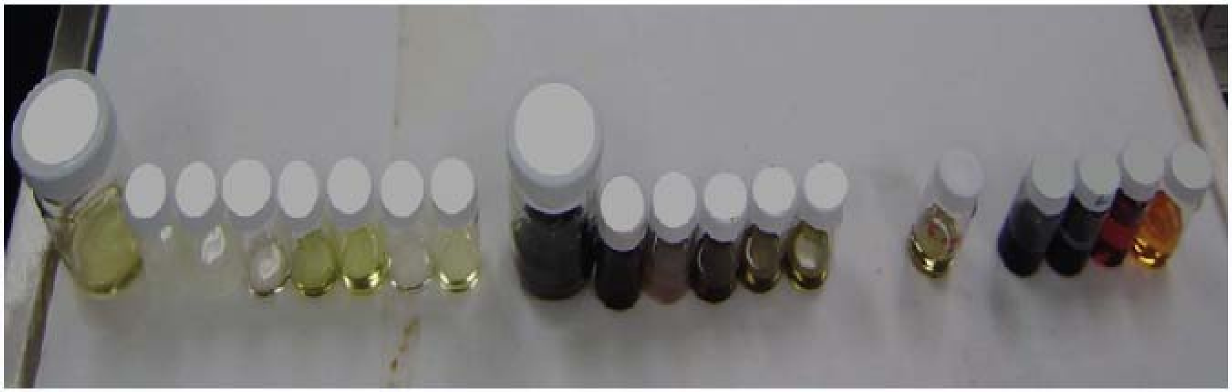
Advantages of Tellurium

- 34% natural abundance
- $2\nu\beta\beta$ rate is low
- no inherent optical absorption lines
- High values of loading feasible (default 0.3%)
- Internal U/Th background can be actively suppressed by identifying ^{214}Bi-^{214}Po alphas

Erice September 2013, Christine Kraus, Laurentian University

10

Loading scintillator



Conventional Loading Method Carboxylate Organometallic Complex

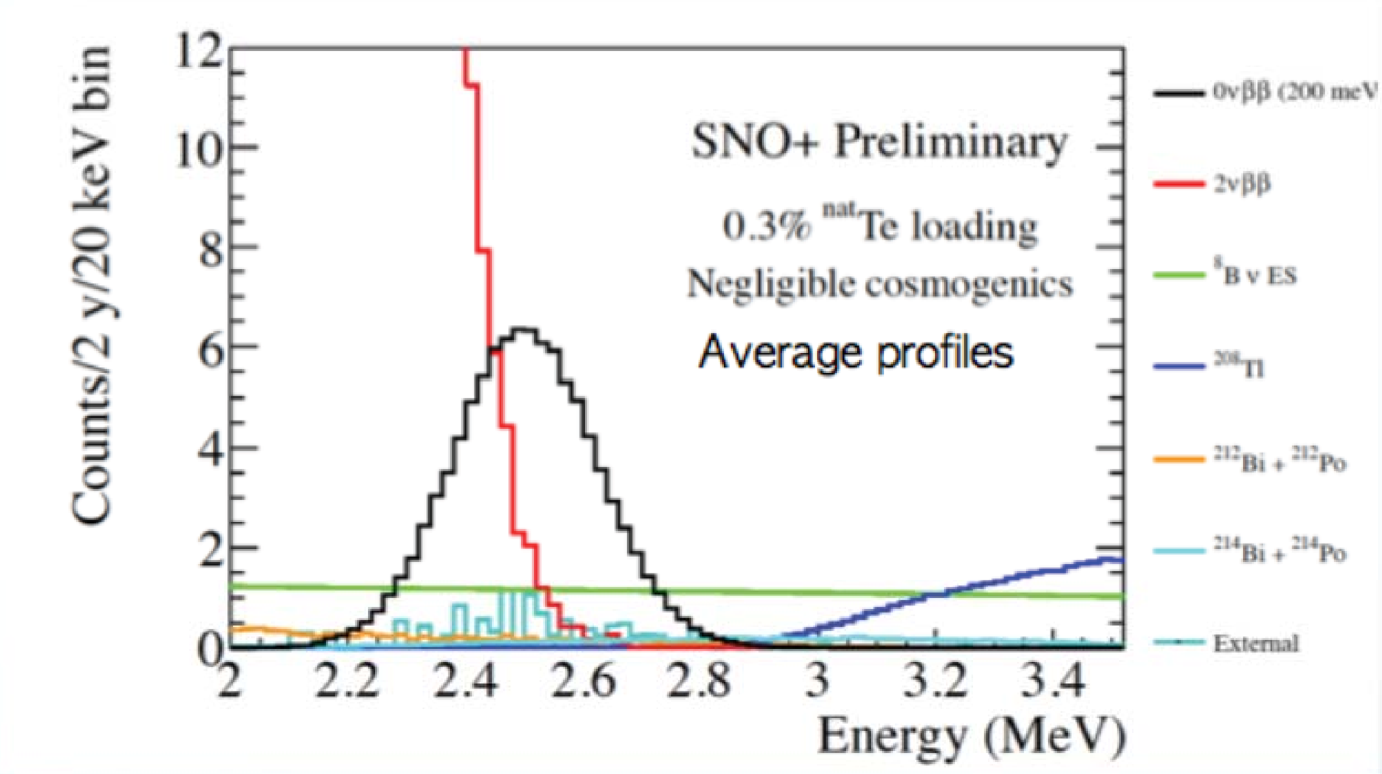
New loading technique (BNL):
Dissolve telluric acid in water and add a few percent of this mixture to LAB using a surfactant. Clear and stable has been demonstrated for more than 1 year.

ICP-MS determined U/Th content of telluric acid to be 2-3 times 10^{11} g/g
U/Th purification factors of >400 in a single pass have been achieved.

11

Erice September 2013, Christine Kraus, Laurentian University

SNO+ expected spectrum



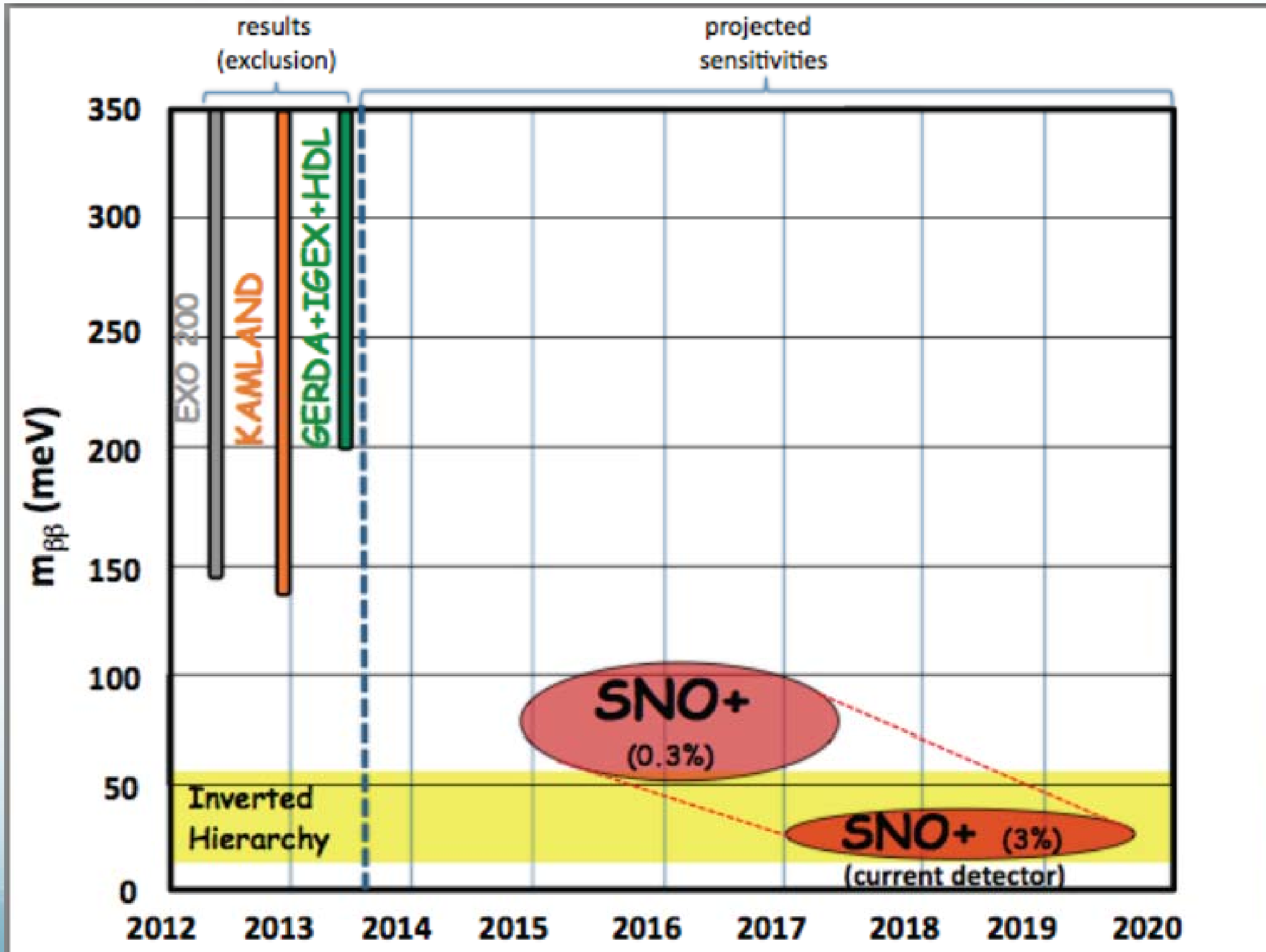
Expected sensitivity is below 100 meV for 0.3% loading (800 kg)

- ★ 2 years lifetime and fiducial volume cut at 3.5 m (20%)
- ★ > 99.99% efficient 214 Bi tag, 97% efficient internal 208Tl tag
- ★ Factor 50 reduction 212BiPo and negligible cosmogenic isotopes
- ★ $m_{0\nu 2\beta}$ = 200 meV assumed for this plot

Erice September 2013, Christine Kraus, Laurentian University

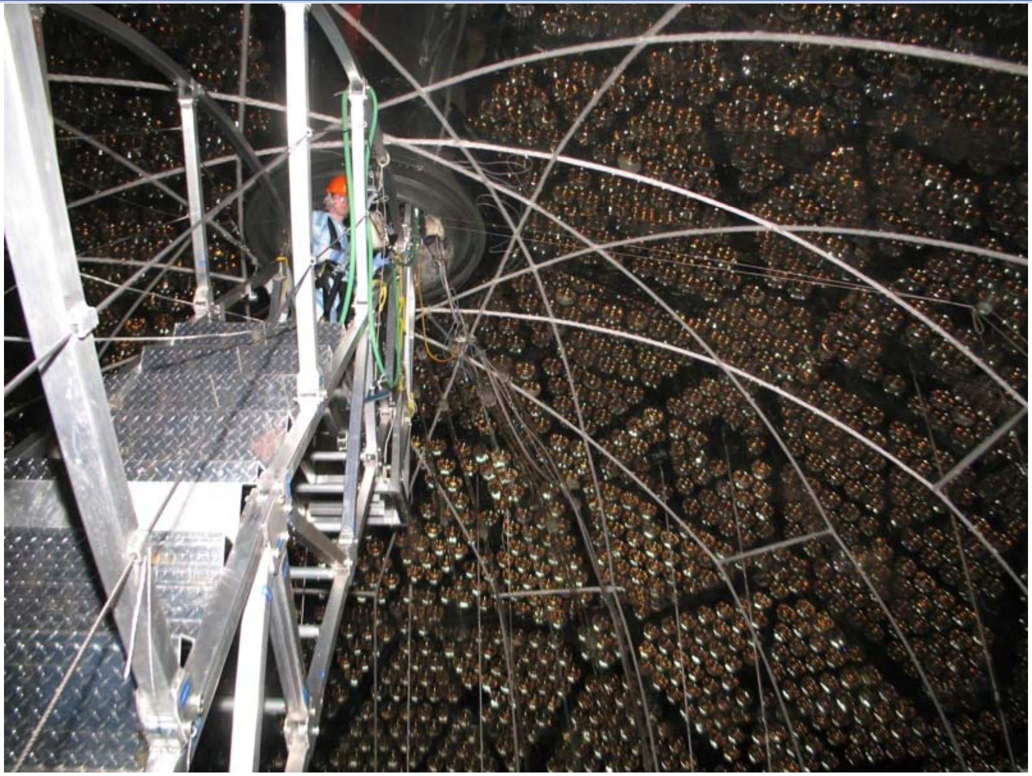
15

SNO+ projected sensitivity

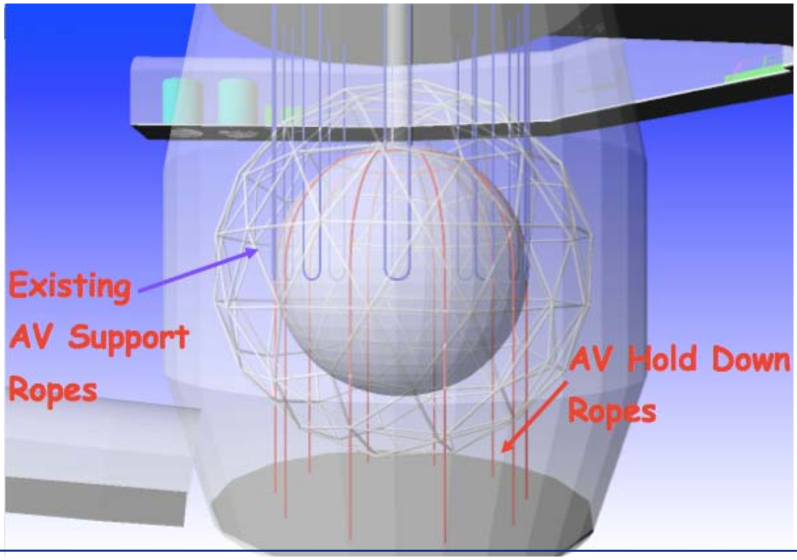


Erice September 2013, Christine Kraus, Laurentian University

SNO+ Status



Development of a scaffold for cleaning internal surface of the acrylic vessel. AV now cleaned and ready for filling with water.



First LAB plant vessel being installed into utility drift. All vessels now in place and interconnects started.

Cavity now being filled with UPW.... Presently ~4m

HALO - a Helium and Lead Observatory

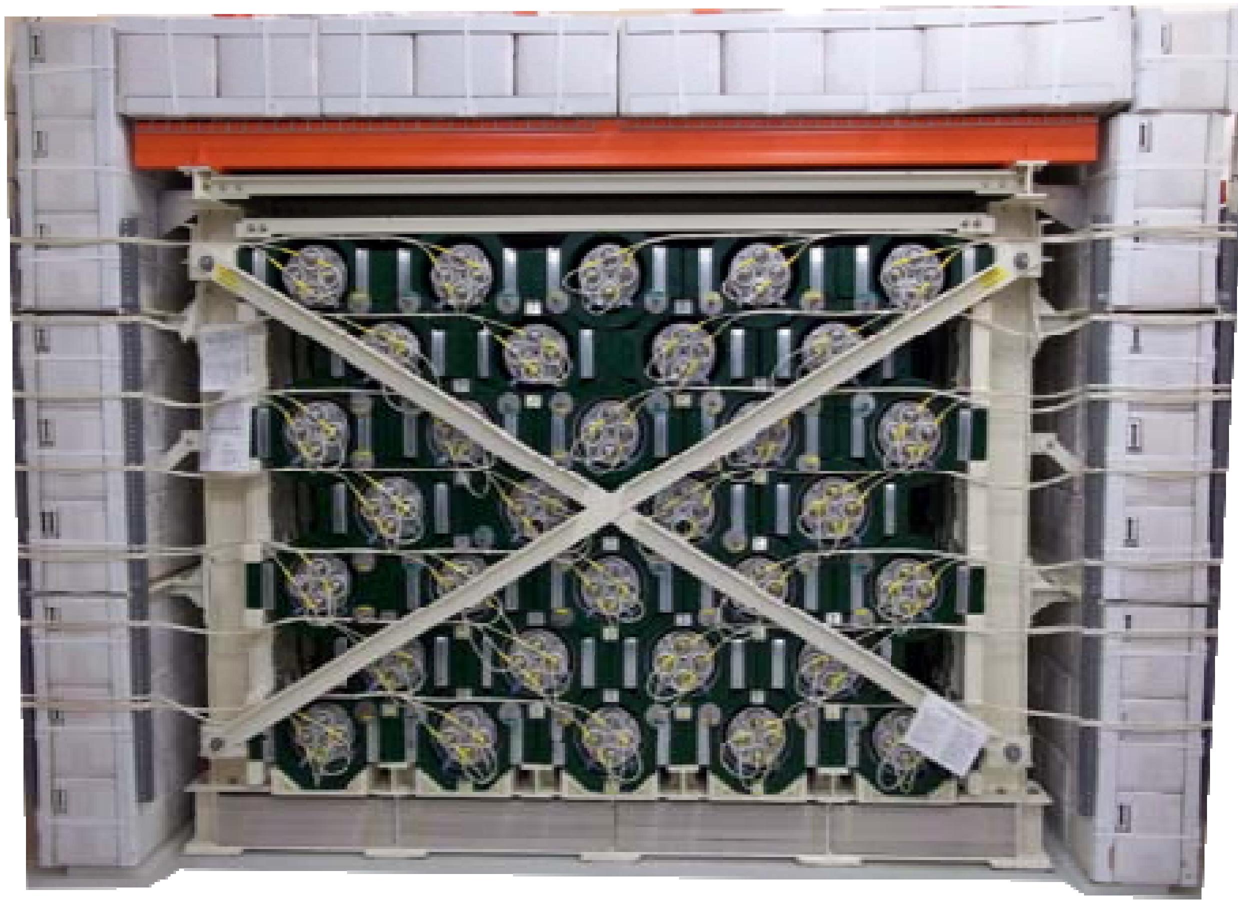
A “SN detector of opportunity” / An evolution of

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

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.

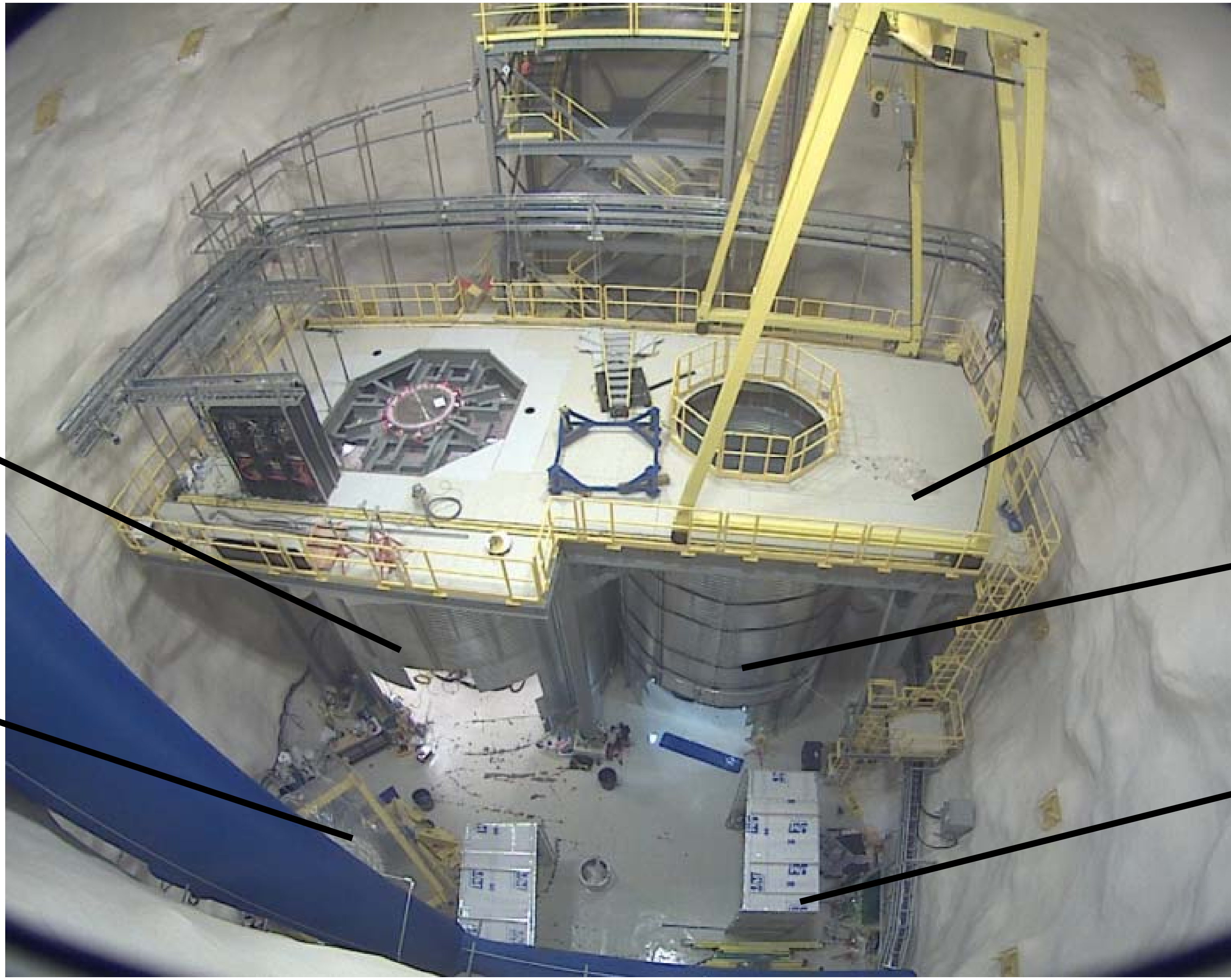
Current programme:
Dark Matter at SNOLAB

- 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.

Cube Hall - DEAP/miniCLEAN

DEAP-3600
water
shielding
tank + outer
vessel

DEAP-3600
AV
machining

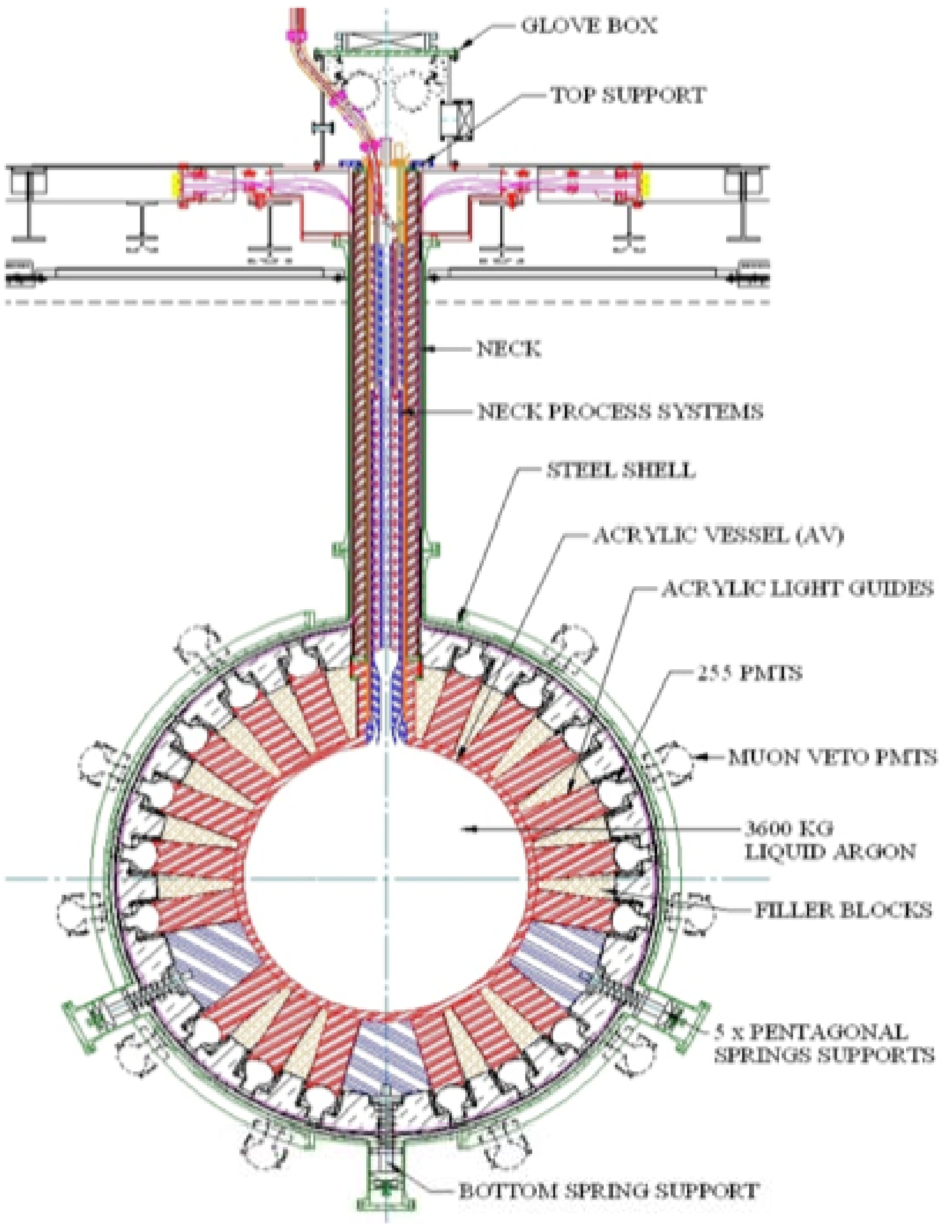


DEAP-3600
MiniCLEAN
mezzanine

MiniCLEAN
water shielding
tank
+ outer vessel

DEAP-3600
AV annealing
oven

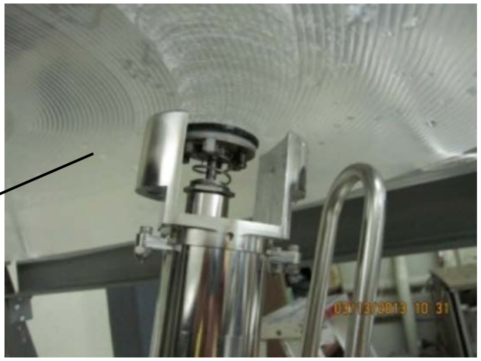
DEAP-3600



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

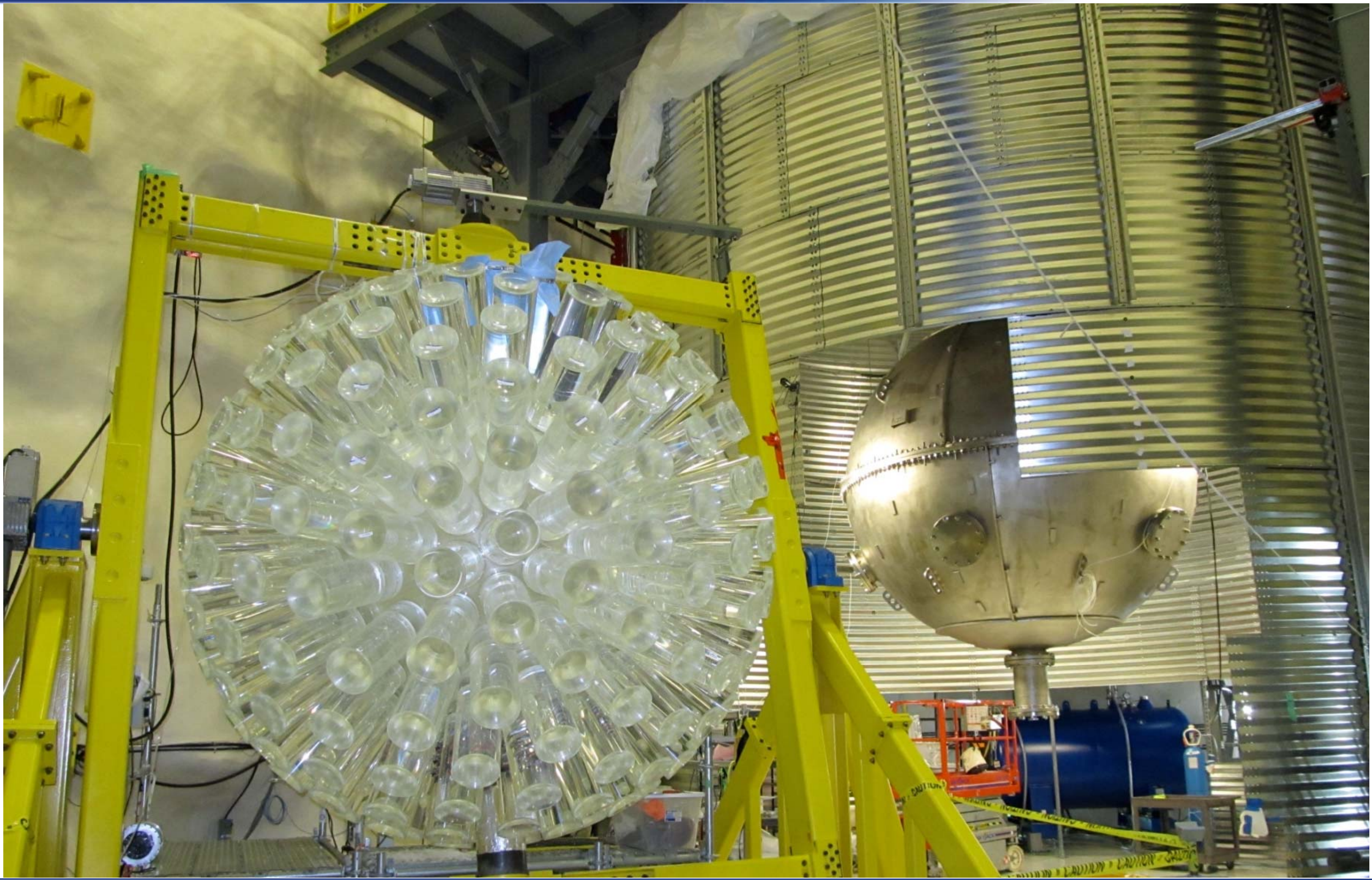


255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)

50 cm light guides + PE shielding provide neutron moderation

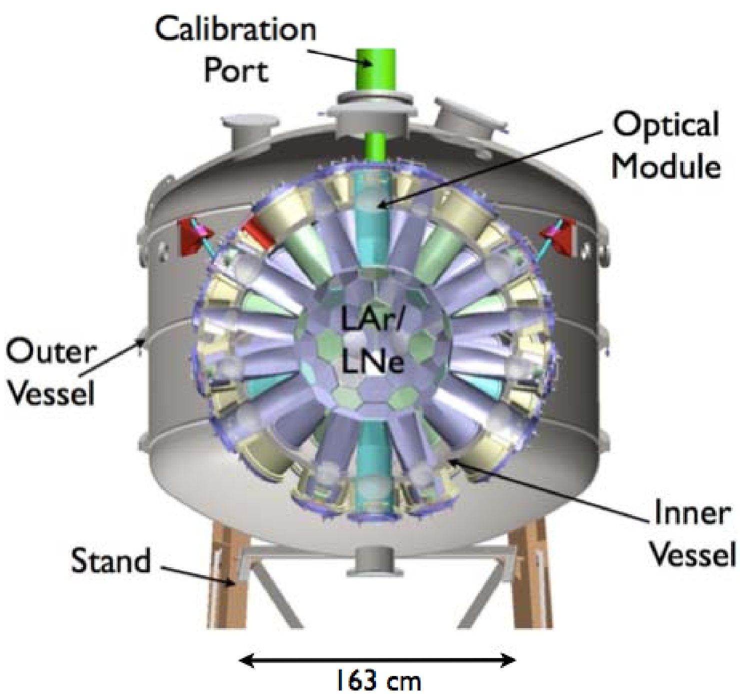
Detector in 8 m water shield at SNOLAB

DEAP acrylic vessel Feb. 2014



MiniCLEAN Detector

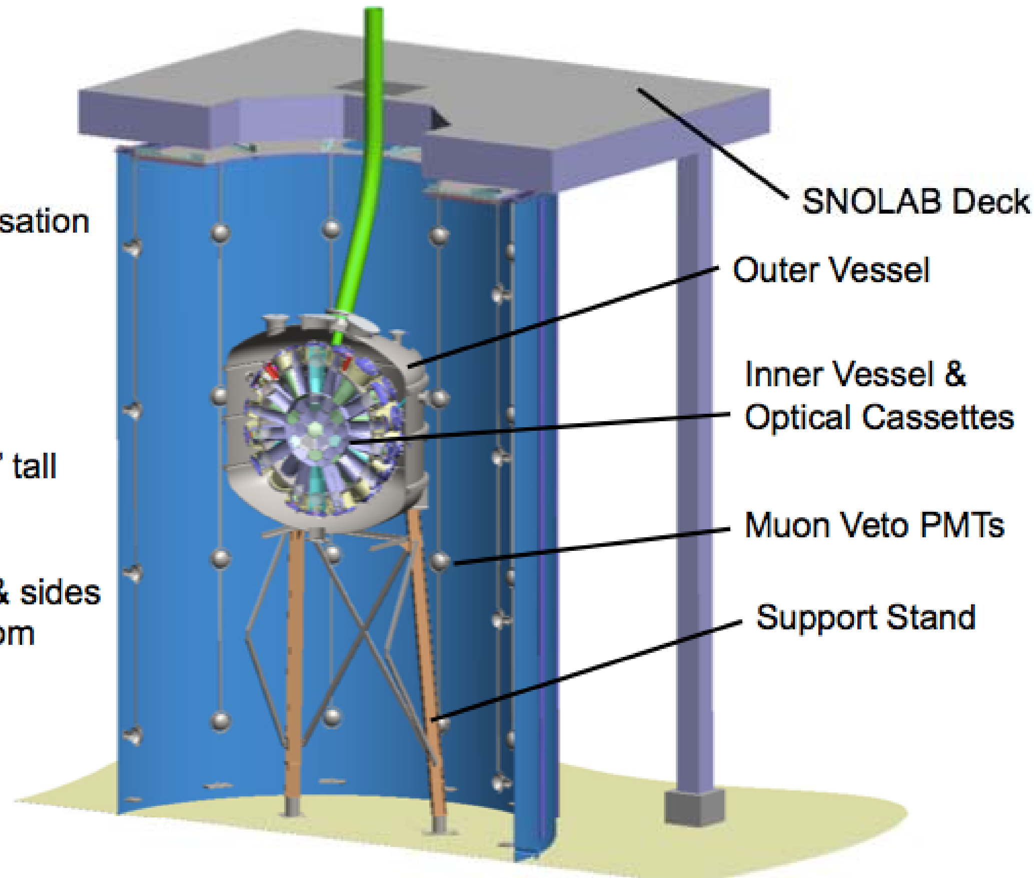
- Single phase LAr/LNe (solar neutrino capability)
- 180kg fiducial volume; PSD discrimination for background rejection
- Wavelength shifter on acrylic plugs
- PMT Cassette into steel vessel



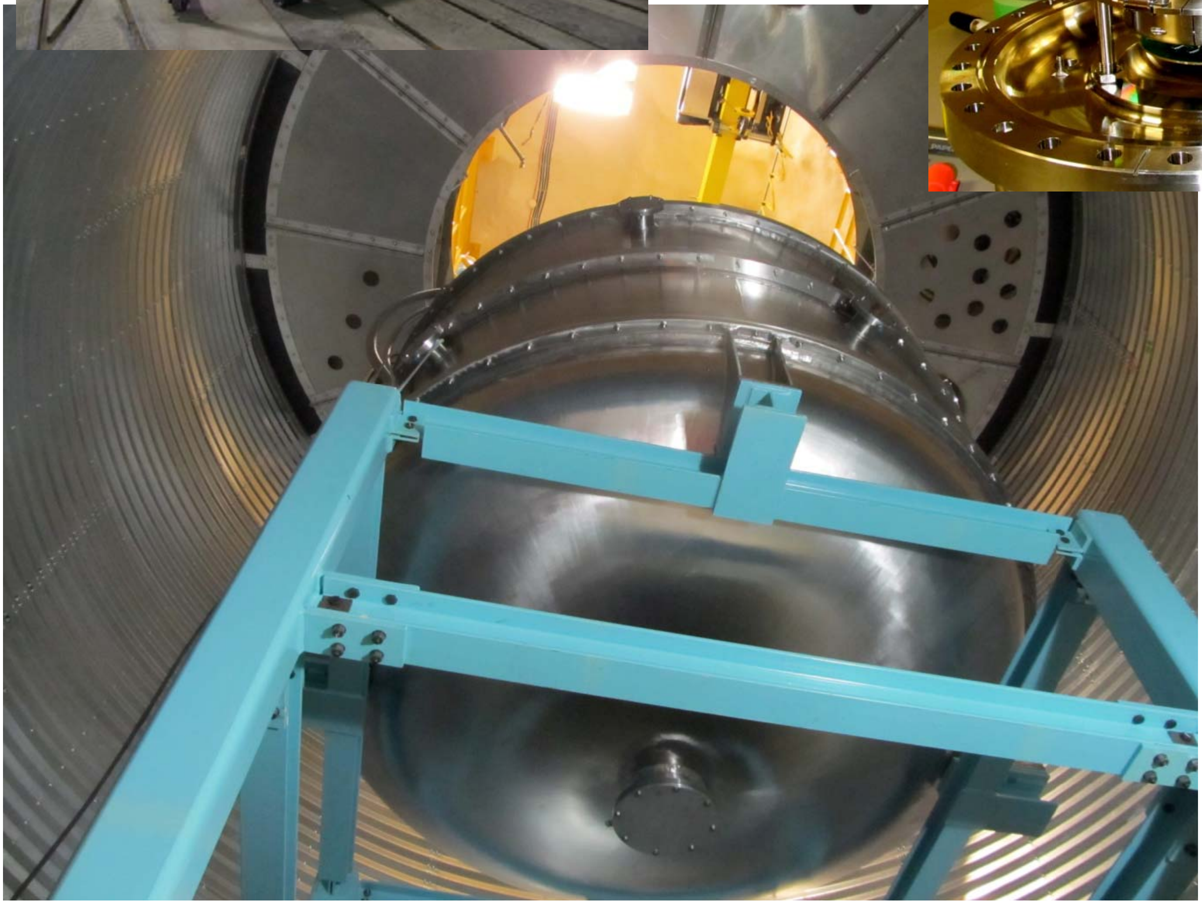
Not Shown:
Magnetic Compensation
Process Systems
Cable Bundles

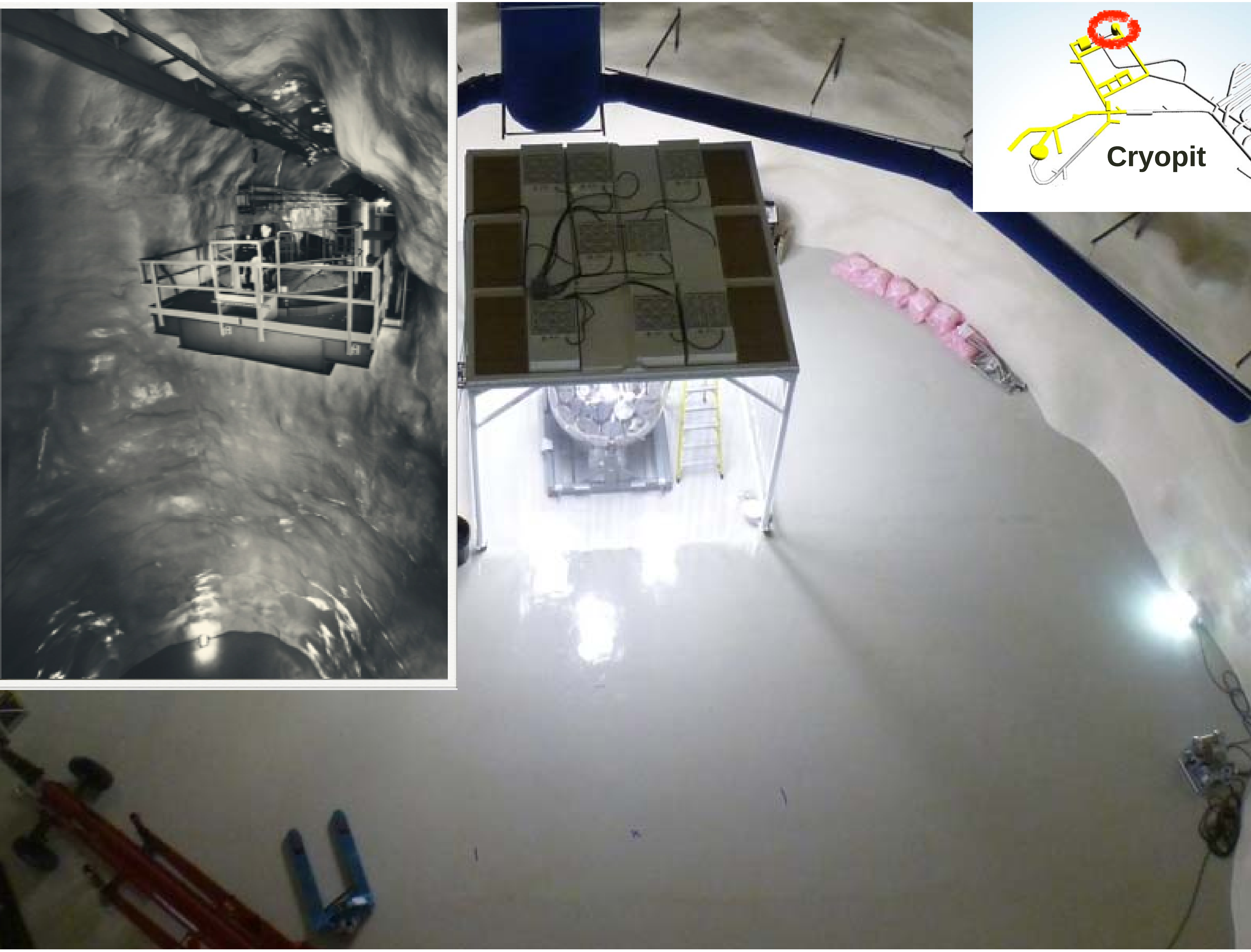
Tank 18' dia. x 25' tall
47,600 gallons

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

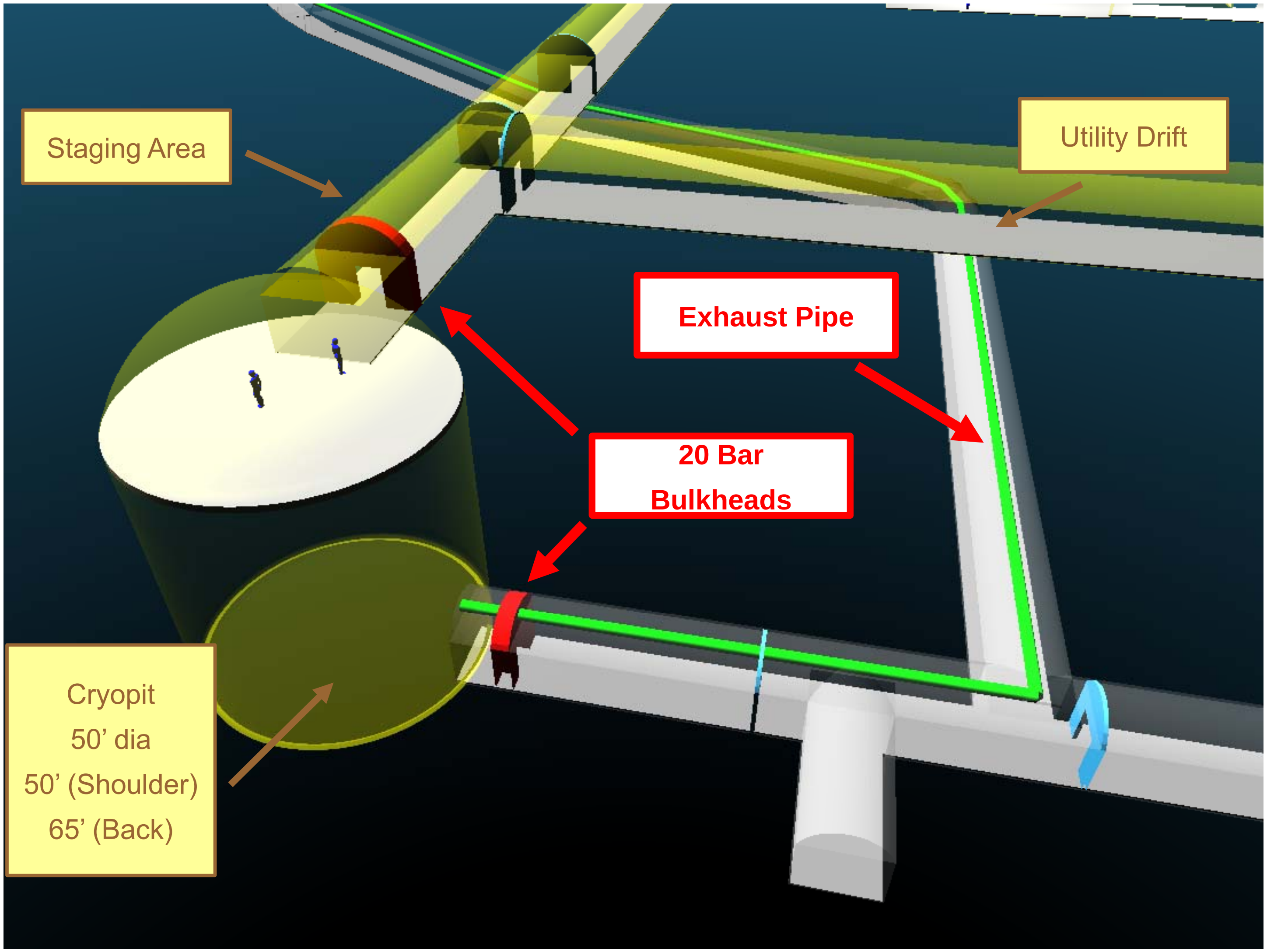


MiniCLEAN Construction




Cryopit

Cryopit - Features



Plus
-Presently unallocated
-Proposals from
• nEXO (DBD)
• Ge 1T (DBD)
• PICO 250 (DM)
• LAr – DEAP6 (DM)
• CLEAN (DM/solar)
• plus 2 letter of interest

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	Operational
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)
2014+	DEAP-3600, MiniCLEAN, (Dark Matter)	SNO+ (Neutrino)
2015+	SuperCDMS (Dark Matter)	nEXO-request (Neutrino)