SUPERNOVA DETECTION AT SNOLAB

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER… L'EXCELLENCE

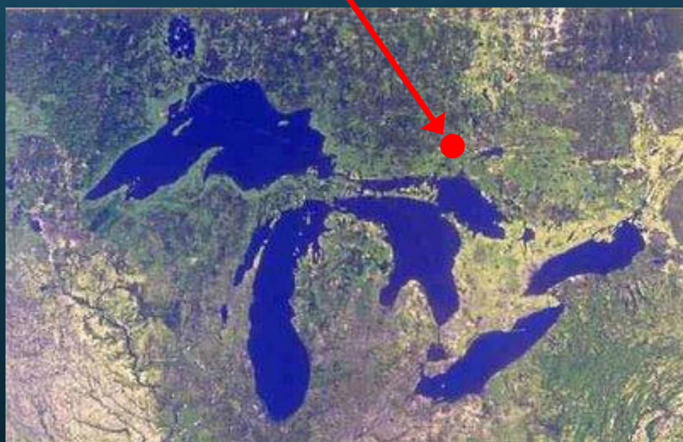
HALO

Laurentian University
Université Laurentienne

Outline

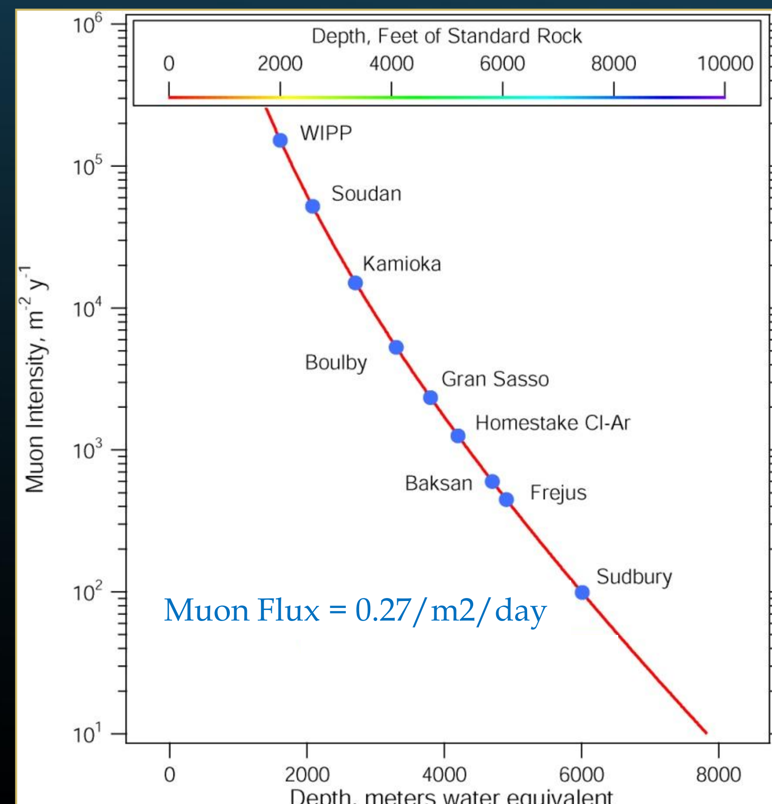
- SNOLAB
  - Experimental program and status
- SN detection at SNOLAB
  - SNO+
  - HALO
- Missing pieces
- Conclusions

Surface Facility



2km flat overburden (6000mwe)

Underground Laboratory

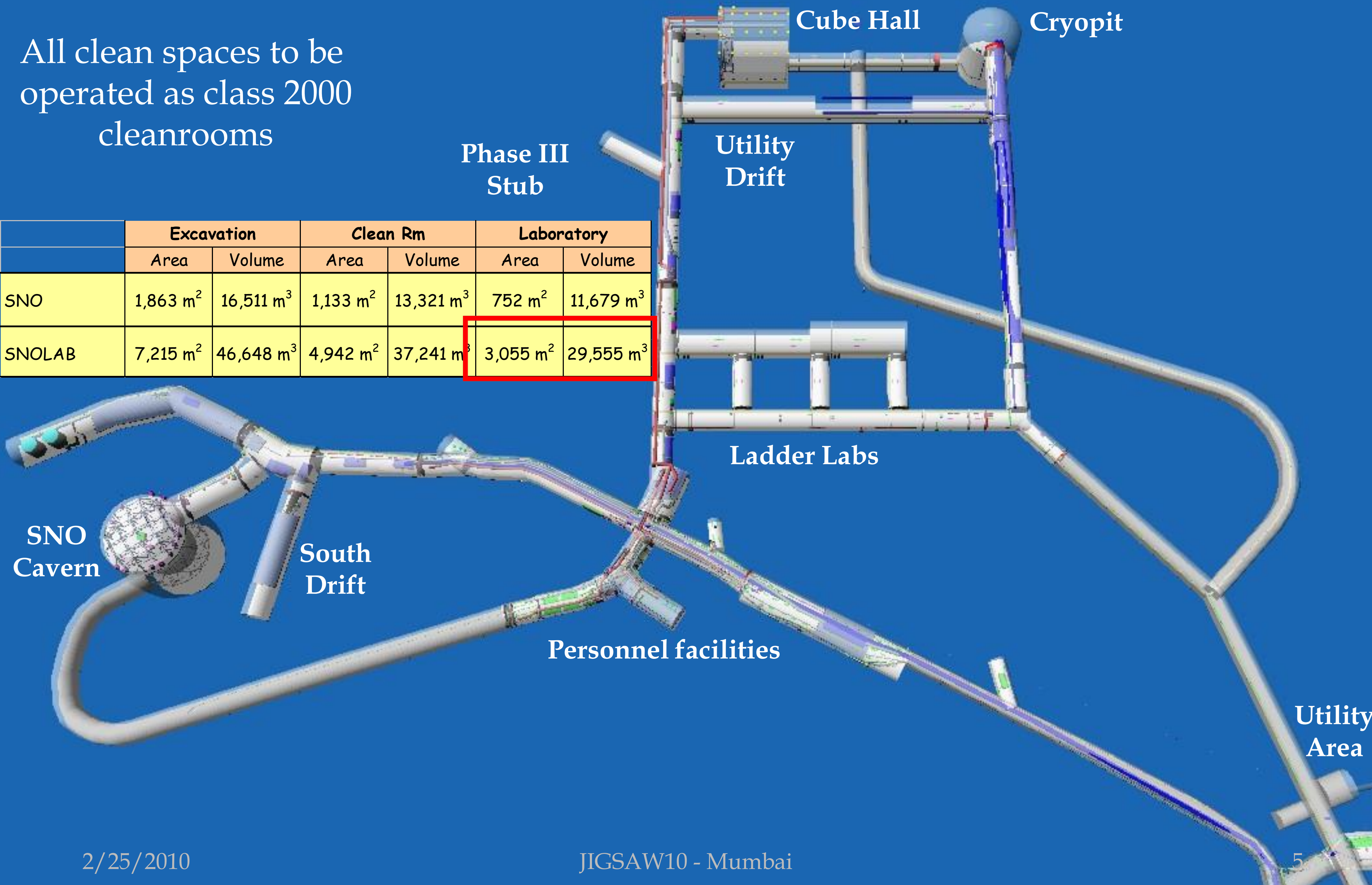


Surface Facilities

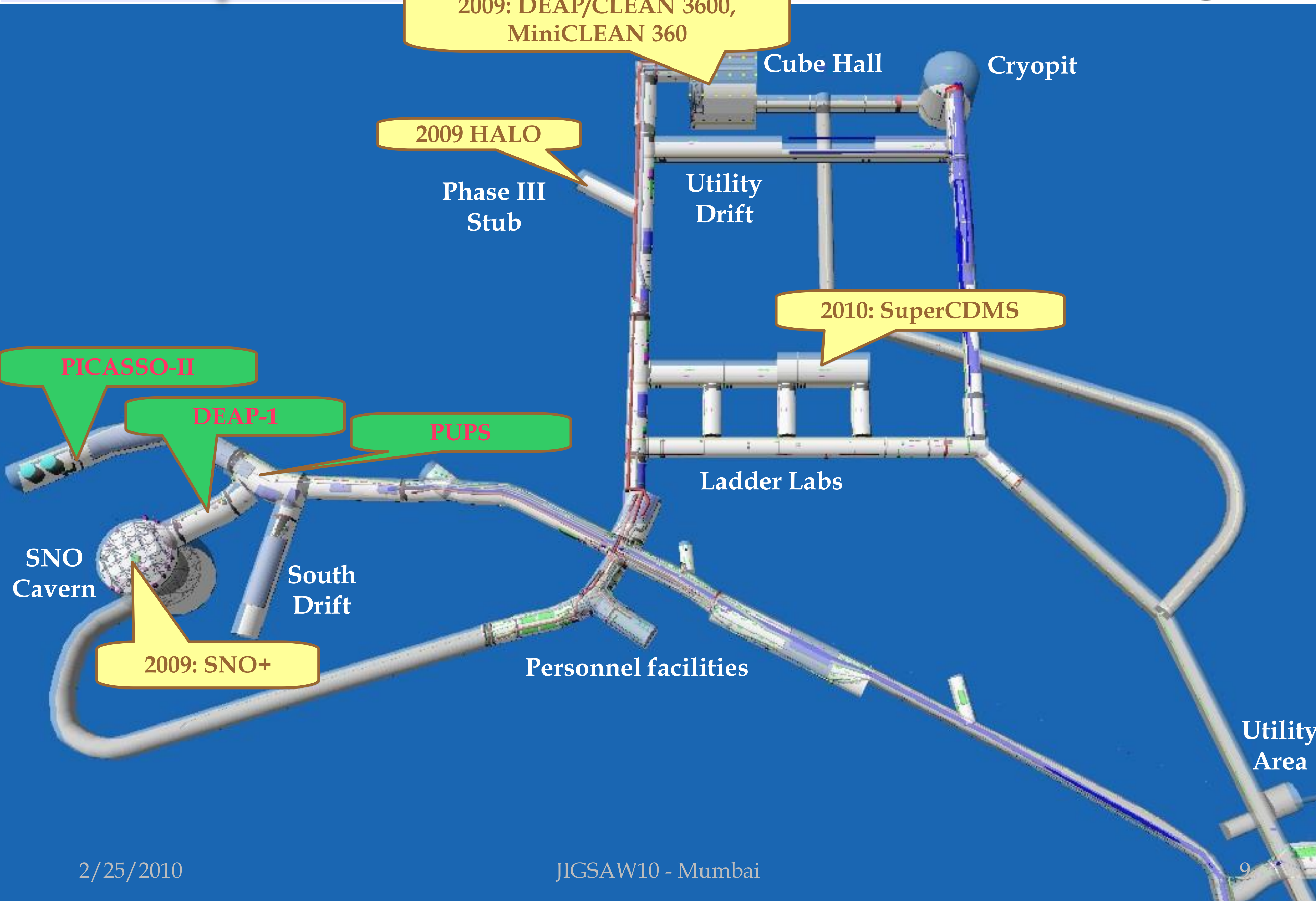
Underground Facilities

All clean spaces to be operated as class 2000 cleanrooms

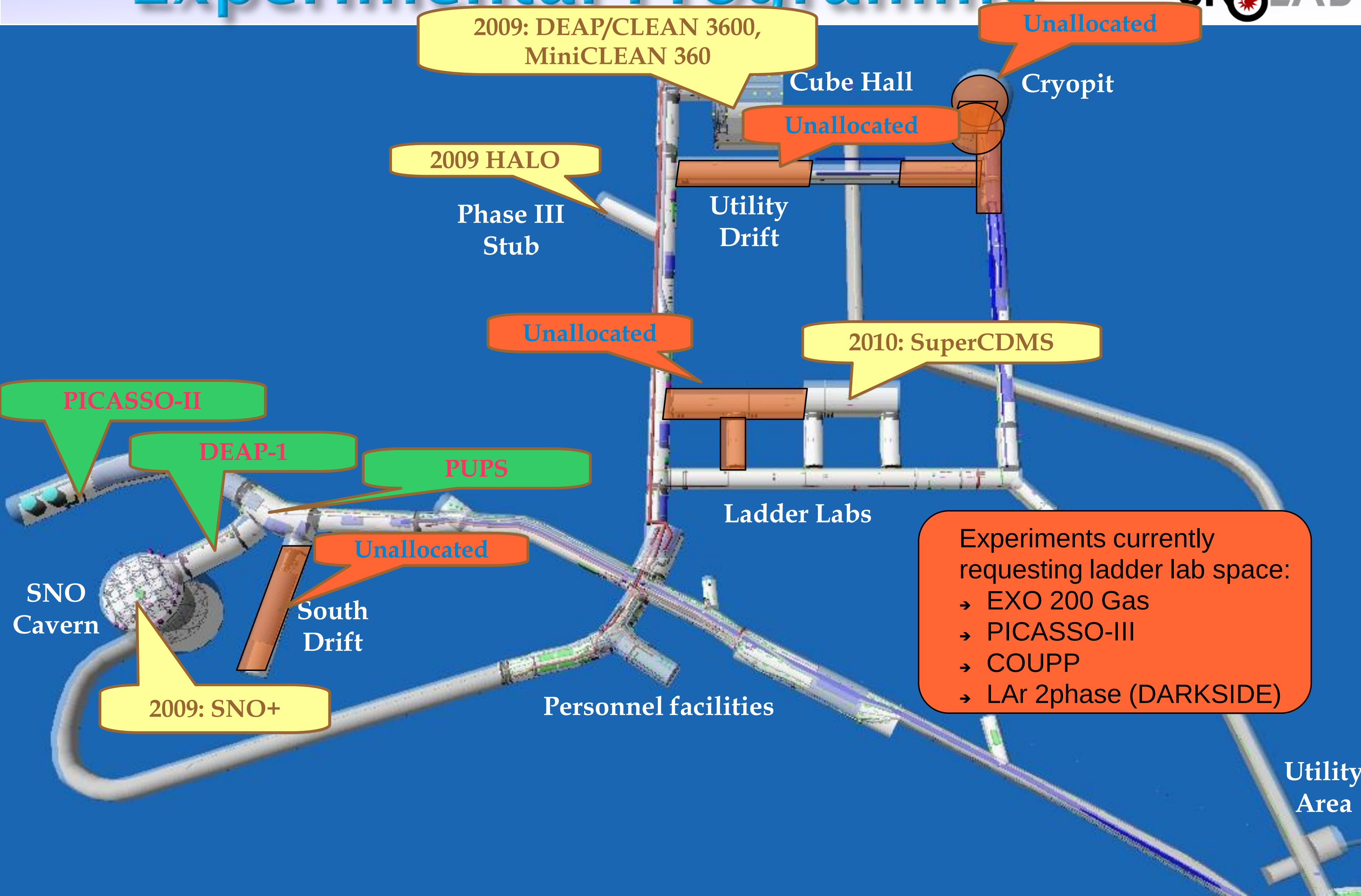
	Excavation		Clean Rm		Laboratory	
	Area	Volume	Area	Volume	Area	Volume
SNO	1,863 m^2	16,511 m^3	1,133 m^2	13,321 m^3	752 m^2	11,679 m^3
SNOLAB	7,215 m^2	46,648 m^3	4,942 m^2	37,241 m^3	3,055 m^2	29,555 m^3



Experimental Programme



Experimental Programme



Experimental Programme Summary

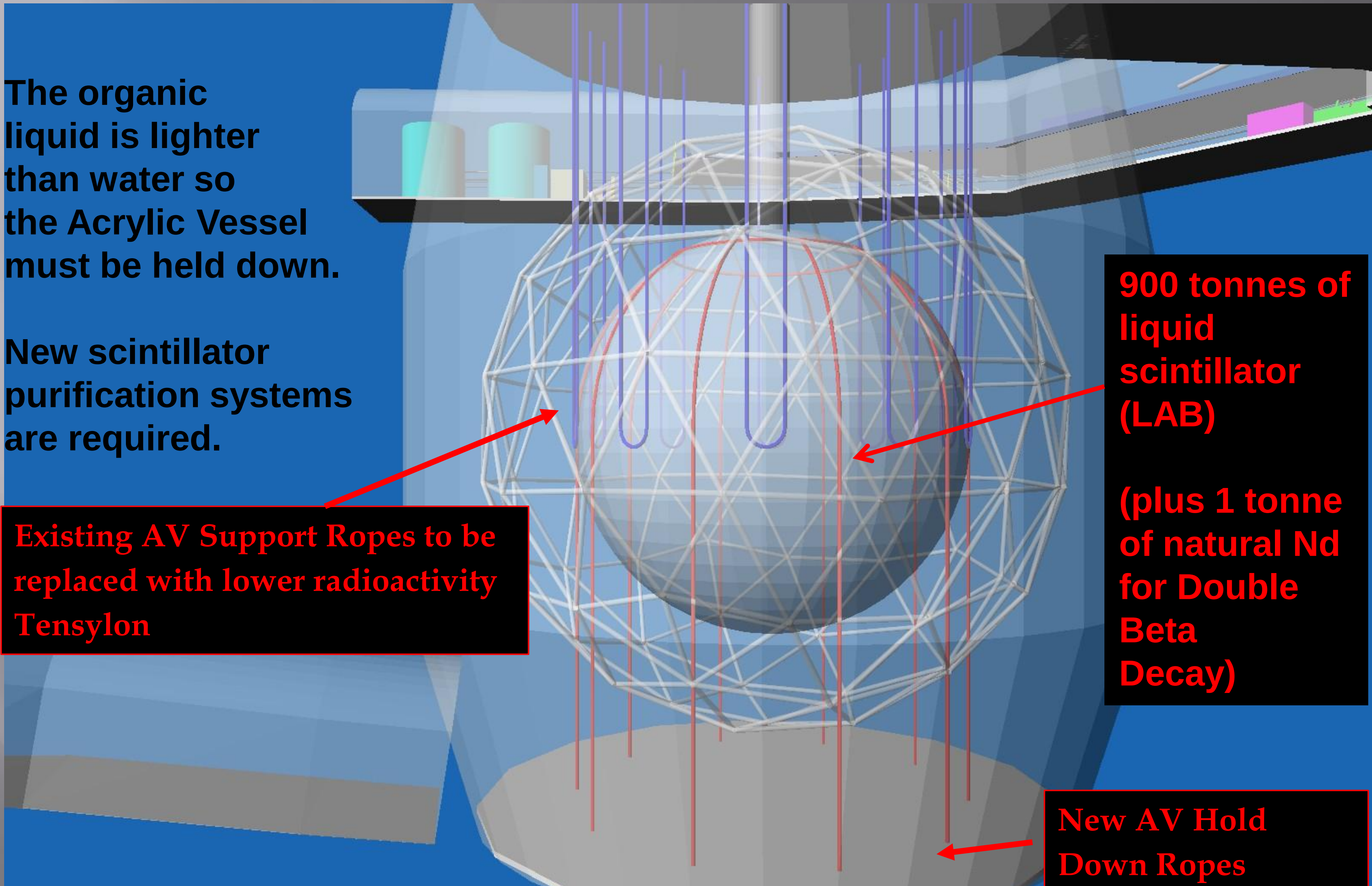
Experiment	Solar nu	0nuBB	Dark Matter	SuperNovae	Geo nu	Other	Space allocated	Status
SNO+	√	√		√	√		SNO Cavern	Underway
PICASSO			√				SNO Utility	Running
DEAP-1			√				SNO Control	Running
DEAP-3600			√				Cube Hall	Underway
miniCLEAN			√				Cube Hall	Underway
HALO				√			Halo Stub	Underway
PUPS						Seismicity	Various	Completed
SuperCDMS			√				Ladder Labs	Request
EXO-gas		√					Ladder Labs	Request
COUPP			√				Ladder Labs	Request
DarkSide			√				Ladder Labs	Request
PICASSO-III			√				Ladder Labs	Planning

SN detection at SNOLAB

- Two very different detectors…
  - SNO+
    - Multi-purpose / multi-phase
      - Transition periods
      - Extensive calibration time
      - Reduced SN livetime
    - Limited duration
    - Man-power intensive
  - HALO
    - Low cost / low maintenance
    - High livetime
    - Dedicated SN detector

SNO+

- Conversion of SNO (water Cerenkov) to SNO+ (liquid scintillator)
  - Replace 1000 tonnes of heavy water with ~900 tonnes of linear alkylbenzene (LAB)
  - Surround (as before) with 7000 tonnes of UPW
  - Some mechanical modifications required as filled acrylic vessel (AV) is now buoyant
- Broad physics programme
  - $0\nu\beta\beta$ decay, low energy solar ν
  - Reactor and terrestrial ν
  - Supernova ν



The organic liquid is lighter than water so the Acrylic Vessel must be held down.

New scintillator purification systems are required.

Existing AV Support Ropes to be replaced with lower radioactivity Tensylon

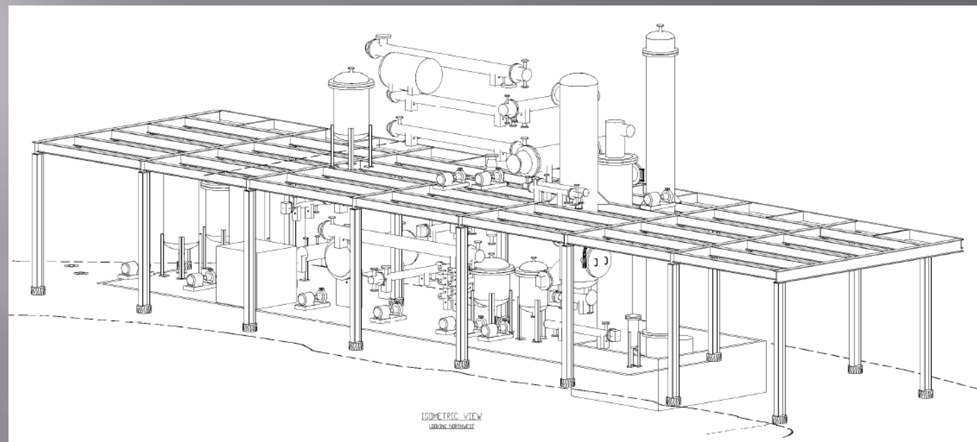
900 tonnes of liquid scintillator (LAB)

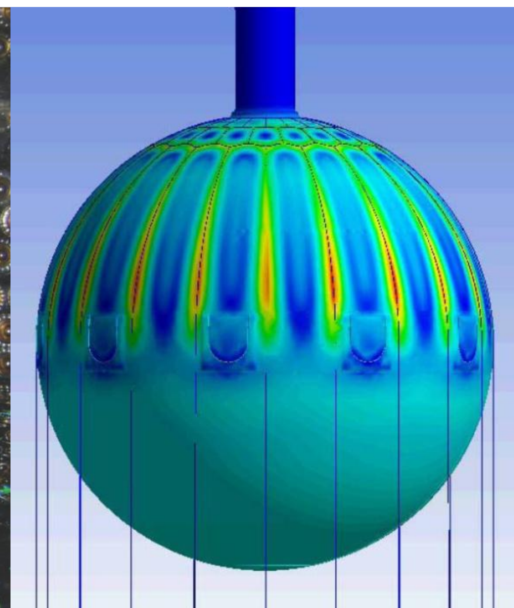
(plus 1 tonne of natural Nd for Double Beta Decay)

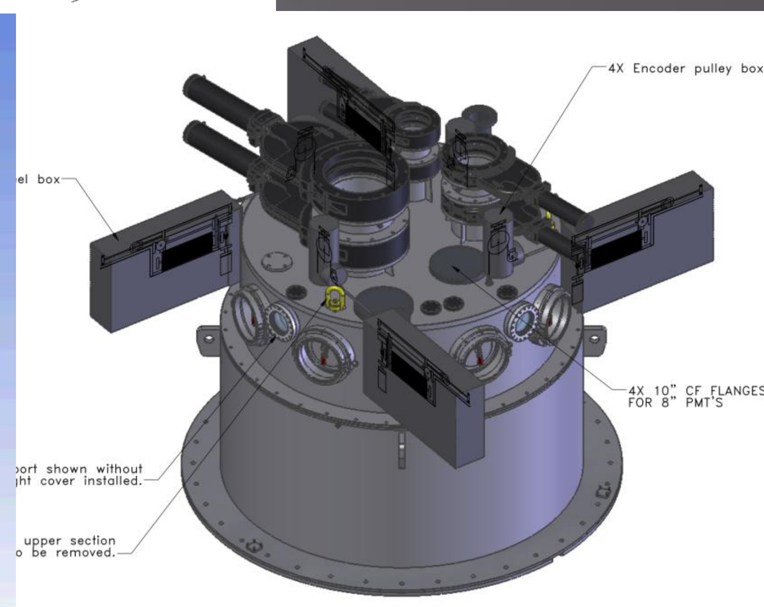
New AV Hold Down Ropes

Otherwise, the existing detector, electronics etc. are reusable.

SNO+ Underway

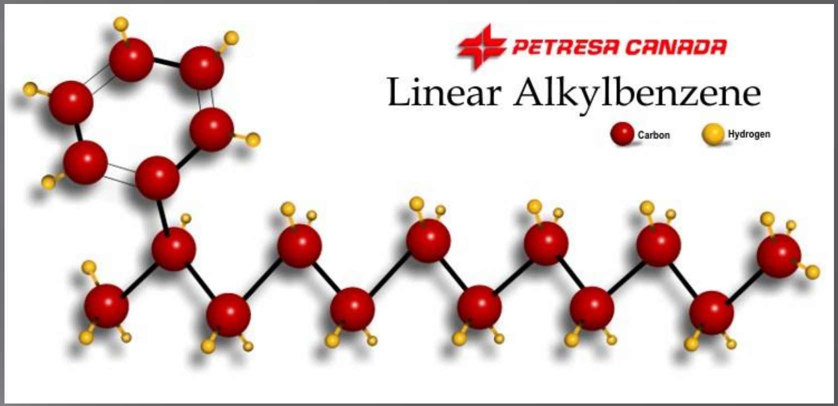






Linear Alkylbenzene, $C_{18}H_{30}$ (LAB)

- compatible with acrylic, undiluted
- high light yield (900 p.e./MeV)
- pure
  - light attenuation length in excess of 20 m at 420 nm
- high flash point (130°C)
- low toxicity
  → safe



pseudocumene (2 4 0)
diesel (0 2 0)

Daya Bay, Hano Hano, LENA, NOvA and others are now also looking at LAB as a scintillator

SN signal in SNO+ for 10 kpc

SNO+

CC:	$\overline{\nu}_e + \mathrm{p}$	$\rightarrow$	$\mathrm{n} + e^+$	(260) 41%	
	$\nu_e + {}^{12}\mathrm{C}$	$\rightarrow$	${}^{12}\mathrm{N} + e^-$	(30) 4.7%	
	$\overline{\nu}_e + {}^{12}\mathrm{C}$	$\rightarrow$	${}^{12}\mathrm{B} + e^+$	(10) 1.5%	
NC:	$\nu_x + {}^{12}\mathrm{C}$	$\rightarrow$	${}^{12}\mathrm{C}^* + \nu_x$	(60) 9.3%	
	$\nu_x + \mathrm{p}$	$\rightarrow$	$\nu_x + \mathrm{p}$	(270) 42%	**
ES:	$\nu_x + \mathrm{e}^-$	$\rightarrow$	$\nu_x + \mathrm{e}^-$	(12) 1.9%	

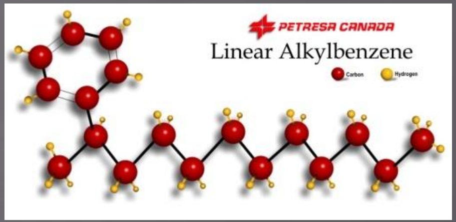
** threshold of 200 keV, above ^{14}C ß endpoint of 156 keV, need to see rates from ^{210}Pb & ^{85}Kr. Quenching factor still to be measured.

** Beacom, Farr, Vogel; Phys.Rev. D66 (2002) 033001

- SNO+ sensitivity extends what would be seen by LVD, Borexino and KamLAND
- SNO+ sensitivity complements S-K sensitivity
- SNO+ will maintain a participation in SNEWS

Impact of changes

- ~ 1kt Linear Alkylbenzene (LAB)



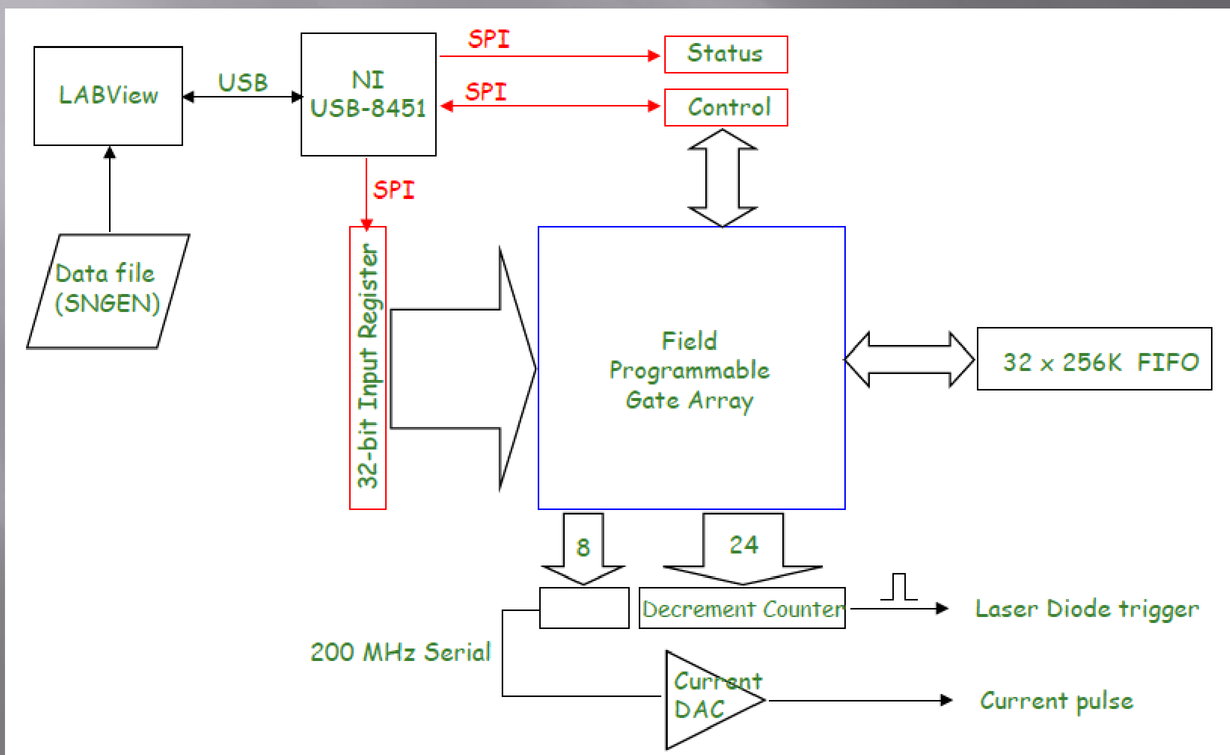
- high yield (up to 900 p.e./MeV, cf 9 p.e./MeV in SNO) and isotropic scintillation light affects the SN signal in several ways
  - → SNO+ will have an increased data volume / flow (x 100) and is upgrading its DAQ
  - → larger events means reduced FEC buffer capacity for a nearby SN (~10^3 events cf 10^6 in SNO), will be compensated by faster readout
  - → loss of directional information
  - → SNO+ will be ~blind to Cerenkov light (9 p.e./MeV) in the 1.3 kt of UPW seen by the PMTs (DAQ trigger threshold ~ 20 MeV in UPW)
  - → Loss of ~300 $\overline{\nu}_e + p \rightarrow e^+ + n$ events
- much of the SNO SN trigger can however be reused

Supernova Calibration Source

Capability to stress test DAQ and calibrate SNO+
At 10's of MeV.

Blue – Violet Laser Diode
405 nm 210mW pulse

For 6x Blu-Ray DVD
216 Mbps
2.3ns pulse width



Sharp to Begin Volume Production of High-Power*1 210-mW Blue-Violet Laser Diodes

Industry's Highest Power Level*2 Enables High-Speed 6X Recording on Next-Generation Dual-Layer DVDs

High-Power Blue-Violet Laser Diode <GH04P21A2G >

Sharp Corporation will begin volume production in May of the High-Power Blue-Violet Laser Diode GH04P21A2G that achieves a power output*1 of 210 mW, the industry's highest*2. This device will enable high-speed 6X recording on next-generation dual-layer Blu-ray Discs (BD) and HD-DVDs.

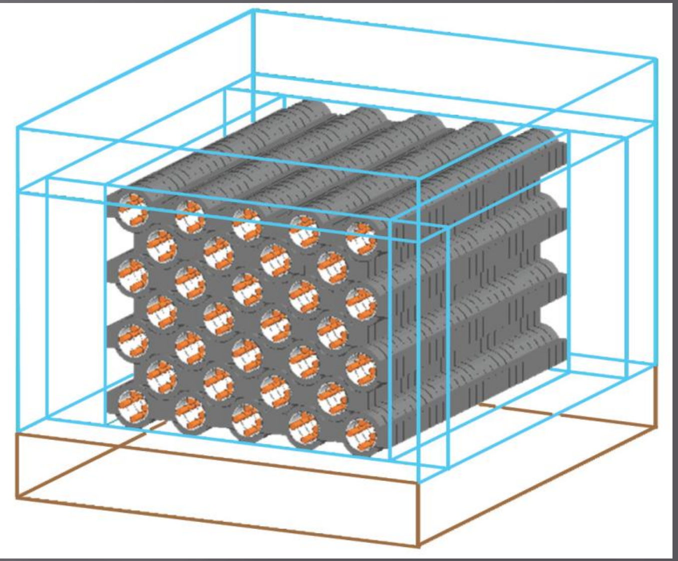
HALO - a Helium and Lead Observatory

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

Philosophy - to produce a

- Very low cost
- Low maintenance
- Low impact in terms of lab resources (space)
- Long-term, high livetime

dedicated supernova detector



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

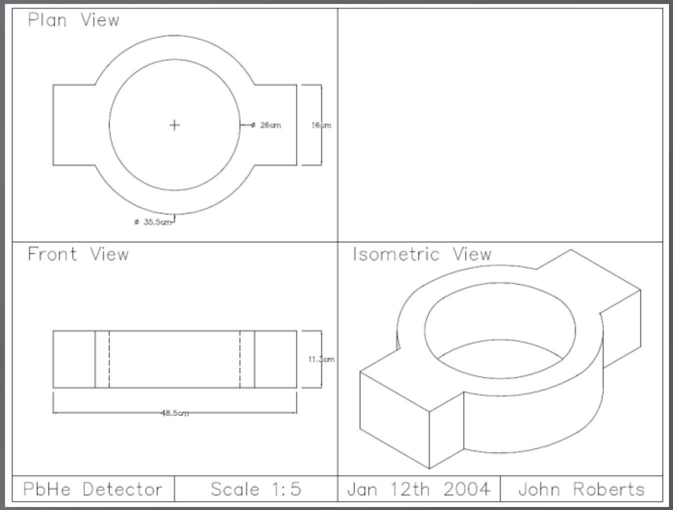
+

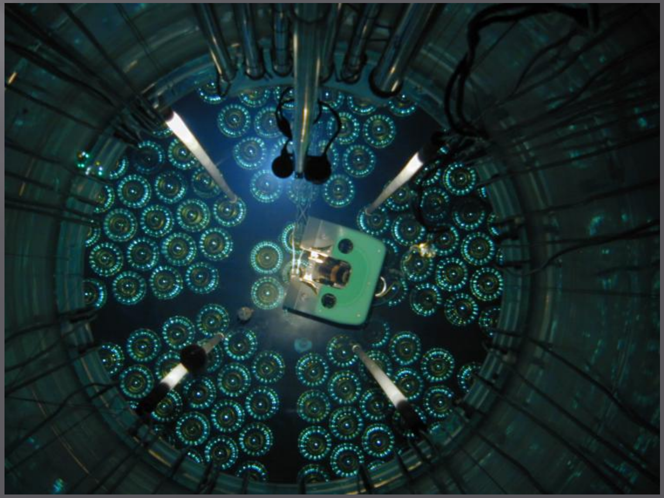
"Lead" – because of high ν-Pb cross-sections, low n-capture cross-sections, sensitivity to ν_e (dominantly) and ν_x complementing water Cerenkov and liquid scintillator detectors

HALO will use an available 76 tonnes of Pb

HALO-I - Design Overview

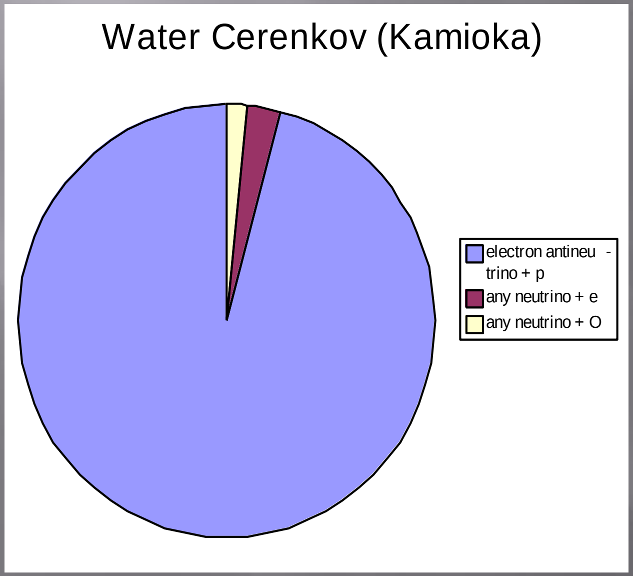
- Lead Array
  - 32 three meter long columns of annular Lead blocks
  - 76 tonnes total lead mass (864 blocks)
- Neutron detectors
  - Four 3 meter ^{3}He detectors per column
  - 384 meters total length
- Moderator
  - 250mm Schedule 40 PP tubing
- Reflector
  - 20 cm thick graphite blocks
- Shielding
  - 30 cm of water

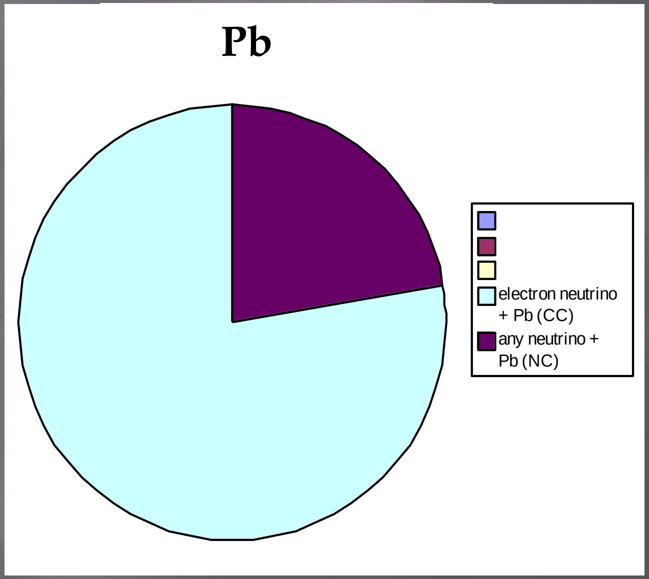


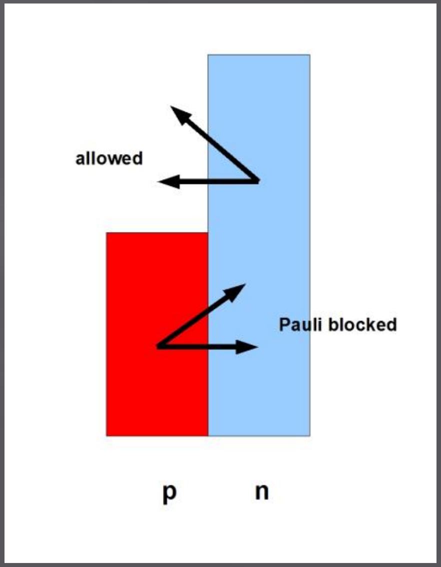


SN ν interactions in Lead

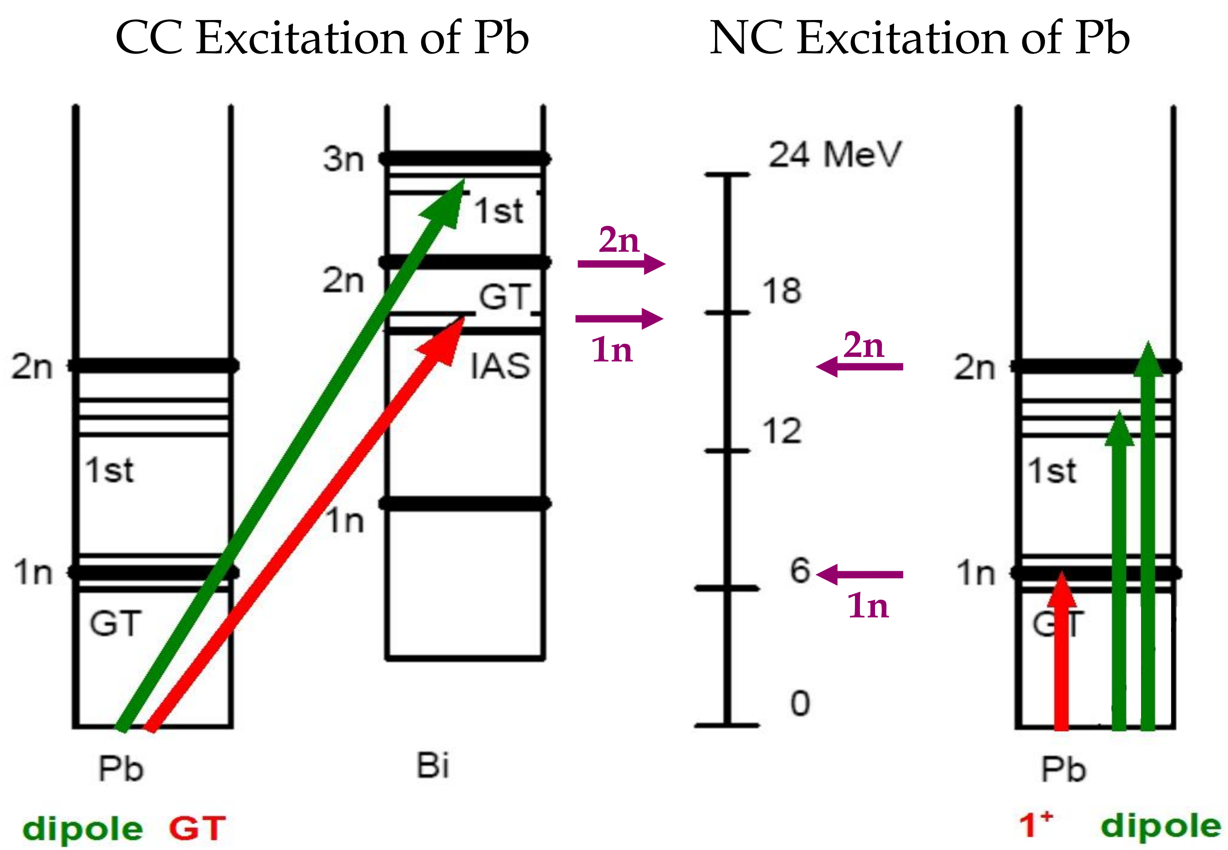
- High Z increases ν_e CC cross-sections relative to $\bar{\nu}_e$ CC and NC due to Coulomb enhancement of electron wavefunction overlap
- Neutron excess (N > Z) Pauli blocks $\overline{\nu}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$ further suppressing the $\bar{\nu}_e$ CC channel
- Results in flavour sensitivity complimentary to water Cerenkov and liquid scintillator detectors







Nuclear Excitation / De-excitation



SN neutrino signal in HALO

In 76 tonnes of lead for a SN @ 10kpc†,

CC:

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

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

NC:

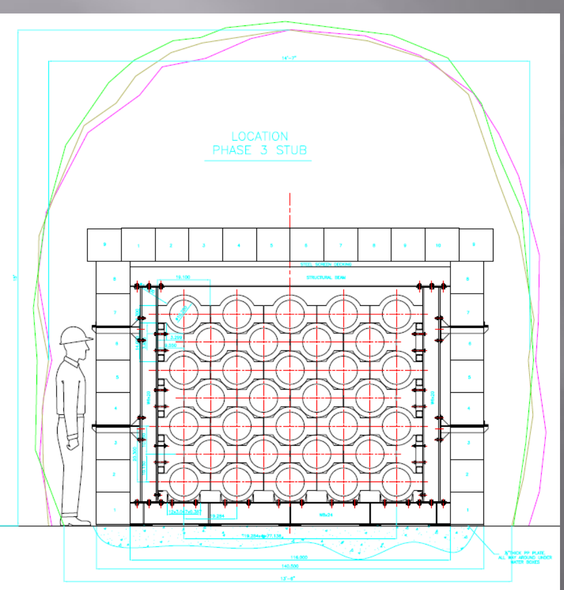
$$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$$

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

- Assuming FD distribution with T=8 MeV for ν_μ's, ν_τ's.
- 65 neutrons through ν_e charged current channels
  - 29 single neutrons
  - 18 double neutrons (36 total)
- 20 neutrons through ν_x neutral current channels
  - 8 single neutrons
  - 6 double neutrons (12 total)

~ 85 neutrons liberated; ie. ~1.1 n/tonne of Pb

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



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

Missing Pieces…

- Measured ν-Pb x-sections
- Improved calculated ν-Pb x-sections
- Parametrized luminosity curves through to end of cooling phase
  - To facilitate physics sensitivity studies
- More lead

Conclusions

- Two new Sn detectors coming online in next 2 years
- SNO+ extends sensitivity of other liquid scintillator detectors
  - Good energy / time resolution, no pointing
  - ~ 700 events for 10kpc, $\bar{\nu}_e$ and ν_x roughly equal numbers
  - NC distinguishable from CC by energy spectrum
- HALO provides "unique" ν_e sensitivity
  - No energy / pointing information
  - Good time information (capture time is few ms)
- We need a larger version of HALO!