SNO+ Status and Prospects

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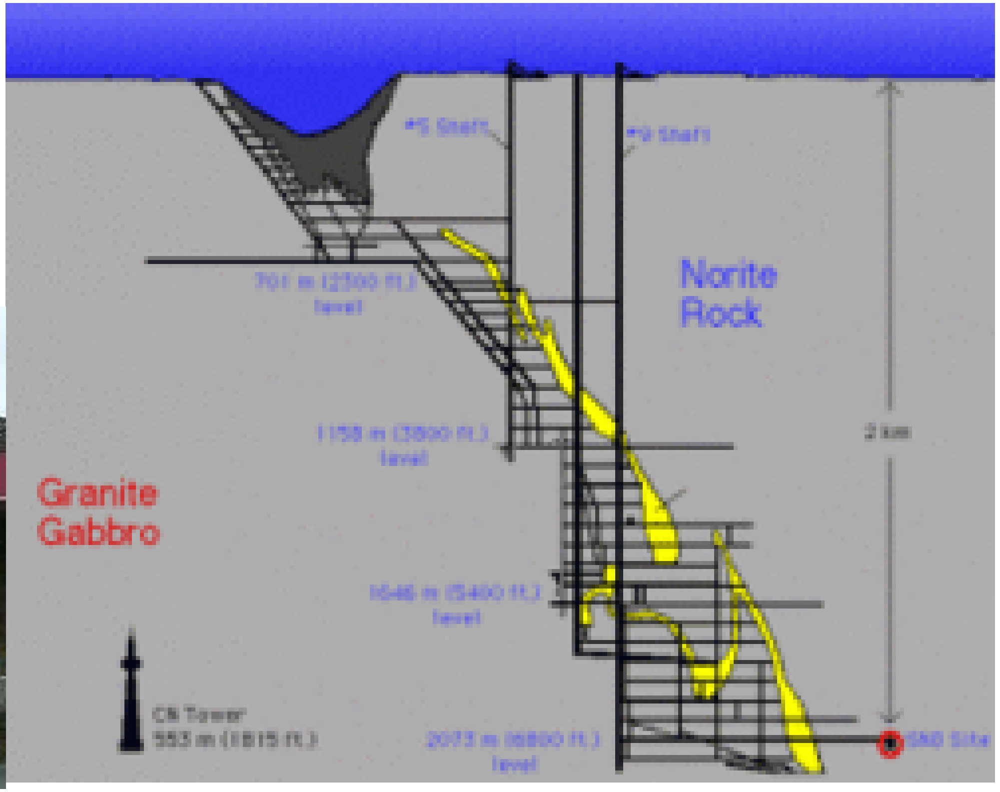
SNO+ Collaboration

- **Canada:** Alberta, Laurentian, Queens, SNOLAB, TRIUMF
- **Germany:** TUD
- **Mexico:** UNAM
- **Portugal:** LIP
- **UK:** Lancaster, Liverpool, Oxford, QMUL, Sussex
- **USA:** Armstrong Altantic, UCBerkeley/LBNL, BNL, UCDavis, UChicago, UNC, Norwich, UPenn, Washington

SNO+ Detector

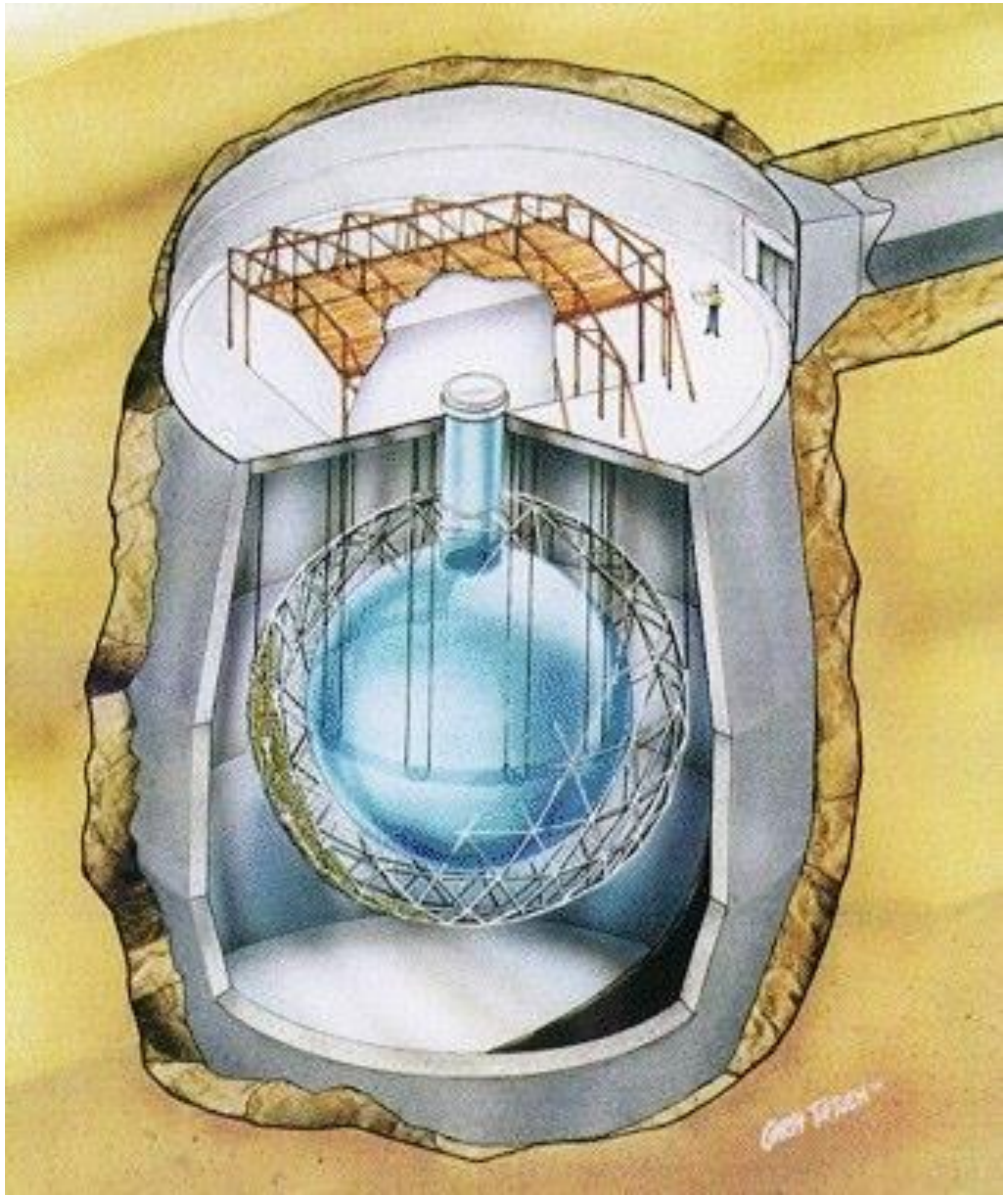
- Large multi-purpose liquid scintillator detector based in Creighton Mine, Sudbury, Canada
- Situated in clean underground lab, SNOLAB, 6800 ft underground (6000 mwe)
- Depth reduces muon flux through detector to 63 per day

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE



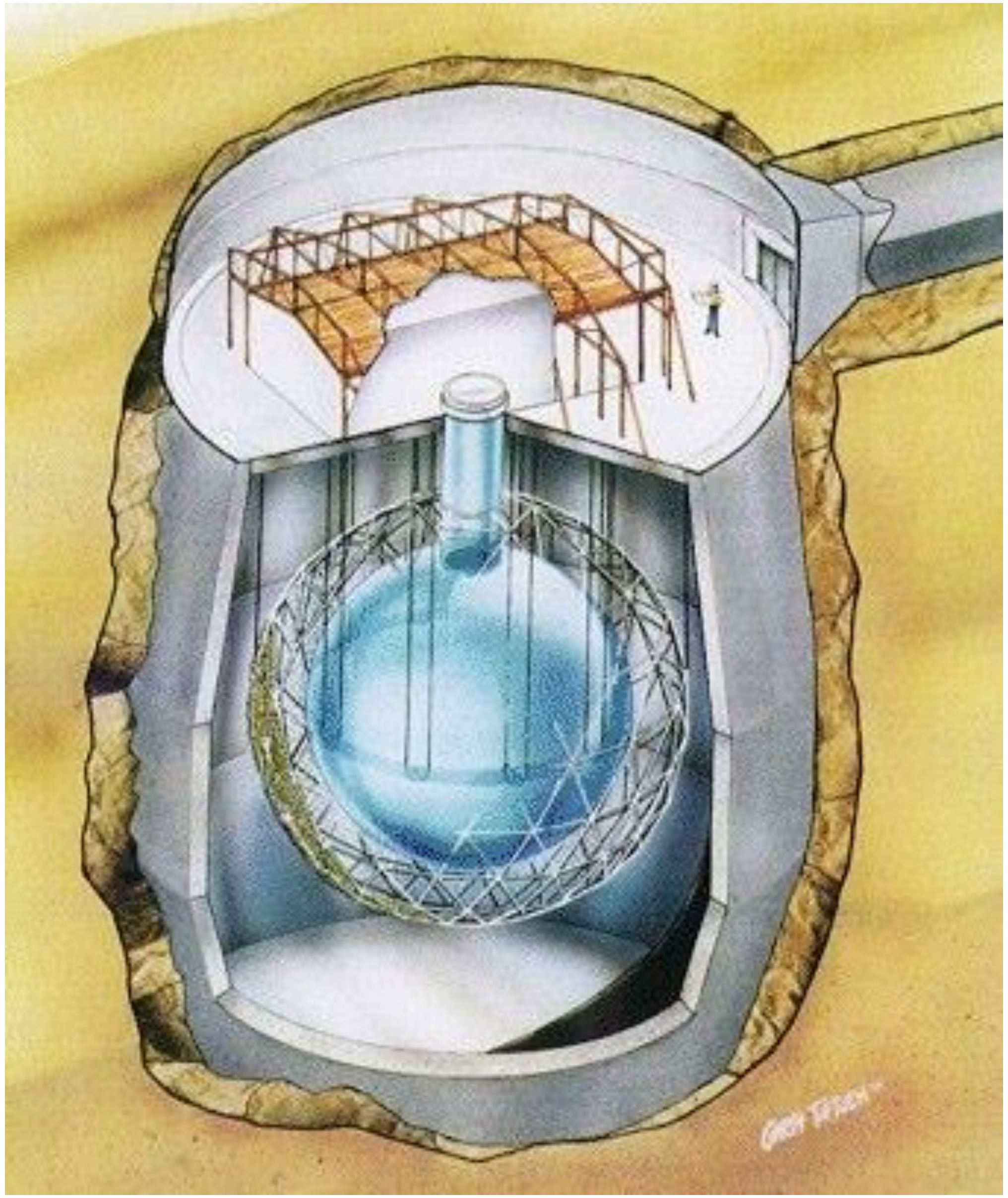
SNO+ Detector

- SNO+ will use an upgraded version of the SNO detector:
  - 780t scintillator contained within 6m radius acrylic sphere
  - Shielded by 7kt of ultrapure water
  - Surrounded by ~9300 PMTs mounted on a stainless steel support structure



SNO+ Detector Upgrades

- Improved electronics
  - Able to handle the higher data rates expected with scintillator
  - Additional functionality that was absent during SNO
- New optical fibre calibration systems
  - Mounted on the PMT support structure
  - Allow calibration of PMTs and scintillator properties without risk of contamination
- Repaired PMTs
  - Mostly problems with the base
  - 391 were able to be repaired and replaced
- Hold-down ropes installed
  - Required due to scintillator buoyancy
- New scintillator plant constructed



Tellurium Loading

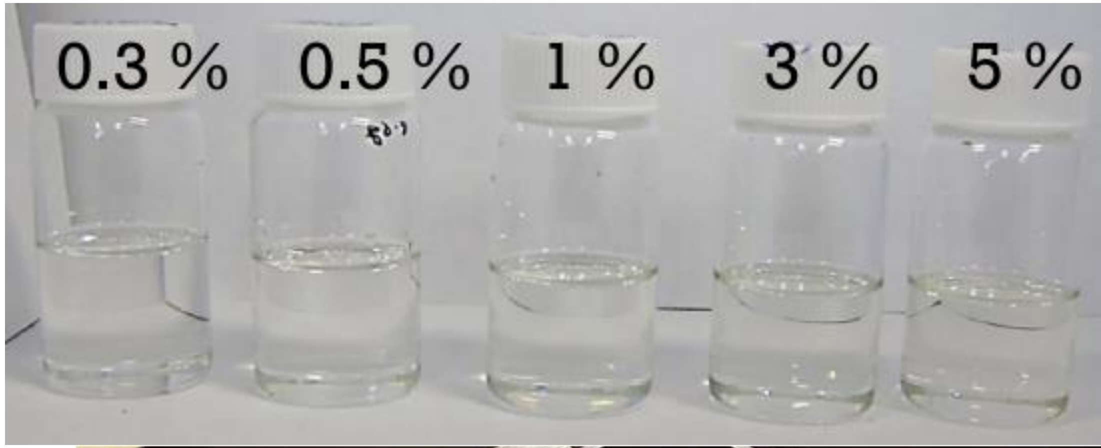
- SNO+ will search for neutrinoless double beta decay using tellurium loaded into the scintillator
  - Initially 0.3% in Phase 1 then onto higher loadings

- Advantages
  - High natural abundance of 34% so no need to enrich
  - Favourable ratio expected between 0v and 2v modes
  - Ability to load without being optically limited

- Challenges
  - Backgrounds must be well understood
  - Purification techniques have been developed
  - Ability to tag backgrounds with beta-alpha discrimination
  - Several phase model gives ability to see how backgrounds change with loading

Development of Tellurium Loading

- Loading of tellurium in LAB scintillator
  - Cocktail has remained stable for over 2 years
  - No intrinsic optical absorption from tellurium
  - Use a second wavelength shifter to raise above absorption of the surfactant
  - LAB+PP0+Te+Surfactant+2^{nd} WLS



- 0.3% loading has been produced in larger batches of 30L and its properties measured
- Higher loadings of over 5% have been tested on a smaller scale

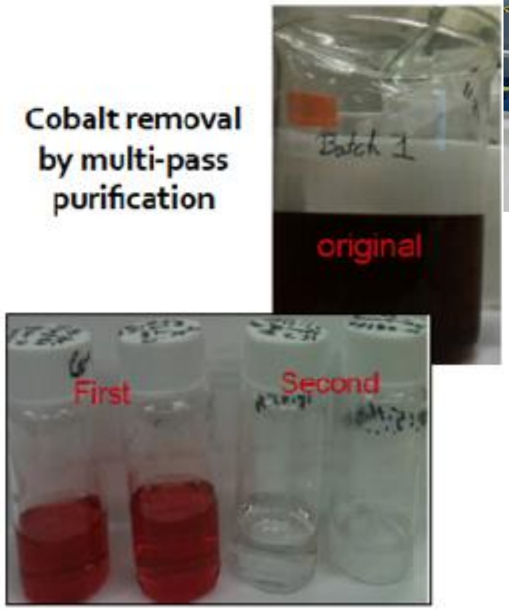
Tellurium Purification

- Cosmic rays could produce long-lived isotopes in tellurium and surfactant which could prove to be a background for any search
- Getting things underground quickly is important
- First batch of tellurium is currently underground

- Will be purified underground using a water/acid rinse cycle
- Tests show reduction factor of 10^3 per pass, 10^6 for two passes for Co60 as well as reduction of optical impurities
- S.Hans et al, “Purification of telluric acid for SNO+ neutrinoless double-beta decay search”, NIM. A795 (2015) 132-139

- Design of tellurium part of scintillator plant is being finalised
- Installation will begin in 2016

Cobalt removal by multi-pass purification



Scintillator Plant

- Scintillator plant has been constructed
    - Helium leak checking is complete
    - Cleaning and passivation is complete
    - Insulation is to be installed
    - Some pre-commissioning has taken place with pumps and valves used to direct flow of citric acid and rinse water in cleaning and passivation

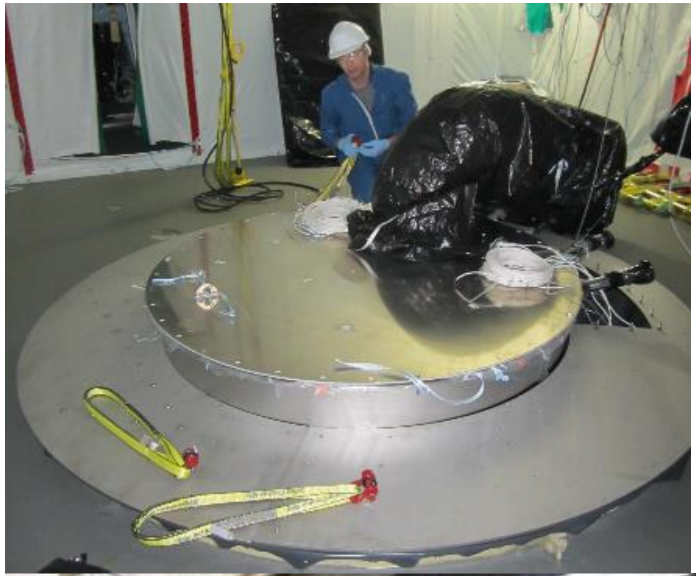
- Still to come:
    - Commissioning with water
    - Safety review
    - Commissioning with scintillator

- Expected completion next Summer

Detector Hardware

- New universal interface controlling access to the detector has been designed
  - Control of sources, level sensors, etc…
  - Lower sliding floor has been installed
  - Upper UI and glove-box will be installed before the end of year

- Cover-gas system provides ^{14}N barrier to prevent ^{222}Rd gas from mine air entering the detector
  - Designed to cope with the more stringent radon requirements of SNO+
  - Flexible bags able to compensate for changes in pressure between detector and deck
  - Installed and commissioned

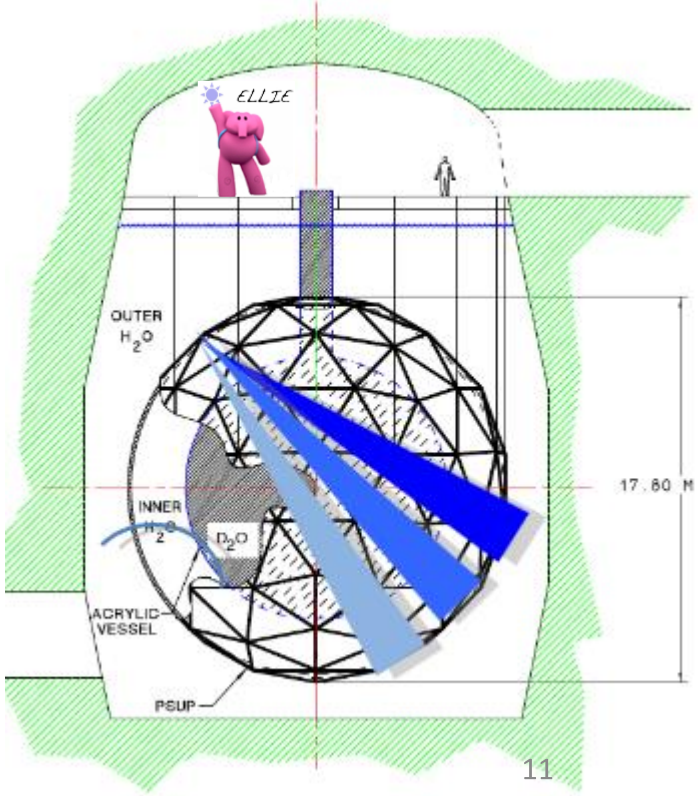


Calibration systems

- New deployed sources have been developed to probe the lower range of energies required in SNO+
- To reduce risk of contamination, work is going into using internal radioactivity of detector for calibration

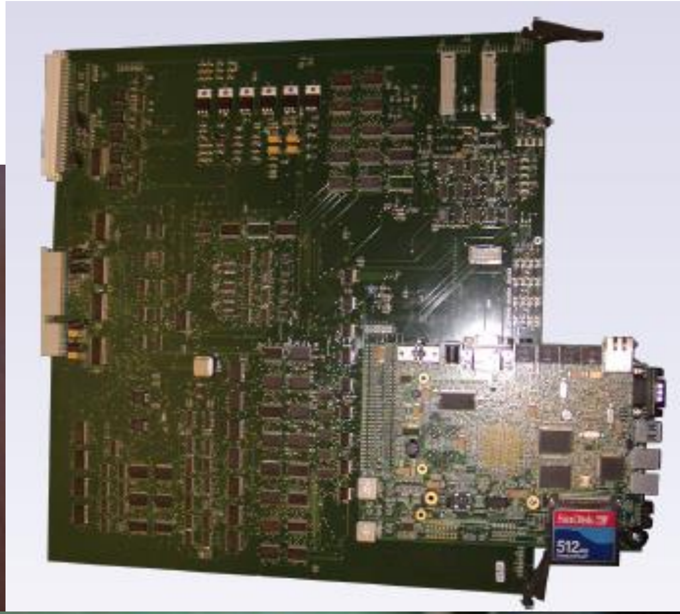
- Deployed optical source from SNO has been refurbished
- Three optical fibre systems developed to allow calibration of PMTs and measurement of scintillator properties within risking contamination
    - Fibres mounted on the PMT support structure (2/3 installed so far)
    - 92 wide-angle fibres, giving full coverage of detector, to calibrate PMTs
    - 12 narrow-angles fibres at different paths through detector and selection of wavelengths to measure scattering
    - 8 wide-angle fibres at different wavelengths to allow monitoring of scintillator properties

- “The calibration system for the photomultiplier array of the SNO+ experiment”, **arXiv:1411.4830**
- Paper on the scattering module in production



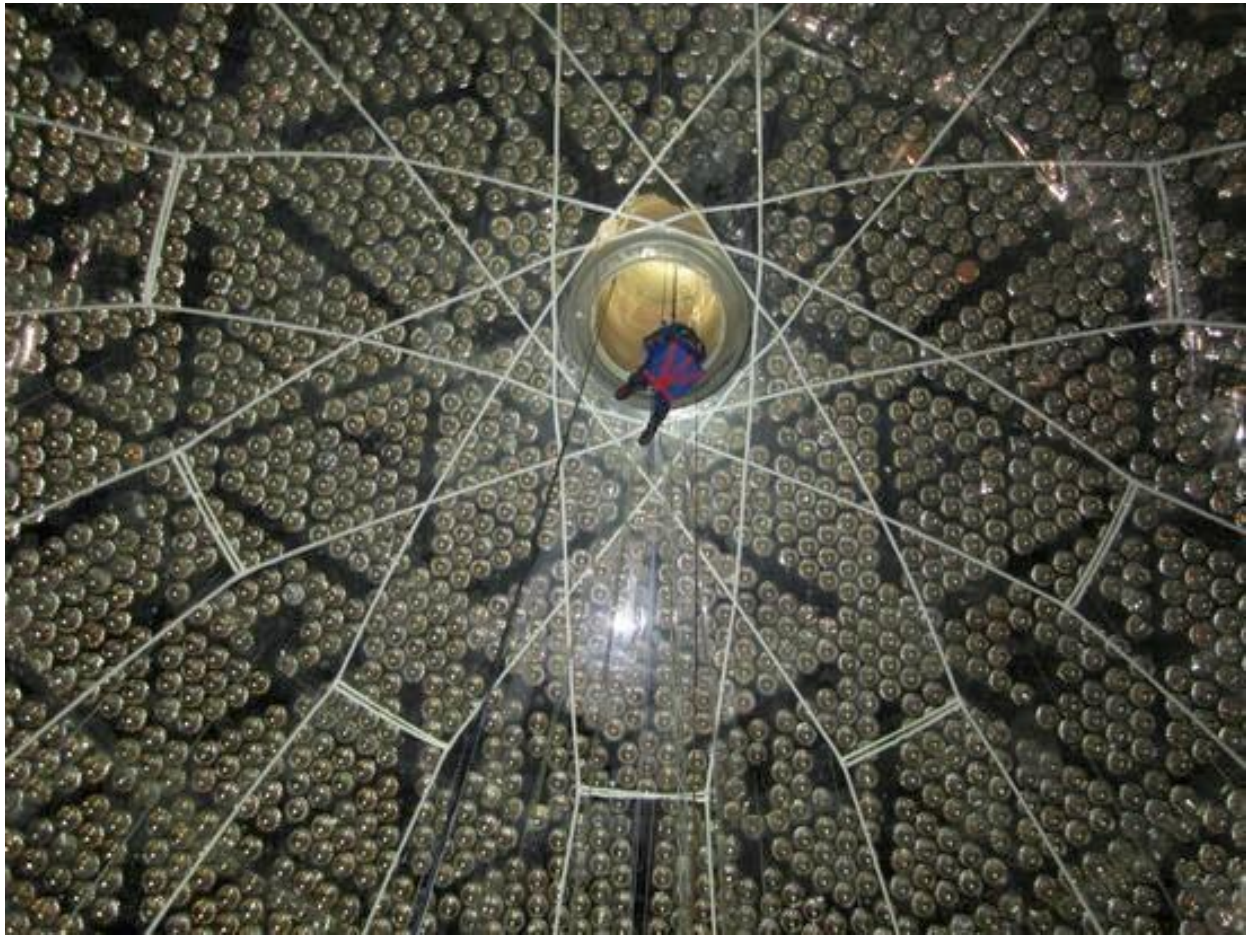
Electronics & DAQ

- Existing SNO electronics will be repaired and reused
- Some new additions:
    - XL3 readout cards can handle the higher data rates expected
    - MTCA trigger cards have ability to handle larger currents generated by greater number of PMT hits and more stable baselines
    - New utility board (TUBii) provides additional functionality, extra triggers, backup clock, pulsers and delays for calibration sources
    - CAEN Digitiser adds trigger waveforms to event data
- New DAQ system ORCA and monitoring tools have been developed



AV Ropes & Cavity

- Existing hold-up ropes replaced for new ropes with lower radioactivity
- Hold-down ropes added to hold buoyant acrylic vessel in position when filled with scintillator
- Paper on the rope system currently in production



- During filling of the cavity, a significant leak was noticed
- Currently, water level has been lowered while this is investigated

Phases of SNO+

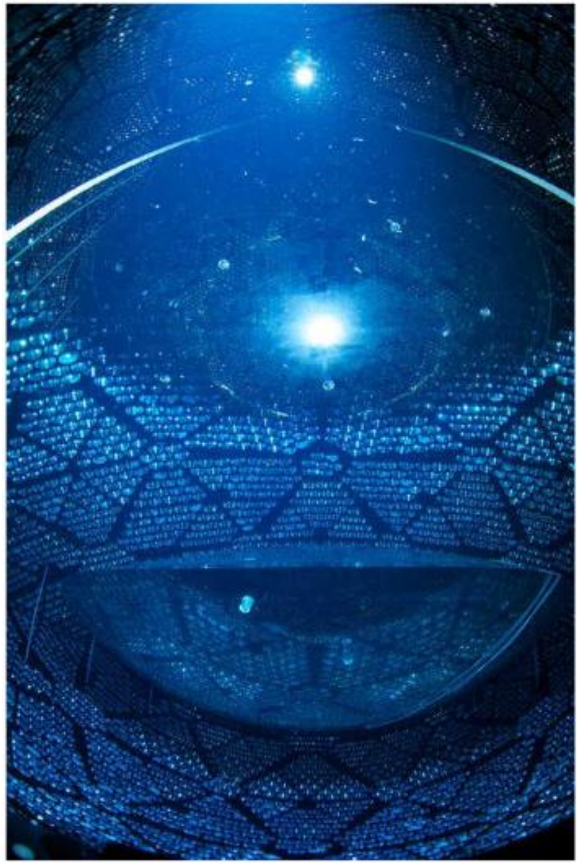
- Water phase:
  - ~ 6 months
  - Commissioning of detector, electronics and calibration sources
  - Measurements of external backgrounds
  - Invisible nucleon decay

- Pure Scintillator
  - Initially 6-12 months for detector commissioning
  - Return for longer pure scintillator phase after double beta phase ends

- Te-Loaded Scintillator
  - Load 0.3% tellurium to look for neutrinoless double beta decay
  - Onward to higher loadings

Physics Goals of SNO+

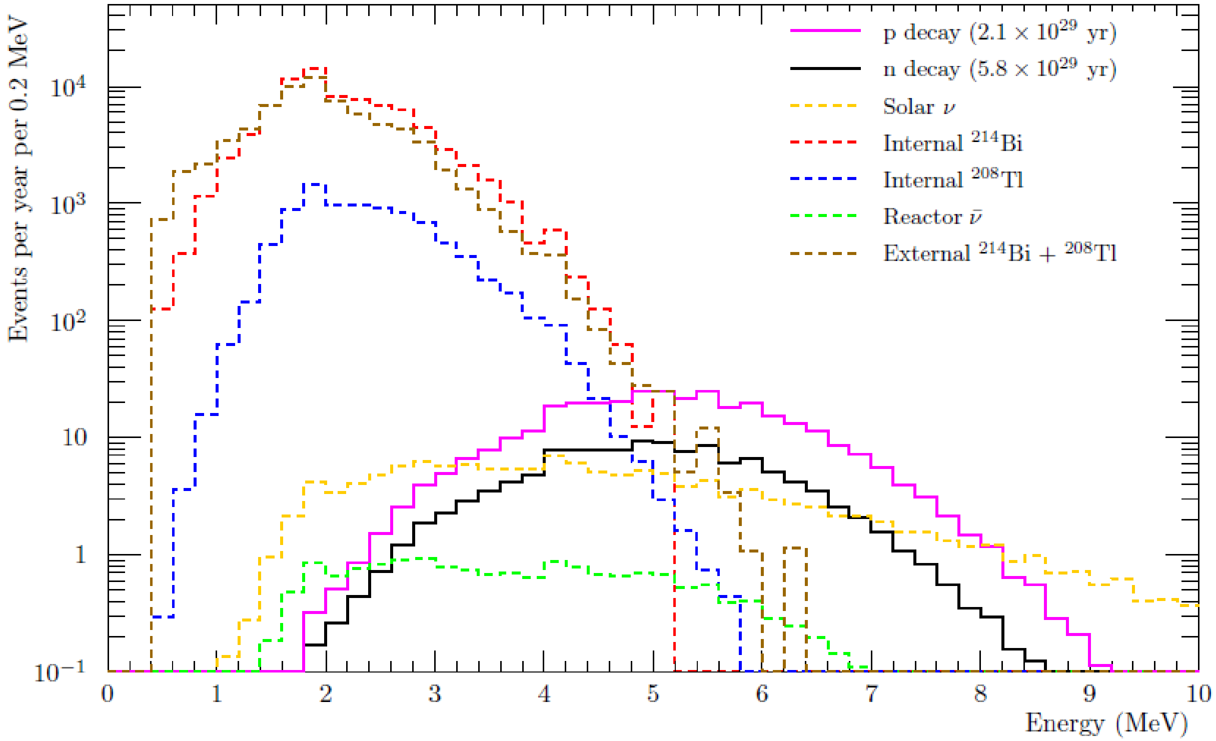
- Neutrinoless double beta decay
- Low energy solar neutrinos
- Supernova neutrinos
- Reactor anti-neutrinos
- Geo-neutrinos
- Invisible nucleon decay
- Other exotics



- New paper:
  "Current Status and Future Prospects of the SNO+ Experiment",
  arxiv:1508.05759

Sensitivity for Invisible Nucleon Decay

- During water phase, SNO+ will look for invisible nucleon decay in ^{16}O
- Model independent search for the decay of a nucleon to some undetected state,
  - e.g. n → ννν
- Decay is detected through de-excitation of remaining nucleus
  - For ^{16}O, ~40% of decays produce a ~6-7 MeV gamma
- First physics result expected from SNO+



- Why can we improve on SNO & Kamland?
  - Switch from D2O to H2O lowers NC background
  - ^{16}O has a more favourable branching ratio than ^{12}C to produce an observable signal

• SNO Limit	$\tau_p > 2.1 \times 10^{29}$ yr
• Kamland Limit	$\tau_n > 5.8 \times 10^{29}$ yr
• Expected SNO+ Limit	$\tau_p > 1.4 \times 10^{30}$ yr
(6 months)	$\tau_n > 1.3 \times 10^{30}$ yr

0νββ Sensitivity (Phase I)

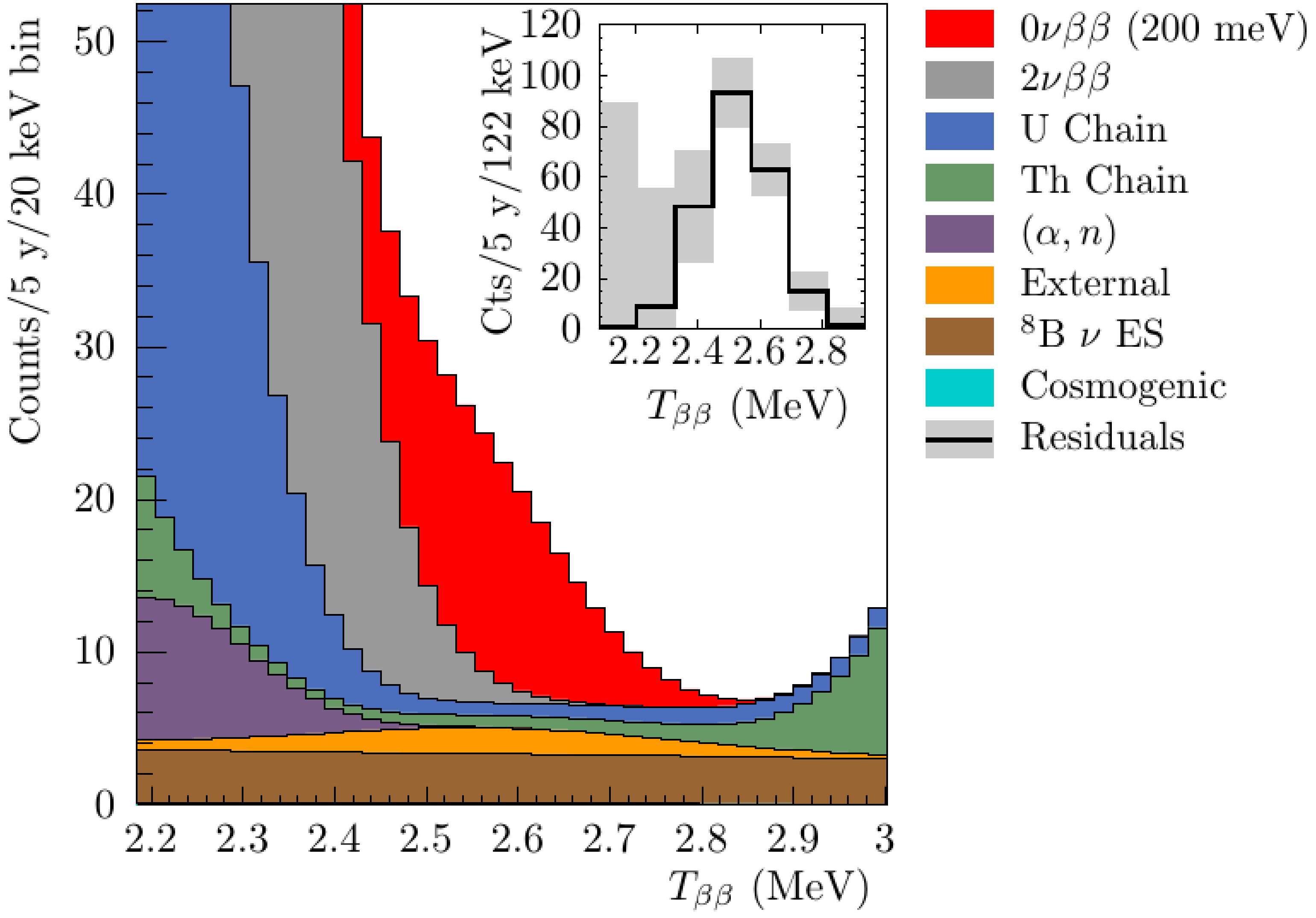
- Top physics priority for SNO+ is a 0νββ using ^{130}Te loaded into the scintillator

- Expected spectrum for 5 years assuming:
  - 0.3% ^{nat}Te loading
  - Fiducial radius of 3.5 m
  - 99.99% rejection of ^{214}BiPo
  - 98% of ^{212}BiPo
  - Light yield of 200 Nhits/MeV

SNO+ can set a lower bound of:

$$T_{1/2}^{0\nu\beta\beta} > 9 \times 10^{25}\ \mathrm{yr}\ \ (90\%\ \ \mathrm{CL})$$

Assuming a phase space factor $G=3.69\times10^{-14}$ yr^{-1} and $g_A=1.269$, this corresponds to an $m_{\beta\beta}$ of 55-133 meV



Understanding Backgrounds

2νββ:

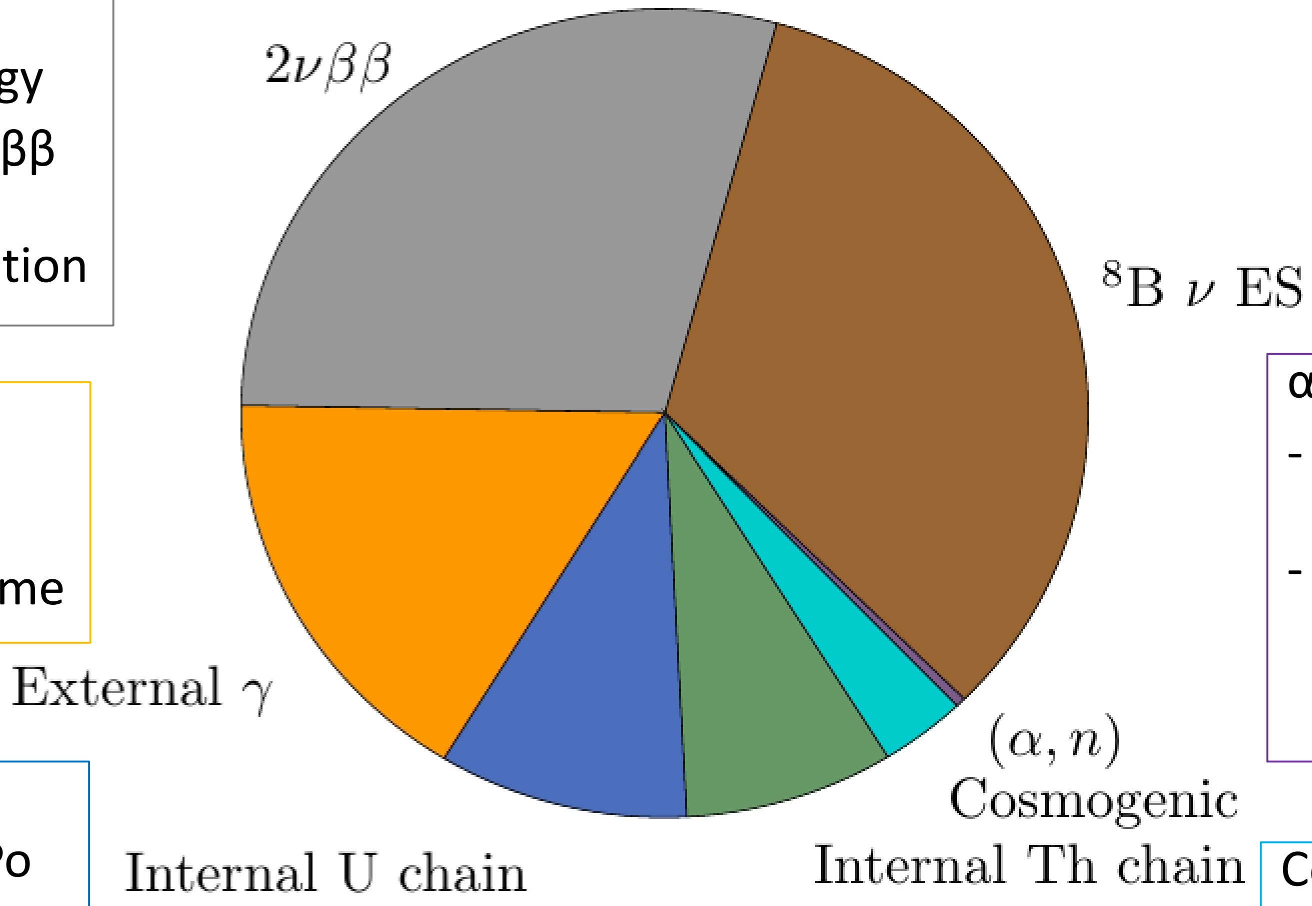
- Sharply falling with energy
- Assymetric ROI about 0νββ signal
- Limited by energy resolution

External BGs:

- From AV, ropes, PMTs, …
- Reduced by fiducial volume

Internal U/Th Chains:

- β from ^{214}BiPo and ^{212}BiPo
- Tag using time-coincidence of α follower



Solar ^{8}B:

- Flat spectrum
- Constrained by SNO/SK
- Limited by energy resolution

α-n:

- Absorption of α produces neutron
- Tagged using time-coincidence between prompt light and neutron capture gamma

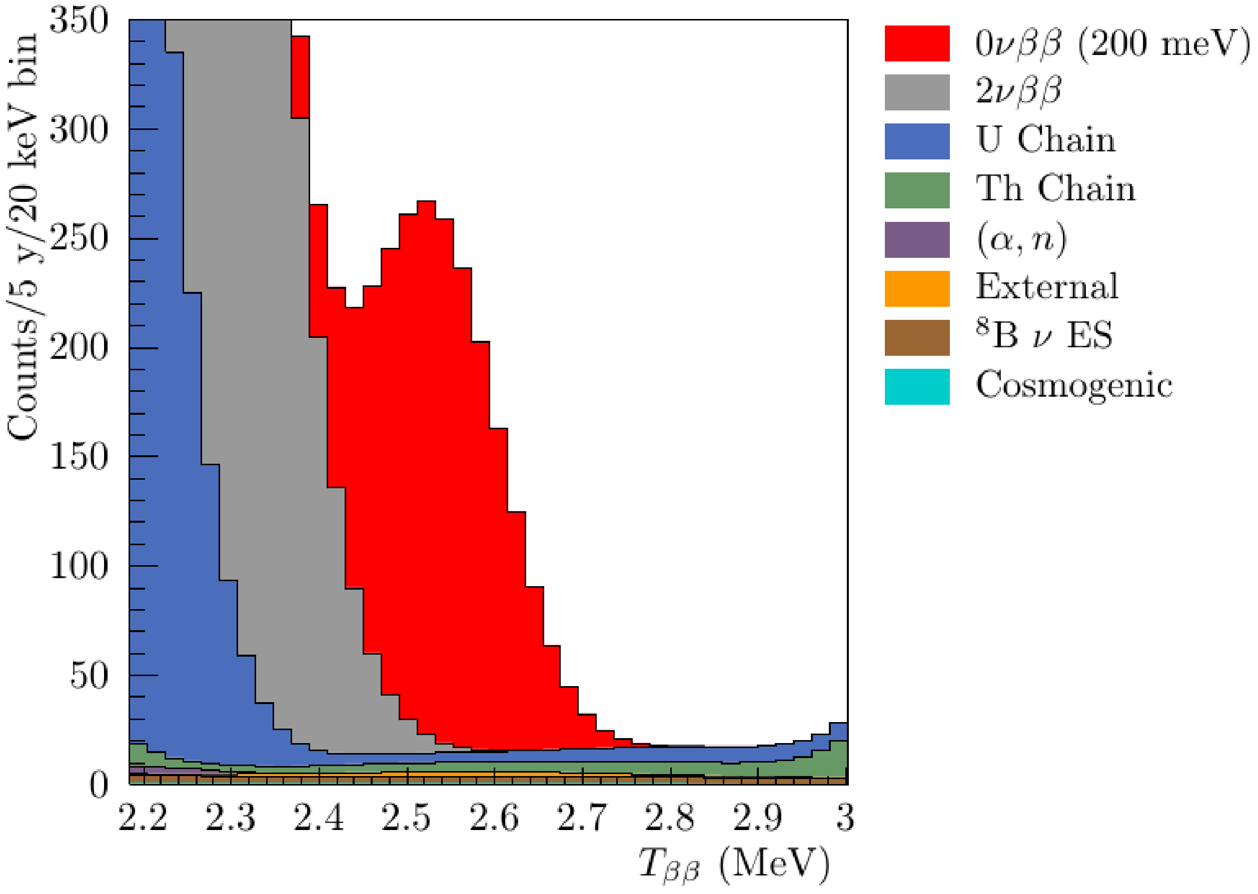
Cosmogenics:

- ^{60}Co, ^{110}Ag, ^{88}Y, ^{22}Na
- Reduced UG cool down period and purification

$0\nu\beta\beta$ Sensitivity (Phase II)

- R&D efforts have shown that 3% loading can be achieved with ~150 Nhits/MeV
- This could be compensated for by replacing PMTs with high QE PMTs and new concentrators, expected to triple light yield

- Assumptions:
  - 3% loading of ^{nat}Te
  - Fiducial radius of 3.5 m
  - Light yield of 450 Nhits/MeV



Preliminary studies suggest a sensitivity at 3% and after 5 years running of:

$$T_{1/2}^{0\nu\beta\beta} > 7 \times 10^{26} \text{ years (90\% C.L.)}$$

and $m_{\beta\beta}$ of 19-46 meV

Current Status

- Currently preparing for water-fill
  - Tests of new ropes using the buoyancy of AV
  - Installing calibration fibres
  - Replacing PMTs
  - Inspections of cavity

- Tellurium development
  - Finalising plans for the loading of 0.3%
  - Further development of higher loadings

- DAQ, electronics and data flow have been tested during “air fill” runs
  - Initial commissioning of calibration systems