

Continuing Prospects of the SNO+ Calibration Program

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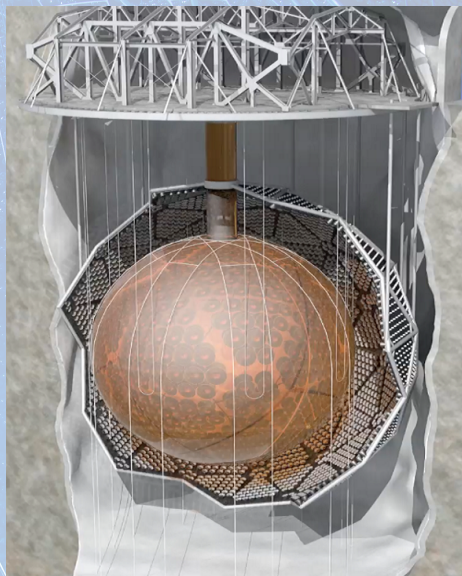
Laurentian University

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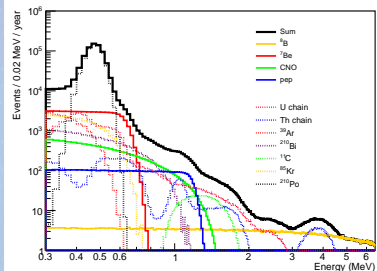
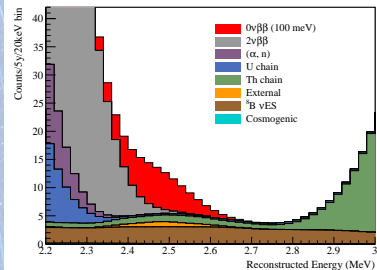
The SNO+ Experiment

- Detector situated in Vale Creighton Mine
 - ▶ 6 km water equivalent rock overburden
 - ▶ Contained in a cavity 30 m tall and 10 m in radius
- Composed of a 6 m radius spherical acrylic vessel
 - ▶ To be filled with a liquid scintillator
 - ▶ Now filled with 900 Ton ultra pure water.
- Surrounded by ≈ 9400 PMTs mounted on a 8.4 m radius geodesic sphere.
- See talk by Aleksandra Bialek (Session M1-8)

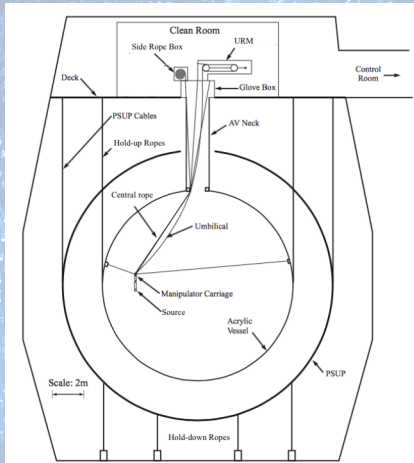


SNO+ Calibration Strategy

- Validate response at energies for
 - ▶ $0\nu\beta\beta$
 - ▶ Low energy solar neutrinos
 - ▶ Reactor anti-neutrinos
 - ▶ Geo anti-neutrinos
- Optical and radioactive sources
- Internal and external deployments
- Optics to be evaluated
 - ▶ PMT response and timing
 - ▶ Rayleigh scattering
 - ▶ Absorption of materials
- Radioactive sources validate
 - ▶ PMT response
 - ▶ Energy reconstruction
 - ▶ Position reconstruction
 - ▶ Event tagging / efficiency



SNO+ Calibration Hardware



- Umbilical/central rope stored in URM
- Four rope boxes control side ropes
- URM and rope boxes connected to AV through Universal Interface (UI)

- Sources deployed via system of ropes
 - ▶ Central rope
 - ▶ Side ropes
 - ▶ Source steered in two dimensions
- Services carried via polyurethane (tygothane) "umbilical"

External Deployment

- Guide tubes pass outside AV
- Complementary source deployment

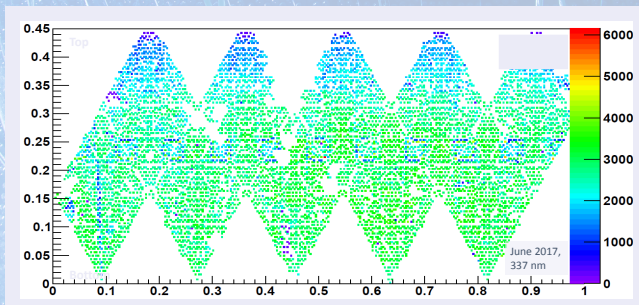


Optical Calibration

- Provides (nearly) isotropic light occupancy
- Provides strong measurement of PMT calibrations

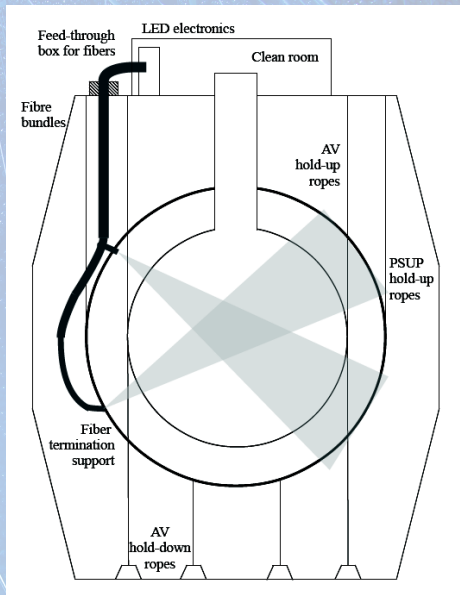
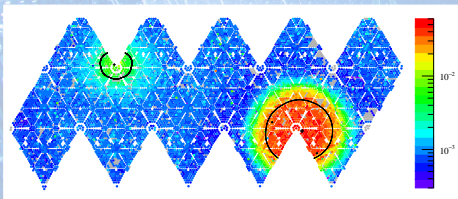


- Diffuser coupled to optical fibre (Laserball)
- Light produced from N2 laser
- Laser dye system used for other wavelengths



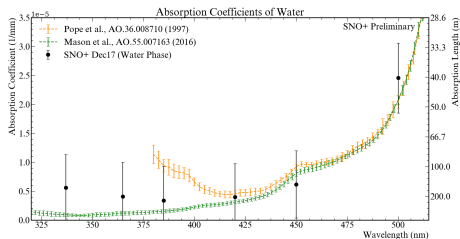
Embedded Laser Light Injection System

- PSUP embedded optical fibres
 - ▶ 106 laser injection sites
 - ▶ 96 dedicated to timing studies
 - ▶ 10 sites dedicated to scattering modules
- Calibrations conducted without deploying source
 - ▶ Plan to run as a constant PMT timing monitor



Leading Optical Results

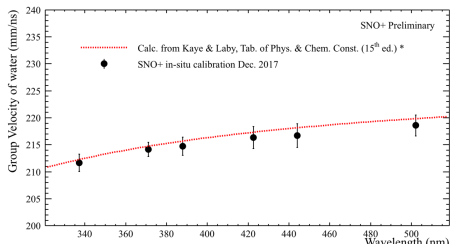
Absorption Coefficient in Water



- Produced from internal and external laserball measurements
- Significant check for water phase reconstruction and simulation

- Water measurements are a useful input to scintillator phase

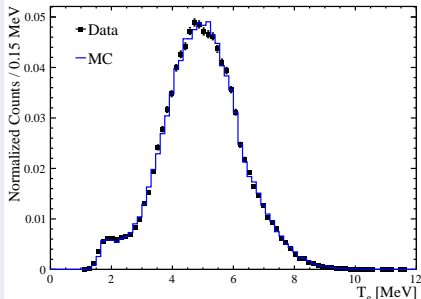
Group Velocity



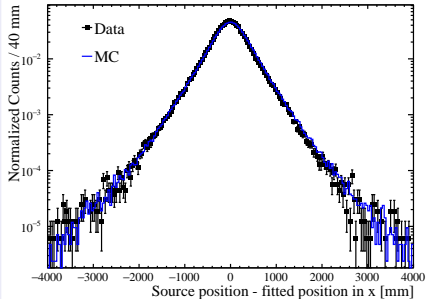
Reconstruction Response

- Measured from ^{16}N in water
 - ▶ $^{16}\text{N} \rightarrow ^{16}\text{O} \beta \gamma$ (6.13 MeV)
- Compton scatters produces signal spectrum
- β used to tag signal
- Signal spectra from data and MC to be compared

Energy Validation

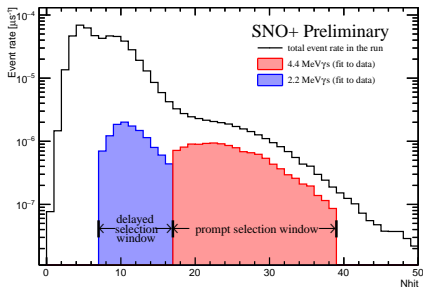


Position Validation

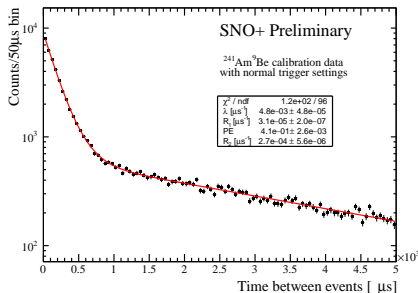


Neutron Capture Measurements

Event Selection



Capture Time

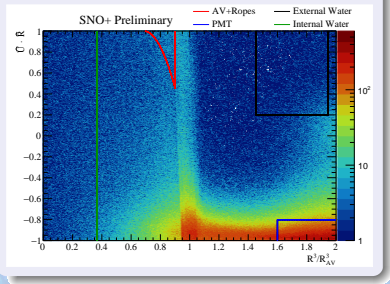


- Completed using $^{241}\text{Am}^9\text{Be}$ source
 - Produces a neutron and a 4.4 MeV γ
 - neutron capture produces a 2.2 MeV γ
- Significant for $\bar{\nu}$ detection
- Neutron detection efficiency $\approx 46\%$

- See poster by Jamie Grove: "AmBe Source Calibrations in Measuring Reactor Antineutrinos in SNO+ Water Phase"

Scintillator Requirements

Backgrounds in Water



- SNO+ requires contamination below 10^{-17} g U/g
 - ▶ Calibration hardware maintains purity requirements
 - ▶ Materials chosen for LAB compatibility

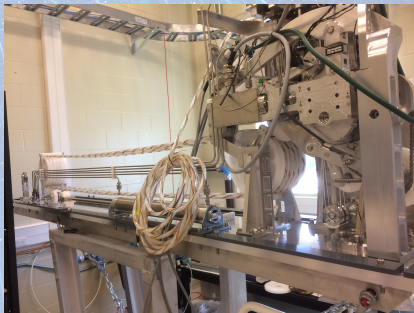
- Static N_2 volume prevents Rn ingress
 - ▶ Systems connected to detector must maintain cover gas
- Dedicated radon monitor tests cover gas purity

Radon Monitor



Hardware Upgrades

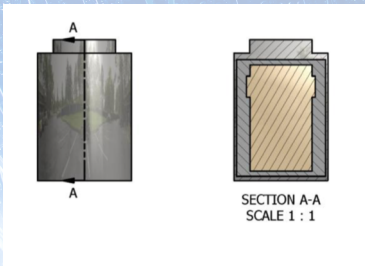
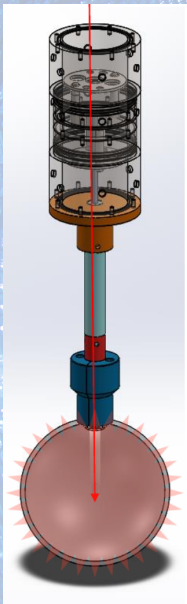
- Complete UI installed
 - ▶ Constructed for use with scintillator
 - ▶ Systems maintain cover gas through calibrations



- New URMs have been developed
 - ▶ First has been assembled and tested in Sudbury
 - ▶ Second is on its way from Portugal

Updated Calibration Sources

- Updated Laserball (Sussex) and AmBe (Snolab) sources in preparation
- Introducing tagged (UofA) and untagged (LIP) encapsulations to contain arbitrary sources



Available Energies

- Several radioactive isotopes under consideration
- First source to be deployed is $^{241}\text{Am}^9\text{Be}$

Source	Method	Deposited Energy Range
^{48}Sc	Beta Tagged	2 - 3.5 MeV
^{137}Cs	Untagged	0.1 - 0.68 MeV
$^{241}\text{Am}^9\text{Be}$	Time Coincidence	0.1 - 4.4 MeV

- Energy range of deposited energy covers that of physics
- Will also deploy ^{16}N source external to AV
 - ▶ Expect to relate measurements to internal water deployments

Conclusion

- Calibration of SNO+ water phase is complete
 - ▶ Results have been used in published papers
 - ▶ Data is still being used to refine analysis for scintillator phase
- SNO+ is progressing towards scintillator phase
- Calibration systems are similarly being upgraded
 - ▶ Embedded injection system commissioned
 - ▶ Deployment systems and sources are in development
- Goal is to begin deployments soon after complete scintillator fill