XXVIII International Conference on Neutrino Physics and Astrophysics – Heidelberg, Germany, 4-9 June 2018

Calibration of the SNO+ Detector with a Light Diffusing Source in the Water Phase

*F. Barão [1], N. Barros [2], R. Bayes [3], M. Depatie [3], **A. S. Inácio** [1], P. Khaghani [3], Y. Liu [4], J. Maneira [1], D. Pracsovics [3], G. Prior [1], P. Skensved [4], on behalf of the SNO+ Collaboration*

[1] LIP Lisbon, [2] University of Pennsylvania, [3] Laurentian University, [4] Queen's University

The SNO+ Experiment

SNO+ consists of a large volume liquid scintillator detector located 2 km underground at SNOLAB, Sudbury, Canada. It reuses most of the components of the SNO detector.

9400 PMTs with reflectors, ~50% coverage, supported by an 8.9 m radius geodesic structure (PSUP).

6 m radius Acrylic Vessel (AV)
* Currently filled with water.
* Will be filled with 780 tons of LAB + PPO (2 g/L) + bisMSB + 0.5%TeLS (1330 kg of ^{130}Te).

Hold-down and hold-up rope systems

7000 tons of ultra-pure water shielding

+ **Updated read-out/trigger electronics** to accommodate higher data rates.
+ **Scintillator Purification System**
+ **New calibration systems**

Physics goals:
- Neutrinoless Double Beta Decay of ^{130}Te;
  - Prove Majorana nature of neutrinos.
  - Demonstrate violation of lepton number.
  - Measurement of effective neutrino mass.
- Solar neutrinos;
- Reactor anti-neutrinos;
- Geo anti-neutrinos;
- Supernovae neutrinos;

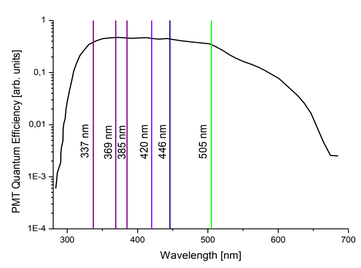
Optical Calibration with the Laserball

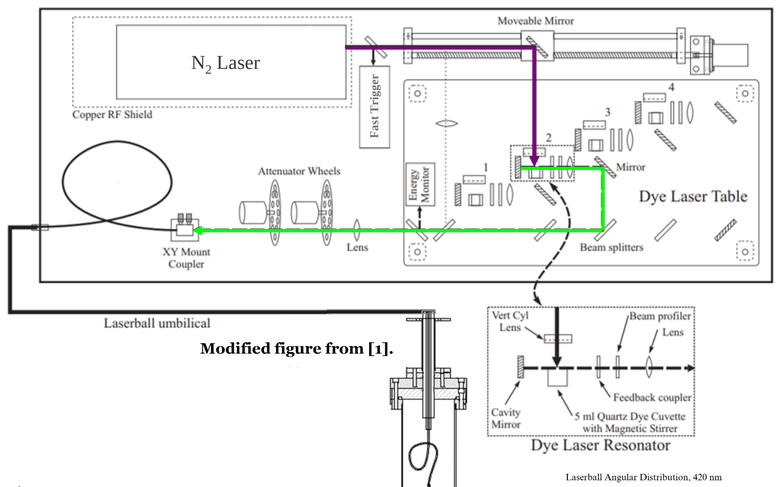
Has the purpose of characterizing how light propagates and is detected in the SNO+ detector.
The measured parameters – media attenuations, PMT response – are used to validate the simulation model and are a direct input for the reconstruction algorithms, contributing to the uniformity of the energy response.

The Laserball Hardware

Consists of a N_2-dye laser coupled to a near isotropic light diffusing sphere.
DAQ triggered externally by signal from photodiode in laser box.

- Can be deployed in several positions inside and outside the AV for:
  - Having different path lengths in each medium;
  - Covering different incidence angles at the PMTs;
- Emits light for 6 wavelengths covering the PMT sensitivity range.

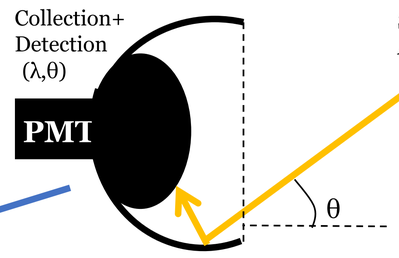


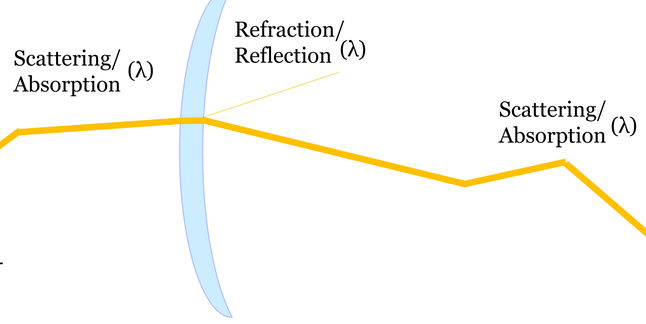


Modified figure from [1].

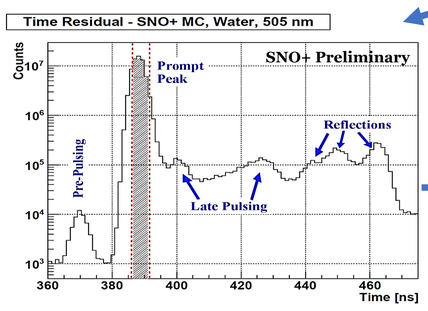
The Optical Model

The Optical Calibration uses a simplified Optical Model that excludes PMTs partially shadowed by detector components, such as ropes, and uses only the direct light detected by the PMTs, identified by the prompt peak.





Water Shielding Volume **AV** **Inner AV Water**

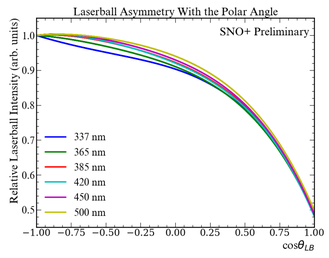


$$O_{ij} = N_i L_{ij} \Omega_{ij} T_{ij} R_{ij} \epsilon_j exp\left(-\sum_{Medium\ k} d_{ij,k}\alpha_k\right)$$

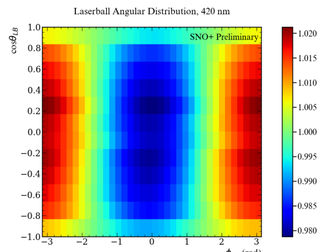
Source

Direct light detected | Solid Angle | Fresnel | PMT Response | PMT Efficiency | Distance travelled | Attenuation

The parameters of the model are extracted from Laserball data through a multiparameter fit.



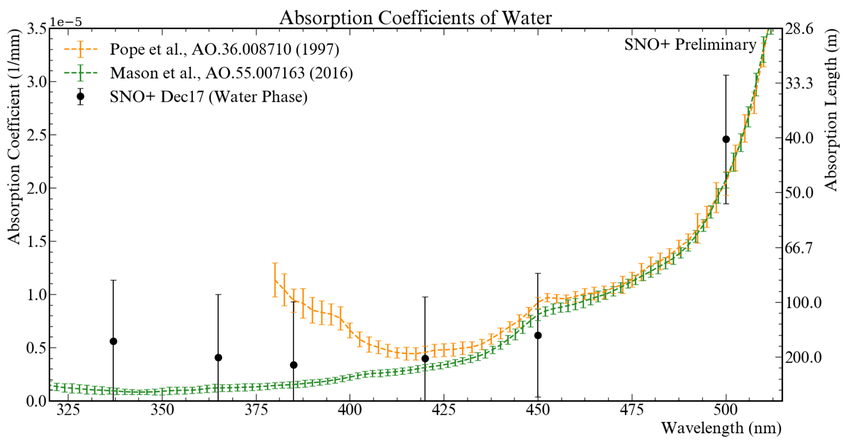
Laserball main anisotropy



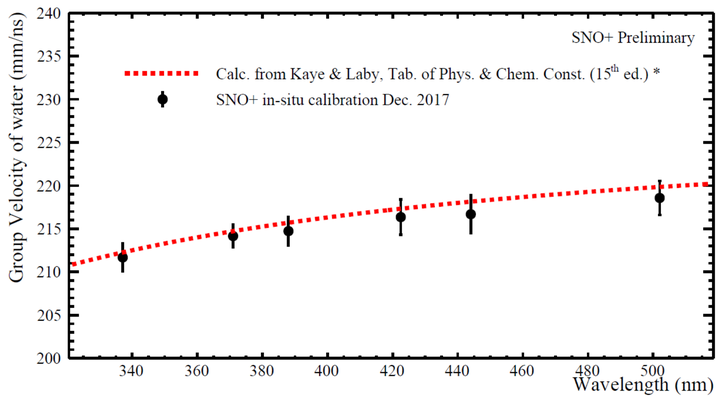
Laserball residual anisotropy

Water Phase Results

Water Properties

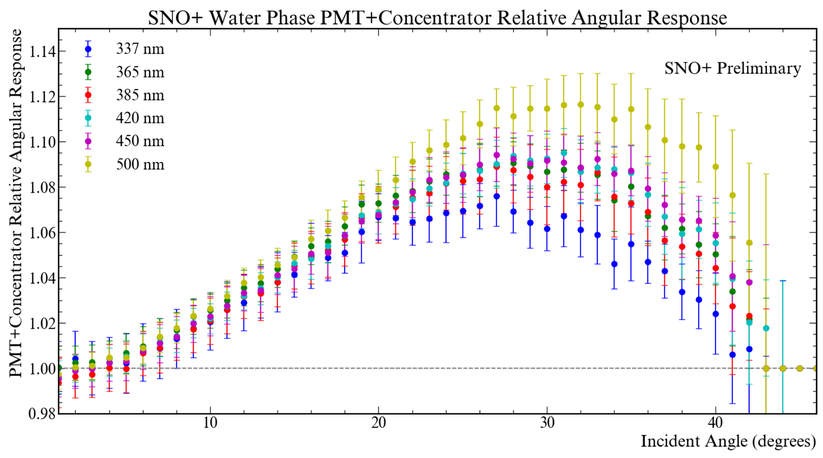


In black, the SNO+ ultra-pure water absorption coefficients (left vertical axis) and lengths (right vertical axis) as a function of wavelength. The coloured data points are from literature references.

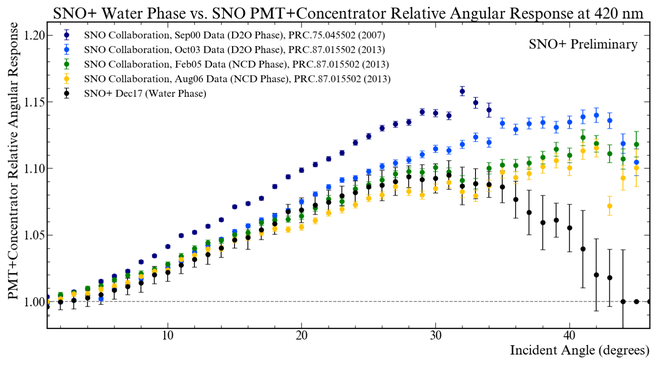


Group velocity measured by comparing PMT timing on pairs of laserball runs at different positions along the detector vertical axis. (*) as referenced by R. Boardman, Ph.D. Thesis, Oxford (1992)

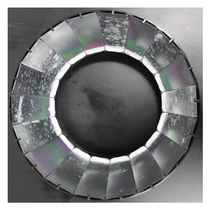
PMT+Concentrator Angular Response



Relative PMT Angular Response as a function of the incidence angle of light at the PMT+concentrator assembly, for the six wavelengths emitted by the Laserball. The angular response values are normalized to the response at a normal incidence.



Measured SNO+ PMT+concentrator angular response at 420 nm compared with previous measurements from the SNO experiment.



Angular Response changes at high incident angles with time due to degradation of the reflectors.

- Laserball deployed inside the SNO+ detector!
  - December 2017: 204 runs collected in 35 positions inside the AV, using the 6 available wavelengths.
  - More data coming during the summer, including positions with the laserball outside the AV.
- The parameters of the Optical Model were successfully extracted from the first set of Laserball data in the Water Phase.
- The knowledge of the detector's optical response is crucial for the simulation and reconstructions throughout all SNO+ phases.

See also:
- Talk "SNO+" by G. D. Orebi Gann
- Poster "AmBe Source Calibration in the SNO+ Water Phase" by Y. Liu
- Poster "Data Quality and Run Selection for SNO+" by E. Caden
- Poster "Internal Backgrounds in the Water Phase of SNO+" by I. Lam
- Poster "SMELLIE: A Laser Calibration System for SNO+" by E. Turner
- Poster "SNO+ Tellurium Loading for Neutrinoless Double Beta Decay" by S. Manecki

References

[1] SNO Collaboration, Optical Calibration Hardware for the Sudbury Neutrino Observatory. Nucl.Instrum.Meth. A554 (2005)

ACKNOWLEDGEMENTS This work is funded by EGI, GridPP, Compute Canada, CFI, STFC, NSERC, CFI, CIFAR, FCT, Deutsche Forschungsgemeinschaft, ERC, DOE, NSF, Berkeley, ASRIP, Ontario MRI, FedNor, Queen's University.
The presenter Ana Sofia Inacio is funded by FCT-IDPASC, PhD grant reference PD/BD/135468/2017, and the FCT project PTDC/FIS-NUC/0640/2014 . We thank SNOLAB and Vale for their valuable support.