Optical Calibration in the SNO+ Water Phase

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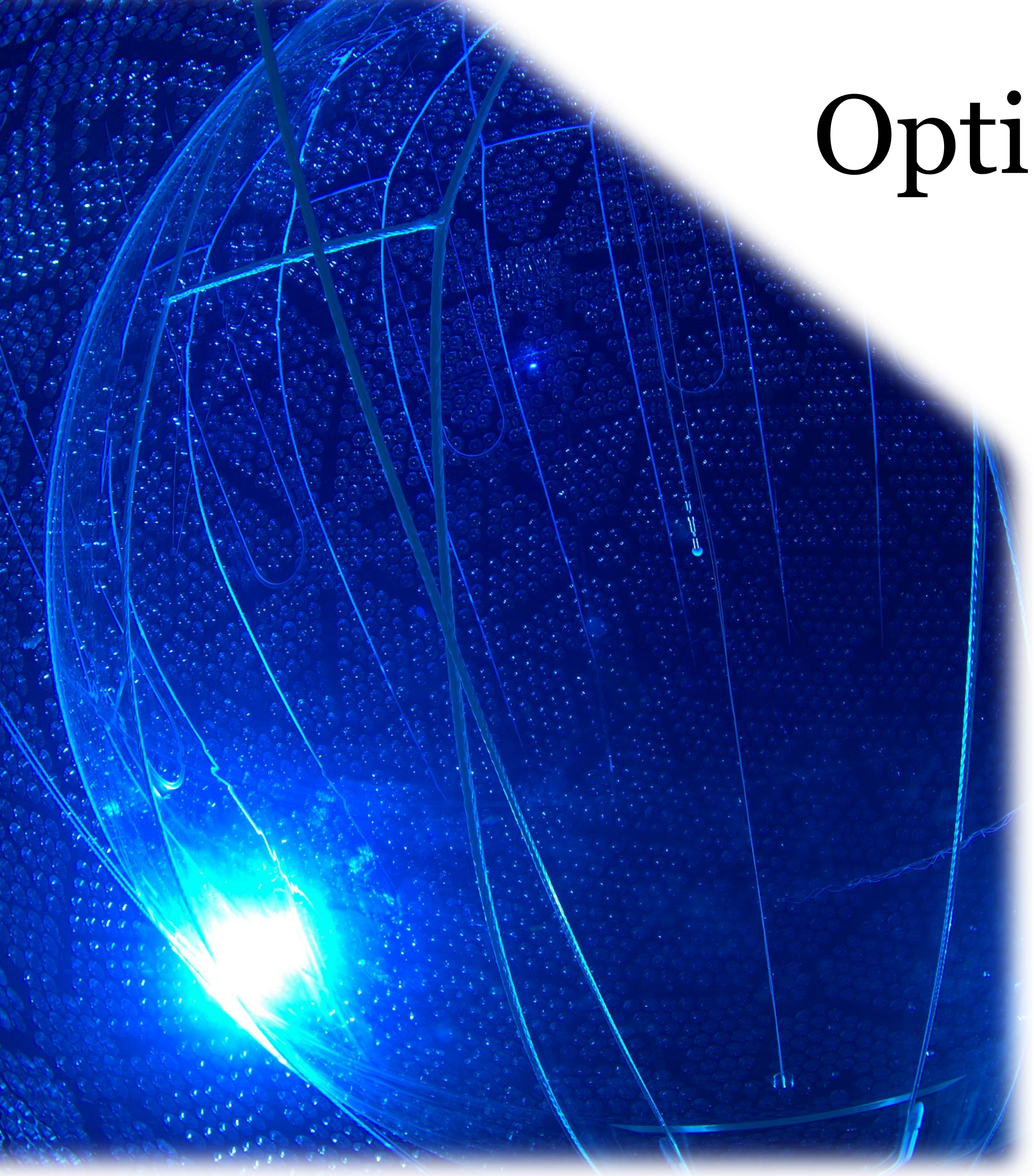


The SNO+ Experiment

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)

- Water Phase: 905 tonnes of ultra-pure water.
- Will be filled with 780 tons of LAB + PPO (2 g/L) + bisMSB + 0.5% natural Te (1330 kg of ^{130}Te).

Hold-down and hold-up rope systems

7000 tons of ultra-pure water shielding

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;

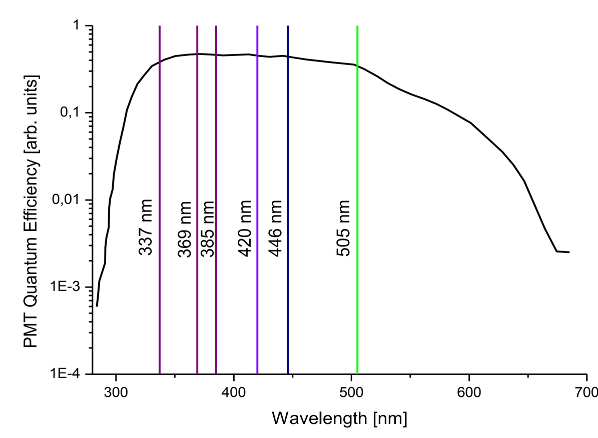
Optical Calibration with the Laserball

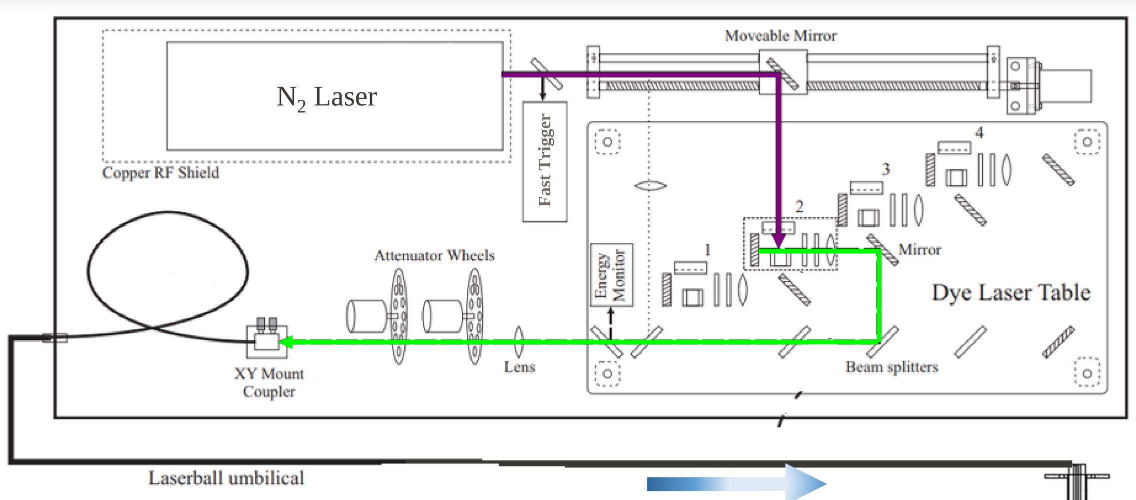
How does light propagates and is detected in the SNO+ detector?
The measured parameters – media attenuations, PMT response – are inputs to the simulation model and reconstruction algorithms, contributing to the uniformity of the energy response.

The Laserball Hardware

N_2-dye laser coupled to a near isotropic light diffusing sphere.

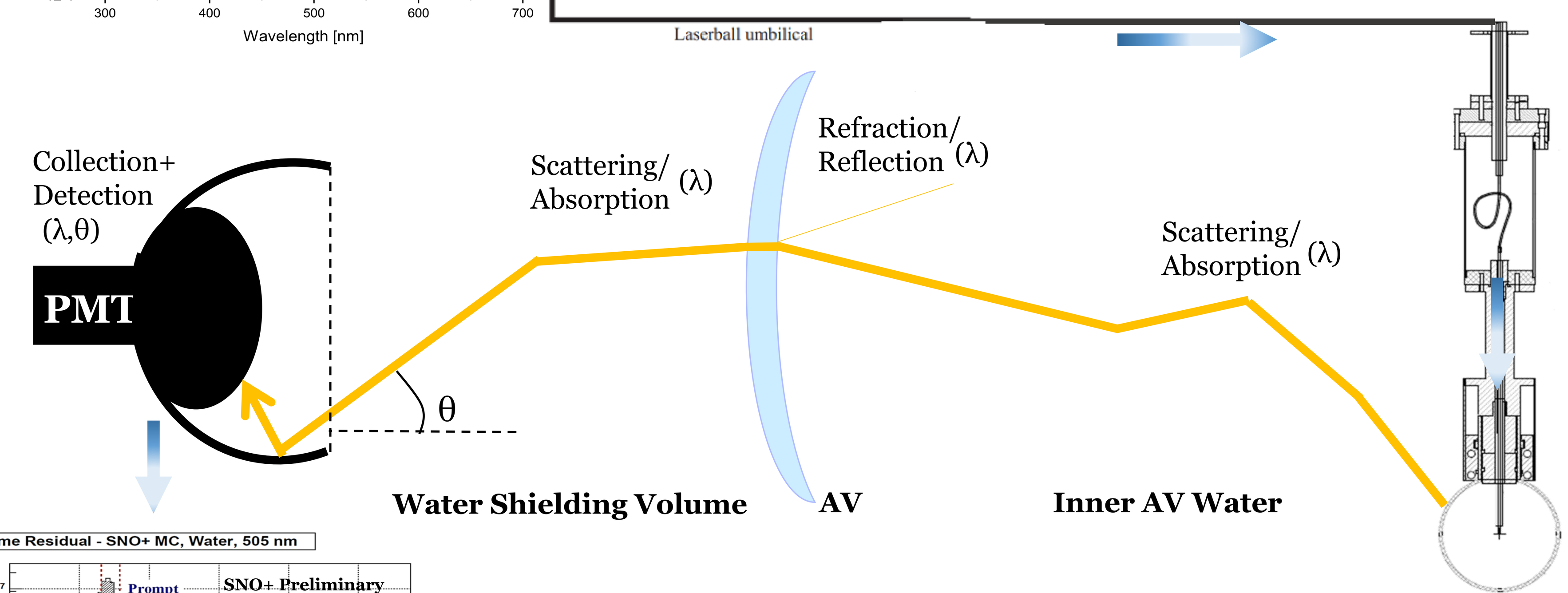
- Deployed in several positions inside and outside the AV:
  - Different path lengths in each medium;
  - Different incidence angles at the PMTs;
- Six wavelengths covering the PMT sensitivity range.

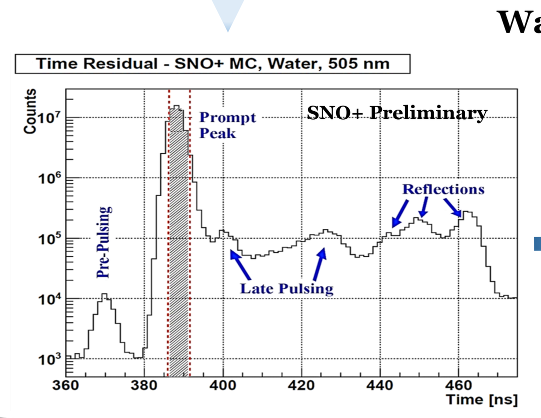




The Optical Model

Simplified model that excludes PMTs shadowed by detector components, and uses only the direct light detected, identified by the prompt peak. The parameters are extracted from data through a multiparameter fit.





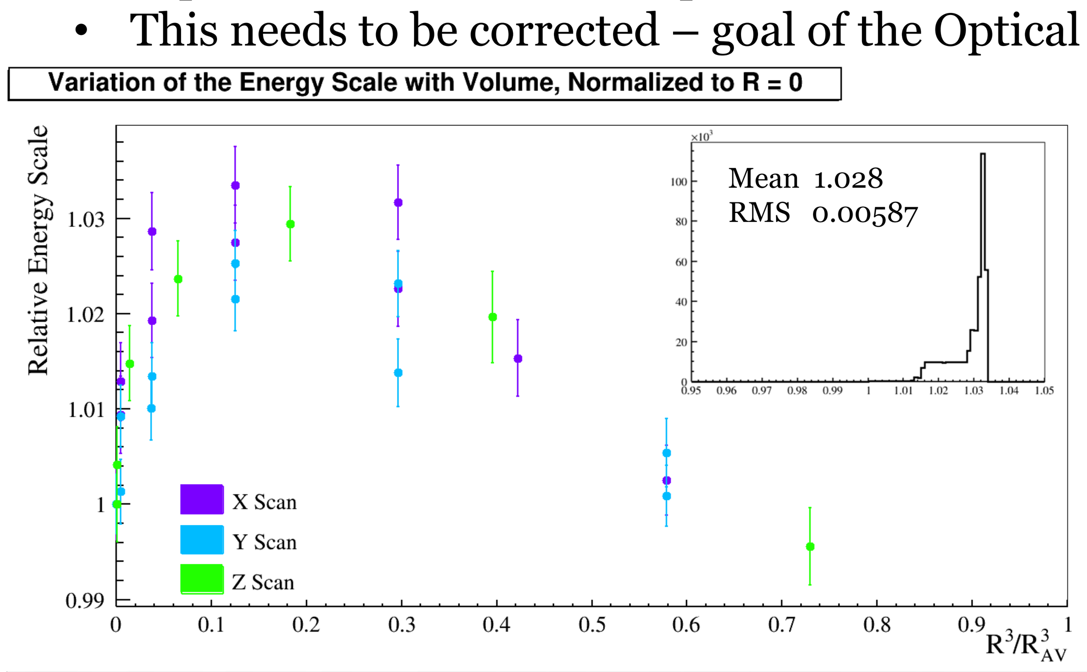
$$O_{ij} = N_i L_{ij} \Omega_{ij} T_{ij} R_{ij} \epsilon_j exp\left(-\sum_{Medium\ k} d_{ij,k}\alpha_k\right)$$

i - run/position, *j* - PMT. Source ($N_i L_{ij}$); Direct light detected "Occupancy" (O_{ij}); Solid Angle (Ω_{ij}); Fresnel (T_{ij}); PMT Response (R_{ij}); PMT Efficiency (ϵ_j); Distance travelled ($d_{ij,k}$); Attenuation (α_k).

Impact of the Optics in the Physics

The reconstructed energy of a physics event is proportional to the number of photons detected.

- The proportionality constant – **energy scale** - is position dependent because of the optics effects.
- This needs to be corrected – goal of the Optical Calibration!

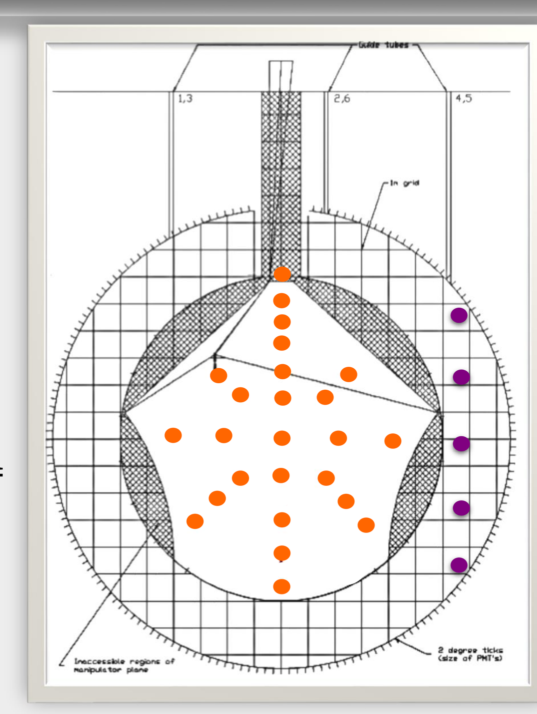


Variation of the energy scale with position up to 3.4%, relative to the center of the detector.

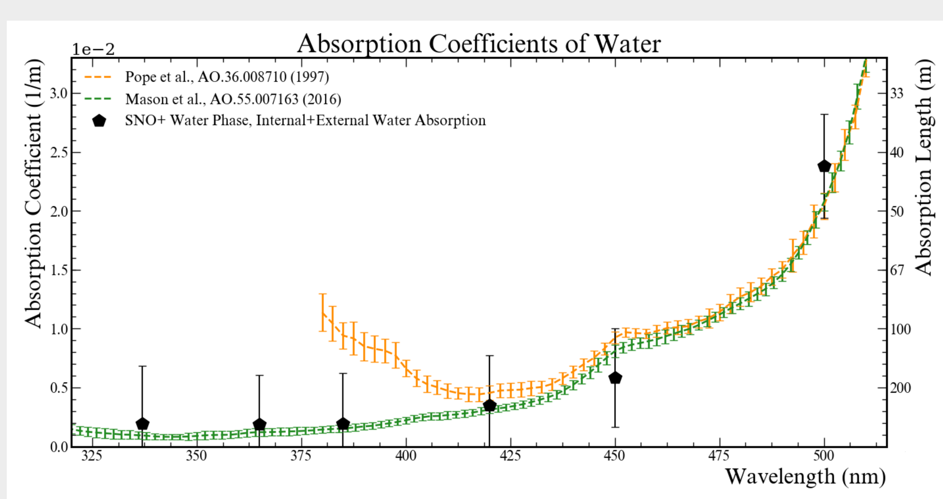
Water Phase Results

- Laserball deployed inside the SNO+ detector!

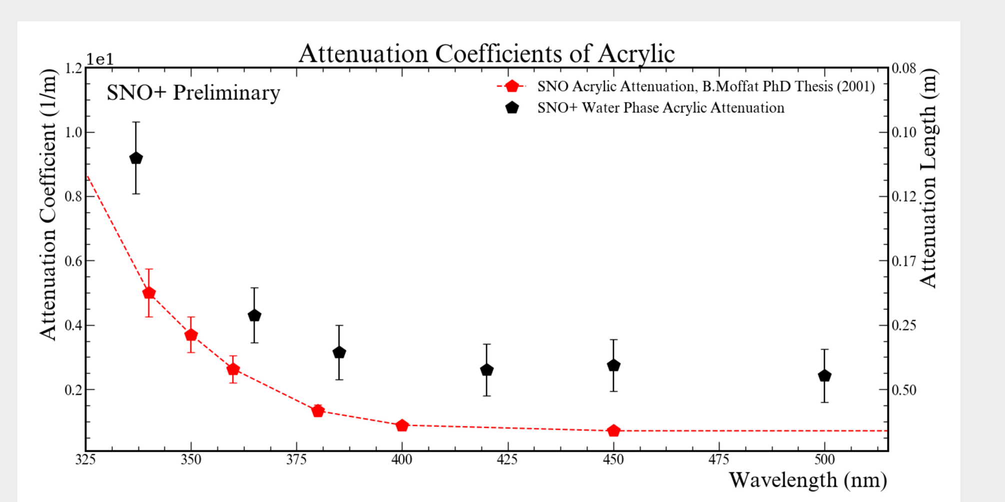
	Runs	Positions	Wavelengths
December 2017	204	35 internal	6
July 2018	384	16 external + 42 internal	6



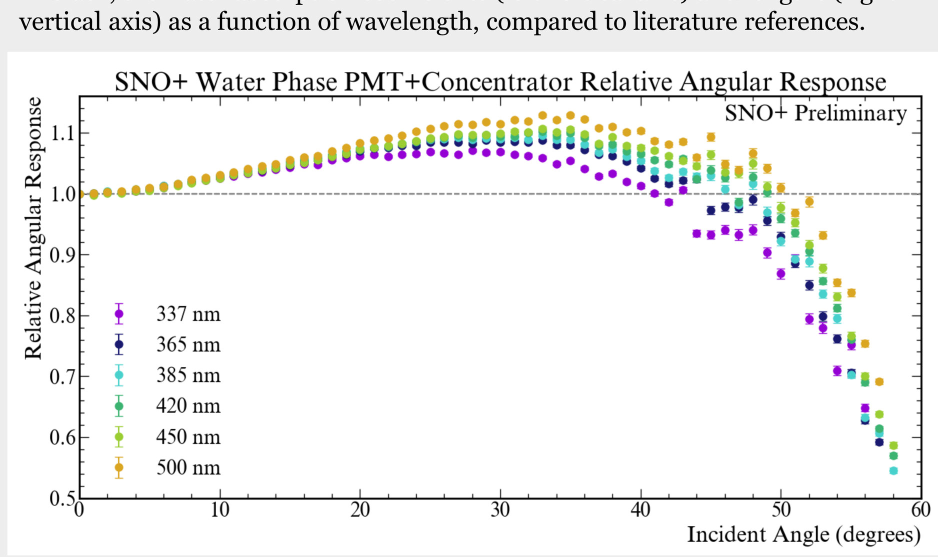
- The parameters of the Optical Model were successfully extracted.
  - **First in-situ measurements of the acrylic attenuation and PMT response at incidence angles above 45 degrees.**
- The knowledge of the detector's optical response is crucial for the simulation and reconstructions throughout all SNO+ phases.



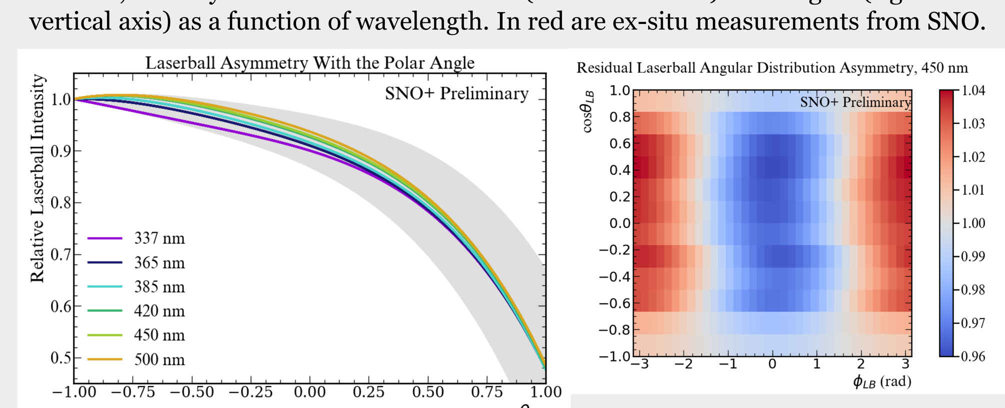
In black, the water absorption coefficients (left vertical axis) and lengths (right vertical axis) as a function of wavelength, compared to literature references.



In black, the acrylic attenuation coefficients (left vertical axis) and lengths (right vertical axis) as a function of wavelength. In red are ex-situ measurements from SNO.



PMT+concentrator angular response as a function of incidence angle. The values at incidence angles higher than 45 degrees were measured for the first time in-situ due to the inclusion of the external laserball runs.



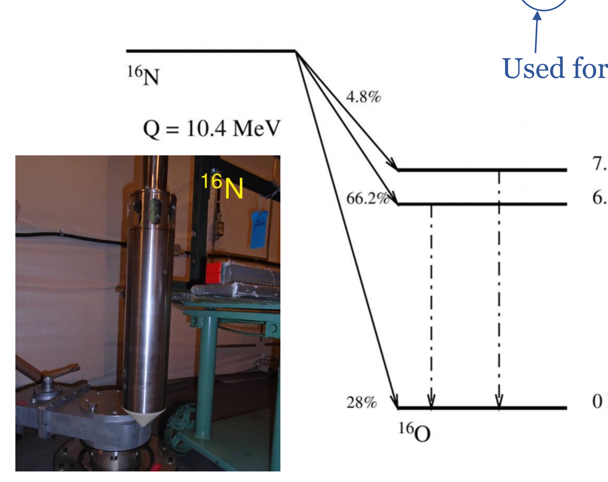
Left: Relative laserball intensity as a function of cos(θ). It shows the top-bottom asymmetry in the intensity of light emitted by the source: it emits less light on the bottom than on the bottom, mainly due to shadowing by the mounting hardware. This is the main anisotropy in the laserball light emission.
Right: Laserball residual asymmetry with the laserball polar (θ) and azimuthal (Φ) angles.

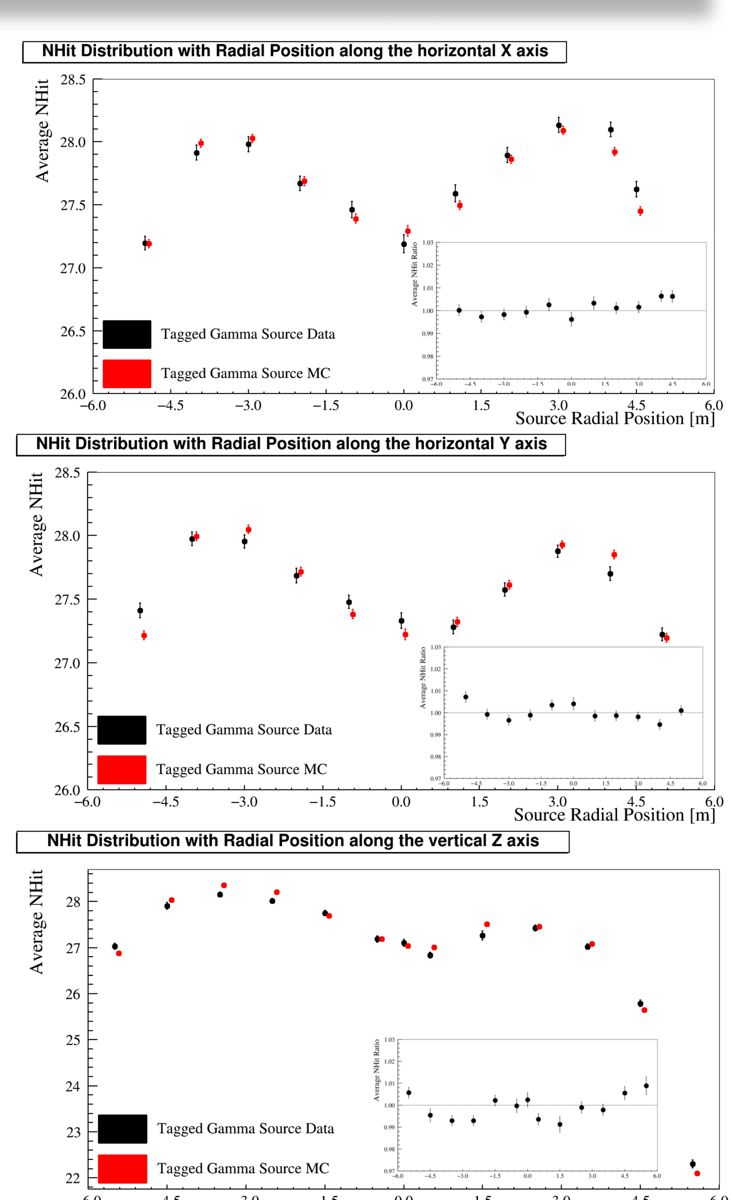
Validating the Results with the ^{16}N Source

Source inherited from SNO, generated on site with a neutron generator:

$$^{16}O + n \rightarrow {}^{16}N + p$$
$$^{16}N \rightarrow {}^{16}O^* + e^- + \overline{\nu}_e$$
$$^{16}O^* \rightarrow {}^{16}O + \gamma$$

Used for the calibration





Validation technique: compare the average number of hits between data and simulation, at different positions inside the AV.

Agreement better than 1%

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