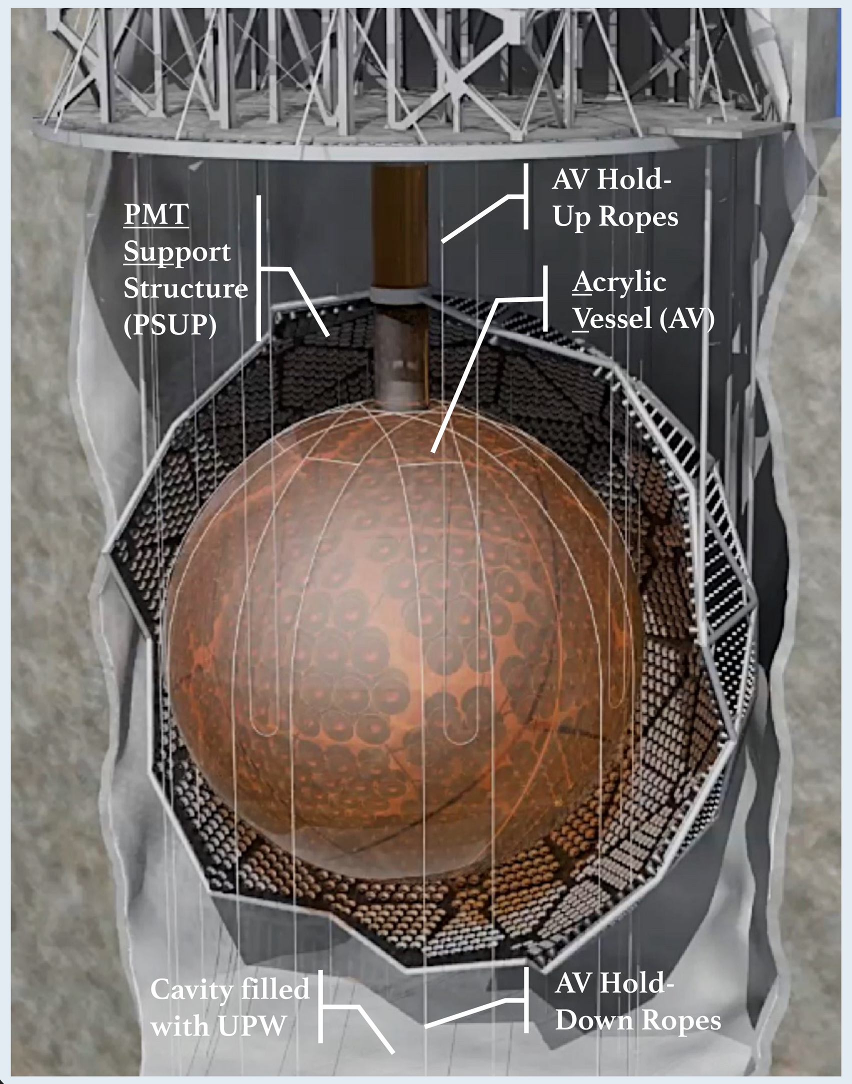
Optical Calibration Using Internal Radioactivity

A. Allega, R. Dehghani & S. Riccetto on behalf of the SNO+ Collaboration

The SNO+ Experiment



- The SNO+ experiment [1] is a multi-purpose neutrino detector situated 2 km underground at SNOLAB in Sudbury, Ontario, Canada.
- The experiment is designed to operate in three phases: water (*completed*), liquid scintillator (*underway*) and ^{130}Te-loaded scintillator (*future*).
  - Water phase physics results are being published [2,6–8].
  - Scintillator phase analyses well advanced.
- The detector contains 780 tonnes of linear alkylbenzene (**LAB**) as the scintillator with 2,5-diphenyloxazole (**PPO**) fluor housed inside of the 12 m-diameter **A**crylic **V**essel (**AV**).
- The AV is surrounded by a support structure of roughly 9500 **P**hoto-**M**ultiplier **T**ubes (**PMTs**).
- The physics program includes the search for neutrinoless double beta ($0\nu\beta\beta$) decay with a ^{130}Te target, invisible nucleon decay, geo-neutrinos, reactor antineutrinos, supernova and low energy solar neutrinos.

Optical Calibration

- An accurate analysis of the data requires understanding the energy response of the detector, which means that the optical properties of the different detector components must be measured and accounted for.
- Optical properties are typically calibrated through:
  - *Ex-situ* measurements [4].
  - Measurements using deployed sources [3].
  - Light injected using a system of permanently installed fibre optics [5].
  - Light produced by trace radioisotopes in the scintillator.

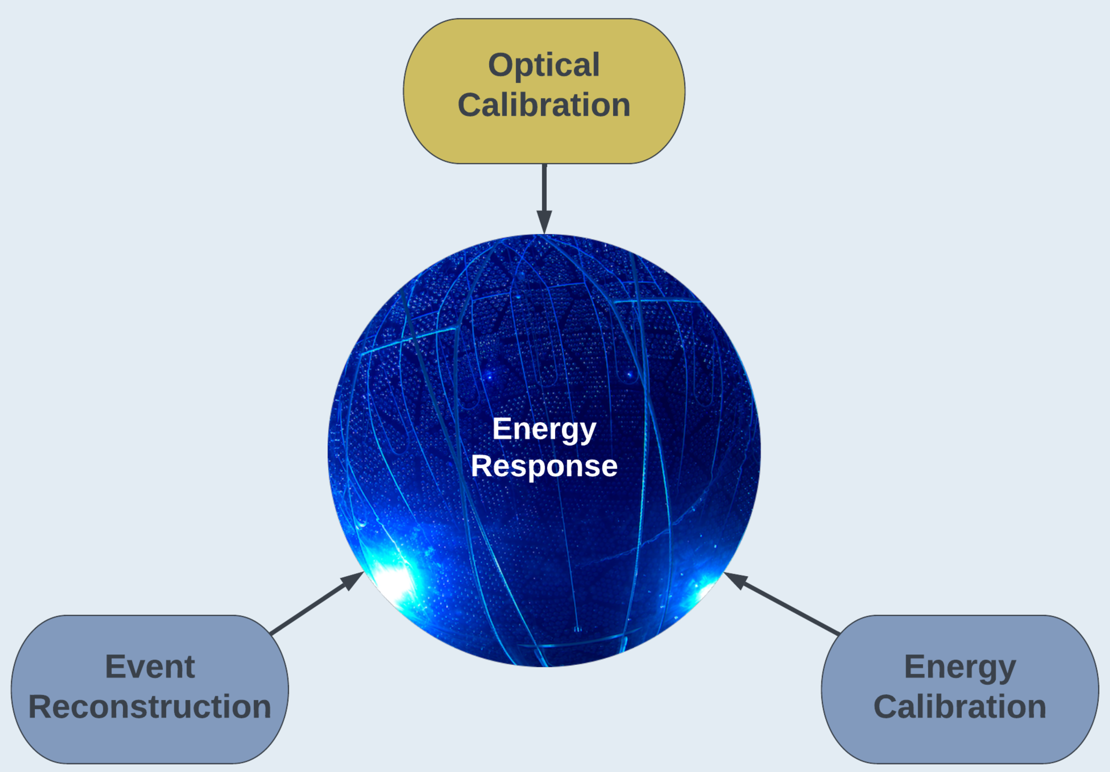


Figure 1: Inputs for characterizing energy response.

In-Situ Approach

- The method presented in this poster uses natural radioactivity in the scintillator to track the optical parameters.
- Using natural internal radioactivity allows for real-time optical calibrations and minimizes the number of calibration source deployments.
  - Radioisotopes that can be used include ^{210}Po and ^{214}Bi-^{214}Po from the ^{238}U decay chain (see Fig. 2).

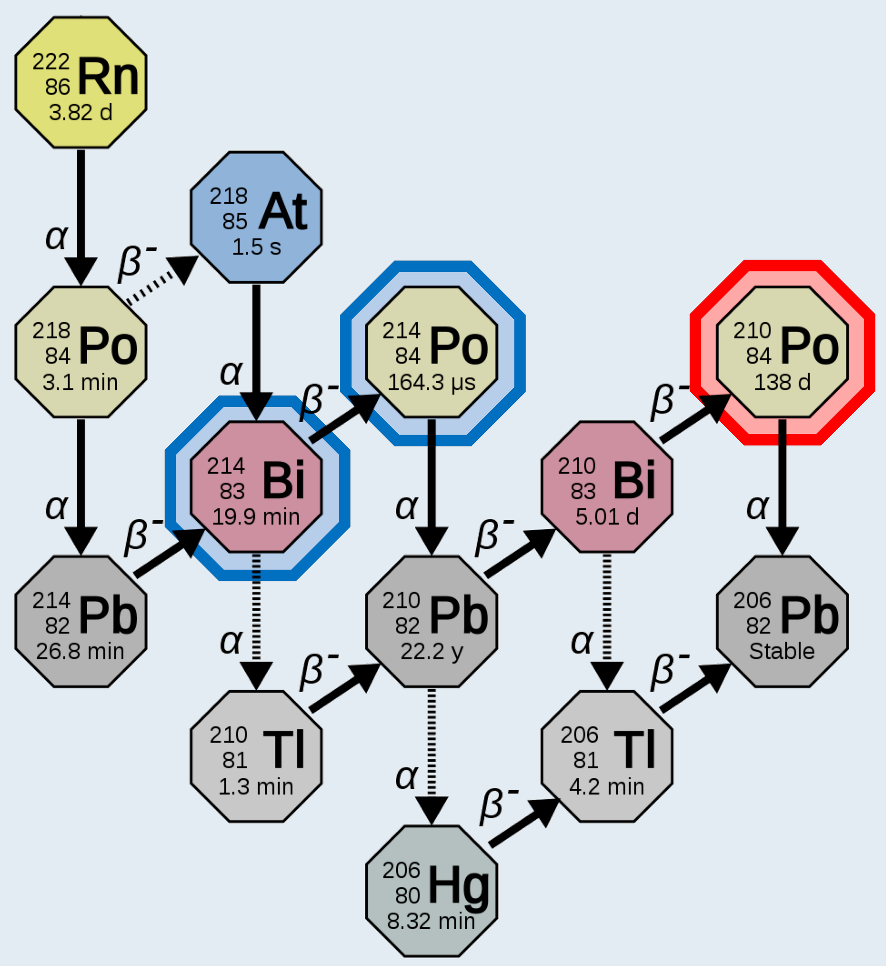


Figure 2: ^{222}Rn decay chain. File modified from Tosaka, licensed under the Creative Commons Attribution 3.0 Unported License.

Extracting Optical Parameters from Radial Profiles

- The simulated light yield of ^{210}Po events in SNO+ as a function of radial position is shown in Fig. 3 (top).
- Fitting the Gaussian mean in each radial slice maps the radial profile of the detector response to the (mono-energetic) ^{210}Po.
- The slope of the detector response for $R < 4$ m depends on the scintillator absorption length. For $R > 4$ m the shape of the response includes increased optical effects from the AV and the PMT angular response.
- Fig. 3 (bottom) shows the mean radial profiles from simulations done with different assumed scintillator absorption lengths. The change in the overall amount of light collected is degenerate with the raw light yield of the scintillator, which must also be calibrated.
  - Fitting the slope of the radial profile for $R < 4$ m gives a simple metric that is sensitive to the scintillator absorption length (see Table 1).

Absorption Scaling (LAB)	Slope from $0\,\mathrm{m} < R < 4\,\mathrm{m}$ [hits/m]
1.00	1.1 ± 0.3
1.25	2.2 ± 0.3
2.00	2.7 ± 0.3
2.50	2.5 ± 0.3
4.00	3.3 ± 0.3
5.00	3.3 ± 0.3

Table 1: Results of linear fit to radial profiles.

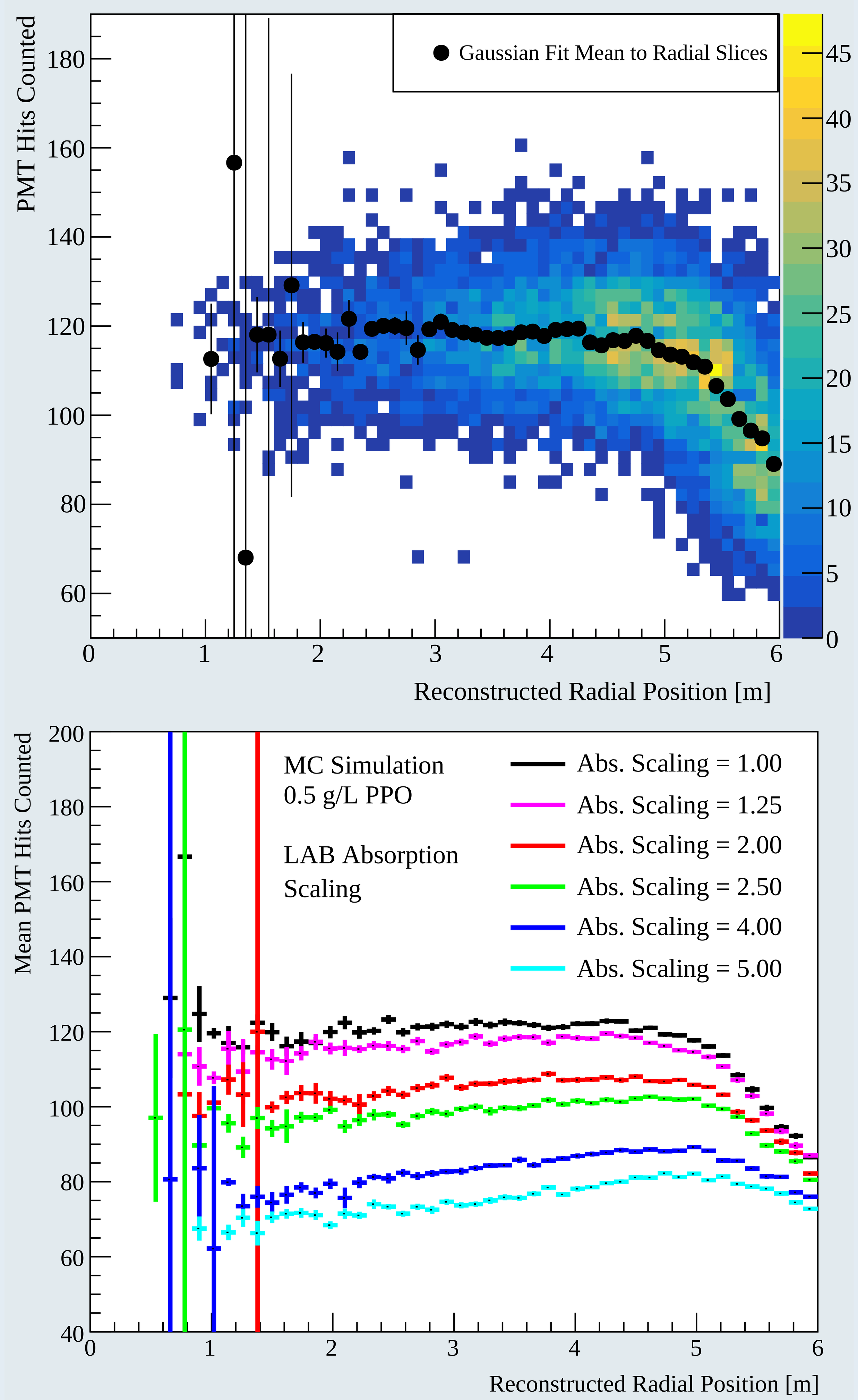


Figure 3: Simulated radial profiles of ^{210}Po.

Conclusions

- Using natural radioactivity within the SNO+ detector allows for real-time optical calibrations by tracking the slope of the radial profile for given sources of radioactivity.
- The method has been used throughout the PPO top-up campaign to monitor the optical response of the scintillator.
- With the PPO concentration now finalized a detailed program to characterize the final scintillator optics is underway.

References

[1] The SNO+ collaboration *et al* 2021 *JINST* **16** P08059
[2] A. Allega et al. (The SNO+ Collaboration). arXiv: 2205.06400. Submitted to Phy. Rev. D.
[3] SNO+ collaboration *et al* 2021 *JINST* **16** P10021
[4] The SNO+ collaboration *et al* 2021 *JINST* **16** P05009
[5] R. Alves *et al* 2015 *JINST* **10** P03002
[6] M. Anderson *et al*. (SNO+ Collaboration) Phys. Rev. D **99**, 012012 (2019)
[7] M. Anderson *et al*. (The SNO+ Collaboration) Phys. Rev. D **99**, 032008 (2019)
[8] M. R. Anderson *et al*. (The SNO+ Collaboration) Phys. Rev. C **102**, 014002 (2020)