Calibrations of the SNO+ PMTs

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Introduction

SNOLAB

Fig. 1: SNOLAB location and depth.

SNOLAB is located in the Creighton mine near Sudbury, Canada. It contains several neutrino and dark matter experiments. At its depth of about 2200m the flat overburden equals about 6000m.w.e.

SNO+

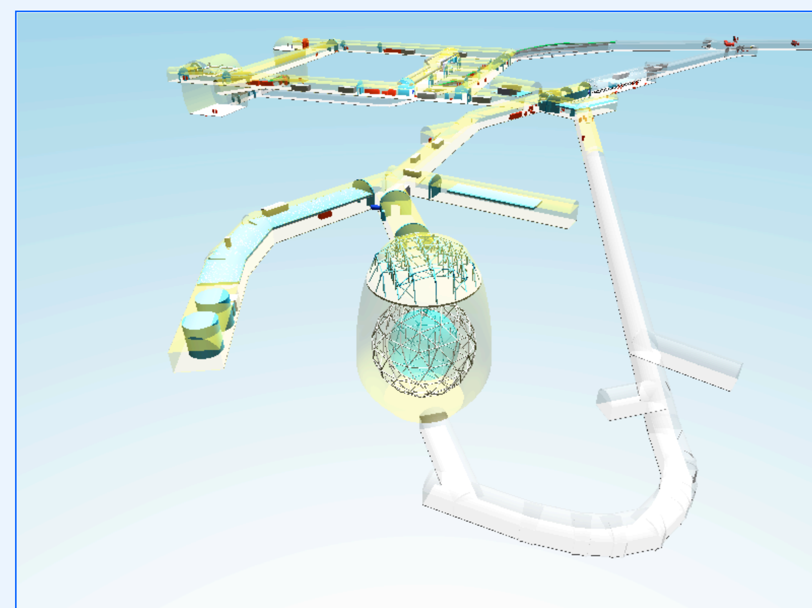

Fig. 2: The location of the SNO+ detector inside SNOLAB.

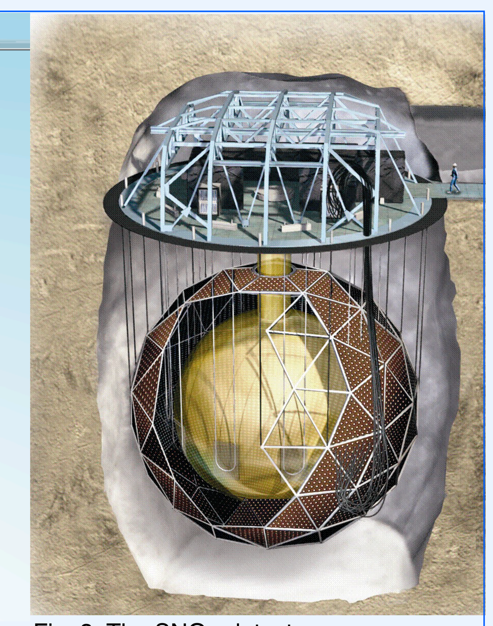

Fig. 3: The SNO+ detector.

The SNO+ experiment uses the existing Sudbury Neutrino Observatory (SNO) detector. The main physics goal of SNO+ is to search for the neutrinoless double beta decay, solar & supernova neutrinos and reactor & geo antineutrinos.

SNO+ PMTs

Fig. 4: The acrylic vessel surrounded by the PMTs.

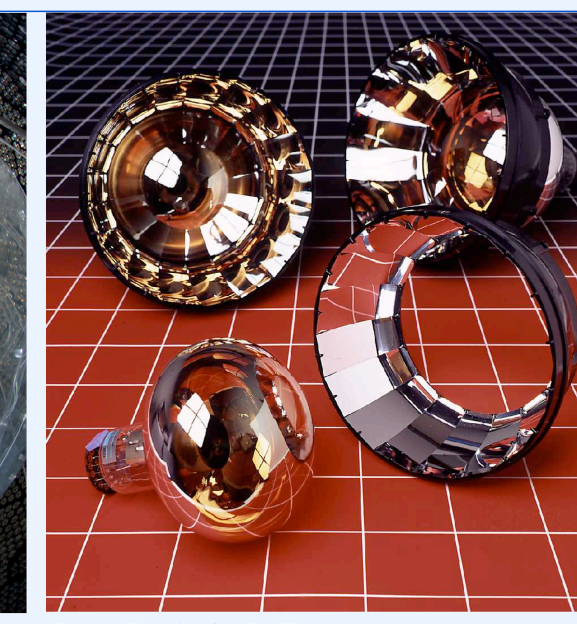

Fig. 5: The SNO+ PMT and concentrators.

9,522 sensitive photomultiplier tubes are attached to a geodesic sphere. They provide a solid angle coverage of about 54%. Accurate calibration of the PMT response is essential for the success of SNO+.

Understanding the PMTs

SNO+ calibrates the PMTs in-situ by using calibration sources. These sources can be fixed, like the LED system, or deployable, like the Cherenkov source.

In SNO data, a change over time in angular response was observed. Different aging models are simulated and compared to data.

Hit-level PMT calibration

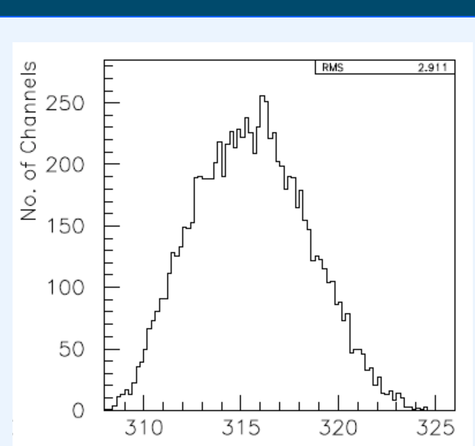

Fig. 6: Cable delays for all SNO PMTs.

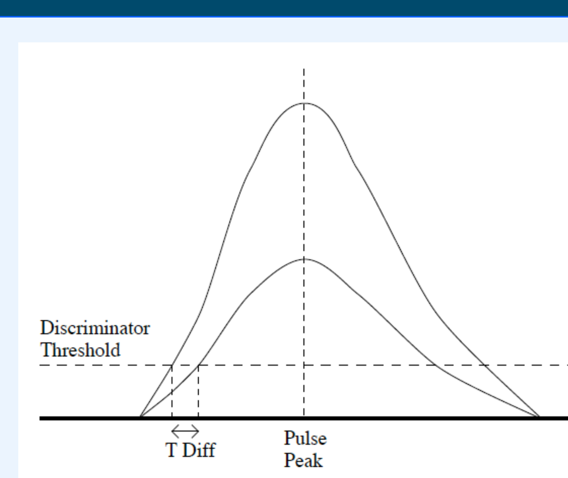

Fig.7: The precise PMT timing depends on the charge.

For each single PMT, we need to determine
• what charge corresponds to a single photoelectron,
• the total cable + electronics delay,
• the effect of the discriminator level on timing.

SNO+ has two sources of optical calibration data:
• ELLIE: external LED & lasers injected via fibers,
• laserball: near-isotropic single-wavelength photon source that can be deployed inside the acrylic vessel.

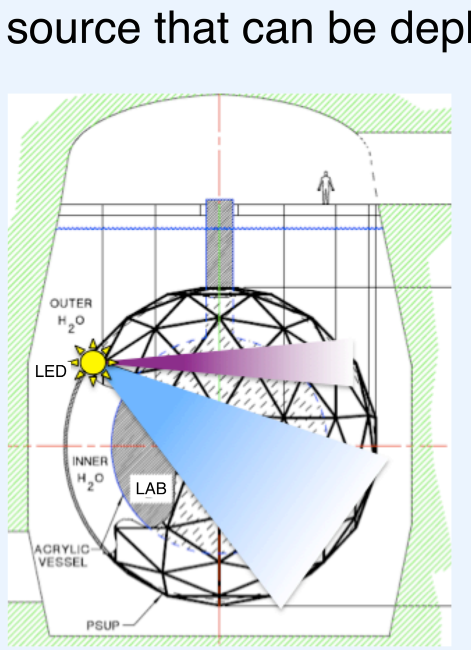

Fig.8: ELLIE LEDS are mounted between the PMTs.

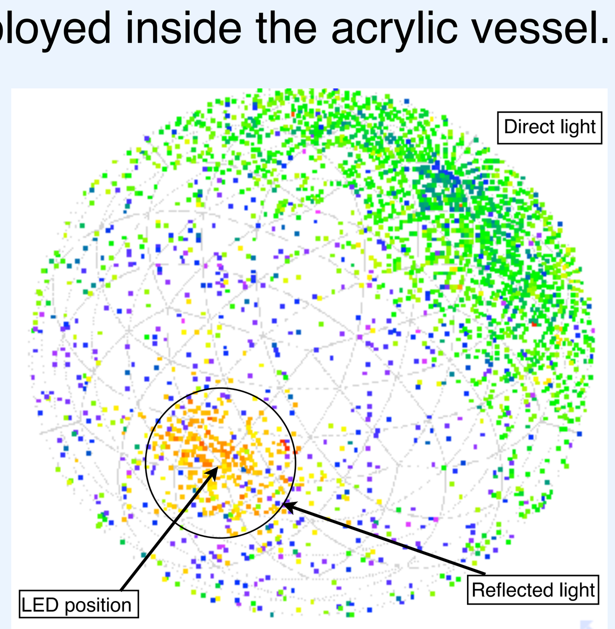

Fig.9: A real ELLIE event, taken during the airfilled phase in October 2012.

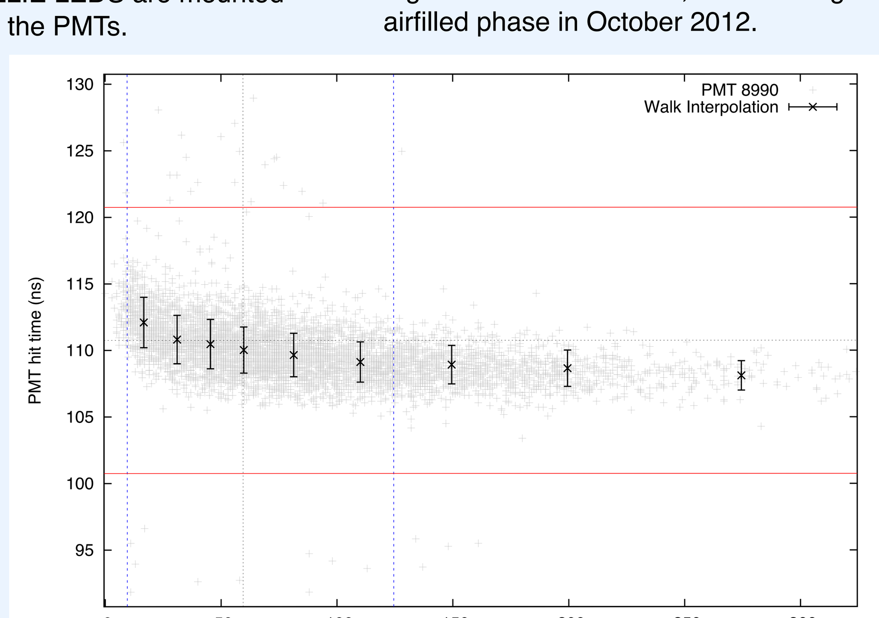

Fig.10: PMT time versus charge for a simulated laserball calibration run. The effect of the constant discriminator is strongest at lower charge. Vertical and horizontal lines indicate the charge and time peaks respectively.

Cherenkov calibration source

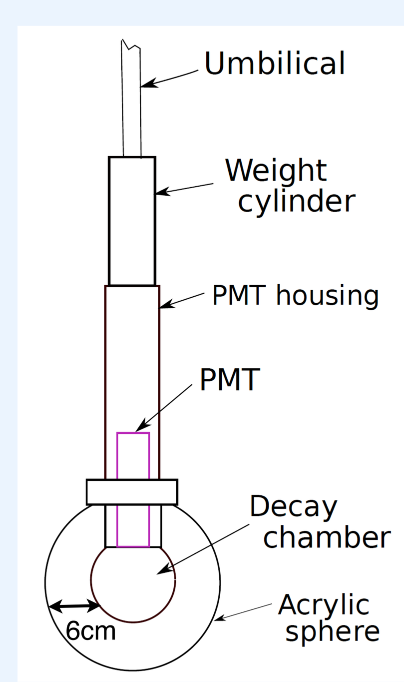

Fig.11: The Cherenkov source

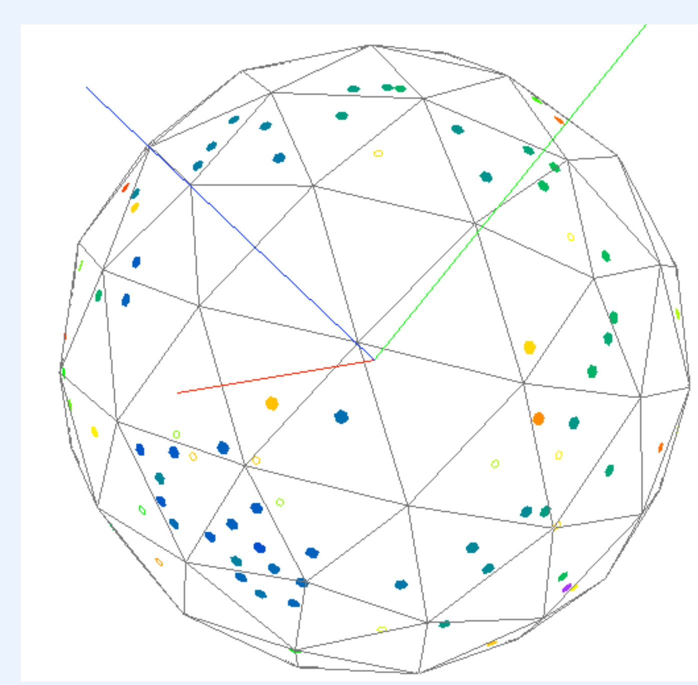

Fig.12: An 8 MeV electron simulated in the center of the Cherenkov source, which is positioned at 2m along the x-axis using UV transparent acrylic.

Cherenkov source principle:

• ^{8}Li carried at high speed by helium gas through a tube into decay chamber
• $^{8}Li \rightarrow {}^{8}Be + \beta^{-} + \nu$ (Q~13 MeV); $^{8}Be \rightarrow 2\alpha$,
• β^{-} enters acrylic wall of decay chamber, produces Cherenkov light, and stops in the acrylic.
• alphas produce scintillation light in the helium gas which can be used to tag the event.
• Use of UV absorbent acrylic minimizes scintillation effects.

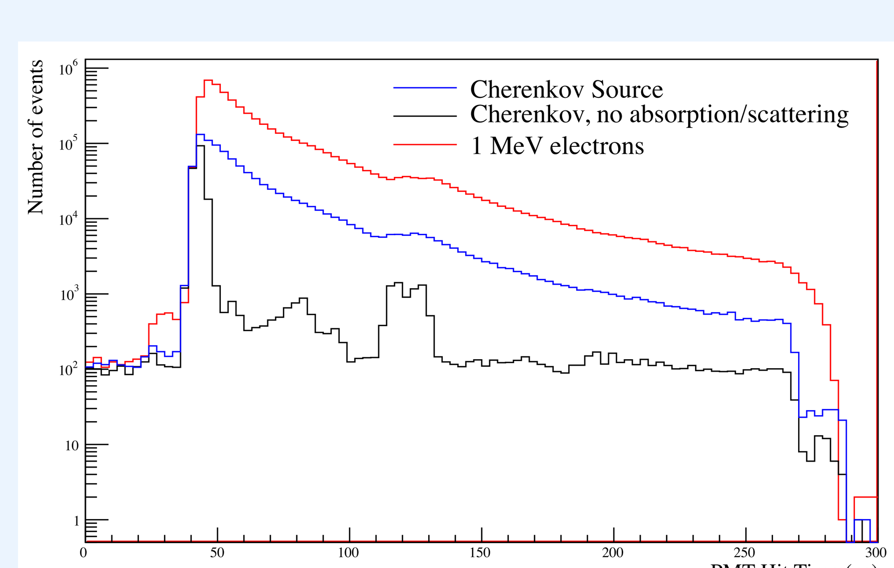

Fig.13: Comparison of the simulated PMT hit time distributions for the UV-transparent Cherenkov source at the center of the detector with (blue) and without (black) absorption-reemission and scattering. The distribution of 1 MeV electrons generated at the center are shown in red.

R&D underway for the Cherenkov source includes:
• Choice of chamber lining to absorb alpha scintillation photons.
• Application of wavelength shifter coating.
• Methods of bonding two acrylic hemispheres together.

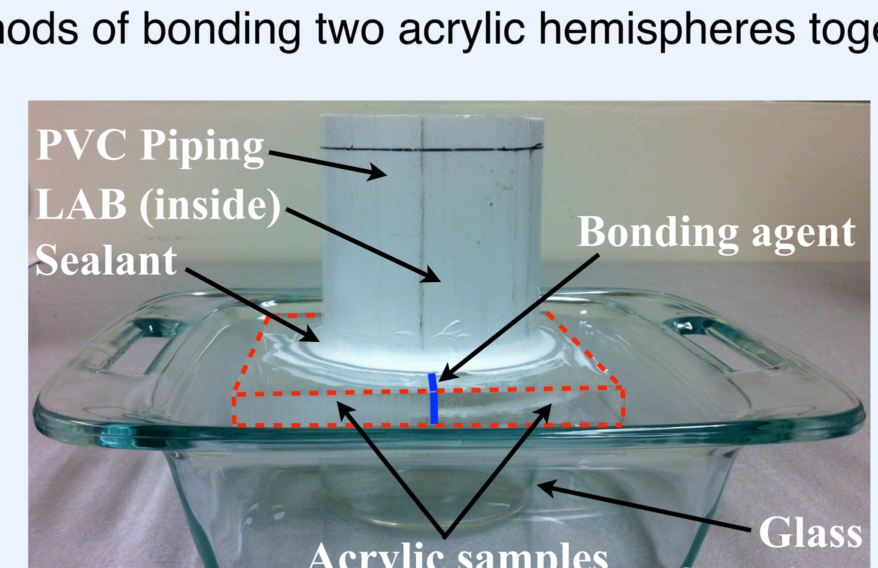

Fig.14: The Cherenkov source acrylic bonding test setup.

PMT Angular response

Fig.15: An in-situ picture of SNO+ PMTs showing the degradation of the concentrator petals.

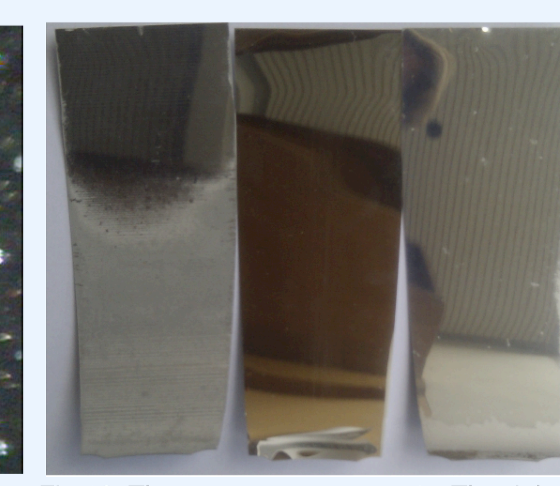

Fig.16: Three concentrator petals. The right and left ones show aging, the middle one is new.

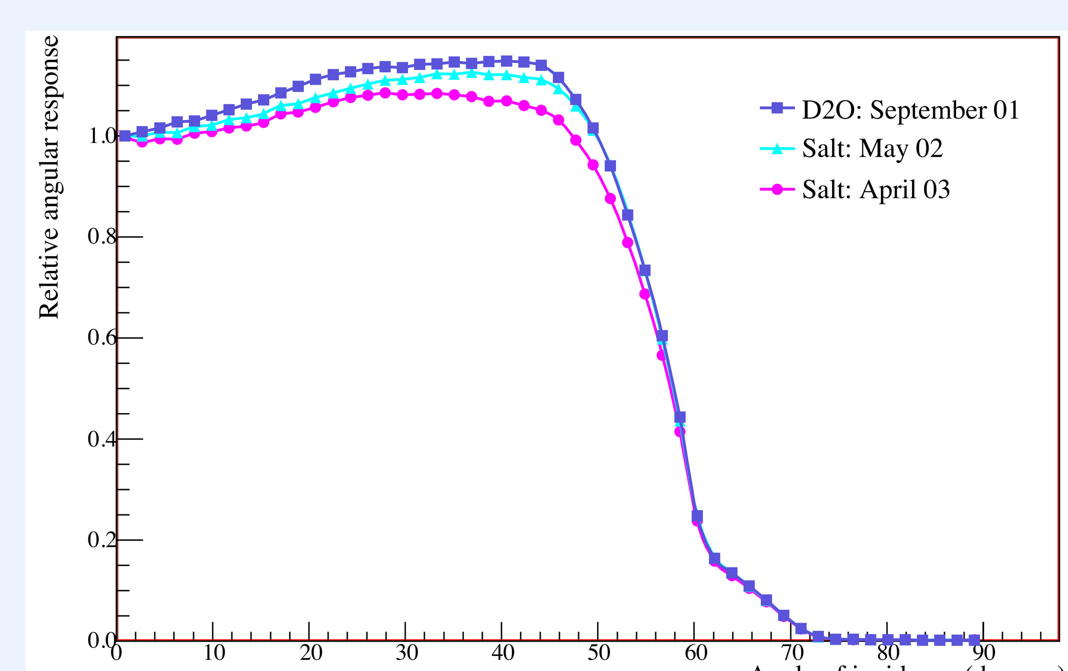

Fig.17: Relative response versus incidence angle at 386nm, averaged over all PMTs as measured in SNO with laserball scans.

In SNO data, we observed a consistent decrease of response, especially at angles from 30 to 50 degrees. This is likely due to petal degradation. The current concentrator response is being simulated with varying models in order to understand the physical change behind it.

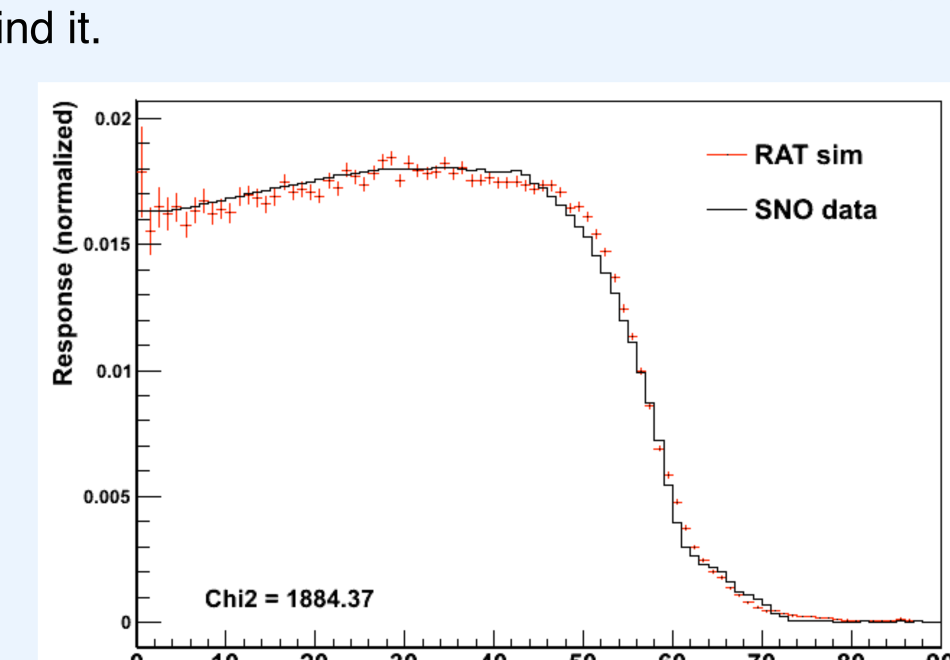

Fig.18: Comparison of angular response between simulation (RAT) and SNO data. RAT uses an exponential degradation of the form $a = 0.3 * e^{(-z/70.0)}$, where z is the height the photon hits on the concentrator. This model only ages the concentrator up to 70mm.

Conclusion

A detailed microphysical understanding of the SNO+ PMT response is a requirement for any high-precision, robust physics result. LBNL / U. C. Berkeley is leading the effort to calibrate the SNO+ PMTs and characterize them in simulations.