Proton light yield of water-based liquid scintillator


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Introduction

Water-based liquid scintillator (WbLS) a new material under development

- Favorable Cherenkov/scintillation ratio
- Scalable

May see deployments in upcoming neutrino detectors

- Neutrino Experiment One (NEO)
- ANNIE
- THEIA

Proton light yield studies of myriad interest

- Background rejection for inverse beta decay (IBD)
- Quenching mechanisms
- Supernova studies via $\nu p$-scattering
Introduction - fast neutron background

Established antineutrino signal emanates from nuclear reactors

Upcoming NEO detector at AIT will be sensitive to reactor-$\nu$ IBD events

“Fast” neutrons ($\sim 10$ MeV) from surrounding rock form coincidence background

Using water-based liquid scintillator, could distinguish signal from background — but need to know what protons “look like”
Technical approach

“Double time-of-flight” method: Pulsed $D$ beam on Be target

- PID-capable secondary detectors

Protons excited via $n$-$p$ elastic scattering internal to measurement sample

Two measures of neutron energy

- Before/after scattering
- Enforce beam-neutron hypothesis

Charge collected in photomultiplier tube (PMT) used as proxy for light

Two samples measured: LAB + 2 g/L PPO and 5% WbLS (from Yeh et al, BNL)

Technical approach

Blind approach: present analysis developed on 20% of data
Technical approach

Outgoing TOF

Incoming TOF

Timing calibrations

Proton energy resolution

Proton energy bins

Nominal charge values

Charge calibration

Relative light yield

PMT nonlinearity correction

γ selection

n selection

Blind approach: present analysis developed on 20% of data
Technical approach - PMT linearization

Simultaneous measurement over broad energy range

PMT readout known to deviate from linear scaling (twice as many photons ⇔ twice as much charge)

Degenerate with nonlinearity in light yield scaling

Desired: correcting function $R^{-1}$ mapping digitizer readout to idealized readout from linear system

Method: Pulse two LEDs, both independently and in coincidence, to measure deviation from linear response

▸ Friend et al, NIM A, 676 (2012)
Technical approach - PMT linearization

Method: Vary the amplitude of one pulse to measure over full range

Postulate that $R$ or $R^{-1}$ is polynomic

Minimize gross deviation from linearity:

$$\sum \left( \frac{R^{-1}(A_1) - R^{-1}(A_2)}{\sigma^2} \right)$$
Technical approach - Charge calibration

Calibrate PMT charge by fitting to Compton edge of $\gamma$ source

Model:
- Monte Carlo energy depositions
- Locally linear charge model
- Power law background

$\frac{dN}{dE}$ expressed numerically

$Q(E) = Q_C + \alpha (E - E_C)$

$B(Q) \propto Q^{-n}$

$\frac{dN}{dQ} = G(\sigma) \otimes \frac{dN}{dQ} + B(Q)$

Caesium source

LABPPO, WbLS
Technical approach

- Outgoing TOF
- Incoming TOF
- Timing calibrations
- Proton energy resolution
- Proton energy bins
- Nominal charge values
- Relative light yield
- Charge calibration
- PID in aux. det.
- PMT nonlinearity correction

γ selection
n selection
Technical approach - Timing calibration

*Incoming TOF*

Charge/time cuts to isolate $\gamma$ peak

*Outgoing TOF*

PSD in secondary detector to select $\gamma$s
Technical approach

- Outgoing TOF
- Incoming TOF
  - **γ** selection
  - **n** selection
- PID in aux. det.
- Timing calibrations
- Nominal charge values
  - Charge calibration
  - PMT nonlinearity correction
- Relative light yield
- Proton energy resolution
  - Proton energy bins
Light yield results

Proton recoil selection achieved by PSD-selecting on neutrons in secondary detectors

2.00 MeV $\leq E_p < 2.25$ MeV

6.00 MeV $\leq E_p < 7.00$ MeV

12.0 MeV $\leq E_p < 14.0$ MeV
Conclusion

- Proton light yield data acquired using 88-Inch cyclotron
- PMT nonlinearity characterized over measurement range
- Next: investigate compatibility with quenching models
- Finalizing LY results for publication

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