Proton light yield of water-based liquid scintillator

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NUCLEAR SCIENCE and SECURITY CONSORTIUM

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 νp-scattering

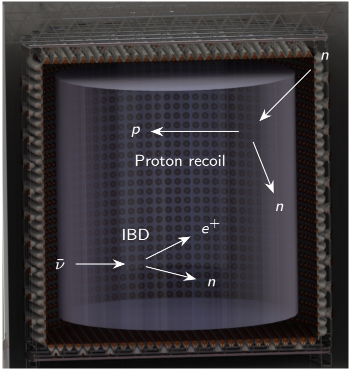
Introduction - fast neutron background

Established antineutrino signal emanates from nuclear reactors

Upcoming NEO detector at AIT will be sensitive to reactor-ν IBD events

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

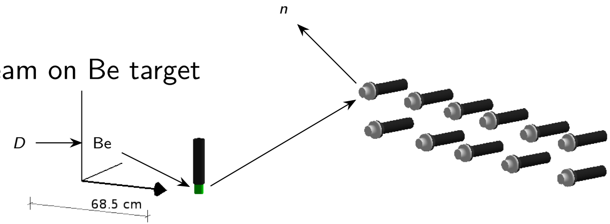
Using water-based liquid scintillator, could distinguish signal from background — but need to know what protons "look like"



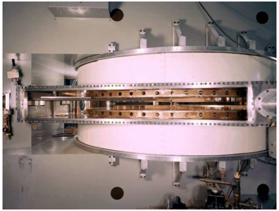
Technical approach

"Double time-of-flight" method: Pulsed *D* beam on Be target

- PID-capable secondary detectors
- Brown et al, J. Appl. Phys. **124** (2018)



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



Two measures of neutron energy

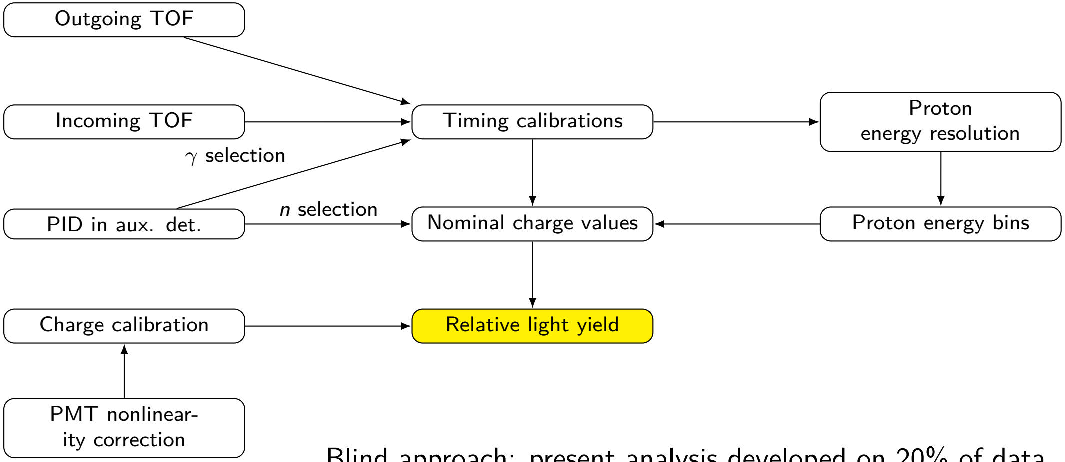
- Before/after scattering
- Enforce beam-neutron hypothesis

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)

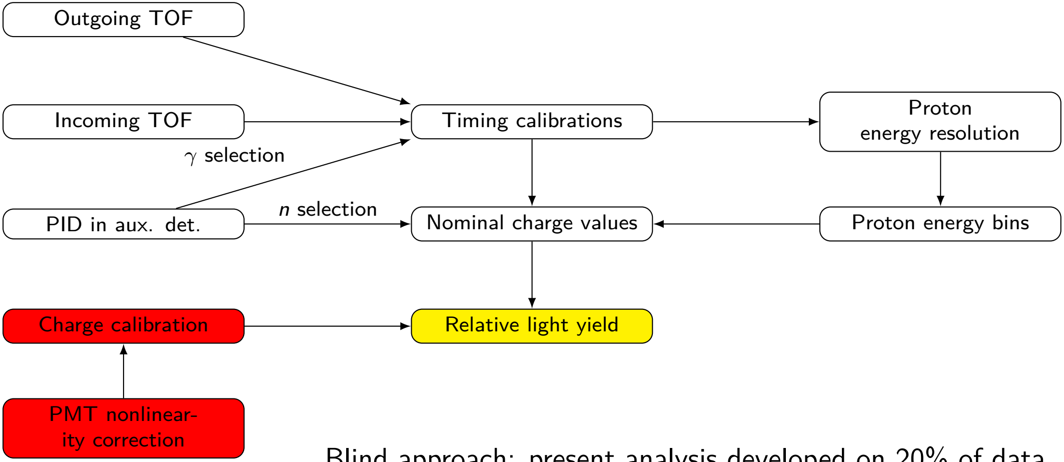
- Existing LABPPO measurement: von Krosig et al, Euro. Jour. Phys. C **73** (2013)

Technical approach



Blind approach: present analysis developed on 20% of data

Technical approach



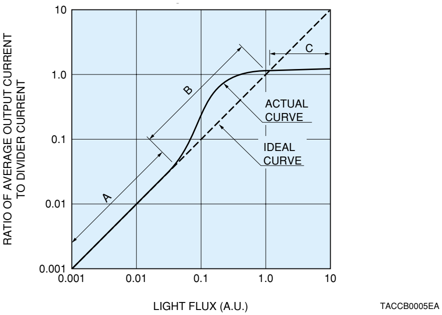
Blind approach: present analysis developed on 20% of data

Technical approach - PMT linearization

Simultaneous measurement over broad energy range

PMT readout known to deviate from linear scaling (twice as many photons $\not\Leftrightarrow$ 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

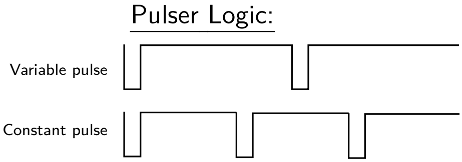
- Friend et al, NIM A, **676** (2012)

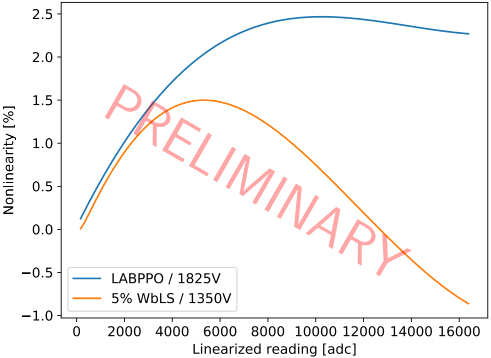
Technical approach - PMT linearization

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: $\sum \left(\frac{R^{-1}(A_{1+2}) - R^{-1}(A_1) - R^{-1}(A_2)}{\sigma^2} \right)$





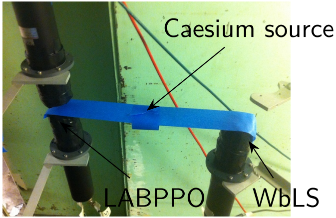
Technical approach - Charge calibration

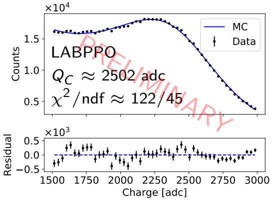
Calibrate PMT charge by fitting to Compton edge of γ source

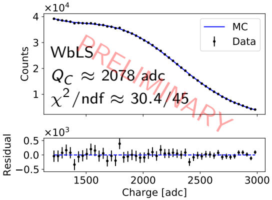
Model:

- Monte Carlo energy depositions — $\frac{\mathrm{d}N}{\mathrm{d}E}$ expressed numerically
- Locally linear charge model — $Q(E) = Q_C + \alpha(E - E_C)$
- Power law background — $B(Q) \propto Q^{-n}$

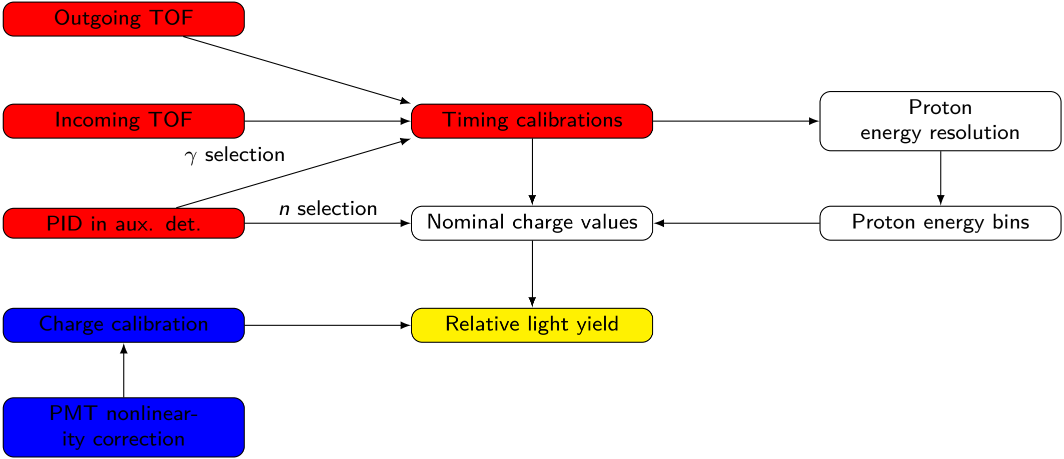
$$\frac{\mathrm{d}N}{\mathrm{d}Q} = G(\sigma) \otimes \frac{\mathrm{d}N}{\mathrm{d}Q} + B(Q)$$







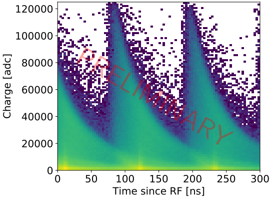
Technical approach

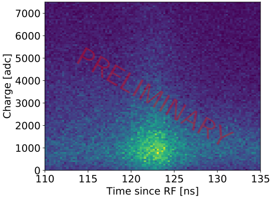


Technical approach - Timing calibration

Incoming TOF

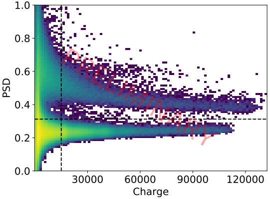
Charge/time cuts to isolate γ peak

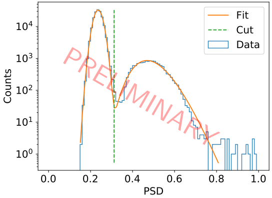


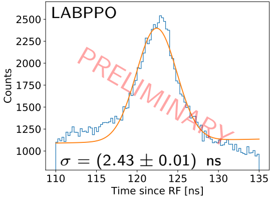


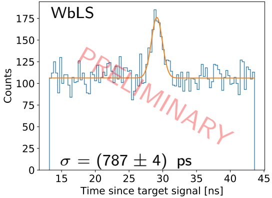
Outgoing TOF

PSD in secondary detector to select γs

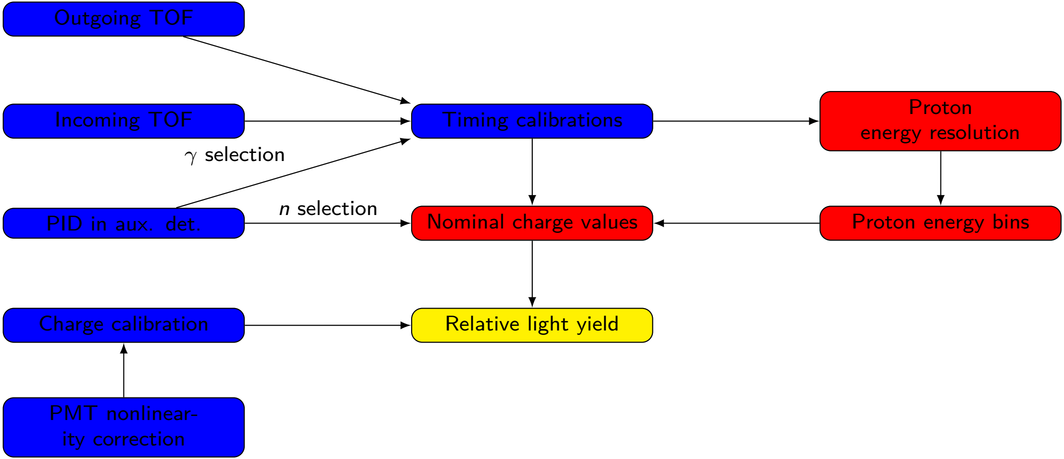






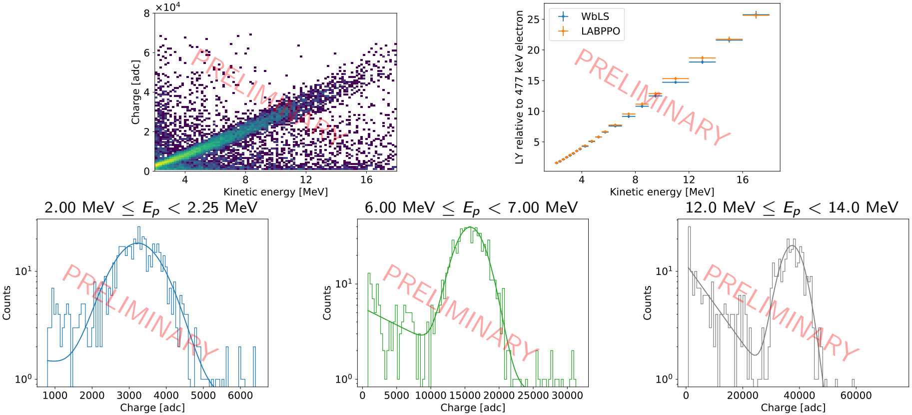


Technical approach



Light yield results

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



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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