Proton Light Yield of a Gd-doped Water-based Liquid Scintillator for Antineutrino Detection

[1]N. A. Tausik, [1,2]B. L. Goldblum, [1]T. A. Laplace, [1]J. A. Brown, [3]D. L. Bleuel, [1]T. Li, [1]A. Venkatraman

[1]Department of Nuclear Engineering, University of California, Berkeley, California 94720 USA
[2]Lawrence Berkeley National Laboratory, Berkeley, California 94720 USA
[3]Lawrence Livermore National Laboratory, Livermore, California 94550 USA

NSSC
Nuclear Science & Security Consortium

Introduction and Motivation

- Gd-doped water-based liquid scintillator (Gd-WbLS)
  - Offers discrimination between scintillation and Cherenkov light
  - Slow neutron sensitivity w/Gd doping (0.1% Gd by mass)
  - Candidate for next-generation antineutrino detectors
- Supports neutrino monitoring to **address advanced reactor safeguards challenges**
- First measurement of the **proton light yield of the Gd-WbLS organic scintillator**
- Uses the double time-of-flight (TOF) method developed under the NSSC at Lawrence Berkeley National Laboratory **measuring simultaneously the neutron energy deposited and corresponding light output**
- Accurate characterization of the Gd-WbLS needed to inform background rate

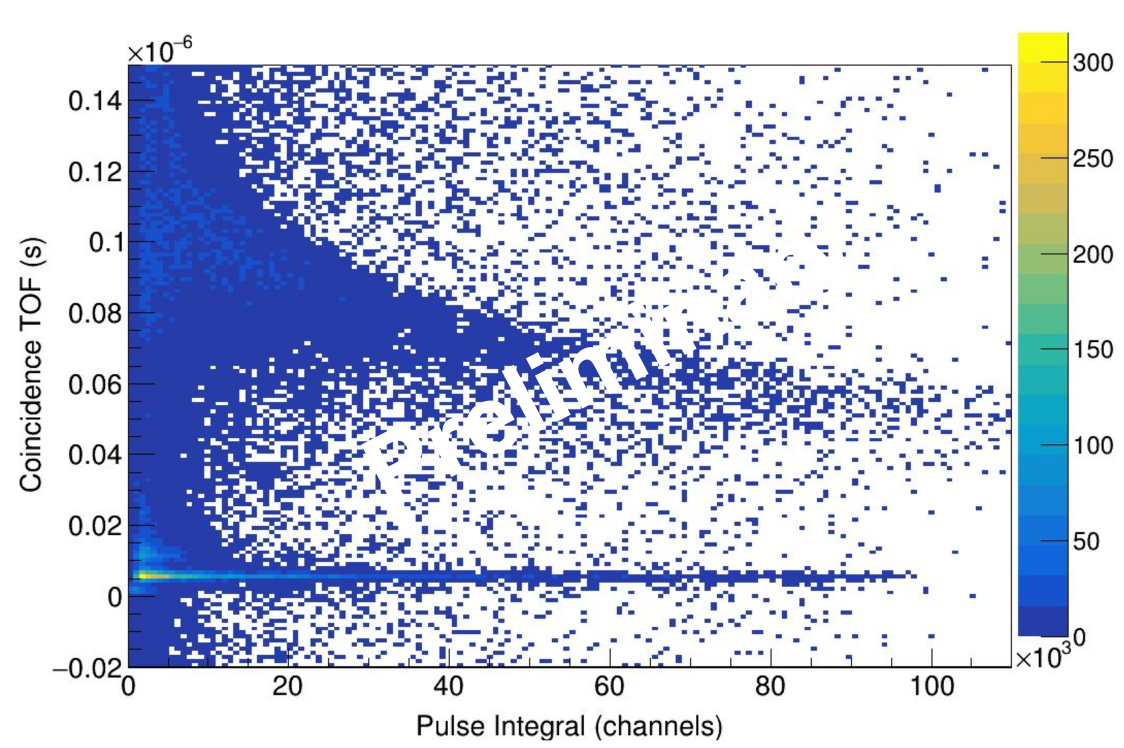
Gd-WbLS Cell

Timing Calibration

- Incident TOF calibration is obtained via time differences between the cyclotron RF signal and γ-ray interactions in target scintillator [1]
- Outgoing TOF calibration is determined via γ−γ coincidences between target and observation detectors and is used to compute the energy of the scattered neutron

Neutrons

Gammas



Pulse Integral vs Coincident TOF, Observation Detector 0

[1] J.A. Brown, Journal of Applied Physics 124 (2018).

Light Yield Measurement

- Double TOF method used to directly measure the proton light yield
- Broad spectrum neutron beam produced using thick-target deuteron breakup at the 88-Inch Cyclotron at Berkeley Lab
- Energy of the incoming and scattered neutrons determined via TOF
- Coincidence measurement allows determination of the energy deposited by the neutron using kinematics

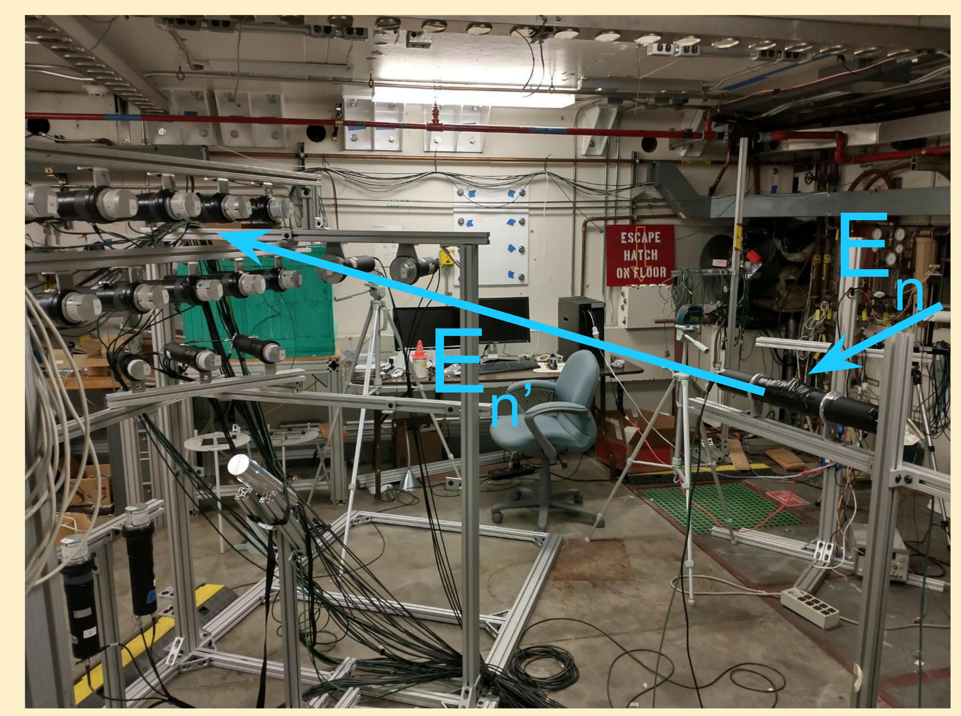
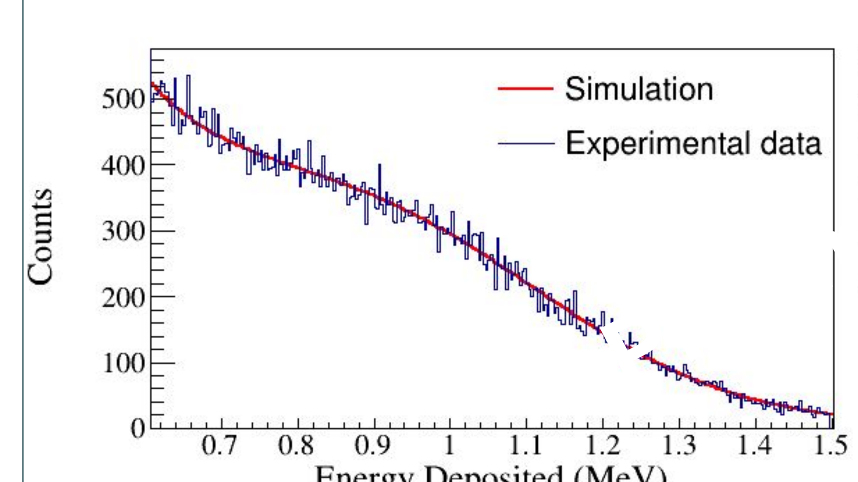


Image of Experimental Setup

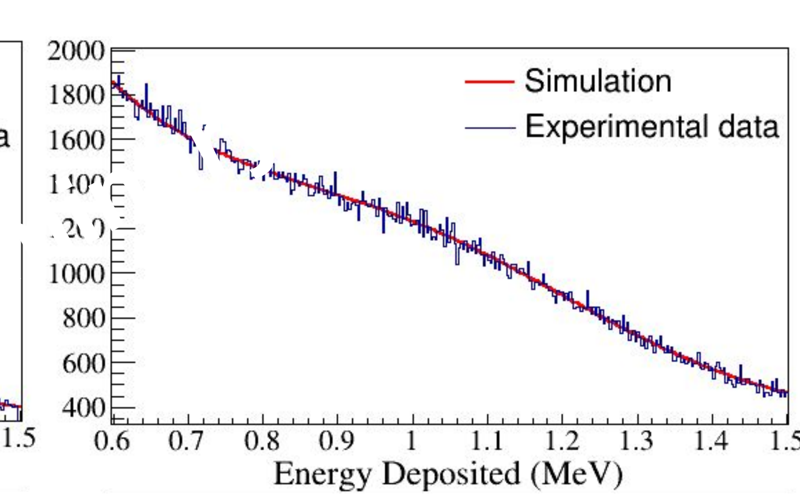
- Broad spectrum neutron source from 33 MeV d breakup on C
- Continuous measurement of proton light yield
- Array of 26 observation detectors
- Digital acquisition recording full traces (CAEN V1730 500MHz)
- 100 ns integration window

Light Yield Calibration

- Light output is calibrated using the minimization of γ-ray source spectra and Geant4-simulated energy deposition spectrum convolved with the detector response function [2]



^{22}Na – 1.275 MeV γ ray

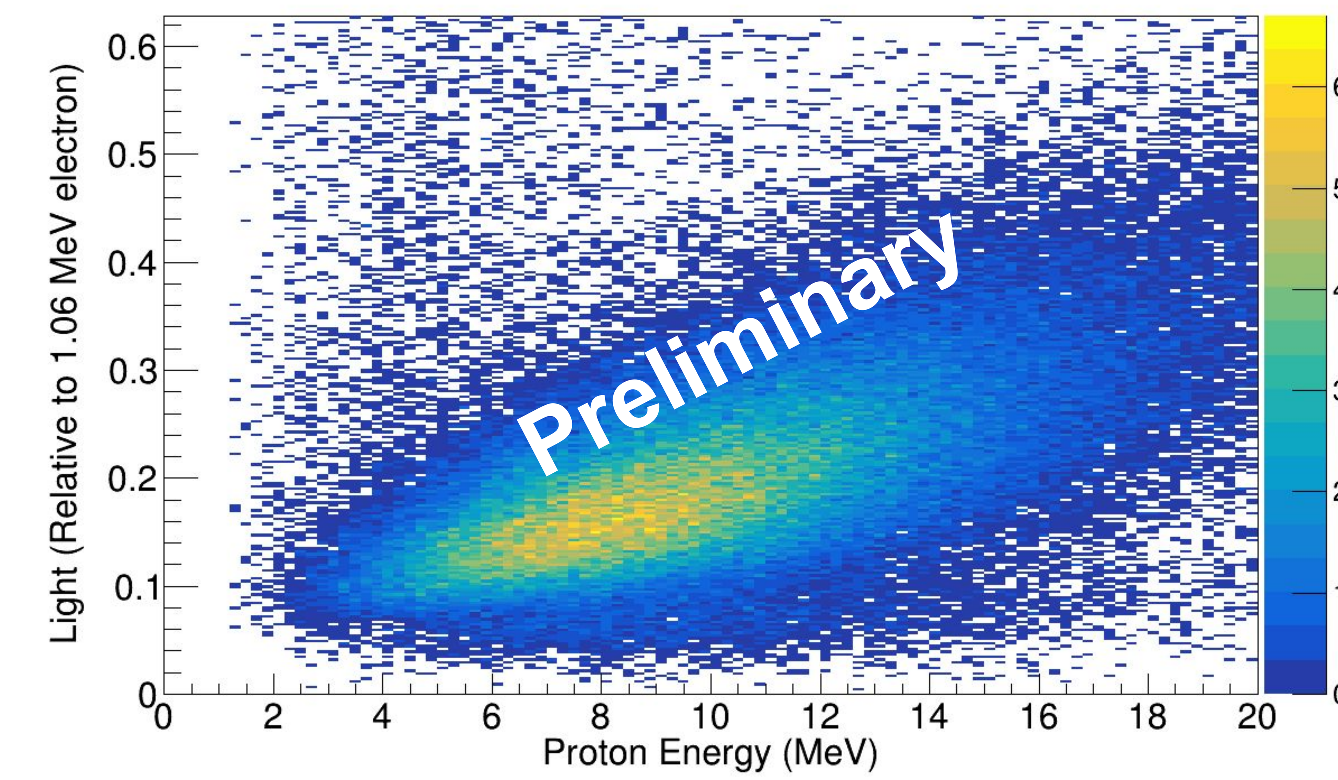


^{24}Na – 1.368 MeV γ ray

[2] G. Dietze and H. Klein, Nuclear Instruments and Methods 193 (1982).

Proton Light Yield

- Light output of Gd-WbLS as a function of proton recoil energy determined using double TOF method



Proton Light Yield

$$E_{n'} = \left(\frac{1}{1-\left(\frac{FP}{TOF\times c}\right)^2}-1\right)m_n c^2$$

$$E_p = E_{n'}\sin^2(\theta)$$

Mission Relevance

- Promising detection medium for future antineutrino detectors
- Promising applications for nuclear security and nonproliferation, including future nuclear deals and advanced reactor safeguards [3]
- Could be deployed to monitor facilities, e.g., for molten salt reactors where traditional accountancy measures may no longer apply
- Possible use in cooperative reactor monitoring as part of future nuclear deals

[3] O. Akindele et al., United States Department of Energy (2021).

Future Work

- Measurement (and, if needed) correction for nonlinearity of PMT response
- Reduction of 2D histogram of light output v. proton energy into data points
- Monte Carlo of systematic uncertainties

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National Nuclear Security Administration