Measurement of Rayleigh Scattering in Liquid Argon at Vacuum Ultraviolet Wavelengths

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Introduction

Liquid Argon Time Projection Chambers use scintillation light and ionization charge to reconstruct time, position, and energy information of particle interactions. Scintillation photons primarily function to measure absolute time for spatial reconstruction, but also can provide a second calorimetric measurement of total event energy. This improves the energy resolution and enables cross-checks of the energy measurement, reducing systematic uncertainty. We measure the attenuation length (dominated by Rayleigh scattering) at vacuum ultraviolet wavelengths (124-180 nm, including Ar and Xe scintillation wavelengths) in liquid argon to enable energy reconstruction from scintillation photons.

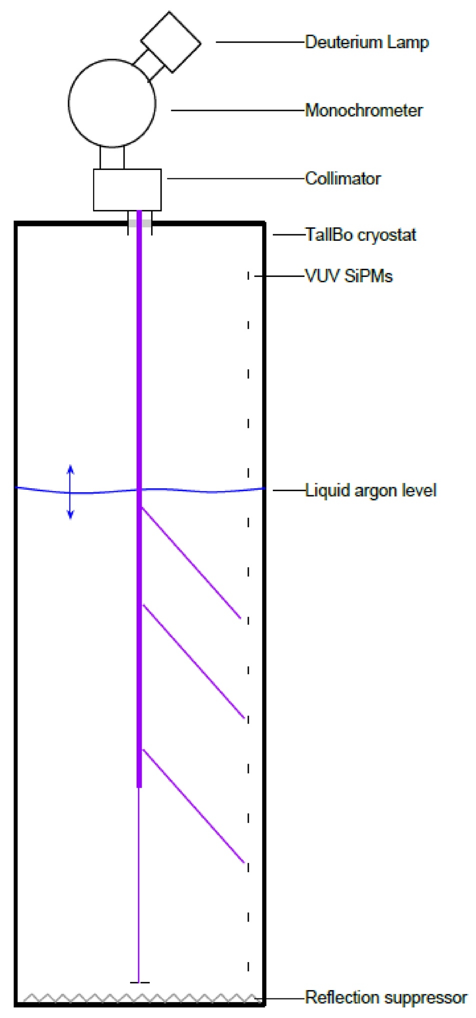


Figure 2: TallBo Cryostat Diagram

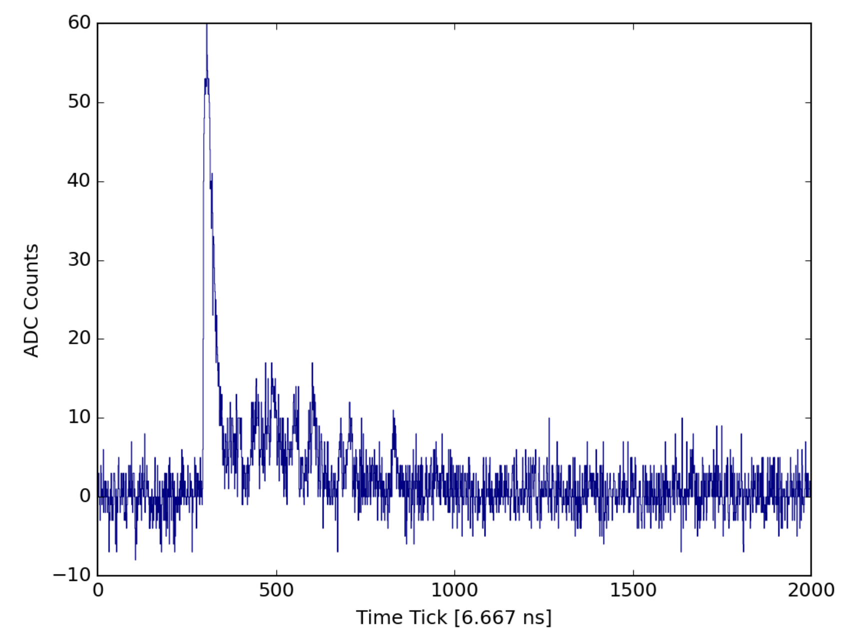


Figure 3: SiPM Waveform

Experimental Design

The measurement is conducted with the TallBo cryostat (Fig. 1) at the Noble Liquid Test Facility, Fermilab. A deuterium lamp, monochromator, and collimator produce a narrow ultraviolet light beam of single wavelength (Fig. 2). Photons travel through liquid argon before detection by silicon photomultipliers (SiPMs) arranged on the cryostat bottom and side. Attenuation length L is related to absorption length L_A and scattering length L_S by:

$$\frac{1}{L} = \frac{1}{L_A} + \frac{1}{L_S} \quad (1)$$

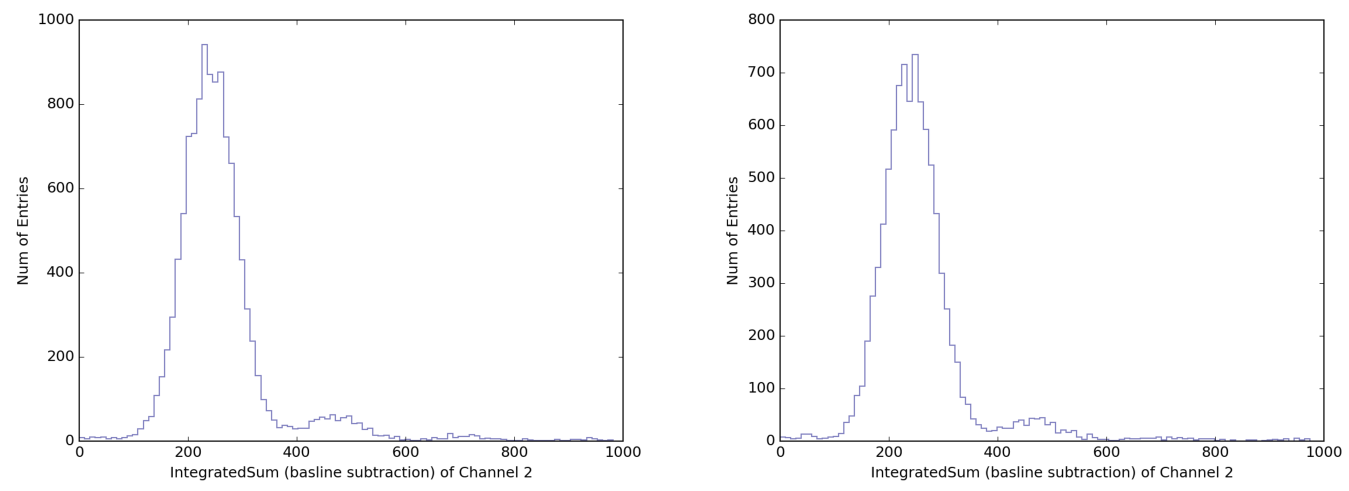
For signal measurement rates at different wavelengths and liquid argon depths, the Rayleigh scattering ratio R at 90° is:

$$R = \frac{I}{I_0}\frac{r^2}{V} \propto \frac{1}{\lambda^4} \quad (2)$$

Where I is scattered intensity, I_0 is incident intensity, r is distance from scattering center to detector, and V is scattering volume.

Figure 5: Background Subtracted Peak Integral Distribution

a) Closed Shutter Integral   b) Open Shutter Integral (124 nm)



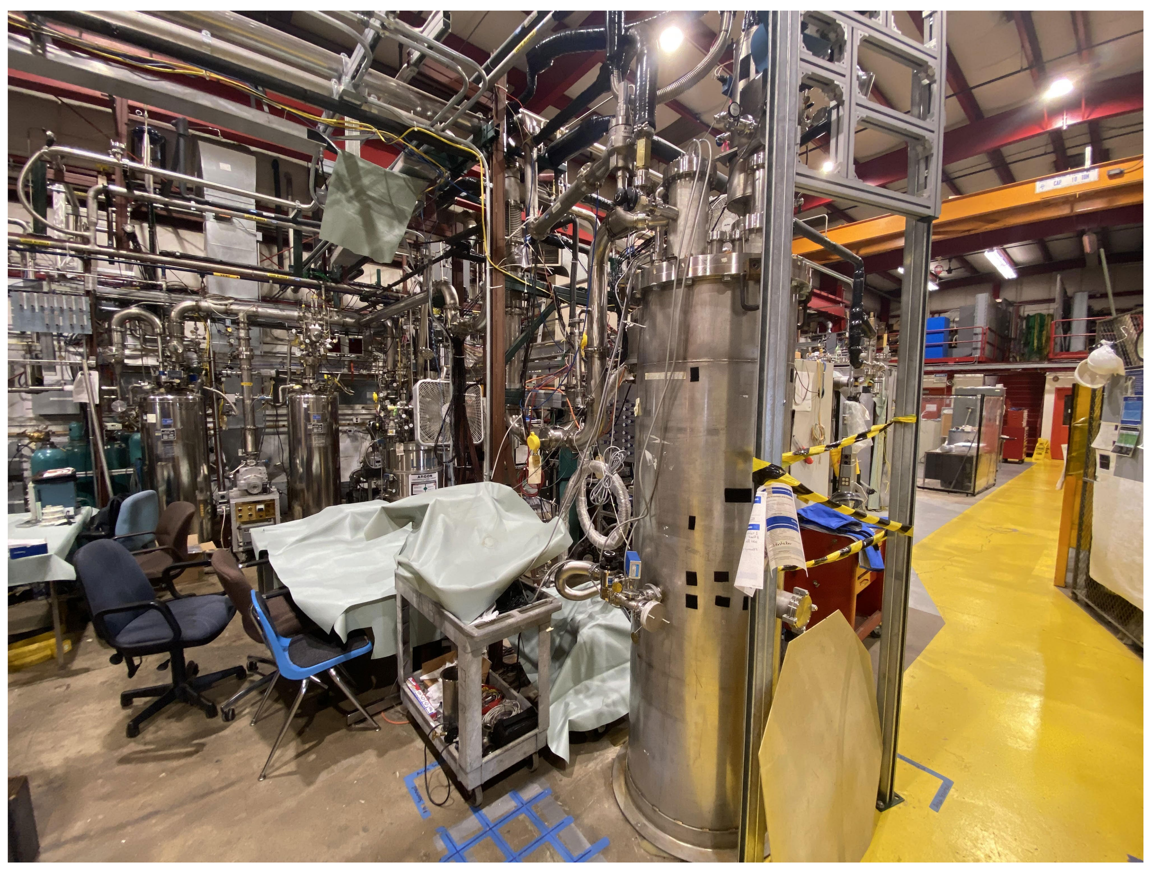


Figure 1: TallBo Cryostat

Preliminary Analysis

SiPM signal waveforms (Fig. 3) exceeding trigger thresholds are processed and recorded in output files. SiPM waveforms and background subtracted integral data show that individual triggers generally correspond to detection of single photons. Comparing shutter closed/open plots (Fig. 5a, 5b) indicates multiple photon detection peaks per trigger results from SiPM crosstalk.

As a result, trigger number per channel measures total number of photon signals per SiPM. (Fig. 4) displays trigger rates for Channels 1 (bottom of cryostat), and 2, 4, 5 (side of cryostat). Theory and simulations predict more light scattered horizontally at smaller liquid argon depths. The side SiPM liquid depth in increasing order is Channel 5, 4, and 2, so the observed trigger rate pattern is qualitatively consistent with predicted results.

Figure 4: Trigger Rate per SiPM Channel

128 nm trigger rate plot from data collection run over a range of ultraviolet wavelengths. Results are qualitatively consistent with simulation expectations.

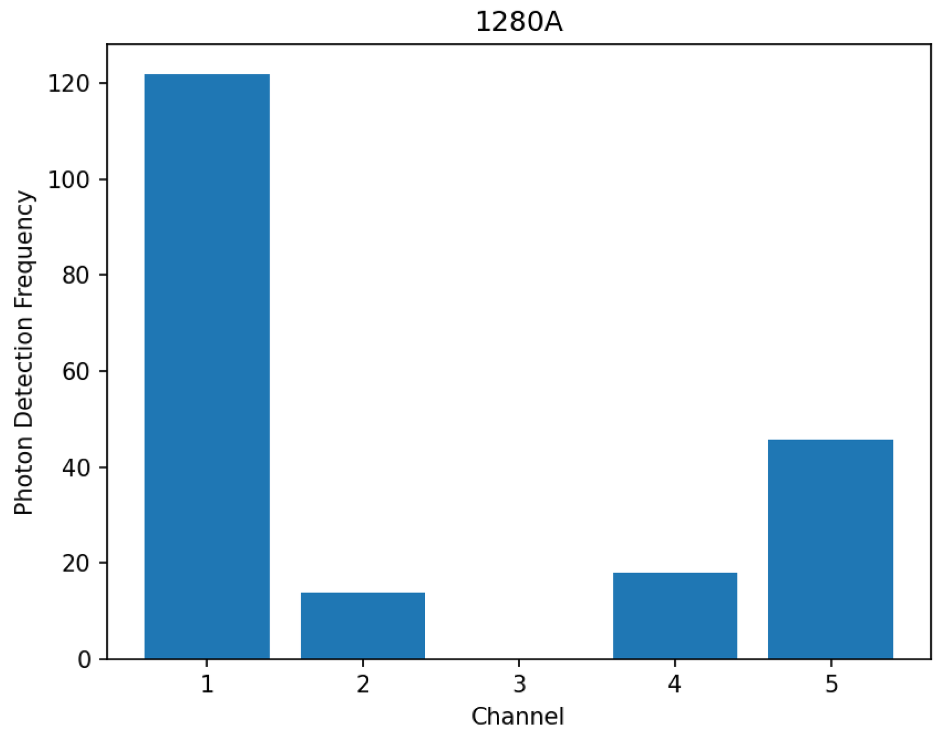


Table 1: Wavelength vs. SiPM Channel Trigger Rate (Hz)

Channel	Light Off	124 nm	128 nm (Ar)	150 nm	178 nm (Xe)	180 nm
1	97.274	198.736	269.075	1118.131	1543.828	1967.734
2	97.614	109.830	117.589	546.993	171.334	186.003
4	97.181	109.427	116.664	510.132	154.930	167.163
5	98.128	152.747	165.001	966.014	220.920	230.486

Status

Analysis of wavelength scan data collected at maximum liquid argon depth (Table 1) indicate photon detection frequencies consistent with the known D_2 lamp spectrum and estimated scattering length.

Next, we will collect data for wavelength scans at different liquid argon depths to measure the Rayleigh scattering length versus wavelength.

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