Characterization of Muon and Gamma Radiations at the PTOLEMY Site

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ABSTRACT

Princeton Tritium Observatory for Light, Early Universe, Massive Neutrino Yield, or PTOLEMY, is an experimental project at Princeton Plasma Physics Laboratory designed to determine the present-day number density of relic neutrinos through measurement of the energies of electrons produced from neutrino capture on tritium [1]. Characterization of the muon and gamma radiation at the PTOLEMY site, located at D-Site at the Princeton Plasma Physics Laboratory, is important for modeling and suppressing background radiation that could interfere with the low expected signal rate.

Motivation for Characterization of Background

The weak interaction cross section for relic neutrino interactions necessitates high sensitivity measurements that could be influenced by high energy particles including cosmic ray muons, gamma rays, and neutrons. The low expected signal rate of approximately 0.3 μHz of neutrino capture events for the PTOLEMY upgrade places tight constraints on the allowed background rate [1]. Various methods for suppression of background are planned for the PTOLEMY upgrade. Characterizing the background experimentally will support modeling of radiation sources and optimizing suppression of background.

The PTOLEY Project and Sites

The PTOLEY prototype, currently configured to include two superconducting magnets on either end of a vacuum chamber, is situated in the Test Cell Basement at PPPL. Approximately 18t. of concrete overburden provides shielding in this location. The proposed PTOLEY upgrade site is the Test Cell, located directly above the Test Cell Basement. Approximately 5t. of concrete overburden provides shielding in the Test Cell [1].

Muon Measurement Method

Muons detected at and below earth’s surface are the decay products from cosmic rays striking particles in the Earth’s atmosphere. Muons are the most abundant energetic charged particles at sea level [2]. High energy muons could penetrate the magnetic field of PTOLEMY and cause ionizing loss in the target. To detect muons, two organic scintillator paddles connected to four photomultiplier tubes are powered with a high voltage power supply and attached to a circuit board programmed to record the characteristic three-fold coincidence of minimum ionization radiation loss associated with high energy muons. Muon counts collected over time provide a rate of muon flux. With the detectors powered at 2150 V in the Test Cell Basement, the muon rate was measured to be 2.2 Hz. At the same voltage at an unsupervised control site in the CAS building at PPPL, the muon rate was measured to be 4.5 Hz. The suppression due to the difference in elevation and shielding at the two sites is approximately twofold.

Gamma Spectrum Measurement Method

A sodium iodide (NaI) crystal scintillator provides data on the spectrum of gamma radiation energies. Gamma ray spectra were collected in the Test Cell Basement with no shielding, lead shielding, and polyethylene shielding. The energies of the spectra were calibrated using Americium-241 and Cesium-137 as radiation sources.

Muon Rates in the Test Cell Basement and an Unshielded Control Site

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<th>Counts</th>
<th>Time (seconds)</th>
<th>Frequency (Hz)</th>
<th>Test Cell Basement</th>
<th>Counts</th>
<th>Time (seconds)</th>
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<td>Average</td>
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</tbody>
</table>

Gamma Spectrum Measurement Method

Unshielded Gamma Spectrum

Unshielded gamma spectrum taken in the Test Cell Basement with a dwell time of 55321 seconds.

Lead shielded gamma spectrum taken in the Test Cell Basement with a dwell time of 11000 seconds. The NaI crystal scintillator shielded by four inches of lead bricks.

Polycarbonate shielded gamma spectrum taken in the Test Cell Basement with a dwell time of 11000 seconds. The NaI crystal scintillator shielded by a 20-inch diameter polycarbonate cylinder.

Moving Forward

Muon rates and the gamma spectrum need to be measured in the Test Cell. Analysis of the sources of the measured gamma radiation in the Test Cell Basement would support efforts to model and determine the correct shielding for suppressing background radiation interference for PTOLEMY.

References
