

Detector R&D of Cold Liquid Scintillator Veto for the PandaX-xT Experiment

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The PandaX-xT experiment is a next-generation multi-tonne liquid xenon time projection chamber (TPC) located at the China Jinping Underground Laboratory, designed for ultra-sensitive direct detection of dark matter. As the experiment approaches the neutrino floor, background rejection becomes a critical limiting factor for discovery sensitivity. In particular, cosmogenic neutrons, secondary neutrons, and external gamma radiation remain significant residual backgrounds that are challenging to suppress using passive shielding and fiducialization alone, thereby motivating the development of a high efficiency active veto system. A Cold Liquid Scintillator (CLS) active veto offers an attractive solution, with the additional benefit of reducing thermal gradients and potentially enabling a thinner liquid xenon cryostat.

We have initiated a dedicated detector R&D program based on a 1-liter CLS prototype operated at temperatures below $-100\text{ }^{\circ}\text{C}$, for the PandaX-xT experiment. The CLS concept combines high scintillation yield, fast decay time, favorable emission spectrum, quenching behavior, viscosity and adequate optical transparency under cryogenic conditions. These properties enable efficient detection and tagging of backgrounds before they reach the xenon target. The detector is instrumented with silicon photomultipliers (SiPMs) coupled to wavelength-shifting (WLS) optical fibers, providing high photon-collection efficiency, low-noise operation, and excellent timing resolution for precise event-by-event correlation with the xenon target.

The primary objective is a systematic characterization of detector performance as a function of temperature, with particular emphasis on charge response, photoelectron yield, energy resolution, and intrinsic noise. Specifically, we investigate the temperature dependence of scintillation light yield. We also study photon transport and attenuation in wavelength-shifting fibers, SiPM gain stability and breakdown voltage, and dark count rate suppression. In addition, we characterize correlated noise processes, including afterpulsing and optical crosstalk, under cryogenic conditions.

Complementary Geant4-based Monte Carlo simulations are employed to model scintillation photon production, optical transport, optimized WLS fiber geometries, and the full detector response within the PandaX-xT detector geometry. These simulations further quantify the rejection power against dominant background sources and guide the optimization of the CLS veto design for next-generation rare-event searches.

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