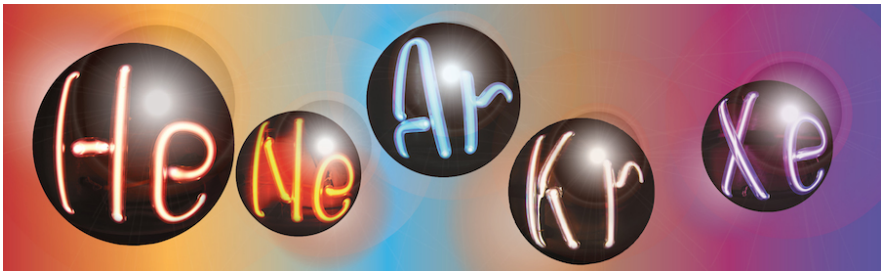

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Design and performance optimizations of the Outer Veto and light detection facilities for the LEGEND-1000 Experiment

The LEGEND-1000 experiment aims to search for neutrinoless double-beta decay with an unprecedented background goal of 10-5 cts/(keV·kg·yr). A critical requirement for reaching this sensitivity is the suppression of cosmogenic backgrounds, specifically muon-induced neutrons that produce 77mGe, to below 10-6 cts/(keV·kg·yr). To achieve this, the experiment utilizes an Outer Liquid Argon (LAr) instrumentation system optimized to detect argon scintillation light within the large-volume atmospheric LAr shield.

The baseline design combines a passive, radiopure PMMA neutron moderator with an active light detection system consisting of Light guiding and Detecting Modules (LDM). These LDMs utilize wavelength-shifting (WLS) doped PMMA light guides wrapped in PEN foil or coated with TPB/PTP to shift 128 nm (or 178 nm in Xe-doped LAr) scintillation light for detection by high-density Silicon Photomultiplier (SiPM) arrays. This contribution details the integrated R&D and performance optimizations conducted across different specialized facilities.

Initial prototype characterization is performed at INFN-LNGS using a cryogenic test stand dedicated to assessing the mechanical stability and optical performance of individual LDM designs.

Development of low-radioactivity SiPM flex PCBs and evaluation of photon detection efficiencies across various module geometries and wavelength-shifting configurations are conducted at INFN-Milano Bicocca setup.

Benchmarking of the complete readout chain, including the SiPMs, optimized front-end electronics, and data acquisition systems, is carried out at the facility at INFN-Roma Tre. Complementing these studies, a setup at INFN-Naples focuses on characterizing Xe-doped liquid argon, exploring how varied xenon concentrations modify scintillation decay time constants, increase the Rayleigh scattering length, and enhance light yield while preserving pulse shape discrimination capabilities.

Finally, the upcoming LEGENDArY facility at INFN-LNGS, currently in its design phase, will scale these efforts as a comprehensive, large-scale cryogenic platform for the mass characterization and testing of the approximately 500 LDMs required for the experiment.

Together, these integrated R&D efforts establish the technical foundation for imminent full-scale prototype testing and the ultimate implementation of an optimized, high-reliability outer veto system for LEGEND-1000 experiment.

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