Enhanced Pulse Shape Discrimination in CsI(Tl) Scintillators via High-Efficiency Photodetection for Dark Matter Searches

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The Korea Invisible Mass Search (KIMS) experiment successfully utilized CsI(Tl) crystals for dark matter detection, relying on Pulse Shape Discrimination (PSD) to distinguish potential nuclear recoil (NR) signals from electron recoil (ER) backgrounds. Historically, the PSD performance was limited by the relatively low light yield of approximately 5 photoelectrons (PE)/keV, a consequence of the spectral mismatch between the CsI(Tl) emission peak and the quantum efficiency (QE) of conventional photomultiplier tubes (PMTs).

In this work, we demonstrate a significant enhancement in light collection by coupling CsI(Tl) crystals to next-generation, high-QE PMTs, achieving a light yield of 11 PE/keV—more than doubling the previous baseline. Given that PSD sensitivity is fundamentally governed by photon statistics, this increase provides a dramatic improvement in discrimination power, particularly in the low-energy region critical for light dark matter searches. We present the results of PSD measurements conducted with a ^{252}Cf neutron source to quantify the separation of NR and ER populations. We evaluate the discrimination performance using the Quality Factor (QF) and discuss the resulting reduction in the analysis threshold for rare-event searches.