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High-Count-Rate Saturation Behavior in MCP-PMT: An Experimental Study

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As the core photoelectric conversion device in Ring Imaging Cherenkov (RICH) detectors, the microchannel plate photomultiplier tube (MCP-PMT) exhibits dynamic response characteristics that critically determine the spatial resolution accuracy of particle trajectory reconstruction. Under high-flux detection conditions, the nonlinear gain attenuation caused by electron cloud saturation effects within microchannels has become a key bottleneck limiting the beam tolerance of these devices. Although atomic layer deposition (ALD) technology has been proven effective in extending the lifetime of MCP-PMTs, ALD MCP-PMTs exhibit slow saturation recovery [Kuinian Li, et al, NIMA 1074(2025)170323] and the influence of ALD coatings on their saturation characteristics remains to be thoroughly investigated.

To elucidate the factors affecting the saturation behavior of MCP-PMTs, this study established a test system based on a nanosecond-pulsed laser source. A systematic control variable approach was employed to investigate the response characteristics of single-anode MCP-PMTs with different ALD coating thicknesses (0-6 nm) under three operational modes:

(1) Constant gain mode (gain maintained at 1E4 or 1E6 levels),

(2) Constant charge output mode (single-pulse output charge stabilized at 10 pC/cm2),

(3) Constant photon flux mode (incident photon count fixed at 1700 ph/ cm2·pulse).

Saturation characteristic curves were obtained through frequency-sweep testing (10 Hz to 10 MHz), and a quantitative evaluation model based on average anode current was established.

Experimental results demonstrate that ALD coatings with thicknesses below 6 nm show no significant impact on the saturation characteristics of MCP-PMTs. Notably, the normalized saturation curves obtained under all three testing modes exhibit remarkable self-consistency, confirming that average anode current serves as a universal evaluation metric independent of specific operational conditions. Under constant photon flux mode, the lower the gain of the MCP-PMT, the higher the tolerable count rate. The established evaluation framework provides quantitative criteria for MCP-PMT selection in high-count-rate applications.

In this report, we will present the latest research findings on the lifetime study, saturation recovery characteristics, and saturation characteristics of ALD MCP-PMTs.

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