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Determination of a Rate-Dependent Gain Correction for the Muon g-2 Calorimeters at Fermilab

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The Muon $g-2$ experiment at Fermilab has measured the anomalous magnetic moment of the muon ($a_\mu \equiv (g_\mu - 2)/2$) to a precision of 127 parts-per-billion. During the experiment, 'fills' of $\mathcal{O}\left(10^5\right)$ 3.1 GeV/c muons were injected into the $g-2$ storage ring, of which $\approx$ 5,000 muons were stored and decay over the course of 700 μs. These stored muons decay into positrons which spiral inward and impact a series of PbF_2 crystal calorimeters read out by silicon photomultipliers (SiPMs) positioned around the inner radius of the storage ring. Over the course of each fill, calorimeter gain stability at the 5×10^{-4} level was required to meet our systematics goals even as the instantaneous rate of positrons changed by 5 orders of magnitude. The gain of the calorimeter was monitored by a dedicated laser system, which corrected for the effect of the large flash of particles at injection and pulse-pair SiPM pixel effects with recovery on the $\mathcal{O}(15\,\text{ns})$ timescale. After the conclusion of the final running period, a series of tests were conducted at the University of Washington to resolve an observed residual gain-like effect after these corrections were applied. Here we describe these measurements, the discovery of the cause of the gain change — the cumulative perturbations the positrons themselves have on the detector gains long after injection, each on the $\mathcal{O}(4-8\,\mu\text{s})$ timescale and with a relative amplitude of $\leq 10^{-4}$ — and the application of the correction in the final publication.

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