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Studies on the Dynamic Range of SiPMs with High Pixel Densities

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The future Circular Electron-Positron Collider (CEPC) is a large-scale experimental facility designed to enable precise measurements of the Higgs boson, electroweak physics, and the top quark. For the CEPC detector system, a highly granular crystal electromagnetic calorimeter is proposed, targeting an electromagnetic energy resolution of less than 3%. This calorimeter features a homogeneous structure with long crystal scintillator bars as the active material and Silicon Photomultipliers (SiPMs) as the preferred photon sensors. Simulations indicate that the energy deposited by a single crystal could reach up to 30 GeV, corresponding to over 300,000 photoelectrons per side based on the light yield of BGO crystals. This necessitates that the SiPMs maintain a linear response across a very wide input range, making high pixel density a critical requirement to avoid saturation.

This study explores the characteristics of SiPMs with varying pixel densities, focusing on their performance across a broad dynamic range. Utilizing a comprehensive experimental setup that combines laser sources and photomultiplier tubes (PMTs) for precise light intensity calibration, we evaluated SiPMs with pixel counts up to 244,719 and pixel sizes as small as 6 micrometers. To complement these experimental findings, we developed a model to simulate the SiPMs' responses under different lighting conditions, incorporating key parameters such as pixel density and photon detection efficiency. The simulations closely matched the experimental results for laser light, revealing similar trends of nonlinearity. For BGO scintillation light, the simulations —accounting for multi-firing effects of pixels—showed significantly higher photon counts compared to the laser-based simulations. Moreover, the simulated responses derived from this research provide a method to correct for SiPM saturation effects, ensuring accurate measurements in high-energy events even when using SiPMs with a limited number of pixels.

Primary authors: ZHAO, Zhiyu (TDLI/SJTU); QI, Baohua (IHEP); LIU, Yong (Institute of High Energy Physics)

Presenter: ZHAO, Zhiyu (TDLI/SJTU)

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