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Simulation and Performance Study of a Scintillator Cube Detector for Electron Tracking Using GEANT4

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This work presents the simulation and study of a three-dimensional scintillator bar detector for the analysis of 100 MeV electrons, using the GEANT4 toolkit. The detector design consists of a segmented array of scintillator cubes, each coupled to a wavelength-shifting (WLS) optical fiber and a silicon photomultiplier (SiPM). This computational study is complemented by an ongoing proof-of-concept involving the physical construction of a two-bar prototype. The simulation models the interaction of high-energy electrons with the scintillator material, the generation and transport of optical photons, and their detection by SiPMs. The detector's performance is characterized in terms of trajectory reconstruction efficiency, spatial resolution, and the correlation between deposited energy and detected optical signal. Results indicate a reconstruction efficiency between 40% and 70% for most events, while spatial resolution is primarily limited by the physical size of the scintillator cubes. A clear positive correlation between deposited energy and the number of detected photons is observed for energies above 50-100 MeV, validating the correct implementation of the optical processes. This study demonstrates the feasibility of the proposed 3D detector concept and provides a foundation for optimizing future designs for high-energy particle tracking.

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