Optimization of GAGG properties for the high-rate environment of the LHCb ECAL Upgrade II

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Garnet-based scintillators are emerging as promising candidates for their use in High-Energy Physics (HEP) detectors due to their radiation hardness, high light yield and fast scintillation properties. In this work we establish optimal and realistic specifications for the inner part of the electromagnetic calorimeter of the LHCb experiment (PicoCal) at HL-LHC. To this end, a dedicated simulation framework was developed using the Geant4 toolkit, featuring a spaghetti calorimeter (SpaCal) model with realistic photomultiplier tube readout.

This framework enables a systematic study of detector response under expected particle flux and hit rates. We performed detailed simulations evaluating light yield, inhomogeneities, slow scintillation and pile-up effects on performance. Particular attention is given to the influence of slow emission and its sensitivity to both tail cancellation techniques and readout integration, which can degrade timing precision and bias energy reconstruction.

GAGG's composition being tunable, it allows for significant adjustments in material properties. In this work, we study how these specific scintillation characteristics directly affect the performance of the SpaCal. We quantify these effects through simulations, demonstrating how the inhomogeneity of the light yield along an ingot impacts the energy resolution, and how the long component of the decay time influences the time resolution. Furthermore, we identify novel meaningful Figures of Merit quantifiable in the laboratory to help select the optimal composition. These combined results yield a set of physics-driven criteria to guide the material selection, production, and characterization of garnet scintillators for next-generation experiments.

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