Scintillation Response of CsI(Tl) to Monoenergetic Single-Electron Excitation at Low Energies

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Understanding scintillation response in the low-energy electron regime is important for both fundamental studies and applications, as electron tracks at energies of a few to a few tens of keV are highly localized and dominated by near-surface energy deposition, where quenching and non-proportionality effects are pronounced. Experimental access to this regime in a controlled and repeatable manner remains challenging.

We present a compact benchtop platform for controlled studies of scintillation response under low-energy electron excitation, enabling event-by-event operation and clear separation of single- and multi-electron interactions in the low energy regime. The system is designed to be applicable to a broad range of scintillator materials. As a first demonstration, we investigate a CsI(Tl) crystal using electron energies between 8 and 20 keV. Photoelectrons are generated from a custom Ag photocathode under pulsed LED/UV illumination and accelerated in vacuum across a tunable high-voltage gap. The electrons are incident on an Al-coated CsI(Tl) scintillator, and the resulting scintillation signal is read out by a directly coupled SiPM. The SiPM single-photoelectron spectrum is used to calibrate the detector response in terms of charge and light yield, while gamma-ray measurements with standard sources on the same CsI(Tl) crystal provide an independent and complementary validation. Pulse-height spectra exhibit a well-resolved pedestal and discrete peaks corresponding to single and multiple accelerated electrons, enabling direct quantification of light yield and resolution as a function of electron energy while explicitly accounting for multi-electron contributions. This controlled low-energy electron excitation provides sensitivity to non-proportionality and quenching mechanisms in the low-energy regime, where near-surface tracks dominate energy deposition.

To support interpretation, the electric-field configuration is modeled in COMSOL, and electron transport and energy deposition are simulated in Geant4 using the experimental geometry. The measured response is further analyzed within a Birks–Onsager framework to constrain effective recombination/quenching parameters relevant to ionization at low electron energies. The presented approach offers a flexible and low-cost route for systematic studies of low-energy scintillation response, bridging experimental characterization with physics-motivated modeling for CsI(Tl) and related inorganic scintillators.

Keywords: CsI(Tl), low-energy electrons, monoenergetic single-electron excitation, SiPM; non-proportionality, quenching, near-surface energy deposition, scintillator characterization.