A Beam Test Study on Timing Resolution of Various Scintillating Crystals

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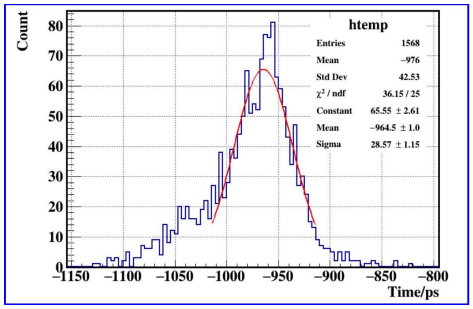
The increasing demand for higher measurement precision in various fields such as high-energy physics and medical imaging has driven the required timing resolution of particle detectors into the picosecond regime[1]. The timing response characteristics of scintillating materials are crucial for achieving high-precision time detection. However, as the relatively slow scintillation process increasingly struggles to meet the growing need for ultra-high timing resolution. Cherenkov radiation has emerged as a cornerstone mechanism for achieving such performance, thanks to its intrinsic picosecond-scale time structure[2].



Coincidence time distribution of BaF_2 under 5 GeV electron beam, reaching a CTR of 28.57 ps.

In this study, first-principles calculations and Geant4 simulations were employed to investigate the luminescence mechanisms and ultimate timing resolution of various scintillator crystals (e.g., BaF_2, BGO, GAGG), and their timing performance limits were evaluated under multiple beam excitation conditions to assess their feasibility as Cherenkov radiators. Experiments employed fast photomultiplier tubes with ultrafast time response (rise time < 300 ps, transit time spread < 30 ps)[3] as the readout. Under multiple beam conditions, the coincidence time resolution (CTR) of these coupled crystals was measured. Results indicate that under beam irradiation, several scintillators demonstrate potential as Cherenkov radiators. Timing using Cherenkov light achieved a resolution of around 30 ps; for example, BaF_2 crystals reached a CTR of 28.57 ps.

By correlating timing spectra with characteristics such as light yield and emission spectra, we evaluated the potential of utilizing or enhancing intrinsic Cherenkov radiation as an effective strategy to surpass the timing limits of traditional scintillation mechanisms.

1. P. Lecoq et al., “Roadmap toward the 10 ps time-of-flight PET challenge,” Phys. Med. Biol., 65, 21RM01 (2020).
2. D. Consuegra et al., "Simulation study to improve the performance of a whole-body PbF2 Cherenkov TOF-PET scanner," Phys. Med. Biol., 65, 055013 (2020).
3. L. Ma et al., “R & D of a novel single anode fast timing MCP-PMT,” Nucl. Instrum. Methods Phys. Res. A, 1041, 167333 (2022).