Investigation of ultra-fast light production mechanisms for charged particles timing detectors in future collider experiments

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Accurate timing evaluation is expected to play a significant role in particle detectors for future collider experiments. A precise timing knowledge can enhance the vertices reconstruction by mitigating the impact of pile-up effects in the challenging radiation environments expected in such experiments. A single-detector time resolution of 20 - 30 ps (sigma) was estimated to be required for accurate event reconstruction. To meet this requirement, previous studies have already demonstrated the feasibility of utilizing dense scintillating materials like LYSO:Ce, LSO:Ce,Ca and aluminium garnets (YAG:Ce, LuAG:Ce, GAGG:Ce) readout by compact silicon photomultipliers (SiPMs) for the implementation of a specialized timing device housed within a larger particle detector.

The objective of this study was to investigate the timing capabilities of various materials that generate light through different mechanisms when used as minimum ionizing particles (MIPs) detectors. These detectors were tested under 150 GeV charged pions irradiation along the H2 extraction line at the CERN SPS proton accelerator. The materials investigated in this work included conventional dense scintillators (e.g. LSO:Ce,Ca, LYSO:Ce, GAGG:Ce and BGO), materials which exploit Cherenkov radiation for timing (e.g. BGSO, $PbWO_4$, PbF_2), and cross-luminescent crystals (e.g. BaF_2, BaF_2:Y). Pixel samples of dimensions 2 x 2 x 10 mm^3 or 3 x 3 x 10 mm^3 were Meltmount-coupled to Hamamatsu SiPMs and their signals were read out using custom high-frequency electronics.

The best result was achieved for a 10 mm long LSO:Ce,Ca pixel, exhibiting a single-detector time resolution of 12.1 ± 0.4 ps (sigma) when time-walk correction is applied. We also observed a sub-20 ps time resolution of many other samples like LYSO:Ce, GFAG, highly doped GAGG:Ce,Mg and EJ232). BaF_2 and BaF_2:Y also achieved an impressive time resolution of about 16 ps despite worse measurement conditions compared to other samples (lower photon detection efficiency, worse crystal-SiPM surface coupling). Finally, timing capabilities with σ ranging from 24 and 36 ps were observed for several materials whose timing properties are mainly determined by Cherenkov emission.