Multi-MeV Gamma Interaction Position Estimation in Large Pure Cherenkov Emitter Crystals for Collimated Prompt-Gamma Imaging

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Proton range verification (PRV) in proton therapy is currently an unmet need and developments in radiation instrumentation are desired for this purpose. Prompt-gamma imaging (PGI) is one of the modalities proposed for PRV that uses the prompt-gammas emitted predominantly in the Bragg peak region as a signature of the end of the proton range. The most successful PGI systems in the clinics to-date consist of heavy mechanical collimation systems with a slit and achieve spatial resolutions as good as 1 mm [1-3]. The detectors used in such systems consist of thick scintillation crystals coupled to photodetectors and rely on their spectroscopic properties to discern between prompt-gammas and background.

In this work, we study the Cherenkov light created by prompt-gammas in monolithic and pure Cherenkov emitter crystals to achieve position estimation for PGI using mechanical collimation. The advantages of a Cherenkov crystal over scintillation ones are i) an exclusively high sensitivity to prompt-gammas, thus allowing for efficient background rejection without energy on time or time gating, ii) fast light decay time, for high count rates, and iii) low cost of specific Cherenkov emitters, such as PbF_2. The potential downside is the complication in extracting information from the relatively low light yields, approximately between 100 and 200 optical photons [4].

Monolithic PbF_2 crystals with dimensions of 25x25x10 mm^3 and 25x25x5 mm^3 were used. The detector consisted of a crystal coupled to a Hamamatsu S13361-3050AE-08 silicon photomultiplier (SiPM) array, which consists of 8x8 elements of 3x3 mm^2 active area each. The detector was mounted on a 2D translation stage and aligned with two tungsten blocks that were used to form a 3 mm slit to collimate high energy gammas. A Th^{228} gamma source was used for the benchtop characterization as it provides gammas of up to 2.6 MeV of energy. The detector was shifted in increments of 3 mm in the Y-axis direction, while the collimation system and source were fixed. Four datasets were acquired at four different detector positions: 0 mm, 3 mm, 6 mm, and 9 mm.

The floodmaps from each dataset and for both crystals showed consistent distribution shifts across the four positions, with relatively clear discrimination between them. The slit was observed for both crystals, with a resolution of 5 mm for the 10 mm thick PbF_2. Hints of position resolution were observed with the current electronics readout. We expect to improve the signal-to-noise ratio by upgrading the readout scheme. Next steps include the characterization of a row-column SiPM readout to enhance the Cherenkov light collection and to deploy the system in a proton beam line.

This working progress presents a novel detector concept for the challenging area of PGI. If successful, this method can provide a solution for PGI that is independent of the beam time structure, potentially with very effective prompt-gamma to background discrimination capacity and expected low production cost.

References

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