In-silico study of quantum ghost imaging with entangled annihilation photons

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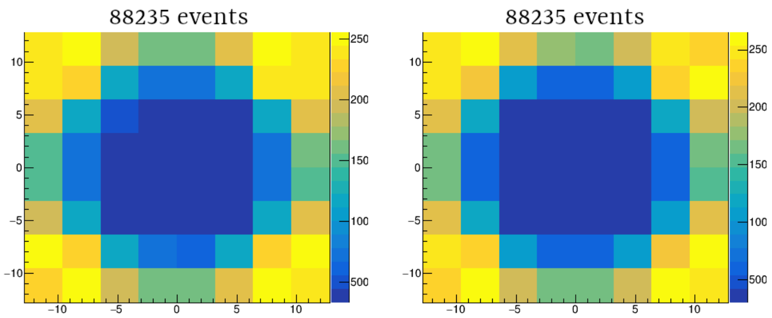
Entangled gamma ray photons produced in the process of positron annihilation have orthogonal polarizations, 511 keV energy and opposite momenta. The characteristics of the annihilation process have been extensively explored for potential enhancement of Positron Emission Tomography (PET), but another interesting way of exploiting the properties of the produced annihilation quanta is ghost imaging, a method of non-local imaging of an object. This phenomenon has been mainly studied with optical and infrared photons, as well as X-rays, but the research in the gamma regime has only just been initiated [1]. In this work, we conduct a first Monte Carlo study in Geant4 of the quantum ghost imaging with annihilation photons. The model coincidence experimental setup consists of two detector modules, each assembled from 64 Gadolinium Aluminum Gallium Garnet crystals doped with Cerium (GAGG:Ce) in 8x8 matrix, with 3x3x20 mm^3 crystal size and 3.2 mm matrix pitch [2]. The modules are set at the distance of 10 cm, with Na-22 source in between. In front of one of the modules, a low transmission object (for example, a lead cylinder (r=5 mm, l=15 mm, ρ=11.35 /cm^3)) is placed in front of one of the detector's face. The principle of the imaging is demonstrated in Fig. 1, in which it is evident that the detector without the object in front has absence of coincidence pairs in the area covered by the object placed in front of the other module, hence creating the ghost image of the object (in this case, the lead cylinder). The study will explore the potential of ghost imaging of various materials of different thicknesses and densities. Quantum ghost imaging with entangled gamma ray photons could potentially be useful for imaging of high-Z, low transmission objects for homeland security and industrial inspection.



a) b)

Fig. 1. 2D histograms of the detector modules. Ghost image in a) of the lead cylinder in front of the detector in b). Events in the histograms selected to reflect experimental coincidence measurements.

1. A. Schneider *et al.*, "Quantum imaging with positronium-decay-emitted gamma rays," *Physical Review A*, **113**, 013715 (2026).
2. S. Parashari *et al.*, "Measurement of angular correlations of Compton-scattered gamma quanta from positron annihilation using GAGG:Ce scintillator matrices with single-side readout" *Journal of instrumentation*, **17(09)**, C09007 (2022).

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