Implementation of the annihilation gamma-ray polarizations in Positron Emission Tomography

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Motivation

To investigate the possibility of image background reduction and image enhancement by measuring the polarization correlations of gamma-rays from positron annihilation in Positron Emission Tomography (PET) [1, 2, 3, 4].

Aim

Investigate the properties of images of two Ge-68 line sources in a phantom, obtained by a novel PET demonstrator device that measures polarization correlations of the annihilation gamma-rays, by utilizing capabilities of the single-layer Compton polarimeters with SiPM read-out [5..9].

Novel PET demonstrator device

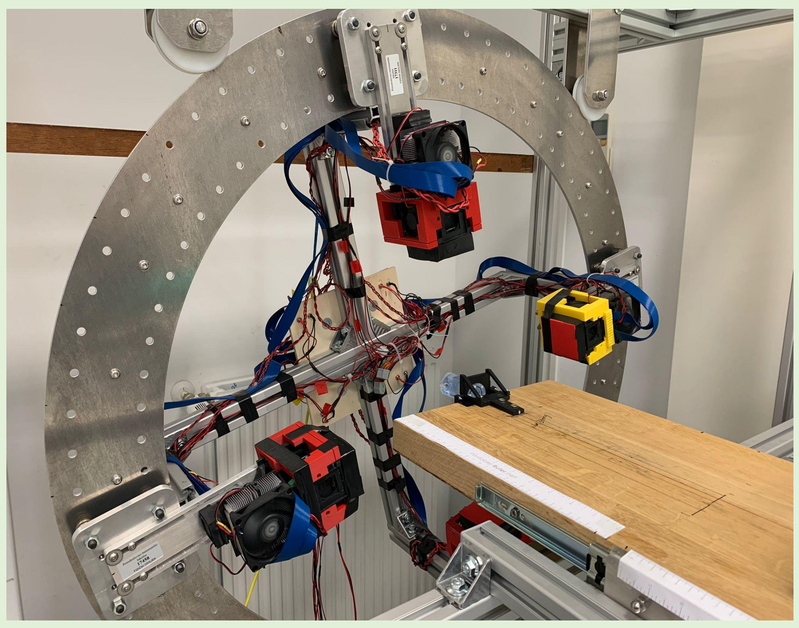


Figure 1: The novel PET demonstrator device. Detector modules based on the single-layer Compton polarimeters mounted on a rotating gantry [5, 7, 8, 9].

- Modules with 3.2 matrix pitch fixed opposite of one another
- GaGG:Ce crystals, E_{res}@511keV ~10%[6]
- 16x16 matrix, 3x3x20 mm^3 each pixel
- Diameter fixed at 430 mm
- Acquisition time: ~ 2.3 h per position
- Number of positions: 12 (15° per rotation)

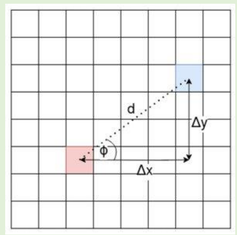
Source and phantom

- Ge-68 line source, 45.5 MBq
- Epoxy phantom is 3 cm in diameter
- Distance between the sources is 1 cm
- One source placed through the middle of the phantom

Results

Data analysis

Coincidence window time: 2500 ps



$$\phi = \operatorname{atan}\left(\frac{\Delta y}{\Delta x}\right)$$

$$\theta = \operatorname{acos}\left(\frac{m_e c^2}{E_{px_1}+E_{px_2}} - \frac{m_e c^2}{E_{px_2}} - 1\right)$$

$$N_{cor}(\phi_1 - \phi_2) = M[1 - \mu\cos(2(\phi_1 - \phi_2))]$$

Figure 2: Polarized gamma-ray Compton scatters in one pixel of the detector and gets absorbed in another. The Compton angles are reconstructed from the equations.

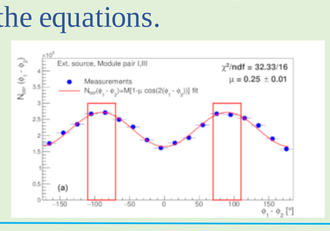


Figure 3: The azimuthal angle differences distribution with the Klein-Nishina fit, with the cuts for 90°±20° used in reconstruction.

Image reconstruction

- Selected events reconstructed with OMEGA software
- OSEM, 10 iterations, 8 subsets
- Images of the size 100x100x31
- FOV: 120 mm x 120 mm

Δφ \ Polar angle interval	82°±10°	82°±5°	70°±10°	70°±5°
0°±20°	99	28	164	43
90°±20°	180	55	280	75

Table 1: The number of coincidence events cuts (per position) for image reconstruction (in thousands). The cut was determined by the maximum number of events that originate from the correlated annihilation gamma-rays.

Reconstructed image of the annihilation gamma-rays with polarization correlations

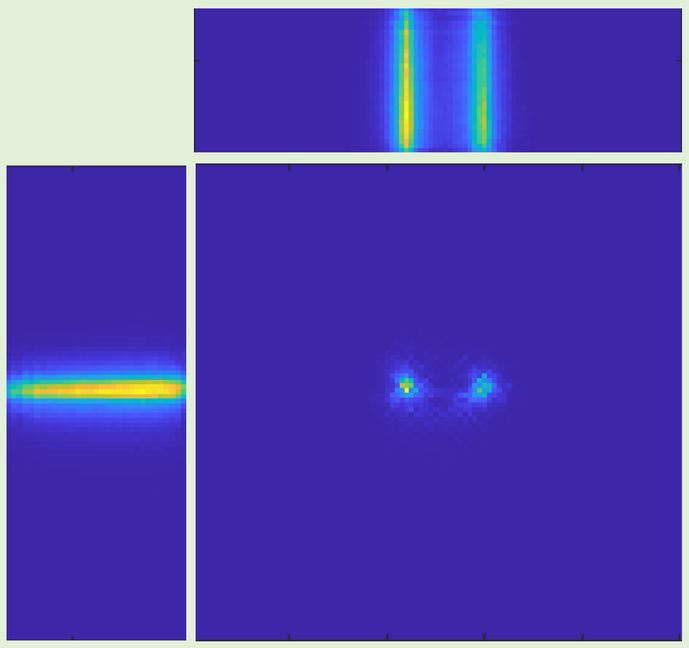


Figure 4: Reconstructed image with the data that corresponds to events in which both gamma-rays scattered with the polar scattering angle 82°±10°, with azimuthal angle difference of 90°±20° (preliminary).

SNR characteristics of the reconstructed images

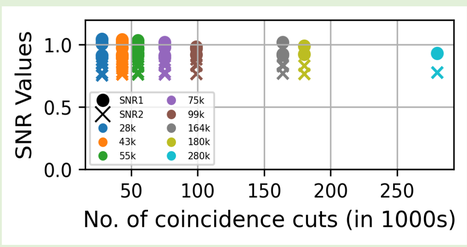
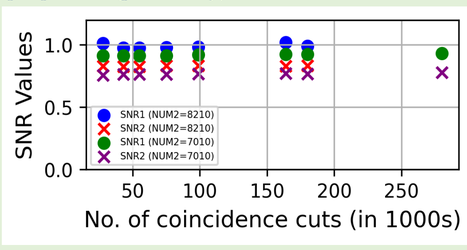
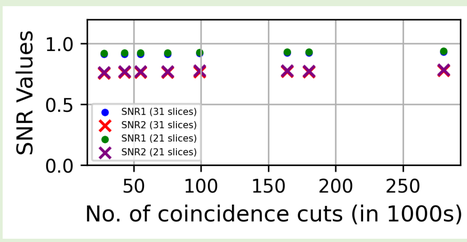


Figure 5: SNR values of all the reconstructed images vs. number of reconstructed coincidences per position (preliminary).





Signal-to-noise ratio (SNR) was evaluated with MATLAB, by dividing the average intensity in the regions of interest (ROI) by their standard deviation . ROI is a circle around each of the sources in the axial image (in Fig. 3, 100x100 image).

Figure 6: SNR values of images with the azimuthal scattering angle difference 90°±20° vs. number of reconstructed coincidences per position (preliminary).

Figure 7: SNR values of images with the difference of azimuthal scattering angle 90°±20° and polar angle 70°±10° vs. number of reconstructed coincidences per position, calculated before and after the removal of the top and bottom 5 slices (preliminary).

Conclusions

We have successfully, for the first time, reconstructed the image of two line sources in a plastic phantom with events that correspond to annihilation gamma-rays with correlations in polarization. Calculated SNR ratios for the reconstructed images show that the ratio is larger for events with a polar angle 82°±10°, than those at 70°±10°. With the removal of five slices from the top and bottom of the image, there is a slight increase in the SNR in each of the coincidence cuts.

References:

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