Probabilistic Sequencing for Compton Imaging Using the Polarized Klein-Nishina Formula

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Introduction and Motivation

- Gamma-ray Compton imaging uses the 3-D position and scattering angle of the first gamma-ray scattering of multiple interaction events to reconstruct the direction of incident photons.
- One technique used by 3-D position sensitive CZT detectors for Compton-scattering sequencing, is the probabilistic method.
- This work focuses on improving the probabilistic method of sequence reconstruction for Compton scattering by accounting for photon polarization.

Mission Relevance

- Determining the sequence of multiple gamma-ray interactions is critical to providing the correct source direction and therefore impacts applications such as detecting and locating gamma-emitting materials.

Technical Approach

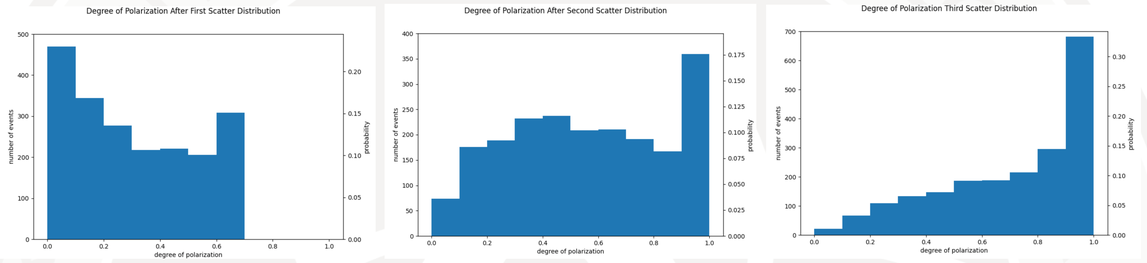
- Verify that the Klein-Nishina cross section for linearly polarized photons will better describe the scattering physics processes

$$d\sigma = \frac{r_0^2}{4} d\Omega \frac{k_1^2}{k_0^2}\left[\frac{k_0}{k_1} + \frac{k_1}{k_0} - 2\sin^2\Theta\cos^2\varphi\right]$$

- Test the proposed sequencing algorithm on simulation data
- Determine how to use this sequencing algorithm in experiment

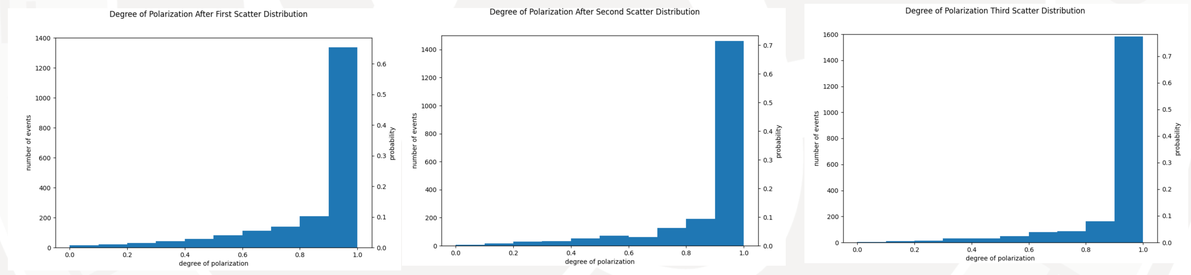
Results

$5 * 10^6$ photons were simulated for an unpolarized 511 keV source 1 meter away from the detector. The initial degree of polarization is 0.



Change in the degree of polarization as the photons scatter for 4-interaction full-energy events.

$5 * 10^6$ photons were simulated for a horizontally polarized 511 keV source 1 meter away from the detector. The initial degree of polarization is 1.



Change in the degree of polarization as the photons scatter for 4-interaction full-energy events.

The proposed sequencing algorithm was tested on simulation data where the polar scattering was calculated as usual with the Compton scattering formula and the azimuthal angle was taken from simulation.

Type of event	Initial polarization/initial degree of polarization	% events correctly sequenced with current probabilistic method	% events correctly sequenced with proposed probabilistic method	Overall improvement
3-interaction full deposition	Unpolarized/0	51.65 % or 11336/21949	68.54 % or 15044/21949	+16.89 %
4-interaction full deposition	Unpolarized/0	42.62 % or 878/2060	58.93 % or 1214/2060	+16.31 %
3-interaction full deposition	Linearly polarized/1	55.41 % or 8936/16127	70.25 % or 11329/16127	+14.84 %
4-interaction full deposition	Linearly polarized/1	47.69 % or 796/1669	63.81 % or 1065/1669	+16.12 %

Expected Impact and MTV Impact

- This work will improve the overall imaging performance of 3-D pixelated CZT detectors.
- MTV has provided me with the opportunity to attend workshops and conferences where I can present my work and learn from others.

Conclusion and Next Steps

- The results of this work show that regardless if the source is initially unpolarized or polarized, as the photon scatters in the detector, it will gain a non-zero degree of polarization.
- Substituting the unpolarized Klein Nishina cross section for the polarized cross section shows improvement in Compton-scattering sequencing.
- The next steps include probabilistically determining the azimuthal scattering angle, since this information cannot be directly calculated with the interaction positions and deposited energies, and implementing this method of sequencing in experiment.

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