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# Gamma-Ray Pair Regime Polarimetry with AMEGO-X

## ABSTRACT

Many astrophysical sources such as gamma-ray bursts, active galactic nuclei (AGN), and pulsars emit high-energy radiation in the form of gamma rays. Analyzing the polarization of these rays can reveal critical information about a source's emission mechanisms, surrounding electromagnetic fields, and energy distributions, which may be otherwise unattainable.

This research presents the first findings in gamma-ray pair regime polarimetry with the consideration of realistic detector effects.

## WHAT IS AMEGO-X?

***All-sky Medium Energy Gamma-ray Observatory eXplorer (AMEGO-X):***

- Proposed NASA telescope designed to detect gamma rays from extreme cosmic sources in the 100 keV to 1 GeV range.
- Above 10 MeV, gamma rays interacting with the detector primarily undergo **pair production**, converting into an electron and positron.

## POLARIZED GAMMA RAYS

**Gamma rays:** Electromagnetic radiation with the shortest wavelengths and highest energy and frequency.

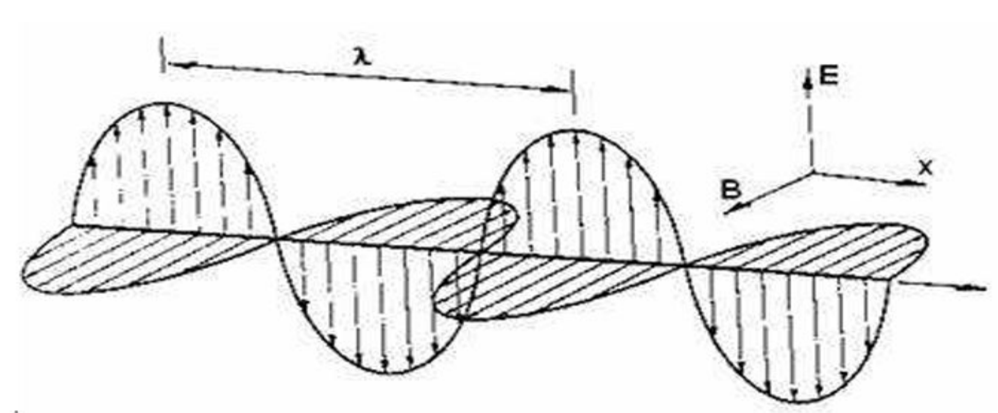


**Fig. 1.** Diagram showing oscillations of the electric (E) and magnetic (B) fields in a linearly polarized electromagnetic wave. [2]

**Polarization:**
Orientation of the electric field vector in an electromagnetic wave as it propagates through space.

**Methods of interaction with the detector:**

Photoelectric effect | Compton scattering | ***PAIR PRODUCTION***

LOW ENERGY → ~100 keV → ~10 MeV → HIGH ENERGY

## PAIR REGIME POLARIMETRY

For **linearly polarized** gamma rays:

- Pair is preferentially emitted in a plane containing the polarization direction of the incident gamma ray
- Distribution of azimuthal angles of the pair is sinusoidal (Eqn.1 and Fig. 4).

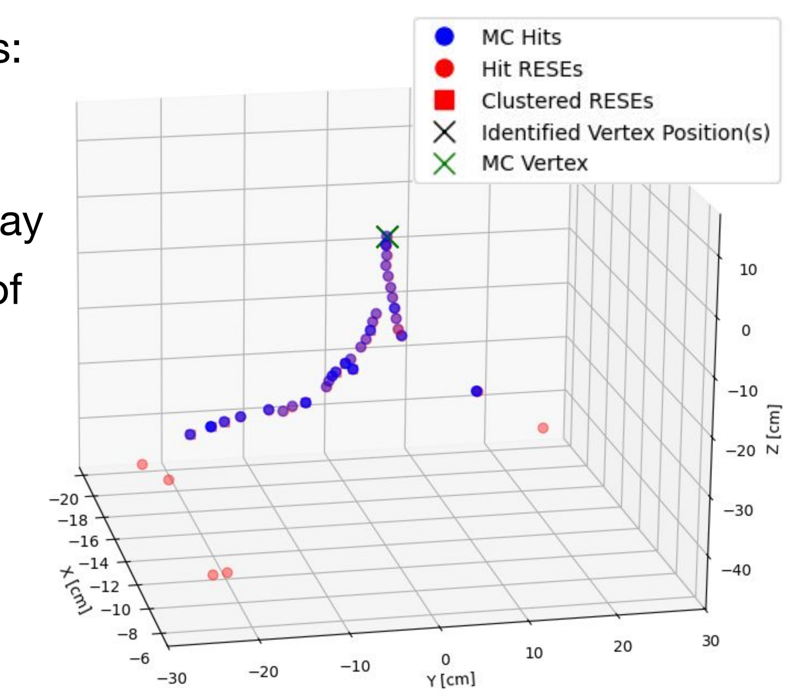


**Fig. 2.** Example of a simulated 30 MeV pair event with the Monte Carlo (MC) vertex and identified vertex indicated.

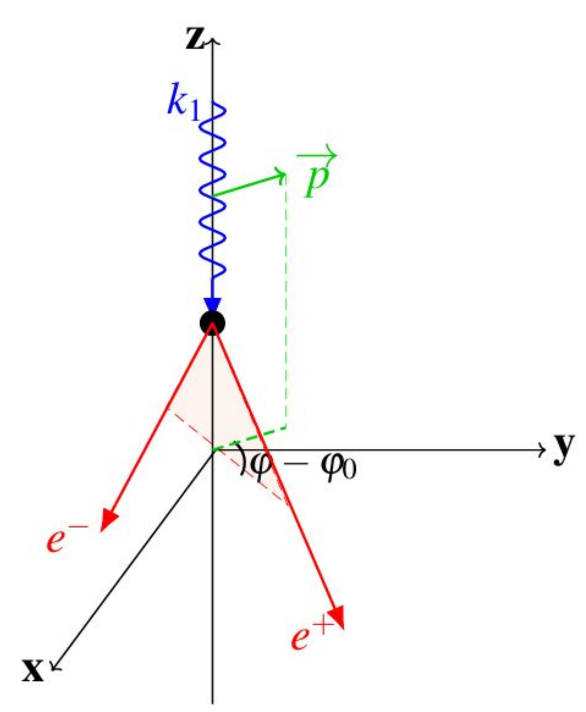


**Fig. 3.** Diagram of the pair production mechanism [1].

***Analysis process:***

1. Select only the MC pair events
2. Apply detector noise and clustering algorithms
3. Apply vertex finding algorithm to all events
4. From identified vertex of each event, compute azimuthal angle

The number of pair events from a polarized source (normalized to the unpolarized source) as a function of azimuthal angle will follow a sinusoidal distribution which can be fit with the following modulation function:

$$\frac{N}{2\pi}\left[1 - A\cos\Big(2(\varphi - \varphi_0)\Big)\right] \qquad (1)$$

where $N$ is the normalization constant, $A$ is the the modulation amplitude, $\varphi$ is the azimuthal angle, and $\varphi_0$ is the polarization angle.

## REFERENCES

[1] Bernard, D., Chattopadhyay, T., Kislat, F., & Produit, N. (2022). *Gamma-Ray Polarimetry.*
[2] Schwartz, M., *Polarization* [Lecture Notes]. PHYSICS 15C, Harvard.

## RESULTS

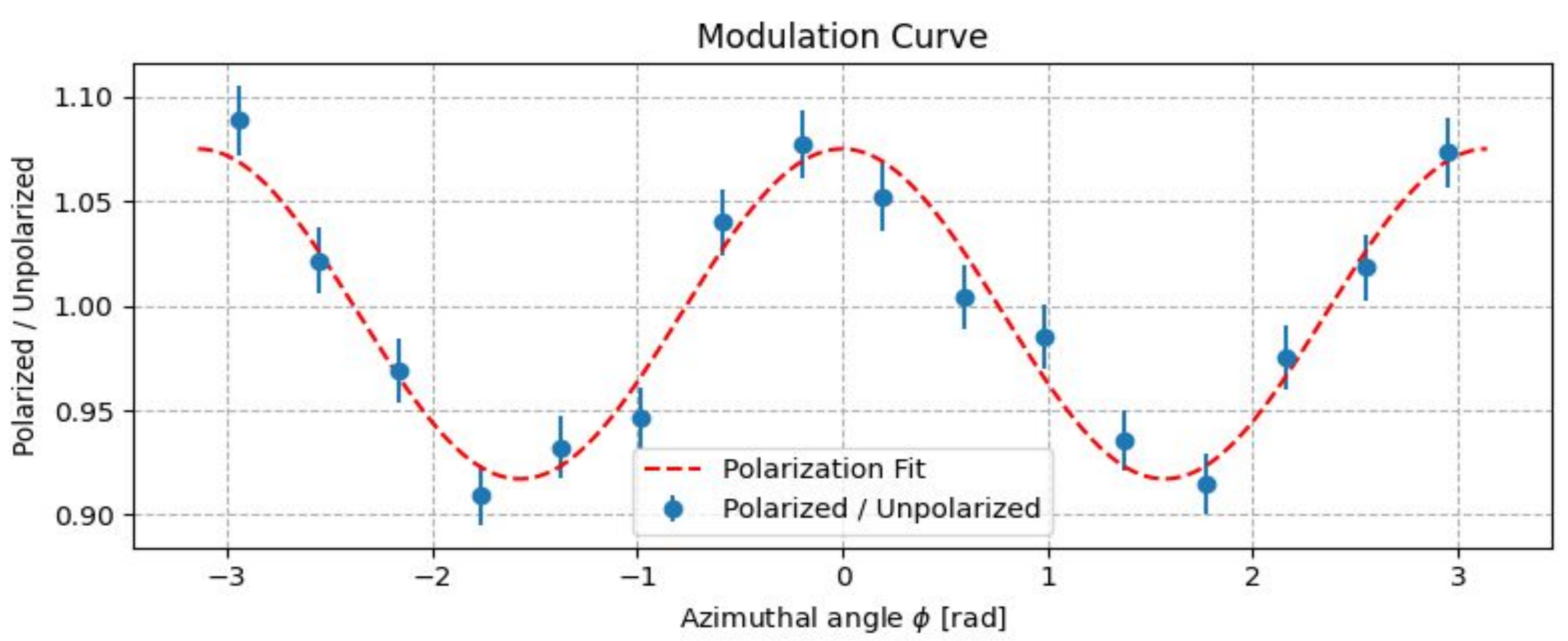


**Fig. 4.** Modulation fit to a binned polarized to unpolarized ratio using Eqn. 1. Simulation was a point source producing 10 MeV gamma rays on-axis (along z-axis) with 100% linear polarization along the negative y-axis. Fit indicates excellent agreement with the theory.

### FIT INFORMATION

Amplitude: $A$ = 0.079 ± 0.005

Polarization: $\varphi_0$ = 89.9° ± 2.0°

$\chi_\nu^2$ = 0.91

Poisson (statistical) errors are considered:

$$\sigma_{ratio} = \frac{P_i}{U_i}\sqrt{\frac{1}{P_i} + \frac{1}{U_i}} \qquad (2)$$

where $i$ is the bin, $P_i$ is the number of polarized counts in $i$, and $U_i$ is the number of unpolarized counts in $i$.

## FUTURE WORK

Current reasonable agreement with ideal detector simulations in [1] indicates that AMEGO-X is a viable candidate for pair regime gamma-ray polarimetry. This allows for multiple areas of future research:

- Simulate **off-axis** sources, different energies, non-point sources, and sources with **varying spectra** (currently all simulations have a monoenergetic spectrum)
- Use information to determine the detector's ability to extract polarization information from **real astrophysical sources** such as jets from AGN

Credit: ESA/Hubble, L. Calçada (ESO)