Polarization measurements with the MEGA telescope

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Abstract

The Medium Energy Gamma-ray Astronomy telescope MEGA is a combined Compton scattering and pair creation telescope in the energy range from 400 keV up to 50 MeV. The prototype has been calibrated in this energy range using monoenergetic and 100% polarized pencil beams. Polarization signatures are detected from 710 keV up to 5 MeV and are in agreement with Geant4 simulations. These properties make MEGA the ideal telescope to measure the polarization of astrophysical objects like gamma-ray bursts.

The MEGA Telescope

The Medium Energy Gamma-ray Astronomy telescope MEGA detects gamma-rays in the energy range from 400 keV up to 50 MeV via Compton scattering and pair creation. It consists of 1) a tracker of double-sided Silicon strip detectors, where the initial scattering process takes place and where the direction of the electrons is determined, and 2) a CsI calorimeter, which stops the secondary particles. The figure on the right describes the principle of measurement.

Calibration of the Prototype

The MEGA prototype, which consists of 1/12 of the volume of a full telescope, has been calibrated at the High Intensity Gamma Source of the Free Electron Laser facility at Duke University during April/May 2003. Exposures to monoenergetic (range 710 keV to 50 MeV, E/E ≤ 2%), 100% polarized pencil beams allow the derivation of the imaging and spectral properties, sensitivity, and field of view of this prototype instrument. Since the gamma-ray test beam is generated by Compton scattering inside a free electron laser the degree and angle of polarization (horizontal) are completely determined. Thus, the test beam is well-suited to determine the polarization response of the prototype.

Polarization Response as a Function of Energy and Compton scatter angle

Most processes in high-energy astrophysics, such as synchrotron radiation, bremsstrahlung, Compton scattering, etc. generate polarized gamma-rays. Therefore, polarization measurements are of great value to understand the emission mechanisms of gamma-rays.

\[
\frac{\partial \sigma}{\partial \Omega} = \frac{r^2}{2} \left( \frac{E_i}{E_f} - 2 \sin^2 \varphi \cos^2 \chi \right)
\]

The polarization preserving properties of the Compton cross-section result in a cosine shaped modulation of the azimuthal scatter angle of the Compton process. The maximum of the modulation is perpendicular to the original polarization vector.

Simulation of a gamma-ray burst with the MEGA satellite telescope

One important tool to reveal the secrets of bursts is the analysis of the emitted gamma-rays and especially their polarization, since their emission is closest to the central engine and thus, they carry most of the information about the progenitor.

The simulation has been performed with the high-energy burst GRB910814 as template. This was the second brightest burst in the first year of Comptel and had a fluence of 123 MeV/cm² in the energy band from 50 keV to 10 MeV. The spectrum followed a broken power law (α0 = -1.0, α1 = -2.57, E0 = 1070 keV).

Some assumptions were: With the onset of the burst, MEGA switches into the following trigger mode: at least one hit in the calorimeter and at least one hit in the tracker. The trigger thresholds are 100 keV in the calorimeter and 50 keV in the tracker. The maximum read-out rate is 5000 counts/sec. The short duration and the selection of only those events, which originate from the burst location, make chance coincidences and false reconstructed events the dominating source of background.

This burst leads to 19000 triggered events of which 9000 where identifiable Compton events starting in the tracker. 4200 where selected for the analysis (E < 3 MeV, 30° ≤ φ ≤ 150°, origin < 10° from source position).

Conclusions

With its ability to detect gamma-rays under large Compton scatter angles and its symmetric geometry MEGA, is an ideal polarimeter.

It has been shown that the prototype can detect polarization signals of Compton events from a 100% polarized up to at least 5 MeV. Variations of the degree of polarization with the Compton scatter angle are as expected.

These properties make MEGA the ideal tool to analyze the polarization of astrophysical sources like gamma-ray bursts.

References


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