

Polarization measurements with the MEGA telescope

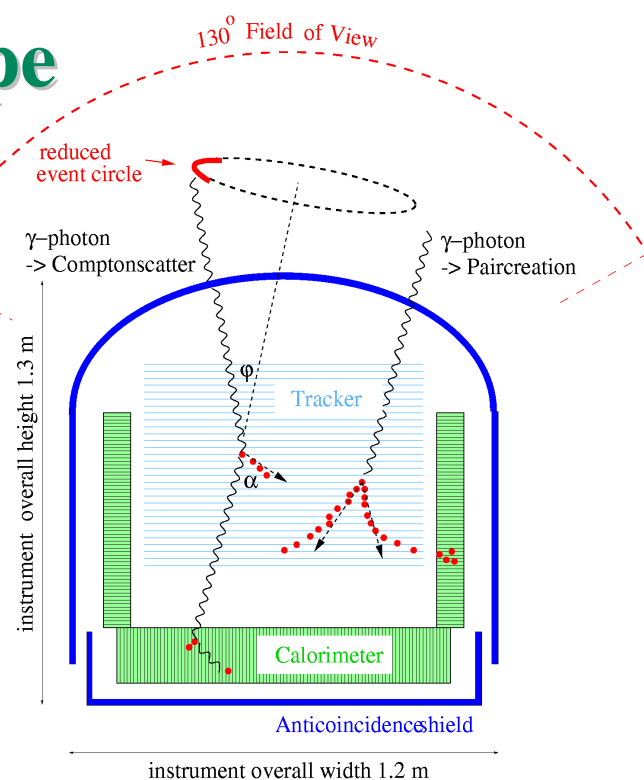
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Abstract

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.

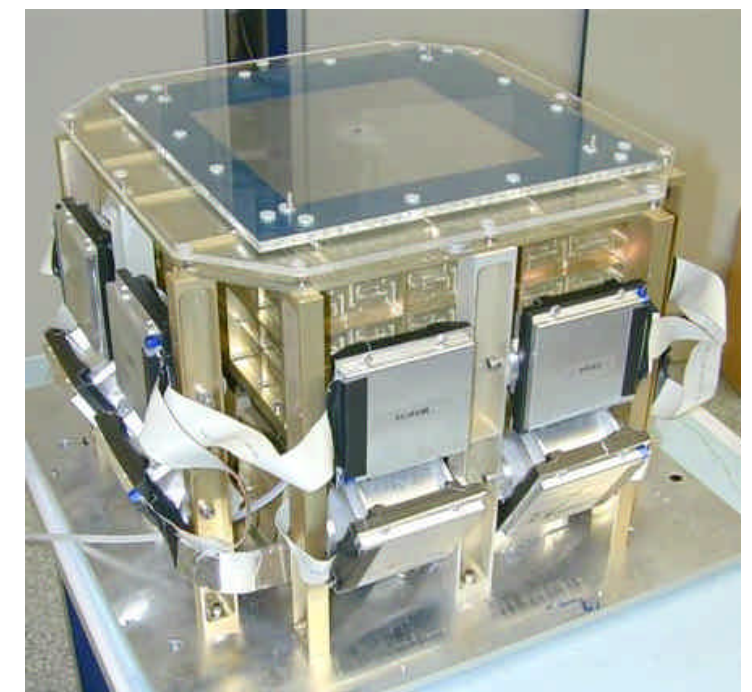
The MEGA Telescope

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, $dE/E < 2\%$), 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.



MEGA prototype: The tracker (central golden box) is surrounded by 20 calorimeters

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.

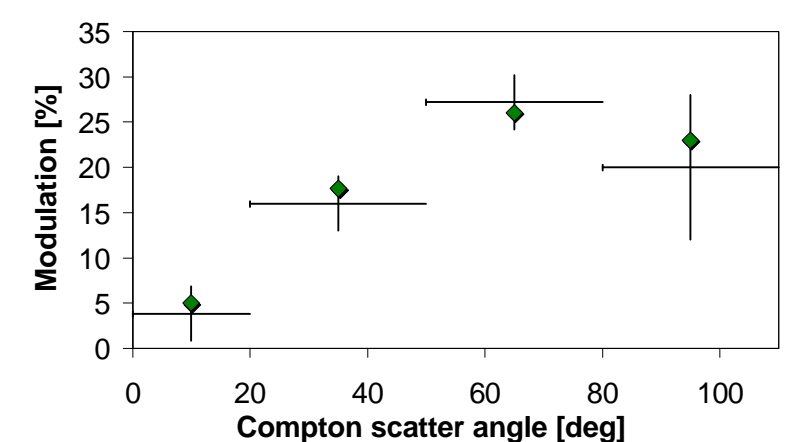
$$\frac{\partial \mathbf{s}}{\partial \Omega} = \frac{r_e^2}{2} \left(\frac{E_g}{E_i} \right)^2 \left(\frac{E_g}{E_i} + \frac{E_i}{E_g} - 2 \sin^2 \mathbf{j} \cos^2 \mathbf{c} \right)$$

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.

The figures below show the azimuthal scatter angle distributions (geometry and efficiency corrected) for the calibration measurements at 0.71, 2.0 and 5.0 MeV. As expected by the beam setup, the maxima of the modulation are found to be at 0° and 180° , perpendicular to the horizontal polarization vector. The detected modulations are in agreement with Geant4 simulations.

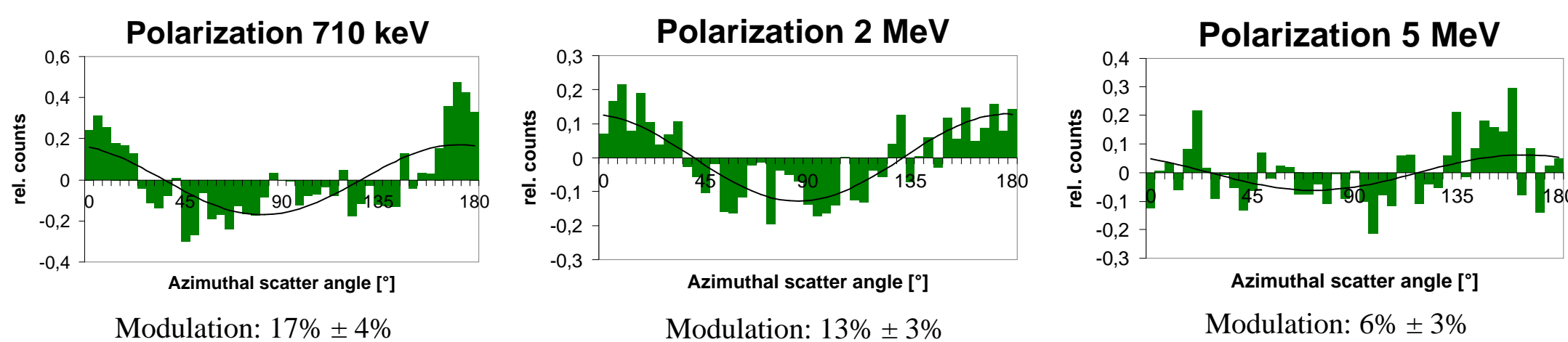
The largest sources of uncertainty in these measurements are varying and not easily correctable efficiencies for the detection of low energy photons in individual detectors. For this reason the polarization signal at 710 keV resembles only roughly a cosine wave.

Event selections have been applied, which assure that all triggers are Compton events, which originate from a 2σ interval around the known source position. Moreover, the energy deposit in the calorimeter has to be at least 300 keV.



Top: Dependence of the degree of modulation on the Compton scatter angle. The green squares represent the values from Geant4 simulations, which are in agreement with the measurements.

According to the Klein-Nishina equation, the degree of polarization reaches its maximum for medium Compton scatter angles. For the 2 MeV calibration beam this angle is 65.8° . The expected maximum for this 2 MeV measurement can be reproduced.



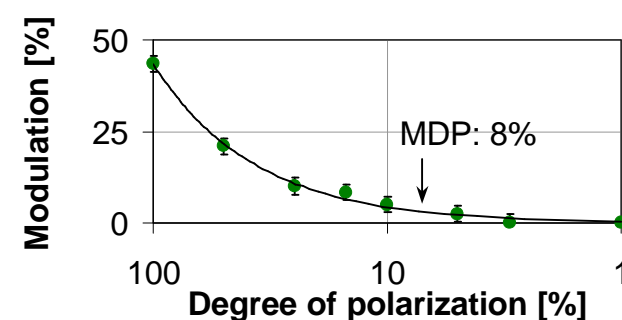
Simulation of a gamma-ray burst with the MEGA satellite telescope

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 ($\alpha_{\min} = -1.0$, $\alpha_{\max} = -2.57$, $E_b = 1070$ keV).

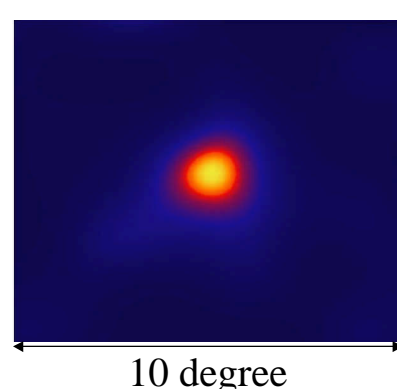
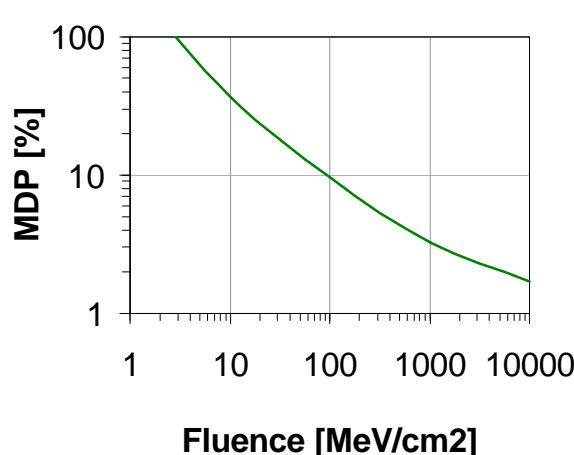
Some assumptions were: With the onset of the burst, MEGA switches into the following trigger mode: at least one hit in the calorimeter and at least one hit in the tracker. The trigger thresholds are 100 keV in calorimeter and 50 keV in tracker. The maximum read-out rate is 5000 counts/sec. The short 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 were identifiable Compton events starting in the tracker. 4200 were selected for the analysis ($E < 3$ MeV, $30^\circ \leq \varphi \leq 150^\circ$, origin $< 10^\circ$ from source position).



Right: Minimal detectable polarization as a function of the fluence of the burst in the energy band 50 keV up to 10 MeV: The burst had the same light-curve and spectrum as GRB910814. The curve flattens due to read-out limitations

Left: Modulation as a function of the degree of polarization of GRB910814: The Minimal Detectable Polarization is 8% (90% confidence level).



Left: Deconvolved image of the burst: The MEGA imaging capabilities allow to quickly localize the burst on the sky. Analyzing only those events, which originate from the source position, most of the background events can be rejected.

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

- G. Kanbach et al. SPIE 4851 (2003) 1209-1220
- V. Litvinenko et al. SPIE 2521 (1995) 55-77
- R. Andritschke et al. NewAR 48 (2004) 281-285
- A. Zoglauer et al. NewAR 48 (2004) 231-235
- S. Agostinelli et al. NIM A 506 (2003) 250-303
- B.E. Schaefer et al. ApJ 393 (1992) 51-54