Max-Planck-Institute for extraterrestrial Physics

Polarization response of the MEGA medium energy gamma-ray telescope

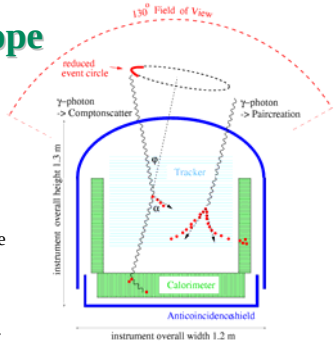
A. Zoglauer, G. Kanbach, R. Andritschke (MPE, Garching) - P. Bloser (GSFC, Greenbelt, MD) - V. Litvinenko (BNL)

Abstract

The Medium Energy Gamma-ray Astronomy telescope MEGA is a combined Compton scattering and pair creation telescope in the energy range from 500 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 for all Compton scatter angles. Within errors the measurements are in agreement with Geant4 simulations.

The MEGA telescope

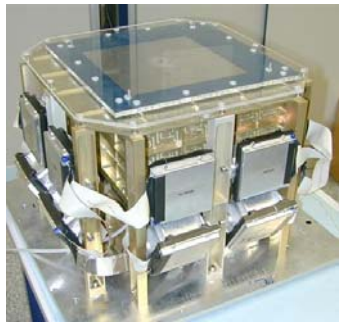
The Medium Energy Gamma-ray Astronomy telescope MEGA detects gamma-rays in the energy range from 500 keV up to 50 MeV via Compton scattering and pair creation. It consists of 1) a tracker of double-sided Silicon strip detectors, where the initial scattering process takes place and where the direction of the electrons is determined, and 2) a CsI calorimeter, which stops the secondary particles. A detailed description can be found in [1].



Principle of measurement

Calibration of the prototype

The MEGA prototype, which consists of l/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 [2] 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 inverse 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

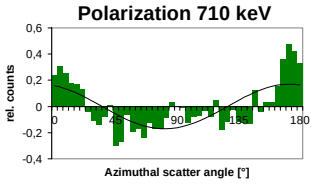
Most processes in high-energy astrophysics, such as synchrotron radiation, bremsstrahlung, Compton scattering, etc. generate polarized gamma-rays. Therefore, polarization measurements are of great value to understand the emission mechanisms of gamma-rays.

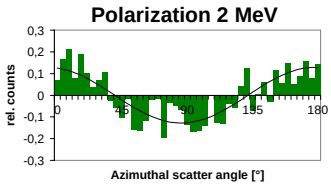
The figures **below** show the azimuthal scatter angle distributions (geometry and efficiency corrected) for the calibration measurements at 0.71, 2.0 and 5.0 MeV. As expected by the beam setup, the maxima of the modulation are found to be at 0° and 180°, perpendicular to the horizontal polarization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

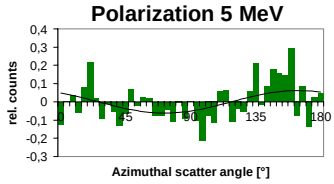
The largest sources of uncertainty in these measurements are varying and not easily correctable efficiencies for the detection of low energy photons in individual detectors. For this reason the polarization signal at 710 keV resembles only roughly a cosine wave.

The following event selections have been applied:

- The hit pattern has to be compatible with a Compton event starting in the tracker and being stopped in the calorimeter (for details about the data analysis see [3]).
- The origin of the event can be reconstructed into a 2σ interval around the known source position: This greatly reduces background and incompletely absorbed events.
- To overcome varying noise and trigger thresholds in the calorimeters, the scattered gamma-ray needs to deposit at least 300 keV in the calorimeter. This implies a restriction on the scatter angle.







Geant4 simulations vs. measurements

A Geant4 (version 6.0) [4] based simulation program is used to verify the performance of the prototype. It includes a detailed geometry description, realistic measurement errors, chance coincidences, read-out limitations, etc.

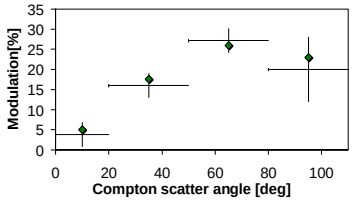
Energy [MeV]	Modulation [%] measured	Modulation [%] simulated	Maximum [°]
0.71	17 ± 4	19 ± 1	172
2	13 ± 3	14 ± 1	176
5	6 ± 3	3 ± 2	164
8	< 3	< 2	

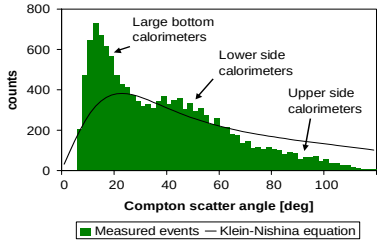
The **above** table compares the measured polarization signature with the simulated one, expected for a 100% polarized gamma-ray beam. Both are in agreement within the measurement errors of the calibrations and for the given event selections. The deviation of the maximum of the polarization signature from the expected 180° can be explained by varying detector efficiencies.

Degree of polarization vs. Compton scatter angle

Right: 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.





Left: Compton scatter angle distribution of the 2 MeV measurement: The black line shows the expected values for an ideal symmetrical detector as determined by the Klein-Nishina equation. Low scatter angles (< 8°) are suppressed by the trigger thresholds in the tracker, large scatter angles by the detector geometry which covers only the lower hemisphere of the detector. The two maxima represent the favoured scatter angles into the bottom calorimeters and the lower side calorimeters.

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.

Finally, all measurements are, within errors, in agreement with Geant4 simulations.

References

[1] G. Kanbach et al. SPIE **4851** (2003) 1209-1220

[2] V. Litvinenko et al. SPIE **2521** (1995) 55-77

[3] A. Zoglauer et al. NewAR **48** (2004) 231-235

[4] S. Agnostinelli et al. NIM A **506** (2003) 250-303

For further information, please contact: zog@mpe.mpg.de