CALIBRATION OF THE MEGA PROTOTYPE

R. Andritschke[1], **A. Zoglauer**[1], **G. Kanbach**[1], **V. Schönfelder**[1], **F. Schrey**[1], **F. Schopper**[2],
P. F. Bloser[3], **S. D. Hunter**[3], **J. Macri**[4], **R. S. Miller**[5], **V. N. Litvinenko**[6], **and I. V. Pinayev**[7]

[1]Max-Planck-Institut für extraterrestrische Physik, 85748 Garching, Germany
[2]Max-Planck-Institut Halbleiterlabor, 81739 München, Germany
[3]NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA
[4]University of New Hampshire, Durham, NH 03824, USA
[5]University of Alabama in Huntsville, Huntsville, AL 35899, USA
[6]Brookhaven National Lab, Upton, NY 11973-5000, USA
[7]Free Electron Laser Laboratory, Physics Department, Duke University, Durham, NC 27708, USA

ABSTRACT

Calibration measurements of the MEGA (Medium Energy Gamma-ray Astronomy) prototype have been performed with radioactive lab sources and at the High Intensity Gamma-ray Source (HIGS) at the Free Electron Laser Laboratory (FELL) of Duke University, Durham, NC. MEGA is a combined Compton scatter and pair creation telescope. It consists of two main detector units, the tracker and the calorimeter. Doublesided Silicon strip detectors form the tracker, which is surrounded by the pixelated CsI(Tl) blocks of the calorimeter. A prerequisite for successful data analysis is a calibration of each individual readout channel. This work is still ongoing. The performance of the detector units will be therefore presented as currently known. The encountered problems and the resulting (single detector) calibration methods will be described briefly. Since we aim at an energy range of 0.3 – 50 MeV, the HIGS — a Compton back-scattering source — with beams of mono-energetic, fully linearly polarized photons in the range of 0.7 – 50 MeV was a good match for the MEGA calibration. Measurements at various energies and for different incidence angles have been performed. Some preliminary results will be presented.

Key words: Compton telescope; pair telescope; Si strip detector; CsI calorimeter; γ-ray; HIGS.

1. INTRODUCTION

The MEGA concept combines the detection principles of a Compton scattering and a pair creation telescope (Kanbach, et al., 2004). The central unit, the tracker, is able to measure the trajectory of charged particles generated in the detector. A second detector, the calorimeter, surrounds the central unit (except for the entrance side) and measures the particles leaving the tracker (fig. 1).

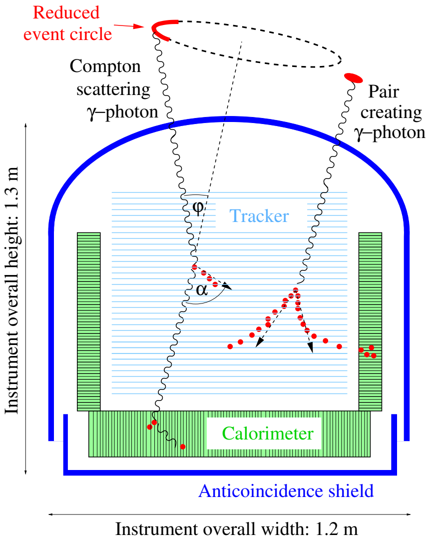

Figure 1. Principle of the MEGA concept

When a Compton scatter event happens in the tracker, the electron's path will be recorded and the scattered photon will be recognized by interactions in the calorimeter. This provides the complete information for reconstructing a Compton event. Due to measurement errors the origin of the photon is smeared out to an arc. In the case of a pair creation event the electron and positron will be measured by the tracker and a fraction of the emerging particles will be recorded in the calorimeter. The photon's origin, derived from the tracks close to the conversion point, can be constrained to a spot.

For event and image reconstruction methods see Zoglauer, et al. (2004) and Zoglauer, et al. (2004b).

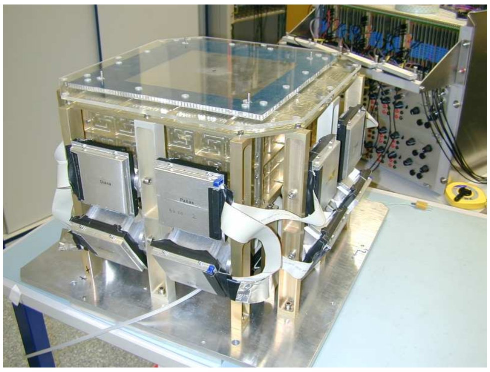

Figure 2. The prototype

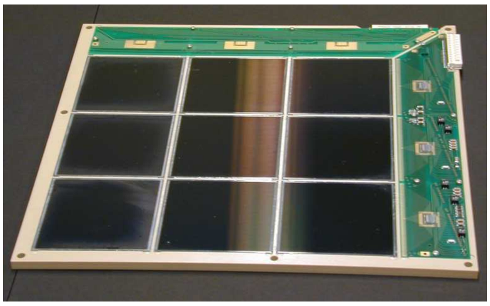

Figure 3. A tracker layer

2. THE PROTOTYPE

For proving the MEGA concept a prototype has been built (fig. 2). It is downscaled compared to an envisioned satellite version by a factor of four in tracker area and a factor of three in tracker depth. Furthermore the prototype's modular calorimeter does not enclose the tracker as completely as in a full version (≈ 30% solid angle coverage of the lower hemisphere as seen from the center of the tracker).

The tracker has 11 layers of double-sided Si strip detectors (sect. 3) and the calorimeter contains 20 blocks with 120 CsI(Tl) crystals each (sect. 4). The laboratory version of the prototype was finished in March 2003. After measurements with radioactive lab sources the instrument was set up at the HIGS facility (sect. 5). The measurements performed at HIGS (sect. 6) are aimed at covering the energy range not accessible to radioactive lab sources and at determining the sensitivity for polarization (Zoglauer, et al., 2004c).

3. DOUBLE-SIDED SILICON STRIP DETECTORS

Each of the 11 layers of the MEGA prototype tracker consists of a 3 × 3 array of 6 cm × 6 cm Silicon wafers, 500 μm thick (fig. 3). The wafers have 128 AC-coupled readout strips on the p-side and (orthogonal) on the n-side with a pitch of 470 μm. The strips of the 3 wafers in one row (column) are interconnected and read out in one channel of the TA1 front end chip (made by IDE, Oslo, Norway).

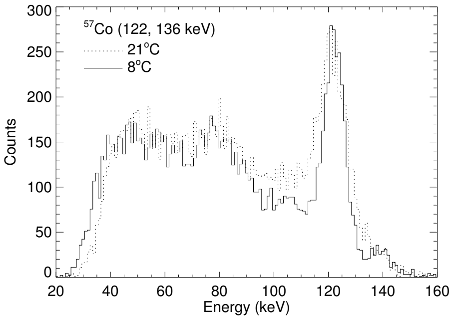

Figure 4. ^{57}Co spectrum for two temperatures. The decrease of leakage current with decreasing temperature improves energy resolution.

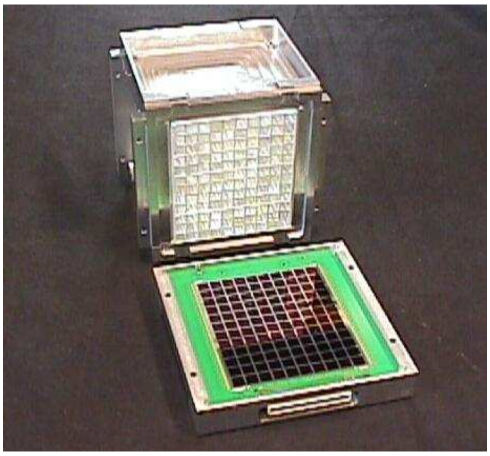

Figure 5. Open calorimeter block (8 cm)

The energy resolution[1] for entire layers at room temperature varies between 16 and 28 keV (FWHM) for the 122 keV line of ^{57}Co (fig. 4) and the position resolution measured with muon tracks in the tracker is 290 μm (FWHM) gained from lab measurements (Bloser, et al., 2003). A single channel energy calibration for the setup at HIGS deliveres a similar energy resolution (15 – 30 keV) and a trigger threshold of about 50 keV.

4. CALORIMETER MODULES

There are three versions of calorimeter modules. They have in common a pixelation of 10 × 12 CsI(Tl) crystals (5 mm × 5 mm) with individual readout by monolithic PIN-diode arrays (fig. 5). The versions differ in length: 2 cm, 4 cm and 8 cm. The 2 and 4 cm versions have readout on one end of the crystals, whereas the 8 cm units have diode arrays on

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[1] The n-side has a 1.5 – 2 times worse energy resolution than the p-side. Thus the achievable energy resolution is dominated by the p-side. The reported energy values are p-side only values.

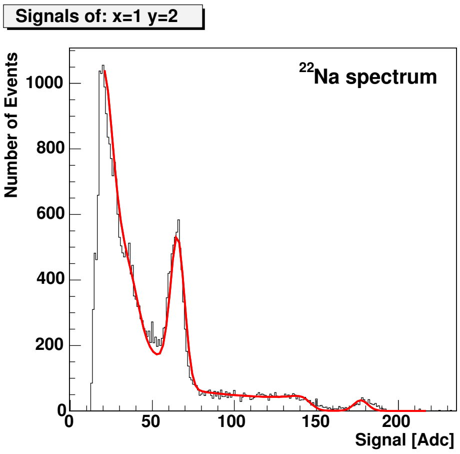

Figure 6. ^{22}*Na spectrum in one crystal with good statistics*

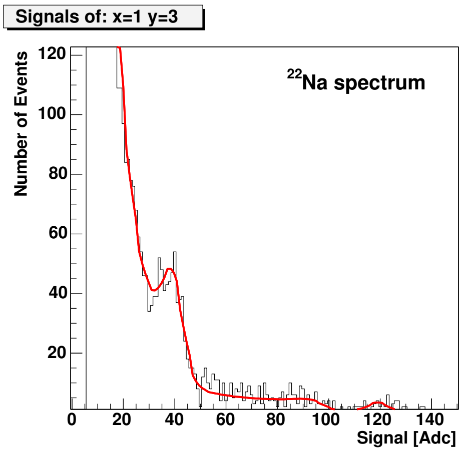

Figure 7. ^{22}*Na spectrum in one crystal with* typical *statistics*

both ends. Two sided readout allows us to obtain position information along the crystal. Position resolution along the crystal achieved so far is 1.5 cm (best), 3 cm (average). To obtain these values the 8 cm modules were temporarily mounted with the crystals in parallel to the tracker layers. Then muon tracks can be extrapolated from the tracker into the calorimeter for calibration along the crystal. For the setup at HIGS a recalibration of each channel is necessary, because the transport from the MPE lab to the HIGS facility changed the optical coupling of the crystals to the diode. Variations of ± 10% in gain have been observed. Since there was no time for measurements in the muon setup configuration, a different analysis method is needed for calibrating the 8 cm blocks, which is currently under investigation and not discussed here.

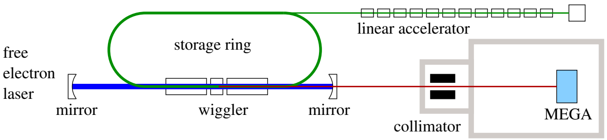

Figure 8. Schematic of the HIGS facility

The FWHM energy resolution of the 2 and 4 cm calorimeter versions is 90 keV (average), 67 keV (best) at 662 keV for a whole block with no significant difference between both versions. The energy threshold of the modules varies between 115 and 260 keV with an average of 180 keV. These results came from single channel calibrations of data taken with the setup at HIGS. Due to the design of the DAQ system, especially the front end chips (TA1 from IDE), non-linearities and offsets in energy measurement occur. To cope with that problem three different energies are used for single channel calibration: 662 keV (^{137}Cs), 511 keV and 1275 keV (^{22}Na). To reduce the error for extrapolating to high energies (saturation of front end electronics ≈ 5 MeV) the 1275 keV line is very important. But it is time consuming to get a reasonable amount of statistics in this line for three reasons: The photopeak efficiency drops with energy; there are two 511 keV photons for one 1275 keV which are detected as well and use up readout capacity of the (slow) DAQ; and the inner crystals are shielded by the outer ones increasing the number of scattered photons at the expense of photopeak events. To cope with limited statistics a calibration method has been developed, which takes advantage of the whole spectrum (especially the Compton edge, fig. 6) instead of fitting the bare photopeaks. There are four components for each line: photo peak, Compton edge, photons scattered in the crystal and absorbed, photons scattered in the crystal and scattered again. Including these components helps to identify 1275 keV lines even in the cases of low statistics (fig. 7). Additionally the 511 keV line position can be identified in spite of a high fraction of incomplete absorbed photons.

5. THE HIGH INTENSITY GAMMA-RAY SOURCE (HIGS)

The HIGS facility (Litvinenko, et al., 1995) is located at the Free Electron Laser Laboratory (FELL) of Duke University in Durham, North Carolina (USA). HIGS generates γ-rays via Compton backscattering, which is realized inside a storage ring free electron laser (fig. 8). The storage ring operates with two equally spaced electron bunches, which generate 100% linearly polarized laser photons with tunable energy (0.6 – 6 eV). The same electrons also collide head-on with the laser photons inside the optical cavity. In this collision the energies of the backscattered laser photons are boosted into the γ-ray range while preserving their polarization. HIGS can deliver a monoenergetic ($\Delta E/E \approx 1-2\%$), fully polarized pencil beam of γ-rays in a wide range of energies from 0.7 to 50 MeV. The energy spread is controlled by lead collimators, which had diameters of 1.25 and 2.5 cm for our measurements. Since the distance between the point-like source and the test area is 60 m, the collimators define the beam width, too.

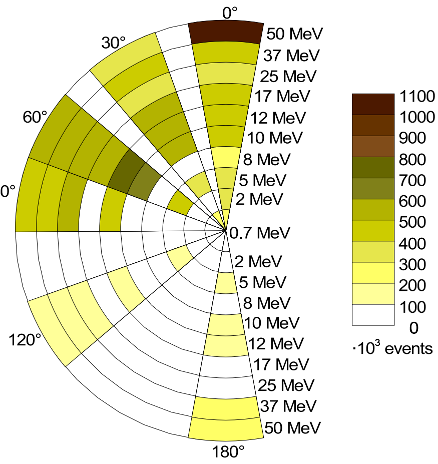

Figure 9. Measured energies and incidence angles of the γ-beam at HIGS. The photon statistics for each position is color coded.

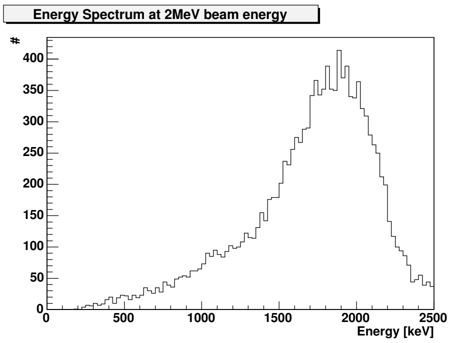

Figure 10. Preliminary energy spectrum measured by the prototype for a 2 MeV beam and on-axis beam incidence.

6. MEASUREMENTS AT HIGS

Measurements were performed at 10 discrete energies and with various incidence angles of the γ-beam (Andritschke, et al., 2004). A summary of the measurements is shown in figure 9. A total of 15.5 million events were collected in April/May 2003. Since the single channel calibration is not yet finished, only preliminary results can be presented. Two examples are shown here: The energy spectrum of a 2 MeV on-axis beam (fig. 10) shows incompletely absorbed photons on the tail of the peak below 2 MeV and chance coincidences above 2 MeV. Fig. 11 demonstrates the wide field of view (diameter > 160°) by reconstructing beam images between 0° (= on-axis incidence) and 80°. The shift in reconstructed source position is due to the "fish-eye" effect described in Zoglauer, et al. (2004). There is a separate article dedicated to the results concerning the sensitivity to polarization in these proceedings (Zoglauer, et al., 2004c).

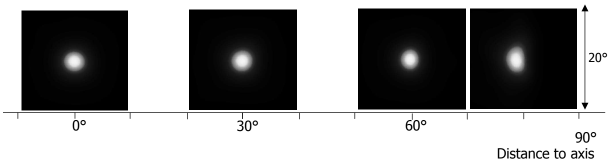

Figure 11. Reconstructed beam images at 50 MeV for incidence angles up to 80°

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