The Calibration Setup of the MEGA Prototype at the High Intensity Gamma-ray Source

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Abstract

We describe the calibration measurements of the MEGA prototype, a tracking Compton and pair creation telescope. The measurements were performed at the High Intensity Gamma-ray Source (HIγS) facility from April 21 to May 06, 2003. The main goal of this calibration was directed at higher energies, above those available from radioactive lab sources, and at polarization. A total of $15.5 \cdot 10^6$ triggered events at 10 energies in the range of $0.7 - 49$ MeV and at 6 angles of incidence ($0° - 180°$) were recorded.

Key words: γ-ray astronomy, Compton telescope, pair telescope, MEGA, calibration, HIγS
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1 Introduction

At the Max-Planck-Institut für extraterrestrische Physik the development of the γ-ray telescope MEGA (Medium Energy Gamma-ray Astronomy) is ongo-

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ing. For the desired energy range of 0.4 – 50 MeV a combined tracking Compton and pair creation design is used. A downscaled prototype of an envisaged satellite version has been built. Calibration measurements with radioactive lab sources have been performed at energies between 0.511 and 4.4 MeV.

The detector consists of two parts, the tracker and the calorimeter (a more detailed description can be found in these proceedings (1)). The tracker measures the Compton electron and the pair creation products. It consists of double-sided silicon strip detectors arranged in 11 layers, each an array of 3 by 3 concatenated wafers (each $6 \times 6\,\mathrm{cm}^2$ area, 500 μm thick, 470 μm strip pitch). An energy resolution of 15 – 20 keV (FWHM) at 21°C and position resolution of 290 μm (FWHM) have been achieved (2).

The calorimeter measures the Compton scattered photon and leaking particles of the pair creation. Its CsI(Tl) scintillator material is pixelated, every pixel with individual silicon PIN photo-diode readout. The pixels are grouped into 10×12 blocks, each block read out by a monolithic PIN diode array. There are three versions of these blocks: 2 and 4 cm with single sided readout and 8 cm with readout on both ends (to achieve also position information along the crystal). The pixelation of $5 \times 5\,\mathrm{mm}^2$ is common to all three versions. Depending on the type and the deposited energy the average energy resolution varies between 40 and 100 keV (FWHM) in the range of 0.511 – 1.274 MeV . For the double sided version a position resolution up to 2 cm (FWHM) along the crystal is achieved (3).

For calibrating higher energies and to test the capability of detecting the polarization of γ photons the prototype was set up at the High Intensity γ-ray Source (HIγS), an extension of the Duke Free Electron Laser Laboratory (FELL, Duke University, Durham, N.C.). This source delivers a monochromatic and fully polarized γ photon beam in the energy range of 0.7 – 50 MeV.

2 Calibration at the HIγS facility

2.1 The HIγS facility

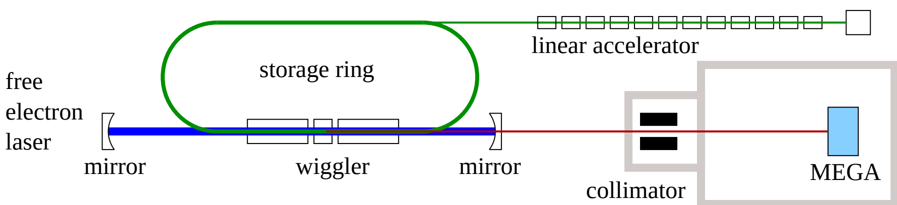

Fig. 1. Schematic plot of HIγS/FEL

HIγS (4) is an inverse Compton beam driven by the Duke Free Electron Laser (FEL) (fig. 1). The γ-ray production works as follows: Electrons are injected in the electron storage ring forming a single bunch. One side of the ring contains wigglers, i.e. many magnets generating an alternating magnetic field. This field forces the electrons on a sinusoidial trajectory, causing them to radiate at wave lengths between IR and UV (determined by the electron energy, the wiggler geometry and the magnetic field strength). Two mirrors forming a laser cavity reflect the photon bunch back and forth. The distances are well defined so that the electron and photon bunches are comoving (overlapping) in the wiggler. This leads to resonant amplification (stimulated emission) of photons. The laser photons are boosted up to γ energies of 0.7 – 50 MeV by injecting a second electron bunch in the storage ring. This second electron bunch collides with the photon bunch in a field free-zone, where the photons are backscattered in inverse Compton interactions, forming the γ beam. Lead collimators (we used 2.54 and 1.27 cm diameters) form a pencil beam with an energy spread of 1 – 2%. Since the laser photons are fully polarized, the γ photons are, too. A high purity Ge detector was available for determining the energy profile of the beam. Two examples can be seen in fig. 2 and 3.

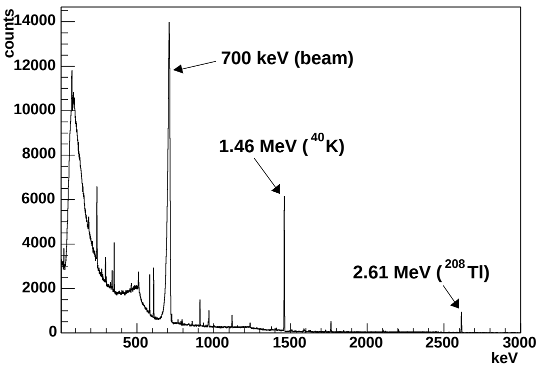

Fig. 2. HPGe spectrum of a 700 keV beam. Background lines used for calibrating the detector are indicated.

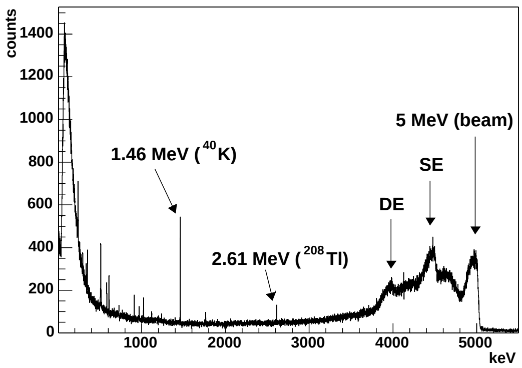

Fig. 3. HPGe spectrum of a 5 MeV beam. Also single escape (SE) and double escape (DE) peaks are indicated.

2.2 Measurement Setup

Like other experiments at HIγS, MEGA was set up in the so called γ-vault (fig. 4). Since the MEGA prototype should be illuminated over its complete area, it was mounted on a computer controlled XY-table. This allowed to move the instrument accurately across the γ-ray beam. To get different incident angles, the XY-table was turnable (by hand). For alignment two theodolites were used. The pattern of the beam incidences is shown in fig. 5.

The beam intensity is not stable due to operational aspects. Therefore a beam

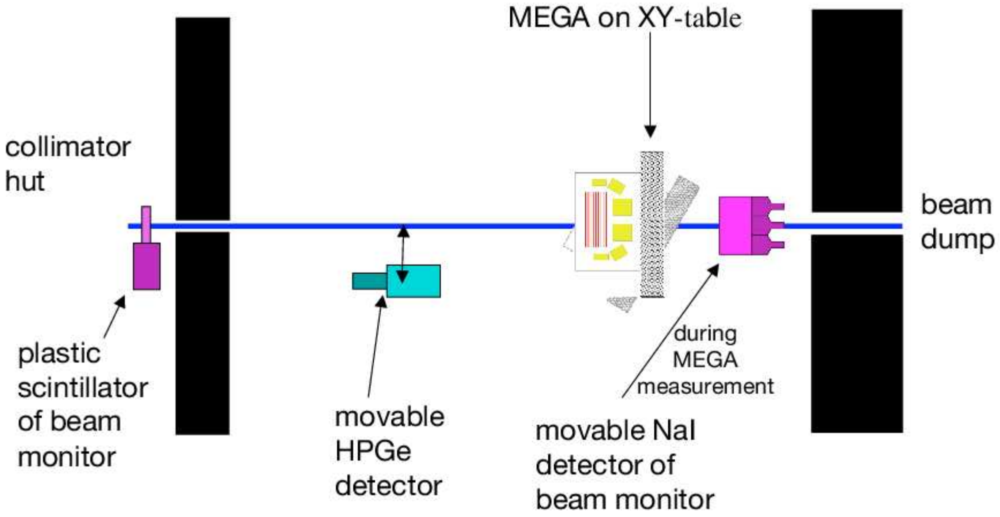

Fig. 4. Measurement setup of MEGA in the gamma vault

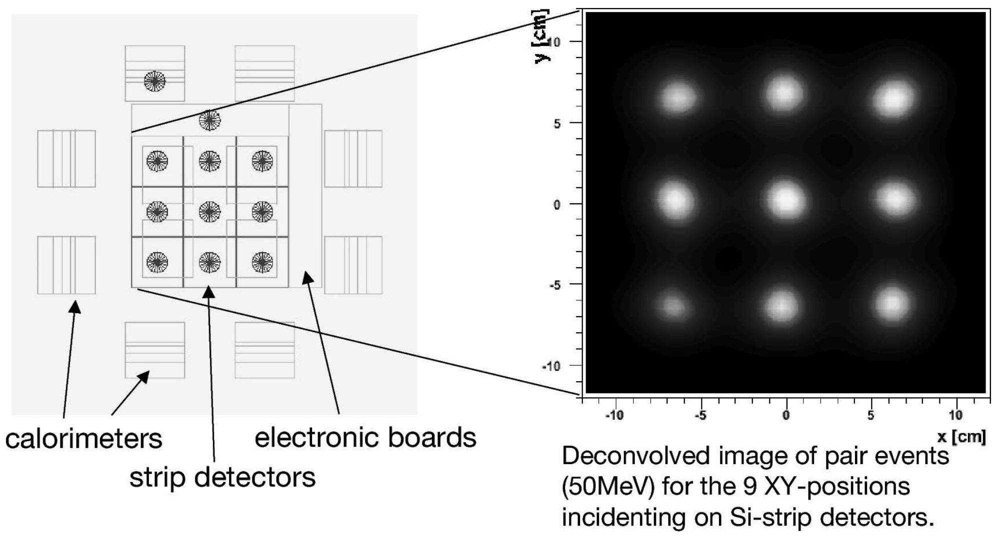

Fig. 5. View along the beam line on MEGA in 0° position, i.e. the beam is perpendicular to the strip detector plane. Left: The patterned circles indicate the 11 beam incidences on the instrument (the diameter correlates to the beam thickness). Right: Reconstructed image of a data set including the 9 different incidences on the strip detectors.

monitor was included in the setup. It consisted of a 1 cm thick plastic scintillator (5 cm $\times$ 5 cm area) immediately behind the collimators. To calibrate its count rate for the different energies the beam was also measured with a NaI detector (25 cm $\oslash$, 12.5 cm thick). The decay of the beam flux can be seen in the plastic detector rate (fig. 6). During the gaps in the rate new electrons were injected into the storage ring.

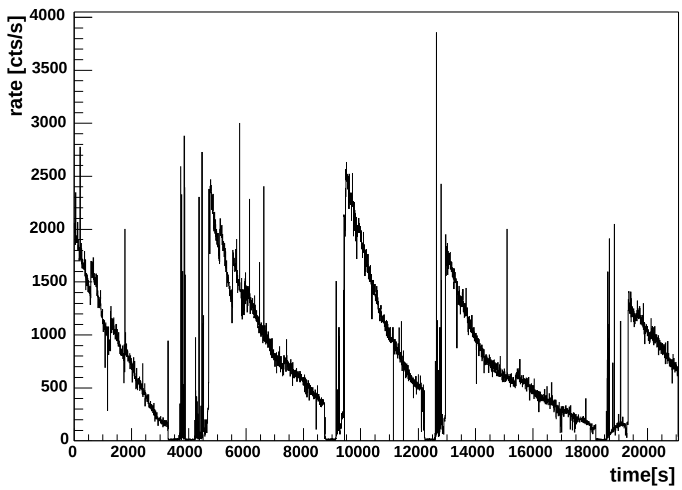

Fig. 6. Count rates of the plastic scintillator of the beam monitor for a 10 MeV beam.

Angles	*Energies*
Full set (0°, 30°, 60°, 80°, 120°, 180°)	5 MeV(no 80°), 12 MeV, 25 MeV(no 180°), 37 MeV, 49 MeV
Up to 60° (0°, 30°, 60°)	10 MeV(additional 180°), 17 MeV
Only 0°	0.7 MeV (additional 30°), 2MeV, 8MeV

Table 1
Energies and angles where measurements at HIγS have been performed

2.3 Measured Energies and Angles

For every XY-table position a number between 10000 and 50000 events were collected. Here a trade off between limited measurement time and statistics needed to be done. For example there is no need to spend a lot of measurement time on positions which have their first interactions in passive material like the electronic boards. An overview of the angle and energies, where measurements have been done, is given in table 1. Two different sets of mirrors were necessary to cover the wide energy range. For low energies ($\leq$ 8 MeV) infrared mirrors were used and for high energies ultra violet ones. During the measurement time from April 21st till May 6th a total of $15.5 \cdot 10^6$ triggered events were taken, most above 8 MeV.

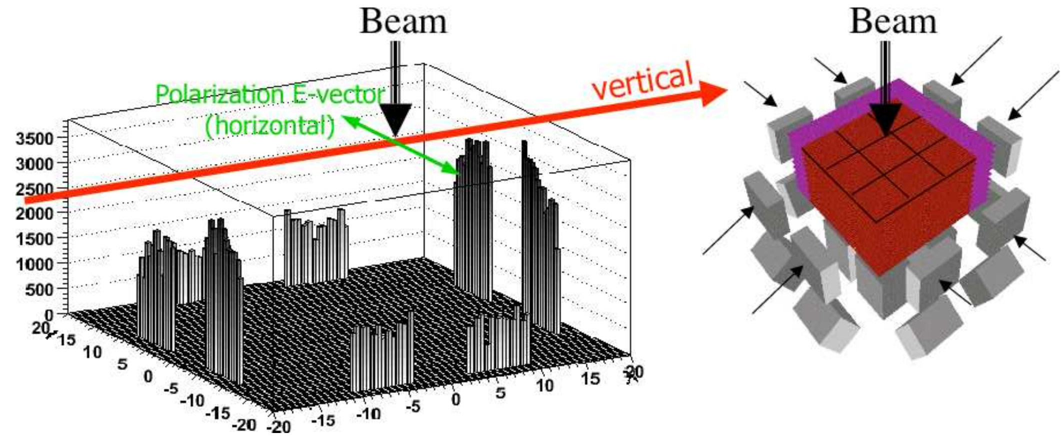

Fig. 7. The left plot shows the number of hits in the small side calorimeters, which are marked with an arrow in the sketch of the instrument (right). Each bump in the histogram corresponds to a calorimeter block.

2.4 Preliminary Results

Since the single detector channel calibration is still ongoing, only some preliminary results can be presented. The imaging capability over a broad energy band and a wide field of view up to 80° incident angle is shown in (5).

The scatter plane of a Compton interaction depends on the polarization of the incoming photon. Fig. 7 shows for a beam energy of 710 keV a clear modulation in the occurence of interactions (mostly Compton scattered photons) in the upper row of calorimeter blocks. Even though no corrections have been applied, the beam polarization can be seen. Since the modulation is stronger than expected from the simulations, reliable conclusions cannot be drawn until more detailed investigations have been done.

References

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