University of California at Berkeley – Space Sciences Laboratory

MEGAlib – Simulation and Data Analysis for Low-to-medium-energy Gamma-ray Telescopes

A. Zoglauer[1], R. Andritschke[2], S. E. Boggs[1], F. Schopper[2], G. Weidenspointner[2], and C. B. Wunderer[1]

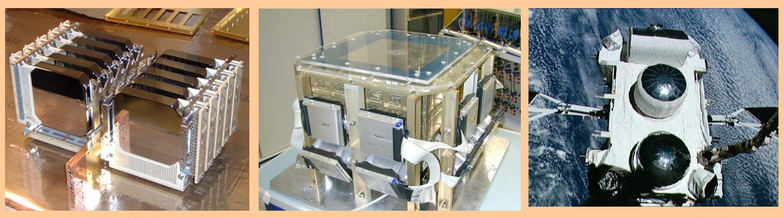
[1]Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA, USA

[2]Max-Planck-Institut für extraterrestrische Physik, Garching, Germany & Max-Planck-Institut Halbleiterlabor, München, Germany

Abstract

The Medium-Energy Gamma-ray Astronomy library MEGAlib is an open-source object-oriented software library designed to simulate and analyze data of low-to-medium-energy gamma-ray telescopes, especially Compton telescopes. The library comprises all necessary simulation and data analysis tools including geometry construction, Monte-Carlo simulation, response creation, event reconstruction, image reconstruction, and other high-level data-analysis tools.

Measured data from existing Compton telescopes:



NCT [1] MEGA [2] COMPTEL [3]

Source description:

Description of the input beams: particle type, spectrum, beam geometry, polarization, etc.

MGGPOD:

Simulation tool based on Geant3, MGEANT, Prompt, Orihet & Decay. Main emphasis is the Monte Carlo simulation of orbital radiation environments and the resulting detector activation [4]. Utilizing MGGPOD's ACT/INIT extensions the fits output can be converted into the MEGAlib simulation format.

Geometry and detector description:

Description of the volumes including their positioning and display options, materials, detector setup and characteristics (e.g. voxel sizes, guardring size, energy and depth resolution, noise and trigger thresholds), trigger criteria, etc.

Measured data

Simulated data

Simulation information & data

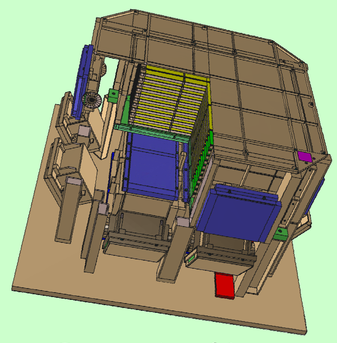
Cosima: Monte Carlo simulations utilizing Geant4

Utilizing the geometry information provided by Geomega, Cosima is capable of simulating a wide variety of beam geometries (e.g. celestial point and extended sources, isotropic emission, near-field point and extended sources) and spectra (e.g. mono energetic, power-law, Band-function, and user defined spectra). Several stopping criteria are implemented (by time, by trigger, or by simulated events). Moreover it is possible to simulate either a single or multiple sources – the latter can be set to be emitted in coincidence. In addition to the discretized hits and energy deposits in active detector material, Cosima can also store the "Monte-Carlo-truth", which is necessary to generate response files.

Simulated data → Instrumental effects engine (noise, thresholds) using Geomega

Geomega library:

Geomega provides an uniform geometry and detector description module for MEGAlib, which includes conversions of the geometry to Geant4, MGGPOD, and ROOT. Its instrumental effects engine allows to discretize simulation data into the detector voxels, to apply thresholds and to noise the data according to the given energy resolution, etc. In addition it provides all necessary geometry information to all other libraries, such as absorption probabilities, visualization, detector information, etc.



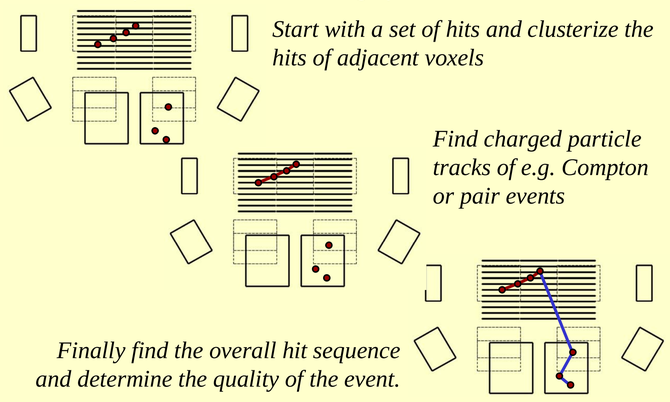
Cutaway-view of the MEGA prototype as seen with Geomega

Revan library: Event reconstruction

The main task of this initial data analysis step is to figure out the sequence of interactions and the parameters of the primary interaction in the detector.

The input for this step are detector hits represented by energy, position, and sometimes time. From the known response of the detector, the kinematics of the event, and redundant Compton scatter information, the sequence of interactions and thus the original properties of the photons can be reconstructed. The implemented algorithms include variations of the classic Compton sequence reconstruction and newer, more advanced Bayesian approaches. The algorithms are capable of identifying Compton events (including several methods for electron tracking), pair creation events, charged particle events, photo-effect events, etc.

All event reconstruction algorithms have the following steps in common to find the correct ordering of the hits:



Start with a set of hits and clusterize the hits of adjacent voxels

Find charged particle tracks of e.g. Compton or pair events

Finally find the overall hit sequence and determine the quality of the event.

Reconstructed events

Response

Sivan library: The simulation information interface

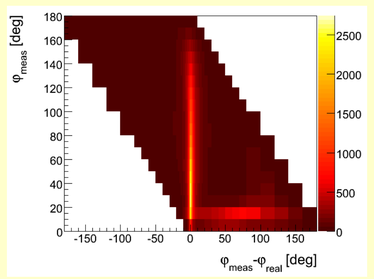
Sivan is responsible for managing ideal simulation information, for comparing this information to what the detector really can measure (input for response generator), for simulation diagnostics, and for performing ideal event reconstruction

Simulation information

Ideally reconstructed events

Detector response generation:

Most medium and high level data analysis tools rely on a known response of the detector to the incoming photons to reconstruct or image events. This tool compares the measured with the original data and provides special matrices describing the relation between initial and measured photon parameters.



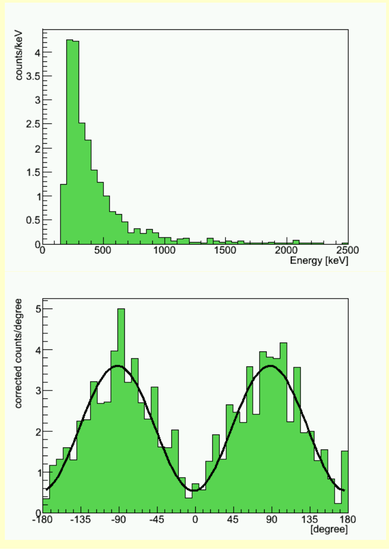
One of the imaging responses: the central peak shows the shape of the Compton cone section as a function of the Compton scatter angle at 1.809 MeV for completely absorbed events.

Imaging response

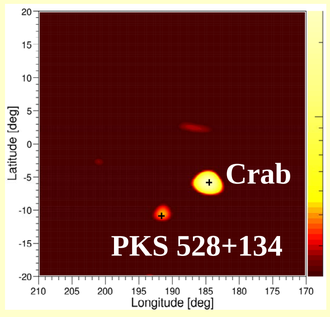
Mimrec library: High-level data analysis

Mimrec includes modules for:

- **Event selections of all performance-relevant parameters of Compton and pair telescopes**
- **List-mode likelihood image reconstruction in galactic, spherical, and Cartesian coordinates (2D, 3D) including different response calculation approaches for Compton and pair creation events**
- **General Compton detector analysis (angular resolution, energy dispersion, scatter angle distributions, etc.)**
- **Performance assessment of event reconstruction algorithms**
- **Background corrected polarization analysis**
- **Sensitivity and background calculation tools**
- **etc.**



LEFT: Simulation of a gamma-ray burst ($F = 10^{-5}$ erg/cm^2, $E_b = 0.15$ MeV, $\alpha_1 = -1$, $\alpha_2 = -2.5$, $t = 10$ s) observed with the satellite version of the MEGA telescope. The top left image shows the measured spectra of the burst. The bottom left image shows the detected polarization signature for a 100% polarized burst (the detected modulation is 75%).



Reconstructed image of the Galactic anti-center region using measured COMPTEL data (viewing periods 1, 413, 426, energy above 12 MeV)

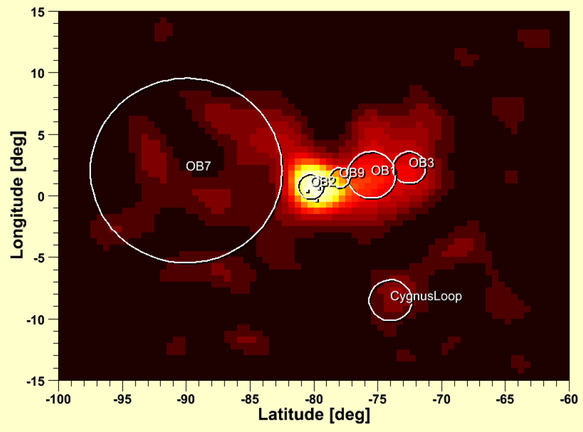


Image obtained by simulations of the Cygnus region in the light of ^{26}Al after 2 years exposure (MEGA satellite version): The diffuse emission of the OB-associations and supernova remnants are clearly visible

MEGAlib is a completely object-oriented software library for low-to-medium-energy gamma-ray telescopes based on ROOT [5] & Geant4 [6].

Supported operating systems are Linux and Mac OS X. The latest version of MEGAlib (v2.18) can be found at http://www.mpe.mpg.de/mega/megalib.html.

References:

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[3] V. Schoenfelder et al. "Instrument description and performance of the imaging gamma-ray telescope COMPTEL aboard the Compton Gamma-Ray Observatory", ApJS 86, 1993
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[5] R. Brun and F. Rademakers, "ROOT – An Object Oriented Data Analysis Framework", NIM A 389, 1997
[6] S. Agostinelli et al. "Geant4 – a simulation toolkit", NIM A506, 2003

For questions, please contact Andreas Zoglauer – zog@ssl.berkeley.edu