MEGAlib — The Medium Energy Gamma-ray Astronomy Library

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Abstract

The Medium Energy Gamma-ray Astronomy library *MEGAlib* is a set of software tools, which are primarily designed to analyze data of the next generation of Compton telescopes. The library comprises all necessary data analysis steps from simulation/measurements via event reconstruction to image reconstruction.

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1. Introduction

The next generation of Compton and pair telescopes records significantly more information about the individual interactions of all particles involved than its predecessors COMPTEL and EGRET. The amount of additional information necessitates a completely different way to determine the sequence of the hits as well as the quality of the reconstruction. Depending on the detector type, time-of-flight information or electron tracks may be available in addition to the kinematics and topology of the interactions of Compton events to determine the sequence of interactions. In this context, a completely new set of tools for data reduction and analysis had to be developed. This toolset is bundled into *MEGAlib* — the Medium Energy Gamma-ray Astronomy library [1].

MEGAlib is completely written in C++ and based on ROOT (1). The library is designed to be easily adaptable to different Compton telescope designs. Included are tracking, multiple Compton and time-of-flight based Compton telescopes, consisting of 2D/3D strip detectors, scintillators or Drift chambers. The necessary steps to apply the software to a different telescope are restricted to defining a new geometry and detector description.

The *MEGAlib* software package encompasses the complete data analysis chain, which consists of four basic steps: (1) data acquisition, either by measurements with a real detector or via simulation, (2) calibration of real data or the introduction of measurement uncertainties to the simulations respectively, (3) event reconstruction, and (4) high-level data analysis including image

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[1] The *MEGAlib* software package is available at http://www.mpe.mpg.de/MEGA/megalib.html

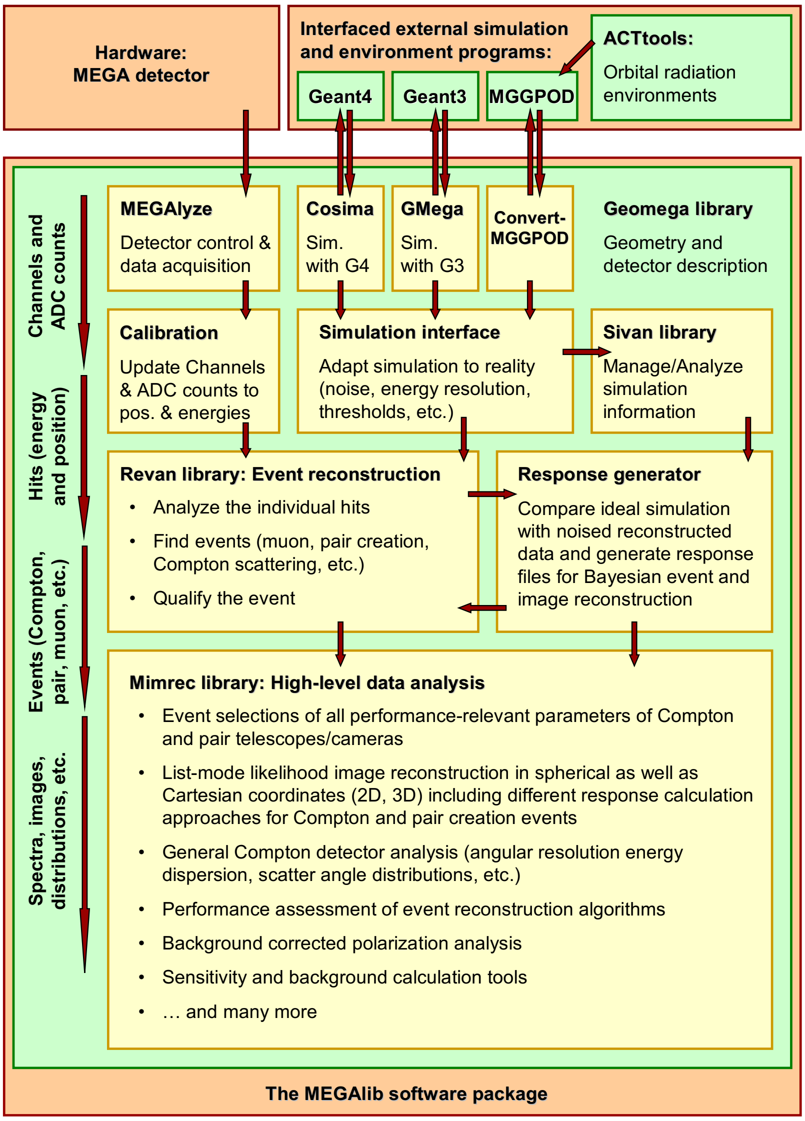

Fig. 1. Basic layout of the *MEGAlib* software package. See the text for a detailed description.

reconstruction, polarization analysis, sensitivity calculation, etc. For all those steps different routines exist in *MEGAlib*.

A schematic overview of the general data flow is shown in Figure 1. The following gives a rough overview of the capabilities of the software, which was originally developed for the MEGA Compton and pair telescope (2).

2. From detector measurements to hits

The *MEGAlyze* program takes care of the control of the detector as well as the data acquisition and management. The detector can be completely controlled by a graphical user interface. The data acquired by the read-out electronics is expressed in detector units. These units are the ID numbers of the detectors and channels which have triggered and the output of the analog-digital-converters in

ADUs (analog-to-digital converter units). The energy information of each channel is calibrated separately. The detector-specific information is converted into physical units: ADUs are transformed into energies and channel numbers into positions. In the case of e.g. strip detectors, all signals of the x- and y-side strips of one detector have to be combined into interaction positions. In the case of depth-sensitive detectors the signal of both sides is not only converted into energy but also into a depth measurement. After this step one event is represented by hits, each of which consists of energy and position in the detector's world coordinate system. Those hits are the input for the later event reconstruction. While all other parts of *MEGAlib* have been applied to a variety of detector concepts, *MEGAlyze* thus far has only been used in conjunction with the MEGA prototype.

3. From simulations to hits

The second path to acquire data are simulations. Their main goal is to accurately predict the measurements and ultimately the performance of the detector — both on ground and in space. In the energy range of a Compton telescope (with deposits from a few keV up to hundreds of MeV), the Geant Monte-Carlo software packages are widely used. For each of those packages simulation interface tools in *MEGAlib* exist: for Geant3 (3) with its MGGPOD (4) extension (simulation of orbital background environments) as well as for its object-oriented pendant Geant4 (5).

To simplify the use of all those simulation programs, a uniform geometry and detector description library was developed (*Geomega*). It allows to use the same geometry description for the simulation as well as for the later data analysis. In addition, it takes care of all special characteristics of the different detector types (strip detectors, scintillators, calorimeters, drift chambers, etc.).

When the simulation is performed, the Geant output information is already in energies and positions, but highly idealized. Measurement uncertainties must be introduced into the simulated data such that analyzing measurements and corresponding simulations gives the same results. This step relies on more detailed detector characteristics than are used in the simulation. It is summarized as "simulation interface" in the overview diagram of Figure 1.

The simulation interface introduces the necessary realism by various means: The ideal energy is modified by applying a Gaussian noise. If the detector consists of voxels, the position information is centered in those voxels. To take into account not-working pixels (dead, not connected, deactivated, etc.), a certain percentage of all hits is rejected on a random basis as defined by the detector description. Additionally, the software takes care of the correct trigger conditions for the events, as well as all thresholds in the individual channels.

After the steps discussed in this and the preceeding section are completed, the real and the simulated data should look very similar. The events are now represented by hits consisting of energy and position.

4. Event reconstruction and response generation

Next, the individual hits must be combined into events (*Revan* library in Figure 1) and the detector response matrices must be determined (Response generator in Figure 1).

The methods of the event reconstruction are described in detail in (6). The basic idea is to look at the structure of the event. From the kinematics, the topology of the event, eventually timing, and the detector geometry along the lines-of-travel of the photons, electrons or positrons, one can estimate what happened in the detector: Did a Compton scattering occur or a pair creation, did a charged particle pass through or was a large shower created? For this task several algorithms exist (correlation based algorithms, classic Compton sequence reconstruction methods, Bayesian reconstruction approaches, etc.), which allow event reconstruction for different Compton telescope types (electron tracking, multiple Compton, time-of-flight). At the end of the event reconstruction, the data is represented by event types and their associated information, e.g. a Compton event with given energy and direction of the recoil electron and the scattered gamma-ray, or a pair event with given direction and energy of electron and positron. All events are accompanied by a quality factor, which describes the probability that the event happened this way. An example of the background rejection performance of the algorithms can be found in (7, these proceedings).

The second important task on this level of data analysis is to generate response matrices. A response maps the properties of the incoming photons to the detector measurement in a multi-dimensional data space. In order to determine the response, the information of the incident photons from the simulation is compared with the characteristics of the reconstructed events. Since this data space is rather complex, different projections optimized for special tasks are determined, for example finding the correct interaction sequence (event reconstruction response) or determining the origin of a photon in image space (imaging response).

The result of this step of data analysis are events, and the description of how the detector reacts on well defined inputs, the response. Next, this information must be used to retrieve the parameters of the original source distributions.

5. High level data analysis

The last step, the high level data-analysis, inverts the measurement process and determines the properties of the sources of the measured gamma rays.

The first crucial step is to find optimized selection criteria for "good" events. The main task of event selections is to exclude those bins of the data space that contain most of the background events. The high-level data analysis tools comprised in *MEGAlib's Mimrec* library allow event selection on basically all performance-relevant parameters for both Compton and Pair events. These include event type, start detector, energy, scatter angles, distance between interactions, event quality factors, earth horizon cut, number of hits, opening angle and initial deposit of the pair events, and many more.

Diagnostics tools assessing angular resolution, energy dispersion, Compton scatter angle distributions, etc. are provided to determine the quality of the event selections as well as the performance of the detector. Moreover, it is possible to perform background corrected polarization studies, determine the effective area and sensitivity of a detector, and more. Examples can be found in (8, these proceedings)

An especially challenging step is the image reconstruction. The implemented list-mode likelihood image reconstruction algorithm (LM-ML-EM) allows to reconstruct sources in spherical as well as Cartesian coordinates (2D as well as 3D) from tracked and not tracked Compton as well as pair events (9). Several different levels of response approximations can be applied to the data. Examples of real data measured with MEGA and reconstructed with *MEGAlib* are given in (10, these proceedings).

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