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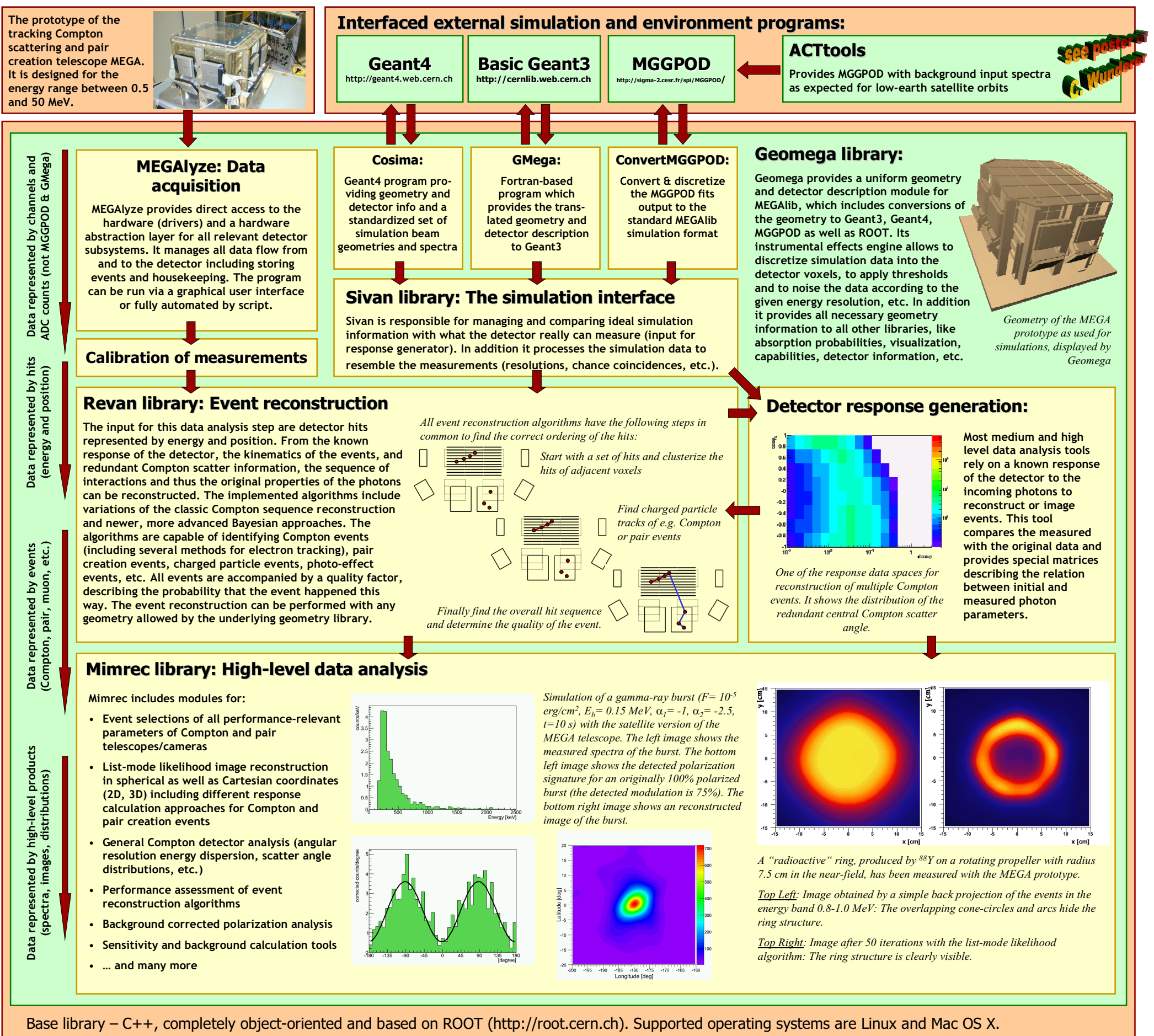
MEGAlib - Medium Energy Gamma-ray Astronomy Library

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Abstract

The next generation of Compton telescopes requires a completely different approach in data analysis compared to that of COMPTEL. The Medium Energy Gamma-ray Astronomy library (MEGAlib) is a set of software tools which are primarily designed to analyze data of next generation Compton telescopes. The library comprises all necessary data analysis steps from simulation/measurement via event reconstruction to image reconstruction.

MEGAlib contains a geometry and detector description tool for the detailed modeling of different detector types and characteristics, and provides interfaces for the simulation tools Geant3, MGeant/MGGPOD and Geant4. For the different Compton telescope candidate detector types (electron tracking, multiple Compton or time-of-flight based) specialized event reconstruction algorithms are implemented in different approaches (Chi-square and Bayesian). The high level data analysis tools allow to calculate response matrices, reconstruct images (list-mode likelihood algorithm), determine energy and angular resolutions, calculate telescope sensitivities, retrieve spectra, determine polarization modulations, etc.

The highly modular and completely object-oriented library is written in C++ and based on ROOT. It contains more than 290,000 lines of code. It has been originally developed for the tracking Compton scattering and Pair creation telescope MEGA and is currently being used to explore different Compton telescope designs for the Advanced Compton Telescope "Vision Mission" study.

The prototype of the tracking Compton scattering and pair creation telescope MEGA. It is designed for the energy range between 0.5 and 50 MeV.

Interfaced external simulation and environment programs:

Geant4
http://geant4.web.cern.ch

Basic Geant3
http://cernlib.web.cern.ch

MGGPOD
http://sigma-2.cesr.fr/spi/MGGPOD/

ACTtools
Provides MGGPOD with background input spectra as expected for low-earth satellite orbits

See poster of C. Wunderer!

MEGAlyze: Data acquisition

MEGAlyze provides direct access to the hardware (drivers) and a hardware abstraction layer for all relevant detector subsystems. It manages all data flow from and to the detector including storing events and housekeeping. The program can be run via a graphical user interface or fully automated by script.

Cosima:
Geant4 program providing geometry and detector info and a standardized set of simulation beam geometries and spectra

GMega:
Fortran-based program which provides the translated geometry and detector description to Geant3

ConvertMGGPOD:
Convert & discretize the MGGPOD fits output to the standard MEGAlib simulation format

Geomega library:
Geomega provides a uniform geometry and detector description module for MEGAlib, which includes conversions of the geometry to Geant3, Geant4, MGGPOD as well as 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, like absorption probabilities, visualization, capabilities, detector information, etc.

Geometry of the MEGA prototype as used for simulations, displayed by Geomega

Calibration of measurements

Sivan library: The simulation interface
Sivan is responsible for managing and comparing ideal simulation information with what the detector really can measure (input for response generator). In addition it processes the simulation data to resemble the measurements (resolutions, chance coincidences, etc.).

Revan library: Event reconstruction

The input for this data analysis step are detector hits represented by energy and position. From the known response of the detector, the kinematics of the events, 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 events are accompanied by a quality factor, describing the probability that the event happened this way. The event reconstruction can be performed with any geometry allowed by the underlying geometry library.

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.

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 response data spaces for reconstruction of multiple Compton events. It shows the distribution of the redundant central Compton scatter angle.

Mimrec library: High-level data analysis

Mimrec includes modules for:

- Event selections of all performance-relevant parameters of Compton and pair telescopes/cameras

- List-mode likelihood image reconstruction in spherical as well as 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

- … and many more

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) with the satellite version of the MEGA telescope. The left image shows the measured spectra of the burst. The bottom left image shows the detected polarization signature for an originally 100% polarized burst (the detected modulation is 75%). The bottom right image shows an reconstructed image of the burst.

A "radioactive" ring, produced by ^{88}Y on a rotating propeller with radius 7.5 cm in the near-field, has been measured with the MEGA prototype.

Top Left: Image obtained by a simple back projection of the events in the energy band 0.8-1.0 MeV: The overlapping cone-circles and arcs hide the ring structure.

Top Right: Image after 50 iterations with the list-mode likelihood algorithm: The ring structure is clearly visible.

Data represented by channels and ADC counts (not MGGPOD & GMega)

Data represented by hits (energy and position)

Data represented by events (Compton, pair, muon, etc.)

Data represented by high-level products (spectra, images, distributions)

Base library – C++, completely object-oriented and based on ROOT (http://root.cern.ch). Supported operating systems are Linux and Mac OS X.

The latest version of MEGAlib can be found at www.mpe.mpg.de/mega/megalib.html, or contact: zog@ssl.berkeley.edu