

Gleam: the GLAST Large Area Telescope Simulation Framework

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Abstract

This paper presents the simulation of the GLAST high energy gamma-ray telescope. The simulation package, written in C++, is based on the Geant4 toolkit, and it is integrated into a general framework used to process events. A detailed simulation of the electronic signals inside Silicon detectors has been provided and it is used for the particle tracking, which is handled by a dedicated software. A unique repository for the geometrical description of the detector has been realized using the XML language and a C++ library to access this information has been designed and implemented.

1 Introduction

The Gamma-ray Large Area Space Telescope (GLAST) is an international mission that will study the high-energy phenomena in gamma-rays universe [1, 2]. GLAST is scheduled for launch in 2006.

GLAST is instrumented with a hodoscope of Silicon planes with slabs of converter, followed by a calorimeter; the hodoscope is surrounded by an anti-coincidence (ACD). This instrument, called the Large Area Telescope LAT, is sensitive to gamma rays in the energy range between 30 MeV and 300 GeV. The energy range, the field of view and the angular resolution of the GLAST LAT are vastly improved in comparison with those of its predecessor EGRET (operating in 1991-2000), so that the LAT will provide a factor of 30 or more advance in sensitivity. This improvement should enable the detection of several thousands of new high-energy sources and allow the study of gamma-ray bursts and other transients, the resolution of the gamma-ray sky and diffuse emission, the search for evidence of dark matter and the detection of AGNs, pulsars and SNRs. One can find a detailed description of the scientific goals of GLAST mission and an introduction to the experiment in [3].

GLAST is a complex system, and detailed computer simulations are required to design the instrument, to construct the response function and to predict the background in the orbit. To accomplish these tasks an object-oriented C++ framework called *Gleam* (GLAST LAT Event Analysis Machine) was adopted and implemented.

The main components Gleam are the subject of this paper.

2 The GLAST Offline Software Framework

The structure of the GLAST offline software is described in figure 1. Most packages has been developed explicitly by the GLAST collaboration for the specific items required by the simulation of a high energy gamma-ray telescope. An important characteristics is the separation of the packages according to their responsibilities.

The GLAST off-line software is based manly on Gaudi, a C++ framework, originally developed at CERN [4]. Gaudi is an open project aimed to provide the necessary interfaces and services for building the framework of event data processing applications for High Energy Physics experiments. A generic application framework should be usable for implementing the full range of offline computing tasks: generation of events, simulation of the detector, event reconstruction, testbeam data analysis, detector alignment, visualisation, etc. The framework gives the possibility to develop such tasks in a unified and coherent way. Tasks such as physics analysis and event reconstruction consist of the manipulation of mathematical or physical quantities (points, vectors, matrices, hits, momenta, etc.) by algorithms which are generally specified in terms of equations and natural language. As a consequence, the Gaudi application framework makes a clear distinction between “data” objects and “algorithm” objects.

In the GLAST framework, Gaudi manages the loop of particles to be simulated, then a series of algorithms are applied to each of them to get the result of the complete simulation and reconstruction chain. The figure 2 shows the flux of simulated events within the Gleam framework based on Gaudi.

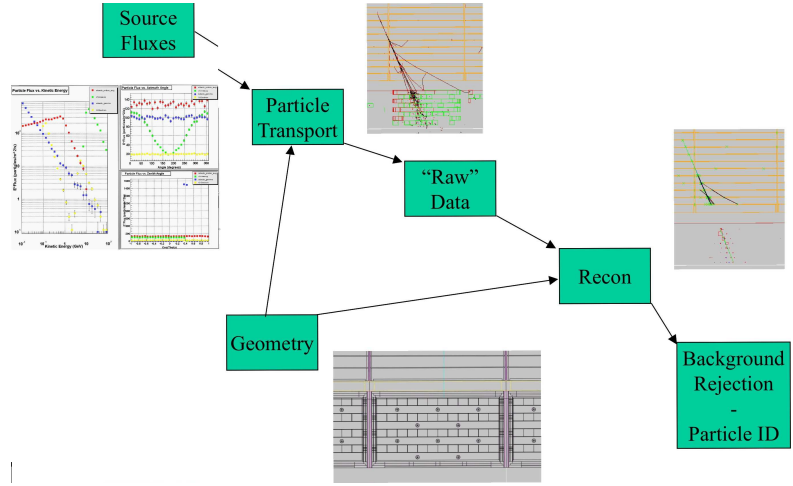


Figure 1: General scheme for simulation and reconstruction within the GLAST off-line software framework

The output from the simulation is in the same format as the real data, and can be processed by the reconstruction package.

3 The Source Generation package

The Source Generation is the first algorithm called within the particle loop. Its task is to generate particles according to certain characteristics. This algorithm must store the information on the temporal and spectral behaviour of the source,

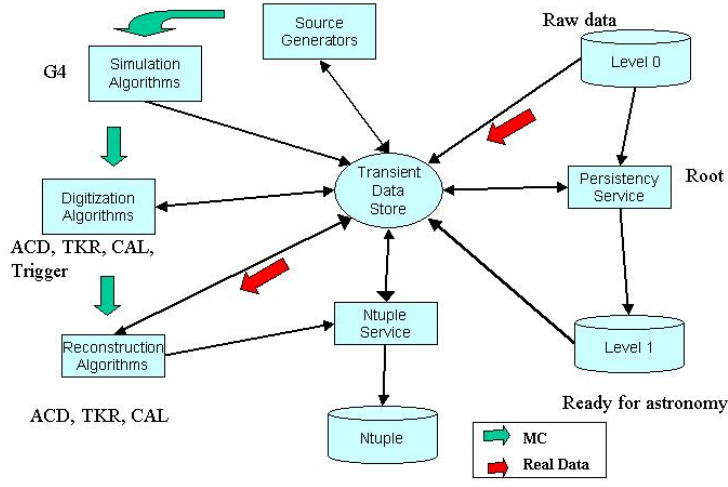


Figure 2: Event processing within the GLAST off-line software framework

as well as on the orbital characteristics of GLAST. It provides a user interface to produce additional incoming particles and is responsible for setting the current time, the particle energy, direction, and type. Within this package a series of default sources are implemented. They include source for testing purposes as well as the description of astrophysical spectra and the expected particle and albedo gamma backgrounds.

An extension of this framework has been implemented for simulating transient sources such as Gamma-Ray Bursts (GRB). It can be used for studying the capability of GLAST for the observation of rapid transient fluxes in general. The physics adopted is based on the fireball model of Gamma Ray Burst, for which a series of shells is injected in the circumburst medium with different Lorentz factor [5]. When a faster shell reaches a slower one a shock occurs, and an accelerated electron distribution is obtained due to the shock acceleration process. Some of the energy dissipated during the shock is converted into a randomly oriented magnetic field. The electrons can lose their energy via synchrotron emission. The characteristic synchrotron spectrum is boosted (and broadened) thanks to the Lorentz factor of the emitting material. The higher energy part of a GRB spectrum can be obtained keeping into account the possibility of Compton scattering of the synchrotron photons against the electron accelerated by the shock (Inverse Compton Scattering) [6]. Figure 3 shows a light curve generated with this package.

The information on the particles generated in the Source Generation package is put in the data store, so that every other piece of code in the framework can use it.

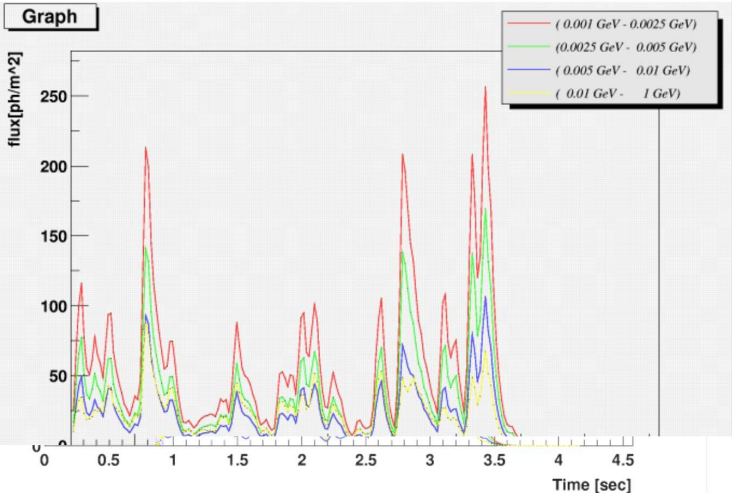


Figure 3: An example of GRB light curve from the GLAST simulator.

4 The Simulation package

The algorithm which is responsible for generating the interactions of particles with the detector is based on the Geant4 MonteCarlo toolkit [7] which is an

Object Oriented (OO) simulator of the passage of particles through matter. Its application areas include high energy physics and nuclear experiments, medical science, accelerator and space physics.

Geant4 (G4) provides a complete set of tools for all the domains of detector simulation: Geometry, Tracking, Detector Response, Run, Event and Track management, Visualisation and User Interface. A large set of Physics Processes handle the diverse interactions of particles with matter across a wide energy range, as required by G4 multi-disciplinary nature; for many physics processes a choice of different models is available. In addition a large set of utilities, including a powerful set of random number generators, physics units and constants, a management of particles compliant with the Particle Data Group, as well as interfaces to event generators and to object persistency solutions, complete the toolkit. G4 exploits advanced Software Engineering techniques and OO technology to achieve the transparency of the physics implementation and hence provide the possibility of validating the physics results. The OO design allows the user to understand, customise or extend the toolkit in all the domains. At the same time, the modular architecture of G4 allows the user to load and use only the components needed. To build a specific application the user-physicist chooses among these options and implements code in user action classes supplied by the toolkit [8].

Within the G4 framework the simulation is managed by the Gaudi algorithm G4Generator [9]. The main simulation is controlled by a customized and version of the G4 standard RunManager. Since the GLAST main event loop is driven by Gaudi and it will not use any graphics or data persistency features of Geant4, we have included in the RunManager only the real necessary parts for setup and run the generator. RunManager itself uses the following classes:

- **DetectorConstruction:** this class provides the list of materials and the geometry of the detector. In our case this information is stored in XML files; to access them the DetectorConstruction class uses methods of a Gaudi service. The Geometry class implements methods to traverse the geometry of GLAST and build a concrete Geant4 representation of it; the Material class does the same for the materials definitions.
- **PhysicsList:** this class is the access point to the physics processes selection and customization. It uses other classes (GeneralPhysics, EMPhysics, HadronPhysics, MuonPhysics, IonPhysics) to set up particular physics processes. Since the Geant4 toolkit is open to new physics processes (along with new description of already present processes), this will be the access point for further development in the physics selection.
- **PrimaryGeneratorAction:** this class is in charge of production and injection of primary particles in the detector simulation. In our cases it is linked to the Gaudi algorithm that is responsible to generate the incoming fluxes of particles.
- **DetectorManager:** this class manages the setup and working of the sensitive detectors of the simulation and their interaction with the GAUDI Data Store. It is concretely implemented in the two subclasses PosDetectorManager and IntDetectorManager; the first one is associated with detector that saves hits information in the Si planes of the LAT tracker

(TRK), while the second one is used for Anticoincidence (ACD) tiles and Calorimeter (CAL) cells.

Figure 4 shows an event generated using Geant4 within the GLAST LAT experiment.

5 The Digitization package

To implement a detailed digitization of the Tracker system a full simulation code has been developed. It takes into account all the main physical processes that take place in a silicon strip detector (SSD) when it is crossed by an ionizing particle [10]. The first version of the code has been written in FORTRAN and uses the HEED package for simulating the energy loss of charged particles in silicon. The present version of the code has been written in C++ and the process of energy loss is simulated by Geant4.

The input parameters of the code are the entry and exit points of the particle in a silicon ladder and the energy deposited by the particle, provided by the simulation package. Starting from these parameters, the e-h pairs are generated

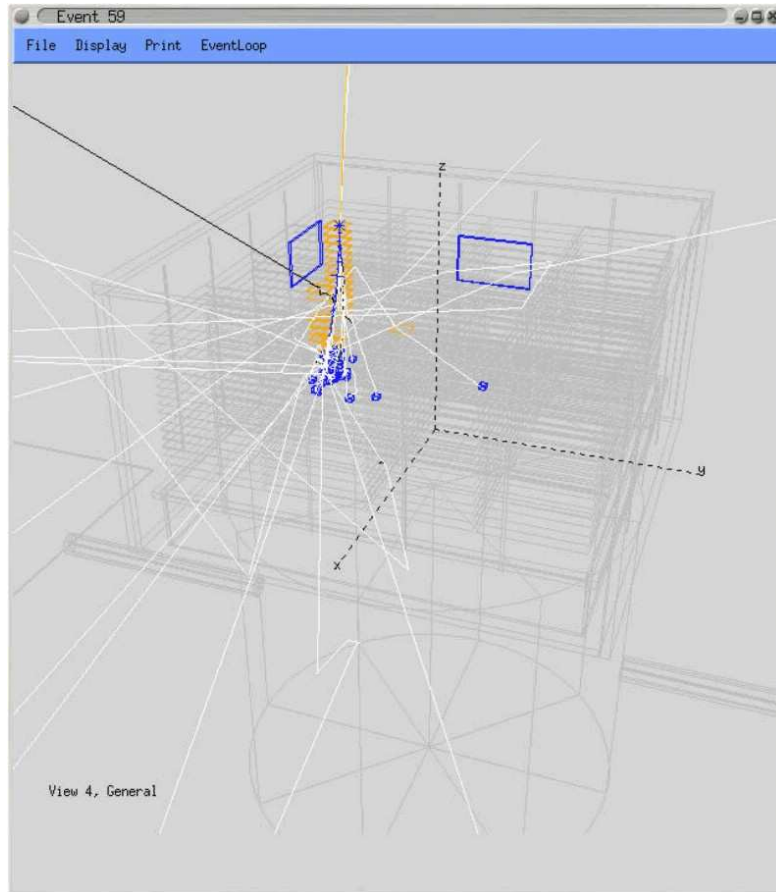


Figure 4: 10 MeV gamma interacting with the GLAST LAT detector

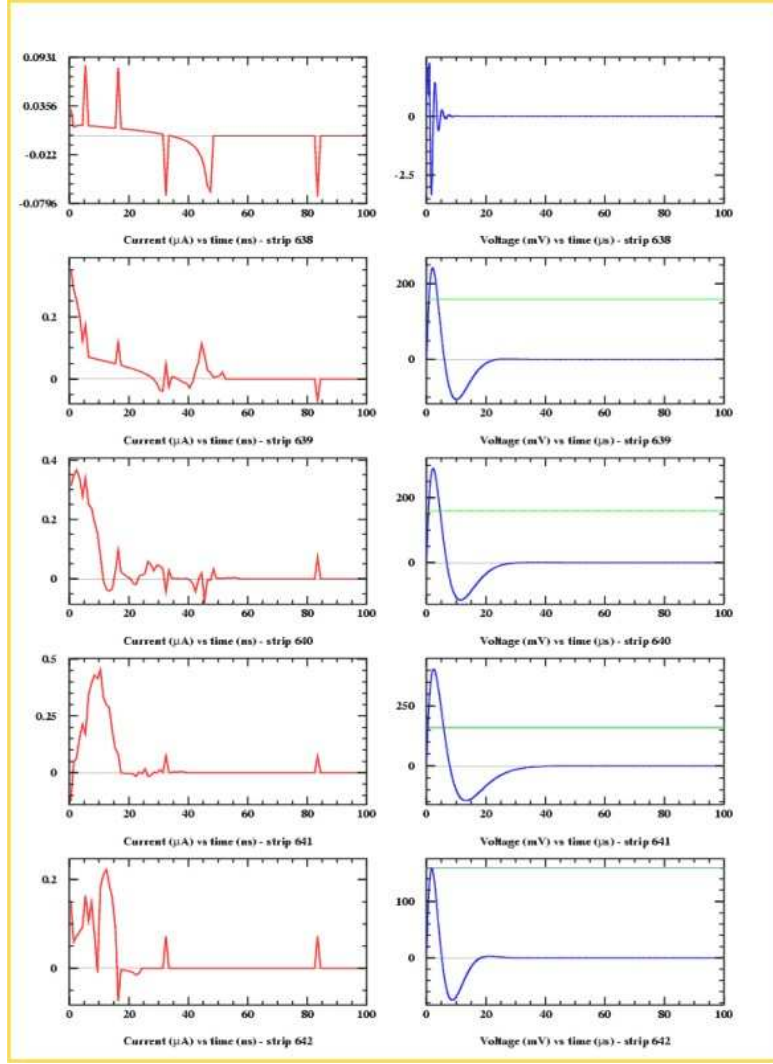


Figure 5: Charge sharing for a 5 GeV electron, crossing the silicon wafer at large zenith angle (60°). The superimposed green line represents the readout threshold voltage

along the track and are propagated towards the electrodes. The current signals induced on each strip are evaluated and are converted into voltage signals using the transfer function associated to the detector electronics, taking into account the detector noise as well as the noise associated to the electronics. The fired strips and the time over threshold (TOT) are then determined after imposing a threshold on the voltage signals. Figure 5 shows some results of this package, concerning the signal generated in a silicon ladder equipped with the GLAST LAT electronics.

Simplified version for the digitization of the signals are provided for the Calorimeter and the Anticoincidence panels.

6 The Reconstruction package

This package contains the code that reconstructs tracks from hit strips in the LAT tracker. It's organized as a series of algorithms that act successively [11]. Starting from digits generated by the Digitization package, it generates a series of clusters, that are used to find and fit the best track candidates. This last procedure is done using alternative pattern recognition algorithms and a Kalman Filter based algorithm. Finally, using the best track found, another algorithm finds the best vertex candidate for gamma events.

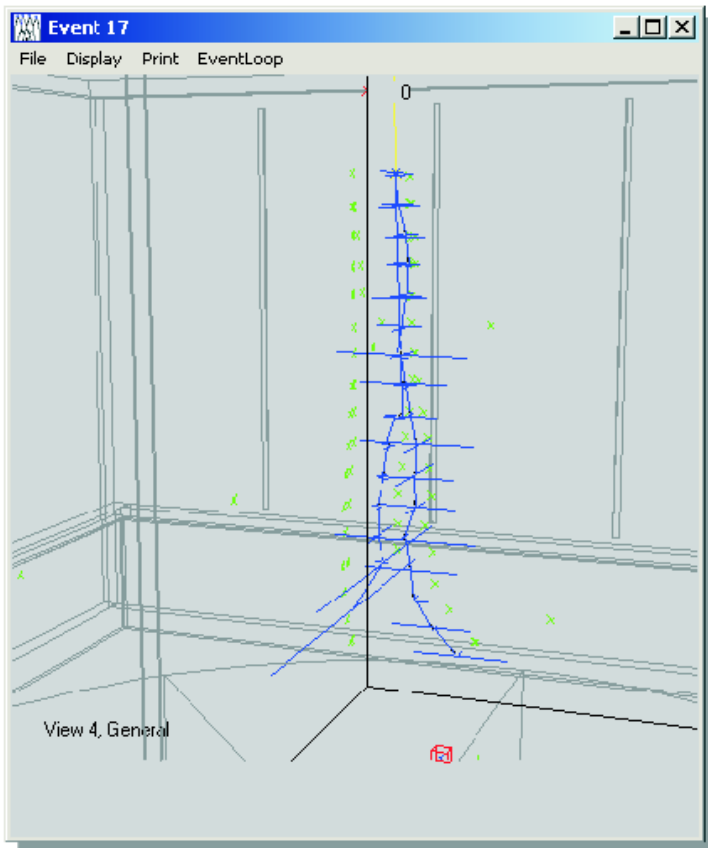


Figure 6: 100 MeV gamma tracked in the LAT

Figure 6 shows a photon track reconstructed in the GLAST LAT.

7 Geometry database access library

The geometrical information of the detector and its materials are stored in an unique repository written using the XML language. A series of methods has been implemented to retrieve this information and make it available to the other packages. Interfaces have been implemented to visualize the geometrical information with different graphical outputs. Figure 7 shows the external

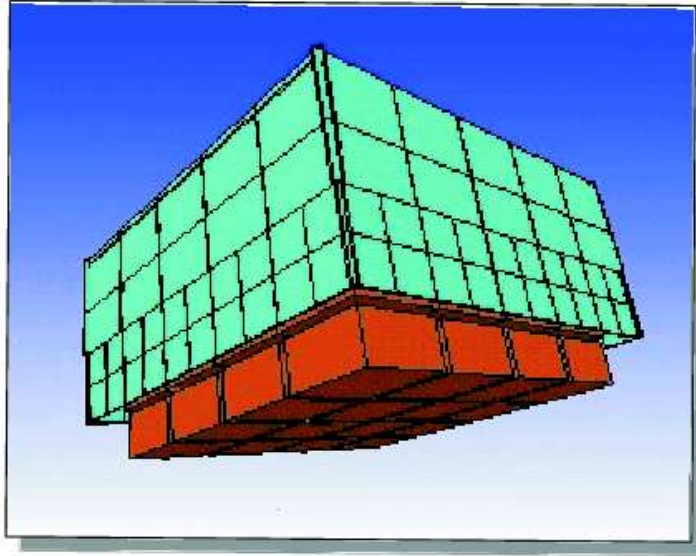


Figure 7: GLAST LAT visualized with VRML

appearance of GLAST visualized with a VRML browser.

8 Event Display and GUI

Although it is not part of the simulation, the visualization package is essential for the use of the simulation itself.

The Gleam event display GUI provides access to several kinds of controls. It includes controls on level of detail in detector display, rendering (or suppression) of digi products, recon products, choice of view, etc. It manages the Event generation with the possibility of choosing among many possible sources, ranging from simple test sources to simulation of albedo and galactic sources.

A new version [12, 14] of the event display based on the HepRep [13] protocol has been developed and will be soon integrated within the framework.

9 Conclusions

The *Gleam* simulation program has been developed in the last few years and now it's ready for simulating the full GLAST satellite and will be used for deriving the final instrumental parameter and for generating a full set of events for the developing of scientific analysis software.

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