Geant4 Simulation of High Energy Gamma Ray Experiments

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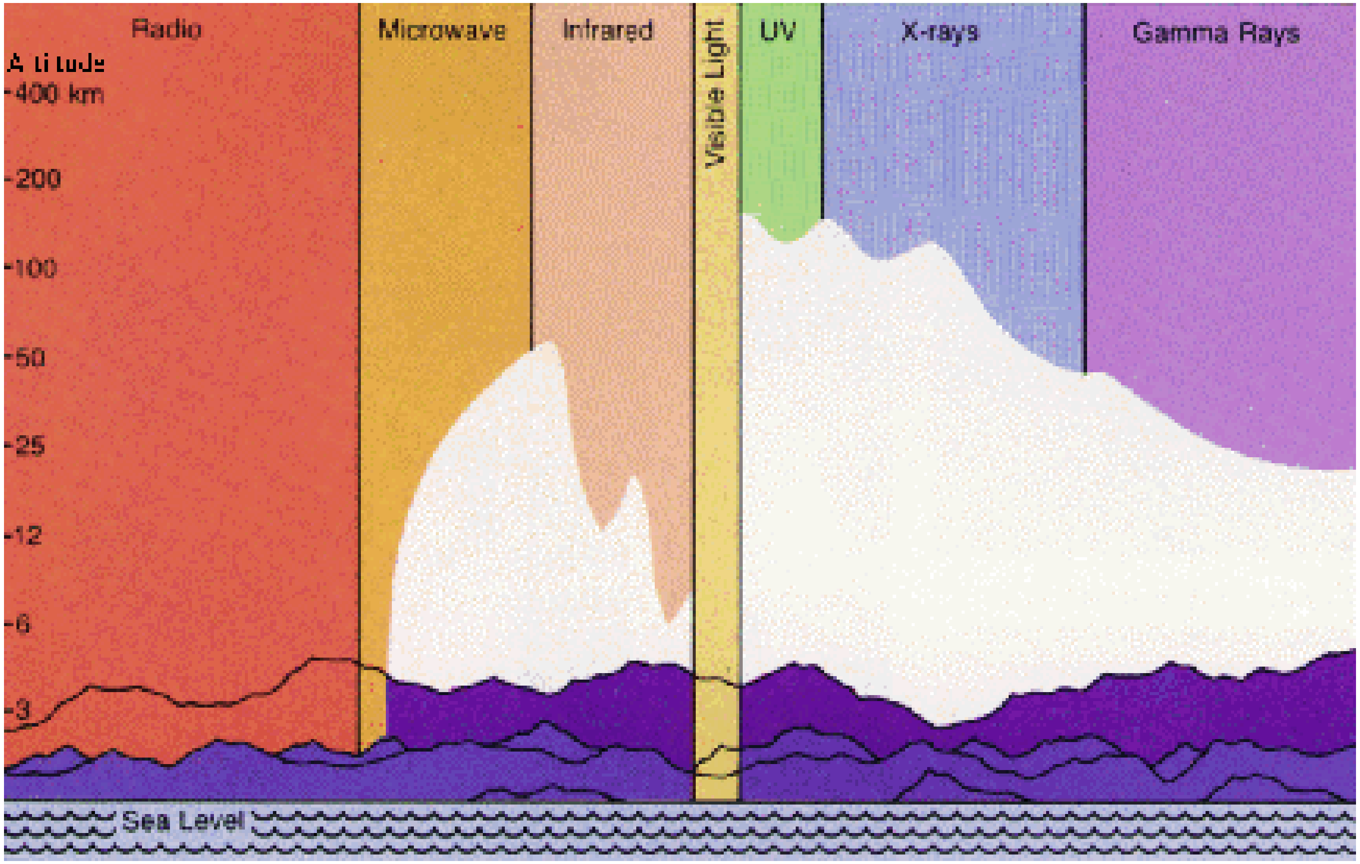
OUTLINE

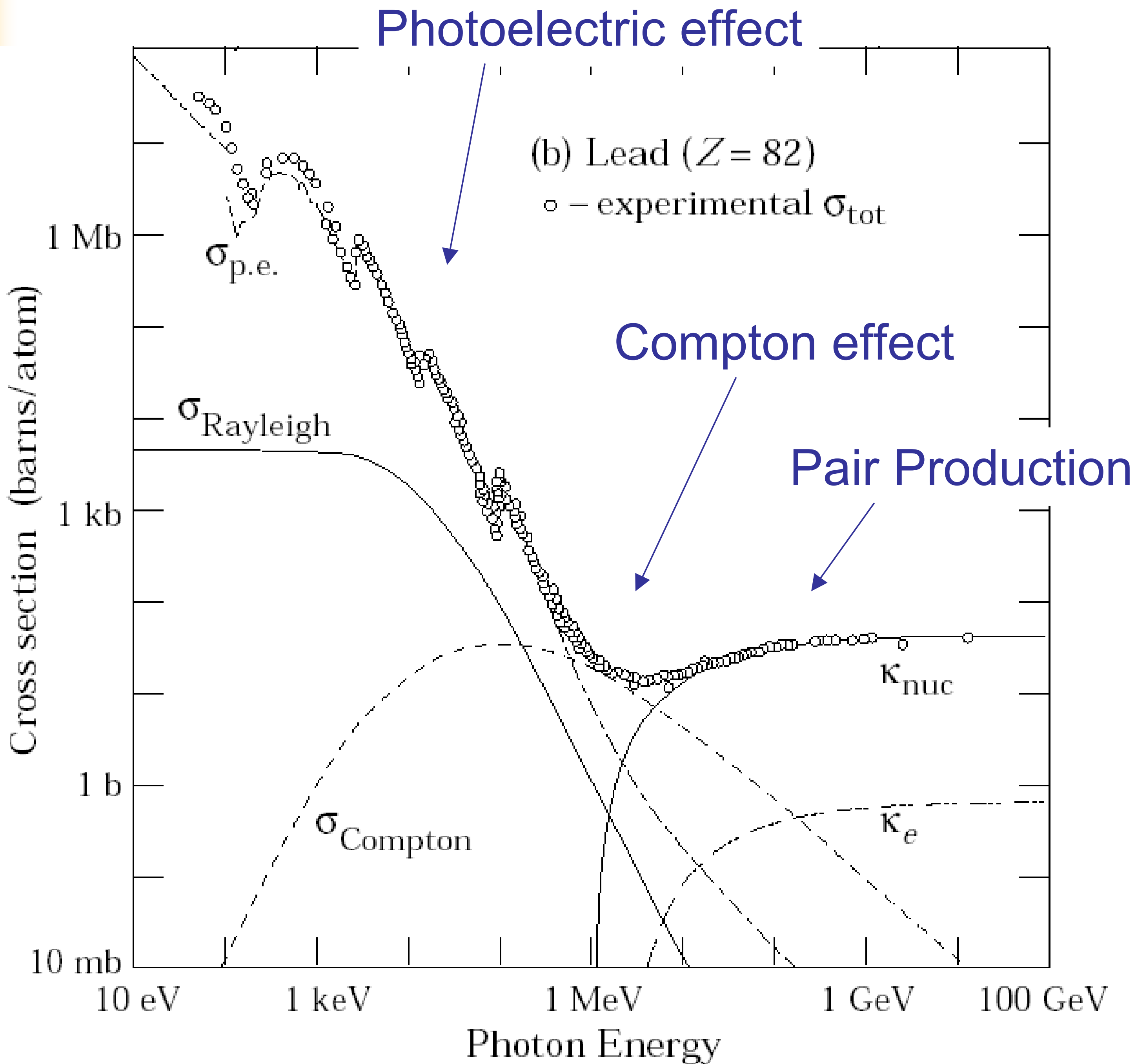
- High Energy Gamma-Ray Astronomy
  - General Introduction
  - Science Objectives
- Gamma-Ray Astronomy Experiments
  - AGILE
  - GLAST
- Simulation Requirements and Implementation
  - AGILE baseline (G3) and prototype (G4)
  - GLAST
- Conclusions

HE Gamma-Ray Astrophysics

- General Introduction (the EGRET experiment)
- Science Objectives and Requirements

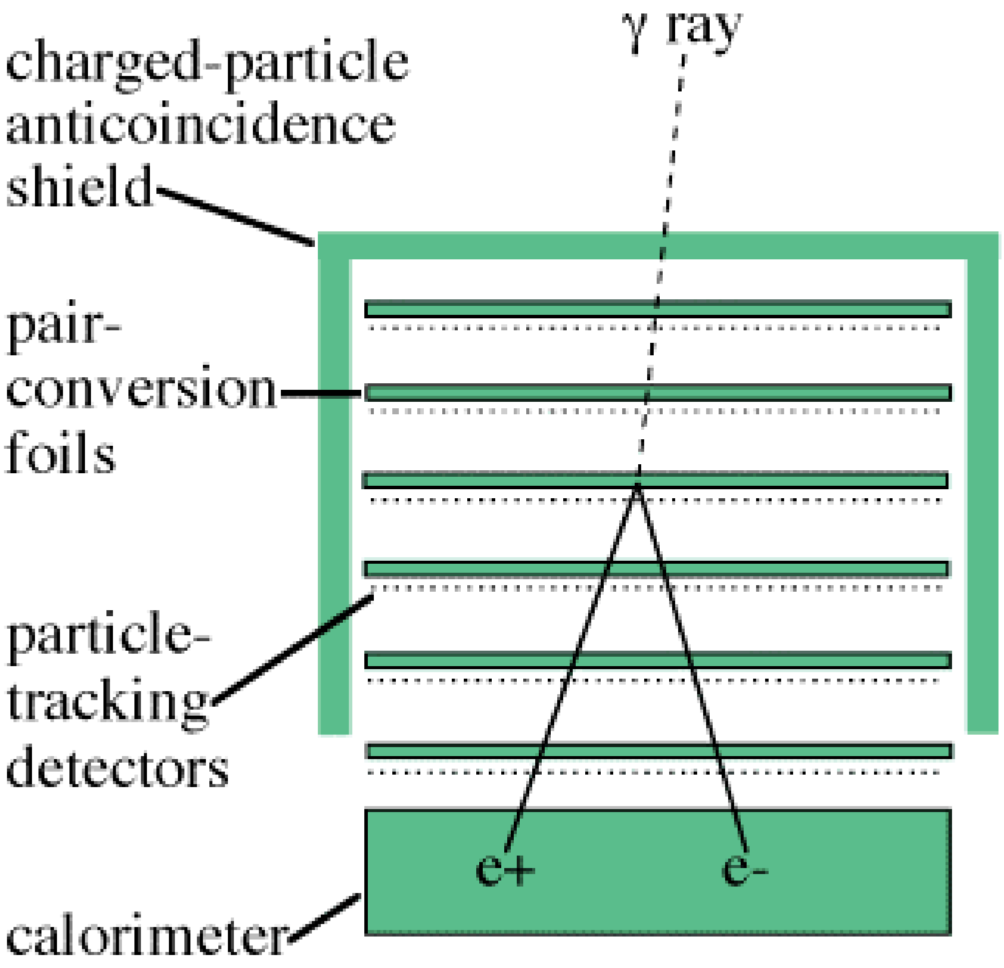
Gamma-Ray Astrophysics





Photoelectric effect
(b) Lead (Z = 82)
○ – experimental σ_tot
σ_p.e.
σ_Rayleigh
Compton effect
Pair Production
κ_nuc
κ_e
σ_Compton
1 Mb
1 kb
1 b
10 mb
Cross section (barns/atom)
10 eV
1 keV
1 MeV
1 GeV
100 GeV
Photon Energy

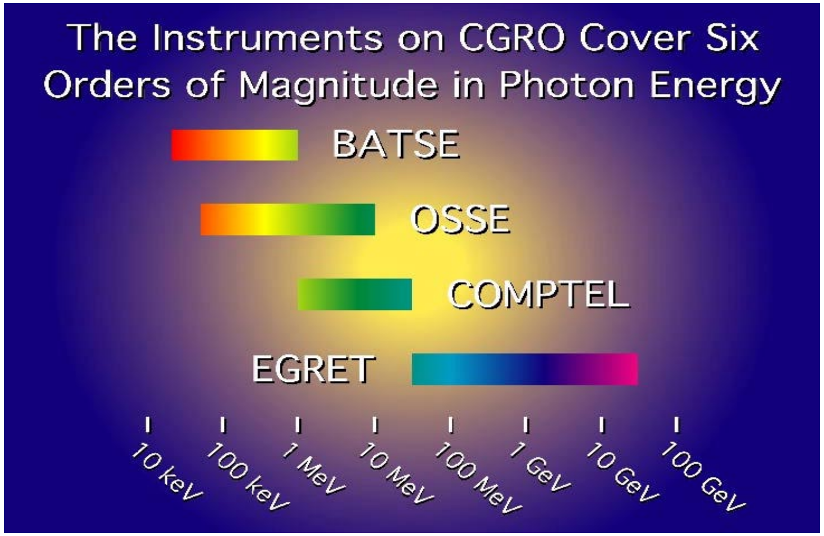
Detection Technique

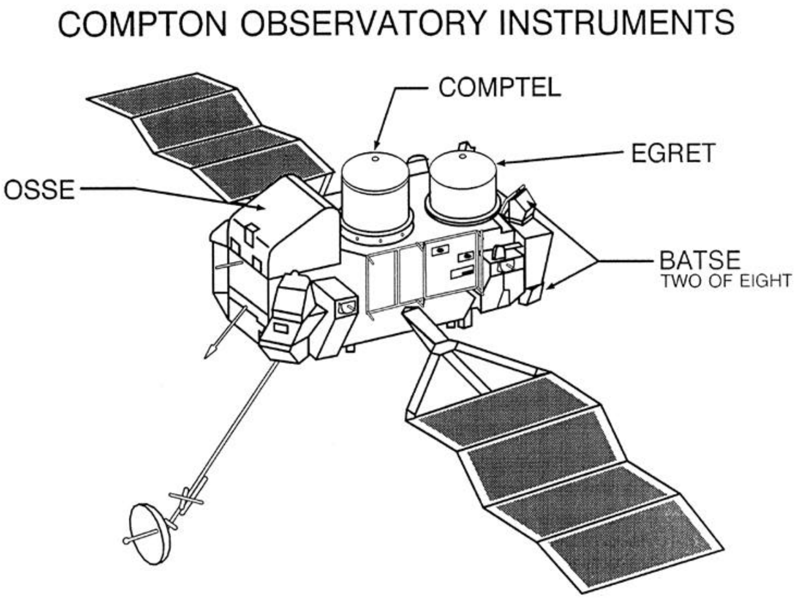


The Compton Gamma Ray Observatory

CGRO satellite (1991-2000)

The Compton Gamma Ray Observatory





The Compton Gamma Ray Observatory (CGRO) is a sophisticated satellite observatory dedicated to observing the high-energy Universe. It is the second in NASA's program of orbiting "Great Observatories", following the Hubble Space Telescope.
While Hubble's instruments operate at visible and ultraviolet wavelengths, Compton carries a collection of four instruments which together can detect an unprecedented broad range of high-energy radiation called gamma rays. These instruments are the Burst And Transient Source Experiment (BATSE), the Oriented Scintillation Spectrometer Experiment (OSSE), the Imaging Compton Telescope (COMPTEL), and the Energetic Gamma Ray Experiment Telescope (EGRET).

The Compton Gamma Ray Observatory

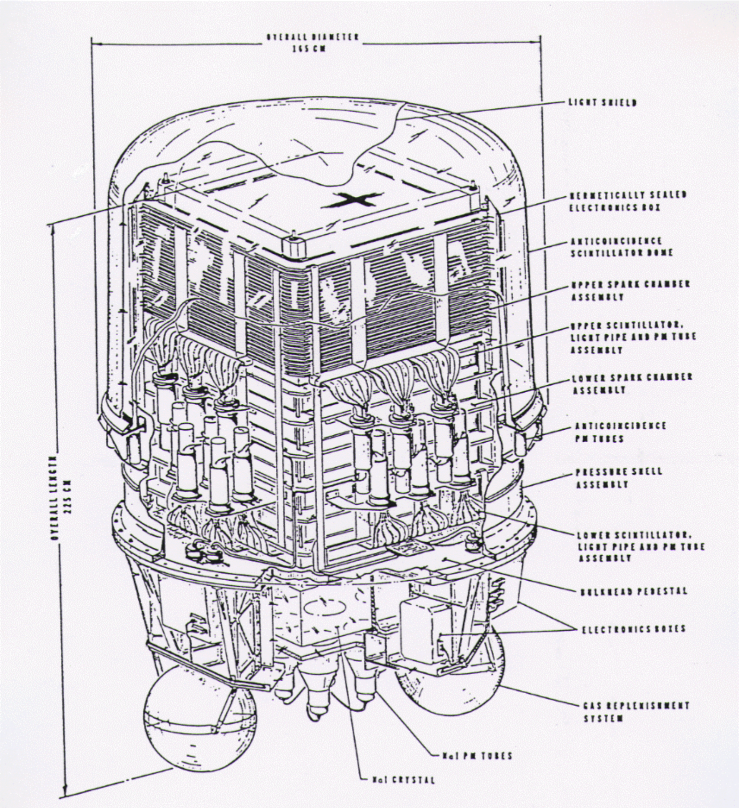
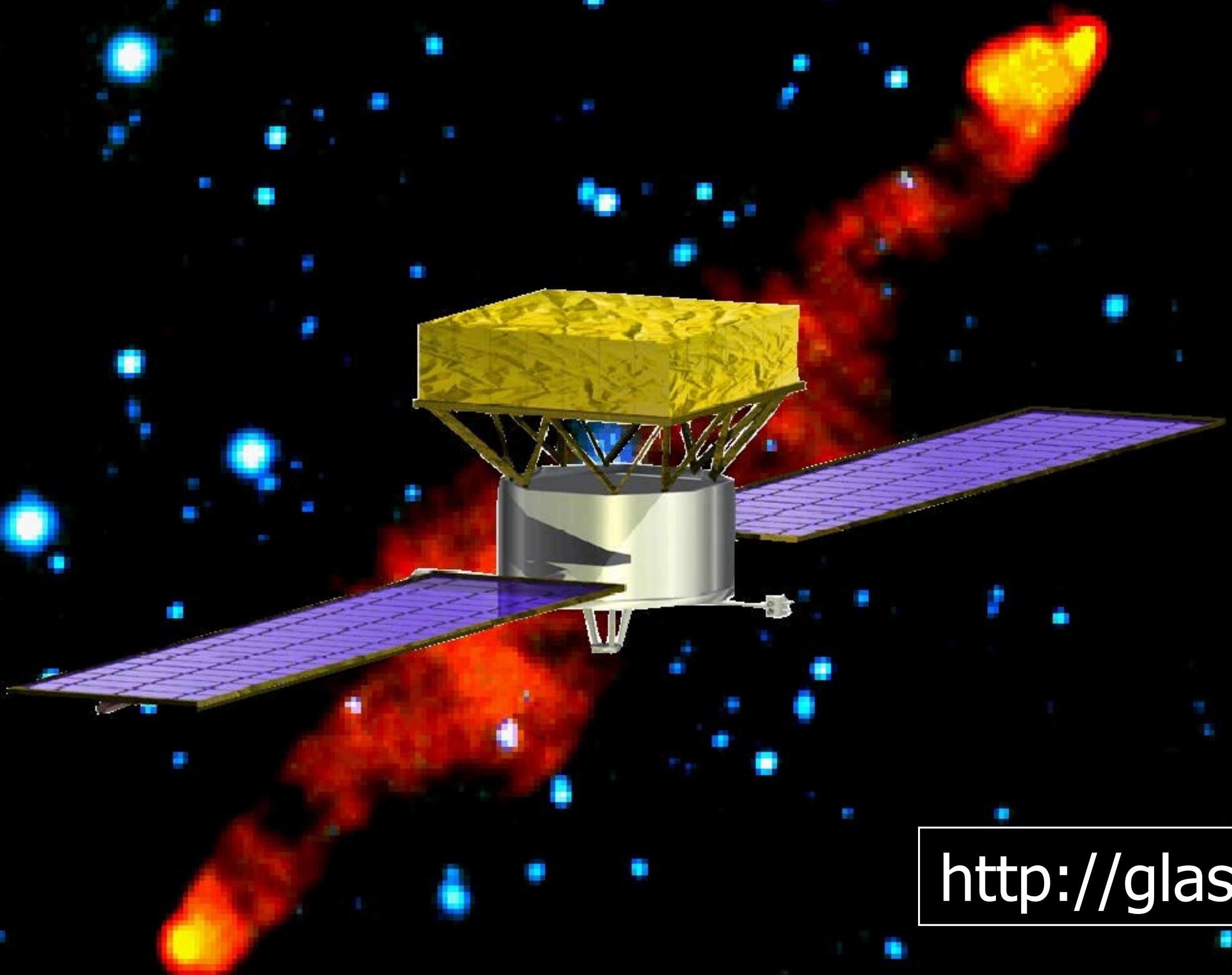


Figure IV-1. The EGRET Instrument

EGRET

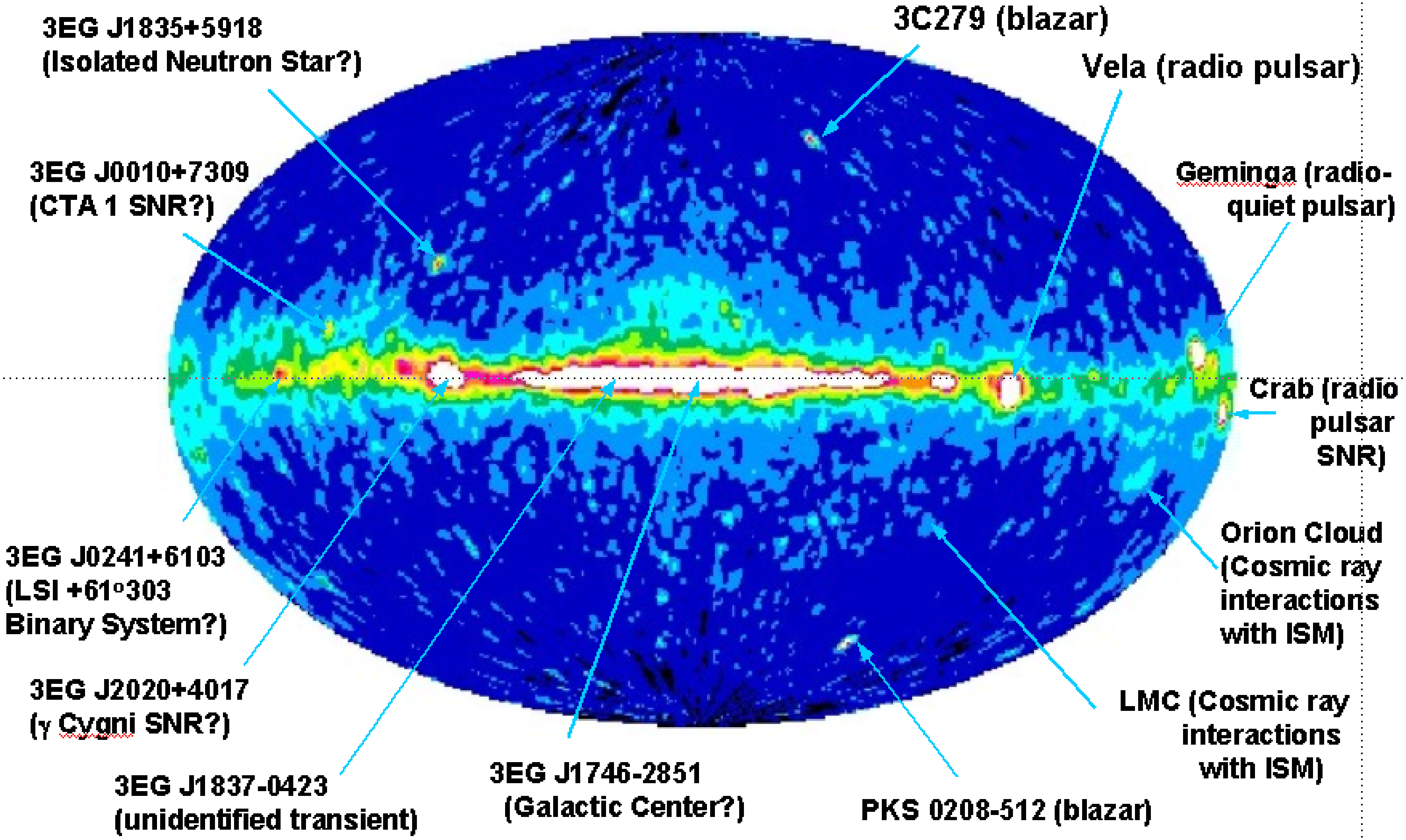
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

Nature's Highest Energy Particle Accelerators



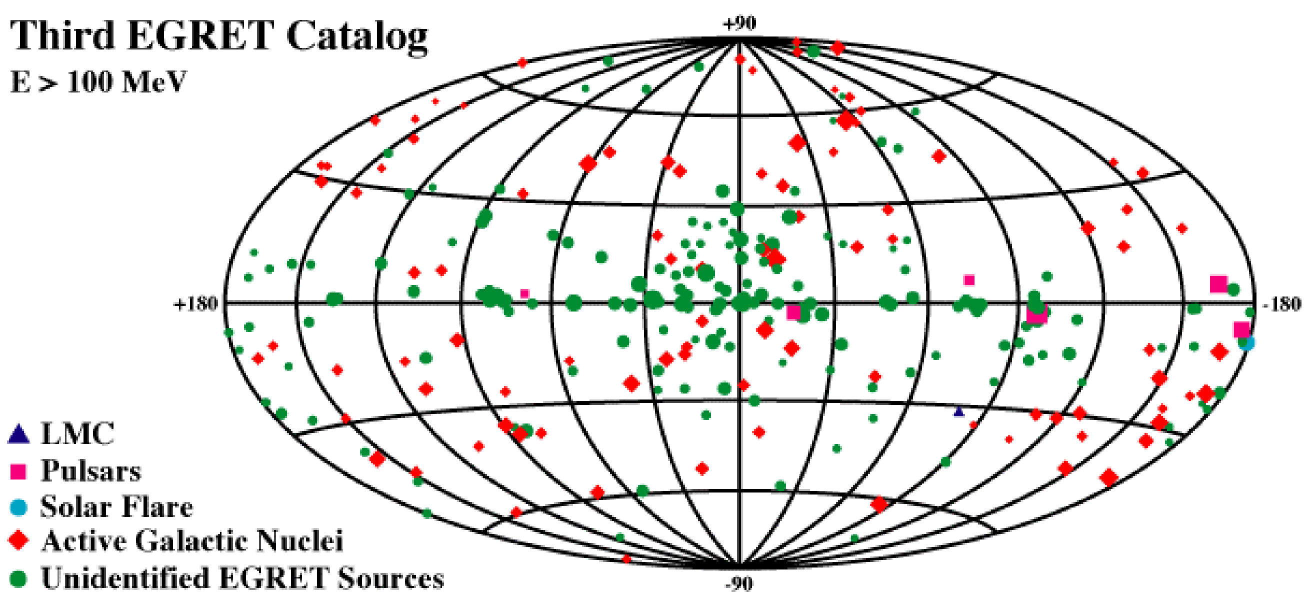
http://glast.gsfc.nasa.gov

EGRET All Sky Map

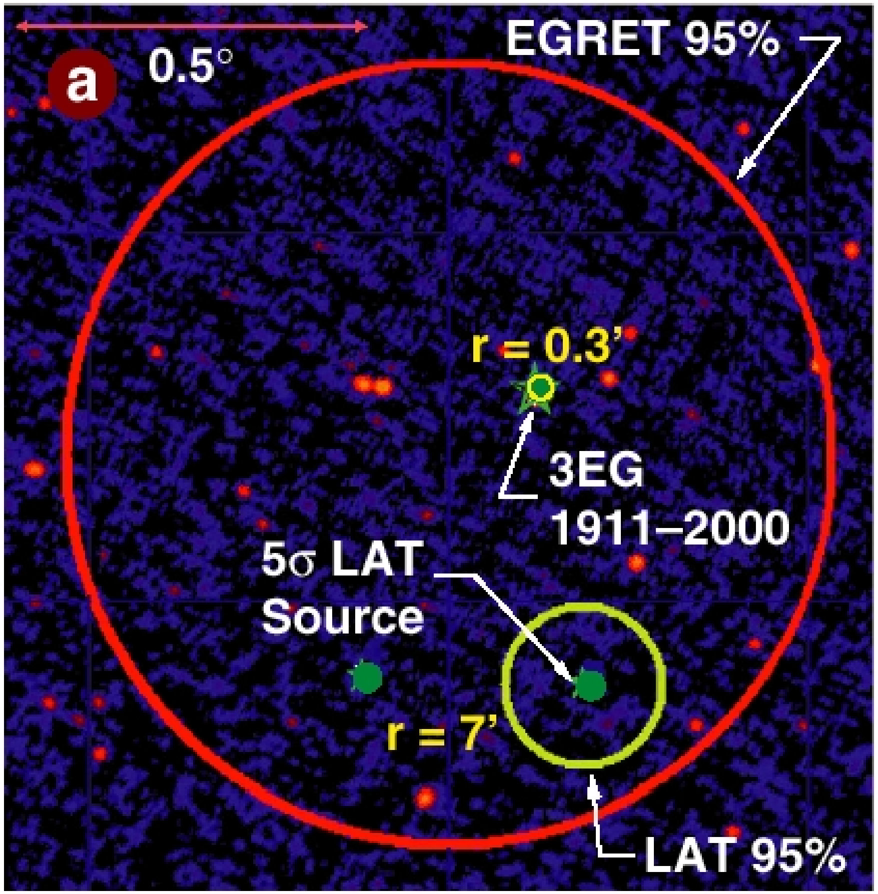


Unidentified Gamma-Ray Sources

- 172/271 sources in 3rd EGRET catalog are unidentified
  - Reduce source location error boxes to a few arcminutes
  - Monitor unidentified sources for time variability with high-duty-cycle
  - Facilitate counterpart searches at X-ray and lower energies and in TeV regimes



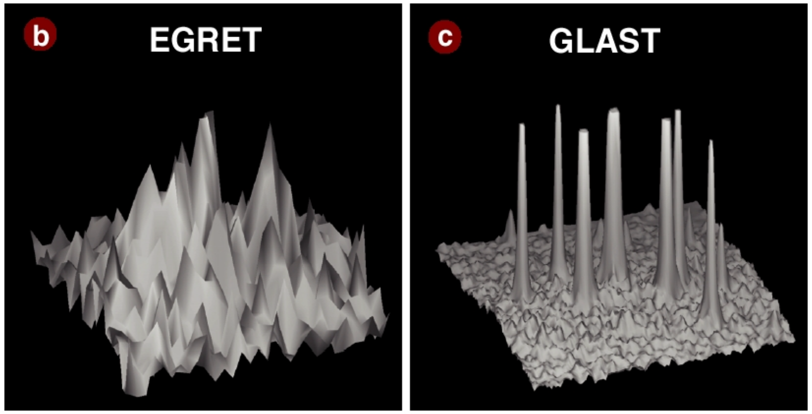
Unidentified Gamma-Ray Sources



● Rosat or Einstein X-ray Source
● 1.4 GHz VLA Radio Source

EGRET source position error circles are ~0.5°, resulting in counterpart confusion.

GLAST will provide much more accurate positions, with ~30 arcsec - ~5 arcmin localizations, depending on brightness.

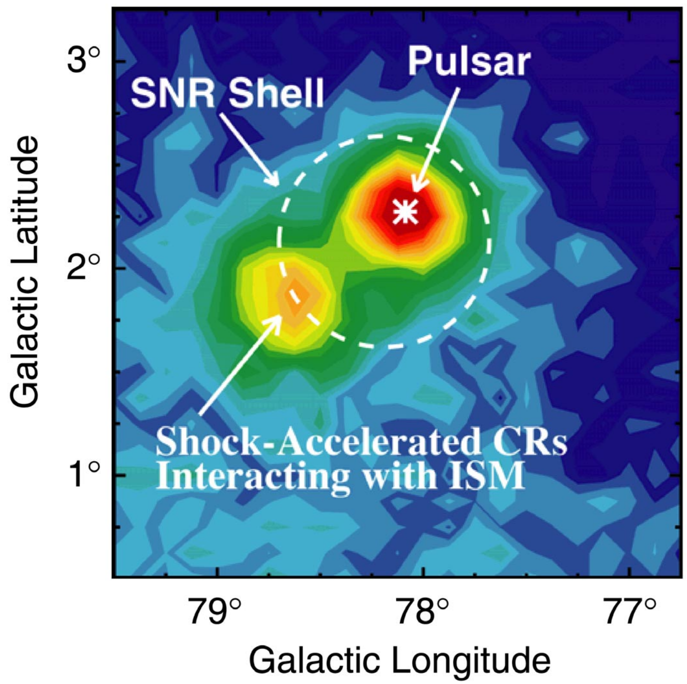


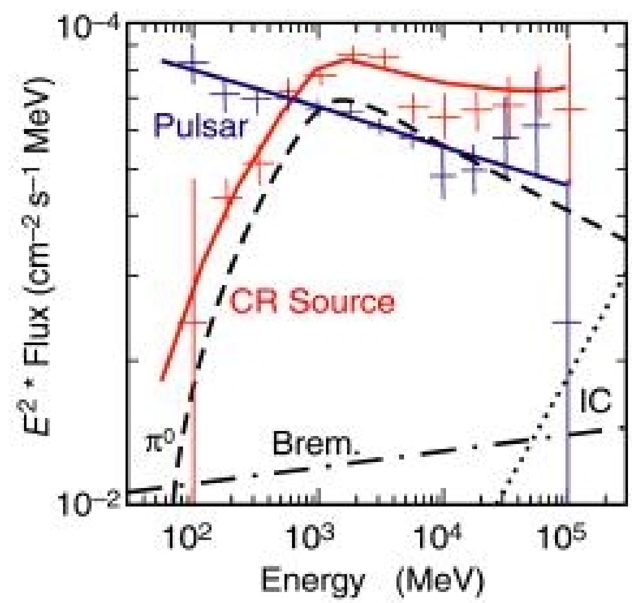
Cygnus region (15x15 deg)

Supernova Remnants

- Separation of electron contribution (brems. and IC) and proton contribution (pi-0) is important. Association of SNRs, history of the galaxy or the cluster

- Even in galactic level, the total energy of cosmic-ray is non-negligible. It can be very important in cluster level.



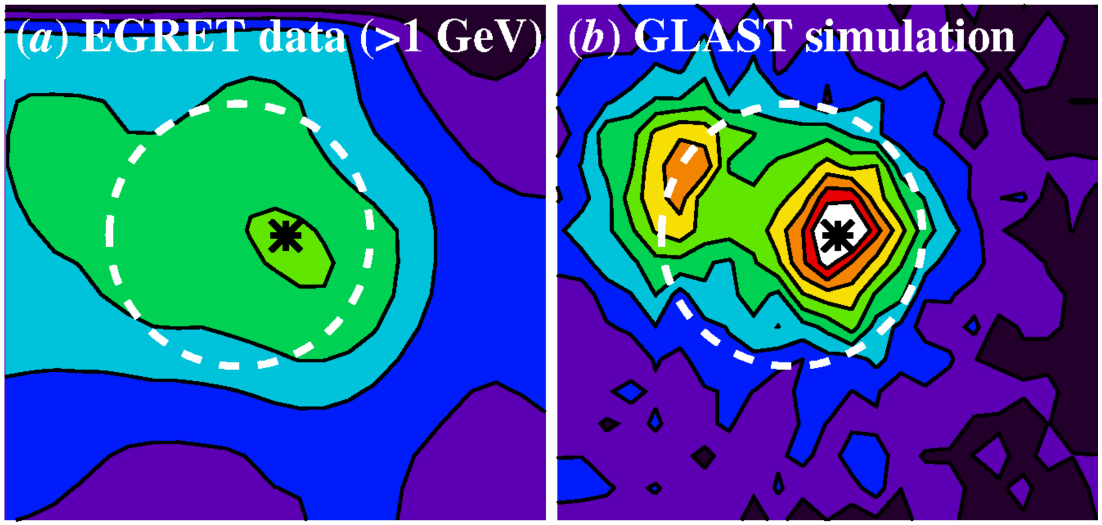


SNR: Spatial Resolution by GLAST

- For SNR candidates, the LAT sensitivity and resolution will allow mapping to separate extended emission from the SNR from possible pulsar components.

- Energy spectra for the two emission components may also differ.

- Resolved images will allow observations at other wavelengths to concentrate on promising directions.



(*a*) Observed (EGRET) and (*b*) simulated LAT (1-yr sky survey) intensity in the vicinity of **γ-Cygni** for energies >1 GeV. The coordinates and scale are the same as in the images of γ-Cygni in the box at left. The dashed circle indicates the radio position of the shell and the asterisk the pulsar candidate proposed by Brazier et al. (1996).

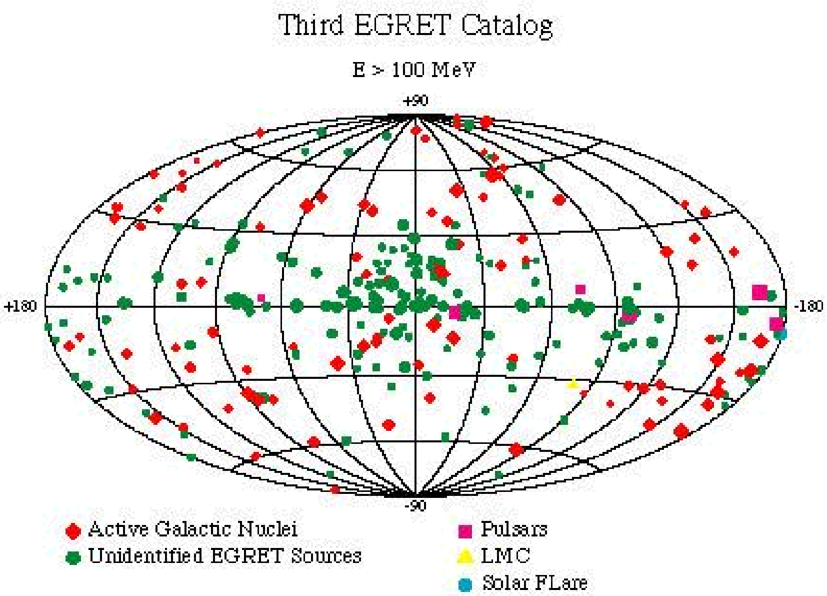
Active Galactic Nuclei

A surprise from EGRET:

detection of dozens of AGN

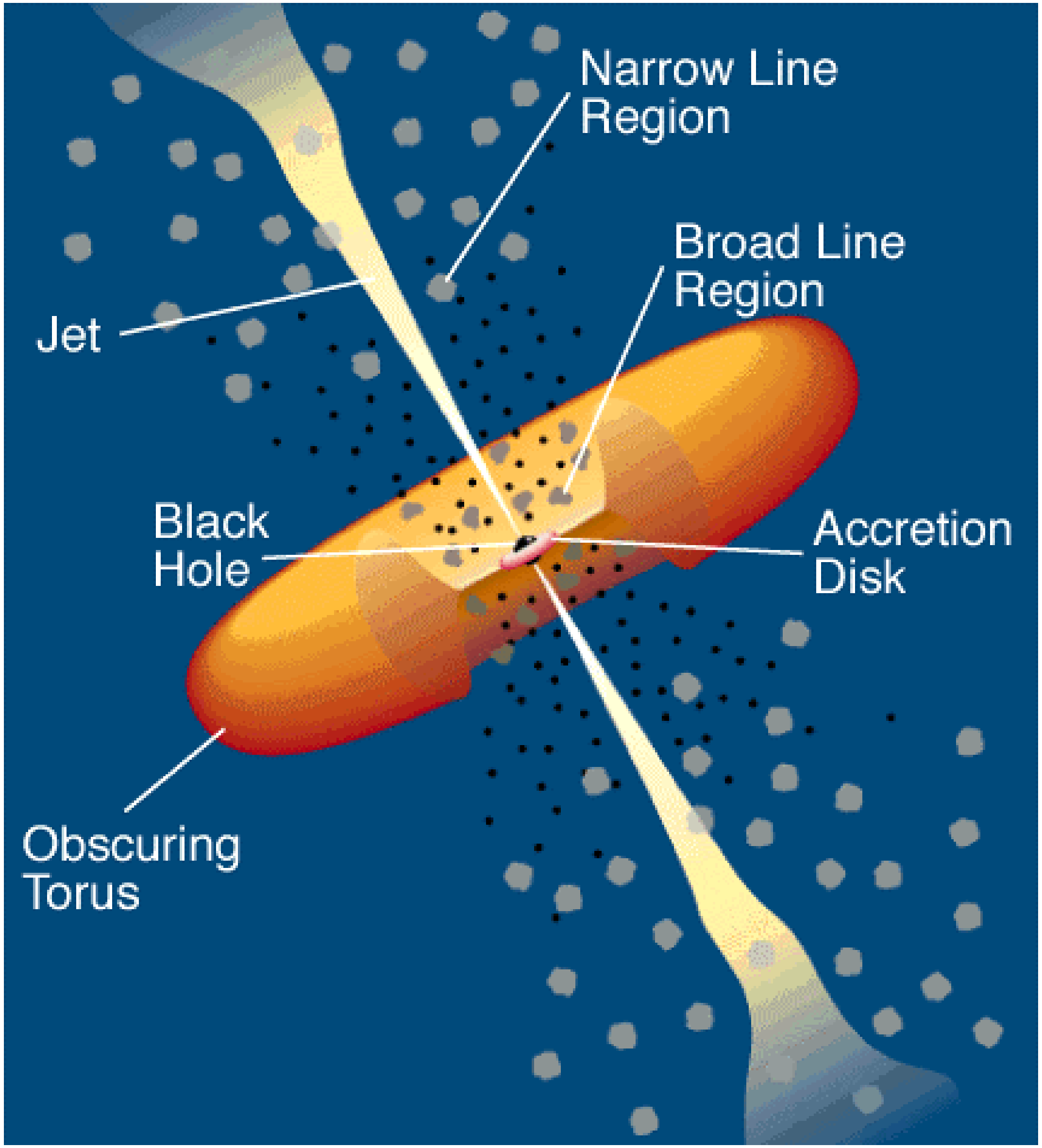
shining brightly in

γ-rays -- Blazars

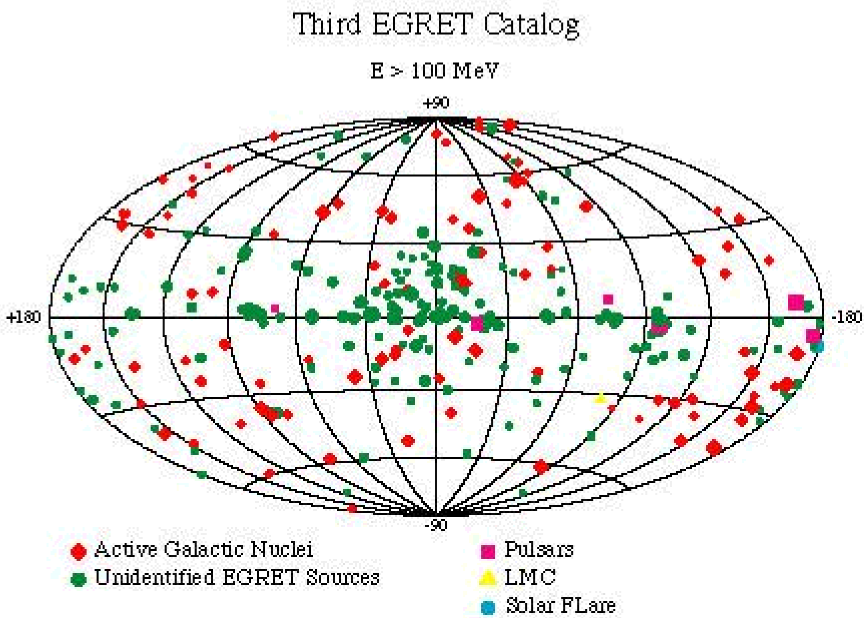


- a key to solving the longstanding puzzle of the extragalactic diffuse gamma flux -- is this integrated emission from a large number of unresolved sources?
- blazars provide a source of high energy γ-rays at cosmological distances. The Universe is largely transparent to γ-rays (any opacity is energy-dependent), so they probe cosmological volumes.

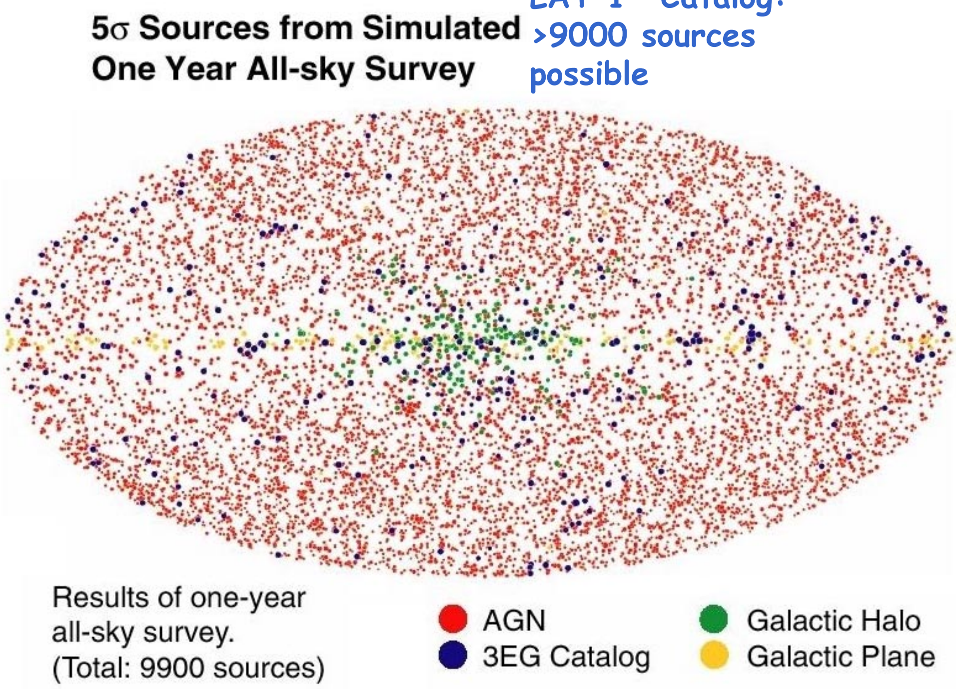
Active Galactic Nuclei



Active Galactic Nuclei



LAT 1st Catalog: >9000 sources possible



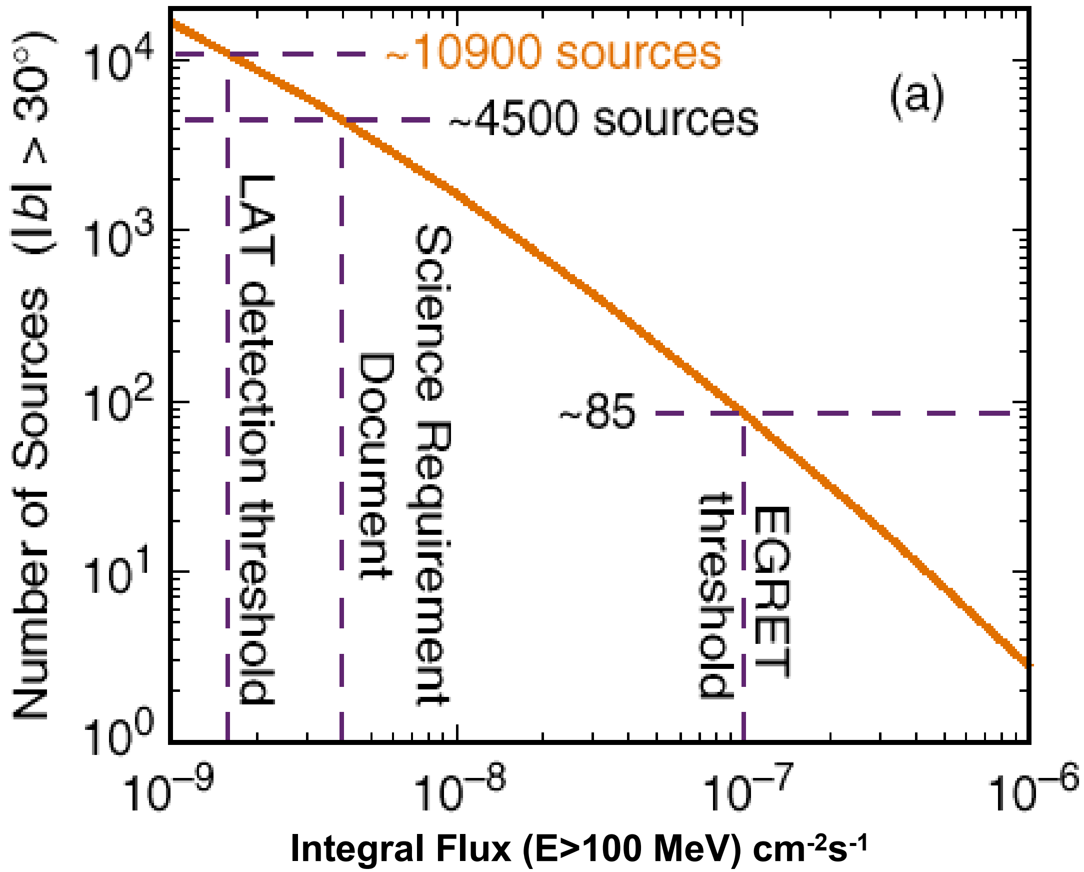
The 271 sources in the third EGRET catalog involved considerable manual processing. The LAT analysis will rely much more heavily on automated processing.

AGN: What GLAST will do

• EGRET detected ~ 70-90 AGN. Extrapolating, GLAST should expect to see dramatically more – many thousands.

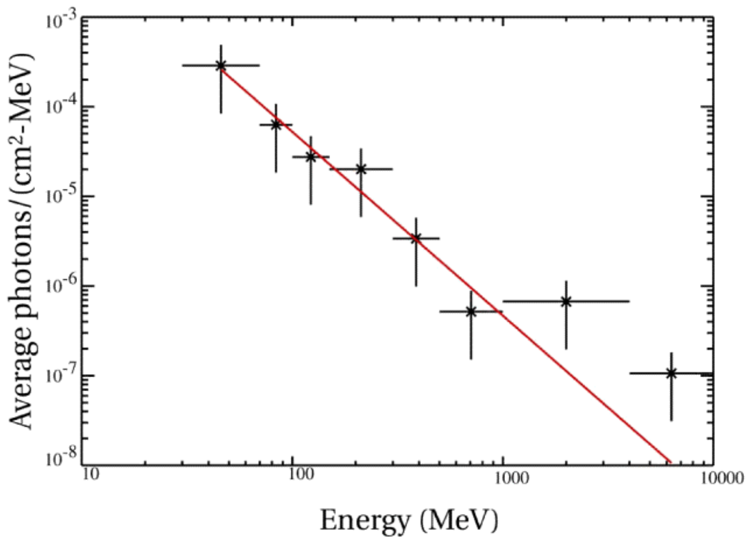
• The GLAST energy range is broad, overlapping those of ground-based experiments for good multiwavelength coverage.

• The wide field of view will allow GLAST to monitor AGN for time variability on many scales.



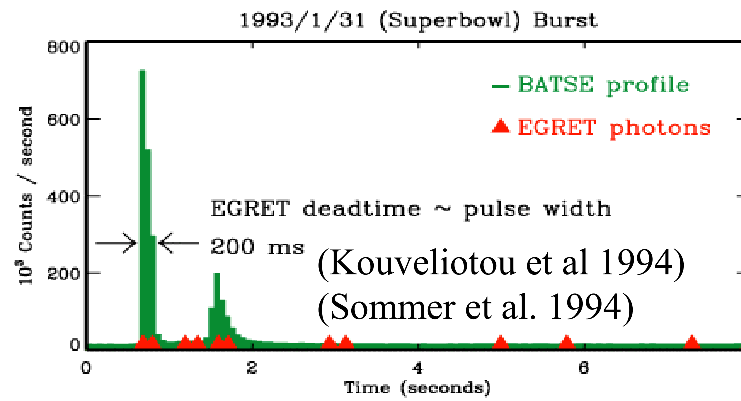
Joining the unique capabilities of GLAST with other detectors will provide a powerful tool.

Gamma-Ray Bursts

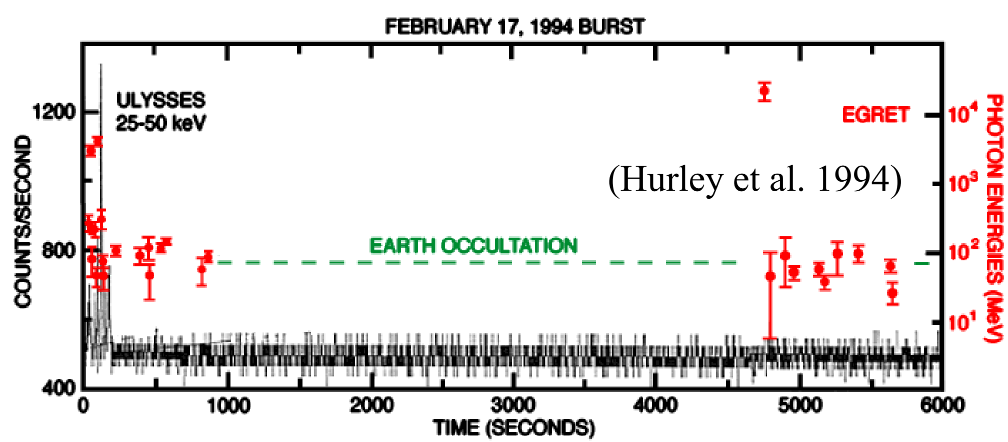


(Dingus et al. 1998)

Prompt Emission (GRB 930131)



Delayed Emission (GRB 940217)

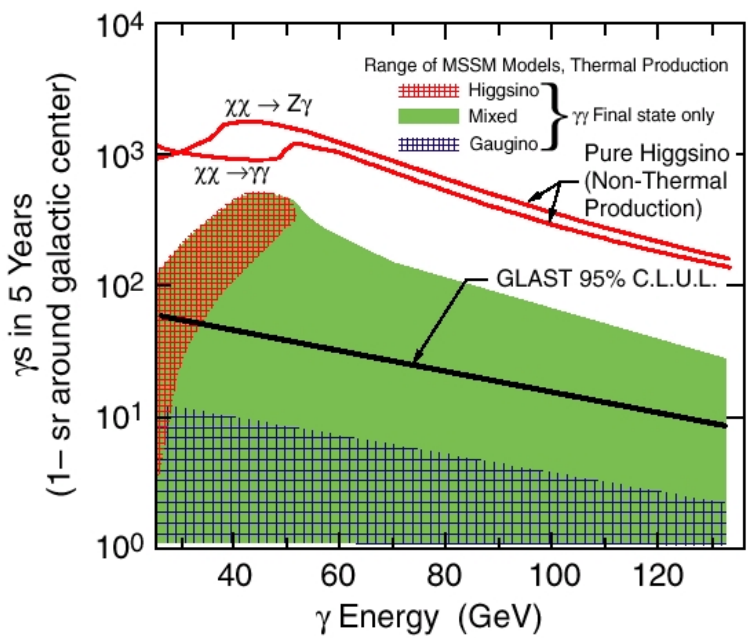


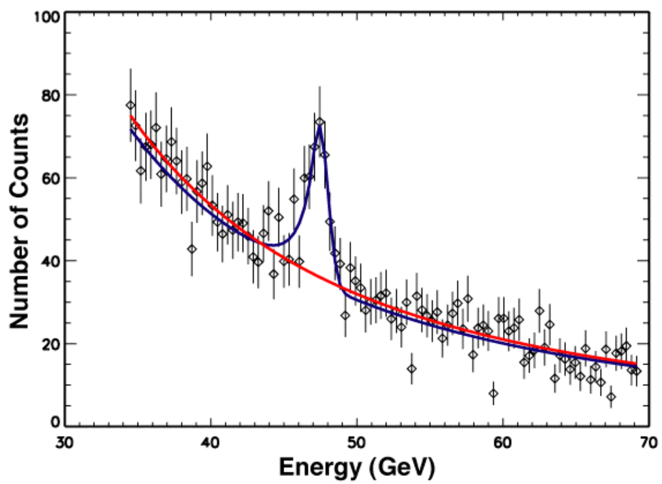
- **EGRET discovered high energy GRB afterglow**
  - **only one burst**
  - **dead time limited observations**
- **GLAST will observe many more high energy afterglows**
  - **strong constraint to GRB models**

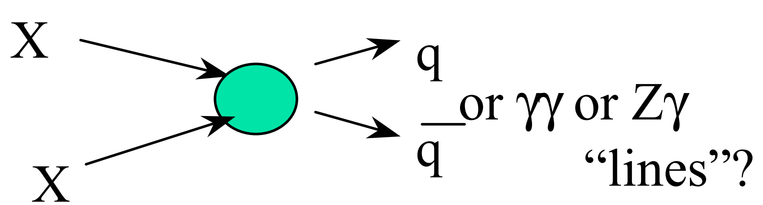
Dark Matter

If the SUSY LSP is the galactic dark matter there may be observable halo annihilations into mono-energetic gamma rays.

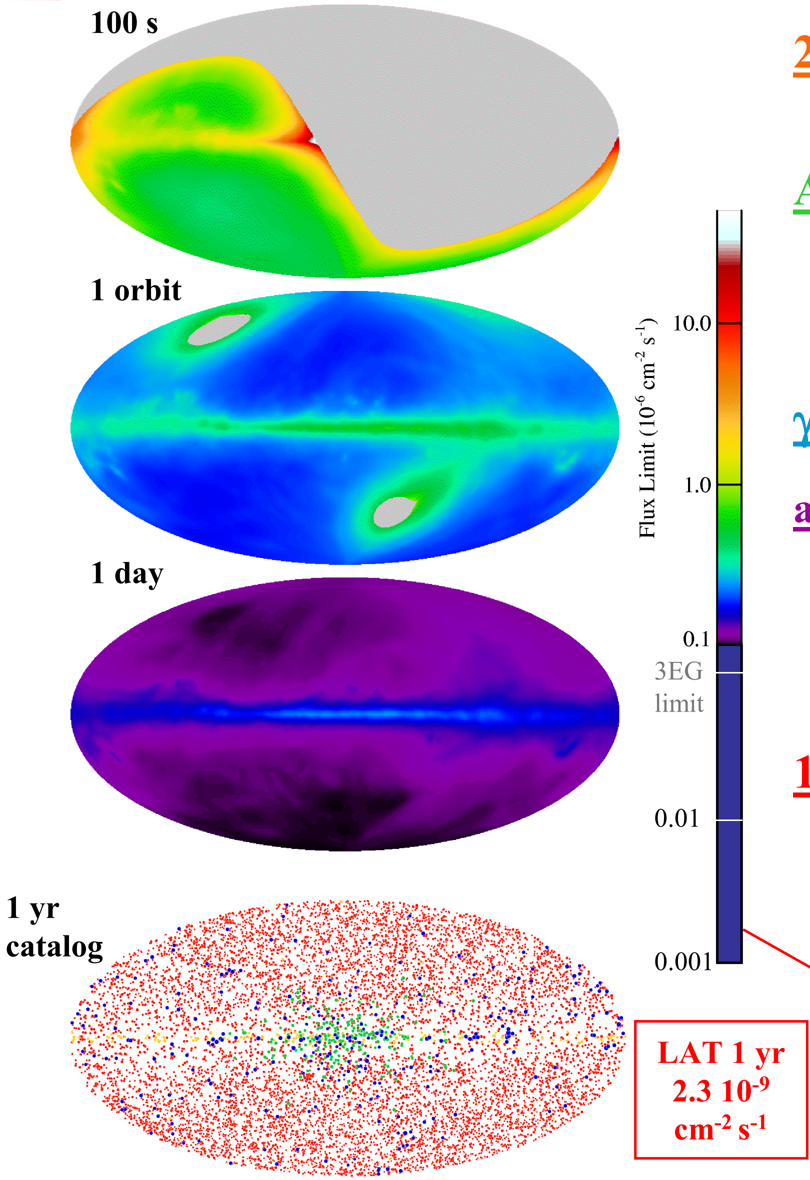
- Constrain cold dark matter candidates
- Identify relatively narrow spectral lines







GLAST science capability



200 γ bursts per year

⇒ **prompt emission sampled to > 20 μs**

AGN flares > 2 mn

⇒ **time profile + ΔE/E ⇒ physics of jets and acceleration**

γ bursts delayed emission

all 3EG sources + 80 new in 2 days

⇒ **periodicity searches (pulsars & X-ray binaries)**

⇒ **pulsar beam & emission vs. luminosity, age, B**

10^4 sources in 1-yr survey

⇒ **AGN: logN-logS, duty cycle, emission vs. type, redshift, aspect angle**

⇒ **extragalactic background light (γ + IR-opt)**

⇒ **new γ sources (μQSO,external galaxies,clusters)**

GLAST science requirements

Quantity	*EGRET*	*GLAST Requirement*	*GLAST Goal*	*Science Driver*
Energy Range	20 MeV - 30 GeV	20 MeV - 300 GeV	10 MeV - > 300 GeV	ALL
Energy Resolution	10%	10% (100 MeV - 10 GeV)[1]	2% (E > 10 GeV)	ALL
Effective Area[2]	1500 cm^2	8000 cm^2	> 10,000 cm^2	ALL
Single Photon Angular Resolution - 68%[3] (on-axis)	5.8° (@100 MeV)	< 3.5° (@100 MeV) < 0.15° (E > 10 GeV)	< 2° (@ 100 MeV) < 0.1° (E > 10 GeV)	ALL
Single Photon Angular Resolution - 95%[3] (on-axis)		< 3 x $\theta_{68\%}$	2 x $\theta_{68\%}$	ALL
Single Photon Angular Resolution (off-axis at FWHM of FOV)		< 1.7 times on-axis	< 1.5 times on-axis	ALL
Field of View[4]	0.5 sr	2 sr	> 3 sr	ALL

GLAST science requirements

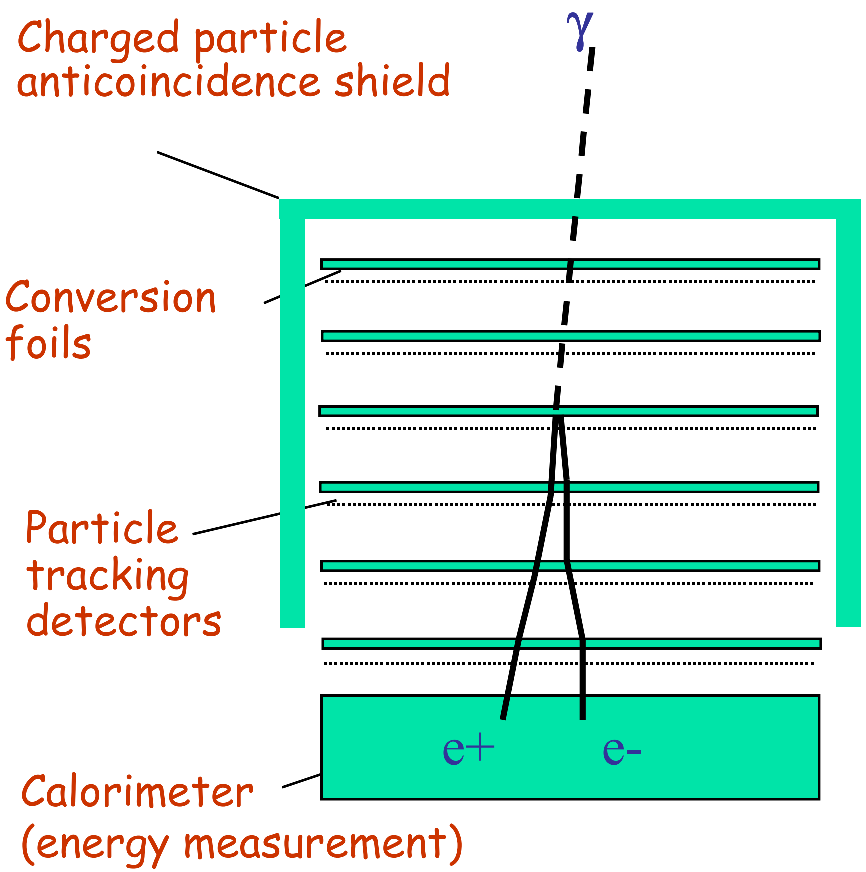
Quantity	***EGRET***	***GLAST Requirement***	***GLAST Goal***	***Science Driver***
Source Location[5,8] Determination	5 - 30 arcmin	1 - 5 arcmin	30 arcsec - 5 arcmin	Unidentified EGRET Sources, GRBs
Point Source Sensitivity[6,8] (> 100 MeV)	~ 1×10^{-7} cm^{-2} s^{-1}	4×10^{-9} cm^{-2} s^{-1}	< 2×10^{-9} cm^{-2} s^{-1}	AGN, Unidentifieds, Pulsars, GRBs
Time Accuracy	0.1 ms	10 μsec absolute[7]	2 μsec absolute[7]	Pulsars, GRBs
Background Rejection	> 10^6:1	> 10^5:1	> 10^6:1	ALL, Especially Diffuse
Dead Time	100 ms/event	< 100 μs/event	< 10% instrument ave. for bursts up to 10 kHz (< 20 μs/event)	GRBs
Transients			Complementary low-energy observations, Trigger and location for S/C repointing, High efficiency recognition and reconstruction of multi-γ events	GRBs, Primordial BHs

Gamma-Ray Experiments

- AGILE
- GLAST

γ detection technique – pair conversion telescope

Pair production is the dominant photon interaction above 10MeV:



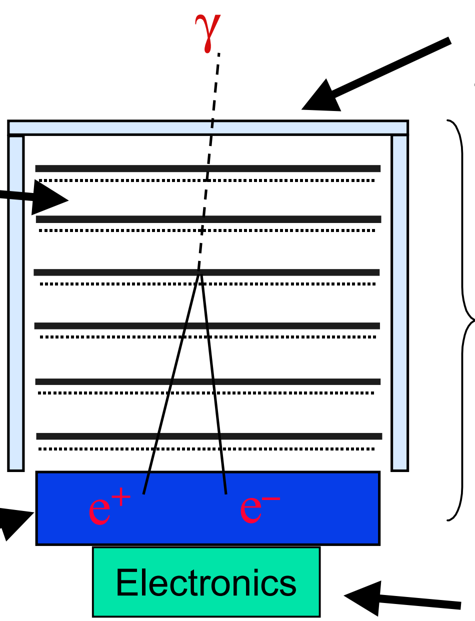
Detector Concept

- Low profile for wide f.o.v.
- Segmented anti-shield to minimize self-veto at high E.
- Finely segment calorimeter for enhanced background rejection and shower leakage correction.
- High-efficiency, precise track detectors located close to the conversions foils to minimize multiple-scattering errors.
- Modular, redundant design.
- No consumables.
- Low power consumption (580 W)

Science Drivers on Instrument Design

Effective area and PSF requirements drive the converter thicknesses and layout. PSF requirements also drive the sensor performance, layer spacings, and drive the design of the mechanical supports.

Background rejection requirements drive the ACD design (and influence the calorimeter and tracker layouts).



Field of view sets the aspect ratio (height/width)

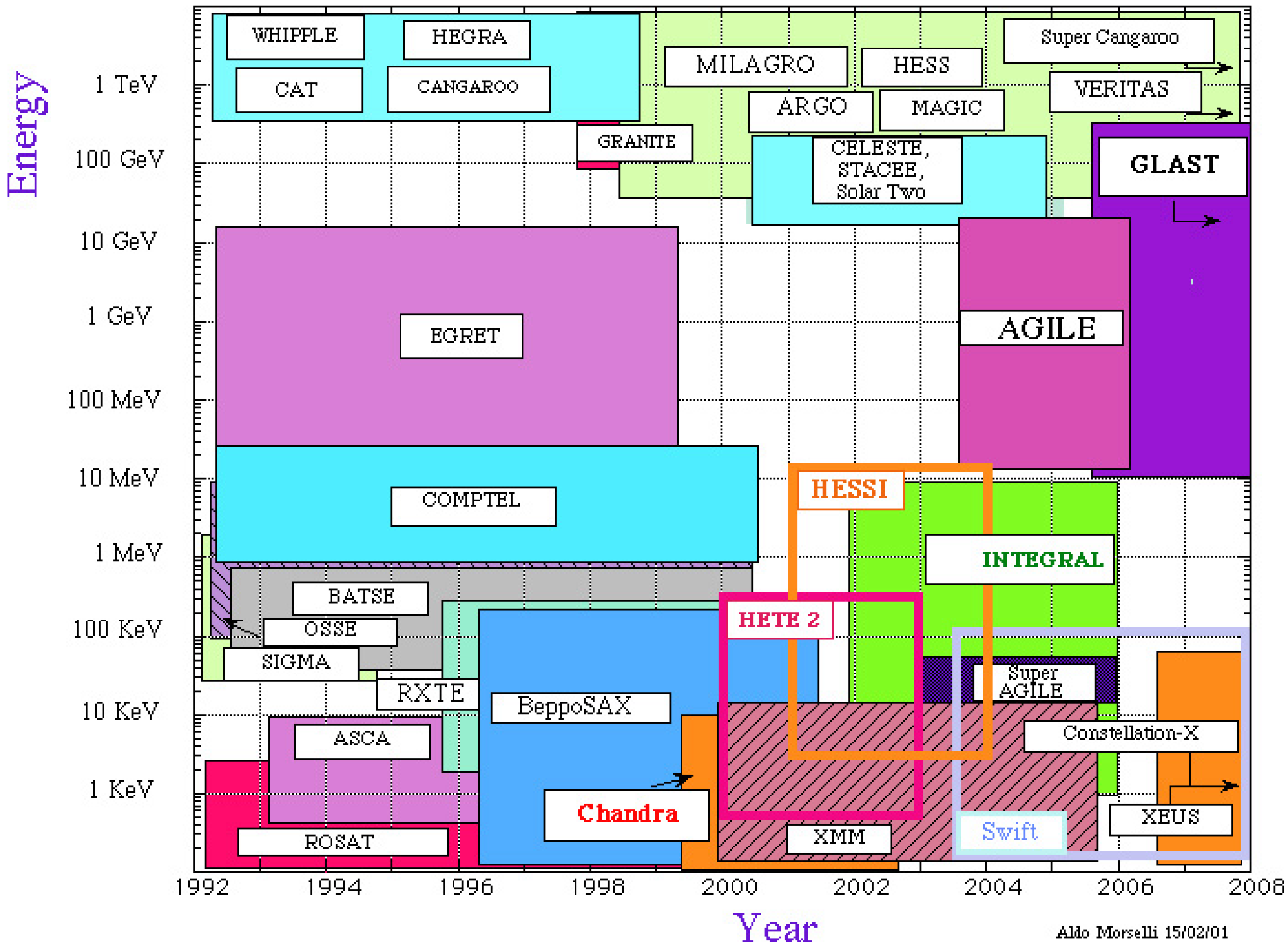
Energy range and energy resolution requirements bound the thickness of calorimeter

Time accuracy provided by electronics and intrinsic resolution of the sensors.

On-board transient detection requirements, and on-board background rejection to meet telemetry requirements, are relevant to the electronics, processing, flight software, and trigger design.

Instrument life has an impact on detector technology choices.
Derived requirements (source location determination and point source sensitivity) are a result of the overall system performance.

New Satellites



AGILE Mission

- AGILE is an ASI Small Scientific Mission dedicated to gamma-ray astrophysics
- (Imaging 30 MeV-50 GeV, 10-40 keV)
- Planned to be operational in 2004
- Only mission entirely dedicated to gamma-ray astrophysics (E>30 MeV) during the period 2004-2006
- Emphasis to rapid reaction to transients
- Multiwavelength follow-up program
- Small Mission with a Guest Observer Program

AGILE team

M.Tavani[1], G.Barbiellini[2], A.Argan[1], N.Auricchio[3], A.Bulgarelli[3], P.Caraveo[1], E.Celesti[3], A.Chen[1]‡, V.Cocco[4], E.Costa[5], E.Del Monte[5], G.Di Cocco[3], G.Fedel[2], M.Feroci[5], M.Fiorini[1], T.Froysland[4]‡, M.Galli[6], F.Gianotti[3], A.Giuliani[1]‡, C.Labanti[3], I.Lapshov[5], F.Lazzarotto[5]‡, P.Lipari[7], F.Longo[2], M.Marisaldi[3], E.Mattaini[1]‡, S.Mereghetti[1], E.Morelli[3], A.Morselli[4], L.Pacciani[5], F.Paladin[2]‡, A.Pellizzoni[1], F.Perotti[1], P.Picozza[4], C.Pittori[4], C.Pontoni[2]‡, G.Porrovecchio[5], B.Preger[5]‡, M.Prest[2], M.Rapisarda[5], E.Rossi[3], A.Rubini[5], P.Soffitta[5], M.Trifoglio[3], E.Vallazza[2], S.Vercellone[1], D.Zanello[7]

(1) IASF/CNR Milano

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(4) IASF/CNR Sezione di Roma

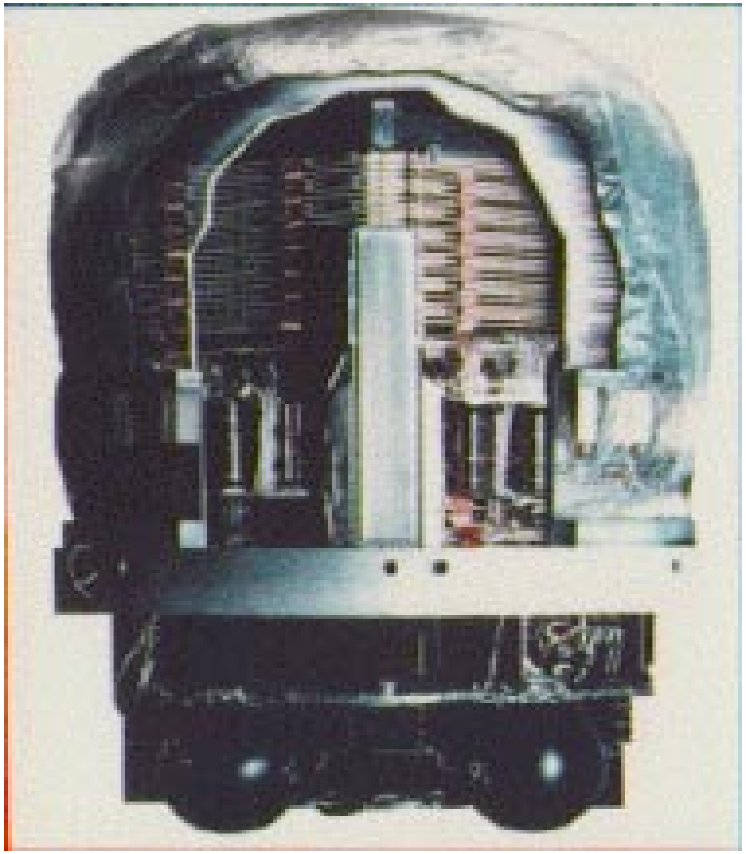
(5) INFN Roma-1 and University "La Sapienza", Roma

(6) ENEA, Bologna

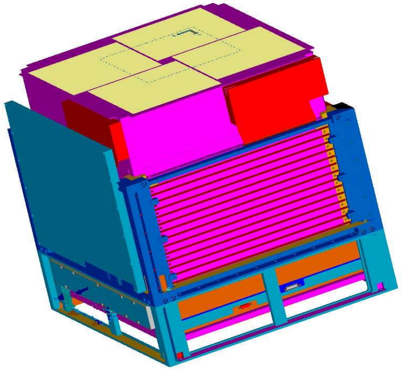
(7) INFN Roma-2 and University "Tor Vergata", Roma

‡ Consorzio Interuniversitario di Fisica Spaziale

EGRET and AGILE



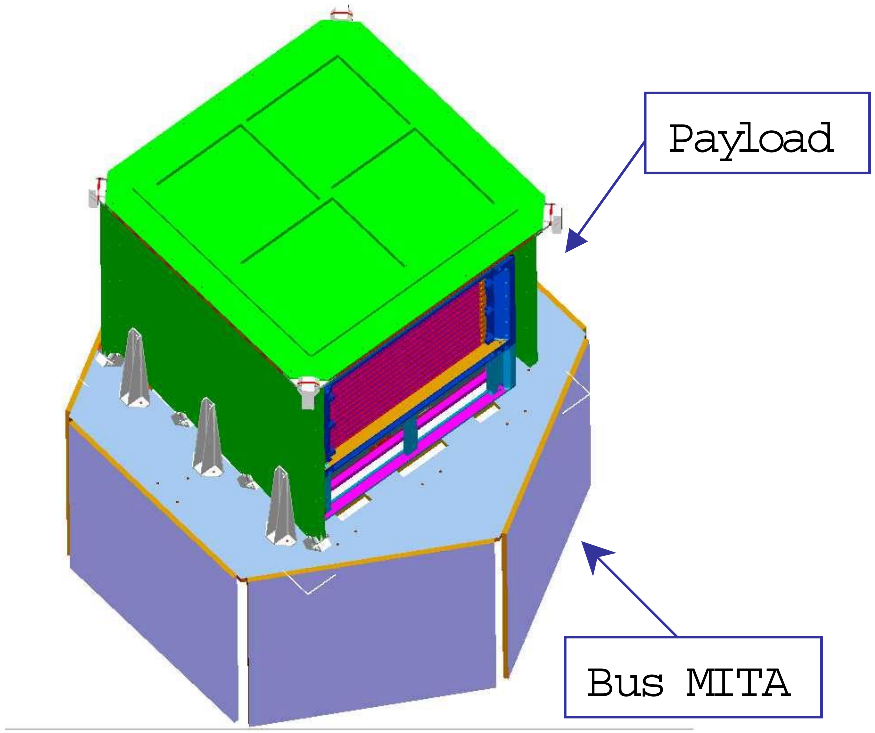
EGRET

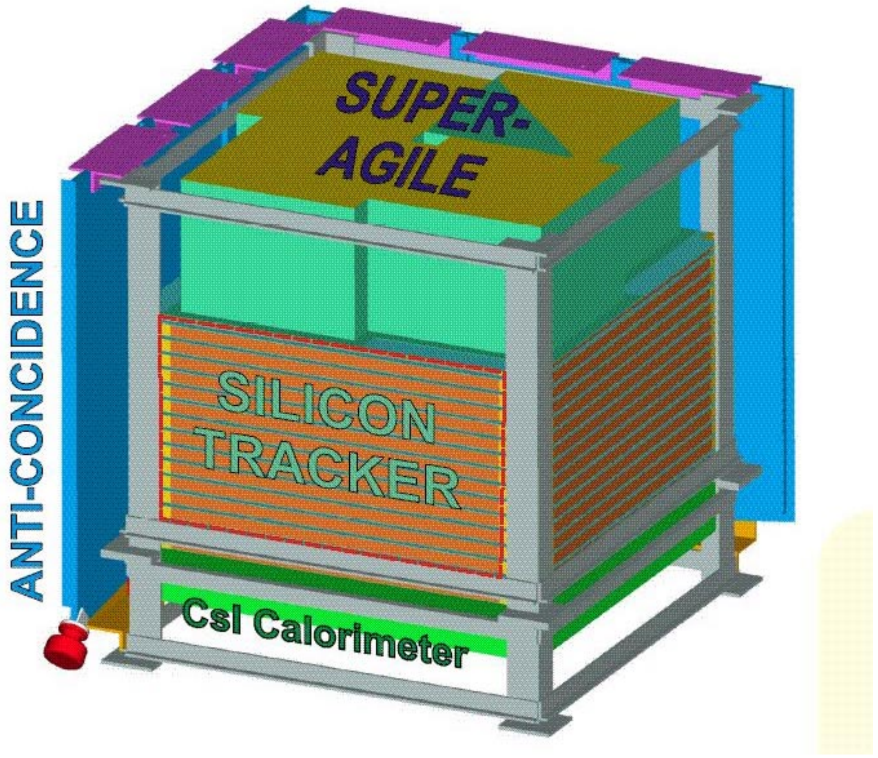


AGILE

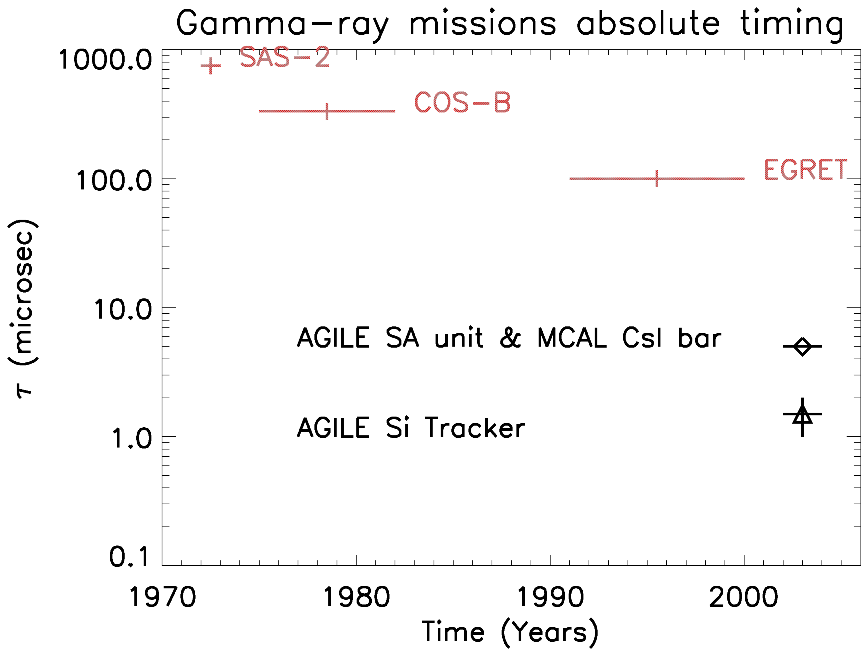
	EGRET	AGILE
Mass	1830 kg	100 kg
Field of View	0.15 π	0.8 π
Dead Time	100 ms	0.1 ms
Energy Range	0.03- 30 GeV	0.03 - 50 GeV
		10 - 40 keV

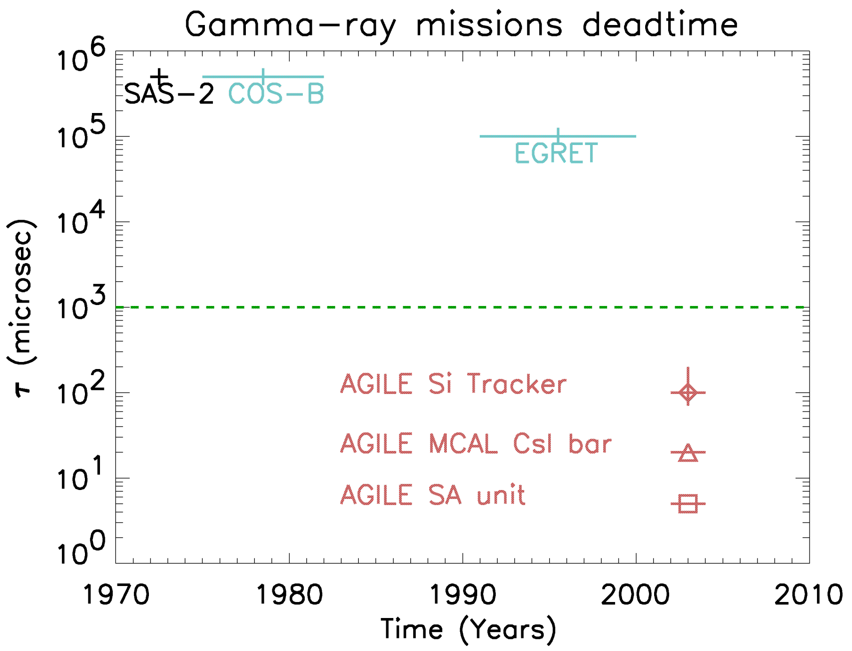
AGILE Instrument





AGILE Scientific Performances

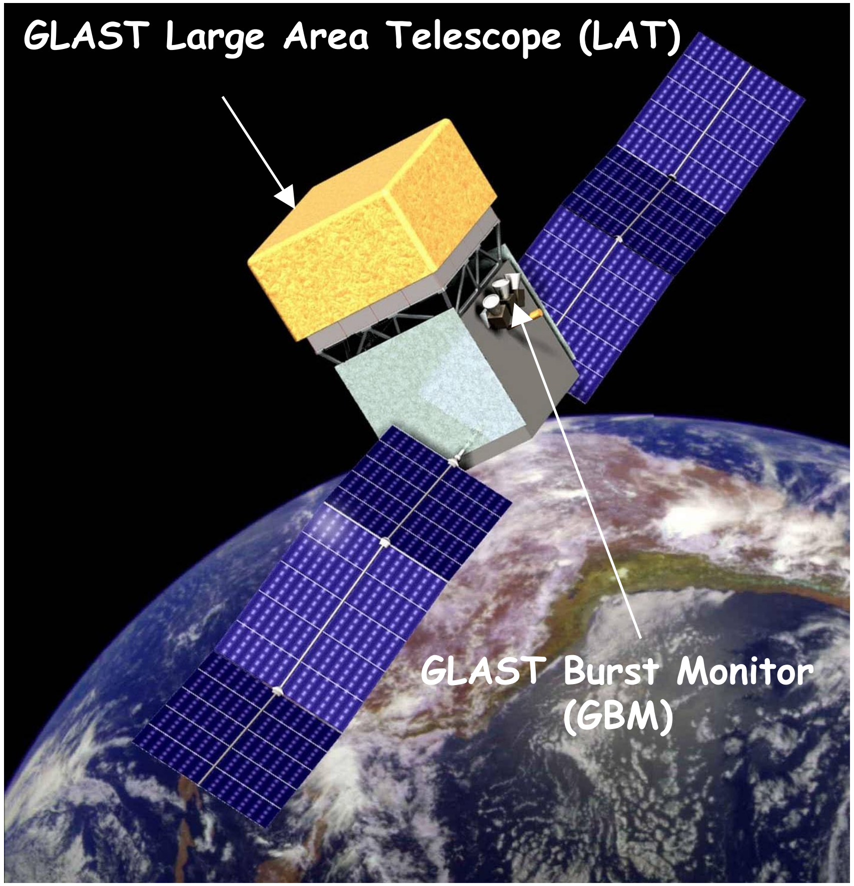




Fast Timing Capability

GLAST – Basic Information

GLAST: Gamma-ray Large Area Space Telescope is the observatory, not the instruments.



Two GLAST instruments:

LAT: 20 MeV – >300 GeV
(LAT was originally called GLAST by itself)

GBM: 10 keV – 25 MeV

Launch: September 2006

Lifetime: 5 years minimum

GLAST High Energy Capabilities

- Huge FOV (~20% of sky)
- Broadband (4 decades in energy, including unexplored region > 10 GeV)
- Unprecedented PSF for gamma rays (factor > 3 better than EGRET for E>1 GeV)
- Large effective area (factor > 4 better than EGRET)
- **Results in factor > 30-100 improvement in sensitivity**
- No expendables ⟶ long mission without degradation

GLAST LAT Collaboration

United States

- California State University at Sonoma
- University of California at Santa Cruz - Santa Cruz Institute of Particle Physics
- Goddard Space Flight Center – Laboratory for High Energy Astrophysics
- Naval Research Laboratory
- Stanford University – Hanson Experimental Physics Laboratory
- Stanford University - Stanford Linear Accelerator Center
- Texas A&M University – Kingsville
- University of Washington
- Washington University, St. Louis

France

- Centre National de la Recherche Scientifique / Institut National de Physique Nucléaire et de Physique des Particules
- Commissariat à l'Energie Atomique / Direction des Sciences de la Matière/ Départment d'Astrophysique, de physique des Particules, de physique Nucléaire et de l'Instrumentation Associée

Italy

- Istituto Nazionale di Fisica Nucleare
- Istituto di Fisica Cosmica, CNR (Milan)

Japanese GLAST Collaboration

- Hiroshima University
- Institute for Space and Astronautical Science
- RIKEN

Swedish GLAST Collaboration

- Royal Institute of Technology (KTH)
- Stockholm University

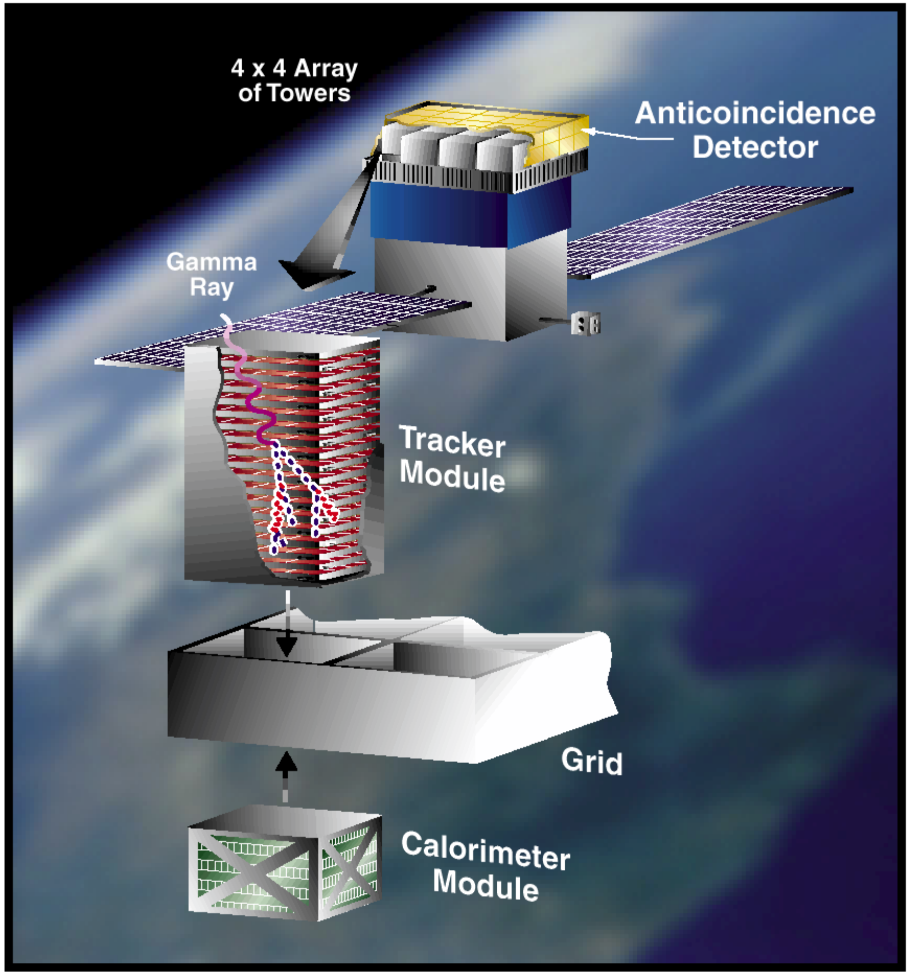
124 Members (including 60 Affiliated Scientists)

16 Postdoctoral Students

26 Graduate Students

Overview of LAT

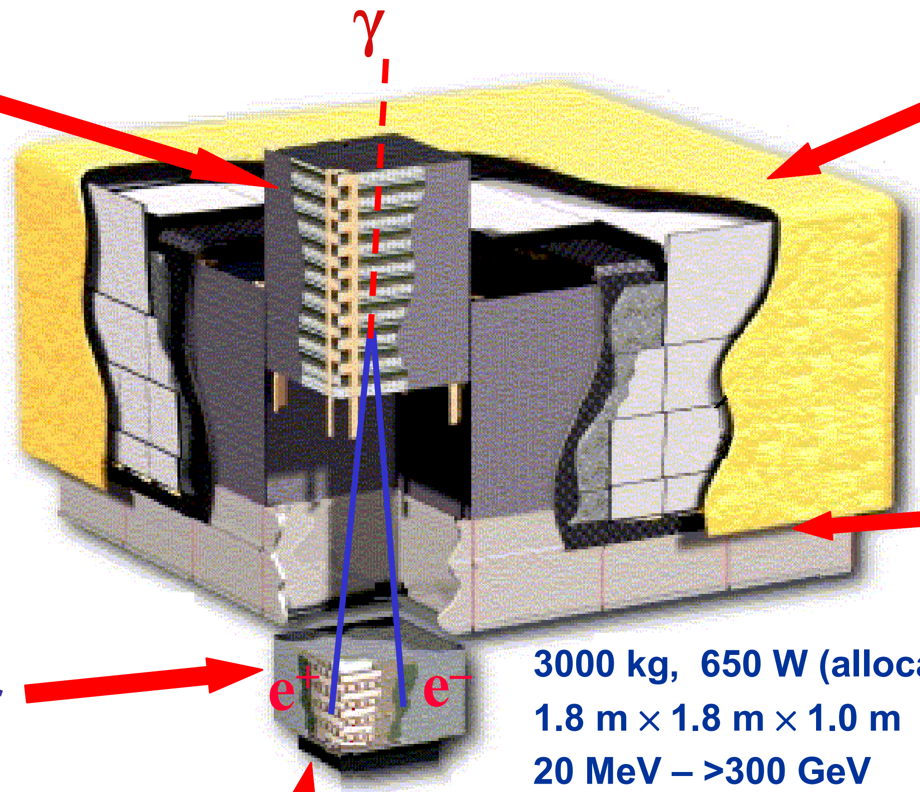
- **4x4 array of identical towers** Advantages of modular design.
- **Precision Si-strip Tracker (TKR)** Detectors and converters arranged in 18 XY tracking planes. Measure the photon direction.
- **Hodoscopic CsI Calorimeter(CAL)** Segmented array of CsI(Tl) crystals. Measure the photon energy.
- **Segmented Anticoincidence Detector (ACD)** First step in reducing the large background of charged cosmic rays. Segmentation removes self-veto effects at high energy.
- **Electronics System** Includes flexible, highly-efficient, multi-level trigger.



Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

GLAST LAT Overview: Design

Si Tracker
pitch = 228 µm
8.8 10^5 channels
12 layers × 3% X_0
+ 4 layers × 18% X_0
+ 2 layers



ACD
Segmented scintillator tiles
0.9997 efficiency
⇒ minimize self-veto

Grid (& Thermal Radiators)

3000 kg, 650 W (allocation)
1.8 m × 1.8 m × 1.0 m
20 MeV – >300 GeV

LAT managed at SLAC

CsI Calorimeter
Hodoscopic array
8.4 X_0 8 × 12 bars
2.0 × 2.7 × 33.6 cm
⇒ cosmic-ray rejection
⇒ shower leakage correction

Data acquisition

Flight Hardware & Spares
16 Tracker Flight Modules + 2 spares
16 Calorimeter Modules + 2 spares
1 Flight Anticoincidence Detector
Data Acquisition Electronics + Flight Software

Simulation requirements and implementation

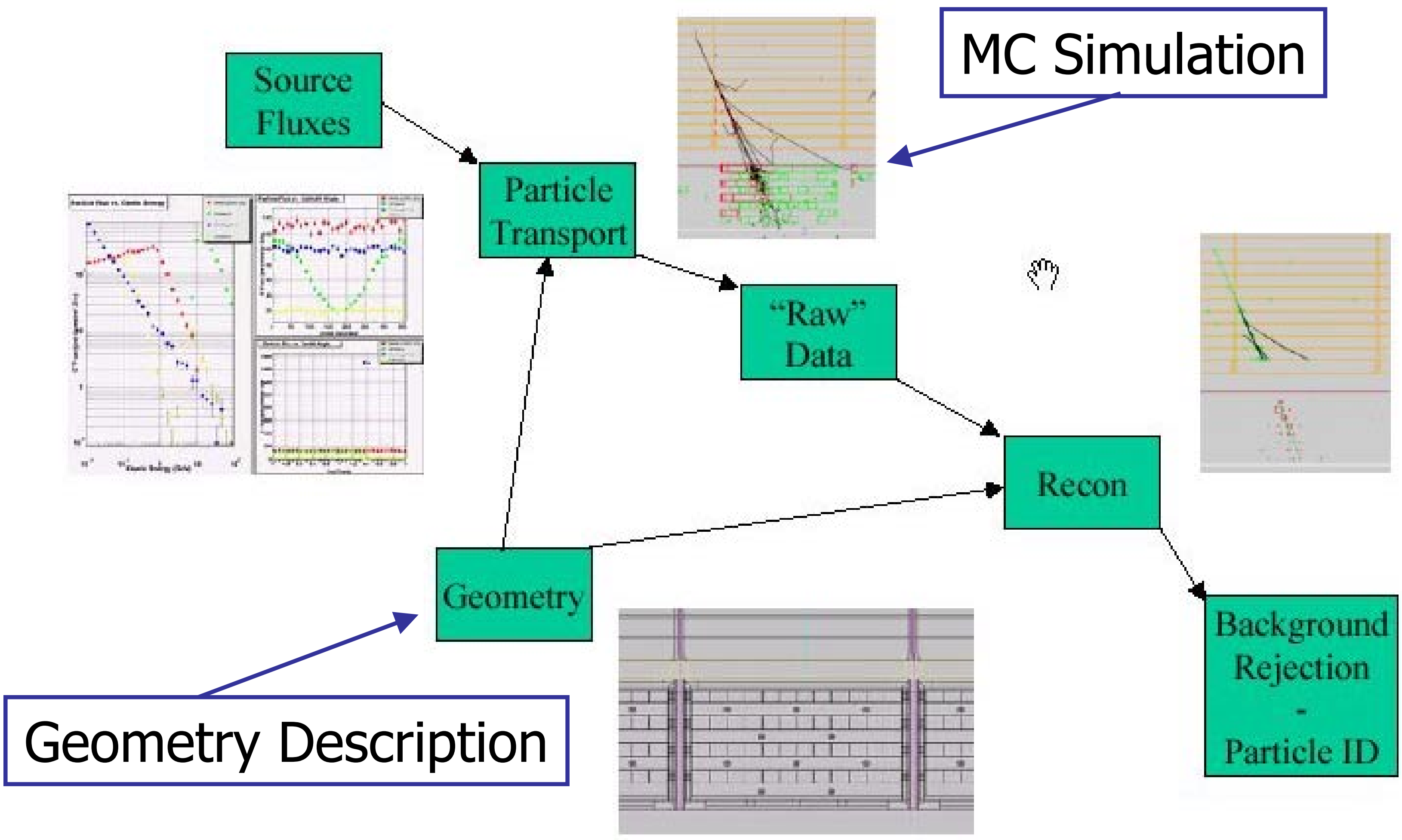
- AGILE G3 baseline and G4 prototype
- GLAST LAT MC Simulation (from Gismo to G4)

SW: general requirements

- Quantitative estimate of project development on scientific performances.
- Background modelling and rejection
- Analysis of Photon performances (PSF, Effective area, Energy resolution, Transients study)
- Scientific parameters for ground analysis

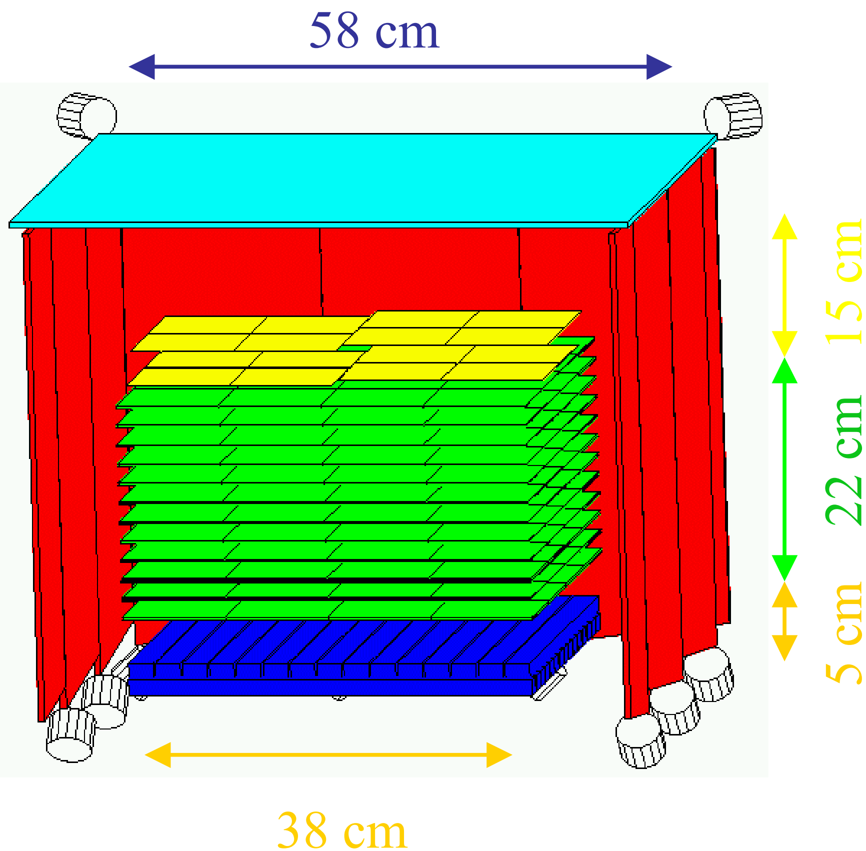
- *Technical requirements*
  - *Modularity*
  - *Documentation*
  - *Mantenaince*
  - *Development*

General requirements for HE gamma simulations



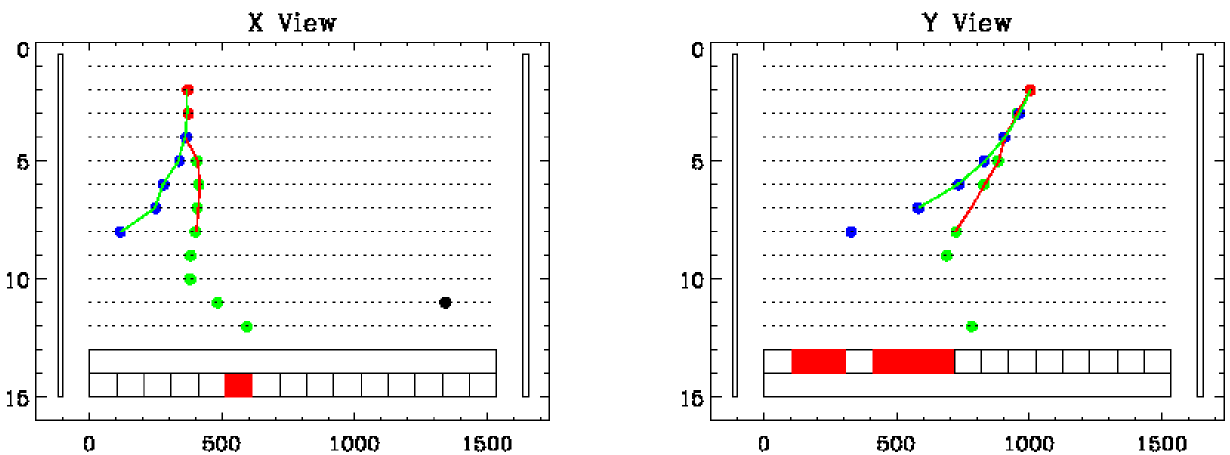
AGILE payload

- Top Anticoincidence
- Lateral Anticoincidence
  (4 x 3 panels)
- Super-AGILE (4 Si detectors): ultra-light coded mask system for hard X-ray detection
- Gamma-ray Silicon Tracker
  (12 planes, on-axis ≈ 0.8 X_0)
- Mini-Calorimeter
  (15+15 CsI bars, on-axis ≈ 1.5 X_0)



http://agile.mi.iasf.cnr.it

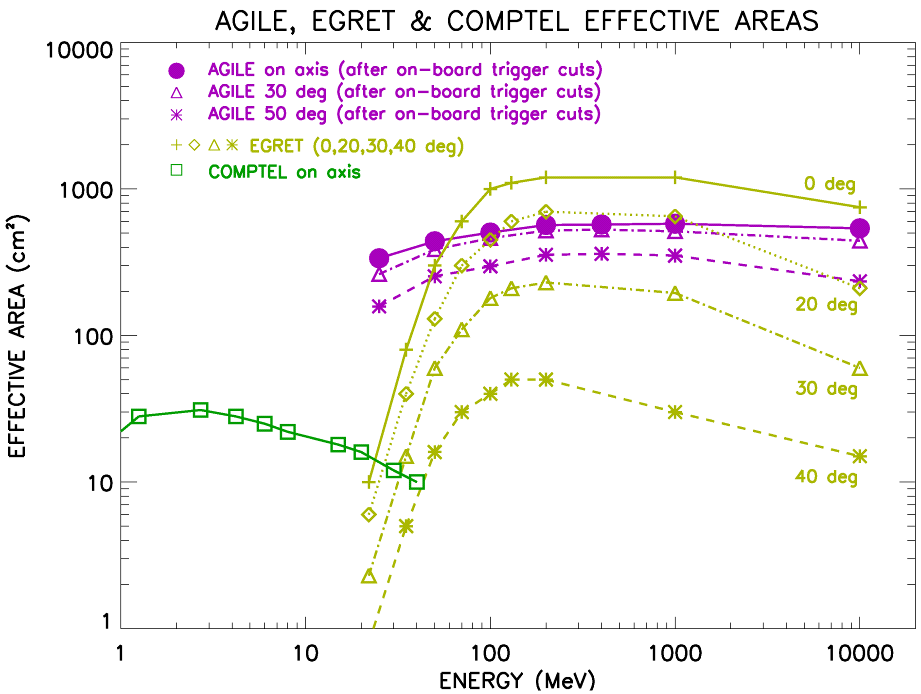
Simulated Gamma-Ray (E=100 MeV, θ=30º)

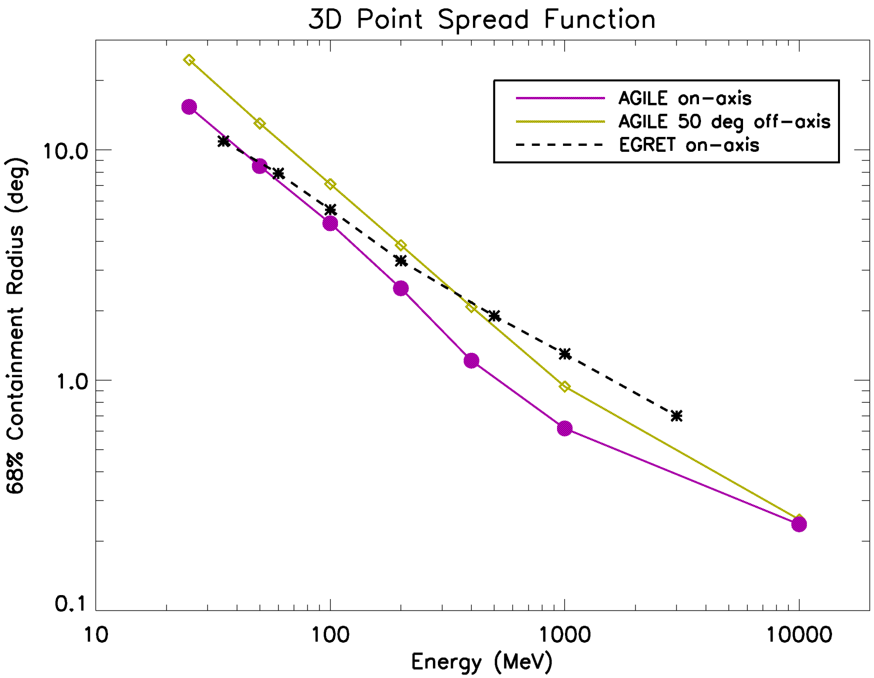


Cluster (Plane)	Center (Strip)	Cluster Charge (MIP)
2	371	1.98020
3	373	3.65160
4	365	5.94130
5	338	3.64600
5	404	1.64040
6	279	1.66700
6	412	1.61930
7	249	4.52440
7	406	1.42130
8	116	17.6118
8	399	1.27680
9	381	1.11450
10	380	1.95450
11	482	5.10660
11	1342	1.53360
12	593	1.77060

Cluster (Plane)	Center (Strip)	Cluster Charge (MIP)
2	1004	2.94580
3	952	1.53640
3	962	1.14200
4	905	10.4424
5	830	1.94460
5	882	1.71970
6	733	5.06380
6	828	1.33220
7	581	4.31720
8	327	18.2392
8	723	1.23720
9	688	1.45900
12	782	2.19340

AGILE Scientific Performances

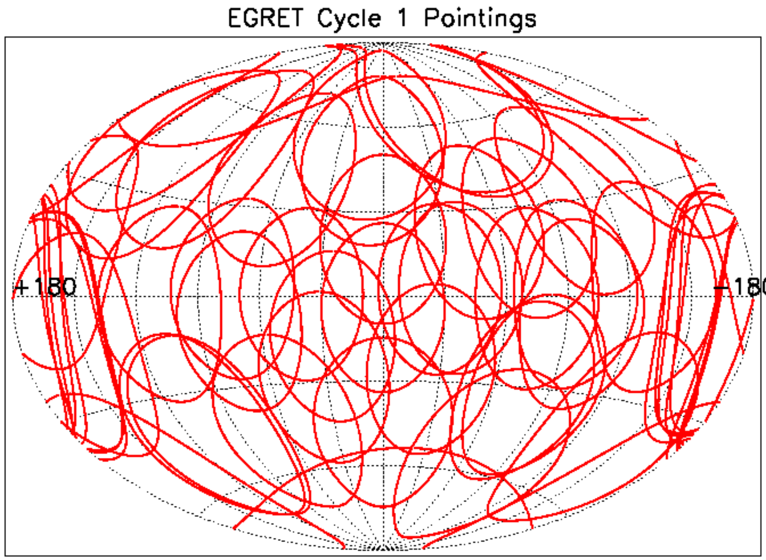


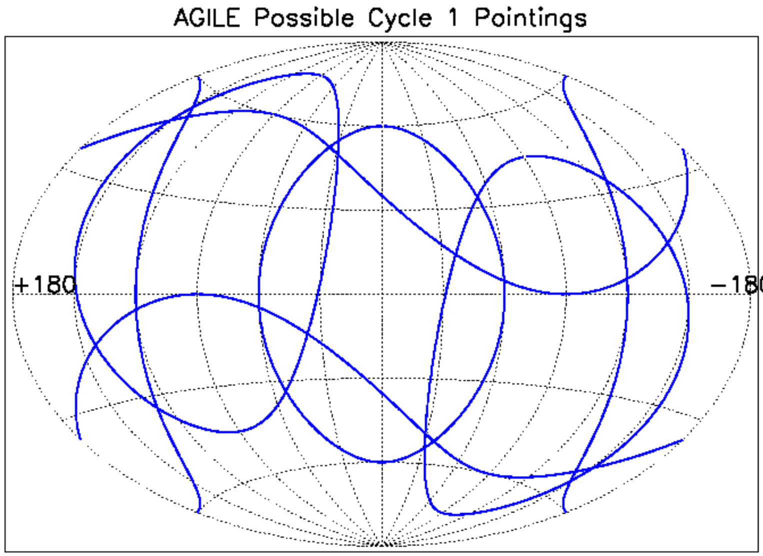


Effective Area

3D PSF

AGILE Scientific Performances





EGRET FoV

AGILE FoV

Trigger Levels

Level-1

- Hardware Implementation
- Information from Silicon Tracker and AC panels
- Track topology at the ‘chip’ level

Level-2

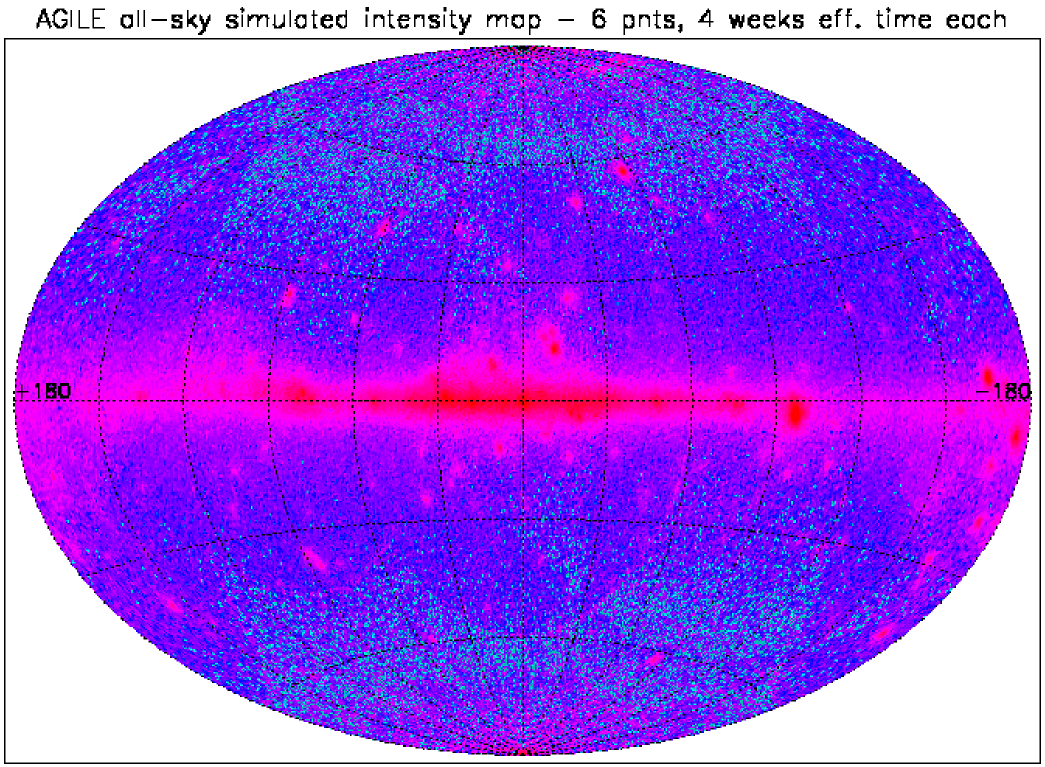
- Software Implementation
- Analog Information on the released charge in the Si-microstrips
- Track topology at the ‘cluster’ level
- 3D-reconstruction to reject albedo photons

SUMMARY OF ON-BOARD BACKGROUND REJECTION

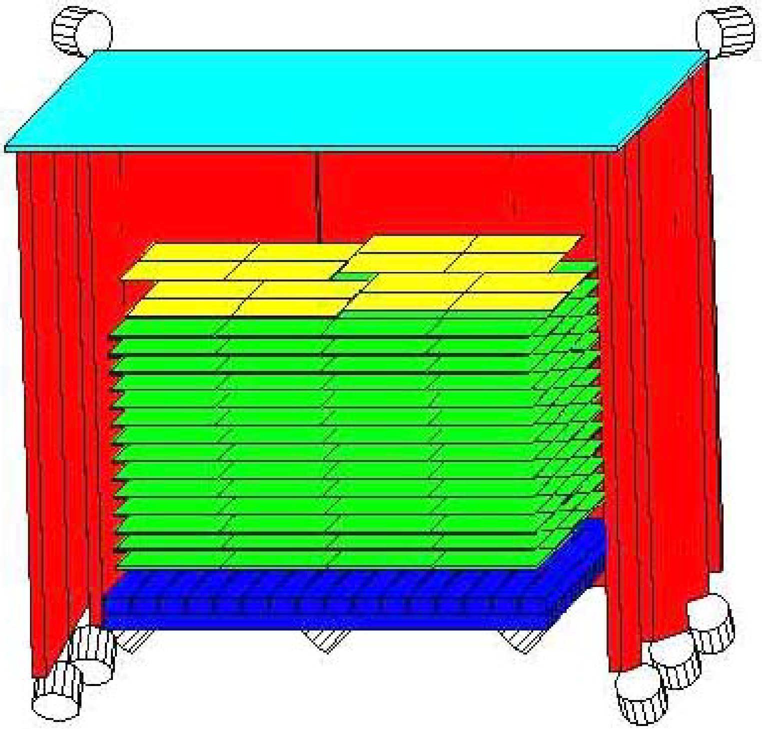
- Expected total rate of particle/albedo-photon entering into the Tracker volume — 2-3 KHz
- Level-1Trigger cut — ≤100 Hz
- Level-2 processing cut — 20-30 Hz

On-board Background Rejection : $\sim 10^{-2}$

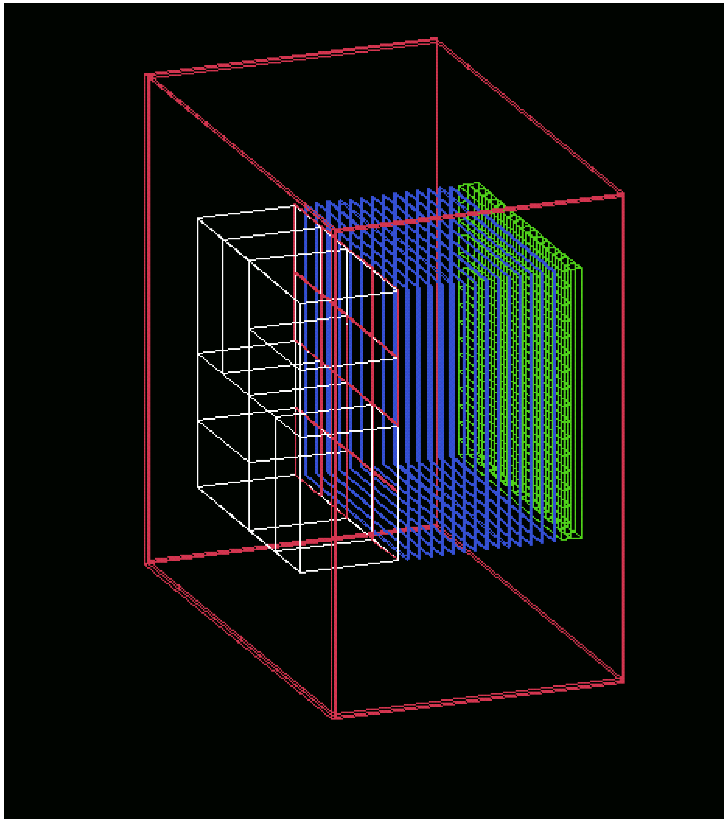
AGILE Simulated all-sky intensity map



AGILE simulation



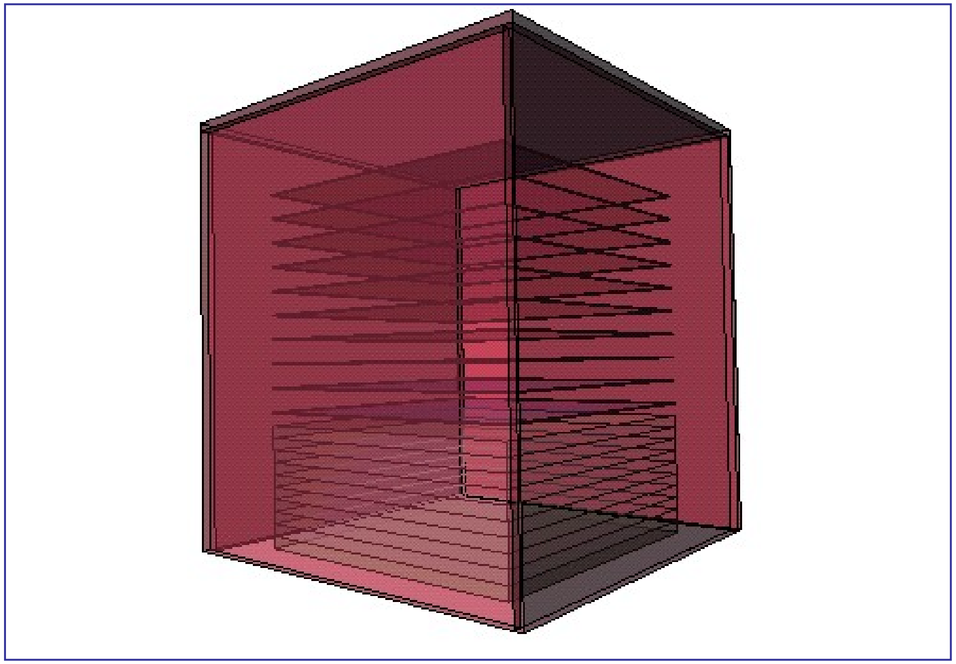
GEANT3 full simulation



G4 preliminary prototype

G4 Advanced examples

- Two are relevant for astrophysics:
  - xray_telescope, illustrating an application for the study of the radiation background in a typical X-ray telescope
  - gammaray_telescope, illustrating a detector “a la AGILE/GLAST”
- EM physics
- Typical GammaRay detectors (TRK, CAL, ACD)
- Source generation



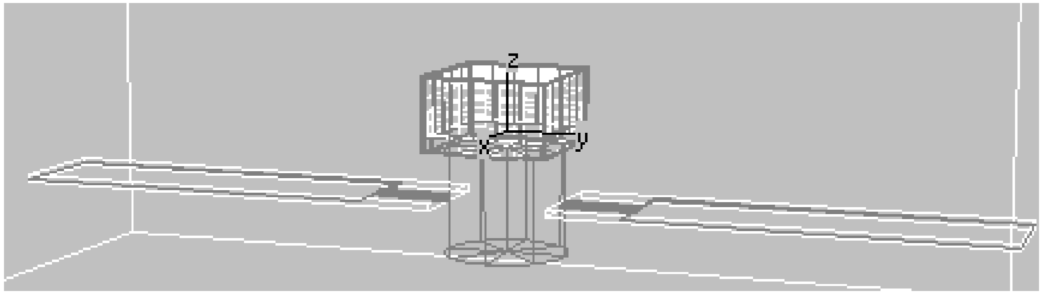

Geant4
FEBRUARY 18–22, 2002
USERS' WORKSHOP
STANFORD LINEAR ACCELERATOR CENTER
ADDITIONAL INFORMATION:
http://geant4.slac.stanford.edu/UsersWorkshop/
email: G4usersworkshop-L@slac.stanford.edu
This workshop is the first Geant4 users workshop to be held in the U.S. The workshop consists of tutorials and presentations. Tutorials start at the novice level, which is aimed at the people who are new to Geant4, then proceed to advanced lectures for experienced users. Presentations are planned both from Geant4 users in various application fields and from Geant4 developers. Participants will be strongly encouraged to describe their own applications. Town meetings involving users and developers will also be held.
XMM (ESA)
GLAST (NASA)
Computer Tomography Scans
BABAR (SLAC)
Geant4 is a general-purpose simulation toolkit for elementary particles interacting with matter. Its usage ranges from high energy cosmic or high energy particle physics, nuclear physics, the assessment of radiation shielding and satellites, and is expanding into medical physics studies.
Stanford Linear Accelerator Center (SLAC), Stanford, California, USA. The workshop is hosted by SLAC and co-sponsored by the US Department of Energy.

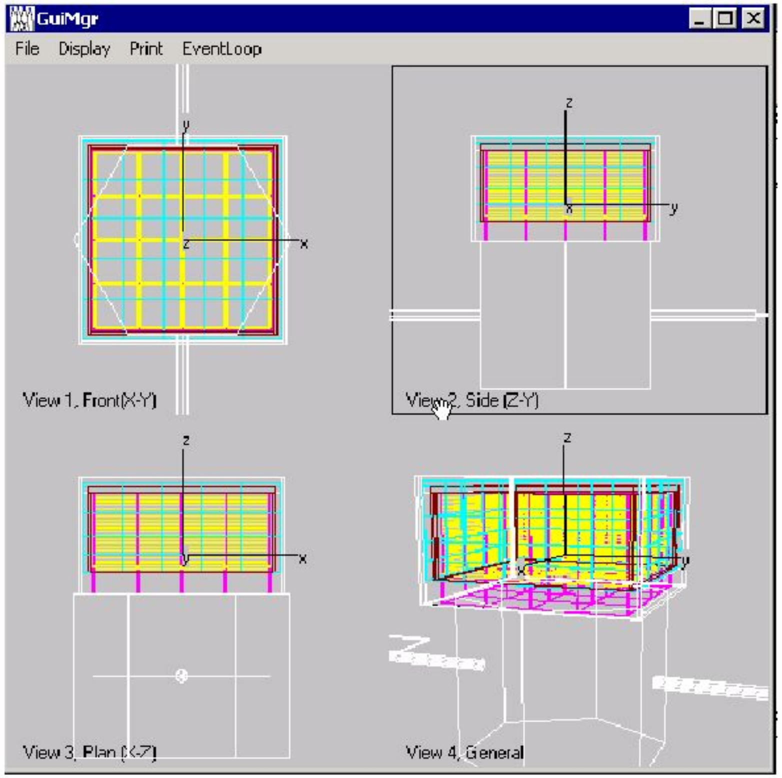
GLAST: structure of the offline sw

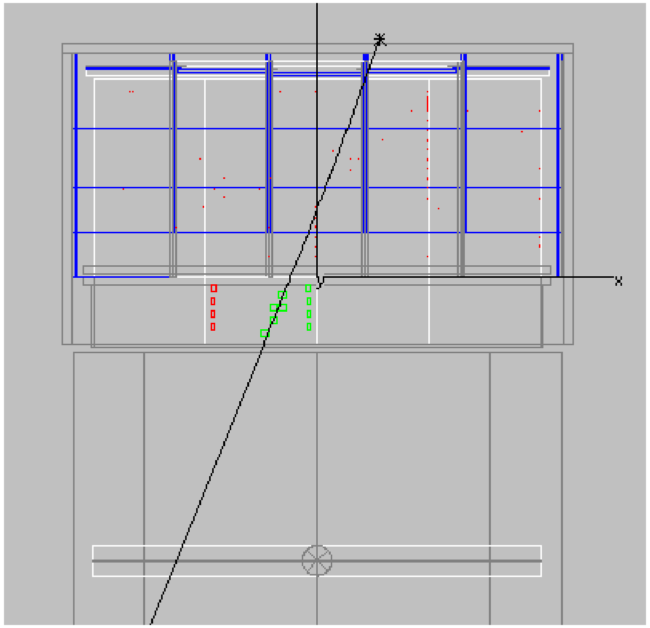
- Worldwide distributed sw dev't (weekly VRVS meetings for cohesion)
  - CVS for concurrent developing
  - CMT for configuration management
- Strictly OO code (mainly C++, possibly some part in Java in the future)
- Code subdivided in packages
  - Clear division of the responsibilities
  - Easier to manage
- 2 Official O/S (Windows, Linux)
- A lot of applications in event production & analysis
  - Flux generation
  - MC propagation
  - Digits from hits
  - Reconstruction
  - Analysis
  - Event display
  - Databasing, ...

how to deal with all of them in a structured way?

GLAST Simulation (GISMO)







Design Performance Validation: GLAST LAT Monte-Carlo Model

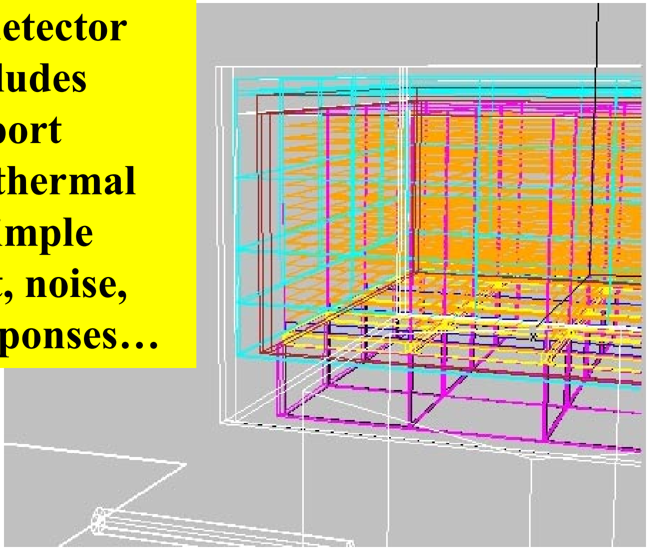
The LAT design is based on detailed Monte Carlo simulations.

Integral part of the project from the start.

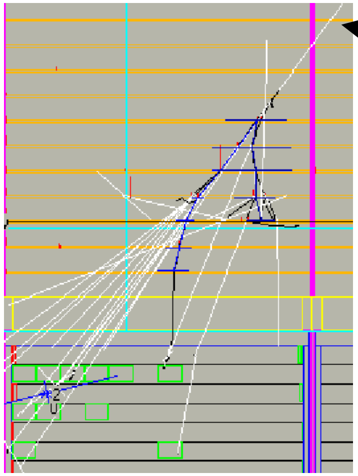
- **Background rejection**
- **Calculate effective area and resolutions (computer models now verified by beam tests). Current reconstruction algorithms are existence proofs -- many further improvements under development.**
- **Trigger design.**
- **Overall design optimization.**

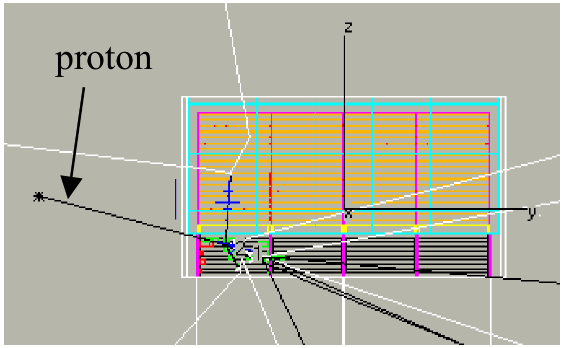
Simulations and analyses are all C++, based on standard HEP packages.

Detailed detector model includes gaps, support material, thermal blanket, simple spacecraft, noise, sensor responses…



Instrument naturally distinguishes gammas from backgrounds, but details matter.



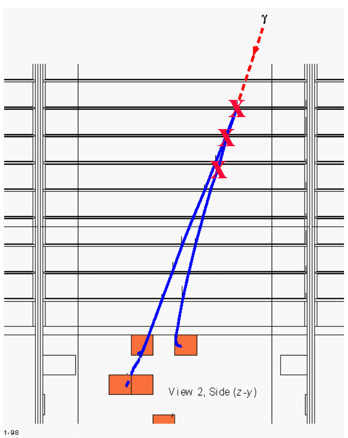


LAT Instrument Triggering and Onboard Data Flow

Level 1 Trigger

Hardware trigger based on special signals from each tower; initiates readout

Function: • "did anything happen?"
• keep as simple as possible



- **TKR 3 *x*•*y* pair planes in a row****
  workhorse γ trigger

OR

- **CAL:**
  LO – independent check on TKR trigger.
  HI – indicates high energy event → disengage use of ACD.

Upon a L1T, all towers are read out within 20μs

Instrument Total L1T Rate: <4 kHz>

****4 kHz orbit averaged without throttle (1.8 kHz with throttle); peak L1T rate is approximately 13 kHz without throttle and 6 kHz with throttle).**

On-board Processing

full instrument information available to processors.

Function: reduce data to fit within downlink

Hierarchical process: first make the simple selections that require little CPU and data unpacking.

- **subset of full background rejection analysis, with loose cuts**
- **only use quantities that**
  - **are simple and robust**
  - **do not require application of sensor calibration constants**
- **complete event information**
- **signal/bkgd tunable, depending on analysis cuts:**
  γ:cosmic-rays ~ 1:~few

Total L3T Rate: <25-30 Hz>

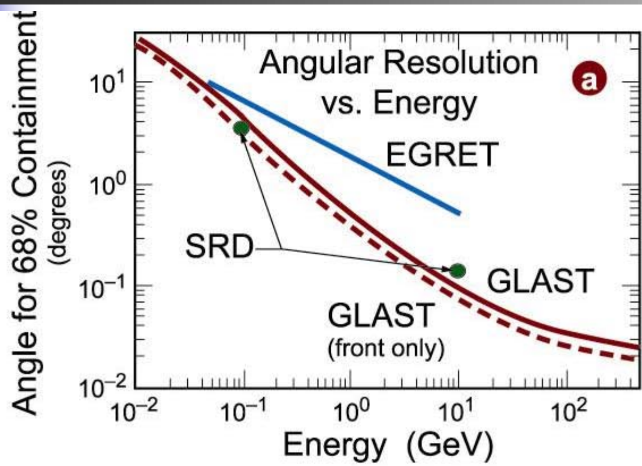
(average event size: ~8-10 kbits)

On-board science analysis:
transient detection (AGN flares, bursts)

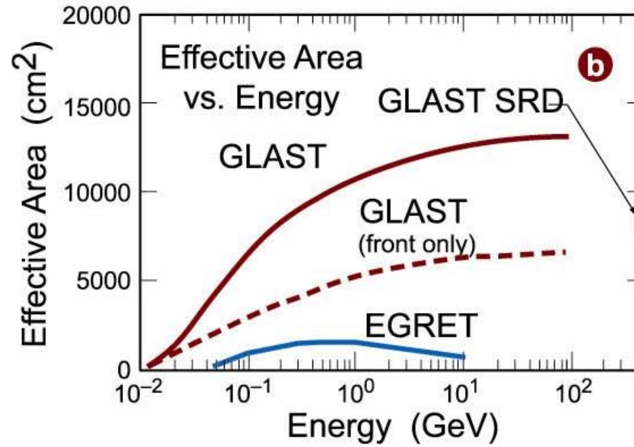
Spacecraft

LAT Instrument Performance

Optimized Point Spread Function



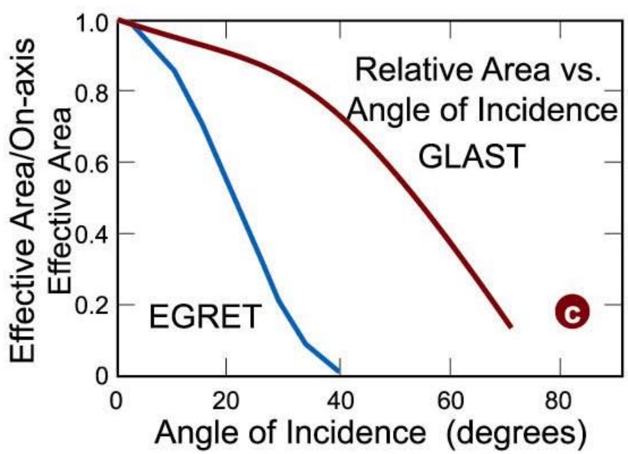
Large Effective Area



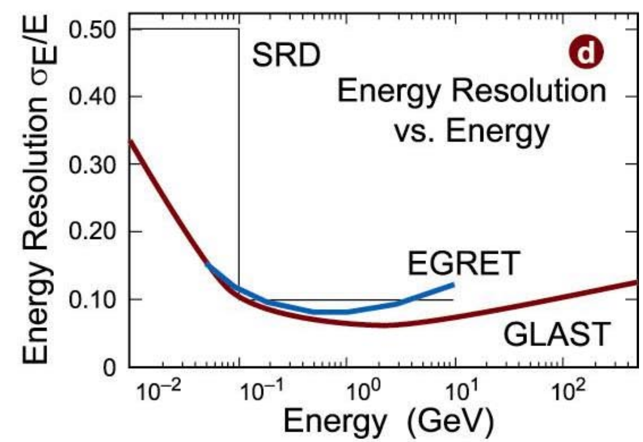
Wide Field of View

FOV: 2.4 Sr

SRD: 2.0 Sr



Good Energy Resolution



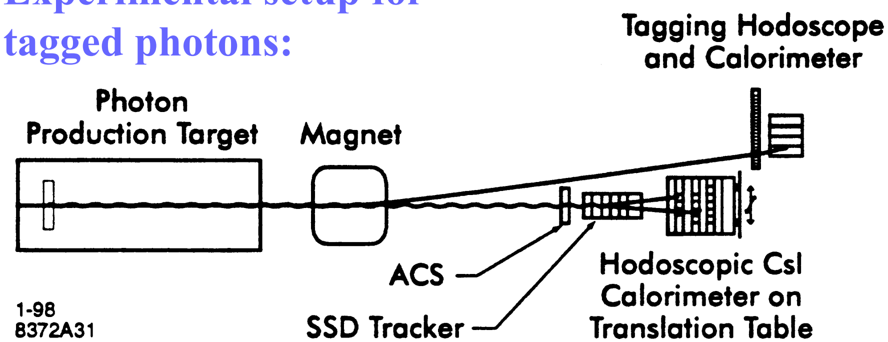
Point Source Sensitivity (high latitude)

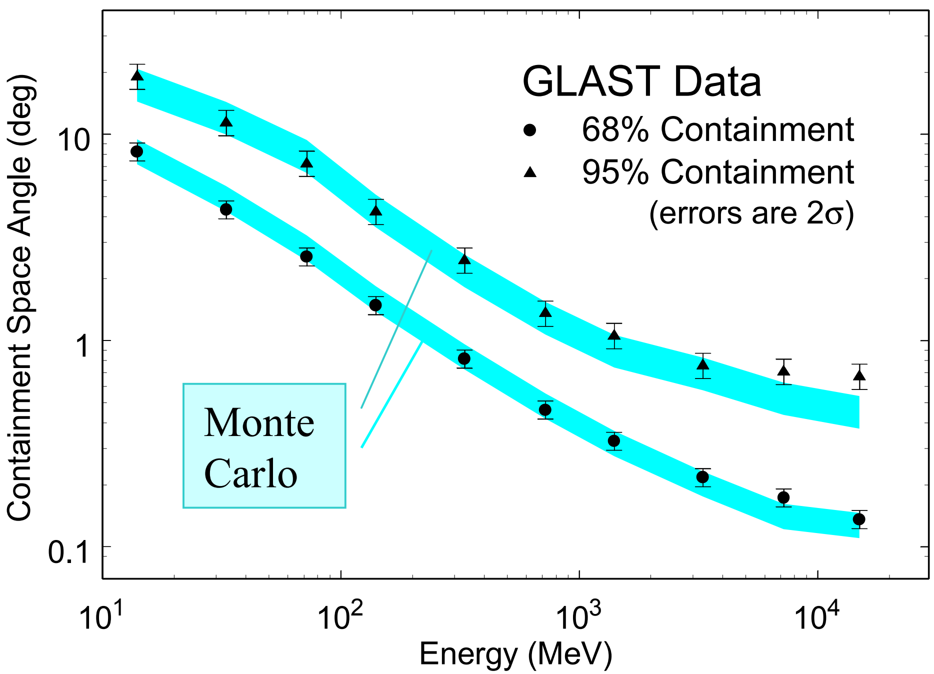
Two Years: = 1.6 x 10^{-9} ph/cm^2/s (> 100 MeV)

Including all Background & Track Quality Cuts

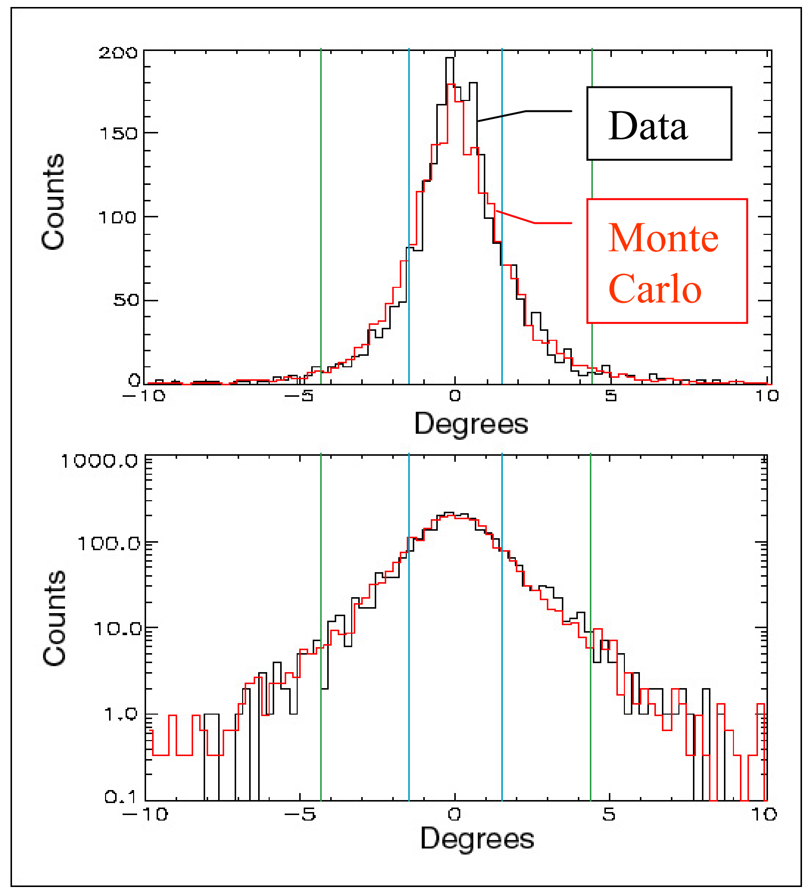
Monte Carlo Modeling Verified in Detailed Beam Tests

Experimental setup for tagged photons:





X Projected Angle
3-cm spacing, 4% foils, 100-200 MeV



Published in NIM A446(2000), 444.

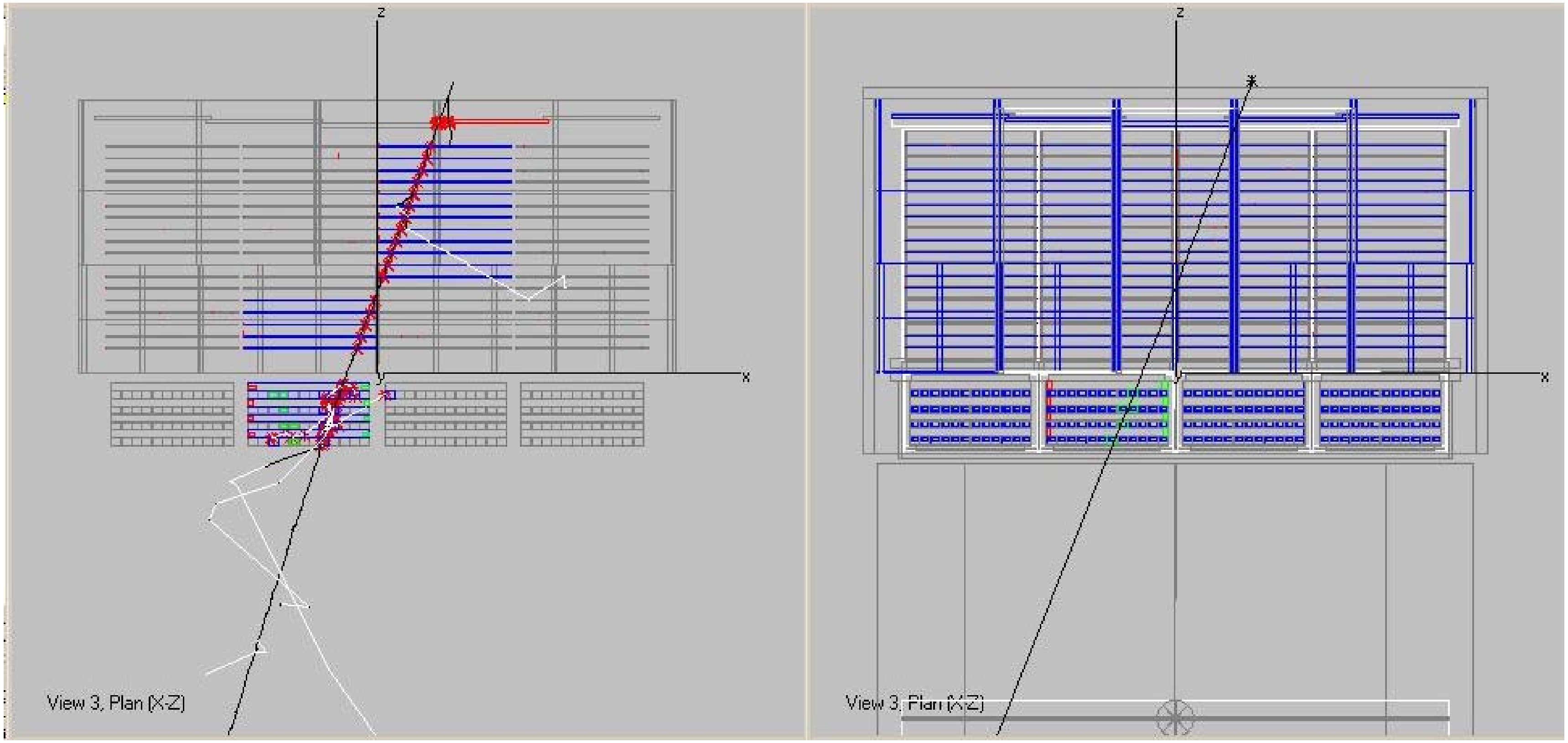
From GISMO to G4

- Why
  - GISMO is now quite obsolete
  - It is no more officially supported (and developed)
  - Physics needed some manpower
  - GEANT4 has arrived in the meanwhile
    - More flexible, maintainable and so on
    - Well supported and used by several experiments
    - Proved reliable for space applications (XRayTel and GammaRayTel)
    - Balloon Flight Simulation

From GISMO to Geant4

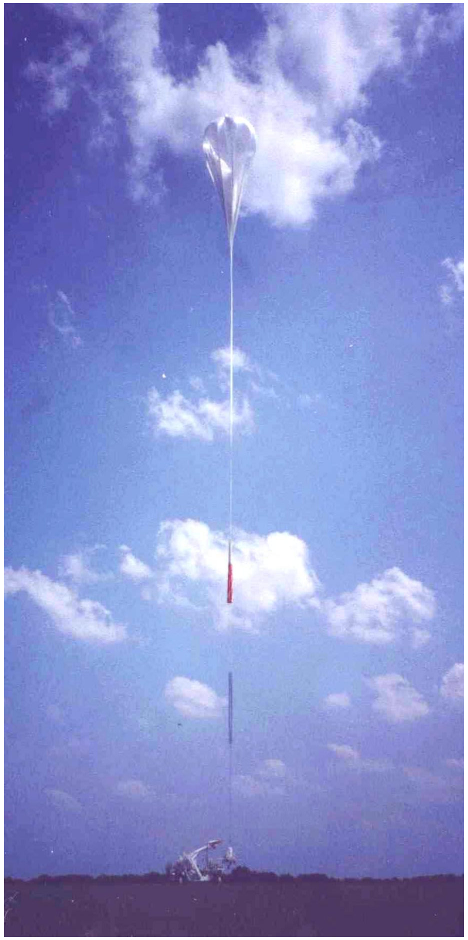
	Now: Gismo	Future: detModel+Geant4	Benefits
Geometry Description	21 classes, 4380 loc one xml file, 250 lines	data: 6830 lines in 30 xml files code: 8200 loc	▪Clean separation between data and code ▪Easy for different clients to have unique views
Simulation	Physics based on EGS4+Gheisha Supported by 1 person All physics, particle property code in 1 MB of code.	New physics code Supported by 100's Physics and particle properties: 75 MB.	▪Better support, documentation. ▪Becoming standard: many more users to validate physics.
Digitization	Hits turned immediately into digis during simulation	Hits in sensitive detectors, and perhaps all vols, accumulated for later processing	▪Energy accounting ▪Tune digitization independently of simulation

Geant4 vs. GISMO



- Incident 2 GeV mu+: Gismo does not support knockons!

LAT Balloon Flight: Goals



Purpose of balloon test flight (2001): expose prototype LAT tower module to a charged particle environment similar to space environment and accomplish the following objectives:

- **Validate the basic LAT design at the single tower level.**
- **Show the ability to take data in the high isotropic background flux of energetic particles in the balloon environment.**
- **Record events for use as a background event data base.**

Balloon Simulation & Data Analysis

Balloon Flight for the GLAST

Balloon Flight Engineering Model (BFEM)

eXternal Gamma-ray Target(XGT)

Objectives

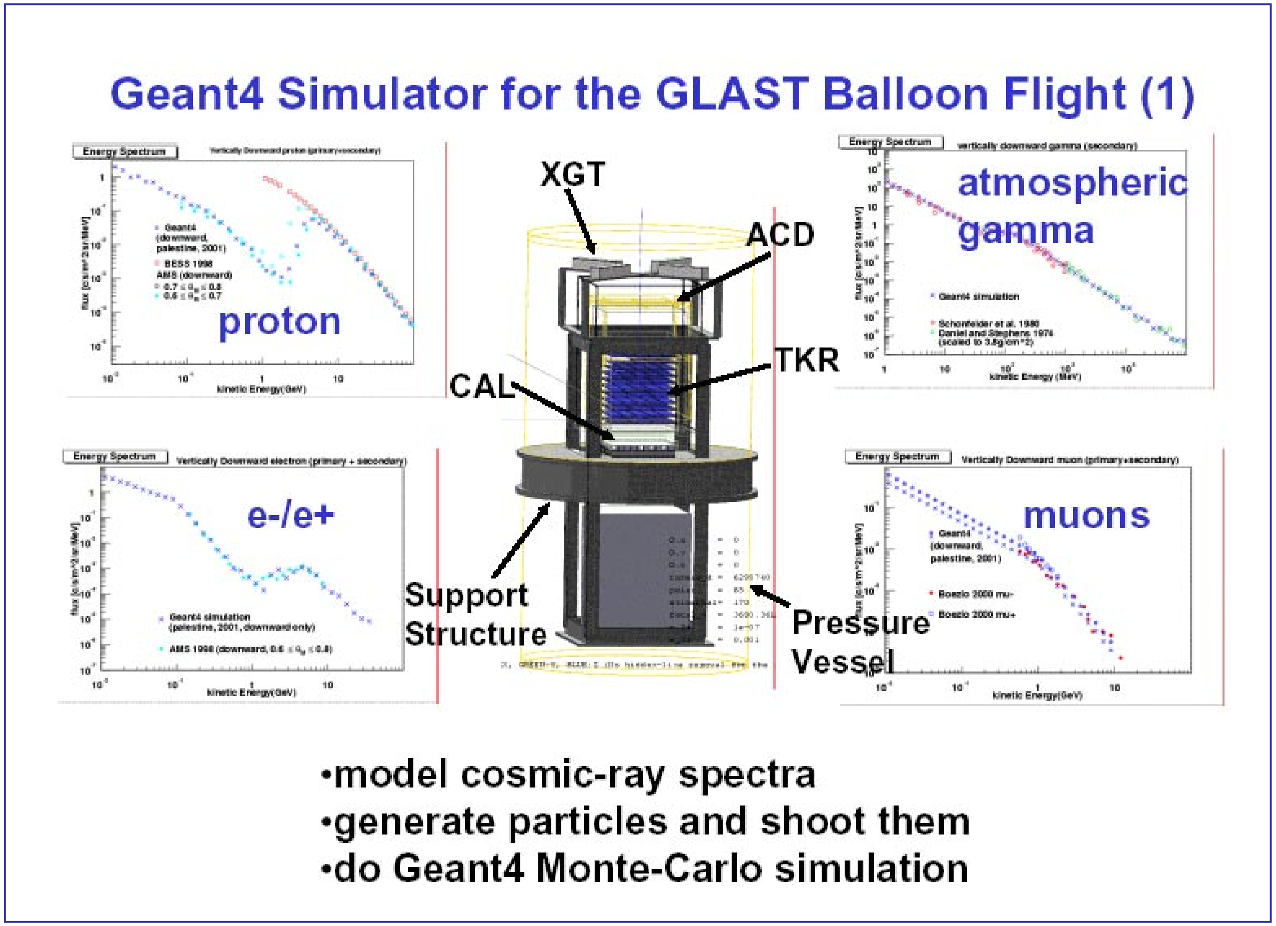
a. Validate the LAT design at the single tower level
b. Show the ability to take data in a space-like environment
c. <u>Collect cosmic-ray events to be used for a background database for the GLAST satellite.</u>

We have developed a cosmic-ray generator and an instrument simulator based on Geant4 (2.0)

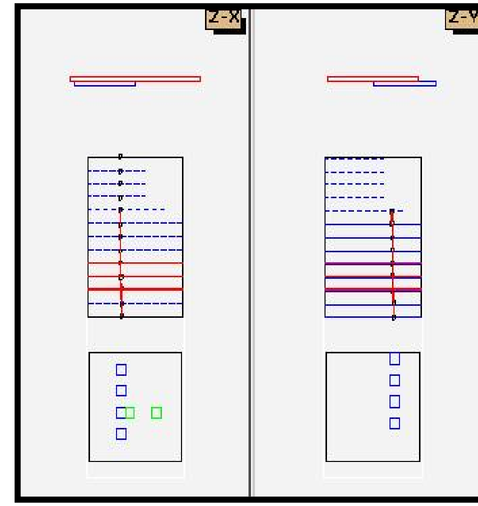
August 04, 2001 @Palestine, Texas
~100000events via telemetry

Mizuno et al. 2002

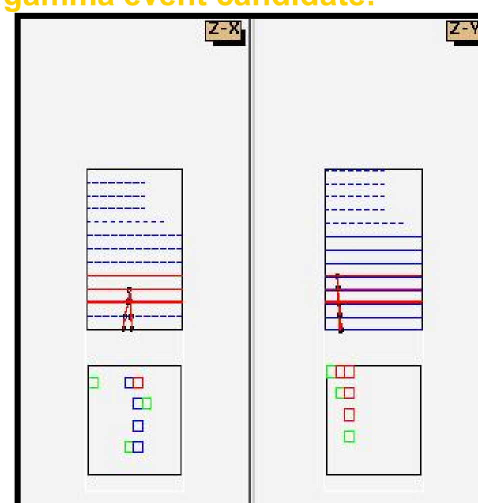
Balloon Simulation & Data Analysis



background event candidate:



gamma event candidate:

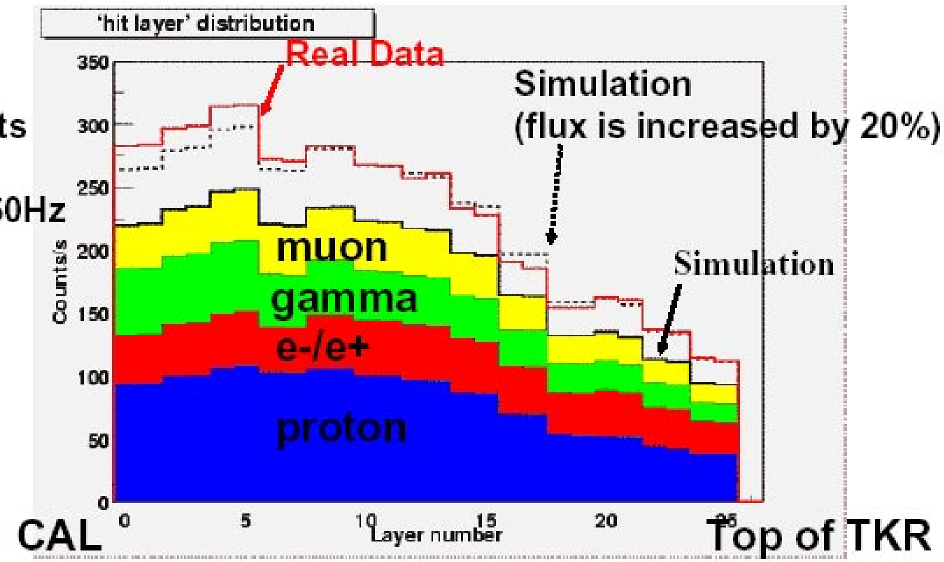


Mizuno et al. 2002

Balloon Simulation & Data Analysis

Hits in each layer for "charged" events (deposit energy in ACD)

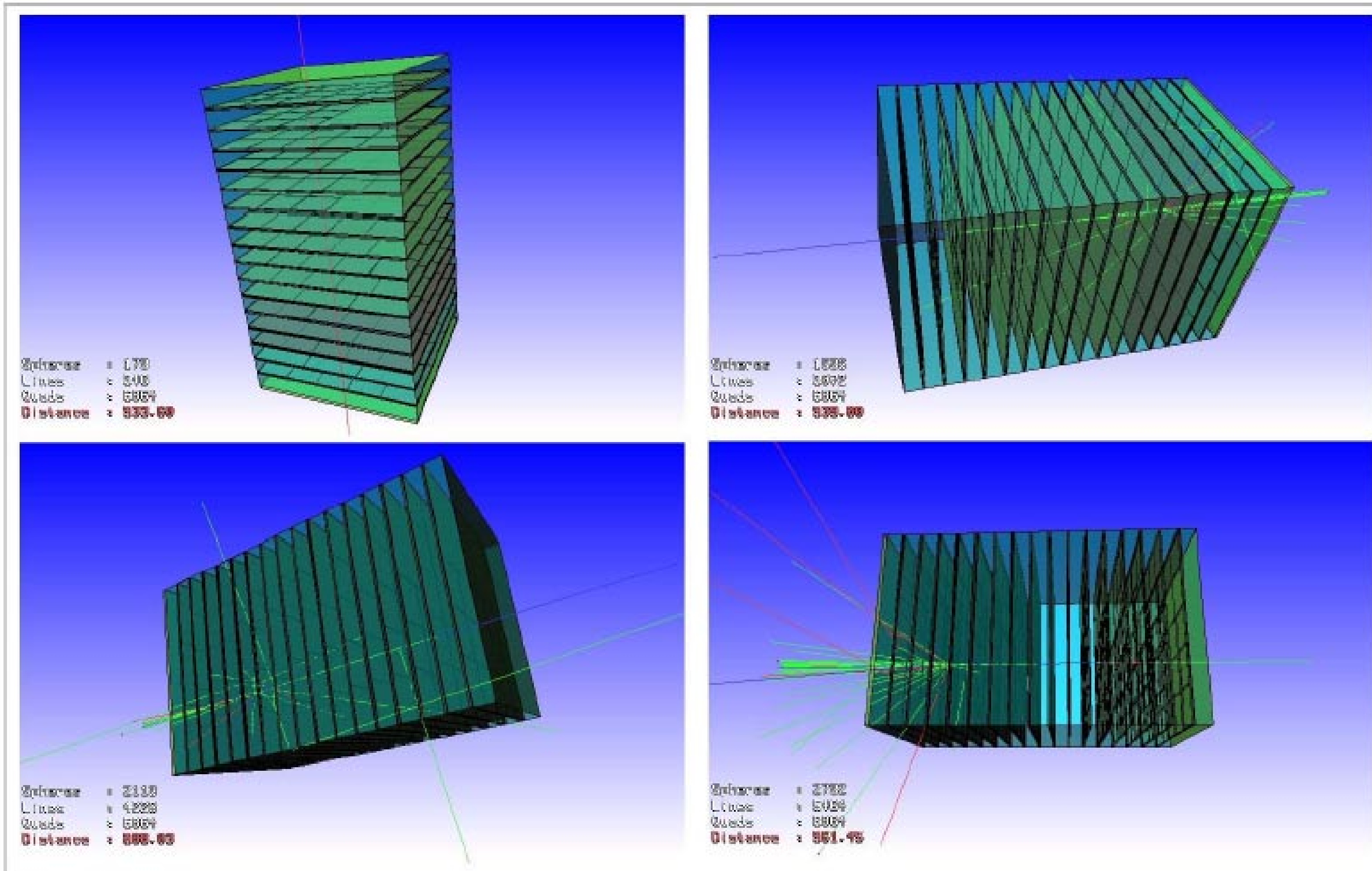
Trigger rate of "charged" events
•data: ~440Hz
•simulation: ~350Hz



•The G4 BFEM simulator and cosmic-ray generators well reproduced hits in TKR (20% difference could be explained by He and the flux uncertainty.)
• small discrepancy is seen in layers near the CAL.

Mizuno et al. 2002

Test Beam G4 Simulation



Cestellini et al. 2001

The GAUDI framework

- First GLAST simulation/analysis programs evidence the need for modularity, scalability, maintainability

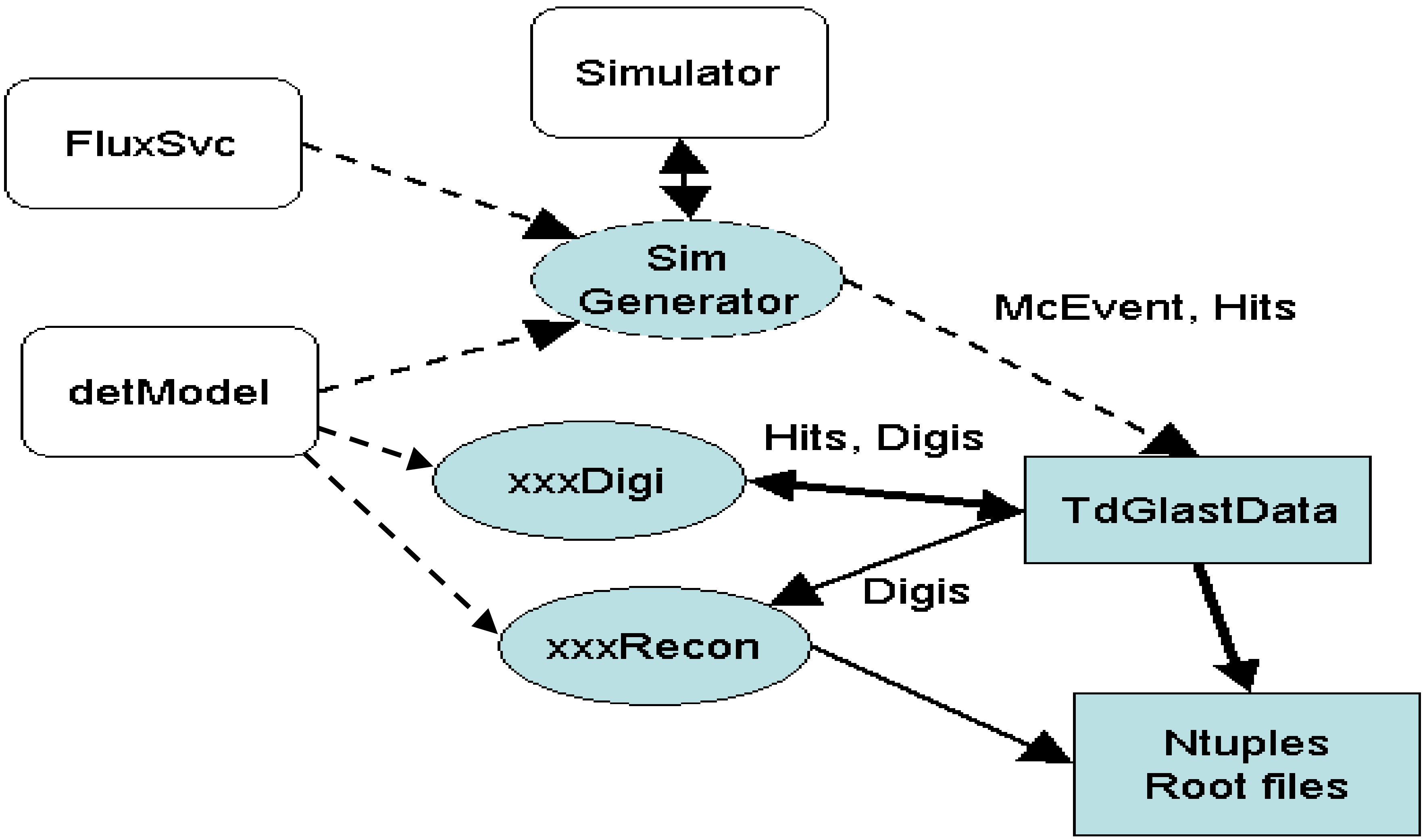
=> a well structured (& well documented) framework: **GAUDI**

  - An application framework designed to facilitate event-oriented analysis, allowing modular development & deployment of processing algorithms
  - Open source project supported by (committed to) LHCb and ATLAS, hopefully guaranteeing long term support

- GLAST sim/rec/analysis is integrated in GAUDI

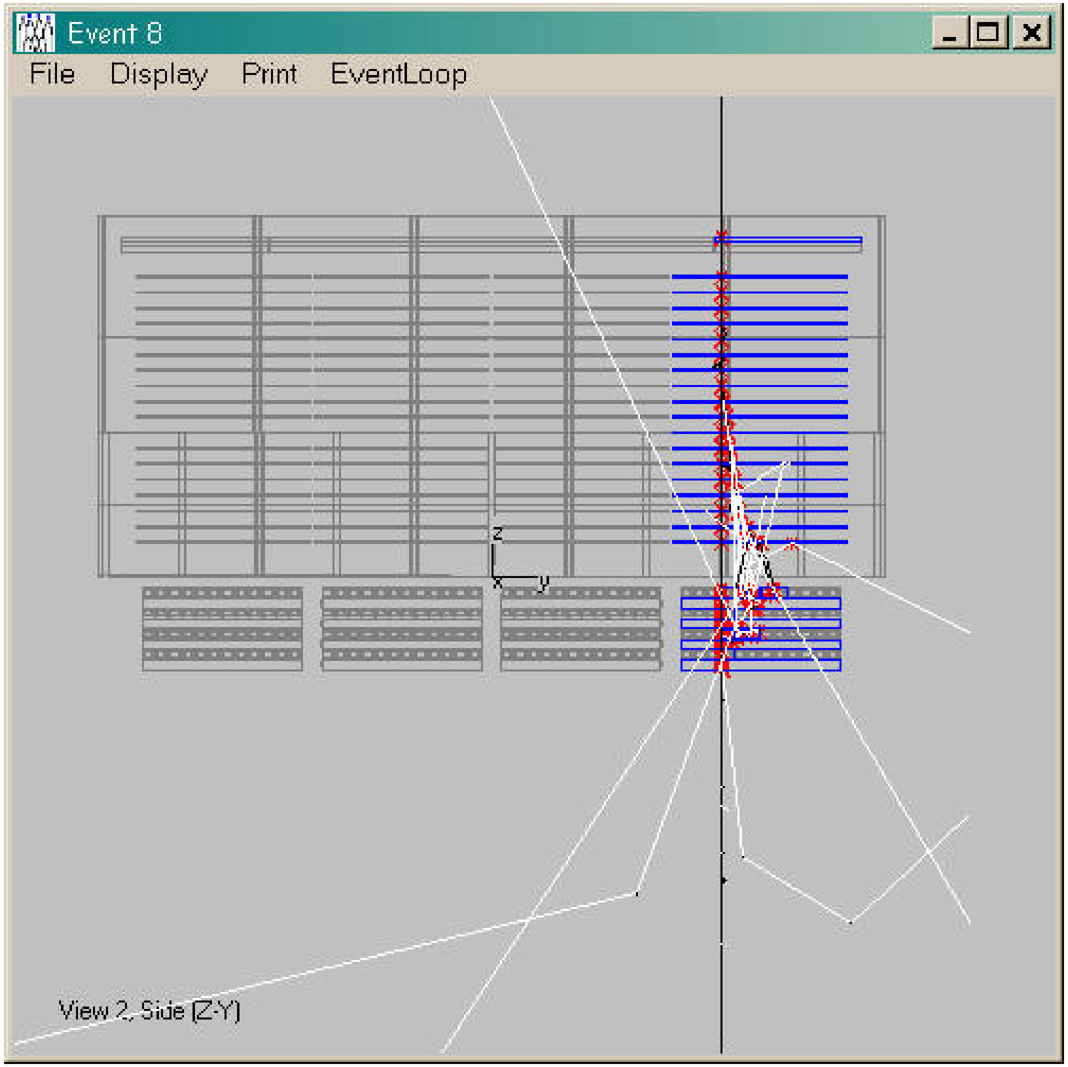
  The MC simulation (G4 for example) is a transport algorithm in the framework, not a standalone application

Sim/Recon SW



Simulator
FluxSvc
Sim Generator
McEvent, Hits
detModel
Hits, Digis
xxxDigi
TdGlastData
Digis
xxxRecon
Ntuples Root files

Simulation: G4Generator

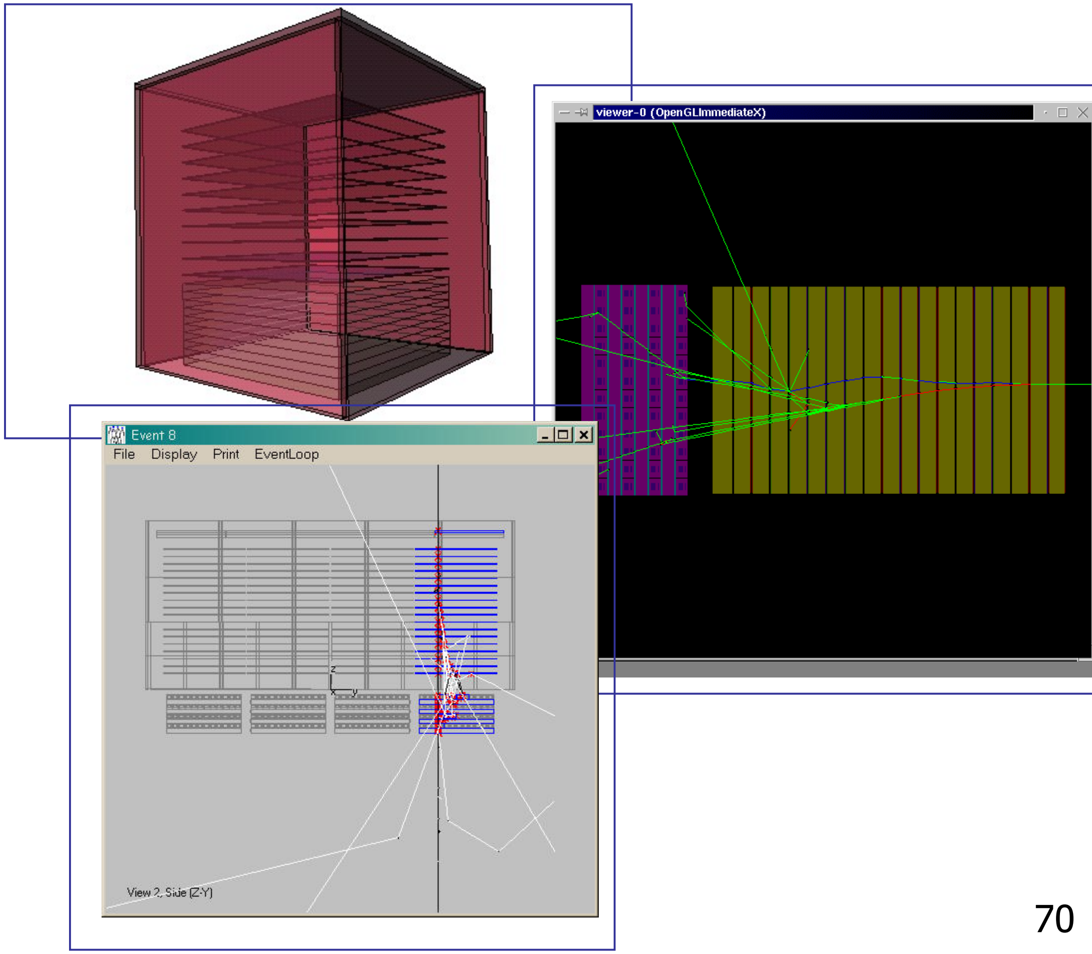


Simulation: GAUDI Implementation

- GAUDI algorithm (G4Generator)
- Incident flux: an independent GAUDI service (FluxAlg)
- Geometry info from an XML file via a GAUDi service (GlastSvc)
- Simulation parameters with GAUDI (jobOptions file)
- GLAST 3D representation GLAST and User Interface
- Hits stored in a GAUDI Transient Data Store for future use by Digi and TkrRecon algorithms
- G4 only for propagation

G4Generator package History

- G4 as proposed MC
- Learning G4 and development of GammaRayTel
- Standalone Packages
  - Test Beam 1999
  - Balloon Flight
- Geometry repository
- Gaudi integration
  - Managing the event loop
  - Source generation
  - Hit structure Filling
  - Digitization
- G4Generator release
- Gleam package released



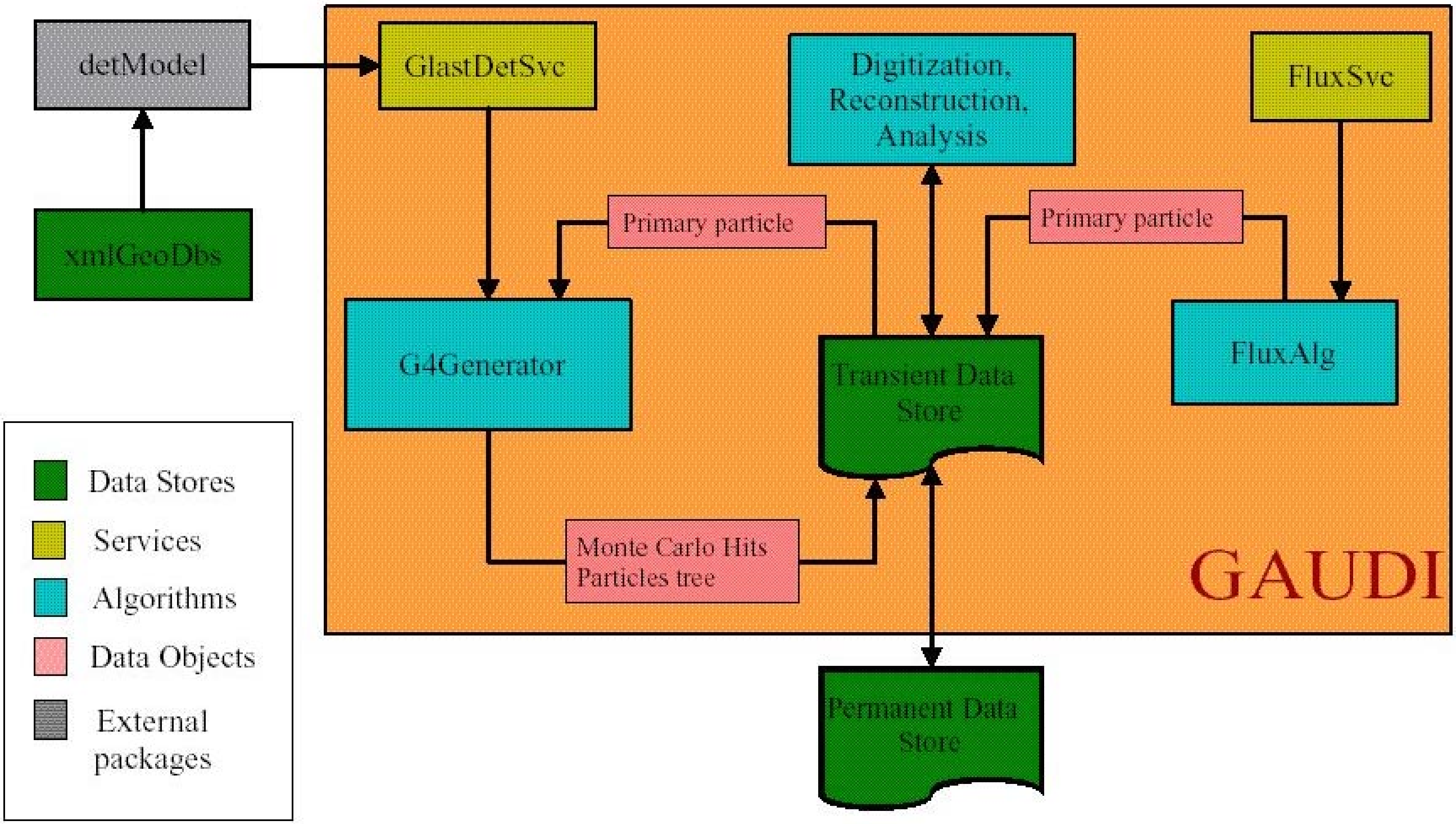
G4Generator requirements

- From Geant4
  - Detector Construction
  - Primary Generator Action
  - Physics List
- From Framework
  - Be able to manage event loop
  - G4 as Algorithm
  - Gismo comparison
- From Geometry
  - Unique source of geometry
  - detModel & GlastSvc (avoid dependences)
- From sources
  - Source generation
- From Digitization
  - Hits filling (by detectors)
- From Visualisation
  - Track colors, Steps

G4Generator implementation

- Framework
  - G4Generator Algorithm
  - jobOptions
  - Customised Run Manager (little set of functionalities)
- Geometry
  - XML persistency
  - GlastSvc (Materials, Volumes, Identifiers)
- Sources
  - McParticle from TDS
- Digitization
  - Collection of data Objects (PositionHits, IntegratingHits, Particles)
- Visualisation
  - (Tracks, Hits, Detectors)

G4Generator implementation

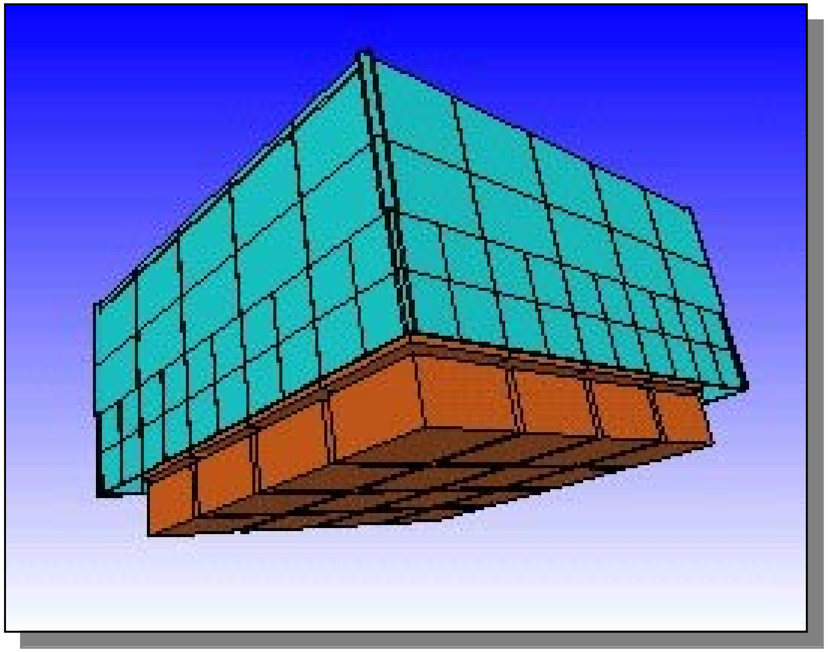


XML for geometry description

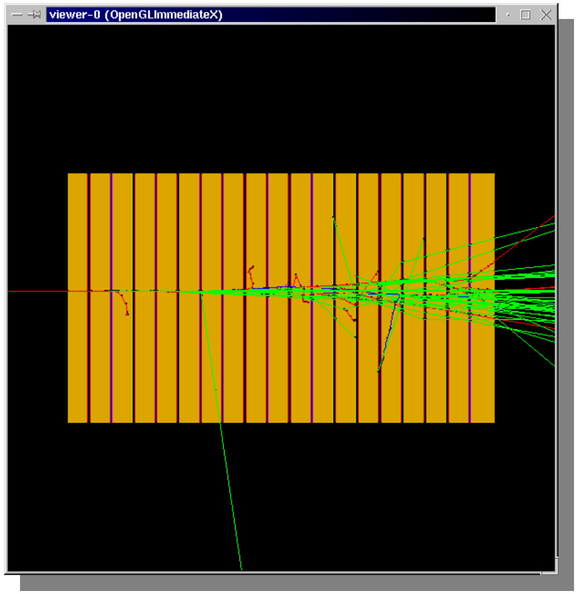
- A specific DTD for the GLAST geometry
- A C++ hierarchy of classes for the XML interface (detModel)
- Many clients
  - Simulation
  - Reconstruction
  - Analysis
  - Event display
- Interfaces for
  - VRML output for the geometry
  - HTML documentation
  - GEANT4 geometry description
  - ROOT
  - Java (partial)

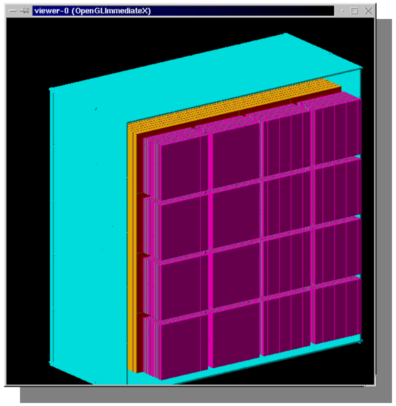
Geometry: XML persistency

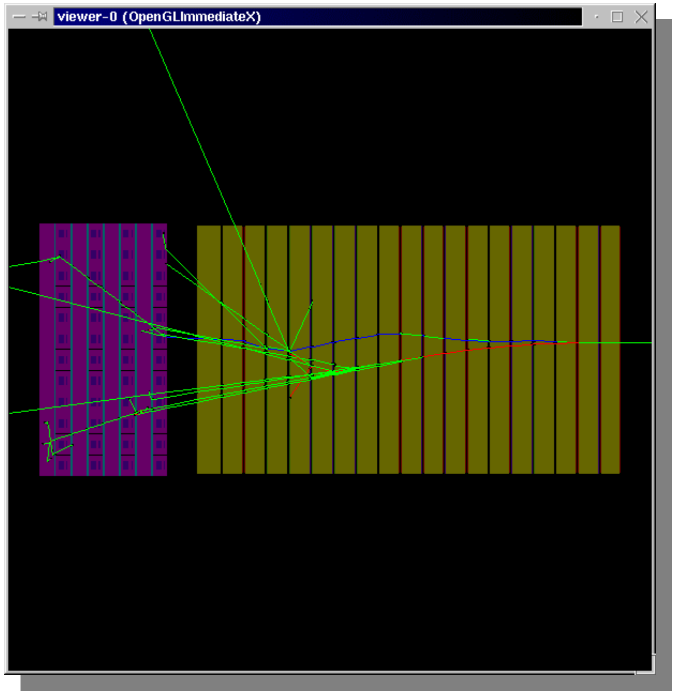
- Class hierarchy in C++ for XML interface (detModel)
- GAUDI service to manage this interface (GlastISvc)
- Various clients
  - Simulation
  - Reconstruction
  - Analysis
  - Event display
- Interfaces for
  - VRML output for the geometry
  - HTML constants documentation
  - GEANT4 and GISMO geometry description
  - ROOT (partial)
  - HepRep (work in progress)

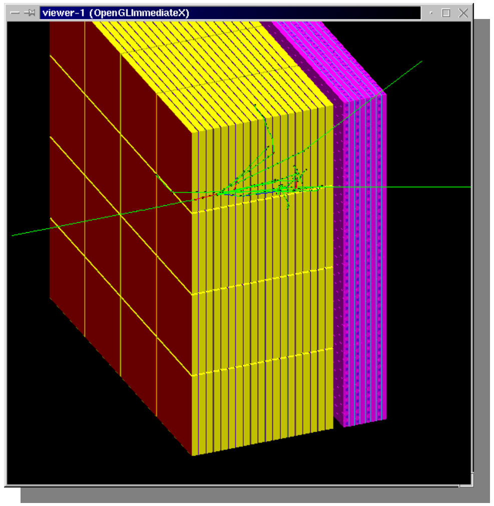


XML: GEANT4 interface

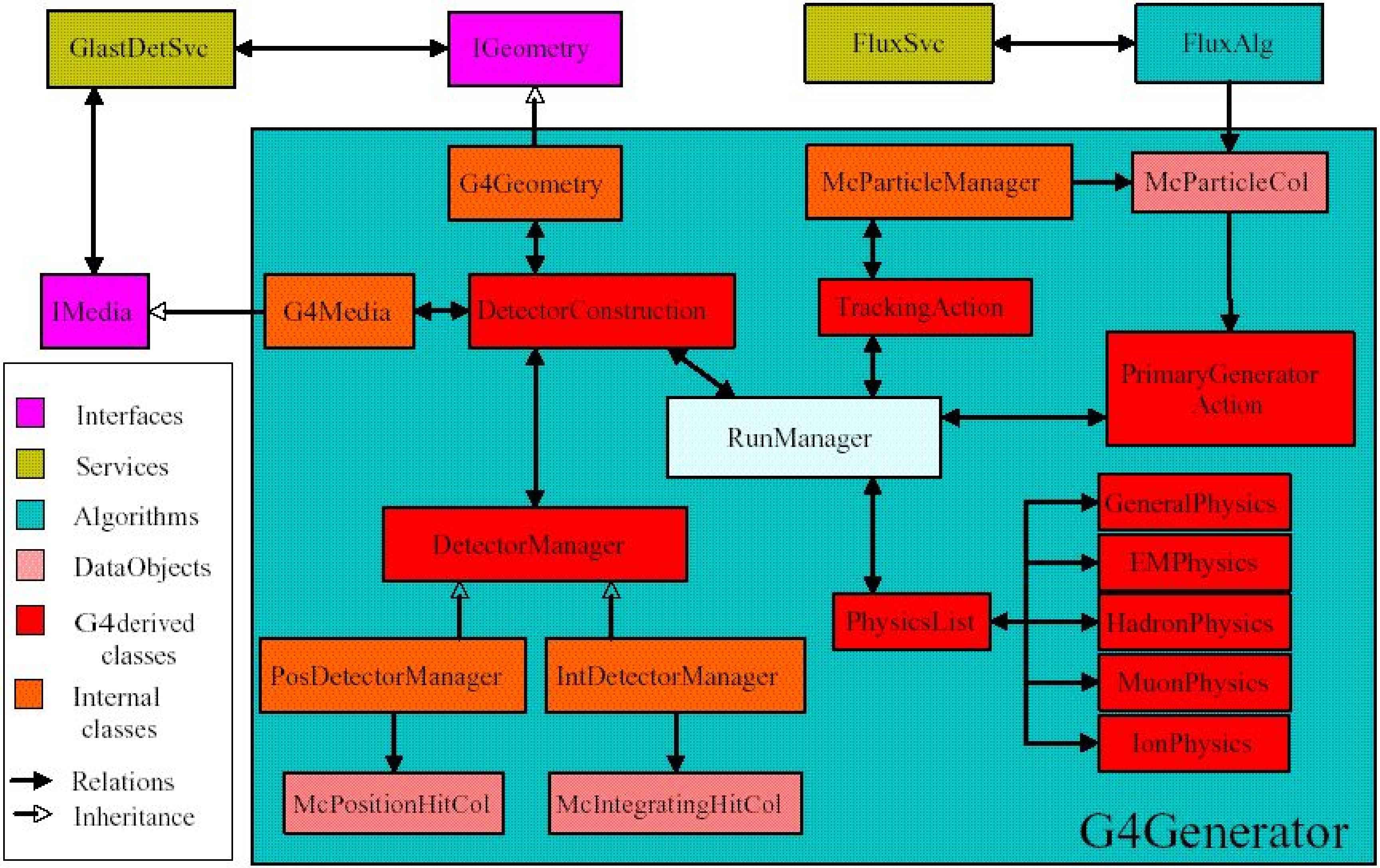




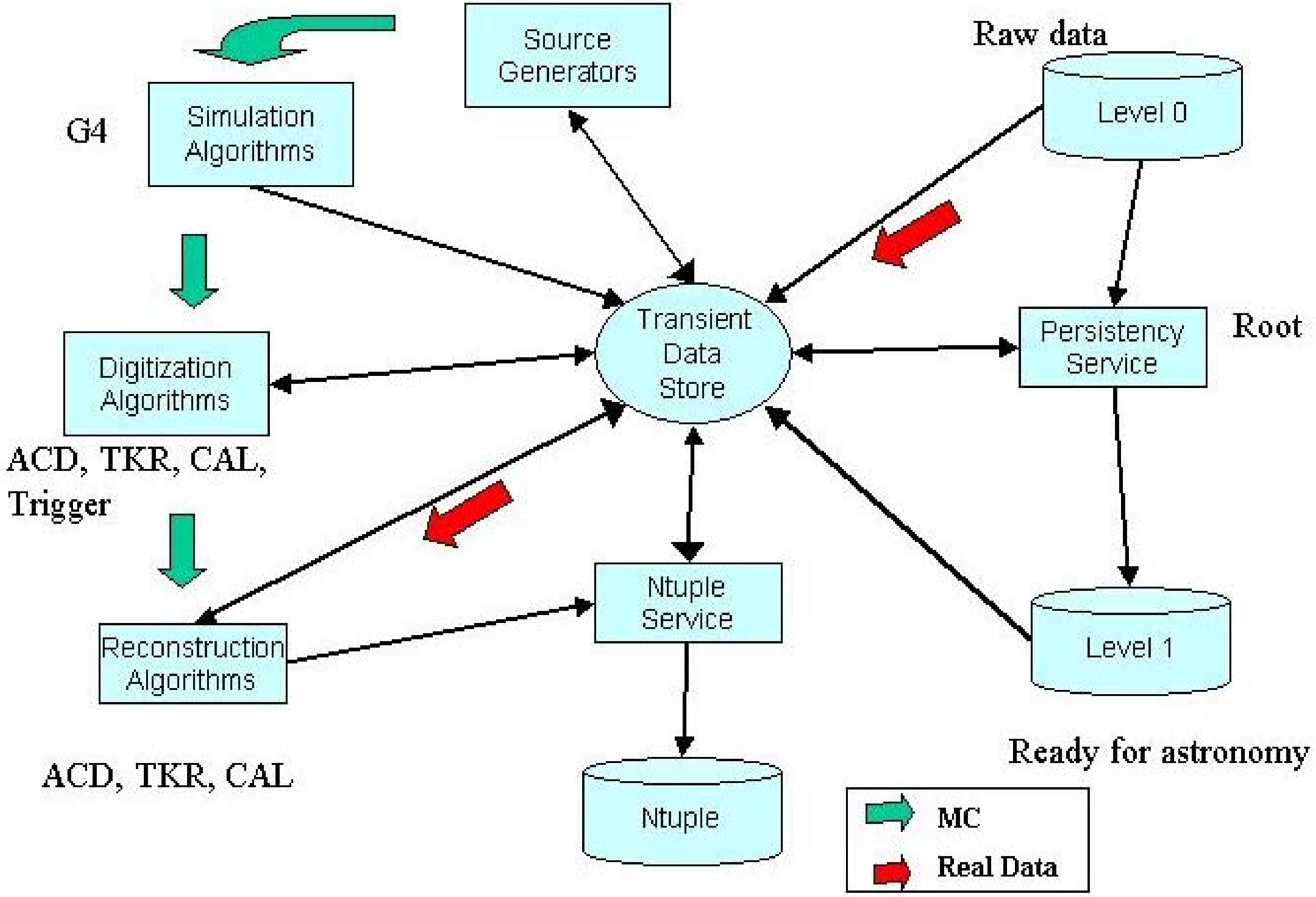




G4Generator implementation



Sim/Recon SW



Source Generators
Raw data
Level 0
G4
Simulation Algorithms
Transient Data Store
Persistency Service
Root
Digitization Algorithms
ACD, TKR, CAL, Trigger
Ntuple Service
Reconstruction Algorithms
Level 1
Ready for astronomy
ACD, TKR, CAL
Ntuple
MC
Real Data

G4Generator requirements

- Physics!
- PhysicsList in G4
- Physics Processes, ProcessManager per Particle
- Requirements to G4:
  - Hadronic and Electromagnetic Processes
  - Tracking Cuts
  - New processes
  - New particles?
- How to specify in Framework?
  - jobOptions?
  - New G4classes? (e.g. particles?)
  - How to compare with Gismo?

Physics in G4

- EM Physics
  - Processes
    - Pair Production
    - Compton
    - PhotoElectric
    - Bremsstrahlung
    - Multiple Scattering
    - Ionisation & Delta Ray Production
    - Positron Annihilation
    - …
  - Different particles
  - Prospects
    - Low Energy?
- Hadronic Physics
  - Hadron Processes
    - Elastic & Inelastic scatter
    - Ionisation
    - Multiple Scattering
    - Annihilation
  - Ion Processes
    - Elastic
    - Multiple Scattering
    - Ionisation
  - Particle Decay
  - Prospects
    - Radioactive Decay
  - Other Hadronics

Validation

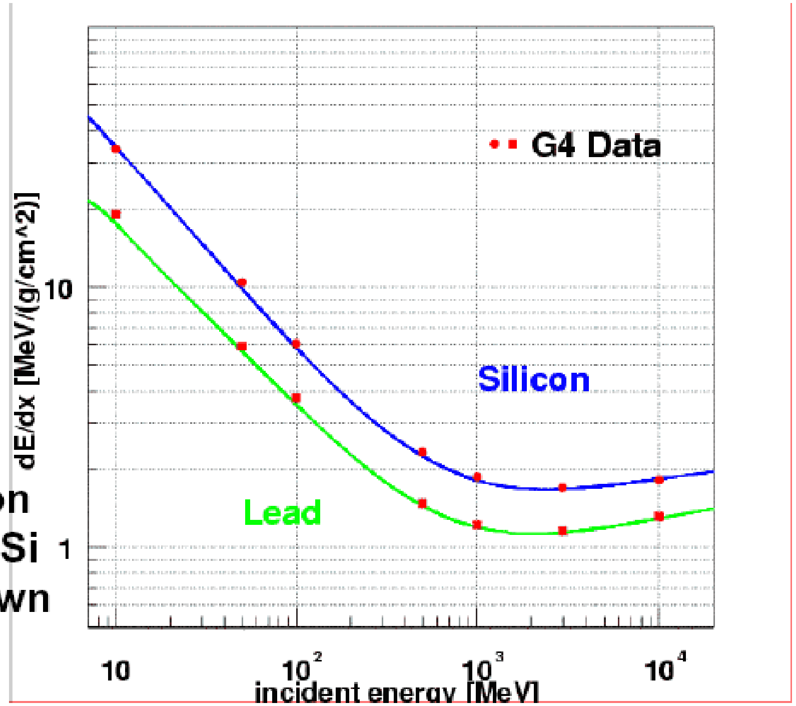
- EM Physics
  - Test Beam
  - Balloon Flight
  - Signal in Silicon and Cal
  - EM shower
  - Lot of data in energy Range
- High Level
  - Test Beam
  - Calibration
  - Balloon
- Low Level
  - Cross Section
  - Angular distribution
  - Implementation
  - Contact with G4 developers

- Hadronic Physics
  - Test beam data?
  - Ion physics
  - Nuclear Interaction
  - CR induced processes
- High Level
  - Comparison with Literature
  - Test beam other detectors
- Low Level
  - Collaboration with Hadronic Working Group
  - Interaction
  - Energy Deposition
  - Activation
  - Radioactive Decay

G4 physics validation

Bethe-Bloch formula for protons

Geant4 well reproduces ionization energy loss in thick Si and Pb of proton down to 10 MeV

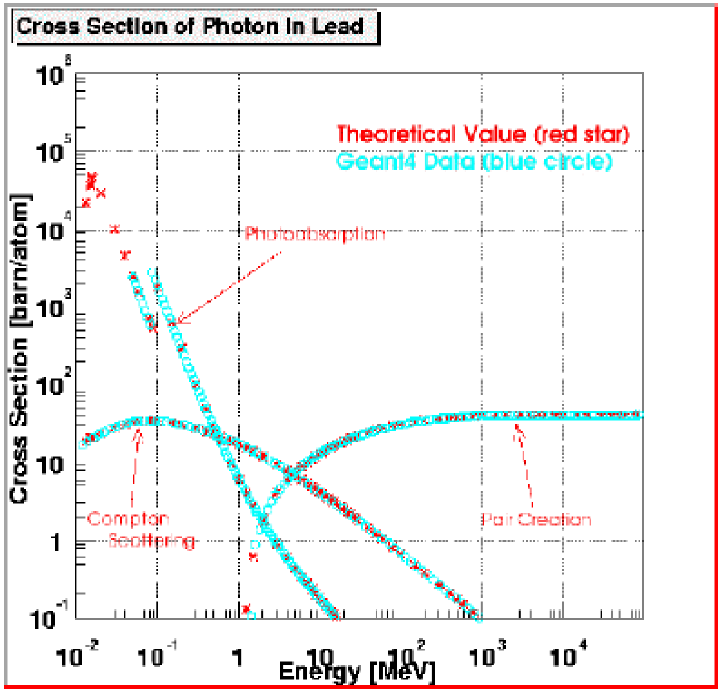


Kamae et al. 2002

G4 physics validation

Pair creation – cross section

Compare the cross section in Pb calculated by Geant4 with that of a reference
(http://physics.nist.gov/PhysRefData/Xcom/Text)



Geant4 correctly calculates cross section down to ~100 keV

Kamae et al. 2002

Conclusions

- AGILE and GLAST are partnership of HEP and Astrophysics communities sharing scientific objectives and technology expertise
- AGILE and GLAST will survey the sky in the 20MeV~1TeV g-ray band, where the most energetic and mysterious phenomena in nature reveal their signature
- AGILE and GLAST are equipped with state-of-the-art particle detectors, resulting in an order of magnitude improvement in sensitivity and resolution with respect to previous missions
- HE gamma ray experiments will therefore:

  ✓detect thousands of new and unknown g-ray sources
  ✓ identify the correct emission models for known classes of sources (e.g. AGN)
  ✓ probe the supersymmetric phase space
  in search for WIMP decay and neutralino annihilation signals
  ✓ provide significant data on the origin and evolution of GRBs

Conclusions

- G4 is suitable as a MC toolkit for HEP and astroparticle applications
- The HEP/AP community is quickly acquiring a good experience
- G4 validation with real data is progressing fast
- G4 is easy to integrate with other software

- G4 is becoming the standard de facto for detector simulations

  The software is profiting of tests within an extended community