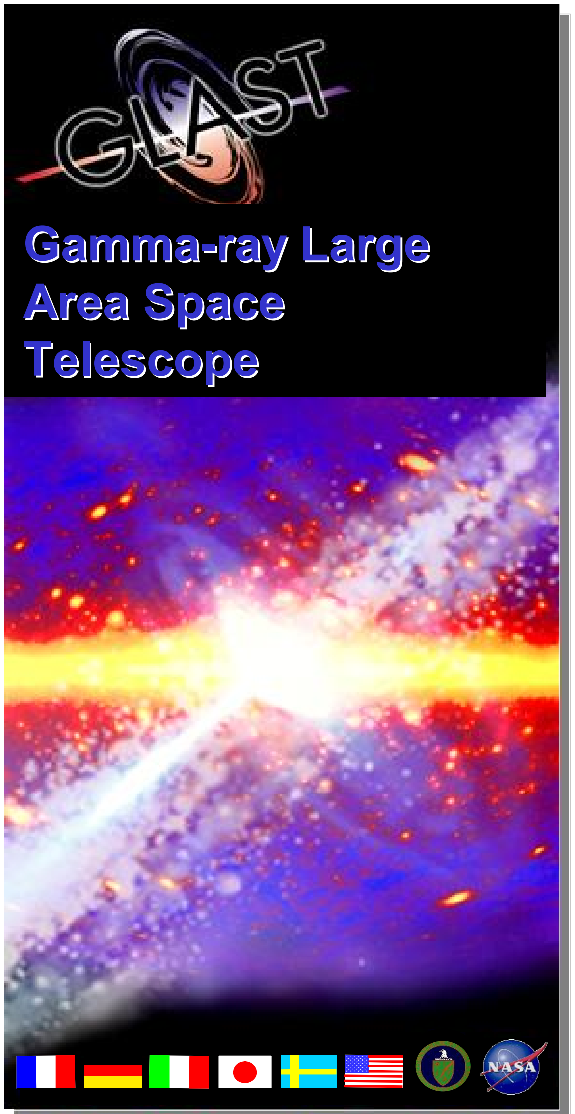


GLAST:

Science in Flight

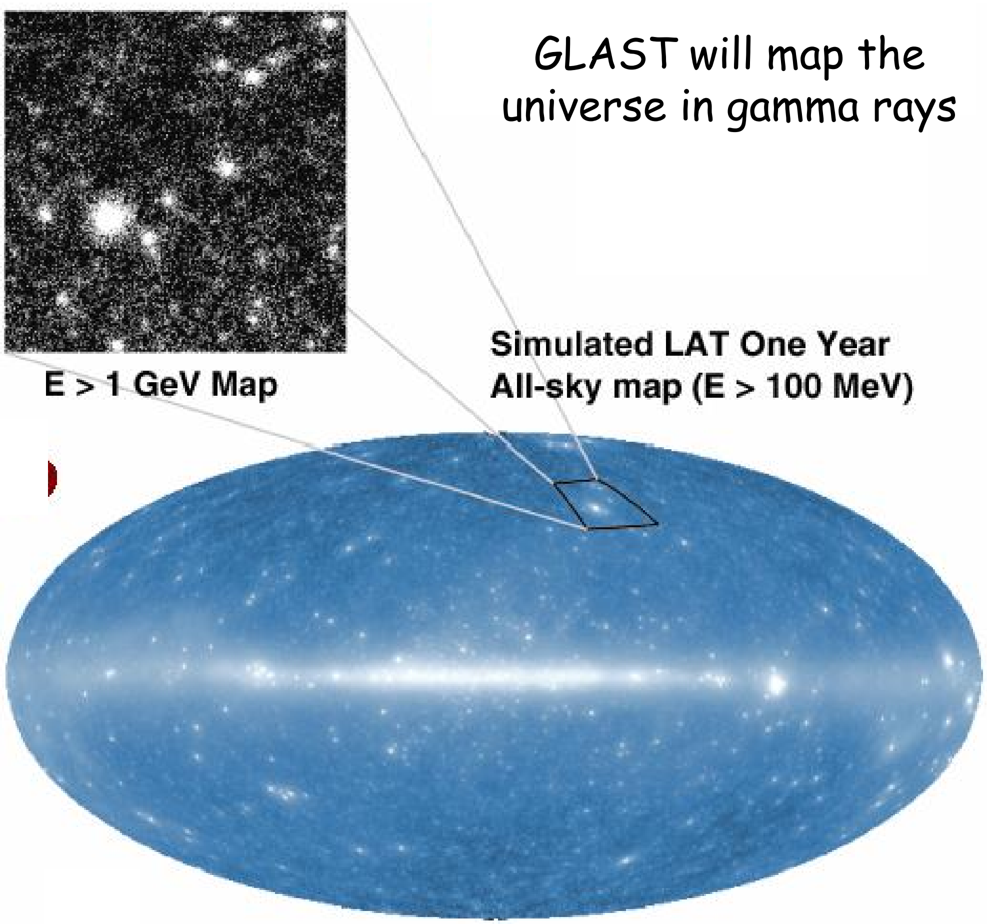
Richard E. Hughes,
The Ohio State University,
The GLAST-LAT Collaboration.

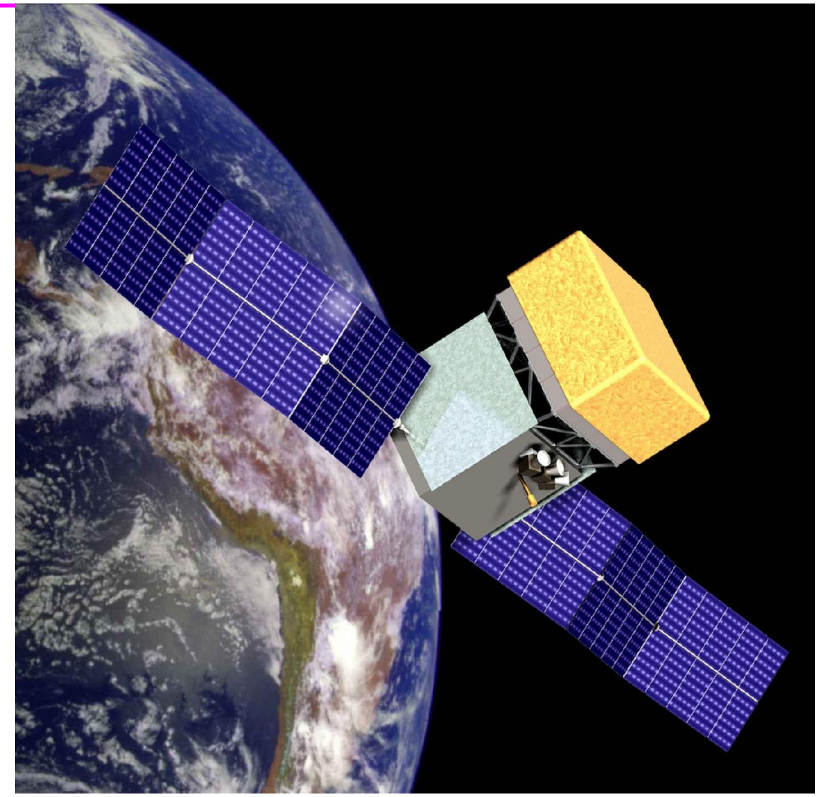
University of Pennsylvania
HEP Seminar

What is GLAST?

Gamma-ray **L**arge **A**rea **S**pace **T**elescope

GLAST will map the universe in gamma rays





Two GLAST instruments:

LAT: 20 MeV – >300 GeV

GBM: 10 keV – 25 MeV

Launch: 2007

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
- The Ohio State University
- Stanford University (SLAC and HEPL/Physics)
- University of Washington
- Washington University, St. Louis

France

- IN2P3, CEA/Saclay

Italy

- INFN, ASI

Japanese GLAST Collaboration

- Hiroshima University
- ISAS, RIKEN

Swedish GLAST Collaboration

- Royal Institute of Technology (KTH)
- Stockholm University

PI: Peter Michelson (Stanford & SLAC)

~225 Members (including ~80 Affiliated Scientists, plus 23 Postdocs, and 32 Graduate Students)

Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

Managed at Stanford Linear Accelerator Center (SLAC).

GBM Collaboration

National Space Science & Technology Center

University of Alabama in Huntsville

- Michael Briggs
- William Paciesas
- Robert Preece

NASA Marshall Space Flight Center

- Charles Meegan (PI)
- Gerald Fishman
- Chryssa Kouveliotou

Max-Planck-Institut für extraterrestrische Physik

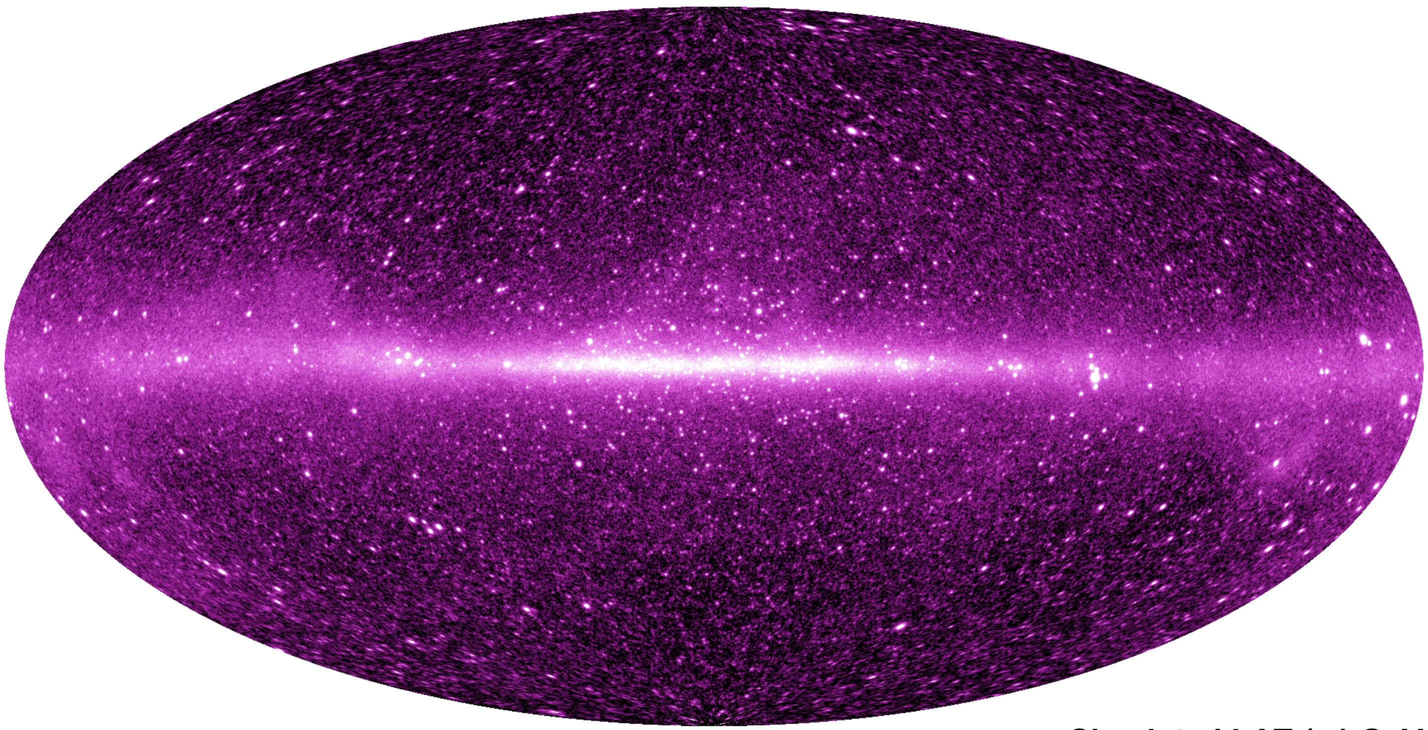
- Giselher Lichti (Co-PI)
- Andreas von Keinlin
- Volker Schönfelder
- Roland Diehl

On-board processing, flight software, systems engineering, analysis software, and management

Detectors, power supplies, calibration, and analysis software

The Gamma-Ray Sky

- Comparing EGRET to GLAST:
  - Illustrating the anticipated improvement in our knowledge of the sky



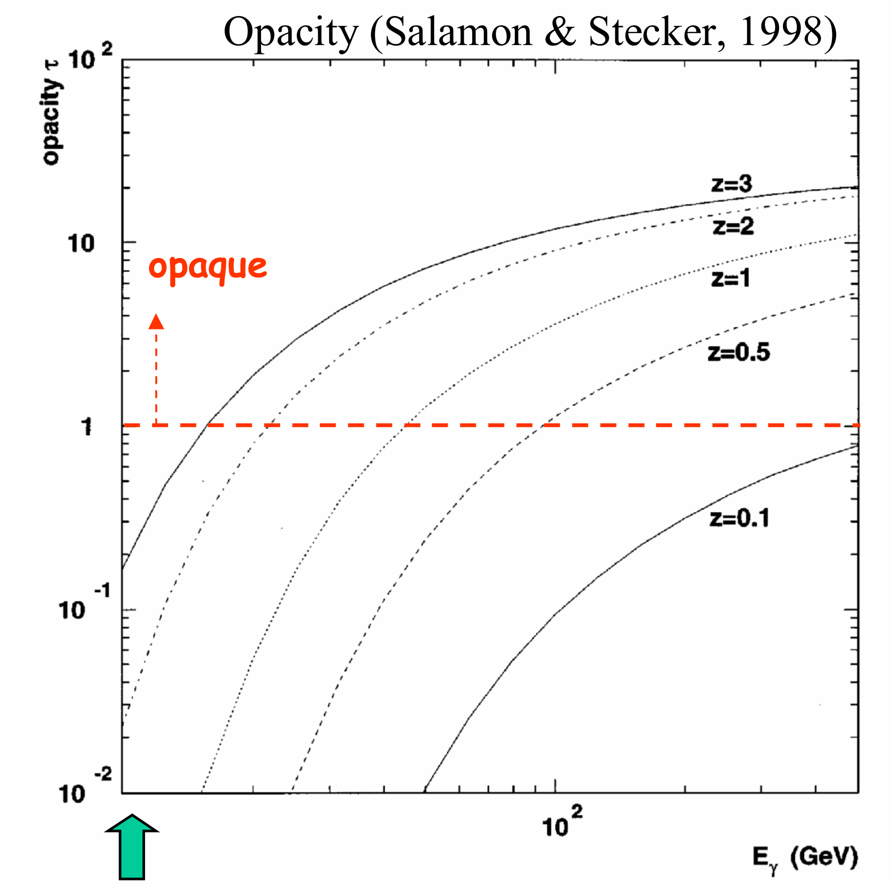
Simulated LAT (>1 GeV, 1 yr)

Why study γ's?

Gamma rays:

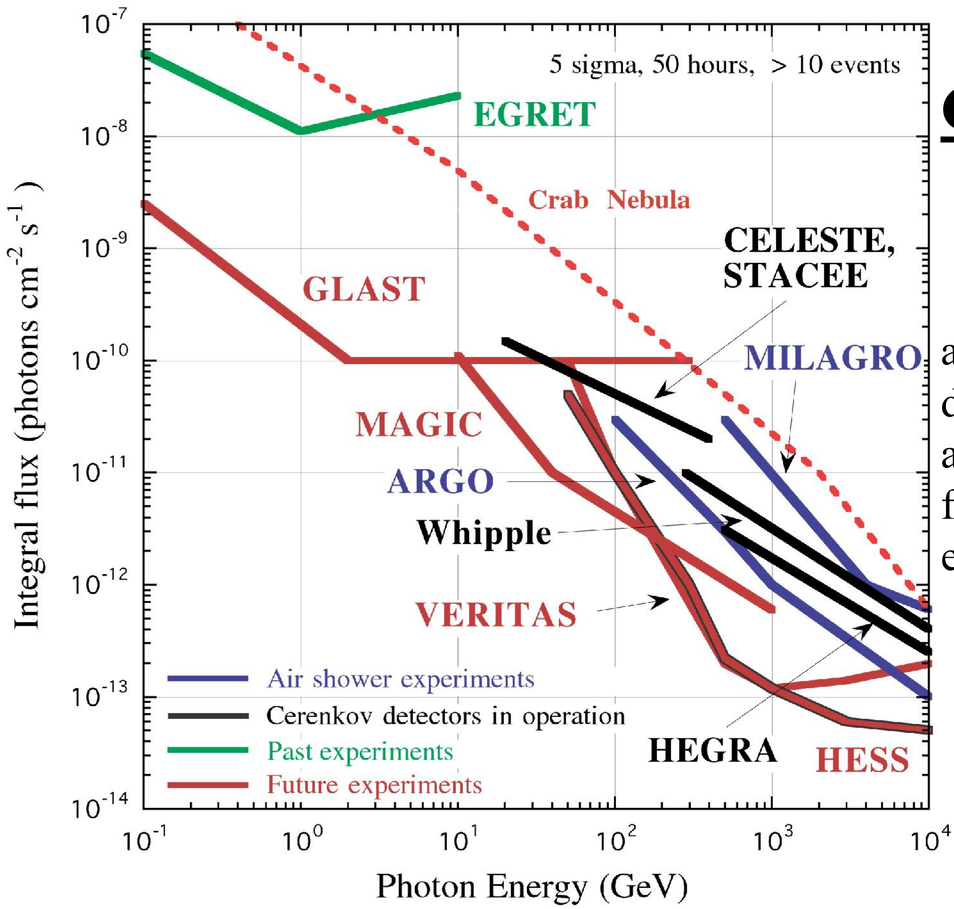
- Source:
  - γ rays do not interact much at their source: they offer a direct view into Nature's largest accelerators.
  - the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent.
  - γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.
- Detection:
  - γ rays readily interact
  - Very clear signature.
- Good probe for new physics!
  - Decays of possible dark matter particles
  - Tests of fundamental physics (lorentz invariance, etc)

only $e^{-\tau}$ of the original source flux reaches us



No significant attenuation below ~10 GeV.

Gamma-ray Observatories



Complementary capabilities

	ground-based		space-based
	ACT	EAS	Pair
angular resolution	good	fair	good
duty cycle	low	high	high
area	large	large	small
field of view	small	large	large+can reorient
energy resolution	good	fair	good, w/ smaller systematic uncertainties

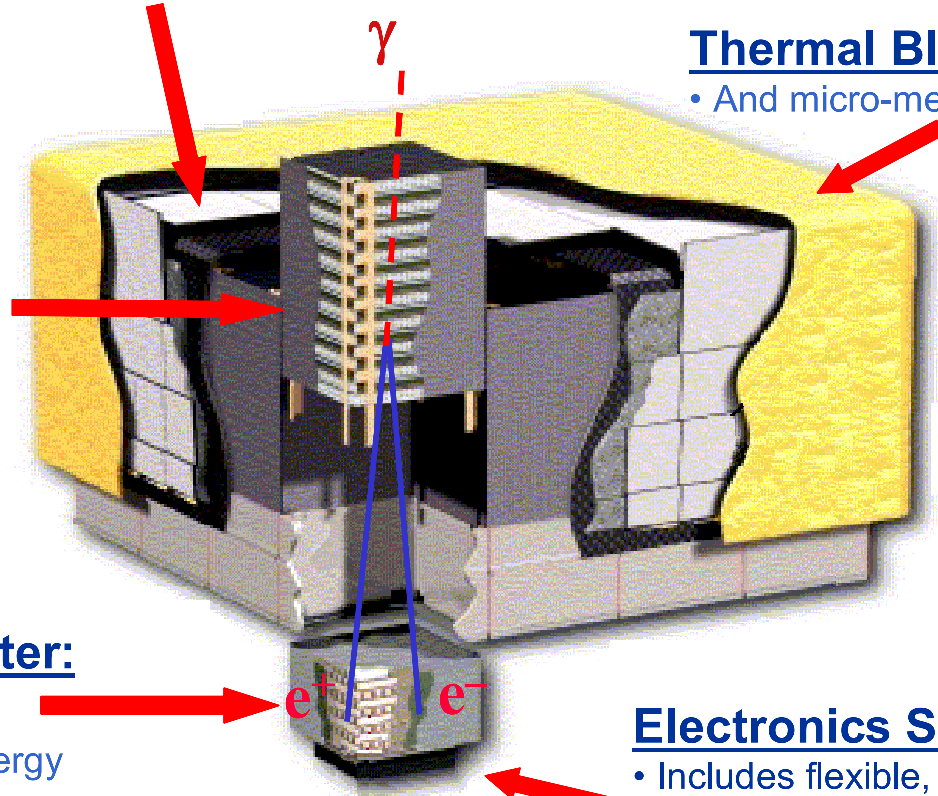
The next-generation ground-based and space-based experiments are well matched.

GLAST LAT Overview: Overall Design

Overall LAT Design:
•4x4 array of identical towers
•3000 kg, 650 W (allocation)
•1.8 m × 1.8 m × 1.0 m
•20 MeV – >300 GeV

Anticoincidence Detector:
• Highly efficient segmented scintillator tiles
• First step in reduction of large charged cosmic ray background
• Segmentation reduces self veto at high energy

Thermal Blanket:
• And micro-meteorite shield



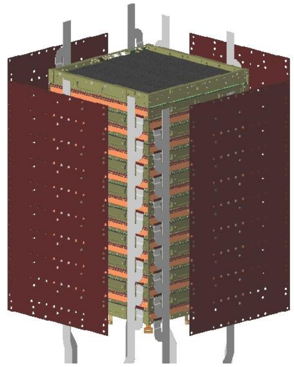
Precision Si-strip Tracker:
• Detectors and converters arranged in 18 x-y tracking planes
• Measures incident gamma direction

Hodoscopic CsI Calorimeter:
• Segmented array of CsI crystals
• Measures the incident gamma energy
• Rejects cosmic ray backgrounds

Electronics System:
• Includes flexible, highly-efficient, multi-level trigger

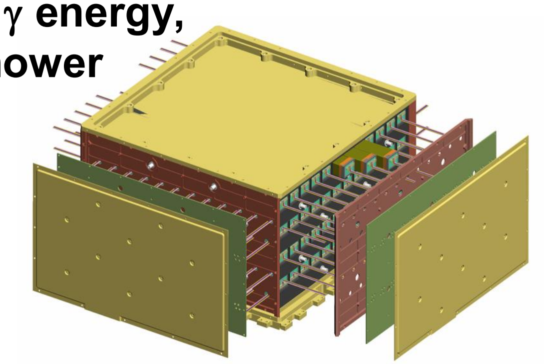
GLAST LAT Overview: Main Components

➢ **Si-strip TKR**
measure the γ direction



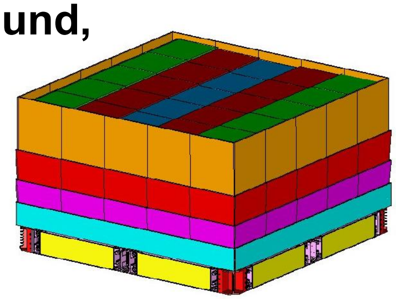
- 18XY tracking planes (~10k single-sided SSD)
- $5.5{\cdot}10^4$ channels (per tower) – $8.8{\cdot}10^5$ total
- 228 μm pitch, digital readout
- self-triggering
- hit efficiency > 99% with noise occupancy <~10^{-5}
- 1.5 X_0 total
- power (total) < 170 W

➢ **Hodoscopic ECAL**
measure the γ energy, image the shower



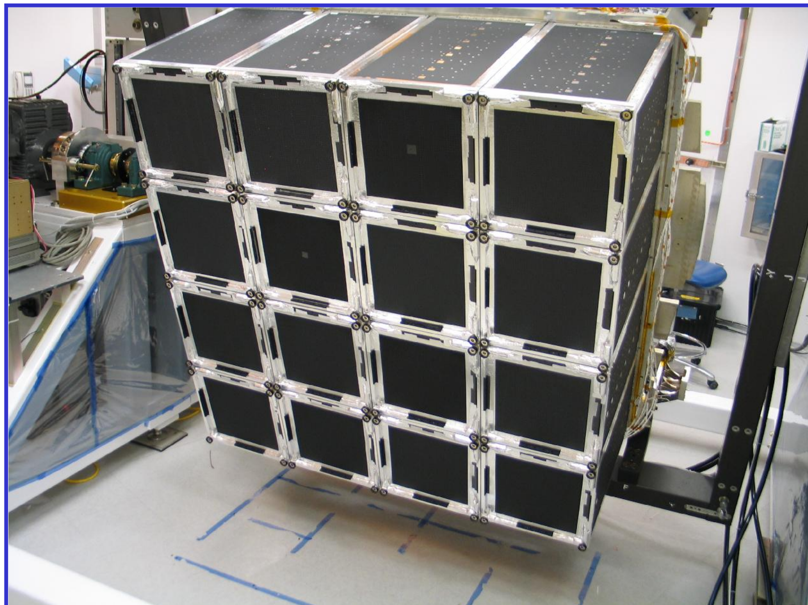
- 1536 CsI crystals (8 layers) 2x2.7x33 cm^3
- 6.1 10^3 channels (per tower)
- 2 PIN diodes per end; 2 gain ranges each
- ~ 1500 kg
- self-triggering
- 8.5 X_0 total
- power (total) < 91 W

➢ **Segmented ACD**
reject C.R. background, removes self-veto effects at high energy

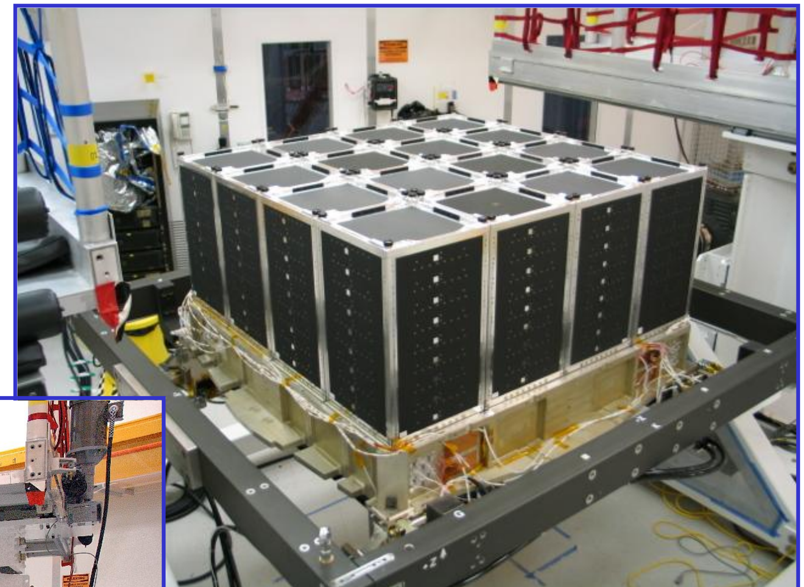


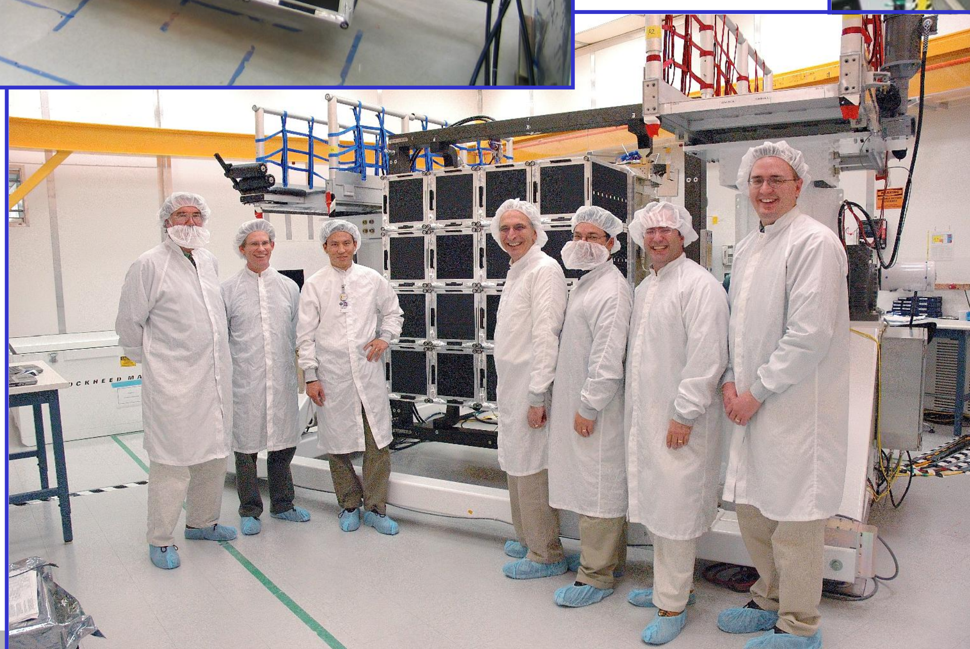
- 89 tiles – 1 cm thick
- 2 phototubes per tile
- Waveshifting fiber embedded
- White Tetratec wrapping
- Charged particle efficiency > 0.9997
- Power < 31 W total

LAT Status: The Real Device!



Pictures of LAT nearing completion of assembly
(before installation of the ACD)





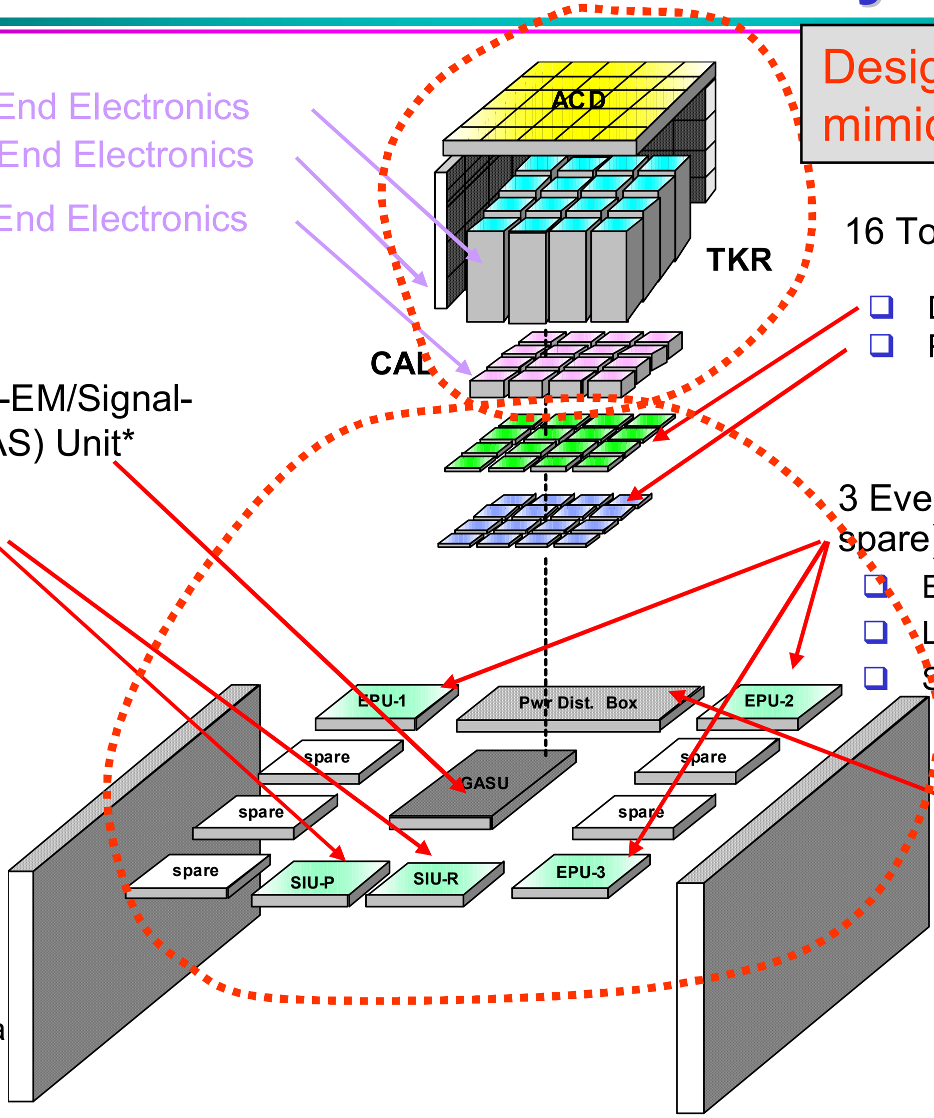
LAT Assembly Complete!!
Will soon leave SLAC for
Integration with spacecraft!

DAQ/Electronics System

Design Test Electronics to mimic Front-End.

TKR Front-End Electronics
ACD Front-End Electronics

CAL Front-End Electronics



16 Tower Electronics Modules (TEM)

- DAQ electronics module (DAQ-EM)
- Power-supplies for tower electronics

Global-Trigger/ACD-EM/Signal-Distribution (GAS) Unit*

Spacecraft Interface Unit (SIU) (1+1 spare)

- Storage Interface Board (SIB): EEPROM Storage, Spacecraft MIL1553 interface, control & data
- LAT control CPU
- LAT Communication Board (LCB): LAT command and data interface

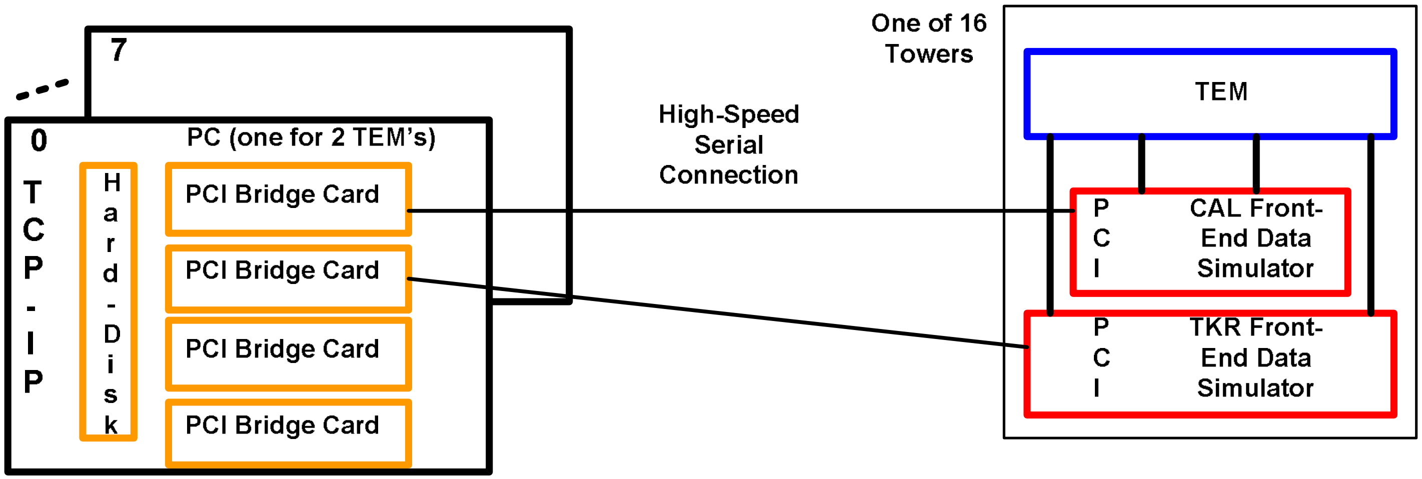
3 Event-Processor Units (EPU) (2+1 spare)

- Event processing CPU
- LAT Communication Board (LCB)
- Storage Interface Board (SIB)

Power-Distribution Unit (PDU)*

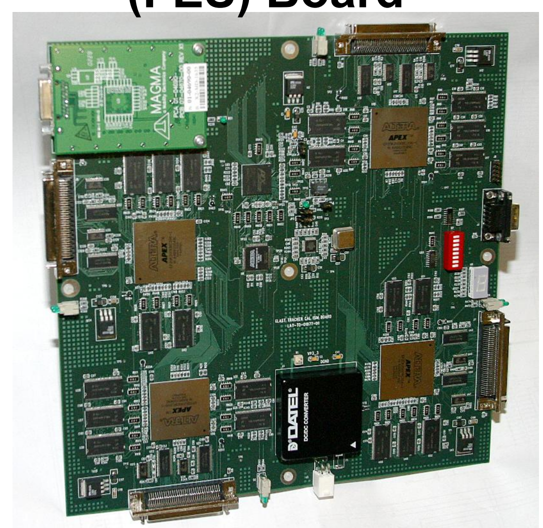
- Spacecraft interface, power
- LAT power distribution
- LAT health monitoring

Front-end Simulator



- System uses 9 PC's
  - 8 PC's for 16 TEM's
  - 1 PC for ACD
- Data transported to towers via high-speed data link; PCI bridge to local bus on simulator
- Data Simulators interface to TEM like CAL and TKR sub-system electronics
  - CAL and TKR simulator board identical except code in FPGA's
- Can operate TEM or LAT with data generated from simulations

Front-end Simulator (FES) Board



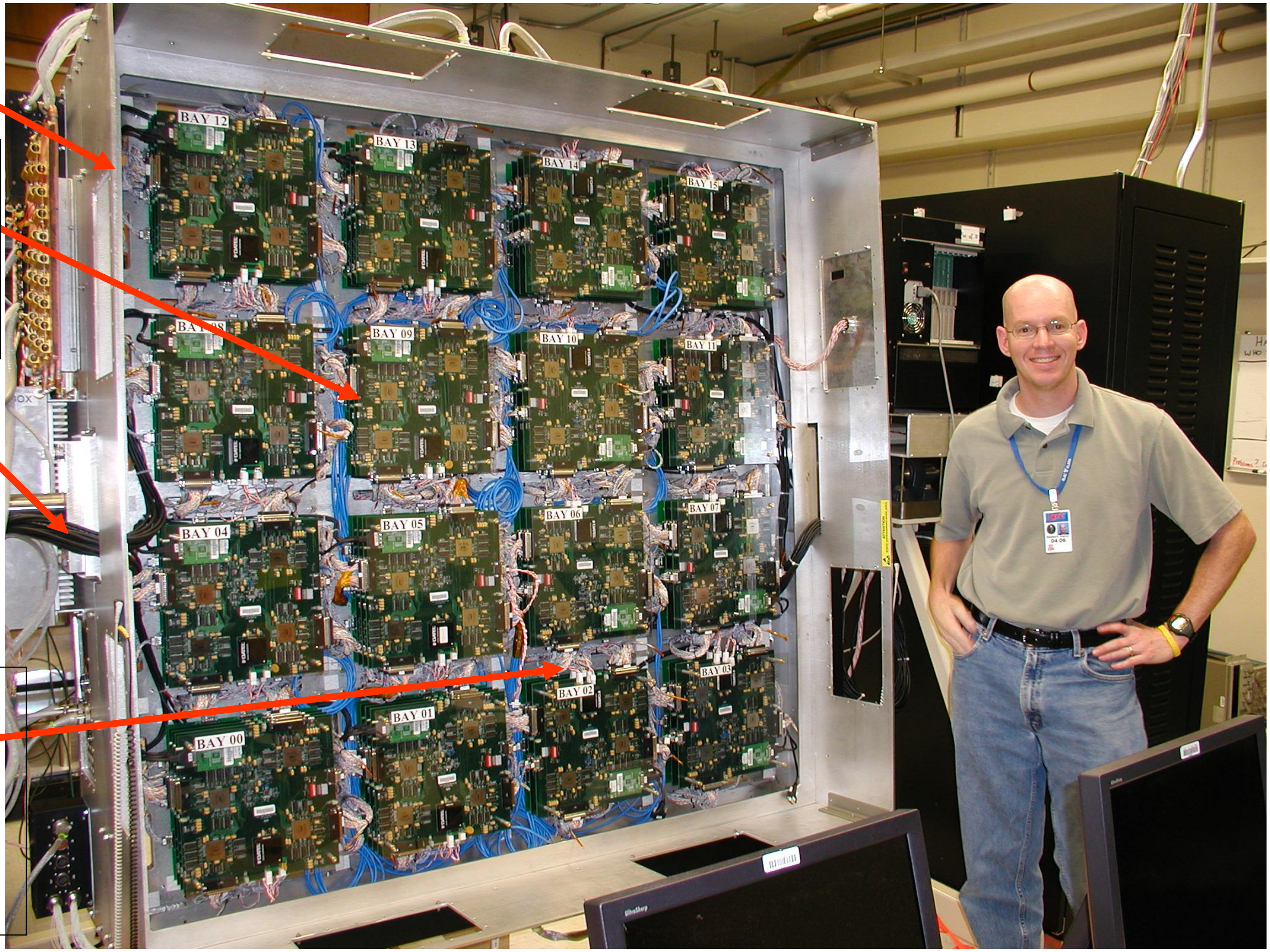
Testbed at SLAC

4 x 4 Array of Towers.

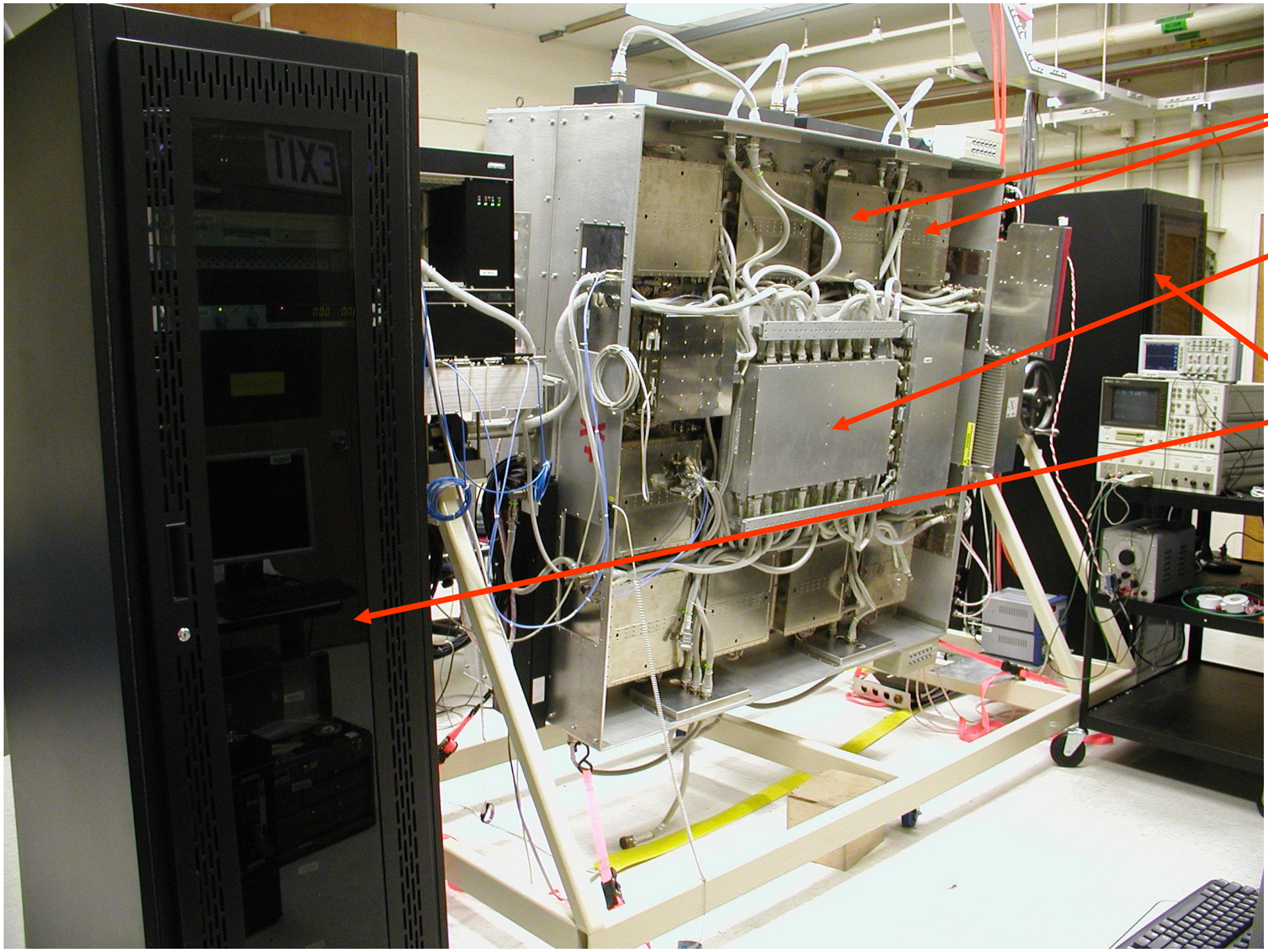
Multiple FES Boards for driving CAL, TKR, ACD, clk

Cables connecting FES Boards to PCs. (Mounted in black racks)

Cables connecting FES Boards to TEMs on opposite side of structure



TestBed at SLAC



TEMs

GASU

Racks with PCs for driving FES boards.

Operation of trigger and filter

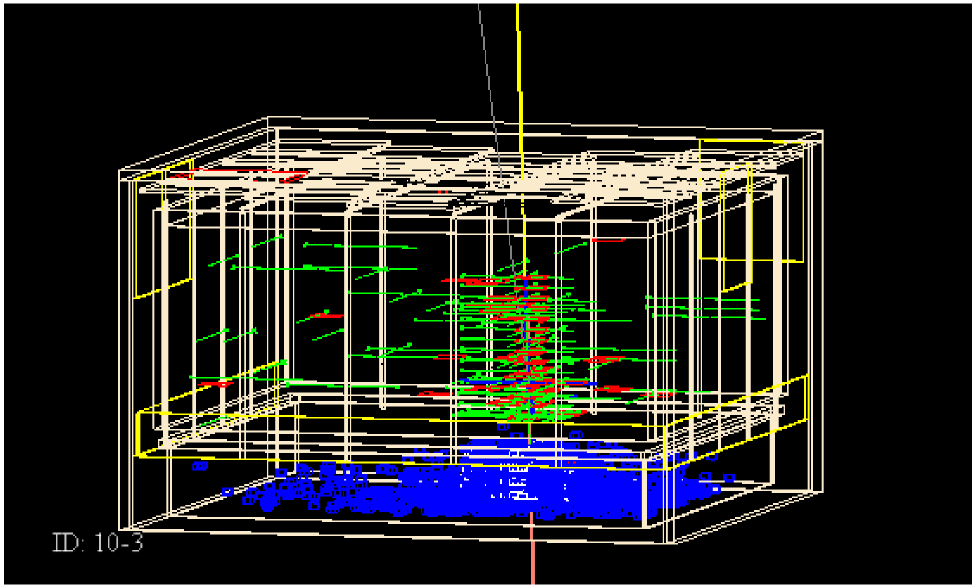
Level 1 Hardware Triggers

(Did anything happen?)

- Tkr 3-in-a-row
  - 3 *x,y* planes hit in a row
  - "workhorse" ©- ray trigger
- CAL-LO
  - any log with >100MeV
- CAL-HI
  - > 0 crystals with > 1GeV
  - indicates a high energy event
- CNO
  - ACD hit with high discriminator signal
- Throttle
  - a tower with a Tkr 3-in-a-row is shadowed by an ACD hit

Combinations of these trigger primitives are used to define a hardware trigger

Example of photon LAT, producing e+/e- pair, triggering a Tkr 3-in-a-row and depositing energy in certain CAL crystals



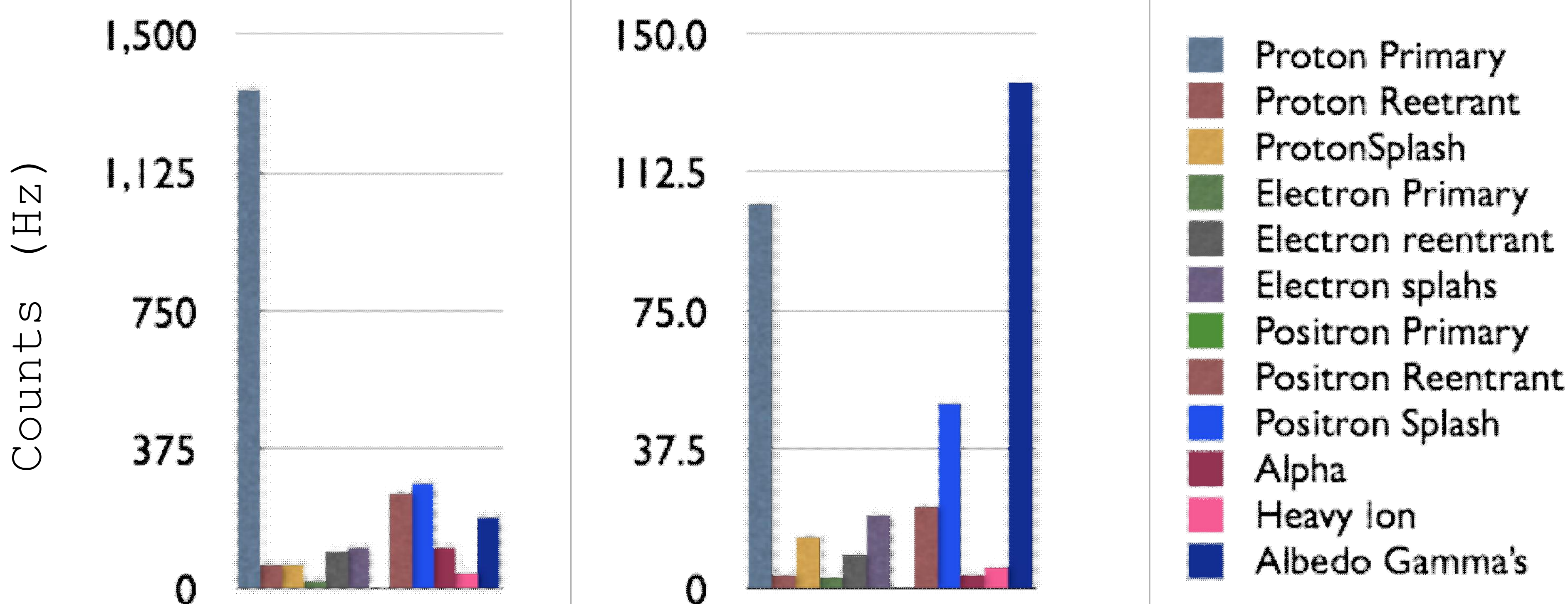
Upon L1trigger: all towers read out within 20µs

L1 trigger rate ~ <3kHz>

Non γ Background Composition

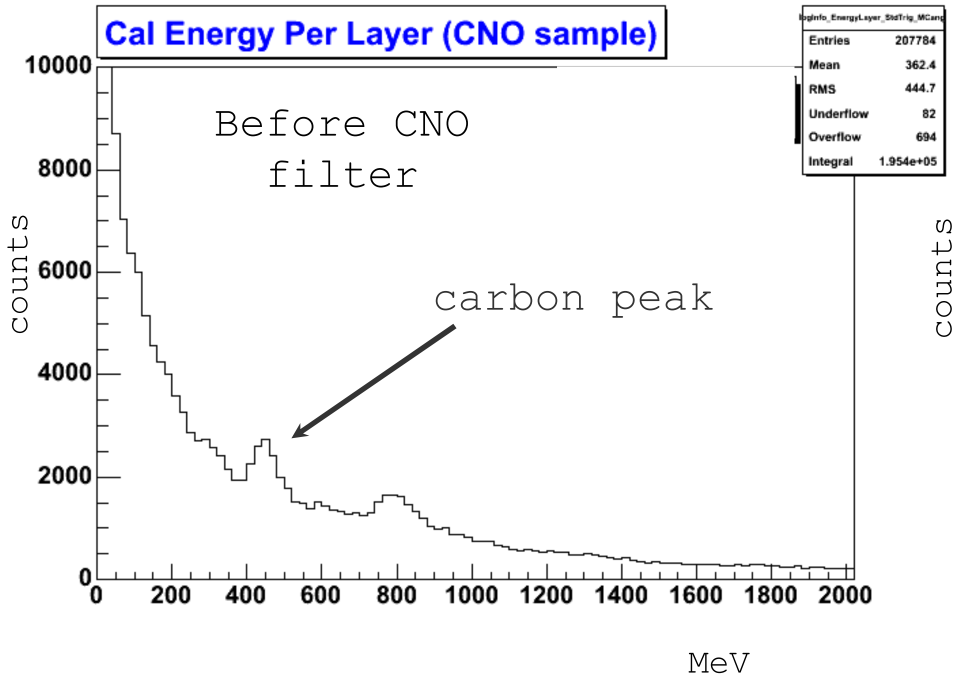
How well does the onboard filter reject the background?

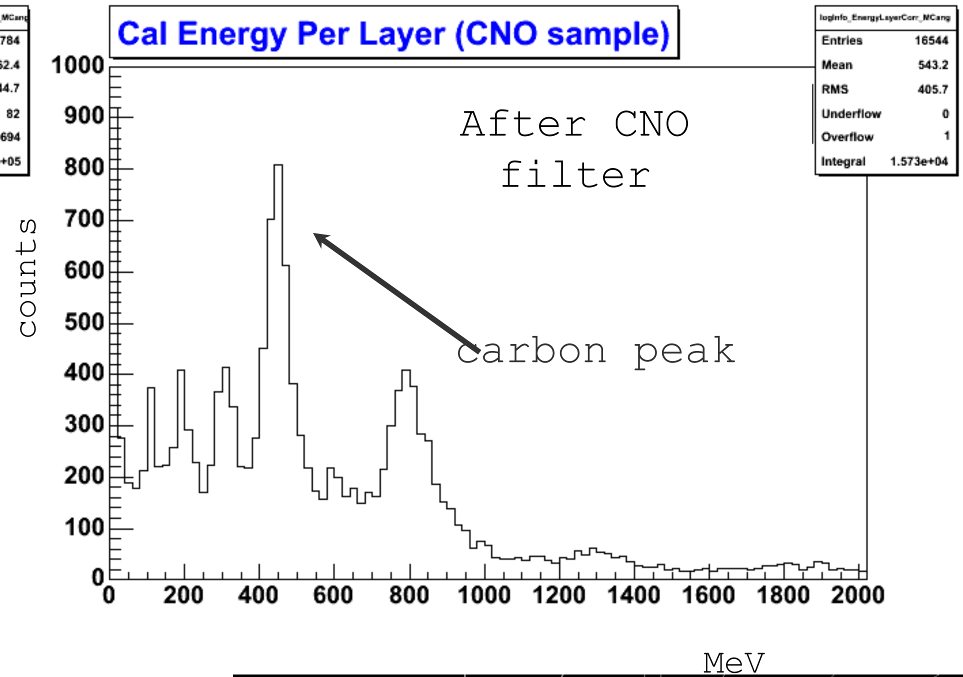
Hardware Trigger	After Onboard Filter



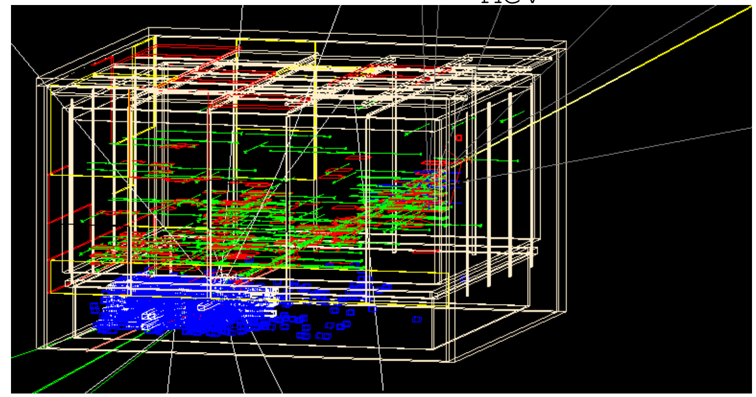
Total Rate ~2600 Hz	Total Rate ~370 Hz

CNO Filter:Energy Calibration



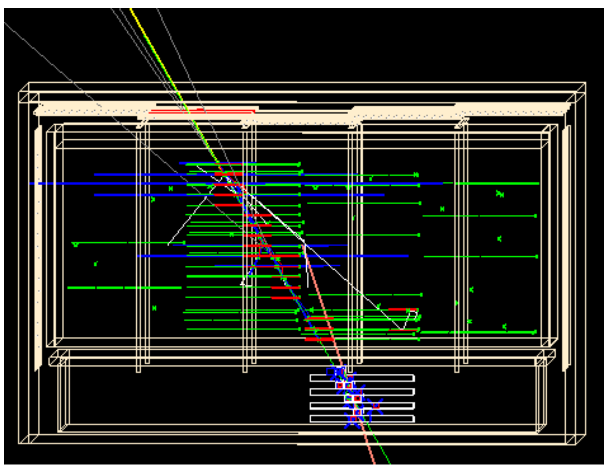


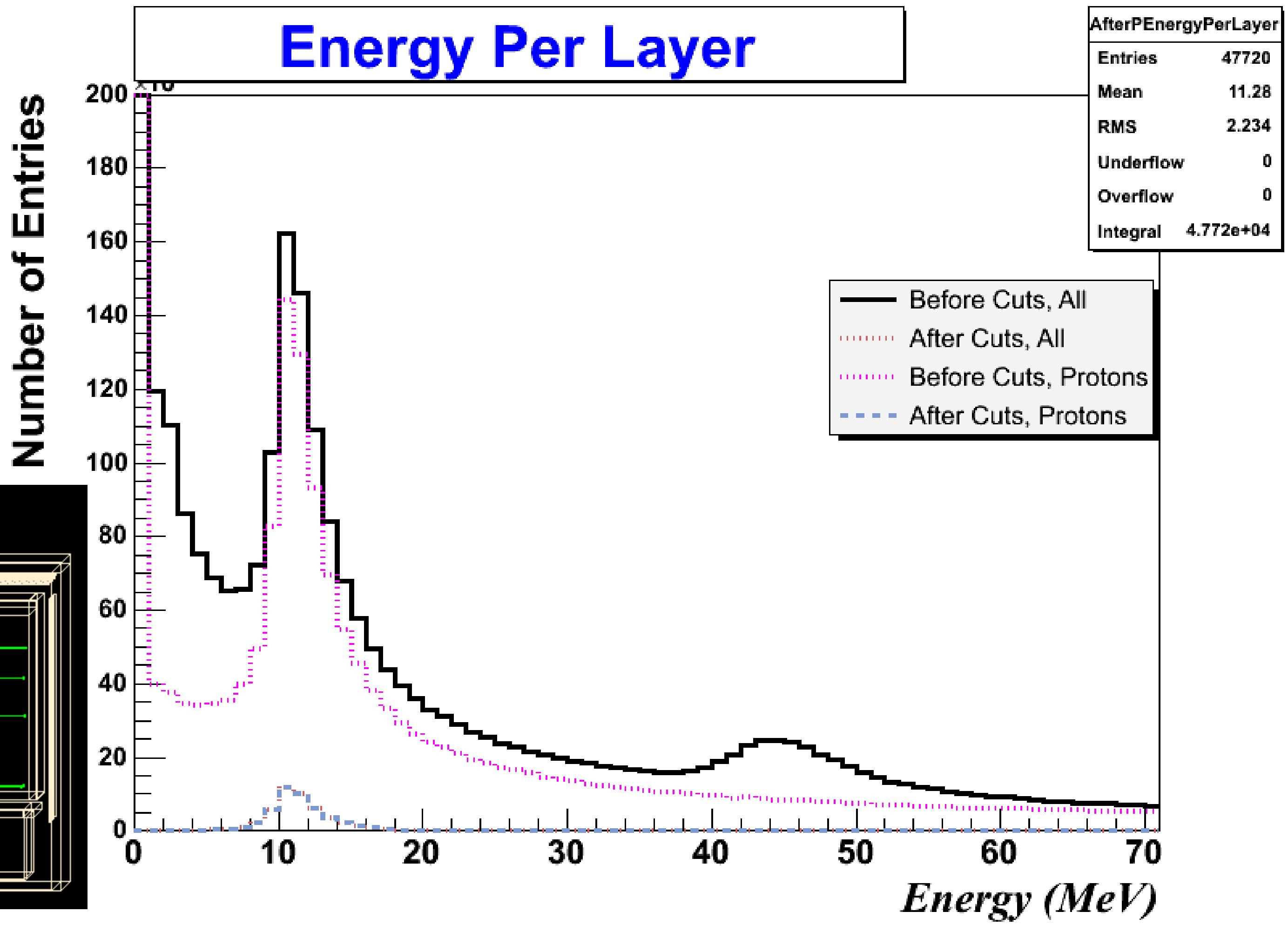
- Use MIPs to calibrate CAL
  - MIPs leave a characteristic amount of energy in each layer
  - MIPs do not shower
- We know the real energy of each peak which allows us to convert signal into the real energy



Tracker alignment filter
For intra-tower alignment

Use MIP protons passing through 2 towers to find relative alignment of towers

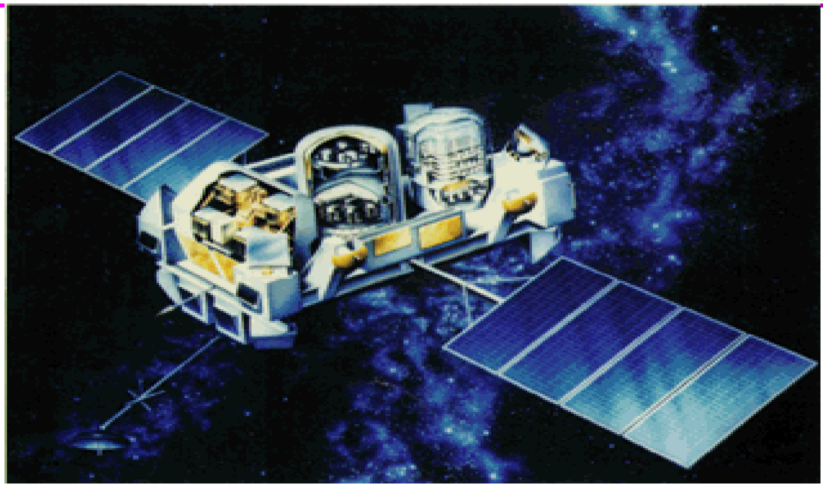


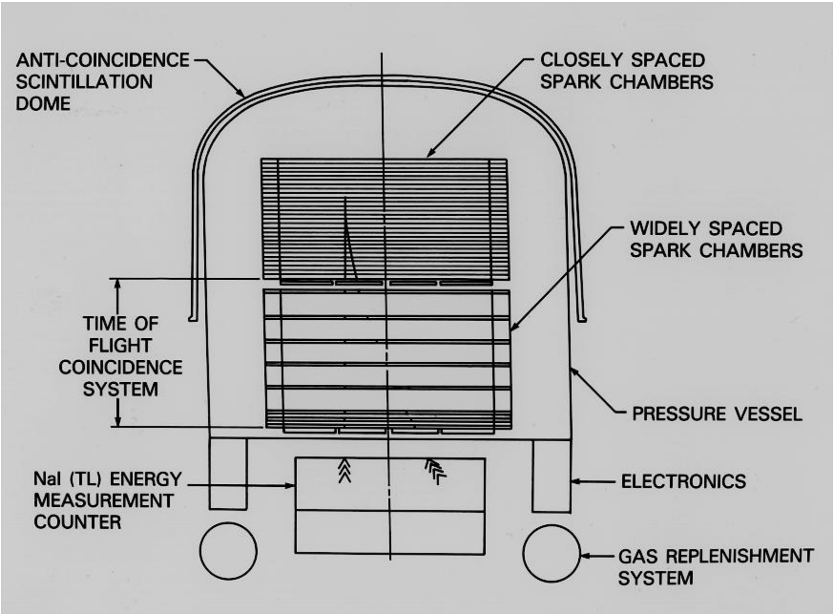


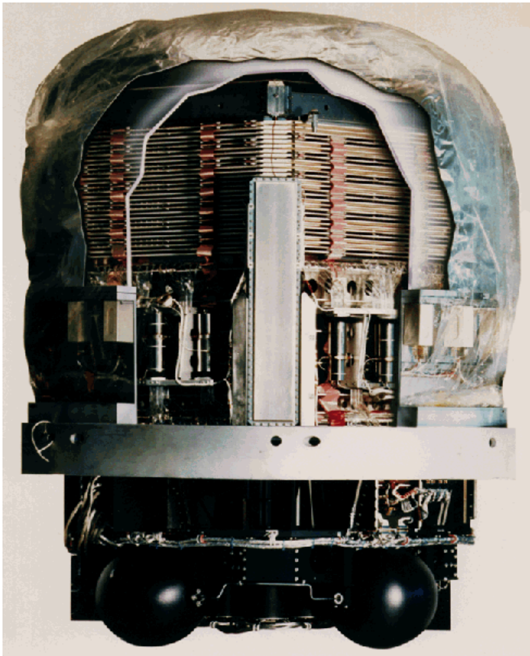
EGRET

Compton Observatory: 1991-2000

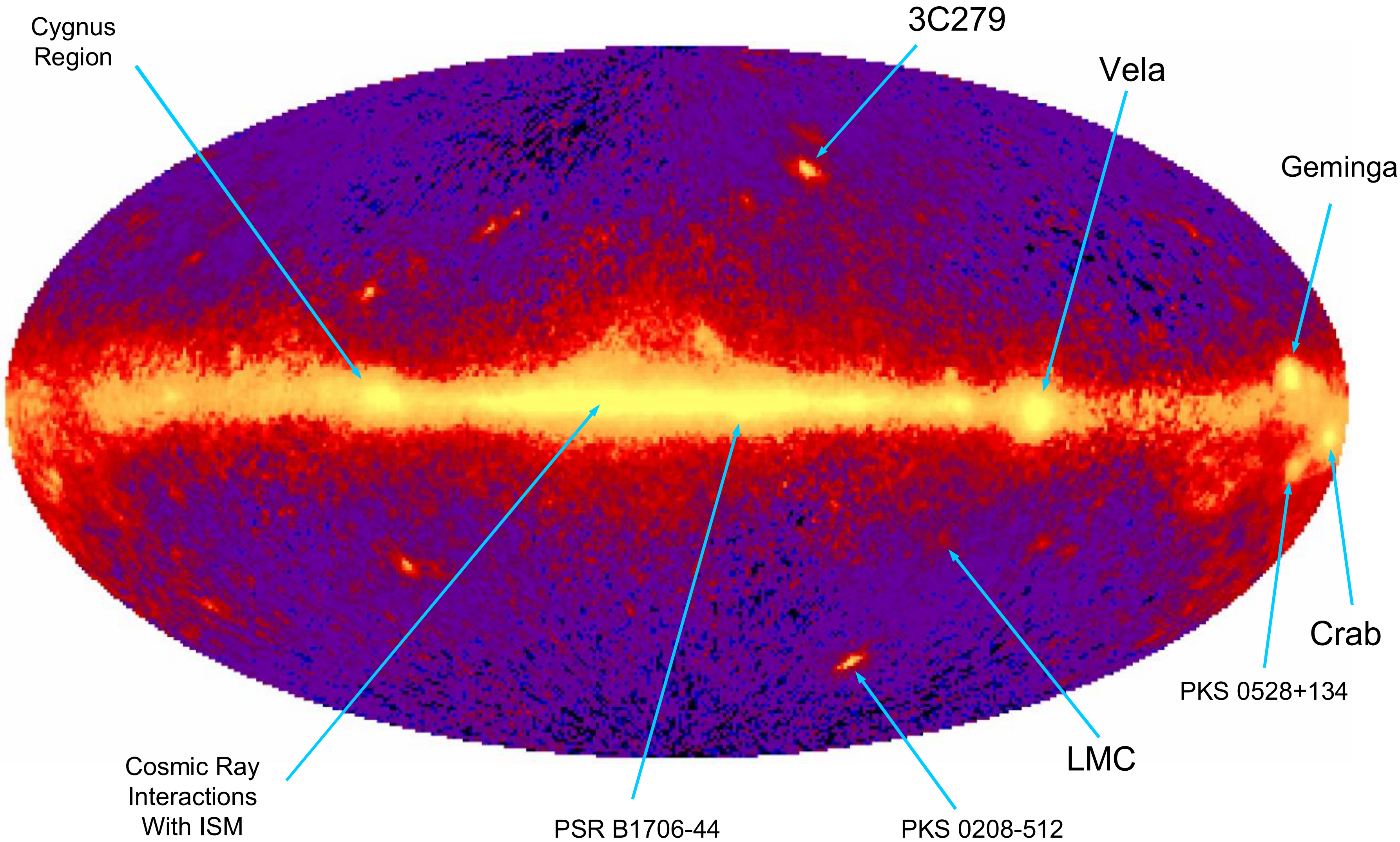
- BATSE, OSSE, and Comptel < MeV
- EGRET 30 MeV – 30 GeV
  - 1st proposed in late 1970s
  - Spark Chamber with NaI calorimeter







EGRET All Sky Map (>100 MeV)



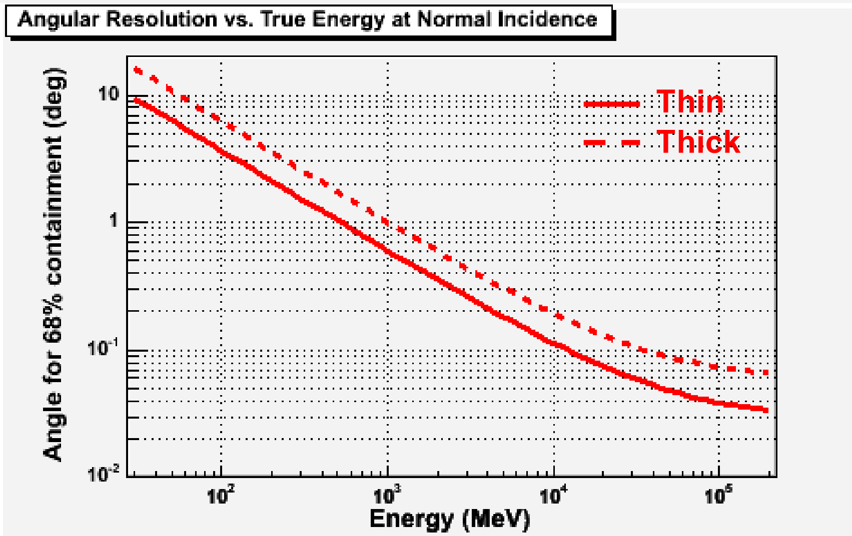
Success of EGRET

- EGRET:
  - First complete survey of the high energy gamma-ray sky
  - 271 point sources
  - Detected 7 gamma-ray pulsars
  - Detected high energy gamma-rays from solar flares
  - Discovered large number of AGNs
  - Discovered multi-GeV emission from gamma-ray bursts (GRBs)

GLAST will explore the unexplored energy range above EGRET's reach, filling in the present gap in the photon spectrum, and will cover the very broad energy range ~ 20 MeV - 300 GeV (→ 1 TeV) with superior acceptance and resolution. Historically, opening new energy regimes has led to the discovery of totally unexpected new phenomena.

Estimated LAT PSF, Energy, A_{eff} Performance

From Detailed Monte Carlo Studies

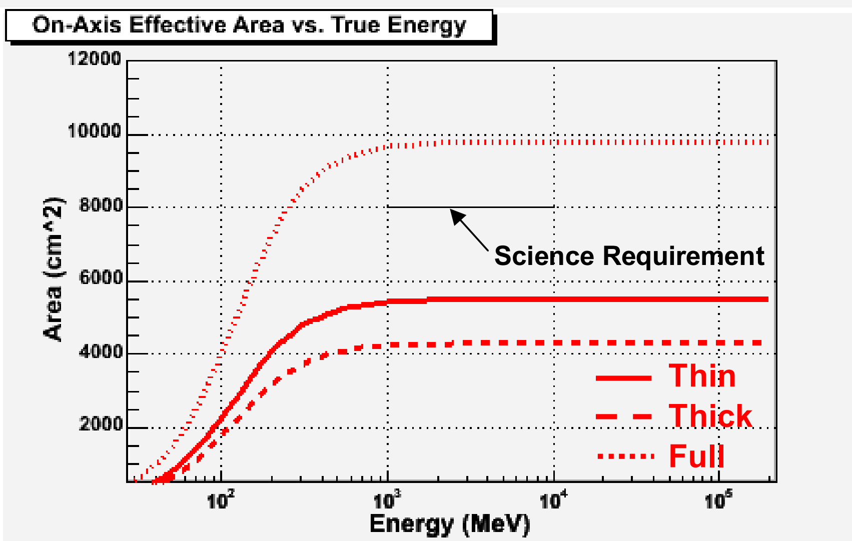


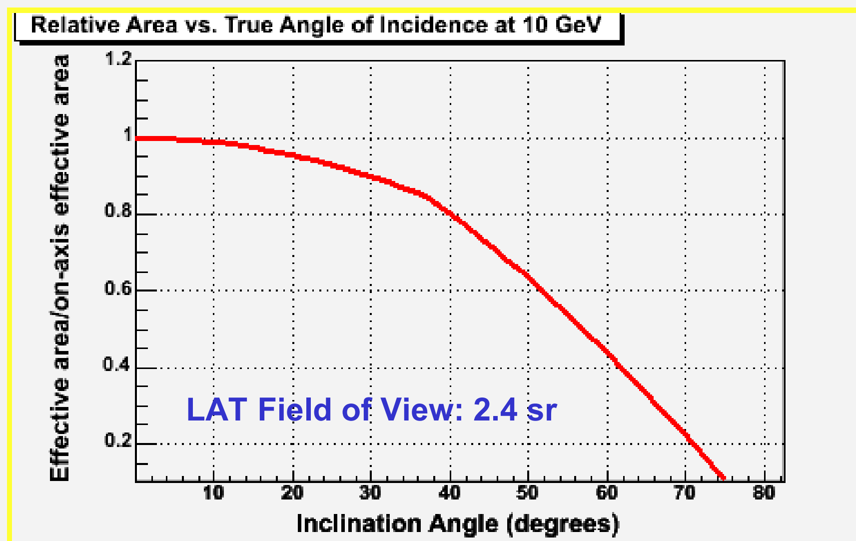
Important Parameters

PSF Requirements:
⇒100 MeV on axis: < 3.5^0
⇒10 GeV on axis: < 0.15^0
⇒95%/68% containment ratio: < 3

Effective Area Requirements:
⇒Peak Aeff (range 1-10 GeV): >8000 cm^2

Field of View: > 2 sr



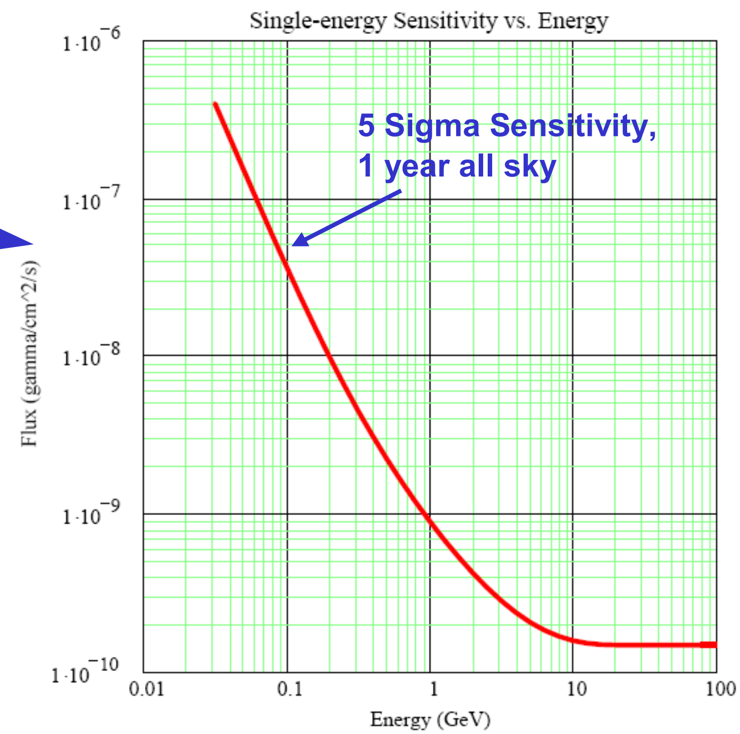


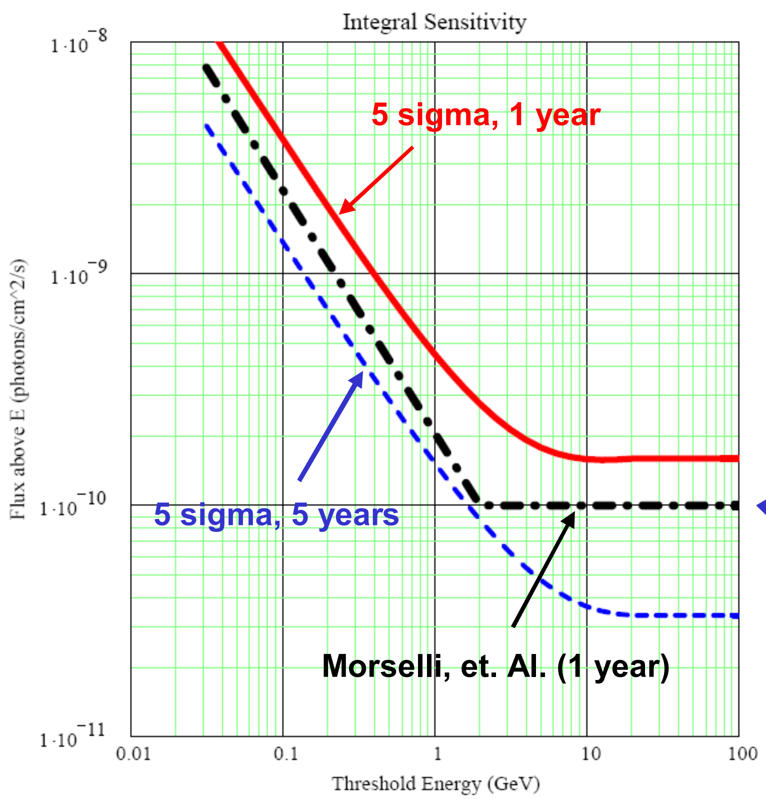
Estimated LAT Performance

Expected Sensitivity With Current Performance Parameters

Single Energy Sensitivity:

- 5 sigma sensitivity to a high latitude source
  - ⇒ Source energy assumed to be a delta function
- This plot:
  - ⇒ One year (livetime) all-sky survey
  - ⇒ Diffuse background flux





Integral Sensitivity:

- Frequently quoted for comparing experiments
  - ⇒ See Morselli, et. al. Nucl Phys B85(2000)
- 5 sigma sensitivity to a high latitude source
  - Source assumed to have a $1/E^2$ spectrum
- This plot:
  - ⇒ 1 year all sky-survey
  - ⇒ 5 year all-sky survey

Science Requirement (E > 100 MeV): 6.10^{-9} $cm^{-2}s^{-1}$

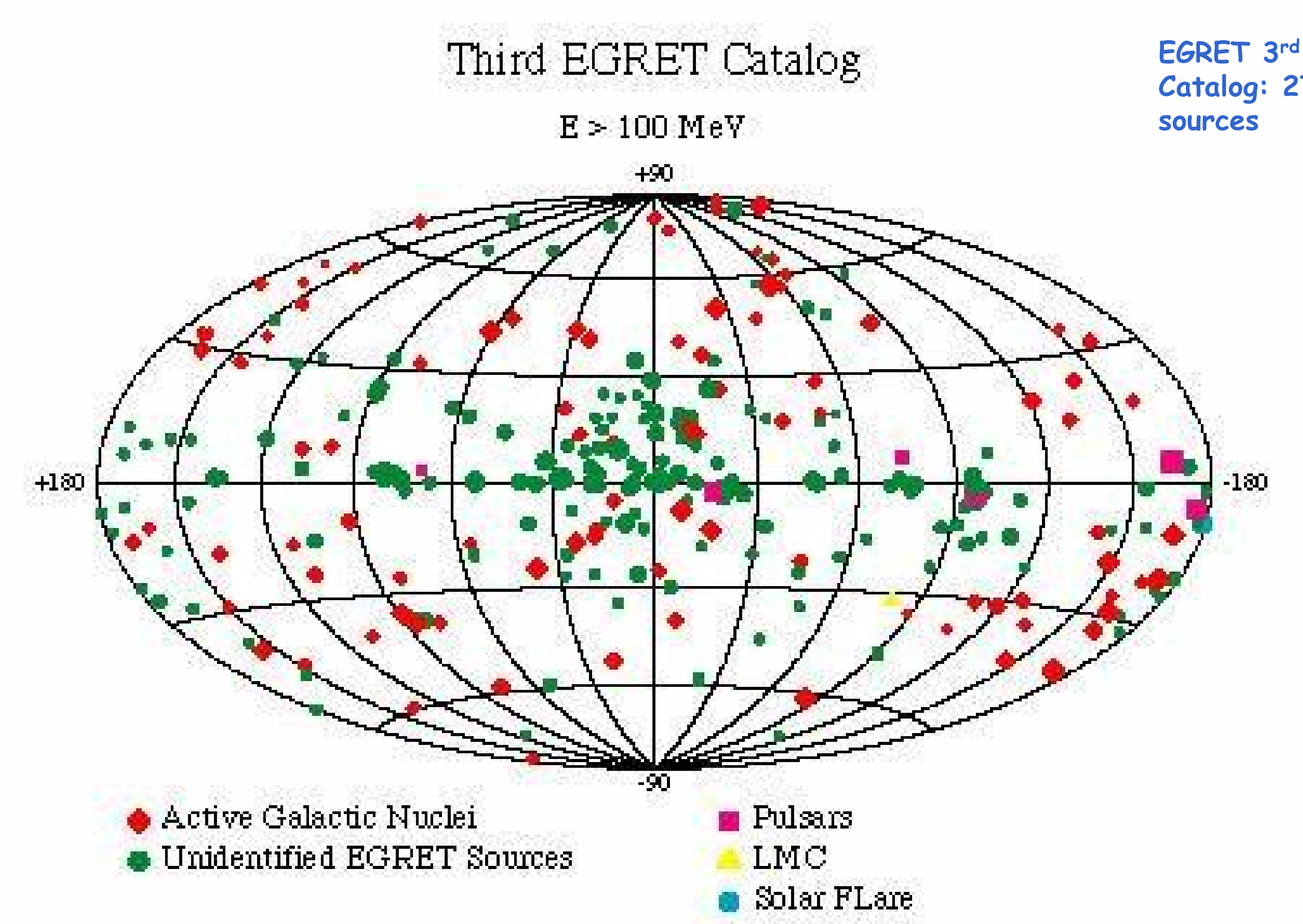
What GLAST expects to see

Source class	Seen by EGRET	Predicted with GLAST
Unidentified sources	170	?
Pulsars	3-6	100-500
Blazars	50-80	>2000
Normal galaxies	2	4-5
Gamma ray bursts	5	>500
Supernova Remnants/plerions	1-5	>10
Radio galaxies	1-1	?
X ray binaries	1-1	?
Starburst galaxies	0	?
Cluster of galaxies	0	?

Rates after 5 years

~7 days of GLAST
= 1 year of EGRET

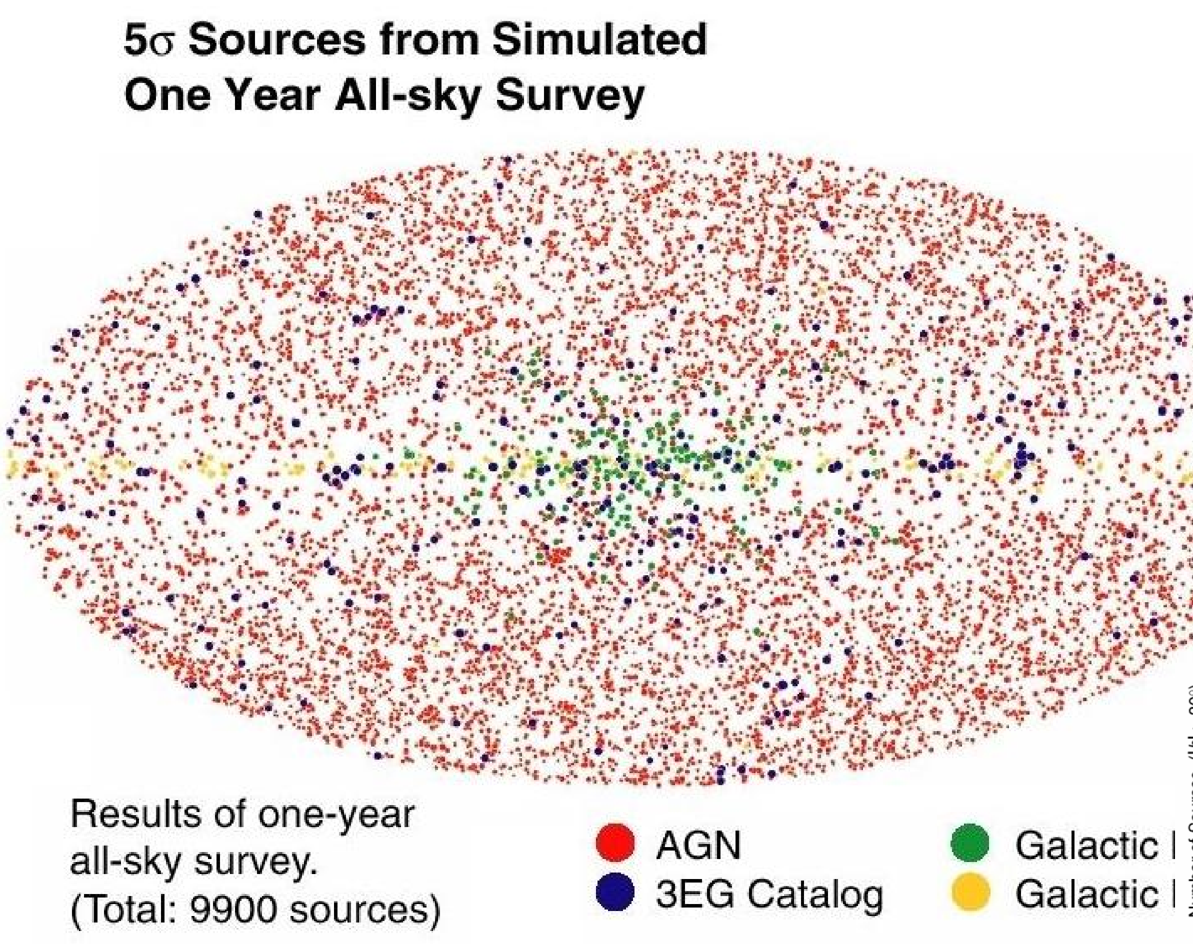
EGRET Sources

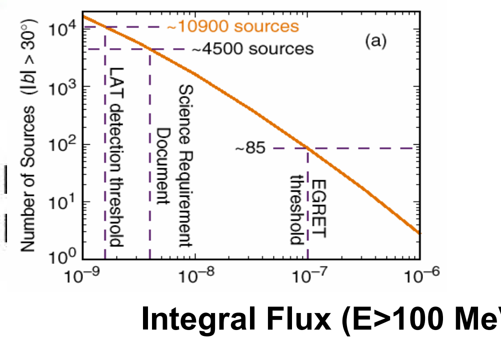


EGRET 3rd Catalog: 271 sources

Expected GLAST Sources

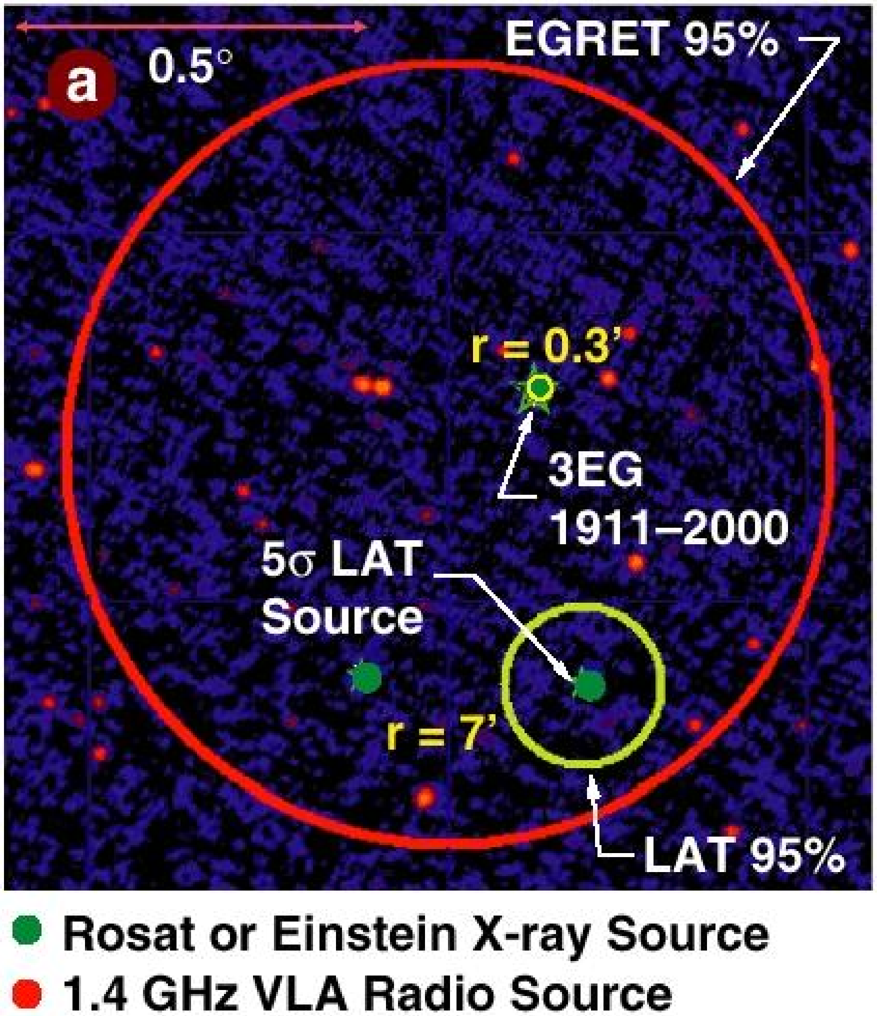
LAT 1st Catalog:
>9000 sources possible





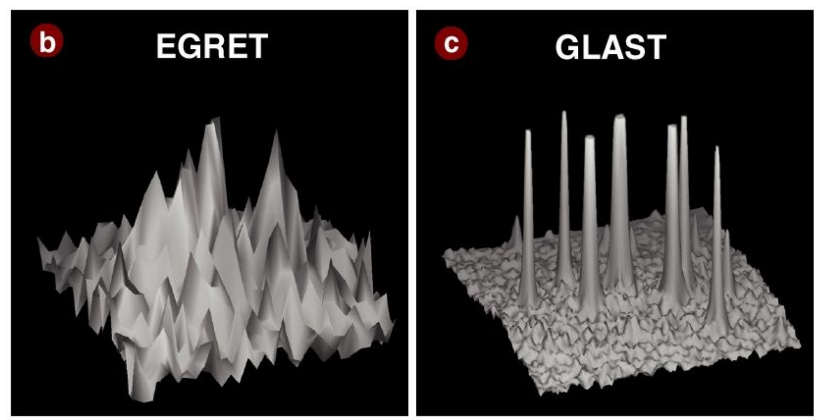
Unidentified Sources

172 of the 271 sources in the EGRET 3rd catalog are "unidentified"



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

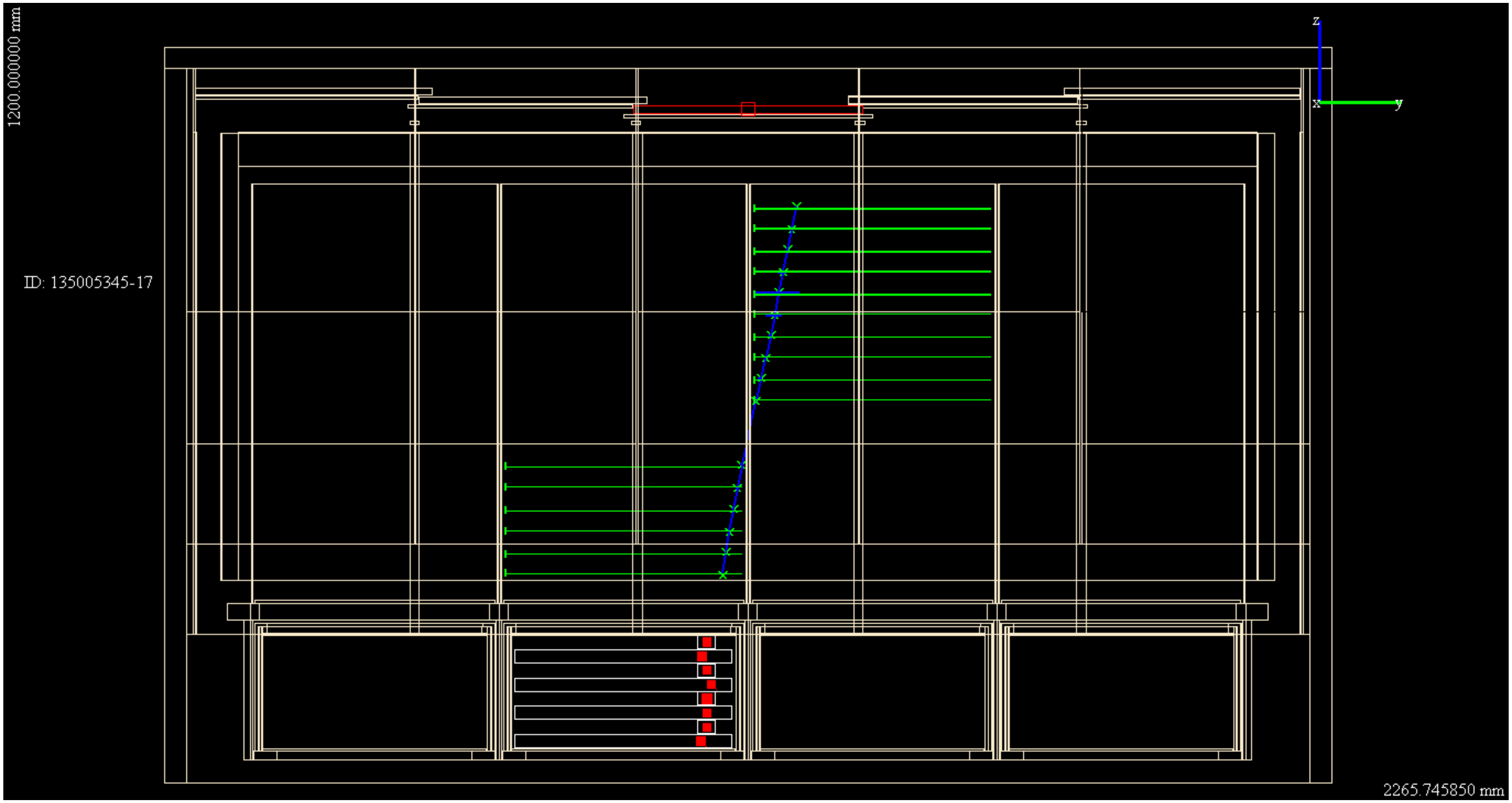
GLAST will provide much more accurate positions, with ~30 arcsec - ~5 arcmin localizations, depending on brightness.



Cygnus region (15x15 deg)

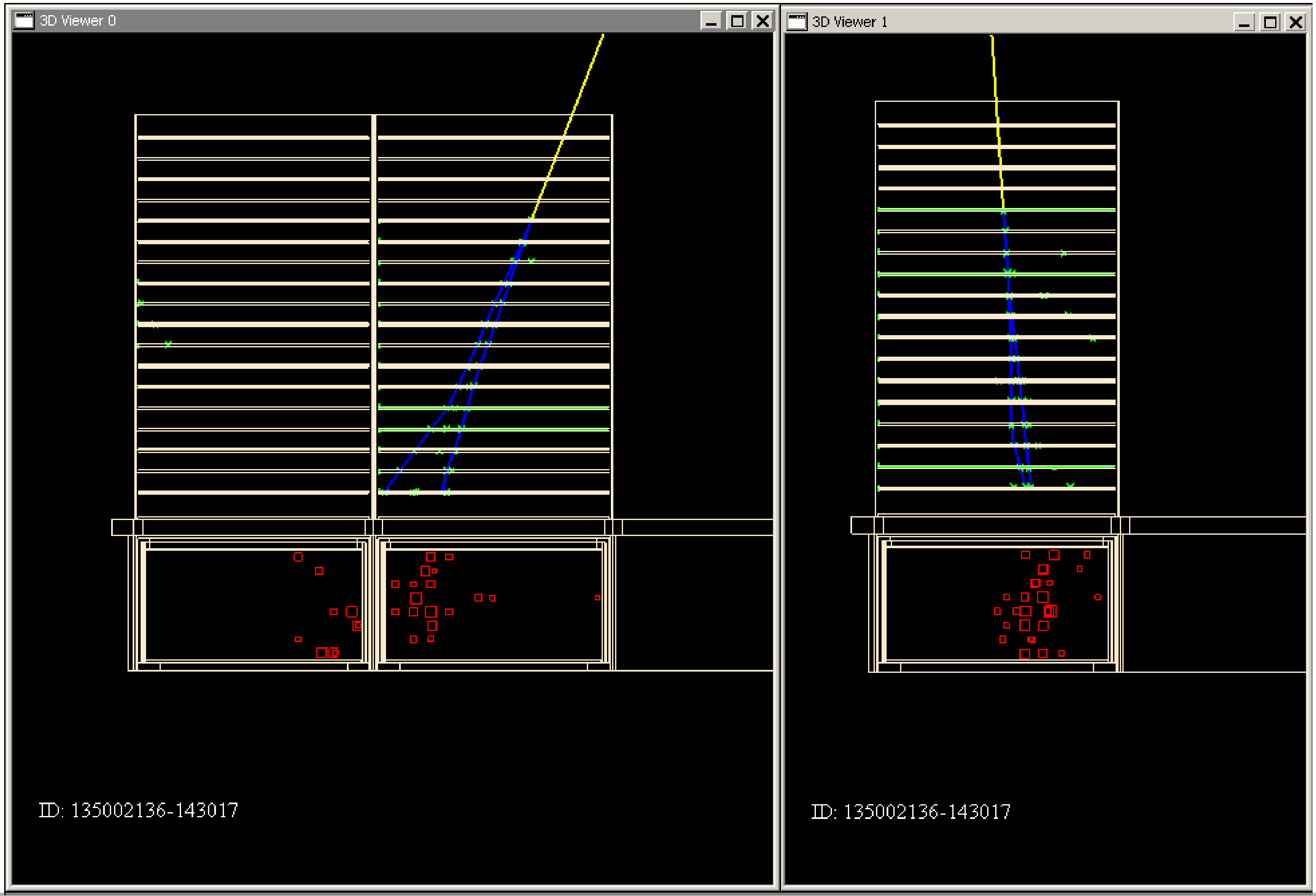
Cosmic Rays in the LAT: The Movie

Muons taken during Integration and Testing with the full LAT



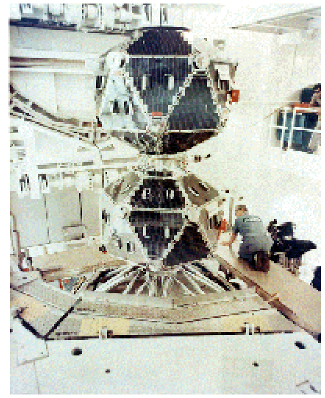
Cosmic Rays in the LAT: A Gamma-Ray

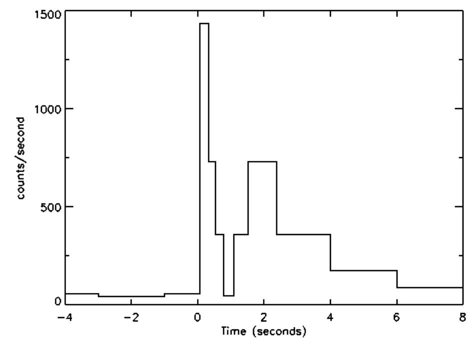
CR Muon induced Gamma-Ray recorded during 2 Tower testing of the LAT



Gamma Ray Bursts

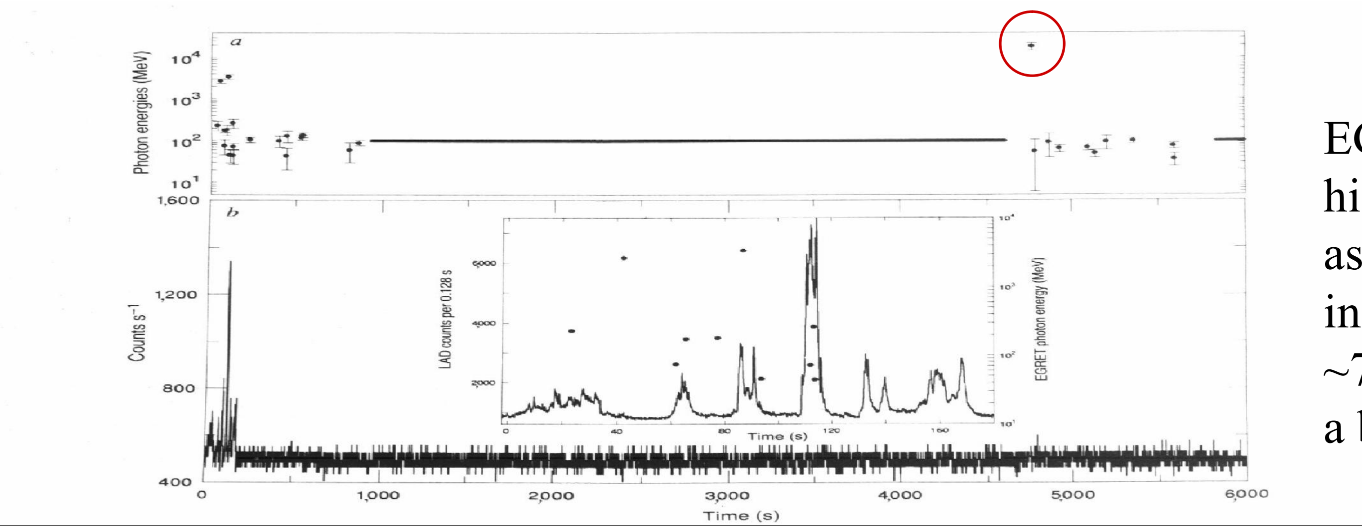
- Extemely bright objects, with very large power output, lasting anywhere from seconds to hours
  - discovered in 1967 by the Vela military satellites, searching for gamma-ray transients
- Right: Hubble images of GRB 050709
  - Detected by HETE
  - Chandra and Swift observed X-ray afterglow
  - Hubble observed optical afterglow (5,10, 19, 35 days after burst)
- Short vs long bursts:
  - Short: Merging binaries?
  - Long: massive star collapsing to black hole?



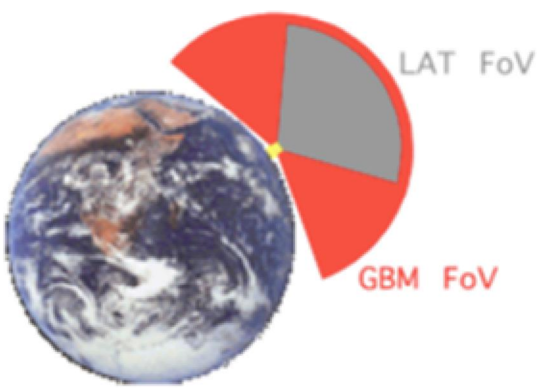


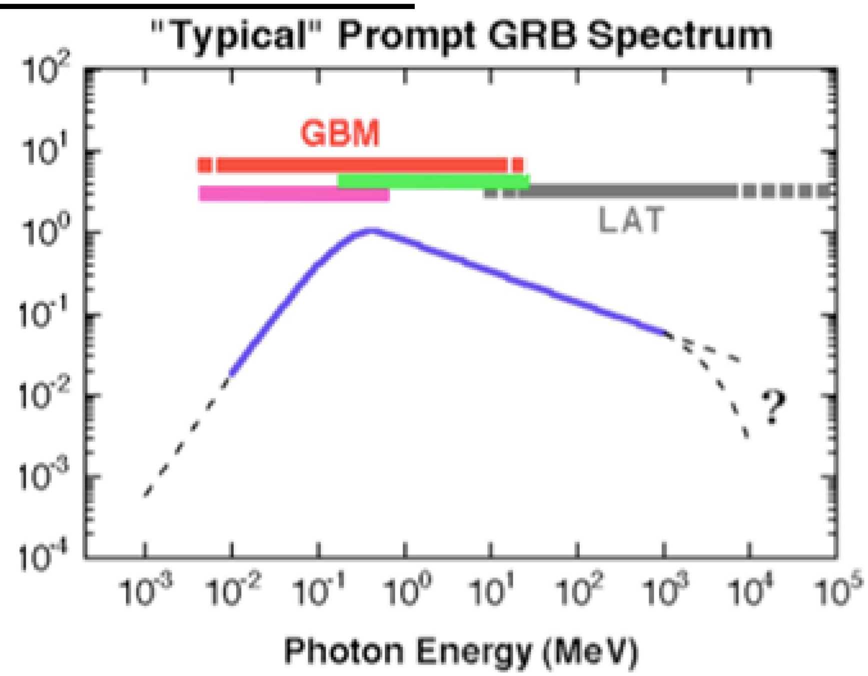
QuickTime™ and a
H.263 decompressor
are needed to see this picture.

GLAST GRB Sensitivity

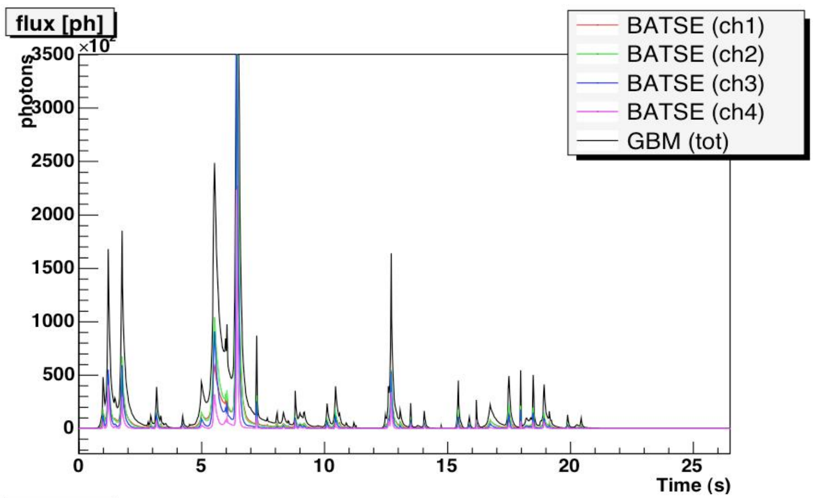


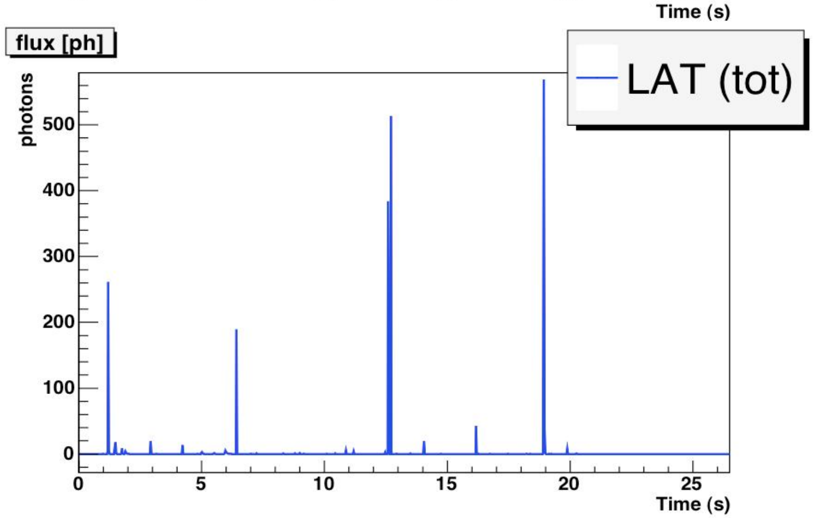
EGRET has detected very high energy emission associated with bursts, including an 18 GeV photon ~75 minutes after the start of a burst:



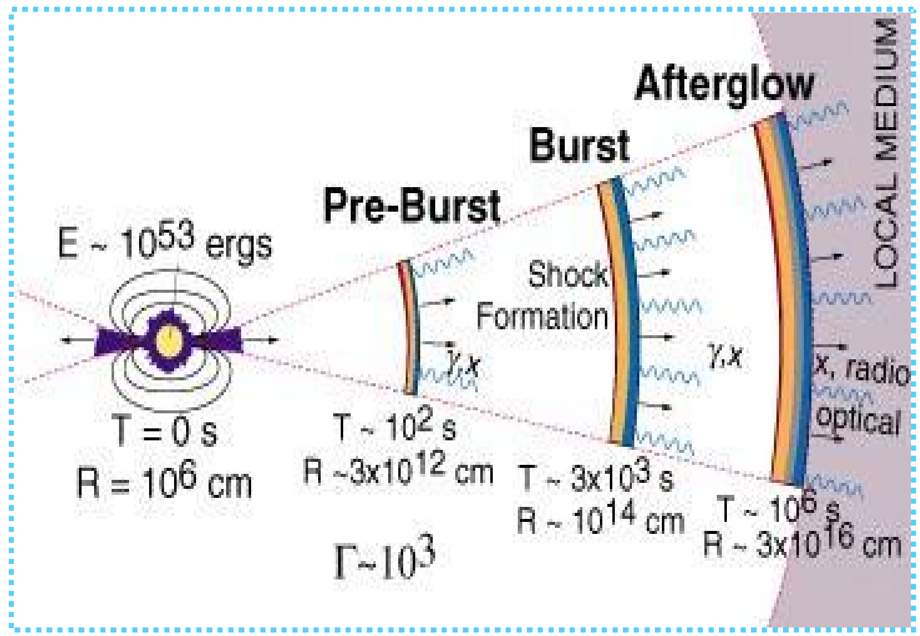


GLAST Simulations: (GRB Models)

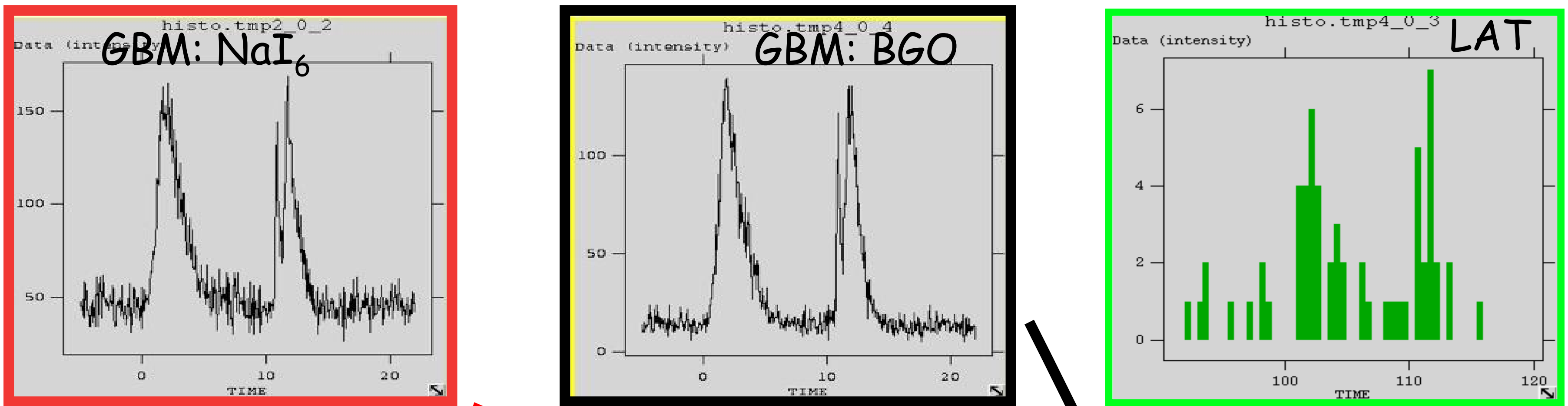




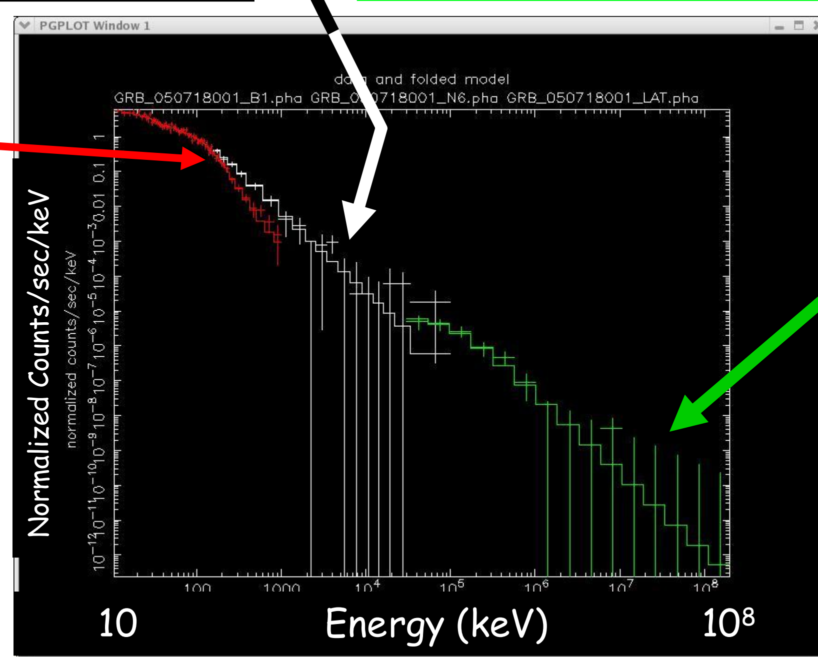
- Phenomenological:
  - Use observed distributions from BATSE.
  - Must extrapolate to LAT Energies.
- Physical Models:
  - Example: Fireball Model (Piran, 1999)
- Generated photons sent through GBM/LAT detector simulation. (See below)



GLAST Simulations: (Detectors)

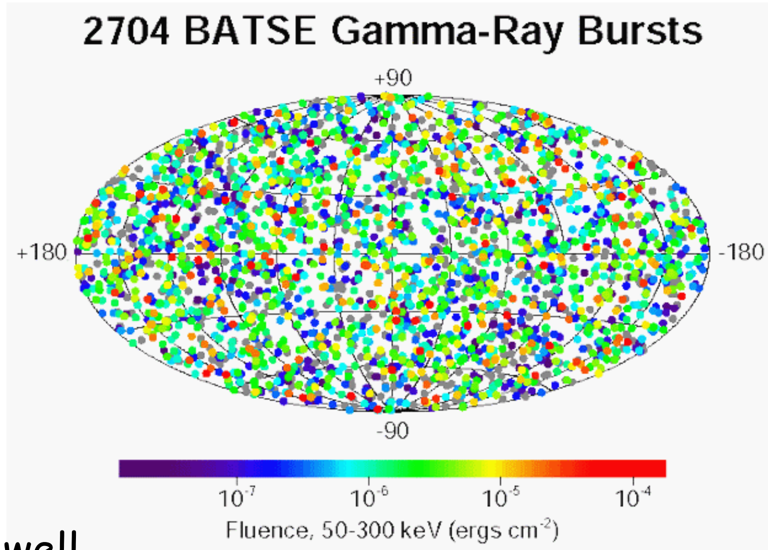


- Two Methods for detector simulation:
  - Full Simulation using GEANT4.
  - Parameterized Response Function.
- Simulate response of both GBM and LAT.
- Energy Spectrum
  - Combined detectors cover ~7 decades in energy.

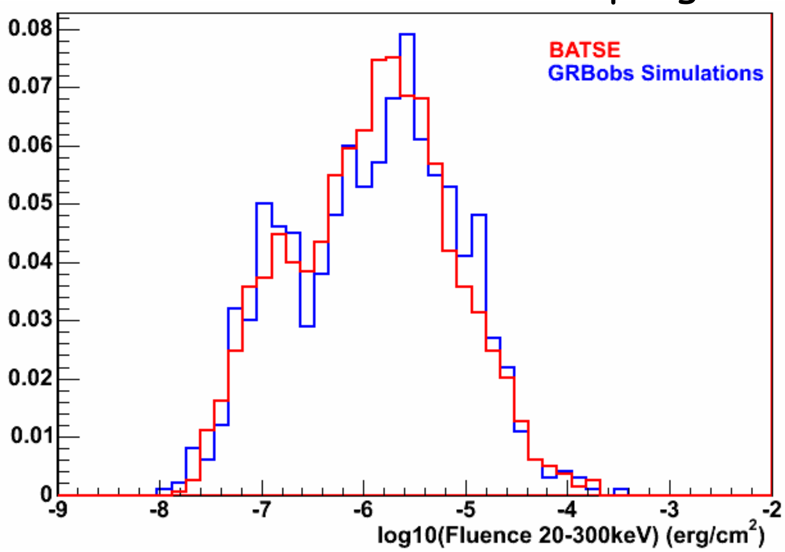


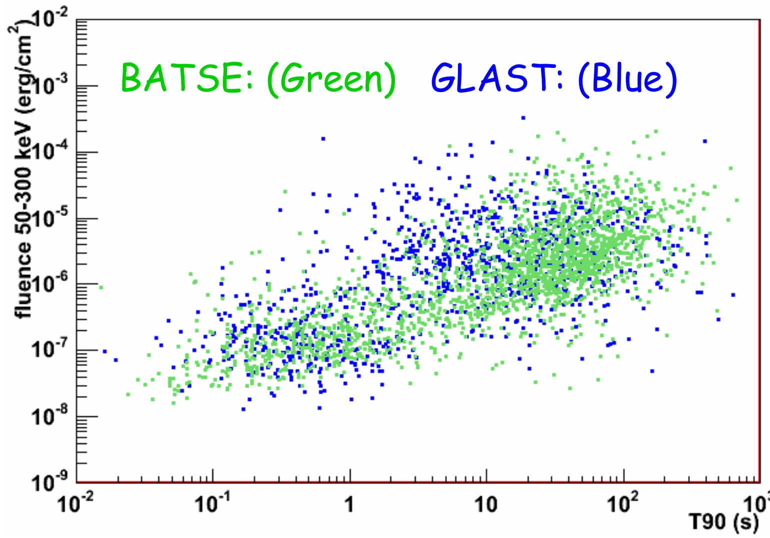
GLAST Simulations: (GRB Rates)

- Start with BATSE Catalog
  - Predict about 650 burst/year per 4π.
  - Sample GRB characteristics
    - Duration, Flux,spec. index, etc.
- Simulate 1 year of GLAST.



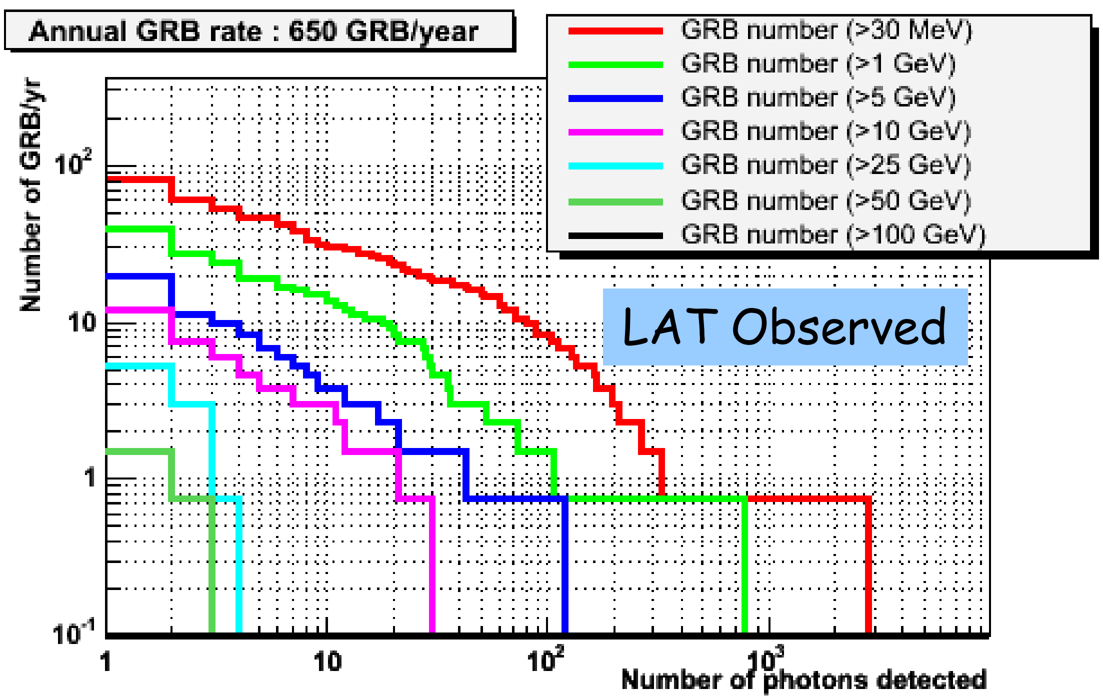
Sampling distributions well



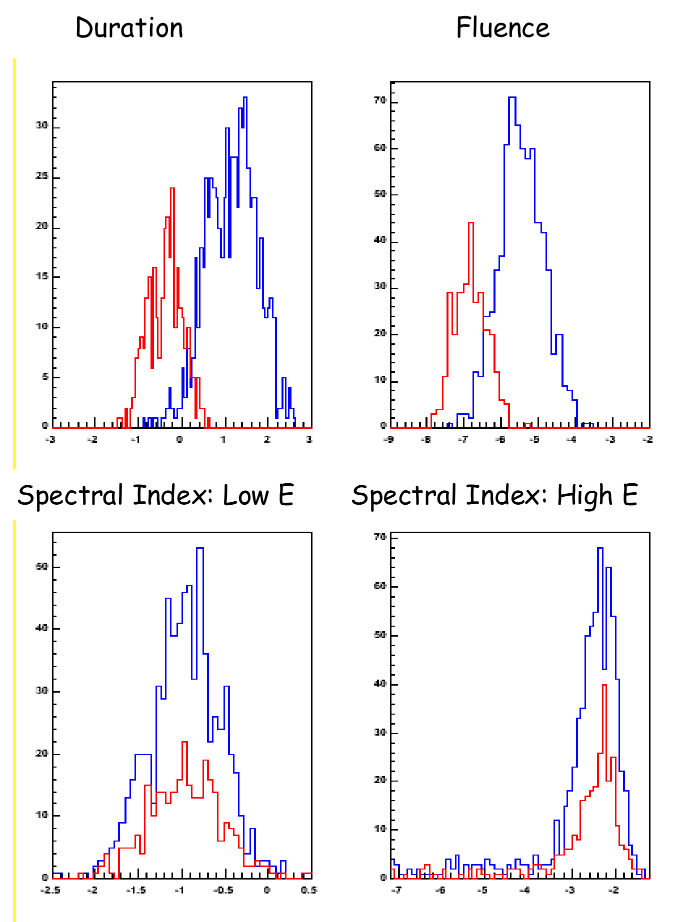


GLAST Simulations: (GRB Yields)

- Use simulations to predict the yield of GRBs in the LAT.
  - Consider different min. energies
  - Number of photons detected.
- GBM Estimated ~200/year

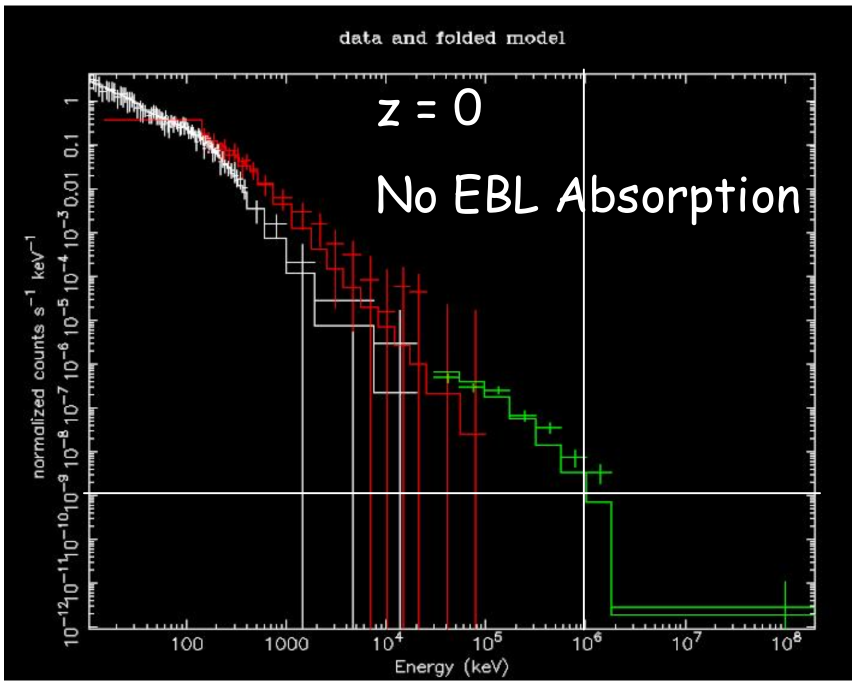


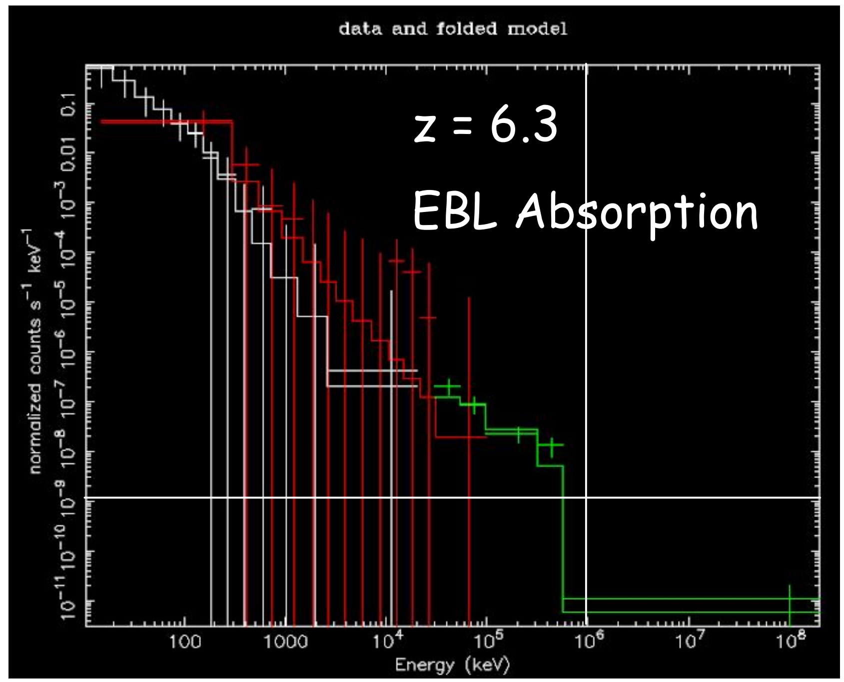
Red: short duration
Blue: long duration



High Redshift GRBs

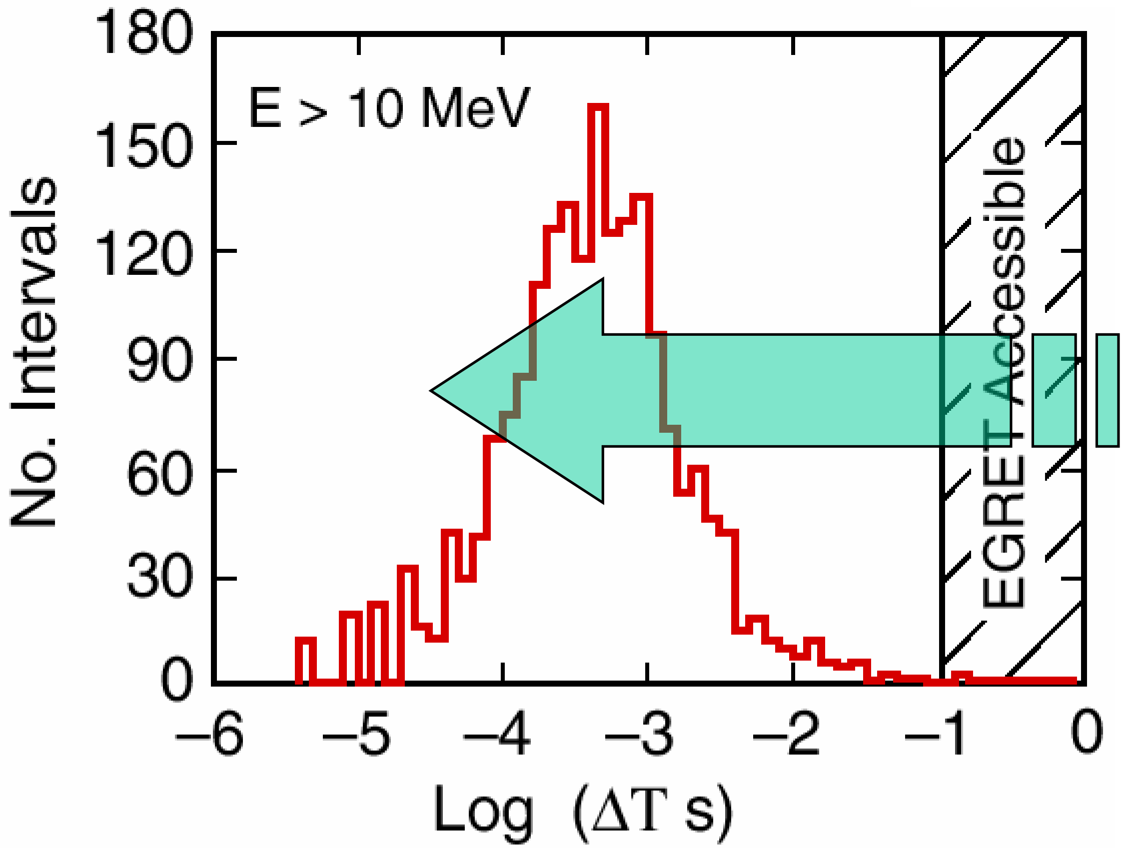
- Modeled GRB observed by Swift 04-Sep-05.
  - Redshift: 6.3, Fluence: 5.4×10^{-6} ergs/sec, Dur: ~500 s
  - Modeled two GRBs, one at z=0 and one at z=6.3
- Simulated GBM and LAT with response functions
- Modeled EBL absorption for z=6.3 GRB.





GRBs and Instrument Deadtime

Distribution for the 20 brightest bursts in a year (Norris et al)



Time between consecutive arriving photons

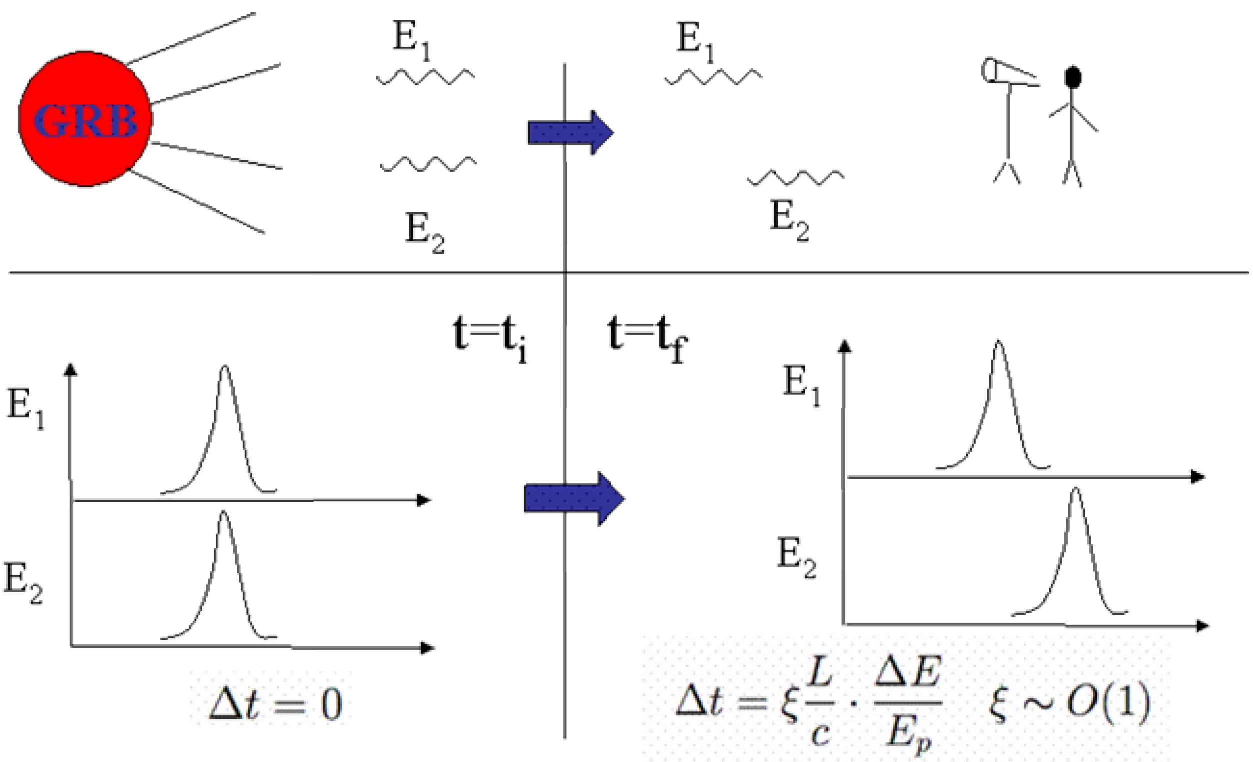
LAT will open a wide window on the study of the high energy behavior of bursts.

EGRET deadtime: ~100ms

Using GRBs as a Probe for New Physics

- Measuring GRB at different redshift can be used as a probe for Lorentz Invari
  - Effects arise in some Quantum Gravity Models.
  - Look for delayed arrival of photons as a function of energy.

$$v = \frac{dE}{dp} \approx c\left[1 - \xi \frac{E_\gamma}{E_{QG}}\right]$$



Credit: F. Longo; GLAST GRB Science Team

Using GRBs as a Probe for New Physics

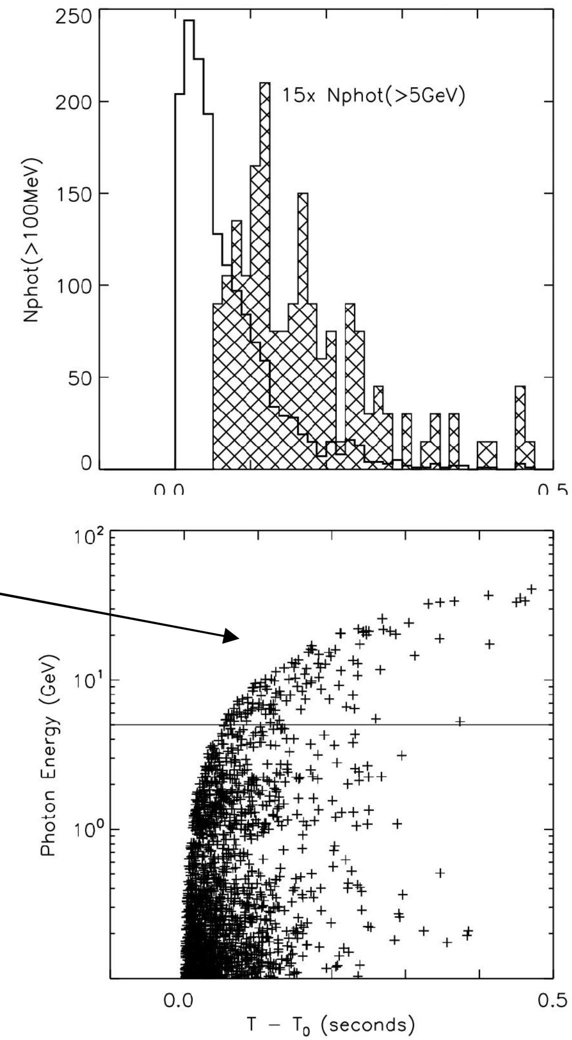
- LAT provides a means to measure the high energy photons and arrival.
  - System clock: 50 ns

$$\Delta t \approx 10\,\mathrm{ms} \times \left[\frac{E_\gamma}{1\,\mathrm{GeV}} \right] \times \left[\frac{d_{CM}}{1\,\mathrm{Gpc}} \right] \quad \text{using } E_{QG} = E_{Plank}$$

- Other observations required to localize and measure redshifts.

20 bright GRBs @ 1 Gpc w/ QG.

Dispersion due to QG.



Norris, Bonnell, Marani, Scargle 1999

Sensitivity

- ΔE : **the lever arm**
  - for the instrument (*Instrumental limit)*
  - for the observed energies (*Observing a source)*
- δt : **the time resolution**
  - the time resolution of the instrument (*Instrumental limit)*
  - the binning time to have enough statistics (*Observing a source)*
- **L: the typical distance of the sources**
- If the instrument doesn't see any delay:

$$E_{qg} > (L \cdot \Delta E)/(c \cdot \delta t)$$

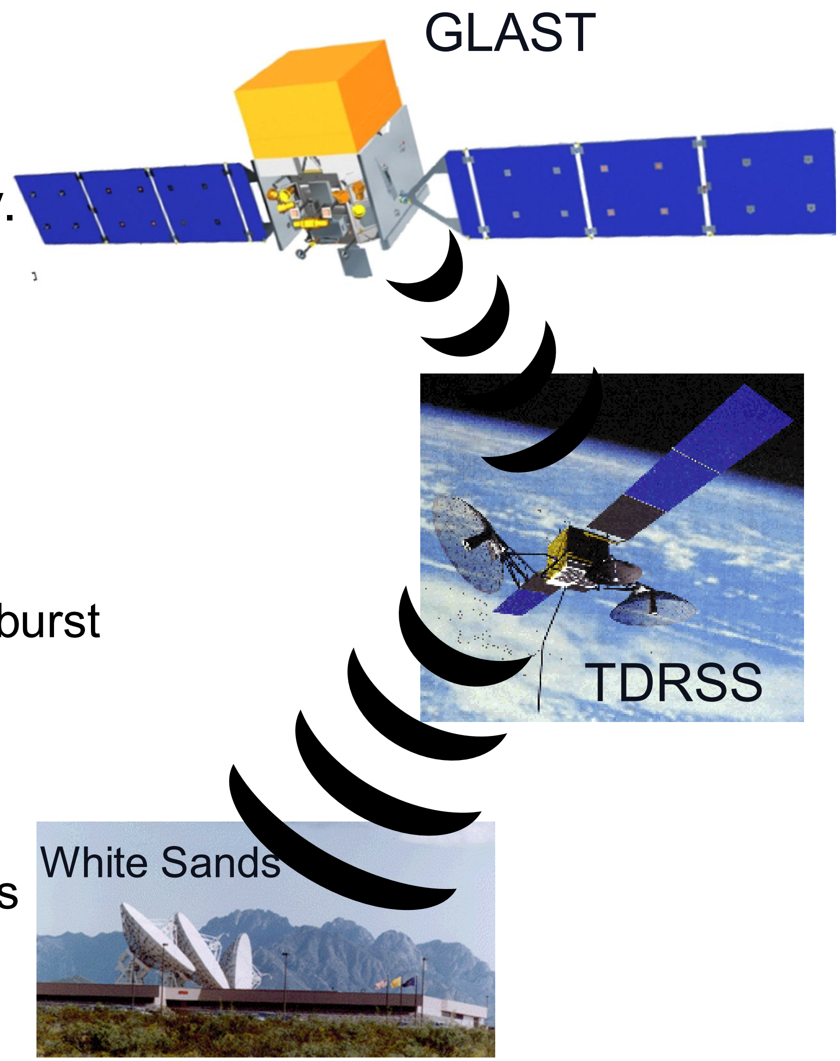
- If I can see a delay ∂t :

$$E_{qg} = (L \cdot \Delta E)/(c \cdot \delta t)$$

$$\left(\frac{L\Delta E}{c\delta t}\right)_{GLAST} = \frac{(10^{28}cm)(10^{2}GeV)}{(10^{10}cm/s)(10^{-4}s)} = 10^{24}GeV$$

Mission Operation & GRB's

- Operational Modes
  - Sky Survey (full coverage every 3 hours)
  - Pointing Mode
- LAT and GBM can trigger independently.
  - GBM will detect ~200 bursts/year
  - > 60 burst/year in LAT FOV
- Position Resolution
  - GBM $< 15^{o}$ (initial) $<5^{o}$ (revised)
  - LAT >~10 arcmin depending on burst
- Autonomous Repoint
  - GLAST can slew to put/keep an intense burst in the field of view.
- Downlink
  - Burst data to ground in near real time (TDRSS)
  - Burst alerts provided to GRB Coordinates Network (GCN) within ~10 sec.
  - Full Science data ~8 times a day.



Remaining Major Milestones

LAT final assembly complete!

Delivery of LAT to NRL for environmental testing (shake/temp tests): May 2006

GLAST integration with spacecraft and testing: Fall 2006 through Summer 2007

Launch: September 2007, Kennedy Space Center

Begin science: 1-2 months after launch

Lifetime of mission: at least 5 years (goal: 10 yrs)

Launch of Spitzer Space Telescope on a Delta II - Heavy

Backup Slides

GRB Science: Catalog

- There is a long list of science goals with GRBs.
- One important task is developing catalogs of the bursts.
  - Exact components of the catalogs is still under consideration.
- GBM Burst Catalog
- LAT Burst Catalog
  - Cross Referenced to GBM Catalog.

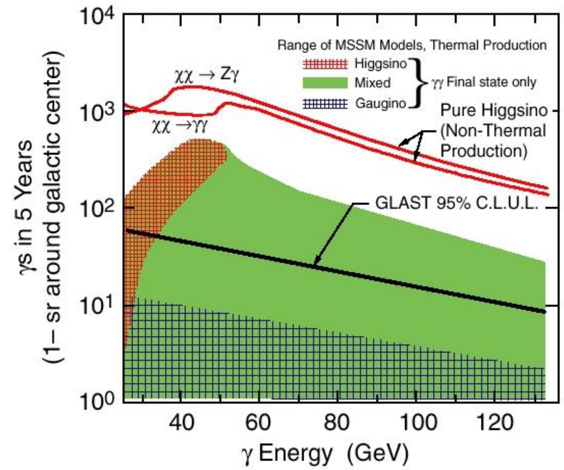
Preliminary

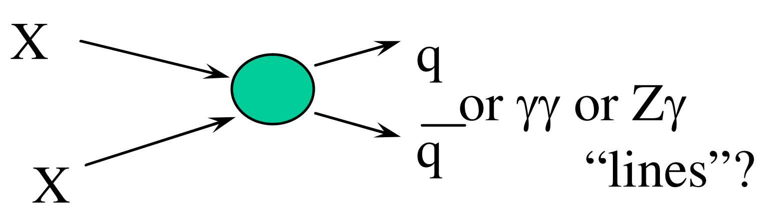
Catalog Entry
GCN Universal Name (GRB YYMMDD)
LAT GRB ID
GBM Catalog ID (x-ref)
Flags (Prompt, Afterglow)
LAT Time (UTC/Mission Elapse Time)
LAT RA & Dec
Radius of Error Circle (90% containment)
Max. Energy Photon, δE, time
Peak Flux > 30 MeV, δF, time
Average photon energy > 30 MeV and $\delta\langle E\rangle$
Average photon energy > 100 MeV and $\delta\langle E\rangle$
Fluences > 30 MeV and uncertainty
Fluences > 100 MeV and uncertainty
Photon Spectral index, uncertainty, E. Range
Rate History > 30 MeV (time vs Energy)

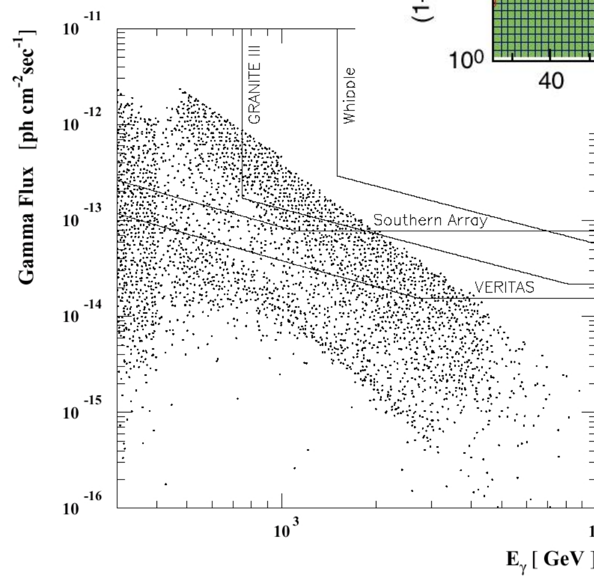
Dark matter searchq   Z≈Ó Ó

Particle Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of gamma rays.







Just an example of what might be waiting for us to find!

PHYSICS

STRING INSTRUMENTS

String theory may soon be testable

The theory of strings, which attributes the infinite variety of the cosmos to the harmonies of subatomic membranes, has emerged over the past two decades as the leading contender for the "theory of everything." It would explain the four forces of nature—gravity, electromagnetism, and the weak and strong nuclear forces—as a single force with different manifestations. But how could such a theory ever be proved? The last time the four forces acted as one was at the big bang; to re-create those conditions, physicists would need a particle accelerator larger than the solar system, which Congress might be reluctant to fund. Despairing of the task, some scientists call theories of everything an exercise in theology. "For the first time since the Dark Ages," physicists Paul Ginsparg and Sheldon L. Glashow wrote 12 years ago, "we can see how our noble search may end, with faith replacing science once again."

That proclamation now seems premature. Researchers have devised the first astronomical probe of theories of everything and have also discovered that the four forces may unite under conditions short of the big bang. "Unification, the theory of everything, might actually be accessible experimentally," says Nima Arkani-Hamed of the Stanford Linear Accelerator Center.

The probe was conceived by Giovanni Amelino-Camelia of the University of Oxford and the Institute of Physics in Neuchâtel, Switzerland, and his colleagues. They propose using gamma-ray bursts to check whether the speed of light in a vacuum depends on its wavelength. According to special relativity, light has the same speed in a vacuum regardless of wavelength. Therefore, the detection of a wavelength-dependent speed would unearth a level of physical law more fundamental than relativity.

Variations in the speed of light are familiar to anyone who has looked at a prism. Because glass, water and other substances allow red light to go faster than blue, the prism splays white light into a rainbow.

Empty space, too, is a substance of sorts. By the laws of quantum mechanics, particles burble in and out of existence as the void fluctuates around complete emptiness. Present quantum theory, which incorporates special relativity but not gravity, says that these fluctuations affect all wavelengths of light equally. But theories of everything also allow for fluctuations in gravity, which might act as subatomic lenses that bend light. The shorter the wavelength of light, the more it might induce such lensing and the slower it would travel.

Although the retardation is predicted to be small, it might show up in gamma-ray bursts. Whatever their mysterious origins, these intense flashes travel billions of light-years and flicker frenetically. The blinking gives astronomers a handle on any dispersion: at shorter wavelengths, a flicker would register a moment after it appeared at longer wavelengths. Across a typical range of gamma rays, the time difference would be around 10 microseconds—not much, considering that the radiation has traveled for 10 billion years. But it may be just enough for current instruments to detect. And the Gamma-ray Large Area Space Telescope, scheduled to begin operation in 2004, will certainly have the requisite resolution.

Meanwhile there is another way that predictions of string theory could be detectable sooner: namely, if the forces of nature unite under unexpectedly mild conditions. Two years ago Edward Witten of the Institute for Advanced Study in Princeton, N.J., and Joseph D. Lykken of Fermi National Accelerator Laboratory in Batavia, Ill., realized that strings could come into play at lesser energies than previously assumed. In other words, maybe strings aren't so tiny.

The standard argument that strings should appear at high energies is based on theoretical extrapolations from the measured strength of the four forces. Electromagnetism and the two nuclear forces should become equally strong at the so-called Grand Unification scale. At a slightly higher energy, the Planck scale, gravity is supposed to join in. Both scales are trillions or quadrillions of times beyond the reach of today's accelerators.

But these extrapolations don't take into account a key prediction of string theory: the presence of extra dimensions, on top of the four familiar ones—three for space, one for time. New dimensions could lower both the Grand Unification scale (as shown recently by Keith R. Dienes, Emilian Dudas and Tony Gherghetta of CERN near Geneva) and the Planck scale (according to Arkani-Hamed, Savas Dimopoulos of Stanford University and Gia Dvali of the Abdus Salam International Center for Theoretical Physics in Trieste).

Specifically, string theory adds six minuscule dimensions, which Dienes compares to hairline cracks in the pavement. Each crack adds an extra (third) dimension to the two-dimensional road, but if it is small, your car rolls right over it.

If the crack is large enough and if your tire is small enough, however, your car rattles. Similarly, if the extra dimensions of space are large enough and a particle is small enough, the particle could begin to vibrate in those dimensions. New harmonics would develop, generating new particles—and altering the way the electromagnetic and the two nuclear forces are transmitted. Gravity might shift in a telltale way, too: for simple geometric reasons, extra dimensions would cause gravity to weaken more rapidly with distance. Experimenters are starting to look for such an effect.

Lower unification scales would allow the Large Hadron Collider, now being built at CERN, to make strings. To be sure, that prospect is still speculative. "All these proposals are in the spirit of 'unlikely to be right, but so extremely interesting if they are that they are well worth thinking about,'" says Sean M. Carroll of the University of California at Santa Barbara. But along with other hints of new physics—the neutrino mass, the cosmological constant, the odd behavior of meson particles [see "The Asymmetry between Matter and Antimatter," on page 76]—they suggest that we won't need to take a theory of everything on faith after all. —*George Musser*

News and Analysis

News and Analysis

24 SCIENTIFIC AMERICAN October 1998

Although the retardation is predicted to be small, it might show up in gamma-ray bursts. Whatever their mysterious origins, these intense flashes travel billions of light-years and flicker frenetically. The blinking gives astronomers a handle on any dispersion: at shorter wavelengths, a flicker would register a moment after it appeared at longer wavelengths. Across a typical range of gamma rays, the time difference would be around 10 microseconds—not much, considering that the radiation has traveled for 10 billion years. But it may be just enough for current instruments to detect. And the Gamma-ray Large Area Space Telescope, scheduled to begin operation in 2004, will certainly have the requisite resolution.

$$V = c\left(1 - \xi \cdot \frac{E}{E_{QG}} + \ldots\right)$$

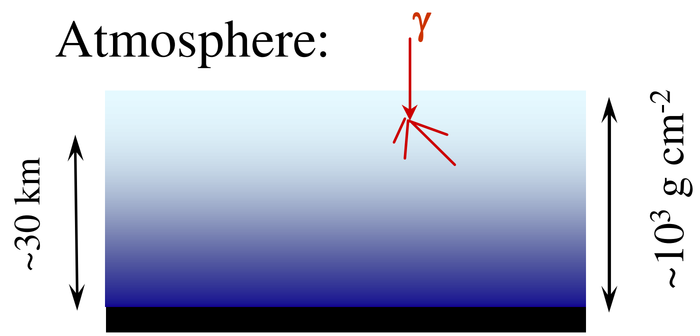
Amelino-Camelia et al,
Ellis, Mavromatos, Nanopoulos

Effects could be O(100) ms or larger, using GLAST data alone. But ?? effects intrinsic to bursts??

Representative of window opened by such distance and energy scales

Cosmic γ-ray Measurement Techniques

Atmosphere:



For $E_\gamma <\sim 100$ GeV, must detect above atmosphere (balloons, satellites)

For $E_\gamma > \sim 100$ GeV, information from showers penetrates to the ground (Cerenkov, air showers)

Photon interaction mechanisms:

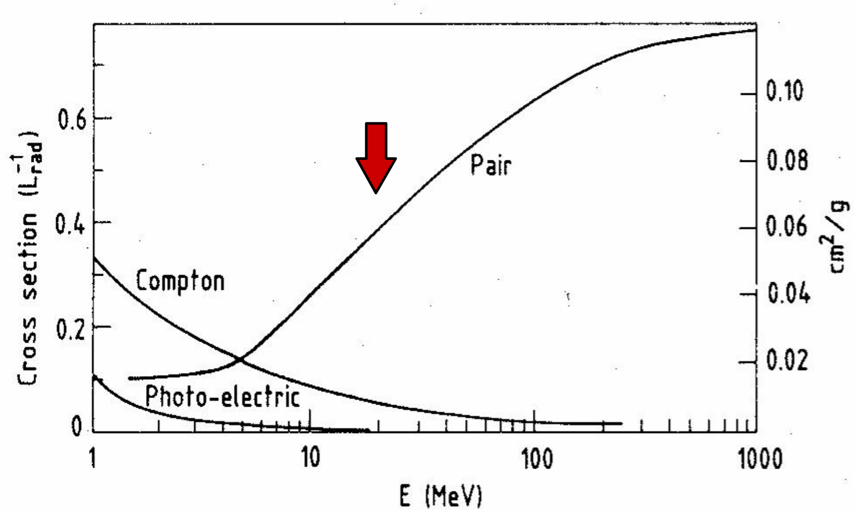
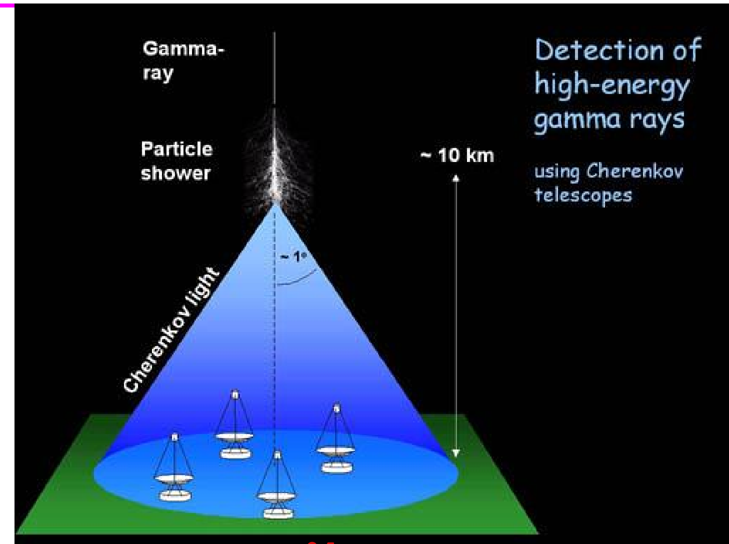
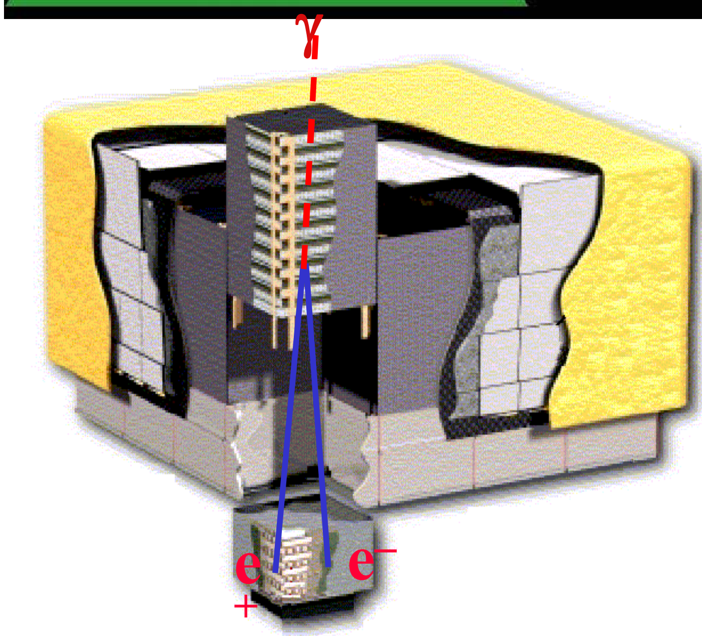


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

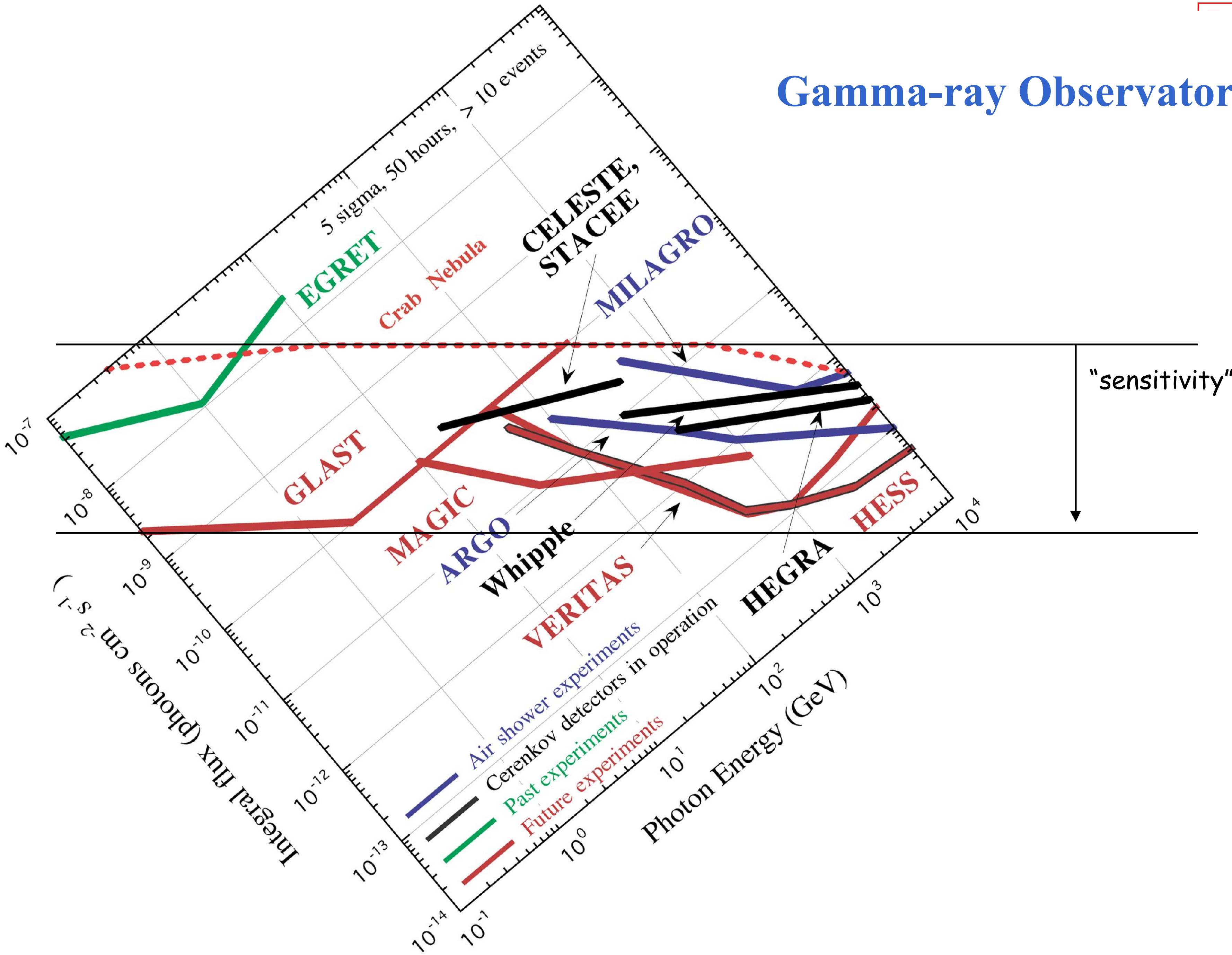
IACTs versus the LAT

- IACTs:
  - Effective Area – $(100\ m)^2$
  - Threshold – 50-1000 GeV
  - Field of View -- ~few degrees
  - E_{Scale} Systematics model dependent, ~20%
  - Resolution < 0.1^o
- LAT:
  - Effective Area – 1 m^2
  - Threshold -- ~10s MeV
  - Field of View – 2 str
  - E_{scale} uncertainty ~10%
  - Resolution ~0.1^o (>10GeV)

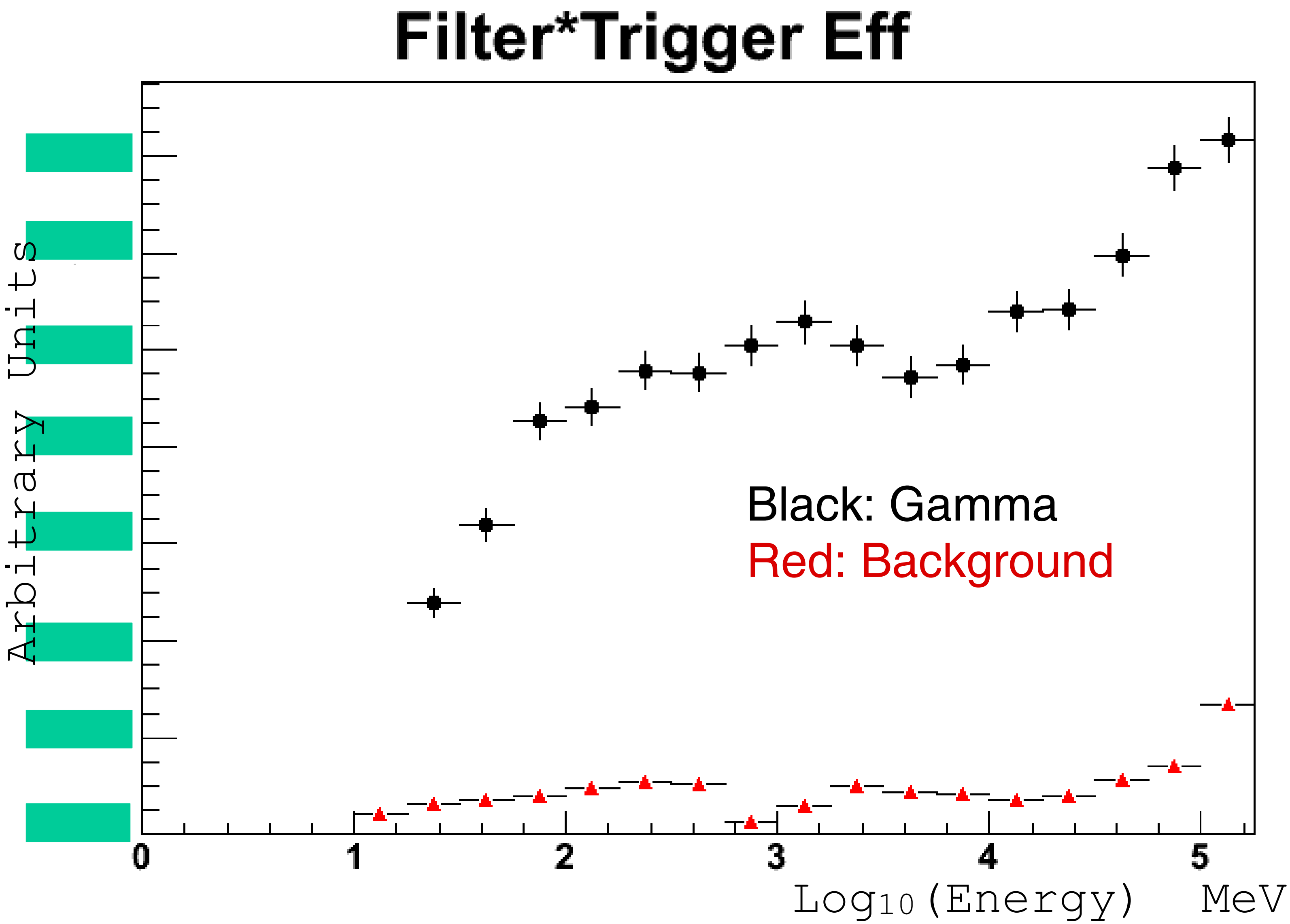




Gamma-ray Observatories



Efficiency of the Onboard Filter when the LAT has triggered



GLAST Science

GLAST will have a very broad menu that includes:

- Systems with supermassive black holes
- Gamma-ray bursts (GRBs)
- Pulsars
- Solar physics
- Origin of Cosmic Rays
- Probing the era of galaxy formation
- Discovery! Particle Dark Matter? Hawking radiation from primordial black holes? Other relics from the Big Bang? Testing Lorentz invariance. New source classes.

Huge increment in capabilities.

GLAST draws the interest of both the the High Energy Particle Physics and High Energy Astrophysics communities.