# GLAST 101

- What are gamma rays? Why study them? Why this energy range? Why do we need a satellite?
- What are some of the fundamental questions GLAST is meant to address? A few examples of science topics (*very* brief overview).
- How do gamma-ray detectors work? Why do the GLAST Instruments (LAT, GBM) look as they do?

see http://glast.gsfc.nasa.gov/, http://www-glast.slac.stanford.edu,
http://gammaray.msfc.nasa.gov/gbm, and links therein

**ASK QUESTIONS!**

# Questions From Project Member 1

1. Whatsagammaray anyway??

# Questions From Project Member 2

1. Is the GLAST mission really justified as opposed to ground based observatories or high flying balloons?
2. Gamma rays being one source of SEUs in electronic circuits in space, it sounds problematic to use electronics to detect rays that upset them. How is this problem mitigated?
3. Gamma rays are shown in diagrams as single photon events. Is this true?
4. Or is there a flux of rays arriving at the sensor from a given source?
5. If there were two LATs in orbit, would they detect bursts from the same source simultaneously?

# Questions From Project Member 3

1. Please present some charts defining the point spread function and some charts that relate it to the specified quantities in the tables of the SRD. Why doesn't the PSF figure prominently in the SRD?

2. Please present some charts describing the localization performance of the LAT and factors affecting that performance.

3. Please provide some charts that reconcile the statement on SDR page 10 with the 10 arcsecond pointing knowledge requirement. "LAT shall have a single photon angular resolution of 10 arcmin at high energies (>10GeV) for good source localization." The layman is tempted to conclude that the two are off by an order of magnitude.

4. Please provide some charts on LAT calibration and alignment that is appropriate in the context of a "LAT 101" presentation.

5. Please describe the time varying nature of the sources. As a layman I can easily conceptualize a constant source that is rotating with respect to the viewer. What mechanisms are at play that are already understood, and what "discovery" type transient phenomena may be encountered?

6. Is there a significant fraction of sources expected that will not be subject to repeated observation opportunities?

7. Describe the relationship(s) between Effective Area and energy of gamma rays.

8. In SRD Table 1 item 3, note 2, describe the inefficiencies necessary to achieve background rejection.

9. Please present some charts that describe the field of view and how its performance varies from the +z observatory axis.

10. SRD Table 1 items 4 & 5 seem to imply that higher energies are harder to resolve in energy. Is this true? Why?

11. Please present the relationship(s) between angle of incidence and energy resolution.

12. What is the significance of 68% and 95% in SRD Table 1 items 7, 8, 9.

13. SRD Table 1 item 6 The incidence angle of 60 degrees is measured with respect to what?

14. Please define side incidence mentioned in SRD Table 1 note 4.

15. Please present a chart defining the space angle referenced in note 6 of SRD table 1.

16. Show a chart of a typical Gamma ray burst event and the expected data rate with respect to time.

17. Please describe the Swift Mission's similarities and differences to GLAST from a science standpoint.

18. How much variation is there in the LAT geometric structure from tower to tower and from tray to tray? Is this significant? Do you need data to characterize it in order to do good science? Is the data collection from outlying towers and trays expected to be significantly greater/less than the ones near the middle of the LAT? (Is there an expected variation in data collection density within the LAT?)

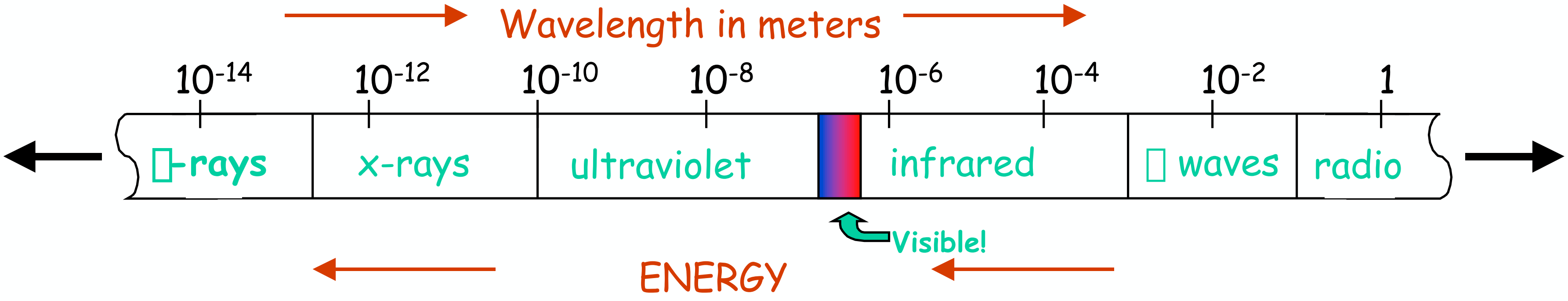
19. Who has responsibility for designing the sky survey profile? It looks like the GNC and ground ops folks may say, "sure, we'll point wherever you want us to". Is this a science issue with engineering only intervening for routine observatory health and safety concerns?

20. Does the whole instrument go dead? (all trays, all towers, all elements?) What is the limitation on the detection of "simultaneous" events? (How much of a limitation is dead time?) Is instrument dead time significant given what is known about the time distribution of the background and sources?

21.

# Whatsagammaray??

The term is historical and not descriptive. It refers to a portion of the electromagnetic spectrum (but they didn't know it at the time the name was invented!):



Wavelength in meters

$10^{-14}$ $10^{-12}$ $10^{-10}$ $10^{-8}$ $10^{-6}$ $10^{-4}$ $10^{-2}$ 1

γ-rays | x-rays | ultraviolet | infrared | μ waves | radio

Visible!

ENERGY

**Einstein (1905) light quantum hypothesis: electromagnetic radiation is composed of discrete particles (later called PHOTONS) whose energy is $E=hc/\lambda$, where h is Planck's constant ($4.1357\times10^{-15}$ eV s), λ is the wavelength, and $c=3\times10^{8}$ m/s.**

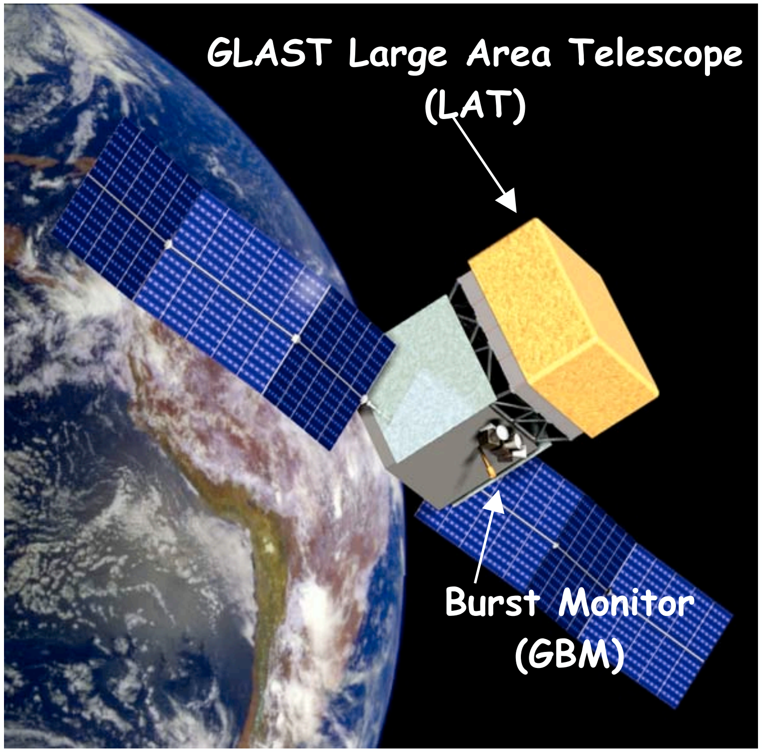
Try this: estimate the number of photons per second emitted by an ordinary 100W red lightbulb (assume $600\times10^{-9}$m wavelength, and 10% of the power is visible). Note that an electronvolt (eV) is a unit of ENERGY: 1 eV = $1.6\times10^{-19}$ J.

Question: why do particle physicists want to build more powerful accelerators?

# Why study γs?

## Gamma rays carry a wealth of information:

- γ rays do not interact much at their source: they offer a direct view into Nature’s largest accelerators.
- similarly, the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent.
- conversely, γ rays readily interact in detectors, with a clear signature.
- γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.



<u>Two GLAST instruments</u>:

LAT: 20 MeV – >300 GeV

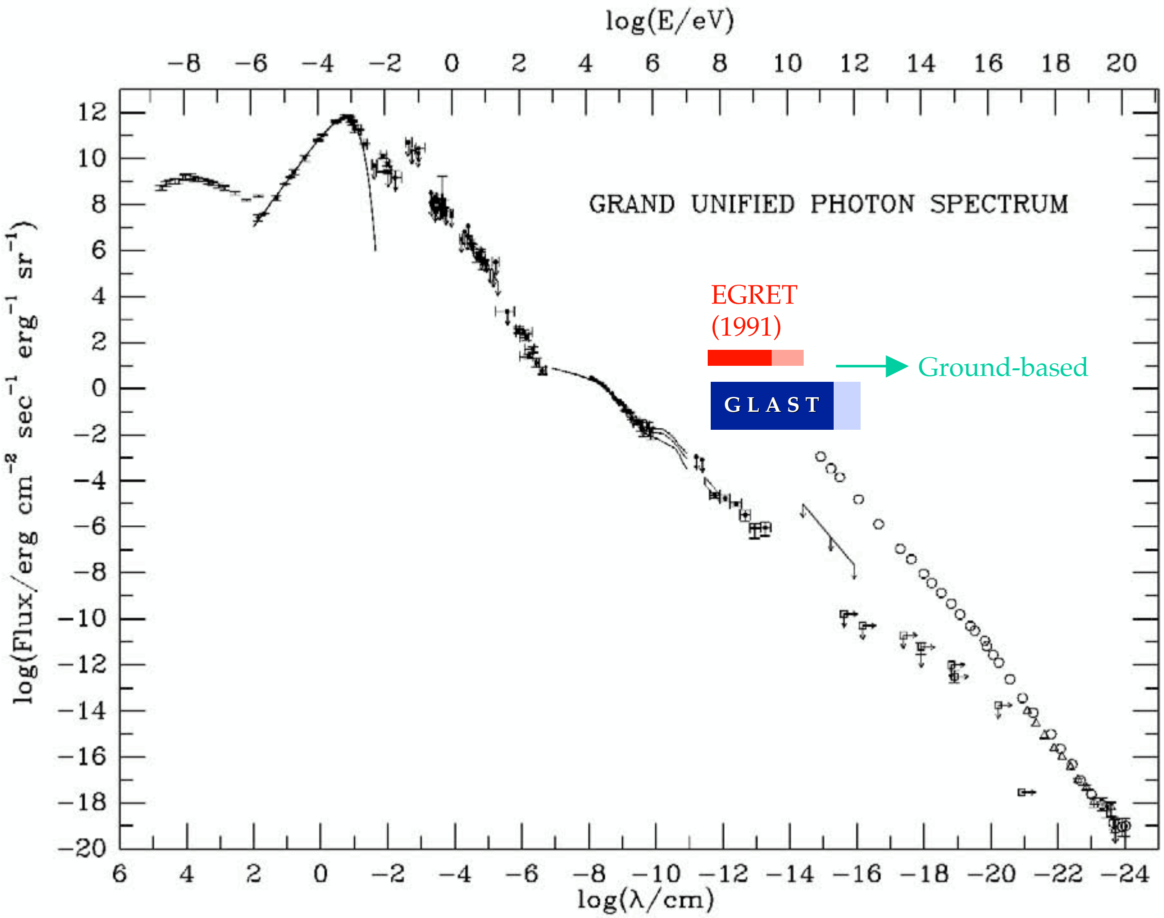
GBM: 10 keV – 25 MeV

Launch: 2006

# Why this energy range? (20 MeV - > 300 GeV)

## The Flux of Diffuse Extra-Galactic Photons

The Grand Unified Photon Spectrum (GUPS) c.a. 1990, Ressell and Turner



Note:

1 MeV=$10^6$ eV

1 GeV=$10^9$ eV

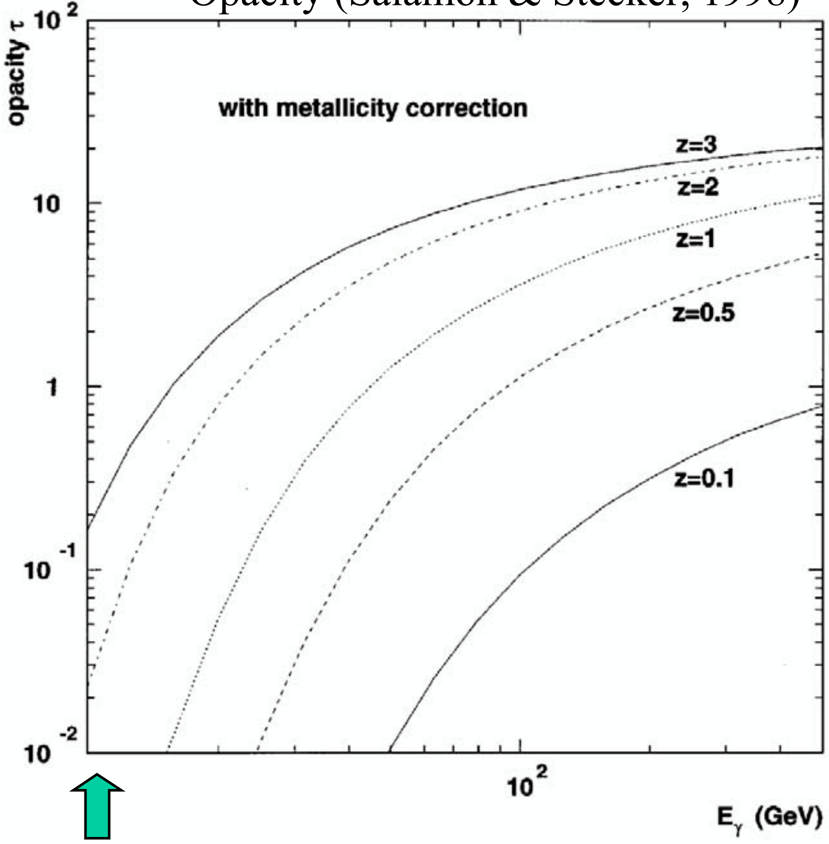
1 TeV=$10^{12}$ eV

1eV=1.6x$10^{-19}$J

# An important energy band for Cosmology

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)

Opacity (Salamon & Stecker, 1998)



No significant attenuation below ~10 GeV.

**EBL over cosmological distances is probed by gammas in the 10-100 GeV range.**

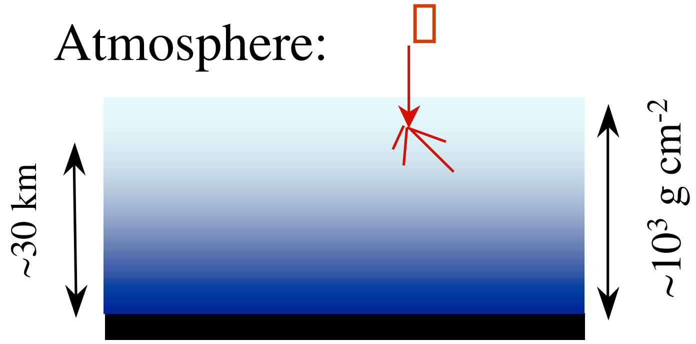
**In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.**

A dominant factor in EBL models is the time of galaxy formation -- attenuation measurements can help distinguish models.

GLAST

# Cosmic γ-ray Measurement Techniques

Atmosphere:



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

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

## Energy loss mechanisms:

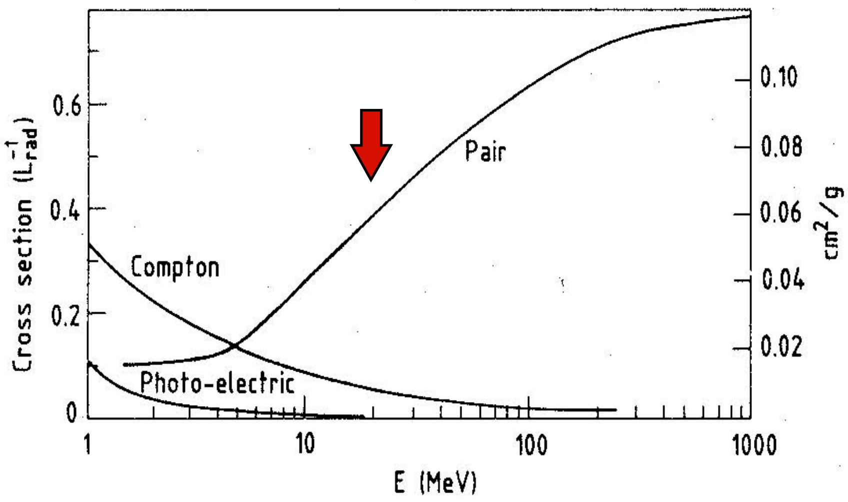
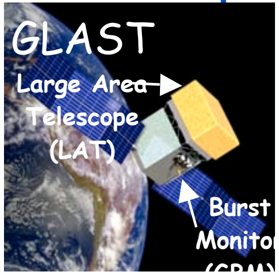
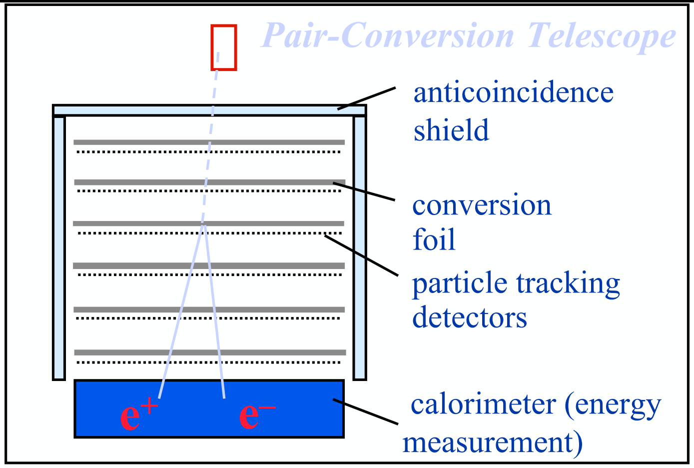


**Fig. 2:** Photon cross-section $\sigma$ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

# Gamma-ray Experiment Techniques

- Space-based:
  - use pair-conversion technique





*Pair-Conversion Telescope*

anticoincidence shield

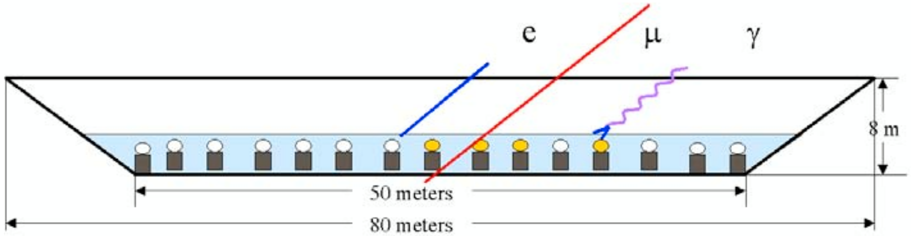
conversion foil

particle tracking detectors

calorimeter (energy measurement)

- Ground-Based:
  - Airshower Cerenkov Telescopes (ACTs)

image the Cerenkov light from showers induced in the atmosphere. Examples: Whipple, STACEE, CELESTE, VERITAS

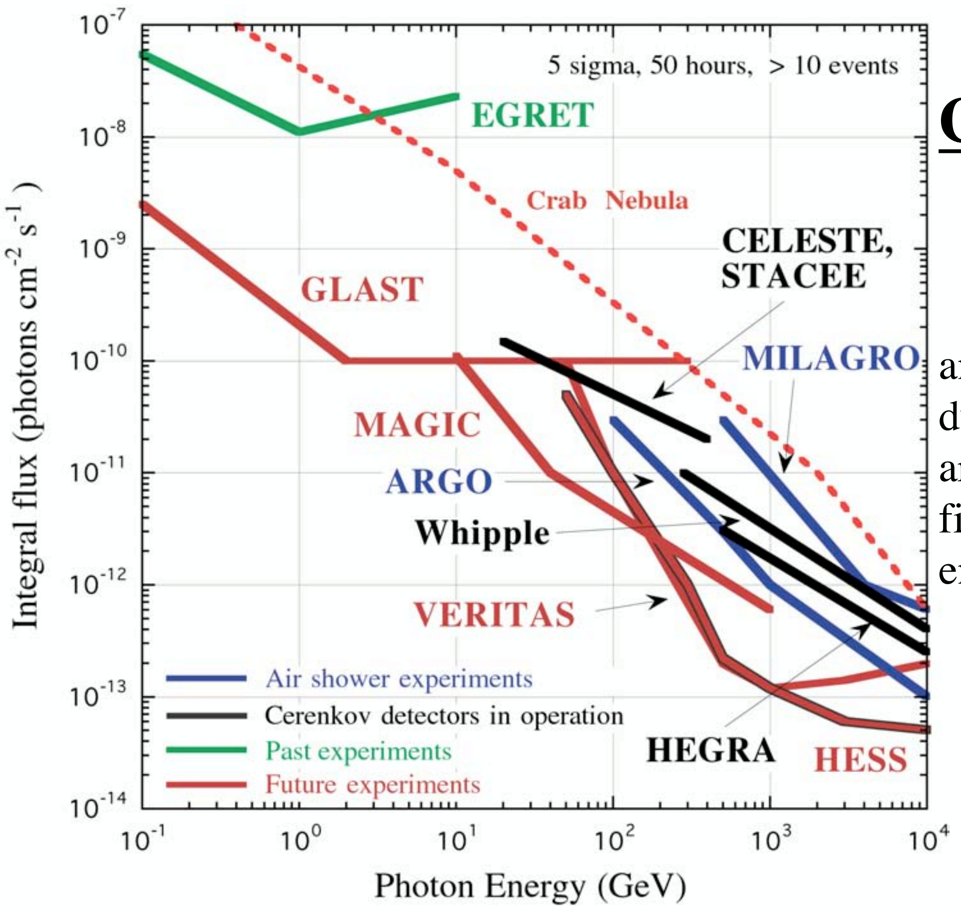


(EAS)

Directly detect particles from the showers induced in the atmosphere.

MILAGRO

# Unified gamma-ray experiment spectrum

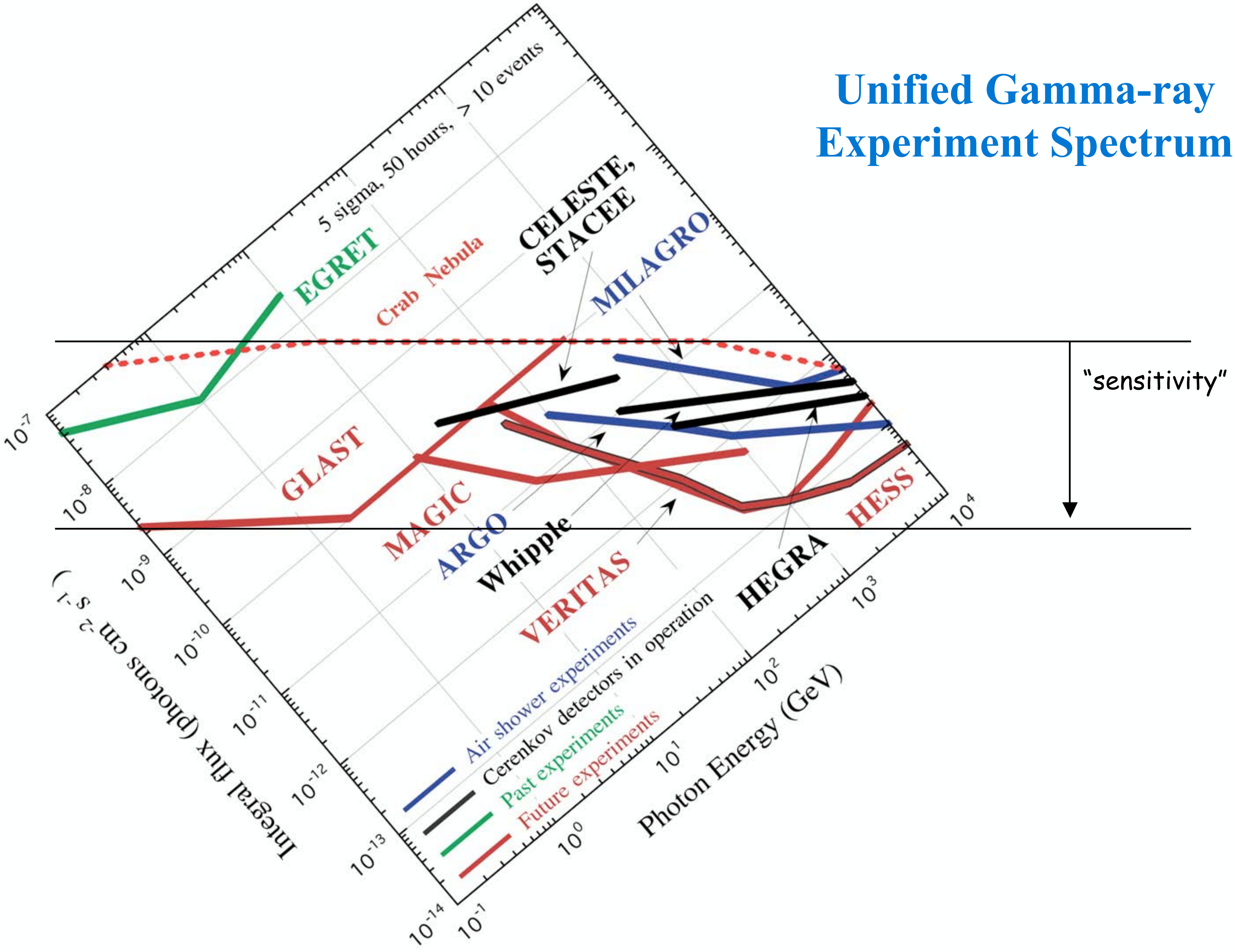


## Complementary capabilities

| | 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 |

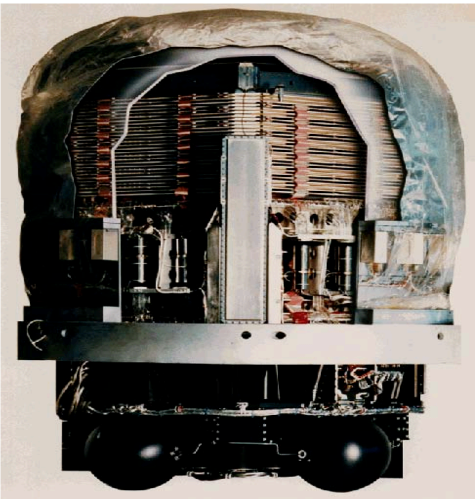
The next-generation ground-based and space-based experiments are well matched.

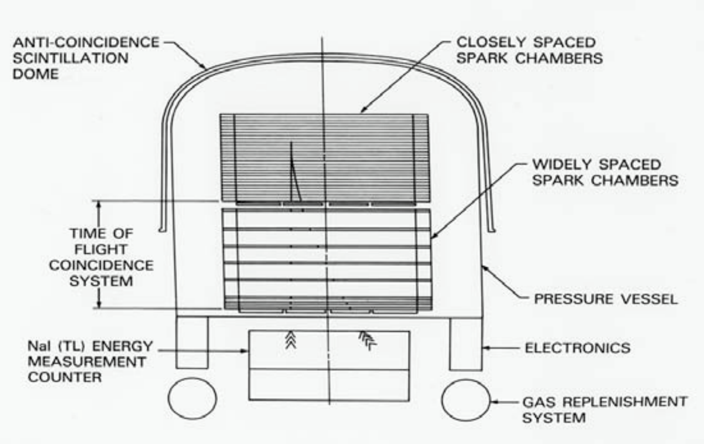
# Unified Gamma-ray Experiment Spectrum



# EGRET

The high energy gamma ray detector on the Compton Gamma Ray Observatory (20 MeV - ~20 GeV)





# The success of EGRET: probing new territory

History:

SAS-2, COSB (1970's-1980's) exploration phase: established galactic diffuse flux

EGRET (1990's) established field:

- increased number of ID'd sources by large factor;
- broadband measurements covering energy range ~20 MeV - ~20 GeV;
- discovered many still-unidentified sources;
- discovered surprisingly large number of Active Galactic Nuclei (AGN);
- discovered multi-GeV emissions from gamma-ray bursts (GRBs);
- discovered GeV emissions from the sun

**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.**

# 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.

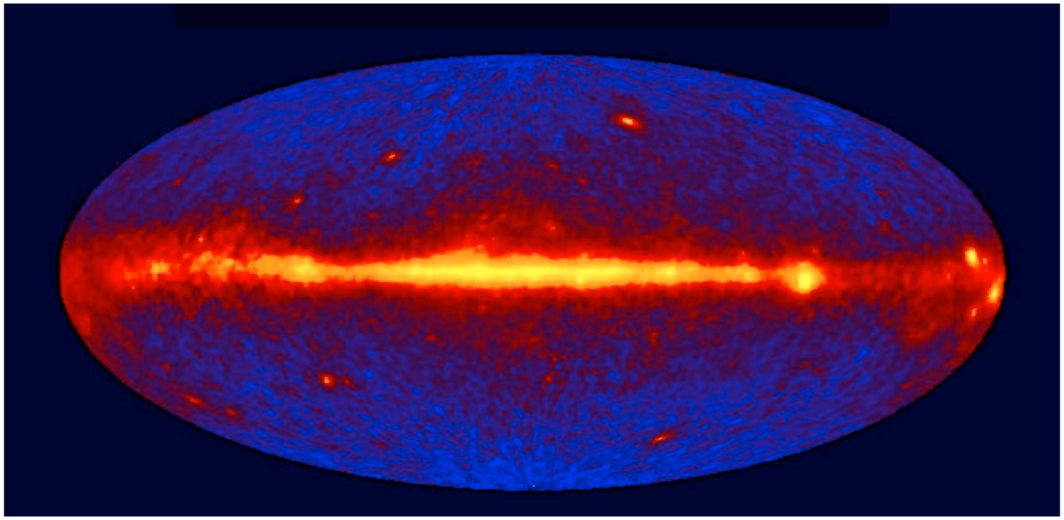
Huge increment in capabilities.

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

# 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

# Features of the gamma-ray sky



EGRET all-sky survey (galactic coordinates) E>100 MeV

diffuse extra-galactic background (flux ~ $1.5 \times 10^{-5}$ $cm^{-2}s^{-1}sr^{-1}$)

galactic diffuse (flux ~O(100) times larger)

high latitude (extra-galactic) point sources (typical flux from EGRET sources O($10^{-7}$ - $10^{-6}$) $cm^{-2}s^{-1}$

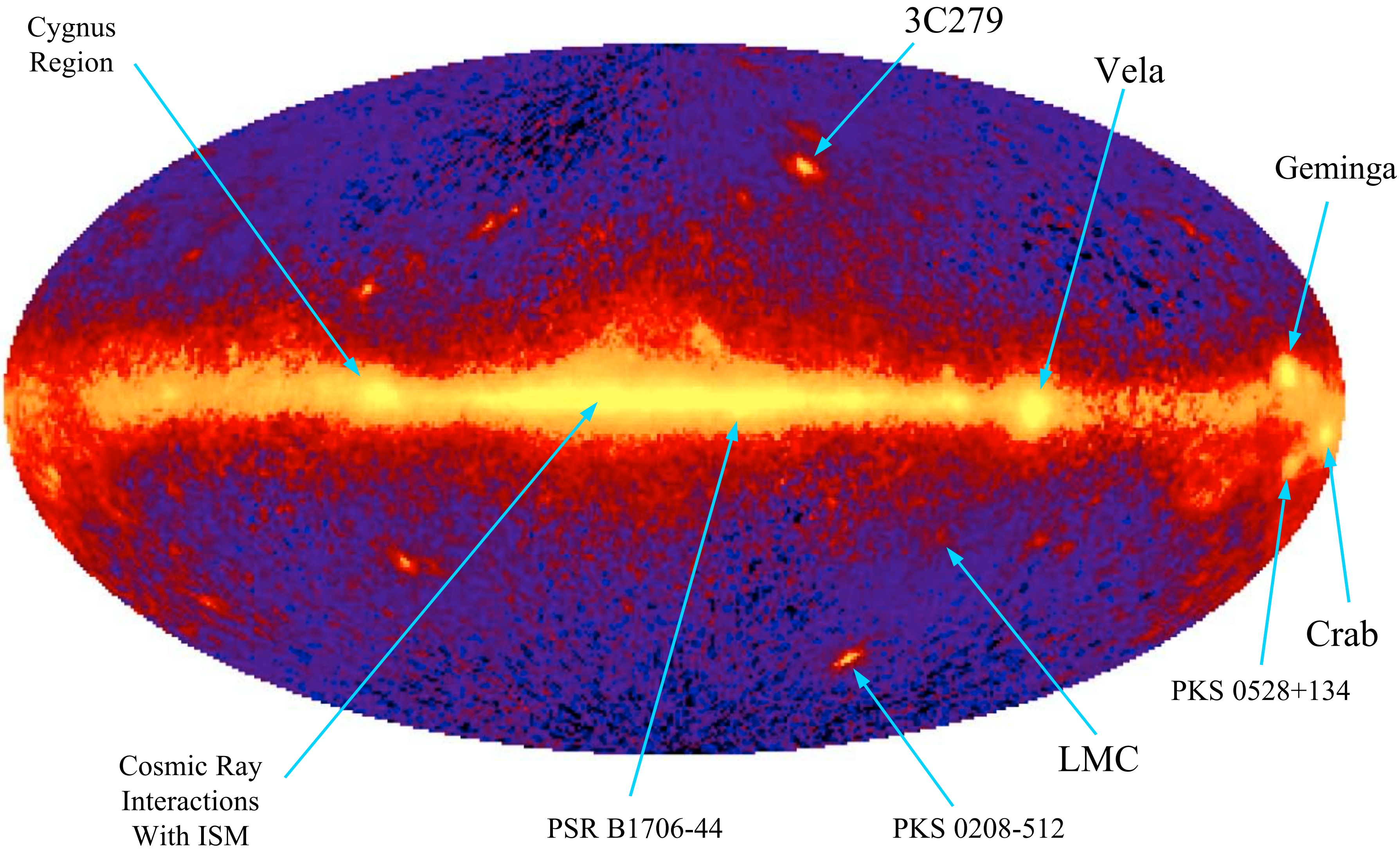
galactic sources (pulsars, un-ID'd)

**An essential characteristic**: VARIABILITY in time!

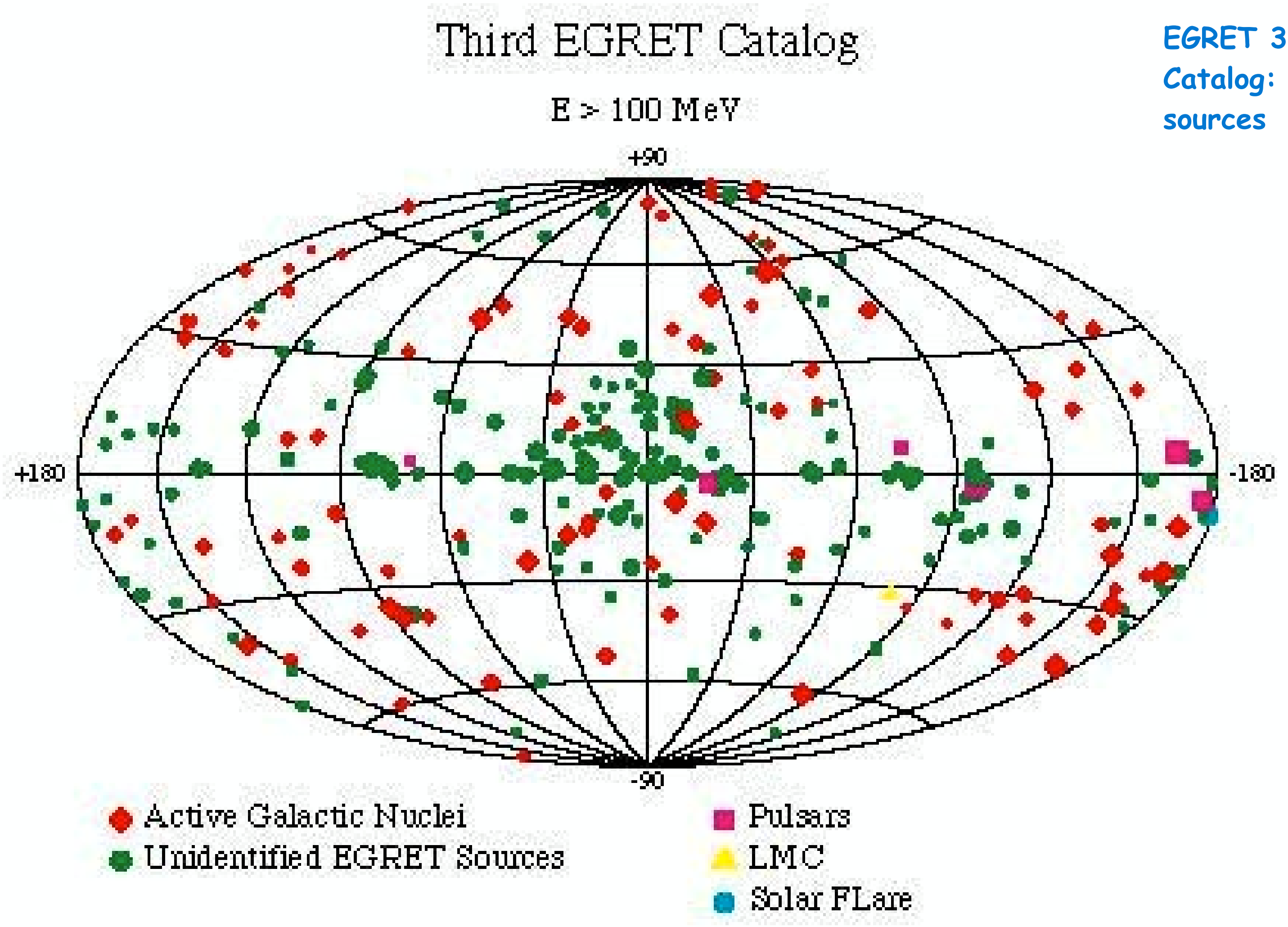
⇨ Field of view, and the ability to repoint, important for study of transients

GLAST

# EGRET All  Sky Map (>100 MeV)



# Sources

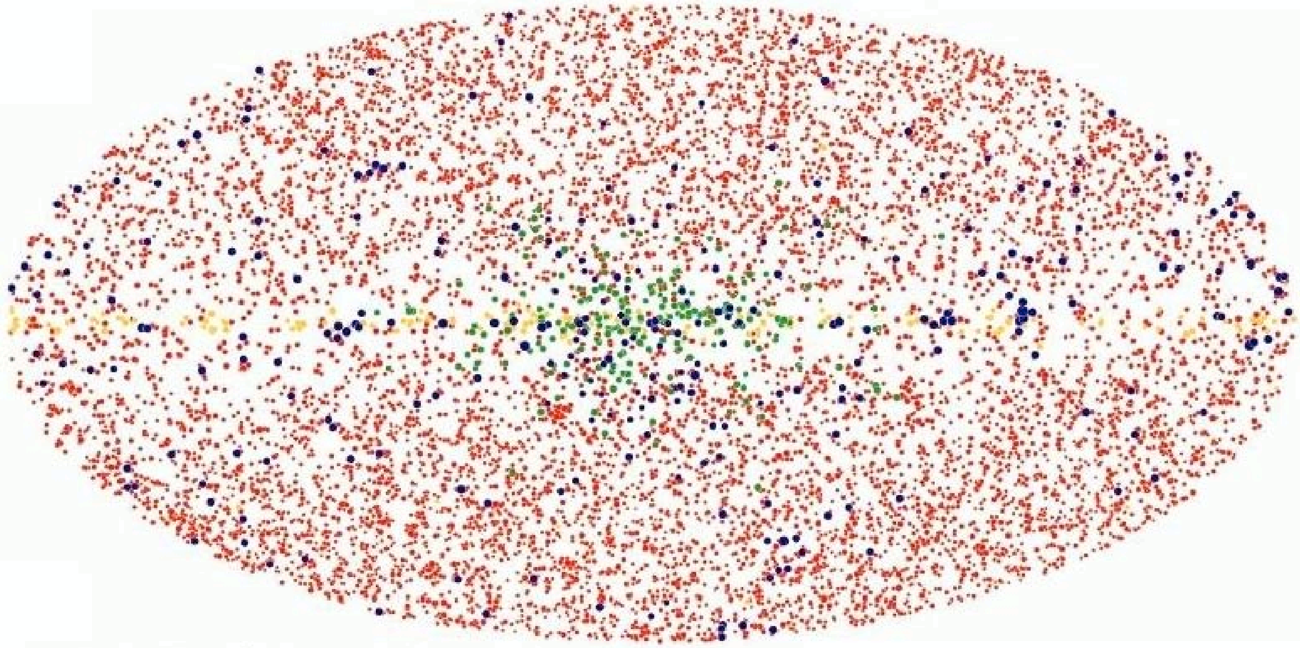


EGRET 3rd Catalog: 271 sources

# Sources

**LAT 1st Catalog:**
**>9000 sources**
**possible**

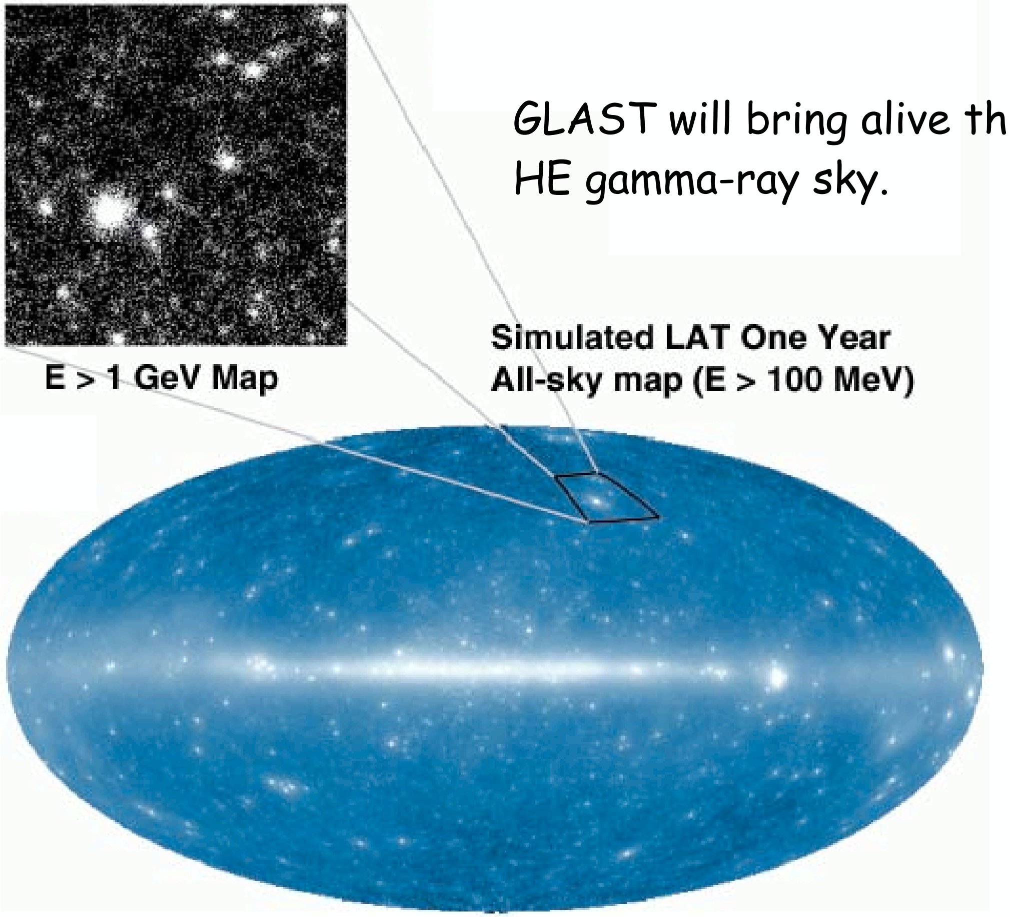
**5σ Sources from Simulated One Year All-sky Survey**



Results of one-year all-sky survey.
(Total: 9900 sources)

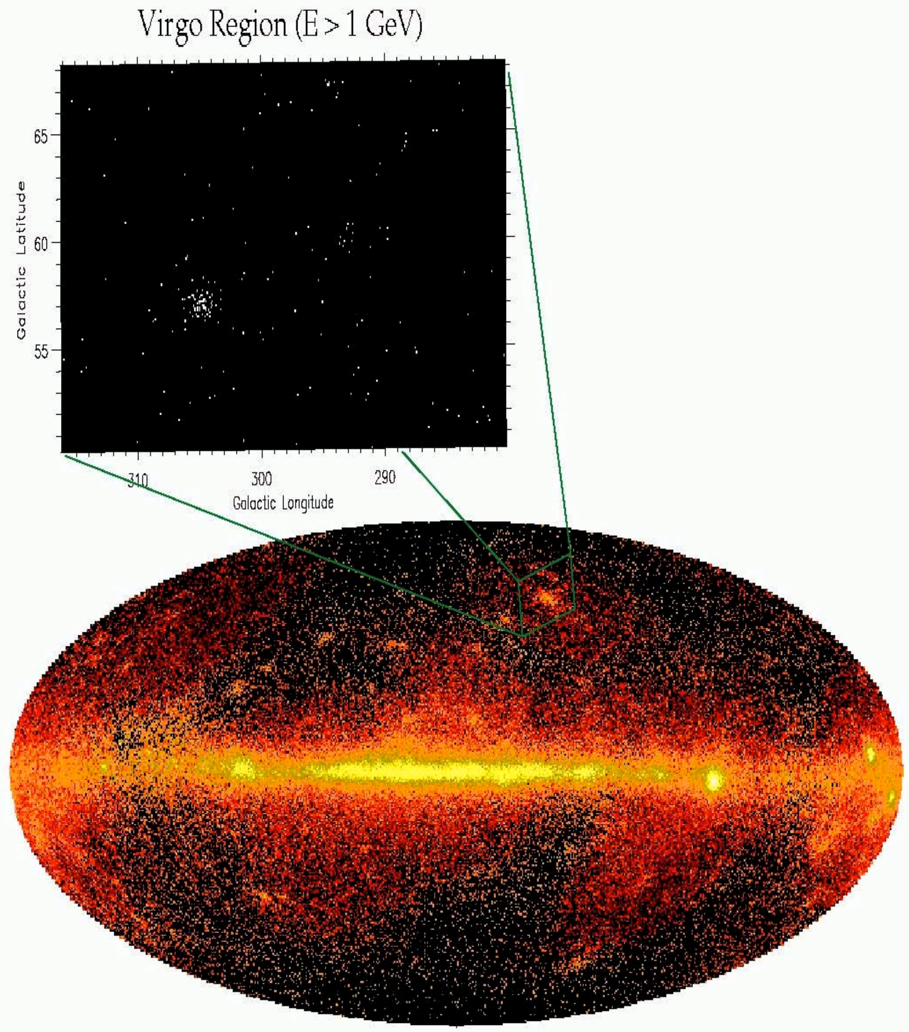
# Diffuse Extra-galactic Background Radiation

Is it really isotropic (e.g., produced at an early epoch in intergalactic space) or an integrated flux from a large number of yet unresolved sources? GLAST has much higher sensitivity to weak sources, with better angular resolution.



GLAST will bring alive the HE gamma-ray sky.

The origin of the diffuse extragalactic gamma-ray flux is a mystery. Either sources are there for GLAST to resolve (and study!), OR there is a truly diffuse flux from the very early universe.



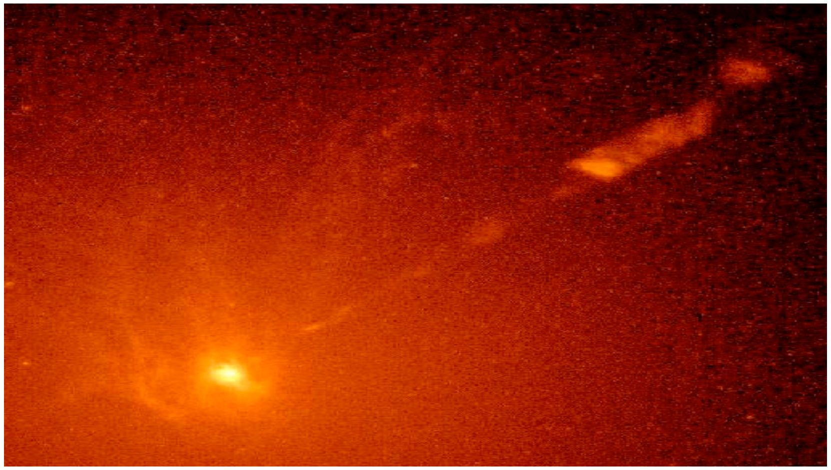
EGRET One-Year All-Sky Survey (E > 100 MeV)

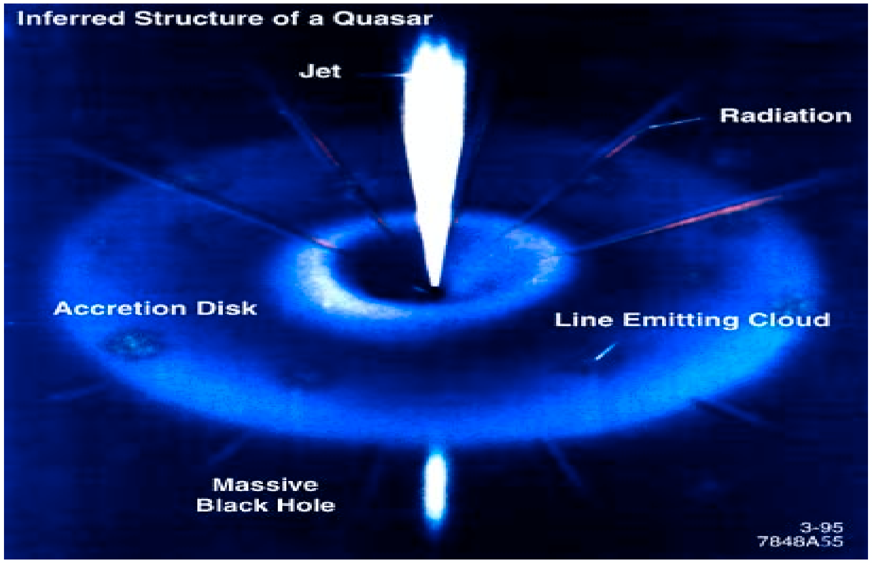
# Active Galactic Nuclei (AGN)

Active galaxies produce vast amounts of energy from a very compact central volume.

Prevailing idea: powered by accretion onto super-massive black holes ($10^6$ - $10^{10}$ solar masses). Different phenomenology primarily due to the orientation with respect to us.

HST Image of M87 (1994)



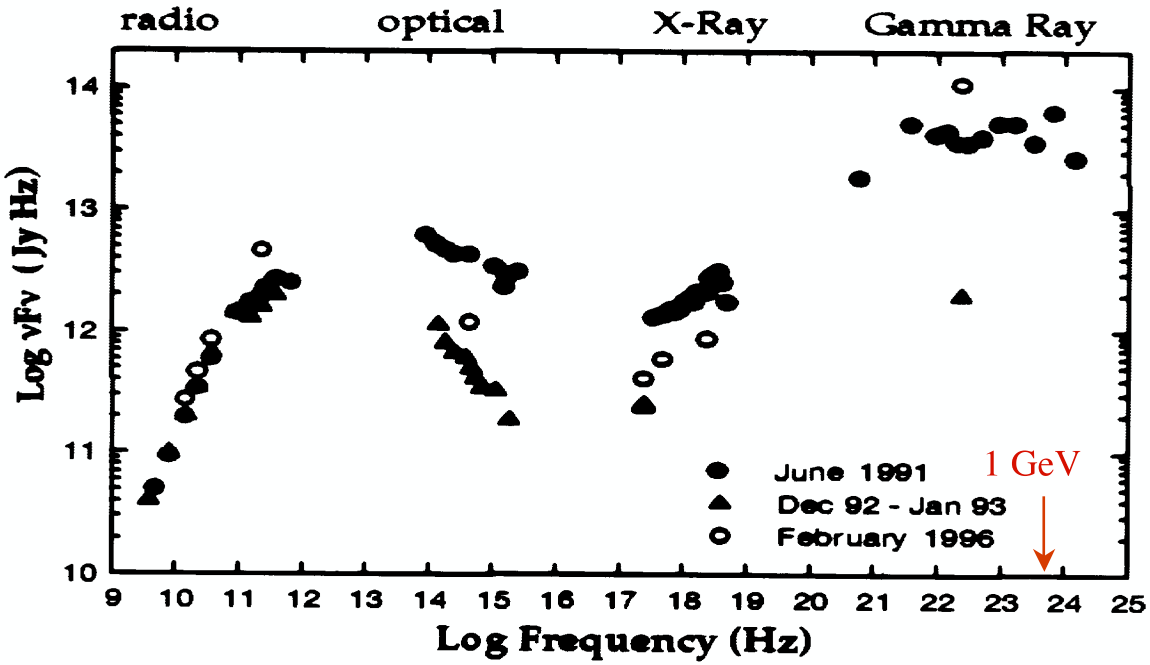


Models include energetic (multi-TeV), highly-collimated, relativistic particle jets. High energy γ-rays emitted within a few degrees of jet axis. Mechanisms are speculative; γ-rays offer a direct probe.

# AGN shine brightly in GLAST energy range

Power output of AGN is remarkable.  Multi-GeV component can be dominant!

Estimated luminosity of 3C 279:
~ $10^{45}$ erg/s
corresponds to $10^{11}$ times total solar luminosity
just in γ-rays!!  Large variability within days.



Multiwavelength Spectrum of 3C 279

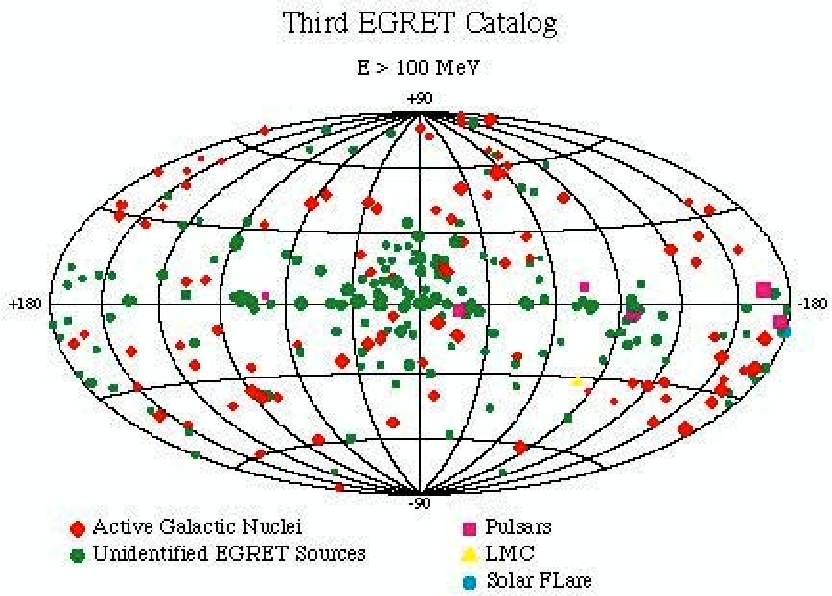
Sum all the power over the whole electromagnetic spectrum from all the stars of a typical galaxy: an AGN emits this amount of power in JUST γ rays from a very small volume!

# A surprise from EGRET:

detection of dozens of AGN

shining brightly in

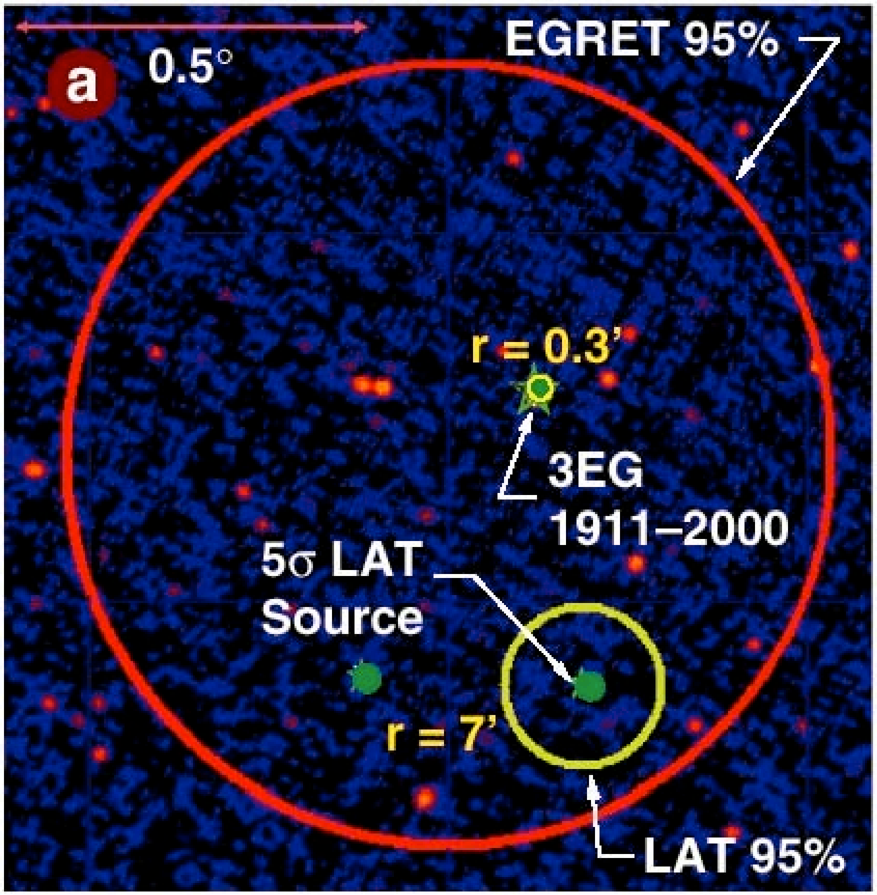
γ-rays -- Blazars



- 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.

# Unidentified Sources

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

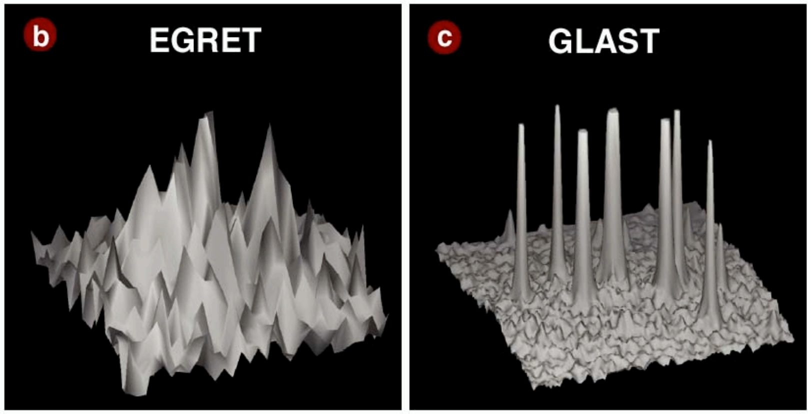


● Rosat or Einstein X-ray Source

● 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.

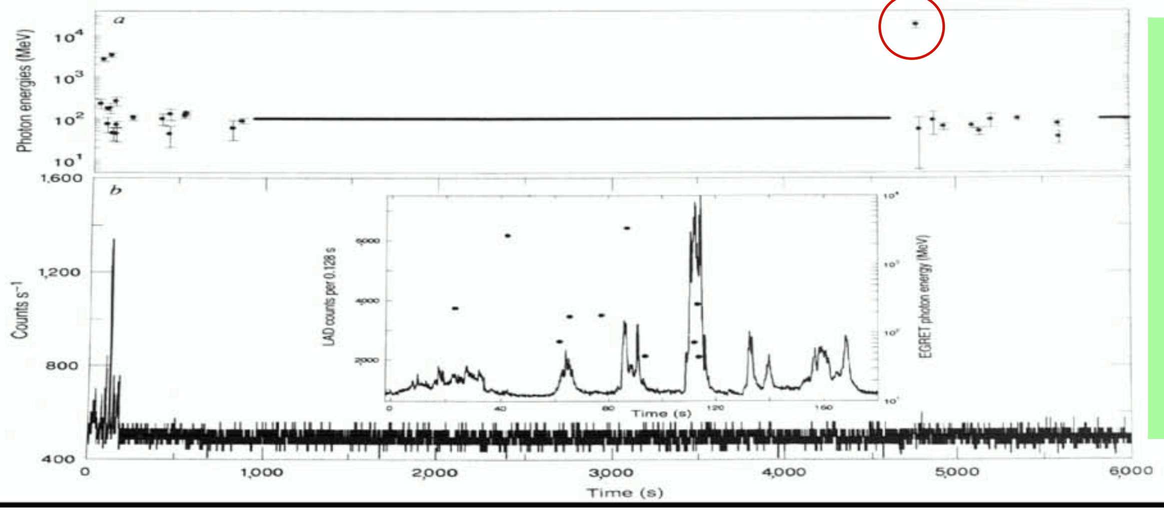


*Cygnus region (15x15 deg)*

# Gamma-ray Bursts

GRBs discovered in 1960’s accidentally by the Vela military satellites, searching for gamma-ray transients (guess why!) The question persists : What are they??

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

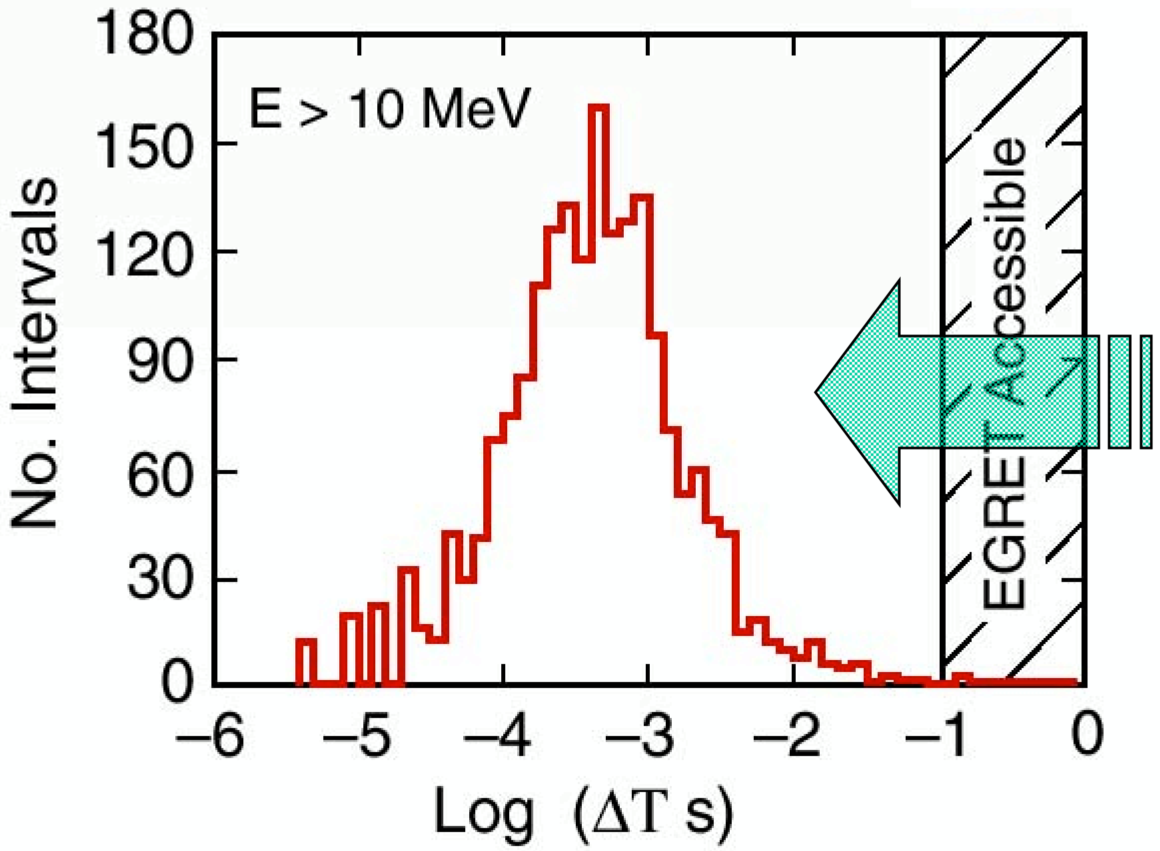


+ **Milagrito** evidence for TeV emission from GRB 970417 (ApJ 533(2000)533.

The next generation of experiments will provide definitive information about the high energy behavior of bursts.

# GRBs and Instrument Deadtime

Distribution for the 20th brightest burst in a year

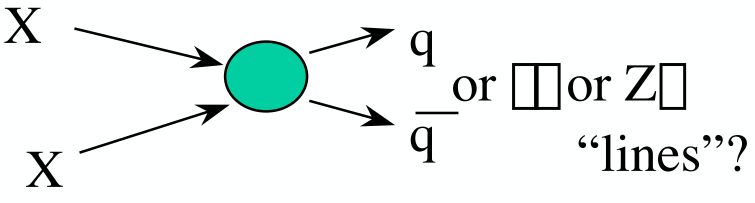


Time between consecutive arriving photons

GLAST opens a wide window on the study of the high energy behavior of bursts!

# Particle Dark Matter

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



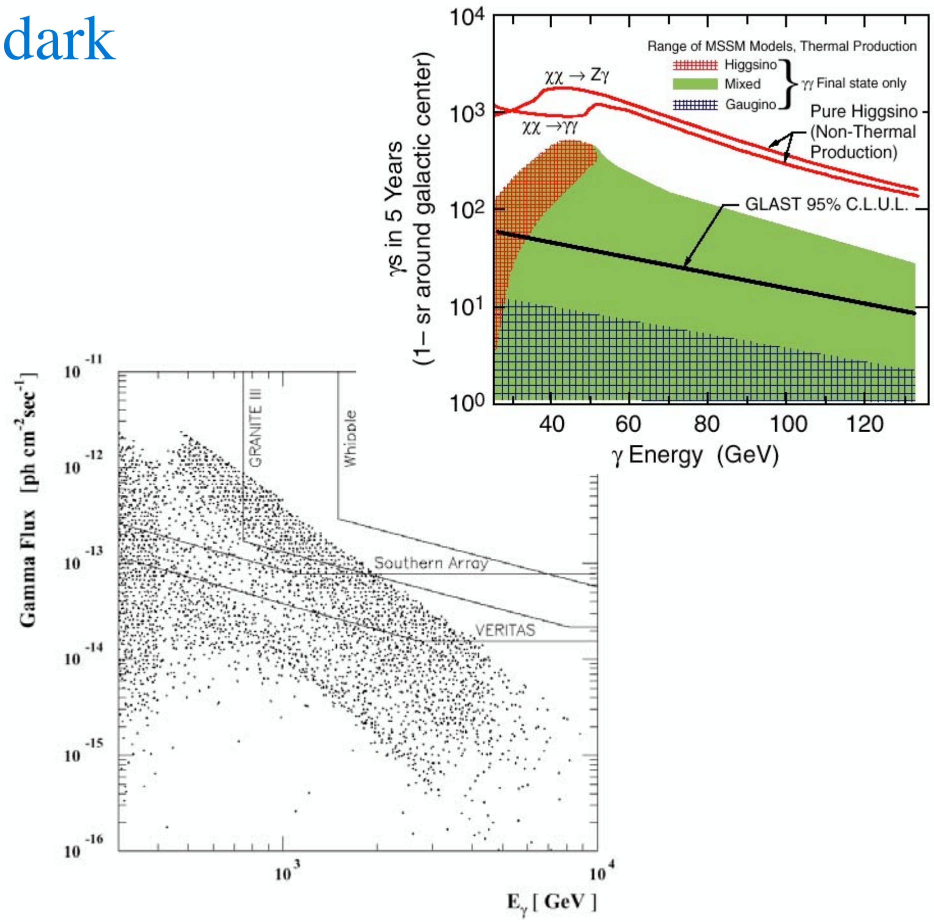
X

X

q

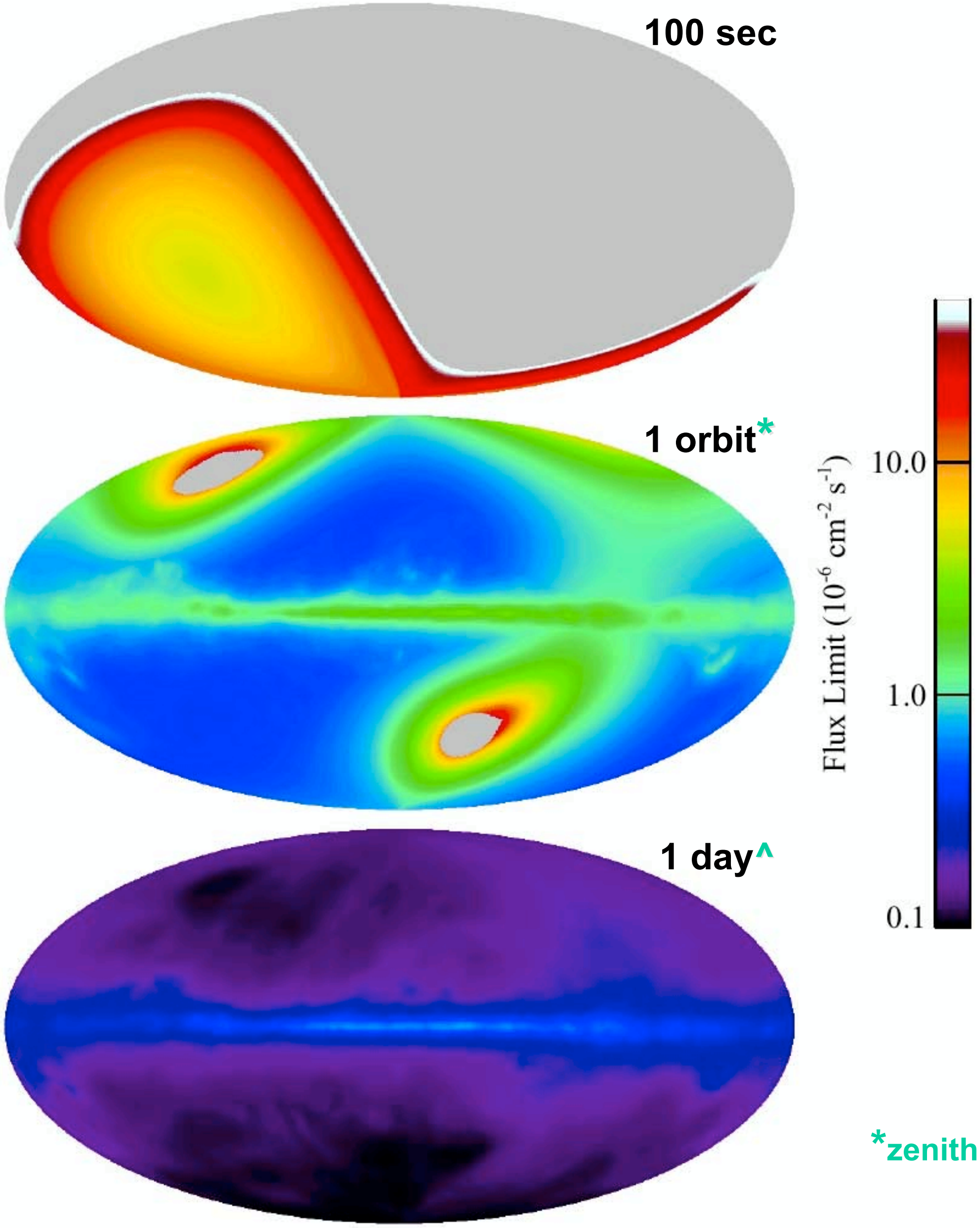
$\bar{q}$ or γγ or Zγ

"lines"?



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

# Transients Sensitivity During All-sky Scan Mode



**EGRET Fluxes**

- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar

- Crab Pulsar
- 3EG 2020+40 (SNR

- 3EG 1835+59
- 3C279 lowest 5σ detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5σ EGRET source

During the all-sky survey, GLAST will have sufficient sensitivity after one day to detect (5σ) the weakest EGRET sources.

*zenith-pointed, ^"rocking" all-sky scan

# Instruments: LAT and GBM

# 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/ Département 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

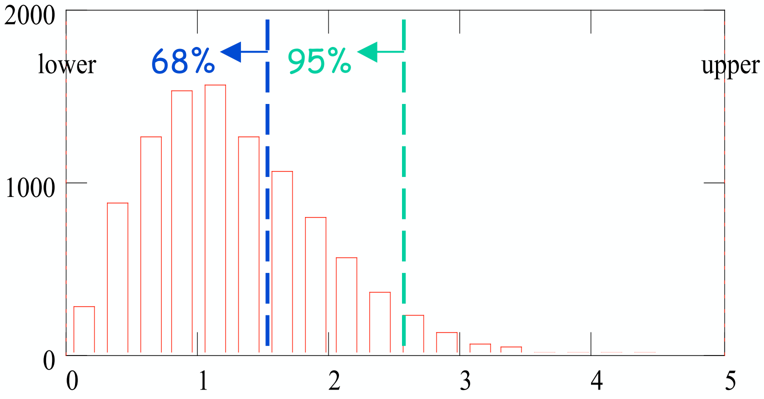
# Aside: some definitions

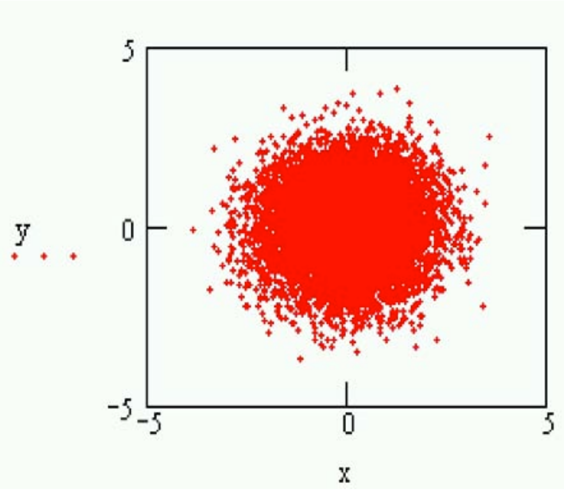
## Effective area

(total geometric acceptance) • (conversion probability) • (all detector and reconstruction efficiencies). Real rate of detecting a signal is (flux) • $A_{eff}$

## Point Spread Function (PSF)

Angular resolution of instrument, after all detector and reconstruction algorithm effects. The 2-dimensional 68% containment is the equivalent of ~1.5□ (1-dimensional error) if purely Gaussian response. The non-Gaussian tail is characterized by the 95% containment, which would be 1.6 times the 68% containment for a perfect Gaussian response.





# Science Performance Requirements Summary

From the SRD:

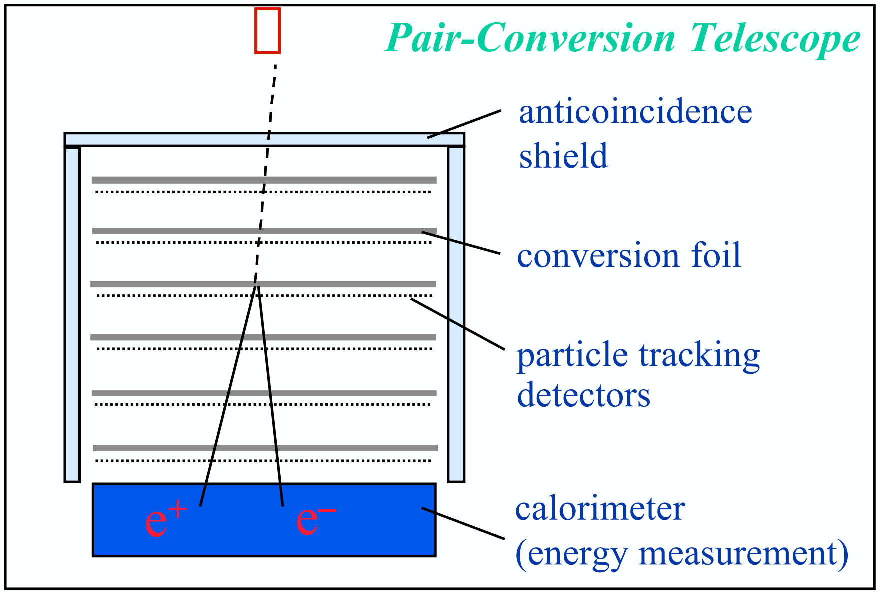
| Parameter | SRD Value |
|---|---|
| Peak Effective Area (in range 1-10 GeV) | >8000 $cm^2$ |
| Energy Resolution 100 MeV on-axis | <10% |
| Energy Resolution 10 GeV on-axis | <10% |
| Energy Resolution 10-300 GeV on-axis | <20% |
| Energy Resolution 10-300 GeV off-axis (>60º) | <6% |
| PSF 68% 100 MeV on-axis | <3.5° |
| PSF 68% 10 GeV on-axis | <0.15° |
| PSF 95/68 ratio | <3 |
| PSF 55º/normal ratio | <1.7 |
| Field of View | >2sr |
| Background rejection (E>100 MeV) | <10% diffuse |
| Point Source Sensitivity(>100MeV) | $<6\times10^{-9}$ $cm^{-2}s^{-1}$ |
| Source Location Determination | <0.5 arcmin |
| GRB localization | <10 arcmin |

# Experimental Technique

- Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):

- photon interactions with matter in GLAST energy range dominated by pair conversion:
  - ➡ determine photon direction
  - ➡ clear signature for background rejection
- limitations on angular resolution (PSF)

**low E: multiple scattering => many thin layers**
**high E: hit precision & lever arm**



*Pair-Conversion Telescope*

anticoincidence shield

conversion foil

particle tracking detectors

calorimeter (energy measurement)

Energy loss mechanisms:

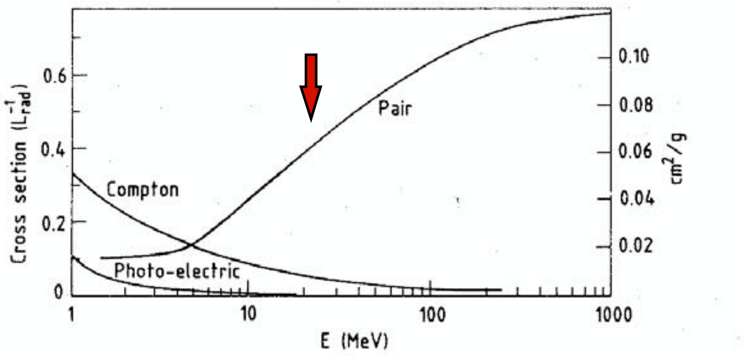
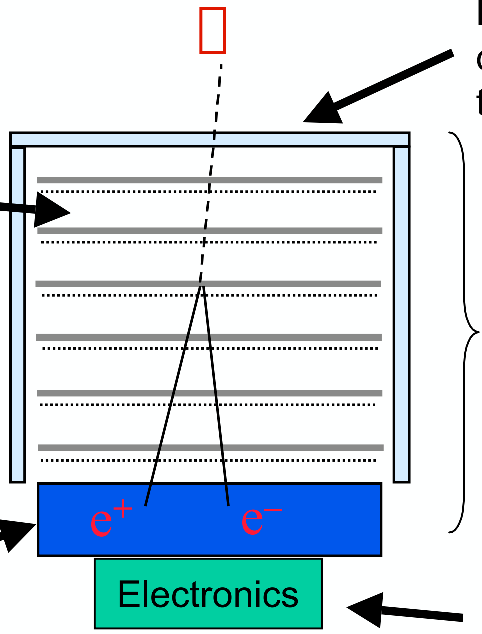


**Fig. 2:** Photon cross-section $\sigma$ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- must detect γ-rays with high efficiency and reject the much larger (~$10^4$:1) flux of background cosmic-rays, etc.;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.

# 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.

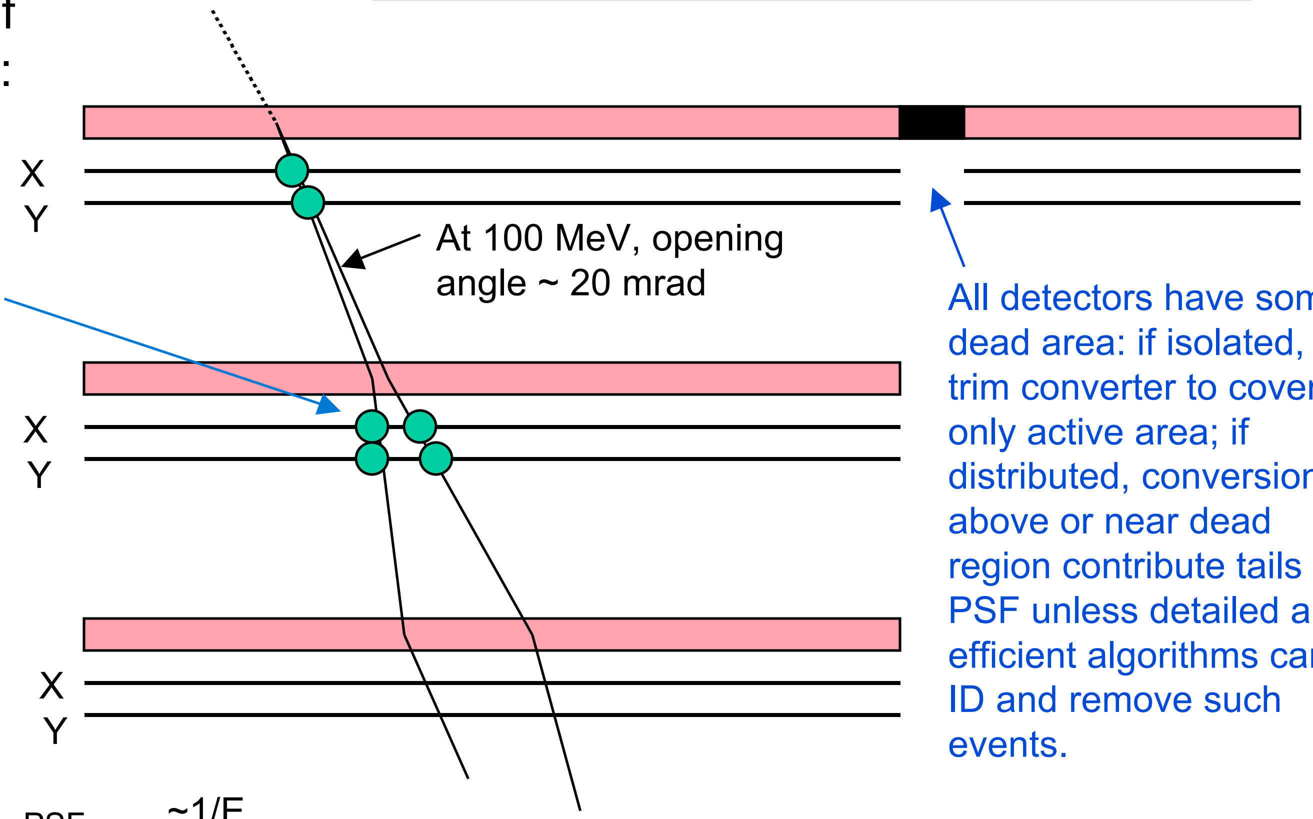
Instrument life has an impact on detector technology choices.
Derived requirements (source location determination and point source sensitivity) are a result of the overall system performance.

GLAST

# Tracker/Converter Issues

## Some lessons learned from simulations

Expanded view of converter-tracker:



At 100 MeV, opening angle ~ 20 mrad

At low energy, measurements at first two layers completely dominate due to multiple scattering-- MUST have all these hits, or suffer factor ~ 2 PSF degradation.

If eff = 90%, already only keep $(.9)^4$= 66% of potentially good photons.

=> want >99% efficiency.

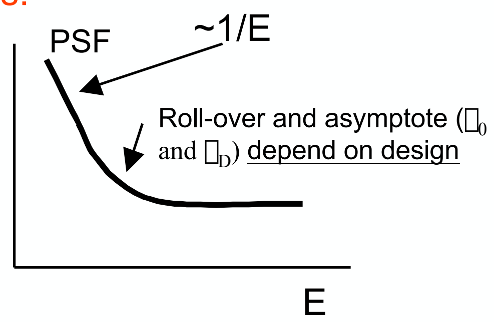
Low energy PSF completely dominated by multiple scattering effects:

$\square_0 \sim 2.9$ mrad / E[GeV]

(scales as $(x_0)$–)

High energy PSF set by hit resolution/plane spacing:

$\square_D \sim 1.8$ mrad.



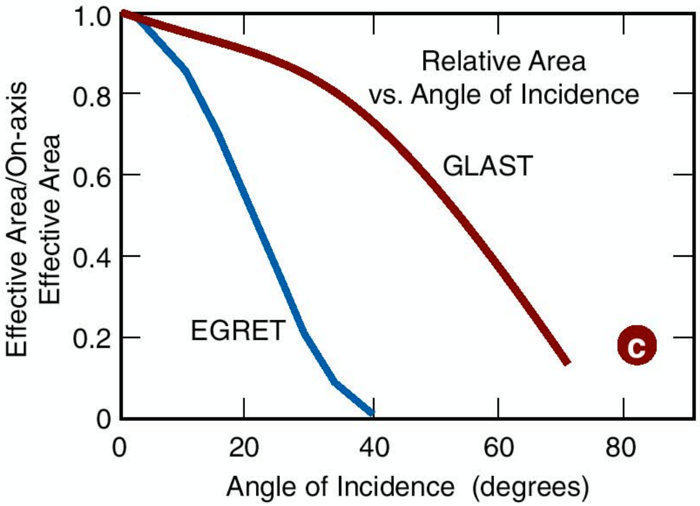
Roll-over and asymptote ($\square_0$ and $\square_D$) depend on design

All detectors have some dead area: if isolated, can trim converter to cover only active area; if distributed, conversions above or near dead region contribute tails to PSF unless detailed and efficient algorithms can ID and remove such events.

At higher energies, more planes contribute information:

| Energy | # significant planes |
|---|---|
| 100 MeV | 2 |
| 1 GeV | ~5 |
| 10 GeV | >10 |

# Field of View and Instrument Aspect Ratio

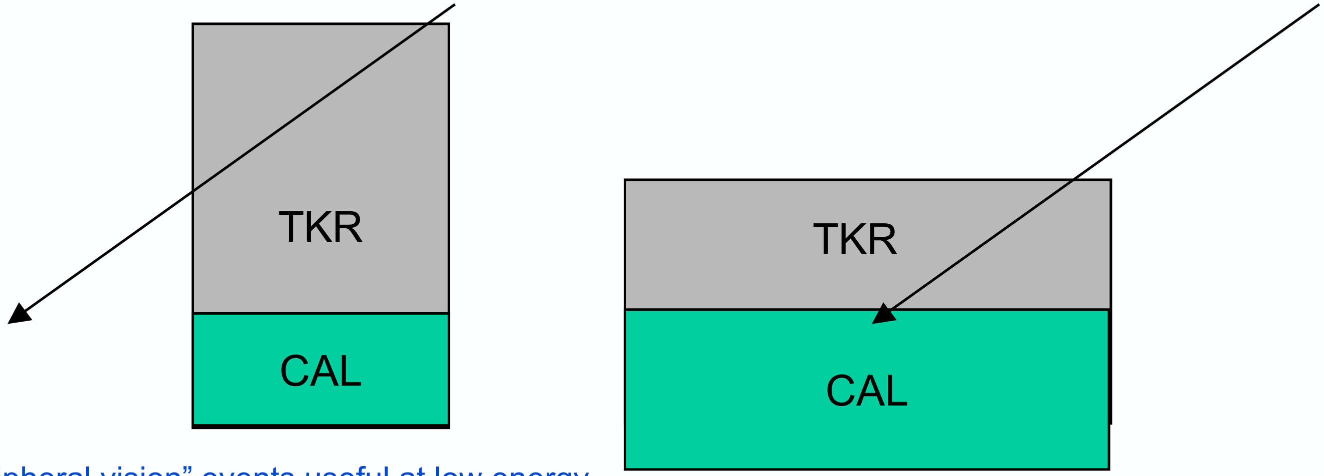


For energy measurement and background rejection, want events to pass through the calorimeter*.

The aspect ratio (Area/Height) then governs the main field of view of the tracker:

EGRET had a relatively small aspect ratio

GLAST has a large aspect ratio



[*] note: "peripheral vision" events useful at low energy, but are not included in performance calculations.

# IRD and MSS Constraints Relevant to LAT Science Performance

- Lateral dimension < 1.8m

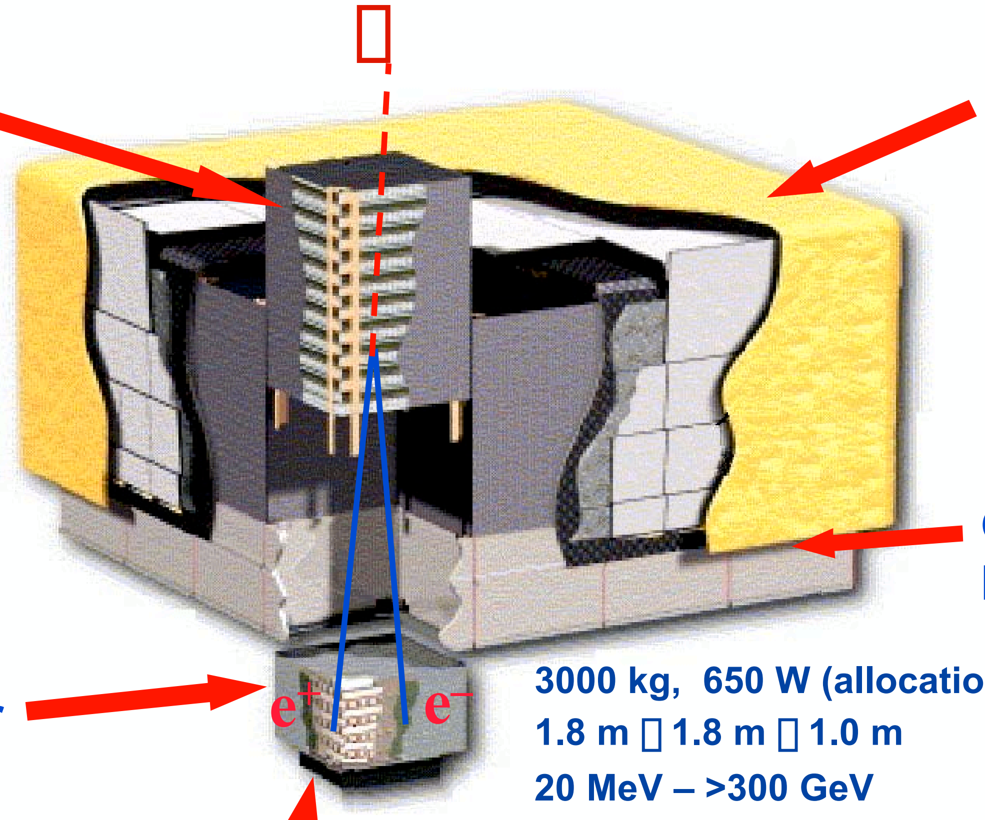
  Restricts the geometric area.
- Mass < 3000 kg

  Primarily restricts the total depth of the CAL.
- Power < 650W

  Primarily restricts the # of readout channels in the TKR (strip pitch, # layers), and restricts onboard CPU.
- Telemetry bandwidth < 300 kbps orbit average

  Sets the required level of onboard background rejection and data volume per event.
- Center-of-gravity constraint restricts instrument height, but a low aspect ratio is already desirable for science.
- Launch loads and other environmental constraints.

# 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)**

**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**

3000 kg, 650 W (allocation)

1.8 m □ 1.8 m □ 1.0 m

20 MeV – >300 GeV

**LAT managed at SLAC**

**Flight Hardware & Spares**

16 Tracker Flight Modules + 2 spares

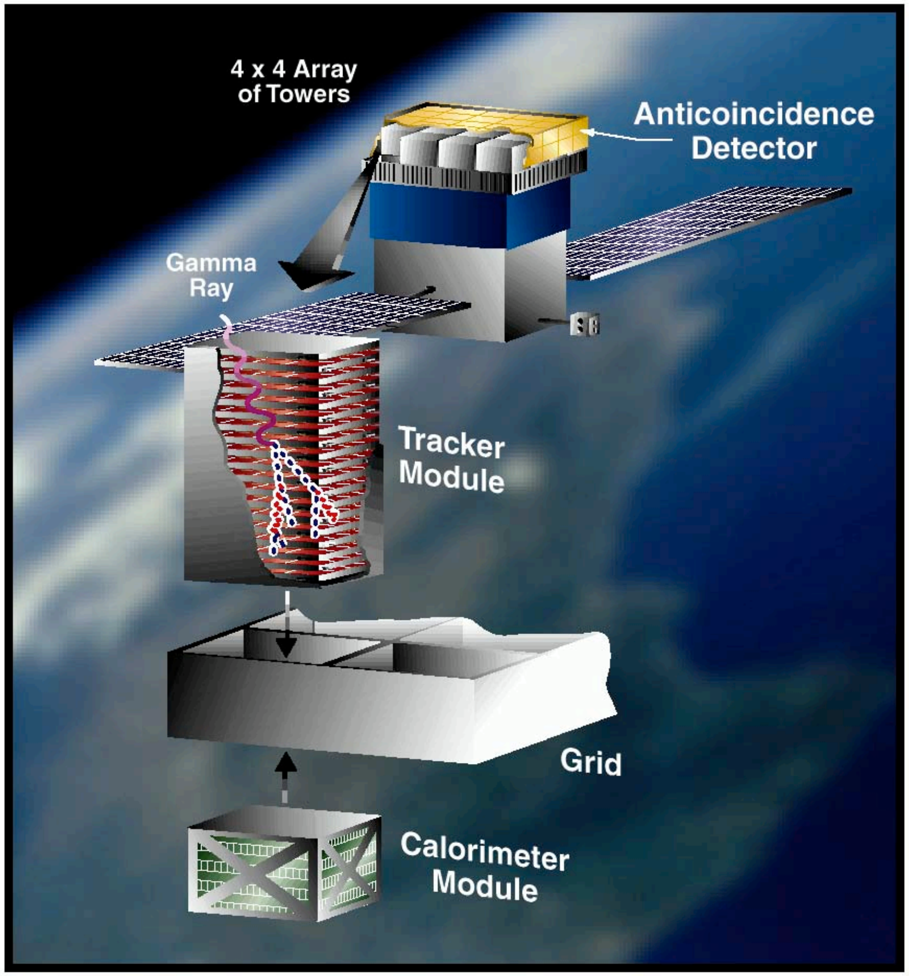
16 Calorimeter Modules + 2 spares

1 Flight Anticoincidence Detector

Data Acquisition Electronics + Flight Software

# Overview of LAT

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



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

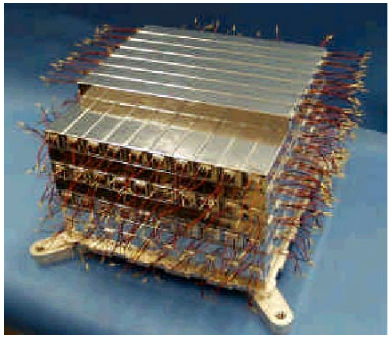
# Detector Choices

- TRACKER

  single-sided silicon strip detectors for hit efficiency, low noise occupancy, resolution, reliability, readout simplicity. Noise occupancy requirement primarily driven by trigger.

- CALORIMETER

  hodoscopic array of CsI(Tl) crystals with photodiode readout

  **for good resolution over large dynamic range; modularity matches TKR; hodoscopic arrangement allows for imaging of showers for leakage corrections and background rejection pattern recognition.**

- ANTICOINCIDENCE DETECTOR

  segmented plastic scintillator tiles with wavelength shifting fiber/phototube readout for high efficiency (0.9997 flows from background rejection requirement) and avoidance of ‘backsplash’ self-veto.

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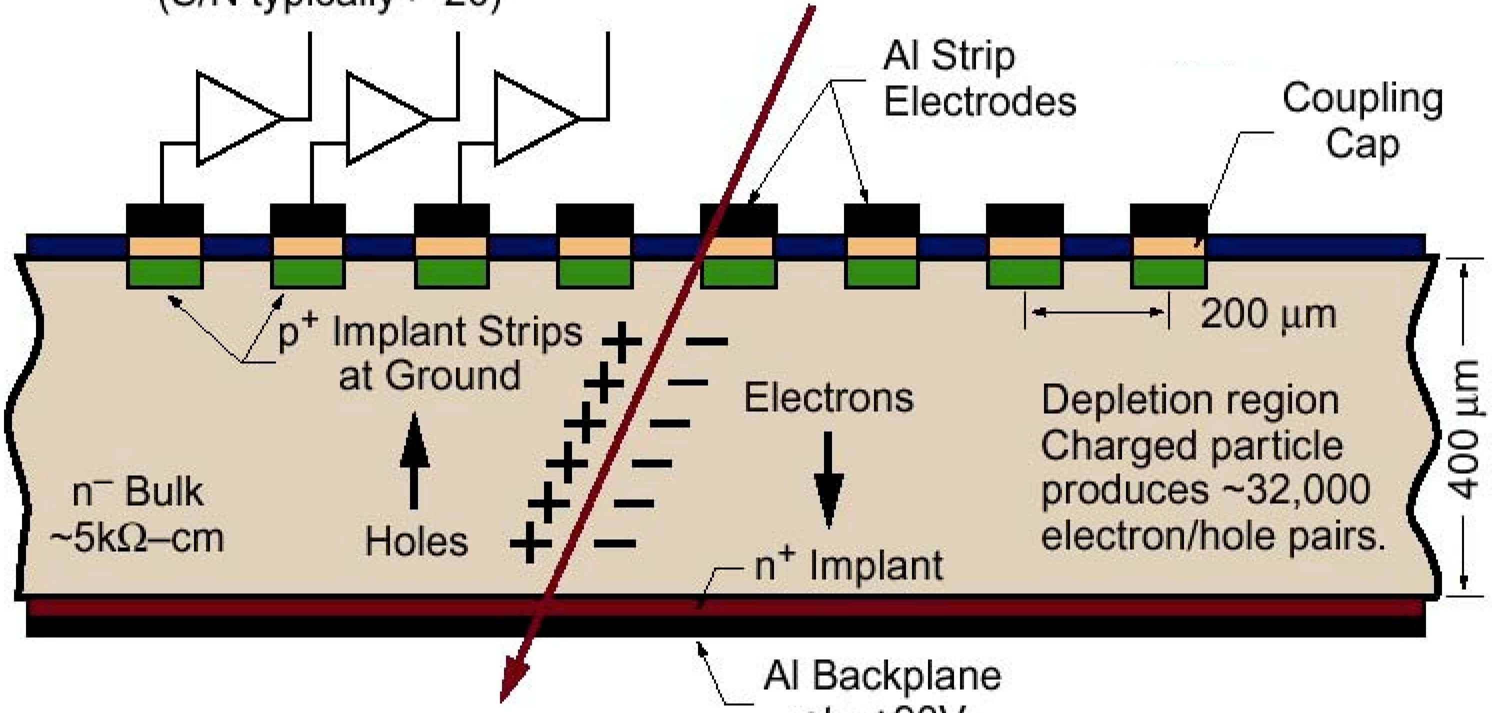
# Silicon Strip Detector Principle



**VLSI**
Low-noise, Low-power
Amplifier/Discriminator
(S/N typically > 20)

Al Strip
Electrodes

Coupling
Cap

$p^+$ Implant Strips
at Ground

200 µm

400 µm

Electrons

Depletion region
Charged particle
produces ~32,000
electron/hole pairs.

$n^-$ Bulk
~5kΩ–cm

Holes

$n^+$ Implant

Al Backplane
at ~+90V

# Tracker Optimization

- Radiator thickness profile iterated and selected.
- Resulting design: *"FRONT":* **12 layers of 3% r.l. converter**
  *"BACK":* **4 layers of 18% r.l. converter followed by 2 "blank" layers**
- Large $A_{eff}$ with good PSF and improved aspect ratio for BACK.
- Two sections provide measurements in a complementary manner: FRONT has better PSF, BACK greatly enhances photon statistics.
- Radiator thicknesses, SSD dimensions (pitch 228 microns), and instrument footprint finalized.

**TKR has ~1.5 r.l. of material.**
**Combined with ~8.5 r.l. CAL provides 10 r.l. total.**

# Design Performance Validation: LAT Monte-Carlo Model

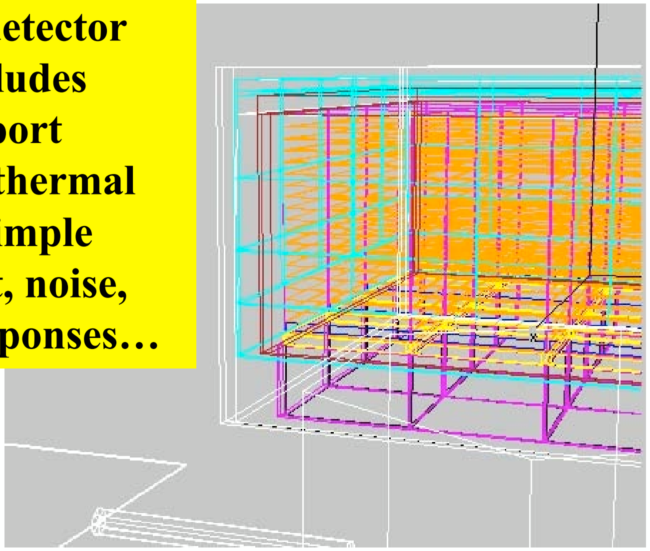
The LAT design is based on detailed Monte Carlo simulations.

Integral part of the project from the start.

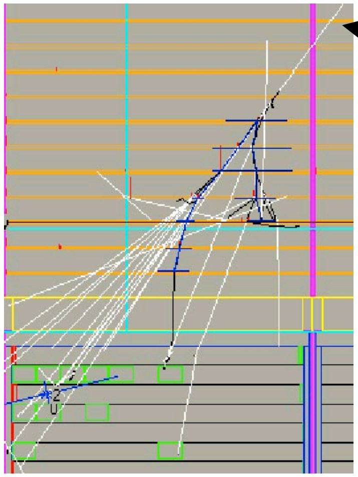
- ➢ **Background rejection**
- **Calculate effective area and resolutions (computer models now verified by beam tests). Current reconstruction algorithms are existence proofs -- many further improvements under development.**
- **Trigger design.**
- **Overall design optimization.**

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

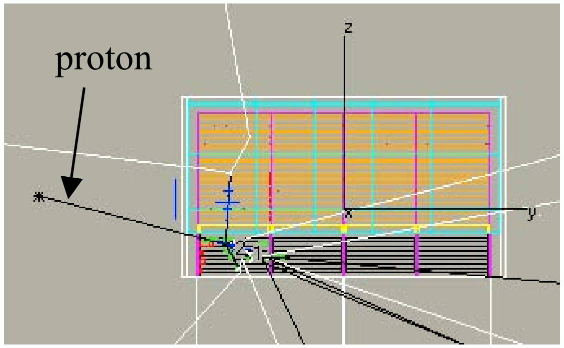
**Detailed detector model includes gaps, support material, thermal blanket, simple spacecraft, noise, sensor responses…**



Instrument naturally distinguishes gammas from backgrounds, but details matter.



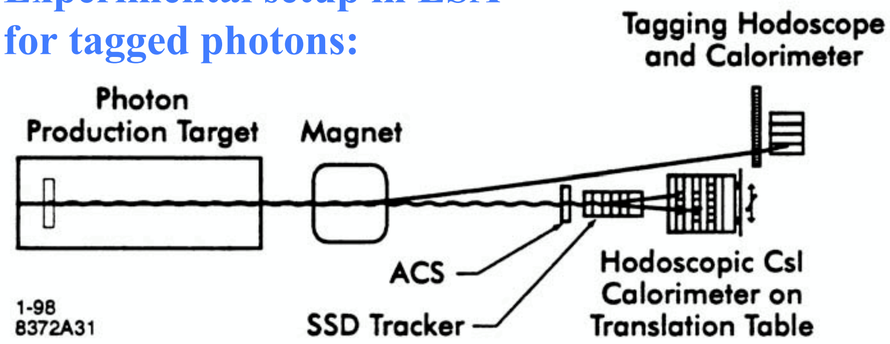
gamma ray

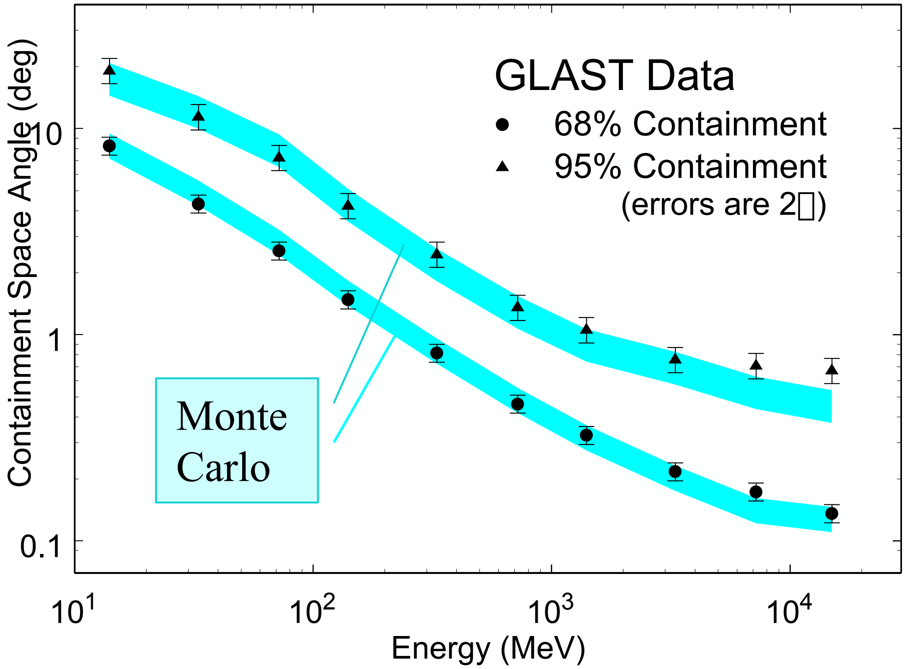


proton

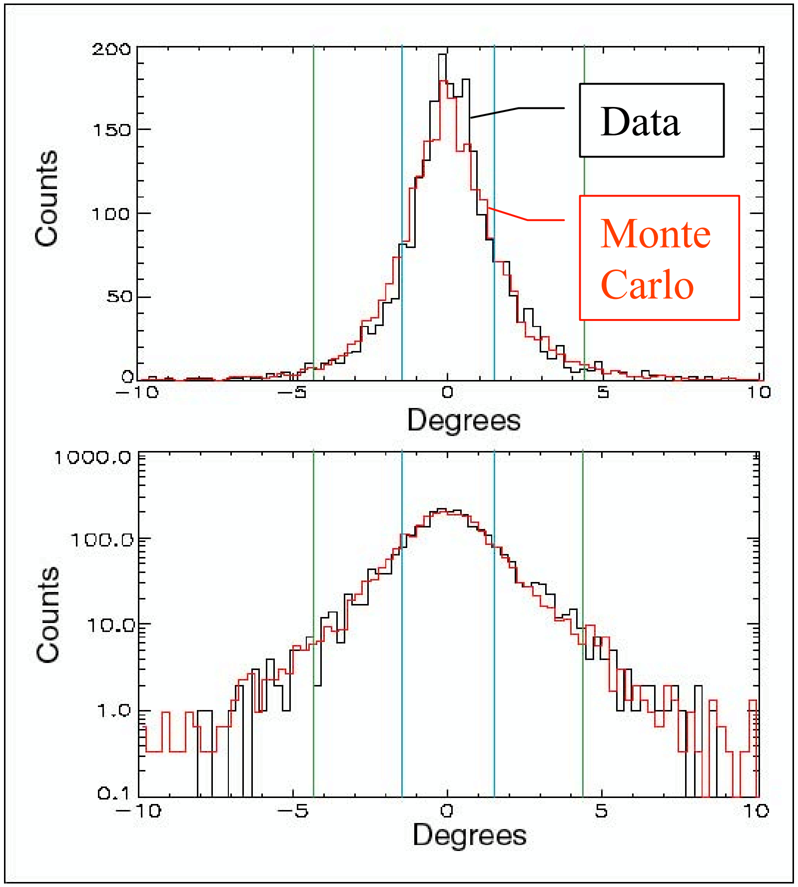
# Monte Carlo Modeling Verified in Detailed Beam Tests

**Experimental setup in ESA for tagged photons:**





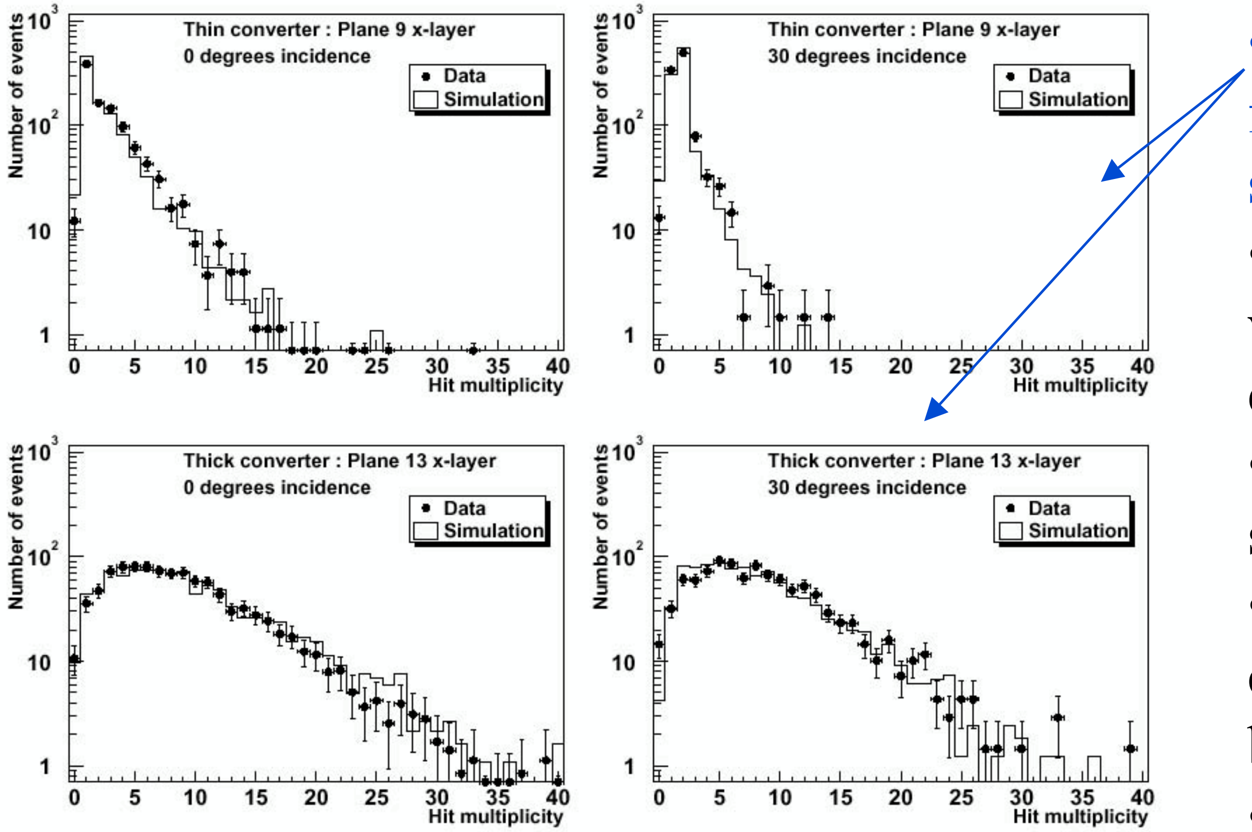
X Projected Angle
3-cm spacing, 4% foils, 100-200 MeV



Published in NIM A446(2000), 444.

# 1999-2000 Beam Test at SLAC

Using beams of positrons, tagged photons and hadrons, with a ~flight-size tower, studies of



- data system, trigger
- hit multiplicities in front and back tracker sections
- calorimeter response with prototype electronics.
- time-over-threshold in silicon
- upper limit on neutron component of ACD backsplash
- hadron tagging and first look at response

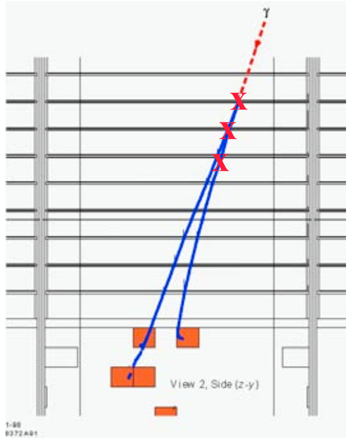
Published in NIM A474(2001)19.

# 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 □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 20□s

**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:**
  **□cosmic-rays ~ 1:~few**

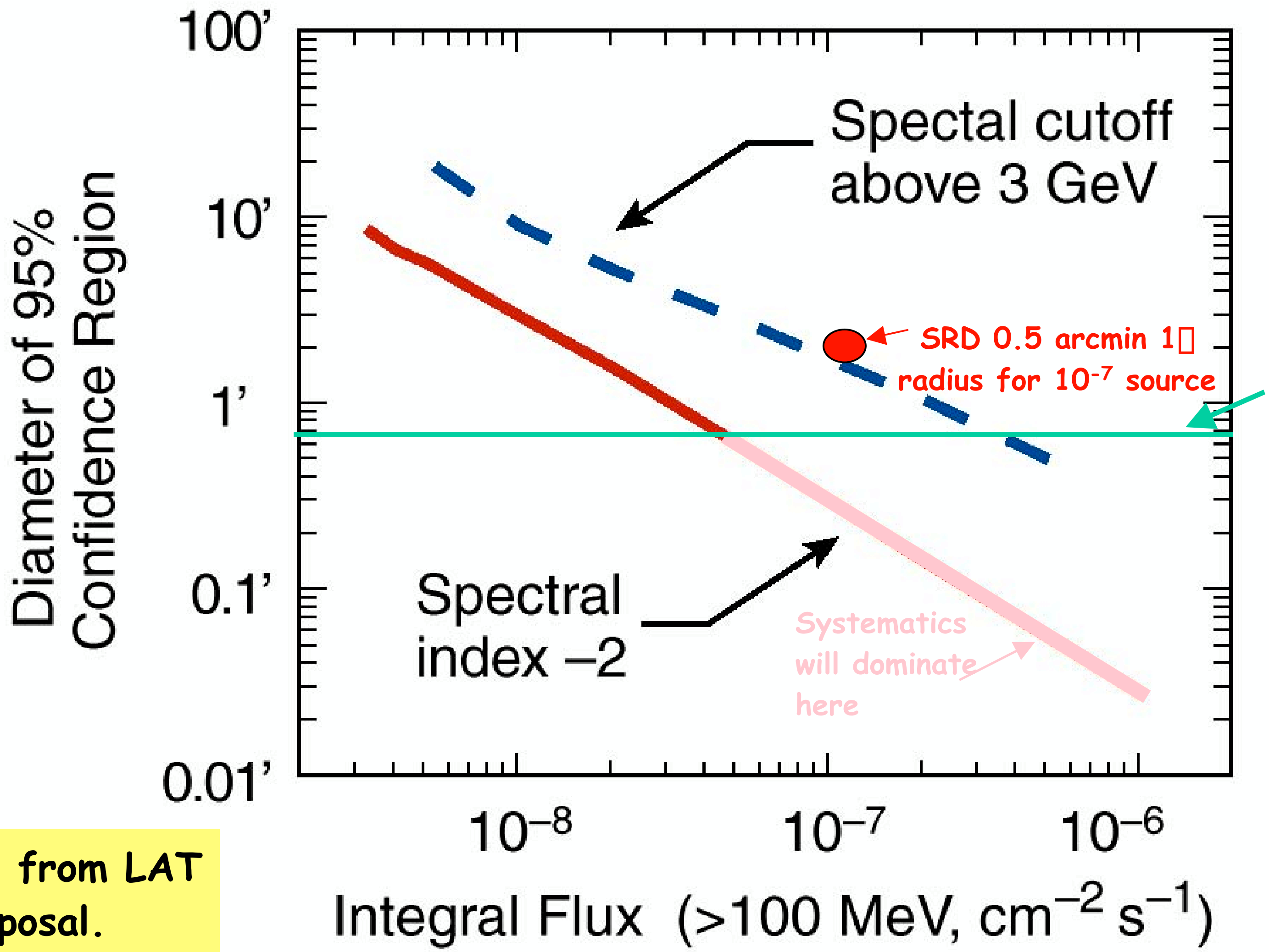
**Total L3T Rate: <25-30 Hz>**

**(average event size: ~8-10 kbits)**

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

**Spacecraft**

# LAT Source Localizations



SRD 0.5 arcmin 1σ radius for $10^{-7}$ source

10 arcsec, 1σ radius

Systematics will dominate here

figure is from LAT proposal.
will be updated.

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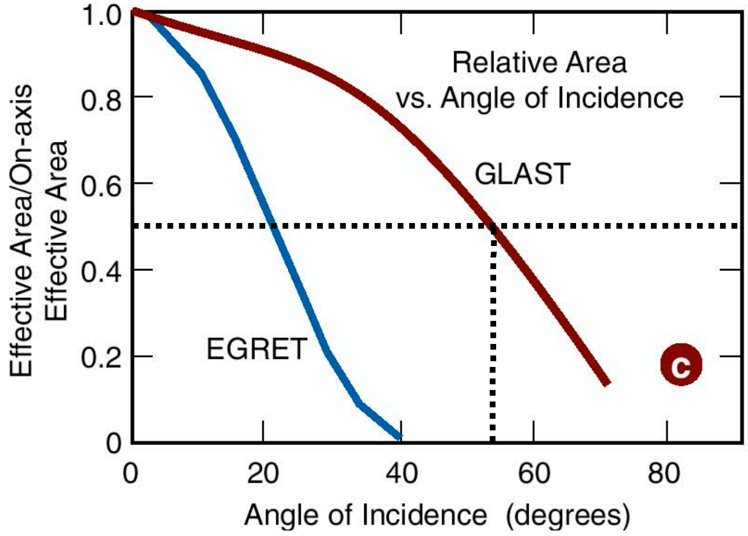
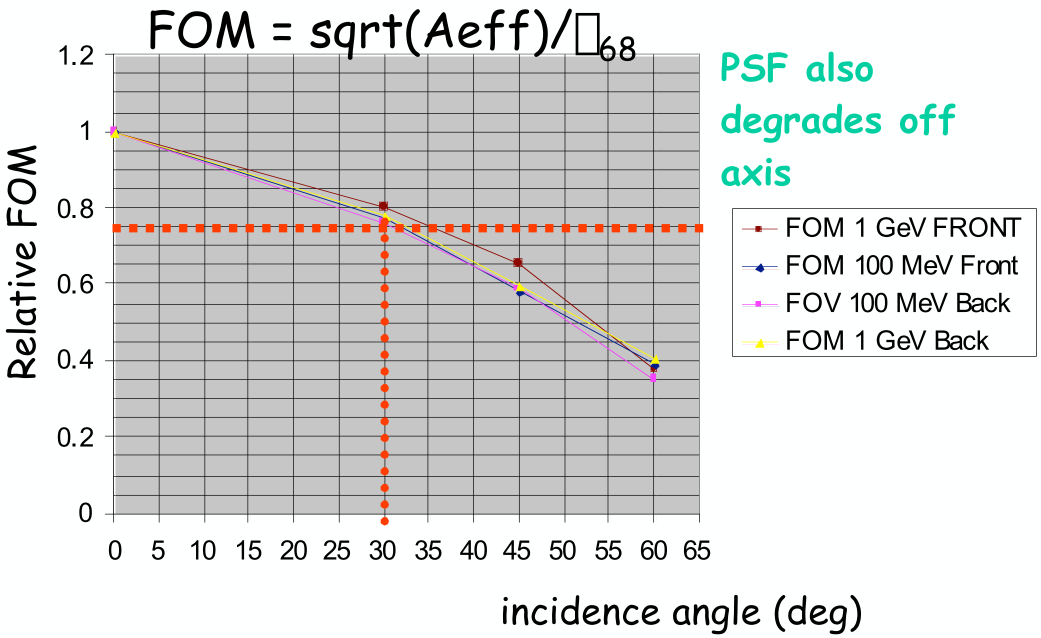
# What does “pointing” mean?

The LAT FOV is huge:





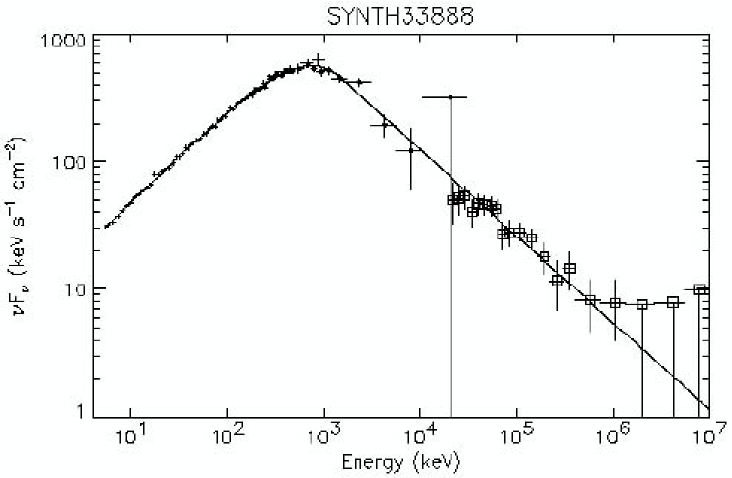
PSF also degrades off axis

For the purposes of setting slew requirements define

- LAT FOV: anything within ±55° (0.96 radian) (TBR) of normal incidence is within the LAT FOV.
- “Pointing”: the target is within ±30° (0.52 radian) (TBR) of normal incidence. Individual targets may have a different criterion, depending on source characteristics.

# GBM (PI: Meegan)

- provides spectra for bursts from 10 keV to 30 MeV, connecting frontier LAT high-energy measurements with more familiar energy domain;



*Simulated GBM and LAT response to time-integrated flux from bright GRB 940217*

*Spectral model parameters from CGRO wide-band fit*

*1 NaI (14 º) and 1 BGO (30 º)*

- provides wide sky coverage (8 sr) -- enables autonomous repoint requests for exceptionally bright bursts that occur outside LAT FOV for high-energy afterglow studies (an important question from EGRET);
- provides burst alerts to the ground.

# 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*

# GBM Instrument Requirements

op-Level GBM Instrument RequirementsParameterRequirementGoalBATSE

| | | | |
|---|---|---|---|
| | | | |
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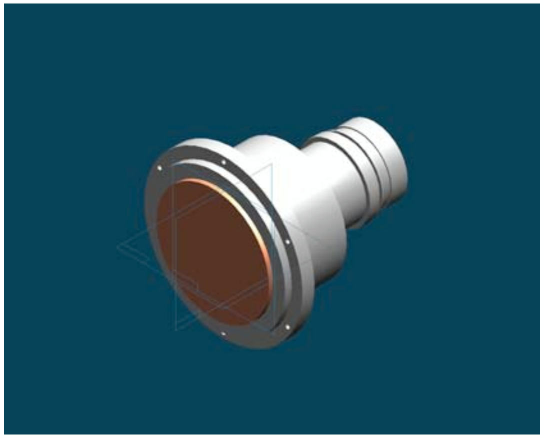
# GBM Instrument Design: Major Components

## 12 Sodium Iodide (NaI) Scintillation Detectors



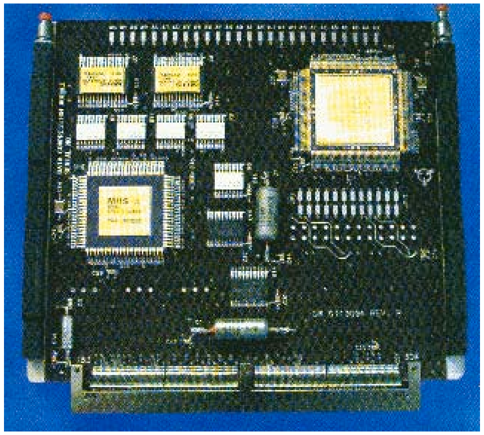
### Characteristics

- 5-inch diameter, 0.5-inch thick
- One 5-inch diameter PMT per Det.
- Placement to maximize FoV
- Thin beryllium entrance window
- Energy range: ~5 keV to 1 MeV

### Major Purposes

- Provide low-energy spectral coverage in the typical GRB energy regime over a wide FoV
- Provide rough burst locations over a wide FoV

## Data Processing Unit (DPU)



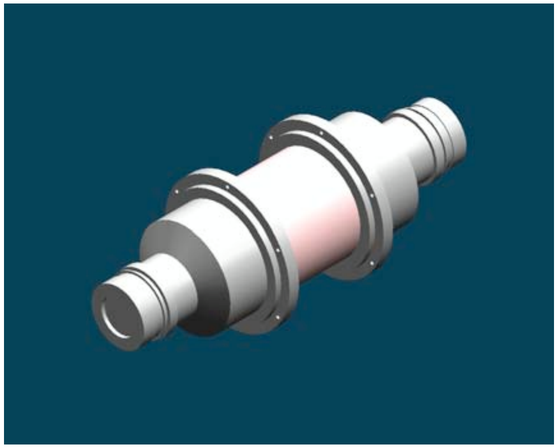
### Characteristics

- Analog data acquisition electronics for detector signals
- CPU for data packaging/processing

### Major Purposes

- Central system for instrument command, control, data processing
- Flexible burst trigger algorithm(s)
- Automatic detector/PMT gain control
- Compute on-board burst locations
- Issue r/t burst alert messages

## 2 Bismuth Germanate (BGO) Scintillation Detectors



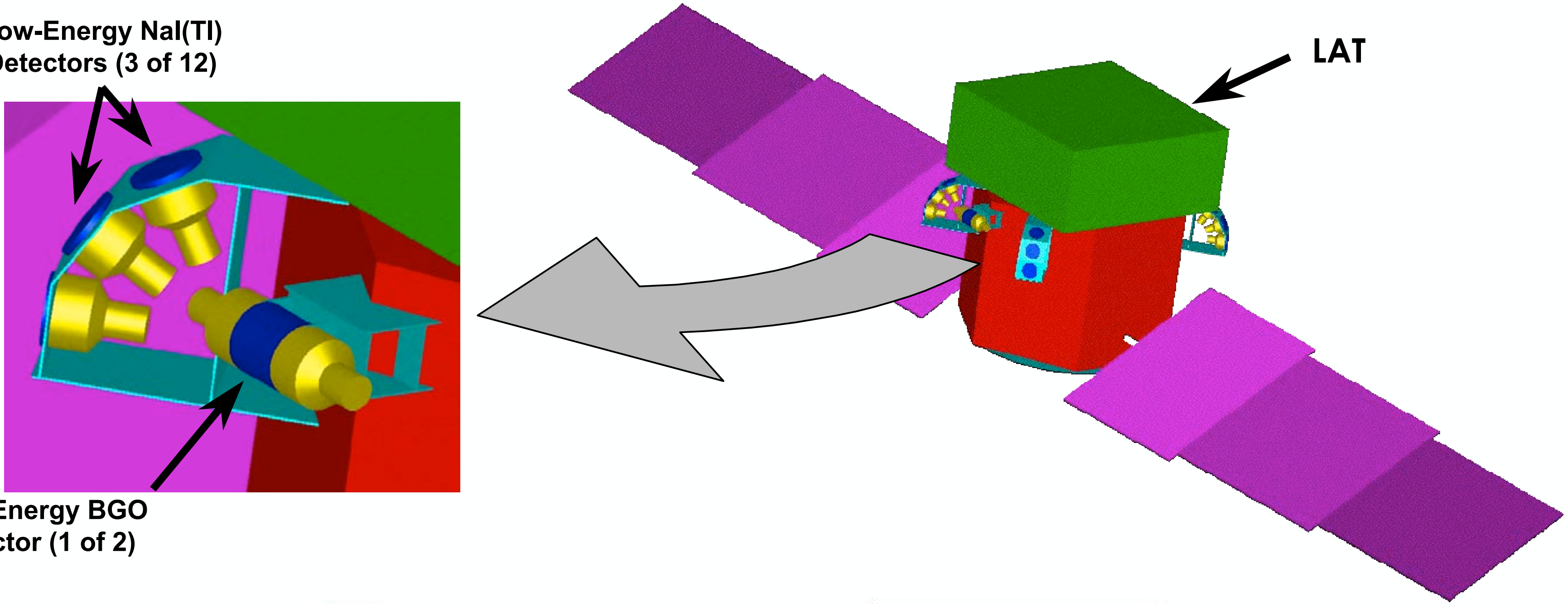
### Characteristics

- 5-inch diameter, 5-inch thick
- High-Z, high-density
- Two 5-inch diameter PMTs per Det.
- Energy range: ~150 keV to 30 MeV

### Major Purpose

- Provide high-energy spectral coverage to overlap LAT range over a wide FoV

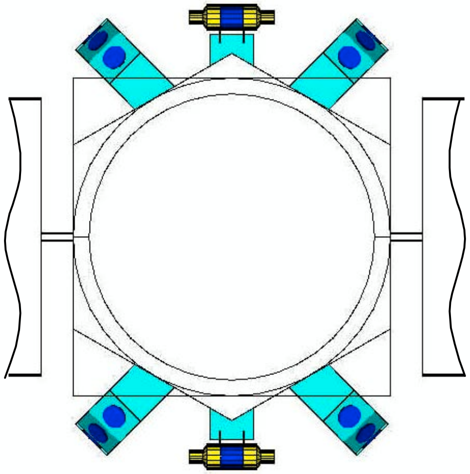
# GBM Detector Placement Concept



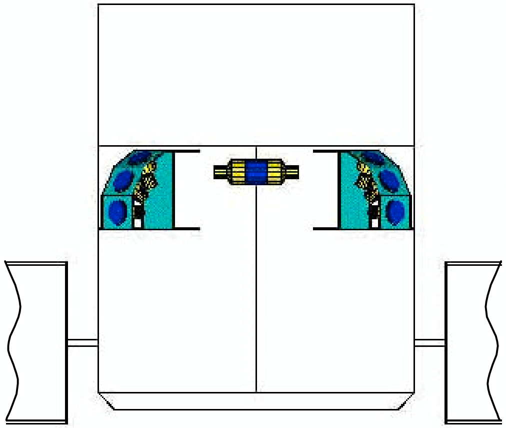
Low-Energy NaI(Tl) Detectors (3 of 12)

LAT

High-Energy BGO Detector (1 of 2)



Top View



Side View

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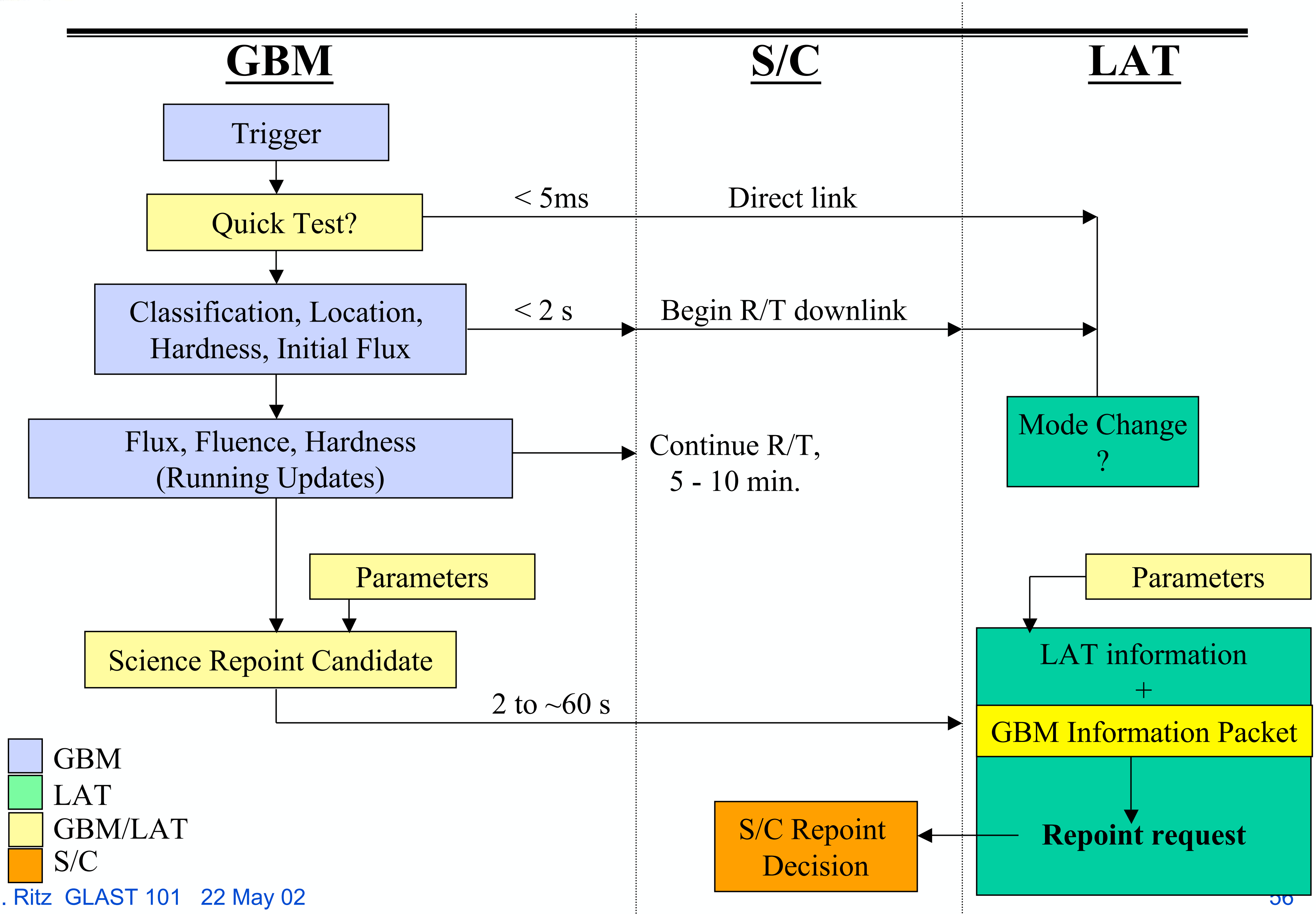
# Burst Alerts



GBM

S/C

LAT

Trigger

Quick Test?

< 5ms

Direct link

Classification, Location, Hardness, Initial Flux

< 2 s

Begin R/T downlink

Flux, Fluence, Hardness (Running Updates)

Continue R/T, 5 - 10 min.

Mode Change ?

Parameters

Science Repoint Candidate

2 to ~60 s

Parameters

LAT information + GBM Information Packet

**Repoint request**

S/C Repoint Decision

🟦 GBM
🟩 LAT
🟨 GBM/LAT
🟧 S/C

# Transients (Bursts)

Summary of plan

**During all-sky scanning operations, detection of a sufficiently significant burst will cause the observatory to interrupt the scanning operation autonomously and to remain pointed at the burst region during all non-occulted viewing time for a period of 5 hours (TBR). There are two cases:**

1. The burst occurs within the LAT FOV. **If the burst is bright enough that an on-board analysis provides >90% certainty that a burst occurred within the LAT FOV, the observatory will slew to keep the burst direction within 30 degrees (TBR) of the LAT z axis during >80% of the entire non-occulted viewing period (neglecting SAA effects). Such events are estimated to occur approximately once per week.**

2. The burst occurs outside the LAT FOV. **Only if the burst is exceptionally bright, the observatory will slew to bring the burst direction within 30 degrees (TBR) of the LAT z axis during >80% of the entire non-occulted viewing period (neglecting SAA effects). Such events are likely to occur a few times per year.**

**After six months, this strategy will be re-evaluated. In particular, the brightness criterion for case 2 and the stare time will be revisited, based on what has been learned about the late high-energy emission of bursts.**

# Transients (AGN)

**PLAN FOR THE FIRST YEAR**

- **Most AGN science can be best addressed by the all-sky scan.**
- **Unusually large flares will be treated as Targets of Opportunity, and studied in a coordinated multi-wavelength campaign.**

**Thus, autonomous repointing of the spacecraft is not required for AGN science during the first year.**

This approach will be re-evaluated after the first year, as new knowledge about AGN might demand a new strategy.