the Science, the LAT, and its Silicon-Strip Tracking System

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Outline

Introduction: EGRET

Pair-Conversions Telescopes

The LAT Design

LAT Performance

GLAST Science Topics

The LAT Tracker Design

LAT 1999/2000 Beam Test

Schedule

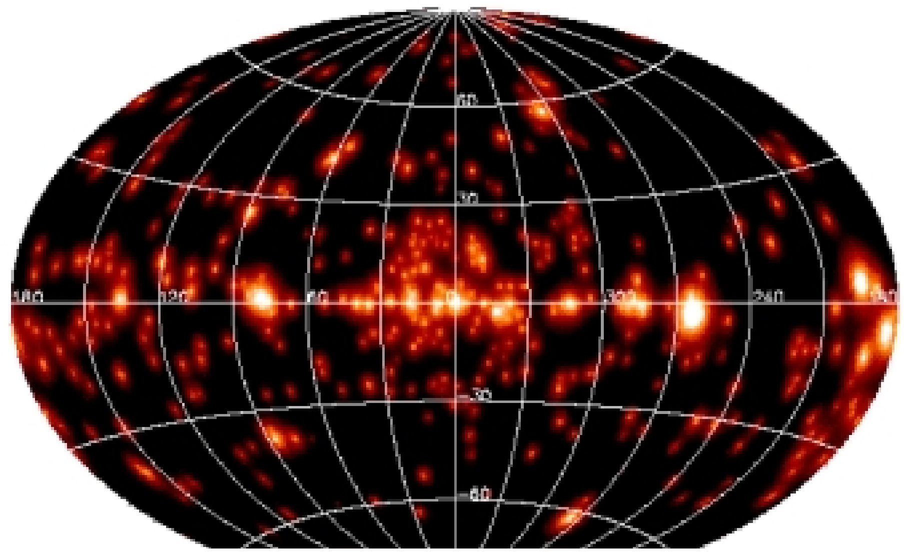
Conclusions

A Successor to EGRET

EGRET's success and the questions raised by its discoveries demand a follow-on mission with greatly expanded capabilities:

The GLAST mission is designed to improve upon EGRET's sensitivity to point sources by a factor of 25 to 50.

- Launch in 1991; de-orbit in 2000
- >60 AGN with >100 MeV γ
- ~6 GRB at high energy
- ~7 pulsars at high energy
- diffuse γ-rays to >10 GeV
- 170 unidentified sources

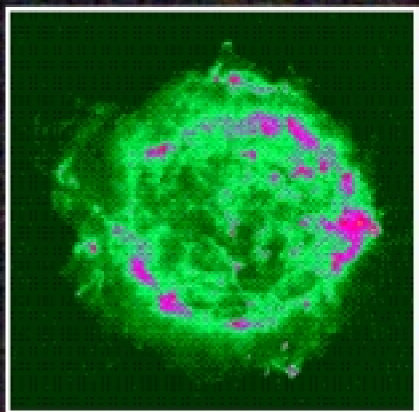


Sources in the 3rd EGRET Catalog

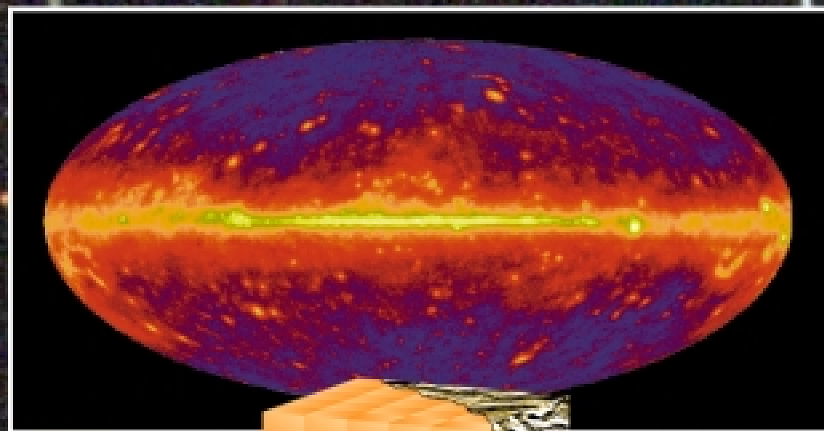
GLAST Science

0.01 GeV	0.1 GeV	1 GeV	10 GeV	100 GeV	1 TeV

Supernova Remnants

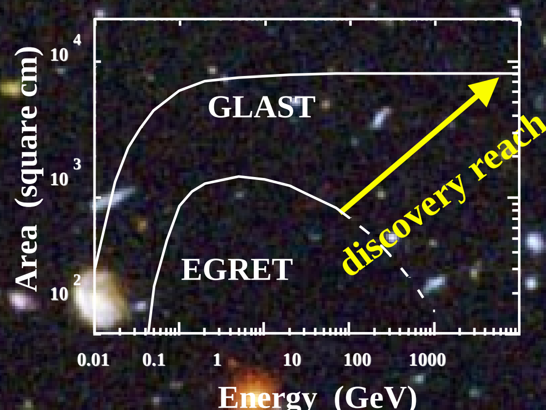


Map the High-Energy Universe



AGN

- GLAST pulsar survey: provide a new window on the galactic neutron star population.
- "Map" the pulsar magnetosphere and understand the physics of pulsar emission.
- Origin of cosmic-rays: characterize extended supernovae sources.
- Determine the origin of the isotropic diffuse gamma-ray background.

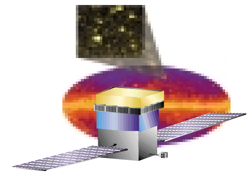


- Physics in regions of strong gravity, huge electric & magnetic fields: e.g. particle production & acceleration near the event horizon of a black hole.
- Use gamma-rays from AGNs to study evolution of the early universe.
- Physics of gamma-ray bursts at cosmological distances.
- Probe the nature of particle dark matter: e.g., wimps, 5-10 eV neutrino.
- Decay of relics from the Big Bang.

GLAST LAT

Factsheet

http://www.glast.stanford.edu



GLAST Large Area Telescope

Relation to GLAST Mission Science

Key Scientific Questions Addressed:

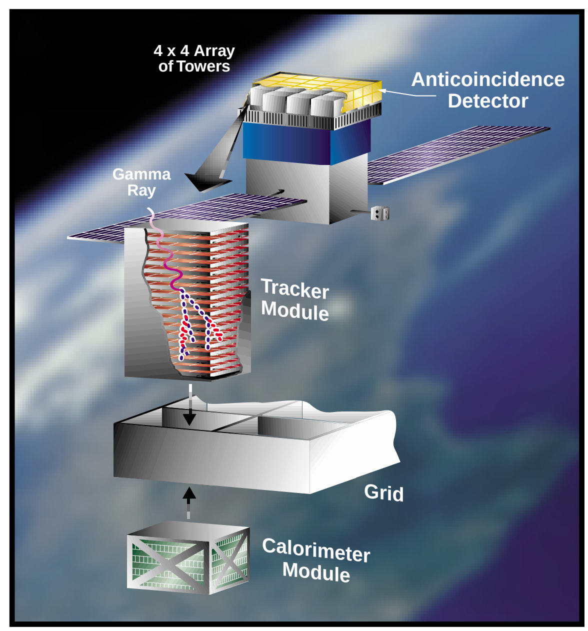
- What are the mechanisms of particle acceleration in the universe?
- What are the origins and mechanisms of Gamma-Ray Bursts and other transients?
- What are the unidentified EGRET gamma-ray sources?
- What are the distributions of mass and cosmic rays in the galaxy and in nearby galaxies?
- How can high-energy gamma-rays be used to probe the early universe?
- What is the nature of dark matter?

GLAST LAT Provides:

- Rapid notification of high-energy transients
- Detection of several thousand sources, with spectra from 20 MeV to more than 50 GeV for several hundred sources
- Point source localization to 0.3 – 2 arcmin
- Mapping and spectra of extended sources such as SNRs, molecular clouds, interstellar emission, and nearby galaxies
- Measurement of the diffuse gamma-ray background to TeV energies

Relation to NASA Space Science and SEU

- Determine the mechanisms of particle acceleration in AGN, pulsars and supernova remnants
- Use high-energy gamma rays as probes of the universe
- Understand the origin of gamma-ray bursts
- Probe the nature of dark matter
- Perform sensitive high-energy gamma-ray survey, the first all-sky survey above 10 GeV



Large Area Telescope

Mature design based on proven technologies and more than 7 years of focused design, development and demonstration efforts by the proposing team

Pair-ConversionTelescope Design:

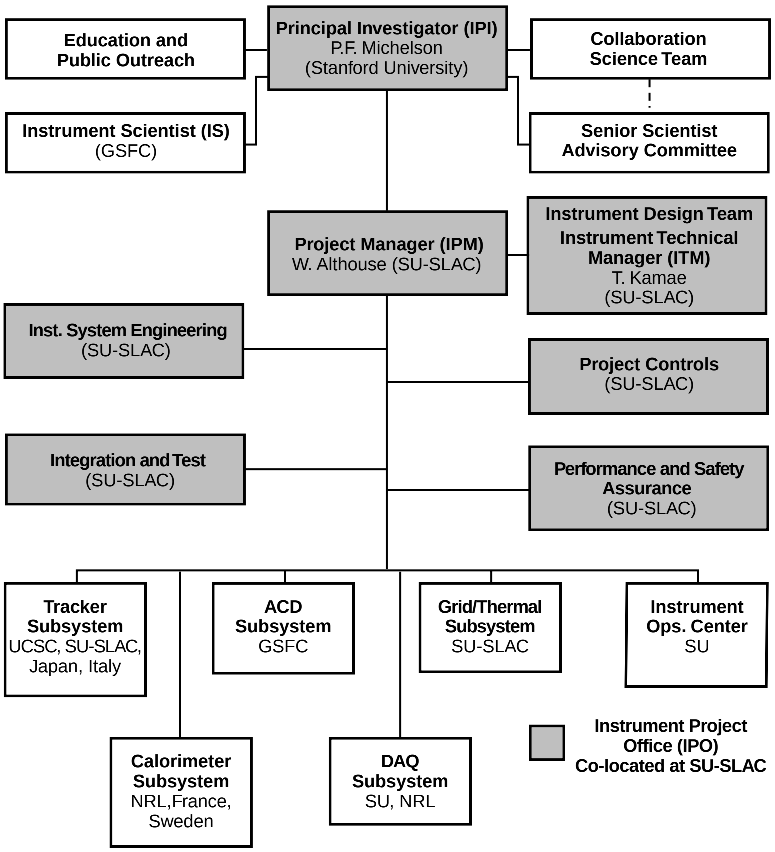
- **Precision Tracker (TKR):** single-sided silicon-strip particle detectors and converters arranged in 18 x,y tracking planes, providing precision determination of photon direction;
- **Calorimeter (CAL):** finely segmented array of CsI(Tl) crystals, read out by PIN diodes for energy measurement and precise shower localization;
- **Anticoincidence Detector (ACD):** array of plastic scintillator tiles covering TKR, read out by waveshifting fibers and PMTs;
- **Modular Design:** TKR and CAL composed of 16 identical tower modules, providing redundancy. Each tower includes an independent data acquisition board (DAQ) to implement level-1 and level-2 triggering and data capture.

Key Telescope Characteristics

Meets all GLAST mission requirements with large performance margins for critical characteristics

- Two-year point source sensitivity: 1.6×10^{-9} cm^{-2} s^{-1}
- Background rejection: $2.5 \times 10^5 : 1$
- Effective area: 12,900 cm^2 @ 10 GeV
- Field of view: 2.4 sr
- Angular resolution: 0.39^o @ 1 GeV
- Energy resolution: $\Delta E/E \leq 10\%$, 100 MeV -100 GeV
- On-board transient analysis for rapid alert
- Mass: 2,557 kg
- Power: 518 W

The GLAST LAT Collaboration brings to the GLAST mission more than 7 years of focused LAT technology development. The team is a partnership of individuals and organizations with broad experience in experimental high-energy particle physics and space science instrumentation. This partnership is reflected in the support for the GLAST LAT team from the U.S. Department of Energy and foreign funding agencies.



Instrument Team Projects

- Conduct All-Sky Survey
- Provide Transient LAT Catalog and Alerts
- Perform in-depth analysis of selected sources

Organizations with Hardware Involvement

Stanford University: SLAC & HEPL

Goddard Space Flight Center

Naval Research Laboratory

University of California, Santa Cruz

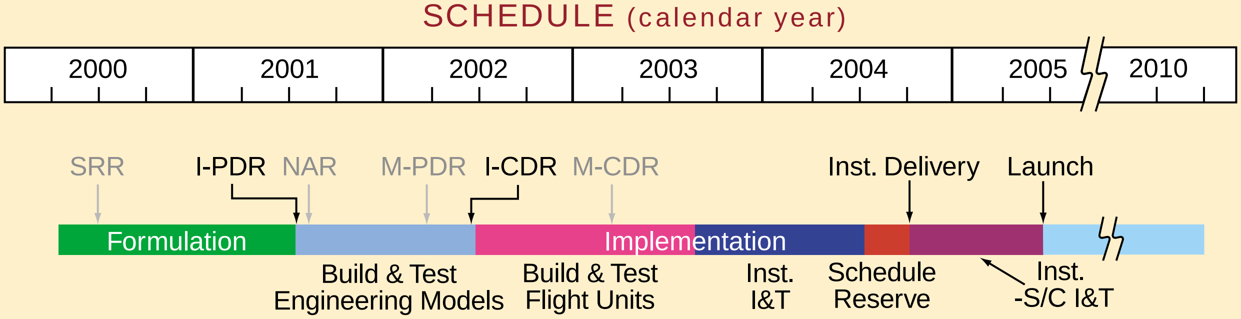
Hiroshima University, University of Tokyo, ISAS, & ICRR, Japan

INFN & ASI, Italy

Laboratoire du Commissariat a l'Energie Atomique & IN2P3, France

Royal Institute of Technology, Stockholm, Sweden

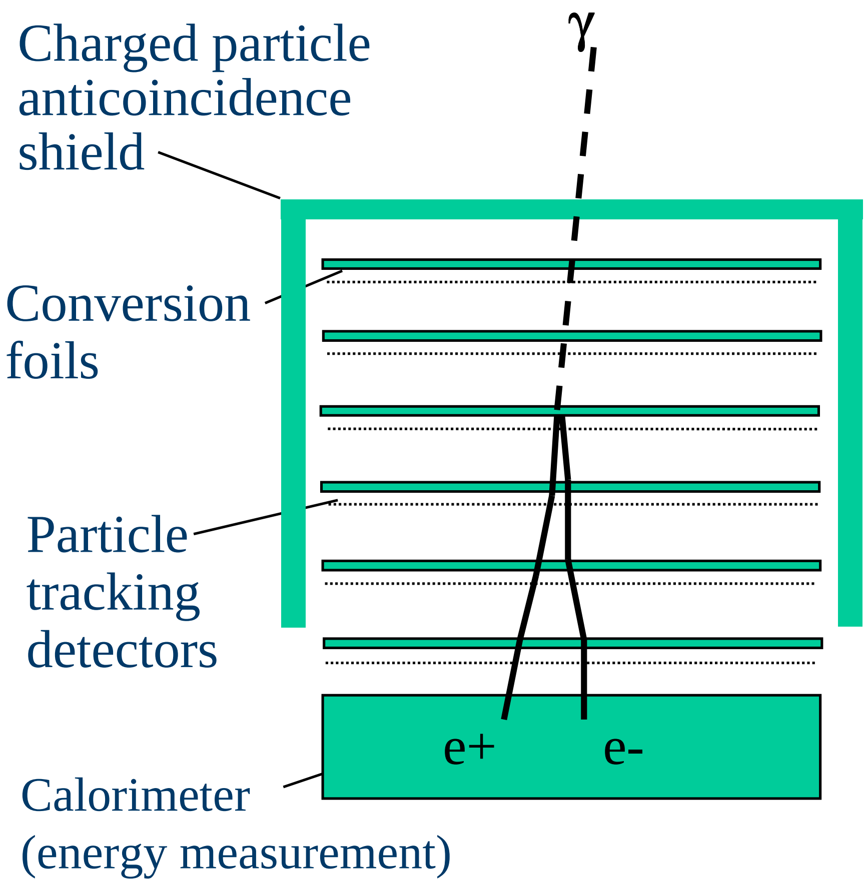
SCHEDULE (calendar year)



Science Investigation Cost:		
	Cost to NASA	Total Cost
Formulation:	$7.0M	$33.6M
Implementation:	$51.9M	$107.0M
Operation:	$7.0M	$41.3M
TOTAL:	**$65.9M**	**$181.9M**

*All costs in FY99$, including reserves

Pair-Conversion Telescope

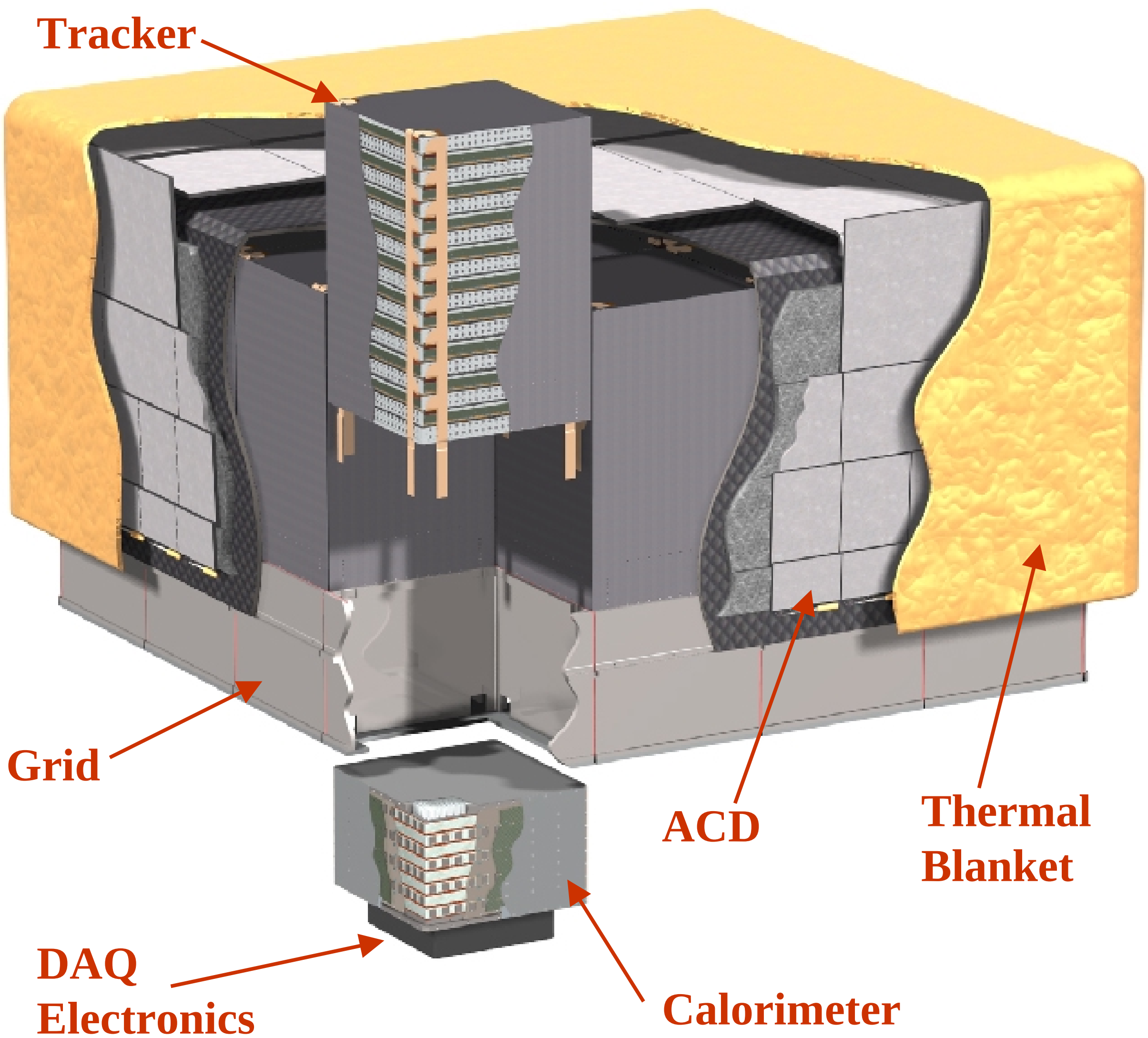


GLAST Concept

(William Atwood)

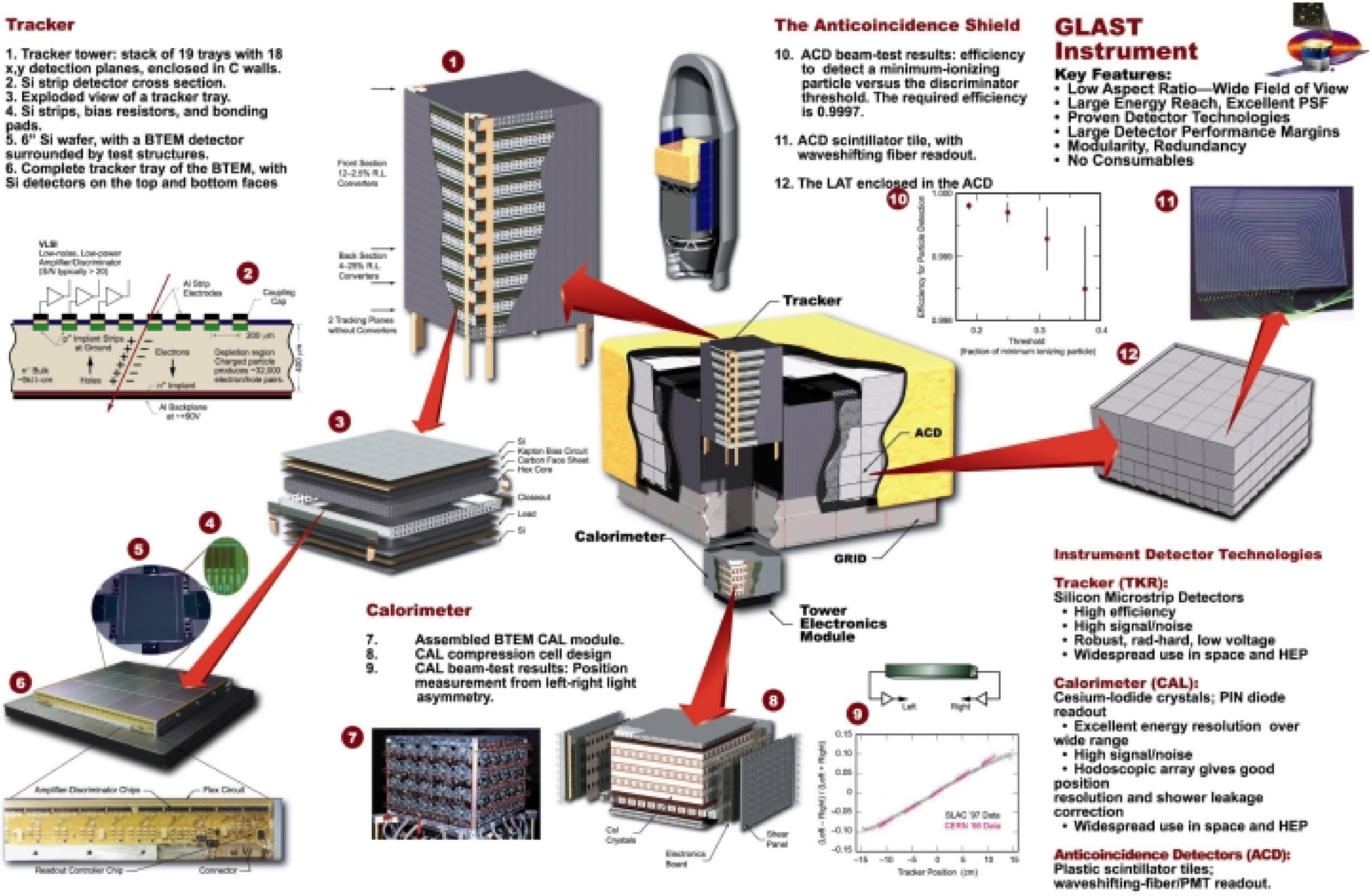
- Low profile for wide f.o.v.
- Segmented anti-shield to minimize self-veto at high E.
- Finely segment calorimeter for enhanced background rejection and shower leakage correction.
- High-efficiency, precise track detectors located close to the conversions foils to minimize multiple-scattering errors.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

The Large Area Telescope (LAT)



- Array of 16 identical "Tower" Modules, each with a tracker (Si strips), calorimeter (CsI with PIN diode readout) and DAQ module.
- Surrounded by finely segmented ACD (plastic scintillator with PMT readout).
- Aluminum strong-back "Grid," with heat pipes for transport of heat to the instrument sides.

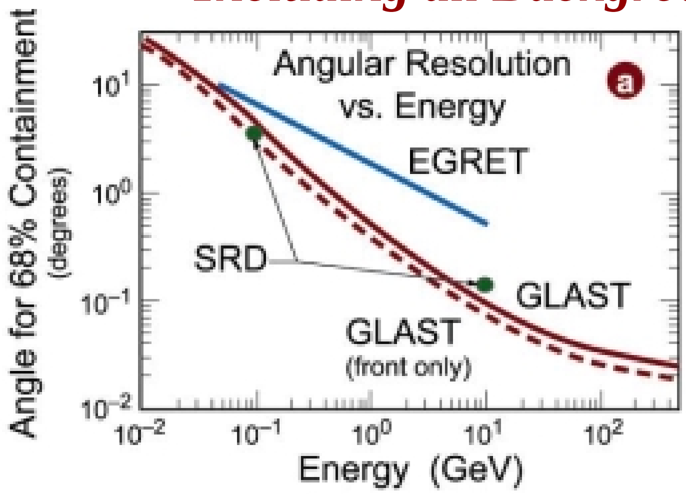
The LAT Hardware



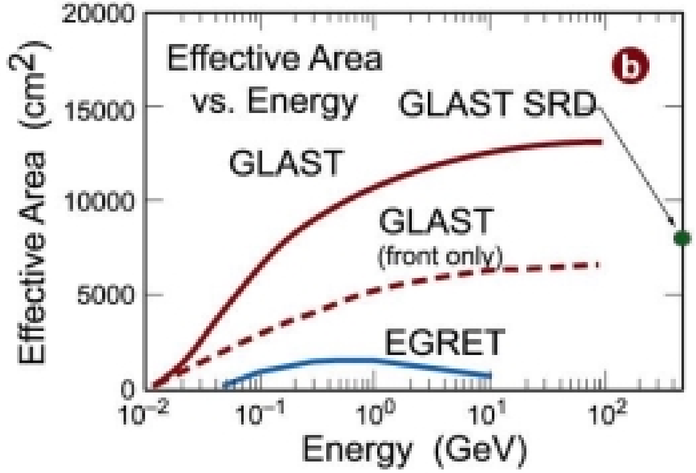
LAT Instrument Performance

Including all Background & Track Quality Cuts

Optimized Point Spread Function



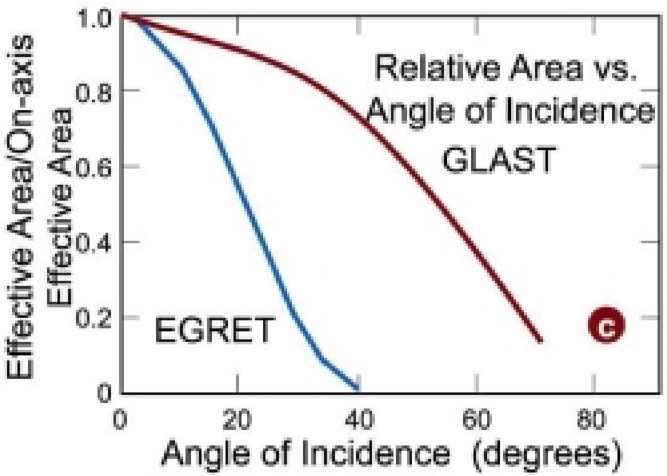
Large Effective Area



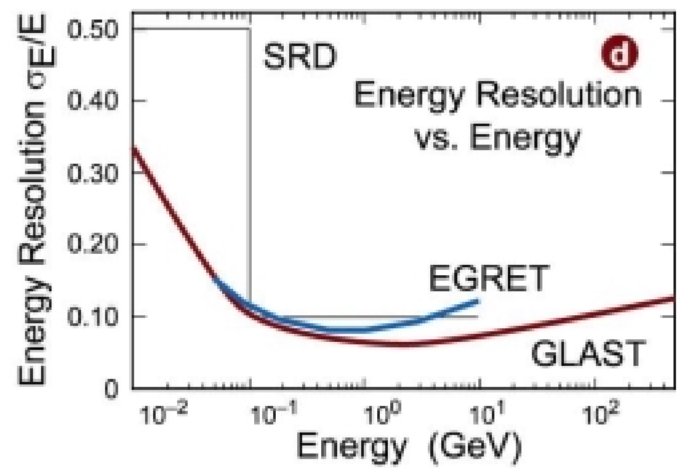
Wide Field of View

FOV: 2.4 Sr

SRD: 2.0 Sr



Good Energy Resolution



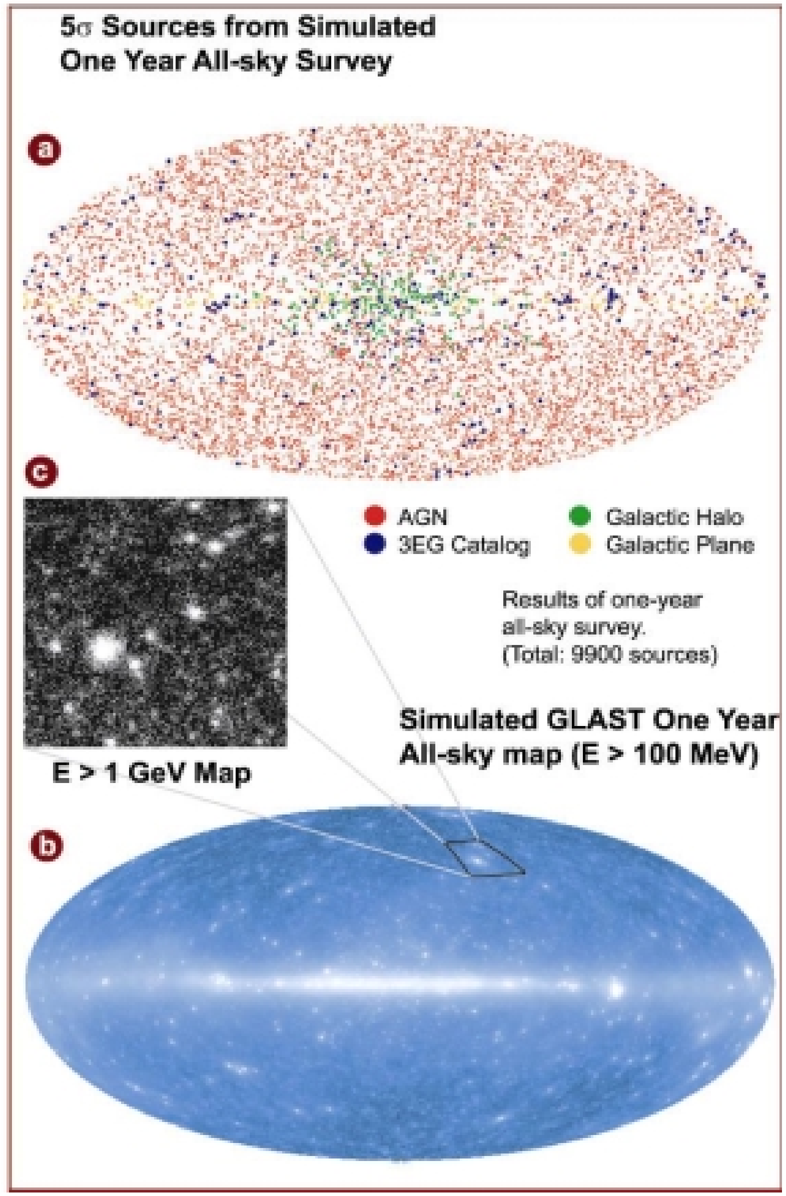
Point Source Sensitivity (high latitude)

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

GLAST Science Capability

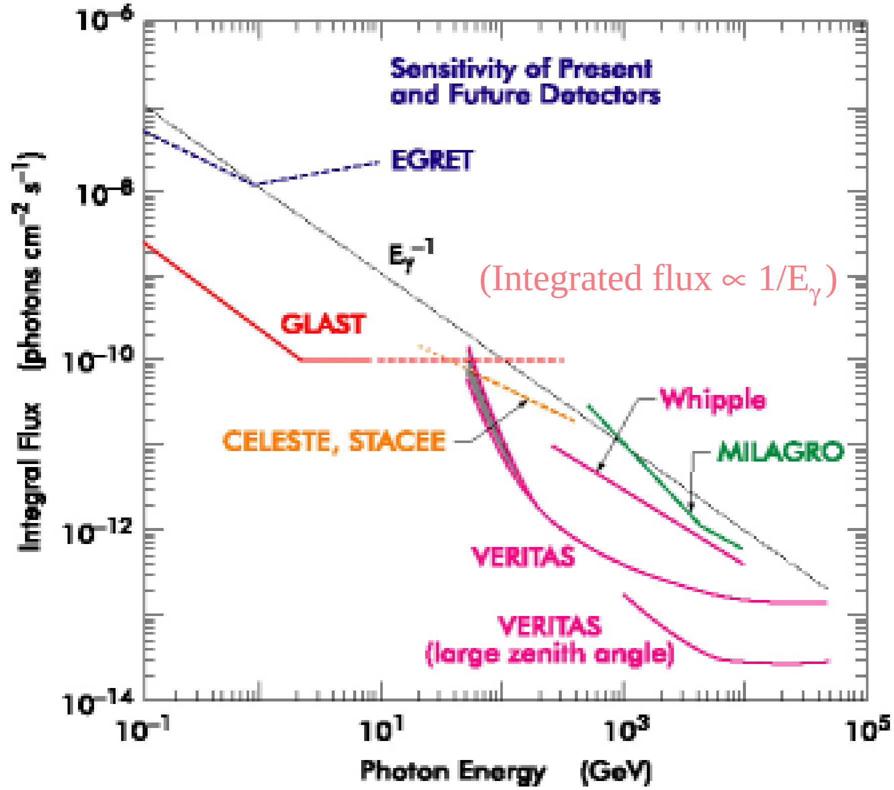
Key instrument features that enhance GLAST's science reach:

- Peak effective area: 12,900 cm^2
- Precision point-spread function (<0.10° for E=10 GeV)
- Excellent background rejection: better than 2.5×10^5:1
- Good energy resolution for all photons (<10%)
- Wide field of view, for lengthy viewing time of all sources and excellent transient response
- Discovery reach extending to ~TeV



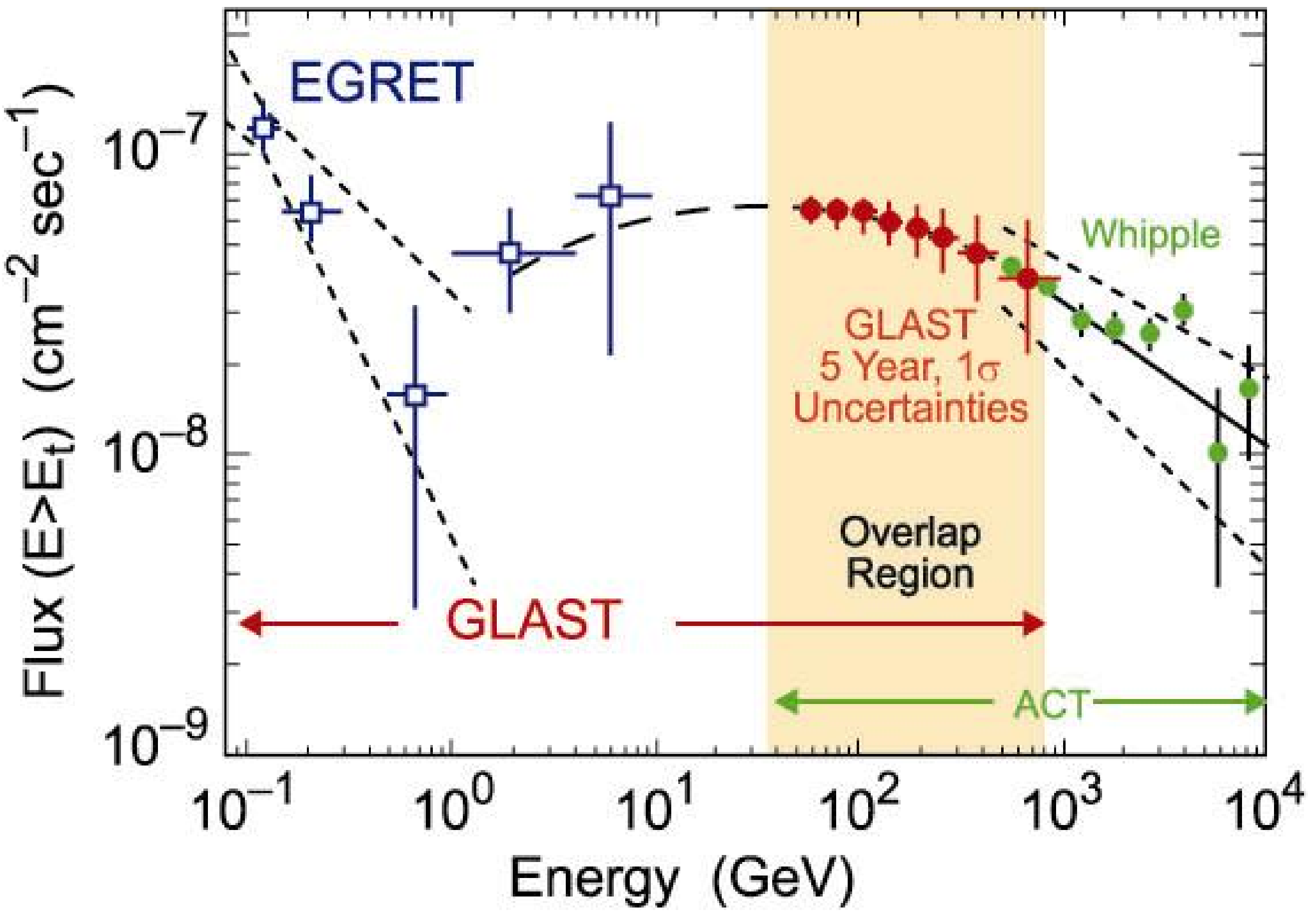
Covering the Gamma-Ray Spectrum

- Broad spectral coverage is crucial for studying and understanding most astrophysical sources.
- GLAST and ground-based experiments cover complimentary energy ranges.
- The improved sensitivity of GLAST is necessary for matching the sensitivity of the next generation of ground-based detectors.
- GLAST goes a long ways toward filling in the energy gap between space-based and ground-based detectors—there will be overlap for the brighter sources.



Predicted sensitivities to a point source.
EGRET, GLAST, and Milagro: 1-yr survey.
Cherenkov telescopes: 50 hours on source.
(Weekes et al., 1996, with GLAST added)

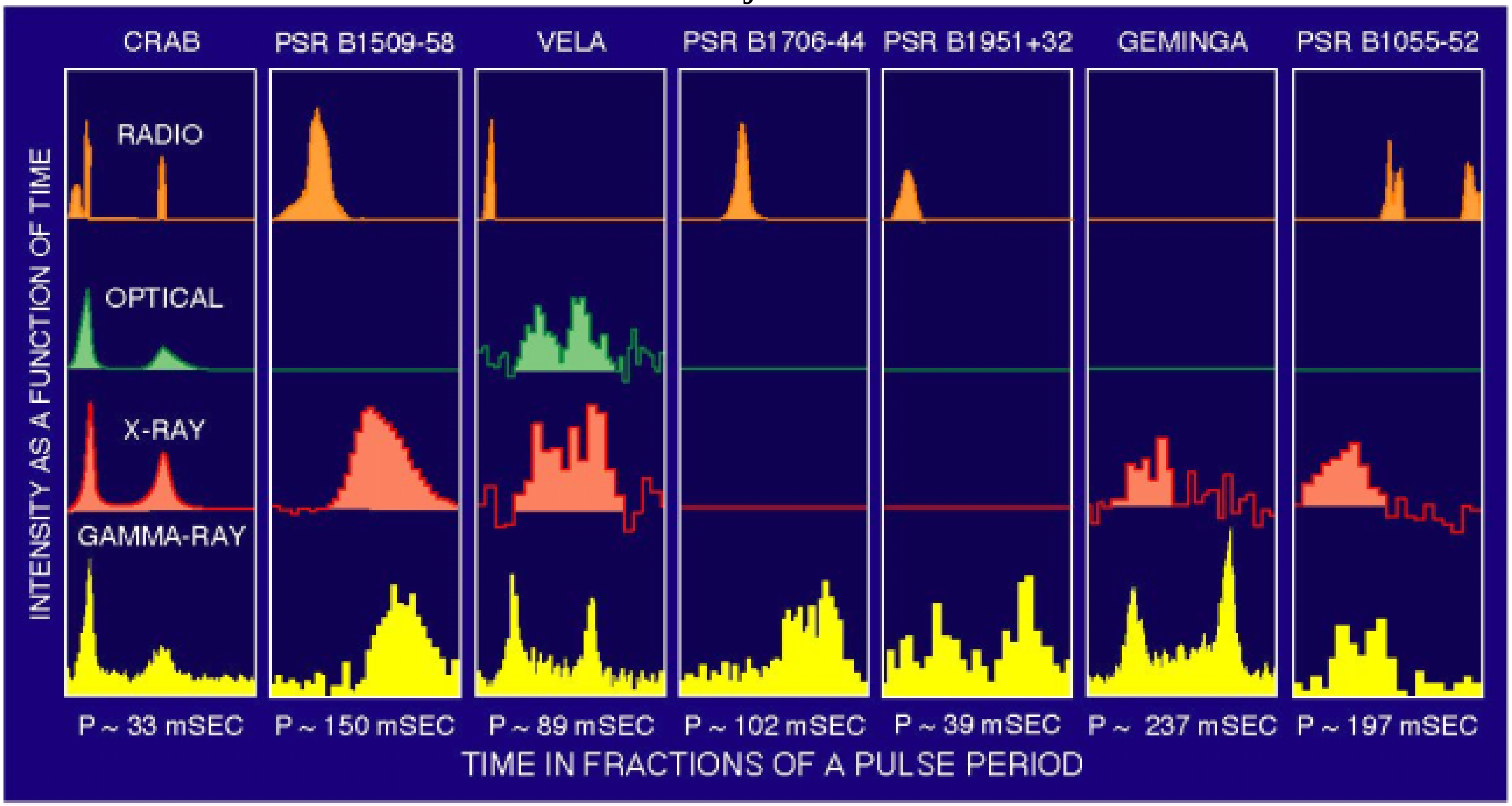
Overlap of GLAST with ACTs



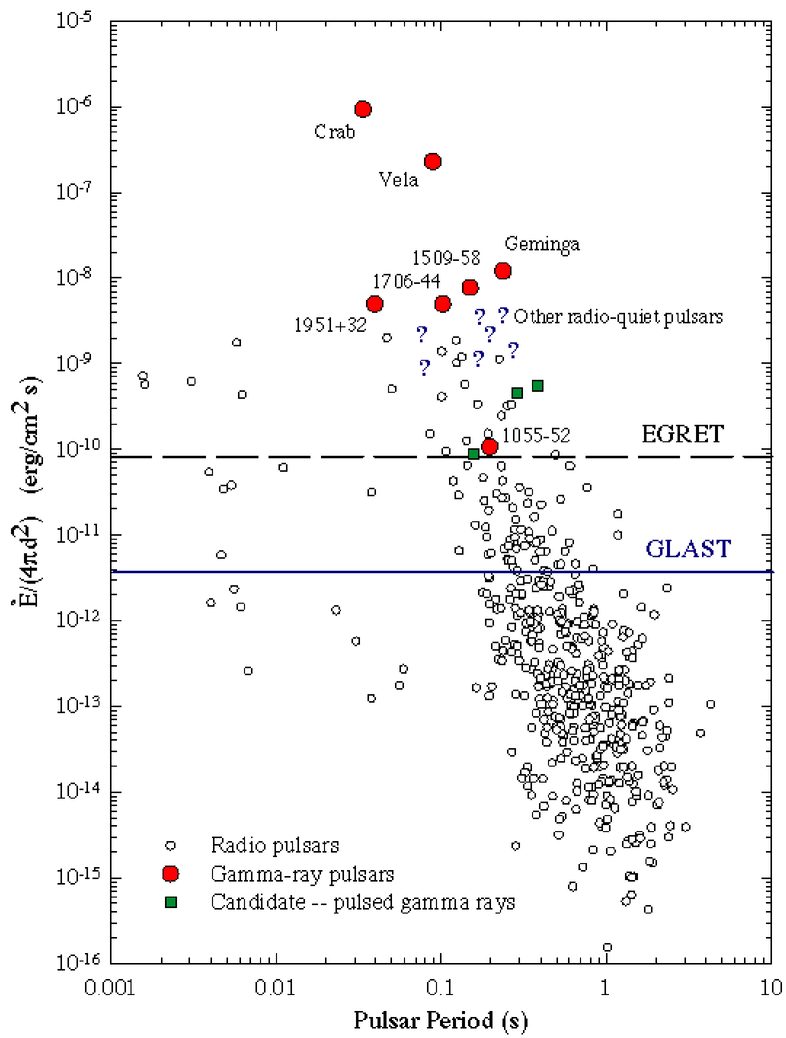
Predicted GLAST measurements of Crab unpulsed flux in the overlap region with ground-based atmospheric cherenkov telescopes.

Pulsars

- Detailed EGRET observations of 7 gamma-ray pulsars have already made major contributions to our understanding of the emission mechanisms.
- Continuation of this work is a major science driver for GLAST.



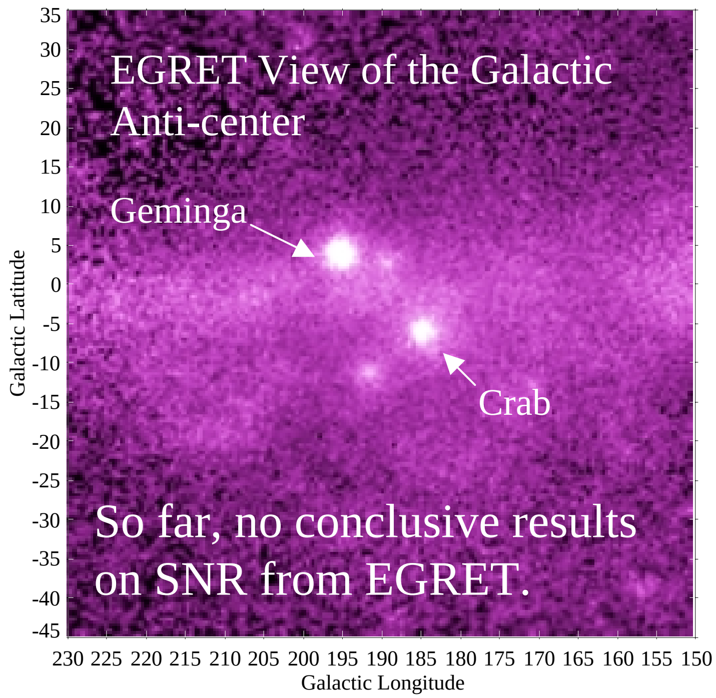
Pulsars: GLAST Prospects

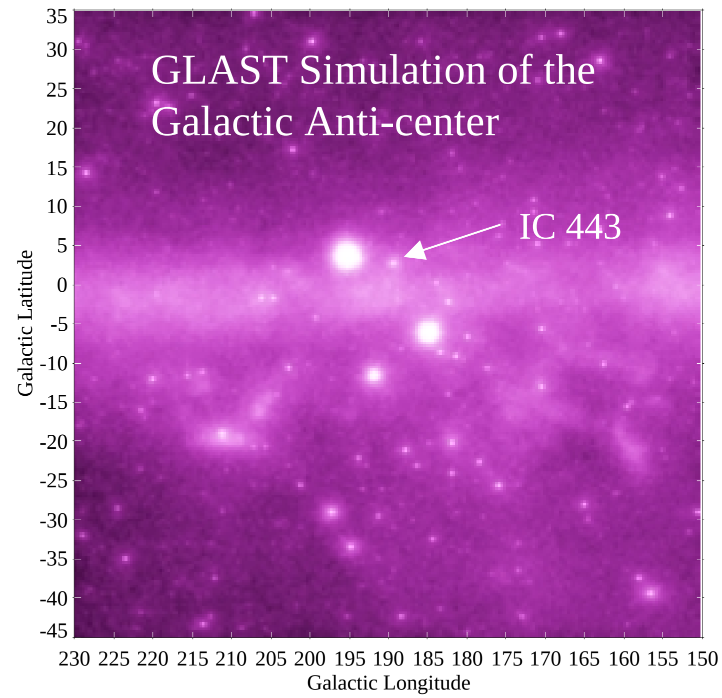


Estimates by R. Romani:

- Detections: >300 sources
  - Up to 1/3 of them may have phase/period information from radio detections.
  - Up to 1/10 might be found by direct pulse searches.
- Physics
  - ≈5 with high quality phase and spectral information.
  - ≈30 with crude but useful phase and spectral information.
  - Polarization information on the few brightest.
- Demography
  - 2 to 15 kpc distance.
  - Primarily young, dE/dt driven.
  - A few millisecond pulsars.

SNR and Cosmic-Ray Production





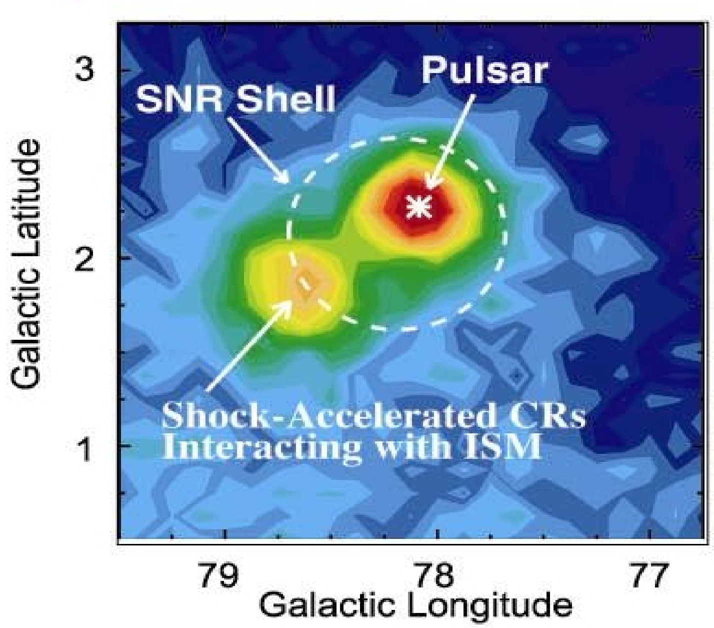
GLAST will provide

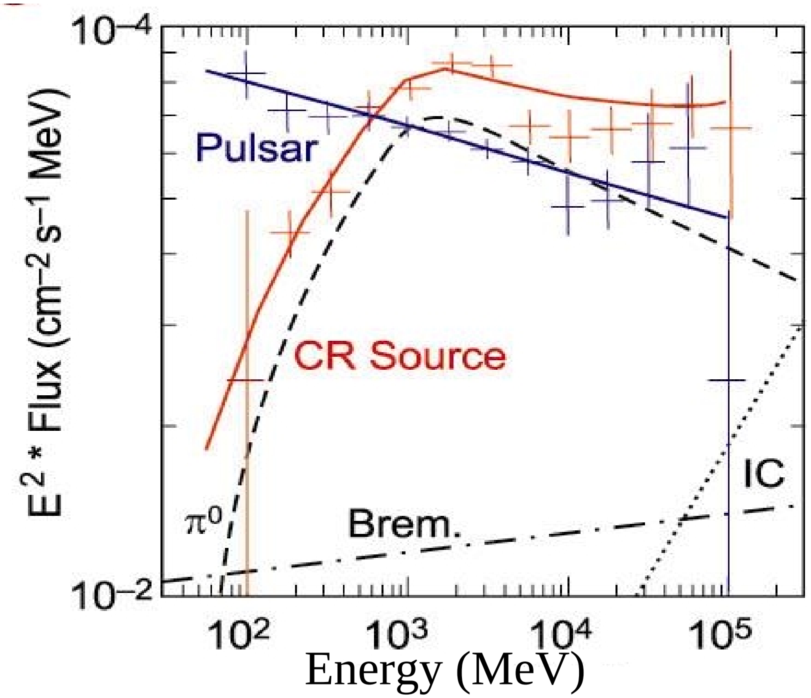
- detailed maps of the galactic diffuse gamma-ray emission.
- measurements of SNR spectra.
- resolved SNR shells at ≈10′ level.
- detailed maps of emission from galactic molecular clouds.

In order to

- locate SNR in the galactic plane.
- determine whether SNR could be the source of cosmic rays.
- map the distribution of cosmic rays in the galaxy.

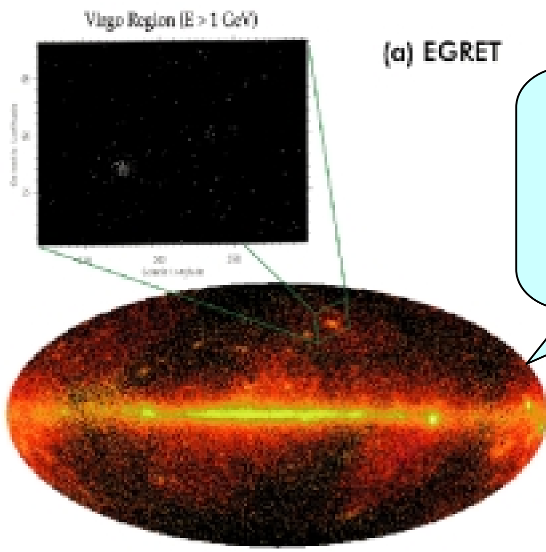
Cosmic-Ray Acceleration





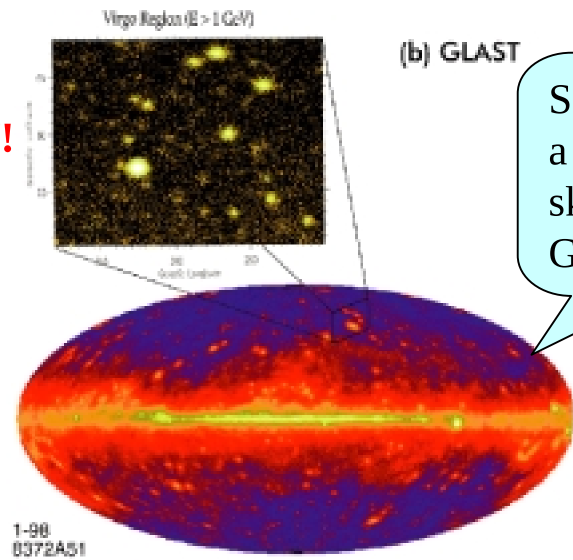
GLAST simulations showing SNR γ-Cygni spatially and spectrally resolved.

Active Galactic Nuclei

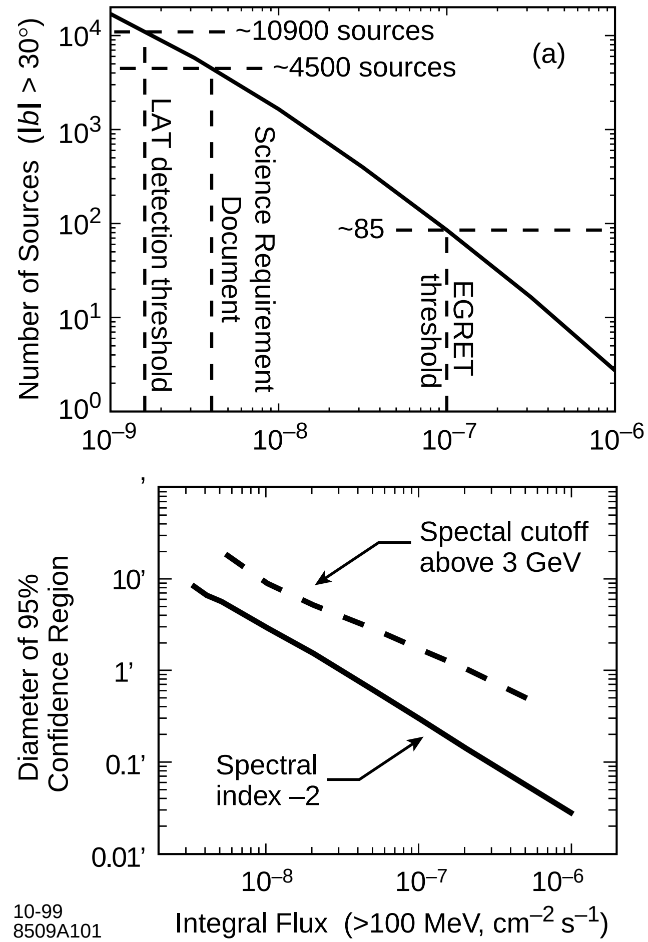


Simulation of a 1-year all-sky survey by EGRET.

E>1 GeV!

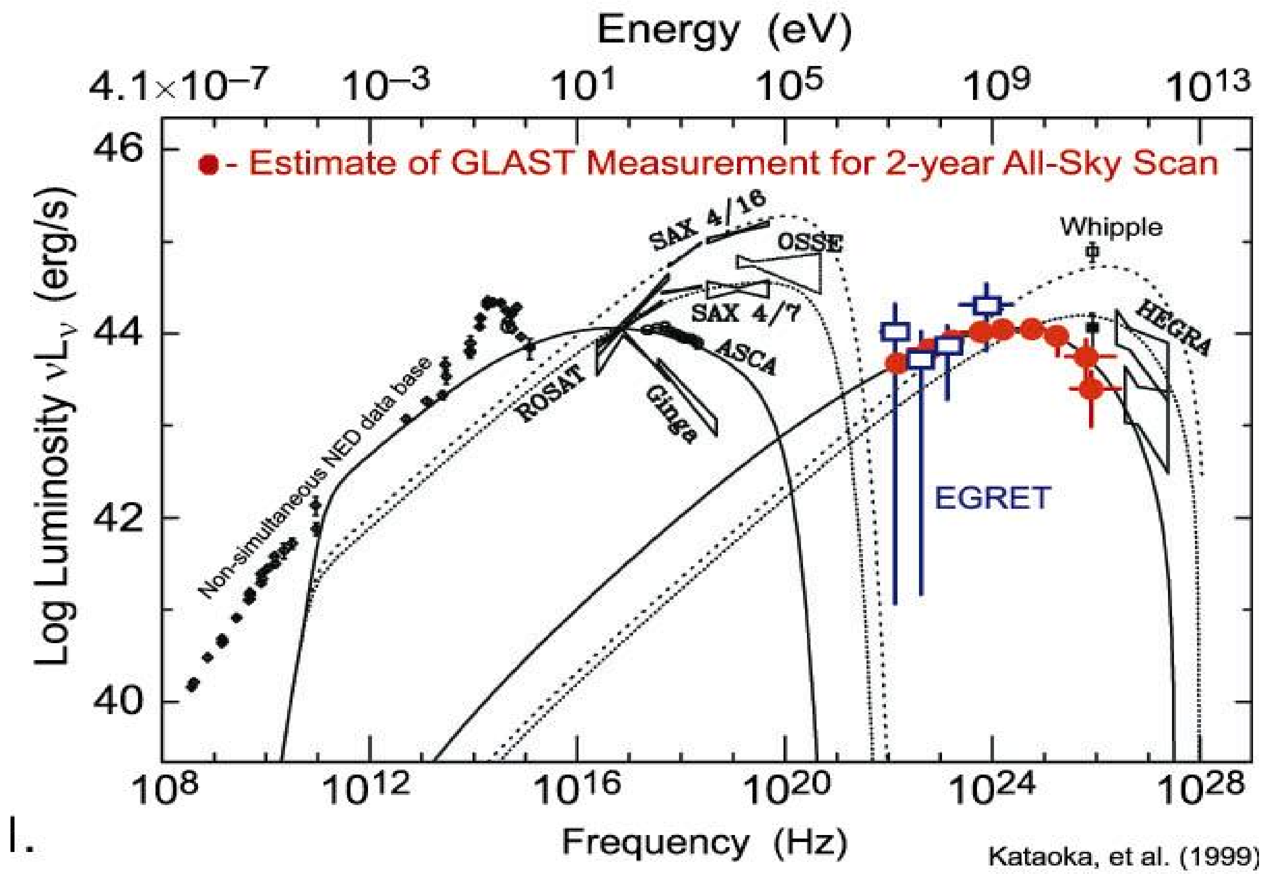


Simulation of a 1-year all-sky survey by GLAST.



A simple extrapolation from EGRET data suggests that GLAST will detect >5000 AGN, in addition to providing far more detailed data on the known sources.

Measurement of AGN Spectra



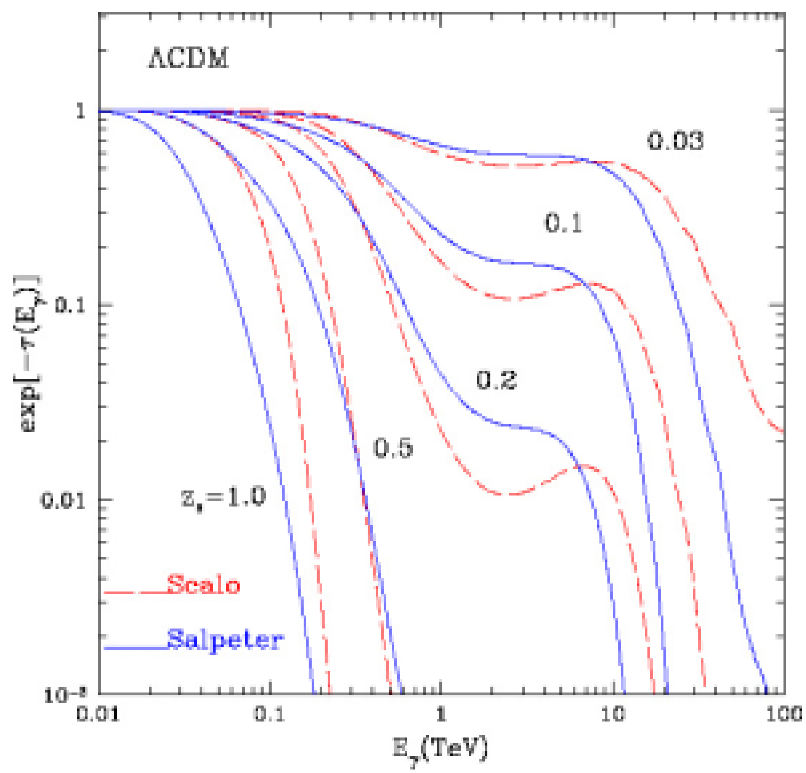
GLAST will measure blazar quiescent emission and spectral transitions to flaring states. Above: GLAST should readily detect low-state emission from Mrk 501.

Gamma-Ray Absorption by EBL

Observations of AGN spectral cutoffs due to extragalactic background light (EBL) absorption are sensitive to two aspects of galaxy formation:

- The era of galaxy formation
  - cutoffs in the TeV range can constrain this with minimal model dependence
  - GLAST is needed to tie down the lower end of the spectrum.
- The stellar initial mass function (IMF)
  - The lower energy range, within the range of GLAST for distant AGNs, is sensitive to these models.

Broad spectral coverage and observations of numerous sources will be necessary to reap solid scientific results map of the correlation between $E_{cut\text{-}off}$ and Z!

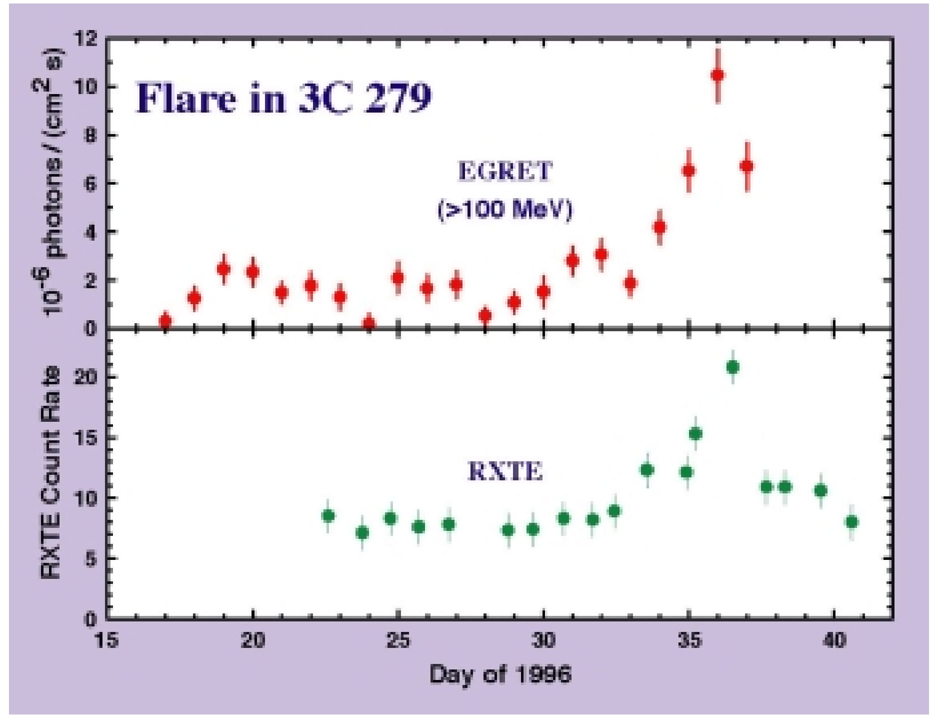


The gamma-ray attenuation factor for ΛCDM models using Scalo and Salpeter models of the IMF.

(Bullock, Somerville, MacMinn, Primack, 1998)

Monitoring AGN Flares

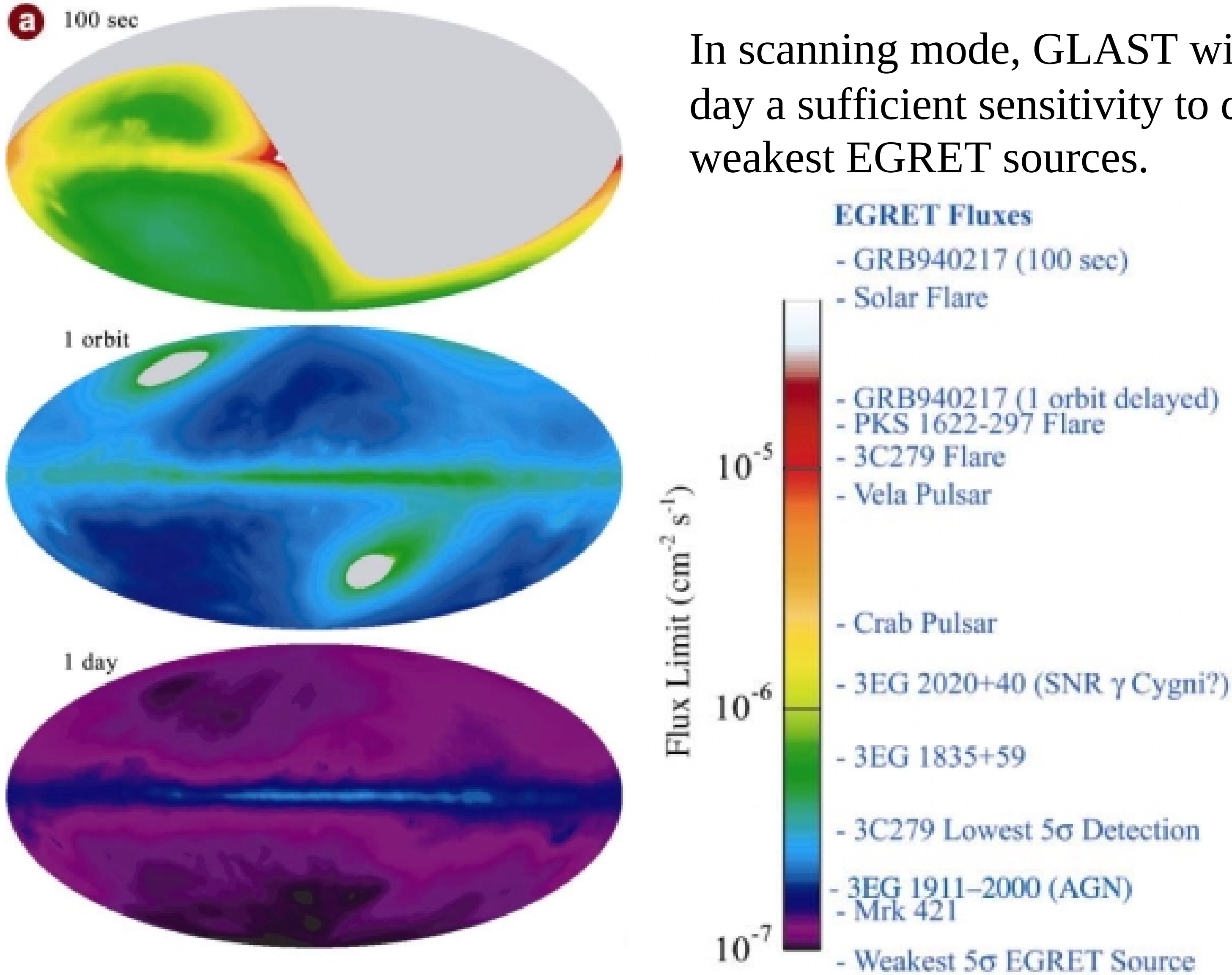
- GLAST will normally operate in a scanning mode, zenith pointing, with periodic rocking toward the orbital poles.
- This makes GLAST ideal for monitoring the temporal behavior of AGN's.
- For example, at a flux of 2×10^{-6} photons/cm^2/s, GLAST would detect roughly 40 γ with E>100 MeV from 3C279 per 90 minute orbit (≈4 with E>1 GeV).
- A flare could be readily detected in as little time as one orbit, depending only on how fast it developed GLAST can search for even faster time structure than observed by EGRET.



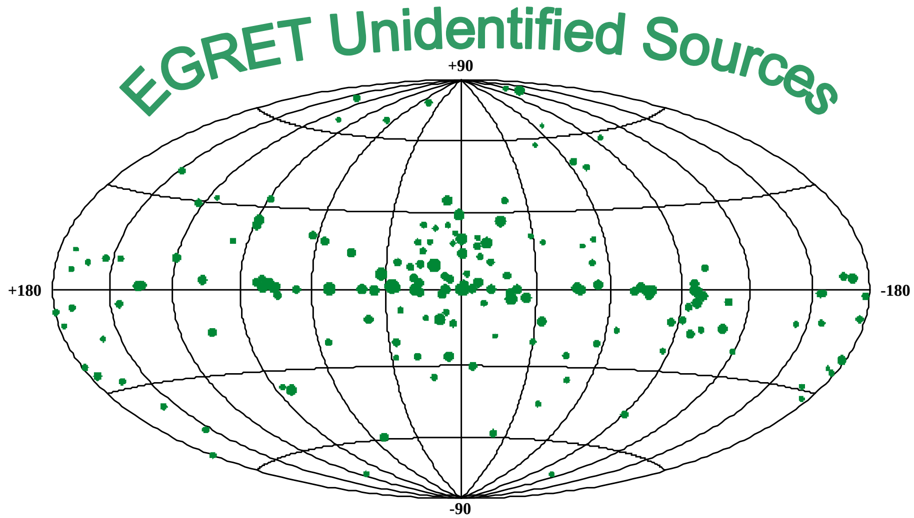
GLAST will not need to be pointing at a source in order to detect quickly a flare and alert ground-based detectors.

Detection of Transients

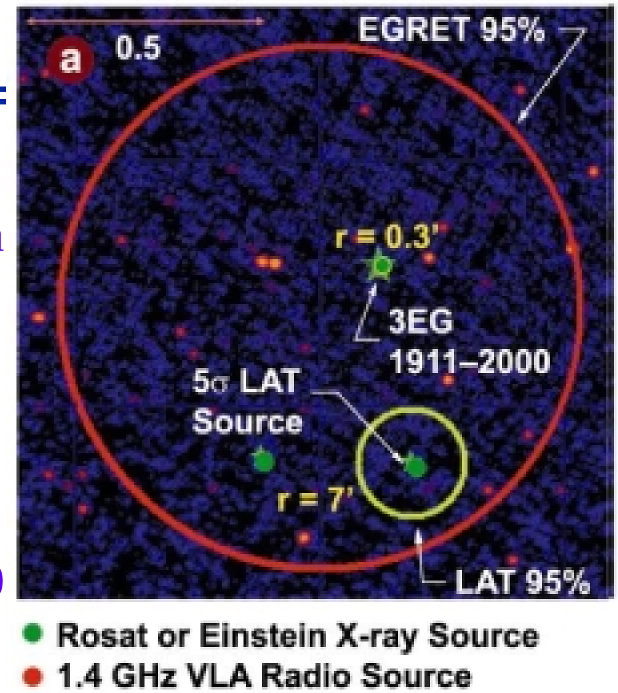
In scanning mode, GLAST will achieve in one day a sufficient sensitivity to detect (5σ) the weakest EGRET sources.



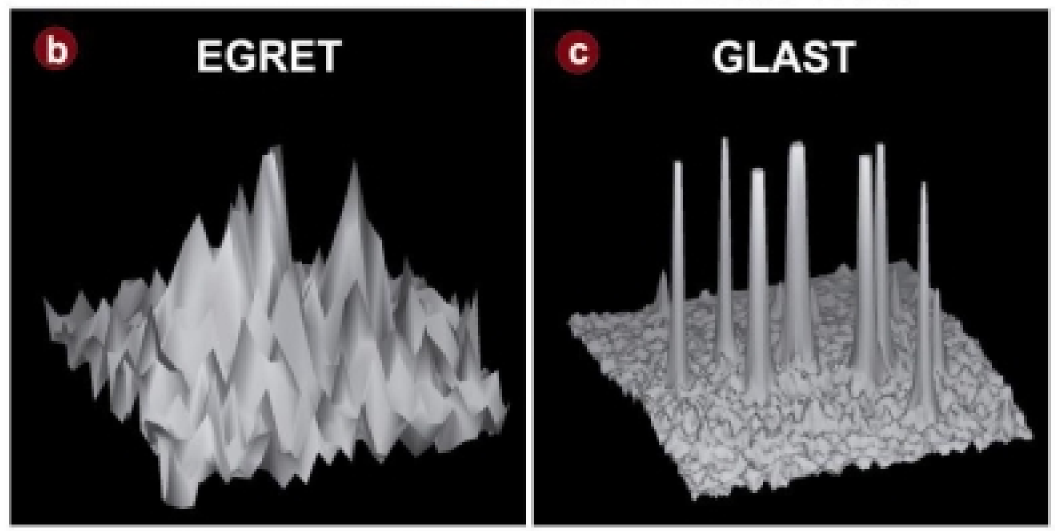
Identifying Sources



GLAST 95% C.L. radius on a 5σ source, compared with a similar EGRET observation of 3EG 1911-2000



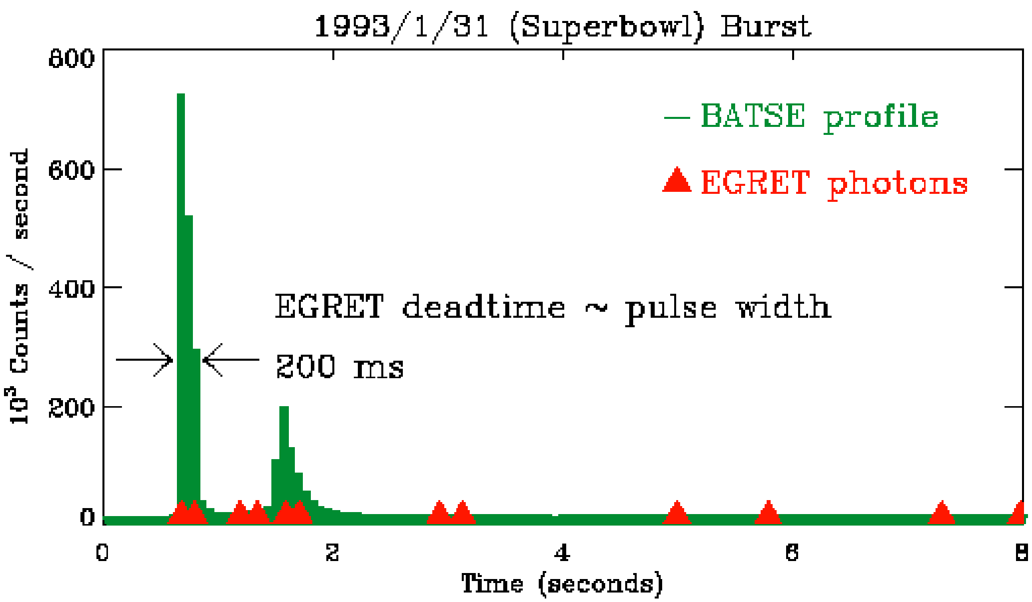
GLAST will make great improvements in our ability to resolve gamma-ray point sources in the galactic plane and to measure the diffuse background.

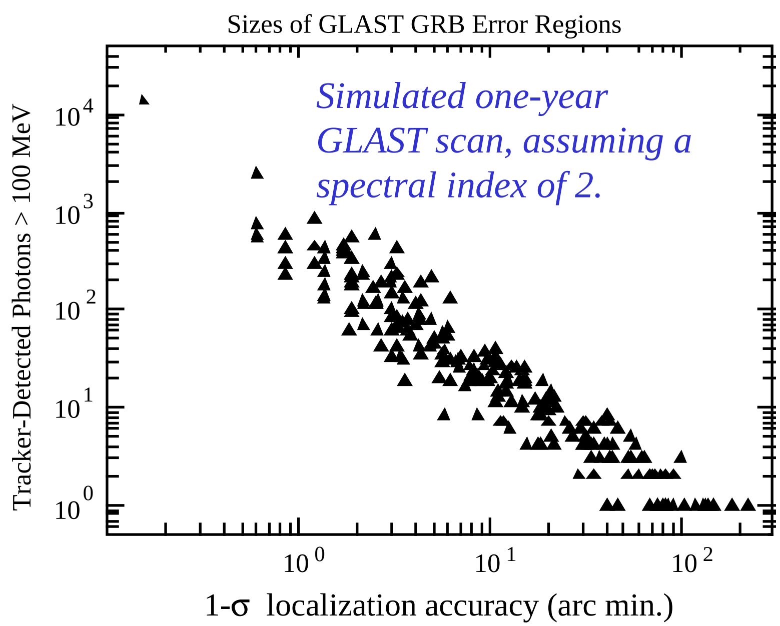


Cygnus region (15^0 x 15^0), $E\gamma > 1$ GeV

Gamma-Ray Bursts

- GLAST will likely be the only experiment in its time frame capable of studying the GeV tail of the gamma-ray burst spectrum.
- GLAST should detect ≈200 GRB per year with E>100 MeV, with a third of them localized to better than 10′, in real time.
- ***Excellent wide field monitor for GRB.*** Nearly real-time trigger for other wavelength bands, often with sufficient localization for optical follow-up.
- With a ≈10μs dead time, GLAST will see nearly all of the high-*E* photons.
- A separate instrument (NASA-MSFC) on the spacecraft will provide a hard x-ray trigger for GRB, allowing measurements with as few as 1 high-*E* photon.





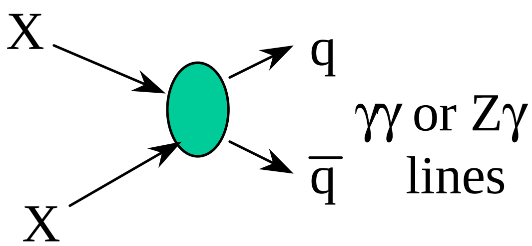
GLAST

Search for the Nature of Dark Matter

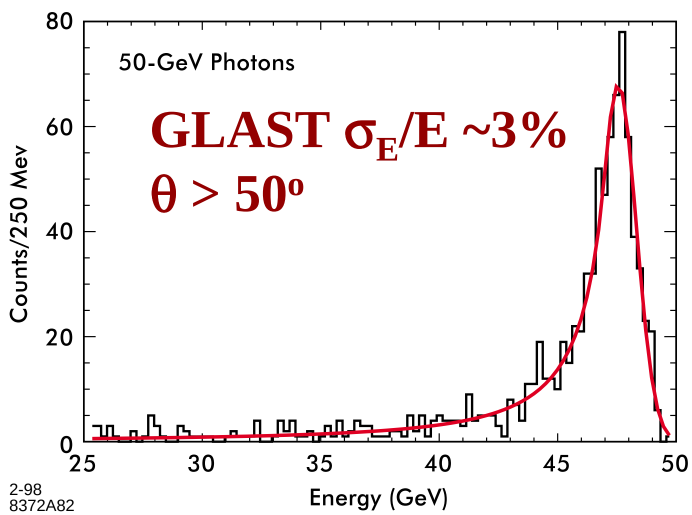
Three examples of GLAST DM Search Opportunities:

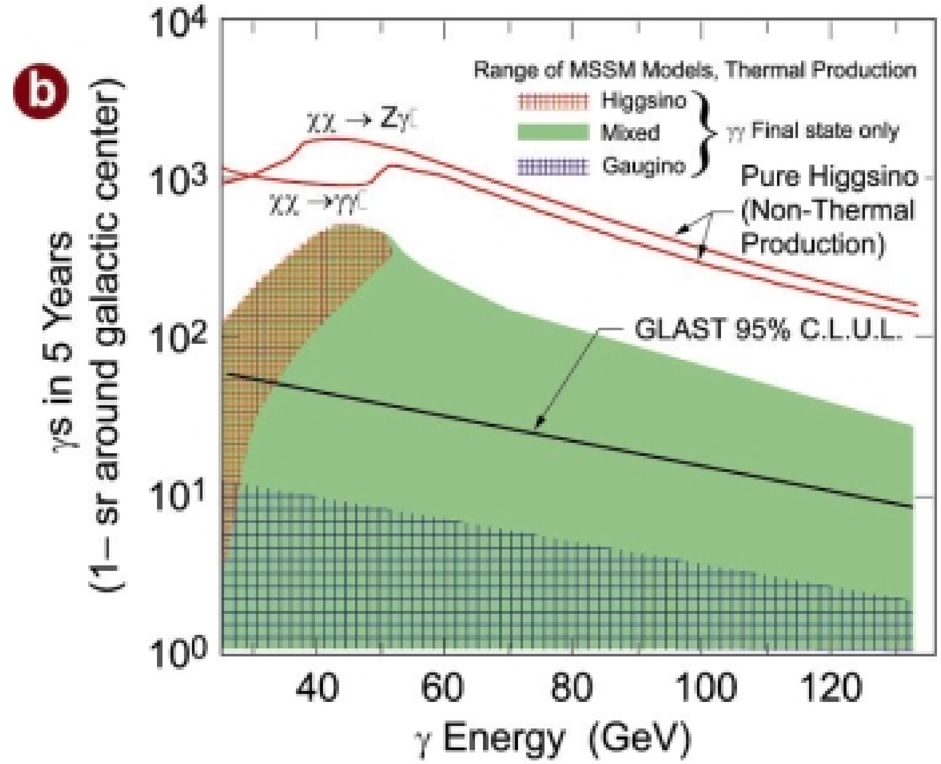
- There is speculation that DM in the Milky Way consists mainly of cold molecular clouds, and cosmic rays penetrate these clouds. The observational consequences for GLAST would be a hardening of the diffuse gamma ray spectrum at energy above ~1 GeV, and an excess diffuse flux of order 50% over that due to known sources. (D. W. Sciama 1999, F. De Paolis, et al. 1999, and references therein).
- Dixon et al. (1998) have reported an extended galactic halo in high-energy gammas, based on a reanalysis of EGRET data. The halo enhancement has a strong statistical significance, but questions persist regarding a possible systematic effect. If such a halo exists, GLAST would easily confirm the effect reported and dramatically increase our understanding of it. Candidates for dark matter, including cold molecular clouds and WIMP annihilation, could produce such a structure.
- The EGRET team (Mayer-Hasselwander et al, 1998) has seen a convincing signal for a strong excess of emission from the galactic center, with $I(E) \times E^2$ peaking at ~ 2 GeV, and in an error circle of 0.2 degree radius including the position $l = 0^o$ and $b = 0^o$. In their paper it was speculated that among other possible causes, this excess could be due to the continuum γ-ray spectrum from WIMP annihilation. With the dramatically improved angular resolution and effective area of GLAST, this effect should become both more localized and pronounced if it is a Galactic Center phenomenon.

Dark Matter Searches: Neutralino



The GLAST CsI calorimeter will be the largest such device ever put into space. It is only 10 X_0 viewed from the front, but from the sides it is up to 1.5 m "thick" and well suited for precision measurements of very high-energy photons.





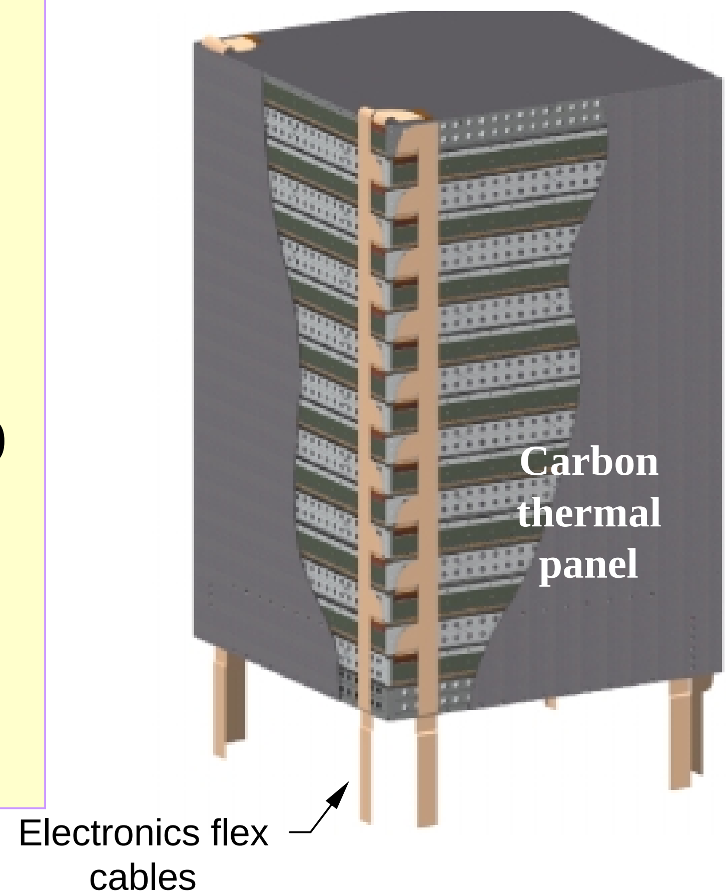
GLAST monoenergetic line sensitivity (95% C.L. upper limit) vs. E. Colored areas are a range of MSSMs within a restricted parameter space from standard assumptions and thermal relic abundance calculations.

GLAST Tracker Design Overview

- 16 "tower" modules, each with 37cm $\times$ 37cm of active cross section. (78m^2 of Si in all)
- 18 *x,y* planes per tower
  - 19 "tray" structures
    - 12 with 2.5% Pb or W on bottom *("Front")*
    - 4 with 25% Pb or W on bottom *("Back")*
    - 2 with no converter foils
  - Every other tray is rotated by 90°, so each Pb foil is followed immediately by an *x,y* plane of detectors
    - 2mm gap between *x* and *y* oriented detectors
- Trays are C-composite panels (Al hexcel core)
- Trays stack and align at their corners
- The bottom tray has a flange to mount on the grid.
- Carbon-fiber walls provide stiffness and the thermal pathway from electronics to the grid.

- Electronics on sides of trays:
  - Minimize gap between towers
  - 9 readout modules on each of 4 sides

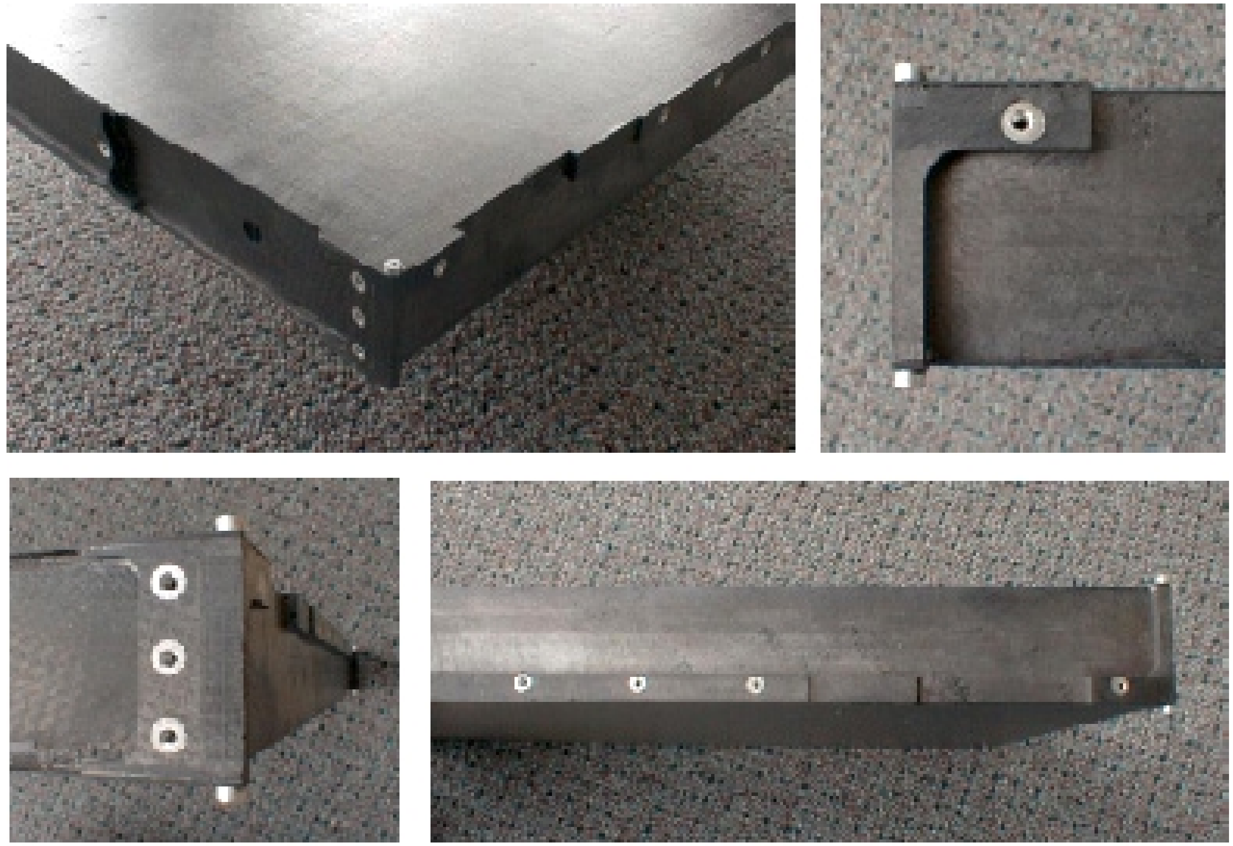
One Tracker Tower Module



GLAST

Tracker Mechanical Structure

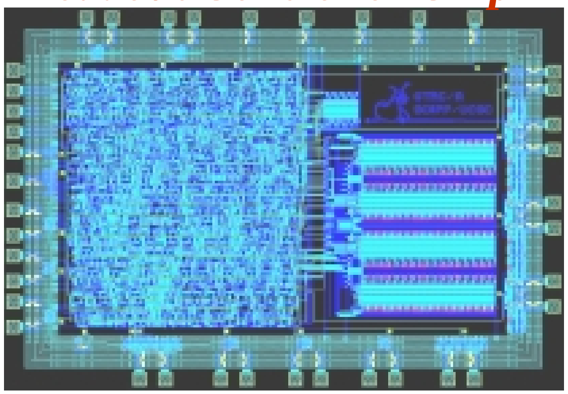
- Carbon-fiber/resin face sheets.
- Aluminum hexcell cores.
- Machined Carbon-Carbon closeouts.
- Various surface passivation methods are under test.

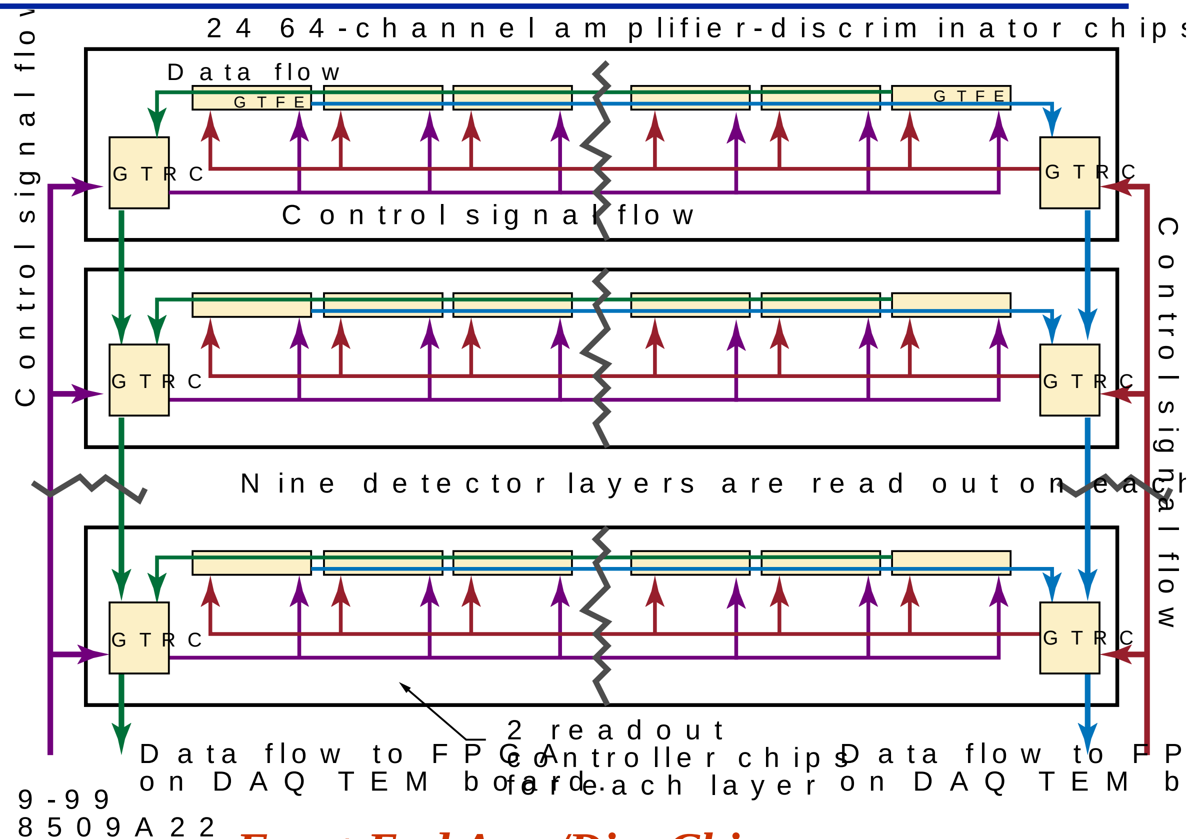


Early prototype Carbon-Fiber based GLAST “tray”. Materials for the 1st prototypes in the final design are on order. A 5-tray tower will be tested by summer 2001.

Tracker Electronics, ASICs

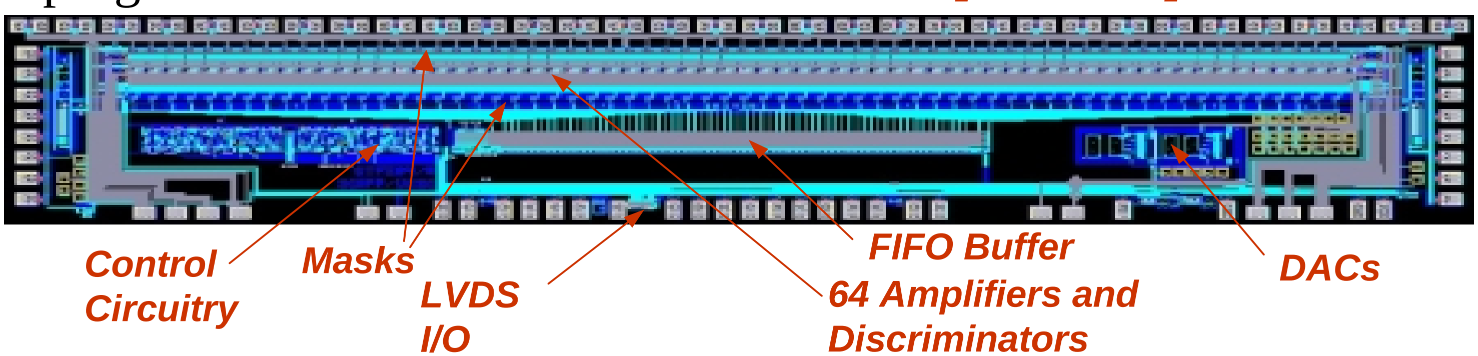
Readout Controller Chip





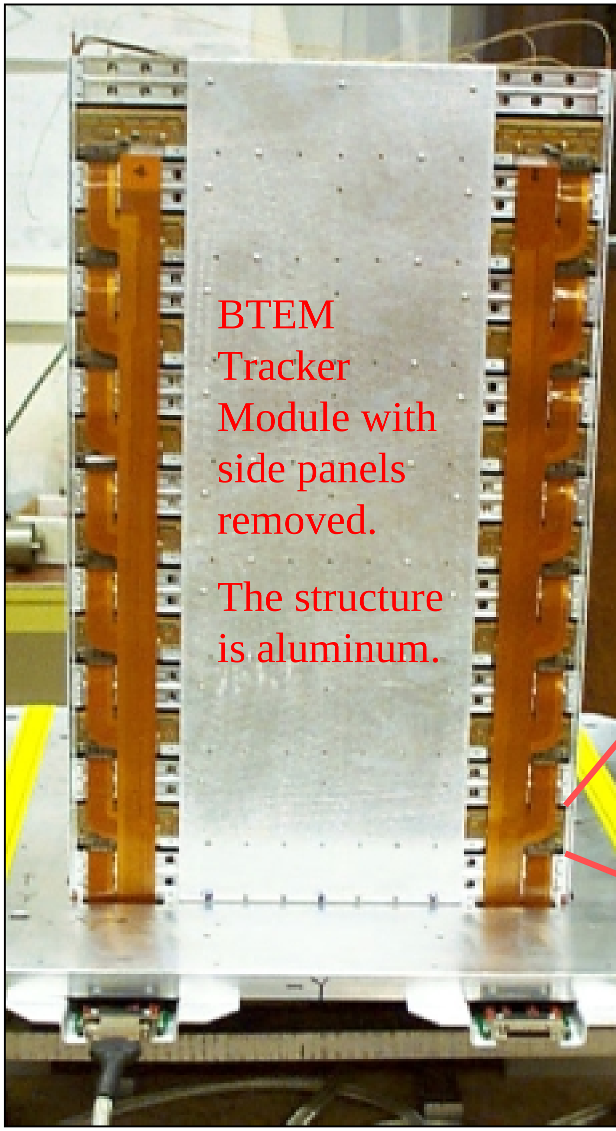
The Tracker readout electronics are based upon two custom ICs. Complete prototypes exist, with the final designs in progress.

Front-End Amp/Disc Chip



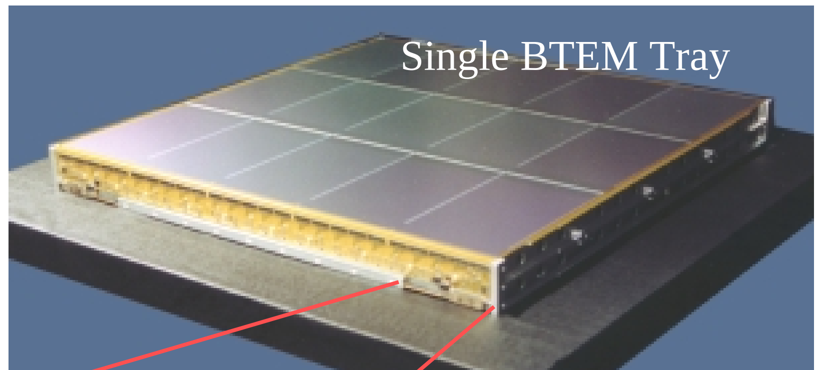
GLAST

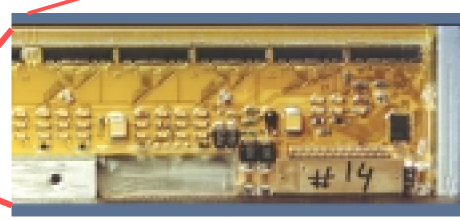
Beam-Test Engineering Model Tracker



The BTEM Tracker, (~1/16 of the flight instrument) for the SLAC test beam (11/99 – 1/00):

- 2.7m^2 silicon, ~500 detectors, 42k channels.
- all detectors are in 32-cm long “ladders.”



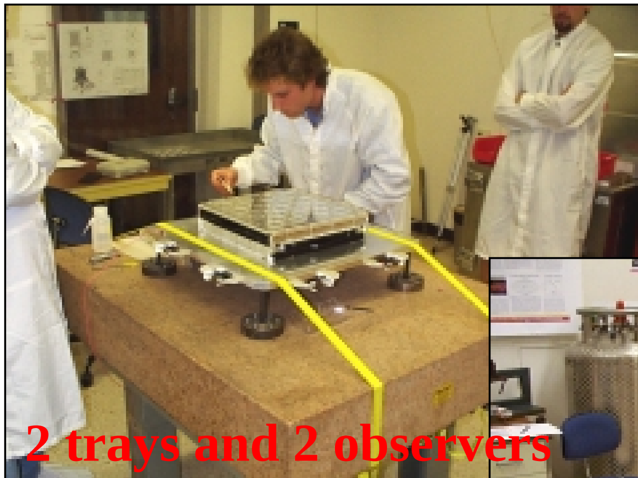


End of one readout hybrid module.

Si Detectors used:

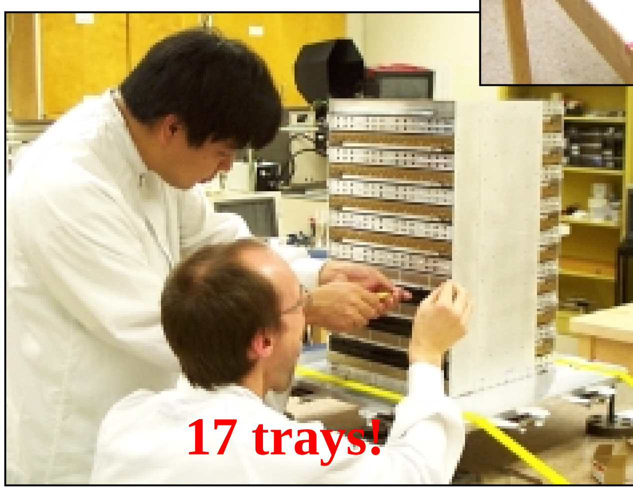
- HPK 296 (4”), 251 (6”)
- Micron 5 (6”)
- Leakage I: 300 nA/detector (HPK)
- Bad strips: about 1 in 5000

Assembly of the BTEM Tracker at SCIPP



2 trays and 2 observers

4 trays, 10 hands



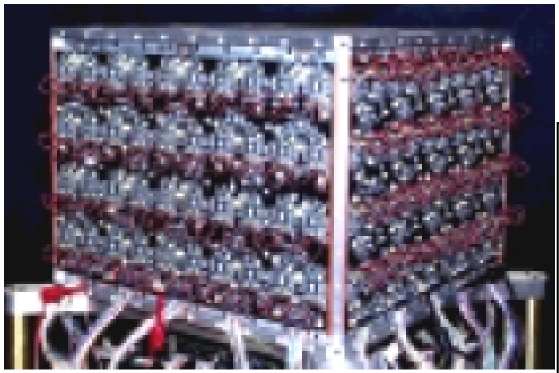
17 trays!

All done and all smiles.

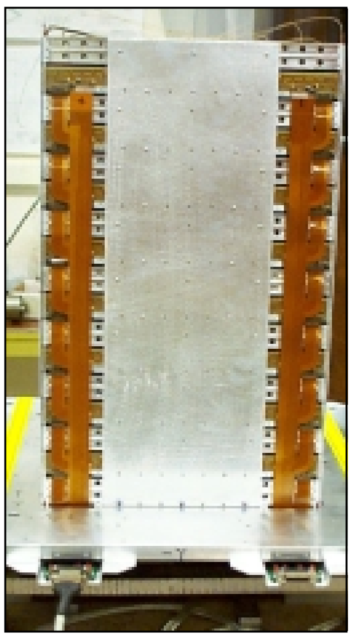
BTEM Installation at SLAC

Beam Test in SLAC's Endstation A (Dec 1999/Jan 2000)

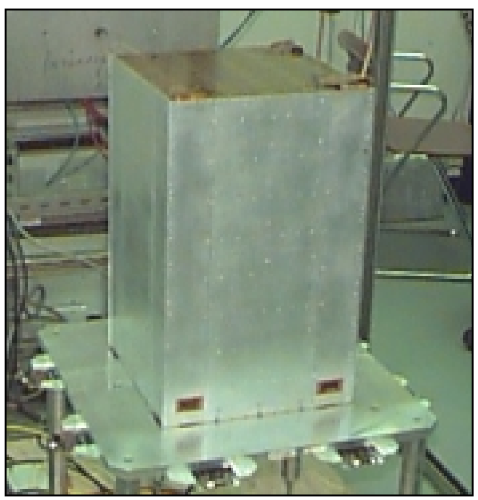
- Test Fabrication Methods
- Verify Performance
  - Resolution
  - Trigger
  - MC Programs

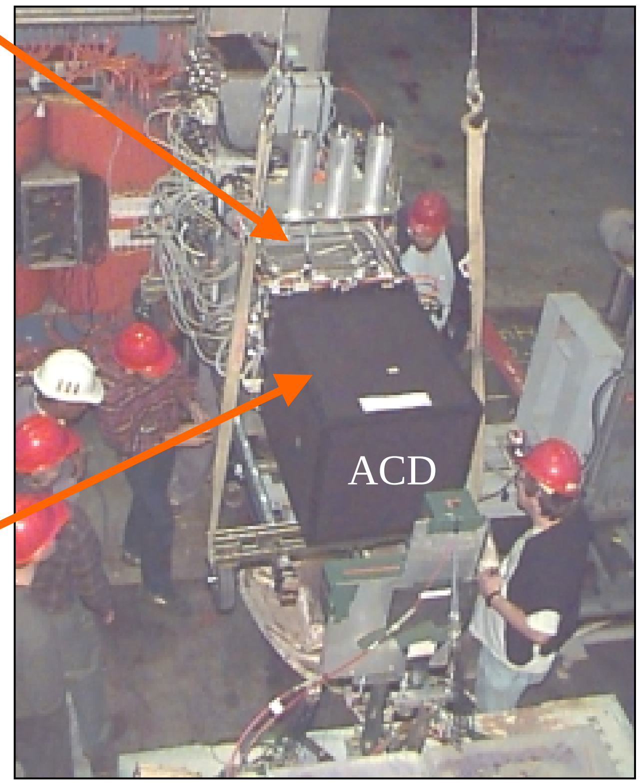


CsI Calorimeter



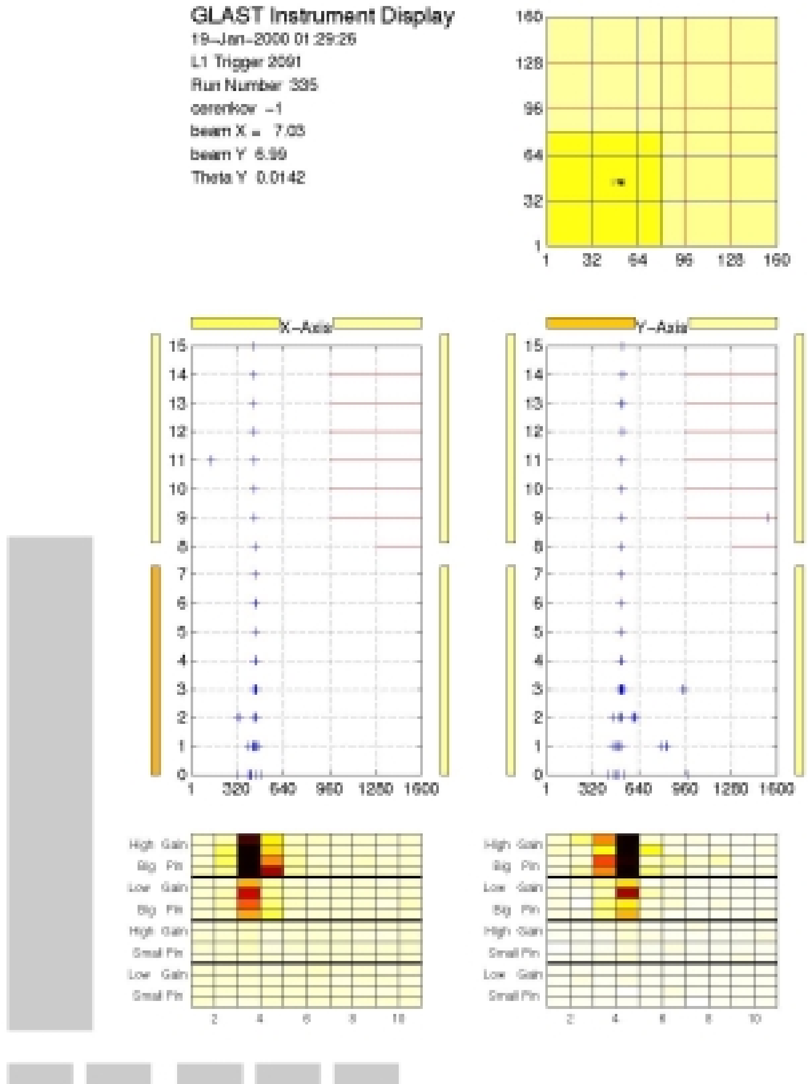
Silicon Tracker



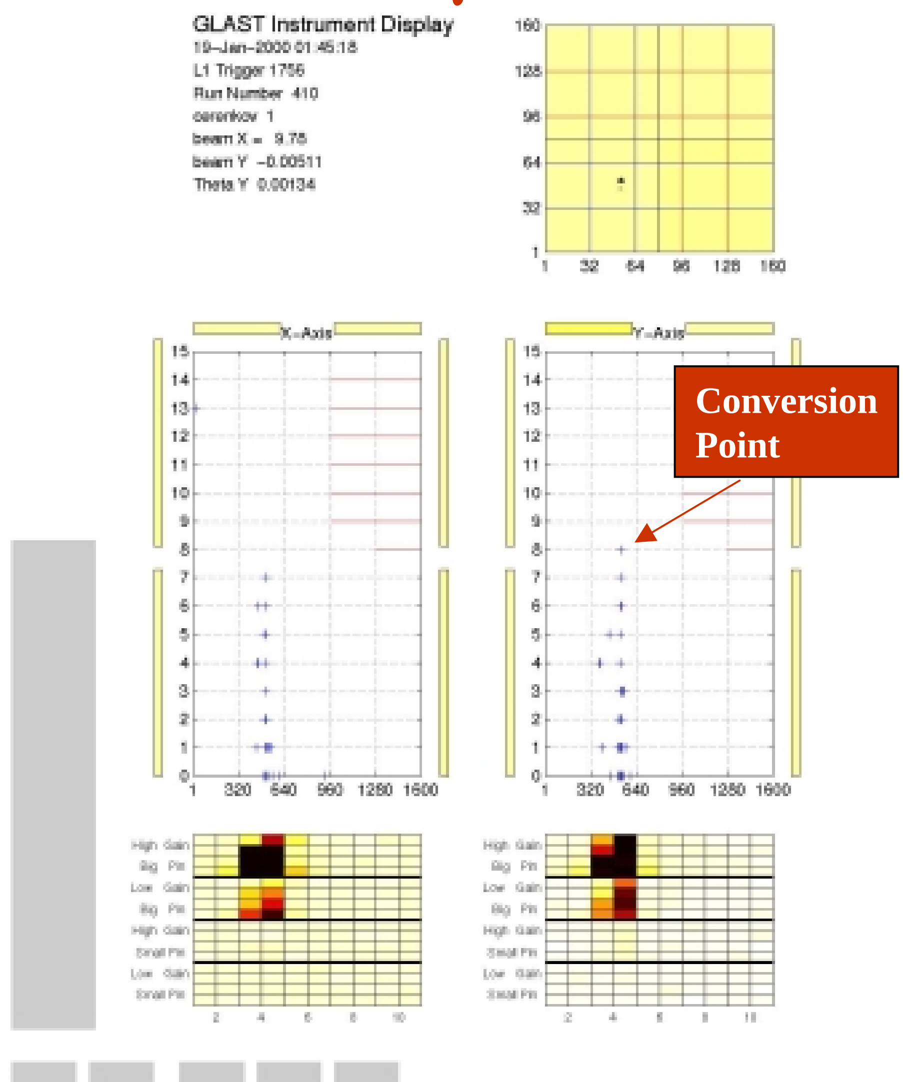


Example BTEM Events

e^+



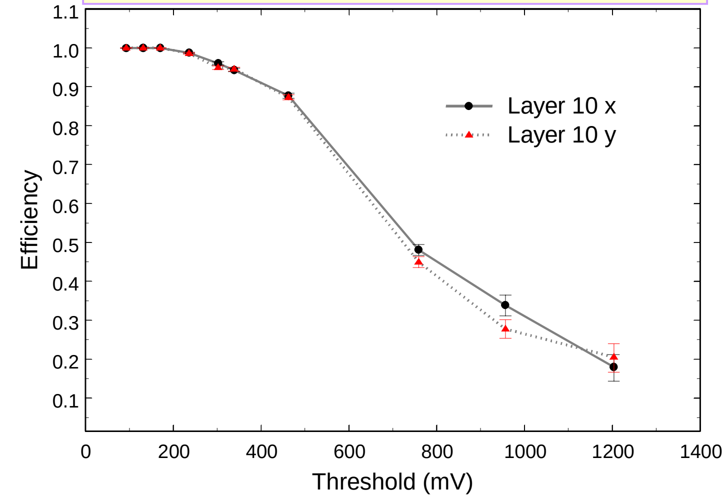
γ

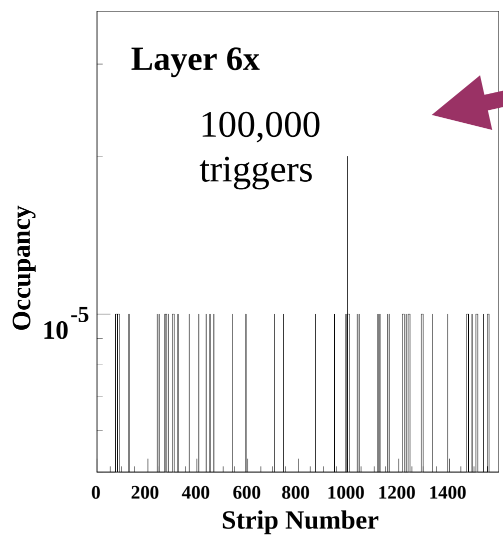


BTEM Electronics Performance

- Noise occupancy determines the noise rate of the LVL1 trigger, a coincidence of 6 layers, each an OR of 1600 channels.
- Hit efficiency was measured using single electron tracks and cosmic-ray muons.
- The requirements were met: 99% efficiency with $<10^{-4}$ noise occupancy.
- All this with only 200 μW of power per channel.

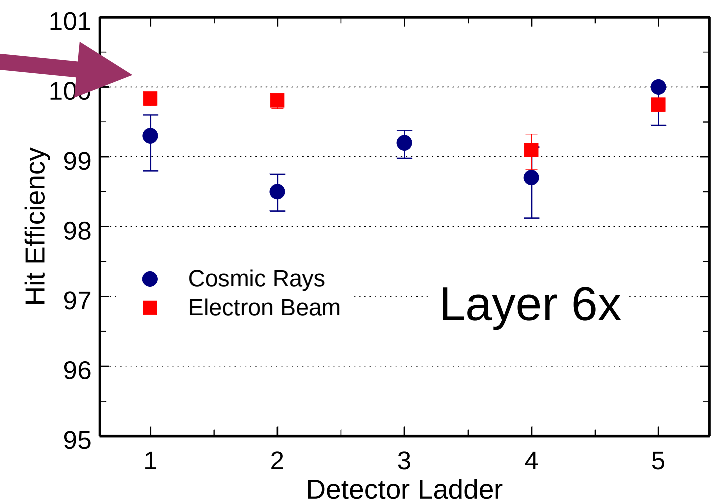
Hit efficiency versus threshold for 5 GeV positrons.



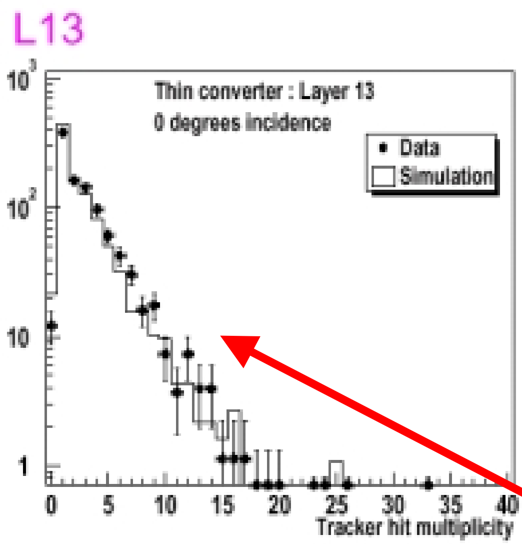


Noise occupancy and hit efficiency for one layer, using in both cases a threshold of 170 mV.

No channels were masked.



BTEM Hit Distributions



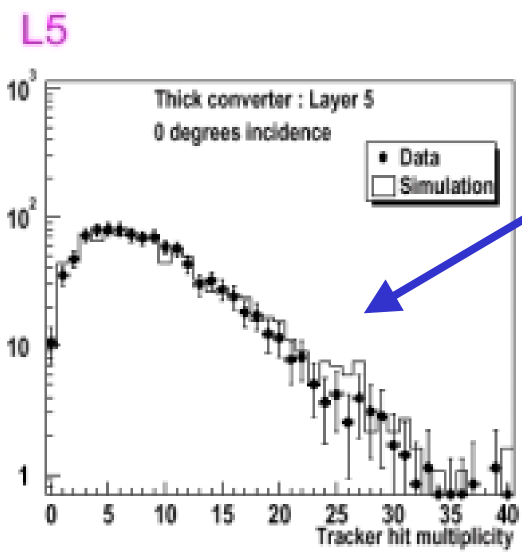
After the Gamma conversion, an electromagnetic shower develops.

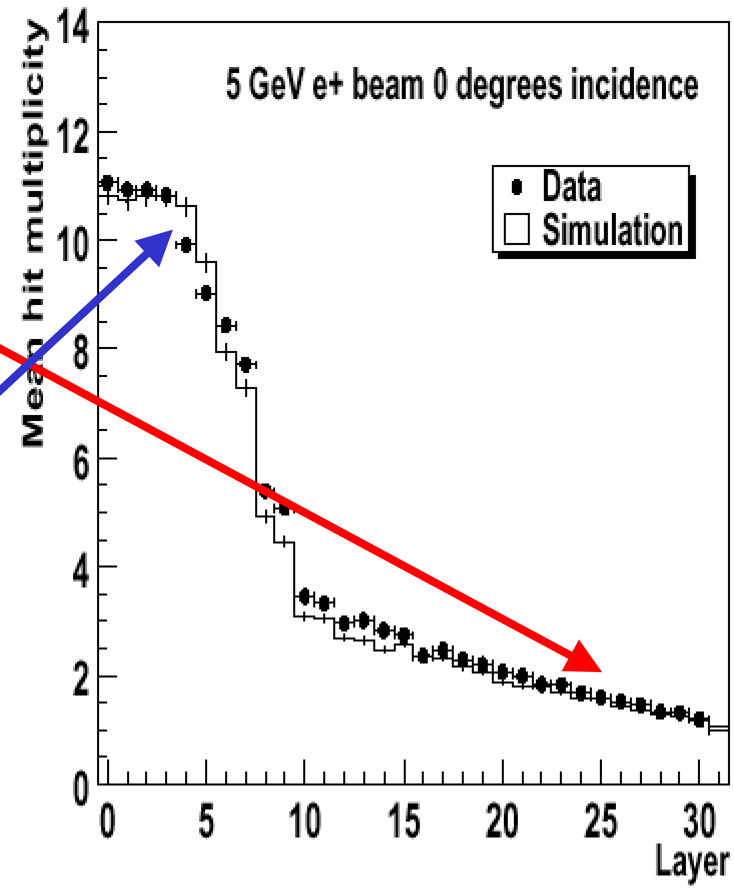
The distribution of # of hits along the track of a 5GeV positron agrees well with prediction at the

Start of the track

and

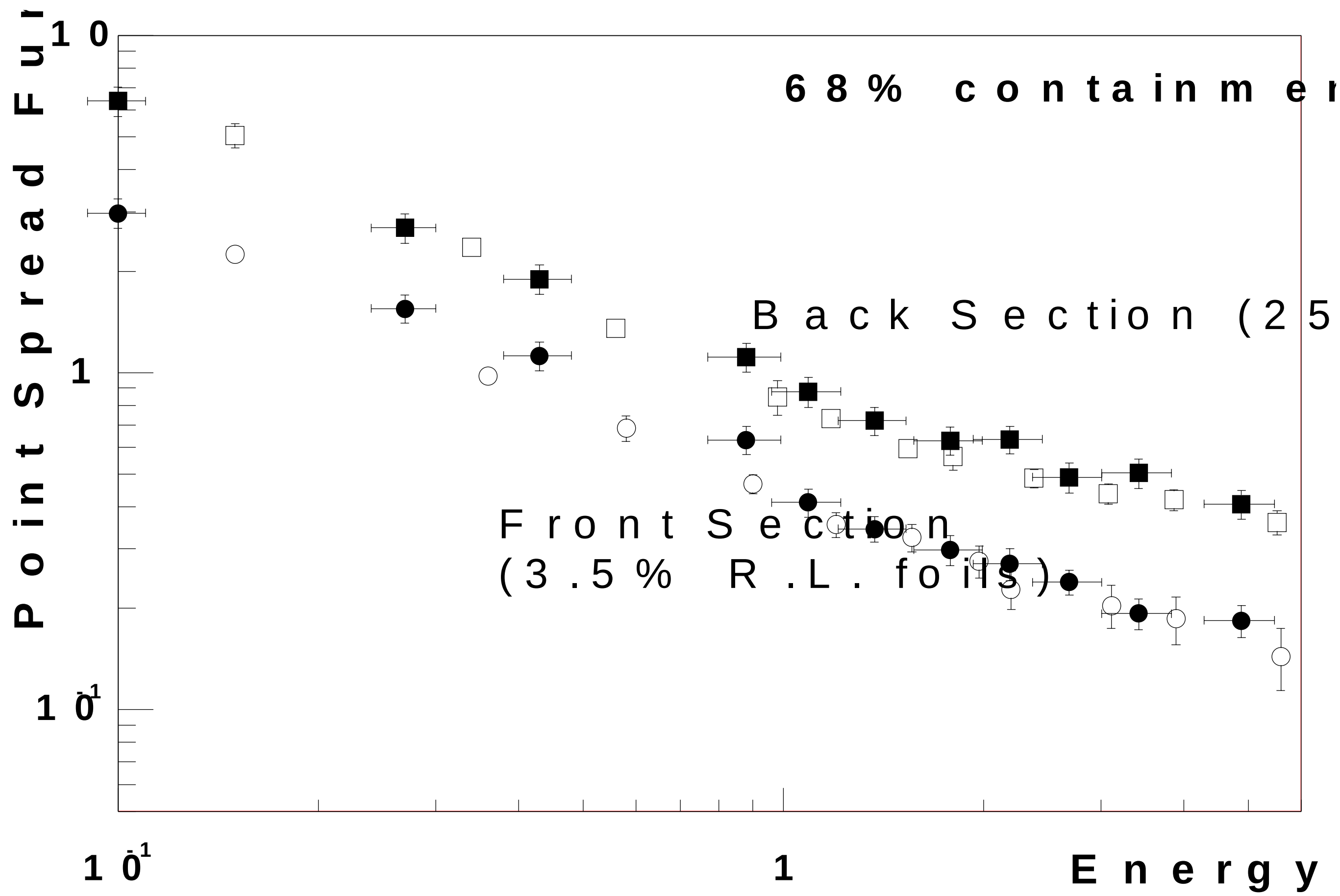
End of the track





GLAST

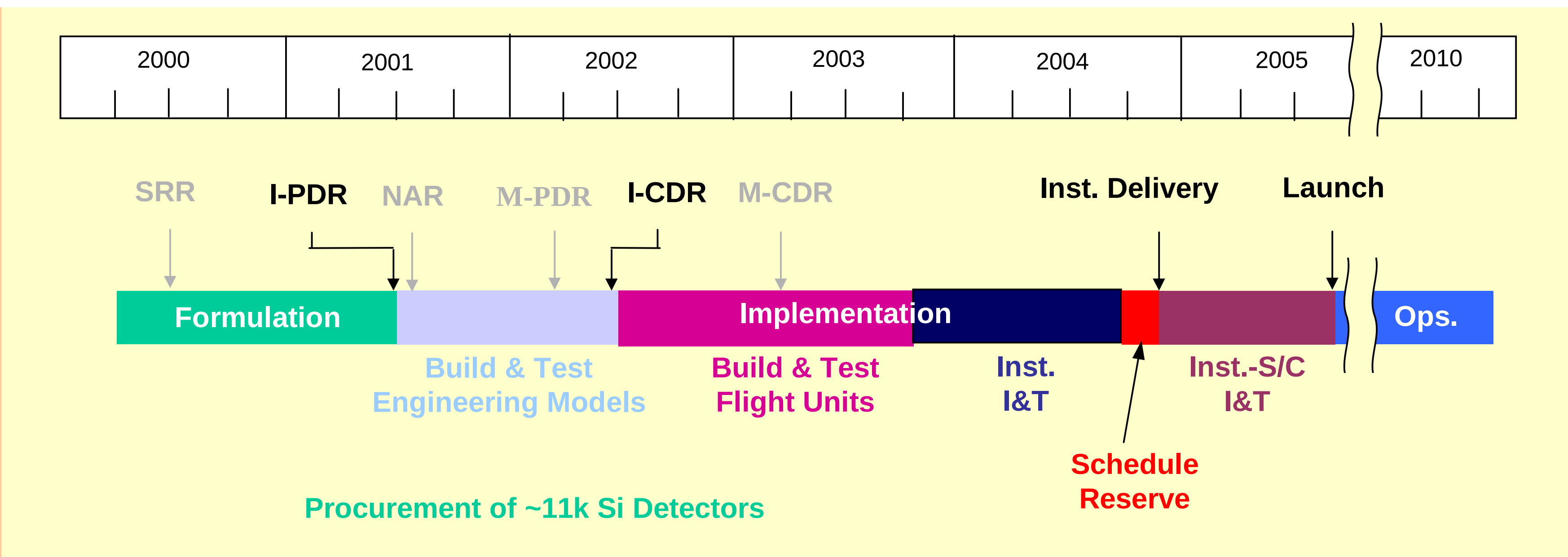
BTEM Angular Resolution



Comparison of the PSF width measured for gamma-ray conversions in the BTEM with Monte Carlo simulations of the same configuration. The analysis is done separately for conversions in the thin and thick and converter sections of the Tracker tower module.

GLAST Schedule

- LAT preliminary design review in the summer of 2001.
- Tracker Engineering Model—a full tower built to the flight design (carbon-fiber structure, final dimensions, final ASICs and Si detectors): completed for the LAT CDR in summer of 2002.
- 18 Tracker tower modules must be fabricated in about 1 year, in California and Italy.
- Launch in 2005. Operations over 5 to 10 years.



Conclusions

- The great success of the EGRET experiment demands a follow-on mission with enhanced capabilities to
  - observe sources with greater precision and higher statistics,
  - increase by orders of magnitude the numbers of visible sources,
  - see deeper into the universe,
  - monitor continuously the complete, rapidly-changing high-energy gamma-ray sky.
- The next generation of ground-based gamma-ray telescopes will need an orbiting observatory to cover the 10 MeV to 100 GeV energy range and to act as an all-sky monitor—for transients and to tie the >100 GeV spectra to lower energies.
- GLAST will readily meet those demands but will also provide such a large improvement in sensitivity that completely new discoveries are more than likely.