GLAST Large Area Telescope:

An Introduction*

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for the LAT Collaboration

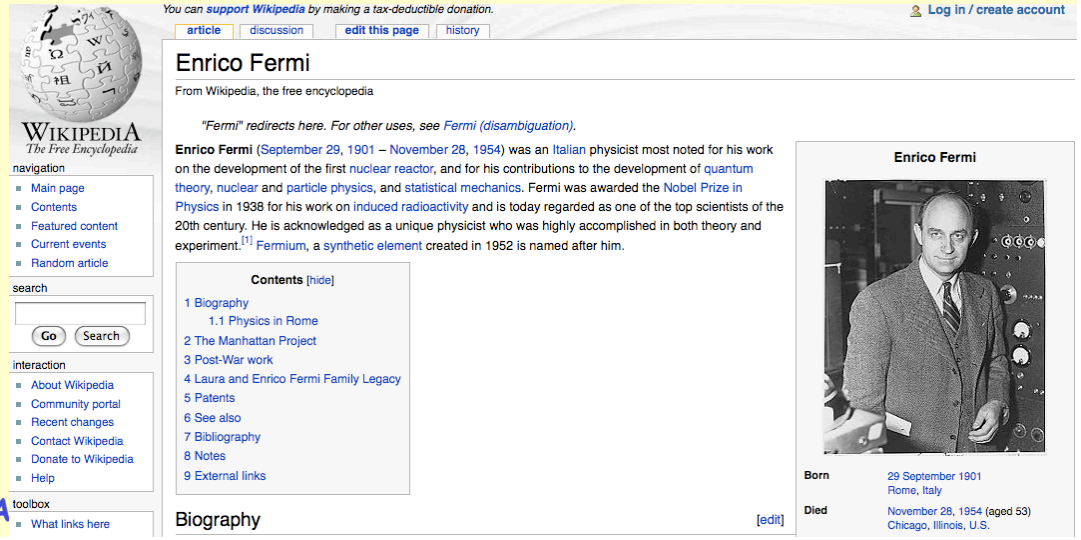
* Liberally purloined from other LAT talks!

What's in a Name?

Fermi

Gamma-ray Space Telescope

GLAST renamed to Fermi on Aug 26



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Enrico Fermi

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"Fermi" redirects here. For other uses, see Fermi (disambiguation).

Enrico Fermi (September 29, 1901 – November 28, 1954) was an Italian physicist most noted for his work on the development of the first nuclear reactor, and for his contributions to the development of quantum theory, nuclear and particle physics, and statistical mechanics. Fermi was awarded the Nobel Prize in Physics in 1938 for his work on induced radioactivity and is today regarded as one of the top scientists of the 20th century. He is acknowledged as a unique physicist who was highly accomplished in both theory and experiment.[1] Fermium, a synthetic element created in 1952 is named after him.

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2 The Manhattan Project
3 Post-War work
4 Laura and Enrico Fermi Family Legacy
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Enrico Fermi

Born 29 September 1901 Rome, Italy

Died November 28, 1954 (aged 53) Chicago, Illinois, U.S.

Biography [edit]

Fermi Gamma-Ray Space Telescope - LAT:

Sky Survey

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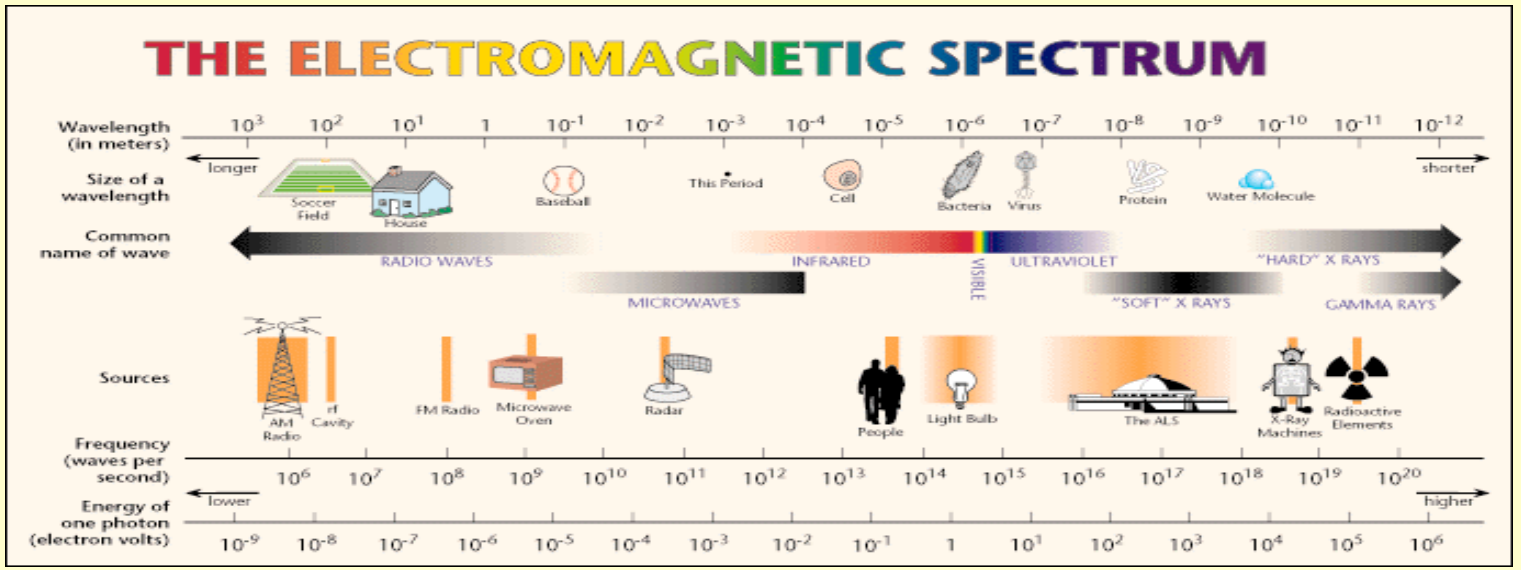
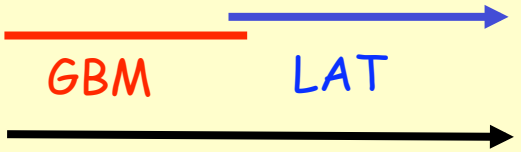
The LAT Team

Gamma-Ray Astrophysics





- **The Fermi energy range falls at the energetic end of this scale!**
- **Very energetic photons require even more energetic particles to produce them -- HE gamma-ray astrophysics does not probe quiet parts of the Universe.**
- **High energy gamma-rays explore nature's accelerators - "Where the energetic things are"**
  - **natural connections to UHE cosmic-ray and neutrino astrophysics**

What is Fermi?

Two Instruments:

Large Area Telescope (LAT)

PI: P. Michelson (Stanford University)

20 MeV - 300 GeV

>2.5 sr FoV

Gamma-Ray Burst Monitor (GBM)

PI: W. Paciesas (NASA/MSFC)

Co-PI: J. Greiner (MPE)

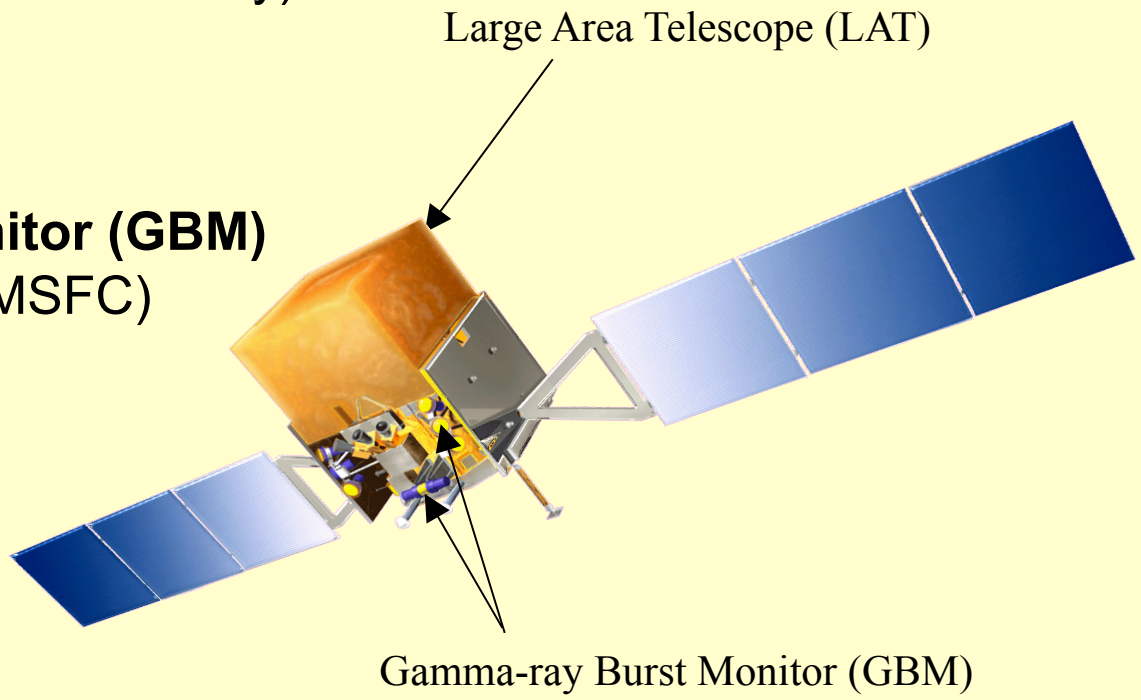
8 keV – 40 MeV

9 sr FoV

Launch: June 11 2008

Lifetime: 5 years (req)

10 years (goal)



Exploring the gamma-ray sky

- **In the detector:**
  - Is the event a gamma-ray or charged cosmic-ray?
  - What is the energy of the event?
  - Where in the sky did the event come from?
  - How well can we estimate our knowledge of the above quantities?
- **With a gamma-ray source:**
  - Are we sure that it is a source?
  - Is there a feature or a cutoff in the energy spectrum?
  - Is it a point source or does it have a spatial extent?
  - Is it variable?
  - Does it show periodic emission?
- **External information:**
  - Is it associated with a known object at other wavelengths?
  - How does the gamma-ray emission compare with the lower energy emission? Temporally? Spatially?
  - How far away is it?

Gamma-ray Energy Loss Mechanisms

- **For photons in matter above ~10 MeV, pair conversion is the dominant energy loss mechanism.**
  - **Pair conversion telescope**

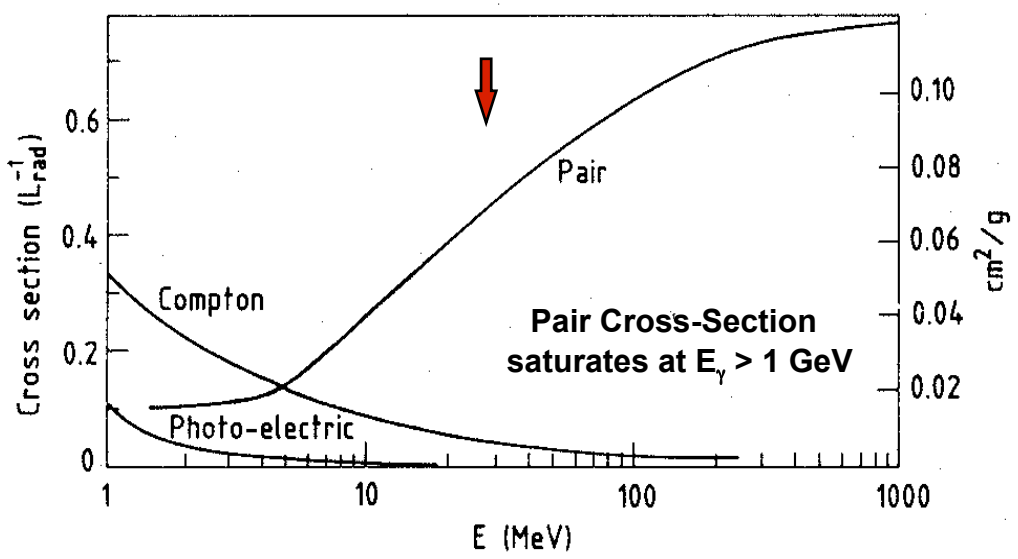
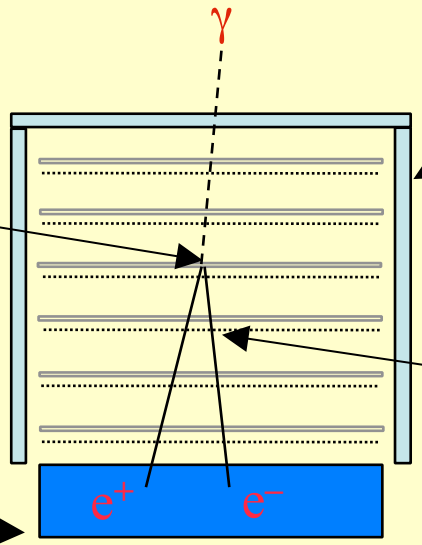


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

Pair Conversion Technique



photon converts to an e+e- pair in one of the conversion foils

The anti-coincidence shield vetos incoming charged particles.

The energy is measured in the calorimeter

The directions of the charged particles are recorded by particle tracking detectors, the measured tracks point back to the source.

Tracker: angular resolution is determined by:
multiple scattering (at low energies) => thin conversion foils
position resolution (at high energies) => fine pitch detectors

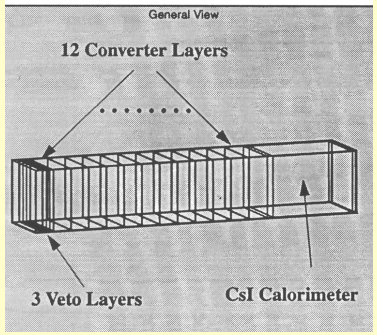
Conversion efficiency -> Thick conversion foils, or many foils

Calorimeter:Enough X_0 to contain shower, shower leakage correction.

Anti-coincidence detector:
Must have high efficiency for rejecting charged particles, but not veto gamma-rays

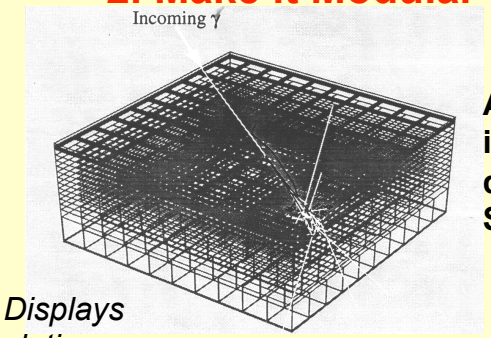
Evolution of Fermi-LAT

1. Select the Technologies



Large area SSD systems and CsI Calorimeters resulted from SSC R&D

2. Make it Modular



Another lesson learned in the 1980's: monolithic detectors are inferior to Segmented detectors

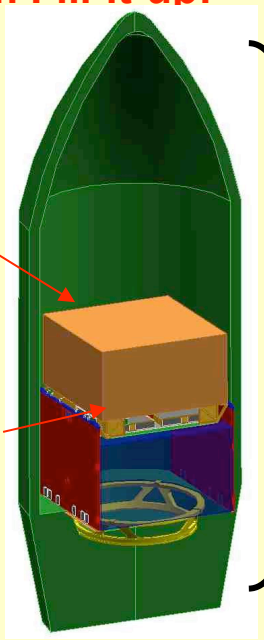
Original GISMO 1 Event Displays from the first GLAST simulations

3. Pick the Rocket

Delta II (launch of GP-B)

Cheap, reliable Communication satellite launch vehicle

4. Fill-it-up!



Diameter sets transverse size

Throw capacity to LEO sets depth of Calorimeter

Rocket Payload Fairing

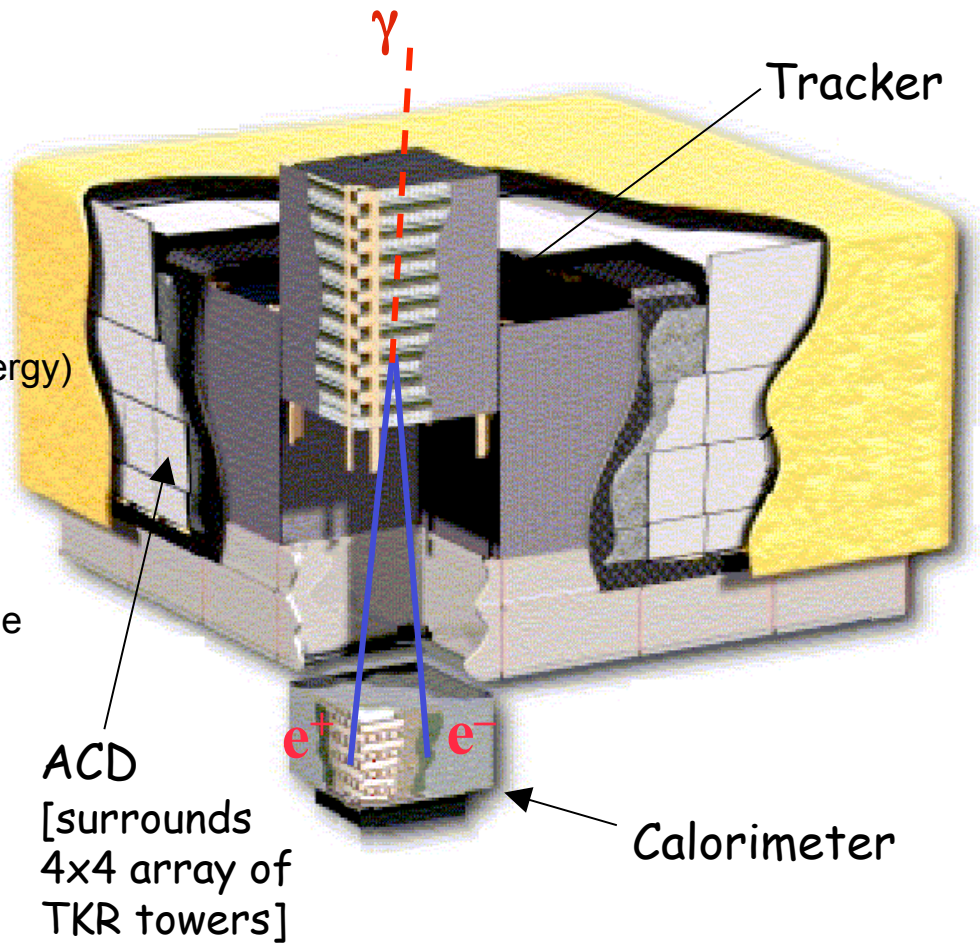
Power budget of 650 W

The Fermi Large Area Telescope

Overall LAT Design:

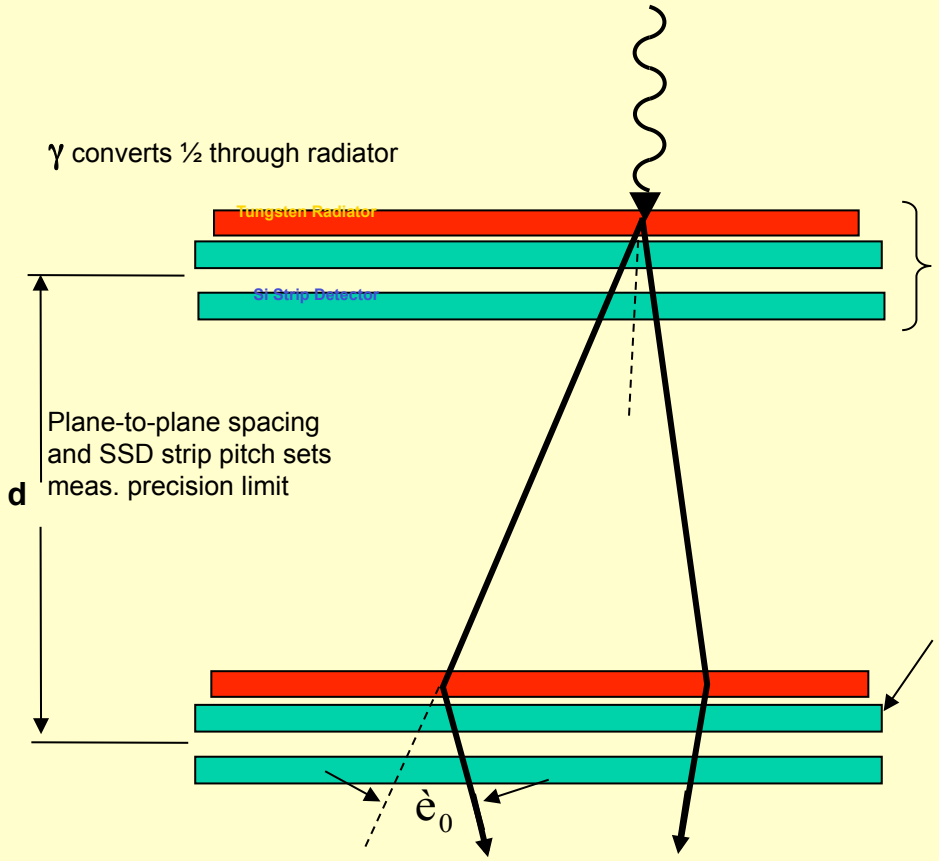
- 4x4 array of identical towers
- 3000 kg, 650 W (allocation)
- 1.8 m × 1.8 m × 1.0 m

- **Precision Si-strip Tracker (TKR)**
  18 XY tracking planes. 228 μm pitch).
  High efficiency.
  Good position resolution (ang. resolution at high energy)
  12 x 0.03 X_0 front end => reduce multiple scattering.
  4 x 0.18 X_0 back-end => increase sensitivity >1GeV
- **CsI Calorimeter(CAL)**
  Array of 1536 CsI(Tl) crystals in 8 layers.
  Hodoscopic => Cosmic ray rejection, shower leakage correction.
  8.5 X_0 => Shower max contained <100 GeV
- **Anticoincidence Detector (ACD)**
  Segmented (89 plastic scintillator tiles)
  => minimize self veto



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

LAT Tracker - details



Close spacing of Radiators to SSDs minimizes multiple scattering effects

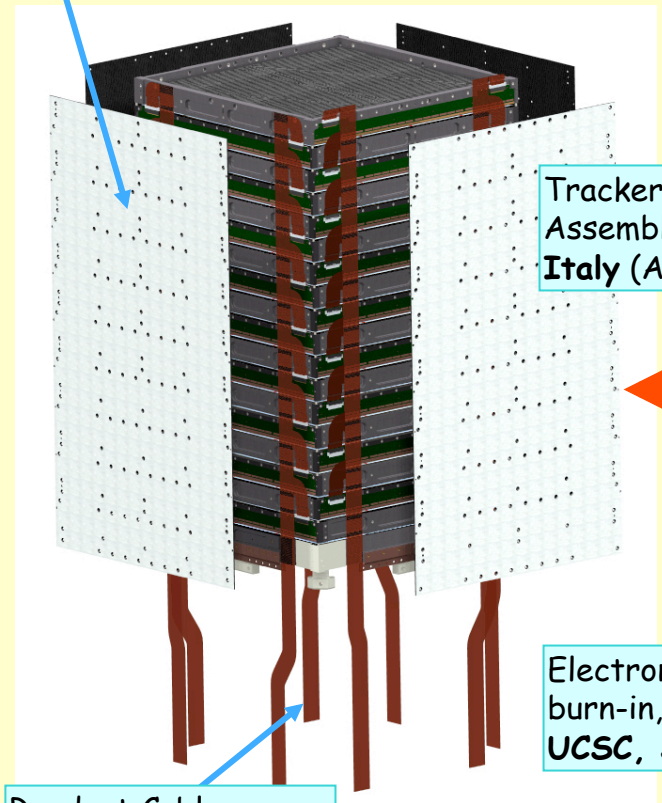
SSD resolution (σ) = strip pitch/sqrt(12)

θ_{det}= sqrt(2) * σ_{ssd}/d = 228 μm/ (32.9mm.sqrt(6)) = 2.8 mrad = 0.16°

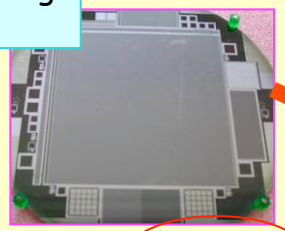
θ_{MS}(100 MeV) ~ 3.1°

Tracker Production Overview

Module Structure Components
SLAC: Ti parts, thermal straps, fasteners.
Italy (Plyform): Sidewalls

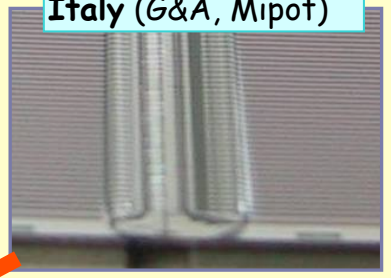


SSD Procurement, Testing
Japan, Italy (HPK)



Parts Count **10,368**

SSD Ladder Assembly
Italy (G&A, Mipot)



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Tray Assembly and Test
Italy (G&A)

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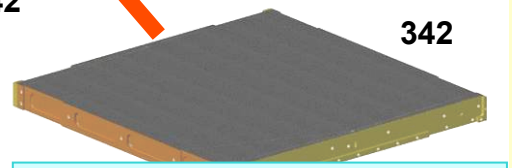

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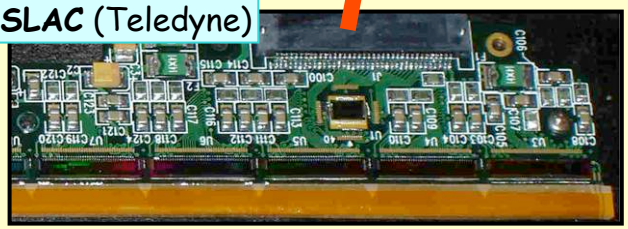
Composite Panel, Converters, and Bias Circuits
Italy (Plyform): fabrication
SLAC: CC, bias circuits, thick W, Al cores

Tracker Module Assembly and Test
Italy (Alenia Spazio)

18

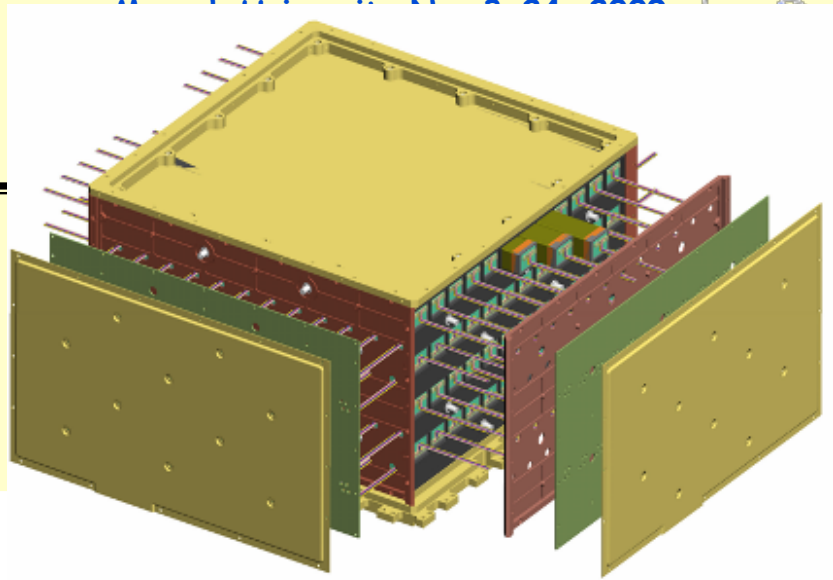
Electronics Fabrication, burn-in, & Test
UCSC, SLAC (Teledyne)

648



Readout Cables
UCSC, SLAC (Parlex)

LAT Calorimeter



Team effort involving physicists and engineers from the United States (NRL), France (IN2P3 & CEA), and Sweden

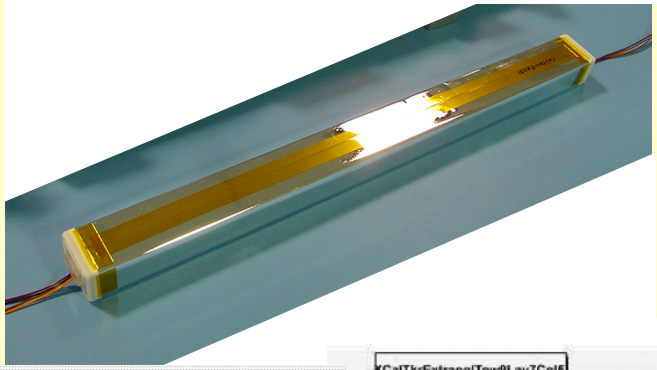
Crossed Hodoscope Log design

(first proposed by Per Carlson, 1989)

Gives 3D image of energy deposition

8 Layers deep (1.08 rad. len./layer)

12 "Logs" per Layer



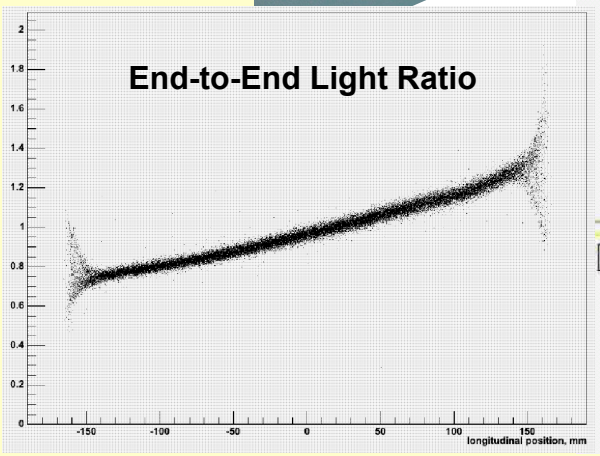
Each Log (or Xtal Element) is readout from both ends by 2 Photodiodes

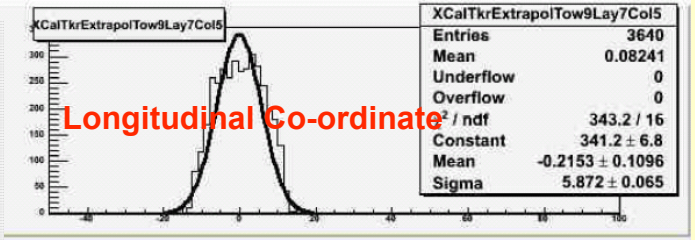
1 - large area, 1 small area

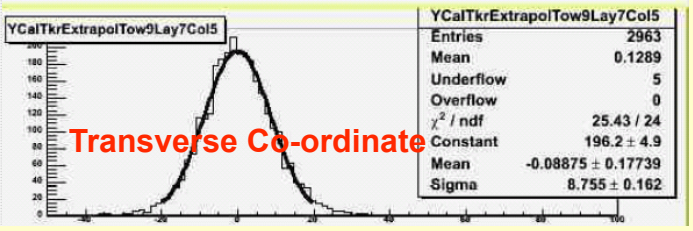
<u>Location of Energy Depositions</u>

2 coordinates by log location

3rd coordinate by end-to-end light asymmetry

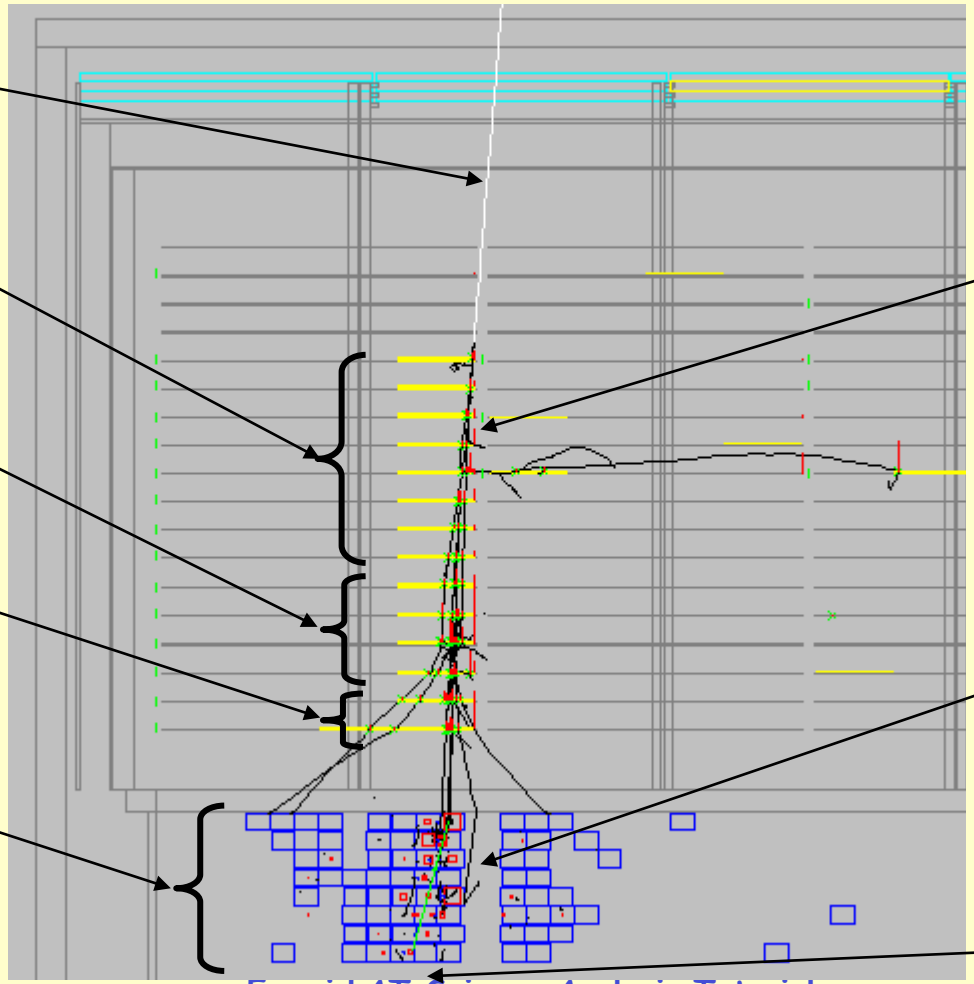






Energy Determination

Issues: Low Energies - Energy loss in Tracker is critical
High Energies - Leakage compensation is critical
Compensation for the numerous gaps



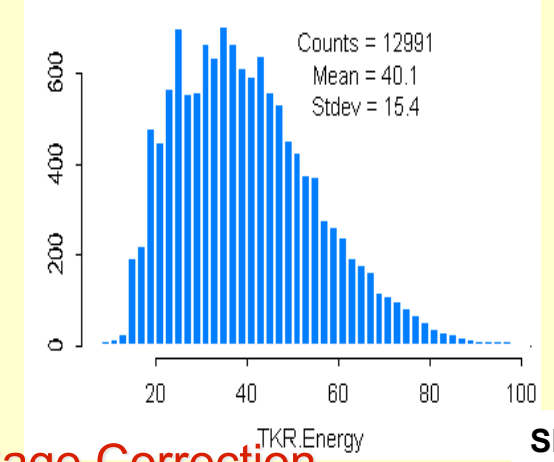
Low Energy: Combining the Tracker with the Calorimeter

Use Tracker as a (poor) Sampling Calorimeter

Count Hits

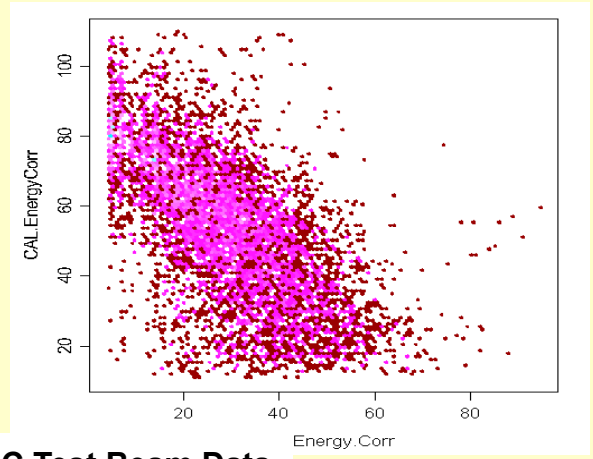
Apply Correction for Inter-Tower Gaps

Tracker Energy Alone
(derived from hit counting)



100 MeV γs ~ on Axis

Tracker - Cal (Anti)Correlation



High Energy: Shower Leakage Correction

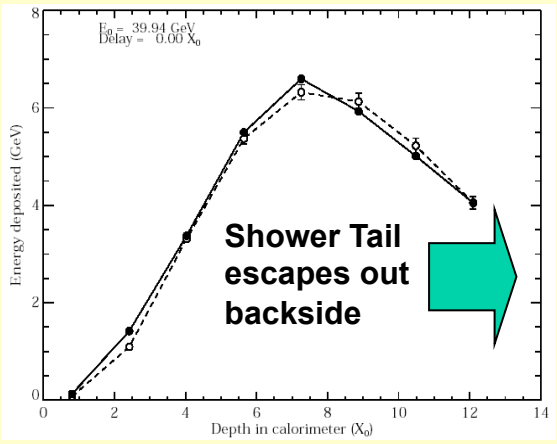
Measured longitudinal profile allows estimation of shower leakage event-by-event

Longitudinal Shower Profile Model

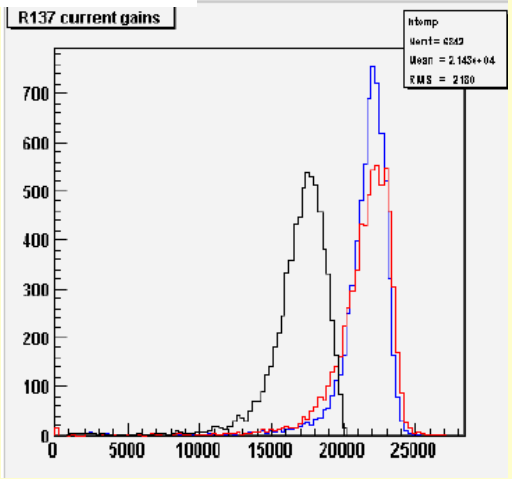
$$\frac{dE}{d(bt)} = E_0 \frac{(bt)^{a-1} e^{-bt}}{\tilde{A}(a)}$$

b is a scale factor ~ .5

a is the scaled shower centroid ~ $\log(E)$

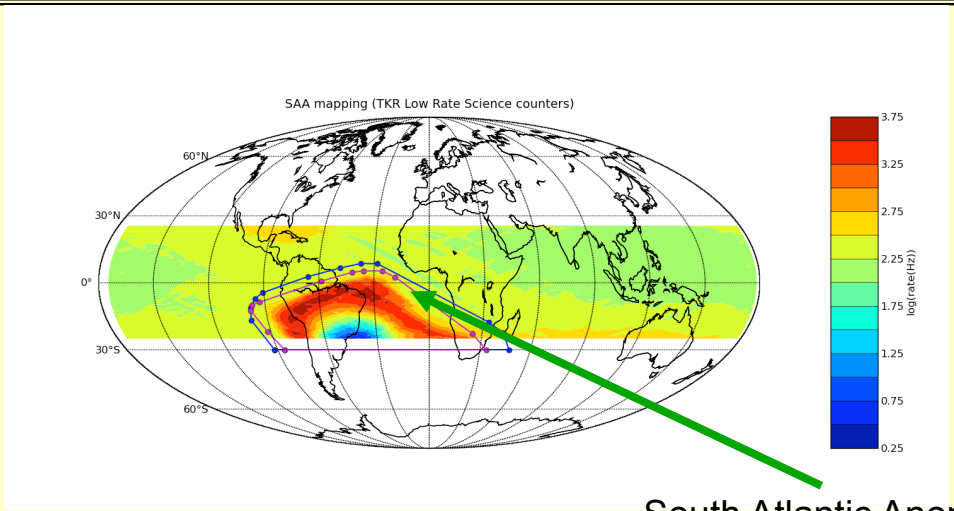


SLAC Test Beam Data

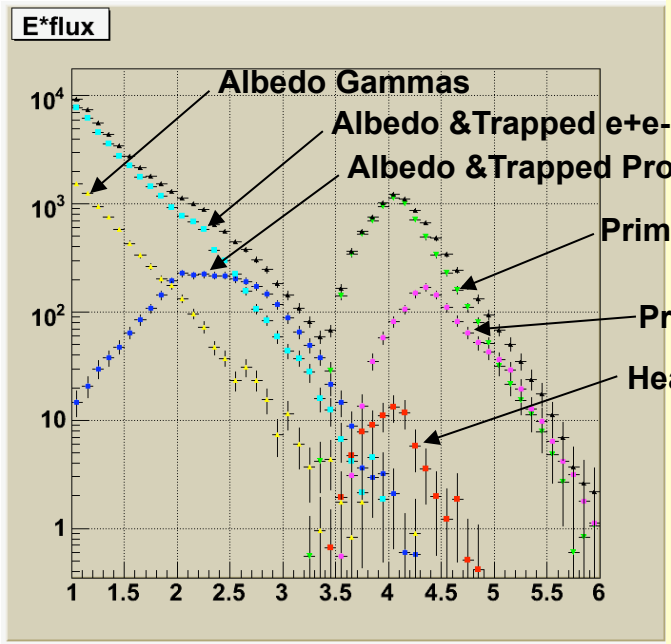


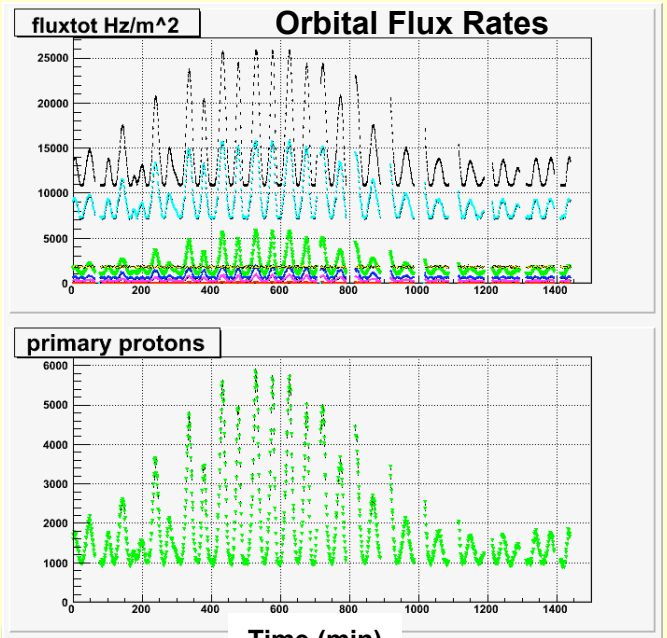
Background Rejection

First: Low Earth Orbit Particle Flux Environment



South Atlantic Anomaly **(Hot Spot)**





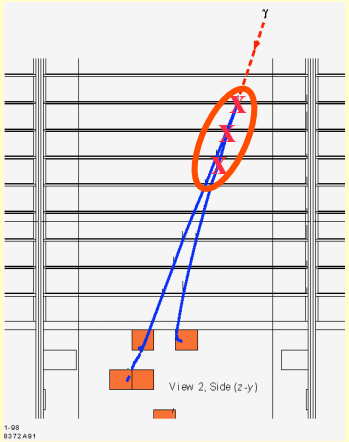
Instrument Triggering and Onboard Data Flow

Hardware Trigger → On-board Processing

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

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

Combinations of trigger primitives:



- **TKR 3 x•y pair layers in a row**
  workhorse γ trigger
- **CAL:**
  LO – independent check, energy info.
  HI – indicates high energy event:

Upon a trigger, all subsystems are read out in ~27μs

Instrument Total Rate: <3 kHz>*

*using ACD veto in hardware trigger

Onboard filters: reduce data to fit within downlink, provide samples for systematic studies.

- **flexible, loose cuts**
- **The FSW filter code is wrapped and embedded in the full detector simulation**
- **leak a fraction of otherwise-rejected events to the ground for diagnostics, along with events ID for calibration**
- **signal/background can be tuned**

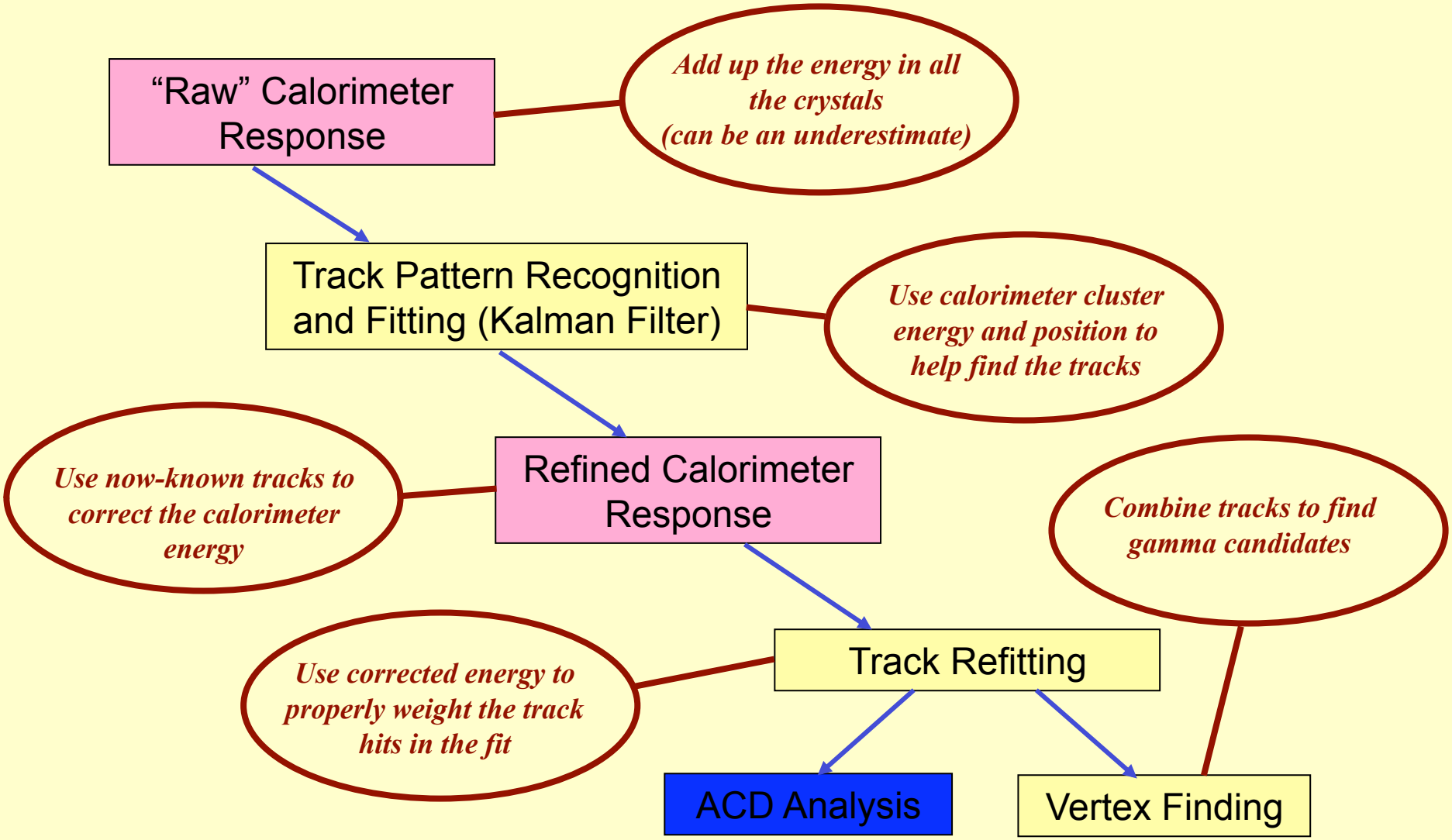
γ rate: a few Hz

Total Downlink Rate: <~400 Hz>

On-board science analysis:
transient detection (bursts)

Spacecraft

Event Reconstruction



Event Classification and Background Rej

- **Several Classification trees:**
  - **Energy resolution**
    - **Choose between 3 energy recon methods**
    - **Calculate probability that energy is well measured (use this as an analysis knob to tune final energy resolution performance)**
  - **PSF analysis**

    Divide events into thick and thin (depending on the thickness of the radiator where they converted)

    Evaluate vertex and single track solutions separately

    Divide events into energy bins (characteristics change dramatically)
    - **Decide whether or not to use vertex solution**
    - **Calculate probability that track was well measured (use to tune final angular resolution performance)**
  - **Background rejection**

    Divide events into vertex/single track and several energy bins
    - **Each path has a set of hard cuts followed by a classification tree that yields a probability that the event was a gamma-ray (use this to tune final background rejection).**

Event Selections

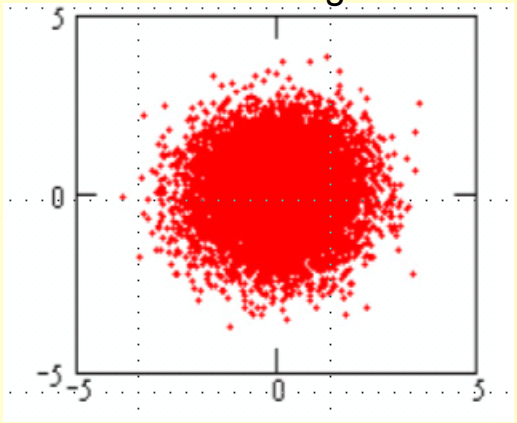
- We have optimized cuts on the CT probability variables for different analysis to provide predefined event selections.
  - Transient class: Relatively loose cuts on background rejection and angular resolution, suitable for short duration (<200 s) analysis (3-5 hz event rate)
  - Diffuse class: Tighter cuts, suitable for analysis of point and extended sources, and analysis of galactic diffuse emission.
  - Ultradiffuse: Currently under validation, very tight cuts to produce clean gamma-ray sample suitable for studies of the extragalactic diffuse emission.

- Montecarlo data is used to parameterise the instrument response for each of these event selections. These parameterizations are known as Instrument Response Function (IRFs)
  - Current IRFs are P6_V3_DIFFUSE and P6_V3_TRANSIENT

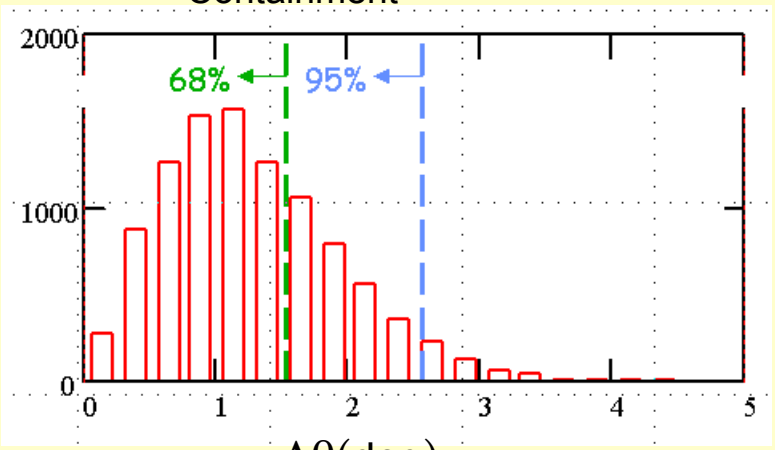
Jargon: PSF, Effective Area

Point-Spread-Function

2D Point Source Image at 275 MeV



PSF Characterized by 68% & 95% Containment



Effective Area- A_{eff}

Not all entering γs pair-convert

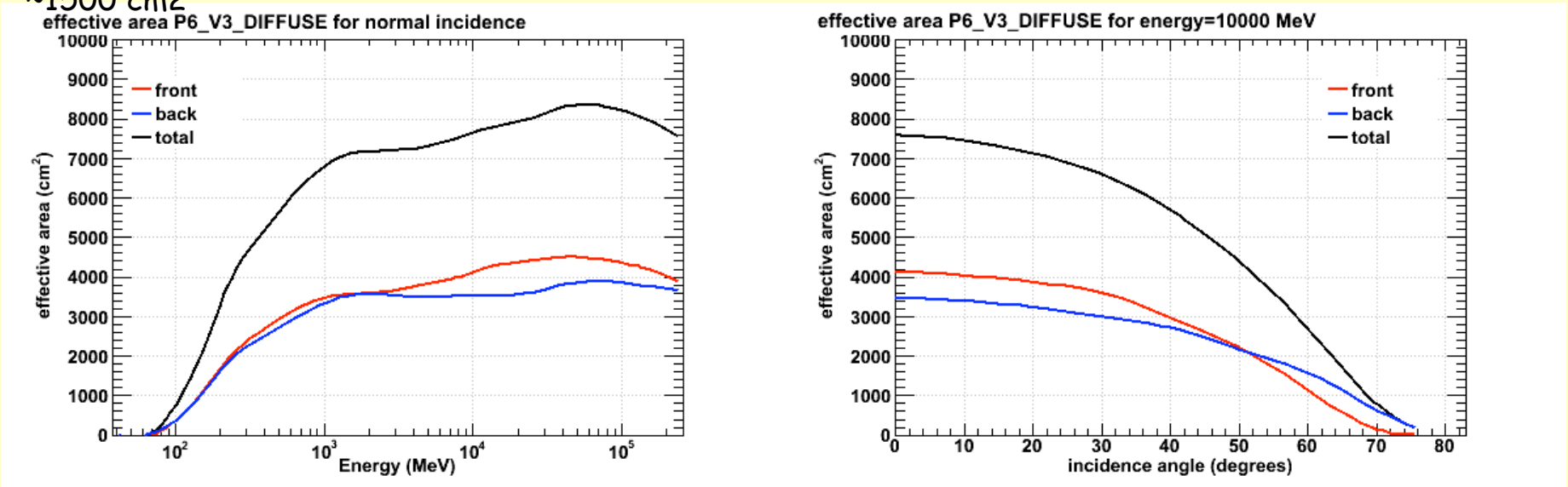
$$P_{conv}(x) = 1 - \exp\left(-\frac{7}{9}\frac{x}{\div_{Mat}}\right)$$

$$A_{eff} \cong A_{Geom} \cdot P_{conv}(depth) \cdot Eff_{Analysis}$$

Typically $Aeff \leq \frac{1}{2} A_{Geom}$

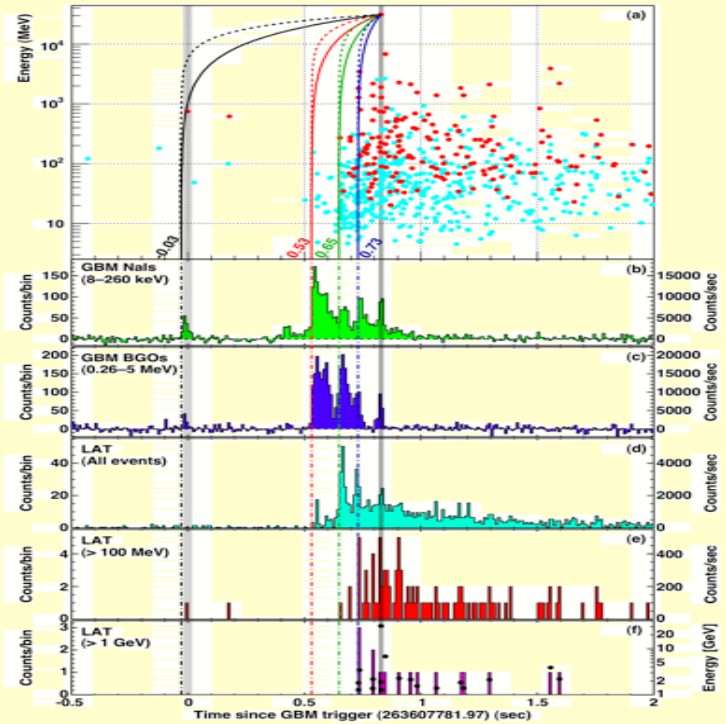
LAT Performance Aeff

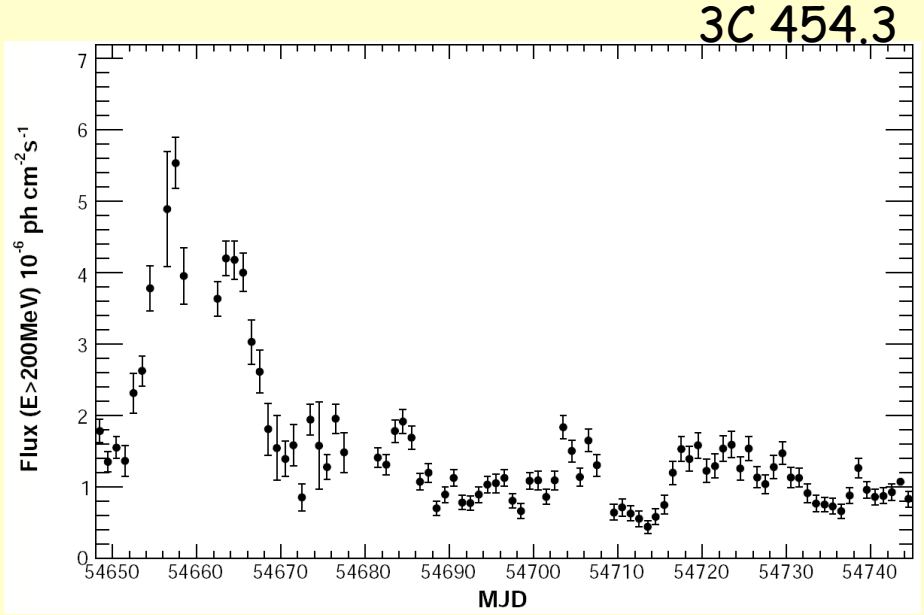
c.f. EGRET
~1500 cm2



- **Effective area rises rapidly up to 1 GeV.**
- **Useful data collected out to 65-70 deg from the LAT boresight.**

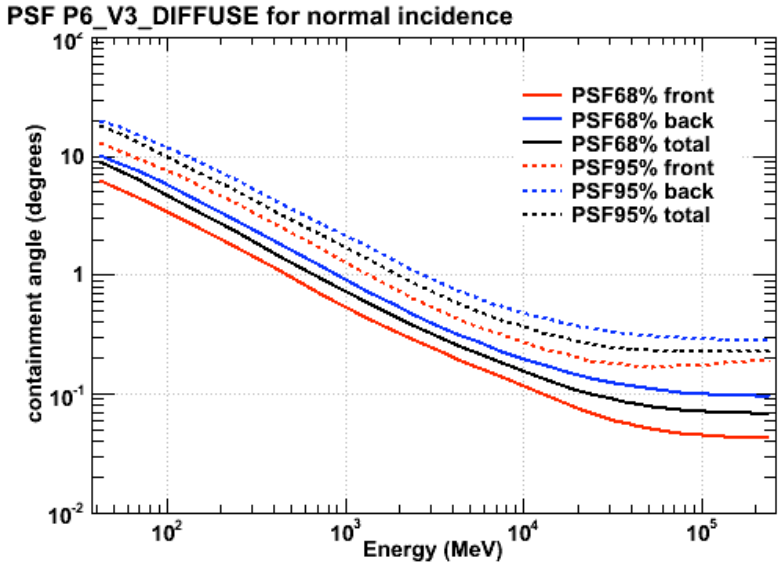
Effective area

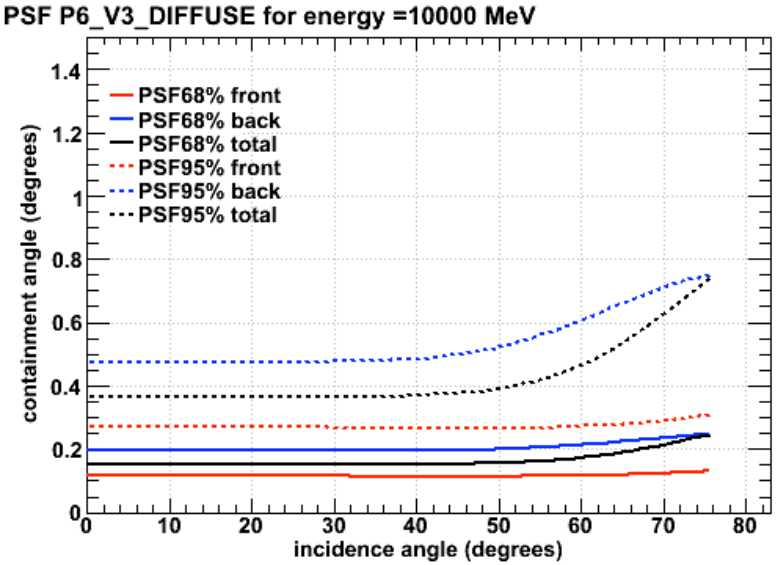




- **Large effective area means that more gamma-rays are detected by LAT for a given source brightness.**
- **Improves sensitivity; observations of rapid variability/transients (typical minimum integration for bright sources is 1 day, but can go smaller for brightest sources)**

LAT Performance: Angular Resolution

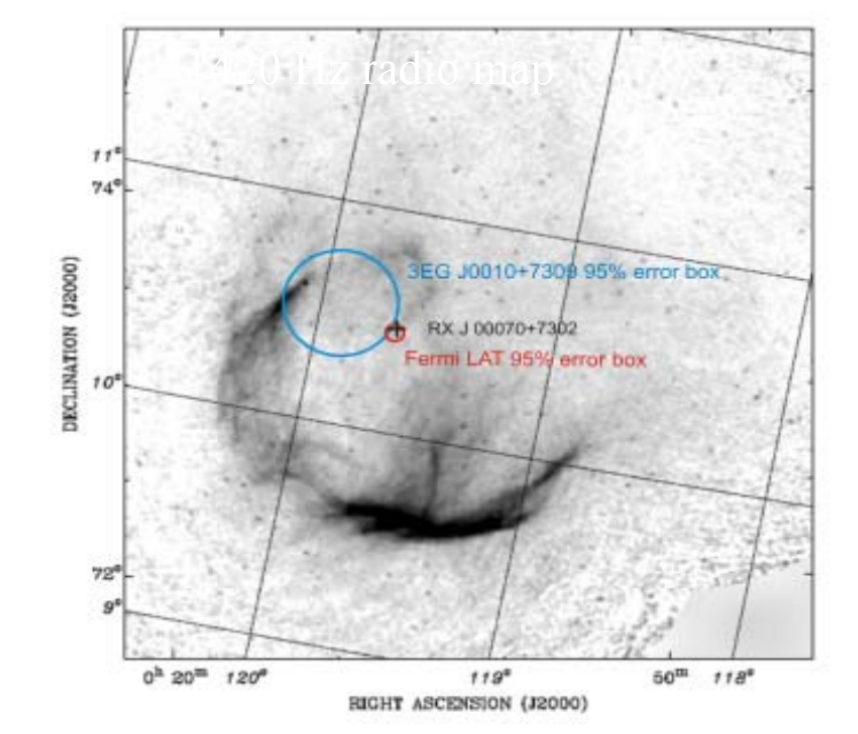




- **Angular resolution rapidly improves with increasing energy.**
- **Improved sensitivity (less background); greatly improved source locations, reduced source confusion - particularly for hard spectrum sources.**
- **Source localizations 5-10's arcmin typically - can follow up with MW observations.**
  - **Everything is better when we know where to look!**

New Pulsar in CTA 1

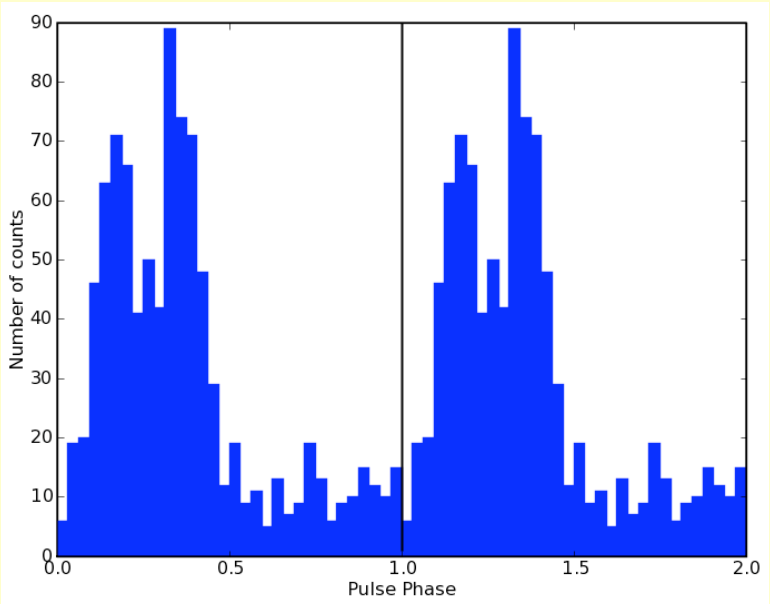
Science Express October 16
Abdo et al., 2008, Science



LAT 95% error radius = 0.038 deg
EGRET 95% error radius = 0.24 deg

P ~ 316 ms
Pdot ~ 3.6 x 10^{-13}
Flux (>100MeV) = 3.8 ± 0.2 x 10^{-7} ph cm-2 s-1

Pulse undetected in radio/X-ray

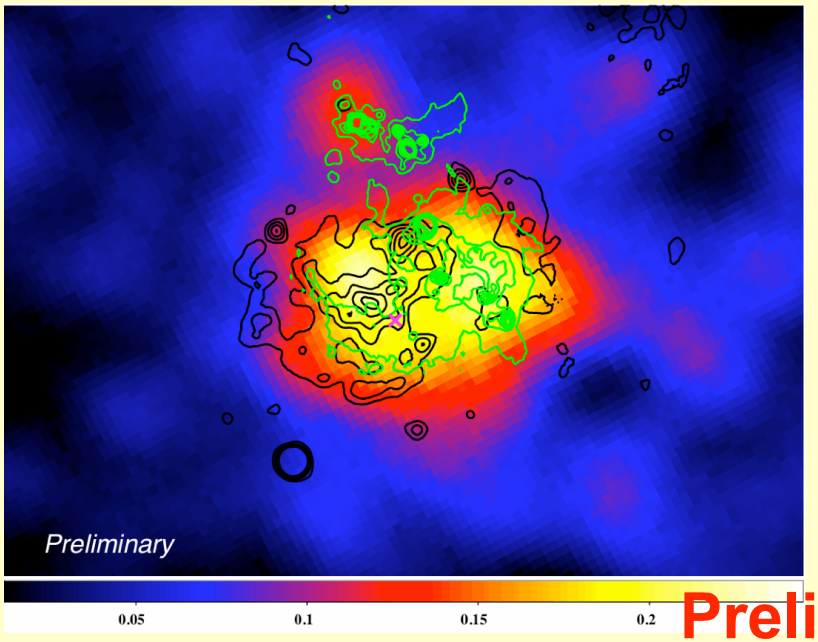


Unidentified EGRET sources - many are pulsars!

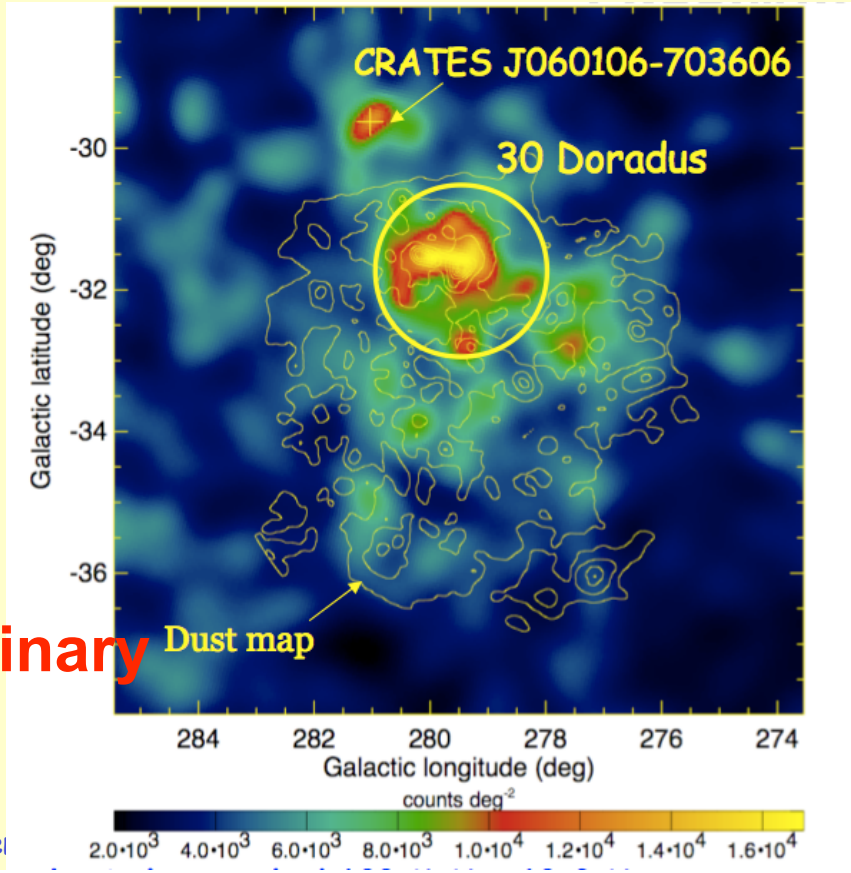
Extended Sources

- **LAT is resolving the MeV-GeV gamma-ray emission from extended sources.**

W51C



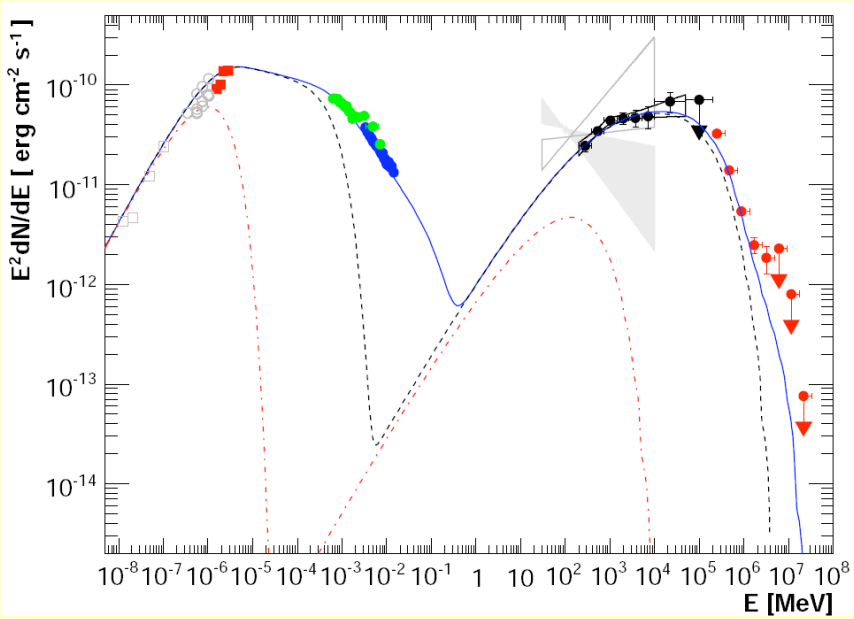
LMC



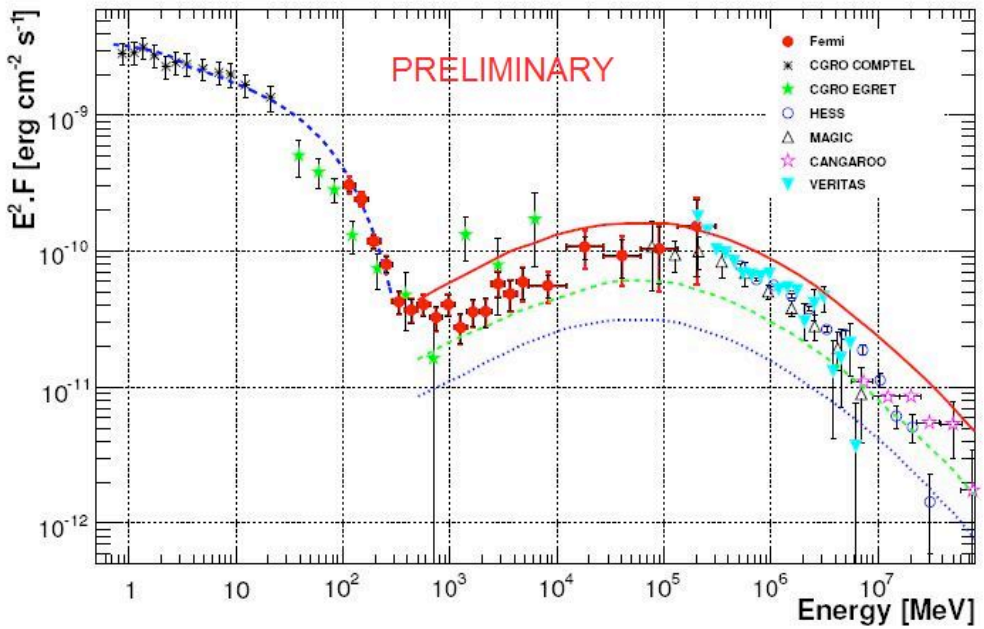
Preliminary

LAT Energy Reach

PKS 2155-304



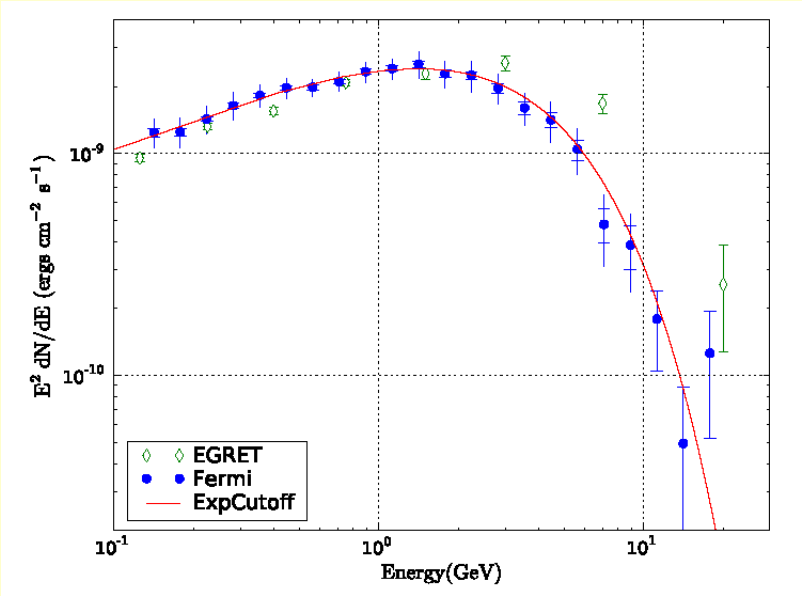
High energy Crab Nebula Spectrum



- **Finally closed the unexplored energy range between 10 and 100 GeV**
- **Joint fits between LAT (MeV-GeV) and IACTs (GeV-TeV)**
- **Peak sensitivity at a few GeV for typical spectra**

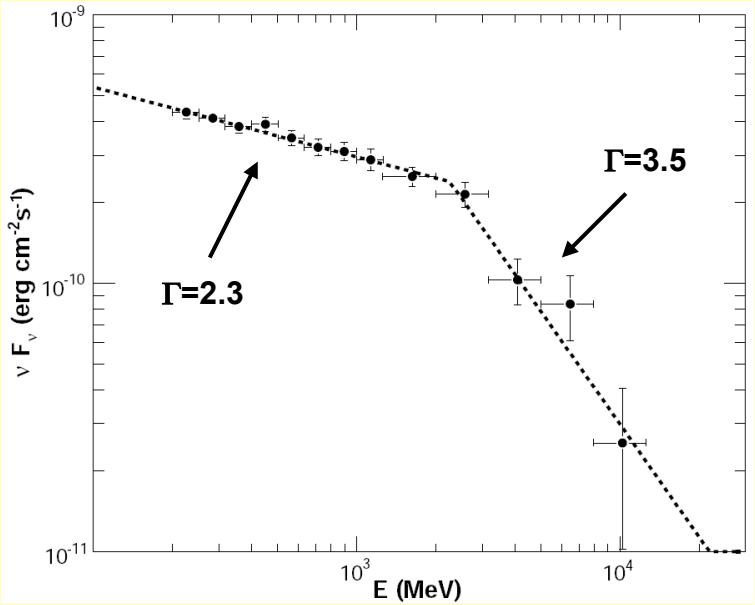
Spectral fits

- **LAT sensitivity and wide bandpass allows the measurement of many non power-law spectra**

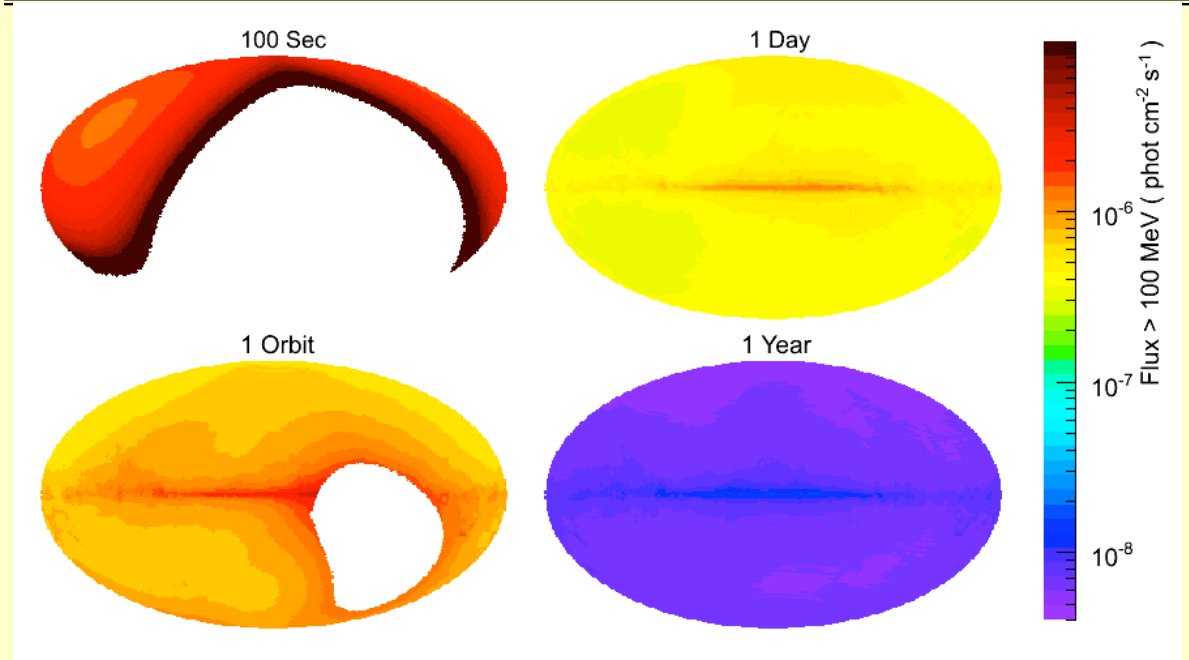


Phase averaged Vela Pulsar spectrum (power-law with exponential cutoff)

3C454.3: Broken power-law



All Sky Sensitivity and Operating Modes



LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 mins), 1 day and 1 year

- **In survey mode, the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time.**
- **Multiwavelength observations in coordination with the LAT will be limited only by the ability to coordinate to other observations in other wavebands.**
- **Can also perform pointed observations of particularly interesting regions of the sky.**

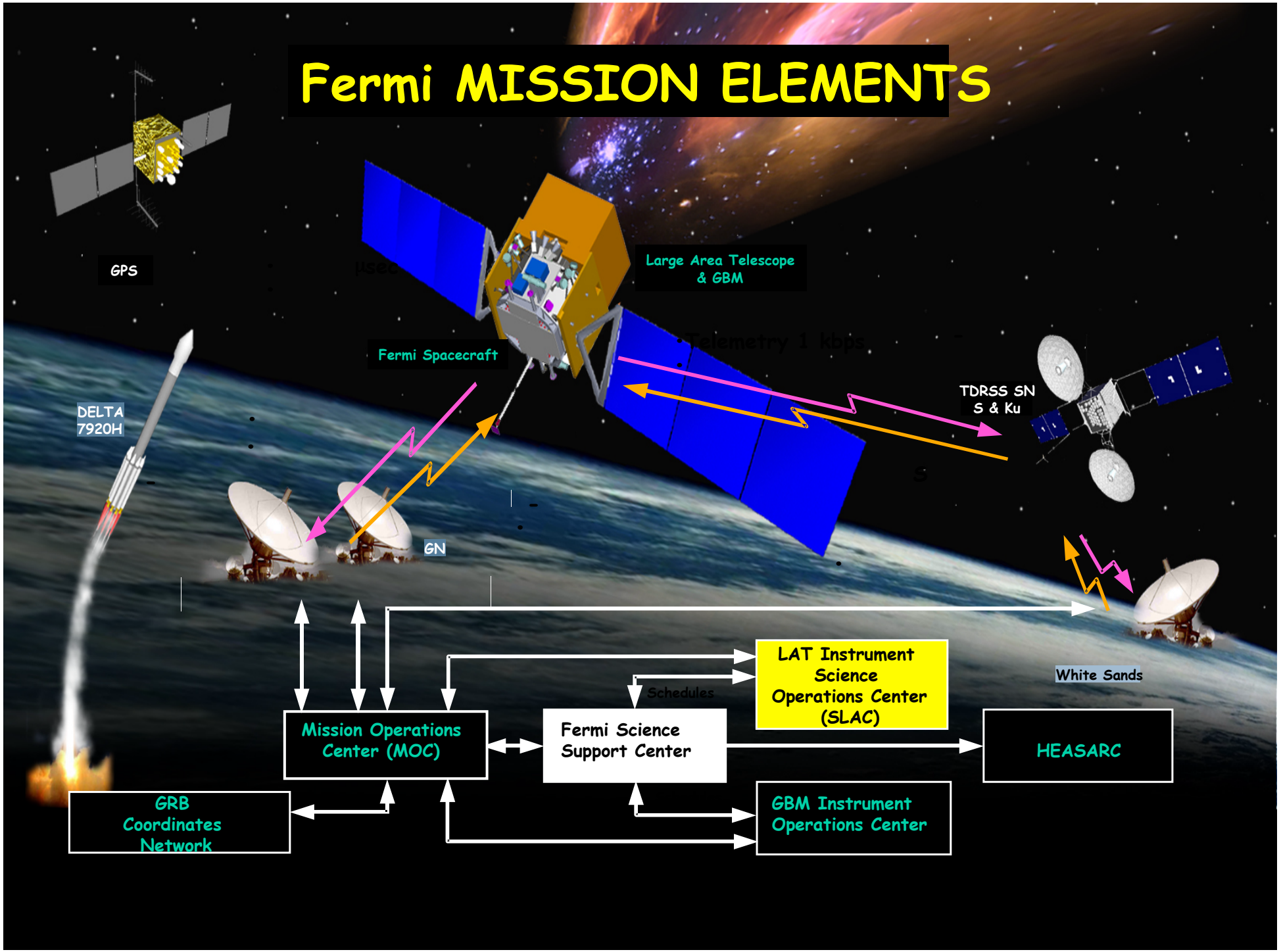
Launch! June 11, 2008

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

Launch Day at GSFC

Launch Day in Florida

A few weeks later - instrument commissioning


Fermi MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
Fermi Spacecraft
DELTA
7920H
TDRSS SN
S & Ku
GN
White Sands
LAT Instrument
Science
Operations Center
(SLAC)
Schedules
Mission Operations
Center (MOC)
Fermi Science
Support Center
HEASARC
GRB
Coordinates
Network
GBM Instrument
Operations Center

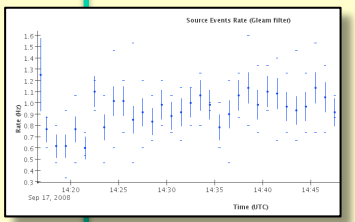
LAT Instrument Science Operations Center

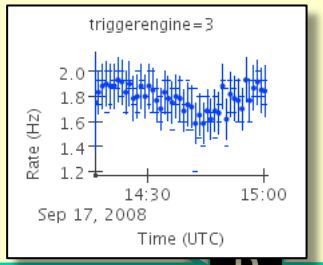
- LAT ISOC facilities at SLAC are running at full speed!
  - **Receiving ~15 GB of raw data from the LAT each day**
- Flight Operations Team
  - **LAT operation and monitoring/trending**
  - **Data receipt and archiving**
- Science Operations Team
  - **Science data monitoring/trending**
  - **Instrument performance analysis**
  - **Initial calibration generation**
- Science Analysis Systems Team
  - **Processing infrastructure support**
  - **Event reconstruction and simulation codes**
  - **Science analysis tools**
  - **Monte Carlo data generation**
- **A large international team of scientists from the LAT Collaboration came to SLAC to support Fermi's 60-day on-orbit commissioning period**
  - Now largely automated with remote spot checking and alarms

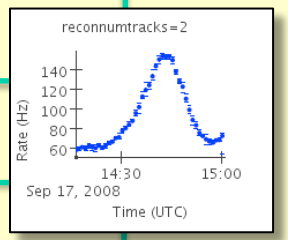
Literally lights out now!

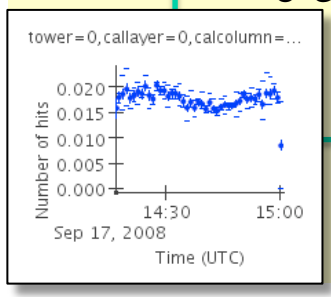
Level 1 Processing Many-Ringed Circus

raw
digi
recon
xrootd used as starting and end points
(xrootd is a cluster filesystem)
Decompress ➔ Root
1 hr
DL
down link
1.5 hr
Fits
Root
Fits
6 GB/day trending data into Oracle
Use 2 TB of dedicated afs buffers throughout

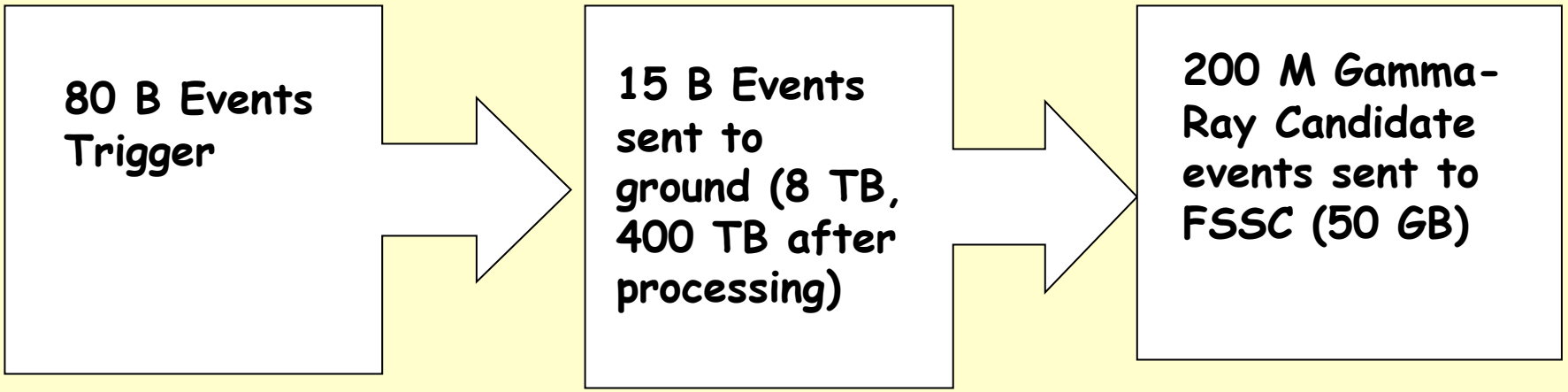






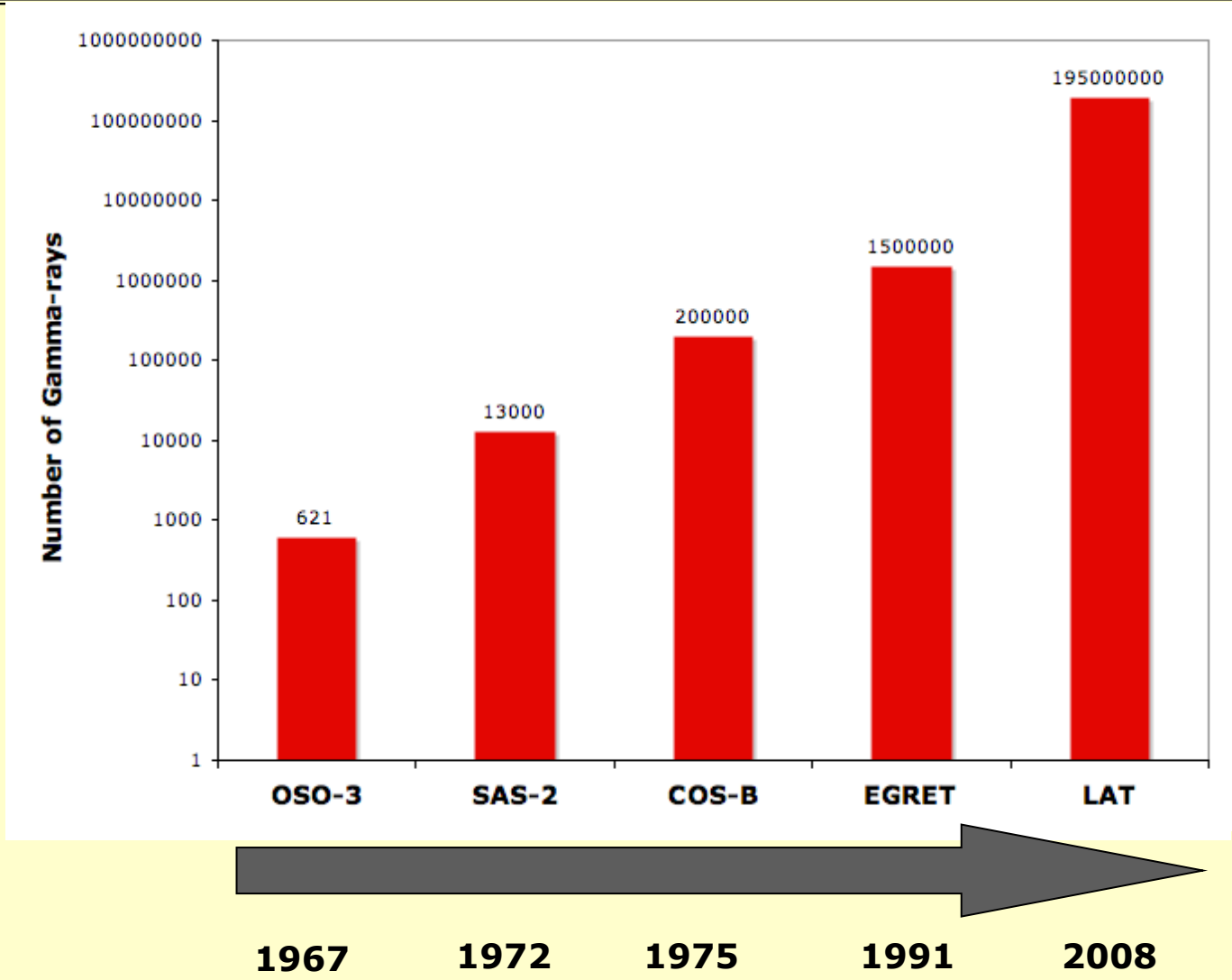


LAT Data Collection and processing



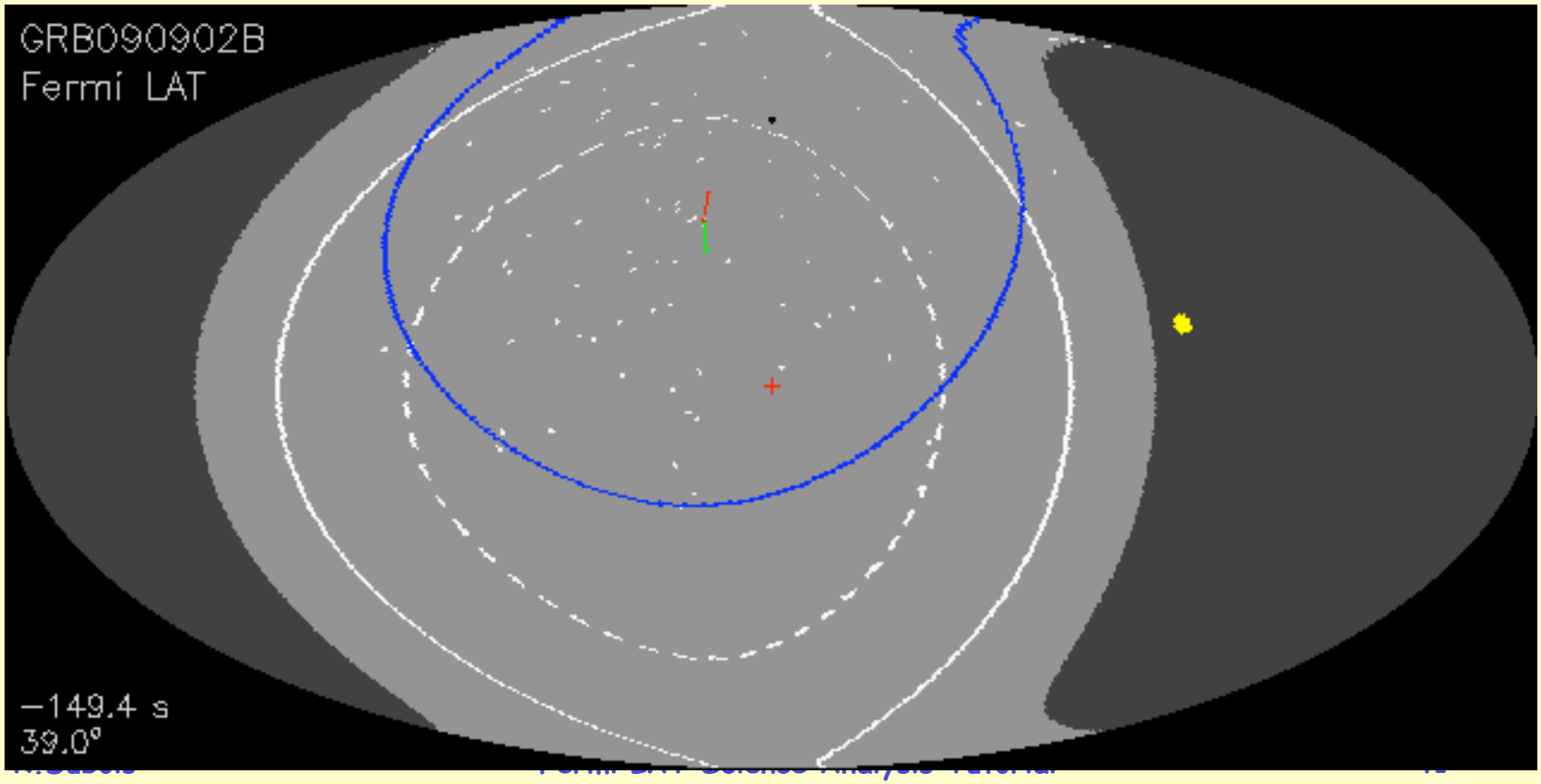
- 160 cpu years worth of processing over 16 months

How many gammas?



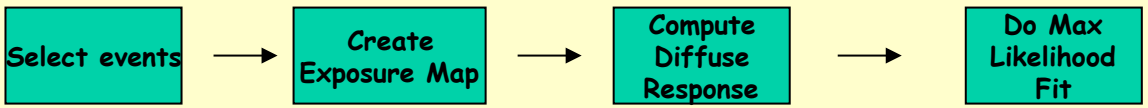
Two instruments together - Autonomous repoints

- LAT pointing in celestial coordinates from -120 s to 2000 s
  - Red cross = GRB 090902B
  - Dark region = occulted by Earth
  - Blue line = LAT FoV (±66°)
  - White points = LAT events (no cut on zenith angle)

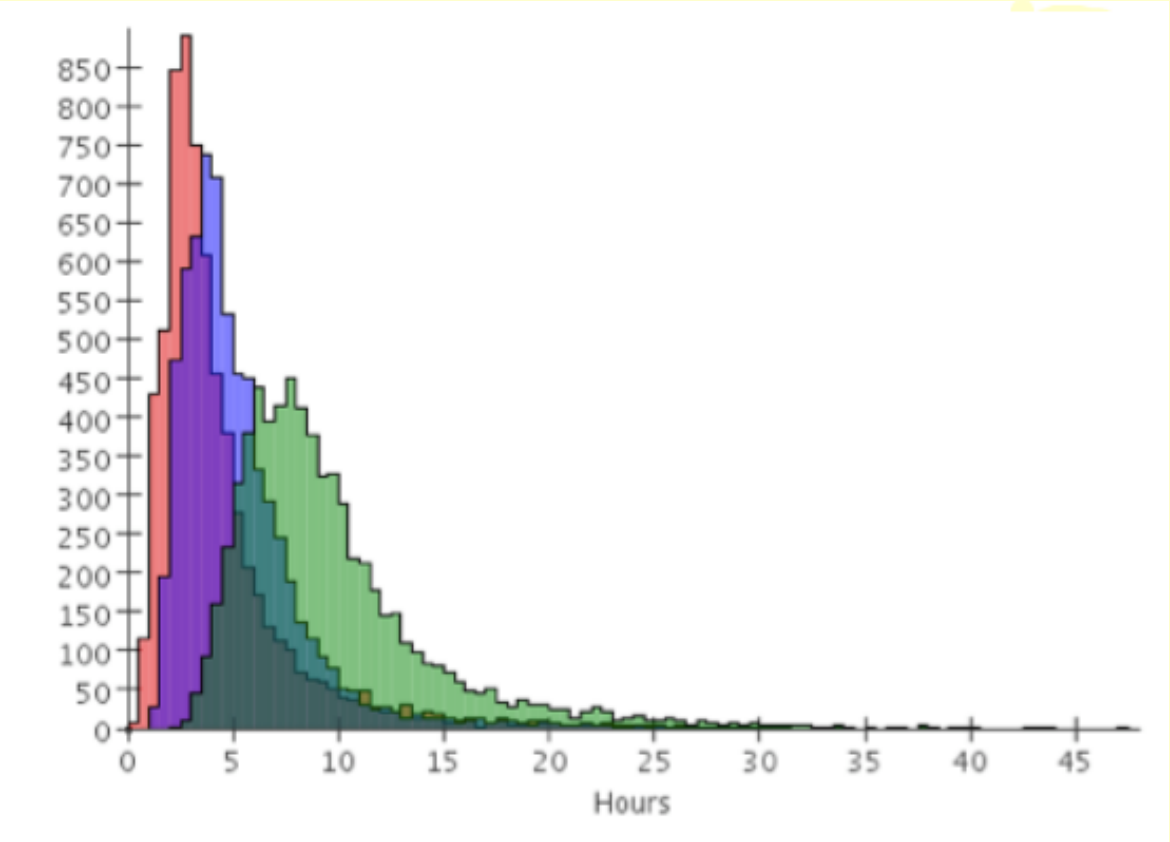


Public Data & Tools: Conforming to HEASARC FTOOLS

- **Agreed from the beginning with Mission that science tools would be jointly developed with (and distributed by) Science Support Center and adhere to FTOOLS standard**
  - **Atomic toolkit with FITS files as input/output to a string of applications, controlled by IRAF parameter files**
  - **Use scripting language to glue apps together**
  - **Very different from the instrument sim/reconstruction code!**
  - **Shared code development environment, languages**
  - **Caused a certain amount of early tension, having to bifurcate coding styles. People are spanning both worlds now.**



LAT Data Latency



- **Typical turnaround is less than 10 hours (time to get data off spacecraft, processed and back to FSSC)**

Data analysis support and workshops

- The FSSC is holding a sequence of regional data analysis workshops
- First workshop was on Oct 1 at GSFC
- 1-day, focus on hands-on activities
- ~<25 participants
  - Larger group limits 1-on-1 interactions
- Future workshops
  - Venues chosen based on community feedback
  - May try internet conferencing analysis workshops

Fermi Users Group Members

- Alan Marscher (Chair)
- Matthew Baring
- Pat Slane
- Buell Januzzi
- Don Kniffen
- Henric Krawczynski
- Jamie Holder
- Wei Cui
- Scott Ransom
- Jim Ulvestad
- Alicia Soderberg

Plus

- Neil Gehrels
- Ilana Harrus
- Julie McEnery
- Bill Paciesas
- Peter Michelson
- Steve Ritz
- Chris Shrader
- Dave Thompson
- Kathy Turner
- Lynn Cominsky

http://fermi.gsfc.nasa.gov/ssc/resources/guc/