GLAST Science and Instrumentation

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Outline

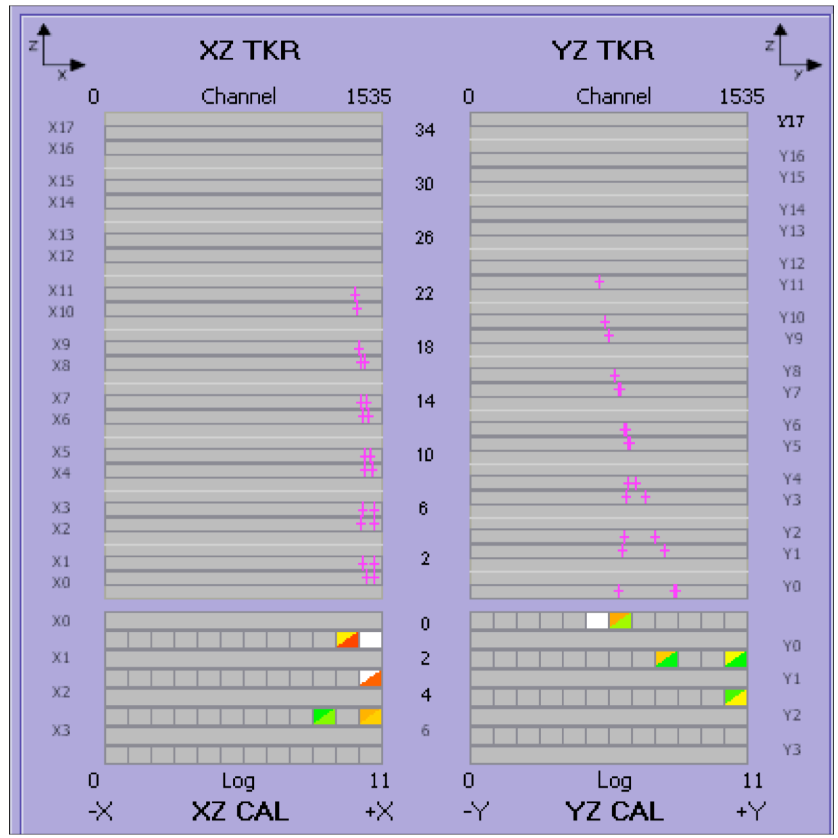
- Overview.
- Science.
- Instrument.
- Status.

November 15, 2005

KEK, Tsukuba, Japan

GLAST/LAT Overview

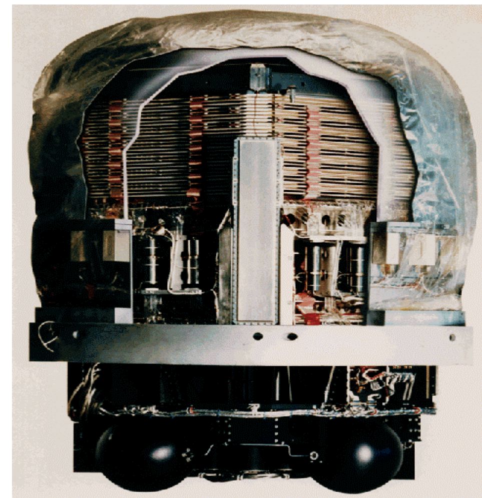
- Satellite experiment to observe gamma-try from Universe.
  - Wide energy range: 20 MeV – 300 GeV
  - Large effective area: > 8000 cm^2 (5xEGRET)
  - Wide field of view: > 2 sr (4xEGRET)
- Pair-conversion telescope.
  - "Clear" signature.
  - Background rejection.

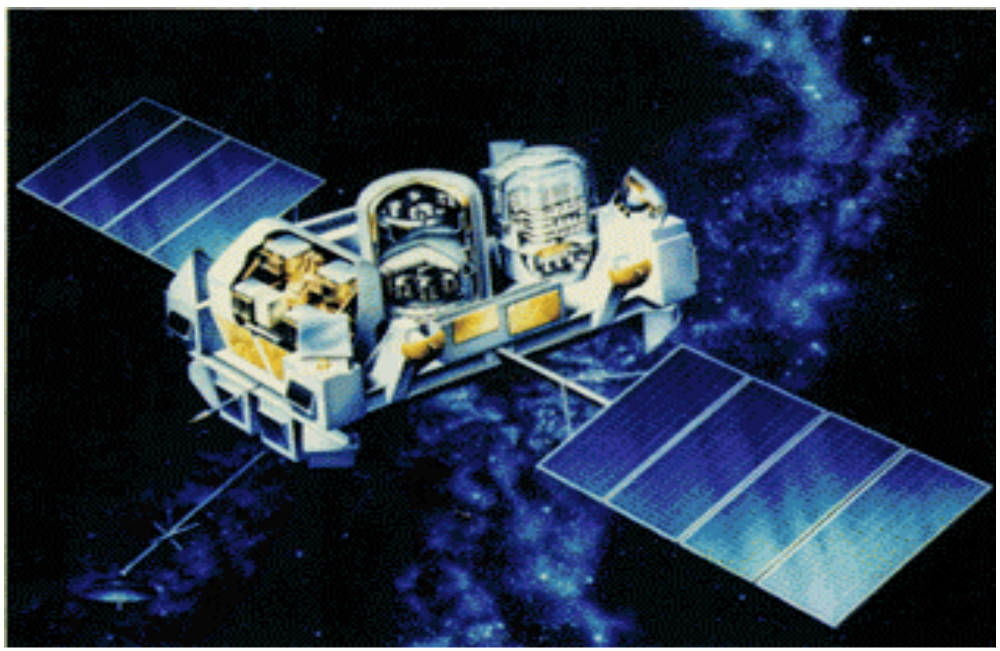


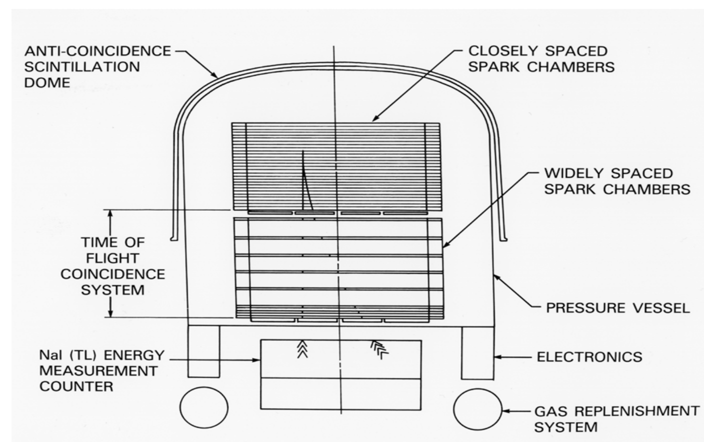
EGRET

High energy gamma-ray instrument onboard Compton Gamma-Ray Observatory

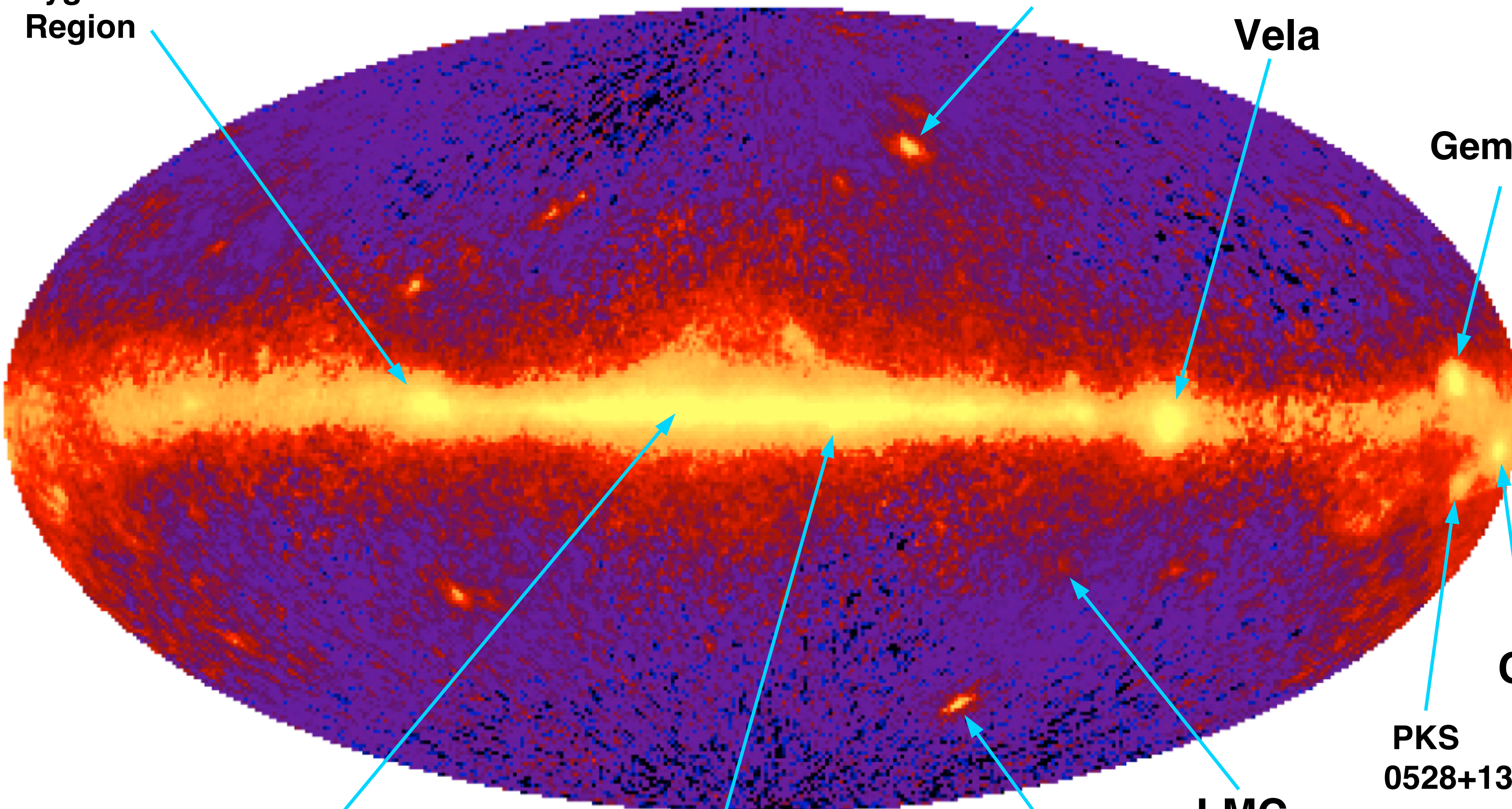
- **Consists of tracker (spark chamber), Calorimeter (NaI crystal) and Anti-Coincidence Scintillation Dome.**
- **Energy range (20 MeV – 20 GeV)**





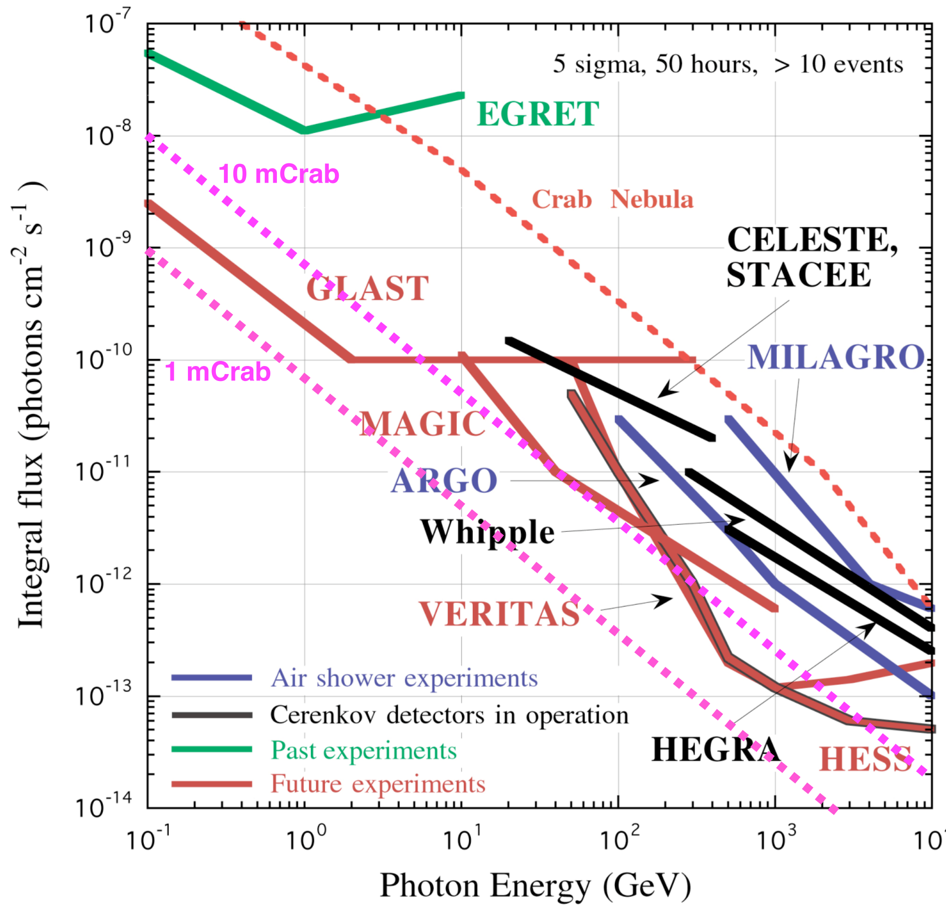


EGRET All Sky Map (E>100 MeV)

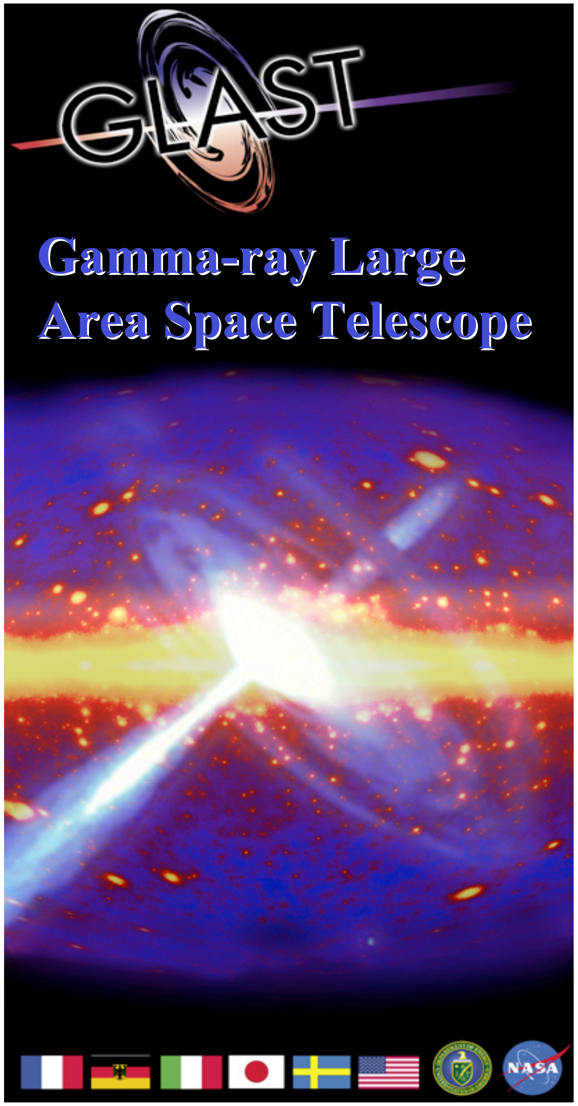


Exploring Gamma-ray Universe

- **GLAST will complement ground based experiments.**
  - **Well calibrated energy response.**
    - Systematic check for ground based experiments
  - **Comparable sensitivity**
    - Good duty cycle
    - Wide field of view



GLAST/LAT Collaboration



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Naval Research Laboratory
University of California at Santa Cruz
Sonoma State University
University of Washington
Texas A&M University – Kingsville
Ohio State University

Commissariat a l'Energie Atomique, Saclay
Ecole Polytechnique, College de France,
CENBG (Bordeaux)

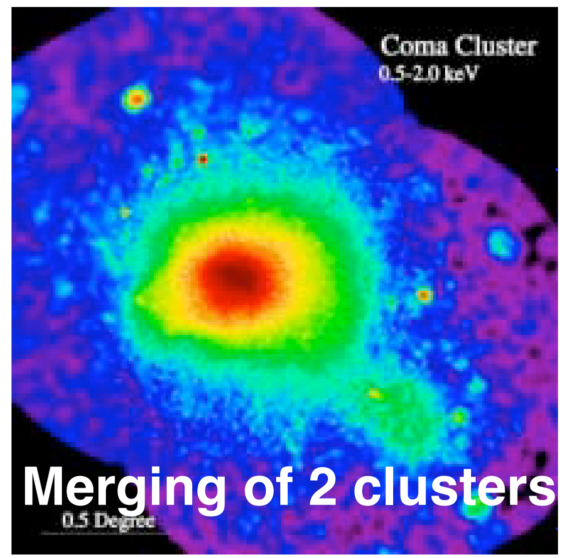
Hiroshima University
Institute of Space and Astronautical Science
University of Tokyo

Instituto Nazionale di Fisica Nucleare
Agenzia Spaziale Italiana
Instituto di Fisica Cosmica, CNR

Royal Institute of Technology, Stockholm
Stockholms Universitet

GLAST Science

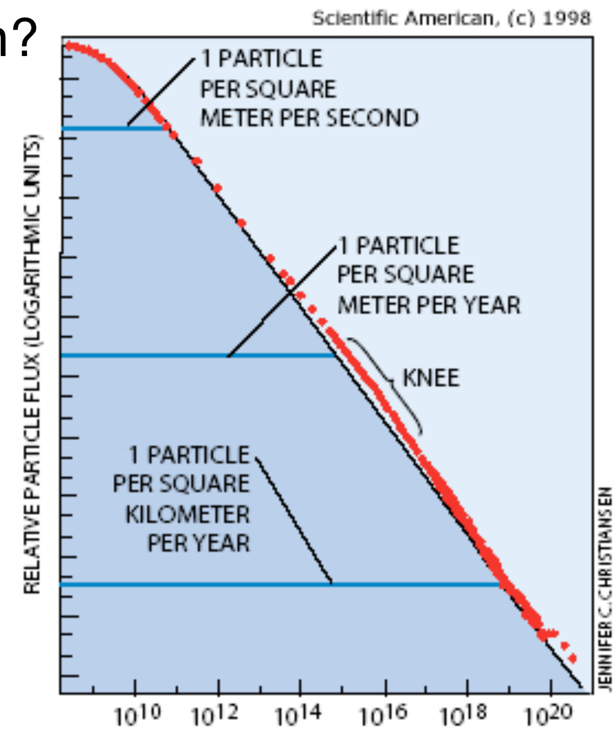
- **All sky survey in gamma-ray band.**
  - **Time variability monitor.**
    - Flares (Blazars, AGNs, Solar corona).
    - Gamma-ray bursts.
  - **New discovery.**
- **Extragalactic background light over cosmic distance.**
  - **Study of galaxy formation.**
- **Particle acceleration.**
  - **Supernovae remnants.**
  - **Gamma-ray bursts.**
  - **Galaxy clusters.**



- **Dark matter (WIMP, neutralino) search.**

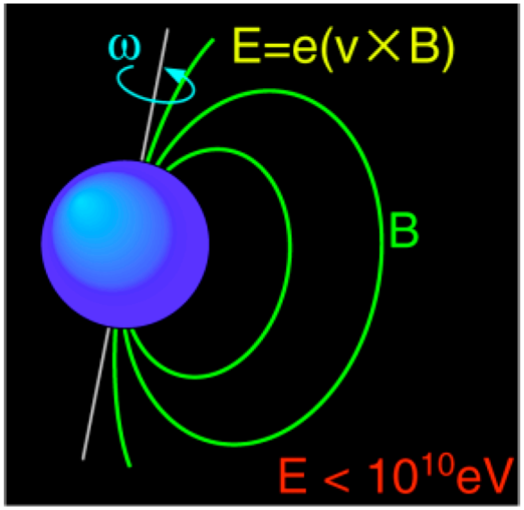
Cosmic Rays

- **Origin of cosmic ray protons?**
  - **Particle accelerator in the Universe?**
  - **Many evidences for electron acceleration.**
    - Electron is efficient gamma-ray emitter.
      - Synchrotron radiation, Compton scattering.
  - **No smoking gun for proton acceleration found.**
    - Why so hard to find proton acceleration?
      - Nuclear interaction.
    - How to distinguish gamma-ray from proton origin?
      - Spectrum.
      - Angular distribution.

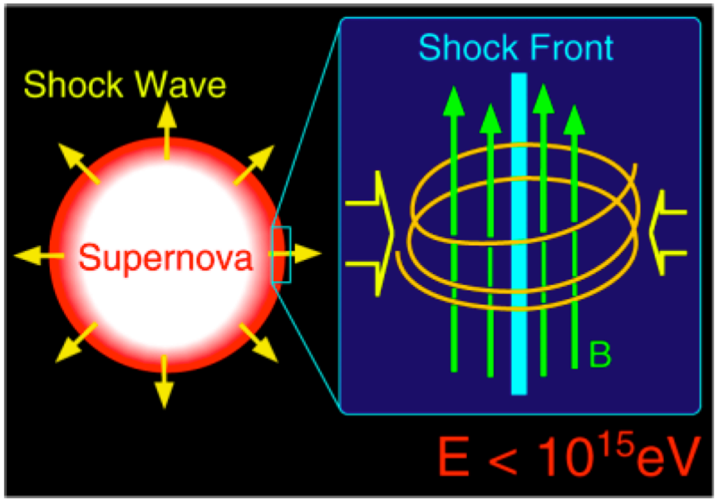


Particle Accelerator in the Universe

- **Strong electromagnetic field.**
  - **Neutron star**



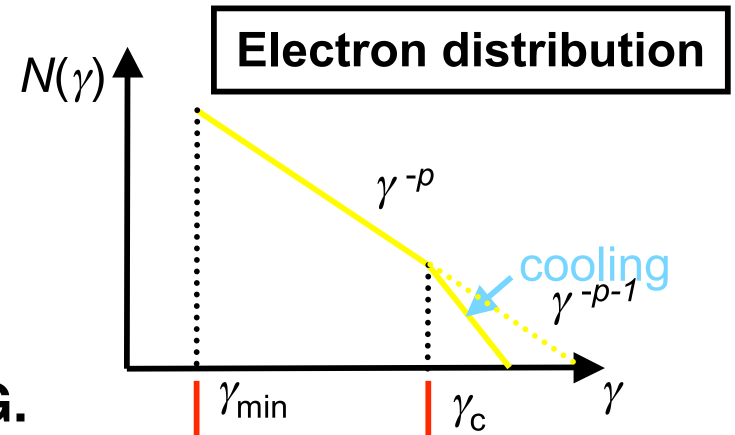
- **Shock acceleration.**
  - **Supernova Remnant.**
  - **Gamma-ray bursts.**

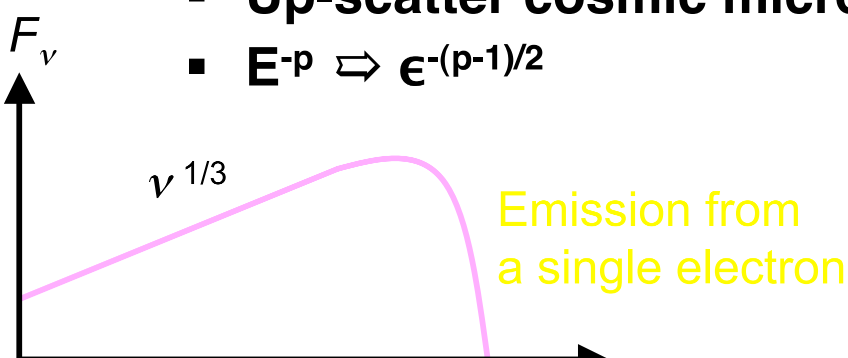


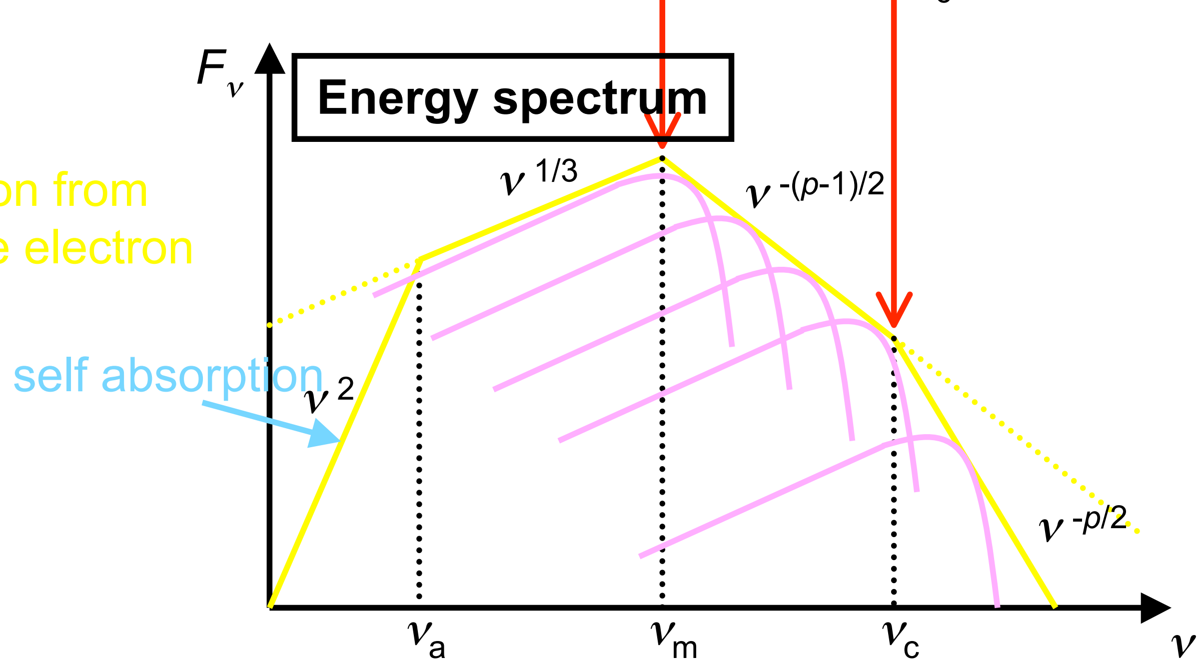
- **Large volume.**
  - **Galaxy clusters.**

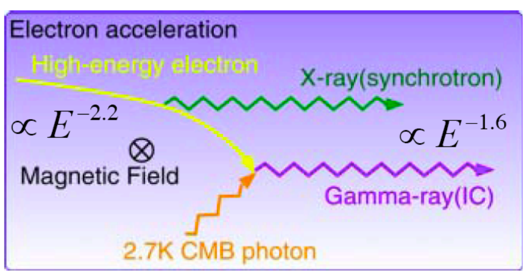
Gamma-ray Emission Processes (1)

- **Synchrotron radiation.**
  - **$E^{-p} \Rightarrow \epsilon^{-(p-1)/2}$**
  - **Polarization.**
  - **Cut off energy:** $5.3\left(\frac{B}{10\,\mu\mathrm{G}}\right)\left(\frac{E_m}{100\,\mathrm{TeV}}\right)^2\ \mathrm{keV}$
- **Compton Scattering.**
  - **Up-scatter cosmic microwave BKG.**
  - **$E^{-p} \Rightarrow \epsilon^{-(p-1)/2}$**







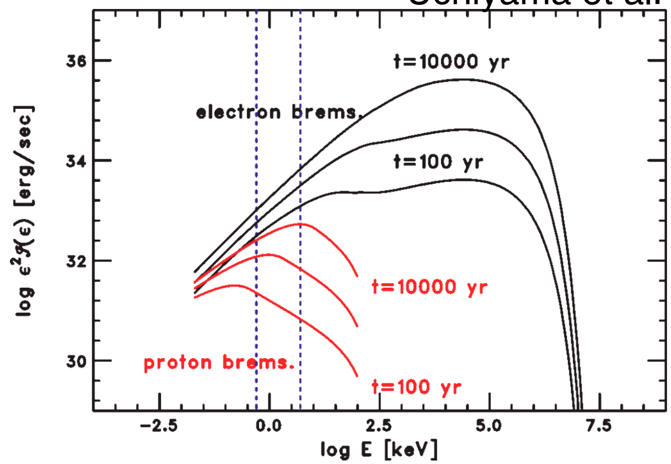


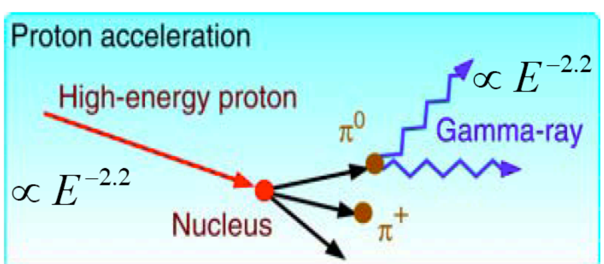
G. Sato

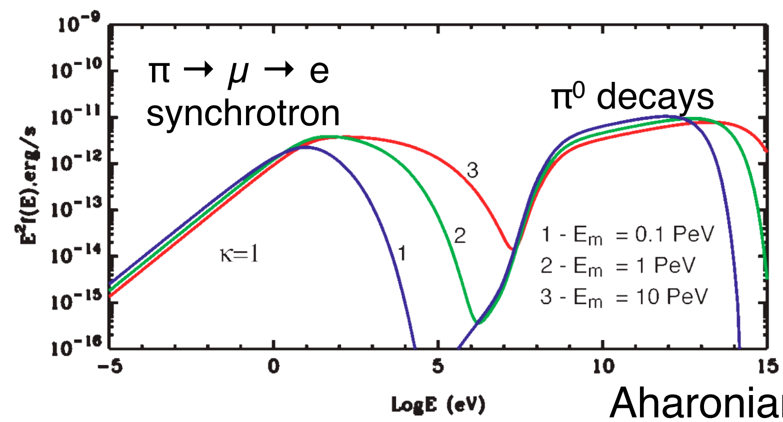
Gamma-ray Emission Processes (2)

- **Interaction with matters.**
  - **Bremsstrahlung.**
    - $E < E_{cou}$: ϵ^{-1} (independent of parent energy spectrum).
    - $E > E_{cou}$: $E^{-p} \Rightarrow \epsilon^{-p}$ (no change).
    - E_{cou}: $230\left(\frac{n}{10\,\mathrm{cm}^{-3}}\right)\left(\frac{\tau_{age}}{1000\,\mathrm{yr}}\right)$ keV
    - $\epsilon_{cou}(p) = m_e/m_p E_{cou}$,
      $\epsilon_{cou}(e) = E_{cou}$.
  - **π^0 decays.**
    - $E^{-p} \Rightarrow \epsilon^{-p}$ (no change).
  - **$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$**
    - Synchrotron, Compton

Uchiyama et al.



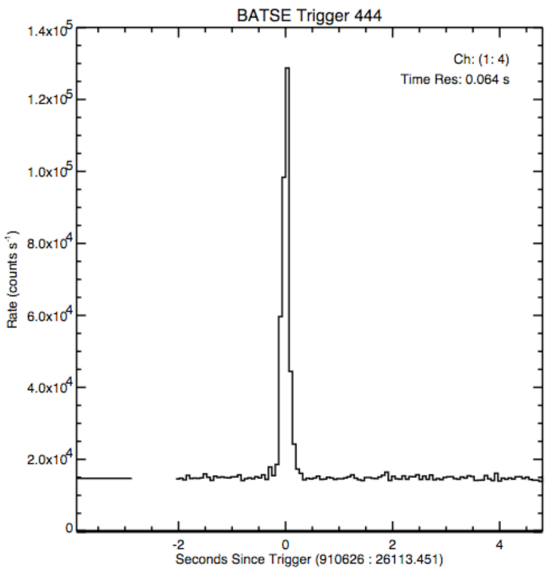




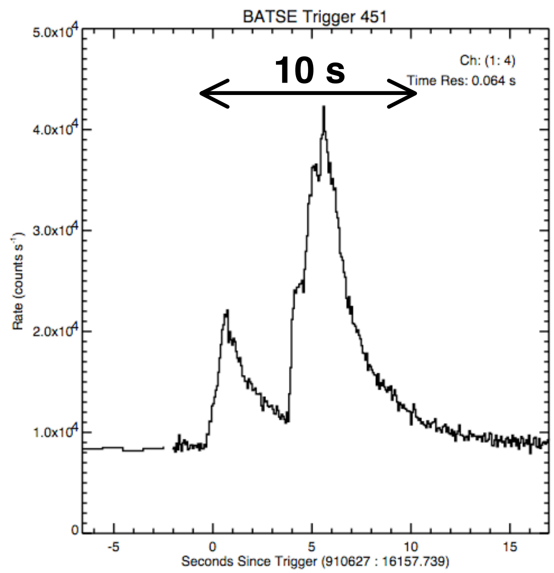
Aharonian

Gamma-Ray Bursts (GRB)

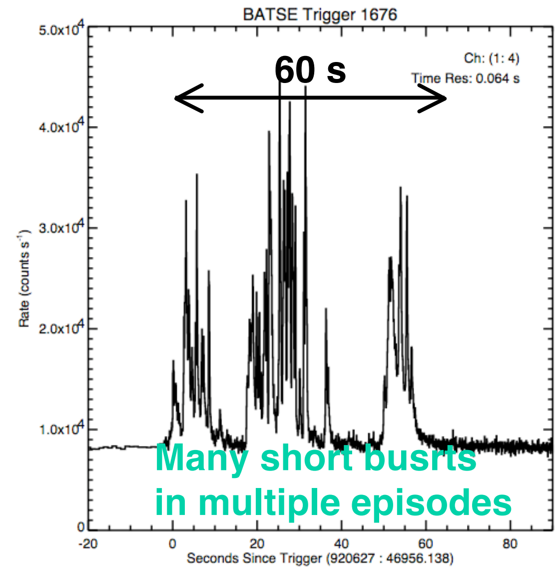
- **Diverse time variability**

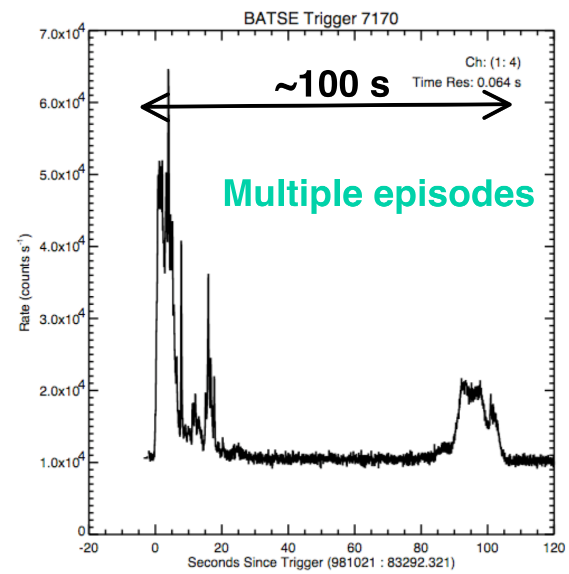


Short (0.4s) burst



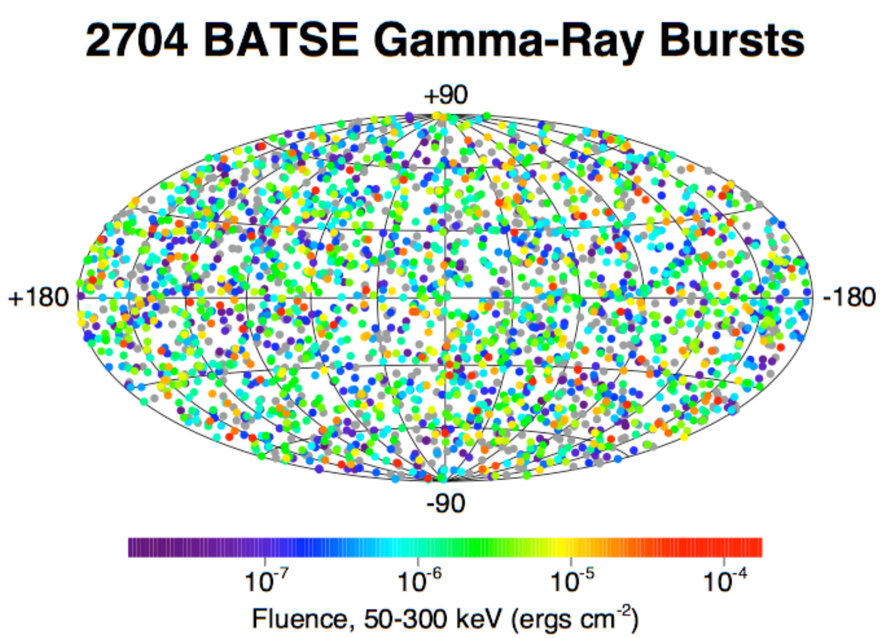
Double peaked



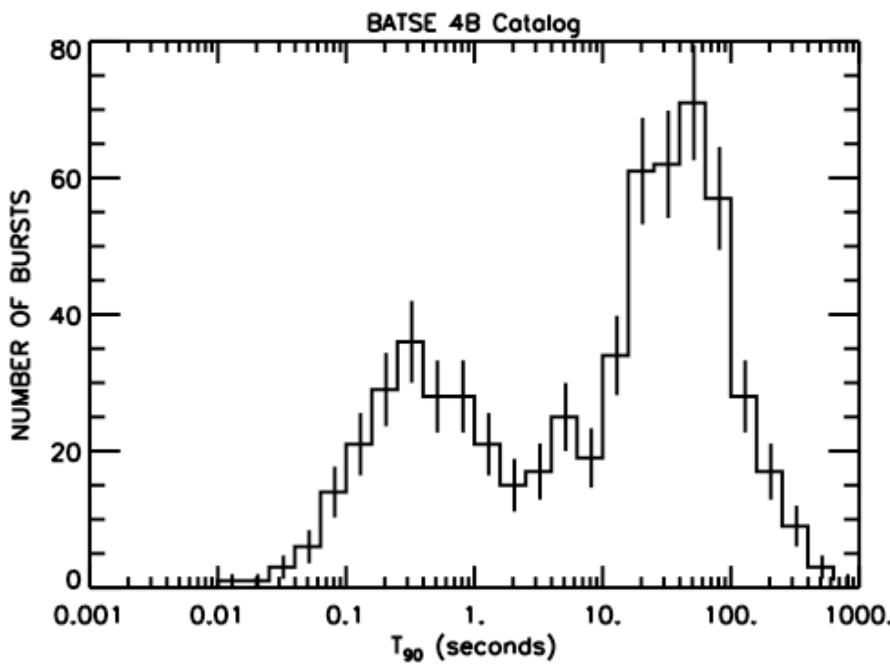


GRB Properties

- **Isotropic spatial distribution: cosmological origin.**
- **Two categories of GRBs: "long" and "short".**
  - **Afterglow of "long" GRBs facilitates extensive studies in optical and radio band.**
    - Leading candidate: Hypernova
  - **"Short" GRBs remain mystery.**
    - Neutron star merger.

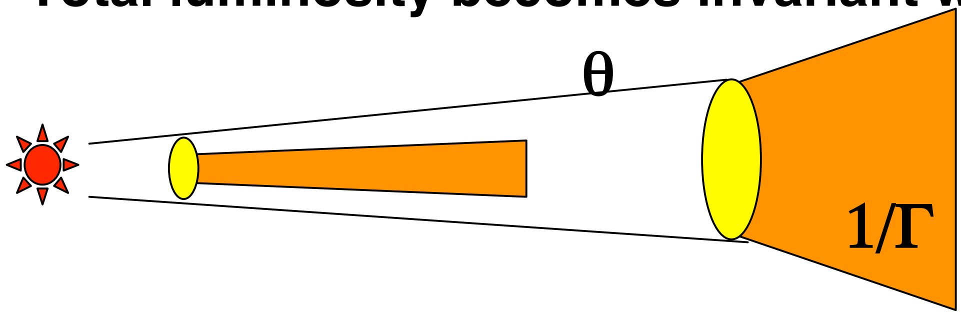


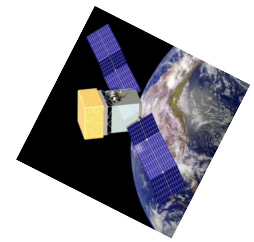
GLAST Science and Instrumentation,
H. Tajima,KEK, NOV. 15, 2005

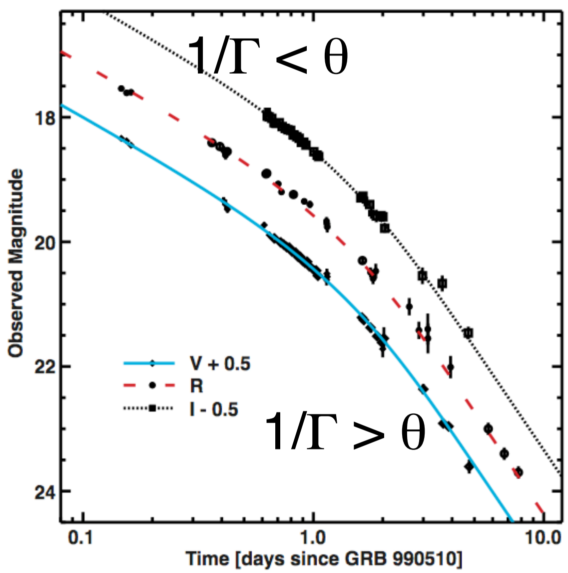


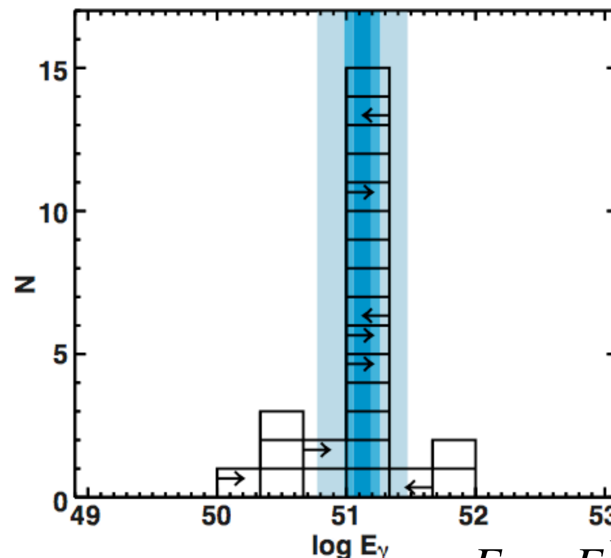
GRB Jet

- **Collimated relativistic outflow**
  - **Natural interpretation for steepening of light curve.**
  - **Total luminosity becomes invariant with jet model.**





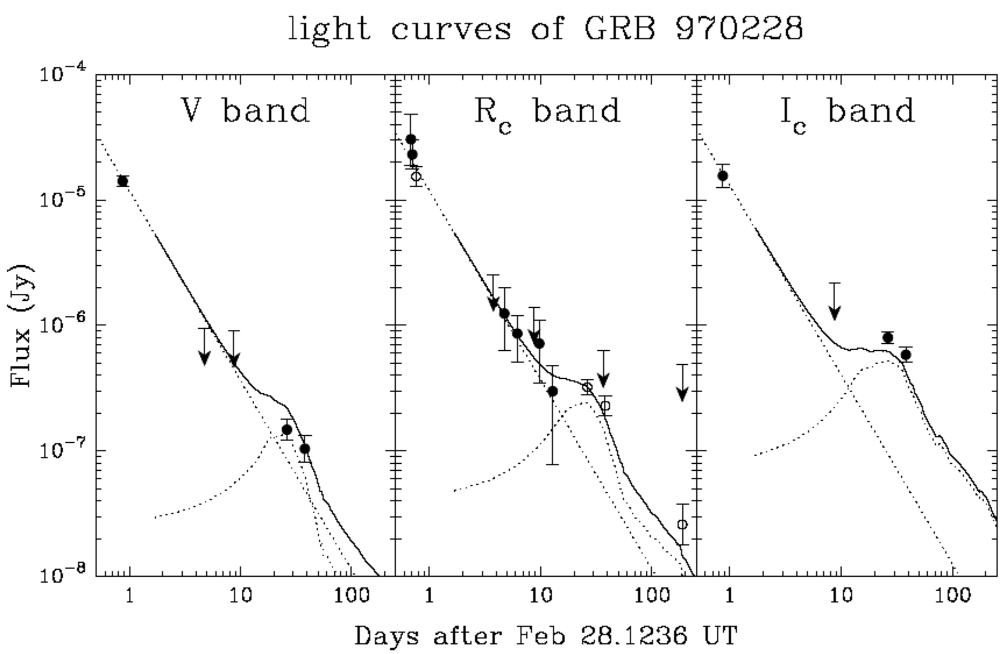




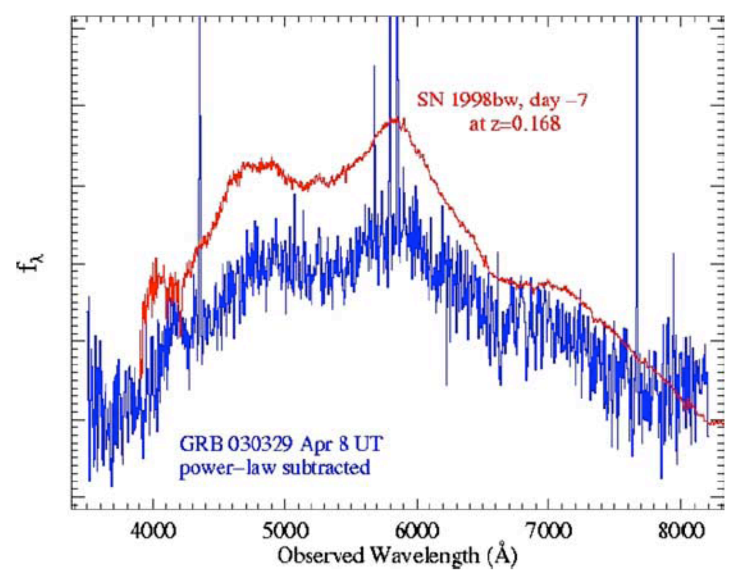
$$E_\gamma = E_\gamma^{\mathrm{ISO}} \cdot \theta^2 / 2$$

Supernova Connection

- **Supernovae observed a few tens of days after GRB.**
  - **Significant deviation from the power law decay.**
  - **Remarkably similar spectrum to the type Ic SN.**



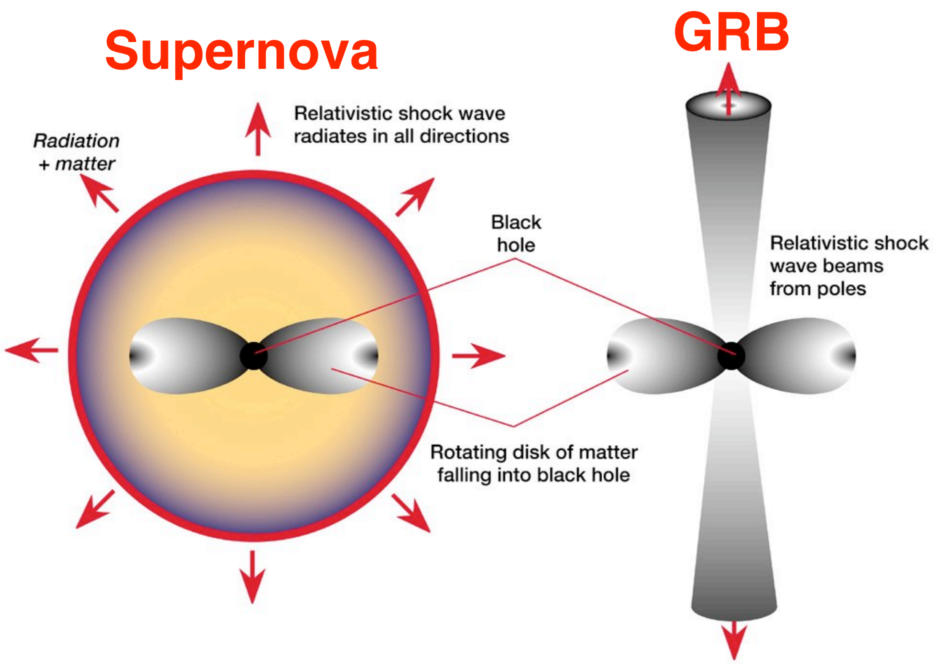
Galama et al. 2000



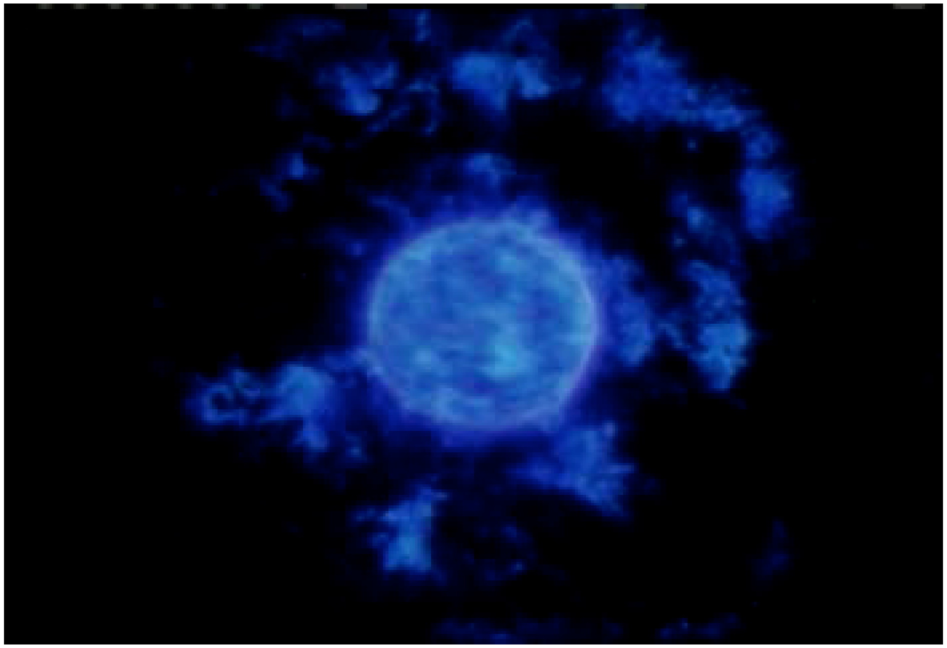
Stanek et al. 2003,
also Fynbo et al., Kawabata et al.

Hypernova

- **Gravitational core collapse supernova.**
  - **Star with > 40 solar mass.**
  - **Resulting black holes produce GRB.**
  - **Supernova takes place a few days after GRB.**



Credit: NASA/Marshall Space Flight Center

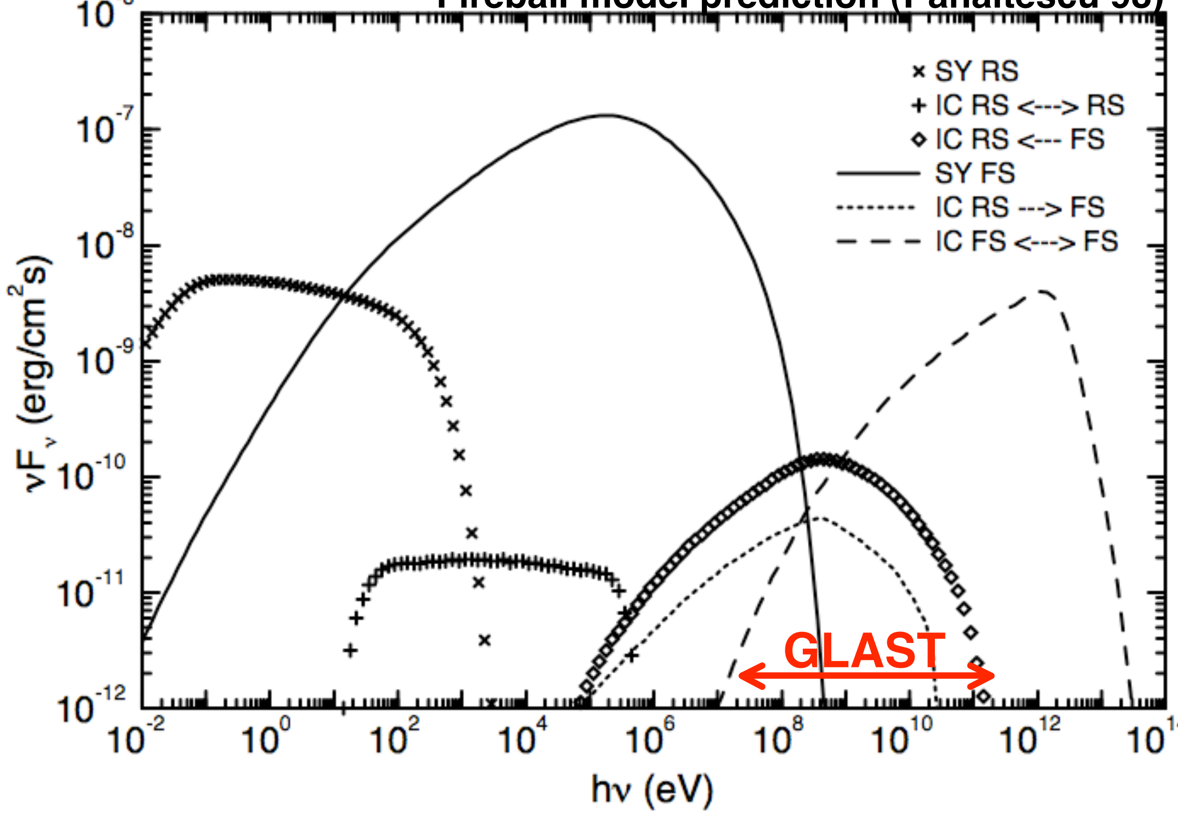


<http://www.nasa.gov/centers/goddard/news/topstory/2004/0910swift.html>

GRB Science with GLAST

- **Constraints on GRB models.**
  - **Gamma-ray production mechanism via multi-wave analysis.**
    - Electron IC (inverse Compton) emission.
    - π^0 decay.

Fireball model prediction (Panaitescu 98)



Parameter Dependence

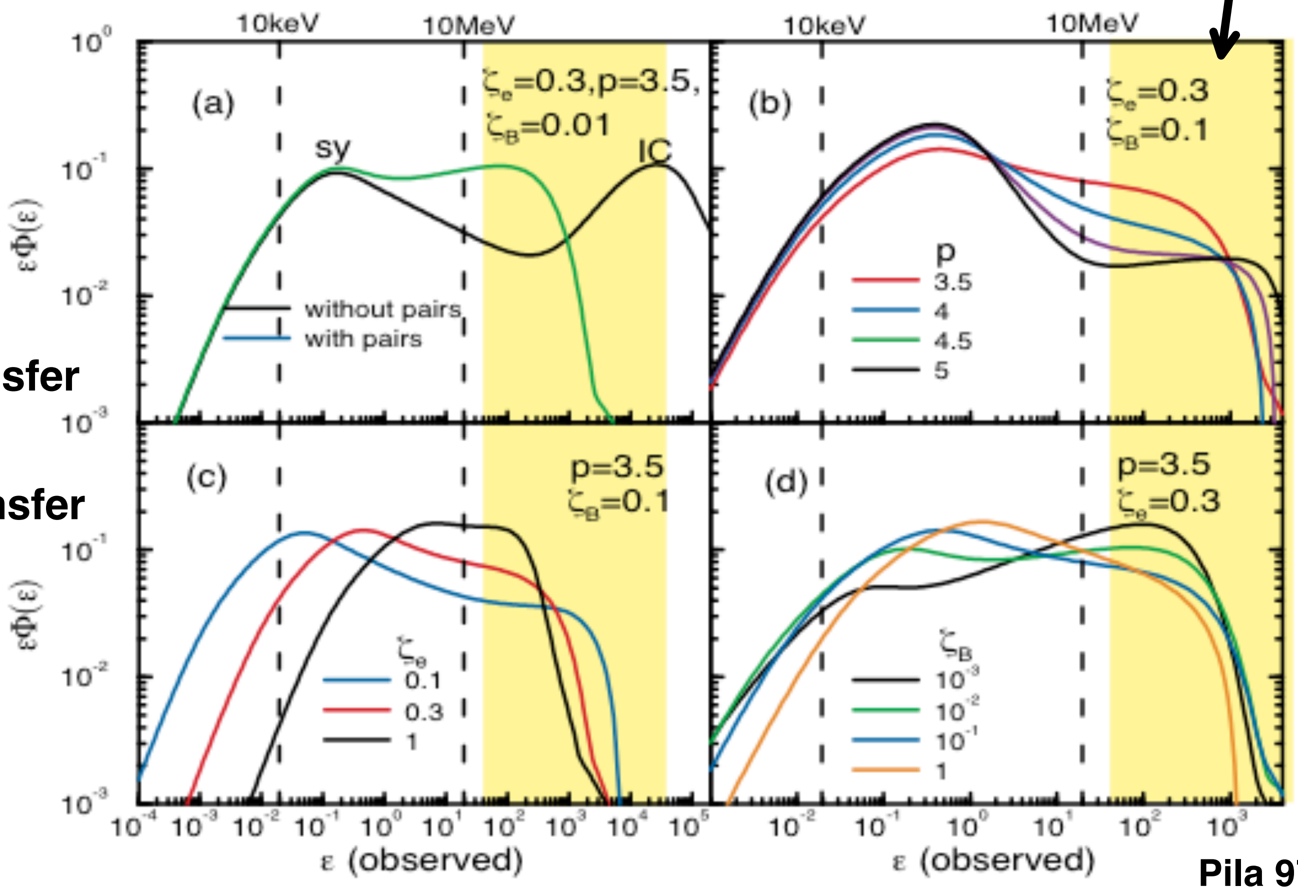
- **More elaborate model calculation.**
  - **Pair creation taken into account.**
  - **Parameter dependence studied.**

GLAST band

p: Fermi-acceleration index

ξ_e: fraction of energy transfer to electrons

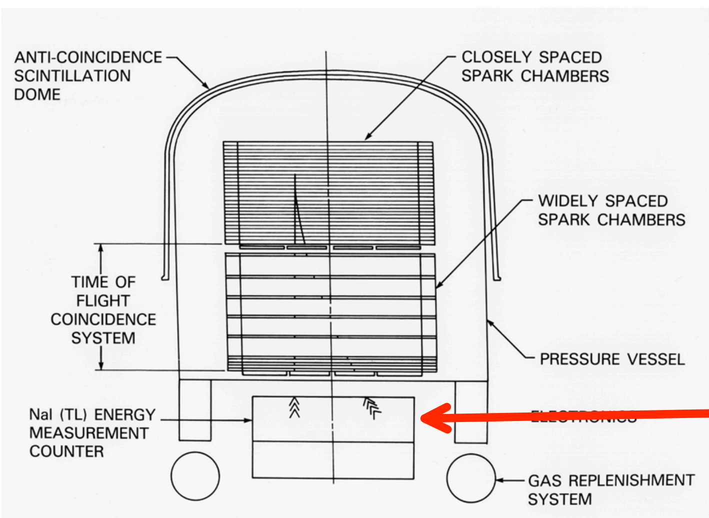
ξ_B: fraction of energy transfer to magnetic energy



Pila 97

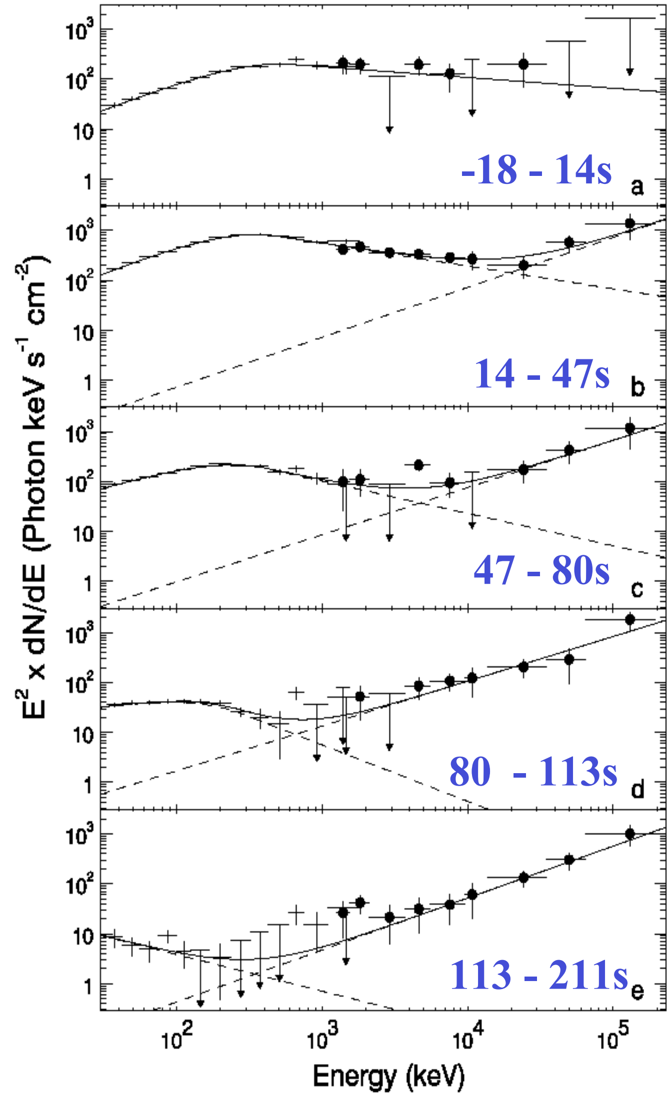
GRB Delayed Gamma-ray Emission

- **Delayed gamma-ray emission from GRB is observed by EGRET.**
  - **It is hard to explain by conventional synchrotron models.**
  - **Evidence for proton acceleration?**
    - Find GRB with only high energy gamma-ray. (> 1 MeV)
      - CGRO/EGRET, Suzaku/HXD



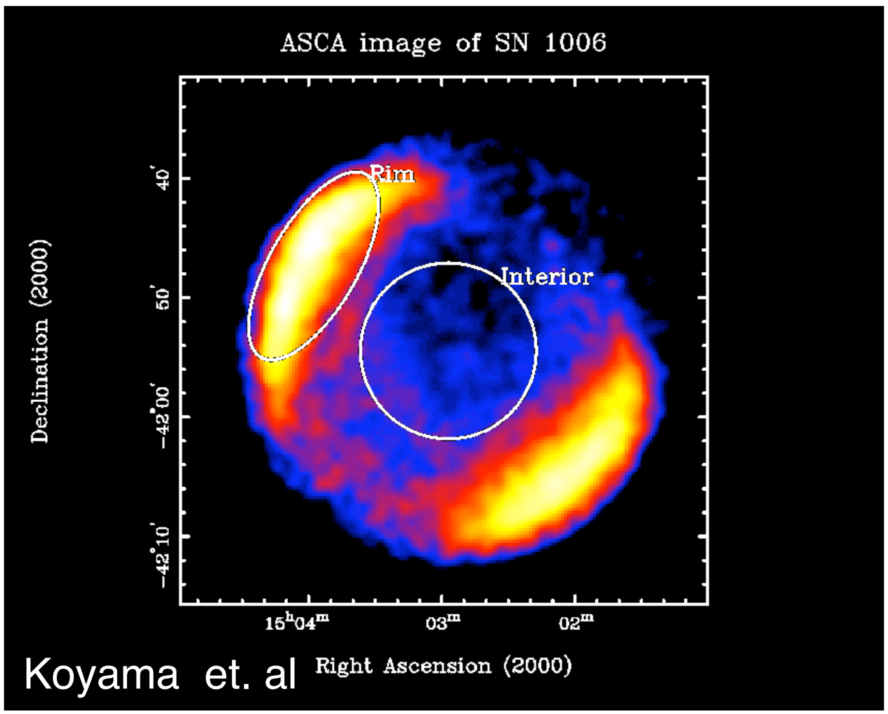
Total Absorption Shower Counter

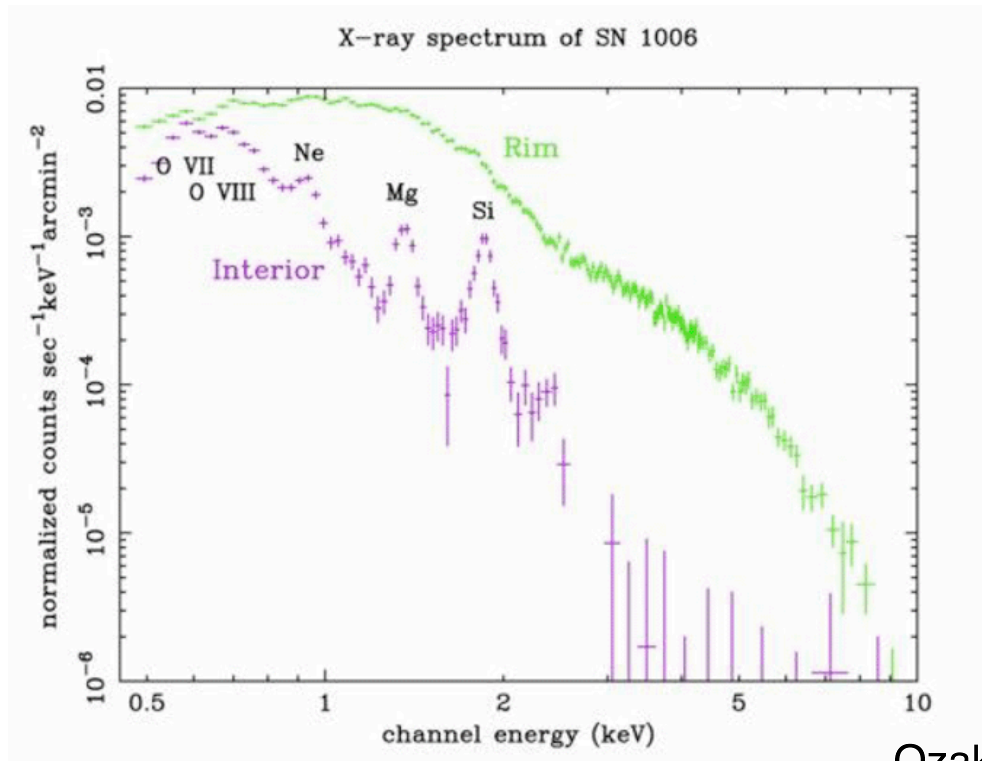
Gonzalez, Nature 2003 424, 749



Particle Acceleration in SNR

- **Young shell-type supernova: SN1006.**
  - **Power law spectrum from rim is best described by synchrotron emission by ultra-relativistic electrons.**
  - **First evidence of particles accelerated to > 10^{14} eV.**





Ozaki

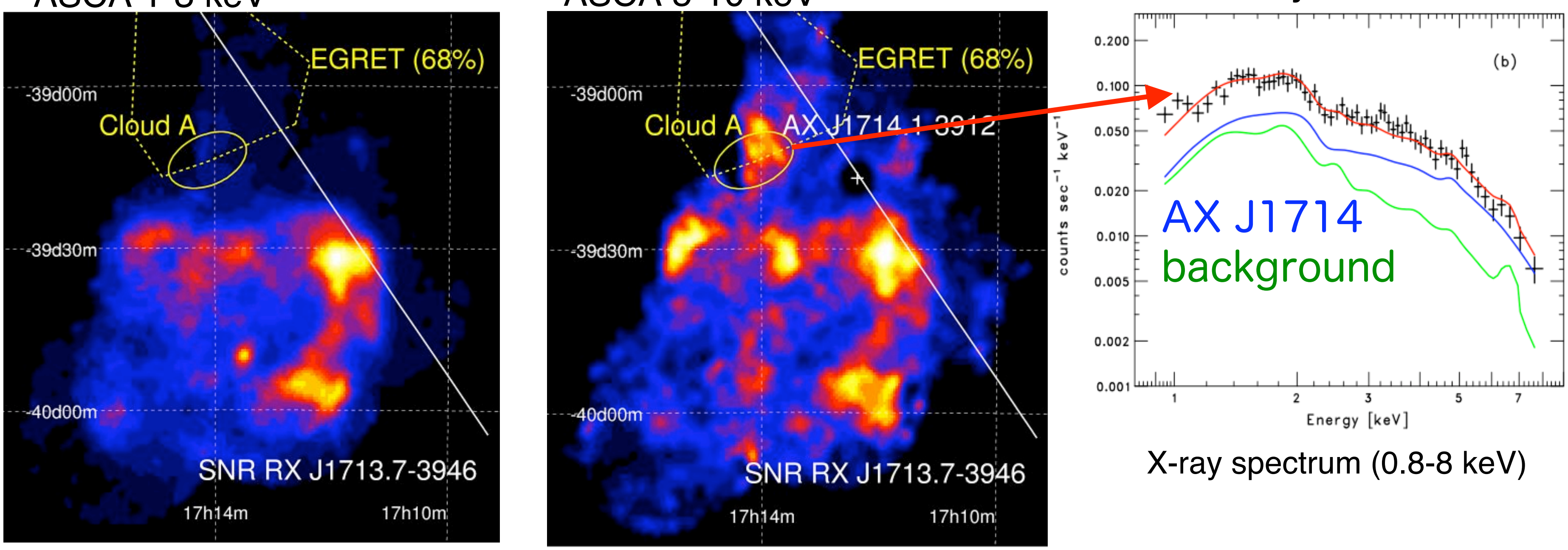
Proton Bremsstrahlung in SNR

- **Evidence of proton bremsstrahlung in RX J1713-3946.**
  - **Spectrum is inconsistent with synchrotron model.**
    - Power law index, no energy cut off
  - **Upper limits from CMPTEL and EGRET rule out electron bremsstrahlung.**

ASCA 1-3 keV

ASCA 5-10 keV

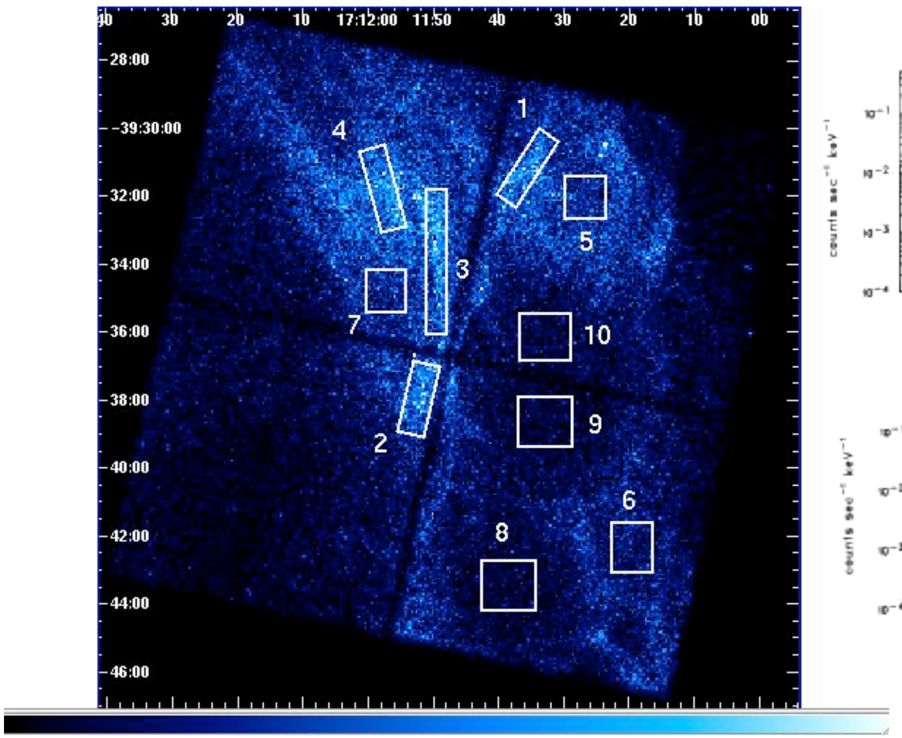
Uchiyama et al.



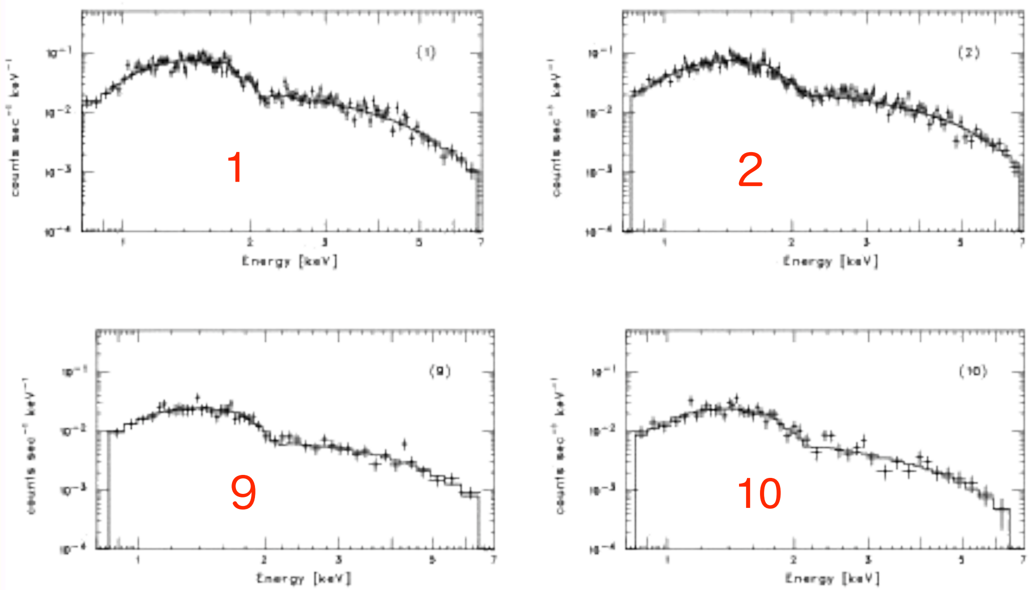
X-ray spectrum (0.8-8 keV)

Issues with Electron Acceleration

- **Chandra observation of RX J1713-3946.**
  - **Energy cut off higher than electron acceleration model.**
  - **Similar spectrum independent of luminosity.**
    - Hard to explain with electron acceleration.



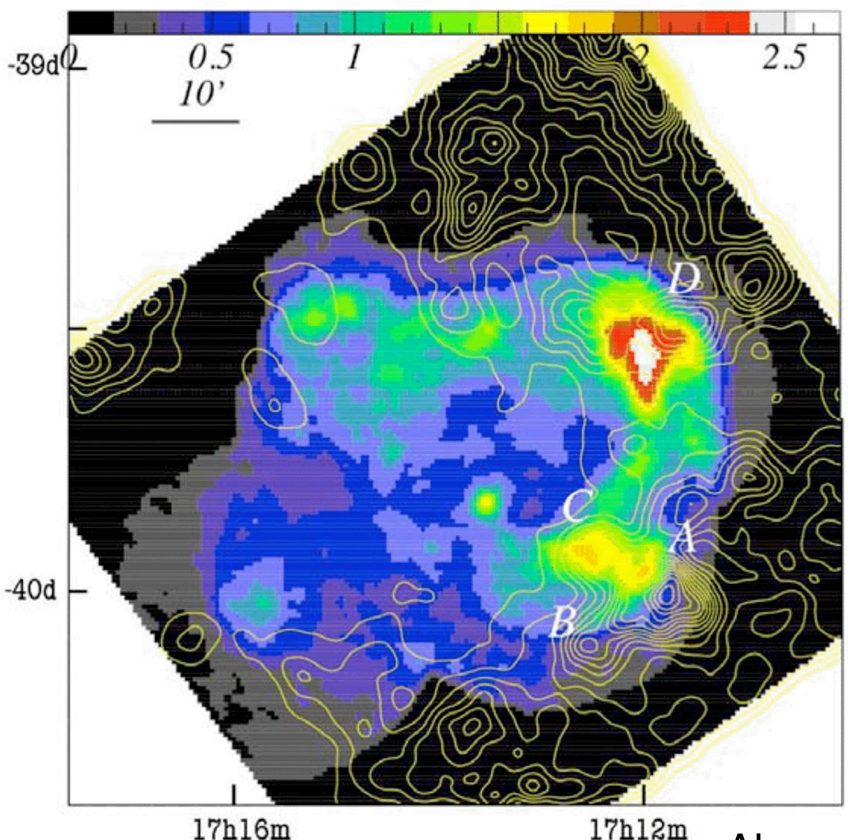
X ray spectrum 0.8-7 keV



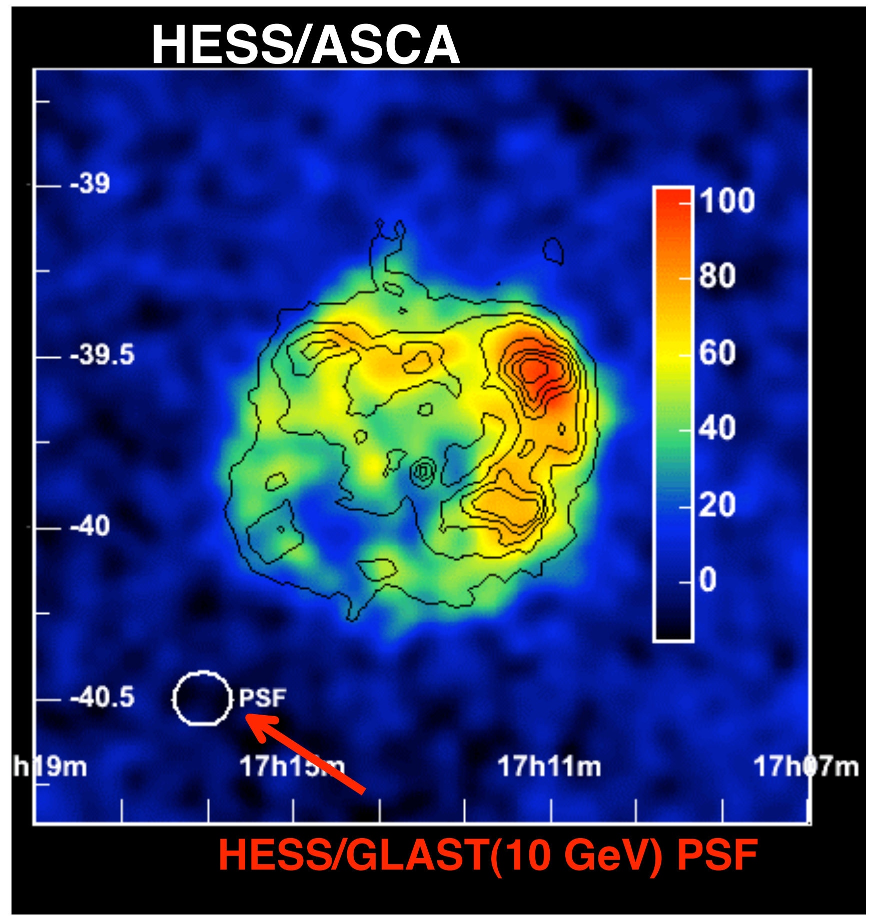
Uchiyama et al. 2002

TeV Gamma-ray from SNR

- **HESS observation of RX J1713-3946**
  - **Evidence for particle acceleration > 100 TeV.**



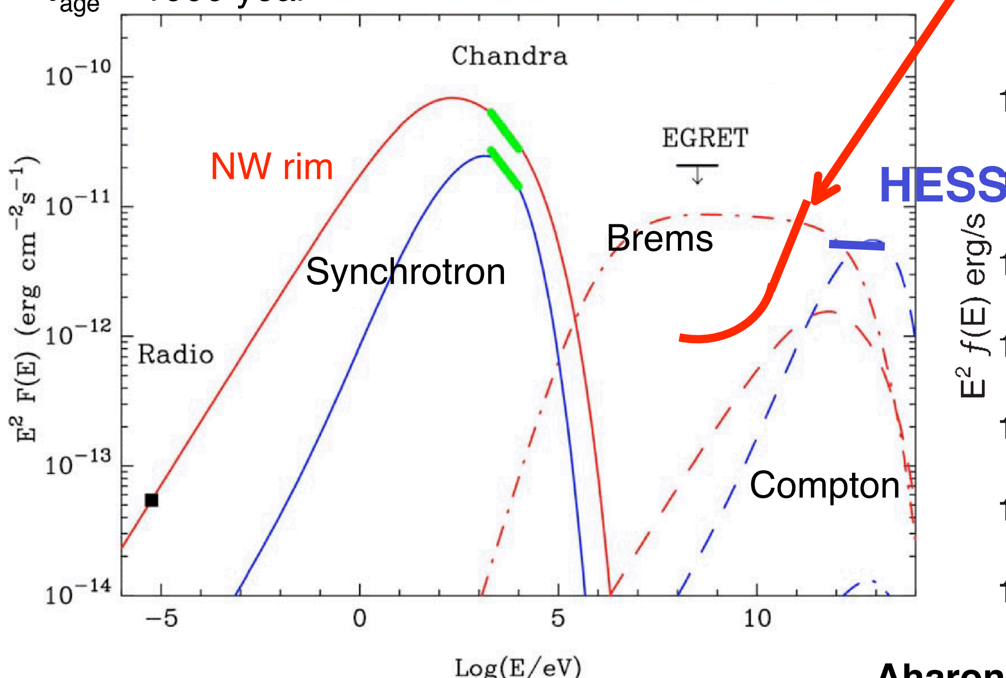
Aharonian

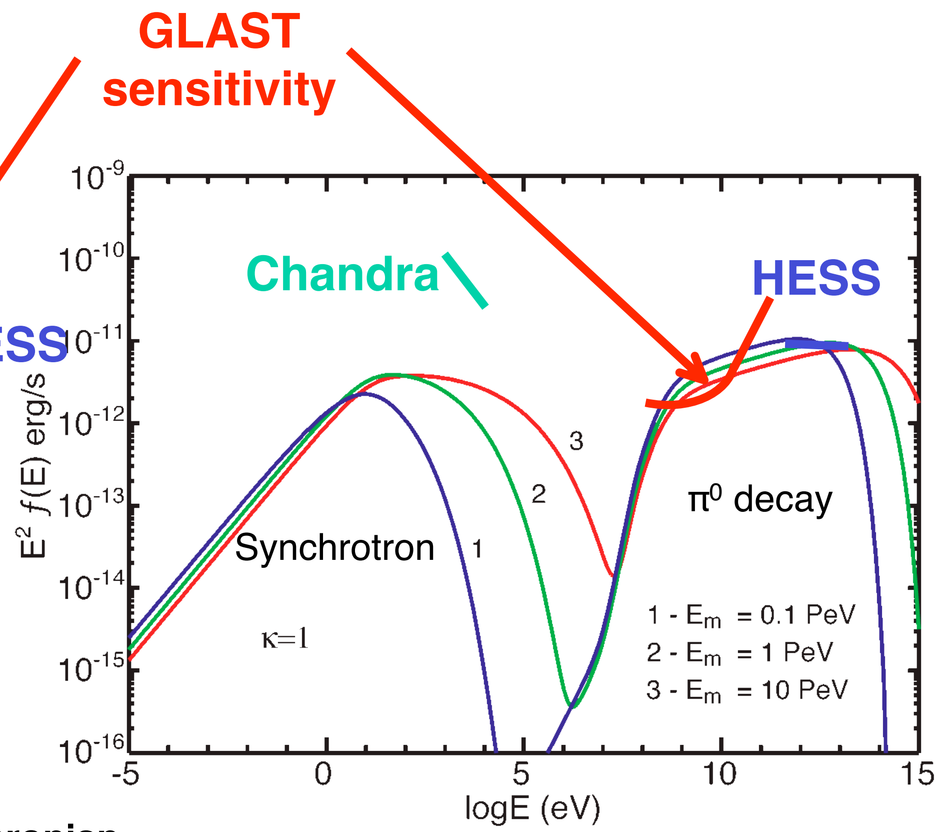


SNR Broad Band Energy Distribution

- **Electron and proton give different spectra.**
  - **Both models are not quit right.**
  - **GLAST can provide more model constraints.**

$B_{int} = 5\ \mu G$
$B_{rim} = 20\ \mu G$
$n_{int} = 1\ cm^{-3}$
$n_{cloud} = 300\ cm^{-3}$
$\tau_{age} = 1000$ year



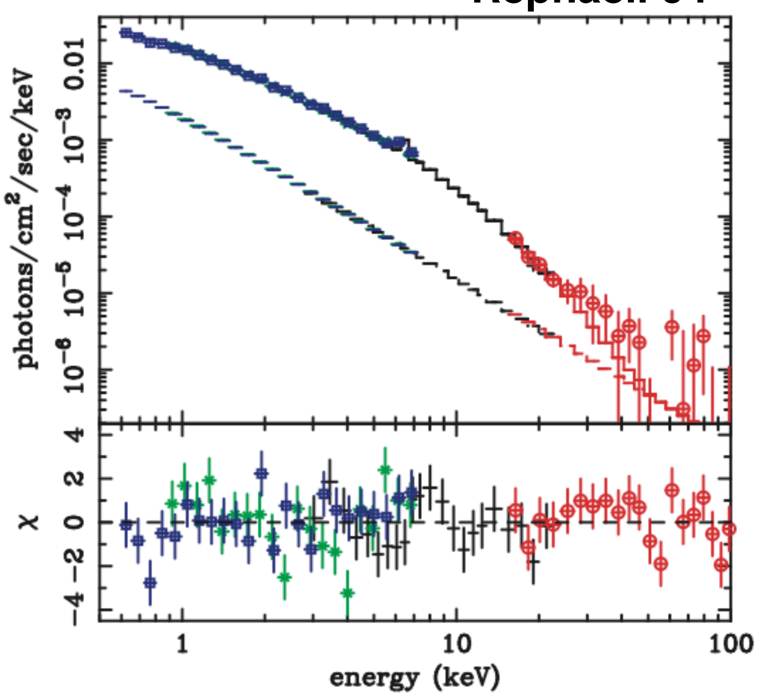


Aharonian

Galaxy Clusters

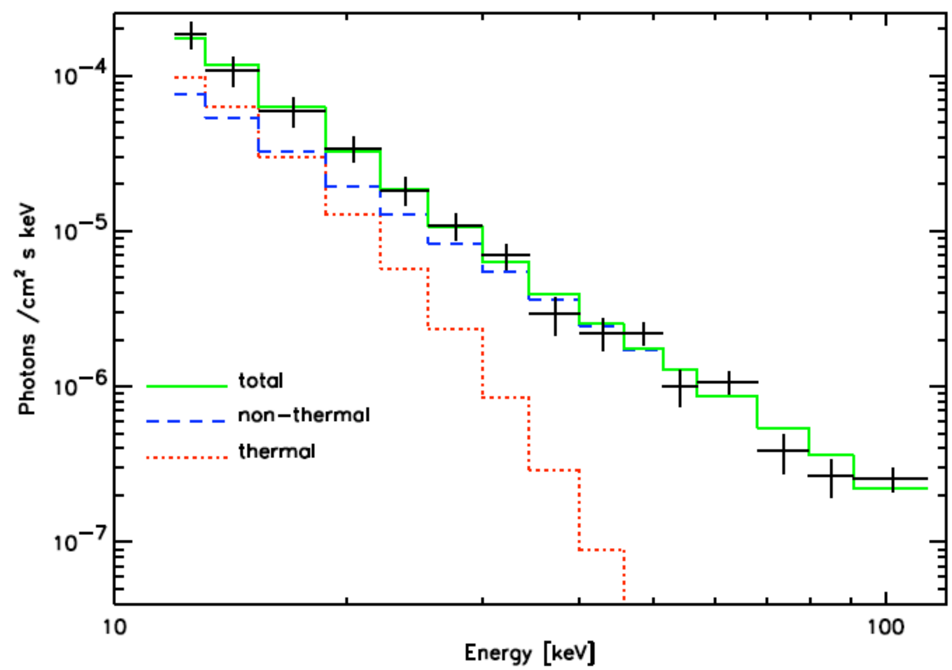
- **Particle acceleration due to accretion shocks following cluster merger.**
  - **Marginal evidence of non-thermal emission from Galaxy clusters in hard X-ray band.**

Rephaeli 04



Abel 2252 spectrum

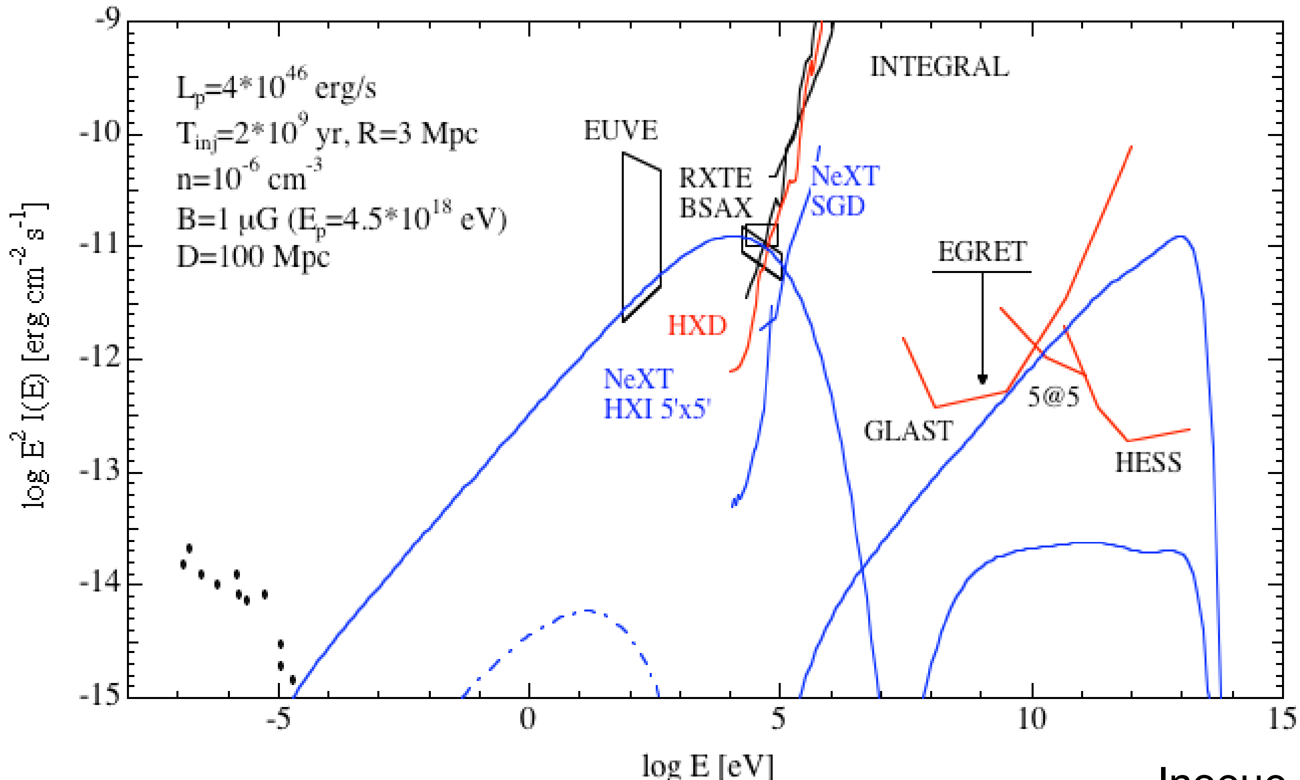
Nevalainen 03



Combined spectrum for many clusters

Cluster Photon Emission Model

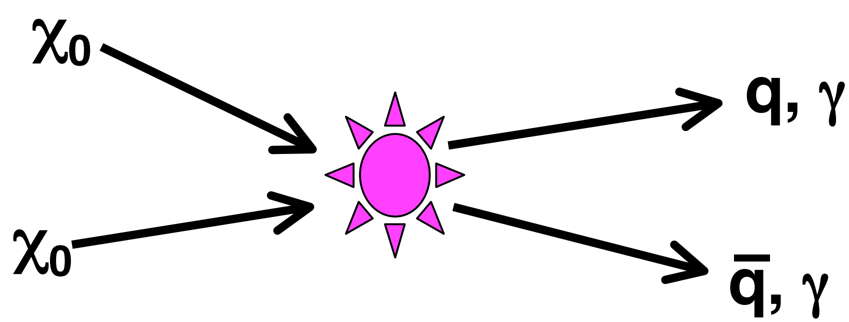
- **Coma cluster.**
  - **Comparison of model and data.**
  - **GLAST sensitivity marginal.**
    - Need to combine several clusters.



Inoeue

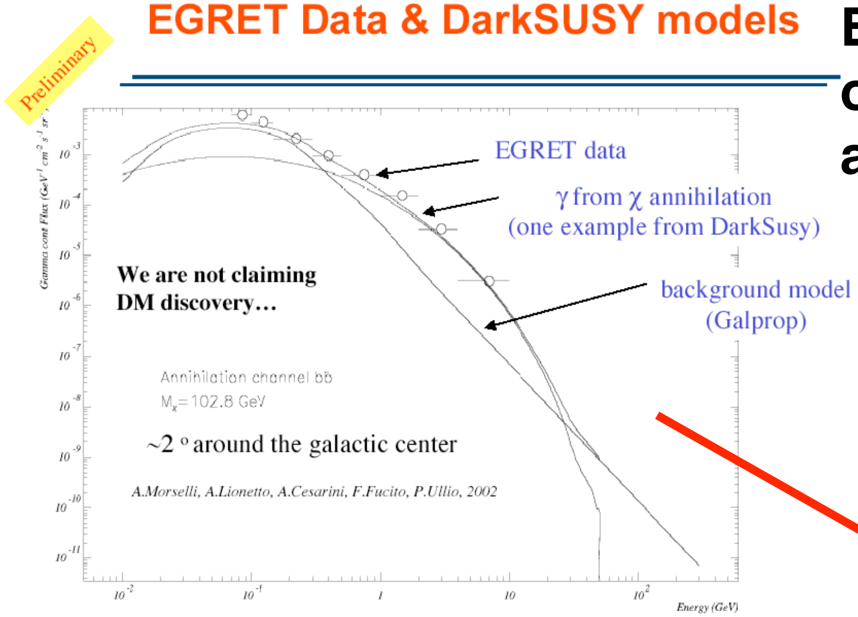
Dark Matter Science with GLAST

- **Baryonic matter accounts for only a few% of Universe.**
  - **Dark energy/matter dominate Universe.**
- **Neutralino can be a good dark matter candidate if its mass is in Electro-Weak scale (~100 GeV).**
  - **GLAST can be sensitive to the photons from neutralino annihilations.**
  - **Peaks at 0.1 M_χ or M_χ.**



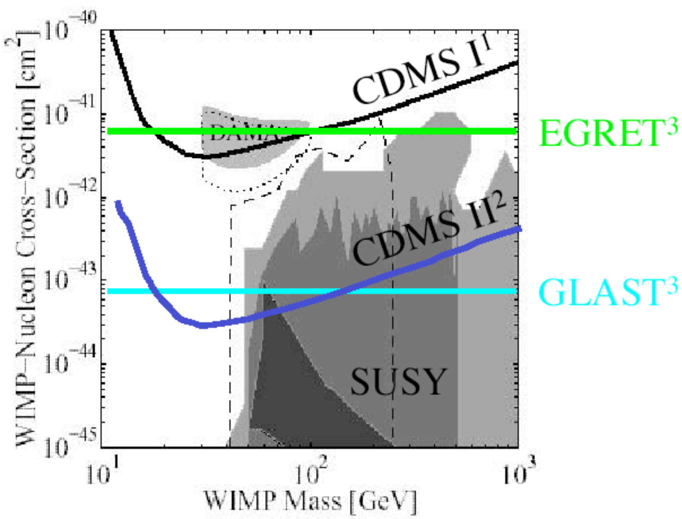
Neutralino Search with GLAST

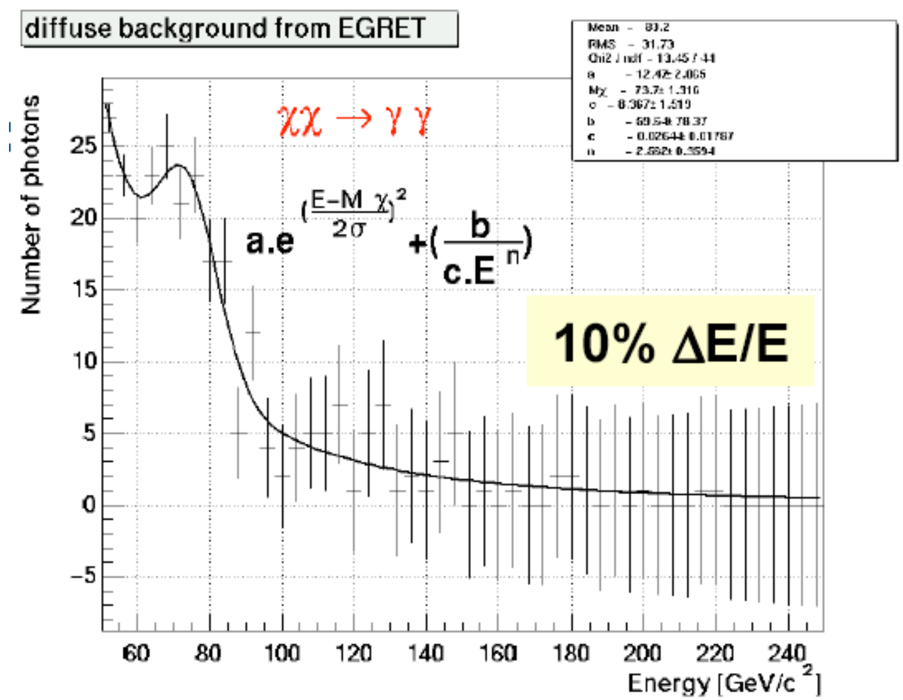
EGRET Data & DarkSUSY models



EGRET data shows a hint of neutralino signal around Galactic center.

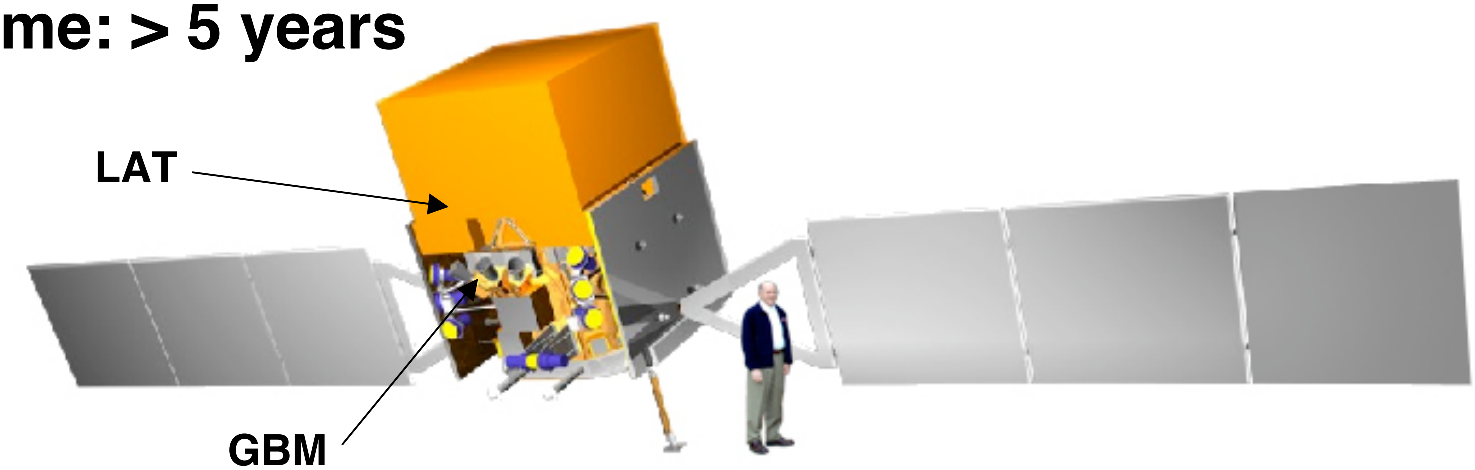
Improved angular/energy resolution and sensitivity by GLAST may reveal neutralino signal at Galactic center.





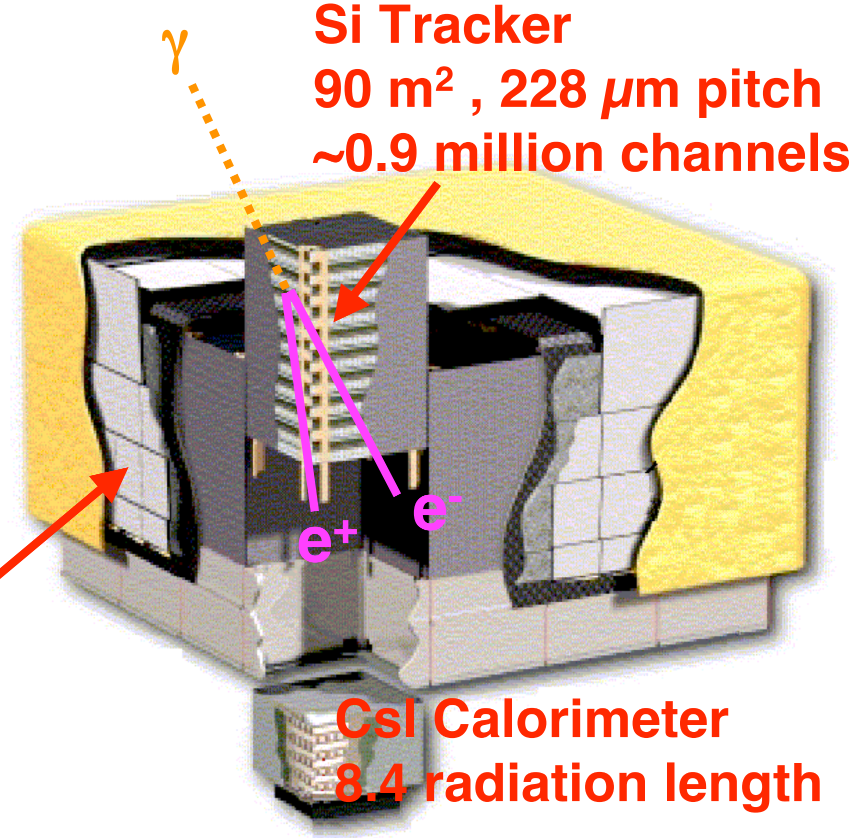
GLAST Mission

- **Two instruments on board.**
  - **LAT (Large Area Telescope).**
    3000 kg, 650 W.
  - **GBM (GLAST Burst Monitor).**
- **To be launched in early 2007 by Delta-II rocket.**
  - **Flight hardware production starting soon.**
- **Orbit: 575 km altitude, 28.5^{o} inclination, 95 minutes period.**
- **Lifetime: > 5 years**



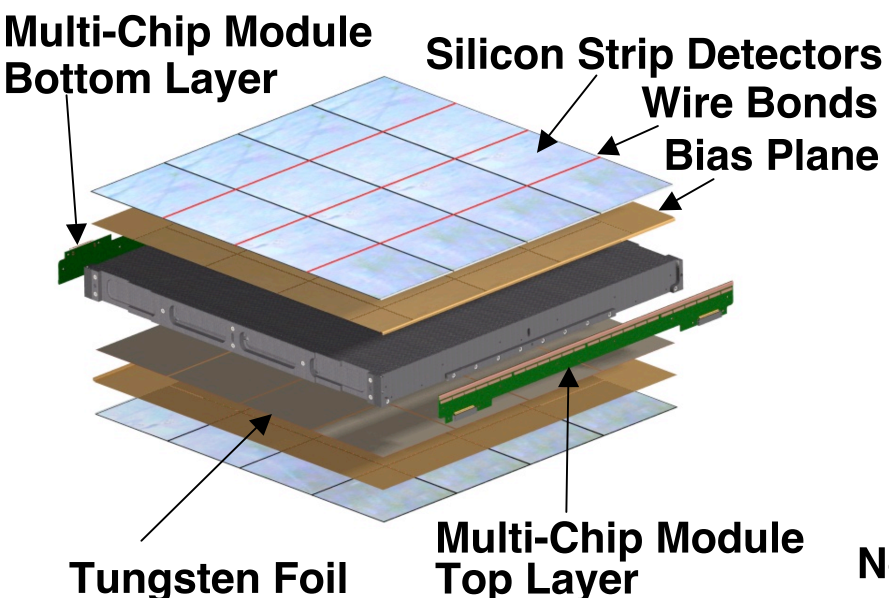
Instrument Configuration

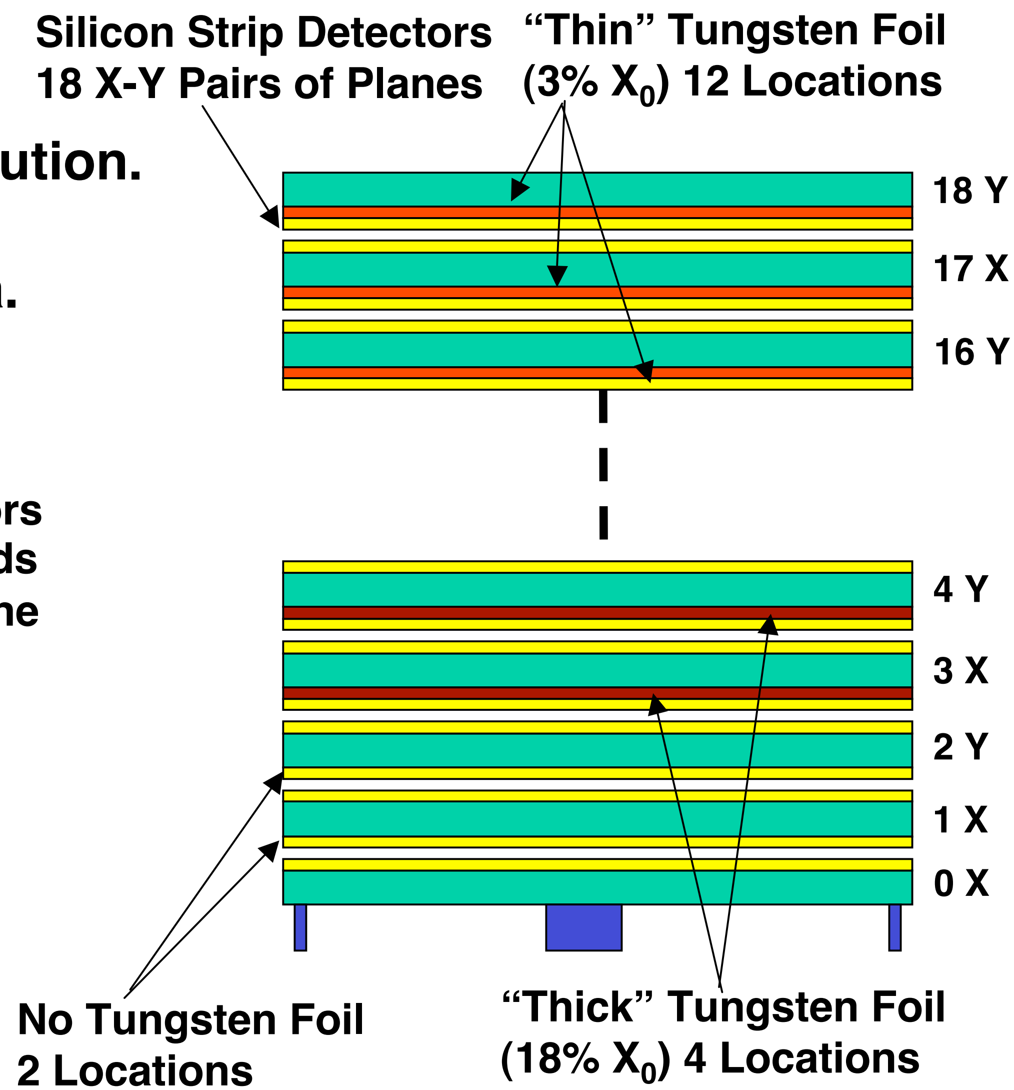
- Tracker: conversion, tracking.
  - Angular resolution is dominated by scattering.
  - Converter thickness optimization.
- Calorimeter: energy measurement.
  - 8.4 radiation length.
  - Use shower development to compensate for the leak.
- Anti-coincidence detector:
  - Efficiency > 99.97%.



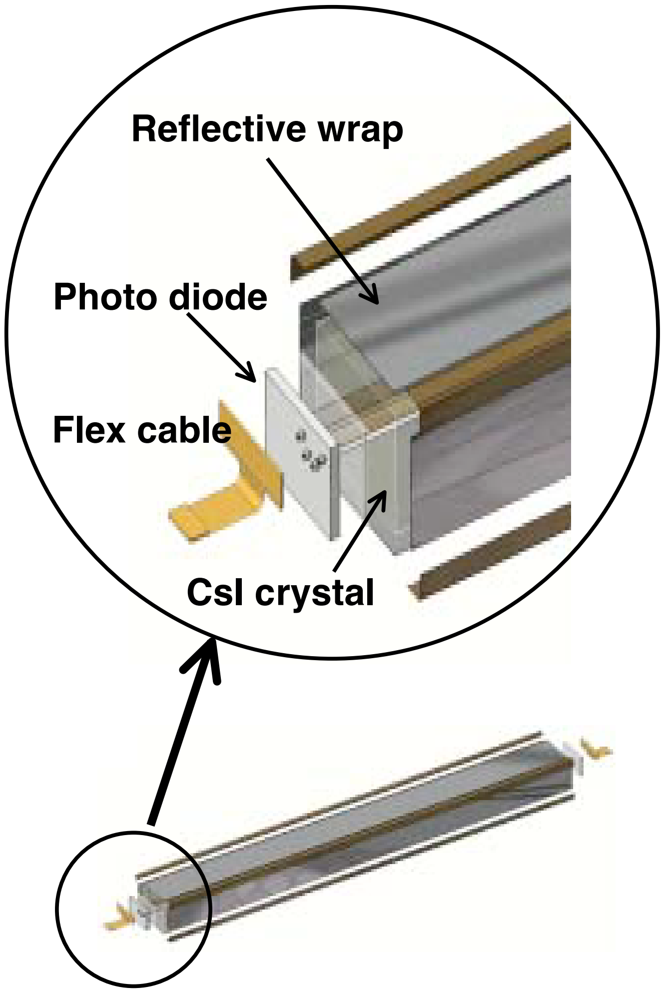
Tracker

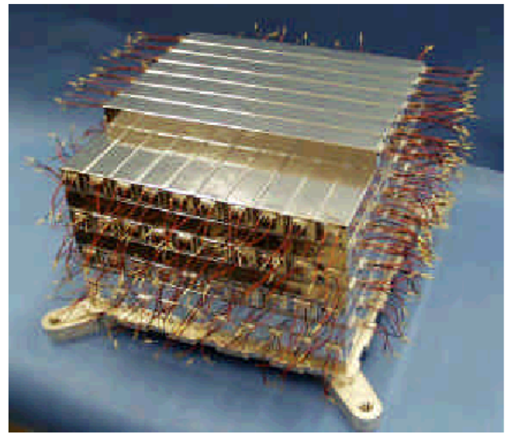
- **Converter thickness.**
  - **Thinner converter for better angular resolution.**
  - **Thicker converter for larger effective area.**





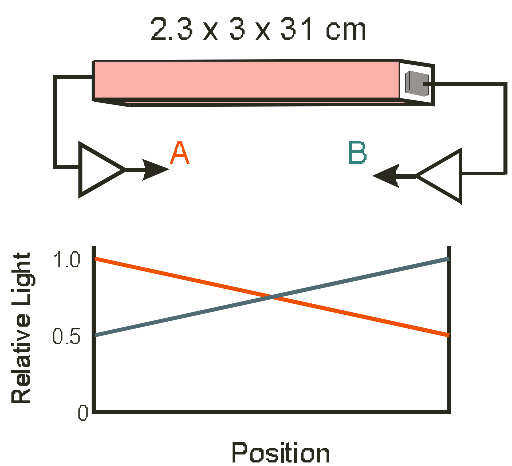
Calorimeter

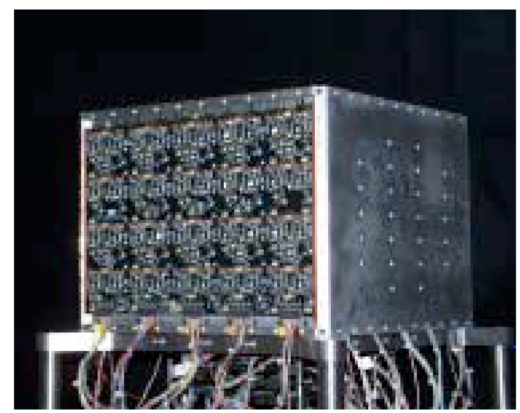




12 logs / layer
8 layers / module

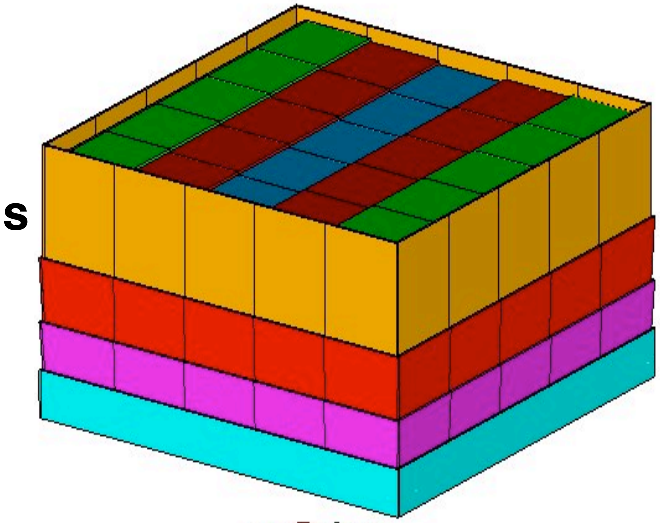
Electronics board



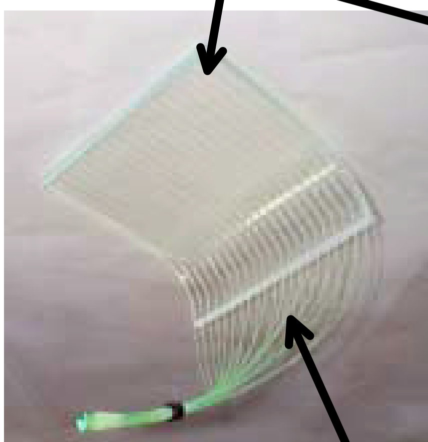


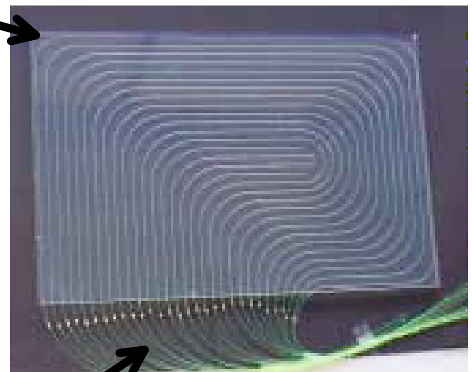
Anti-Coincidence Detector

Tile Shell Assembly (TSA)
- **89 Tile Detector Assemblies**
- **8 Ribbon Detectors**
- **Composite Honeycomb Panels**

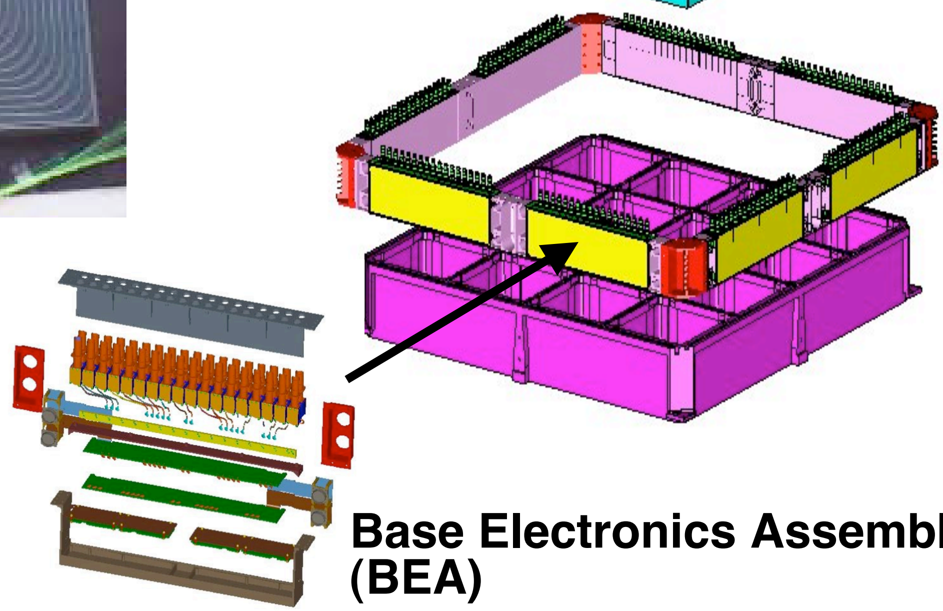


Scintillator



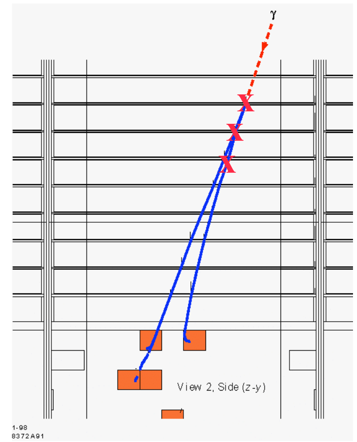


Optical fiber



Base Electronics Assembly (BEA)

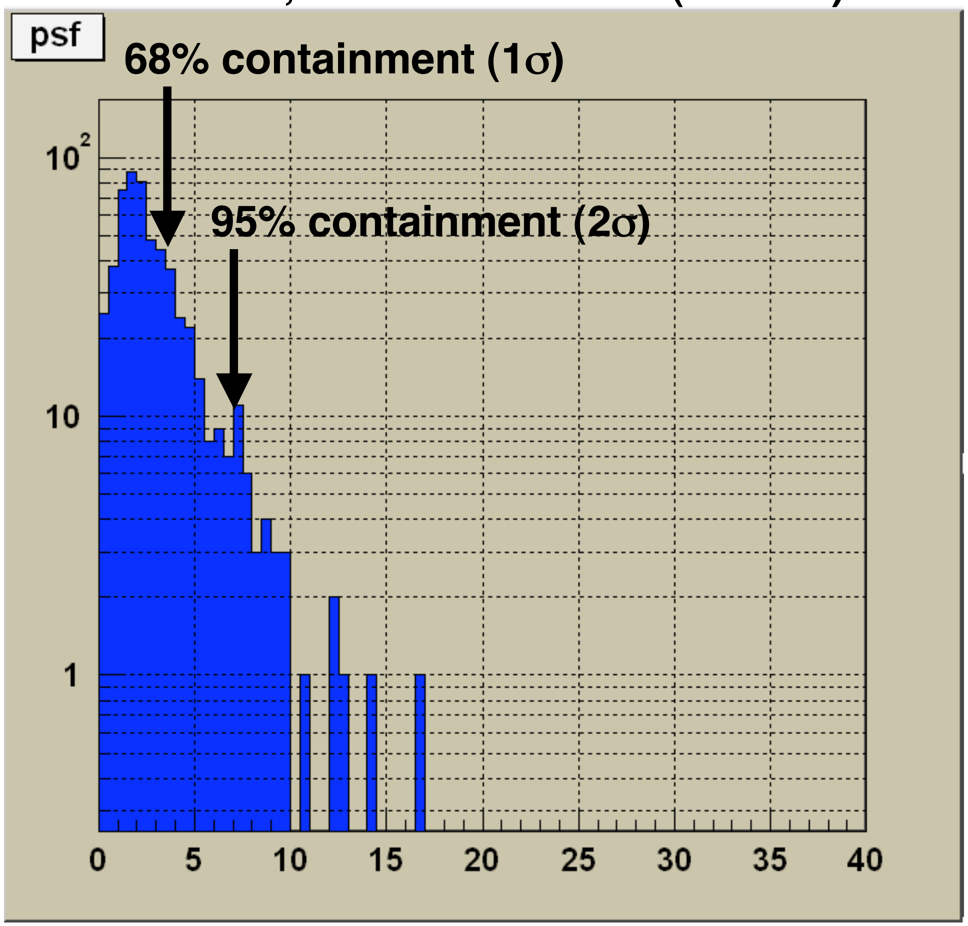
Data Flow



- **Level 1 trigger.**
  - **TKR 6-in-a-row: 4-12 kHz.**
- **On board filtering.**
  - **Downlink rate: ~300 Hz.**
  - **Hierarchical filtering: simple → complex filtering.**
  - **Science analysis to detect transient detection due to AGN flares or GRBs.**
- **ISOC (Instrument Science Operations Center).**
  - **Data processing.**
  - **Calibrations.**
- **SSC (Science Support Center)**
  - **Data products.**
  - **Science tools.**

Angular Resolution

100 MeV, normal incidence (FRONT)



68% containment radius:

100 MeV

Requirement: <3.5°

MC: 3.37° FRONT (4.64° Total)

10 GeV

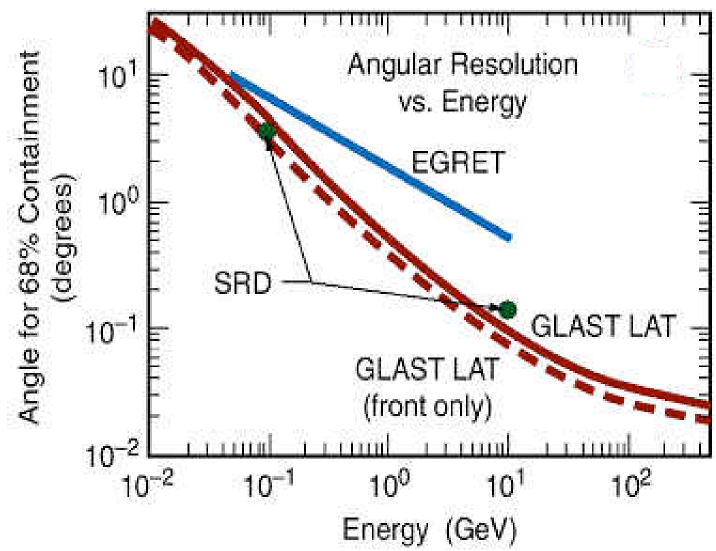
Requirement: <0.15°

MC: 0.08° FRONT (0.115° Total)

95/68 ratio:

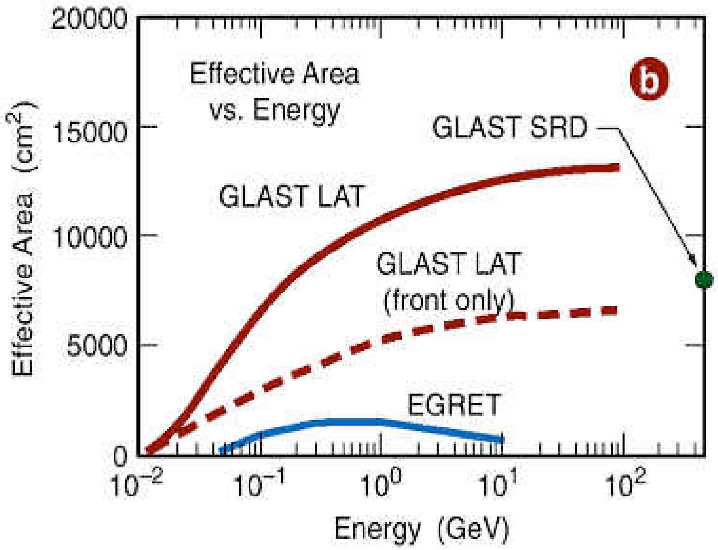
Requirement: <3

MC: 2.1 FRONT (BACK: 2.6)



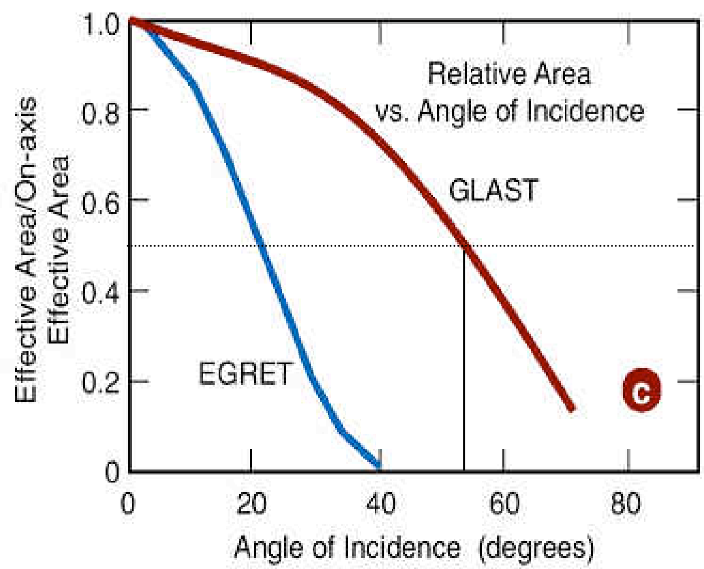
SRD: Science Requirement Document

Effective Area, Field of View

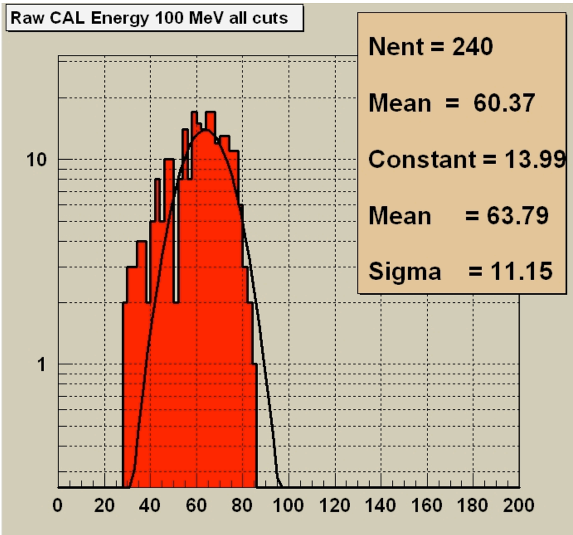


Effective Area:
Requirement: > 8,000 cm^2
(1 – 10 GeV)
MC: > 10,000 cm^2

Field of View:
Requirement: > 2.0 sr
MC: 2.4 sr

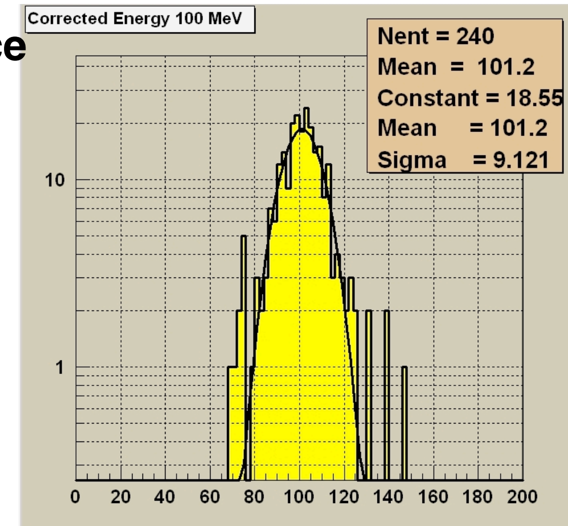


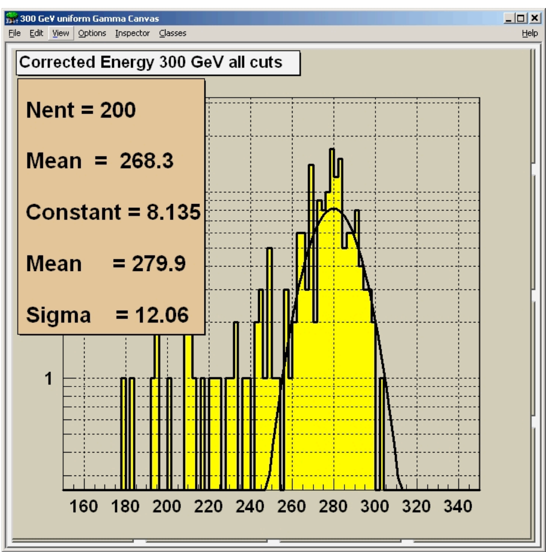
Energy Resolution



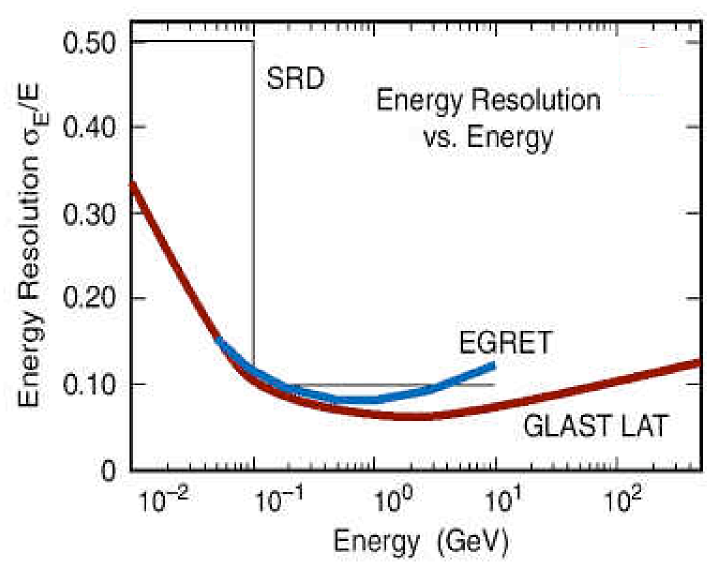
100 MeV, Normal-incidence
Requirement: $\sigma_E < 10\%$
$\sigma_E < 9\%$ (MC)

Leakage correction using longitudinal profile



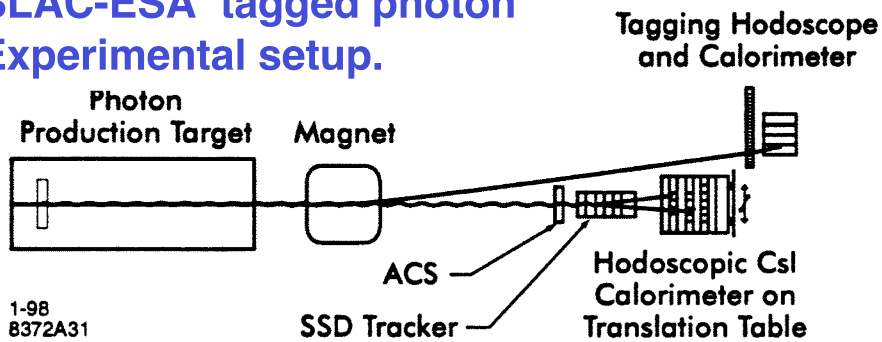


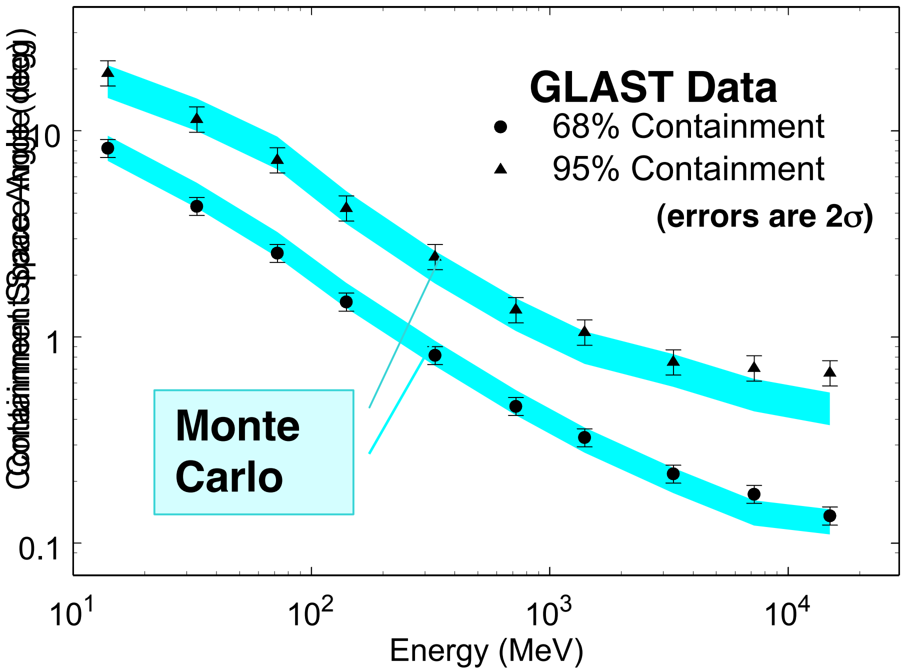
300 GeV, >60° off-axis
Requirement: $\sigma_E < 6\%$
$\sigma_E < 4.3\%$ (MC)



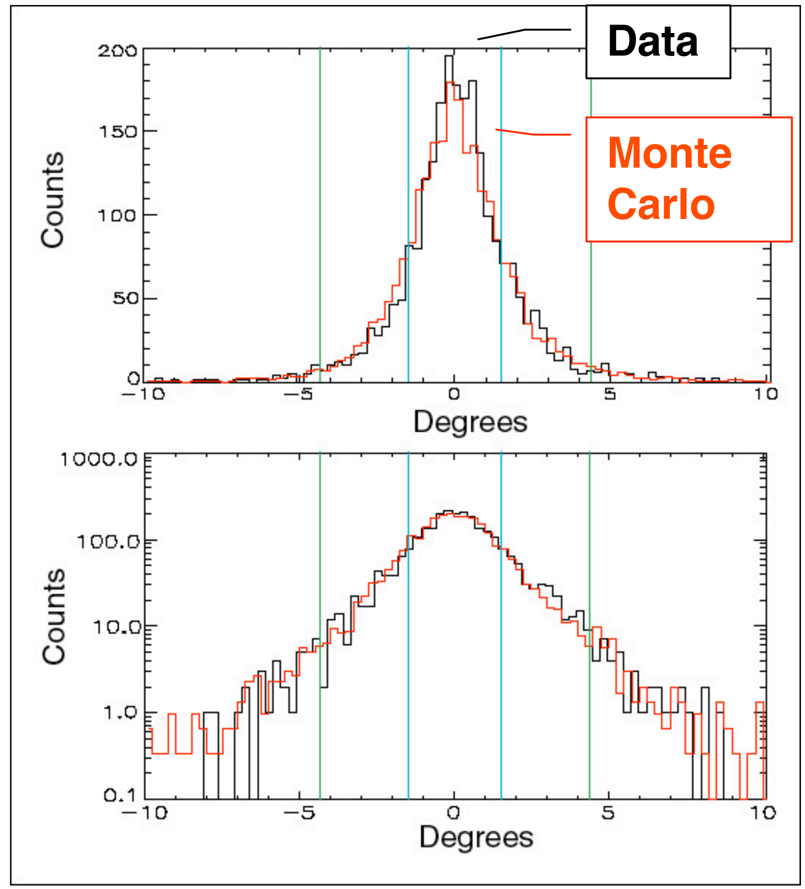
MC Validation

SLAC-ESA tagged photon Experimental setup.



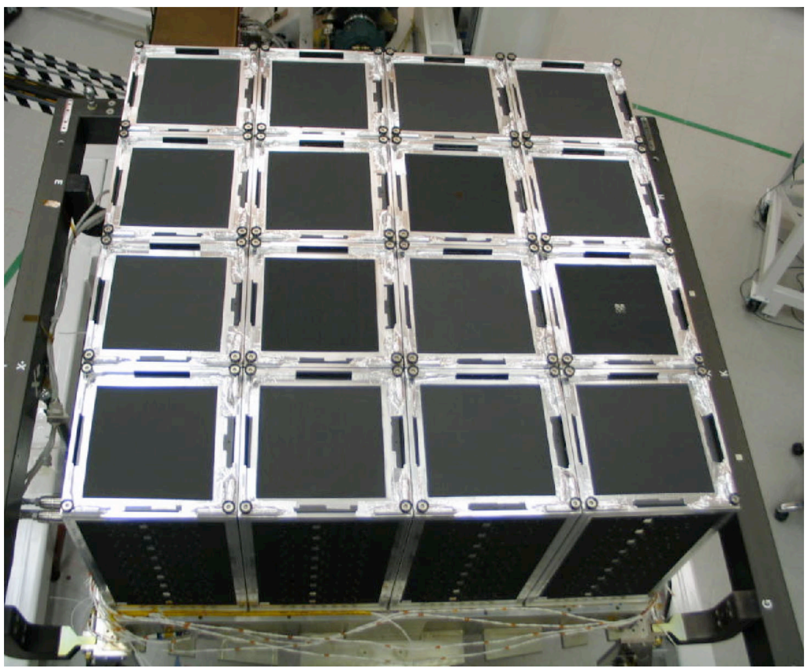


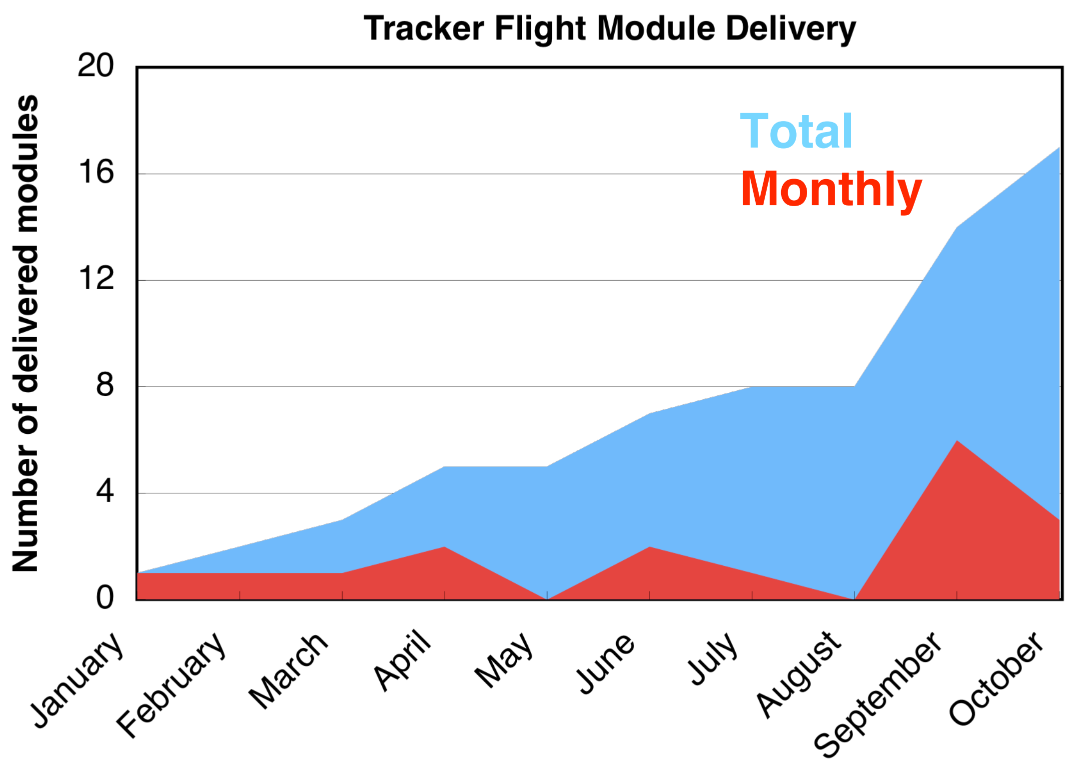
X Projected Angle
3-cm spacing, 4% foils, 100-200 MeV



Flight Module Delivery

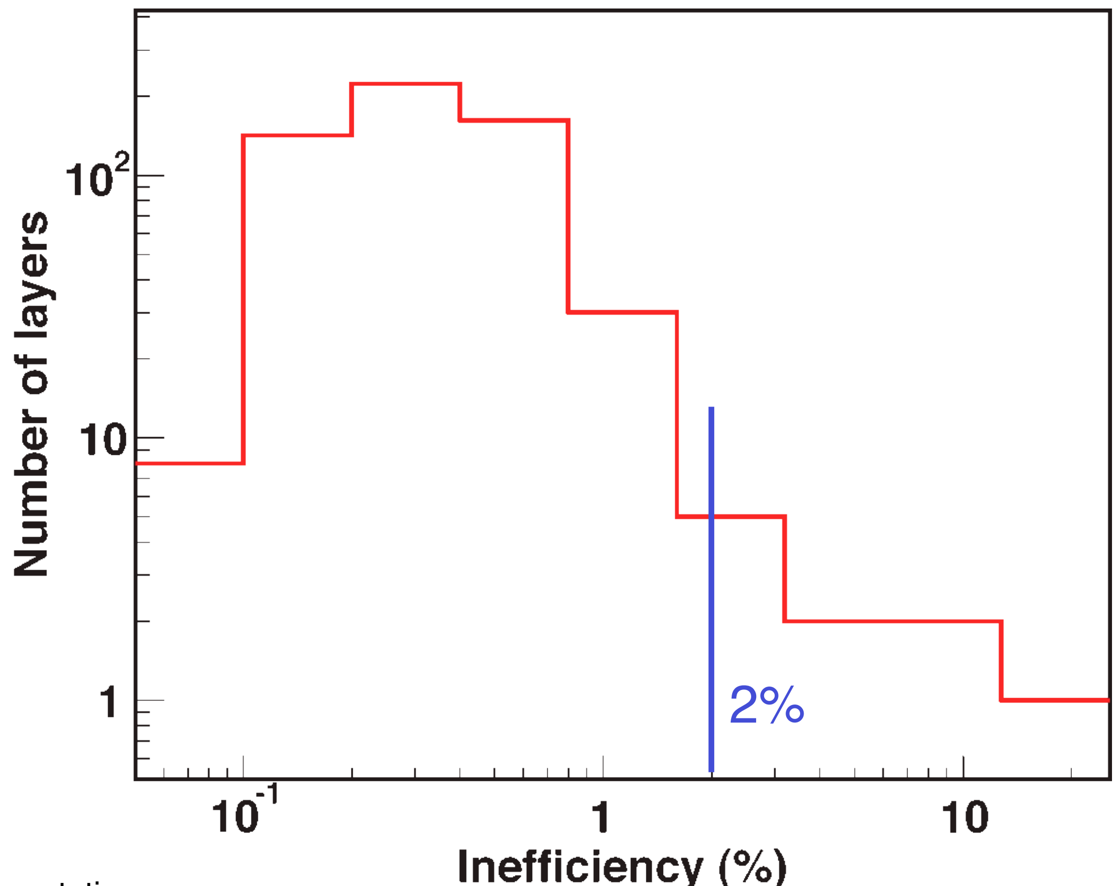
- **All flight modules are delivered and integrated.**
  - **Flex cable delivery has been bottle neck.**
- **ACD is being integrated.**





Hit Efficiencies

- Specification: hit efficiency > 98%.
  - 99.0% of layers satisfy the specification.
  - Average efficiency: 99.6%.
  -



Current Status and Future Schedule

- All flight detector modules are delivered.
  - Tracker meet all specifications.
- DAQ integration and online software test.
  - Now – Jan 2006.
- Environmental test at NRL.
  - Feb – June 2006.
- Beam test at CERN(?)
  - Spare modules.
  - Proposal in preparation.
  - ~ June 2006.
- Space craft integration.
- Launch from Kennedy SFC.
  - Sep 2007.
  - Largest Silicon Detector in the Space. (near Earth)

Spitzer Telescope Launch on a Delta II Heavy