A New Look at the Galactic Diffuse GeV Excess

Brian Baughman
Santa Cruz Institute for Particle Physics

Overview

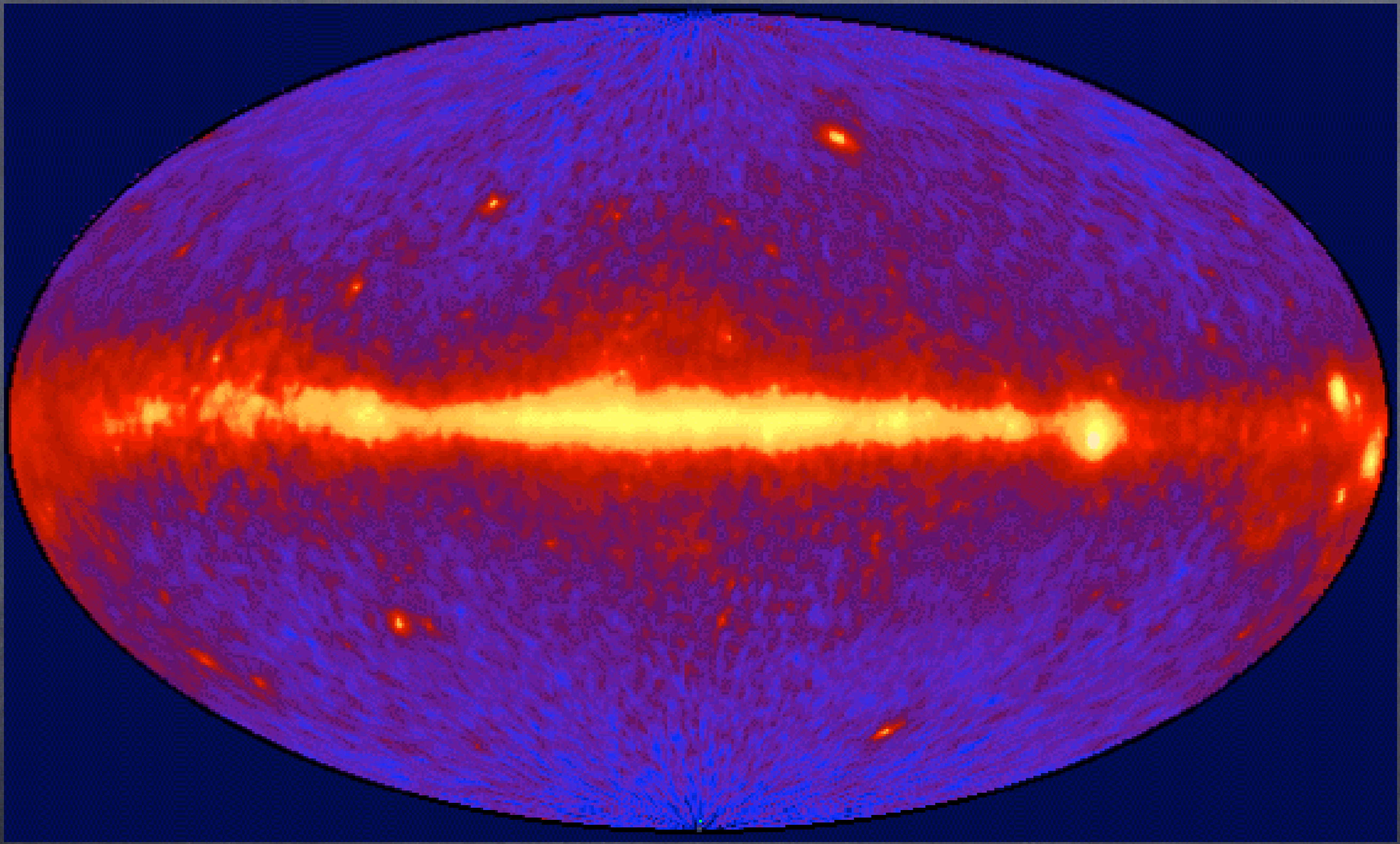
- Diffuse gamma-ray emission
- The Galactic diffuse gamma-ray GeV excess
- Discussion of the EGRET instrument
- Simulation of EGRET
- Re-scaled measurement of diffuse gamma-ray emission from the inner Galaxy

Diffuse Gamma-ray Emission

- Galactic diffuse
  - Cosmic-ray interactions with inter-stellar medium (ISM) provide dominate component
  - Unresolved sources are thought to contribute a low amount at energies above 50 MeV (Pohl et al. ApJ 491:159-164, 1997; Hunter et al. ApJ 481:205-240, 1997)

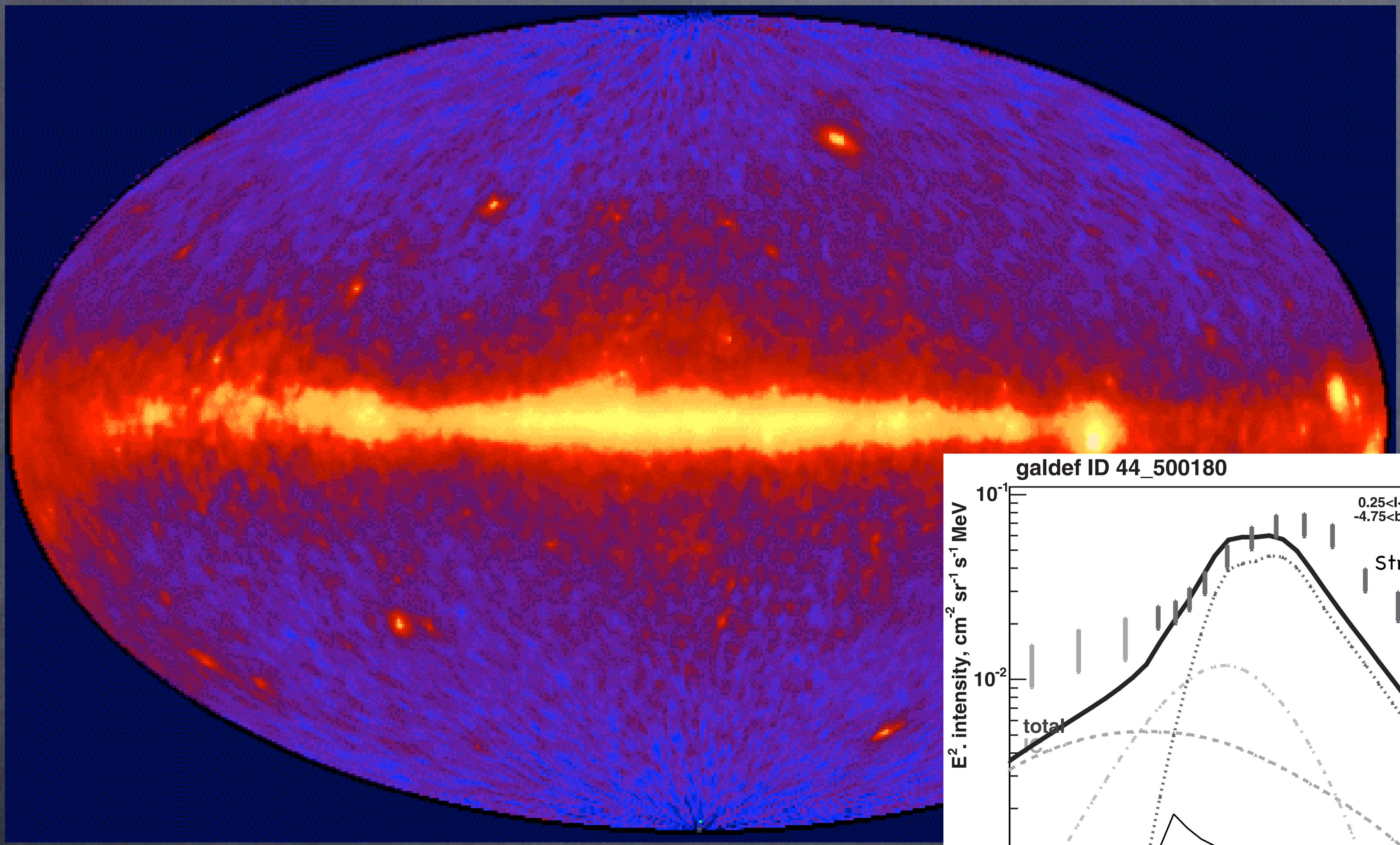
3

Diffuse Gamma-ray Production

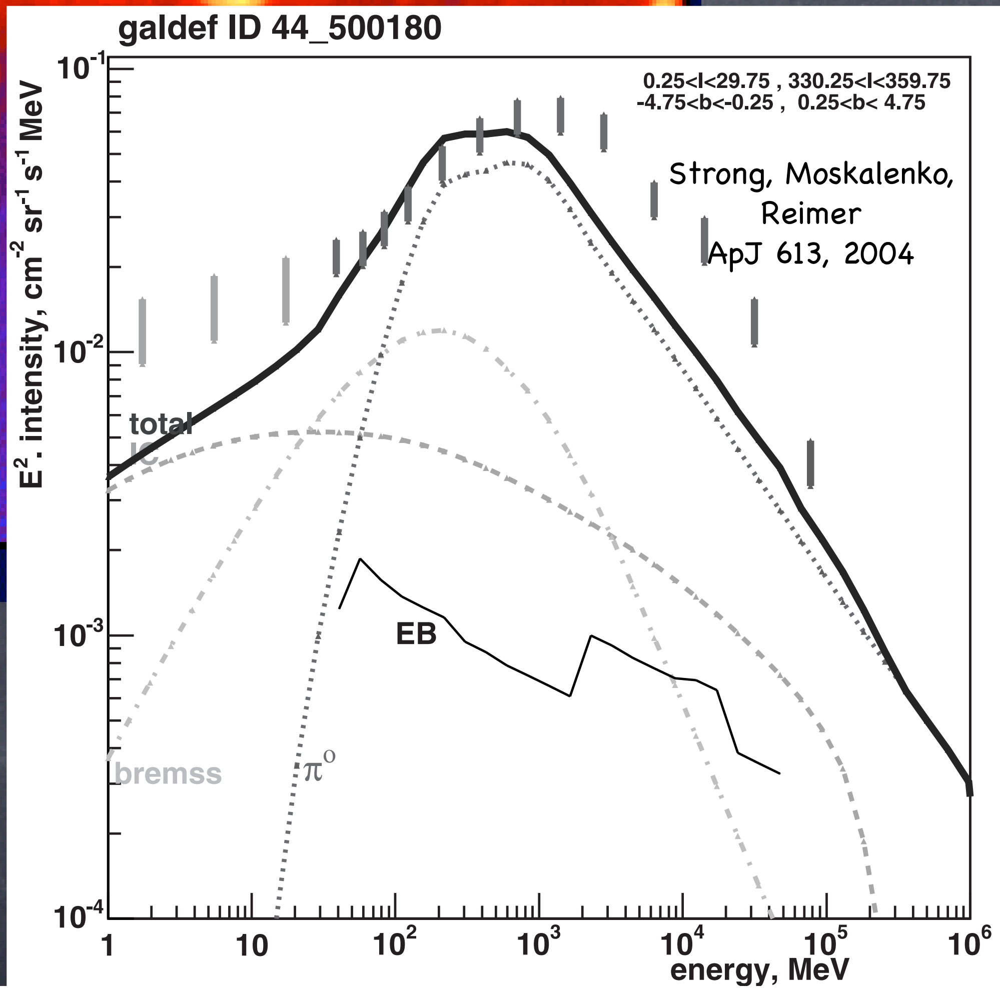


Courtesy of Seth Digel

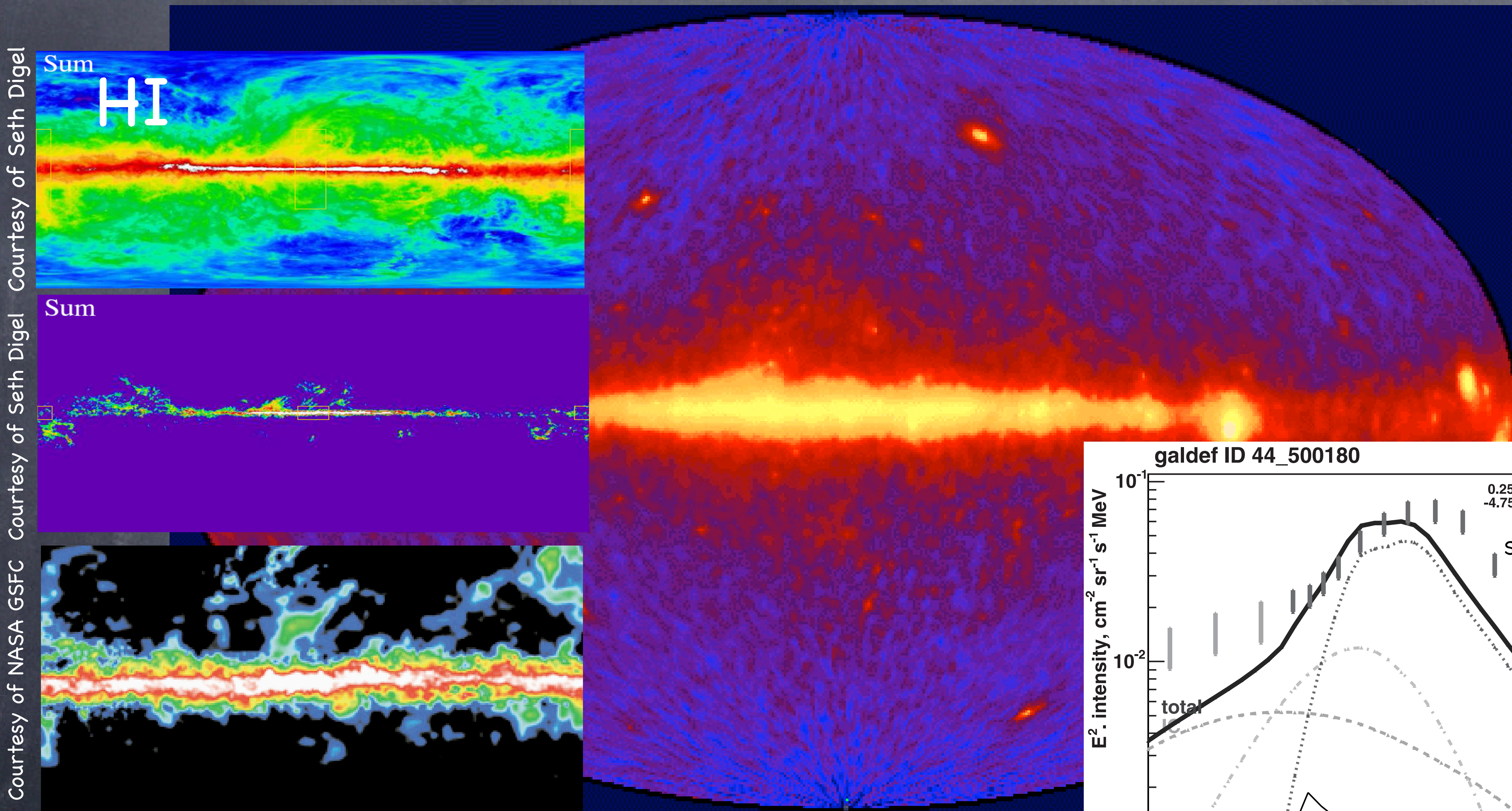
Diffuse Gamma-ray Production



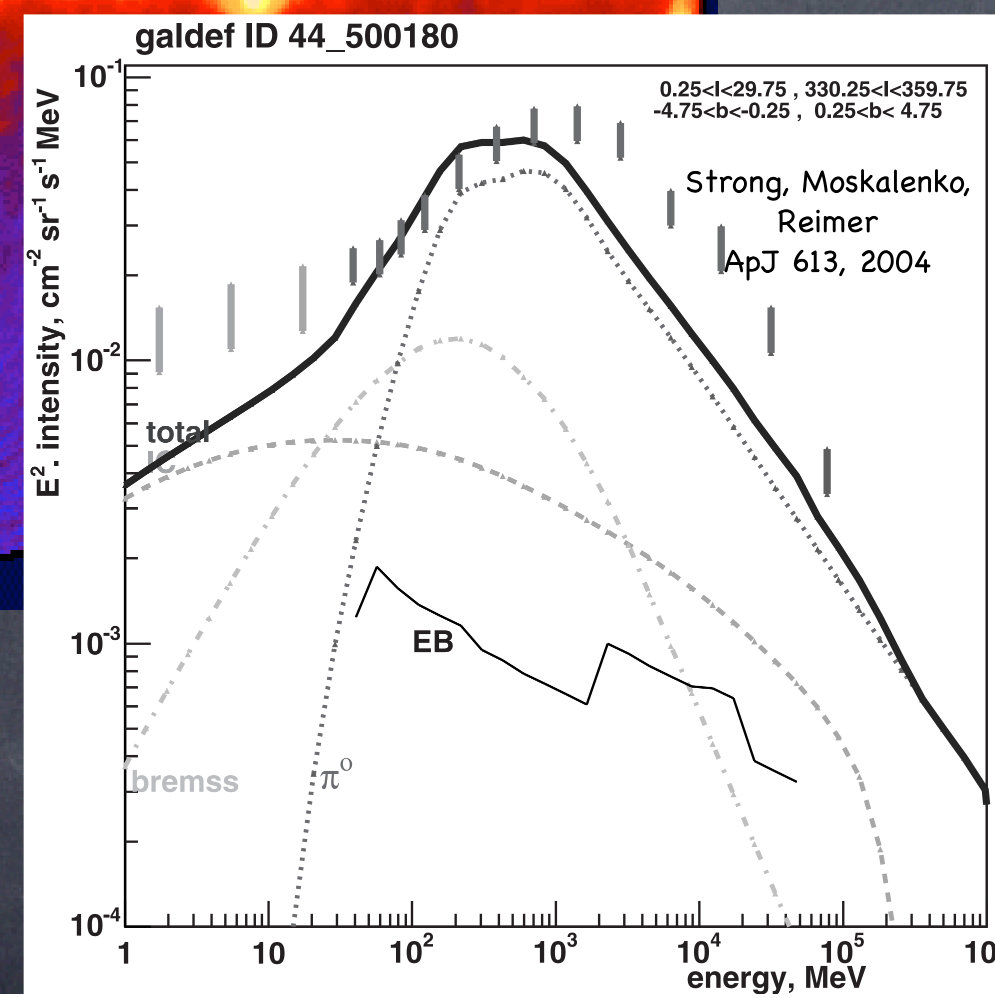
Courtesy of Seth Digel



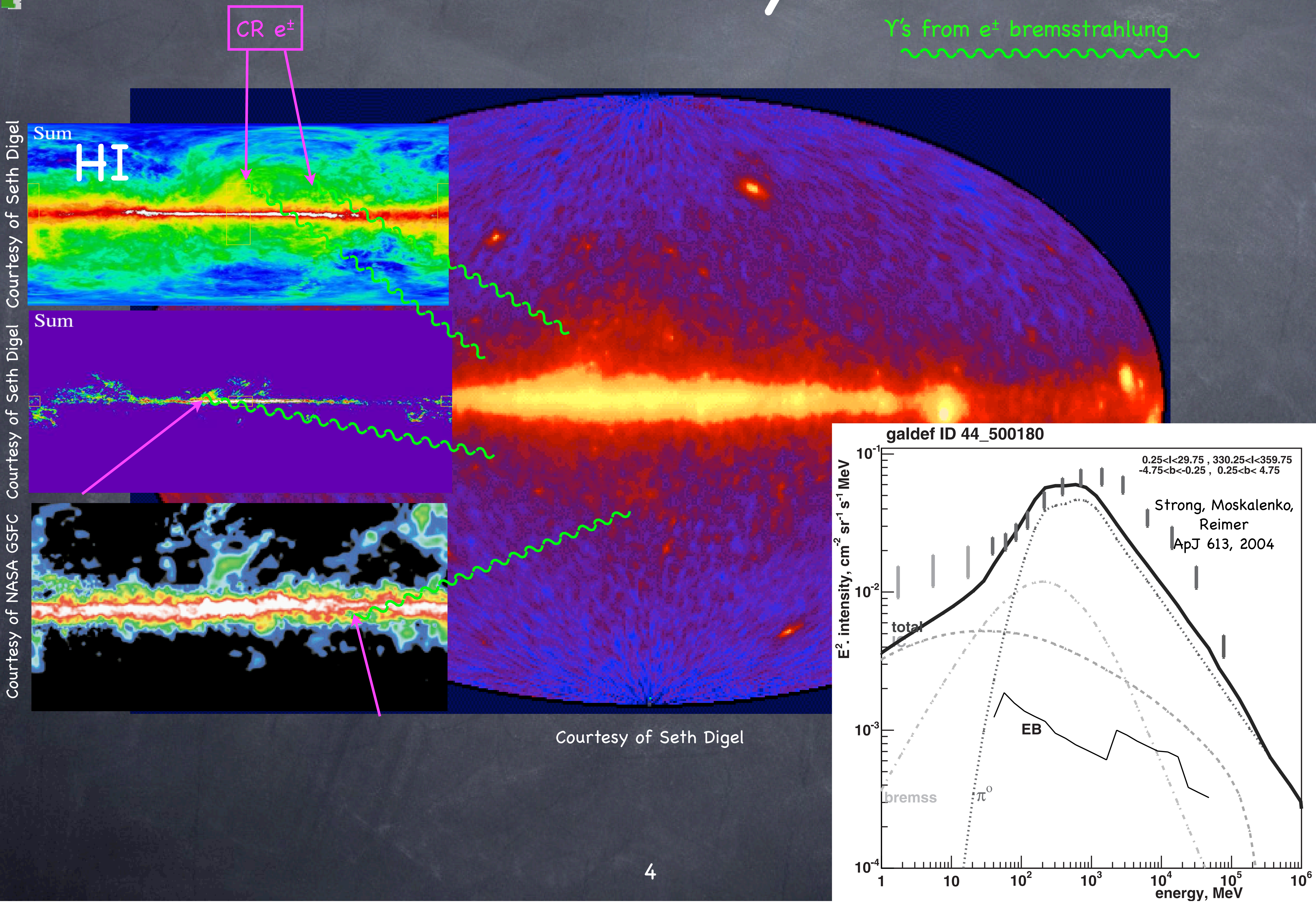
Diffuse Gamma-ray Production



Courtesy of Seth Digel



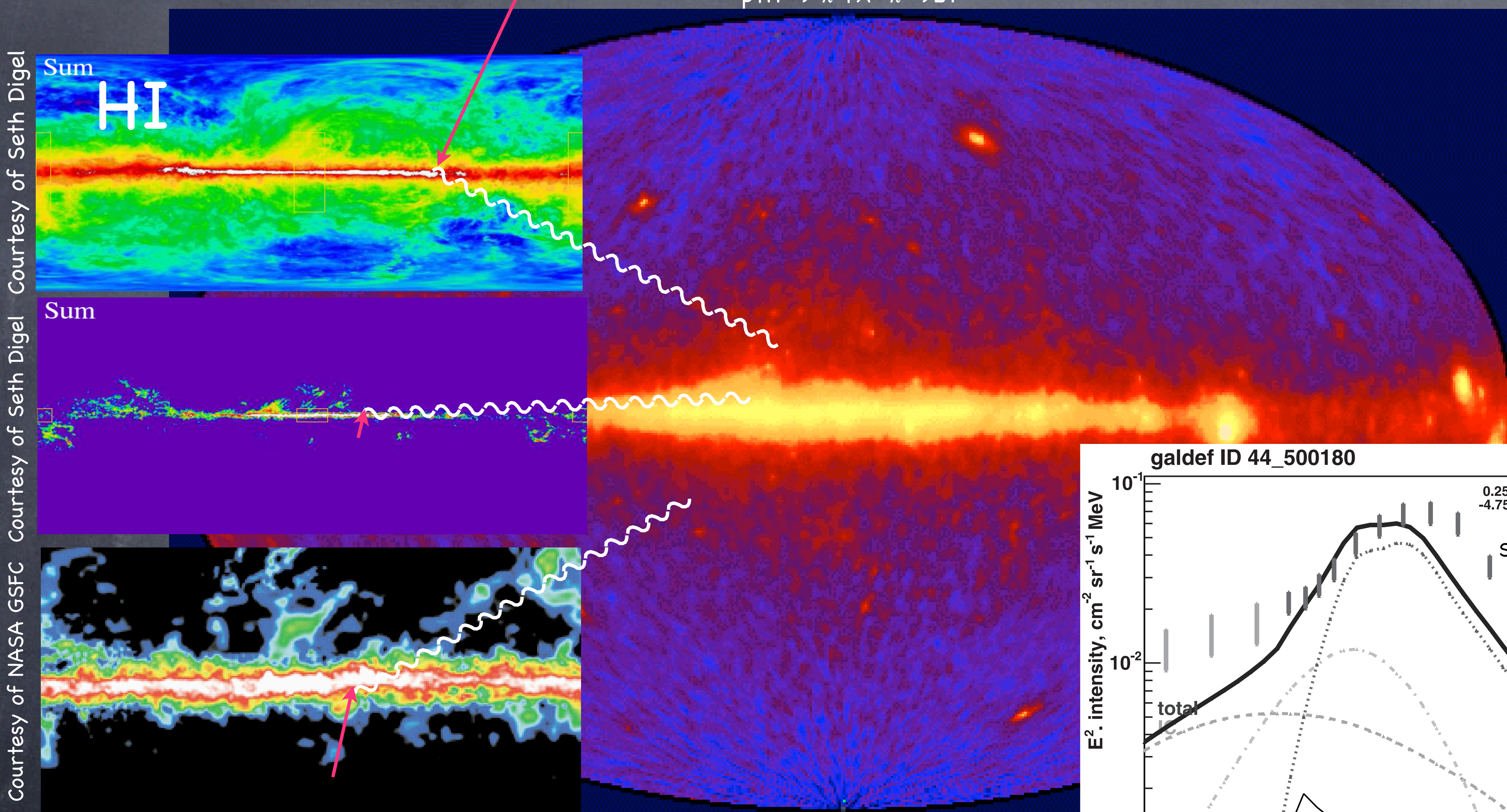
Diffuse Gamma-ray Production



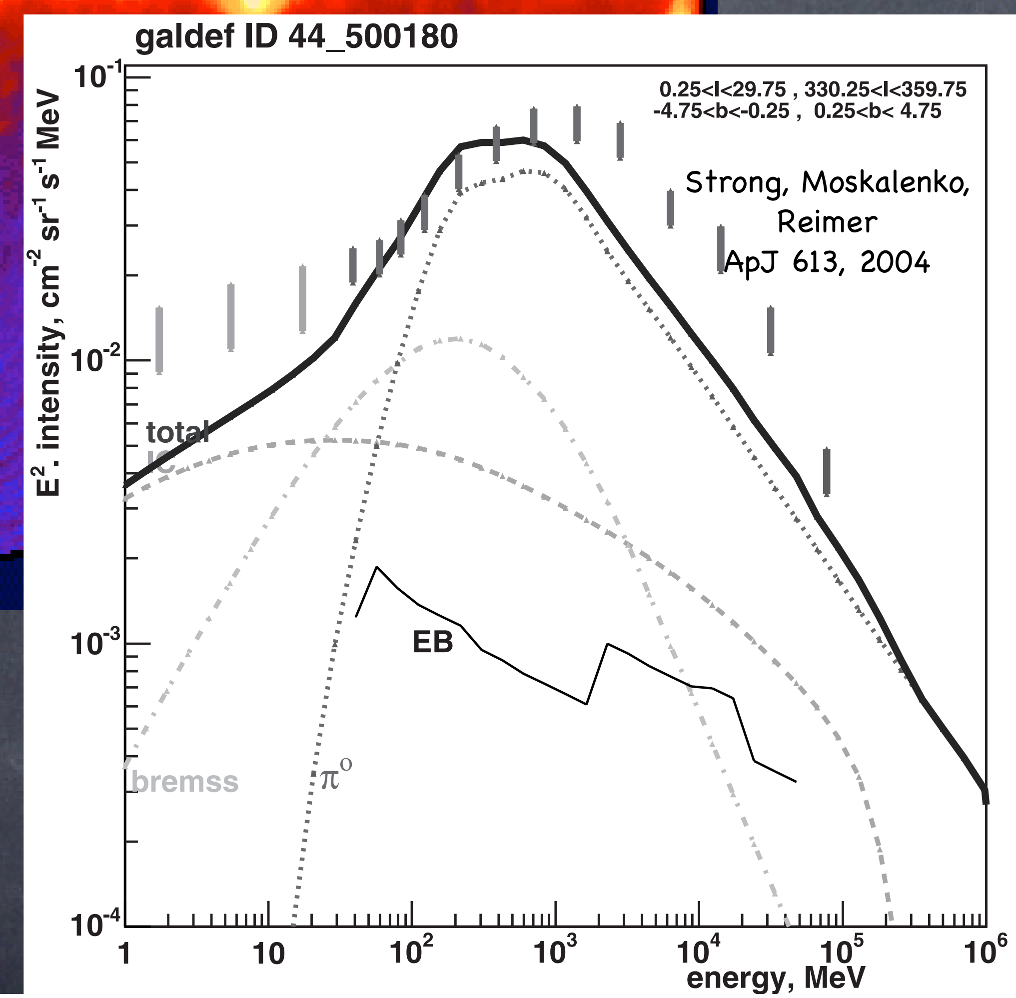
Diffuse Gamma-ray Production

γ's from π° decay

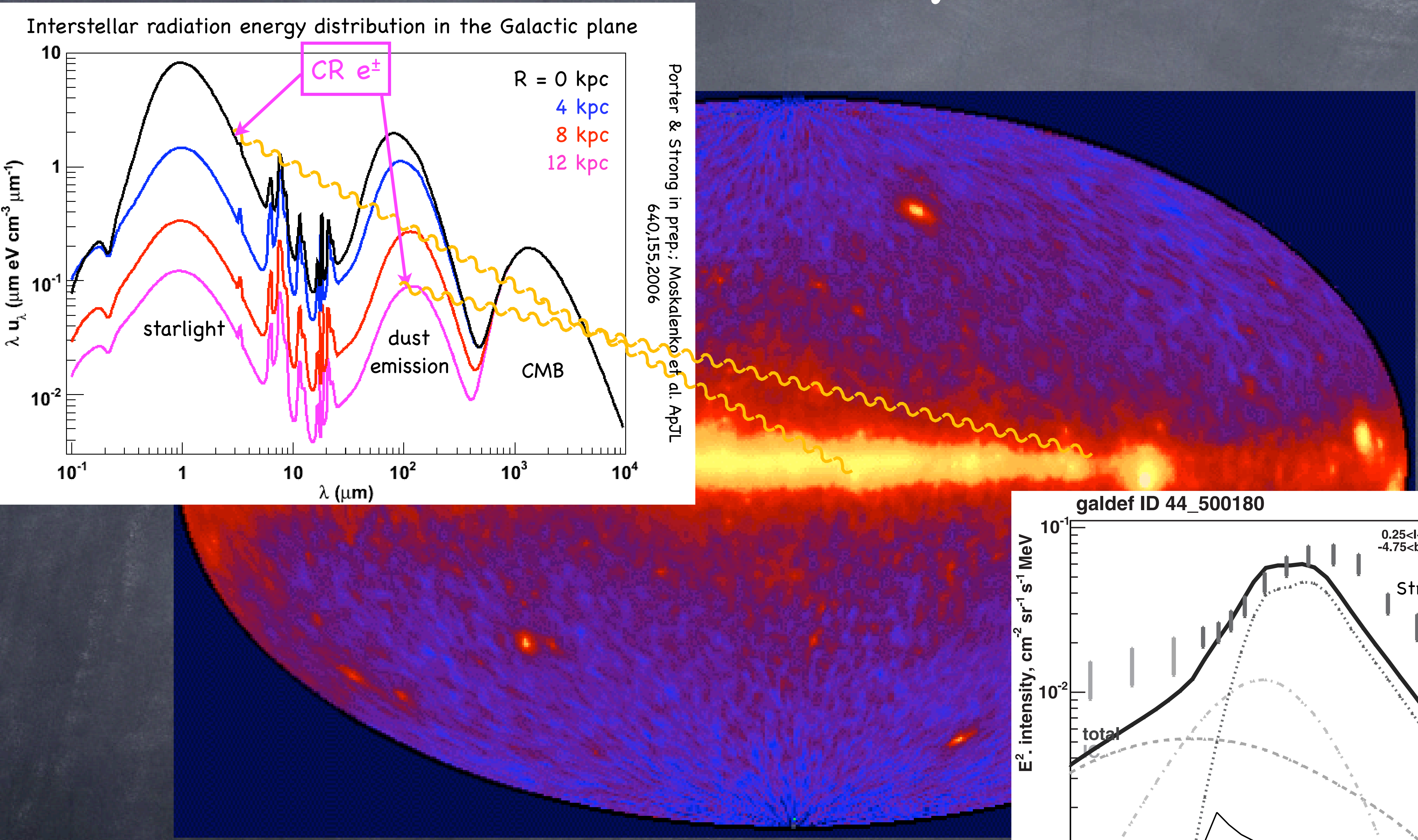
$p+H \rightarrow \pi^0+X \quad \pi^0 \rightarrow 2\gamma$



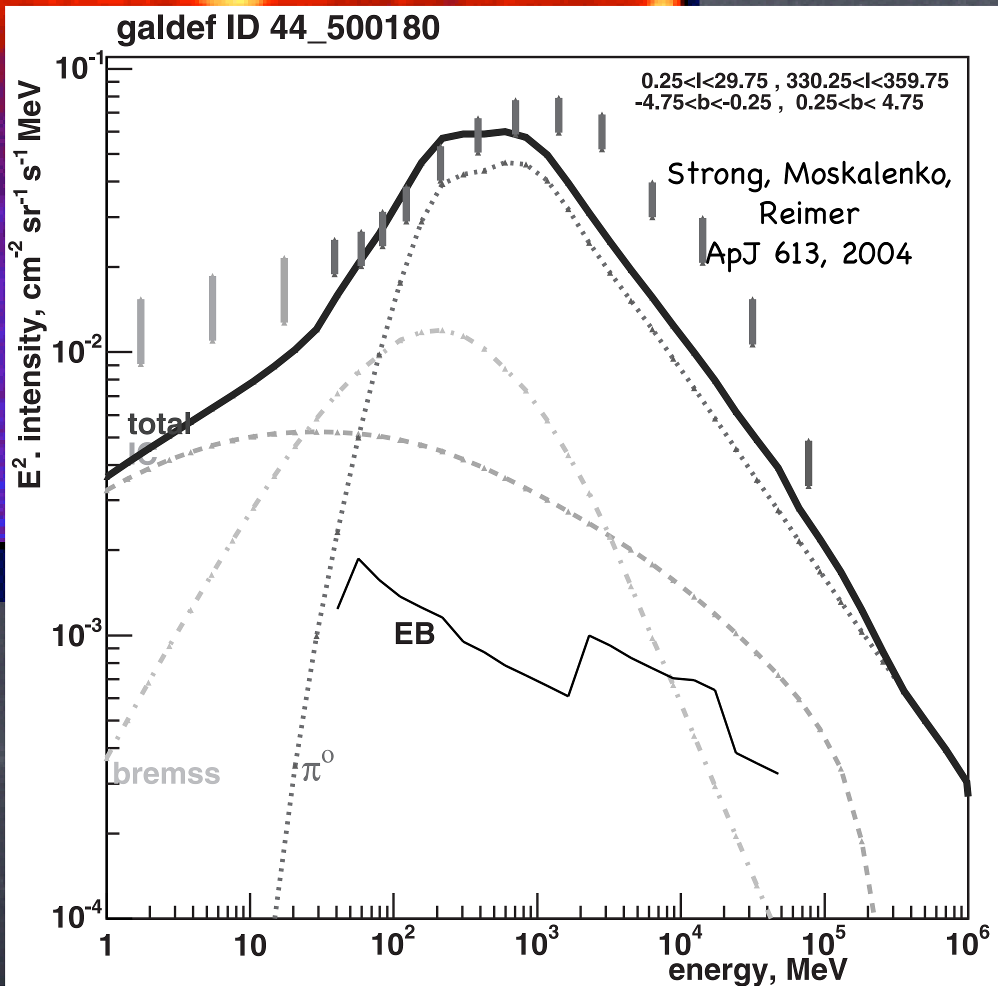
Courtesy of Seth Digel



Diffuse Gamma-ray Production



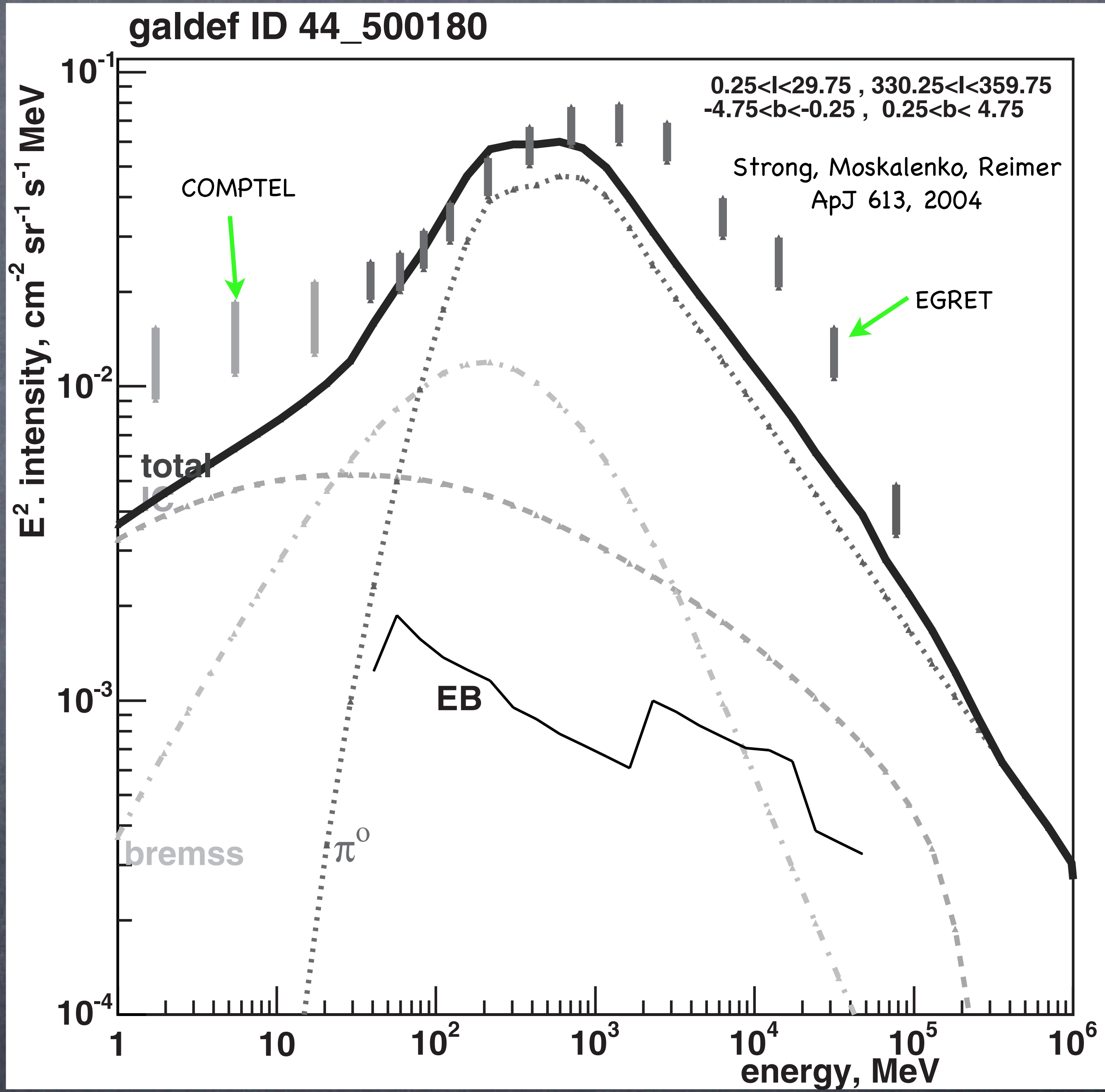
Courtesy of Seth Digel



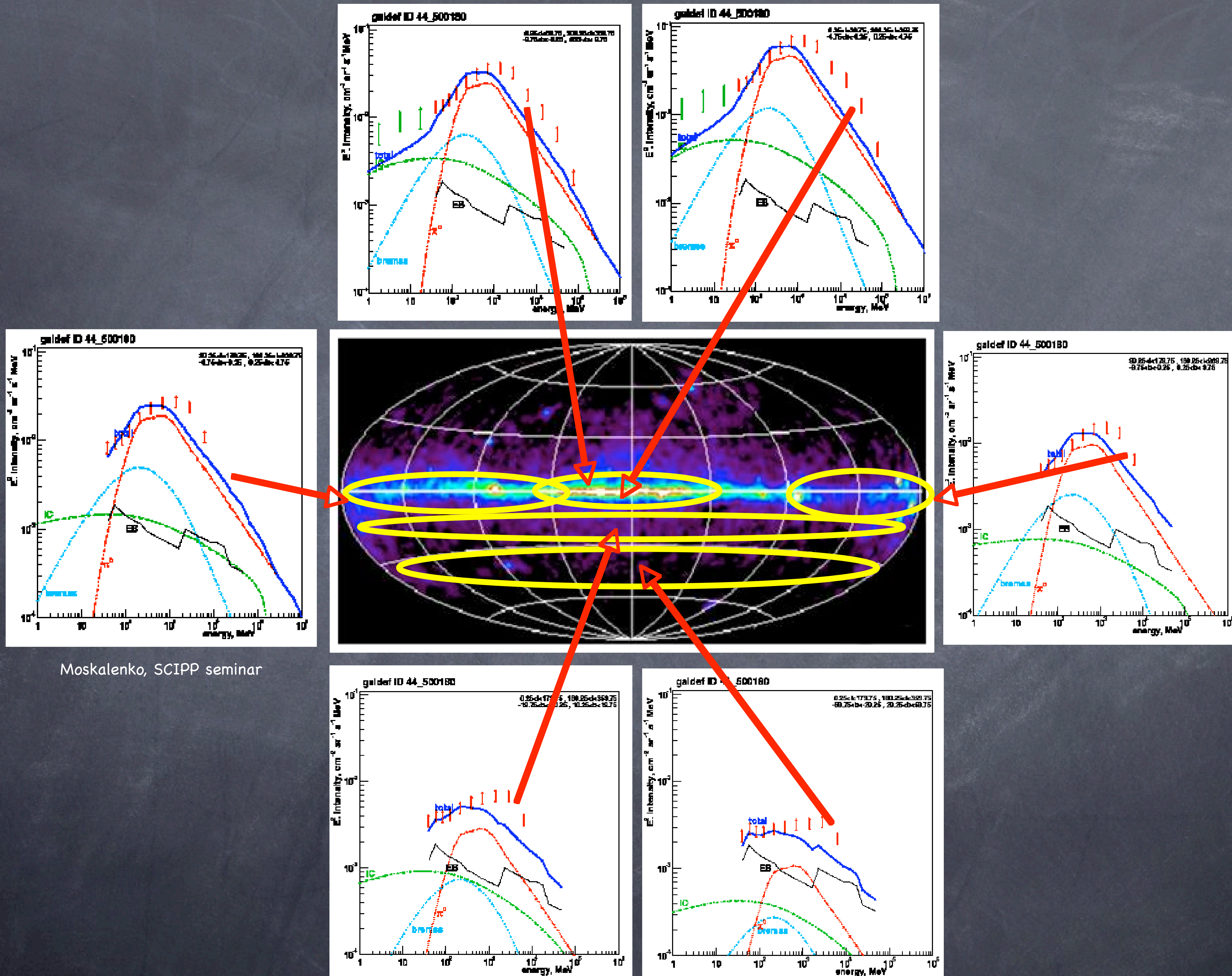
γ's from $e^{\pm}$ inverse Compton

The Galactic GeV Excess

- Hunter et al. published original EGRET Galactic diffuse gamma-ray emission in 1997, their measurement shows a clear excess from their models above 1 GeV
- Strong, Moskalenko, and Reimer have presented the conventional model based on their Galprop simulations
- Isotropic diffuse
  - Presumably extragalactic in origin
  - Over an order of magnitude lower in flux than Galactic diffuse



Model based on ISM observations, Cosmic ray component spectra, and well studied physical processes (bremsstrahlung, inverse Compton, pion decay); no attempt has been made to fit this model to the gamma ray observations.

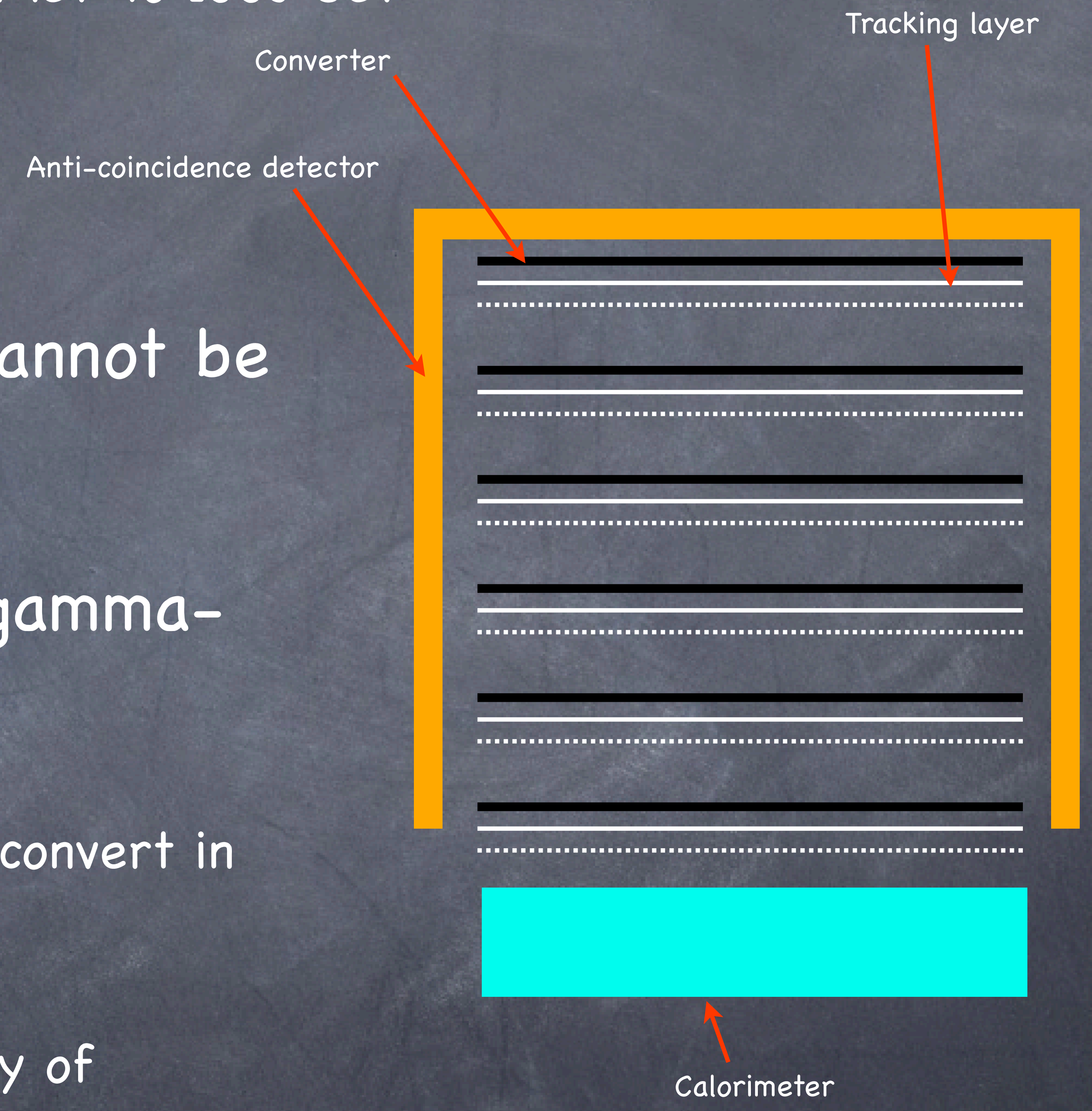


Moskalenko, SCIPP seminar

The GeV excess is observed across the sky

Gamma-ray Detectors

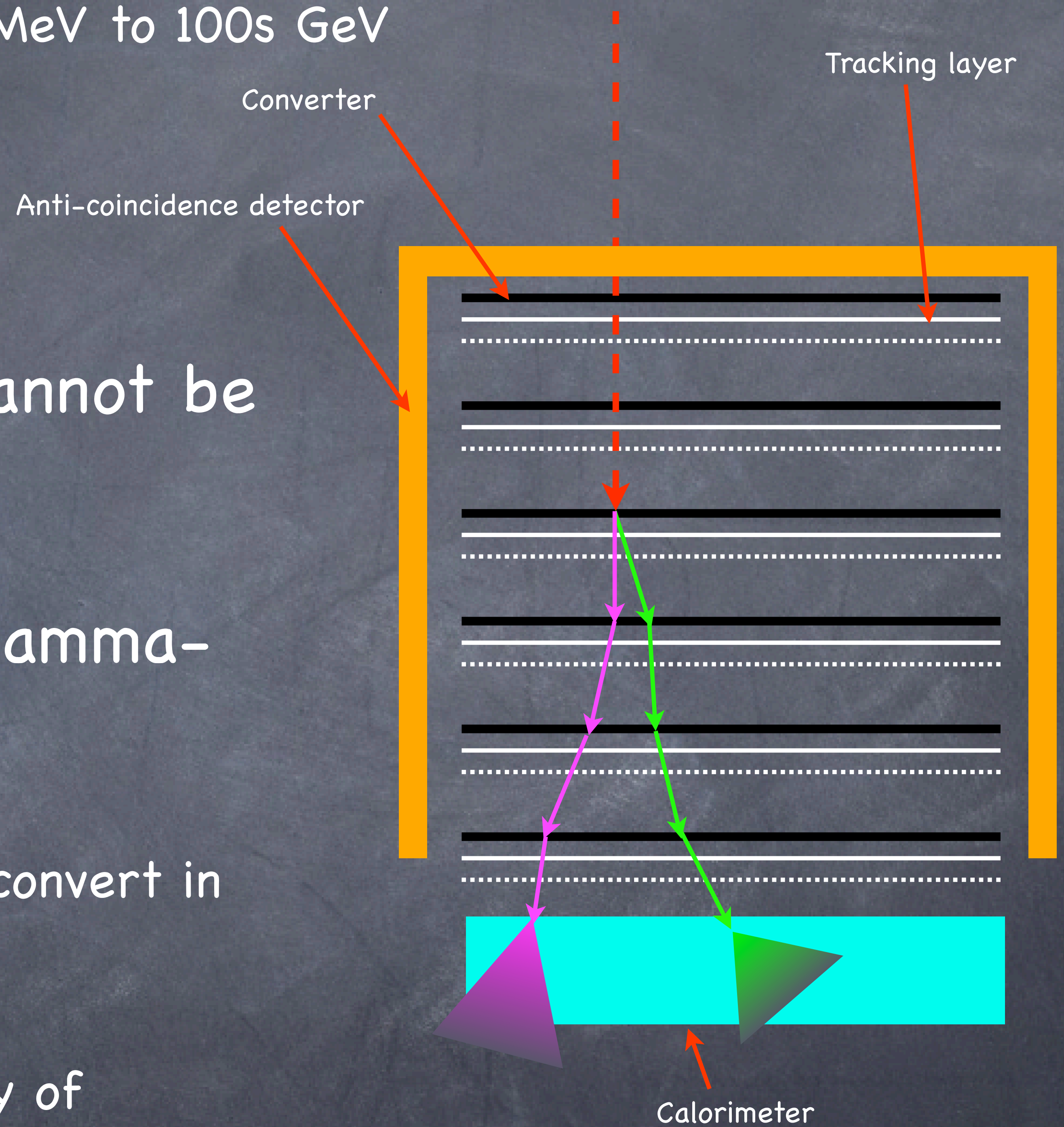
from 10s MeV to 100s GeV



- Gamma-rays' trajectories cannot be directly detected
- Reconstruction of original gamma-ray trajectories is possible:
    - $e^{\pm}$'s produced when gamma-rays convert in high Z materials(lead, tungsten)
    - $e^{\pm}$'s can be tracked with a variety of charged particle tracking technologies (spark wire chamber, silicon, etc.)

Gamma-ray Detectors

from 10s MeV to 100s GeV



- Gamma-rays' trajectories cannot be directly detected
- Reconstruction of original gamma-ray trajectories is possible:
  - $e^{\pm}$'s produced when gamma-rays convert in high Z materials(lead, tungsten)
  - $e^{\pm}$'s can be tracked with a variety of charged particle tracking technologies (spark wire chamber, silicon, etc.)

EGRET Detector

- EGRET launched aboard the Compton Gamma-Ray Observatory April 5, 1991 and was de-orbited on June 4, 2000

- EGRET consists of four main detector systems:
  - Anti-coincidence dome
  - Spark chamber tracker
  - Time of flight
  - NaI calorimeter

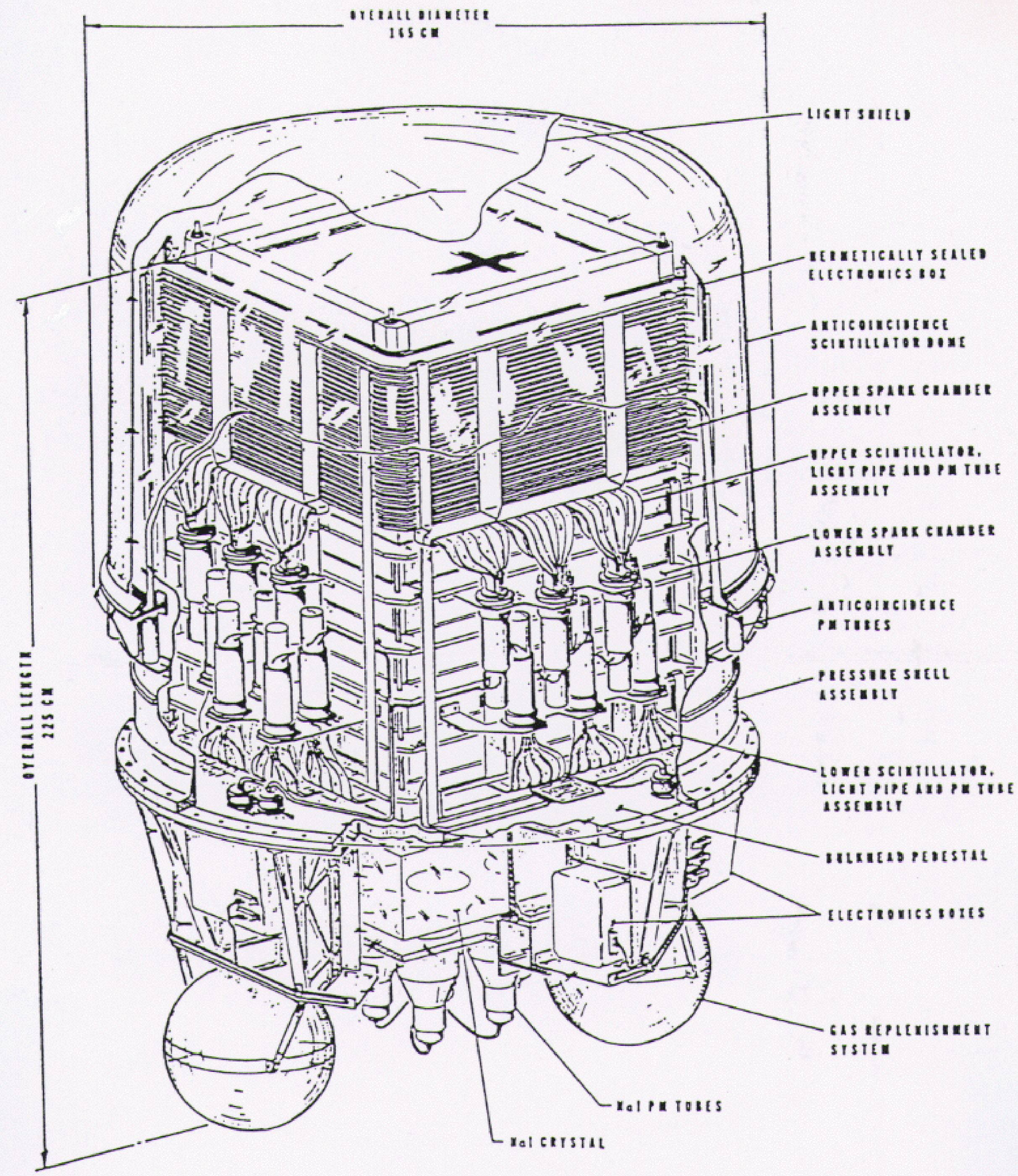


Figure IV-1. The EGRET Instrument

Courtesy of the EGRET collaboration

Characterization of the EGRET Detector

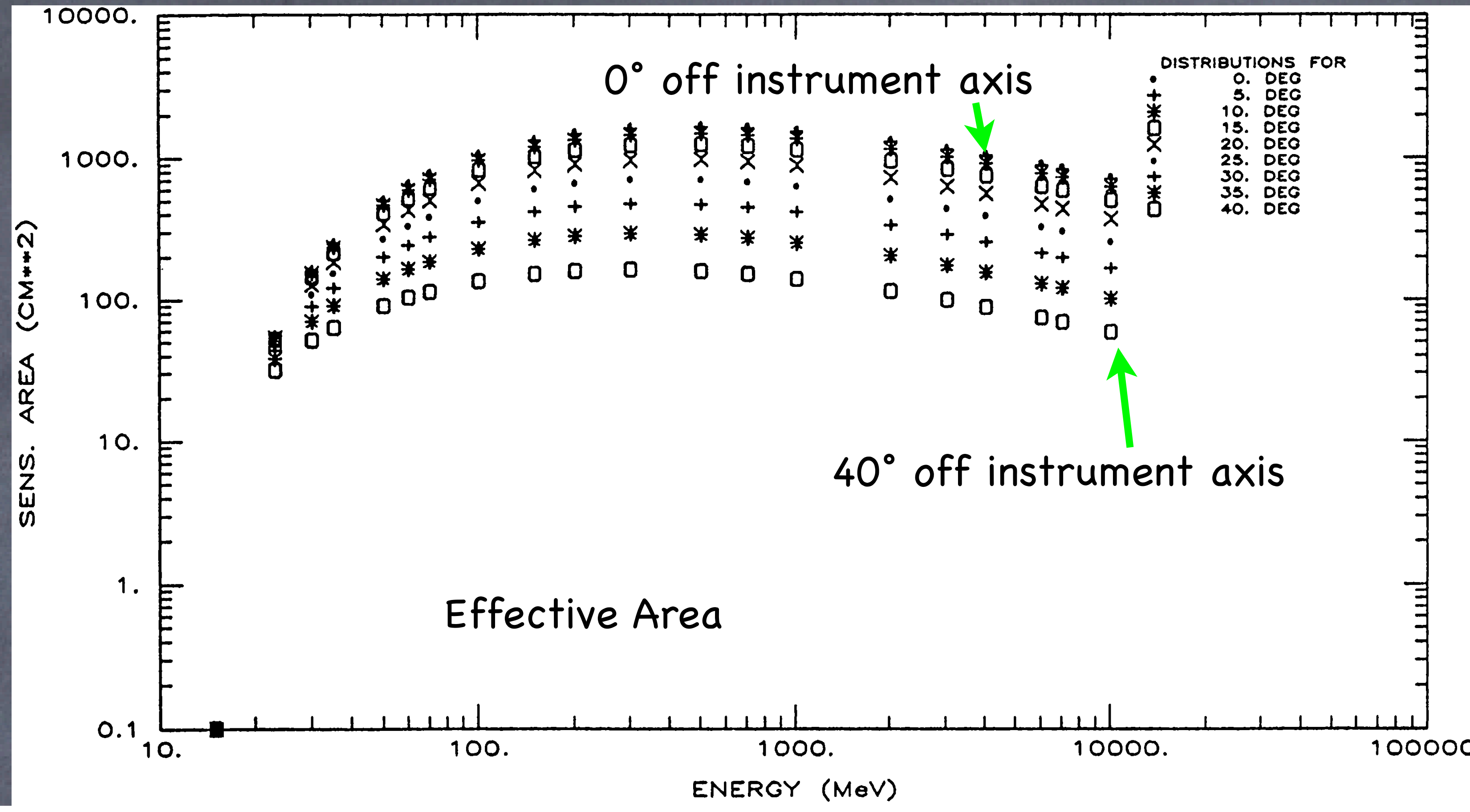
- Mapping of EGRET's instrument response occurred at two primary facilities: Stanford Linear Accelerator Center and Bates Linear Accelerator

- Goal of systematically mapping the instrument response functions (IRFs)

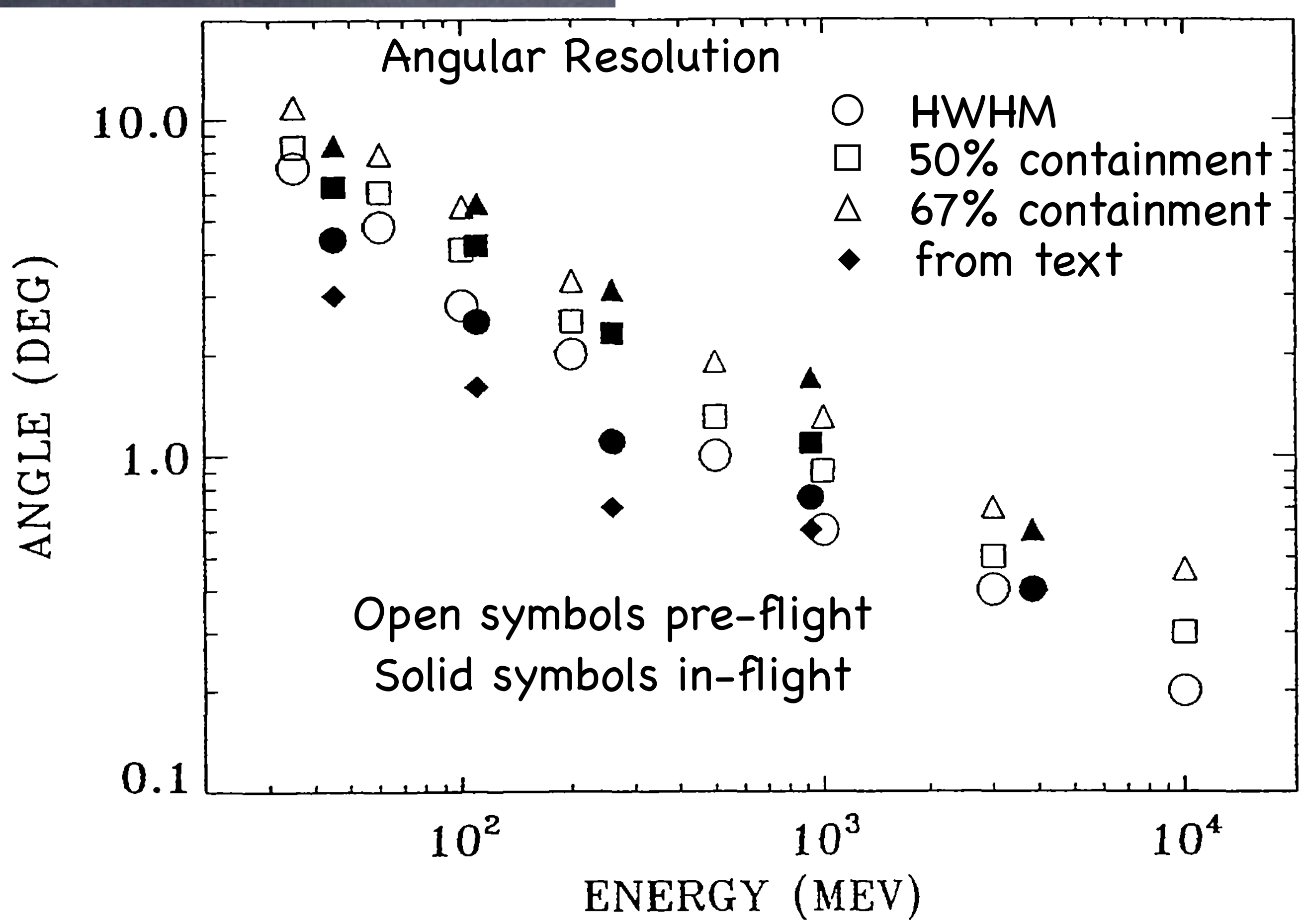
Courtesy of the EGRET collaboration, via Dave Thompson

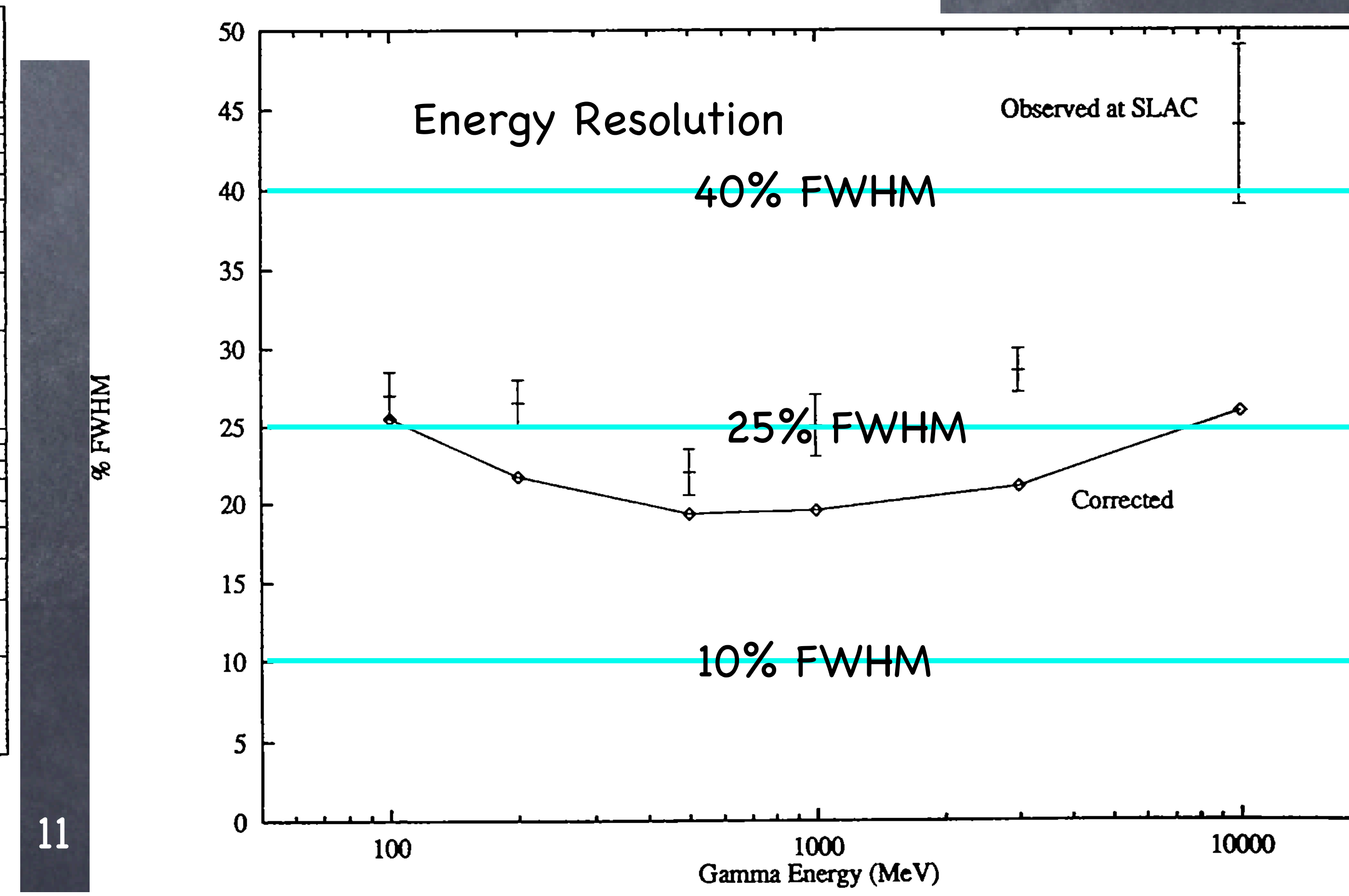
10

SLAC Beam Test



Thompson et al. ApJS, 86:629-650 1993 June





Bates Beam Test

- Re-calibrate IRFs
  - Calibrate newly optimized spark-chamber performance
  - 20 keV (SLAC value) and 100 keV (new value) A-dome veto thresholds tested
    - 5.7±2% increase in effective area was measured at 790 MeV with the new 100 keV A-dome veto threshold
  - Calibrate rebuilt portions of instrument

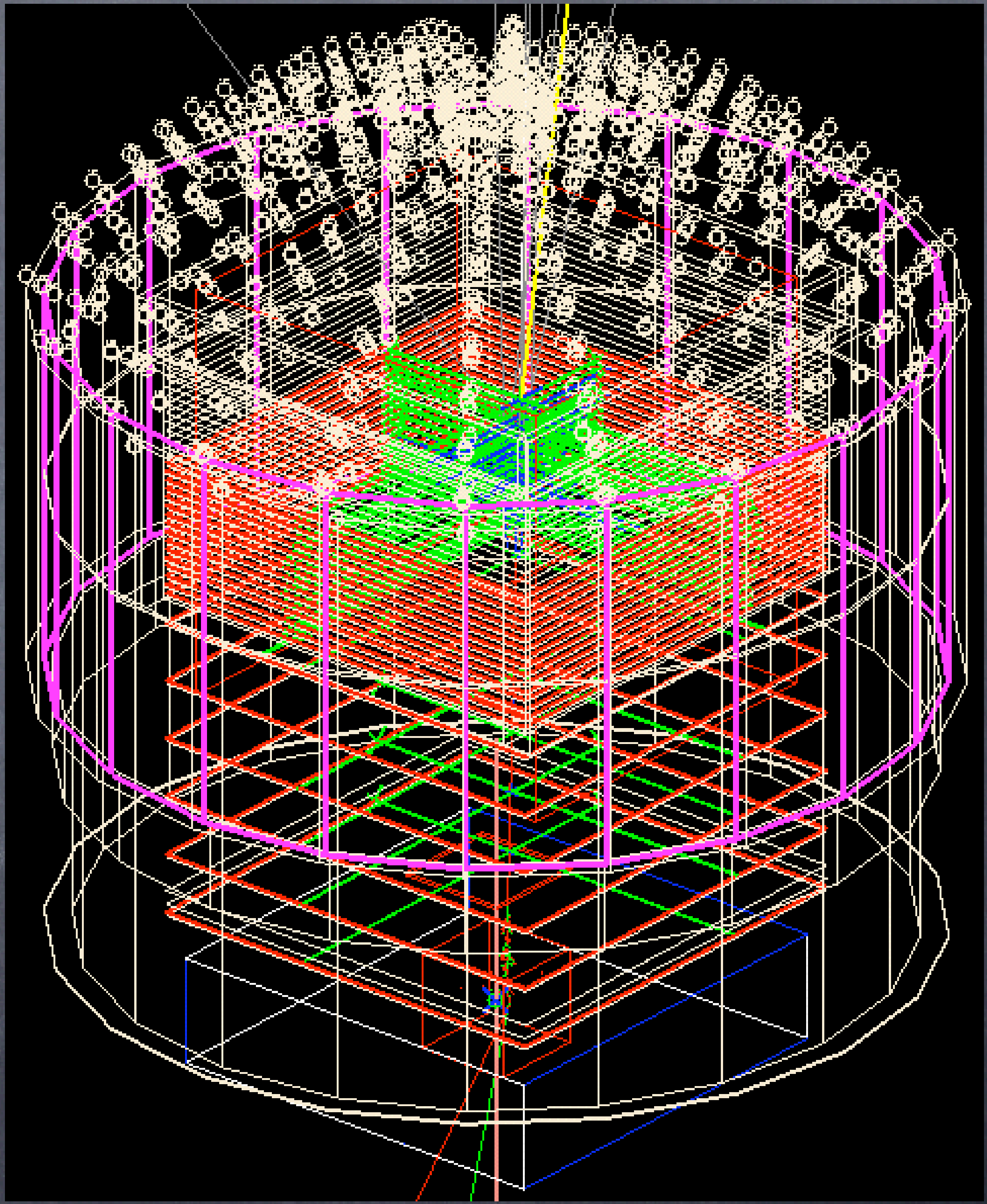
12

Simulation of EGRET

- There have been no published Monte Carlo simulations of the EGRET tracker
- While the BATSE team has published results from a GEANT3 simulation of CGRO, their simulations were not adapted for use with EGRET

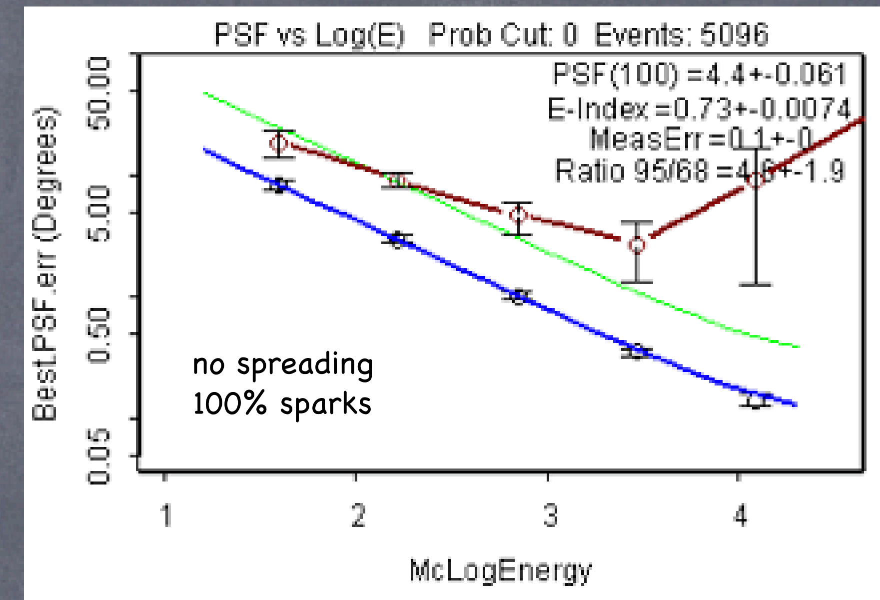
Simulation of EGRET

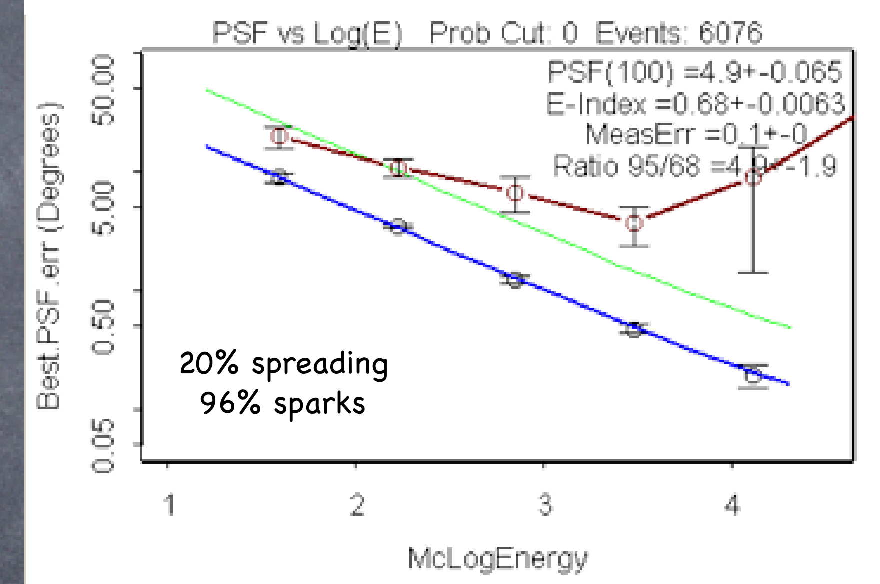
- Uses the simulation framework developed for use with GLAST
  - GEANT4 based physics with multiple scattering corrections
- I have created a detailed model of the EGRET instrument
- Accounted for many instrumental effects
  - Layer efficiency
  - Spark spreading
  - A-dome light attenuation

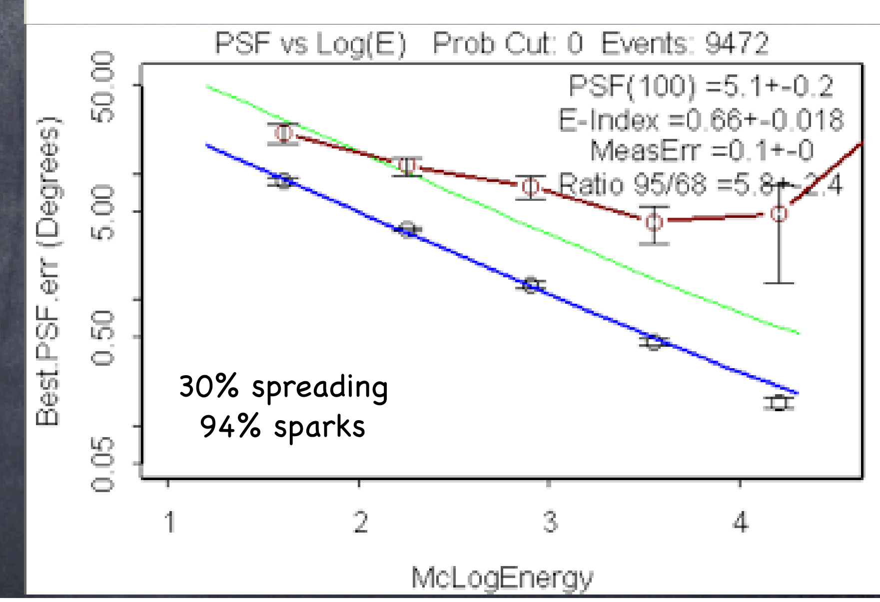


Layer Efficiency and Spark Spreading

- Layer/Spark efficiency
  - Greatly affects the quality of reconstruction which can be accomplished
  - If any one of the first few sparks are missing then the reconstruction is generally poor
  - Does not have large effect on number of tracks found
- Spark Spreading
  - While measurable from the EGRET data and implemented in our simulations spark spreading has little quantitative effect on the results



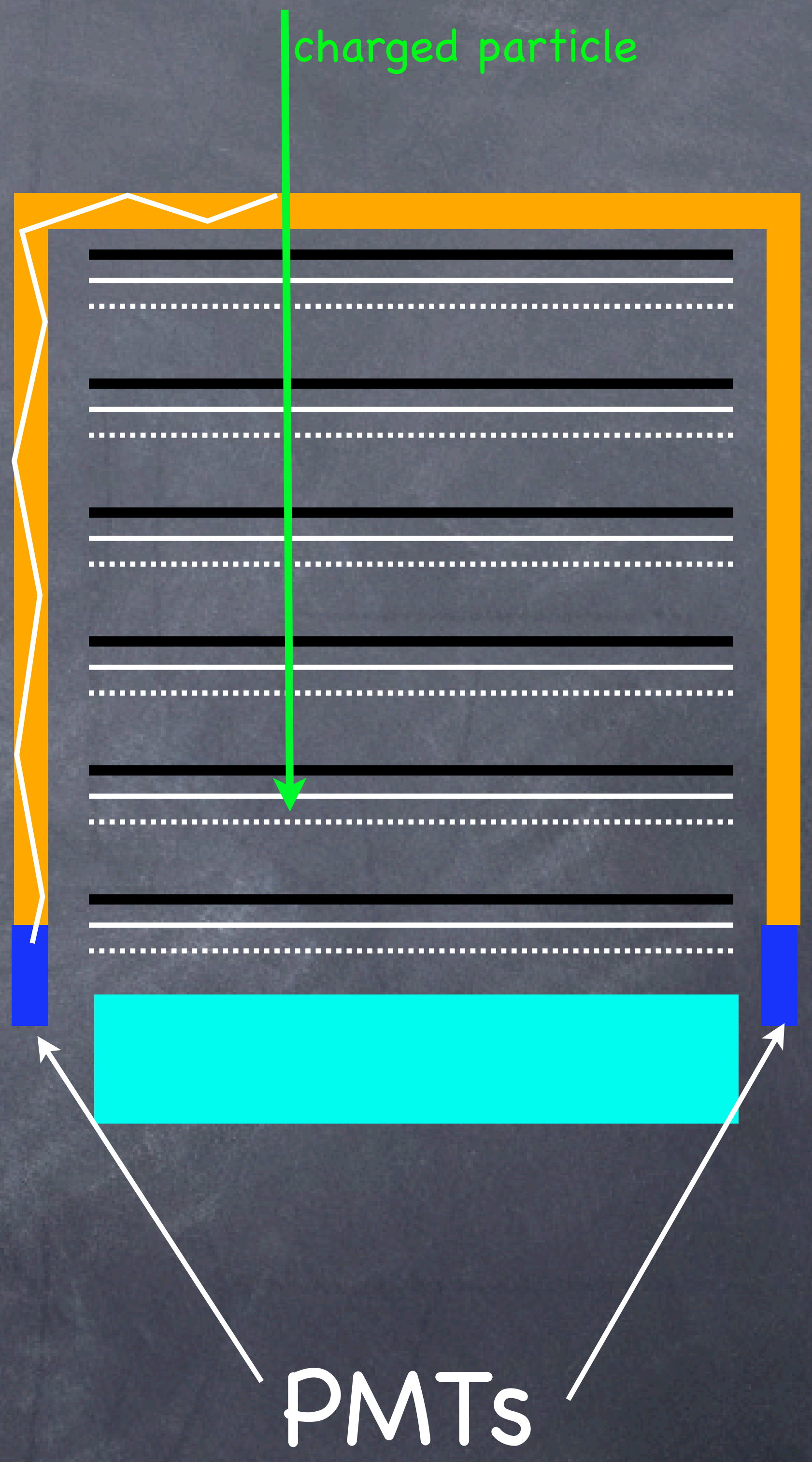




15

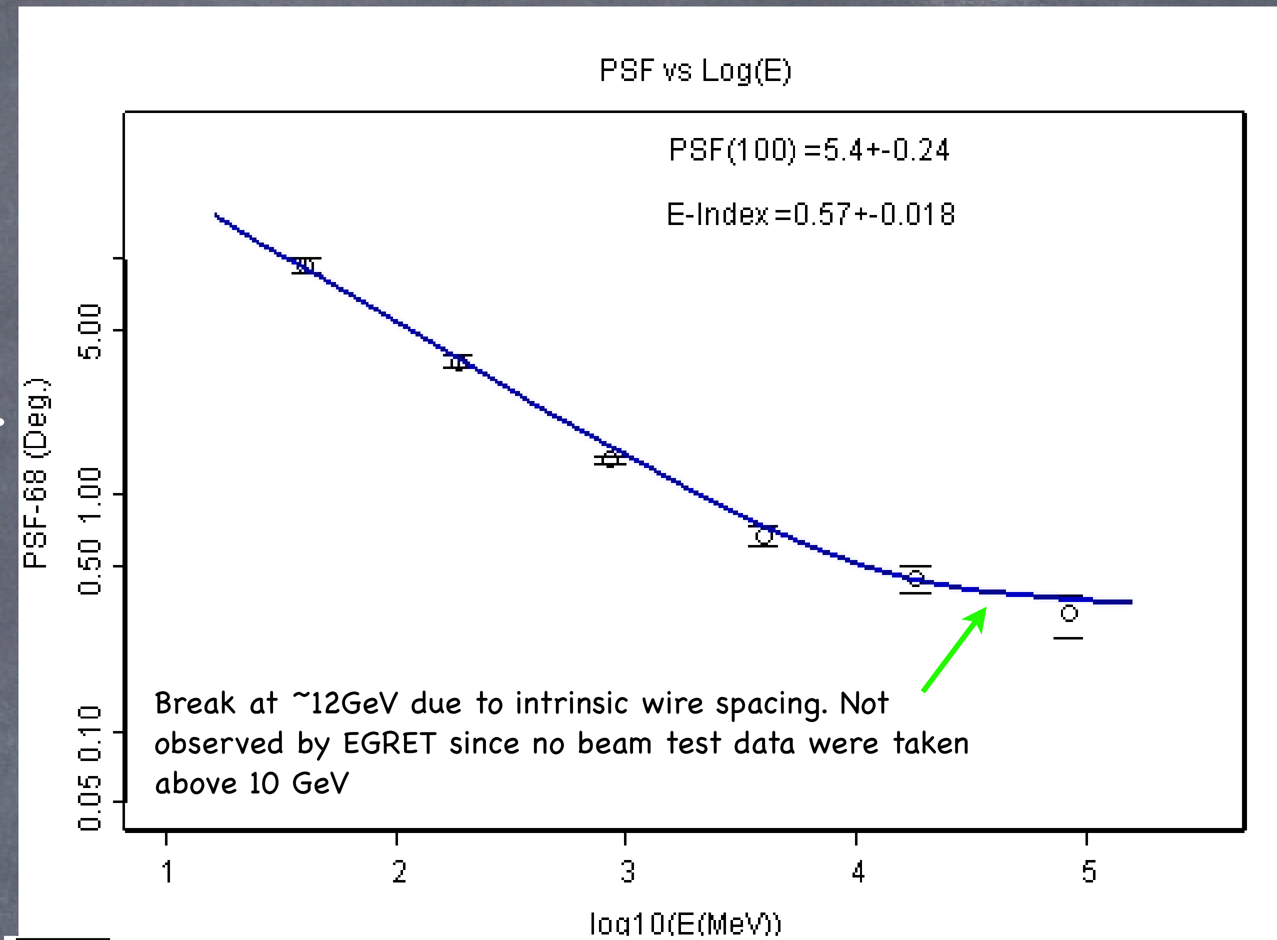
A-dome Light Attenuation

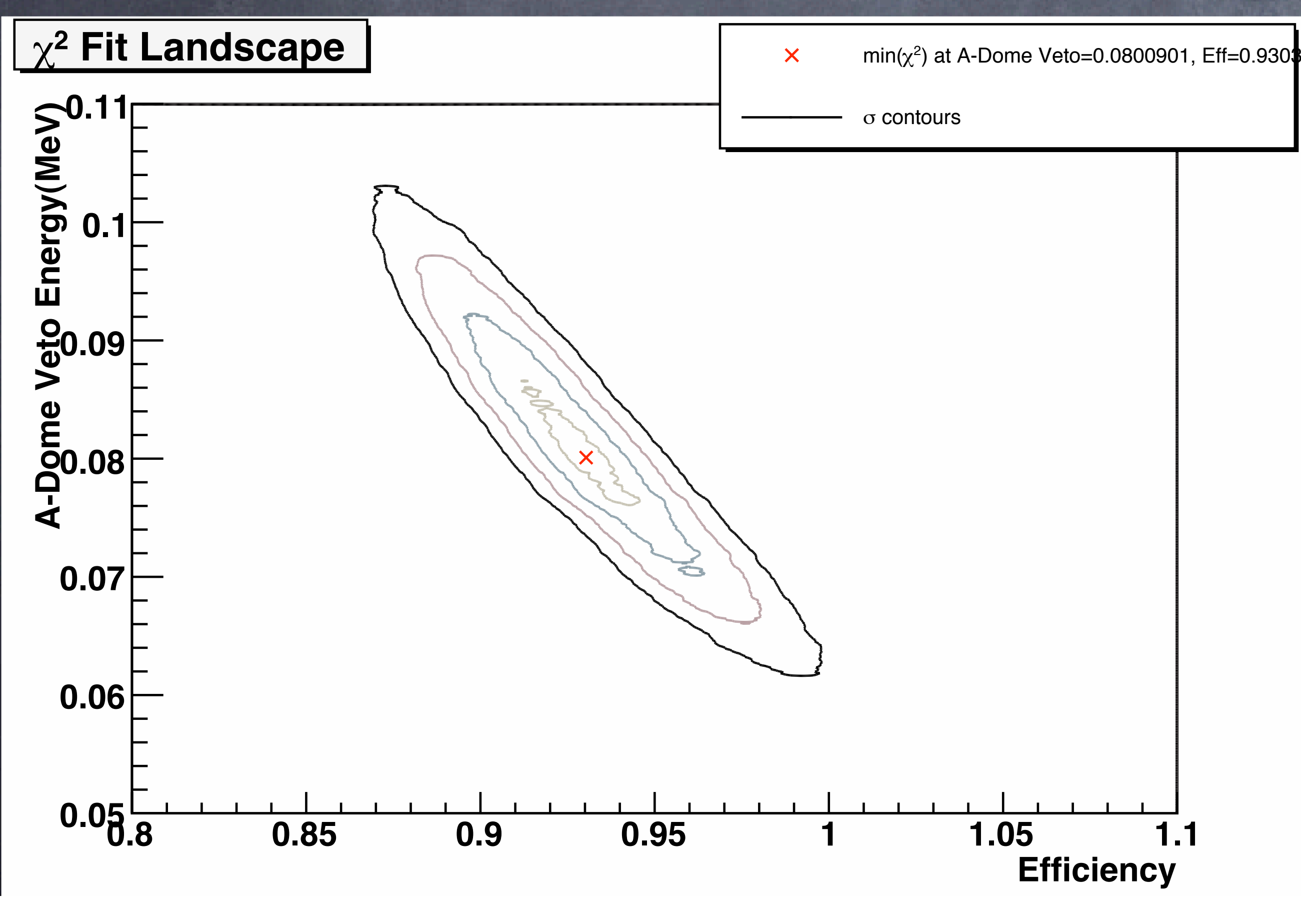
- When particles interact with the A-dome and deposit energy they do not generally deposit it close to the PMTs used to measure it
- As the light travels through the scintillator it is attenuated
- I have modeled this attenuation in our simulations
  - Exponential fall off for shortest distance to bottom of A-Dome (where the light measurement is taken)
  - Overall efficiency at interface of dome with cylinder

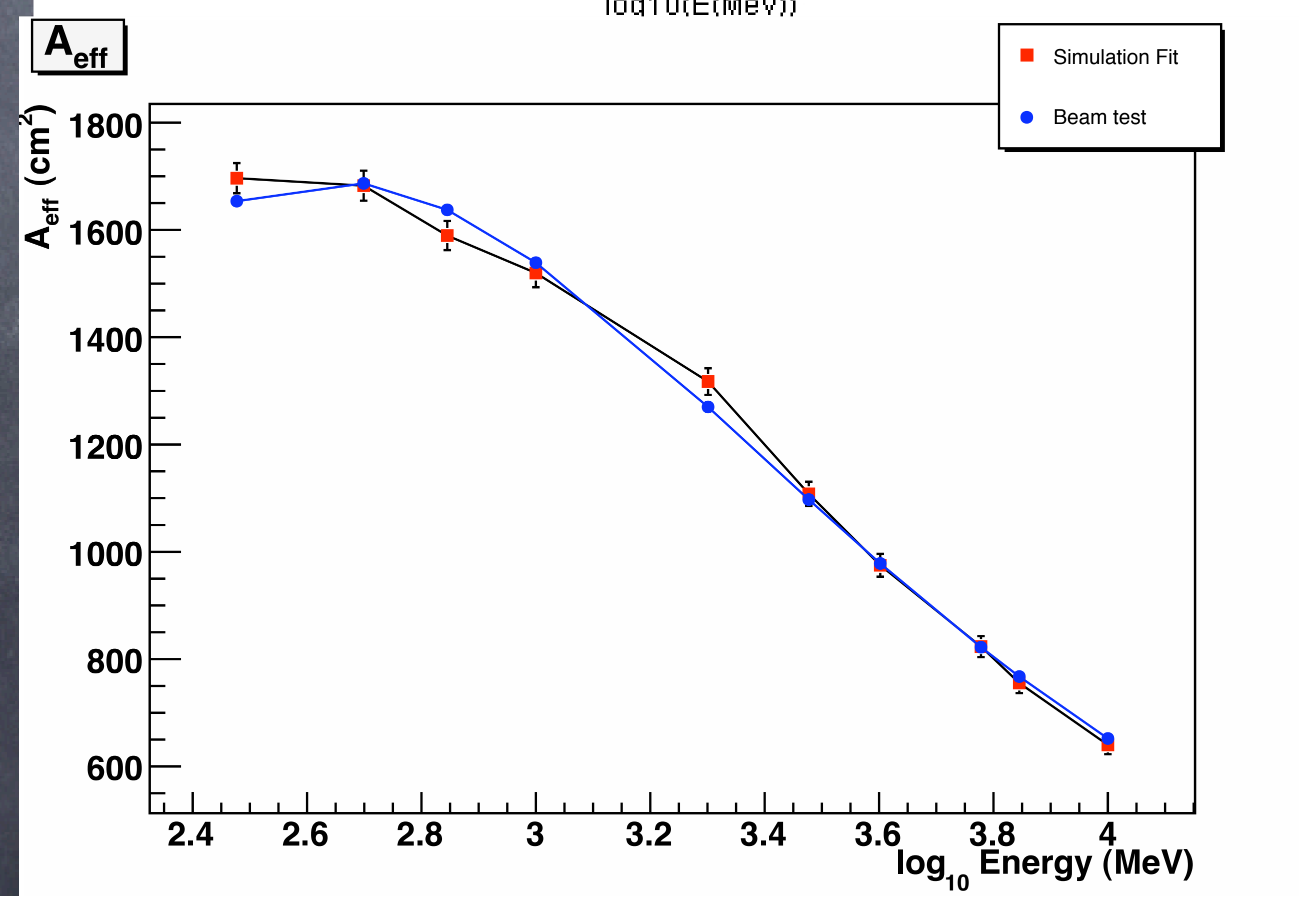


Validation of Simulations

- Using SLAC beam test geometry
- Point Spread Function (PSF) measured PSF(100)=5.85 and E-index 0.534
- Effective area, fit using two parameter fit: efficiency and A-dome veto threshold



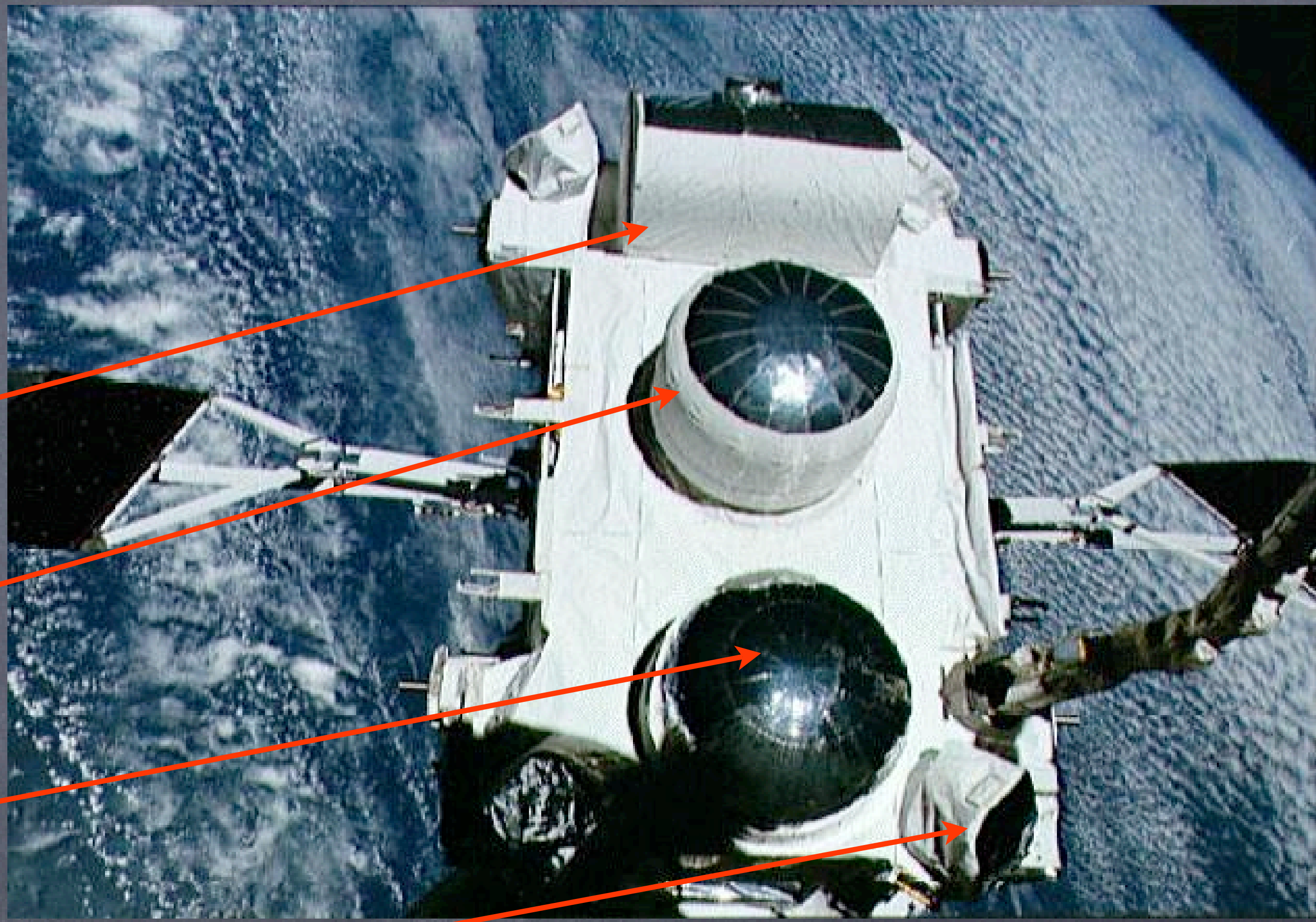




17

EGRET in Orbit

- When in orbit EGRET was onboard the Compton Gamma-ray Observatory(CGRO)
  - OSSE
  - COMPTEL
  - EGRET
  - BATSE

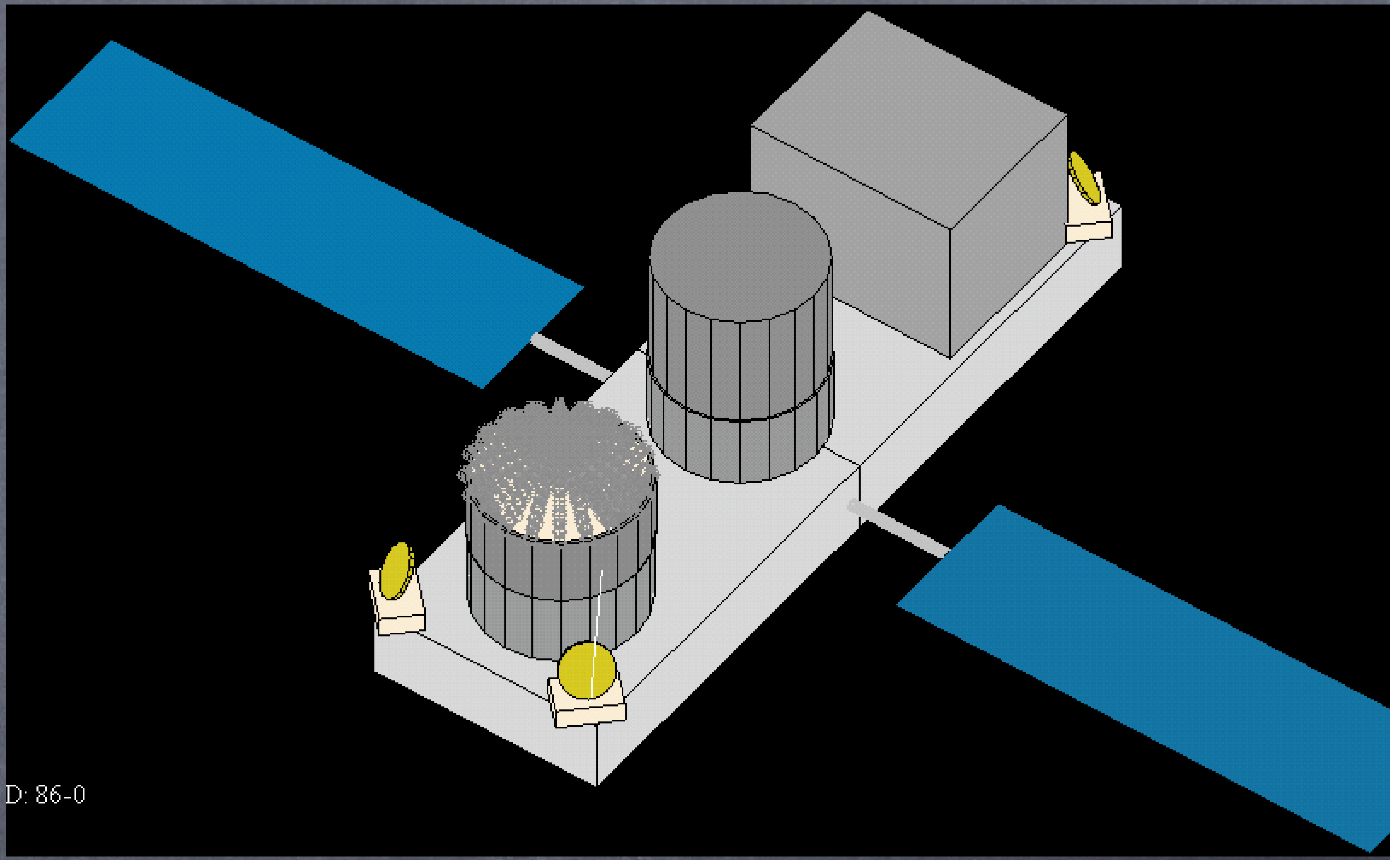


Courtesy of the EGRET collaboration

18

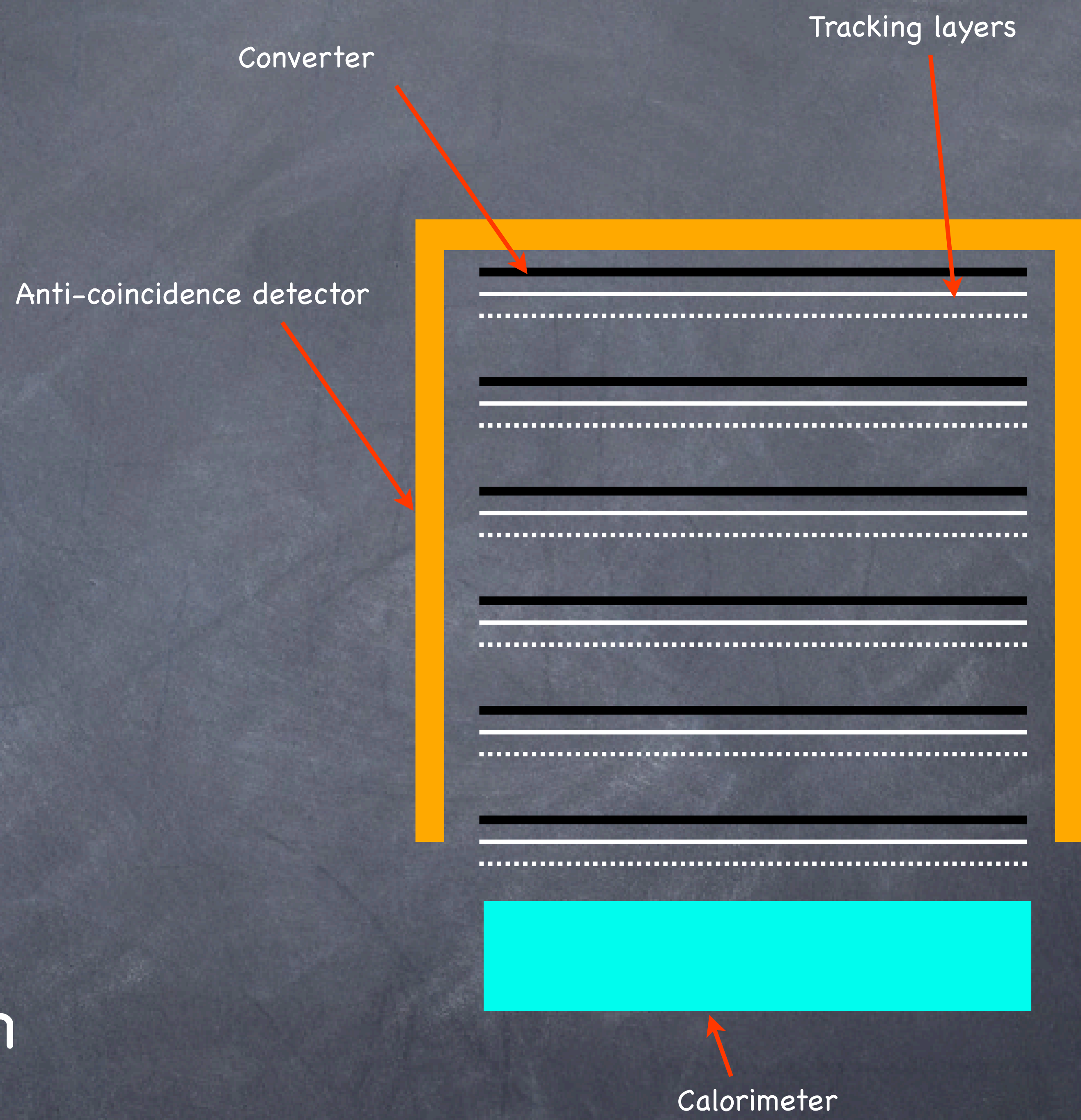
Accounting for CGRO

- Current simulations use a simple block model for CGRO
  - Has proper mass and average density
- COMPTEL and OSSE
  - General shape and average density were used
- BATSE
  - NaI scintillators with base
  - Expected to have minimal effect on self-veto



Measuring Self-veto

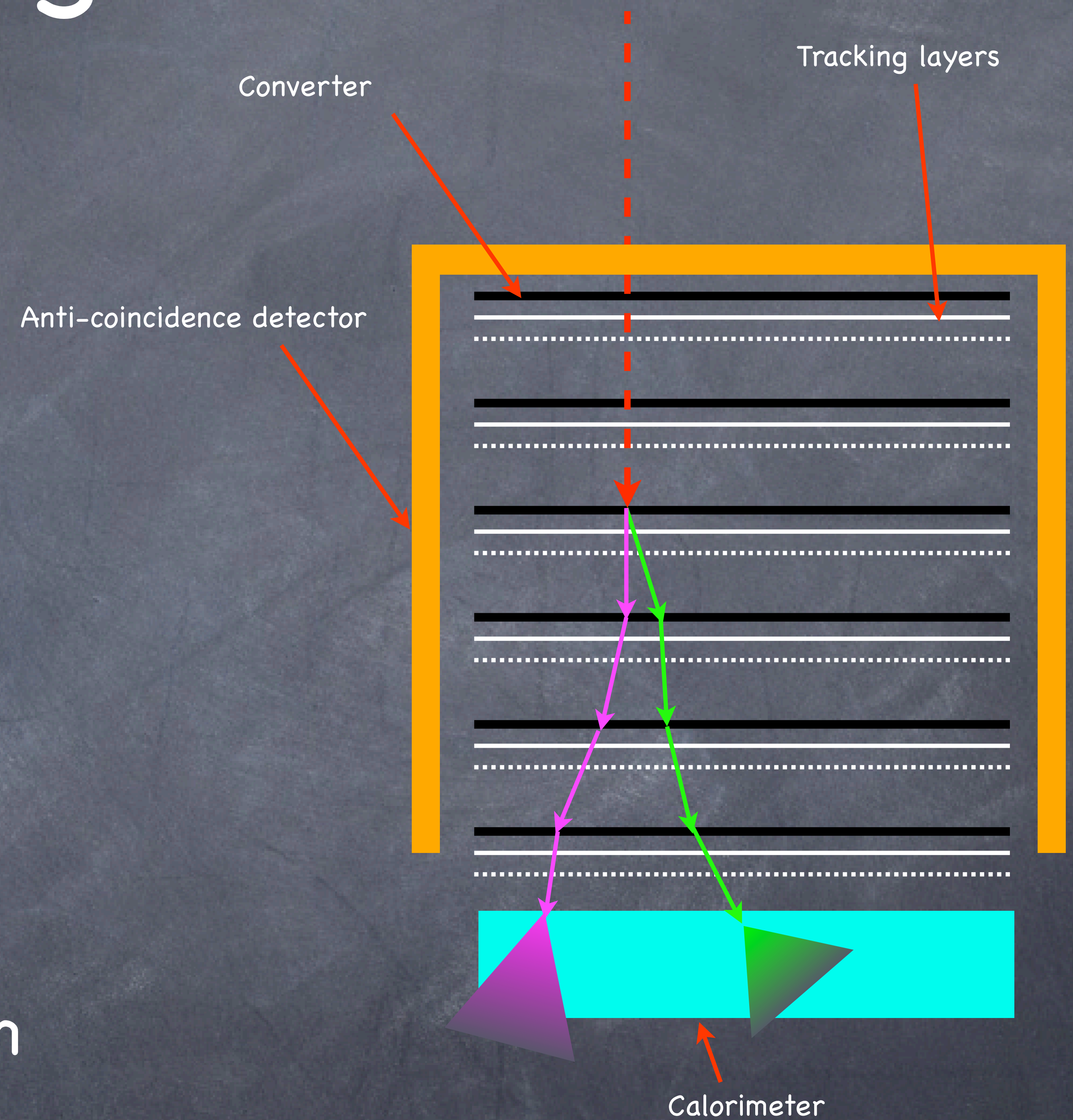
- Self-veto was observed at SLAC beam above 1 GeV
- Self-veto occurs when a gamma-ray converts within the tracking volume and a secondary particle, usually x-ray, causes a trigger in the Anti-coincidence system



20

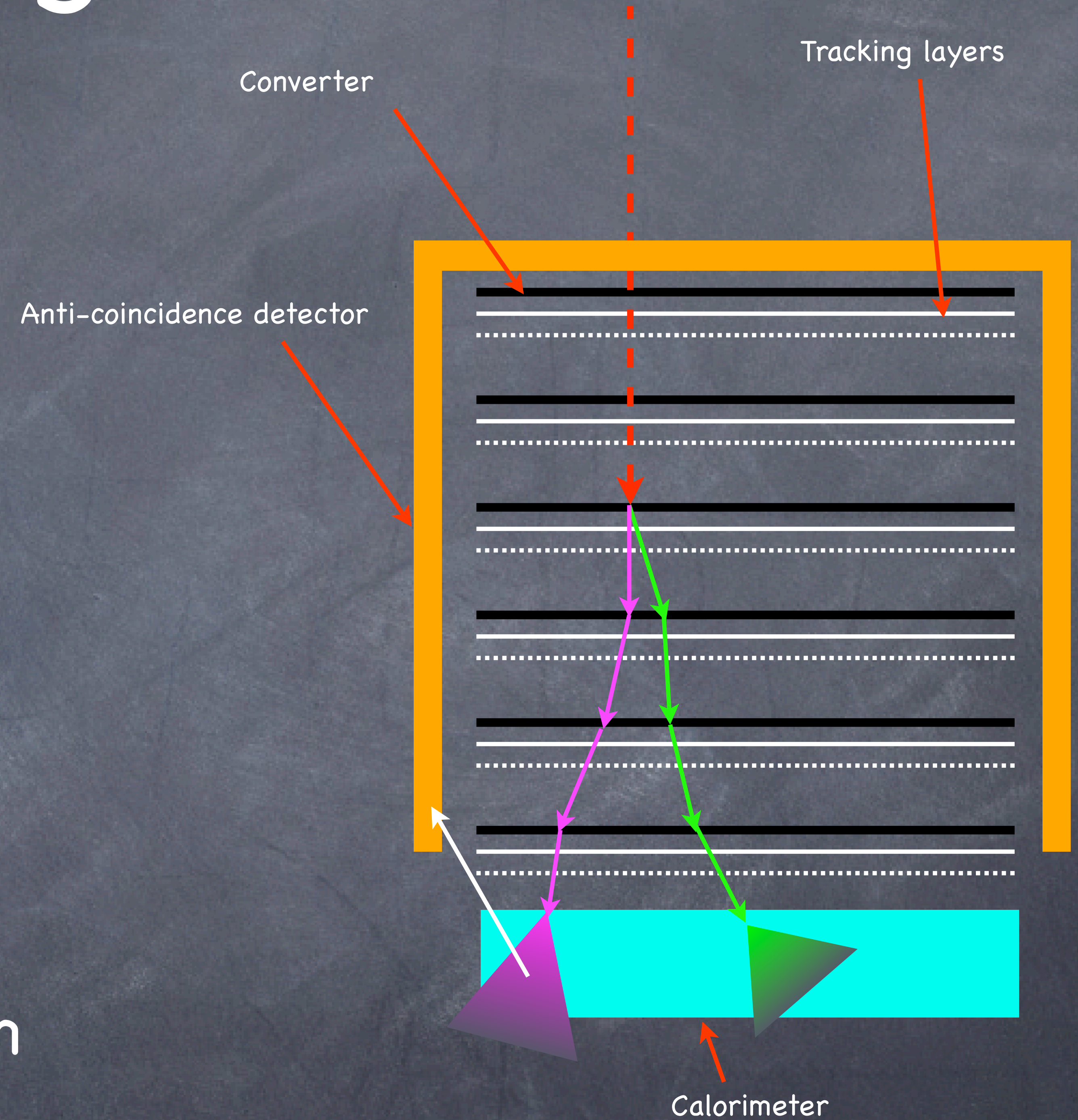
Measuring Self-veto

- Self-veto was observed at SLAC beam above 1 GeV
- Self-veto occurs when a gamma-ray converts within the tracking volume and a secondary particle, usually x-ray, causes a trigger in the Anti-coincidence system



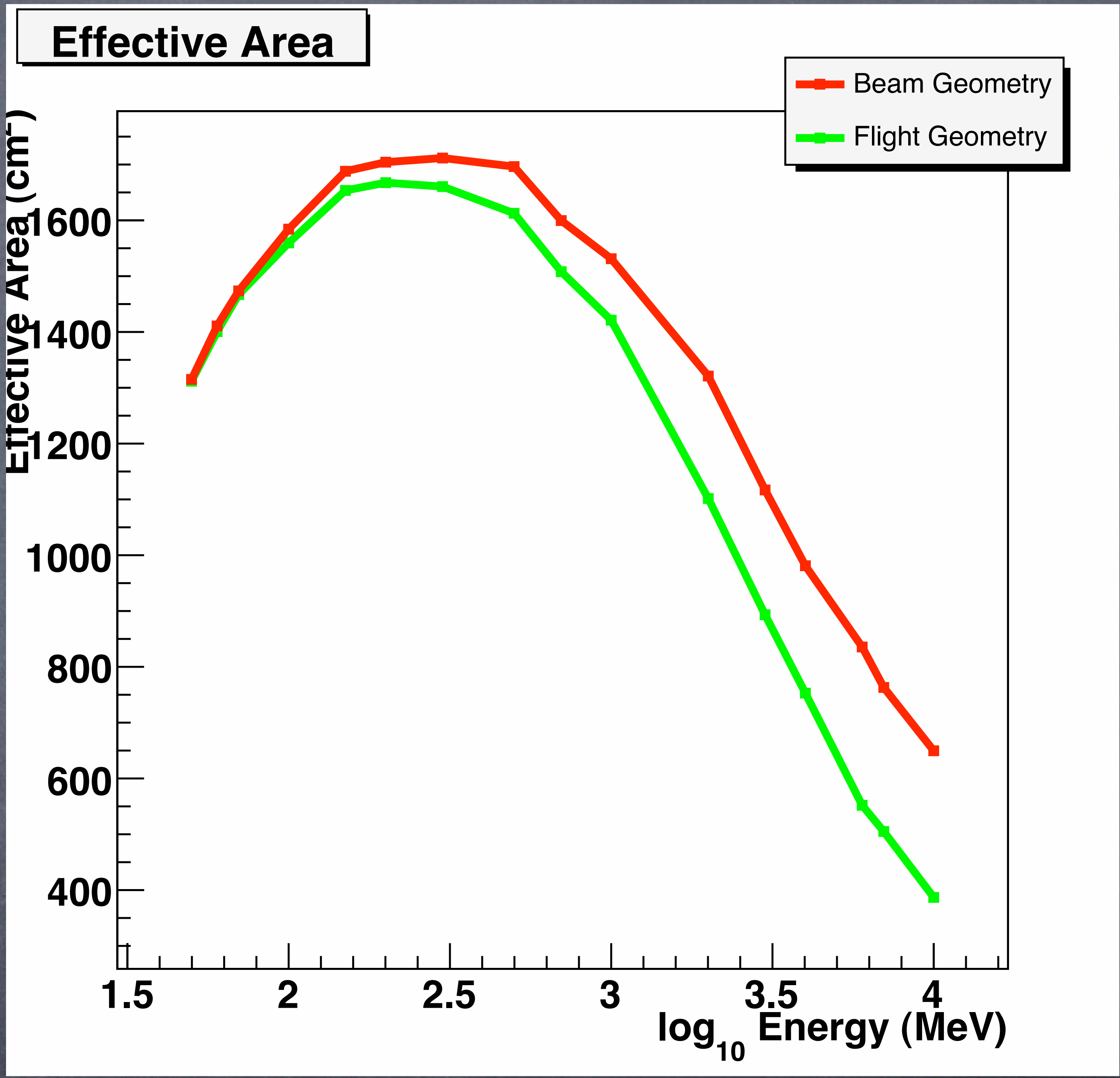
Measuring Self-veto

- Self-veto was observed at SLAC beam above 1 GeV
- Self-veto occurs when a gamma-ray converts within the tracking volume and a secondary particle, usually x-ray, causes a trigger in the Anti-coincidence system



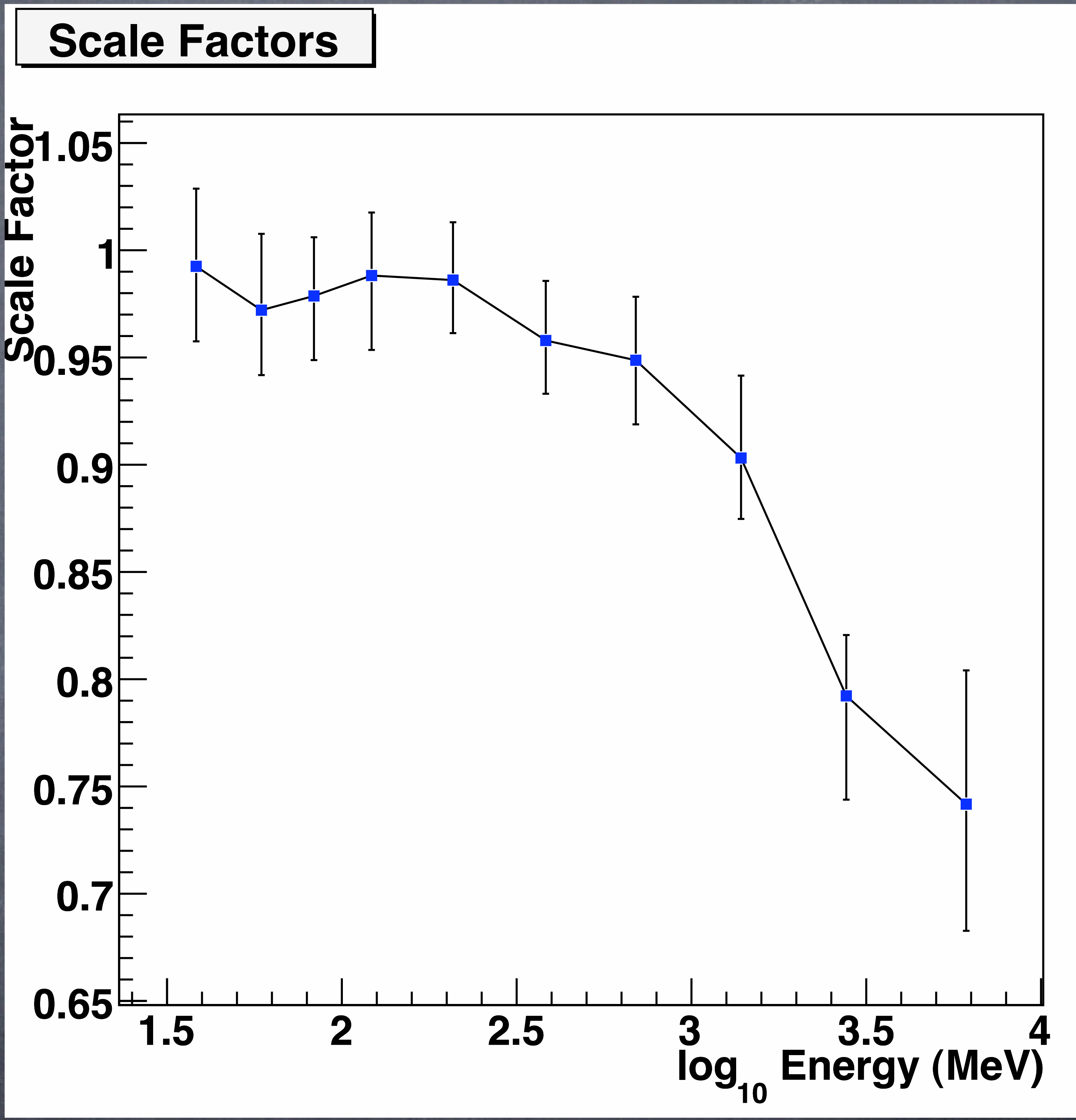
Measuring Self-veto

- Plotted to the right is the number of effective area vs. energy
- The red line for the beam geometry and the green with for the flight geometry



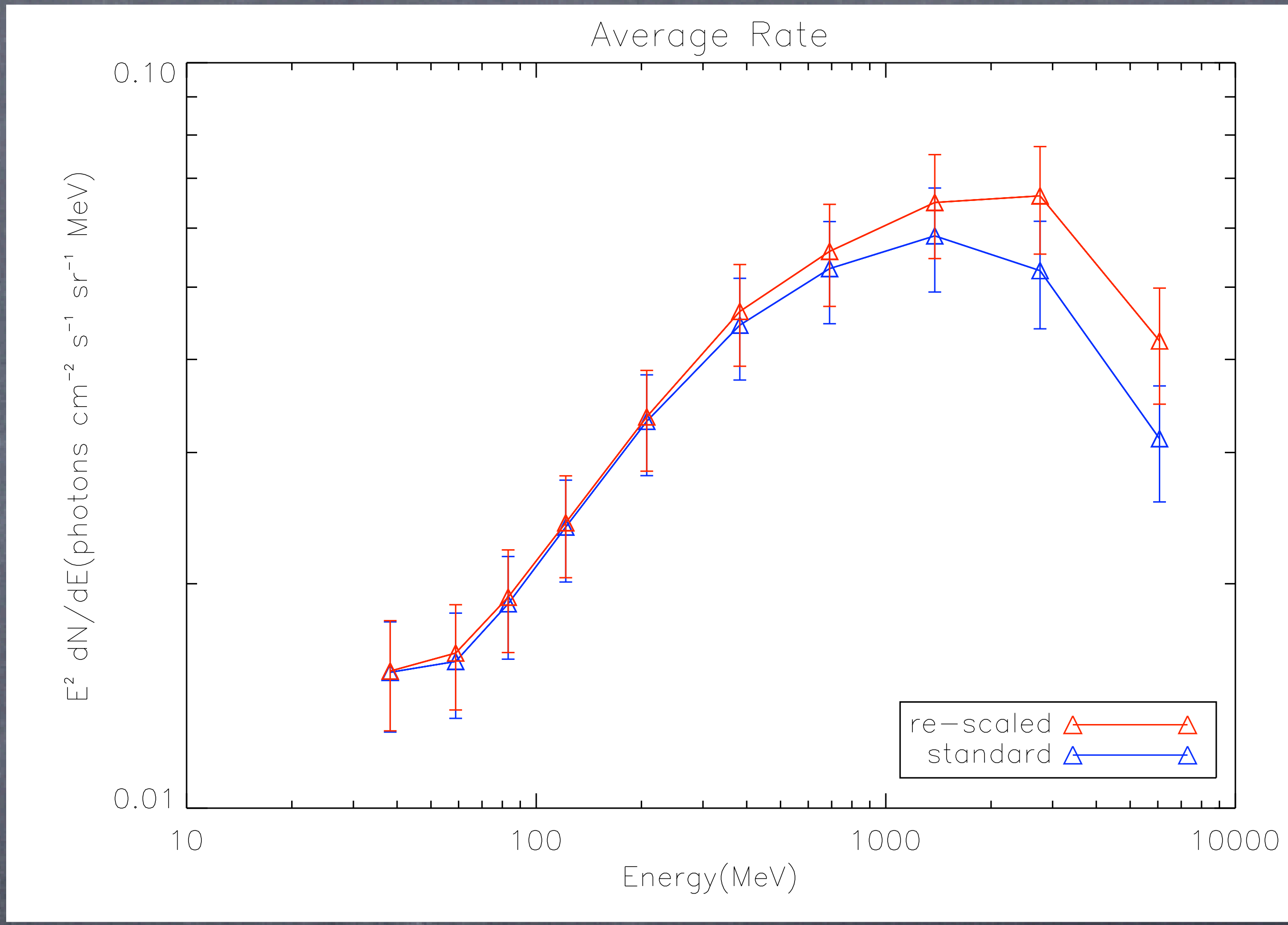
Correcting for Self-veto

- Generated 200k events in $E^{-2.1}$ for each of EGRETs 10 small energy bins in both beam and flight geometries
    - $E^{-2.1}$ used to properly weight scaling factors
- Applied beam fit A-dome veto threshold
- Calculated ratio of tracked, non-vetoed events, found in flight geometry to those found in beam geometry



Diffuse Emission from the Inner Galaxy

- Applying the found scaling factors to the corresponding EGRET exposure maps allows for calculation of new fluxes
- The plot to the right shows both the original and re-scaled E^2 flux for the inner Galaxy

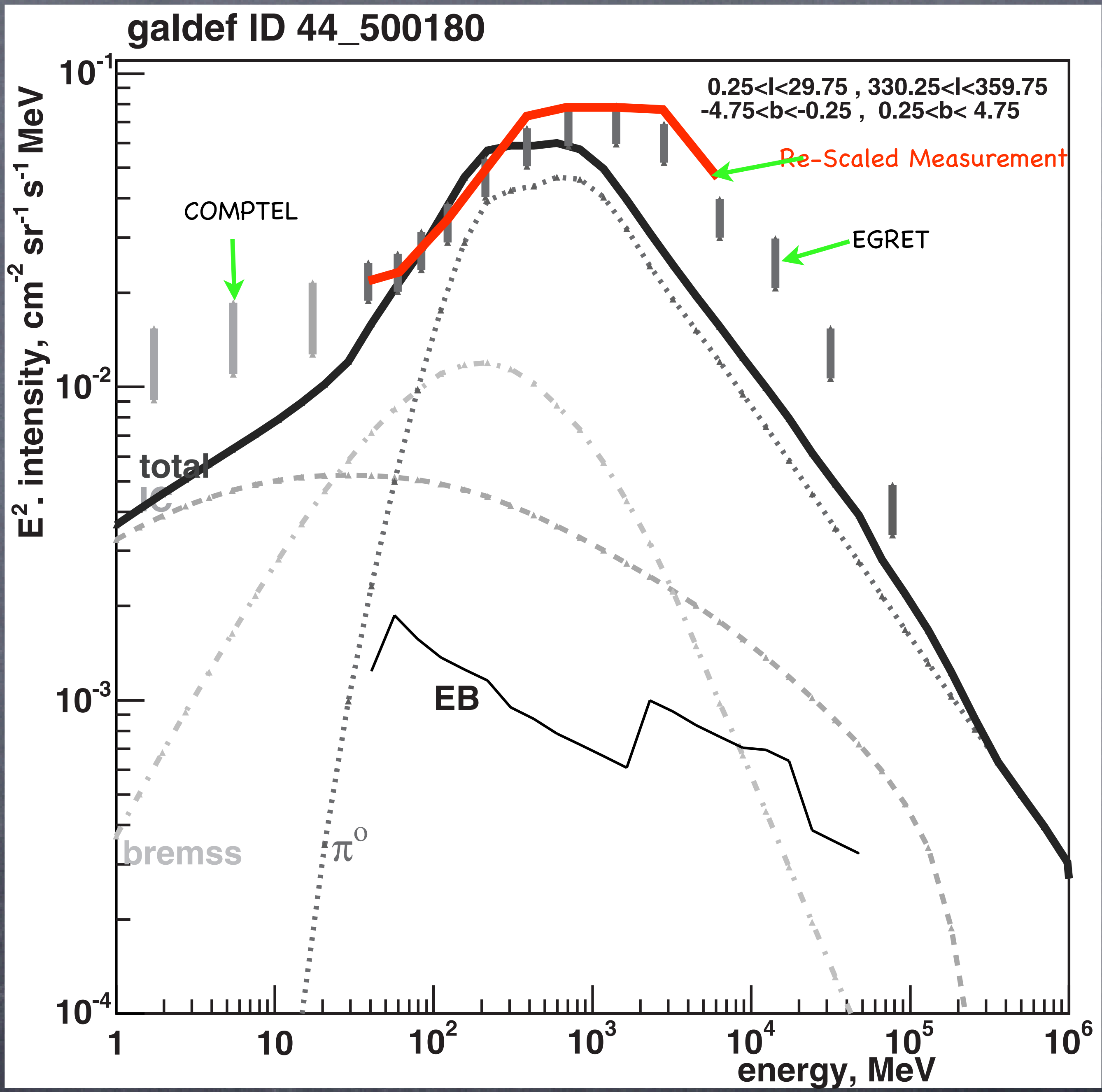


Exacerbating the GeV Excess

- Many theories have been put forth recently to explain the GeV excess none have yet to be commonly accepted

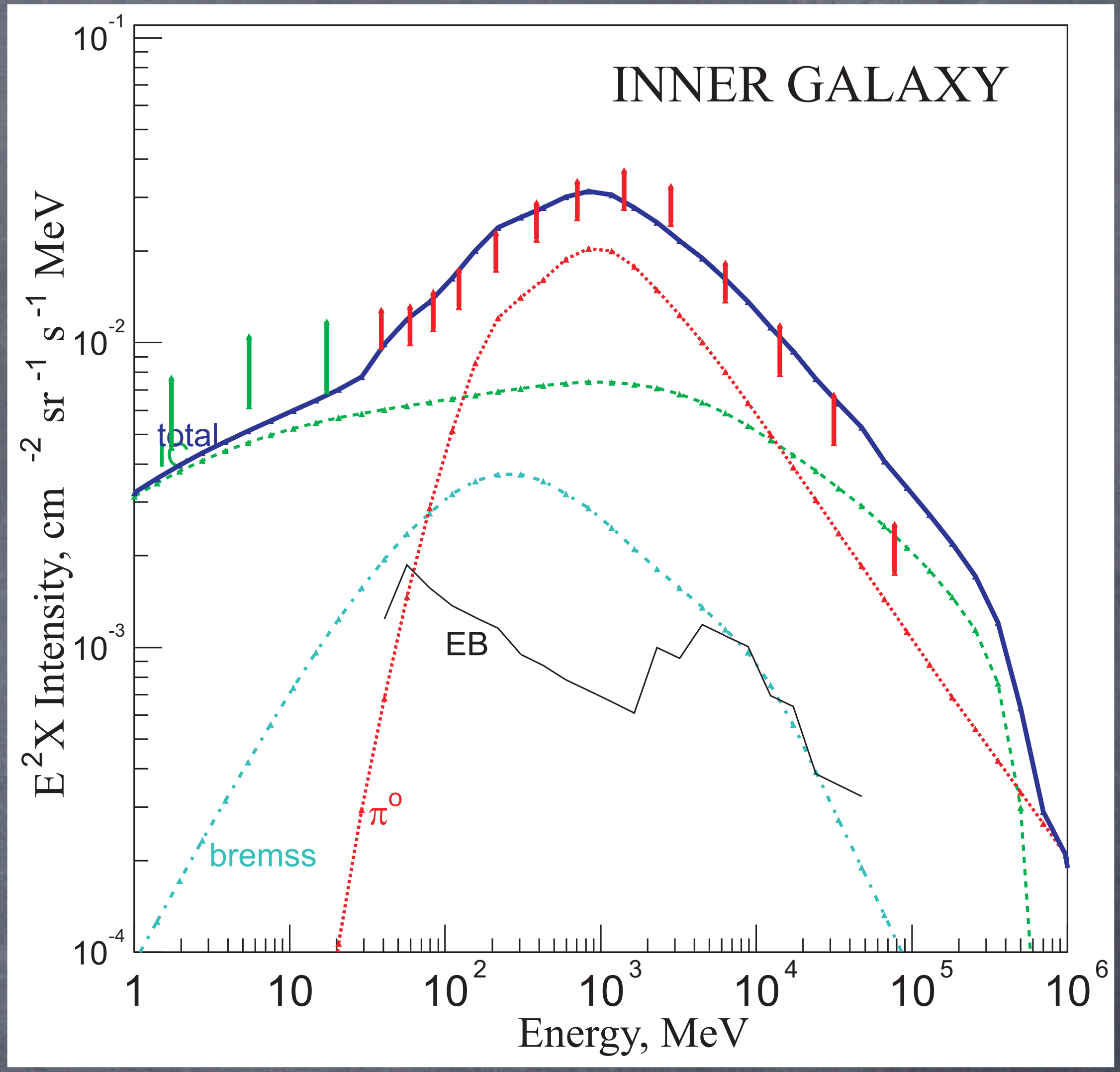
- I thought that properly accounting for instrumental effects might reduce the discrepancy, instead there appears to be the opposite effect

Strong et al. ApJ, 613:962 - 976, 2004 October



Possible Physical Explanations

Strong, Moskalenko, Reimer ApJ 613, 2004

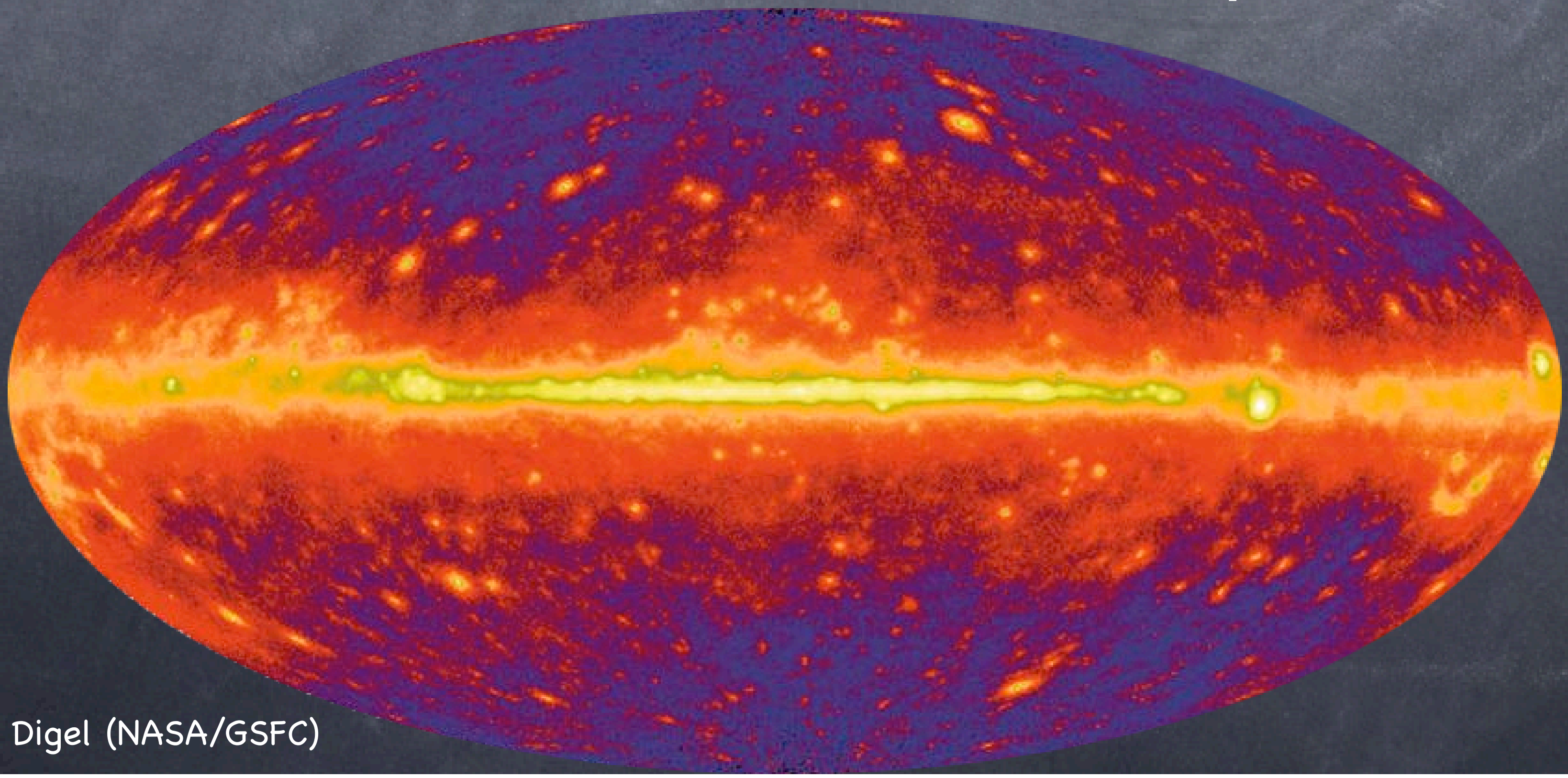


- Instrumental effects aside there have been some physical explanation proposed
  - It has been suggested that significant increases in inverse Compton emission would better fit the observations (Mori, ApJ 478, 225 (1997); Porter and Protheroe, JPhysG 23, 1765 (1997); Strong et al., ApJ 537, 763 (2000))
  - Unresolved sources: Pulsars, TeV sources (Casanova and Dingus, astro-ph/0609306, Harding)

Energy(GeV)

Future Insight with GLAST

- GLAST is due to launch later this year, and expecting to reach the sensitivity for the entire EGRET mission in approximately 2 months
- Huge field of view will provide virtually uniform all sky coverage in a single day
- The GLAST mission is sure to shed new light on the GeV excess



simulated GLAST sky map, S.W. Digel (NASA/GSFC)

Extra

Accounting for COMPTEL

- The COMPTEL instrument is within close enough proximity to EGRET to have an small effect on the sky exposure

- I expect this effect to be less than 10% since the majority of EGRET's effective area is within 20° of the instrument axis

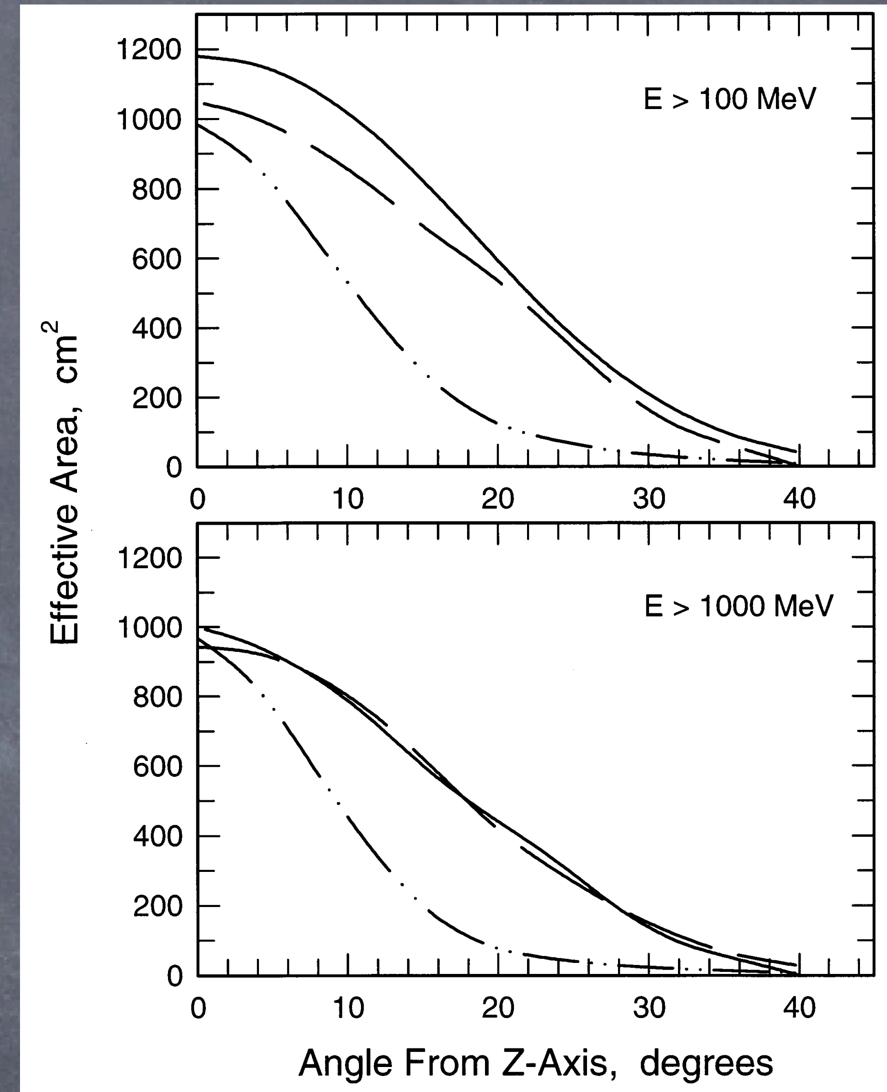
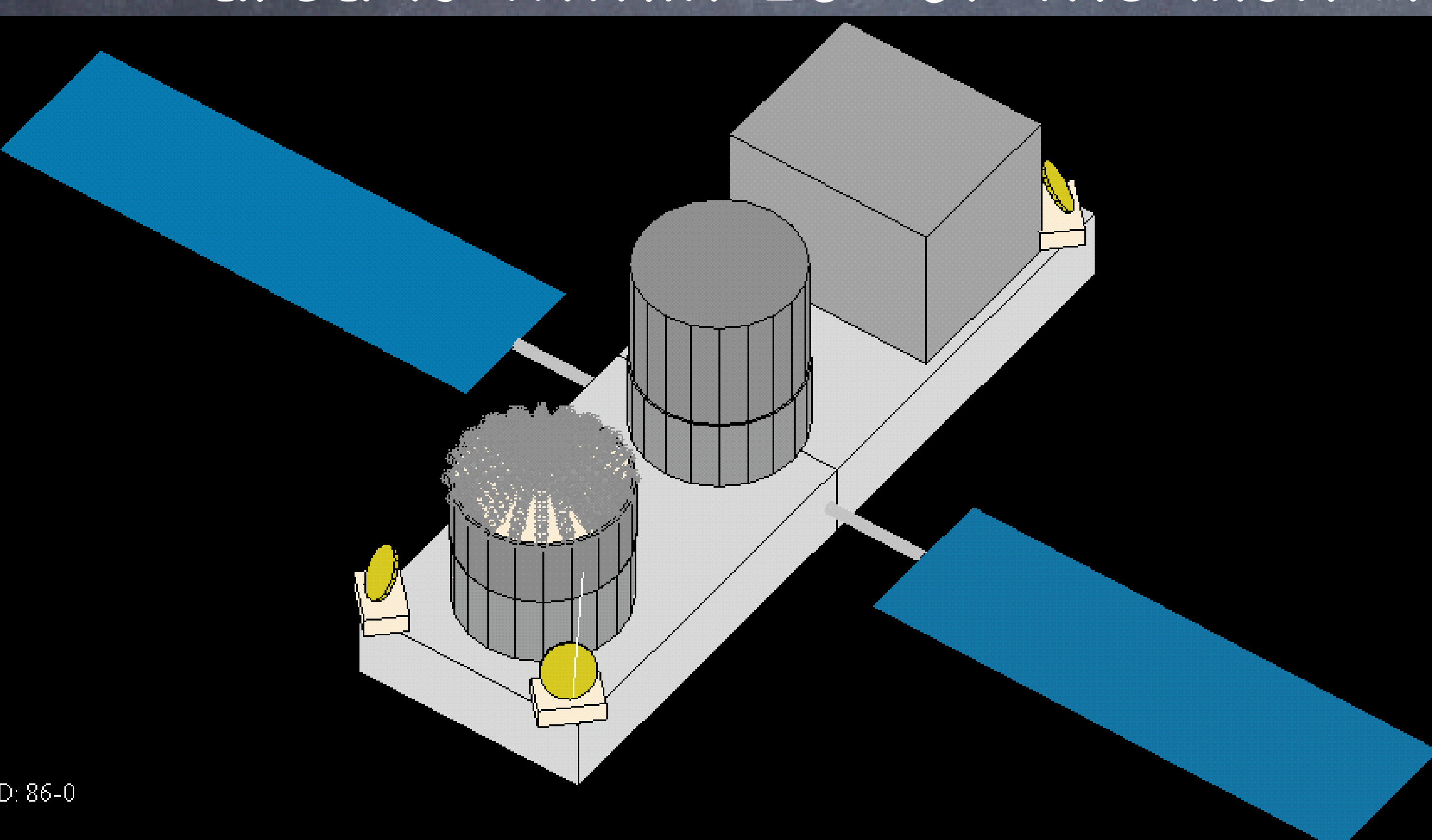


FIG. 8.—EGRET effective area as a function of the incidence angle for the three different telescope modes. The solid curves are for the wide-angle mode, the dashed curves are for the strip mode for sources along the long axis, and the dash-dotted curves are for the narrow-angle mode. Two energy regimes are shown as noted.

Esposito et al.,ApJS, 123 : 203-217, 1999 July



Detailed CGRO Model

- Since no detailed model of CGRO is available I have attempted to bound the possible error associated with our block model
- Running simulations where the density of the material used for CGRO is changed by ±50% and taking the spread to be a measure of the error

28

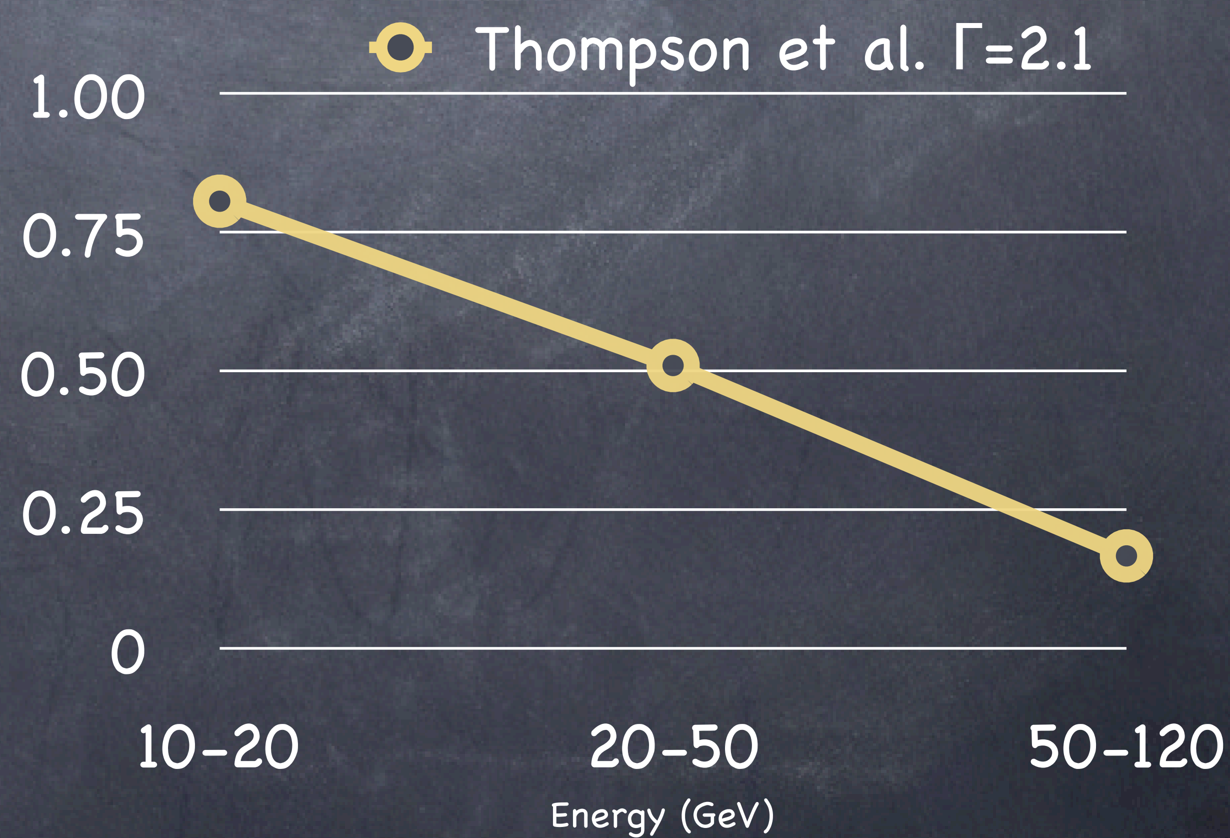
Above 10 GeV

- Calibration of EGRET did not occur above 10 GeV
- While extrapolations of the effective area have been made assuming
  - $A_{eff}(E>10GeV) \propto e^{(-E/36GeV)}$
- This is generally achieved through estimating the effective area at the $E^{-2.1}$ weighted mean energy of a given bin then taking the ratio over the 4-10 GeV value

Thompson et al. ApJS 157:324 - 334, 2005 April

Effective Area Relative to the 4–10 GeV Value

Energy Range (GeV)		Relative Effective Area		
Low	High	Spectral Index = 1.80	Spectral Index = 2.10	Spectral Index = 2.40
10	20	0.807	0.808	0.809
10	50	0.683	0.706	0.723
10	70	0.649	0.678	0.702
10	100	0.616	0.655	0.678
10	120	0.602	**0.645**	0.681
20	50	0.514	0.512	0.528
20	70	0.464	0.478	0.491
20	100	0.421	0.443	0.463
20	120	0.403	0.429	0.452
50	70	0.233	0.234	0.234
50	100	0.183	0.186	0.189
50	120	0.164	0.169	0.173
70	100	0.120	0.121	0.121
70	120	0.102	0.104	0.105



Above 10 GeV

- Similar to previous extension of the EGRET effective area above 10 GeV I have calculated scale factors relative to the 4-10 GeV exposure maps
- Our extension is the first to be based off a detailed Monte Carlo