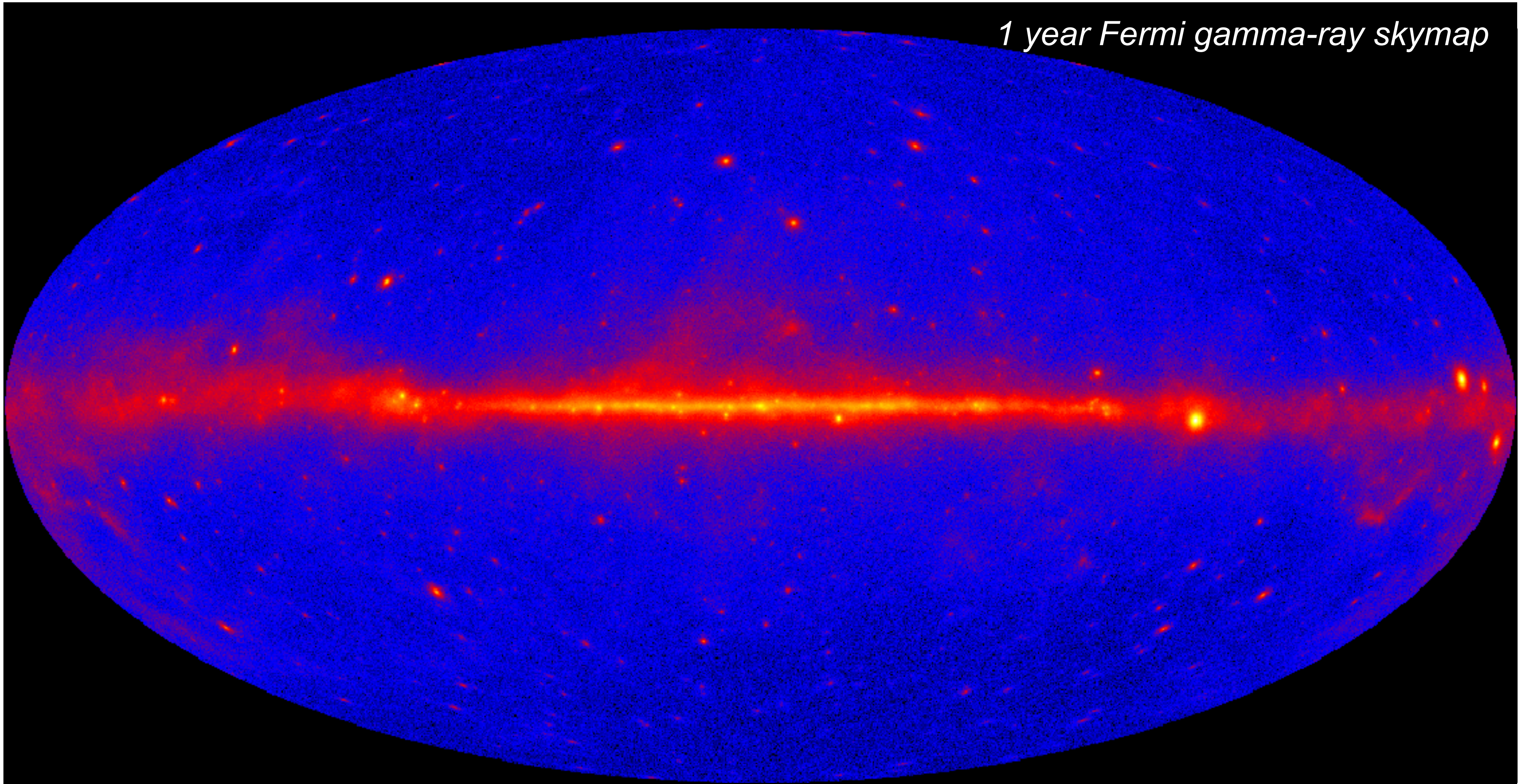
Fermi

Gamma-ray Space Telescope

Cosmic Ray Electrons with Fermi-LAT

L. Latronico
INFN-Pisa
On behalf of the Fermi Mission Team

Cosmic ray backgrounds in Dark Matter Searches
Albanova, Stockholm, 25-27/1/2010

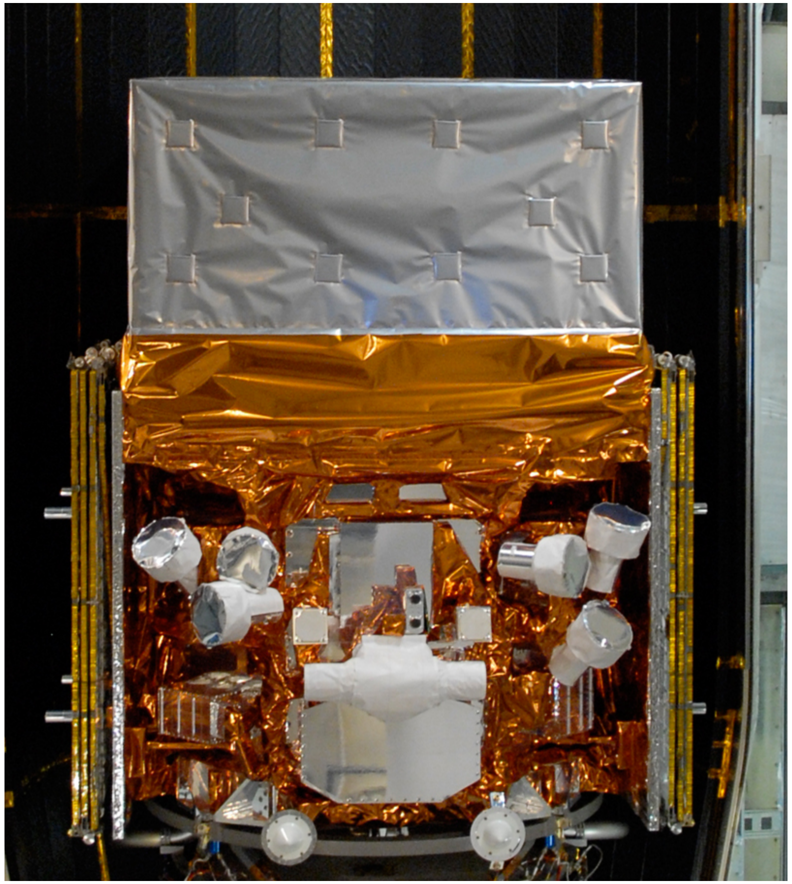


Intro – impact of the Fermi observatory

Detection of CRE with the Fermi LAT

CRE spectrum update

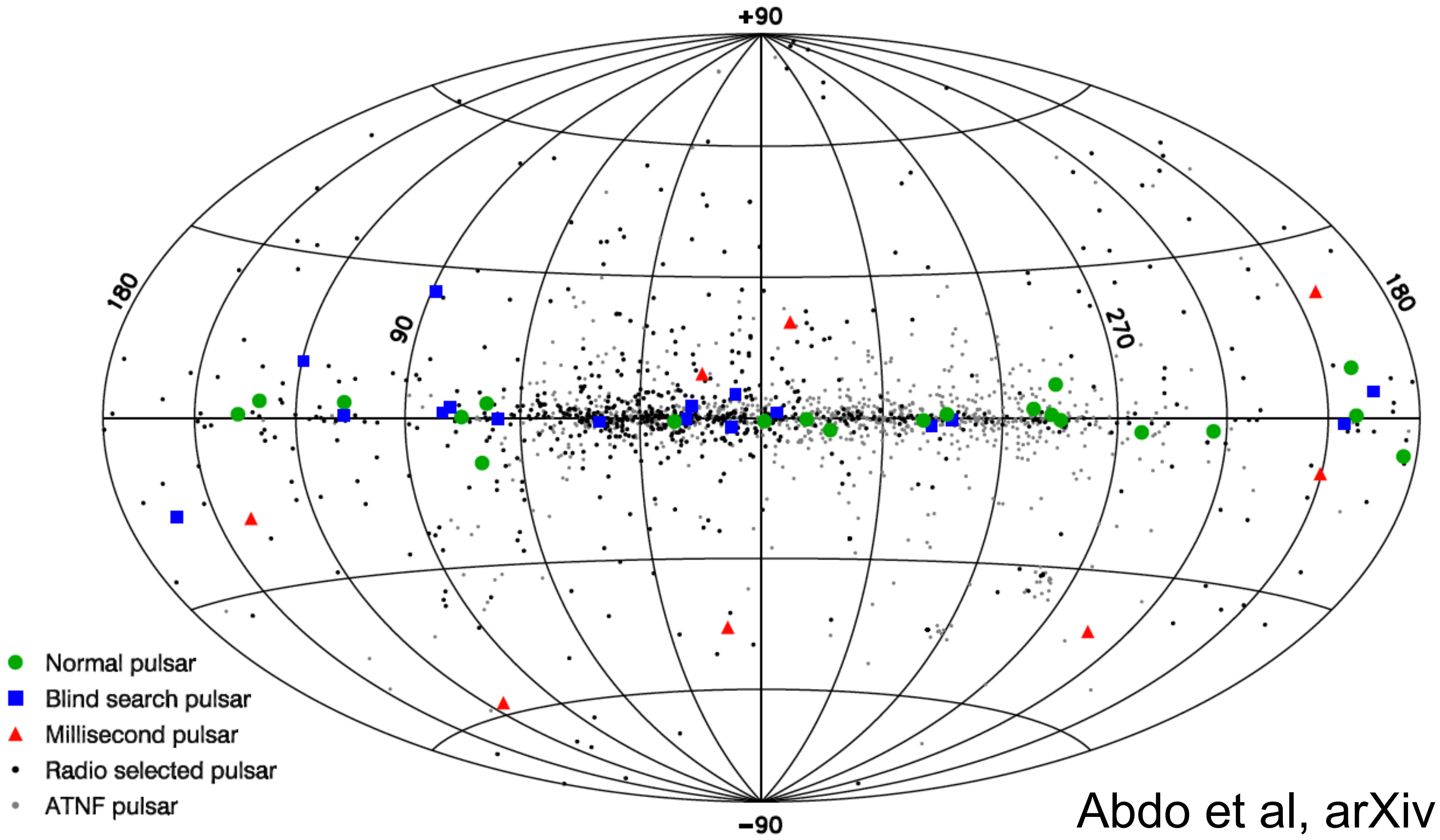
The Fermi observatory



- Satellite gamma-ray telescope
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV
- Key features
  - Huge field of view (full sky every 3 hours for 30 mins)
  - Huge energy range
- Milestones
  - 11 jun 2008: launch
  - 04 aug 2008: science ops start
  - 13 aug 2009: data go public
  - 22 dec 2009: 90B triggers

Pulsar Catalog

- In addition to the search for new pulsars, 762 known pulsars with ephemerides were searched for pulsations in nine months of data
  - 46 pulsars were detected: 16 blind search PSRs, 8 radio-loud MSPs, 22 radio-loud normal PSRs.



Abdo et al, arXiv:0910.1608

Fermi pulsars are in the top 10 results of 2009 according to Science

http://www.sciencemag.org/cgi/content/full/326/5960/1589

see J. Bregeon's talk

naturenews

nature news home | news archive | specials | opinion | features | news blog | events

comments on this story

Stories by subject

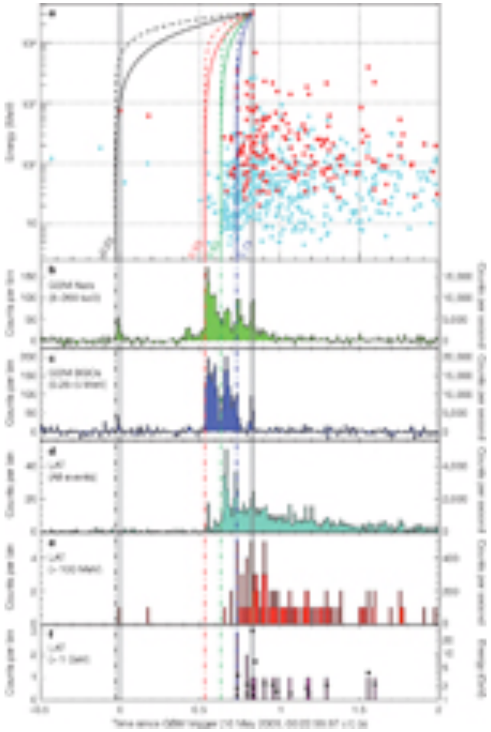
- Physics
- Space and astronomy

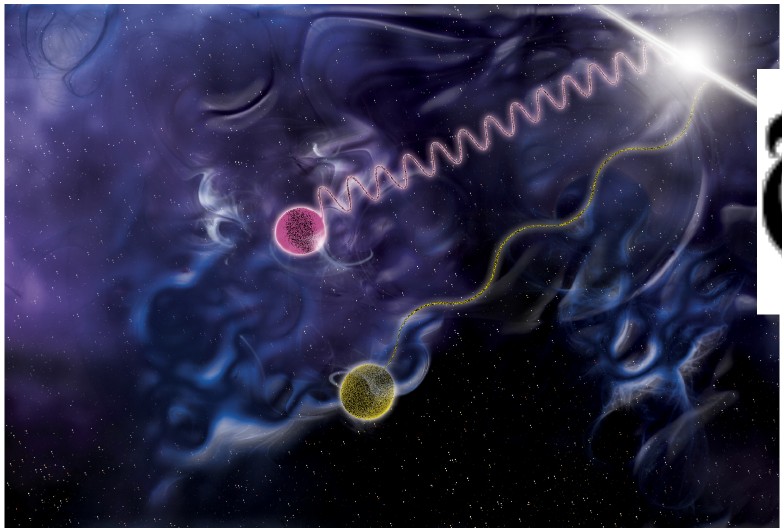
Published online 28 October 2009 | Nature | doi:10.1038/news.2009.1044

News

An intergalactic race in space and time

A burst of γ-rays lets scientists test quantum theories of gravity.





The New York Times

7.3 Billion Years Later, Einstein's Theory Prevails

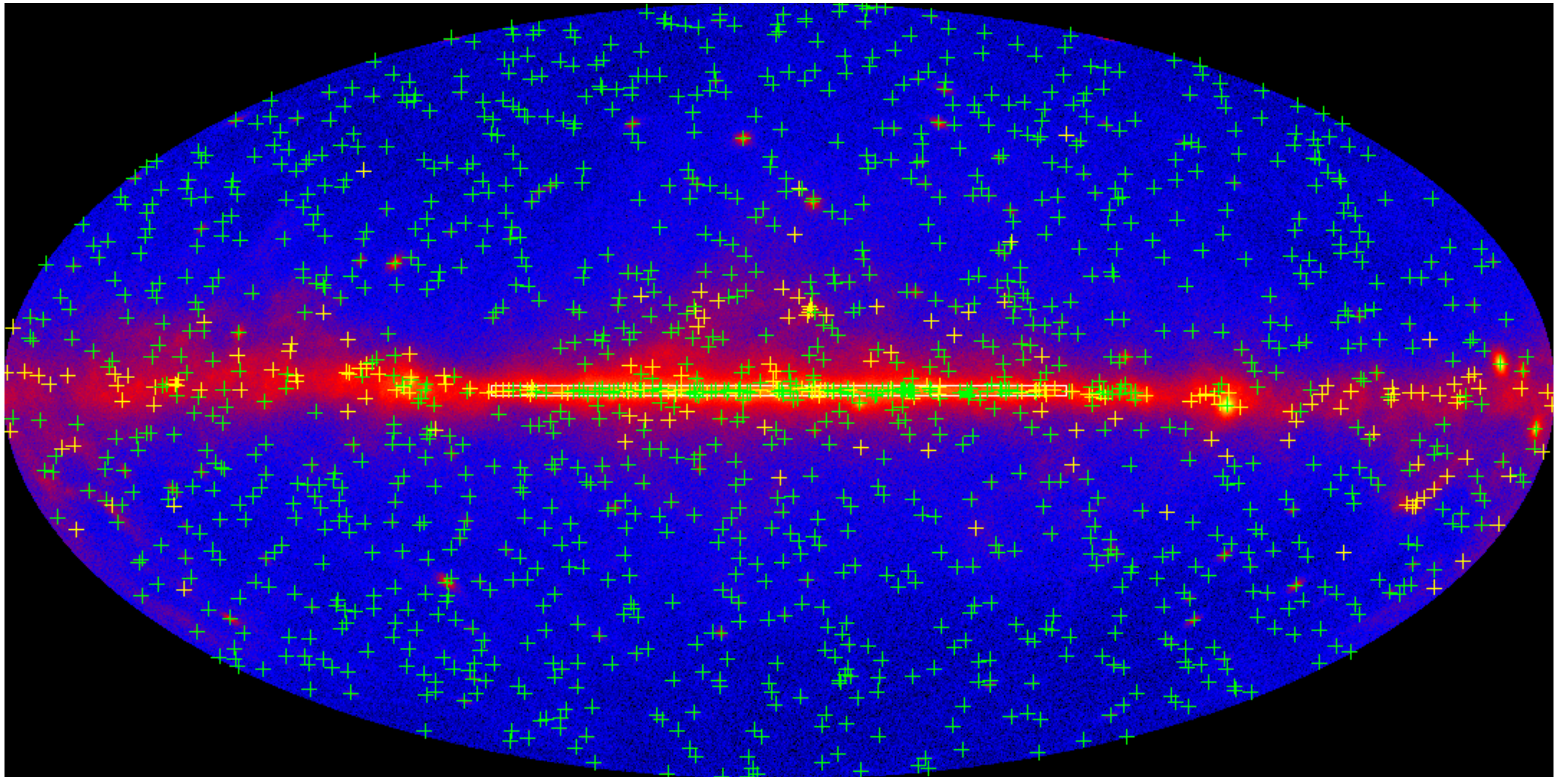
By DENNIS OVERBYE
Published: October 28, 2009

SIGN IN TO RECOMMEND
TWITTER
SIGN IN TO E-MAIL

Astronomers said Wednesday that a race halfway across the universe had ended in a virtual tie. And so the champion is still Albert Einstein — for now.

Number 9 of Slate Magazine's top twelve stories oct. 29 →

Fermi Year One Catalog

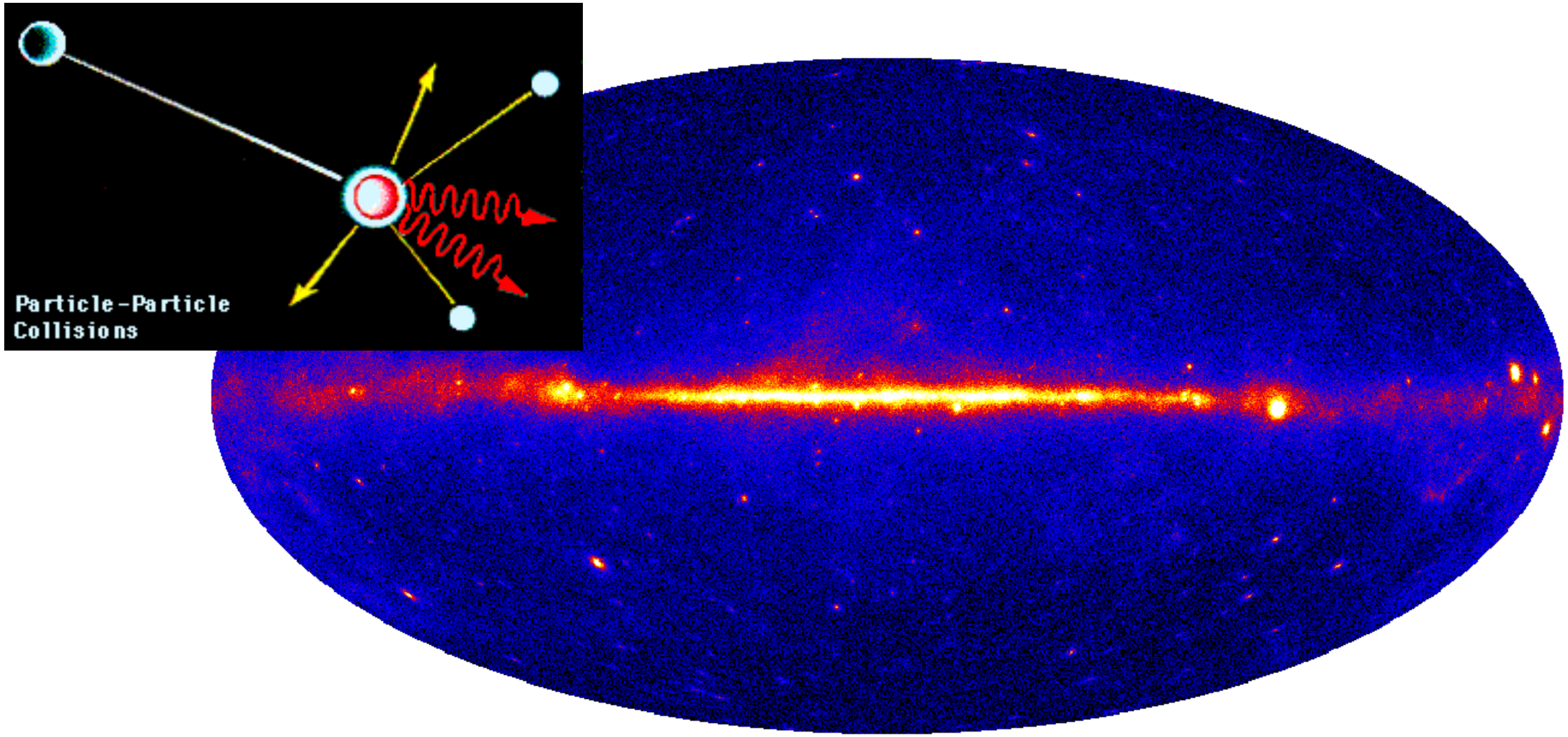


http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/

More than 1000 sources in year one catalog

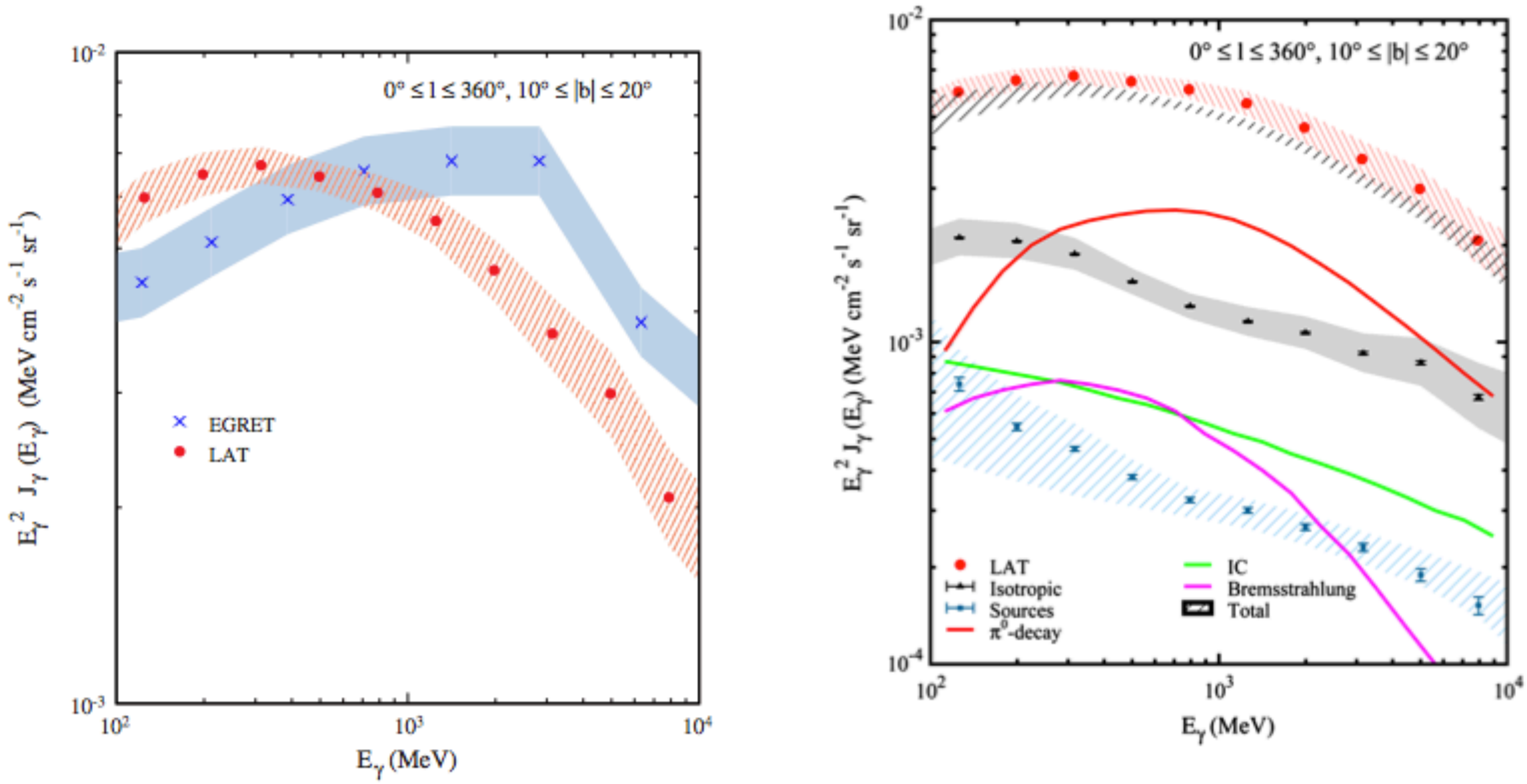
- **About 250 sources show evidence of variability**
- **Half the sources are associated positionally, mostly blazars and PSRs**
- **Other classes of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)**
- **Uncertainties due to the diffuse model, particularly in the Galactic ridge**

Cosmic Rays – Gamma-rays connection



- Galactic gamma rays trace cosmic-ray proton interactions (cosmic-ray acceleration sites & propagation)
- Observations of nearby galaxies provide an outside view
- Primary targets: galactic plane, starburst galaxies, LMC, SNR
- Direct CR observations

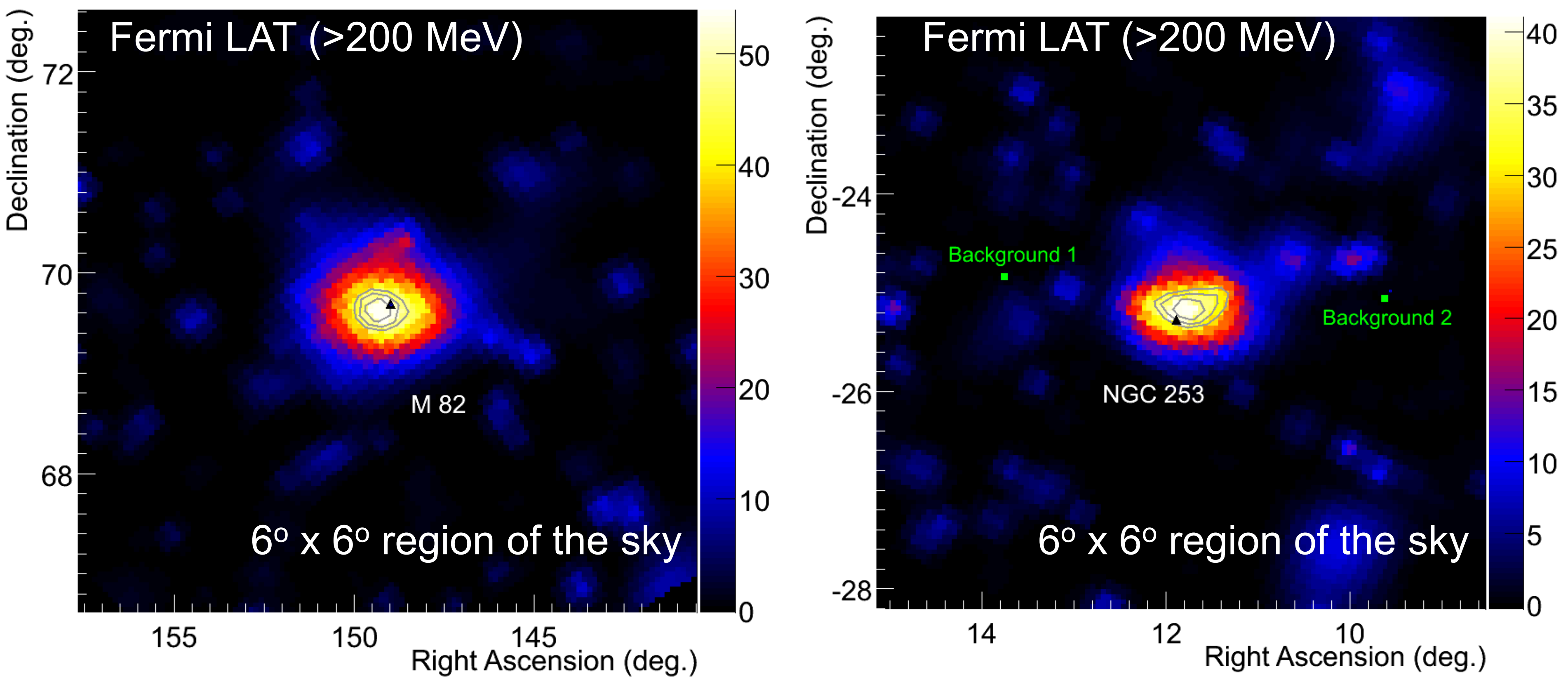
Fermi Large Area Telescope Measurements of the Diffuse Gamma-Ray Emission at Intermediate Galactic Latitudes



see A. Strong talk

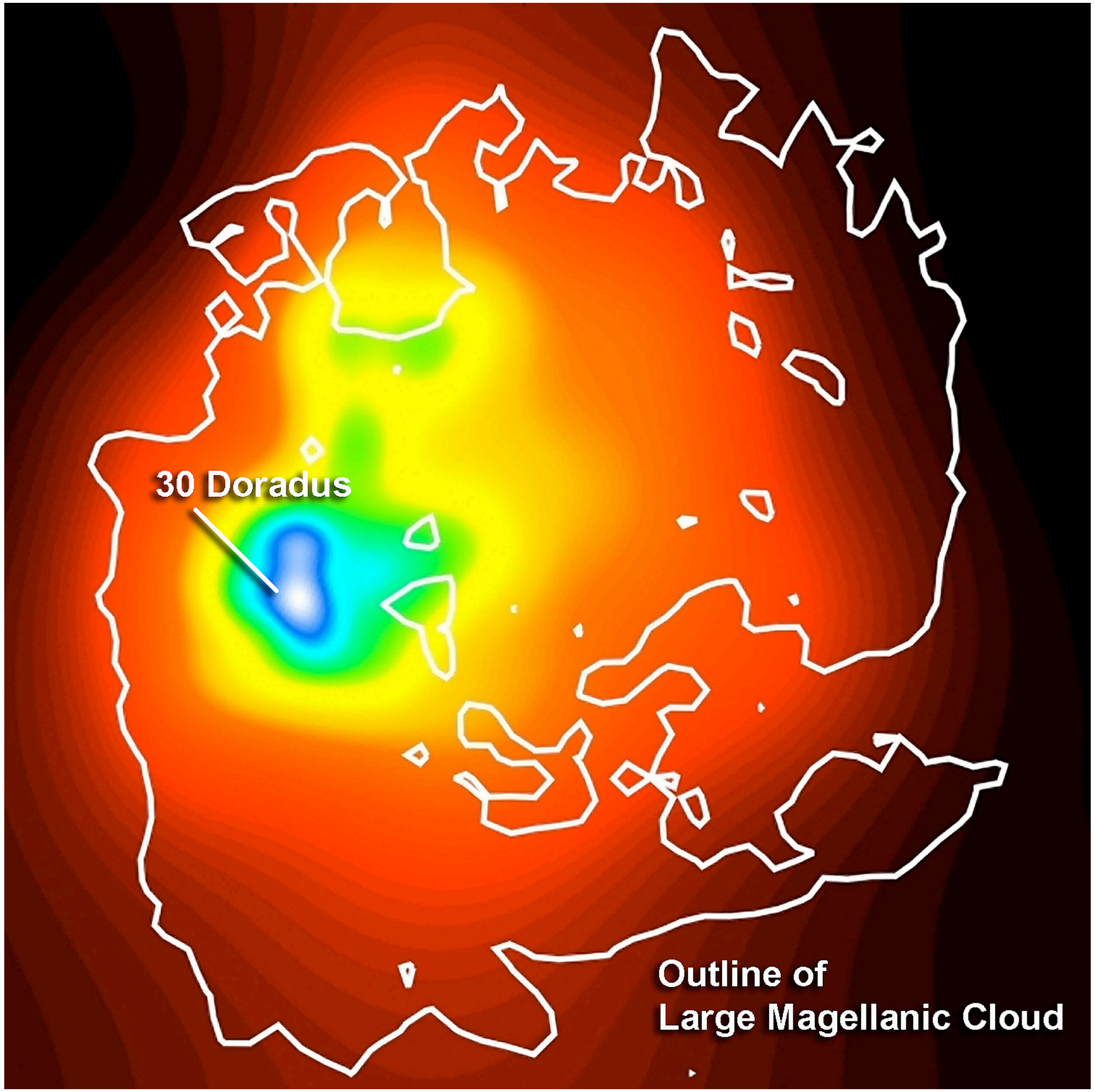
The Astrophysical Journal Letters, 709:L152–L157, 2010 February 1 doi:10.1088/2041-8205/709/2/L152

DETECTION OF GAMMA-RAY EMISSION FROM THE STARBURST GALAXIES M82 AND NGC 253 WITH THE LARGE AREA TELESCOPE ON *FERMI*



Accepted by A&A

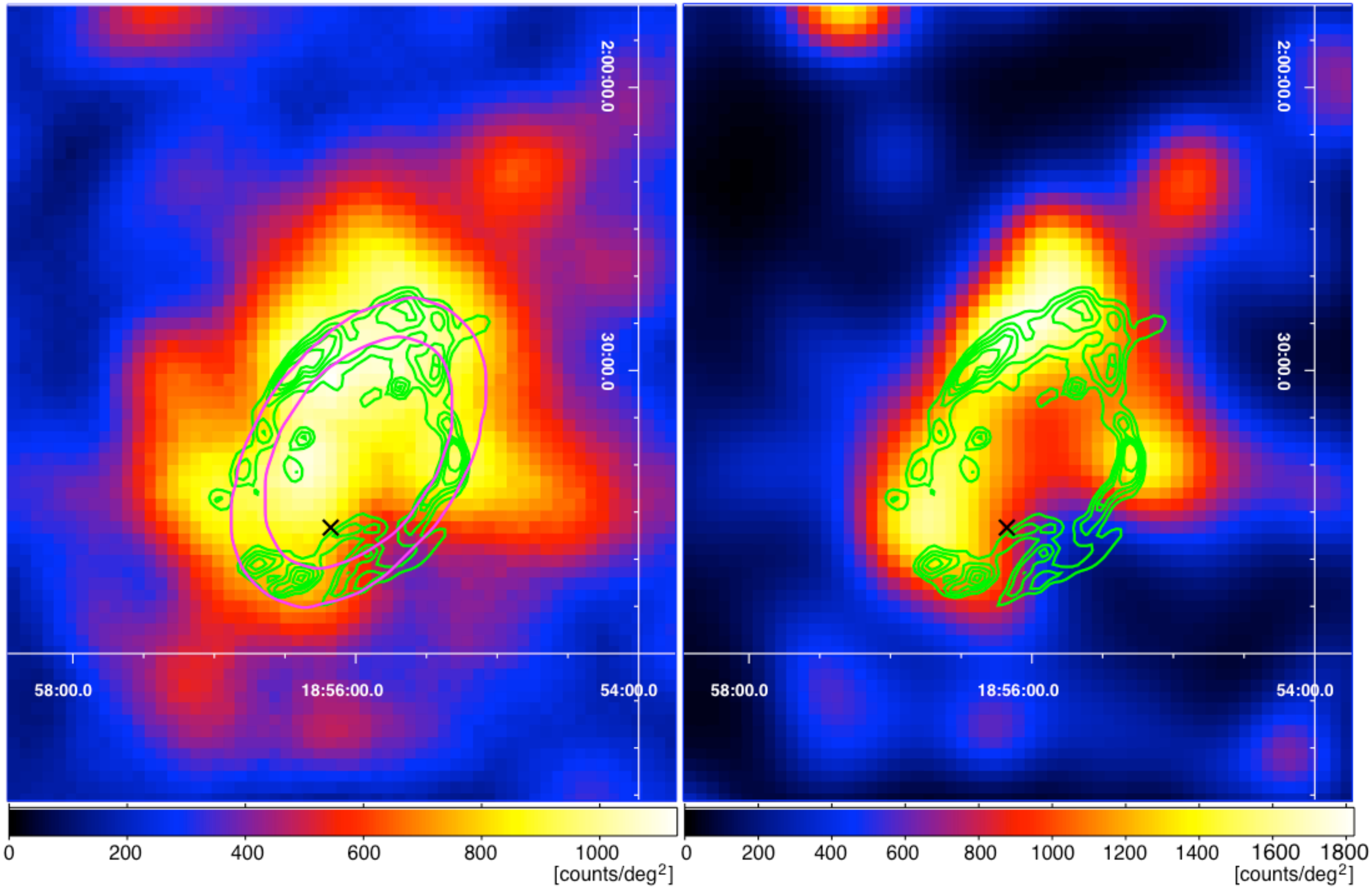
Observations of the Large Magellanic Cloud with *Fermi*



Published Online January 7, 2010
Science DOI: 10.1126/science.1182787

REPORTS

Gamma-Ray Emission from the Shell of Supernova Remnant W44 Revealed by the Fermi LAT



Importance of a direct CRE measurement

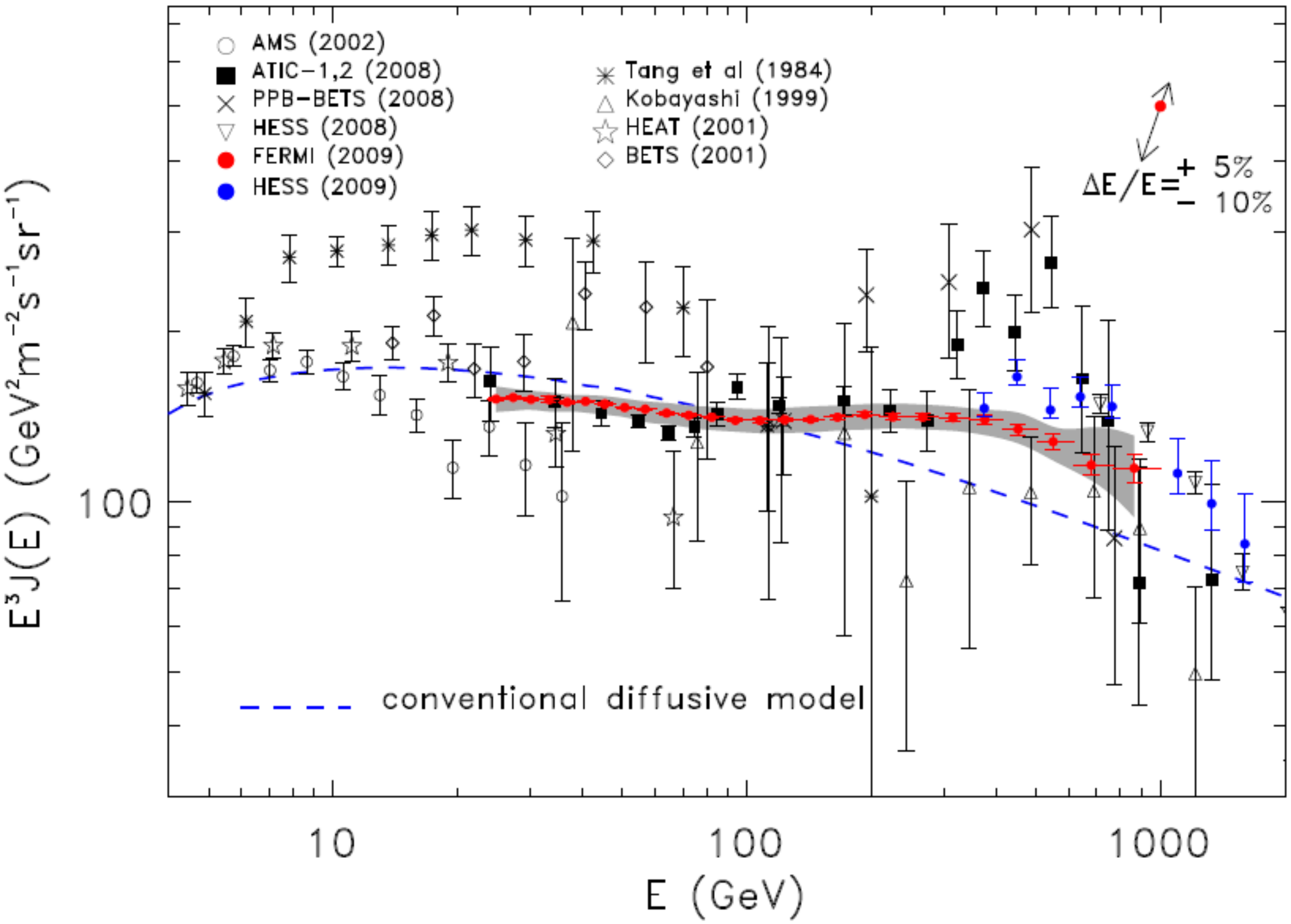
- Probe CR models
  - Sources (including DM), interactions, propagation, diffusion
- Probe CR targets (ISM, ISRF)
  - Propagation and diffusion
  - Strong connection with diffuse gamma-ray radiation
- Probe possible nearby sources
  - limited electron lifetime within Galaxy
- Answers to long-standing questions and vast literature

THE ASTROPHYSICAL JOURNAL, 162:L181–L186, December 1970

PULSARS AND VERY HIGH-ENERGY COSMIC-RAY ELECTRONS

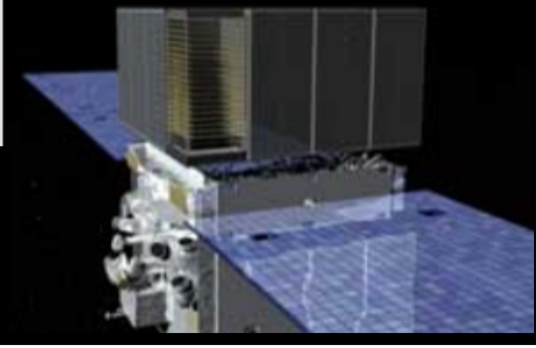
C. S. SHEN*
Department of Physics, Purdue University, Lafayette, Indiana 47907
Received 1970 June 8; revised 1970 September 19

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope



NASA's Fermi Explores High-energy *Space Invaders*

Since its launch last June, NASA's Fermi Gamma-ray Space Telescope has discovered a new class of pulsars, probed gamma-ray bursts and watched flaring jets in galaxies billions of light-years away. Today at the American Physical Society meeting in Denver, Colo., Fermi scientists revealed new details about high-energy particles implicated in a nearby cosmic mystery.



Physics: Cosmic light matter probes heavy dark matter

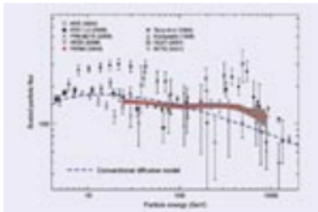
May 4, 2009

New results from the Fermi Gamma-Ray Space Telescope, the most precise to date in the energy range 20 GeV to 1 TeV, should help resolve whether cosmic rays composed of the lightest charged particles, i.e., electrons and positrons, come from dark matter or some other astrophysical source.
[Viewpoint on Phys. Rev. Lett. **102,** 181101 (2009)]

CERN COURIER

Jun 8, 2009

Fermi measures the spectrum of cosmic-ray electrons and positrons



Spectrum

The Fermi Gamma-Ray Telescope can find out about more than gamma rays. It has now provided the most accurate measurement of the spectrum of cosmic-ray electrons and positrons. These results are consistent with a single power-law, but visually they suggest an excess emission from about 100 GeV to 1 TeV. The additional source of electrons and positrons could come from nearby pulsars or dark-matter annihilation.

SLAC ✳ today

High-energy Electrons Could Come from Pulsars—or Dark Matter

by Michael Wall

Something in our galactic neighborhood seems to be producing large numbers of high-energy electrons, according

An artist's conception of the Fermi Gamma-ray Space Telescope. (Image: NASA.)

Lights Out for Dark Matter Claim?

By Adrian Cho
*Science*NOW Daily News
2 May 2009

Last November, data from a balloon-borne particle detector circling the South Pole revealed a dramatic excess of high-energy particles from space--a possible sign of dark matter, the mysterious substance whose gravity seems to hold our galaxy together. But satellite data reported today stick a pin in that

+ Enlarge Image

Fermi CRE measurement peculiarities

- Highest statistics
  - >> balloons (short exposure)
  - > spectrometers (smaller acceptance)
  - Forces careful study of systematic effects
- High quality data between old data and HESS
  - Disprove ATIC claim of strong spectral feature
  - Confirm harder spectrum
- Unable to separate e- from e+ (no magnet on-board)
  - On-going effort to use earth magnetic field to do this
- Potentials for
  - Anisotropies (see Mazziotta's talk)
  - Energy extentions
    - Low energy: orbit-dependent, see later in this talk
    - High energy (> 1TeV): require specific new CAL recon

How the LAT detects electrons

Trigger and downlink

Very versatile and configurable

- **Triggering on ~ all particles that cross the LAT**
  - **Including electrons (8M/yr)**

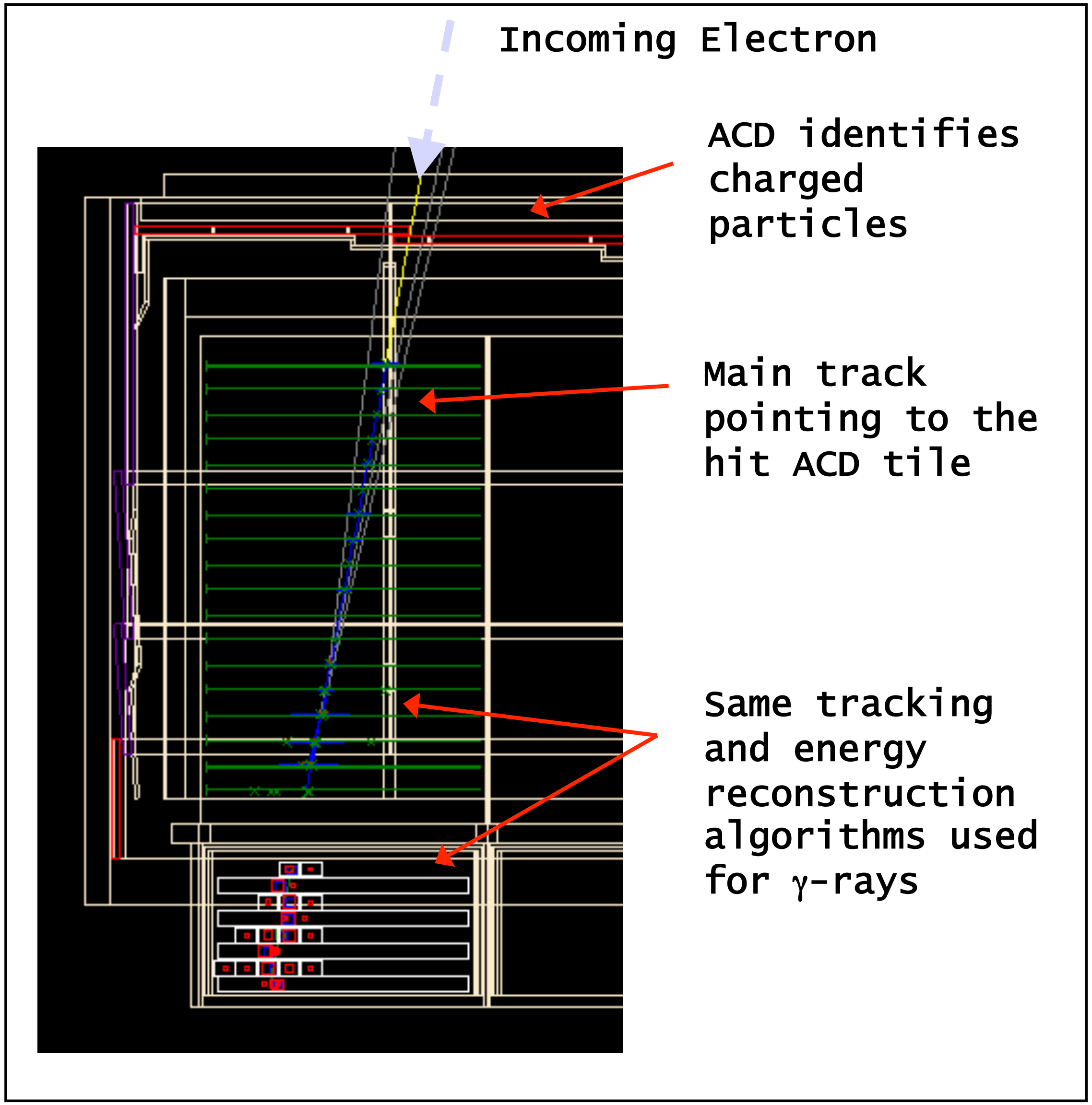
On board filtering to fit bandwidth

- **Remove many charged particles**
- **Keeps all events with more than 20 GeV in the CAL (HE)**
- **Prescaled (1:250) sample of unfiltered triggers (LE)**

Electron identification

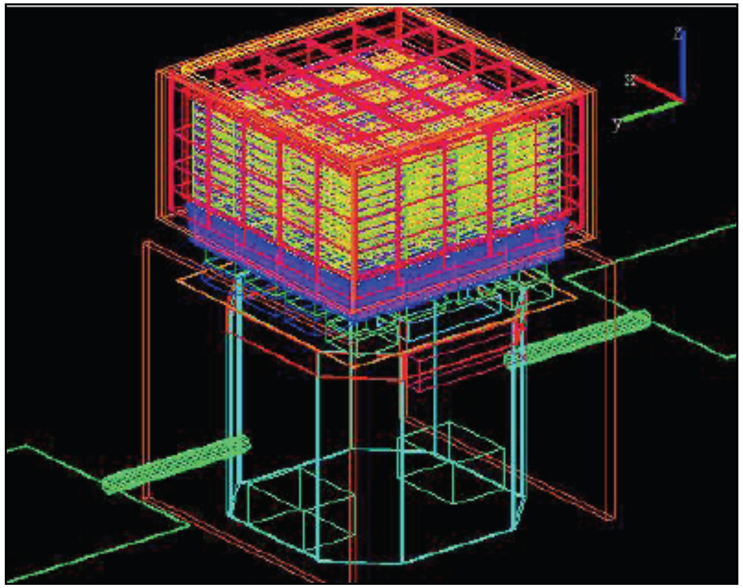
The challenge is identifying the good electrons among the proton background

- **Rejection power of $10^3 – 10^4$ required**
- **Can not separate electrons from positrons**
- **→ Dedicated high energy electron event selection**



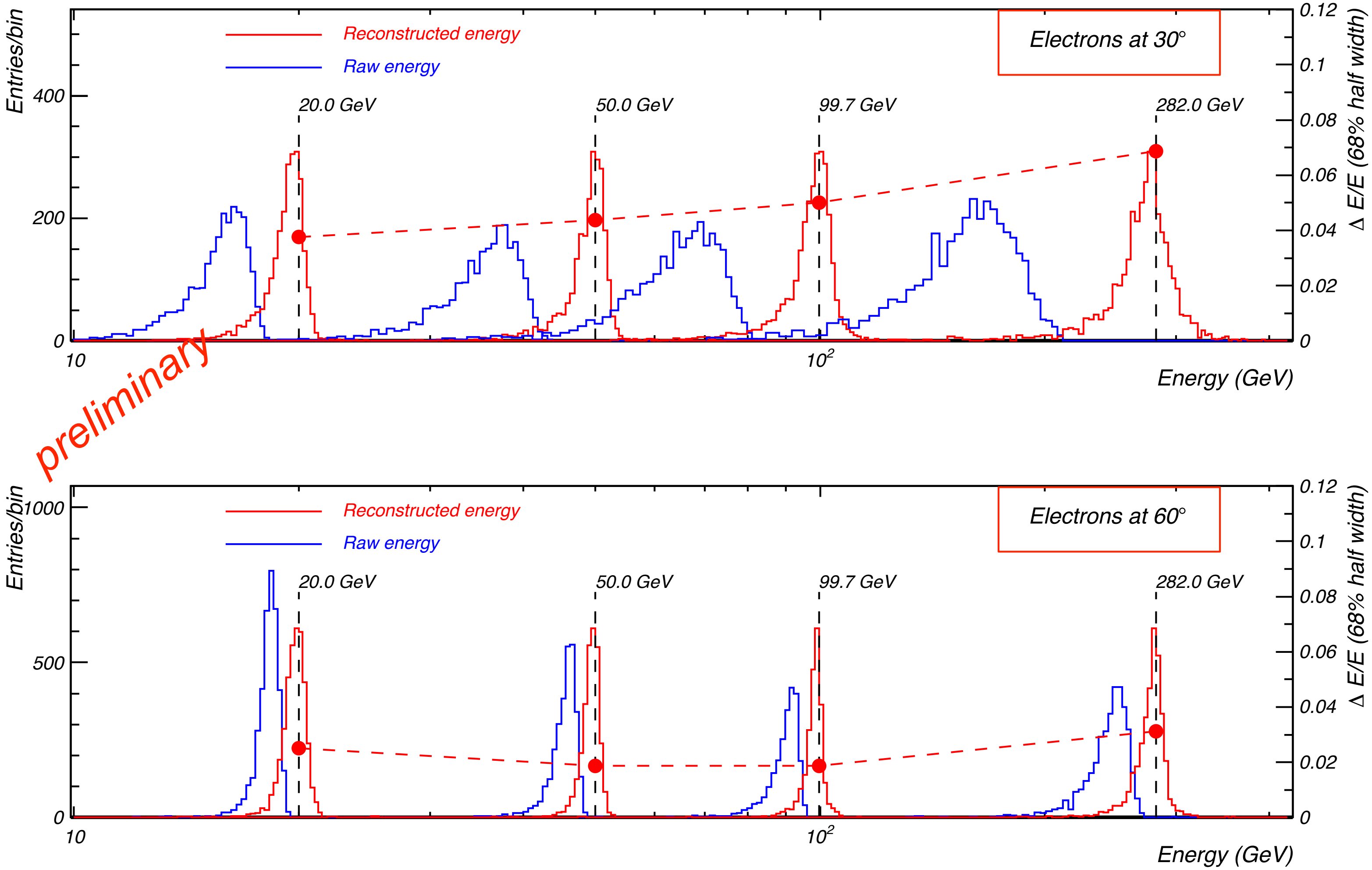
Event Simulation and Reconstruction

- Very accurate Monte Carlo
  - >45k active volumes
  - Geant4 optimized physics
- Simulation is key for
  - Reconstruction tuning
  - Event selection and performance
  - Estimate residual contamination

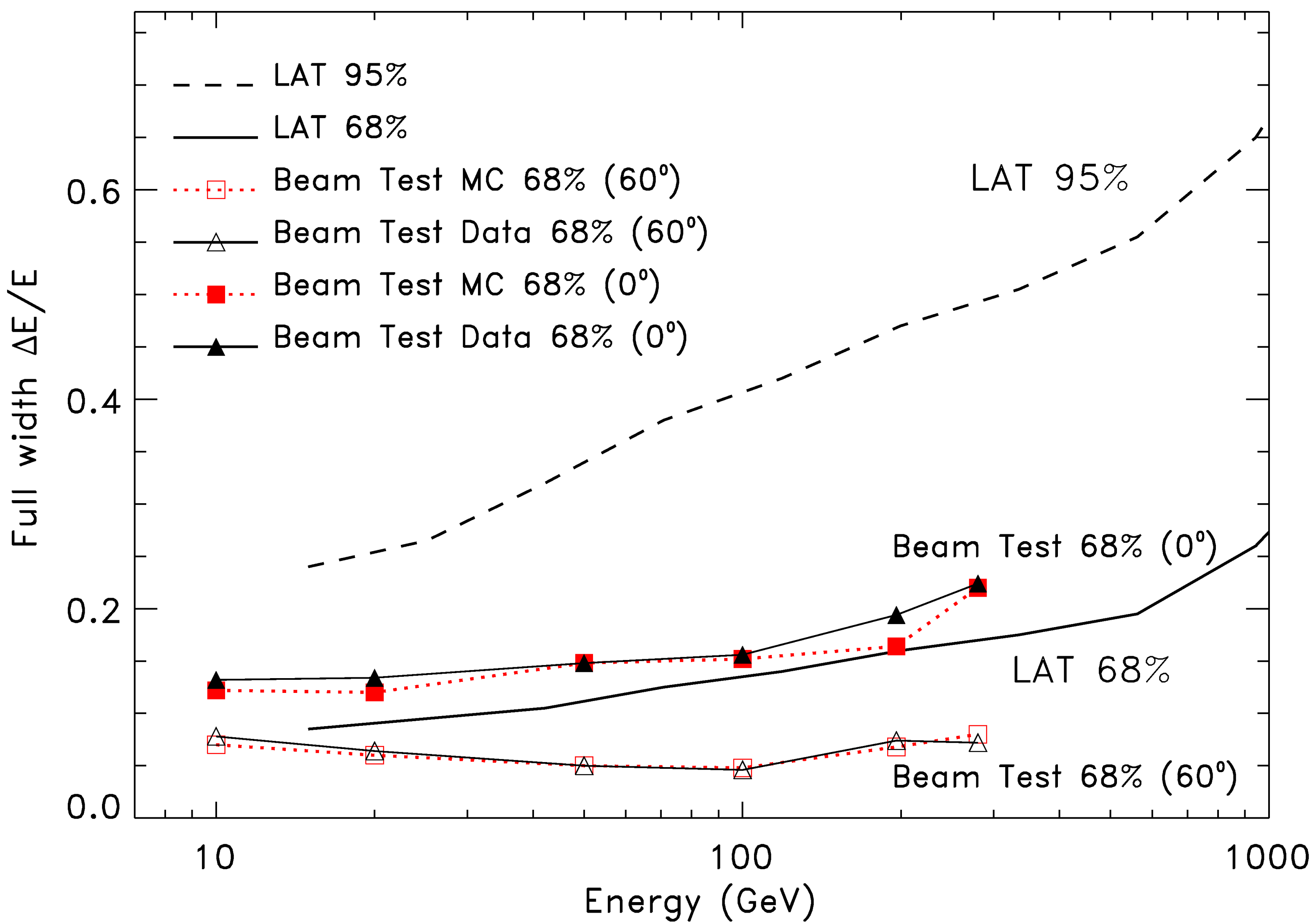


- Full subsystems reconstruction
  - ACD - PH analysis
  - TKR - powerful tracking
  - CAL - 3D shower profile recon, handles cracks and saturation

Energy resolution validations with BT electrons

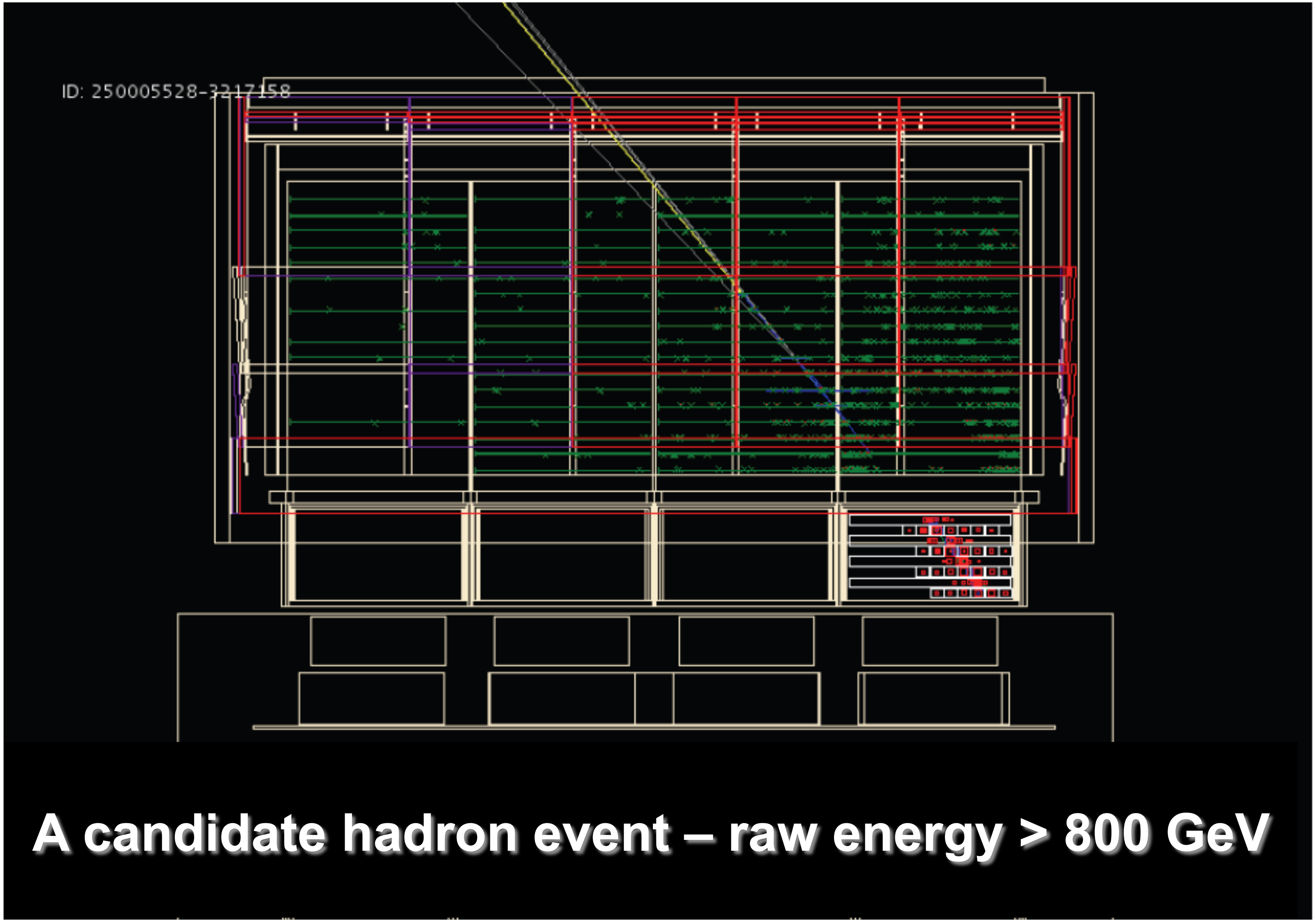


Energy resolution – MonteCarlo vs BT electron data



Event Selection, Global Performance and Systematics

- Event selection tuned on simulation and validated with real data
  - 100s variables describing key event topology in each subsystems
    - Prefilters +
    - Classification Trees (CT) optimizing electron efficiency and hadron rejection
- Peak geometry factor 2.8 m^2sr at 50 GeV, rejection power up to 1:10^4 at 1 TeV
- Systematic uncertainties kept below 20%
  - Data-MC disagreement and event selection effect on acceptance <20%
  - Proton spectrum <20%
  - Energy calibration uncertain (+5%,-10%)→ rigid shift of the spectrum



CalEnergyRaw
8.228e+05

CTBBestEnergy
1.026e+06

CTBBestEnergyProb
0.146

TkrNumTracks
5

CalCsIRLn
10.9

CTBBestZDir
-0.387

CTBTKRHEEProb
N/A

CTBCALHEEProb
N/A

CalLRmsAsym
0.00419

CalTrSizeTkrT95
1022.6

CalTransRms
34.4

Tkr1CoreHC
1

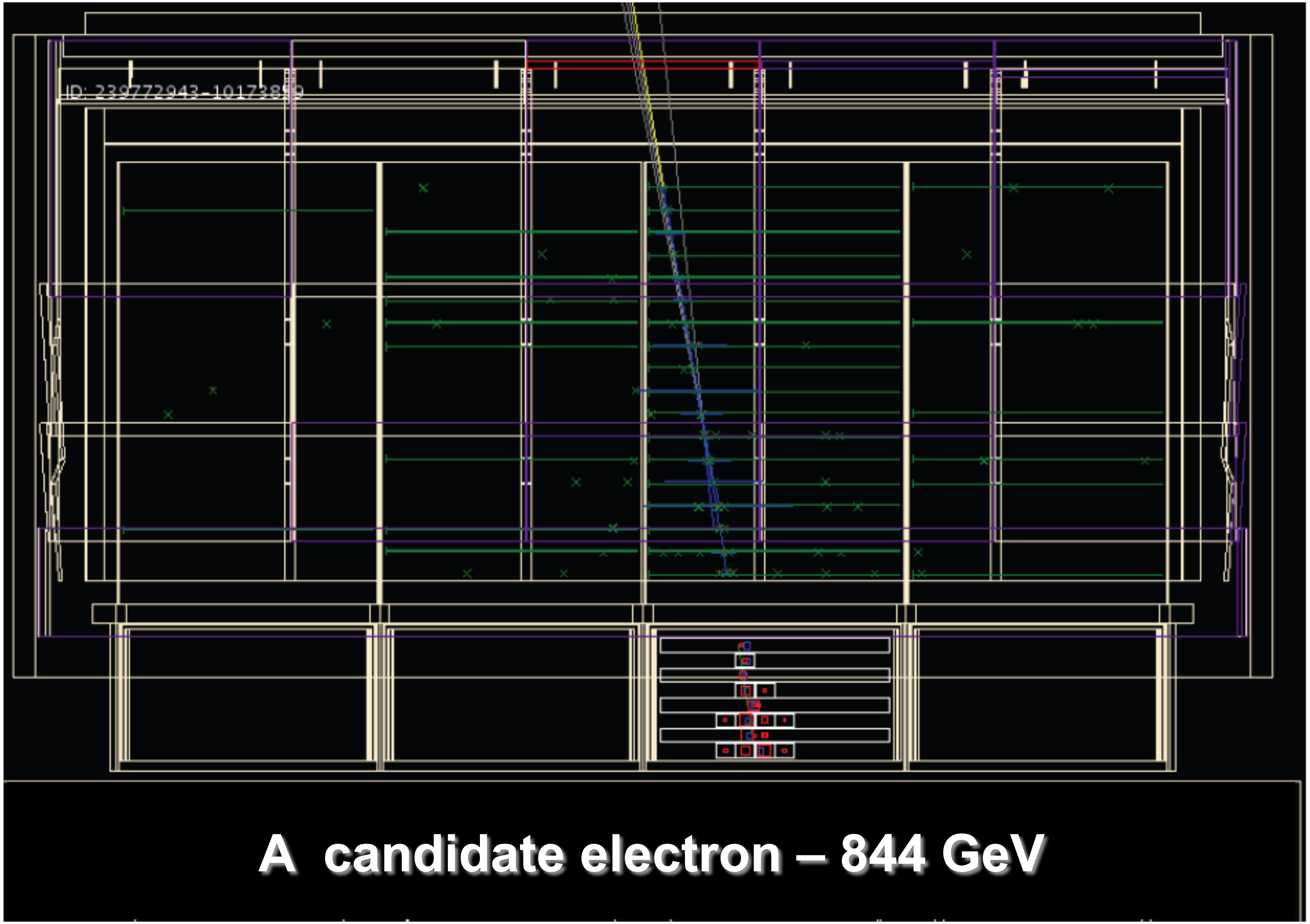
Tkr1Hits
6

Tkr1ToTTrAve
0

AcdTotalEnergy
660.7

AcdTileCount
65

- **ACD: large energy deposit per tile**
- **TKR: small number of extra clusters around main track, large number of clusters away from the track**
- **CAL: large shower size, low probability of good energy reconstruction**

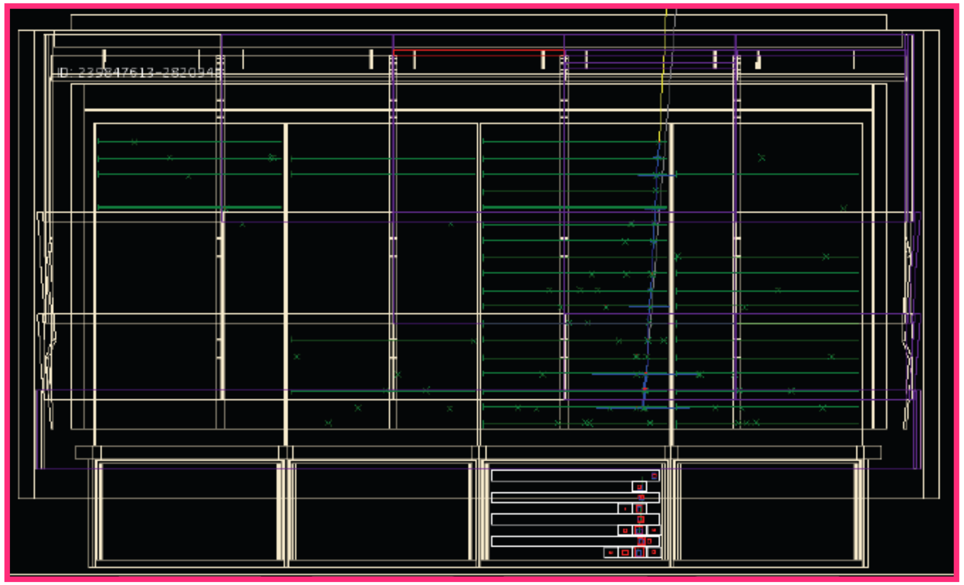


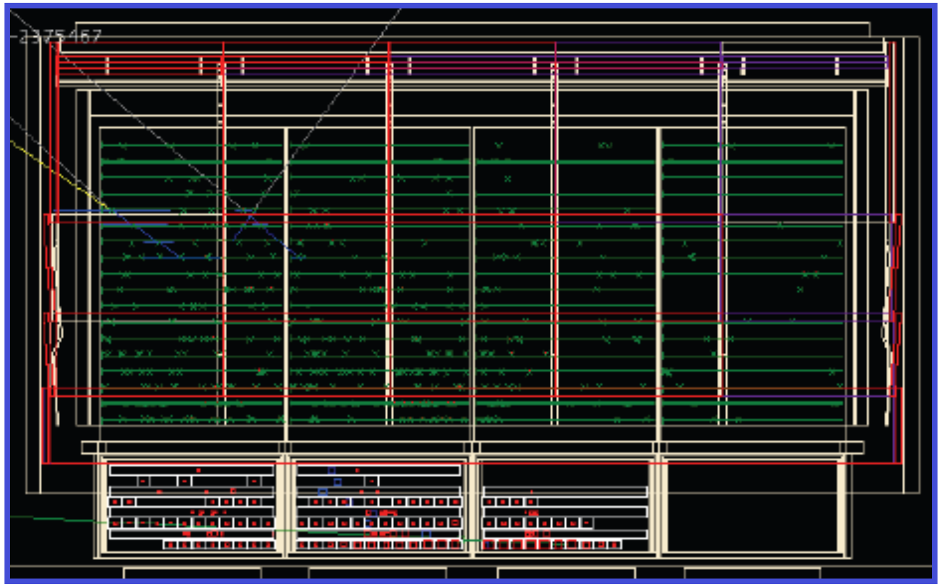
CalEnergyRaw
2.501e+05
CTBBestEnergy
8.443e+05
CTBBestEnergyProb
0.531
TkrNumTracks
5
CalCsIRLn
8.49
CTBBestZDir
-0.986
CTBTKRHEEProb
0.924
CTBCALHEEProb
0.733
CalLRmsAsym
0.0656
CalTrSizeTkrT95
9.73
CalTransRms
23.8
Tkr1CoreHC
29
Tkr1Hits
35
Tkr1ToTTrAve
5.40
AcdTotalEnergy
8.99
AcdTileCount
20

- ACD: few hits in conjunction with track
- TKR: single clean track, extra clusters around main track clusters (preshower)
- CAL: clean EM shower not fully contained in CAL

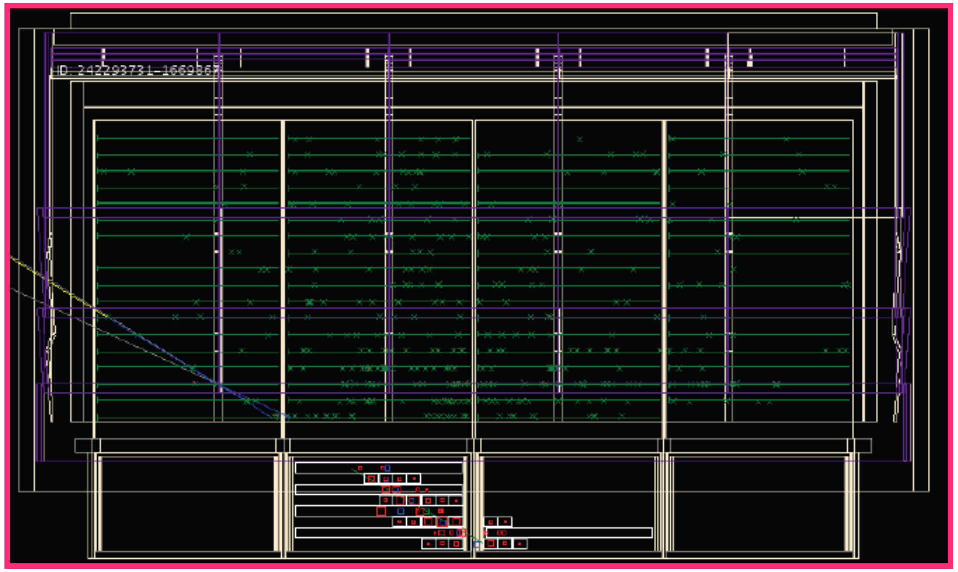
Electrons

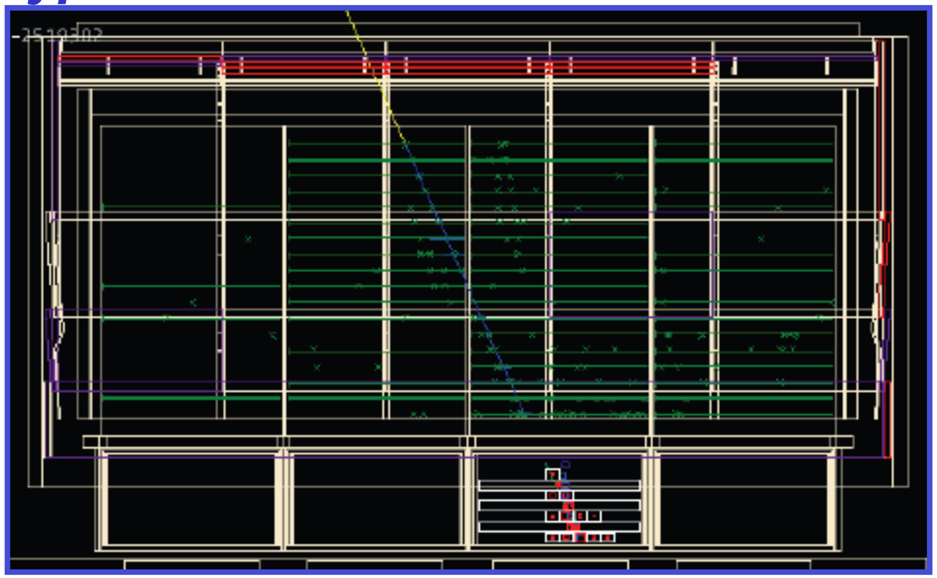
Hadrons





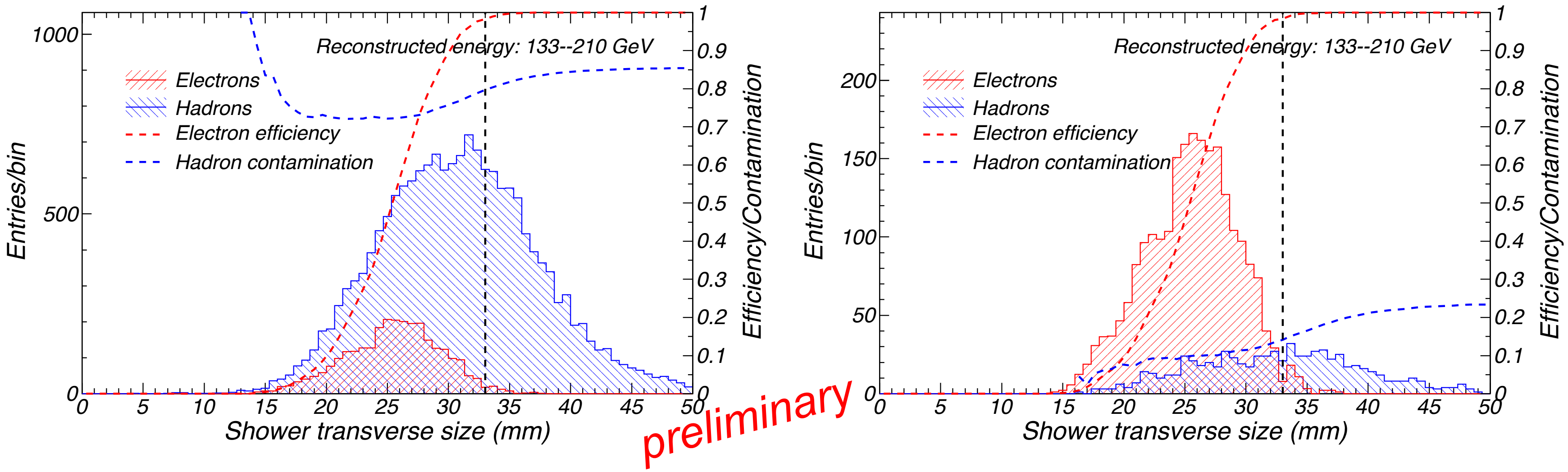
more simple type events





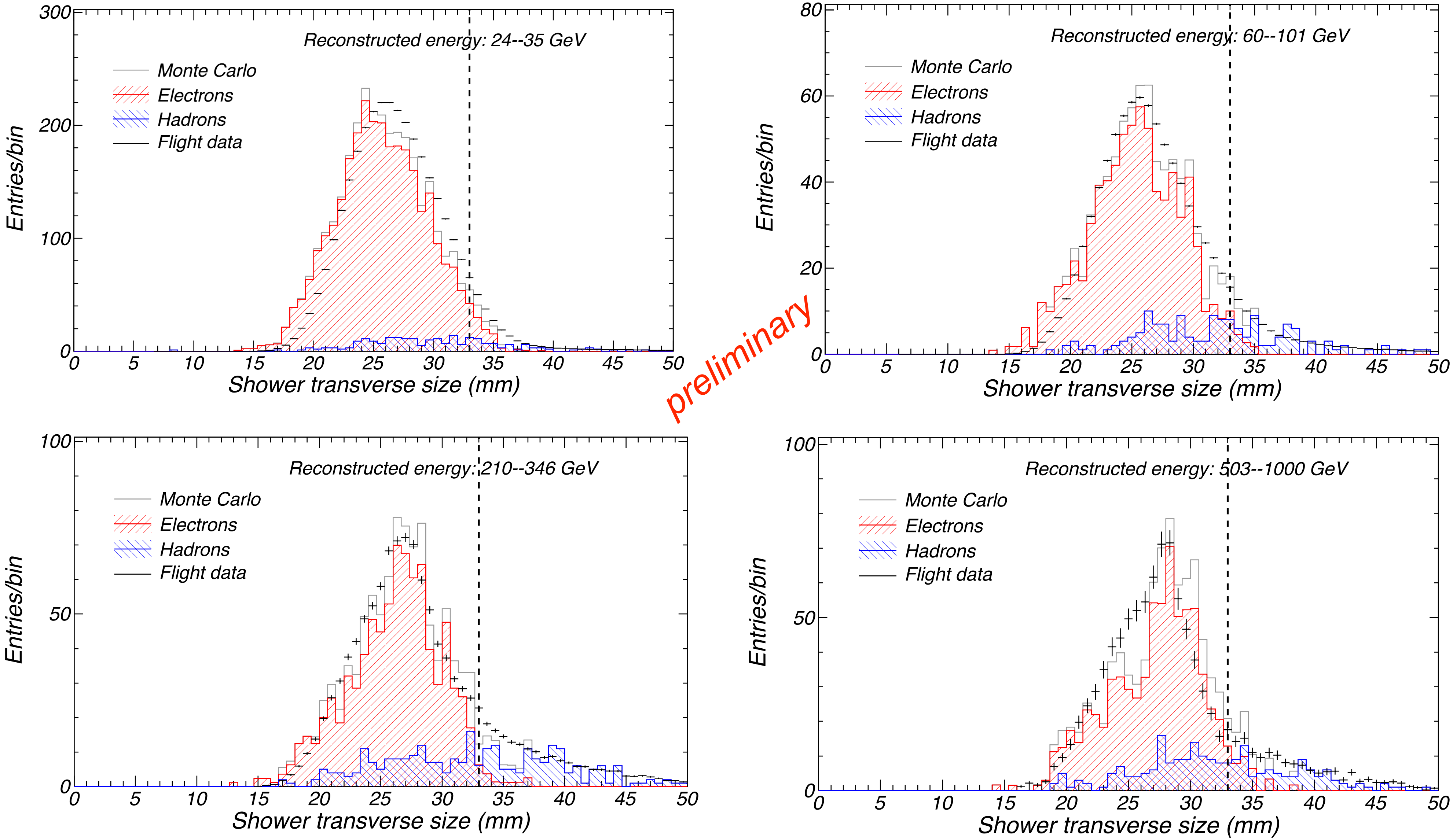
Examples of less obvious events well tagged

Shower size at different selection steps



- **CAL variables cuts only**
  - **High electron efficiency**
  - **Large hadron contamination**
- **All cuts**
  - **acceptable hadron contamination**

Shower size data-MC comparison vs energy

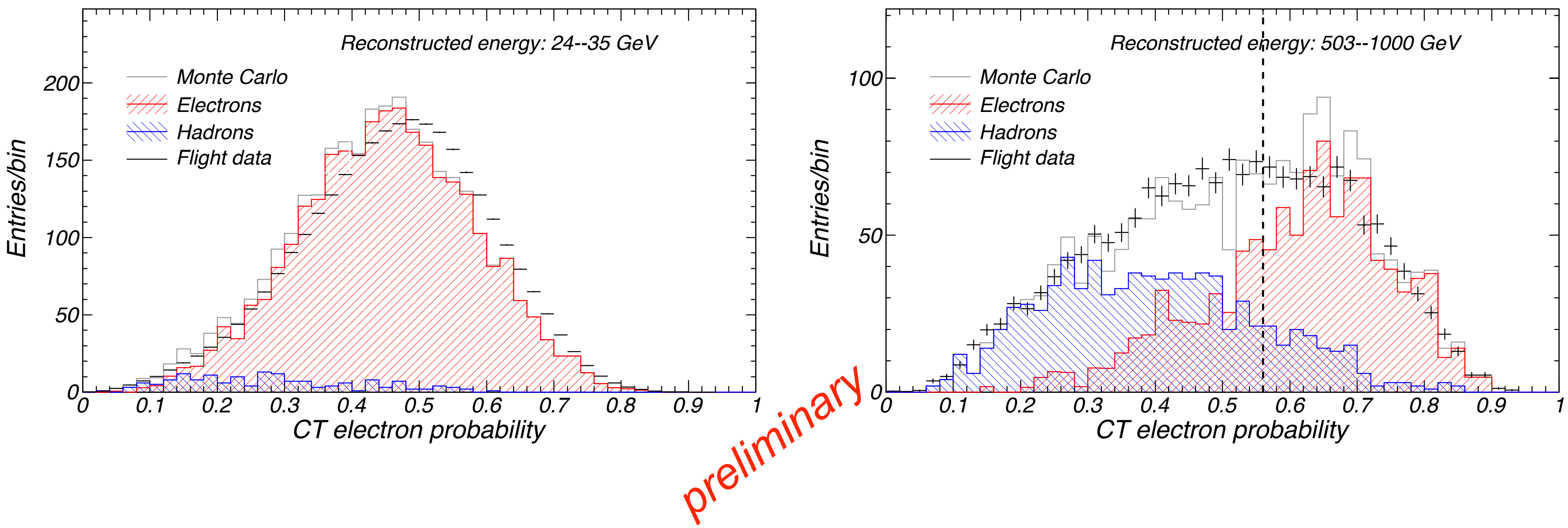


Good agreement over whole spectrum

HE event selection – cutting on CT variable

Energy dependent selection on combined electron probability from CAL and TKR probabilities

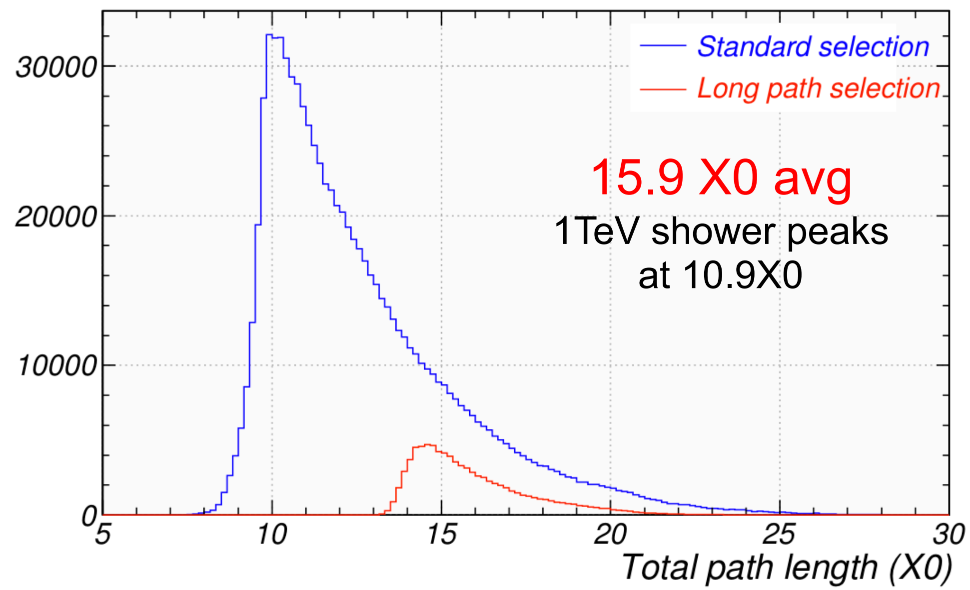
$$P^e_{comb} = \mathrm{sqrt}(p^e_{tkr} \times p^e_{cal})$$

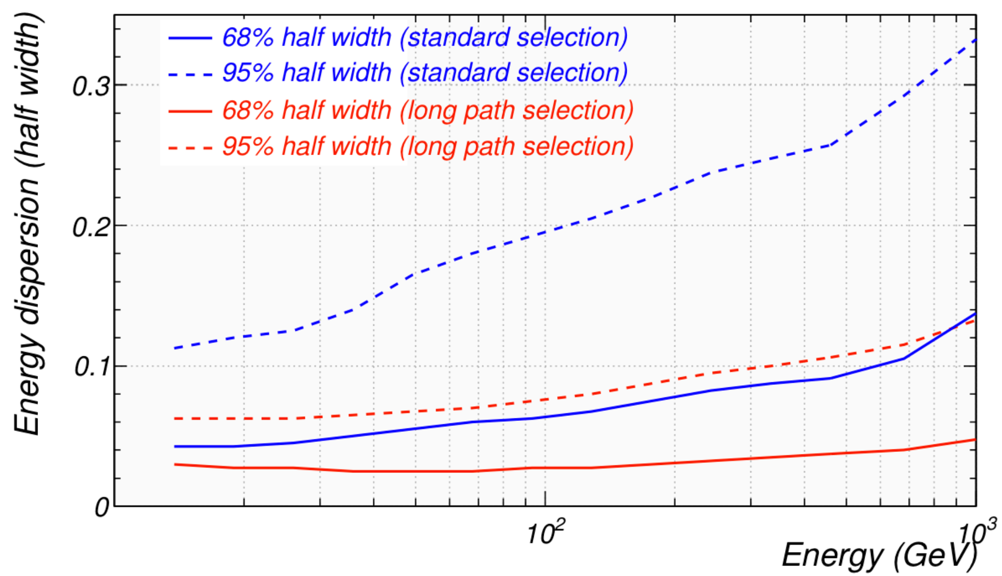


Good agreement over whole spectrum no CT cut need at low energies

Energy resolution checks – High X0 events

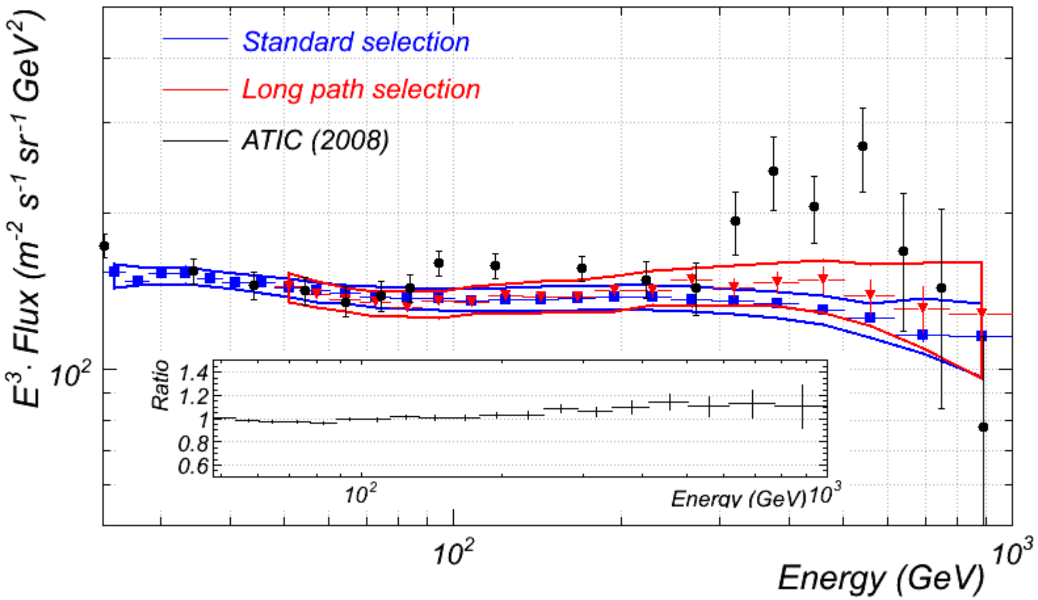
- ❑ **Critical for high energies**
  - – **Shower leakage from CAL**
- ❑ **Select subsample of events with long path-length (HI-X0)**
  - – **X0>13**
    - – **12 in CAL + minimum track length in TKR + events contained in a single CAL module**
- 🡅 **Energy resolution X ~ 2 – 4**
  - – **Down to 5% at 1 TeV (68% containment half-width)**
- 🡇 **Instrument acceptance to ~ 5% of standard and limited to a specific portion of instrument phase space**
  - – **Much higher systematics**



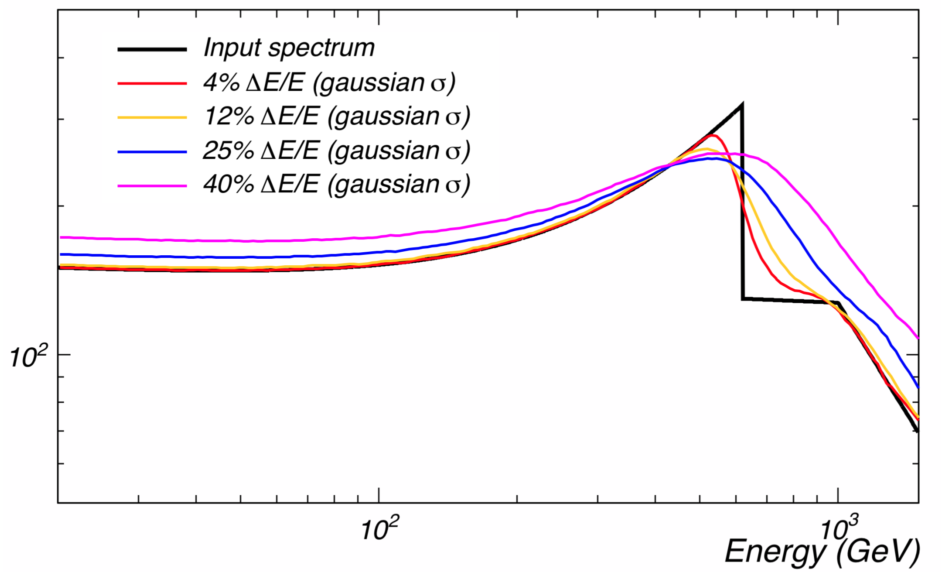


Comparison of standard and High-X0 spectra

- Consistent within their own systematics



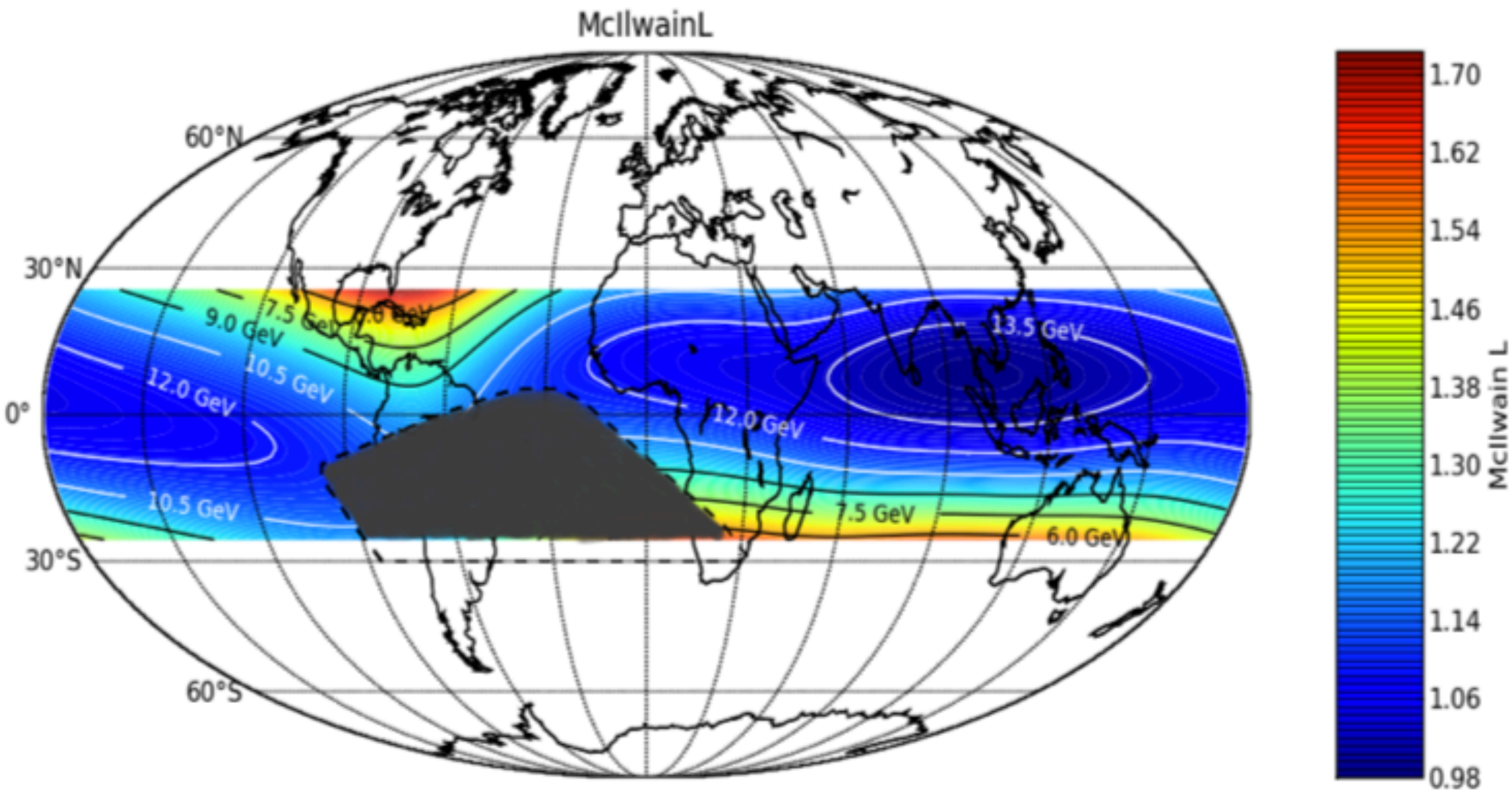
- already demonstrated by simulation of LAT response to spectral features with artificially worsened resolution



➔ the LAT energy resolution is adequate to detect prominent spectral features

➔ the Fermi spectrum is NOT dependent on the energy resolution of the bulk of the events

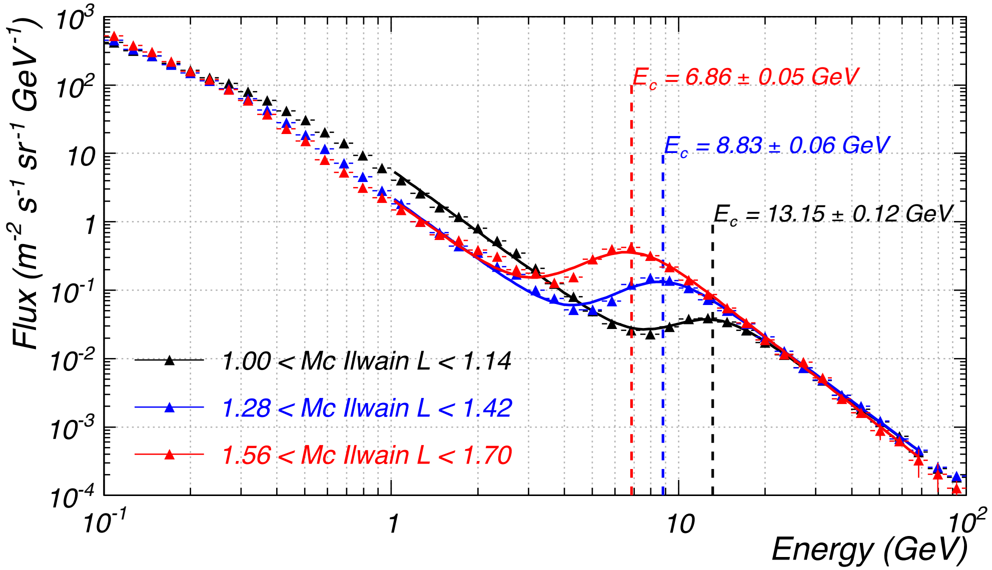
Extension to low energy measurements

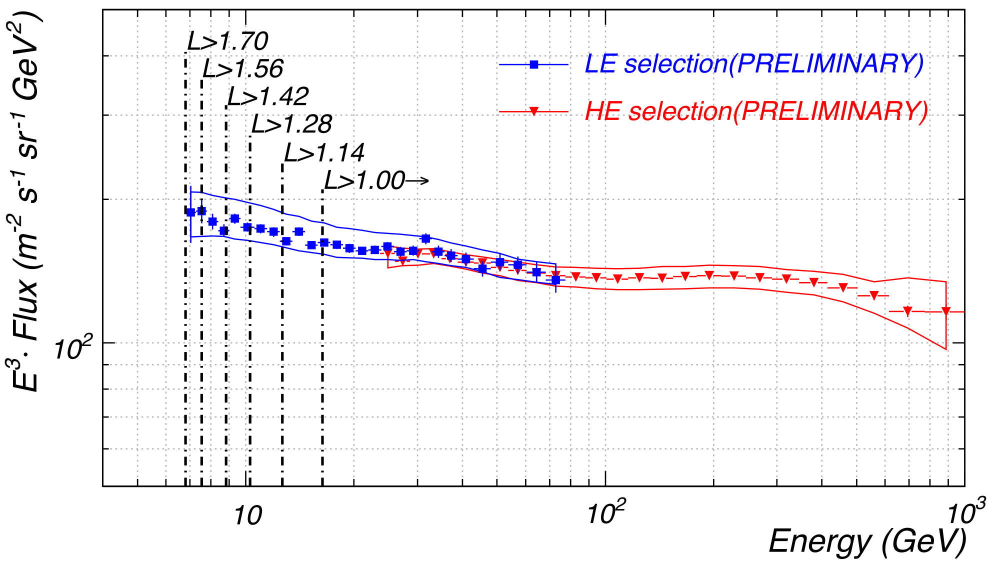


~ 7 GeV is the natural lower limit

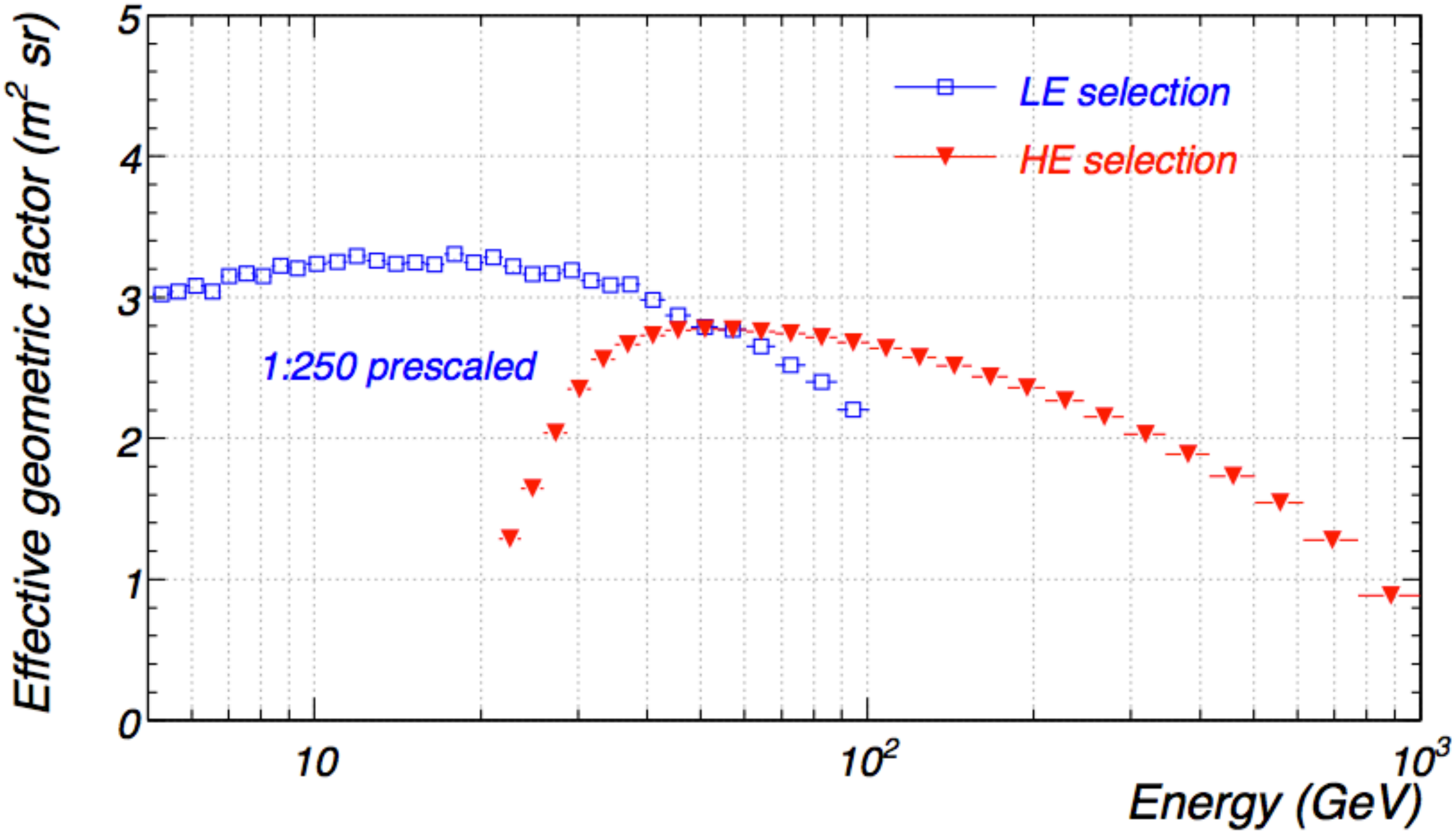
Extension to low energy measurements

- Determine geomagnetic cutoff energy as a function of geomagnetic orbital coordinates
  - Higher McIlwainL, lower cutoff energy
- Measure spectrum for primary component above cutoff
- Recombine spectra into global spectrum

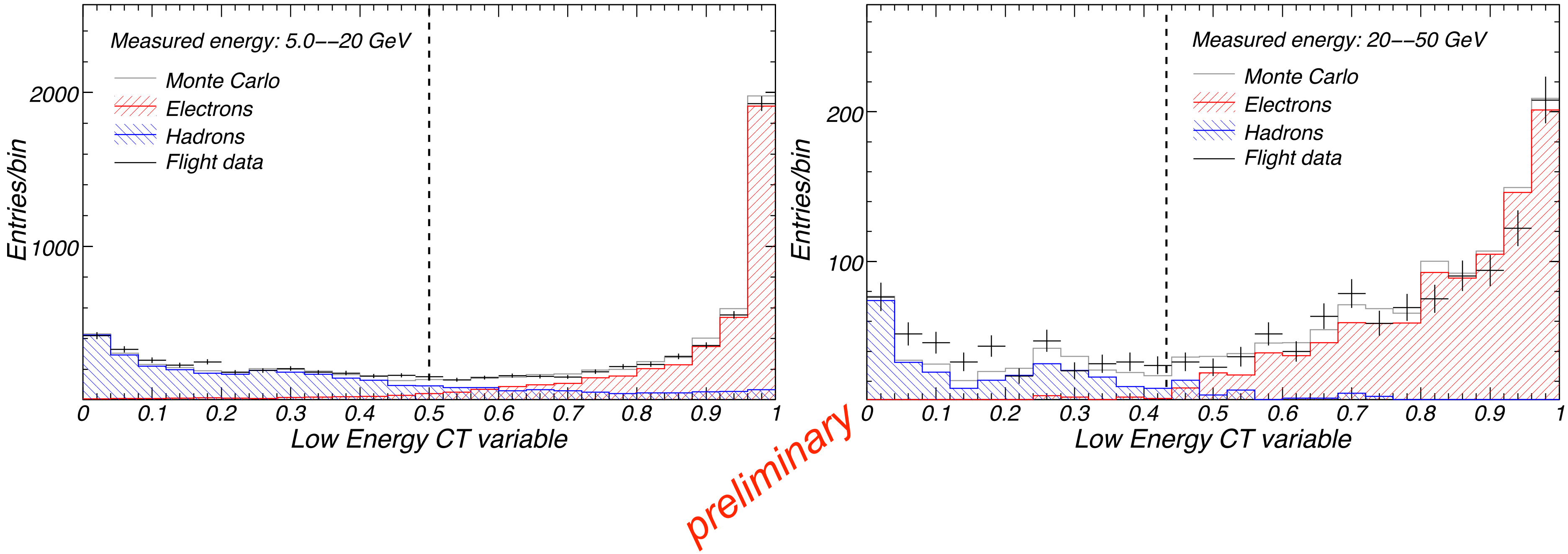




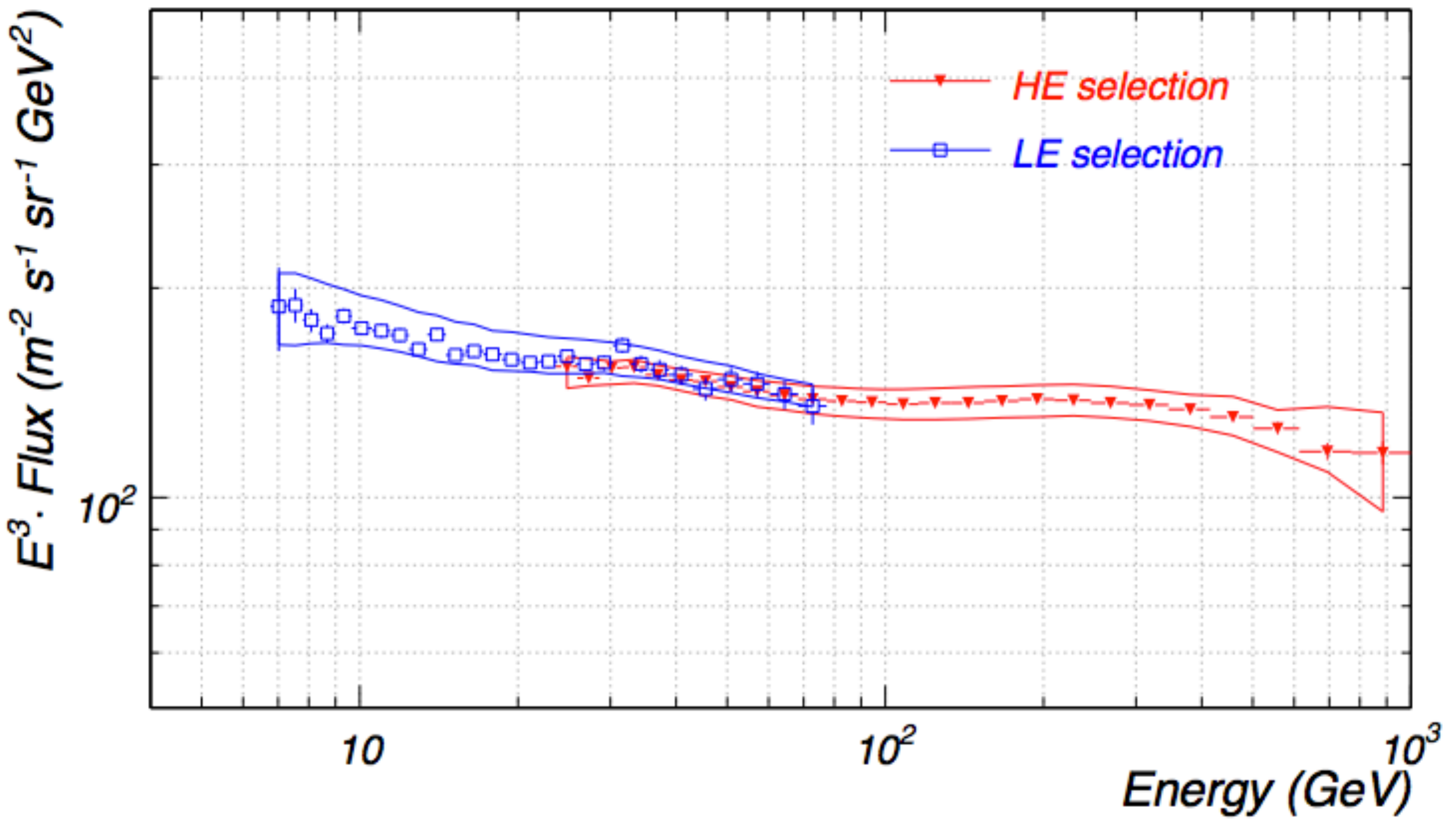
Extension to low energy measurements



LE selection variables validation



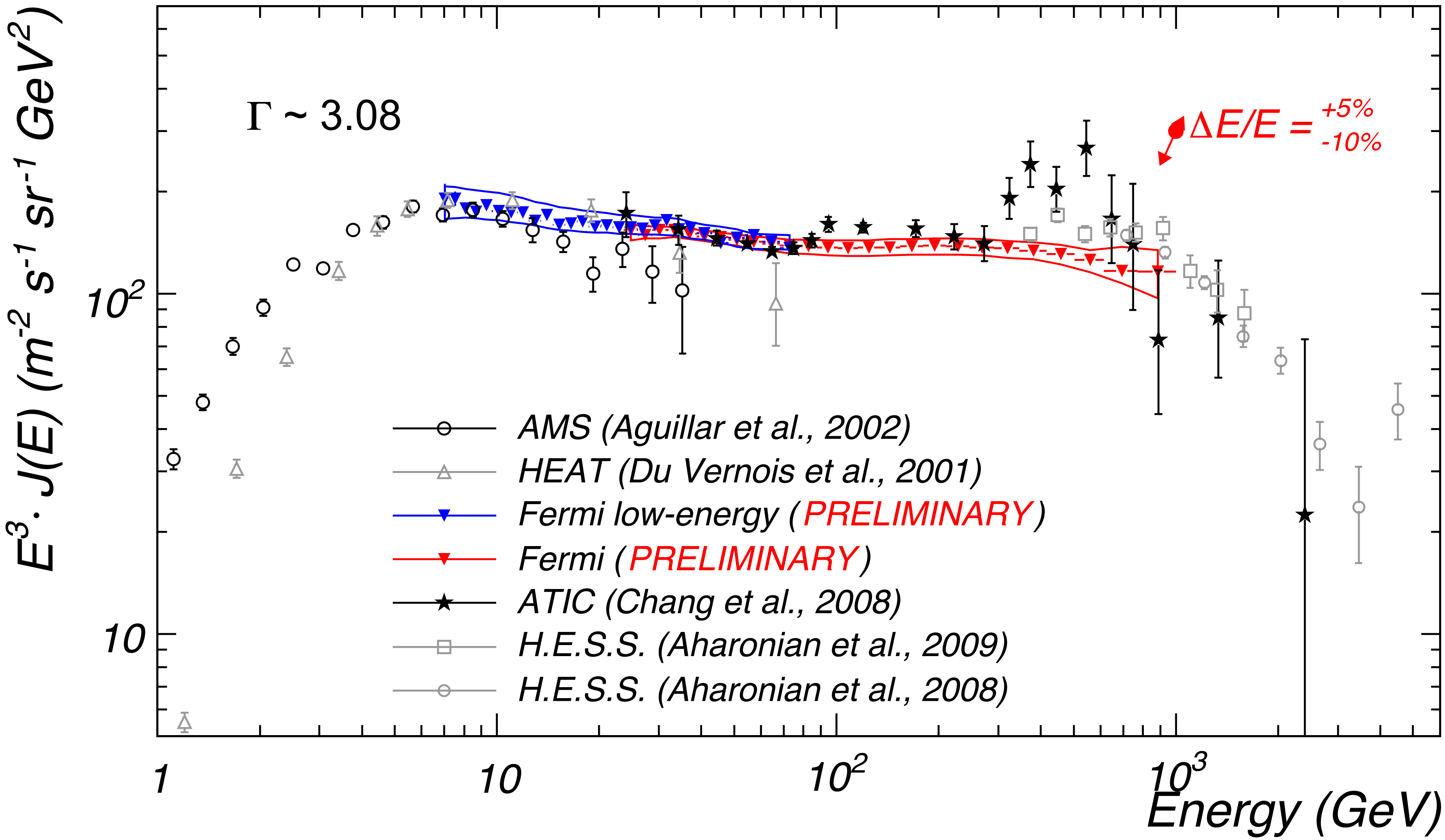
Combined Analysis



Provides extension to lower energies

Provides consistency check with HE analysis up to ~100 GeV

The Fermi CRE spectrum as of Nov. 2009

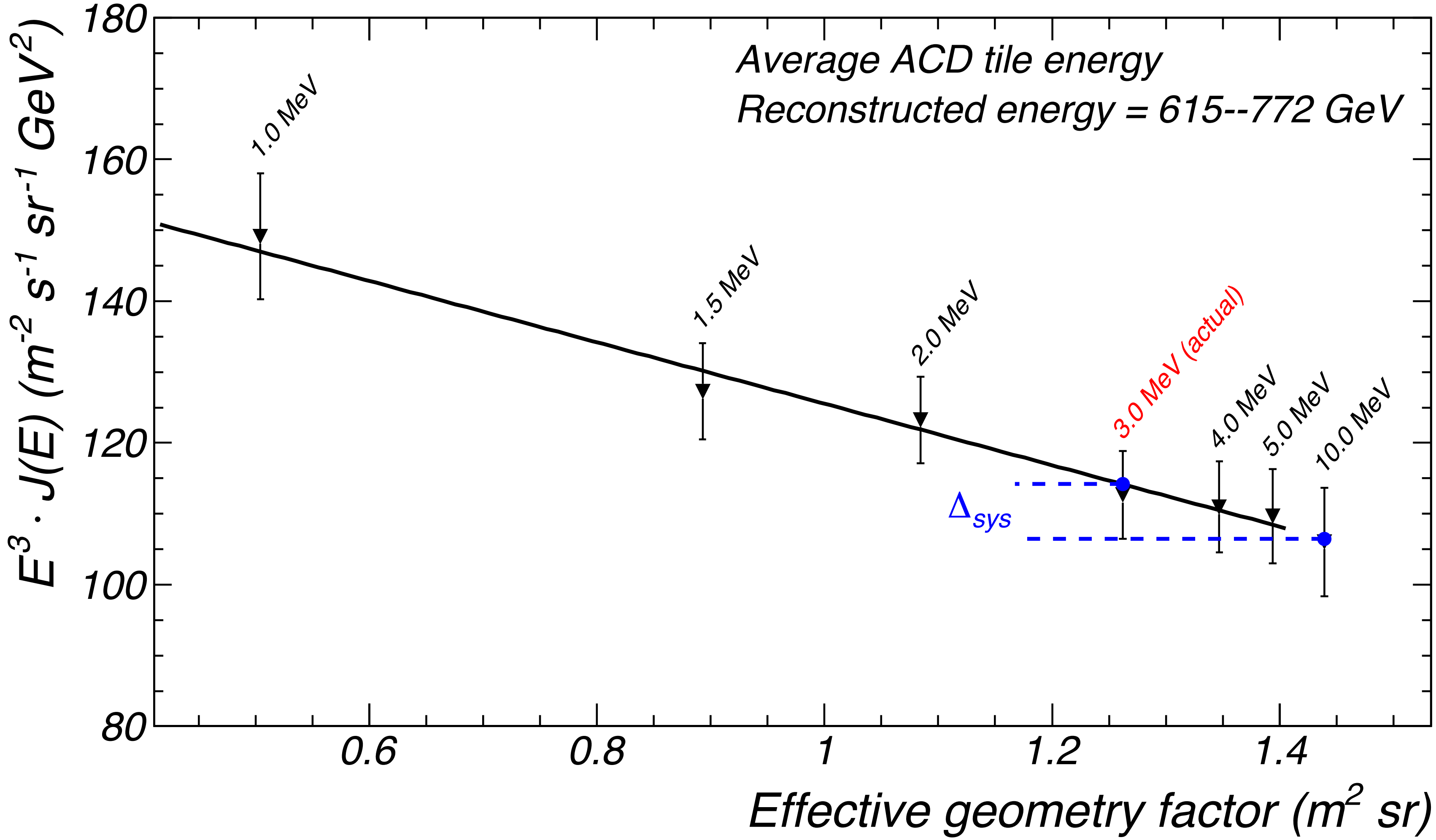


Conclusions and prospects

- Fermi CRE measurement extended down to 7 GeV and to 1 year statistics
- Event selection checks with long path-length requests indicate no dependence of the measured spectrum on energy resolution
- Spectrum adds valuable information below 10 GeV where strong constraints to propagation models can be imposed
- Several possible interpretations possible
  - see many talks in this meeting
- Further work
  - extend energy above 1 TeV to find TeV spectral cut-off
  - Reduce systematics to constrain different components in the overall spectrum
  - Search for anisotropies (see Mazziotta's talk)

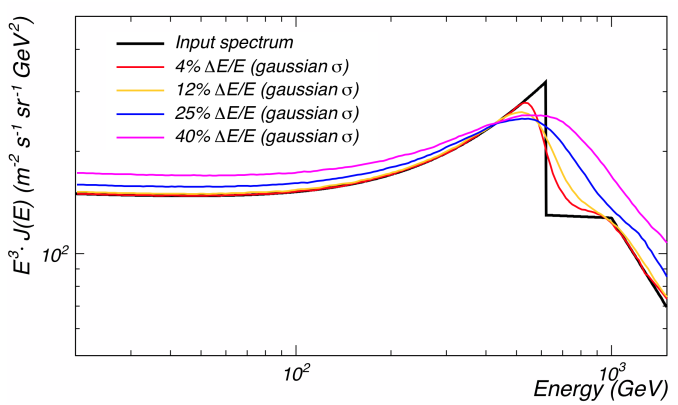
BACKUP

Systematic uncertainties

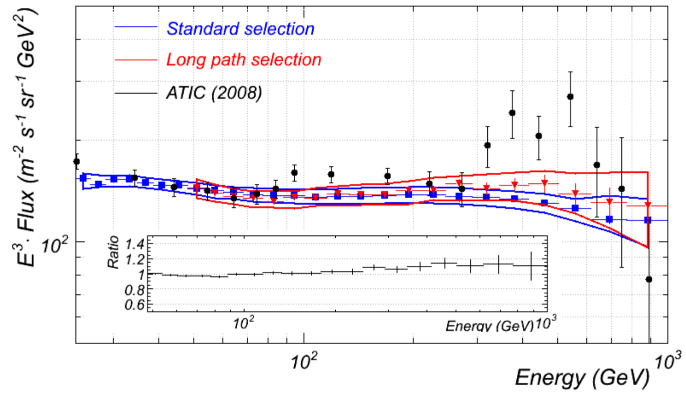


Absence of high energy features

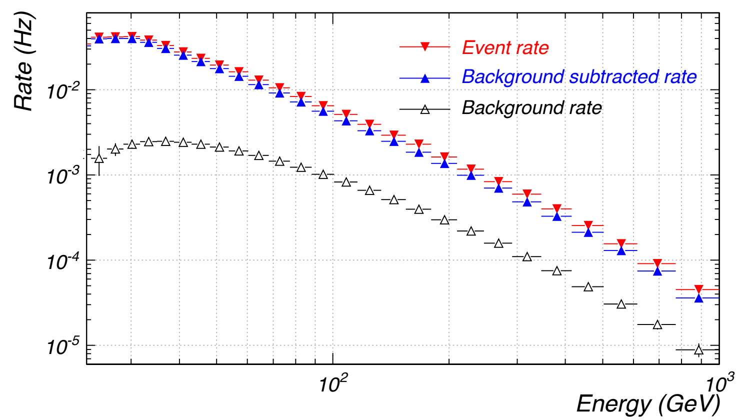
- Sensitivity to spectral features demonstrated



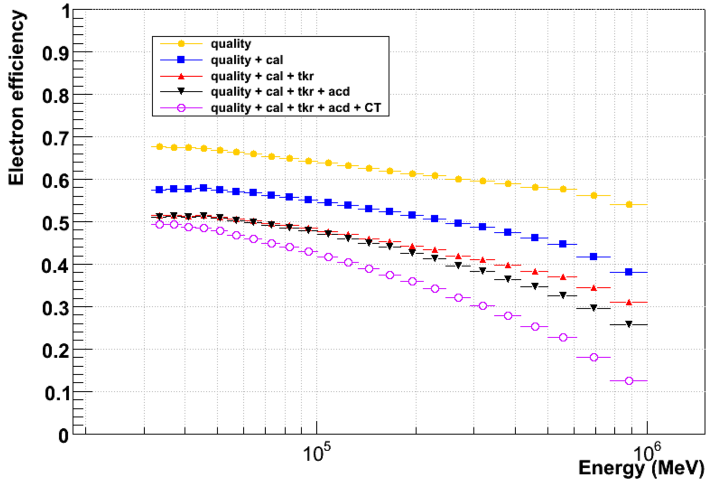
- Spectrum with best possible energy resolution compatible with main spectrum

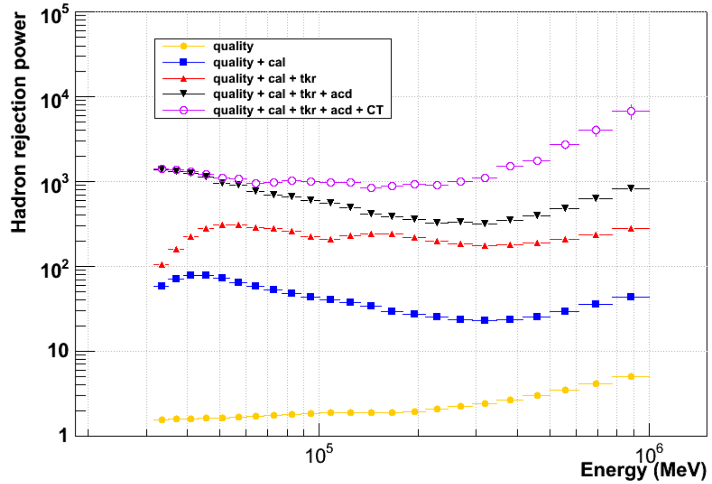


- Event rate before background subtraction does not show any feature



LAT Electron performance



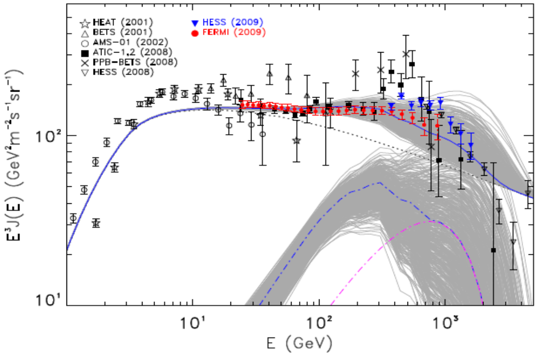


- **Performance is a trade-off among:**
  - electron-acceptance – hadron contamination - systematics
- **Geometry factor**
  - ~ 3 m^2sr (50 GeV) to ~ 1 m^2sr (1 TeV)
  - > 10x wrt previous experiments
- **Rejection power: ~ 1:10^3 (20 GeV) to ~ 1:10^4 (1 TeV)**
- **Maximum residual contamination ~ 20% (1 TeV)**
- **Maximum systematic uncertainty ~ 20% (1 TeV)**

Some possible interpretations

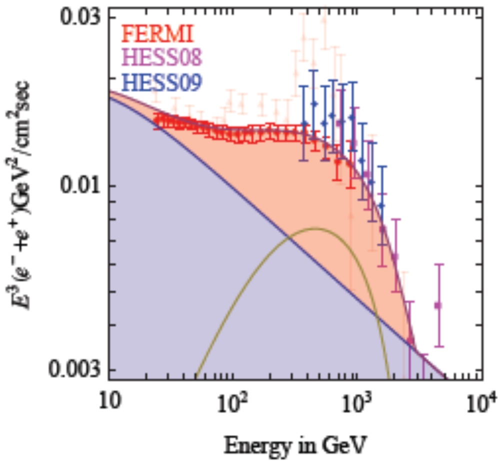
- Several papers already published to explain electron spectrum
  - Together with other observations (positron fraction, diffuse γ-ray)

Pulsars



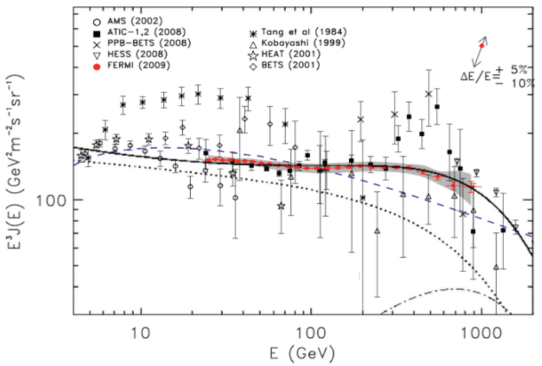
Grasso et al. 2009

Dark Matter



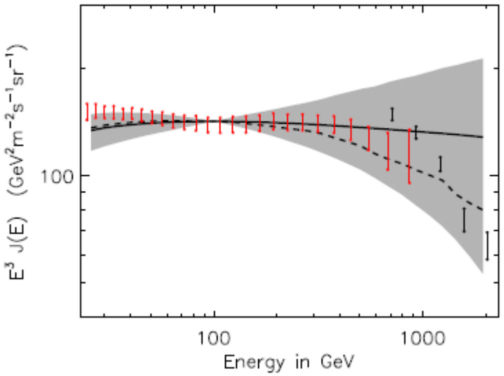
Strumia et al. 2009

Secondary CR acc.



Blasi 2009

Source stocasticity

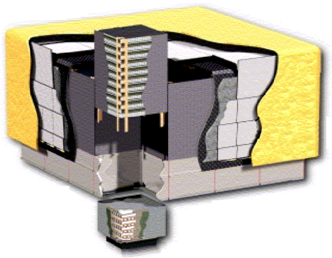


Grasso et al. 2009

Science impact by citation

- "Measurement of the Cosmic Ray $e^{+}+e^{-}$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope" (05/2009) — ~190
  - Cited across a broad range - cosmic-ray, astronomy, particle physics (D0, BABAR)
- "Fermi/Large Area Telescope Bright Gamma-Ray Source List" (07/2009) — ~85
- "Fermi Observations of High-Energy Gamma-Ray Emission from GRB 080916C" (03/2009) — ~74
- "Bright Active Galactic Nuclei Source List from the First Three Months of the Fermi Large Area Telescope All-Sky Survey" (07/2009) — ~62
- "The Fermi Gamma-Ray Space Telescope Discovers the Pulsar in the Young Galactic Supernova Remnant CTA 1" (11/2008) — ~41

Overview of the Large Area Telescope

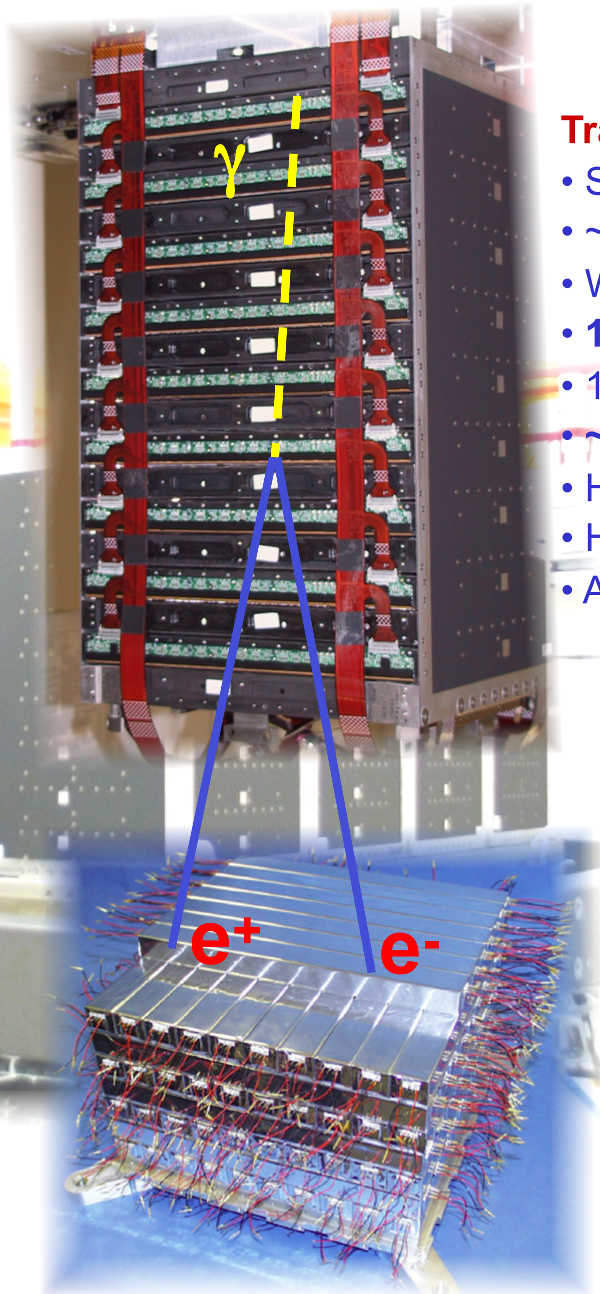


LAT:

- modular - 4x4 array
- 3ton – 650watts

Anti-Coincidence (ACD):

- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**



Tracker/Converter (TKR):

- Si-strip detectors
- ~80 m^2 of silicon (total)
- W conversion foils
- **1.5 X0 on-axis**
- 18XY planes
- **~10^6 digital elx chans**
- Highly granular
- High precision tracking
- Average plane PHA

Calorimeter (CAL):

- 1536 CsI(Tl) crystals
- **8.6 X0 on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction
- EM vs HAD separation