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

論文講読

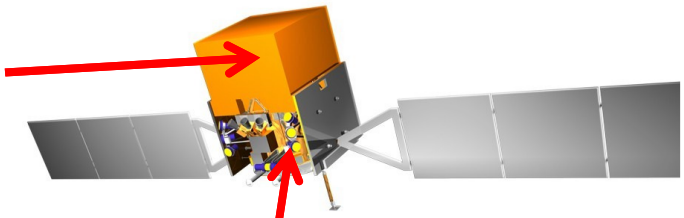
24th Nov. 2009

Kohei Yoshida

Introduction

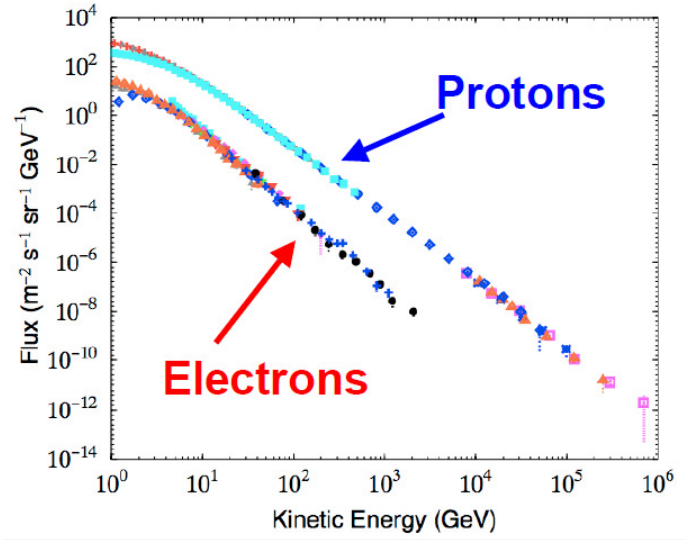
The GLAST Mission(→Fermi)

- Part of NASA's Office of Space and Science Strategic Plan
- Two instruments
  - The Large Area Telescope(LAT): primary
    - High energy(20MeV~300GeV)
    - follows in the footsteps of the CGRO-EGRET experiment
  - The GLAST Burst Monitor(GBM): complementary
    - Low energy(8keV~30MeV)



Theory

- $e^-(e^+)$: $\propto E^{-3.0}$
- proton: $\propto E^{-2.7}$



Motivation

Motivation

- Pamela,ATIC,H.E.S.S. and PPB-BETS report deviations from model.
  - **Pamela**: an increase e^+ with respect to $e^- + e^+$ at energy above a few GeV
  - **ATIC,PPB-BETS**: prominent spectral feature at around 500 GeV in the total e^- plus e^+ spectrum
  - **H.E.S.S**: significant steeping of the spectrum above 600 GeV

→These indicate the presence of a nearby primary source of e^- and e^+.

- The source is nearby pulsar? or dark matter annihilation in the Galactic halo?

→Accurate measurements of high-energy cosmic ray $e^- + e^+$ is necessary.

Launch!

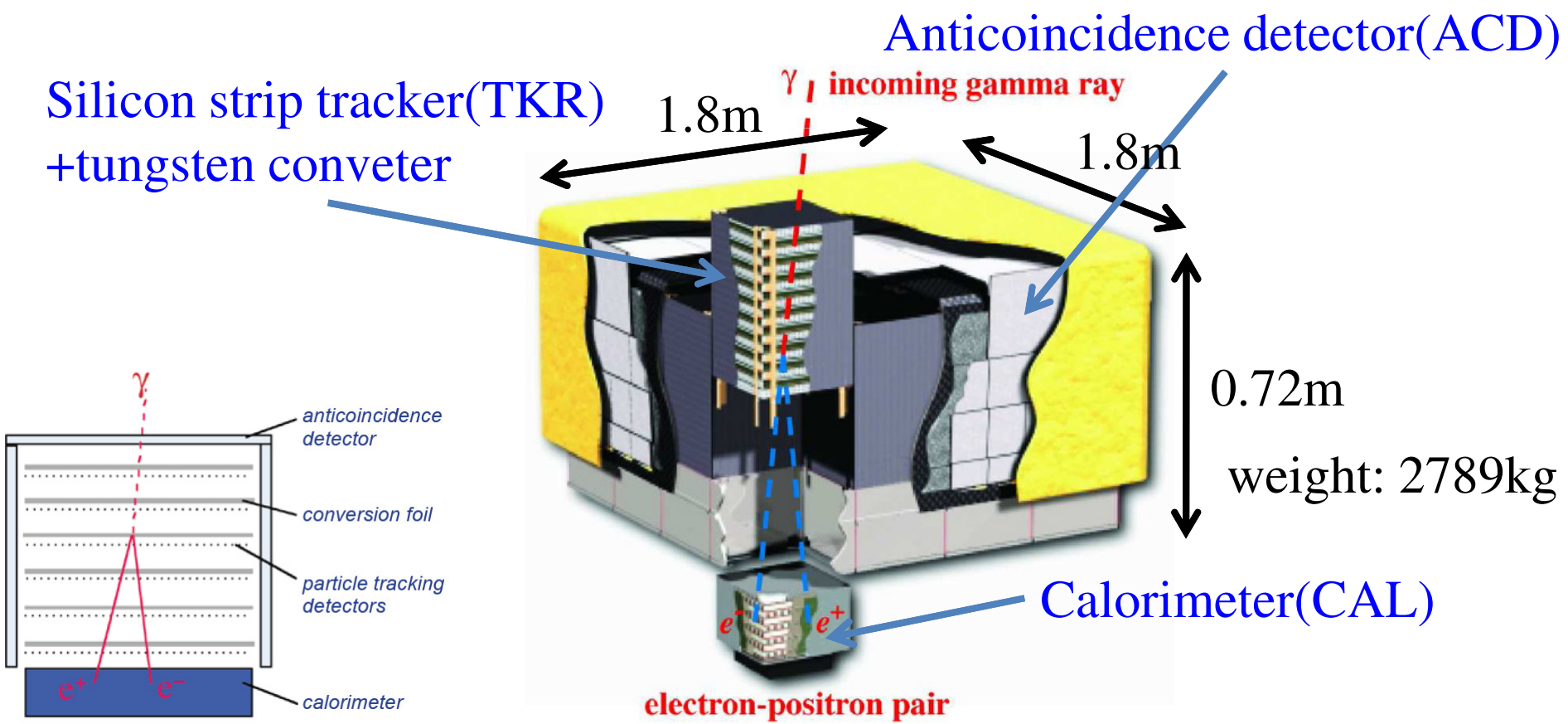
Launch

- 11th June 2008 at 12:05PM EDT
- From the Kennedy Space Center (Cape Canaveral)
- circular orbits : 565km

The Large Area Telescope(LAT)

Overview

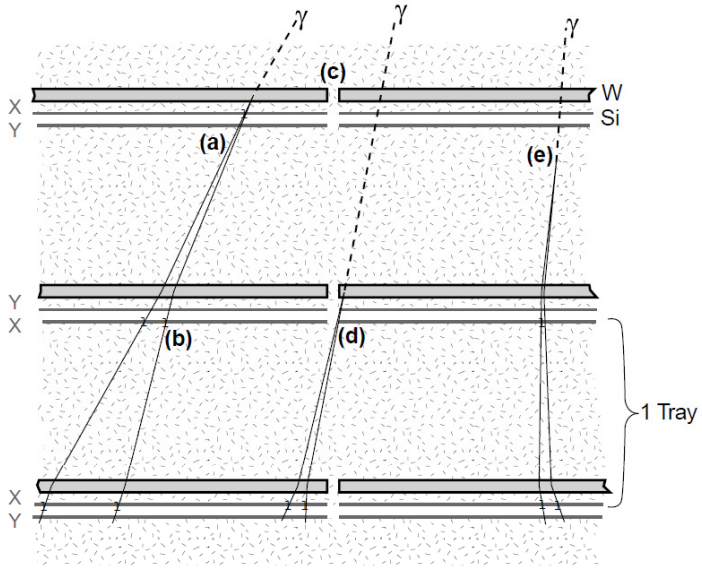
- 4 × 4 array of towers(a tracker and a calorimeter in each)
- Tracker surrounded by Anticoincidence detector

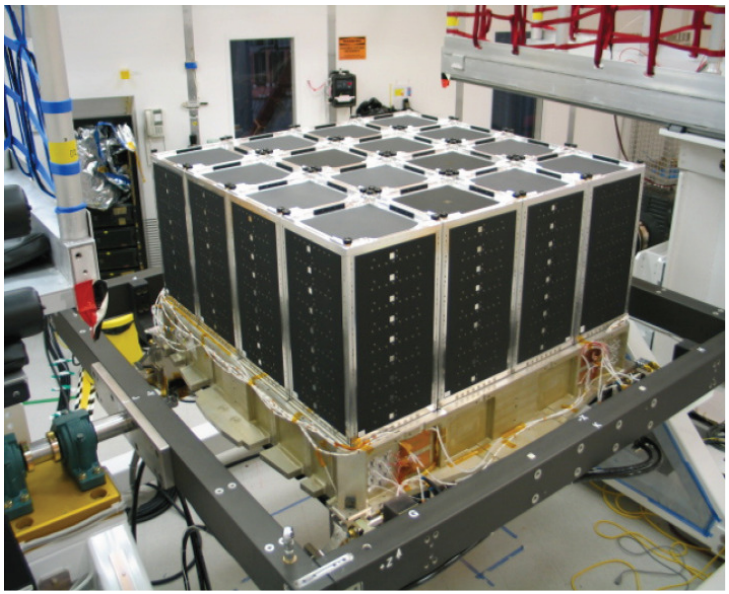


Precision converter-tracker

Tracker

- 4 × 4 array of tower modules
- Detector: single-sided silicon-strip detector
  - 18 plane include 2 layer in a module
  - direction: x,y-axis
- Converter: thin tungsten foil
  - interleaved at the top of first 16 planes
  - thickness: 12 × 0.03X_0(0.01cm/foil)
    : 4 × 0.18X_0(0.072cm/foil)
- Total radiation length: 1.5X_0

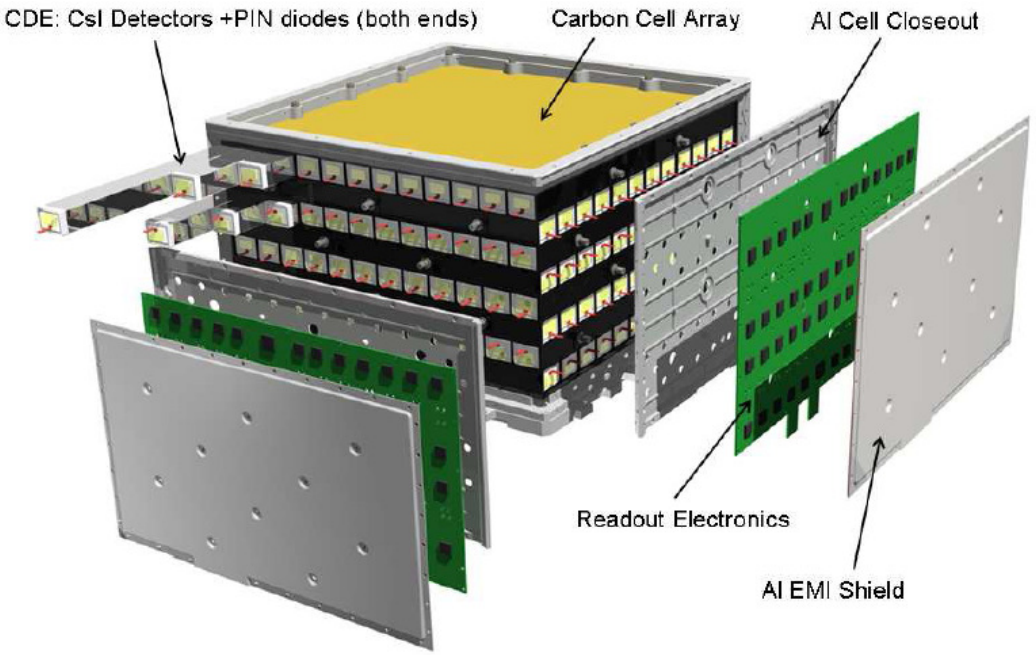




Calorimeter

Calorimeter

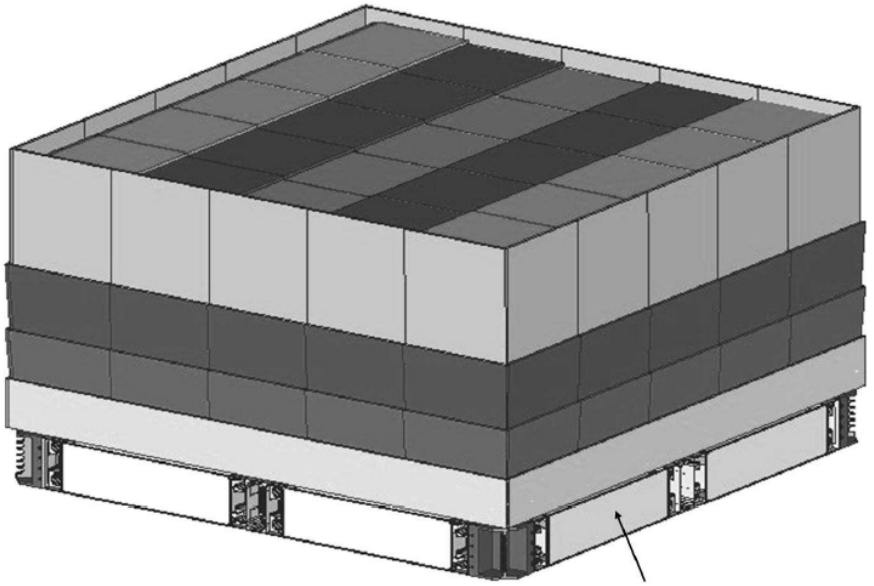
- purpose: measurement of energy of particle
  : shower profile
- 4 × 4 modules
- 96 CsI(TI) crystals in each module(8 layer of 12 crystals each)
- crystal size: 2.7cm × 2.0cm × 32.6cm
- Total radiation length: 8.6X_0



Anticoincidence detector

Anticoincidence detector

- purpose: rejection of charged-particle background
- efficiency: at least 0.9997 for singly charged particles
- a total of 89 plastic scintillator tiles
  - 5 × 5 array on the top
  - 16 tiles on each of the 4 sides



Event selection

Event selection

- target: high-energy $e^-(e^+)$
- dedicated event selection
  - large geometry factor
  - residual contamination
    - hadron: <20%, gamma: <2%

Rejection power

Energy	~200GeV	1TeV
Rejection power	$1:10^3$	$\sim 1:10^4$

Selection efficiency

Energy	20GeV	1TeV
efficiency	50%	12.5%

Contents of dedicated event selection

- ACD vetoes failure
- difference between EM and hadronic showers
  - EM: more compact, hadronic: wider
- different distributions of energy and hits in the ACD
- two training classification trees(CT)
  - one: based on TKR variables, other: based on CAL variables

Energy reconstruction & validation

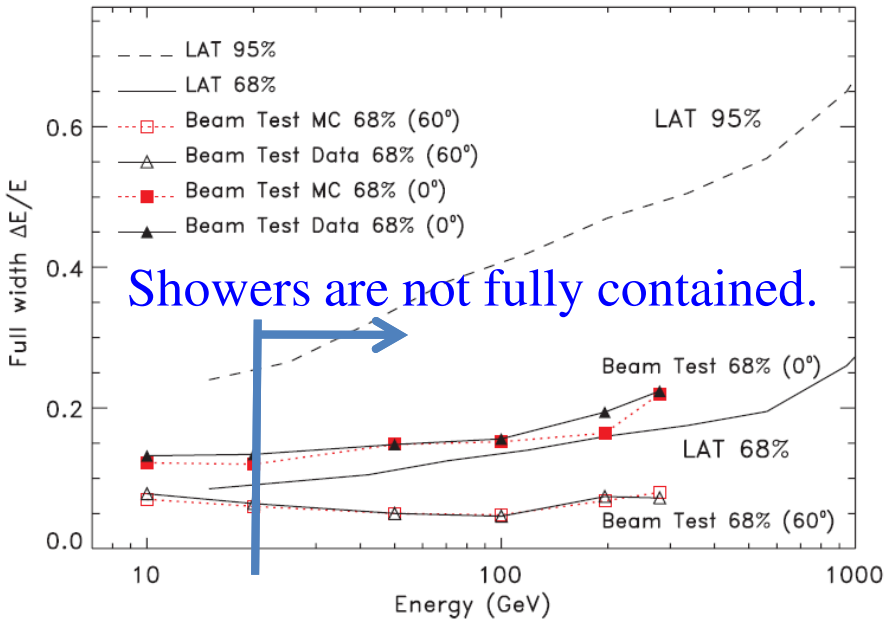
Energy reconstruction is critical.

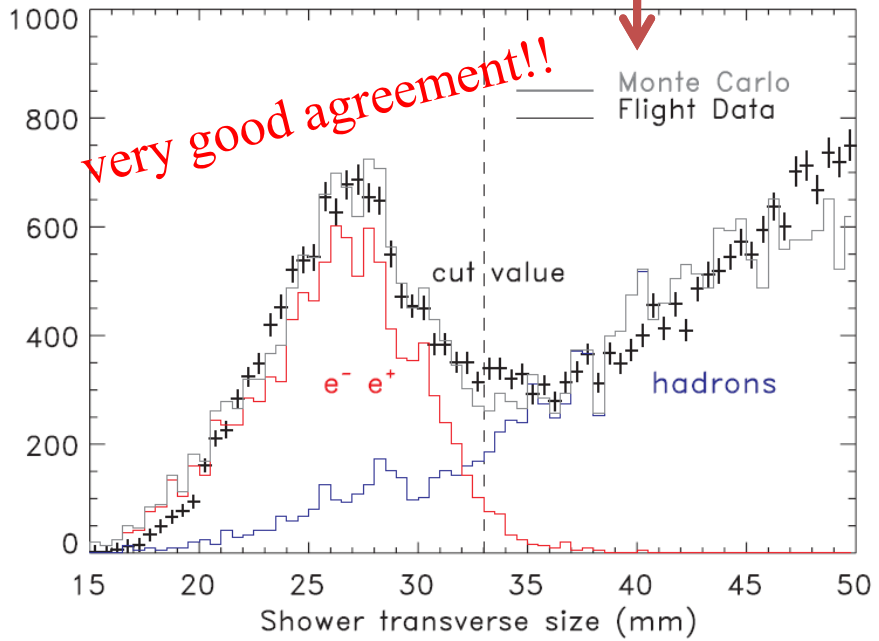
- a large fraction of E falls outside of CAL for high-E EM cascades.

→correct for E leakage by shower profile

→incoming energy is able to estimated with good accuracy.

- algorithm was extensively verified and fine-tuned using beam test data.
- To avoid bias, flight data and MC are compared.



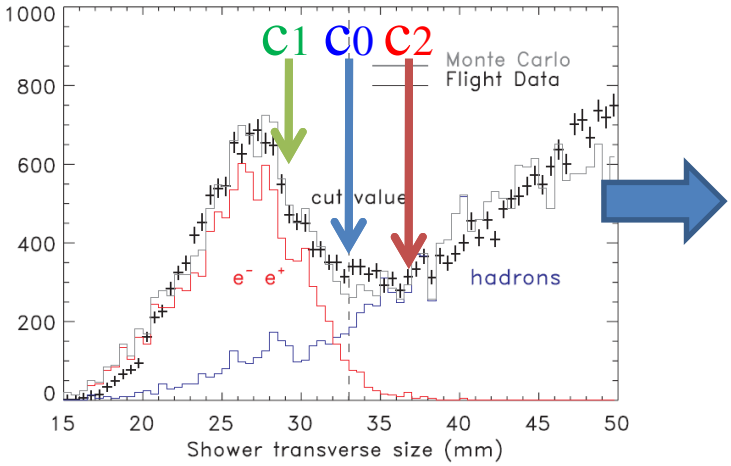


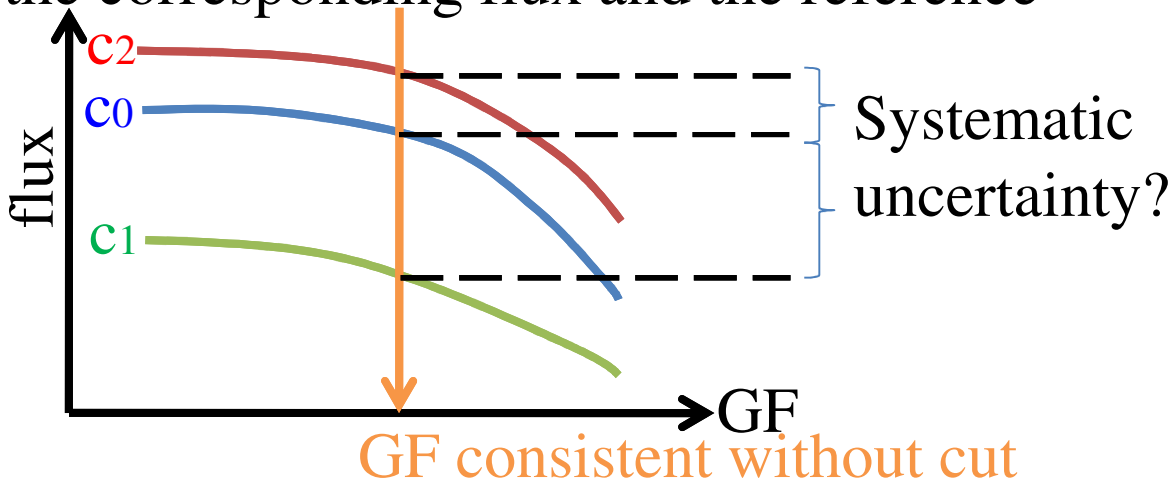
Error

Systematic uncertainty of event selection

- determined for all energy bins and each step in the event selection
- Maximum sys. error: <20% (final tuned event selection)
- Procedure
  - scan a range of thresholds around the reference value used by cut
  - derive the flux vs GF curve
  - extrapolate the curve to a GF consistent with a null cut

→relative difference of the corresponding flux and the reference





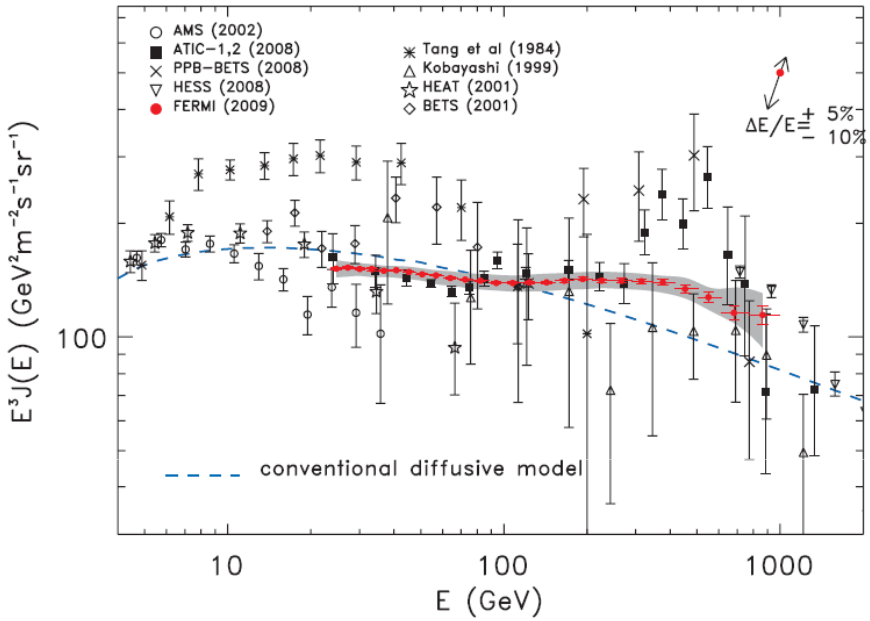
Result & discussion

Data

- more than 4M electron events
- 4 August 2008 ~ 31 January 2009

Result

- $\propto E^{-3.04}$ (χ^2: 9.7, d.o.f: 24)
- suggest the presence of one or more local sources of high-E CR $e^{\pm}$



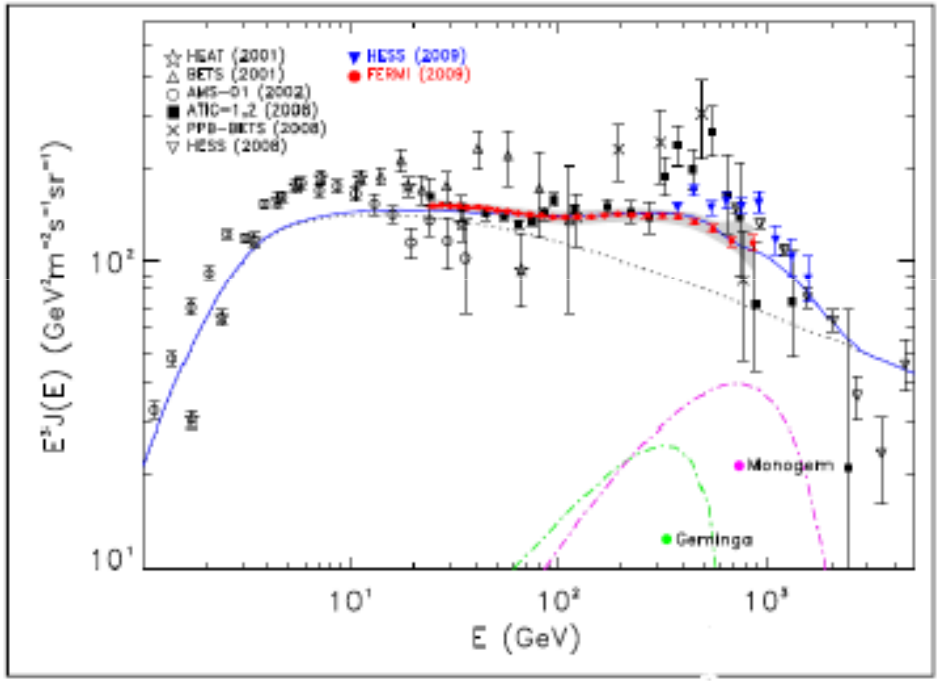
- LAT spectrum can be nicely fit by adding $J_{\mathrm{extra}}(E) \propto E^{-\gamma_e} \exp\{-E/E_{\mathrm{cut}}\}$

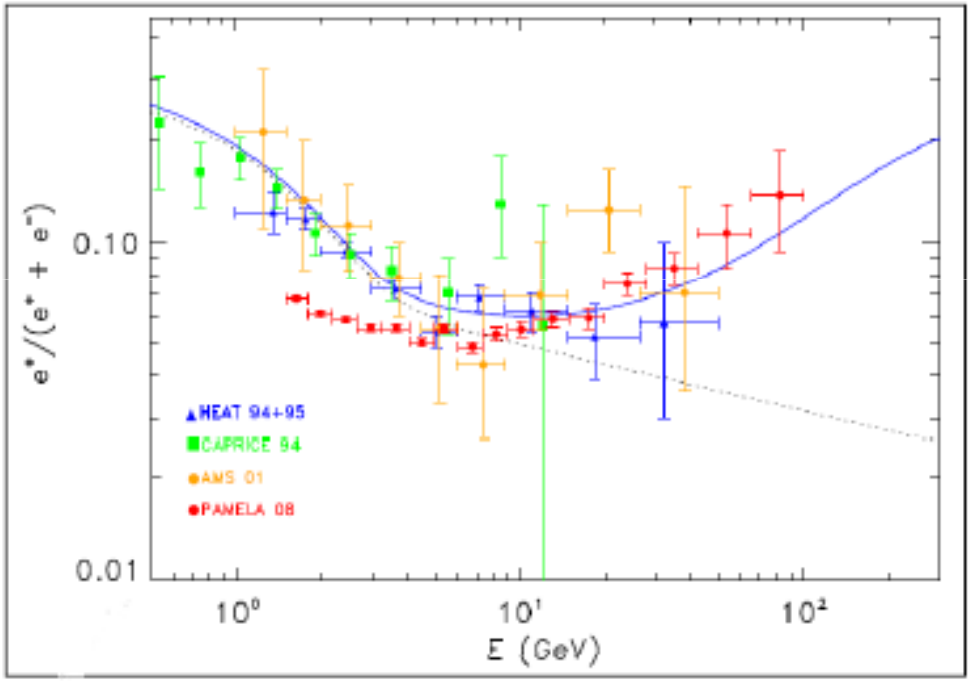
→reconcile theoretical predictions with both Fermi and Pamela data

→explain steepening of spectrum above 1 TeV(H.E.S.S.)

- the most natural candidate: pulsars
- other astrophysical interpretations, DM scenarios can not be excluded.

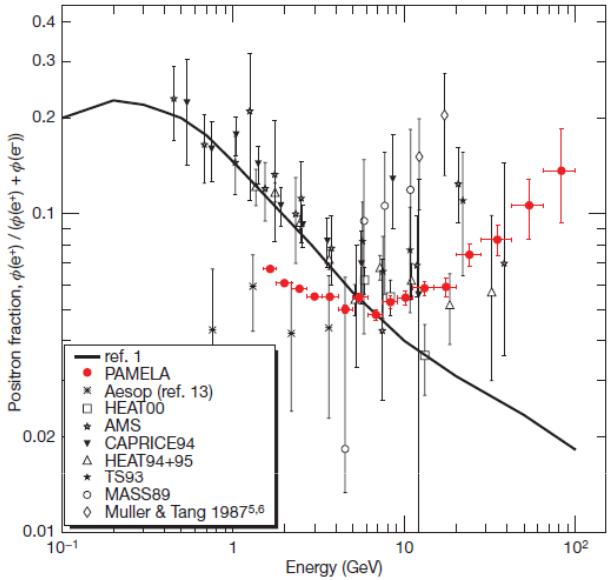
おまけ


HEAT (2001)
BETS (2001)
AMS−01 (2002)
ATIC−1,2 (2008)
PPB−BETS (2008)
HESS (2008)
HESS (2009)
FERMI (2009)
Monogem
Geminga
E³J(E) (GeV²m⁻²s⁻¹sr⁻¹)
E (GeV)

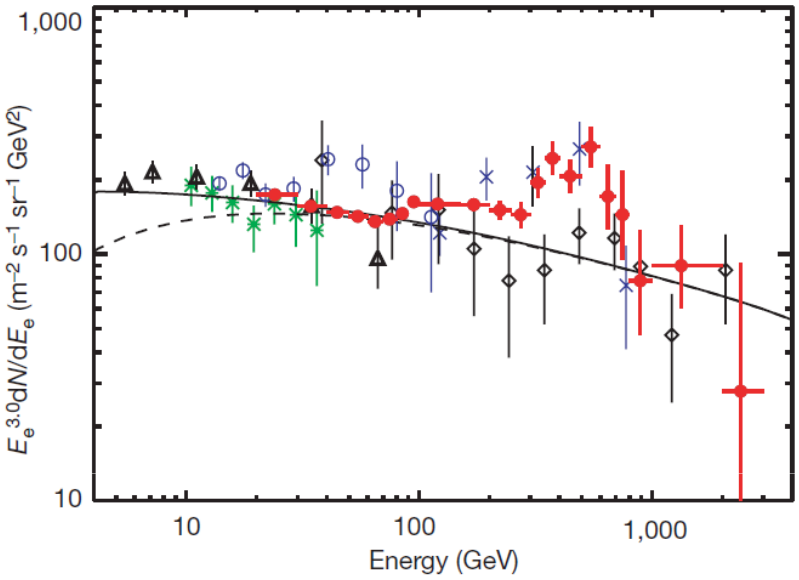

HEAT 94+95
CAPRICE 94
AMS 01
PAMELA 08
e⁺/(e⁺ + e⁻)
E (GeV)

other experiments

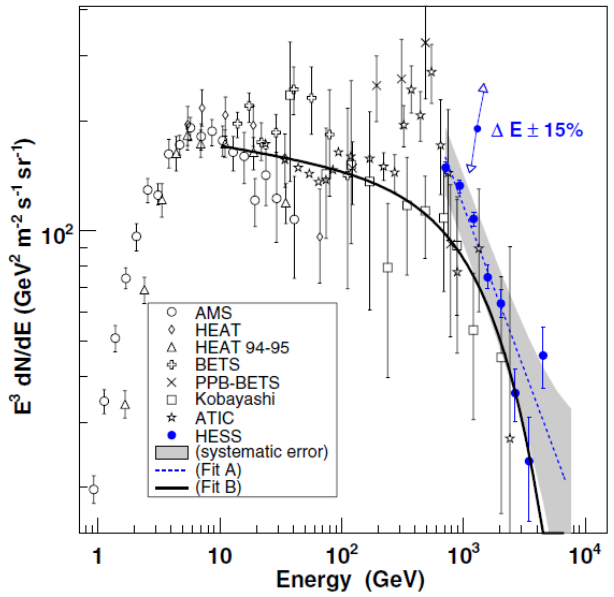
Pamela



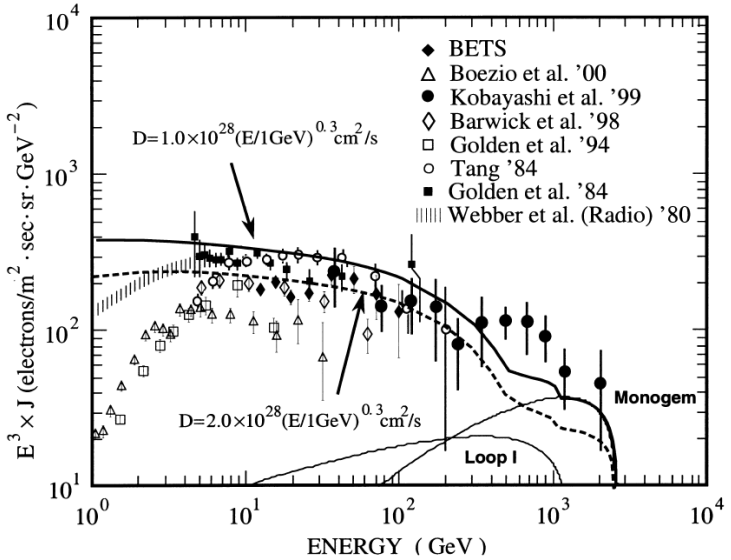
ATIC



H.E.S.S



PPB-BETS



Definition

Field of View (sr) Ω : Solid angle that detector can see at once

Effective area (cm^2) A_{eff} : efficiency × active area of detector

→ depends on particle angle and energy

Geometry Factor (cm^2 sr) GF : $\Omega \times A_{eff}$

→ depends on energy

Event rate at given energy : Flux ($cm^{-2}s^{-1}sr^{-1}$) × GF