High energy cosmic electrons: messengers from nearby cosmic ray sources or dark matter?

Alexander Moiseev

NASA Goddard Space Flight Center and CRESST / University of Maryland

Fermi Gamma-ray Space Telescope was launched on June 11, 2008

1901 – 1954

…

…

2008 - ……

"There are two possible outcomes: If the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery. " ***Enrico Fermi***

The Fermi Gamma-Ray Space Telescope

- Large Area Telescope (LAT) (20 MeV – >300 GeV)
- Gamma-ray Burst Monitor (GBM) (8 keV – 40 MeV)

Spacecraft with LAT and GBM before shipping to KSC

LAT collaboration

France
- IN2P3/LLR Ecole Polytechnique
- IN2P3/CENBG Bordeaux
- IN2P3/LPTA Montpellier
- CEA/Saclay
- CESR Toulouse

Germany
- MPI fuer extraterrestr. Physik, Garching

Italy
- INFN Bari, Padova, Perugia, Pisa, Rome, Trieste, Udine
- ASI
- INAF-IASF

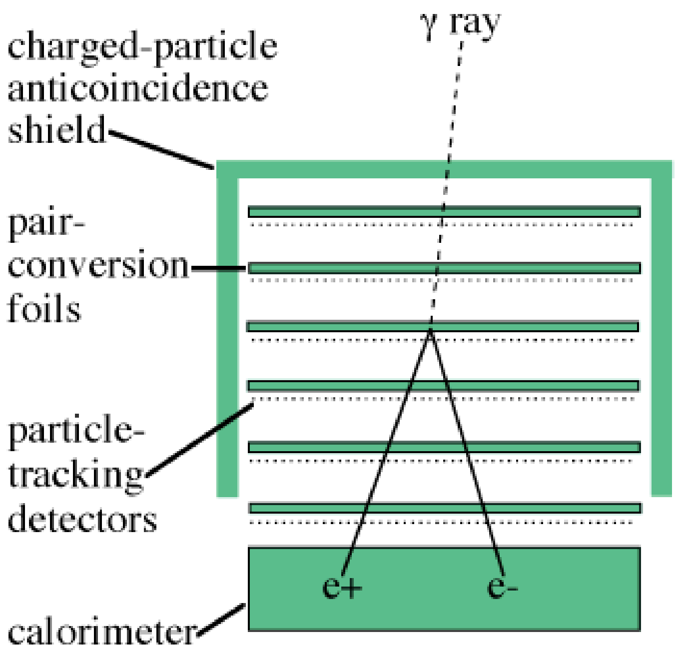
Japan
- Hiroshima University
- ISAS/JAXA
- Tokyo Institute of Technology

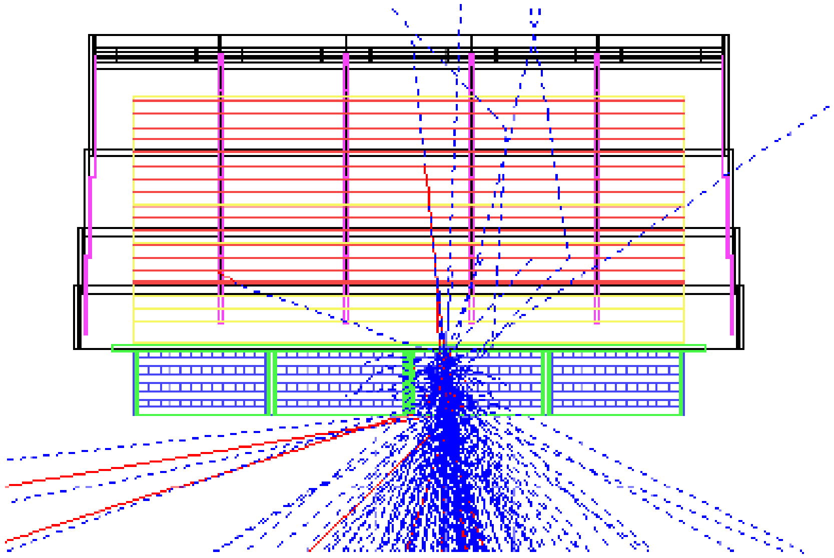
Spain
- IEEC-CISC, Barcelona

Sweden
- Royal Institute of Technology (KTH)
- Stockholm University

United States
- Stanford University (HEPL/Physics, SLAC, KIPAC)
- UC Santa Cruz
- Goddard Space Flight Center
- Naval Research Laboratory
- Sonoma State University
- Ohio State University
- University of Washington
- University of Denver
- Purdue University – Calumet

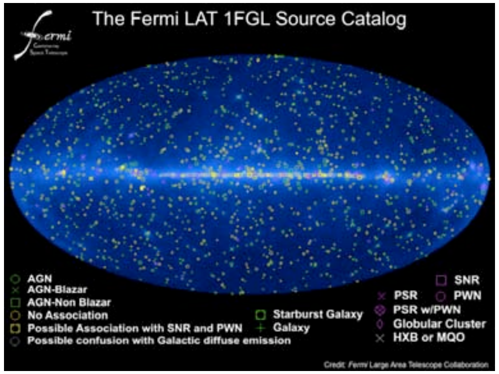
This is a pair – conversion telescope to detect high energy photons through pair-conversion process



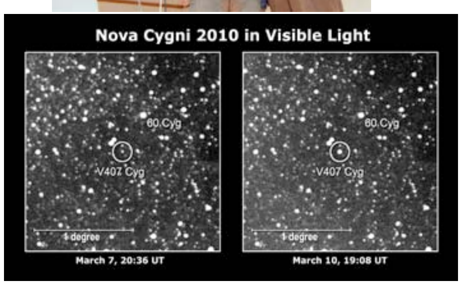


1. Incident photon converts into an electron-positron pair in one of the pair-conversion foil
2. Incident photon directions is determined by the tracks of electron and positron, detected in the tracker
3. The energy is determined by the CsI Calorimeter

Fermi LAT science objectives cover practically all aspects in astrophysics

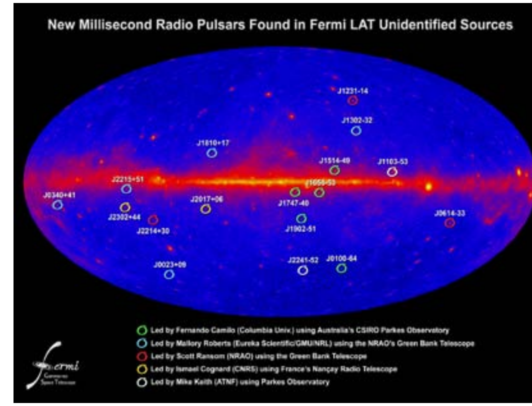


First Fermi source catalog (1,451 source)

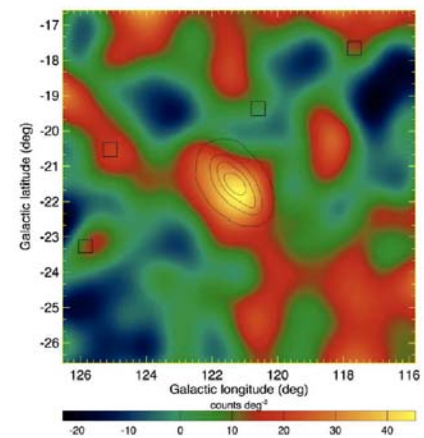


Gamma-signal from Nova Cygni

- Active galactic nuclei
- Gamma ray bursts
- Supernova remnants
- Pulsars
- Solar system objects
- Galaxies, clusters of galaxies, X-ray binaries
- Unidentified sources/new populations
- Diffuse gamma-ray emission
- Cosmic-ray acceleration & propagation
- Extra-galactic background light (EBL)
- Search for Particle Dark matter



Milliseconds Pulsars



Detection of gamma-signal from M31 Andromeda

Fermi results recognized as one of the top 10 science breakthroughs of 2009 (Science, December 2009)

Many discoveries in different topics. Fermi LAT Collaboration just has published its 117-th paper (~ 2,500 citations to date). 6 more are in press and 20 have been submitted

Each of these paper is a complete high-level analysis covering one of the topics listed above.

Why electrons?

• Due to their low mass high energy cosmic ray electrons (CRE) lose their energy rapidly (as $-dE/dt \sim E^2$) by synchrotron radiation on Galactic magnetic fields (≈ 3-6 μG) and by inverse Compton scattering on the interstellar radiation field (starlight and 2.7 K CMB, ≈ 1eV/cm^3)

• The life-time of CRE due to these energy losses is

$t = E/\left(-dE/dt\right) \approx 3\times10^{8}\left(E/1\,GeV\right)^{-1} yr \quad \Rightarrow$ age of CRE observed at 1 TeV is ~ 10^5 yr

• The typical distance over which a 1 TeV CRE loses half of its energy is ~ 300-400 pc

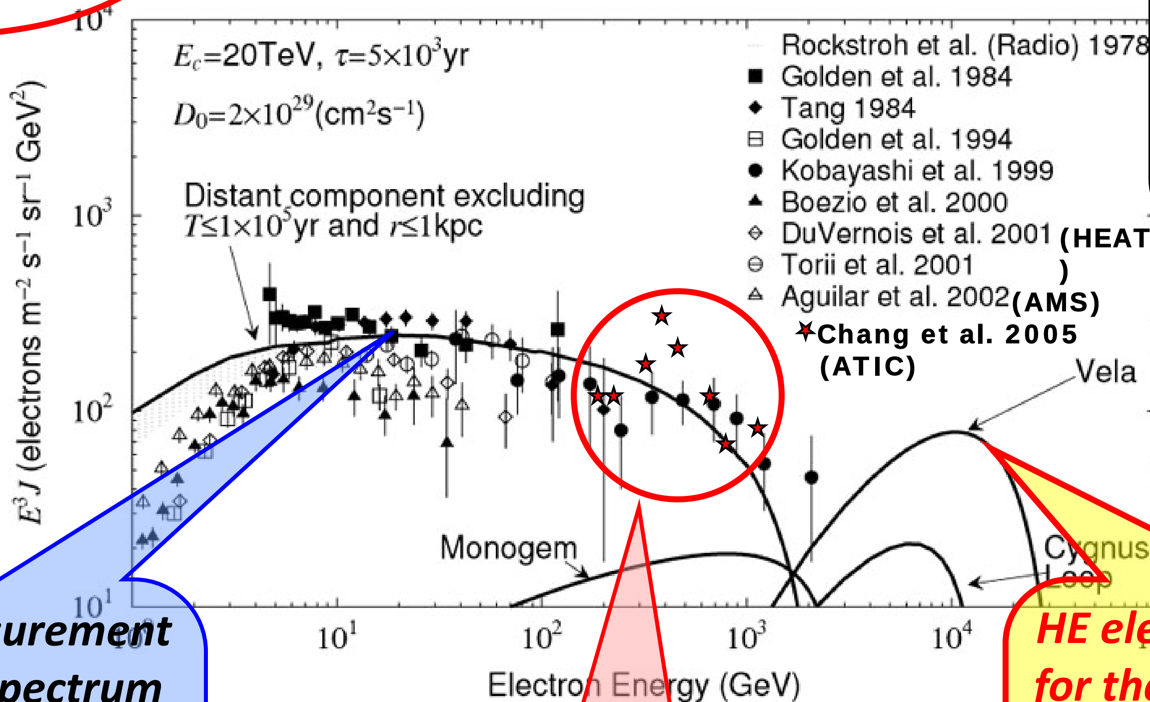
• Observation of such HE CRE would imply existence of a nearby source of TeV electrons

• This makes CRE a unique tool for probing nearby Galactic space (Galactic halo is ~ 40 kpc diameter, ~ 4 kpc thick)

What can be learned from HE electrons (E > 10 GeV) ?

As we realized it in 2006

Search for anisotropy in HE electron flux : nearby sources, streaming of local magnetic fields?

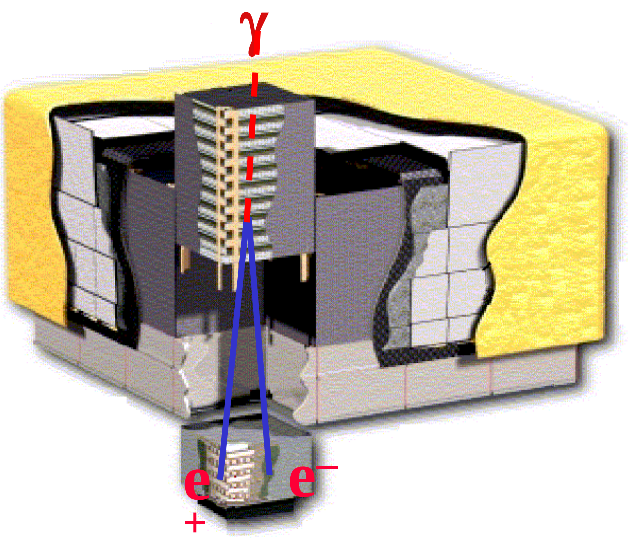


Precise measurement of electron spectrum above 10 GeV (CR diffusion model; IC gamma ray flux model calibration, GALPROP)

Search for Dark Matter Signatures

HE electrons origin: Search for the signature of nearby HE electrons sources (believed to be SNR) in the electron spectrum above ~ TeV

LAT as a detector of high energy cosmic ray electrons



- The LAT is composed of a 4x4 array of identical towers. Each tower has a Tracker and a Calorimeter module. Entire LAT is covered by segmented Anti-Coincidence Detector (ACD)

- Although the LAT was designed to detect photons, it was recognized early in its design that the LAT is a capable detector of high energy electrons too

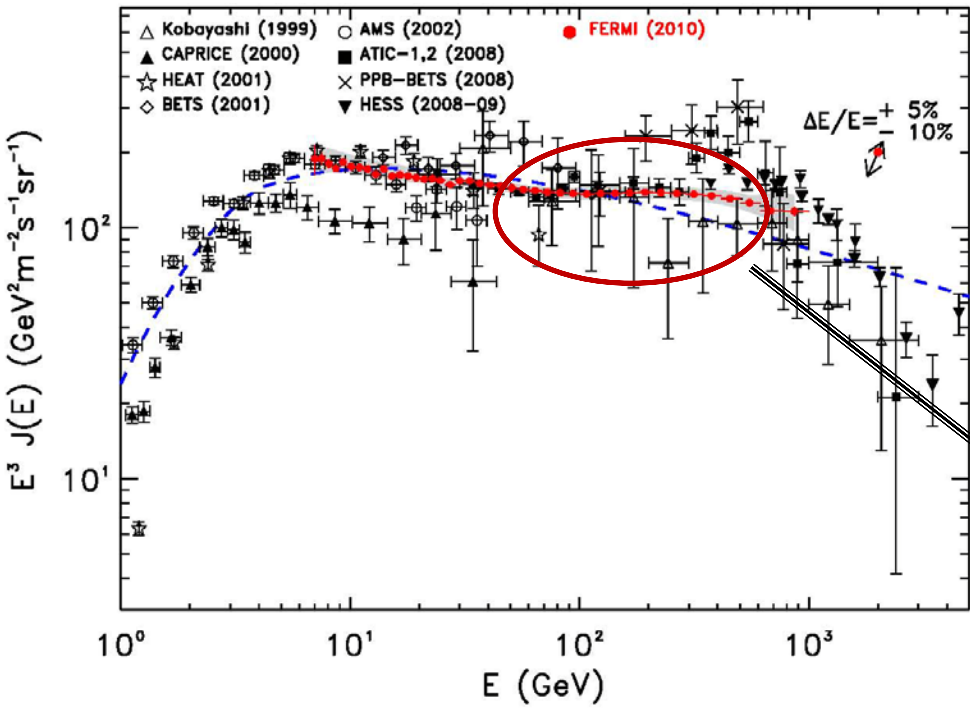
- The electron data analysis is based on that developed for photons. The main challenge is to identify and separate electrons from all other charged species, mainly CR protons (for gamma-ray analysis this is provided by the Anti-Coincidence Detector)

- The hadron rejection power must be $10^3 – 10^4$ increasing with energy

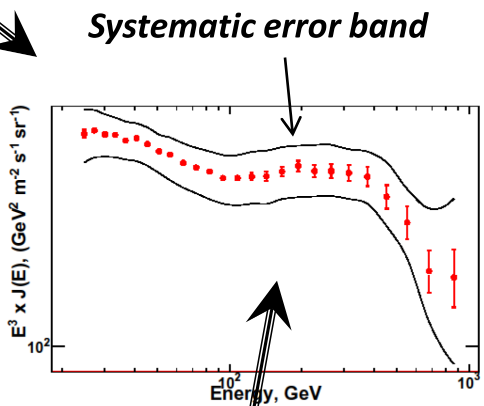
- Another challenge – assessment of systematic errors : statistical errors will be very small

Fermi LAT electron+positron spectrum 7 GeV – 1 TeV

Ackerman et al., Fermi LAT Collaboration, Phys. Rev. D82, 092004, November 2010 (arXiv 1008.3999)



Our first results were published in PRL 102, 181101, 2009. It is the most cited Fermi LAT paper so far (over 400 times)



Data collected for the first 12 months of operation

- Total statistics 7.95 M electron candidate events
- More than 1000 events in highest energy bin (772 – 1000 GeV)
- Noticeable deviation from single power law spectrum

Interpretation

Conventional model: $e^+ + e^-$ spectrum consists of dominating "primary" (produced in quasi-uniformly distributed distant astrophysical sources, thought to be SNR) e^-, plus contribution from "secondary" e^+ and e^-, produced in interactions of cosmic rays with interstellar matter

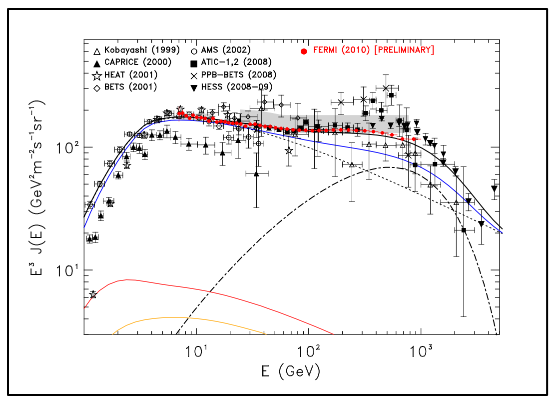
Additional component: it is assumed that there is a source of HE $e^+ + e^-$ with hard spectrum

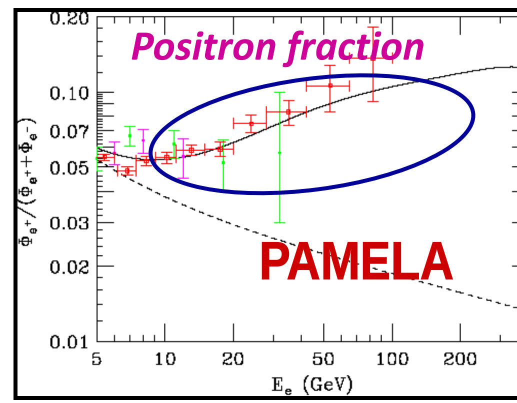
model

Task: find a model which agrees with all relevant experimental results

Inputs:

- Results
  - ✓ Fermi $e^+ + e^-$ spectrum
  - ✓ HESS $e^+ + e^-$ spectrum
  - ✓ Pamela $e^+/(e^+ + e^-)$ ratio
  - ✓ Pamela p^-/p ratio
- Models
  - ✓ diffusion propagation (plain, Kolmogorov, Kraichman)
  - ✓ solar modulation
  - ✓ single vs. additional (several) components in the electron flux





D. Grasso et al., AstroPart Physics 32 (2009), 140

Interpretation (cont.)

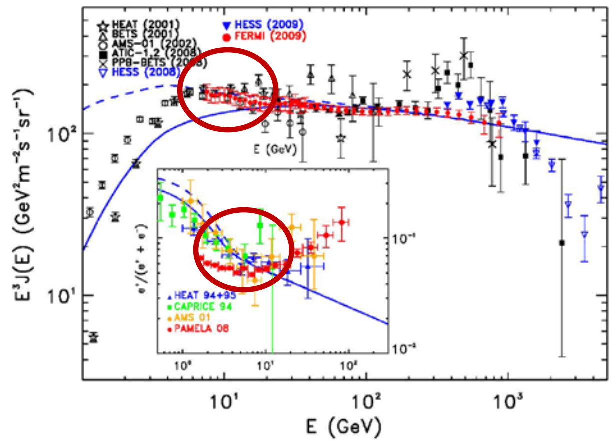
Fermi - LAT:

- We were rather successful to fit our first spectrum published in PRL paper (20 GeV – 1 TeV) with a single component (single power law fit).
- With our new spectrum extended down to 7 GeV we tested many combinations of injection spectra, diffusion models and solar modulation. It appears that the spectral flattening at 20-100 GeV and the softening at ~ 500 GeV cannot be satisfactory fitted by the single component model.
- Most important, the Fermi LAT spectral slope between 7 and 100 GeV cannot be reproduced

Pamela:

- Positron fraction cannot be reproduced as well

Conclusion: new Fermi LAT electron spectrum cannot be explained within conventional single-component model



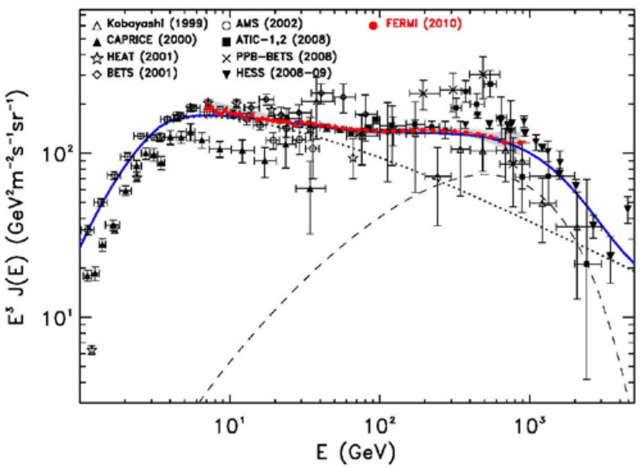
For details see D. Grasso, talk in Galileo Galilei Institute http://www.ggi.fi.infn.it/talks/talk1547.pdf. Paper is in preparation

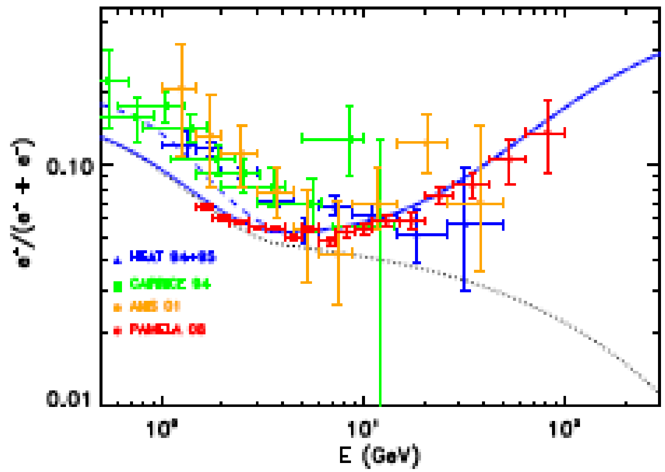
Interpretation (cont.)

Now we introduce an additional component of the CRE flux.

It is assumed that the additional source (can be astrophysical or "exotic", such as dark matter clump) provides equal amount of e^+ and e^-, in order to satisfy Pamela positron ratio.

Important to notice that though the new extended Fermi LAT spectrum needs an additional hard spectrum source, it does not have to be e^+ and e^-; only e^- suffice. However it has to be harder that "conventional"





Fit of Fermi LAT and Pamela data with 2-component model. Standard component: injection spectral index 2.0/2.65 above/below 4 GeV and E_{cut} = 3 TeV. Additional component with spectral index 1.5 and E_{cut} = 1.4 TeV. Solar modulation parameter Φ= 550 MV

SUMMARY: More results – more questions!

- **Why are the e^+ e^- sources not seen at lower energy, where the positron fraction agrees with their pure secondary origin ?**
- **What could be the origin of the e^++e^- hard spectrum?**

✓ **There are several models, including acceleration of "secondary" e^+ and e^- in the CR acceleration regions (Blasi 2009), consideration of Klein-Nishina suppression of energy losses near the points of origin (Aharonian & Atoyan 1991, Stawarz et al. 2009), enhanced e^++e^- acceleration in pulsar polar cap (Biermann et al. 2009)**

✓ **Multiple cascading in pulsar magnetosphere can also provide needed acceleration of e^++e^-**

✓**Promising sources of high energy pairs could be MSP (with many discovered by Fermi)**

✓**Dark matter nature of these sources is not excluded !**

THANK YOU !

AMS (2002)
ATIC-1,2 (2008)
PPB-BETS (2008)
HESS (2008)
FERMI (2009)
Tang et al (1984)
Kobayashi (1999)
HEAT (2001)
BETS (2001)
$\Delta E/E = ^{+5\%}_{-10\%}$
$E^3J(E)$ ($GeV^2m^{-2}s^{-1}sr^{-1}$)
100
diffusive model based on pre-Fermi data
10
100
1000
E (GeV)