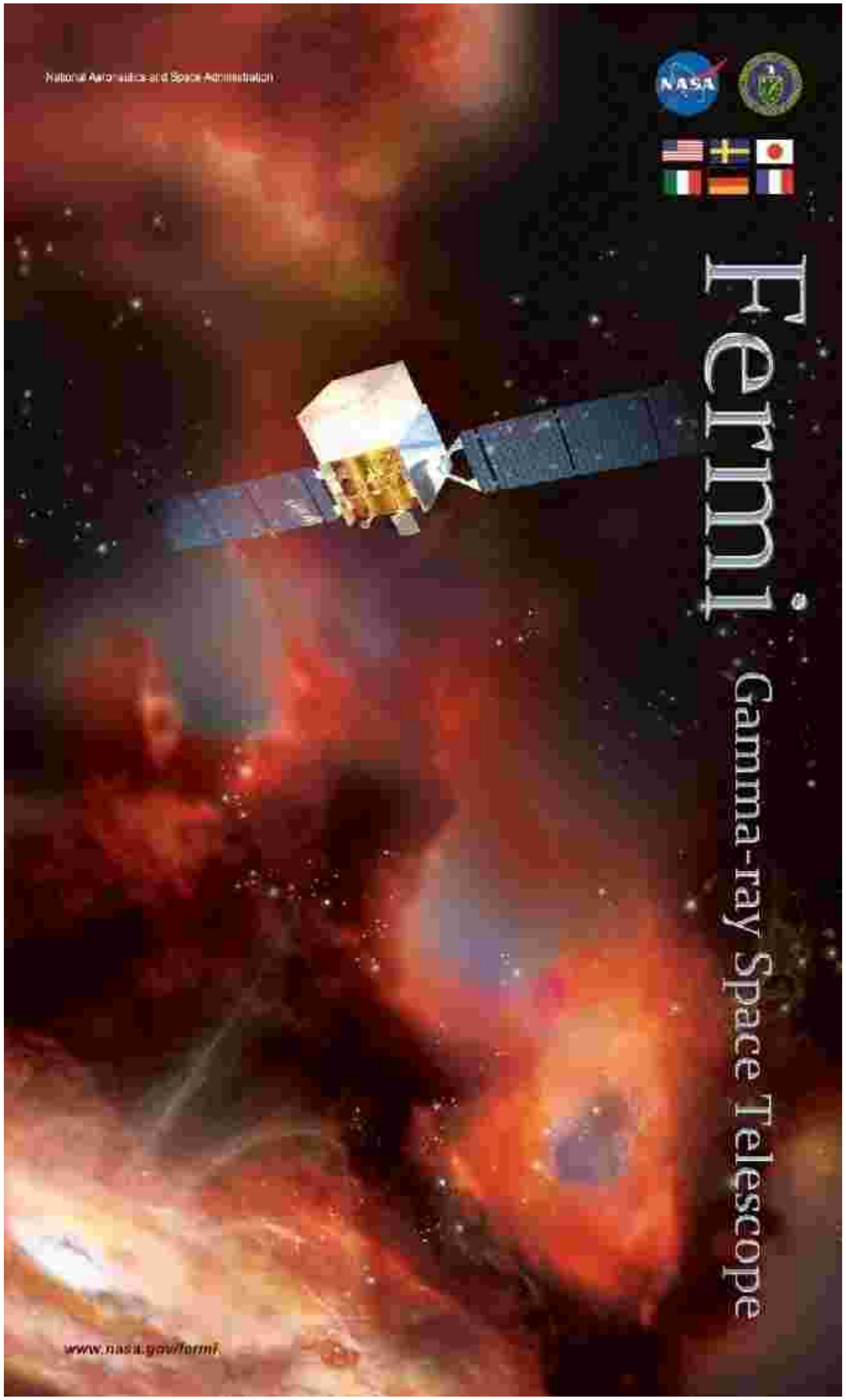


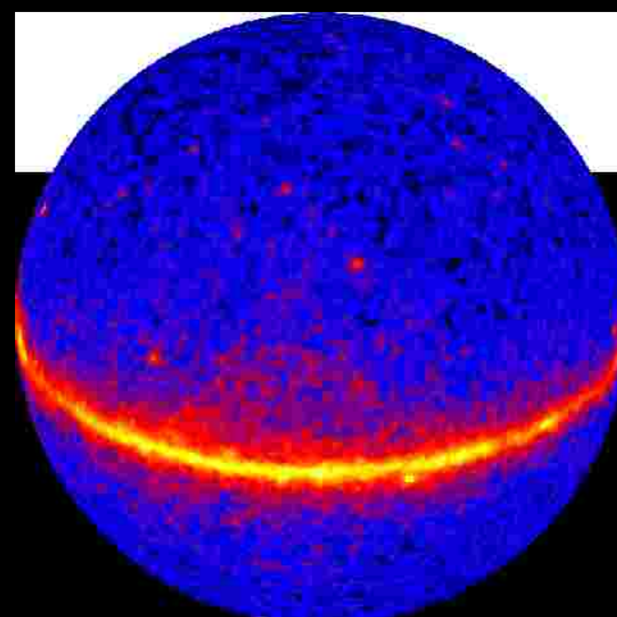
The Fermi Gamma-Ray Space Telescope: the first 8 months

Ronaldo Bellazzini (INFN-Pisa)

on behalf of the Fermi LAT Collaboration

May 28 2009 – XI Pisa meeting

- The Fermi -ray observatory
- Fermi -ray science highlights
- The Fermi-LAT CR electron spectrum from 20 GeV to 1 TeV



The Gamma-ray Observatory

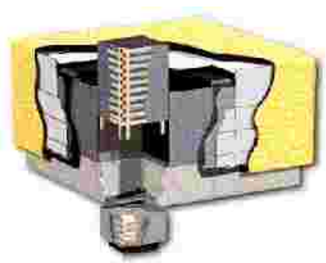
Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

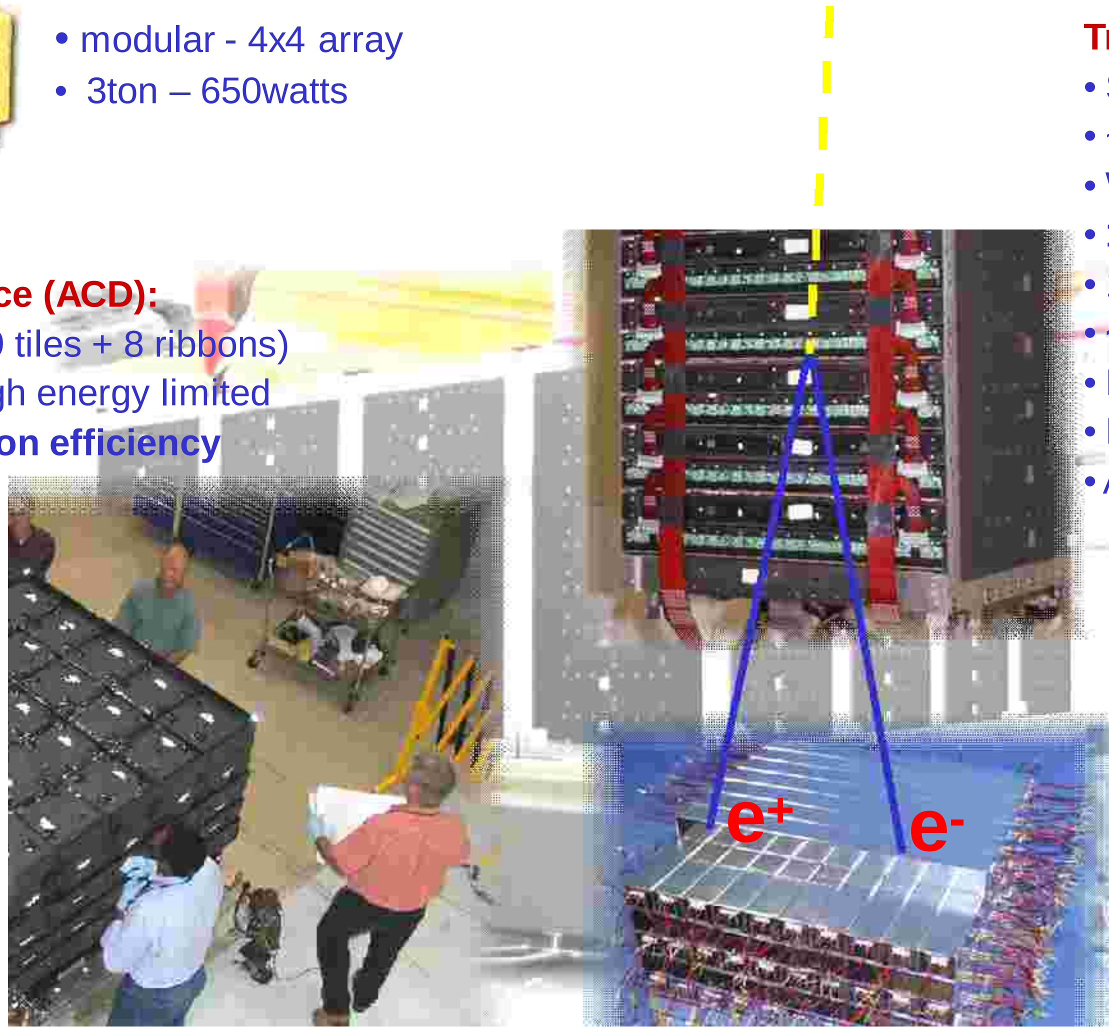
- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV à <u>>7 energy decades!</u>**
- **very small deadtime, <1us absolute timing accuracy**
- **Large leap in all key capabilities. Great discovery potential.**

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

LAT Collaboration – an HEA-HEP partnership

~390 Members
(~95 Affiliated Scientists, 68 Postdocs, and 105 Graduate Students)

- **France**
  - **CNRS/IN2P3, CEA/Saclay**
- **Italy**
  - **INFN, ASI, INAF**
- **Japan**
  - **Hiroshima University**
  - **ISAS/JAXA**
  - **RIKEN**
  - **Tokyo Institute of Technology**
- **Sweden**
  - **Royal Institute of Technology (KTH)**
  - **Stockholm University**
- **United States**
  - **Stanford University (SLAC and HEPL/Physics)**
  - **University of California, Santa Cruz - Santa Cruz Institute for Particle Physics**
  - **Goddard Space Flight Center**
  - **Naval Research Laboratory**
  - **Sonoma State University**
  - **The Ohio State University**
  - **University of Washington**

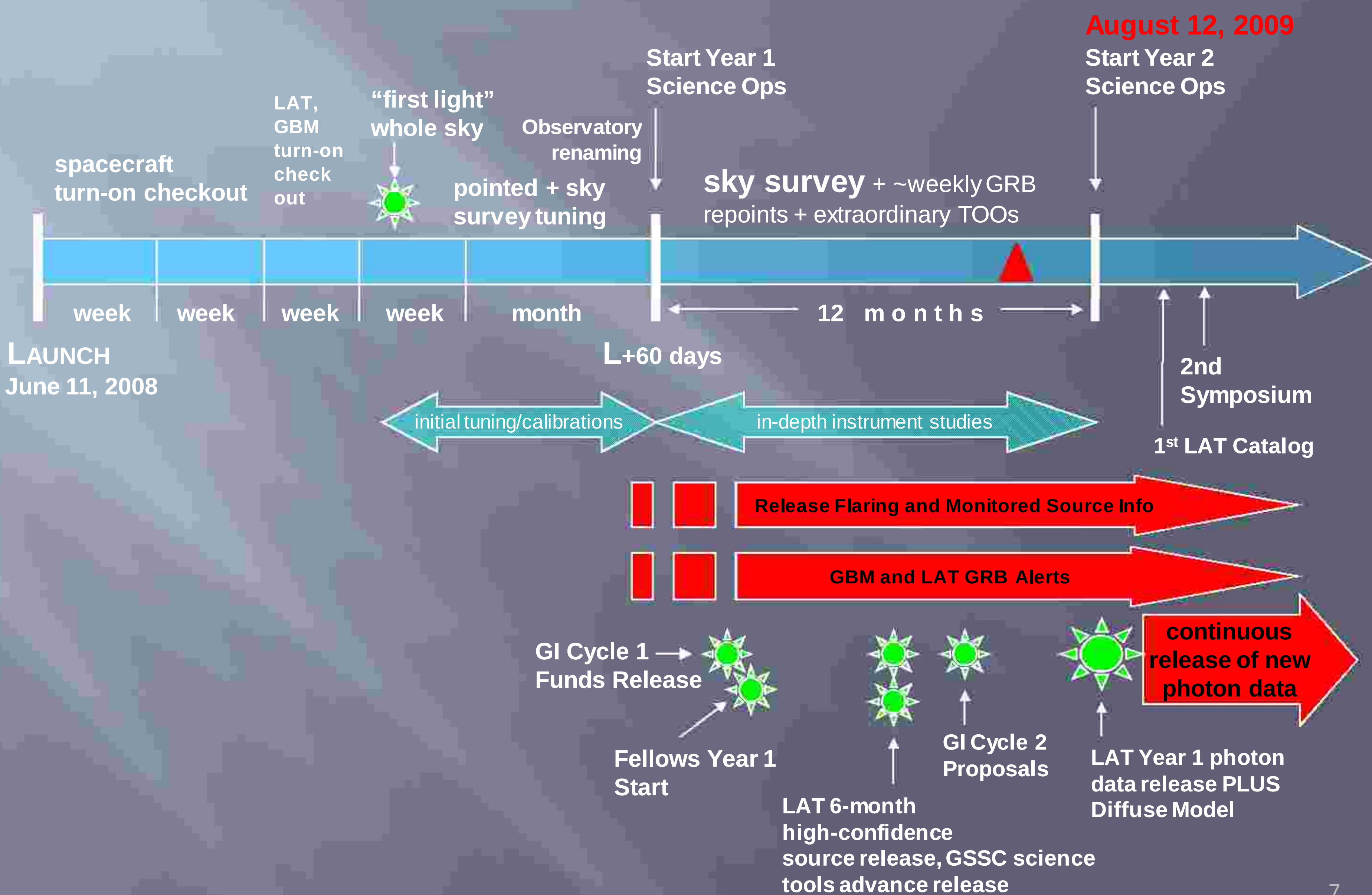
Sponsoring Agencies

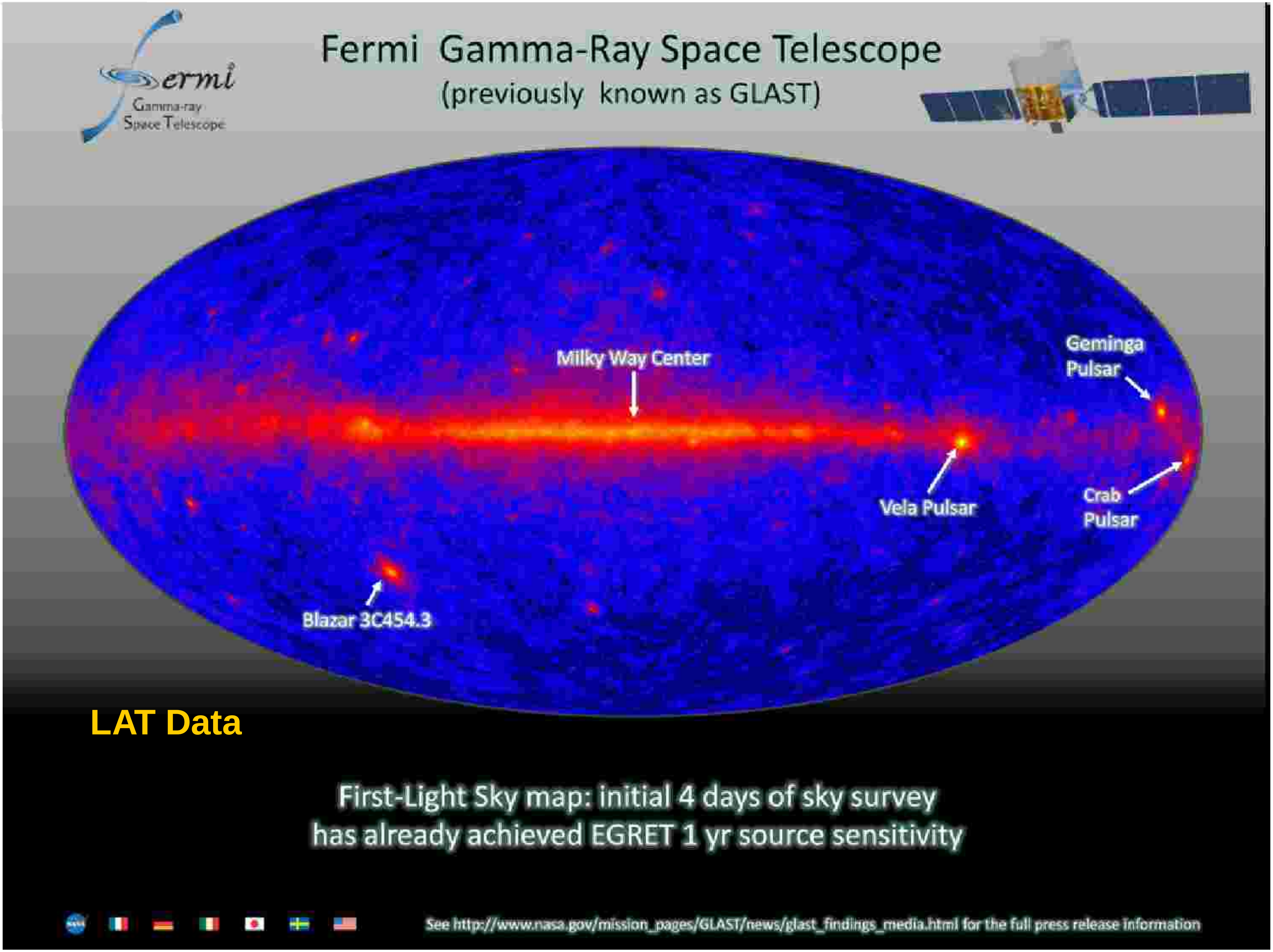
Department of Energy
National Aeronautics and Space Administration

CEA/Saclay	ASI
IN2P3/CNRS	INFN
MEXT	K. A. Wallenberg Foundation
KEK	Swedish Research Council
JAXA	Swedish National Space Board

June 11, 2008

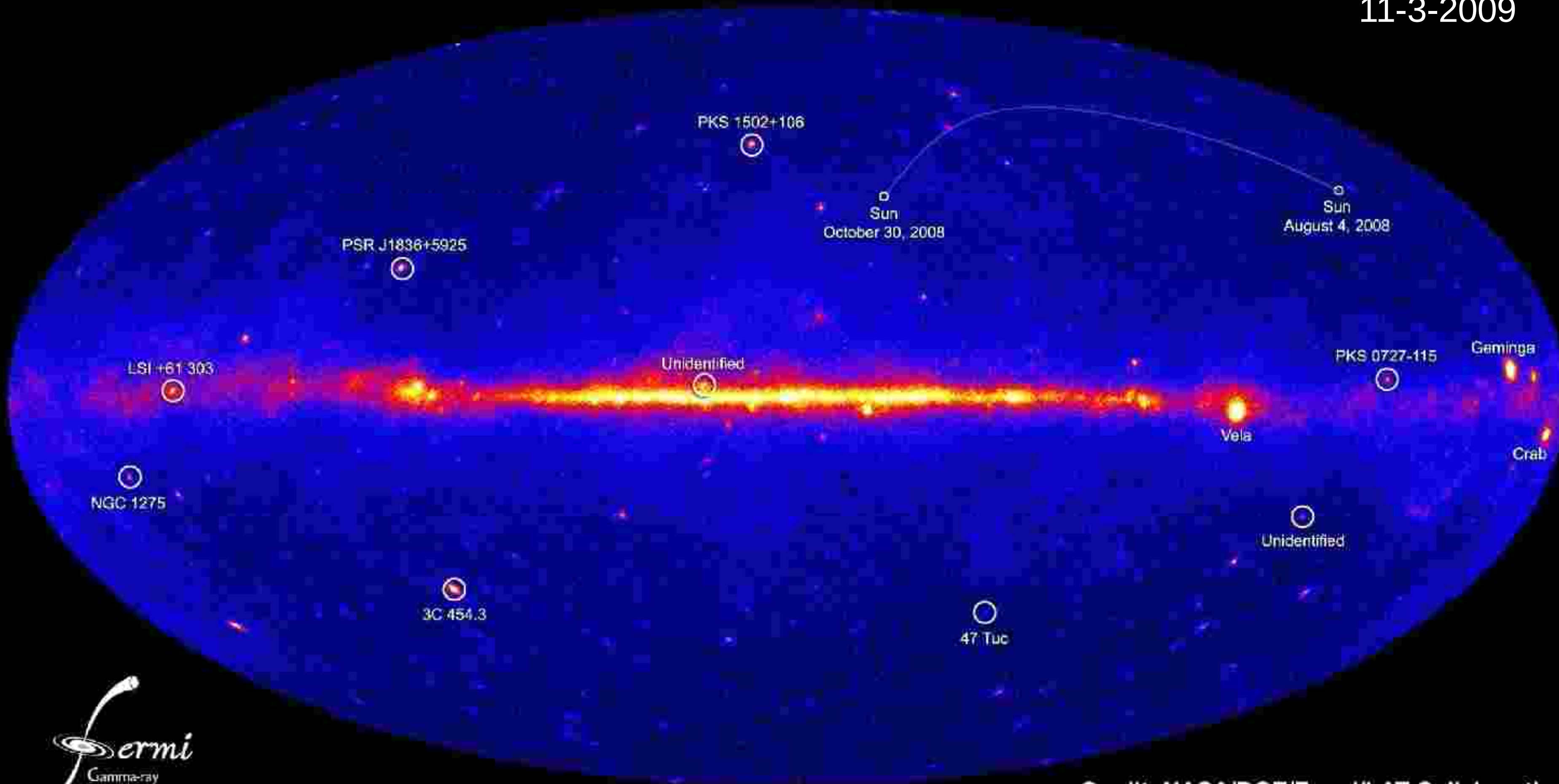
Year 1 Science Operations Timeline Overview




Fermi Gamma-Ray Space Telescope
(previously known as GLAST)
Fermi
Gamma-ray
Space Telescope
Milky Way Center
Geminga
Pulsar
Vela Pulsar
Crab
Pulsar
Blazar 3C454.3
LAT Data
First-Light Sky map: initial 4 days of sky survey
has already achieved EGRET 1 yr source sensitivity
See http://www.nasa.gov/mission_pages/GLAST/news/glast_findings_media.html for the full press release information

NASA's Fermi telescope reveals best-ever view of the gamma-ray sky

11-3-2009



Fermi Gamma-ray Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

5 top sources within our Galaxy

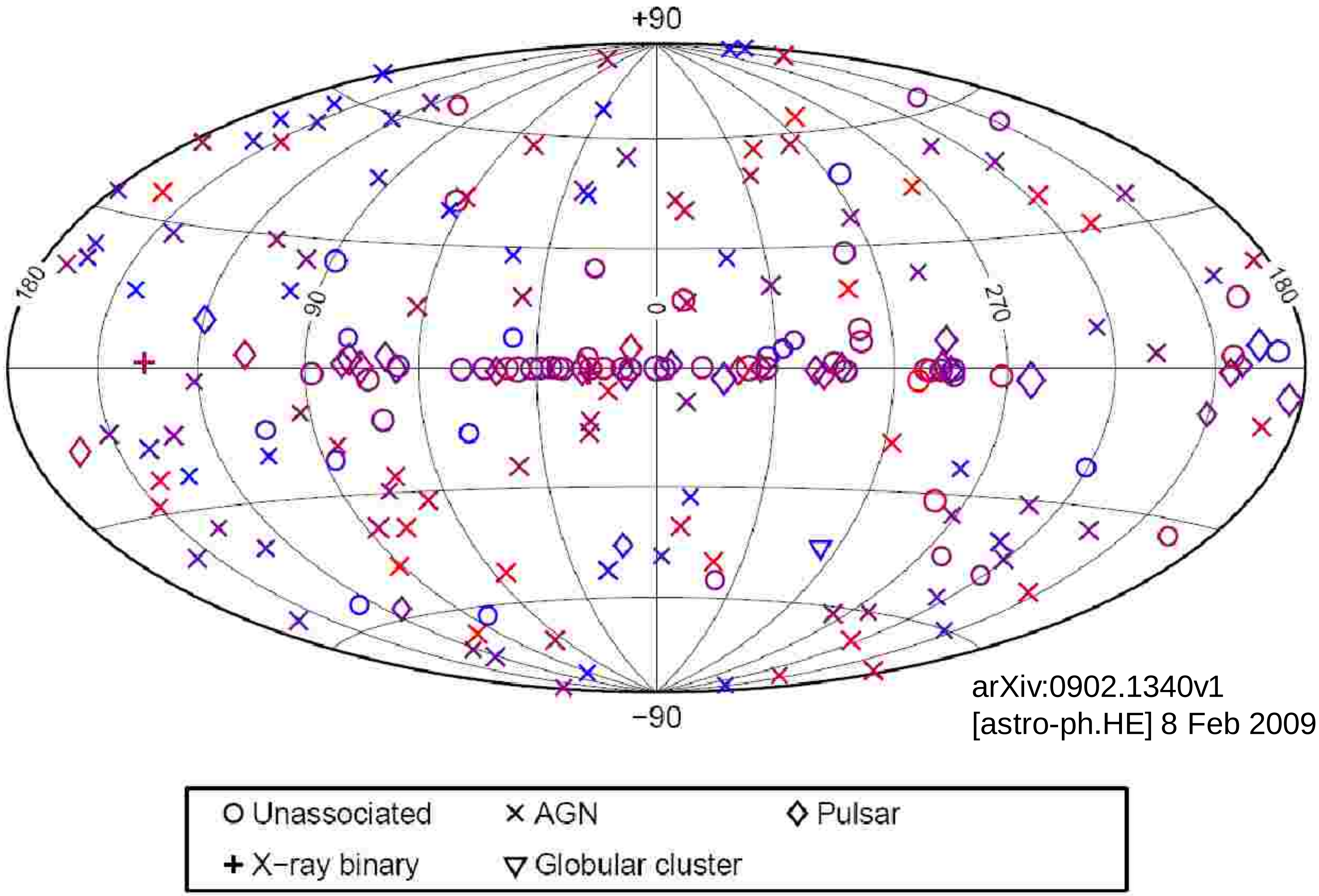
- the quiet sun (moving in the map)
- LSI +61 303 - a high-mass X-ray binary
- PSR J1836+5925 – a gamma-ray-only pulsar
- 47 Tucanae – a globular cluster of stars
- unidentified, new and variable, 0FGL J1813.5-1248

5 top sources beyond our Galaxy

- NGC 1275 – the Perseus A galaxy
- 3C 454.3 – a wildly flaring blazar
- PKS 1502+106 – a flaring 10.1 billion ly away blazar
- PKS 0727-115 – a quasar
- unidentified known, 0FGL J0614.3-3330

LAT High Confidence Bright Source list

3 months LAT data – 206 sources with > 10 significance
only 60 associated with EGRET sources – variability!

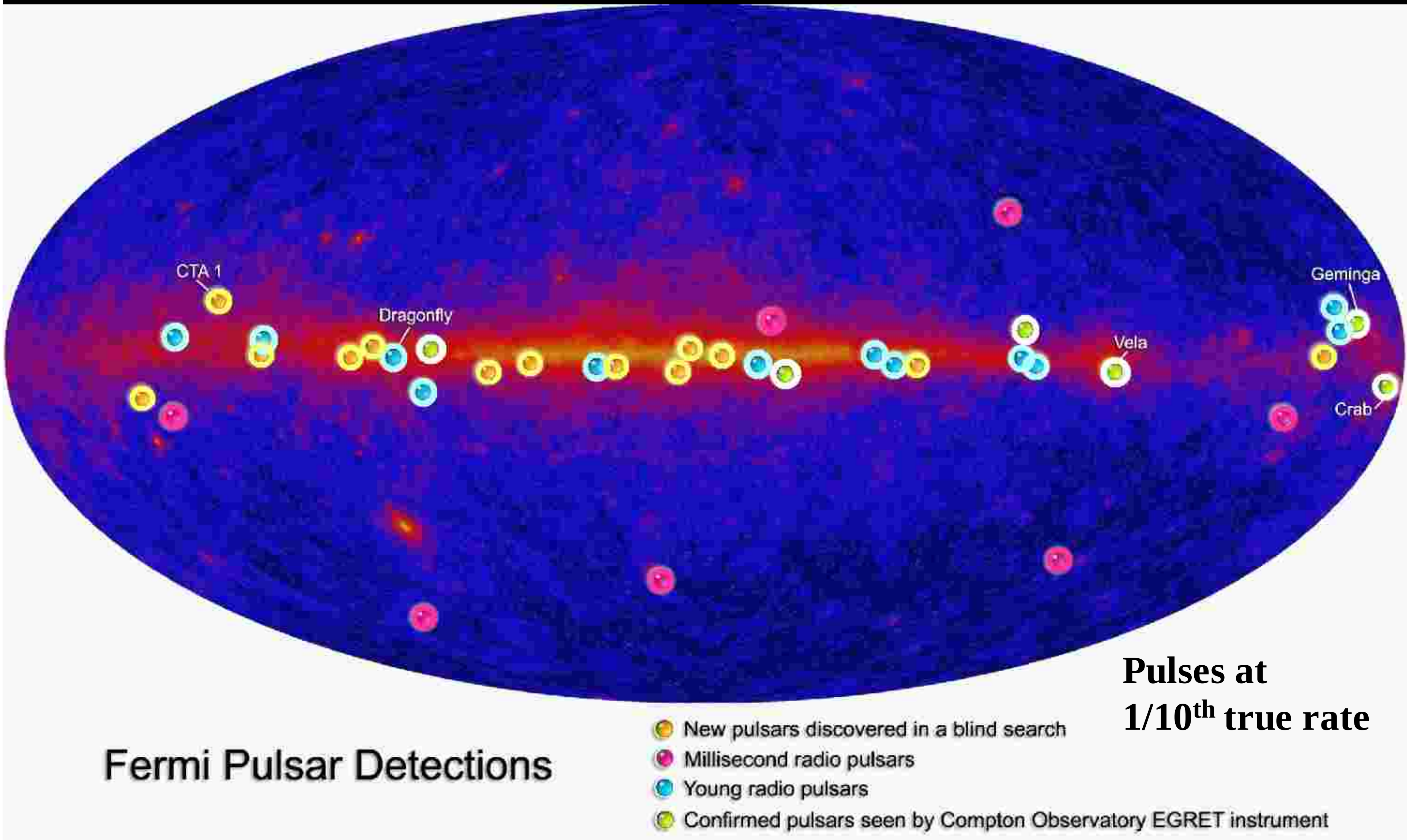


arXiv:0902.1340v1
[astro-ph.HE] 8 Feb 2009

Fermi Unveils Dozen New Pulsars

6-1-2009

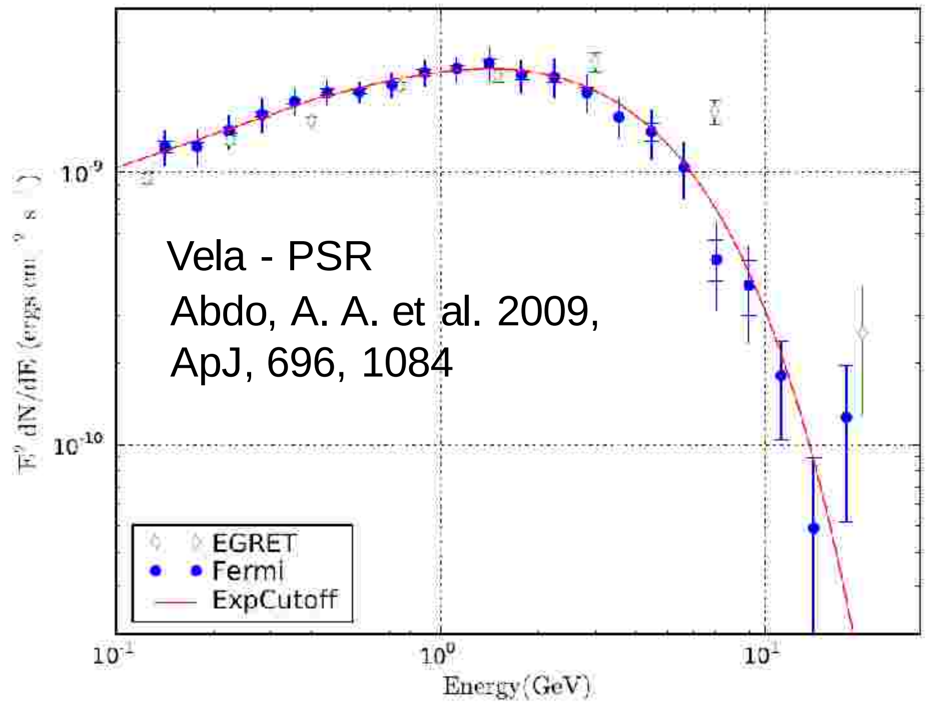
The Fermi Space Telescope has discovered 12 new gamma-ray-only pulsars and detected pulses from 18 others.

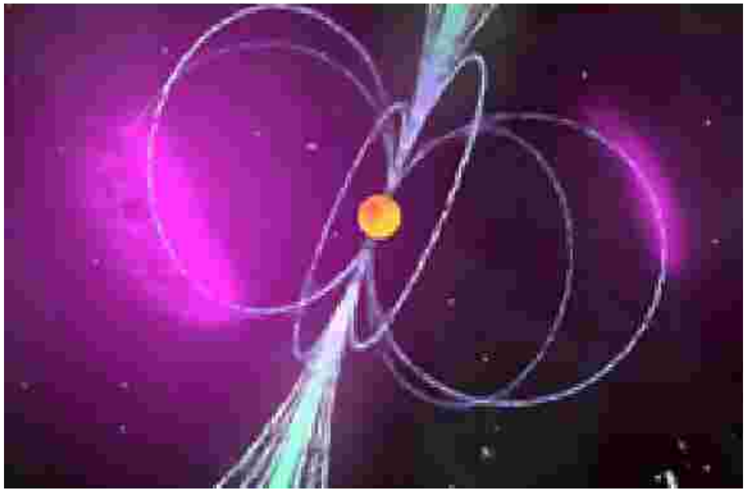


Pulses at $1/10^{th}$ true rate

Fermi -ray pulsars discovery update

- **We have discovered a large number of gamma-ray pulsars - as of 28/2/2009:**
  - **31 -ray and radio pulsars (including 8 ms pulsars)**
  - **16 -ray only pulsars**
    - **radio and -ray fan beams separated**
- **Evidence of -ray emission in the outer magnetopshere due to absence of super-exponential cutoff**





Fermi Sees Most Extreme Gamma-ray Blast Yet

GRB080916C

located at 12B light years from us using observations of optical afterglow by the GROND observatory

The first burst to be seen in high-res by the Fermi telescope had the greatest total energy, the fastest motions and the highest-energy initial emissions ever seen.

› Read More

19-2-2009

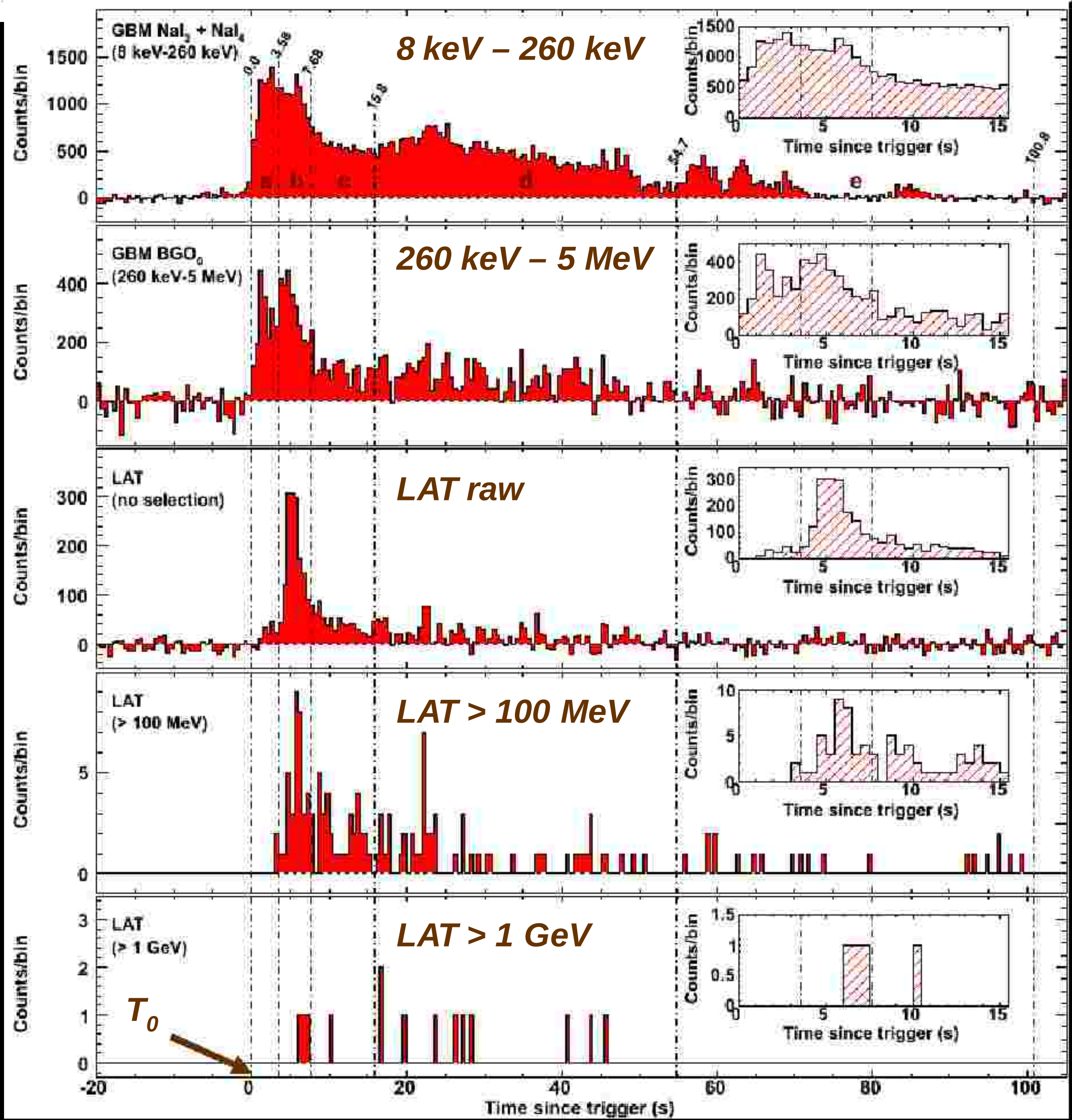
Large fluence (2.4×10^{-4} erg/cm^2)

& redshift ($z = 4.35 \pm 0.15$)

⇒ record breaking

- $E_{?,iso}$ ~ 8.8×10^{54} erg ~ 4.9 $M_{¤}$ c^2
- G_{min} ~ 890 ± 20

GRB 080916C - LAT and GBM light curves



- For the first time, can study time structure > tens of MeV, 14 events above 1 GeV
- First low-energy GBM peak is not observed at LAT energies

- High energy emission delayed
- The bulk of the emission of the 2nd peak is moving toward later times as the energy increases
- Clear signature of spectral evolution

Science Express, 19 Feb 2009, pg 1

Fermi sets a new constraint on the QG energy scale

q **Some QG models postulate violation of Lorentz invariance: v (E) ? c**

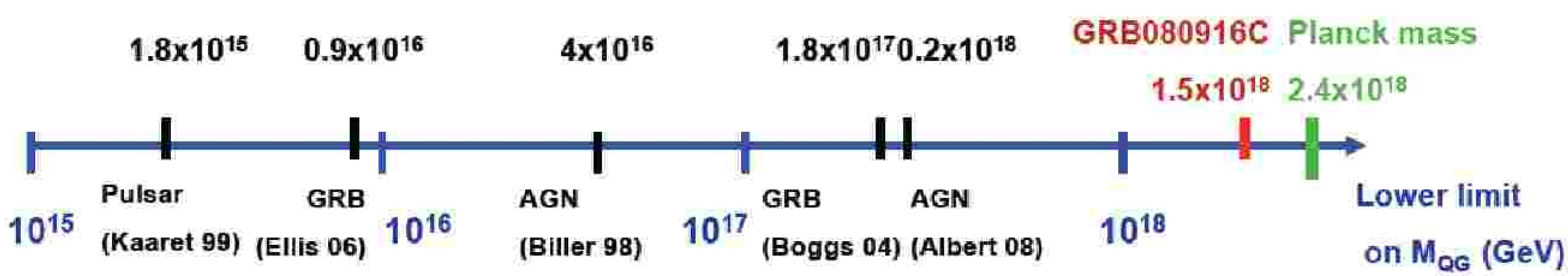
q **A high-energy photon E_h would arrive after (or possibly before in some models) a low-energy photon E_l emitted simultaneously**

$$\Delta t = \frac{(1+n)}{2H_0}\frac{E_h^n - E_l^n}{(M_{QG,n}c^2)^n}\int_0^z \frac{(1+z')^n}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}\,dz'$$

(Jacob & Piran 2008)

q **GRB080916C: highest energy photon (13 GeV) arrived 16.5 s after low-energy photons started arriving (= the GRB trigger)**

Ø **a conservative lower limit: $M_{QG,1} > (1.50 \pm 0.20)\times10^{18}$ GeV/c^2**



The CR Electron Spectrum with Fermi

Selected for a Viewpoint in *Physics*
PRL 102, 181101 (2009) PHYSICAL REVIEW LETTERS week ending 8 MAY 2009

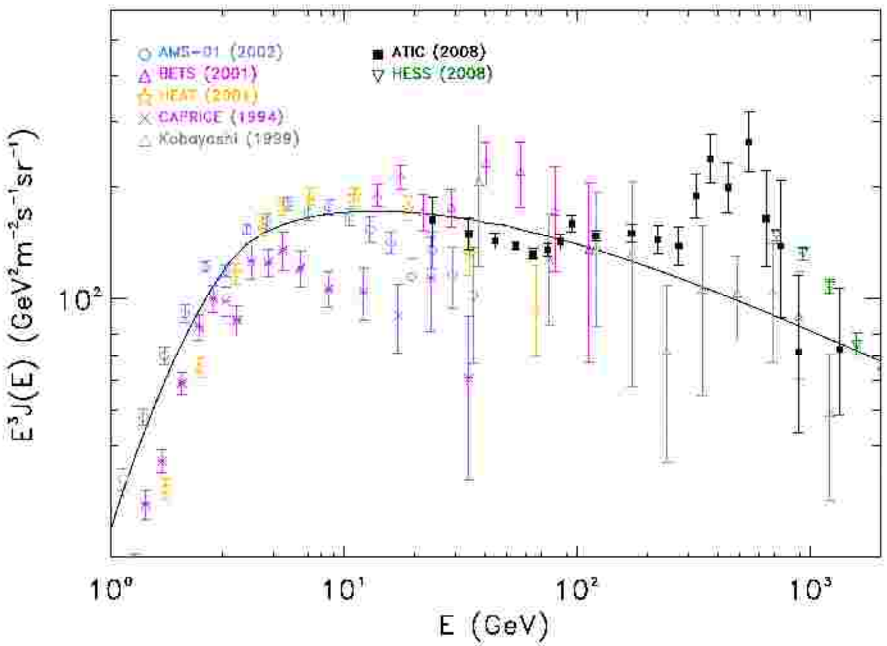
Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

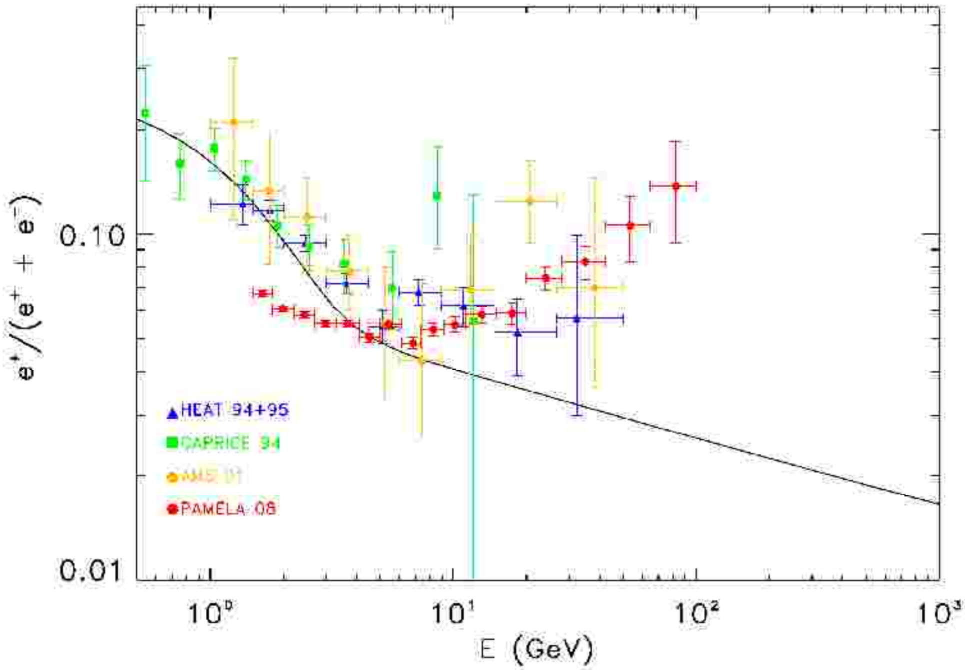
A. A. Abdo,[1,2] M. Ackermann,[3] M. Ajello,[3] W. B. Atwood,[4] M. Axelsson,[5,6] L. Baldini,[7] J. Ballet,[8] G. Barbiellini,[9,10] D. Bastieri,[11,12] M. Battelino,[5,13] B. M. Baughman,[14] K. Bechtol,[3] R. Bellazzini,[7] B. Berenji,[3] R. D. Blandford,[3] E. D. Bloom,[3] G. Bogaert,[15] E. Bonamente,[16,17] A. W. Borgland,[3] J. Bregeon,[7] A. Brez,[7] M. Brigida,[18,19] P. Bruel,[15] T. H. Burnett,[20] G. A. Caliandro,[18,19] R. A. Cameron,[3] P. A. Caraveo,[21] P. Carlson,[5,13] J. M. Casandjian,[8] C. Cecchi,[16,17] E. Charles,[3] A. Chekhtman,[22,2] C. C. Cheung,[23] J. Chiang,[3] S. Ciprini,[16,17] R. Claus,[3] J. Cohen-Tanugi,[24] L. R. Cominsky,[25] J. Conrad,[5,13,26,27] S. Cutini,[28] C. D. Dermer,[2] A. de Angelis,[29] F. de Palma,[18,19] S. W. Digel,[3] G. Di Bernardo,[7] E. do Couto e Silva,[3] P. S. Drell,[3] R. Dubois,[3] D. Dumora,[30,31] Y. Edmonds,[3] C. Farnier,[24] C. Favuzzi,[18,19] W. B. Focke,[3] M. Frailis,[29] Y. Fukazawa,[32] S. Funk,[3] P. Fusco,[18,19] D. Gaggero,[7] F. Gargano,[19] D. Gasparrini,[28] N. Gehrels,[23,33] S. Germani,[16,17] B. Giebels,[15] N. Giglietto,[18,19] F. Giordano,[18,19] T. Glanzman,[3] G. Godfrey,[3] D. Grasso,[7] I. A. Grenier,[8] M.-H. Grondin,[30,31] J. E. Grove,[2] L. Guillemot,[30,31] S. Guiriec,[34] Y. Hanabata,[32] A. K. Harding,[23] R. C. Hartman,[23] M. Hayashida,[3] E. Hays,[23] R. E. Hughes,[14] G. Jóhannesson,[3] A. S. Johnson,[3] R. P. Johnson,[4] W. N. Johnson,[2] T. Kamae,[3] H. Katagiri,[32] J. Kataoka,[35] N. Kawai,[36,37] M. Kerr,[20] J. Knödlseder,[38] D. Kocevski,[3] F. Kuehn,[14] M. Kuss,[7] J. Lande,[3] L. Latronico,[7,*] M. Lemoine-Goumard,[30,31] F. Longo,[9,10] F. Loparco,[18,19] B. Lott,[30,31] M. N. Lovellette,[2] P. Lubrano,[16,17] G. M. Madejski,[3] A. Makeev,[22,2] M. M. Massai,[7] M. N. Mazziotta,[19] W. McConville,[23,33] J. E. McEnery,[23] C. Meurer,[5,26] P. F. Michelson,[3] W. Mitthumsiri,[3] T. Mizuno,[32] A. A. Moiseev,[39,33,†] C. Monte,[18,19] M. E. Monzani,[3] E. Moretti,[9,10] A. Morselli,[40] I. V. Moskalenko,[3] S. Murgia,[3] P. L. Nolan,[3] J. P. Norris,[41] E. Nuss,[24] T. Ohsugi,[32] N. Omodei,[7] E. Orlando,[42] J. F. Ormes,[41] M. Ozaki,[43] D. Paneque,[3] J. H. Panetta,[3] D. Parent,[30,31] V. Pelassa,[24] M. Pepe,[16,17] M. Pesce-Rollins,[7] F. Piron,[24] M. Pohl,[44] T. A. Porter,[4] S. Profumo,[4] S. Rainò,[18,19] R. Rando,[11,12] M. Razzano,[7] A. Reimer,[3] O. Reimer,[3] T. Reposeur,[30,31] S. Ritz,[23,33] L. S. Rochester,[3] A. Y. Rodriguez,[45] R. W. Romani,[3] M. Roth,[20] F. Ryde,[5,13] H. F.-W. Sadrozinski,[4] D. Sanchez,[15] A. Sander,[14] P. M. Saz Parkinson,[4] J. D. Scargle,[46] T. L. Schalk,[4] A. Sellerholm,[5,26] C. Sgrò,[7] D. A. Smith,[30,31] P. D. Smith,[14] G. Spandre,[7] P. Spinelli,[18,19] J.-L. Starck,[8] T. E. Stephens,[23] M. S. Strickman,[2] A. W. Strong,[42] D. J. Suson,[47] H. Tajima,[3] H. Takahashi,[32] T. Takahashi,[43] T. Tanaka,[3] J. B. Thayer,[3] J. G. Thayer,[3] D. J. Thompson,[23] L. Tibaldo,[11,12] O. Tibolla,[48] D. F. Torres,[49,45] G. Tosti,[16,17] A. Tramacere,[50,3] Y. Uchiyama,[3] T. L. Usher,[3] A. Van Etten,[3] V. Vasileiou,[23,51] N. Vilchez,[38] V. Vitale,[40,52] A. P. Waite,[3] E. Wallace,[20] P. Wang,[3] B. L. Winer,[14] K. S. Wood,[2] T. Ylinen,[53,5,13] and M. Ziegler[4]

(Fermi LAT Collaboration)

Submitted March 19, accepted April 21, Published May 4

High-energy Electron Measurements up to 2008





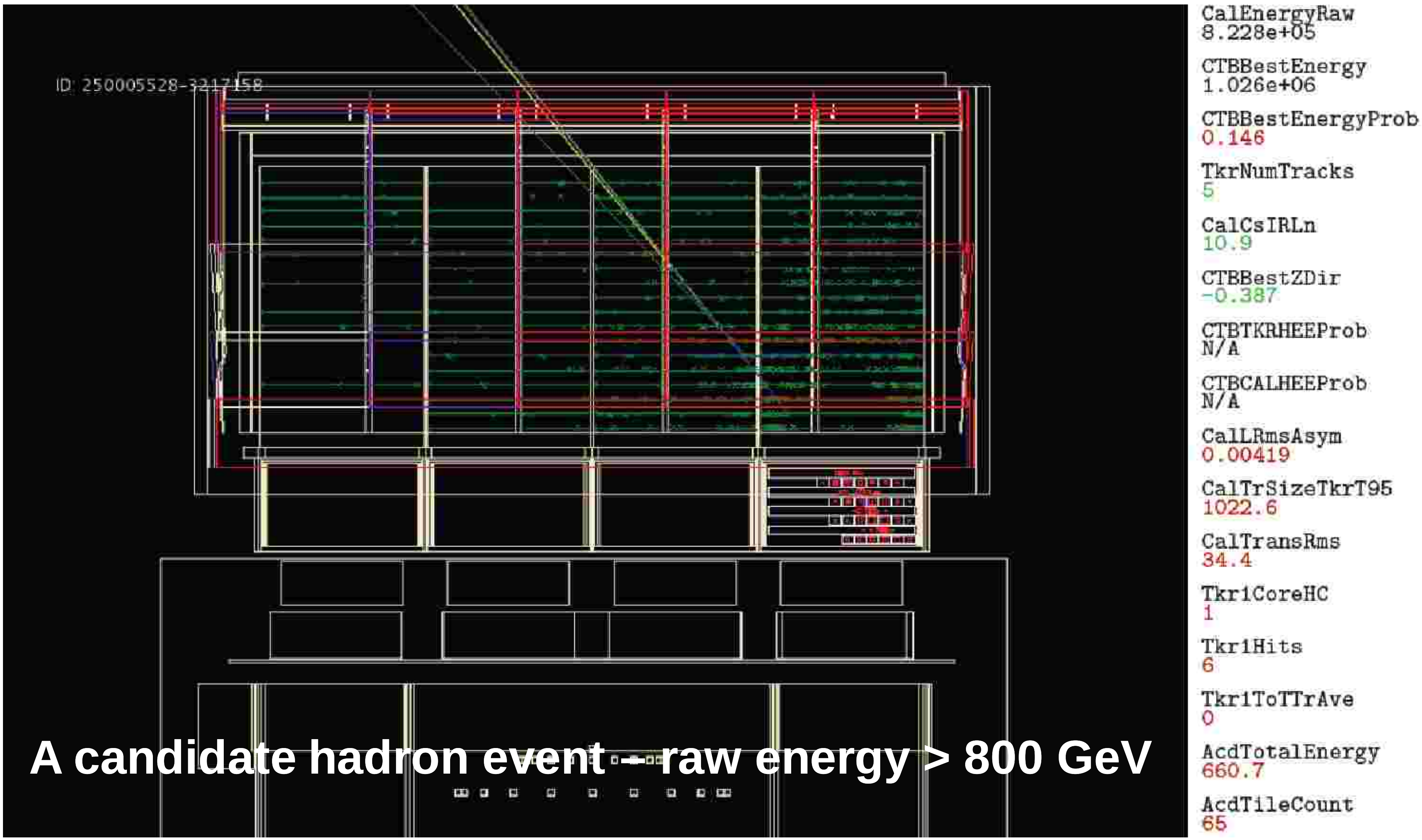
- ATIC and PPB-BETS report an excess at ~ 600 GeV
- HESS measures a cutoff around 1TeV

- PAMELA measures an increase in the $e^+/(e^-+e^+)$ fraction

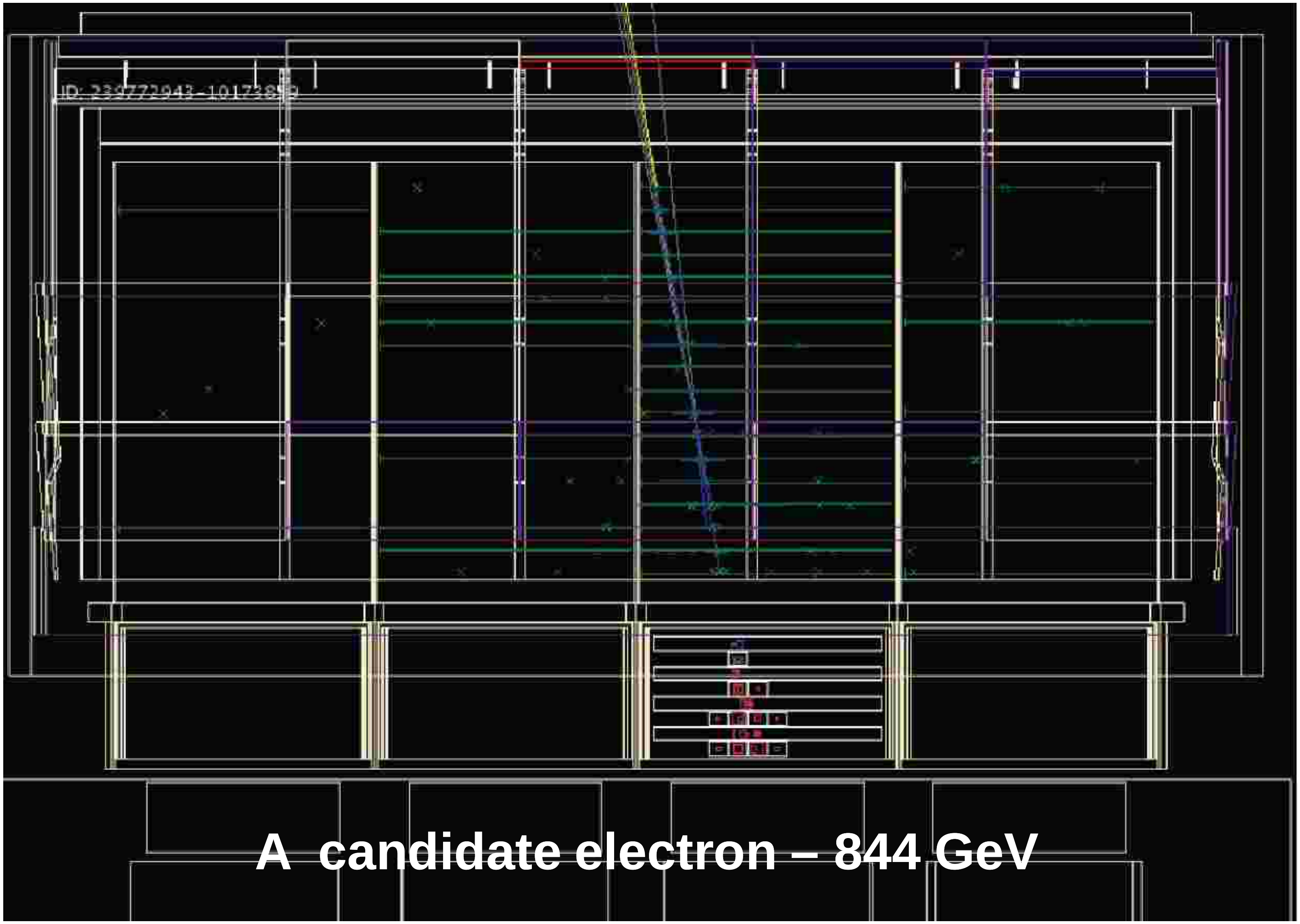
Ø more than 200 papers in the last year

Ø local source of electrons – astrophysical? Dark Matter?

A candidate hadron event – raw energy > 800 GeV



- 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

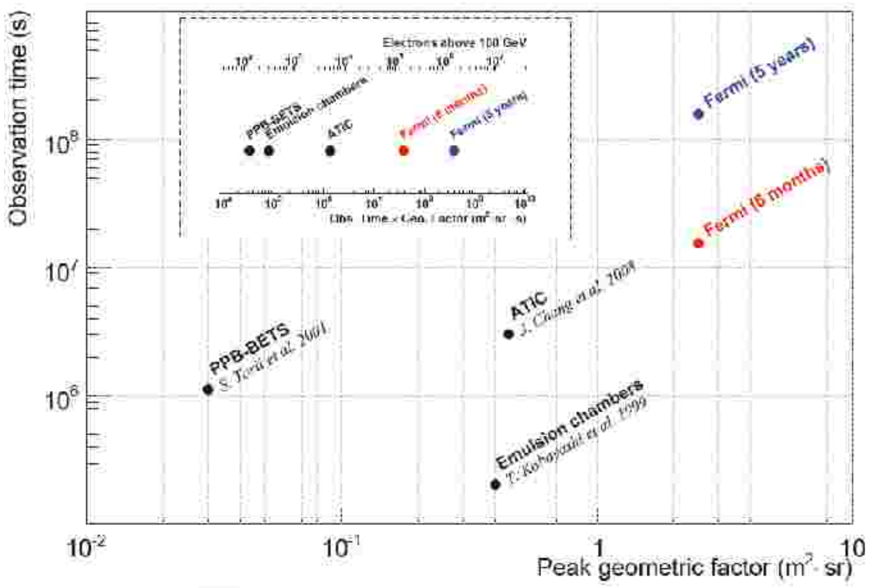
Tkr1ToTTrAve
5.40

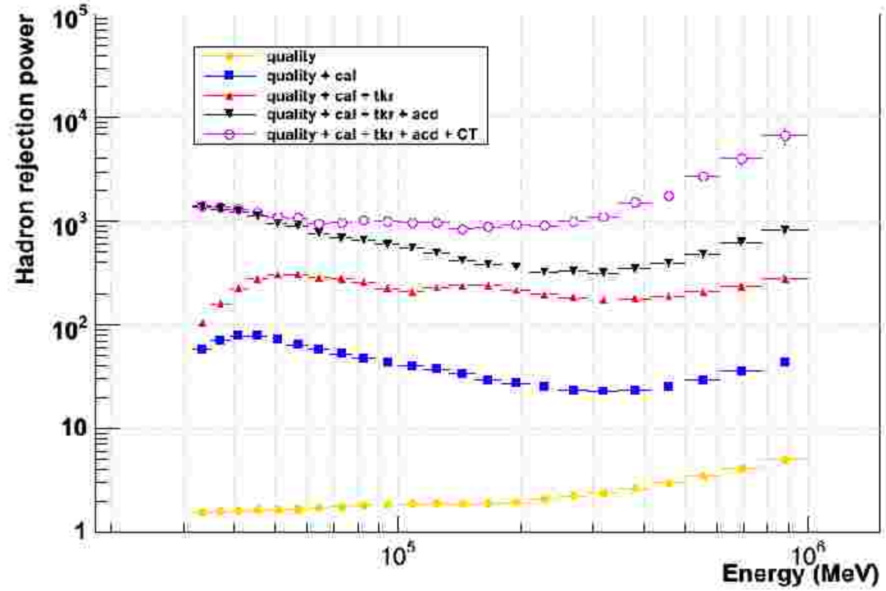
AcdTotalEnergy
8.99

AcdTileCount
20

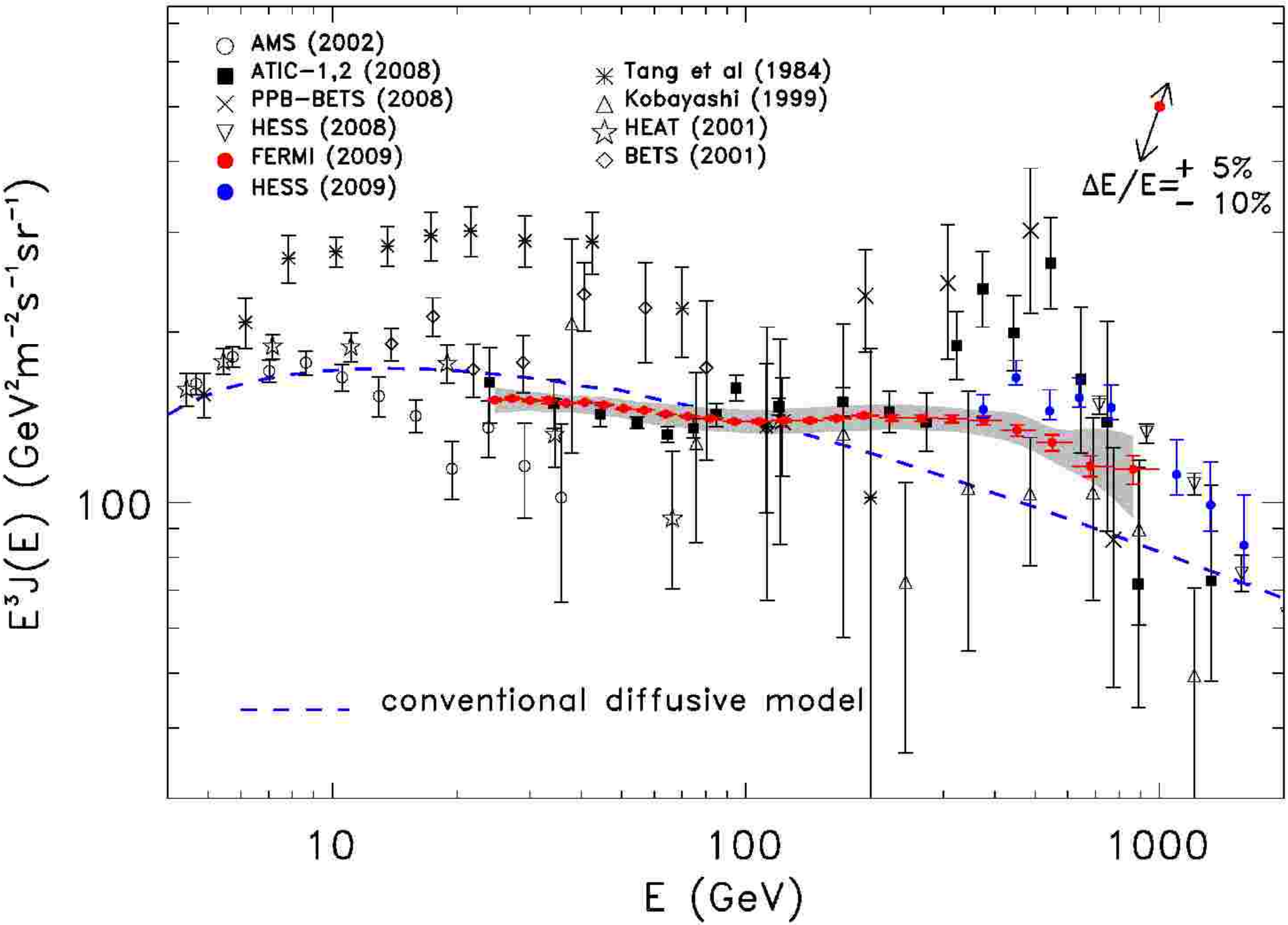
- **ACD: few hits in conjunction with track**
- **TKR: single clean track, extra clusters around main track clusters (preshower)**
- **CAL: clean EM shower not fully contained in CAL**

LAT Electron performance



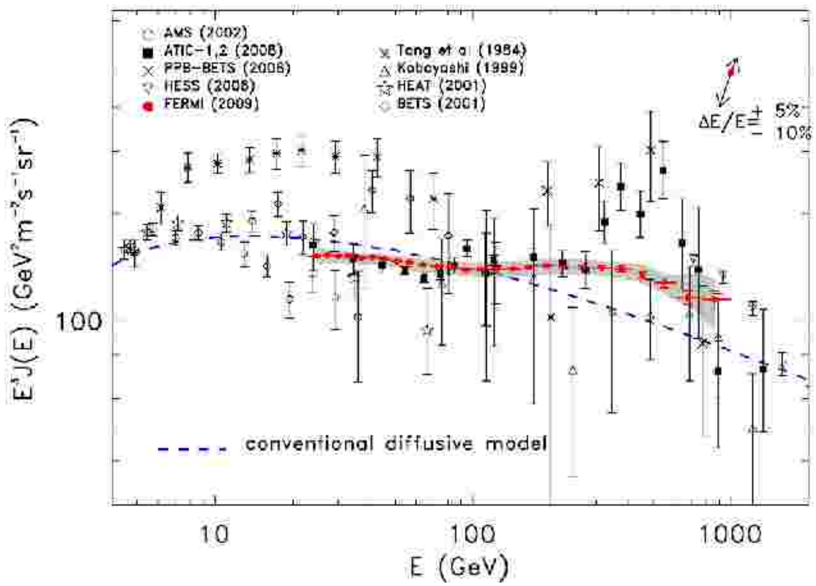


- Performance is a trade-off among:
  - electron-acceptance – hadron contamination - systematics
- Geometry factor
  - ~ 3 m^2sr (50 GeV) to ~ 1 m^2sr (1 TeV)
  - > 10x wrt previous experiments
- Rejection power: ~ 1:10^3 (20 GeV) to ~ 1:10^4 (1 TeV)
- Maximum residual contamination ~ 20% (1 TeV)
- Maximum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



AMS (2002)
ATIC-1,2 (2008)
PPB-BETS (2008)
HESS (2008)
FERMI (2009)
HESS (2009)
Tang et al (1984)
Kobayashi (1999)
HEAT (2001)
BETS (2001)
ΔE/E= + 5% − 10%
conventional diffusive model
100
10
100
1000
E (GeV)
E³J(E) (GeV²m⁻²s⁻¹sr⁻¹)

The Fermi-LAT CRE Spectrum

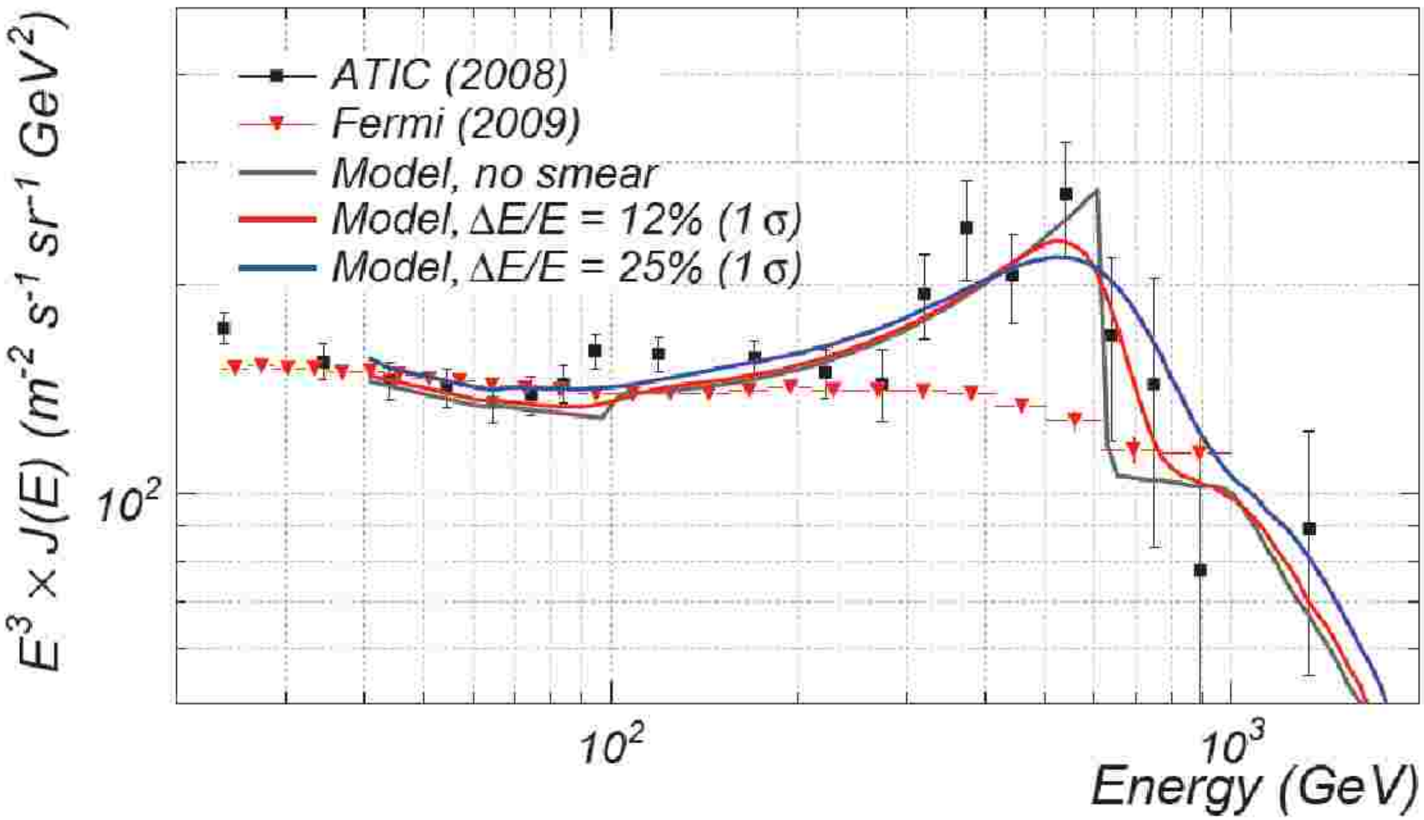


Energy (GeV)	GF ($m^2 sr$)	Residual contamination	Counts
...	...	...	...
291–346	2.04	0.18	7207
346–415	1.88	0.18	4843
415–503	1.73	0.19	3036
503–615	1.54	0.20	1839
615–772	1.26	0.21	1039
772–1000	0.88	0.21	544

More than 400 electrons in the last energy bin 772-1000 GeV

- **High statistics 4.5M events in 6 months**
  - **systematics dominate but small wrt existing literature**
- **Not compatible with pre-Fermi diffusive model**
  - **E^{-3} versus $E^{-3.3}$**
- **No evidence of the dramatic ATIC spectral feature**
  - **Conservative statistical+systematic error allow good fit with a simple power law**

Would the LAT see a feature like that of ATIC?



- ATIC excess: 70 electrons between 300 and 800 GeV
  - we would have seen an excess of 7000 electrons
- Simulated LAT response to similar model as from Chang al (2008)
  - Broken power law with =-3.1 below 1TeV, -4.5 above
  - Harder feature (=-1.5) with break at 620 GeV

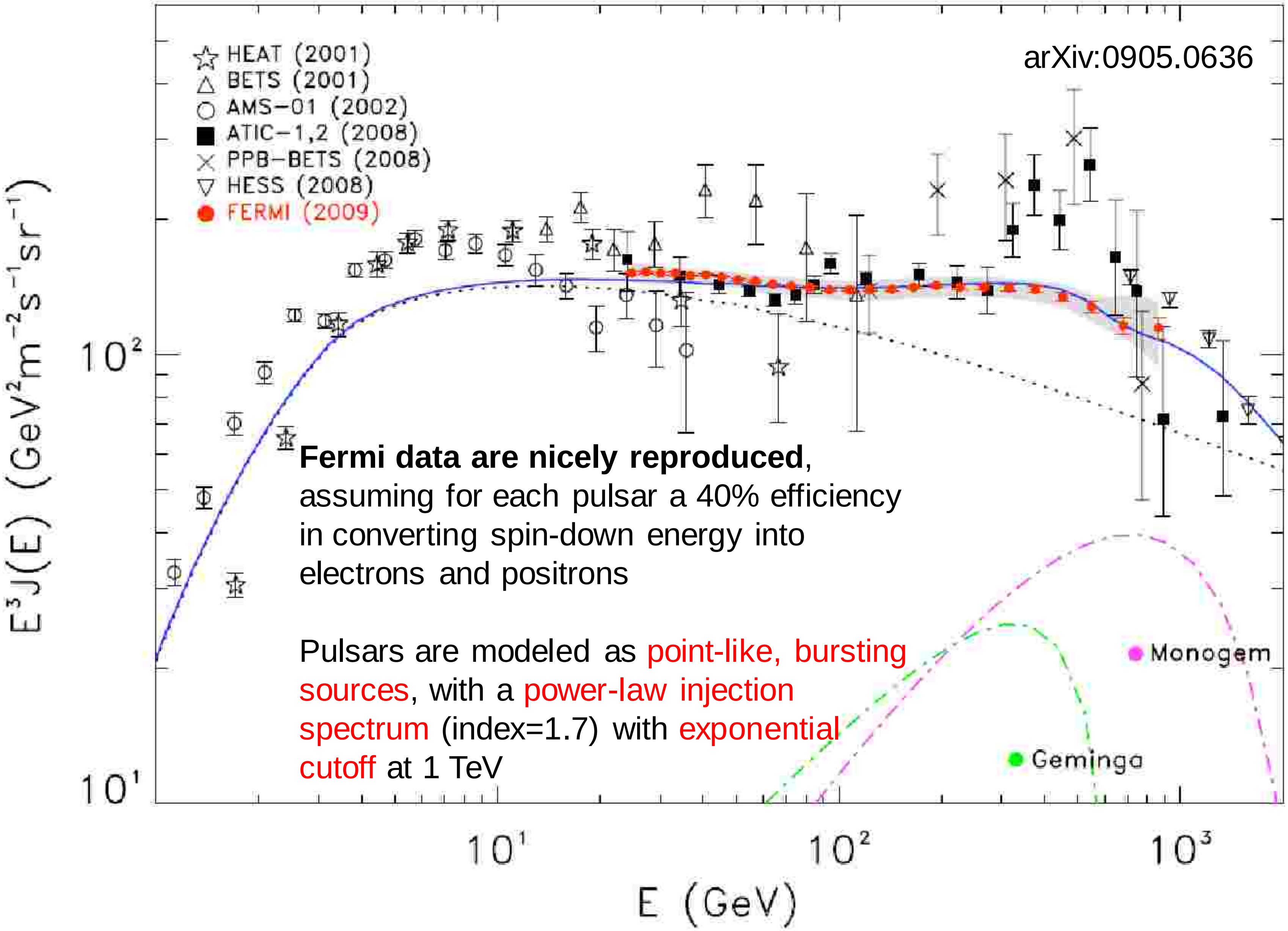
The possible role of local sources

Pulsars are candidate sources of relativistic electrons and positrons (see e.g. Shen 1970, Harding & Ramaty 1987)

– e+/e- pairs believed to be produced in the magnetosphere and re-accelerated in the wind

1. Characteristics needed to explain Fermi/Pamela excesses wrt conventional models
   – Nearby, because of synchrotron energy losses
   – Mature, because electrons remain confined in the PWN until it merges with the ISM
   – But not too old, because old electrons are already diluted in space
2. Considering distributions of pulsars from the ATNF catalog
   – With d<3kpc with age 5×10^4 yr - 10^7 yr
     - Injection index, cutoff energy, e+/e- conversion efficiency, delay between pulsar birth and electron release
   – Create different possible summed contributions of all pulsars

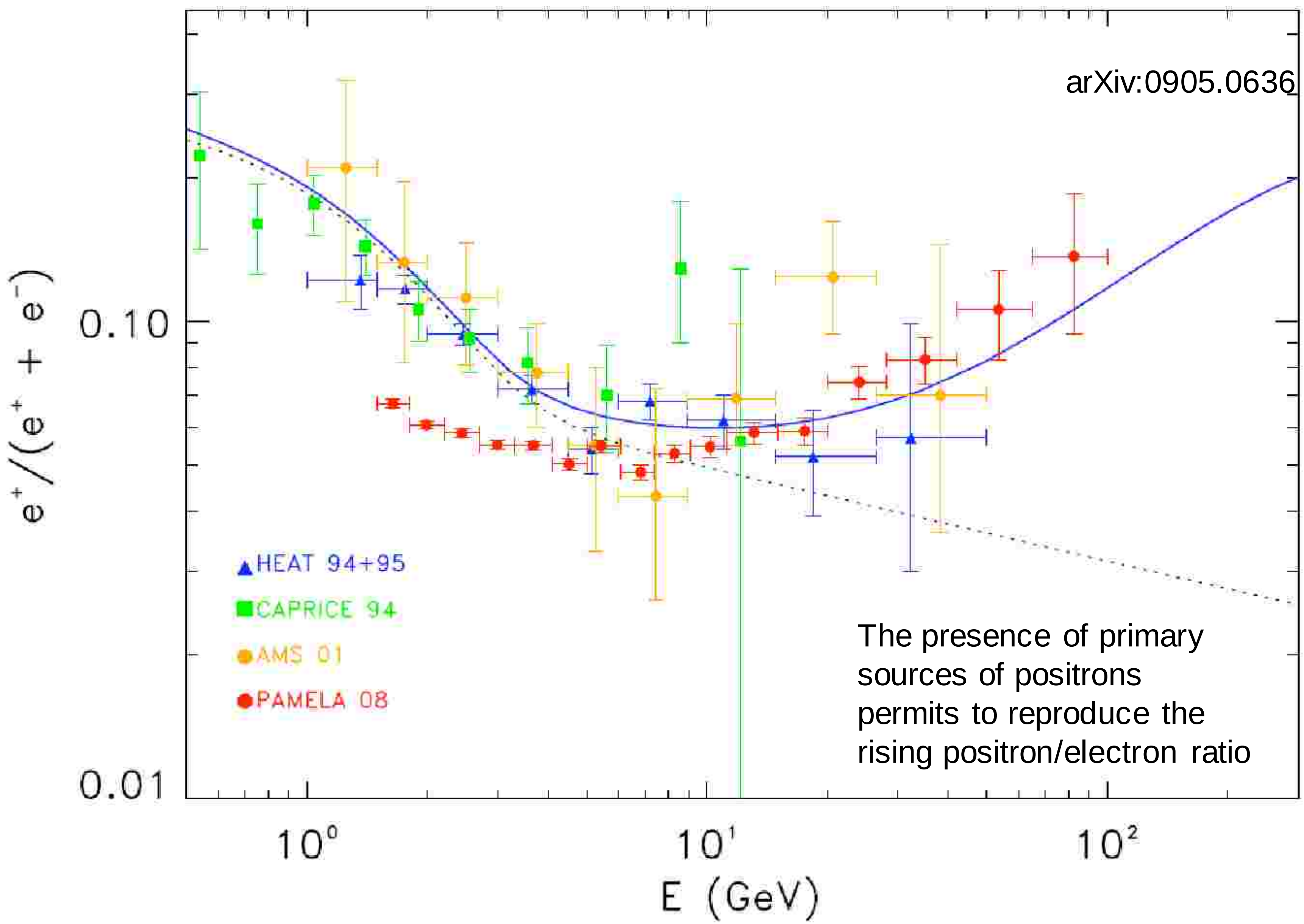
Adding candidate pulsars within 1Kpc



Fermi data are nicely reproduced, assuming for each pulsar a 40% efficiency in converting spin-down energy into electrons and positrons

Pulsars are modeled as point-like, bursting sources, with a power-law injection spectrum (index=1.7) with exponential cutoff at 1 TeV

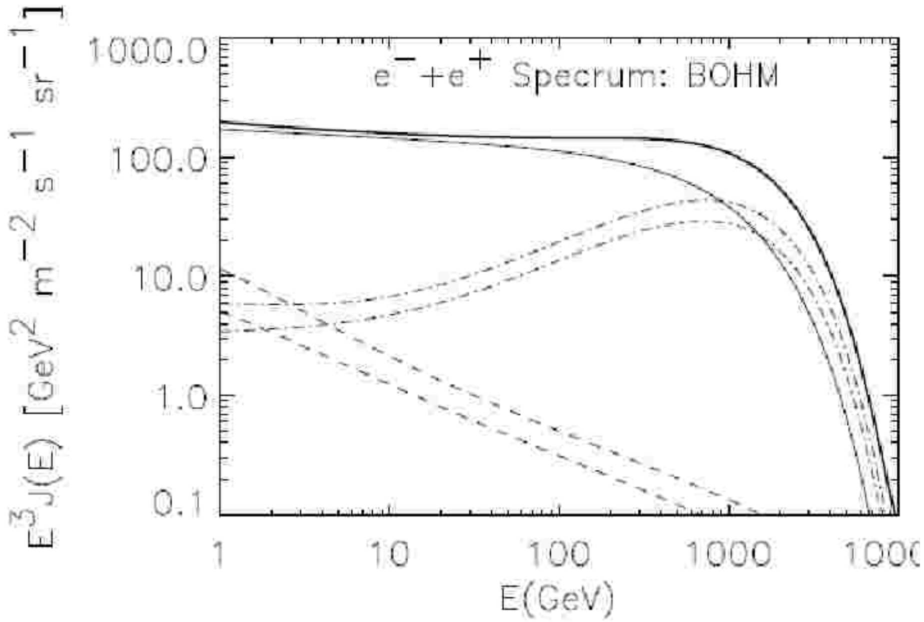
works for Pamela too

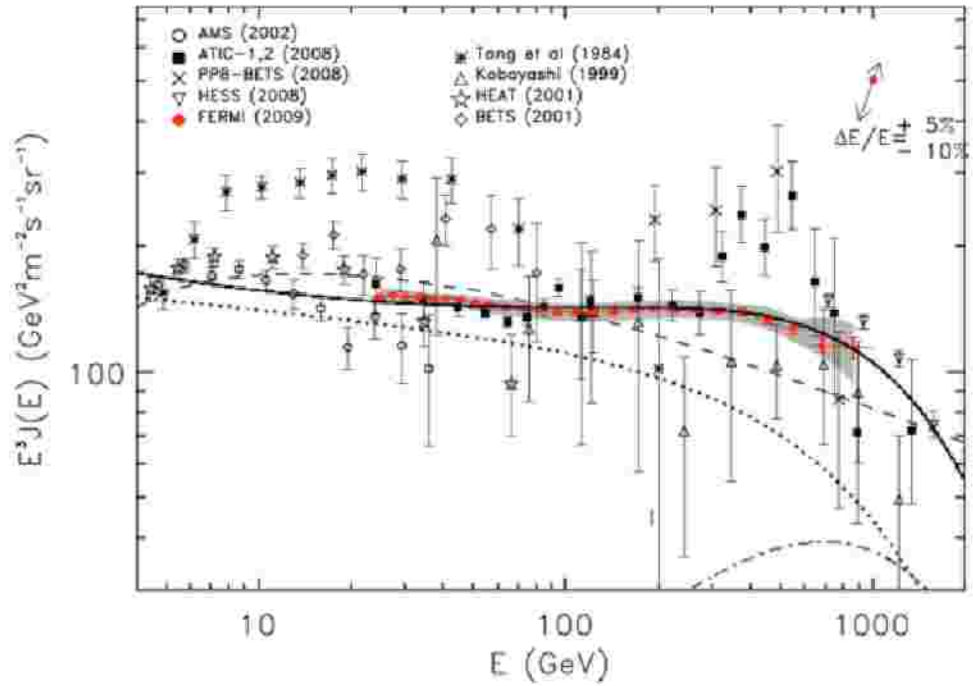


The Dark Matter possibility

- If the Pamela positron excess is from DM annihilation or decay, Fermi CRE data set stringent constraints on such interpretation
- Even neglecting Pamela, Fermi CRE data are useful to put limits on rates for particle DM annihilation or decay
- We find that a DM interpretation of the Pamela data consistent with Fermi CRE data is a viable possibility
- Fermi studies of anisotropies in the electron distribution will help choosing between pulsar and DM scenarios
- Fermi pulsar studies will provide relevant information to support astrophysical interpretation
- Fermi observation of diffuse -rays will be crucial for discerning astrophysical and DM interpretations and resolving different DM scenarios (annihilation vs decay)

A preview of papers to come





P. Blasi arXiv:0903.2794

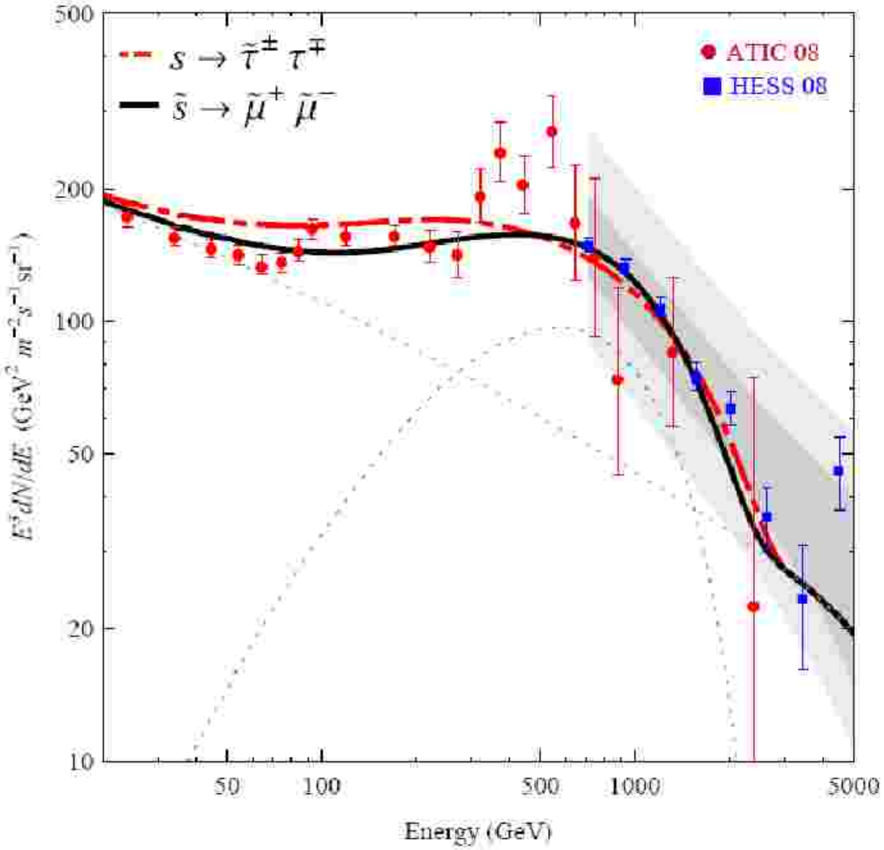
- - - e+/e- from CR interactions in the Galaxy

-·-· e+/e- from production in astrophysical source

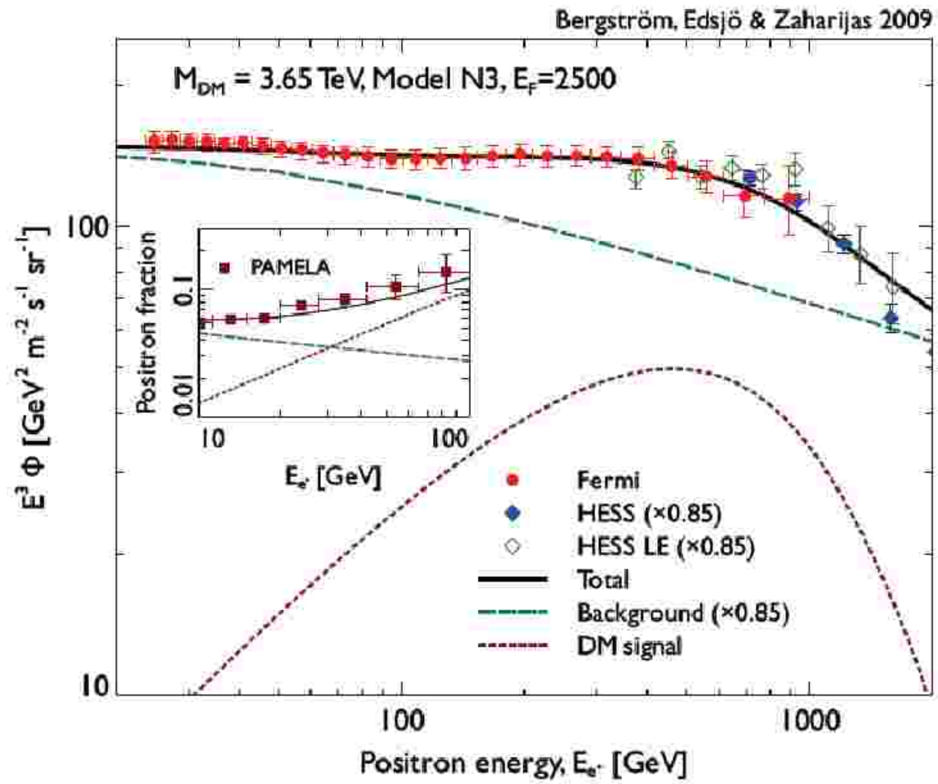
—— e+/e- total

Update from the recent Tango conference after publication of our results

A review of papers to come

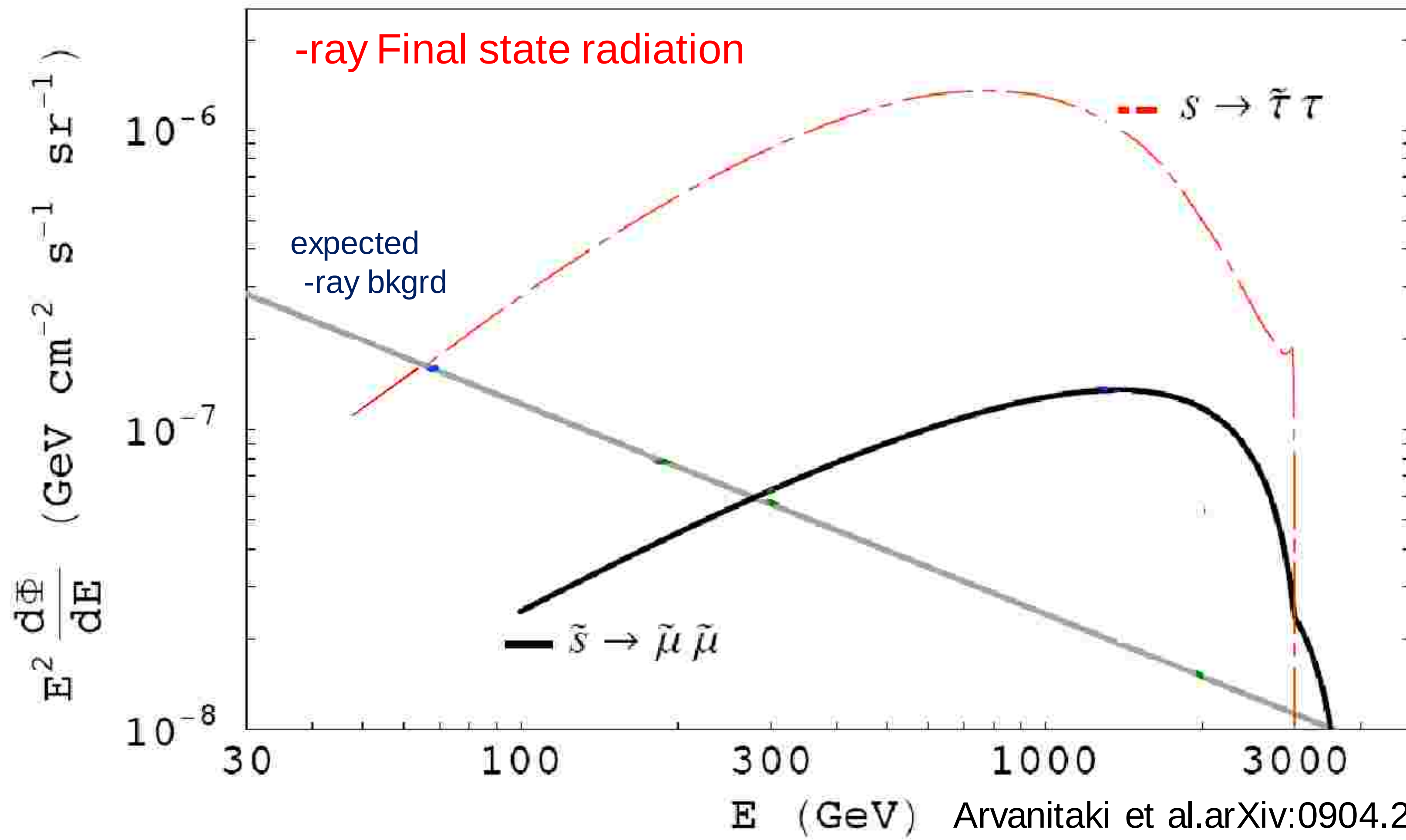


Arvanitaki et al.arXiv:0904.2789v1
Decaying SUSY dark matter



Bergstrom et al.arXiv:0905.0333v1
Annihilating DM

Fermi could look for signature in the diffuse gamma-ray

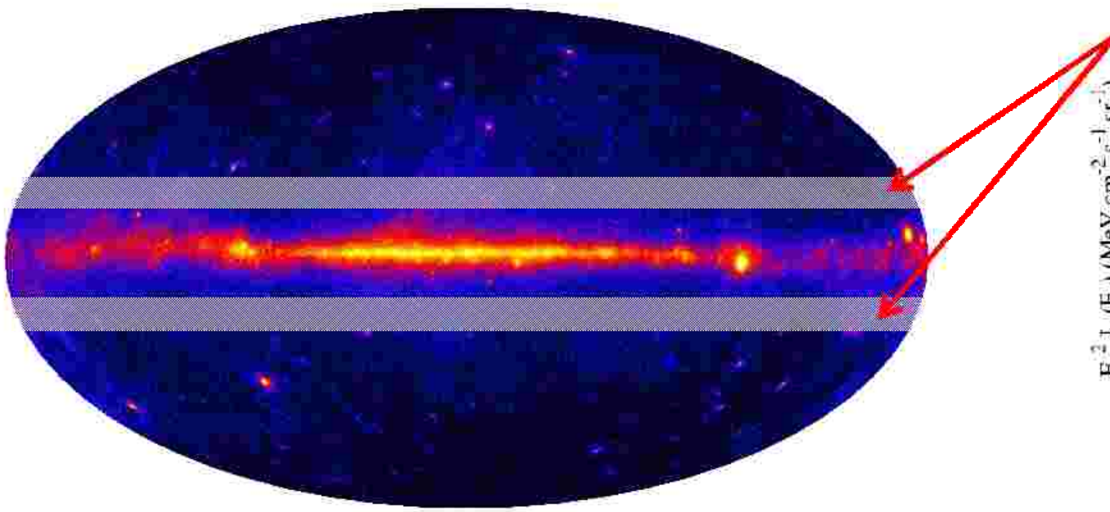


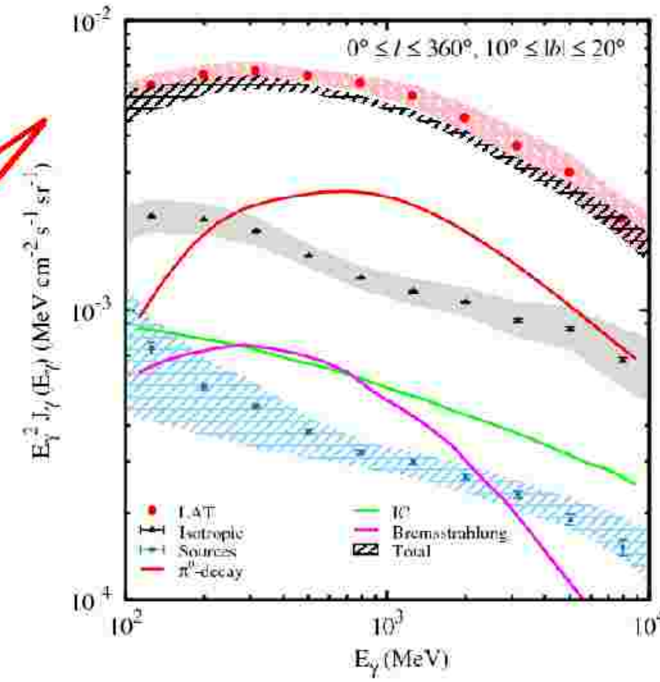
Arvanitaki et al.arXiv:0904.2789v1
Decaying SUSY dark matter

…. expect to see lots of papers about both astrophysical and DM interpretations in the near future

The LAT view on diffuse gamma-ray emission: absence of the GeV-excess

100 MeV – 10 GeV





- **Spectra shown for mid-latitude range ? EGRET GeV excess in this region of the sky is <u>not</u> confirmed**
- **Sources are a minor component**
- **LAT errors are systematics dominated and estimated ~10%**
- **Work to analyse and understand diffuse emission over the entire sky and broader energy range is in progress**

Conclusions - I

- q **The Fermi Gamma-Ray Space Telescope is performing very well and into second half of first survey mode year**
- q **Wealth of results in -ray astrophysics**
  - **~50 pulsars detected, many only in -rays;**
  - **Many flaring active galaxies observed**
    - **About half not seen by EGRET**
  - **8 GRB**
    - **Evidence of delayed emission above 100MeV where statistics allow light curve study (4 GRBs)**
    - **Spectra over > 5 decades consistent with single *Band* function**
  - **No confirmation of the EGRET GeV-excess in diffuse emission**

Conclusions - II

- First high statistics measurement of CR electron spectrum (20 GeV – 1 TeV)
  - not compatible with pre-Fermi conventional diffusive models
  - shows an excess of electrons at high energy
  - Several interpretations of the excess are possible
    - Improved conventional model
    - Local sources of different origin (significant when considering Pamela positron fraction results)
      - Nearby pulsars
      - Dark Matter
- Future observations from the Fermi-LAT will help to find the right answer
  - gamma-ray from PSR and diffuse emission
  - improved statistics, improved systematics and anisotropies in electron arrival directions

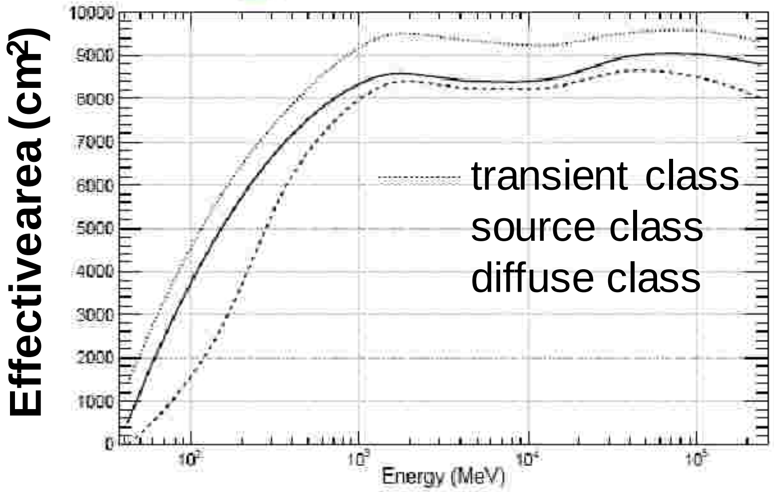
BACKUP

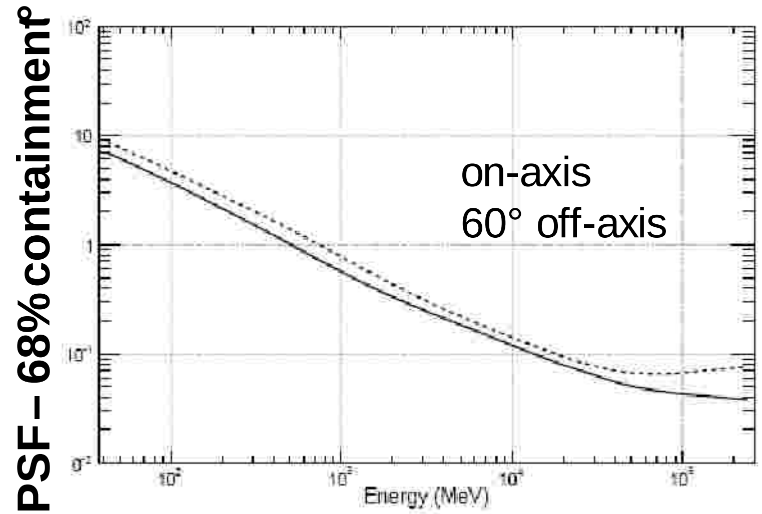
Big Questions From EGRET Era

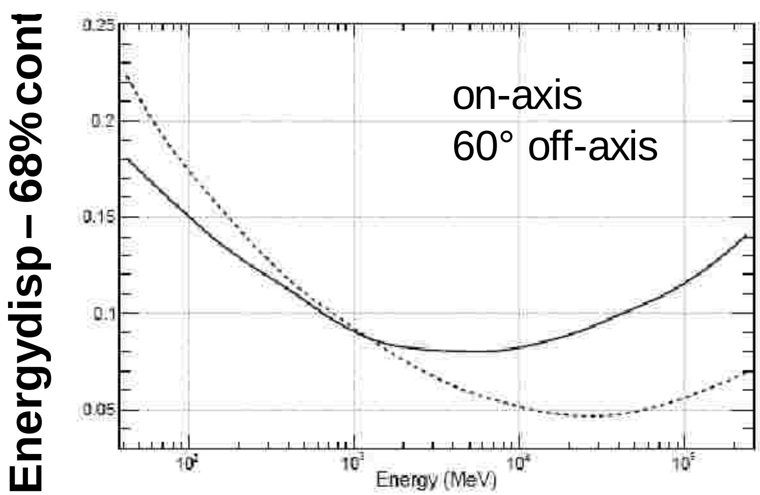
- How and where do pulsars emit gamma rays? How common are radio-quiet pulsars?
  - necessary clue to magnetic field configurations and dynamics
- What are the EGRET Unidentified Sources?
  - most of the EGRET detected sources are a mystery
- What are the energy budgets of gamma-ray bursts? What are the temporal characteristics of the high-energy emission?
  - not well characterized yet, key tests of models, beaming
- What are the origins of the diffuse emissions?
  - galactic: cosmic-ray and matter distributions; sources
  - extragalactic: populations
  - new sources (Dark Matter annihilations, clusters, …)
- How do the supermassive black hole systems of AGN work? Why do the jets shine so brightly in gamma rays?
  - temporal and spectral variability over different timescales
- What remains to be discovered with great new capabilities??
  - EGRET showed us the tip of the iceberg. New sources and probes for new physics.

Instrument Response Functions

Google: lat performance → http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

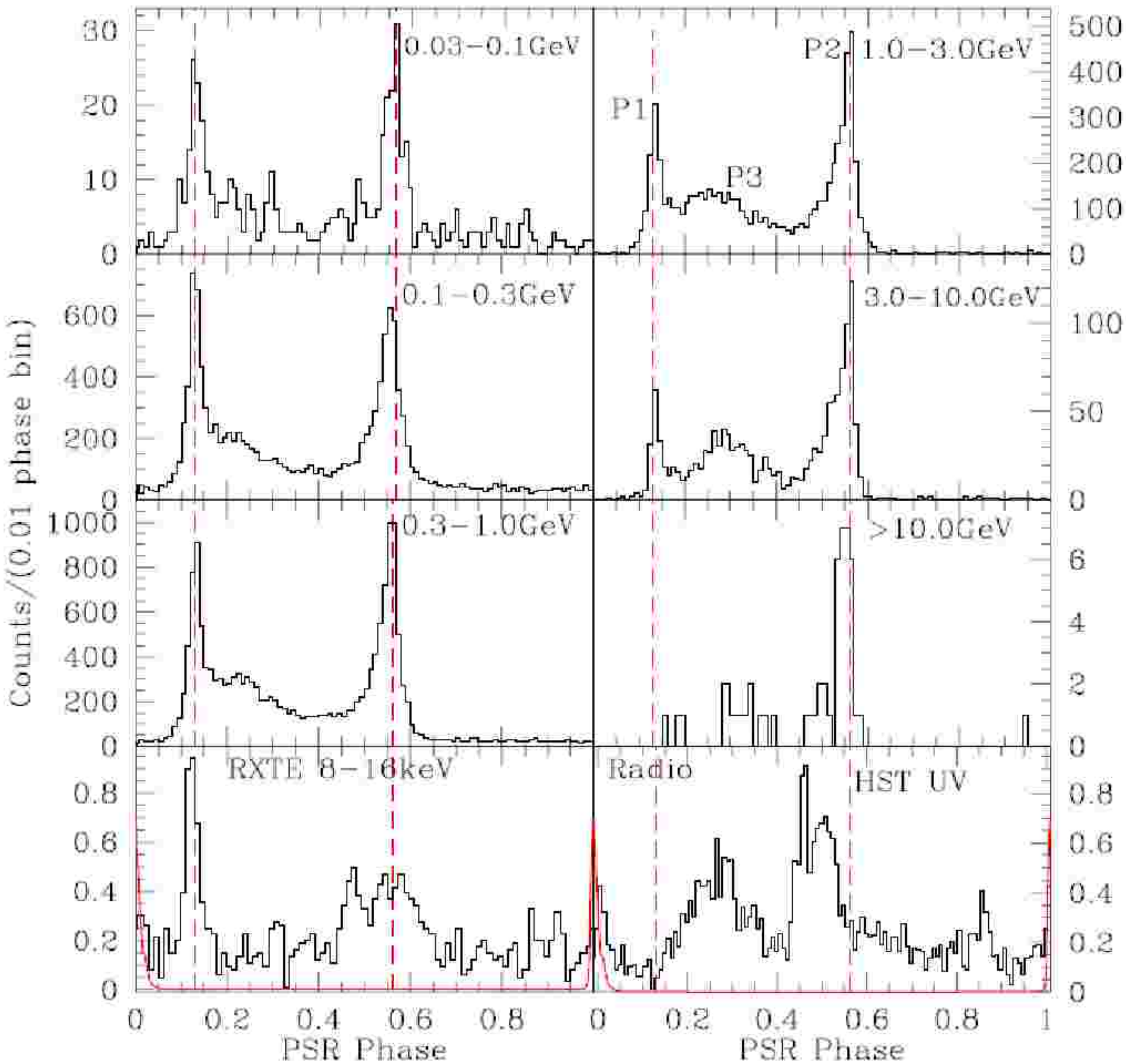






- **Philosophy**
  - **Instrument response mapped into analytical functions or simple tables**
  - **General simulation for all-purpose analysis vs specific analysis MC sim**
  - **Serve large community of users**
  - **Systematics from response representation choice and MC fidelity**

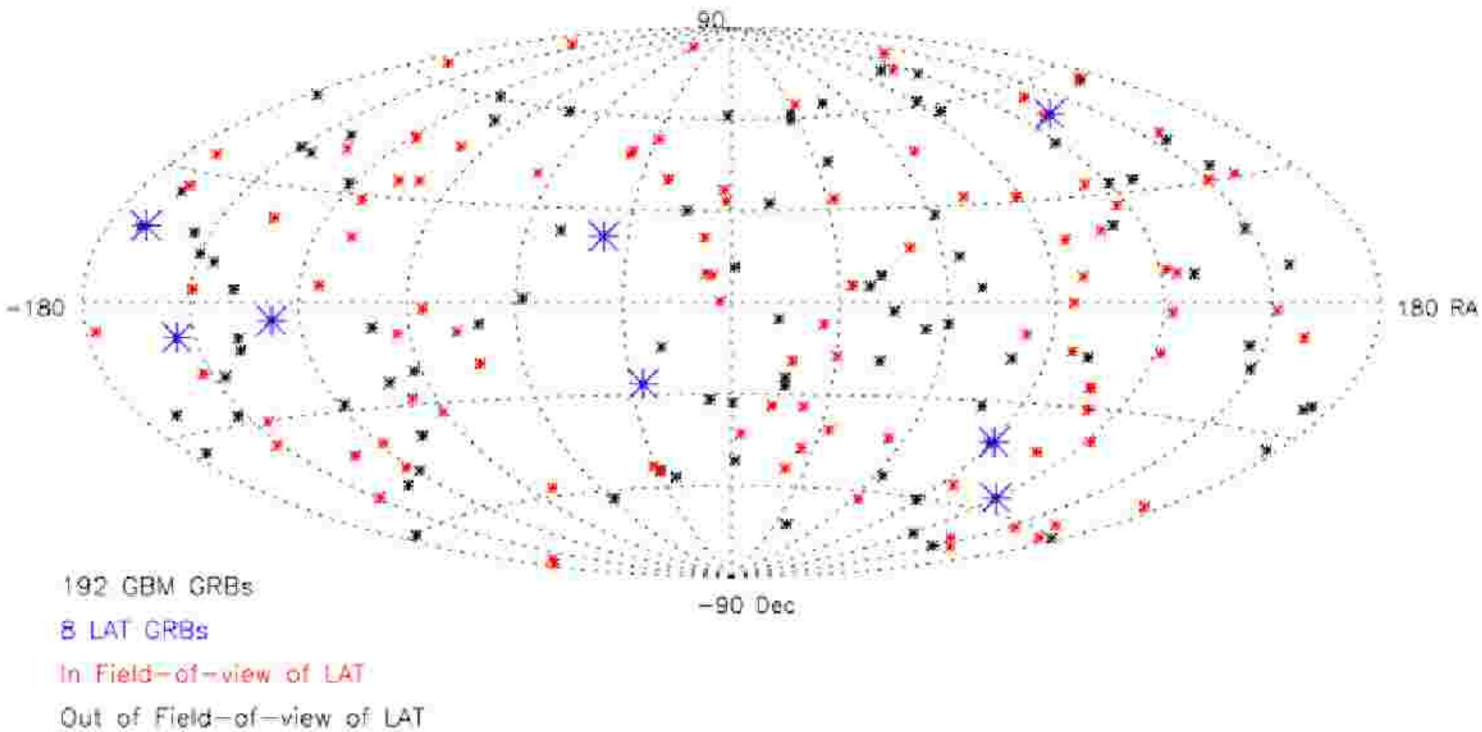
Vela Light curve evolution with energy



Large LAT energy window puts Vela pulsar in multiwavelength context !

UV peak possibly connected to high energy IC emission in P3

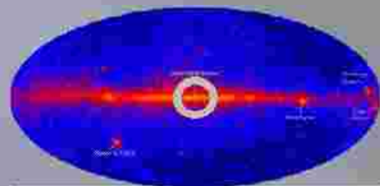
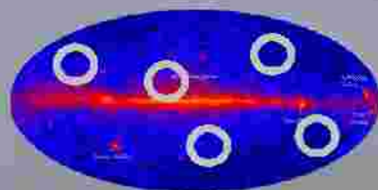
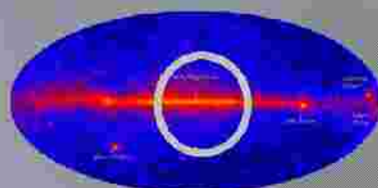
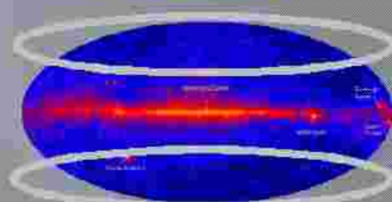
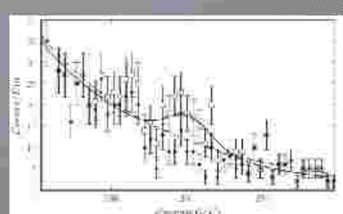
Fermi GRBs as of 090510



8 LAT-detected high-energy bursts

- **GRB 080825C**
- **GRB 080916C – very strong, z=4.35**
- **GRB 081024B – short**
- **GRB 081215A – LAT rate increase**
- **GRB 090217**
- **GRB 090323 – ARR, z=3.6**
- **GRB 090328 – ARR, z=0.736**
- **GRB 090510 – short, intense, 1st LAT GCN notice, z=0.9**

Searching for Dark Matter

Search Technique		advantages	challenges
Galactic center		Good Statistics	Source confusion / Diffuse background
Satellites, subhalos Point sources		Low background, Good source id	Low statistics
Milky Way halo		Large statistics	Galactic diffuse background
Extra-galactic		Large Statistics	Astrophysics, galactic diffuse background
Spectral lines		No astrophysical uncertainties, good source id	Low statistics

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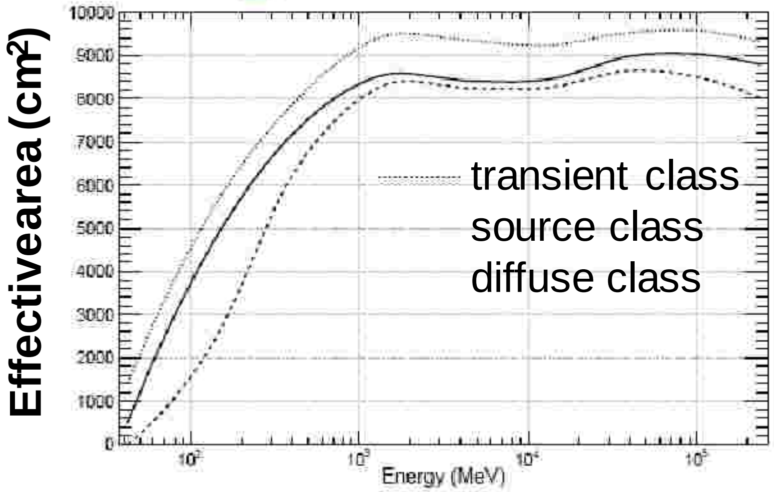

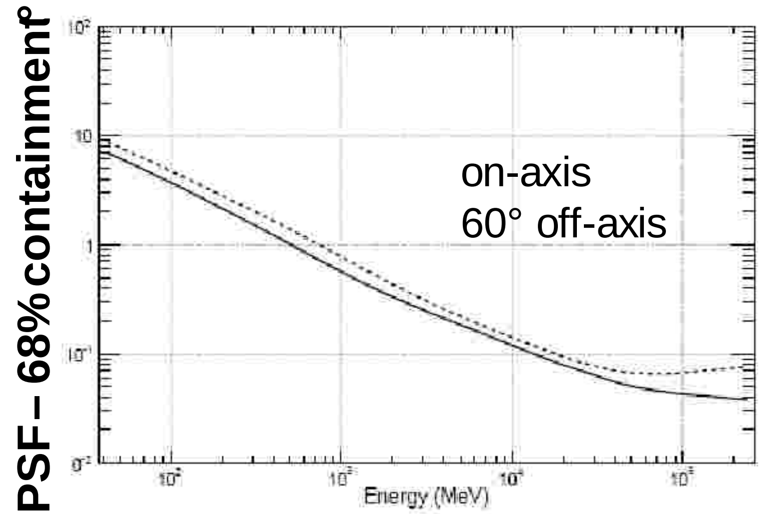

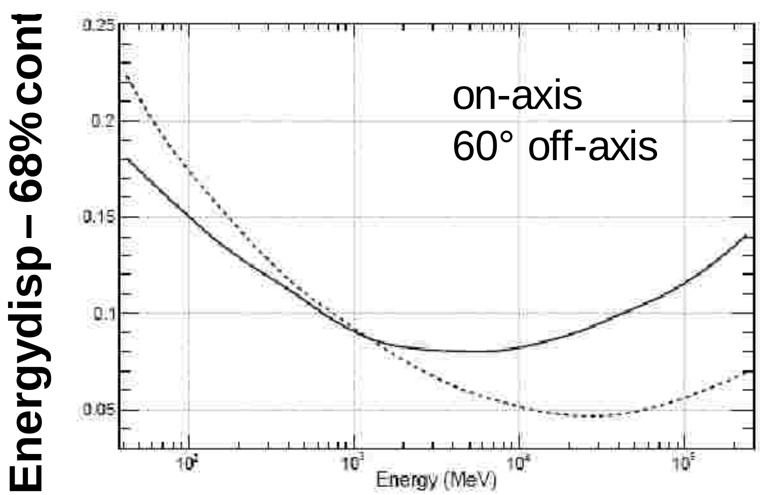

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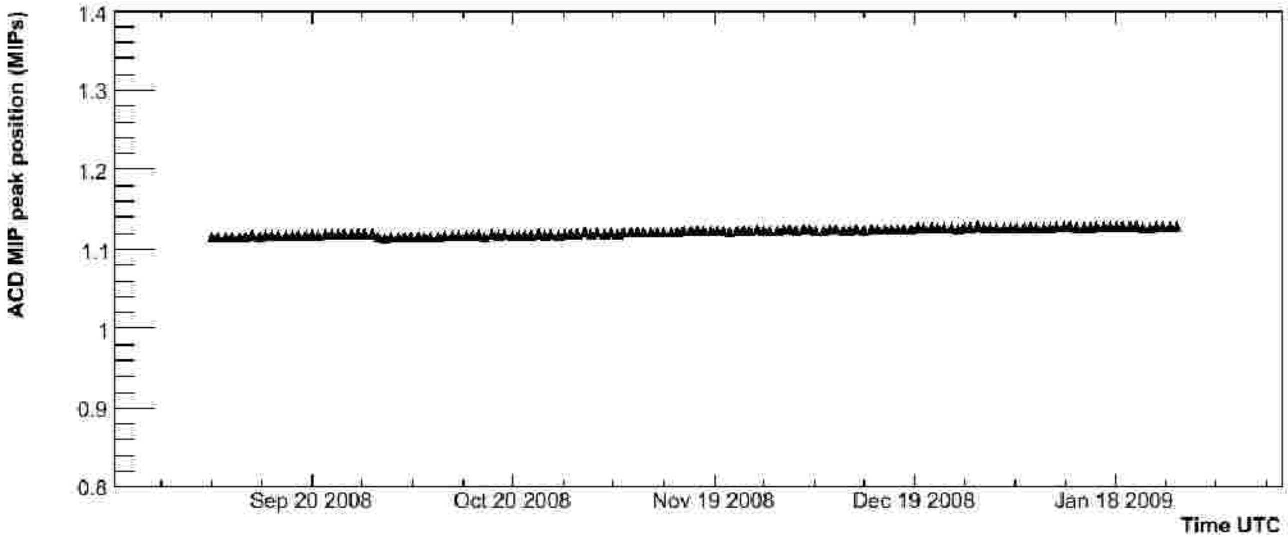
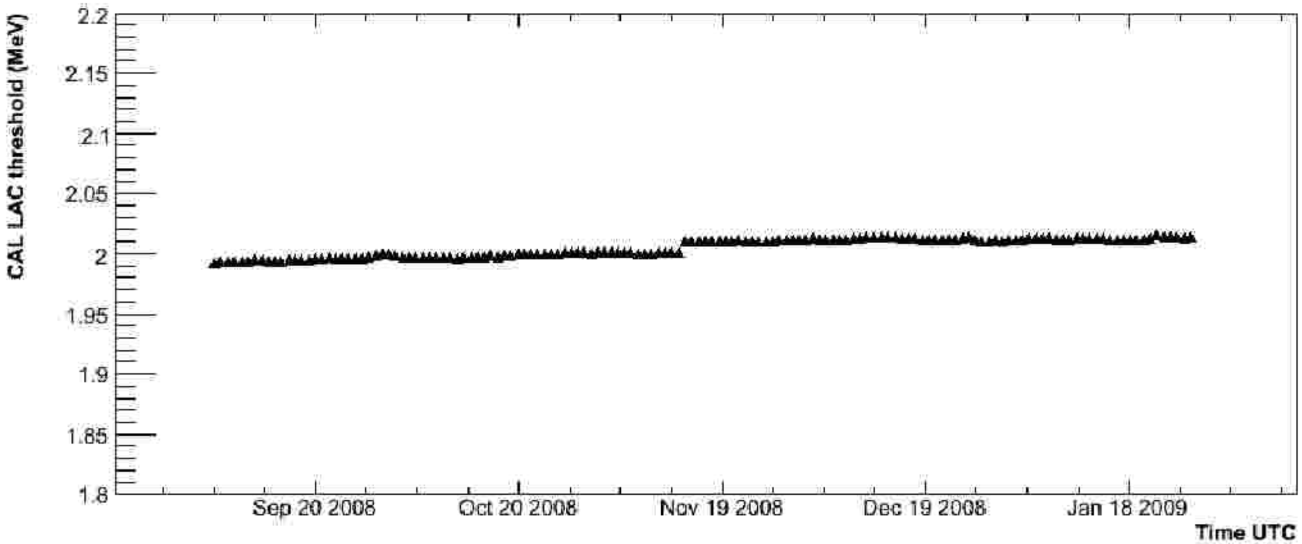
The Large Area Telescope on the Fermi Gamma-ray Space Telescope
Atwood, W. B. et al. 2009, ApJ, 697, 1071, arXiv:0902.1089v1

Stability of CAL and ACD



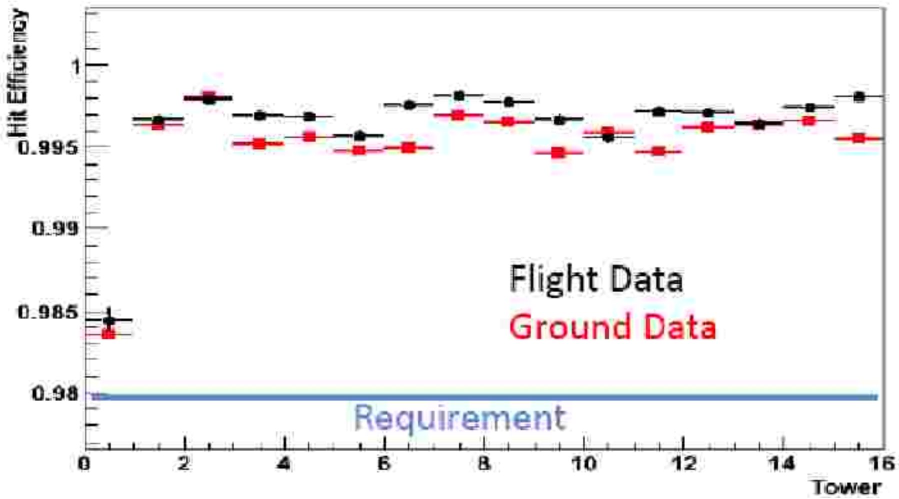
ACD veto threshold set to 0.4MIPs – 1% drift over 4 months

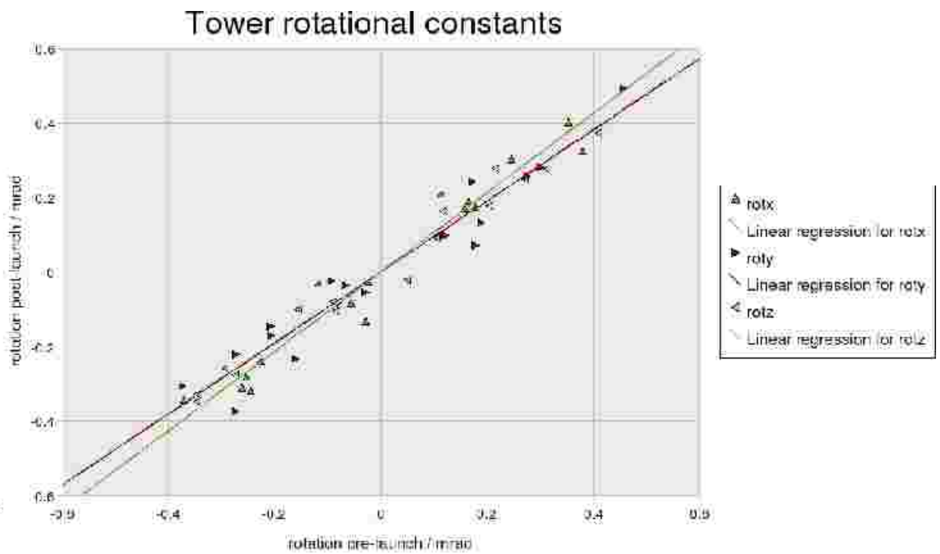


CAL average zero-suppression threshold – 1% drift over 4 months

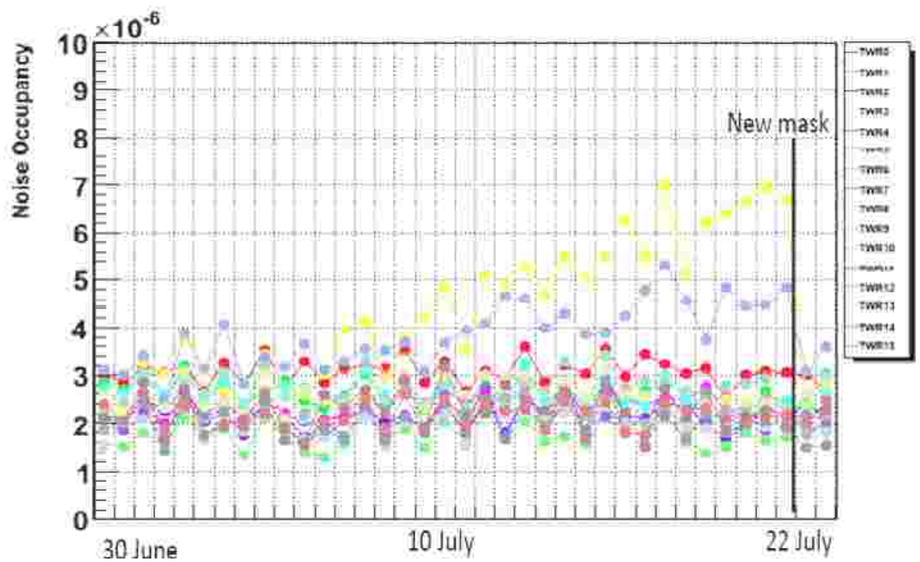
The On-orbit Calibrations for the Fermi Large Area Telescope
arXiv:0904.2226v1

Tracker performance and calibration



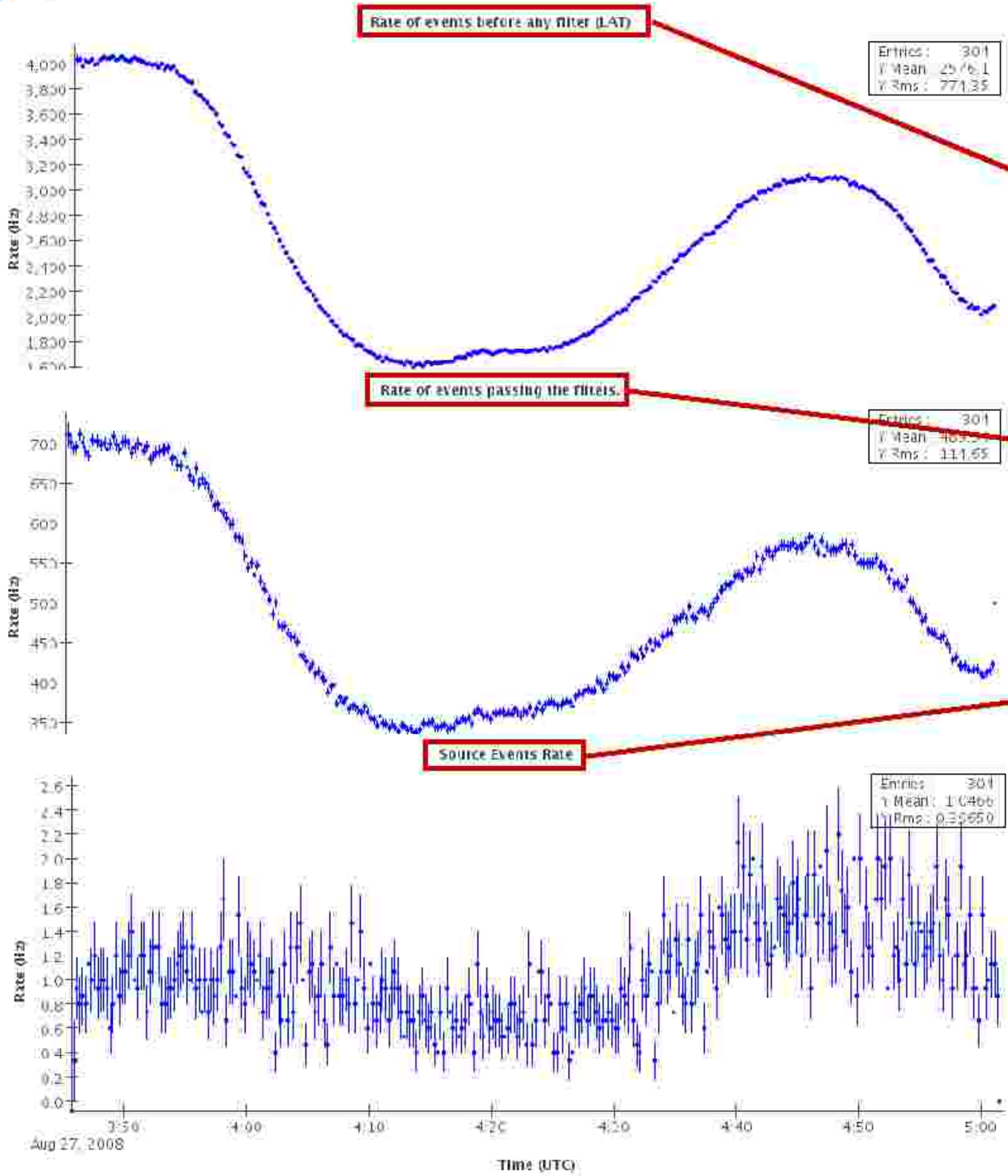


- No evidence of a reduction in hit efficiency (well above 99% on average)
- No significant change in the alignment constants (intra and inter-tower) after the launch (the LAT underwent up to 4 g acceleration + vibration)
- No evidence of any increase in the overall noise level (~1 noise hit per event for the full LAT).



The On-orbit Calibrations for the Fermi Large Area Telescope arXiv:0904.2226v1

On orbit rates in nominal configuration



ü Overall trigger rate: ~few KHz

ü Huge variations due to orbital effects.

ü Downlink rate: ~400—500 Hz

ü ~90% from GAMMA filter

ü ~20—30 Hz from DGN filter

ü ~5 Hz from HIP filter

ü Rate of photons after the standard background rejection cuts for source study: ~1 Hz

ü Most of the downlinked events are in fact background, final ~ 1000:1 rejection is done in ground processing.