The Fermi Large Area Telescope

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on behalf of the Fermi LAT collaboration

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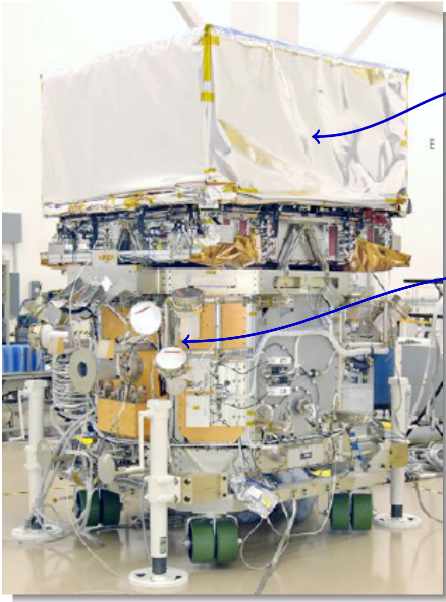
Outline

- Not a standard Fermi overview talk.
- Status of the mission.
- Review of some selected science highlights:
  - With emphasis on cosmic rays and dark matter searches.
- What's next for Fermi?
- And a lot of additional material for discussion of specific items.

Fermi Gamma-ray Space Telescope

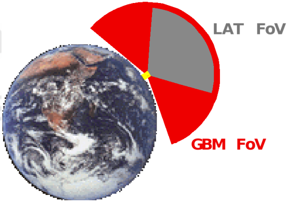


Large Area Telescope (LAT)

- Pair conversion telescope.
- Energy range: 20 MeV–300+ GeV.
- Sees 20% of the sky at any time (the full sky for half a hour every 3 hours).

Gamma-ray Burst Monitor (GBM)

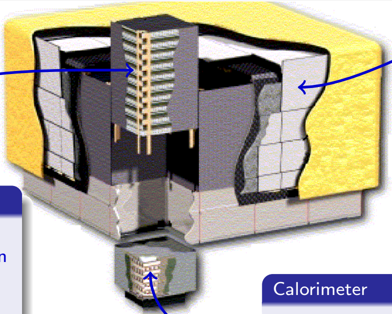
- 12 NaI and 2 BGO detectors.
- Energy range: 8 keV–30 MeV.



The Large Area Telescope

Large Area telescope

- Overall modular design.
- 4×4 array of identical towers (each one including a tracker and a calorimeter module).
- Tracker surrounded by an Anti-Coincidence Detector (ACD).
- 1.8×1.8 m^2 footprint, $\sim$ 3000 kg weight, $\sim$ 650 W power budget.
- All subsystem contribute to the necessary $\sim 10^6 : 1$ background rejection power.



Anti-Coincidence Detector

- Segmented (89 tiles) to minimize self-veto at high energy.
- 0.9997 average efficiency (8 fiber ribbons covering gaps between tiles).

Tracker

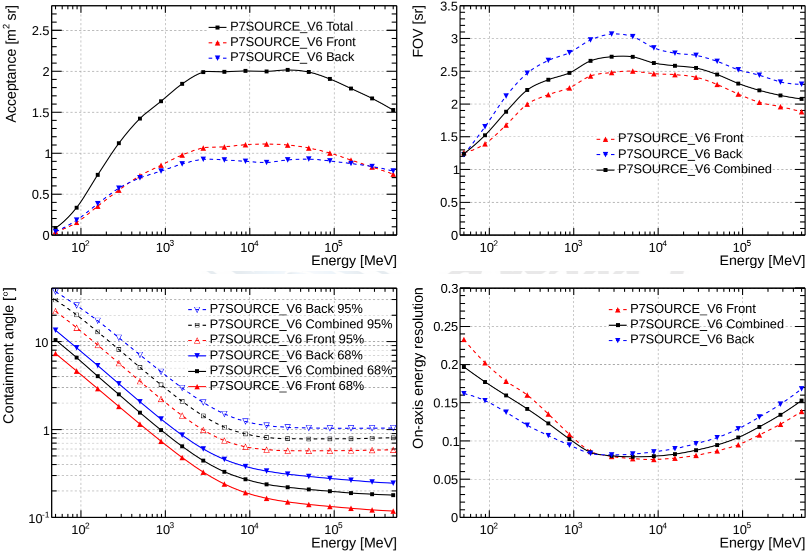
- Silicon strip detectors, W conversion foils; 1.5 radiation lengths on-axis.
- 10k sensors, 73 m^2 of silicon active area, 1M readout channels.
- High-precision tracking, short instrumental dead time.

Calorimeter

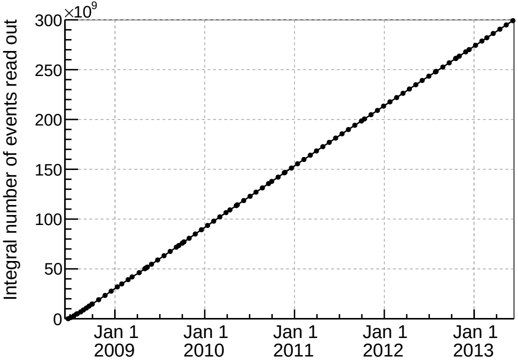
- 1536 CsI(Tl) crystals; 8.6 X_0 on-axis.
- Hodoscopic, 3D shower profile reconstruction for leakage correction and background rejection.

LAT Instrument Response Functions

Ackerman et al., ApJS **203**, 4 (2012) or arXiv:1303.3514

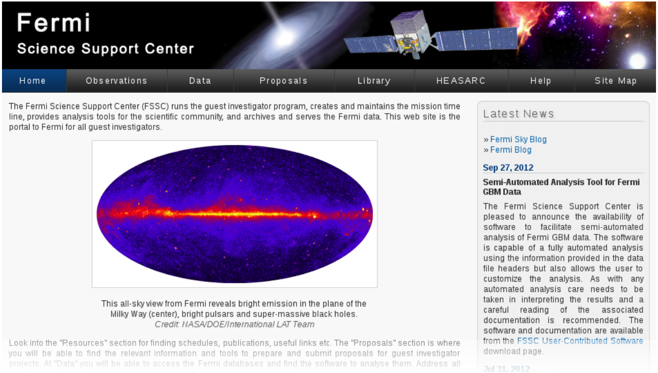


Mission status at L + 5



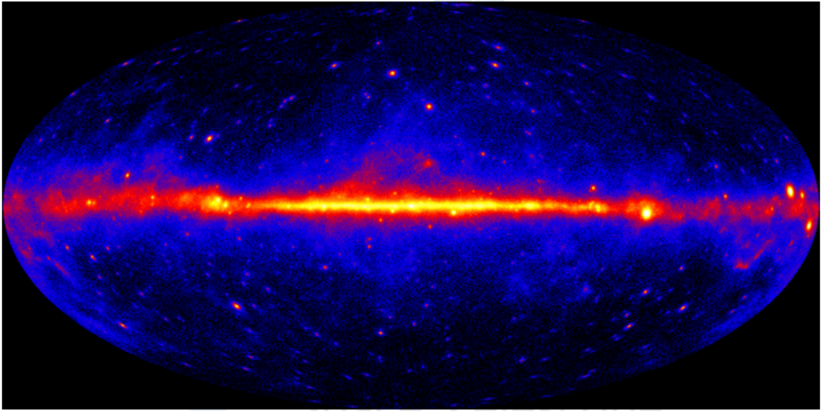
- Event statistics:
  - The LAT hit 300 B triggers in orbit on June 12, 2013;
  - (i.e., exactly 5 years and 1 day into the mission);
  - 62,598,889,468 events down-linked (as of September 3, 2013);
  - 788,396,498 gamma rays distributed to the community.
- All subsystem working properly, no sign of performance degradation.
- More than 99% up-time collecting science data.
  - Including detector calibrations/hardware issues.

Fermi LAT data are public

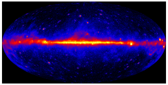
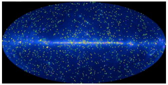


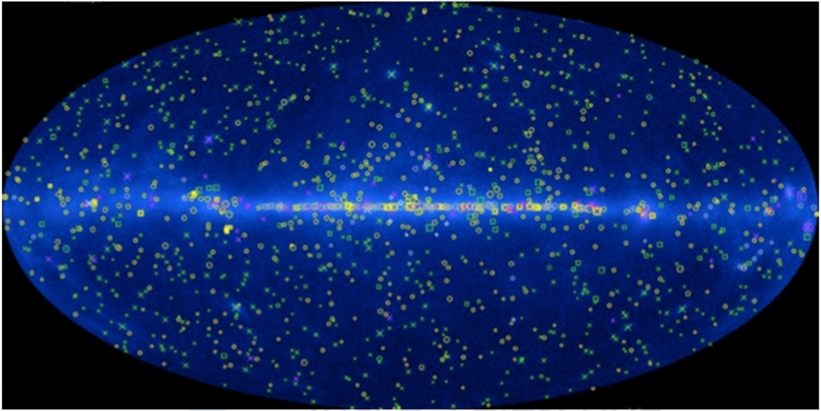
- All LAT photon data go public *immediately* (i.e. within a few hours).
  - Data access at `http://fermi.gsfc.nasa.gov/ssc/`
- The LAT collaboration also maintains and distributes the necessary analysis elements (instrument response functions, diffuse models).
- Significant effort to make all the analysis improvements available to the community at large as soon as possible.

Gamma-ray Space Telescope

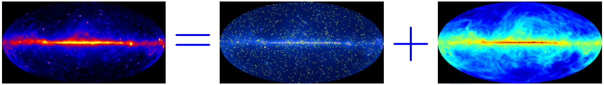


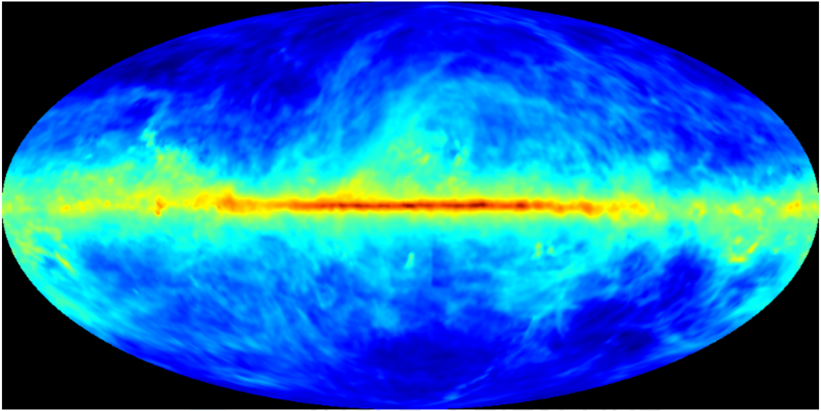
- The γ-ray sky:
  - Rate map (exposure corrected) of γ-candidates above 200 MeV collected during the first year of data taking.

 = 

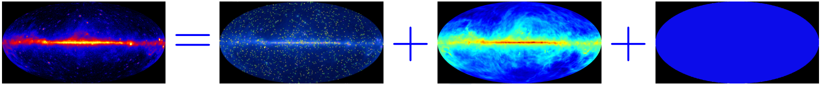


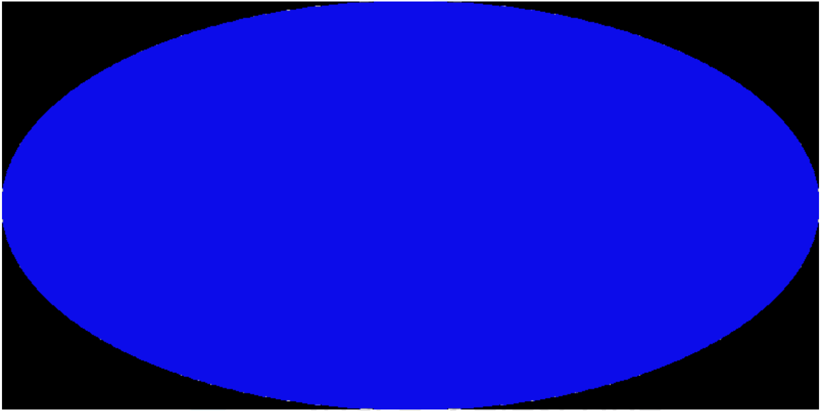
- Resolved point sources:
  - The catalogs are among the most important collaboration science products (more about this in the following)





- Galactic diffuse radiation (accounts for the majority of photons):
  - Cosmic-ray interactions with the interstellar medium (synchrotron, inverse Compton, π^0 decay, bremsstrahlung).





- Isotropic diffuse emission:
  - Unresolved sources and truly diffuse (extragalactic) emission;
  - Residual cosmic-rays surviving background rejection filters.

And a reach Science menu

a.k.a. tag cloud of the titles from 241 collaboration papers

1fgl (3) 3c (9) activity (7) agn (4) analysis (4) anisotropies (3) background (5) binary (4) bl (6) blazar (15) blind (5)
bright (9) burst (4) case (4) catalog (9) constraints (13) cosmic ray (14) crab (4) curves (4) cygnus (5)
dark matter (13) data (7) detection (21) diffuse (11) discovered (3) discovery (30)
distribution (6) dwarf (5) early (3) electron (5) emission (55) energetic (3) energy (26)
fermi (160) flare (12) galactic (12) galaxies (19) gamma ray (117)
gev (13) globular (3) grb (9) hard (6) hess (5) j0948 (4) jet (4) lacertae (5)
large area telescope (63) lat (57) light (6) limits (4) line (8) magic (4)
measurement (5) milky (4) millisecond pulsars (7) models (5) monitoring (3) multi (5) multifrequency (3)
multiwavelength (5) narrow (7) nebula (4) nuclei (4) object (5) observations (66) outburst (7)
pks (11) pmn (4) population (3) properties (4) psr (20) pulsar wind nebula (8) pulsar (20) pulsed (6) quasar (5)
radio (30) ray (6) region (4) results (3) search (17) seyfert (7) simultaneous (3) source (11) space (4) spectra (3)
spectral (11) spectrum (6) star (4) state (4) study (7) supernova remnant (15) survey (4)
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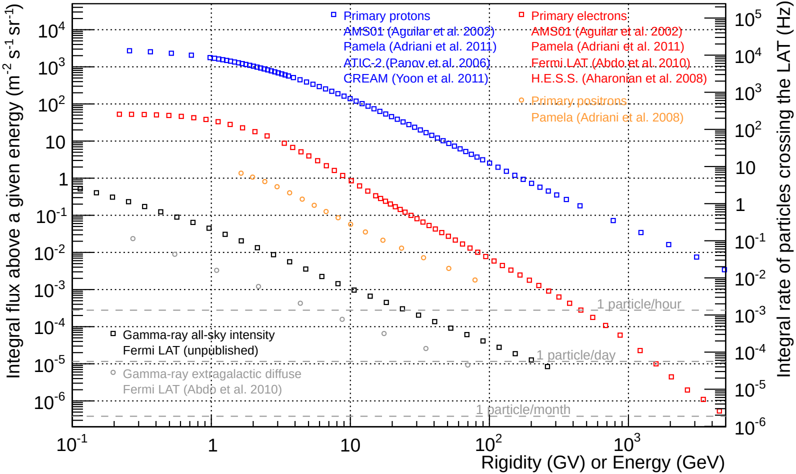
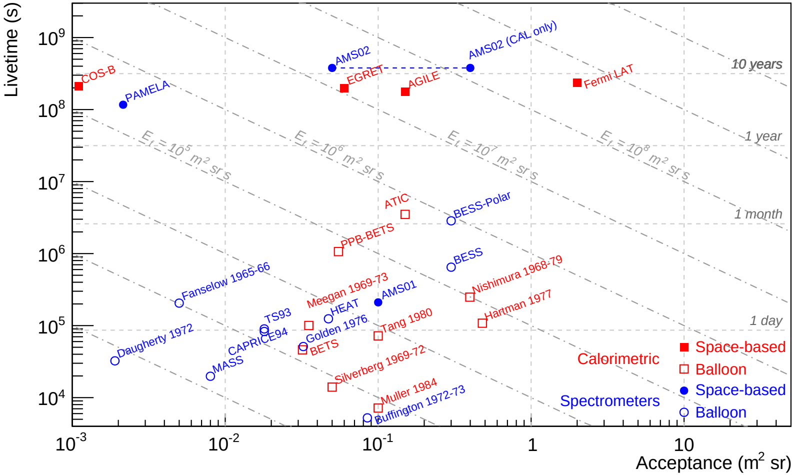
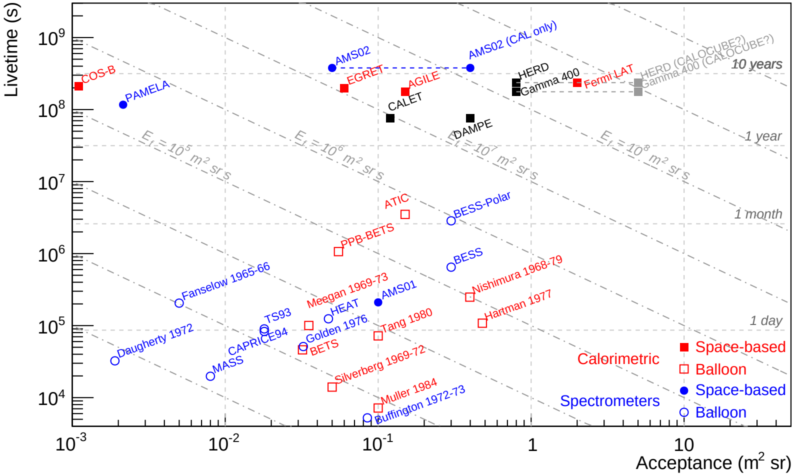


- Celestial γ-rays constitute a tiny fraction of the cosmic radiation.
  - ~ 1 γ-ray per week above 1 TeV *crossing* the LAT;
  - A handful/year of which from the isotropic background.

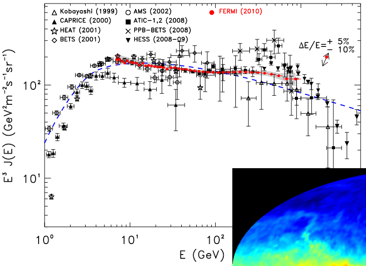
Fermi in context

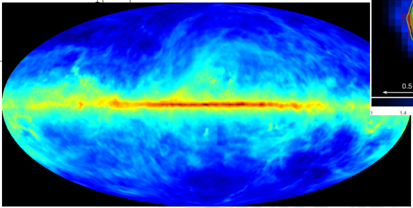


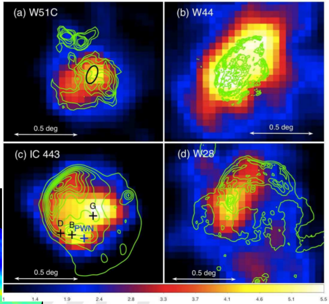
- Fermi was deliberately designed maximizing the acceptance:
  - Hard to imagine a bigger γ-ray detector in the near future.
- Key complementarity in design and science menu with AMS-02.



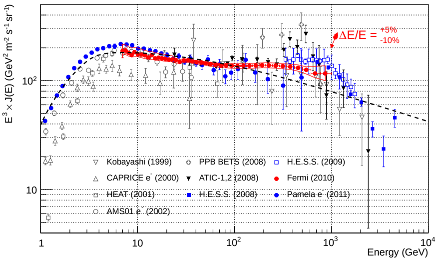
- Most future detectors optimized for energy resolution:
  - And no spectrometer competitive with AMS planned.
- And CTA, not shown, is coming along!

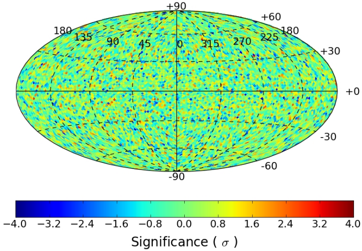




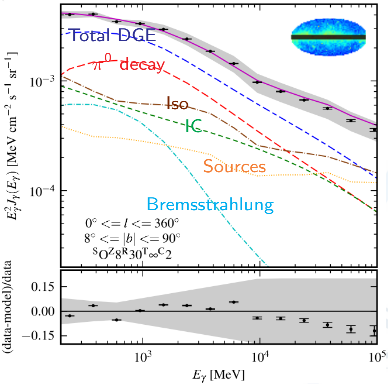


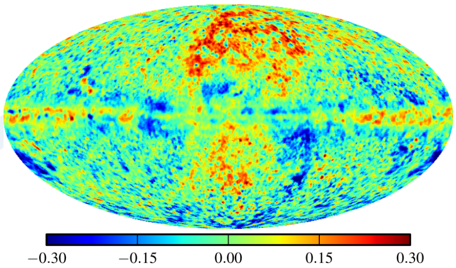
- Three lines of research related to cosmic rays:
  - Direct CR measurements (electrons and positrons).
  - Study of the large-scale gamma-ray diffuse emission, a.k.a. GDE (Galactic Diffuse Emission).
  - γ-ray properties of likely acceleration sites (SNRs).





- First systematic-limited measurement of the CRE spectrum between 7 GeV and 1 TeV.
  - Significant work put toward improving the energy reconstruction at very high energy (confirm the cutoff seen by H.E.S.S.?).
- Most stringent upper limits to date on possible CRE anisotropies:
  - Key factors: large exposure factor and large field of view.
- First measurement of separate electron and positron spectra up to 200 GeV.
  - Now this is effectively AMS playground.

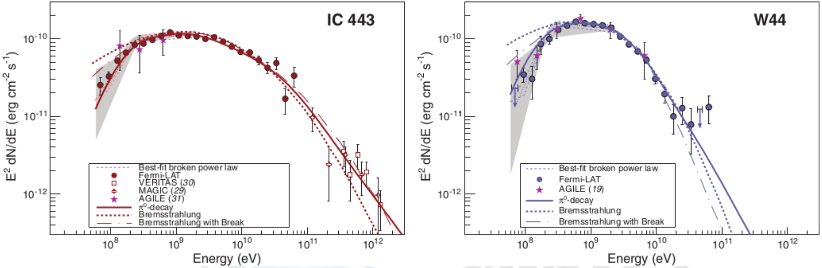




- A huge amount of external inputs going into the modeling of the Galactic diffuse emission.
- Highly non-trivial task:
  - Spatial residuals of $\sim$ 20% (on different scales) not uncommon;
  - There is no such thing as the *perfect* DGE model.
- One the basic ingredients for most of the science analyses (notably faint and/or extended sources, catalogs, DM searches).

Supernova Remnants Produce Cosmic Rays

Ackermann et al., Science **339**, 807–811 (2013) or arXiv:1302.3307



- "SNR paradigm": Galactic Cosmic Rays accelerated in SNRs:
    - Provide environment for diffusive shock acceleration, energetics ok;
    - Smoking gun: "pion bump" in gamma-ray emission.
- Fermi observations strongly disfavoring leptonic scenarios.
- Most of the gamma-ray emission must be of hadronic origin.
- Difficult measurement involving the study of extended sources at low energies.

Fermi and indirect dark-matter searches

Galactic center

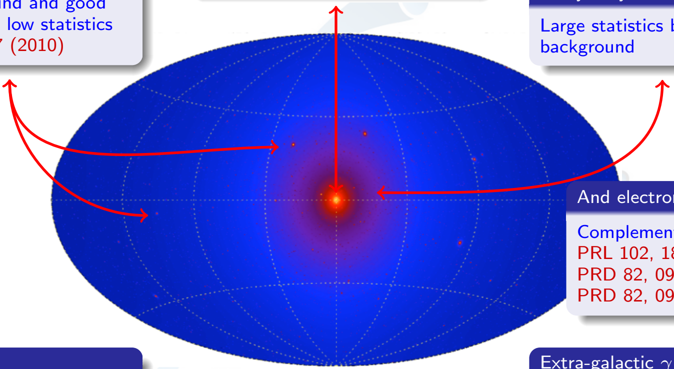
Good statistics but source confusion and diffuse background

Satellites

Low background and good source id, but low statistics
ApJ, 712, 147 (2010)

Milky Way halo

Large statistics but diffuse background



And electrons/positrons!

Complementary to γs
PRL 102, 181101 (2009)
PRD 82, 092004 (2010)
PRD 82, 092003 (2010)

Spectral lines

No astrophysical uncertainties, good source id but small branching ratio
PRL 104, 091302 (2010)

Galaxy clusters

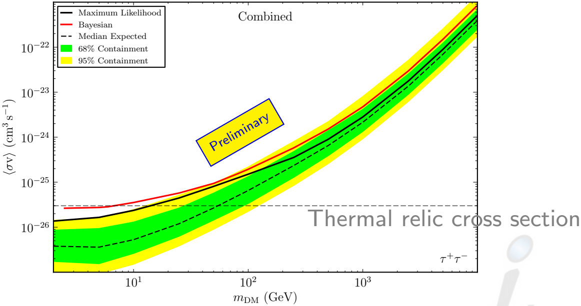
Low background but low statistics
JCAP 05, 025 (2010)

Extra-galactic γ radiation

Large statistics, but astrophysics and galactic diffuse background
JCAP 04, 014 (2010)

Dwarfs Spheroidal Galaxies

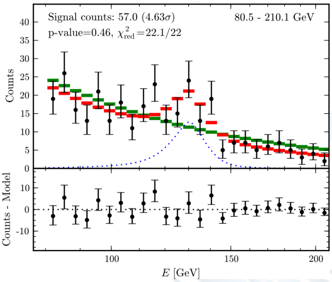
Our cleanest target and the most stringent upper limits

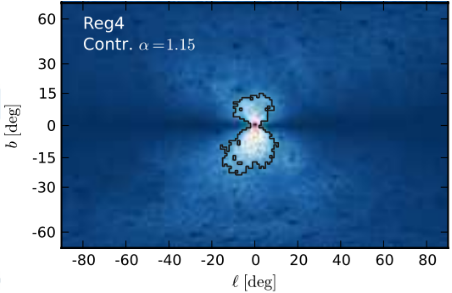


- Systems with very large mass/luminosity ratio:
  - $\sim$ 25 discovered through optical surveys.
  - More expected in the near future.
- Joint likelihood of 15 dSphs (4 years of reprocessed data) about to be submitted.
  - Non detection of dSphs allows to put our most constraining limits on WIMP annihilation.

A gamma-ray line in the Galactic center?

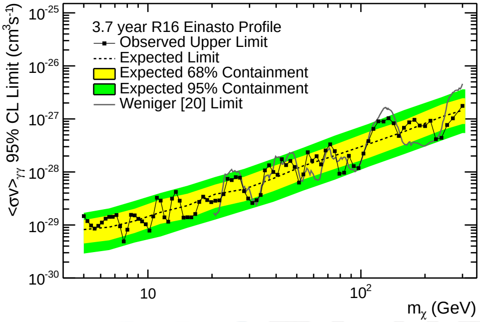
Weniger, JCAP **1208**, 007 (2012) and many others





- Good example of a results based on Fermi data from outside the collaboration with a huge echo in the community.
- Call for white papers on possible modifications to the observation strategy on March 27, 2013.
  - 96% of the observing time in nominal survey mode through the prime phase of the mission.
  - More emphasis on the GC starting from next December.
- And routinely pointing the Earth limb for a few hours a week.

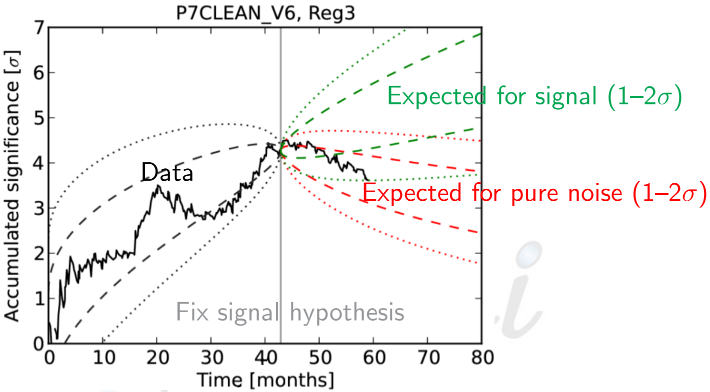
A gamma-ray line in the Galactic center?
arXiv:1305.5597



- Line-search paper submitted to PRD by the LAT collaboration.
- Broader scope, but addressing the question of the 130 GeV line.
  - Significance slightly lower with updated instrument calibration and better energy dispersion model.
  - Feature seems to be narrower than the energy resolution.
  - (Smaller) feature at the same E in the Earth limb control sample.
- Too early to draw any definitive conclusion with 3.7 years of data.

A gamma-ray line in the Galactic center?

Time evolution of the signal, see arXiv:1303.1798



- Weniger's updated results are consistent with the results from the recent LAT line-search paper.
  - Likely that the original putative line signal was a statistical fluctuation.
- More data, Pass 8 (see next slides) and the new observing strategy will give the final word.

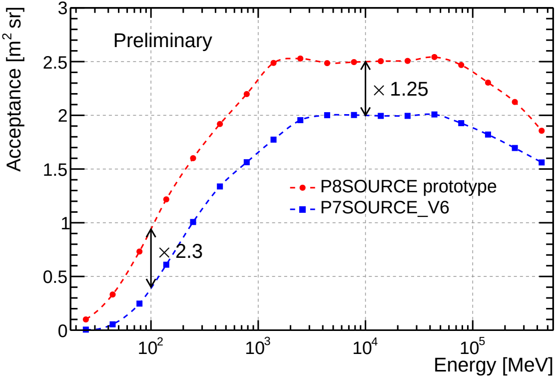
What's next? The extended Fermi mission

- Mission extensions are negotiated through *Senior Review* process every two years:
  - All operating missions in (or about to begin) their extended phase.
  - SR committee evaluates the anticipated science productivity of each mission over the next four years, focusing on the next two years.
- Fermi successfully underwent its first SR in 2012 and is preparing for the next one in 2014.
  - The current baseline (goal) is to operate through 2016 (2018).
- Benefits of the extended mission well beyond the expectation from a deeper exposure:
  - Time-domain astronomy (e.g., transient phenomena) in synergy with other observatories;
  - Multiwavelenght/multimessenger astronomy;
  - Improving external knowledge: pulsar radio timing solutions, inputs to DGE modeling, more dSphs. . .
  - Better understanding of the instrument and the environment;
  - Analysis and operational improvements.
- And Pass 8 is coming along! (See next slide.)

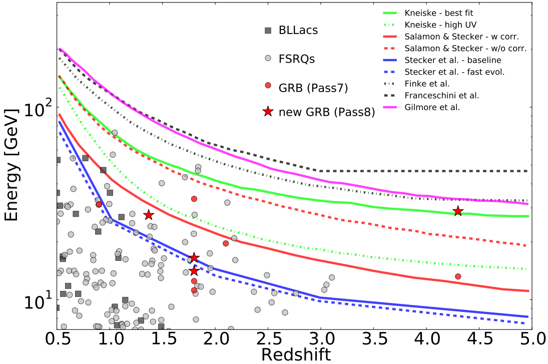
What's next? Pass 8

Maximizing the science return from the LAT

- Long term effort aimed at a substantial rewrite of the LAT event-level analysis:
  - Monte Carlo simulation;
  - Event reconstruction;
  - Background rejection.
- Main goal: deliver to the community a new instrument with significantly better science performance.
  - Better effective area, angular resolution, S/N ratio.
  - Better control over the systematic uncertainties.
  - Extend the scientific reach to unexplored areas (e.g., multi-photon events, polarization).
- Project started in 2009 (!), event reconstruction now frozen and preliminary event selection in place.
  - Full data reprocessing (from the start of the mission) started—to be completed by December this year.
  - The first two years of Pass 8 reprocessed data internally available for science validation.



- First iteration of the event selection in place.
  - Uniformly larger acceptance;
  - Huge increase at $\sim$ 100 MeV and below;
  - Largely the result of the reconstruction improvements.
- All the analysis components ready to analyze real data.
- Opening new observational windows at very low and very high energies.



- Pass 8 reveals more high-energy γs from GRBs.
- Sample of 10 GRBs with measured redshift re-analyzed.
  - 4 new photons above 10 GeV (in addition to the 6 previously known).
  - Interesting implications for the γ-ray opacity of the Universe.
- First Pass 8 science paper.

To conclude: a personal wish list

I know different people have different opinions

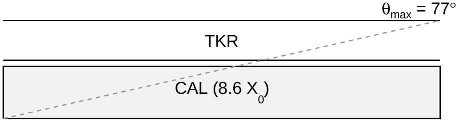
- Largest acceptance?
  - Low energy ★★☆☆: part of this is coming with Pass 8.
  - Mid energy ☆☆☆☆: systematic-dominated for most of the analyses.
  - High energy ★★★★: need more γ rays (but IACTs?)
- Better angular resolution?
  - Low energy ★★★★: a sub-degree PSF @ 100 MeV would be terrific!
  - Mid energy ★★☆☆: better is good.
  - High energy ★☆☆☆: source analysis dominated by counting stat.
- Better energy resolution?
  - Low energy ★★★☆: edisp couples with steeply rising acceptance.
  - Mid energy ★☆☆☆: irrelevant for most of the analyses.
  - High energy ★★☆☆: beneficial to specific analyses.
- The three items are tied to each other:
  - e.g., you have trade acceptance for better energy/angular resolution.
- Finding the optimal balance is a complex trade-off.
  - And "optimal" has a precise meaning only in the context of a specific science case.

[1](Totally arbitrary) legend: read "Low energy" as below 200 MeV, "Mid energy" between 200 MeV and 20 GeV and "High energy" above 20 GeV.

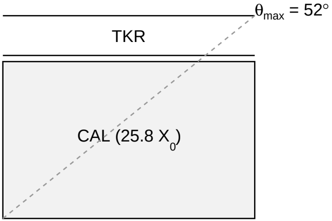
A simplistic example (1/2)

A toy Monte Carlo fixing the weight of the detector

On-axis A_{eff} = 0.90 m^2
Field of view = 2.48 sr
Acceptance = 2.23 m^2 sr
$\Delta E/E$ = 7% @ 130 GeV

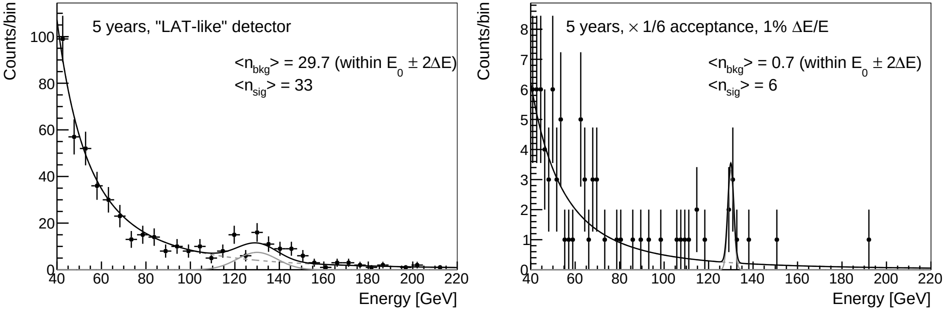


On-axis A_{eff} = 0.30 m^2 (× 1/3.0)
Field of view = 1.23 sr (× 1/2.0)
Acceptance = 0.37 m^2 sr (× 1/6.1)
$\Delta E/E$ = 1% @ 130 GeV



- Start with a "LAT-like" geometry, then make the CAL ×3 deeper:
  - Much better energy resolution;
  - On-axis effective area reduced by a factor of 3;
  - Field of view reduced by a factor of 2;
  - Acceptance reduced by a factor of 6.

Gamma-ray Space Telescope



- Much better S/N ratio, but start hitting the low-count regime.
- Pointing continuously at the GC will give you 3–5 times more exposure.
  - With obvious impact on other science targets.

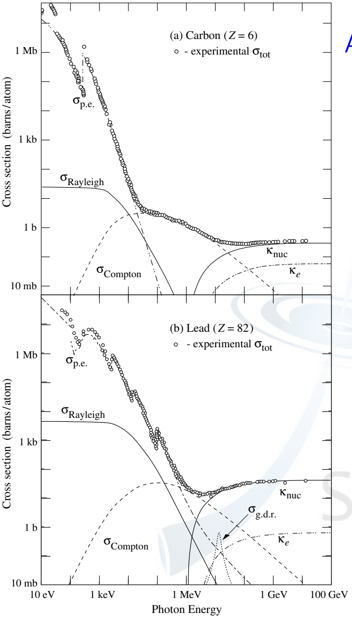
Conclusions

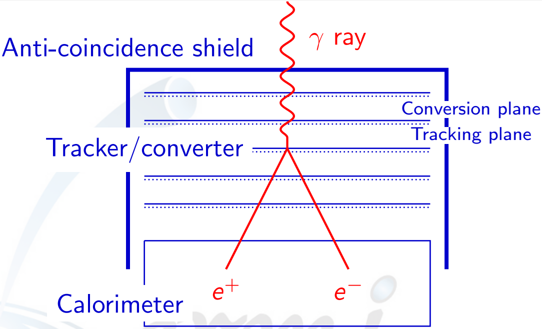
- Fermi is through an extremely successfull prime phase of the mission.
  - The observatory is operating with no sign of performance degradation.
  - The collaboration remains vital by all metrics.
  - A wide community interested in Fermi science (and data).
- The current baseline is to operate through 2016, pending the senior review next year.
  - Benefits of the extended mission well beyond the expectation from a deeper exposure.
  - Significant effort of the LAT collaboration to maximize the scientific reach of the observatory at all levels
- Fermi is one of the benchmarks for future instruments.

Fermi Gamma-ray Space Telescope

Spare slides

Detection principle





- Pair production is the dominant interaction process for photons in the LAT energy range;
- e^+e^- pair provides the information about the γ-ray direction/energy;
- e^+e^- pair provides a clear signature for background rejection (really?).

Science design drivers

- Effective area and Point Spread Function:
  - Thickness and layout of conversion layers;
  - PSF also drives the design of the sensors, the spacing of the detection planes and the overall TKR design.
- Energy range and resolution:
  - Thickness and design of the calorimeter;
- Field of view:
  - Determined by the aspect ratio of the instrument;
- Charged particle background rejection:
  - Mainly drives the ACD design;
  - Also impacts the TKR and CAL design (which are needed for the background rejection).
  - Need for a flexible triggering and event filtering system.

Mission design drivers

- Launcher type and allocated space:
  - Maximum possible lateral dimensions of the instruments (i.e. geometric area);
  - About $\sim 1.8 \times 1.8$ m^2 for Fermi (the LAT footprint is actually $\sim 1.5 \times 1.5$ m^2).
- Power budget:
  - Number of electronics readout channels in the tracker (i.e strip pitch, number of layers);
  - about 650 W overall for Fermi;
- Mass budget:
  - Essentially limits the total depth of the calorimeter (once the footprint is fixed);
  - 3000 kg for Fermi.
- Telemetry bandwidth:
  - Need onboard filtering.
- Launch and operation in space:
  - Sustain the vibrational loads during the launch;
  - Operate in vacuum, sustain thermal gradients.

Fermi Gamma-ray Space Telescope

Silicon Tracker/Converter (1/2)

Atwood et al., Astropart. Phys. **28**, 422–434 (2007)

- Primary roles:
  - Convert γ rays into electron/positron pairs;
  - Main event trigger (more on this later);
  - Direction reconstruction.
- Also important for:
  - Background rejection (SSD veto, hit counting);
  - Energy measurement at low energy (i.e., below a few hundred MeV).
- Use of Silicon Strip Detector (SSD) technology:
  - Precise tracking with $\sim$ no detector-induced deadtime;
  - Self-triggering.
- Key features:
  - ~ 73 m^2 of single-sided SSDs (400 μm thickness, 228 μm pitch);
  - 884,736 independent readout channels (~ 200 μW per channel);
  - Digital readout (plus layer OR time over threshold);
  - $\sim 10^{-6}$ noise occupancy at the nominal 1/4 of a MIP threshold (providing $\sim 100\%$ detection efficiency).

Fermi Gamma-ray Space Telescope

Silicon Tracker/Converter (2/2)

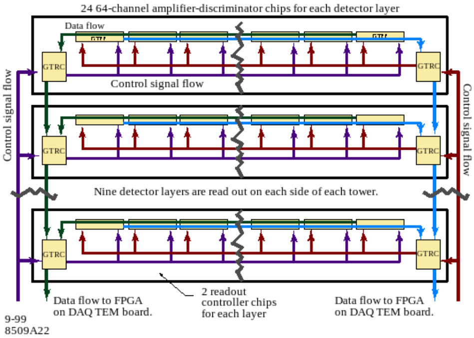
Atwood et al., Astropart. Phys. **28**, 422–434 (2007)

- Trade-offs in the design of the tracker converter:
  - Overall thickness of the converter foils: conversion efficiency vs. multiple scattering (limiting the angular resolution at low energy);
  - Number and spacing of the planes: energy dependence of the PSF;
  - strip pitch: hit resolution vs. power consumption.
- 18 paired x–y layers ($\sim$ 36 cm on a side, spaced by $\sim$ 3.5 cm) in two distinct sections:
  - Front has better PSF and lower background contamination;
  - 1.5 X_0 on axis—that's a lot for a tracker!

The Tracker Electronic System

Baldini et al., IEEE Trans. on Nucl. Sci. **53**, 466–473 (2006)

- Basic design
  - 24 front-end chips and 2 controllers handle one Si layer
  - Data can shift left/right to either of the controllers (can bypass a dead chip)
  - Zero suppression takes place in the controllers (hit strips + layer OR TOT in the data stream)
  - Two flat cables complete the redundancy



- Key features
  - Low power consumption ($\approx 200\ \mu$W/channel)
  - Low noise occupancy (≈ 1 noise hit per event in the full LAT)
  - Self-triggering (three x–y planes in a row, i.e. sixfold coincidence)
  - Redundancy, Si planes may be read out from the right or from the left controller chip
  - On board zero suppression

Electromagnetic Calorimeter (1/2)

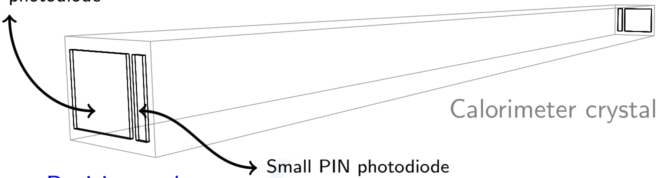
Grove and Johnson, Proc. of SPIE **7732**, 77320J-1 (2010)

- Primary roles:
  - Energy reconstruction;
  - Contribution to the event trigger (more on this later);
- Also important for:
  - Background rejection (shower shape);
  - Seeding the tracker reconstruction.
- Crystal detector elements:
  - 8 layers of 12 CsI(Tl) crystals ($27 \times 20 \times 326$ mm^3) per tower;
  - Hodoscopic stacking (alternating orthogonal layers);
  - 8.6 X_0 on-axis.
- Readout electronics:
  - Dual PIN photodiode on each crystal end;
  - Each one processes by two electronics chains ($\times 1$, $\times 8$);
  - Four readout ranges, dynamic range 2 MeV–70 GeV per crystal.

Fermi Gamma-ray Space Telescope

Electromagnetic Calorimeter (2/2)

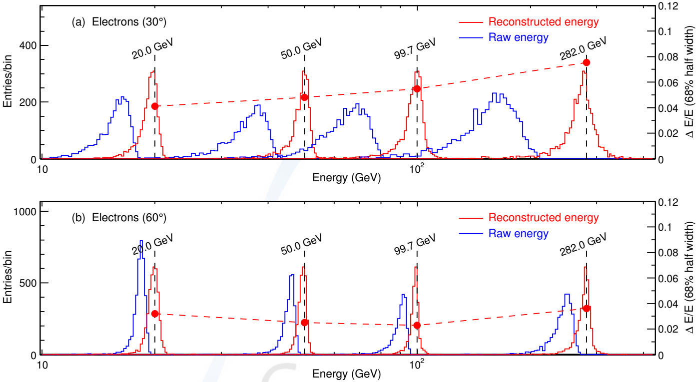
Grove and Johnson, Proc. of SPIE **7732**, 77320J-1 (2010)



- CAL xtals with readout at each end:
  - Measure longitudinal position of the energy deposition from light asymmetry;
  - Provide a full 3-dimensional image of the EM shower;
- CAL imaging capabilities are crucial for both background rejection and energy reconstruction at high energy:
  - Remember, the LAT is $\sim 10\ X_0$ on axis, so there is a significant shower leakage out the back of the CAL.

Energy resolution at high energy

Ackermann et al., PRD **82**, 92004 (2010)



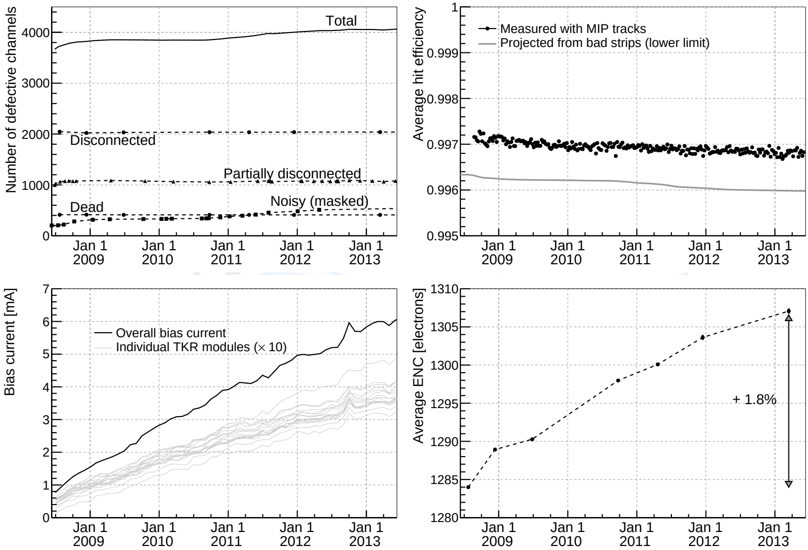
- Shower leakage becomes the main limiting factor above ~ 10 GeV.
  - The LAT is $1.5 + 8.6 = 10.1\ X_0$ thick on axis—but the acceptance in the FoV peaks at around $\sim 40^\circ$.
- Energy reconstruction through a 3D fit of the shower profile:
  - $< 10\%$ energy resolution at ~ 300 GeV demonstrated at beam tests;
  - Simulations indicate a decent energy resolution up to at least 1 TeV.

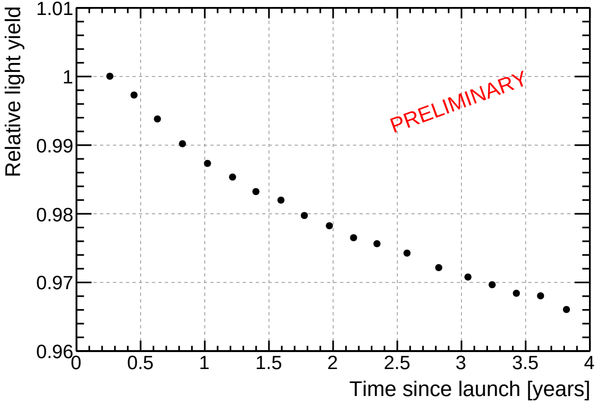
The Anticoincidence Detector

Moiseev et al., Astropart. Phys. **27**, 339–358 (2007)

- Primary roles:
  - Event triggering and onboard filter (more on this later);
  - Background rejection.
- Also important for:
  - Identifying heavy ions for CAL calibration purposes.
- One important lesson learned from the previous mission:
  - Backsplash from the CAL in high-energy event can hit the ACD;
  - Can cause *self-veto*, especially for monolithic shields.
- The LAT ACD is segmented:
  - 89 tiles (overlapping in one dimension) plus 8 *ribbons* (covering the gaps in the other);
  - Can extrapolate tracks to specific tiles;
  - This also makes complete hermeticity more difficult to achieve.

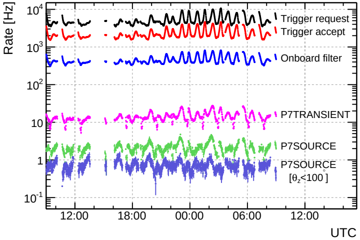
Detector performance stability: TKR




Relative light yield
1.01
1
0.99
0.98
0.97
0.96
0
0.5
1
1.5
2
2.5
3
3.5
4
Time since launch [years]
PRELIMINARY

Trigger and On-Board Filter

Ackerman et al., ApJS **203**, 4 (2012) or arXiv:1303.3514

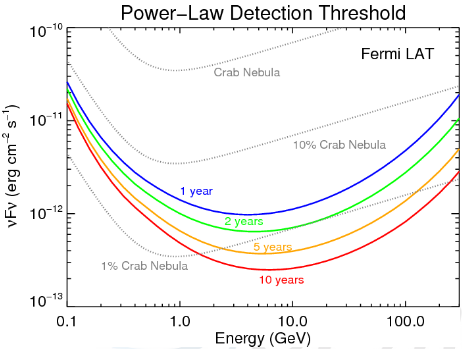


- All subsystems contribute to the L1 hardware trigger ($\sim$ 2.2 kHz):
  - `TKR`: three consecutive TKR x-y planes hit in a row;
  - `CAL_LO`: single CAL log with more than 100 MeV (adjustable);
  - `CAL_HI`: single CAL log with more than 1 GeV (adjustable);
  - `ROI`: MIP signal in the ACD tiles close to the triggering TKR tower;
  - `CNO`: signal in one of the ACD tiles compatible with a heavy.
- Adjustable hardware prescales to limit the deadtime fraction.
- Programmable on-board filter to fit the data volume into the allocated bandwidth ($\sim$ 1.5 Mb/s average).
  - Most of the $\sim$ 400 Hz of events passing the gamma filter and downlinked to ground are actually charged-particle background.

Power law source detection threshold

—Low energy

Bkg. dominated
$\propto \sqrt{t}$

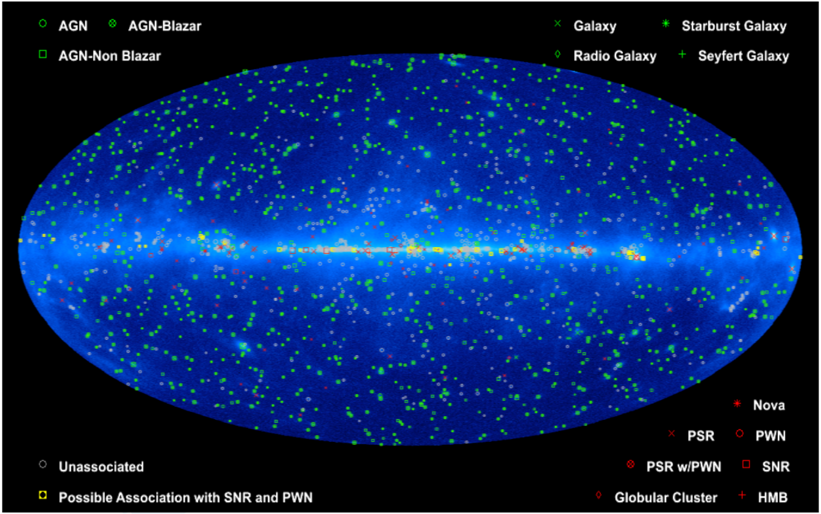


—High energy

Photon counting
$\propto t$

- Envelope of the minimum detectable power-law spectra over the full band, varying the spectral index (not a *differential sensitivity plot*).
  - Accounts for uncertainties in the background and source density
- High-energy limiting sensitivity comes from photon counting statistics (rather than the background)
  - Fermi sensitivity increasing linearly with time;
  - Note: a better background rejection or PSF won't help much.
  - (And more: complementarity with ground-based telescopes).

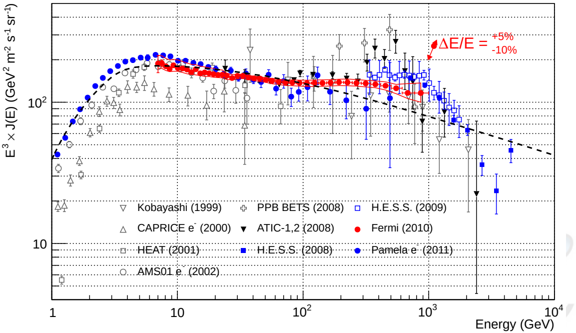
The Second Fermi Catalog (2FGL)
Nolan, P. L. et al. 2012, ApJS, 199, 31



- Dataset: 24 months of data (100 MeV–100 GeV), 35.7 M events.
- 1873 sources (the deepest catalog ever in this energy range).

Cosmic-Ray Electron Spectrum

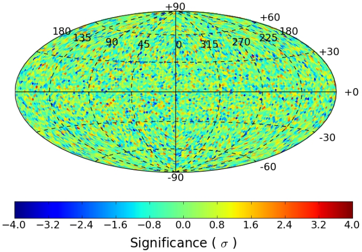
Ackermann, M. et al. 2010 Phys. Rev. D 82, 092004

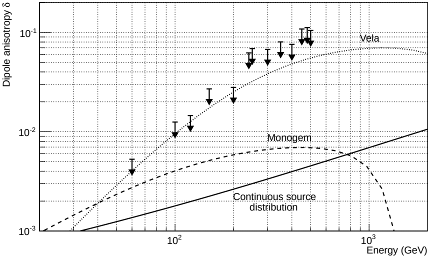


- First systematic-limited measurement of the CRE spectrum between 7 GeV and 1 TeV.
- Significant work put toward improving the energy reconstruction at very high energy (a few TeV is the goal).
  - Calorimeter crystal saturation currently limiting the energy reach.
  - See http://arxiv.org/abs/1210.2558 for the state of the art.
- Confirming the cutoff measured by H.E.S.S. would clearly be of great interest.

CRE anisotropies

Ackermann et al., Phys. Rev. D 82, 092003 (2010)

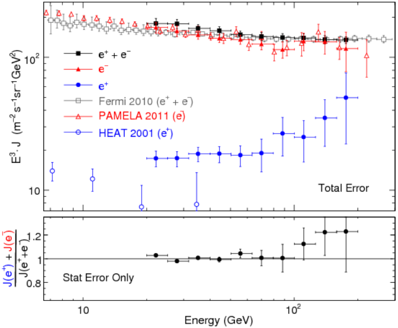


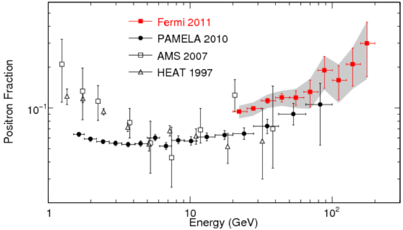


- Fermi offers a unique opportunity for the measurement of possible CRE anisotropies
  - Key factors: large exposure factor and large field of view
- Most stringent upper limits to date based on one year of data
  - More than 1.6 M CRE candidate above 60 GeV
- Limits are comparable to the level of anisotropy expected in realistic models
  - Can potentially expect to detect a signal in 8–10 years
- Again: need a (even) larger exposure if you want to do better!

Separate CR Electron and Positron Spectra

M. Ackermann et al. 2012, PRL 108, 011103



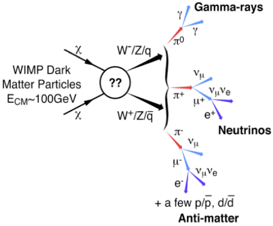


- First measurement of separate electron and positron spectra in this energy range.
  - Limited by statistics at high-energy, as we need special data-taking runs *looking down* for this analysis).
- Positron fraction increasing with energy (consistent with Pamela).
- This is now officially AMS' playground.

Gamma-ray production from Dark Matter

"Particle physics factor"
(from theory)

$$\frac{d\Phi}{dE_\gamma}(E_\gamma, \phi, \theta)^{\,1} = \frac{1}{4\pi}\frac{\langle \sigma_{\rm ann} v\rangle}{2m^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f \times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{\text{line of sight}} \rho^2\left(l(\phi')\right) dl(\phi')$$



Dark Matter distribution
(from measurements and simulations)

- Expected flux
  - (Particle Physics) Model dependent
  - DM distribution subject to large uncertainties
  - Astrophysical "backgrounds"
- Measured flux (from the detector)
  - Instrument related systematics

[1] For Dark Matter decay (rather than annihilation): $\langle \sigma_{\rm ann} v\rangle / 2m^2 \rightarrow 1/\tau m$, $\rho^2 \rightarrow \rho$