
The FERMI view of the sky
Aldo Morselli
INFN Roma Tor Vergata
20 July 2011
ROMA


Fermi
Gamma-ray Space Telescope
Happy 3rd Birthday Fermi !!
11 June 2008

Fermi is Making a Major Impact

Science, December 2009

THE RUNNERS-UP >>

Opening Up the Gamma Ray Sky

LIKE A LIGHTHOUSE BLINKING IN THE NIGHT, A pulsar appears to flash periodically as it spins in space, sweeping a double cone of electromagnetic radiation across the sky. Since the discovery of the first pulsar 4 decades ago, astronomers have detected hundreds more of these enigmatic objects from the pulsing radio waves they emit. Now, astronomers have opened a new channel of discovery—the highly energetic gamma ray spectrum—to find pulsars that radio observations could not detect. The advance, part of a torrent of recent gamma ray observations, is giving researchers an improved understanding of how pulsars work, along with a rich haul of new pulsars that could help in the quest to detect gravitational waves.

The findings come from the Fermi Gamma-ray Space Telescope, which has been mapping the gamma ray universe since it was launched by NASA in June 2008. Combing through data the telescope collected in its first few months, an international team discovered 16 new pulsars; strong gamma ray pulsations from eight previously known pulsars with spin times of milliseconds, proving that these objects pulse brightly at gamma wavelengths as well as in the radio range; and high-energy gamma rays from the globular cluster 47 Tucanae indicating that the cluster harbors up to 60 millisecond pulsars.

Those Fermi results might be just the beginning. Armed with their new knowledge of pulsar behavior, researchers are checking whether some of the unidentified gamma ray sources Fermi has detected might be pulsars. In November alone, teams of astronomers in the United States and France discovered five new millisecond pulsars by training ground-based radio telescopes on candidate objects Fermi had pointed out—a much more targeted search technique than scanning the sky blindly with ground-based radio telescopes.

Gamma ray beams of pulsars are believed to be wider than their radio beams, so in principle a space-based gamma ray telescope should be more likely to encounter and discern a pulsar's sweep than a radio telescope on Earth is. However, Fermi's forerunner—the Compton Gamma Ray Observatory, which flew from 1991 to 2000—did not have much luck finding these objects. What has made the difference is Fermi's high sensitivity, which enables it to detect pulsations that would have been too faint for Compton.

Already, the discoveries are shedding new light on the physics of pulsars. Researchers

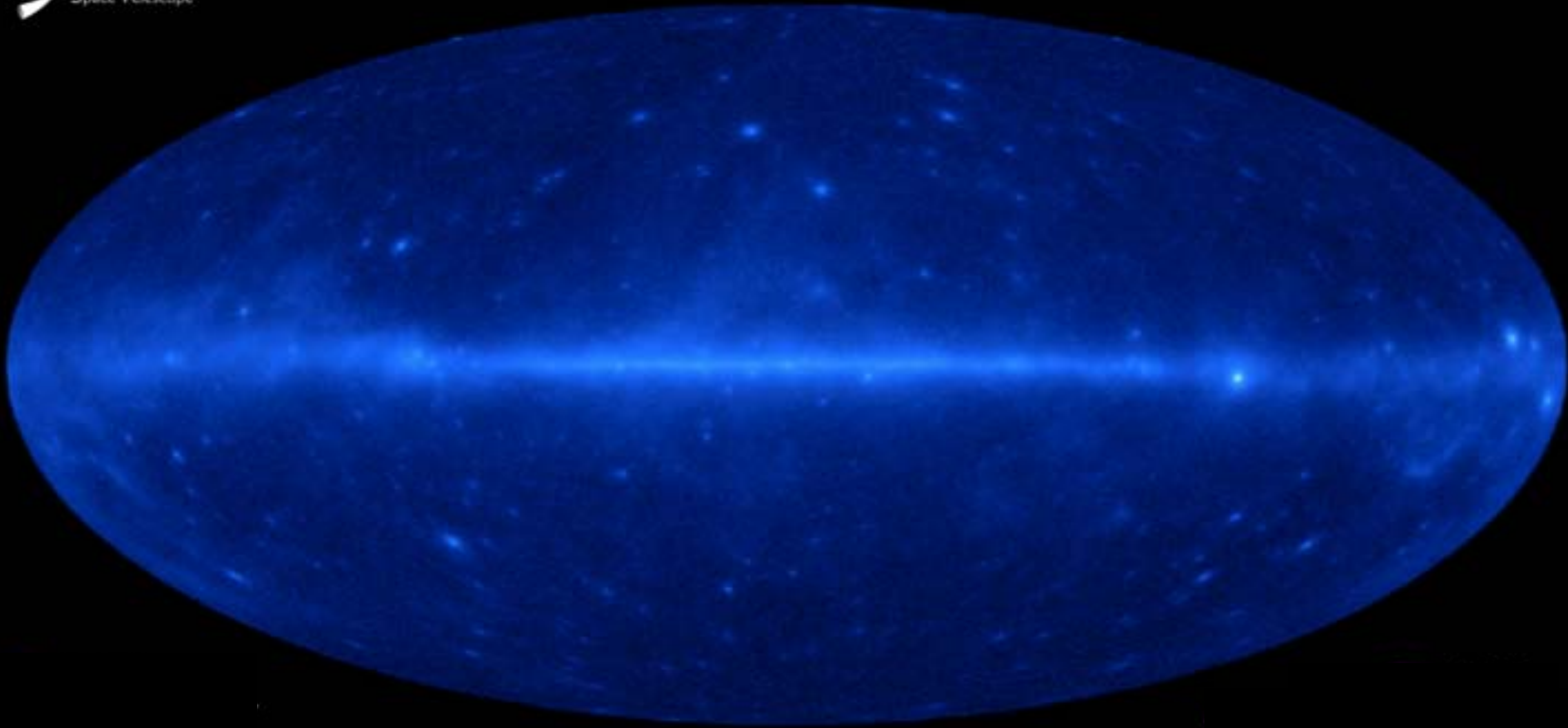
Breakthrough of the Year was the reconstruction of the 4.4-million-year-old ***Ardipithecus ramidus*** skeleton

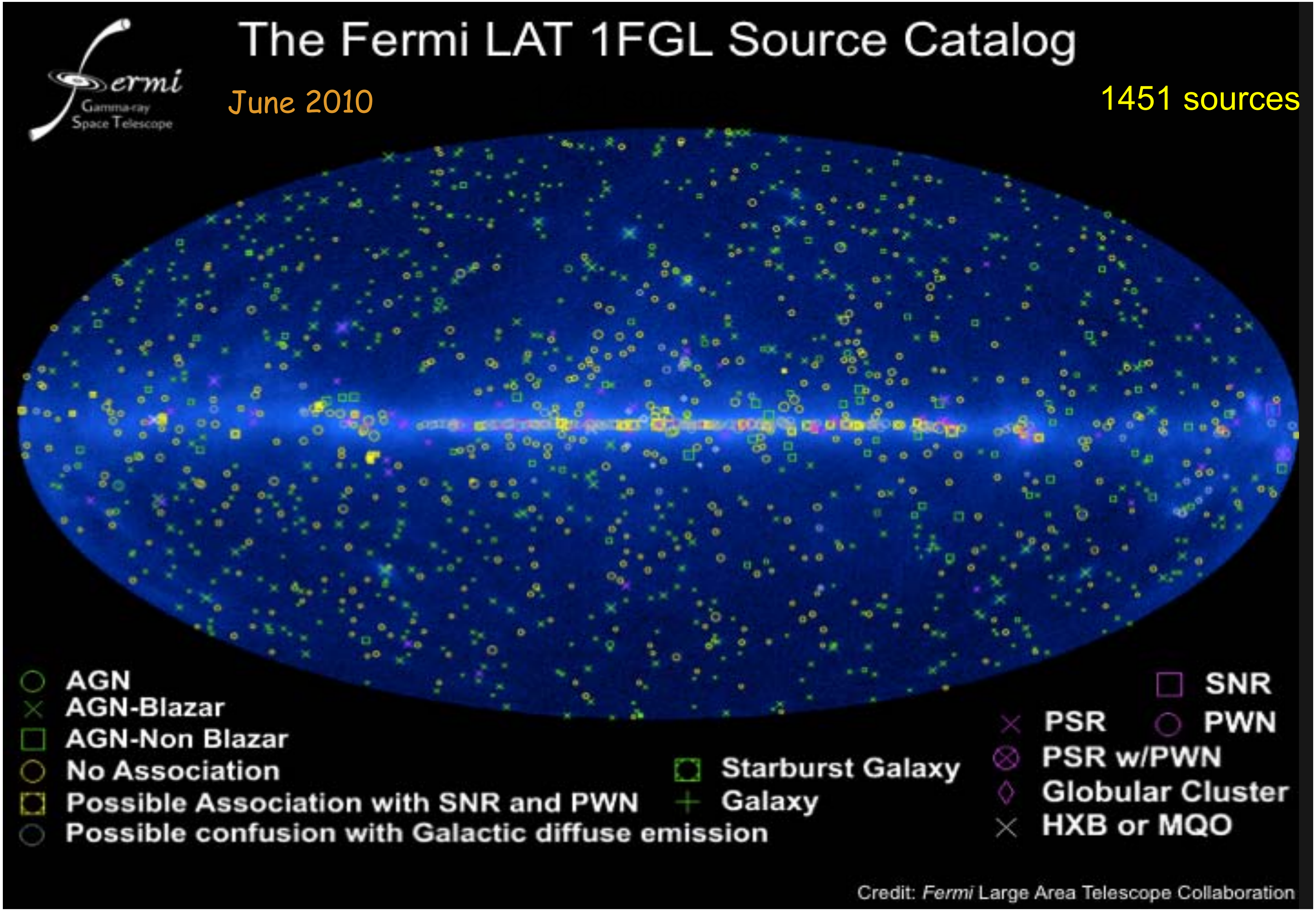
2011 Rossi Prize

- The 2011 Rossi Prize is awarded to the Fermi Gamma Ray Space Telescope Large Area Telescope team for enabling, through the development of the Large Area Telescope, new insights into neutron stars, supernova remnants, cosmic rays, binary systems, active galactic nuclei, and gamma-ray bursts.

The Fermi LAT 1FGL Source Catalog

1451 sources




The Fermi LAT 1FGL Source Catalog
Fermi
Gamma-ray
Space Telescope
June 2010
1451 sources
AGN
AGN-Blazar
AGN-Non Blazar
No Association
Possible Association with SNR and PWN
Possible confusion with Galactic diffuse emission
Starburst Galaxy
Galaxy
SNR
PSR
PWN
PSR w/PWN
Globular Cluster
HXB or MQO
Credit: Fermi Large Area Telescope Collaboration

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12 July 2011 Last updated at 09:22 GMT

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Fermi catalogue update shows 'violent Universe' changes

By Jason Palmer
Science and technology reporter, BBC News

The catalogue that lists the most violent neighbourhoods in the Universe has been updated.

The Fermi space telescope captures gamma rays - the highest-energy light in nature, which hints at the cosmos' most extreme conditions and processes.

The second Fermi catalogue represents a full two years of data, improving on the first edition's 11 months.

It lists 1,873 gamma-ray sources; some 589 remain unidentified and could represent entirely new cosmic objects.

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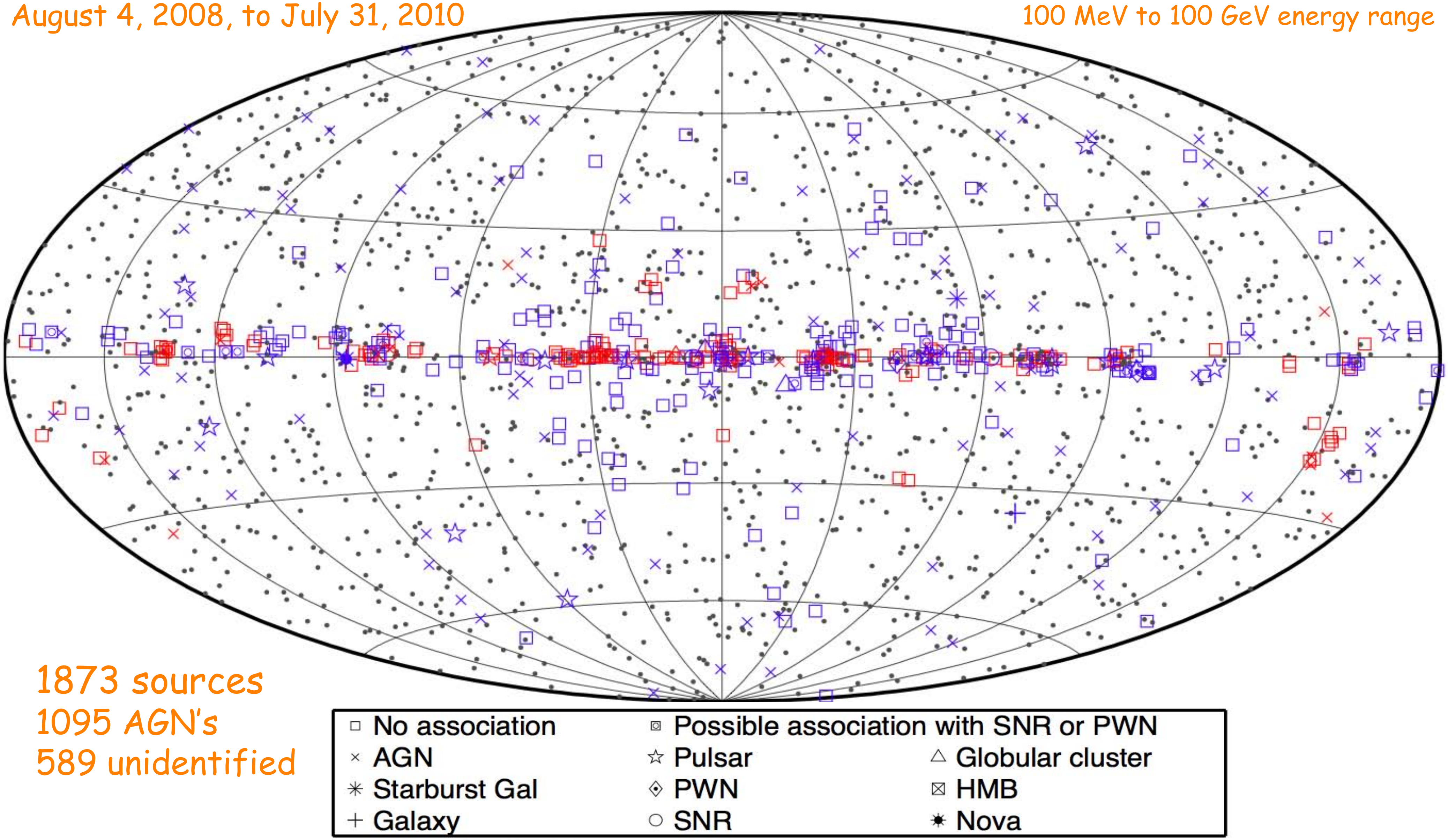
The Fermi LAT 2FGL Source Catalog

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



1873 sources
1095 AGN's
589 unidentified

- **Some highlights from the first ~3 years in orbit:**
  - **γ-ray only pulsars**
  - **population of γ-ray millisecond pulsars; implications for gravitational wave searches**
  - **high-energy GRBs; new window to look for violations of Lorentz invariance**
  - **Large population of active galaxies detected: emission by supermassive black holes**
  - **new source populations: novae, globular clusters, starburst galaxies**
  - **γ-ray flares from Crab nebula**
  - **limits on dark matter and interesting data from the galactic center**
  - **Precision measurement of electron-positron spectrum of cosmic rays**

- **Some highlights from the first ~3 years in orbit:**

~170 billion LAT event triggers

- GBM Triggers: 1194 (654 GRB, 141 TGF, 174 SGR, 56 solar flare)
- # Autonomous Repoint Requests (ARR):58
- Highest-z LAT GRB: 4.35
- Highest-energy photon from a GRB: 33 GeV (at 82s, z=1.82)
- Highest-z LAT AGN:3.1
- # Gamma-ray pulsars: 88
- # Millisecond Pulsars (MSPs): 27
- # Gamma-ray-only (blind) pulsars: 26
- # new radio MSPs due to LAT data: 31
- Public data access: >8TB

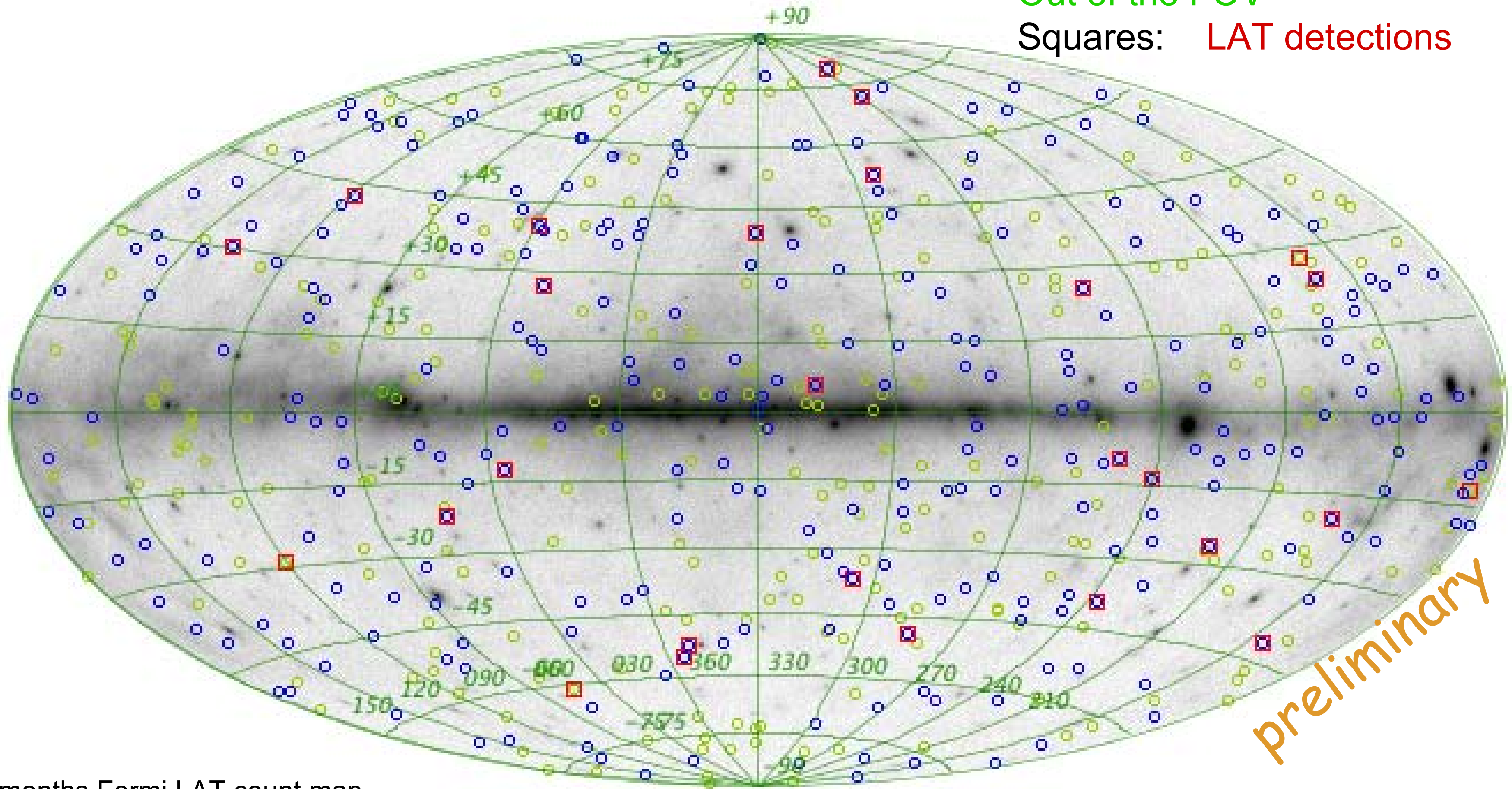
- **Towards the Second Fermi LAT Catalog 2FGL:**

Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/ Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

GRB's Fermi detections as of 2011-01-20

~550 GBM GRB (since Aug 2008)
27 LAT GRB (7 LAT LLE-only GRB)

Circles: In Field-of-view of LAT (<70˚): 275
Out of the FOV
Squares: LAT detections



11 months Fermi LAT count map

High Energy Activity from the Crab

AGILE detection of enhanced gamma-ray emission from the Crab Nebula region

ATel #2855; M. Tavani (INAF/IASF Roma), E. Striani (Univ. Tor Vergata), A. Bulgarelli (INAF/IASF Bologna), F. Gianotti, M. Trifoglio (INAF/IASF Bologna), C. Pittori, F. Verrecchia (ASDC), A. Argan, A. Trois, G. De Paris, V. Vittorini, F. D'Ammando, S. Sabatini, G. Piano, E. Costa, I. Donnarumma, M. Feroci, L. Pacciani, E. Del Monte, F. Lazzarotto, P. Soffitta, Y. Evangelista, I. Lapshov (INAF-IASF-Rm), A. Chen, A. Giuliani(INAF-IASF-Milano), M. Marisaldi, G. Di Cocco, C. Labanti, F. Fuschino,M. Galli (INAF/IASF Bologna), P. Caraveo, S. Mereghetti, F. Perotti (INAF/IASF Milano), G. Pucella, M. Rapisarda (ENEA-Roma), S. Vercellone (IASF-Pa), A. Pellizzoni, M. Pilia (INAF/OA-Cagliari), G. Barbiellini, F. Longo (INFN Trieste), P. Picozza, A. Morselli (INFN and Univ. Tor Vergata), M. Prest (Universita` dell'Insubria), P. Lipari, D. Zanello (INFN Roma-1), P.W. Cattaneo, A. Rappoldi (INFN Pavia), P. Giommi, P. Santolamazza, F. Lucarelli, S. Colafrancesco (ASDC), L. Salotti (ASI)
on ***22 Sep 2010; 14:45 UT***
Distributed as an Instant Email Notice (Transients)
Password Certification: Marco Tavani (tavani@iasf-roma.inaf.it)

Subjects: Pulsars
Referred to by ATel #: 2856, 2858, 2861, 2866, 2867, 2868, 2872

AGILE is detecting an increased gamma-ray flux from a source positionally consistent with the Crab Nebula.

Integrating during the period 2010-09-19 00:10 UT to 2010-09-21 00:10 UT the AGILE-GRID detected enhanced gamma-ray emission above 100 MeV from a source at Galactic coordinates (l,b) = (184.6, -6.0) +/- 0.4 (stat.) +/- 0.1 (syst.) deg, and flux F > 500 e-8 ph/cm2/sec above 100 MeV, corresponding to an excess with significance above 4.4 sigma with respect to the average flux from the Crab nebula (F = (220 +/- 15)e-8 ph/cm^2/sec, Pittori et al., 2009, A&A, 506, 1563).

We strongly encourage multifrequency observations of the Crab Nebula region.

No corresponding flare in X-rays with INTEGRAL (Atel # 2856), Swift (Atel # 2858, 2866), or RXTE (Atel # 2872) or NIR (Atel #2867). No evidence for active AGN near Crab (Swift, Atel # 2868).

Fermi LAT confirmation of enhanced gamma-ray emission from the Crab Nebula region

ATel #2861; R. Buehler (SLAC/KIPAC), F. D'Ammando (INAF-IASF Palermo), E. Hays (NASA/GSFC) on behalf of the Fermi Large Area Telescope Collaboration
on ***23 Sep 2010; 17:34 UT***
Distributed as an Instant Email Notice (Transients)
Password Certification: Rolf Buehler (buehler@slac.stanford.edu)

Subjects: >GeV, Pulsars
Referred to by ATel #: 2866, 2867, 2868, 2872

Following the detection by AGILE of increasing gamma-ray activity from a source positionally consistent with the Crab Nebula occurred from September 19 to 21 (ATel #2855), we report on the analysis of the >100 MeV emission from this region with the Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope.

Preliminary LAT analysis indicates that the gamma-ray emission (E >100 MeV) observed during this time period at the location of the Crab Nebula is (606 +/- 43) x10^-8 ph/cm2/sec, corresponding to an excess with significance >9 sigma with respect to the average flux from the Crab nebula of (286 +/- 2) x10^-8 ph/cm2/sec, estimated over all the Fermi operation period (only statistical errors are given). Ongoing Fermi observations indicate that the flare is continuing.

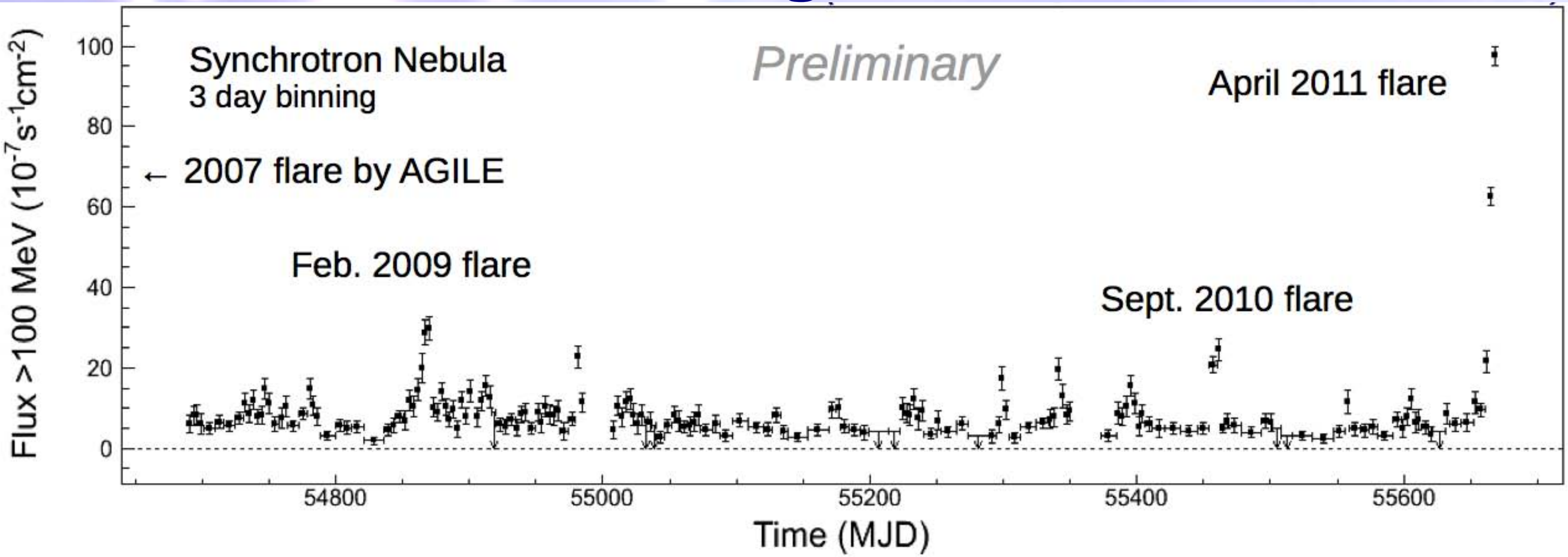
The flaring component has a spectral index of 2.49 +/- 0.14. Its position, Ra: 83.59 Dec: 22.05 with a 68% error radius of 0.06 deg, is coincident with the Crab Nebula.

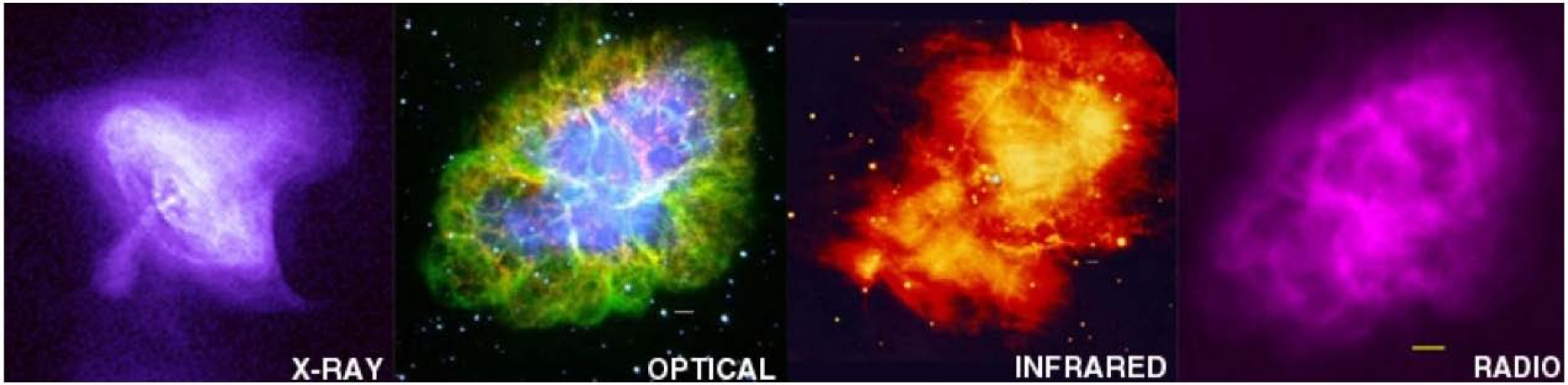
Fermi will interrupt its all-sky scanning mode between 2010-09-23 15:49:00 UT and 2010-09-30 15:49:00 UT to observe the Crab Nebula. Afterwards regular gamma-ray monitoring of this source will continue. We strongly encourage further multifrequency observations of that region.

For this source the Fermi LAT contact person is Rolf Buehler (buehler@stanford.edu).

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

Flaring CRAB

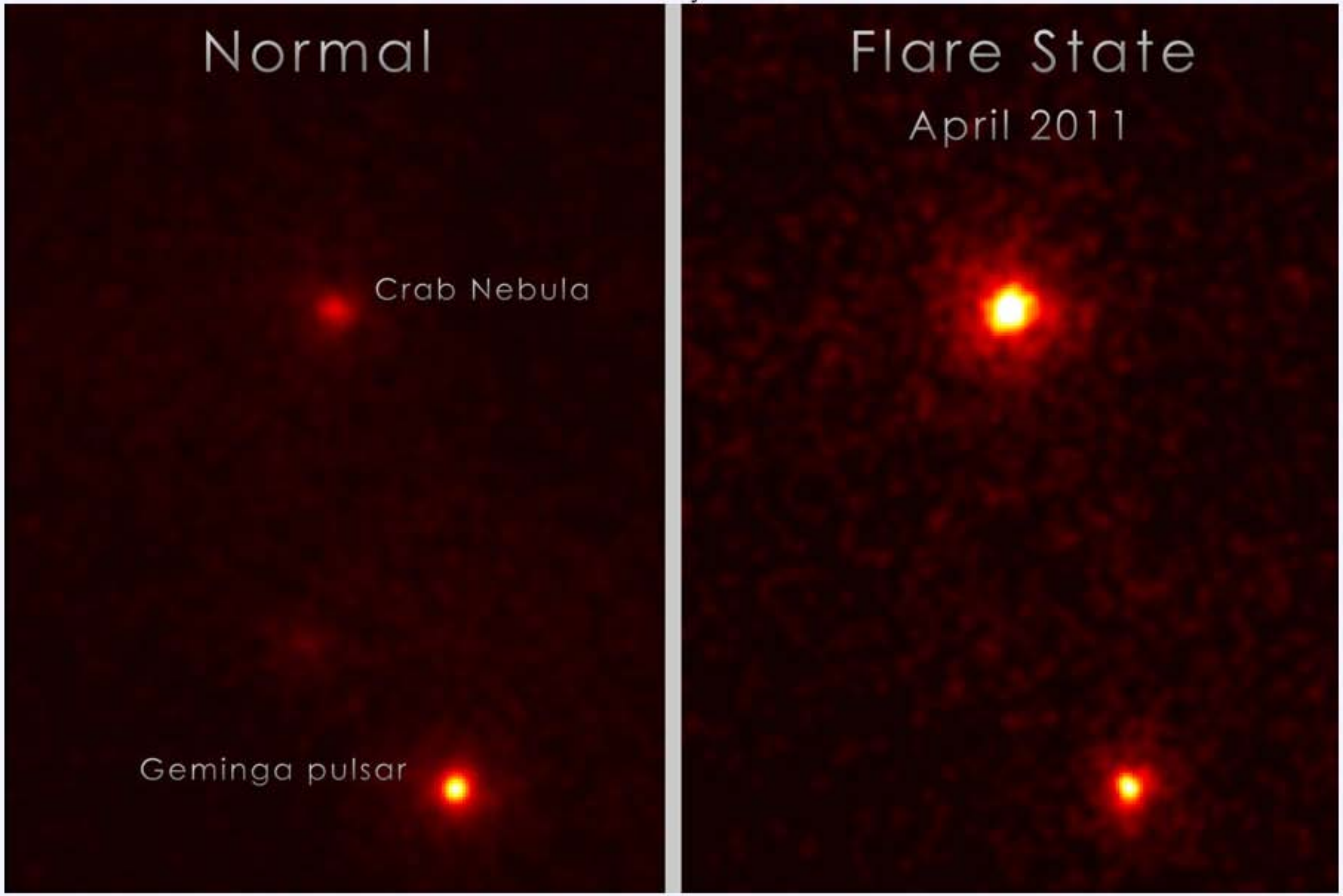




Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

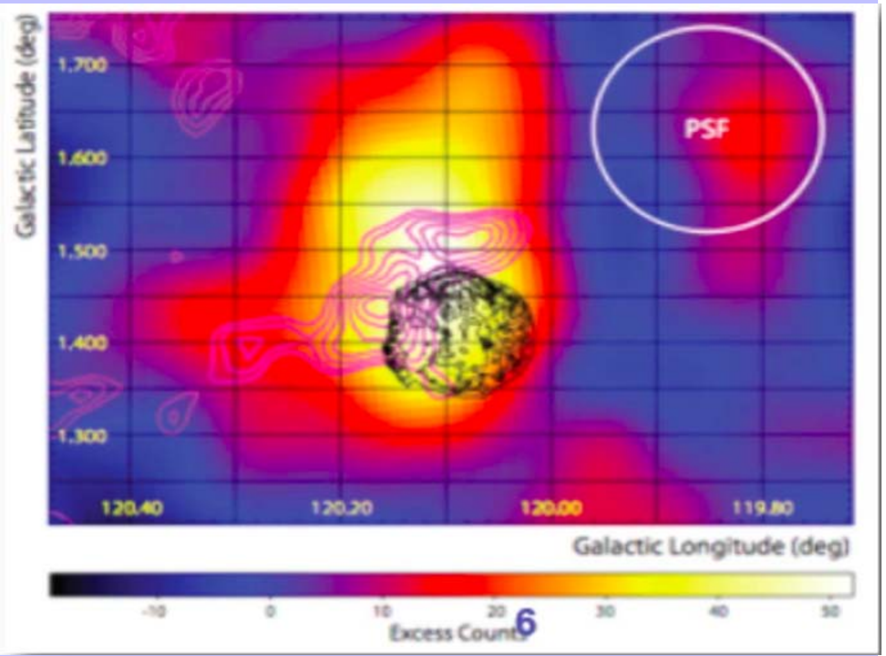
2011 May 23



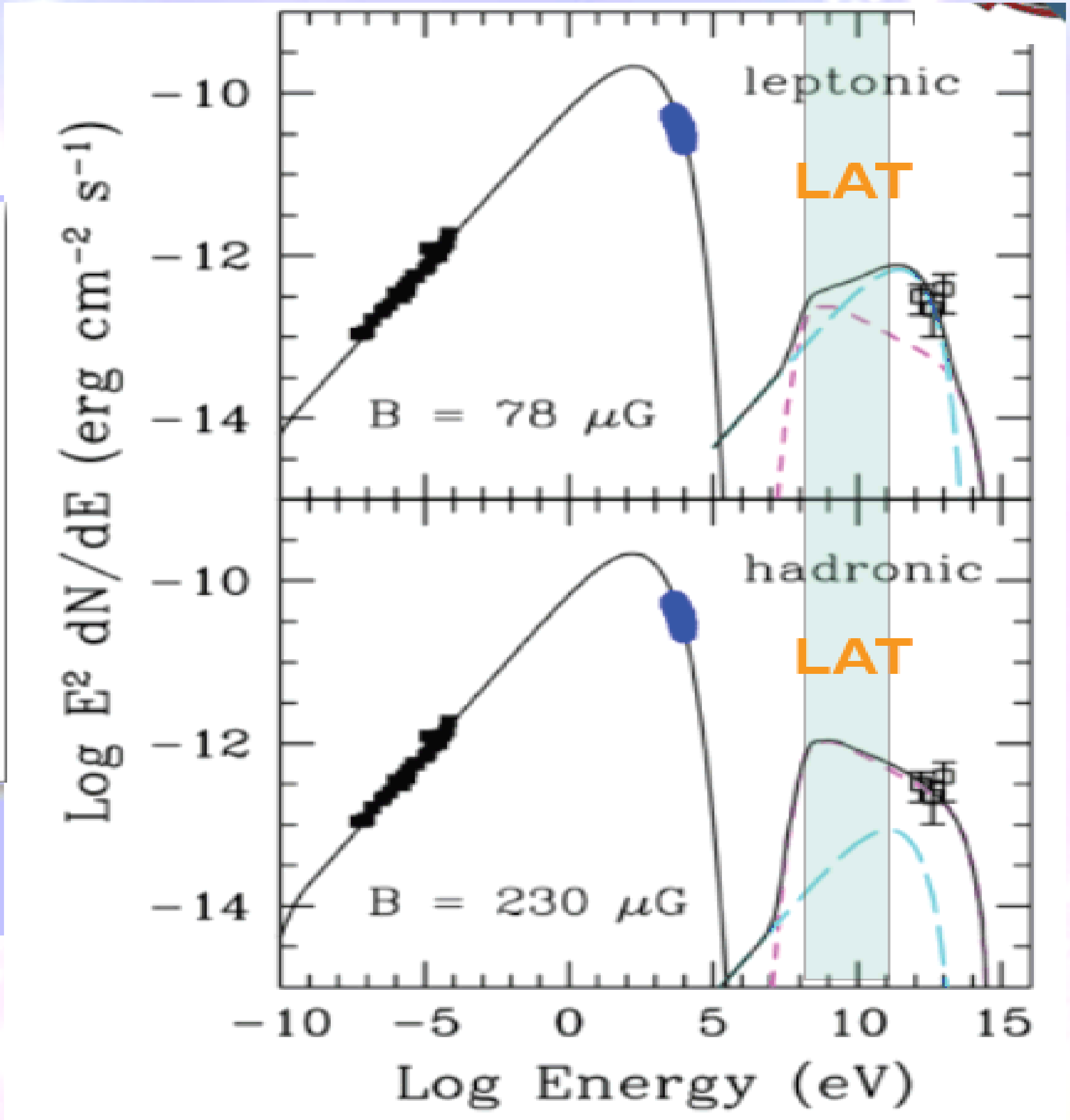
An Unexpected Flare from the Crab Nebula
Credit: NASA, DOE, Fermi LAT, R. Buehler (SLAC, KIPAC)

Origin of Cosmic Rays SNR. Example: TYCHO

Acciari et al 2011

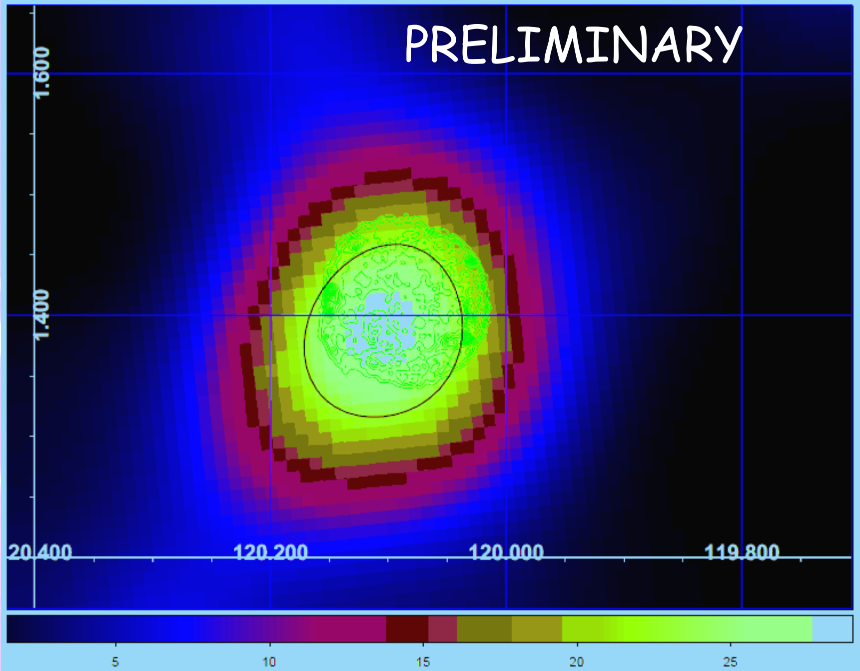


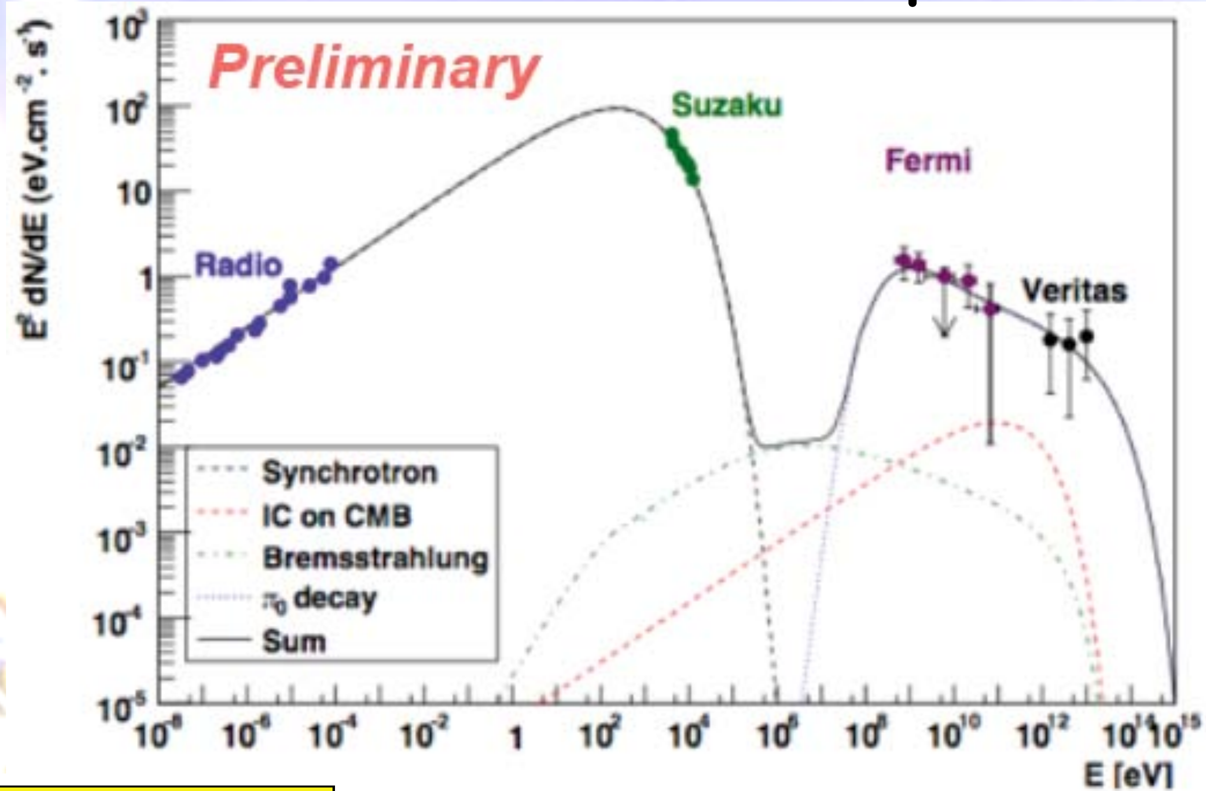
Flux(>1 TeV) ~ 1% Crab
5.0σ detection (post-trial)



Tycho with the Fermi-LAT: Hadronic or Leptonic?

Giordano et al. in prep.





Se=2.2-2.3
Eb=6-7TeV
B~200uG

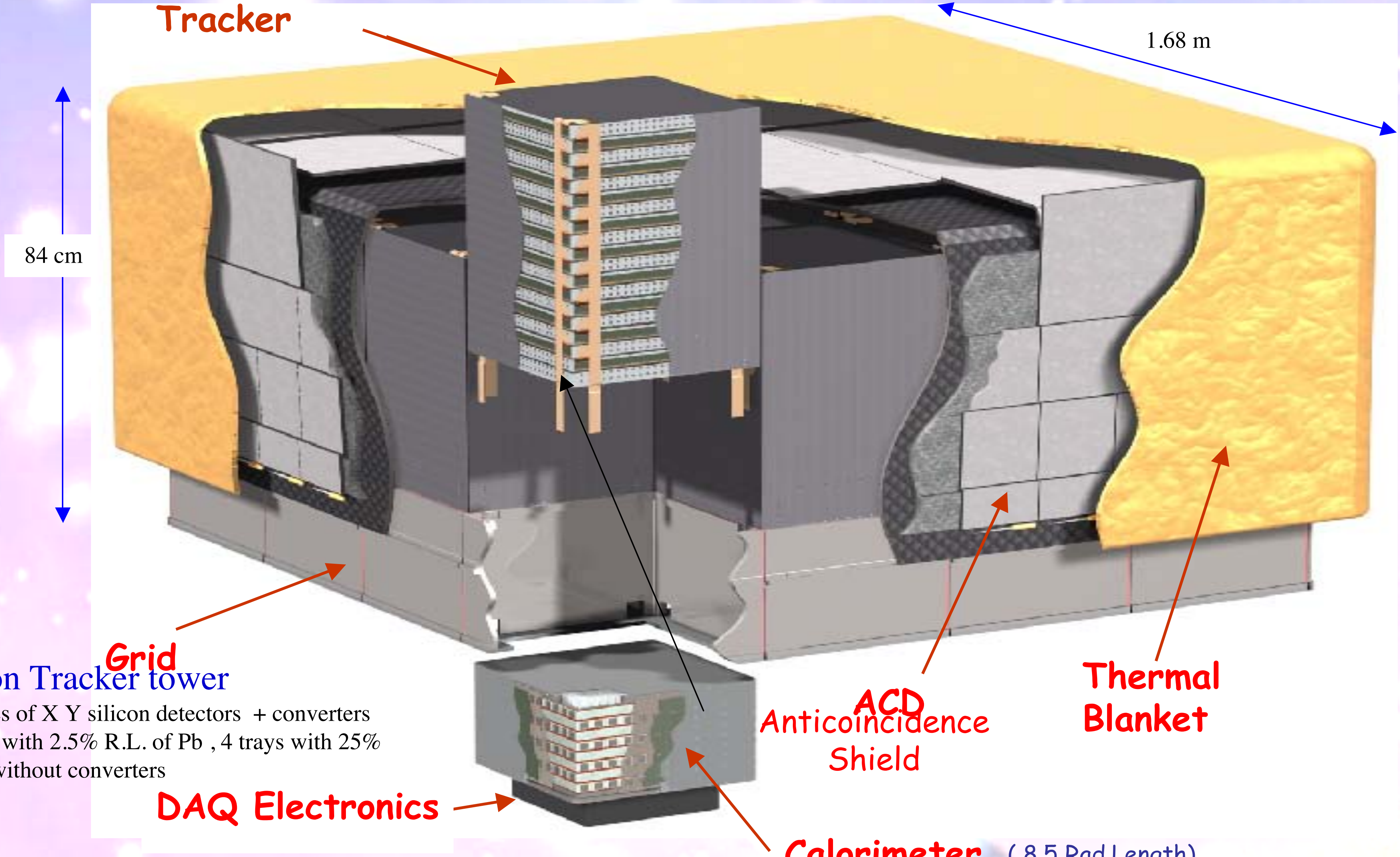
~6-8% of E_{SN} transferred to CRs.

Case	D_{kpc}	n_H [cm^{-3}]	E_{SN} [10^{51}erg]	$E_{p,tot}$ [10^{51}erg]	K_{ep}
Far	3.50	0.24	2.0	0.150	4.5×10^{-4}
Nearby	2.78	0.30	1.0	0.061	7.0×10^{-4}

Leptonic not-favoured for:

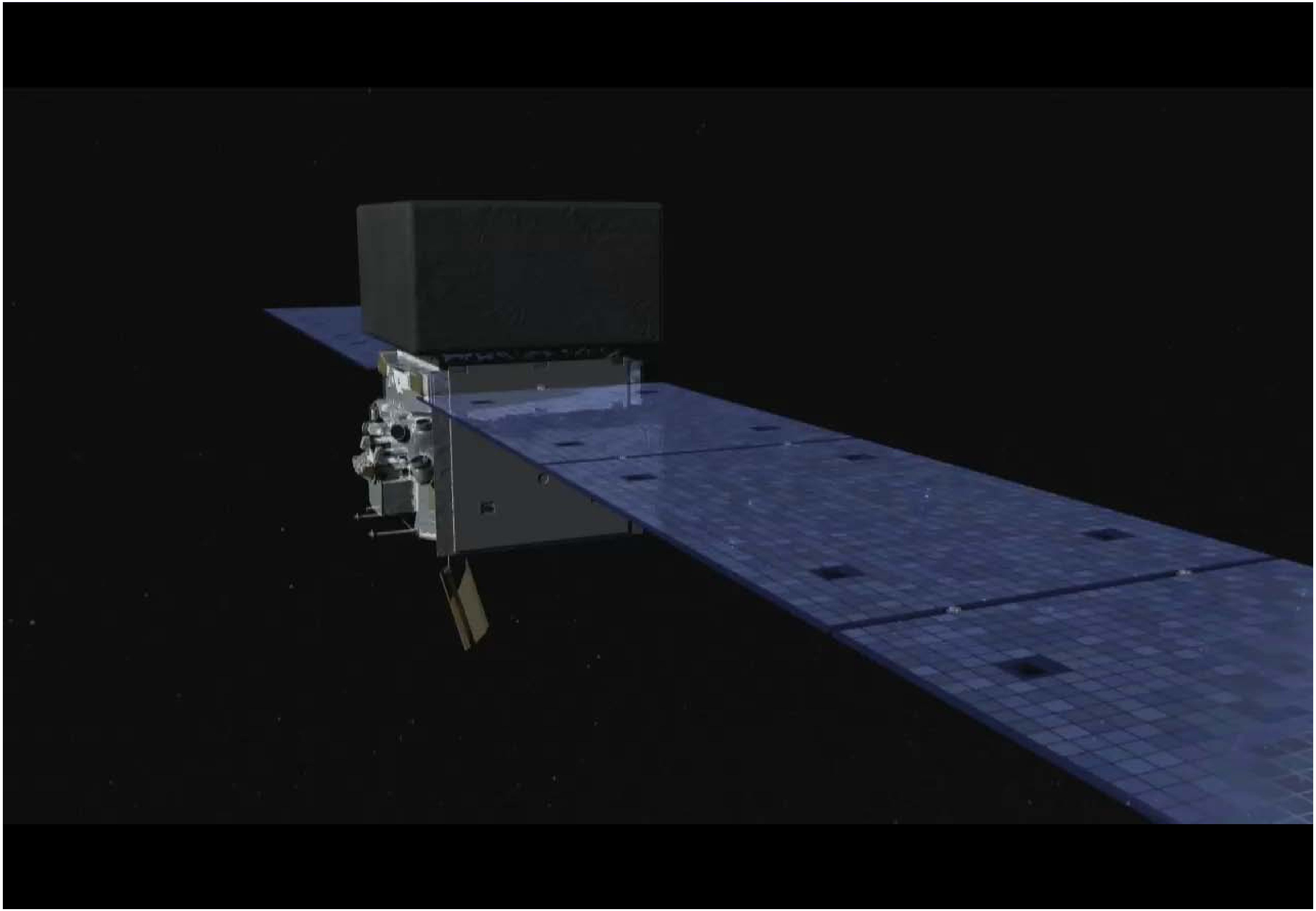
- IC does not fit the data
- Bremss
  - N_e fixed by IC
  - n_H ↑ up to $10cm^{-3}$
  - B ↓ down to 65uG
- Kep~0.1

Fermi Gamma-Ray Large Area Space Telescope



Silicon Tracker tower

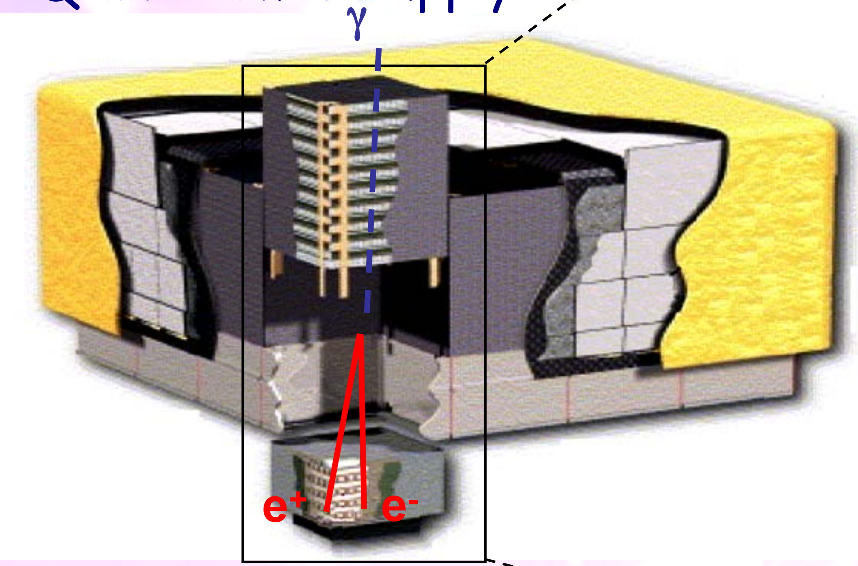
18 planes of X Y silicon detectors + converters
12 trays with 2.5% R.L. of Pb , 4 trays with 25%
2 trays without converters



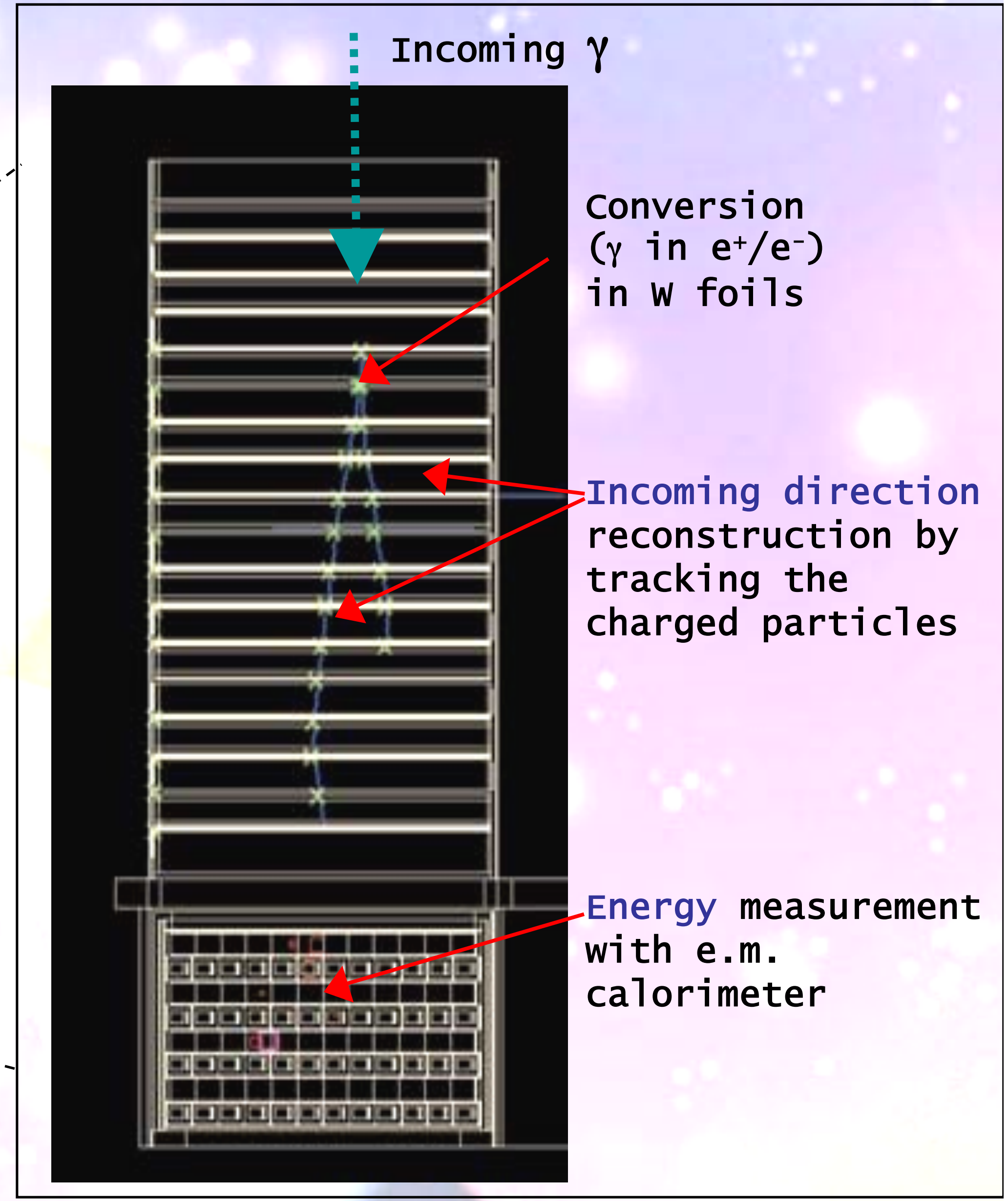
How Fermi LAT detects gamma rays

4 x 4 array of identical towers with:

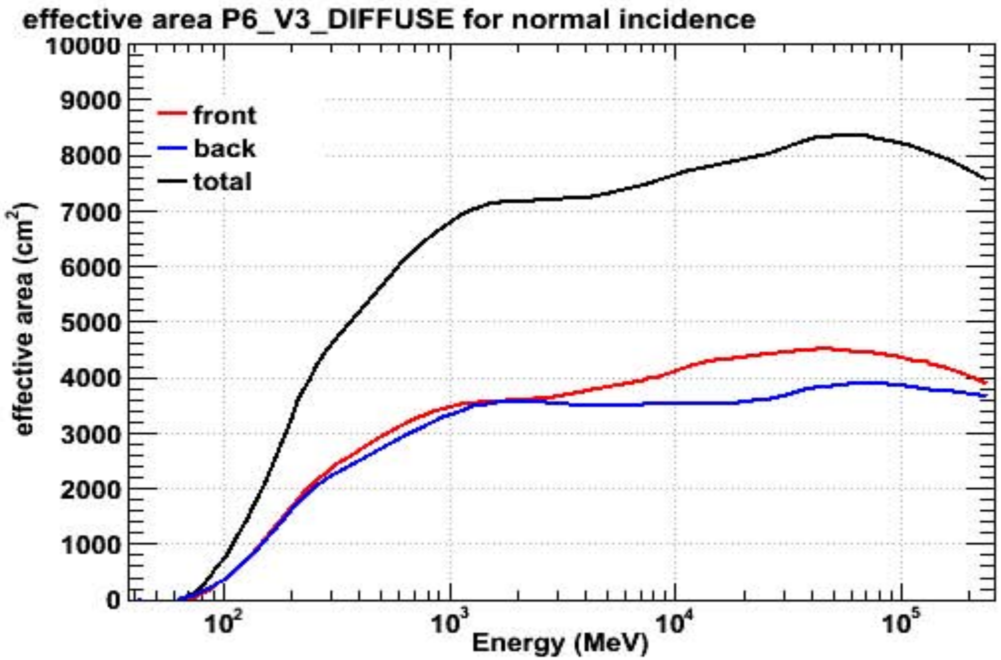
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box

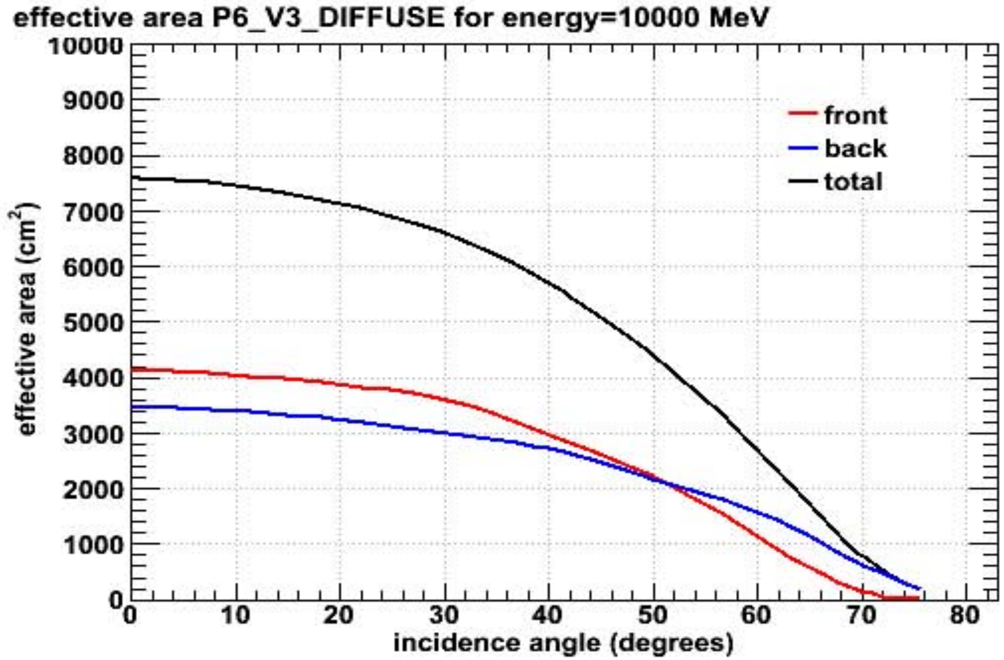


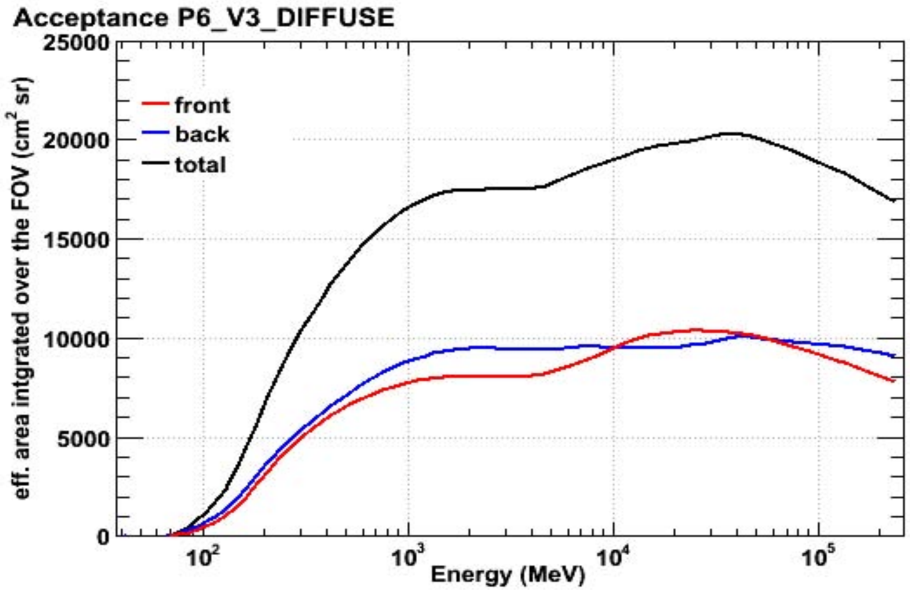
An anticoincidence detector around the telescope distinguishes gamma-rays from charged particles



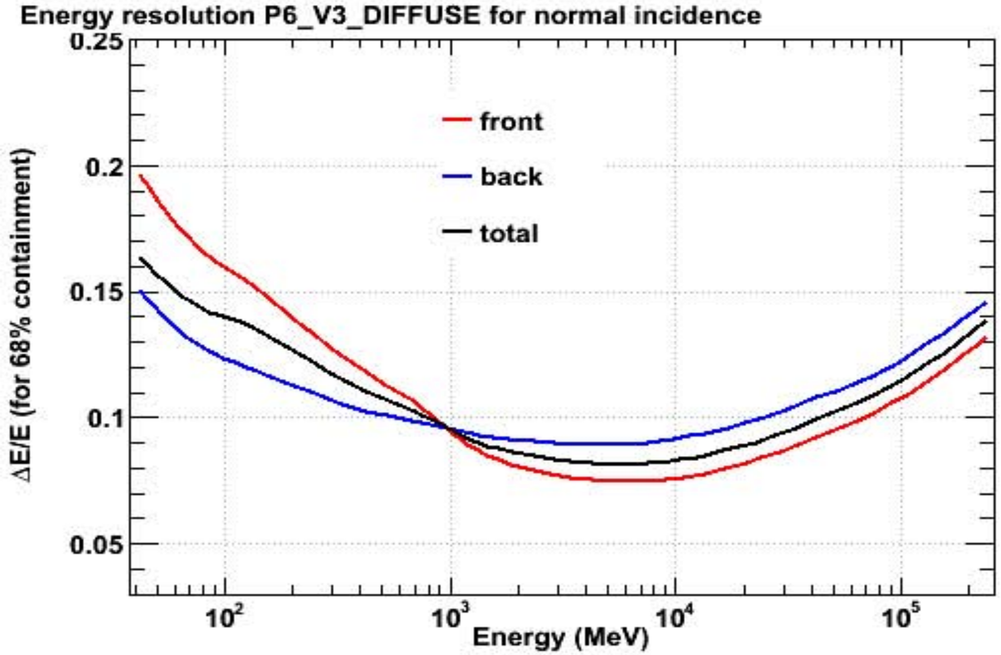
Fermi IRF

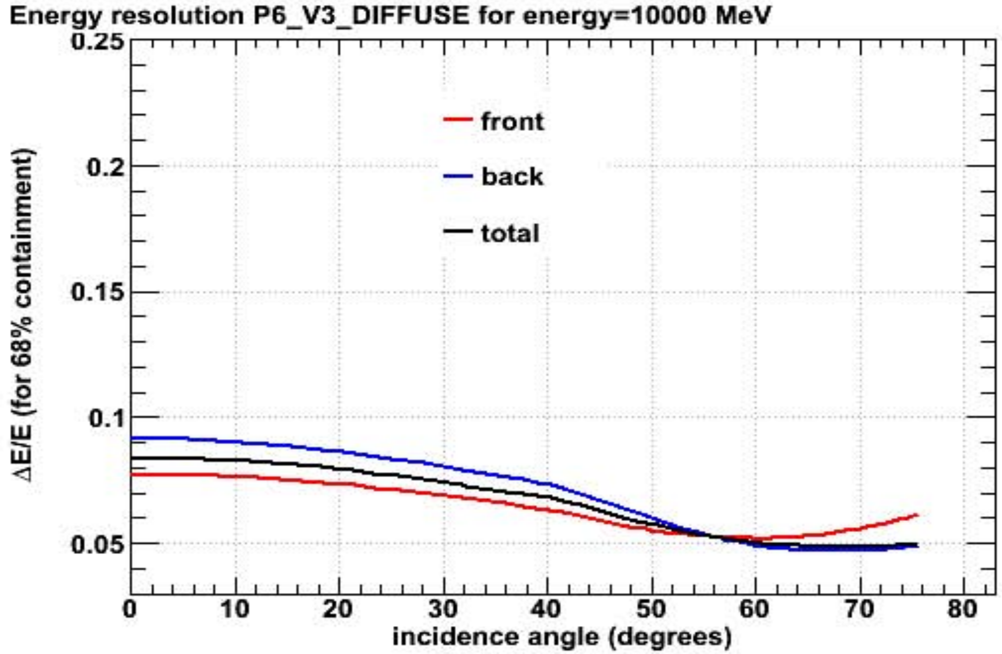

effective area P6_V3_DIFFUSE for normal incidence
front
back
total
effective area (cm^2)
Energy (MeV)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10^2
10^3
10^4
10^5

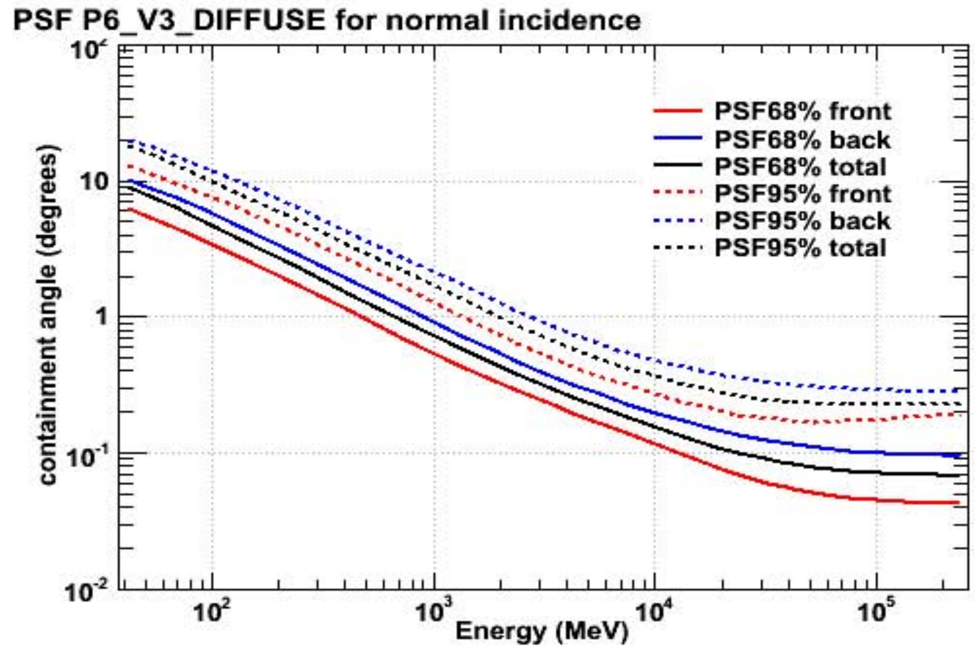

effective area P6_V3_DIFFUSE for energy=10000 MeV
front
back
total
effective area (cm^2)
incidence angle (degrees)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80

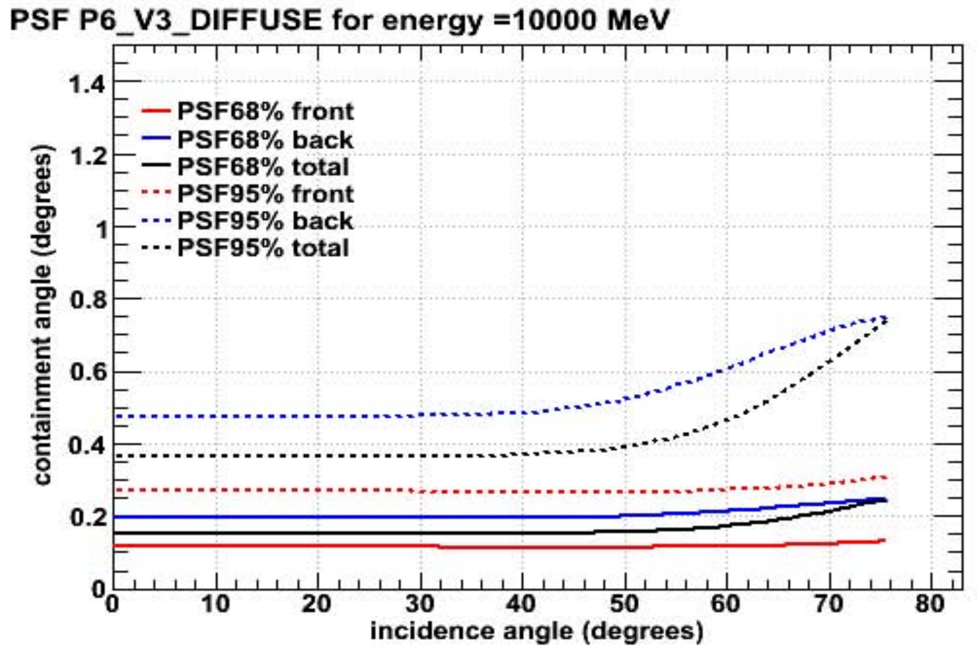

Acceptance P6_V3_DIFFUSE
front
back
total
eff. area intgrated over the FOV (cm^2 sr)
Energy (MeV)
25000
20000
15000
10000
5000
0
10^2
10^3
10^4
10^5

Fermi IRF


Energy resolution P6_V3_DIFFUSE for normal incidence
ΔE/E (for 68% containment)
0.25
0.2
0.15
0.1
0.05
front
back
total
10^2
10^3
10^4
10^5
Energy (MeV)


Energy resolution P6_V3_DIFFUSE for energy=10000 MeV
ΔE/E (for 68% containment)
0.25
0.2
0.15
0.1
0.05
front
back
total
0
10
20
30
40
50
60
70
80
incidence angle (degrees)


PSF P6_V3_DIFFUSE for normal incidence
containment angle (degrees)
10
1
10^-1
10^-2
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total
10^2
10^3
10^4
10^5
Energy (MeV)


PSF P6_V3_DIFFUSE for energy =10000 MeV
containment angle (degrees)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total
0
10
20
30
40
50
60
70
80
incidence angle (degrees)

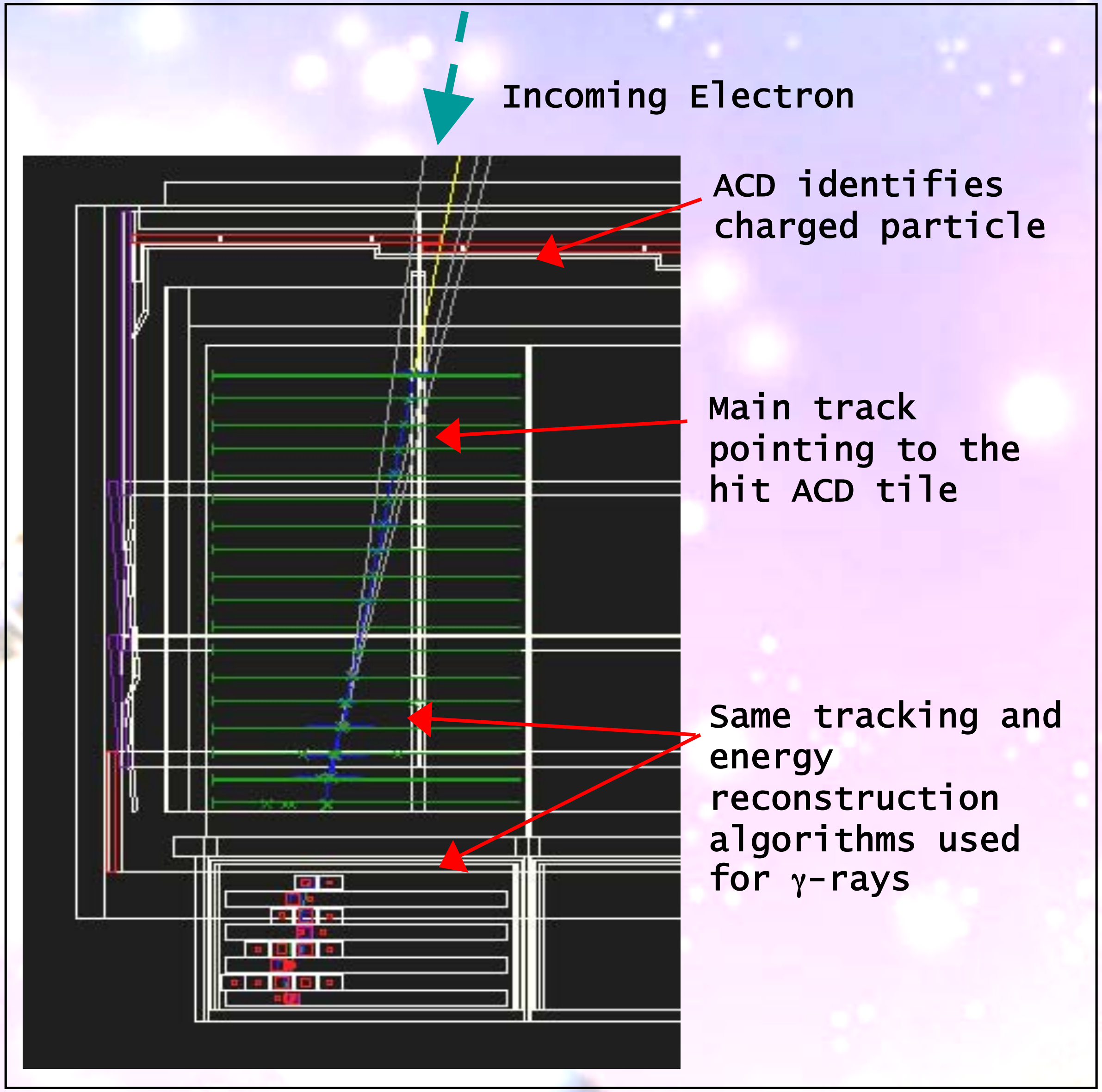
How Fermi LAT detects electrons

Trigger and downlink

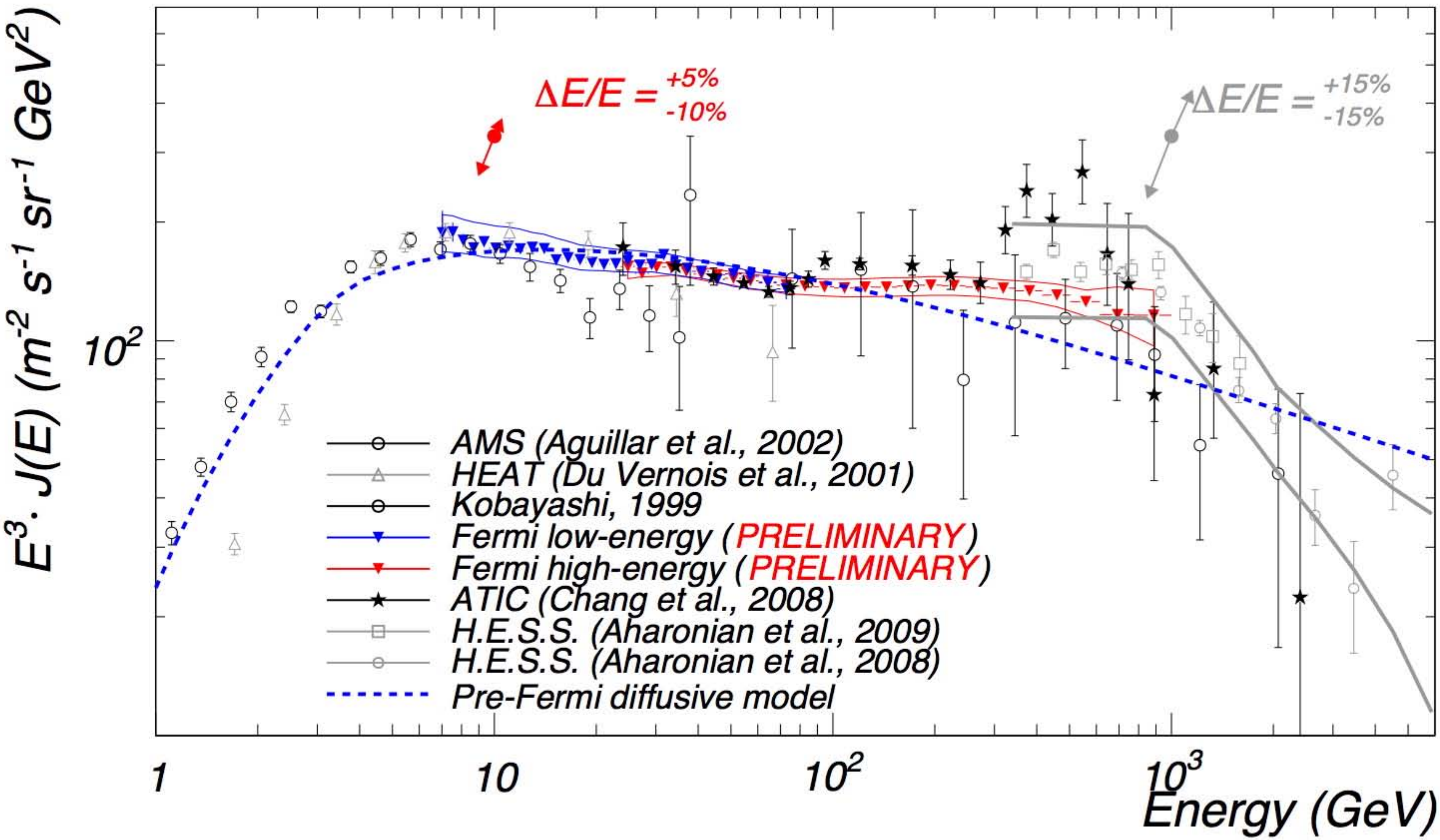
- LAT triggers on (almost) every particle that crosses the LAT
  - ~ 2.2 kHz trigger rate
- On board processing removes many charged particles events
  - But keeps events with more that 20 GeV of deposited energy in the CAL
  - ~ 400 Hz downlink rate
- Only ~1 Hz are good γ-rays

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



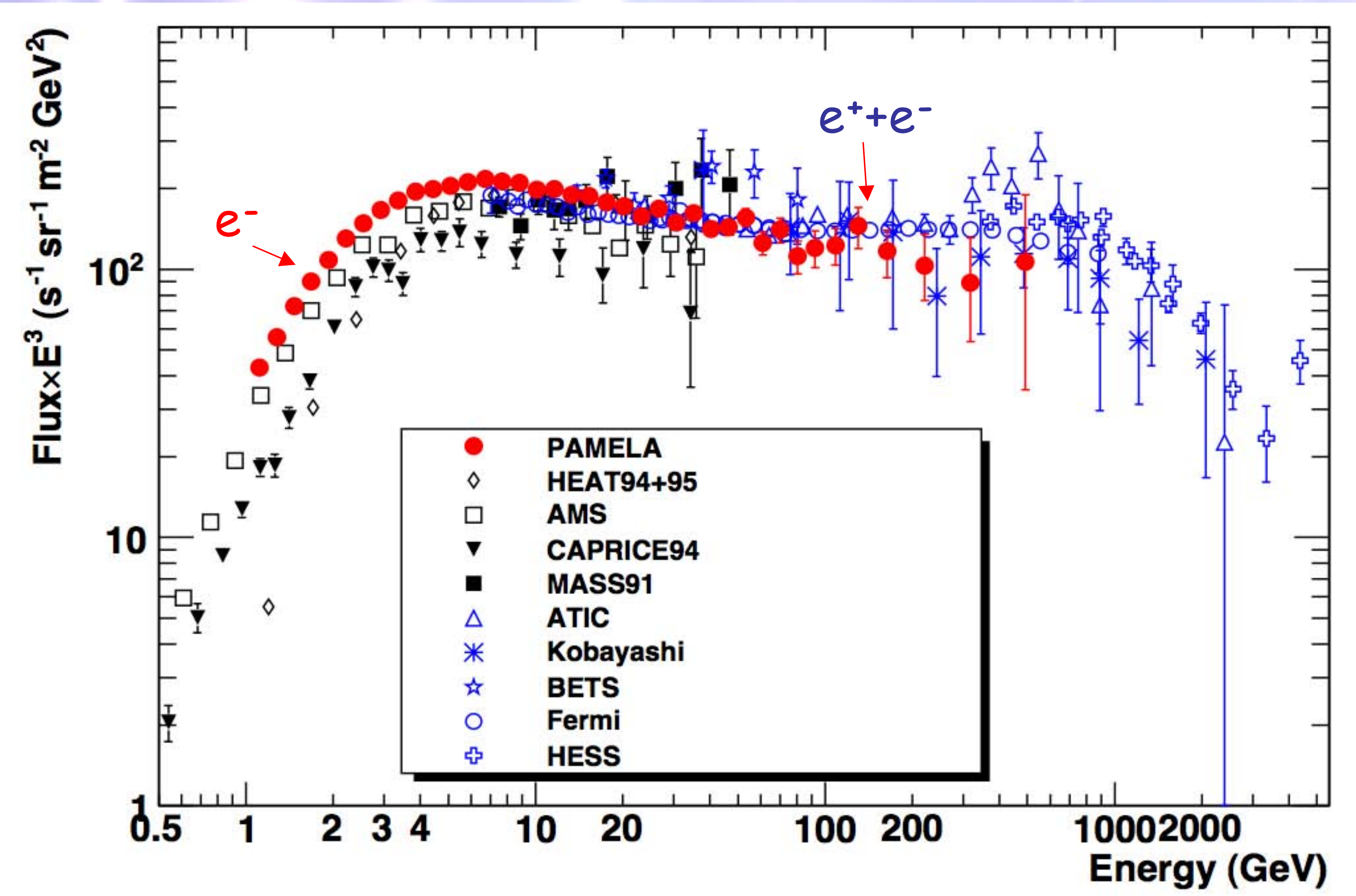
Fermi Electron + Positron spectrum



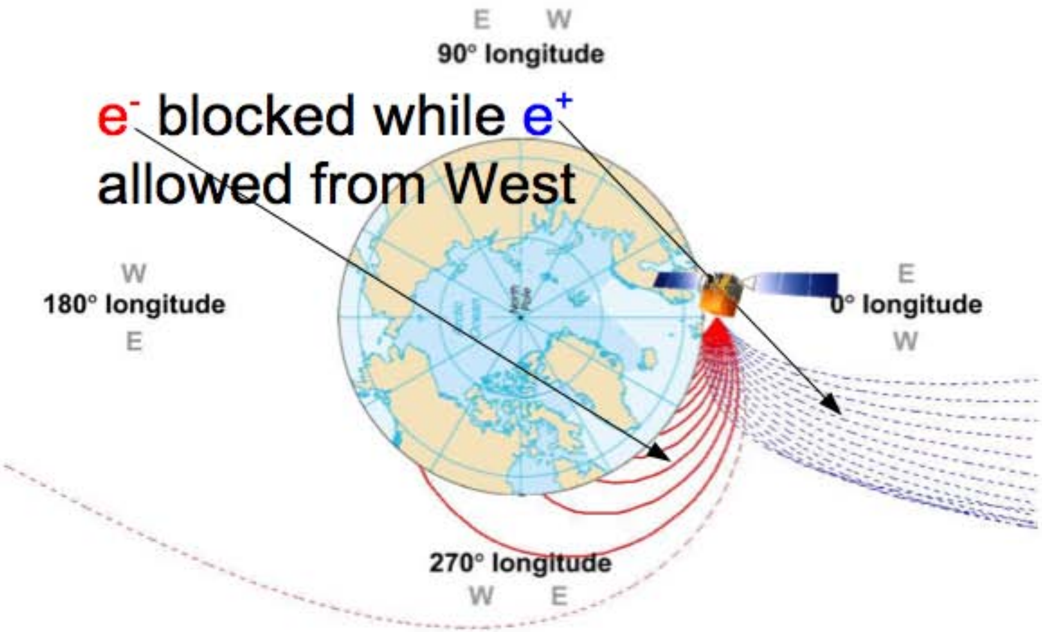
Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

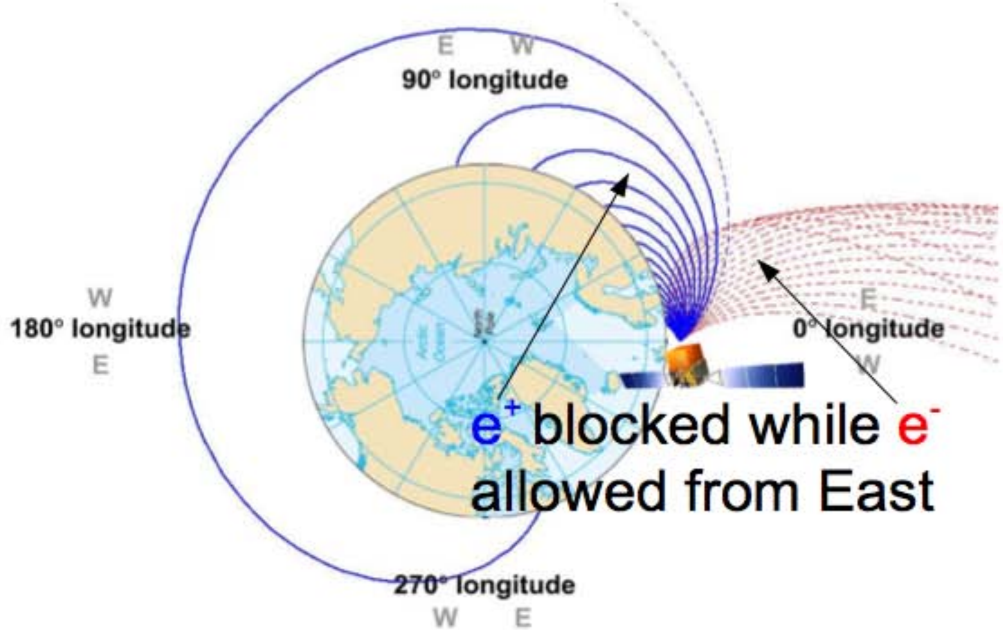
Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

e^- from PAMELA and $e^+ + e^-$ from FERMI



Principle: Use the Earth's Magnetic Field to Distinguish e^+ and e^-





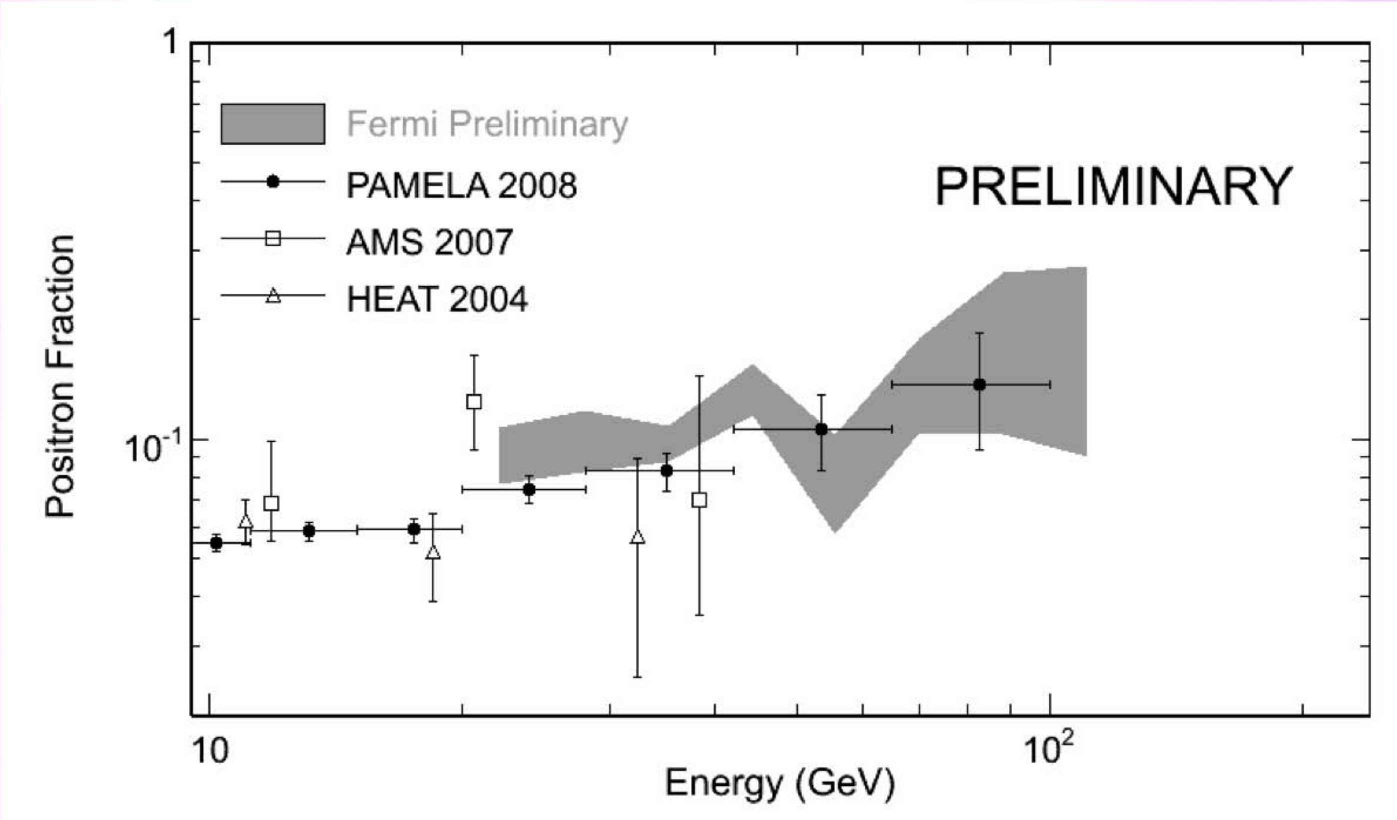
- Pure e^+ region is in the west and same for e^- in the east
- The regions vary with particle energy and the LAT position
- To locate these regions, we use a code written by Smart, D. F. and Shea, M. A.* which numerically calculates a particle's trajectory in the geomagnetic field

**Center for Space Plasmas and Aeronomic Research, The University of Alabama in Huntsville*

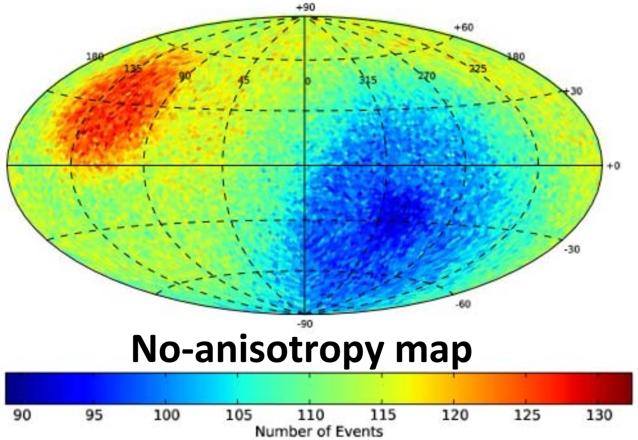
Positron Fraction

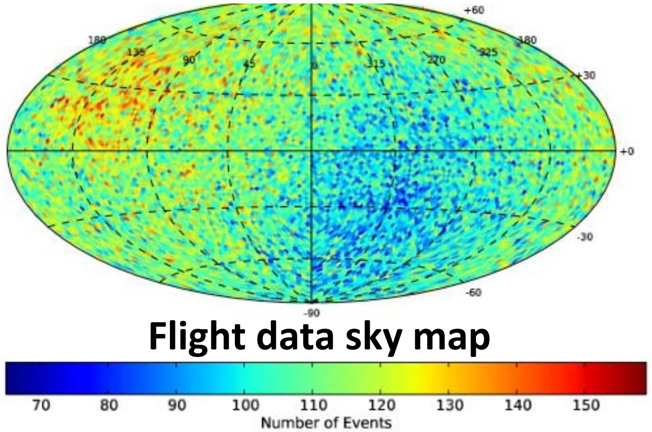
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth's magnetic field as a charge discriminator

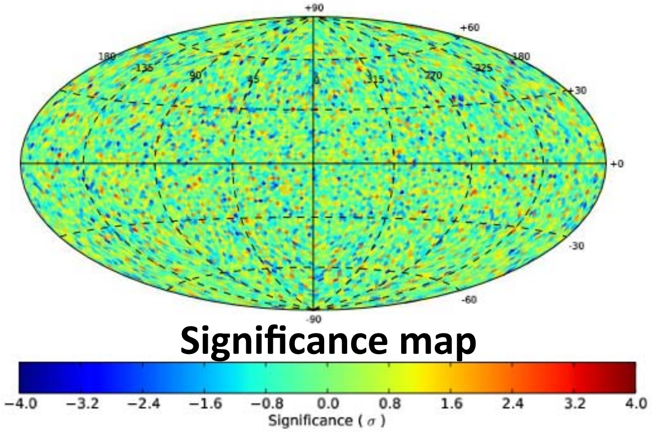
- **The two independent methods of background subtraction, Fit-Based and MC-Based, produce consistent results**
- **The observed positron fraction is consistent with the one measured by PAMELA**



Cosmic Ray Electrons Anisotropy

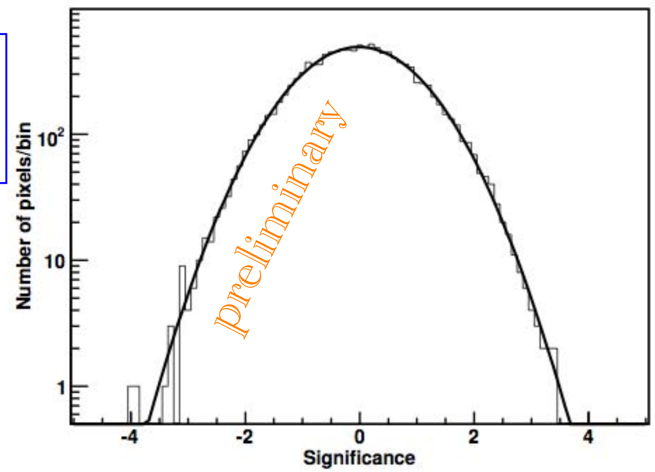






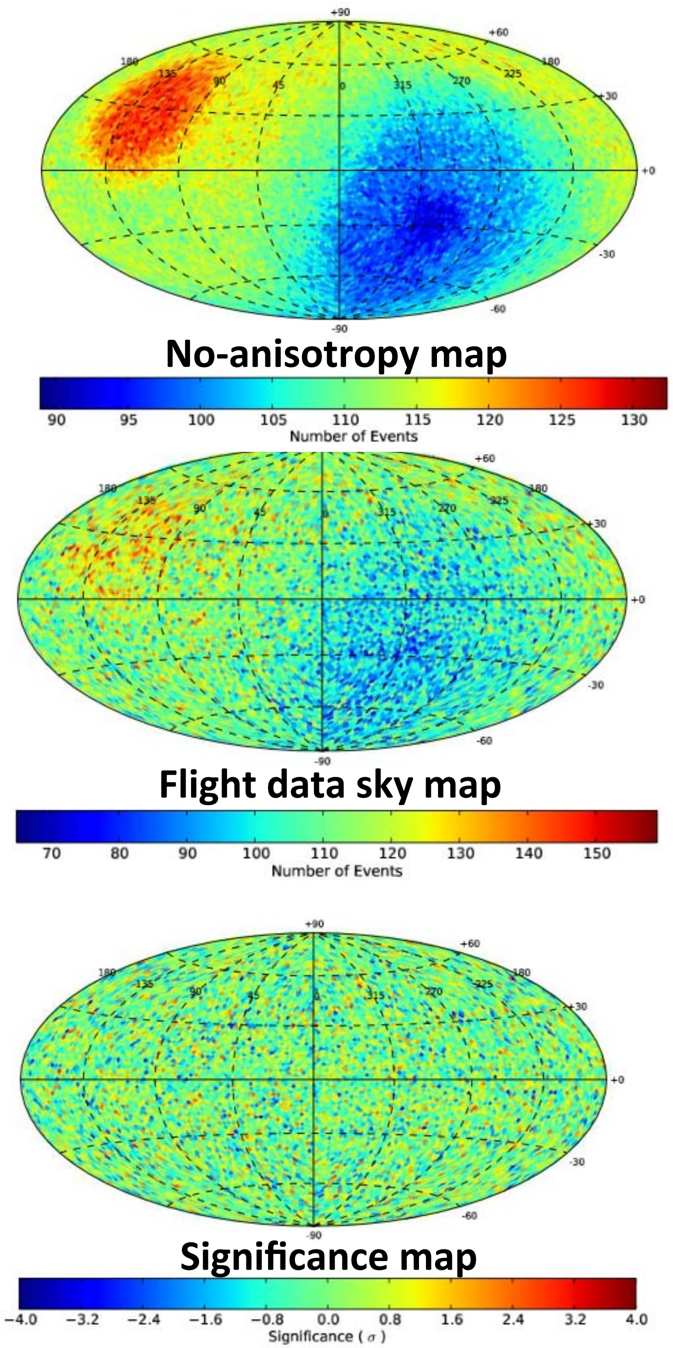
<u>the levels of anisotropy expected for Geminga-like and Monogem-like sources</u> (i.e. sources with similar distances and ages) <u>seem to be higher than the scale of anisotropies excluded by the results</u>
However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters

Distribution of significance, fitted by a Gaussian →



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

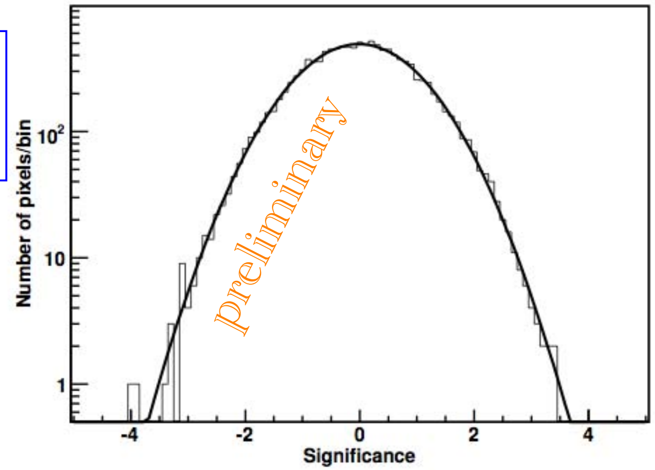
Cosmic Ray Electrons Anisotropy



More than 1.6 million electron events with energy above 60 GeV have been analyzed on anisotropy

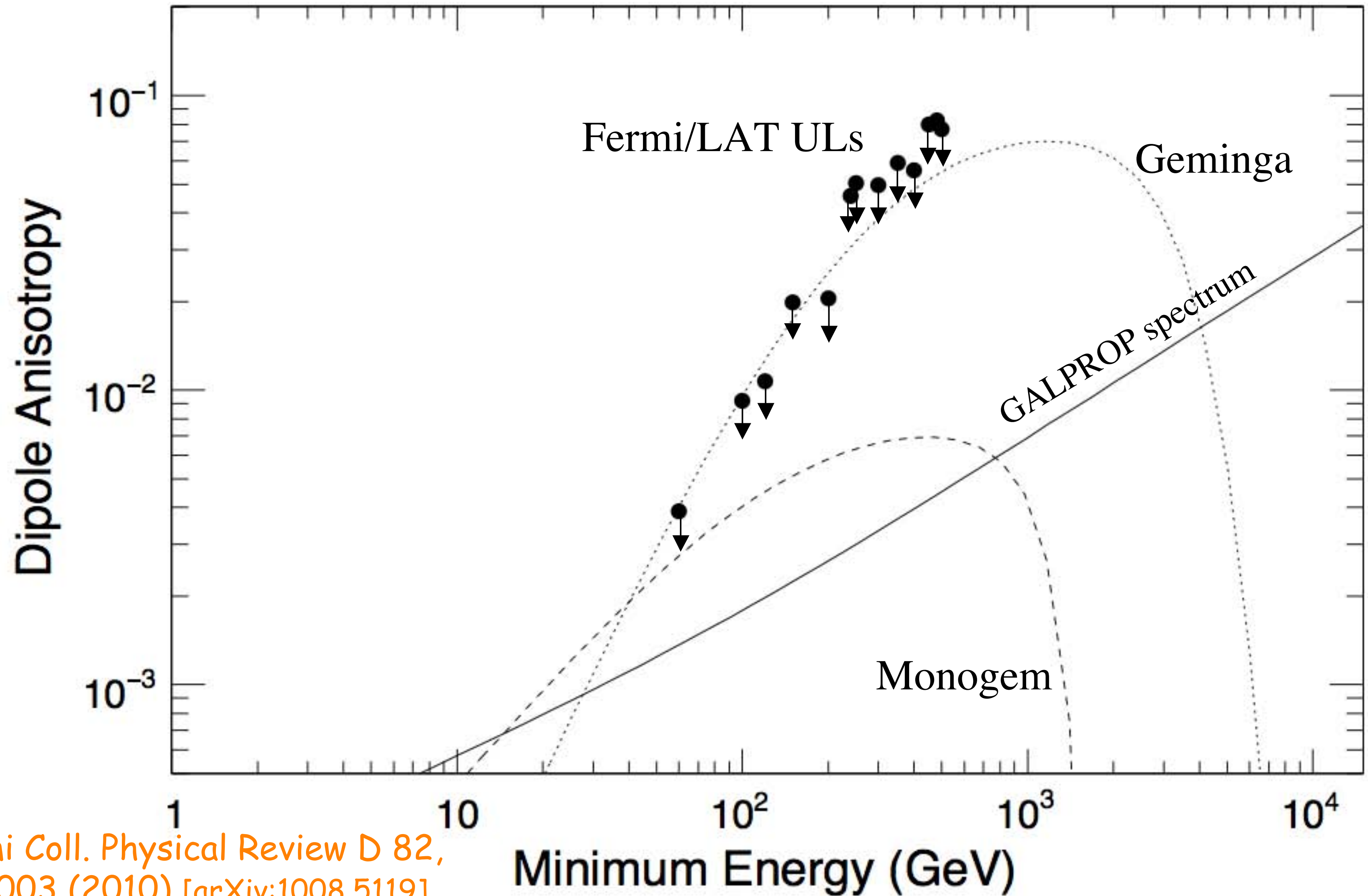
- Upper limit for the dipole anisotropy has been set to 0.5 – 5% depending on the energy
- Upper limit on fractional anisotropic excess ranges from a fraction to about one percent depending on the minimum energy and the anisotropy's angular scale

Distribution of significance, fitted by a Gaussian →



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

electron + positron expected anisotropy in the directions of Monogem and Geminga

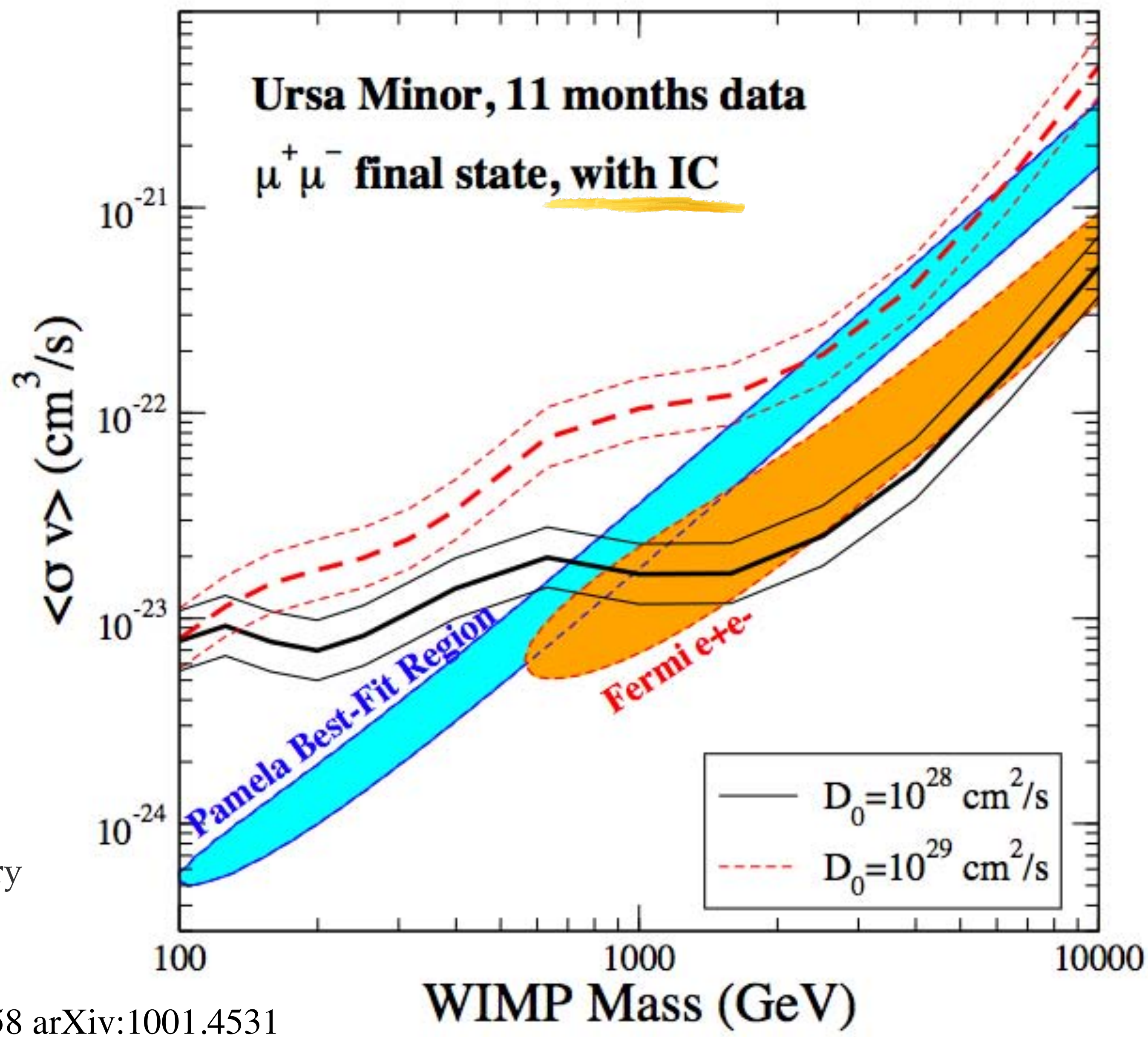


Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

Dwarf Spheroidal Galaxies upper-limits

Exclusion regions already cutting into interesting parameter space for some WIMP models

Stronger constraints can be derived if IC of electrons and positrons from DM annihilation off of the CMB is included, however diffusion in dwarfs is not known ⇒ use bracketing values of diffusion coefficients from cosmic rays in the Milky Way

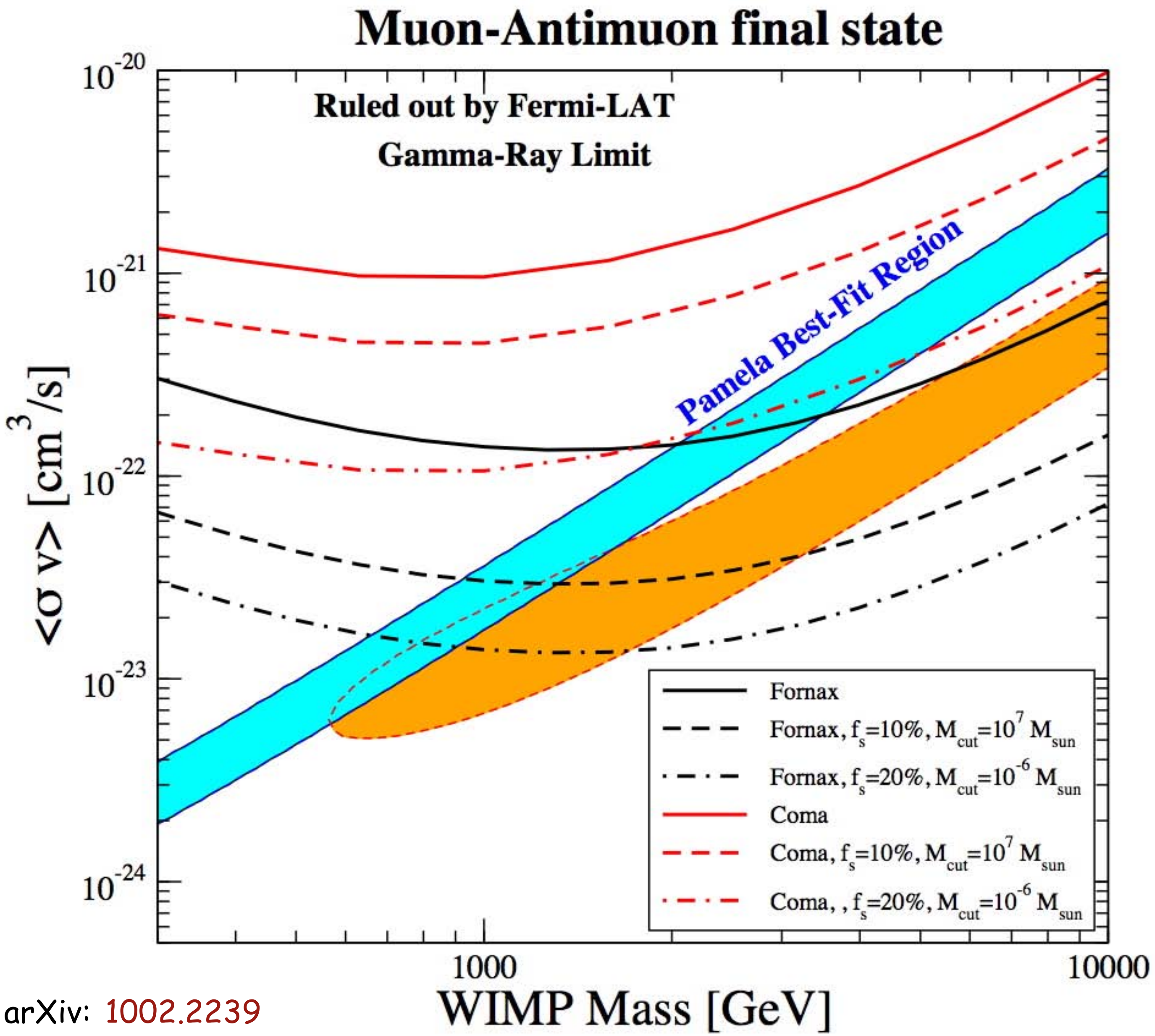


(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

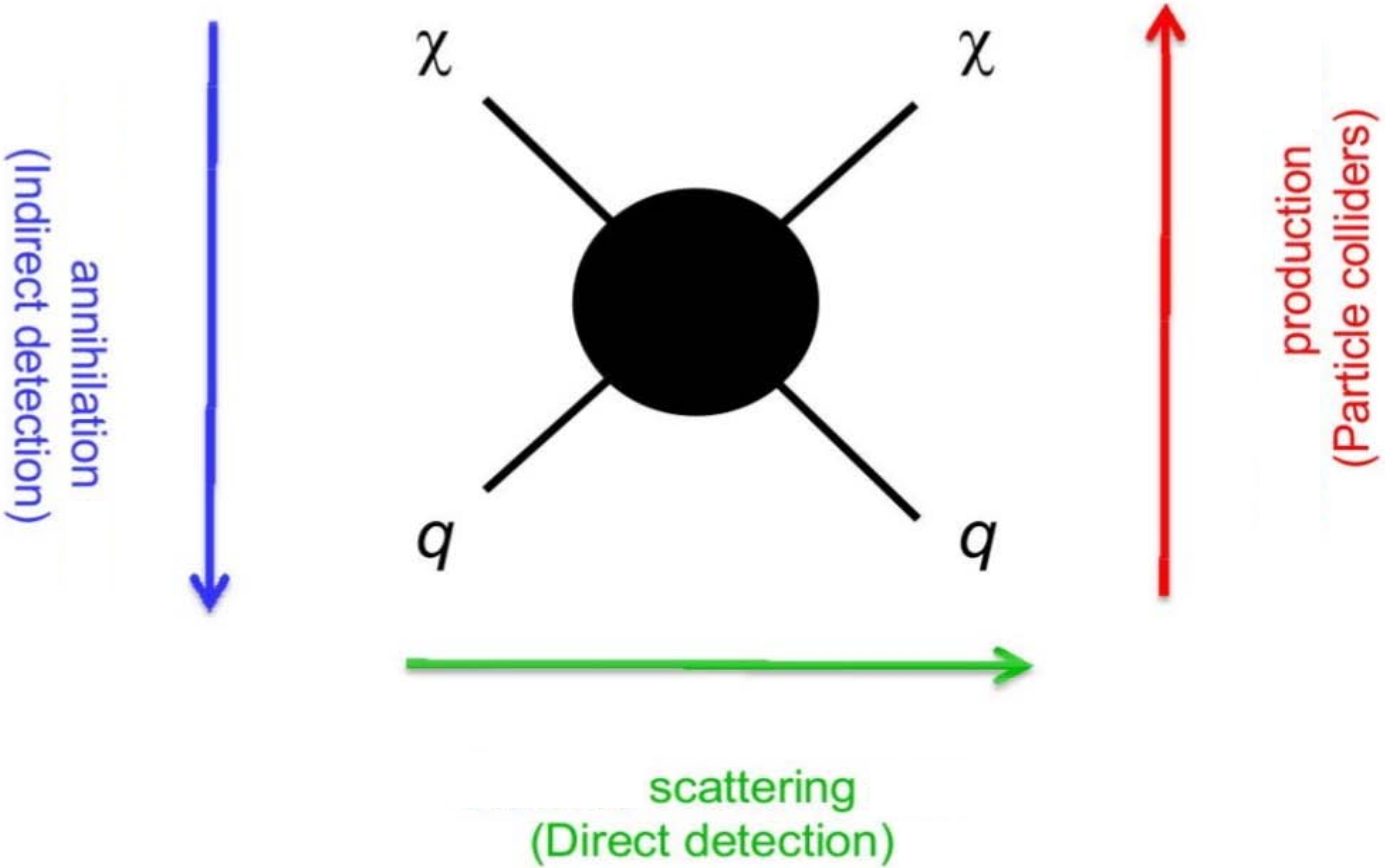
Fermi Coll. ApJ 712 (2010) 147-158 arXiv:1001.4531

Galaxy Clusters upper-limits

Stronger constraints on leptophilic DM models can be derived with galaxy clusters when the IC contribution off the CMB of secondary electrons (from DM annihilation) is included



Fermi Coll. JCAP 05, 025 (2010), arXiv: 1002.2239



annihilation
(Indirect detection)
χ
χ
q
q
production
(Particle colliders)
scattering
(Direct detection)

They Play Together!

Direct Detection

Relic scattering RIGHT HERE at low energy. Push to larger target mass, lower backgrounds, directional sensitivity?

Accelerators

Direct production. Push to higher energy

Observations

Push toward finding and studying galactic halo objects and large scale structure.

Indirect Detection

Relic interactions (annihilations, decays) Understand the astrophysical backgrounds in signal-rich regions. Reveal the detailed astrophysical distribution of dark matter.

Simulations

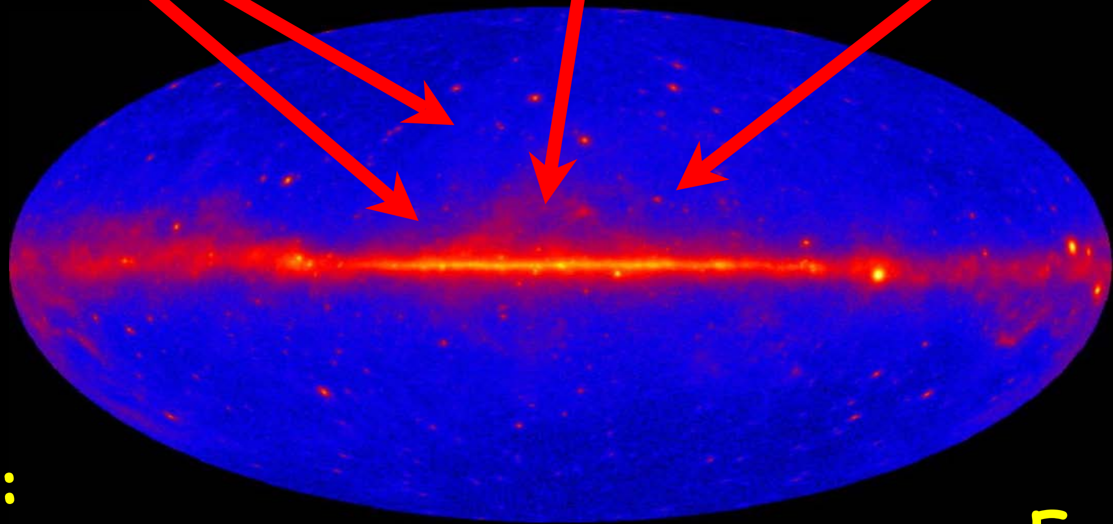
Large scale structure formation. Push toward larger simulations, finer details.

Search Strategies

Satellites:
Low background and good source id, but low statistics

Galactic center:
Good statistics but source confusion/diffuse background

Milky Way halo:
Large statistics but diffuse background



And electrons!
and
Anisotropies

Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:
Low background but low statistics

Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

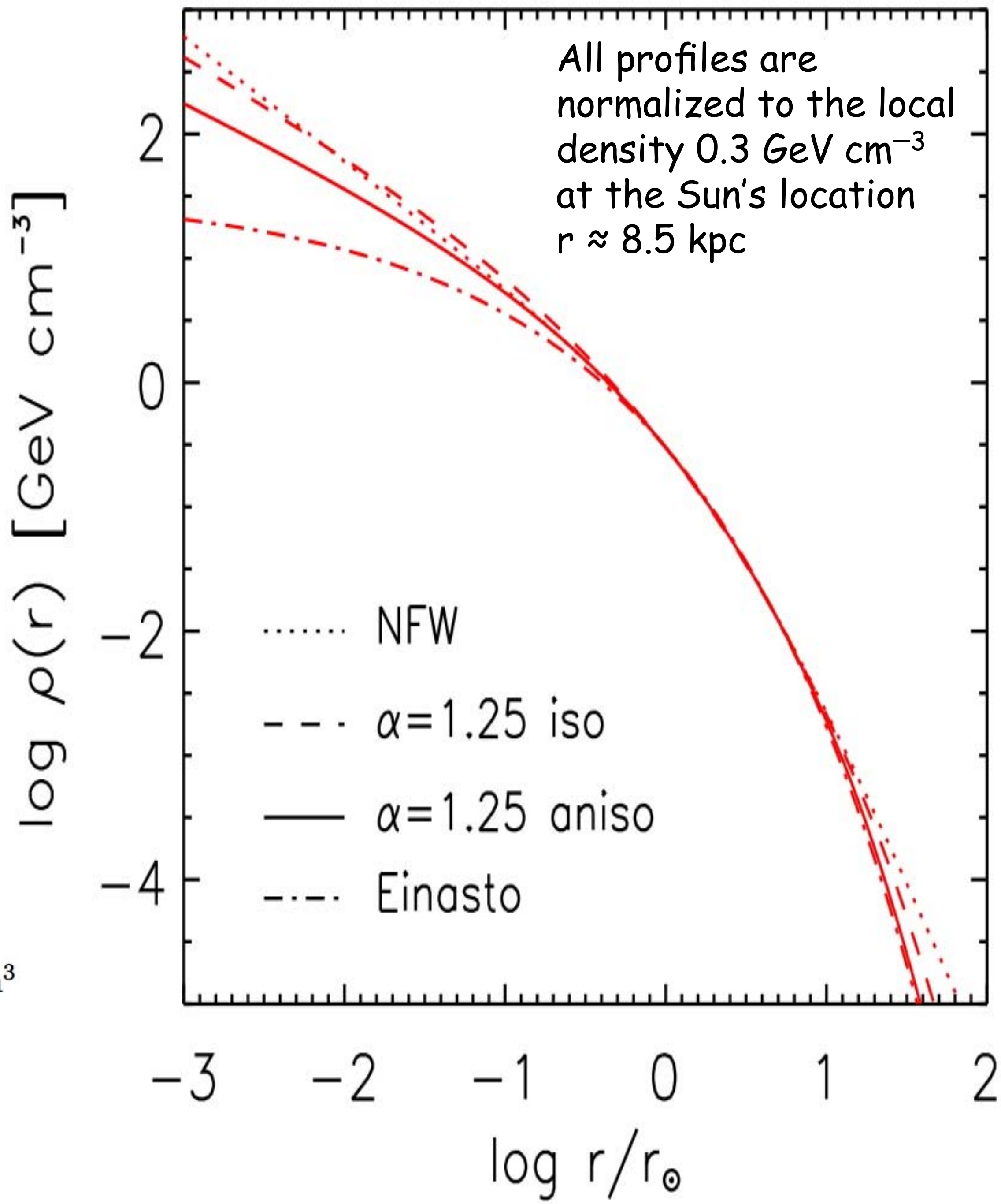
Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Milky Way Dark Matter Profiles

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1 + (r_\odot/r_s)^\alpha}{1 + (r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

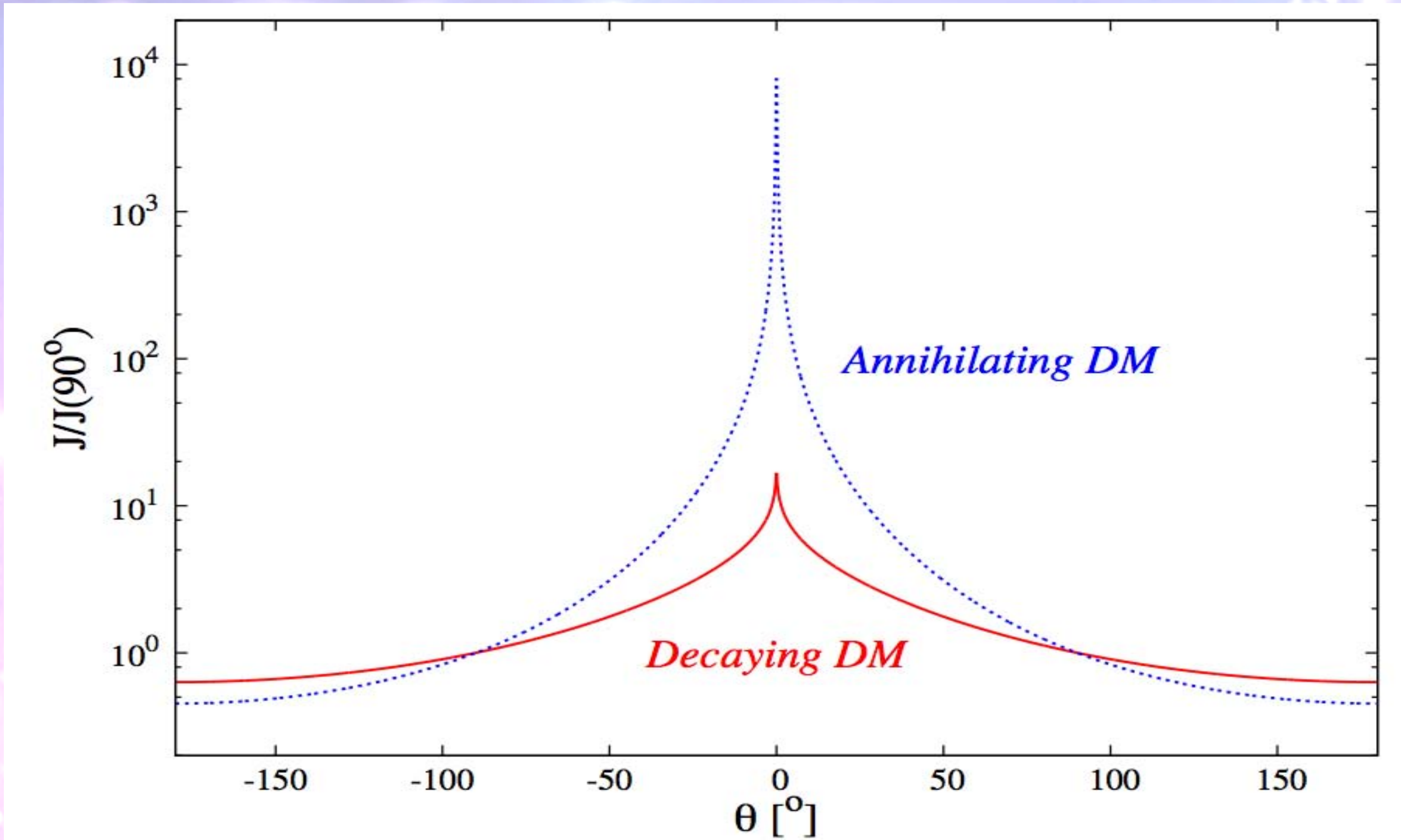
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$



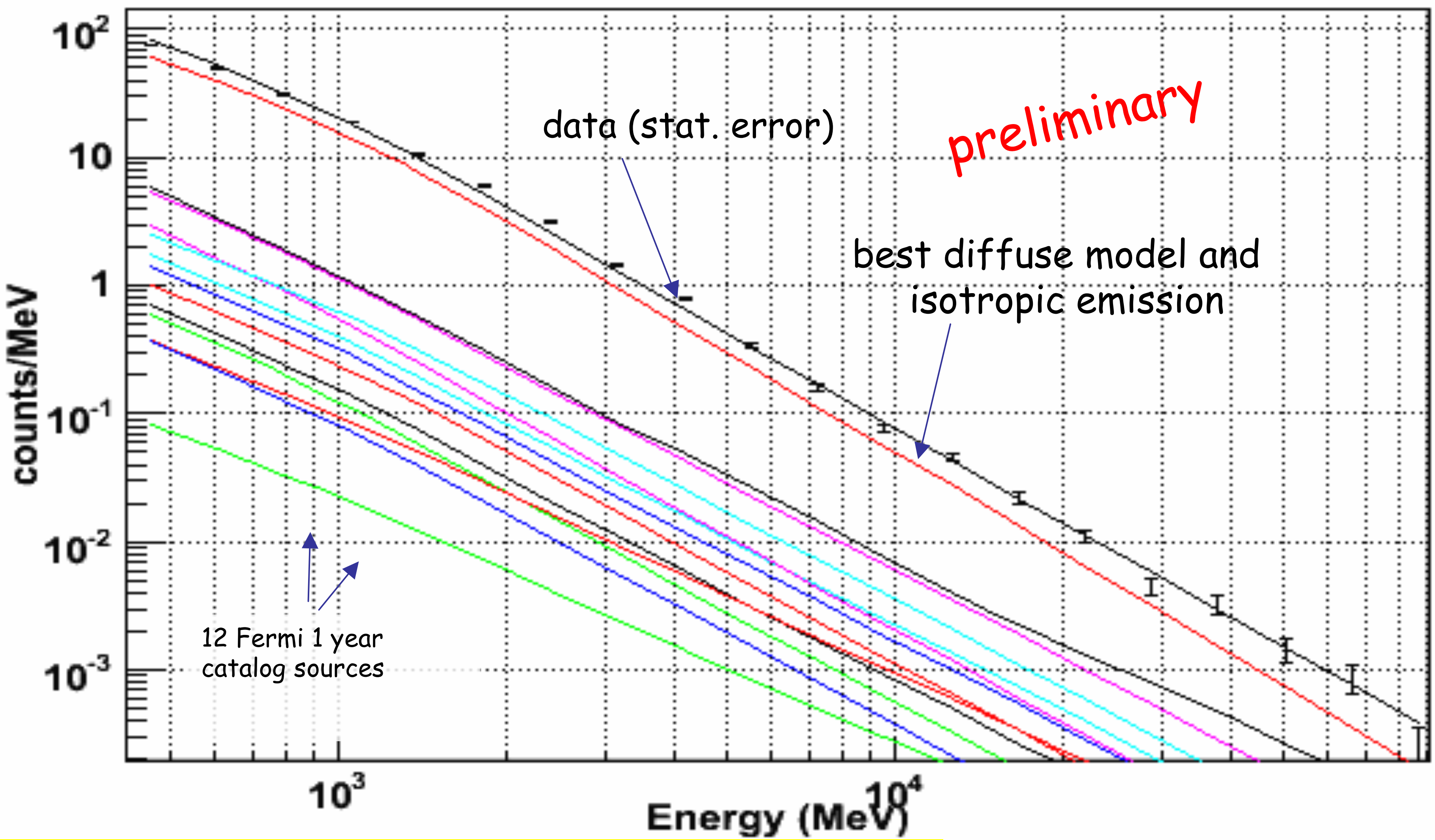
A.Lapi et al. arXiv:0912.1766

Different spatial behaviour for decaying or annihilating dark matter



The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

Spectrum (E> 400 MeV, 7°x7° region centered on the Galactic Center analyzed with binned likelihood analysis)

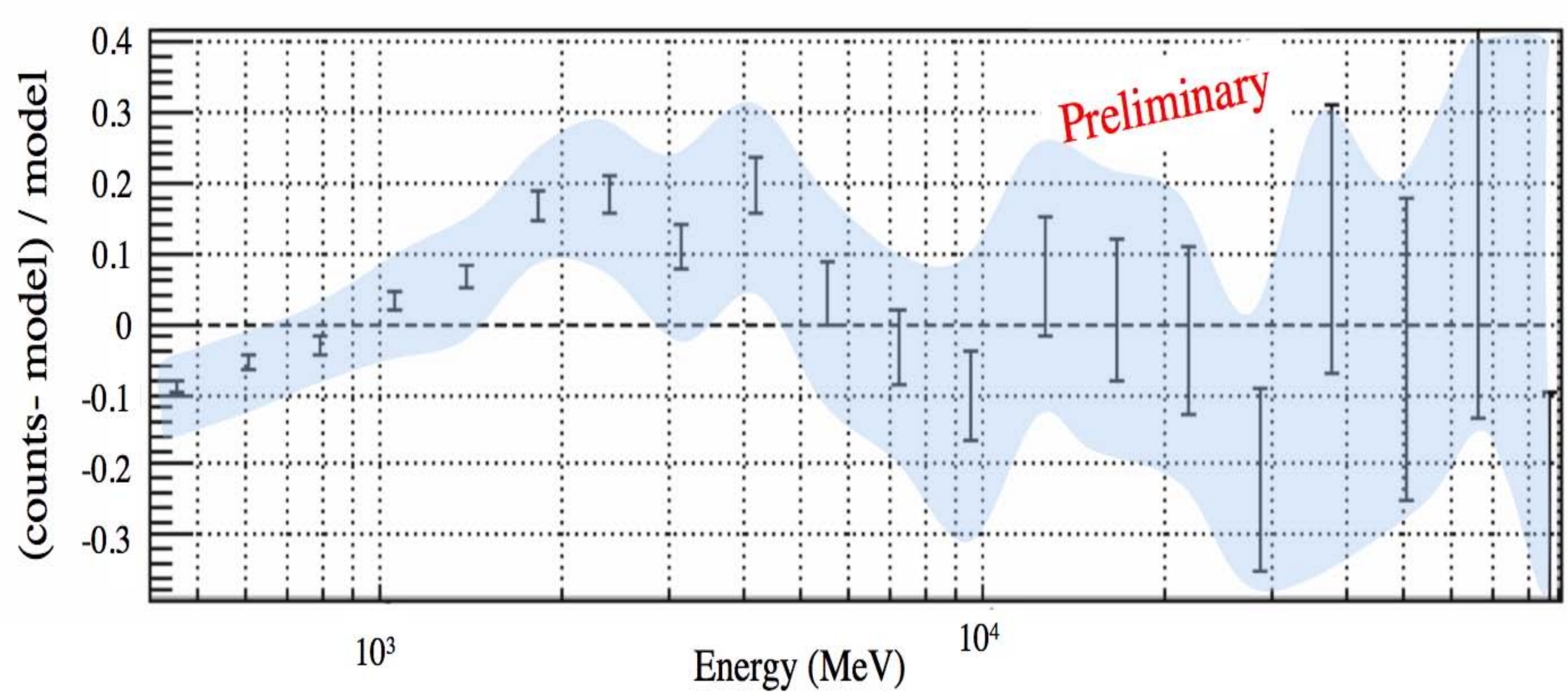


V.Vitale, A.Morselli on behalf of the Fermi LAT Coll., arXiv:0912.3828

GC Residuals

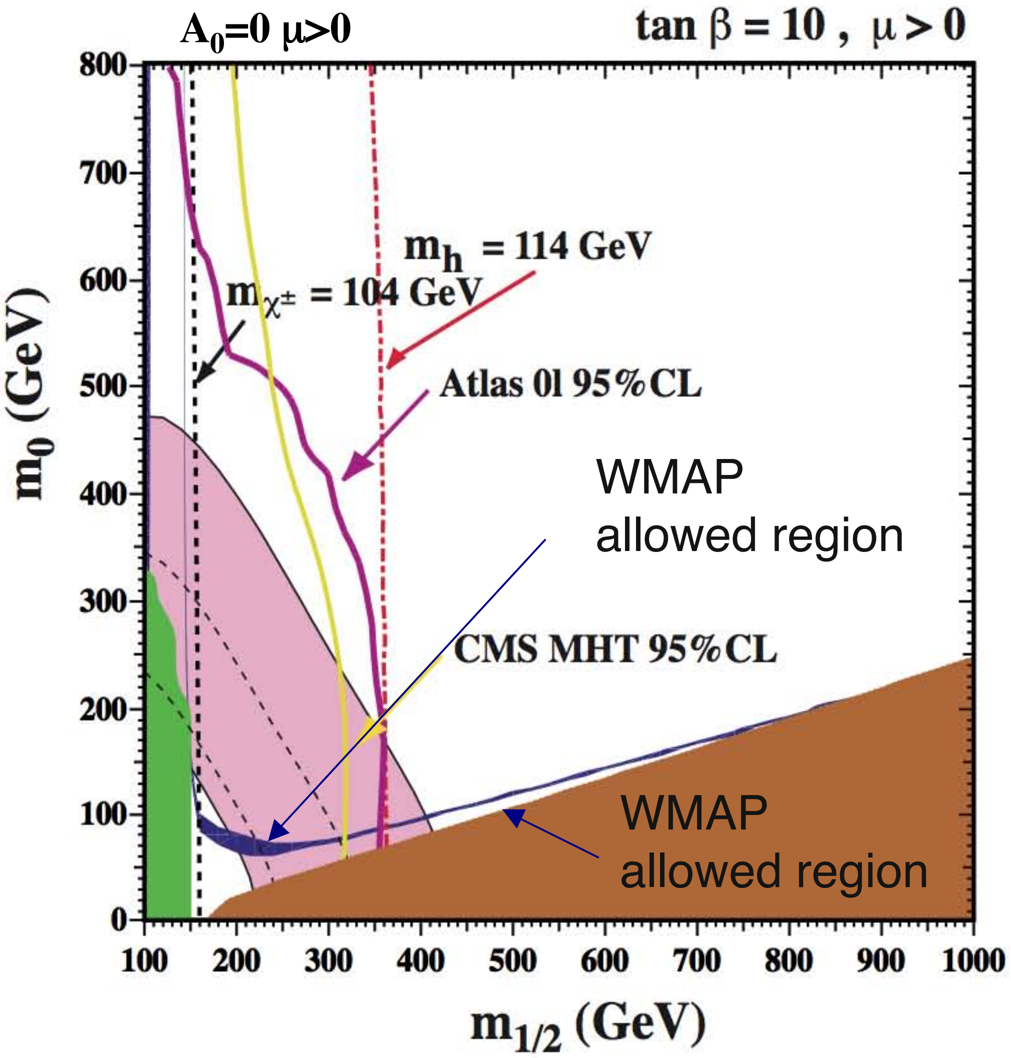
7°x7° region centered on the Galactic Center
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

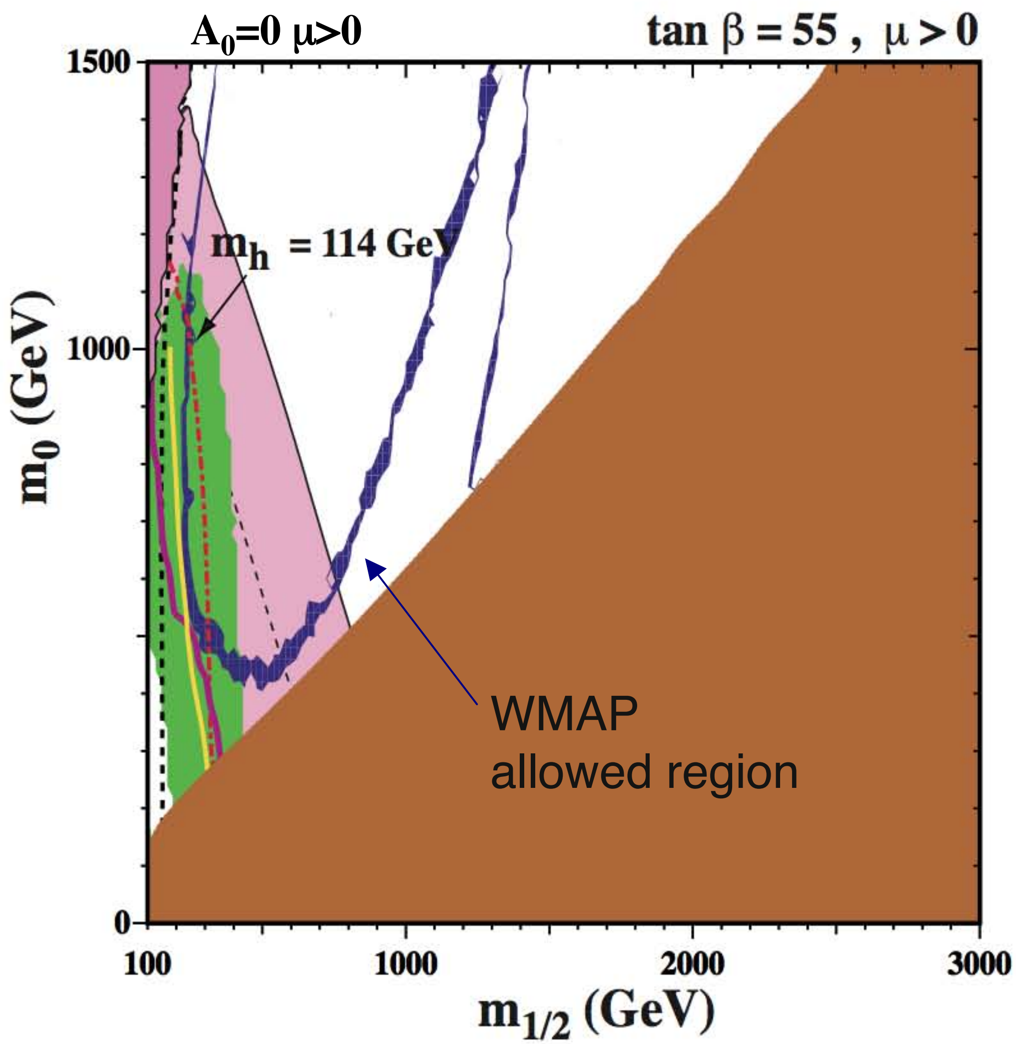
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



V.Vitale, A.Morselli on behalf of the Fermi LAT Coll., arXiv:0912.3828

Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios

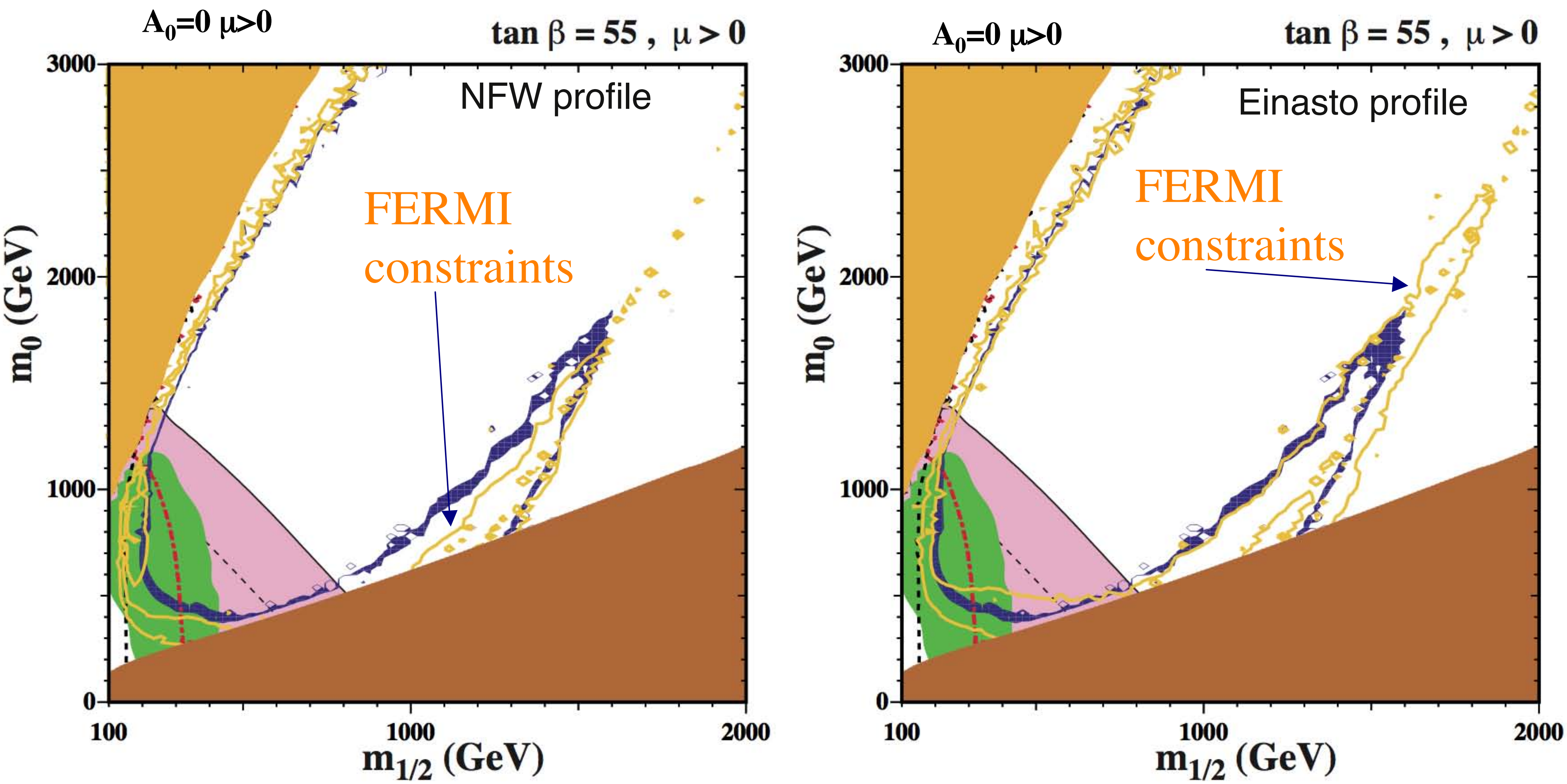




The constraints due to the absences of charginos and the Higgs boson at LEP are also shown, as black dashed and red dot-dashed lines, respectively. Regions excluded by the requirements of electroweak symmetry breaking and a neutral LSP are shaded dark pink and brown, respectively. The green region is excluded by $b \to s\gamma$, and the pink region is favoured by the supersymmetric interpretation of the discrepancy between the Standard Model calculation and the experimental measurement of $g_\mu - 2$ within 1 and 2 standard deviations (dashed and solid lines, respectively)

Ellis et al., arXiv:1106.0768

Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios



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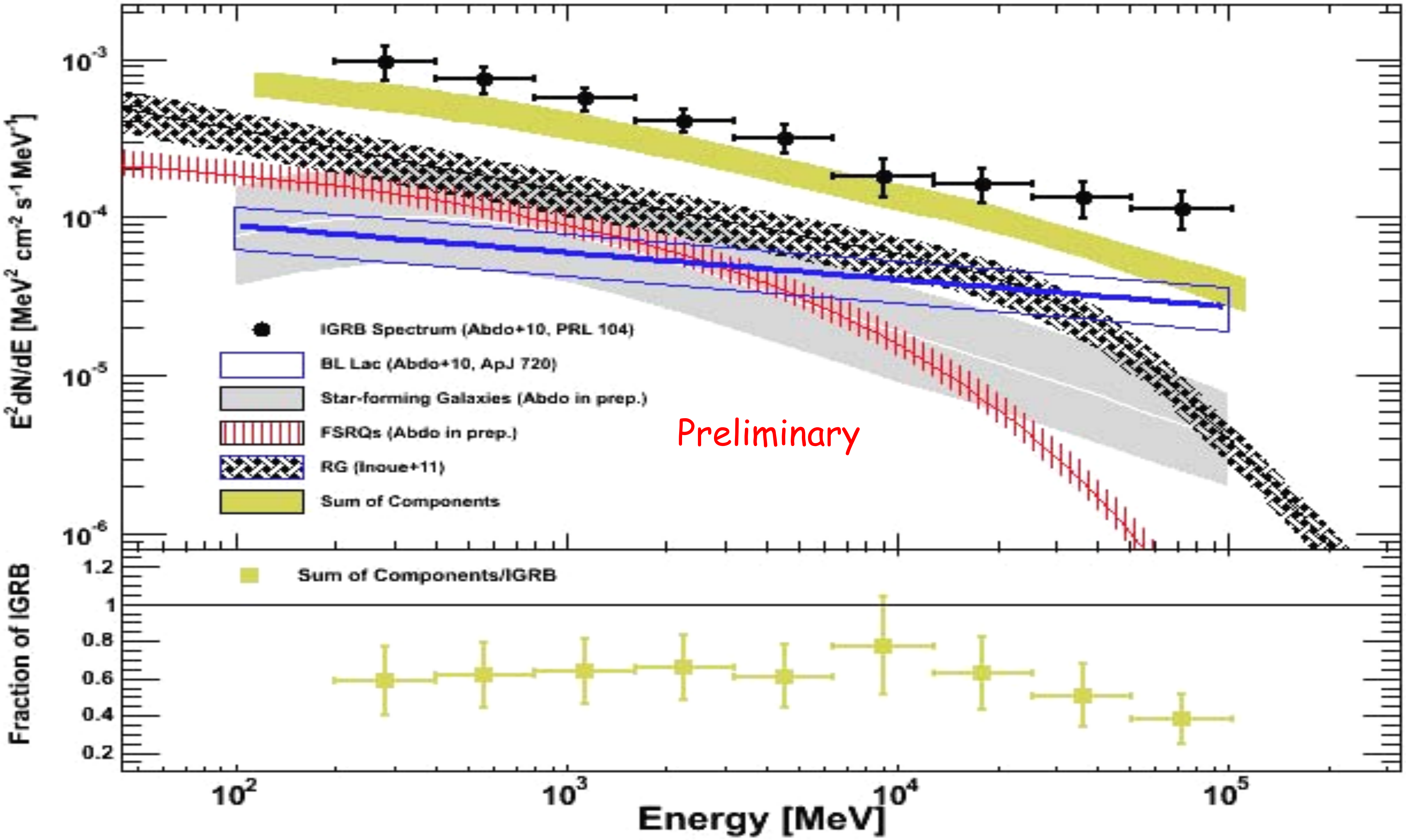
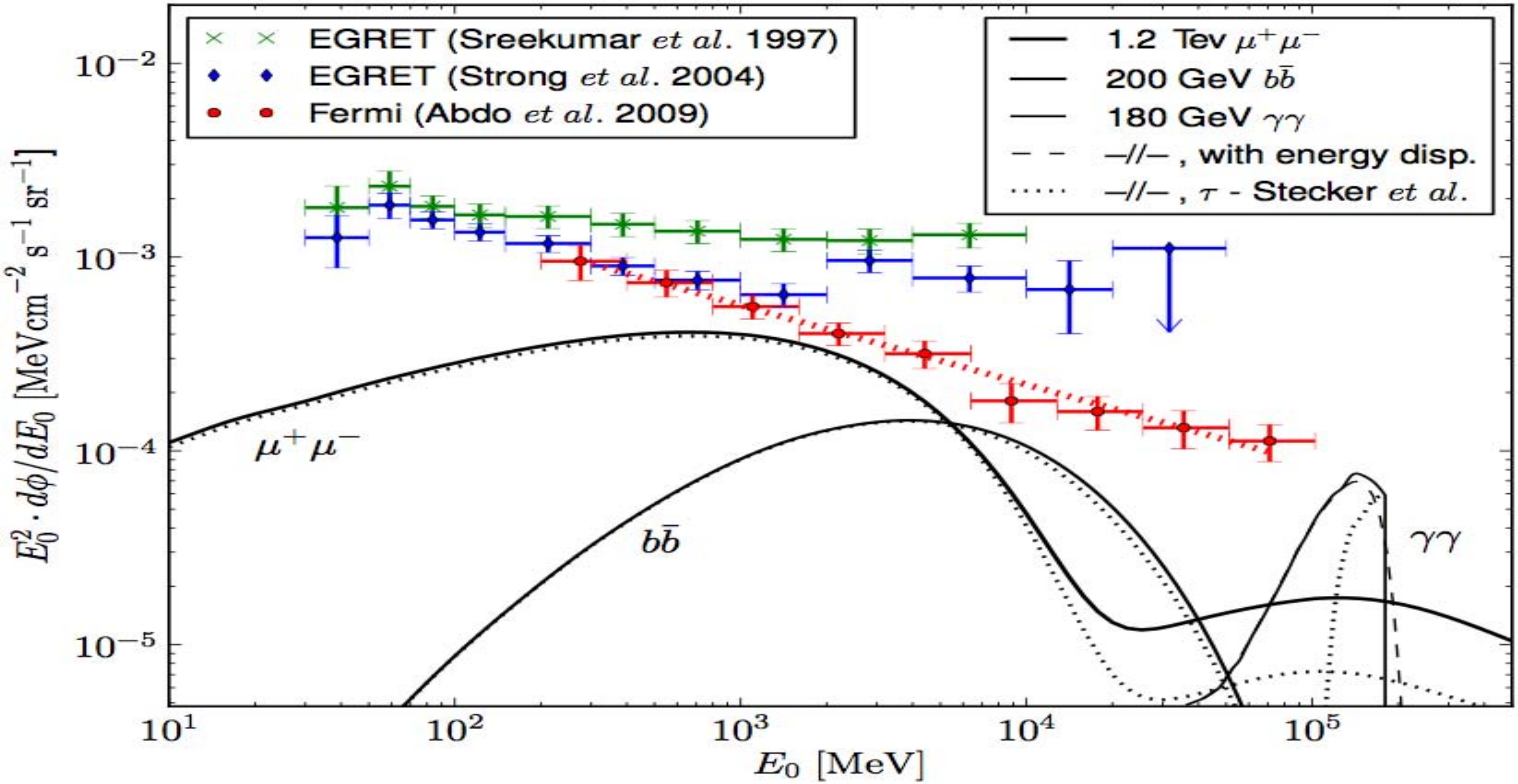
Ellis et al., arXiv:1106.0768

Fermi Bubble

Update on the Isotropic Gamma-ray Background (IGRB)



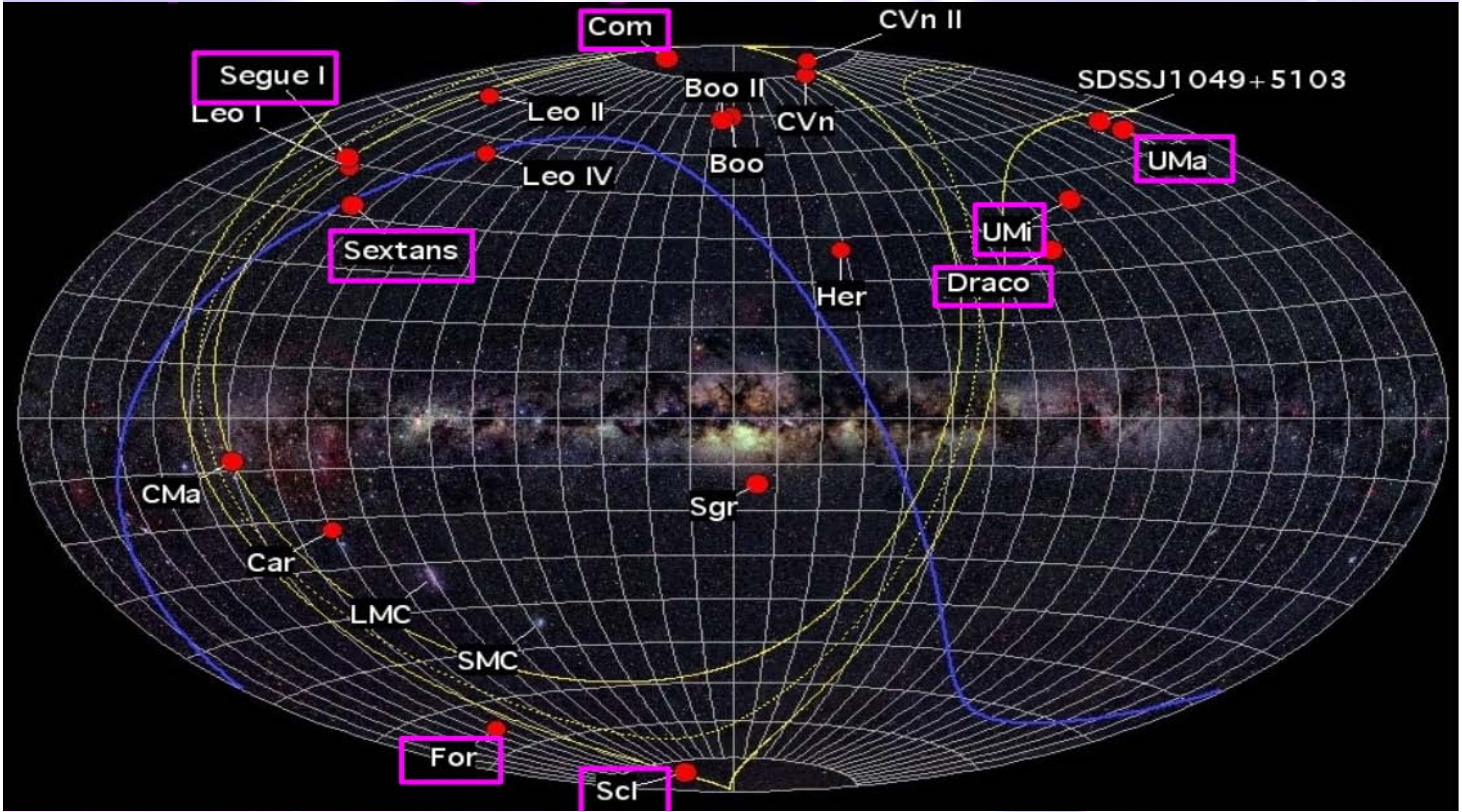
extragalactic gamma-ray spectrum



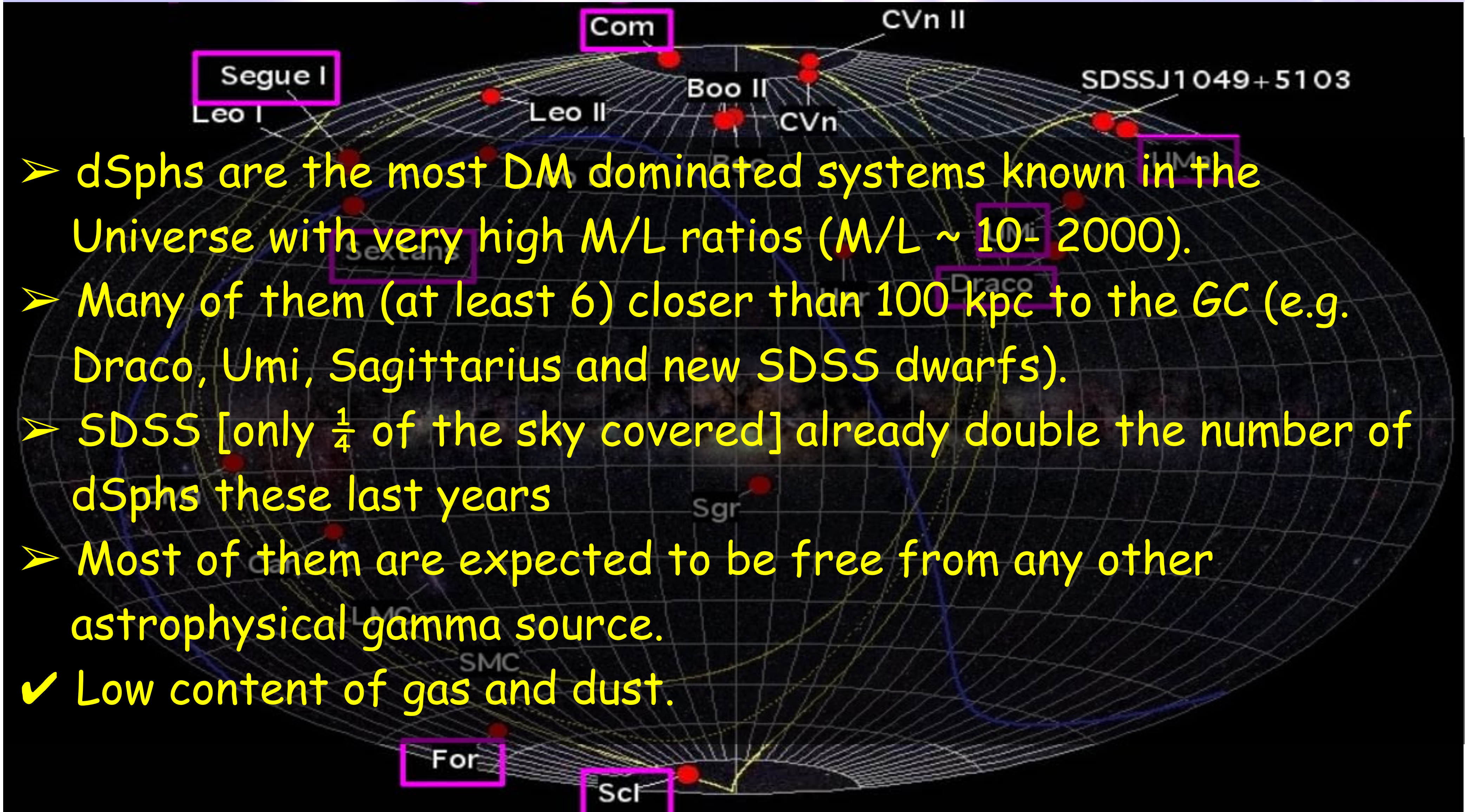
Fermi Coll. JCAP 04 (2010) 014 arXiv:1002.4415

others possible contributions to the extragalactic gamma-ray spectrum

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

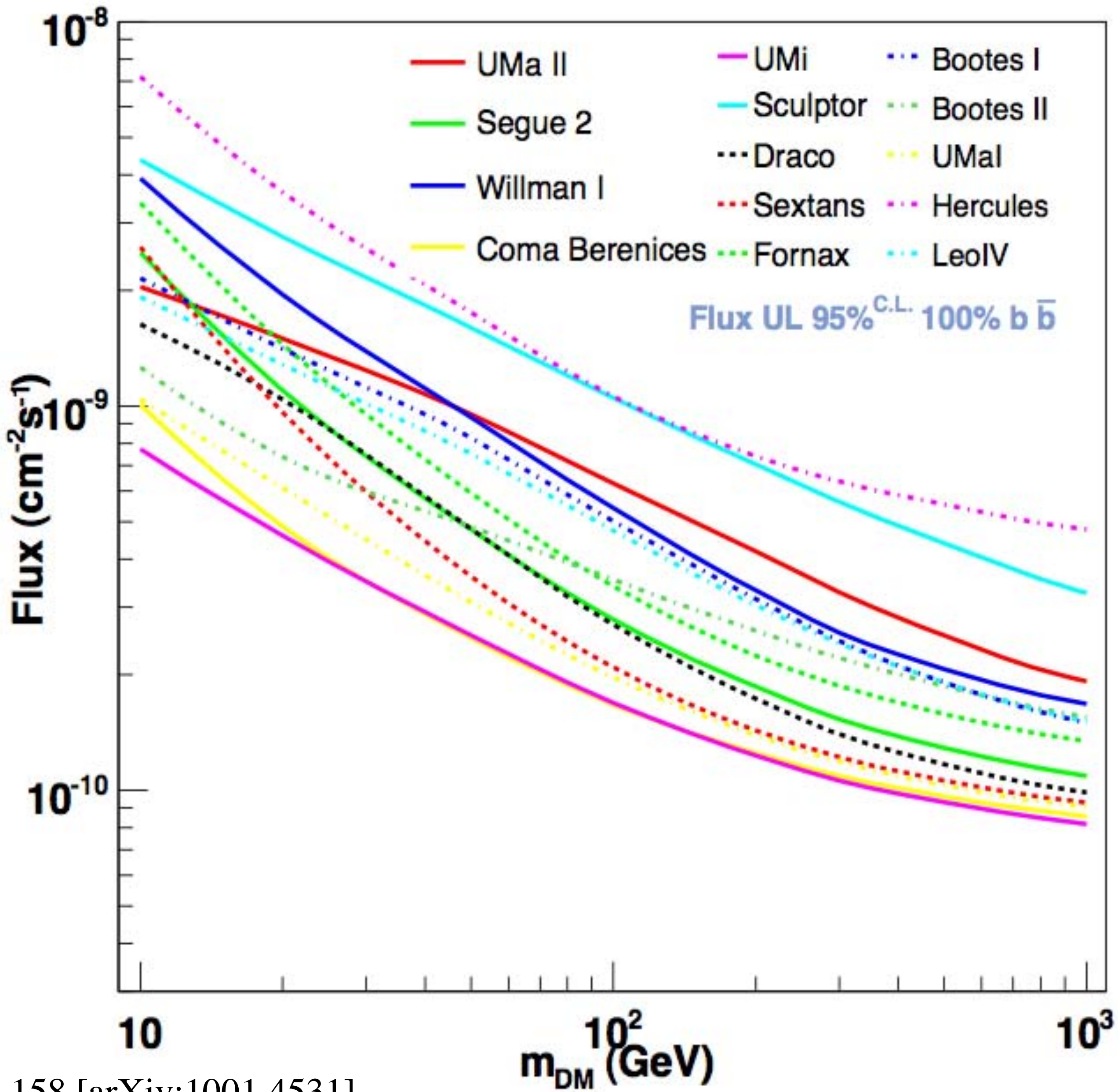


- ➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- ➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- ➢ SDSS [only $\frac{1}{4}$ of the sky covered] already double the number of dSphs these last years
- ➢ Most of them are expected to be free from any other astrophysical gamma source.
- ✔ Low content of gas and dust.

Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

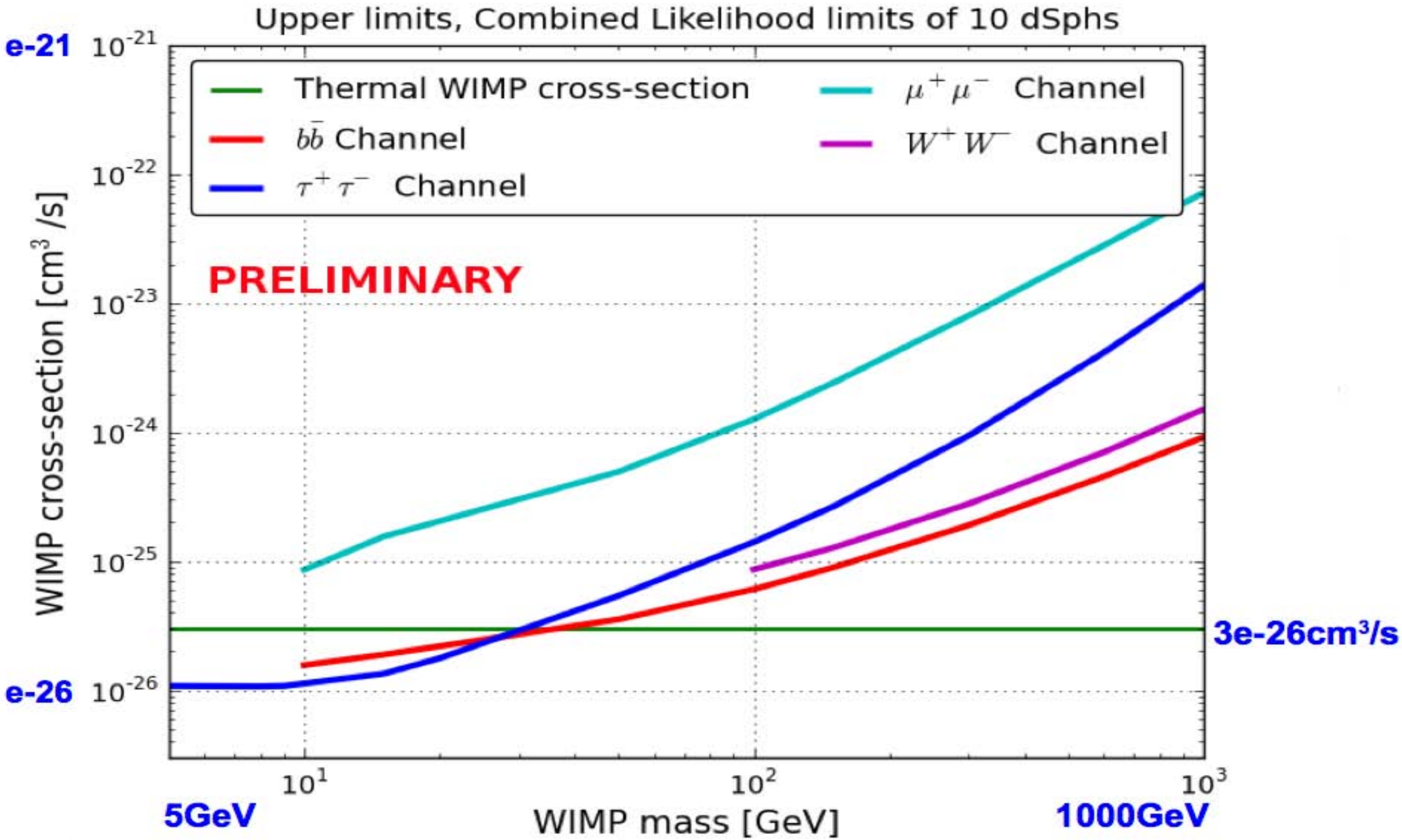
- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on < σv> vs WIMP mass for specific DM models



(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

Fermi Coll. ApJ 712 (2010) 147-158 [arXiv:1001.4531]

Dwarf Spheroidal Galaxies upper-limits Update



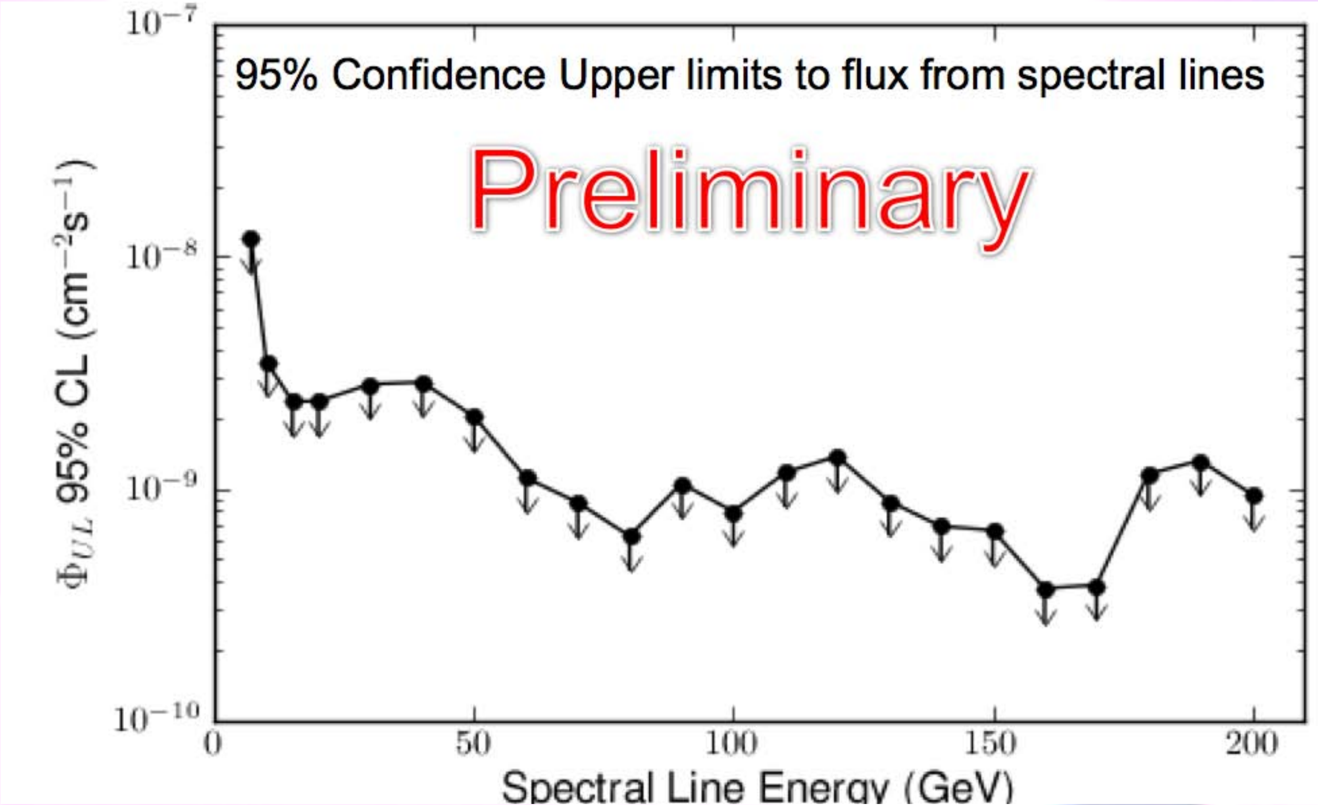
robust constraints including J-factor uncertainties

Fermi LAT 23 Month Line search results Flux Upper Limits, 7 GeV – 200 GeV

- ± 20 % overall scale systematic error (+20 % systematic for UL).

Additional systematic on spectral structures with LAT resolution for E < 13.2 GeV of s/bg ~ 1%.

- **7 and 10 GeV bins use a modified event selection to reduce the systematic uncertainty associated with public IRFs**.
- For E > 12 GeV no indication of a spectral structure systematic effect is seen.



Fermi LAT 23 Month γZ-Cross-section limits 7 GeV – 200 GeV

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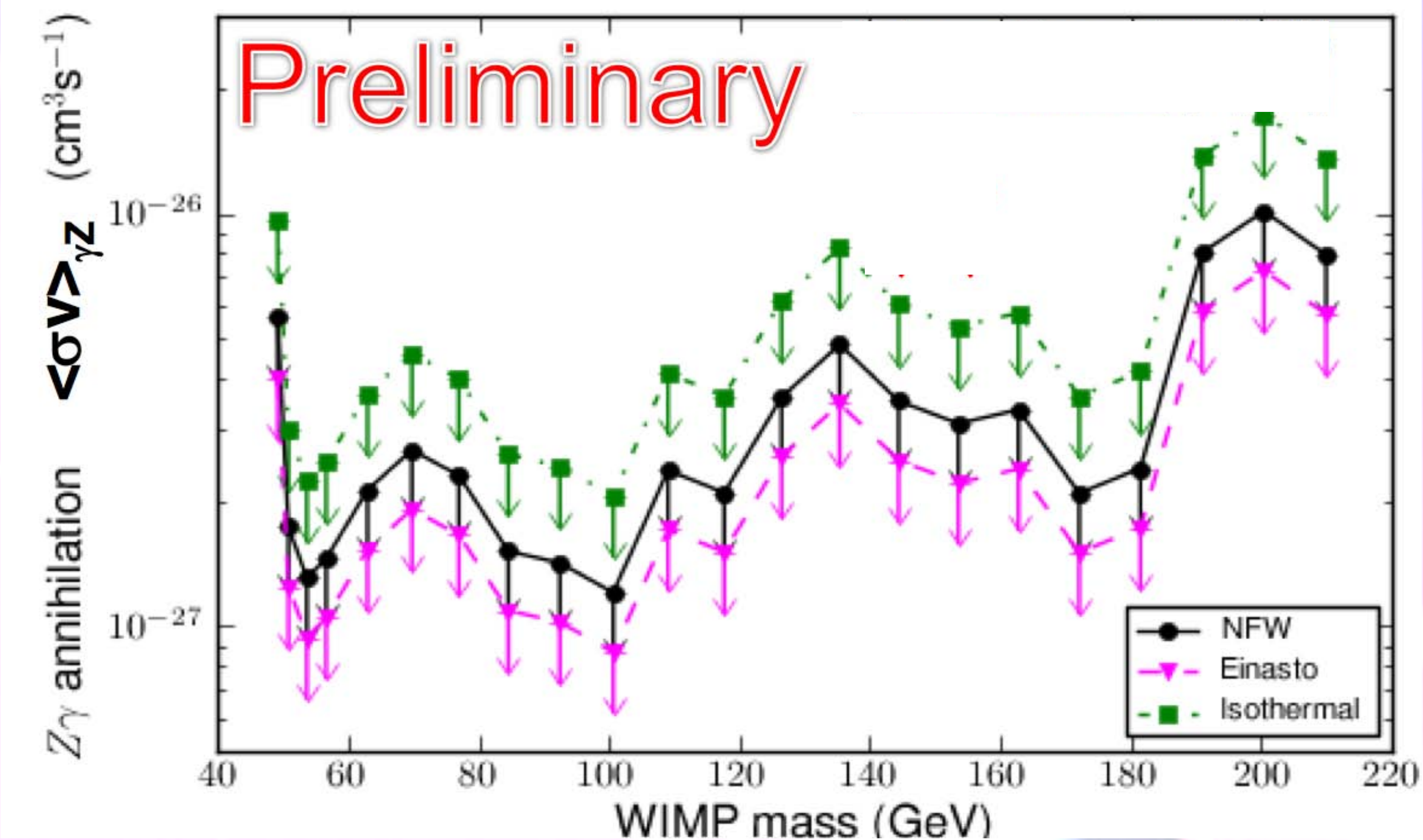
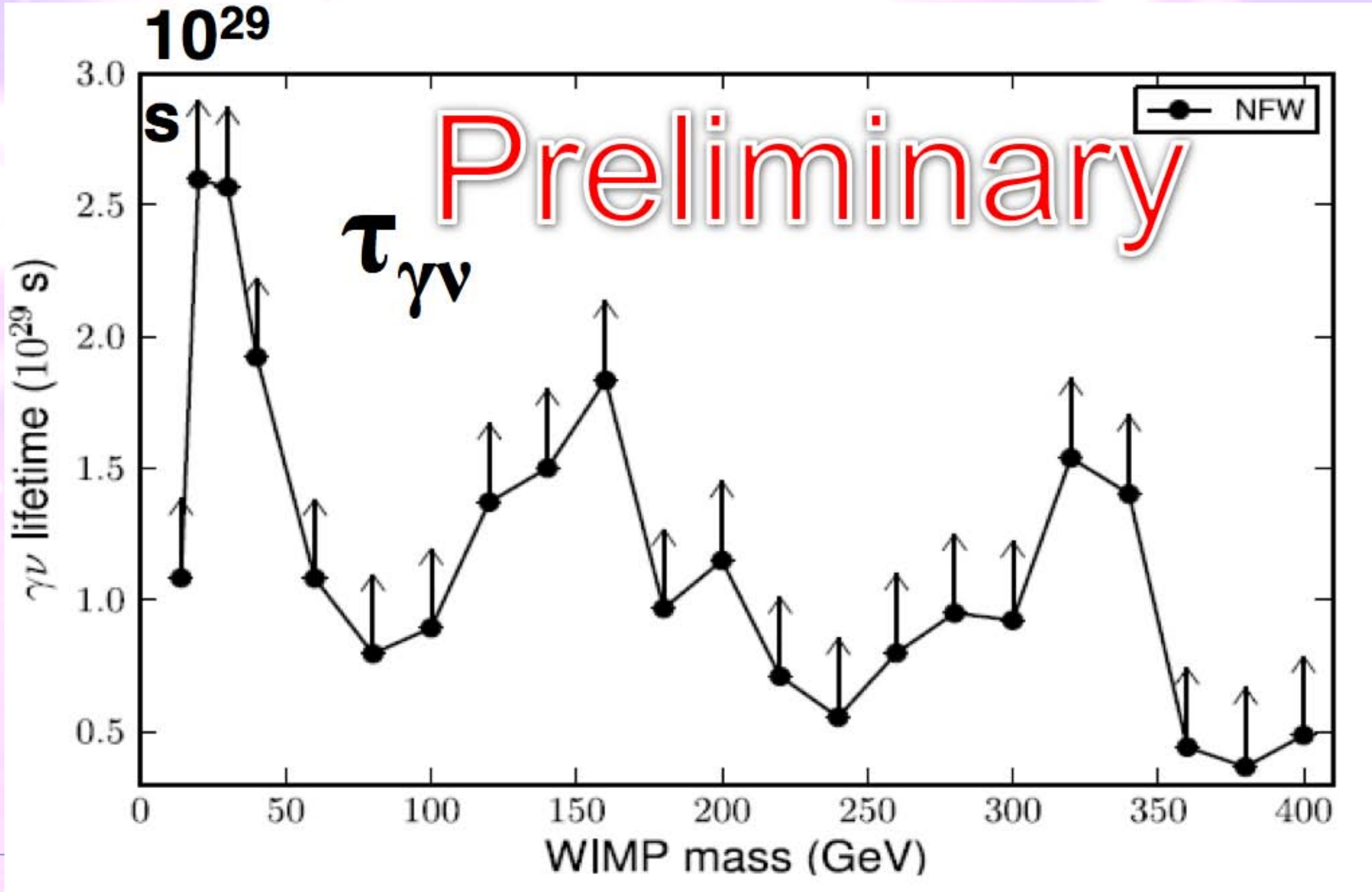
Additional systematic on spectral structures with LAT resolution for E<13.2 GeV of s/bg ~ 1%.



Decay lifetime lower limits

- Limits similar for all 3 DM density profiles due to linear dependence of flux on ρ
- Disfavors lifetimes smaller than 10^{29} s



Looking Ahead

http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

Many further improvements in instrument performance in progress

- Event reconstruction and choices of event selection “knobs” all determine instrument performance. For stability, standard event class definitions established with IRFs.
- Data were released with Pass6.
- Some known issues, described in Caveats on FSSC site and inLAT papers, addressed with patch to IRFs.
- Longer-term: Pass7 and Pass8 to address the remaining issues.
- Pass7 release imminent

Improved standard photon classes

Event analysis taking into account “ghost” events

- Working closely with FSSC on ease of use for user community.
- Exciting progress on Pass8, expected to be the ultimate version.

Future Surprises

We are just beginning...

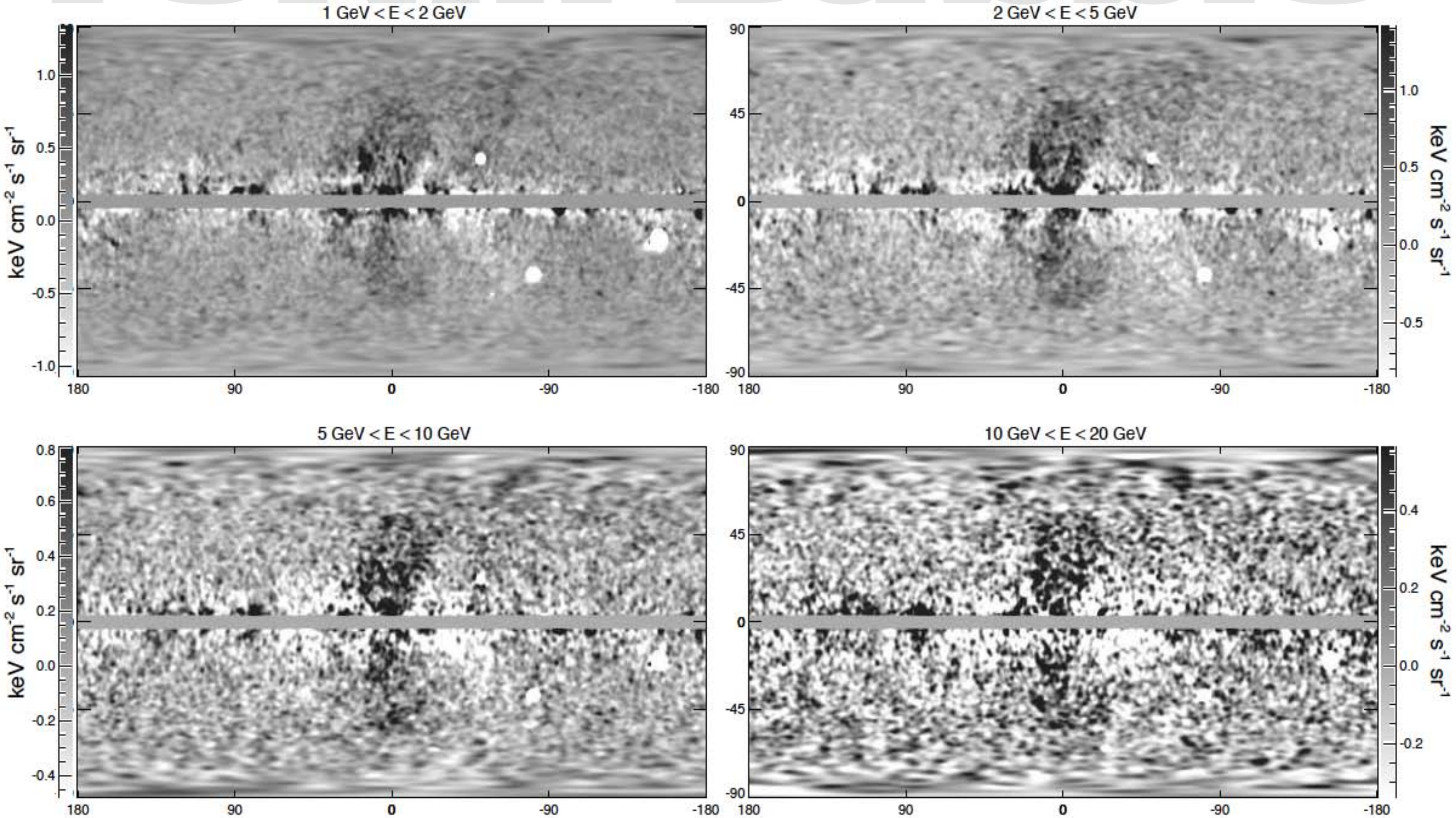
- Exposure continues to increase
  - Fainter sources become detectable
  - Increasingly detailed studies of bright sources
  - Catalogs become deeper and more detailed
- Time domain studies enter longer regimes
- Solar cycle beginning to warm up
- Plus, efforts continue to further improve performance and enhance analysis, particularly at low and high energies

The longer we look, the more surprises we will see

Liz Hays

thank you !

Data minus Fermi diffuse emission model:



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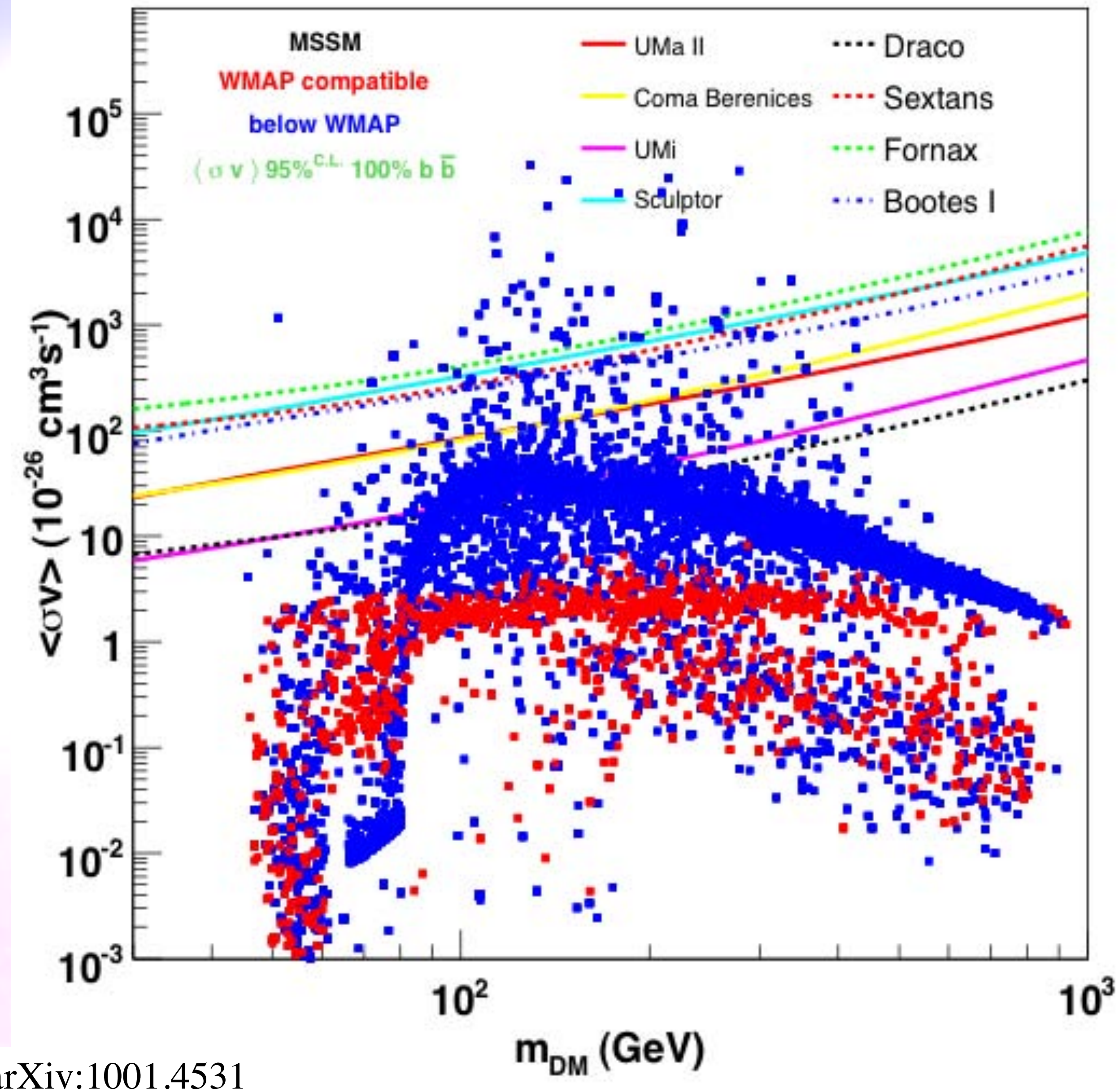


Fermi Coll. ApJ 712 (2010) 147-158 arXiv:1001.4531

greetings from the Fermi Symposium

Inverse Compton Emission and Diffusion in Dwarfs

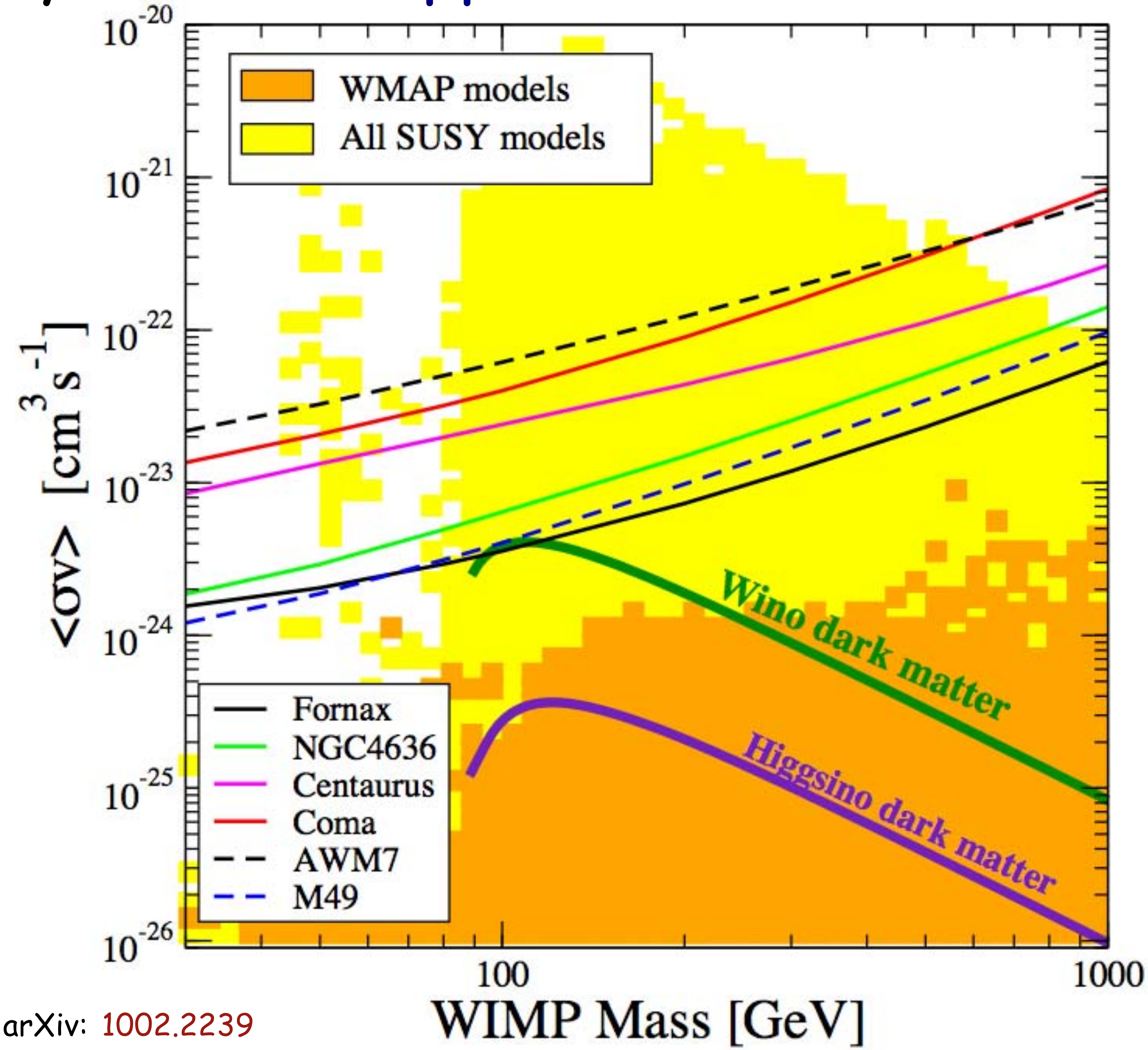
- We expect significant IC gamma-ray emission for high mass WIMP models annihilating to leptonic final states.
- The IC flux depends strongly on the uncertain/unknown diffusion of cosmic rays in dwarfs.
- We assume a simple diffusion model similar to what is found for the Milky Way

$D(E) = D_0 E^{1/3}$ with $D_0 = 10^{28}$ cm^2/s

(only galaxy with measurements, scaling to dwarfs ??)

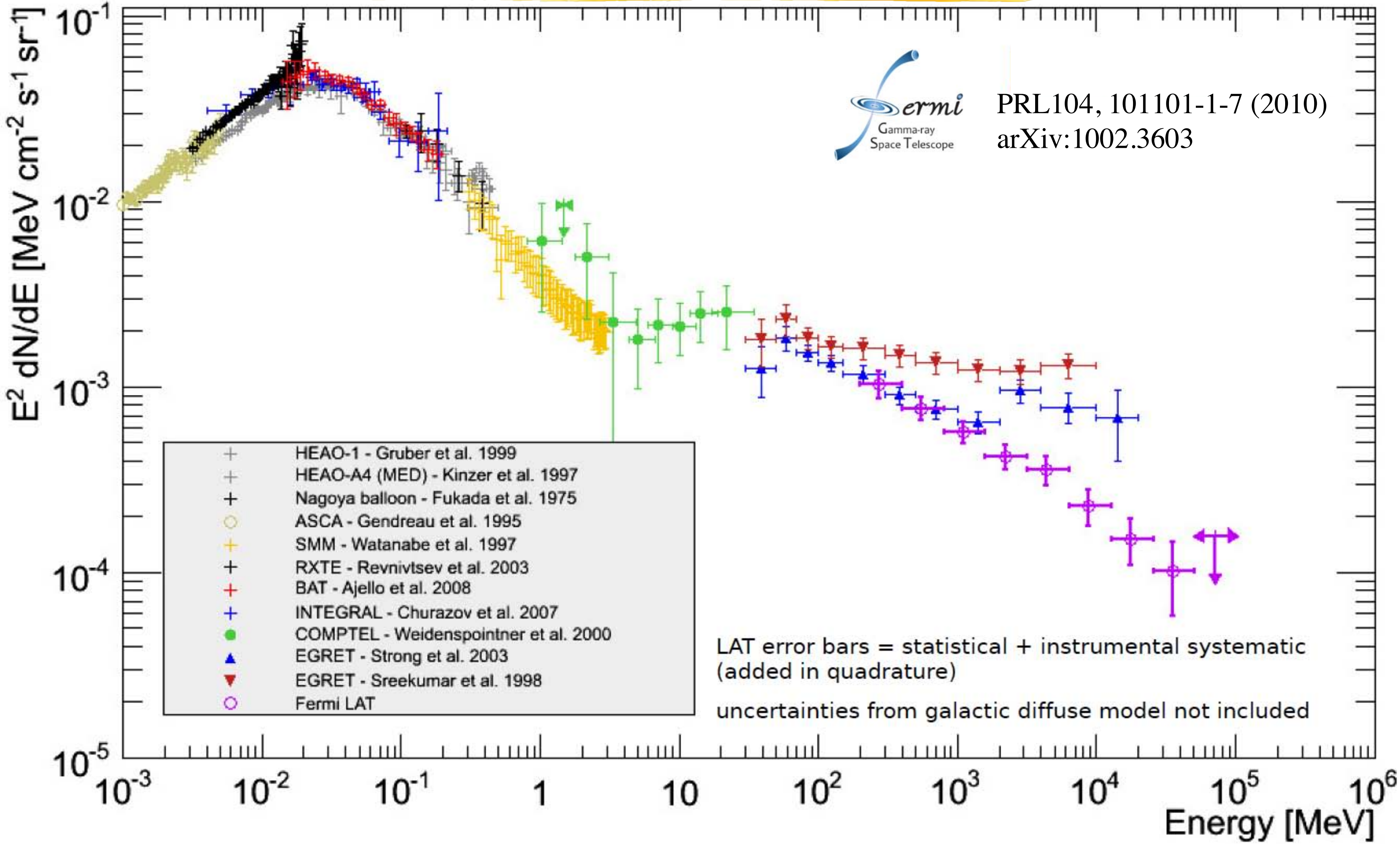
Galaxy Clusters upper-limits

- Constraints for a b-bbar final state are weaker than or comparable to (depending on the assumption on substructures) the ones obtained with dSph

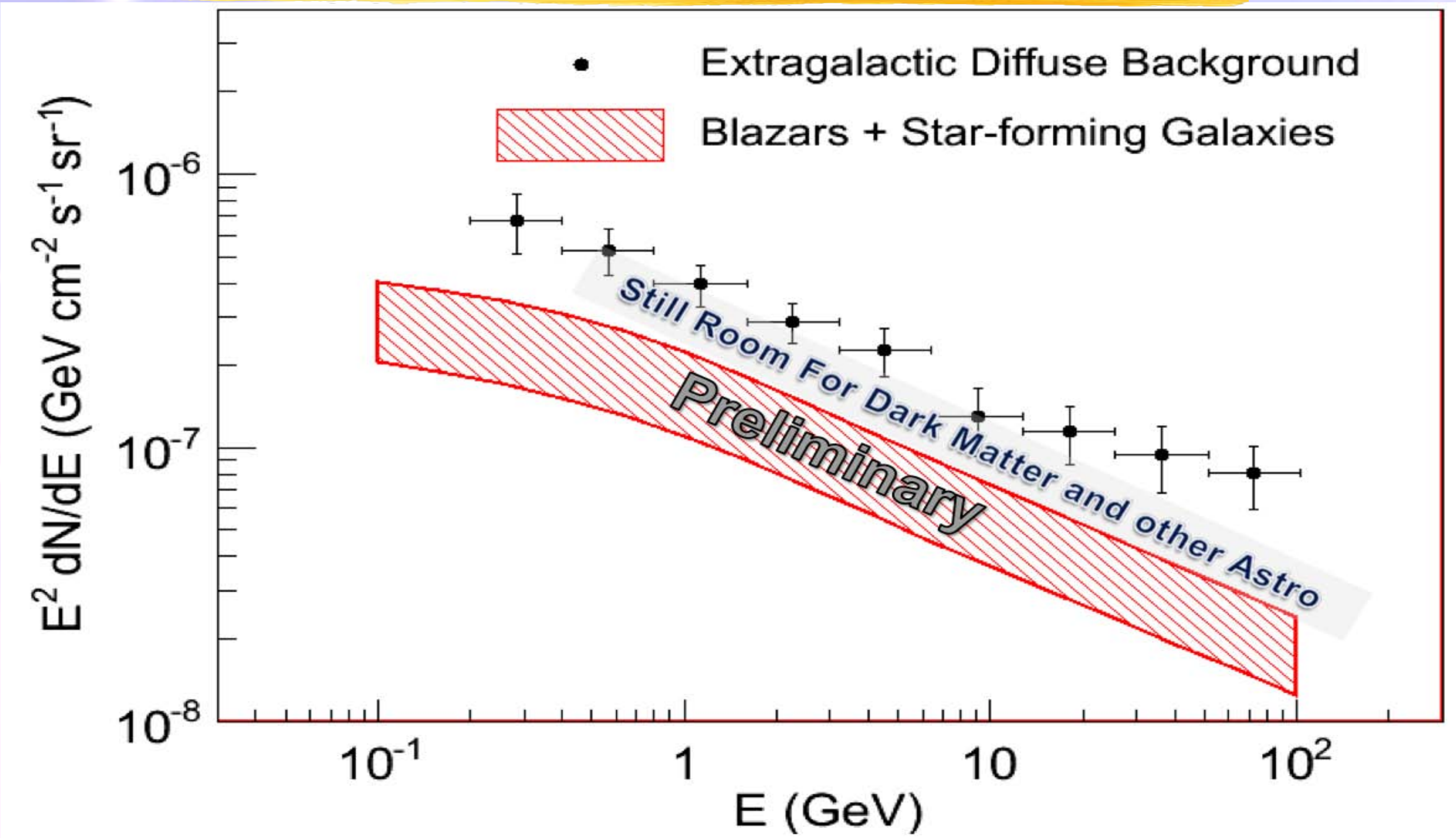


Fermi Coll. JCAP 05, 025 (2010), arXiv: 1002.2239

SED of the isotropic diffuse emission (1 keV–100 GeV)



Comparison of the Extragalactic Diffuse γ-ray Background to Calculations of Contributions from Blazars + Star-forming Galaxies

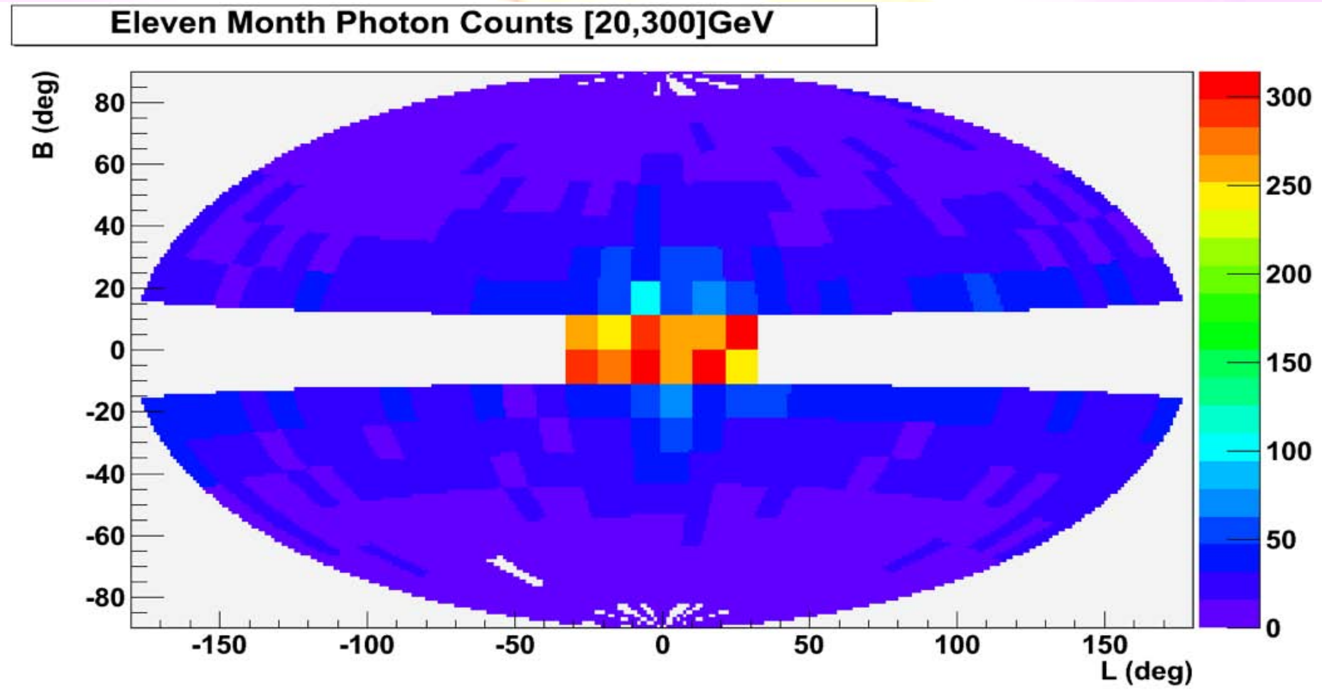


Blazars: Abdo, A. A., et al. [Fermi Coll.] 2010, ApJ. **720**, 435

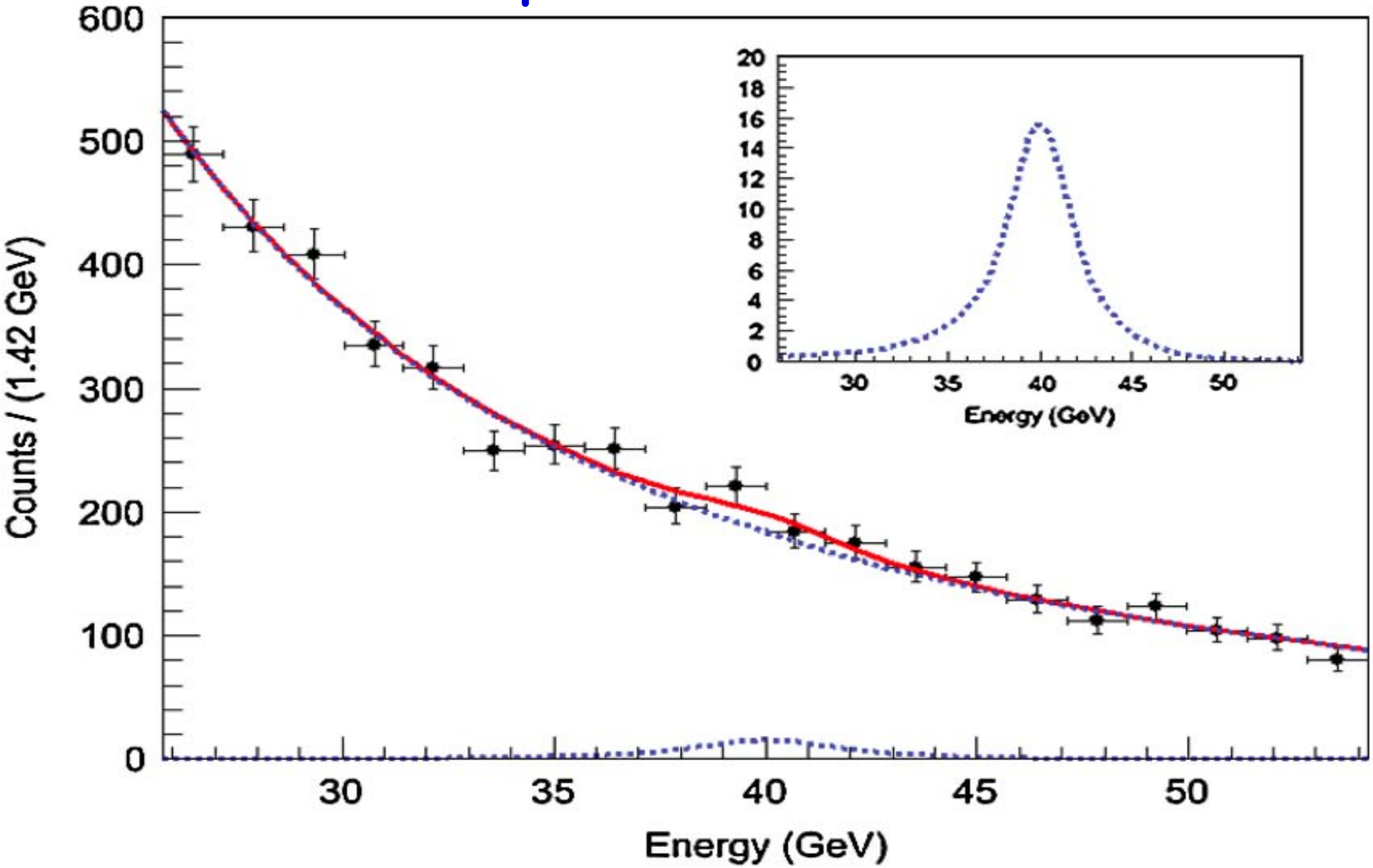
Star forming galaxies : Fermi Coll. in preparation

Search for Spectral Gamma Lines

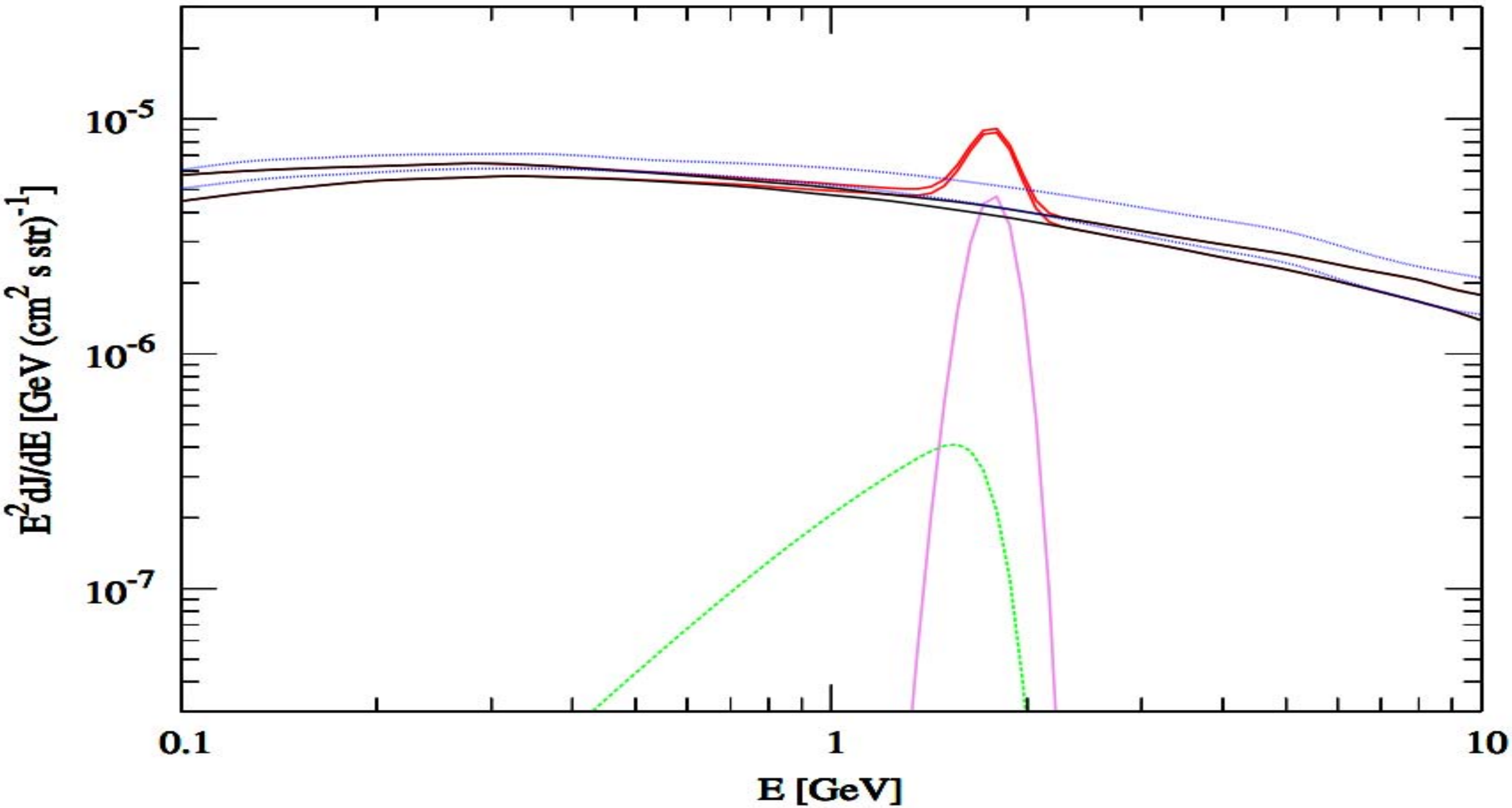
- Smoking gun signal of dark matter
- Search for lines in the first 11 months of Fermi data (30-200 GeV en.range)
- Search region $|b|>10^{o}$ and 30^{o} around galactic center
- For the region within 1^{o} of the GC, no point source removal was done as this would have removed the GC
- For the remaining part of the ROI, point sources were masked from the analysis using a circle of radius 0.2 deg
- The data selection includes additional cuts to remove residual charged particle contamination.



Wimp lines search

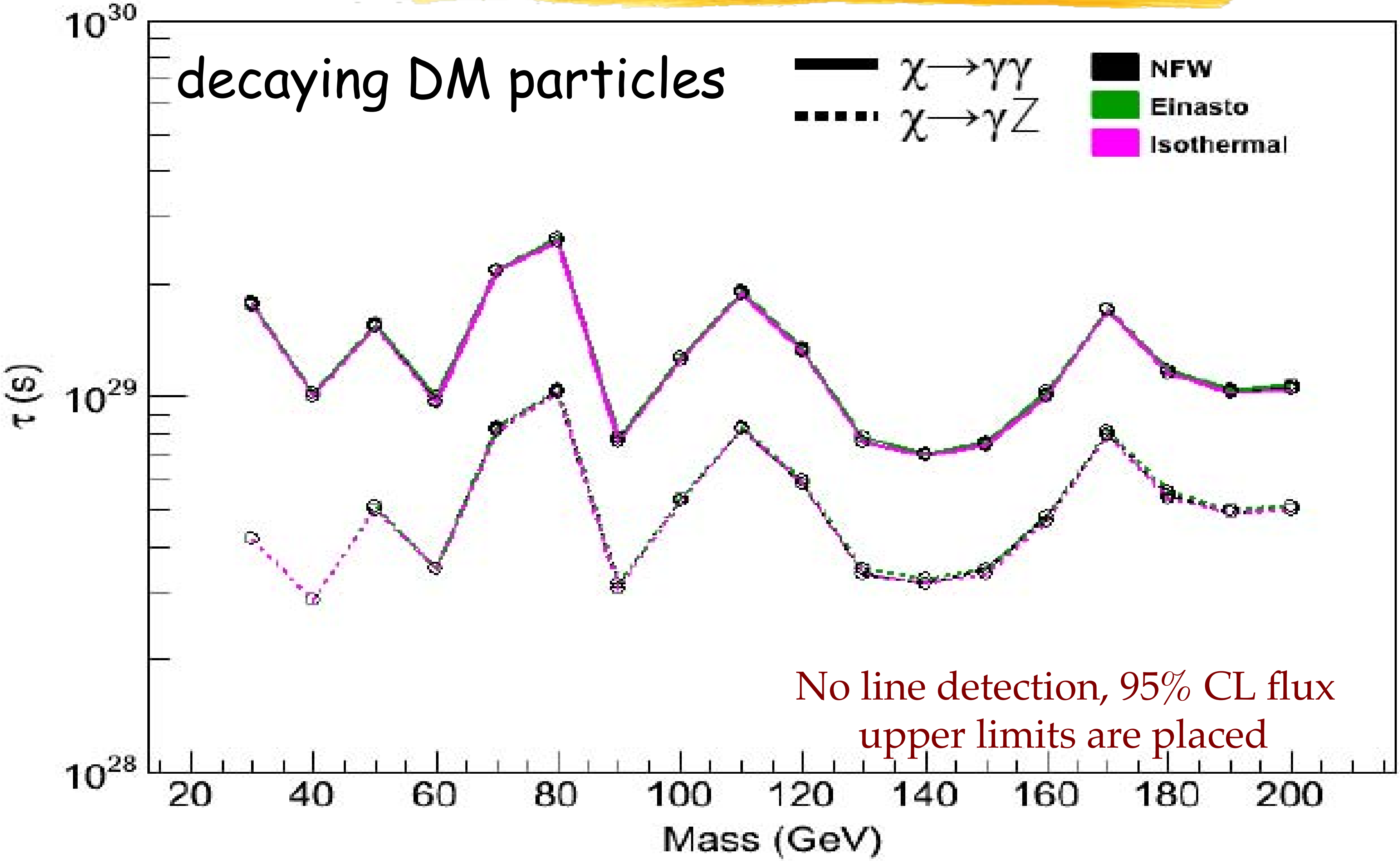


Gamma-ray detection from gravitino dark matter decay in the μνSSM



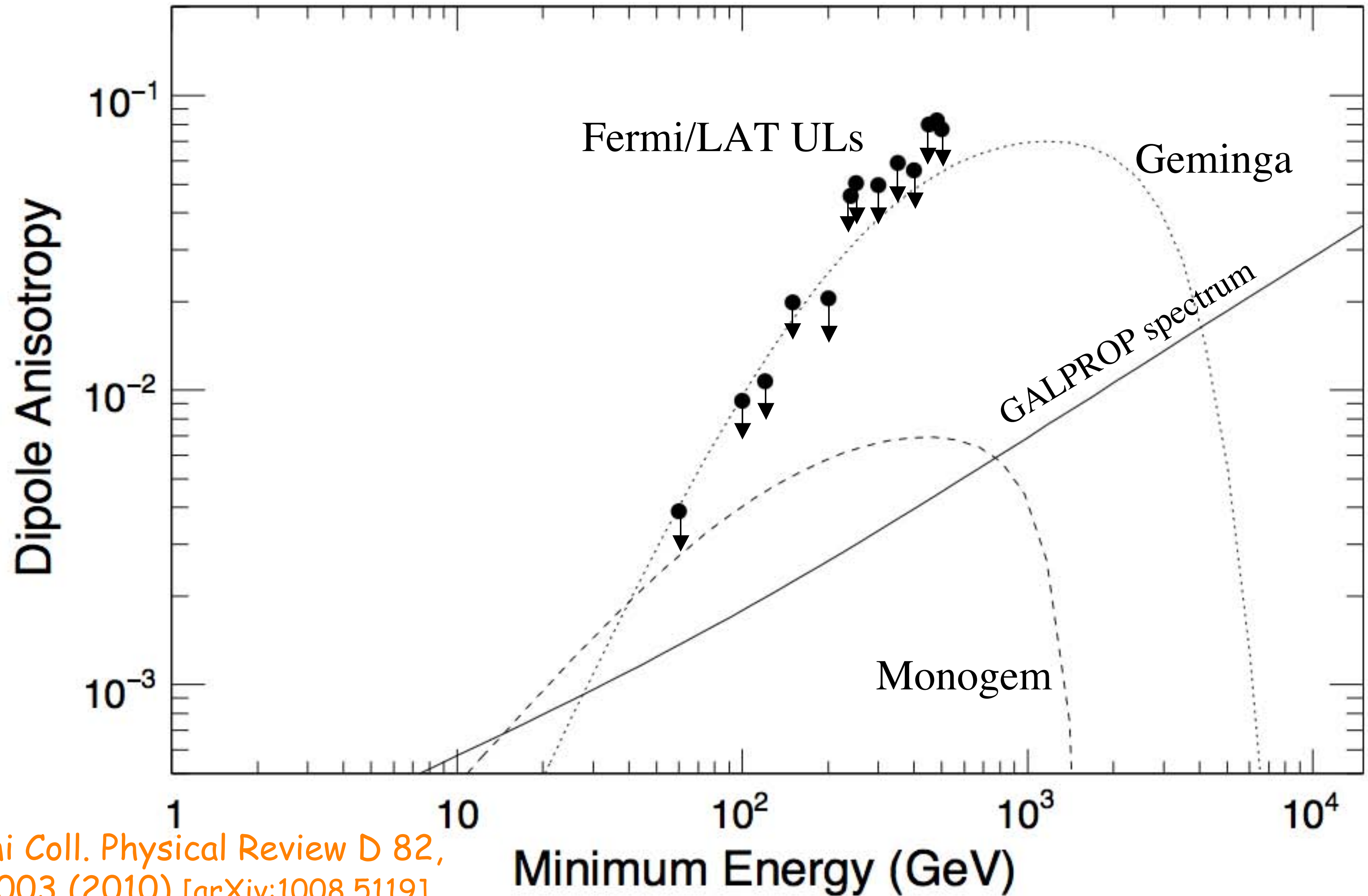
Ki-Young Choi, Daniel E.Lopez-Fogliani, Carlos Munoz, Roberto Ruiz de Austri, arXiv:0906.3681

Search for Spectral Gamma Lines



Fermi LAT Coll. PRL 104, 091302-08 (2010), arXiv:1001.4836

electron + positron expected anisotropy in the directions of Monogem and Geminga



Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

Conclusion:

The Electron+positron spectrum (CRE) measured by Fermi-LAT is significantly harder than previously thought on the basis of previous data

Adopting the presence of an extra e^+ primary component with ~ 1.5 spectral index and E_{cut} ~ 1 TeV allow to consistently interpret Fermi-LAT CRE data (improving the fit), HESS and PAMELA

Such extra-component can be arise if the secondary production takes place in the same region where cosmic rays are being accelerated (to be tested with future B/C measurements)

- or by pulsars for a reasonable choice of relevant parameters (to be tested with future Fermi pulsars measurements)
- or by annihilating dark matter for model with $M_{DM} \approx 1$ TeV

- Improved analysis and complementary observations

(CRE **anisotropy**, spectrum and angular distribution of diffuse γ, DM sources search in γ) are required to possibly discriminate the right scenario.

2nd Conclusion : Gamma

- No discovery (yet)....
- .... however promising constraints on the nature of DM have been placed

(exclusion of a lot of DM models that explain the origin of the Fermi/Pamela lepton excess)

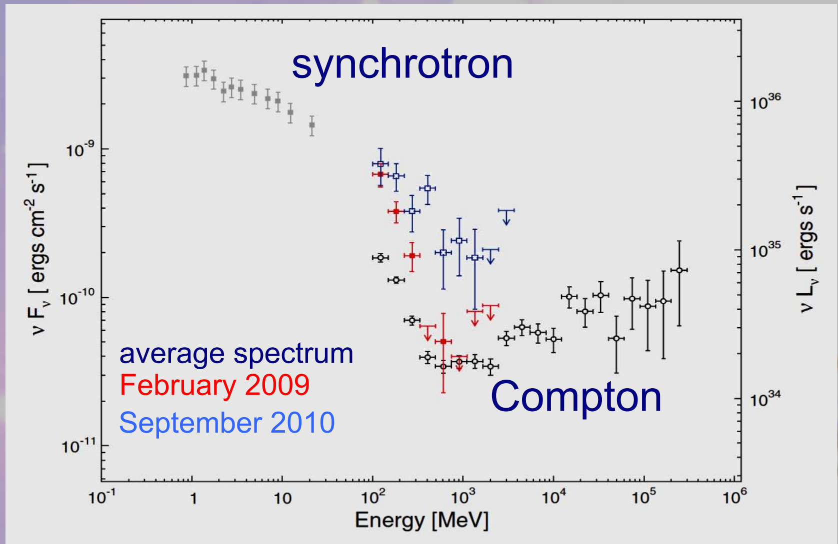
- In addition to increased statistics, better understanding of the astrophysical and instrumental background will improve our ability to reliably extract a potential signal of new physics or set stronger constraints
- Further improvements are anticipated for analysis that benefits from multi-wavelength observations (for example galactic center, dwarf spheroidal galaxies and DM satellites)

Gamma-ray flares from the Crab Nebula

Science **331,** 817 (2010); also seen by AGILE

1st reports of variability of high-energy γ-ray emission from Crab nebula

Spectral energy distribution (25 months)

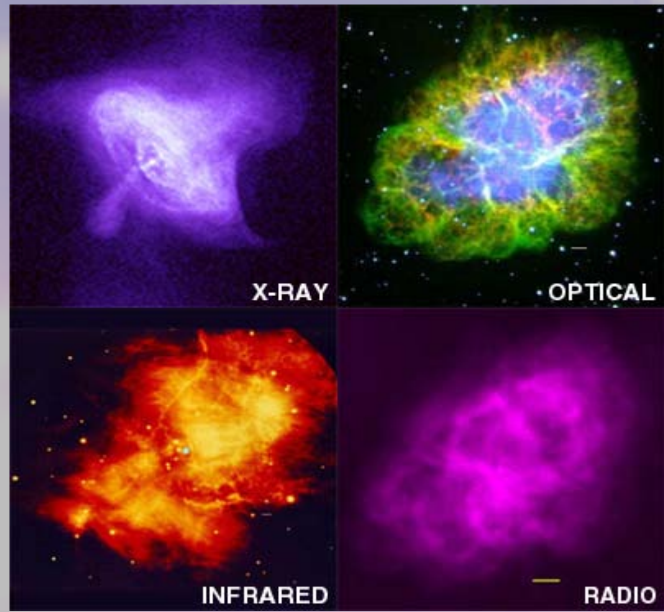


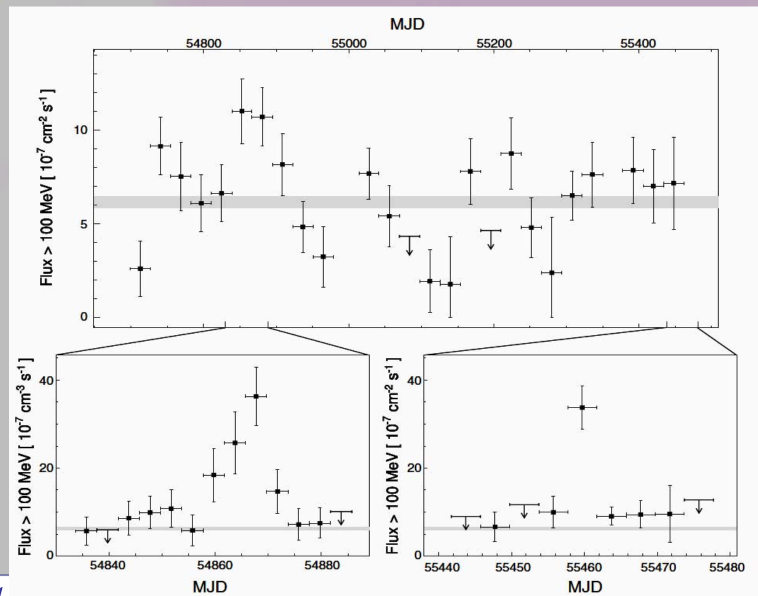
brief flare time scales (4 days) imply compact flaring region:

$L < Dct < 1.4\text{x}10^{-2}$ pc

(1.5 arcsec)

Structures this small only found in inner part of nebula, close to the pulsar wind termination shock, the base of the jet, or the pulsar.





spectrum and short flare time scales imply that **emission is synchrotron radiation** (electron cooling timescales for IC emission & bremsstrahlung ≥ 10^7 yr.)

detection of synchrotron photons up to ≥ 1 GeV implies electrons accelerated to ≥ 1 PeV in the nebula.

efficiency of synchrotron losses requires a strong electric field to compensate; severe difficulties for diffusive shock acceleration mechanism.

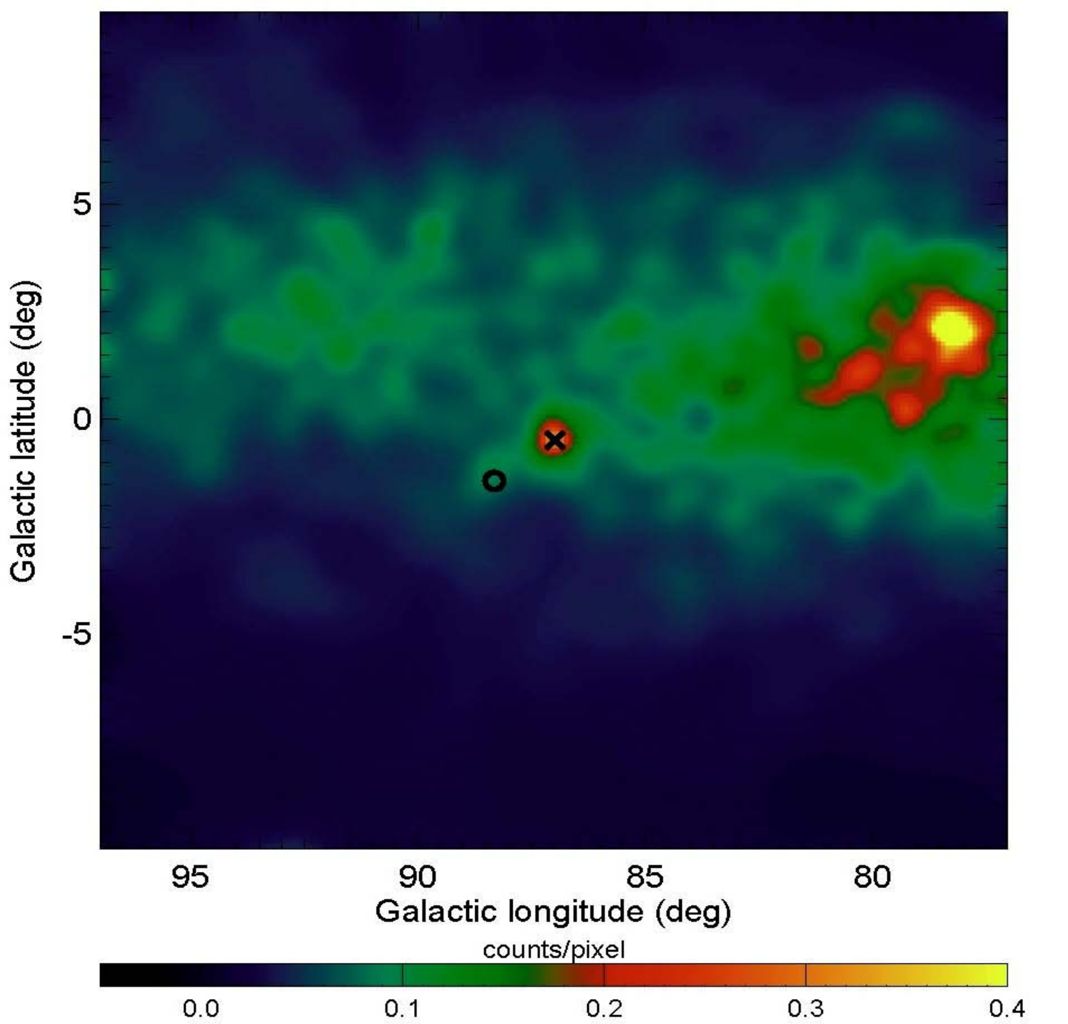
Fermi LAT discovery of galactic transient: Nova in the Symbiotic Binary V407 Cygni

Science ***329, 817*** **(2010*)***

- Found in routine LAT processing for transients
- Initially, counterpart was unknown

Later developments established this was:

- first gamma-ray detection of any nova
- first detection of high-energy gamma-ray emission associated with a white dwarf



RA 21 02 09.81 Dec +45 46 33.0

Galactic latitude -0.5 deg

Distance: ~ 2.7 kpc

System = RG + WD

RG: Mira-like, M6 III, with anomalous Li abundance

Orbital period of system not certain

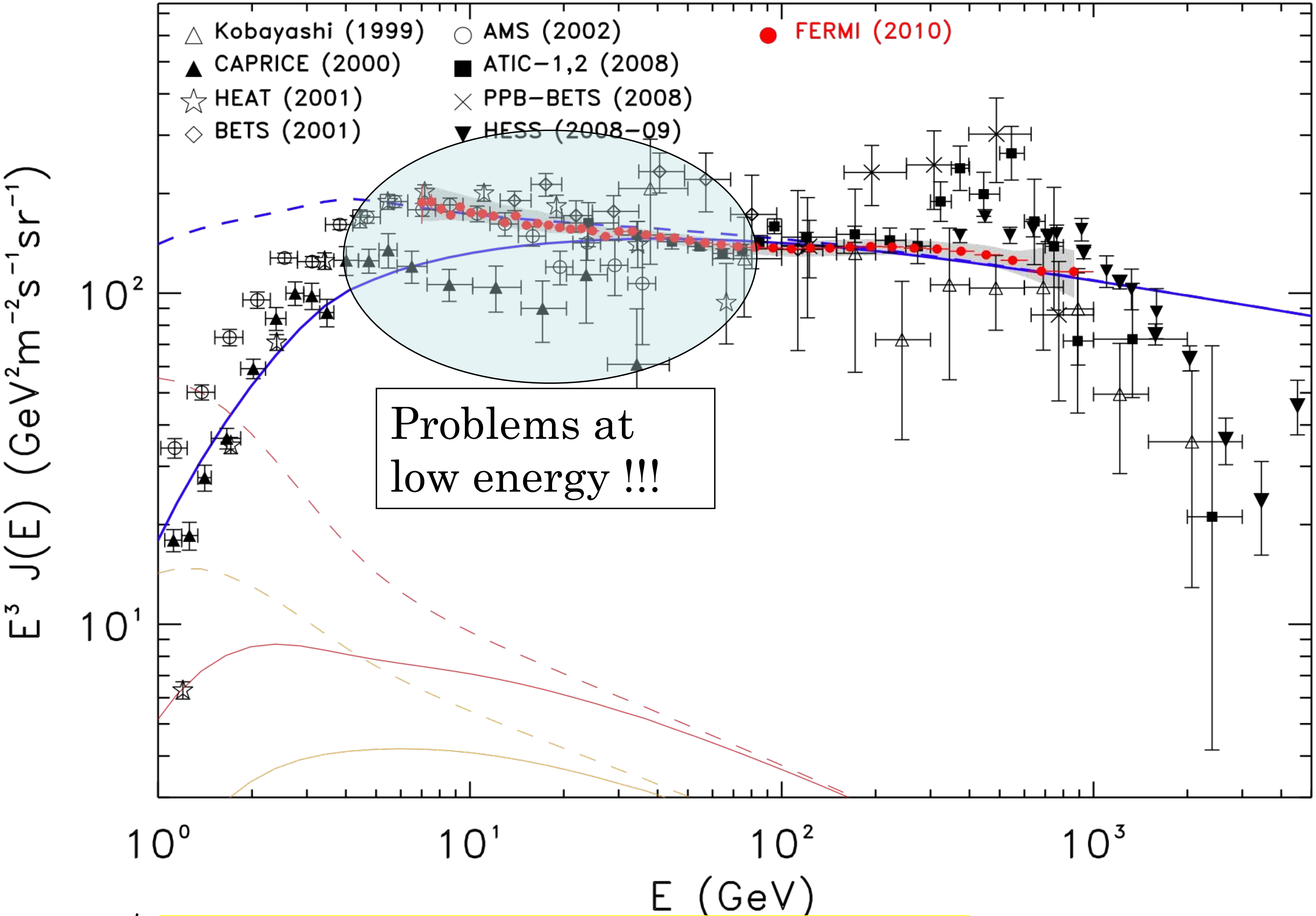
optical nova discovery March 10, 2010 (peak mag. ~7)
gamma-ray peak: March 13-14, 2010

Neutralino WIMPs

Assume χ present in the galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) is an interesting signature
- ie: χ χ --> anti p + X
- Produced from (e. g.) χ χ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

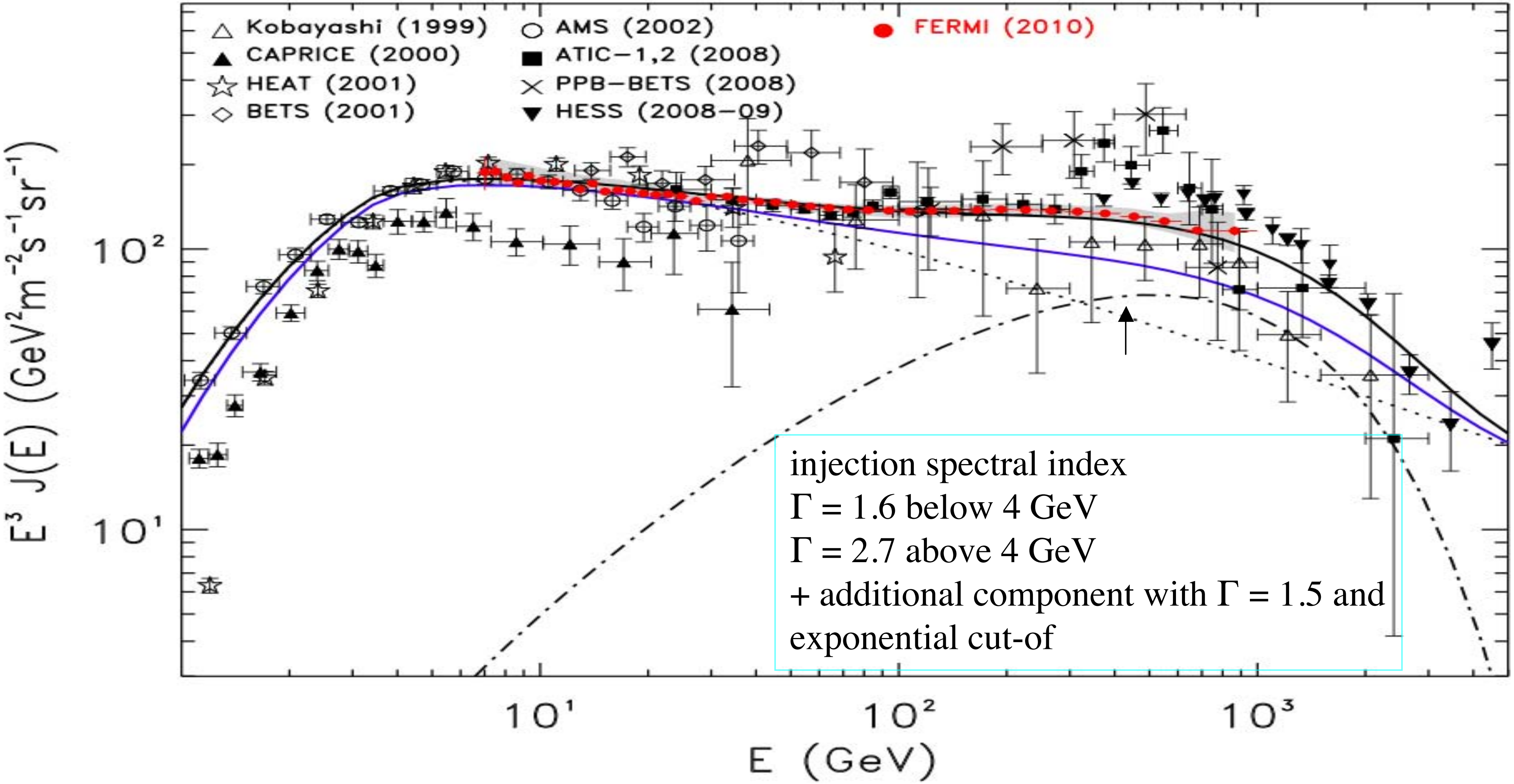
New Fermi-LAT data



Problems at low energy !!!

Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

Electron spectrum and a conventional GALPROP model +...



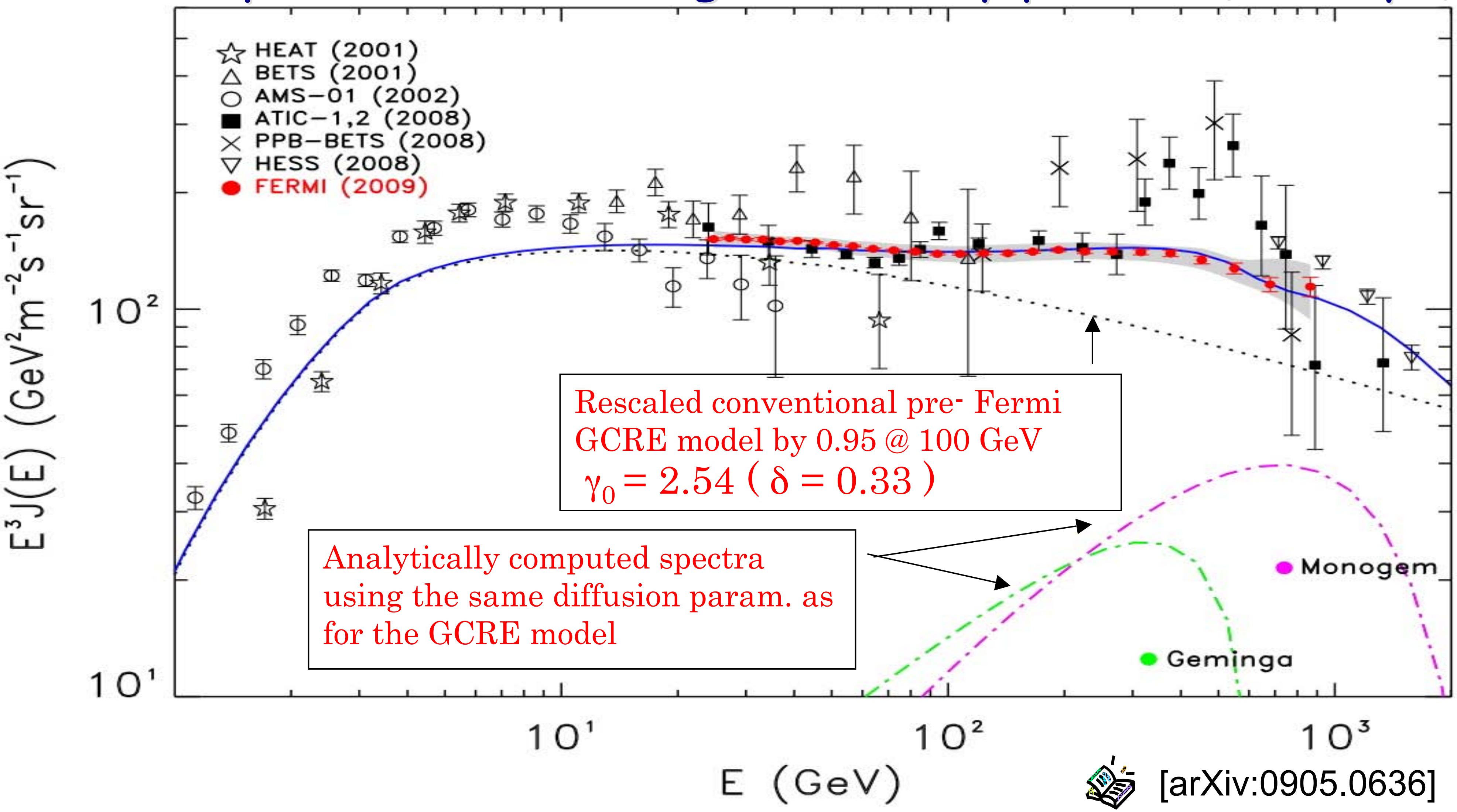
Hard to get a good fit with a single-component diffusive model

Good fit possible with an additional high-energy component

If it is an e+/e− (e. g. nearby pulsars or dark matter), the Fermi spectrum and Pamela positron fraction can be simultaneously fitted

Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

The CRE spectrum accounting for nearby pulsars (d < 1 kpc)

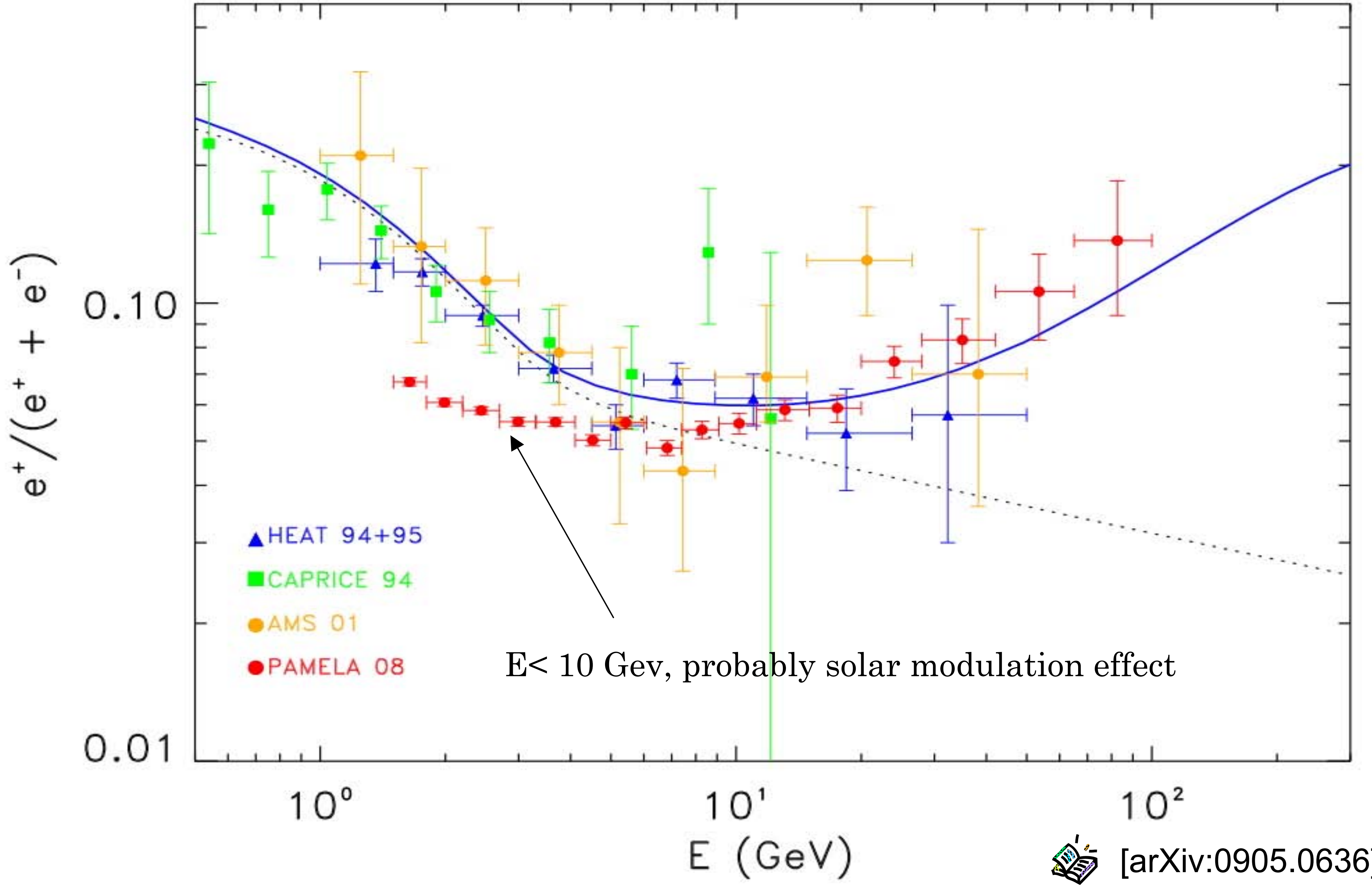


[arXiv:0905.0636]

This particular model assumes: 40% $e^{\pm}$ conversion efficiency for each pulsar

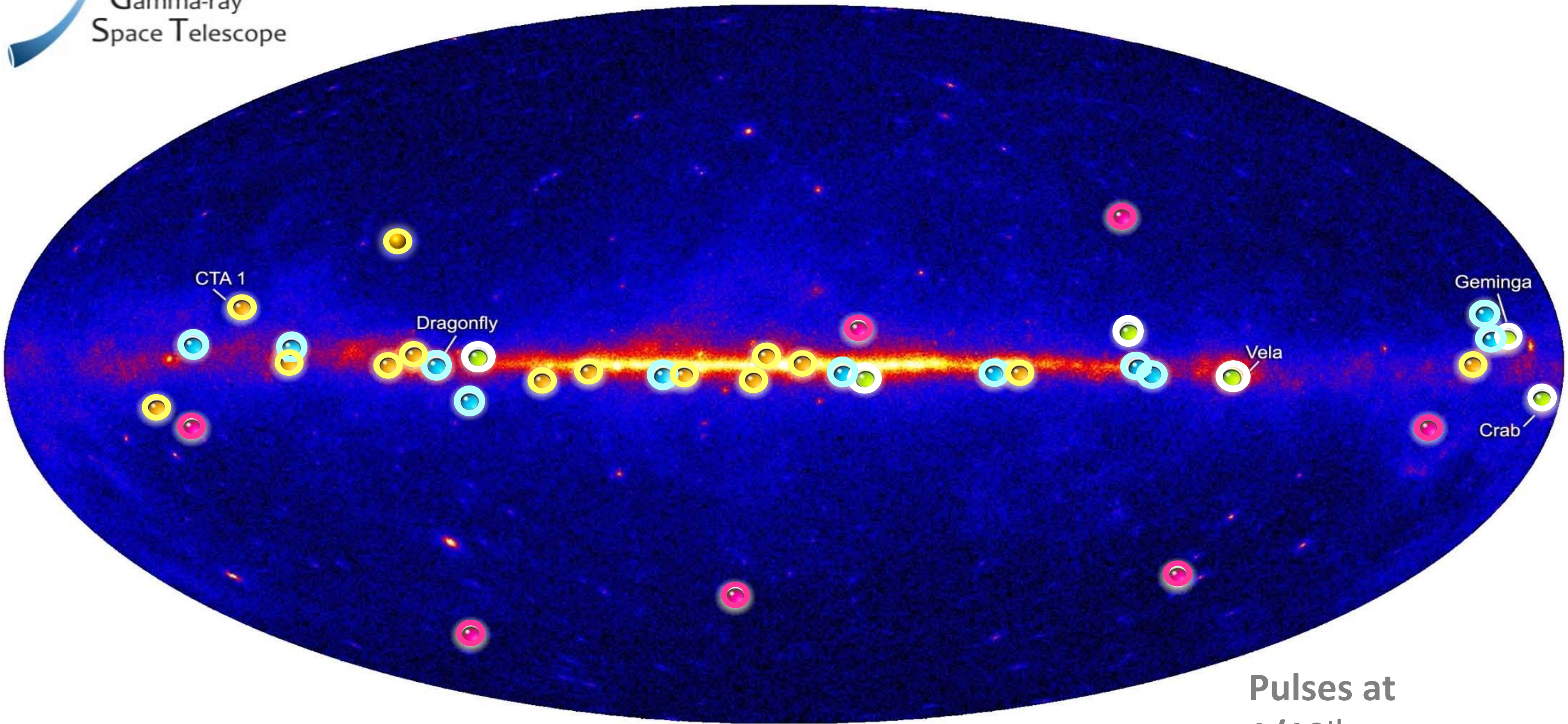
- pulsar spectral index $\Gamma = 1.7$ $E_{cut} = 1$ TeV . Delay = 60 kyr

the positron ratio accounting for nearby pulsars (d < 1 kpc)



[arXiv:0905.0636]

65 Gamma-Ray Pulsars, with 24 from blind searches



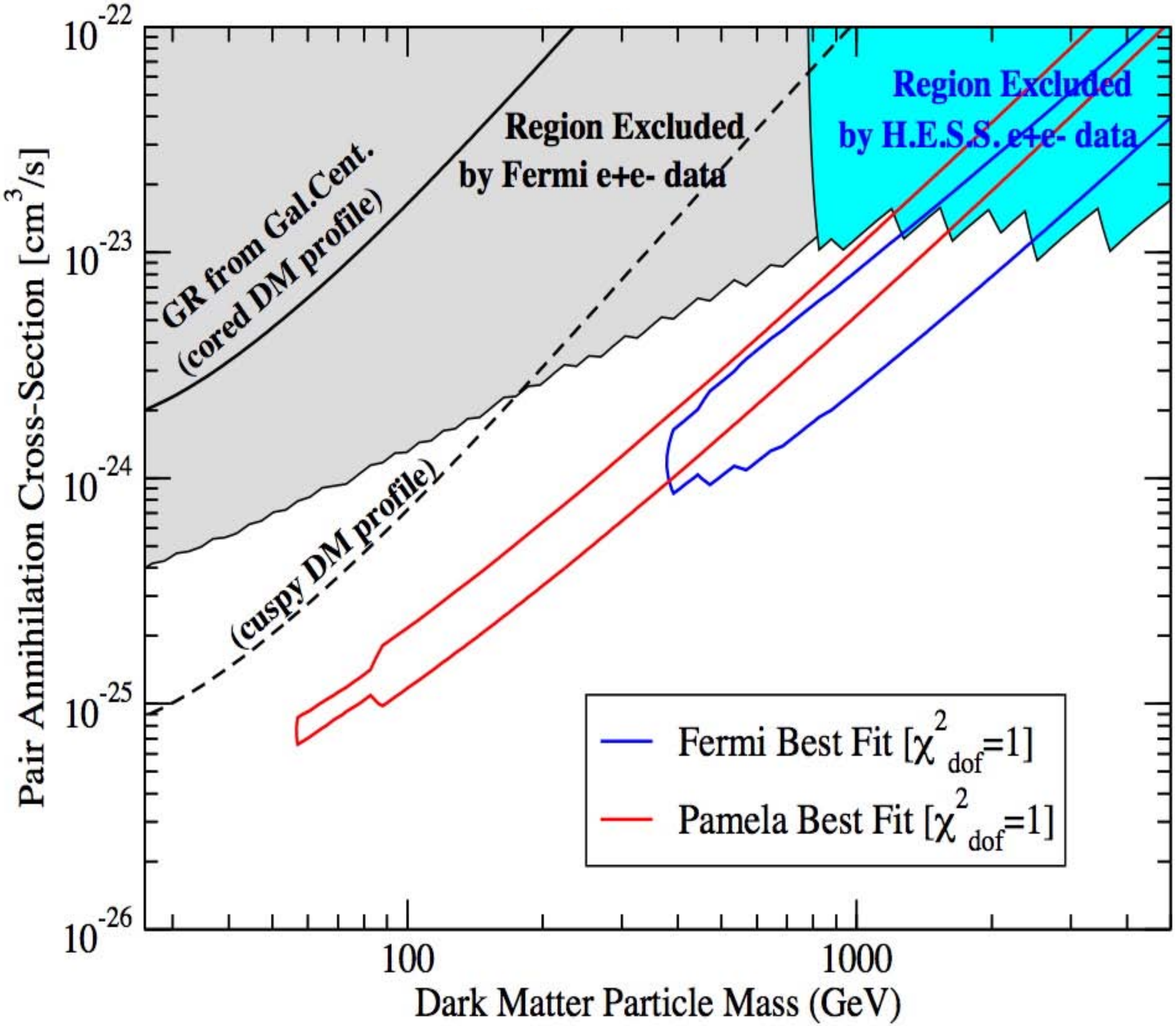
Pulses at
1/10th true rate

The Pulsing γ-ray Sky

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+τ- Here too antiprotons are not produced in dark matter pair annihilation.

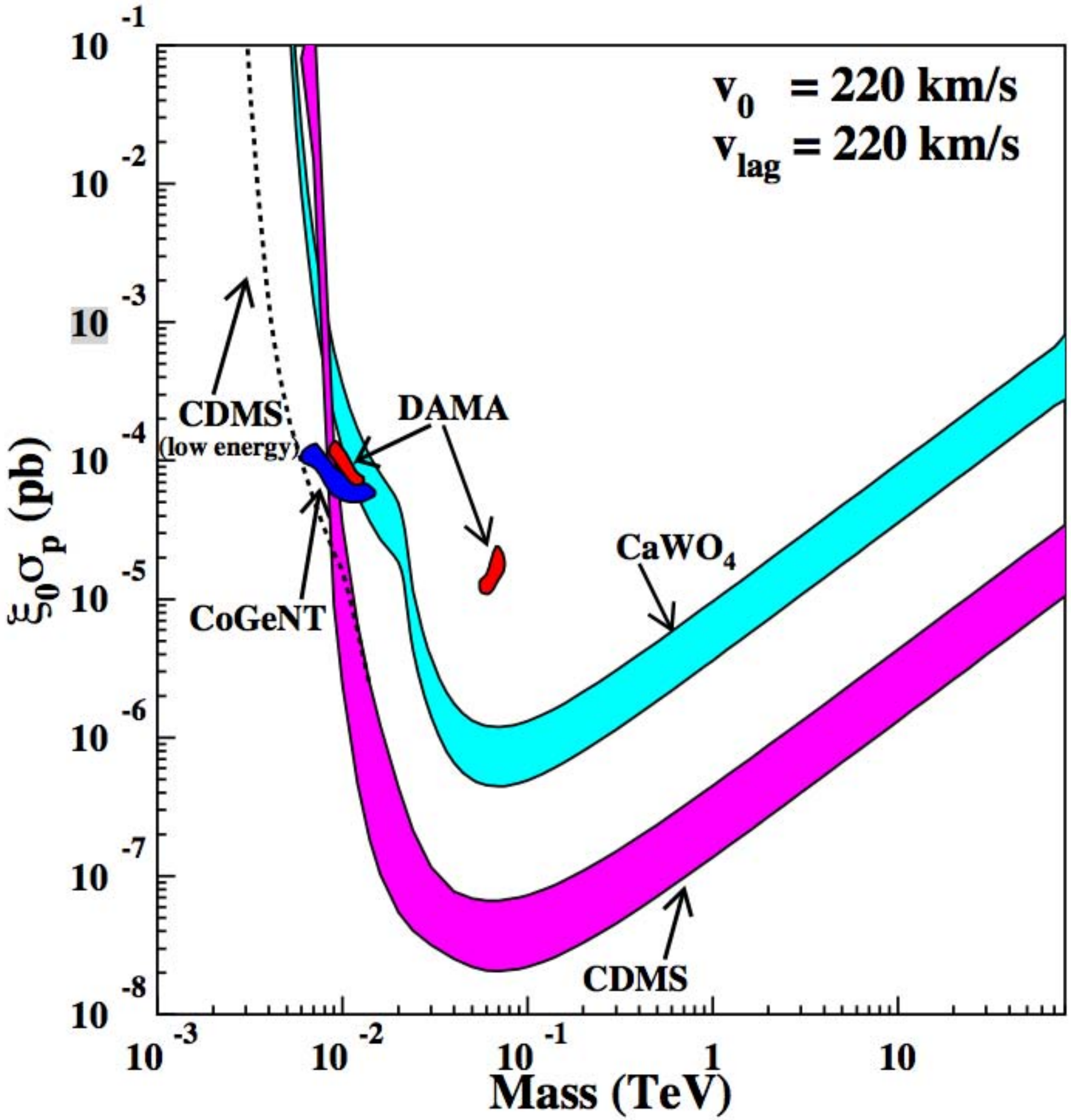


[arXiv:0905.0636]

Direct searches

Allowed configurations at 2σ C.L. obtained for a isothermal halo model with v_0 =220 km/s and v_{lag} = 220 km/s.

$$\xi_0 = \frac{\rho_{DM}}{0.3GeV/cm^3}$$

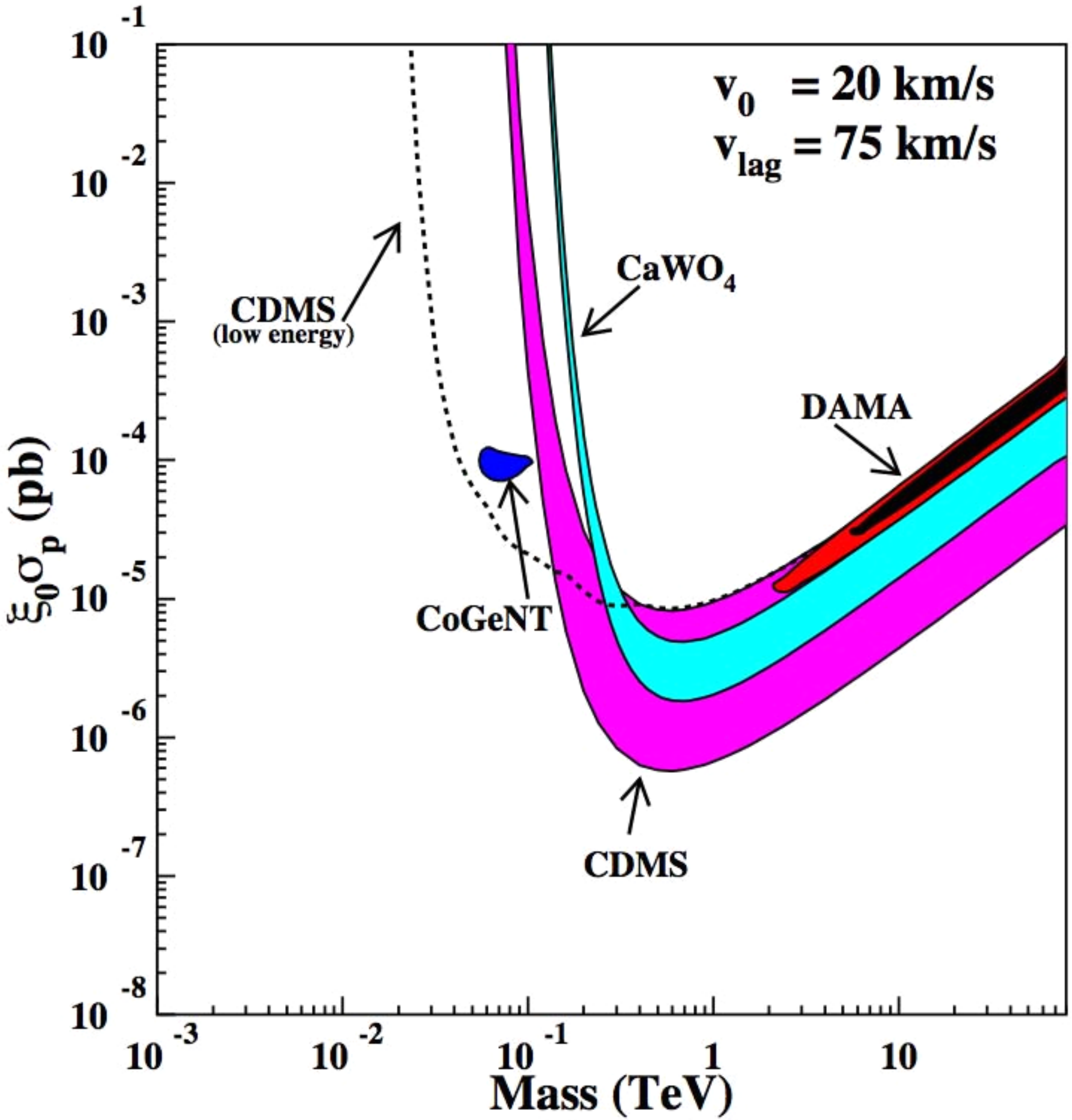


[arXiv:1103.6091]

Direct searches

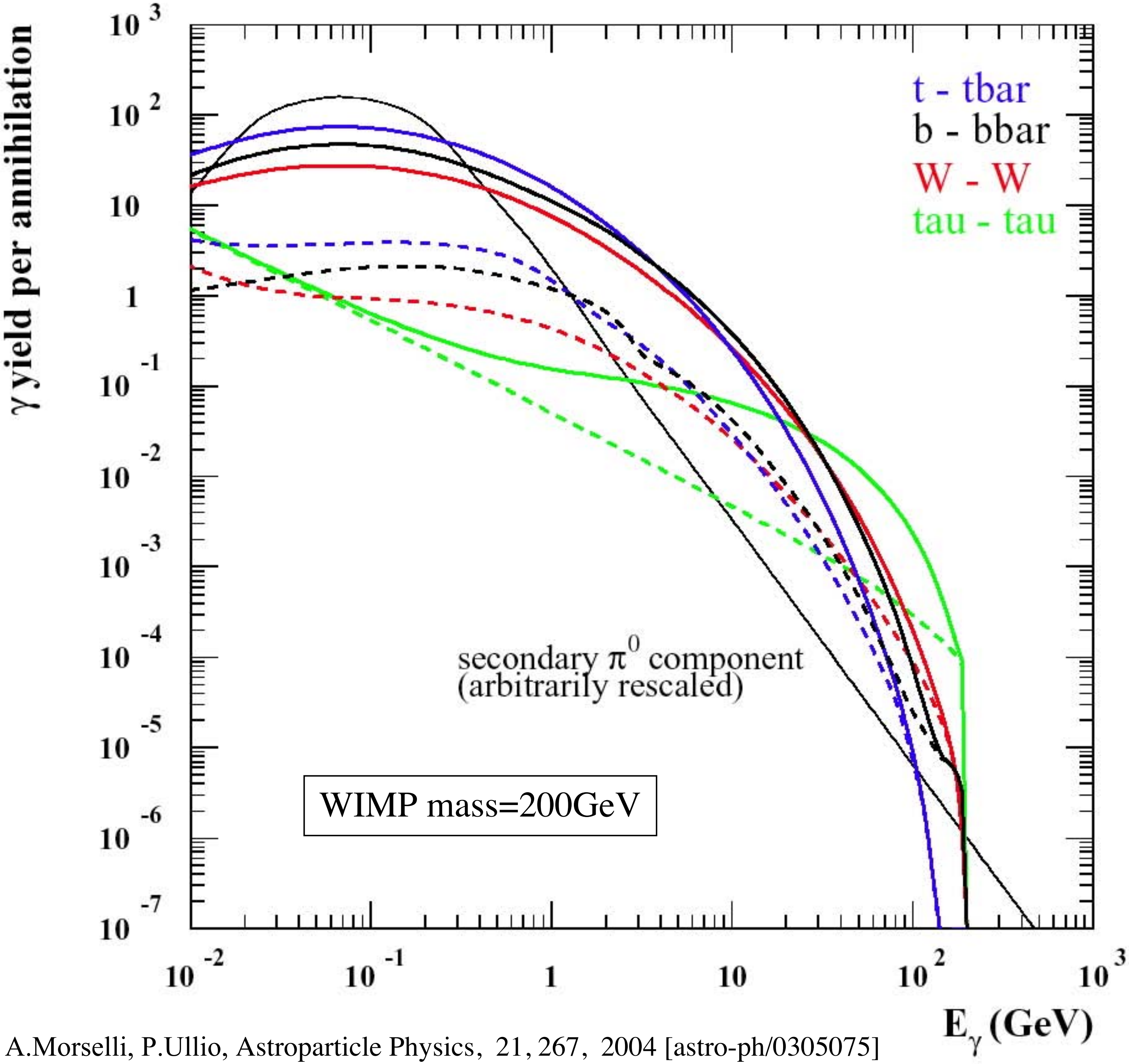
Allowed configurations at 2σ C.L. obtained for a cold corotating halo with v_0 =20 km/s and v_{lag} = 75 km/s.

The black filled area inside the DAMA region marks the configurations allowed at 1σ C.L.



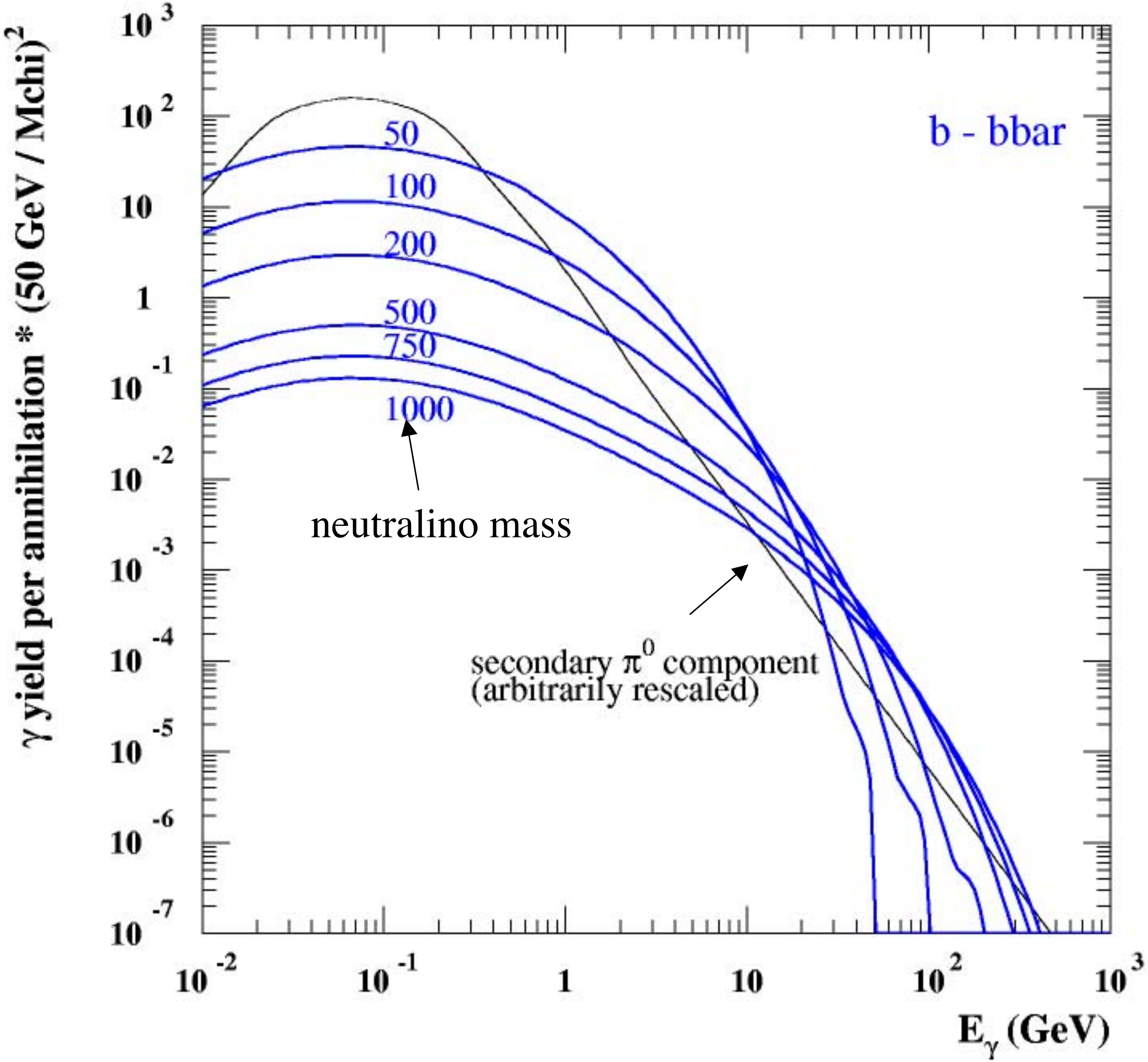
[arXiv:1103.6091]

Differential yield for each annihilation channel



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

Differential yield for b bar



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Search for Dark Matter in the Galactic Center

- Steep DM profiles ⇒ Expect large DM annihilation/decay signal from the GC!
- Good understanding of the astrophysical background is crucial to extract a potential DM signal from this complicated region of the sky:
  - source confusion: energetic sources near to or in the line of sight of the GC
  - diffuse emission modeling: uncertainties on the intensity and spectra of the CRs and distribution of gas and radiation field targets along the line of sight

GRB's Fermi detections

Bottom line

- The broad band spectra seen by Fermi **does not** fit into any of the frameworks of existing models.
- Fermi results forces us to re-think of questions that were thought to be solved.

Preliminary Analysis

7° x 7° Region Of Interest centered at RA=266.46° Dec=-28.97°

- 11 months of data
- events from 400 MeV to 100 GeV
- IRFs Pass6_v3
- Diffuse Class events, converting in the front part of the tracker
- Model of the Galactic Center includes:
- 11 sources from Fermi 1st year Catalog (inside or very near the ROI)
- Galactic and Extragalactic Diffuse Background
- Binned likelihood analysis using the GTLIKE tool, developed by the Fermi/LAT collaboration

Search for Dark Matter in the Galactic Center

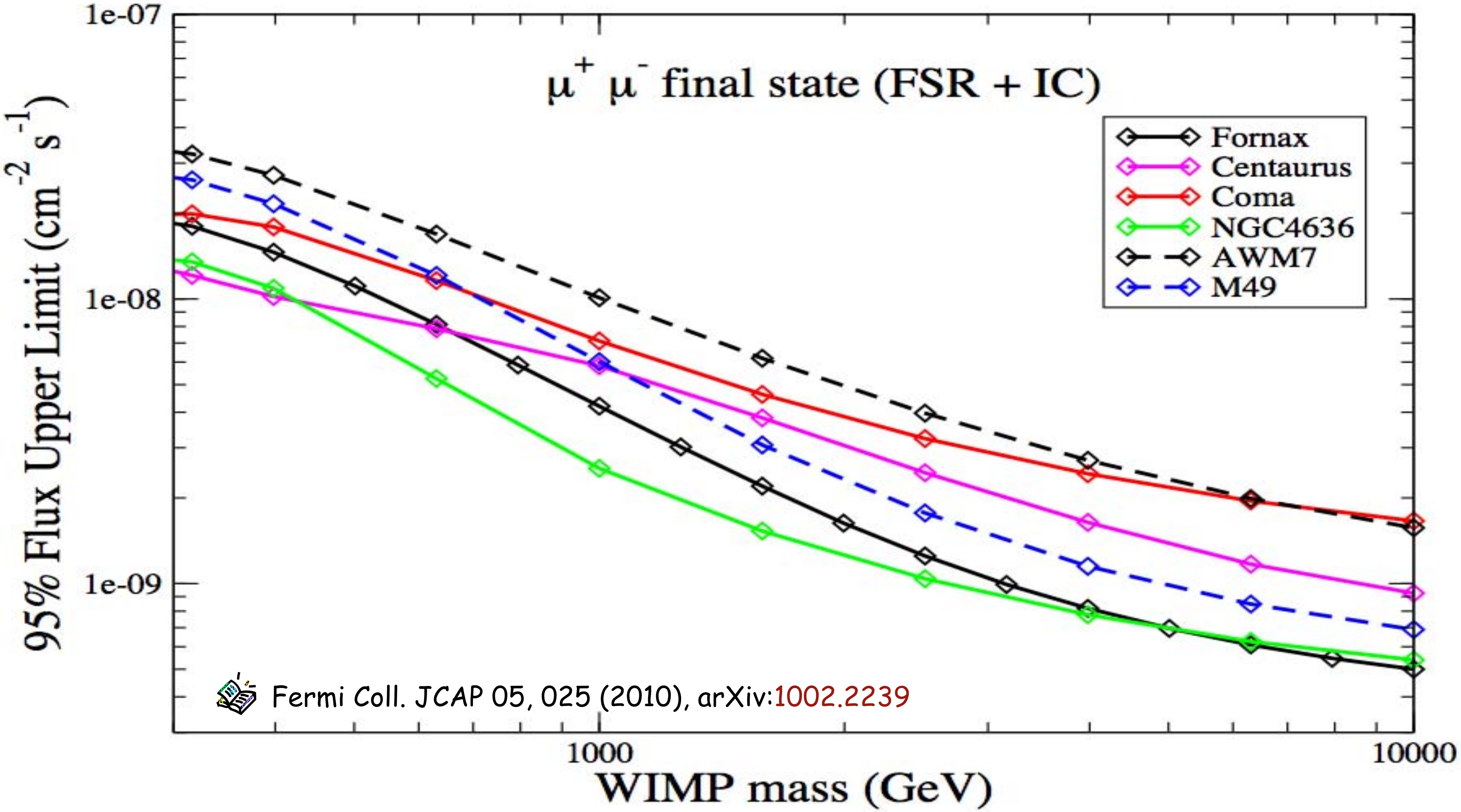
- Model generally reproduces data well within uncertainties. The model somewhat under-predicts the data in the few GeV range (spatial residuals under investigation)

- Any attempt to disentangle a potential dark matter signal from the galactic center region requires a detailed understanding of the conventional astrophysics and instrumental effects

- More prosaic explanations must be ruled out before invoking a contribution from dark matter if an excess is found (e.g. modeling of the diffuse emission, unresolved sources, ...)

- Analysis in progress to updated constraints on annihilation cross section

Galaxy Clusters upper-limits



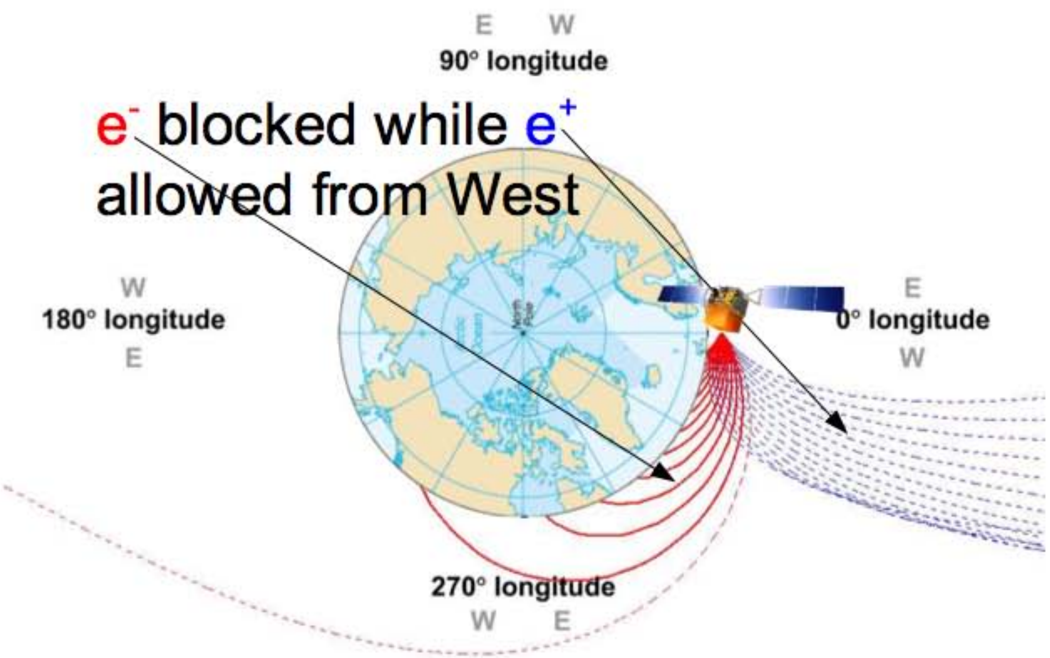
Fermi Coll. JCAP 05, 025 (2010), arXiv:1002.2239

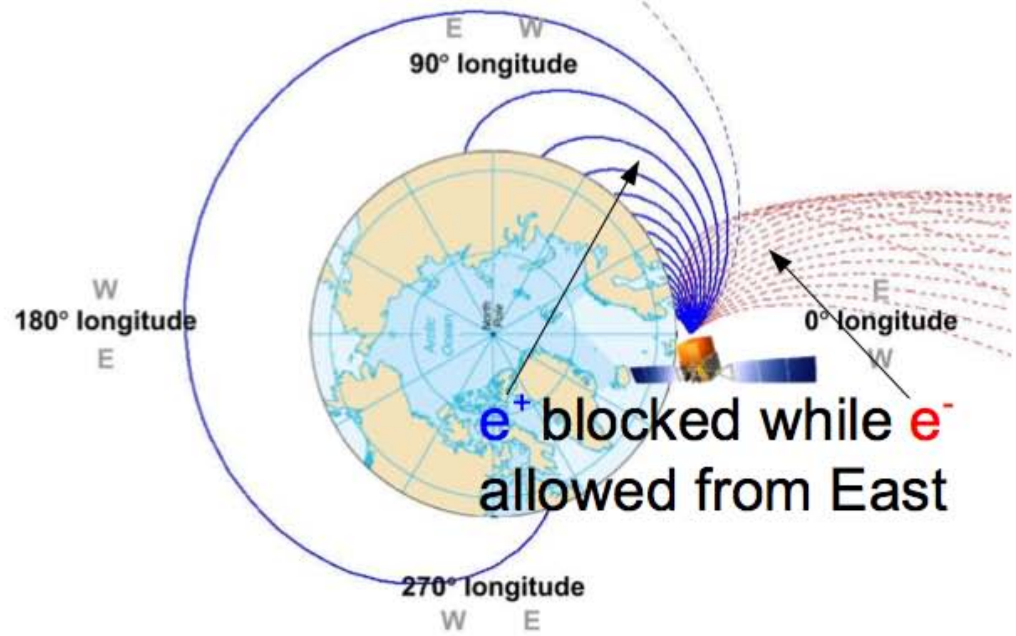
Flux upper limits as a function of particle mass for an assumed $\mu+\mu-$ final state, including the contributions of both FSR and IC gamma-ray emission

Fermi Bubble

- *Continue observation of Fermi*
- *XMM-Newton data coming soon*
- *The eROSITA and Planck experiments will provide improved measurements of the X-rays and microwaves, respectively, associated with the Fermi bubbles*
- *Magnetic field structure of the bubbles*
- *Study of the origin and evolution of the bubbles also has the potential to improve our understanding of recent energetic events in the inner Galaxy and the high-latitude cosmic ray population.*

Principle: Use the Earth's Magnetic Field to Distinguish e+ and e-





- Pure e+ region is in the west and same for e- in the east
- The regions vary with particle energy and the LAT position
- To locate these regions, we use a code written by Smart, .and Shea, which numerically calculates a particle'strajectory in the geomagnetic field

- **the Second Fermi LAT Catalog 2FGL:**

2FGL almost ready to go, with following features

- ❑ Much improved diffuse representation, new limb component
- ❑ ~1888 sources, vs. 1451 (1134 for (revised))1FGL
- ❑ 12 extended sources
- ❑ Pulsars fit with exponential cutoff, others log parabola if appropriate
  - o better characterization of sources, improved fits to nearby weaker sources
- ❑ Better source finding efficiency: both detecting faint sources and resolving nearby sources

• 277 1FGL sources are not represented

Some reasons:

New requirements for localization

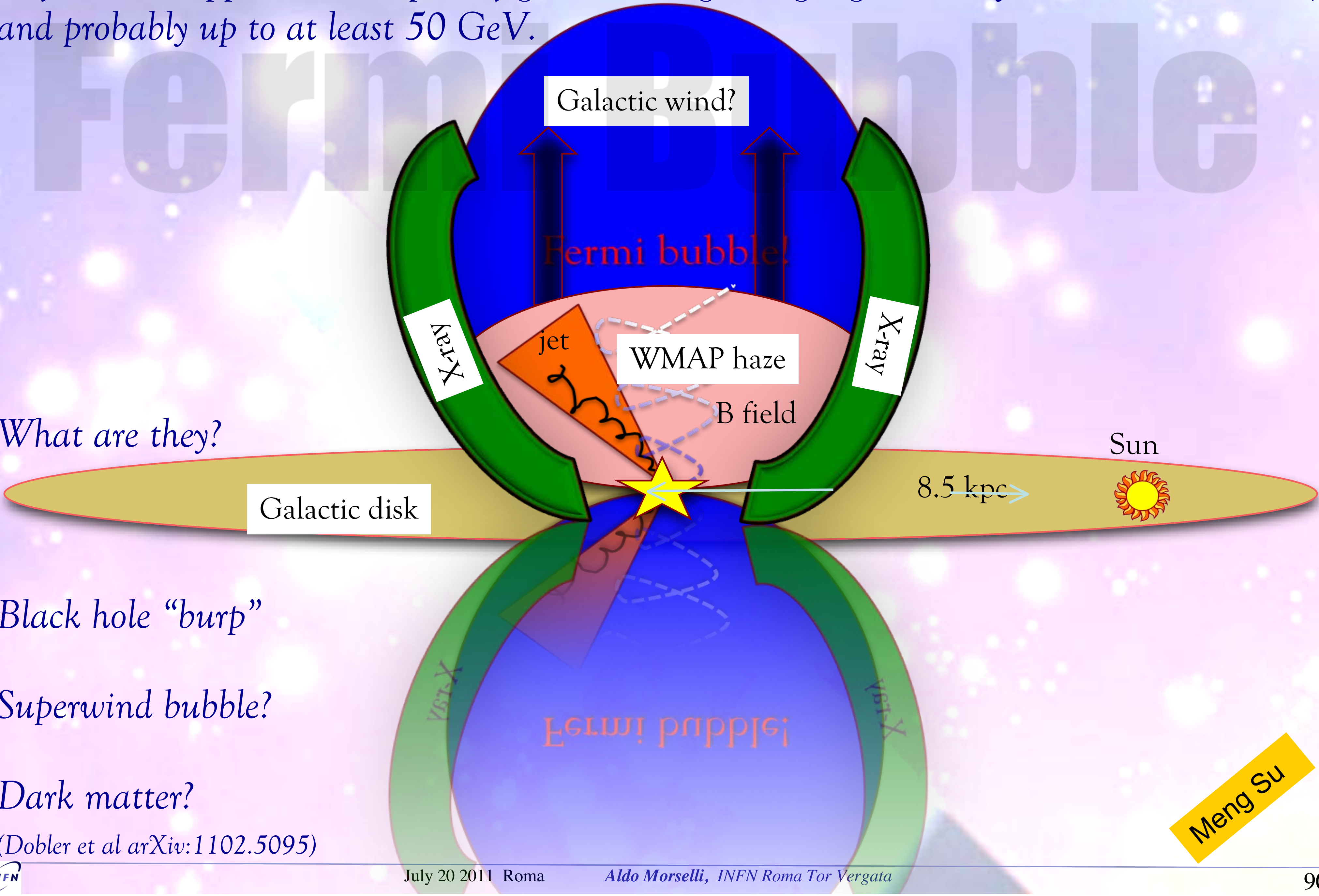
Extended sources were represented by more than one point source

Improved galactic diffuse model

There, but not significant enough (flared during first 11 months)

So far: there appear to be a pair of giant (50 degree high) gamma-ray bubbles at 1-5 GeV, and probably up to at least 50 GeV.

What are they?



Black hole "burp"

Superwind bubble?

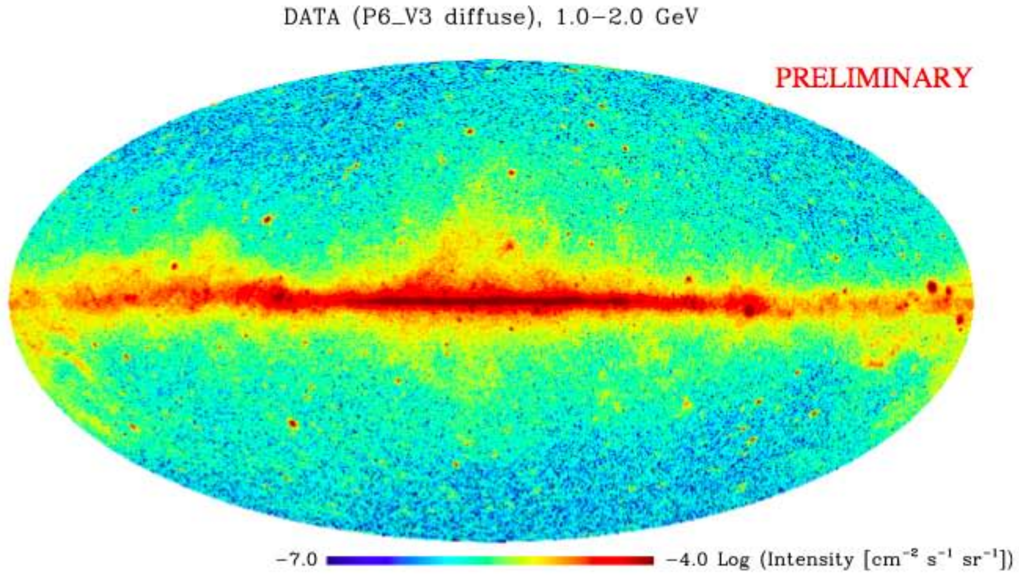
Dark matter?

(Dobler et al arXiv:1102.5095)

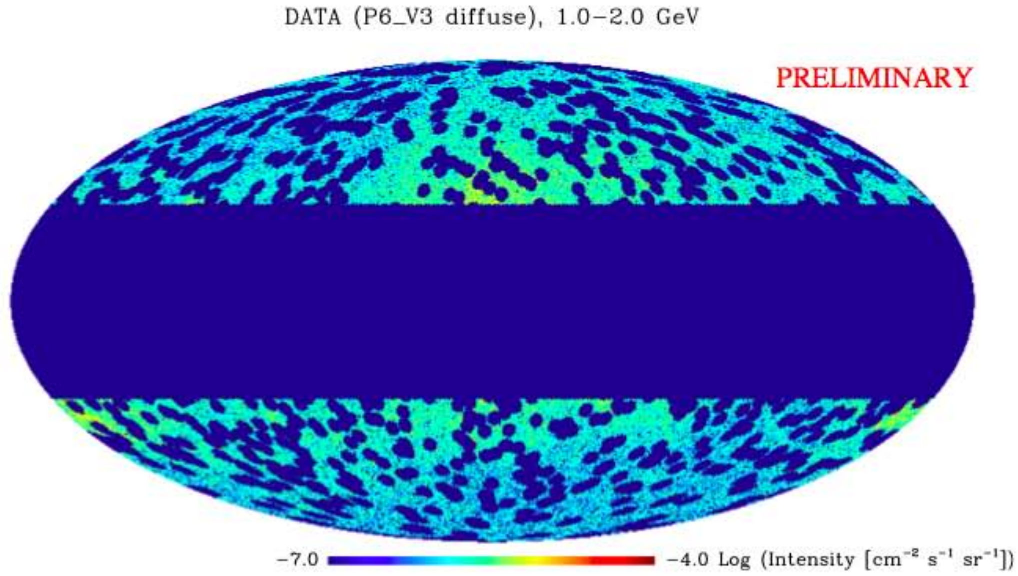
Anisotropies

1-2 GeV

All-sky map



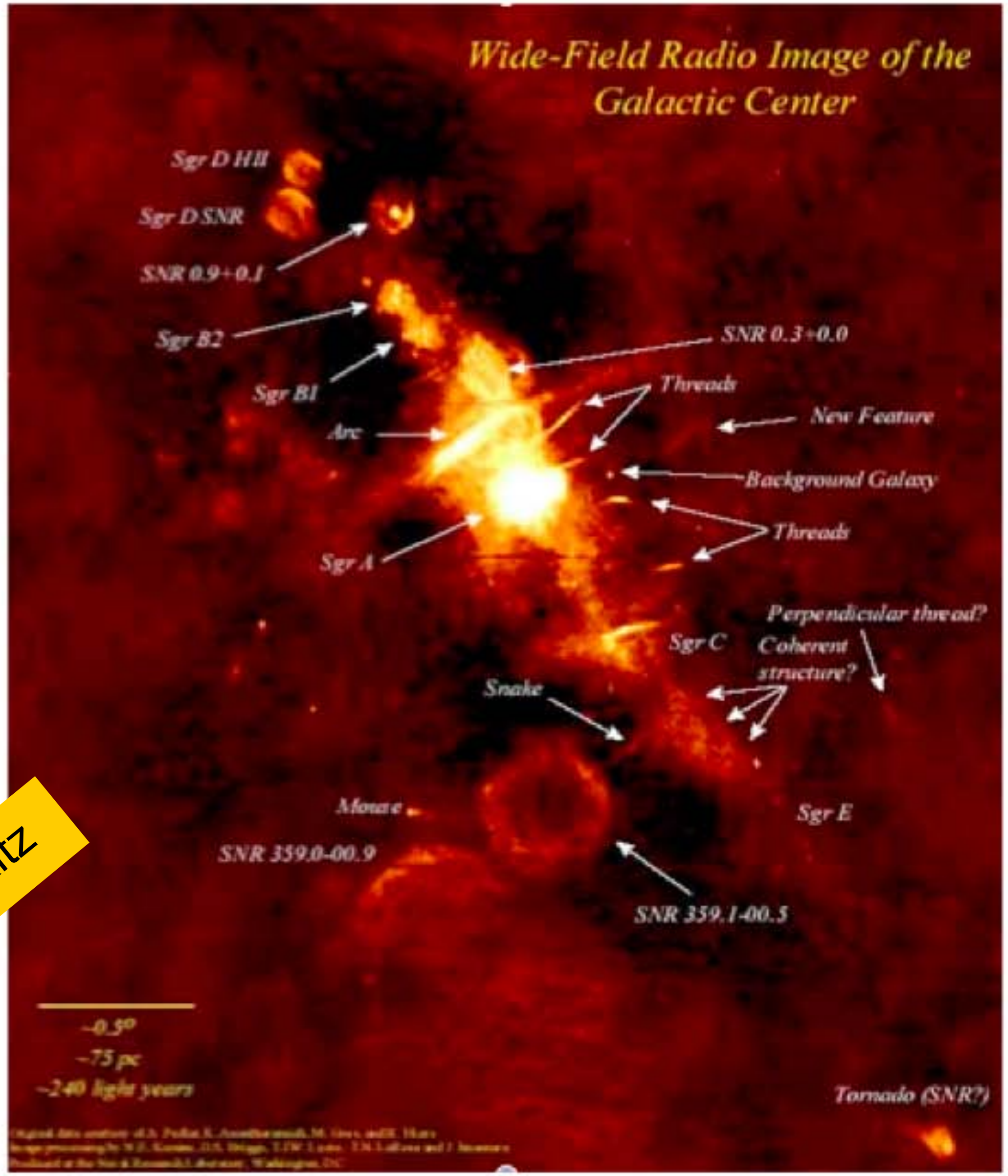
Map with default mask applied



Inner Galaxy

- *"Lasciate ogne speranza, voi ch'intrate"* – Dante Alighieri
- *"If you're going through hell, KEEP GOING!" - Winston Churchill* (emphasis added)

Steve Ritz



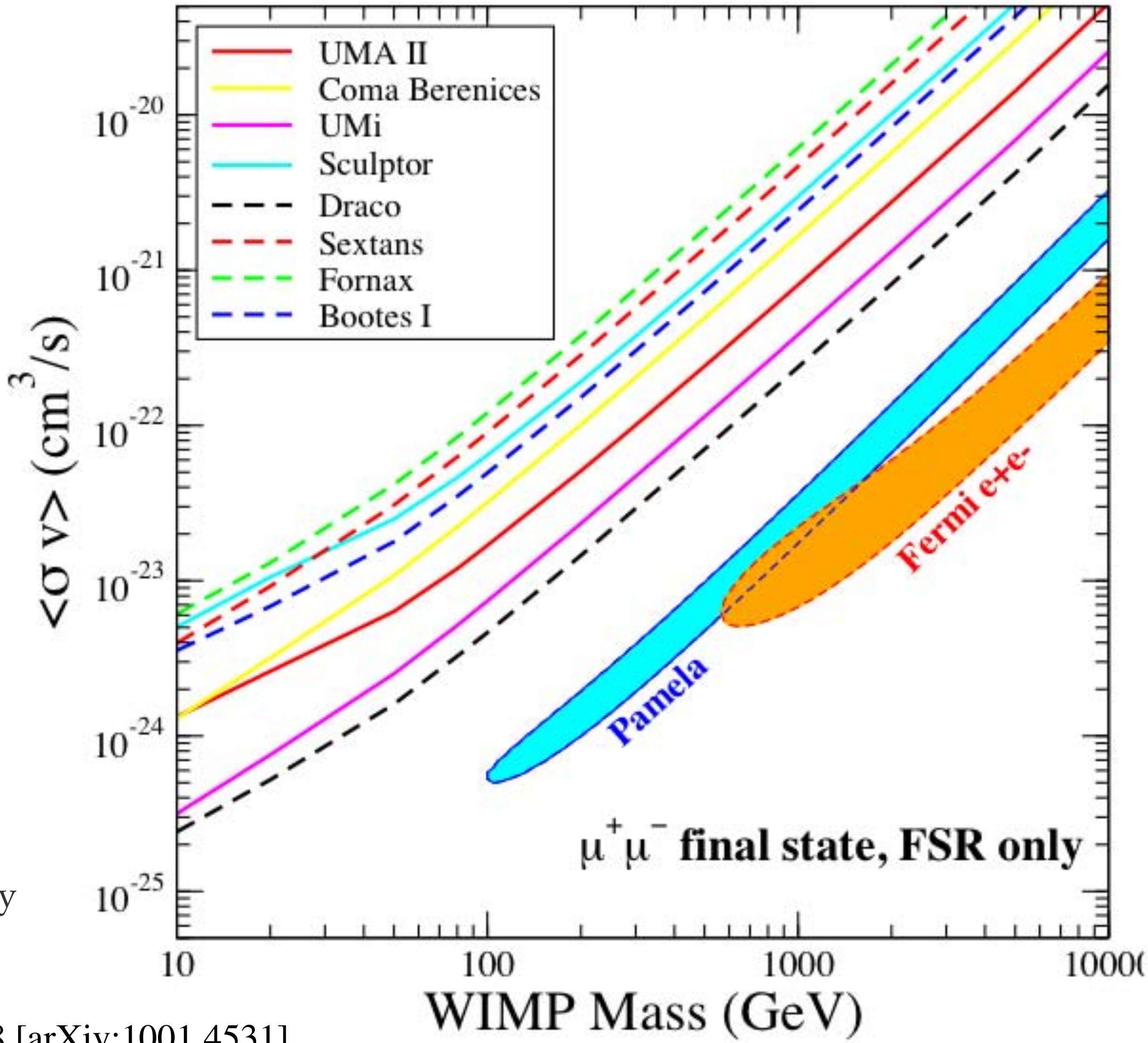
see talk by Beatriz Canadas afternoon 26

Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on < σv> vs WIMP mass for specific DM models

(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)



Fermi Coll. ApJ 712 (2010) 147-158 [arXiv:1001.4531]