Dark Matter search with the Fermi gamma ray telescope: a progress report

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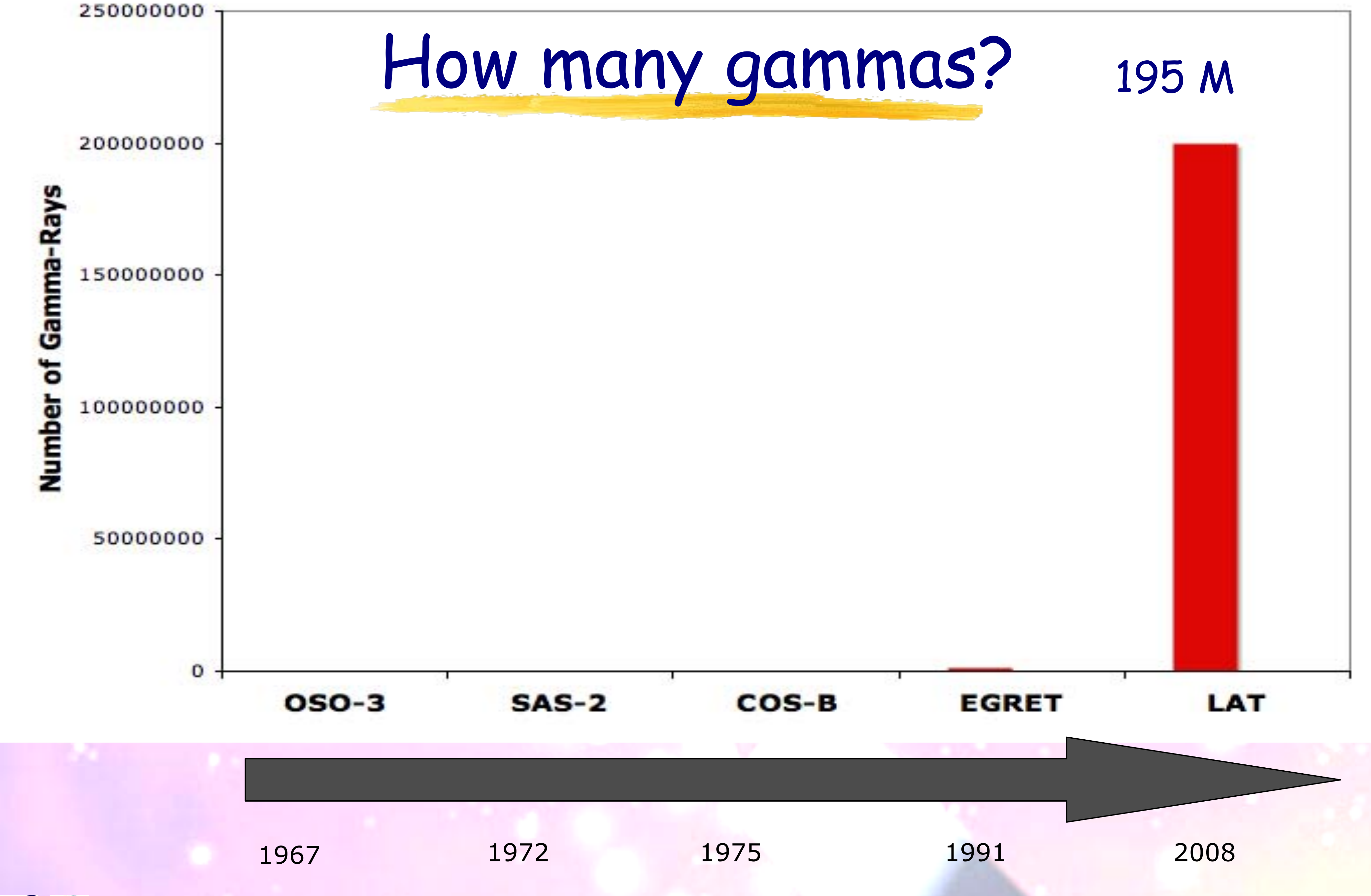
Representing the
Fermi-LAT Collaboration

Multi^3 - A cubic approach to Dark Matter

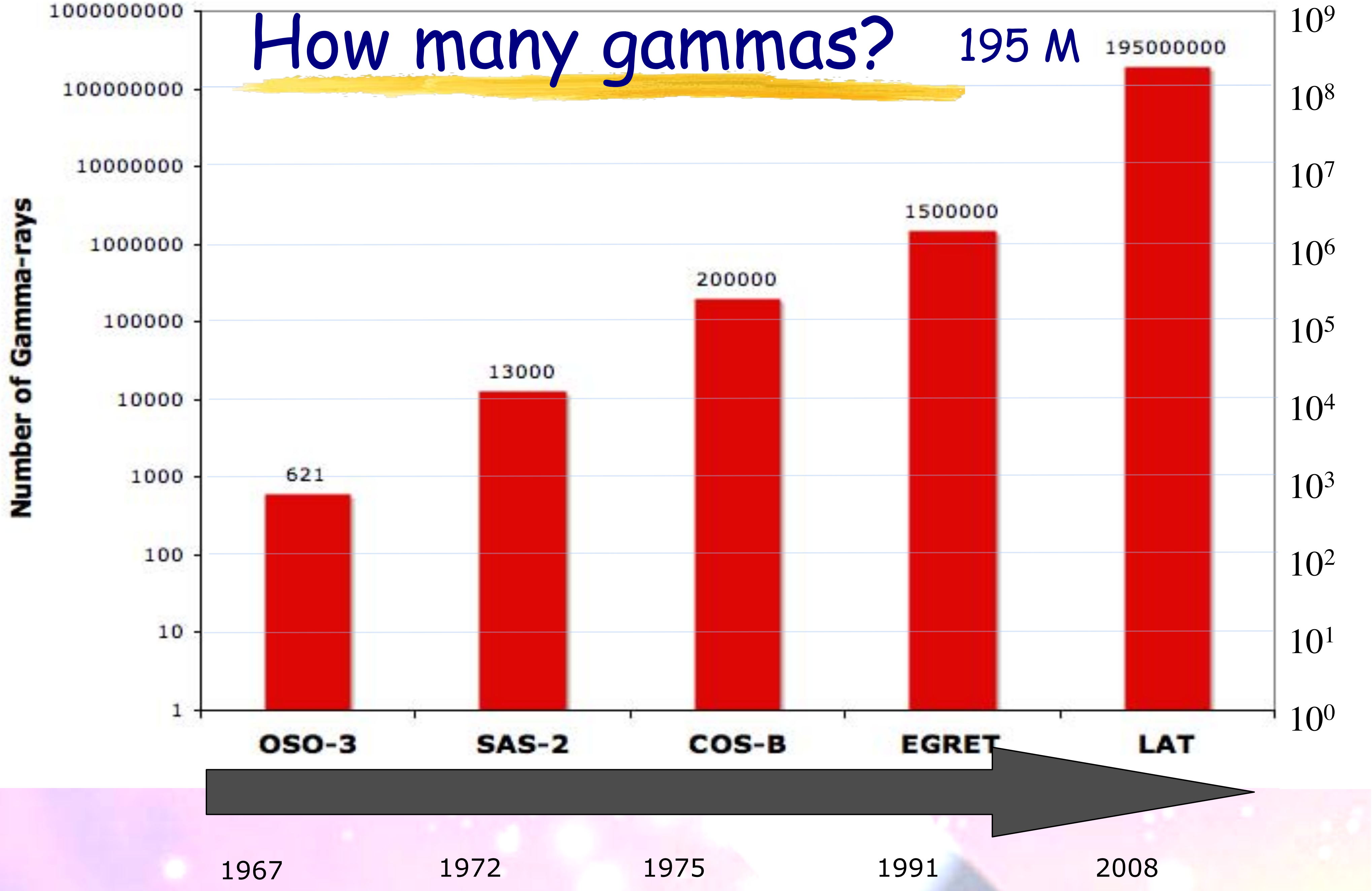
Padova, Department of Physics G.Galilei, March 1-4, 2010

How many gammas?



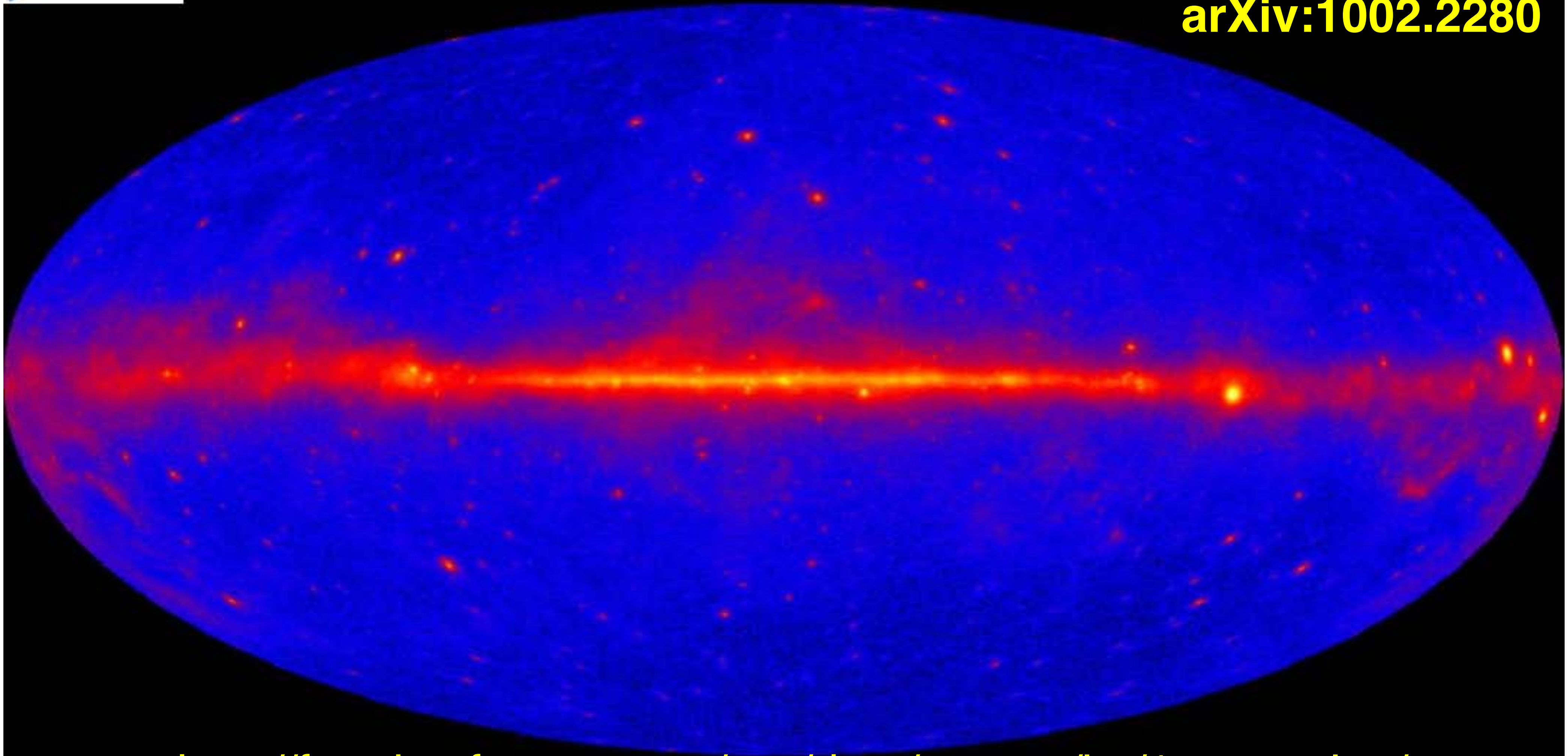
How many gammas?

195 M



First Fermi LAT Catalog (11 month)
1451 sources

arXiv:1002.2280

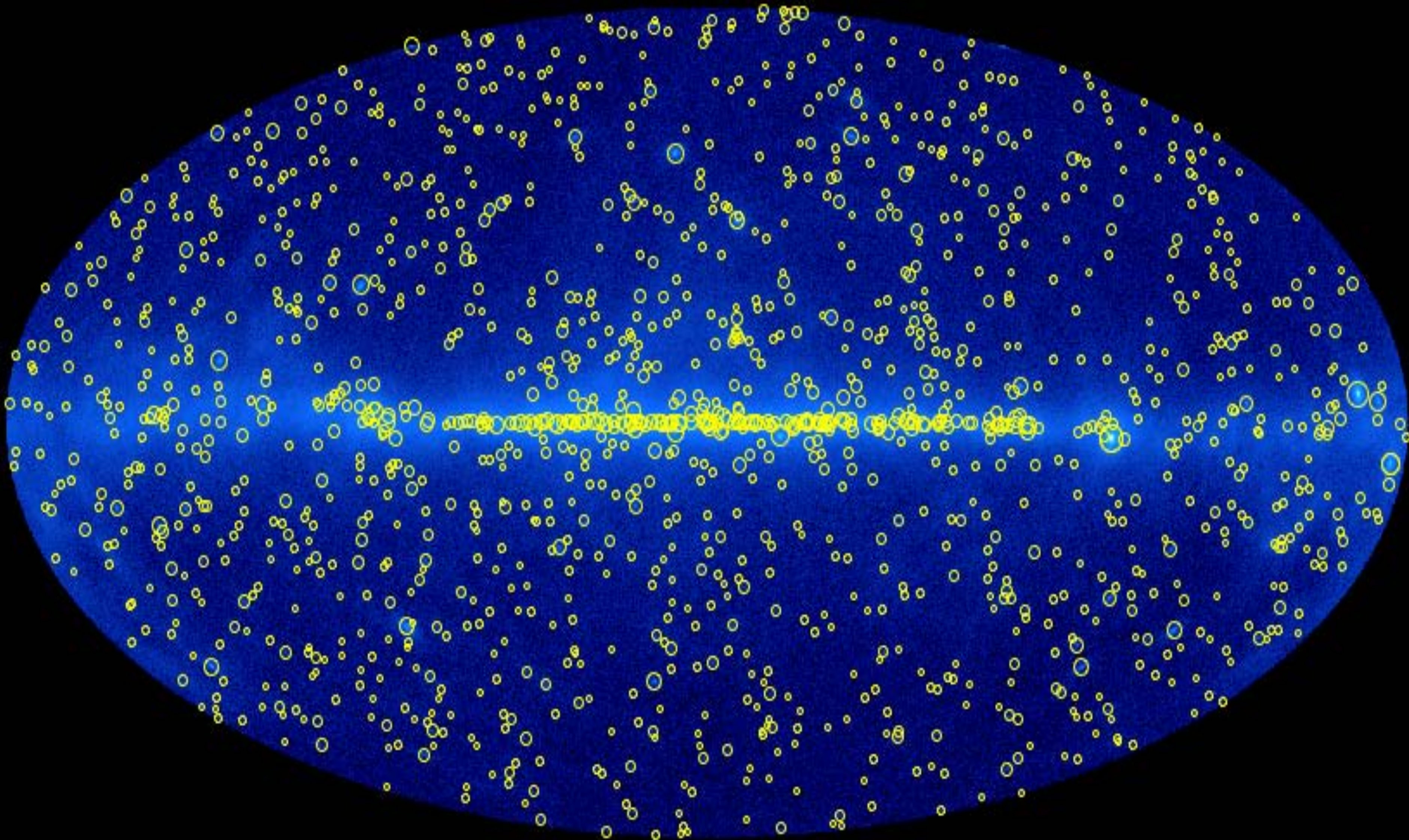


http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1yr_catalog/

- Front > 200 MeV, Back > 400 MeV, log color scale
- Galactic coordinates, Aitoff projection

First Fermi LAT Catalog

The Galactic ridge (|lat| < 1° , |lon| < 60°) has serious difficulties: sources are close to each other, are not high above the background below 3 GeV, and the Galactic diffuse model is very uncertain there.



1451 sources (4.1 σ significance threshold); symbol size encodes >1 GeV flux

First Fermi LAT Catalog (11 month)
1451 sources

- Typical 95% error radius is 10′.
- Absolute accuracy is better than 1′
- 241 sources show evidence of variability
- ~ Half the sources are associated positionally, mostly with blazars (~ 680) and pulsars (56)
- Other classes of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)

Fermi Coll., ApJS submitted [arXiv:1002.2280]

Fermi Science After ~ 1.5 Years

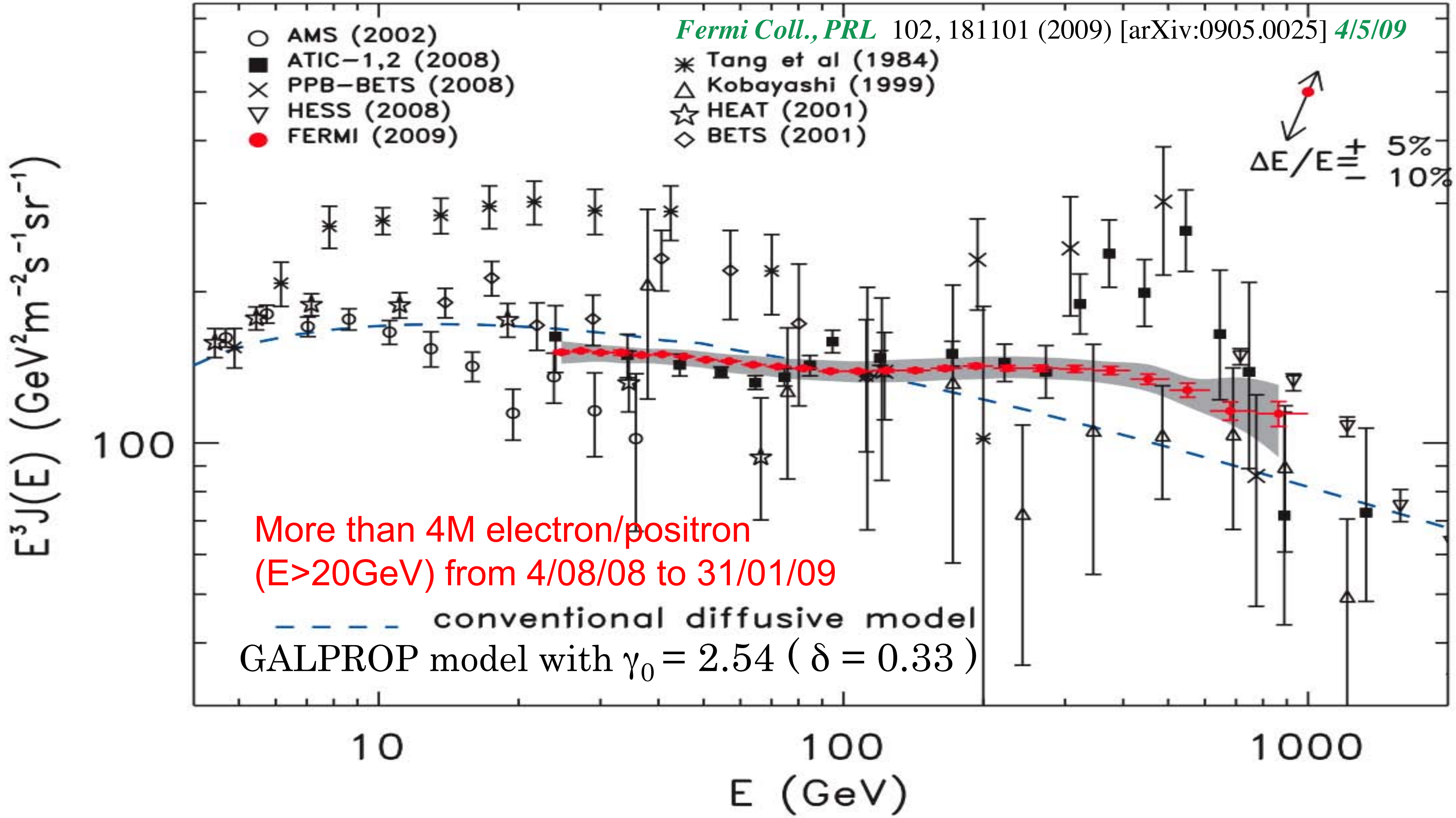
Approximately 80 Papers (AGN, Pulsars, Starburst Galaxies, GRB, diffuse background, electrons, dark matter searches ...)

- Fermi Catalog, 1FGL – Public data release, Pass 6V3 **arXiv:1002.2280**

Dark matter search publications (CAT I)

- Measurement of the Cosmic Ray e+ + e- spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope; PRL; arXiv:0905.0025
- Observations of Milky Way Dwarf Spheroidal galaxies with the Fermi LAT detector and constraints on Dark Matter models; ApJ; arXiv:1001.4531
- Probing Dark Matter Annihilation with Fermi Observations of Clusters of Galaxies; Submitted to JCAP; arXiv:1002.2239
- Fermi Large Area Telescope search for photon lines from 30 to 200 GeV and dark matter implications; PRL; arXiv:1001.4836
- Constraints on Cosmological Dark Matter Annihilation from the Fermi LAT Isotropic Diffuse Gamma-Ray Measurement ; Submitted to JCAP arXiv:1002.4415

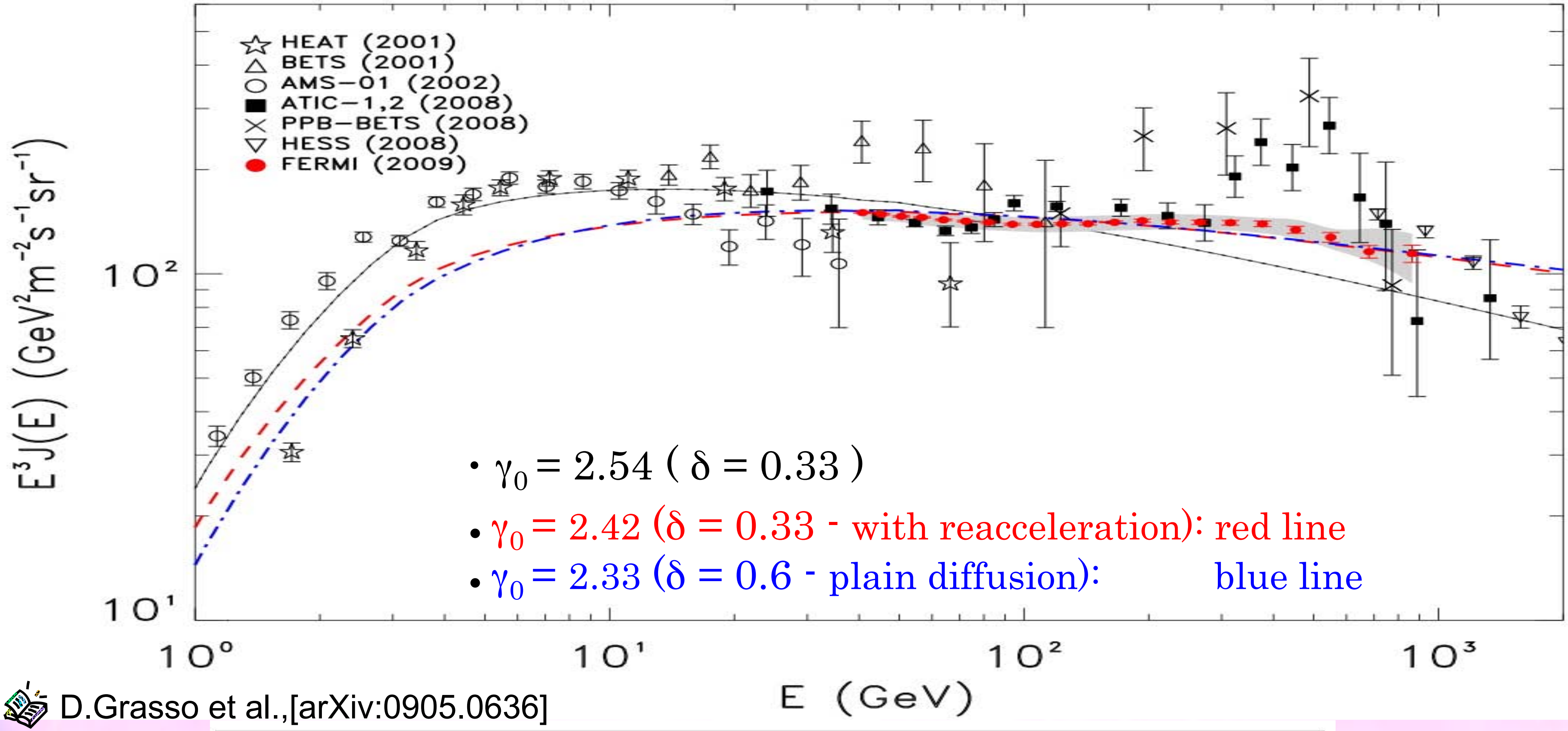
Fermi-LAT CRE data vs the conventional *pre-Fermi* model



Although the feature @~600 GeV measured by ATIC is not confirmed

<u>Some changes are still needed respect to the *pre-Fermi conventional model*</u>

Cosmic Ray Electron propagation models

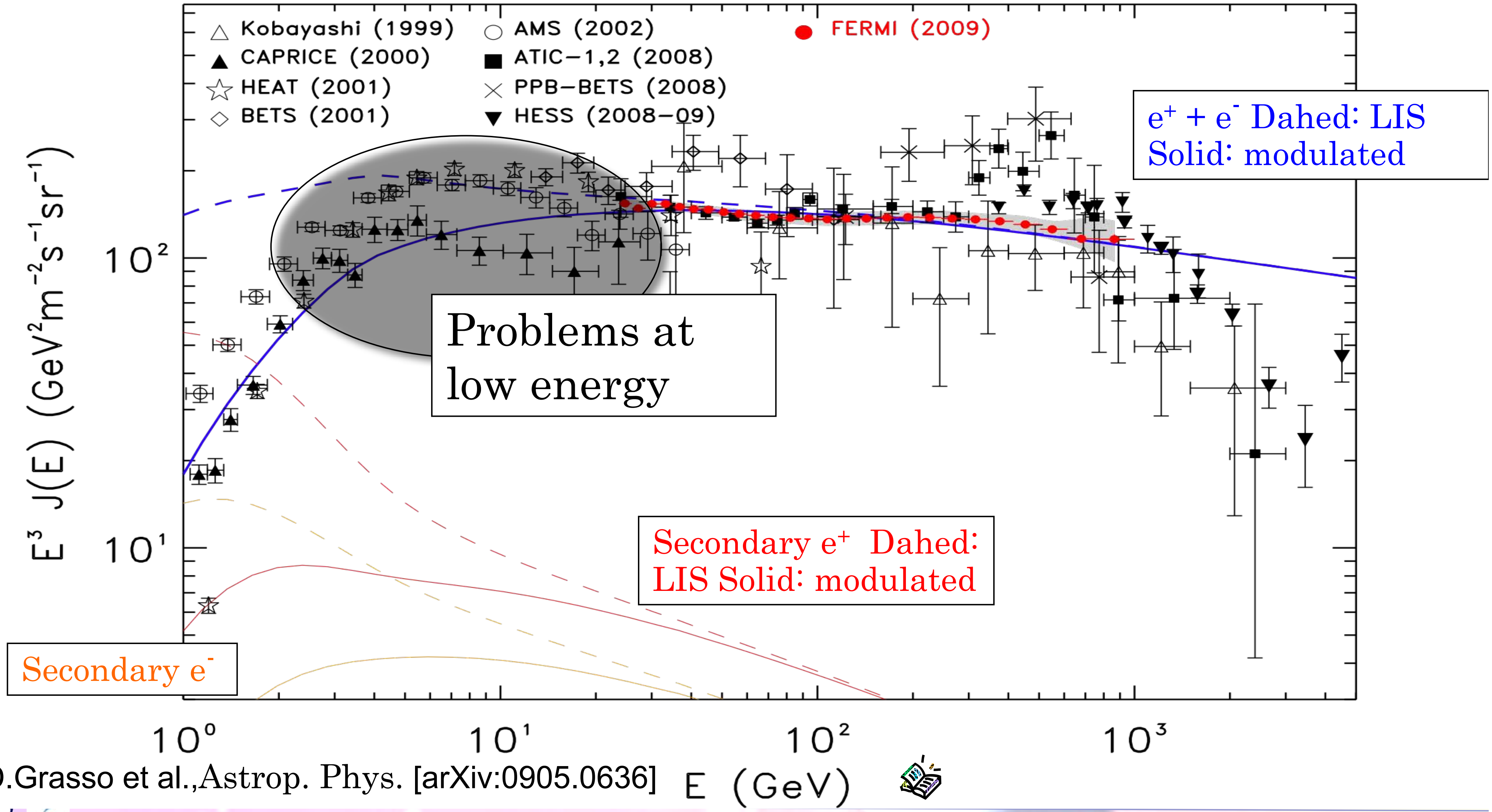


D.Grasso et al.,[arXiv:0905.0636]

Model #	D_0 $(cm^2 s^{-1})$	δ	z_h (kpc)	γ_0	N_{e^-} $(m^{-2}s^{-1}sr^{-1}GeV^{-1})$	γ_0^p
0	3.6×10^{28}	0.33	4	2.54	1.3×10^{-4}	2.42
1	3.6×10^{28}	0.33	4	2.42	1.3×10^{-4}	2.42
2	1.3×10^{28}	0.60	4	2.33	1.3×10^{-4}	2.1

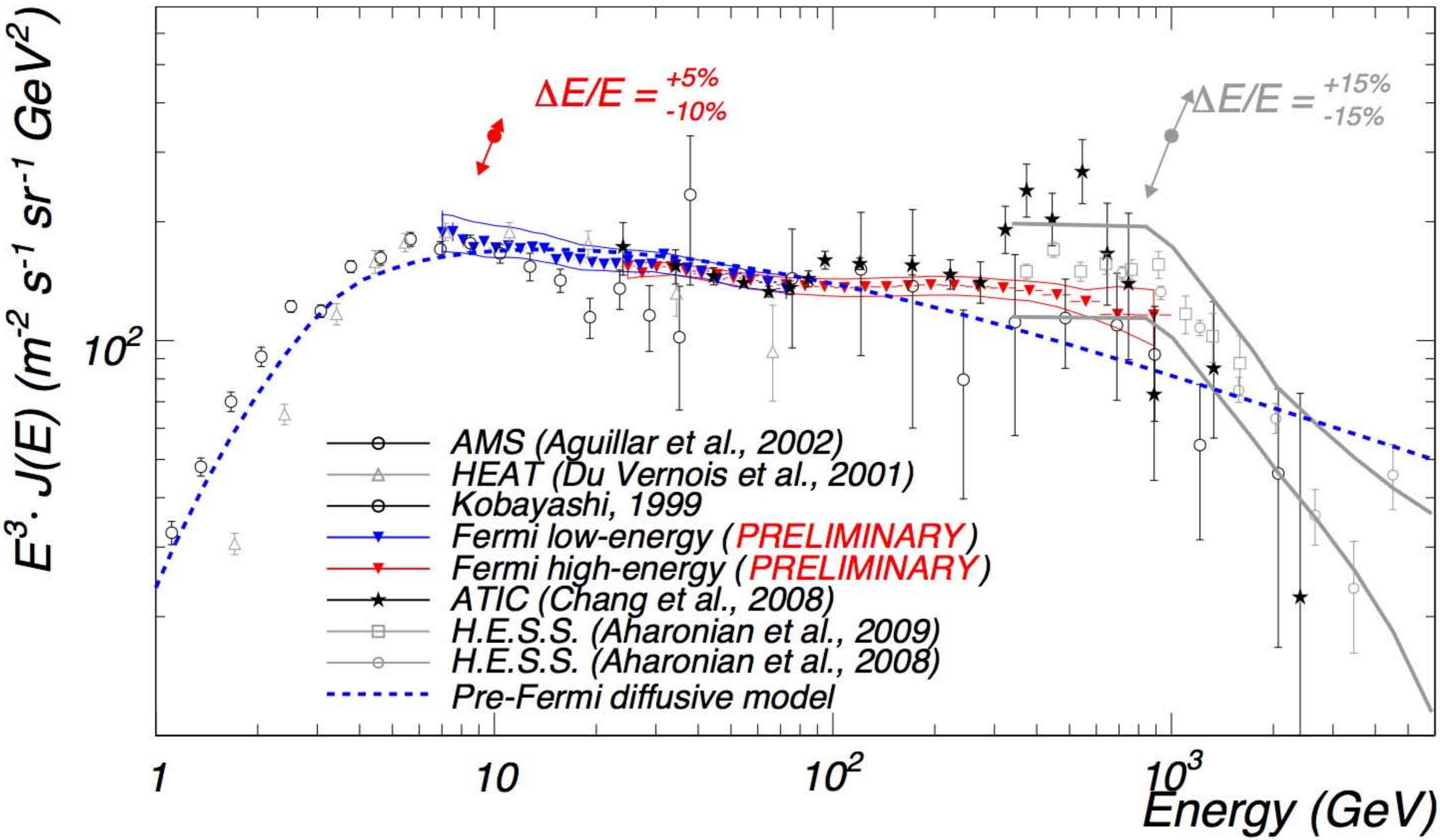
Models 0 and 1 account for CR re-acceleration in the ISM, while 2 is a plain-diffusion model. All models assume γ_0 = 1.6 below 4 GeV.

"Conventional" model with injection spectrum 1.60/2.42 (break at 4 GeV)



D.Grasso et al.,Astrop. Phys. [arXiv:0905.0636]

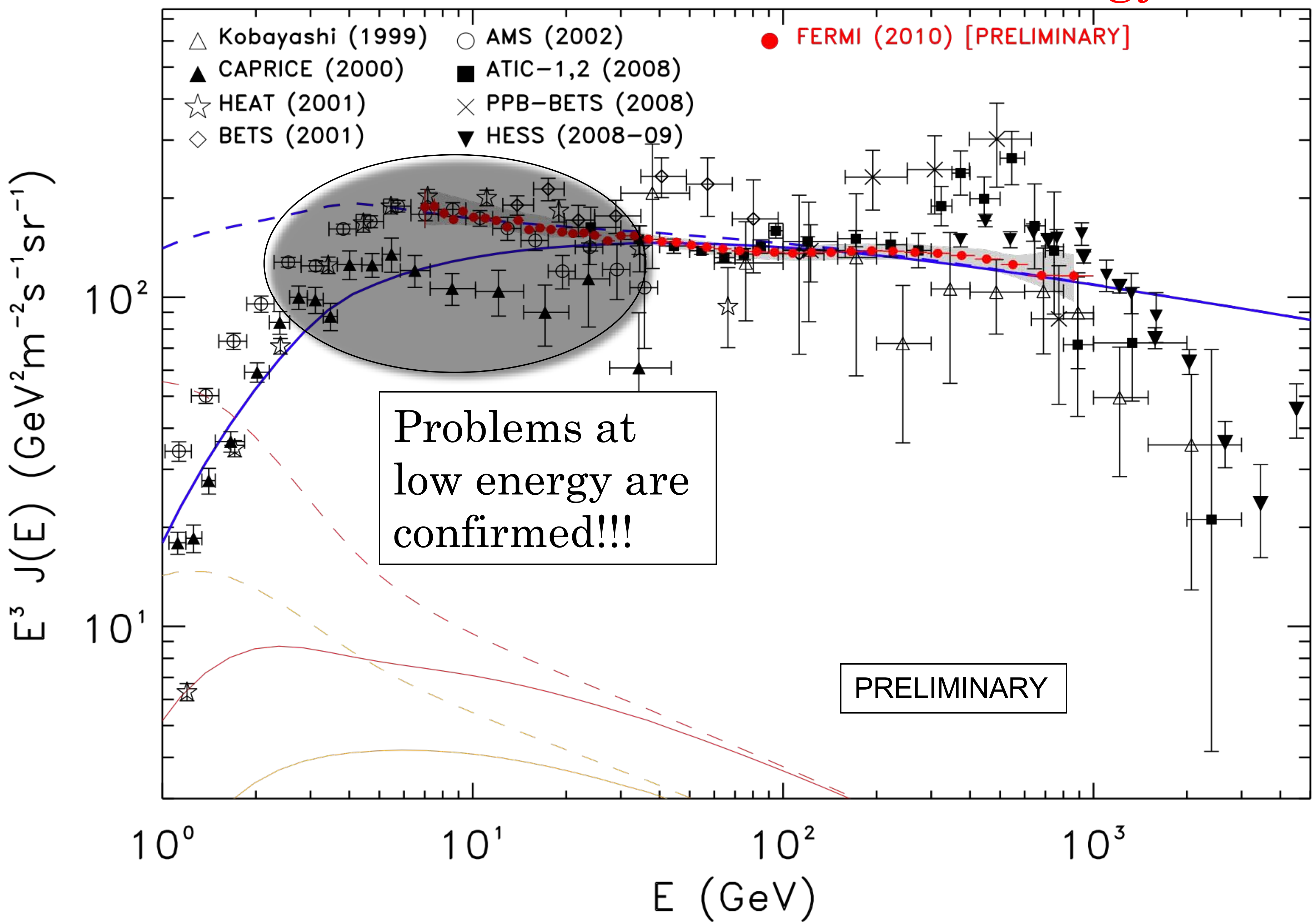
new : Fermi Electron + Positron spectrum (end 2009)



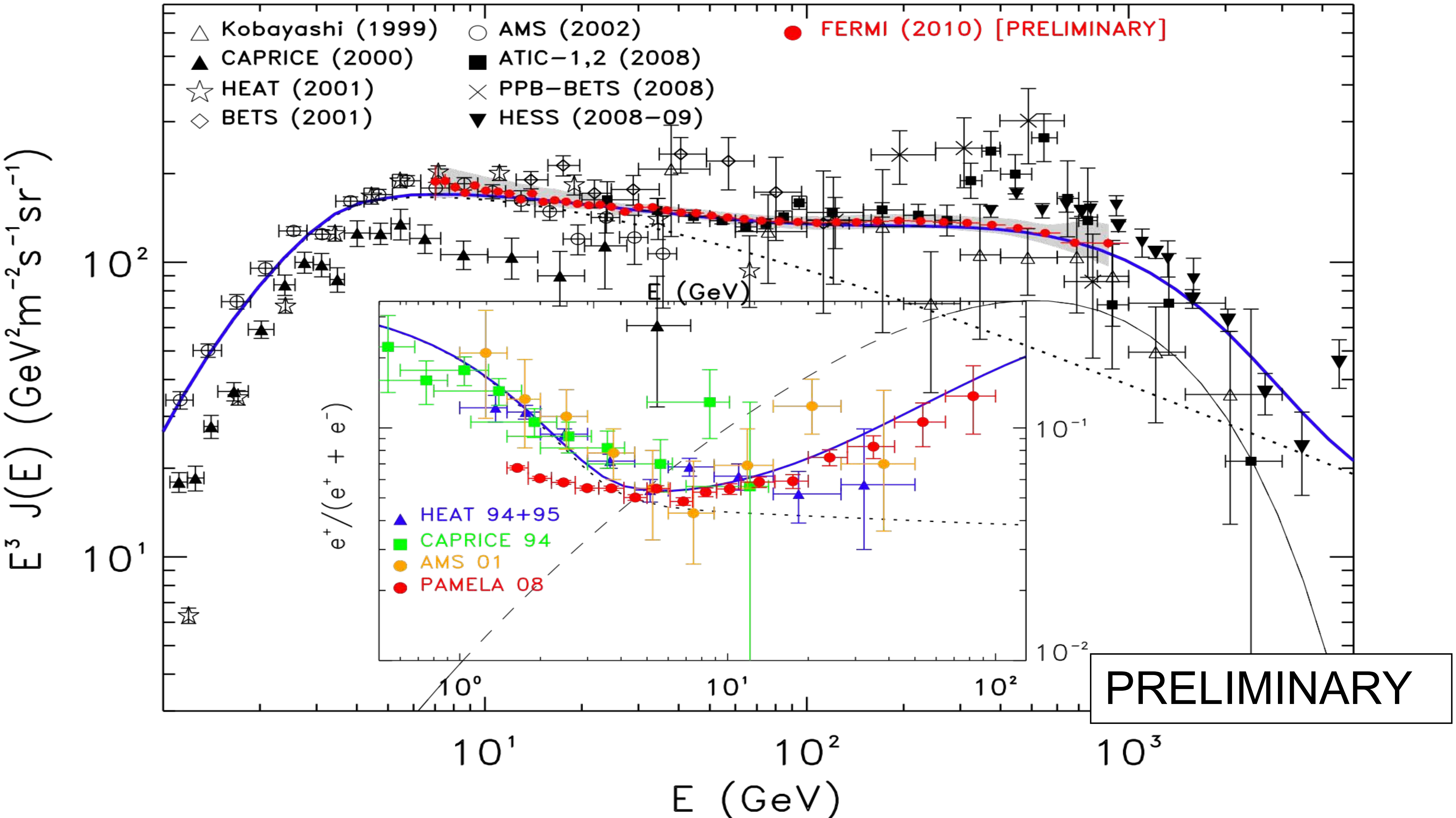
Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

Fermi LAT Coll. in preparation

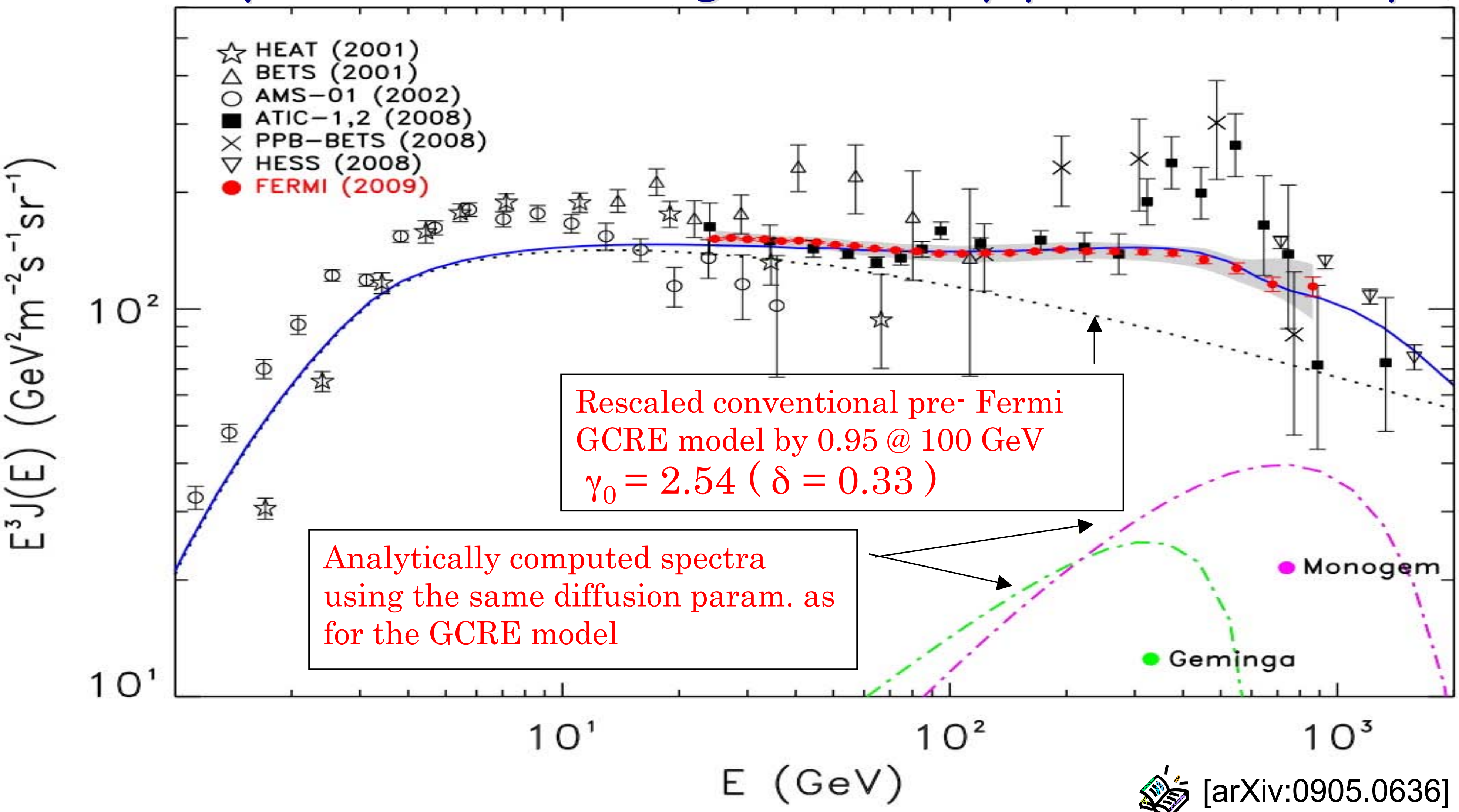
New Fermi-LAT data at low energy



An extra-component with injection index = 1.5 and an exponential cutoff at 1 TeV gives a good fit of all datasets!



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

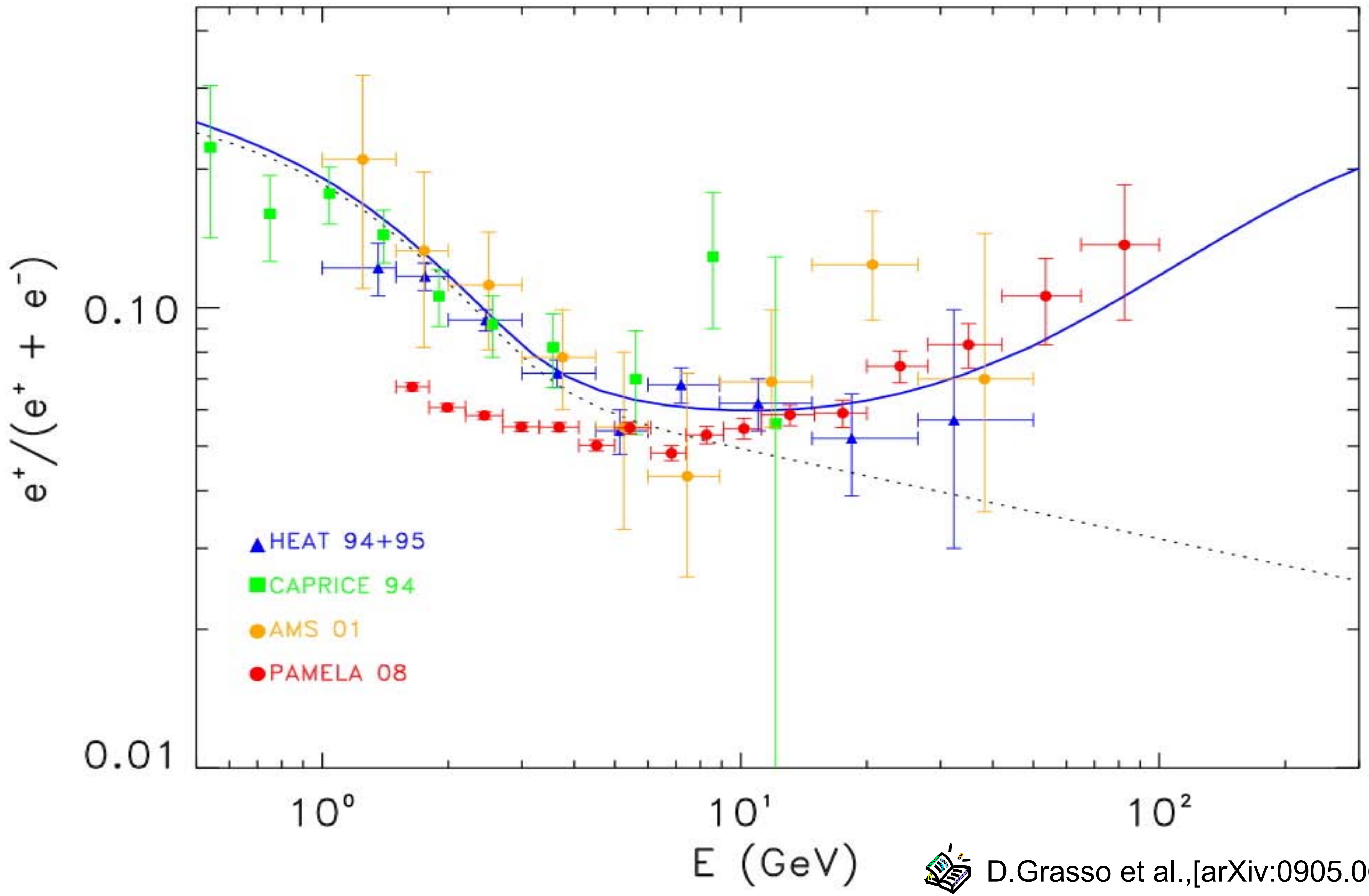


[arXiv:0905.0636]

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

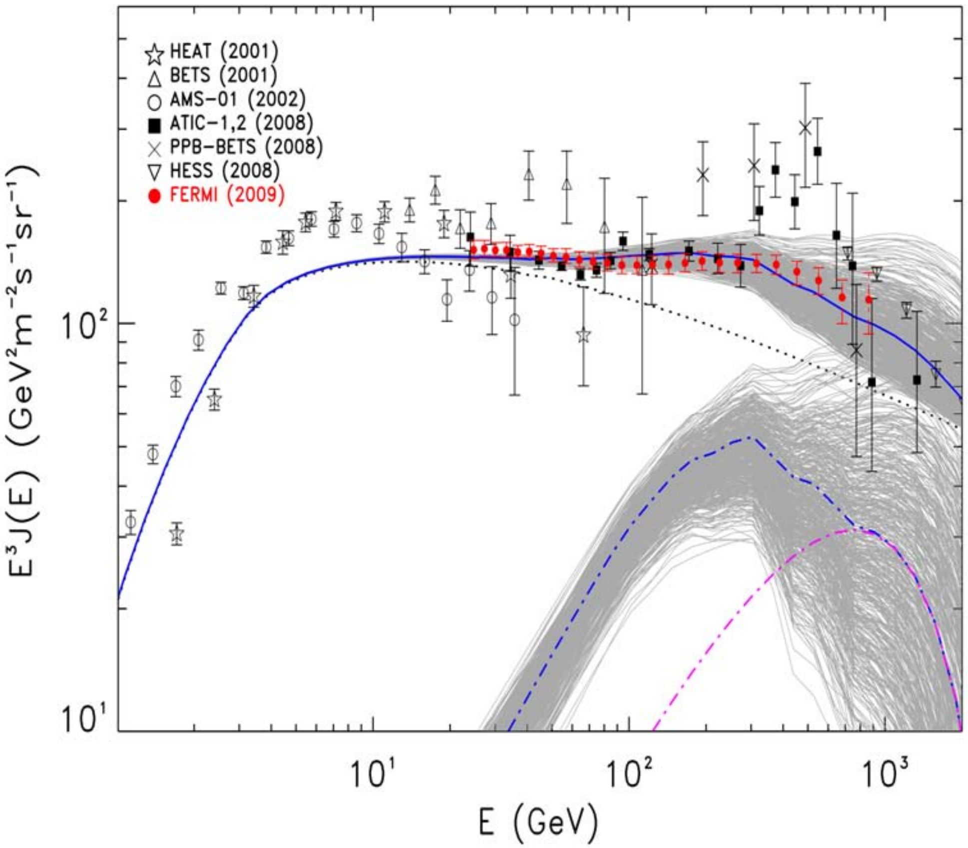
the positron ratio accounting for nearby pulsars (d < 1 kpc)

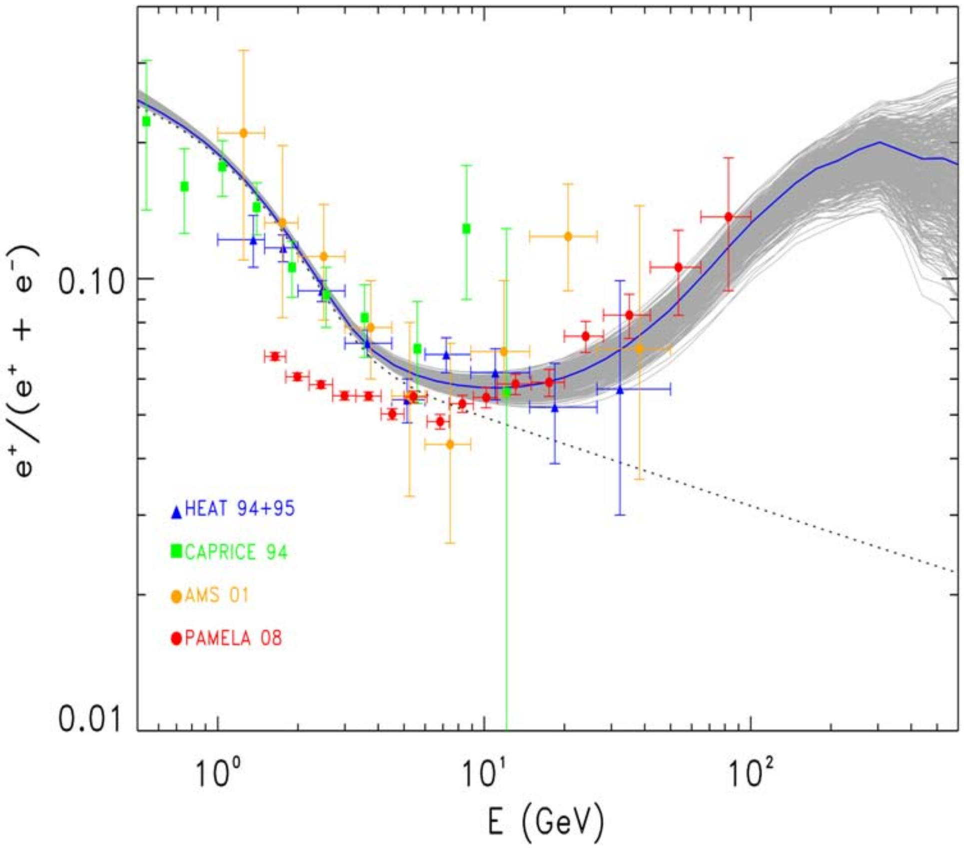


D.Grasso et al.,[arXiv:0905.0636]

What if we randomly vary the pulsar parameters relevant for e+e- production?

(injection spectrum, e+e- production efficiency, PWN "trapping" time)

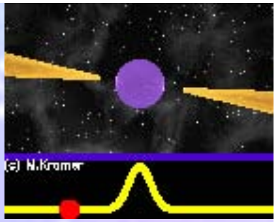




Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

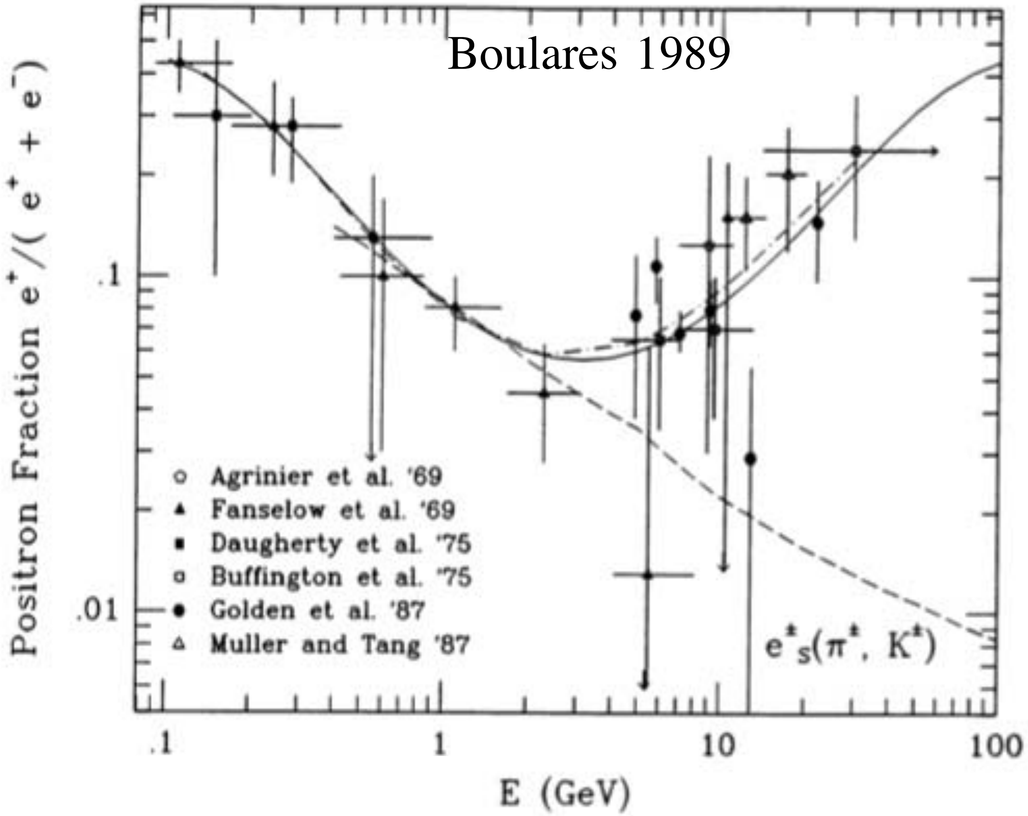
D.Grasso et al.,[arXiv:0905.0636]

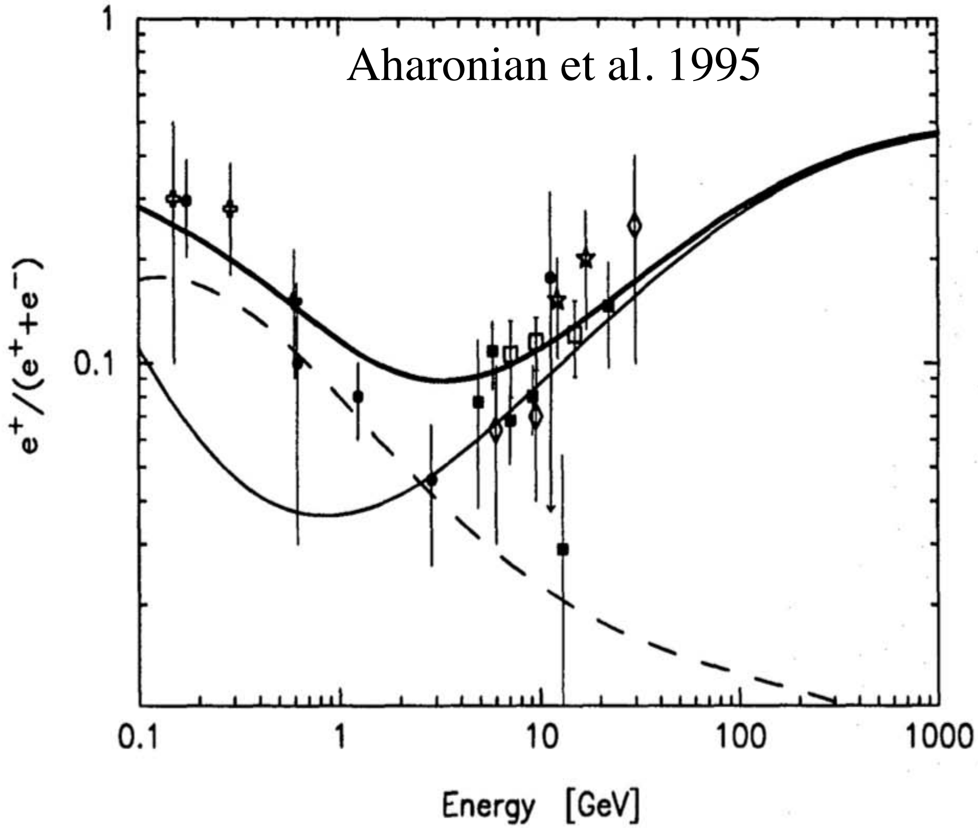
Pulsars as sources of $e^{-/+}$ pairs



not a new idea

- A.Boulares APJ 342 (1989) 807-813
- Aharonian et al., A&A 294 (1995) L41
- A. M. Atoyan, F. A. Aharonian, and H. J. Volk, Phys. Rev. D52 (1995) 3265.
- T. Kobayashi, Y. Komori, K. Yoshida and J. Nishimura, ApJ 601 (2004) 340.





Pulsars

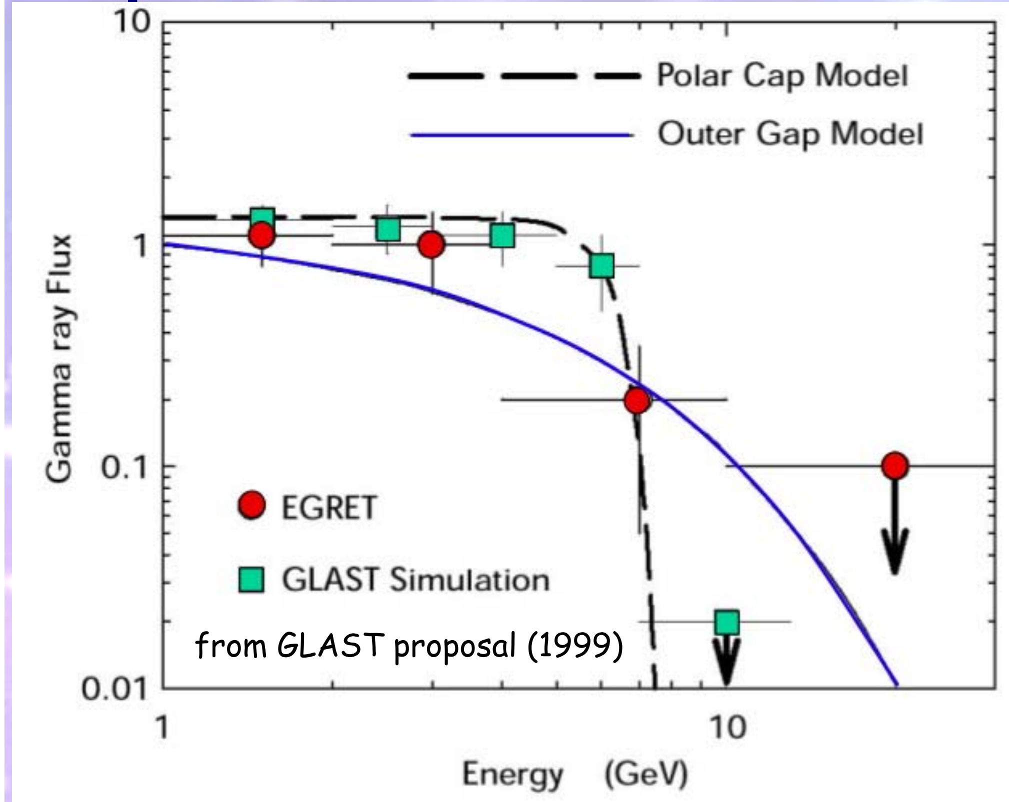
1. On purely energetic grounds they work (relatively large efficiency)

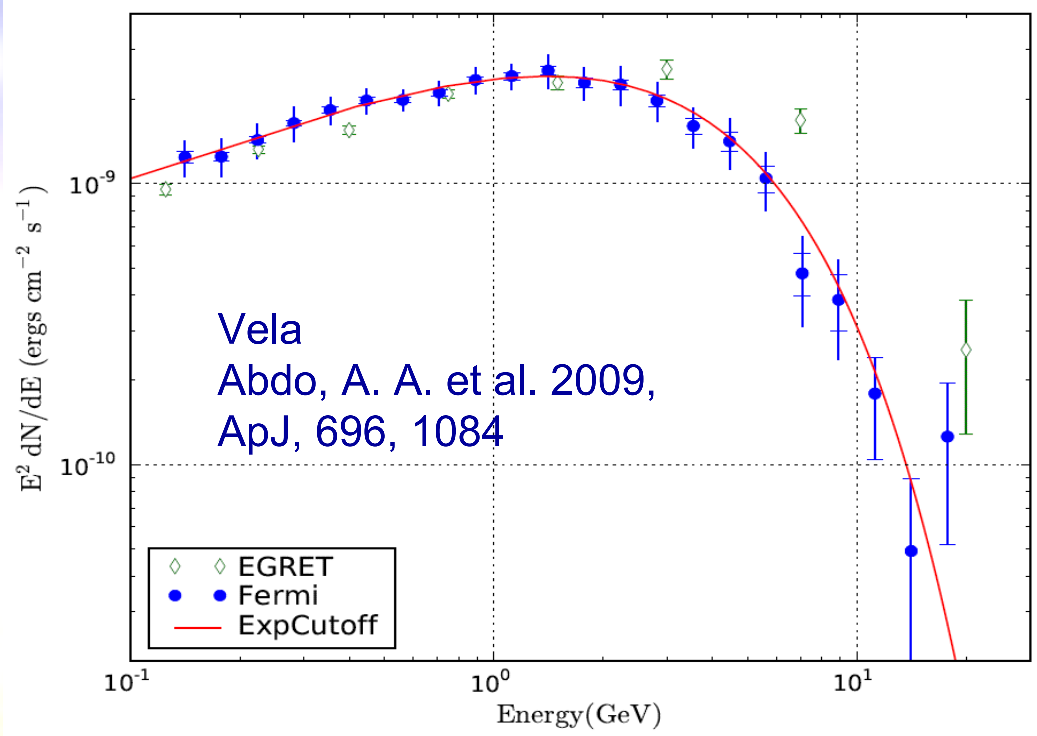
2. On the basis of the spectrum, it is not clear
   1. The spectra of PWN show relatively flat spectra of pairs at Low energies but we do not understand what it is
   2. The general spectra (acceleration at the termination shock) are too steep

The biggest problem is that of escape of particles from the pulsar
1. Even if acceleration works, pairs have to survive losses
2. And in order to escape they have to cross other two shocks

New Fermi data on pulsars will help to constrain the pulsar models

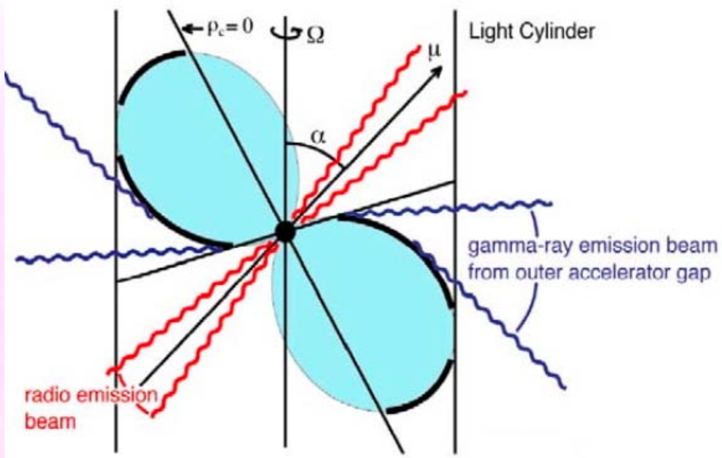
Spectral measurements and emission models

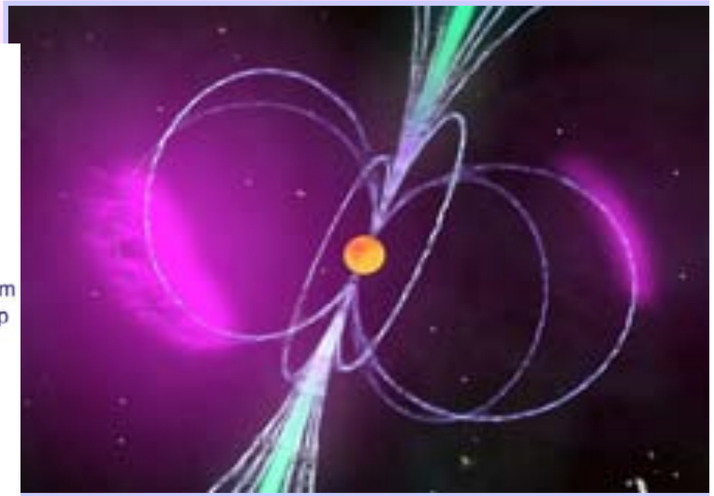




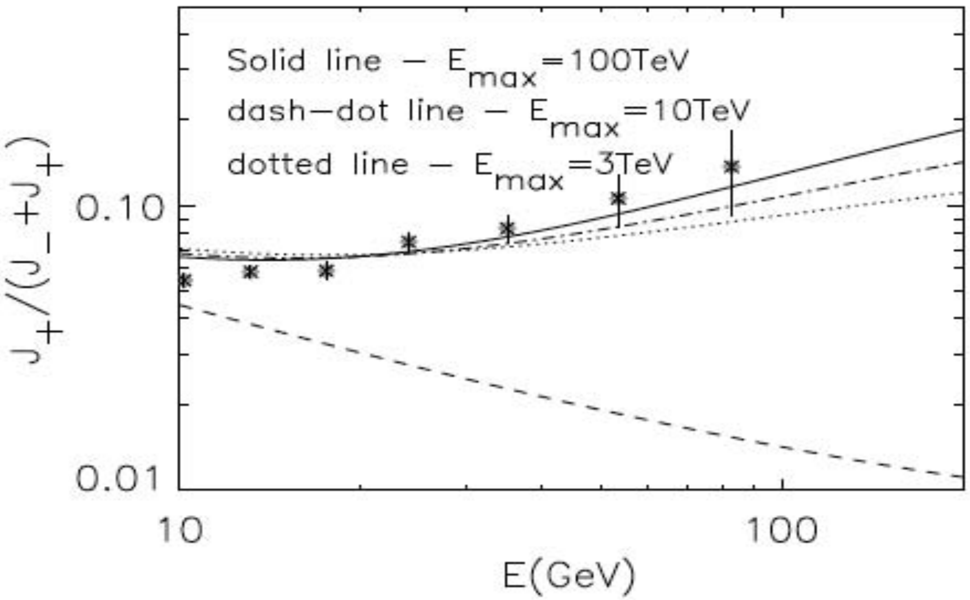
Evidence of γ-ray emission in the outer magnetopshere due to absence of super-exponential cutoff

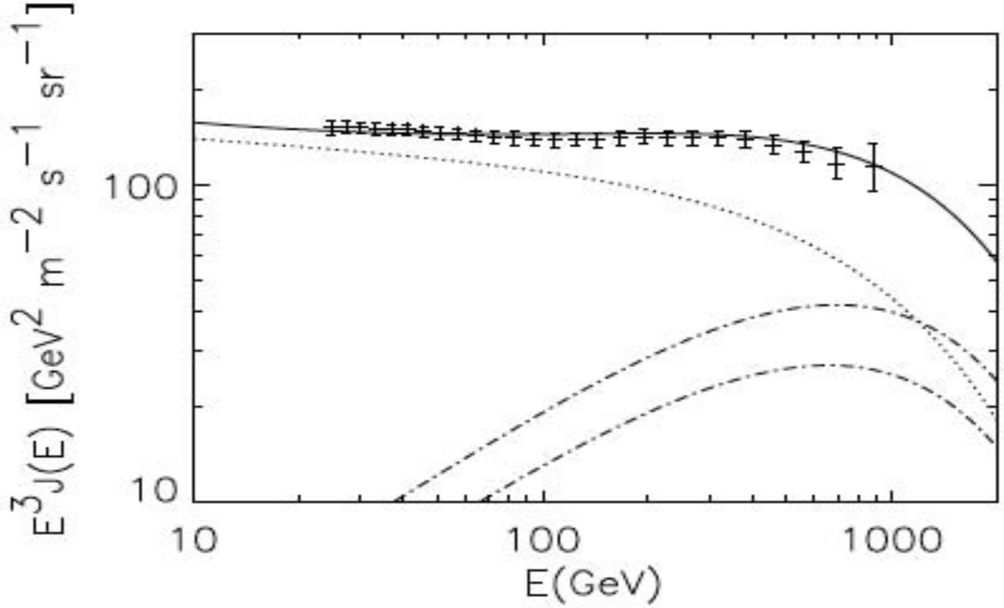
- Radio and γ-ray fan beams separated
- γ-ray only PSRs





other Astrophysical solution





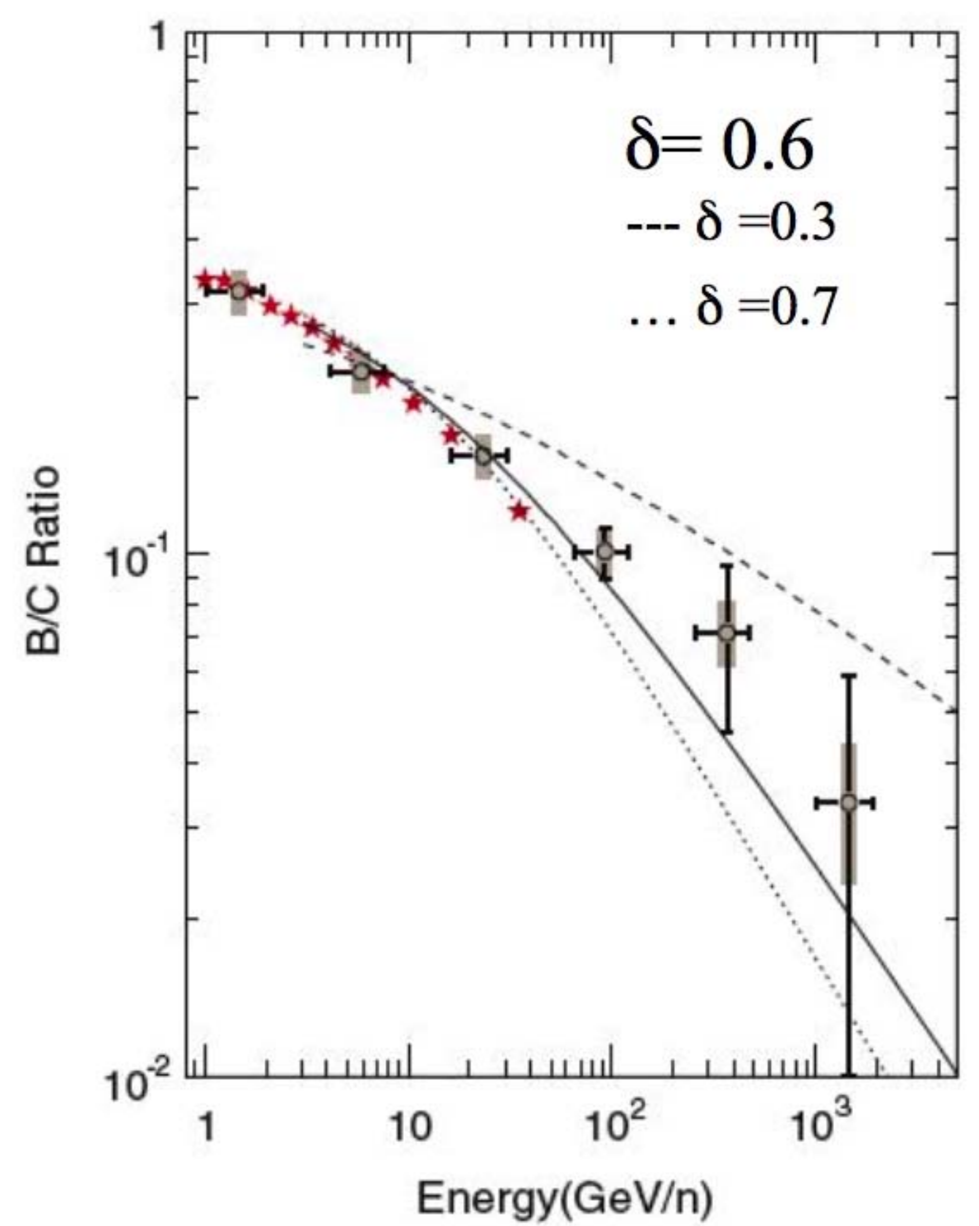
• Positrons created as secondary products of hadronic interactions inside the sources

• Secondary production takes place in the same region where cosmic rays are being accelerated

-> Therefore secondary positron have a very flat spectrum, which is responsible, after propagation in the Galaxy, for the observed positron excess

Blasi, arXiv:0903.2794

Boron-to-Carbon Ratio



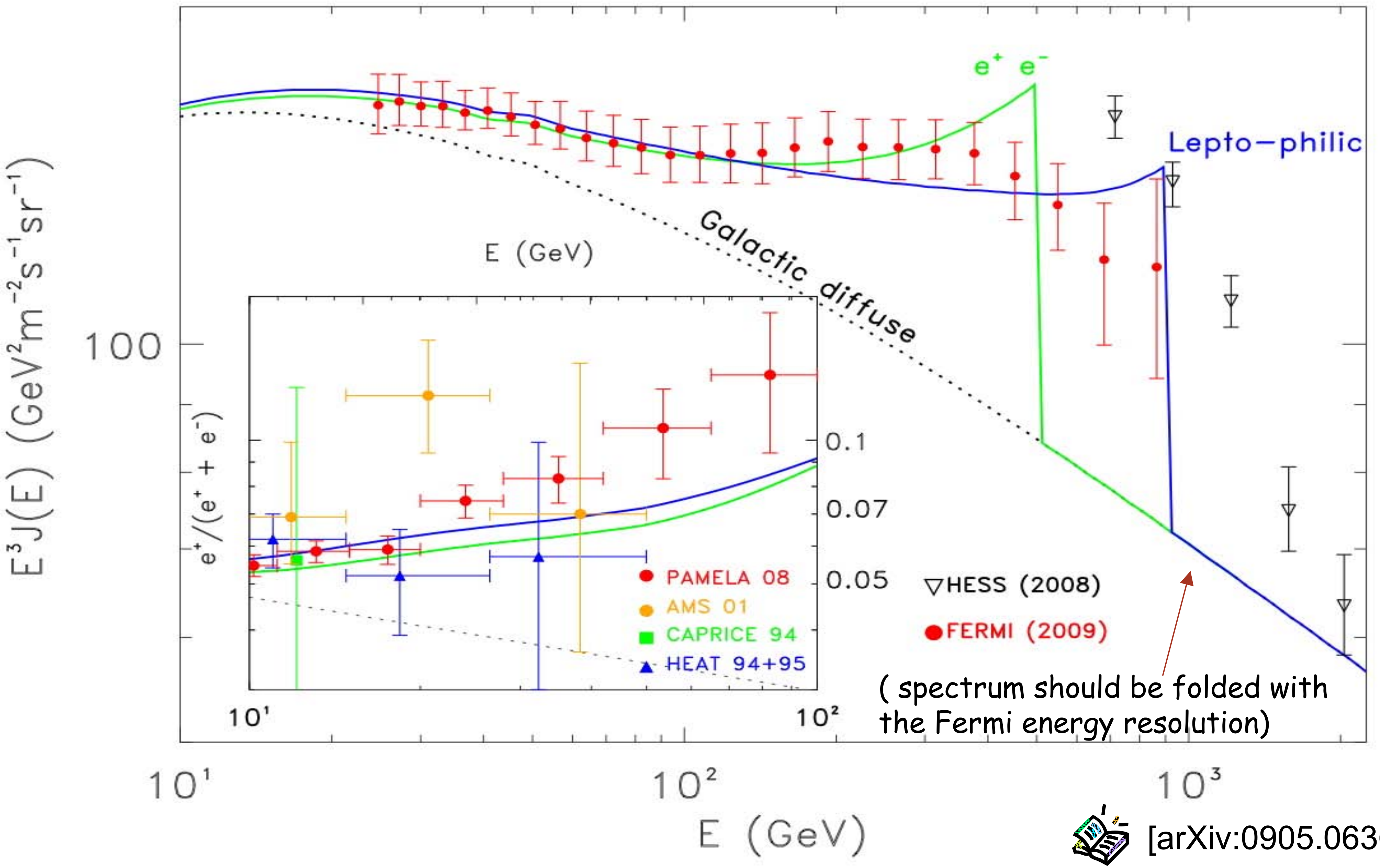
- - - spallation during propagation only

—— spallation also during acceleration

CREAM: Ahn et al. 2008, Astroparticle Phys. **30**, 133

A rise would rule out the DM and pulsar explanation of the PAMELA positron excess.

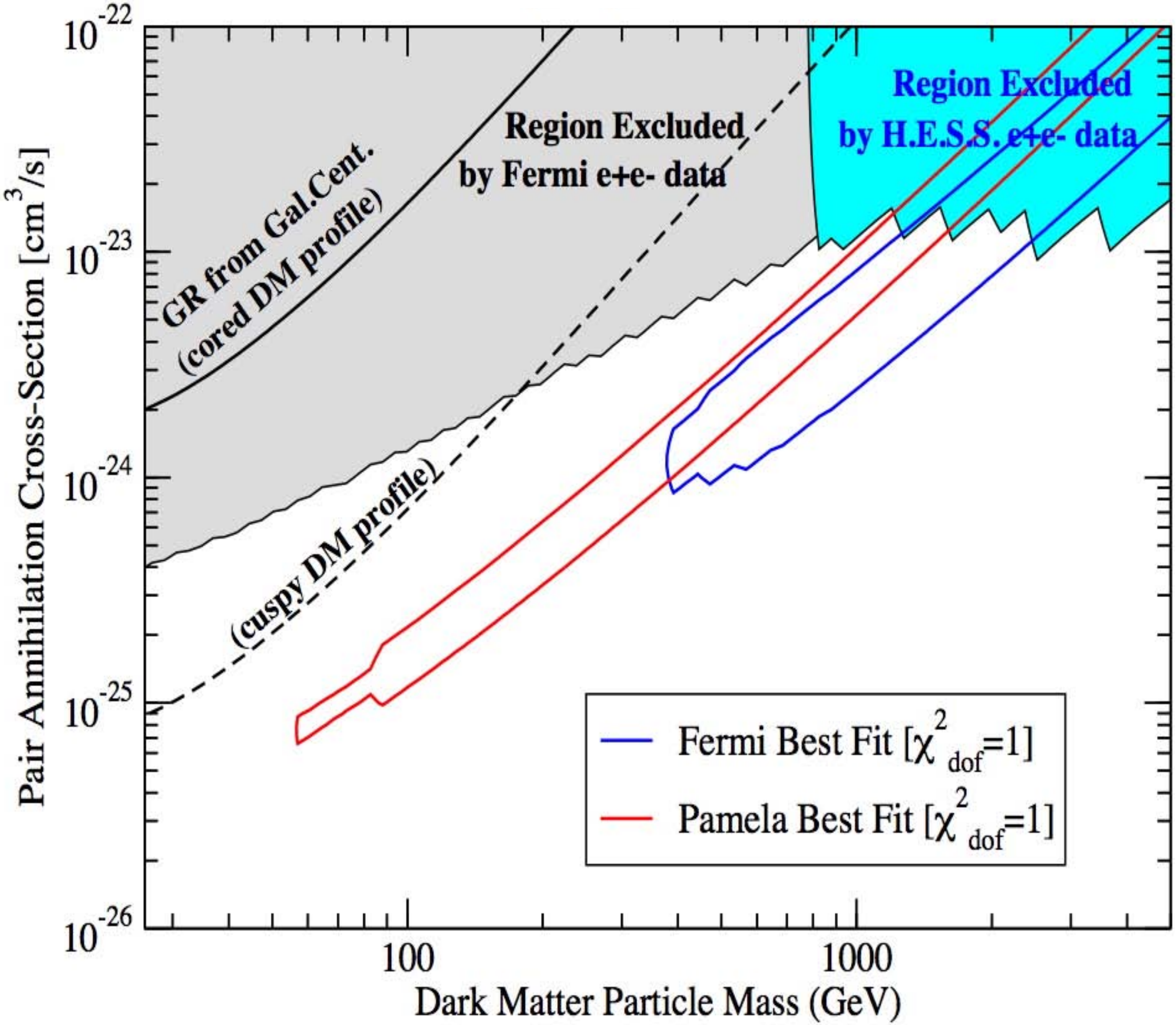
Predictions for the CRE spectrum from two specific dark matter models



[arXiv:0905.0636]

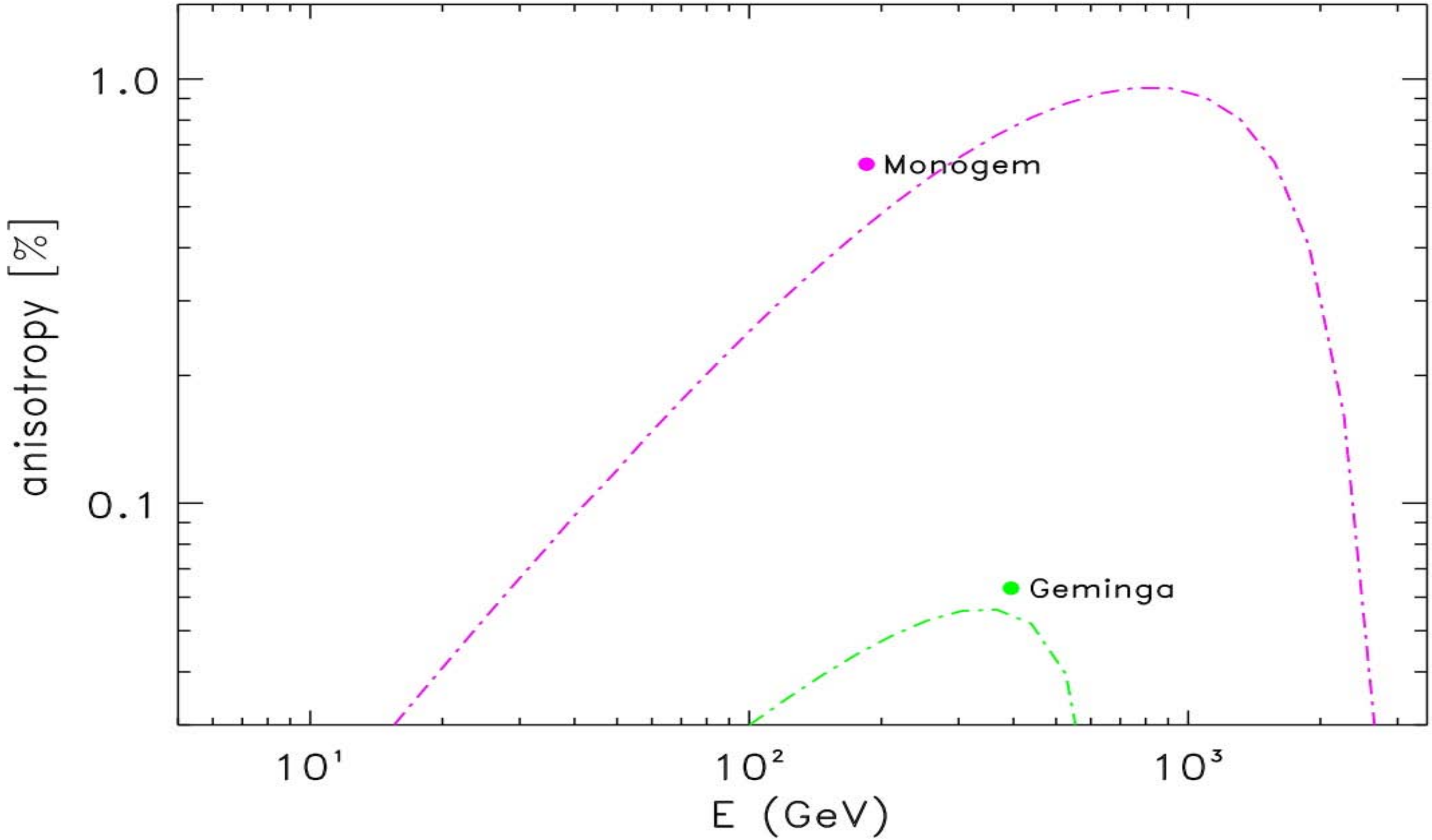
Lepto-philic Models

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]

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



Search Strategies

Satellites:

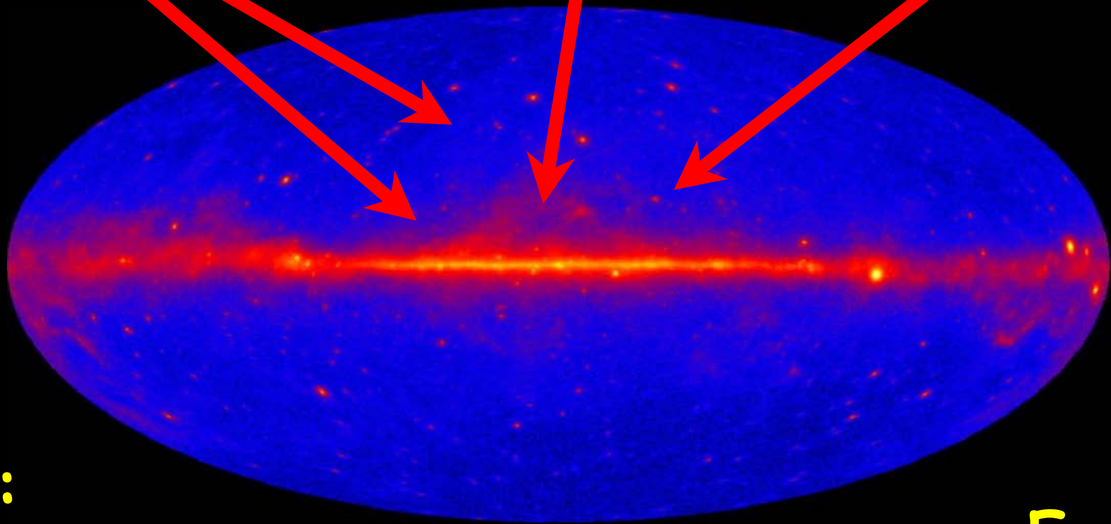
Low background and good source id, but low statistics

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

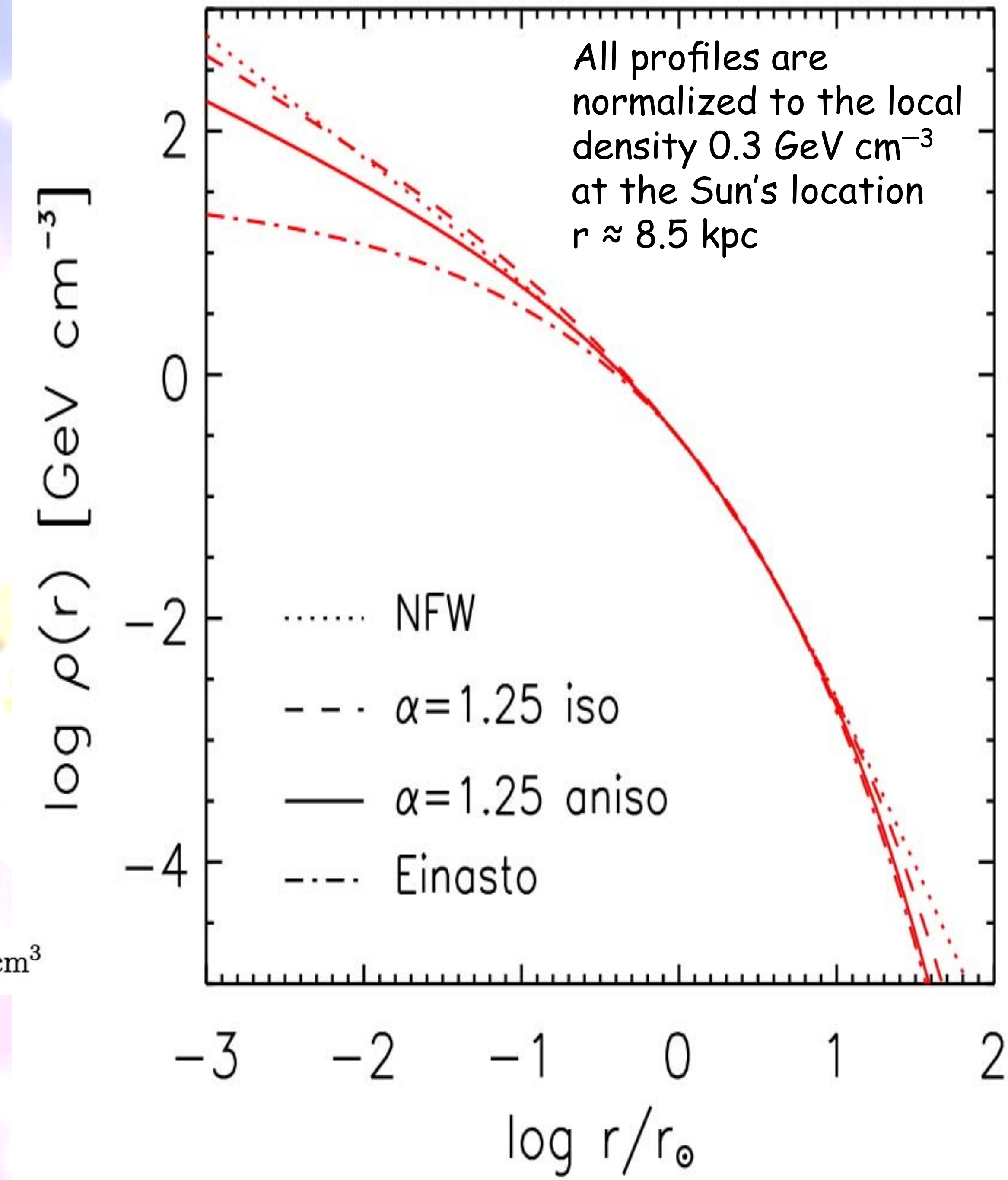
Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Milky Way Dark Matter Profiles

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

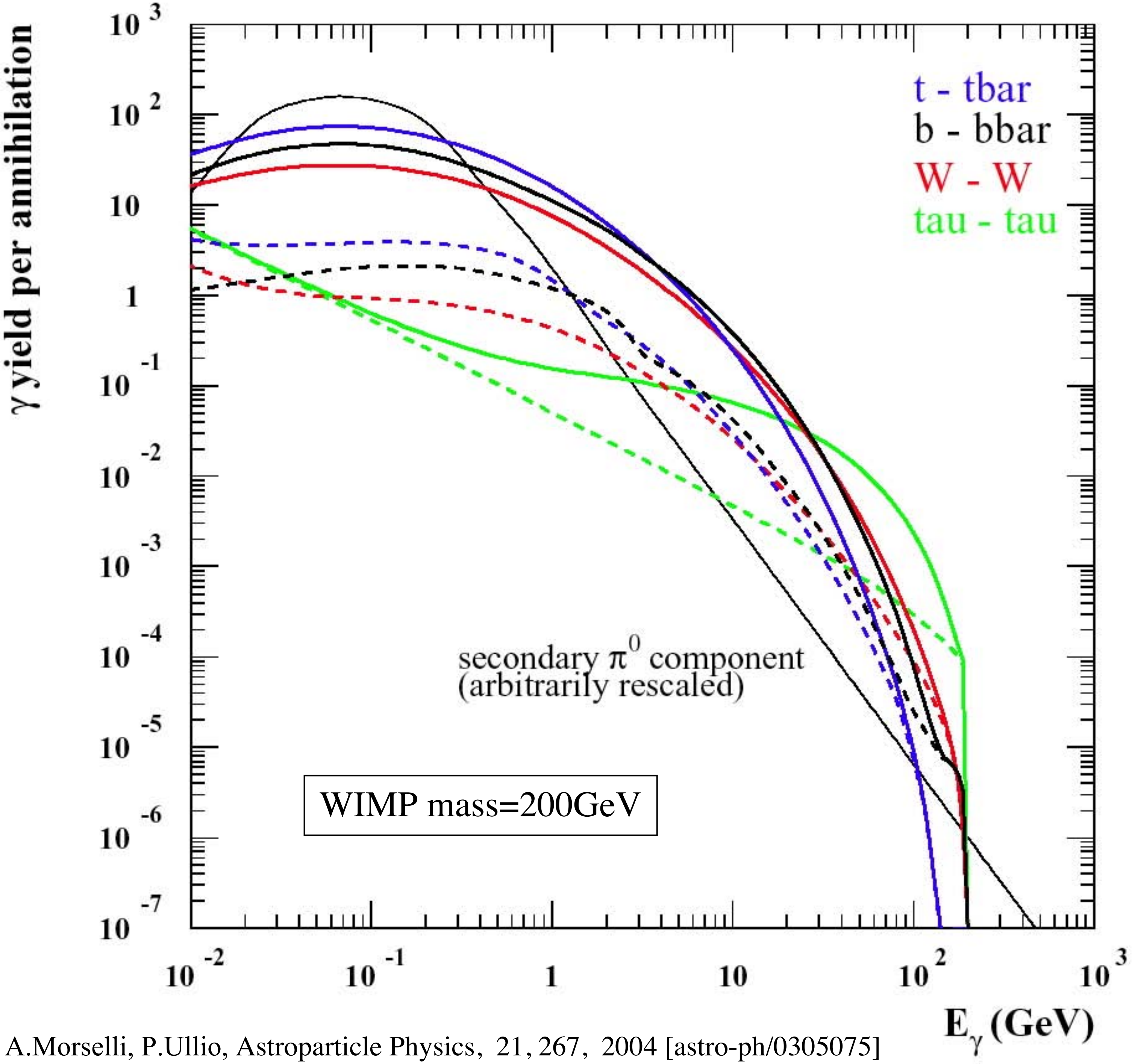
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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



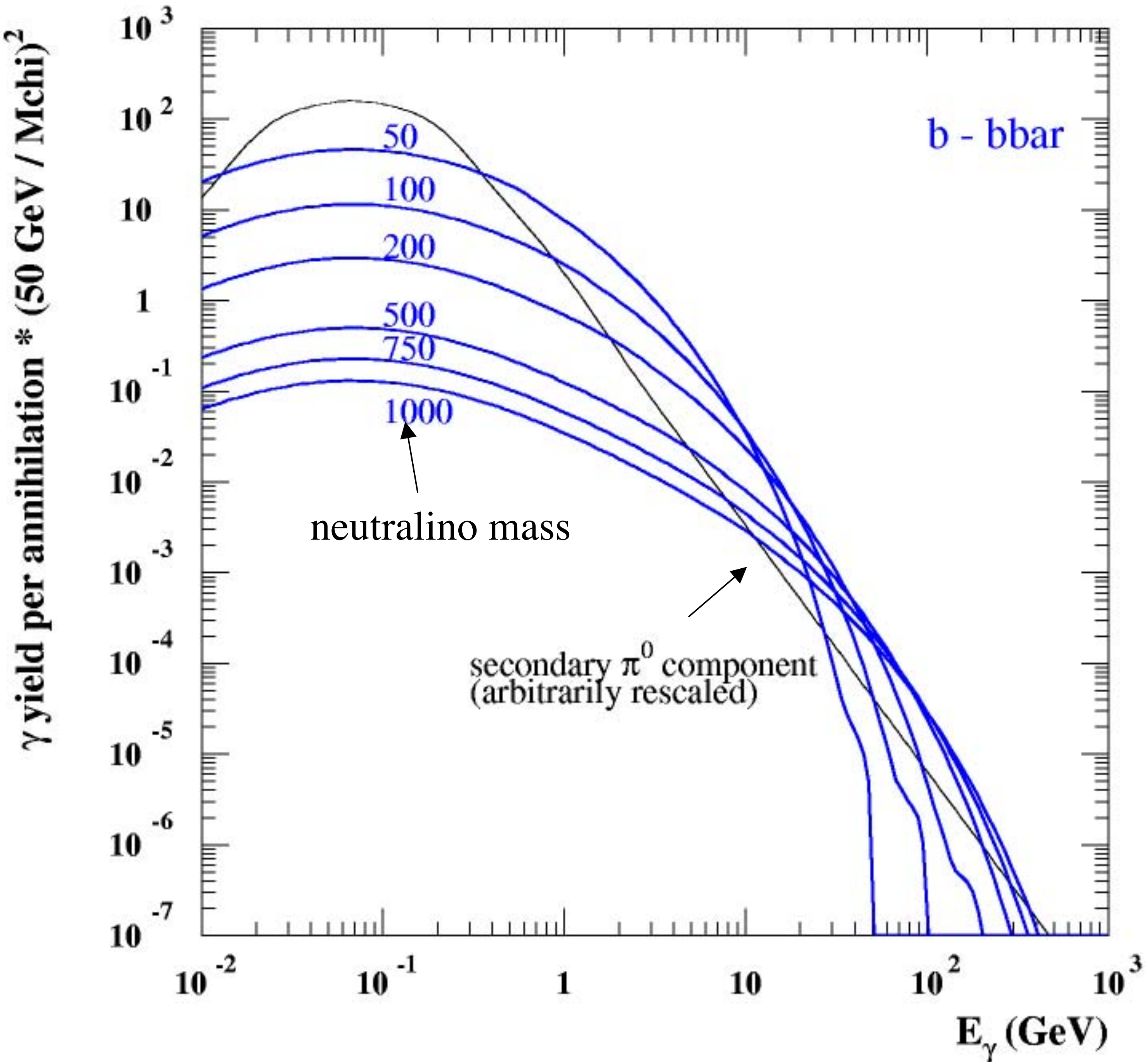
A.Lapi et al. arXiv:0912.1766

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

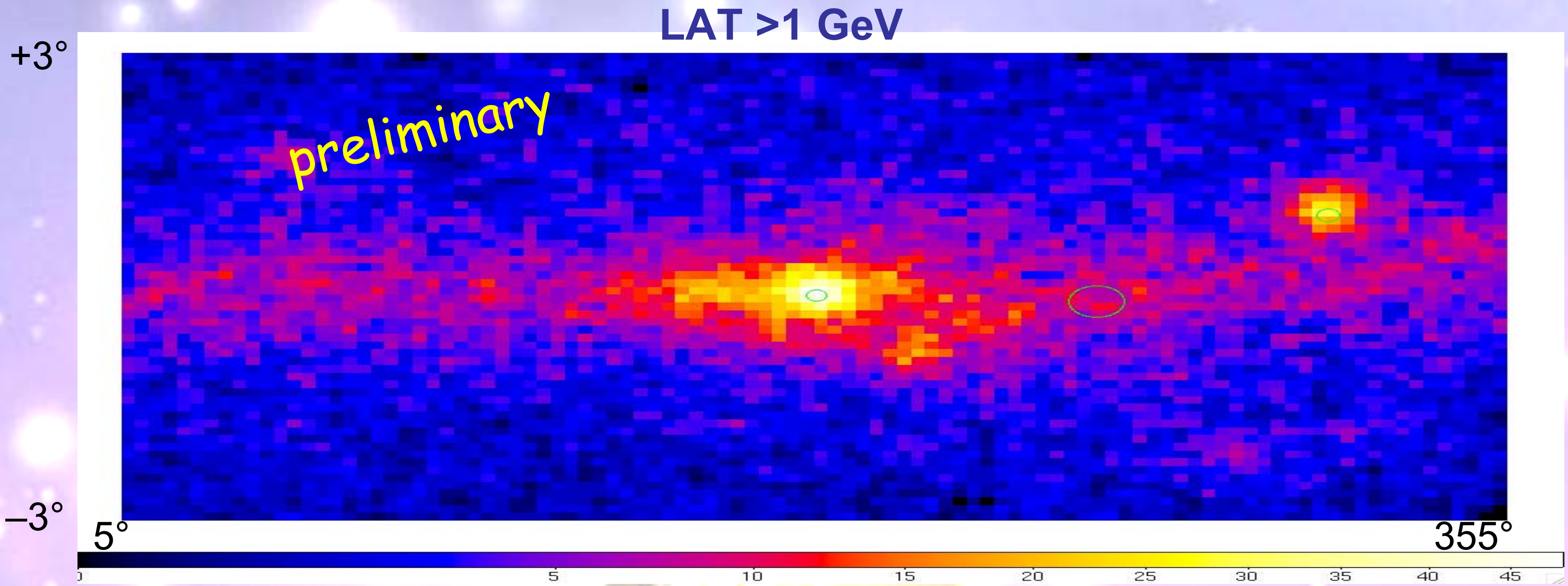


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

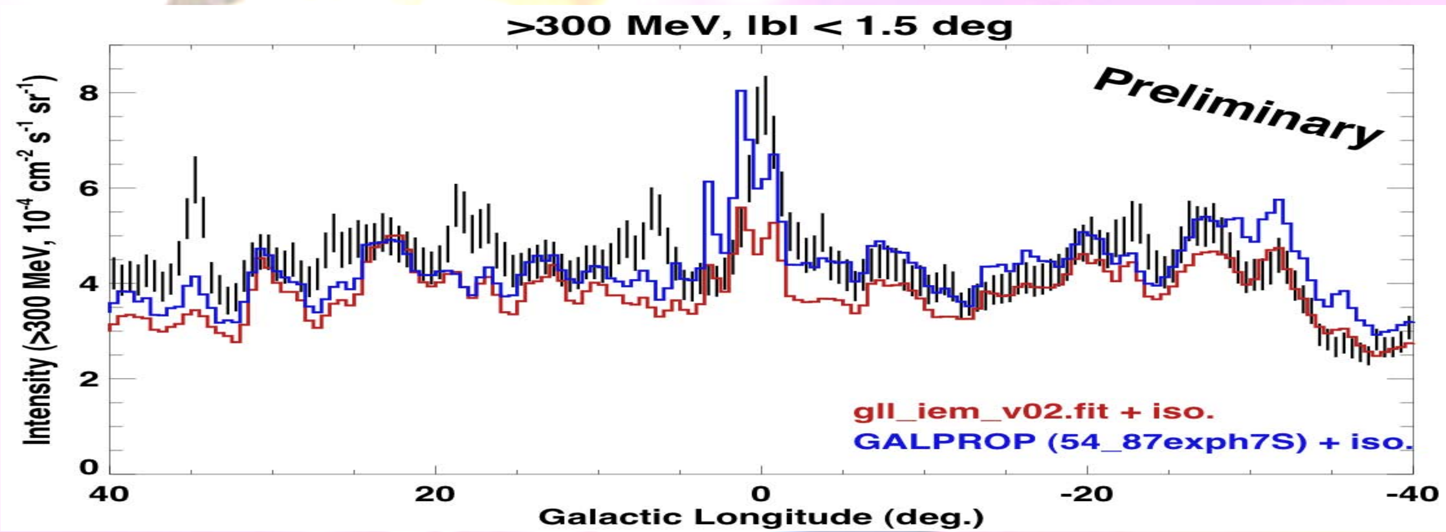
Search for DM in the GC

- 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 in the integration over the line of sight in the direction of the GC, very difficult to model

Fermi LAT Observations of the GC

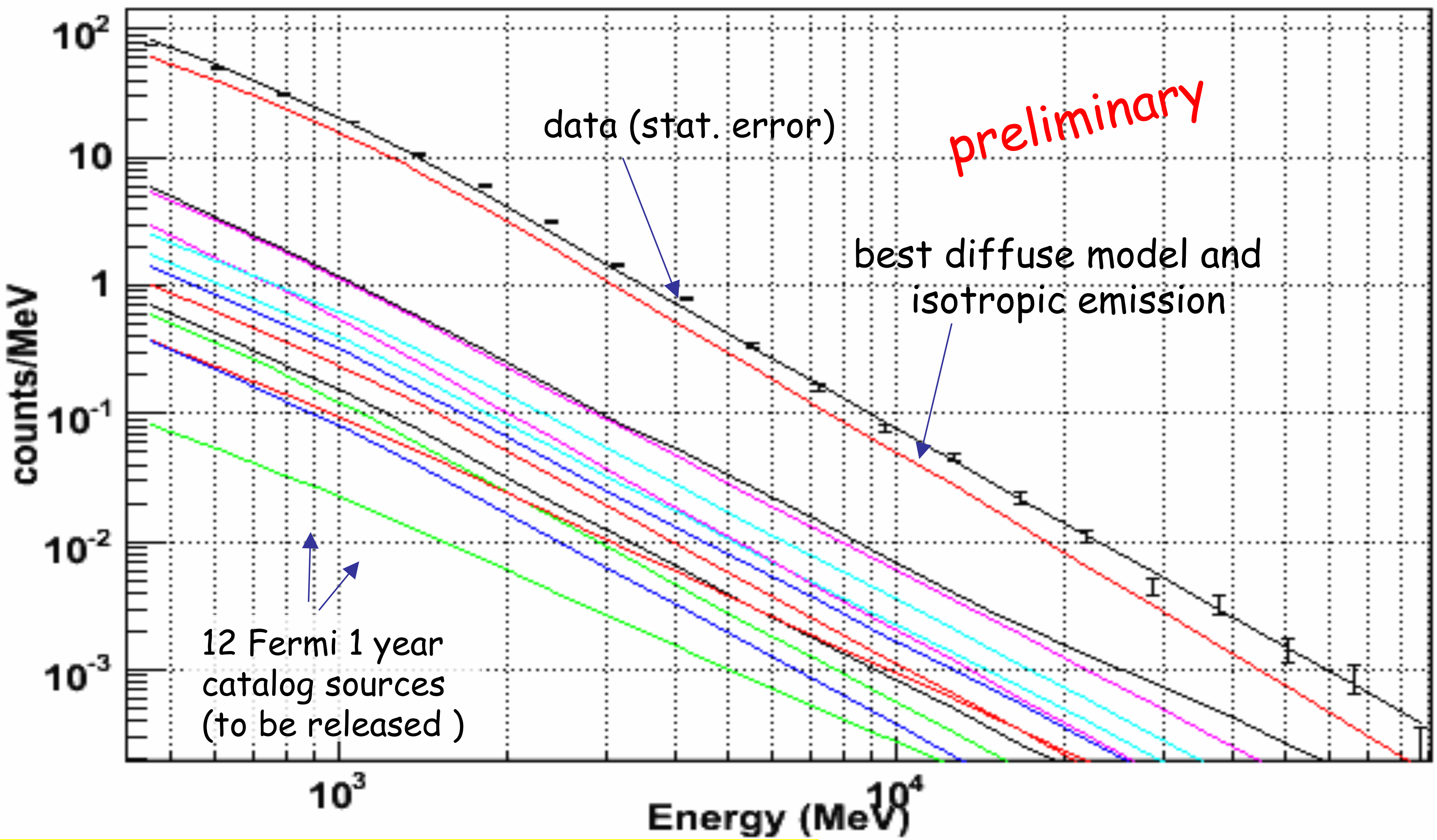


12-month data set, Diffuse class,
Front only
smoothed with σ = 0.1°
BSL source location circles overlaid



Fermi LAT Coll. in preparation

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

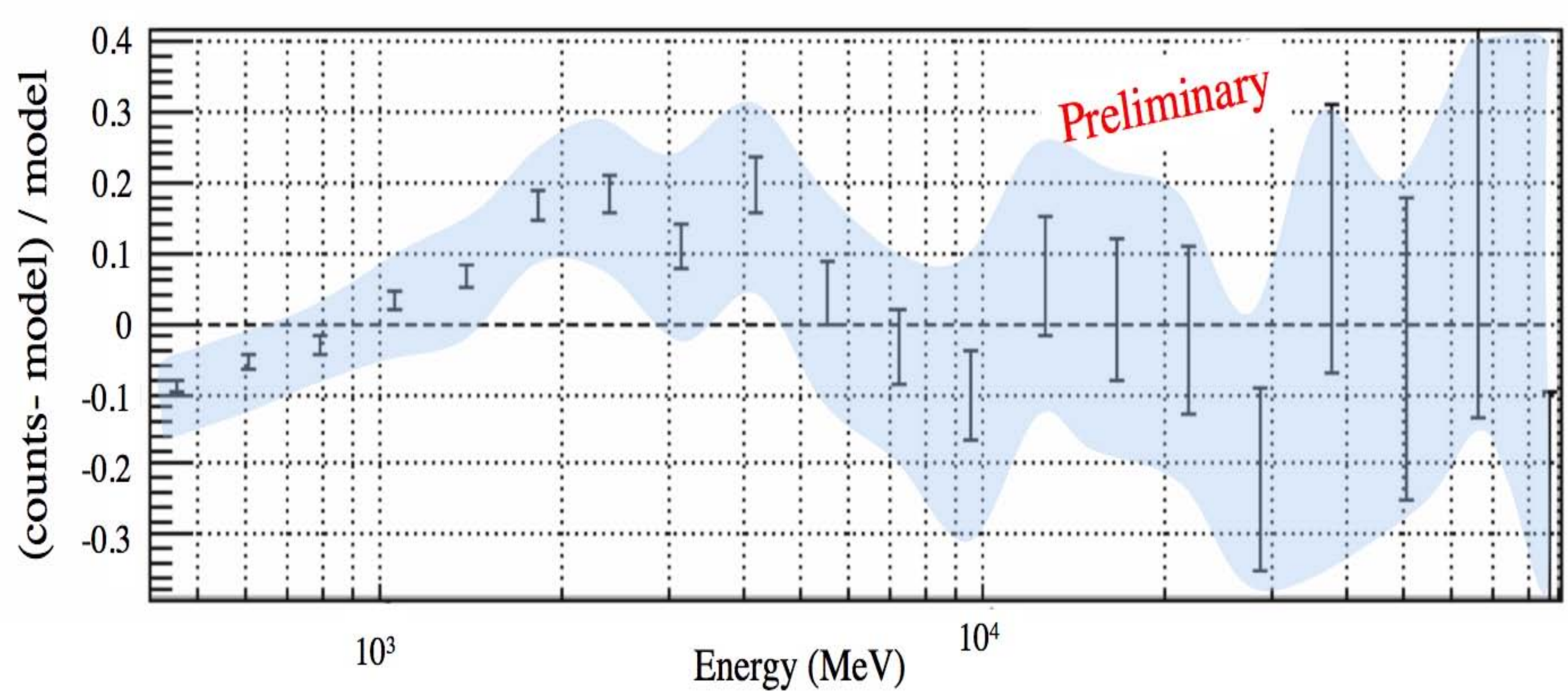


Fermi LAT Coll. in preparation, Fermi Symp. arXiv:0912.3828

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)

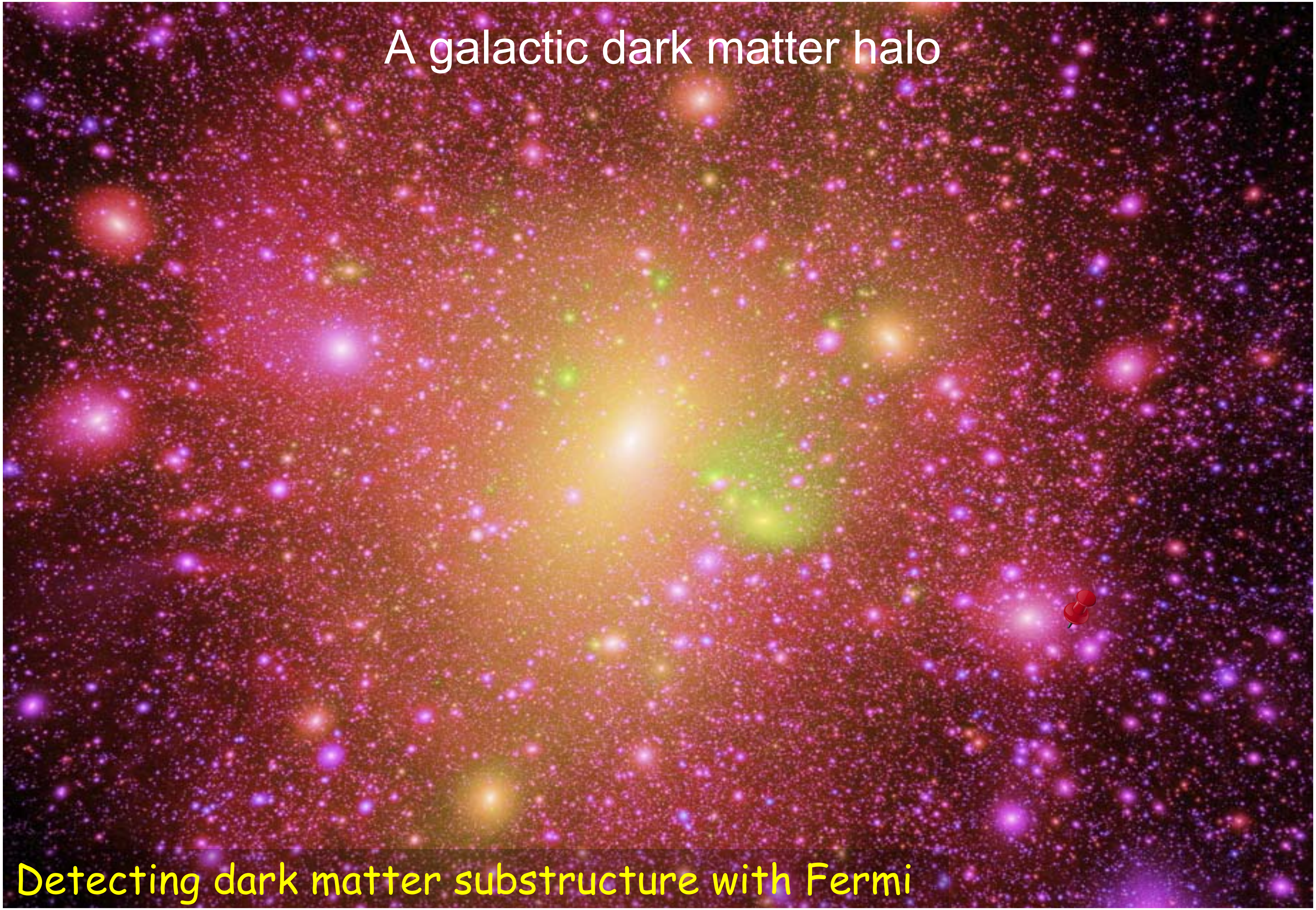
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



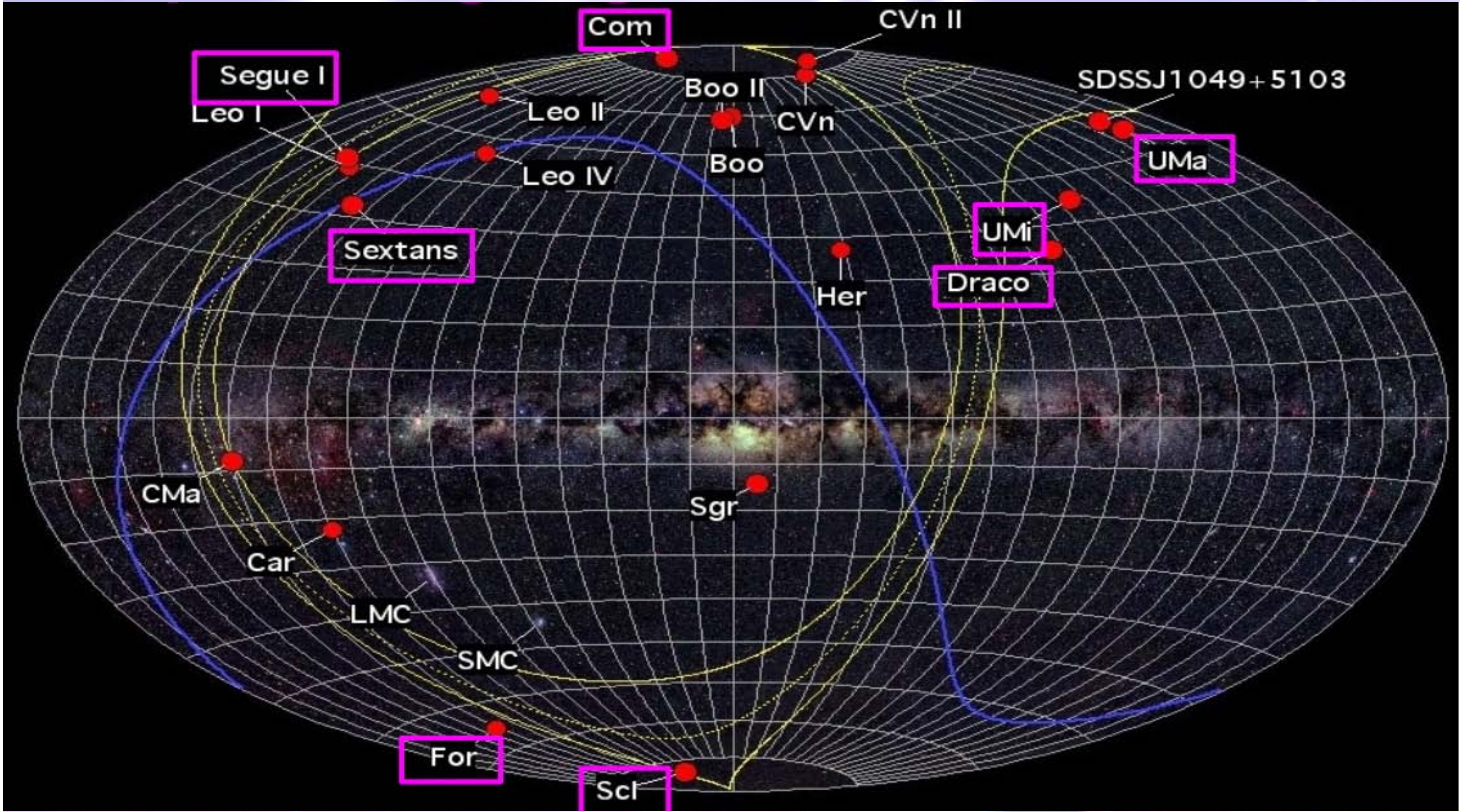
Fermi LAT Coll. in preparation, Fermi Symp. arXiv:0912.3828

Search for DM in the GC

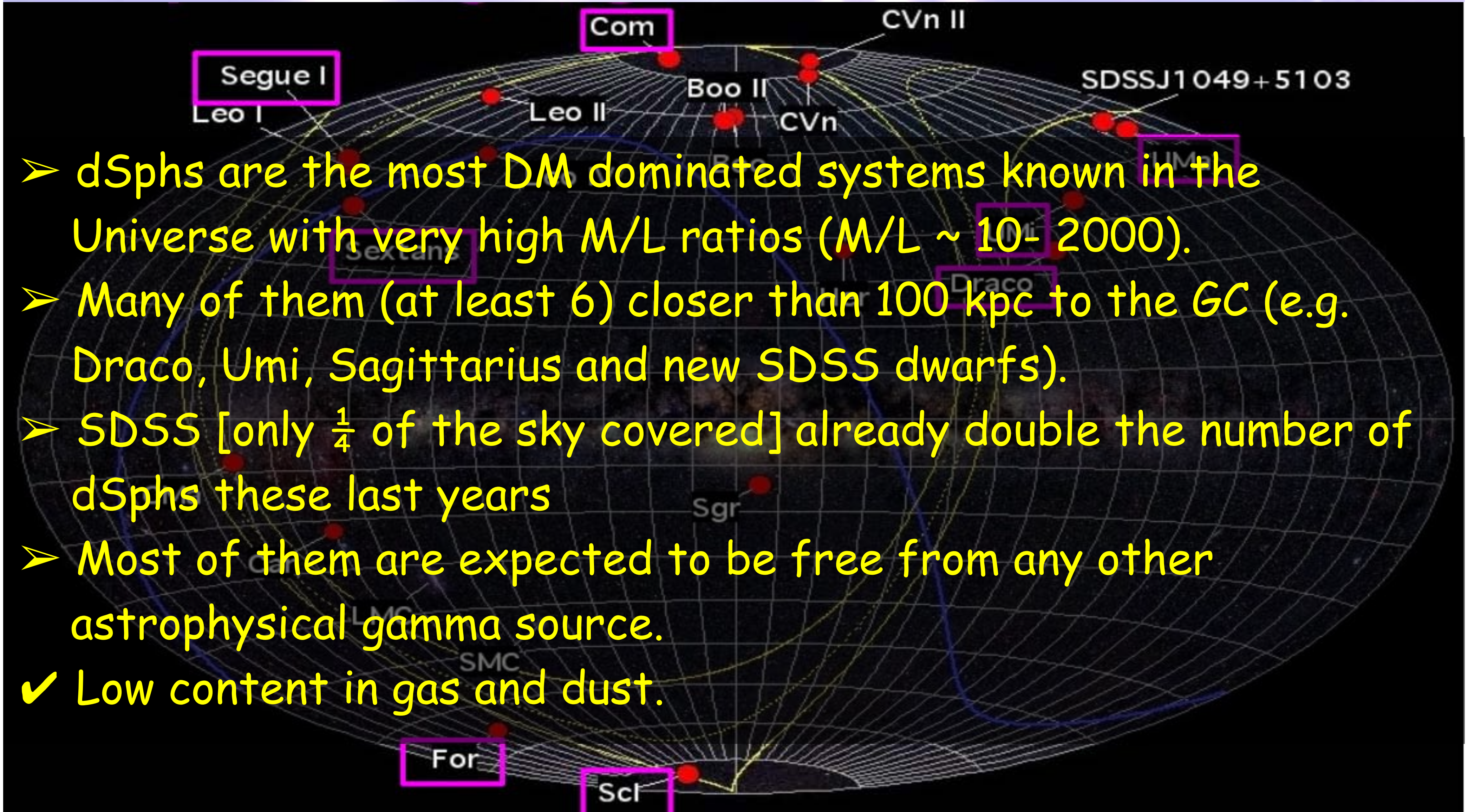
- ➡ Model generally reproduces data well within uncertainties. The model somewhat under-predicts the data in the few GeV range (spatial residuals under investigation)
- ➡ Any attempt to disentangle a potential dark matter signal from the galactic center region requires a detailed understanding of the conventional astrophysics
- 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


A galactic dark matter halo
Detecting dark matter substructure with Fermi

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 ¼ 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.

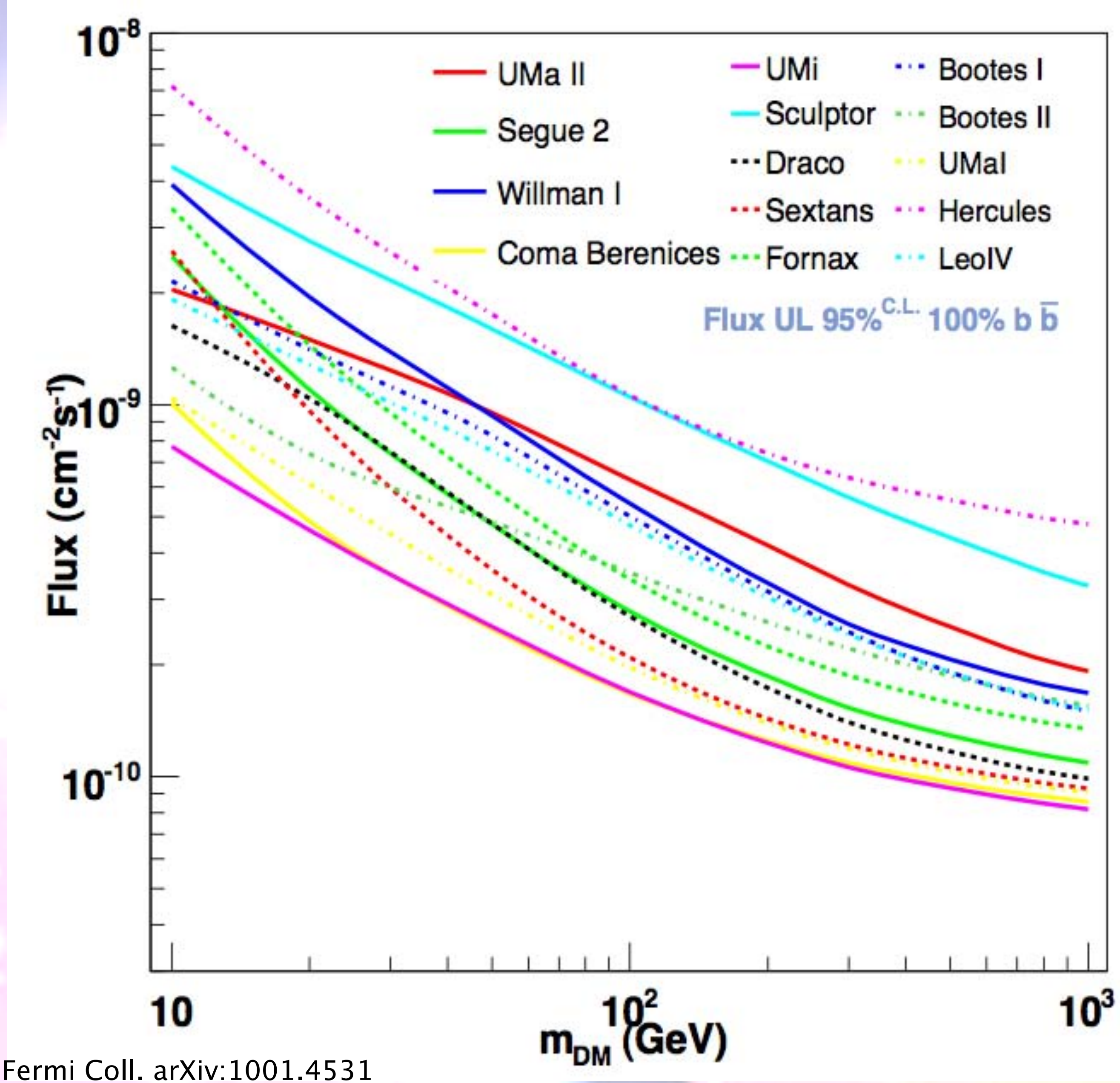
✔ Low content in gas and dust.

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) on quality of stellar data) to extract constraints on $\langle \sigma v \rangle$ vs WIMP mass for specific DM models

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



Fermi Coll. arXiv:1001.4531

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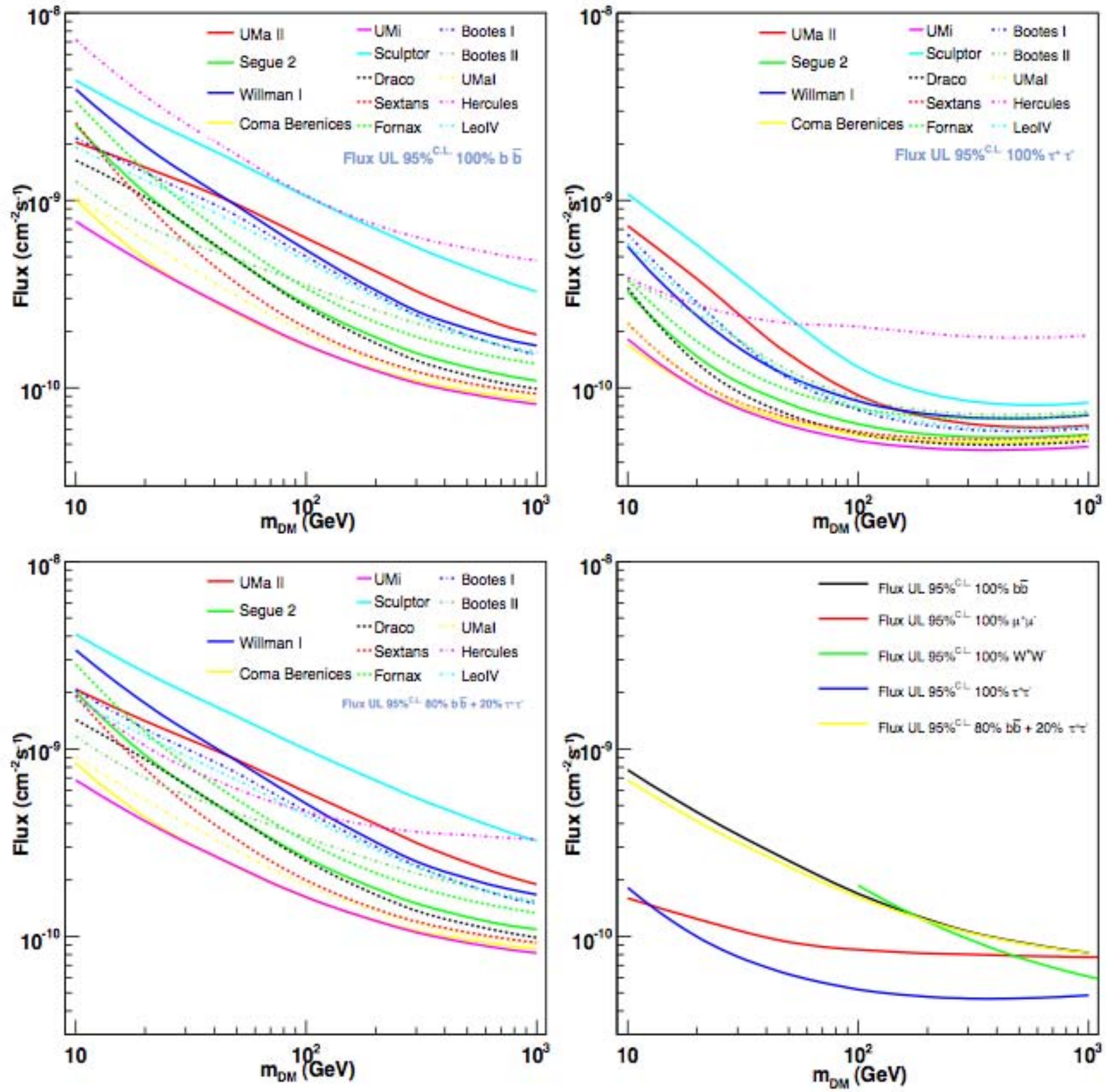

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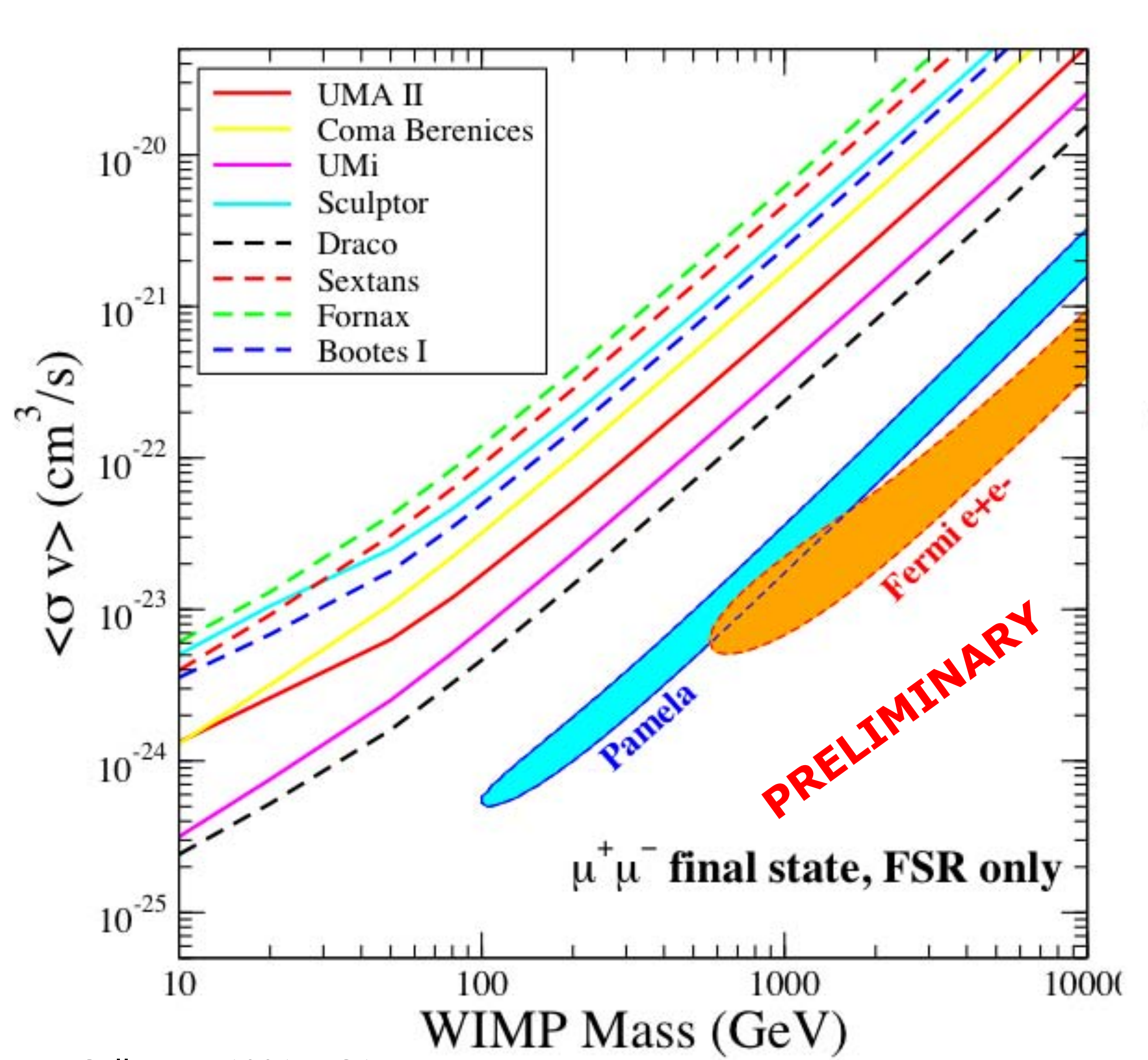

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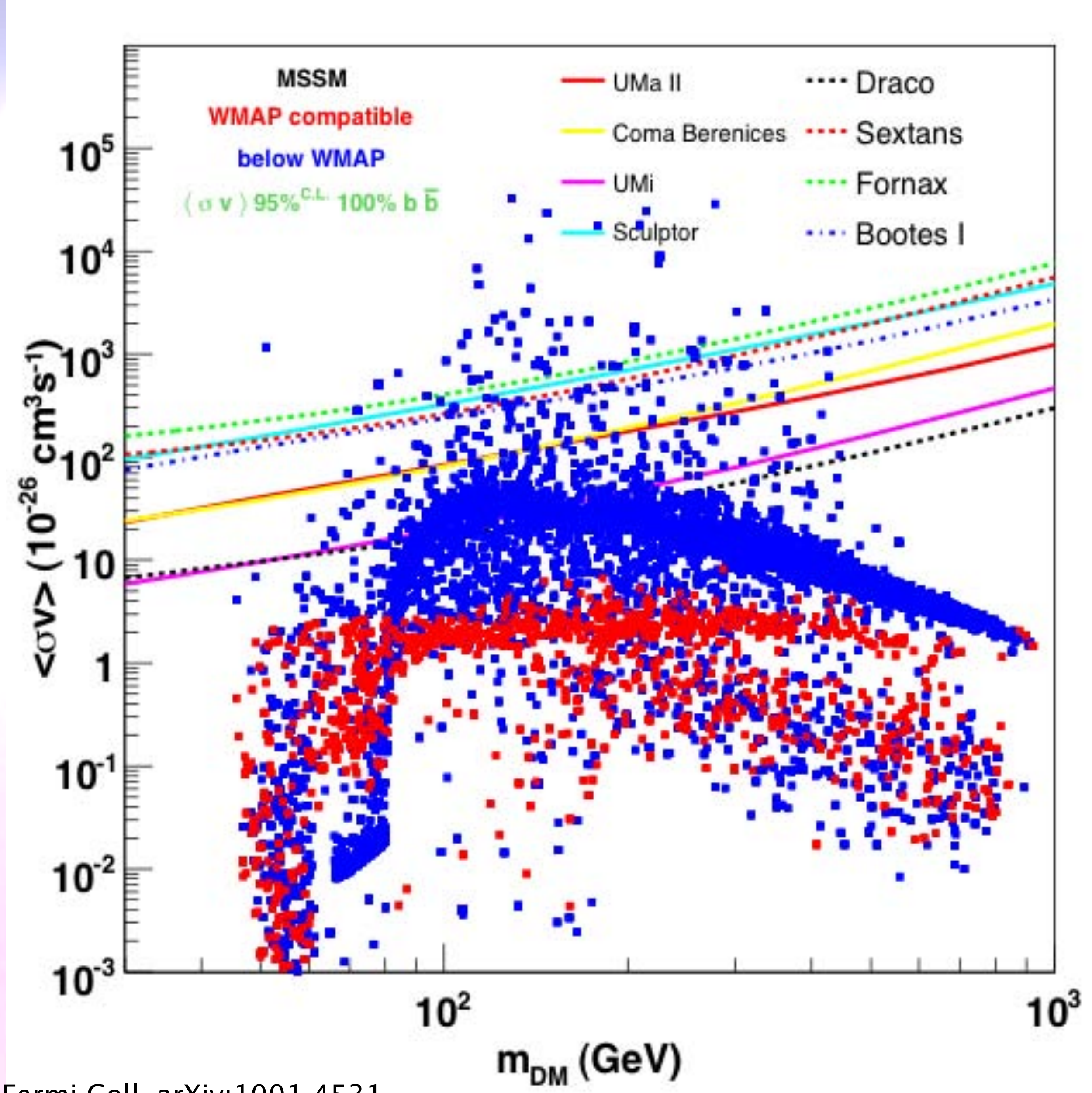


Fermi Coll. arXiv:1001.4531

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

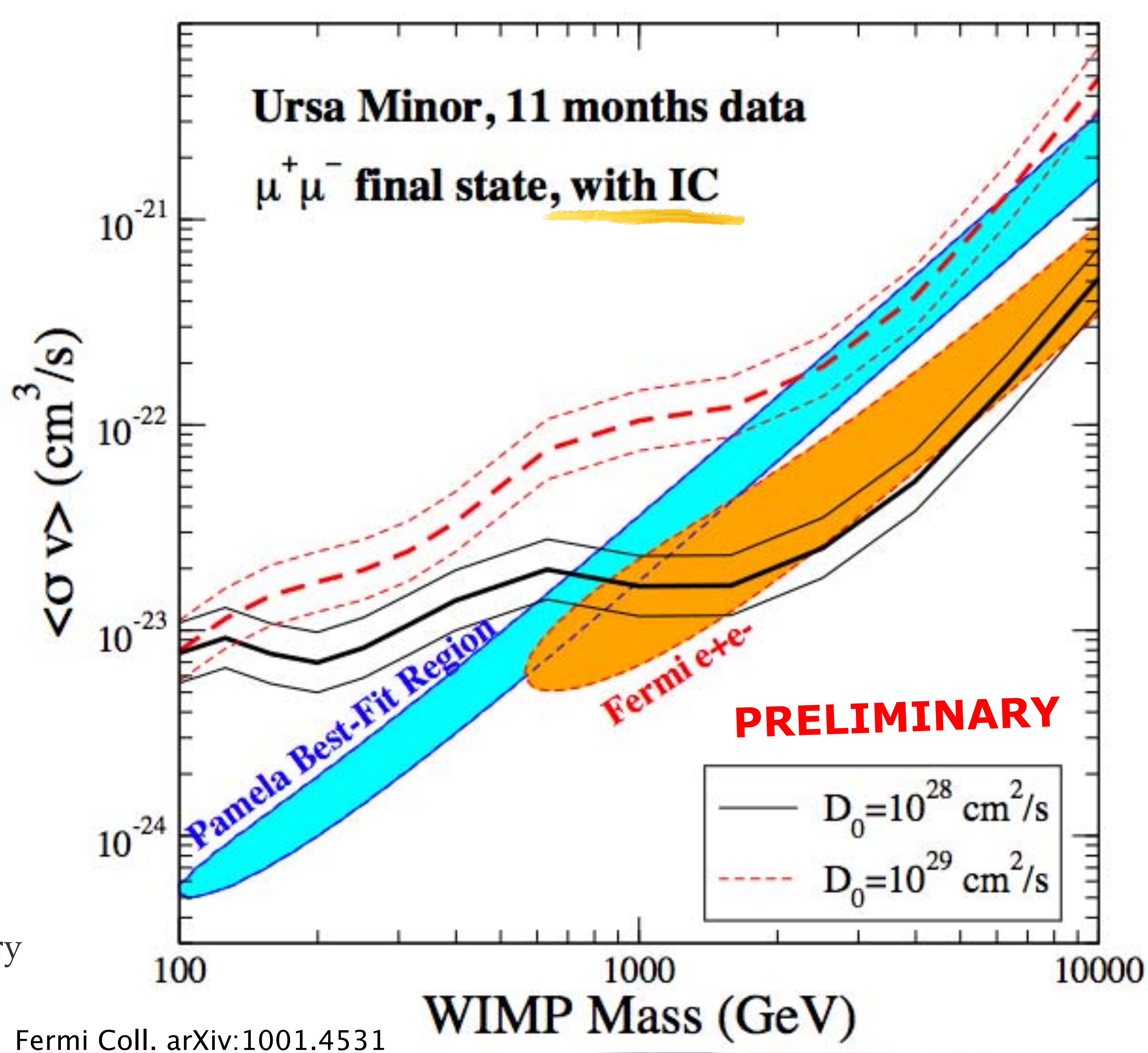
(only galaxy with measurements, scaling to dwarfs ??)

Dwarf Spheroidal Galaxies upper-limits

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

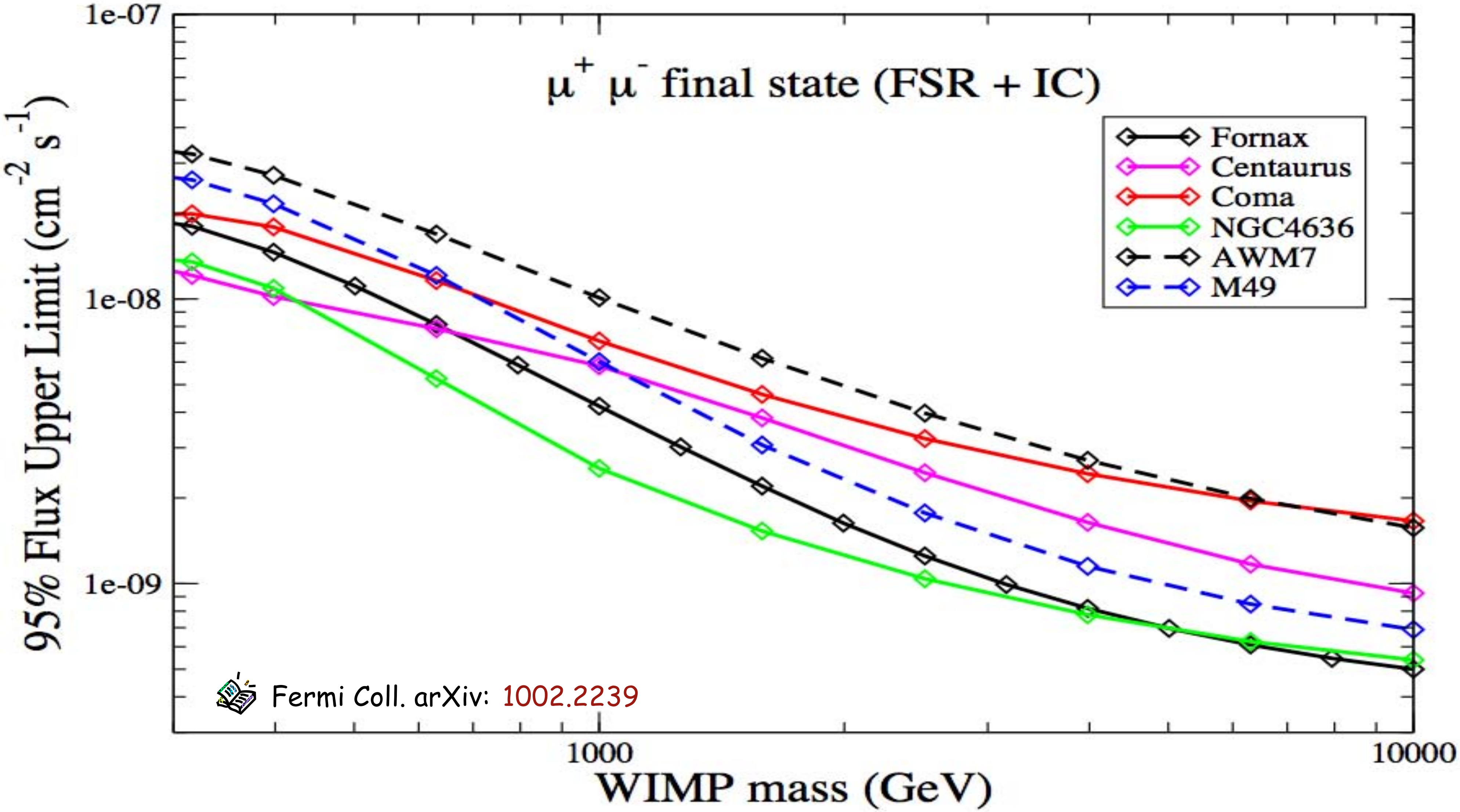
Stronger constraints can be derived if IC of electrons and positrons from DM annihilation off of the CMB is included, however diffusion in dwarfs is not known ⇒ use bracketing values of diffusion coefficients from cosmic rays in the Milky Way

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



Fermi Coll. arXiv:1001.4531

Galaxy Clusters upper-limits

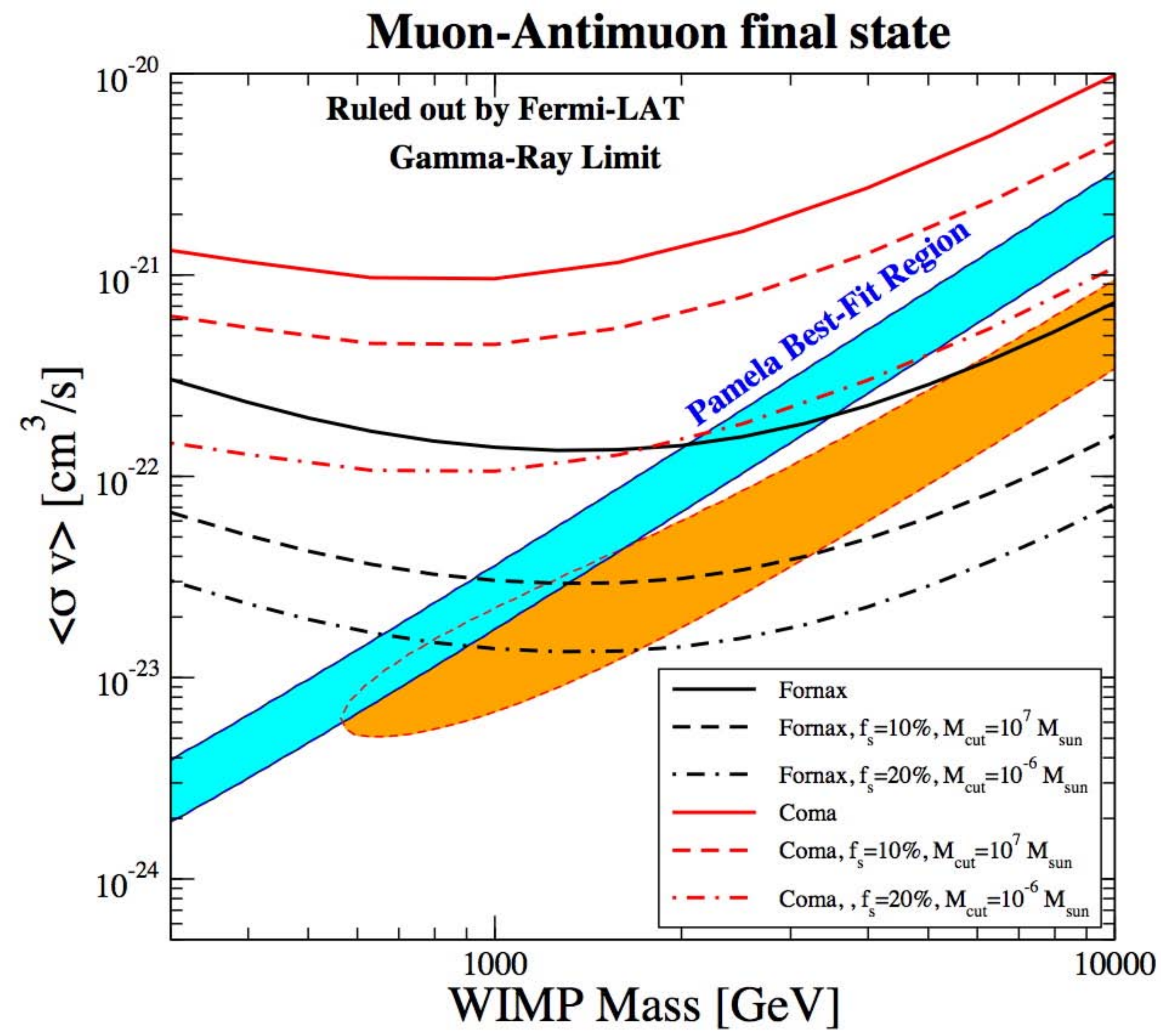


Fermi Coll. arXiv: 1002.2239

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

Galaxy Clusters upper-limits

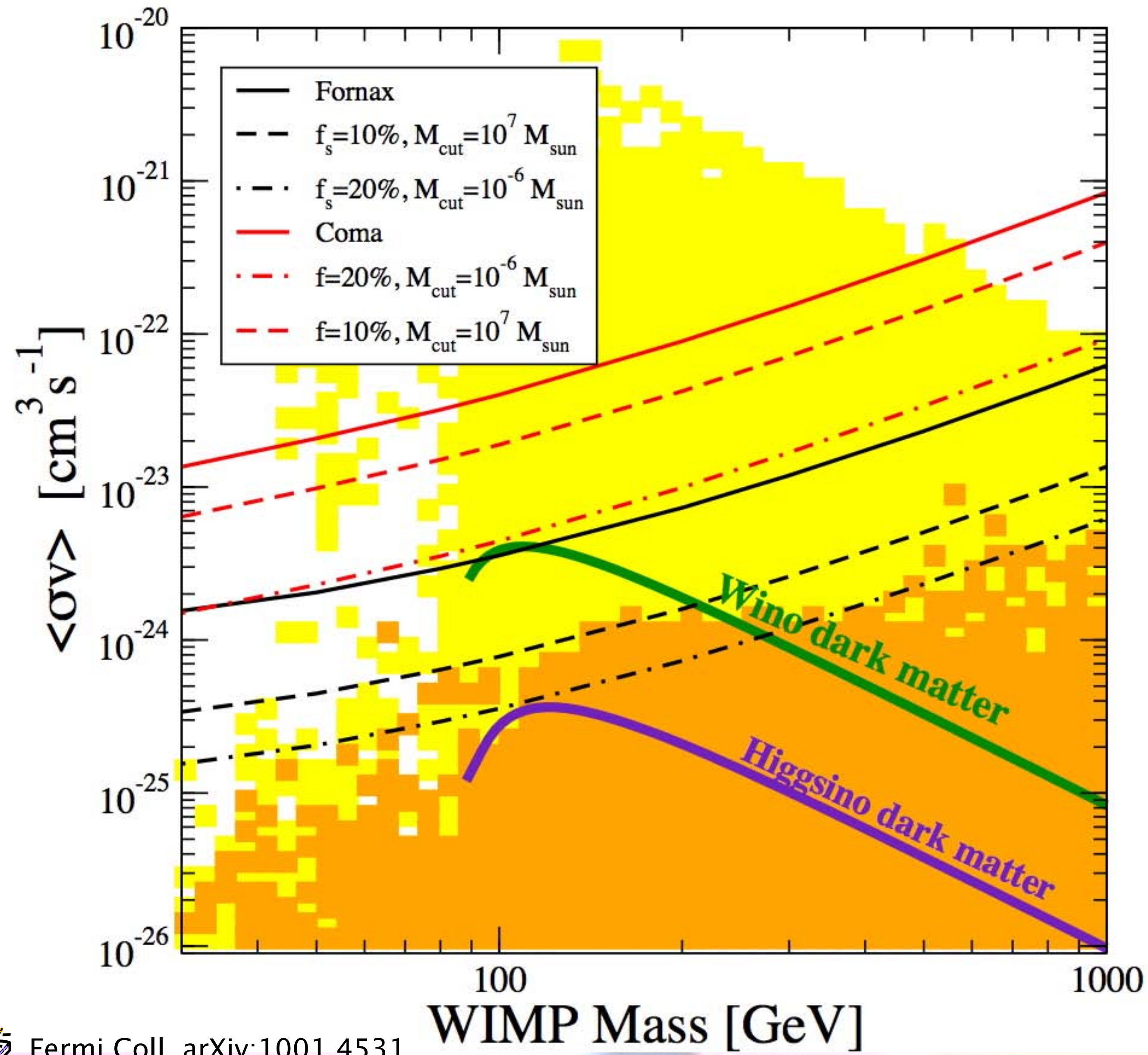
Stronger constraints on leptophilic DM models can be derived with galaxy clusters when the IC contribution off the CMB of secondary electrons (from DM annihilation) is included



Fermi Coll. arXiv: 1002.2239

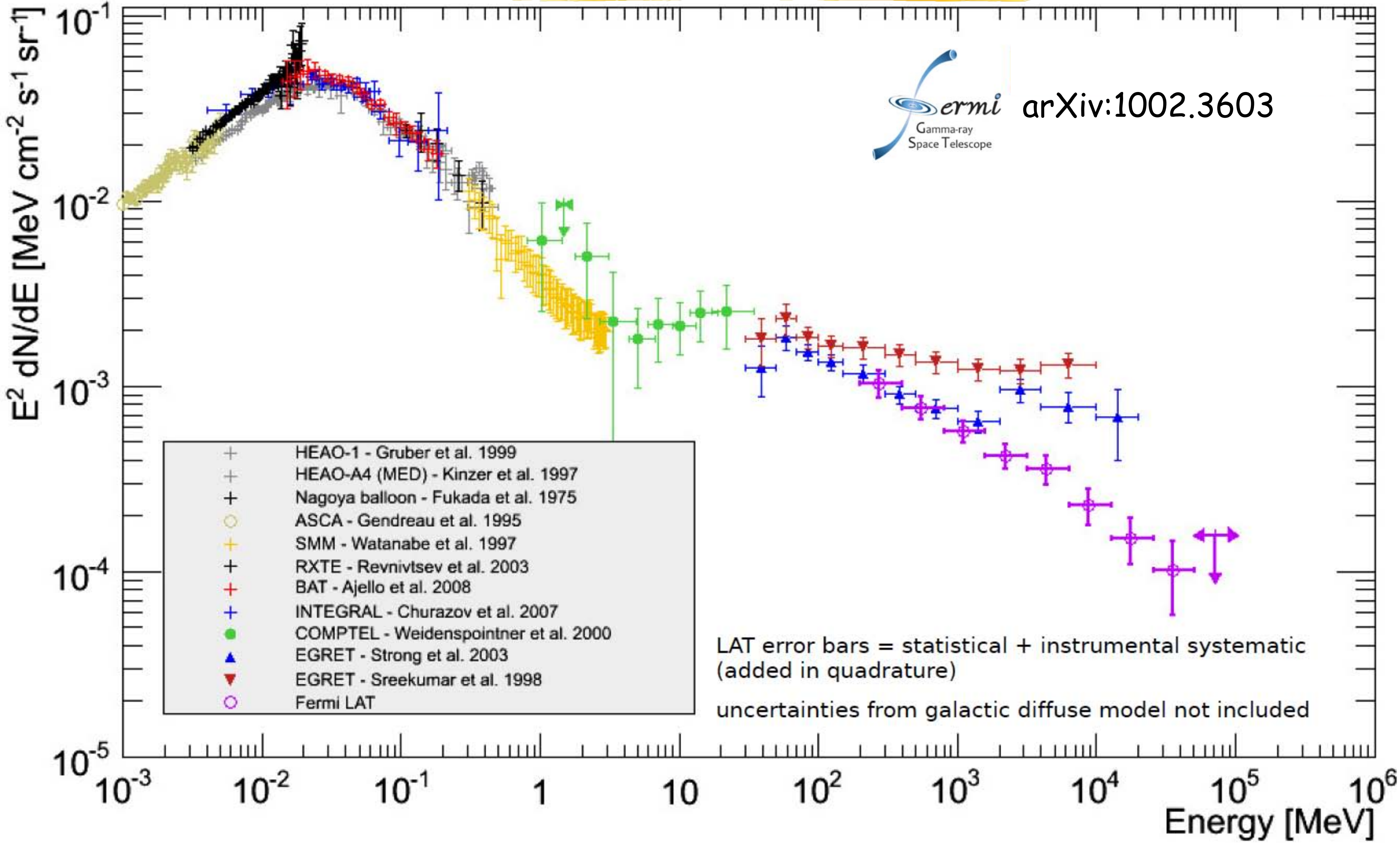
Galaxy Clusters upper-limits

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

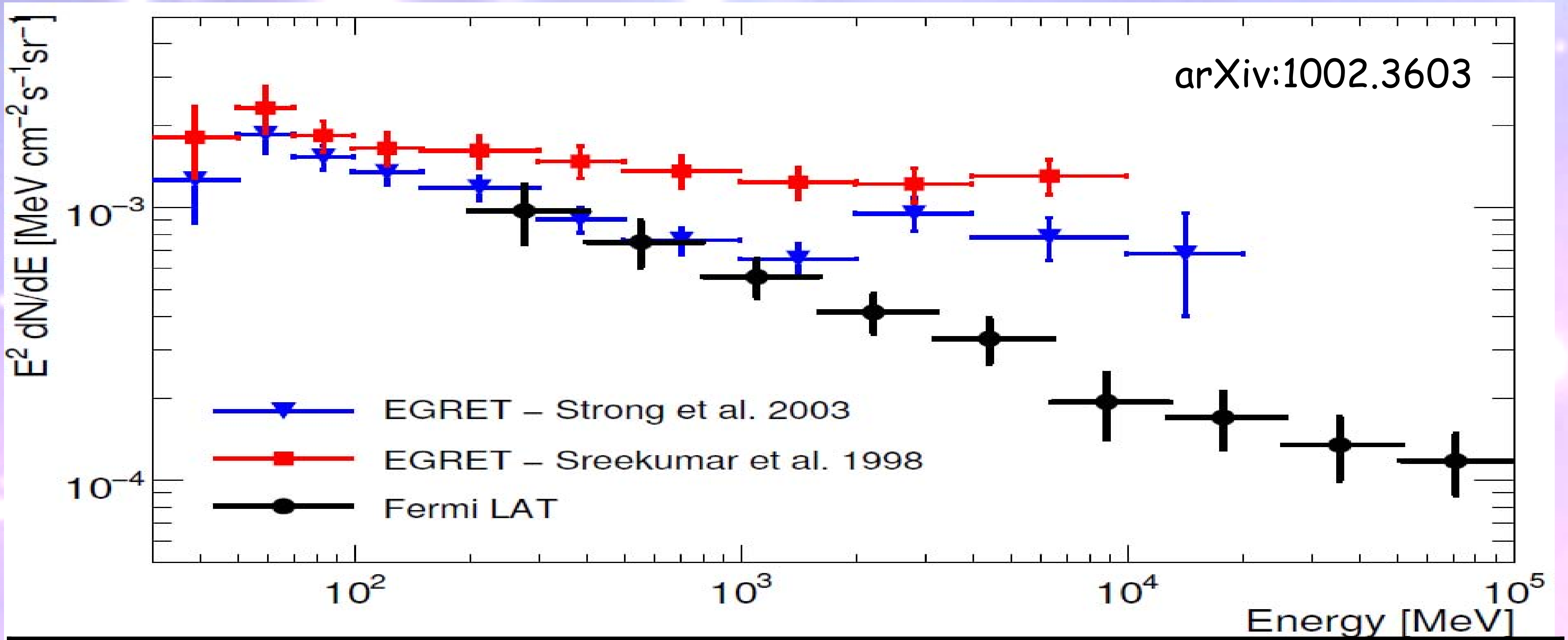


Fermi Coll. arXiv:1001.4531

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

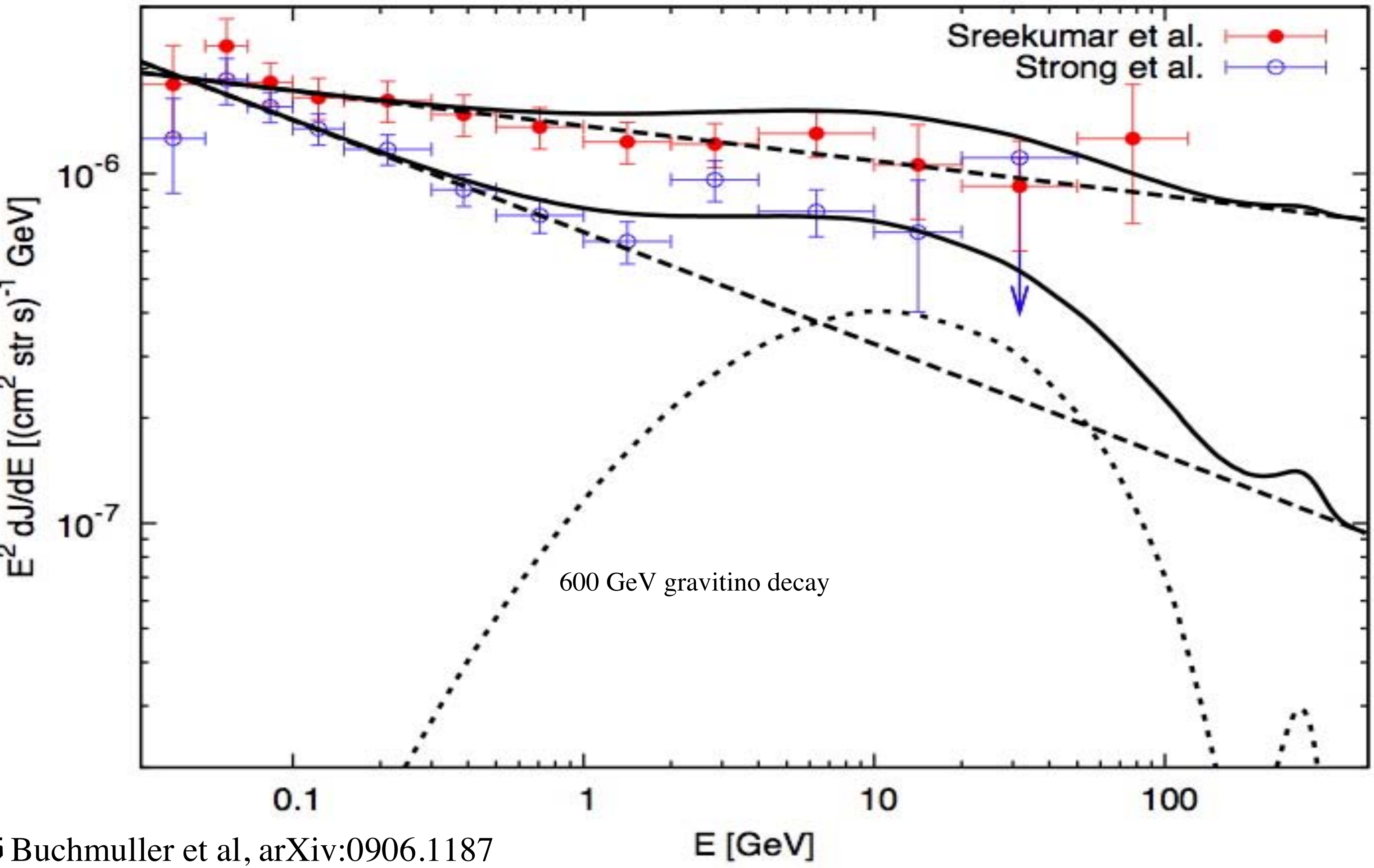


SED of the isotropic diffuse emission (1 keV–100 GeV)



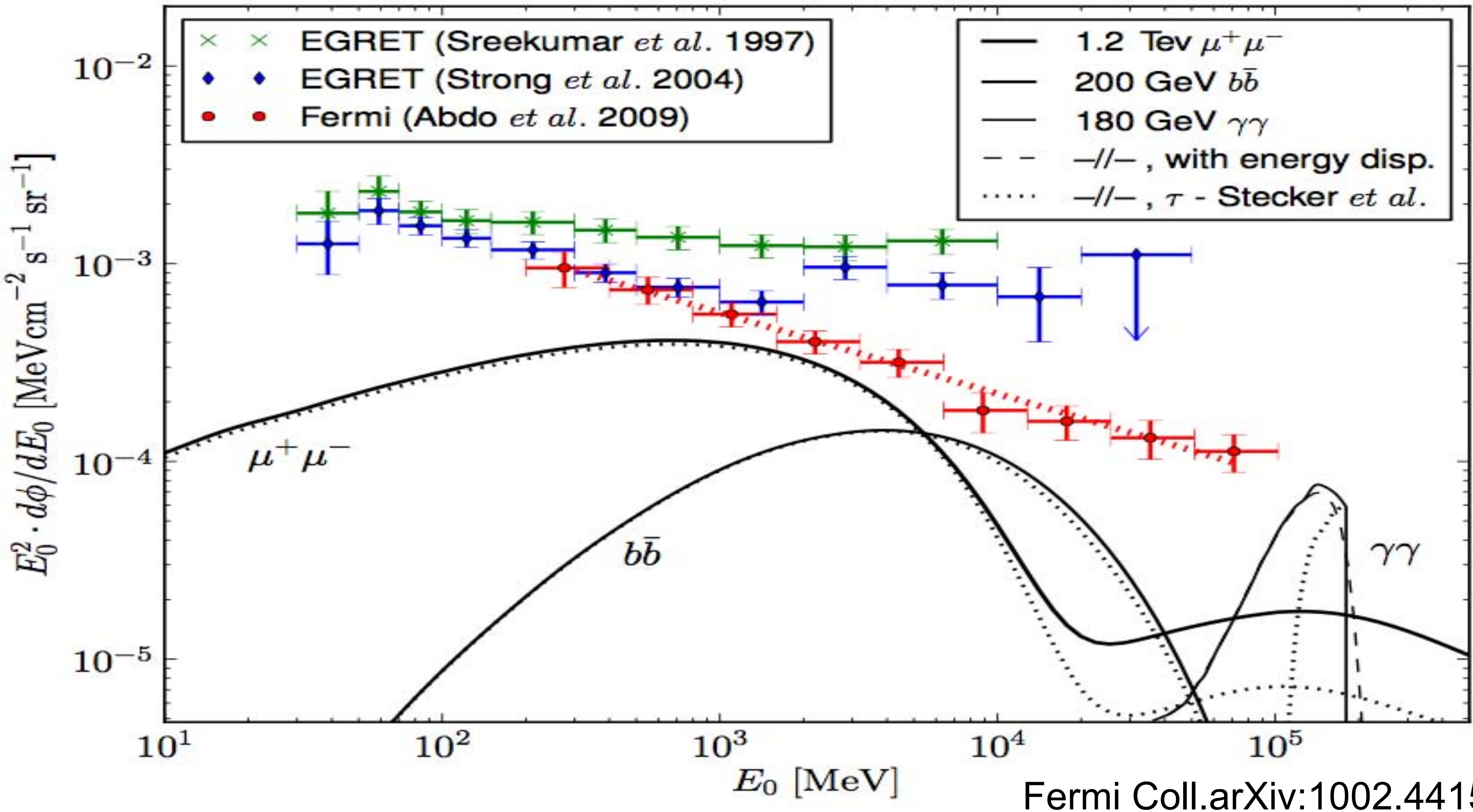
	Flux, E>100 MeV	spectral index
Fermi LAT	**1.03 +/- 0.17**	**2.41 +/- 0.05**
EGRET (Sreekumar et al., 1998)	1.45 +/- 0.05	2.13 +/- 0.03
EGRET (Strong et al. 2004)	1.11 +/- 0.10	
LAT + resolved sources below EGRET sensitivity	1.19 +/- 0.18	2.37 +/- 0.05
	x 10^{-5} cm^{-2} s^{-1} sr^{-1}	

extragalactic gamma-ray spectrum



Buchmuller et al, arXiv:0906.1187

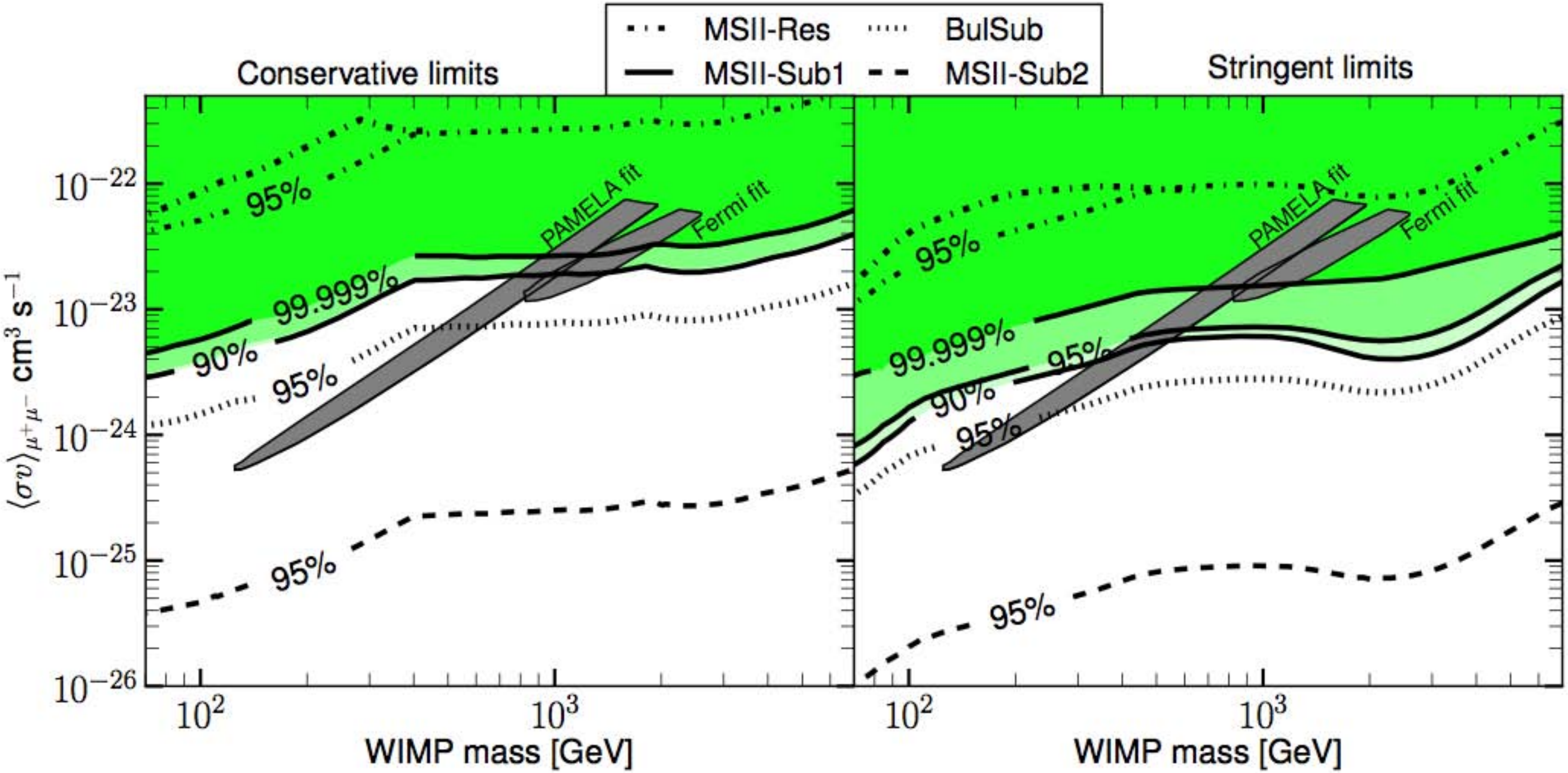
extragalactic gamma-ray spectrum



Fermi Coll.arXiv:1002.4415

others possible contributions to the extragalactic gamma-ray spectrum

extragalactic gamma-ray spectrum



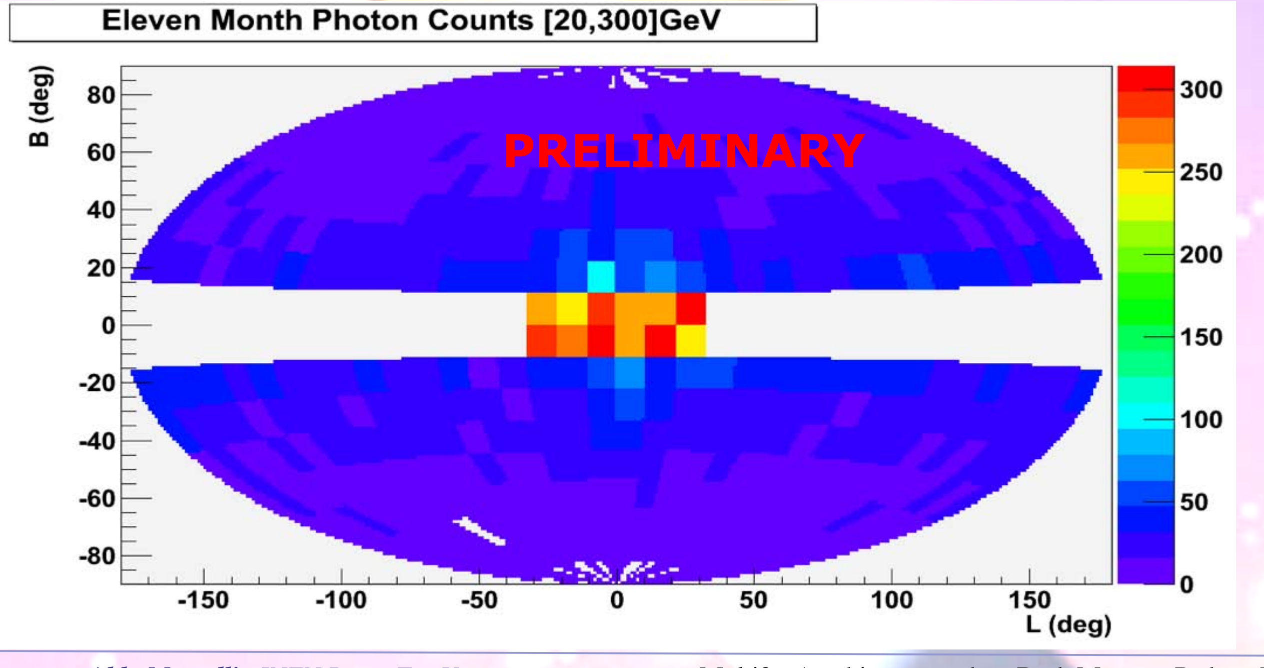
Fermi Coll.arXiv:1002.4415

limits on dark matter annihilation into μ+μ— final states

Search for Spectral Gamma Lines

➡ Smoking gun signal of dark matter

- Search for lines in the first 11 months of Fermi data in the 30-200 GeV energy range
- Search region
  - |b|>10° and 30° around galactic center
- Remove point sources (for |b|>10°). The data selection includes additional cuts to remove residual charged particle contamination.

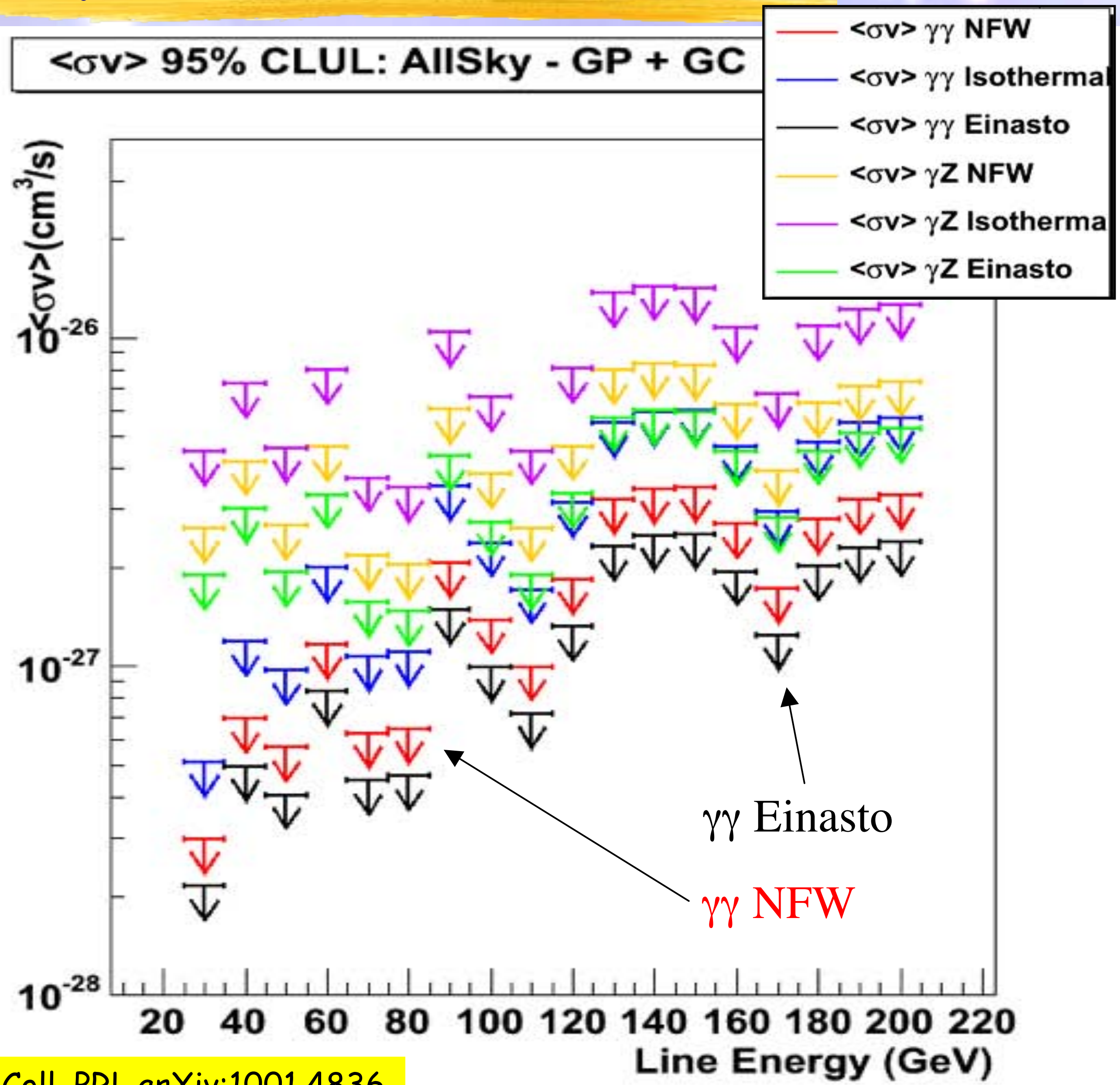


Search for Spectral Gamma Lines

DM annihilation

➡ No line detection, 95% CL flux upper limits are placed

- For each energy (WIMP mass) the flux ULs are combined with the integral over the line of sight of the DM density^2 to extract UL on the annihilation cross section <σv>



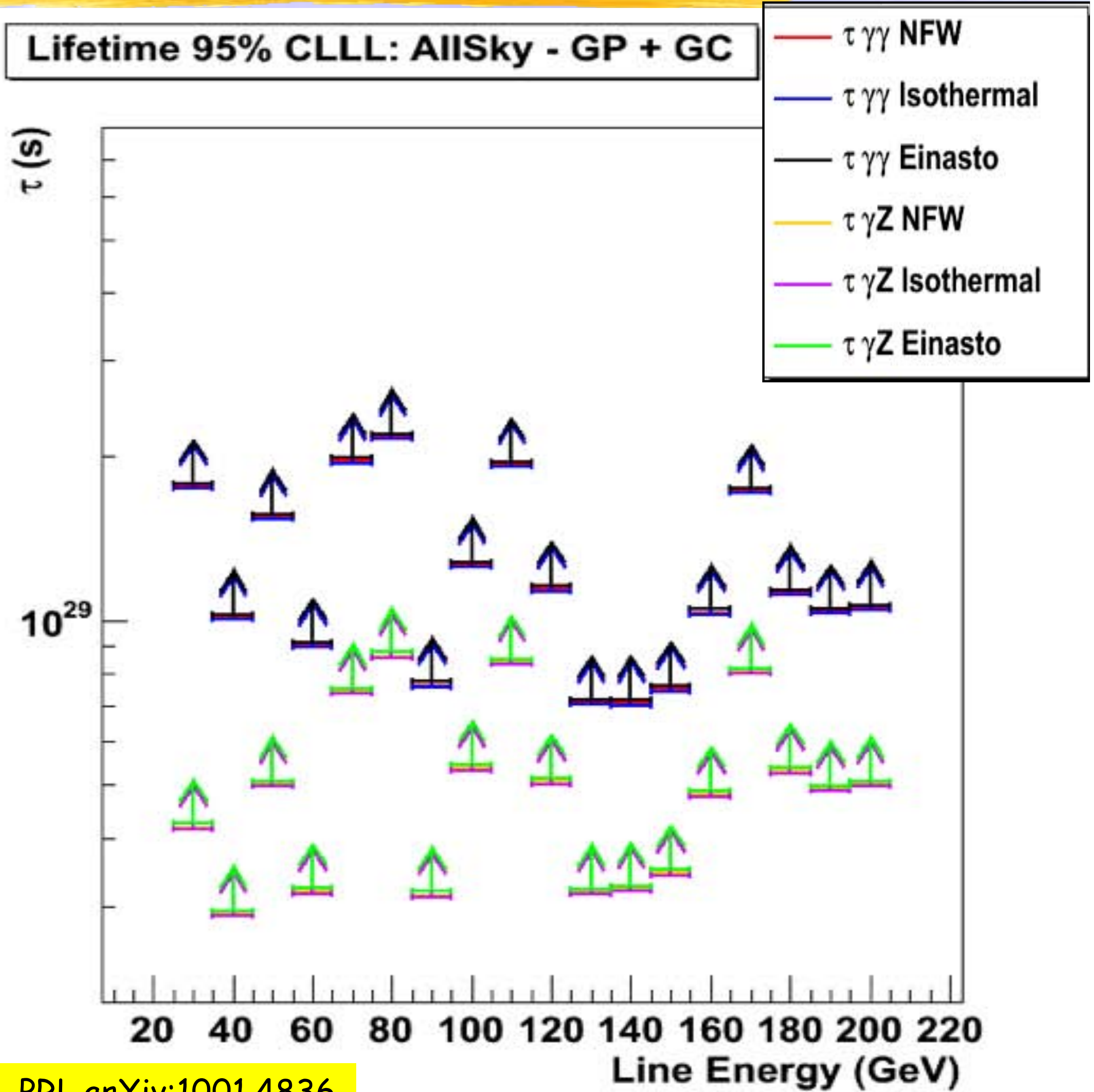
Fermi LAT Coll. PRL,arXiv:1001.4836

Search for Spectral Gamma Lines

decaying DM particles

- No line detection, 95% CL flux upper limits are placed

- For each energy (WIMP mass) the flux ULs are combined with the integral over the line of sight of the DM density to extract LL on lifetime for decaying DM particles)



Fermi LAT Coll. PRL,arXiv:1001.4836

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 originated 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
- 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)

Announcement for SciNeGHE 2010

3rd

Roma International Conference on Astro-Particle Physics

MAY 25 -27, 2011

All of you are invited to the third edition of RICAP in 2011 that will be hosted in INFN & Roma TRE University

http://ricap09.roma2.infn.it/