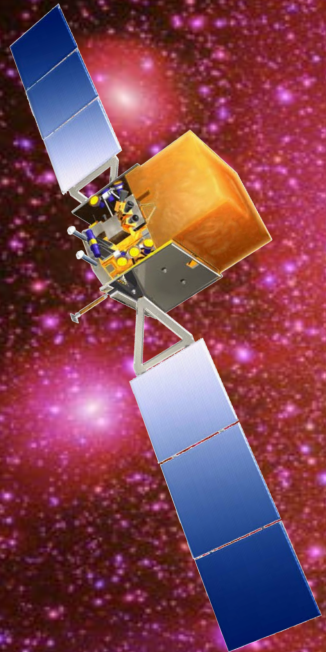
Search for Dark Matter with the Fermi Large Area Telescope



Aldo Morselli

INFN Roma Tor Vergata

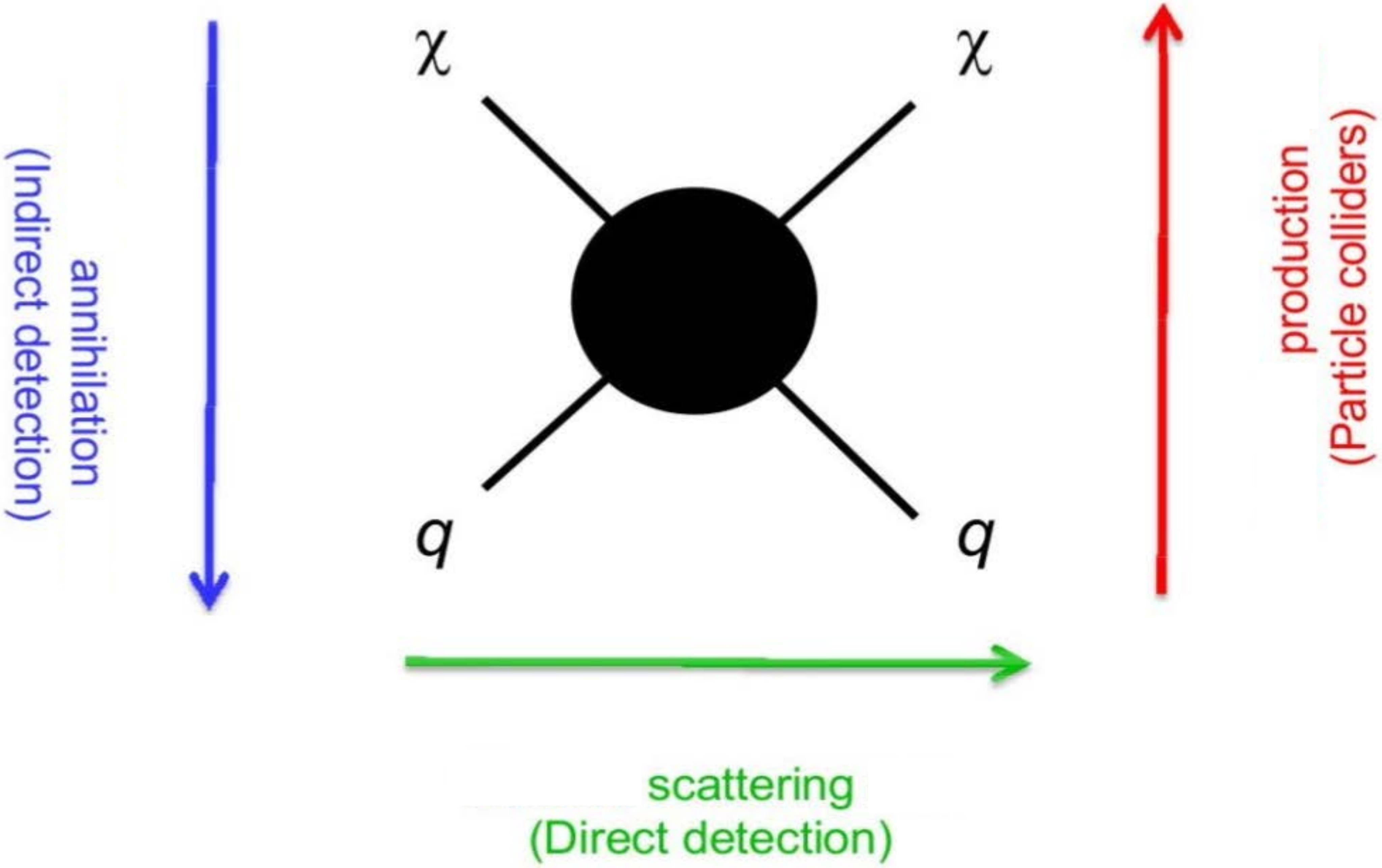
on behalf of the Fermi-Lat Collaboration

ICHEP2012 Melbourne

36th International Conference on High Energy Physics

ICHEP2012

Melbourne 7 Jul 2012

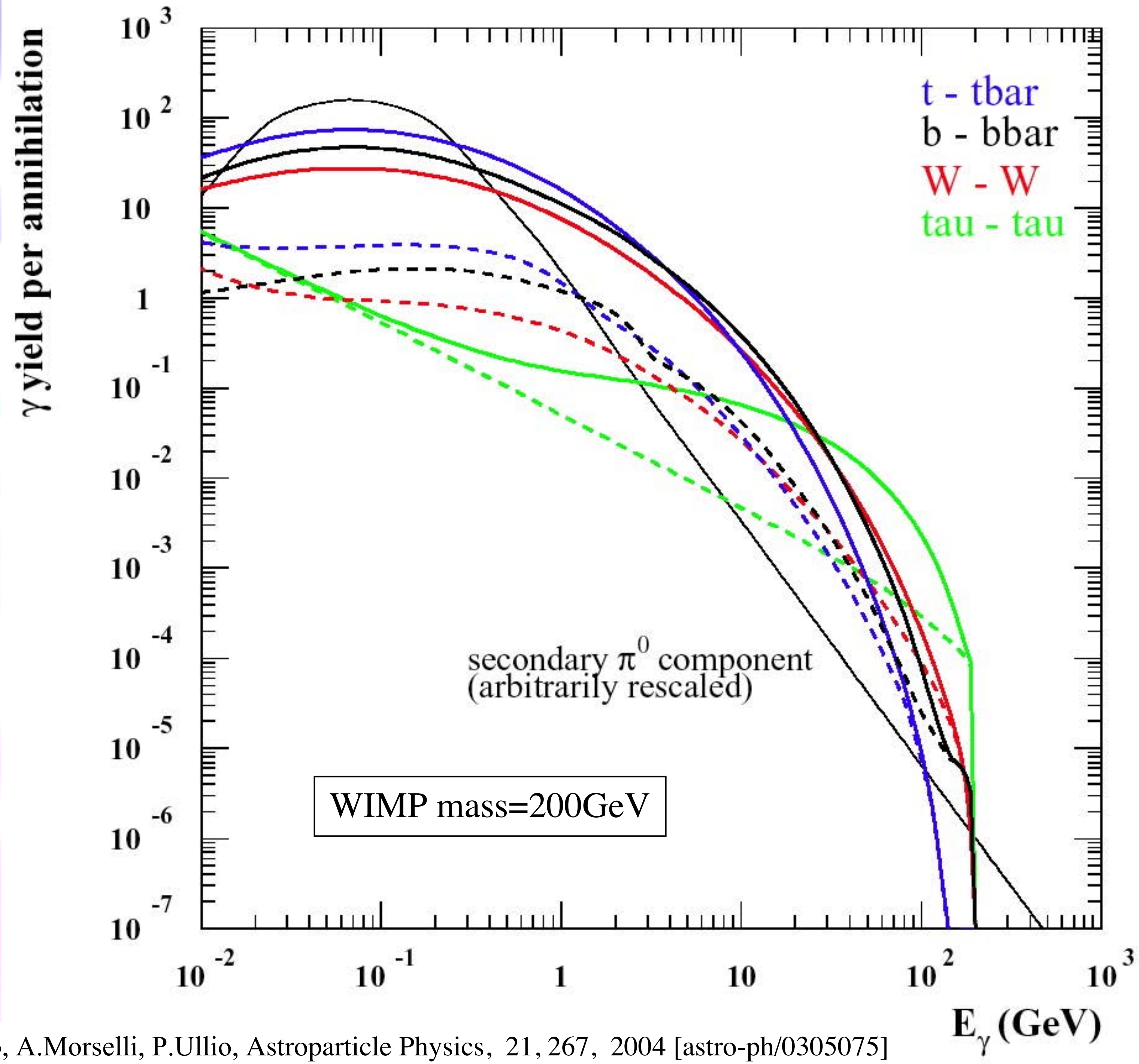

χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)

Neutralino WIMPs

Assume χ present in the galactic halo

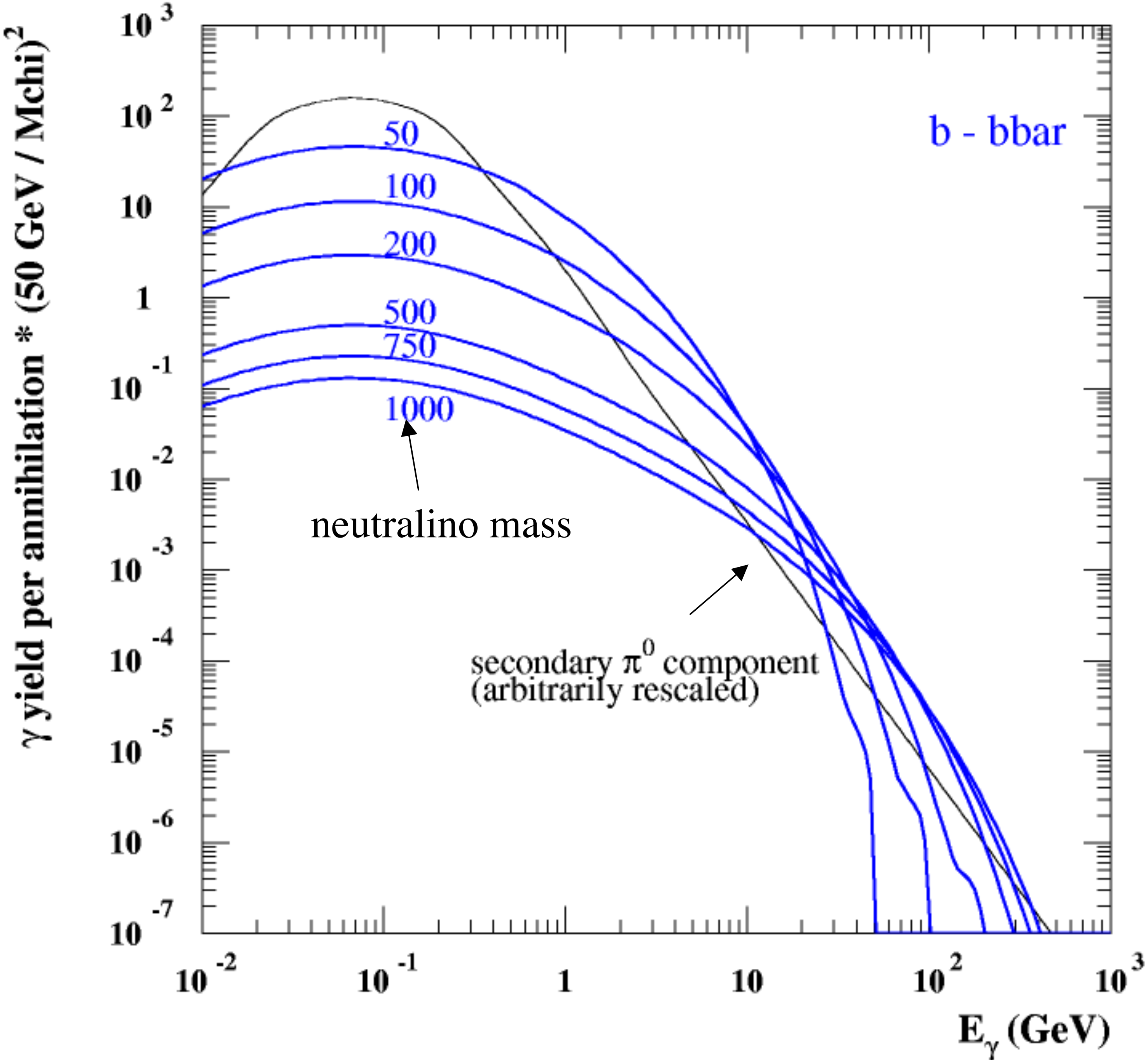
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation) 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.

Differential yield for each annihilation channel



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

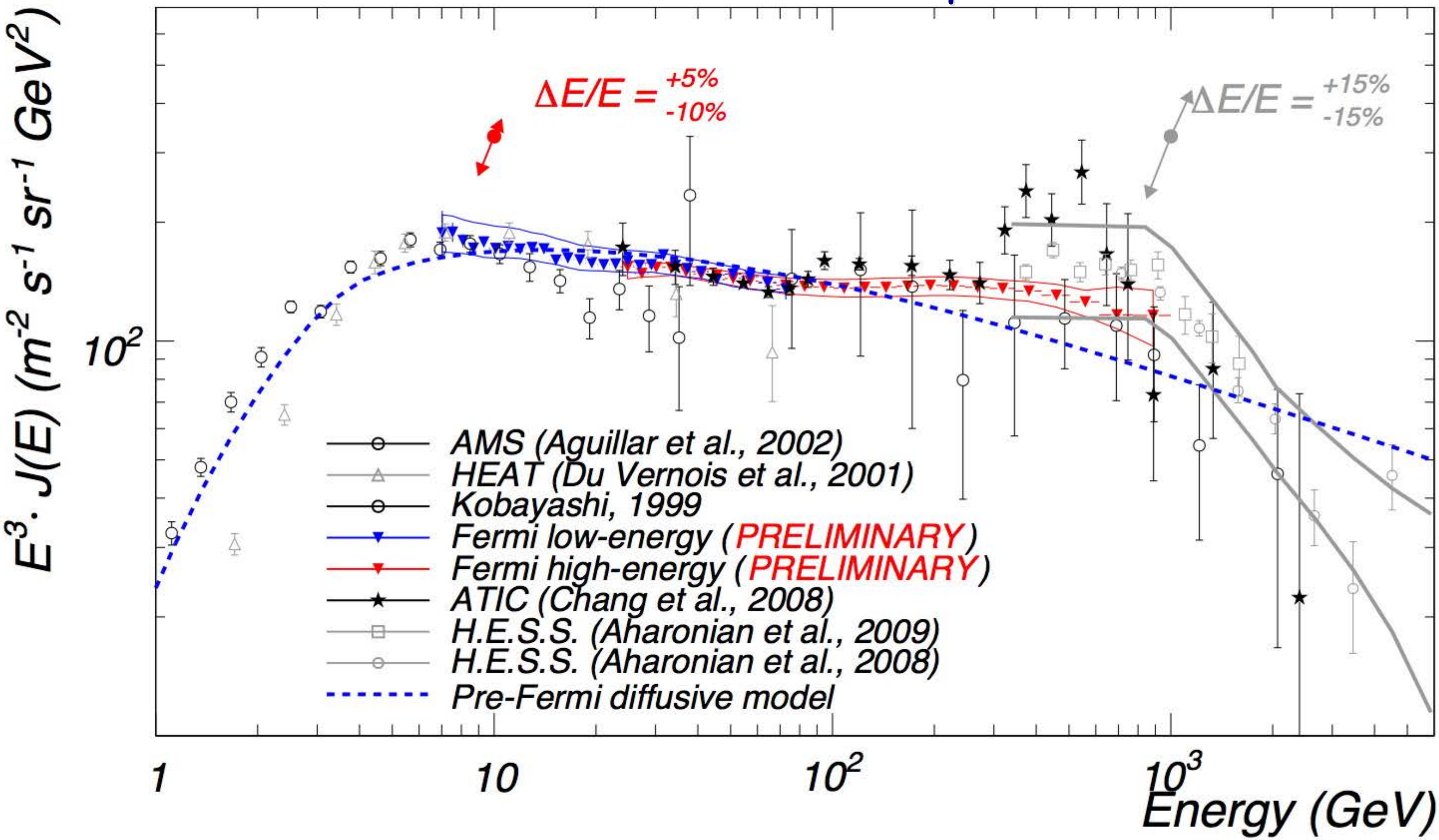
Differential yield for b bar



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


Fermi Gamma-ray Space Telescope
Happy 4th Birthday Fermi !!
11 June 2008
talk by Eric Charles

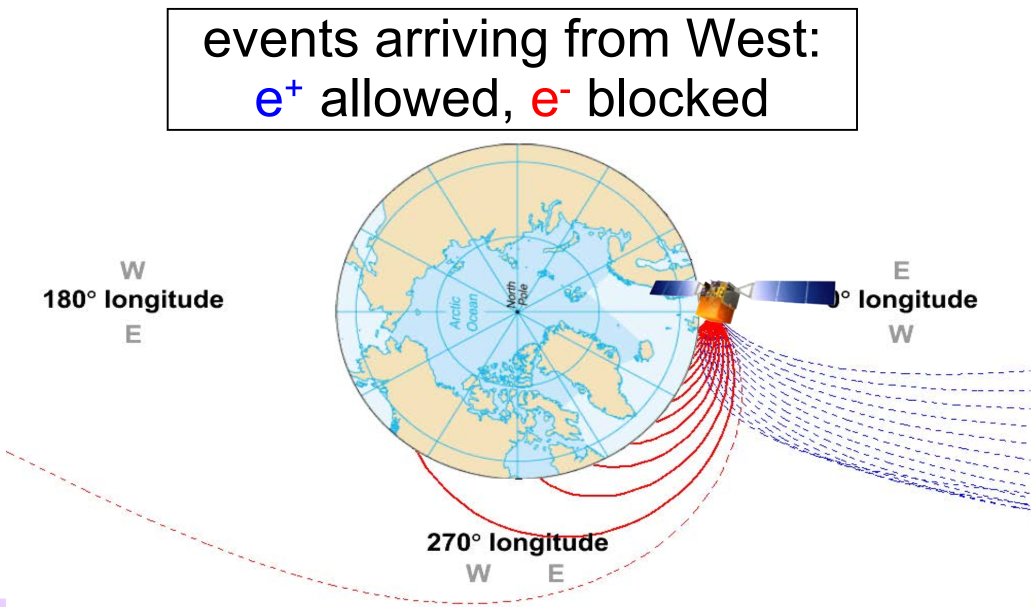
Fermi Electron + Positron spectrum

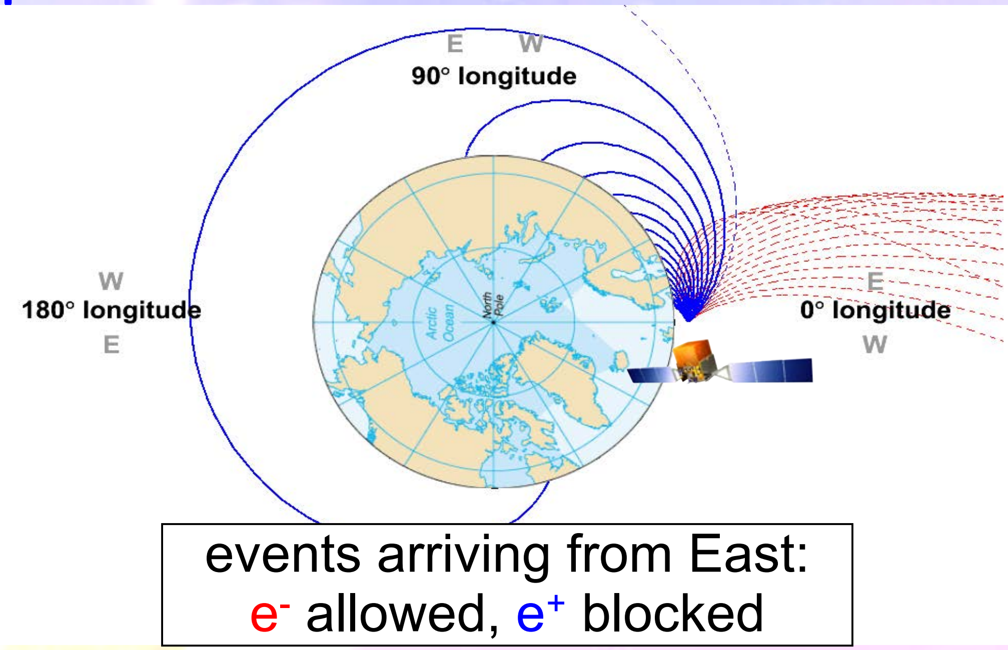


Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

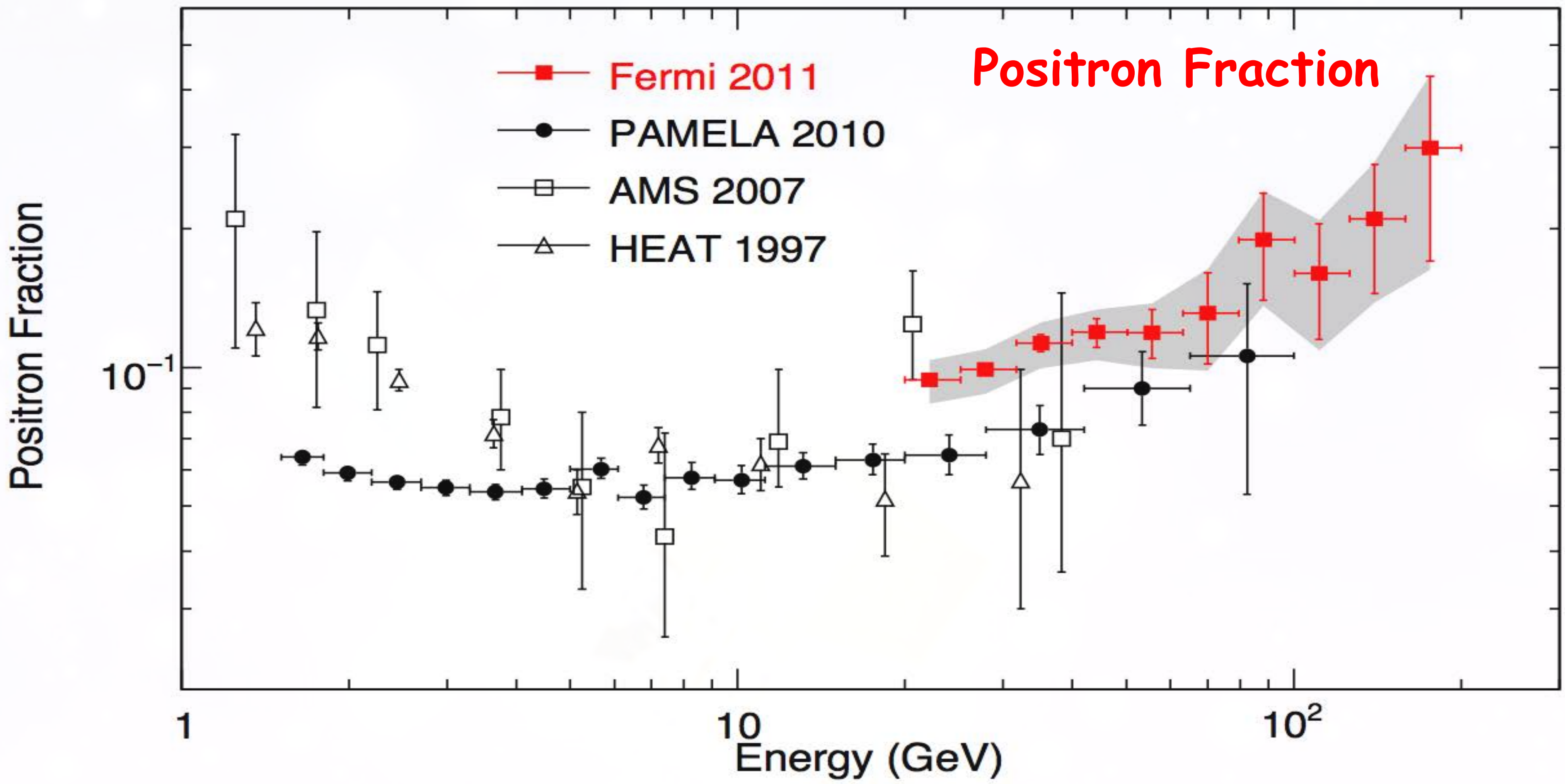
Fermi LAT Coll. Physical Review D, 82 092004 (2010) [arXiv:1008.3999]

Geomagnetic field + Earth shadow = directions from which only electrons or only positrons are allowed





- For some directions, e^- or e^+ forbidden
- Pure e^+ region looking West and pure e^- region looking East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Don Smart and Peggy Shea (numerically traces trajectory in geomagnetic field)
- Using International Geomagnetic Reference Field for the 2010 epoch



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

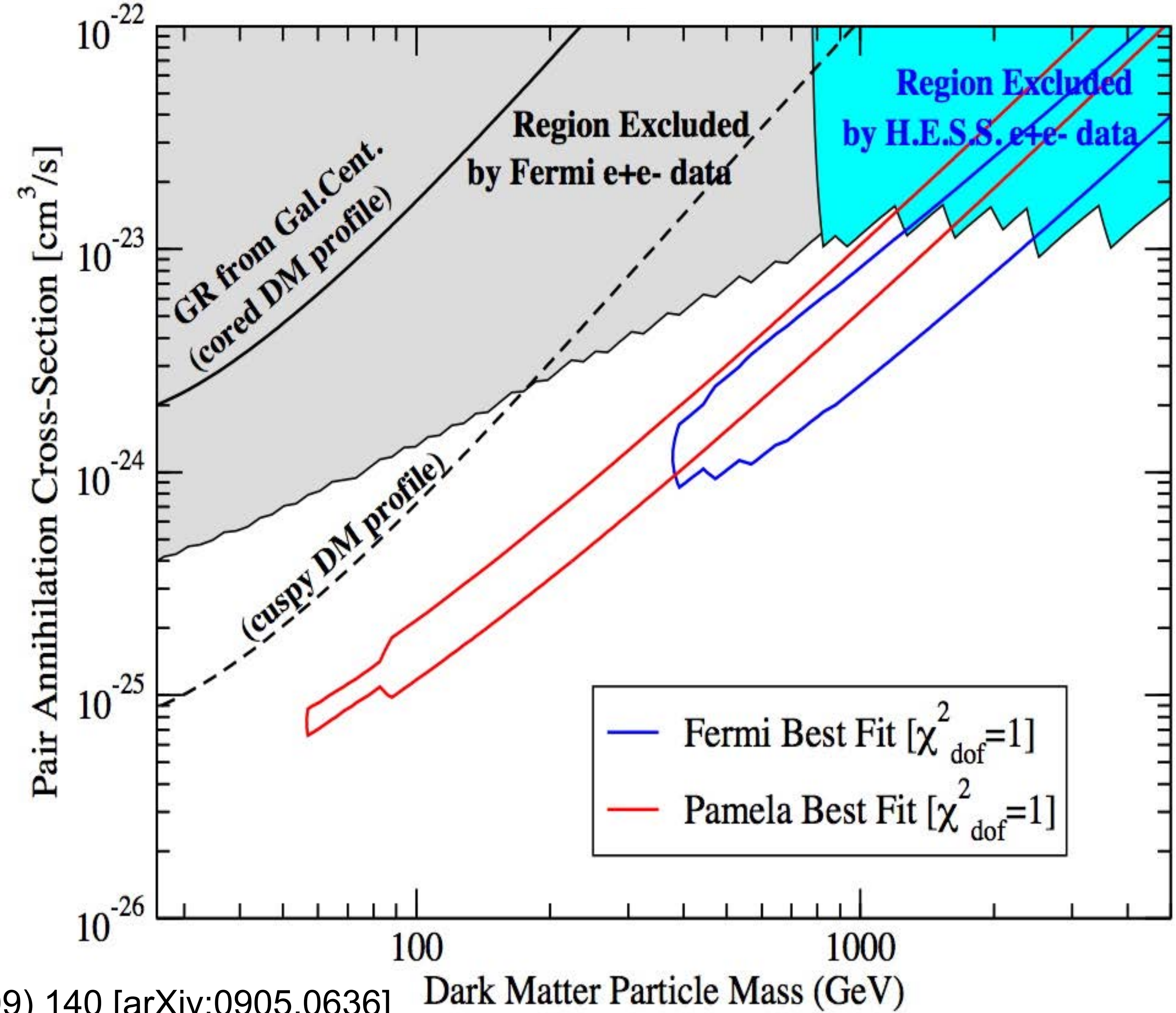
- **Two independent methods of background subtraction produce consistent results**
- **The observed positron fraction is consistent with the one measured by PAMELA**

Differences between different experiments below few GeV's probably due to charge-sign-dependent modulation but still under study

Fermi Coll., PRL, 108 (2012) 011103 arXiv:1109.0521

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.



Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Lepto-philic Models

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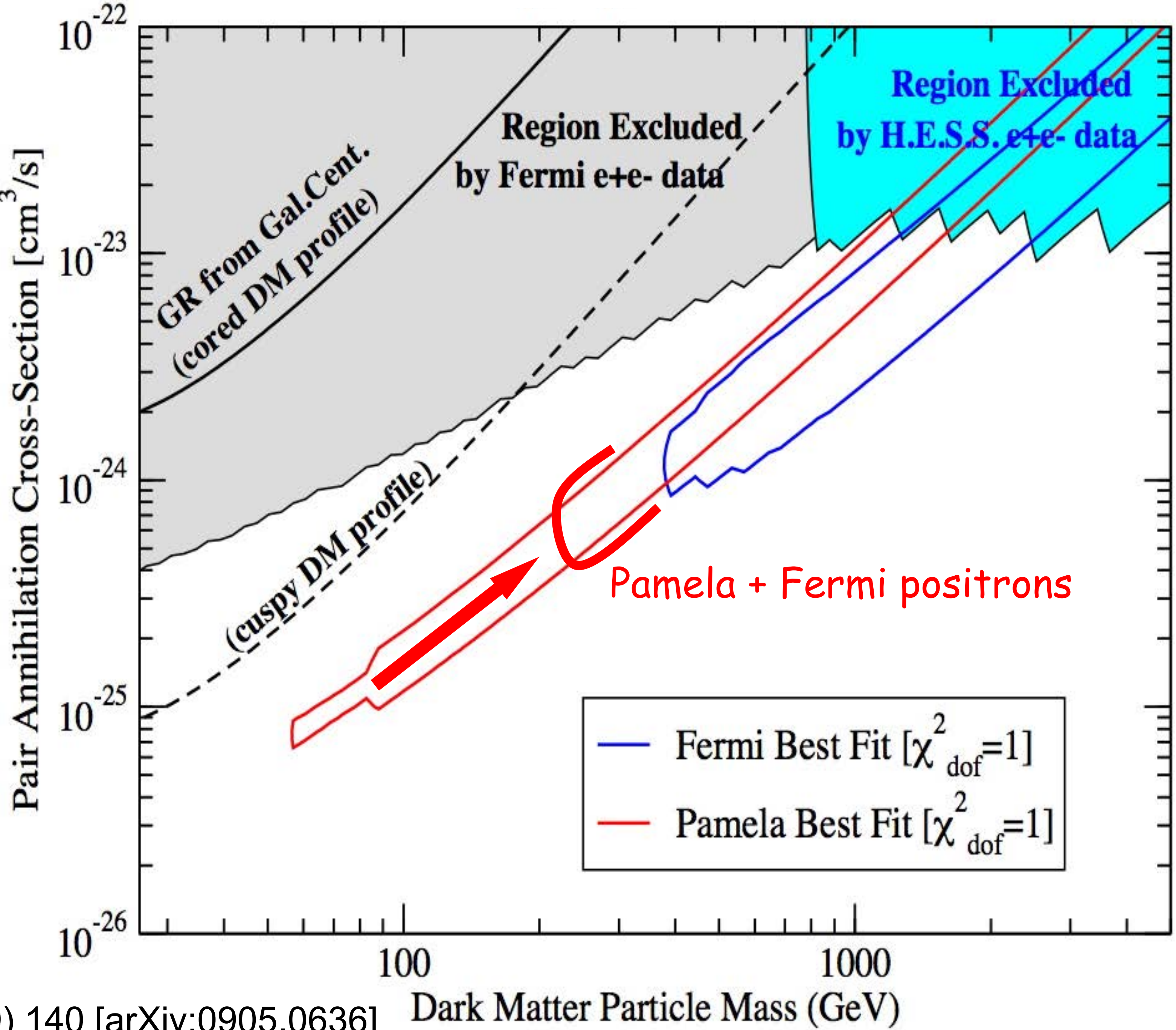


Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

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

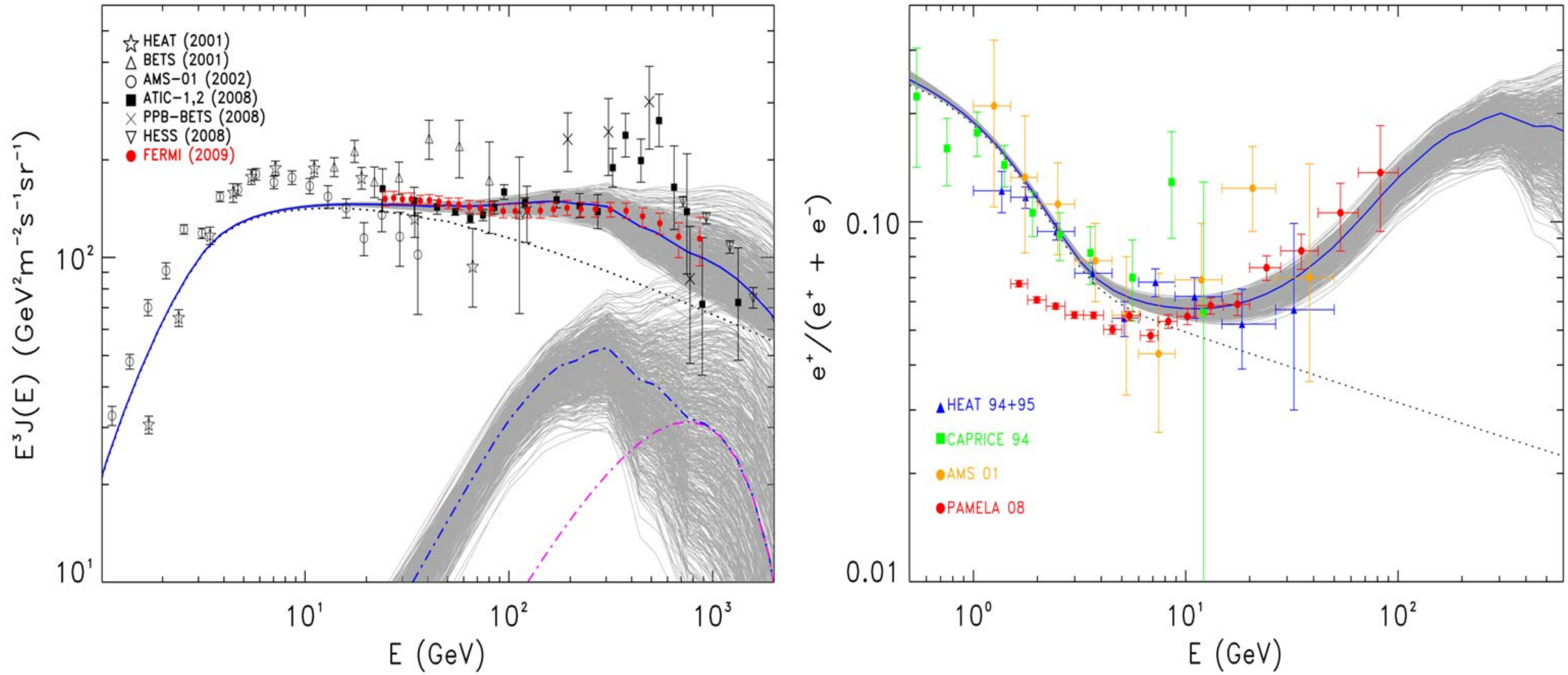
The biggest problem is that of escape of particles from the pulsar
   1. Even if acceleration works, pairs have to survive losses
   2. And in order to escape they have to cross other two shocks

Extensive discussion two week ago @ GGI (Serpico, Blasi ..)

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

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

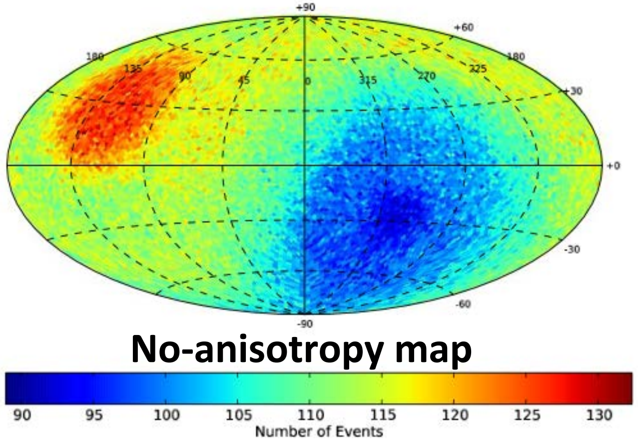
(*injection spectrum, e+e- production efficiency, PWN "trapping" time*)



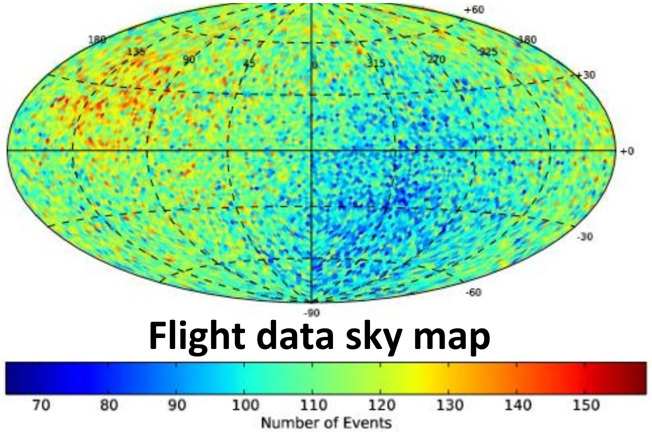
Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

D.Grasso et al. Astropart. Phys. 32 (2009), pp.140 [arXiv:0905.0636]

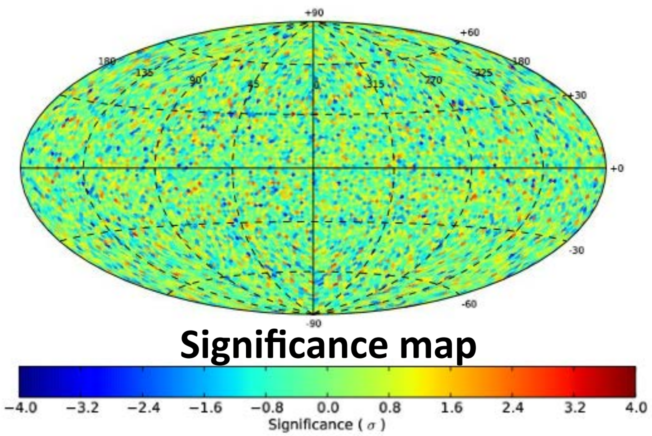
Cosmic Ray Electrons Anisotropy



No-anisotropy map



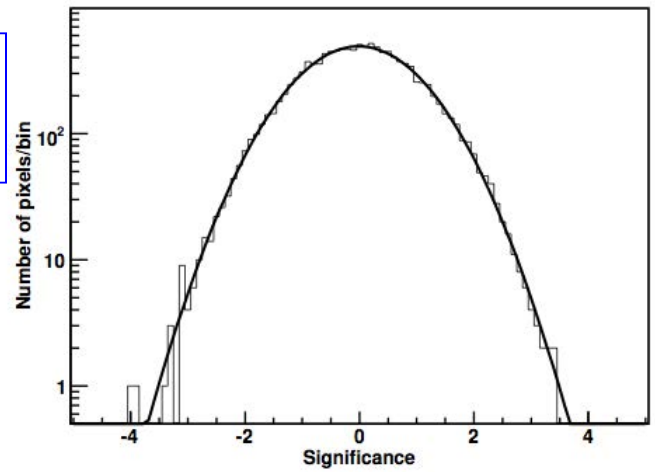
Flight data sky map



Significance map

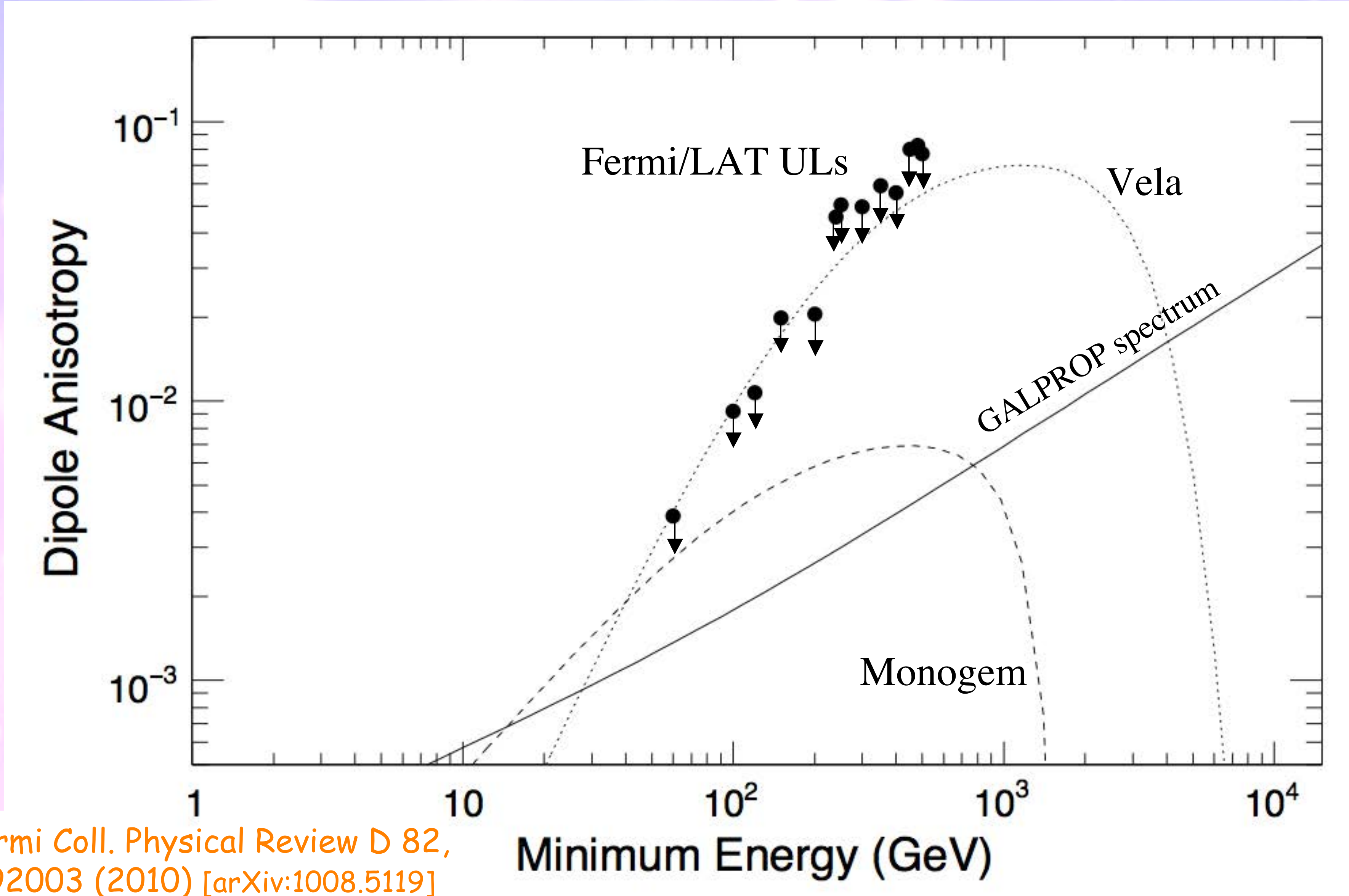
the levels of anisotropy expected for Geminga-like and Monogem-like sources (i.e. sources with similar distances and ages) seem to be higher than the scale of anisotropies excluded by the results
However, it is worth to point out that the model results are affected by large uncertainties related to the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

Distribution of significance, fitted by a Gaussian →



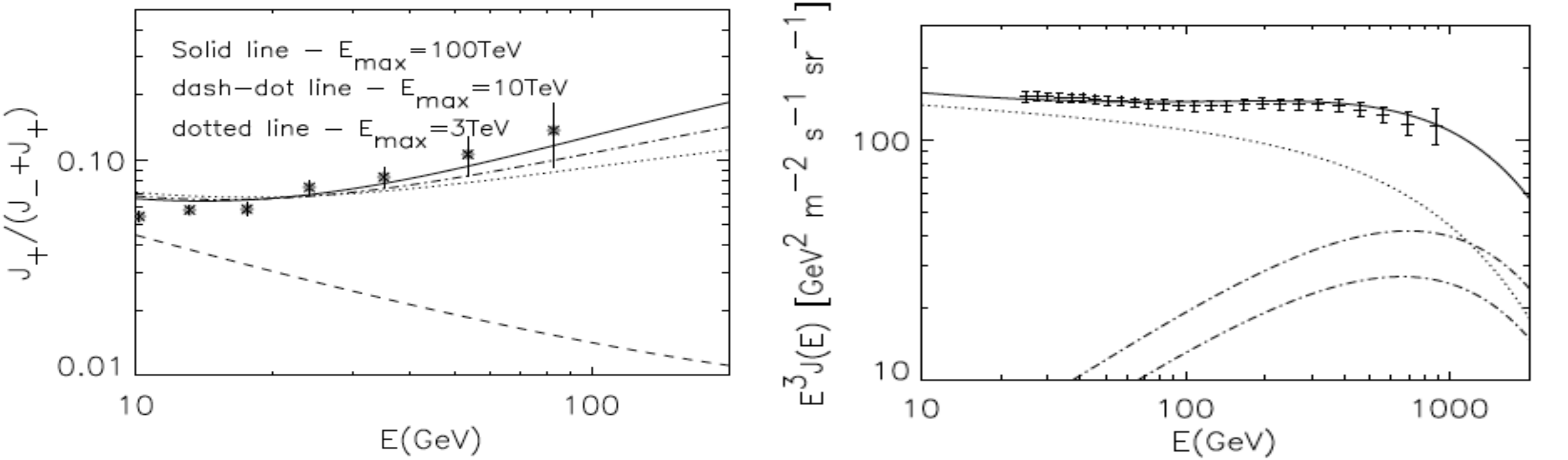
Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

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



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

other Astrophysical solution

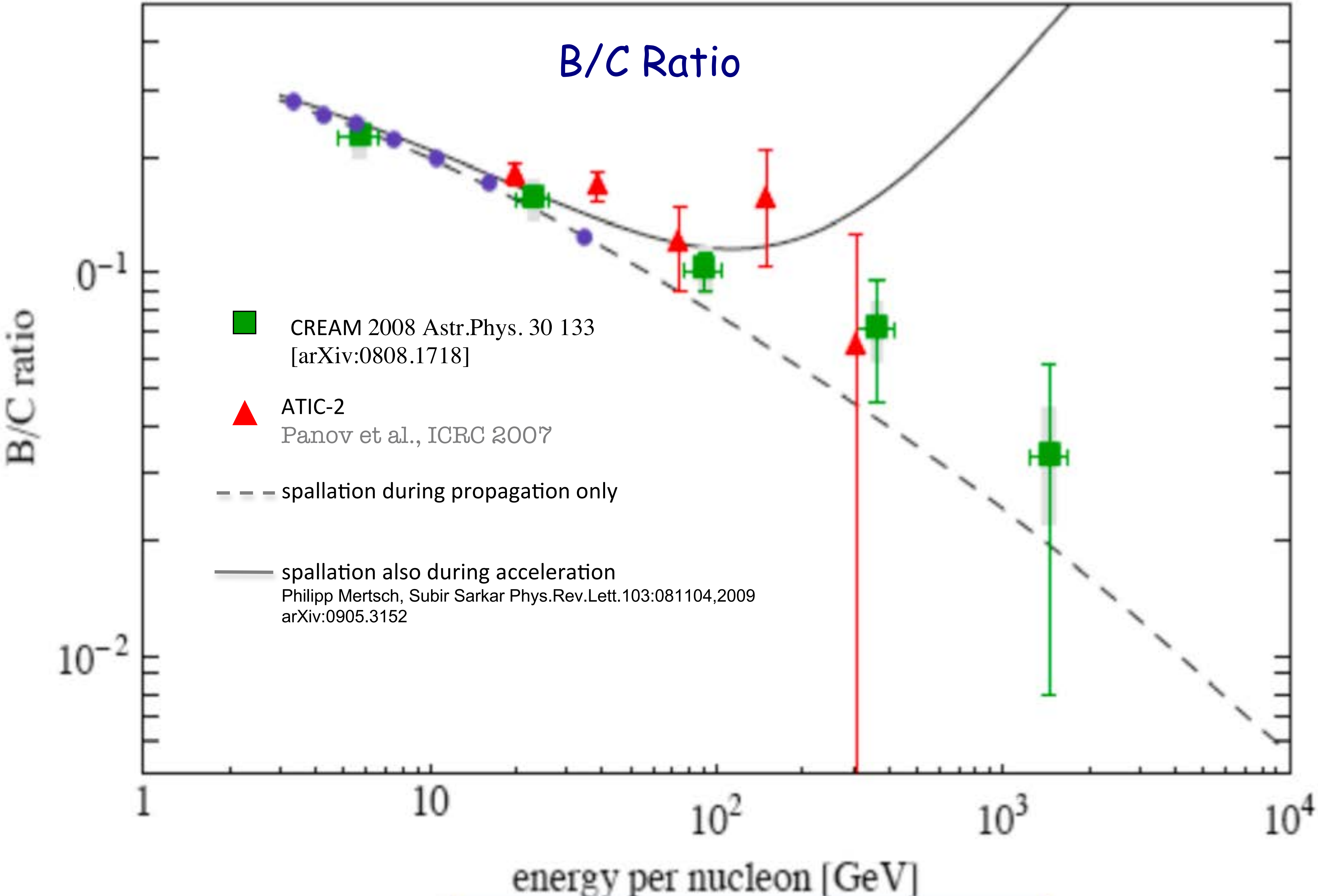


- Positrons created as secondary products of hadronic interactions inside the sources
- Secondary production takes place in the same region where cosmic rays are being accelerated

-> 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

B/C Ratio



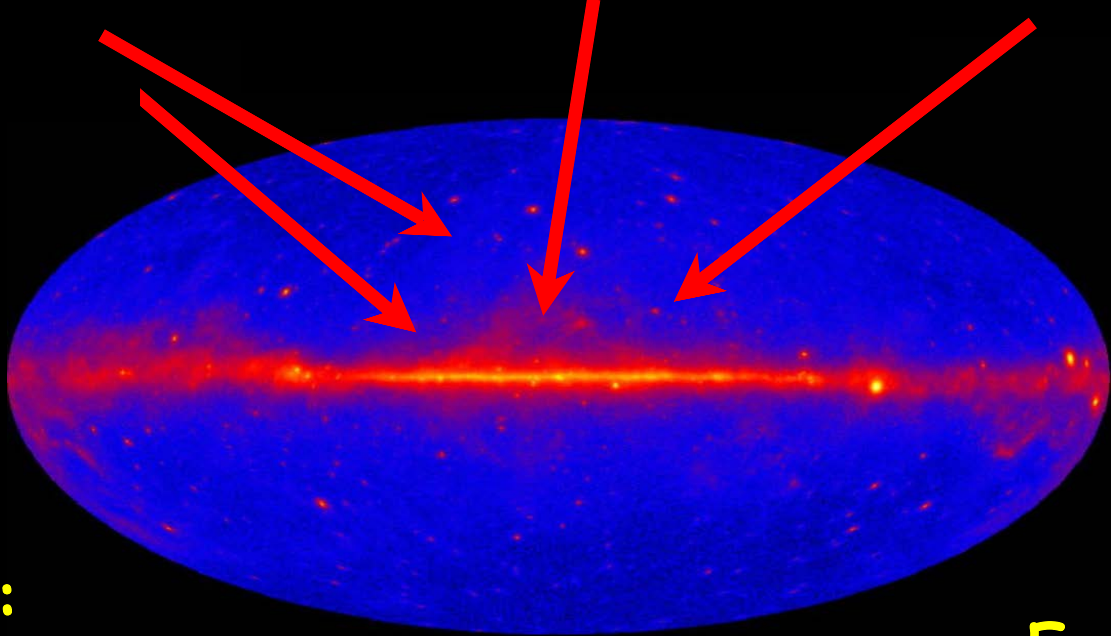
CREAM 2008 Astr.Phys. 30 133
[arXiv:0808.1718]
ATIC-2
Panov et al., ICRC 2007
spallation during propagation only
spallation also during acceleration
Philipp Mertsch, Subir Sarkar Phys.Rev.Lett.103:081104,2009
arXiv:0905.3152
B/C ratio
energy per nucleon [GeV]

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

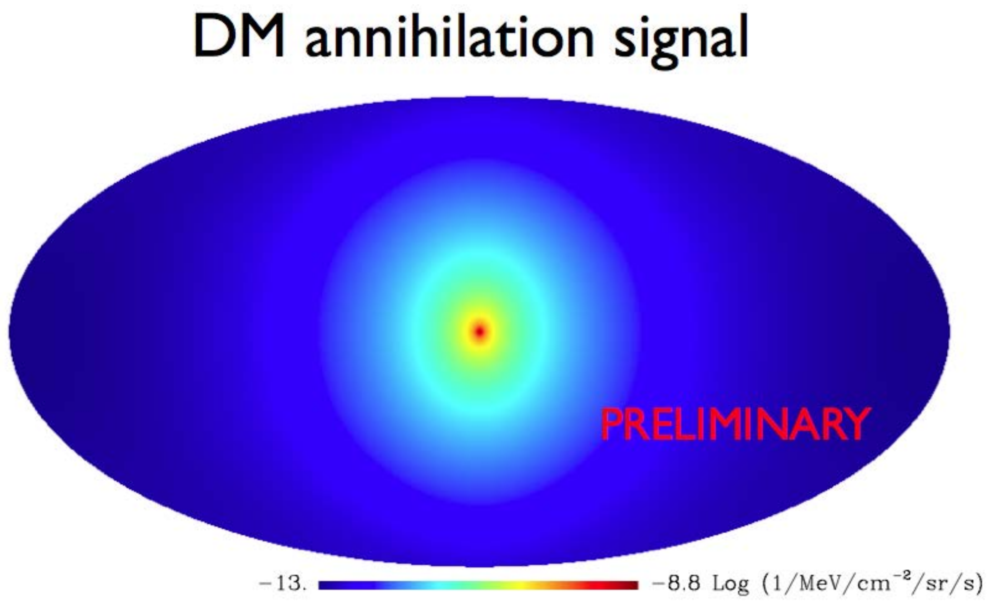
Galaxy clusters:
Low background but low statistics

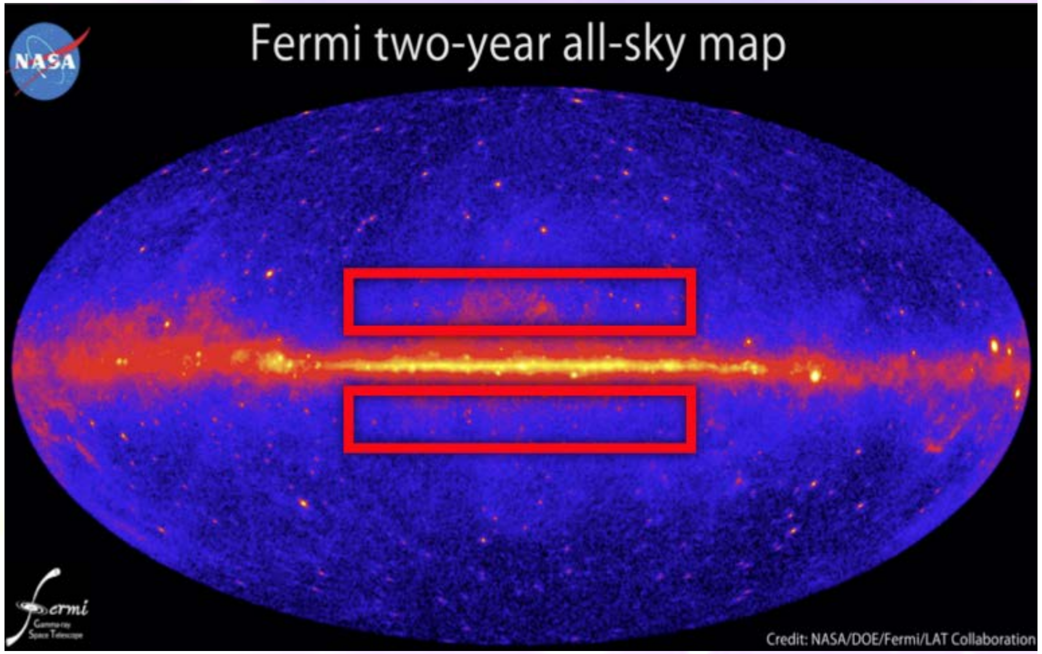
Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

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

Constraints from the Milky Way halo

testing the LAT diffuse data for a contribution from a Milky Way DM annihilation/decay signal



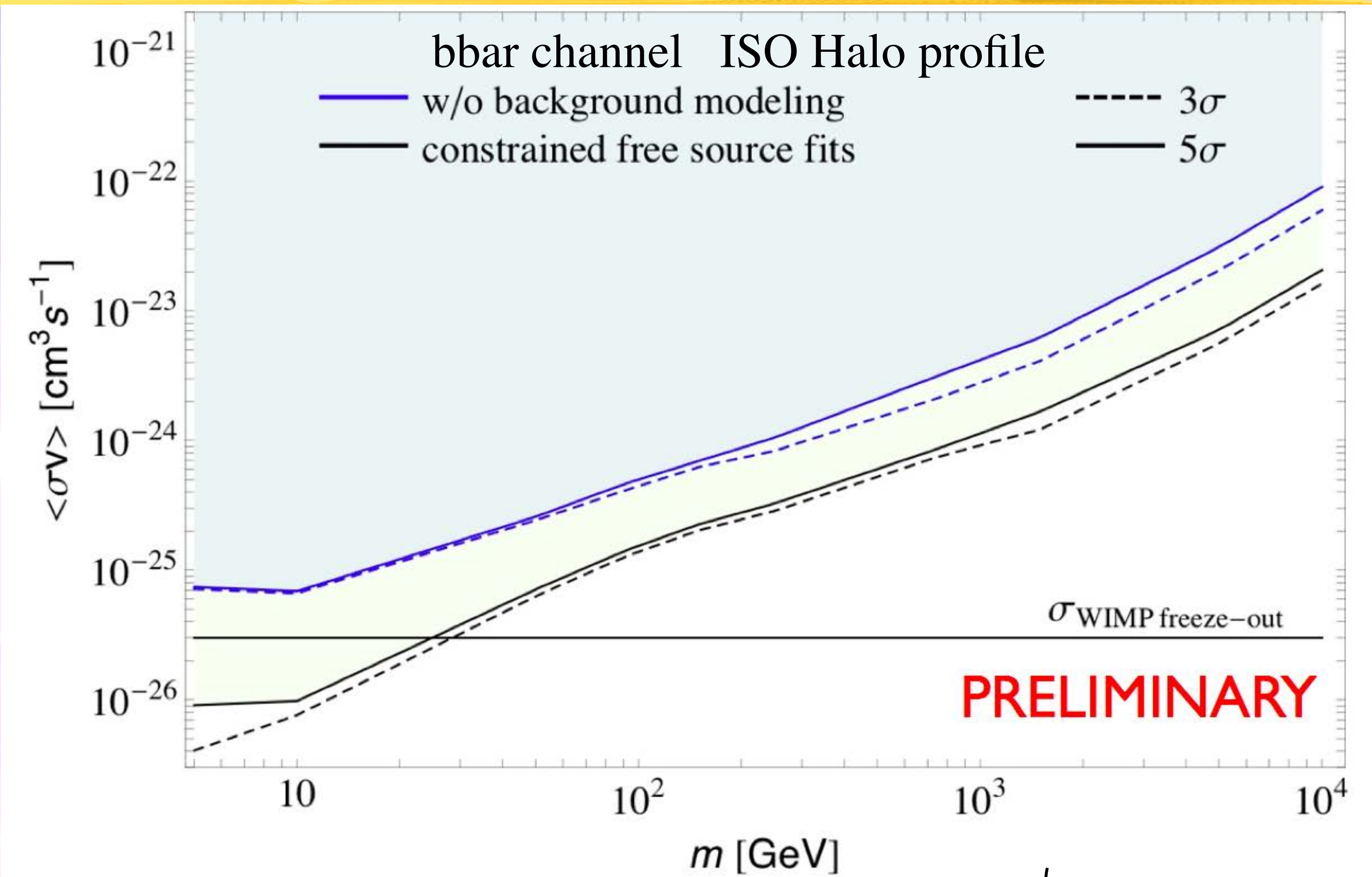


2 years of data   1-100 GeV energy range

ROI: 5° <|b|<15° and |l|<80°, chosen to:

- minimize DM profile uncertainty (highest in the Galactic Center region)
- limit astrophysical uncertainty by masking out the Galactic plane and cutting-out high- latitude emission from the Fermi lobes and Loop I

Constraints from the Milky Way halo



Fermi Coll. arXiv:1205.6474

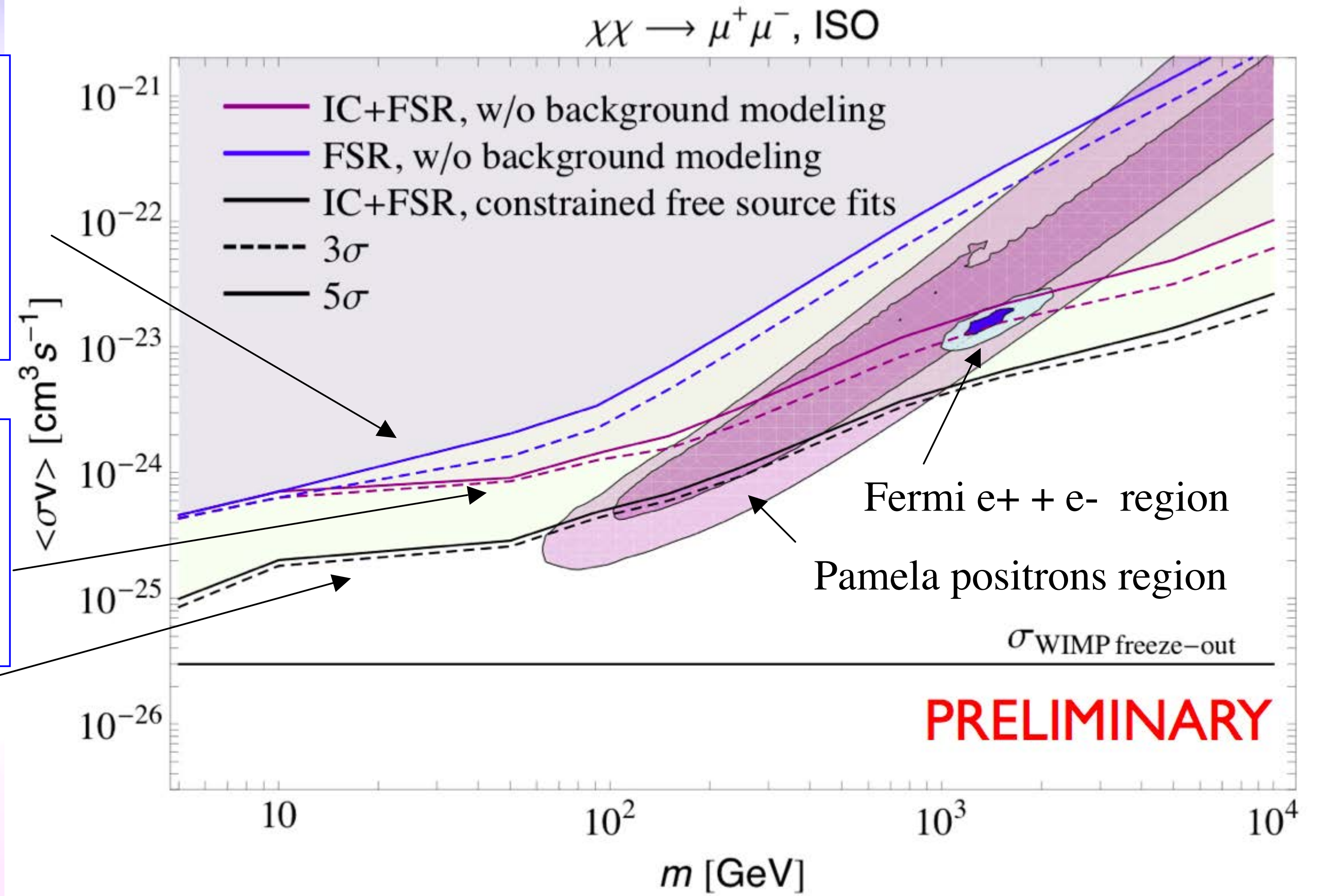
- Blue = "no-background limits"
- Black = limits obtained by marginalization over the CR source distribution, diffusive halo height and electron injection index, gas to dust ratio, and in which CR sources are held to zero in the inner 3 kpc
- Limits with NFW density profile (not shown) are only slightly stronger

Constraints from the Milky Way halo

only photons produced by muons (no electrons) to set "no-background limits"

"no-background limits" including FSR+IC from dark matter

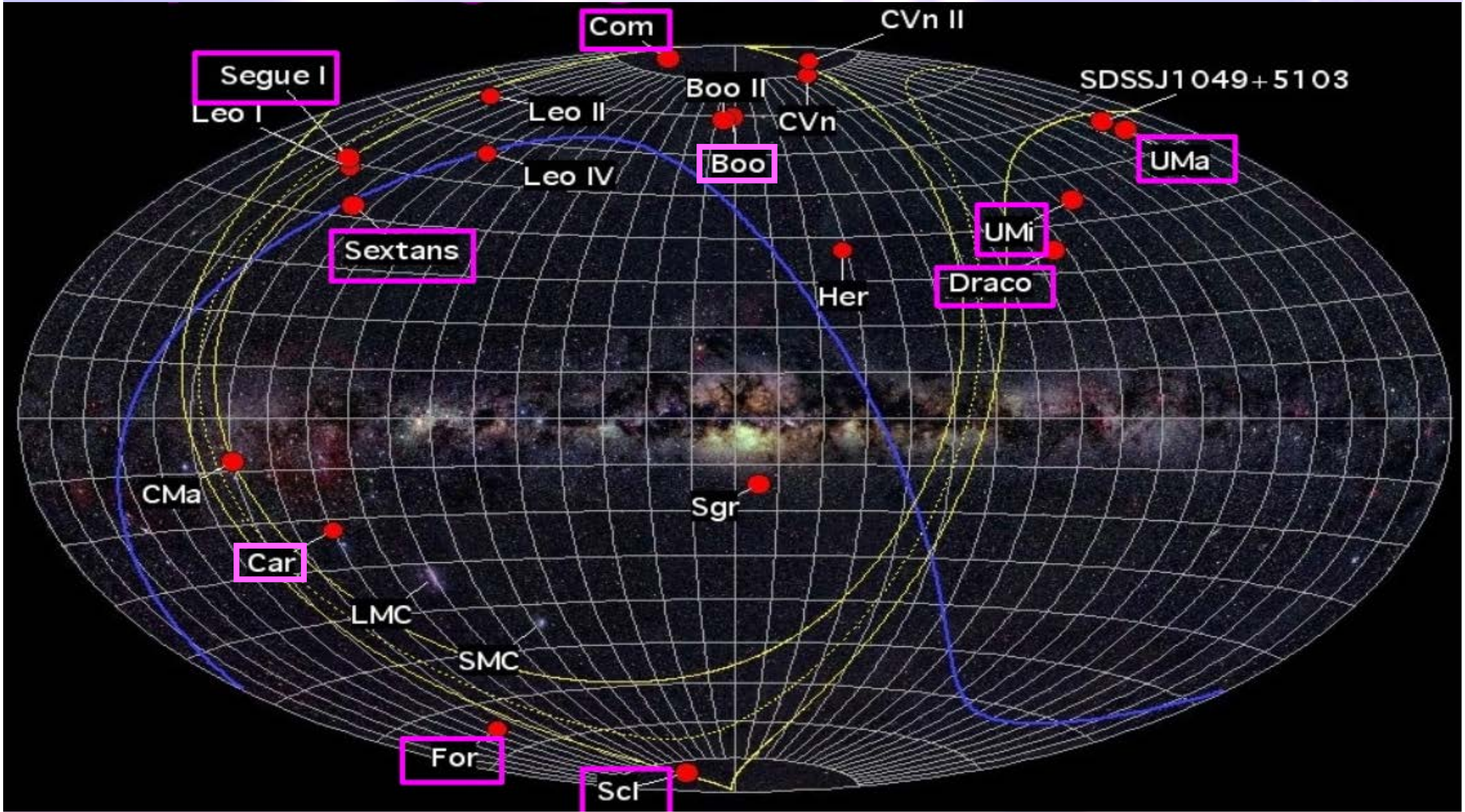
limits from profile likelihood and CR sources set to zero in the inner 3 kpc



DM interpretation of PAMELA/Fermi CR anomalies disfavored

Fermi Coll. arXiv:1205.6474

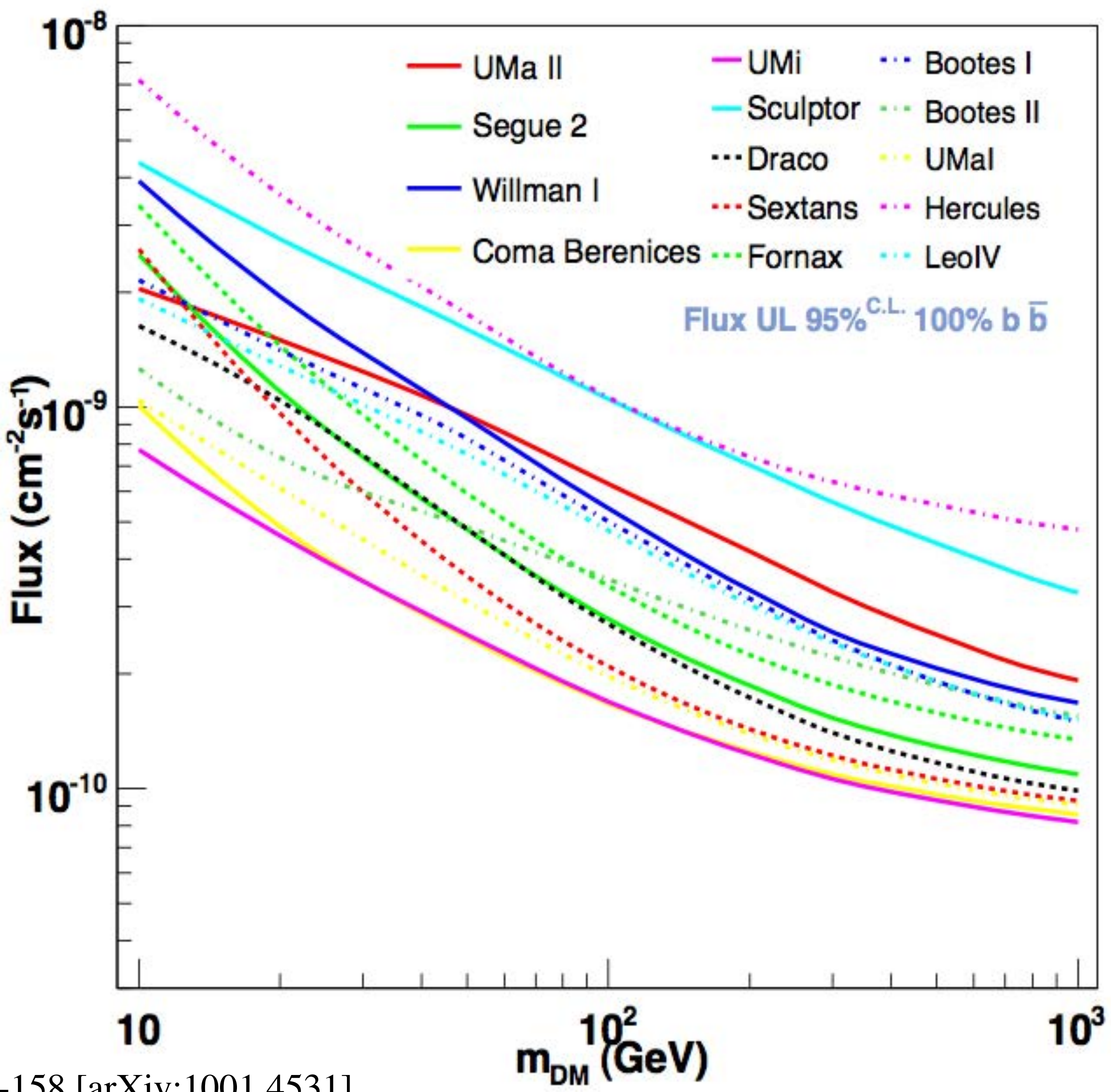
Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



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.

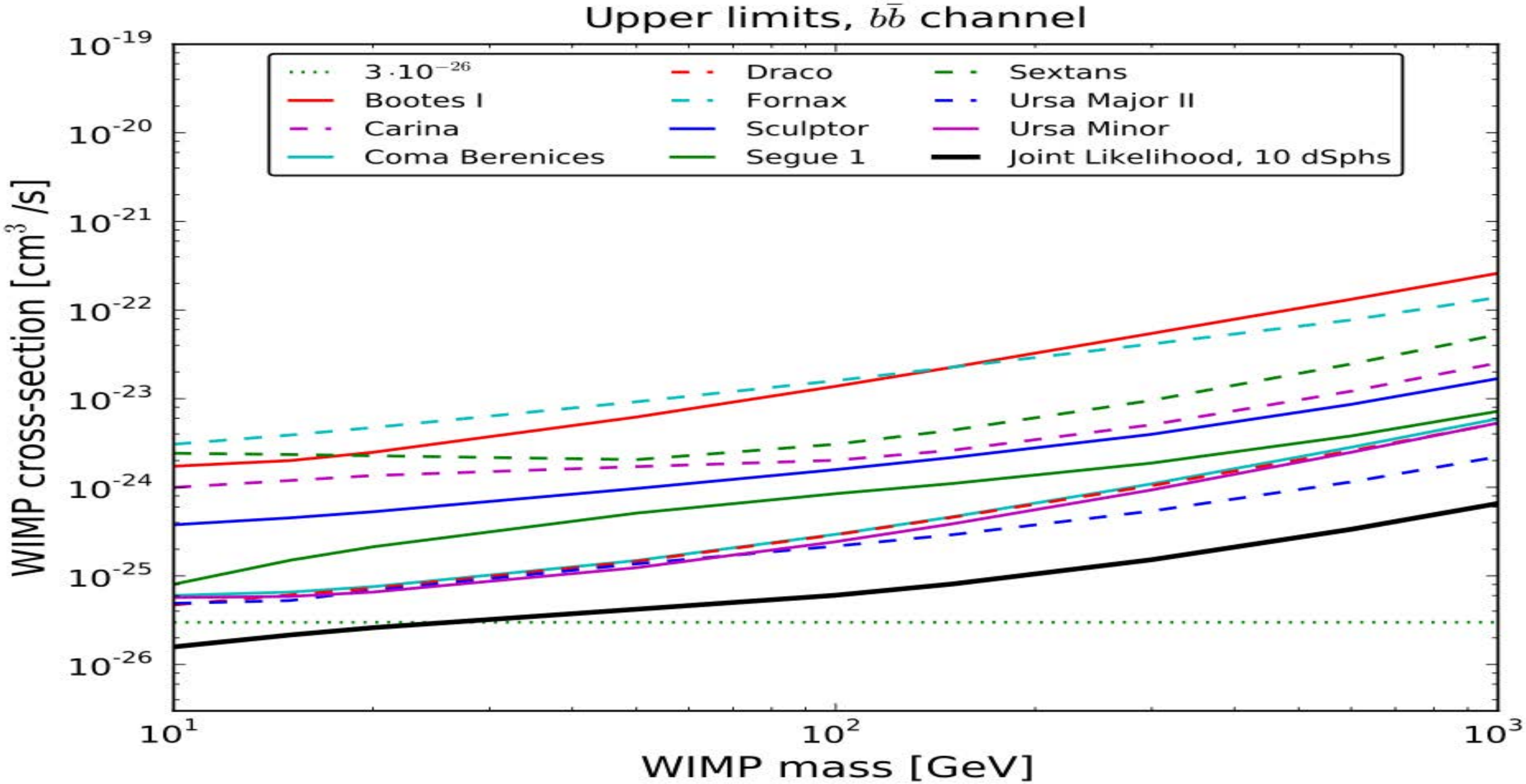
- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on < σv> vs WIMP mass for specific DM models



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

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

Dwarf Spheroidal Galaxies combined analysis

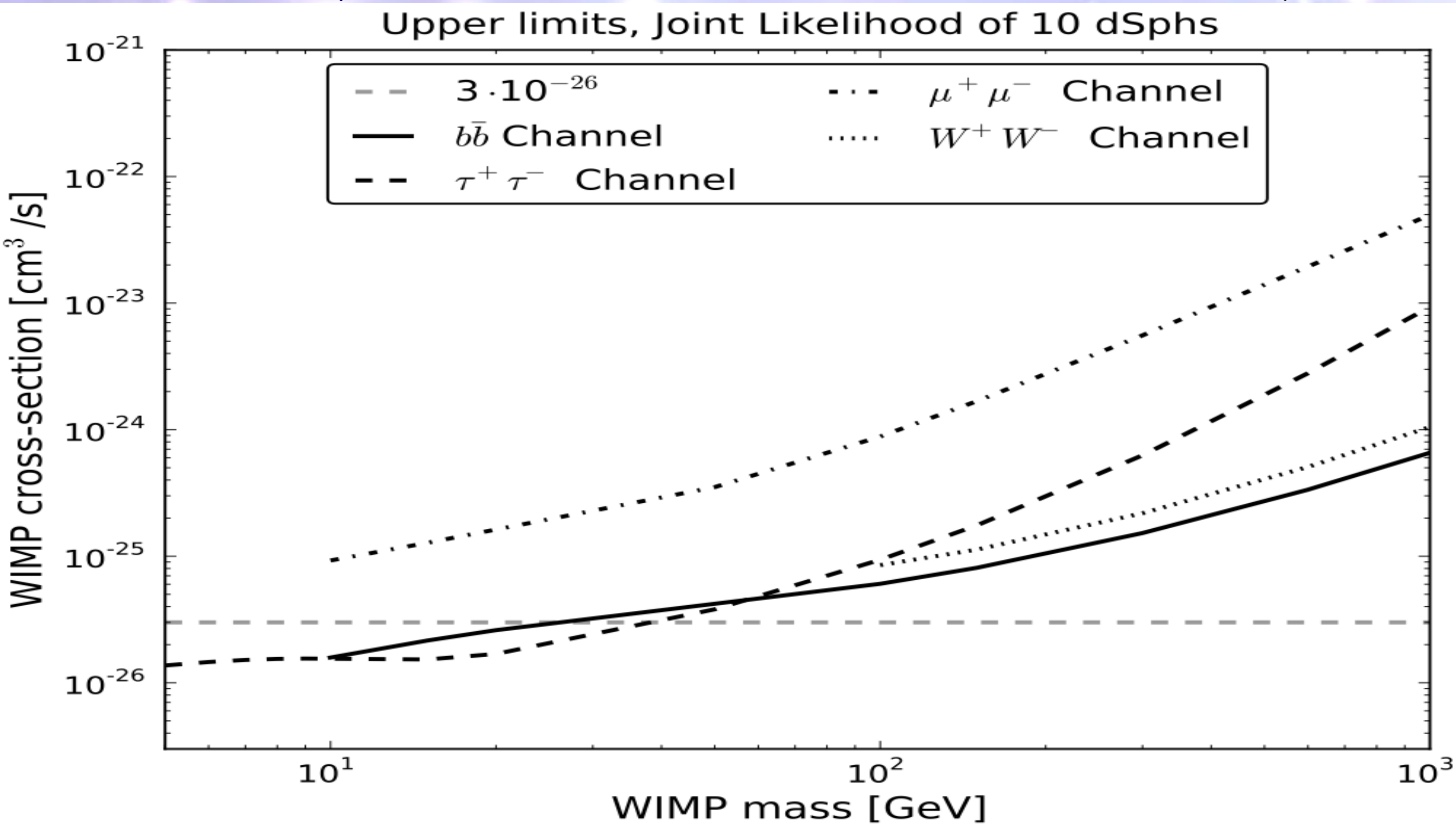


robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies combined analysis

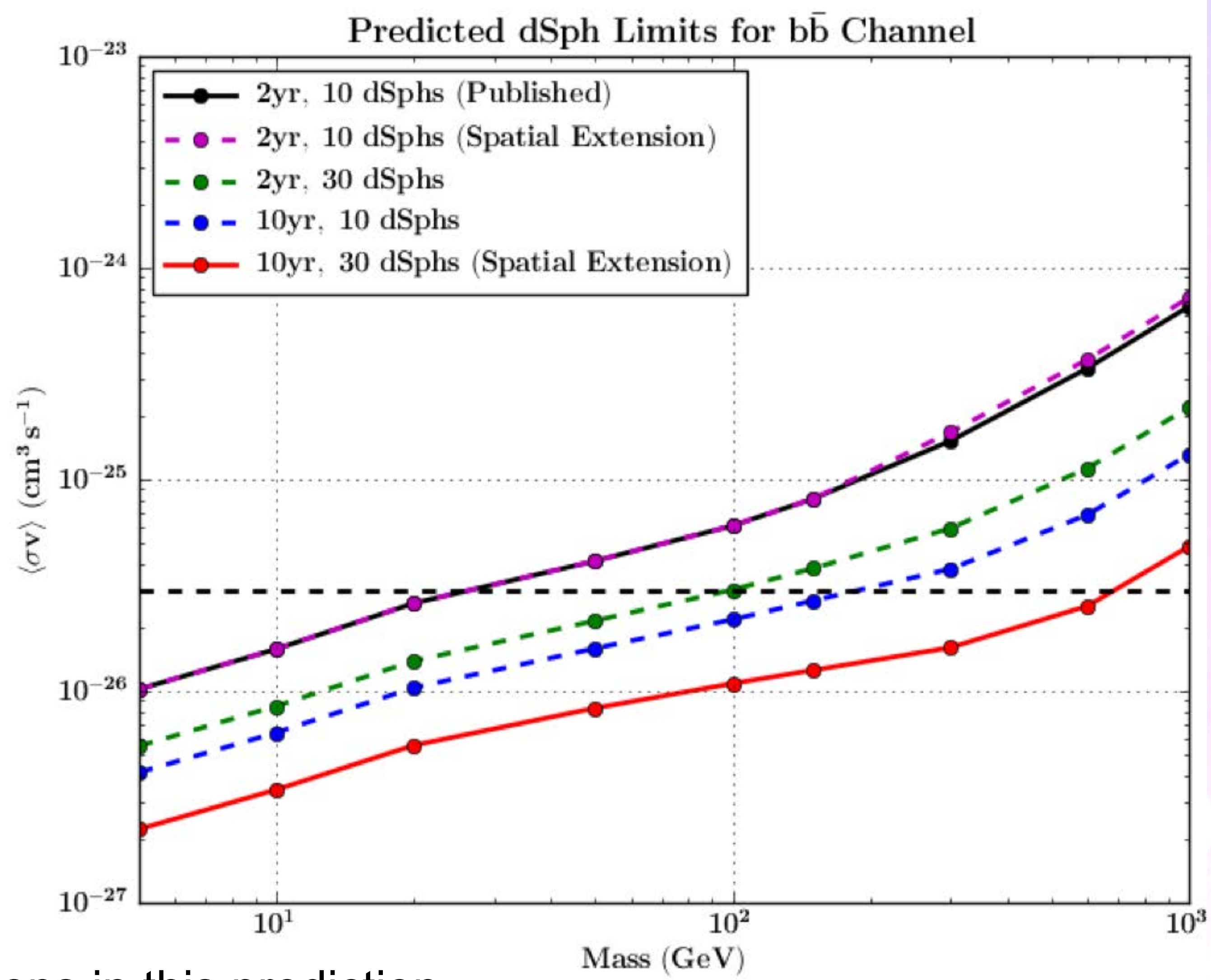


robust constraints including J-factor uncertainties from the stellar data statistical analysis

Fermi Lat Coll., PRL 107, 241302 (2011)
[arXiv:1108.3546]

DM limit improvement estimate in 10 years with the composite likelihood approach (2008- 2018)

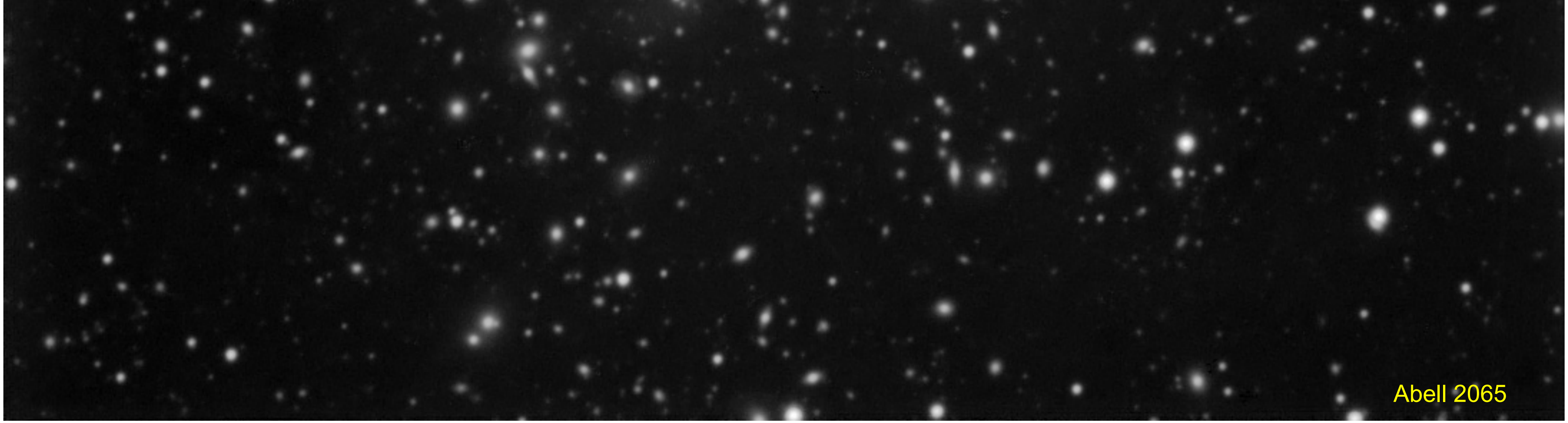
- 10 years of data instead of 2(5x)
- 30 dSphs (3x) (supposing that the new optical surveys will find new dSph)
- -10% from spatial extension (source extension increases the signal region at high energy E > 10 GeV, M > 200 GeV)



- There are many assumptions in this prediction
- Doesn’t deal with a possible detections.

Clusters of galaxies

- Largest virialized and most massive structures in the universe :
- • Radio emission suggests cosmic ray (CR) population
- Lensing and X-Ray observations indicate large dark matter (DM)



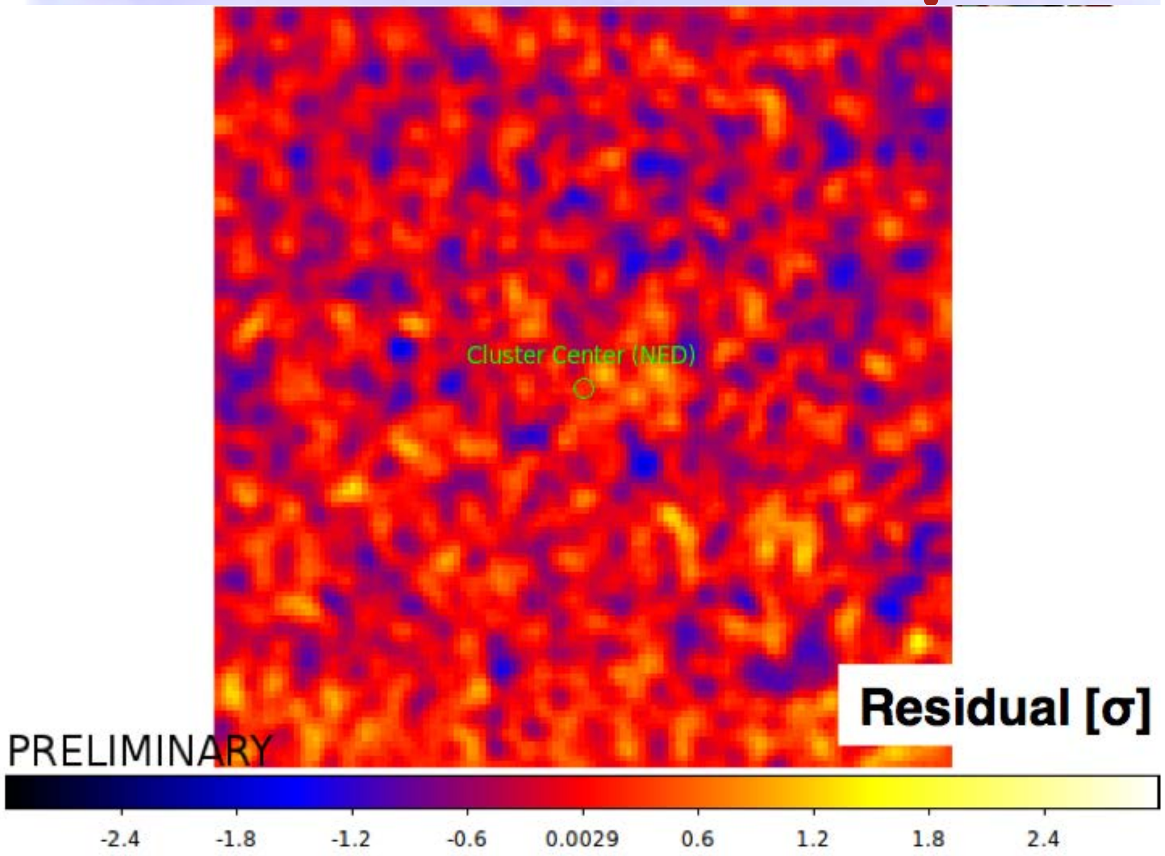
Abell 2065

6 Clusters Stacked Residual Map

- 24 Months of LAT **P6V11 Diffuse** data (P7V6 analysis ongoing)
- Binned analysis, **10 deg ROI**

20 Energy Bins from 200 MeV to100 GeV

- Clusters modeled as **point sources**
- **No significant excess in stacked residual map!**

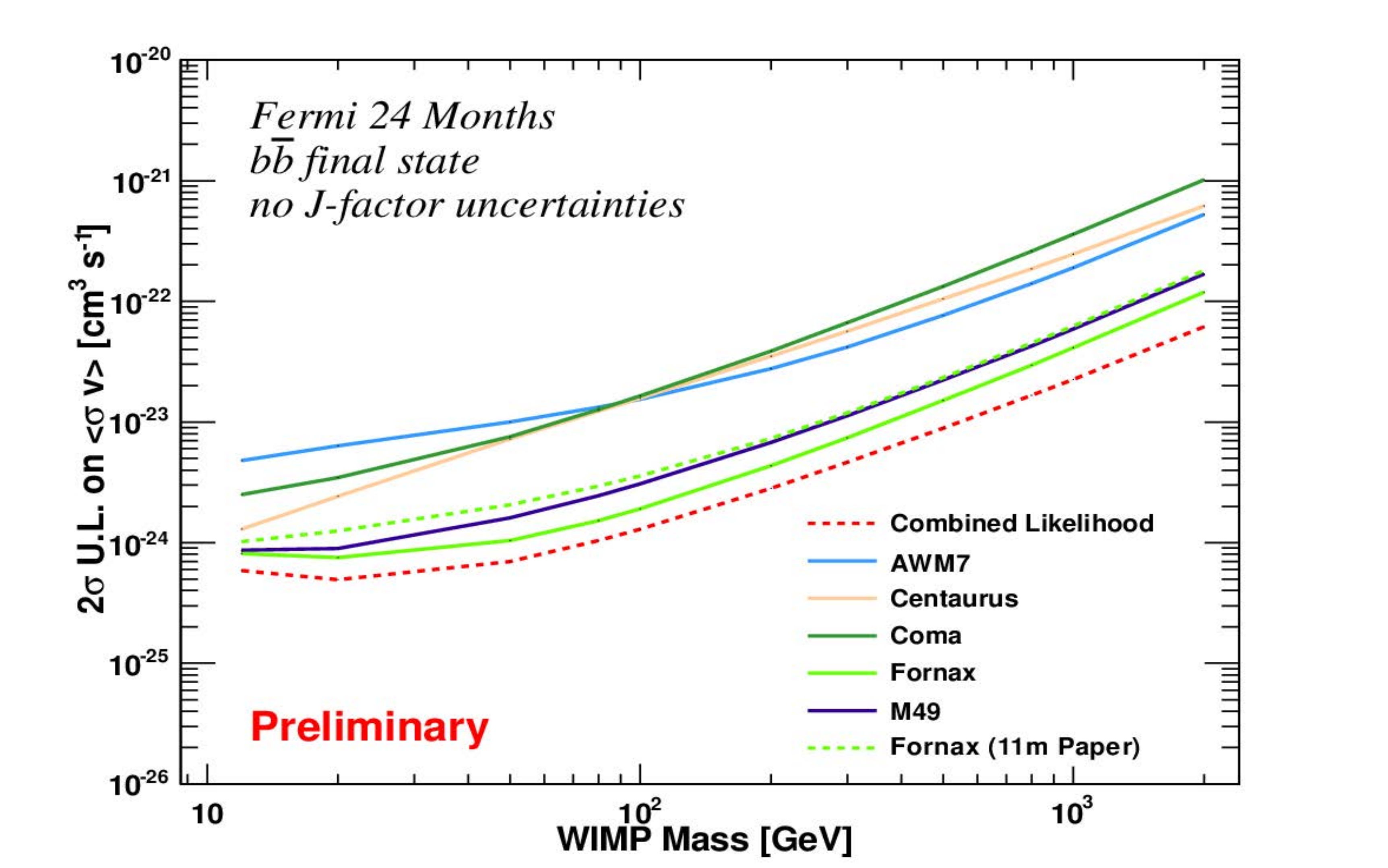


And from outside the collaboration: • Using 3y P7V6 data and 8 clusters (together and singularly) authors ofJCAP01(2012)042 don't find signal above 3σ.

• Authors of arXiv:1201.1003v1, using 3 years of P7V6 data and assuming no CR emission, they obtain a detection of DM in Virgo at 4.4σ (2.1 σ when optimal CR model is included

Fermi LAT Clusters Combined Upper Limits on <σv>

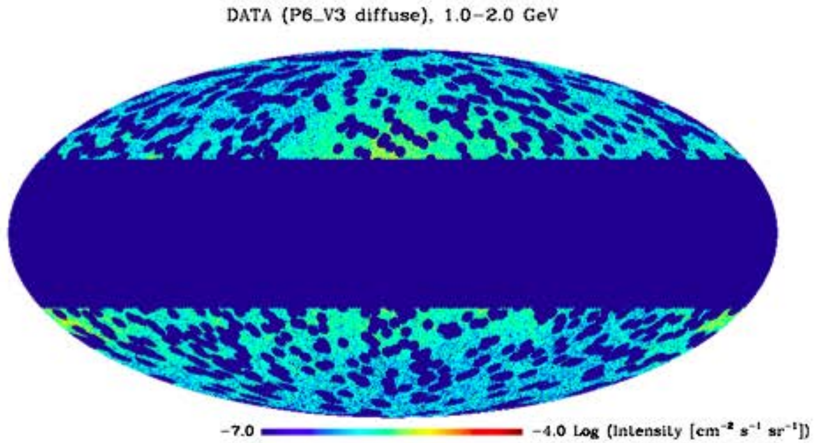
(from P6V11 analysis, currently working on P7V6)



- Combined DM Limits ~ **factor 2 better than individual** ones
- S/N tests indicates **several more within reach** of Fermi-LAT

Anisotropy constraints on dark matter

- angular power spectrum analysis of the large-scale isotropic gamma-ray background (IGRB) yielded a significant (>3σ) detection of angular power up to 10 GeV, lower significance power measured at 10-50 GeV
- measured (dimensionless) fluctuation angular power consistent with a constant value in four energy bins spanning 1-50 GeV
- fluctuation angular power measurement constrains fractional contribution of individual source classes, including DM, to the IGRB intensity

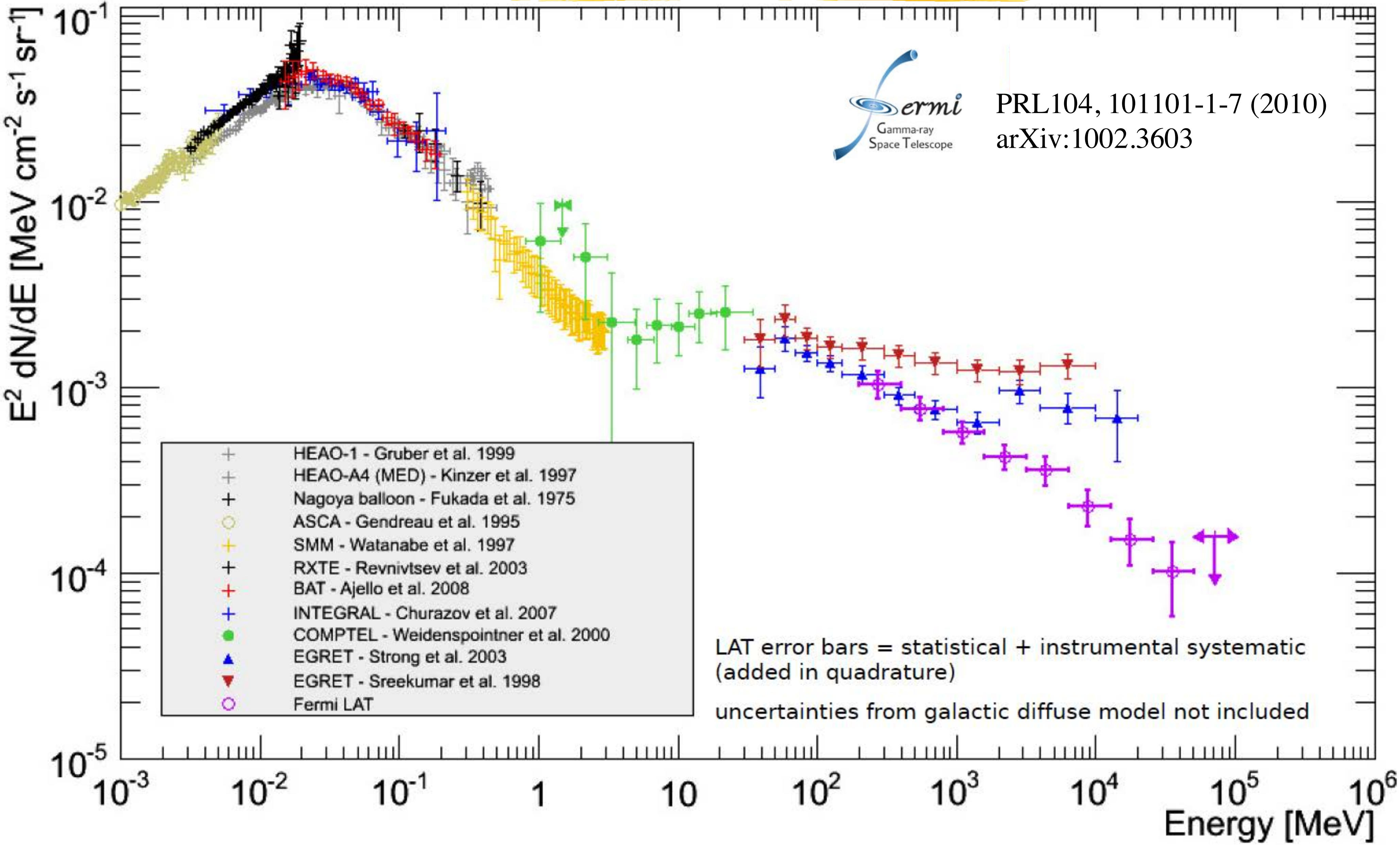


Constraints from best-fit constant fluctuation angular power (l ≳ 150) measured in the data and foreground-cleaned data

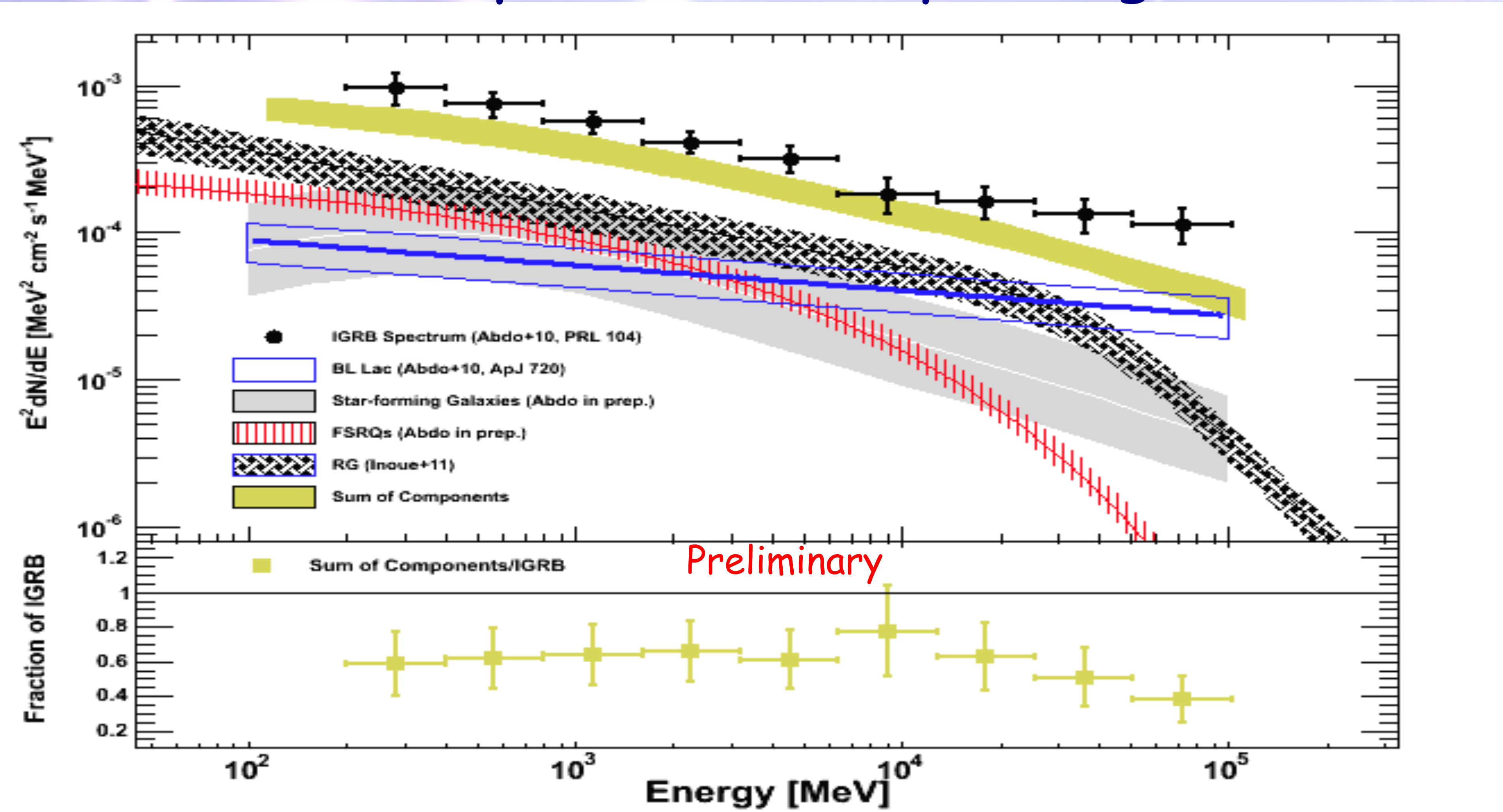
Source class	Predicted $C_{100}/\langle I \rangle^2$ [sr]	Maximum fraction of IGRB intensity DATA	DATA:CLEANED
Blazars	2×10^{-4}	21%	19%
Star-forming galaxies	2×10^{-7}	100%	100%
Extragalactic dark matter annihilation	1×10^{-5}	95%	83%
Galactic dark matter annihilation	5×10^{-5}	43%	37%
Millisecond pulsars	3×10^{-2}	1.7%	1.5%

Fermi Lat Coll., PRD 85, 083007 (2012) [arXiv:1202.2856]

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



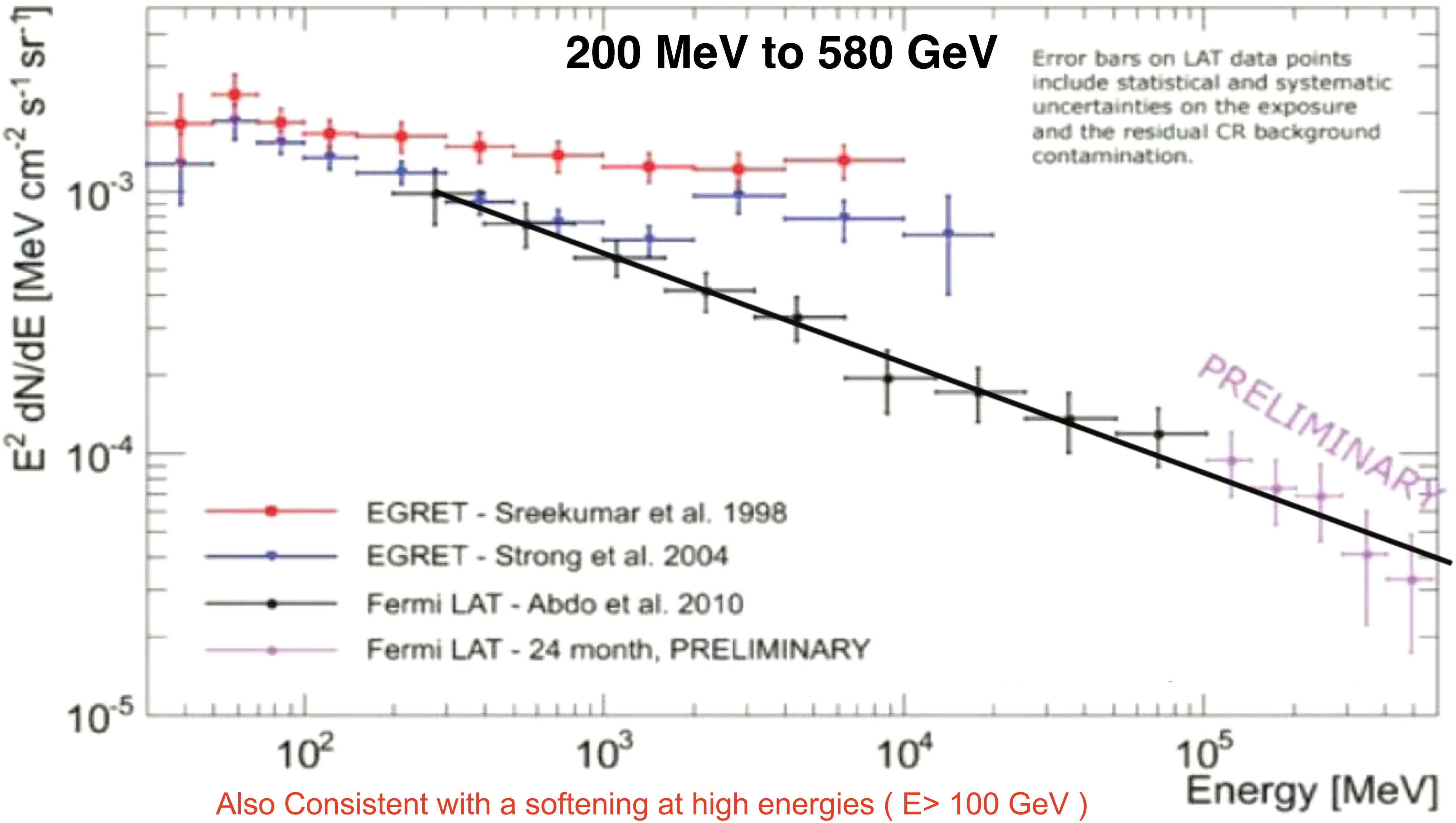
the Isotropic Gamma-ray Background (IGRB)



- Total contribution from FSRQ + BL Lac + Radio galaxies + Star-forming galaxies: ~ 50%- 80%
- 25% foreground modeling uncertainty not included in EGB error bands.

The remaining contribution could be due to more unresolved point sources populations or different diffuse process (as cosmological DM annihilation).

Update on the Isotropic Gamma-ray Background (IGRB)

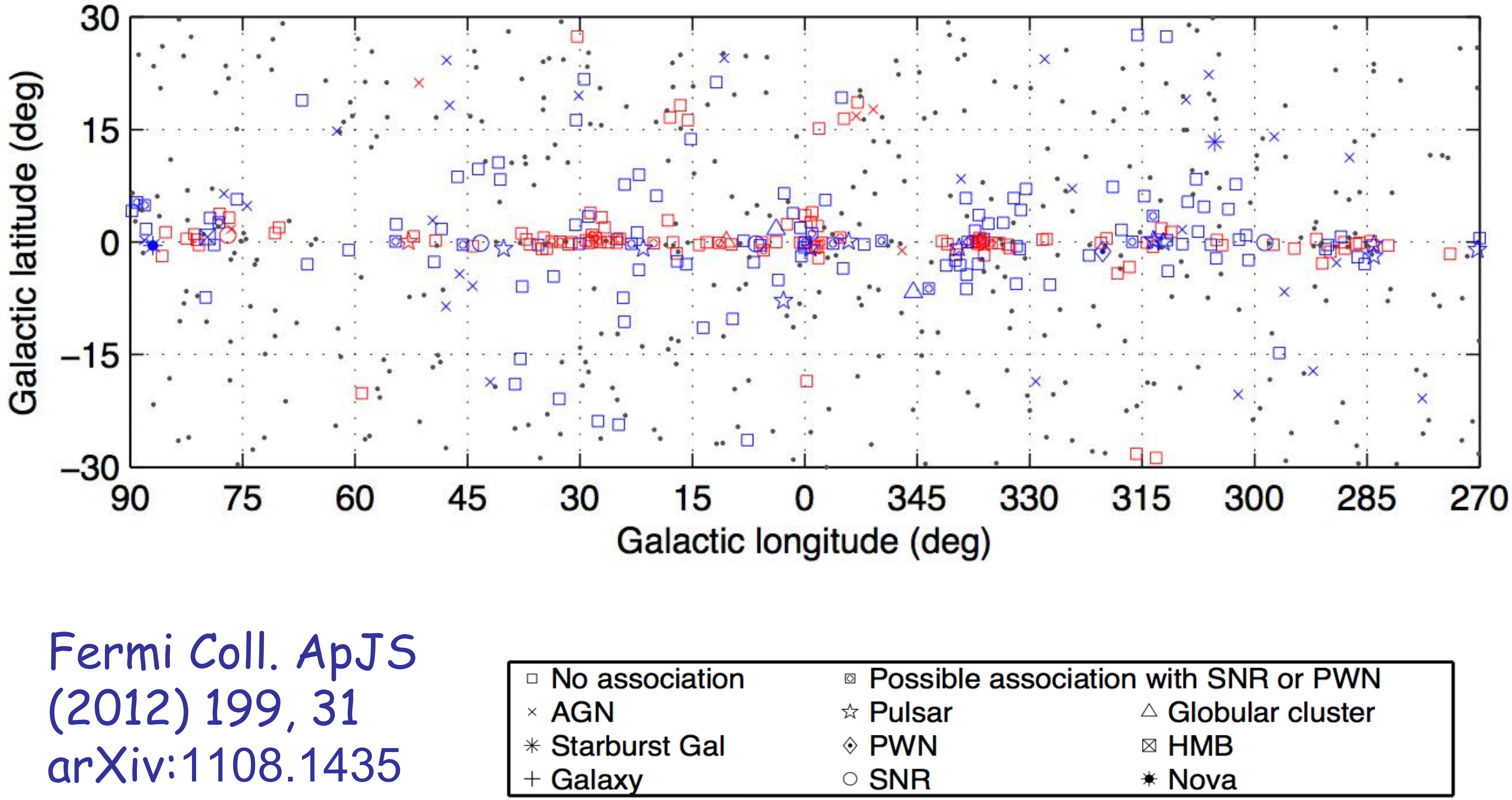


Also Consistent with a softening at high energies (E> 100 GeV)

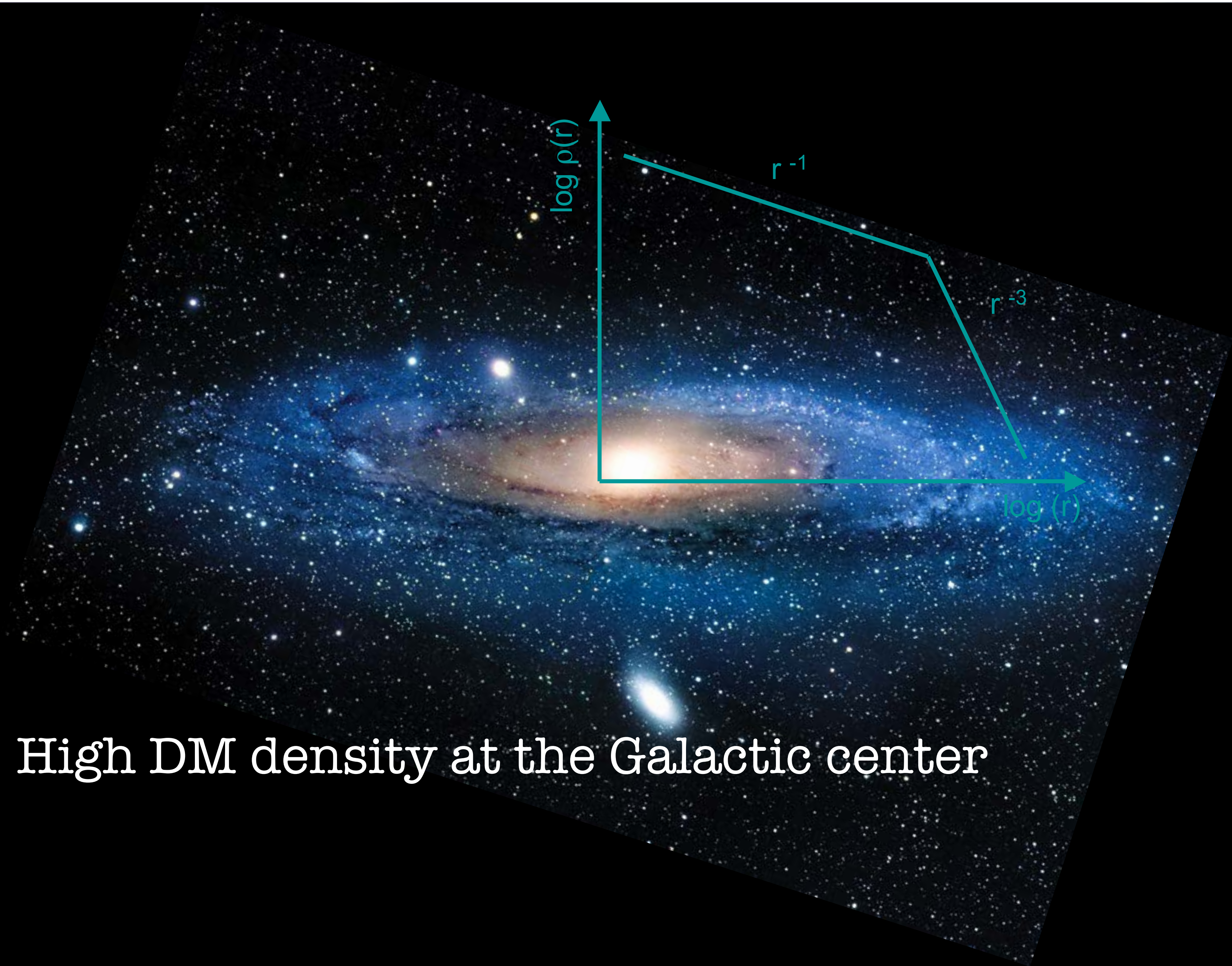
The Fermi LAT 2FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



Fermi Coll. ApJS (2012) 199, 31
arXiv:1108.1435



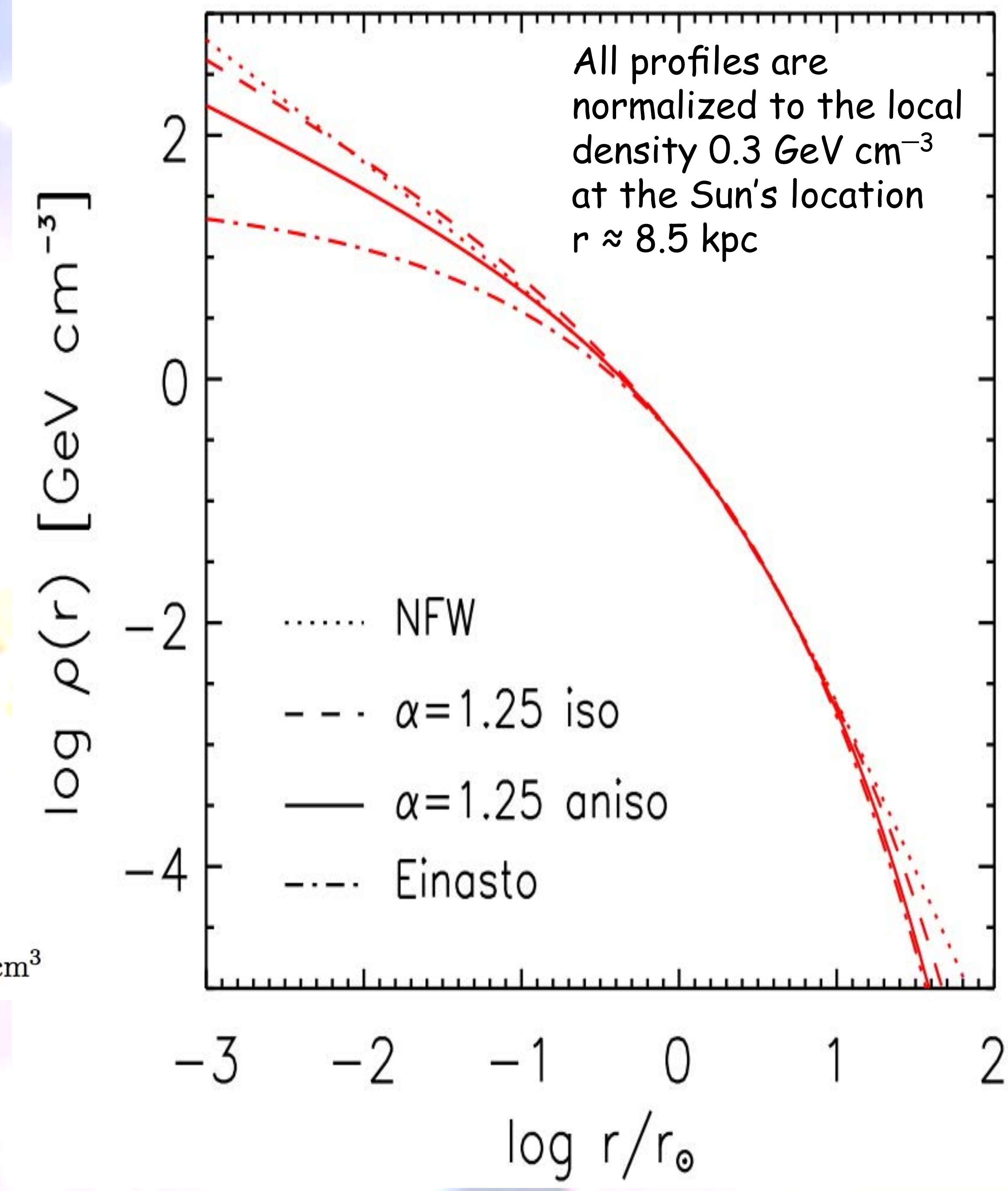
High DM density at the Galactic center

Milky Way Dark Matter Profiles

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

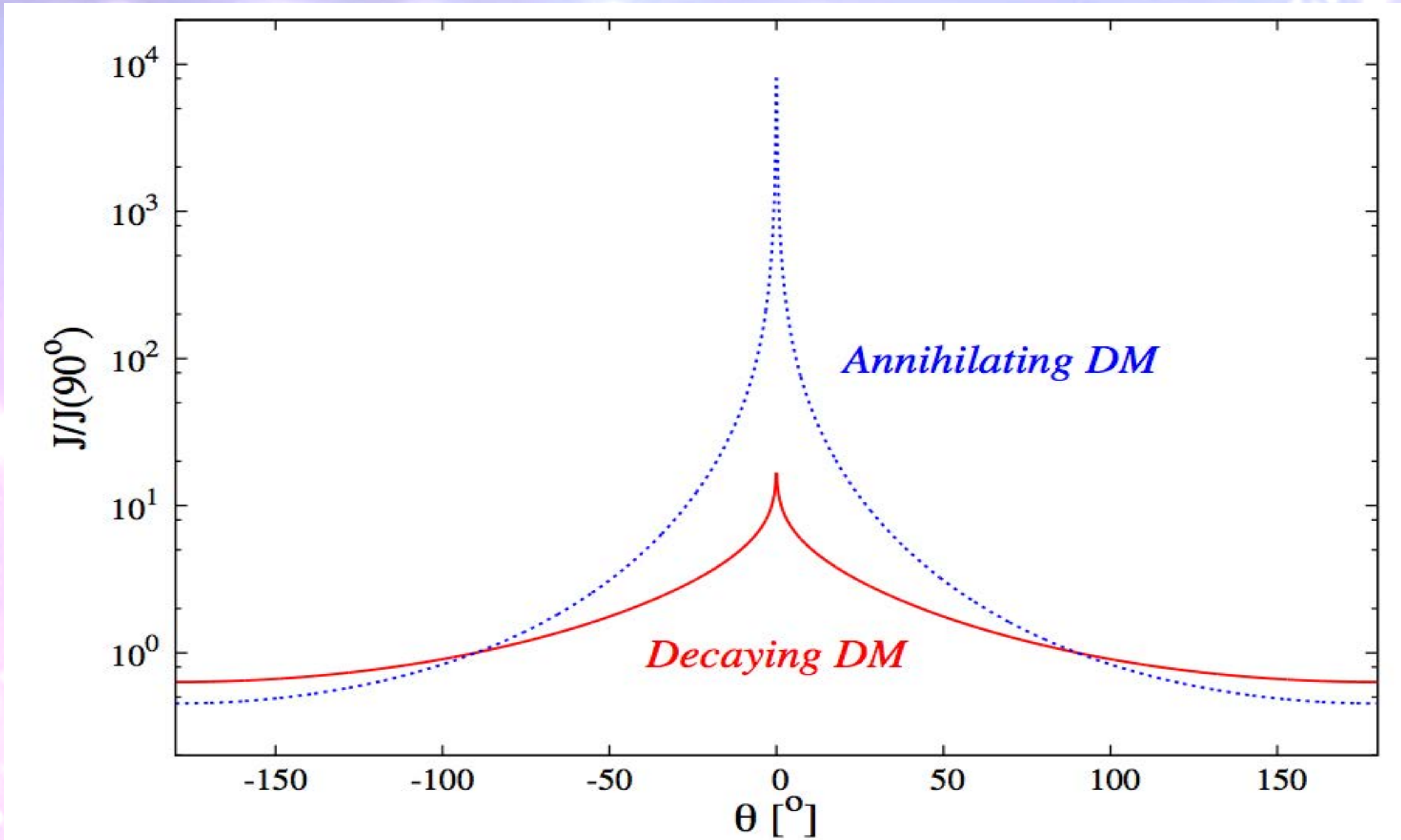
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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



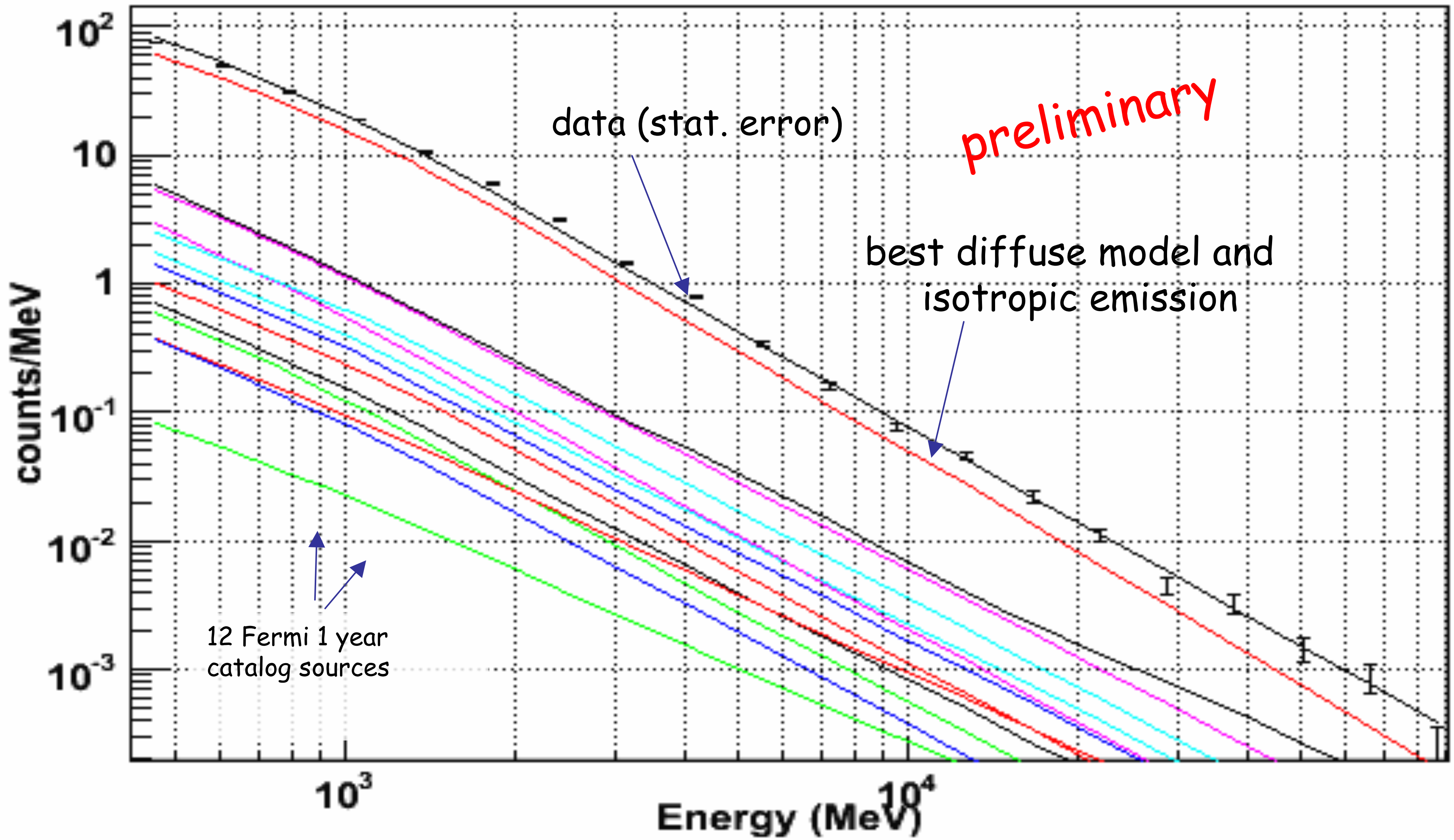
A.Lapi et al. arXiv:0912.1766

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)

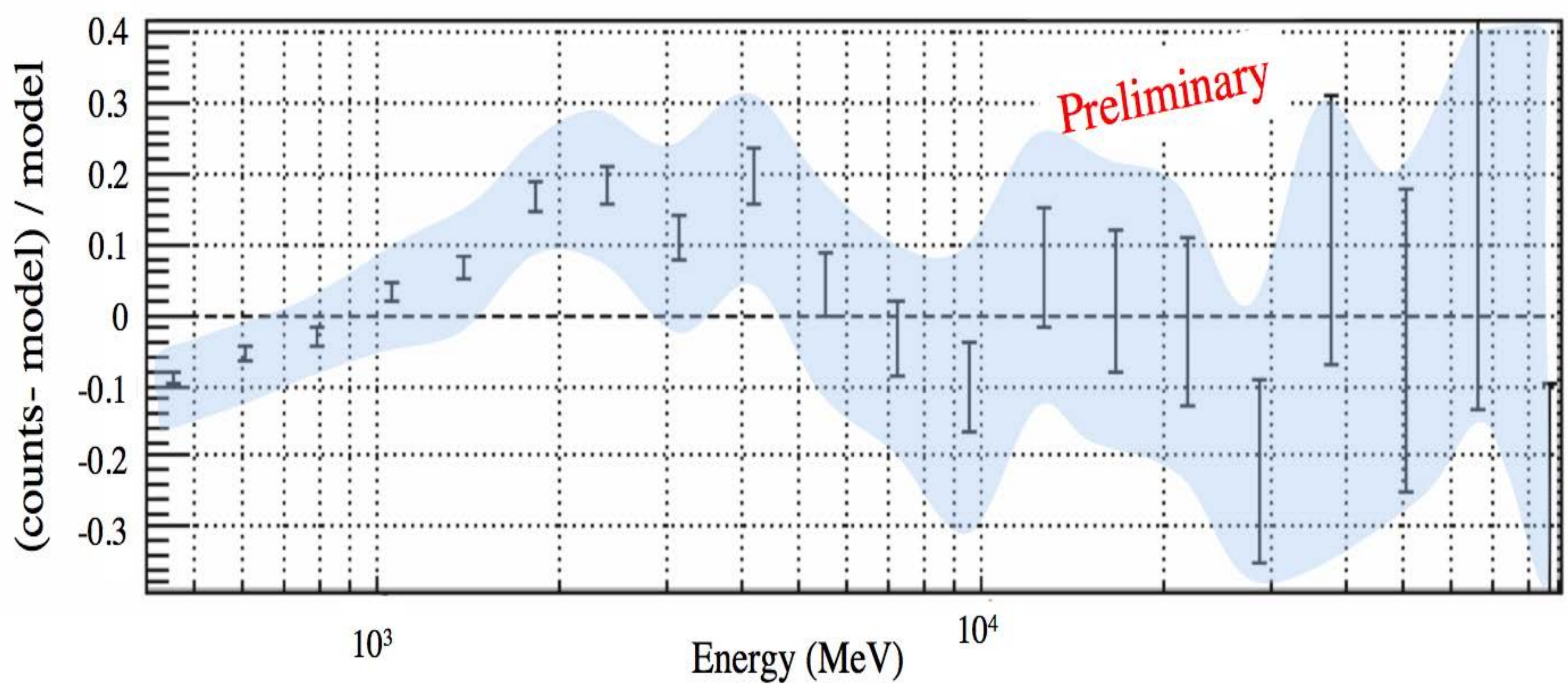


Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

GC Residuals 7°x7° region centered on the Galactic Center

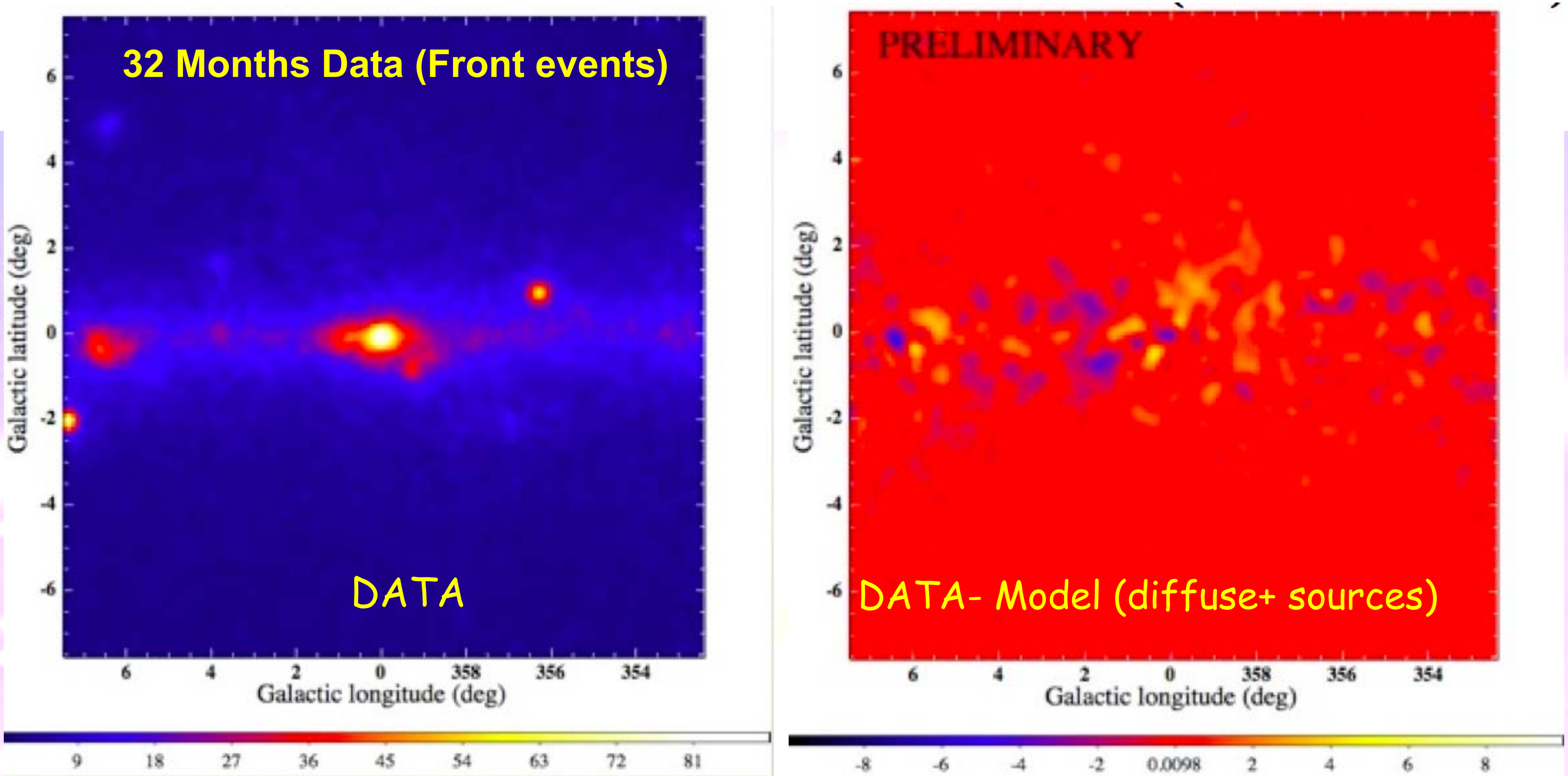
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- 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 Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

Residual Emission for 15 * 15 degrees around the Galactic center

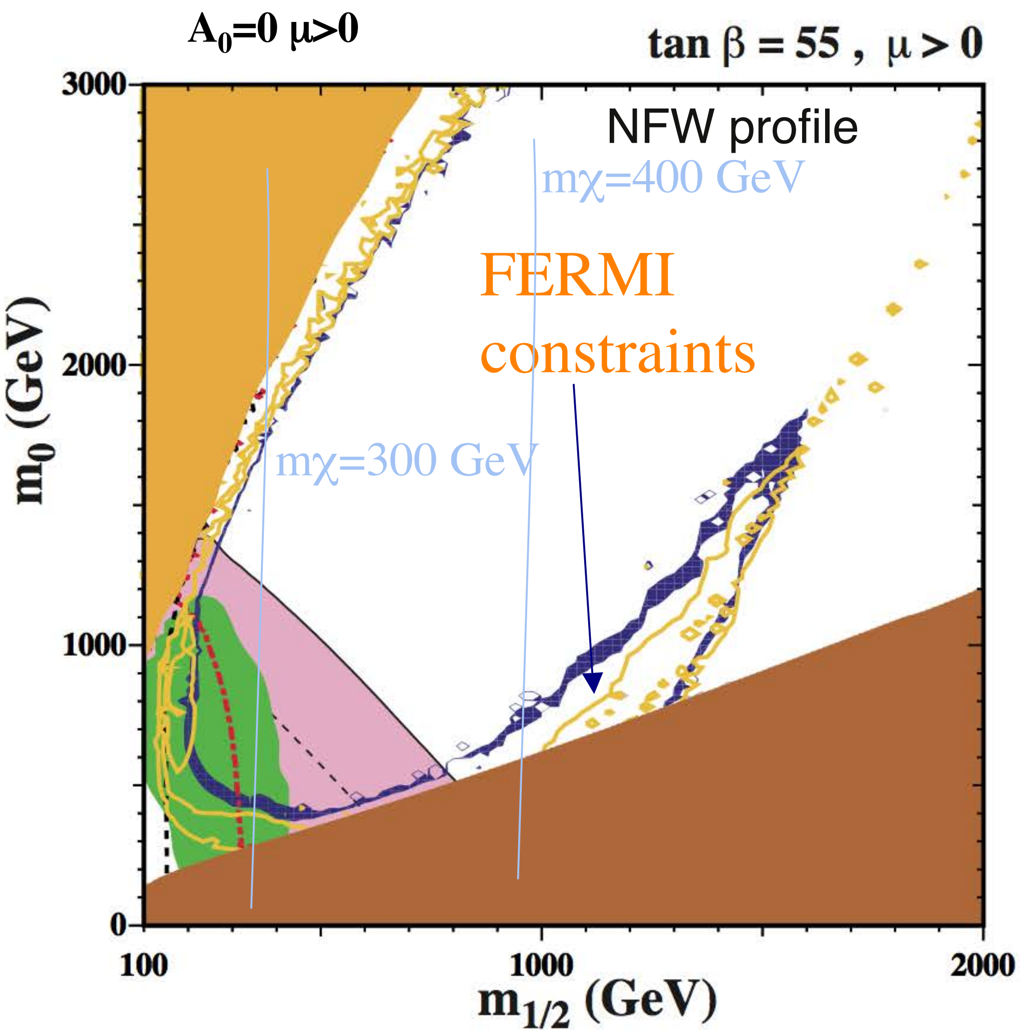


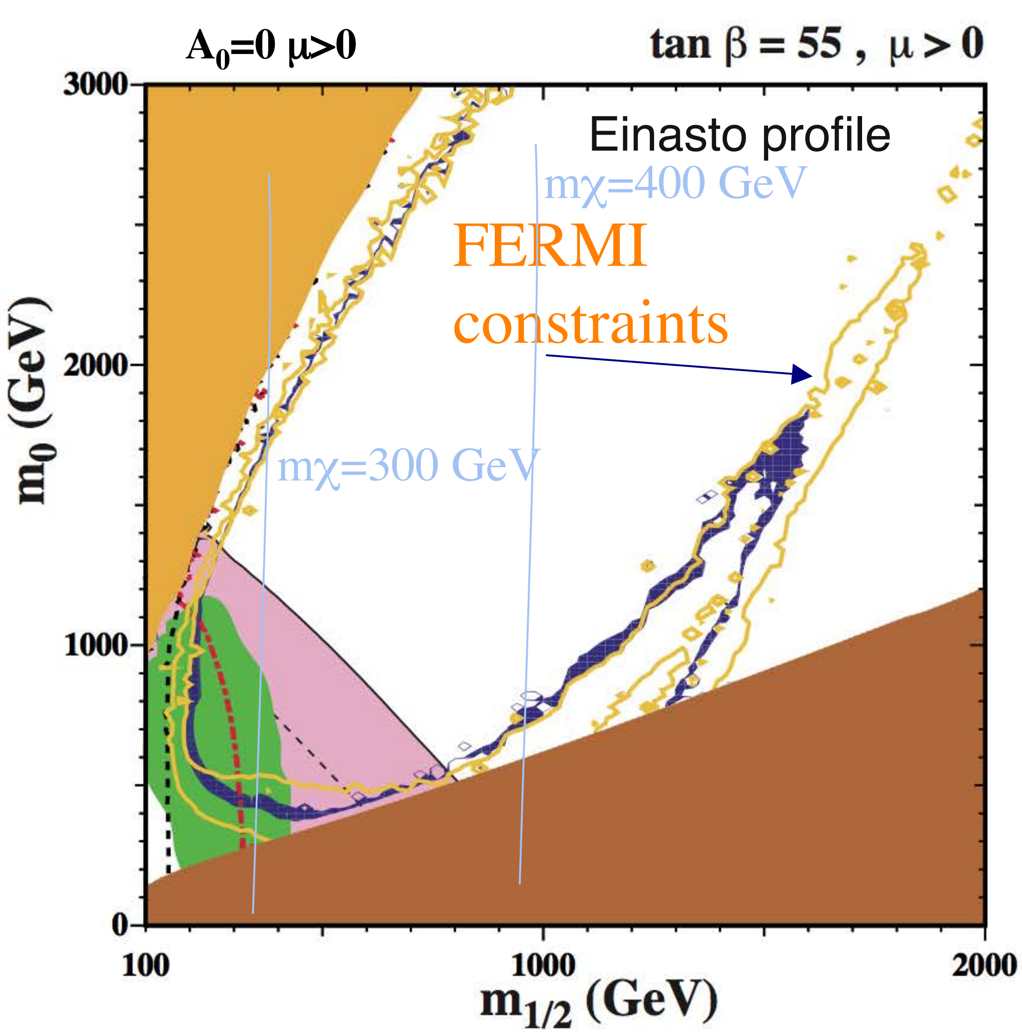
Diffuse emission and point sources account for most of the emission observed in the region.

Low-level residuals remain, the interpretation of these is work in-progress

Papers are forthcoming and will include dark matter results.

Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios

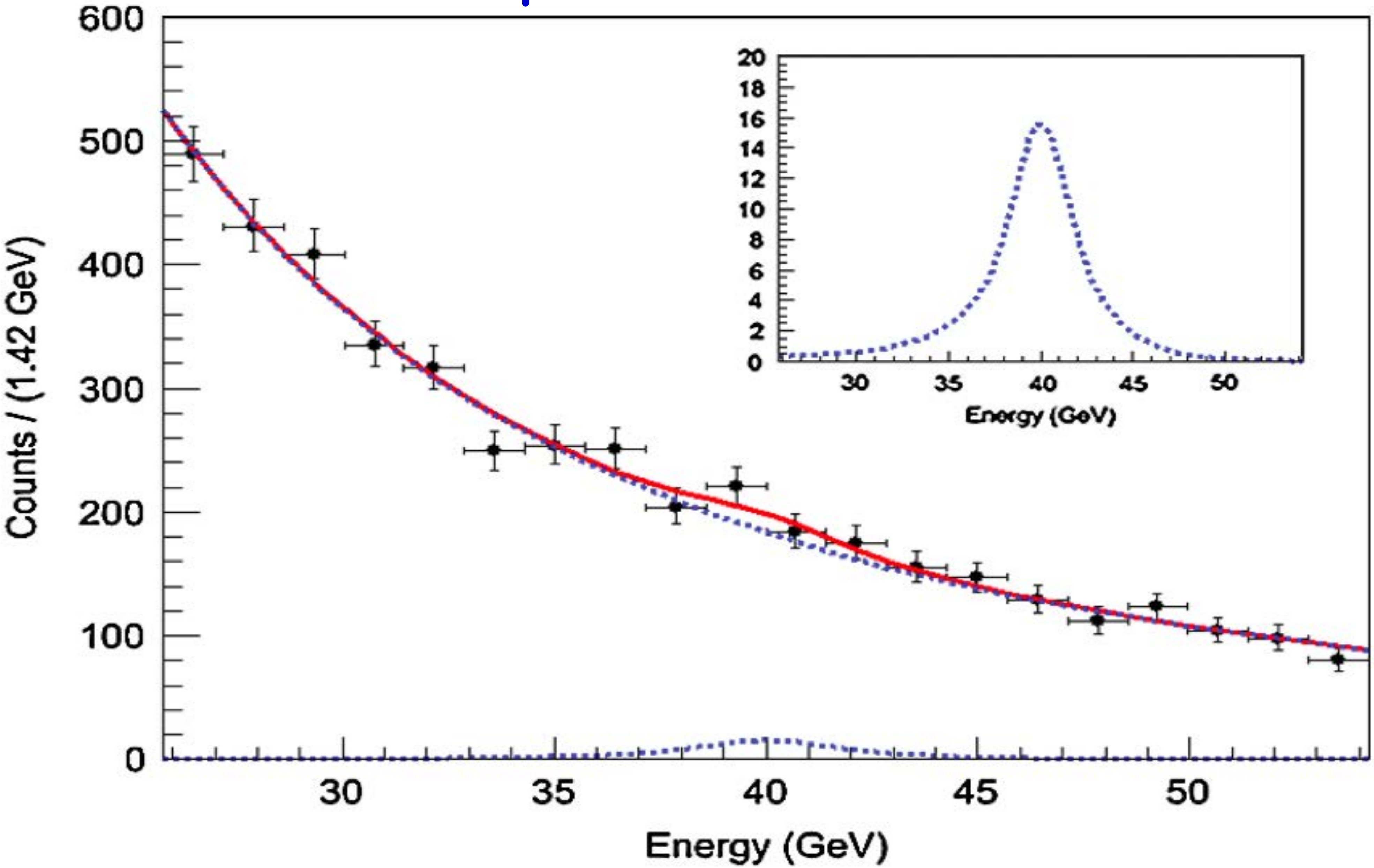




The constraints due to the absences of charginos and the Higgs boson at LEP are also shown, as black dashed and red dot-dashed lines, respectively. Regions excluded by the requirements of electroweak symmetry breaking and a neutral LSP are shaded dark pink and brown, respectively. The green region is excluded by $b \rightarrow s\gamma$, 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)

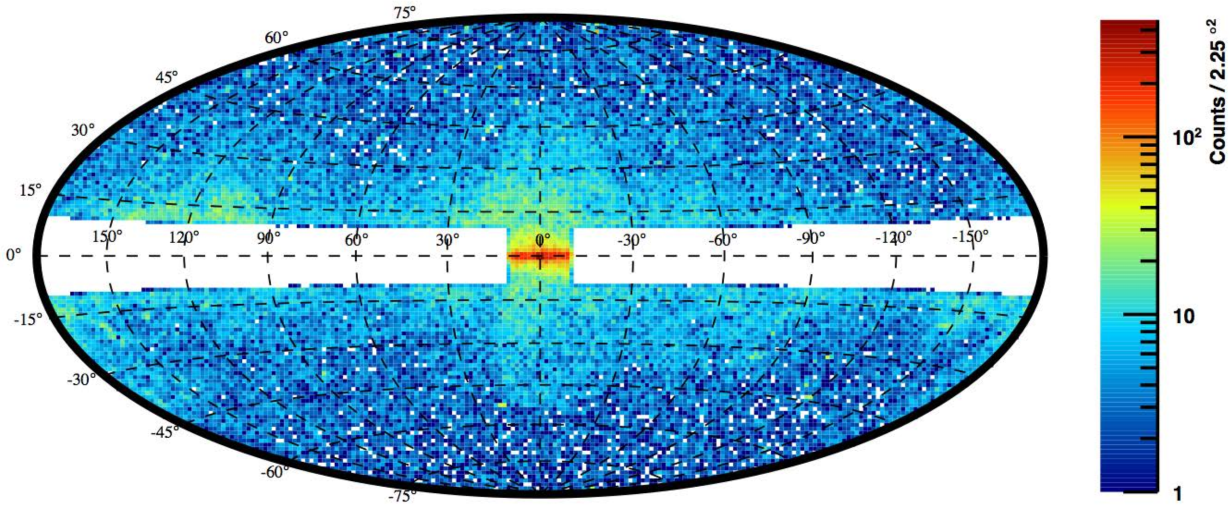
Ellis et al., arXiv:1106.0768

Wimp lines search



Search for Spectral Gamma Lines

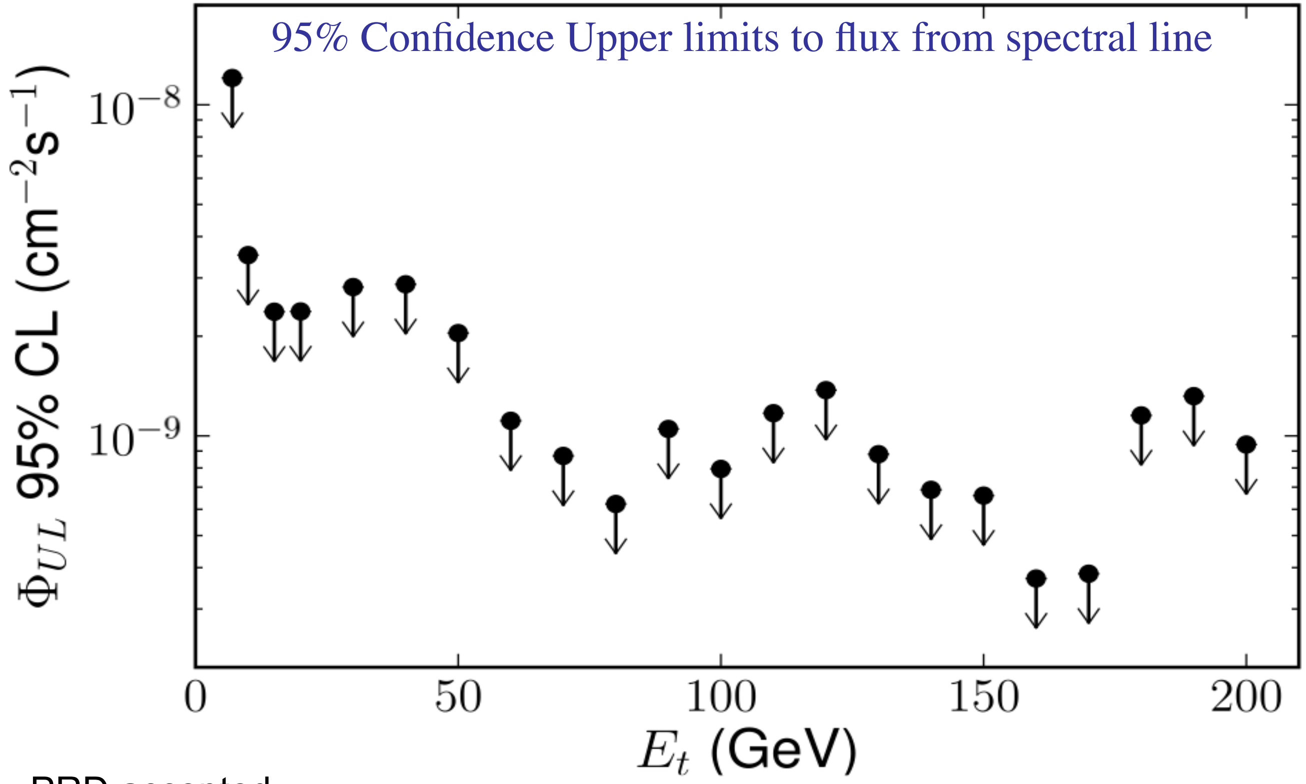
- Smoking gun signal of dark matter
- Search for lines in the first 23 months of Fermi data (7-200 GeV en.range)
- Search region |b|>10° plus a 20°x 20° square centered at the galactic center
- For the region within 1°of the GC, no point source removal was done as this would have removed the GC
- For 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.



Region-of-interest for line search

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

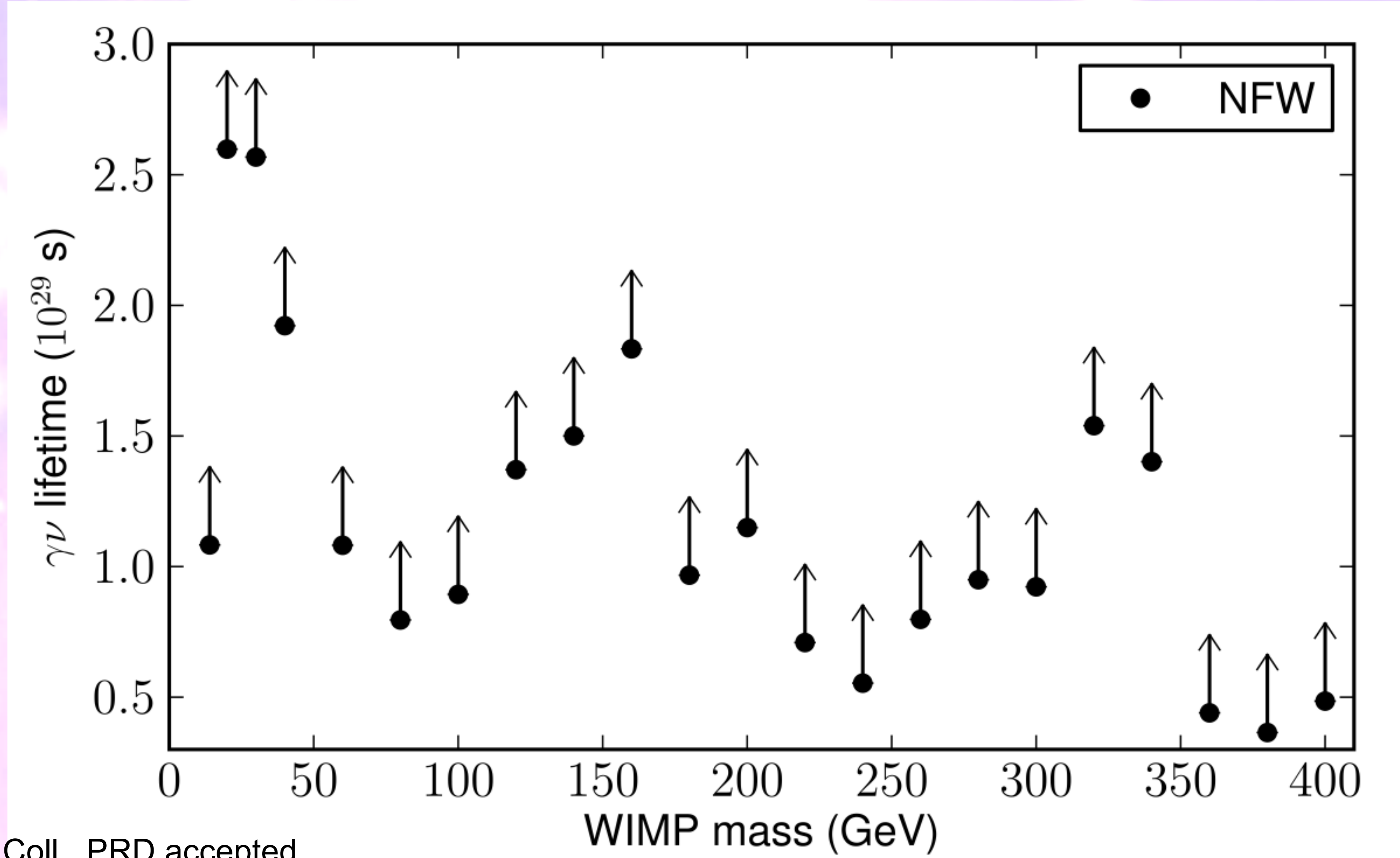
- 23 % systematic uncertainty for E < 130 GeV and 30% for E > 130 GeV
- **7 and 10 GeV bins use a modified event selection to reduce the systematic uncertainty associated with public IRFs**.
- For E > 12 GeV no indication of a spectral structure systematic effect is seen.



Fermi Lat Coll., PRD accepted
arXiv:1205.2739

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



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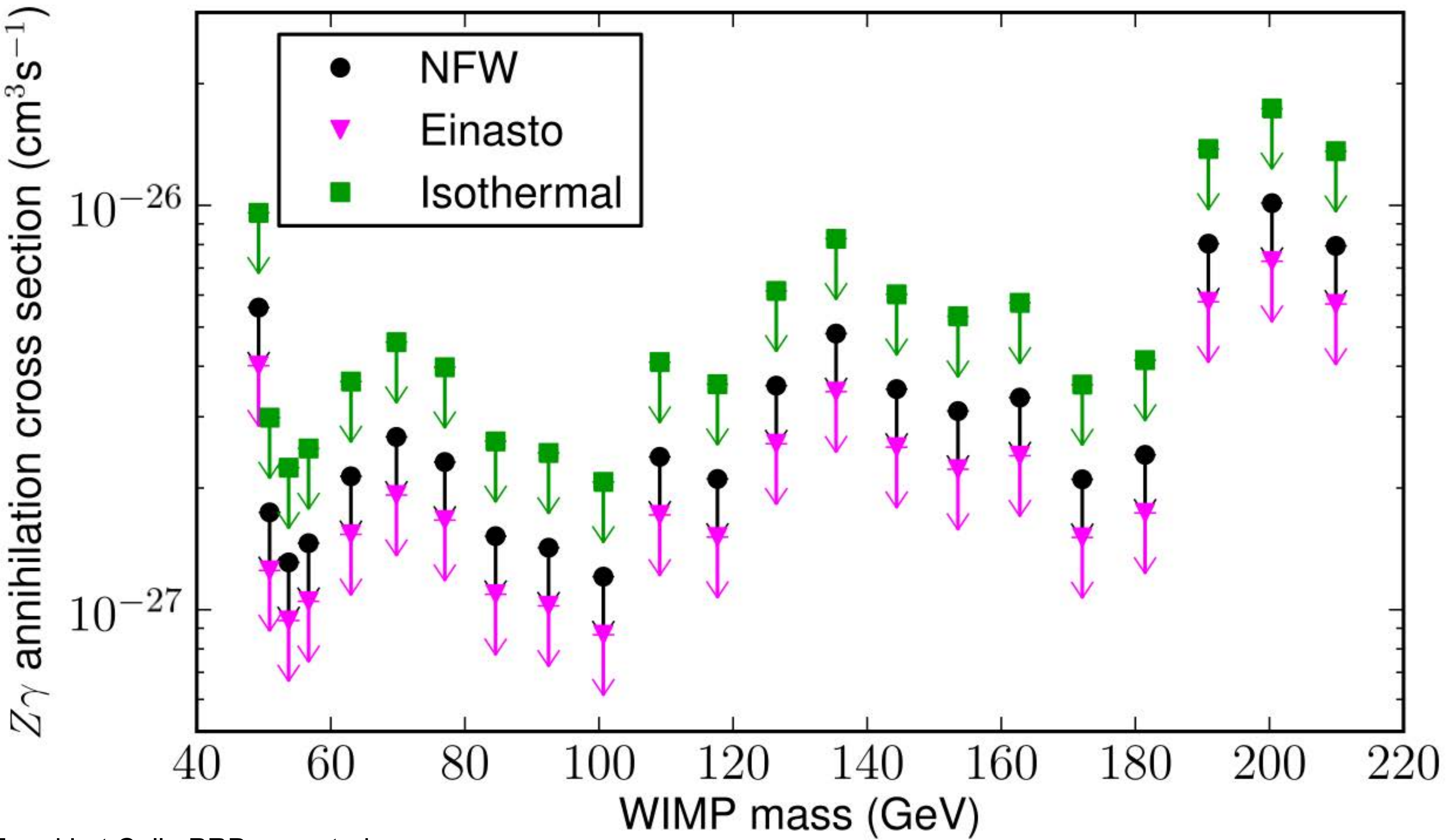
Fermi LAT 23 Month Zγ-Cross-section limits 7 GeV – 200 GeV



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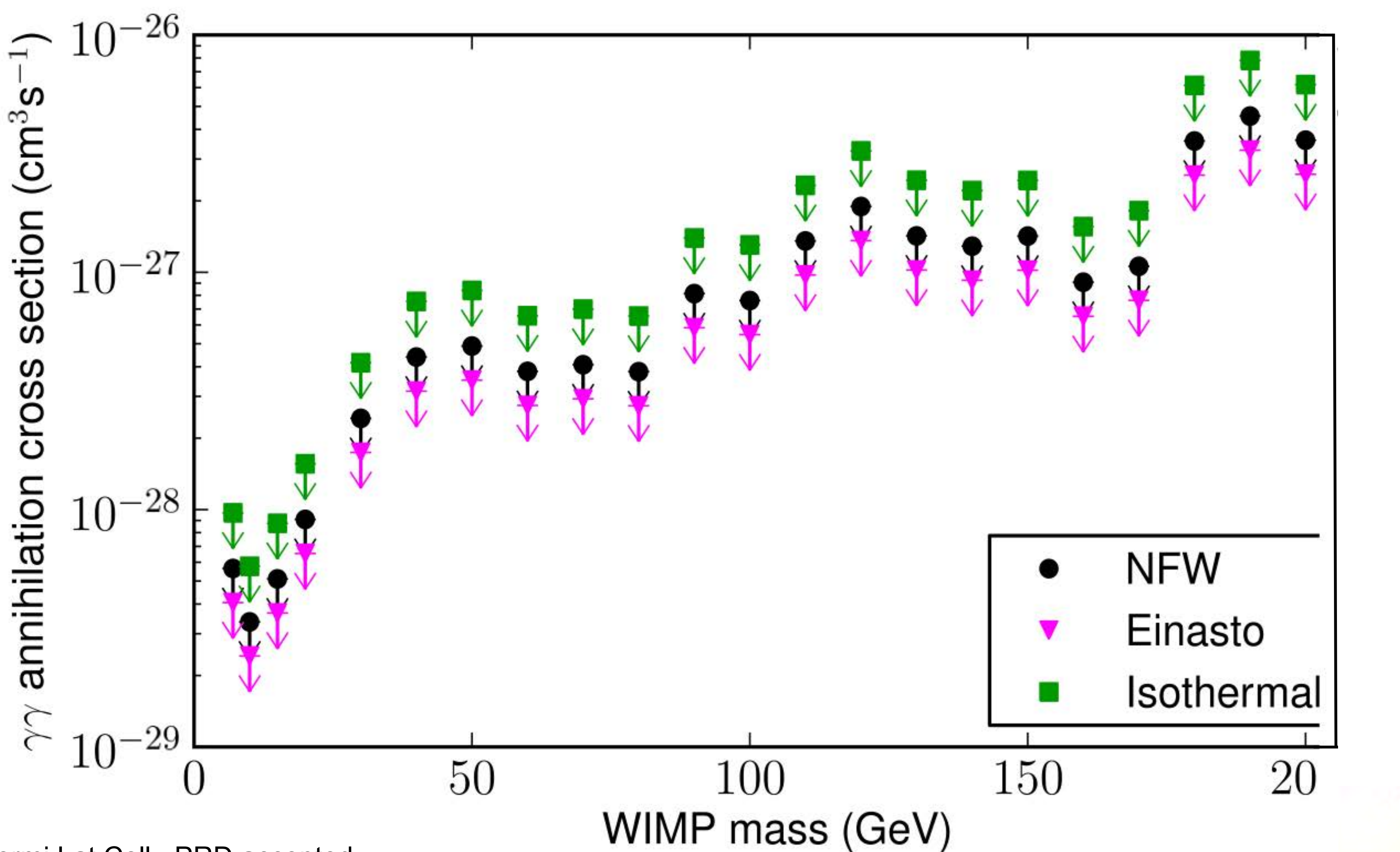
Fermi LAT 23 Month γγ-Cross-section limits 7 GeV – 200 GeV



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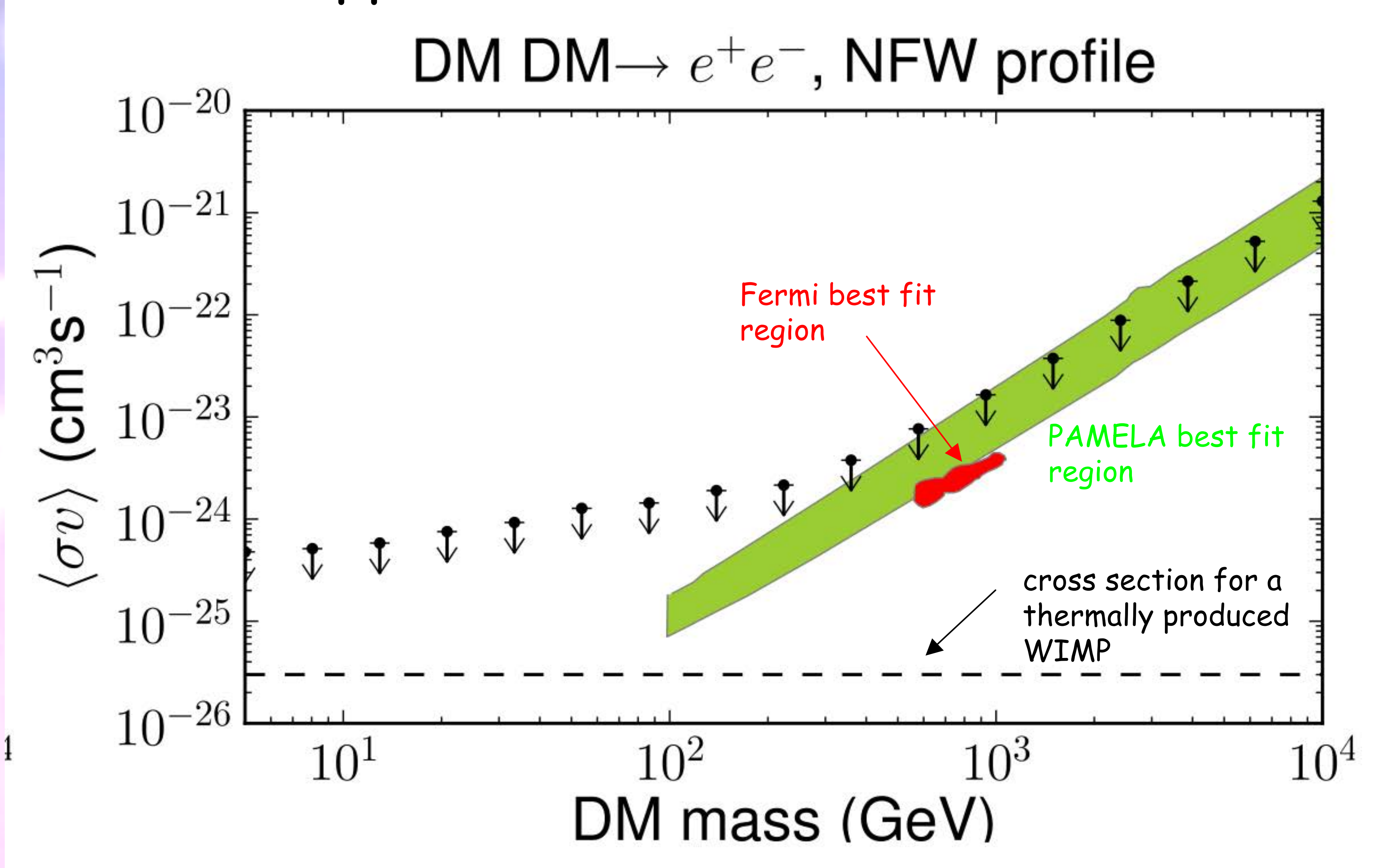
Cross section upper limits for dark matter annihilation



No photons from astrophysical background sources have been included, making these limits very conservative.

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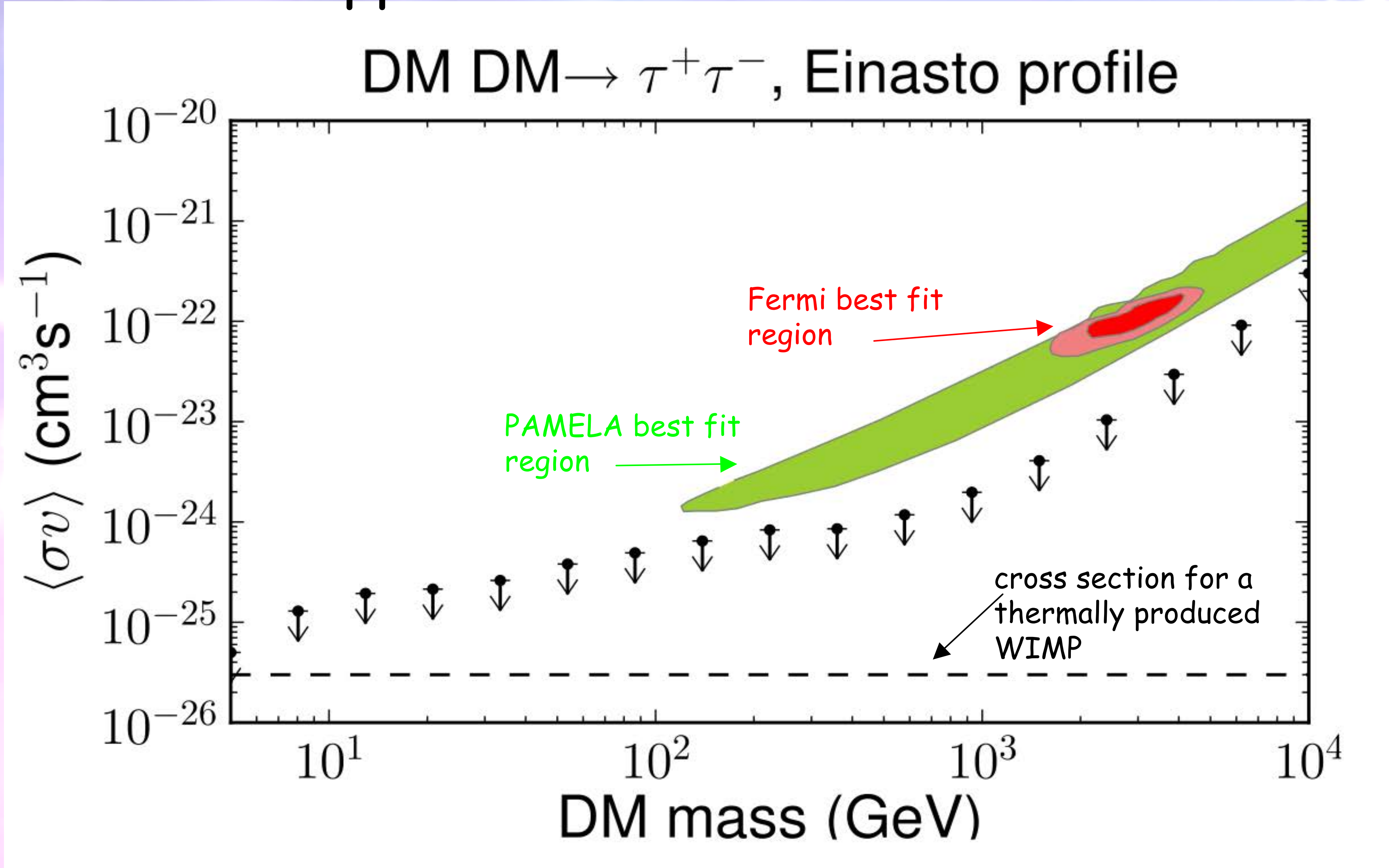

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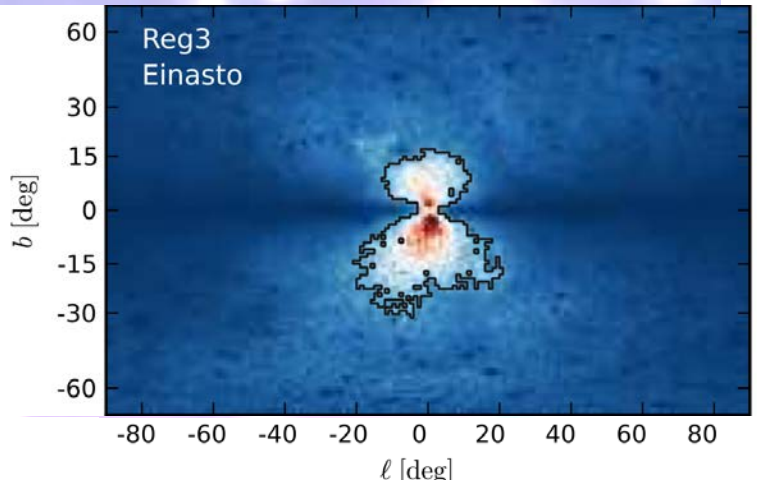
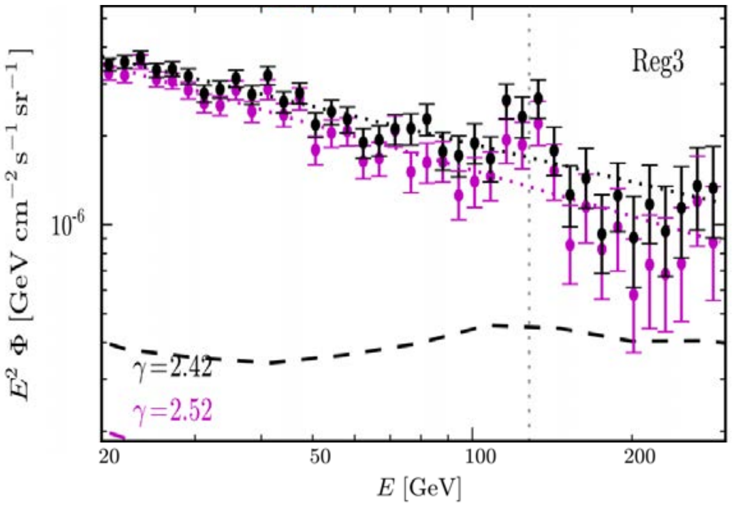
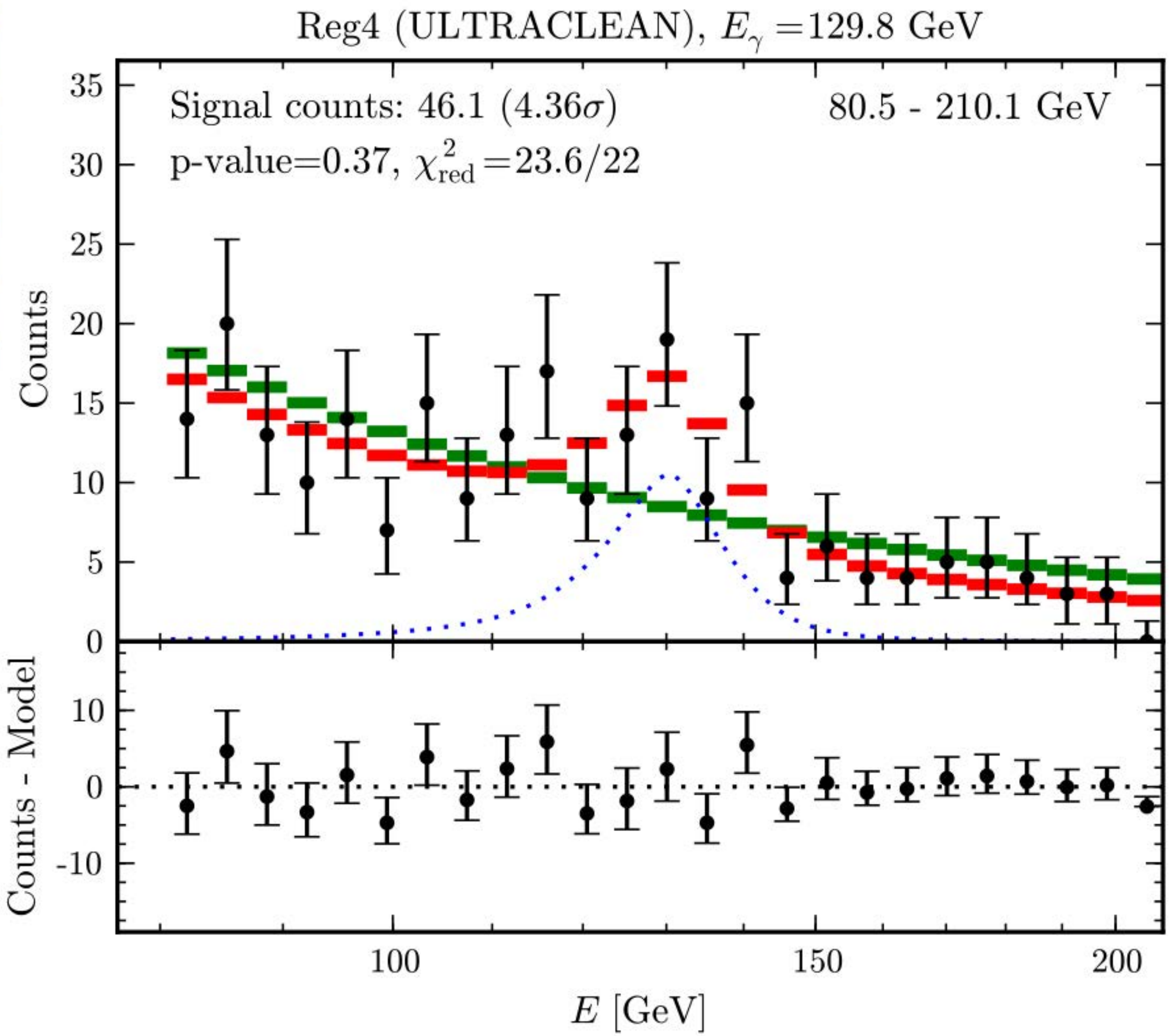
A line at ~ 130 GeV ?







Weniger arXiv:1204.2797

A line at ~ 130 GeV ?

see also

Tempel et al. arXiv:1205.1045

Kyae & Park arXiv:1205.4151

Dudas Mambrini et al. arXiv:1205.1520

Boyarsky et al. arXiv:1205.4700

Lee et al. arXiv:1205.4700

Acharya, Kane et al. arXiv:1205.5789

Buckley, Hooper arXiv:1205.6811

Su, Finkbeiner arXiv:1206.1616

Chu,Hambye et al. arXiv:1206.2279

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Fermi-LAT analysis is in progress

Summary and Conclusions

- The Fermi-LAT has made great progress toward constraining/ identifying the nature of DM
  - Many independent search strategies (dSphs, clusters, MW halo, etc.)
  - Best LAT constraints (dwarf stacking) are already beginning to reach some interesting areas of parameter space
- Fermi-LAT DM sensitivity is anticipated to improve

-Improved understanding of astrophysical backgrounds

-Increased exposure (sensitivity gain linear in time at high energies)

-Improvements in analysis and understanding of detector response

- Constraints provided by the Fermi-LAT are highly complementary to direct and accelerator searches

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

Exciting progress on Pass8, expected to be the ultimate IRF version.

The longer we look, the more surprises we will see

thank you for your attention !