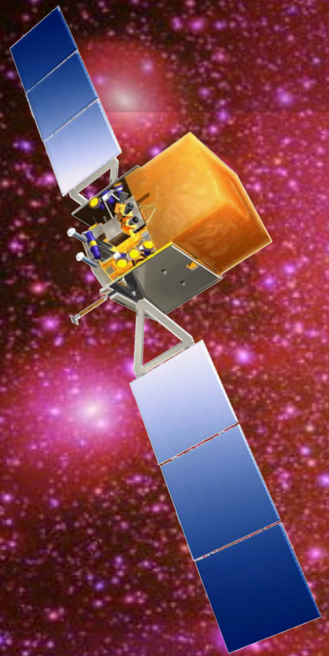
Fermi Large area telescope results: The sky at high energies and the Quest for Dark Matter signals



Aldo Morselli
INFN Roma Tor Vergata

4 April 2012

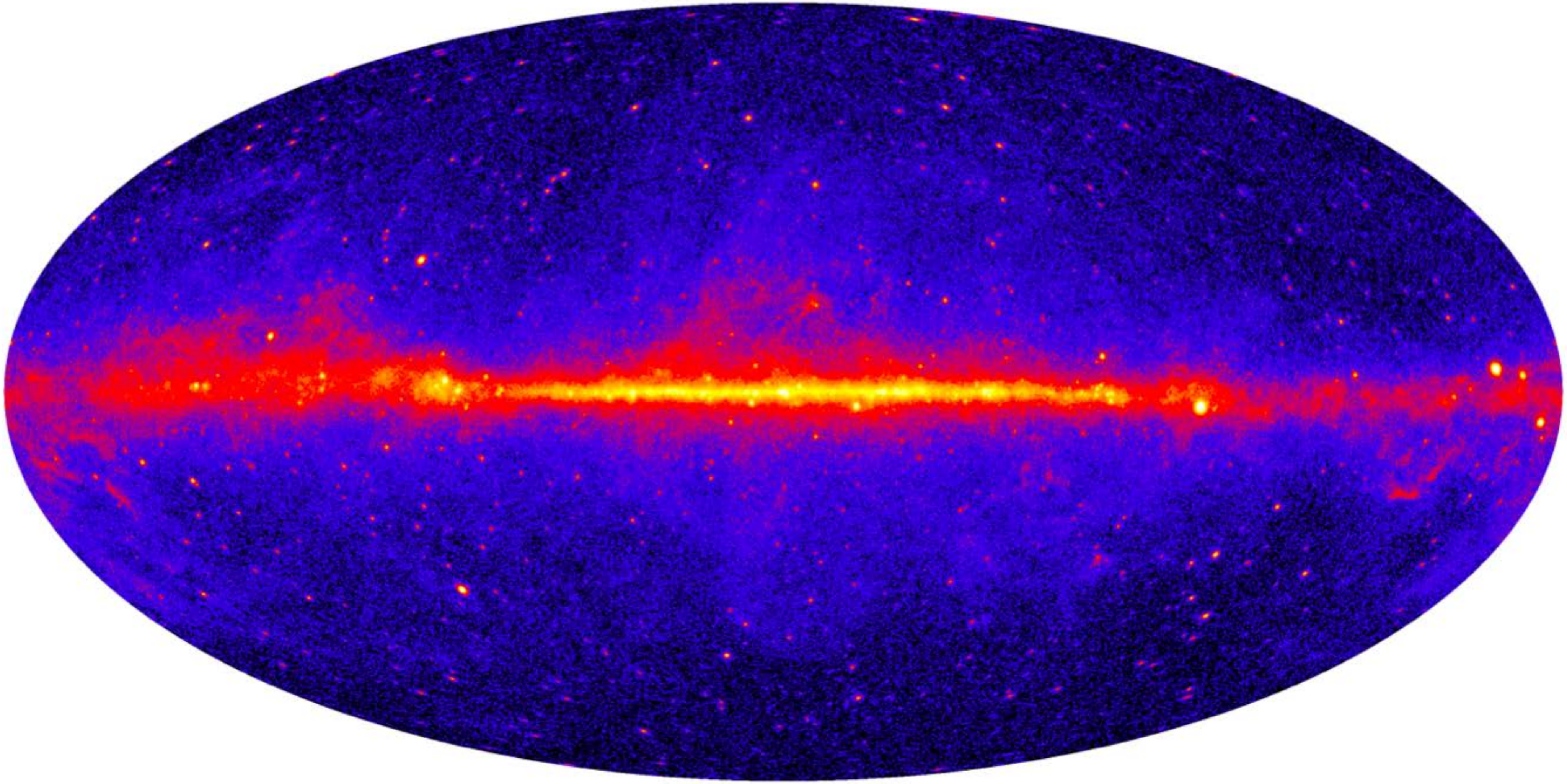
Joint High Energy Particle Physics and Astro-Particle Physics meeting
Queen Mary University, London


Gamma-ray
Space Telescope
11 June 2008

Fermi Symposium Roma, May 9-12 1011

The Fermi LAT gamma-ray sky

3-year all-sky map, E > 1 GeV

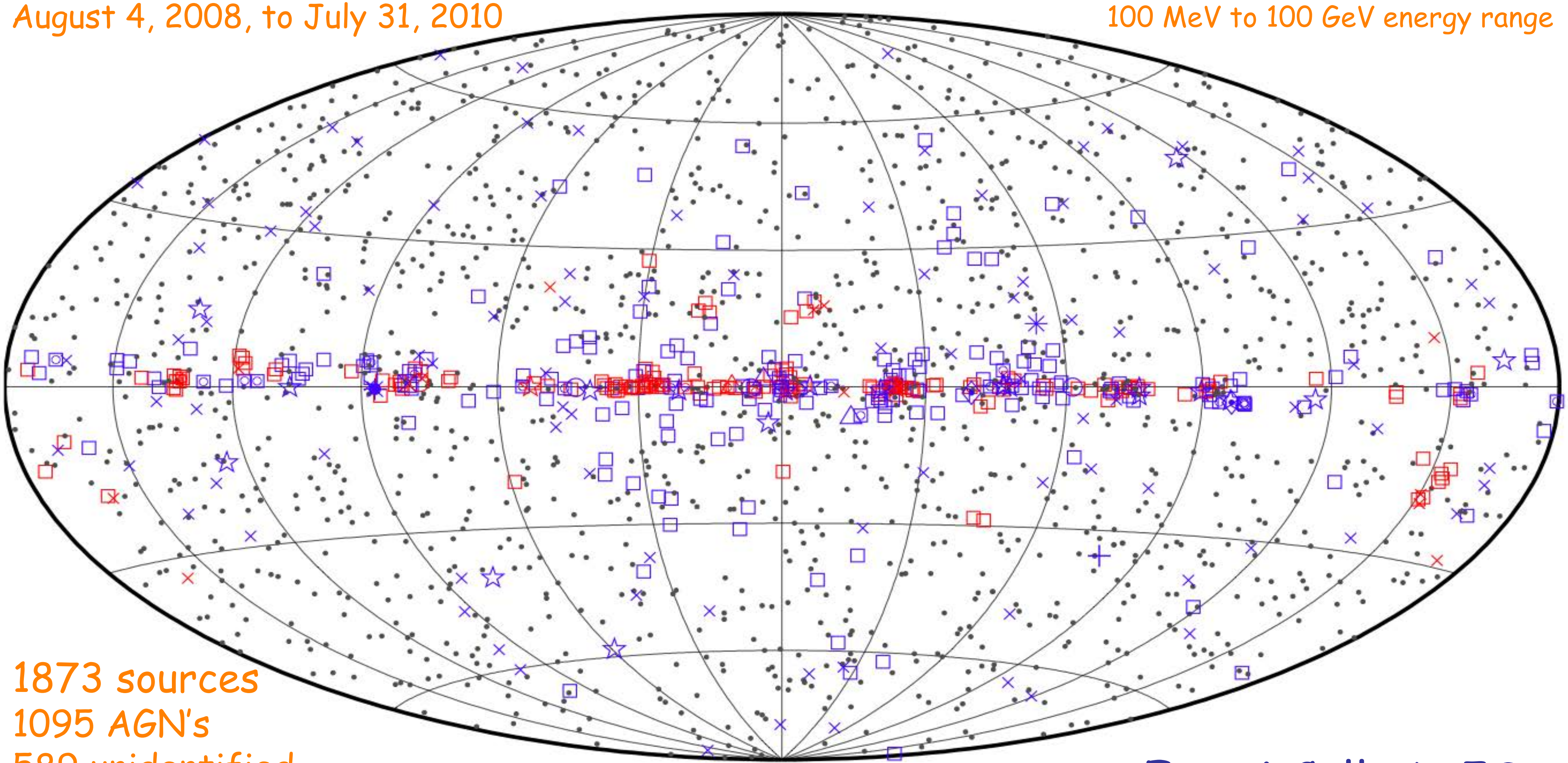


The Fermi LAT 2FGL Source Catalog

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

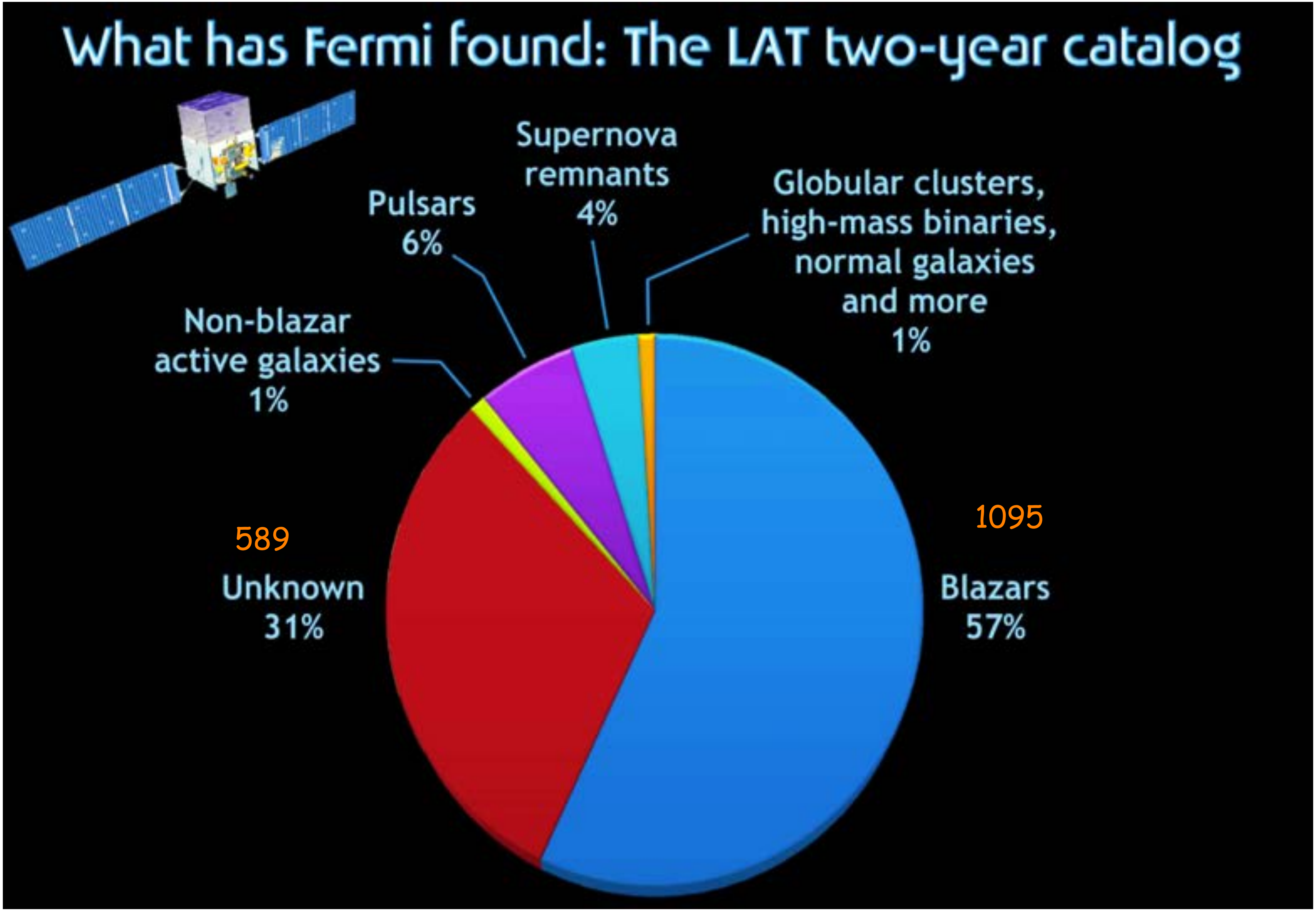
August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



1873 sources
1095 AGN's
589 unidentified

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

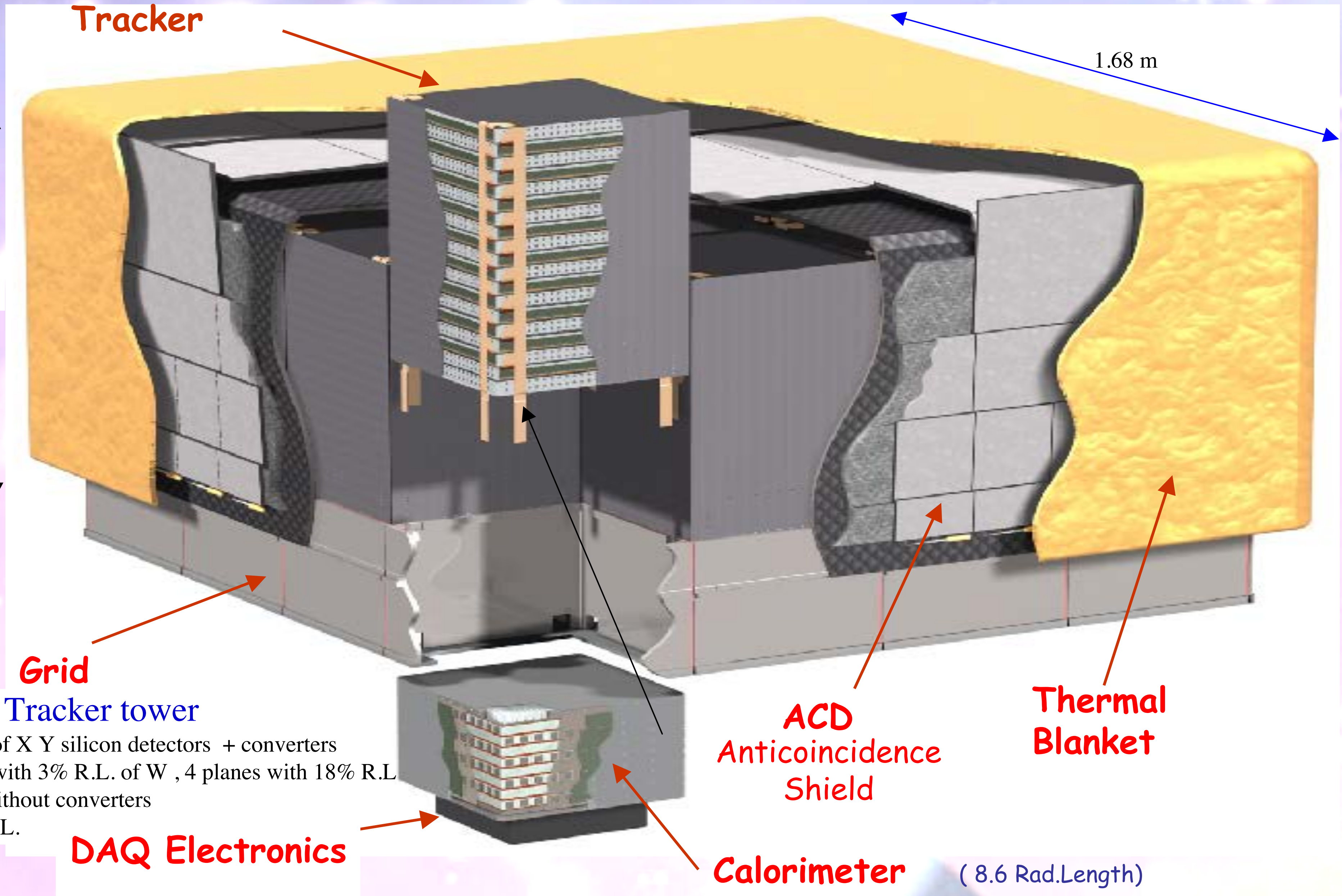

What has Fermi found: The LAT two-year catalog
Supernova remnants 4%
Pulsars 6%
Globular clusters, high-mass binaries, normal galaxies and more 1%
Non-blazar active galaxies 1%
589
Unknown 31%
1095
Blazars 57%

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.

Fermi Gamma-Ray Large Area Space Telescope



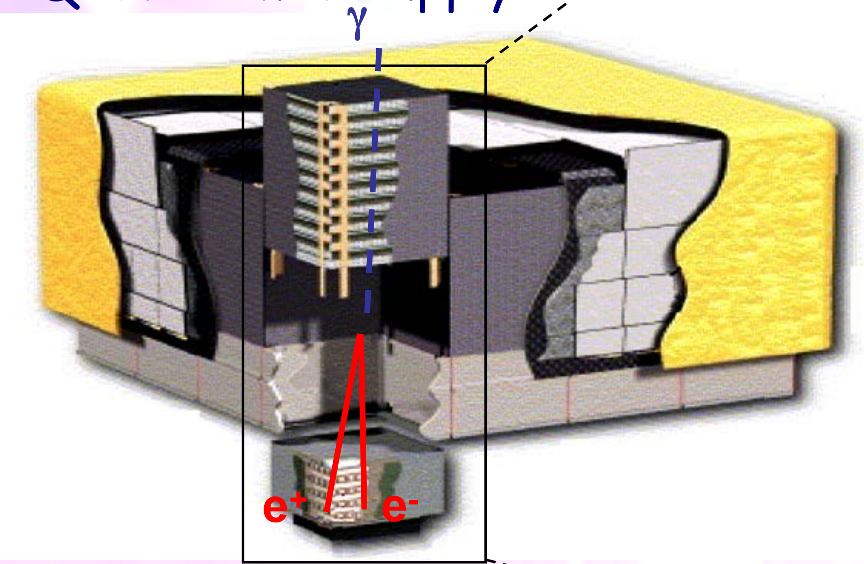
Silicon Tracker tower

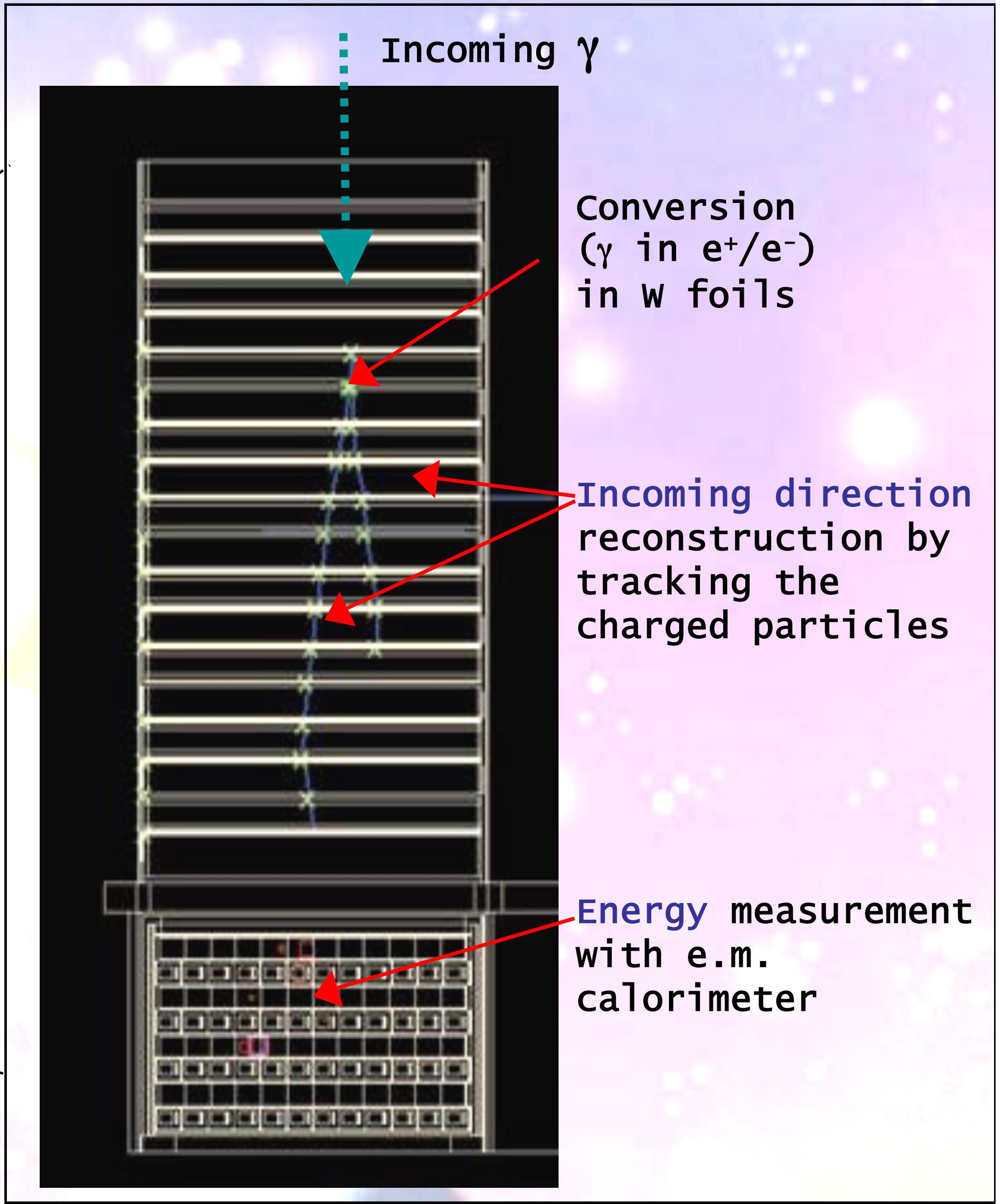
18 planes of X Y silicon detectors + converters
12 planes with 3% R.L. of W , 4 planes with 18% R.L
2 planes without converters
total 1.5 R.L.

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

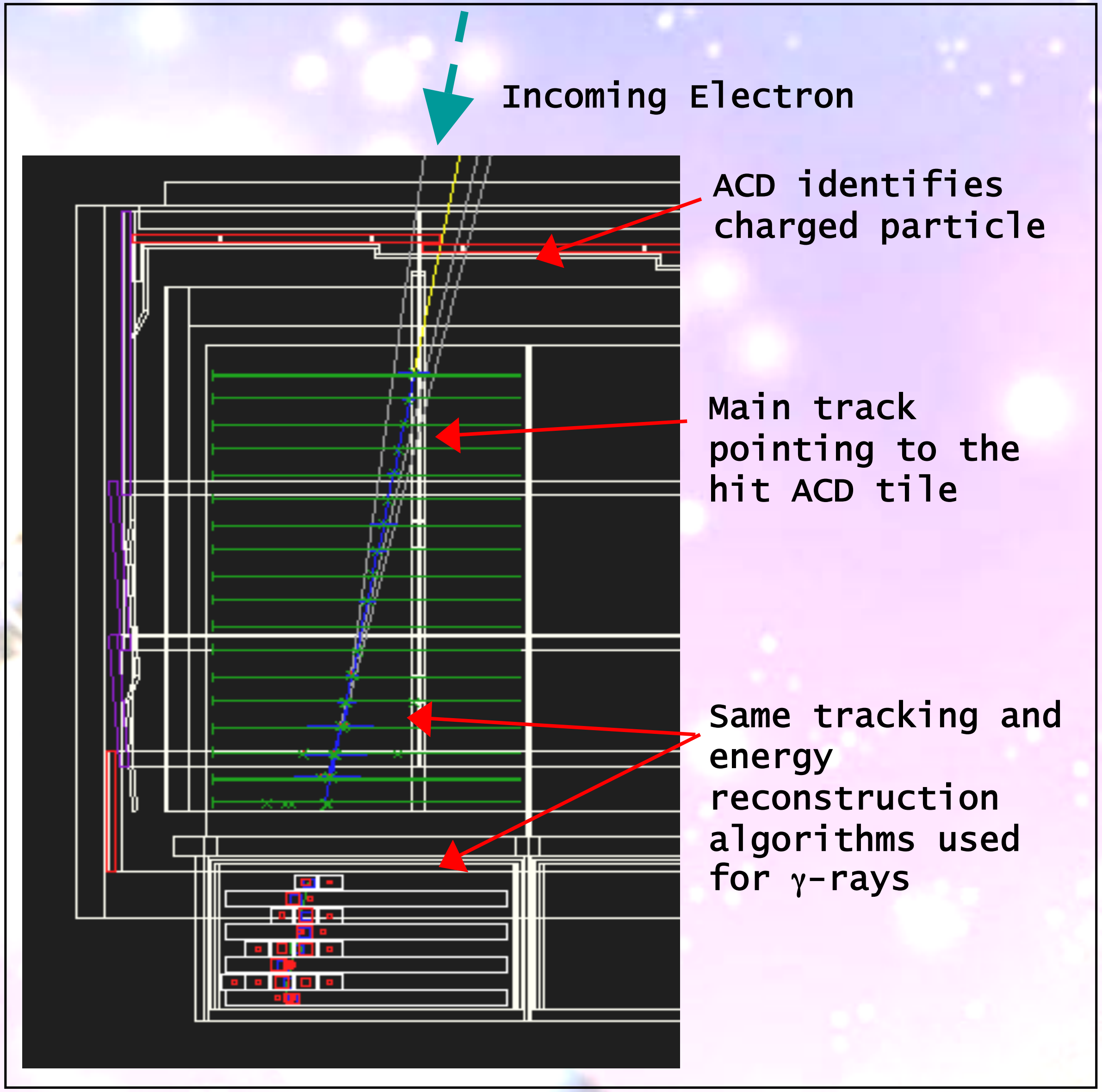
How Fermi LAT detects electrons

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

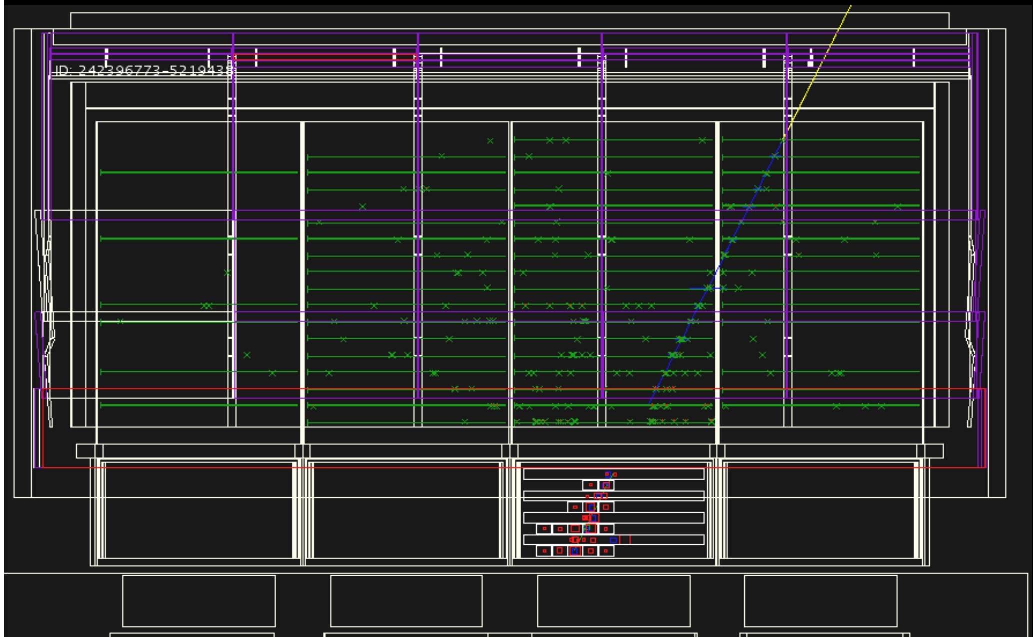
Electron identification

- 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



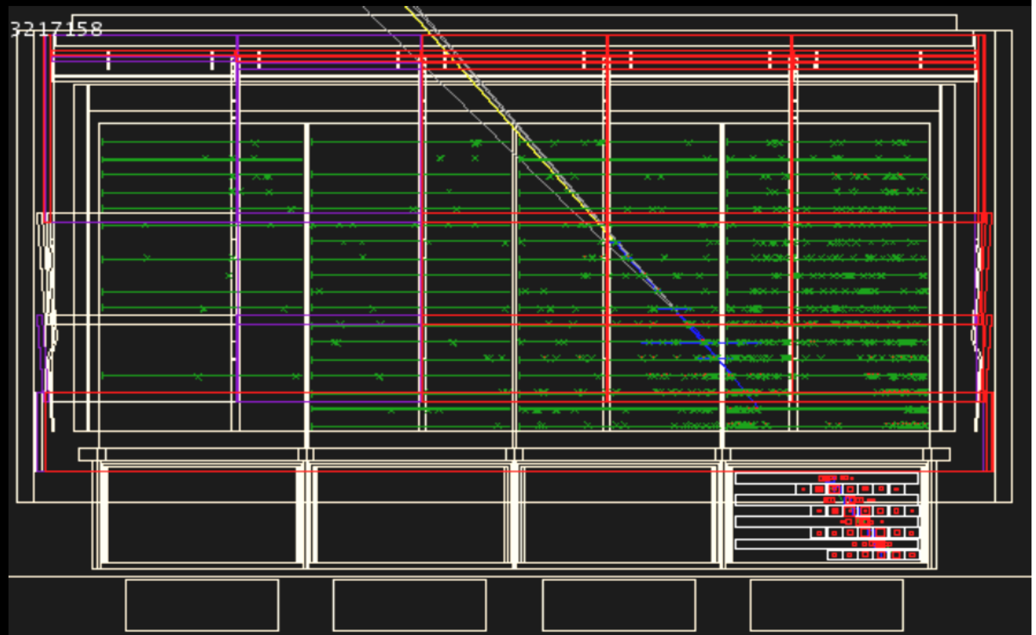
Event topology

A candidate electron
(recon energy 844 GeV)



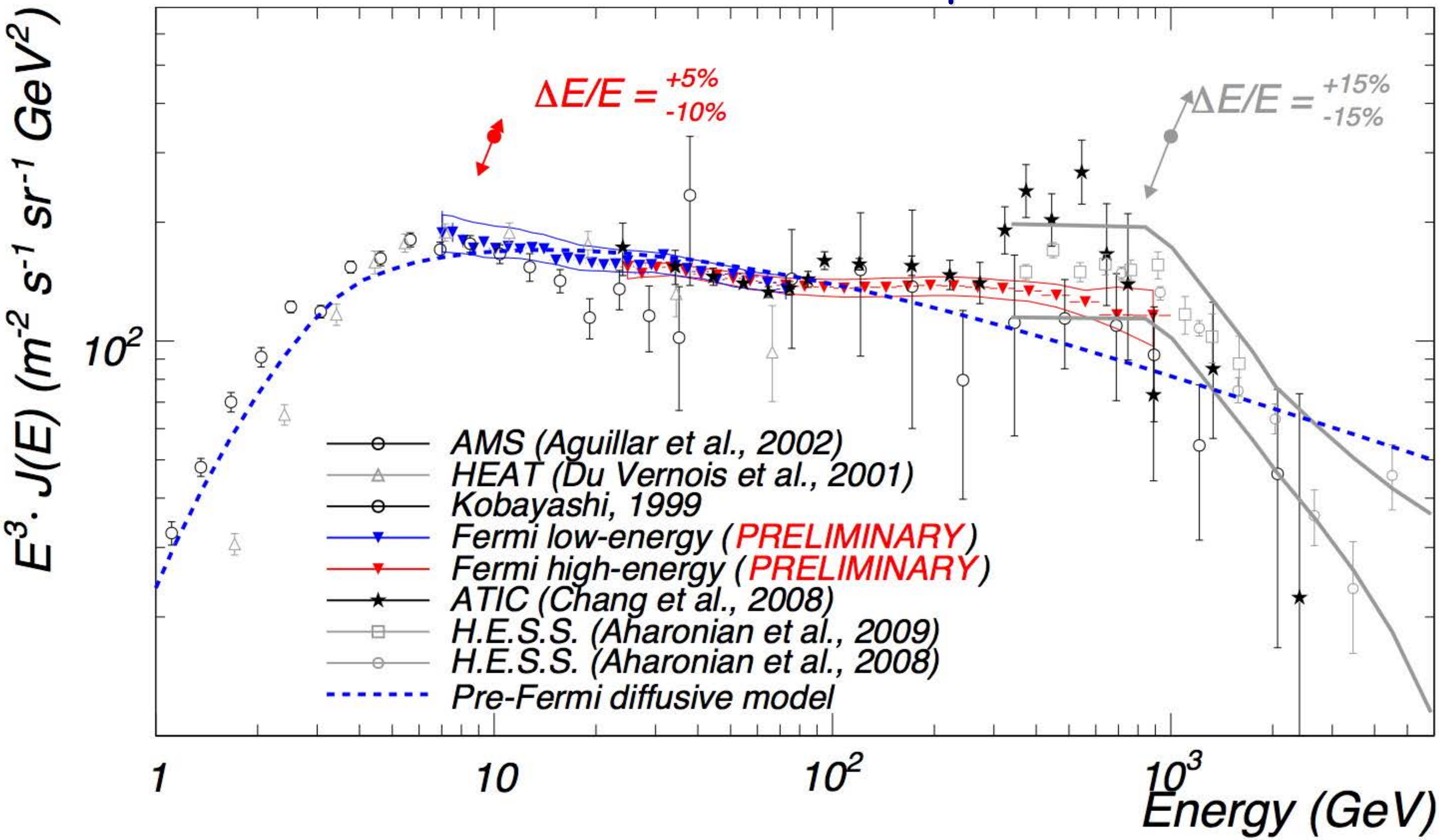
- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

A candidate hadron
(raw energy > 800 GeV)



- TKR: small number of extra clusters around main track
- CAL: large and asymmetric shower profile
- ACD: large energy deposit per tile

Fermi Electron + Positron spectrum

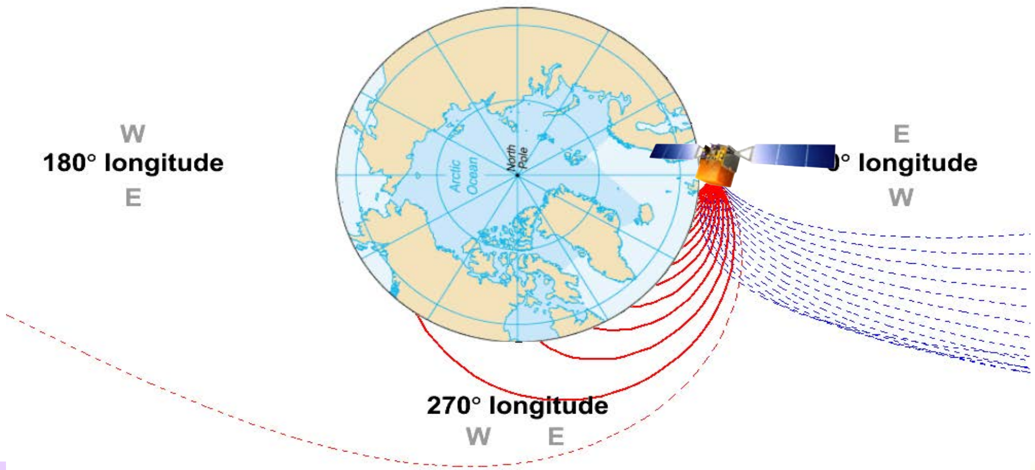


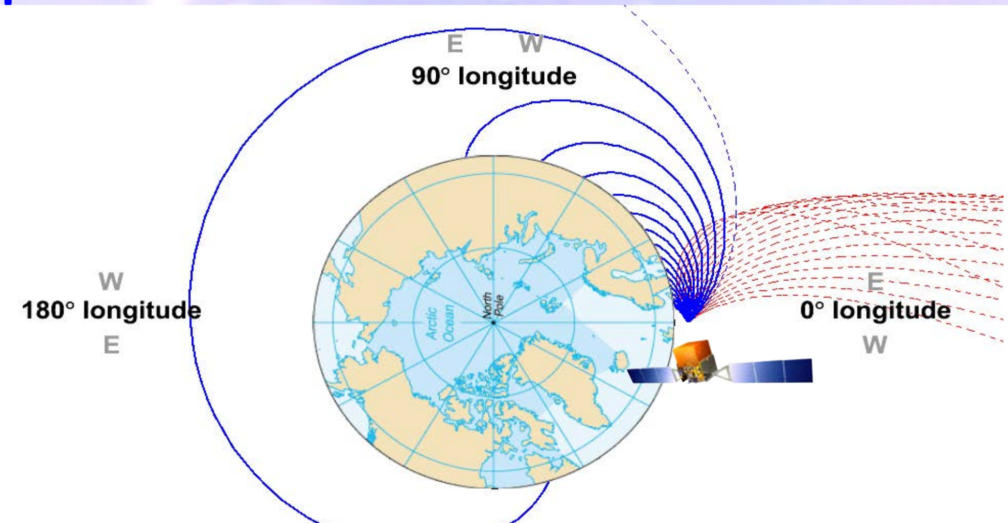
Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

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

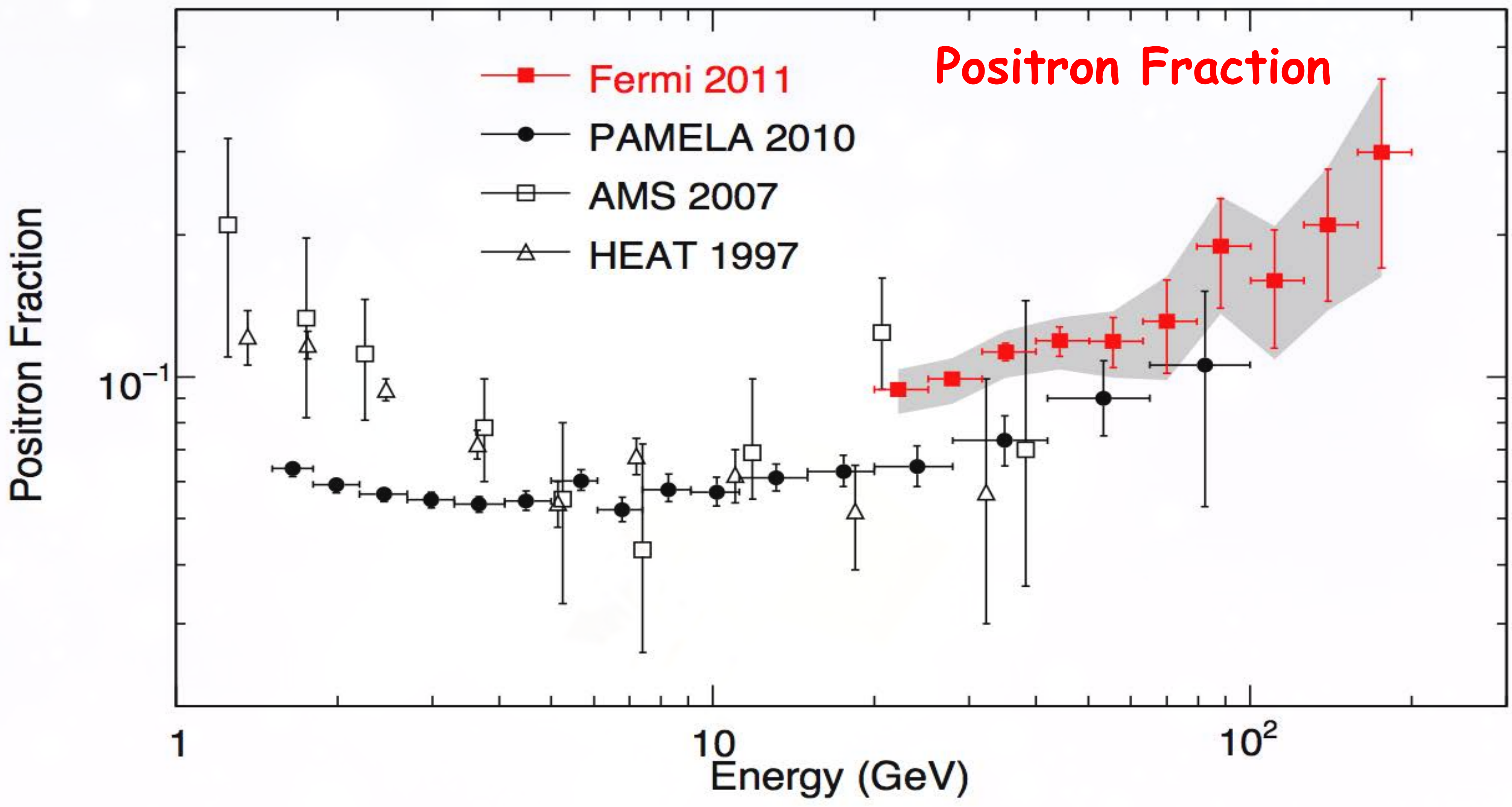
events arriving from West:
e^+ allowed, e^- blocked





events arriving from East:
e^- allowed, e^+ blocked

- 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



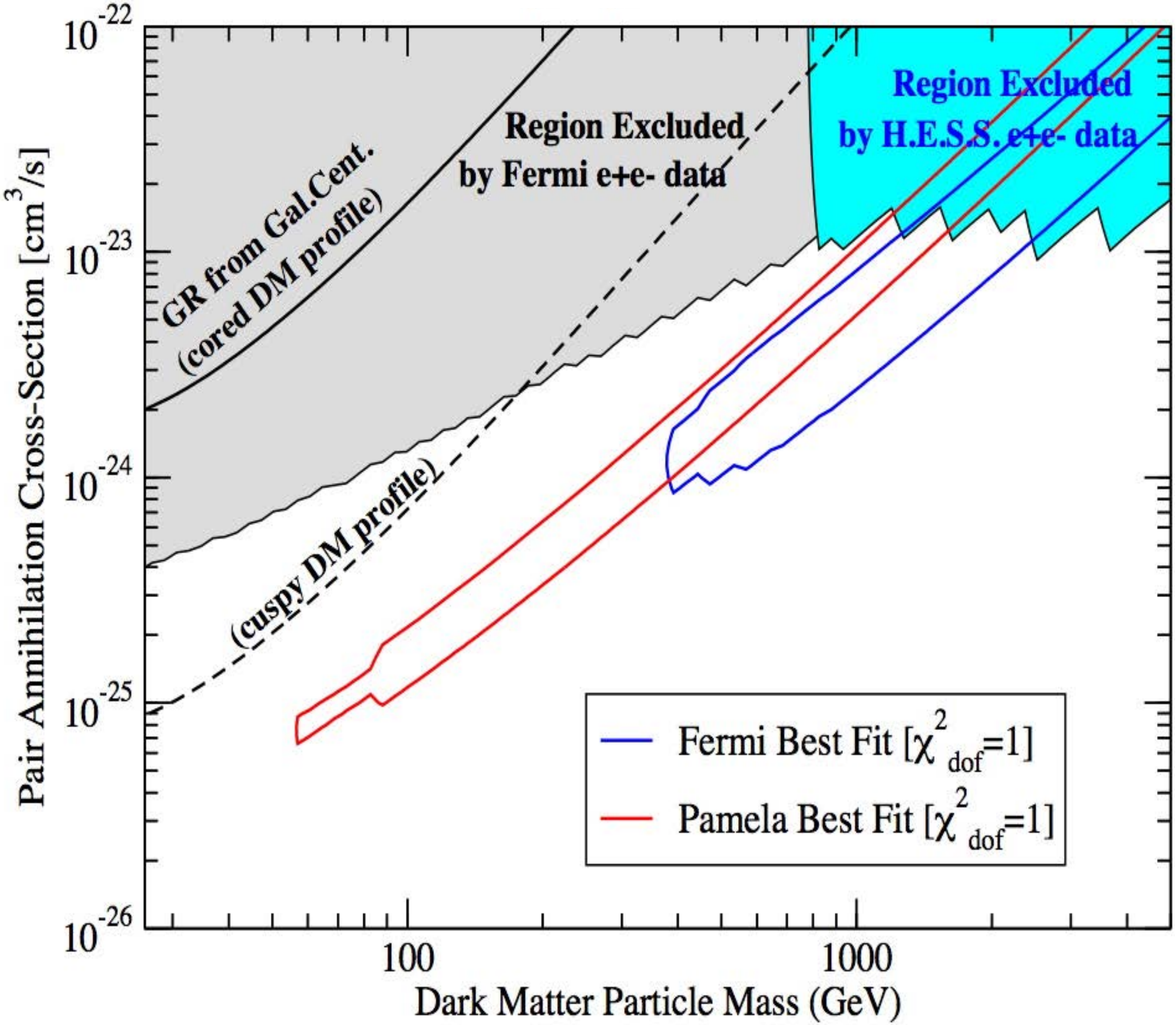
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth's magnetic field as a charge discriminator

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

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.



[arXiv:0905.0636]

Lepto-philic Models

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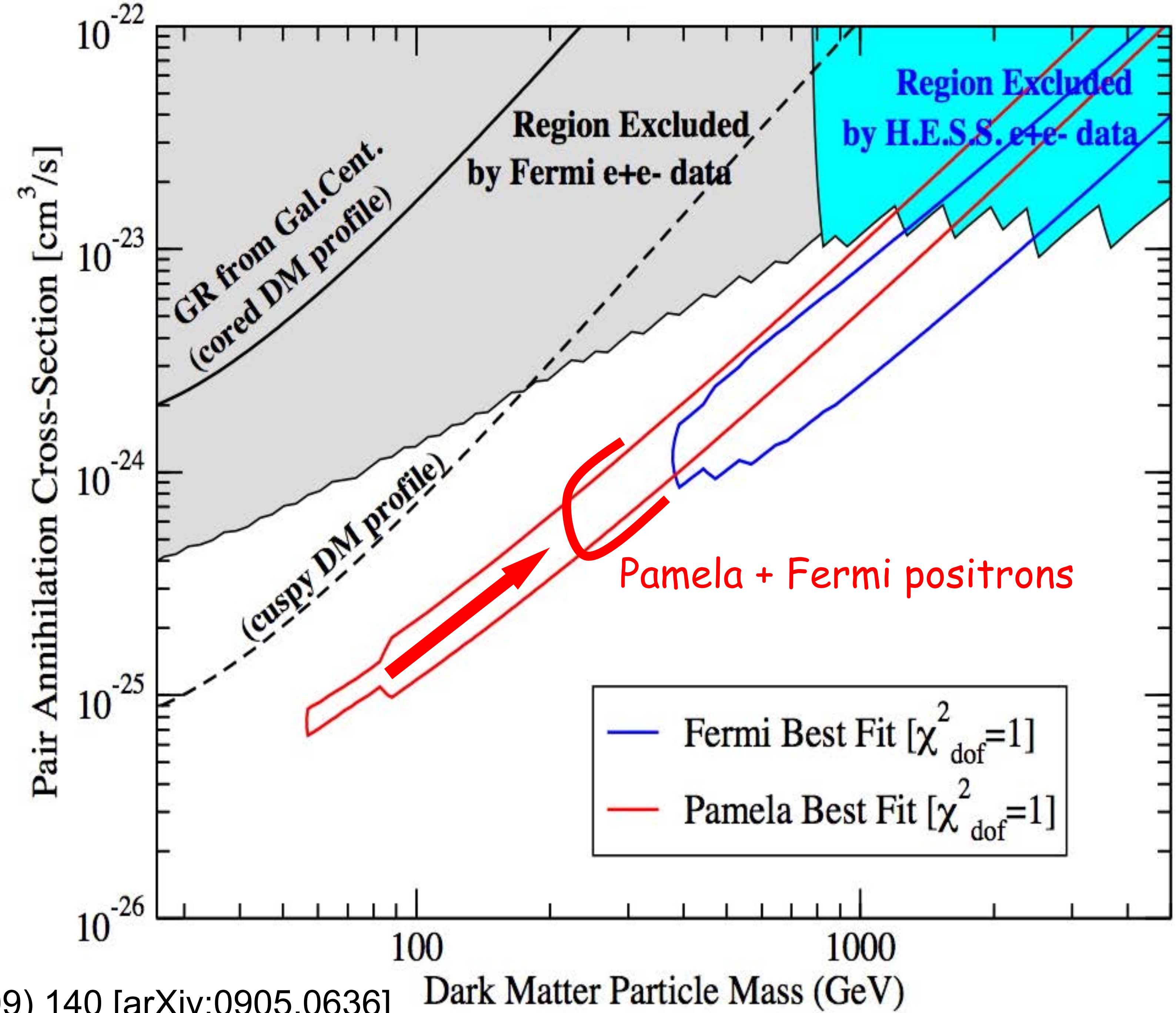


Astrp Phys.32 (2009) 140 [arXiv:0905.0636]

Search Strategies

Satellites:

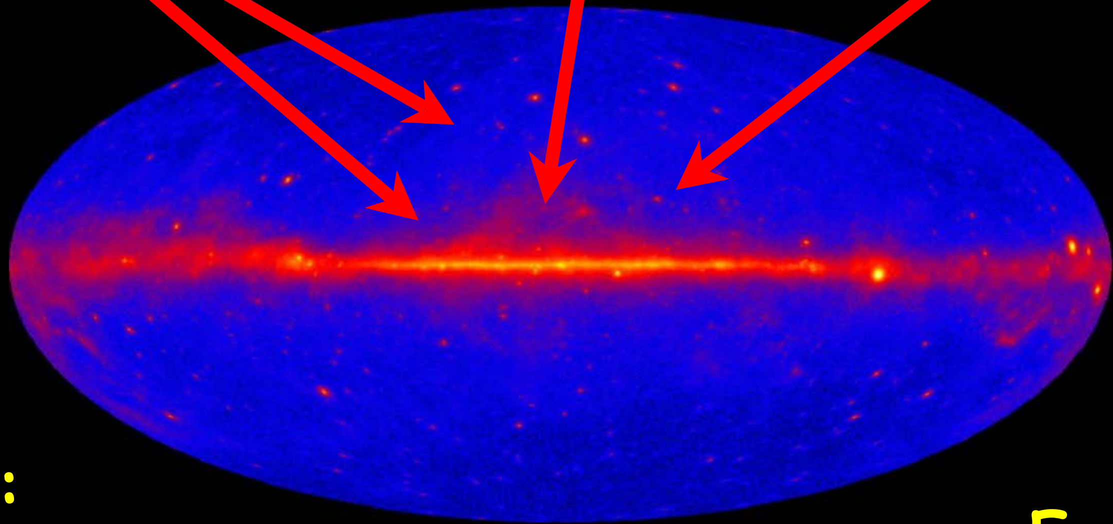
Low background and good source id, but low statistics

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

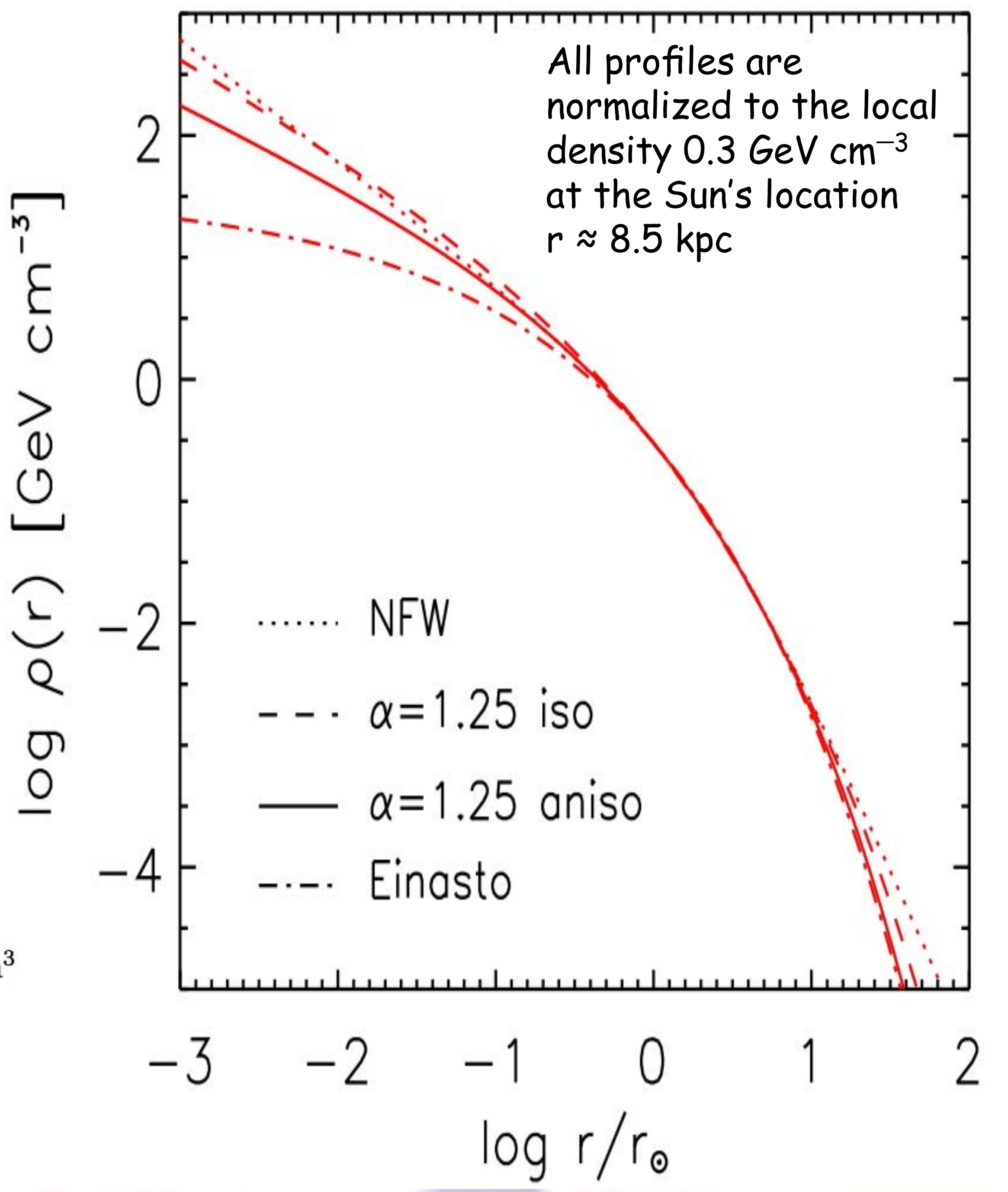
Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

Milky Way Dark Matter Profiles

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

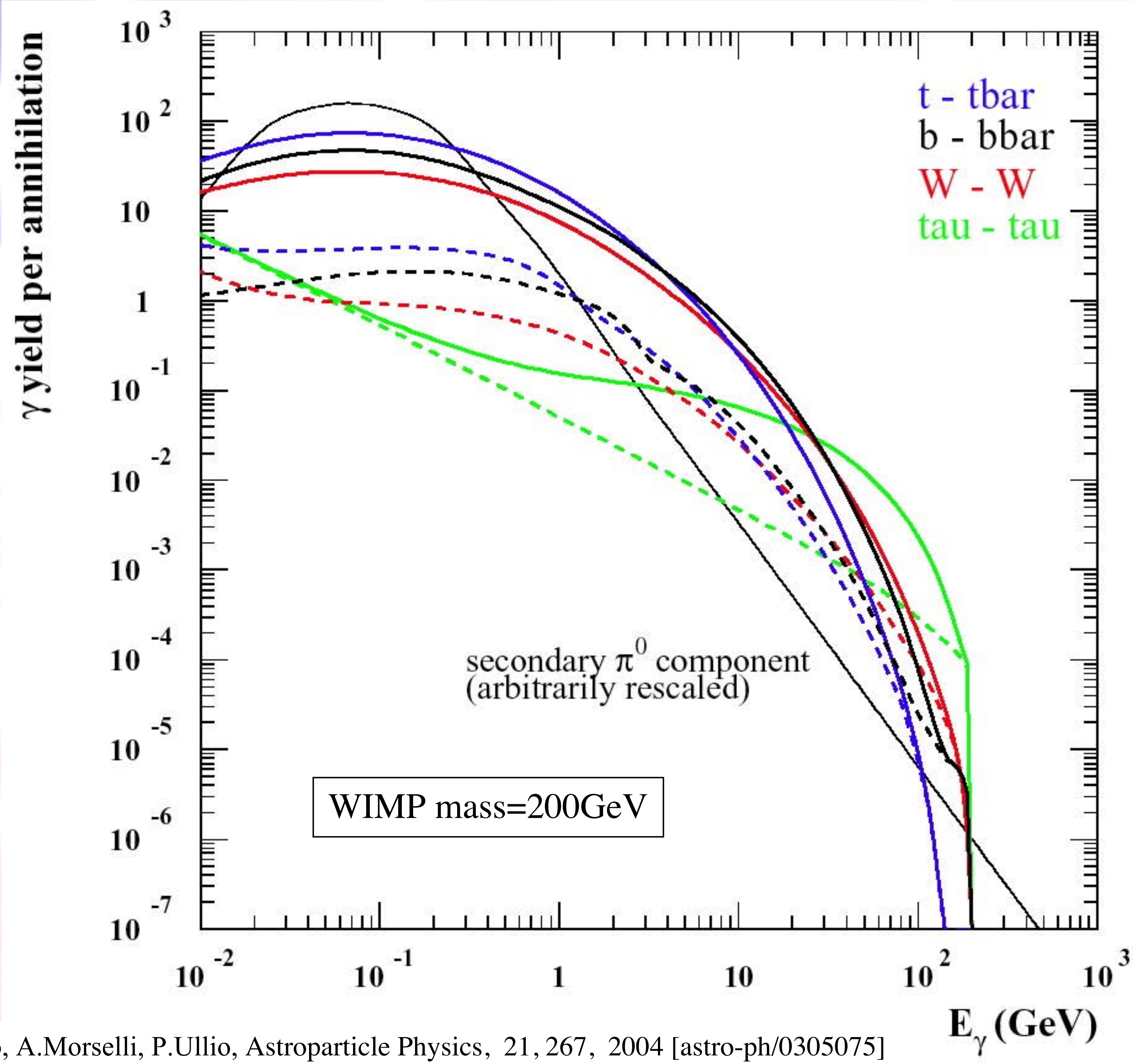
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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



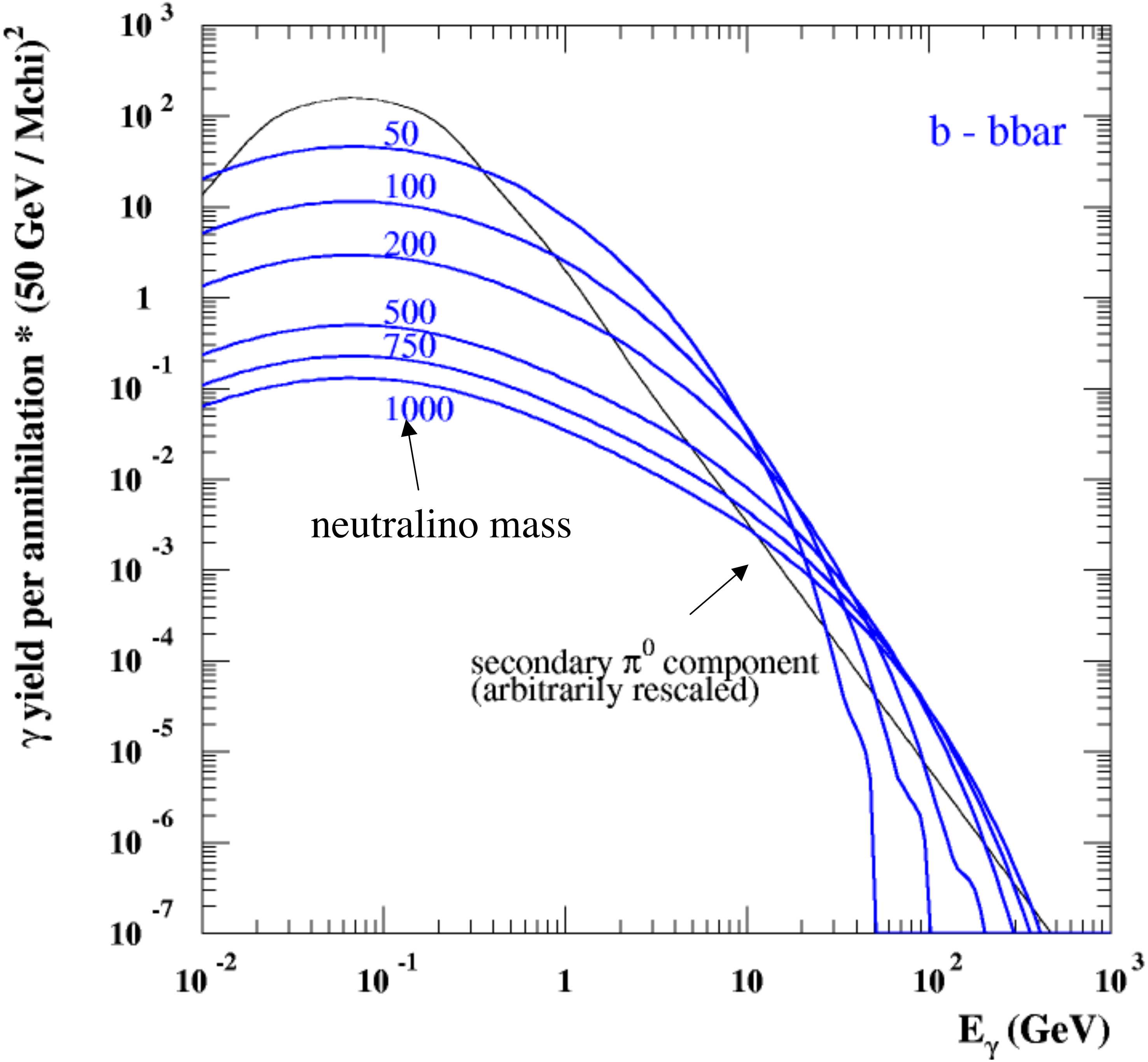
A.Lapi et al. arXiv:0912.1766

Differential yield for each annihilation channel



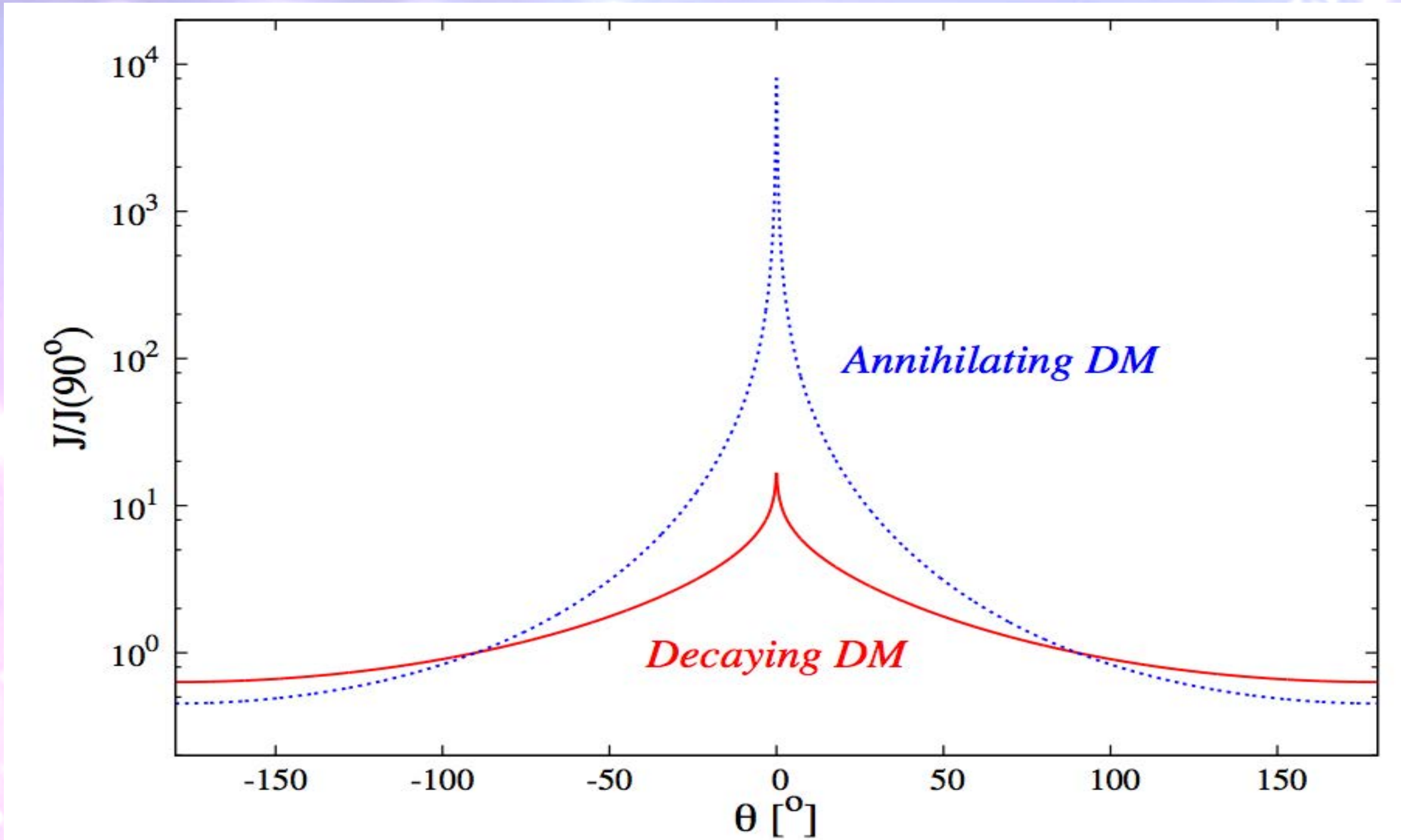
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

Differential yield for b bar



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

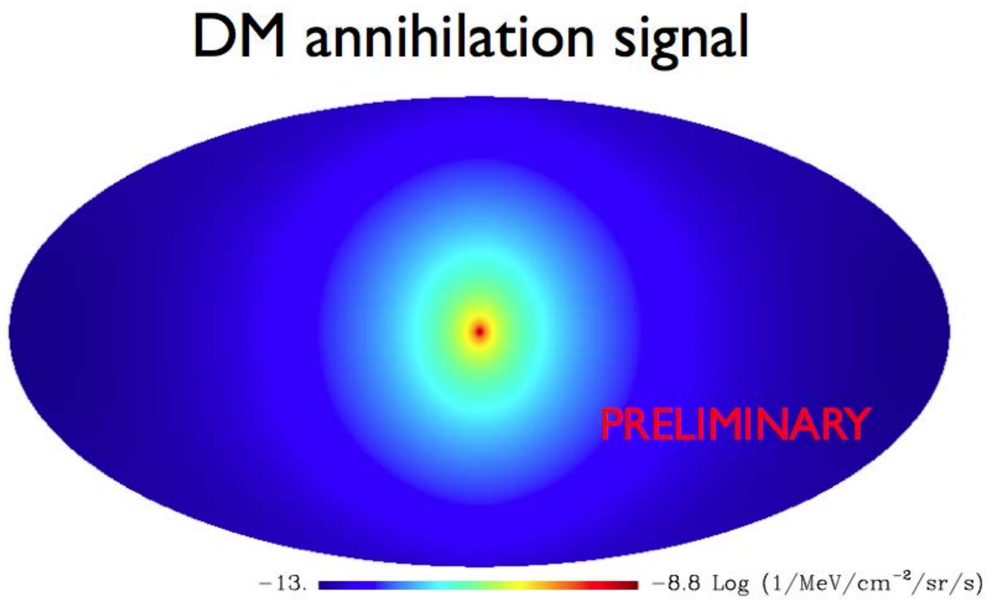
Different spatial behaviour for decaying or annihilating dark matter

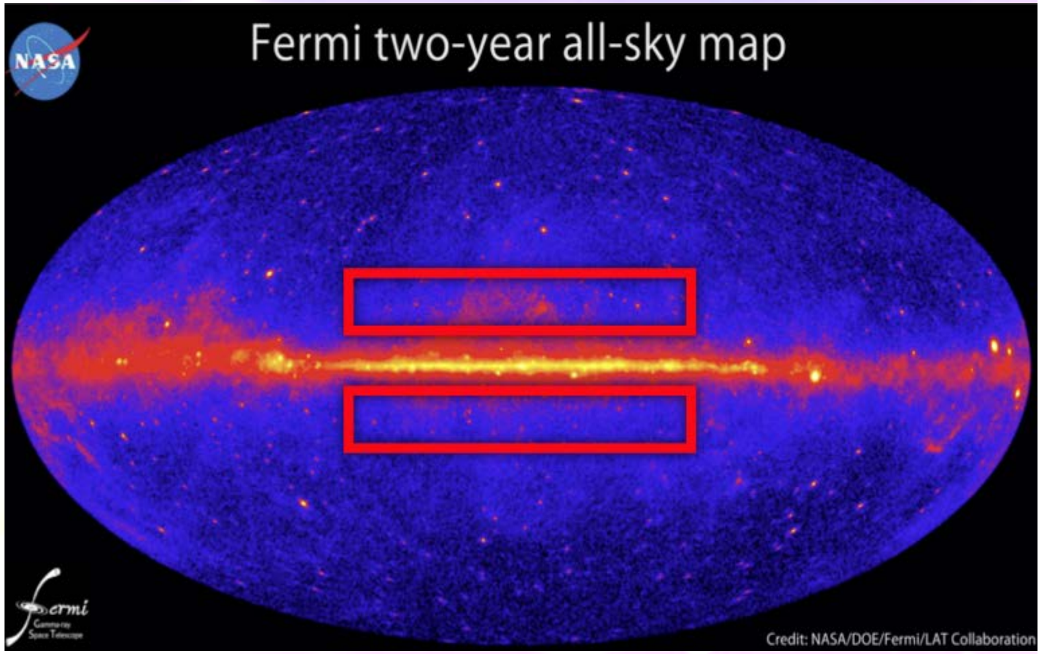


The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

Constraints from the Milky Way halo

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



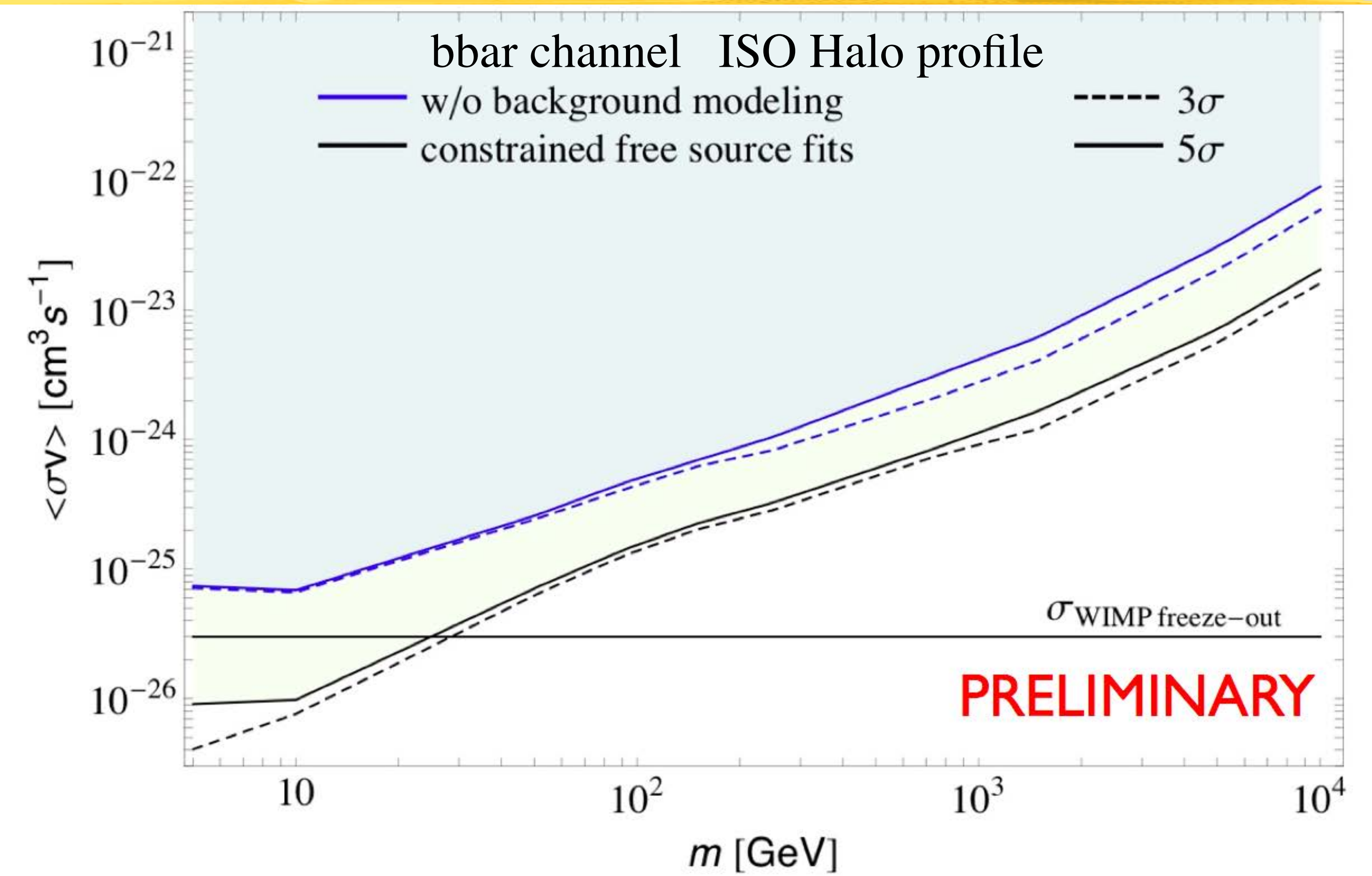


2 years of data   1-100 GeV energy range

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



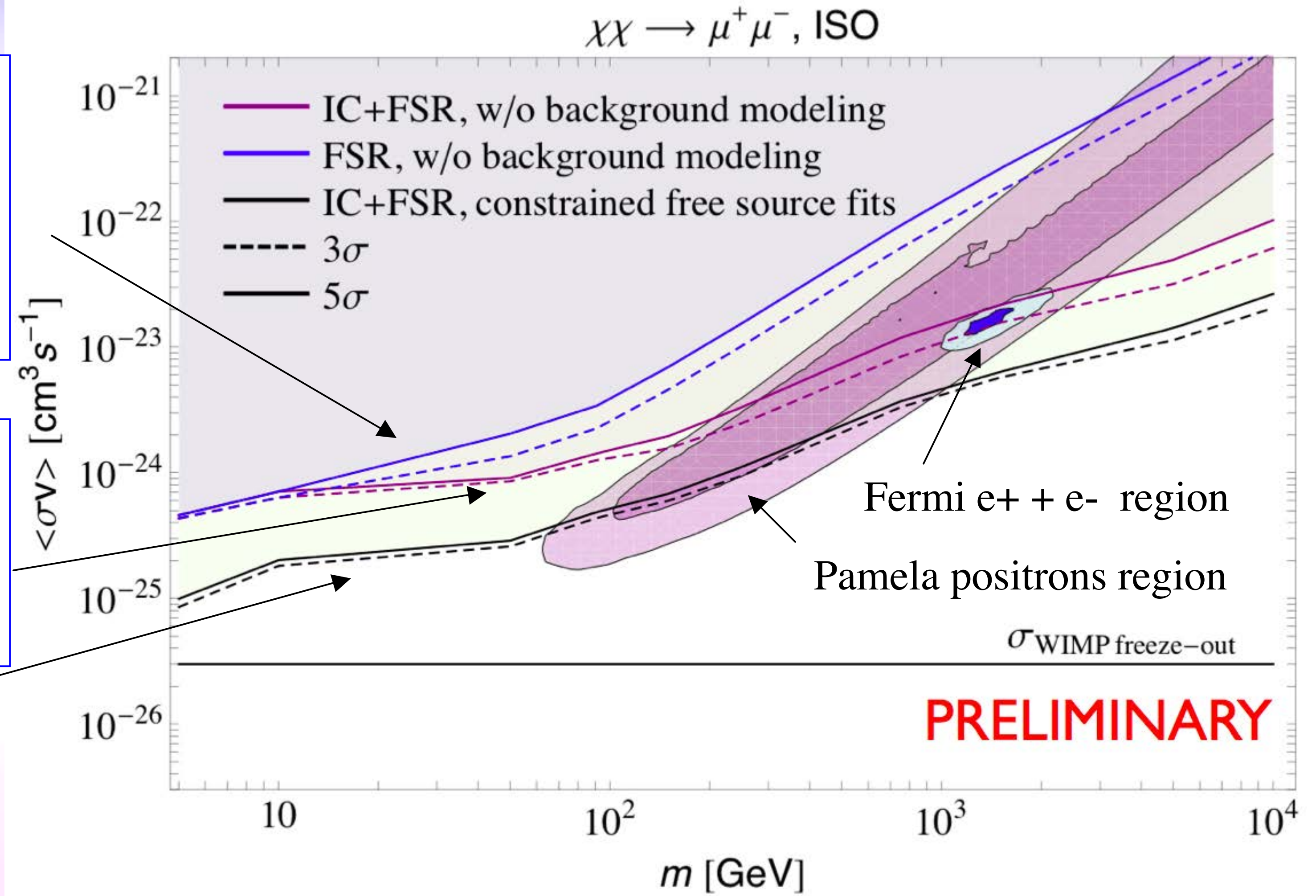
- Blue = “no-background limits”
- Black = limits obtained by marginalization over the CR source distribution, diffusive halo height and electron injection index, gas to dust ratio, and in which CR sources are held to zero in the inner 3 kpc
- Limits with NFW density profile (not shown) are only slightly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

Constraints from the Milky Way halo

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

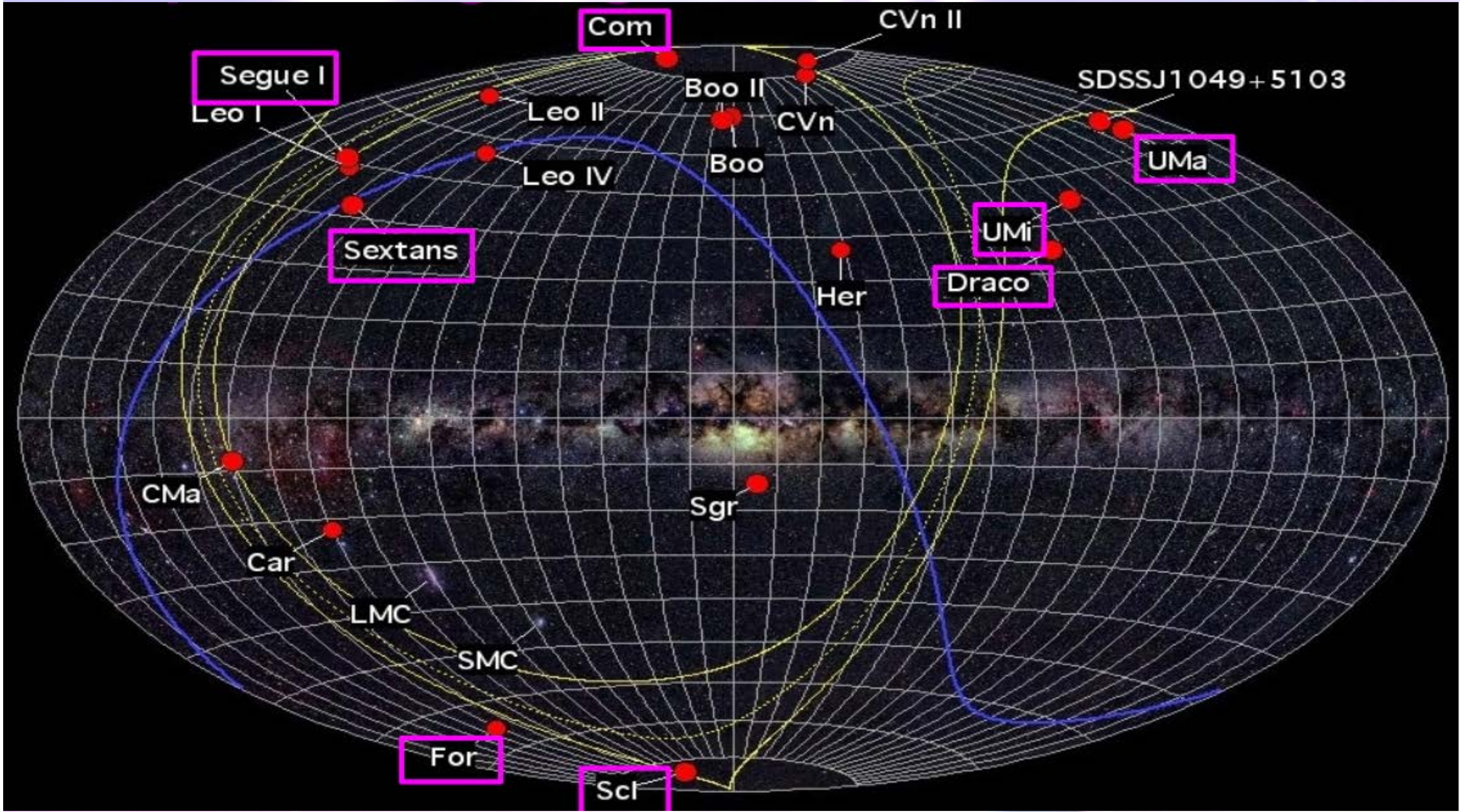
"no-background limits" including FSR+IC from dark matter

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



DM interpretation of PAMELA/Fermi CR anomalies disfavored

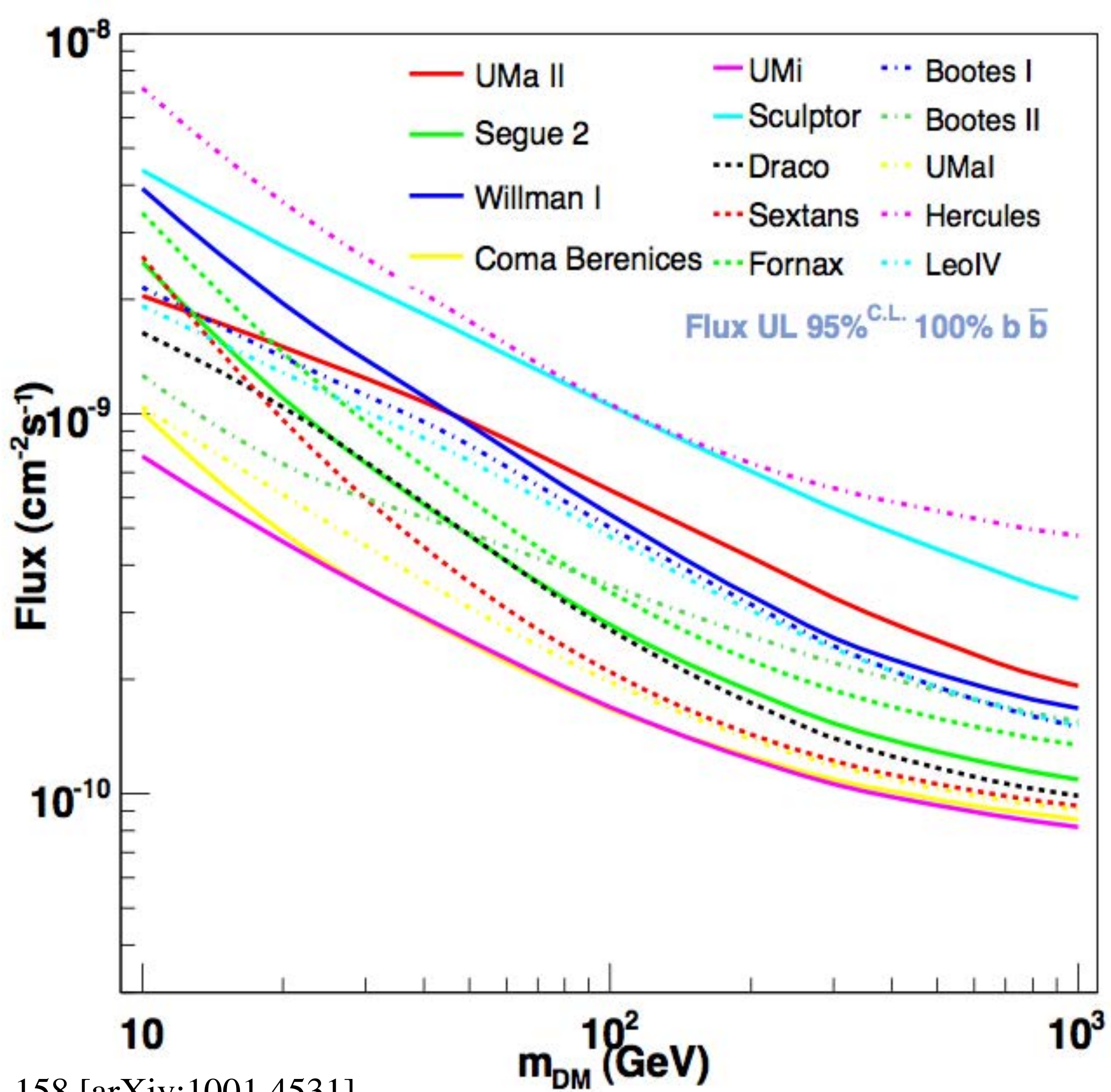
Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



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.

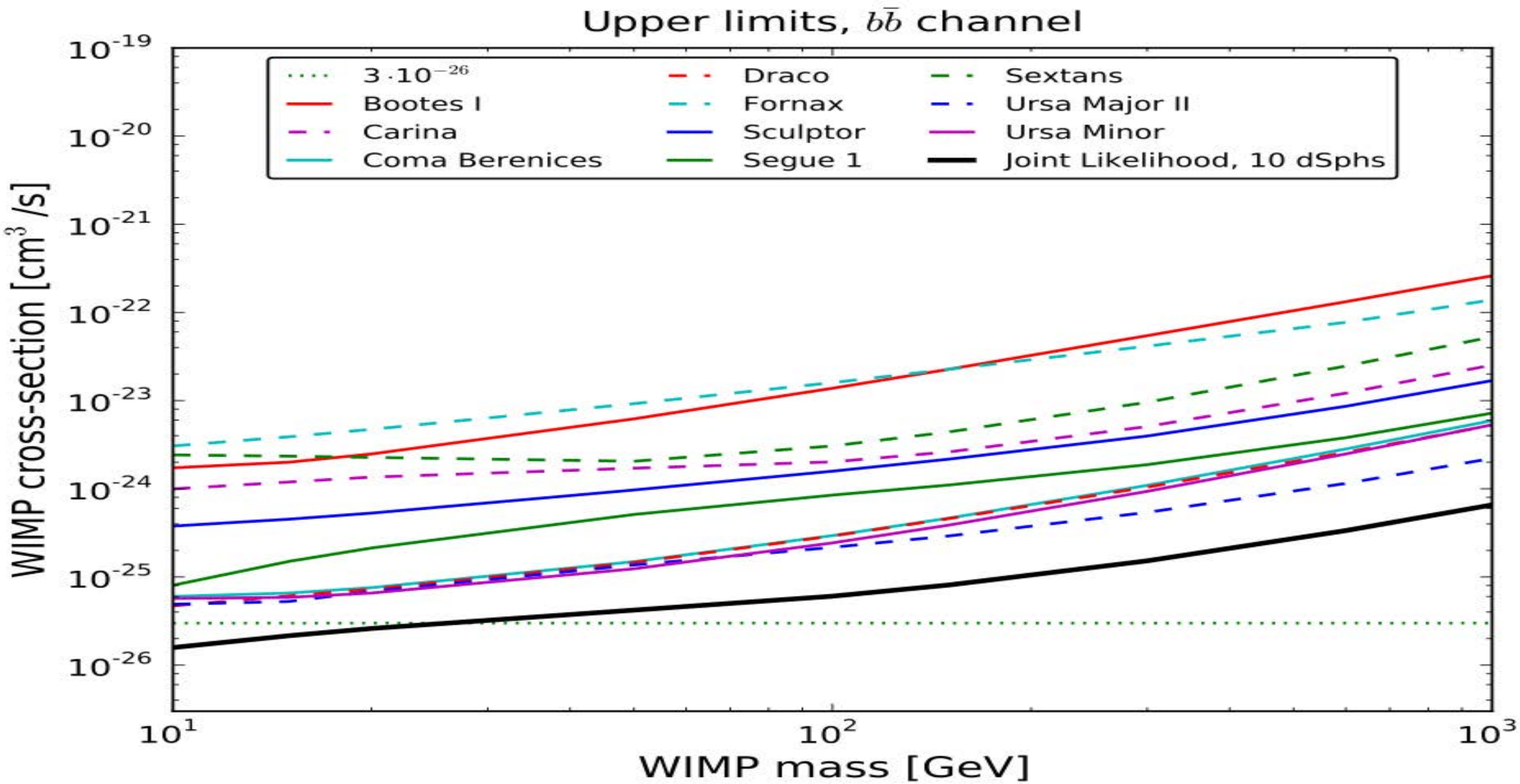
- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) on quality of stellar data) to extract constraints on < σv> vs WIMP mass for specific DM models



(*) 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

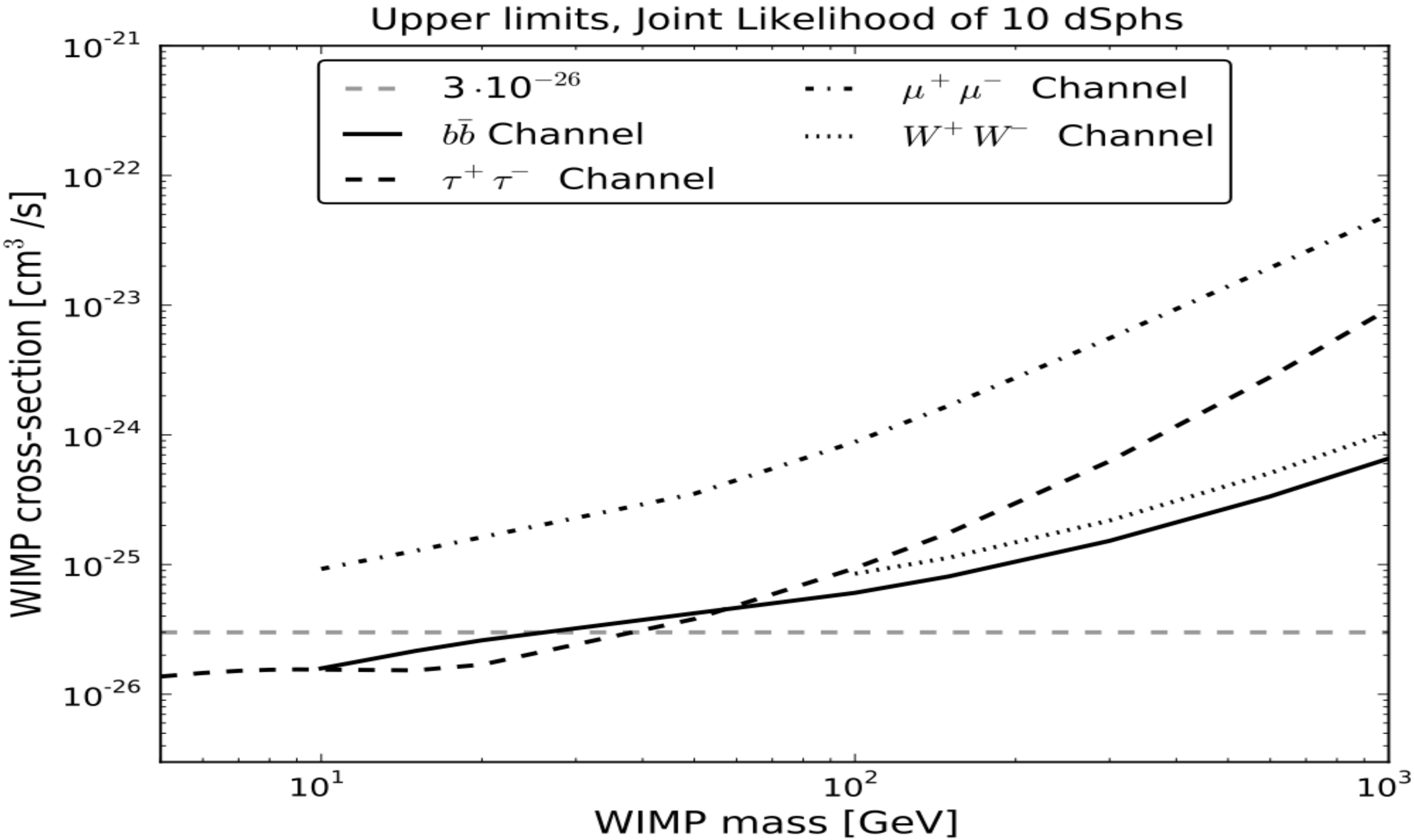


robust constraints including J-factor uncertainties

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 upper-limits Update

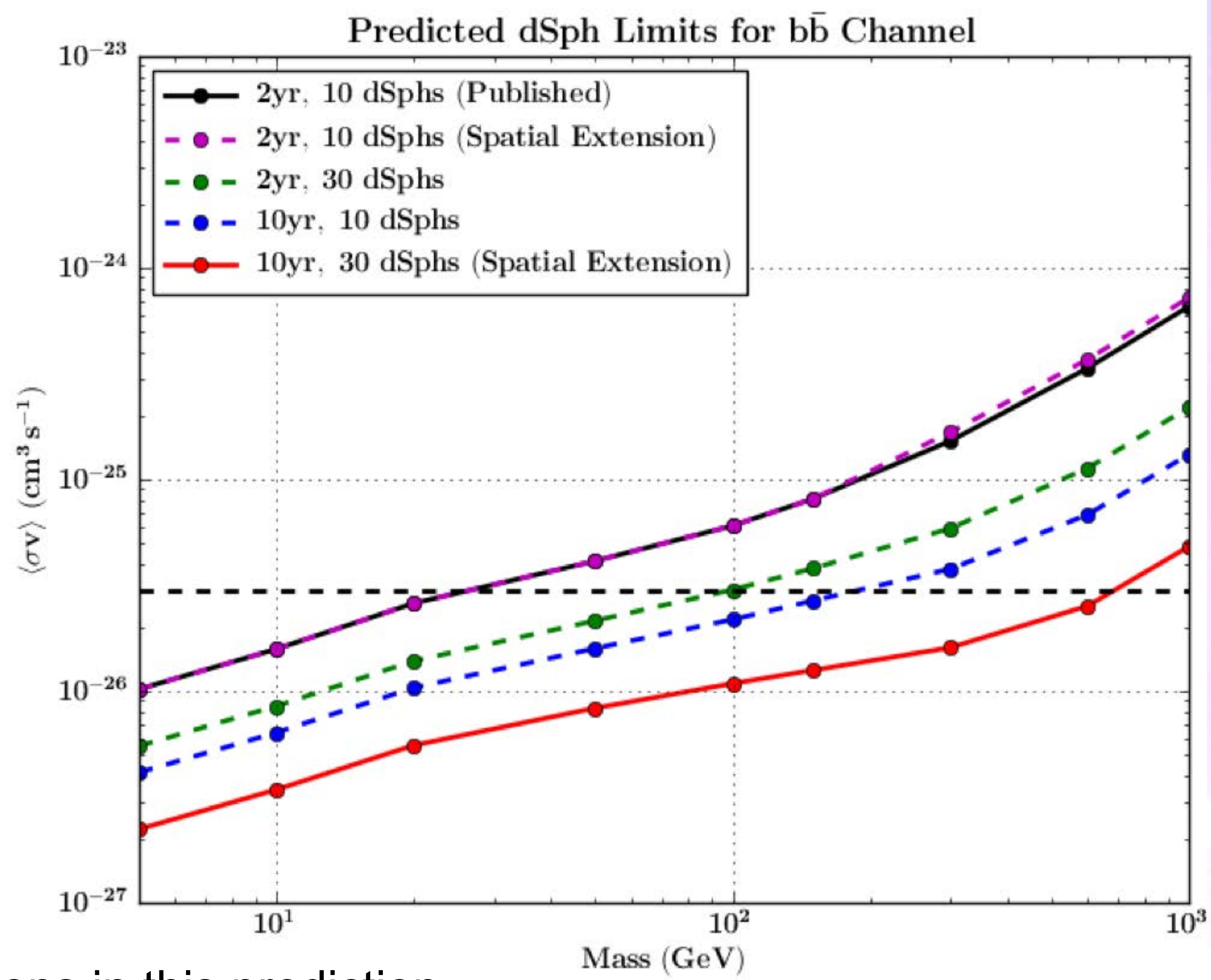


robust constraints including J-factor uncertainties

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

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

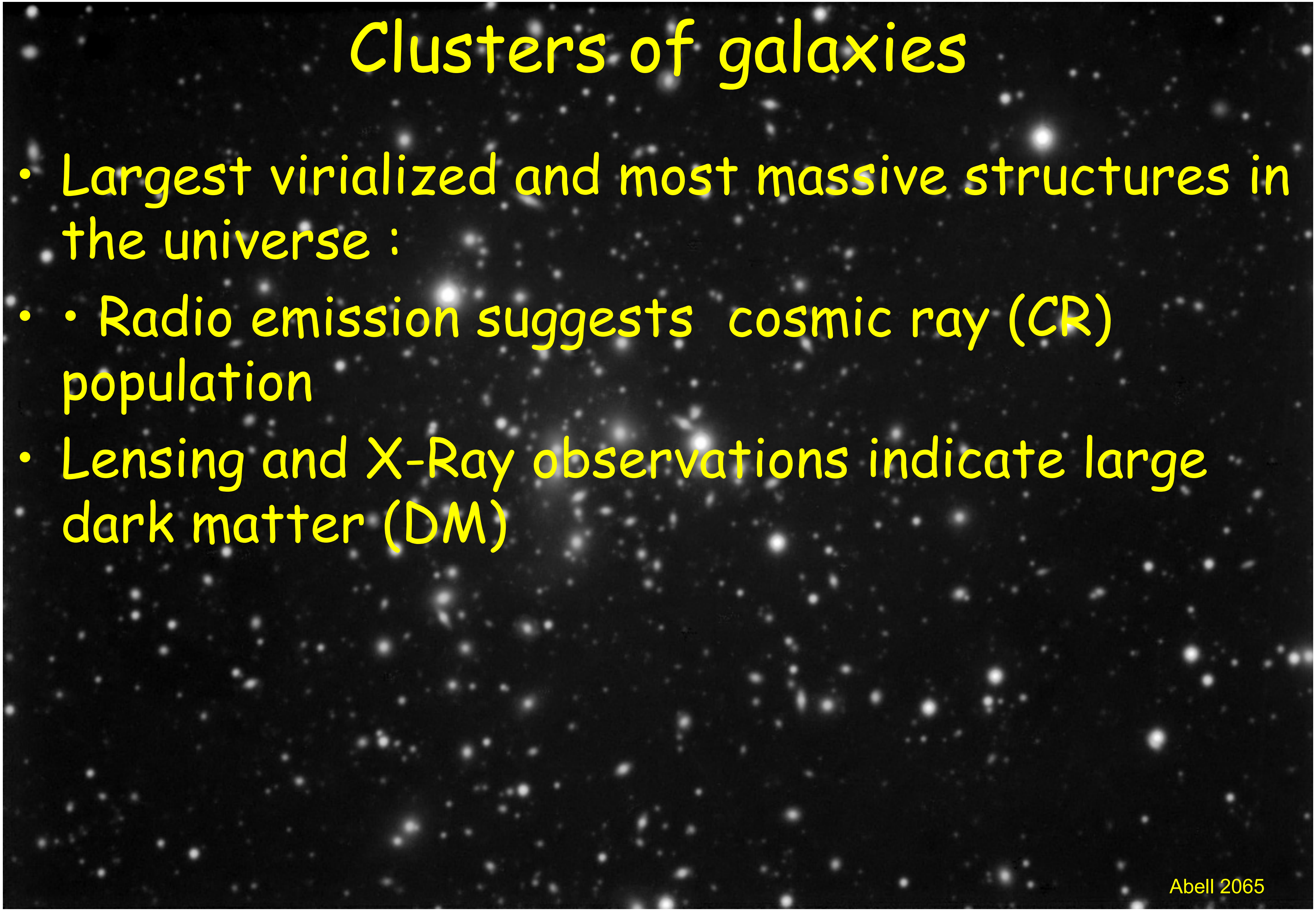
- 10 years of data instead of 2(5x)
- 30 dSphs (3x) (supposing that the new optical surveys will find new dSph)
- -10% from spatial extension (source extension increases the signal region at high energy E > 10 GeV, M > 200 GeV)



- 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)

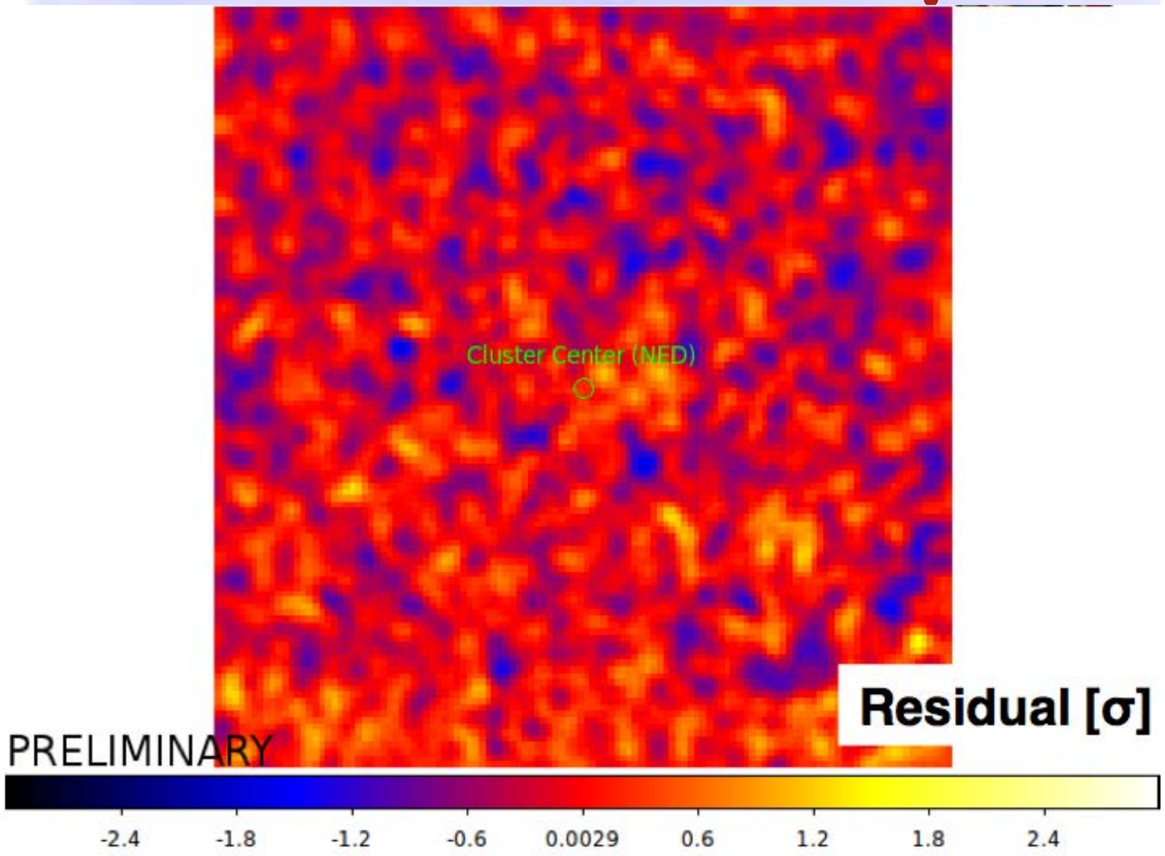


6 Clusters Stacked Residual Map

- 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!**

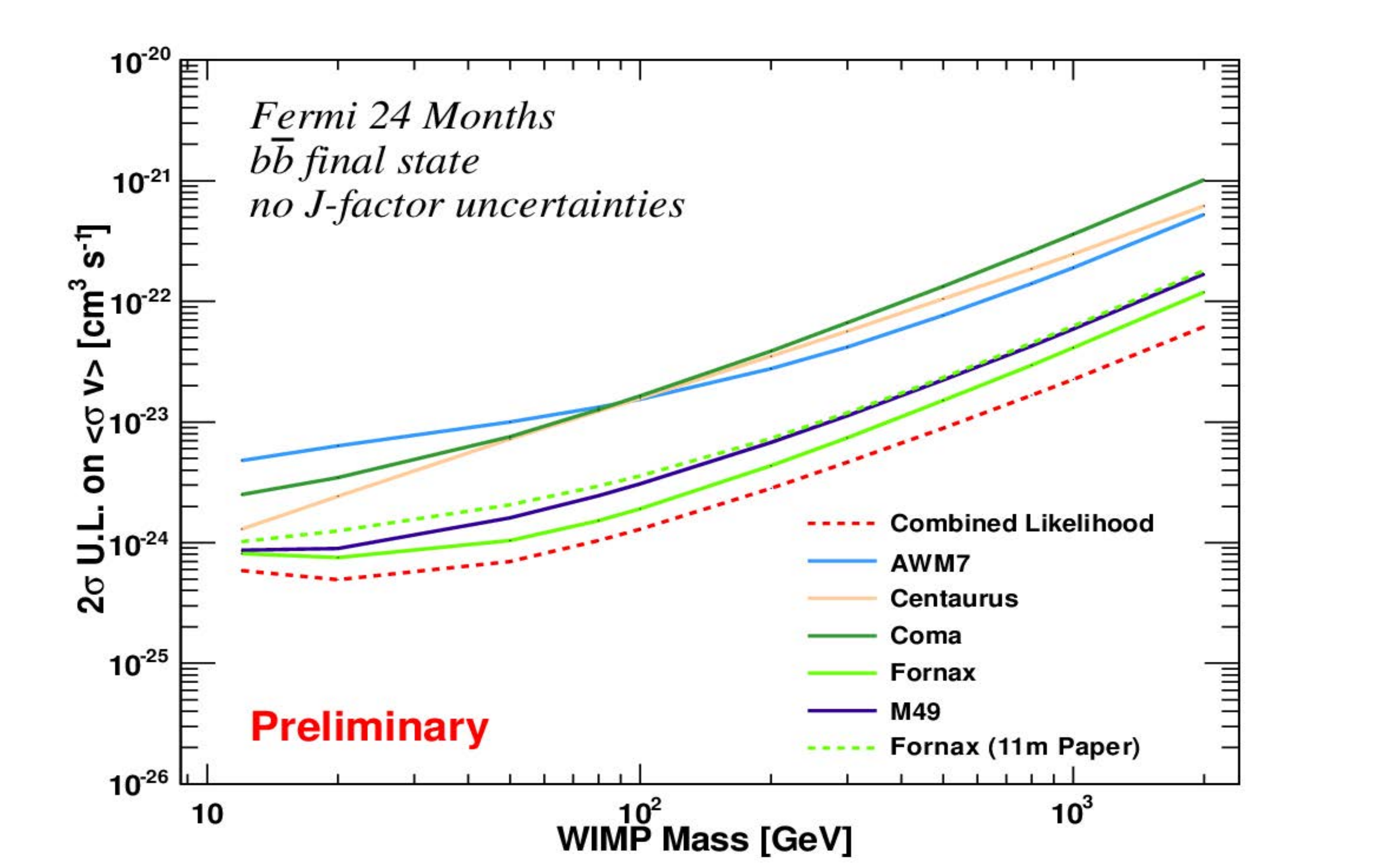


And from outside the collaboration: • Using 3y P7V6 data and 8 clusters (together and singularly) authors ofJCAP01(2012)042 don't find signal above 3σ.

• 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

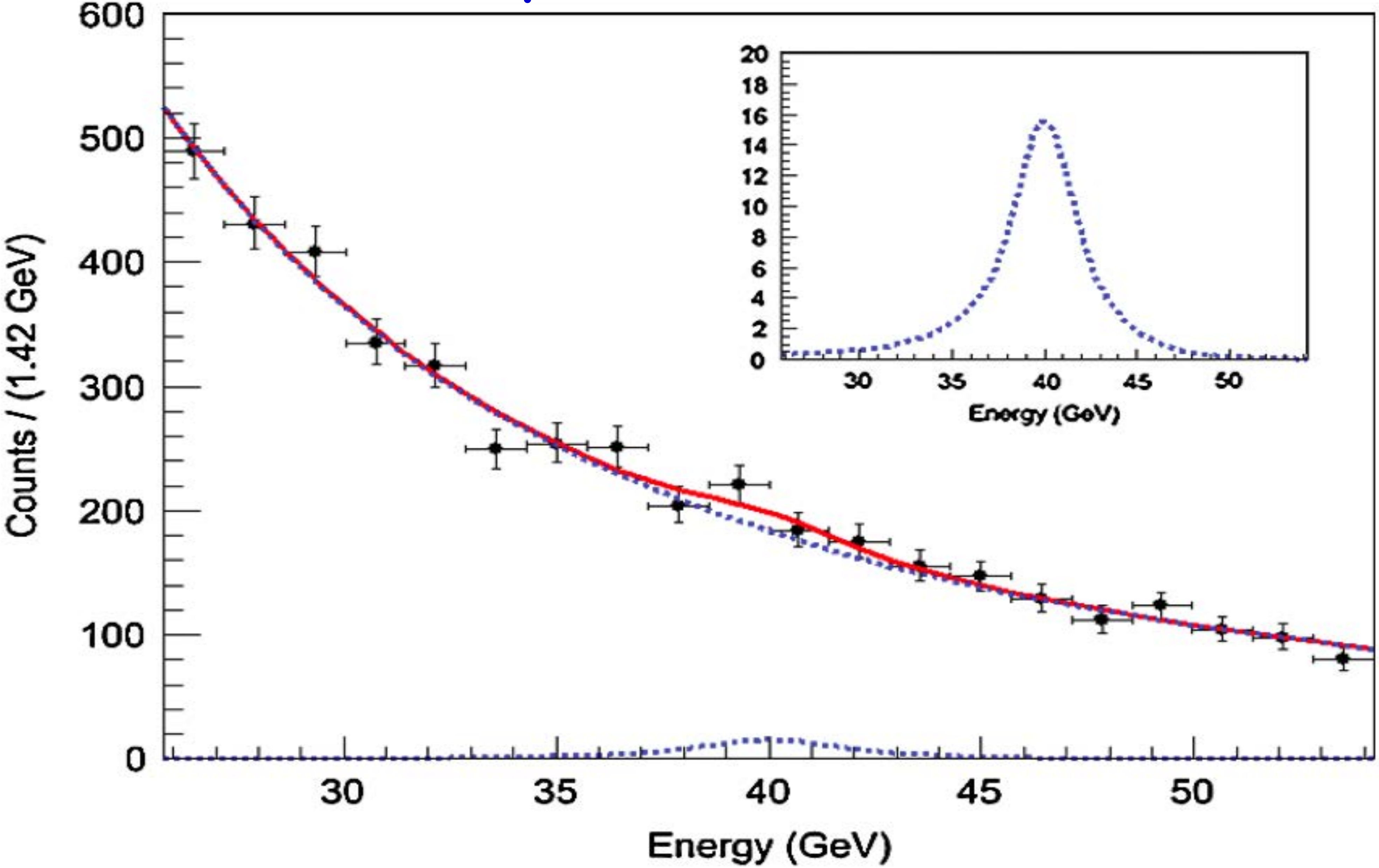
Fermi LAT Clusters Combined Upper Limits on <σv>

(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

Wimp lines search

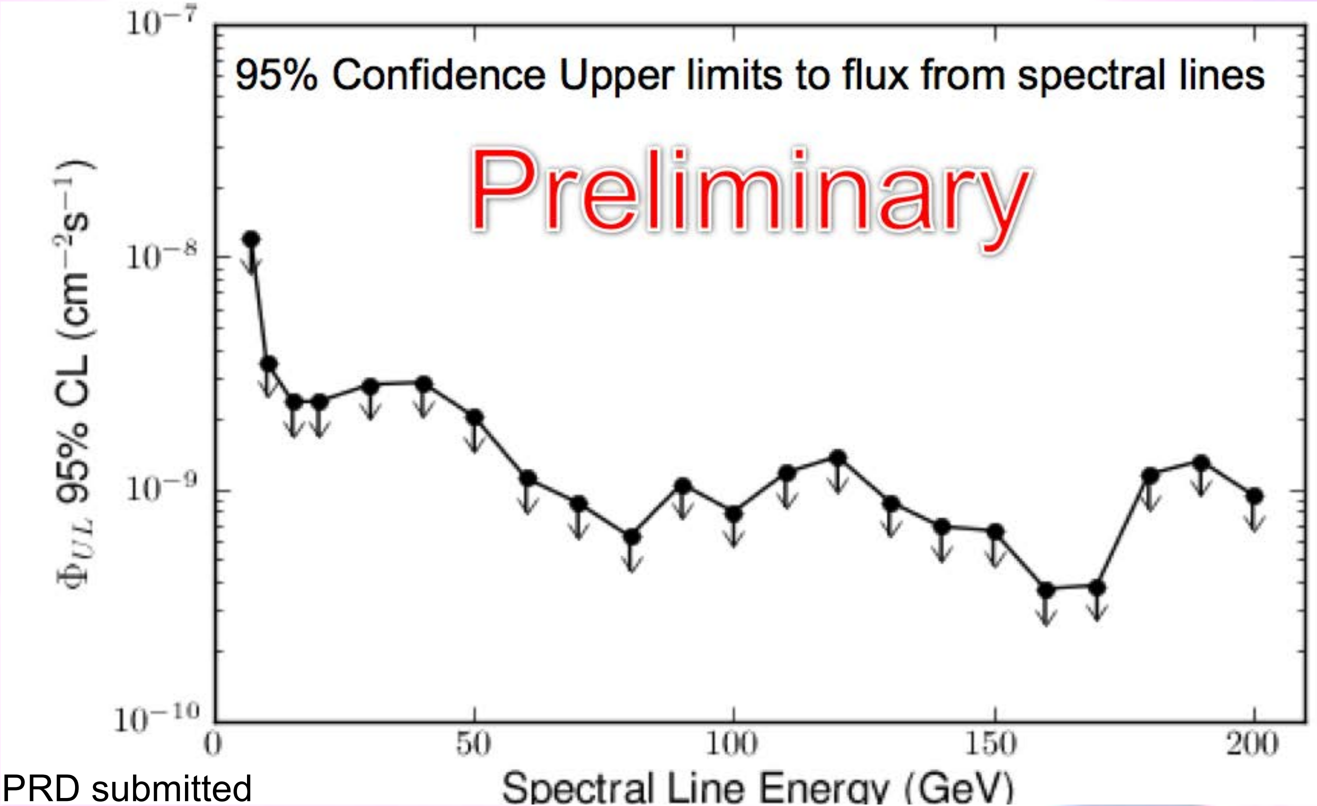


Fermi LAT 23 Month Line search results Flux Upper Limits, 7 GeV – 200 GeV

- ± 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.

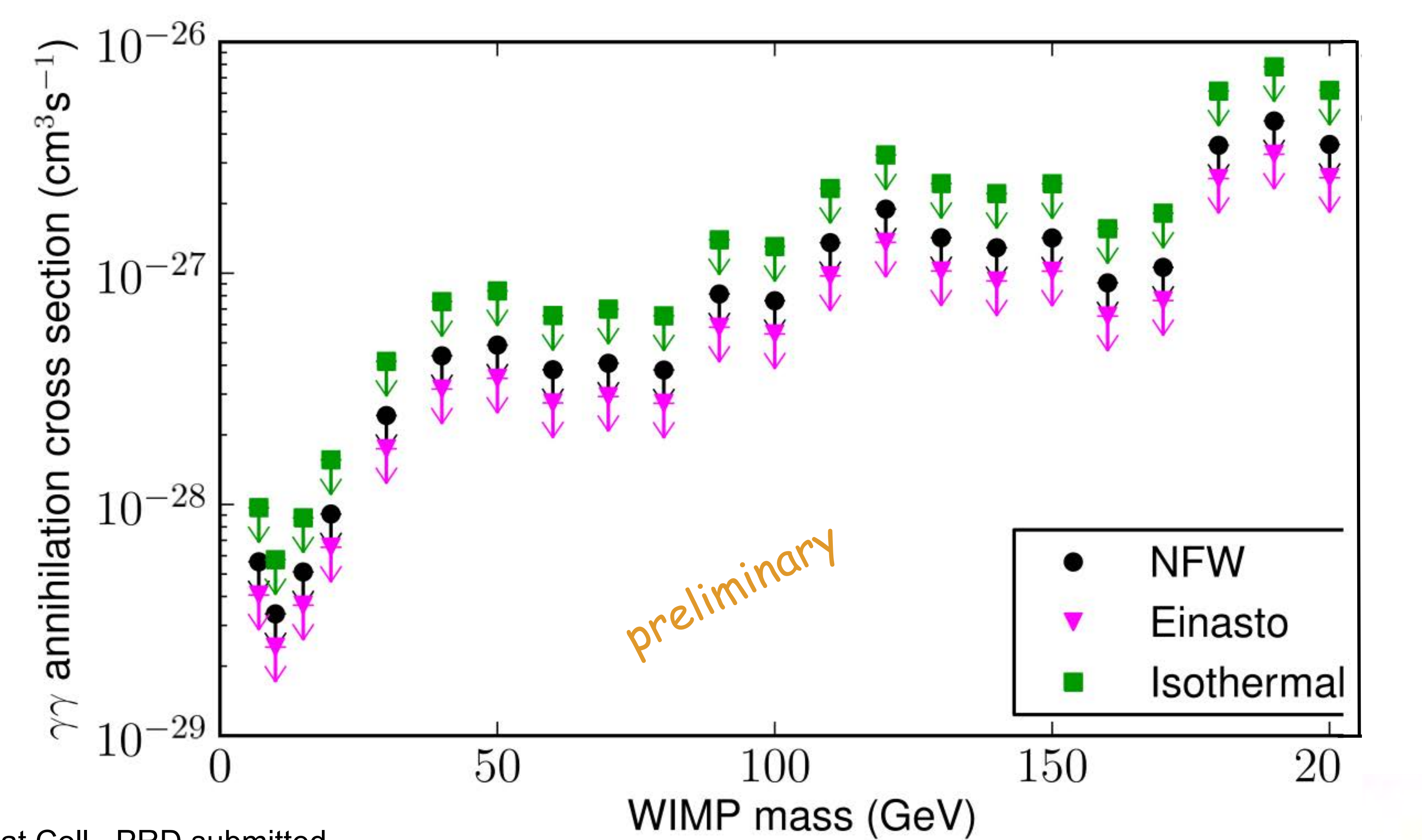


Fermi Lat Coll., PRD submitted

Fermi LAT 23 Month $\gamma\gamma$-Cross-section 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%.

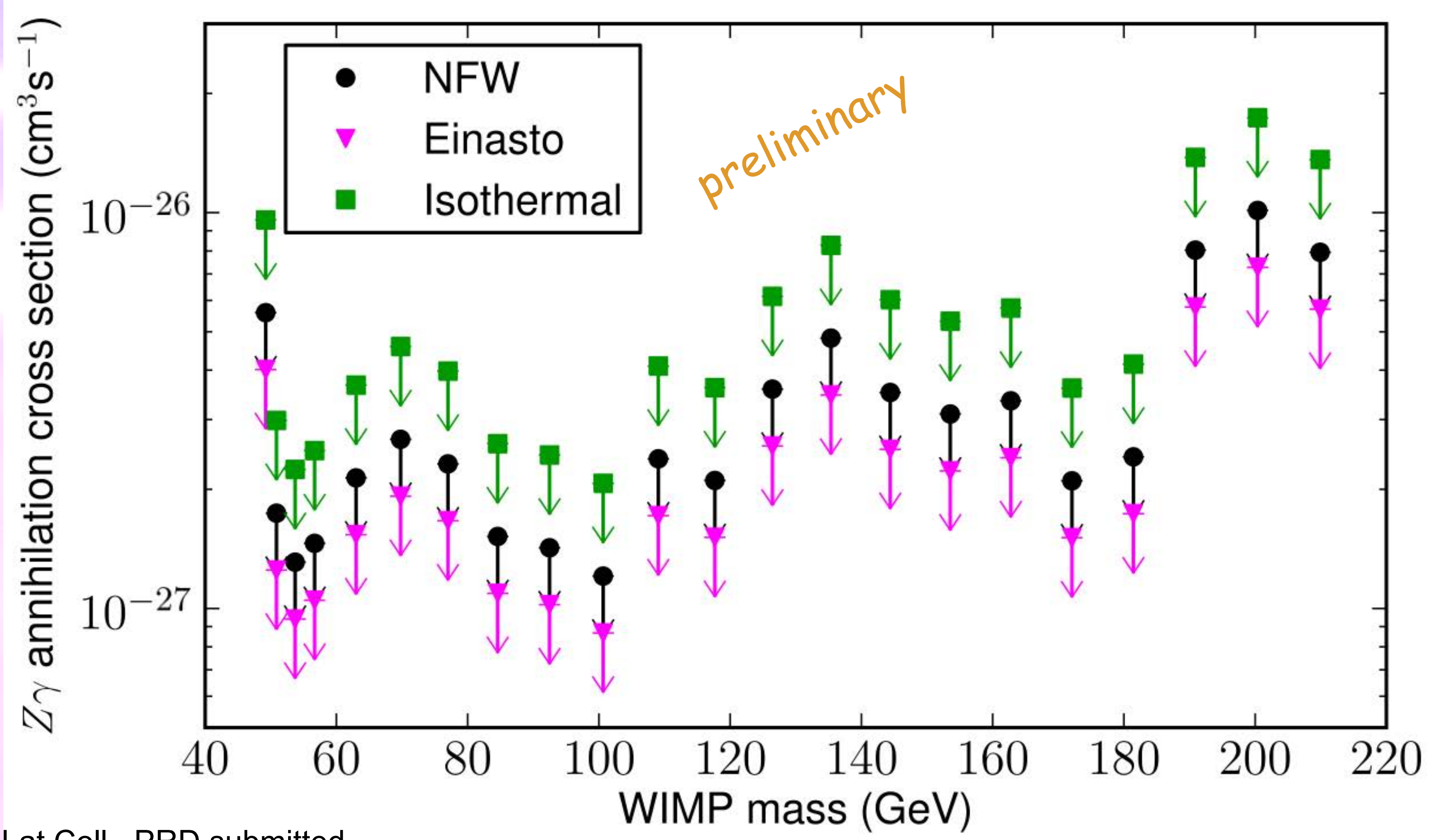


Fermi Lat Coll., PRD submitted

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

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

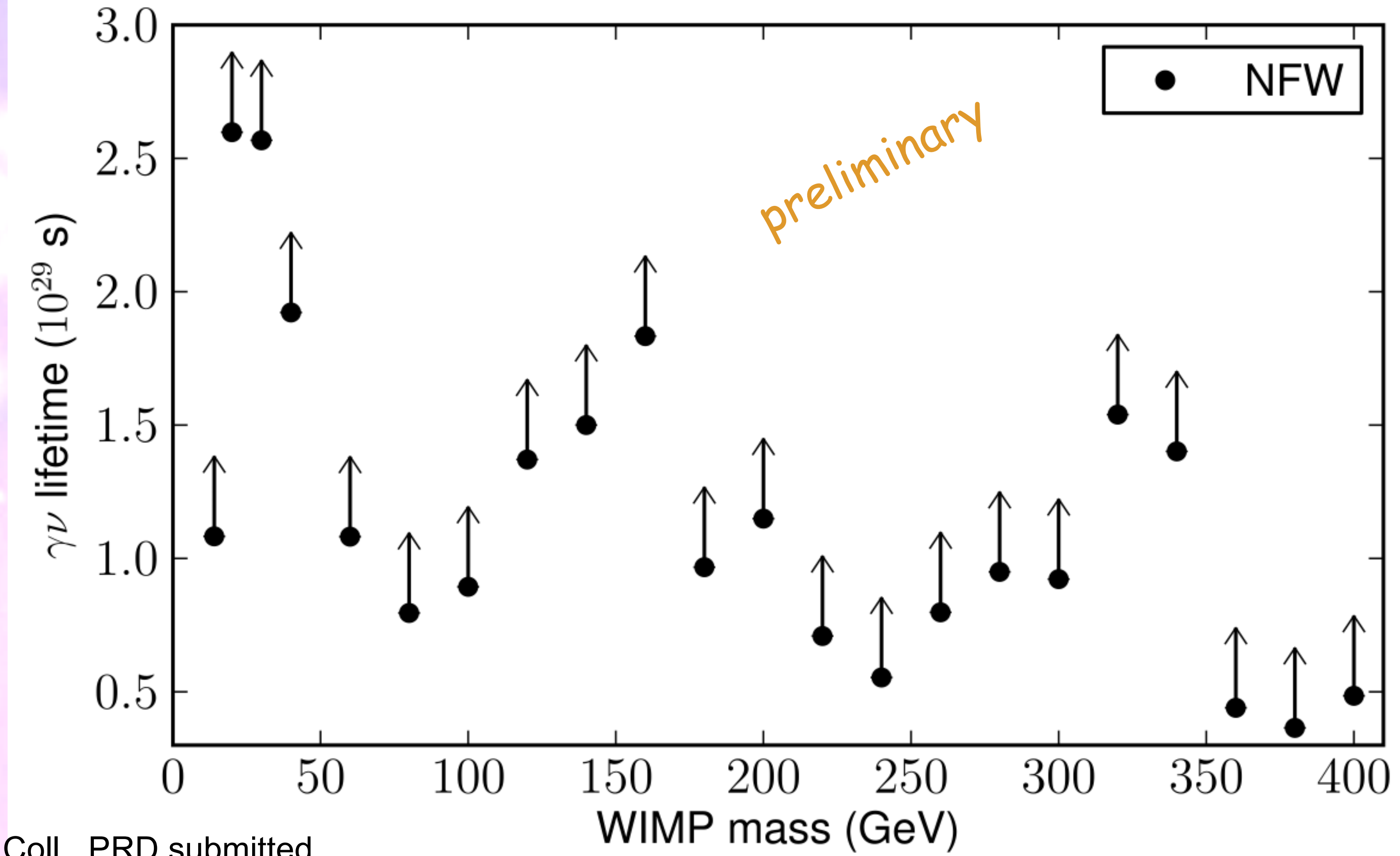
Additional systematic on spectral structures with LAT resolution for E<13.2 GeV of s/bg ~ 1%.



Fermi Lat Coll., PRD submitted

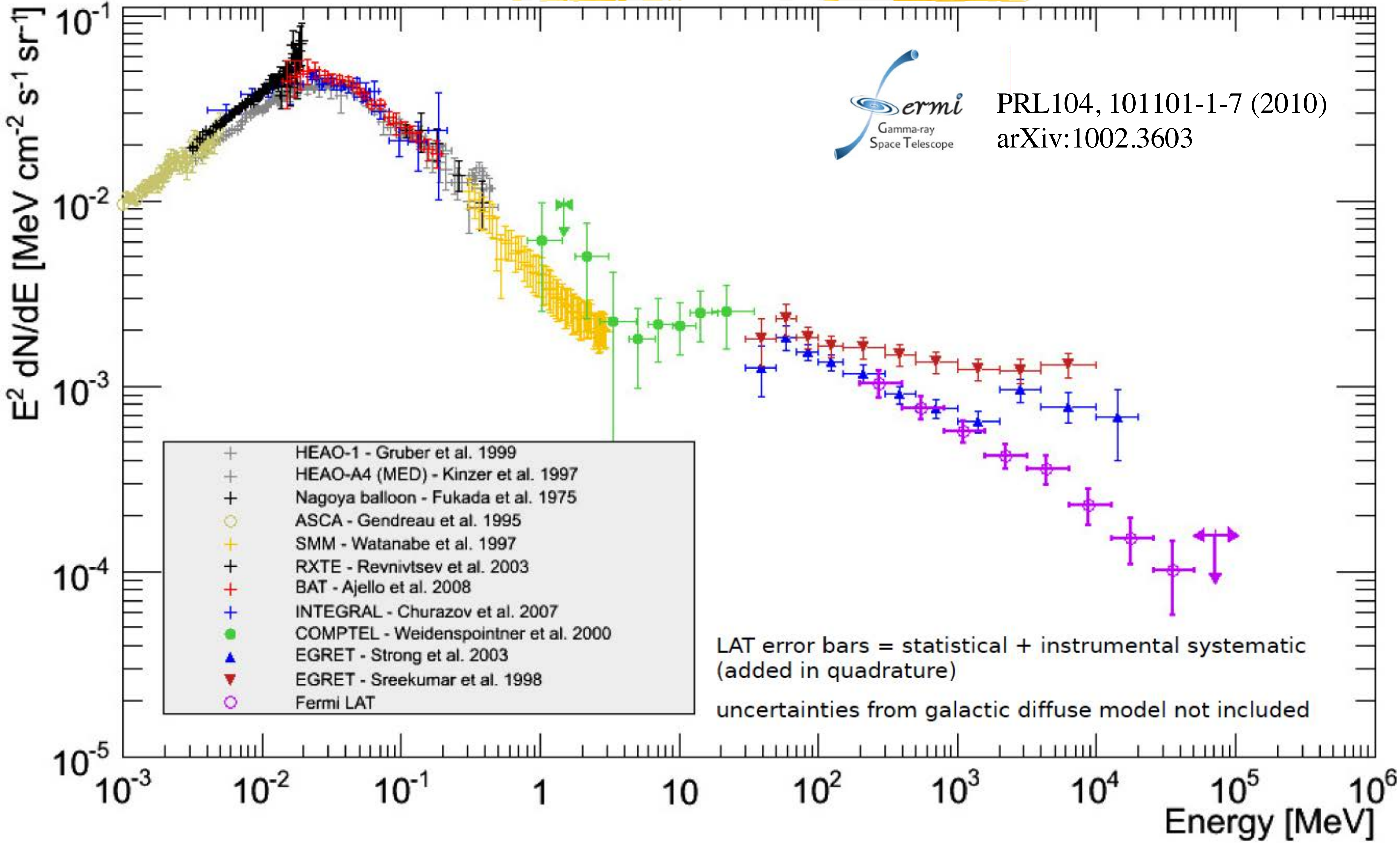
Decay lifetime lower limits

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

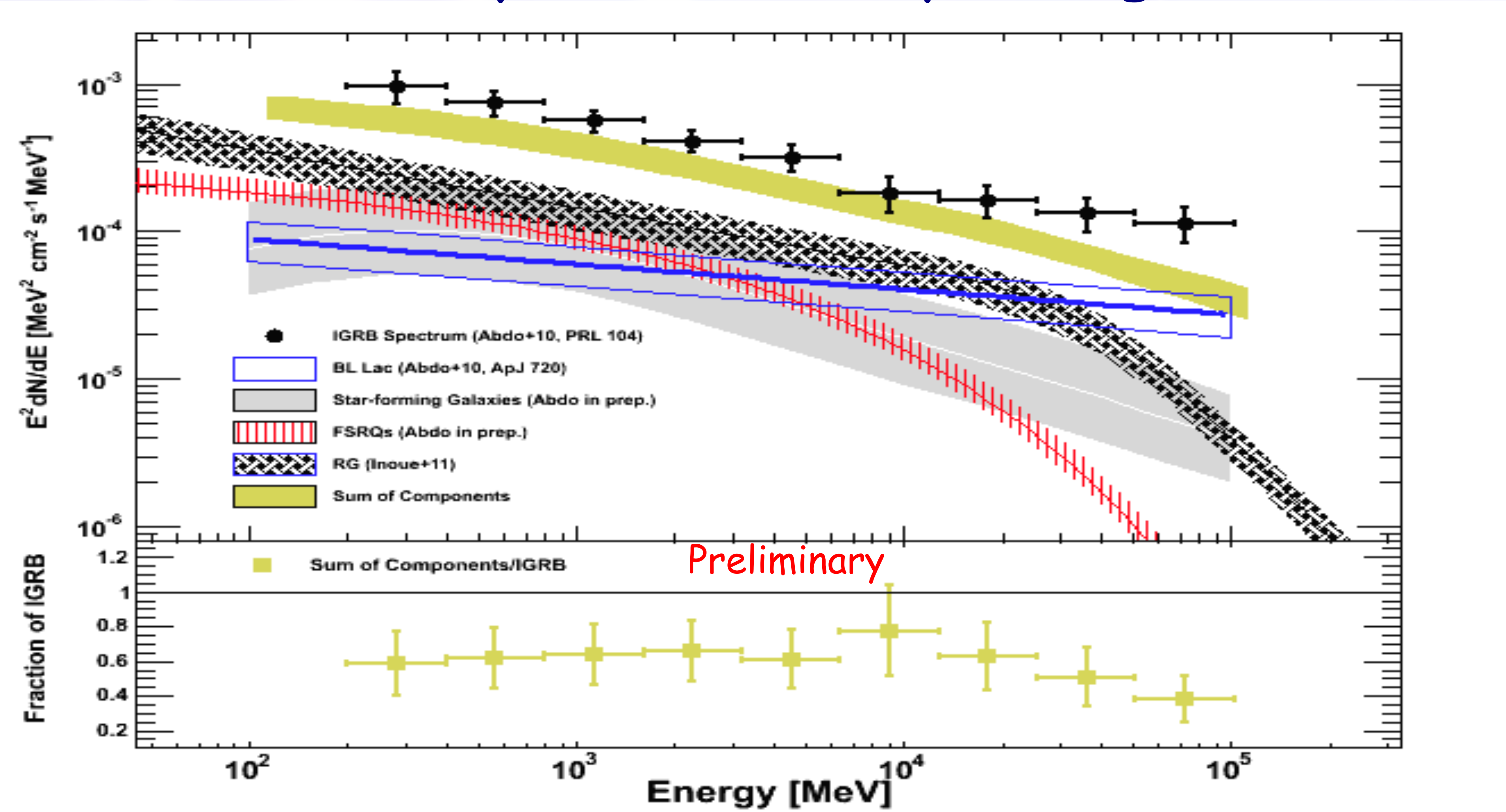


Fermi Lat Coll., PRD submitted

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



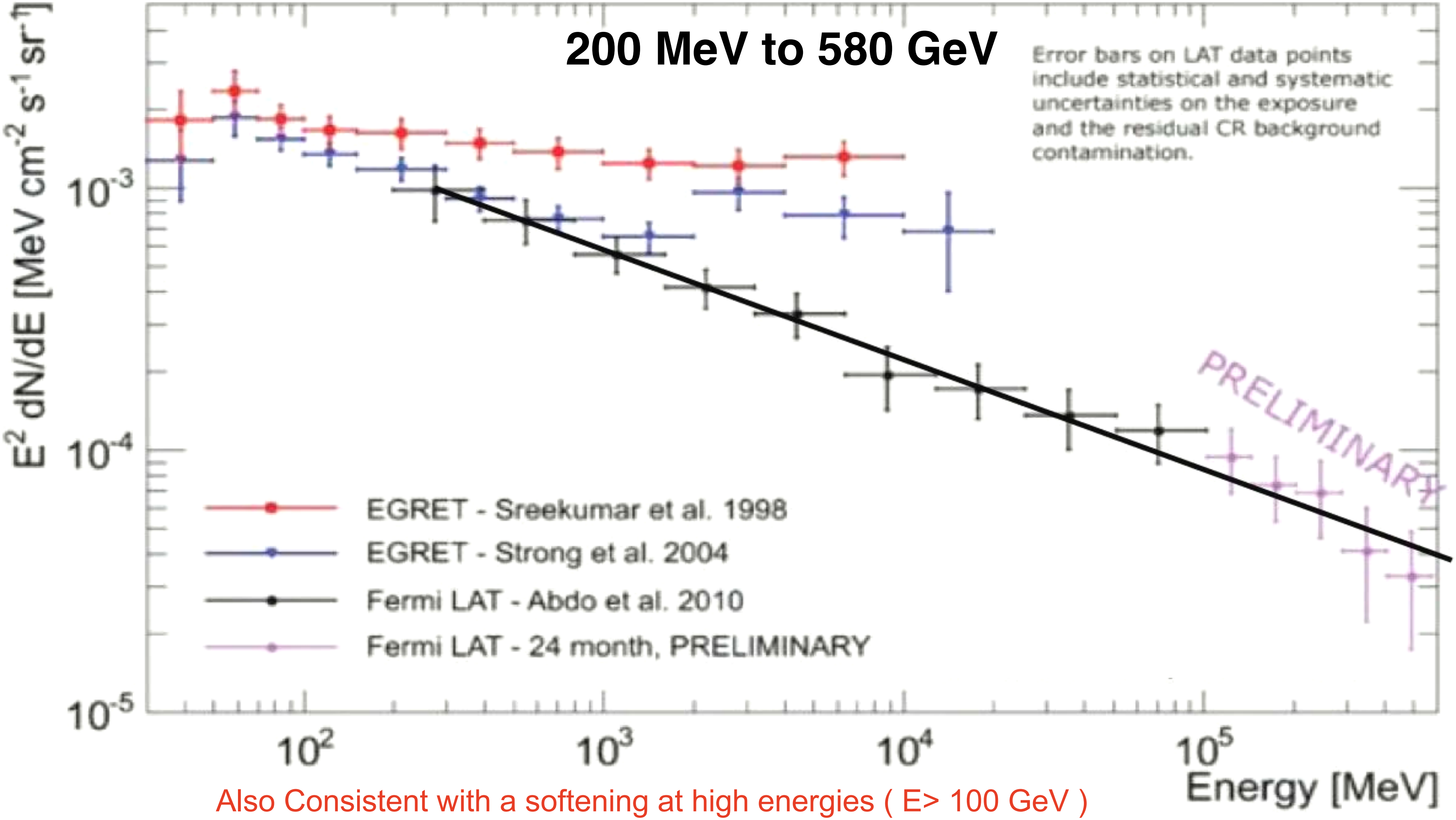
the Isotropic Gamma-ray Background (IGRB)



- 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)

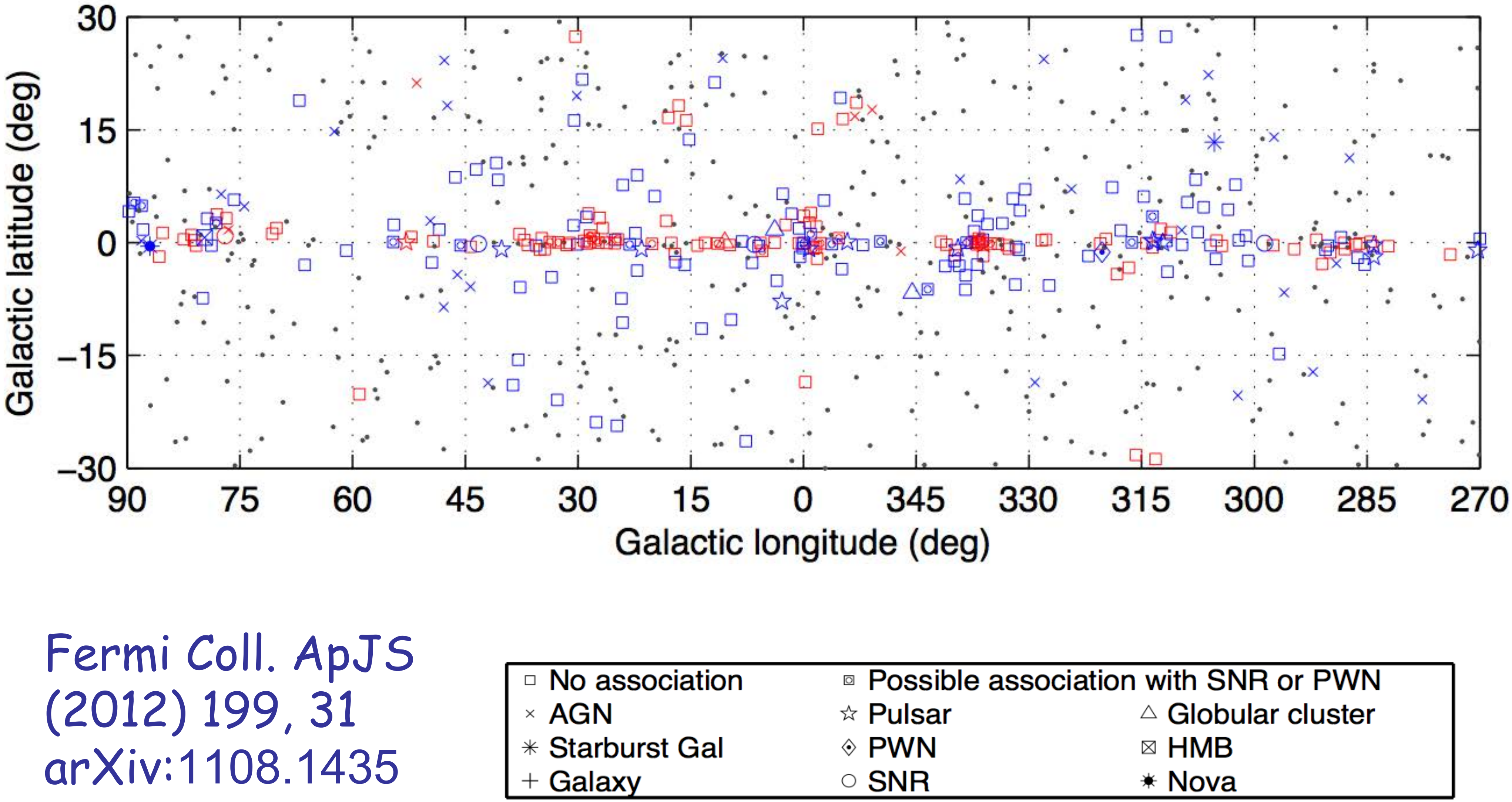


Also Consistent with a softening at high energies (E> 100 GeV)

The Fermi LAT 2FGL Inner Galactic Region

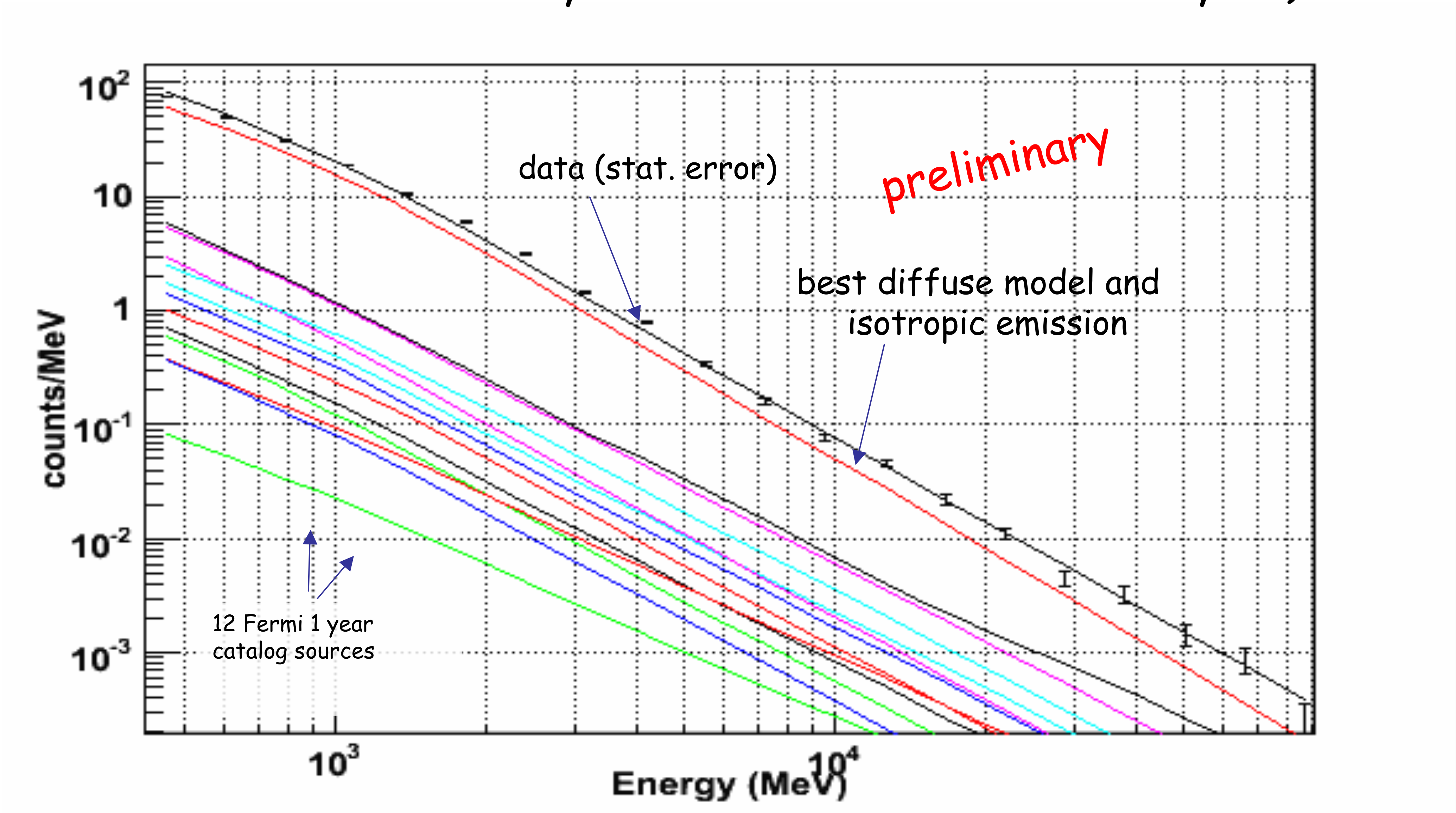
August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range



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

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

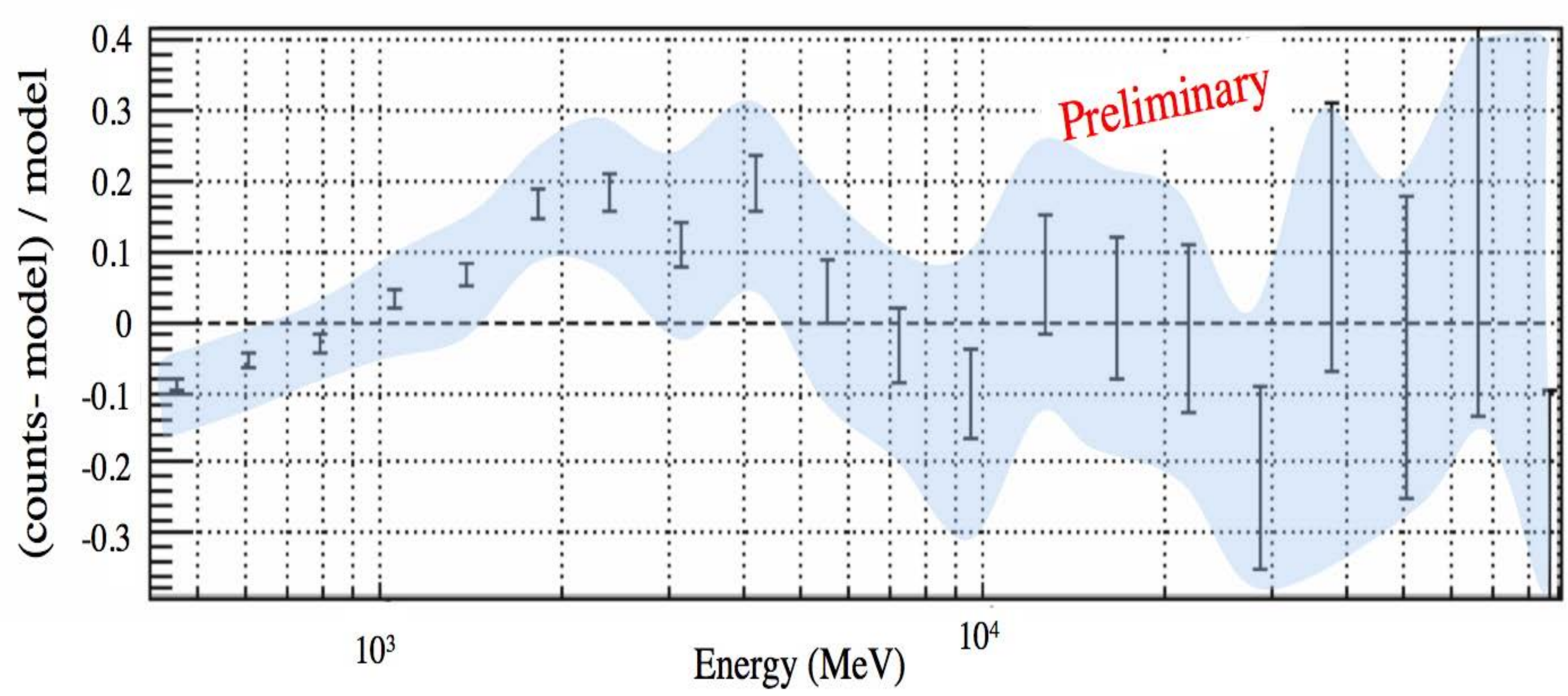


Fermi Coll. NIM A630 (2011) 147 [arXiv:0912.3828]

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]

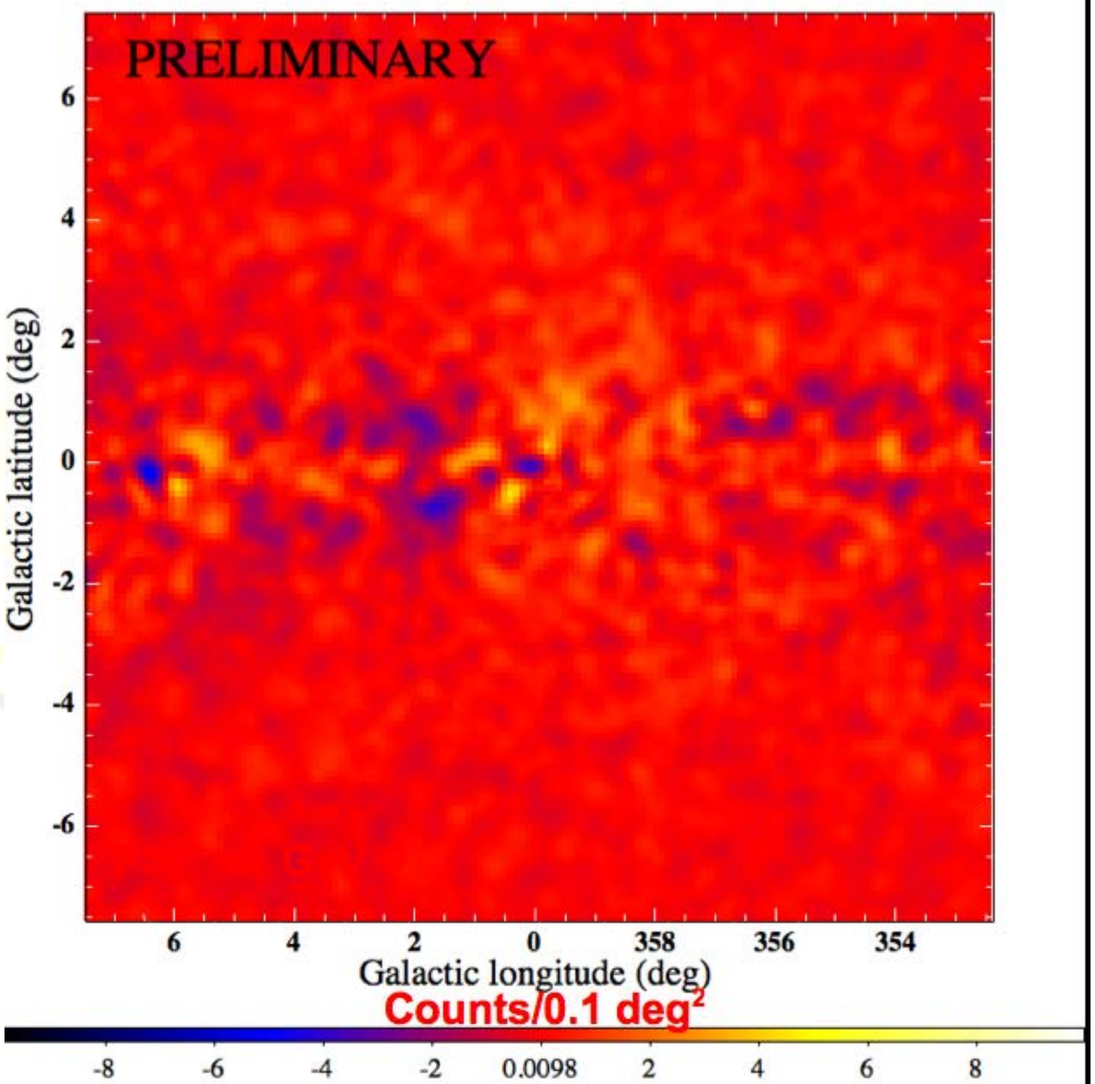
Residual Emission for 15 * 15 degrees around the **Galactic center**

32 Months Data (Front events)

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.



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

The longer we look, the more surprises we will see

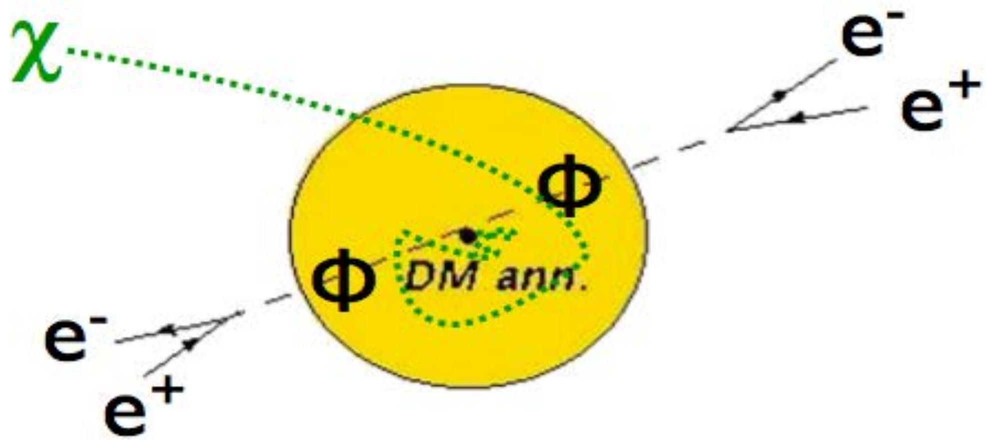

SciNeGhe 2012
9th Workshop on Science with the New Generation of High Energy Gamma-ray Experiments
you are all invited
From high energy gamma sources to cosmic rays, one century after their discovery
The 2012 edition of the SciNeGHE conference will focus on the interplay between studies and measurements concerning high energy gamma ray sources and cosmic rays. A special session will be devoted to the history of the cosmic radiation research in the centenary of its discovery. An update on the current and planned research with space-borne and ground-based experiments dedicated to the observation of the gamma and cosmic ray sky will be given, together with the analysis of up to date theoretical scenarios. R&D programs going on to set up new observational techniques and devices will also be covered.
Lecce, 20-22 June 2012
http://scineghe2012.le.infn.it/

additional slides

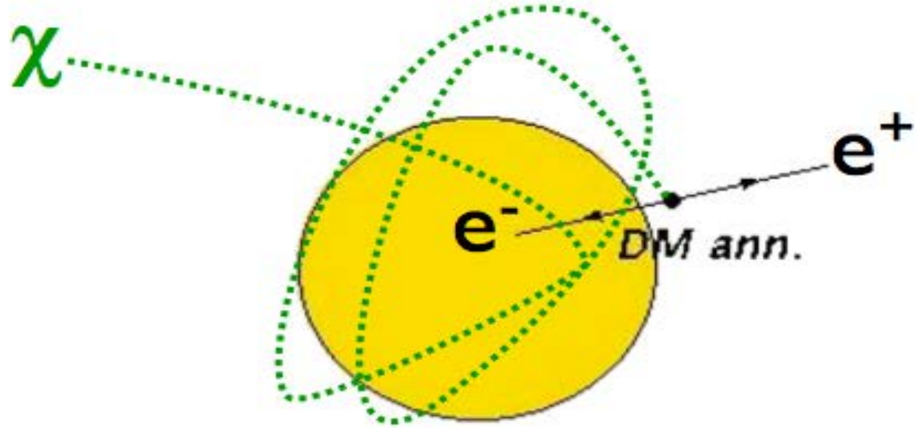
CREs from DM annihilation

Schuster et al. (2010) discuss 2 scenarios in which dark matter annihilation leads to cosmic-ray electron and positron (CRE) fluxes from the Sun:

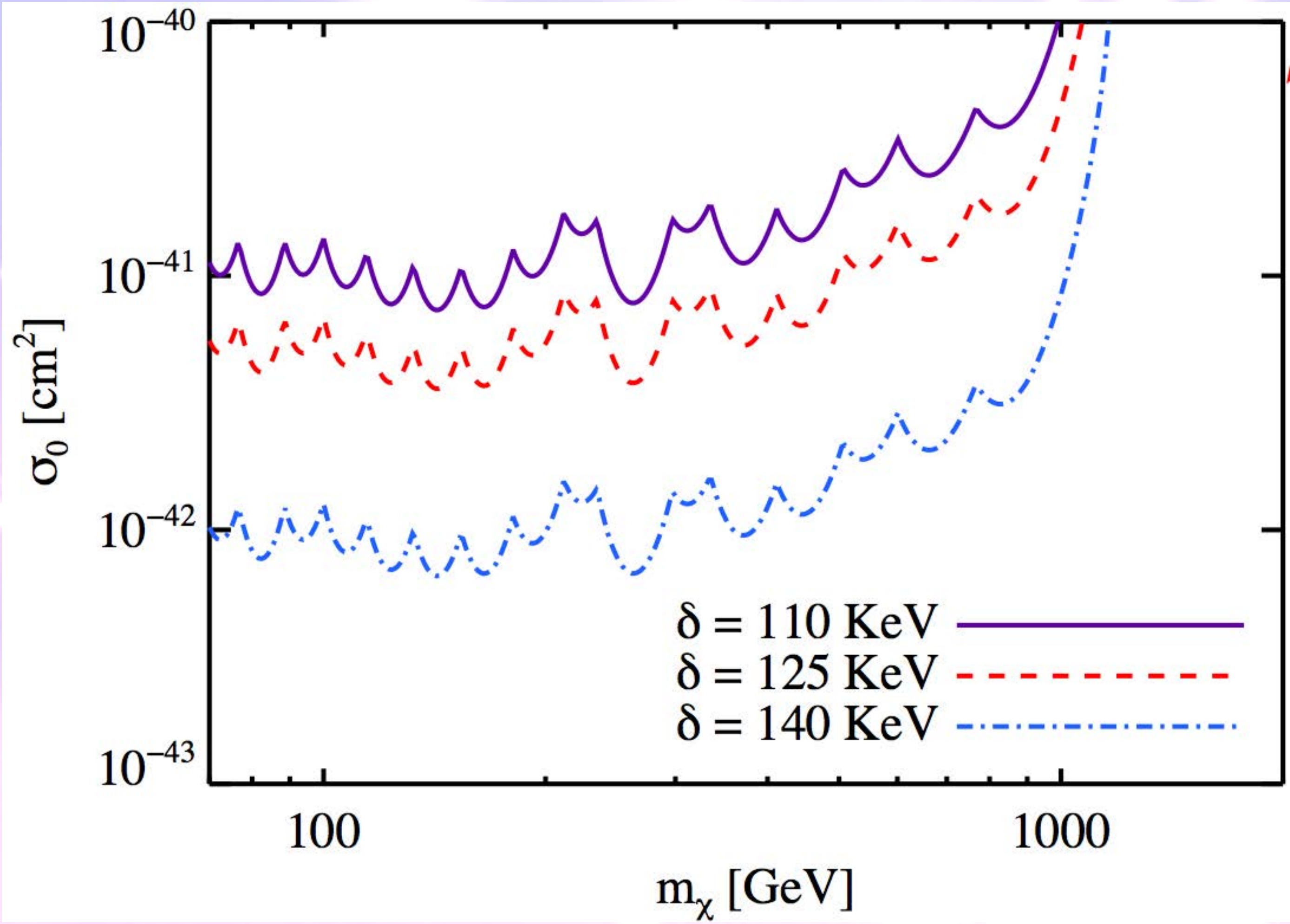
- intermediate state scenario: Dark matter annihilates in the center of the Sun into an intermediate state Φ which then decays to CREs outside the surface of the Sun



- iDM scenario: Inelastic dark matter (iDM) captured by the Sun remains on large orbits, then annihilates directly to CREs outside the surface of the Sun



Limits on inelastic scattering cross-section with electrons from the Sun



There is a class of models that has garnered interest recently in light of claims that iDM could naturally explain such observations as the 511 keV line observed by INTEGRAL/SPI and the apparently inconsistent results of DAMA/LIBRA and CDMS if the DM scattered inelastically and thereby transitioned to an excited state with a slightly heavier mass. The bounds we derive exclude the relevant cross sections by 1–2 orders of magnitude -> the parameter space of models preferred by DAMA/LIBRA can be ruled out for m >70 GeV for annihilation to e+e-

Fermi Coll.Phys. Rev. D 84, 032007 (2011) [arXiv:1107.4272]

Looking Ahead

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

Many further improvements in instrument performance in progress

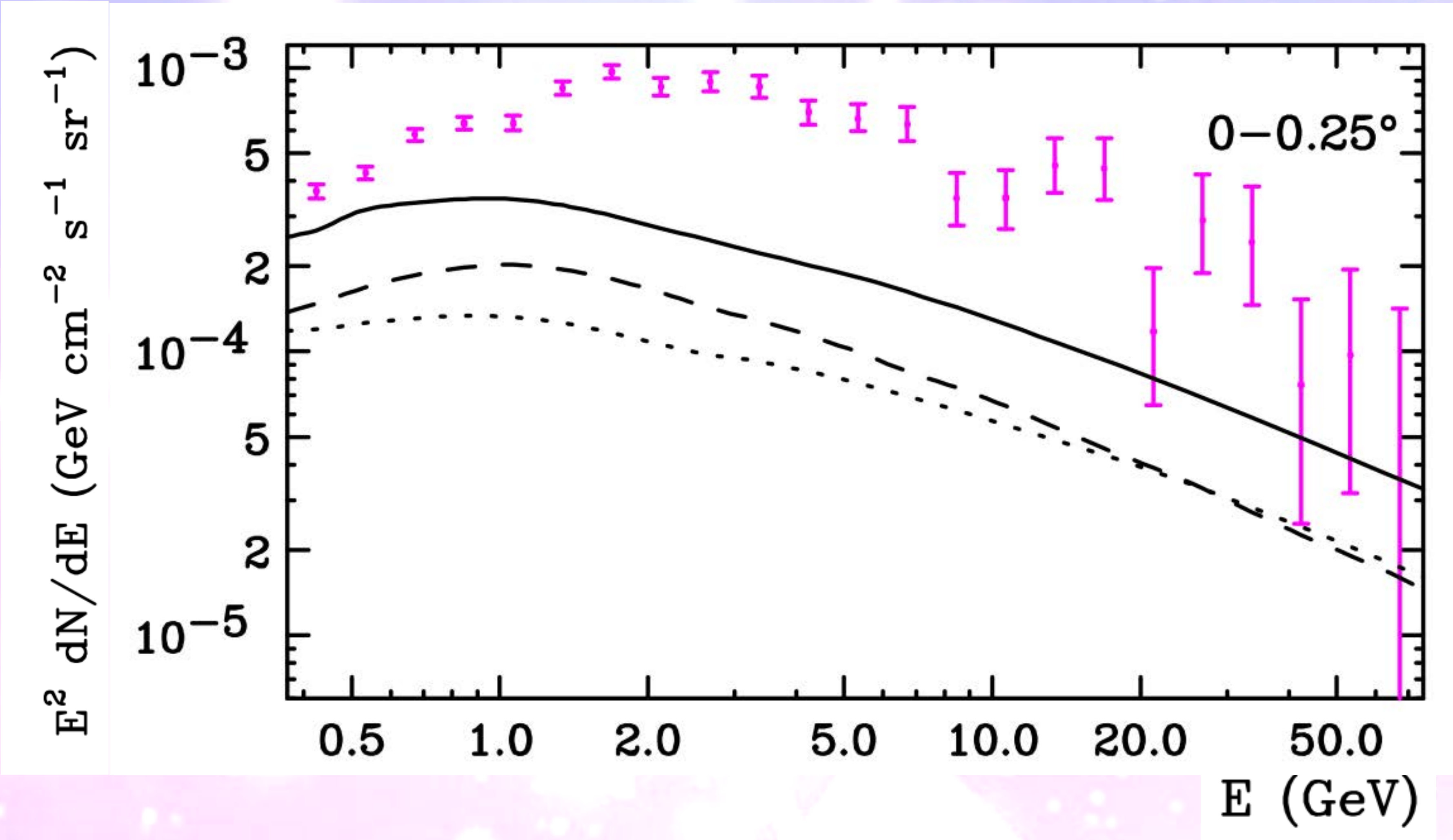
- Event reconstruction and choices of event selection "knobs" all determine instrument performance. For stability, standard event class definitions established with IRFs.
- Data were released with Pass6.
- Some known issues, described in Caveats on FSSC site and inLAT papers, addressed with patch to 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.

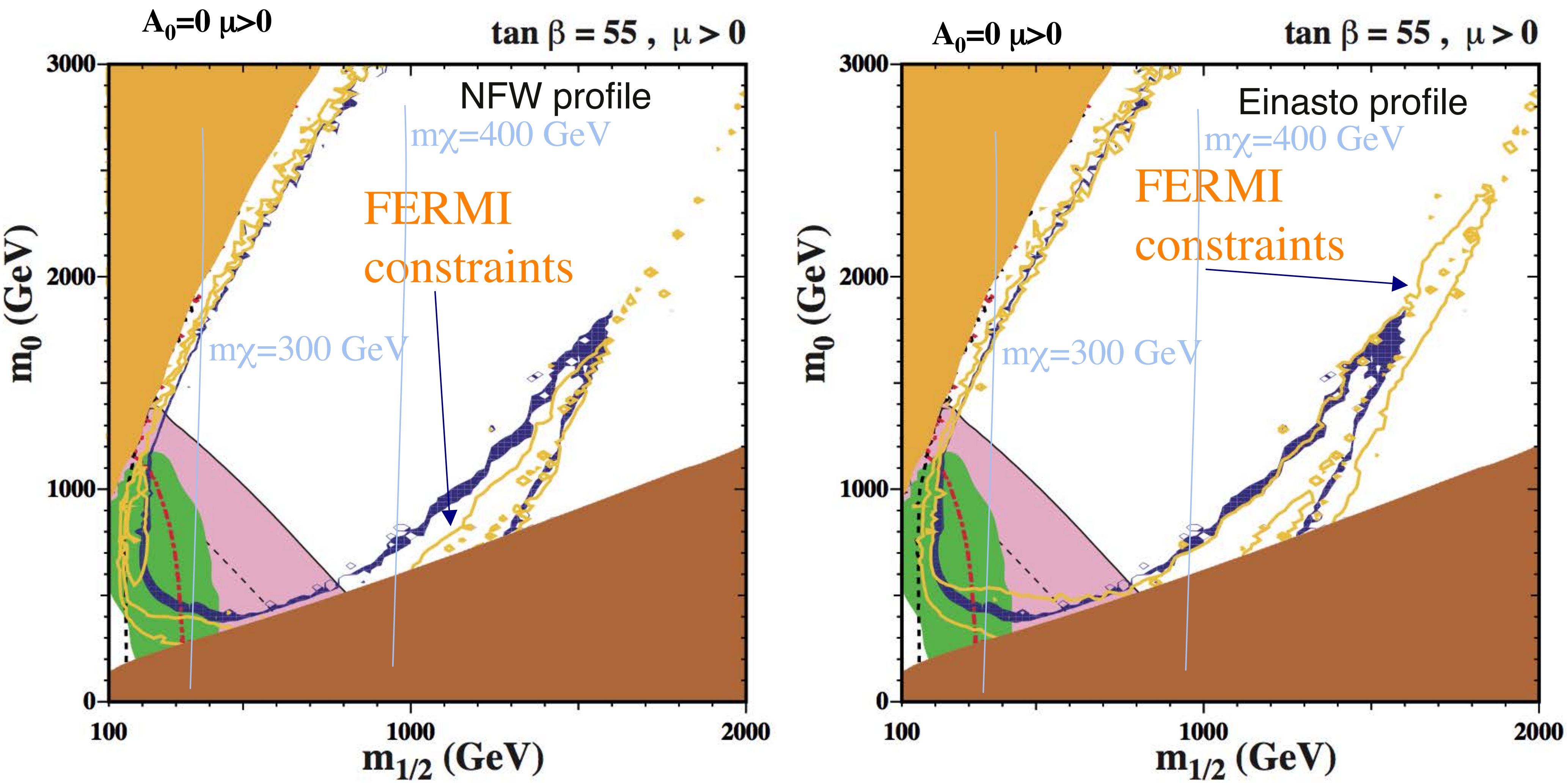
Dark Matter Signal from the Galactic Center ?



systematic uncertainties and diffuse model uncertainties should be taken in account

Hooper and Goodenough arXiv:1010.2752v2

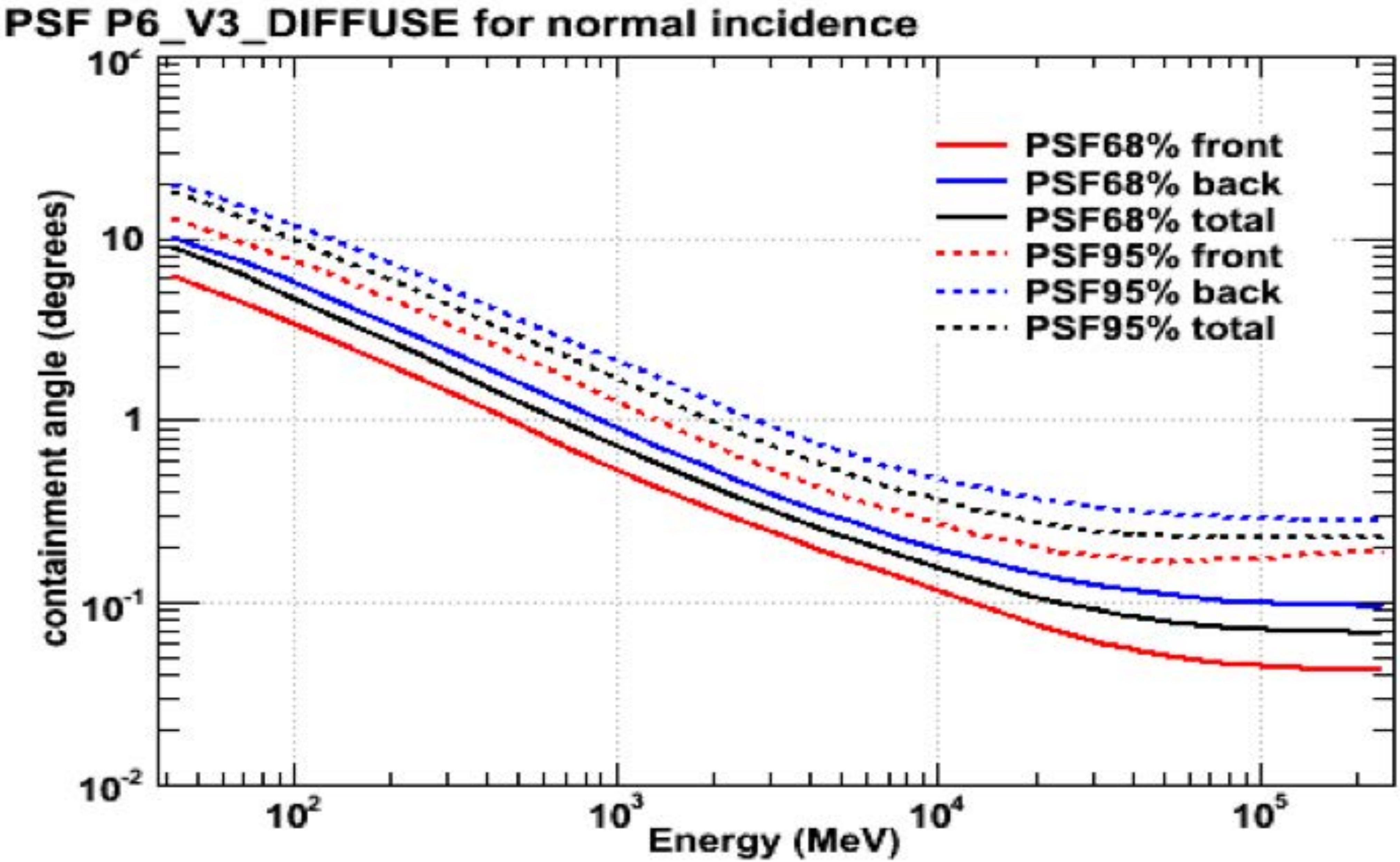
Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios



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

Fermi IRF

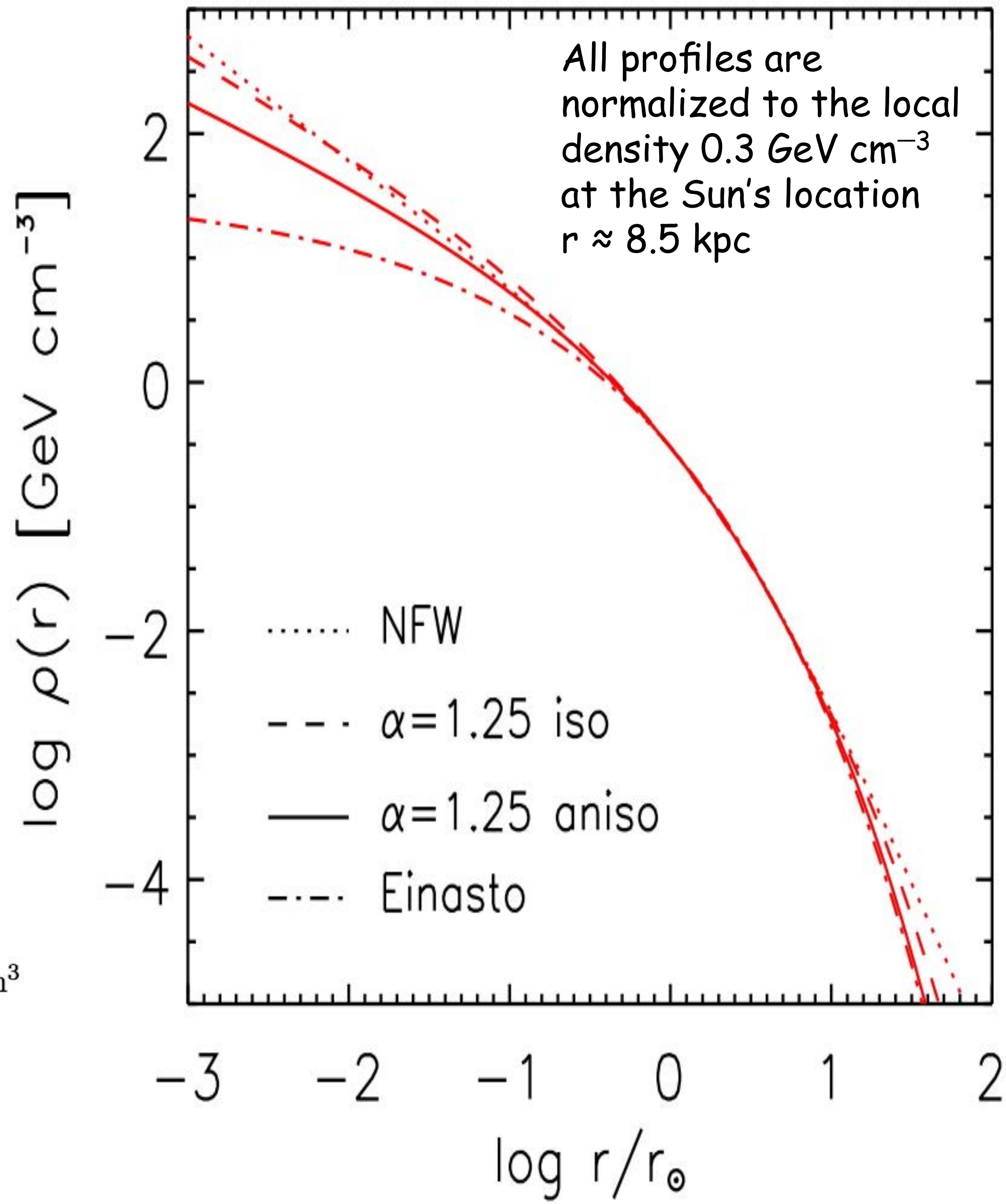

PSF P6_V3_DIFFUSE for normal incidence
containment angle (degrees)
Energy (MeV)
10^2
10^3
10^4
10^5
10
1
10^-1
10^-2
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total

Milky Way Dark Matter Profiles

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

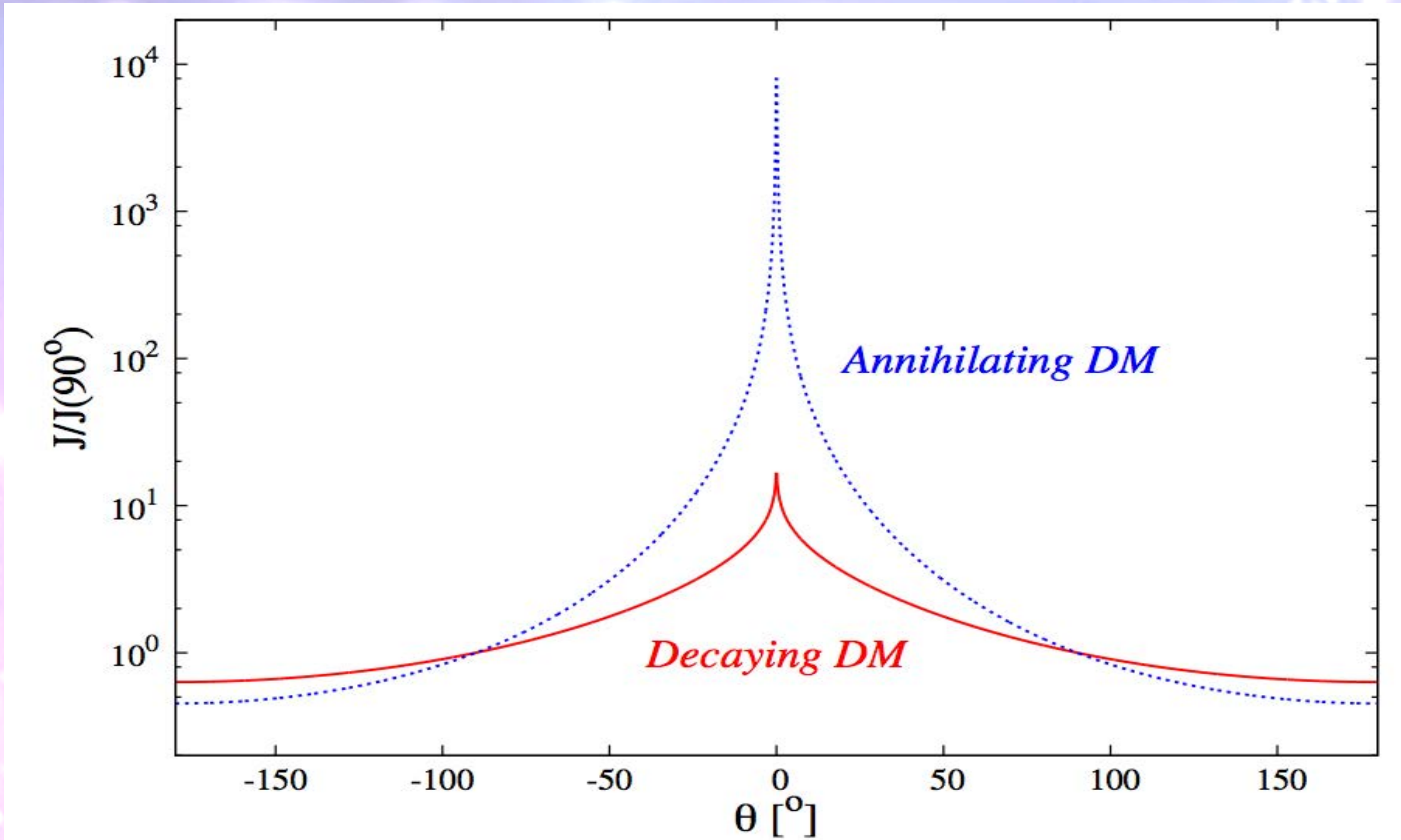
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

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

Search for Dark Matter in the Galactic Center Conclusion

- 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

The Galactic Center
Disentangling the Many Sources of Gamma- Ray Emission is Challenging ...

The emission from the inner Galaxy consists of a number of components:

Outer Galaxy

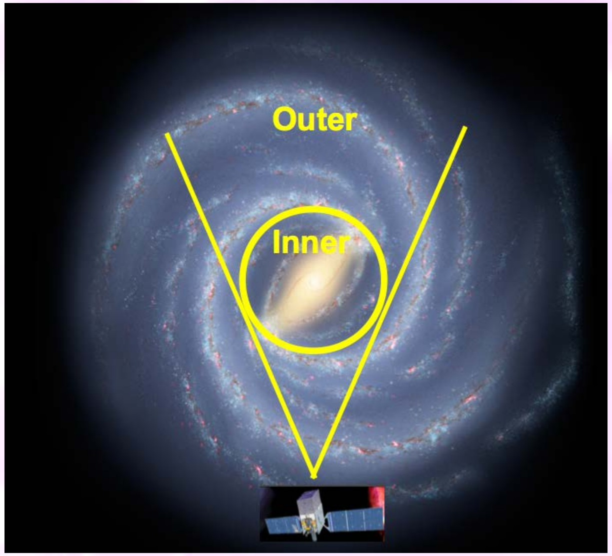
True inner Galaxy

Point or small extended sources

Unresolved sources

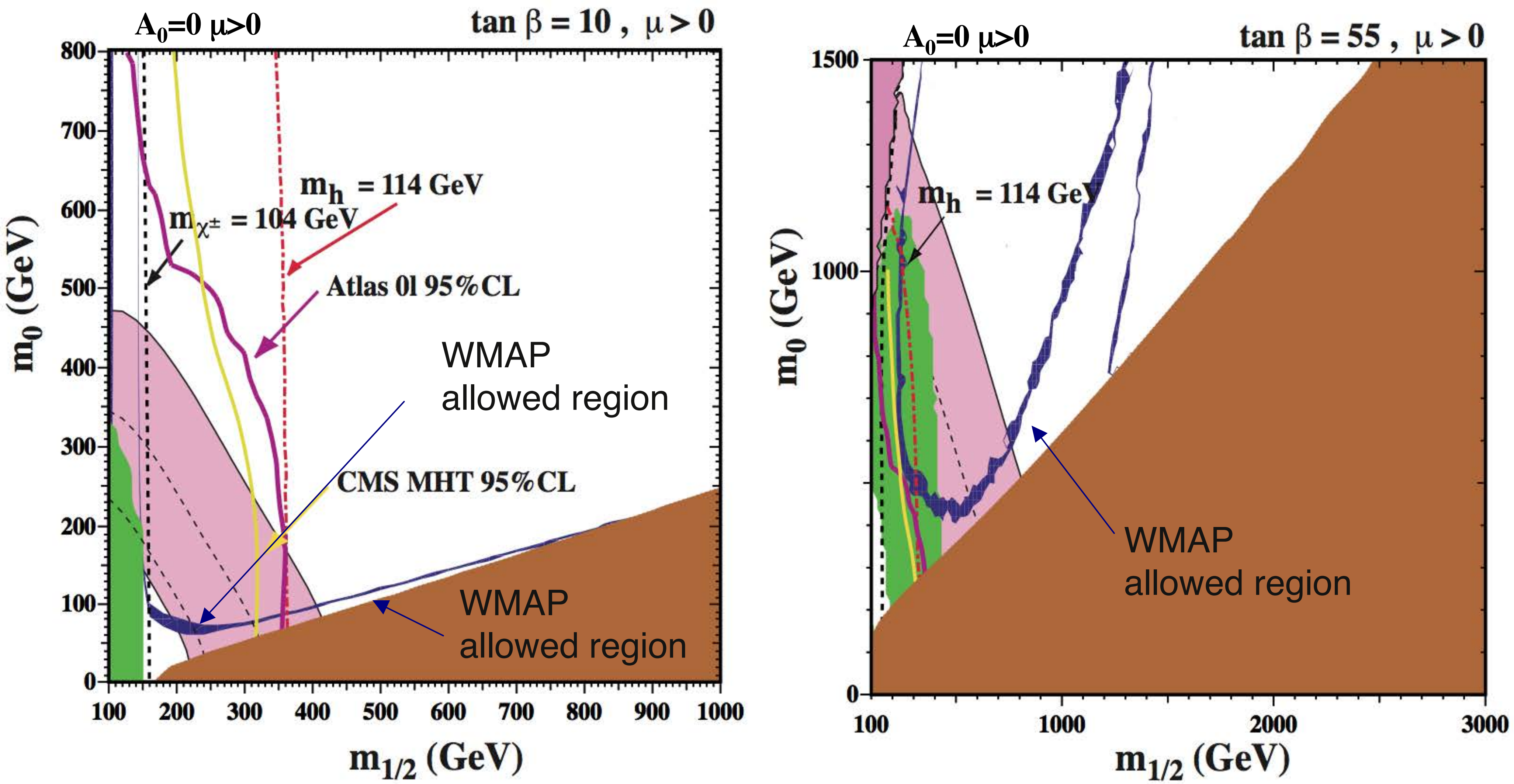
Extragalactic emission

Cosmic-ray instrumental background



Diffuse gamma rays produced by cosmic rays interacting with the interstellar gas and radiation fields

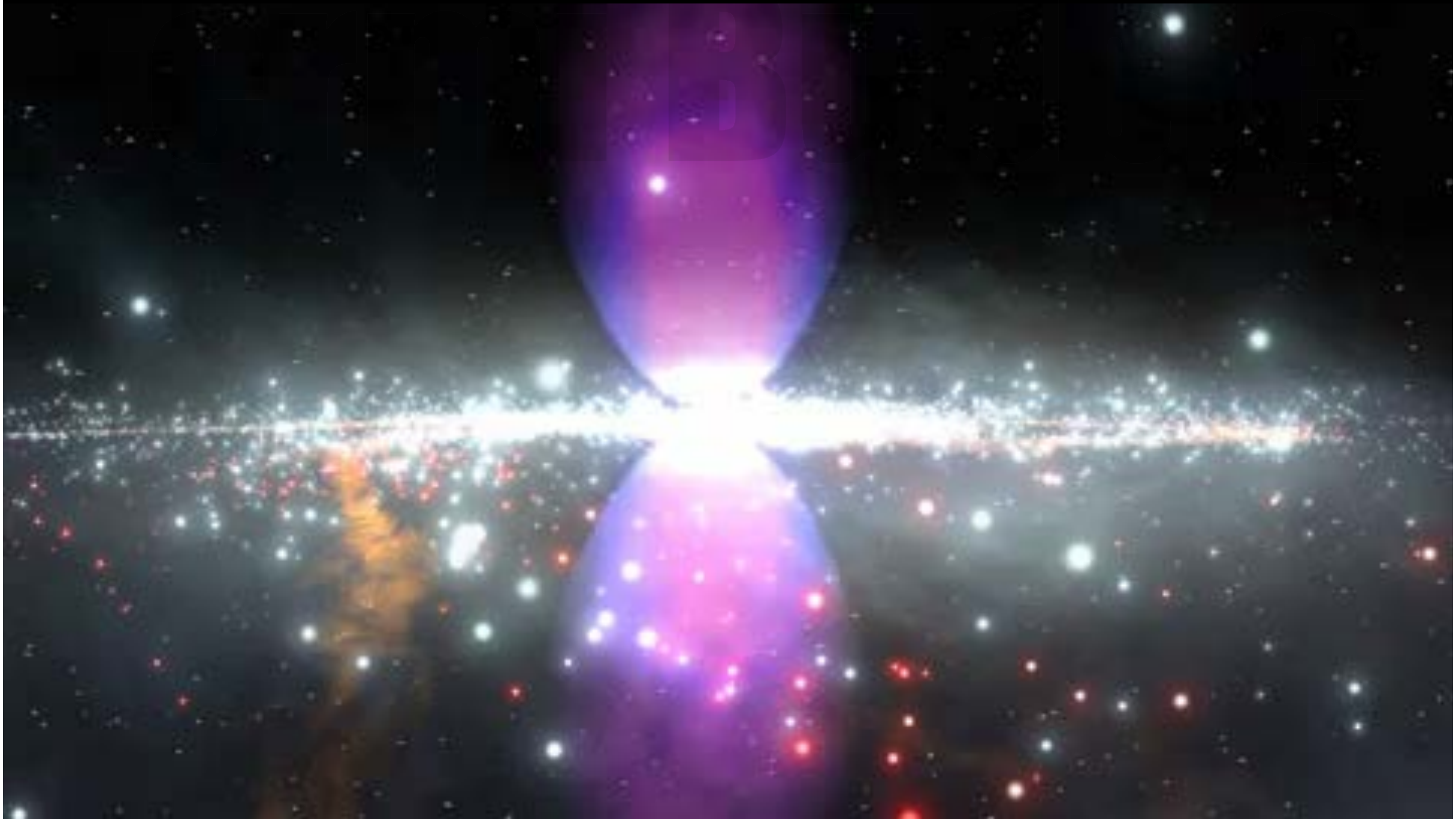
Galactic-Centre Gamma Rays in CMSSM Dark Matter Scenarios



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

Fermi Bubble

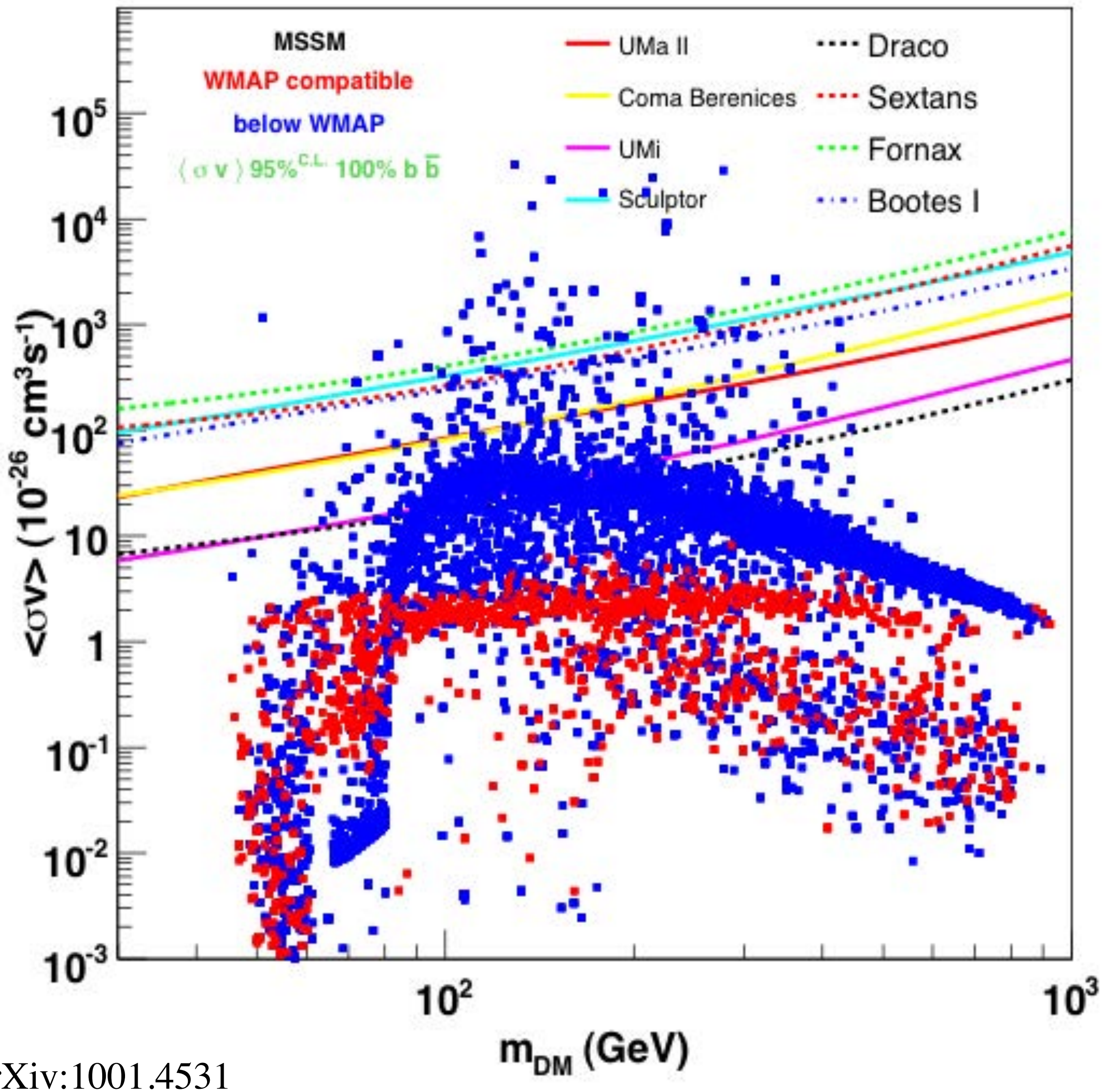


Dwarf Spheroidal Galaxies upper-limits

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 $<\sigma v>$ 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

Inverse Compton Emission and Diffusion in Dwarfs

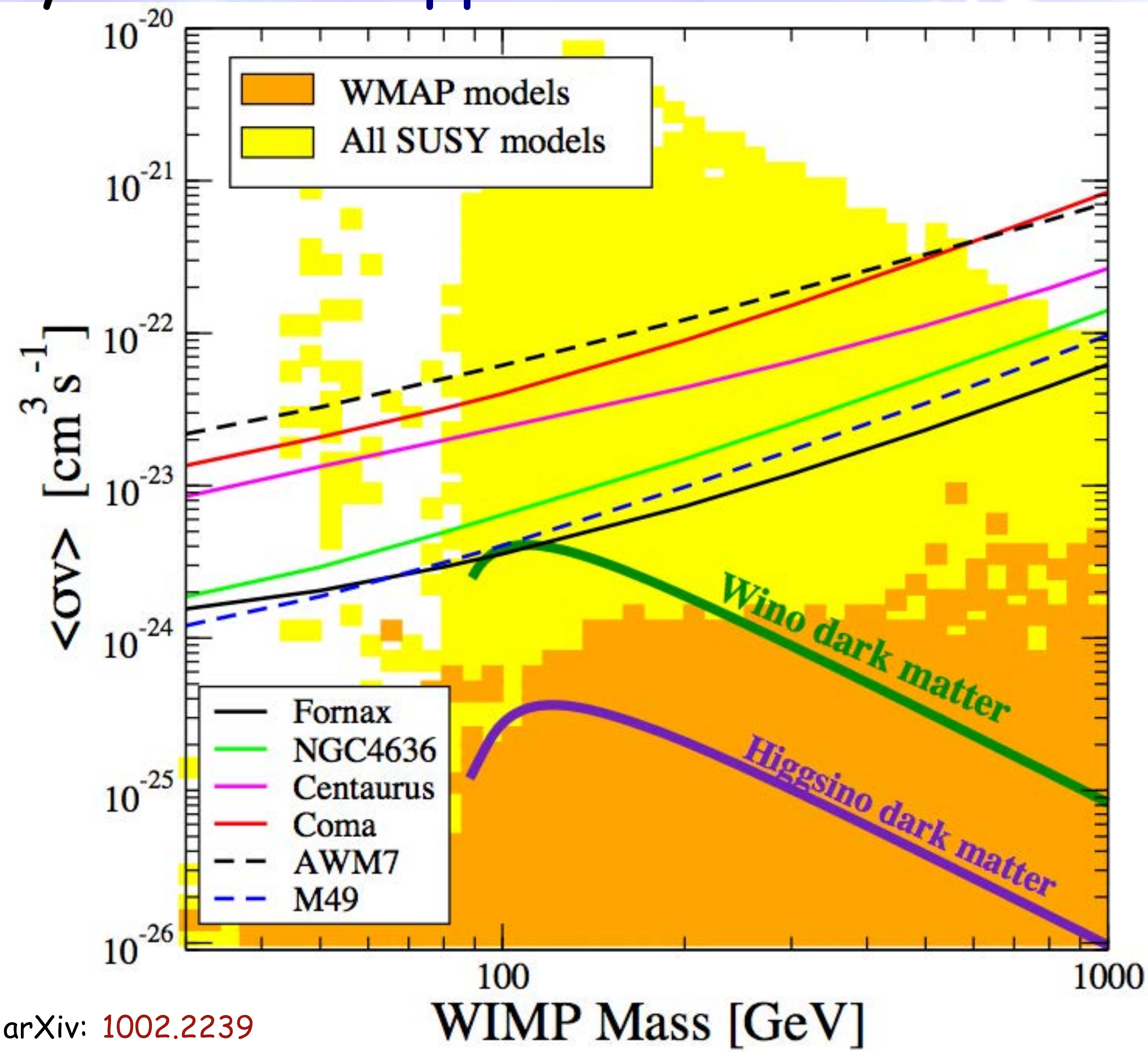
- We expect significant IC gamma-ray emission for high mass WIMP models annihilating to leptonic final states.
- The IC flux depends strongly on the uncertain/unknown diffusion of cosmic rays in dwarfs.
- We assume a simple diffusion model similar to what is found for the Milky Way

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

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

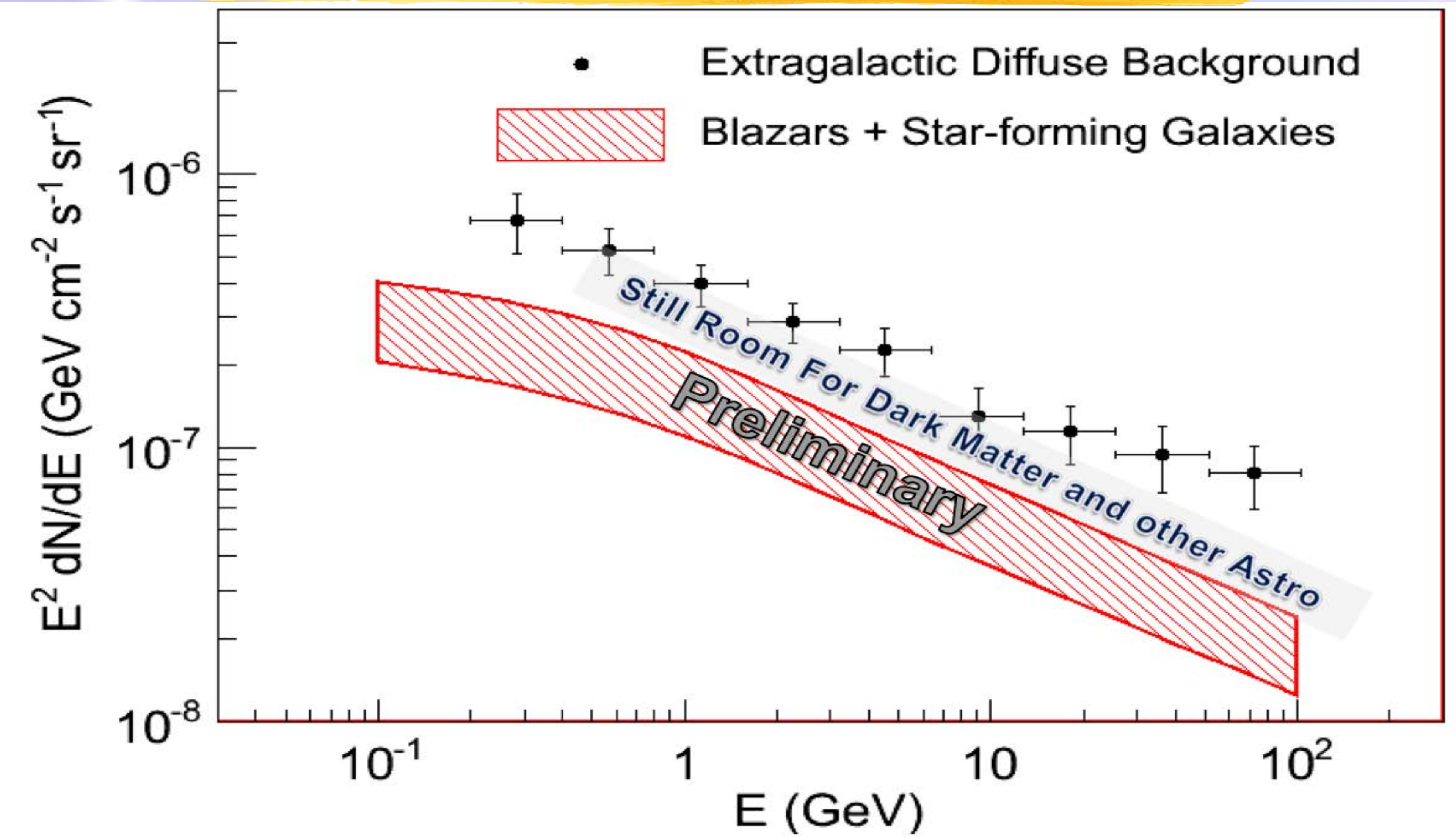
Galaxy Clusters upper-limits

- 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

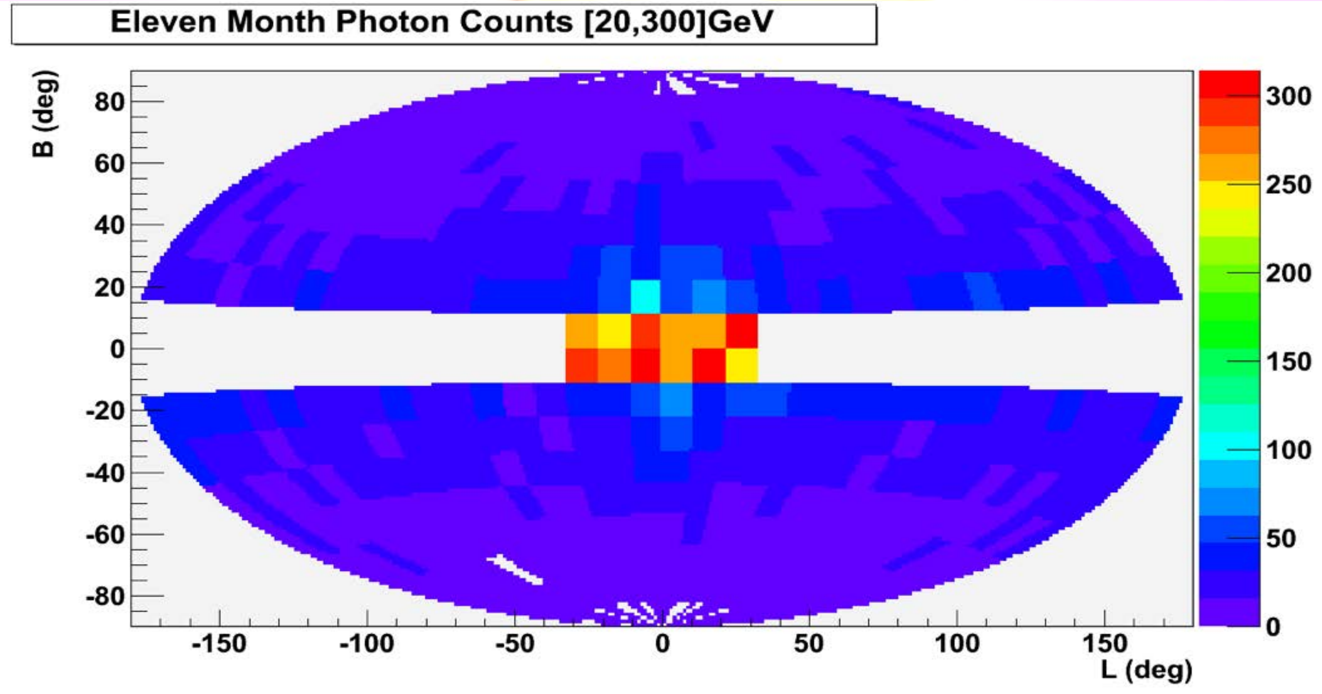
Comparison of the Extragalactic Diffuse γ-ray Background to Calculations of Contributions from Blazars + Star-forming Galaxies



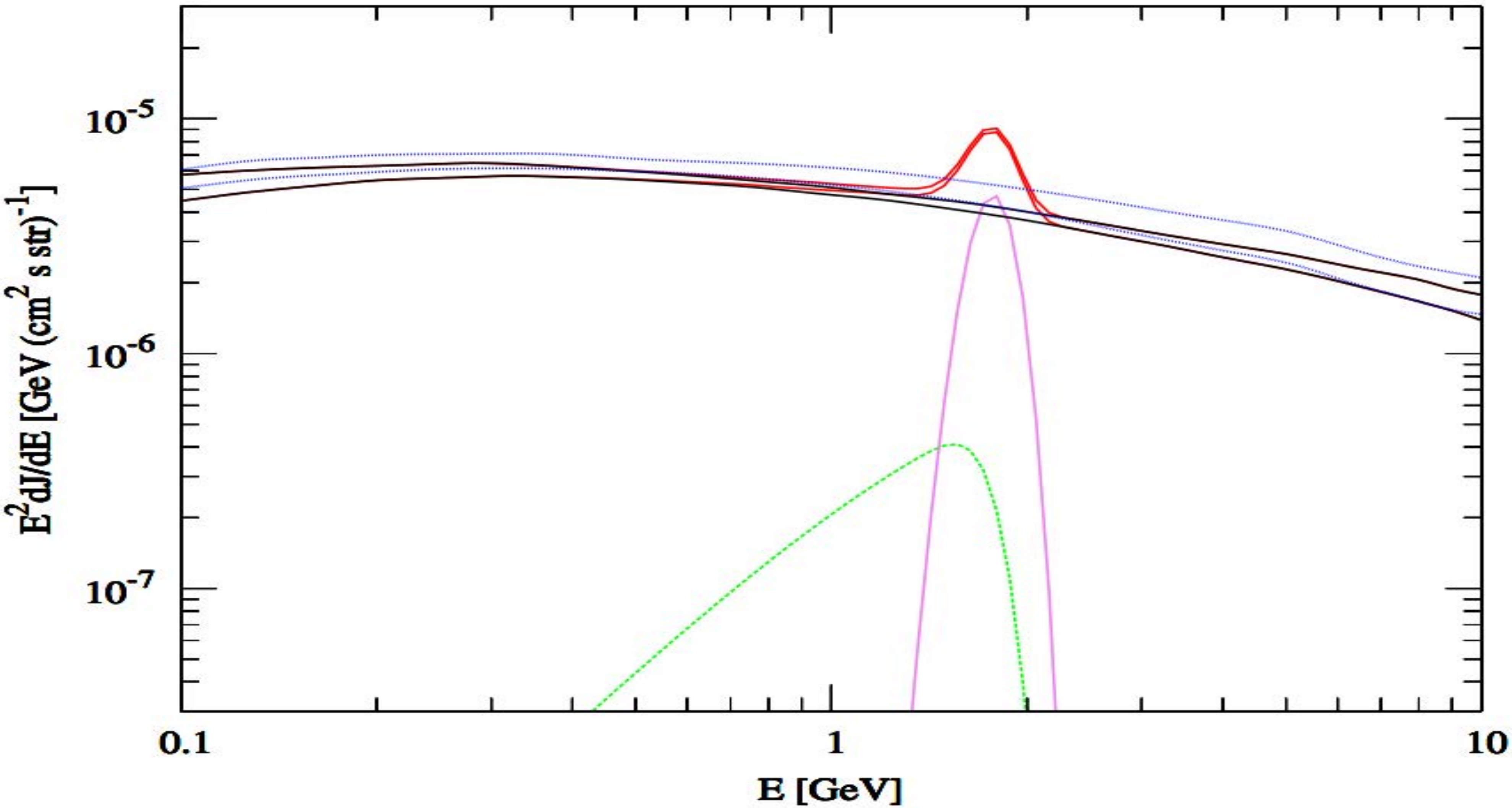
Blazars: Abdo, A. A., et al. [Fermi Coll.] 2010, ApJ. **720**, 435
Star forming galaxies : Fermi Coll. in preparation

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° and 30° around 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.

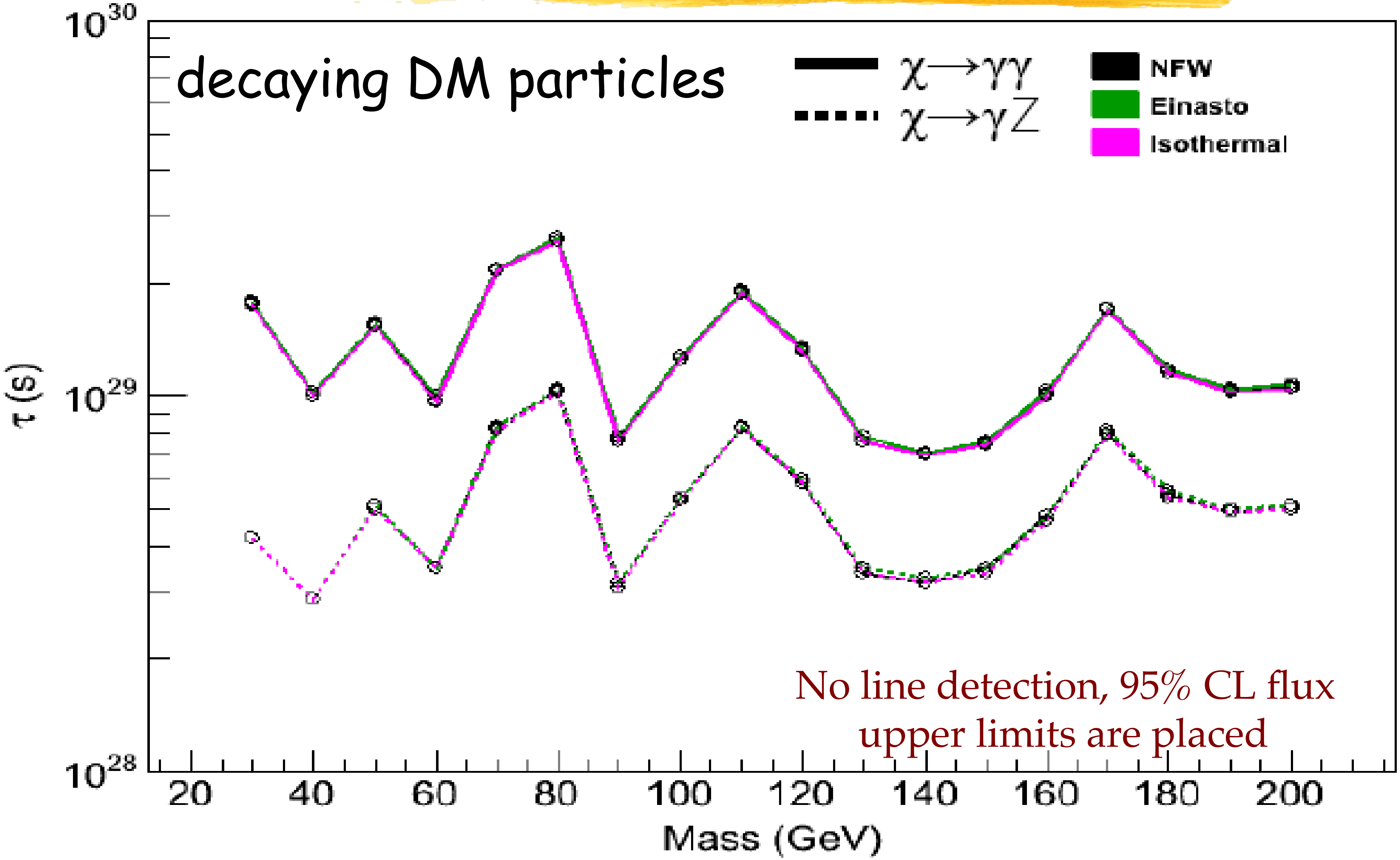


Gamma-ray detection from gravitino dark matter decay in the μνSSM



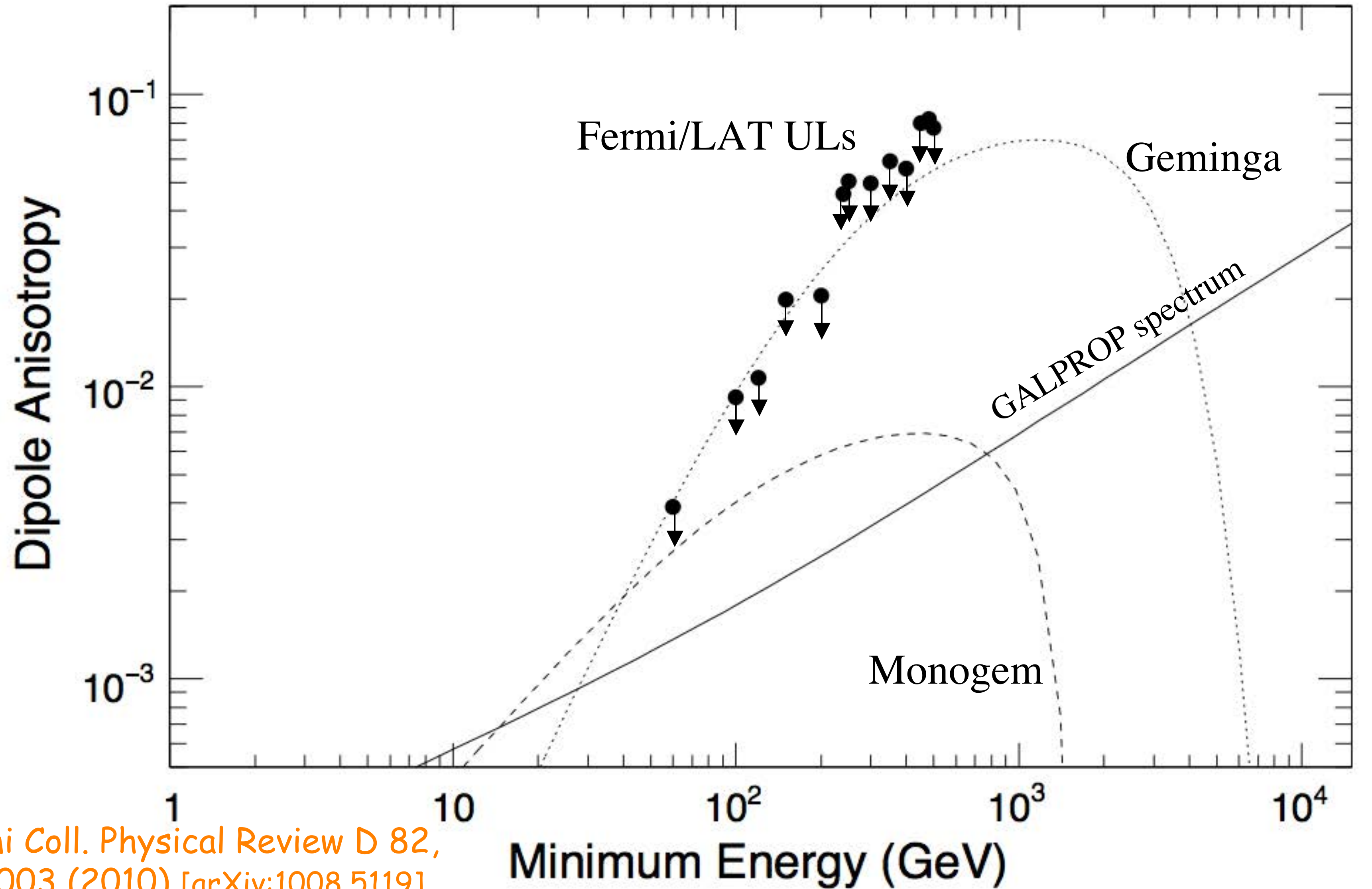
Ki-Young Choi, Daniel E.Lopez-Fogliani, Carlos Munoz, Roberto Ruiz de Austri, arXiv:0906.3681

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



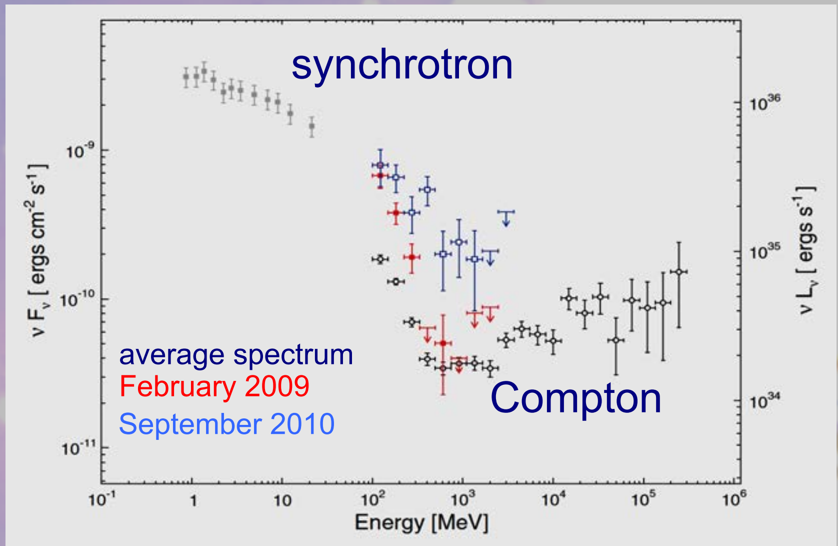
Fermi Coll. Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

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)

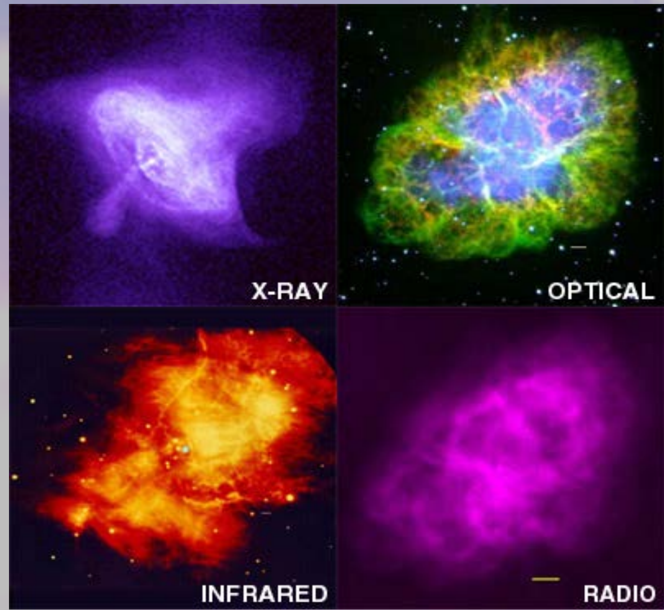


brief flare time scales (4 days) imply compact flaring region:

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

(1.5 arcsec)

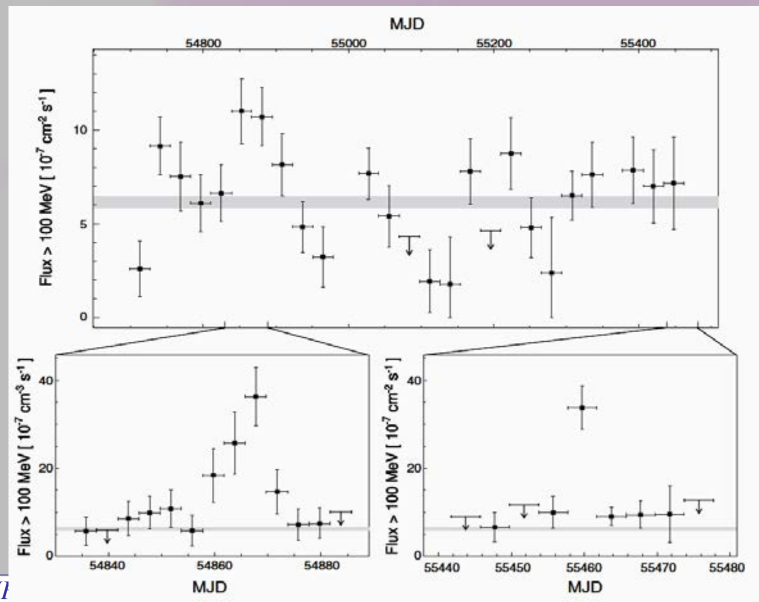
Structures this small only found in inner part of nebula, close to the pulsar wind termination shock, the base of the jet, or the pulsar.



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

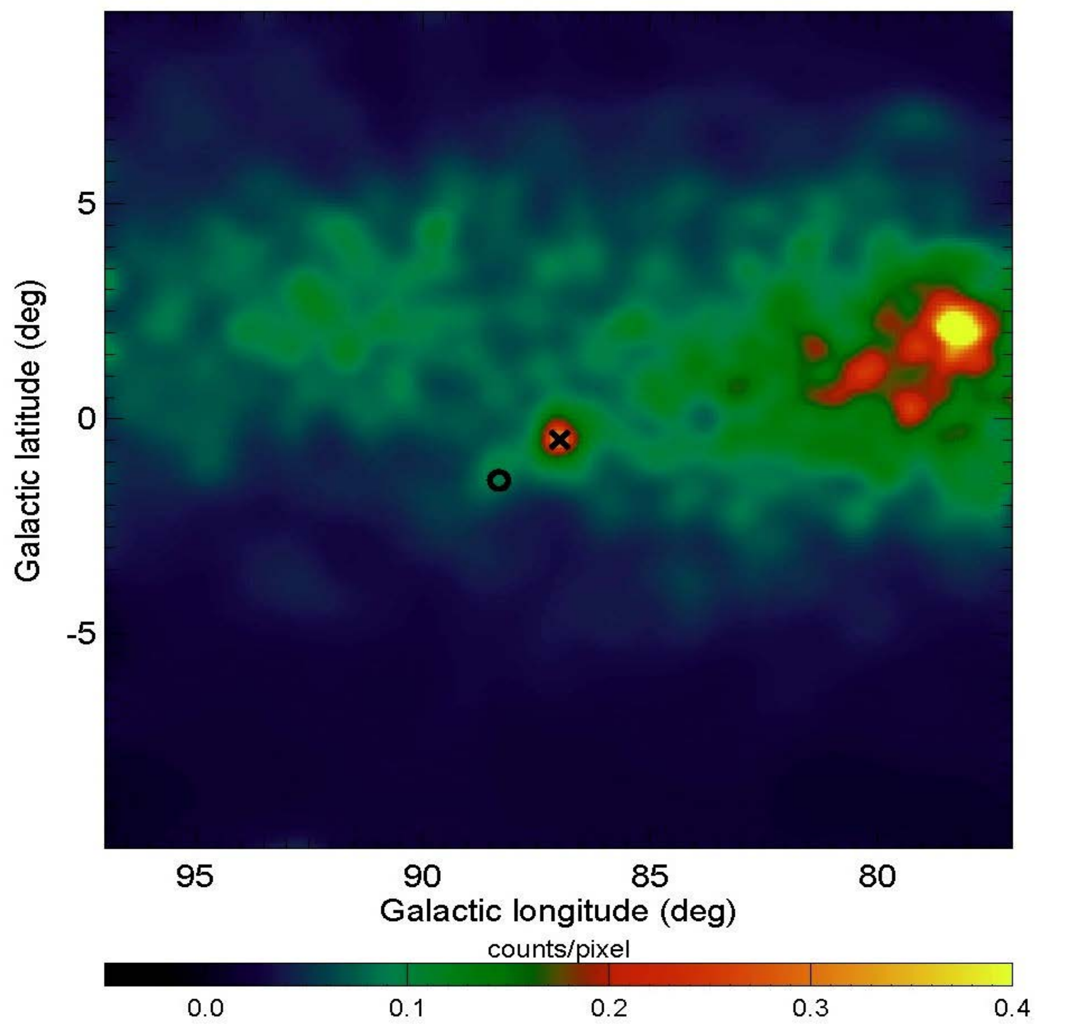
Galactic latitude -0.5 deg

Distance: ~ 2.7 kpc

System = RG + WD

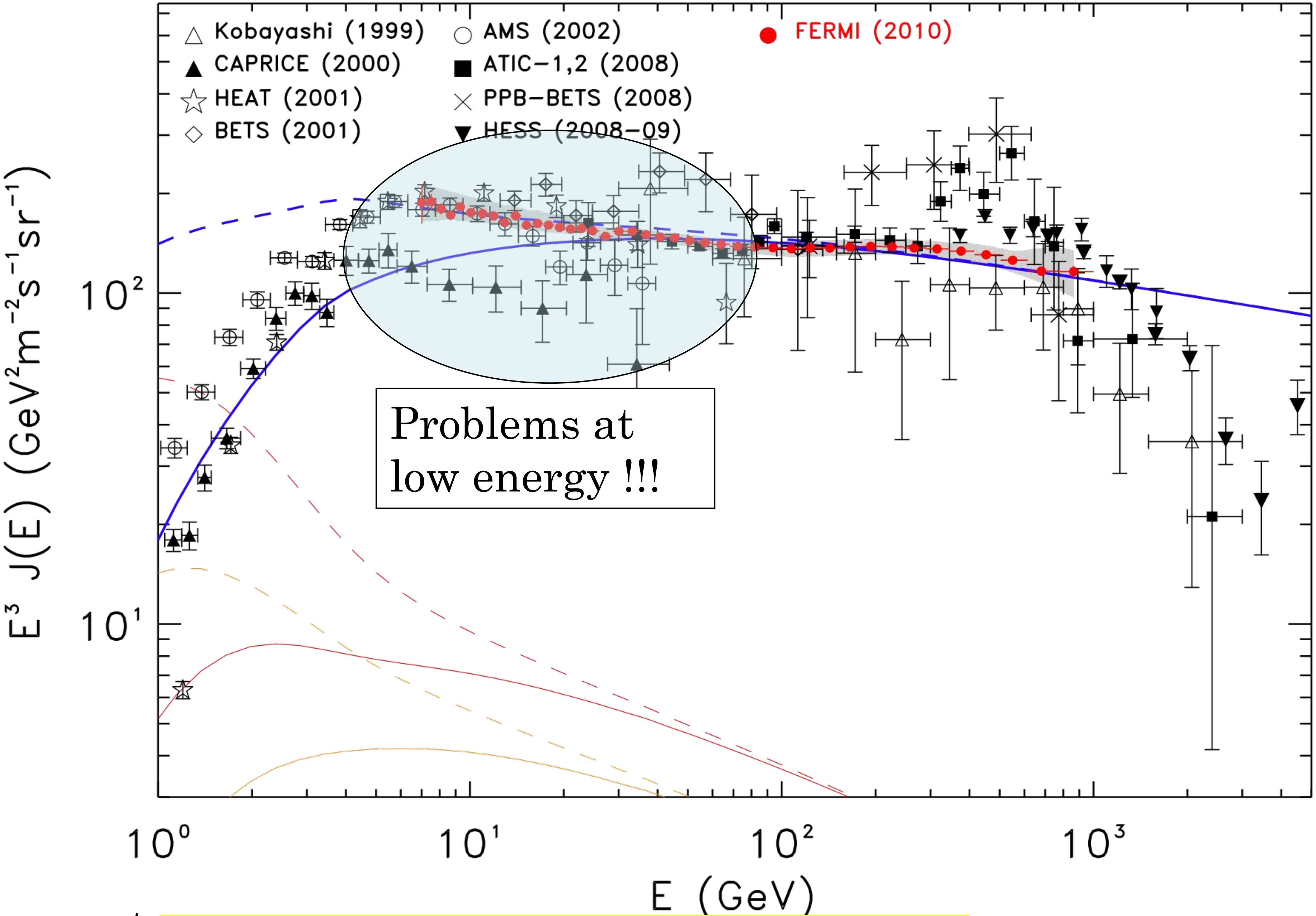
RG: Mira-like, M6 III, with anomalous Li abundance

Orbital period of system not certain



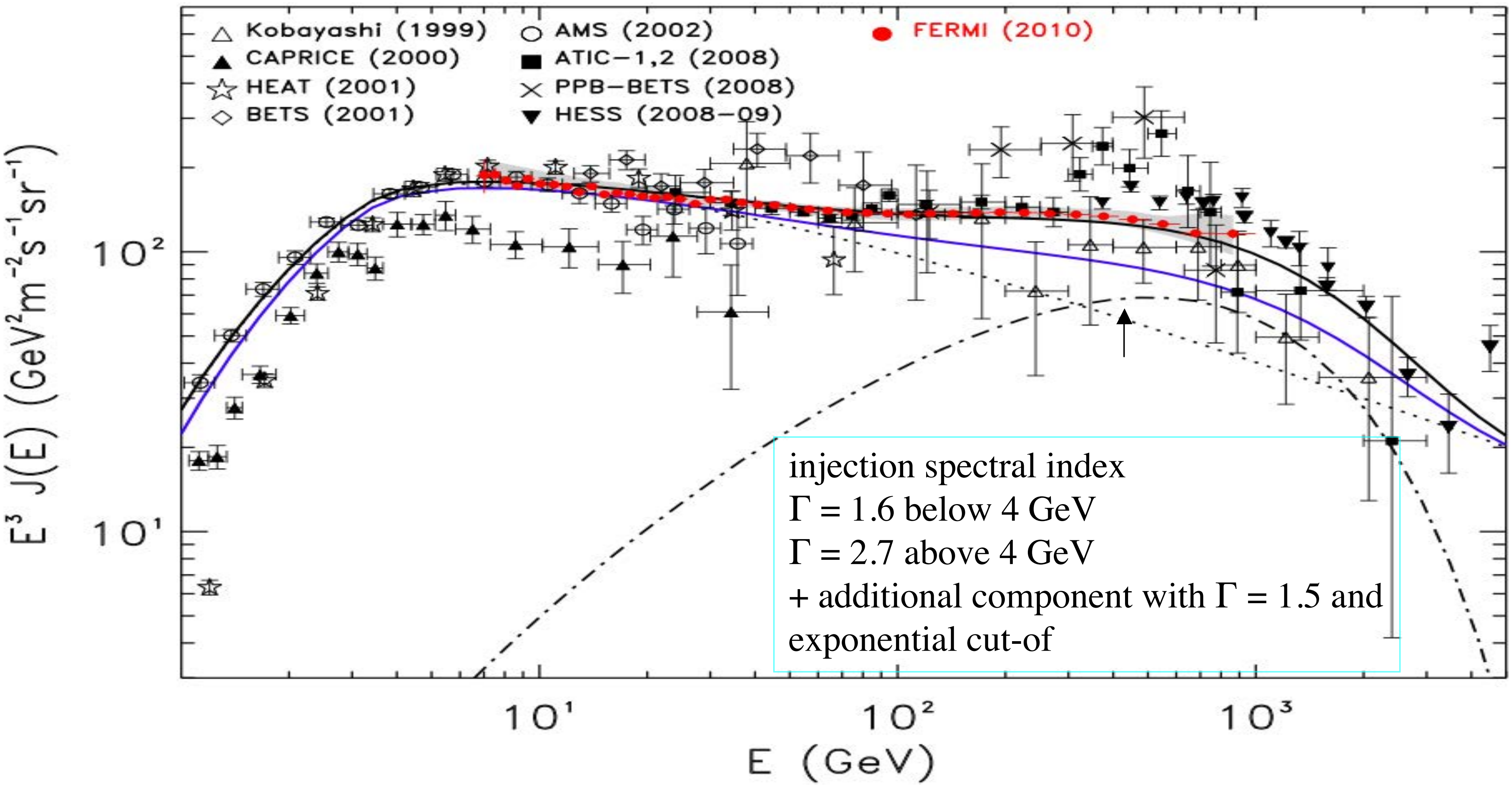
optical nova discovery March 10, 2010 (peak mag. ~7)
gamma-ray peak: March 13-14, 2010

New Fermi-LAT data



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

Electron spectrum and a conventional GALPROP model +...



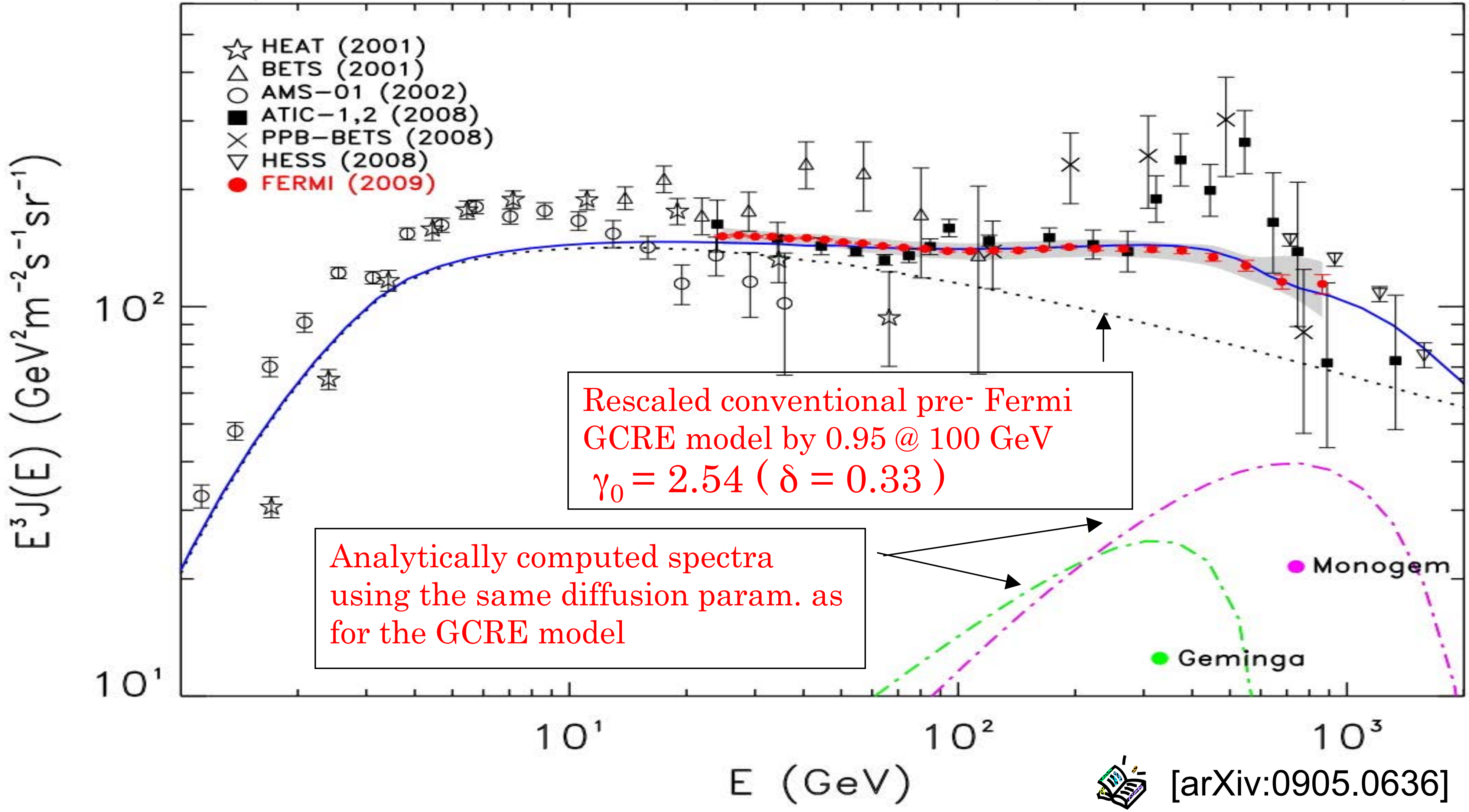
Hard to get a good fit with a single-component diffusive model

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]

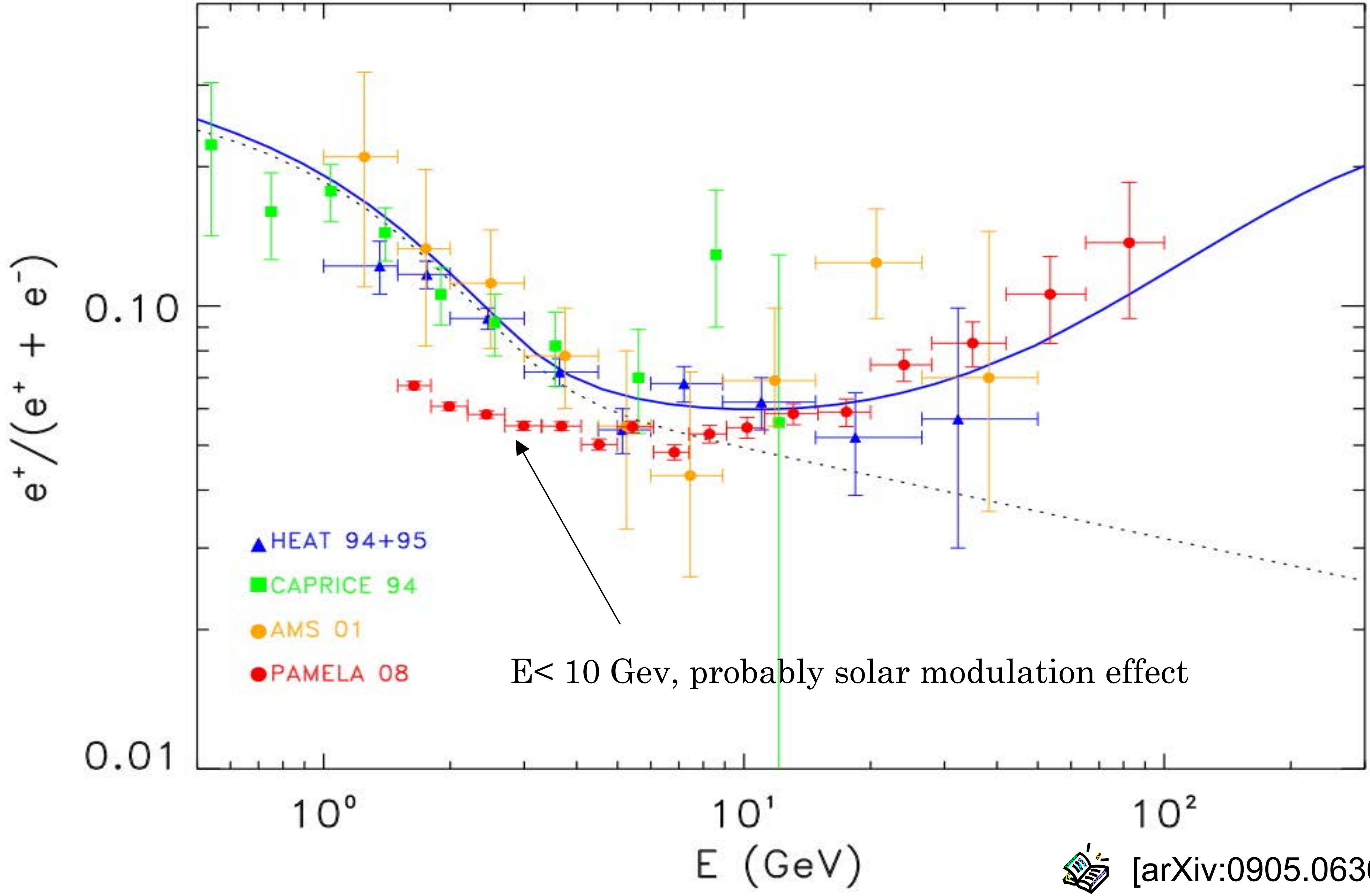
The CRE spectrum accounting for nearby pulsars (d < 1 kpc)



[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]

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

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

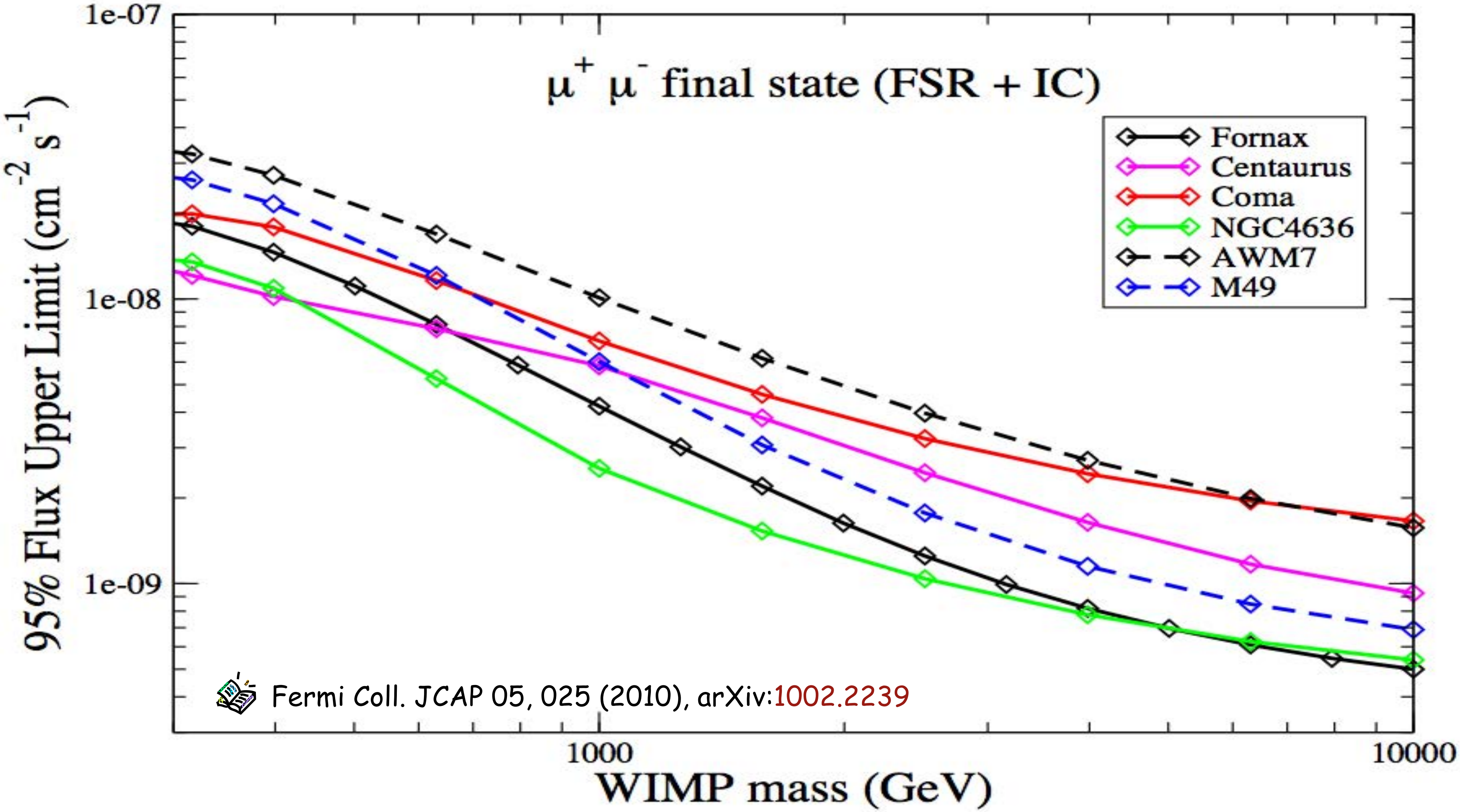
- Model generally reproduces data well within uncertainties. The model somewhat under-predicts the data in the few GeV range (spatial residuals under investigation)

- 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

Galactic Center Observation

- **2011-8-31 12:00:00 - 2011-9-2 12:00:00**
- **Part of an intensive campaign with Herschel and XMM to search for correlated 20-60 min flares.**
- **Additional ground-based observatories**
- **EVLA, VLBA, CSO, CARMA, GBT, ATCA, Subaru, APEX, SMA**

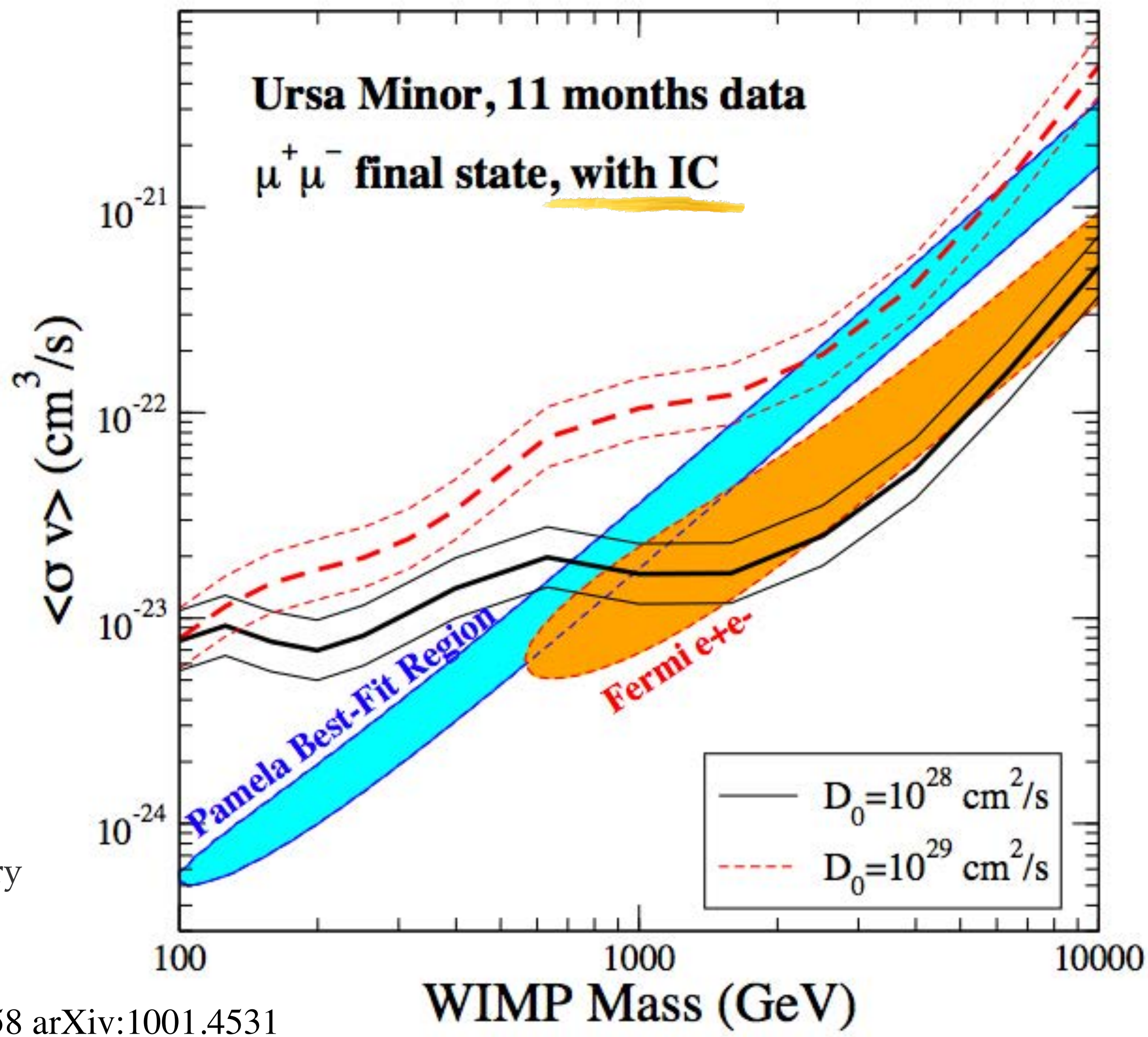
Dwarf Spheroidal Galaxies upper-limits

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

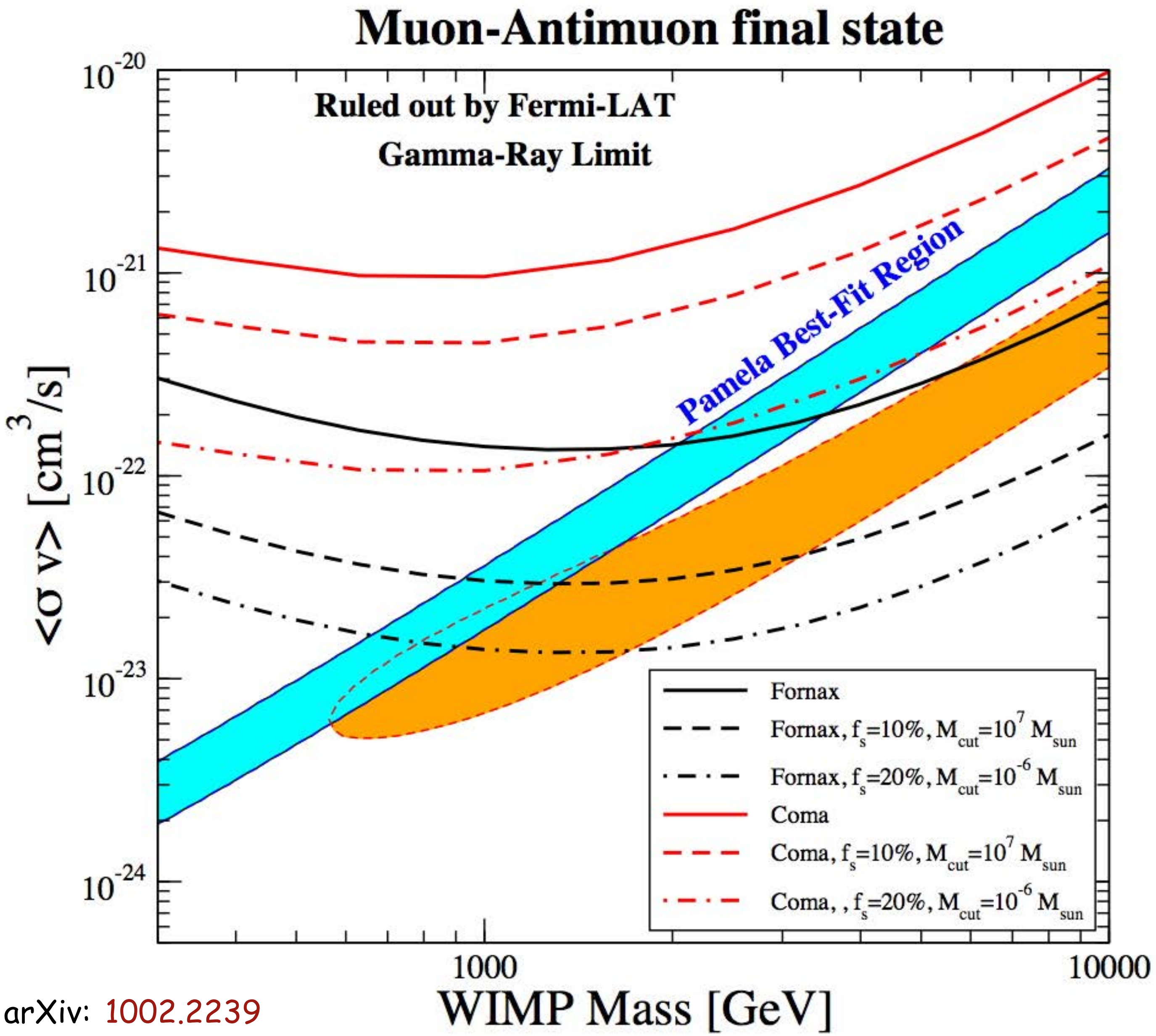
(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)



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

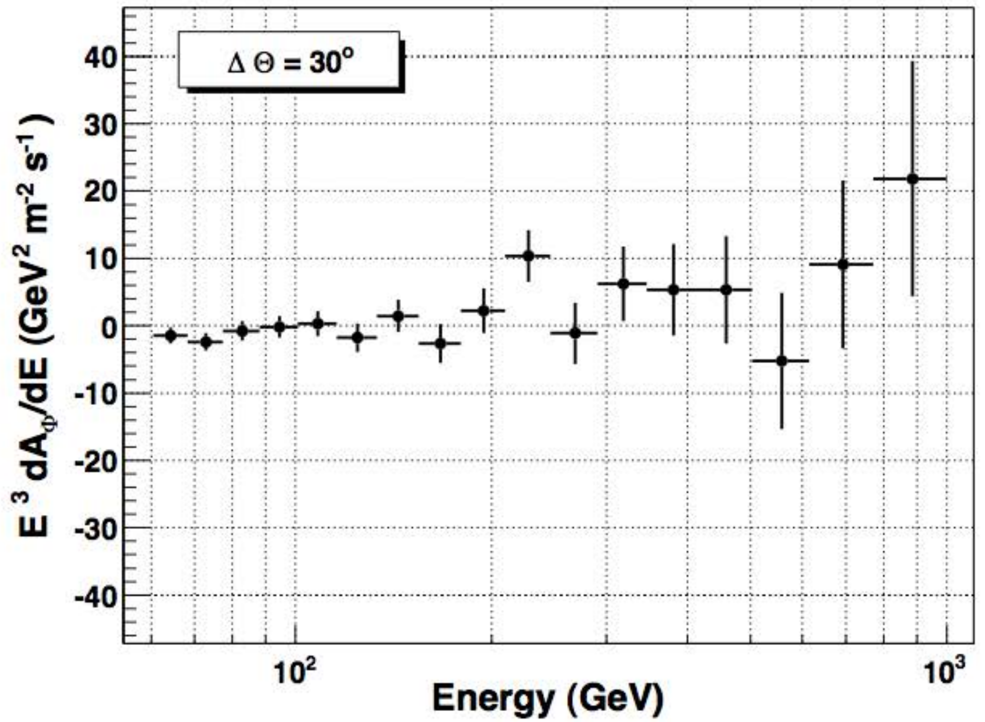


Fermi Coll. JCAP 05, 025 (2010), arXiv: 1002.2239

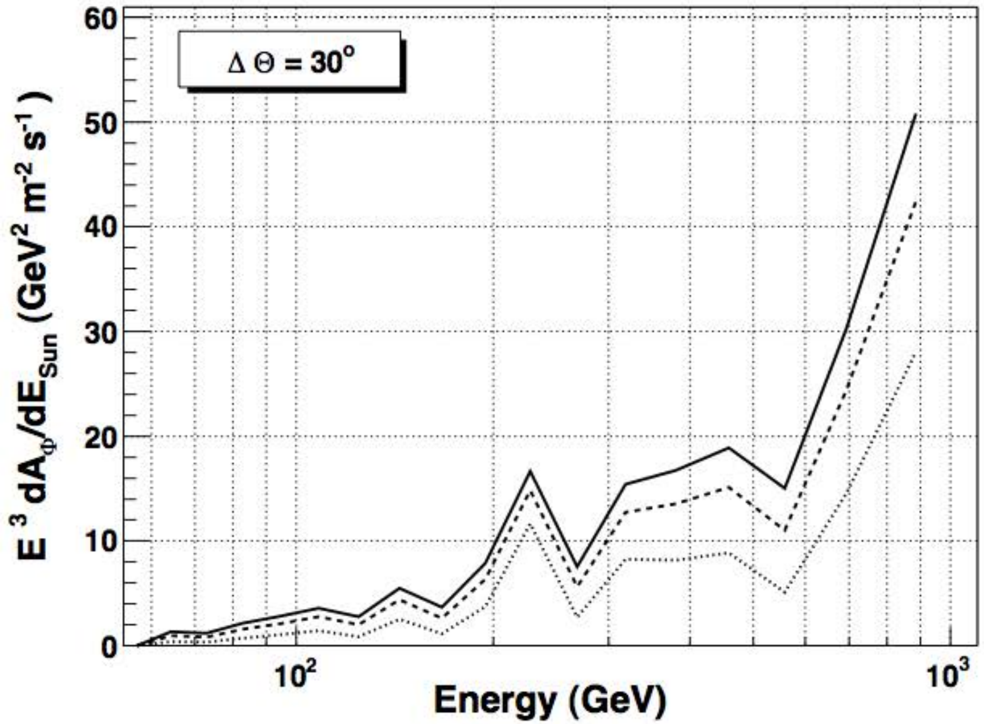
Flux asymmetry (real vs. fake Sun)

- fluxes evaluated in a cone of 30° angular radius centered on the real or fake Sun

flux difference (real Sun - fake Sun)



flux upper limits (68%, 95%, 99% CL)

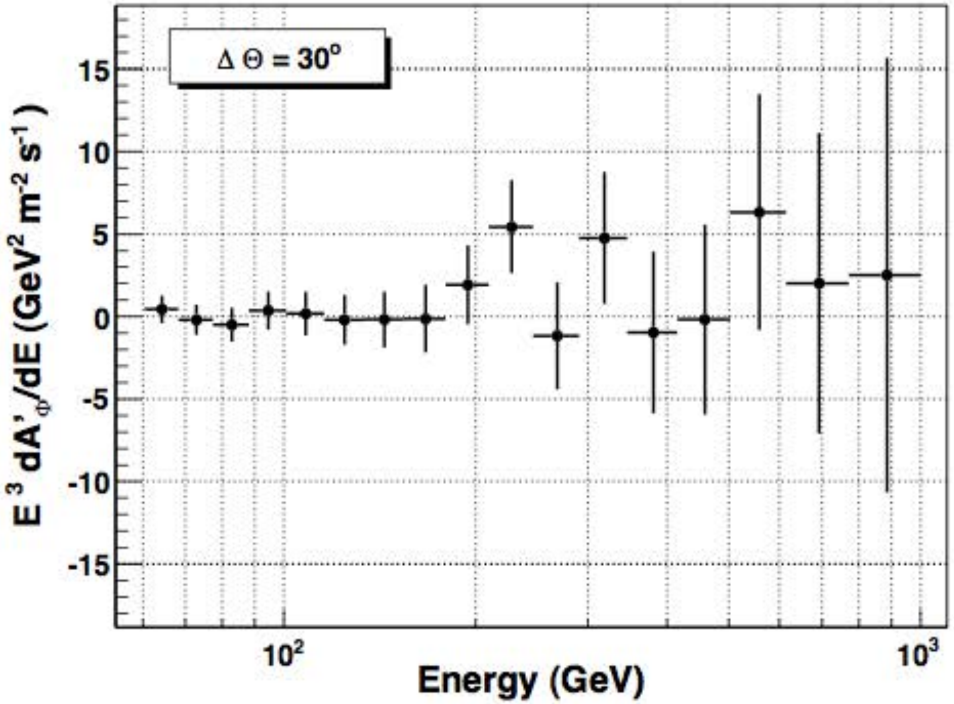


no flux excess detected in any energy bin at > 3σ

Comparison with isotropic flux

fluxes evaluated in a cone of 30° angular radius centered on the real Sun

flux difference (real Sun - simulated isotropic)



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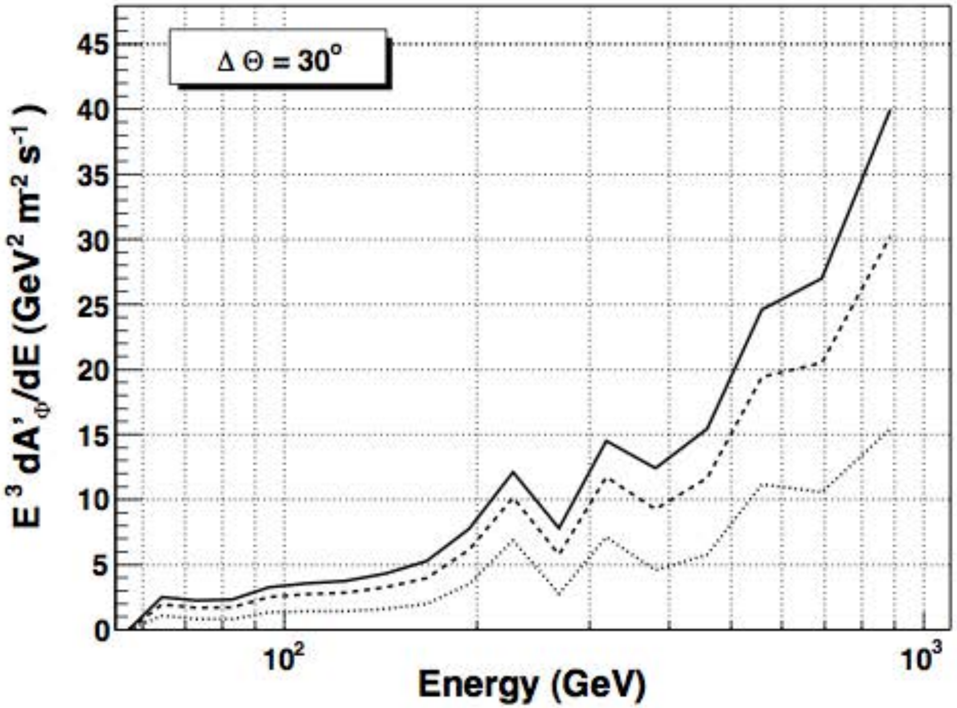
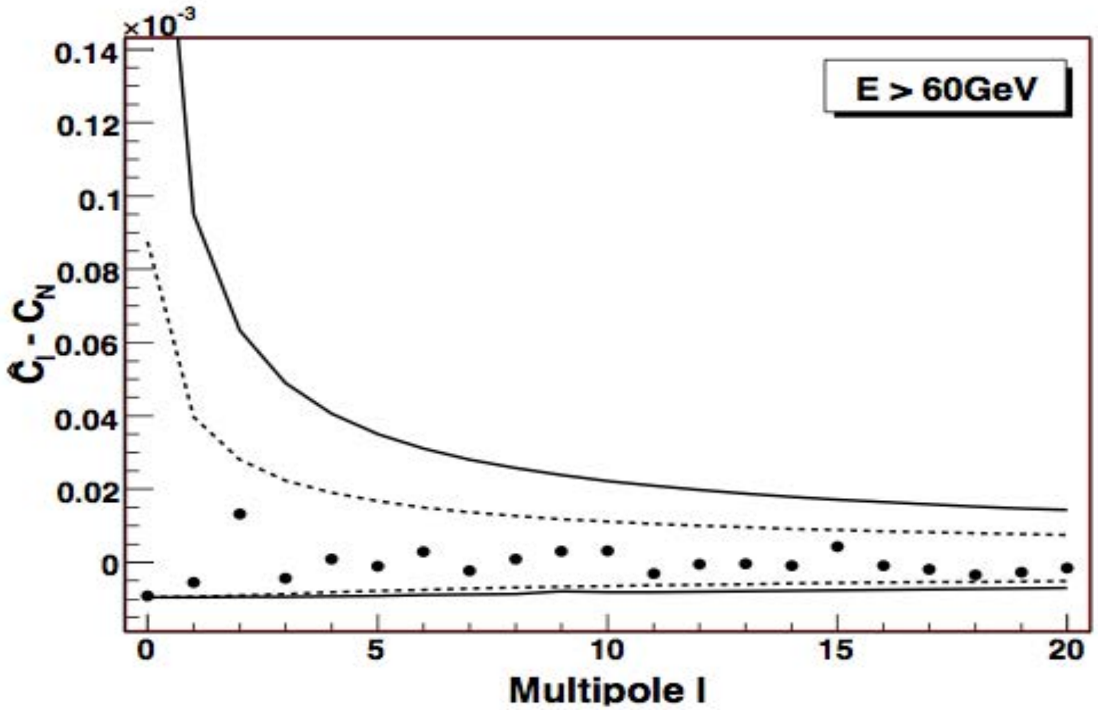


no flux excess detected in any energy bin at > 3σ

Spherical harmonics analysis

fluctuation angular power spectrum of events E>60 GeV

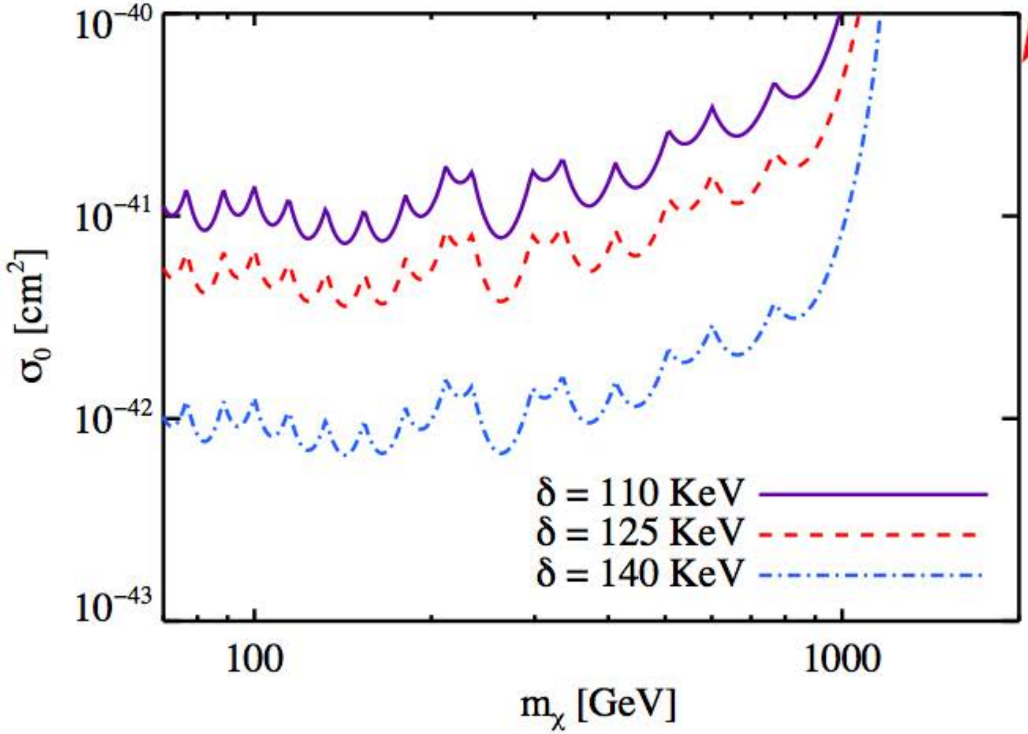


dotted and dashed lines show 3σ and 5σ limits on probability distribution of shot noise C_N

no significant angular power detected in this multipole range

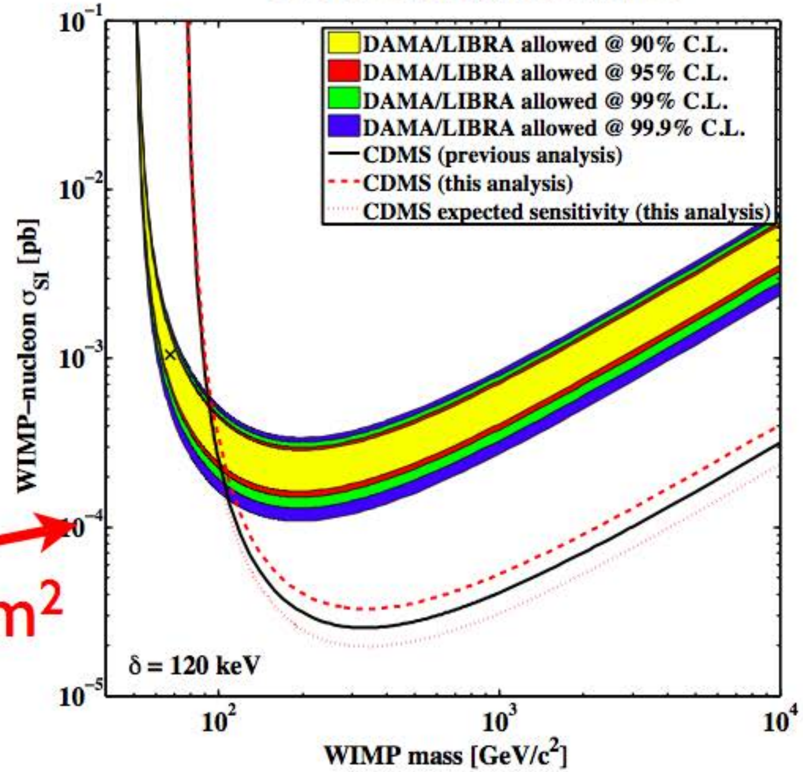
Limits on inelastic scattering cross-section

Parameter space above curves excluded at 95% CL for CRE final state



10^{-40} cm^2

DAMA/LIBRA allowed regions and CDMS exclusion curves



solar CRE constraints exclude by ~ 1-2 orders of magnitude all of the parameter space compatible with an inelastic DM explanation of DAMA/LIBRA and CDMS for DM masses greater than ~ 70 GeV, assuming DM annihilates to CREs

CDMS Collaboration (2011)

- **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:**

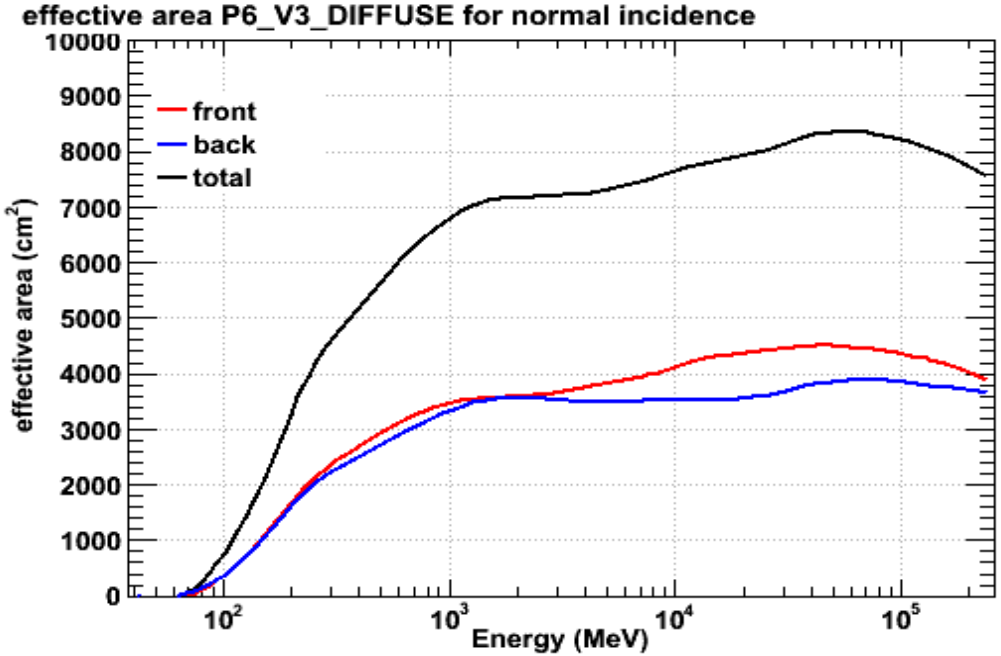
~170 billion LAT event triggers

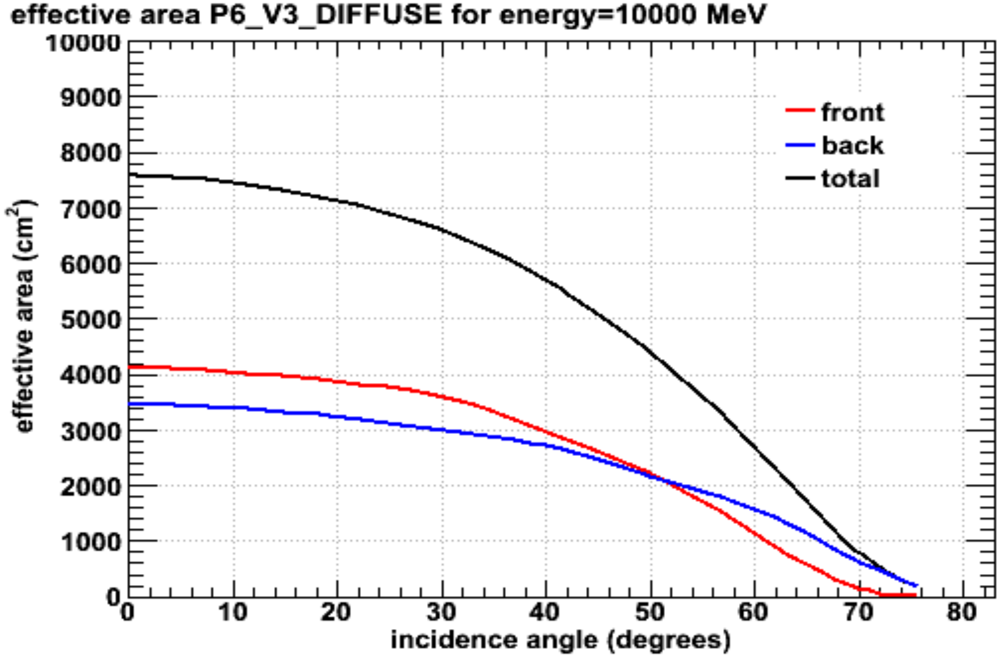
- GBM Triggers: 1194 (654 GRB, 141 TGF, 174 SGR, 56 solar flare)
- # Autonomous Repoint Requests (ARR):58
- Highest-z LAT GRB: 4.35
- Highest-energy photon from a GRB: 33 GeV (at 82s, z=1.82)
- Highest-z LAT AGN:3.1
- # Gamma-ray pulsars: 88
- # Millisecond Pulsars (MSPs): 27
- # Gamma-ray-only (blind)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

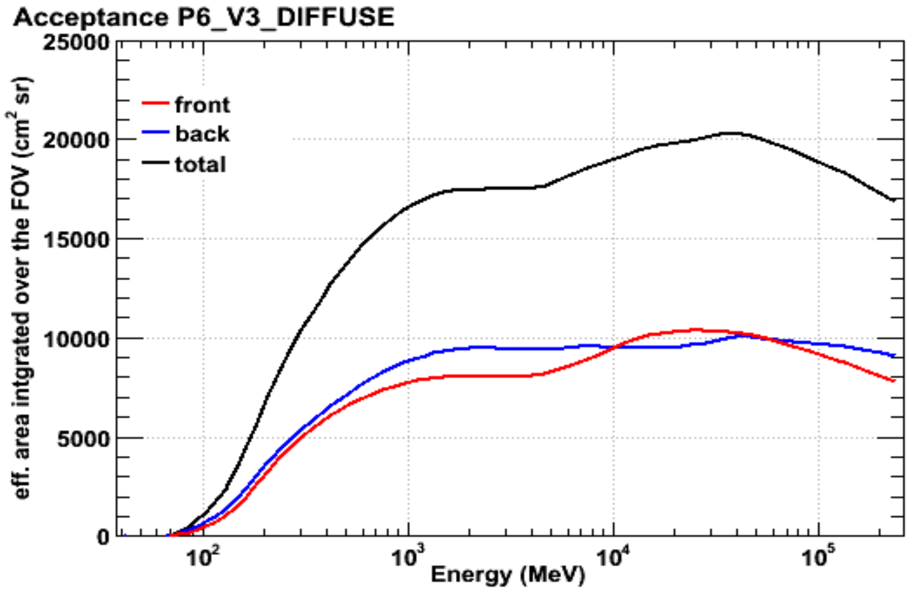
- **the Second Fermi LAT Catalog 2FGL:**

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%

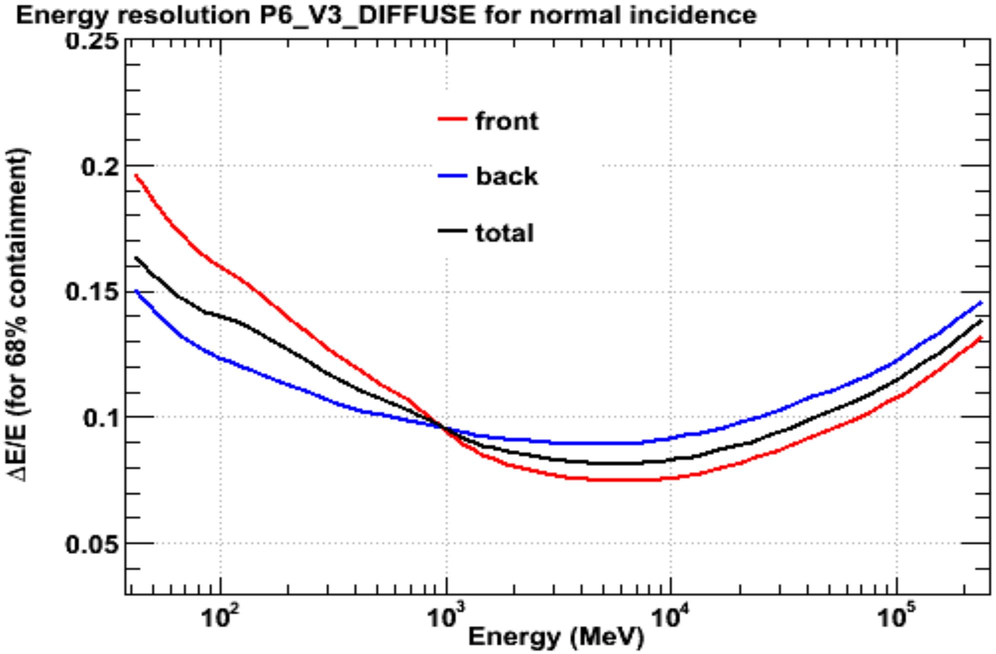
Fermi IRF

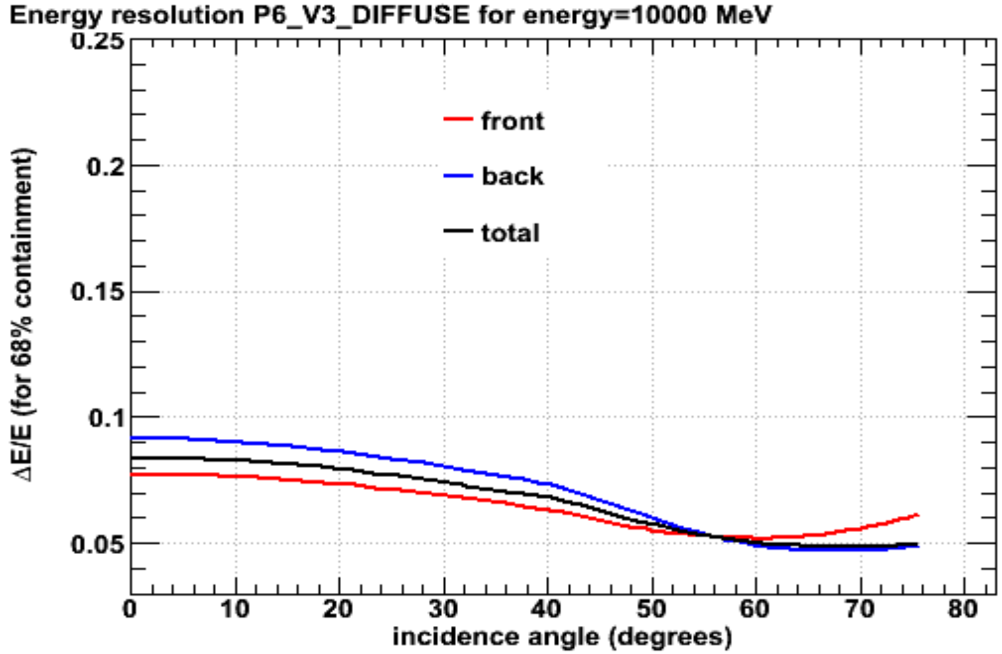

effective area P6_V3_DIFFUSE for normal incidence
effective area (cm^2)
Energy (MeV)
front
back
total
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
10^2
10^3
10^4
10^5

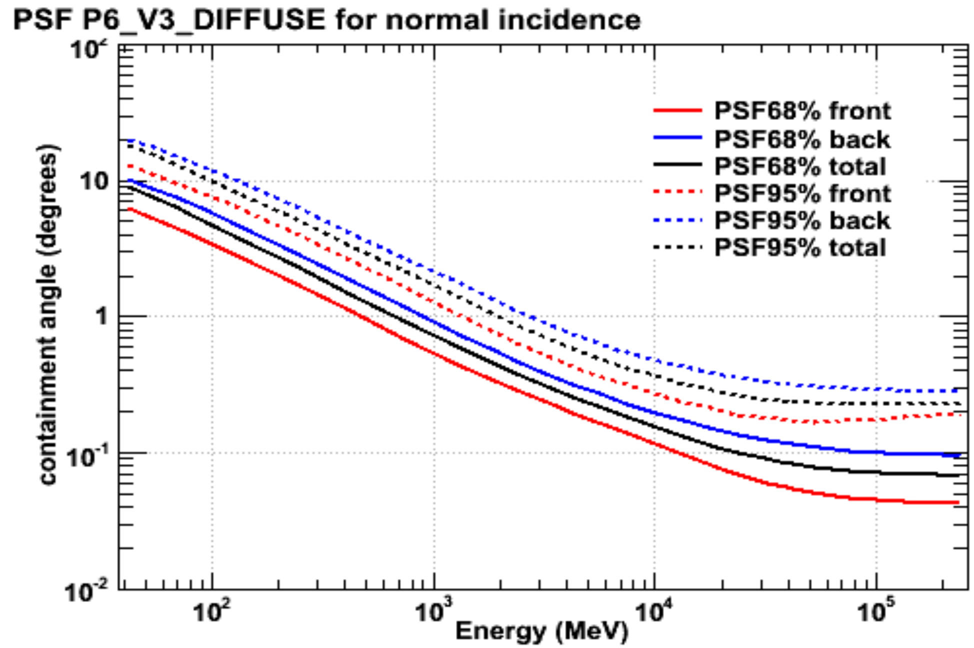

effective area P6_V3_DIFFUSE for energy=10000 MeV
effective area (cm^2)
incidence angle (degrees)
front
back
total
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
10
20
30
40
50
60
70
80

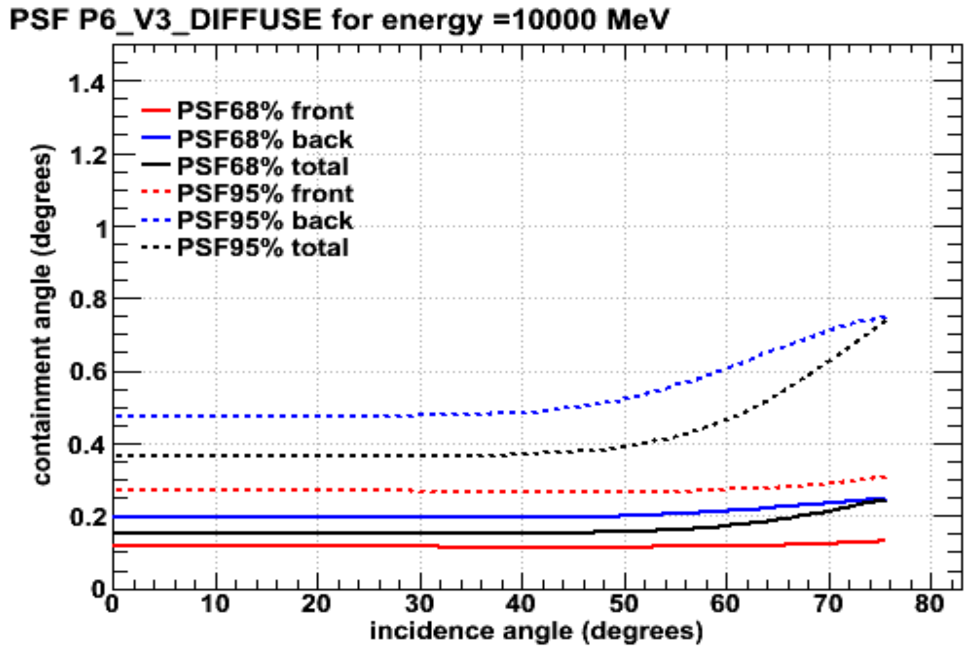

Acceptance P6_V3_DIFFUSE
eff. area intgrated over the FOV (cm^2 sr)
Energy (MeV)
front
back
total
0
5000
10000
15000
20000
25000
10^2
10^3
10^4
10^5

Fermi IRF

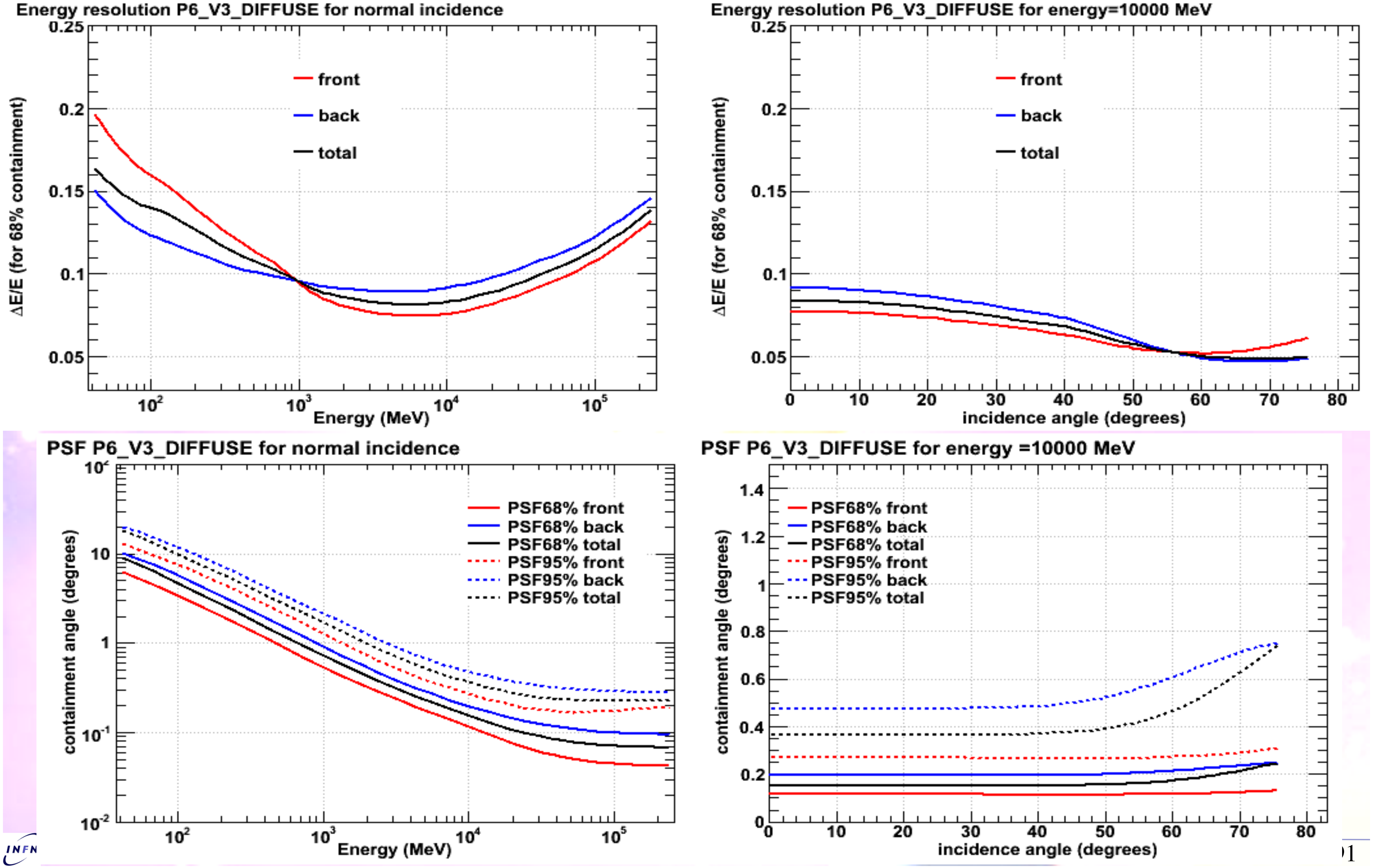

Energy resolution P6_V3_DIFFUSE for normal incidence
ΔE/E (for 68% containment)
Energy (MeV)
front
back
total


Energy resolution P6_V3_DIFFUSE for energy=10000 MeV
ΔE/E (for 68% containment)
incidence angle (degrees)
front
back
total

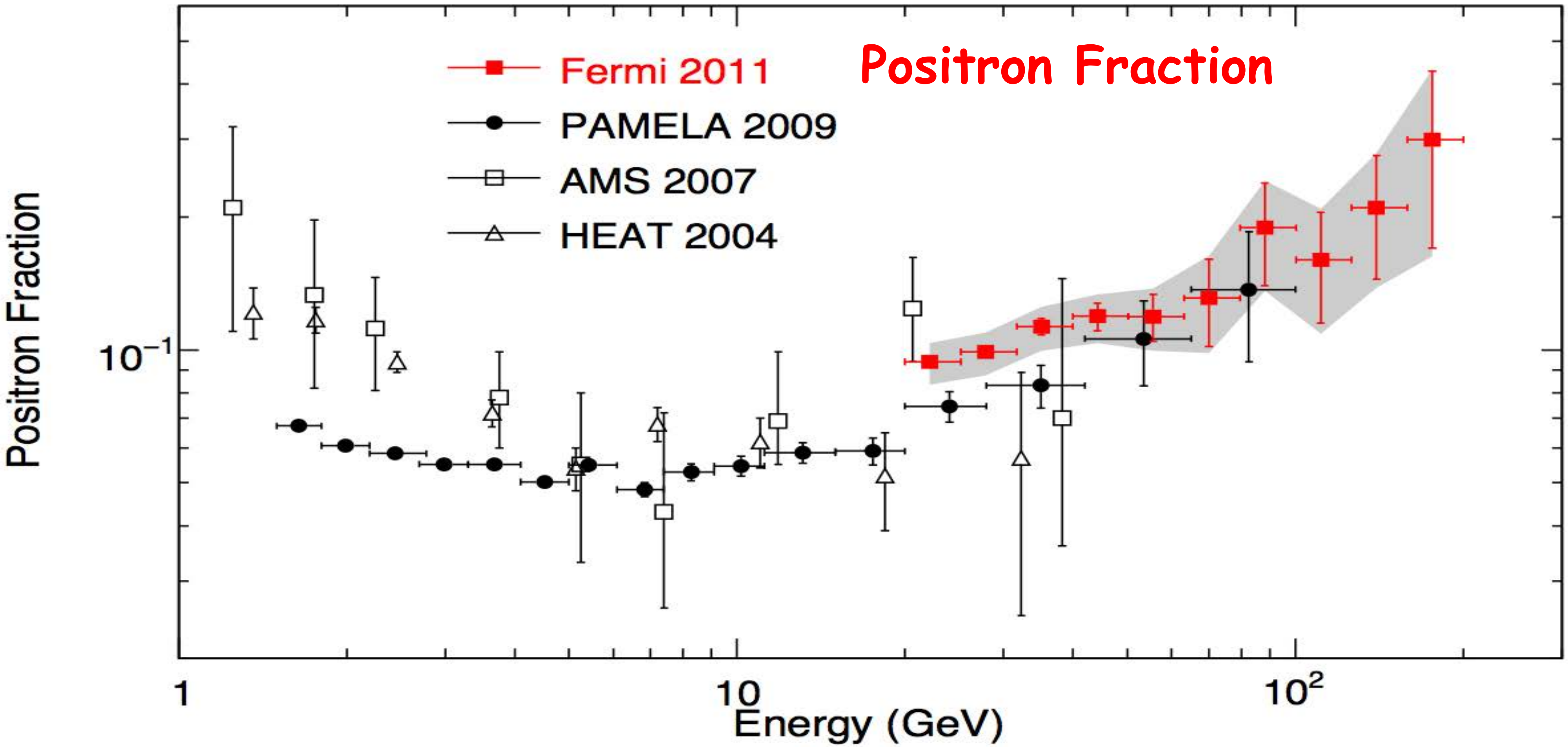

PSF P6_V3_DIFFUSE for normal incidence
containment angle (degrees)
Energy (MeV)
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total


PSF P6_V3_DIFFUSE for energy =10000 MeV
containment angle (degrees)
incidence angle (degrees)
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total

Fermi IRF



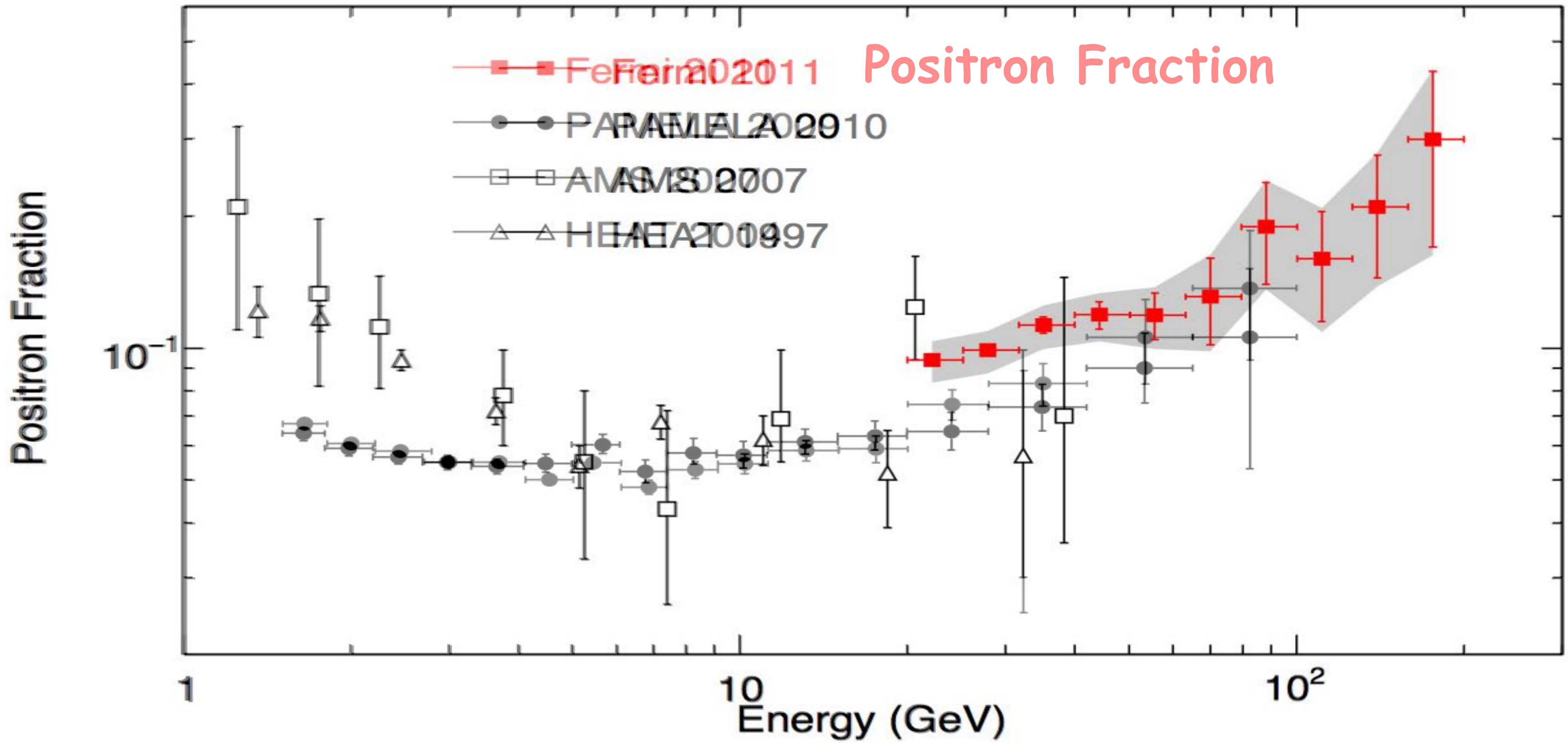
Energy resolution P6_V3_DIFFUSE for normal incidence
ΔE/E (for 68% containment)
Energy (MeV)
front
back
total
Energy resolution P6_V3_DIFFUSE for energy=10000 MeV
ΔE/E (for 68% containment)
incidence angle (degrees)
PSF P6_V3_DIFFUSE for normal incidence
containment angle (degrees)
Energy (MeV)
PSF68% front
PSF68% back
PSF68% total
PSF95% front
PSF95% back
PSF95% total
PSF P6_V3_DIFFUSE for energy =10000 MeV
containment angle (degrees)
incidence angle (degrees)



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**

Fermi Coll. arXiv:1109.0521



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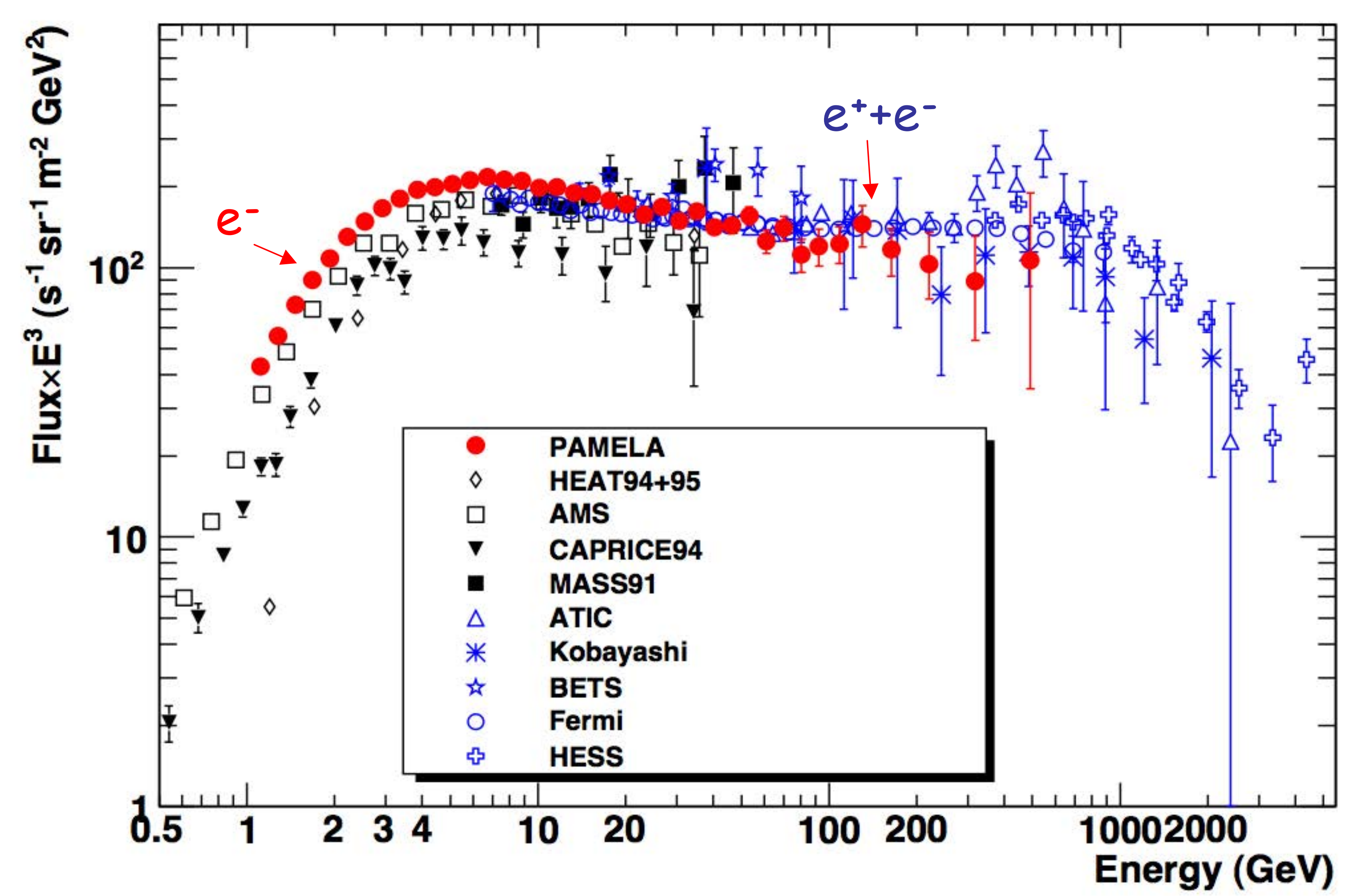
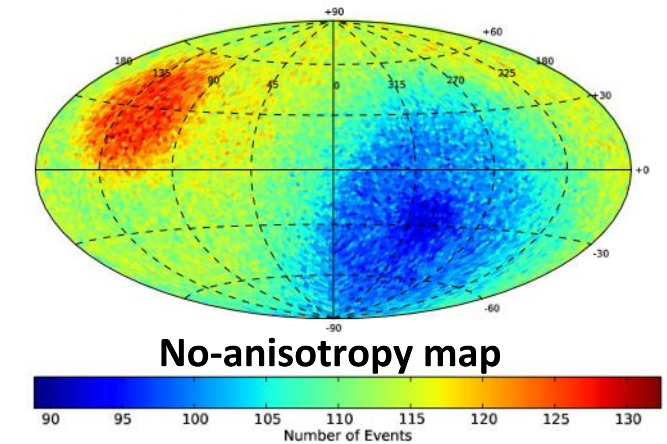
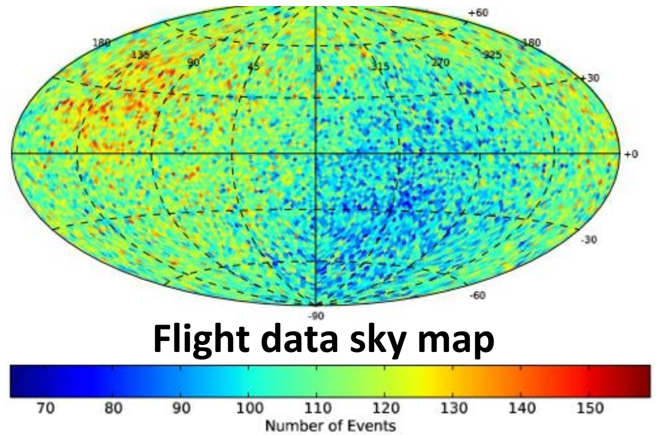
Fermi Coll. arXiv:1109.0521

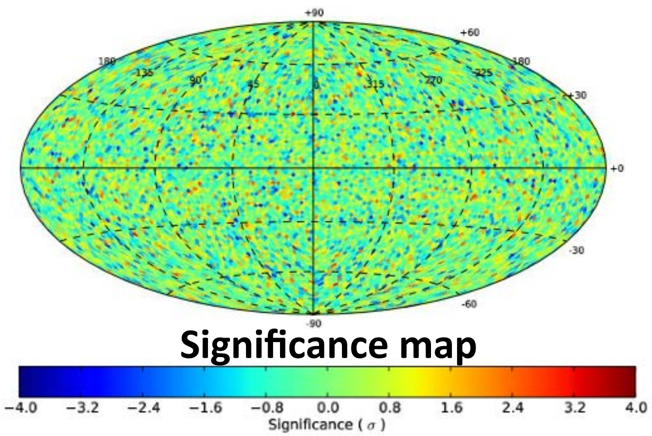
e^- from PAMELA and e^++e^- from FERMI



Cosmic Ray Electrons Anisotropy



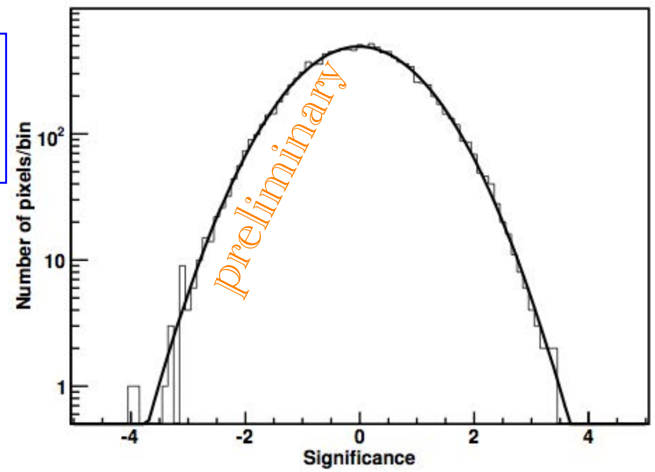




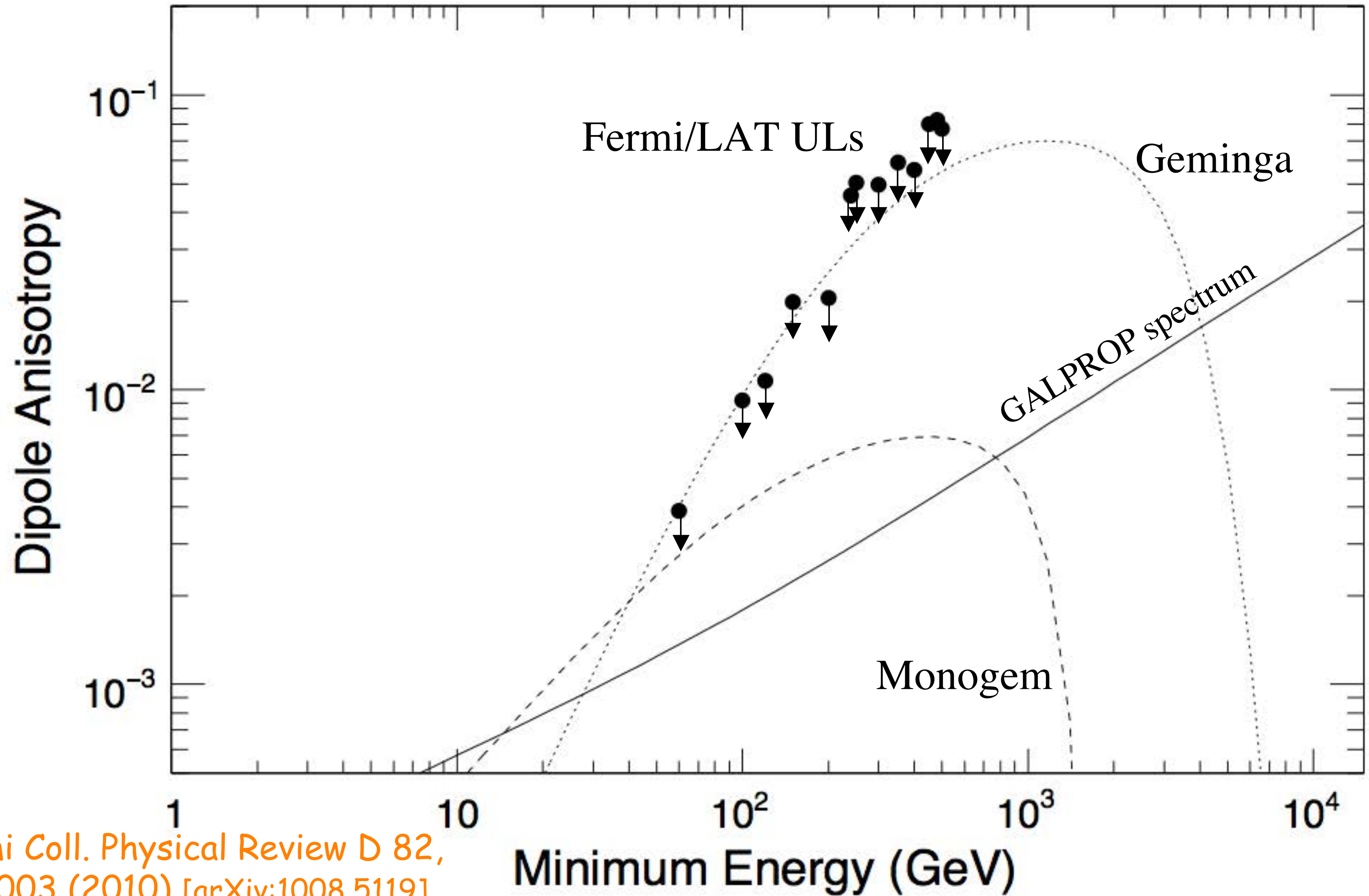
the levels of anisotropy expected for Geminga-like and Monogem-like sources (i.e. sources with similar distances and ages) seem to be higher than the scale of anisotropies excluded by the results However, it is worth to point out that the model results are affected by large uncertainties related to the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

Distribution of significance, fitted by a Gaussian →

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

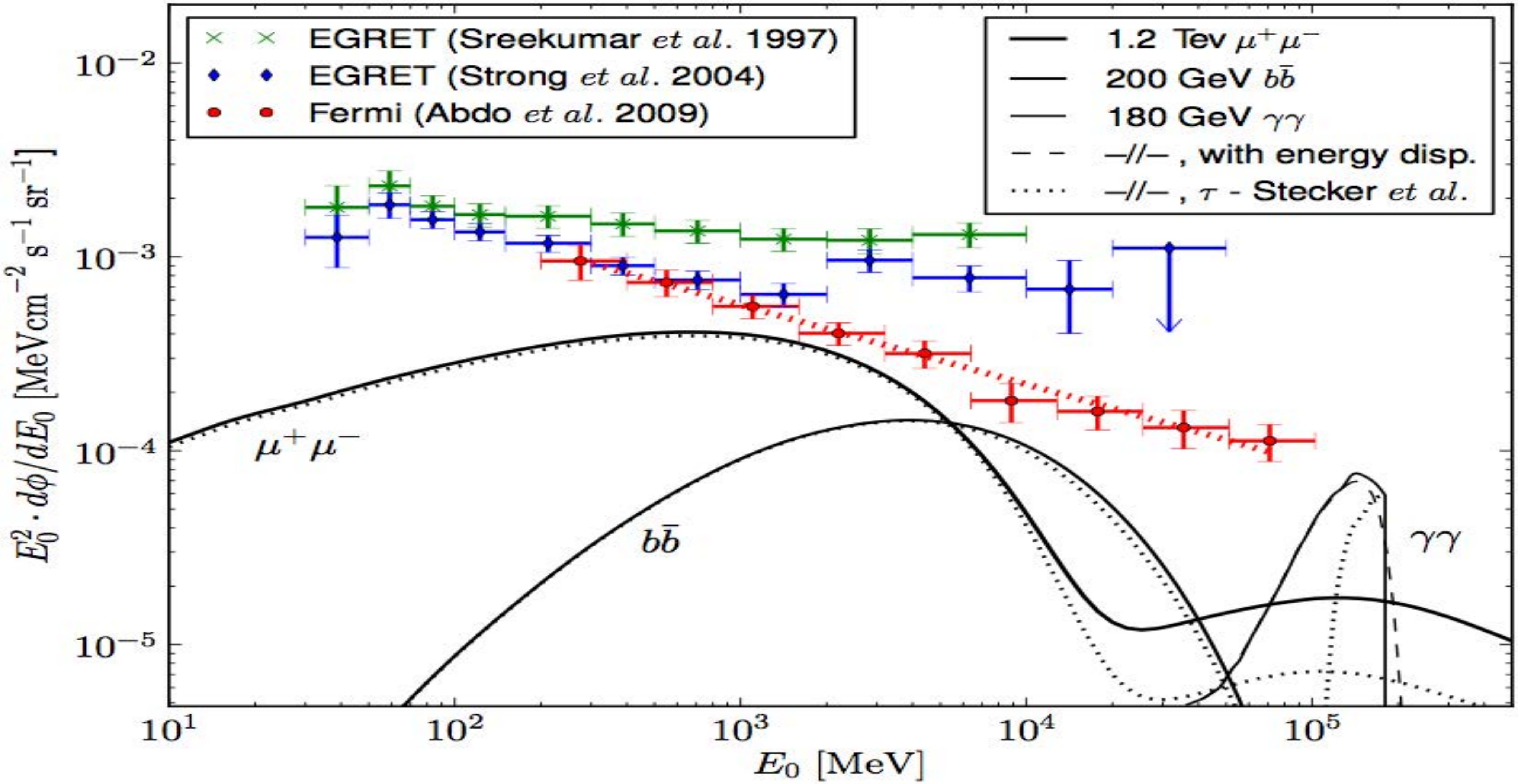


electron + positron expected anisotropy in the directions of Monogem and Geminga



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

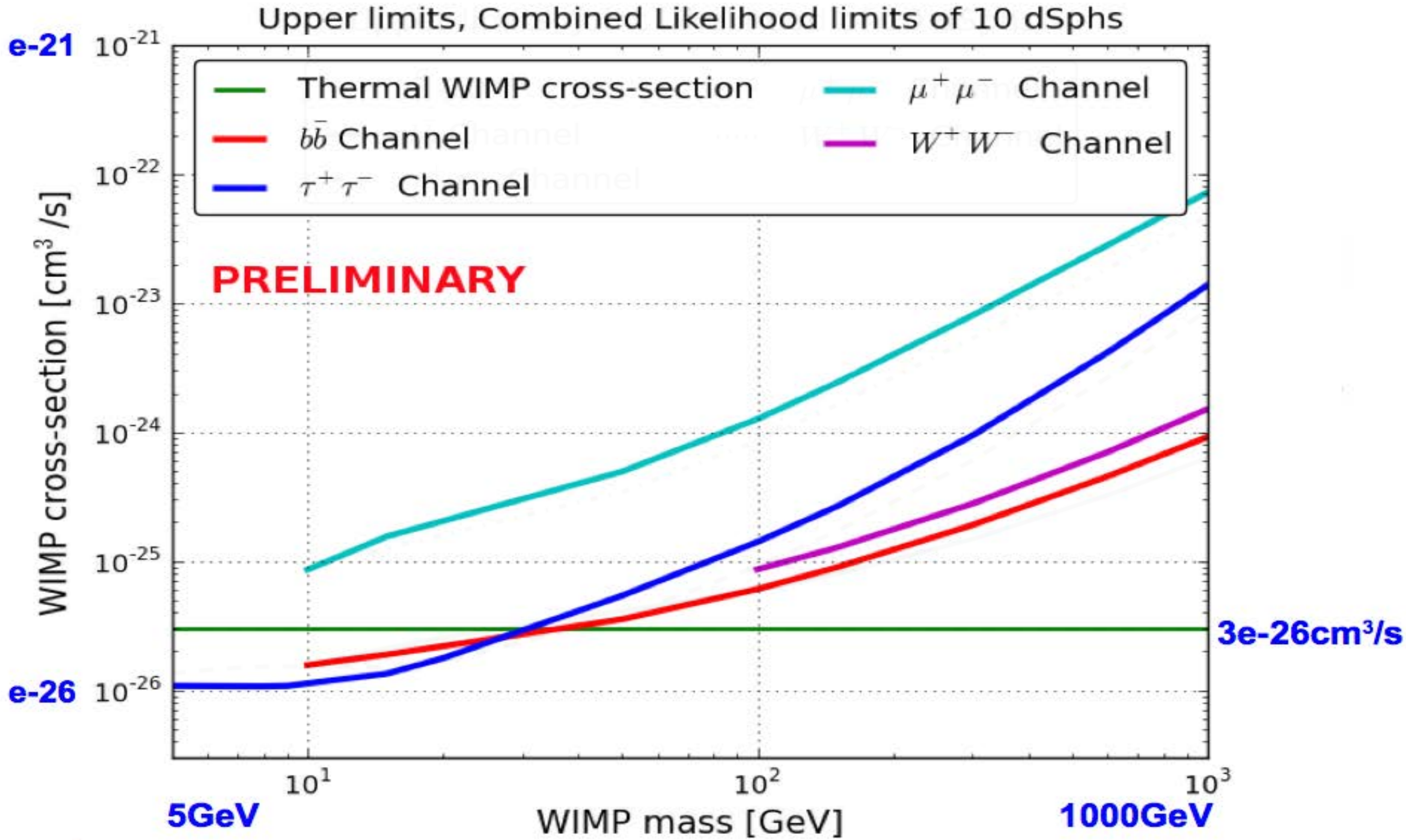
extragalactic gamma-ray spectrum



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

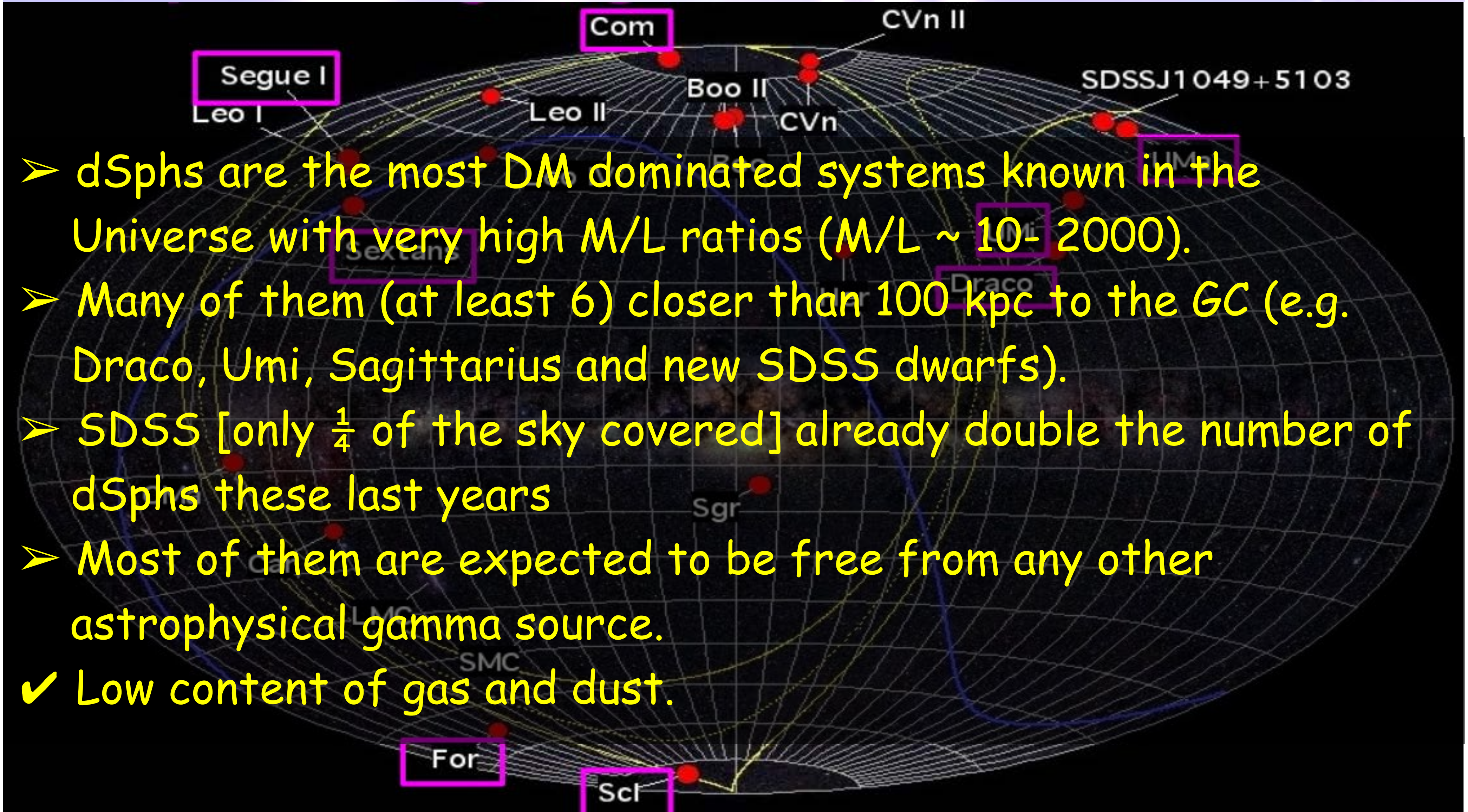
others possible contributions to the extragalactic gamma-ray spectrum

Dwarf Spheroidal Galaxies upper-limits Update



robust constraints including J-factor uncertainties

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

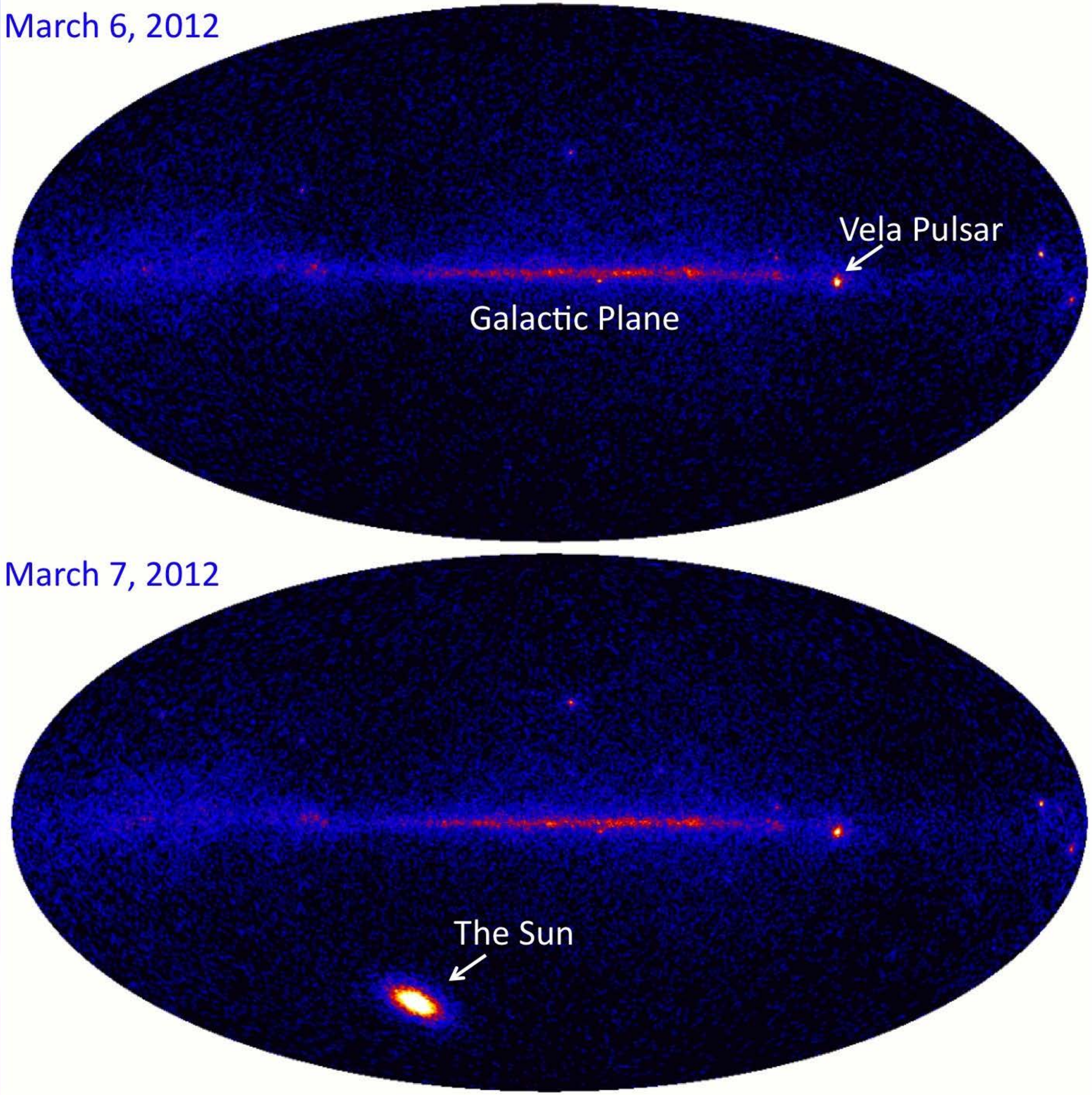


- ➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- ➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- ➢ SDSS [only $\frac{1}{4}$ of the sky covered] already double the number of dSphs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

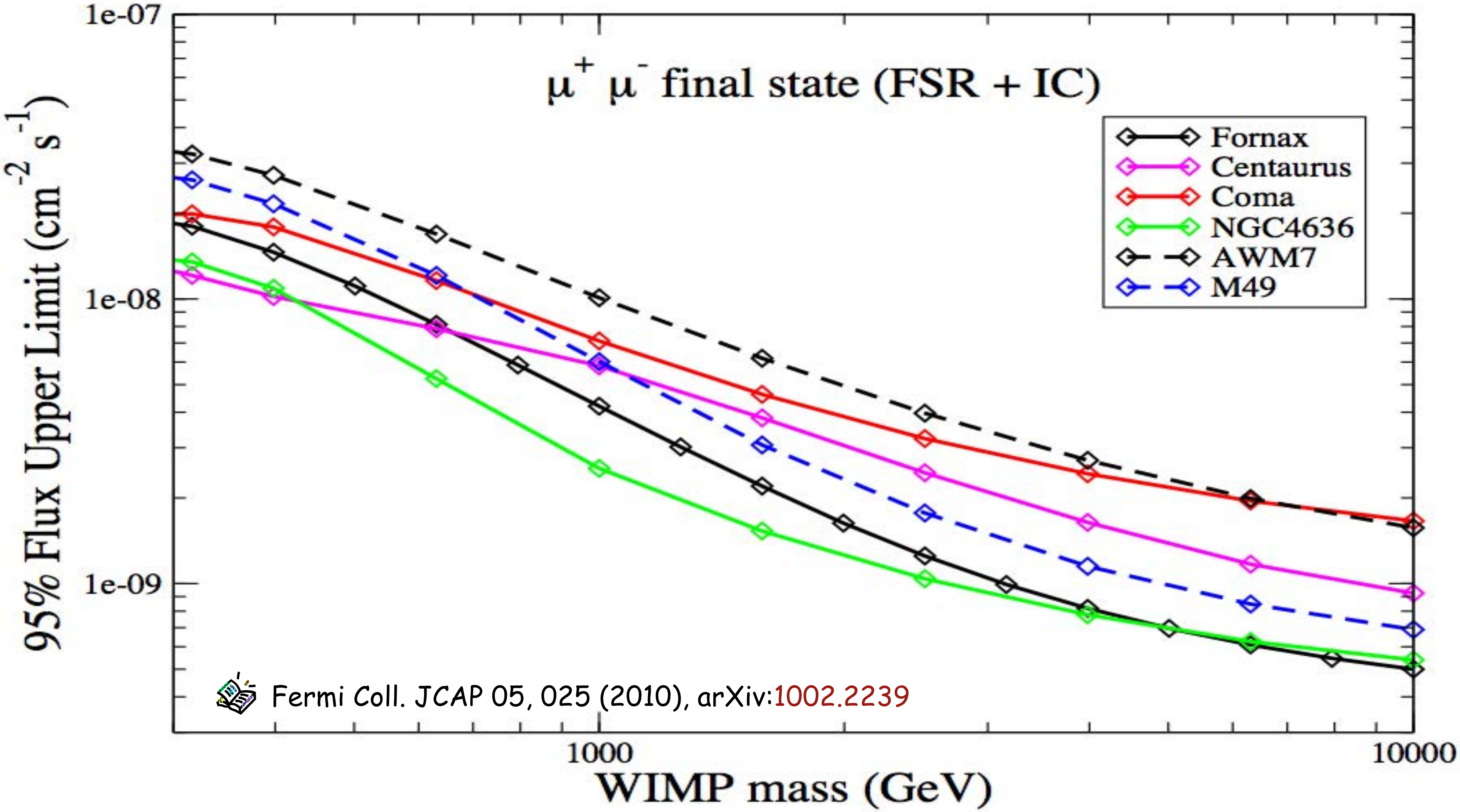
Solar flares

on March 7, a powerful solar flare dominated the gamma-ray sky

the became nearly 100 times brighter than the Vela Pulsar



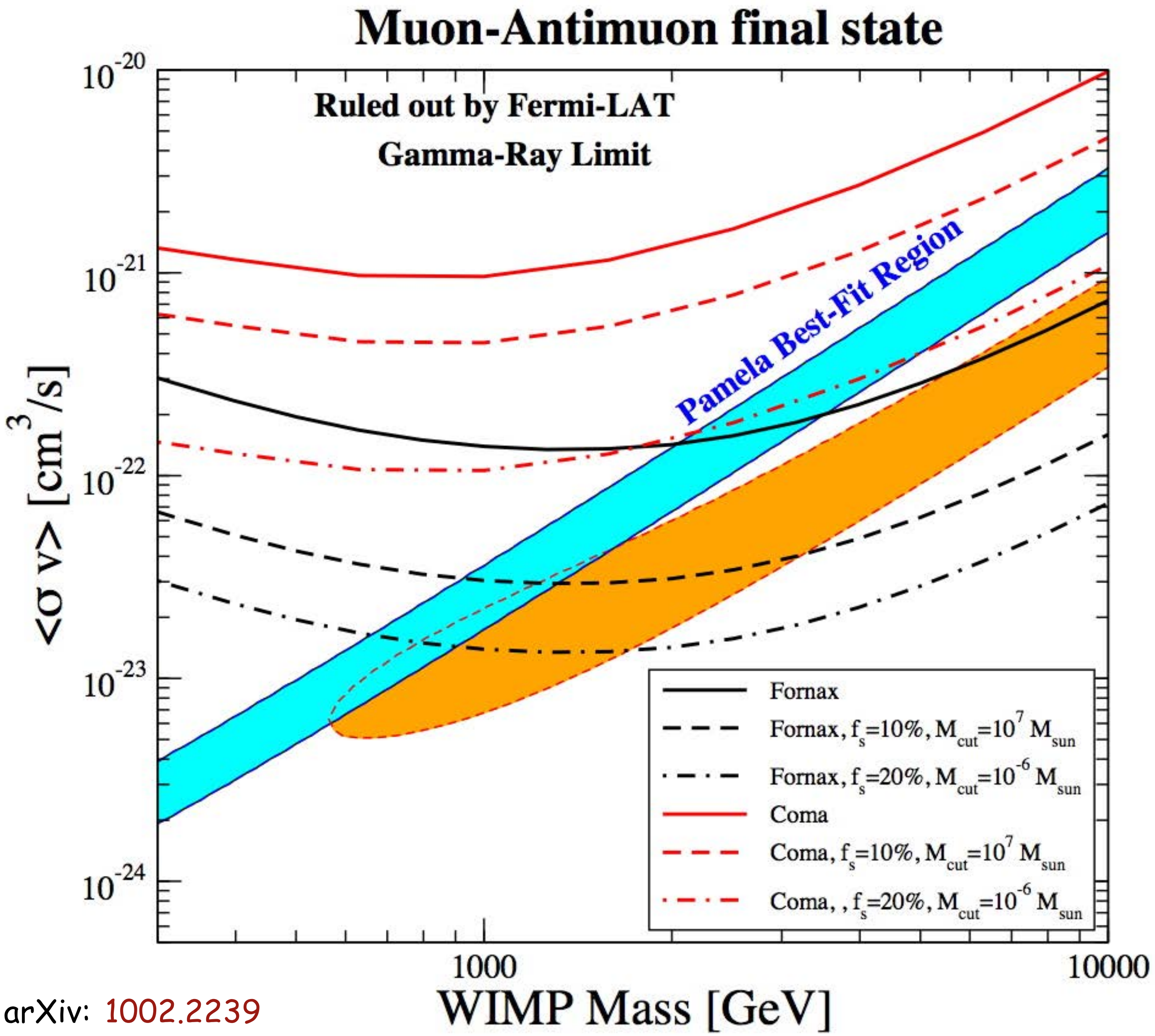
Galaxy Clusters upper-limits



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

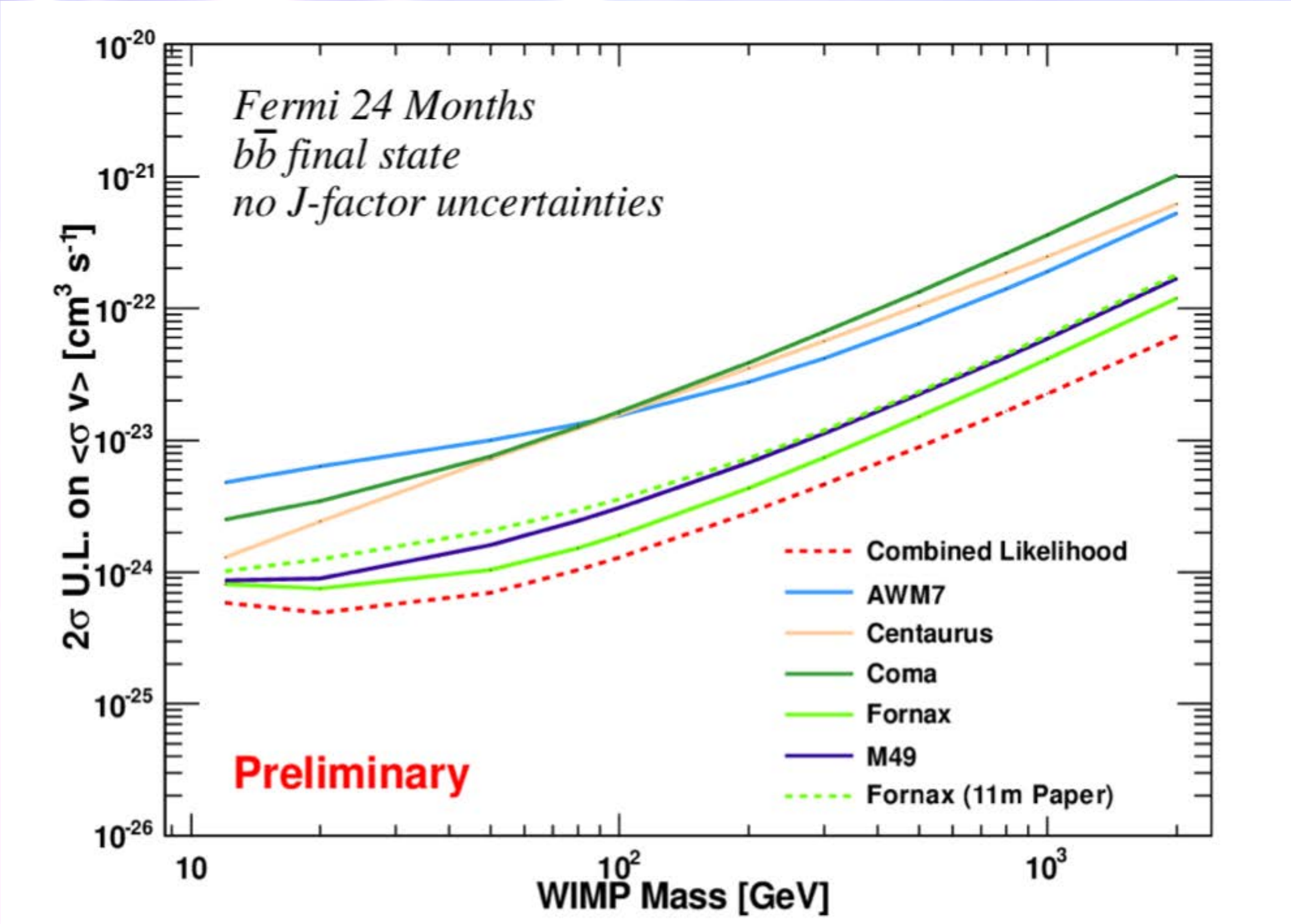
Galaxy Clusters upper-limits

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

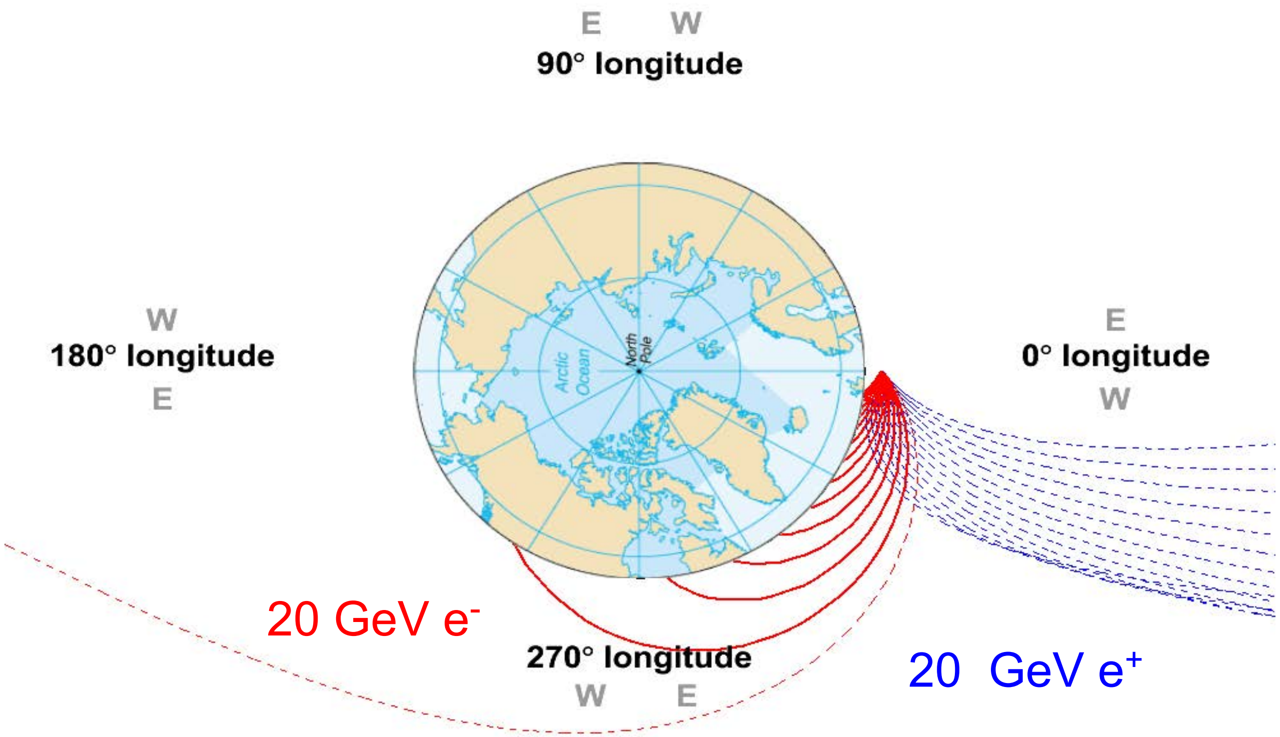


Fermi Coll. JCAP 05, 025 (2010), arXiv: 1002.2239

Galaxy Clusters upper-limits



The east-west effect in cosmic rays



- Looking west at particular energy, positrons allowed and electrons forbidden because trajectory blocked by the Earth
- Looking east, electrons allowed and positrons forbidden
- In 1930s this is how primary cosmic rays were determined to have positive sign (larger flux from west than east)
- Super-K detected same effect in atmospheric neutrinos in 1999 (larger flux from west than east)

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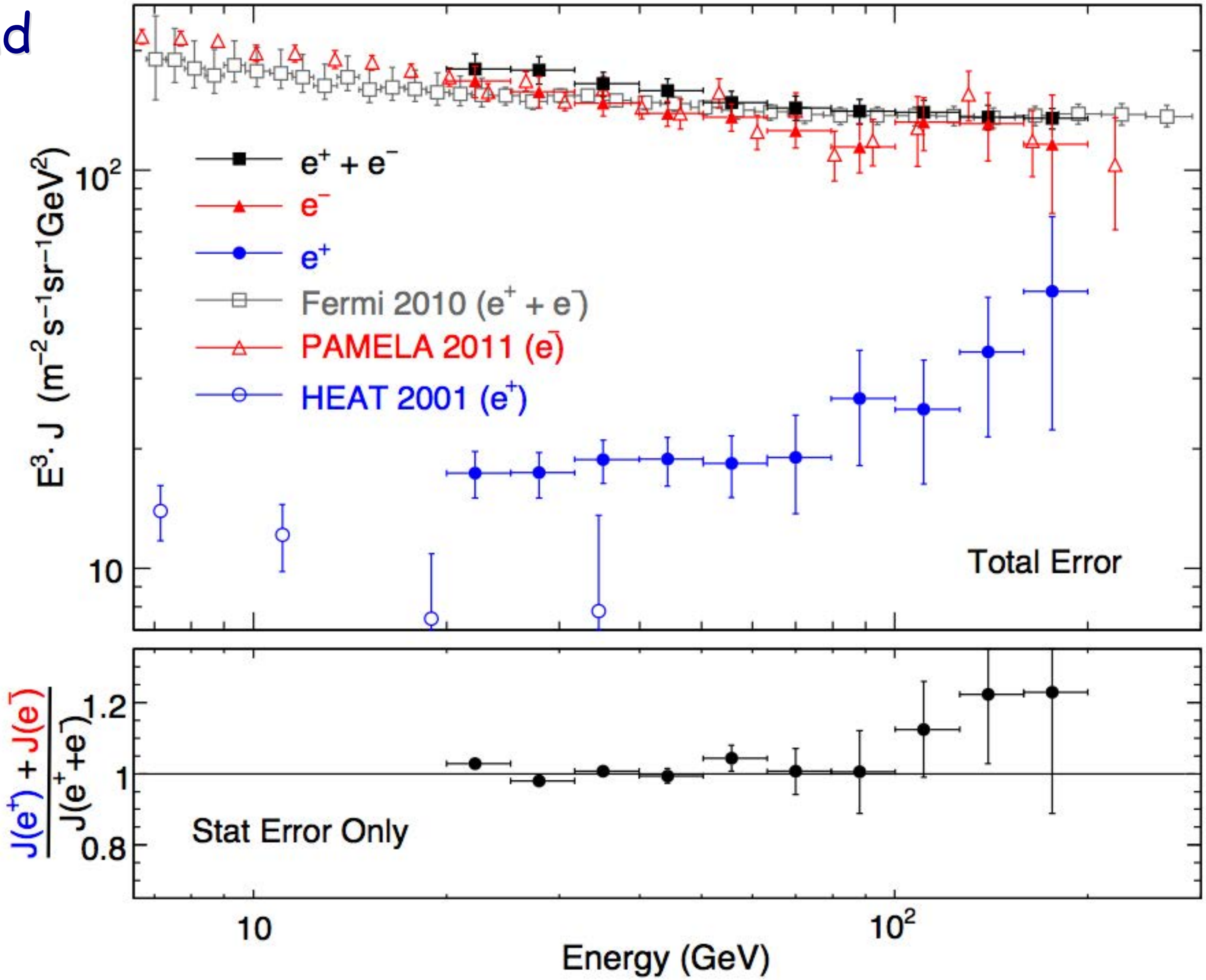
Electron and Positron spectrum



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