Fermi

Gamma-ray Space Telescope

Dark Matter Searches with Fermi

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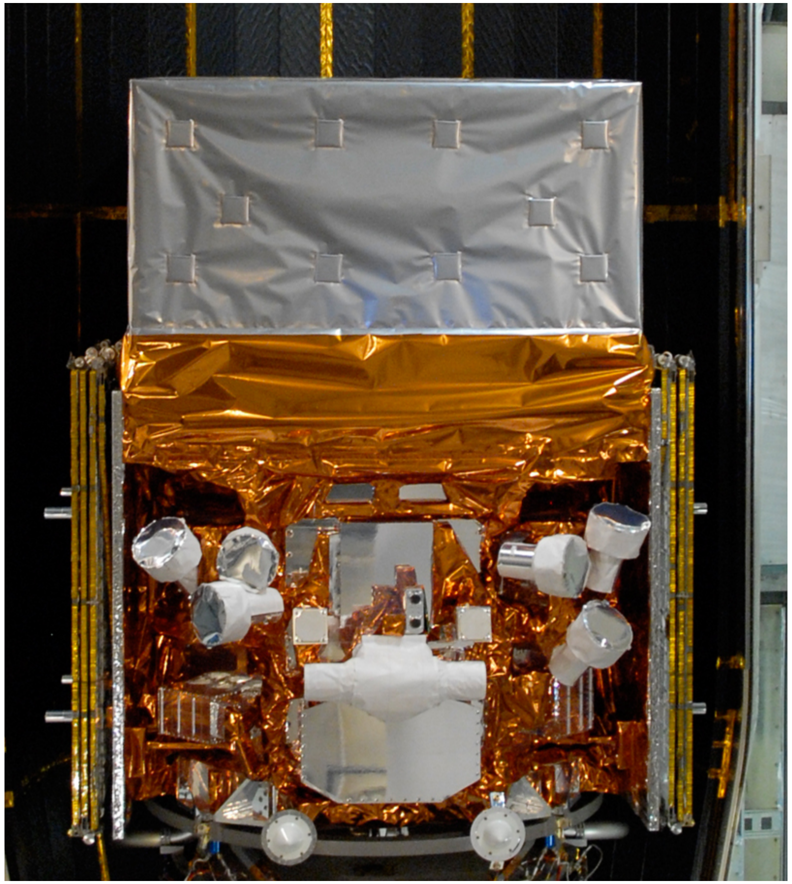
INFN-Pisa
On behalf of the Fermi Mission Team

LINK Workshop: Probing physics beyond the Standard Model with CTA

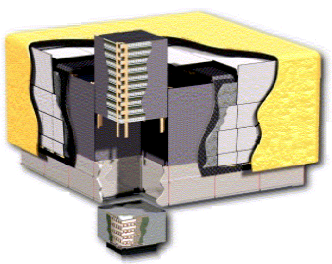
Abingdon, November 12 2010

The Fermi observatory



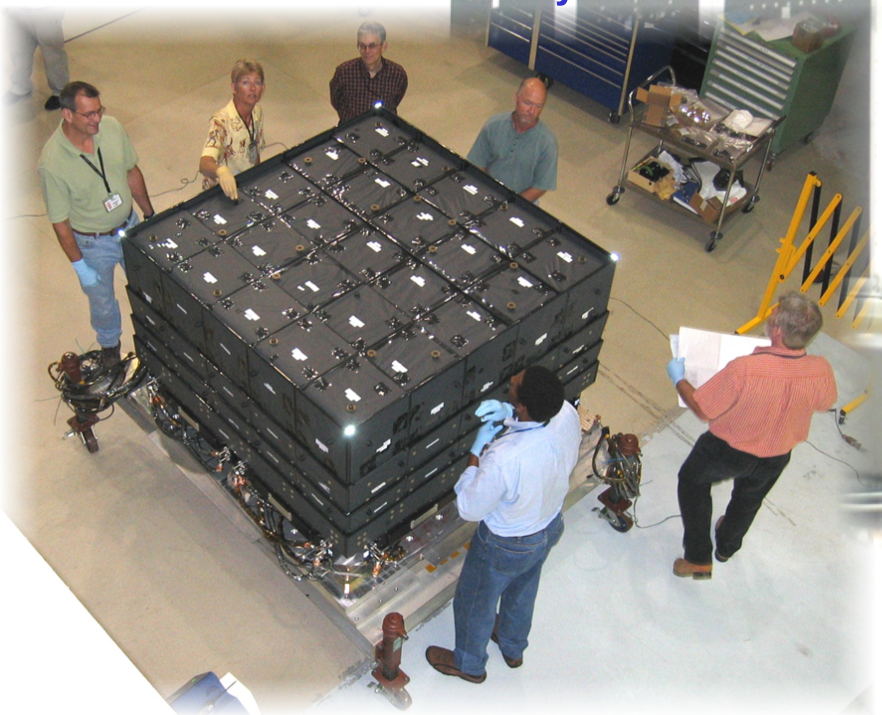
- Satellite gamma-ray telescope
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV
- Key features
  - Huge field of view (30’ full sky any 3 hrs)
  - Huge energy range
- Milestones
  - 11 jun 2008: launch
  - 04 aug 2008: science ops start
  - 13 aug 2009: γ data go public
  - 18 feb 2010: 100B triggers
  - 11 jun 2010: 2^{nd} year
    - 99.1% uptime from launch
    - 99.99% from October 2009

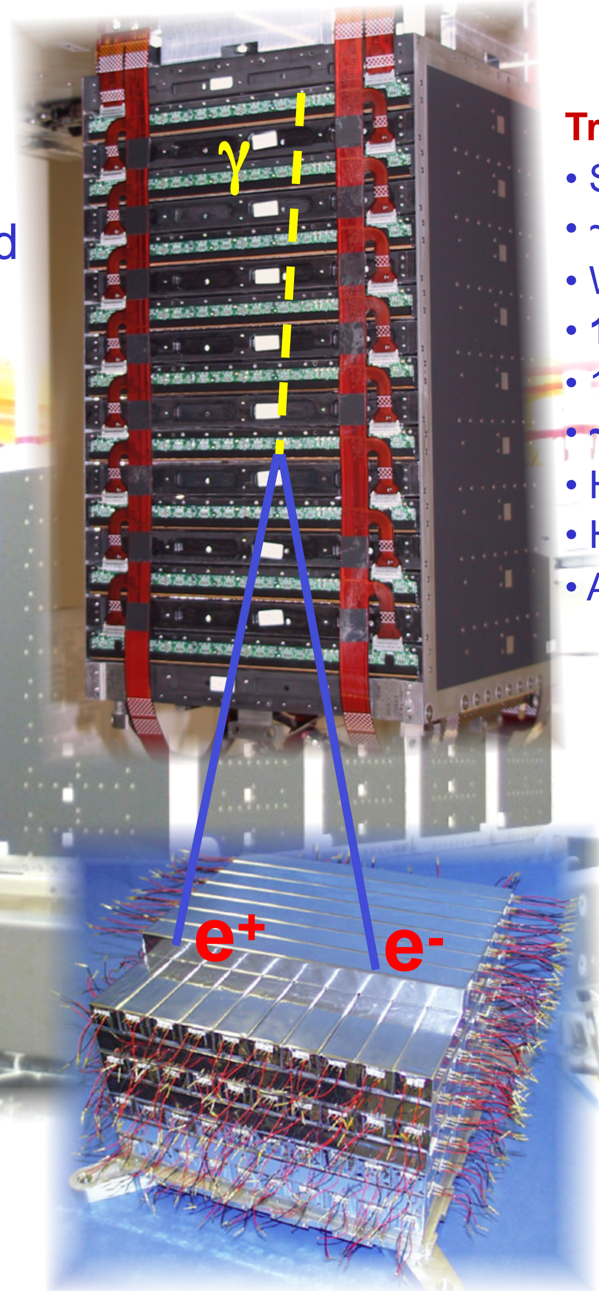
Overview of the Large Area Telescope



The LAT is complex – performance can be optimized for specific studies (as for CRE and EGB)

Anti-Coincidence (ACD):
- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**





Tracker/Converter (TKR):
- Si-strip detectors
- ~80 m^2 of silicon (total)
- W conversion foils
- **1.5 X0 on-axis**
- 18XY planes
- **~10^6 digital elx chans**
- Highly granular
- High precision tracking
- Average plane PHA

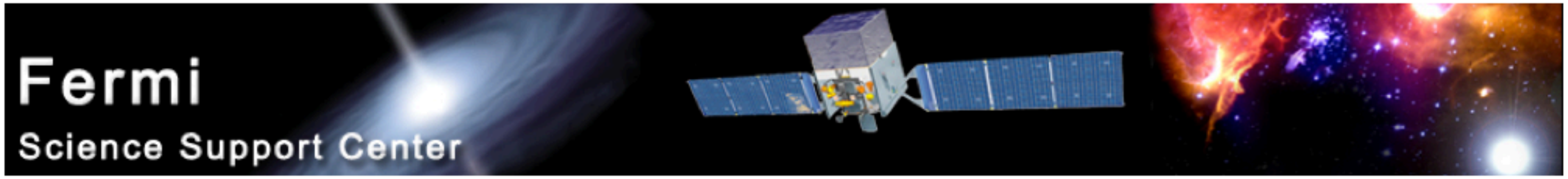
Calorimeter (CAL):
- 1536 CsI(Tl) crystals
- **8.6 X0 on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction
- EM vs HAD separation

Fermi Science Support Center

GODDARD SPACE FLIGHT CENTER

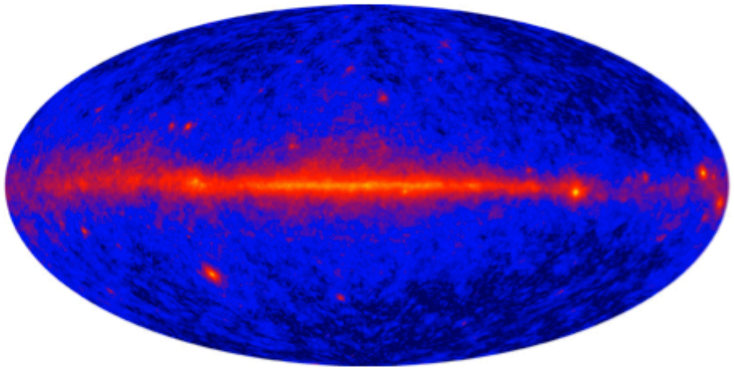
+ NASA Homepage
+ GSFC Homepage
+ Fermi Homepage

SEARCH Fermi: Search + GO



HOME | RESOURCES | PROPOSALS | DATA | HEASARC | HELP | SITE MAP

The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This all-sky view from Fermi reveals bright emission in the plane of the Milky Way (center), bright pulsars and super-massive black holes.
Credit: NASA/DOE/International LAT Team

News

April 13, 2010
Multiwavelength Coordination is Important
The recent ToO on 3C 454.3 serves as a reminder of the need for community input on multiwavelength coordination with Fermi. In evaluating the impact of a ToO, we review scheduled or ongoing multiwavelength observations that have been reported to the FSSC. To ensure your planned observations are taken into consideration, please provide details via our multiwavelength reporting page.
+ Learn More

Public data and extensive support for science Analysis Tools

http://fermi.gsfc.nasa.gov/ssc/

Independent analysis from outside the collaboration are encouraged

Fermi Dark Matter Publications

https://www-glast.stanford.edu/cgi-bin/pubpub

2010

Fermi Sensitivity to Via Lactea II Dark Matter Subhalos
Anderson, B. et al. 2010, ApJ, 718, 899 Show links

Constraints on Dark Matter Annihilation in Clusters of Galaxies with the Fermi Large Area Telescope
Ackermann, M. et al. 2010, JCAP, 05, 025 Show links

Constraints on Cosmological Dark Matter Annihilation from the Fermi-LAT Isotropic Diffuse Gamma-Ray Measurement
Abdo, A. A. et al. 2010, JCAP, 04, 014 Show links

Observations of Milky Way Dwarf Spheroidal galaxies with the Fermi-LAT detector and constraints on Dark Matter models
Abdo, A. A. et al. 2010, ApJ, 712, 147 Show links

Fermi LAT Search for Photon Lines from 30 to 200 GeV and Dark Matter Implications
Abdo, A. A. et al. 2010, Phys. Rev. Lett., 104, 091302 Show links

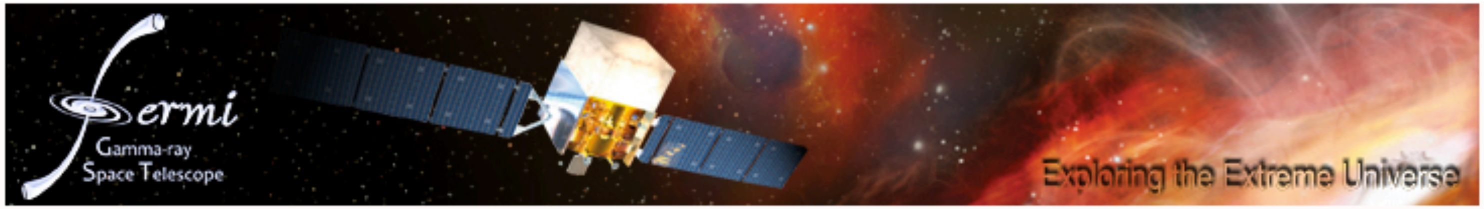
Direct constraints on minimal supersymmetry from Fermi-LAT observations of the dwarf galaxy Segue 1
Scott, Pat et al. 2010, JCAP, 01, 031 Show links

Anisotropies in the Diffuse Gamma-Ray Background and Dark Matter with Fermi LAT: A closer look (Submitted to journal)
Cuoco, A. et al. 2010, MNRAS Show links

2009

2008

Pre-launch estimates for GLAST sensitivity to Dark Matter annihilation signals
Baltz, E. A. et al. 2008, JCAP, 7, 013 Show links



Summary of Fermi LAT science publications

8 November 2010

Category I and II papers in refereed journals

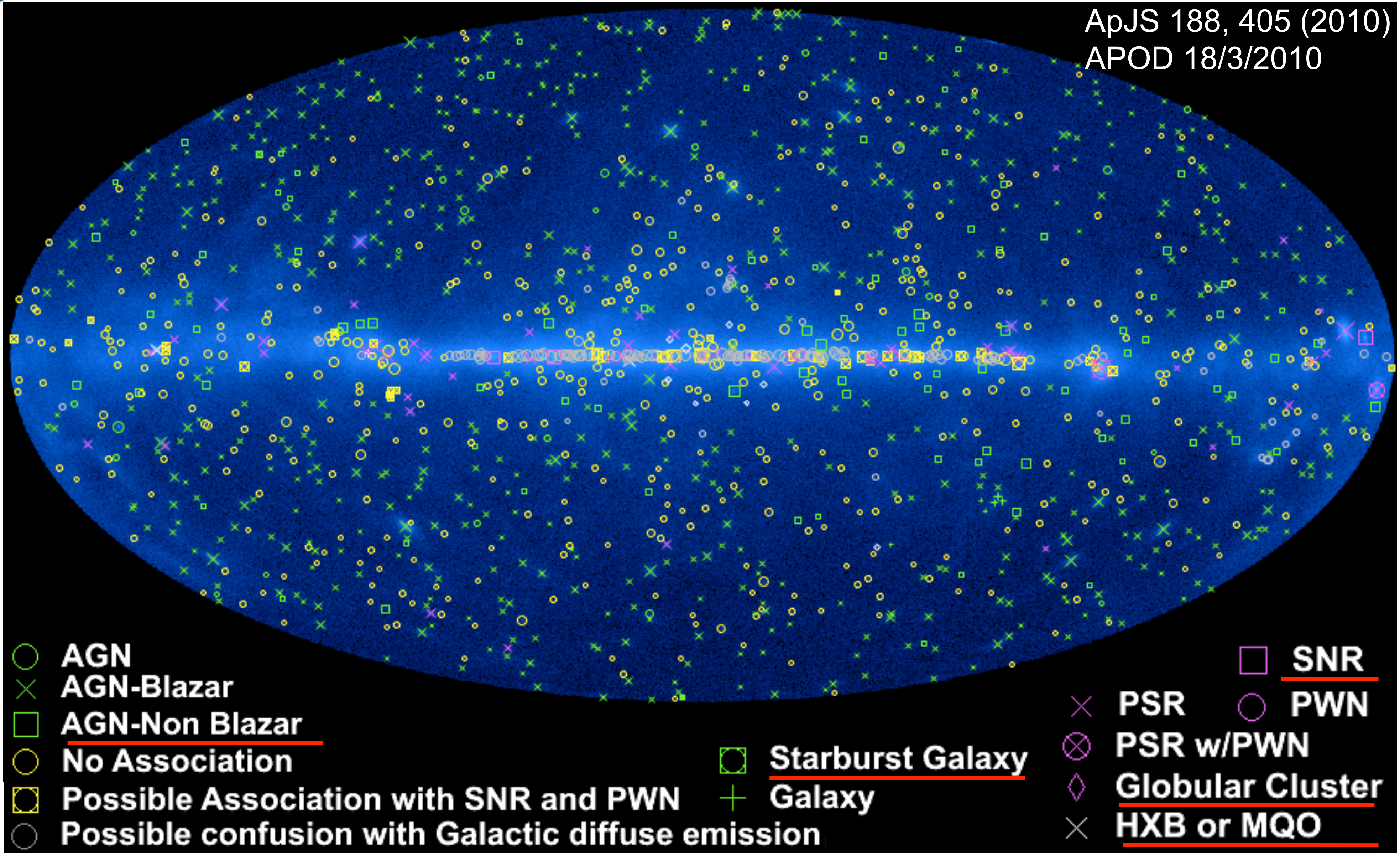
Journal	Published	In press	Total
Astronomy and Astrophysics	1+1=2	4	6
Astroparticle Physics	1+2=3	-	3
Astrophysical Journal	46+5=51	4	55
Astrophysical Journal Letters	16+3=19	1	20
Astrophysical Journal Supplement	3+0=3	-	3
Journal of Cosmology and Astroparticle Physics	2+2=4	-	4
Nature	2+0=2	-	2
Physical Review D	1+0=1	2	3
Physical Review Letters	4+0=4	-	4
Science	9+0=9	-	9
Total	85+13=98	11	109

List of papers

Papers submitted to journals: 14
Near submission: 5
Published category III papers: 29

Rapid publications:
Astronomers' telegrams: 114
GCN circulars: 29

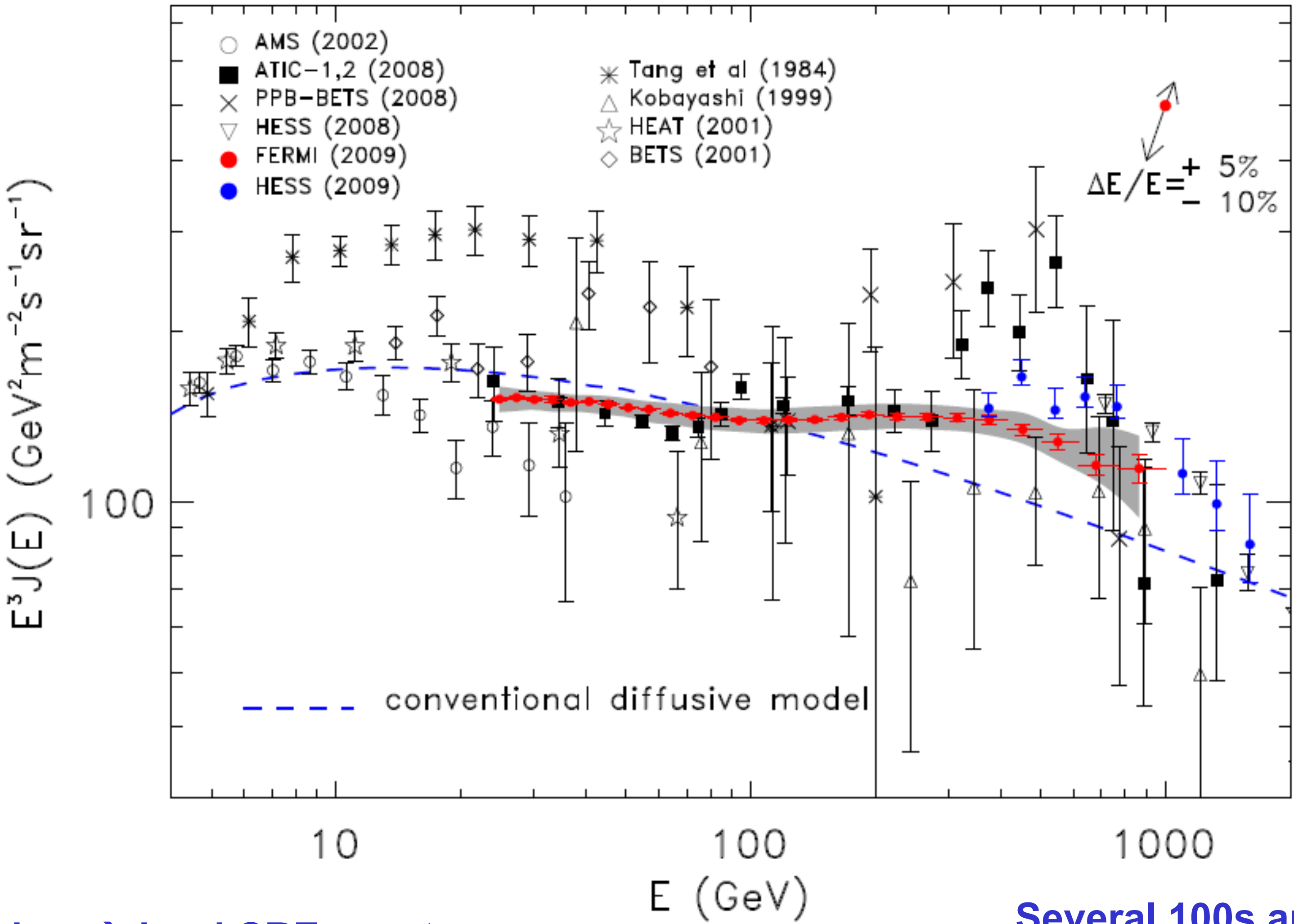
Backgrounds for DM search: astrophysical sources and diffuse emission



New classes not (confidently) associated with g-ray sources from EGRET

Selected for a Viewpoint in *Physics*
PRL **102,** 181101 (2009) PHYSICAL REVIEW LETTERS week ending 8 MAY 2009

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope



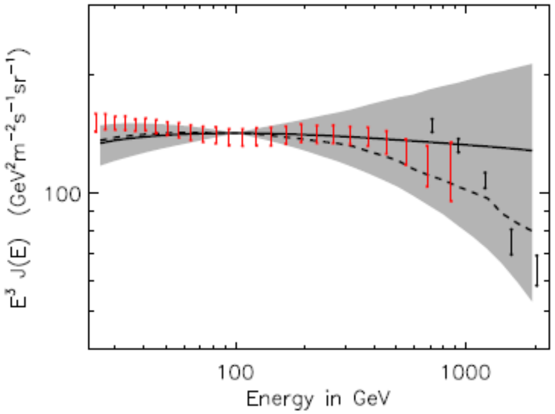
Fermi → hard CRE spectrum
PAMELA → positron excess

→ *Cosmic Ray Lepton puzzle* →

Several 100s articles, mostly discussing DM scenarios – much ado about no DM ?

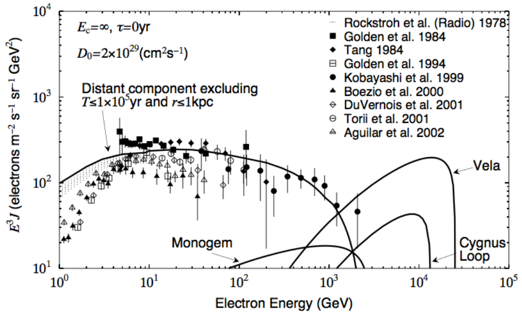
Other possible interpretations? Many !

1) Source stochasticity



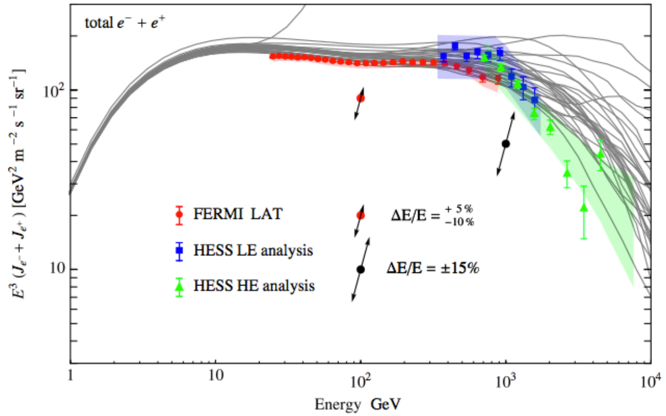
Grasso et al. arXiv 0905.0636

2) Nearby PSR



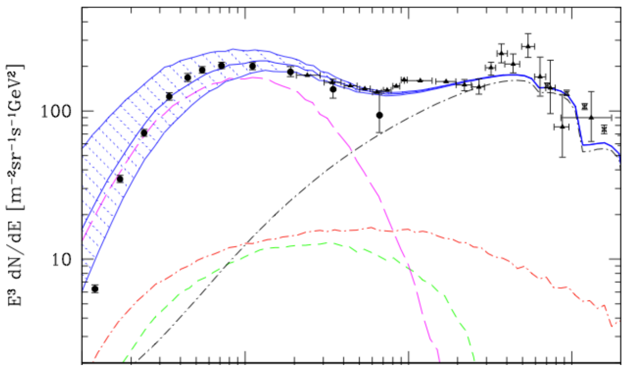
Kobayashi et al. arXiv 038470
(before Fermi and PAMELA)

3) Secondary CR acc.



Blasi arXiv 0903.2794
Ahlers et al. arXiv 0909.4060

4) SNR inhomogeneity



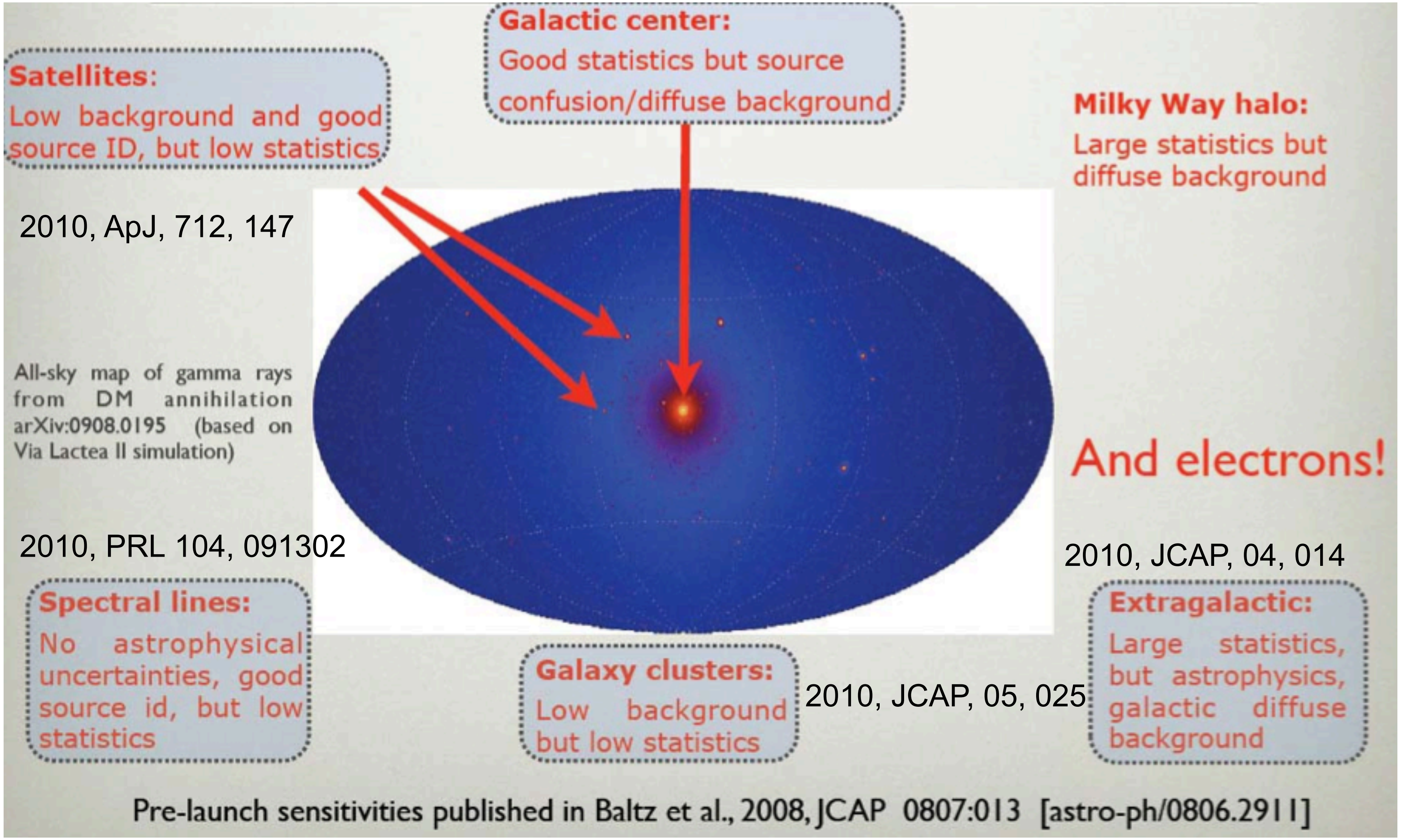
Piran et al. arXiv 0902.0376

But with specific signatures

1. Spectral features
2. CRE anisotropy
3. Rising fractions of secondaries (i.e. antiprotons/p, B/C)
4. Falling positron ratio above 100 GeV

… plus if it is DM it should be detected elsewhere

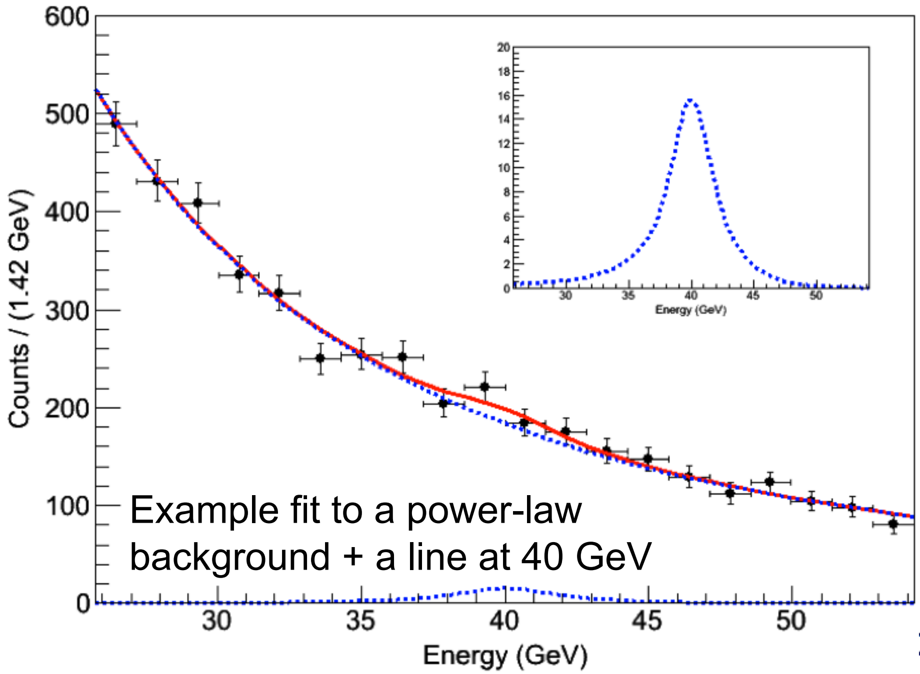
Indirect DM detection - active Fermi searches

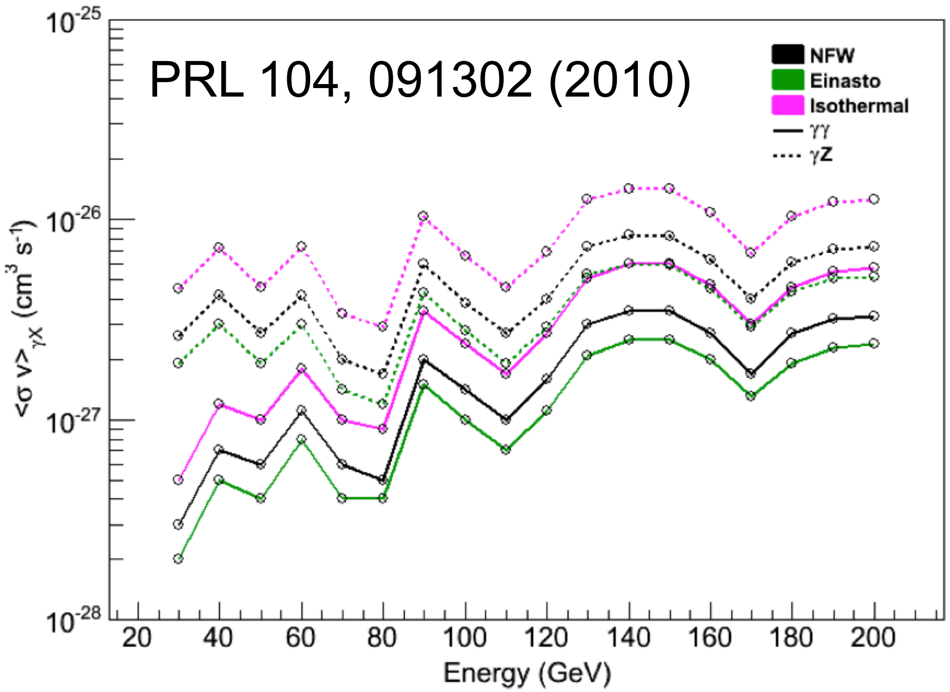


No detection so far, but upper limits start cutting into interesting parameter space, $\langle\sigma v\rangle \sim 10^{-25}$ $cm^3 s^{-1}$ from Dwarf Spheroidal

No *smoking-gun* line signal

11 months, 30-200 GeV, |b|>10 + 20x20 around GC, sources removed



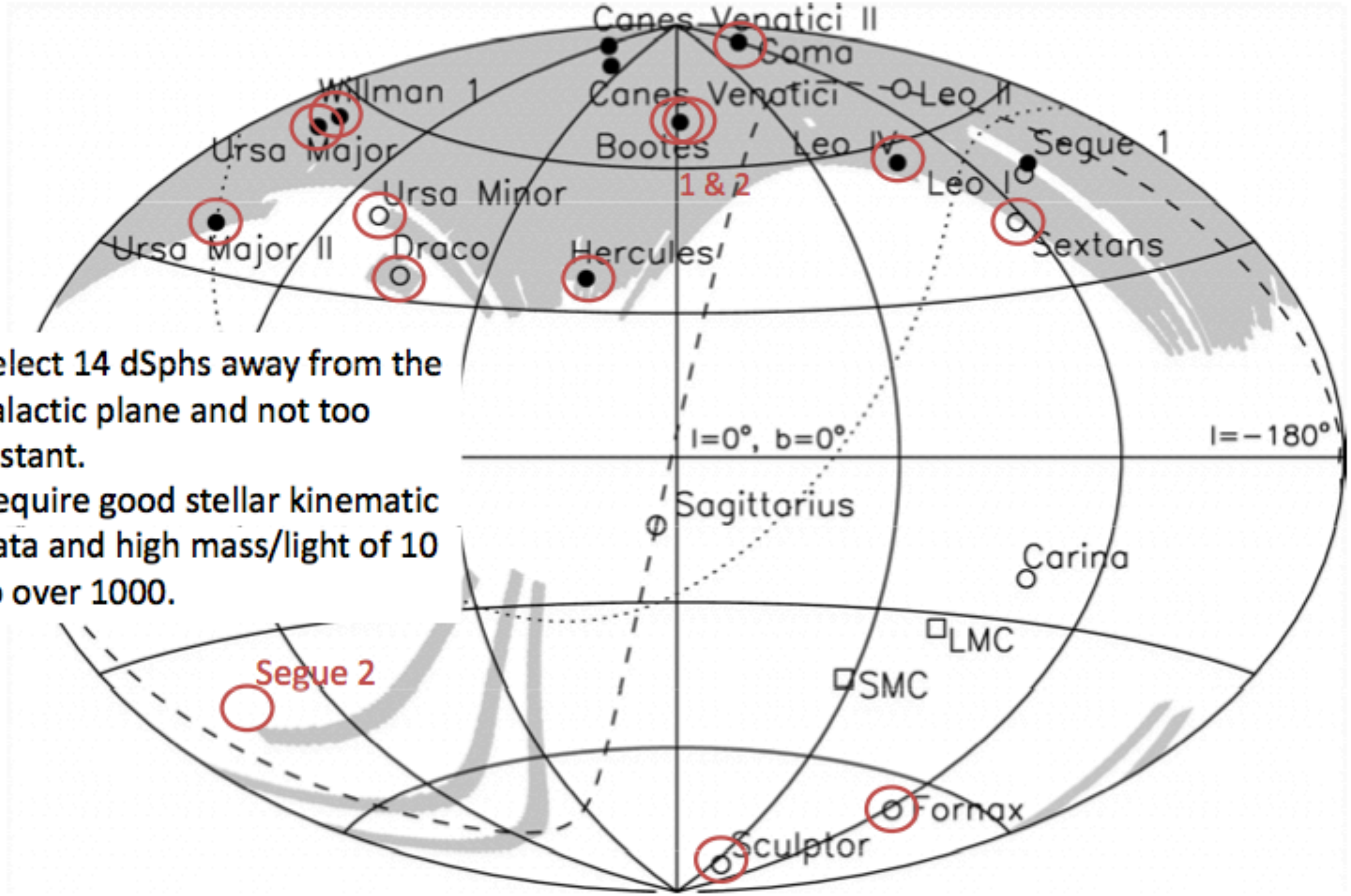


- Signal fraction and PL index are free parameters in the fit
- Energy resolution is key to the analysis
- On-going work to extend analysis between 5 and 200 GeV

- limits on annihilation too weak to constrain thermal WIMP (some non-thermally produced WIMPs are constrained)
- Limits on decaying DM constrain some gravitino decay models

Fermi Gamma-ray Space Telescope

Dwarf Spheroidals as targets



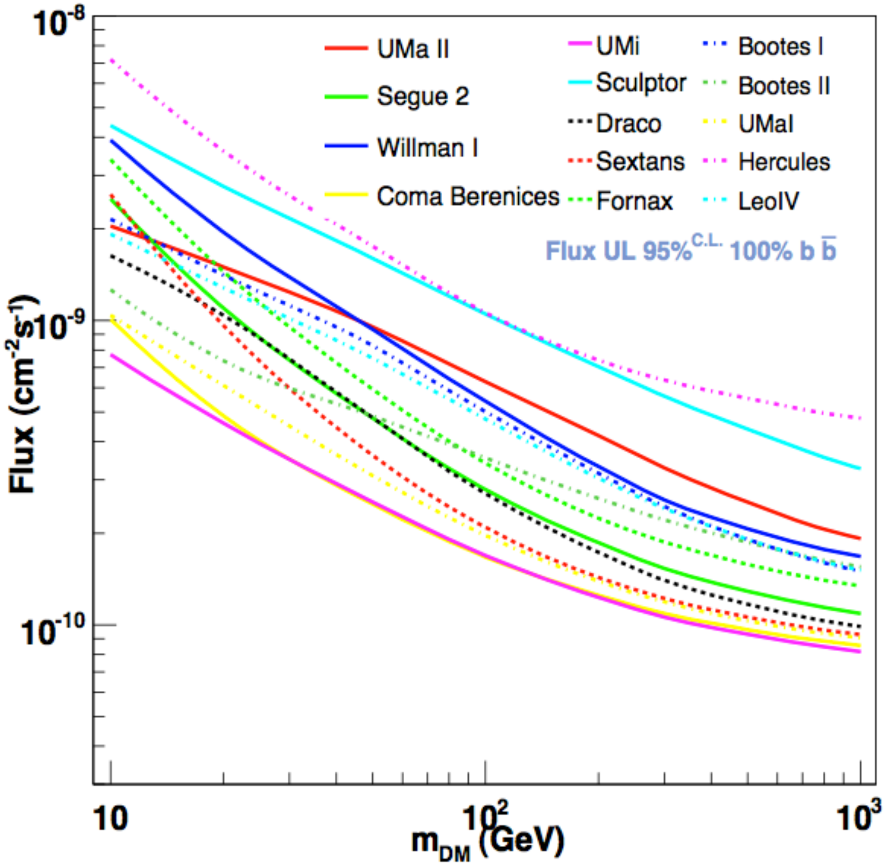
Select 14 dSphs away from the galactic plane and not too distant.
Require good stellar kinematic data and high mass/light of 10 to over 1000.

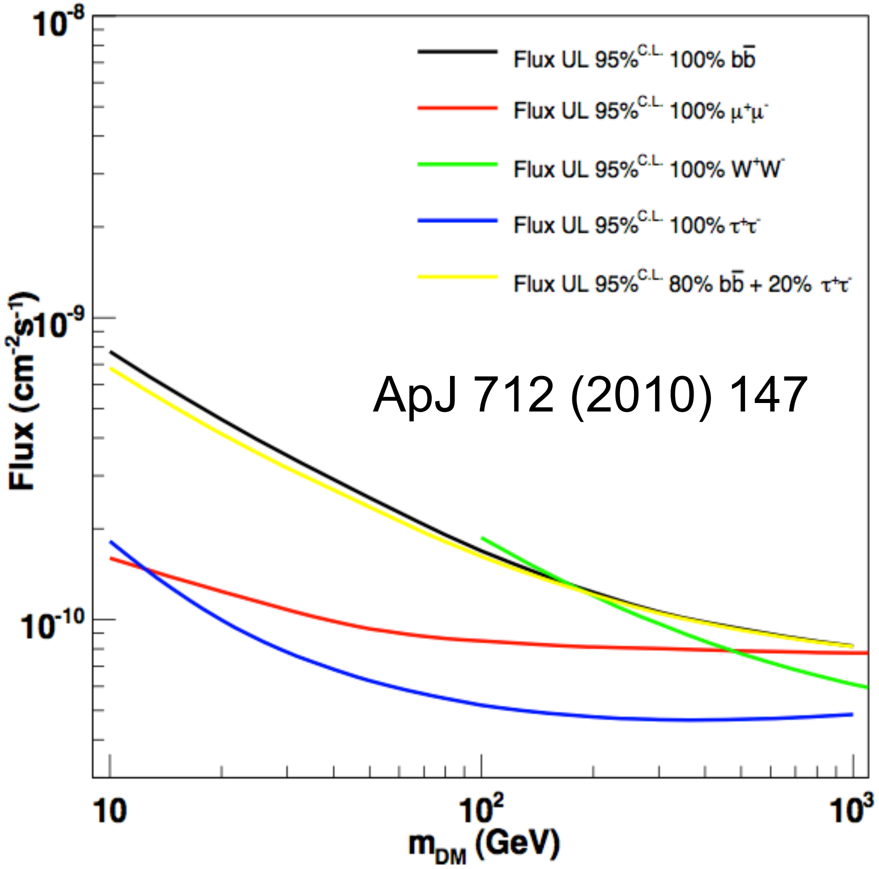
Belokurov, V., et al. 2007, ApJ, 654, 897

Stellar data for 8 dSphs from the Keck observatory (Martinez, Bullock, Kaplinghat)

No detection of gamma-rays from dwarfs

No detection with 11 months of data – but useful upper limits

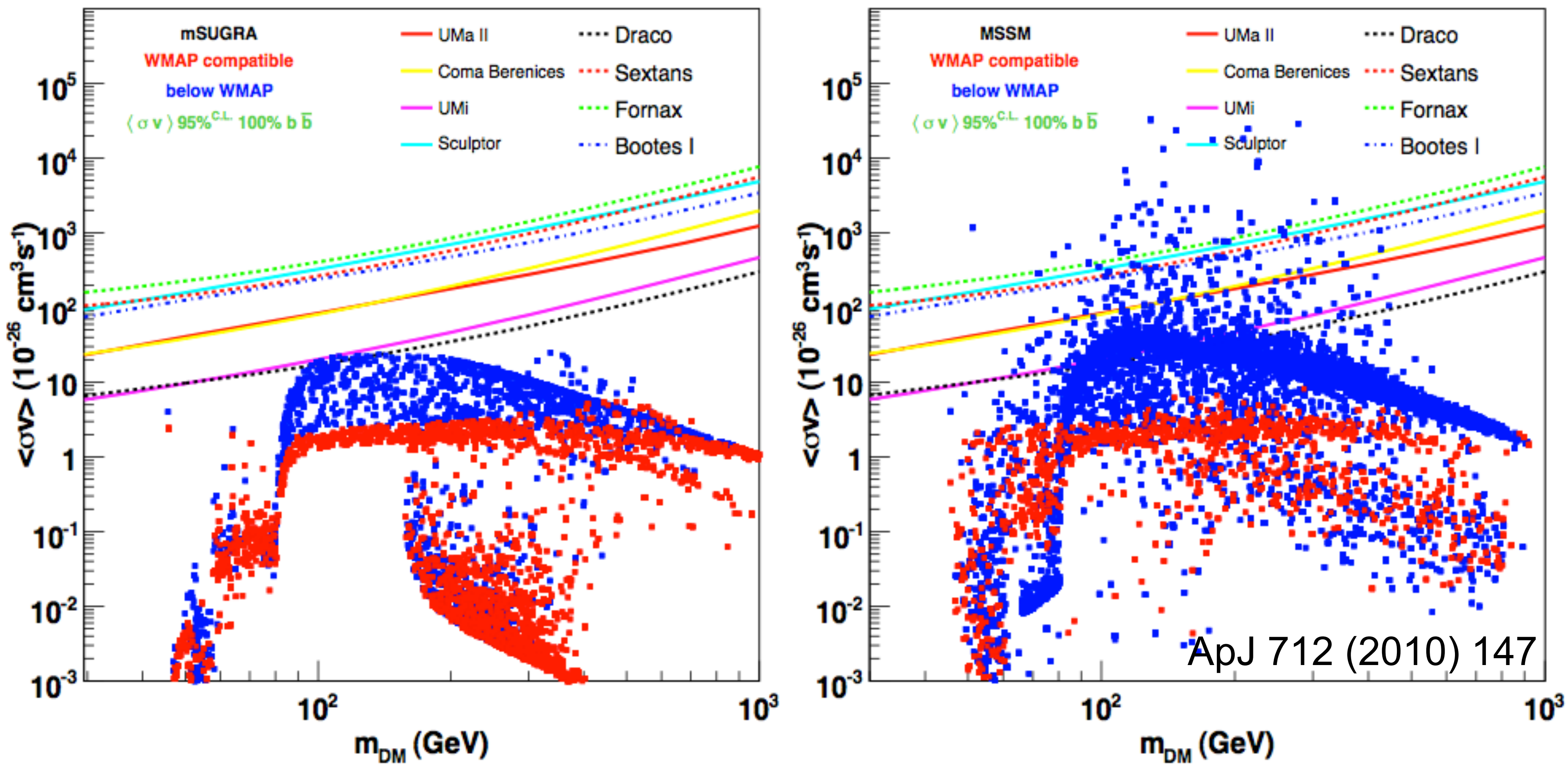




95% flux UL for several possible annihilation final states
To be combined with DM density (from stellar data) to extract <σv>

Limits depend on WIMP mass and final state

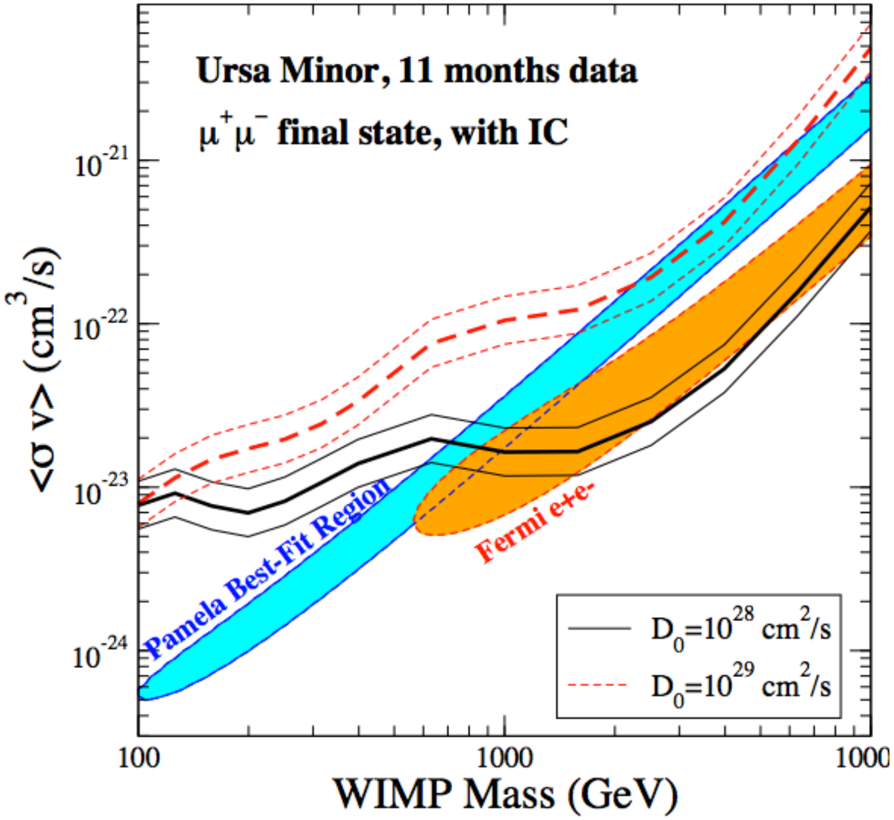
DM models constraints from dSphs



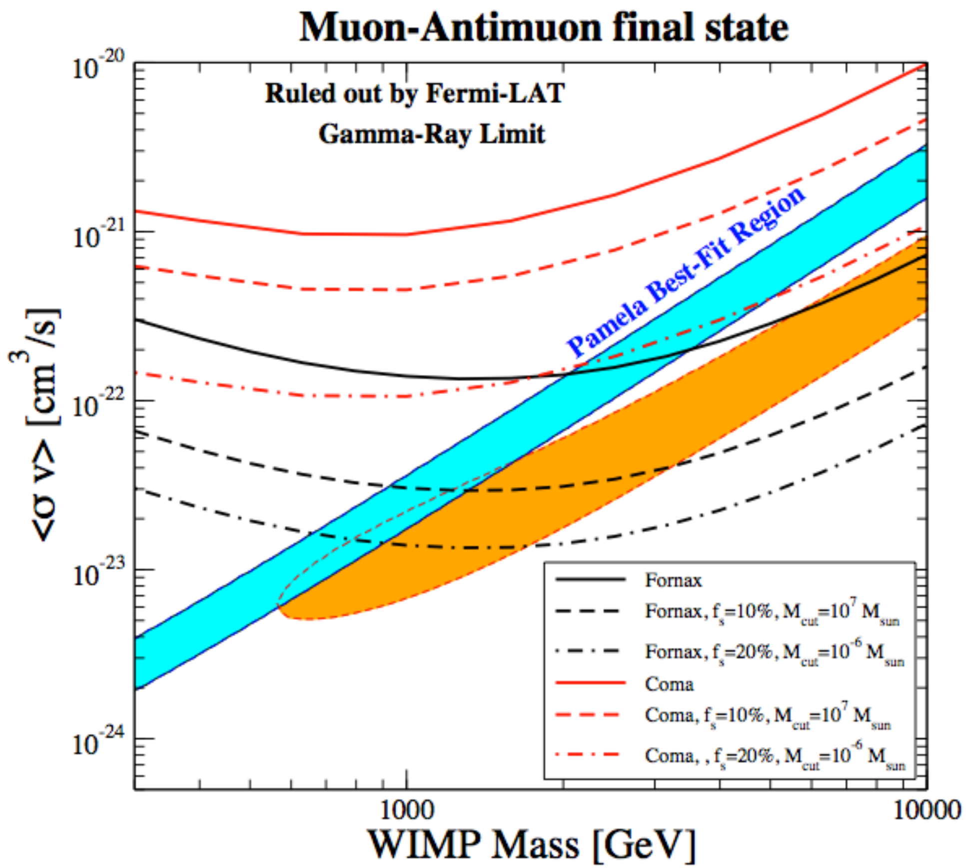
Red points are models with a cosmological WIMP thermal relic density compatible with WMAP data

Work in progress to combine all dwarfs into a single limit (expected sensitivity improvement on flux ~40% TBC)

Limits on lepto-philic models



ApJ 712 (2010) 147



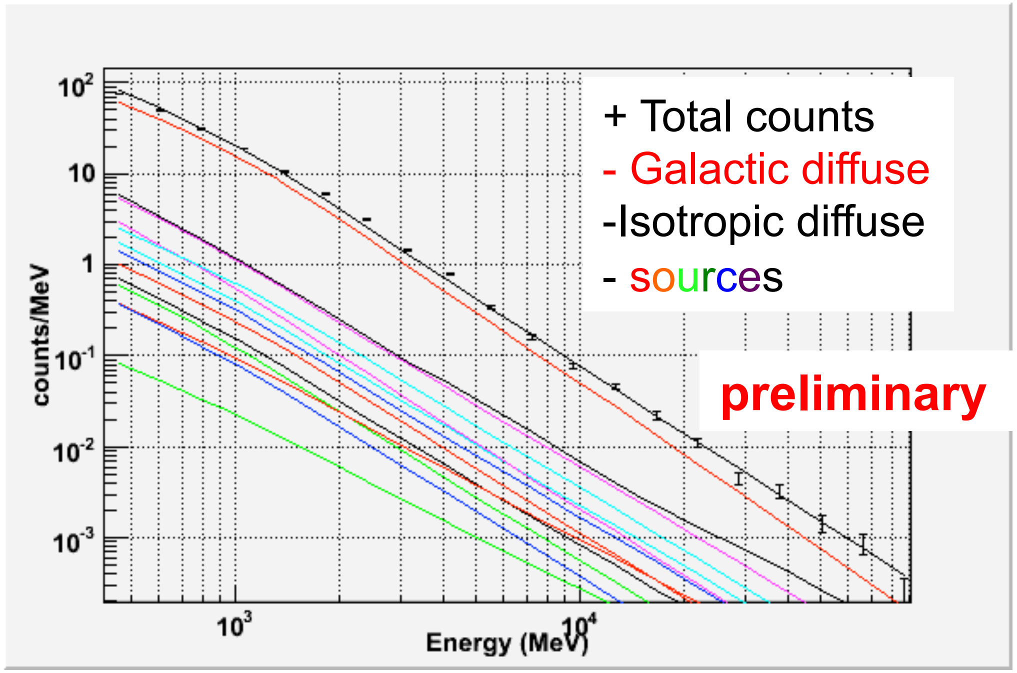
JCAP 1005:025 (2010)

dSphs and Galaxy Clusters can rule out lepto-philic models proposed to explain CRE excesses from Fermi and Pamela (another evidence for an astrophysical interpretation of such excesses)

On-going searches for potential DM sources from LAT UnID γ-ray sources

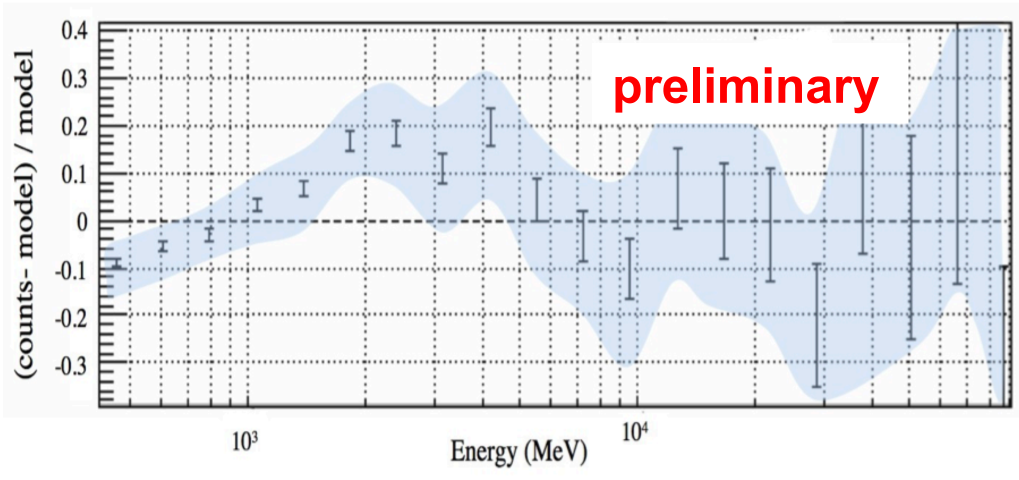
The Galactic Center

- Unbinned Likelihood analysis of 7°x7° region around GC
- 11 months of data, events > 400 MeV, front-converting (narrower PSF)
- Galactic Diffuse emission from GALPROP
- Sources from Fermi catalog



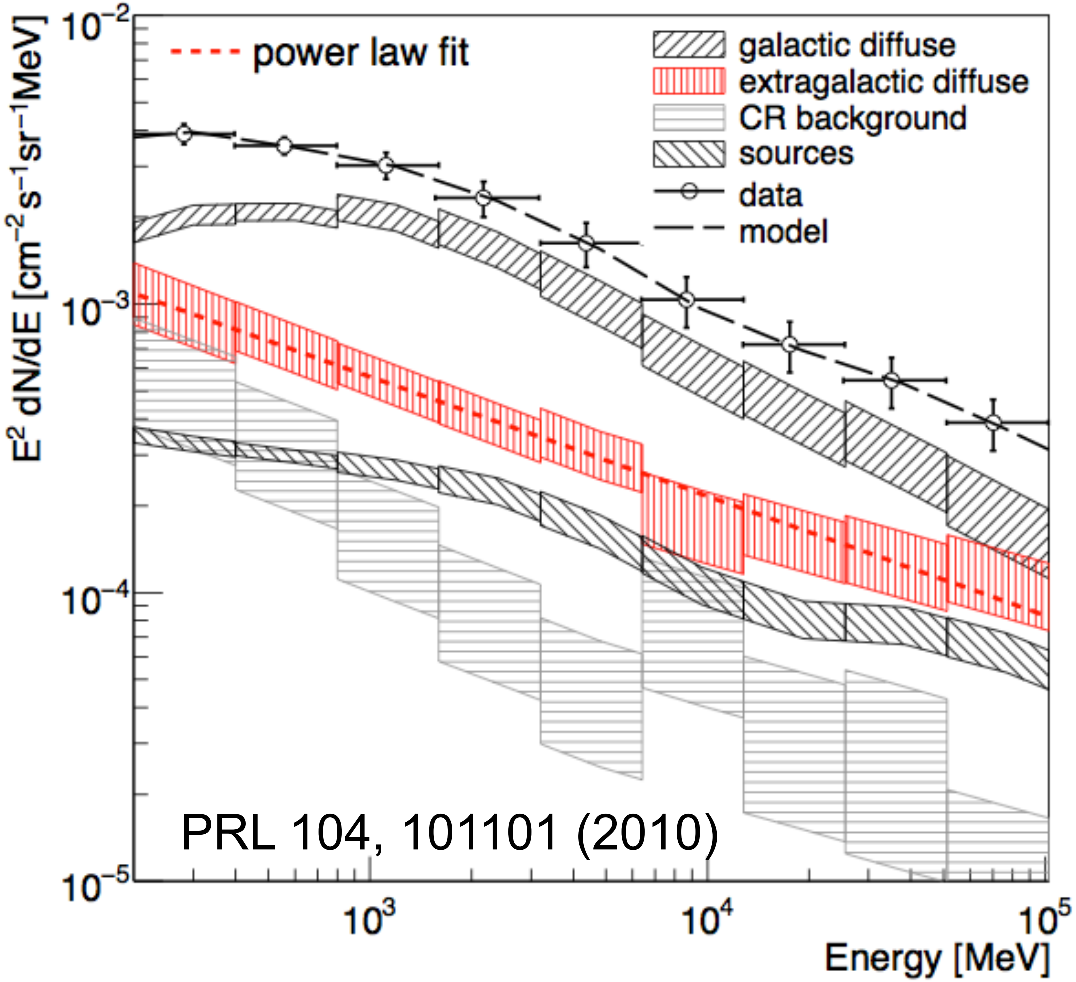
arXiv:0912:3828

- Working on fully characterizing largest uncertainties from
  - Small-scale diffuse emission
  - Sources in the region
  - Instrumental effects

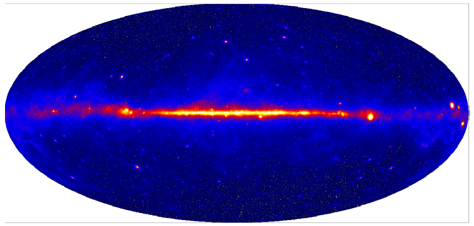


Isotropic extragalactic diffuse emission

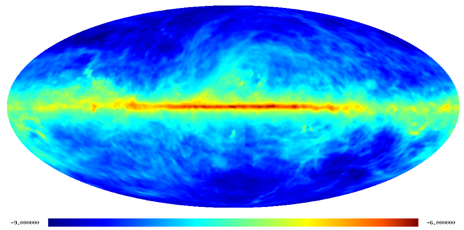
Maximum Likelihood fit to all |b|>10° sky



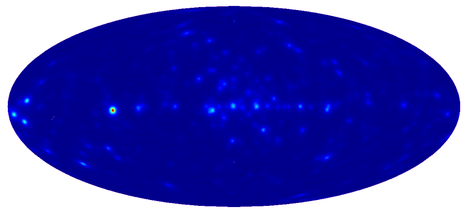
Data clean photon sample was necessary



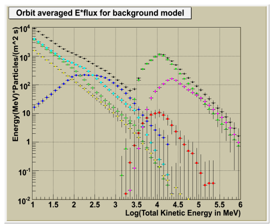
γ-ray sky



Galactic diffuse model



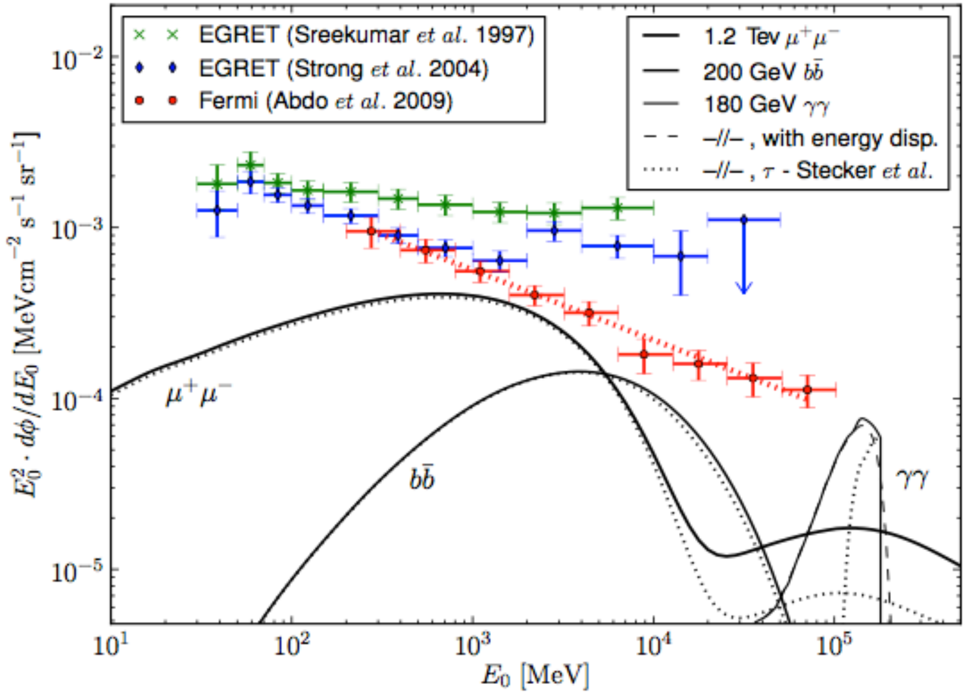
Known sources

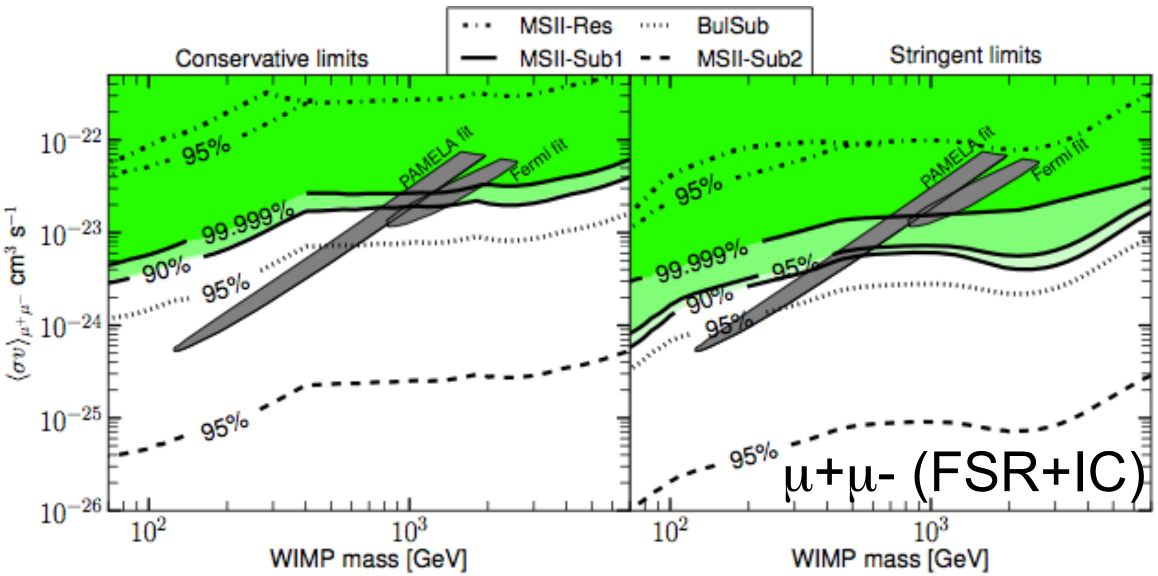


Residual instrumental bkg (MC)

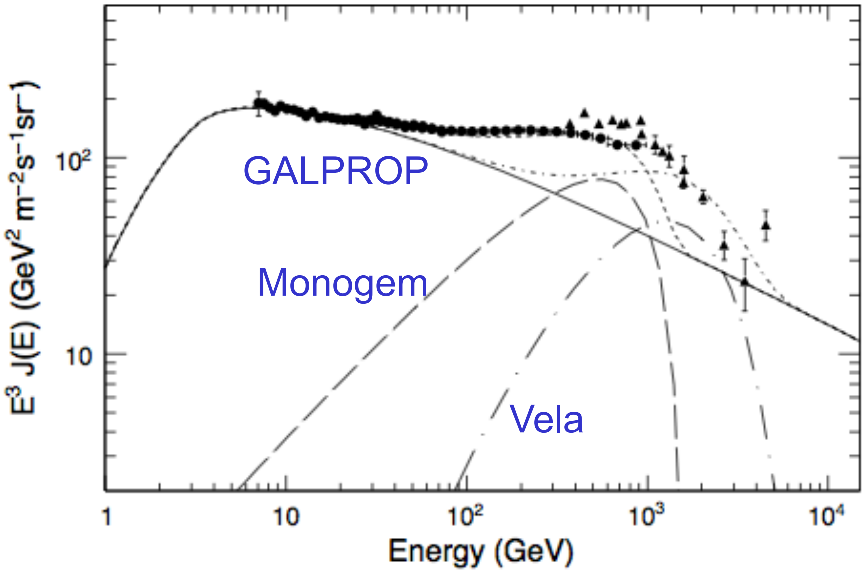
Constraints on Cosmological DM

- Search for a DM signal from all halos at all redshifts
- Limits from Fermi EGB
- Predictions affected by
  - DM distribution
  - γ-ray opacity
- Under reasonable assumptions can exclude most DM models explaining CR lepton excess from Fermi and Pamela





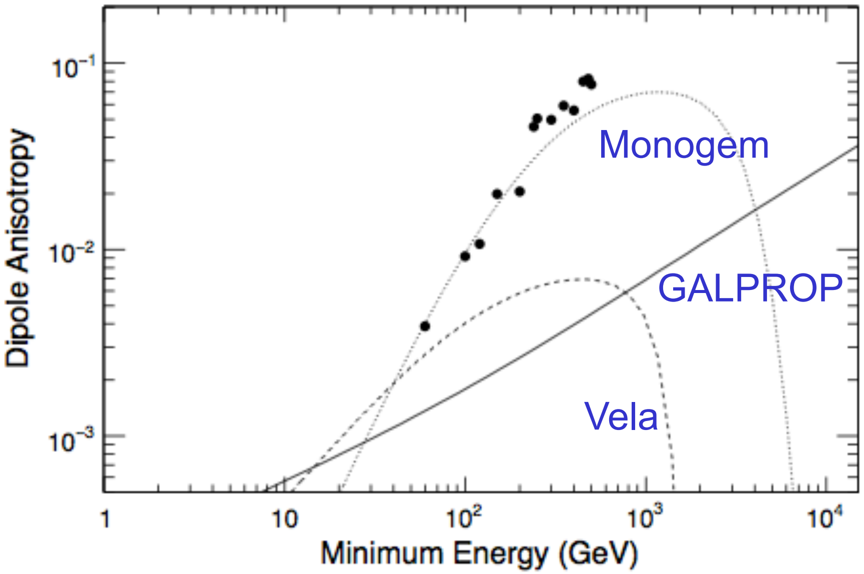
Back to CRE measurements

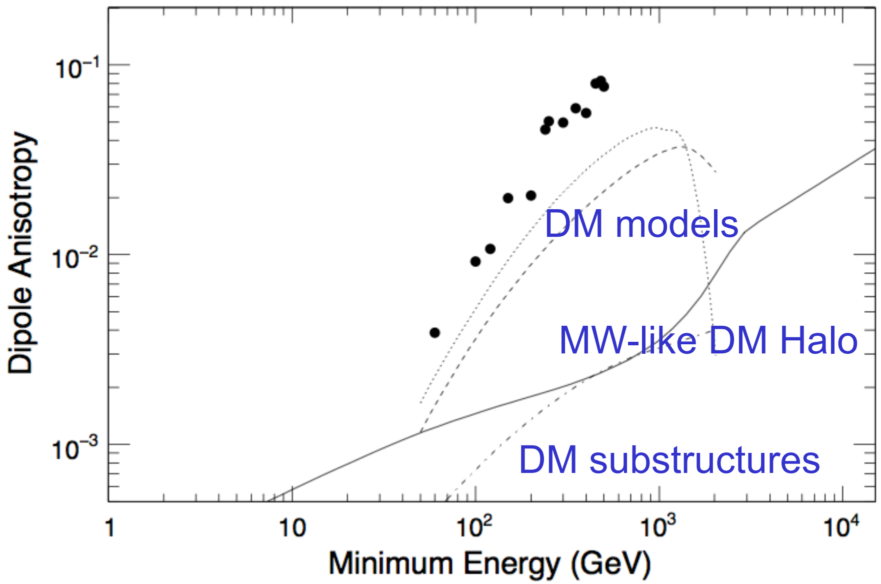


arXiv:1008.5119, accepted by PRD

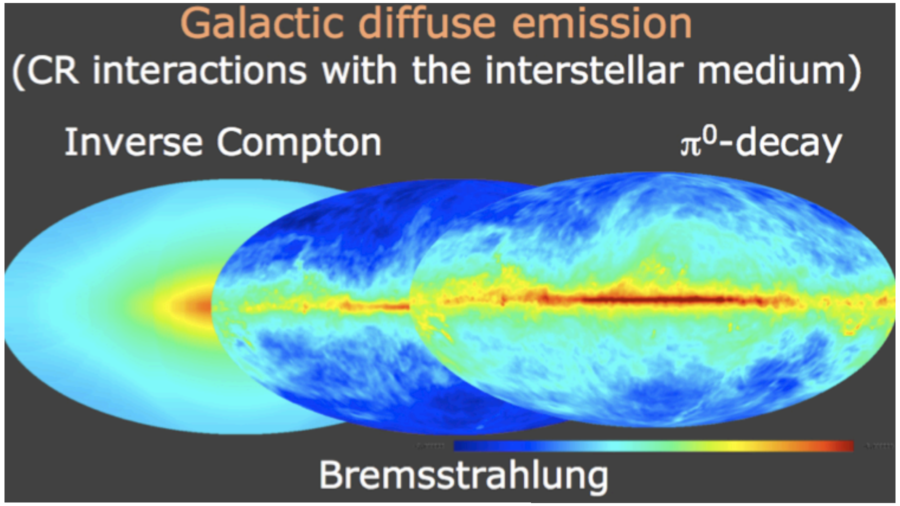
CRE spectrum extension to 7 GeV worsen simple diffusive fit

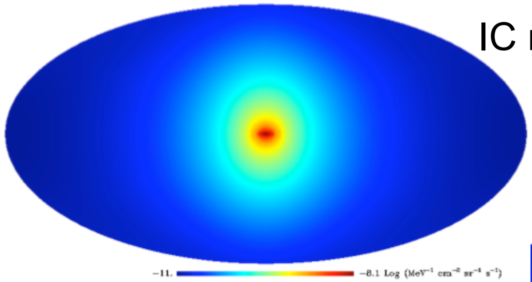
Upper limits on dipole anisotropy from CREs close to exclude single dominant local source (still room for a standard halo DM profile)



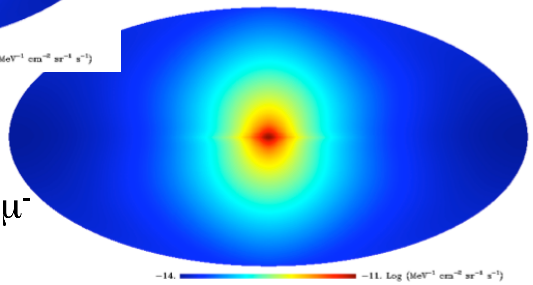


Limits from Dark Matter Halo – work in progress

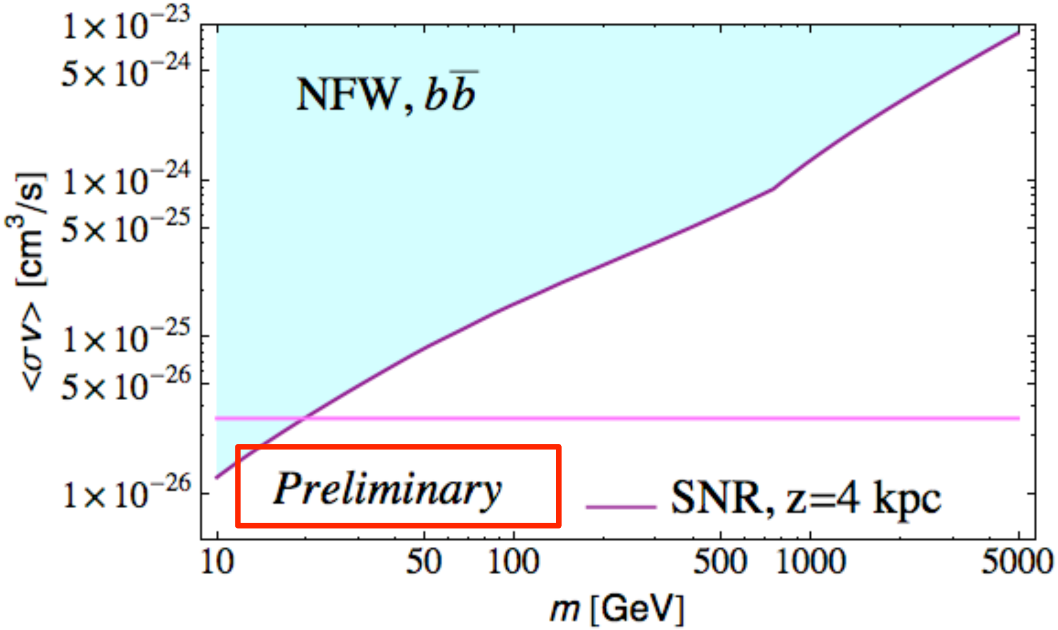




IC map from DM → $b\bar{b}$



IC map from DM → $\mu^+\mu^-$



Exploits both spectral and spatial features of gamma-ray signal to disentangle DM from astrophysical diffuse emission

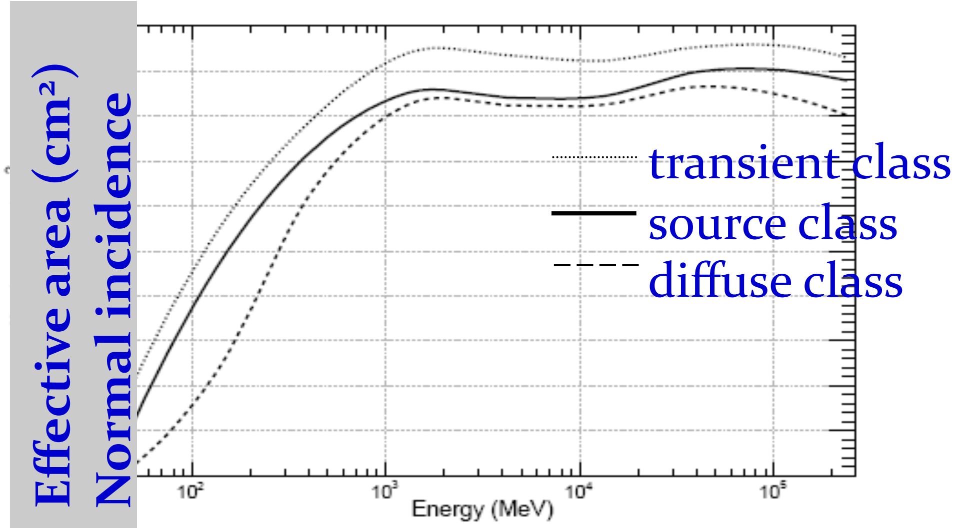
Limits strongly dependent upon astrophysical models of the Galaxy (CR distribution, halo height, diffusion)

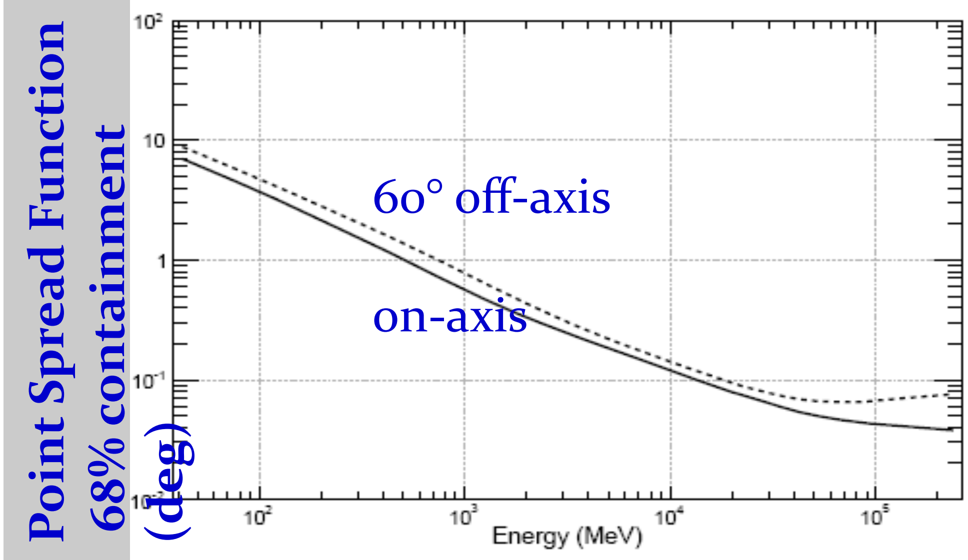
Conclusions and prospects

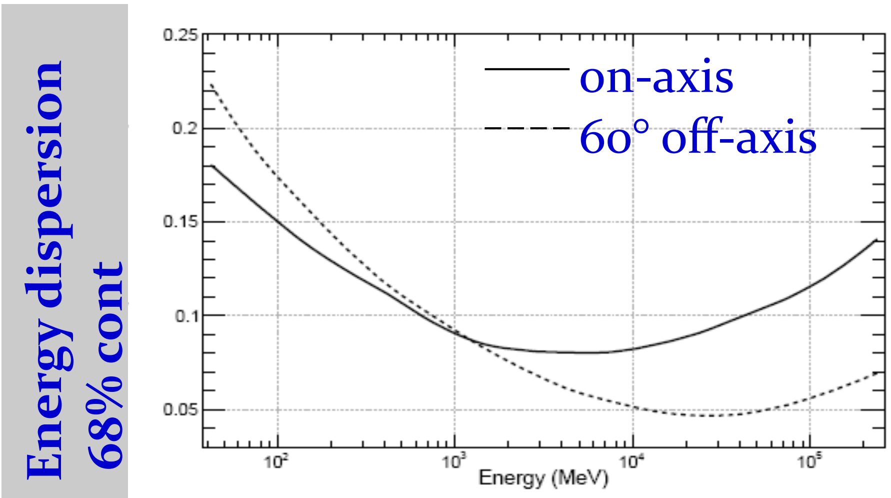
- Completing pre-launch DM search strategy
  - Published limits from dwarfs, clusters, cosmological DM, lines
  - Most competitive limits from dwarf galaxies
    - approaching thermal relic cross-section in the low-mass range (<~10 GeV) for stacking analysis
- Initial allure of DM origin of CRE excess fading out
  - Needs boost, high mass, leptonic final states
  - At odd with limits from photon searches
  - Not excluded by anisotropy constraints
- Refining our strategy – not just waiting for more statistics
  - Mapping astrophysical uncertainties
    - Sources + diffuse emission (critical for GC and Halo)
  - Improving instrument performance
    - Extending energy acceptance
  - Better statistical methods
    - Combining UL from satellites

BACKUP

Fermi-LAT Performances for photons







The Large Area Telescope on the Fermi Gamma-ray Space Telescope
Atwood, W. B. et al. 2009, ApJ, 697, 1071

These are pre-launch estimates

Instrument performance updated after launch and distributed (arXiv.0907.0626)

On-going efforts to improve it (see examples later)

Annihilation Signal

particle physics

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f$$

$$\times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')$$

DM distribution

For DM decay:

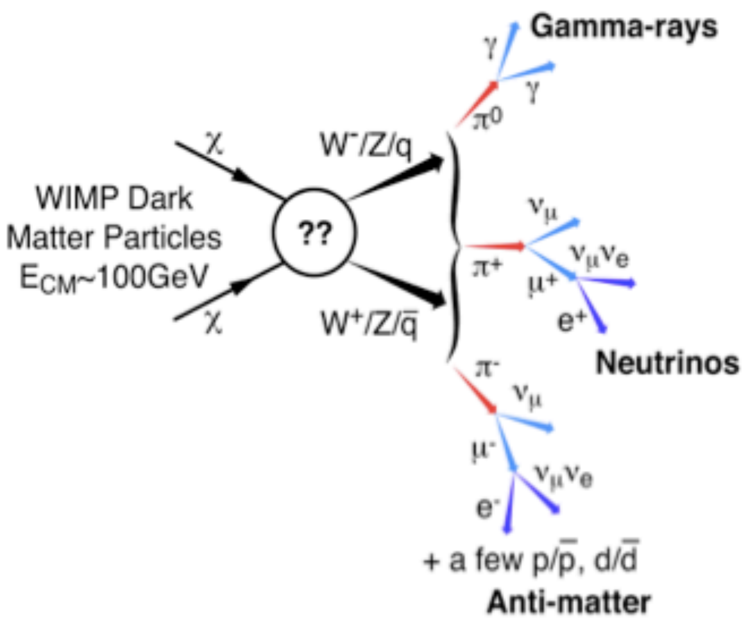
- $<\sigma_{ann}v>/2m^2_{WIMP} \rightarrow 1/\tau m_{WIMP}$
- $\rho^2 \rightarrow \rho$

WIMP Dark Matter Spectrum

- Several theoretical models have been proposed that predict the existence of WIMPs (Weakly Interacting Massive Particle) that are excellent DM candidates
- In addition to photons, with Fermi we can also probe electron+positron final states

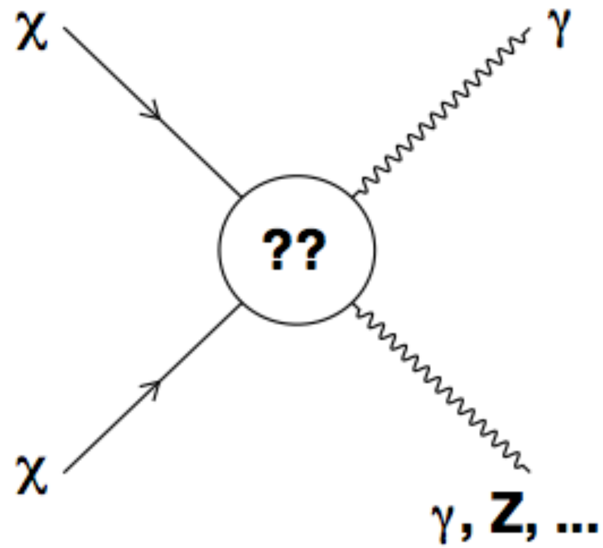
Continuum spectrum with cutoff at M_{DM}

Annihilation (or decay) into γ



Spectral line

Prompt annihilation into $\gamma\gamma$, γZ, γH^0...
(also prompt decay into photons)



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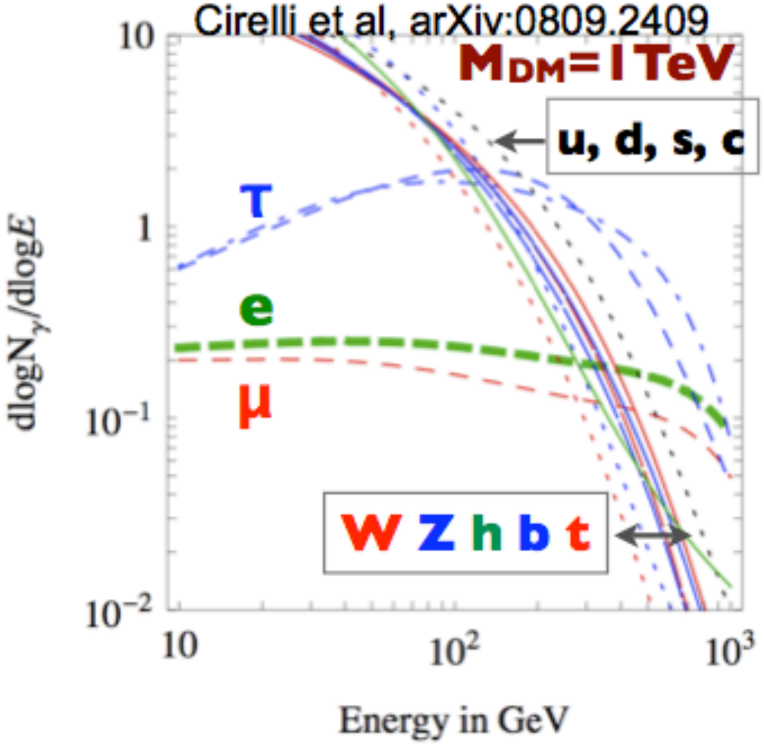


Spectral line

Prompt annihilation into γγ, γZ, γH⁰...
(also prompt decay into photons)

Generally suppressed (10^{-1}-10^{-4}), but enhanced in some models

For γγ final state:

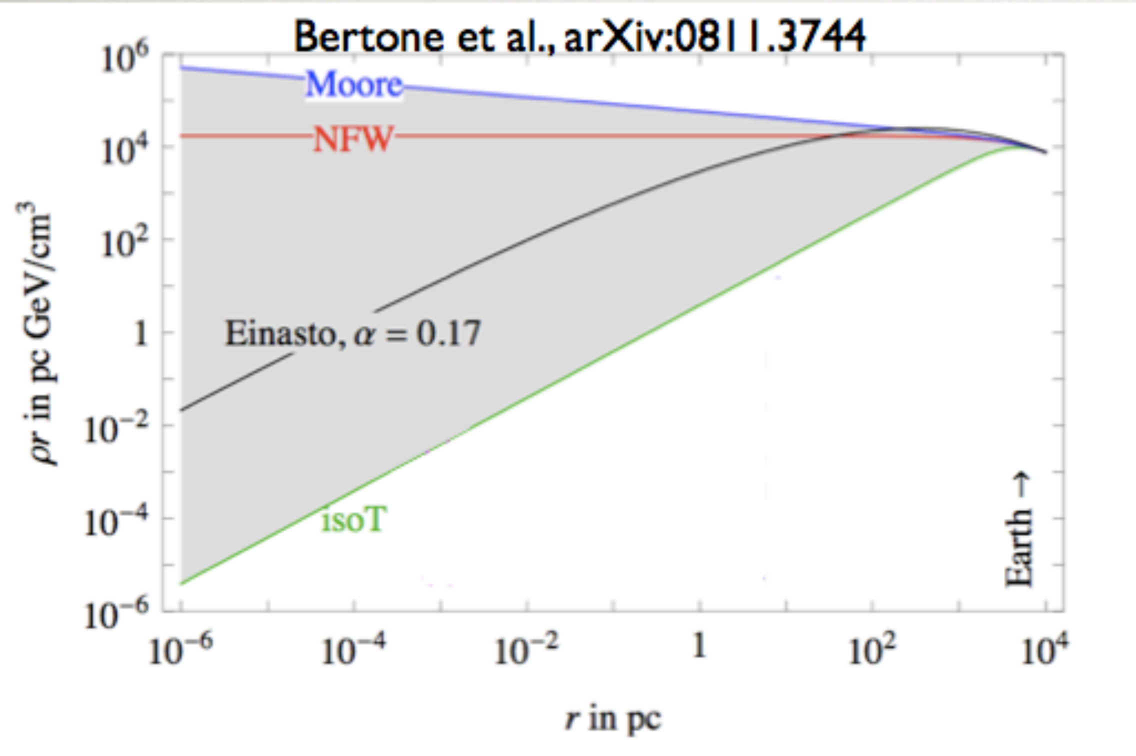
$$E_\gamma = M_{DM}$$

For γX final state:

$$E_\gamma = M_{DM} - \frac{M_X^2}{4M_{DM}}$$

Dark Matter Distribution

- The dark matter annihilation (or decay) signal strongly depends on the dark matter distribution.
- Cuspier profiles and clumpiness of the dark matter halo can provide large boost factors



NFW profile

Navarro, Frenk, and White 1997

$$\rho(r) = \rho_0 \frac{r_0}{r} \frac{1 + (r_0/a_0)^2}{1 + (r/a_0)^2}$$

$$\rho_0 = 0.3 \text{ GeV/cm}^3$$

$$a_0 = 20 \text{ kpc}, \; r_0 = 8.5 \text{ kpc}$$

✓ Via Lactea II (Diemand et al 2008) predicts a cuspier profile, $\rho(r) \propto r^{-1.2}$

✓ Aquarius (Springel et al 2008) predicts a shallower than r^{-1} innermost profile

Recent claims about DM in the GC

Hooper and Goodenough recently claimed evidence for low-mass WIMPs annihilating with ~thermal cross section in the GC from LAT data (arXiv: 1010.2752)

We emphasize the challenges in analyzing this region mostly associated to uncertainties in:

- source population
- confusion along the line of sight
- diffuse emission
- instrumental effects

see some example press coverage at

http://www.symmetrymagazine.org/breaking/2010/10/22/fermilab-theorist-sees-dark-matter-evidence-in-public-data/
http://www.space.com/scienceastronomy/dark-matter-annihilation-fermi-101027.html
http://www.newscientist.com/article/dn19655
http://physicsworld.com/cws/article/news/44203