Search for Dark Matter in the Galactic Halo

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On behalf of the Fermi LAT Collaboration

Fermi Gamma-ray Space Telescope

Abstract

One possible explanation for dark matter is the existence of weakly interacting massive particles (WIMPs) which represent an extension to the standard model of particle physics. Our galaxy is expected to reside in a large dark matter halo whose density is peaked toward the Galactic center but still has significant density at high Galactic latitudes. These WIMPs may manifest themselves through annihilations that produce high-energy gamma rays observable by the Fermi Large Area Telescope (LAT). However, diffuse gamma-ray emissions from cosmic-ray interactions in the galaxy represent a formidable source of background. Using the excellent energy resolution and large effective area of the Fermi LAT, we have performed an indirect search for dark matter annihilations in the Galactic halo. The search uses both the spatial distribution and energy spectrum of gamma-rays to attempt to separate dark matter from other astrophysical sources. We will present the methods of our analysis and estimates of performance from pseudoexperiments.

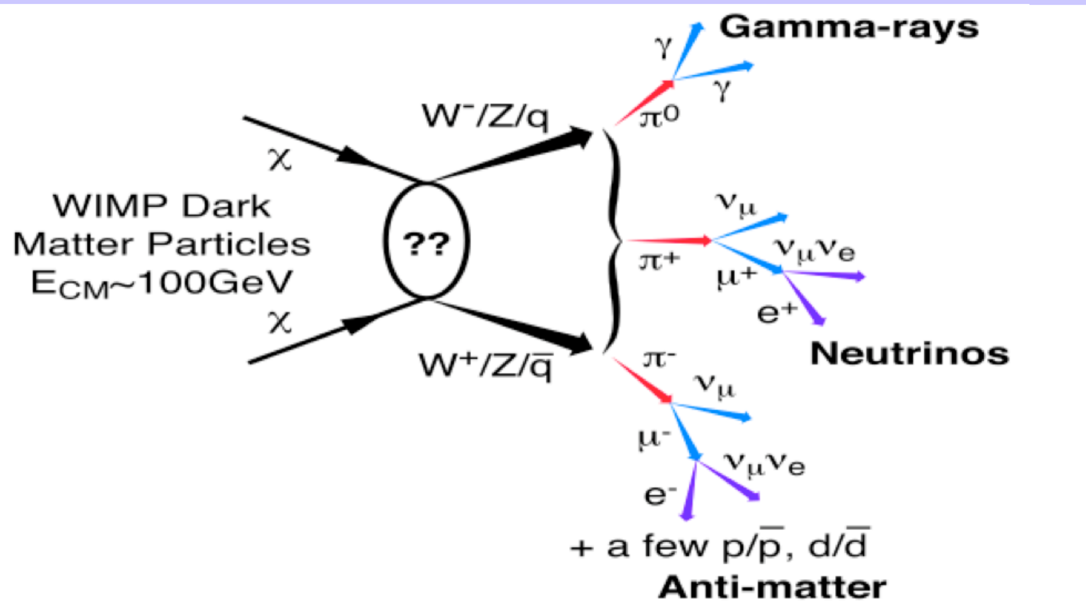


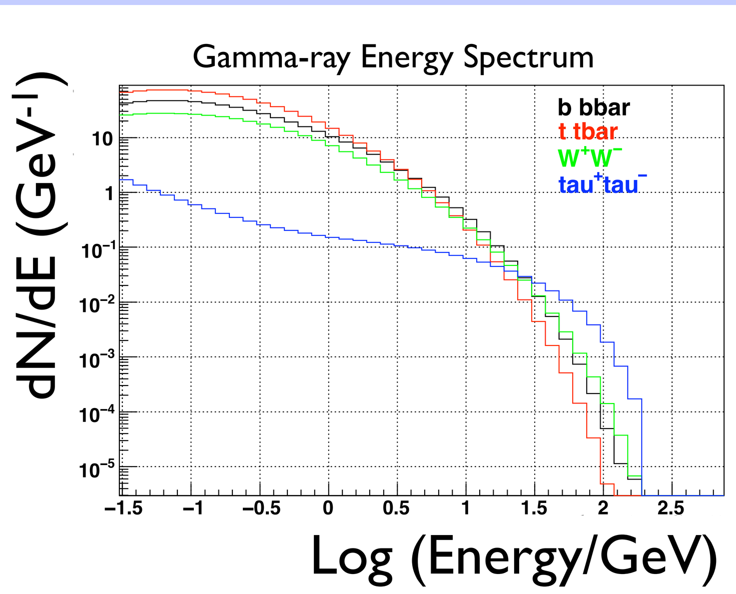
Diagram [1] showing WIMP Dark Matter particles annihilating via unkown process to W,Z, or quark pairs that hadronize and produce π^0 that decay into two photons.

Dark Matter

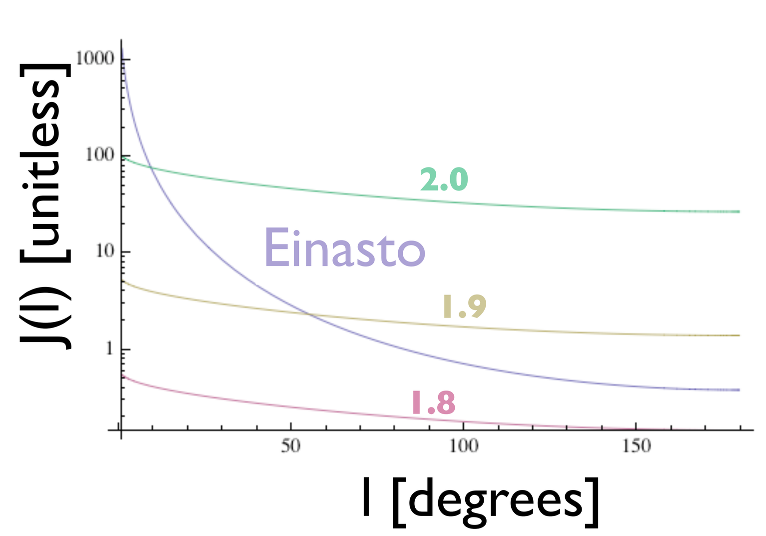
- Indirect detection via pair annihilation to $q\bar{q}$ pairs (continuum), $Z\gamma$, or $\gamma\gamma$ (spectra for selected channels shown below)
- Various analytic and n-body halo models are considered:
  - NFW[6]
  - Einasto [2]
  - Moore [5]
  - Via Lactae II [4]
- The flux is given by the following relation

$$\phi_\chi(E,\psi) = \frac{\sigma v}{8\pi} \sum_f \frac{dN_f}{dE} B_f \underbrace{\int_{\text{l.o.s.}} dl(\psi) \frac{\rho(l)^2}{m_\chi^2}}_{J}$$

where the line of sight integral (J shown below) that depends on the square of the dark matter density, ρ(l).



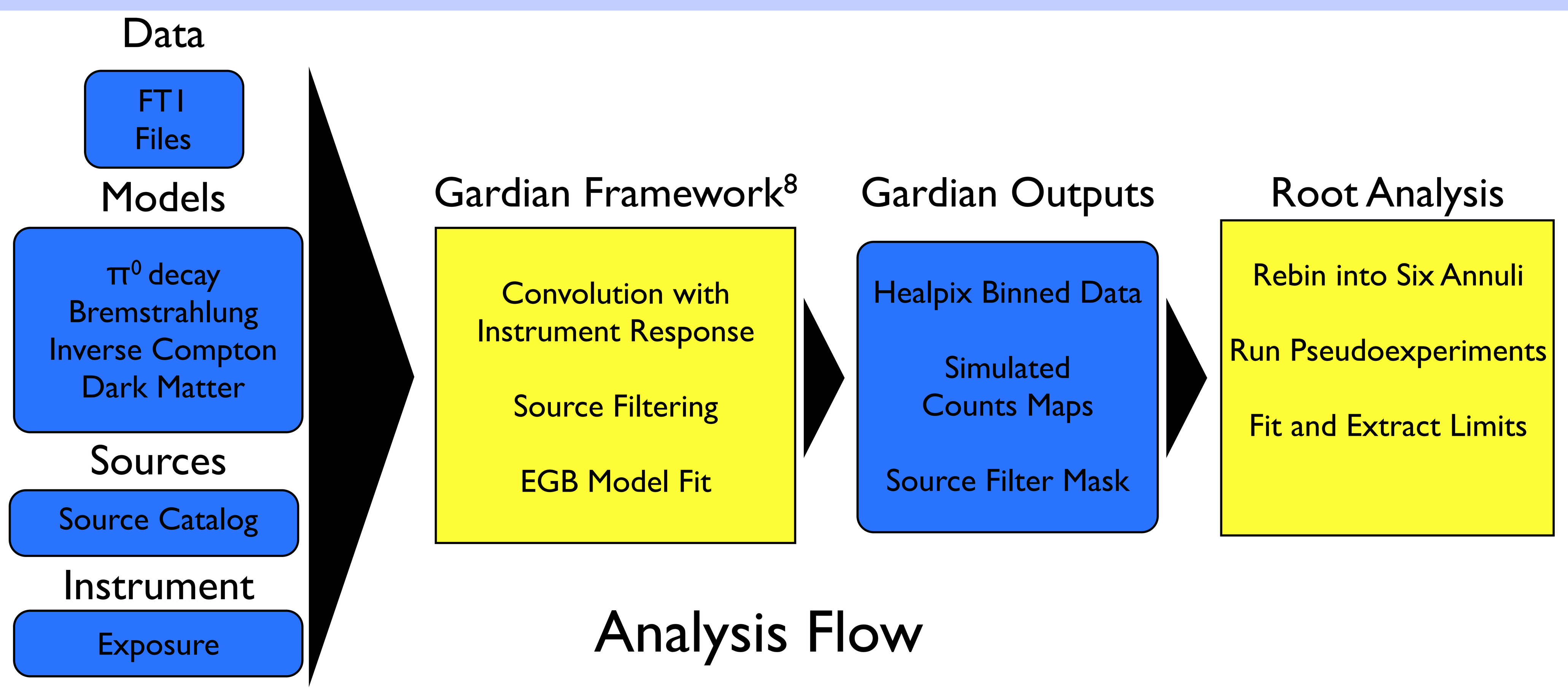
Model independent differential gamma yield for the selected decay channels



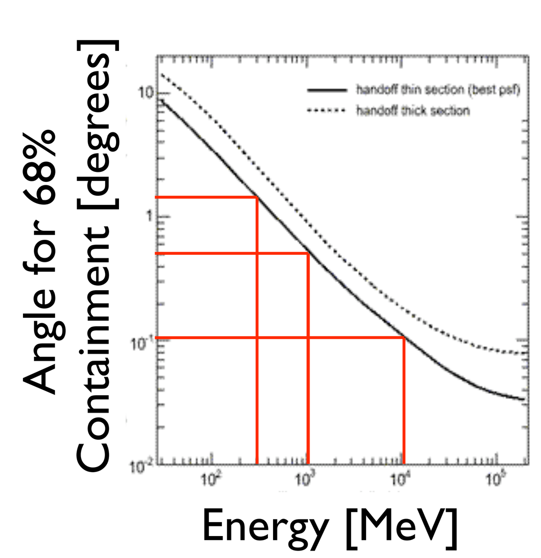
Comparison of a smooth Einasto halo with contributions from unresolved subhalos with mass function slopes of 1.8, 1.9, and 2.0

Methods

- Diffuse model components generated with *galprop* [7] model:
  - Inverse Compton, Pion Decay, and Bremstrahlung
- Dark matter yield calculated with *DarkSUSY* [3]
- Sources filtered using the 11 month catalog with three source masks
  - 317 MeV - 1 GeV, 3° radius + 10° Galactic plane (GP) cut
  - 1 GeV - 10 GeV, 2° radius + 10° GP cut
  - 10 GeV - 100 GeV, 1.6° radius + 10° GP cut
- Sample models to investigate scenarios with pseudoexperiments:
  - Halo profile shape (shown in bottom left)
  - Primary decay channel
  - Spatial binning

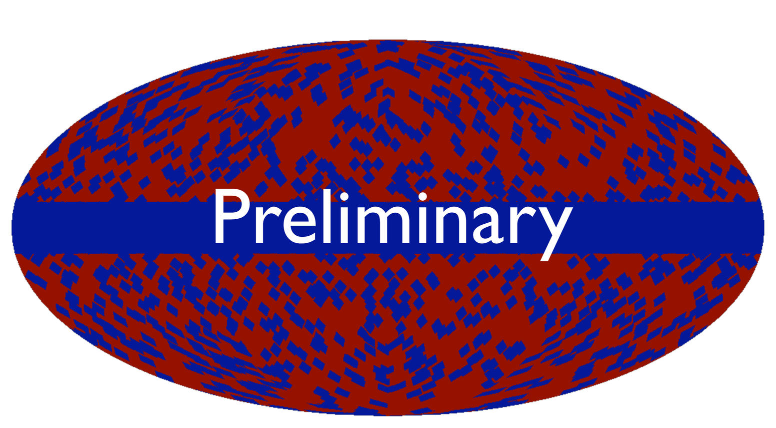


Analysis Flow



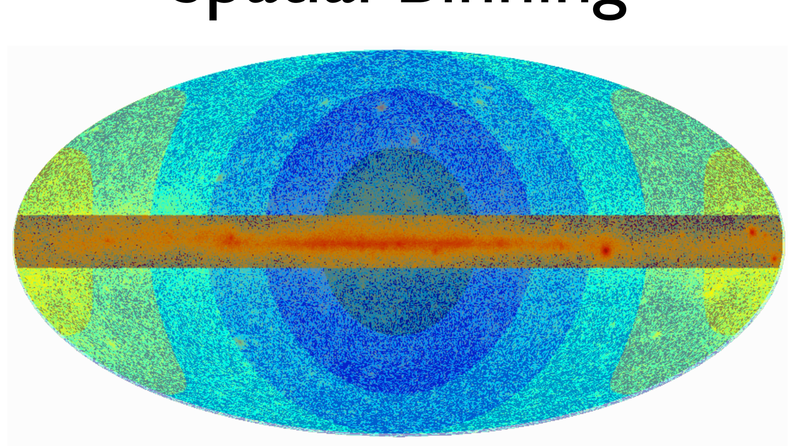
Point-spread function for the LAT, showing the three energy bins for the filter mask (317 MeV-1 GeV, 1-10 GeV, 10-100 GeV)

Source Filter Mask



Source removal mask for 1 GeV - 10 GeV, 2 degrees radius filtered around each source (filtered pixels in blue)

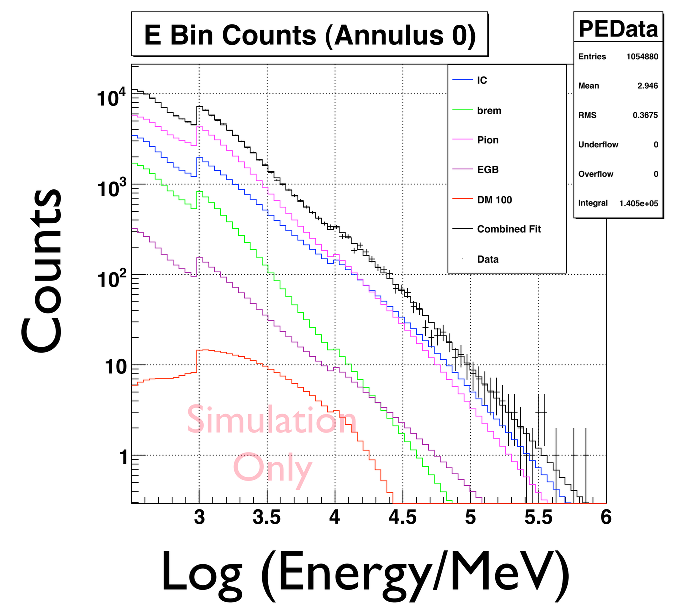
Spatial Binning



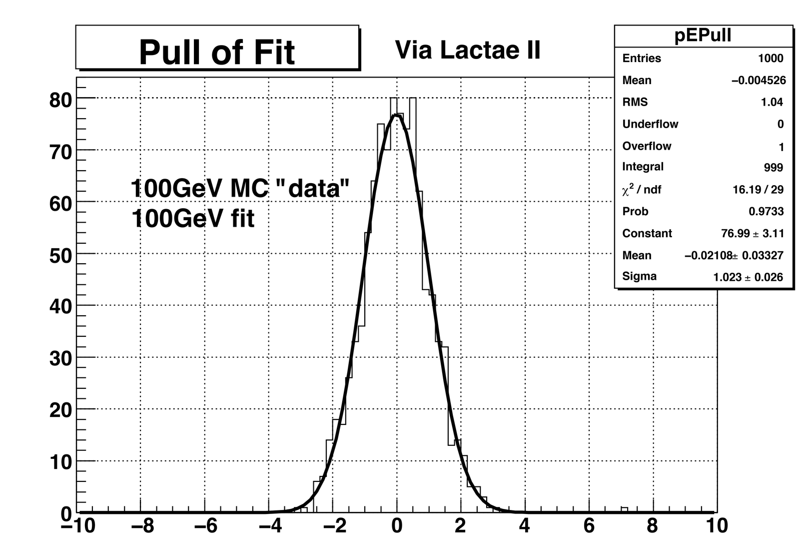
The sky binned in a series of six annuli and a 10 degree mask around the Galactic plane

Example Pseudo-Experiment

We created pseudoexperiments using Monte Carlo (MC) with a WIMP mass of 100 GeV for 1 year of simulated observation. Each pseudoexperiment was fitted assuming the same WIMP mass of 100 GeV.



Energy spectra from a single pseudoexperiment using an NFW profile.



Distribution of the quantity:

$$\frac{S_{fit} - S_{MC}}{\sigma_{S_{fit}}}$$

where S_{fit} is the fitted signal, S_{MC} is the generated signal, and σ_{Sfit} is the error on the fitted signal for 1000 pseudoexperiments.

Performance

We perform pseudoexperiments where a fit using our diffuse model and assuming certain DM characteristics (WIMP mass, smooth vs clumpy, etc) is made on Monte Carlo sample.

Shown below is fractional error averaged over these pseudo-experiments at each WIMP mass. The smooth NFW profile is the pessimistic case without clumps, while the Via Lactae II (VL II) profile is the more optimistic case where unresolved subhalos are included.

Mass (GeV)	Profile	100	200	300	400	500	600
Mean FracErr	NFW	0.58	0.66	0.73	0.76	0.76	0.77
Mean FracErr	VLII	0.11	0.19	0.26	0.34	0.42	0.47

$$\text{Mean FracErr} = \left\langle \frac{\sigma_{S_{fit}}}{S_{fit}} \right\rangle$$

Summary/Plans

- Study alternative diffuse backgrounds using a grid of galprop model parameters
- Investigate alternative dark matter models
- Explore contributions from unresolved millisecond pulsars
- Draft paper in preparation

References

[1] Baltz et. al., JCAP, 7 (2008) 13 (0806.2911)
[2] Einasto J., 1969, Astrofizika, 5, 137
[3] P. Gondolo, J. Edsjö, P. Ullio, L. Bergstöm, M. Schelke and E.A. Baltz, JCAP 07 (2004) 008 (astro-ph/0406204)
[4] Kuhlen M., Diemand J., Madau P. 2008, ApJ, 686, 262, (astro-ph/0805.4416)
[5] Moore et. al., Mon. Not. Roy. Astron. Soc. 310 (1999) 1147 (astro-ph/9903164)
[6] J.F. Navarro, C.S. Frenk and S. D. White, Astrophys. J. 462 (1996) 563 (astro-ph/9508025)
[7] Strong A.W., Moskalenko I.V. Astrophys. J. 509:212 (1998)
[8] Gardian is a Fermi LAT internal software framework developed by Gudlaugur Johannesson