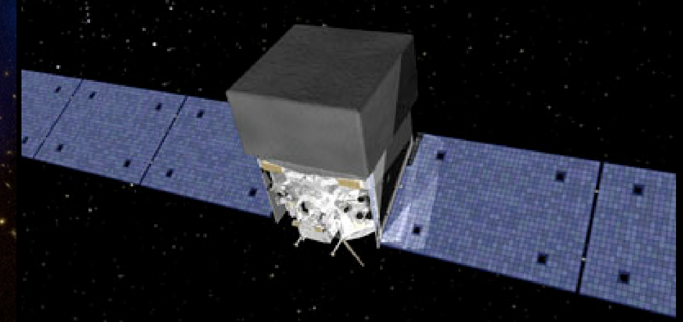

Dark Matter and New Physics Searches with Fermi

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Representing the Fermi LAT Collaboration

Dark Matter and New Physics Working Group

Fermi Symposium, 7 March 2009, Tokyo

Outline

- Overview of Fermi/LAT prospects for detecting a dark matter signal: analysis challenges and sensitivities
- Solving the dark matter puzzle: hints from space
- Conclusions

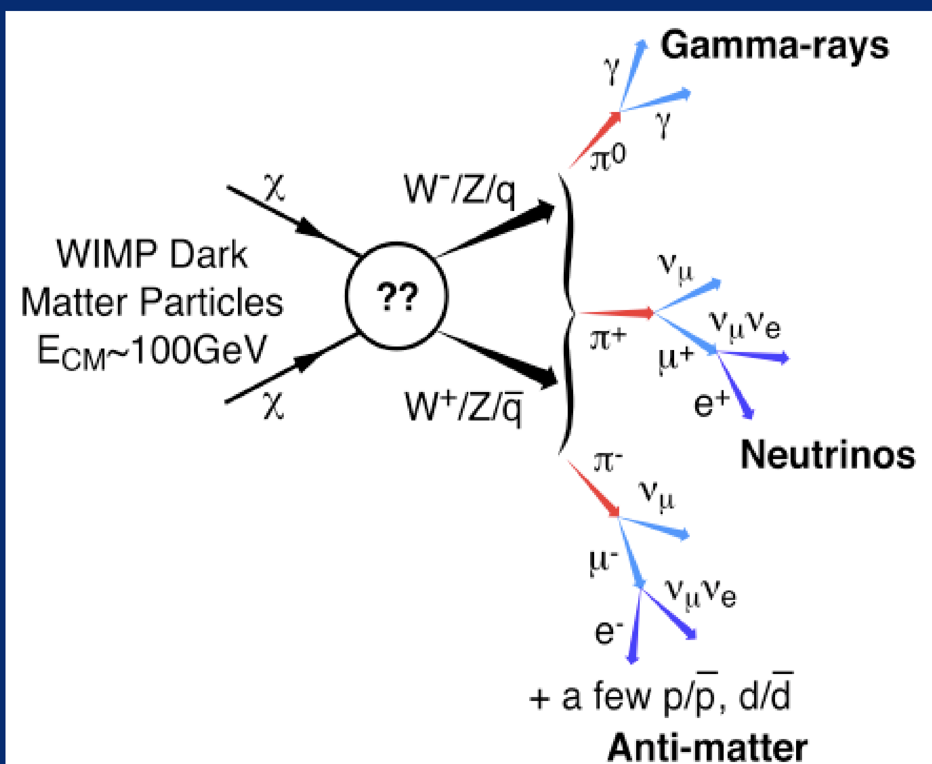
Solving the Puzzle

- A (very reasonable) assumption: dark matter is made out of particles!
- Several theoretical models (Supersymmetry, Universal Extra Dimensions, etc.) have been proposed that naturally predict the existence of a WIMP at the weak scale that is a natural dark matter candidate
- The Fermi LAT has a unique perspective and it will investigate the existence of WIMPs indirectly primarily through their annihilation or decay <u>into photons and into electrons.</u>
- Indirect detection of a dark matter signal would be complementary to direct detection and collider searches and it would provide invaluable information on the distribution of dark matter in space

➡ <u>Not an easy task! Large uncertainties in the signal (DM distribution, underlying particle physics model) and in the background (particle background, photons from diffuse emission and point sources in the galactic center)</u>

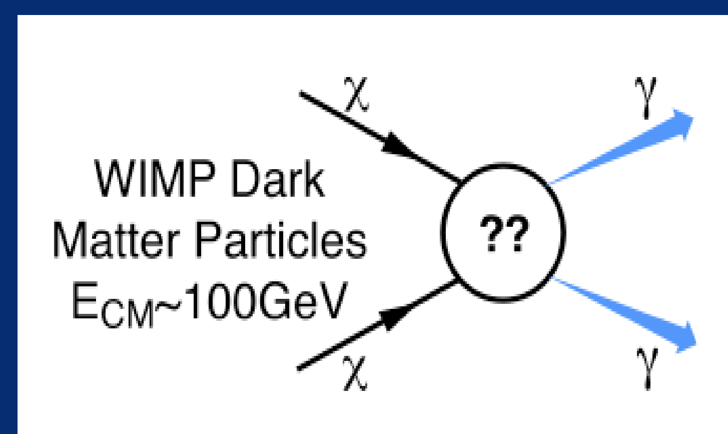
γ from WIMP Annihilation

Continuum spectrum with cutoff at M_χ



Spectral line at M_χ (for γγ)

- Detection of prompt annihilation into γγ (γZ^0) would provide smoking gun for dark matter annihilation
- Requires best energy resolution
- However, annihilation fraction in the range 10^{-3}-10^{-4} (depending on the model)



Annihilation Signal

particle physics

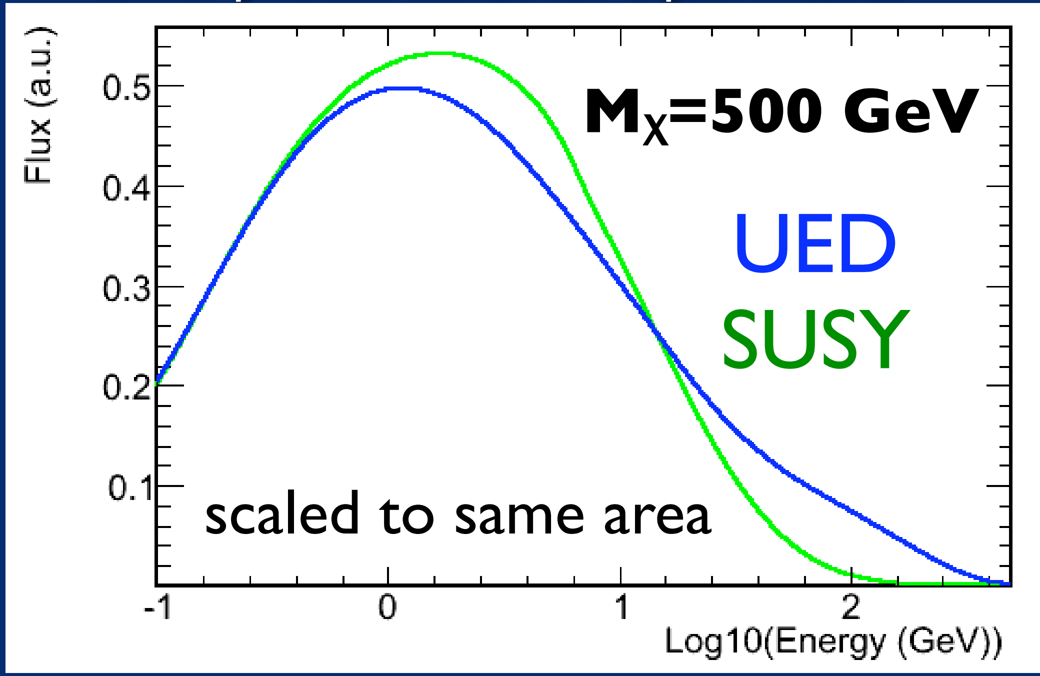
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \phi, \theta) = \boxed{\frac{1}{4\pi}\frac{< \sigma_{ann} v >}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f}$$

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

DM distribution

Two different Particle Physics Scenarios: UED vs SUSY

- Consider the photon spectrum from 500 GeV WIMP annihilation in SUSY and in UED (*):
  - ★ UED: photons mostly from lepton bremsstrahlung
  - ★ SUSY: photons mostly from b quark hadronization and then decay, energy spread through many final states lower photon energy. p-wave dominated cross-section yields lower photon fluxes for equal masses



➡**Spectra can look very different in these scenarios**

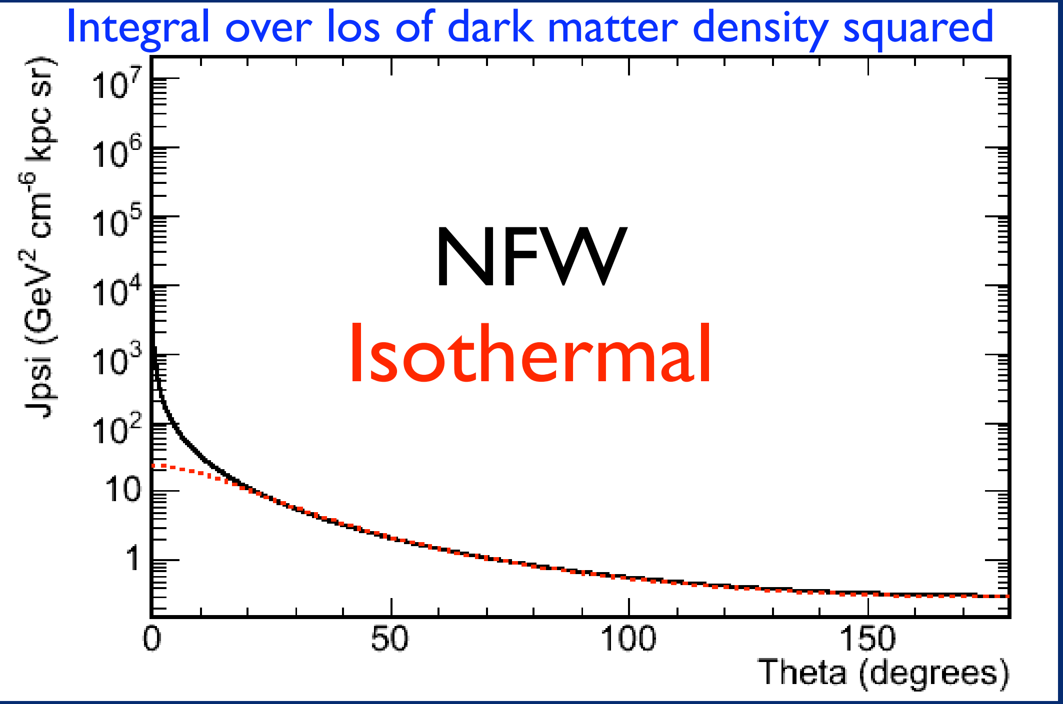
mSUGRA parameters:

$$\begin{aligned} m_0 &= 500\ \mathrm{GeV} \\ m_{1/2} &= 1160\ \mathrm{GeV} \\ A_0 &= 0, \quad \tan\beta = 10 \end{aligned}$$

(*) G. Bélanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. 174 (2006) 577; hep-ph/0405253
G. Bélanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. 149 (2002) 103; hep-ph/0112278

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

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

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

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

$$\text{cut radius} = 10^{-5} \text{ kpc}$$

Isothermal profile

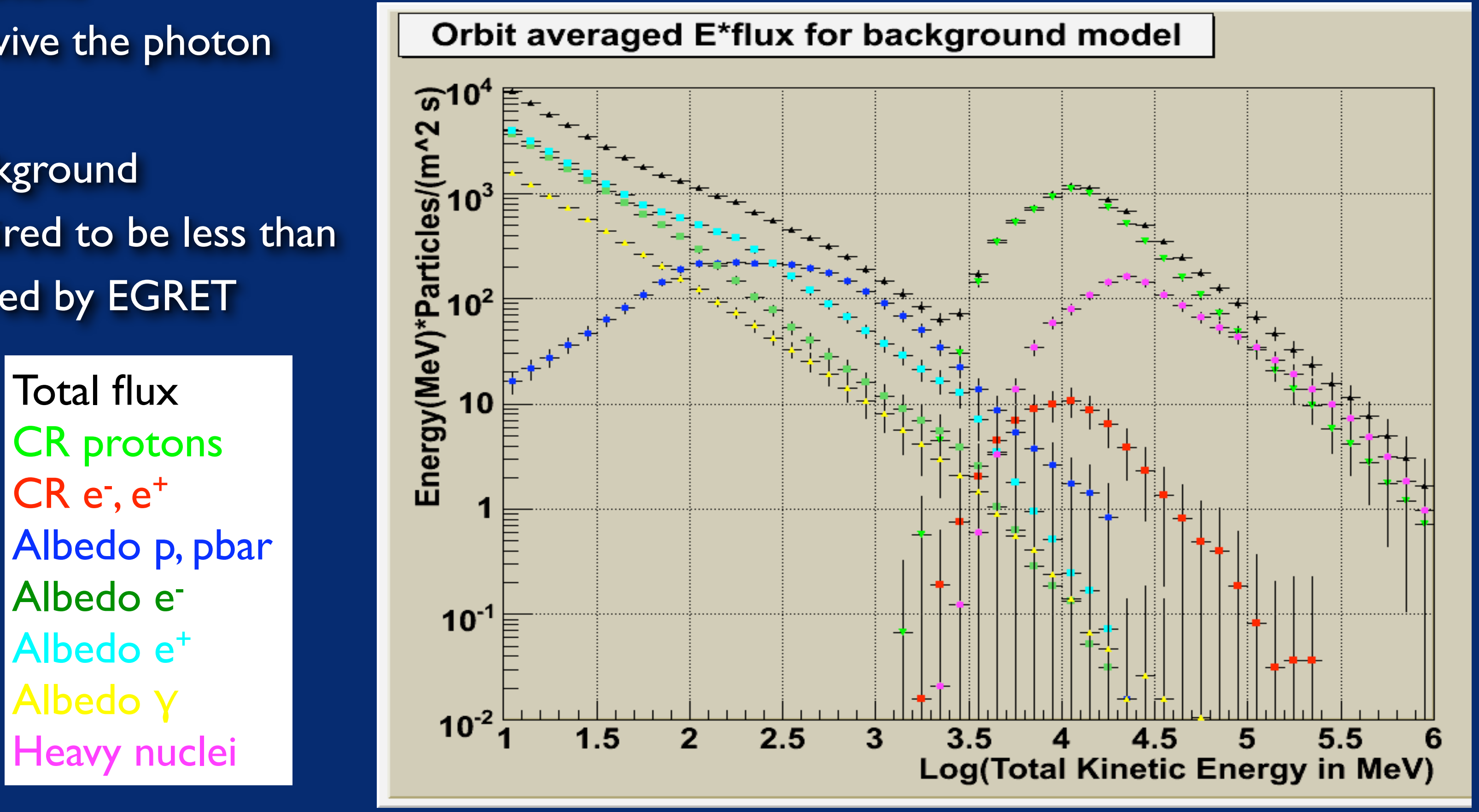
$$\rho(r) = \rho_0 \frac{1 + (r_0/a_0)^2}{1 + (r/a_0)^2}$$

$$\text{cut radius} = 10^{-10} \text{ kpc}$$

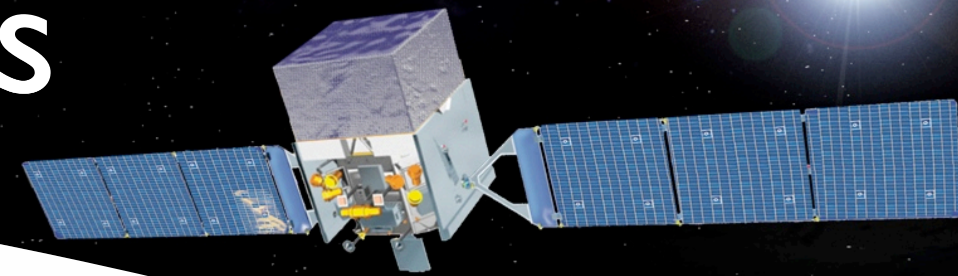
$$a_0 = 3.5 \text{ kpc}$$

Backgrounds

- Photons from galactic diffuse emission (due to CR particles interactions - IC, π^0 decay, bremsstrahlung - with gas in the ISM and low energy photons in the IRF), photons from extra-galactic diffuse emission
- Charged particles (protons, electrons, positrons), some neutrons, Earth albedo photons. They dominate the flux of cosmic photons
- Less than 1 in 10^5 survive the photon selection
- Above a few GeV, background contamination is required to be less than 10% of EGB γ measured by EGRET



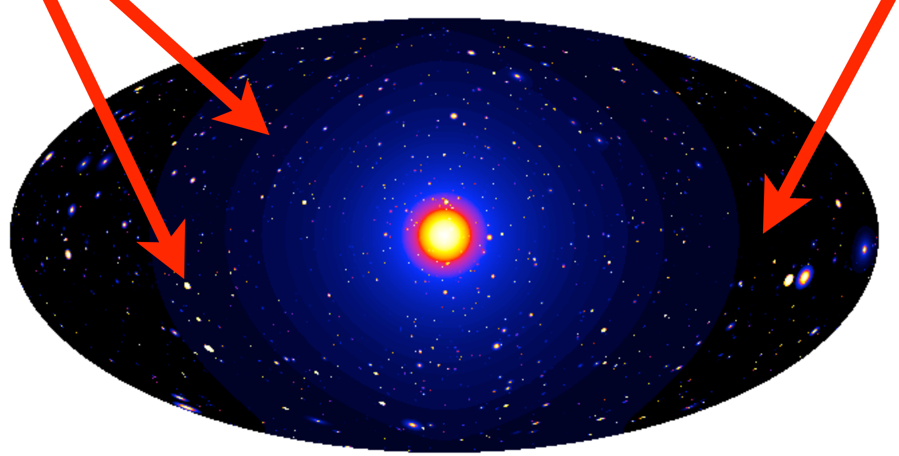
Search Strategies



Galactic center:
Good Statistics but source confusion/diffuse background

Satellites:
Low background and good source id, but low statistics, astrophysical background

Milky Way halo:
Large statistics but diffuse background



All-sky map of DM gamma ray emission (Baltz 2006)

Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

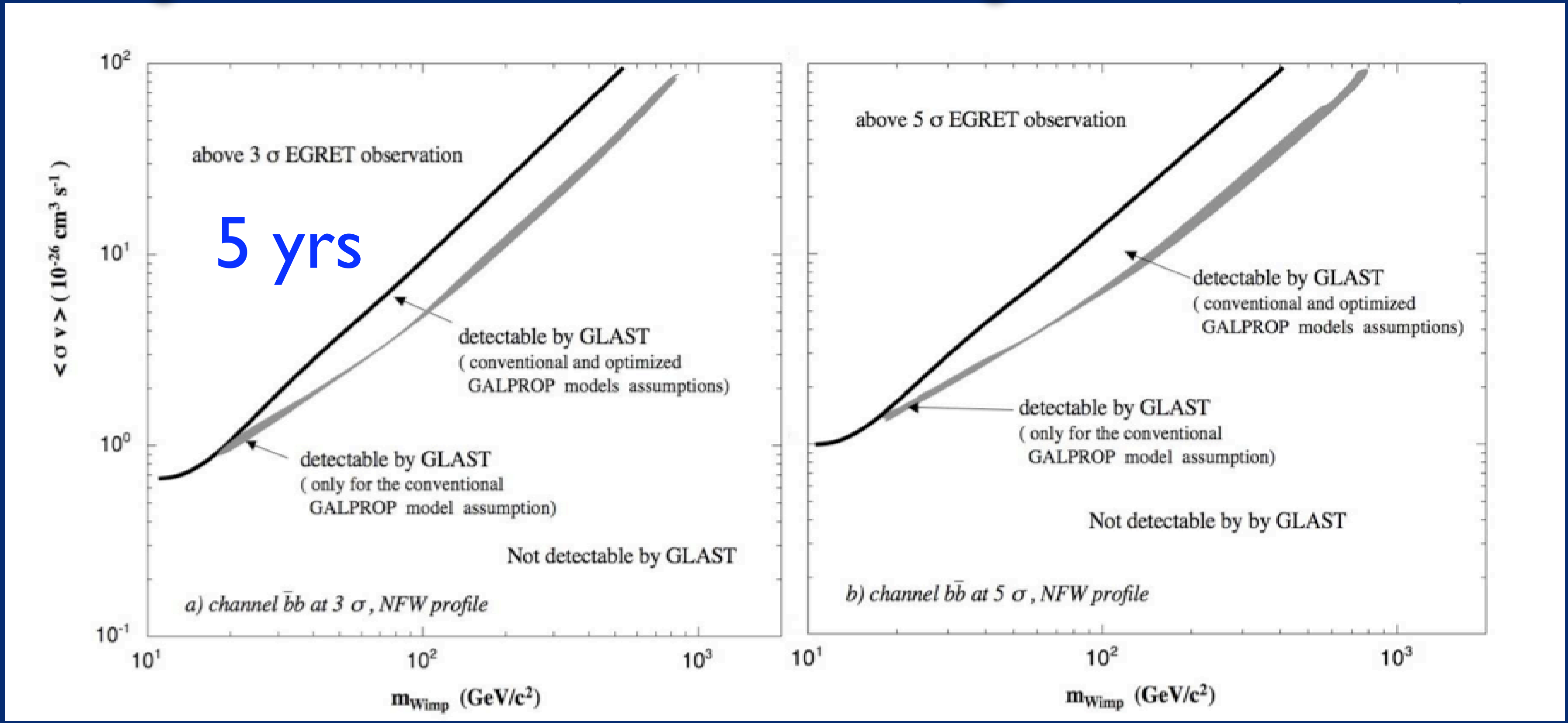
Extra-galactic:
Large statistics, but astrophysics, galactic diffuse background

➡ Uncertainties in the underlying particle physics model and DM distribution affect all analyses

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

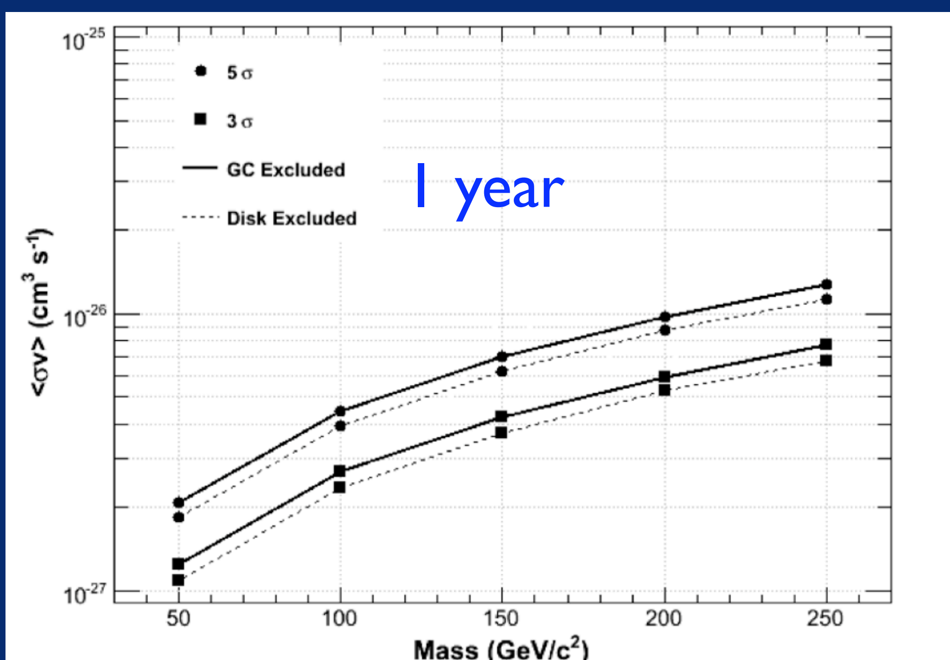
Galactic Center

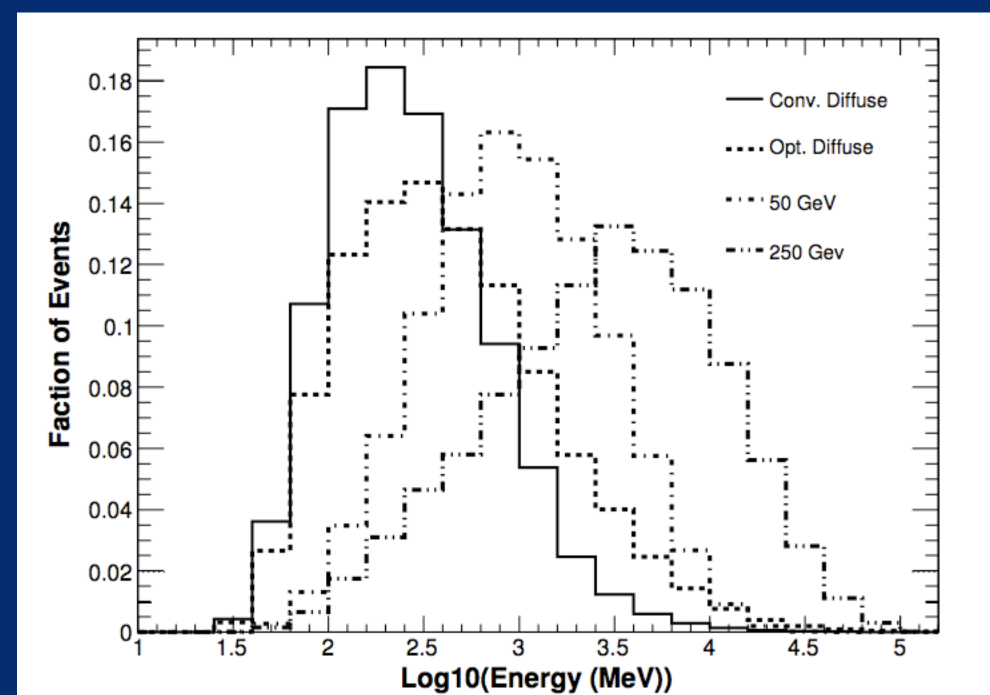
- Select a region of 0.5^{O} around the galactic center, assume NFW profile and consider one WIMP annihilation channel at the time
- Remove astrophysical sources (based on spectral analysis, multiwavelength observations. Difficult, their behavior at these energies is not known) in the region and perform χ^2 test to disentangle dark matter contribution from diffuse background



Galactic Halo

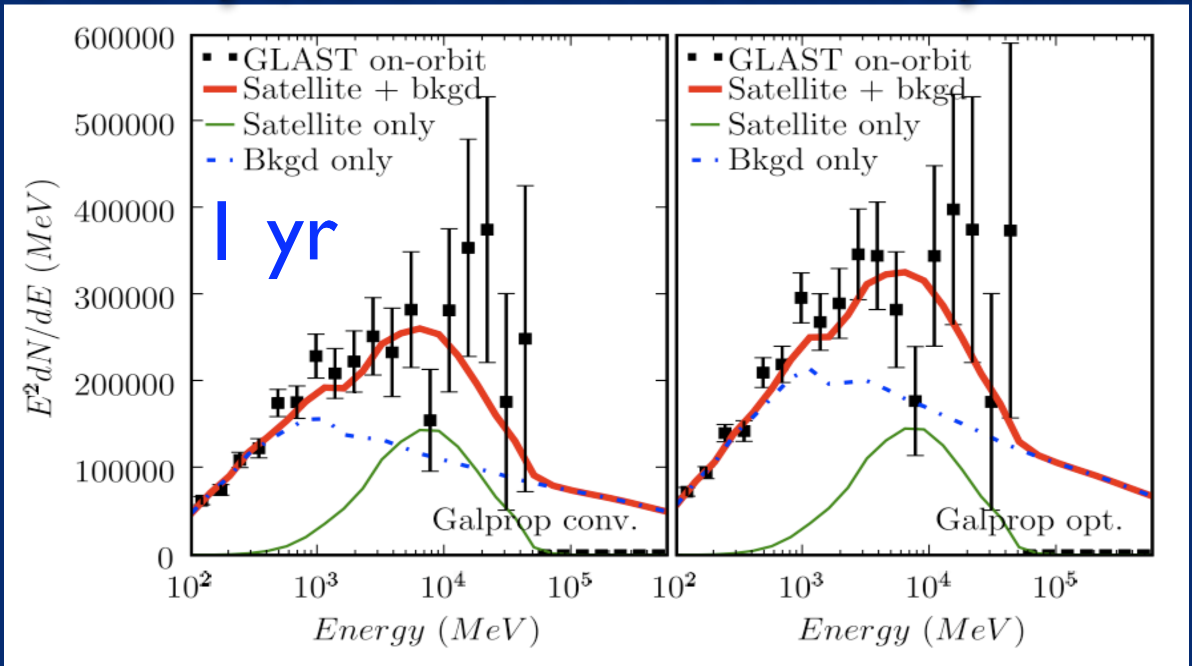
- Complementary to galactic center analysis: no source crowding, but significant uncertainty in astrophysical background
- Determine sensitivity by removing ±10° band in galactic latitude around the galactic disk, or by removing galactic center only (10° radial cut.) Assume NFW profile
- Log-likelihood fit in energy, spatial distribution to exploit differences between signal and background

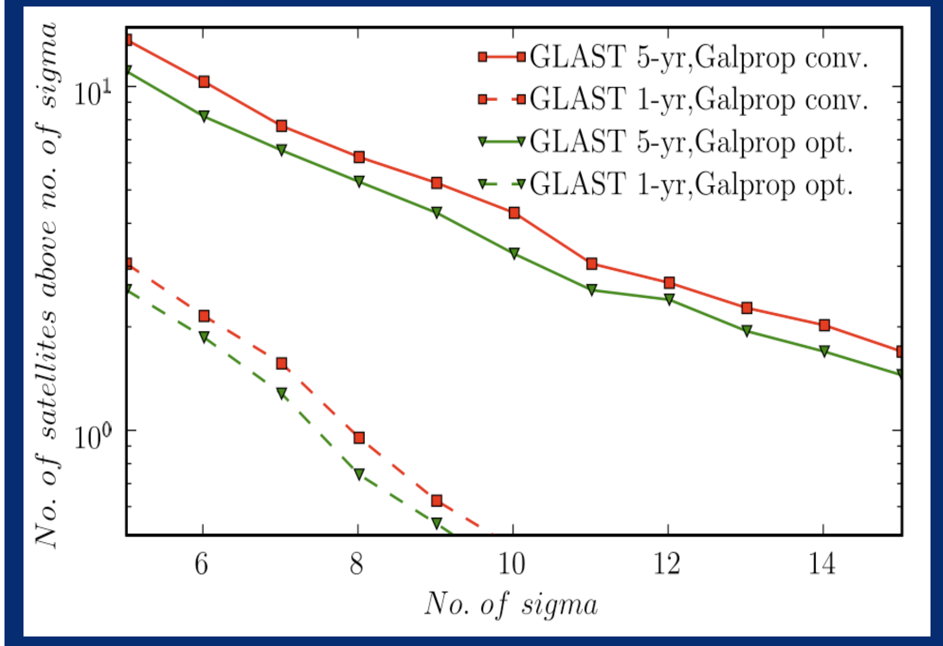




Dark Matter Satellites

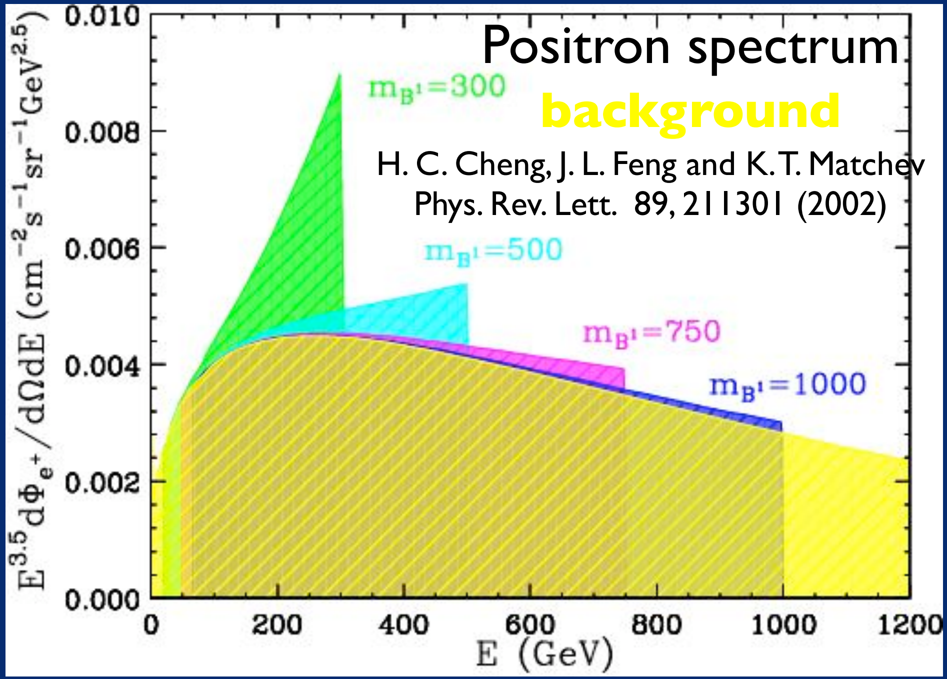
- Expect isotropic distribution of subhaloes in the galactic halo
- DM spectrum very different from power law, no appreciable counterpart in radio, optical, X-ray, TeV; emission is expected to be constant in time
- Assume NFW profile+tidal stripping (satellite distribution by Taylor and Babul, Mon. Not. Roy. Astron. Soc. 364 (2005) 535-551); 100 GeV WIMP, $<\sigma v> = 2.3\times10^{-26}$ cm^3/sec annihilating into b-bbar. Background: extra-galactic, galactic emission
- Generic observable (5σ, 1 yr) satellite: high galactic latitude, ~9kpc from the sun, 3×10^7 $M_\odot$, 1° angular size
- After 4 yrs, EGRET wouldn't have detected any satellites and after 9 yrs, no satellites above 5 σ





Other Searches

- Not only photons! In UED theories for example, the largest annihilation channel is into leptons and thus the signal can be strong when probing leptonic final states directly (more on this later):



- Large Extra Dimensions can also be tested with Fermi. Long lived KK states (~MeV) may be produced in supernovae, stay gravitationally bound by the supernova core and form a halo around the neutron star. They could produce a detectable signal through their decay into photon pairs.
- Probe the existence of axion-like particles searching for distortions in AGN spectra due to axion-photon oscillations in magnetic fields

Hints from Space

- Tantalizing signals from space could be interpreted as dark matter annihilation/interaction:

    WMAP haze

    EGRET GeV excess

    PAMELA positron fraction

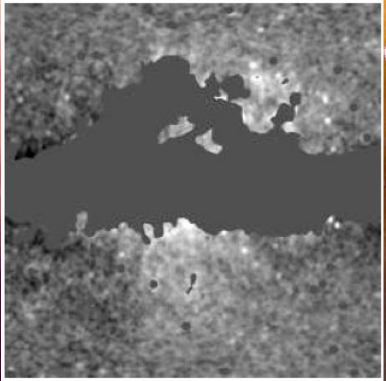
    ATIC (and PPB-BETS) electron spectrum

    HESS electron spectrum

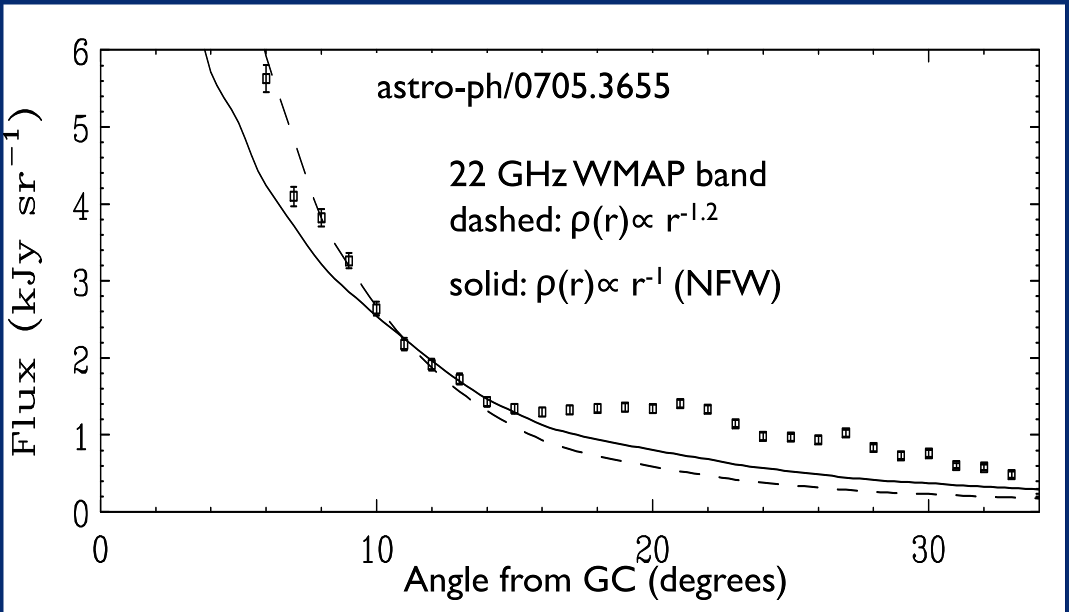
    (Integral/SPI)

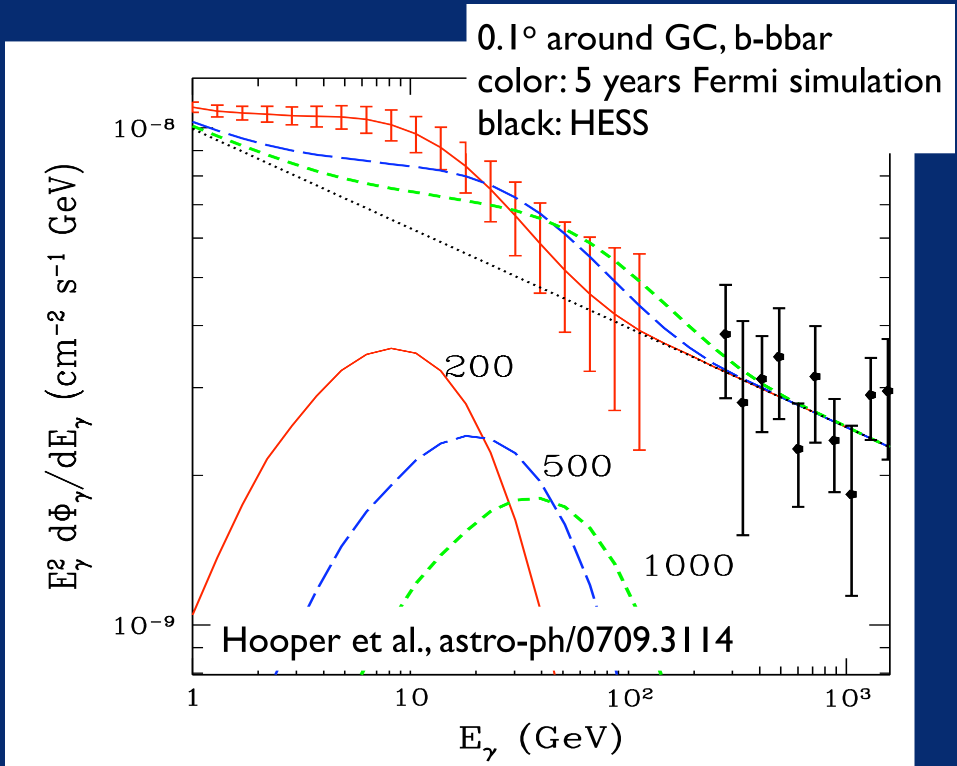
    (DAMA/LIBRA)

WMAP Haze



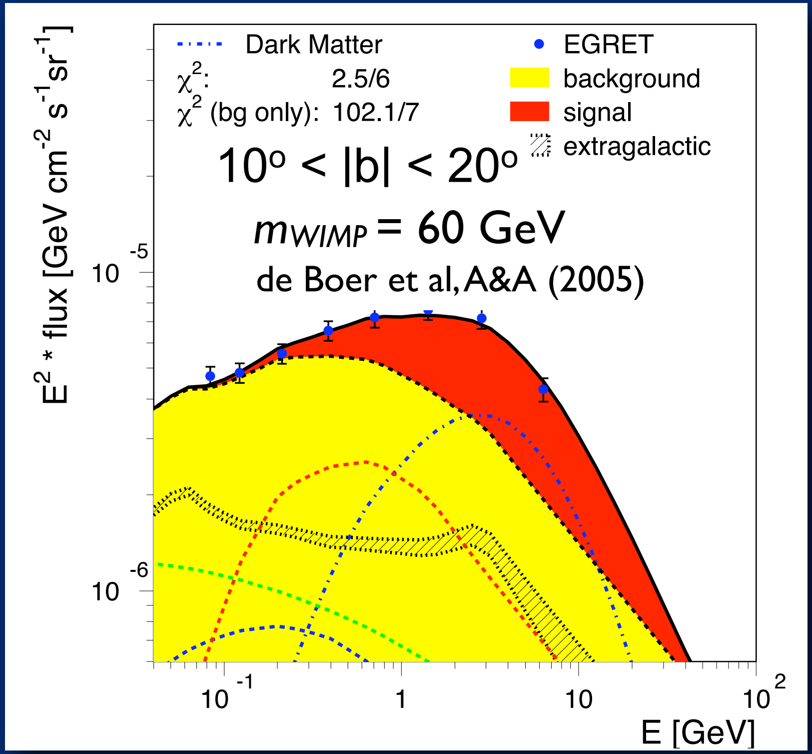
- Excess of microwave emission from the inner galaxy
- It can be interpreted as synchrotron emission from e+ e- from annihilation of dark matter particles with a mass 100 GeV to TeV (Hooper, Finkbeiner, and Dobler, astro-ph/0705.3655)
- Spatial distribution and intensity consistent with a dark matter cusped halo profile and with the predicted annihilation cross section for a thermal relic. No boost factors are required.
- If the haze is the product of dark matter annihilation, it could yield a signal in gamma-rays observable by Fermi





EGRET GeV Excess

- EGRET observed an all sky excess in the GeV range compared to predictions from cosmic ray propagation and γ ray production models which could be attributed to dark matter annihilation



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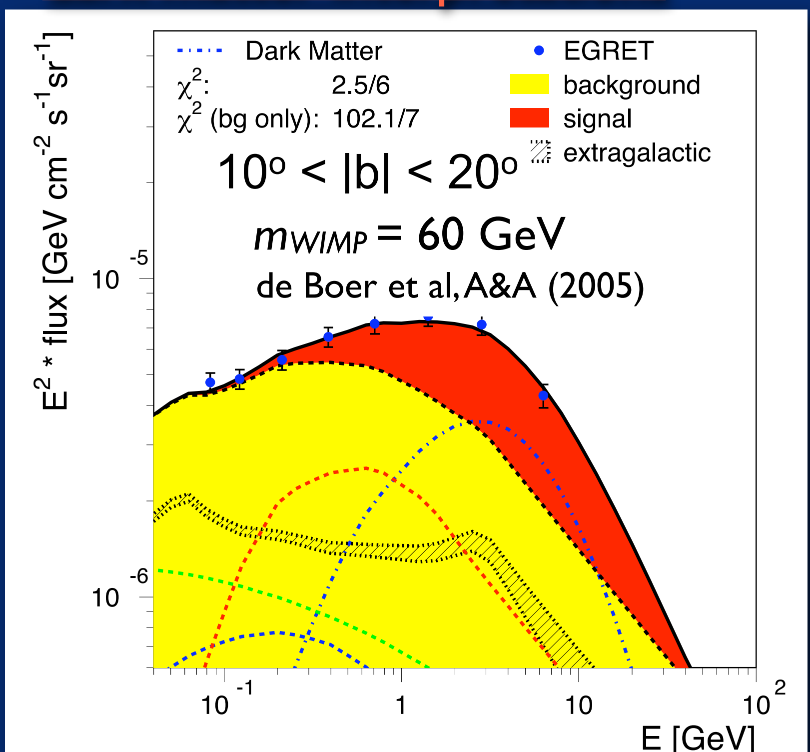
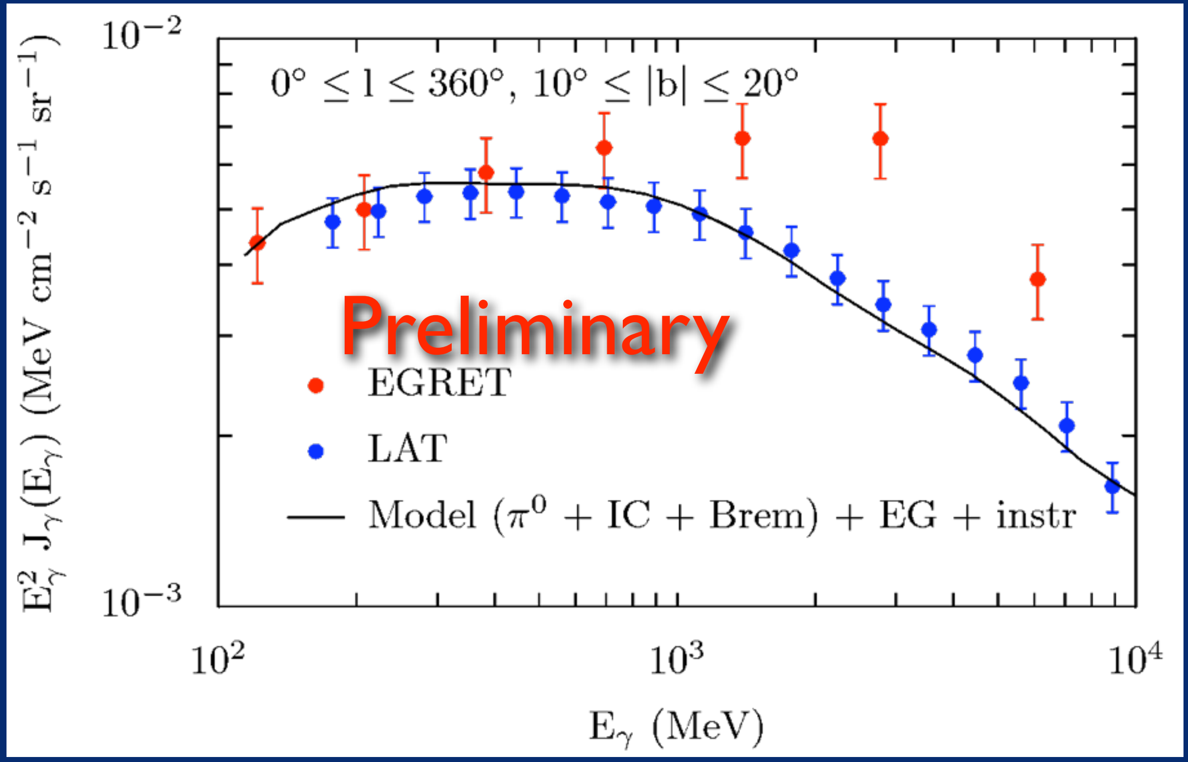
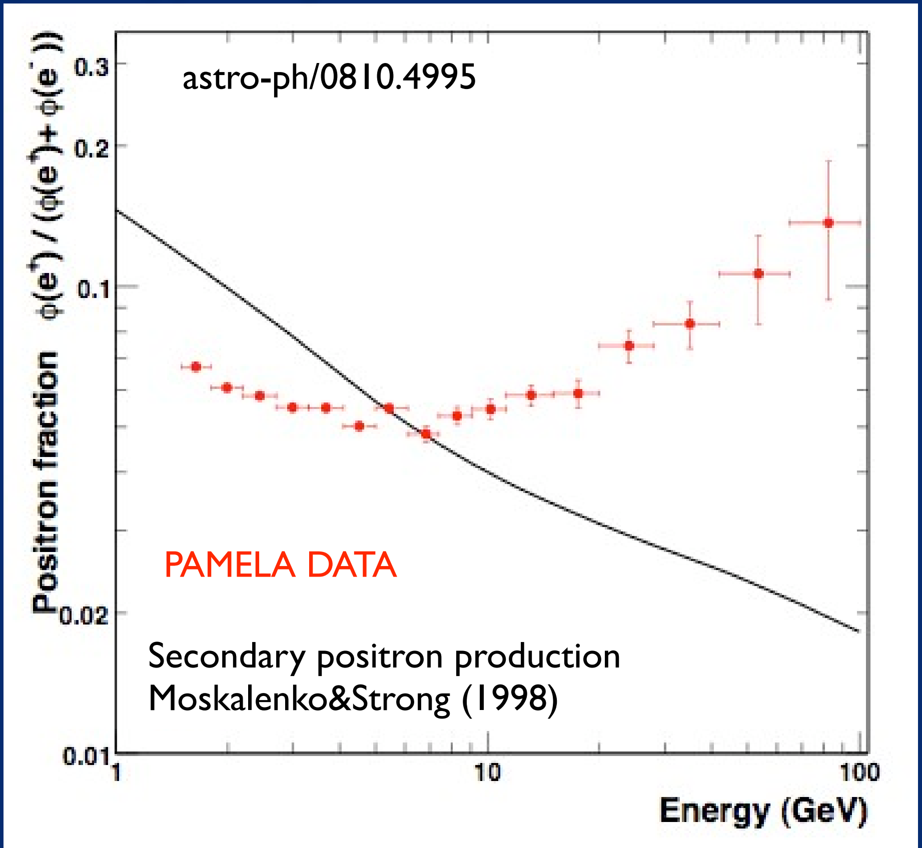
➡ The data collected by the Fermi LAT during the first 5 months of operation does not confirm the excess at intermediate latitudes (see T. Porter's talk) and strongly constrains dark matter interpretations

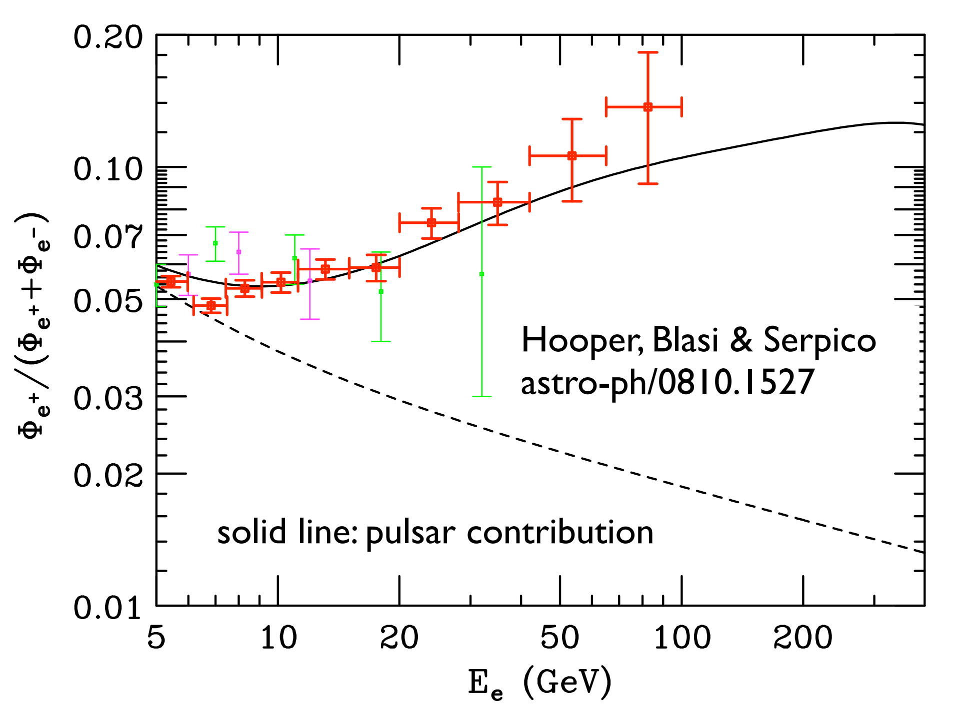




CR e^+e^- Measurements

- PAMELA's increase of the positron fraction at high energy is in disagreement with theoretical predictions for secondary positron production
- The data could be interpreted introducing a primary positron source, for instance a nearby pulsar(s), or by dark matter annihilation in a nearby clump





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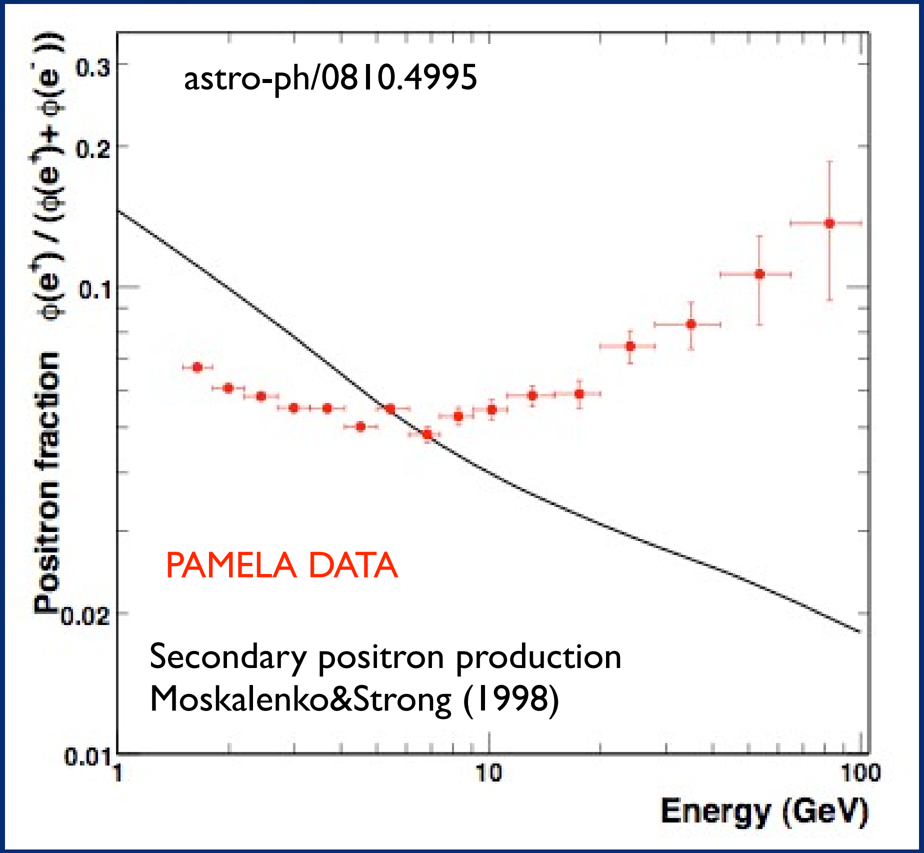
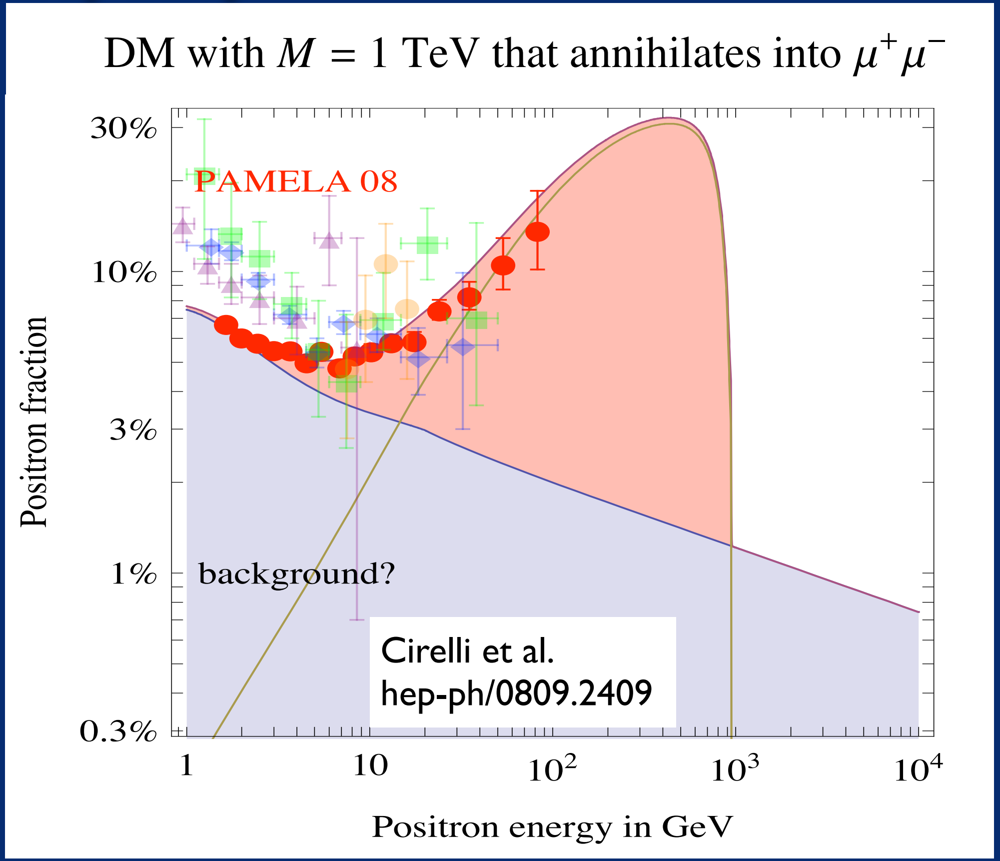
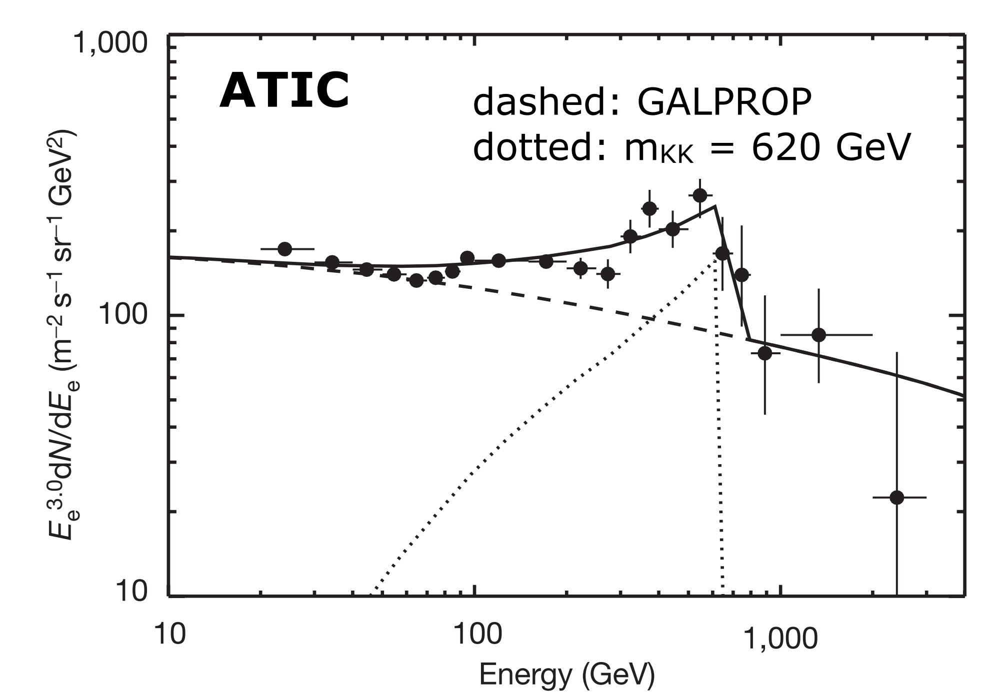


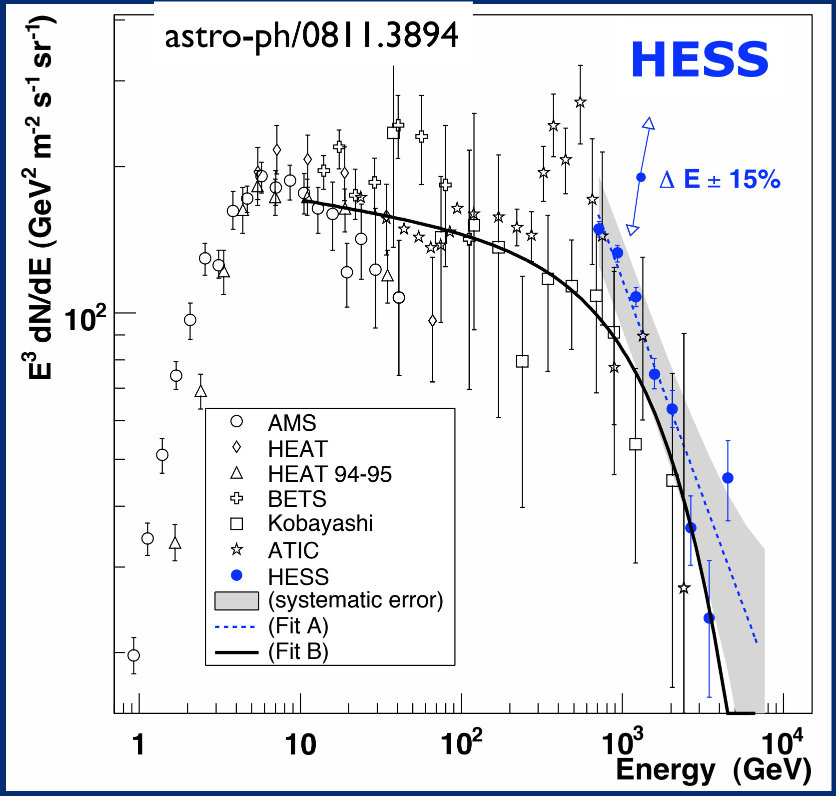


CR e^+e^- Measurements

- ATIC has observed an excess of electrons in the 300-800 GeV range with a steepening at the high energy end also observed by HESS
- In addition to astrophysical explanations for these measurements (nearby source of high energy electrons), heavy dark matter primarily annihilating into leptons, such as suggested by UED theories, could explain the excess and the high energy downturn



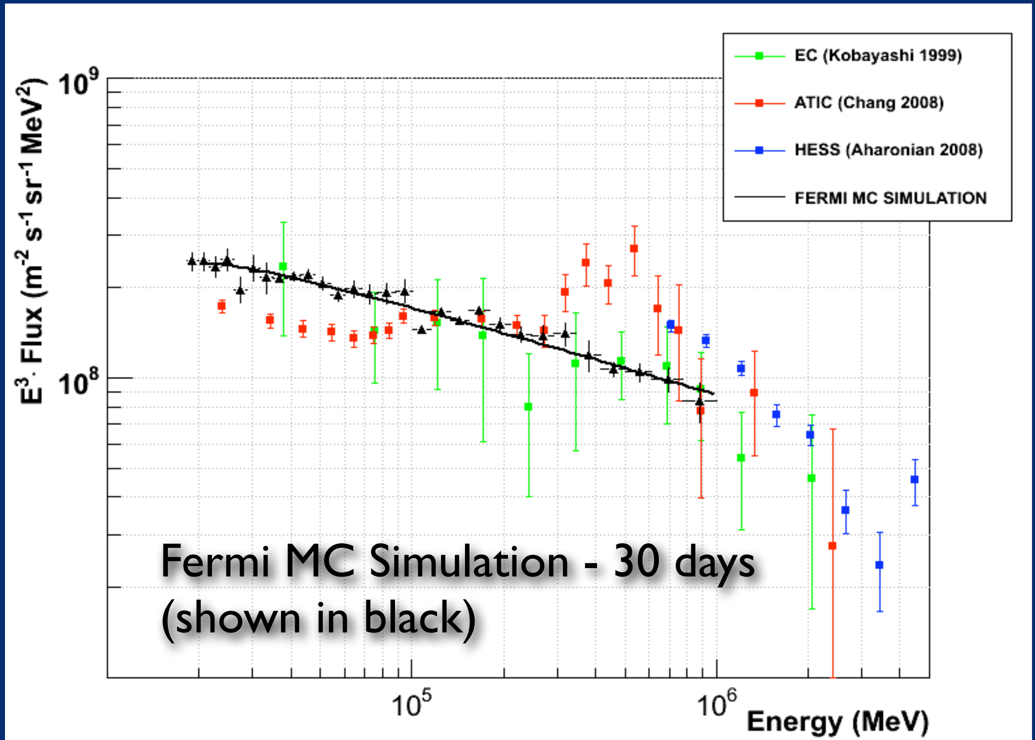
Chang et al., Nature **456**, 362-365 (2008)

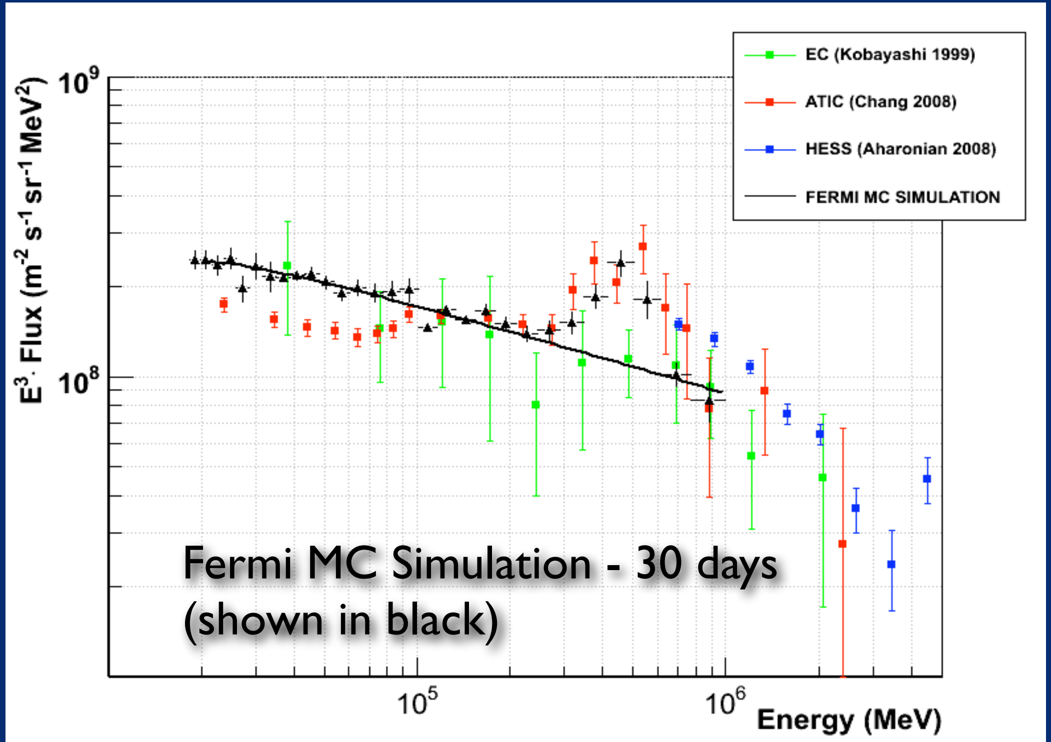


Electrons with the LAT

- The Fermi LAT is an excellent electron+positron detector (but it can’t discriminate charge)
- It will provide a measurement of the combined CR electron+positron spectrum (up to energies of ~1 TeV) with very large statistics:

  over 200k events above 100 GeV (2.5k above 500 GeV) in 6 months
- Demonstrated background contamination <20% at all energies





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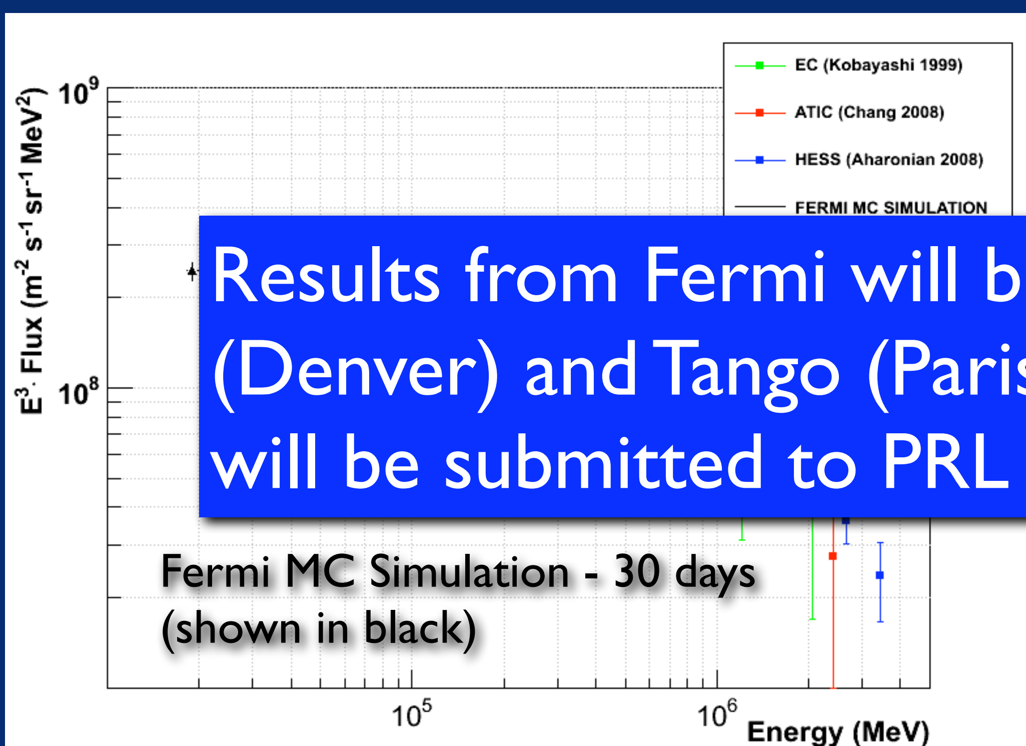
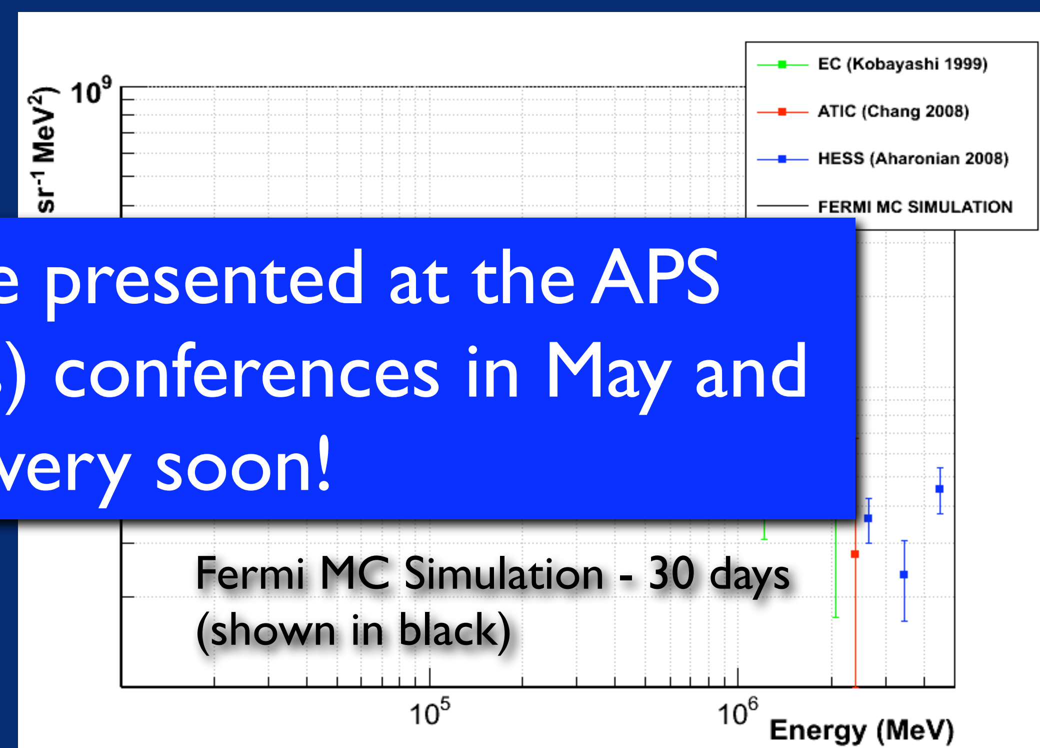




Results from Fermi will be presented at the APS (Denver) and Tango (Paris) conferences in May and will be submitted to PRL very soon!

Summary

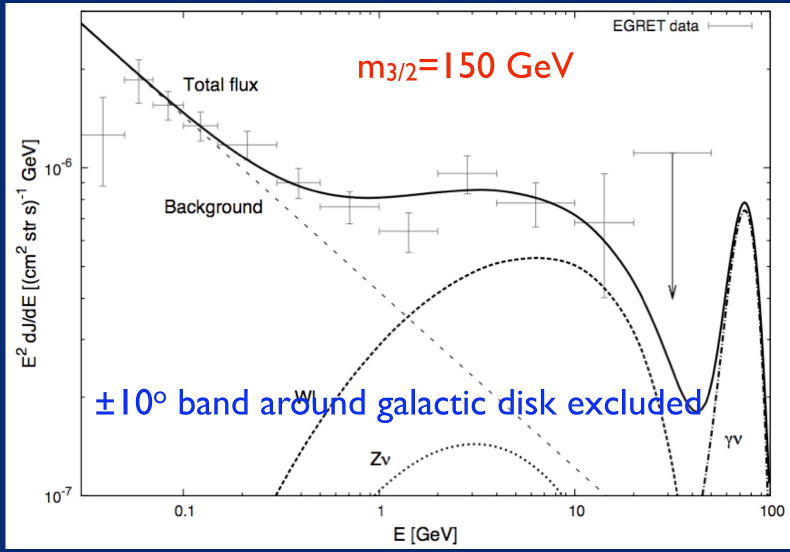
- The Fermi/LAT has great capabilities for indirect dark matter and new physics searches. Analyses are underway
- Many hints of possible dark matter signals from space make these analyses particularly exciting and Fermi can contribute information to any of these potential signals.
- With the measurement of the galactic diffuse emission at intermediate latitudes, the data coming from the LAT have already made significant impact in the dark matter interpretation of the EGRET excess
- Measurements of the CR electrons and positrons by several experiments could be attributed to dark matter annihilation. The Fermi/LAT measurement is eagerly awaited and it will be released very soon!

Enhancement of the Signal

Decaying DM

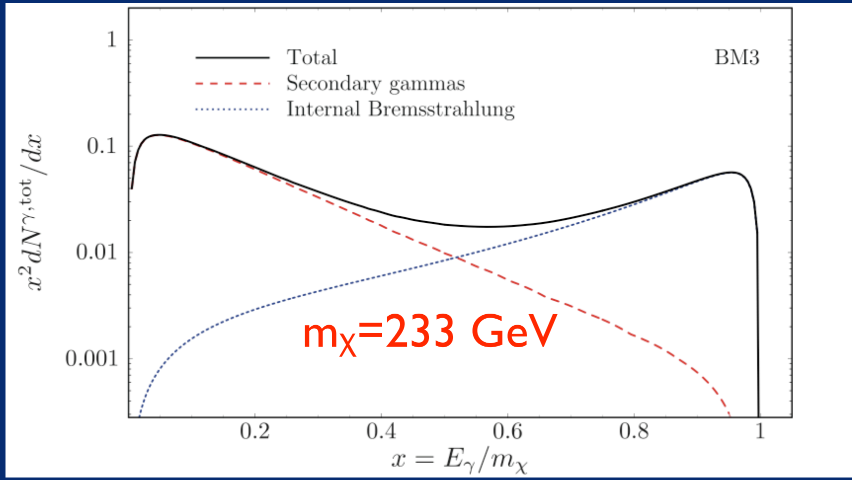
- Gravitino as LSP, lifetime much longer than the age of the Universe (decay rate suppressed by Planck mass and small R-parity violation)
- Decay can produce photons in the GeV range. Very distinctive spectral line, hard to mimic by astrophysical sources

A. Ibarra and D. Tran, arXiv:0804.4596 [astro-ph]



Radiative Corrections

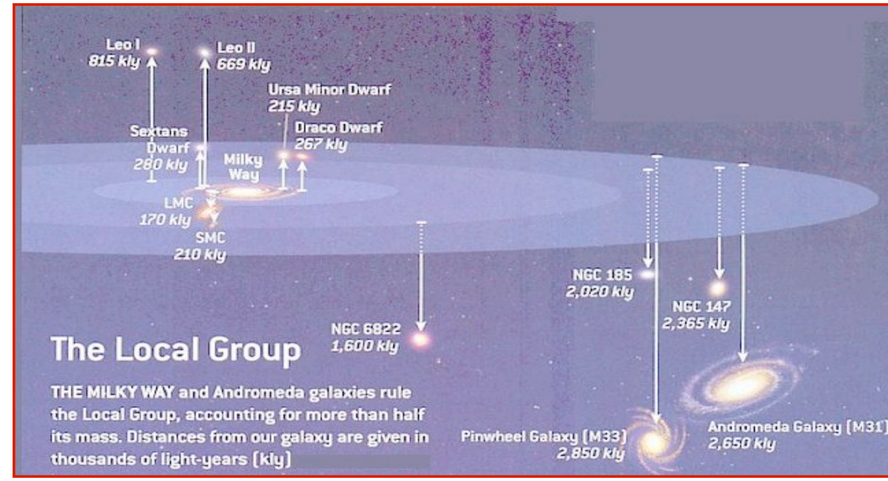
- Enhancement in the high energy gamma ray signal from internal bremsstrahlung effects in WIMP annihilation into charged particle final states
- Very distinctive spectral features

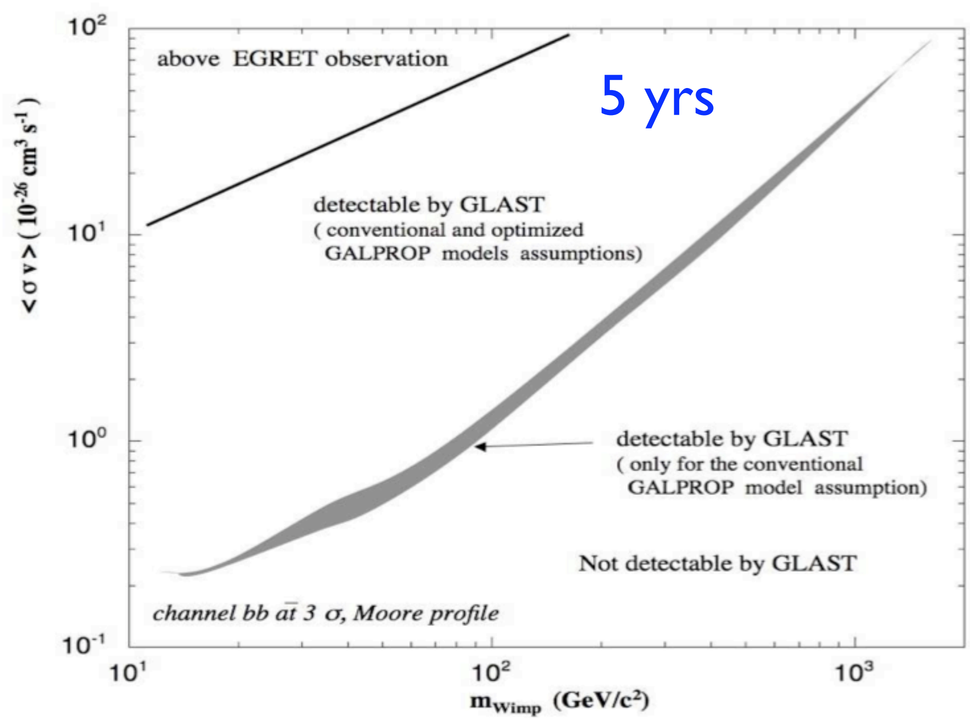


T. Bringmann, L. Bergstrom and J. Edsjo, JHEP 0801, 049 (2008), arXiv:0710.3169 [hep-ph]

Dwarf Galaxies

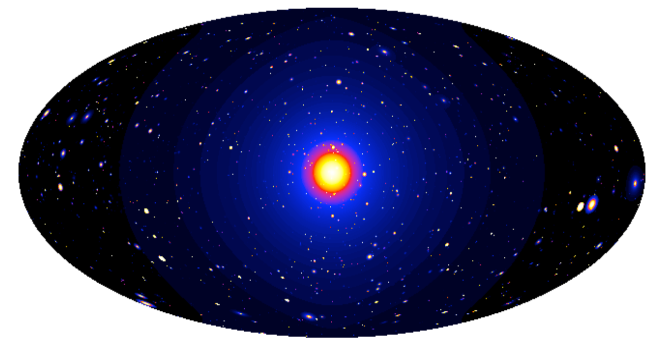
- Dwarf spheroidal (dSph) galaxies are DM dominated (large mass to light ratio). Promising targets for indirect DM detection
- Sagittarius dwarf is closest to the sun (24 kpc). Assume Moore profile and WIMP annihilation into b-bbar





➡10x worse sensitivity if the NFW profile is considered

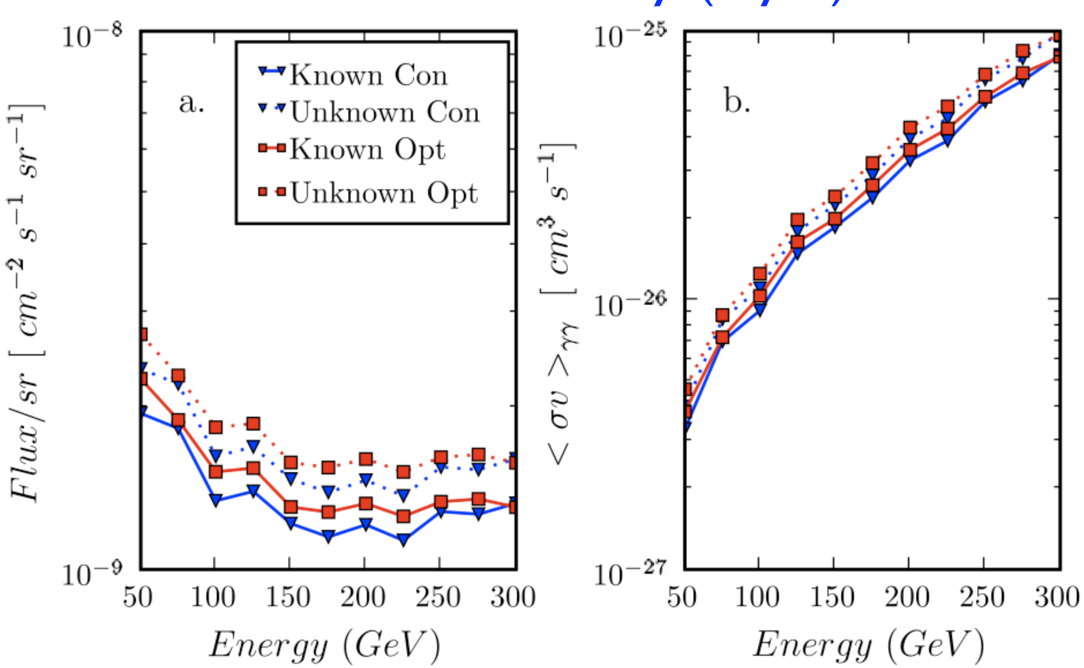
Lines

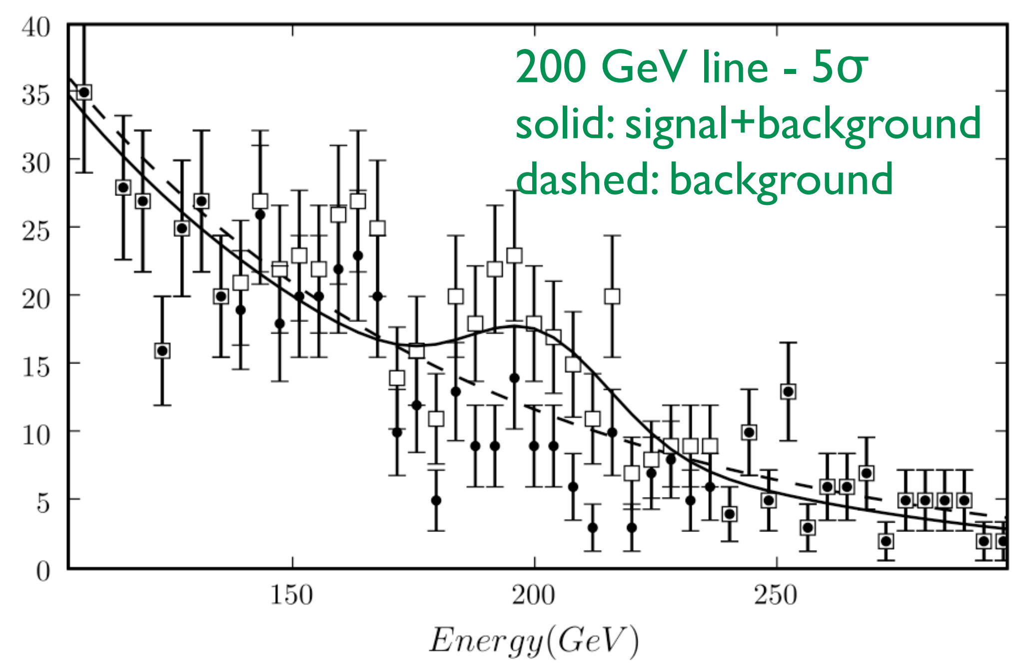


- Search region: annulus between 20°-35° in galactic latitude, removing ±15° band from the galactic disk (signal to background ratio >10x larger than galactic center). Assume NFW profile
- Very distinctive spectral signature
- Generate lines between 50-300 GeV+diffuse background for 5 yrs.
- Better sensitivity is achieved if location of the line is known (discovery at LHC, for example)

➡ For the assumed annulus and profile, boost factors of ~500 are needed to explore interesting MSSM regions

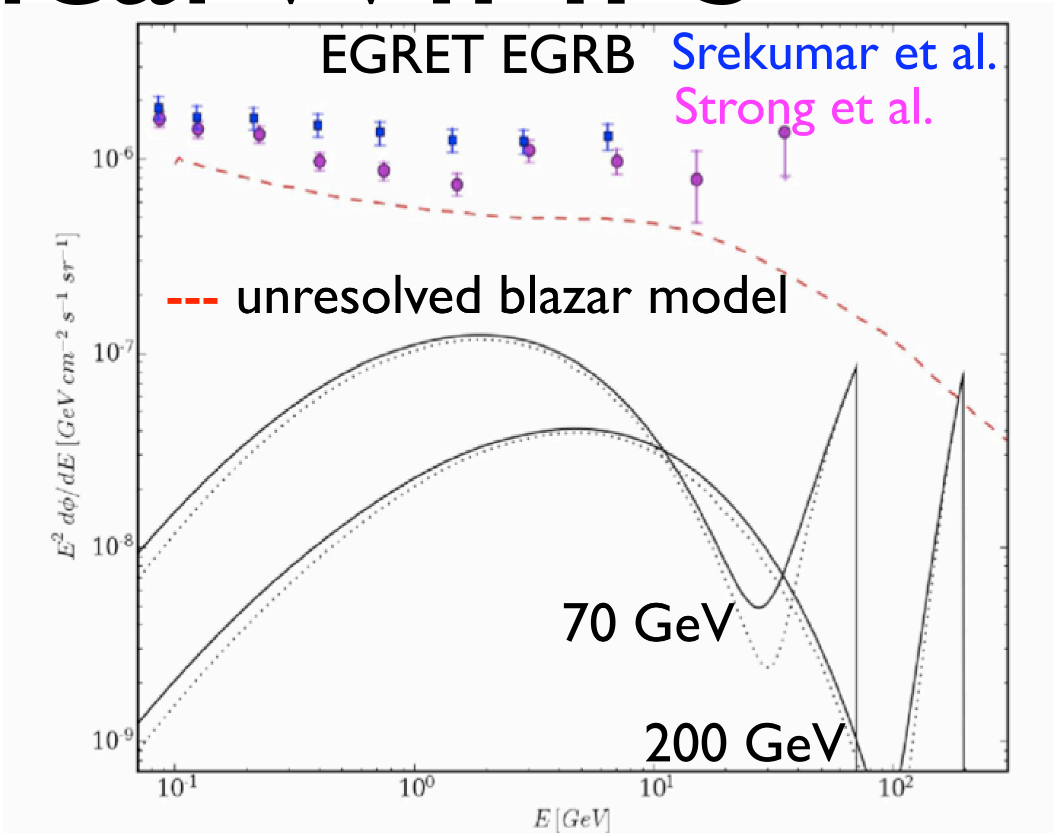
5σ sensitivity (5 yrs)

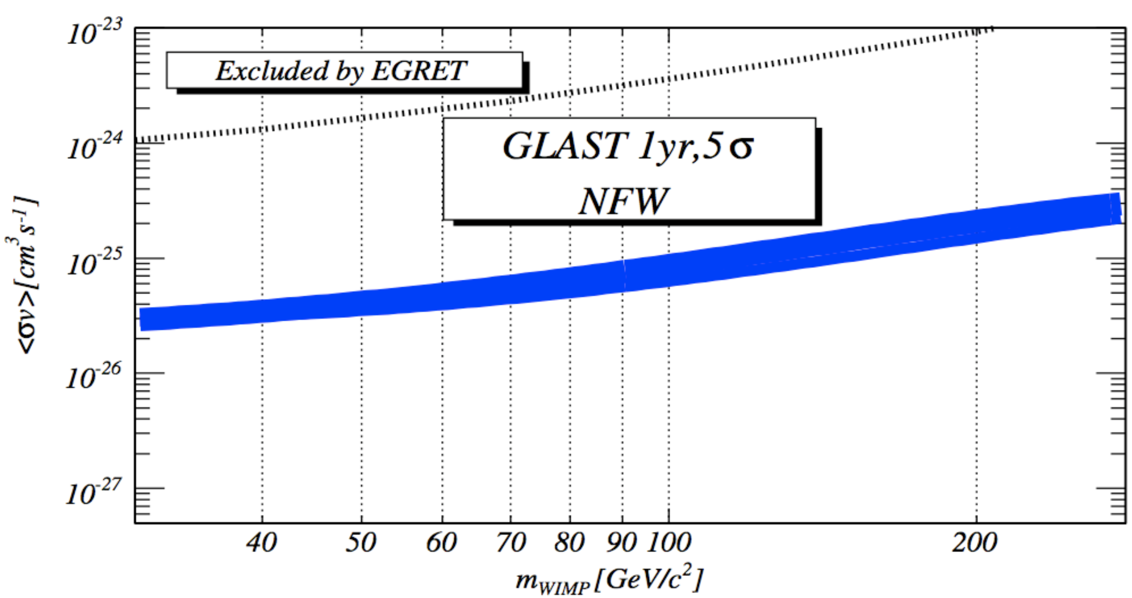




Cosmological WIMPS

- Search for WIMP annihilation signal at all redshift. Spectral distortion caused by integration over redshift
- Assume generic WIMP (masses 50-250GeV) annihilating into b-bbar, with $5x10^{-4}$ annihilation fraction into lines
- Uncertainties in DM distribution over cosmological scales (but less sensitive to exact choice of profile) and absorption of high energy γ in the intergalactic medium
- Different assumptions for the background: EGRB measurement by EGRET, unresolved blazar model





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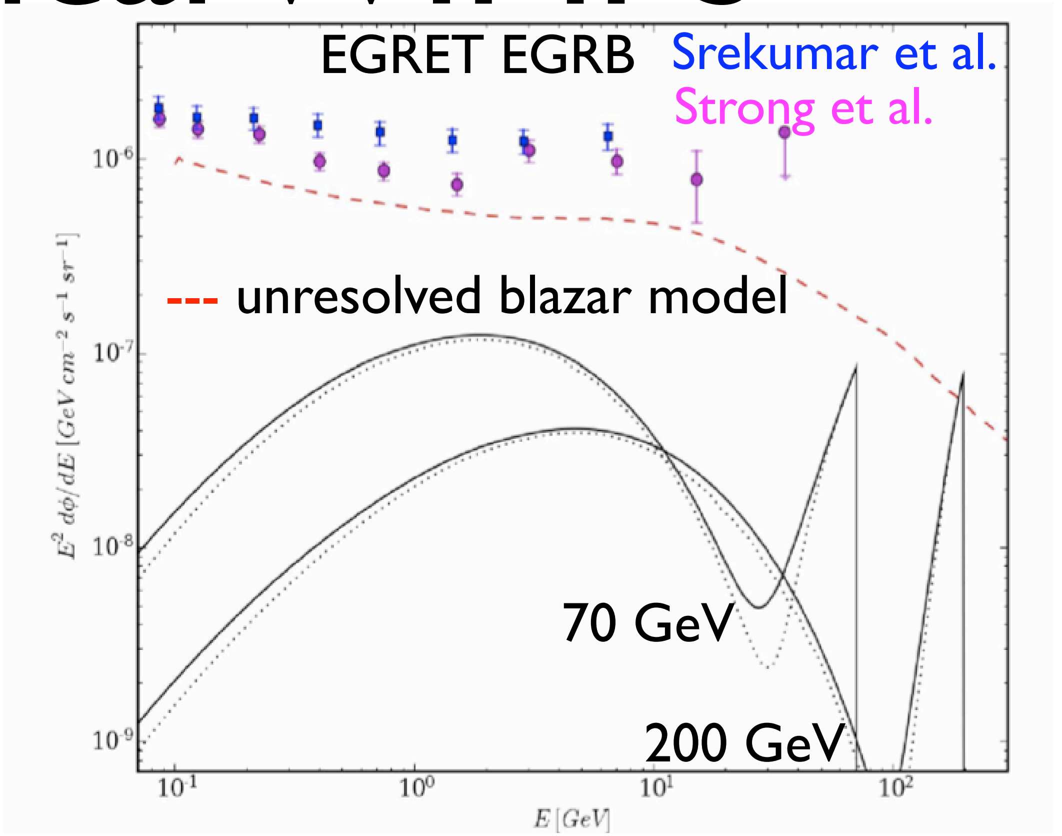
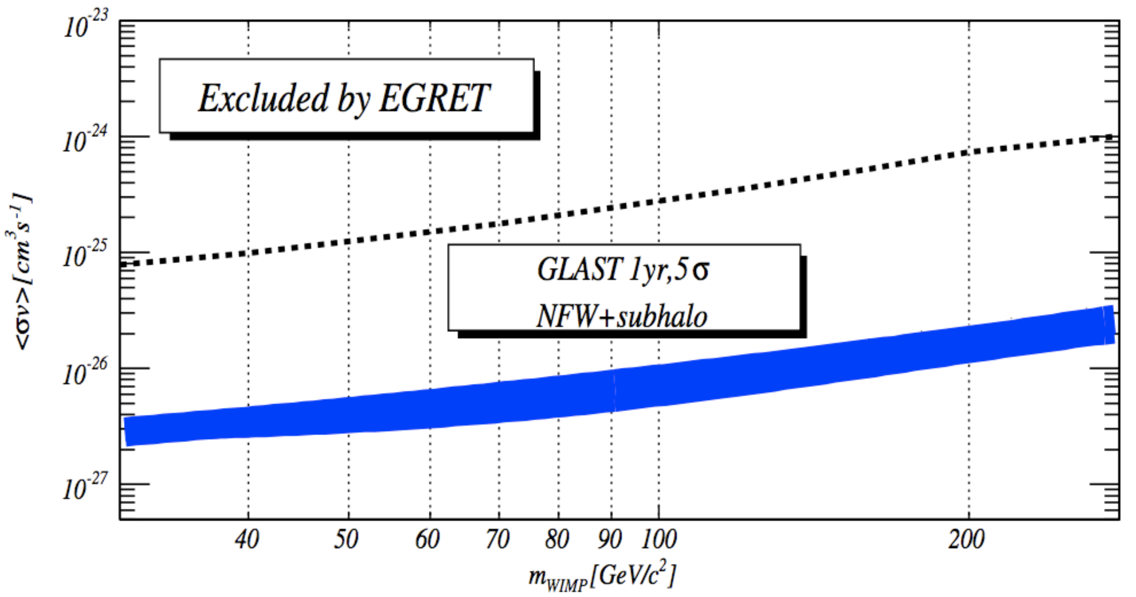
➡High concentration of dark matter in substructures yields better sensitivity



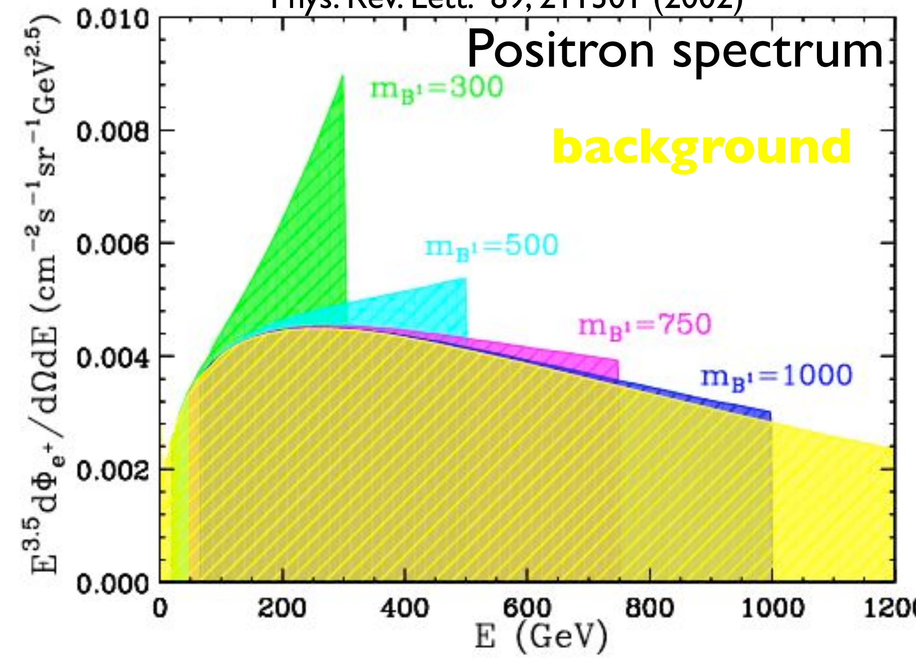


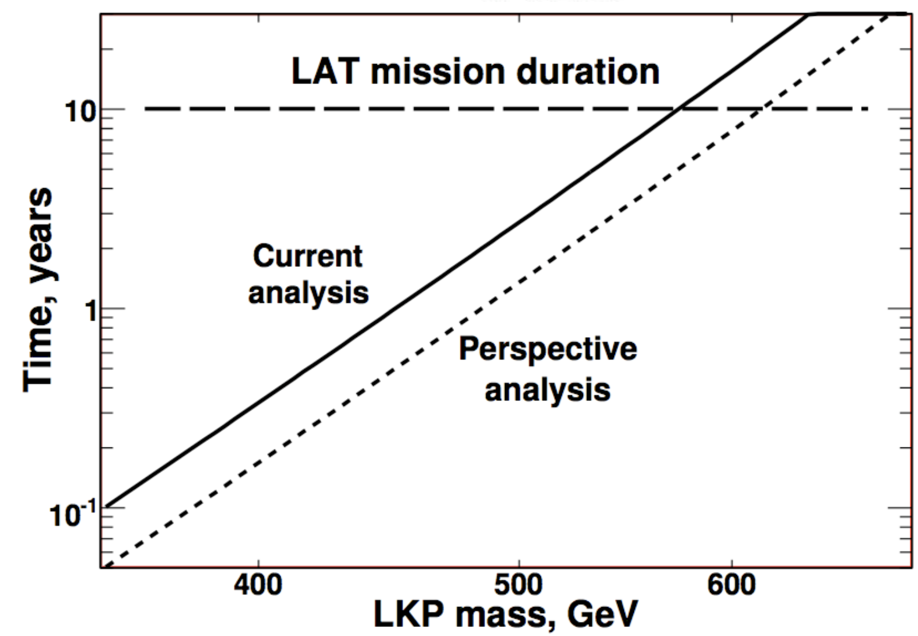
Sensitivity to UED

- Annihilation of into leptons dominant for Lightest KK Particle (B^l, the KK mode of the hypercharge boson)
- Search for B^l annihilation into e^+e^-: sharp cutoff in e^+e^- spectrum at the LKP mass (cannot discriminate charge)
- Assume NFW profile with boost factor of 5 and local density 0.4 GeV cm^{-3}
- 3% residual background from hadrons in e^+e^- sample after selection, 5-20% energy resolution in 20 GeV to 1 TeV range. Expect ~10^7 events/yr

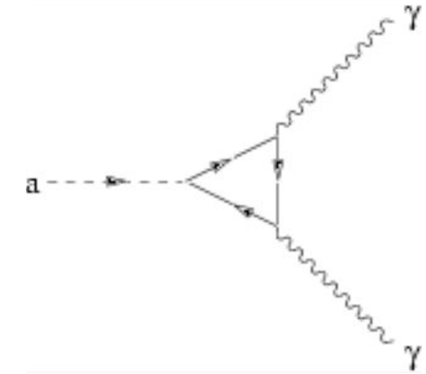
➡5σ detection after 5 yrs possible up to LKP masses ~500-600 GeV

H. C. Cheng, J. L. Feng and K.T. Matchev
Phys. Rev. Lett. 89, 211301 (2002)





Axions



- Search for evidence of axion like particles (ALPs) in AGN spectra
- Spectral distortion due to ALP-photon oscillation in B fields

$$P_{osc} = \sin^2(2\theta)\sin^2\left[\frac{g_{a\gamma}Bs}{2}\sqrt{1+\left(\frac{\xi}{E}\right)^2}\right] \qquad \xi = \frac{m^2}{2g_{a\gamma}B}$$

- Efficient conversion can be achieved for $15 g_{11} B_G \cdot s_{pc} >\sim 1$. $g_{a\gamma}$ ~2×10^{-12} GeV^{-1} can be probed. This is true for AGNs
- As benchmark, use 3c279, which is the strongest AGN in the GLAST energy range (~100 ph/day above 0.1 GeV)
- Background: galactic, extragalactic diffuse emission diffuse, intrinsic source emission. Hard to disentangle source spectrum, not very well understood, from signal.

➡ 10 days of GLAST data sufficient to observe attenuation due to ALP-photon conversion