Searching for Dark Matter Annihilation in Dwarf Spheroidal Galaxies with Fermi

Tesla Jeltema
UC Santa Cruz
on behalf of the Fermi LAT Collaboration

Outline

- The Fermi Gamma-Ray Space Telescope
- Gamma rays from dark matter annihilation
  - Fermi searches
- Dwarf spheroidal galaxies
  - targets and density profiles
- Fermi-LAT preliminary 9 month results
  - flux upper limits
  - DM annihilation cross-section upper limits
  - comparison to clusters of galaxies

Fermi Gamma-Ray Space Telescope

- ➢ Launched June 11, 2008
- ➢ Fermi-LAT began all-sky gamma-ray survey August 2008
    - 20 MeV to > 300 GeV
    - more 10x EGRET sensitivity
- ➢ Broad science:

AGN, GRBs, Pulsars, SNRs, galactic and extragalactic diffuse emission, EBL, cosmic rays, indirect dark matter searches

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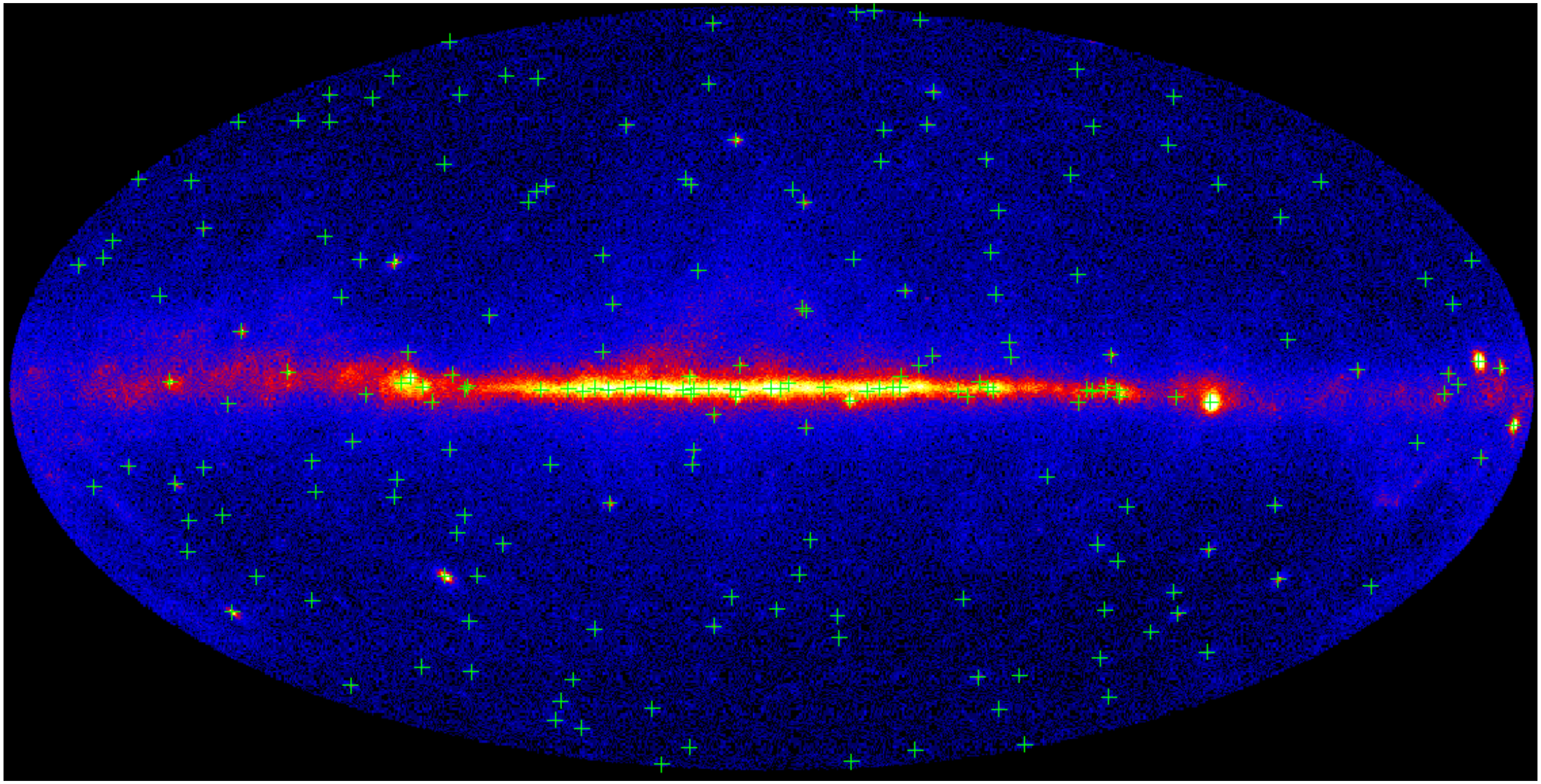
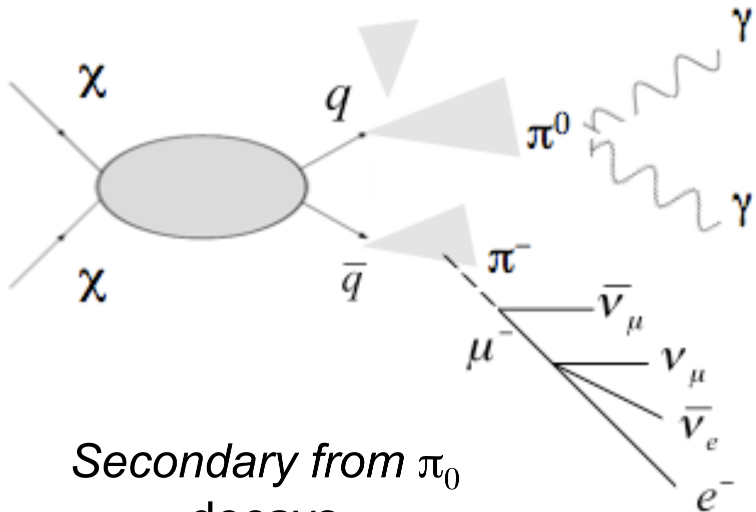
Fermi-LAT 3 Month Sky Map

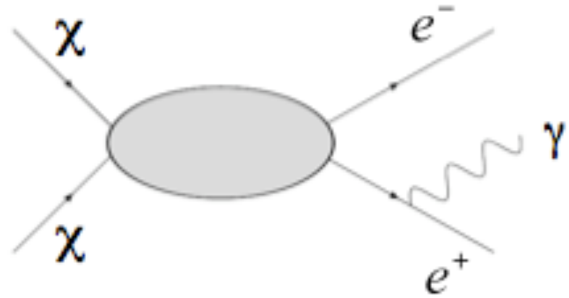
206 bright sources (detected > 10 σ) in the 3 month catalog,
2/3 at |b| > 10 degrees



Gamma rays from WIMP annihilation



Secondary from π_0 decays



Prompt lepton pair production

$$\Phi_{WIMP}(E,\Psi)=J(\Psi)\times\Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi)=\int_{l.o.s} dl(\Psi)\rho^2(l)$$

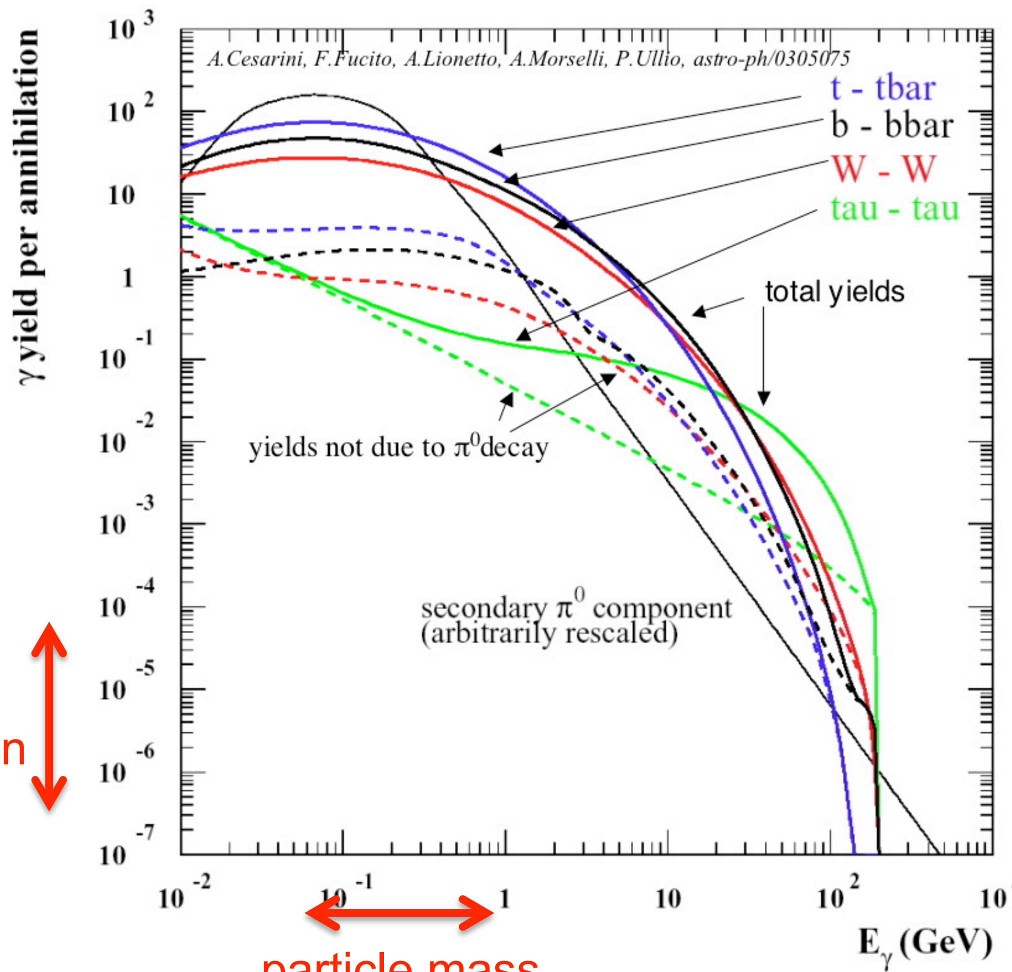
Particle physics factor

$$\Phi^{PP}(E)=\frac{1}{2}\frac{\langle\sigma v\rangle}{m_{WIMP}^2}\sum_f\frac{dN_f}{dE}B_f$$

Gamma-ray Spectrum from WIMP annihilation

Gamma-ray yield for a 200 GeV WIMP

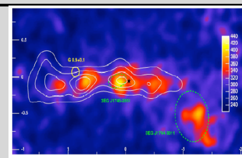
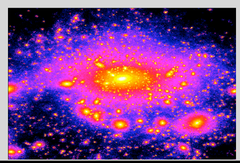
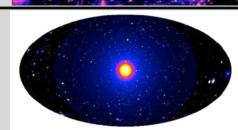
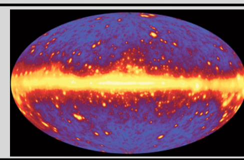
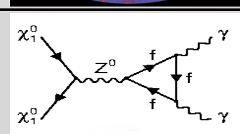
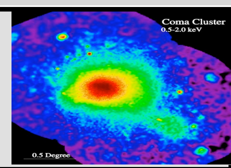
- cutoff at WIMP mass
- some final states give similar spectra



DM density distribution
annihilation cross-section

particle mass
final state

Fermi Dark Matter Searches

Search Technique		advantages	challenges
Galactic center		Good Statistics	Source confusion/Diffuse background
Satellites, Subhalos		Low background, Good source id	Low statistics
Milky Way halo		Large statistics	Galactic diffuse background
Extra-galactic		Large Statistics	Astrophysics, galactic diffuse background
Spectral lines		No astrophysical uncertainties, good source id	Low statistics
Clusters of Galaxies		Low background, Good source id	Low statistics

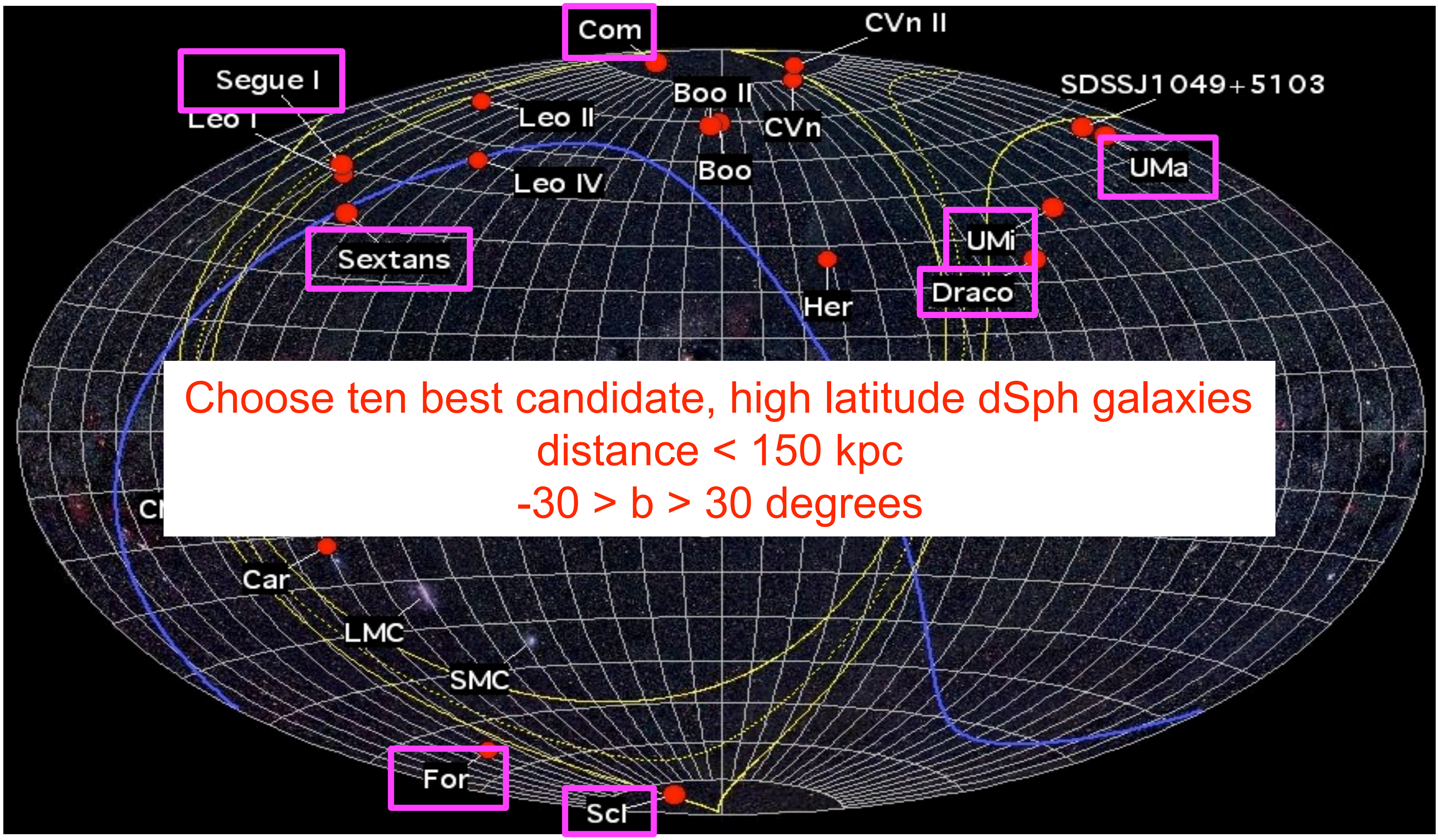
E.A. Baltz et al. JCAP07 (2008) 013

Dwarf Spherodial Galaxies: Promising Targets for DM Signal

Milky Way dwarf spheroidals are:

- nearby
- very dark matter dominated (M/L ~ 10 – 2000)
- most are expected to be free of other astrophysical gamma-ray sources
- SDSS searches have doubled the number of known dwarfs

Candidate Dwarf Spheroidals



Choose ten best candidate, high latitude dSph galaxies
distance < 150 kpc
-30 > b > 30 degrees

Dark Matter Density Profiles

Astrophysical factor based on modeling of stellar kinematic data assuming NFW profile (e.g. Strigari et al. 2007, Geha et al. 2009)

Name	ρ_s $(M_\odot\ pc^{-3})$	r_s (kpc)	J^{NFW} $(10^{19} GeV^2 cm^{-5})$
Segue 1	1.65	0.05	0.97
Ursa Major II	0.17	0.25	0.57
Segue 2	0.61	0.06	0.1
Willman 1	0.417	0.17	0.84
Coma Berenices	0.232	0.22	0.42
Usra Minor	0.04	0.97	0.35
Sculptor	0.063	0.52	0.12
Draco	0.13	0.50	0.43
Sextans	0.079	0.36	0.05
Fornax	0.04	1.00	0.11

Considering Fermi PSF, can approximate dwarfs as point sources

(dwarf r_s = 0.1-0.8° compared to 68% PSF ~ 5° at 100 MeV and 0.75° at 1 GeV)

Fermi-LAT Data Analysis

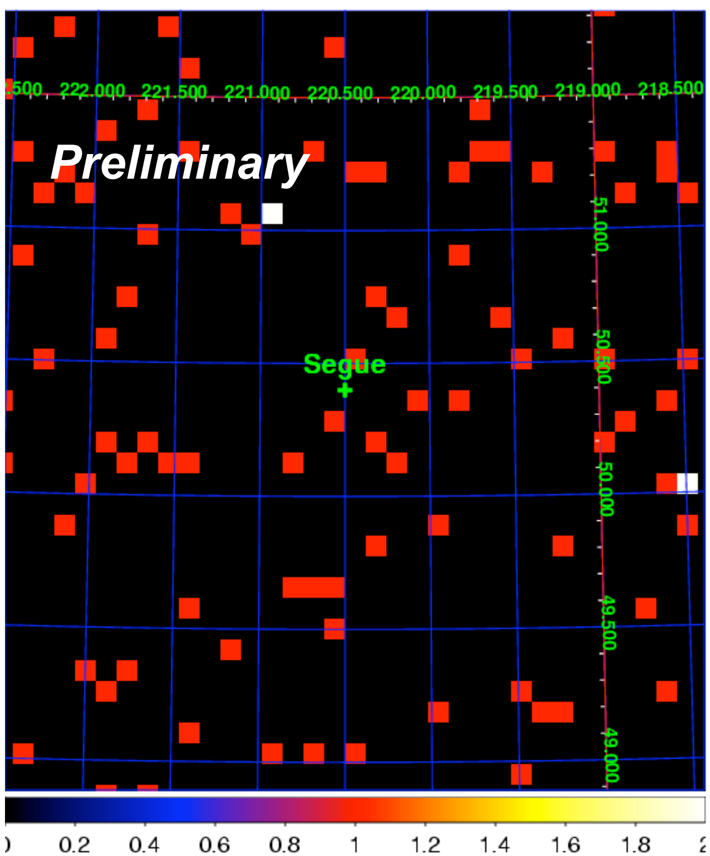
- 9 months of data
  - cuts to remove particle background and Earth's albedo
  - energy range 100 MeV to 50 GeV
  - 10 degree radius
  - binned analysis
- Backgrounds:
  - model galactic and isotropic diffuse
  - include point sources from 9 month catalog

→ first-year paper coming soon

Fermi-LAT Results

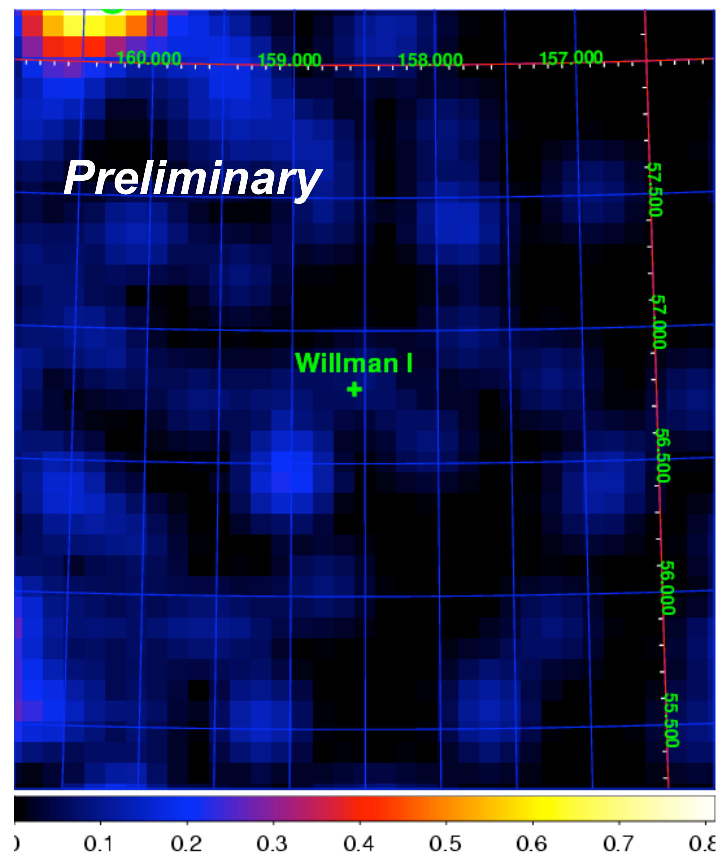
Unfortunately, no dwarf spheroidal galaxies detected so far.

Example raw count map > 1 GeV



5°x5° centered on Segue 1

Example smoothed count map > 1GeV



5°x5° centered on Willman 1

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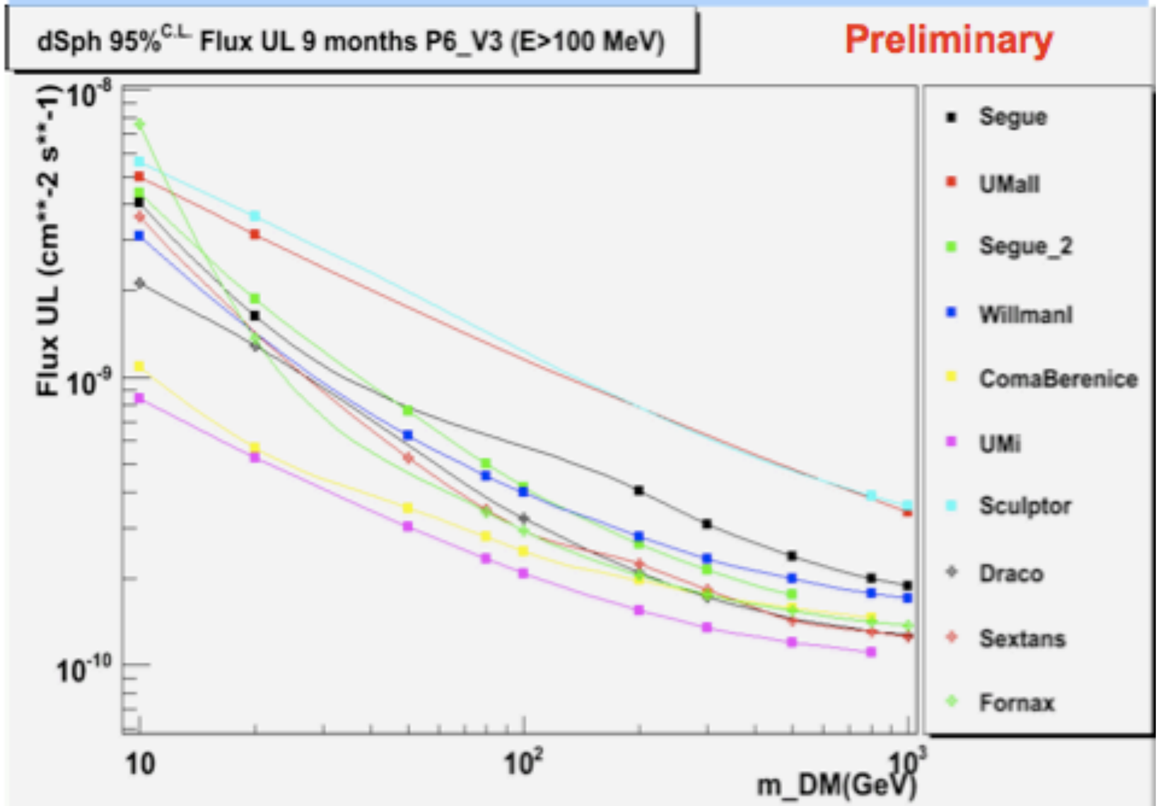
Fermi-LAT Flux Upper Limits

Flux upper limits assuming a point-like source at the dwarf location

power-law with fixed spectral index of $\gamma = -2$

Name **Preliminary**	Flux UL (95%) $(E > 100\ MeV)$ $10^{-9}\ ph/cm^2/s$
Segue I	1.83
UMa II	4.60
Segue II	2.13
Willman I	2.12
Coma Berenice	0.97
UMi	0.72
Sculptor	4.79
Draco	1.16
Sextans	1.33
Fornax	1.67

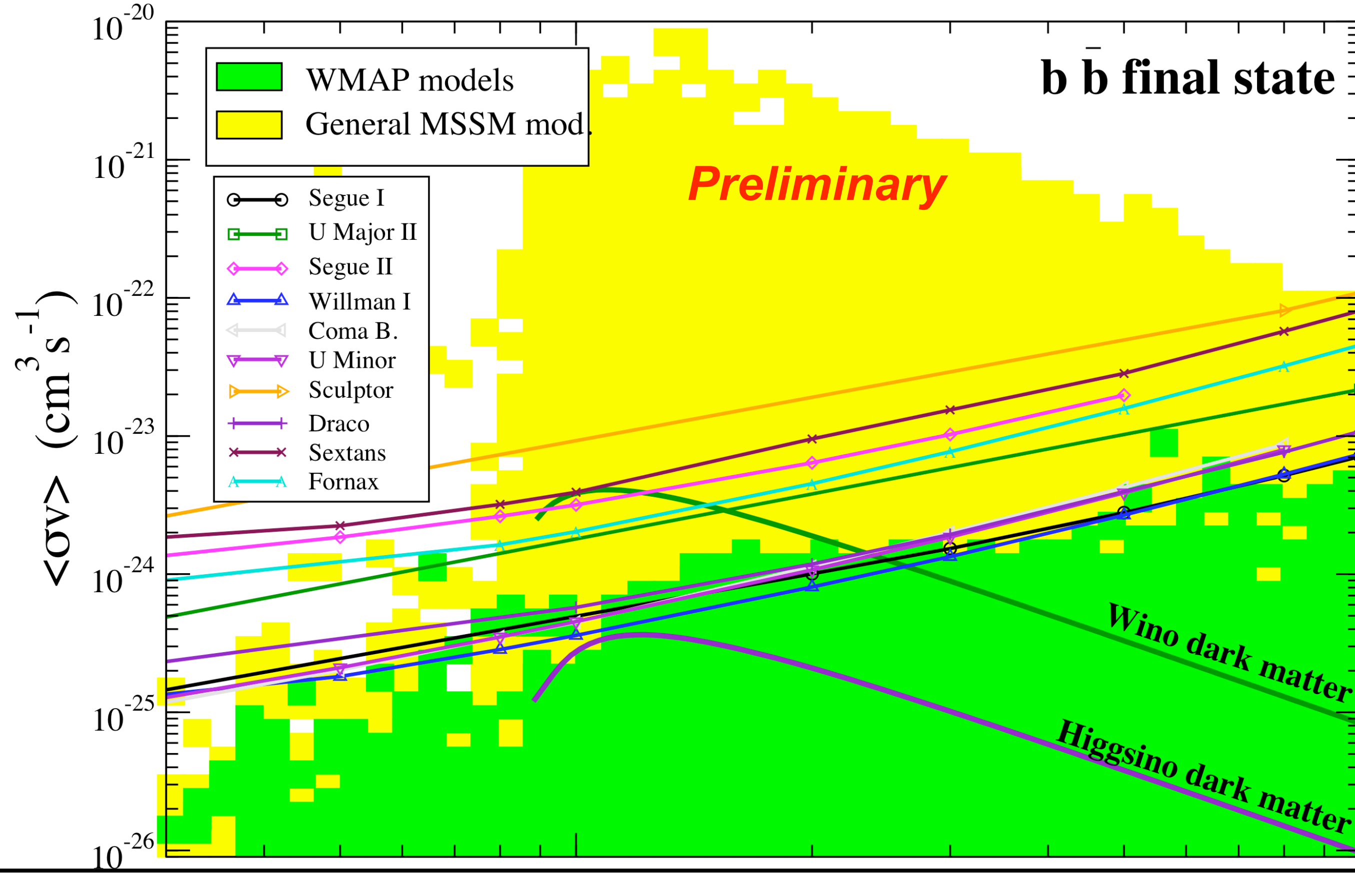
100% b-bbar DM annihilation



Using DMFIT package, Jeltema & Profumo 2008

Annihilation Cross-Section Limits

- Use 95% confidence upper limits on > 100 MeV flux
- Assume a $\bar{b}$ b final state

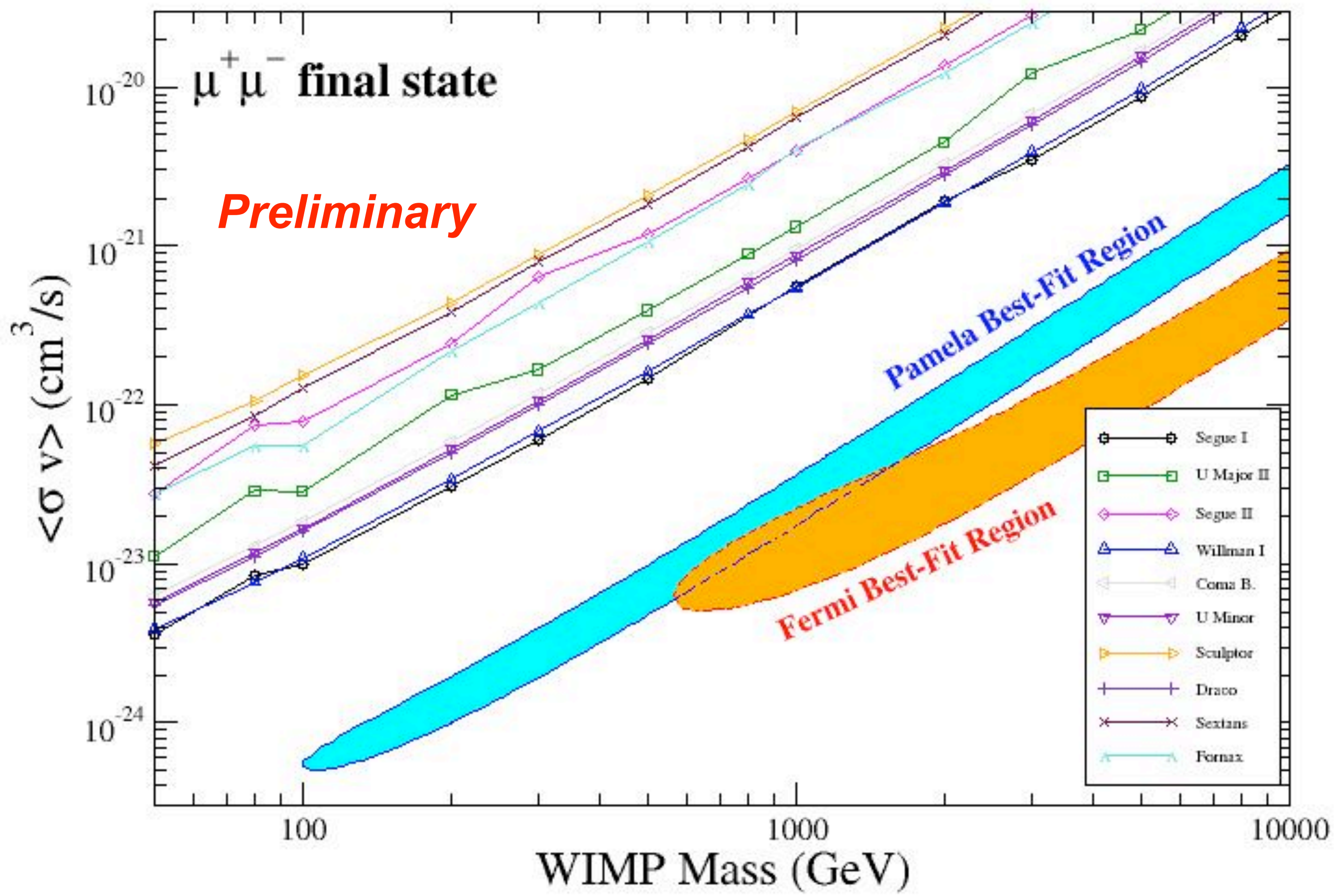


General MSSM: includes temperature dependent resonance effects (Profumo 2005)

Beginning to constrain some thermally produced WIMP models with the right relic density (NFW, no substructure).

Annihilation Cross-Section Limits

- Same for $\mu^+\mu^-$ final state
- Limits considering only final state radiation



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.

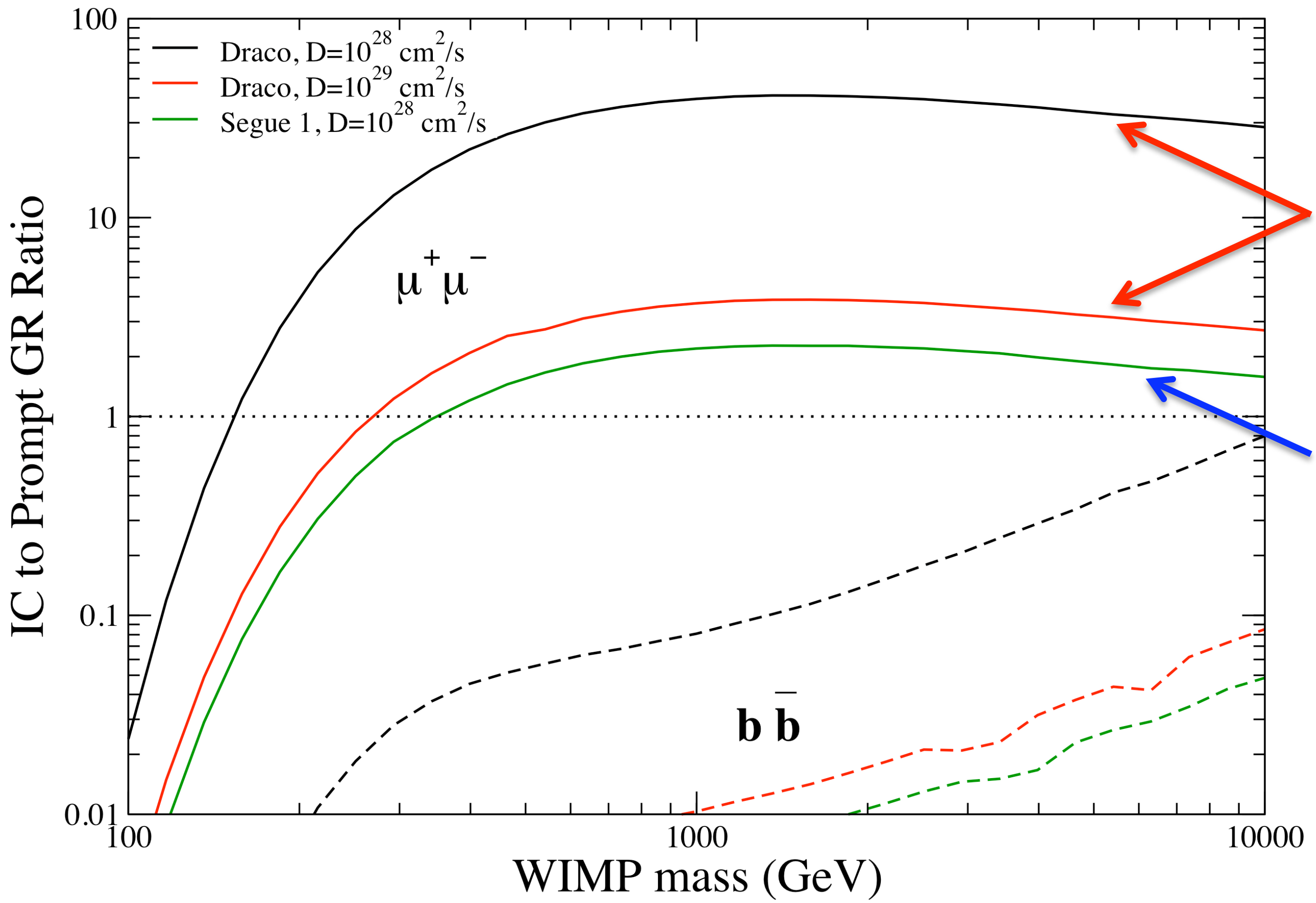
- We assume a simple diffusion model similar to what is found for the Milky Way

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

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

Inverse Compton Contribution

IC emission can dominate for leptonic final states at m > 300 GeV.



Draco: variation in diffusion coeff. 10^{28} vs. 10^{29}

Segue 1: diffusion more significant in small dwarfs

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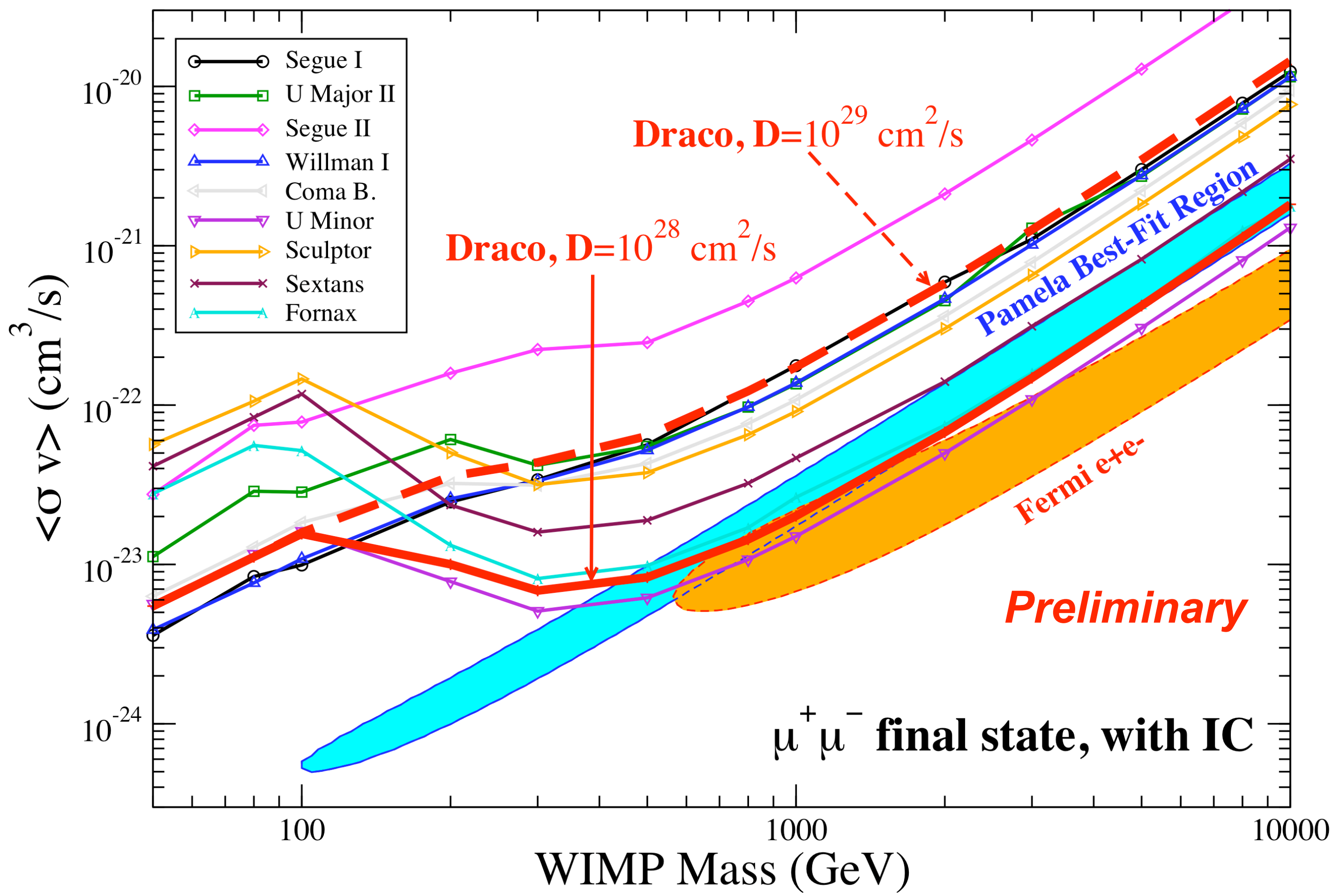
Constraints Including IC Emission

Combined constraints for FSR plus IC with reference diffusion model ($D_0 = 10^{28}$ cm^2/s).



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Comparison to Cluster of Galaxies

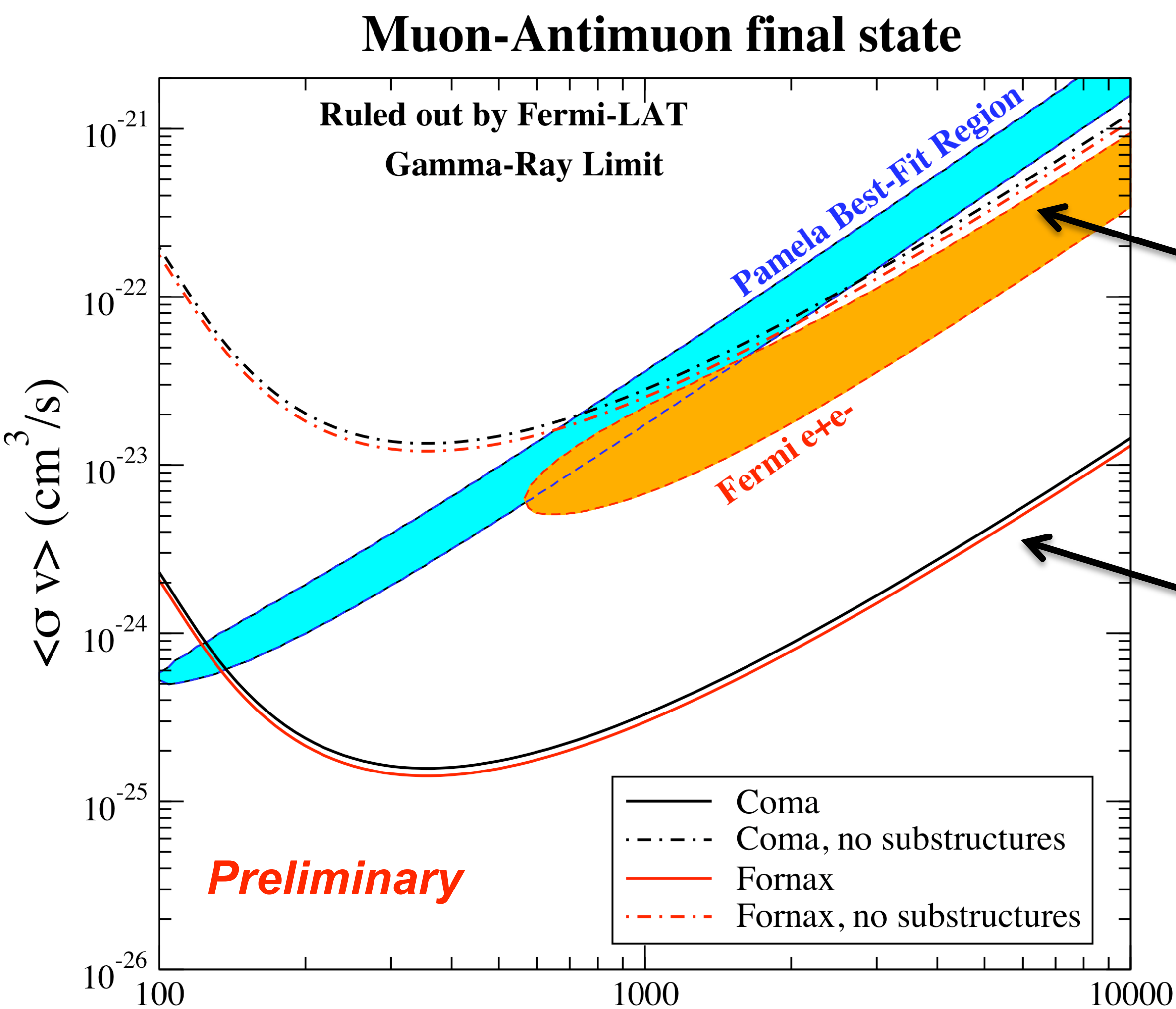
- Large DM densities and low backgrounds, similar to dwarfs
(see Jeltema et al. 2009, Pinzke et al. 2009)

- Not detected in 9 months of data
(see Keith Bechtol's talk at TeV PA)

- Diffusion of $e^{+}e^{-}$ is not expected to be significant, reducing the model dependence of the predicted IC emission.

Comparison to Cluster of Galaxies

Constraints for combined FSR + IC



Fornax and Coma clusters: NFW, no substructure

50% of mass in substructure

Beginning to constrain some models for Pamela e^+ excess.

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Conclusions

- Fermi-LAT provides a new window for indirect searches for dark matter.

- No dSph galaxies detected in 9 months of data.

- Flux upper limits are beginning to constrain some thermally produced WIMP models with the right relic density (NFW, no substructure).

- Fermi observations of clusters and dwarfs (diffusion dependent) are beginning to probe DM models fitting the Fermi and Pamela e^+e^- data.


IDM 2010
8th International Workshop on
Identification of Dark Matter
http://www.lpta.univ-montp2.fr/idm2010
26-30 July 2010
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Montpellier, France
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Dark matter direct searches
Dark matter indirect searches
Connections with accelerator searches
Halo models and structure formation
Gravitational lensing
Neutrino physics
Cosmology and dark energy
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