Dark Matter search with Fermi

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representing the Fermi LAT Collaboration

SciNeGHE 2010

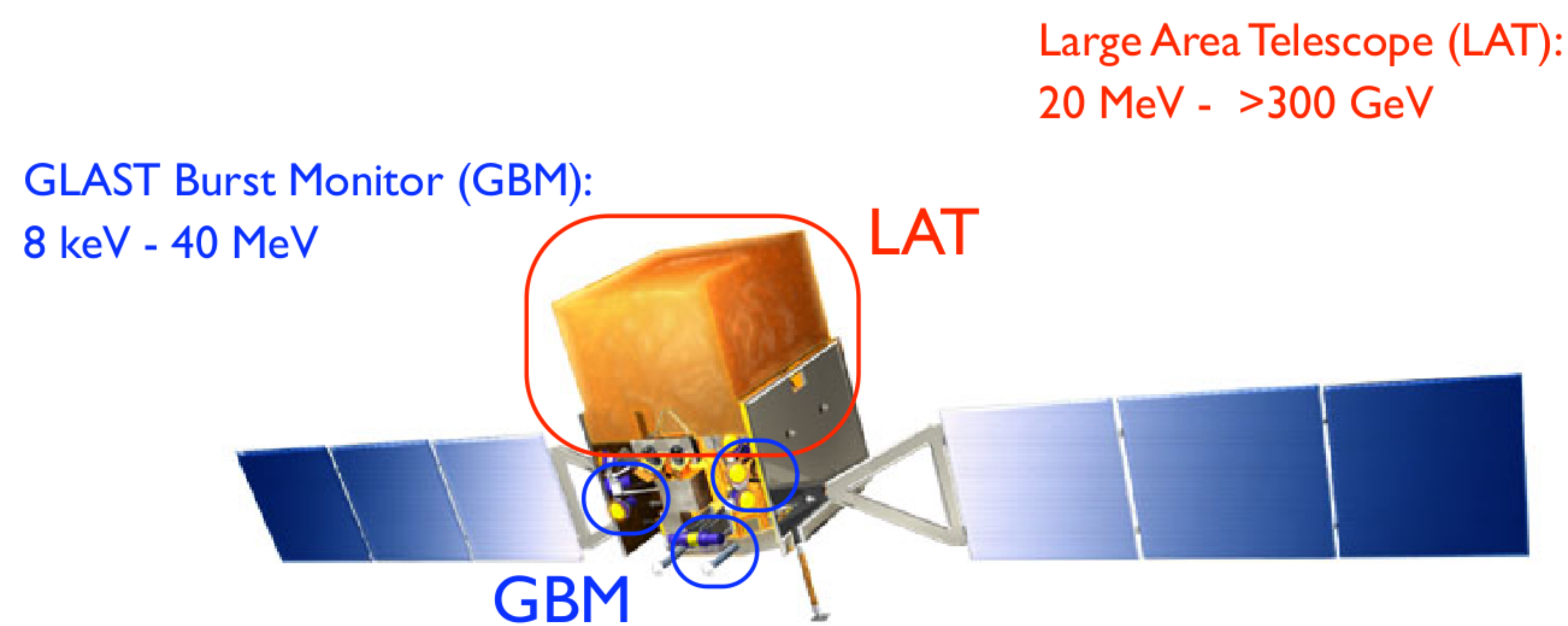
Sept. 10th

Trieste

outline

- Fermi Observatory
- Dark Matter Annihilation
- Active Searches in DM
    - Galactic Center (next talk by Aldo)
    - Halo
    - Subhalos
    - Galaxy Clusters
    - Cosmological DM
    - Lines
- Summary

The Fermi Large Area Telescope (LAT)

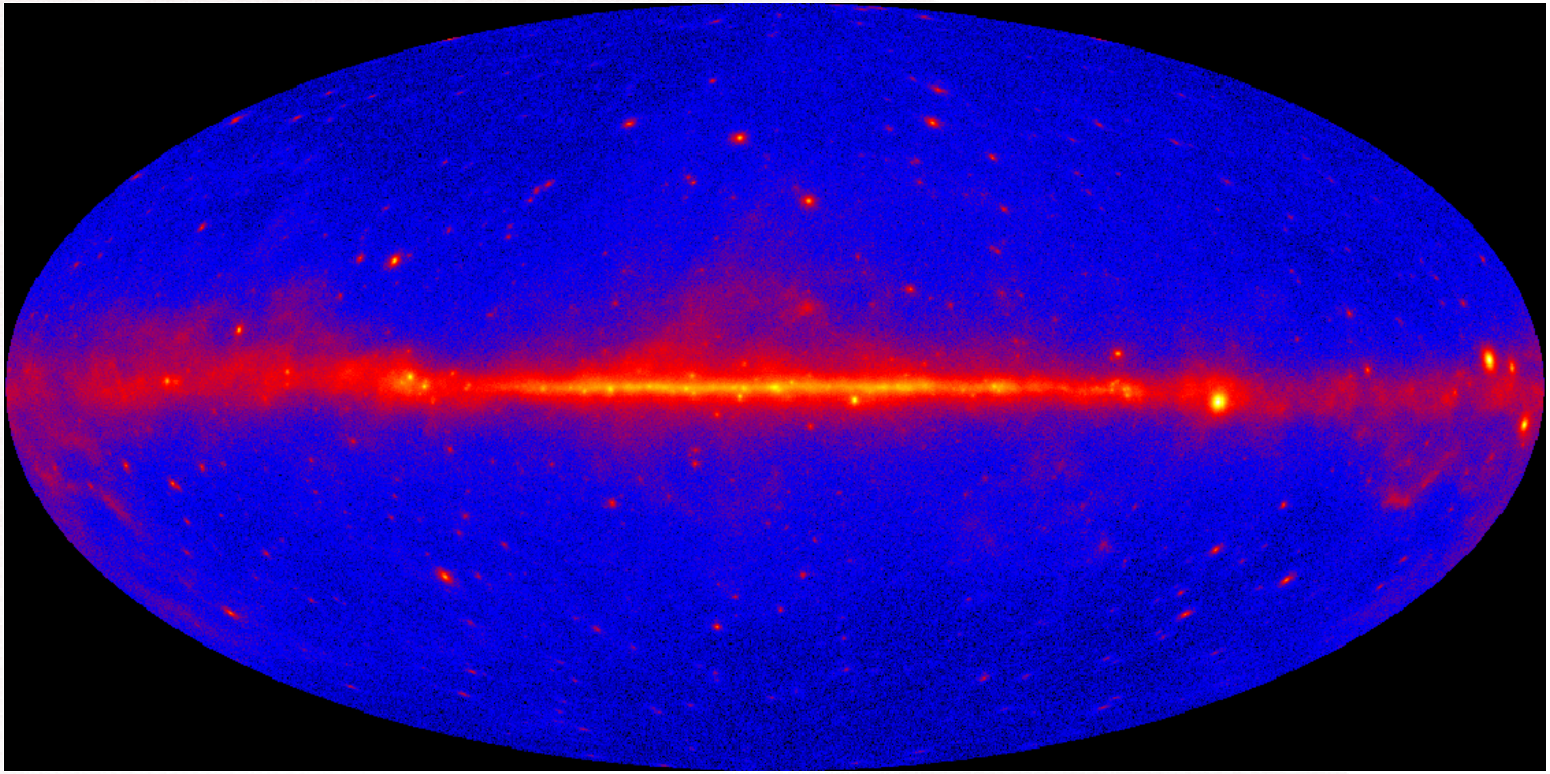


Main instrument (LAT):

- 0.1 deg angular resolution above 10 GeV
- covers unexplored energy range (>10 GeV)
- unprecedented sensitivity ($3\cdot10^{-9}$ ph cm^{-2} s^{-1}, E>100MeV)

1-year sky survey

- 1451 sources (11 months data catalog)
- 43% of the sources not associated
- 241 variable sources

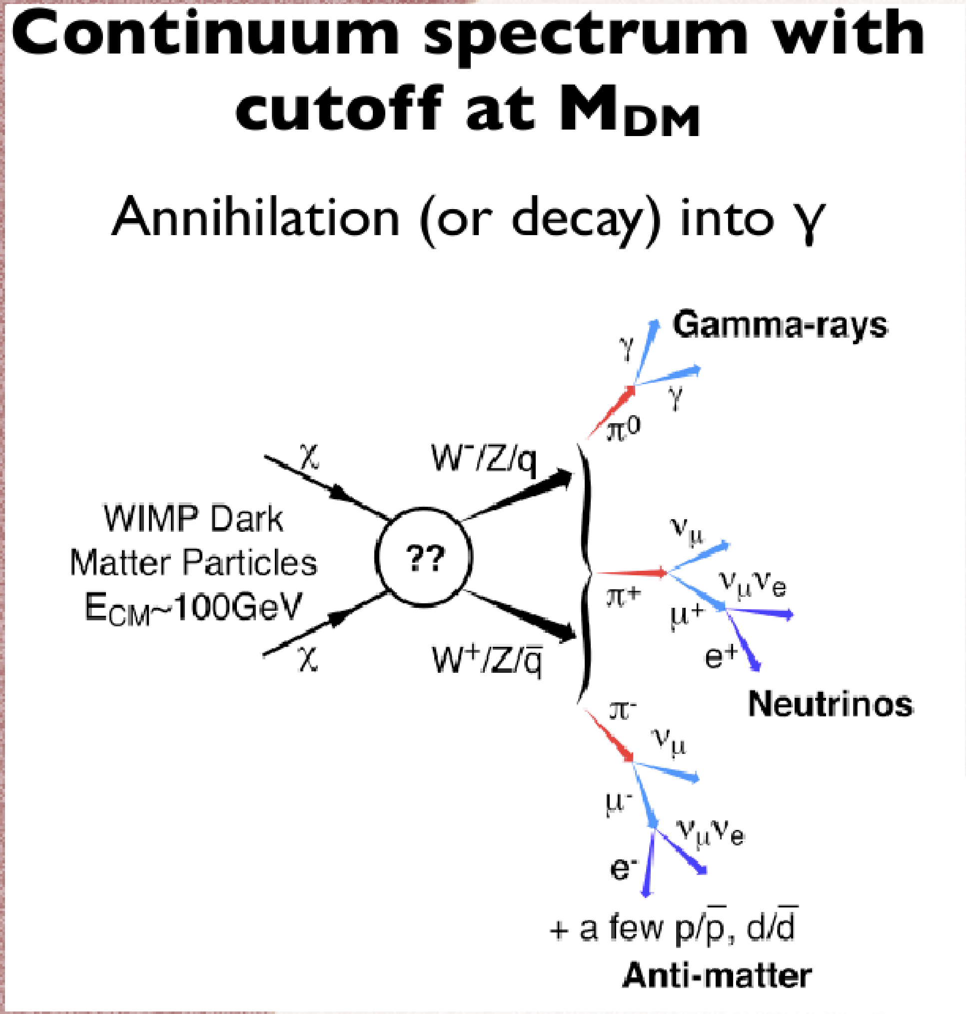


DM annihilation

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\theta,\phi) = \frac{1}{4\pi}\boxed{\frac{\langle\sigma v\rangle_{T_0}}{2\,M_\chi^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f}\cdot\boxed{\int_{\Delta\Omega(\theta,\phi)} d\Omega' \int_{l.o.s.} dl\ \rho_\chi^2(l)}$$

- DM gamma-ray spectrum can be factorized in two contributions
  - spectral shape (i.e. involving particle physics)
  - spatial distribution.
- The DM spectrum has two components
  - continuum
  - line

DM annihilation - continuum

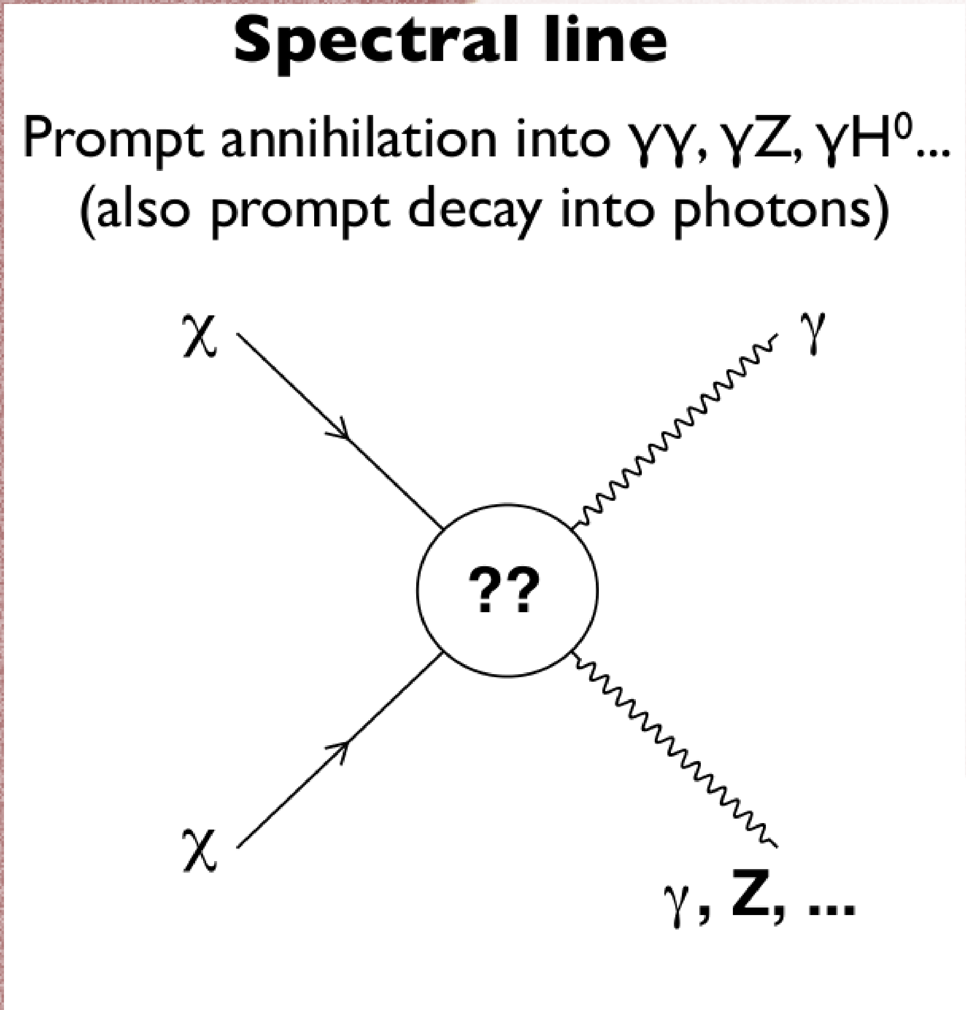


Several models with different spectral features

Prompt emission
- neutral pion decay (main component)
- final state radiation

Radiative processes (if relevant branching ratio into leptons)
- Inverse Compton Scattering (IC)
- Bremsstrahlung

DM annihilation - lines



for $\chi\chi \rightarrow \gamma\gamma \quad E_\gamma = M_\chi$

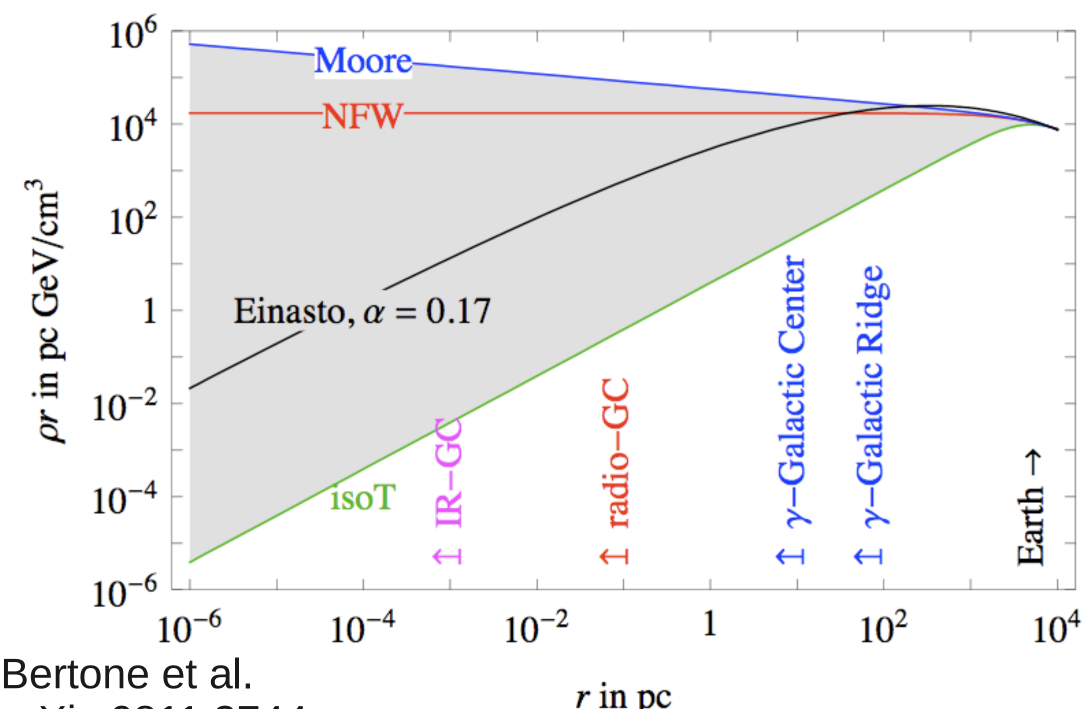
for $\chi\chi \rightarrow \gamma X \quad E_\gamma = M_\chi - \dfrac{M_X^2}{4M_\chi}$

- "smoking gun"
- loop suppressed (10^{-1}–10^{-4})

DM annihilation - distribution

DM annihilation is strongly dependent on its spatial distribution

Many models predicted, with possible signal enhancement



Bertone et al.
arXiv:0811.3744

NFW density profile:

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

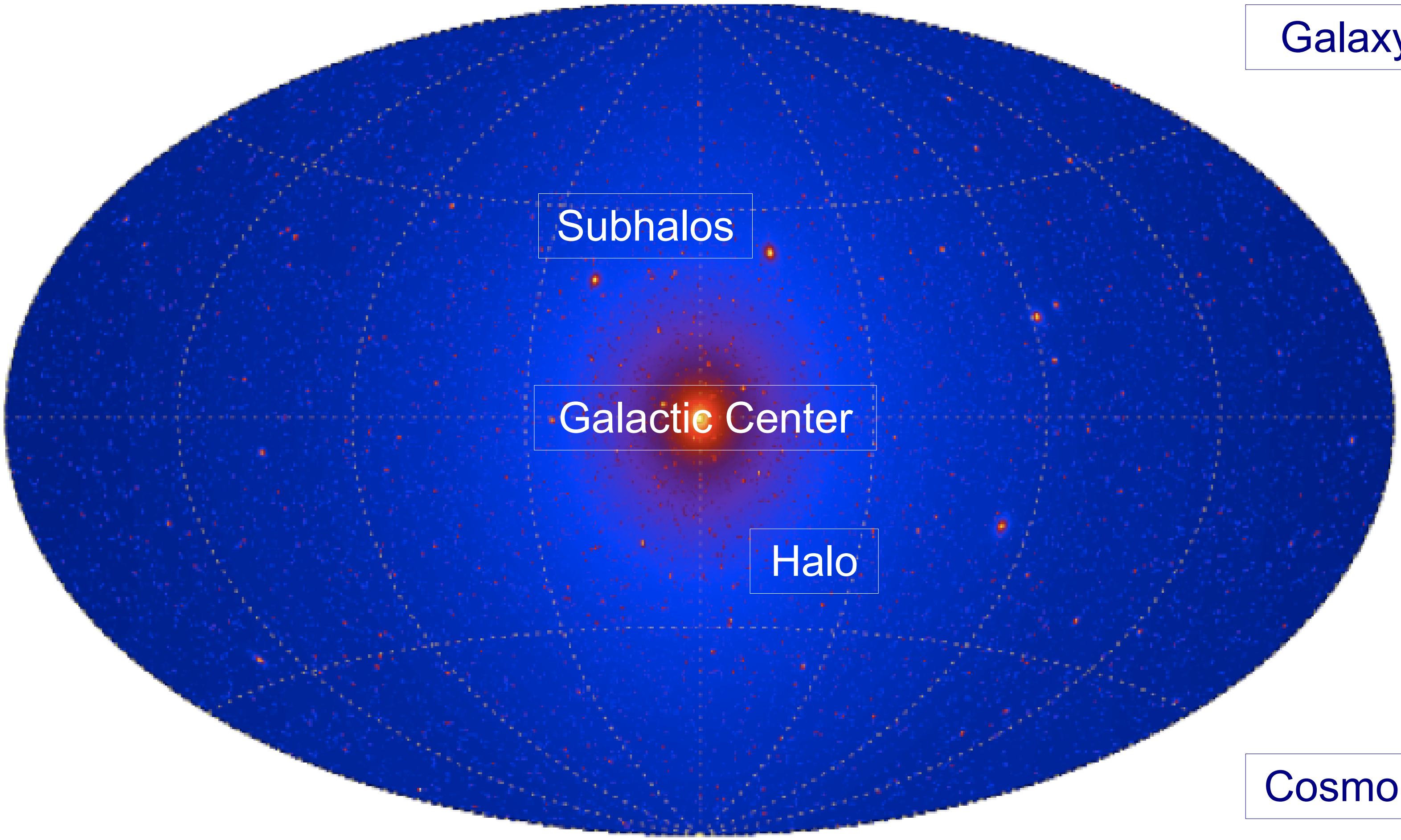
Via Lactea II (Diemand et al., 2008) predicts a cuspier profile:

$$\rho(r) \propto r^{-1.2}$$

Aquarius (Springel et al., 2008) predicts a shallower profile.

Dark Matter Targets

DM annihilation simulation (based on Via Lactea II)



Galaxy Clusters

Lines

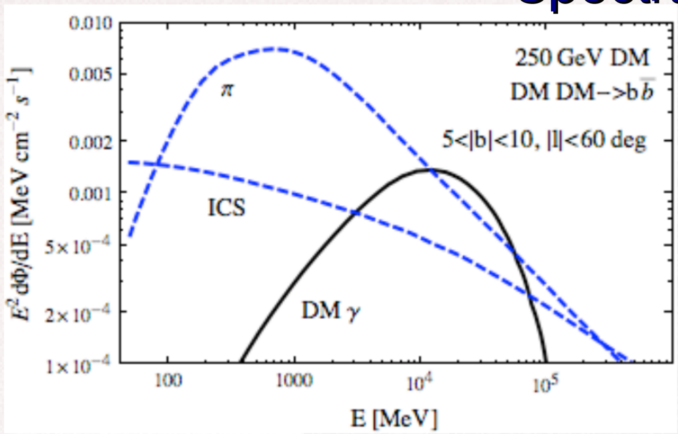
Cosmological DM

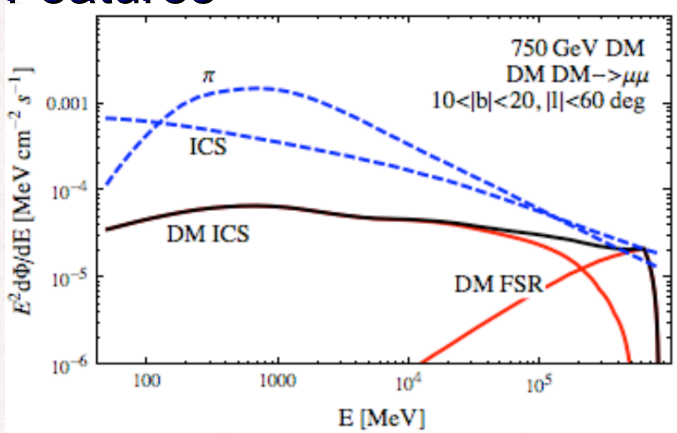
Halo - I

Data from the whole Galactic Halo are considered

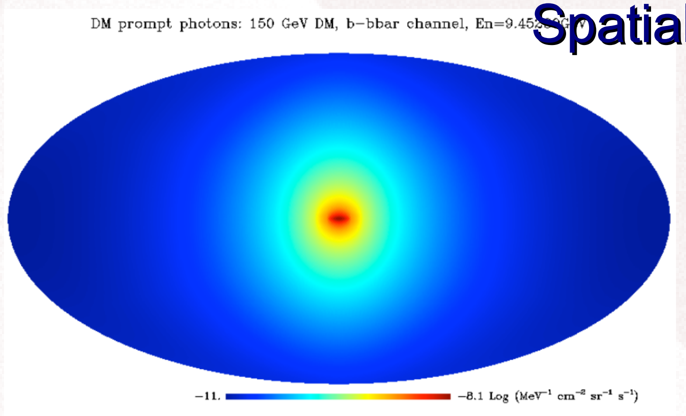
- ✓ high statistics
- ✗ diffuse emission uncertainties:
  - high background
  - BG modeling

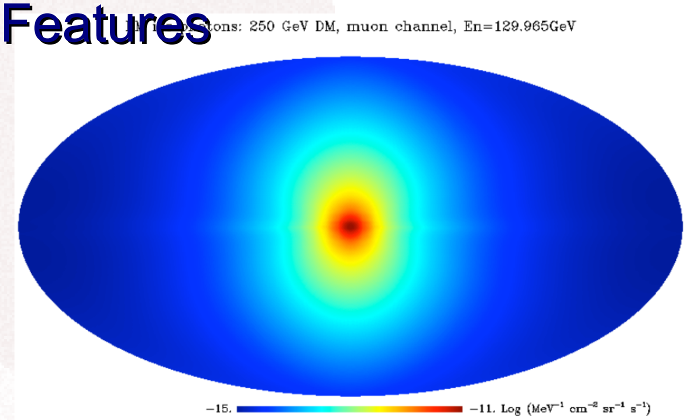
Spectral Features





Spatial Features





DM produces a peculiar signal peaking around the 10-100 GeV band: possible to discriminate from other contributions.

Halo - II

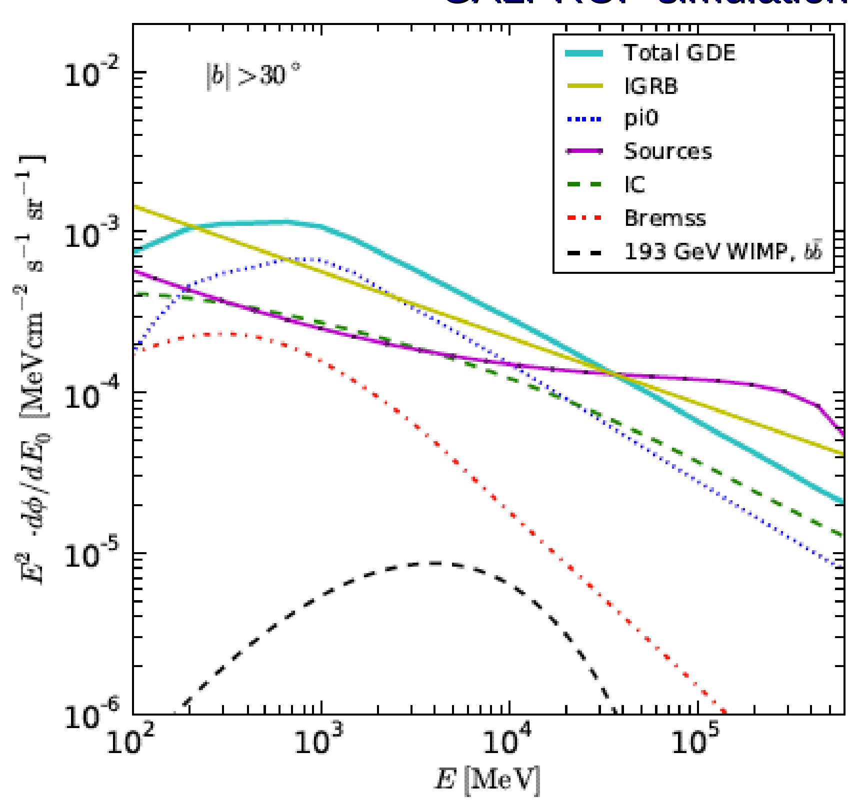
21 months of data
0.8-100 GeV energy range.
Mask for the galactic disk (-5<b<10 deg) and for point sources.

The DM components have been added to the likelihood fit of the halo region.

Other component:

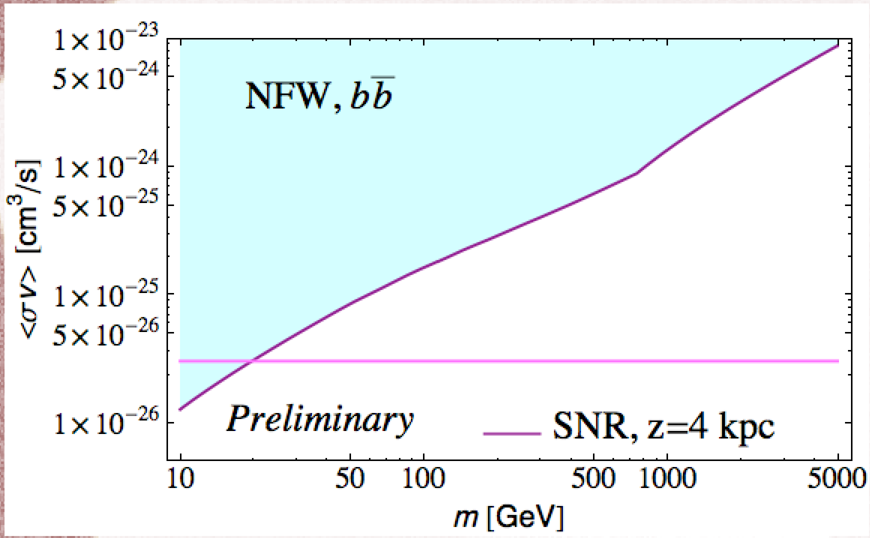
- Galactic Diffuse Emission (GALPROP)
  - IC
  - π^0 decay
  - Bremsstrahlung
- Isotropic Diffuse
- Residual Point Sources

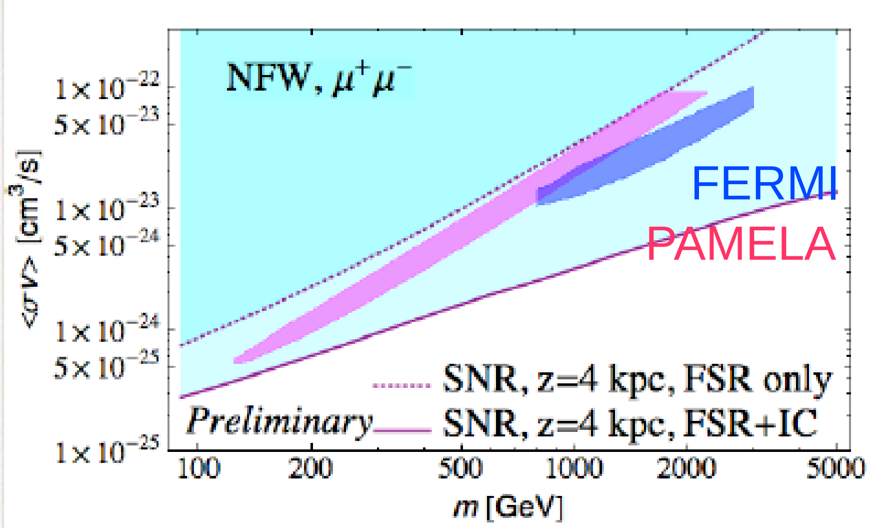
GALPROP simulation



Halo - III

Upper Limits (3σ) for DM
Limits depend weakly on spatial distribution.





With FSR+IC the Fermi/PAMELA region is excluded regardless of the DM profile:
The interpretation of the e+/e- excess is not confirmed to come from DM.

For low WIMP masses the freeze-out cross section is probed (b-bbar)

Still uncertainties on Diffuse model: work in progress.

Subhalos

Hypothesis:

- DM can undergo density enhancement with consequent raise of annihilation rate (i.e. higher signal)

DM satellites:

- substructures with emission from DM annihilation only
  - never been observed
- could lie within few kpc from the Sun
  - spatial extension could be resolved by the LAT

Dwarf Spheroidal Galaxies:

- observed in the optical band
  - 25 discovered, many others predicted by N-body simulations
- should not have gamma-ray emission (except DM)
- should be seen as point-sources from the LAT

Subhalos – DM Satellites

N-body simulations predicts substructures in Galactic Halo.
All sky search of possible candidates among the Fermi unassociated sources:

- no counterpart at other wavelengths
- steady emission

- ✓ Low background
- ✗ Low statistic
  - → only sources far from Galactic Plane (|b|>10 deg) have been tested.

DM spectrum has been tested only versus a PowerLaw hypothesis:
results are still very preliminary.

No evidence for sources with DM annihilation features in the μ+/μ- channel.
No evidence for a population of sources in the b/bbar channel.

Work in progress:

- determining reliable selection parameters: discrimination of a candidate DM source from other known objects (Pulsars, AGNs);
- find limits on annihilation rate.

Subhalos – dSph - I

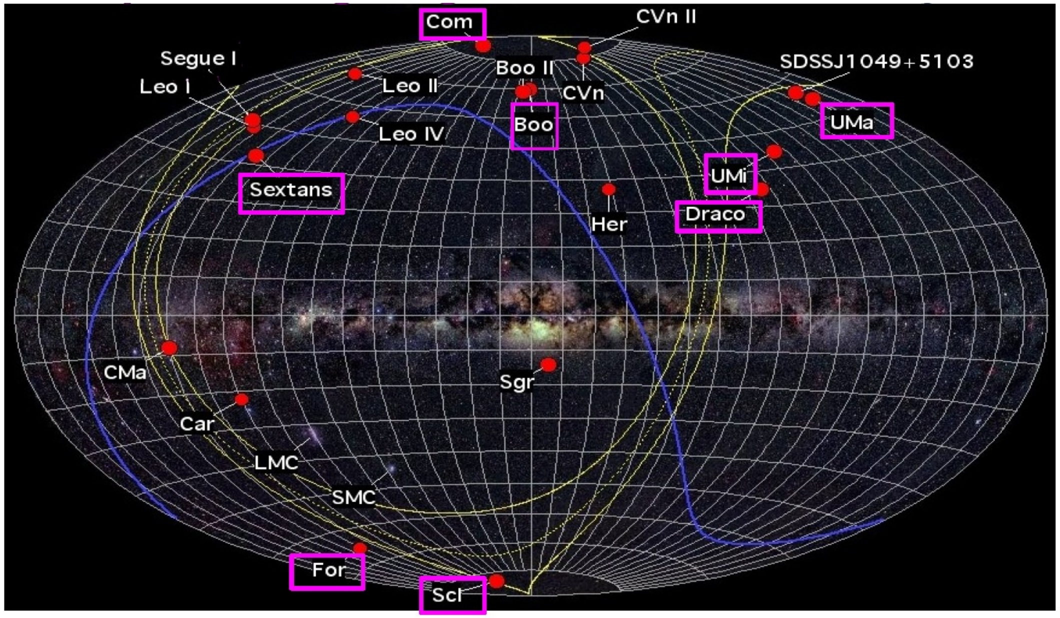
Dwarf Spheroidal Galaxies (dSph) are promising DM annihilation sites:

- high M/L ratios (up to 1000, ~10 for Milky Way)
  - DM dominated
- closer than 180 kpc from the Sun

- Low background:
  - small content of gas and dust
  - no other gamma sources
- Low statistics

Data selection:

- 11 months of data
- 100 MeV – 50 GeV energy range
- 14 dSphs
  - 8 with DM distribution from stellar kinematics
  - point like sources



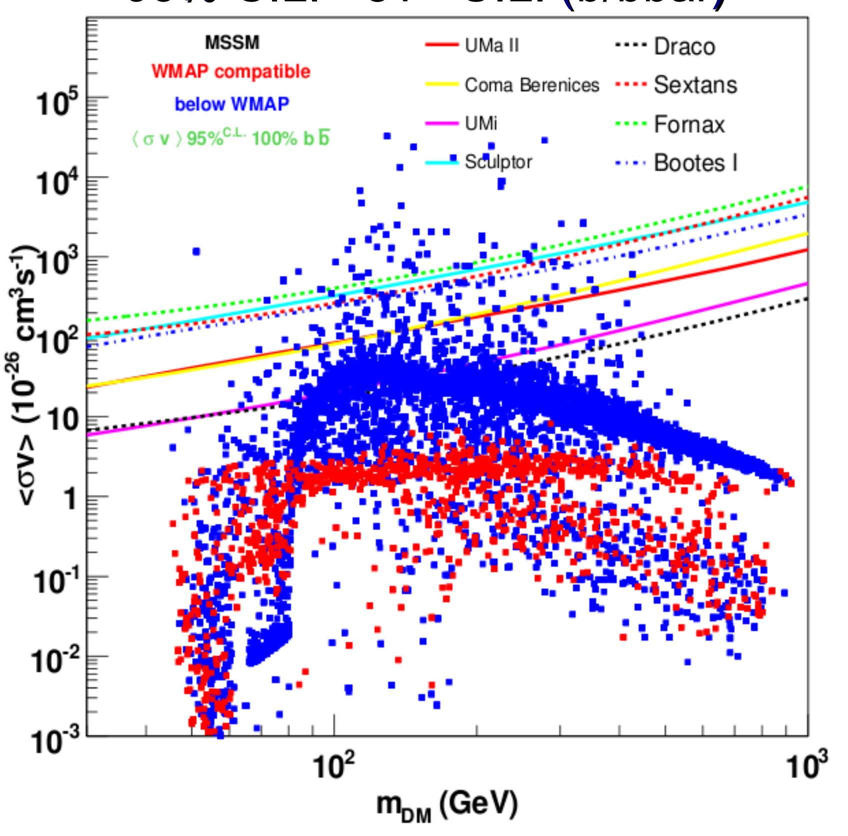
Subhalos – dSph - II

No detection with Fermi

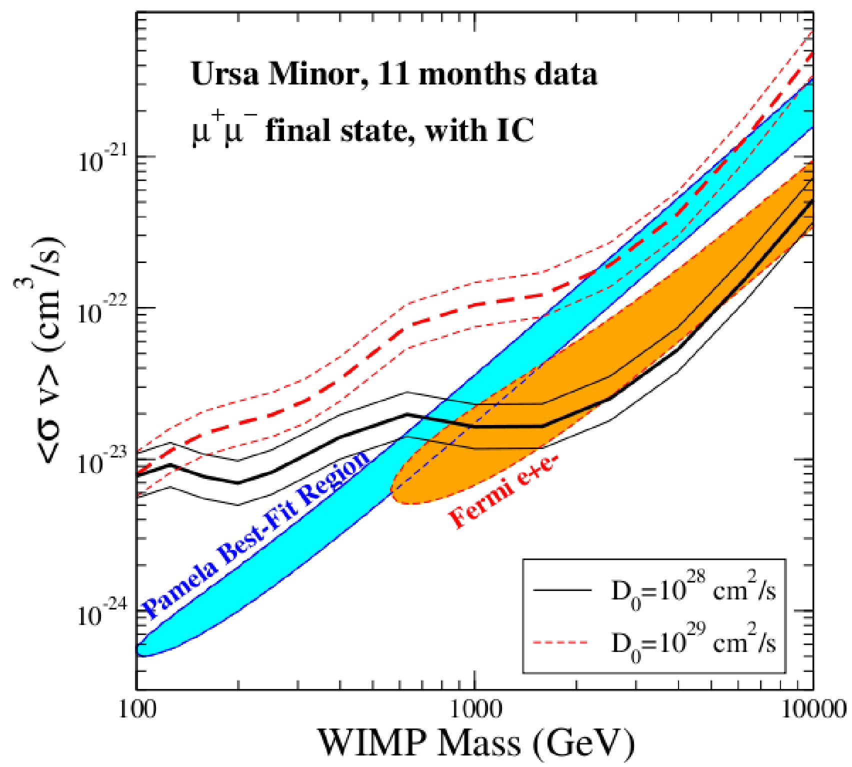
- Upper limits on flux
- DM density profile
  - ➔ Upper Limits on <σv>

11 months results in
Astrophys. J. 712, 147 (2010)

95% C.L. <σv> U.L. (b/bbar)



95% C.L. <σv> U.L.
(μ^+/μ^-, FSR+IC)



Subhalos – dSph - III

Work in progress:

Idea: DM spectrum is the same in all dSphs
- use data from all dSphs for stacking analysis
- combined likelihood with different parameters but same mass and annihilation rate

Combined limits are less sensitive to background fluctuations and J-factor uncertainties

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

Preliminary:

Combined limits are more strict than individual ones and cover very interesting parameter Space.

Galaxy Clusters

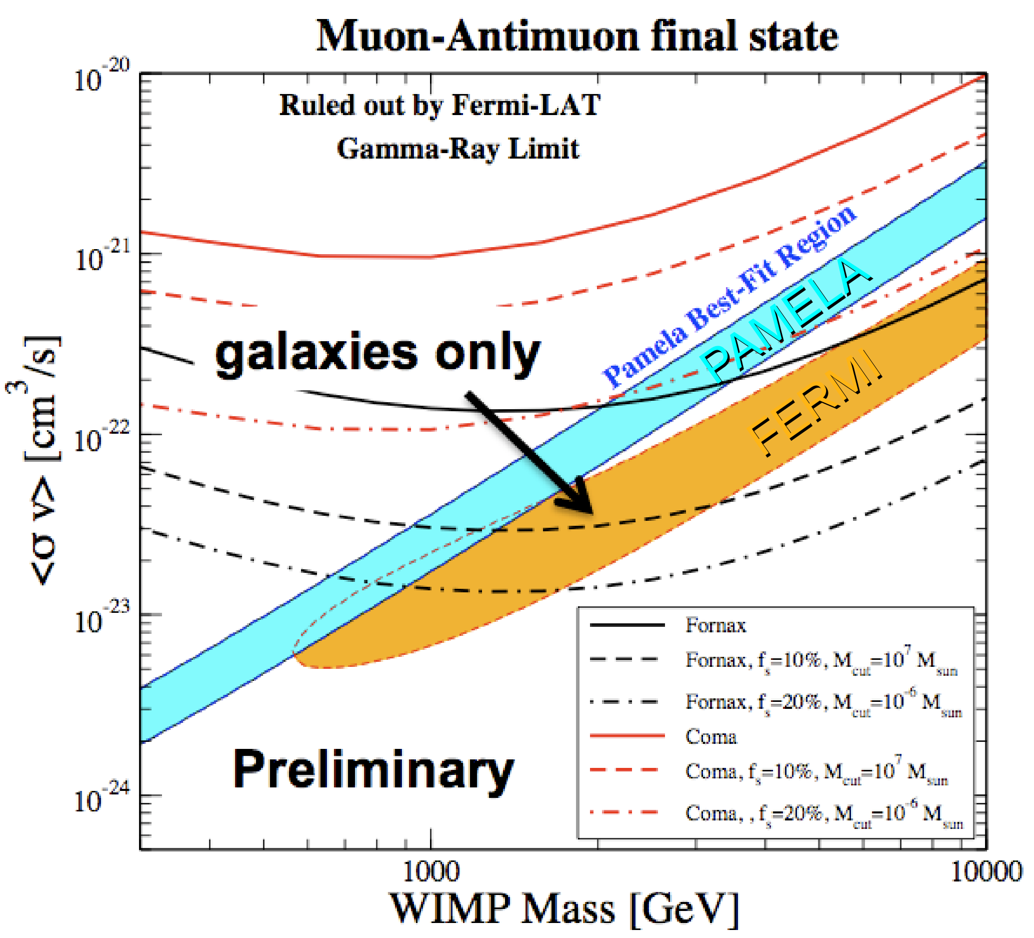
JCAP 1005:025,2010
arXiv preprint: 1002:2239

DM dominated distant objects
6 X-ray bright clusters
11 months data
100 MeV – 100 GeV energy range

<u>No detection by Fermi</u>

95% gamma-ray flux U.L.

- Strong constraints for μ^+/μ^- channel when ICS off the CMB is included
- Constraints for b/bbar models are weaker than ones from dSphs
- Limits depend on substructures assumptions



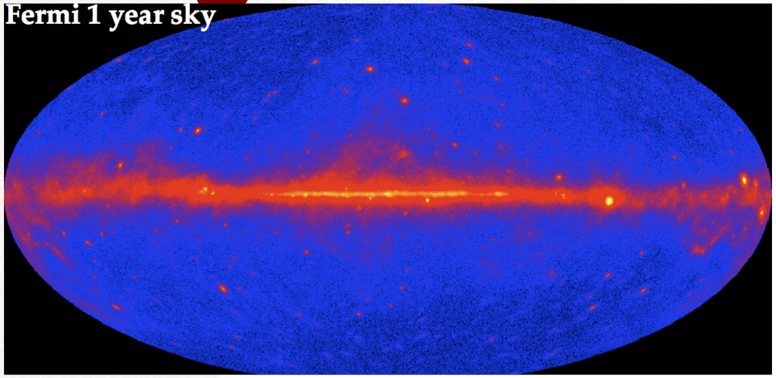
Cosmological DM - I

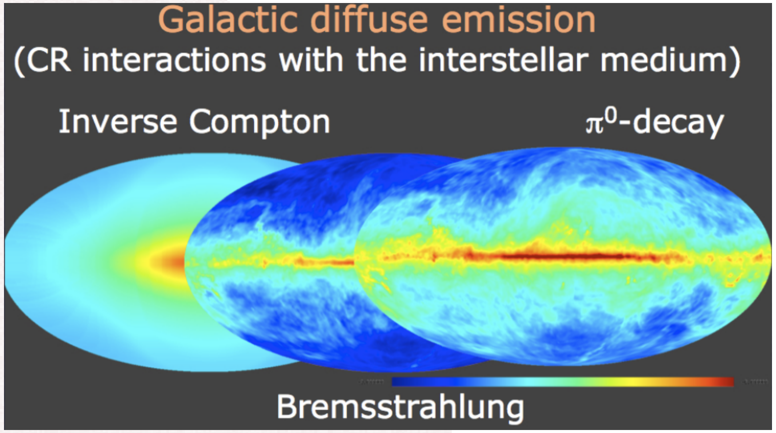
Fermi gamma-ray sky:

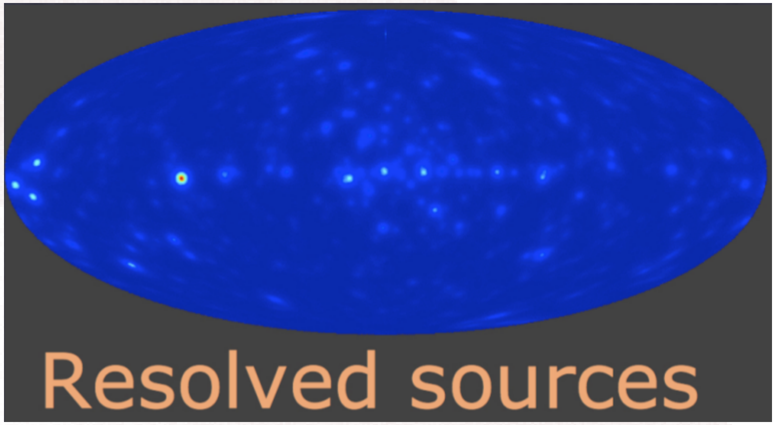
- Galactic Difuse Emission
  - Inverse Compton Scattering
  - Bremsstrahlung
  - π^0 decay
- Resolved sources
- Isotropic background

Remove galactic diffuse, resolved sources and residual CRs.

→ Isotropic gamma-ray BG
  - Known unresolved sources
    - AGNs
    - UHECR proton EM cascades
    - Star forming galaxies
  - Dark matter?







Cosmological DM - II

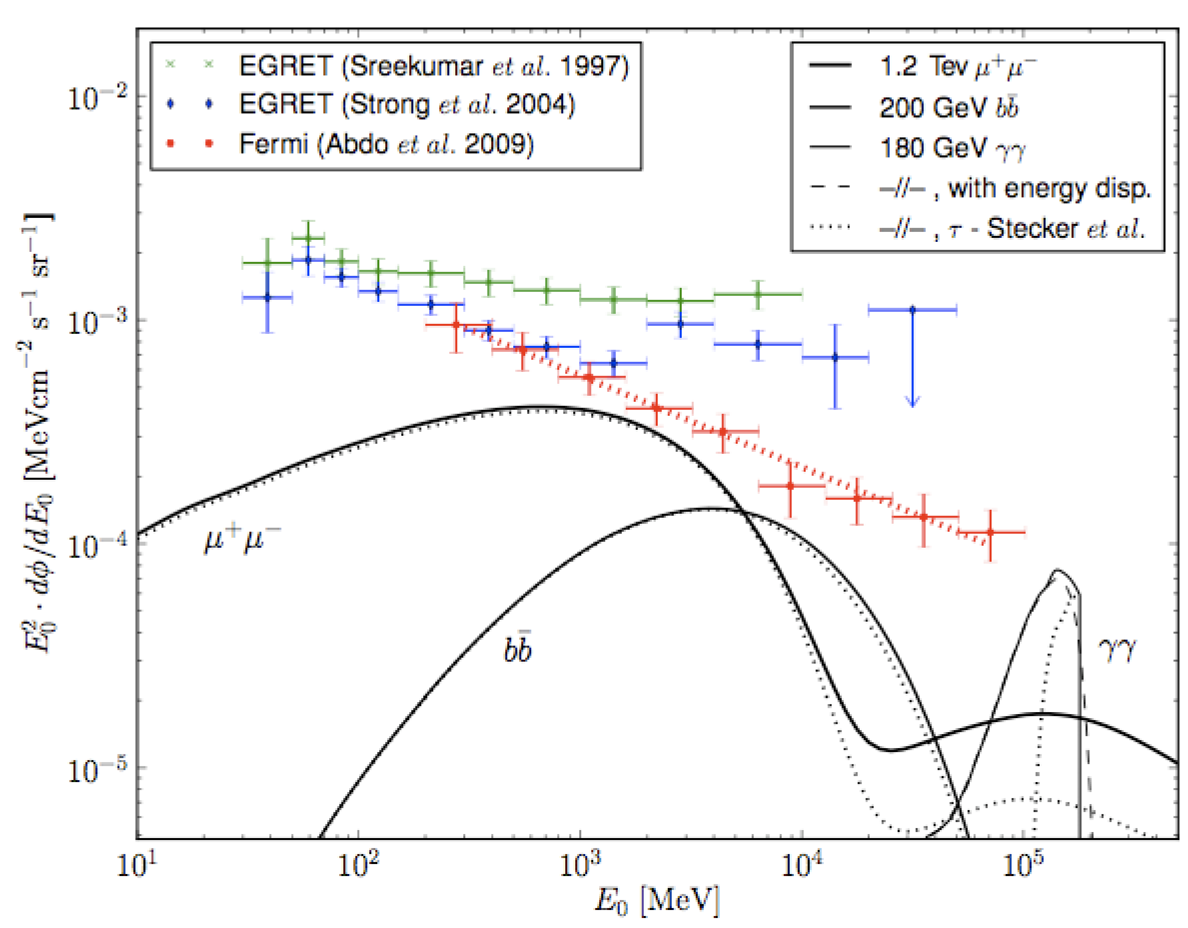
200 MeV – 102 GeV

Fermi spectrum compatible with a PL (Index=-2.41 ± 0.05)

The DM annihilation shape is the key to disentangle DM signal from other components.

Main contribution to DM signal from very low mass gravitationally collapsed regions

- beyond simulation resolution (10^5 $M_\odot$): uncertainties on flux



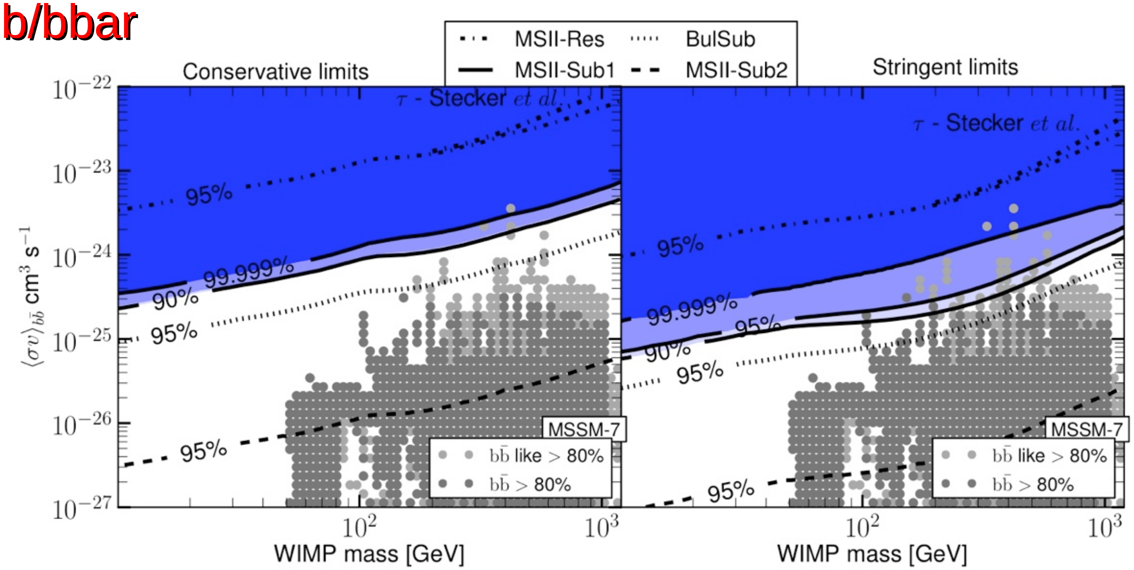
Cosmological DM - III

Very constraining limits for different models even under conservative hypotheses

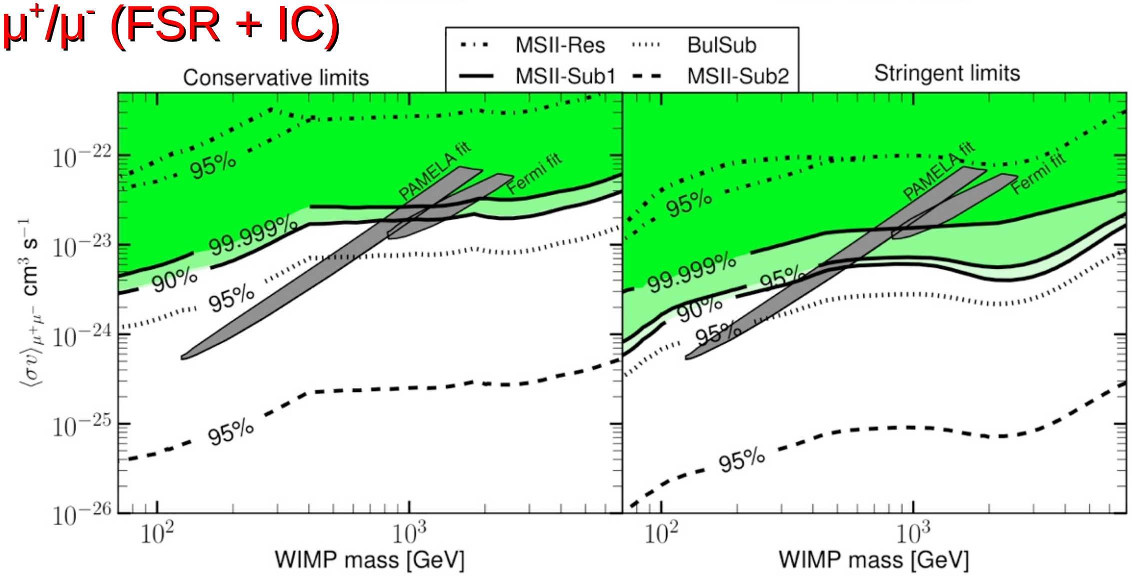
Flux to become lower as Fermi detects more extragalactic sources:

- more precise BG modelization
- increased sensitivity for DM

b/bbar



μ^+/μ^- (FSR + IC)



JCAP 1004:014,2010
arXiv preprint: 1002.4415

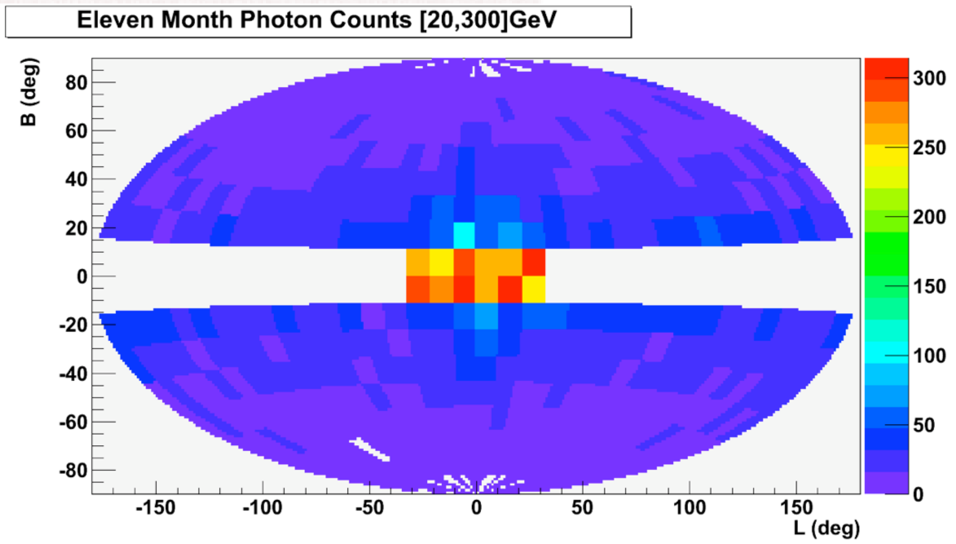
Lines - I

Direct WIMP annihilation into final γγ or γX states.

- ✓ No astrophysical uncertainties
  - ✓ "Smoking gun" for DM detection
- ✗ Low signal
  - ✗ Branching ratios suppressed (10^{-1}-10^{-4} depending on different models)

11 months of data
Search in 30-200 GeV energy range
Removed point sources
Extra cuts to remove residual charged particles contaminations

Search region:
|b| > 10 deg +
|l| < 20 deg, |b| < 20 deg



Lines - II

Energy resolution ~10% @ 100GeV

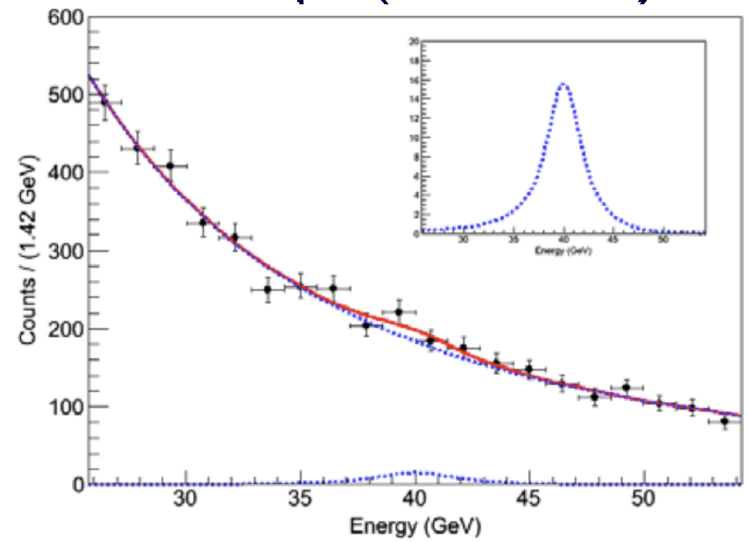
The response of the detector has been characterized for the line search

S(E) is the Signal PDF

The back ground is a PL

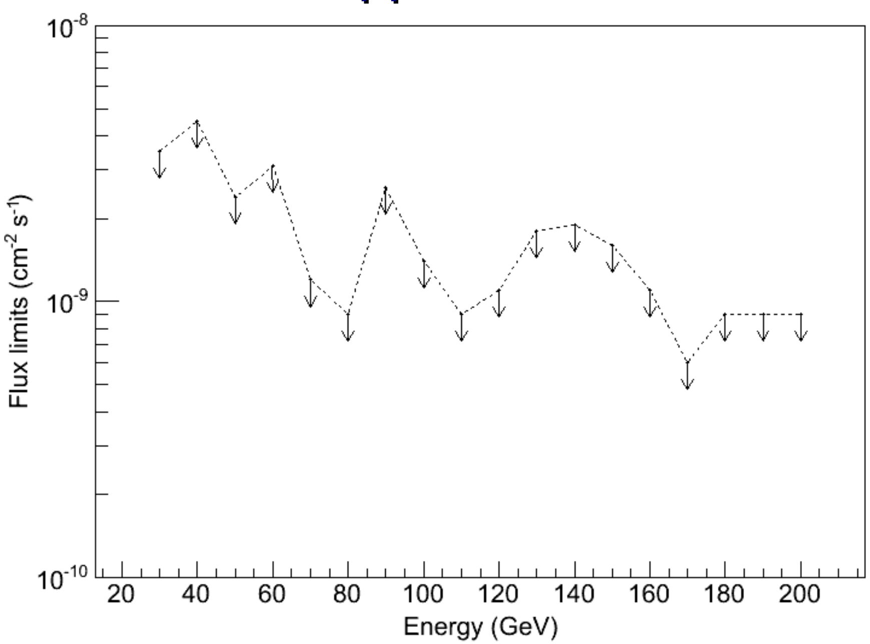
$$L = \prod_{i=1}^{N} (f \cdot S(E_i) + (1-f) \cdot B(E_i))$$

Fit example (40 GeV line)



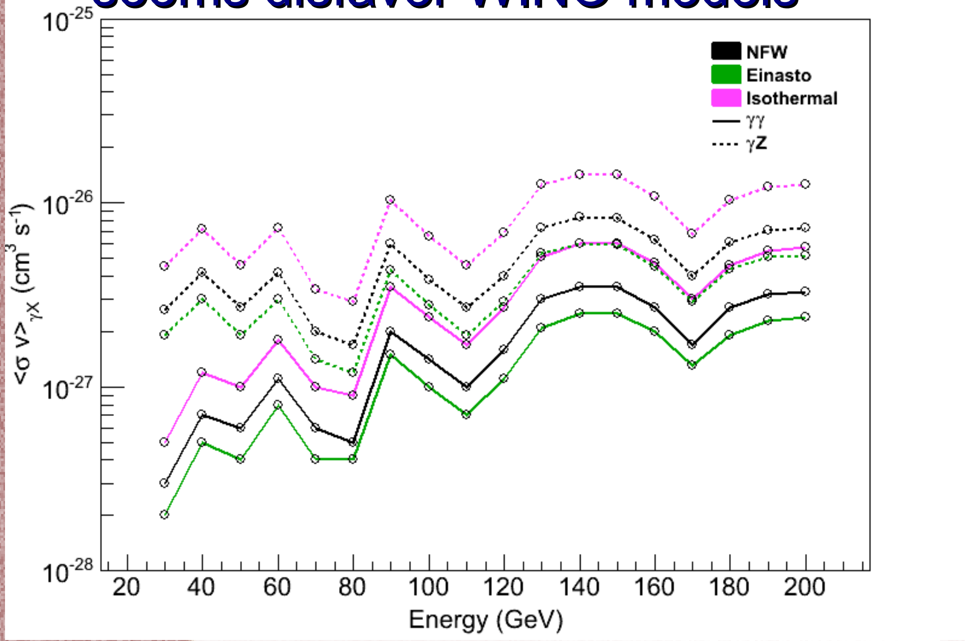
No detection of lines

95% CL upper limits

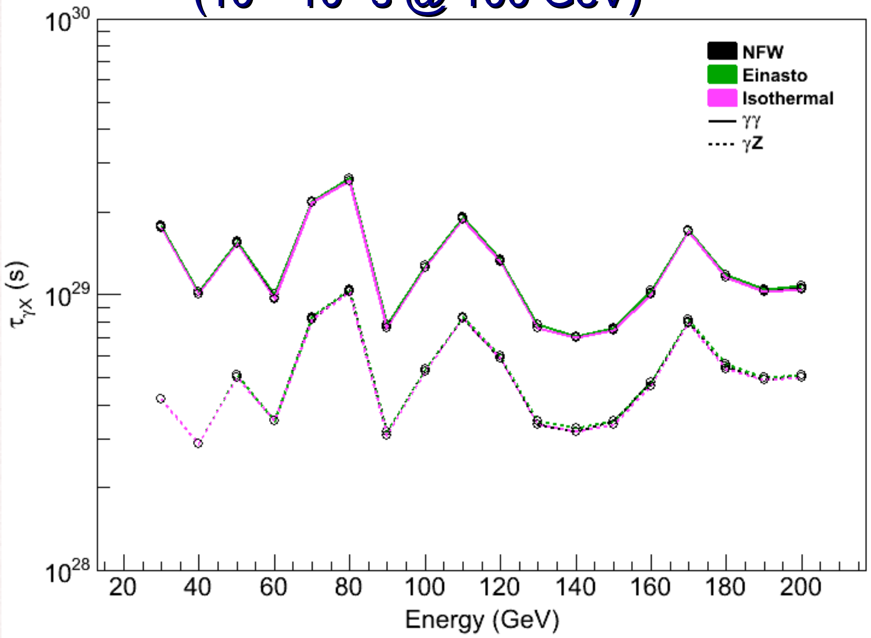


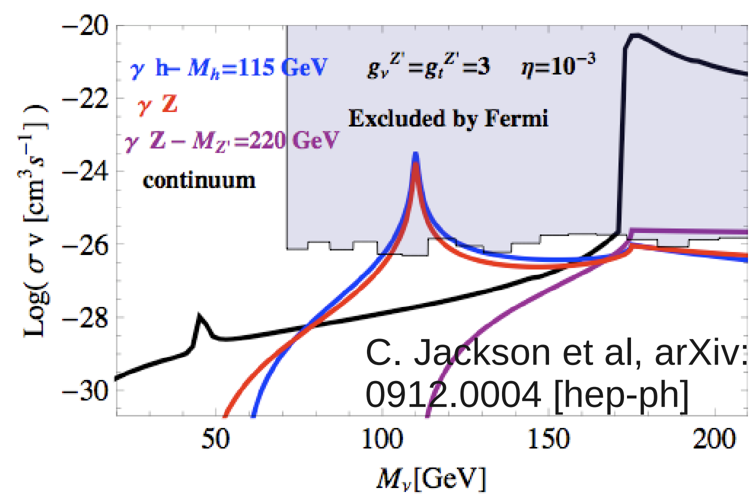
Lines - III

Constraints on annihilation cross-section
too weak for thermal WIMP models
seems disfavor WINO models



Constraints on lifetime
Gravitino $\tau<10^{29}$ s
(10^{23}-10^{37} s @ 100 GeV)





C. Jackson et al, arXiv: 0912.0004 [hep-ph]

Constraints on Higgs models

Conclusions

- No detection
  - very interesting constraints on DM properties
    (e.g. Fermi and PAMELA cosmic rays data)
- Work in progress to better understand the instrument response
- Indirect searches with Fermi will benefit form
  - Diffuse background model
  - DM density distrubution
  - Multiwavelength analyses
- Much time to gain data (only 2 years since launch)