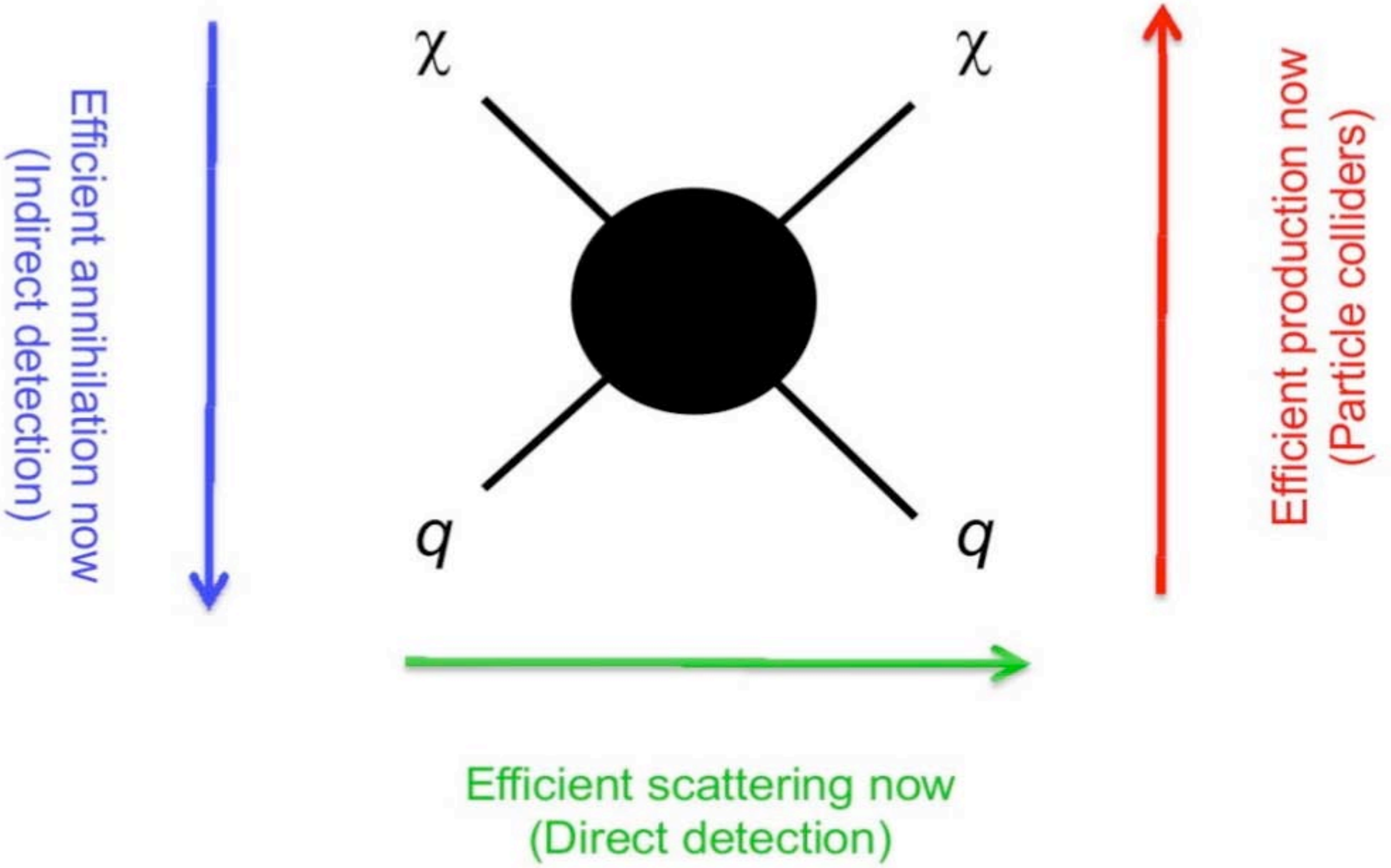
Search for Dark Matter in the Sky

Aldo Morselli
INFN Roma Tor Vergata

Scineghe09
Assisi, 7 /10/ 2009

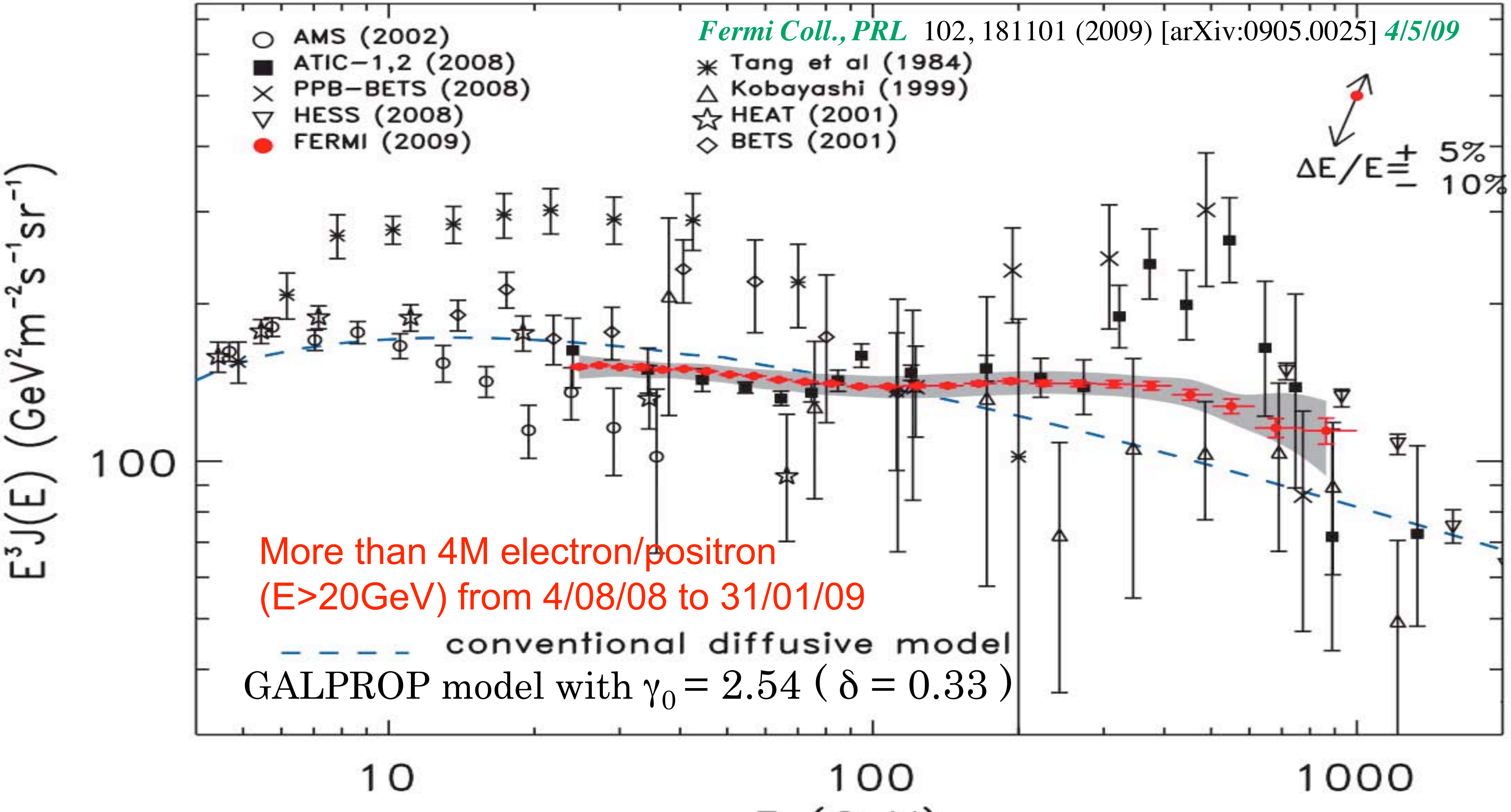

Efficient annihilation now
(Indirect detection)
χ
χ
q
q
Efficient production now
(Particle colliders)
Efficient scattering now
(Direct detection)

Neutralino WIMPs

Assume χ present in the galactic halo

- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources ($\chi\,\chi$ annihilation) is an interesting signature
- ie: $\chi\,\chi$ --> anti p + X
- Produced from (e. g.) $\chi\,\chi$ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

Fermi-LAT CRE data vs the conventional *pre-Fermi* model



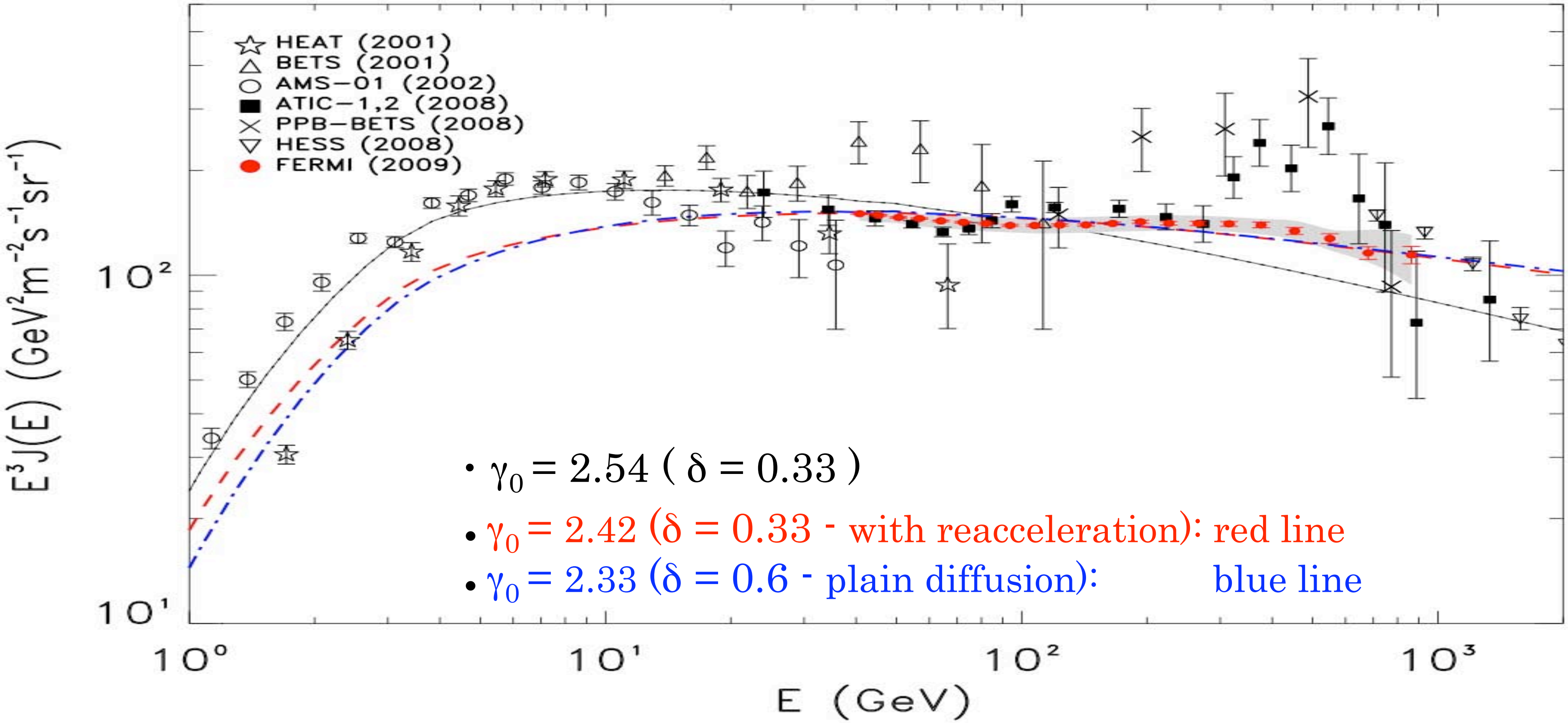
~130 citation ~ > 1/day average

Francesco Loparco Friday

Although the feature @~600 GeV measured by ATIC is not confirmed

<u>Some changes are still needed respect to the *pre-Fermi conventional model*</u>

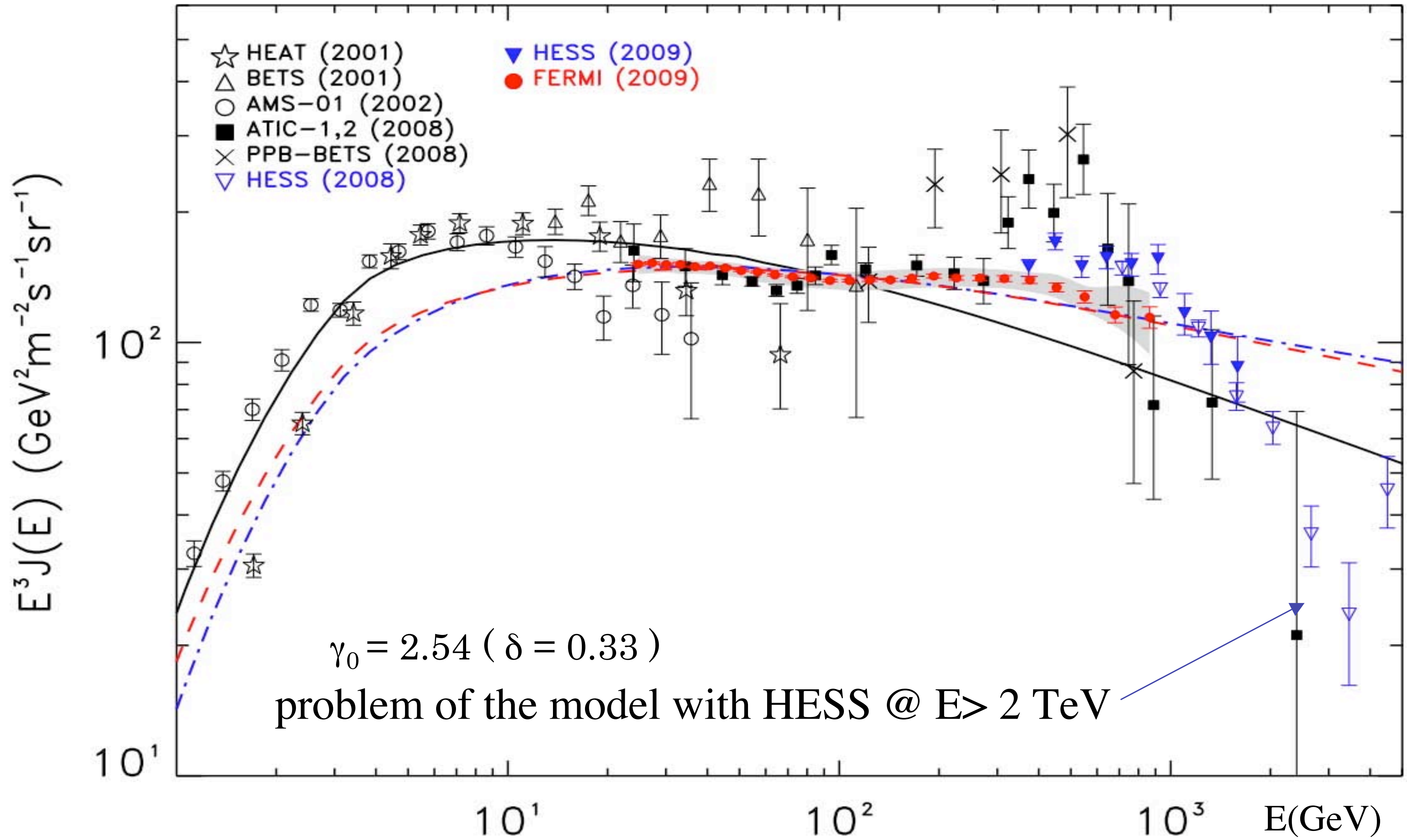
Cosmic Ray Electron propagation models



Model #	D_0 $(cm^2 s^{-1})$	δ	z_h (kpc)	γ_0	N_{e^-} $(m^{-2}s^{-1}sr^{-1}GeV^{-1})$	γ_0^p
0	3.6×10^{28}	0.33	4	2.54	1.3×10^{-4}	2.42
1	3.6×10^{28}	0.33	4	2.42	1.3×10^{-4}	2.42
2	1.3×10^{28}	0.60	4	2.33	1.3×10^{-4}	2.1

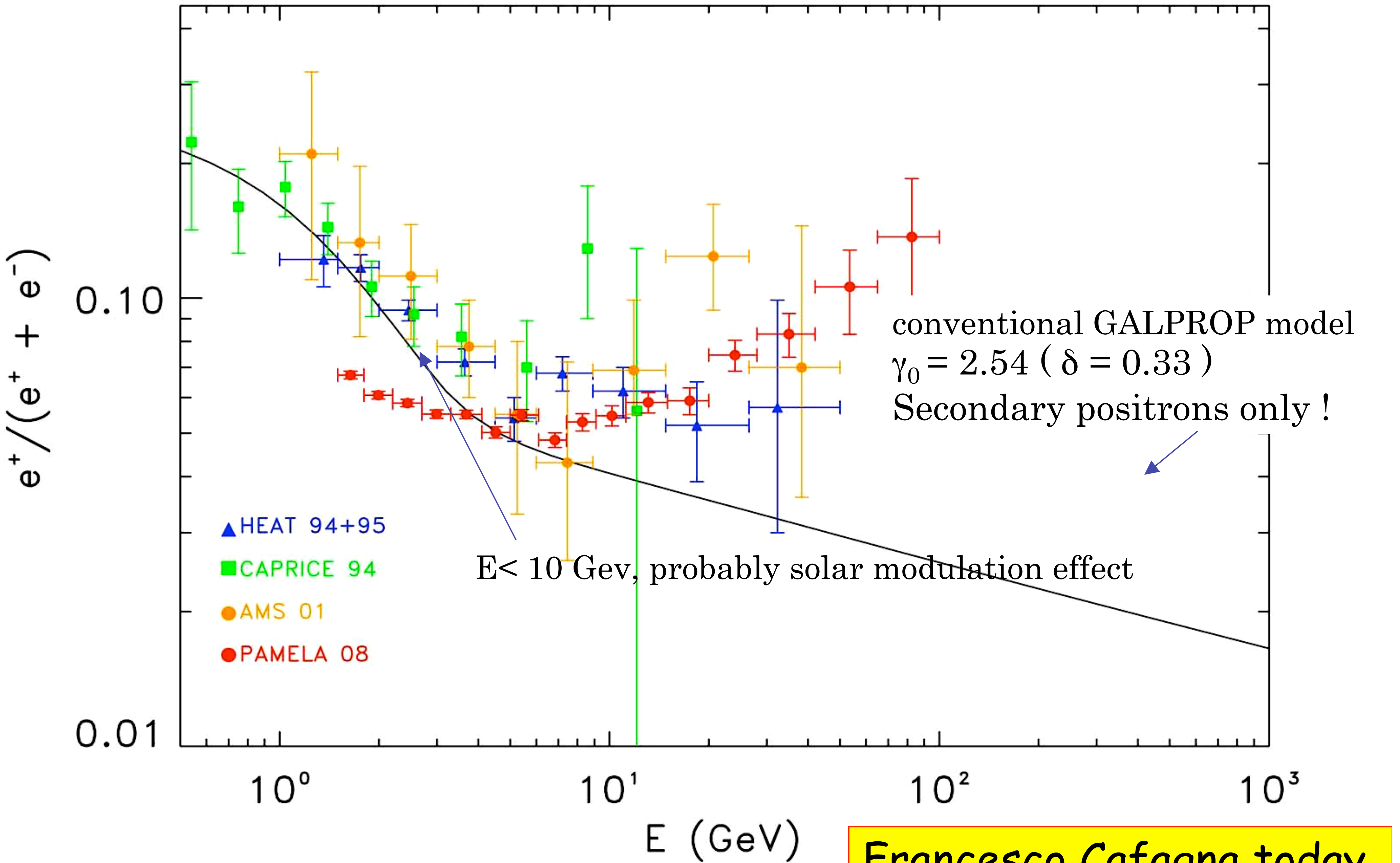
Models 0 and 1 account for CR re-acceleration in the ISM, while 2 is a plain-diffusion model. All models assume γ_0 = 1.6 below 4 GeV.

Fermi & HESS data vs the conventional *pre-Fermi* model



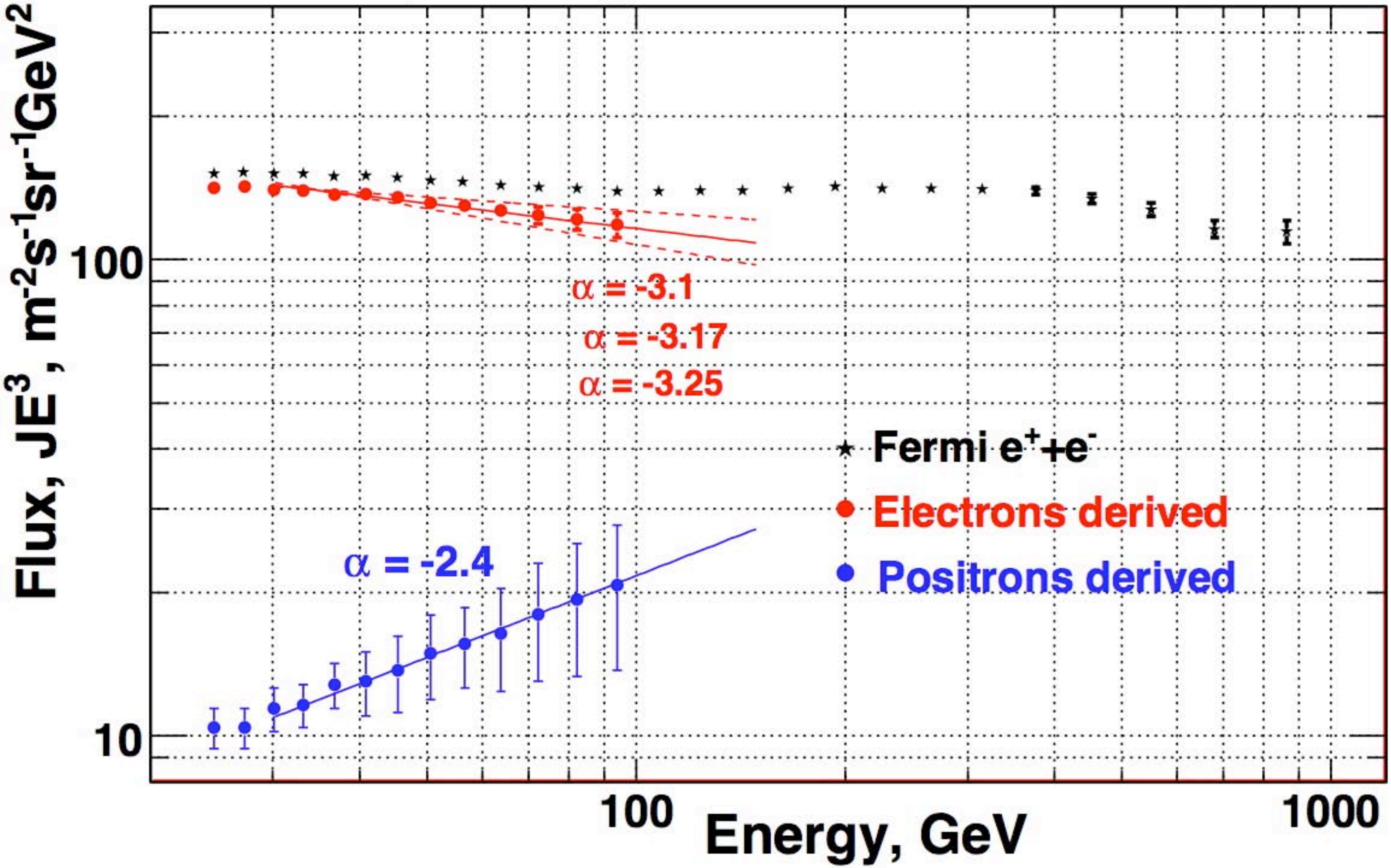
cutoff in the CRE source spectrum or breakdown of the source spatial continuity?

2009: PAMELA results



Francesco Cafagna today

Electron and positron spectra derived from Fermi and Pamela



Primary electrons in Cosmic Rays

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 70, NO. 11 JUNE 1, 1965

Letters

Observation of the Cosmic Ray Electron-Positron Ratio from 100 Mev to 3 bev in 1964

R. C. HARTMAN AND PETER MEYER

Enrico Fermi Institute for Nuclear Studies and Department of Physics University of Chicago, Chicago, Illinois

R. H. HILDEBRAND

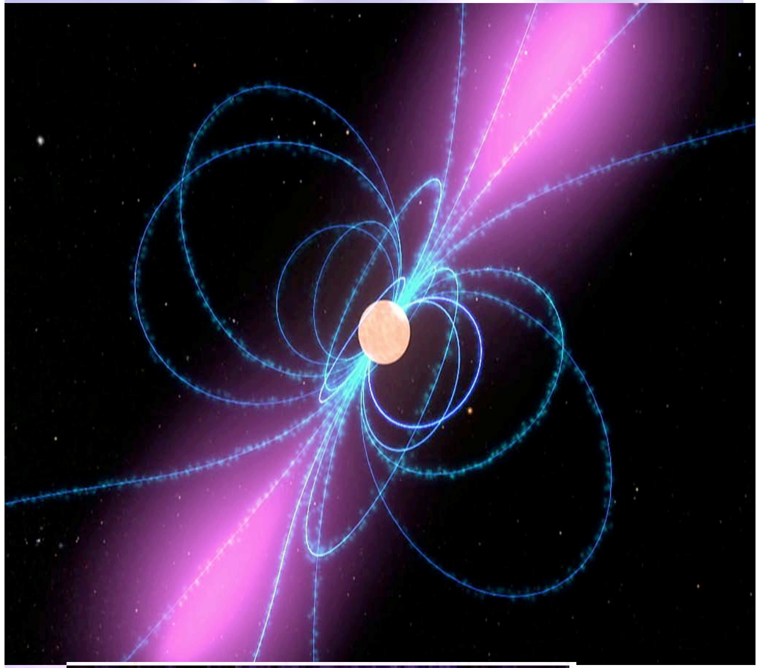
Argonne National Laboratory and University of Chicago Chicago, Illinois

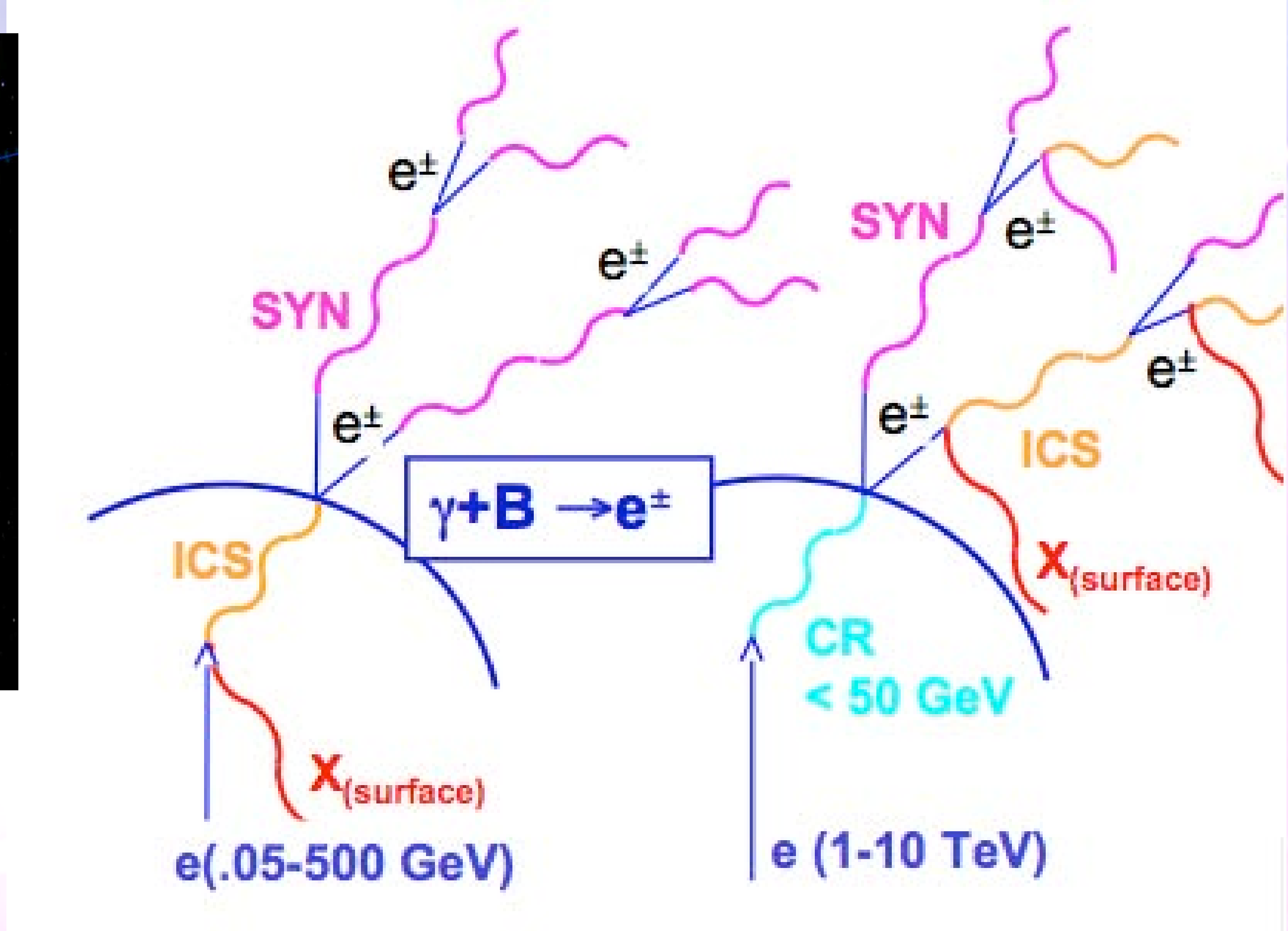
nent. In 1963, *DeShong, Hildebrand, and Meyer* [1964] reported the results of an experiment designed to measure this ratio in the energy interval from 100 to 1000 Mev. They found an excess of negative electrons which led them to conclude that the electron component consists mainly of directly accelerated particles. Their

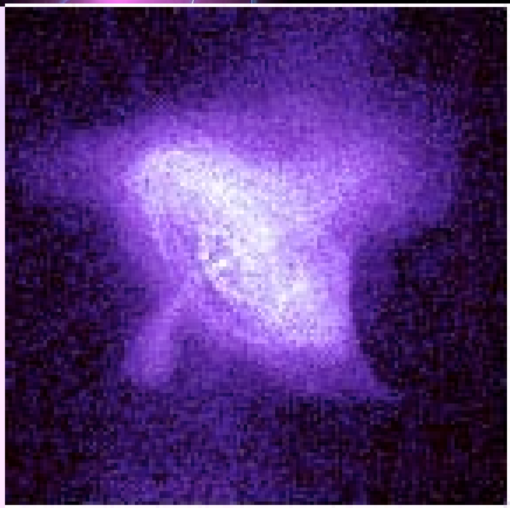
- Now, ~45 years later PAMELA excess in positron fraction and Fermi results on the electron+positron spectrum unavoidably testifies the presence of ***primary positrons*** in CRs

which are the **sources** of the primary positrons ?

Pulsars as sources of $e^{-/+}$ pairs

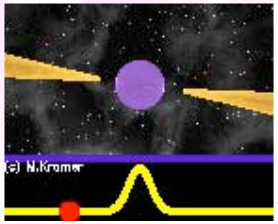




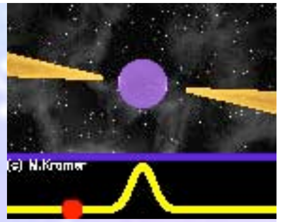


Crab Pulsar Wind Nebula (PWN)

$e^{\pm}$ pairs are produced in the magnetosphere and accelerated by the electric fields and/or the pulsar wind.

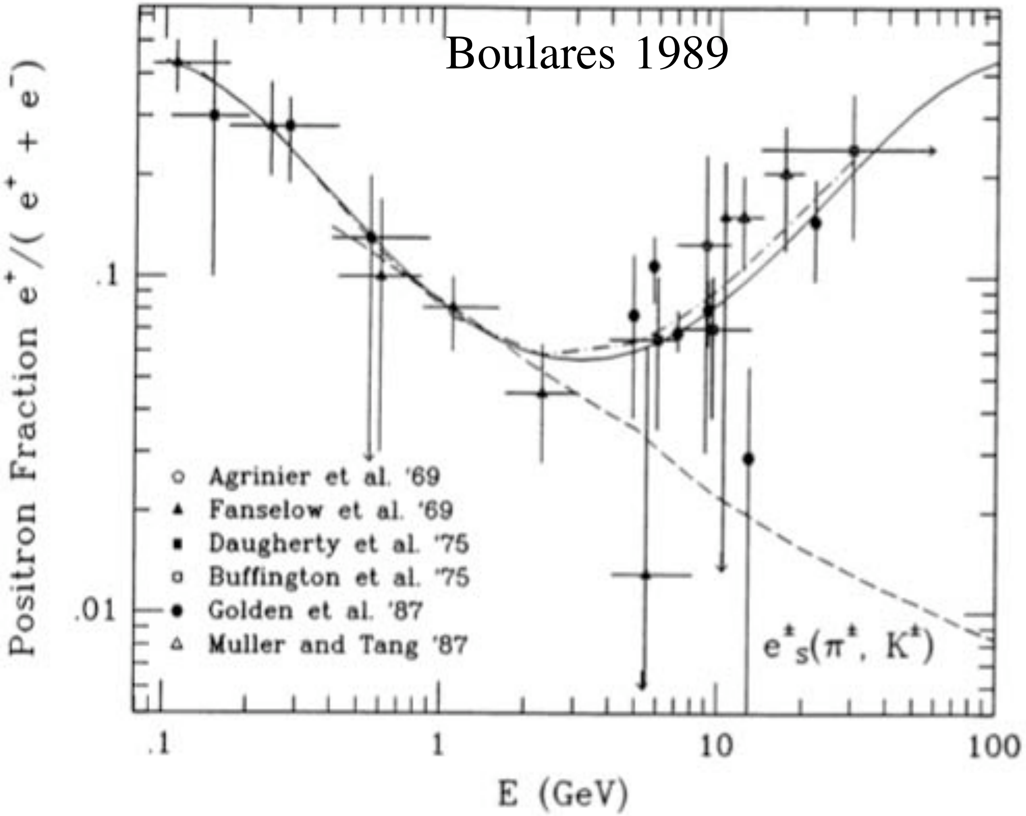


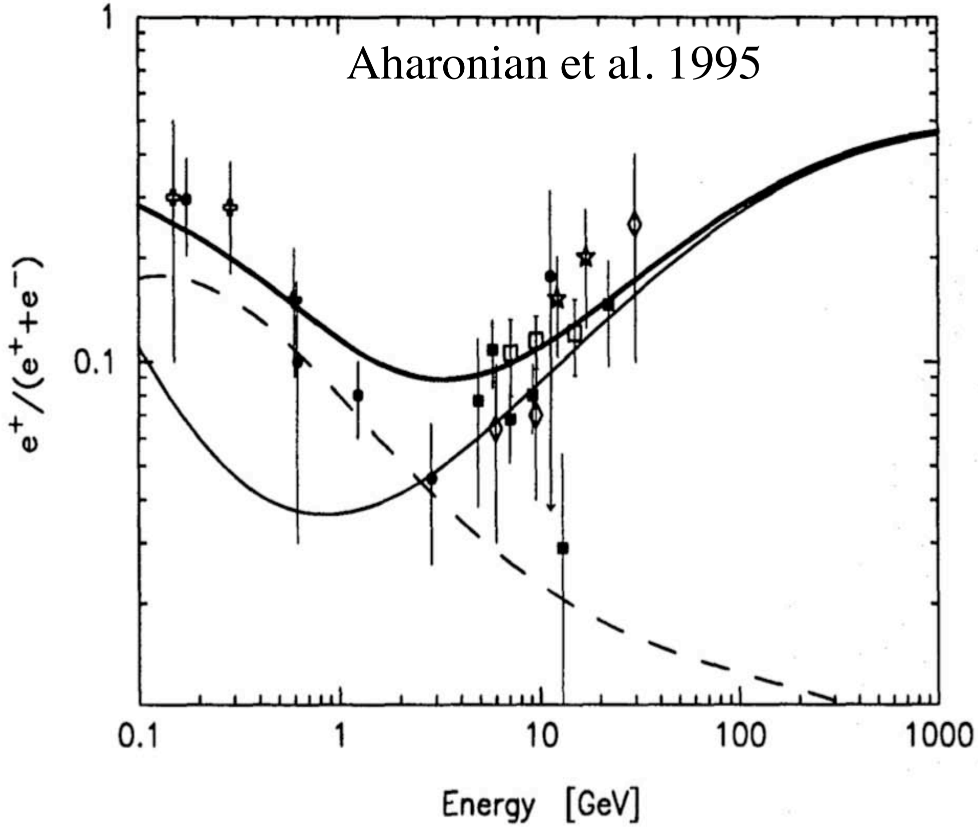
Pulsars as sources of $e^{-/+}$ pairs



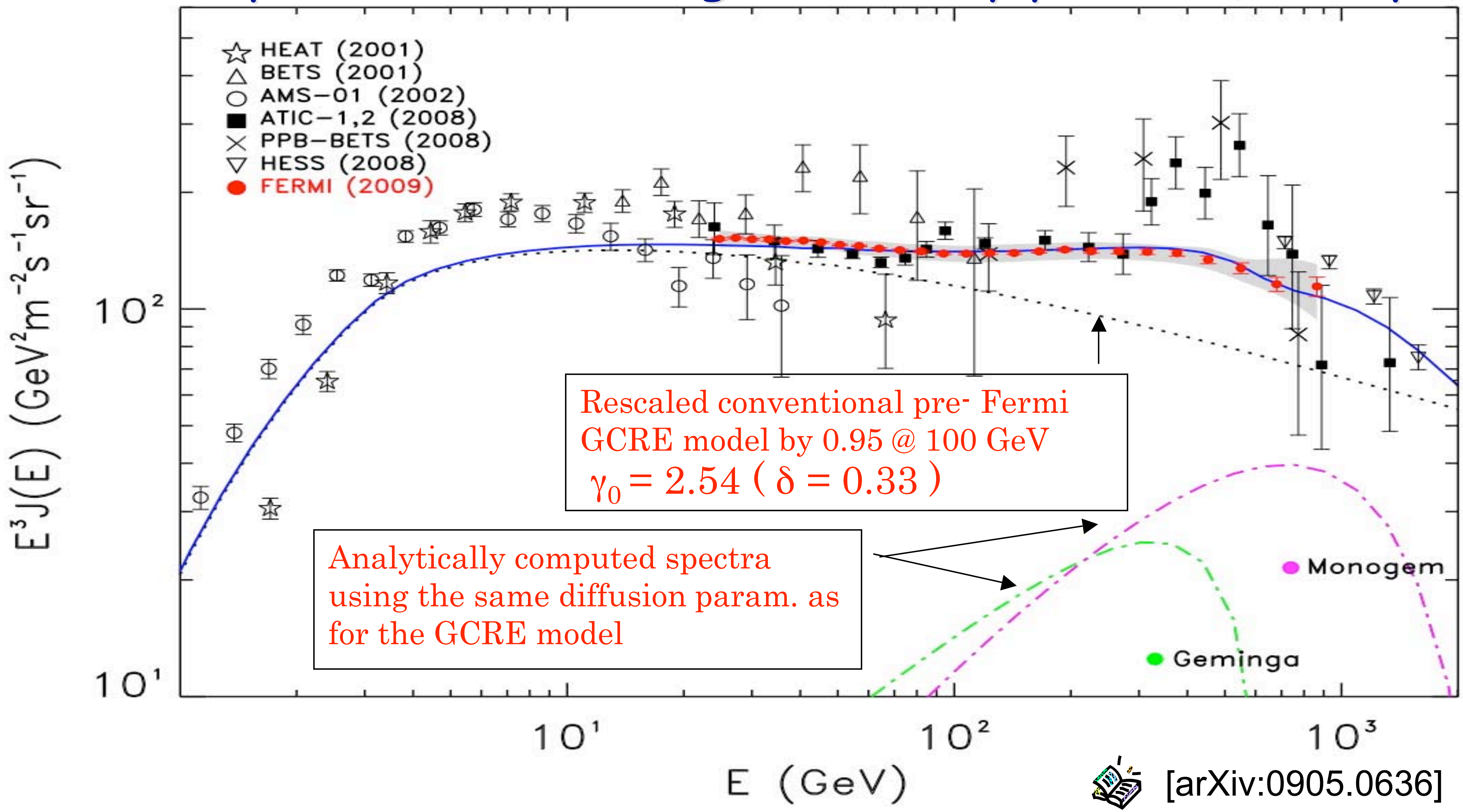
not a new idea

- A.Boulares APJ 342 (1989) 807-813
- Aharonian et al., A&A 294 (1995) L41
- A. M. Atoyan, F. A. Aharonian, and H. J. Volk, Phys. Rev. D52 (1995) 3265.
- T. Kobayashi, Y. Komori, K. Yoshida and J. Nishimura, ApJ 601 (2004) 340.





The CRE spectrum accounting for nearby pulsars (d < 1 kpc)

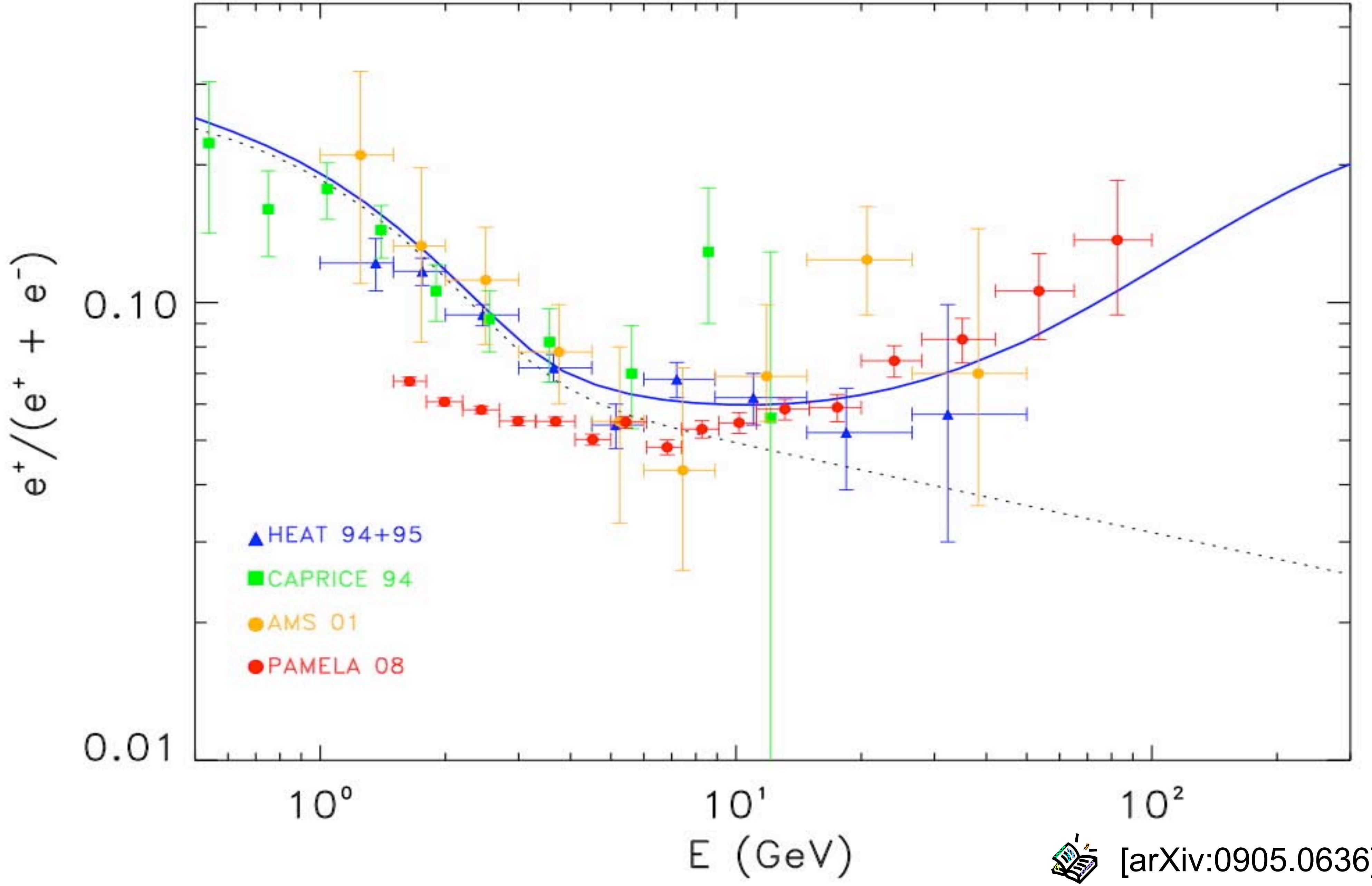


[arXiv:0905.0636]

This particular model assumes: 40% $e^{\pm}$ conversion efficiency for each pulsar

- pulsar spectral index $\Gamma = 1.7$ $E_{cut} = 1$ TeV . Delay = 60 kyr

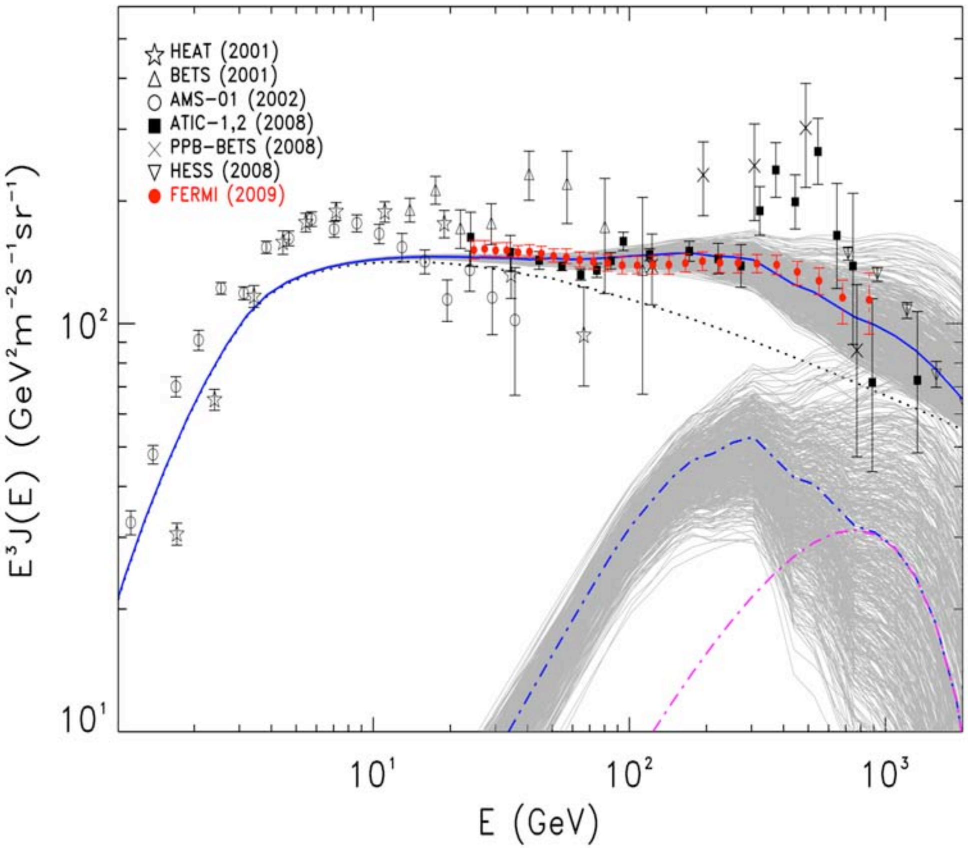
the positron ratio accounting for nearby pulsars (d < 1 kpc)

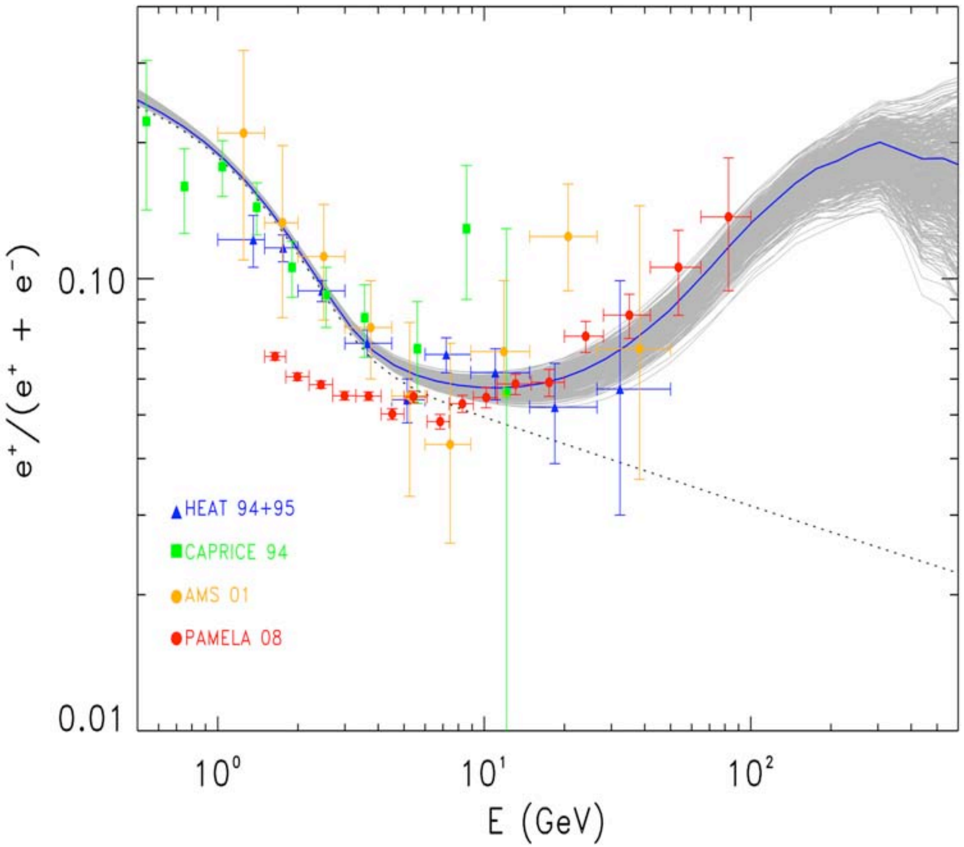


[arXiv:0905.0636]

What if we randomly vary the pulsar parameters relevant for e+e- production?

(*injection spectrum, e+e- production efficiency, PWN "trapping" time*)



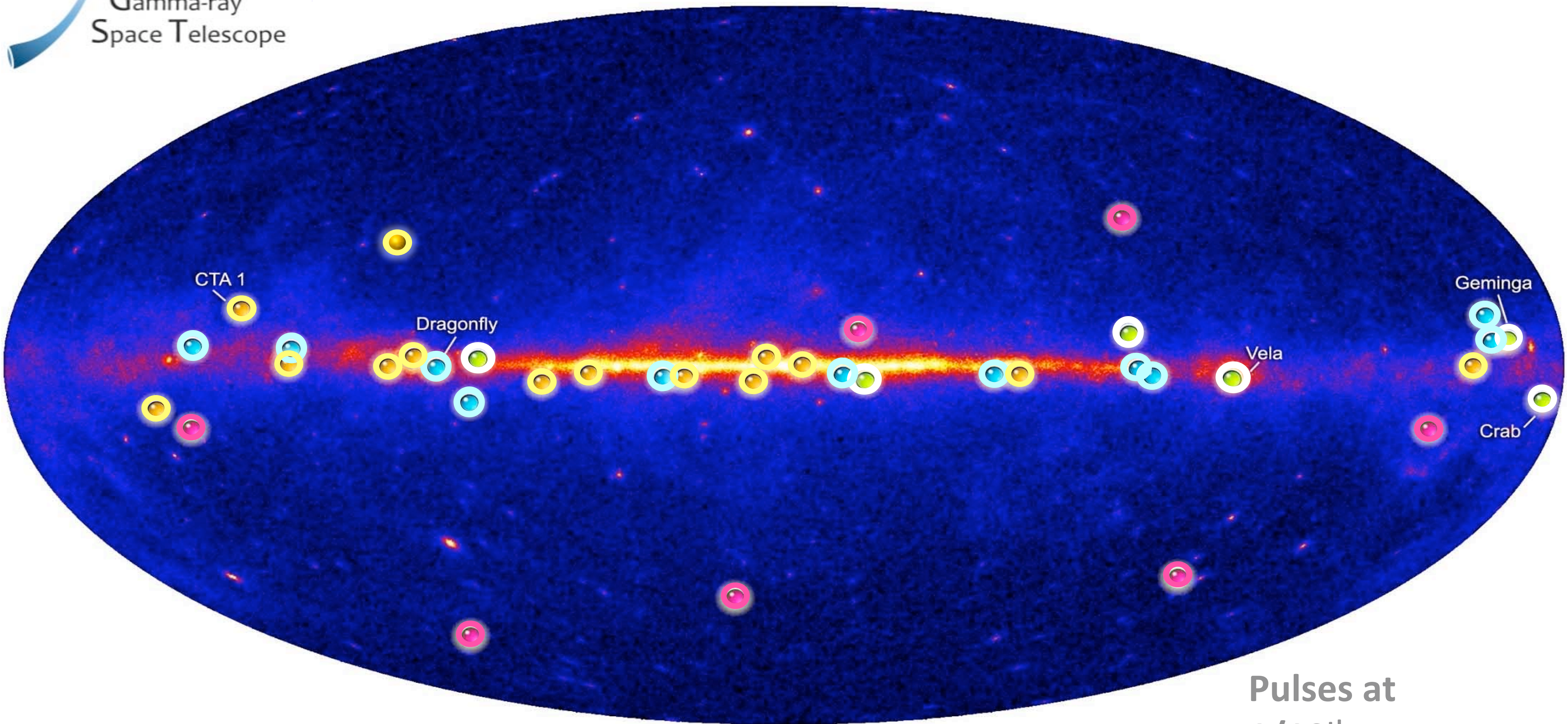


Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results.

[arXiv:0905.0636]

fermi
Gamma-ray
Space Telescope

16 Gamma-Ray Pulsars Through Blind Frequency Searches
Science 325 (5942), 840-844
A Population of Gamma-Ray Millisecond Pulsars Seen with Fermi
Science 325 (5942), 848-852 (14 August 2009)



Pulses at
1/10th true rate

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

The Pulsing γ-ray Sky

Francesco Giordano Friday


14 August 2009 | $10
Science
Fermi
Detecting Gamma-Ray Pulsars
AAAS

Pulsars

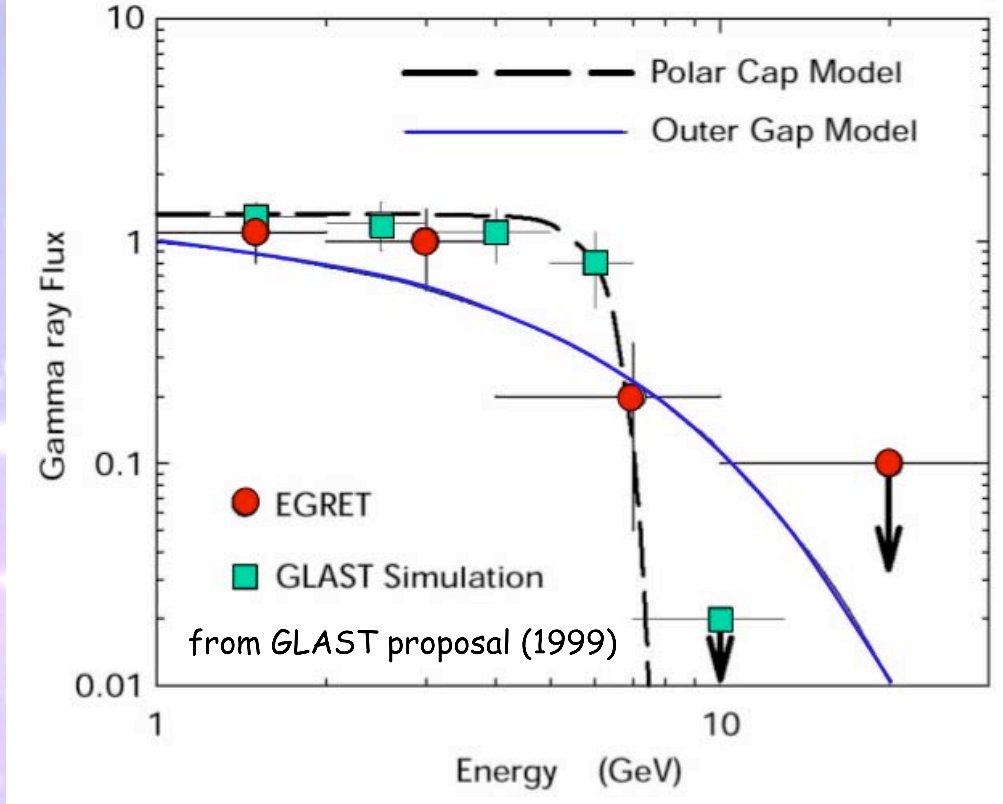
1. On purely energetic grounds they work (relatively large efficiency)

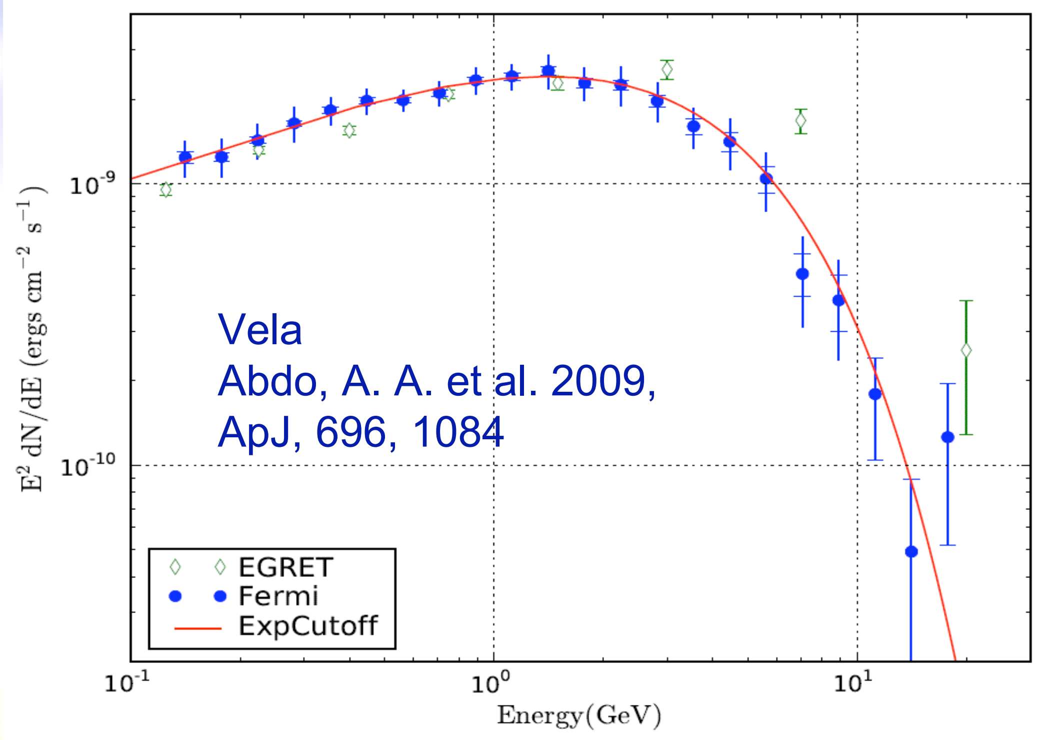
2. On the basis of the spectrum, it is not clear
   1. The spectra of PWN show relatively flat spectra of pairs at Low energies but we do not understand what it is
   2. The general spectra (acceleration at the termination shock) are too steep

The biggest problem is that of escape of particles from the pulsar
1. Even if acceleration works, pairs have to survive losses
2. And in order to escape they have to cross other two shocks

New Fermi data on pulsars will help to constrain the pulsar models

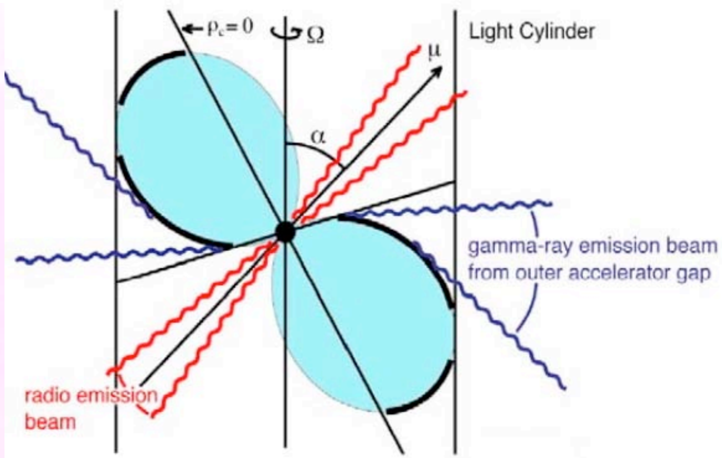
Spectral measurements and emission models

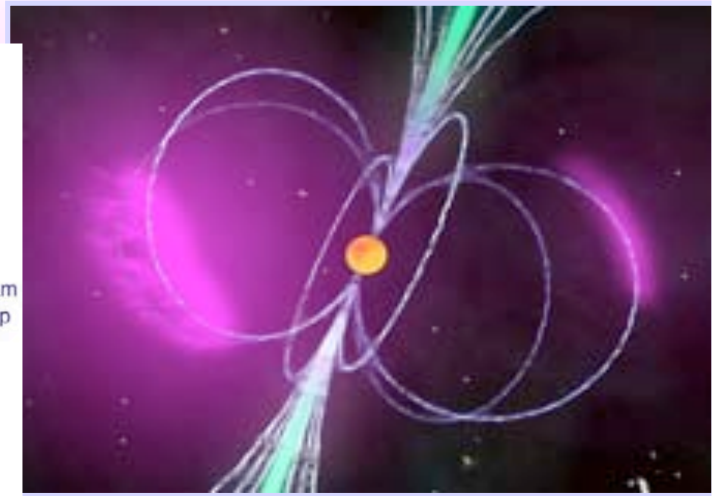




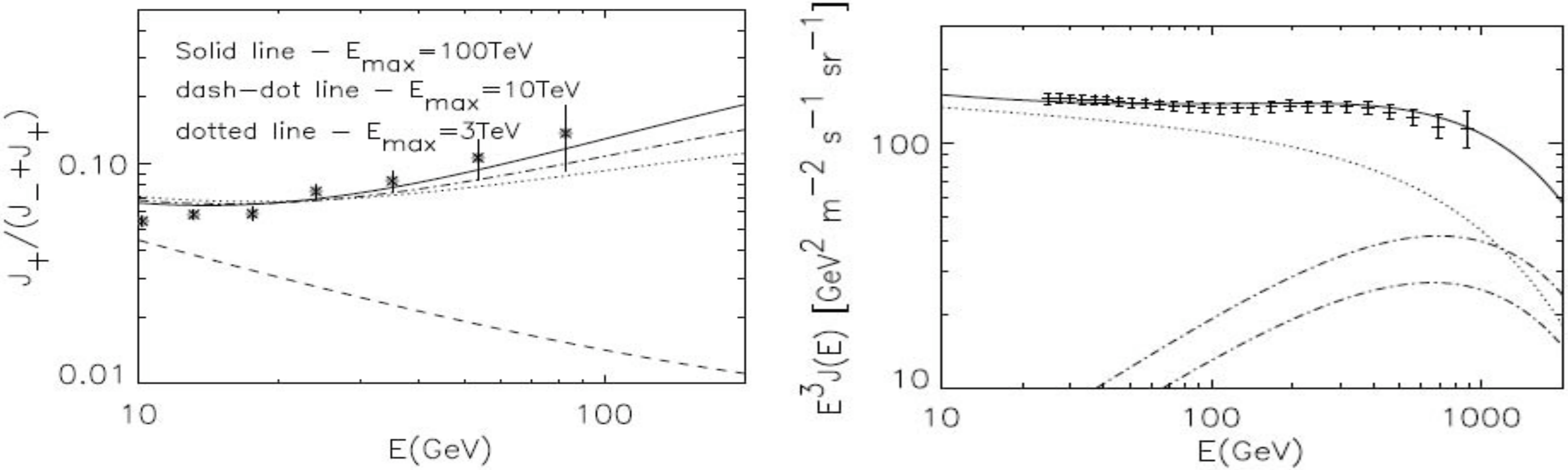
Evidence of γ-ray emission in the outer magnetopshere due to absence of super-exponential cutoff

- Radio and γ-ray fan beams separated
- γ-ray only PSRs





other Astrophysical solution



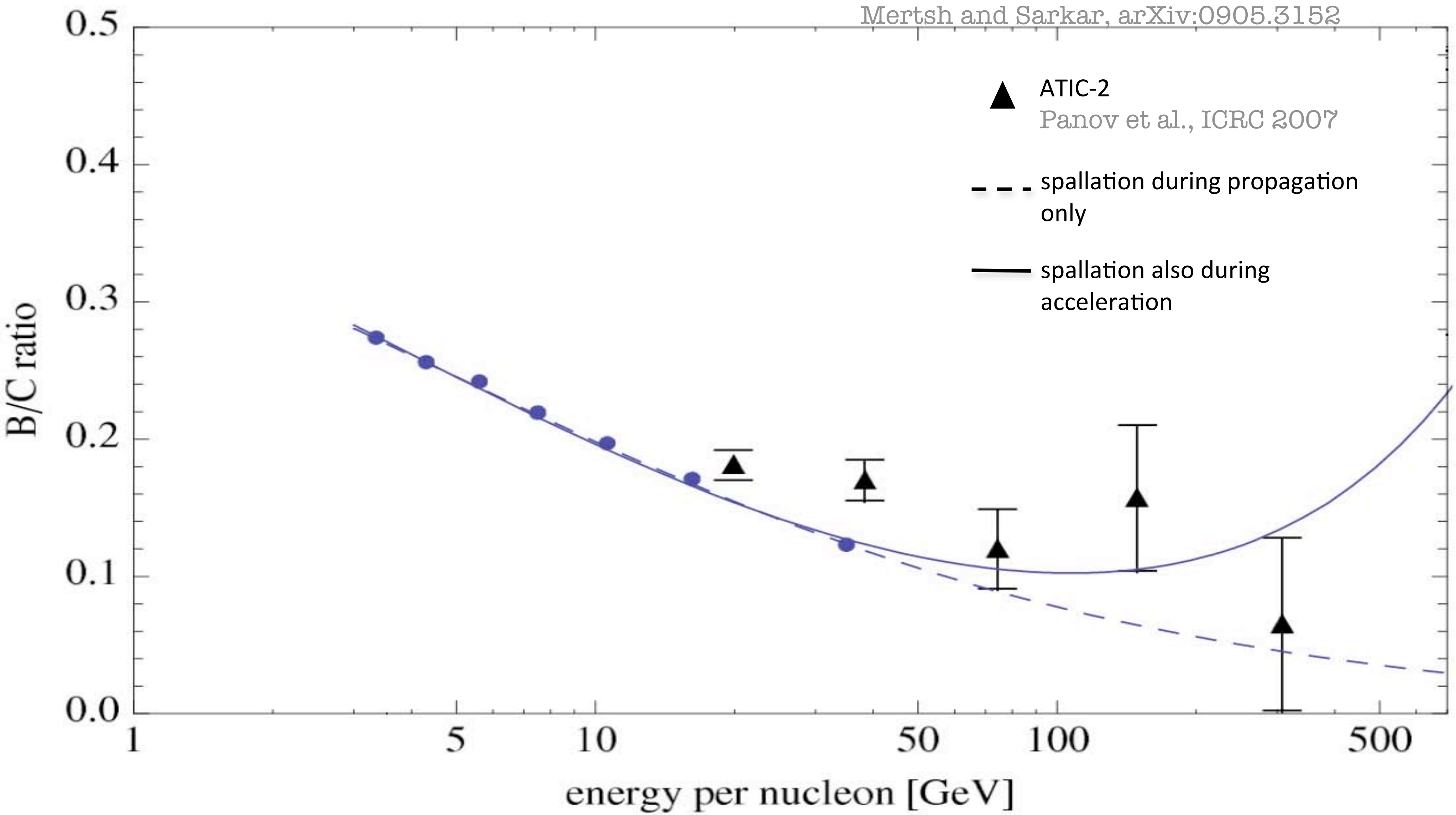
• Positrons created as secondary products of hadronic interactions inside the sources

• Secondary production takes place in the same region where cosmic rays are being accelerated

-> Therefore secondary positron have a very flat spectrum, which is responsible, after propagation in the Galaxy, for the observed positron excess

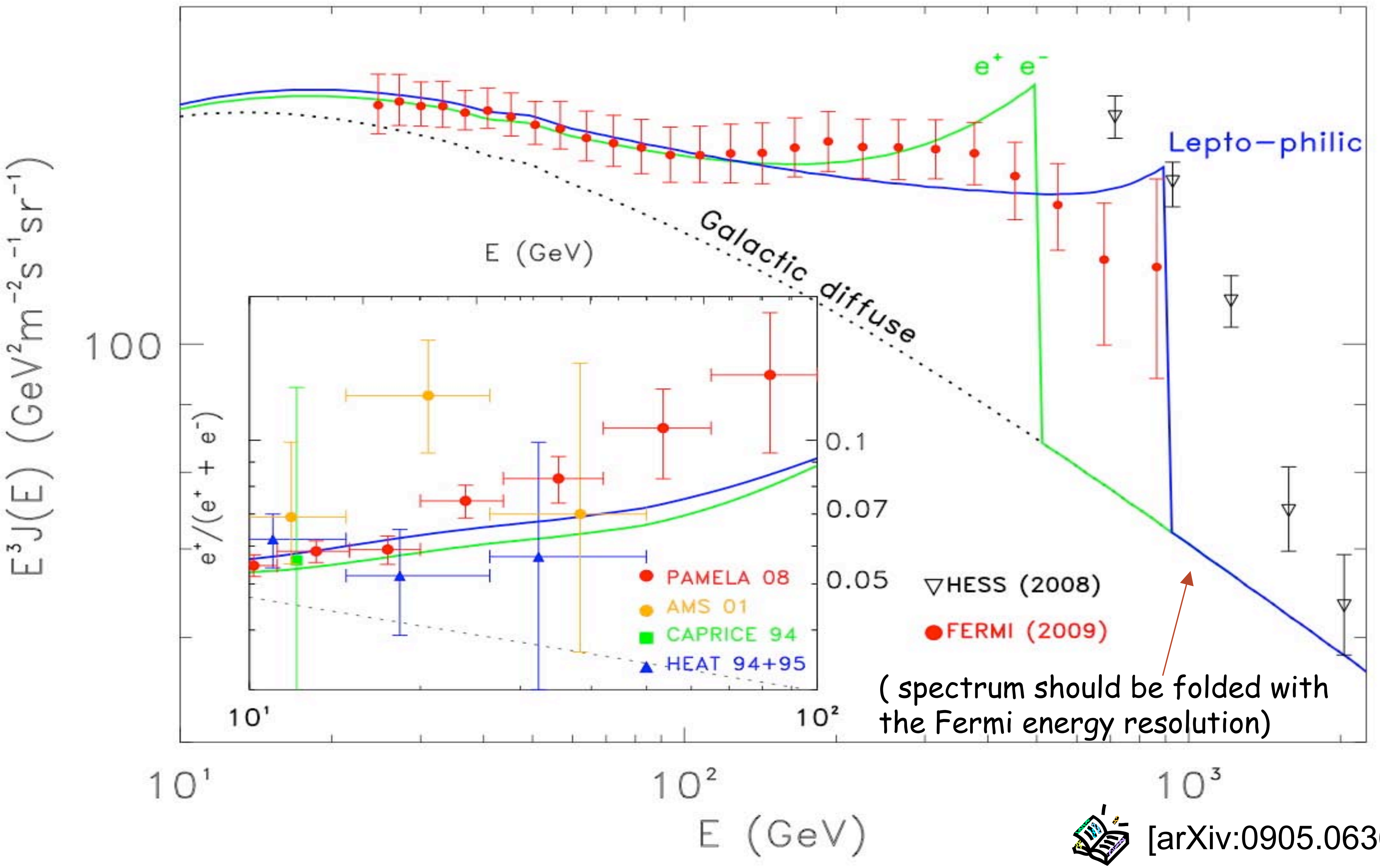
Blasi, arXiv:0903.2794

Boron-to-Carbon Ratio



A rise would rule out the DM and pulsar explanation of the PAMELA positron excess.

Predictions for the CRE spectrum from two specific dark matter models

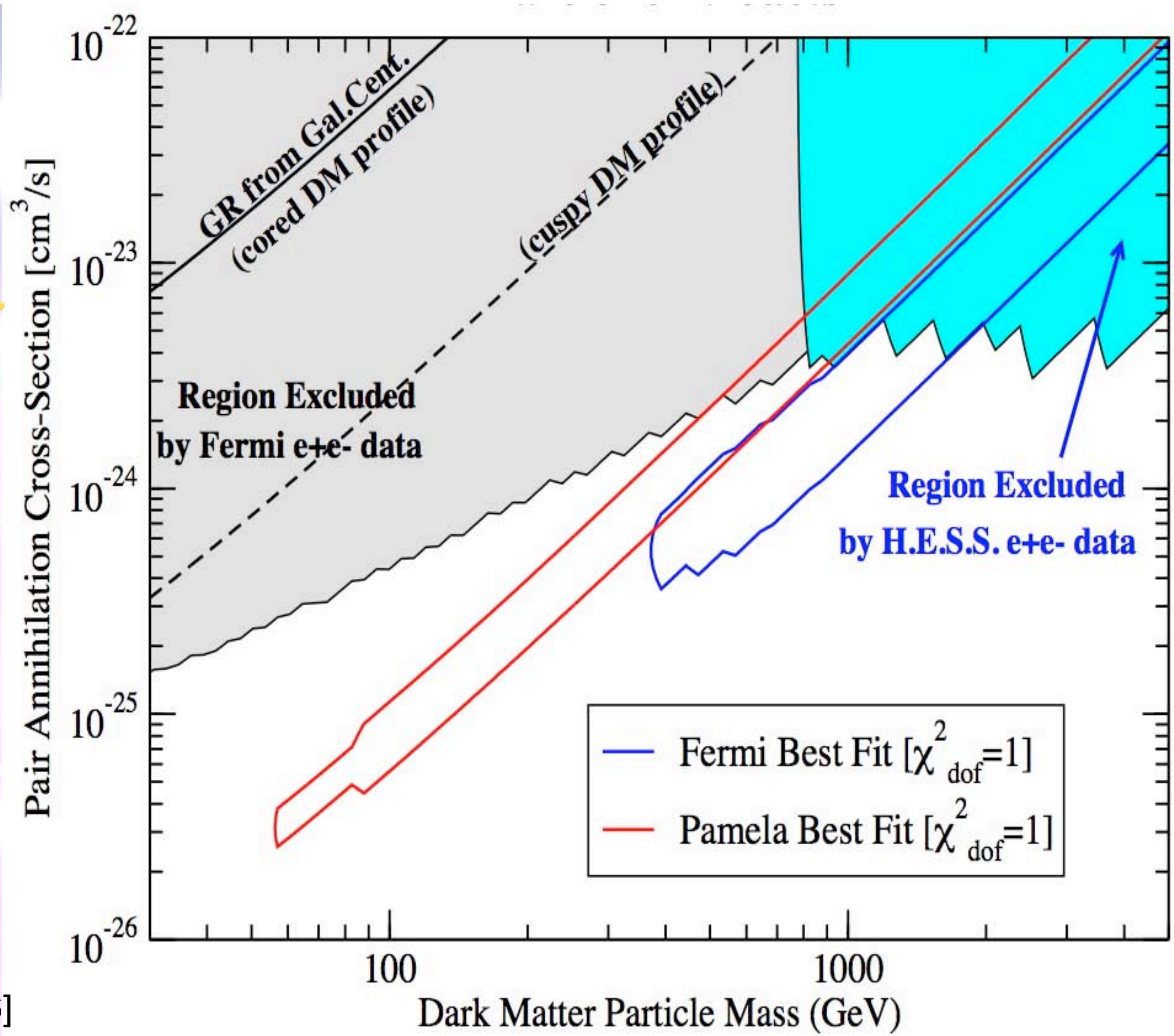


(spectrum should be folded with the Fermi energy resolution)

[arXiv:0905.0636]

Pure e+e- Models

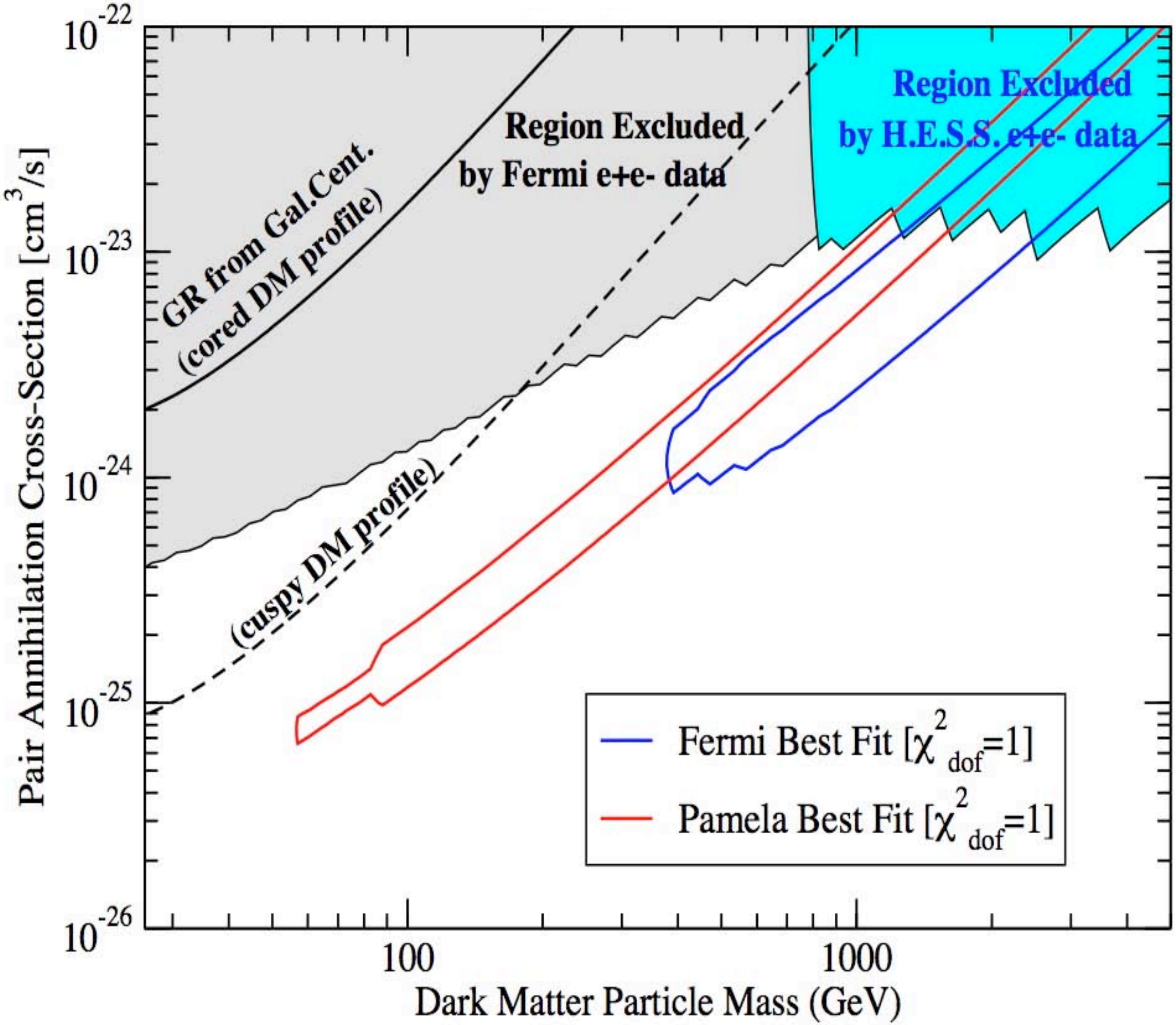
the dark matter pair annihilation always yields a pair of monochromatic e+e-, with injection energies equal to the mass of the annihilating dark matter particle



[arXiv:0905.0636]

Lepto-philic Models

here we assume a democratic dark matter pair-annihilation branching ratio into each charged lepton species: 1/3 into e+e-, 1/3 into μ+ μ- and 1/3 into τ+τ-   Here too antiprotons are not produced in dark matter pair annihilation.

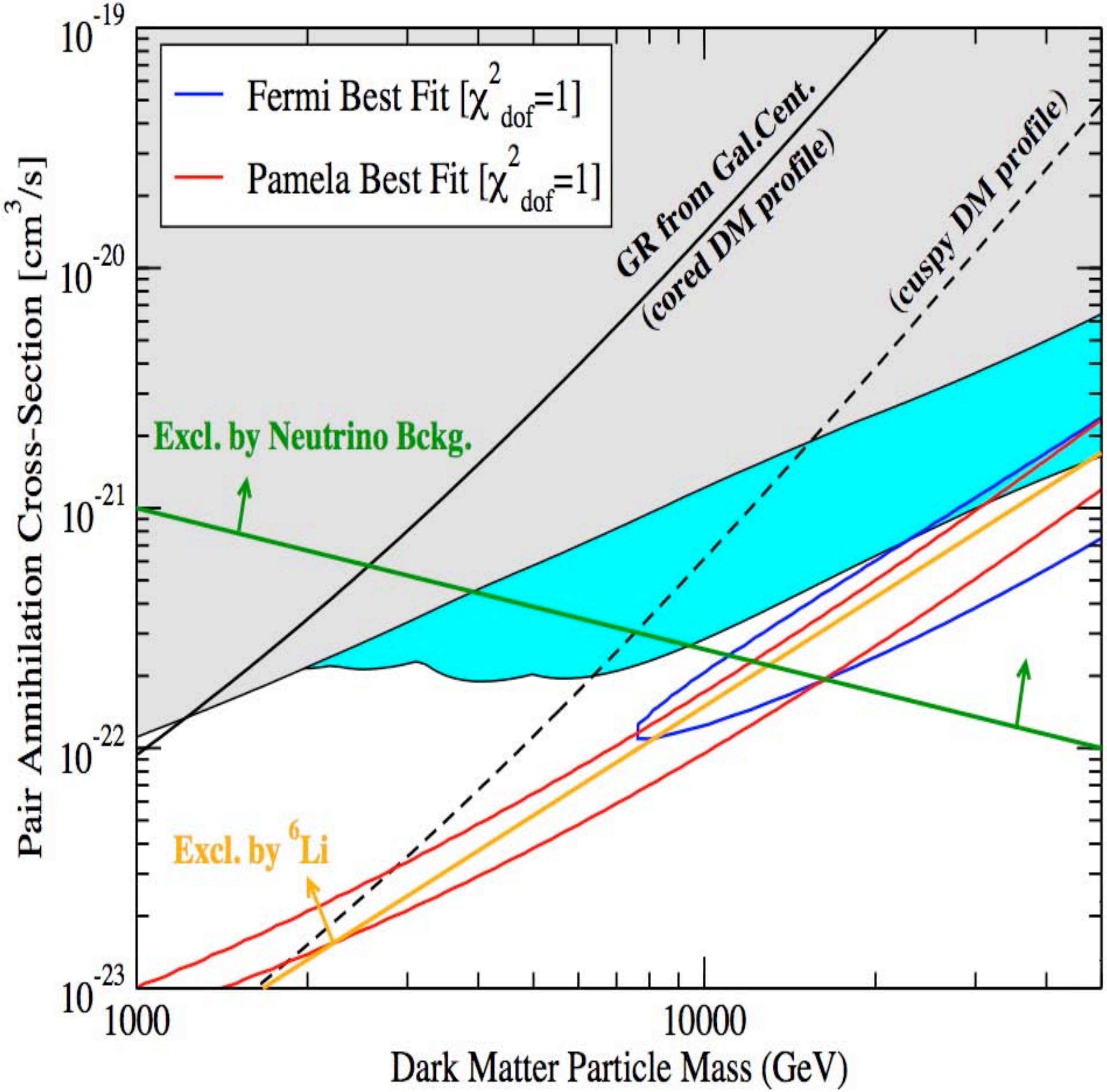


[arXiv:0905.0636]

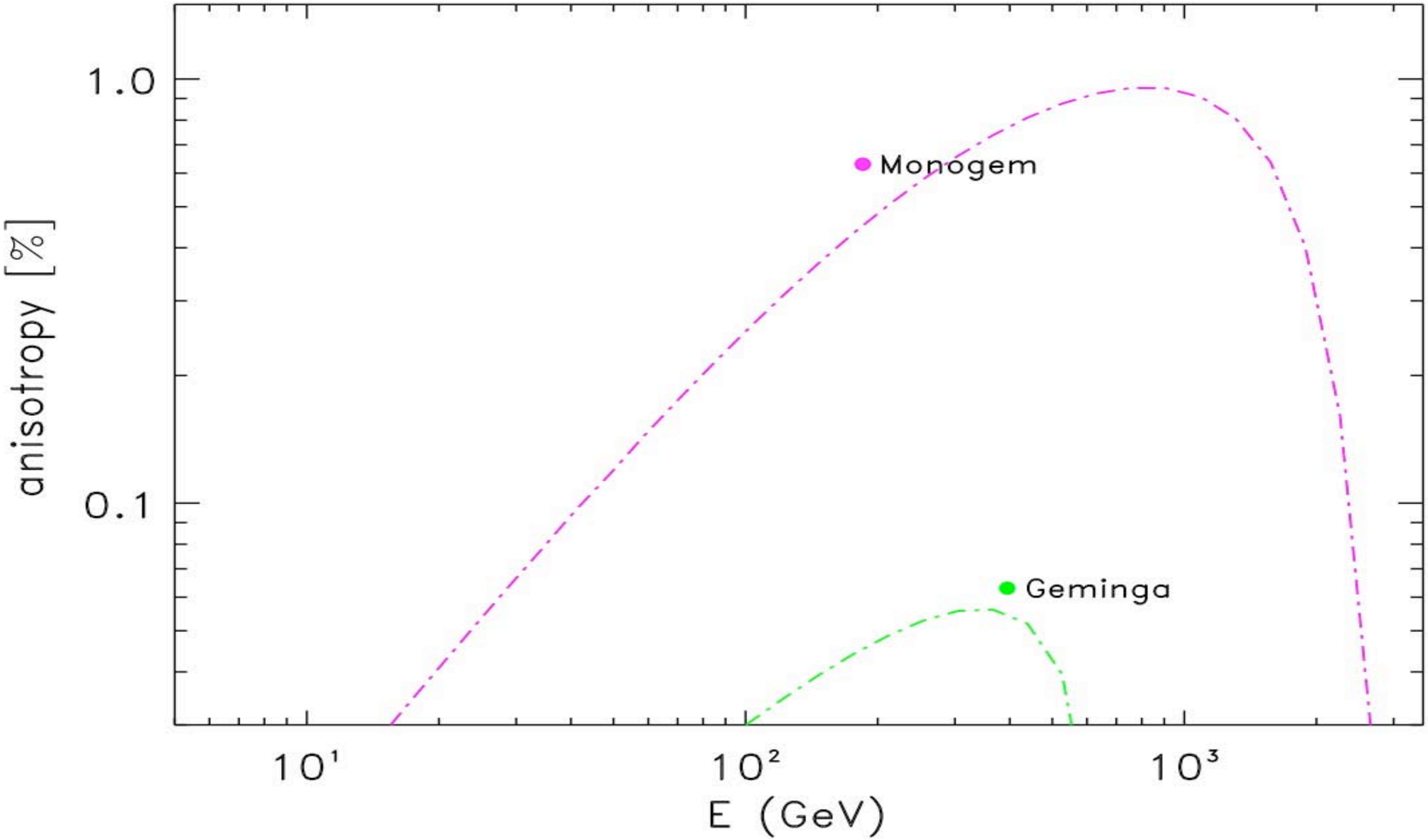
Super-heavy Models (ann. in gauge bosons)

Super-heavy dark matter models: antiprotons can be suppressed below the PAMELA measured flux if the dark matter particle is heavy (i.e. in the multi-TeV mass range), and pair annihilates e.g. in weak interaction gauge bosons. Models with super-heavy dark matter can have the right thermal relic abundance, e.g. in the context of the minimal supersymmetric extension of the Standard Model

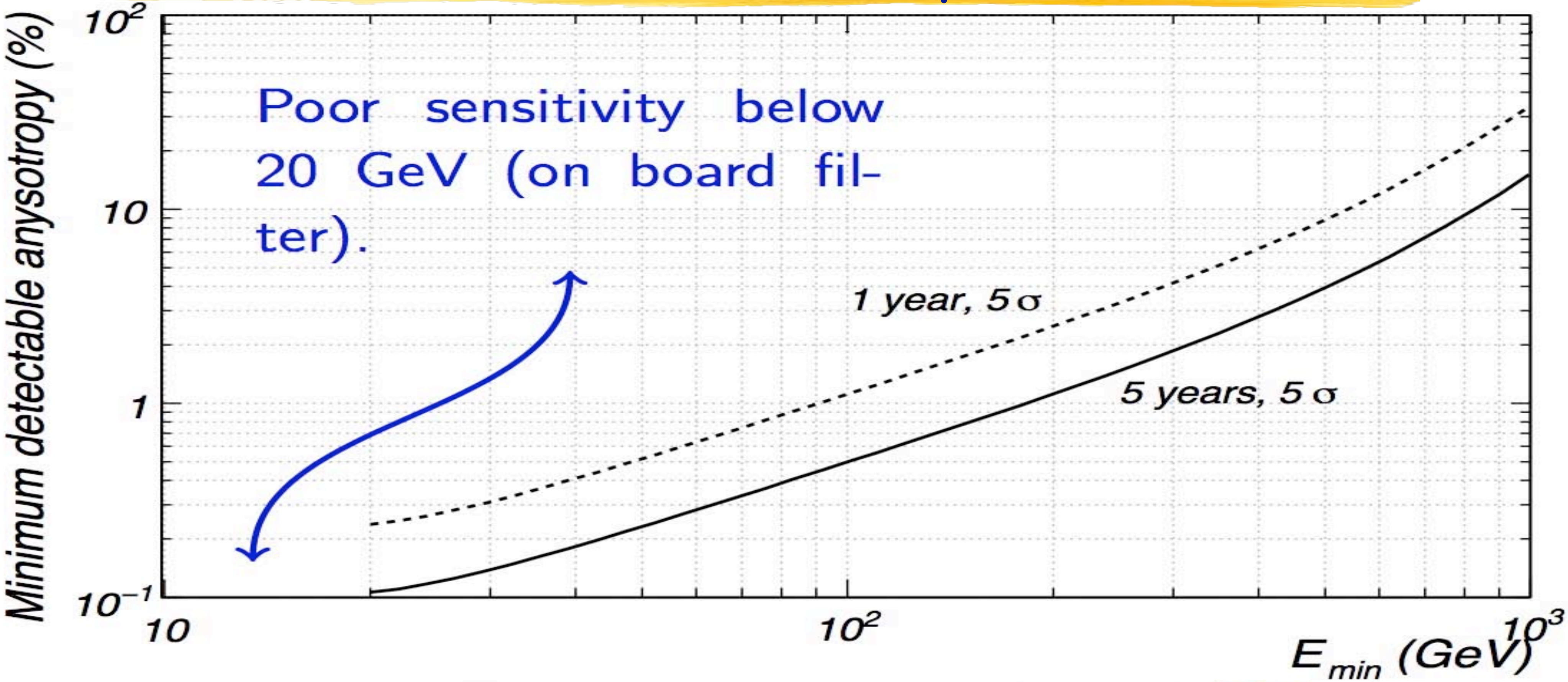
[arXiv:0905.0636]



electron + positron expected anisotropy in the directions of Monogem and Geminga



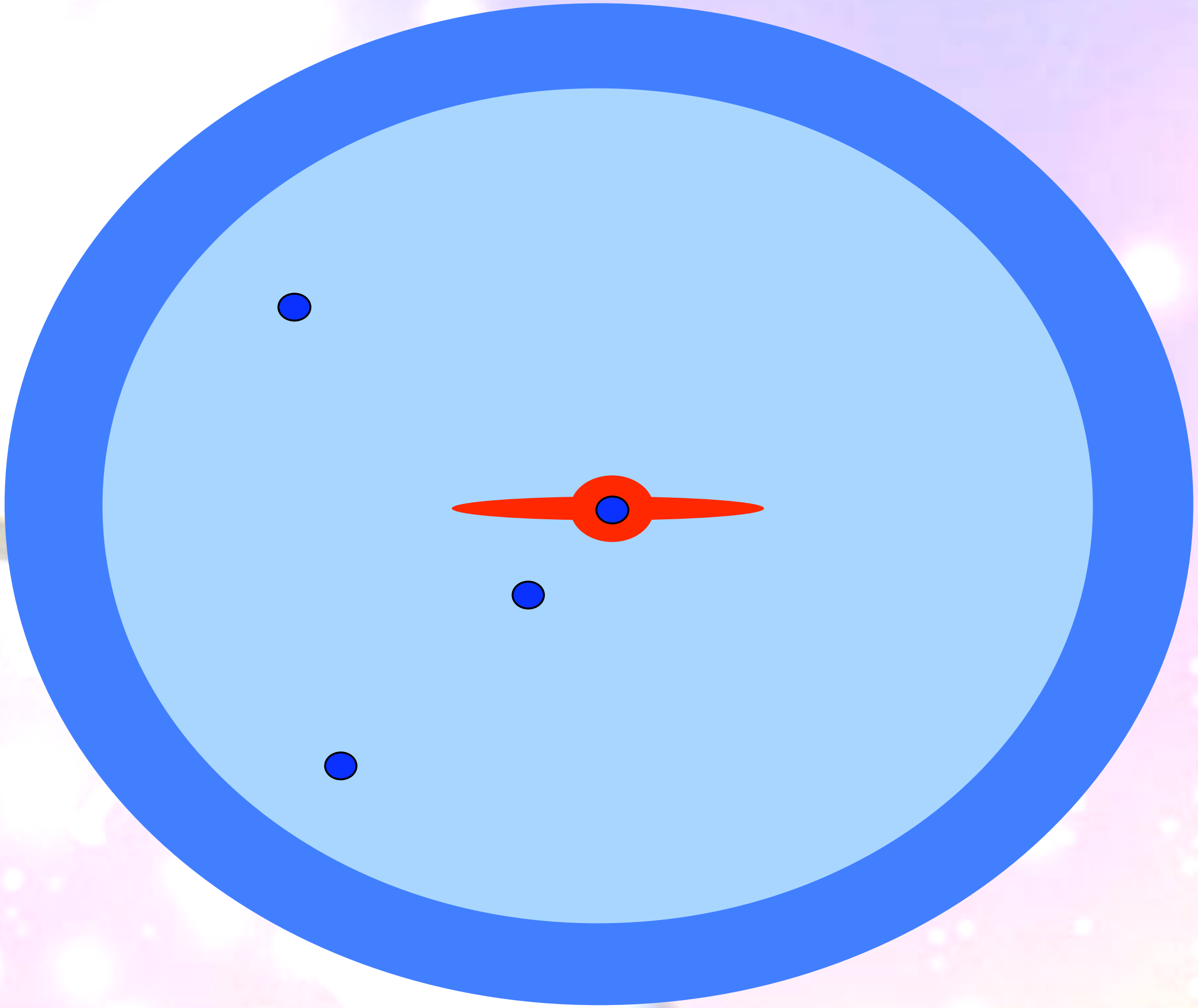
Measurement of anisotropies: statistics



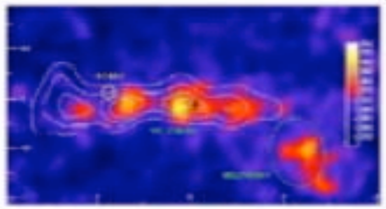
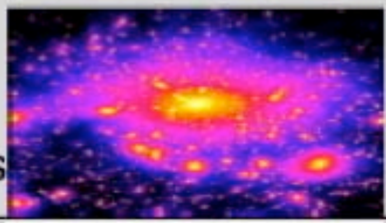
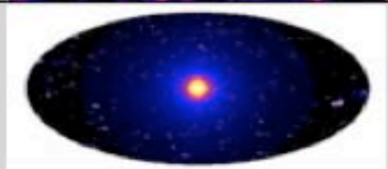
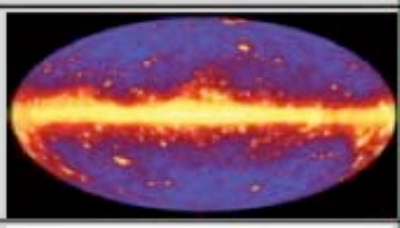
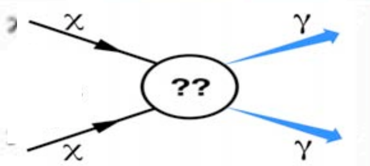
- Statistical limit for the integral anisotropy set by $\delta = \frac{\sqrt{2}N_\sigma}{\sqrt{N_{events}}}$
- The plot includes all the instrument effects:
- Energy-dependent effective geometry factor;
- Instrumental dead time and duty cycle, On board filter.
- Room for improvements with a better event selection!

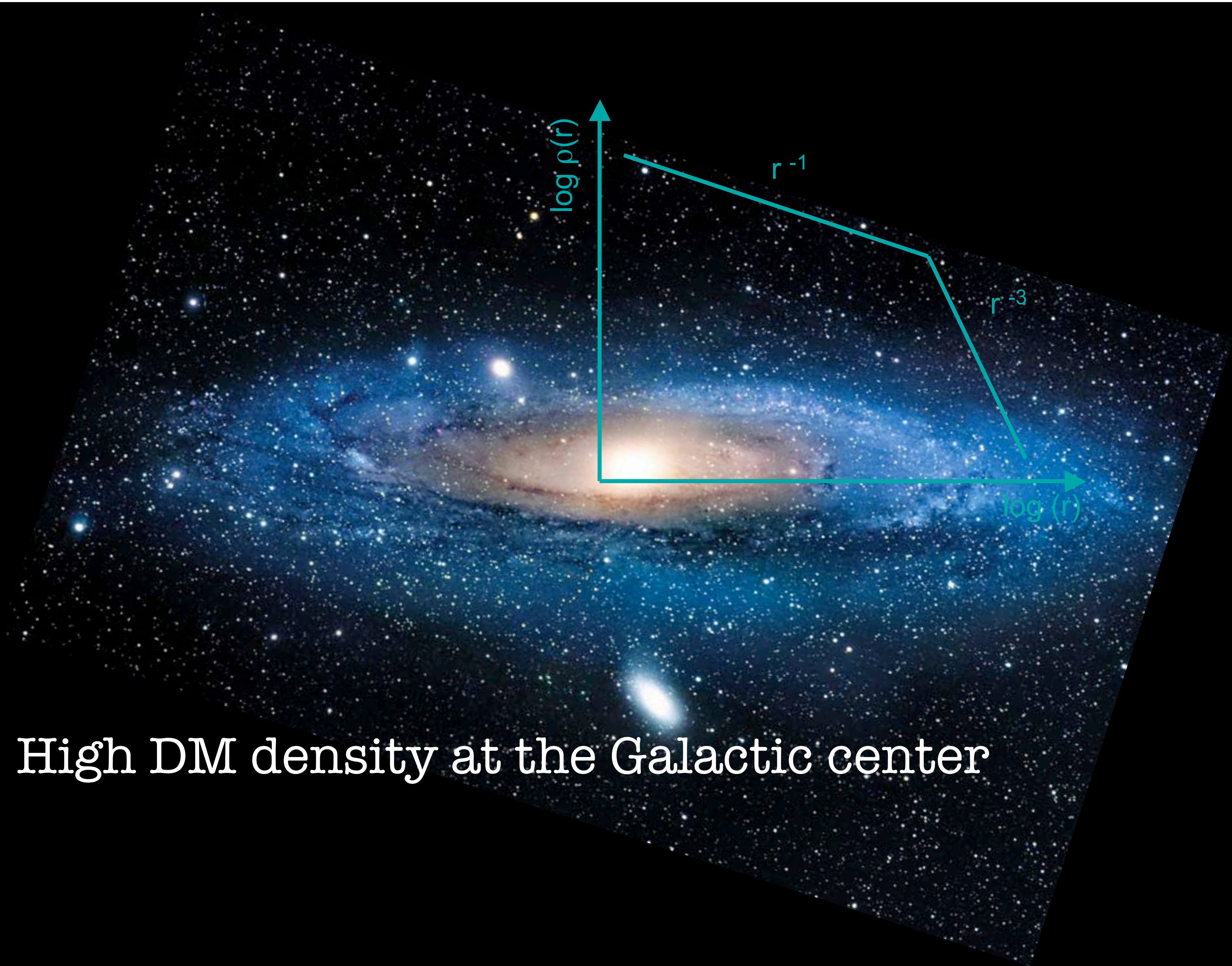
Where should we look for Dark Matter with FERMI ?

- Galactic center
- Galactic satellites
- Galactic halo
- Extra-galactic

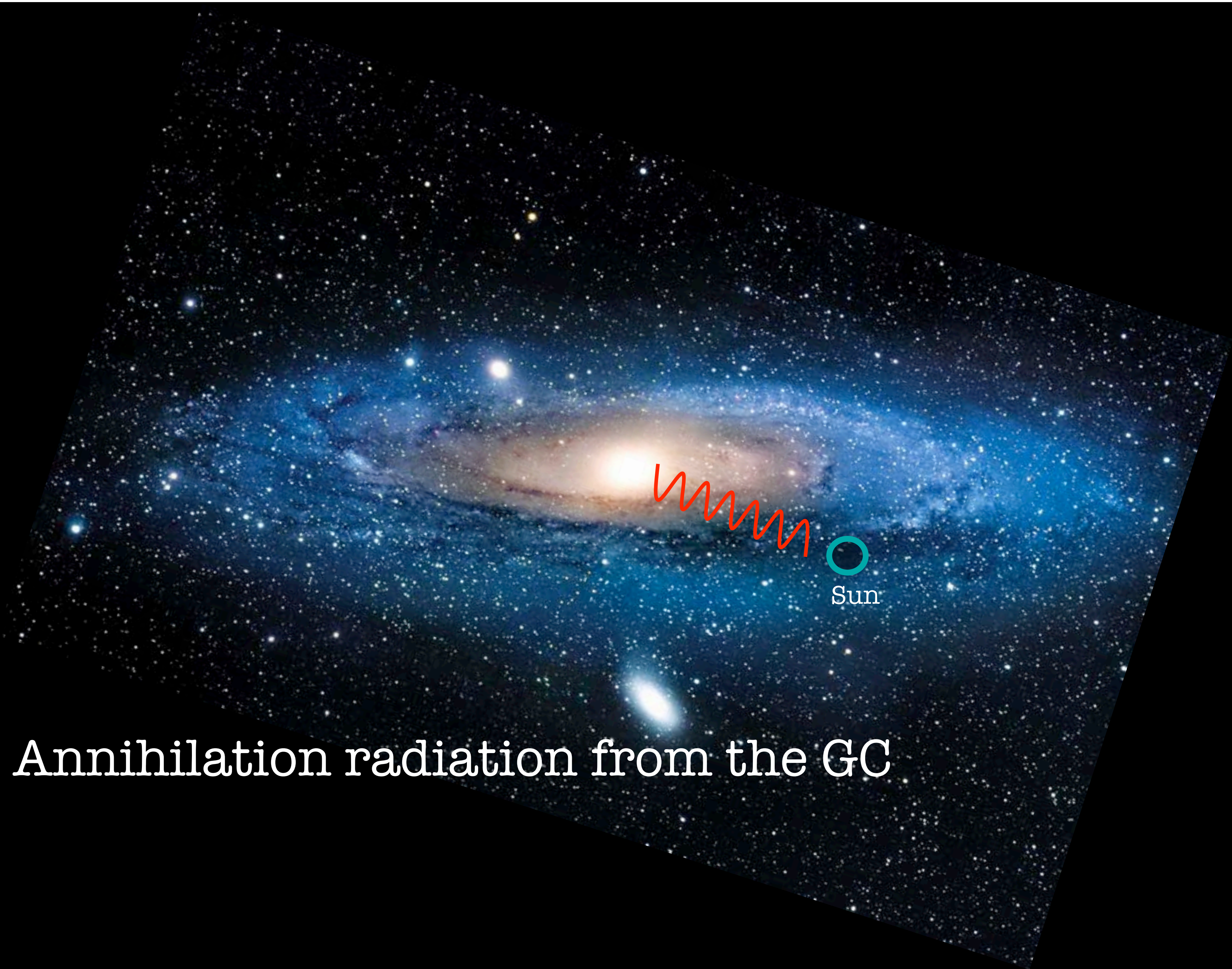


How the GLAST-LAT* telescope could help to disentangle the Dark Matter puzzle ?

Search Technique	advantages	challenges
Galactic center 	Good Statistics	Source confusion/Diffuse background
Satellites, Subhalos, Point Sources 	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



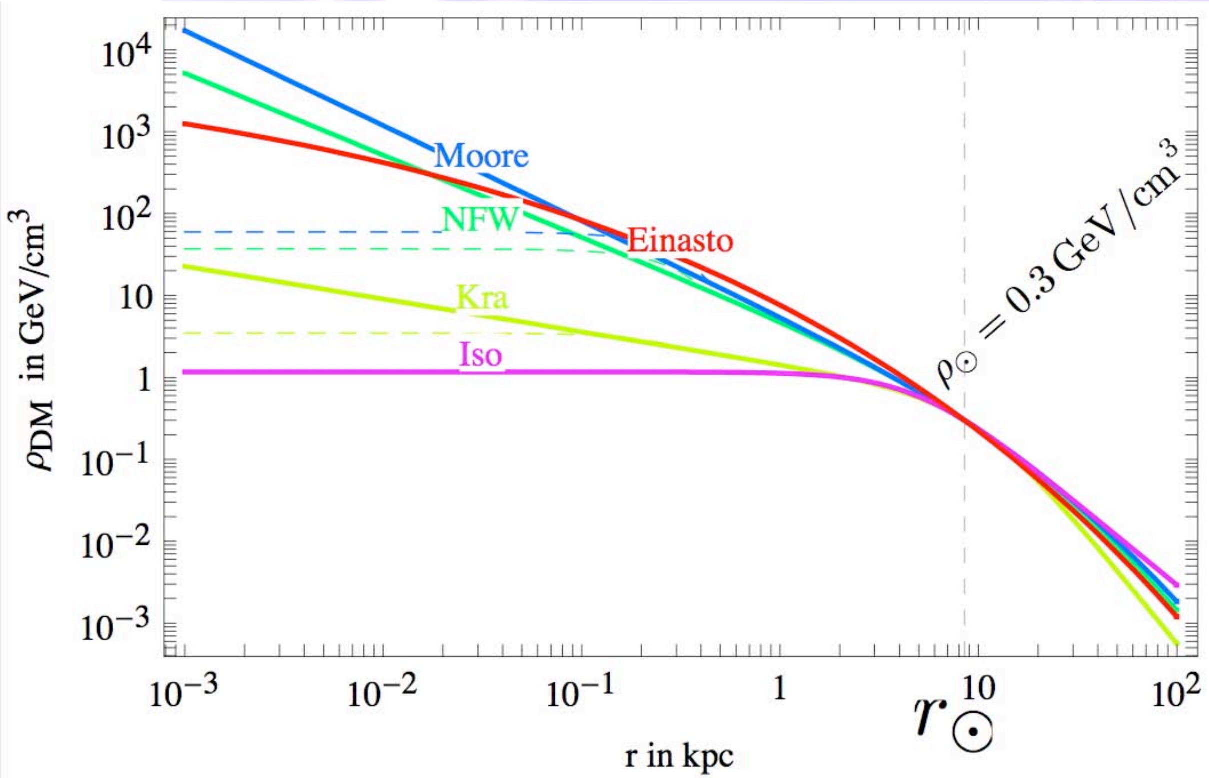
High DM density at the Galactic center



Annihilation radiation from the GC

The Galactic Center possible profiles

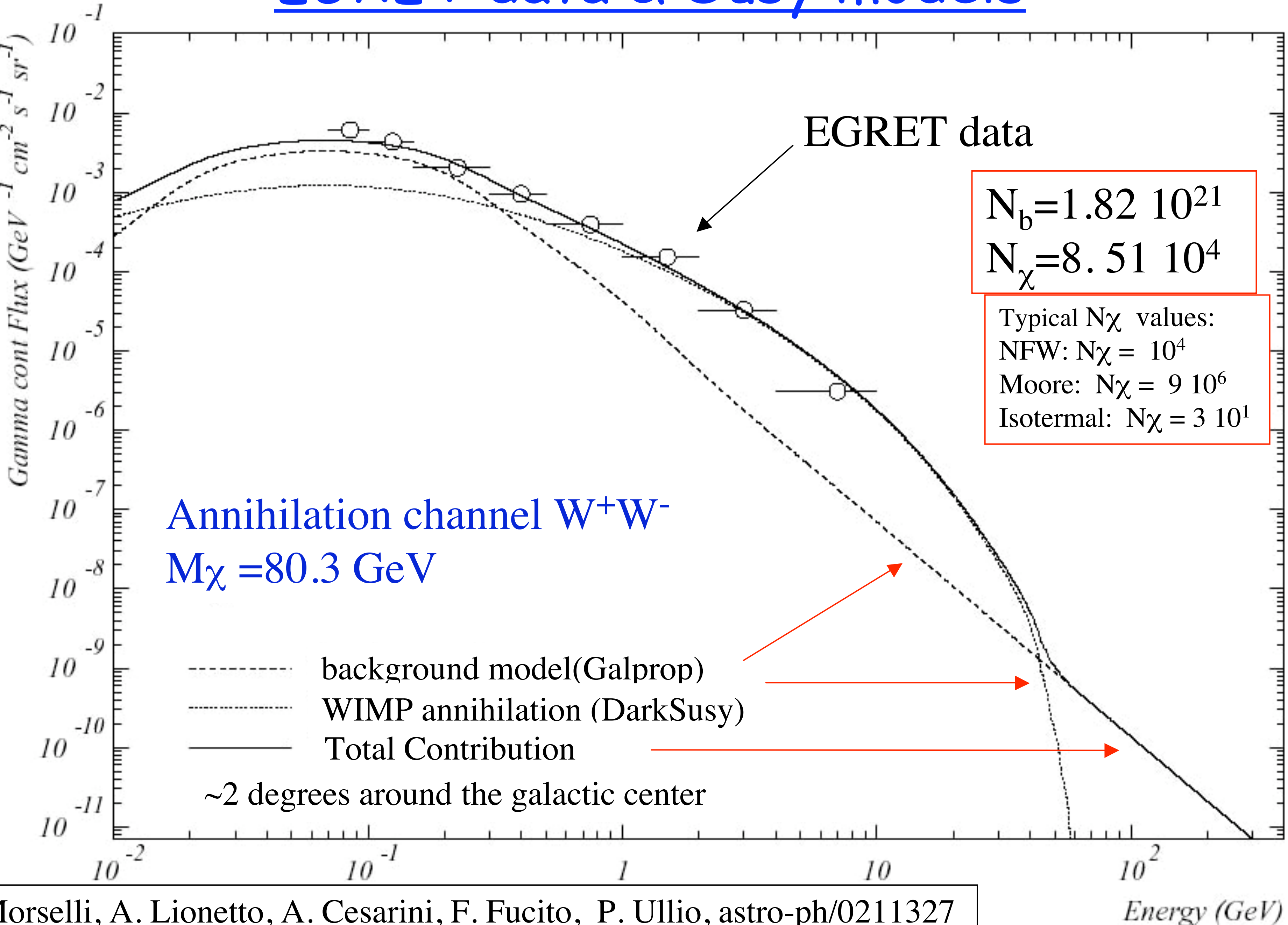
$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+(r_\odot/r_s)^\alpha}{1+(r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$



Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

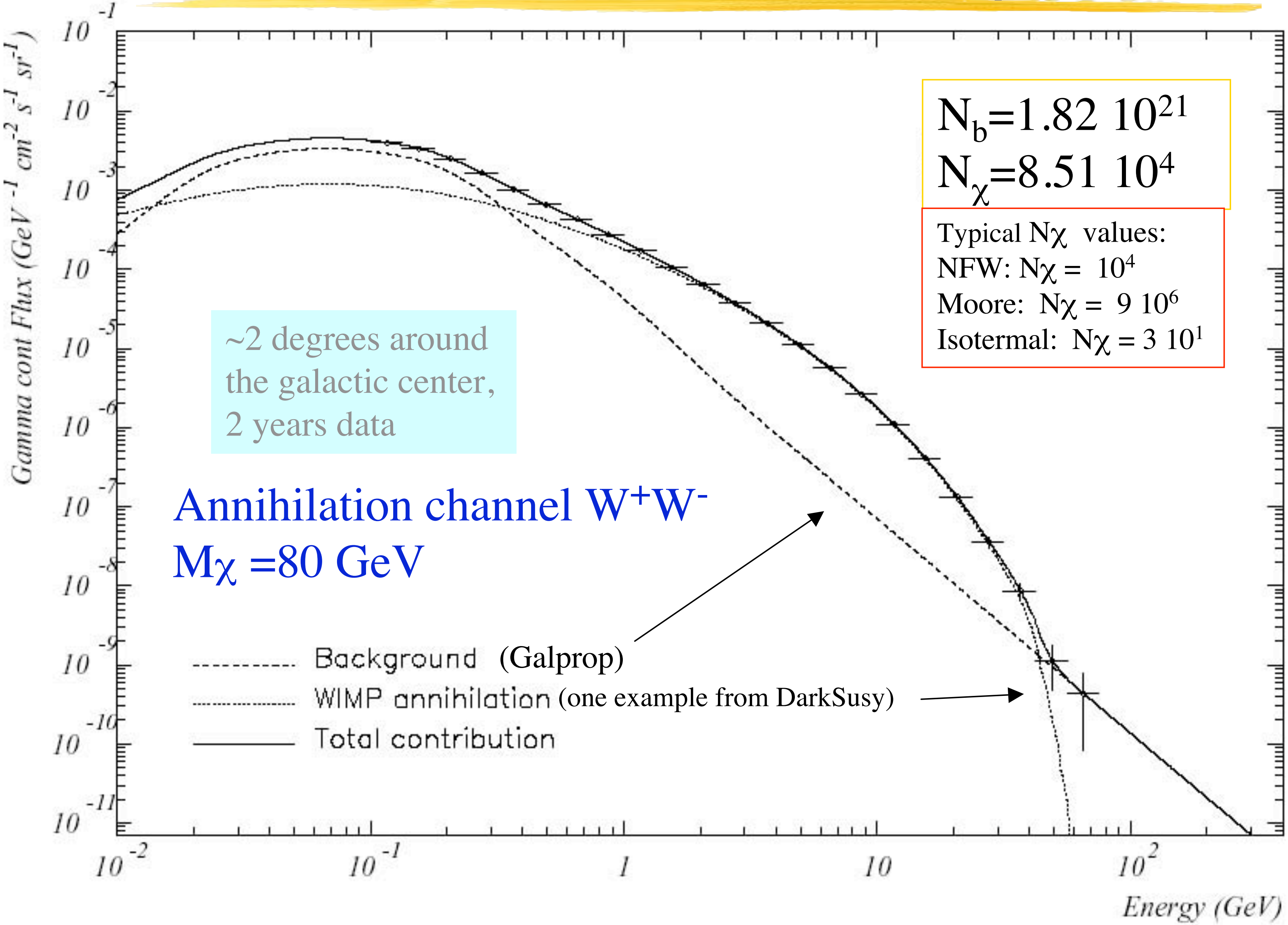
Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$

EGRET data & Susy models



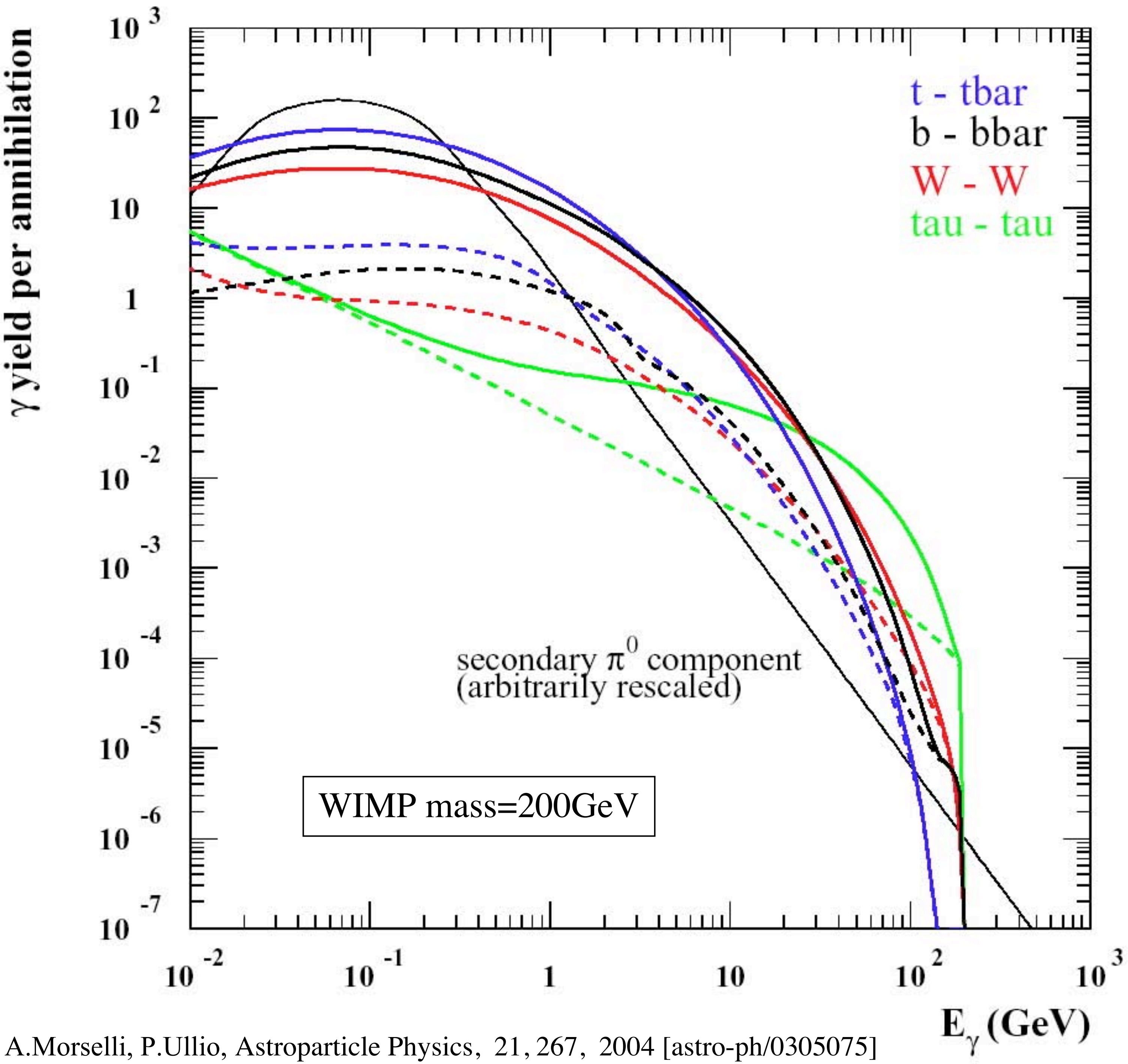
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327

Fermi Expectation & Susy models



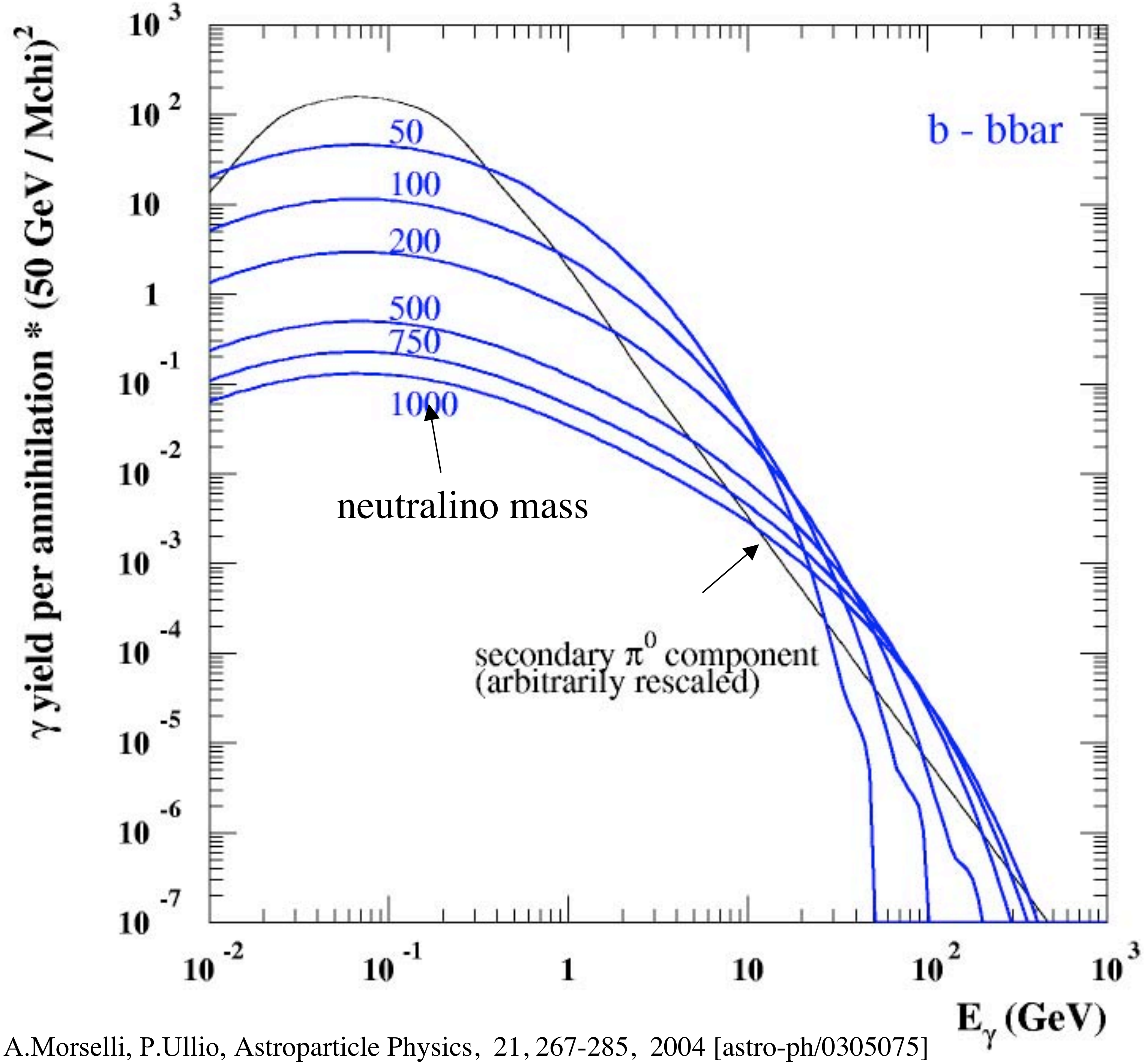
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, June 2004 [astro-ph/0305075]

Differential yield for each annihilation channel



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

Differential yield for b bar

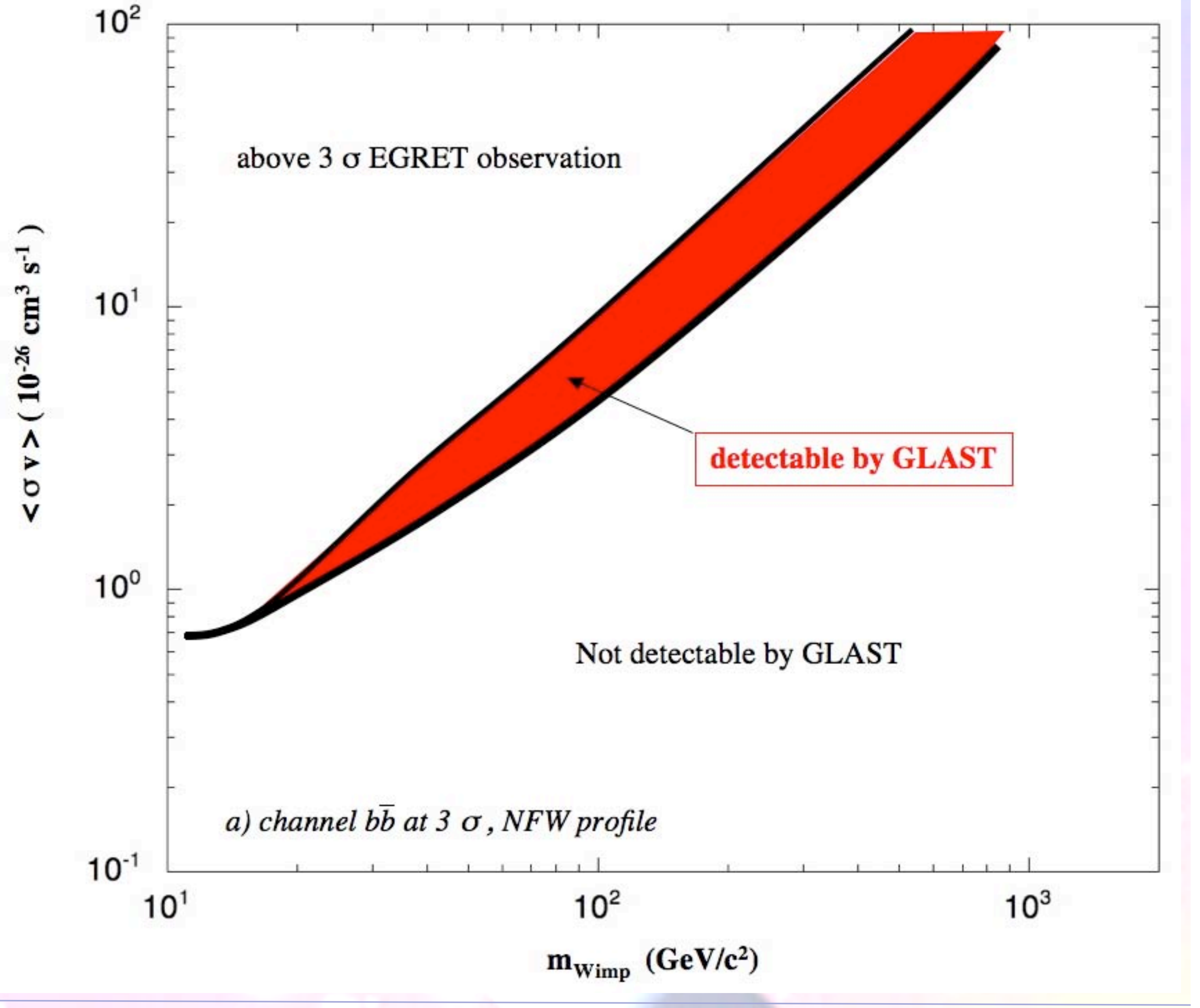


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 [astro-ph/0305075]

Model independent results for the GC

after the Fermi Galactic Diffuse Emission data

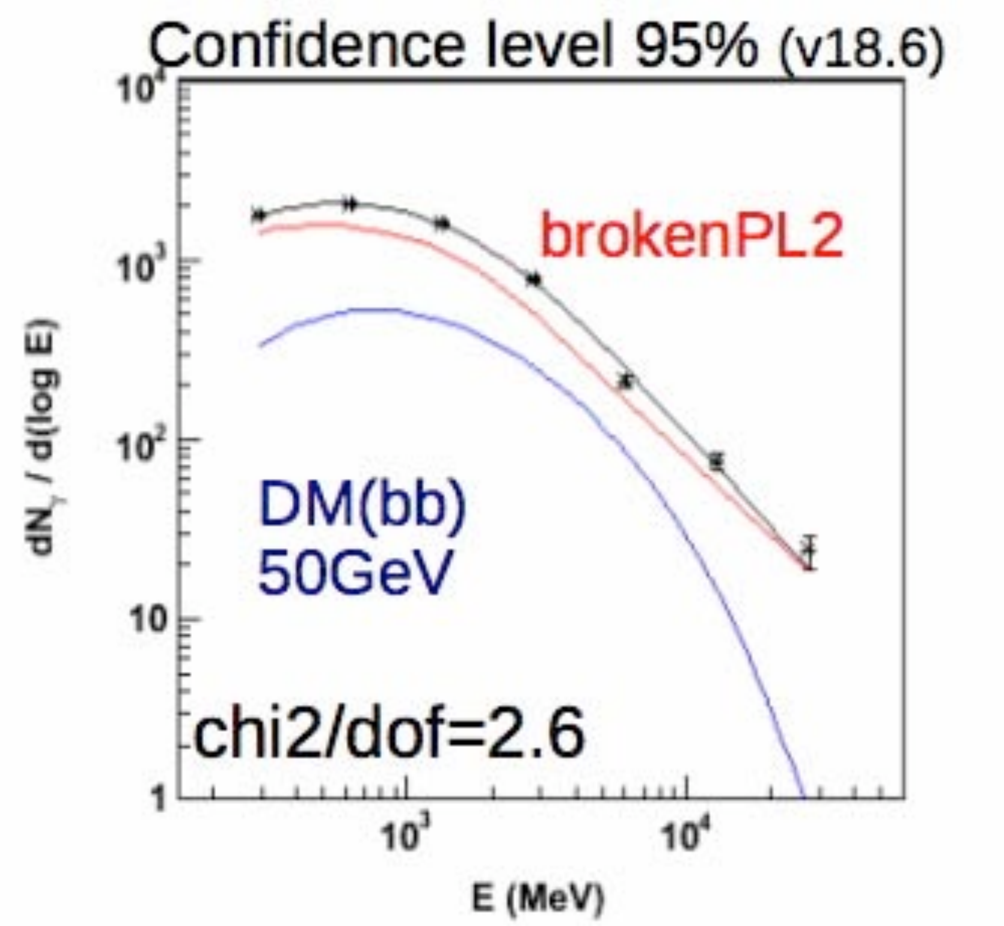
5 years of operations, truncated NFW



upated from arXiv:0806.2911

Upper limit for DM flux (100MeV-50GeV) and DM cross section (100Me 50GeV)

Vincenzo Vitale Friday



Confidence level 95% (v18.6)
flux(DM) = 3.05 * 10^{-6} cm^{-2} s^{-1}
σ v (DM) = 4.99 * $10^{-24}$$cm^{-2}$$s^{-1}$

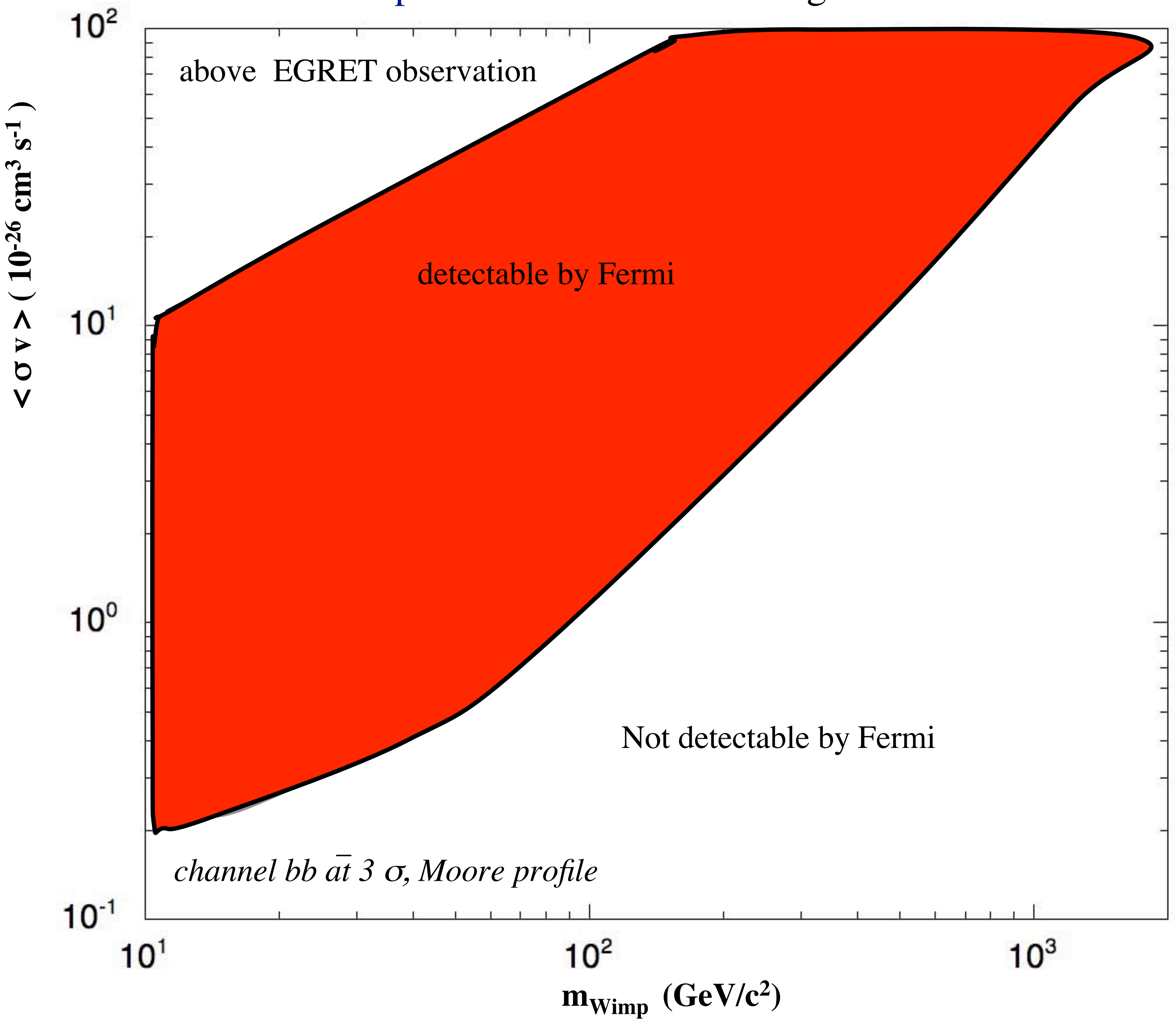
Confidence level 99% (v18.8)
flux(DM) = 4.26 * 10^{-6} cm^{-2} s^{-1}
σ v (DM) = 6.97 * $10^{-24}$$cm^{-2}$$s^{-1}$

The given upper limits for Dark Matter are conservative ones.

Vincenzo Vitale and Aldo Morselli for the Fermi Lat Collaboration, ICRC09

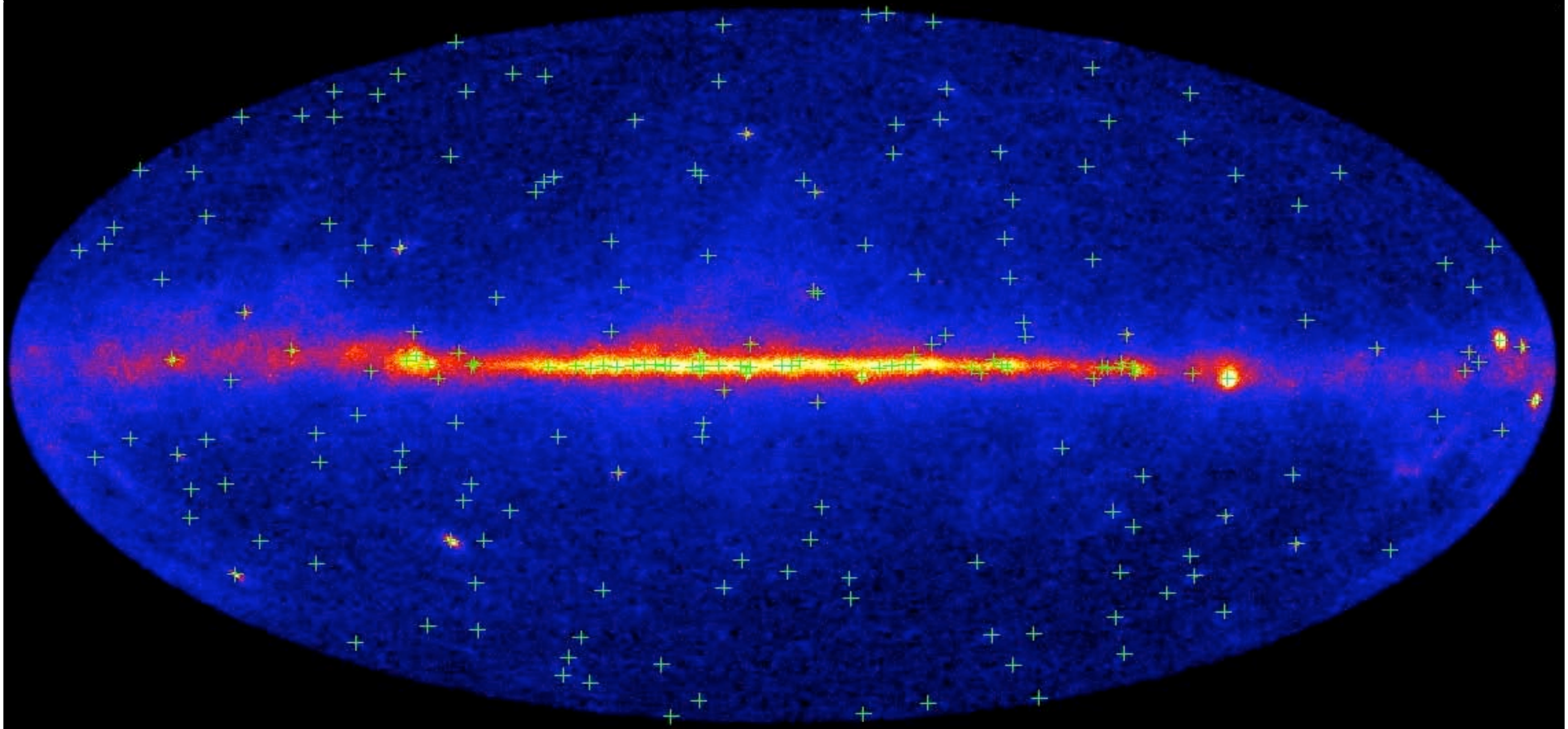
Model independent results for the Sagittarius Dwarft

after the Fermi Galactic Diffuse Emission data



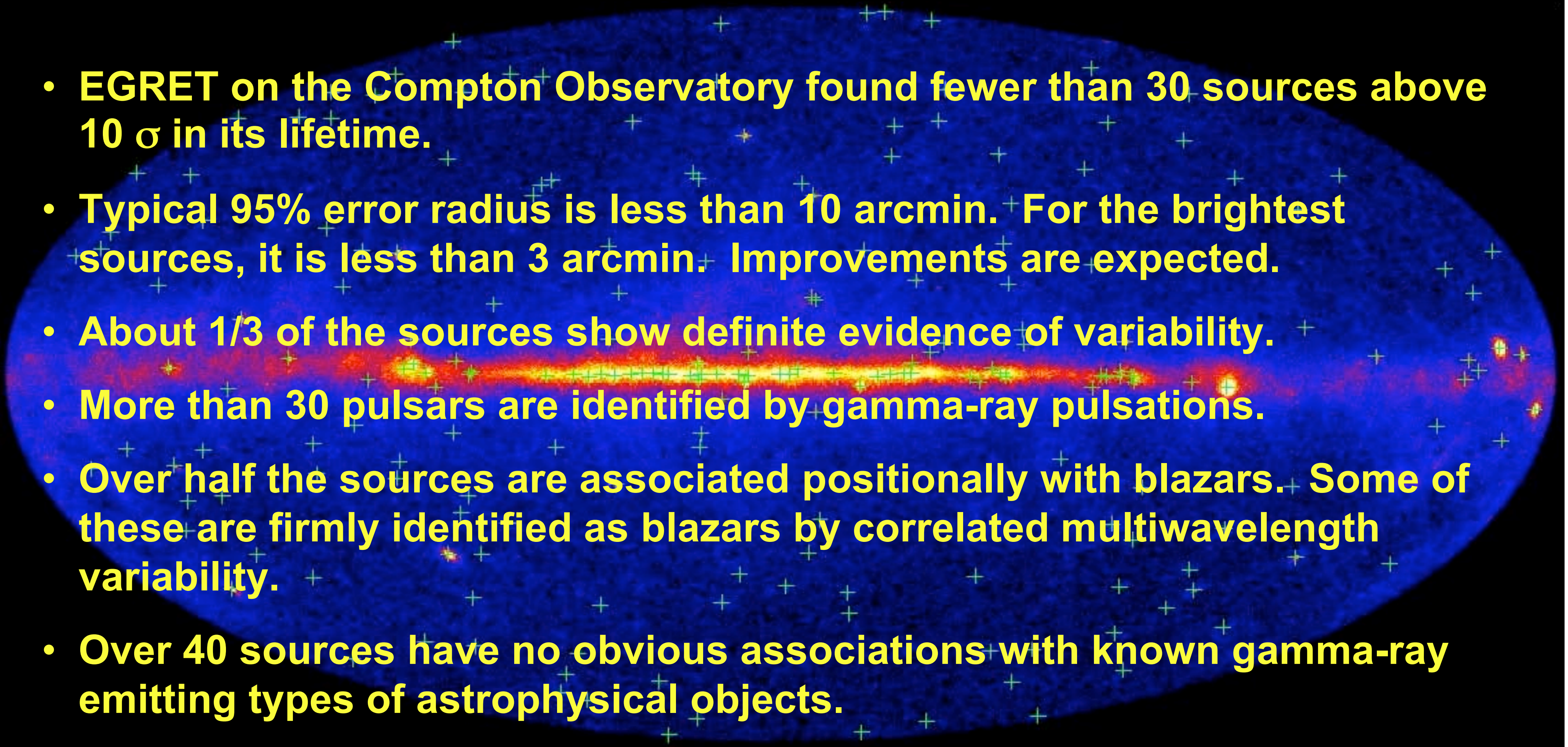
upated from arXiv:0806.2911

205 Preliminary Fermi LAT Bright Sources



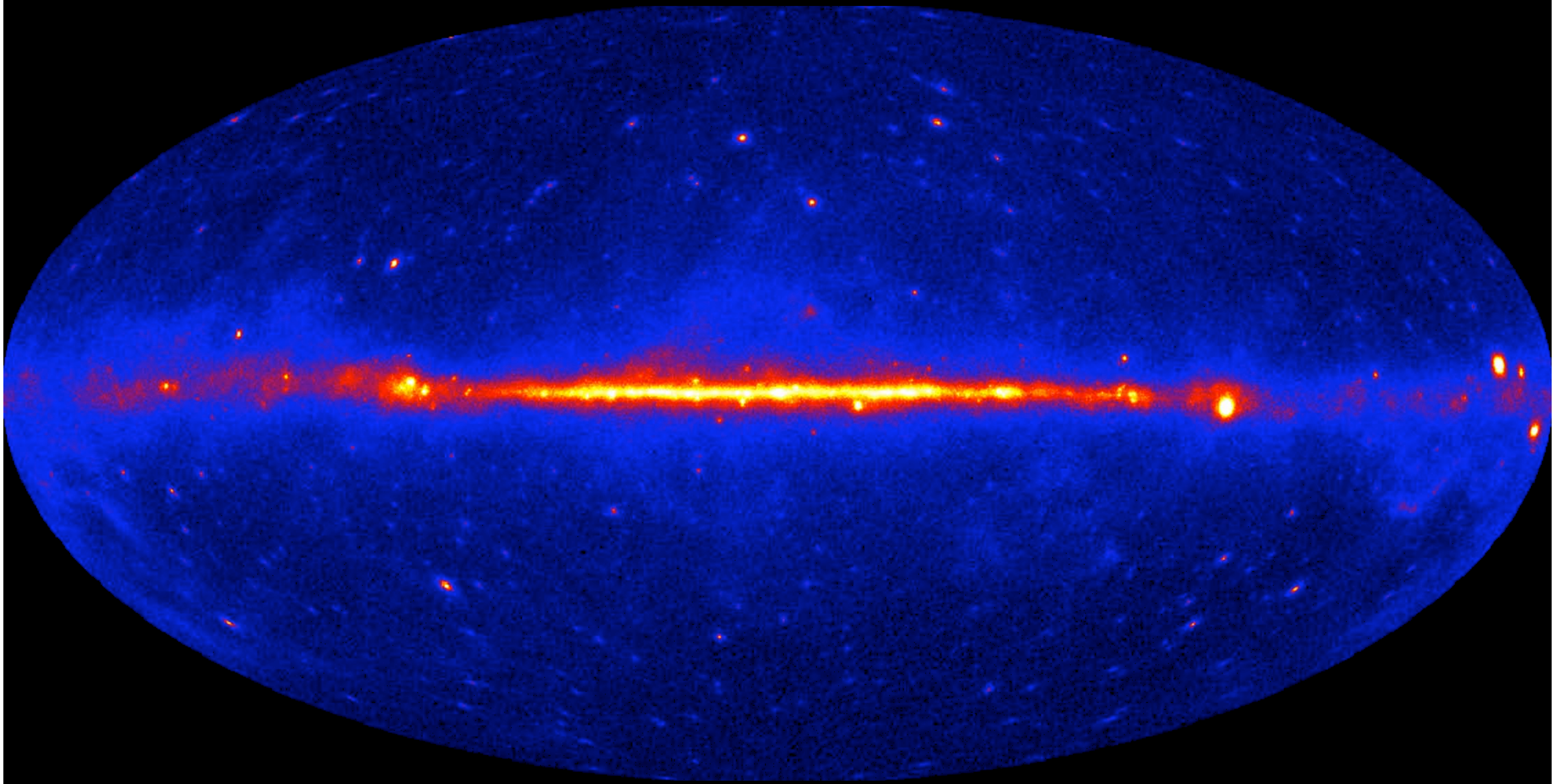
Crosses mark source locations, in Galactic coordinates.

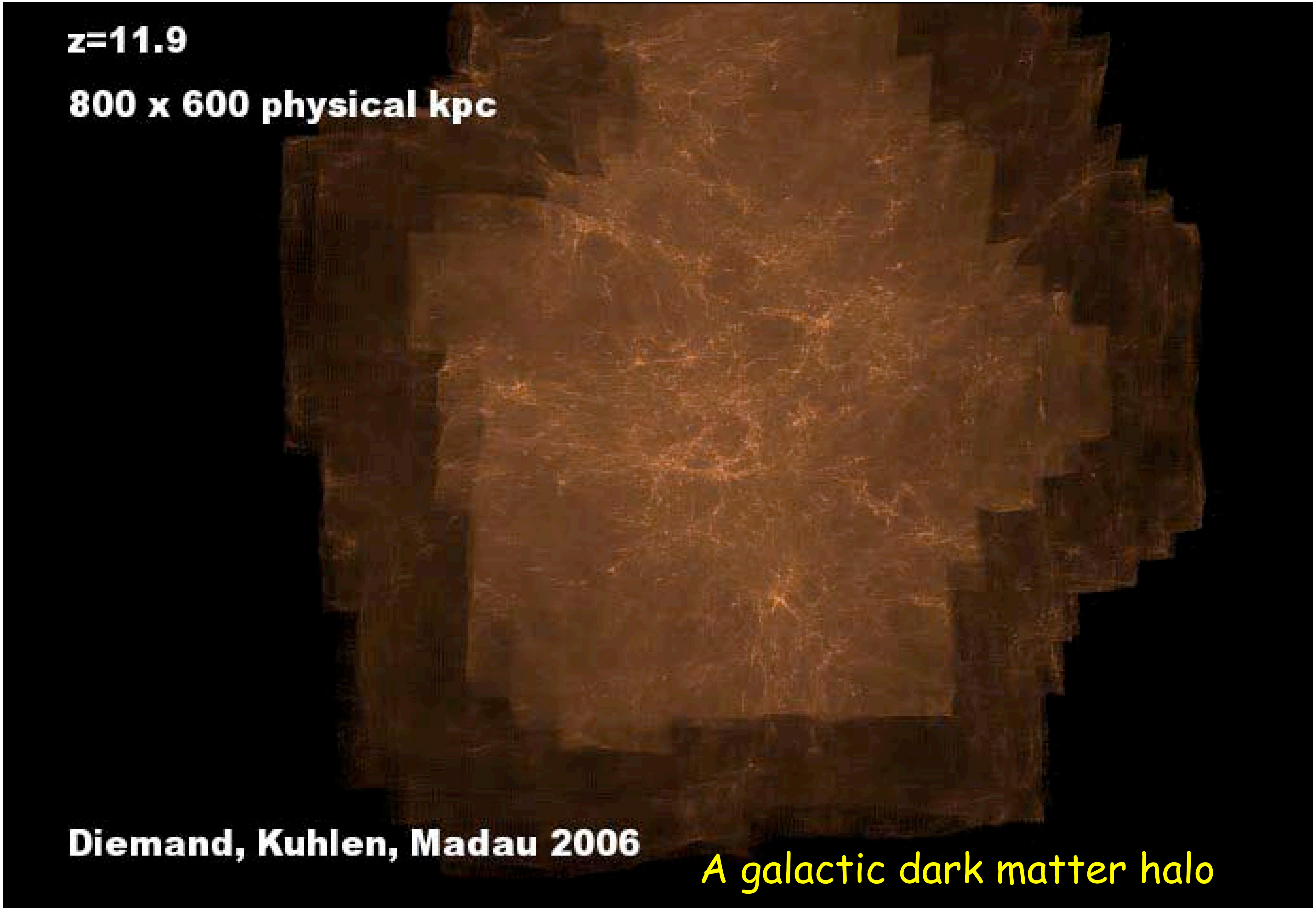
205 Preliminary LAT Bright Sources - Some Information



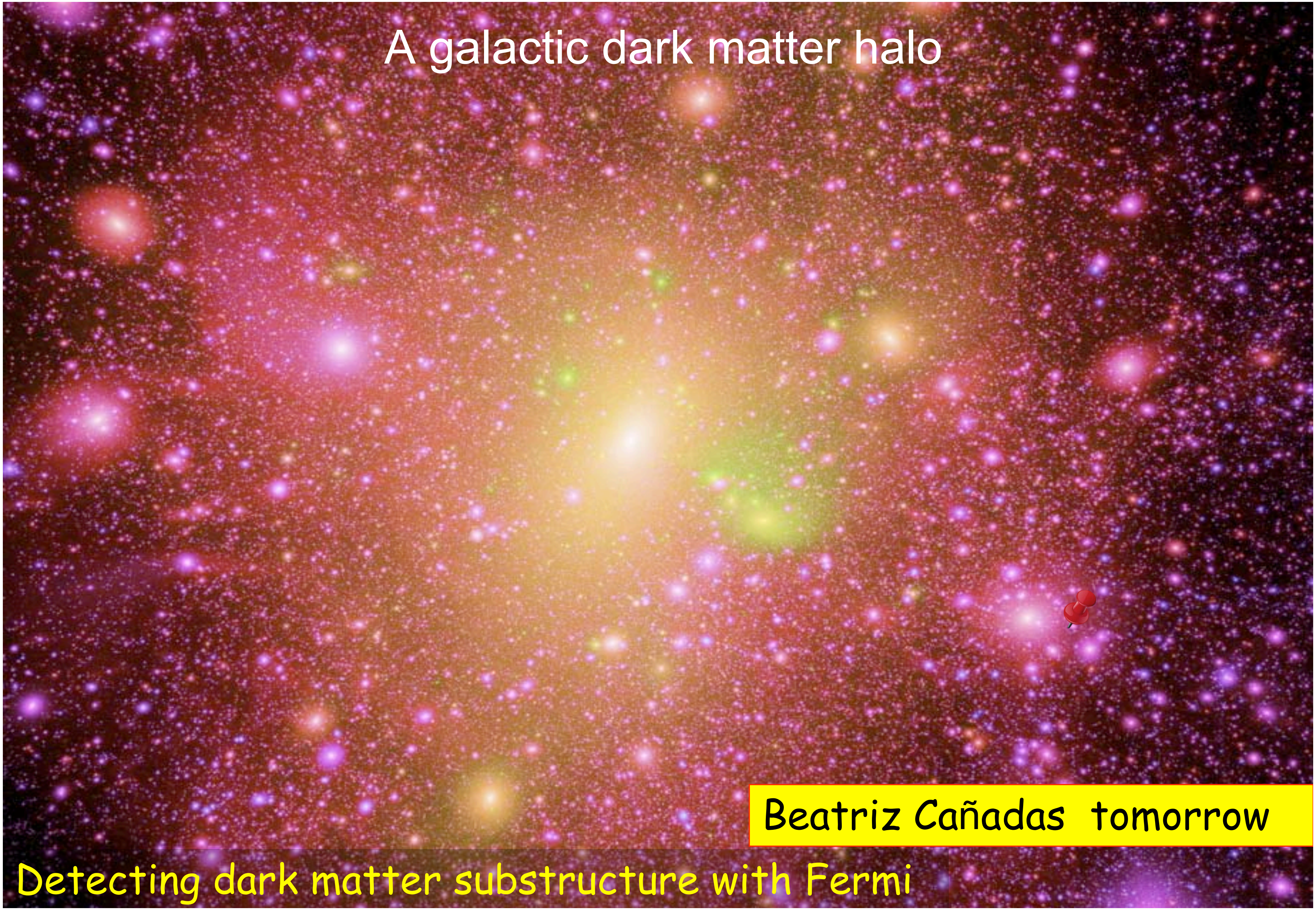
- **EGRET on the Compton Observatory found fewer than 30 sources above 10 σ in its lifetime.**
- **Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.**
- **About 1/3 of the sources show definite evidence of variability.**
- **More than 30 pulsars are identified by gamma-ray pulsations.**
- **Over half the sources are associated positionally with blazars. Some of these are firmly identified as blazars by correlated multiwavelength variability.**
- **Over 40 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.**

9 month observation

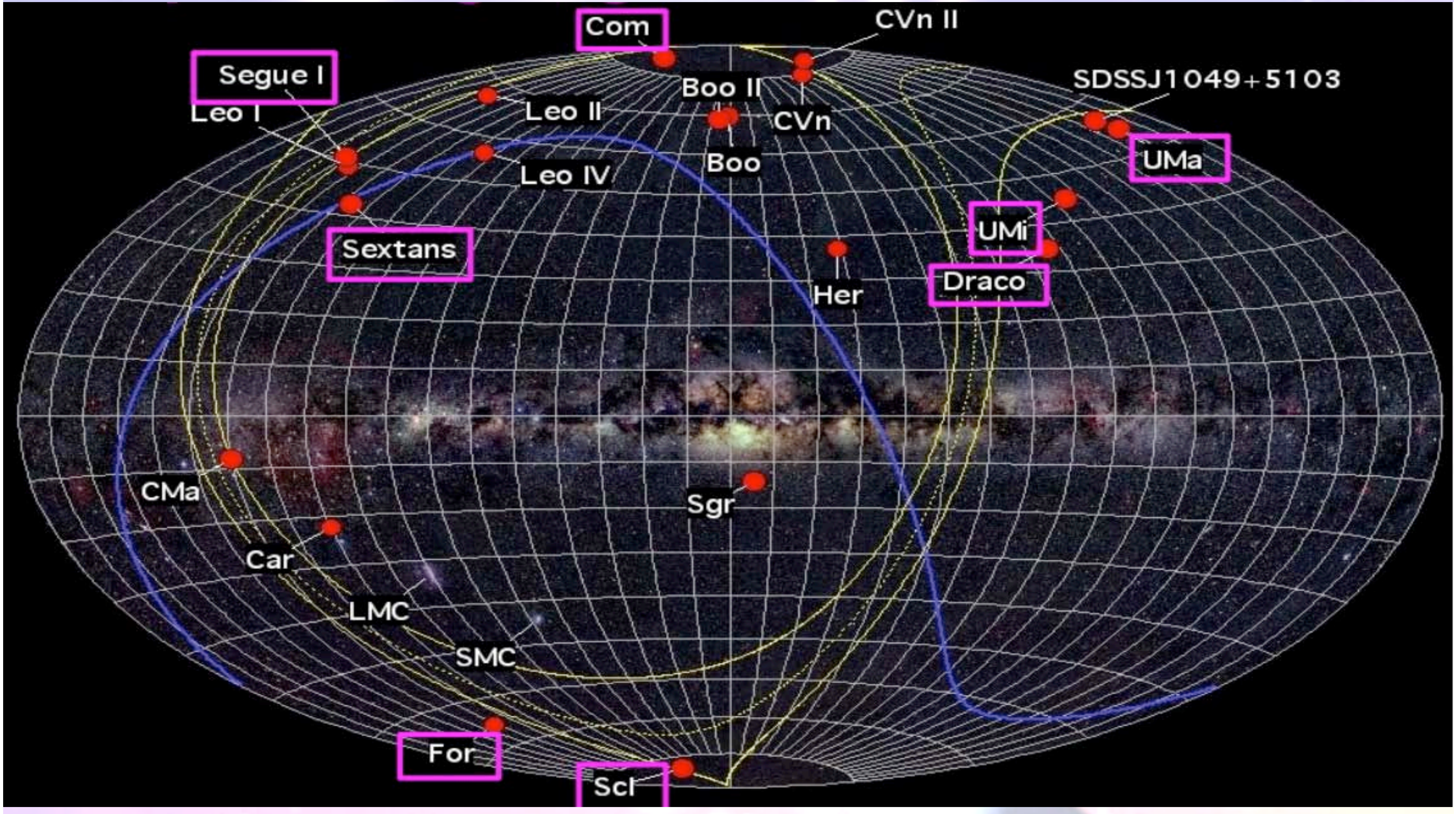




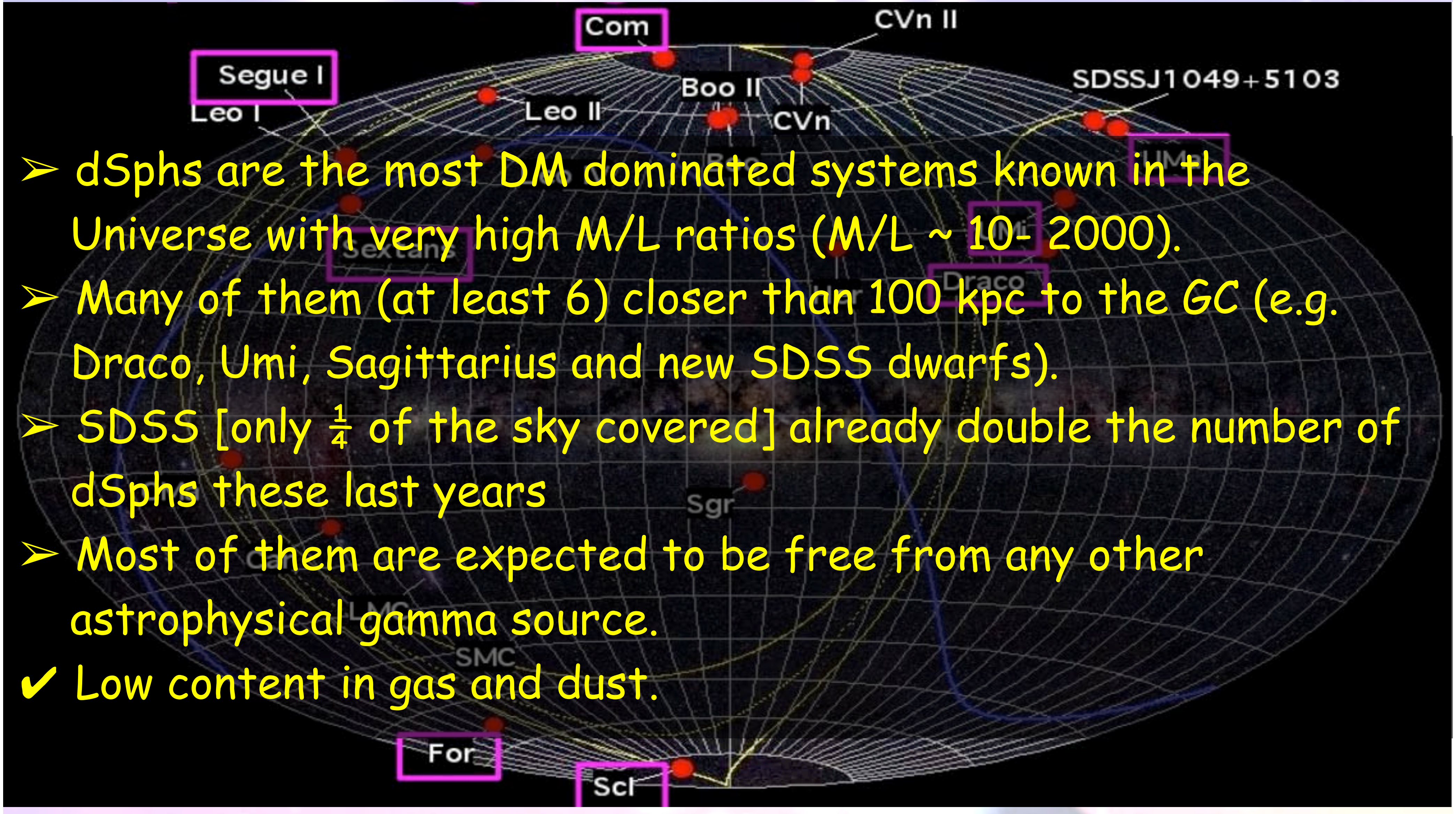
A galactic dark matter halo


A galactic dark matter halo
Beatriz Cañadas tomorrow
Detecting dark matter substructure with Fermi

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

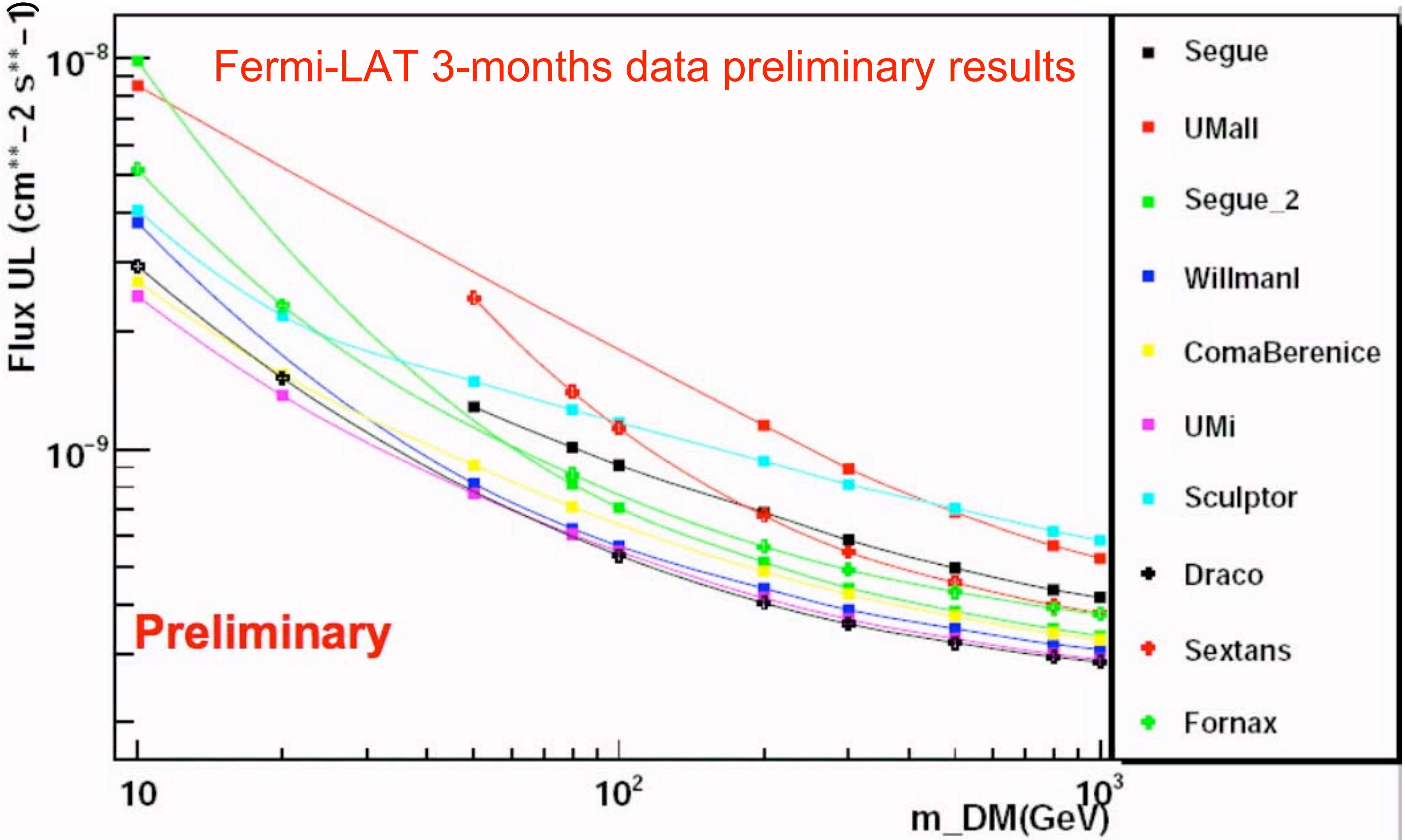


Dwarf spheroidal galaxies (dSph) : promising targets for DM detection

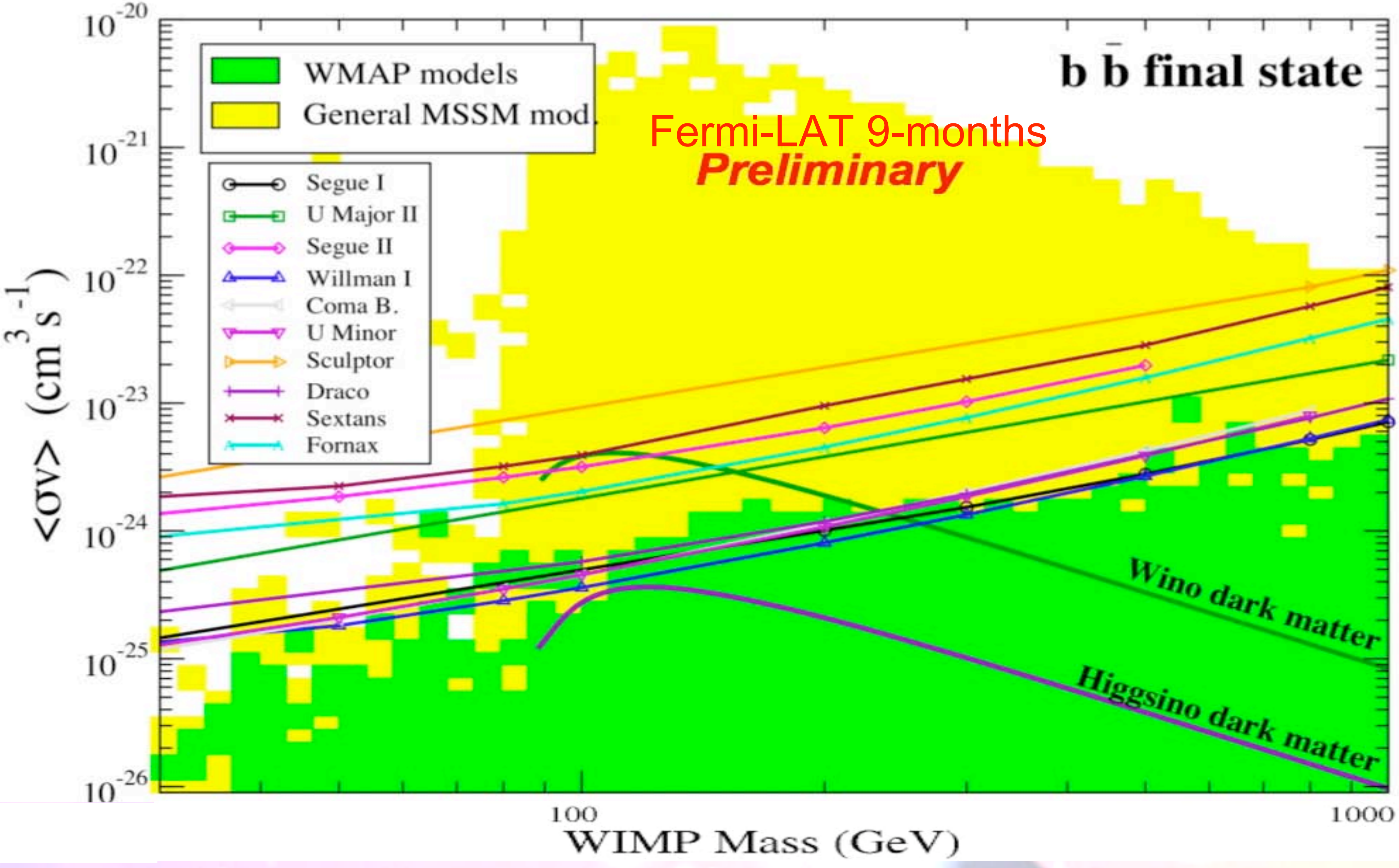


- ➢ dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- ➢ Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- ➢ SDSS [only ¼ of the sky covered] already double the number of dSphs these last years
- ➢ Most of them are expected to be free from any other astrophysical gamma source.
- ✔ Low content in gas and dust.

Dwarf Spheroidal Galaxies upper-limits



Annihilation cross-section upper-limits in Dwarf Spheroidal Galaxies



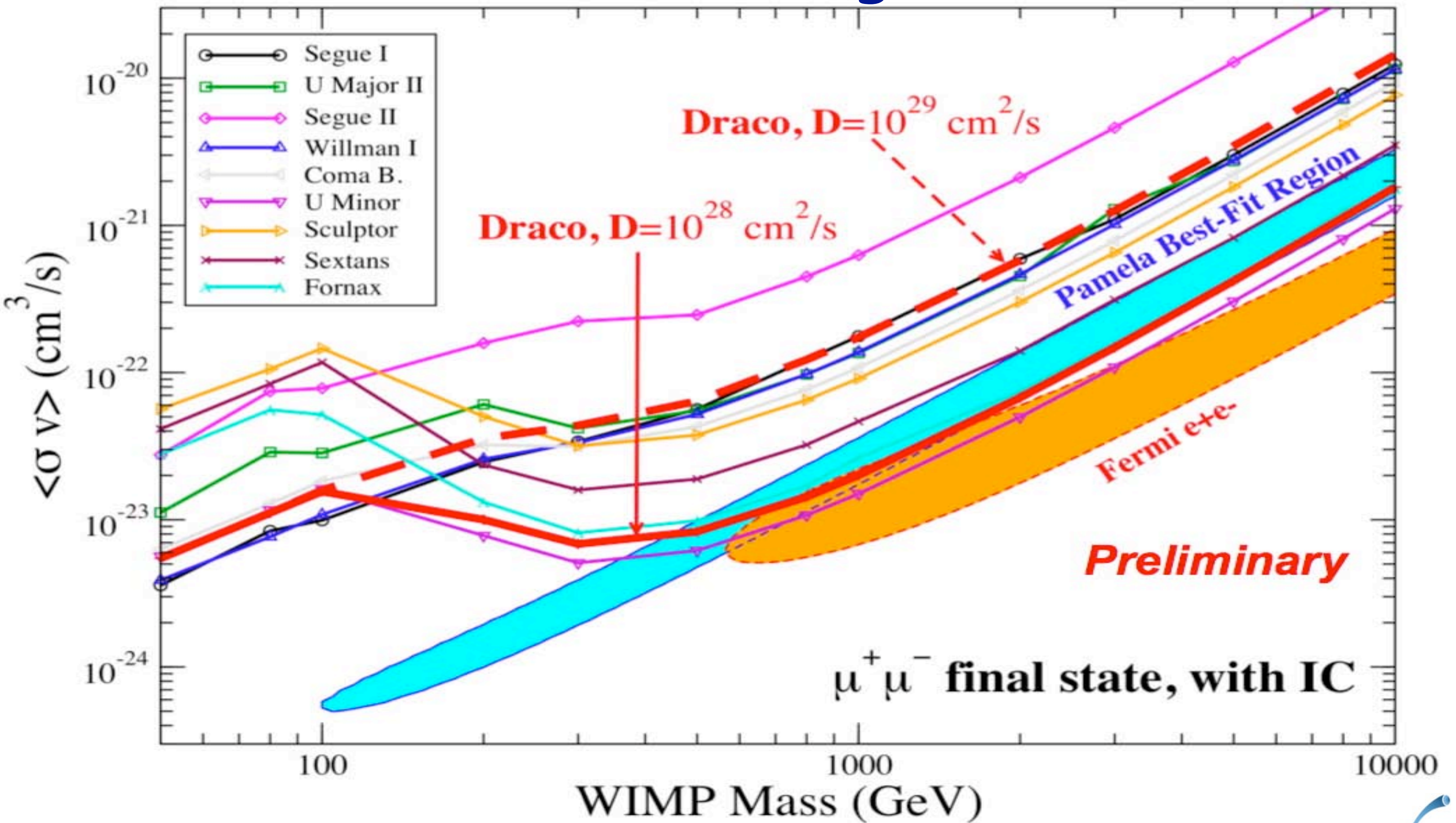
Inverse Compton Emission and Diffusion in Dwarfs

- 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 $D_0 = 10^{28}\ cm^2/s$

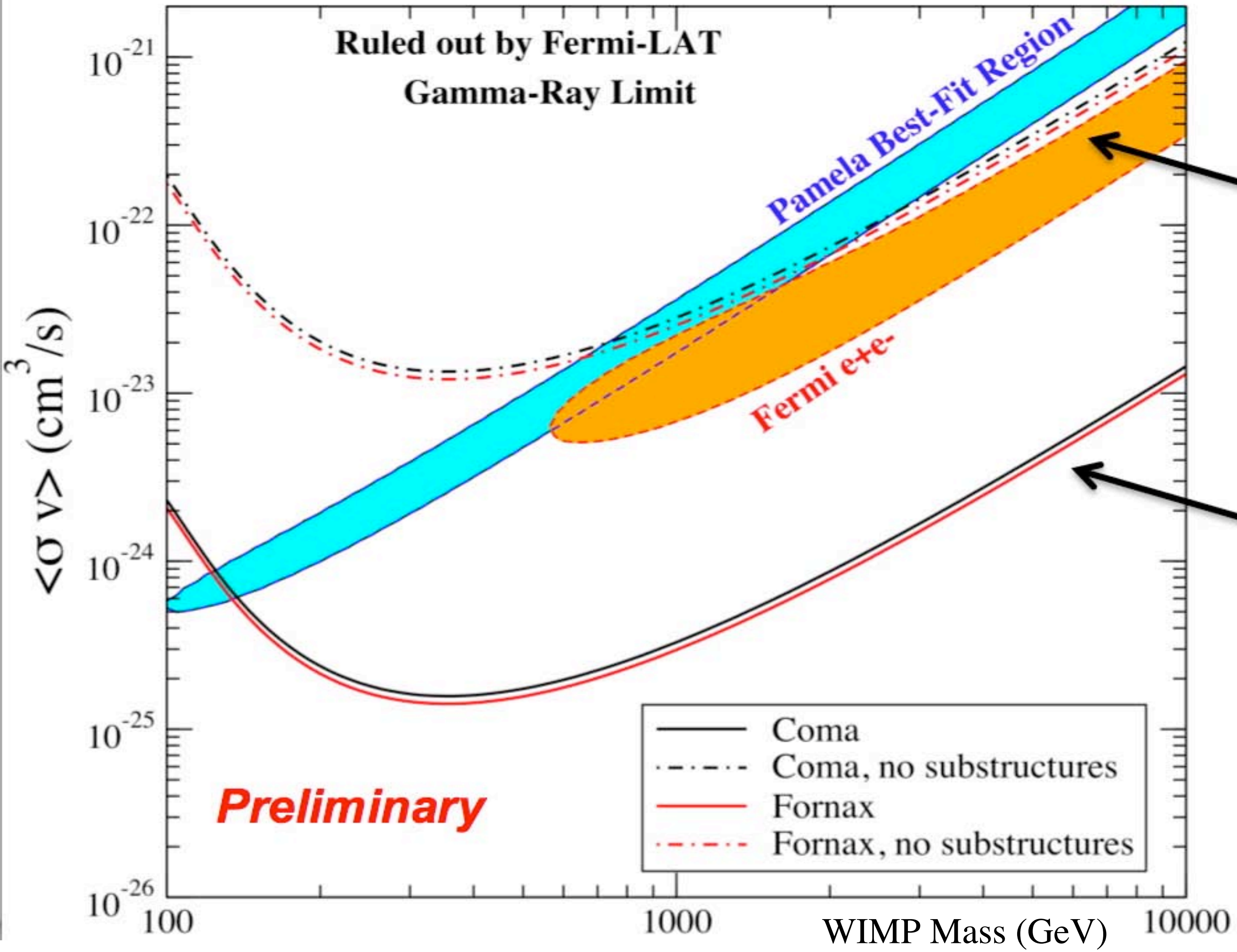
(only galaxy with measurements, scaling to dwarfs ??)

Constraints Including IC Emission



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

Cluster of Galaxies: muon antimuon final state

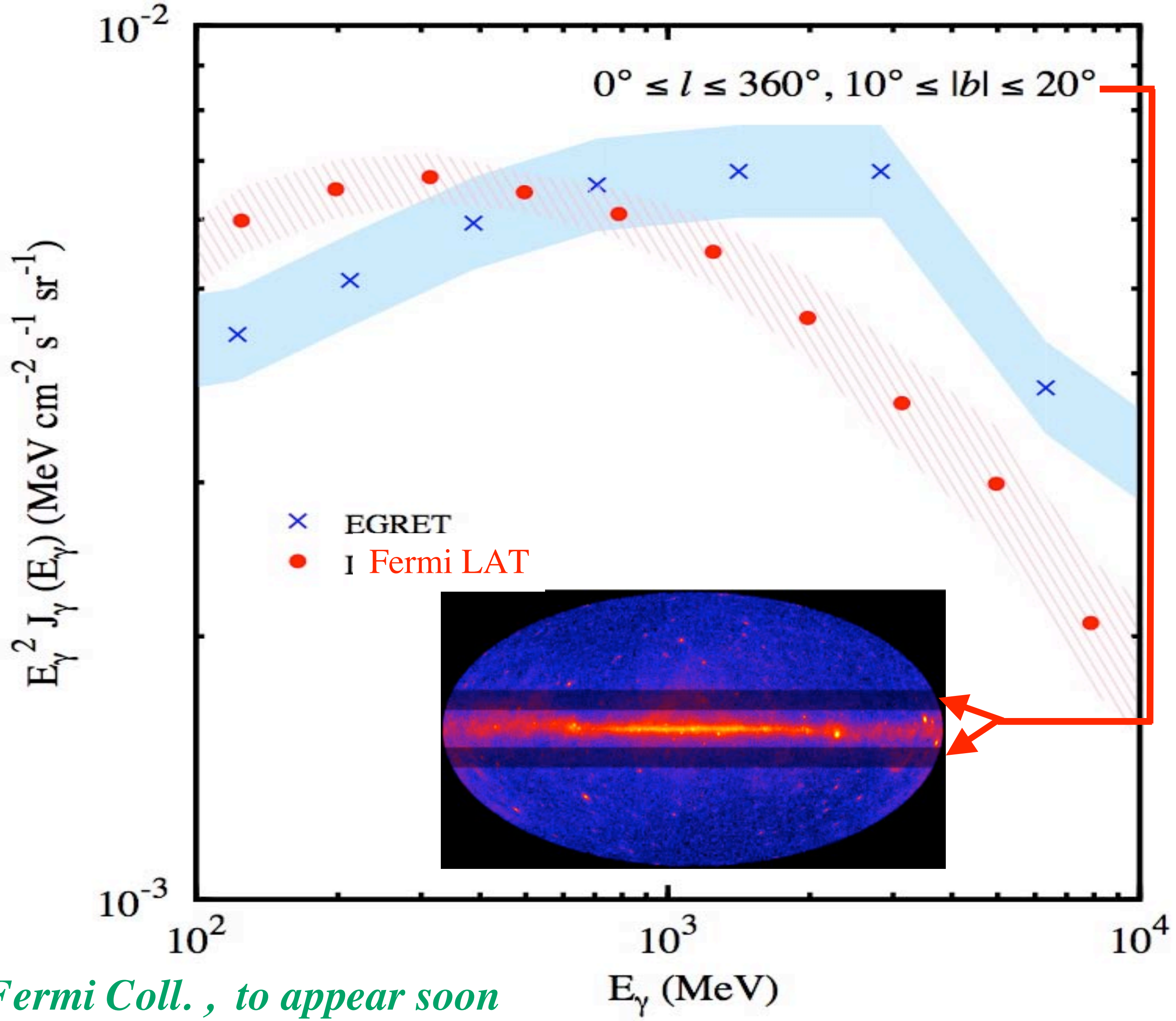


Fornax and Coma clusters: NFW, no substructure

50% of mass in substructure

Combined constraints for Final State Radiation (FSR) plus IC

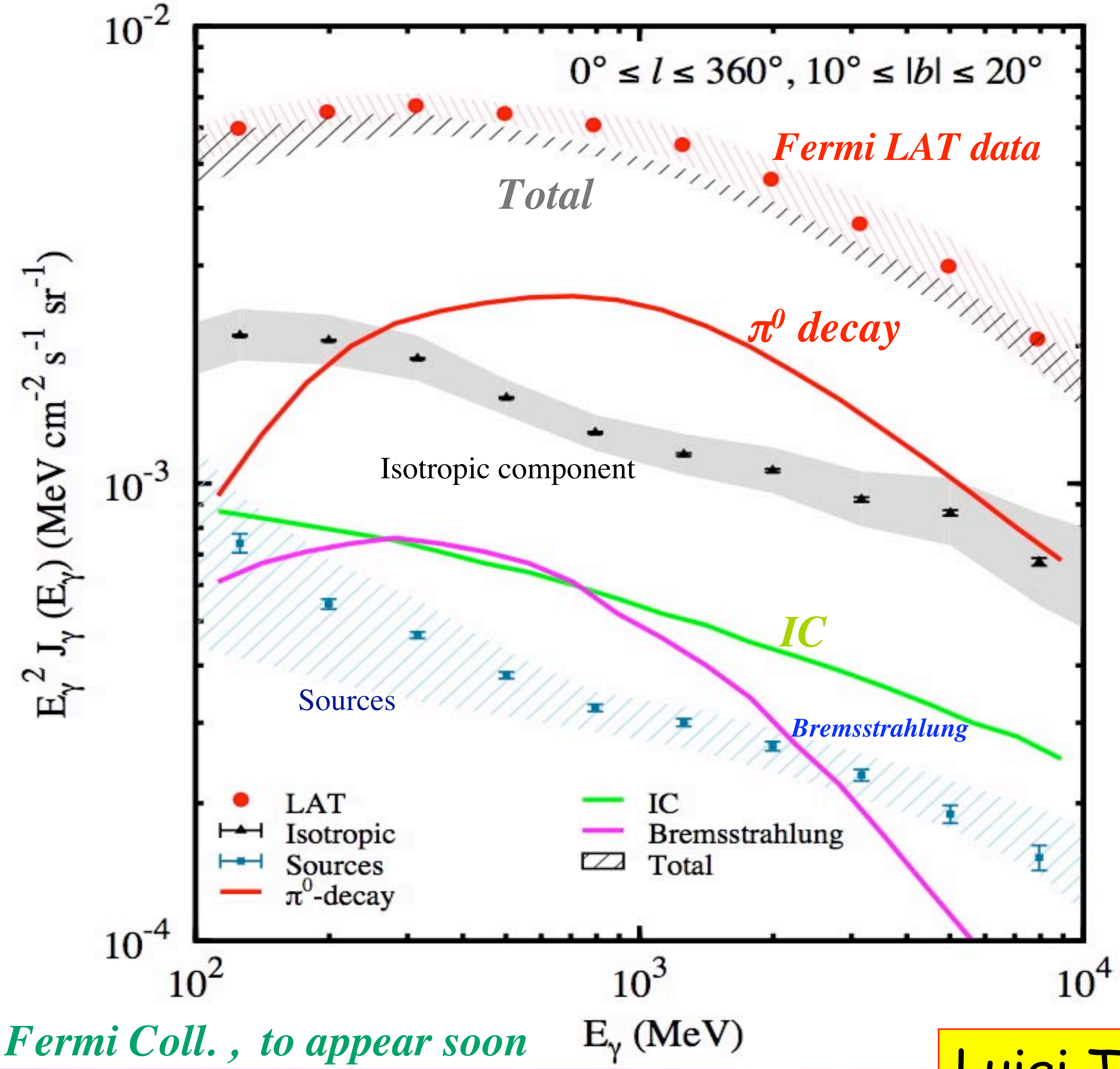
The Galactic Diffuse Emission



Fermi Coll. , to appear soon

- Spectra shown for mid-latitude range → GeV excess in this region of the sky is not confirmed.
- Sources are not subtracted but are a minor component.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% → this is preliminary.

2009: Fermi-LAT diffuse gamma-ray spectrum first measurements



Fermi Coll. , to appear soon

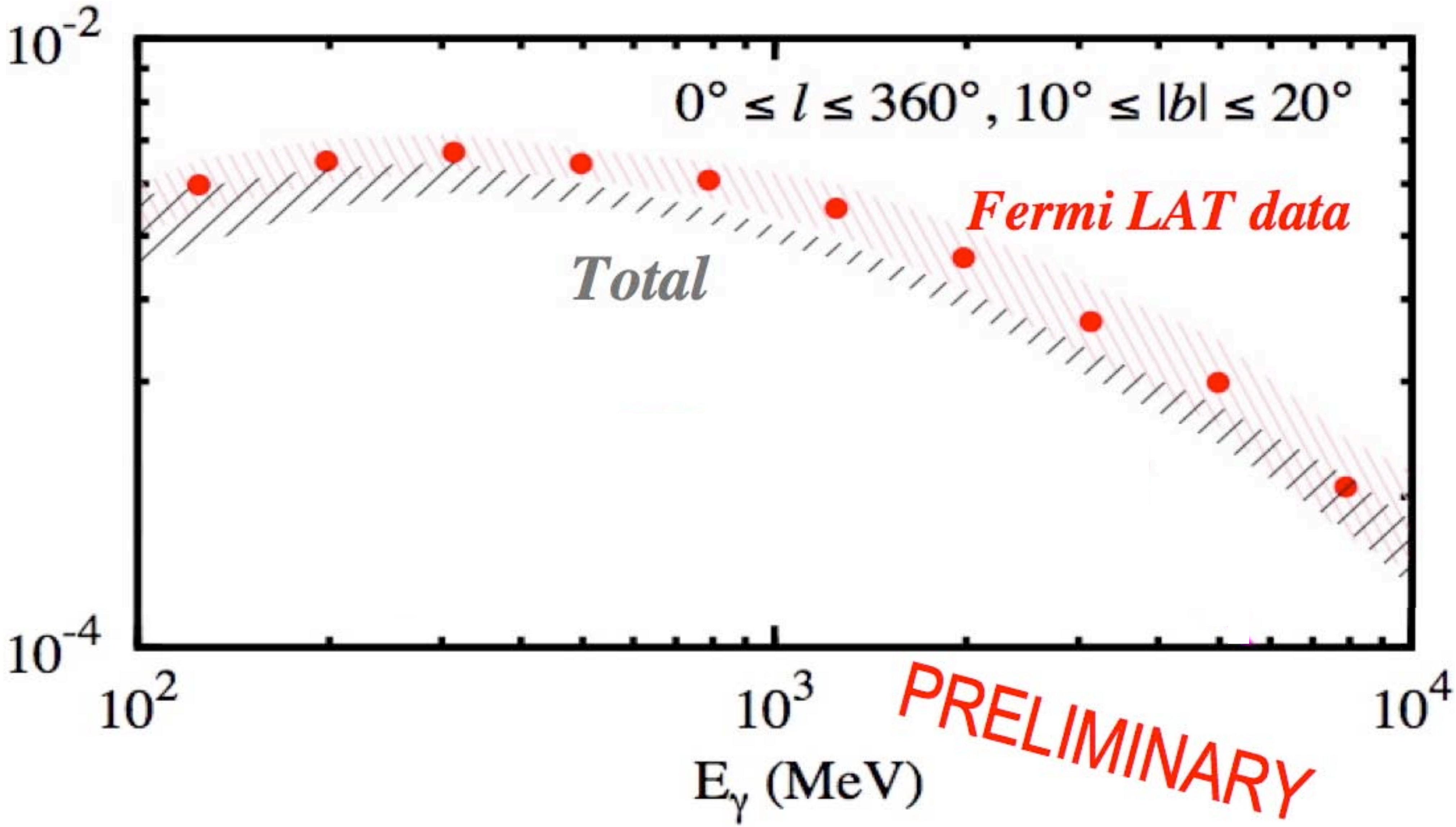
EGRET GeV excess was not observed ⇒ Conventional models (based on the locally measured CR fluxes) can be used

The conventional model with $\gamma_0 = 2.54$ ($\delta = 0.33$) gives a satisfactory description of Fermi-LAT gamma-ray data

Conventional model are weakly affected by small changes in the electron spectrum.

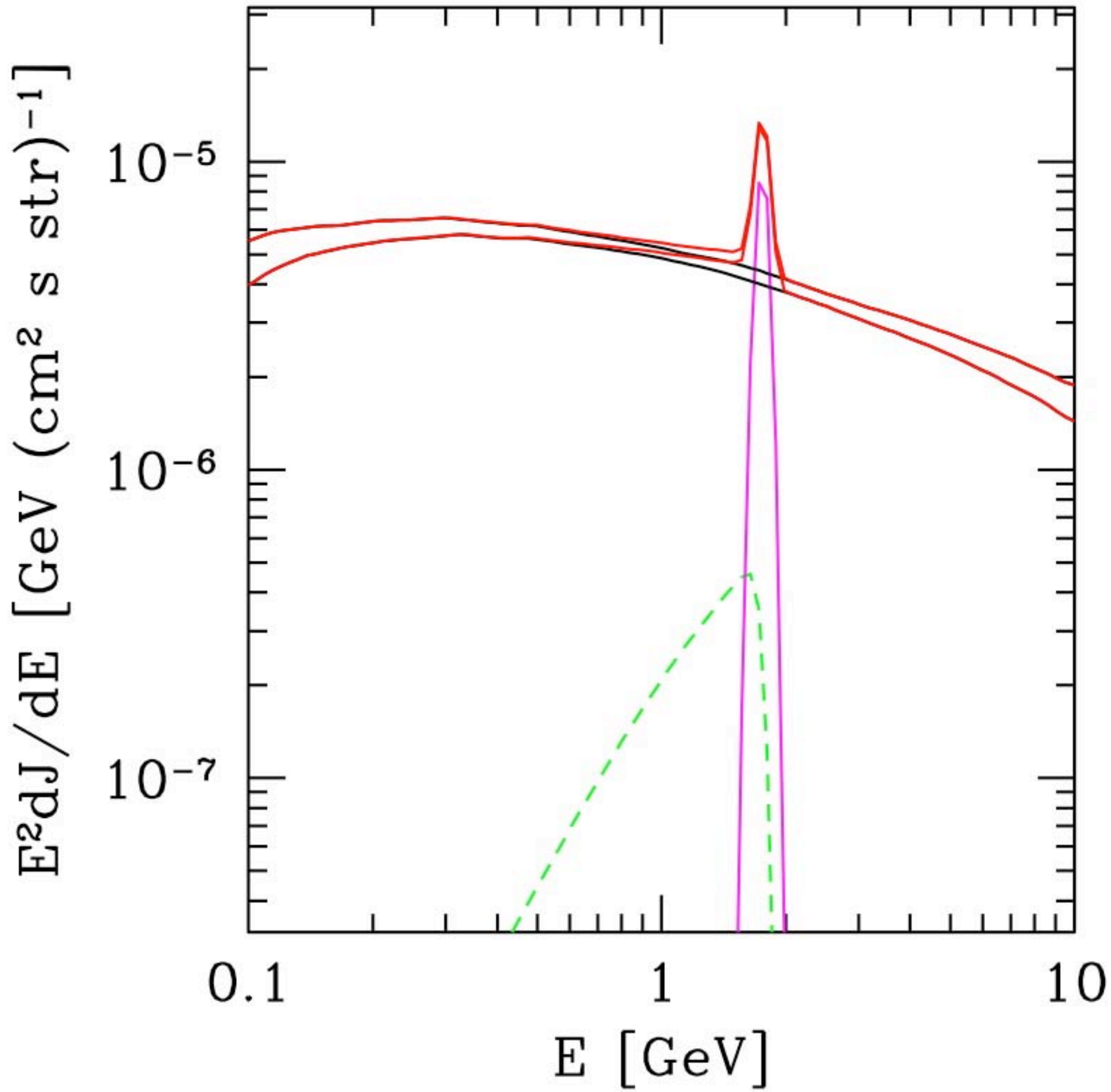
Luigi Tibaldo Friday

2009: Fermi-LAT diffuse gamma-ray spectrum first measurements



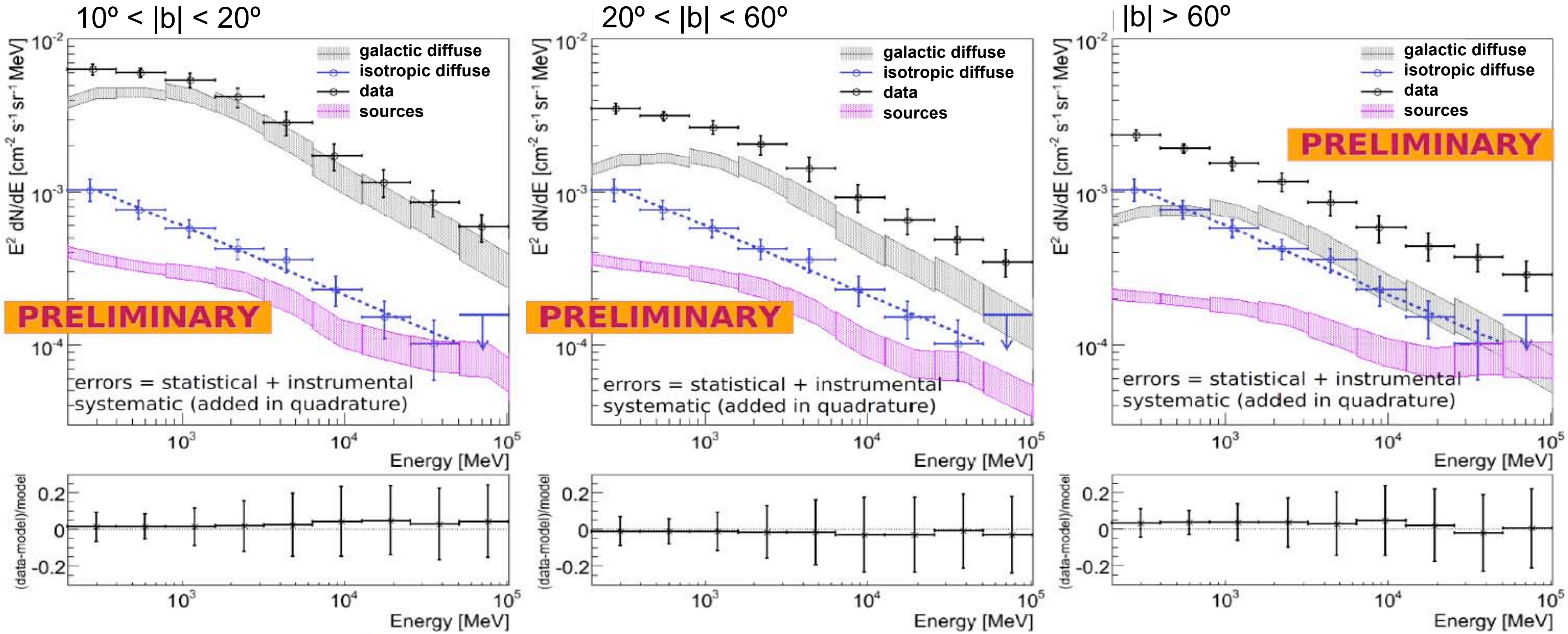
gamma-ray spectrum for an example of gravitino dark matter decay in the mid-latitude range

- $10^0 \leq |b| \leq 20^0$



Gamma-ray detection from gravitino dark matter decay in the μνSSM arXiv:0906.368

The LAT isotropic diffuse flux (200 MeV – 100 GeV)



Low galactic latitudes | High galactic latitudes | Galactic poles

Galactic diffuse flux (from fit)

LAT data

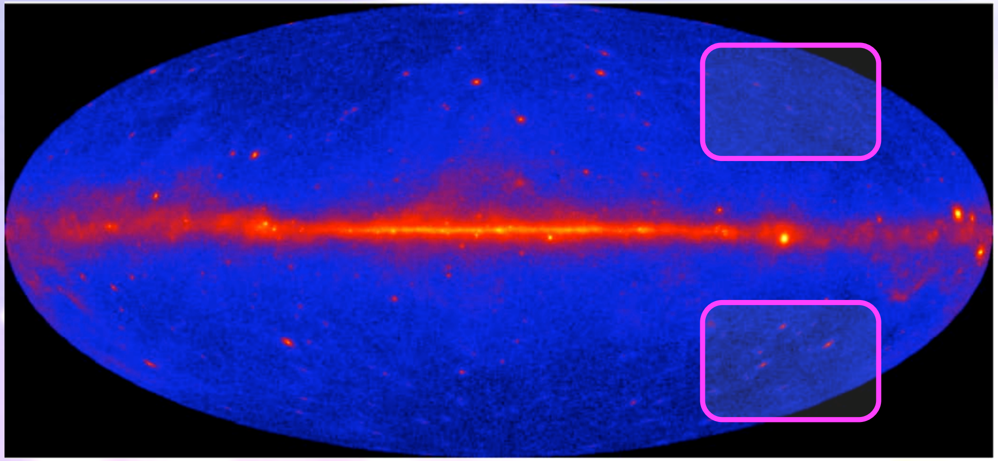
Total point source contribution (from fit)

Isotropic diffuse emission (isotropic component from fit, residual CR background subtracted)

Power law fit to isotropic diffuse emission with index $\gamma = 2.45$

error bars / bands: statistical error + LAT effective area uncertainty + residual background contamination uncertainty

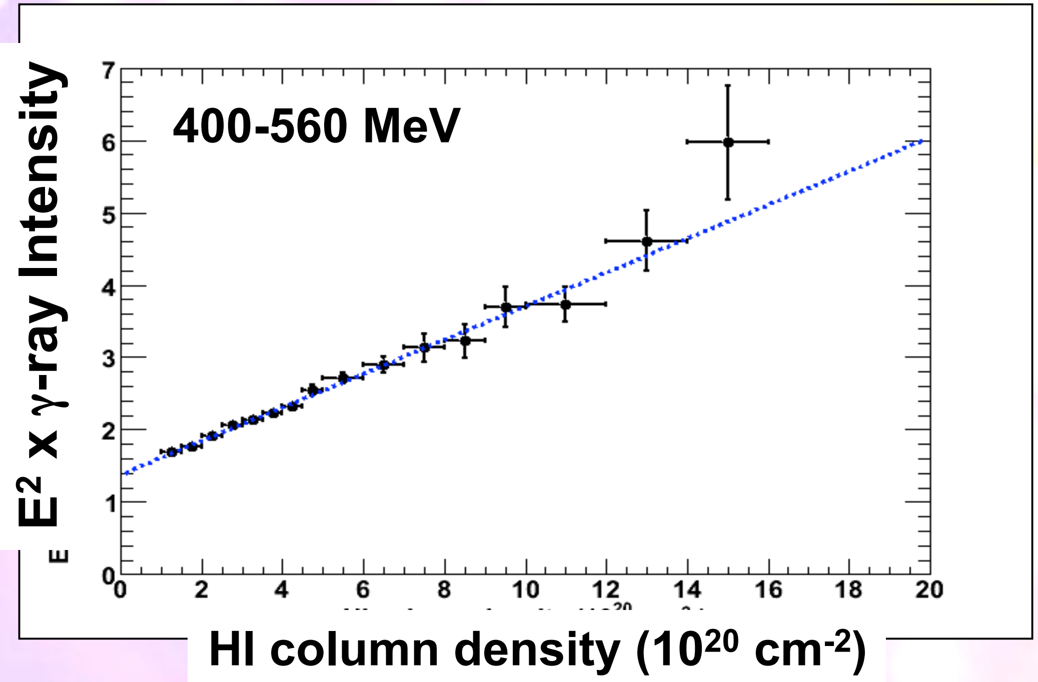
Accurate Measurements of Local CRs (1)

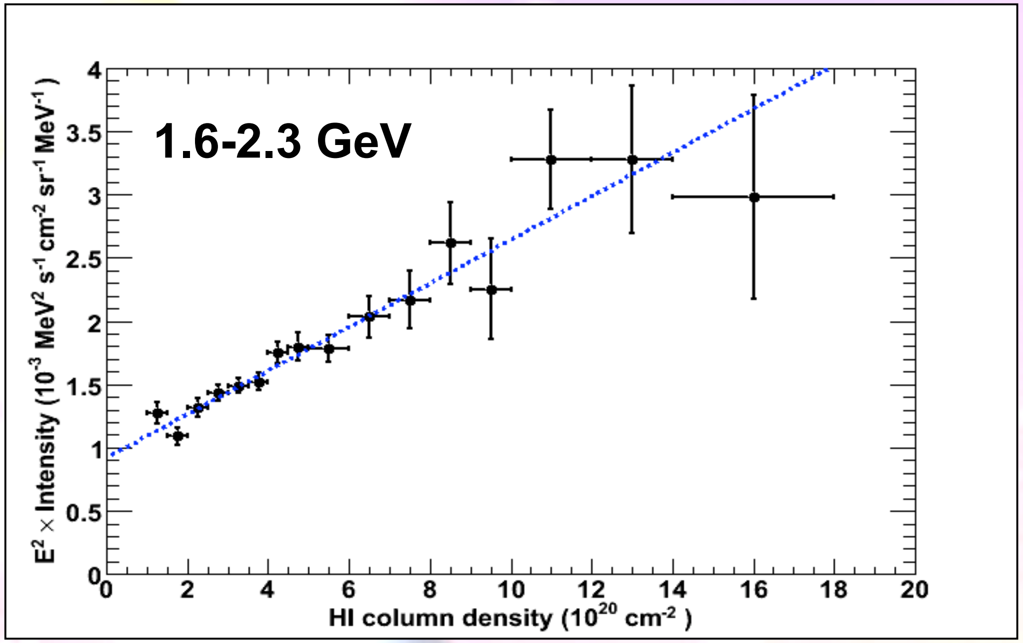


Mid-high lat. region in 3rd quadrant:

- small contamination of IC and molecular gas
- correlate γ-ray intensity and HI gas column density

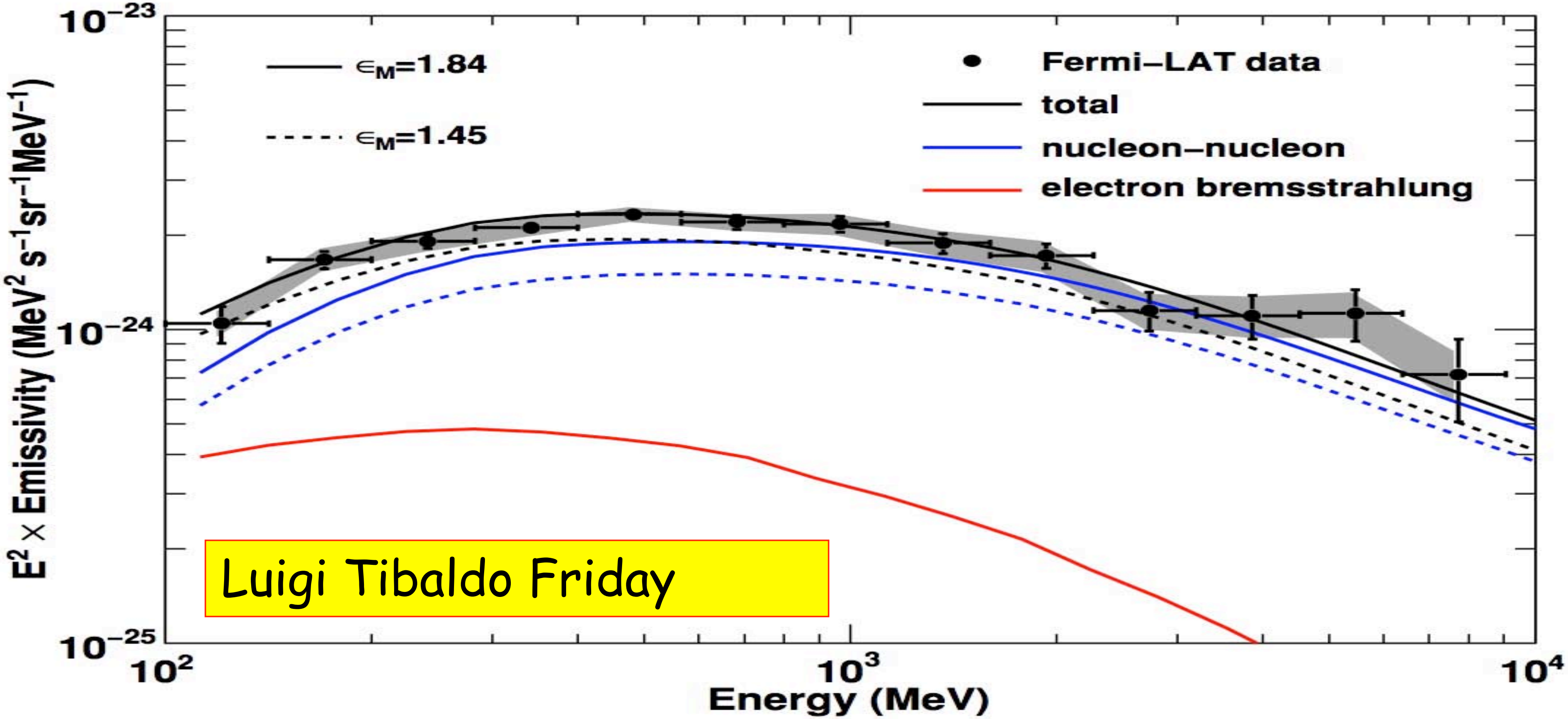
Abdo et al. 2009, accepeted by ApJ (arXiv:0908.1171)





Diffuse emission
Accurate Measurement of Local CRs

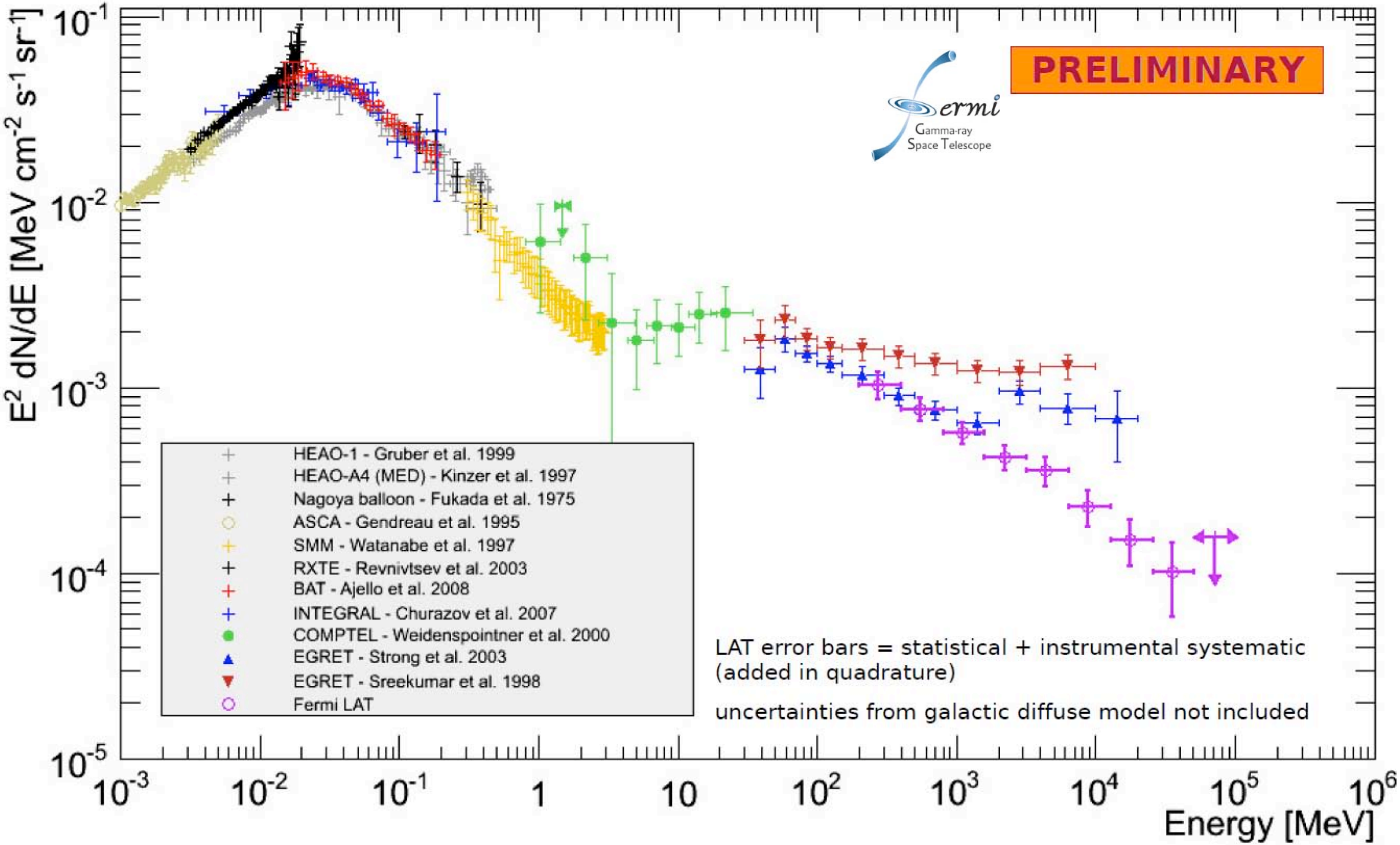
- Best quality γ-ray emissivity spectrum in 100 MeV-10 GeV (Tp = 1-100 GeV)
- Agree with the model prediction from the local interstellar spectrum (LIS)



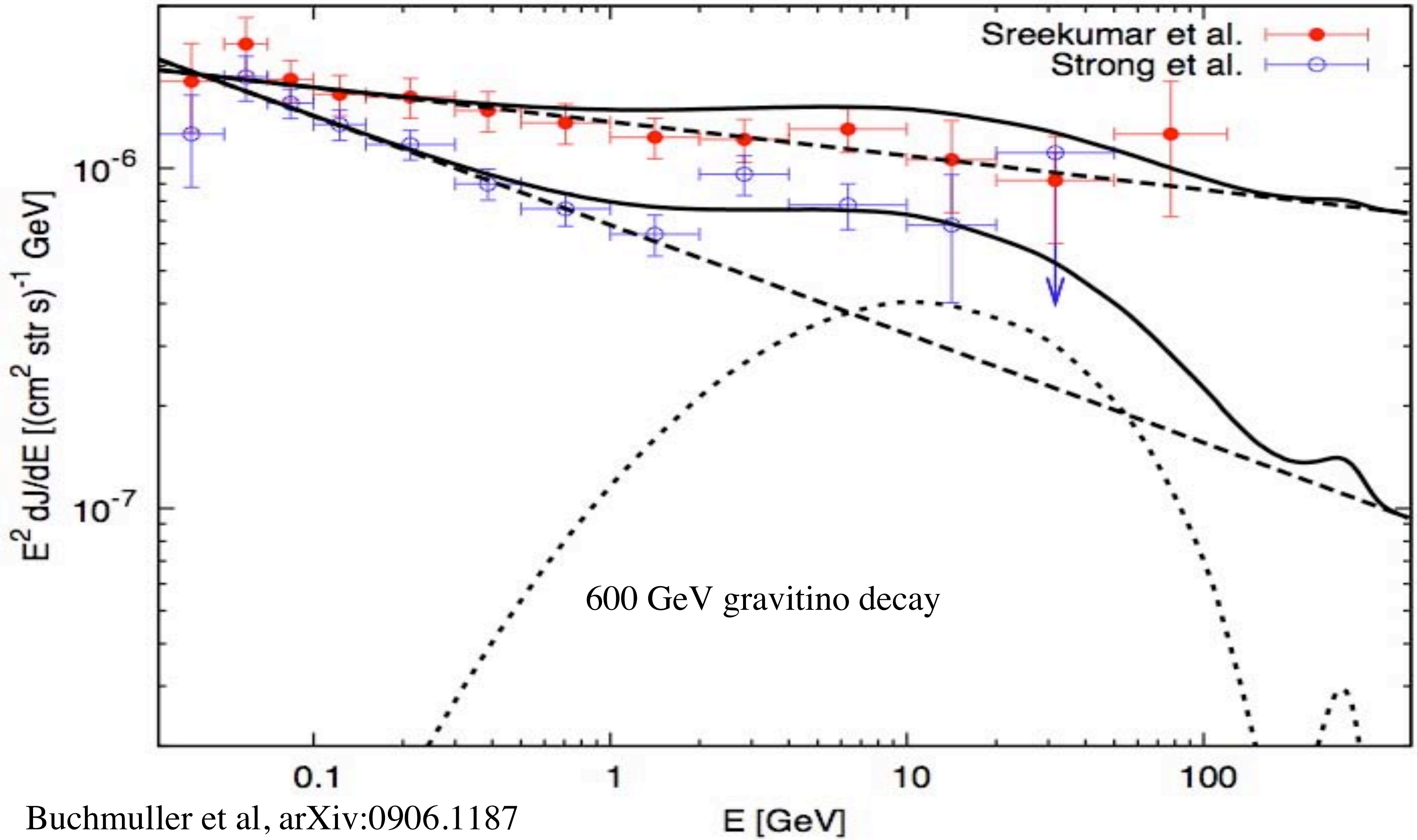
Prove that local CR nuclei spectra are close to those directly measured at the Earth

Fermi Coll. ApJ 703 (2009) 1249-1256 [arXiv:0908.1171]

SED of the isotropic diffuse emission (1 keV–100 GeV)

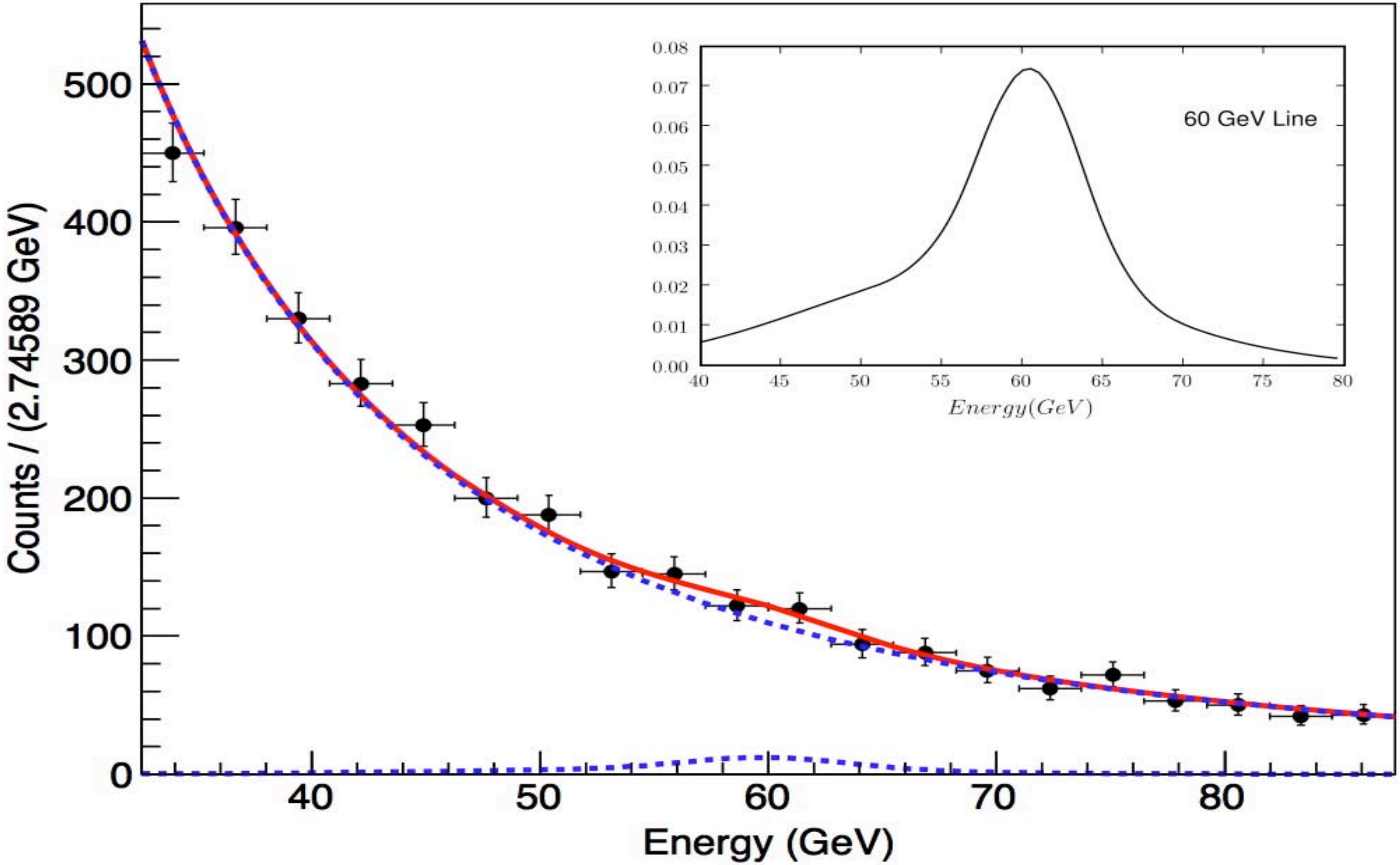


extragalactic gamma-ray spectrum



Buchmuller et al, arXiv:0906.1187

Wimp lines search



New Data is Forthcoming

Electron Spectrum:

- **PAMELA & FERMI (GLAST)** (taking data in space);
- **ATIC-4** (had successful balloon flight,under analysis);
- **CREST** (new balloon payload under development);
- **AMS-02** (launch date TBD);
- **CALET** (proposed for ISS);
- **ECAL** (proposed balloon experiment).

Comparison of High-Energy Electron Missions

Mission	Upper Energy (TeV)	Collecting Power ($m^2 sr$)	Calorimeter Thickness (X_0)	Energy Resolution (%)
CALET	20	0.75	30.8	< 3 (over 100 GeV)
PAMELA	0.25 (spectrometer) 2 (calorimeter)	0.0022 0.04	16.3	5.5 (300 GeV) 12 (300 GeV) 16 (1TeV)
GLAST	0.7	2.1 (100 GeV) 0.7 (700 GeV)	8.3	6 (100 GeV) 16 (700 GeV)
AMS-02	0.66 (spectrometer) 1 (calorimeter)	0.5 0.06 (100 GeV) < 0.04 (1 TeV)	16.0	< 3 (over 100 GeV)

Positron / Electron Separation: **PAMELA & AMS-02**

Conclusion:

The CRE spectrum measured by Fermi-LAT is significantly harder than previously thought on the basis of previous data

Adopting the presence of an extra $e^{\pm}$ primary component with ~ 2.4 spectral index and E_{cut} ~ 1 TeV allow to consistently interpret Fermi-LAT CRE data (improving the fit), HESS and PAMELA

Such extra-component can be originated by pulsars for a reasonable choice of relevant parameters

- or by annihilating dark matter for model with $M_{DM} \approx 1$ TeV

- Improved analysis and complementary observations
- (CRE **anisotropy**, spectrum and angular distribution of diffuse γ, DM sources search in γ) are required to possibly discriminate the right scenario.

In September 2009 Fermi data will be open to the community
You are all invited to join !

thank you for the attention !