Multimessenger constraints for the dark matter interpretation of the Fermi-LAT Galactic center excess

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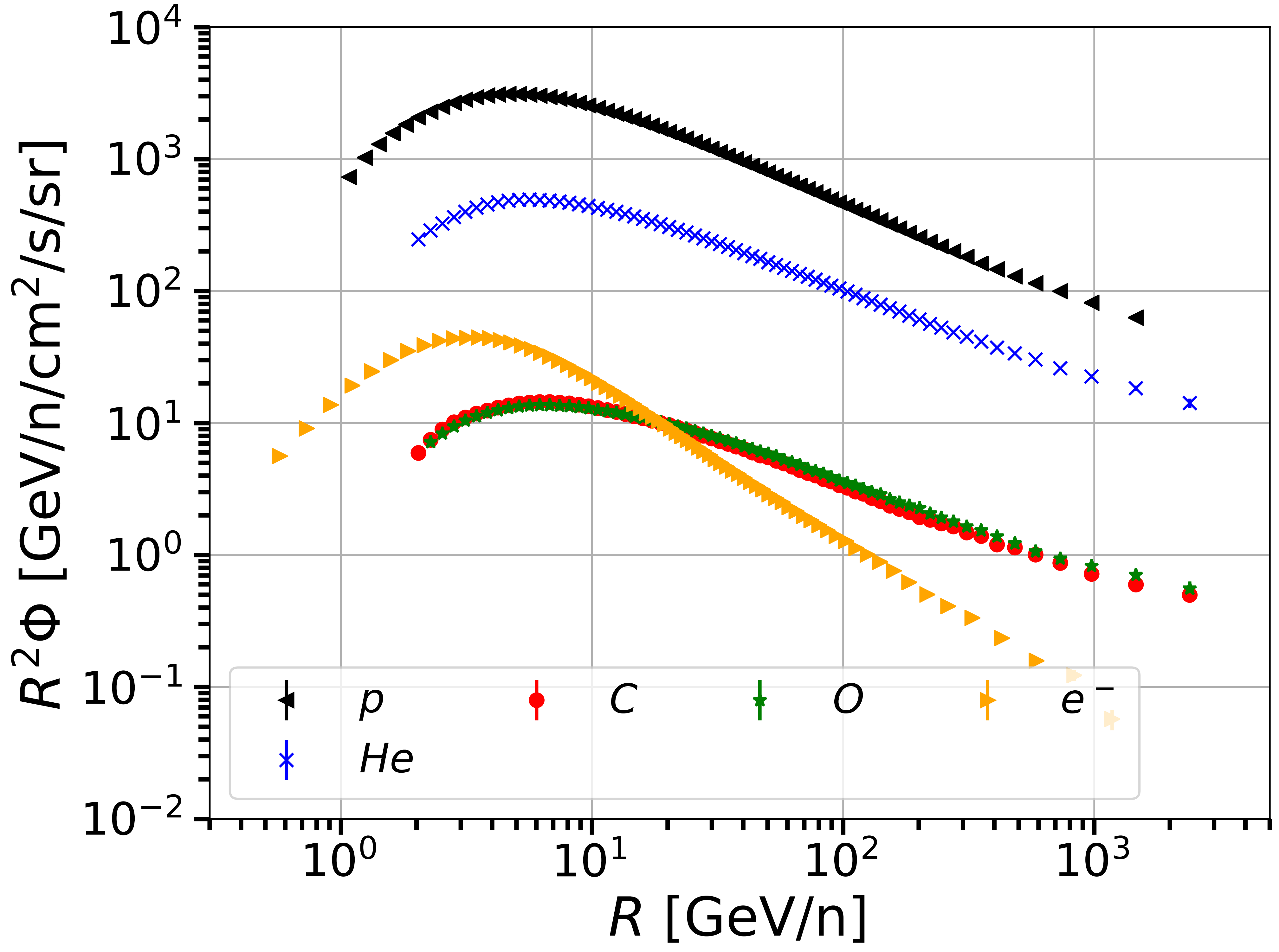
Fellowship for Innovation at INFN

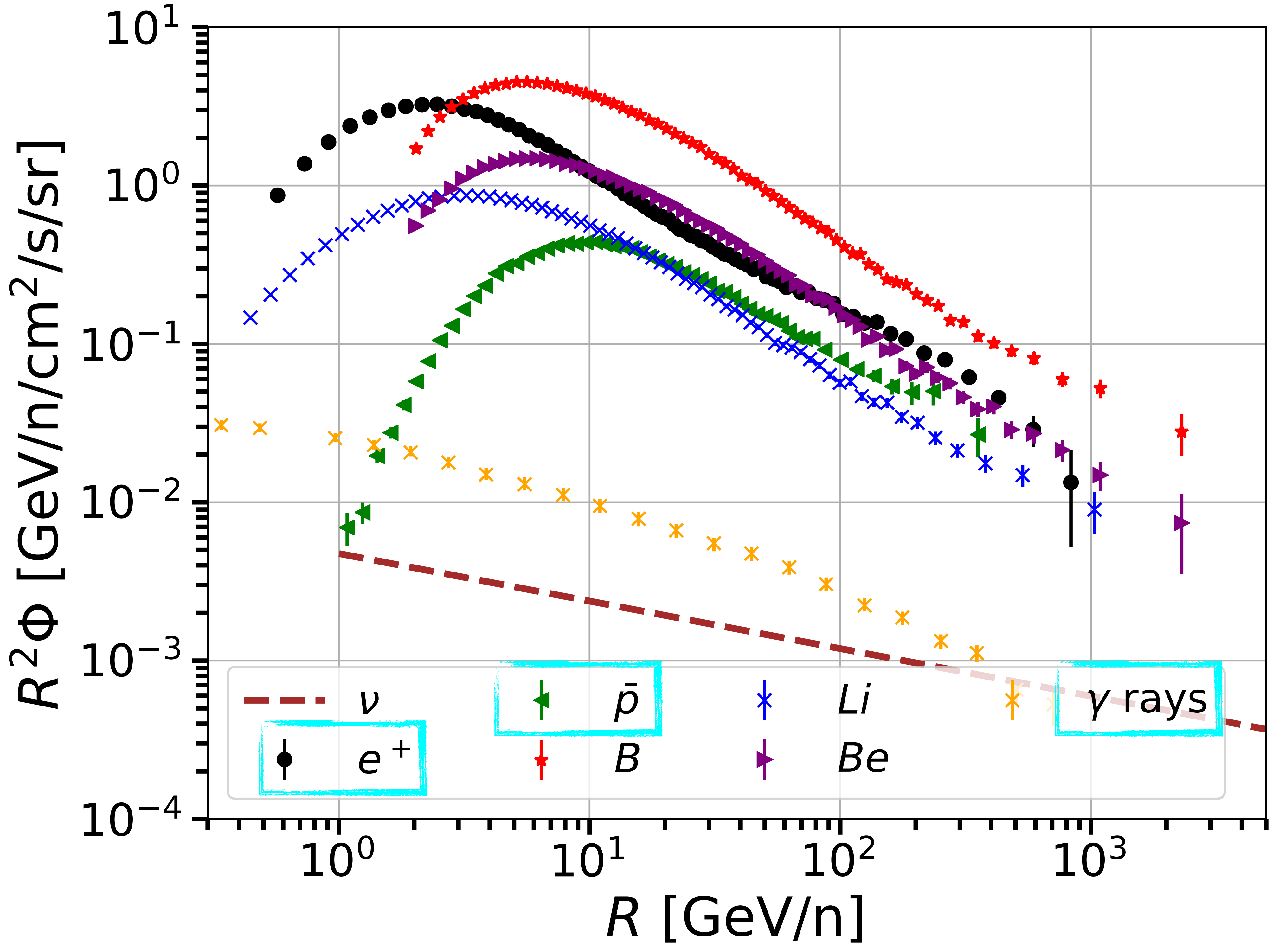
Istituto Nazionale di Fisica Nucleare

Background image: ESO
Central image: Fermi-LAT

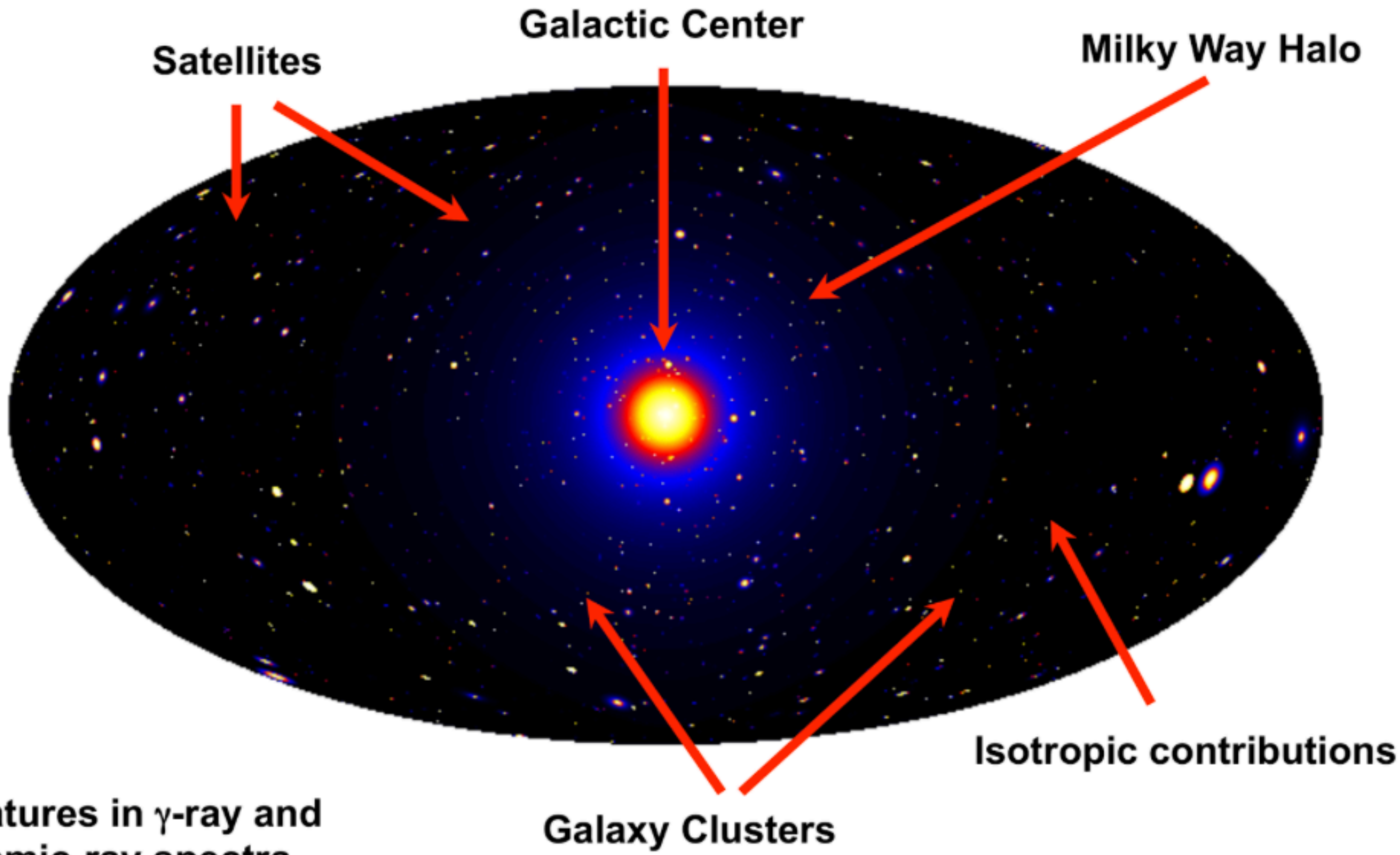
Multimessenger search for a DM signal in cosmic particles

- Among all cosmic rays, secondaries are the most interesting for DM searches.
- In particular antiprotons, e+, gamma rays and neutrinos are the most studied.
- Antinuclei are also considered because the DM production should exceed the secondary one at low energy.





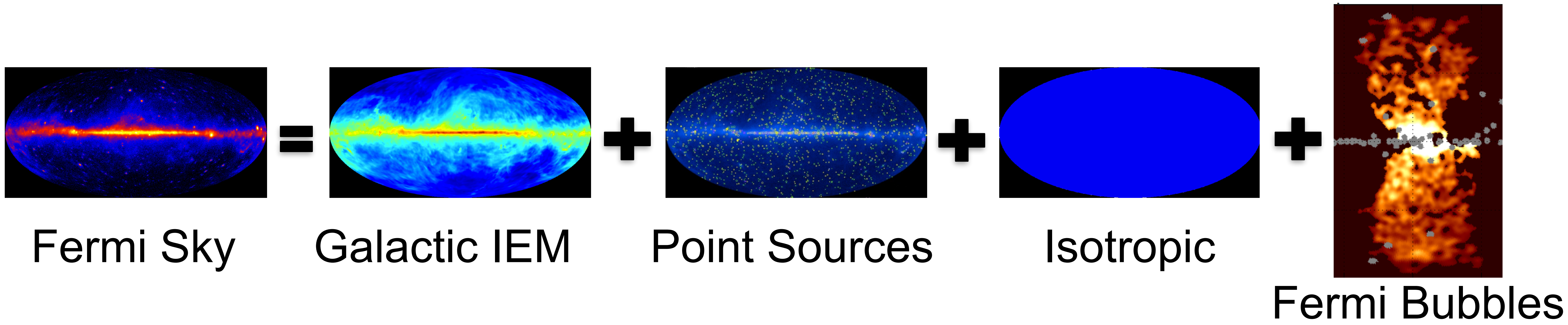
Gamma-ray map from dark matter annihilation

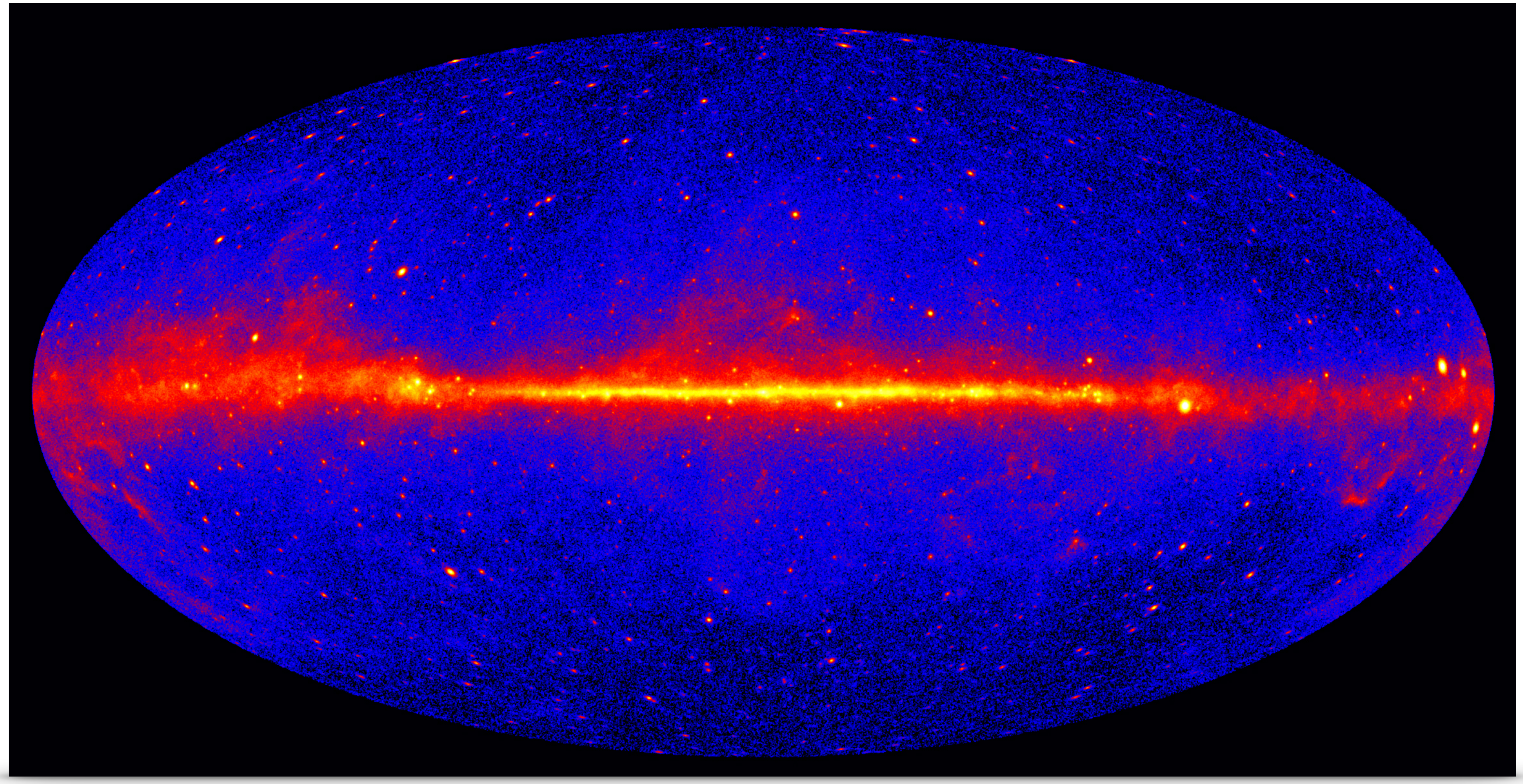


Features in γ-ray and cosmic-ray spectra

Dark Matter simulation: Pieri+
2011PhRvD..83b3518P

Standard picture for the gamma-ray sky





Papers related to this talk

Investigating the *Fermi* Large Area Telescope sensitivity of detecting the characteristics of the Galactic center excess

Paper I

PRD 102, 103013 2020

Mattia Di Mauro,*
NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA and
Catholic University of America, Department of Physics, Washington DC 20064, USA

The characteristics of the Galactic center excess measured with 11 years of *Fermi*-LAT data

Paper II

PRD 103, 063029 (2021)

Mattia Di Mauro,*
NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA and
Catholic University of America, Department of Physics, Washington DC 20064, USA

Multimessenger constraints on the dark matter interpretation of the *Fermi*-LAT Galactic center excess

Paper III

PRD 103, 123005 (2021)

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Gamma rays from dark matter annihilation

Velocity averaged annihilation cross-section

Signal intensity:
[photon flux per steradian per energy]

Photon energy spectrum per annihilation

$$\frac{d\phi}{d\Omega dE} = \frac{\langle \sigma v_{\rm rel} \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE} \times \int_{\rm l.o.s.} ds \; \rho(\vec{r}[s,\Omega])^2$$

Dark matter mass density

Dark matter mass

Line-of-sight integral

Particle Physics

Astrophysics

Characteristic **Energy Spectrum**

Characteristic **Morphology**
(point-like, extended or diffuse)

[review DM searches with gamma rays: Bringmann & Weniger (2012)]

It is convenient to define a "J-value":

$$J_{\Delta\Omega} \equiv \int_{\Delta\Omega} d\Omega \int_{\rm l.o.s.} ds \rho(r[s,\vec{\Omega}])^2$$

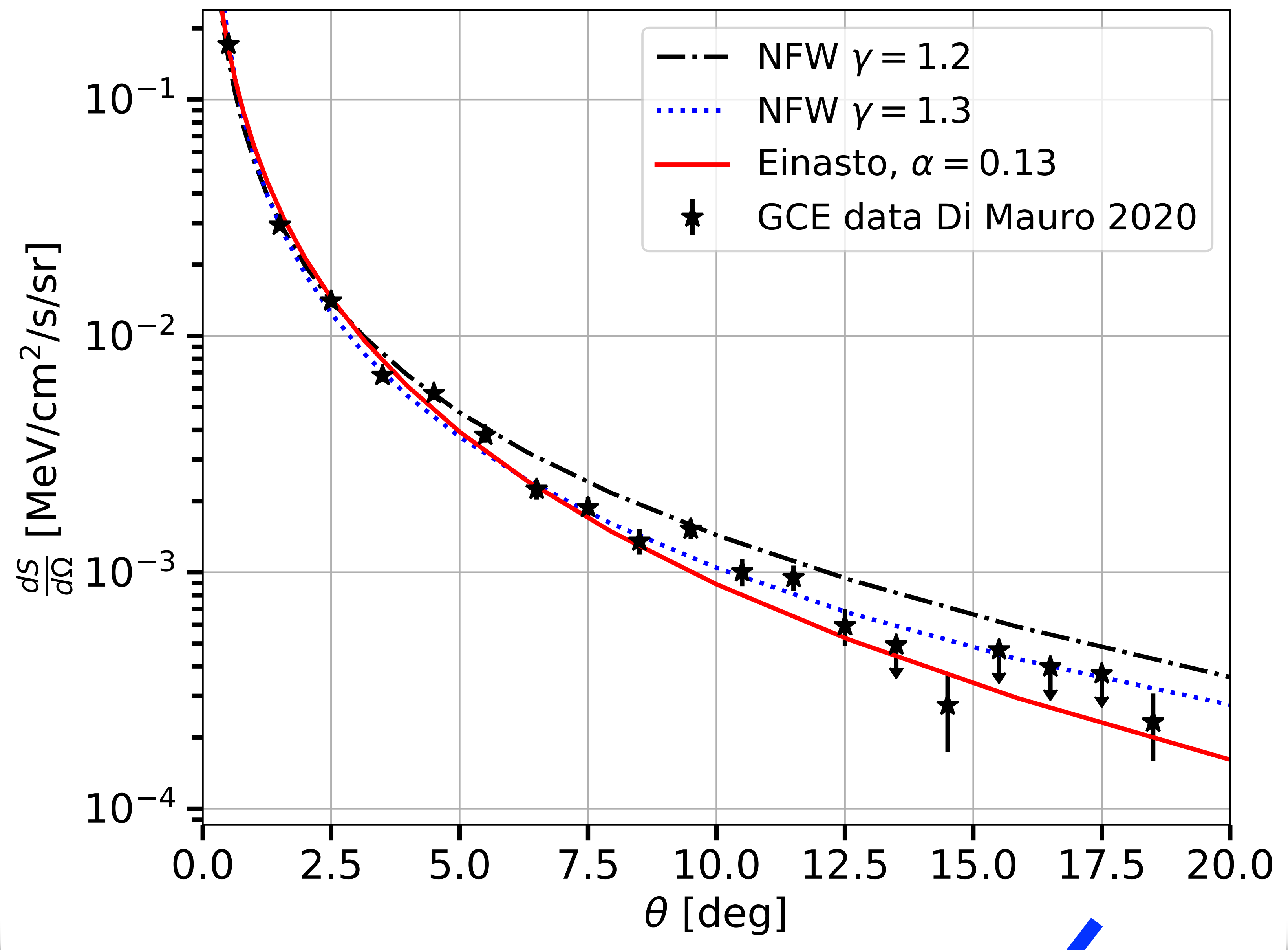
Dark matter density distribution

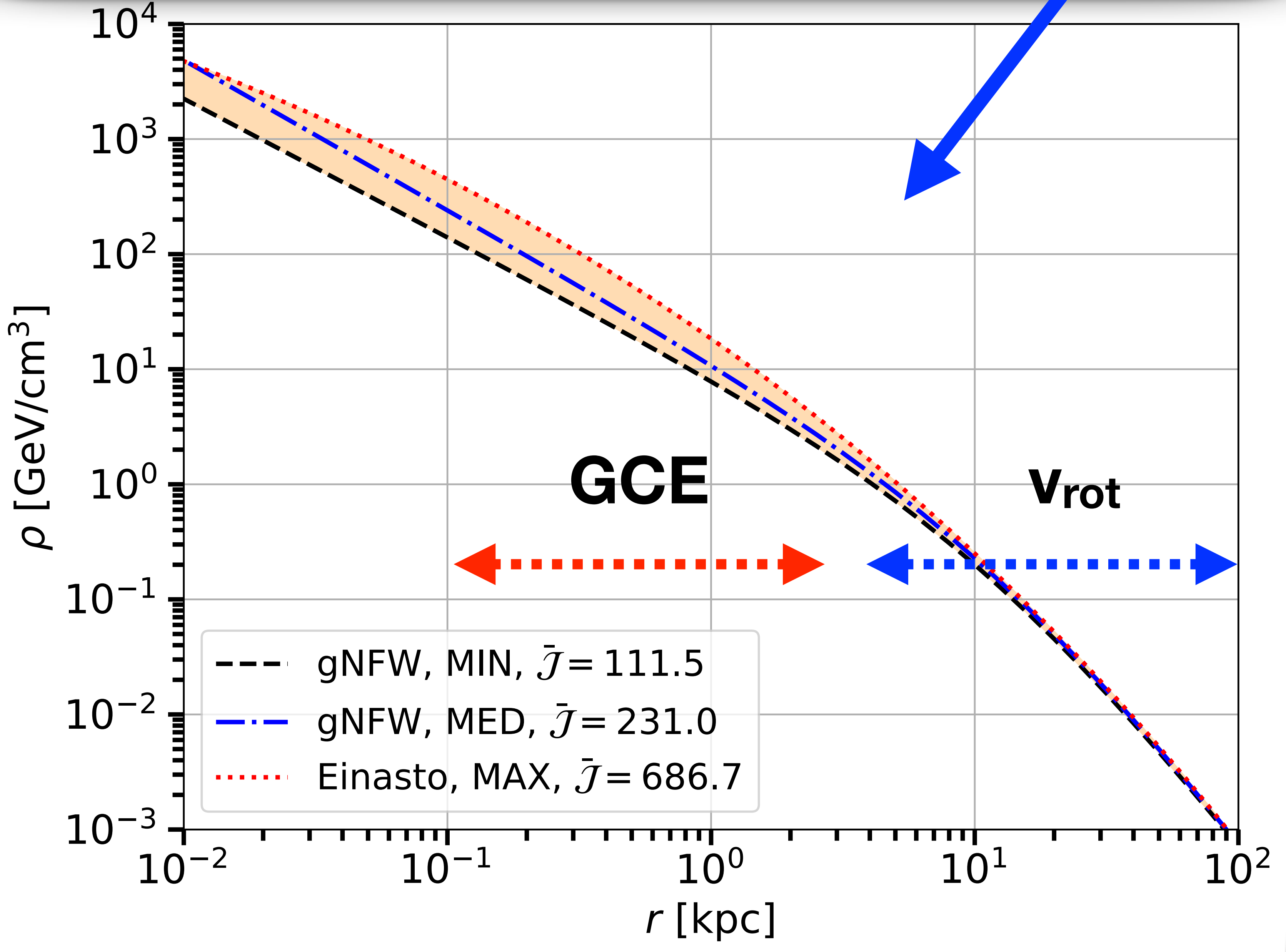
Salas et al. 2019 Rotation curve galaxy data

DM density	slope	ρ_s [GeV/cm^3]	r_s [kpc]	$\mathcal{J}$	
$\rho_\odot = 0.30$ GeV/cm^3 $M_{200} = 5.5 \cdot 10^{11}$ $M_\odot$					
gNFW	1.20	0.416	12.87	111.5	**MIN**
gNFW	1.30	0.314	14.18	155.3	
Einasto	0.13	0.376	7.25	288.9	
$\rho_\odot = 0.34$ GeV/cm^3 $M_{200} = 6.2 \cdot 10^{11}$ $M_\odot$					
gNFW	1.20	0.587	11.57	166.1	
gNFW	1.30	0.449	12.67	231.0	**MED**
Einasto	0.13	0.569	6.35	449.3	
$\rho_\odot = 0.38$ GeV/cm^3 $M_{200} = 7.0 \cdot 10^{11}$ $M_\odot$					
gNFW	1.20	0.851	10.20	246.8	
gNFW	1.30	0.649	11.20	339.1	
Einasto	0.13	0.864	5.51	686.7	**MAX**

$$\bar{\mathcal{J}} = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{l.o.s.} \frac{ds}{r_\odot}\left(\frac{\rho(r(s,\Omega))}{\rho_\odot}\right)^2$$

Geometrical factor integrate in our ROI

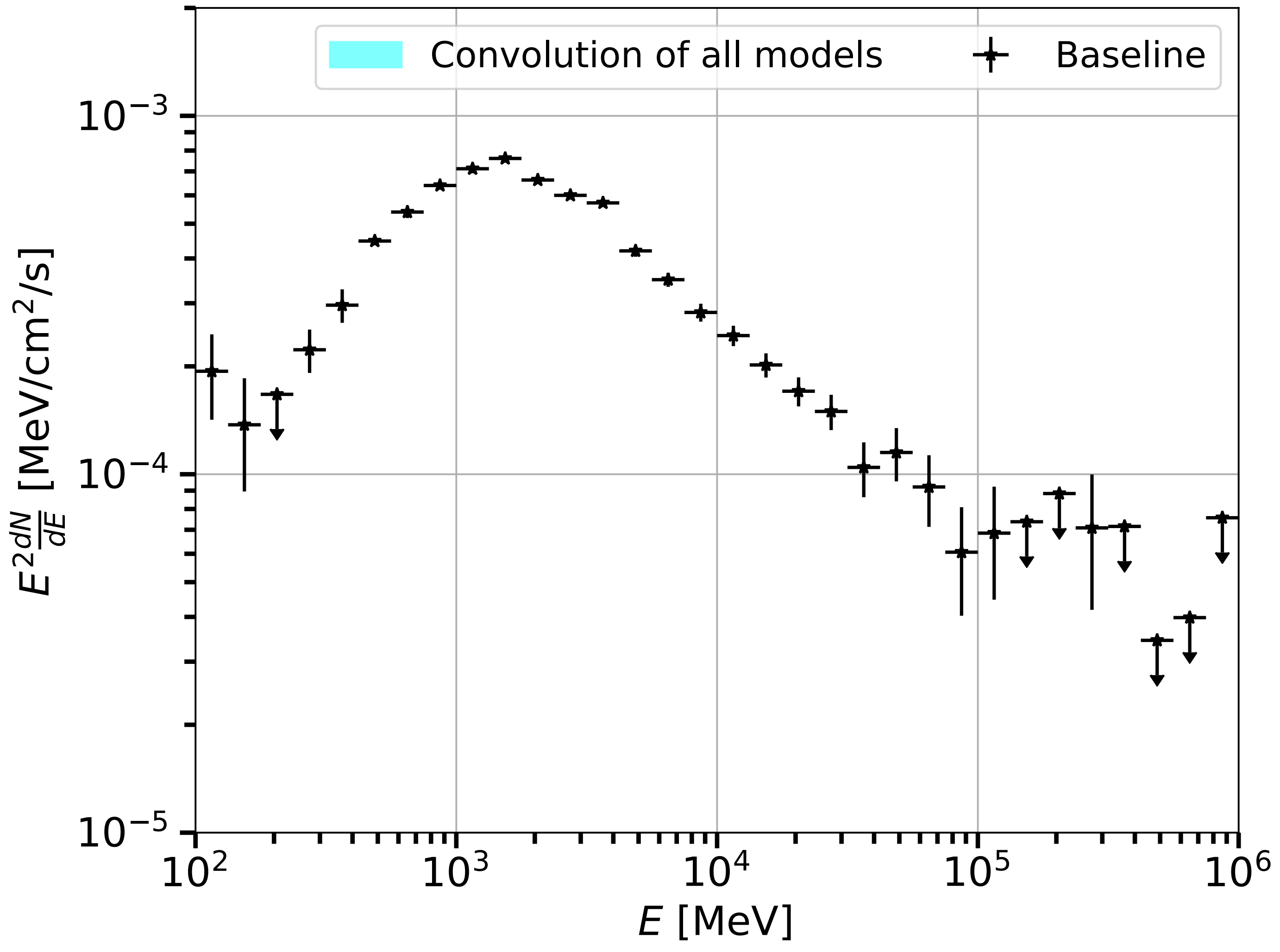




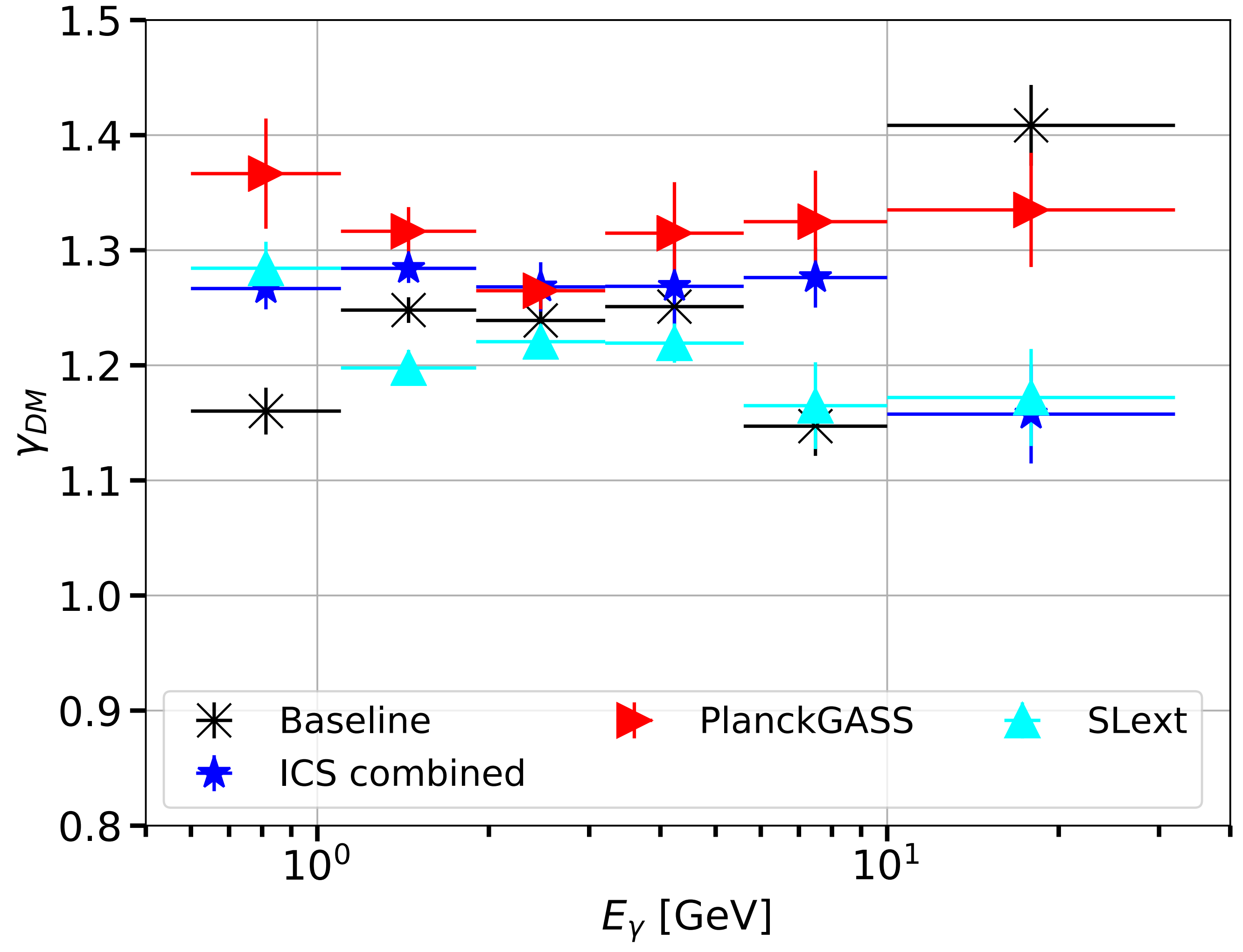
Paper II

Characteristics of the GCE: Summary

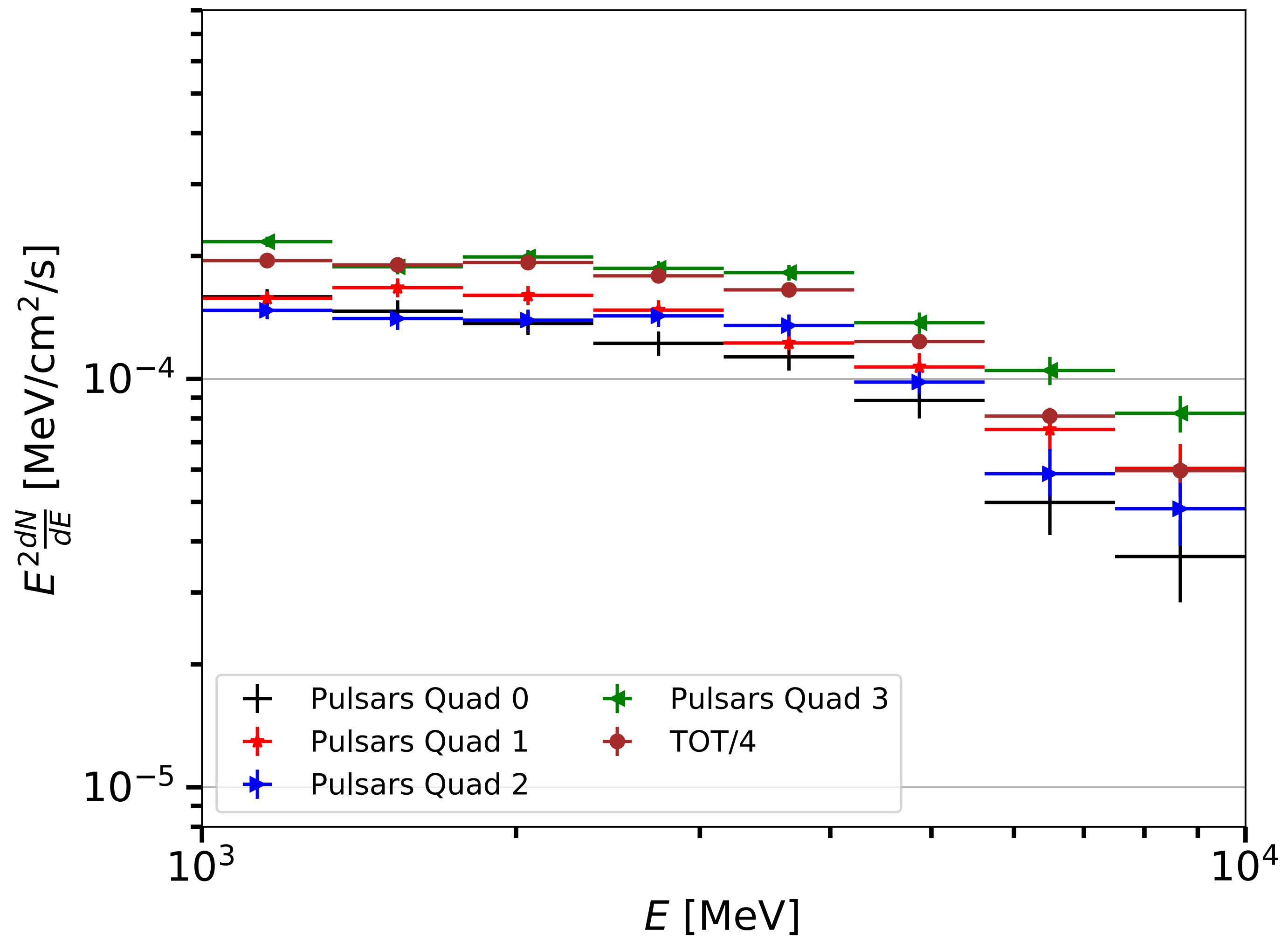
Spectrum peaked at a few GeV



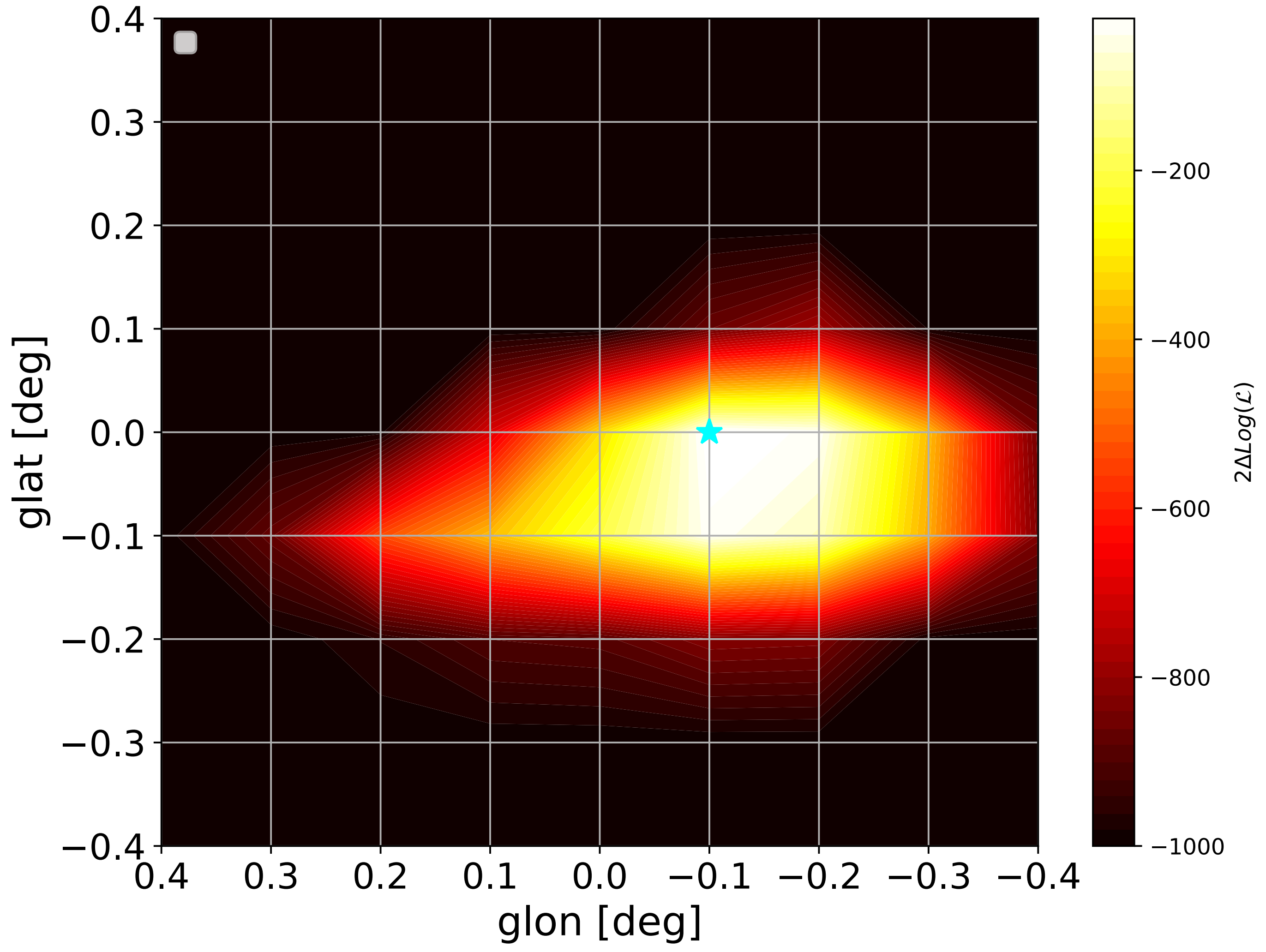
No energy dependence of spatial morphology.



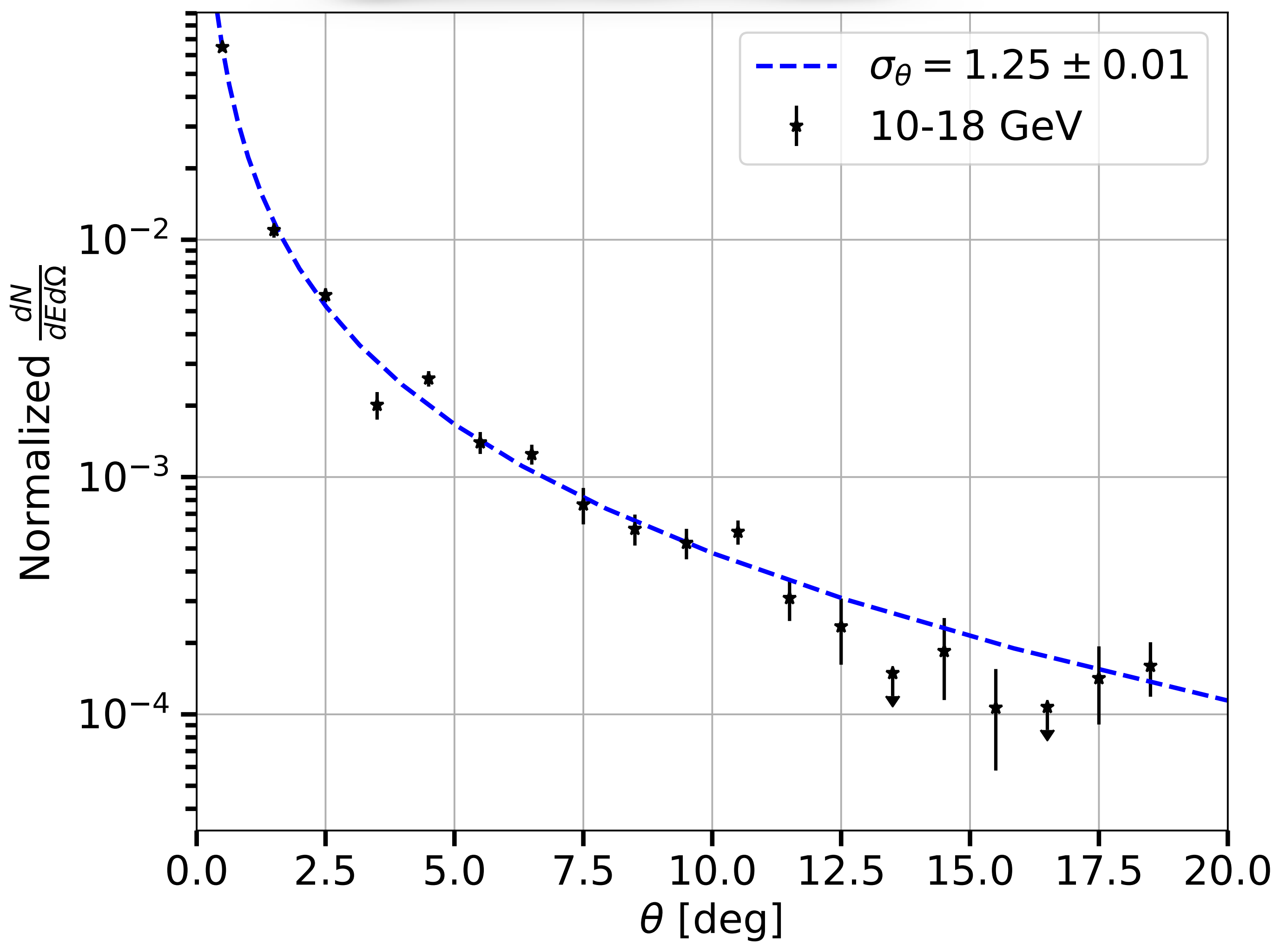
The GCE is approximatively spherically symmetric.

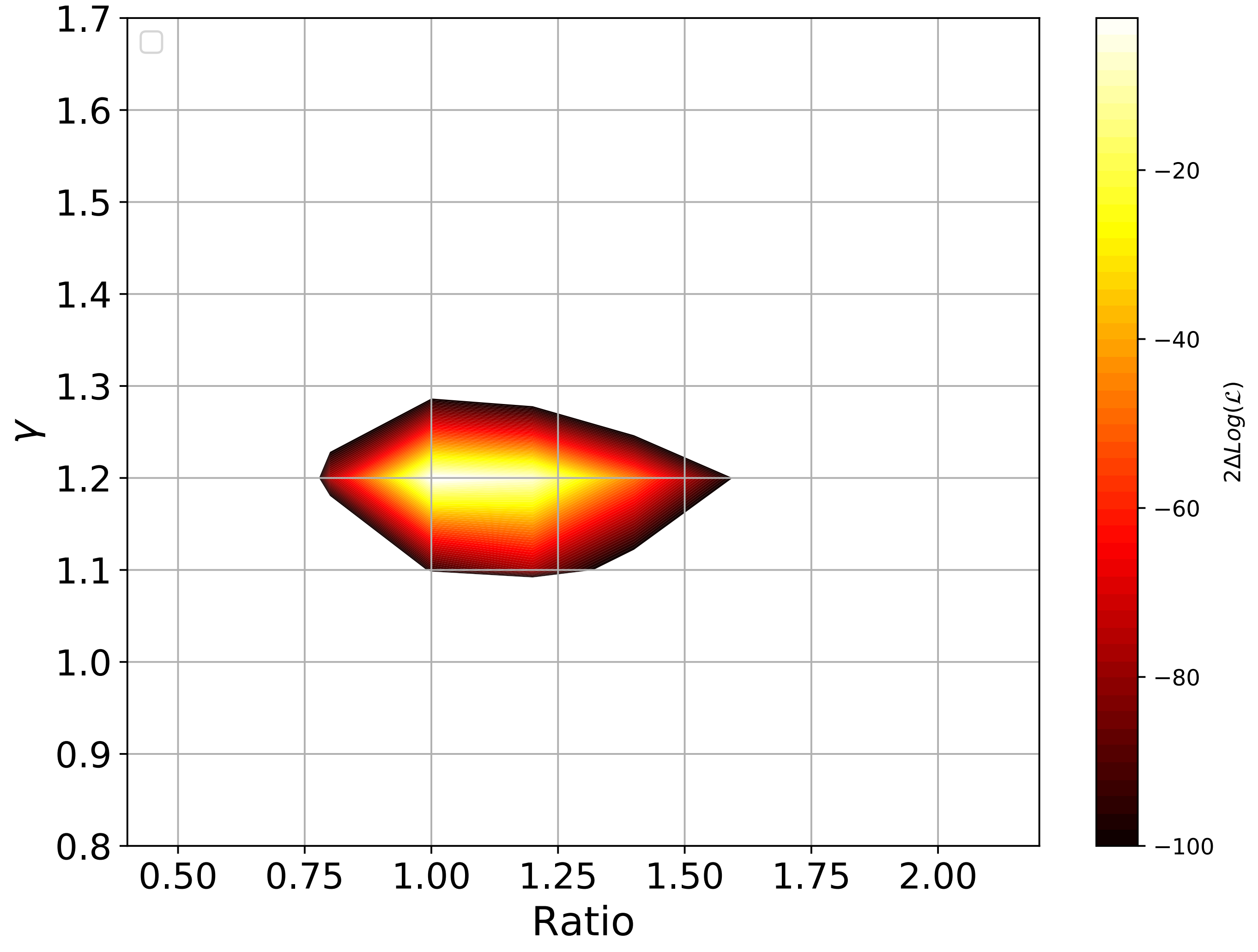


Centered in the GC



gamma=1.25



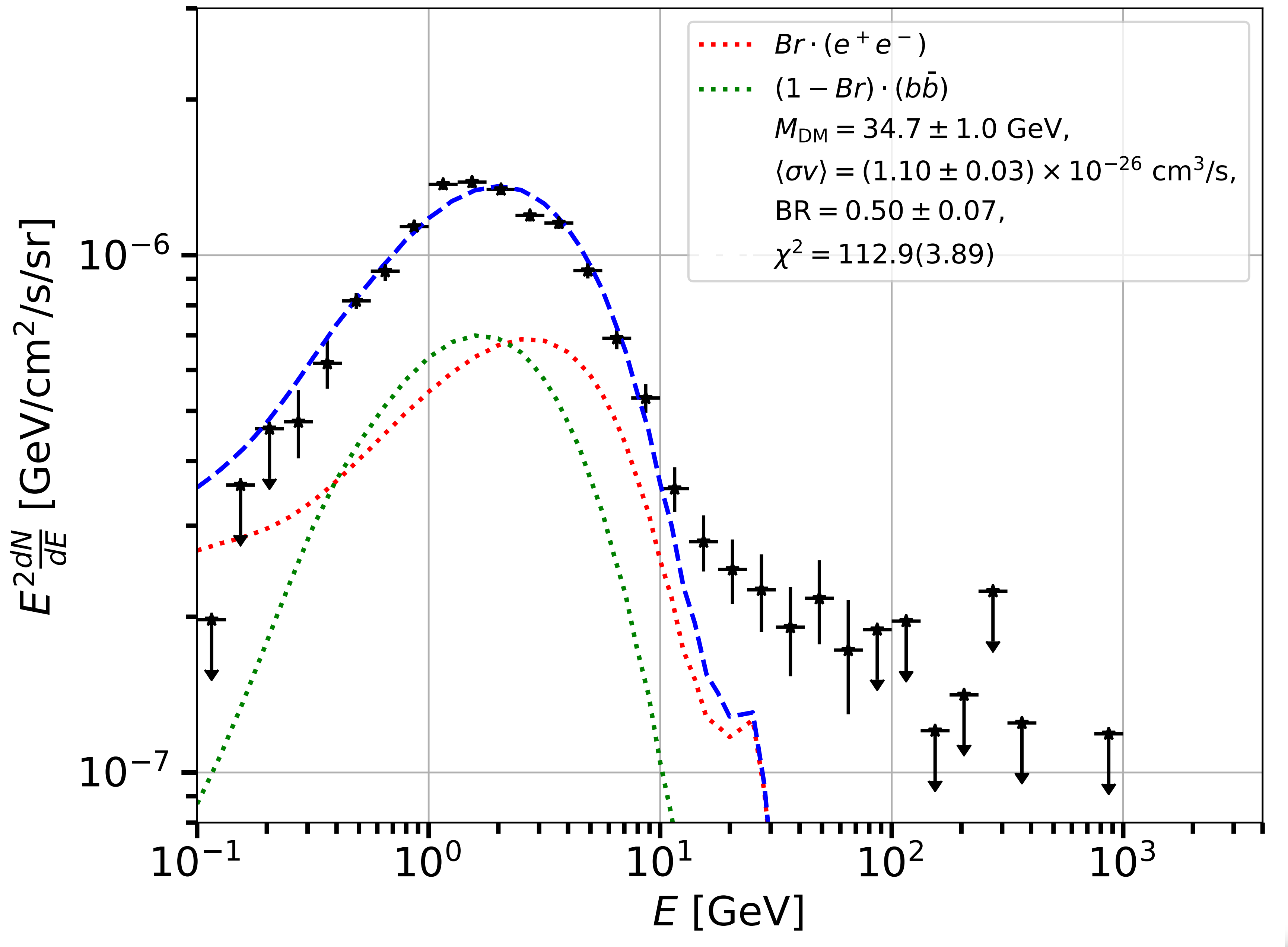


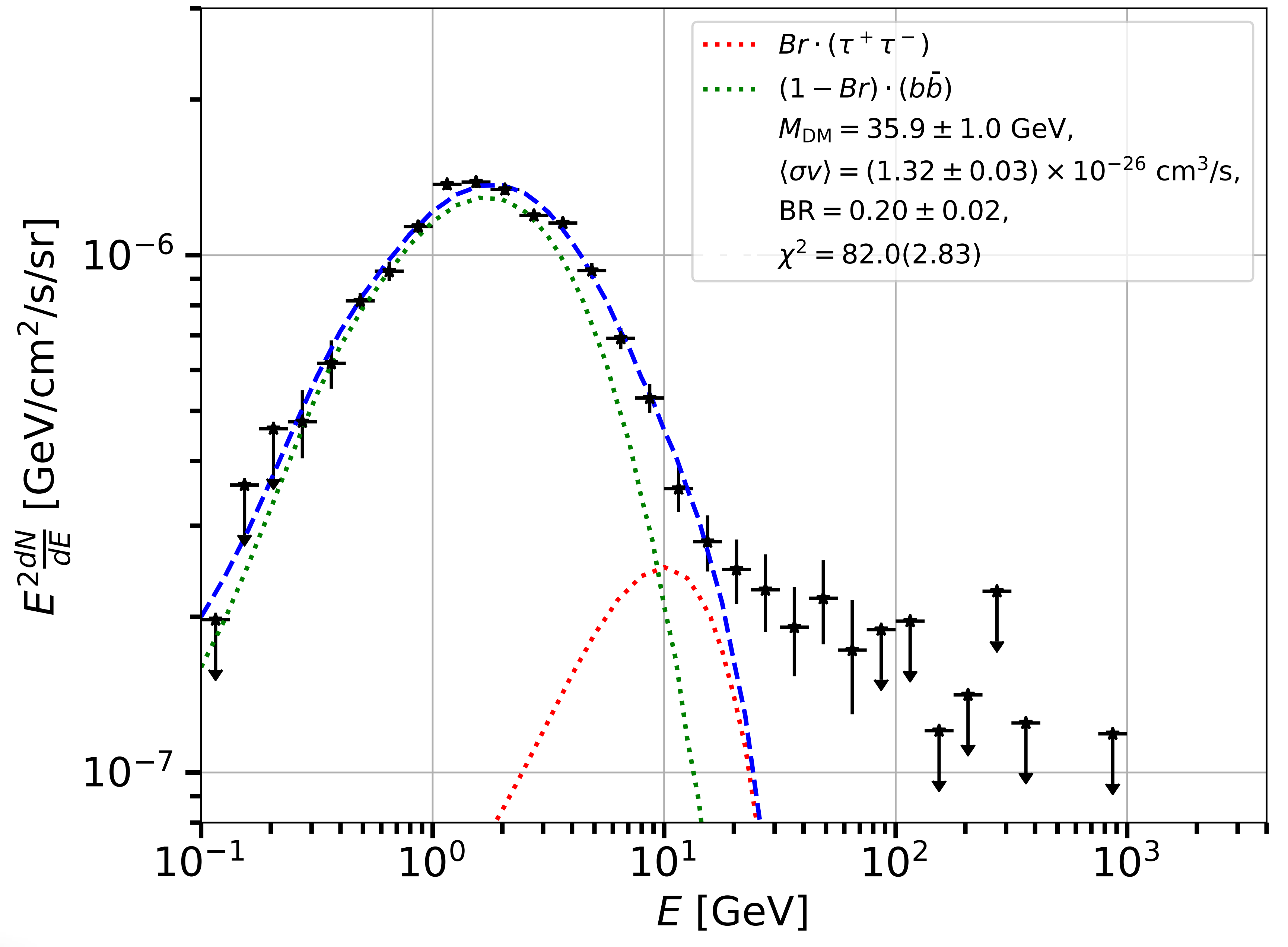
Paper III

Fitting the GCE data with two channels

Channel 1	Channel 2	$M_{\rm DM}$ [GeV]	$\langle\sigma v\rangle$ [10^{-26} cm^3/s]	Br	$\chi^2(\tilde{\chi}^2)$	$\Delta\chi^2$(sign.)
$\tau^+\tau^-$	$b\bar{b}$	35.9	1.32	0.20	82.0(2.83)	82(9.0σ)
$\mu^+\mu^-$	$b\bar{b}$	47.8	2.42	0.65	90.5(3.12)	74(8.4σ)
e^+e^-	$\tau^+\tau^-$	27.1	0.95	0.84	113.7(3.92)	31(5.4σ)
e^+e^-	$c\bar{c}$	24.3	0.79	0.50	112.3(3.87)	32(5.5σ)
e^+e^-	$b\bar{b}$	34.7	1.10	0.50	112.9(3.89)	32(5.5σ)
$c\bar{c}$	$b\bar{b}$	33.8	1.11	0.32	115.1(3.97)	61(7.7σ)

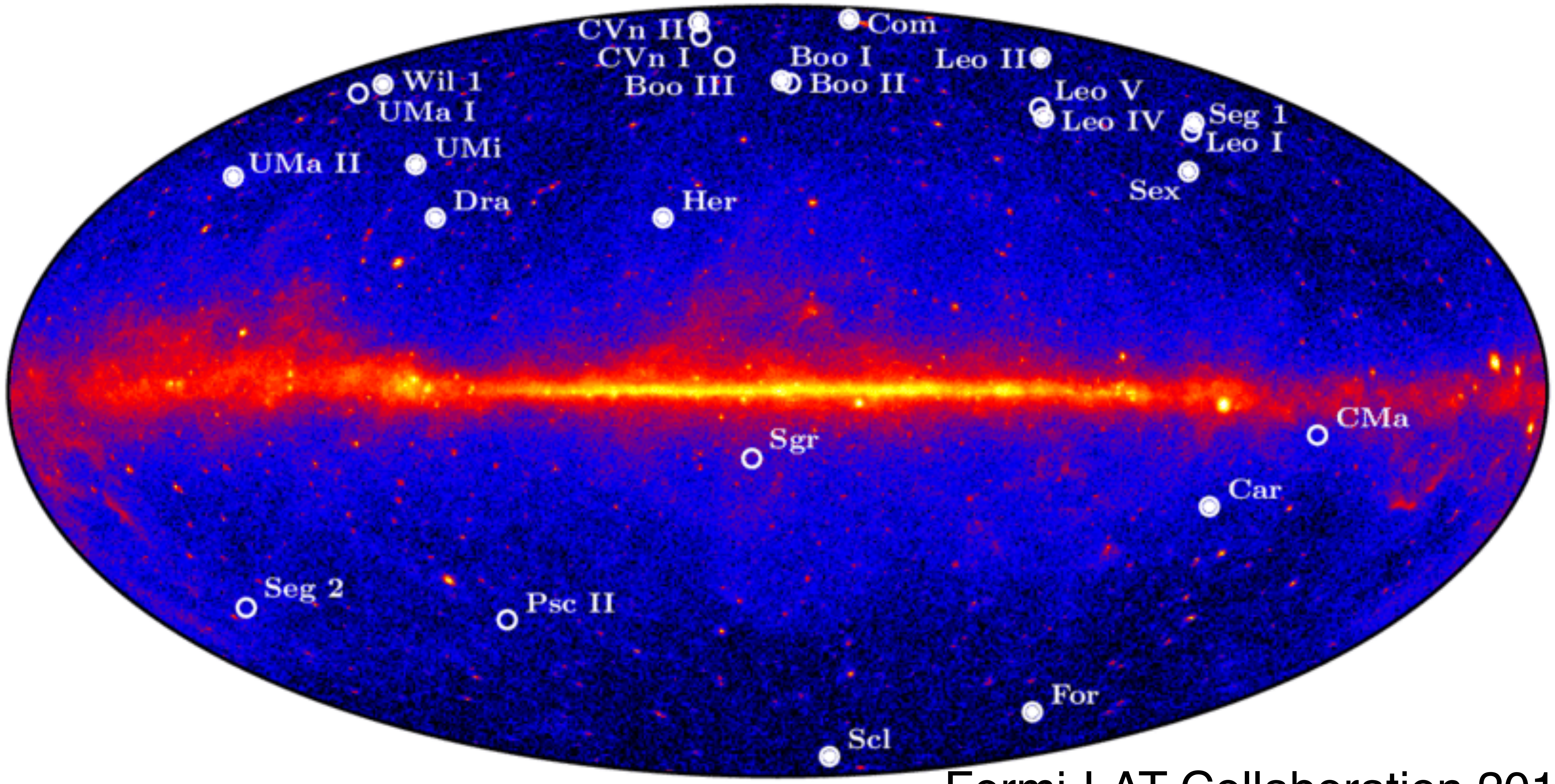
$$\frac{dN_\gamma}{dE} = Br\frac{dN_{\tau^+\tau^-}}{dE} + (1-Br)\frac{dN_{b\bar{b}}}{dE}$$





Milky Way dwarf spheroidal satellite galaxies

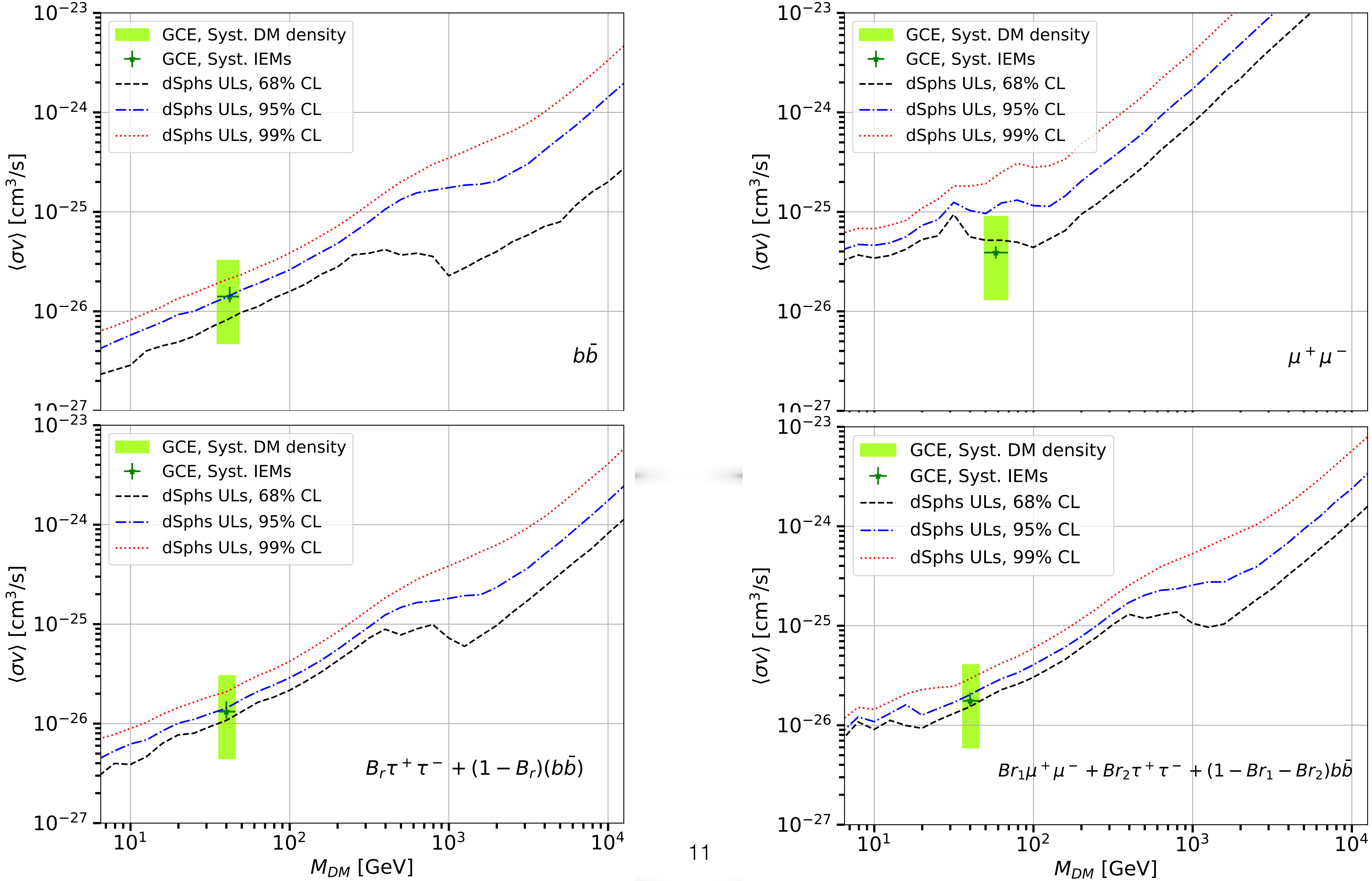
- dSphs are among the most promising targets for the indirect search of DM with γ-rays.
- Mass-to- luminosity ratio of the order of 100 – 1000.
- They have an environment with predicted low astrophysical background



Fermi-LAT Collaboration 2013

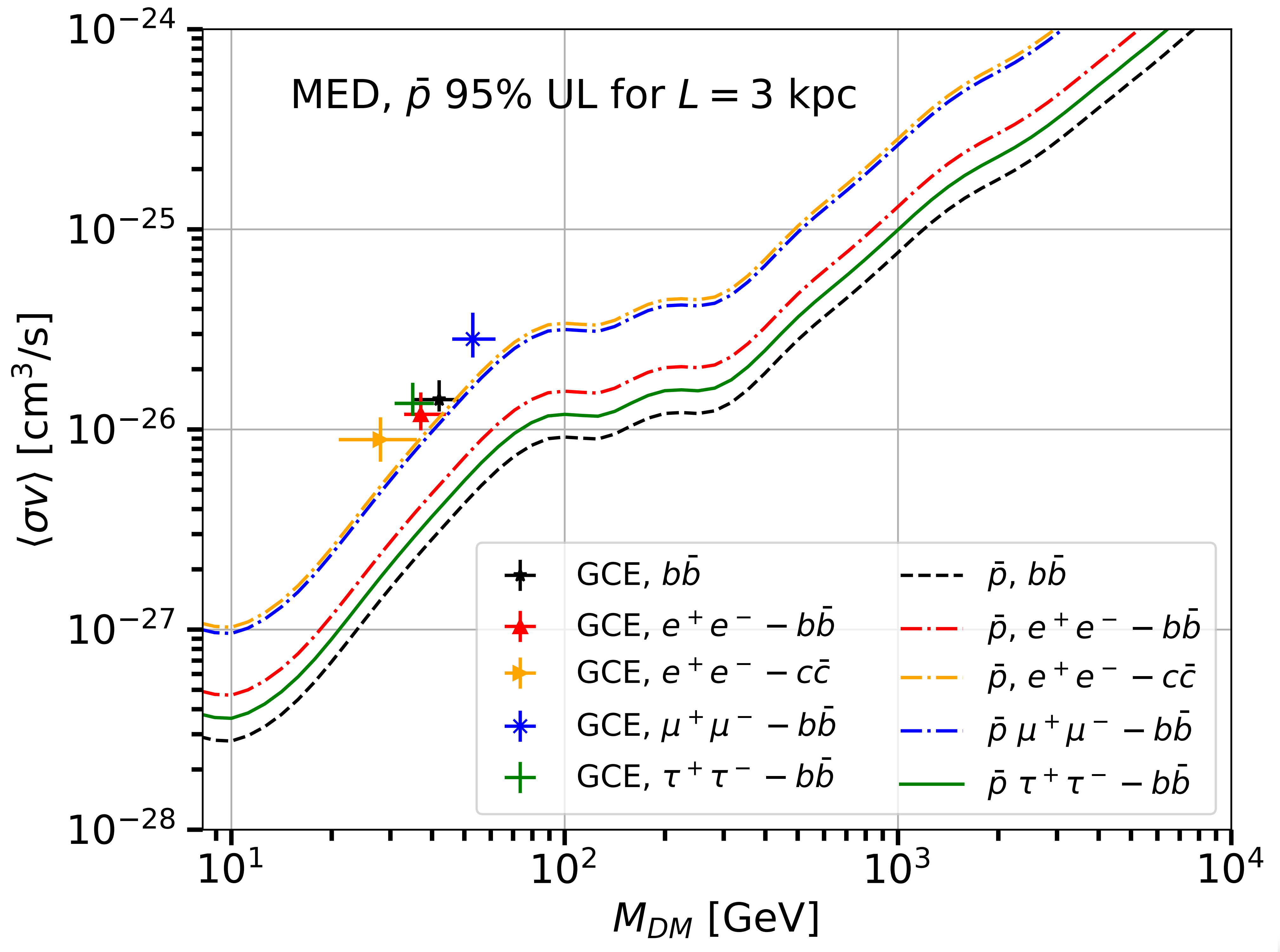
Paper III

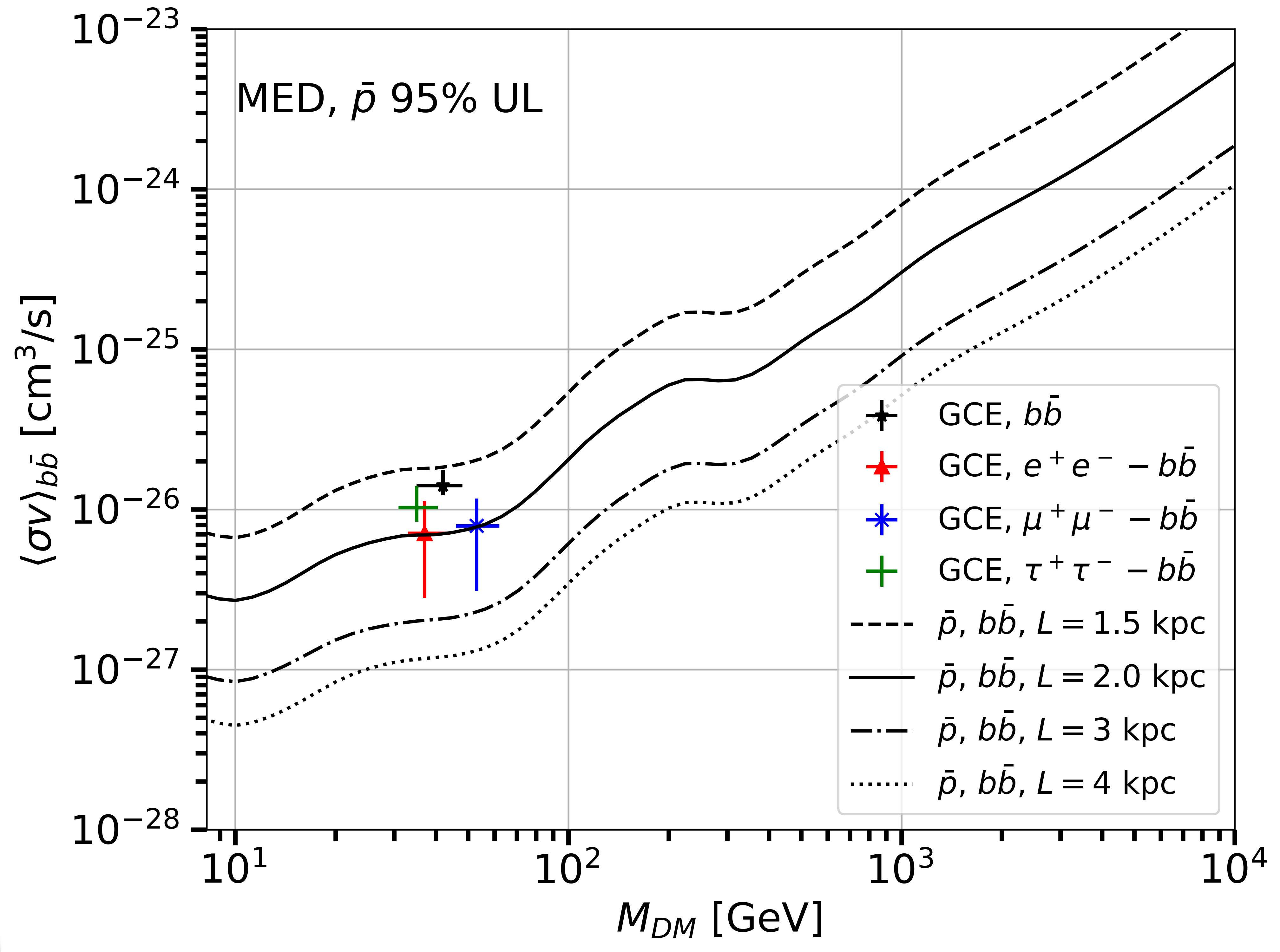
dSphs vs GCE



Antiprotons vs GCE

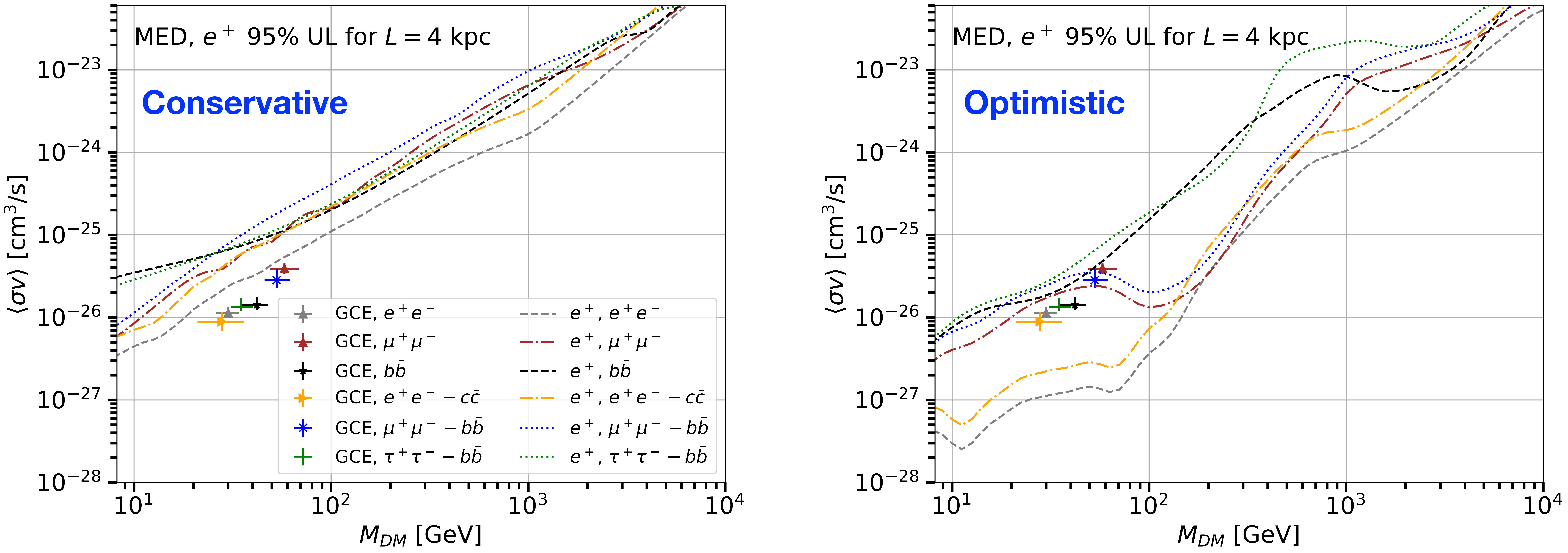
- GCE DM candidates with purely hadronic final states compatible with ULs only for L < 1.8 kpc.
- This constraints on L are relaxed for semi-hadronic final states with L ≤ 2.6 kpc, respectively.
- ULs on L are 2-3σ below results obtained with latest radioactive CR data.





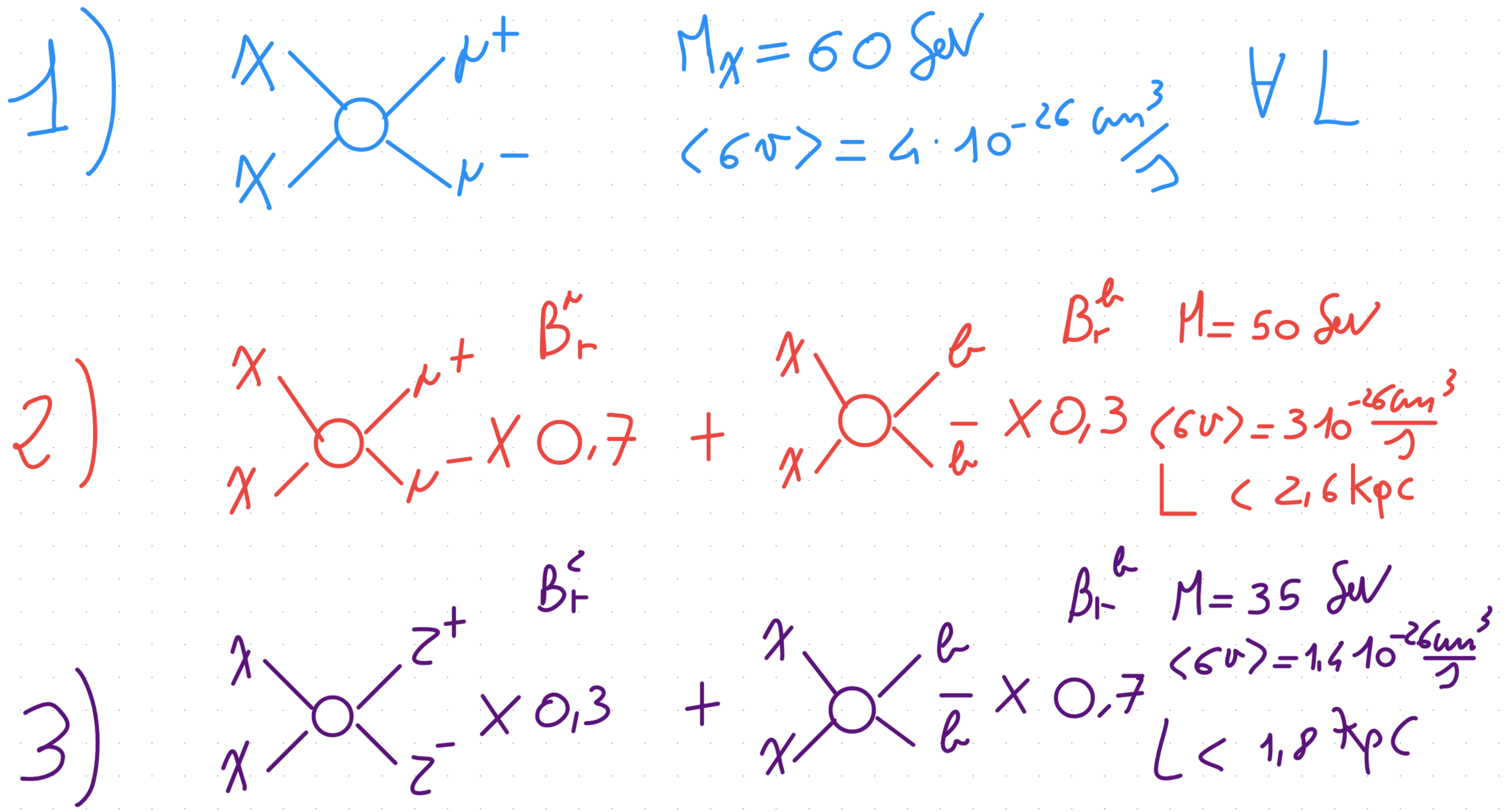
Positrons vs GCE

- The conservative upper limits are all compatible with the GCE.
- Instead, the optimistic ones are compatible for the bb, and mixed channels with muons and tau leptons.
- The channels with electrons are below the GCE DM candidates cross sections.



Conclusions

- **The GCE has all the right characteristics to be due to annihilating DM particles.**
- ULs from dSphs are compatible with the GCE candidates.
- ULs from antiprotons put tight constraints on purely hadronic final state DM.
- ULs from positrons put severe constraints on DM annihilating, even partially, into electrons.



Points for discussion and open questions

- What's the origin of the GCE?
  - Further study are needed about the pulsar contribution.
  - Several of these pulsars in the Galactic bulge should be probably already detected by Fermi-LAT.
- Improve the Galactic interstellar emission model and use latest Fermi-LAT catalogs to improve even more the measurements for the GCE.
- Study the GCE and CRs upper limits in the contest of Beyond Standard Model theories.
  - Connect study of dark matter from astroparticle physics with direct detection and collider searches.