The dark matter interpretation of the Fermi-LAT Galactic center excess

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On Behalf of the Fermi-LAT Collaboration

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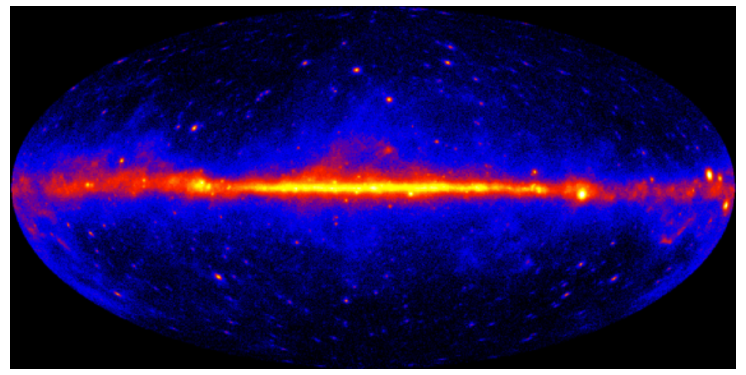
The GeV Excess in the Galactic Center



Fermi Sky

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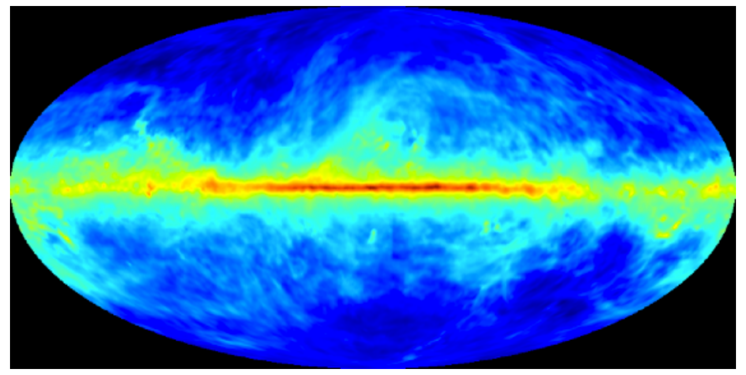

Galactic IEM

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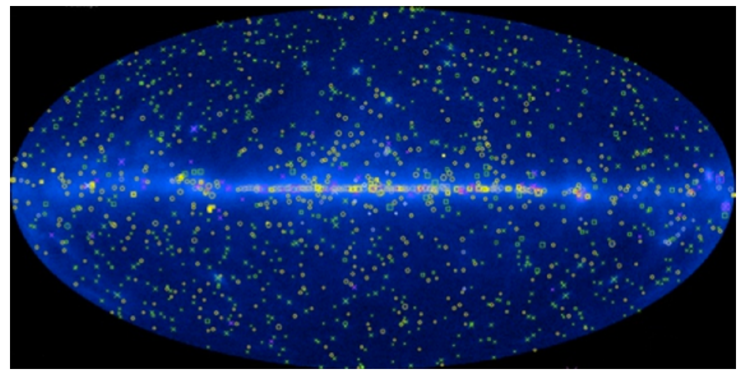

Point Sources

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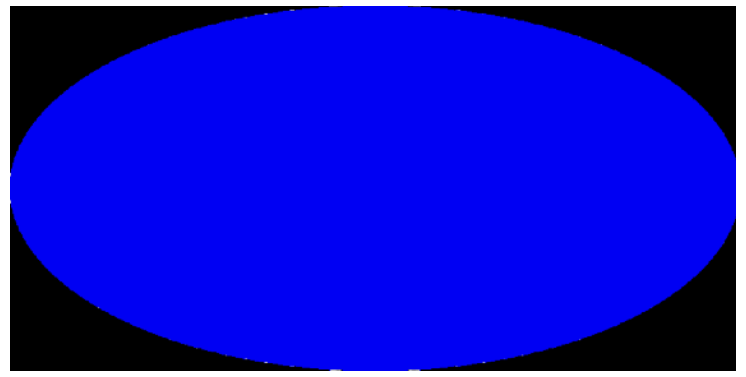

Isotropic

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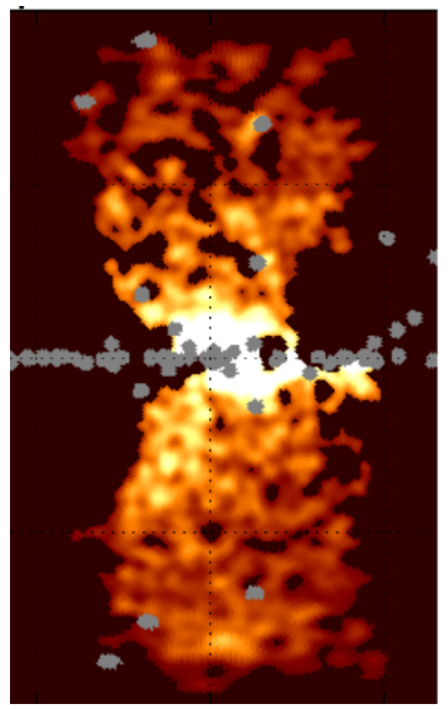

Fermi Bubbles

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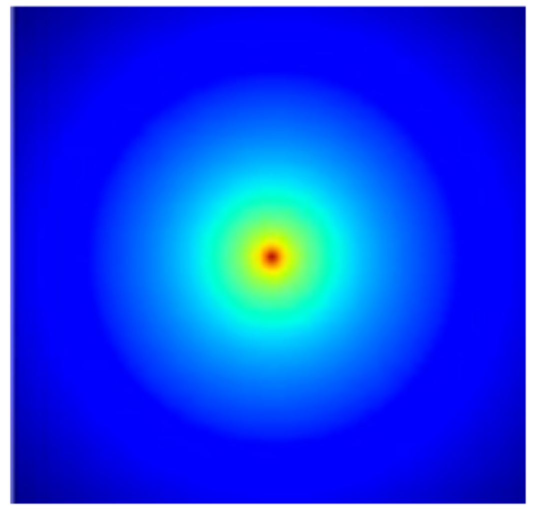
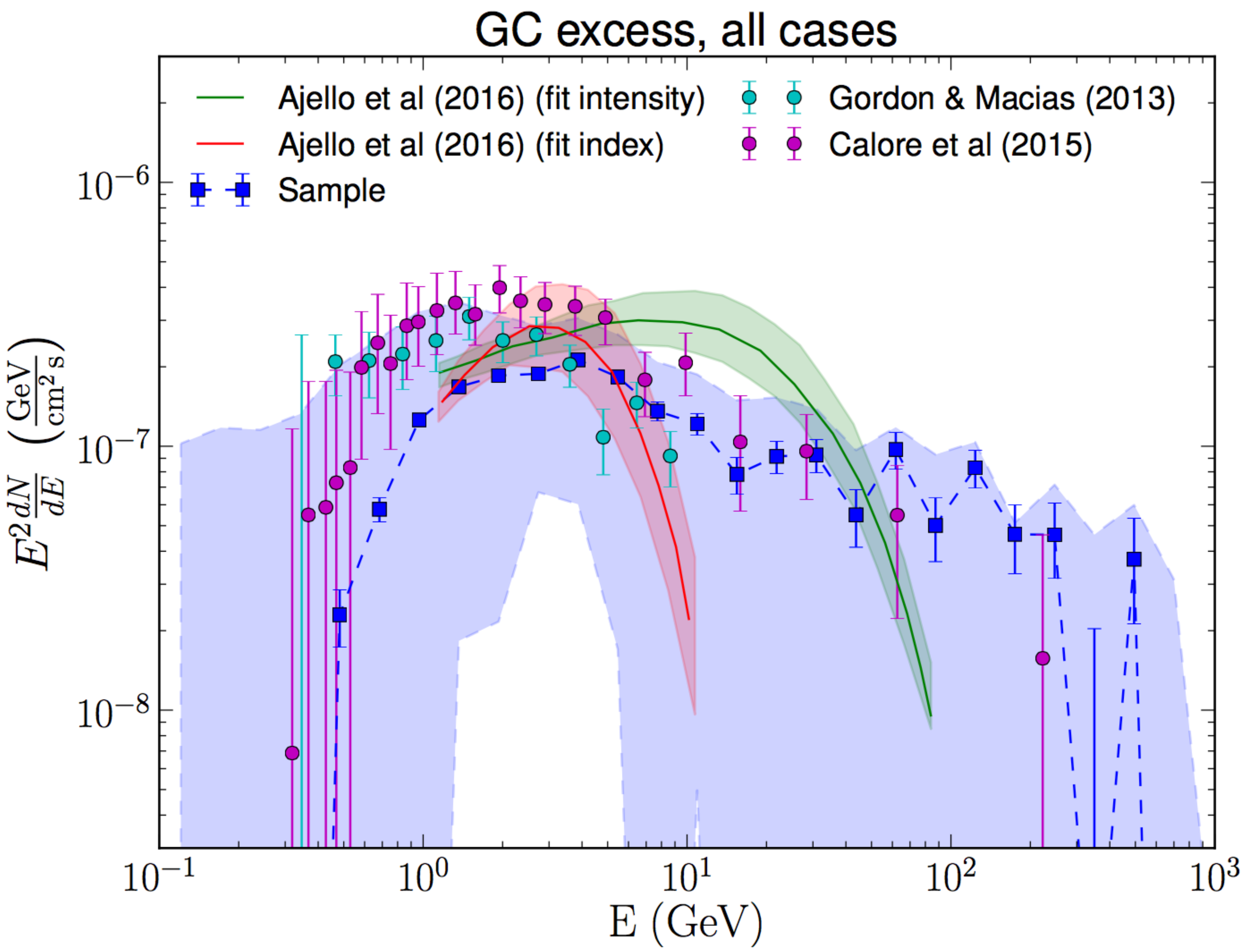


DM

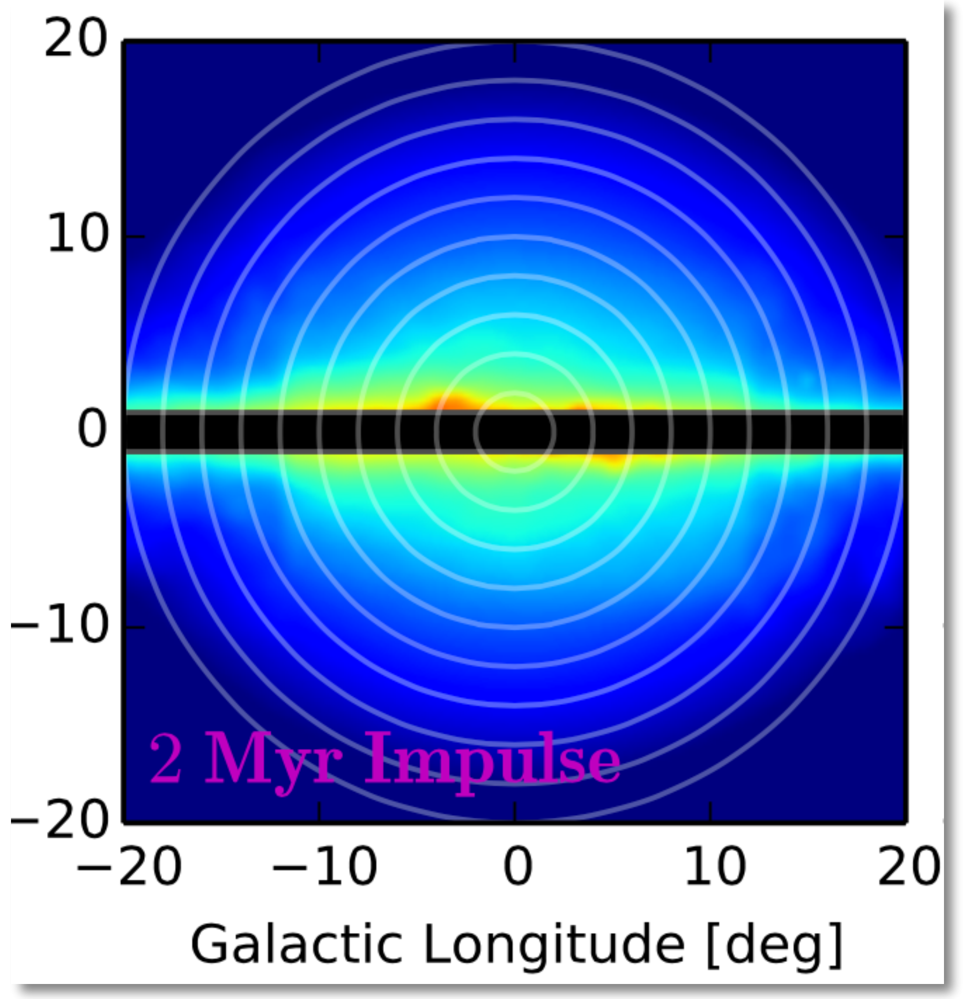


Ajello et al. 2017

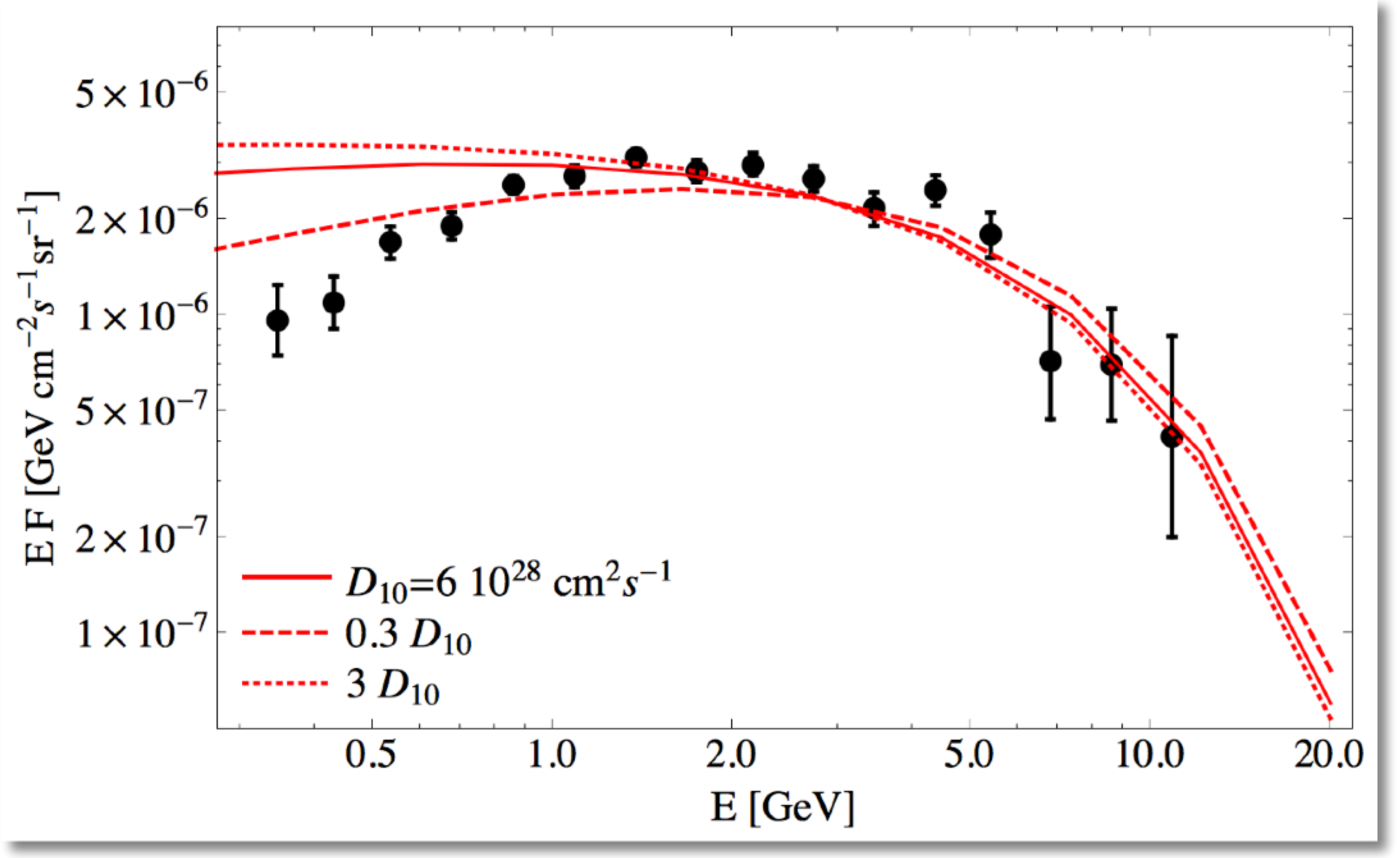
- **Bright** and highly significant.
- **Spatially symmetric** around the Galactic center: $dN/dV \propto r^{-2.5}$ —> compatible with a gNFW profile.
- **Energy spectrum peaked at a few GeV** —> DM annihilating into a bb M_{DM}=40 GeV.
- **Annihilation cross** section roughly equal to the thermal cross section.

Possible interpretations of the GeV excess

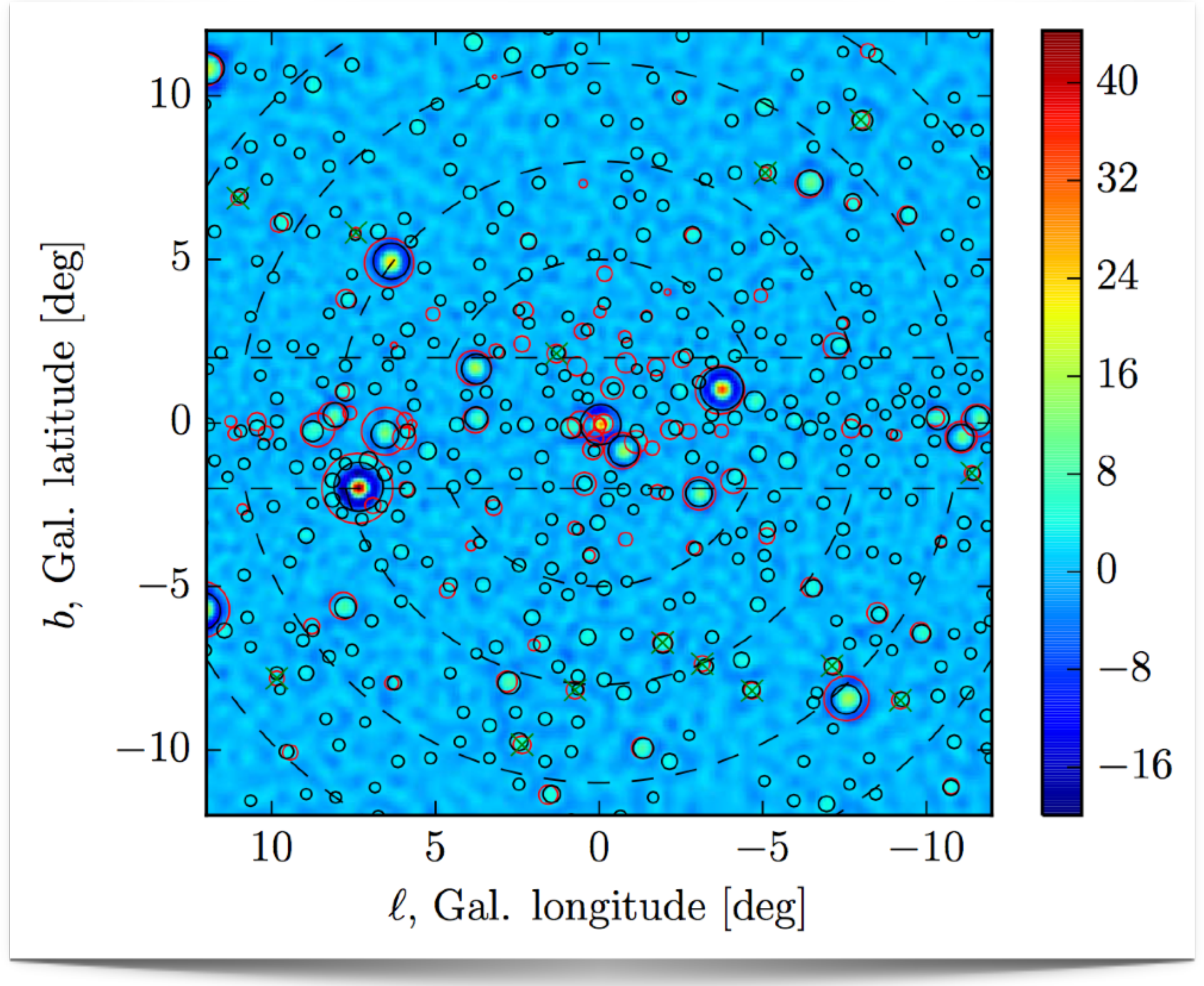
- Possible interpretations:
  - Recent outbursts of CR protons or of CR leptons.
    - **Hadronic scenario:** γ-ray signal extended along the Galactic plane (Petrovic et al. 2014).
    - **Leptonic outburst:** correct spatial distribution but it requires at least two outbursts (Petrovic et al. 2014; Carlson et al. 2014; Cholis et al. 2015a; Gaggero et al. 2015).
  - **Additional population of supernova remnants near the GC** (Gaggero et al. 2015; Carlson et al. 2016).
  - **Population of faint pulsars** distributed in the Galactic bulge of our Galaxy (Bartels et al. (2015), Lee et al. (2015), Macias et al. 2016-2020).
  - **Dark matter particle annihilation** (Hooper et all. 2009-2011, Calore et al. 2014-2015,…..).
- **Recent debate on the pulsar vs DM interpretation:** ***Leane et al. 2019/2020, Chang et al. 2019, Zhong et al. 2019, Buschmann et al. 2020, Calore et al. 2021.***



Carlson et al. 2014



Petrovic et al. 2014



Bartels et al. 2015

Overview of the 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)

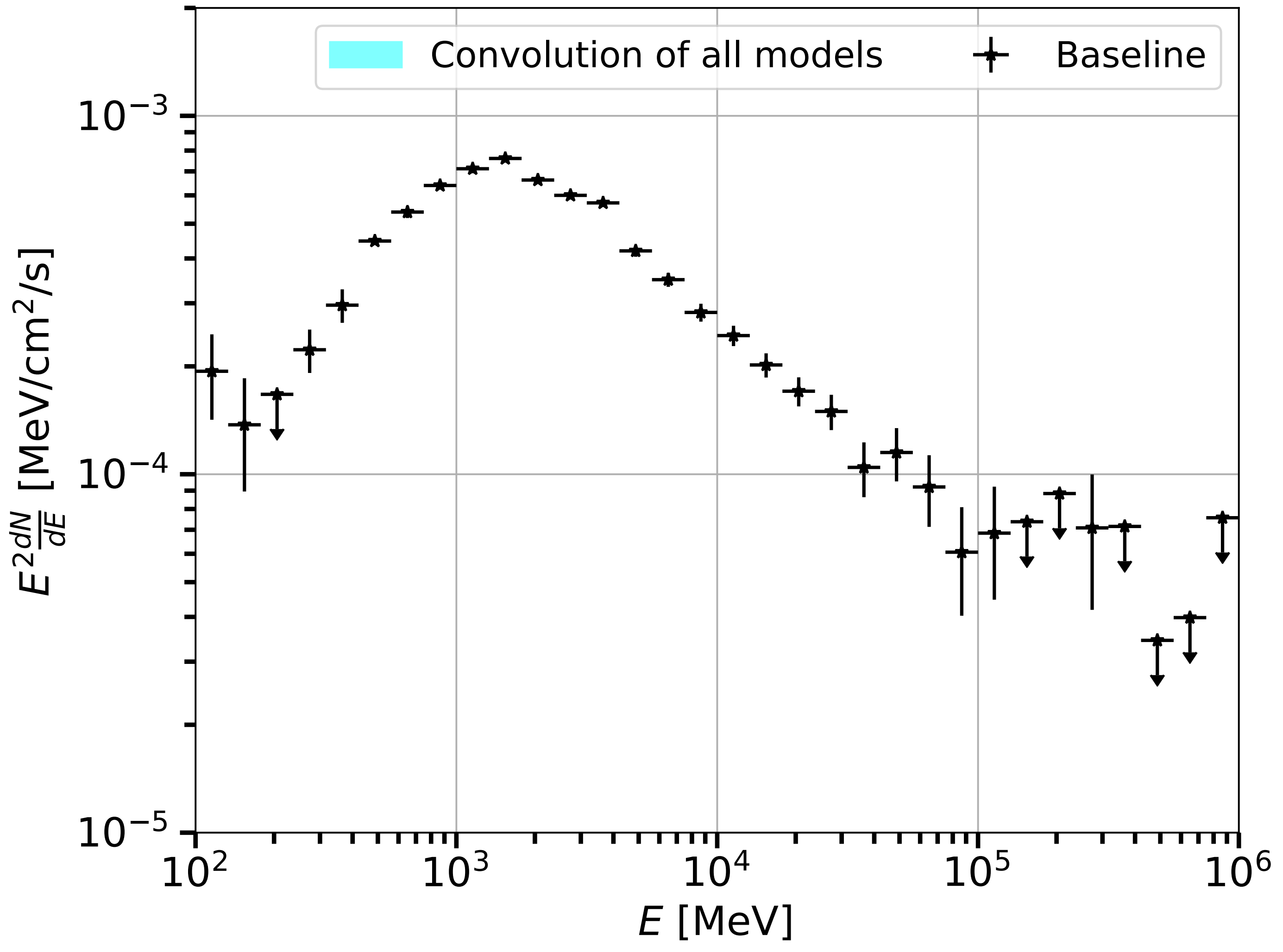
Mattia Di Mauro
Istituto Nazionale di Fisica Nucleare, via P. Giuria, 1, 10125 Torino, Italy

Martin Wolfgang Winkler
Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden

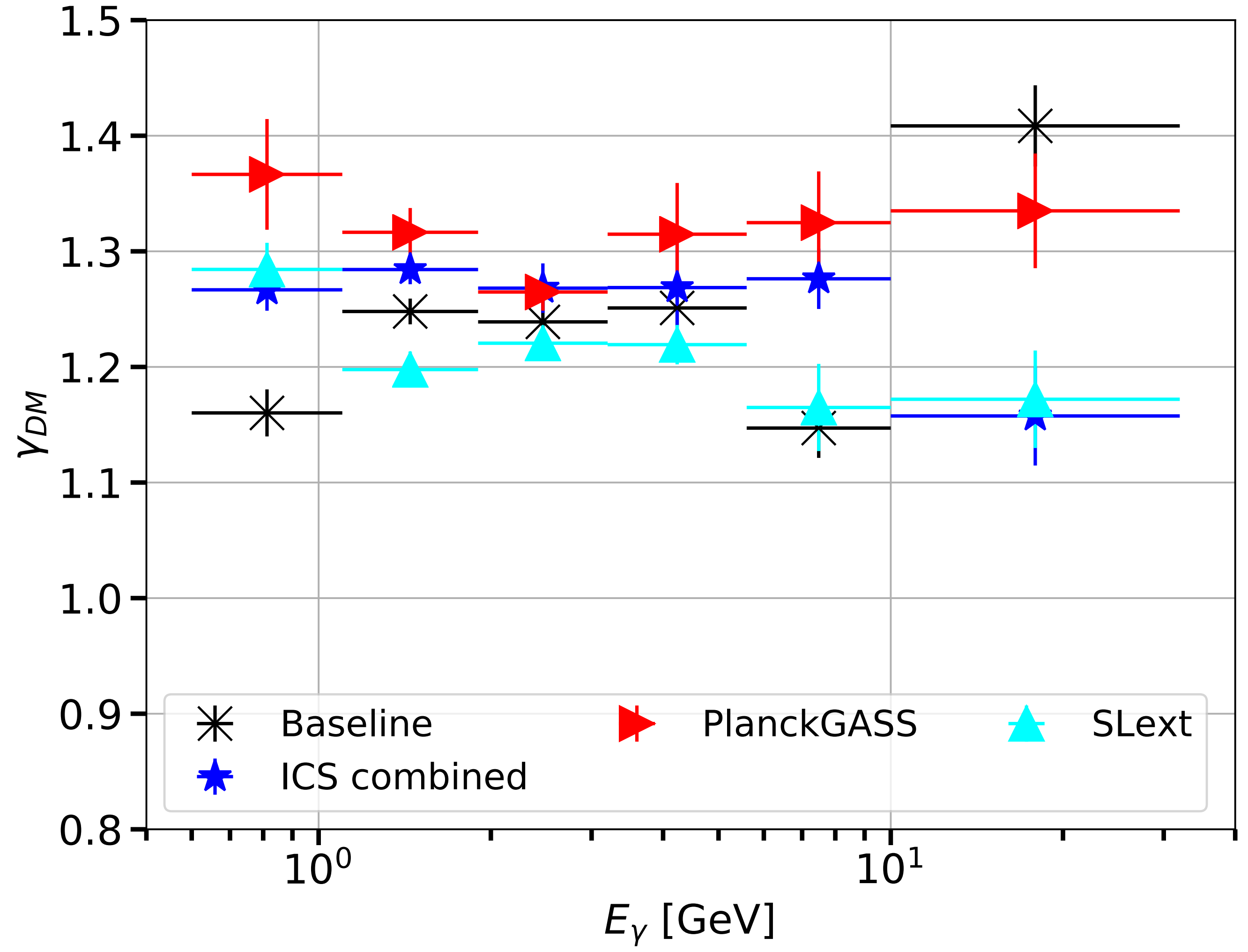
Paper II

Characteristics of the GCE: Summary

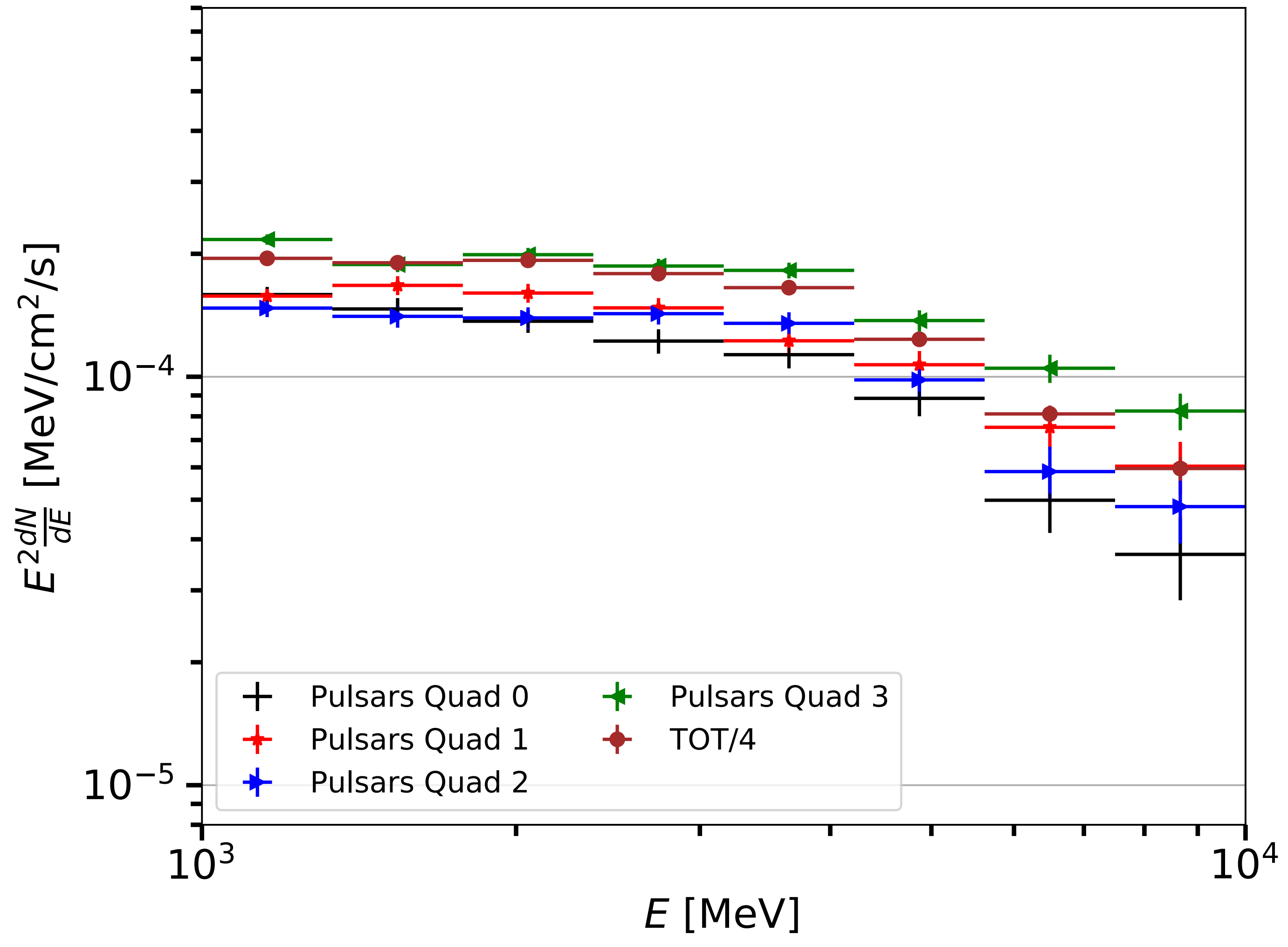
Spectrum peaked at a few GeV



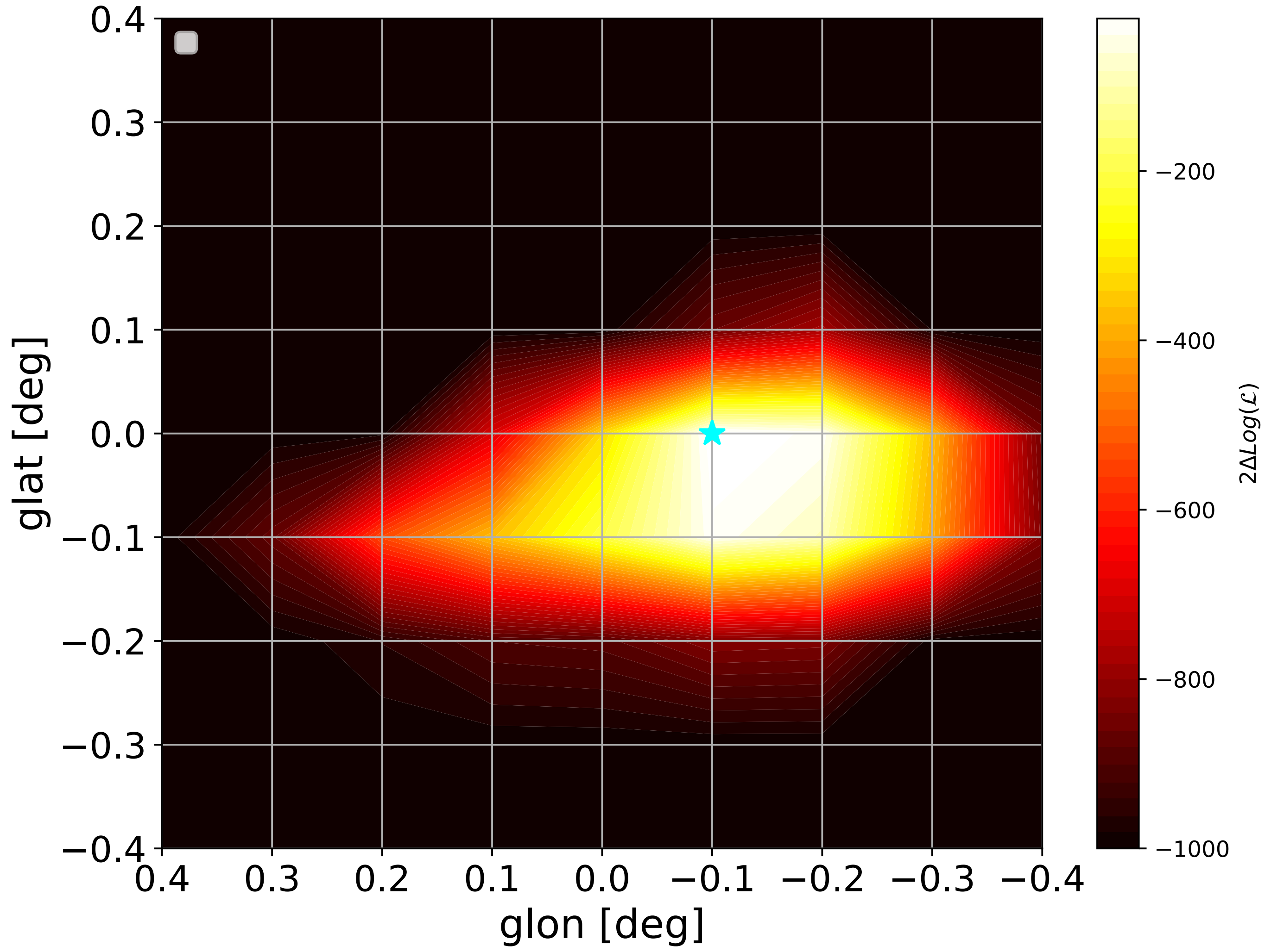
No energy dependence of spatial morphology.



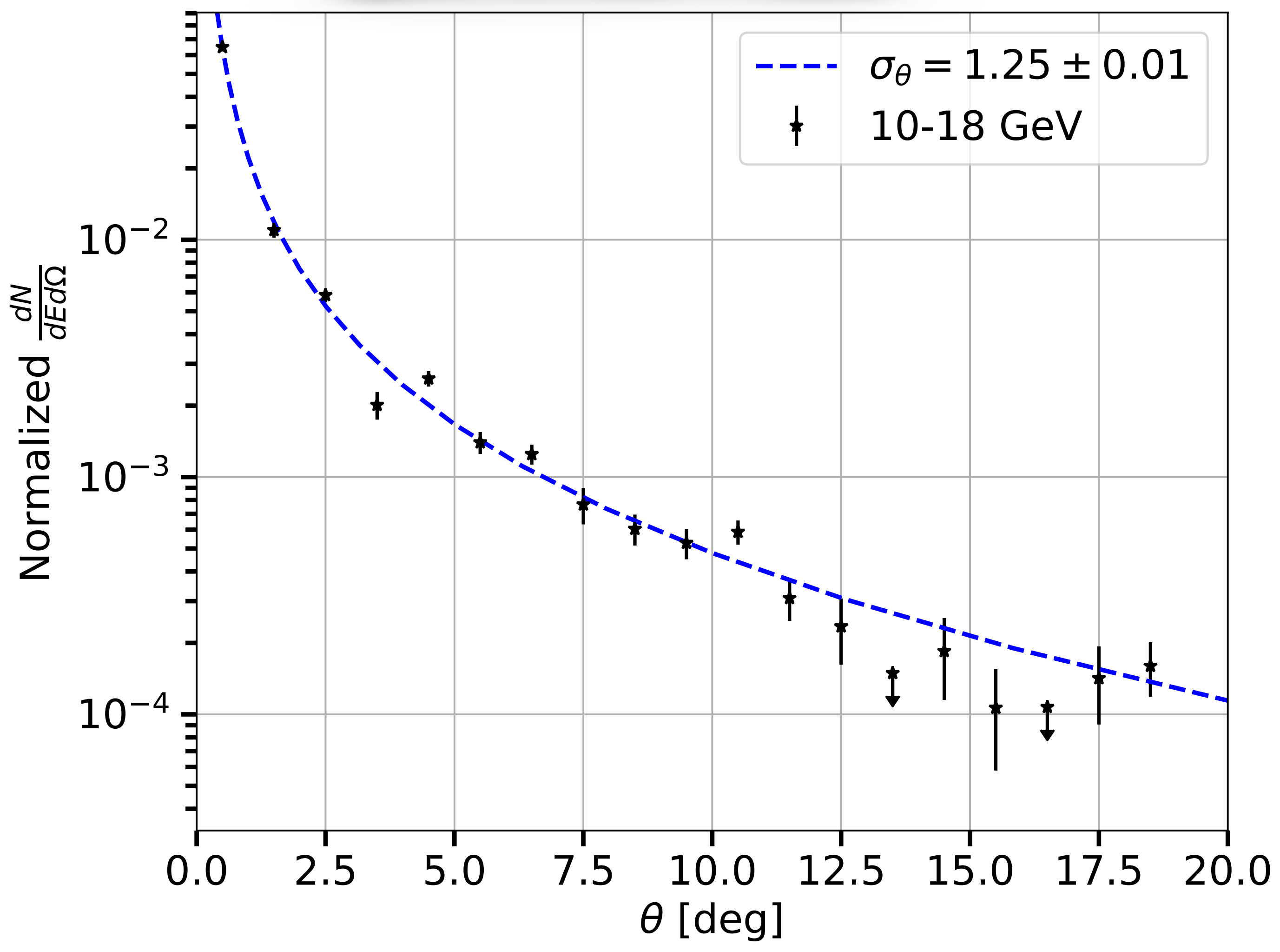
The GCE is approximatively spherically symmetric.

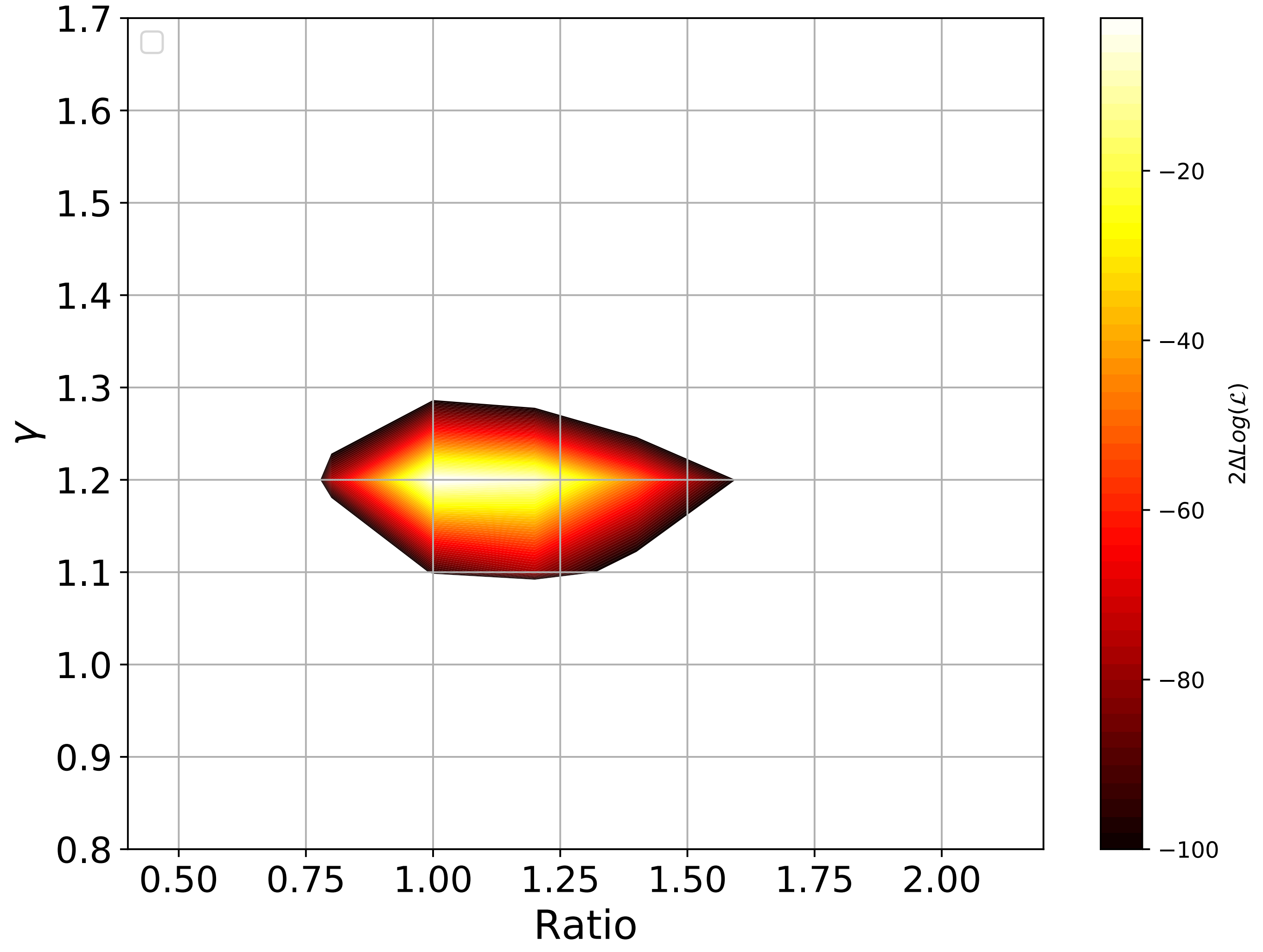


Centered in the GC



gamma=1.25





Paper III

Dark matter density distribution

Salas et al. 2019 Rotation curve galaxy data

DM density	slope	ρ_s [GeV/cm^3]	r_s [kpc]	$\bar{\mathcal{J}}$
$\rho_\odot = 0.30$ GeV/cm^3 $M_{200} = 5.5 \cdot 10^{11}$ $M_\odot$				
gNFW	1.20	0.416	12.87	111.5
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
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

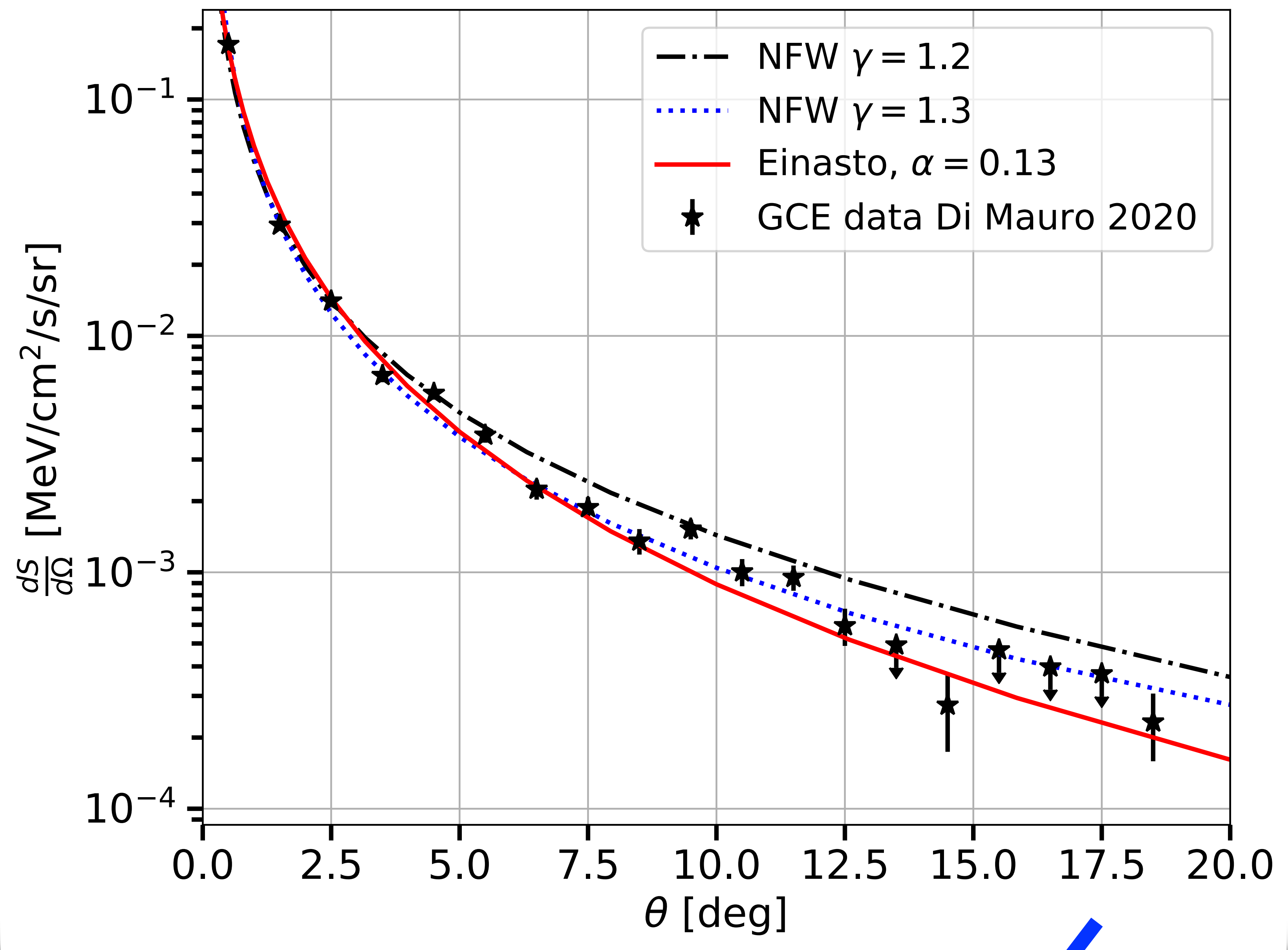
MIN

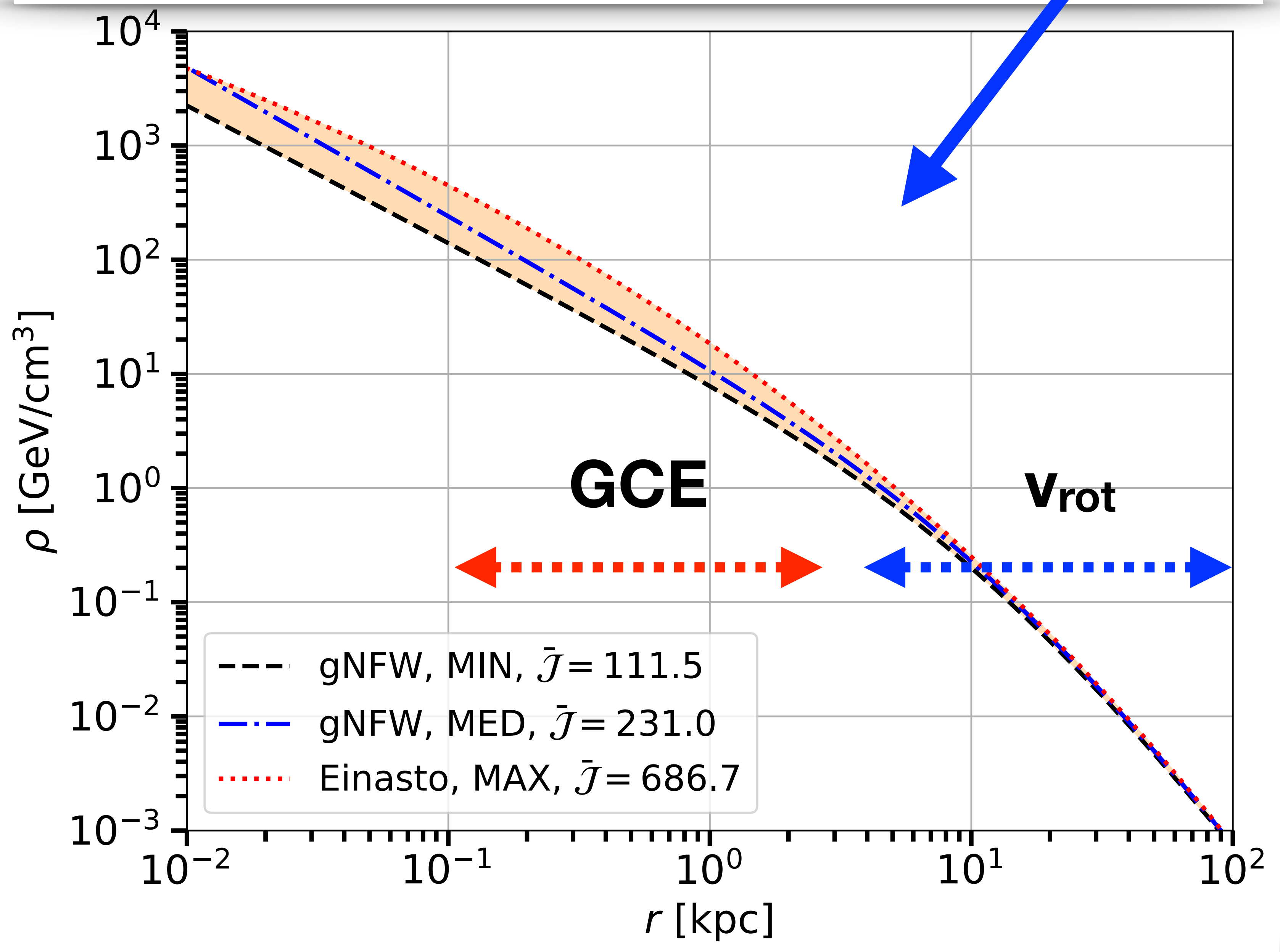
MED

MAX

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

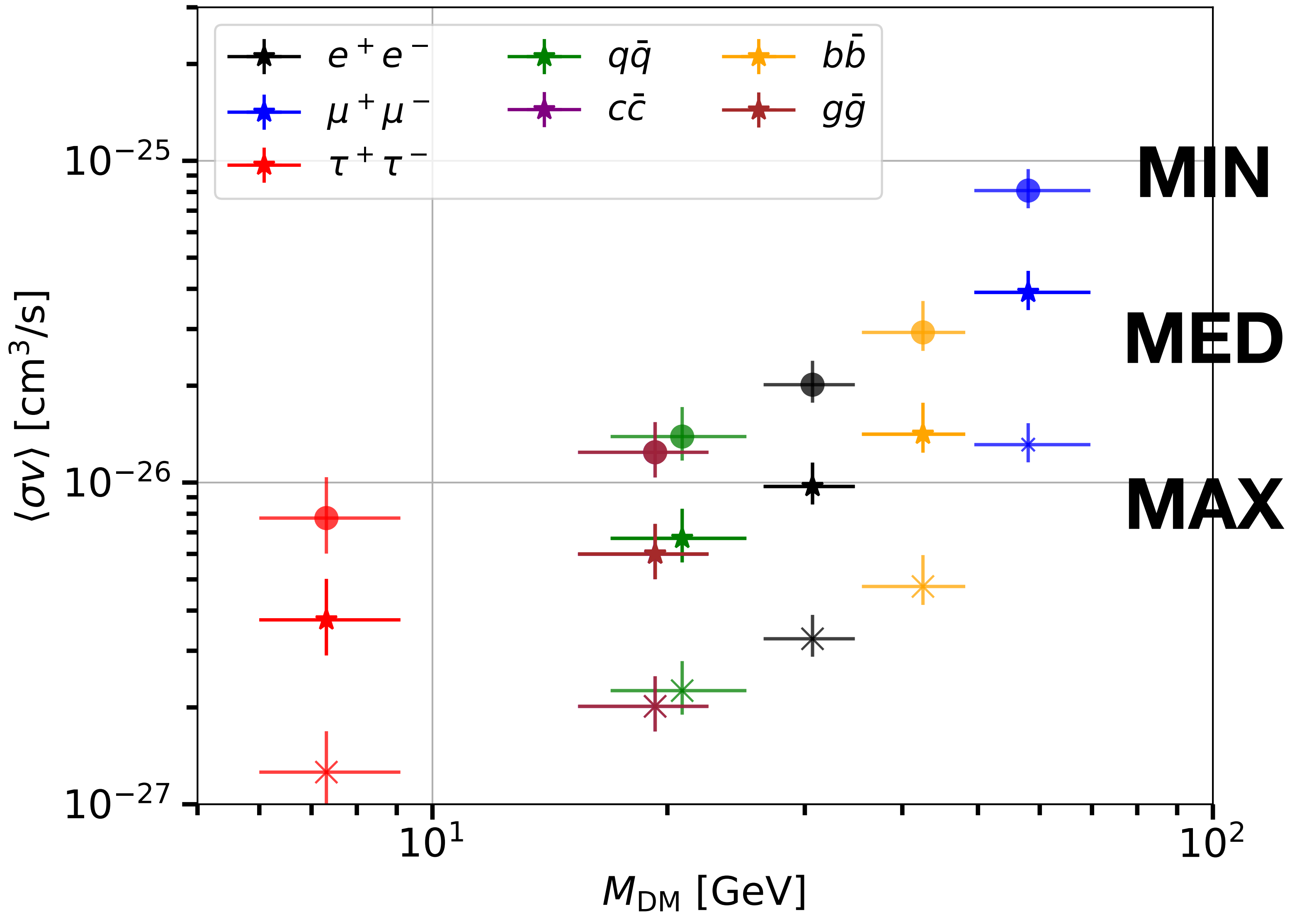
Geometrical factor integrate in our ROI

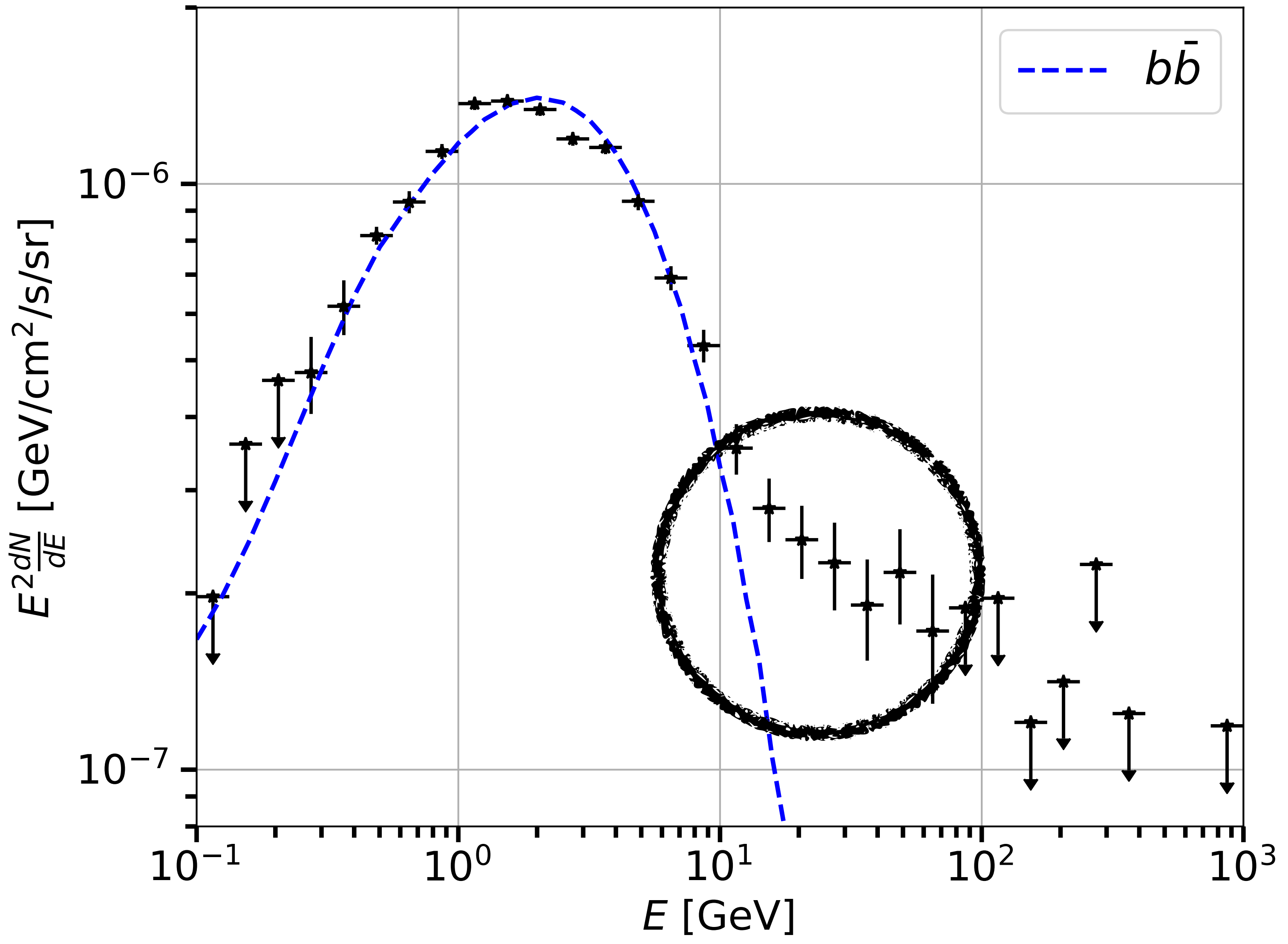




Fitting the GCE SED data with DM

One Channel

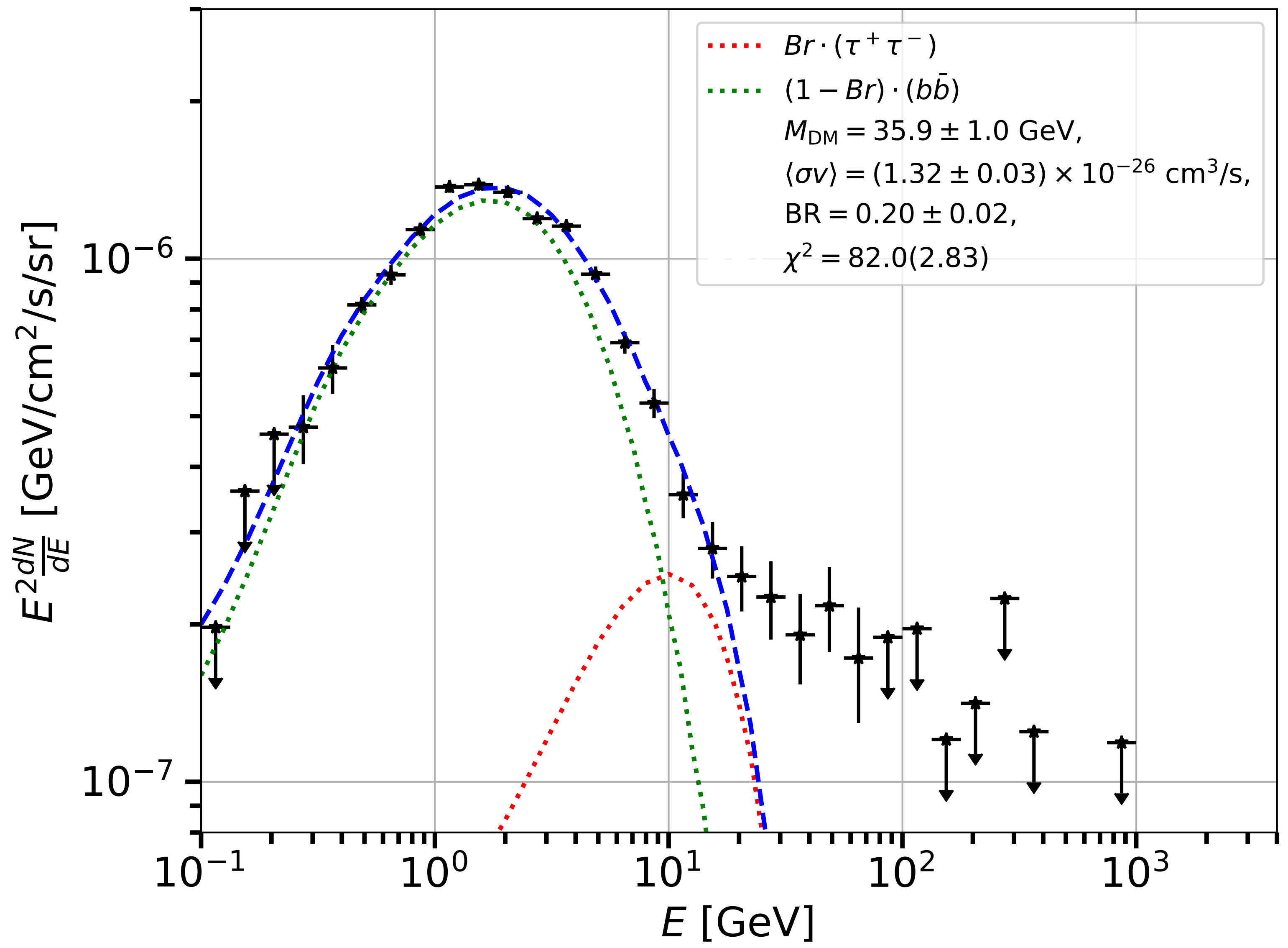




Two Channels

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

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)



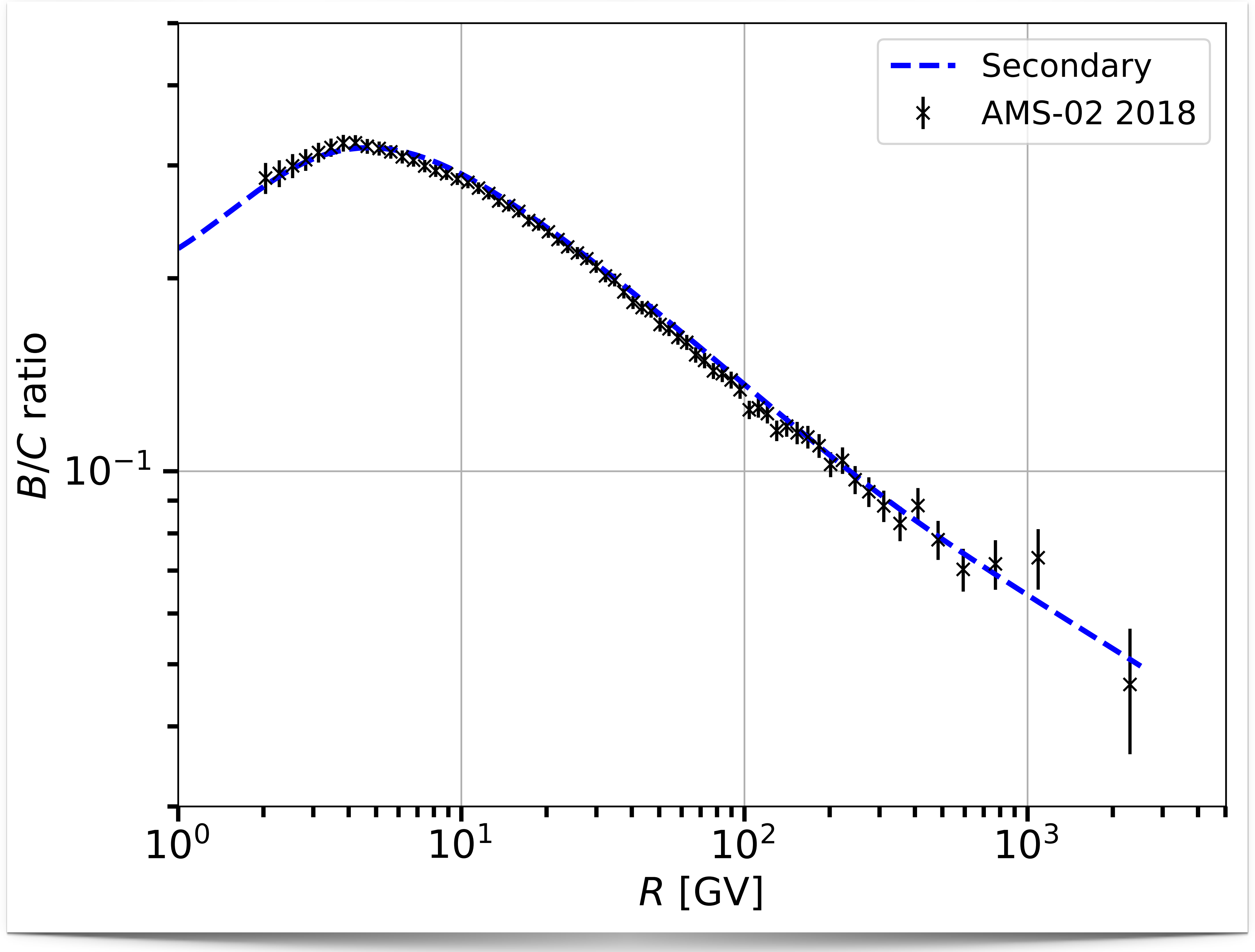
Stacking analysis for dSphs

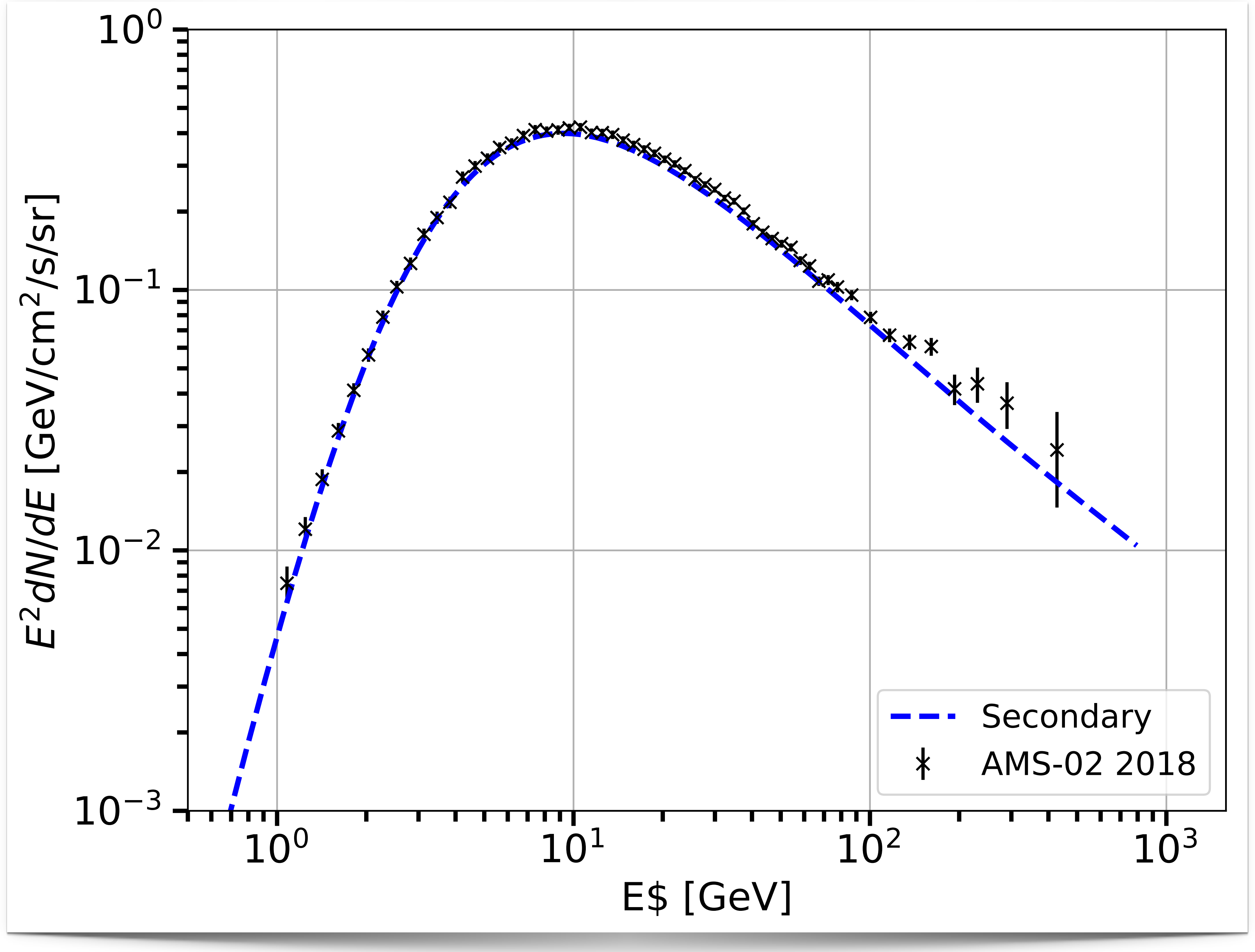
- We perform a combined analysis of 48 dSphs (taken from Pace and Strigari 2018).
  - We also test the sample from Albert et al. 2017.
- There is no significant emission in the stacked sample.
- The DM interpretation of the GCE is compatible with the constraints from dSphs.

Antiprotons vs GCE

- We use the same analysis as in **Reinert and Winkler 2018**.
  - A combined fit to AMS-02 and Voyager p, AMS-02 and Pamela anti-p, AMS-02 B/C is performed.

- **δ = 0.459**
- **L = 4 kpc (fixed)**
- **K_0 = 0.042 kpc²/Myr**
  - **K_0/L should stay fixed**
- **Fisk potential I use phi = 0.72 GV**

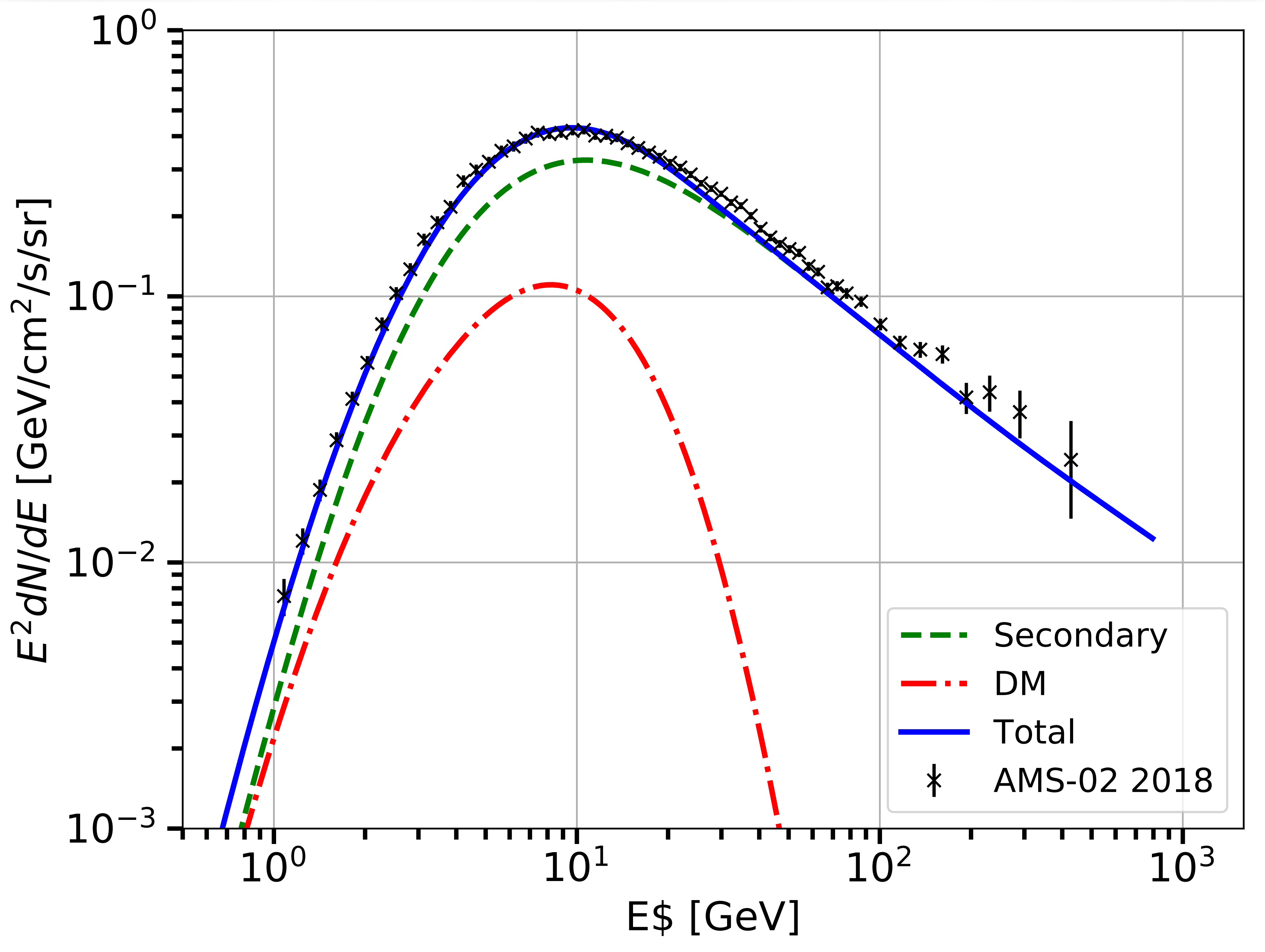


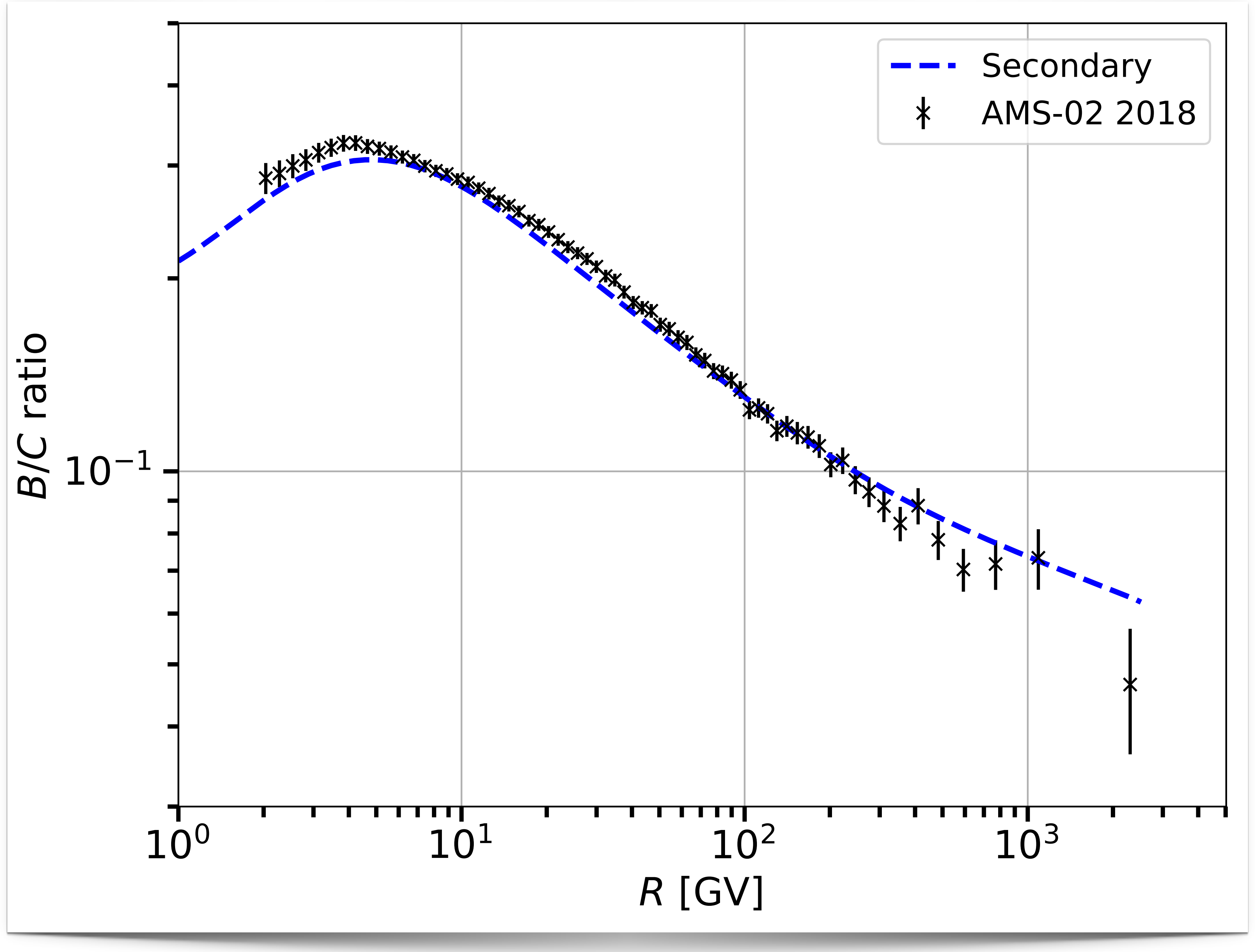


Antiprotons vs GCE

- We use the same analysis as in **Reinert and Winkler 2018**.
  - A combined fit to AMS-02 and Voyager p, AMS-02 and Pamela anti-p, AMS-02 B/C is performed.

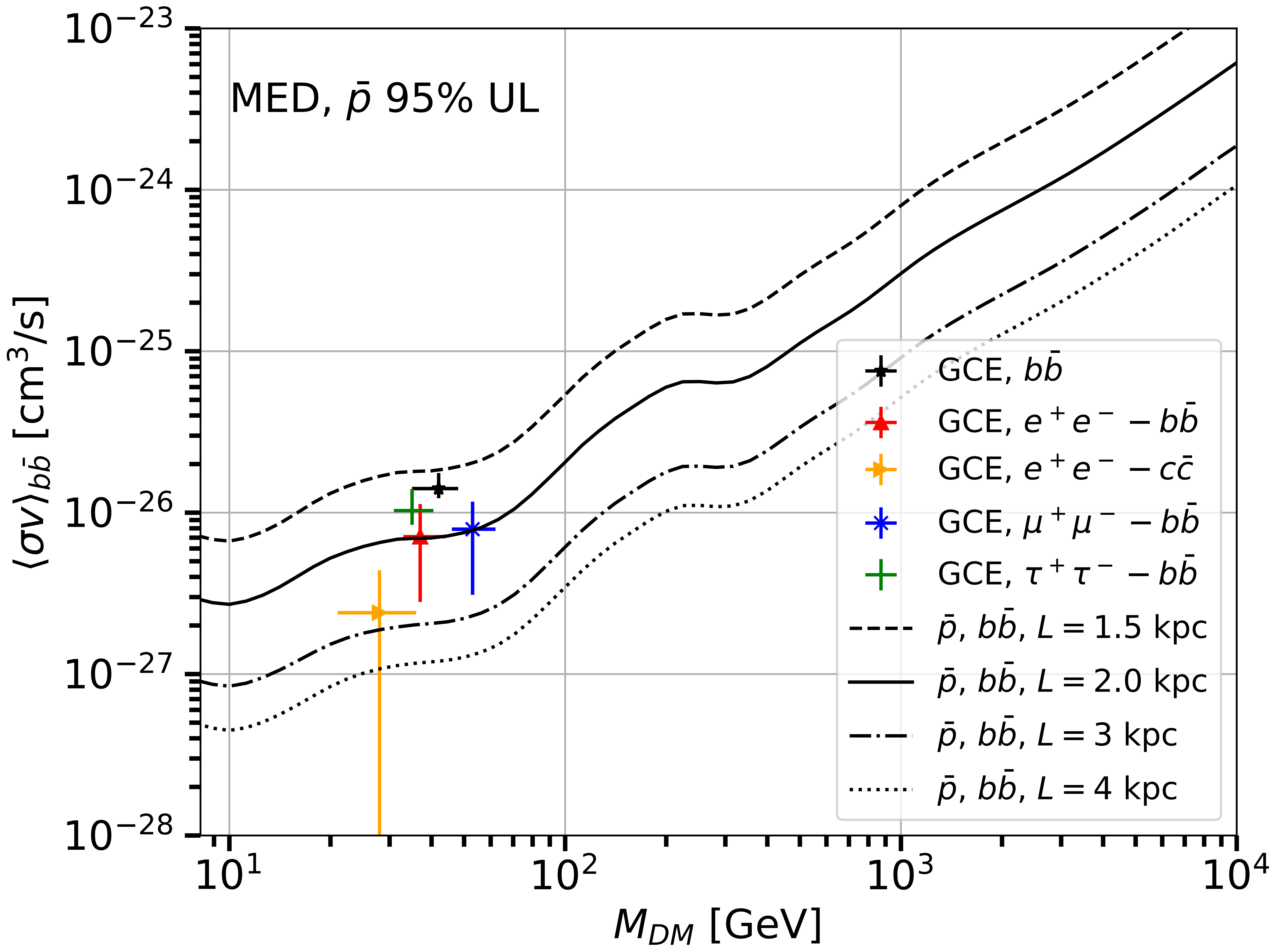
- **The addition of best-fit DM for the GCE with bottom channel worsens the fit with a delta chi-square of 44 (6σ worsening).**
- **We have used L=3kpc.**





Antiprotons vs GCE

- We use the same analysis as in **Reinert and Winkler 2018**.
  - A combined fit to AMS-02 and Voyager p, AMS-02 and Pamela anti-p, AMS-02 B/C is performed.
- **The DM interpretation of the GCE is compatible with the GCE for:**
  - **L<1.7 kpc for the bb and cc channels**
  - **L<2.5-2.6 kpc for the mixed hadronic channels $\mu^+\mu^-$bb and e^+e^-bb**
  - **L<1.7 kpc for the $\tau^+\tau^-$bb channel**
  - **The e^+e^-cc is compatible also with Br=1.**

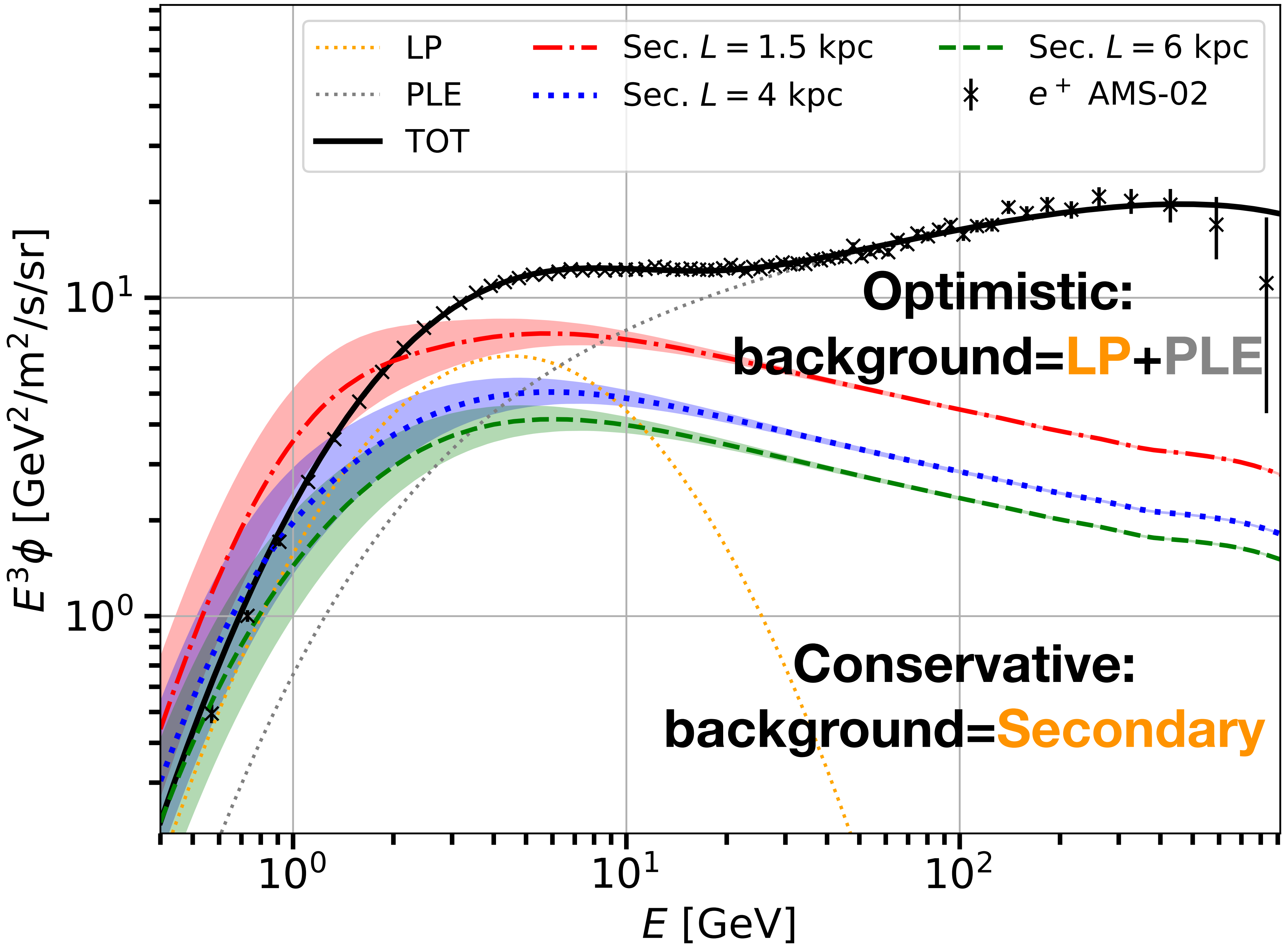


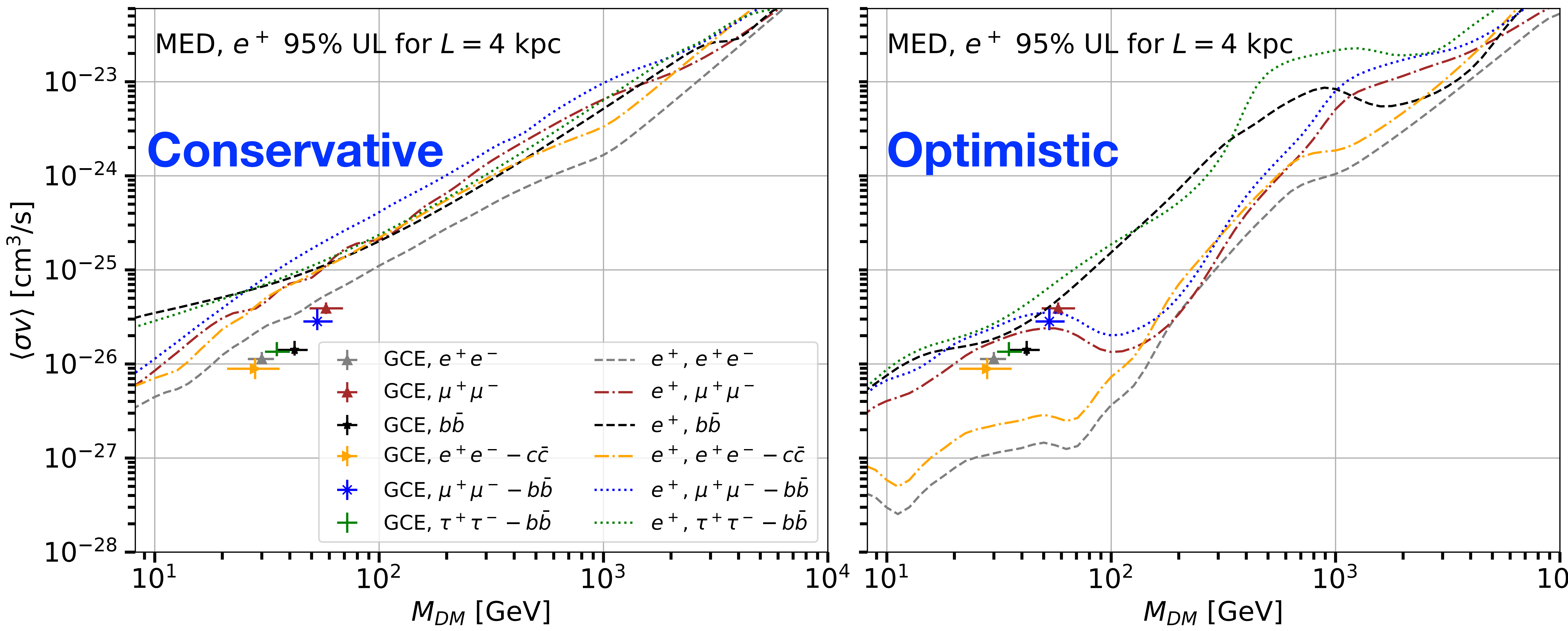
- Constraints from CRs L>2-3kpc (Genolini et al. 2019-2021).
- Constraints from gamma-ray and radio observations (Ackermann et al. 2012, Bringmann et al. 2012).

Paper III

Positrons vs GCE

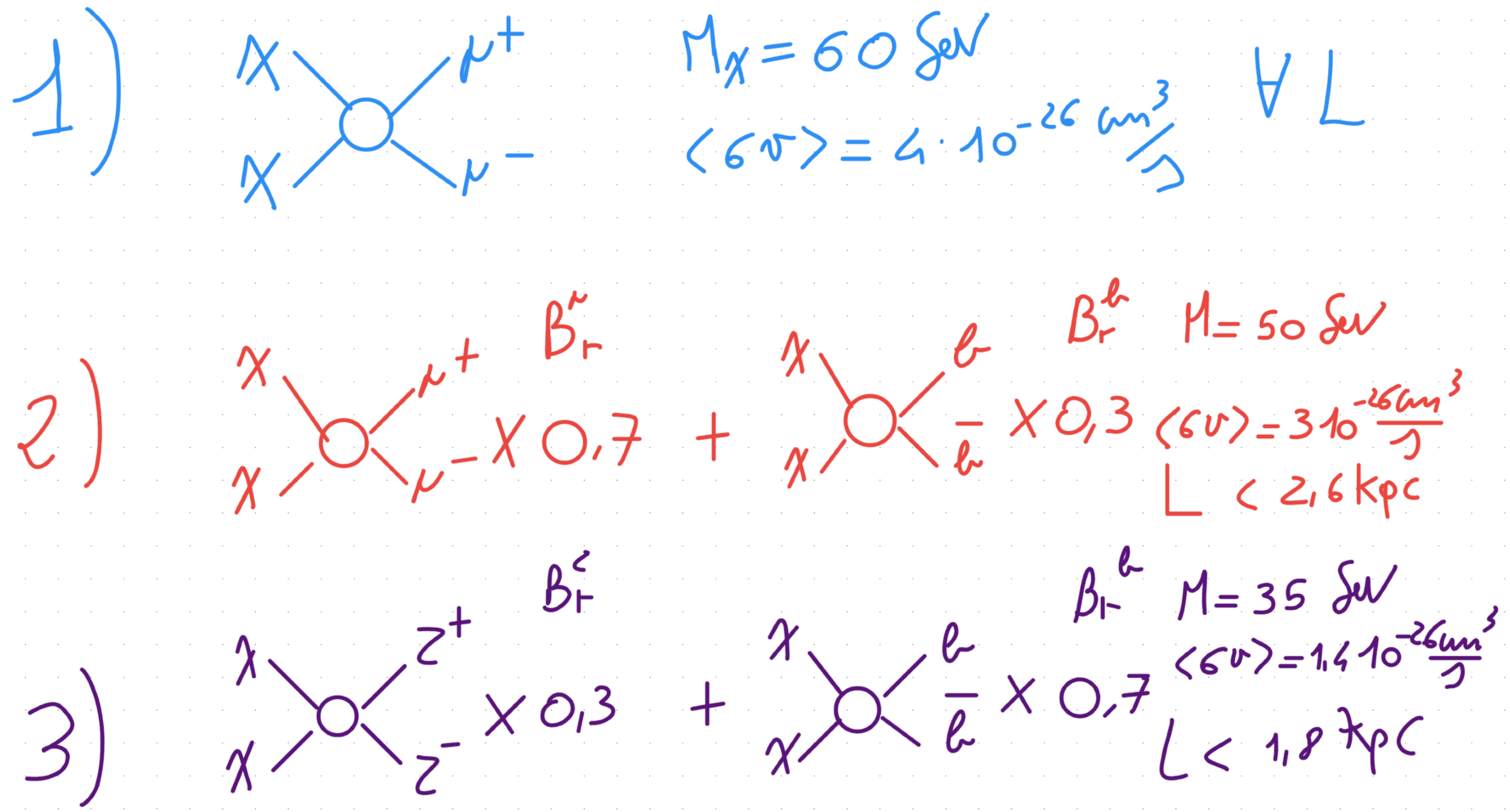
- The conservative upper limits are all compatible with the GCE.
- Instead, the optimistic ones are compatible for the bb, and mixed channels with muons and tau leptons.
- The channels with electrons are below the GCE DM candidates cross sections.
  - **e^+e^-cc, and pure e^+e^- channels are ruled out by positron data (similar to Bergstrom et al. 2013).**





Conclusions

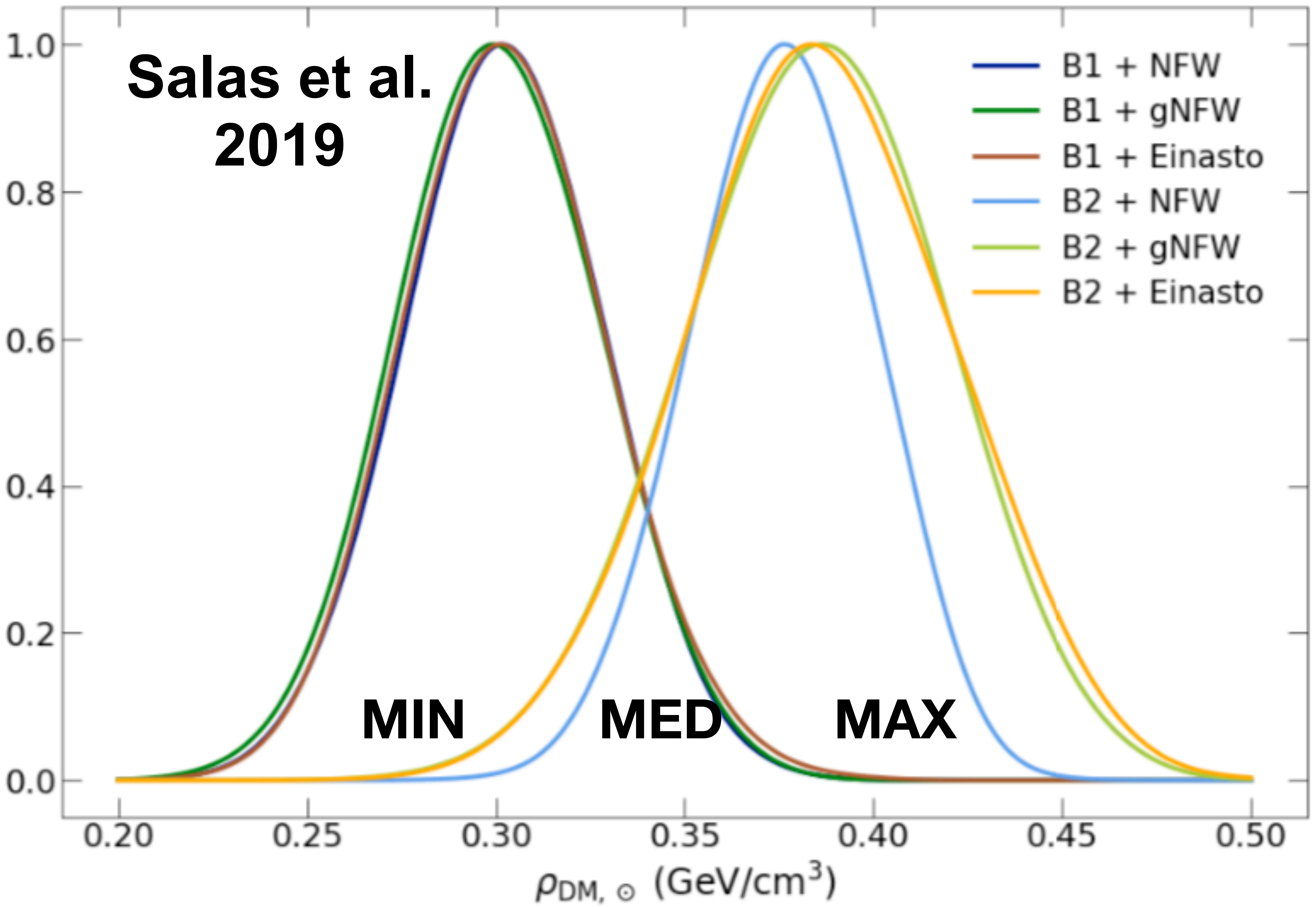
- **The GCE has all the right characteristics to be due to annihilating DM particles.**
- ULs from dSphs are compatible with the GCE candidates.
- ULs from antiprotons put tight constraints on purely hadronic final state DM.
- ULs from positrons put severe constraints on DM annihilating, even partially,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



Backup slides

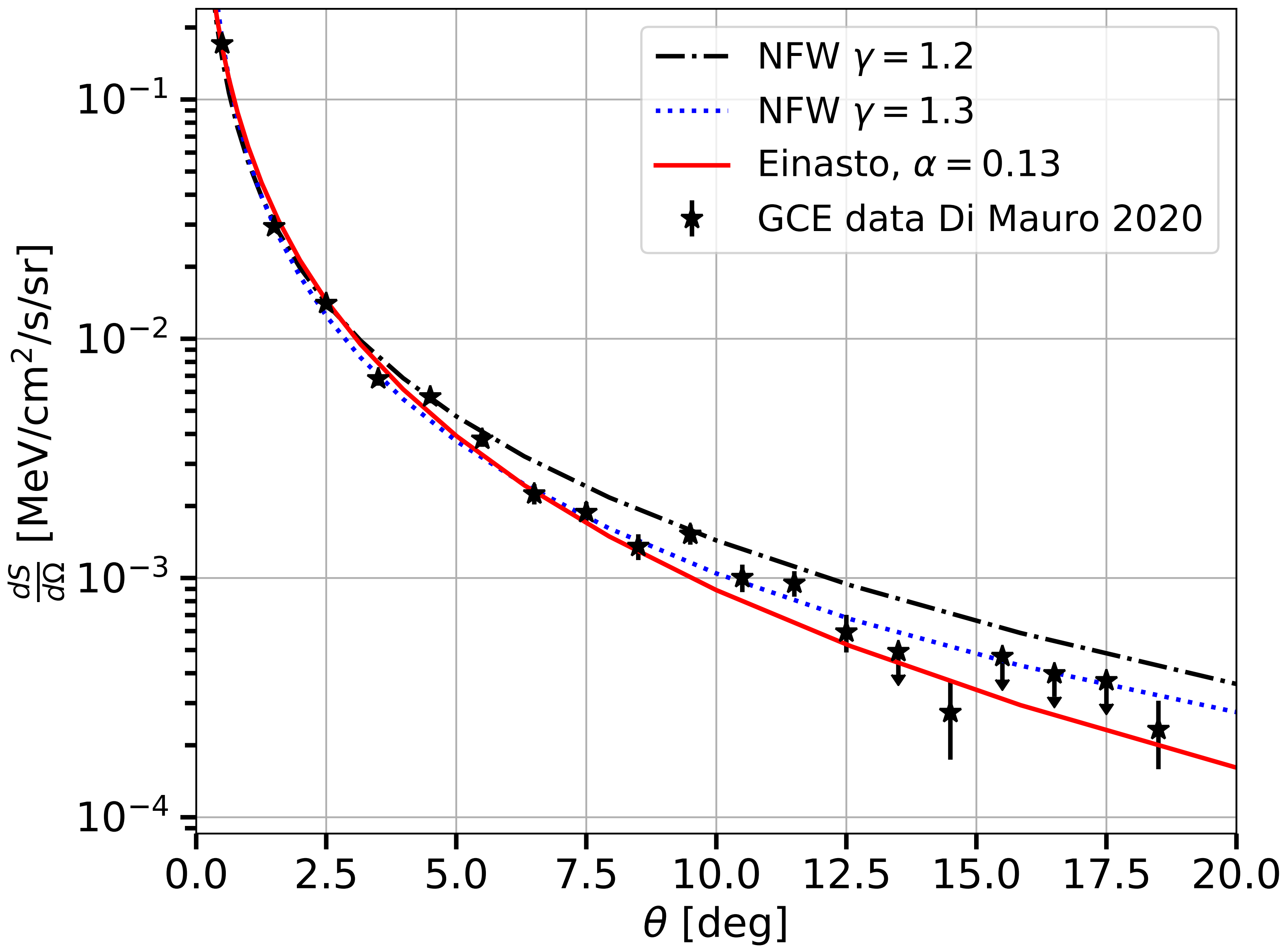
Paper III

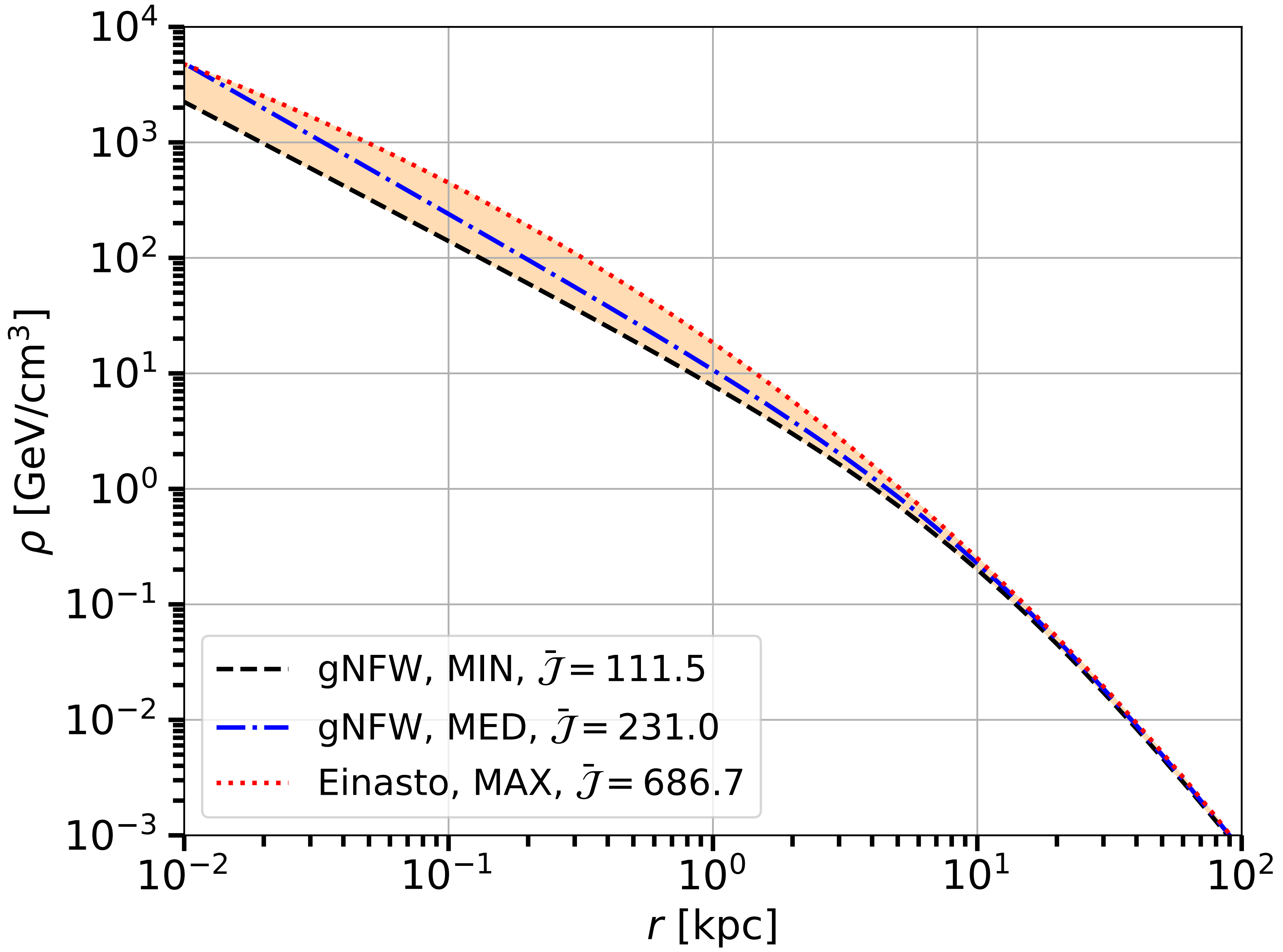
Dark matter density distribution



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

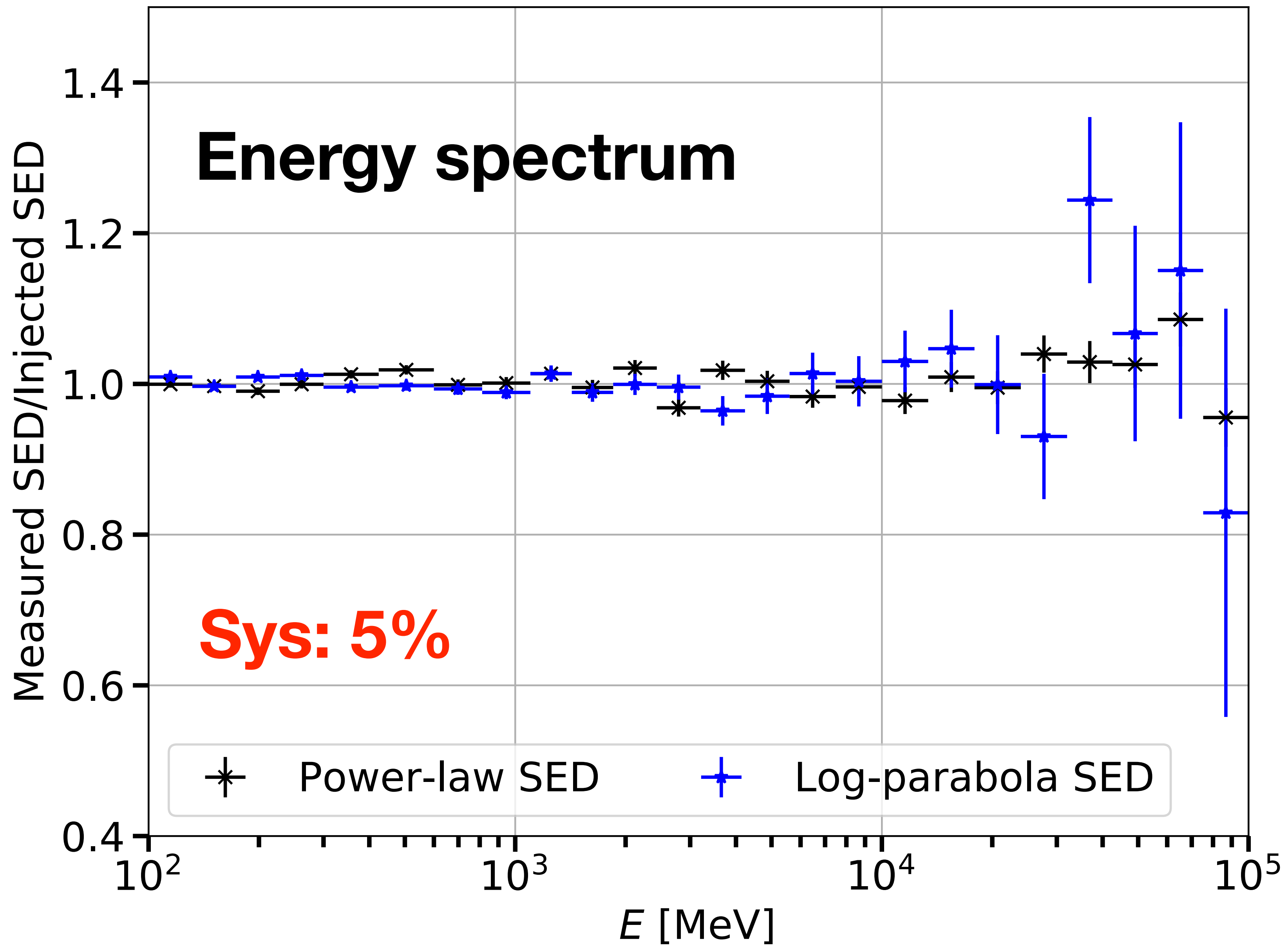
Geometrical factor integrate in our ROI

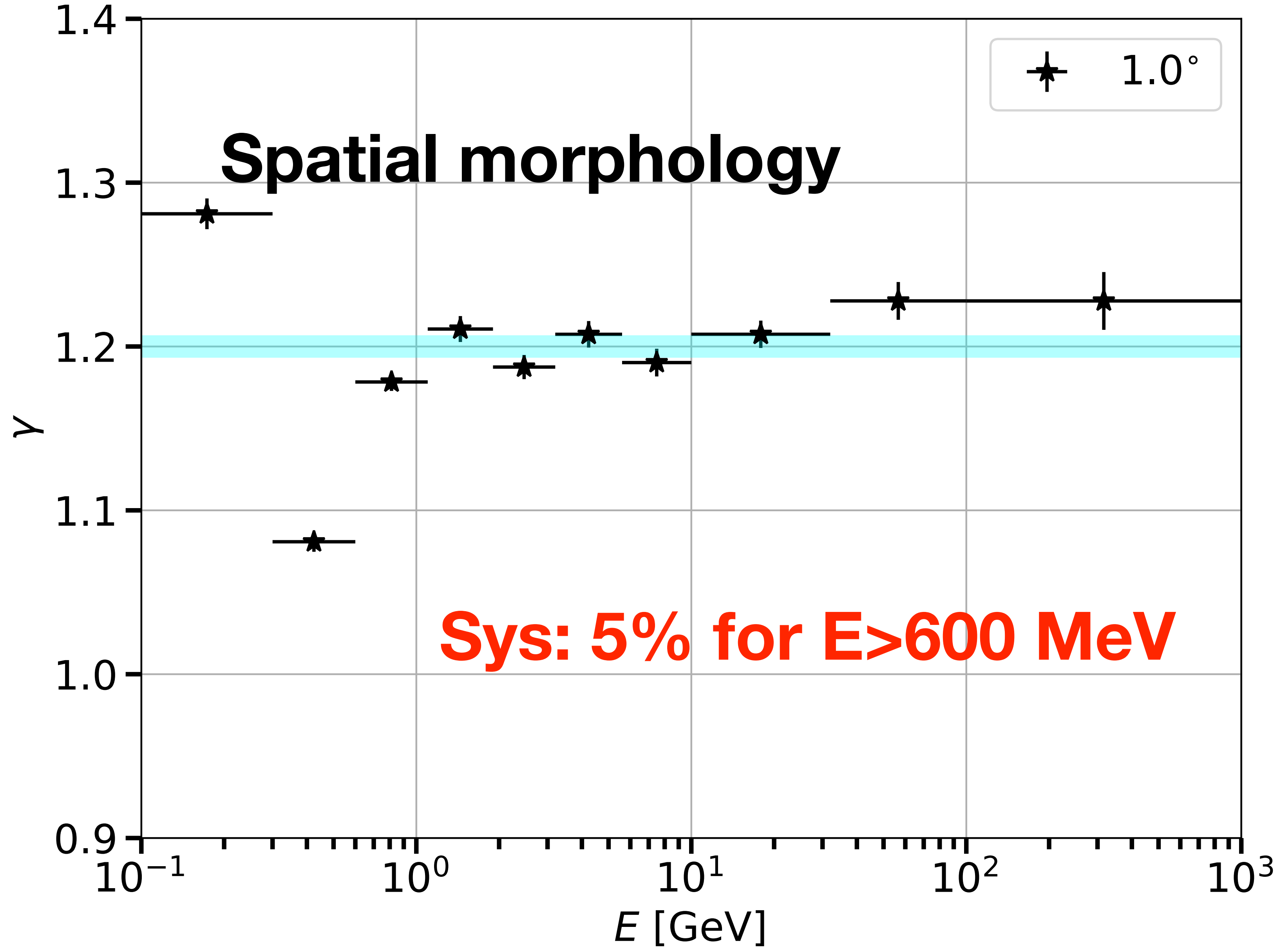




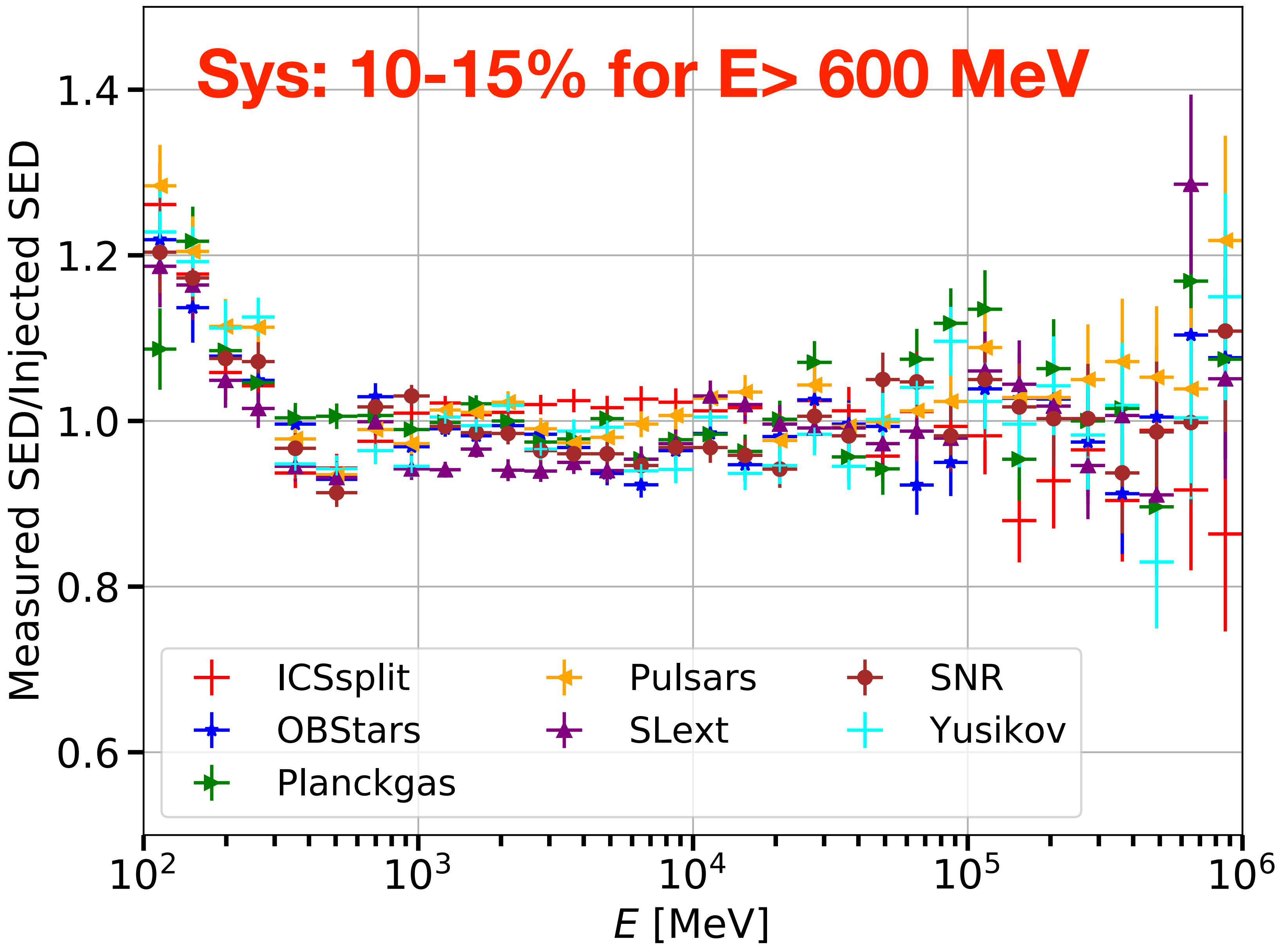
Results with Simulations

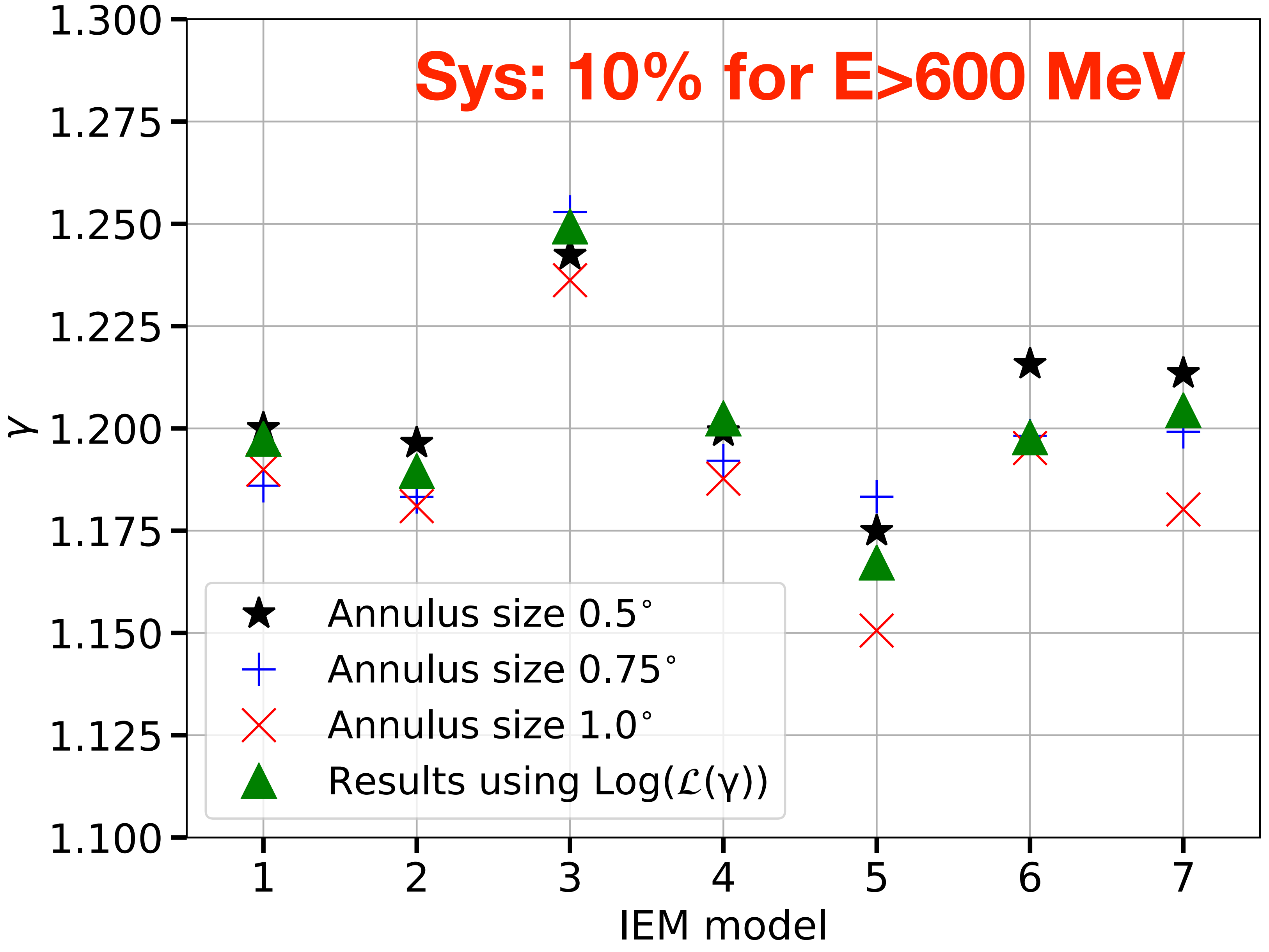
Ideal case:
Perfect knowledge of the background components.





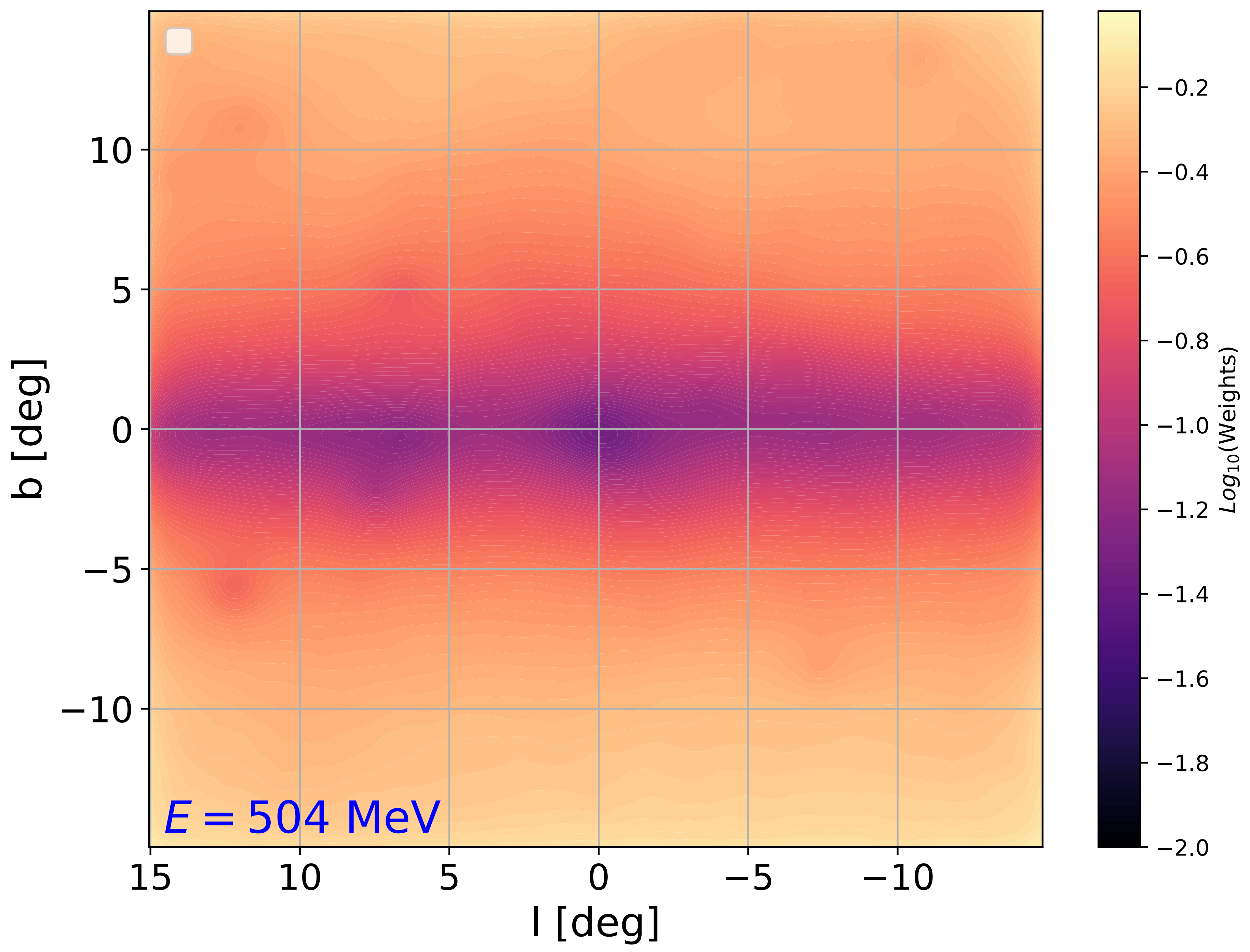
Imperfections in the IEM:
I simulate with one IEM but I use an other one to analyze the data

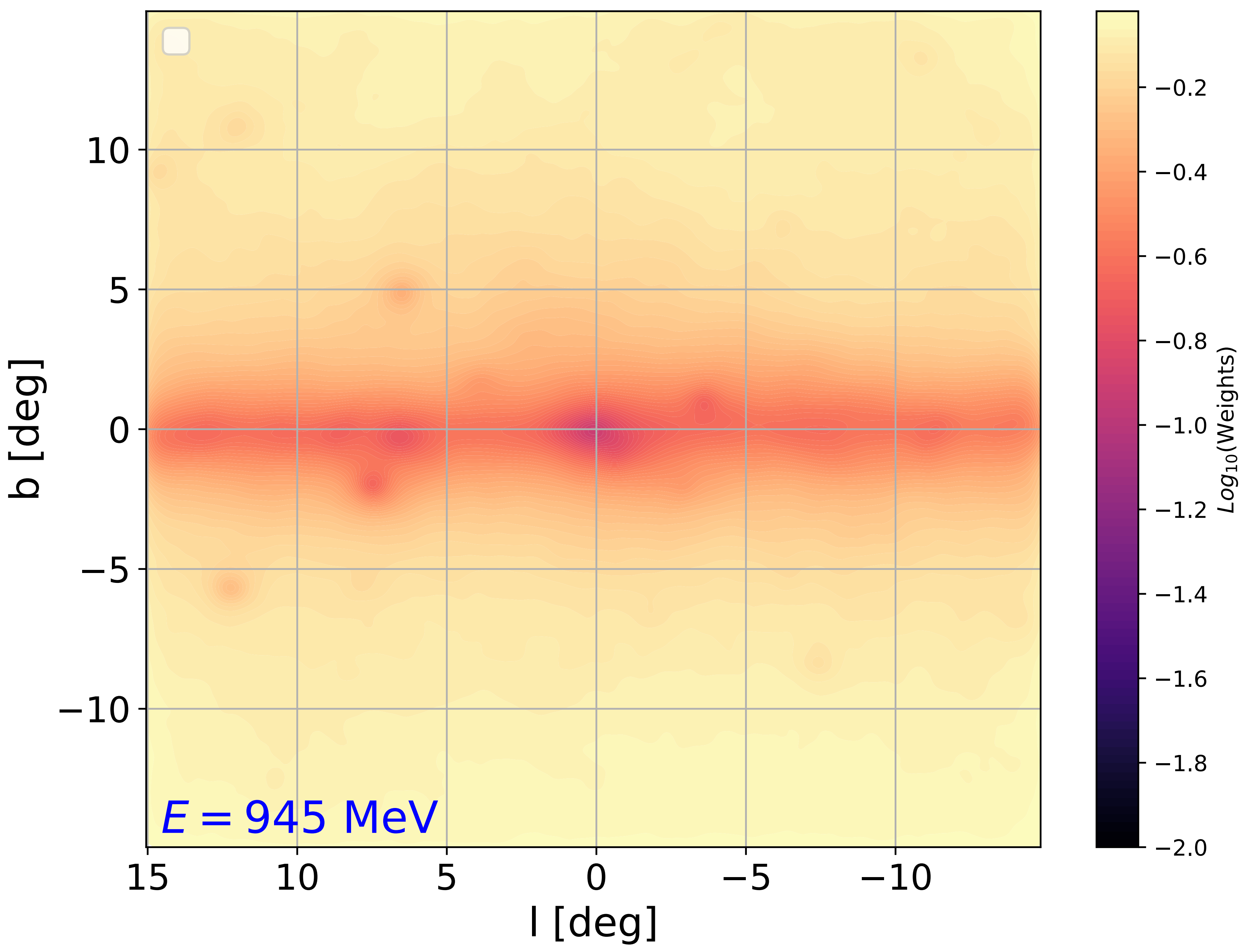




Weighted likelihood technique

- Weights for every pixel of the sky according to the number of counts.
- Weights are multiplied to the Log(L) of the maximum likelihood analysis.
- This procedure thus penalizes pixels with a very large number of photons and in which the systematics for the choice of the IEM could be larger

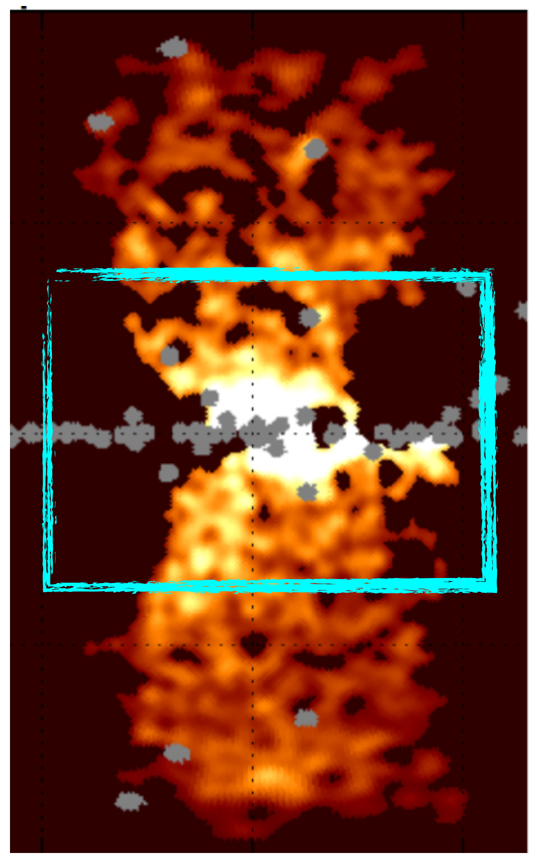


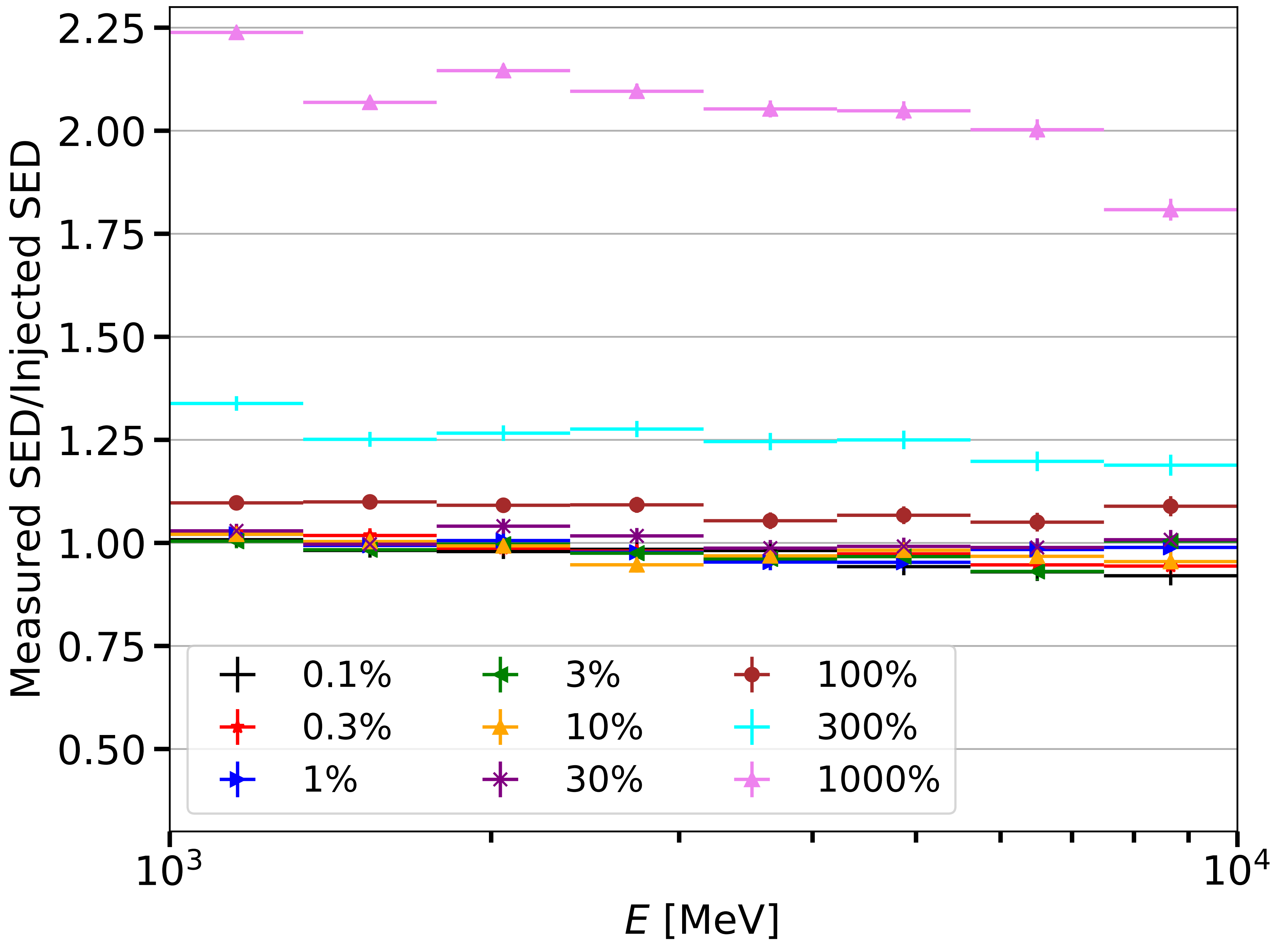


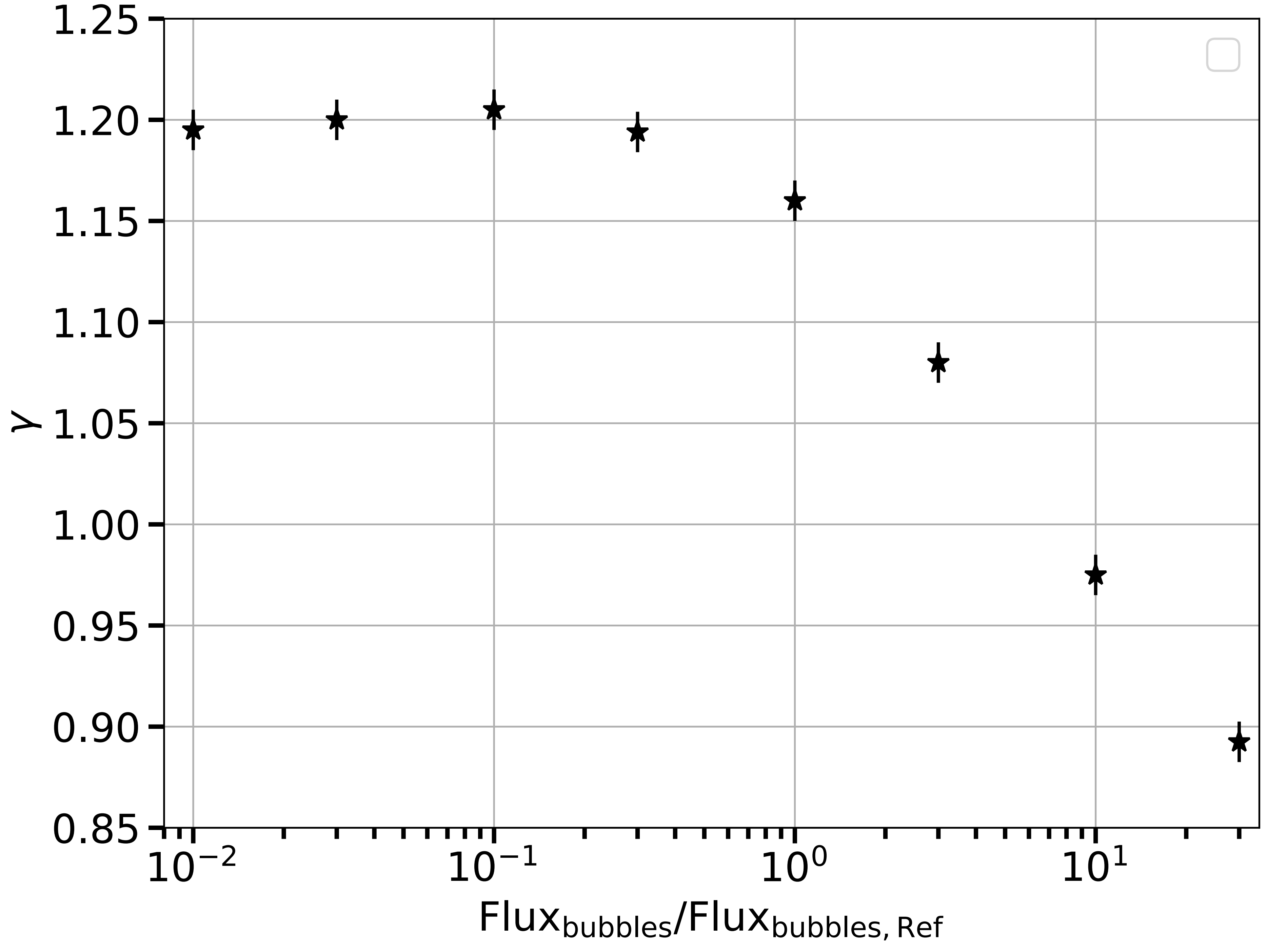
https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/weighted_like.pdf

Missing component in the IEM

- We simulated with the low-latitude comp. of the Fermi Bubbles.
- A missing component affects the results of the SED and spatial distribution when its flux is at least 10-20% of the one of the GCE.

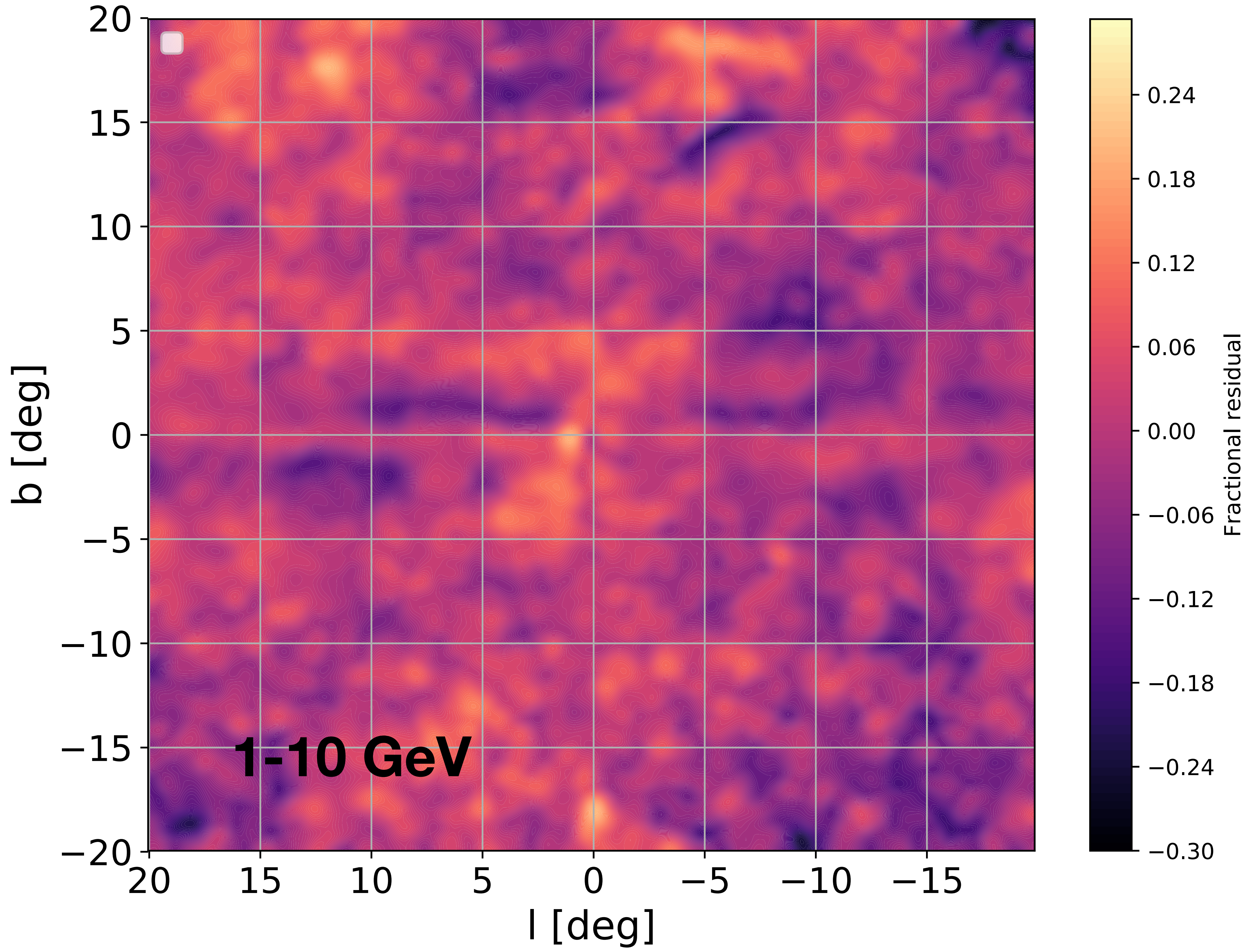


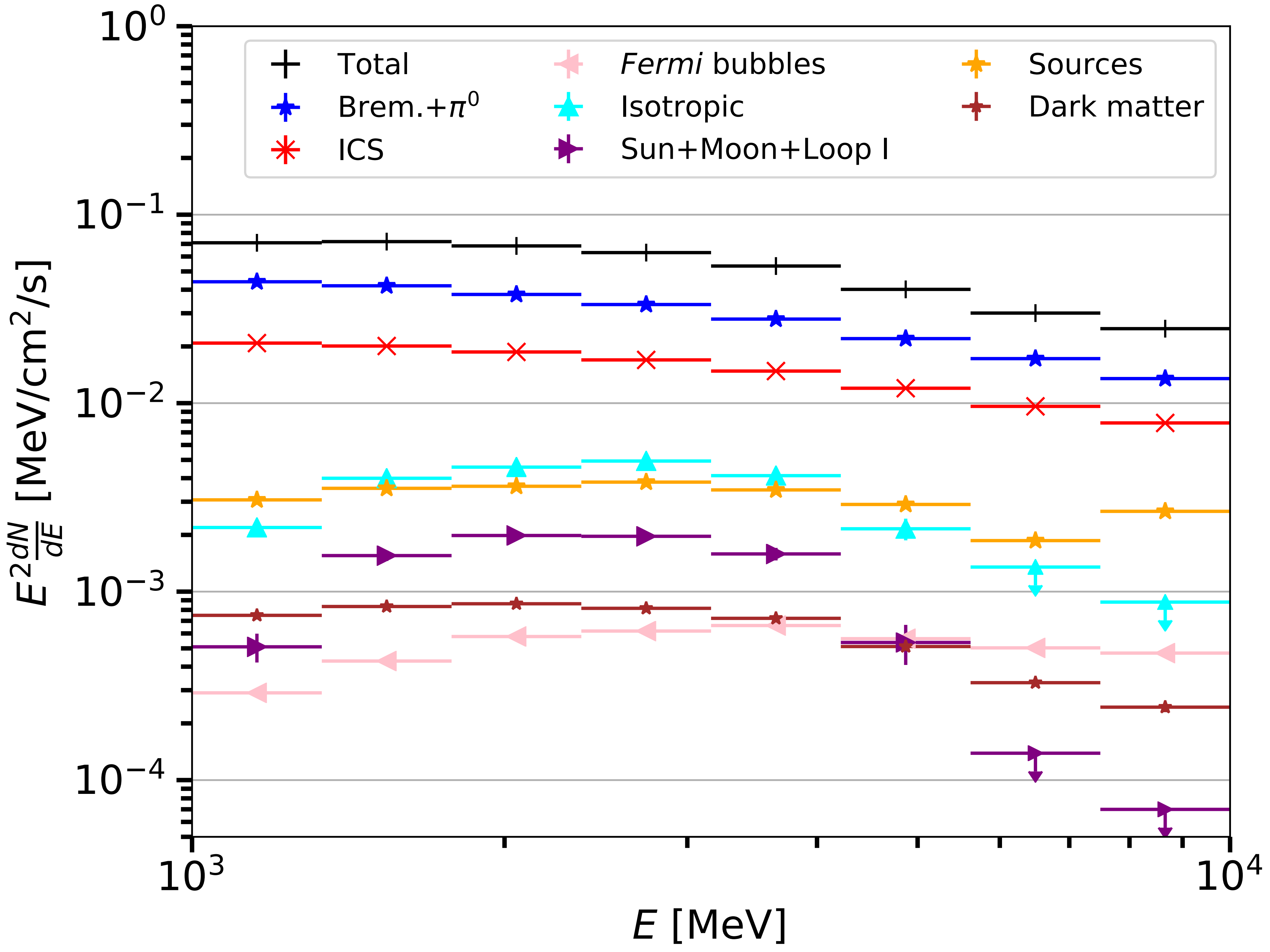




Test of the components to be left free

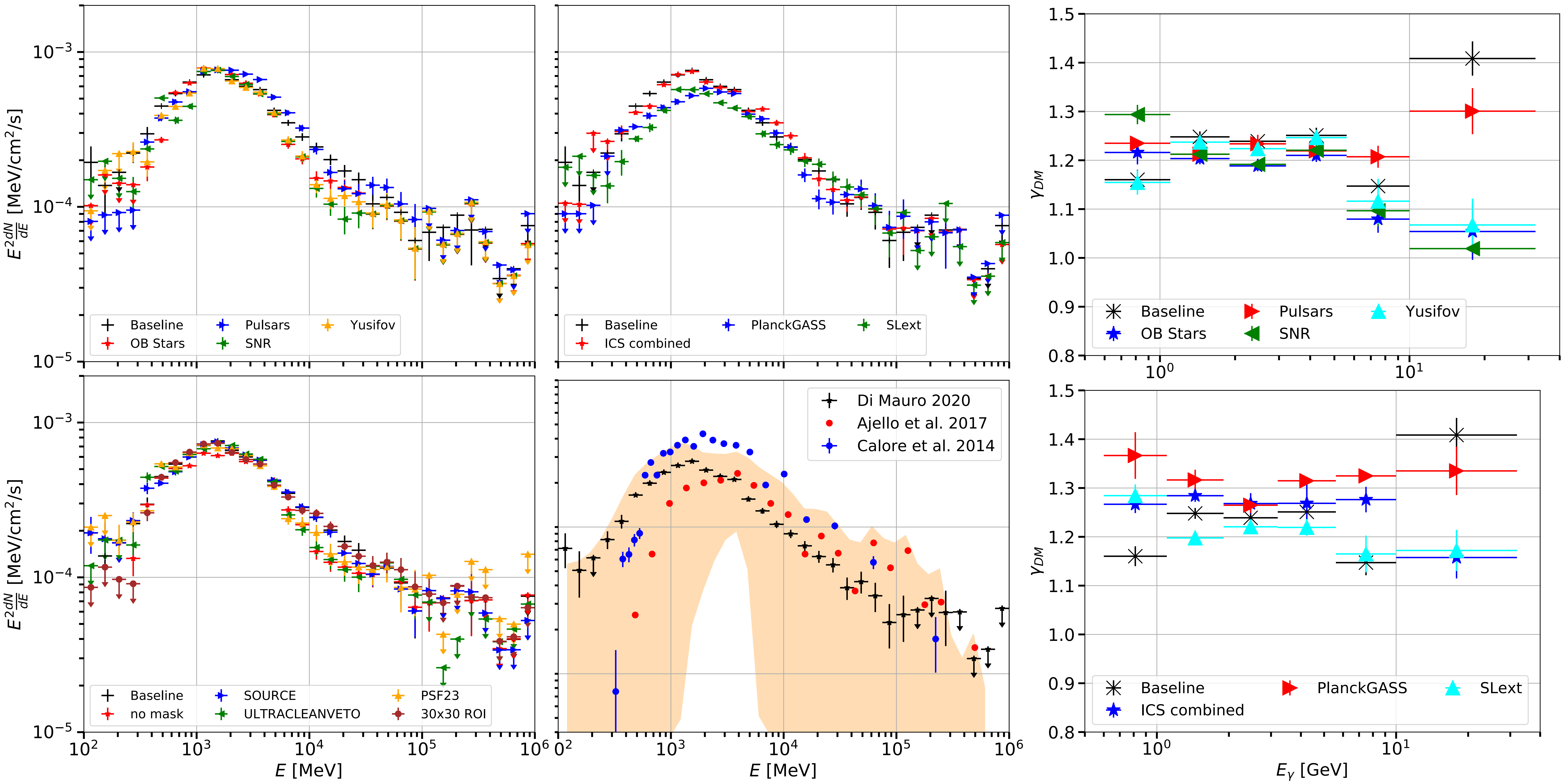
- We use as in the reference the following components:
  - Bremsstrahlung, π^0, ICS divided into 1,2,3, isotropic component, Sun/Moon/Loop I in a unique component and the low and high latitude bubble components.
- The residuals are roughly at the level of 20-25% of the data.
  - The GCE is at the level of % of the data!!





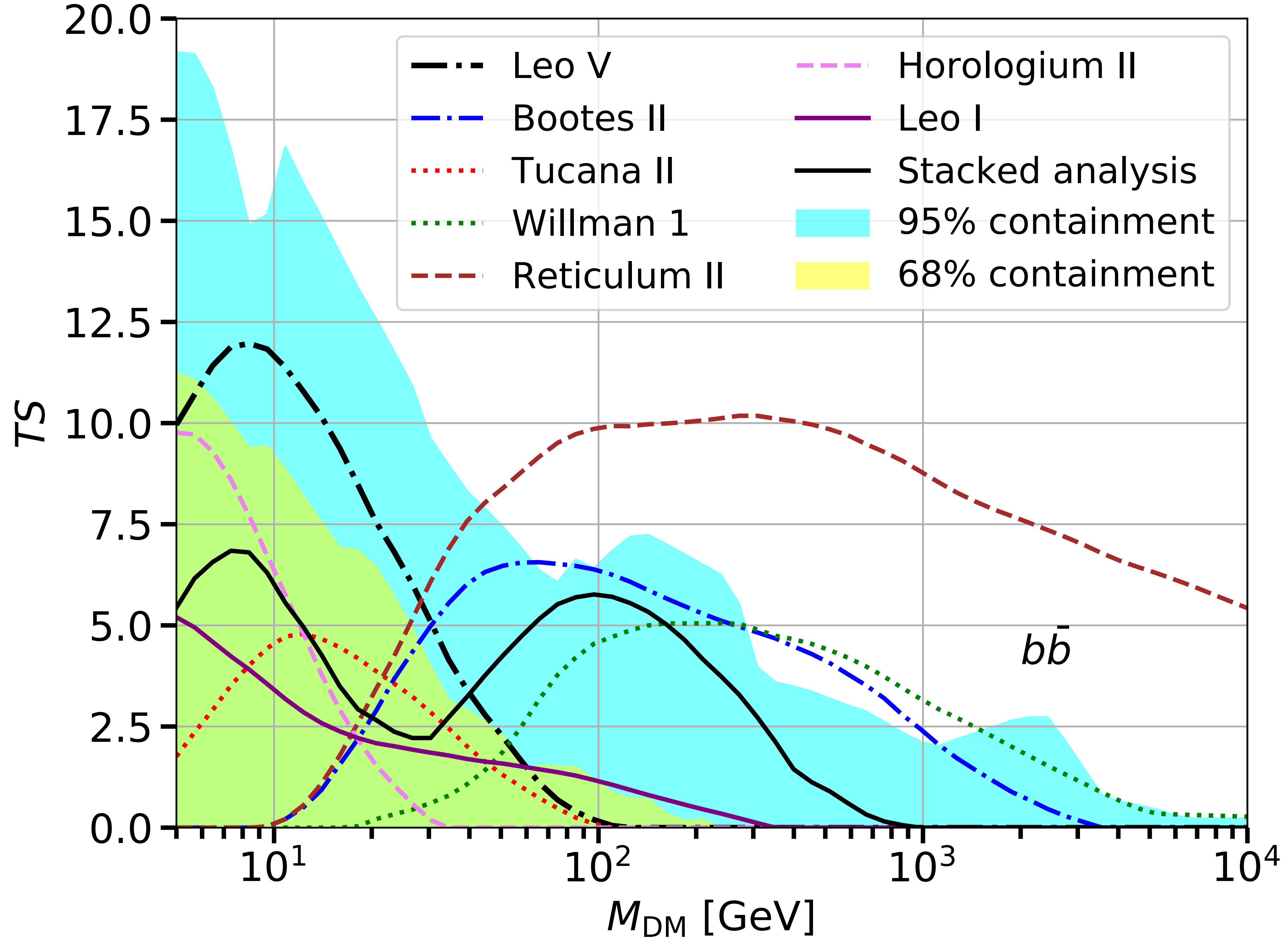
Paper II

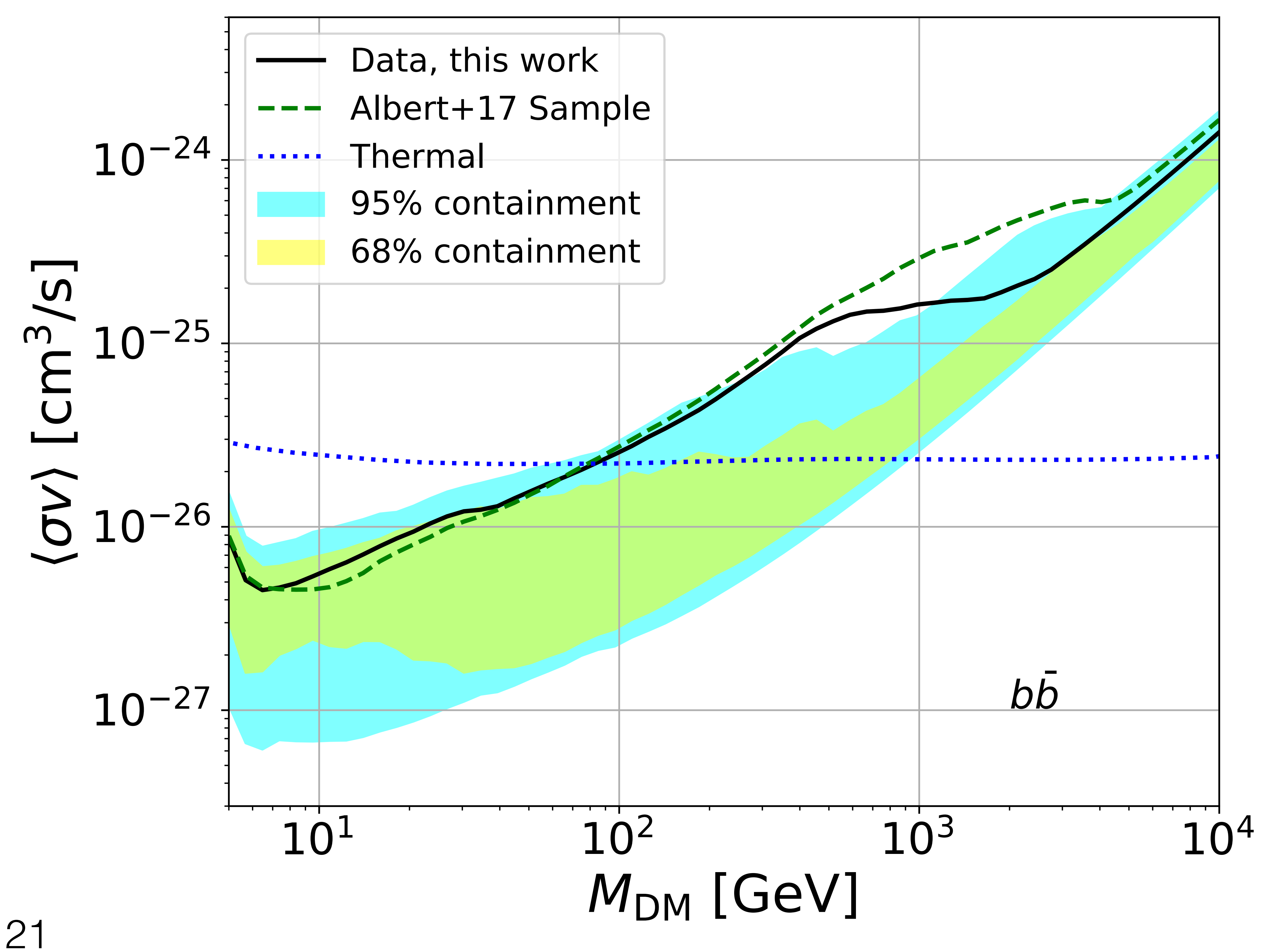
GCE Characteristics



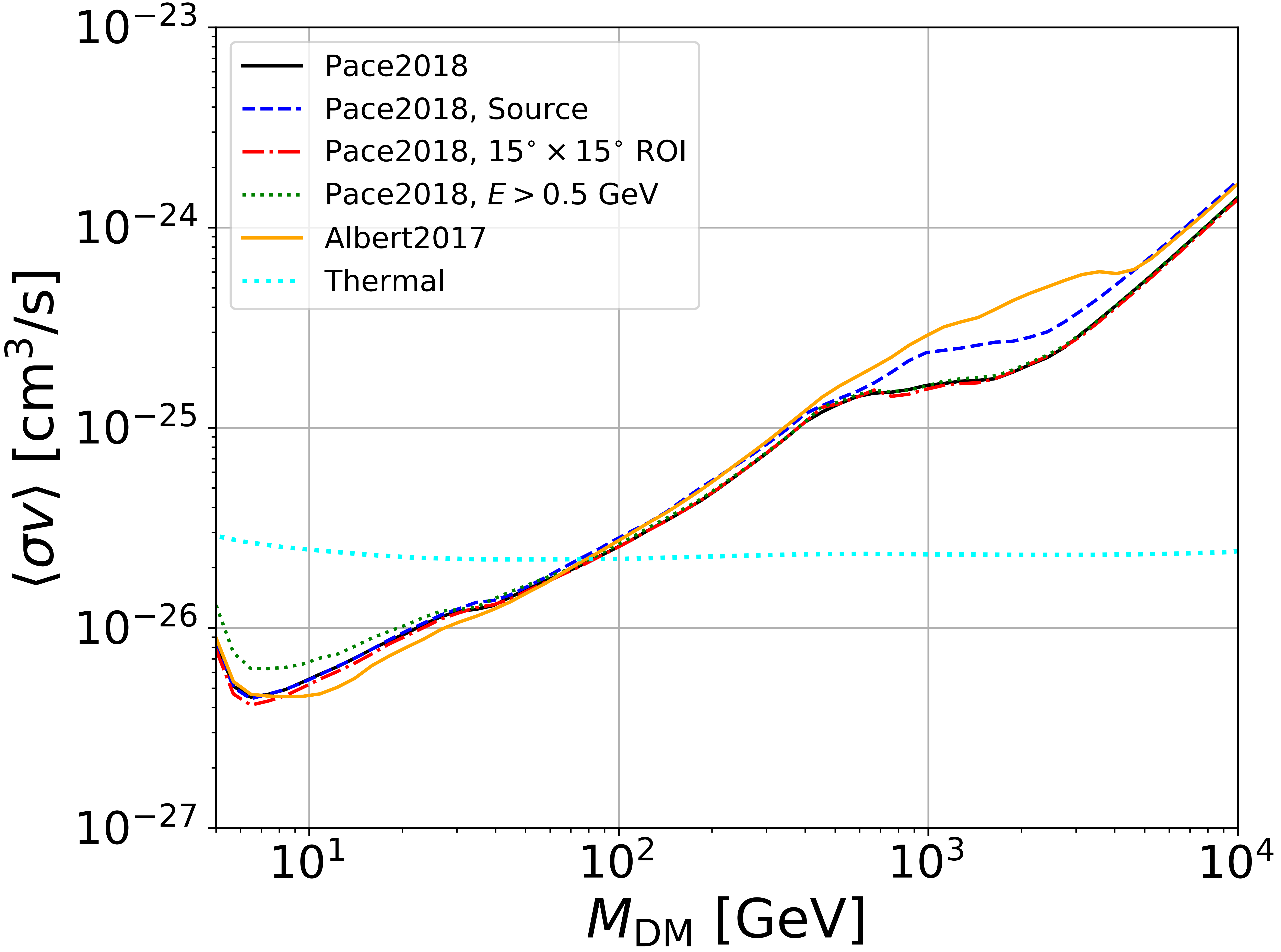
Stacking analysis for dSphs

- We perform a stacking analysis of dSphs using the sample of 48 objects from Pace and Strigari 2018.
  - We also test the sample from Albert et al. 2017.
- The pipeline we use is the one employed in previous *Fermi*-LAT papers.
- There is no significant emission in the stacked sample.





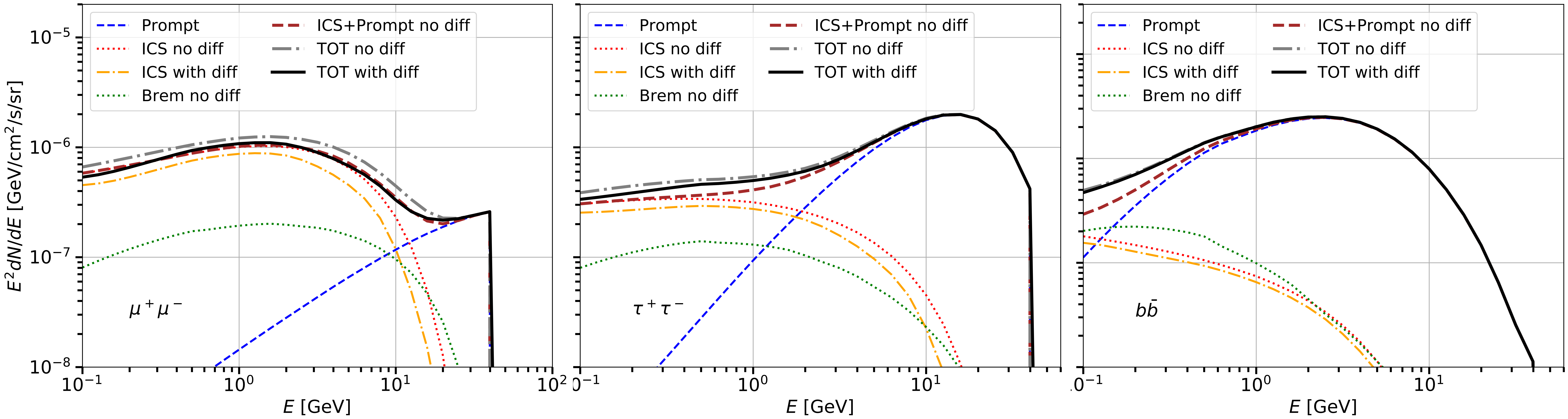
Systematics on the analysis of the dSphs



Paper III

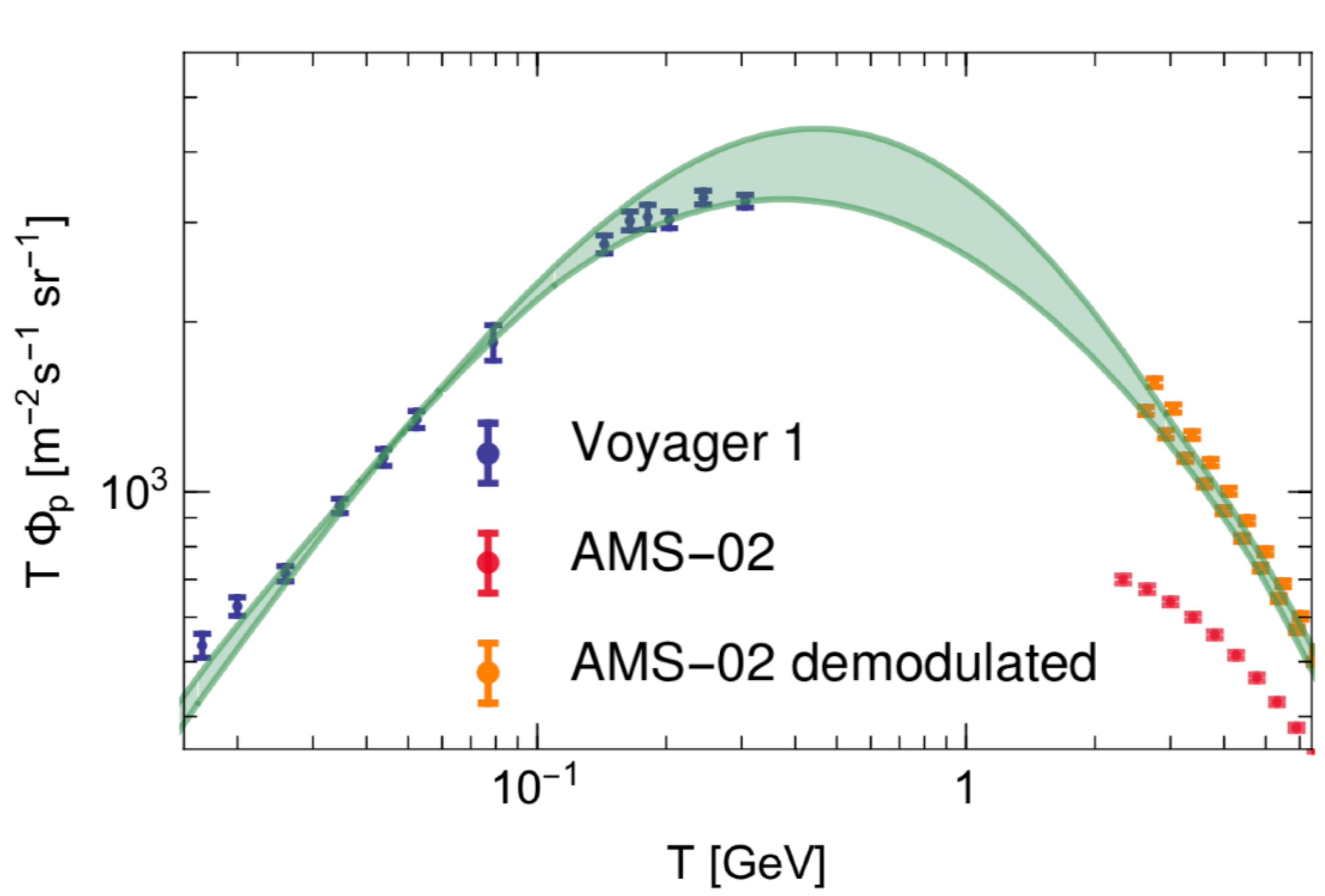
Gamma-ray flux from Dark matter

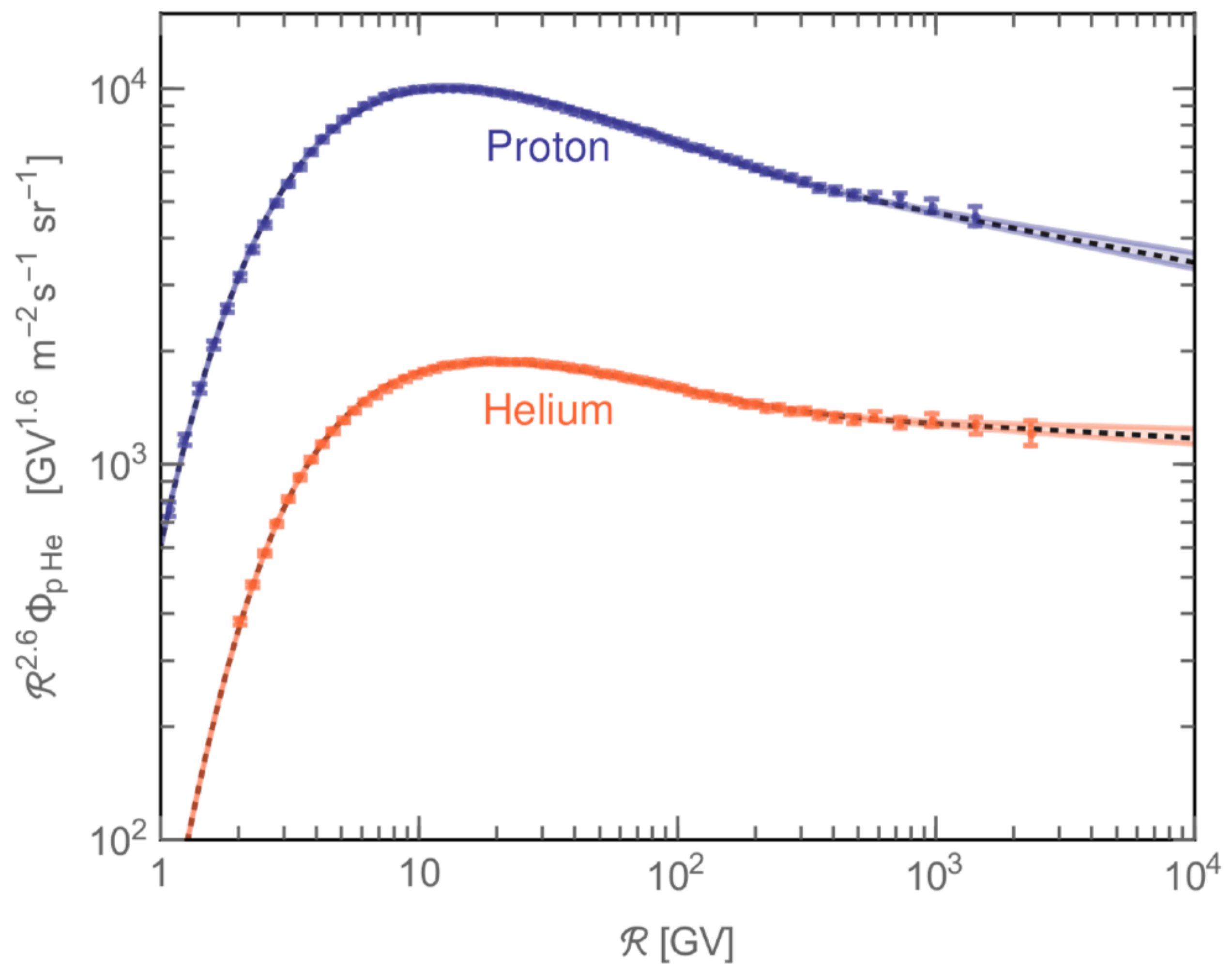
- We use a model that accounts for prompt and ICS emission from DM
- The diffusion has a much smaller effect that energy losses in the GC.
- The bremsstrahlung component is also negligible.

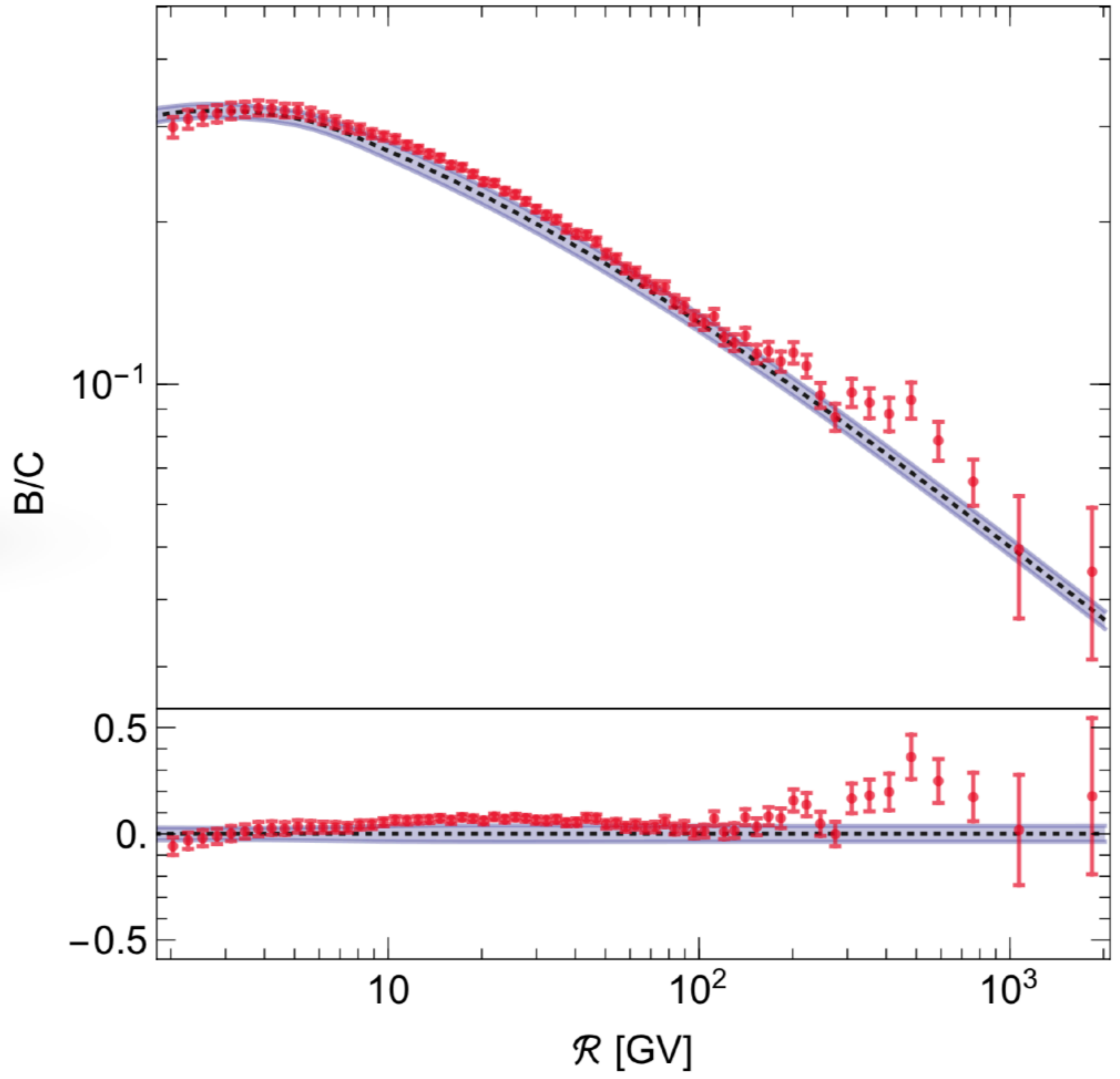


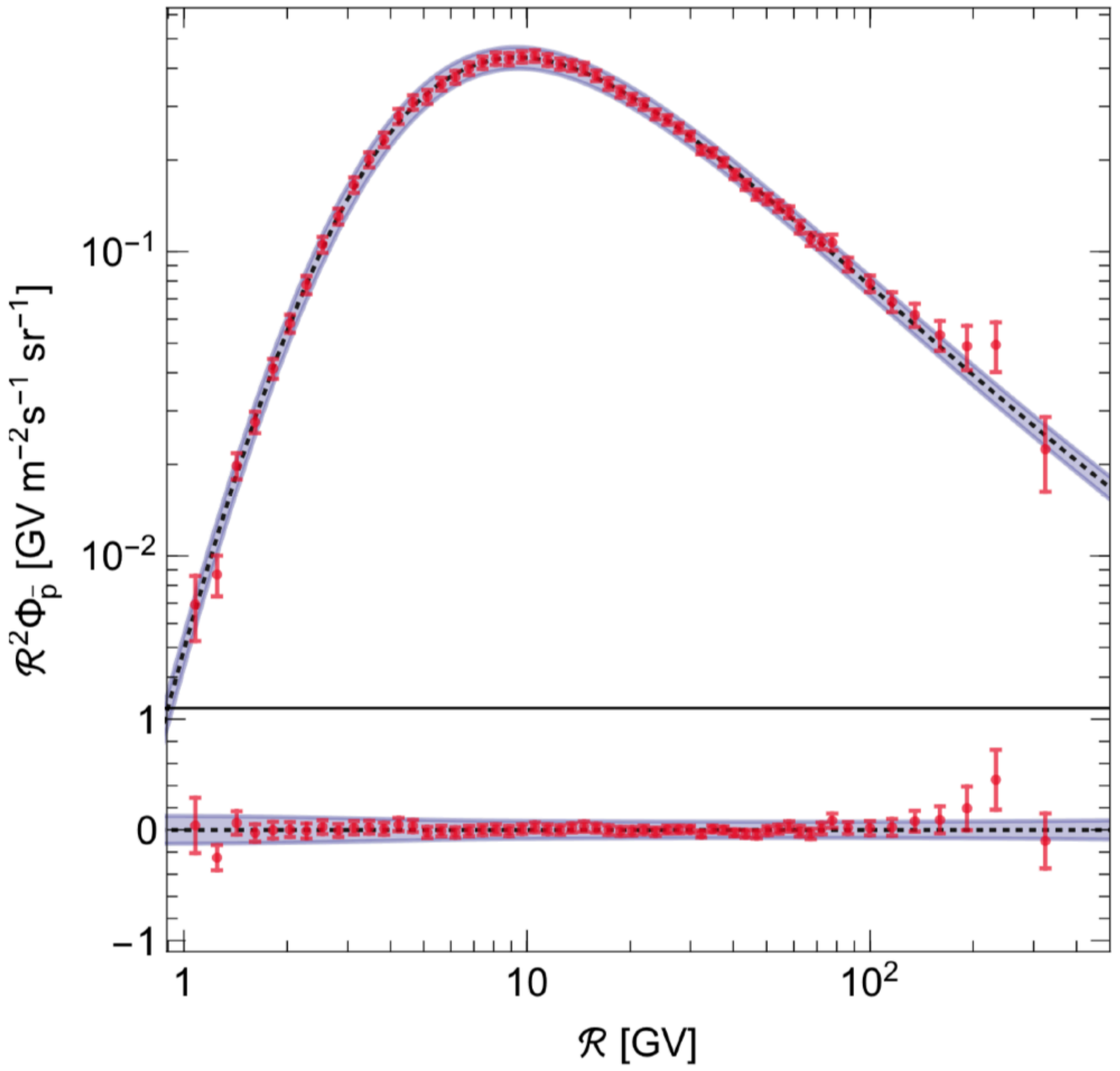
Antiprotons: Calibrating Model parameters

- $\delta = 0.459$
- $L = 4$ kpc (fixed)
- $K_0 = 0.042$ kpc^2/Myr
  - K_0/L should stay fixed
- Fisk potential I use phi = 0.72 GV









Same method as in Reinert and Winkler 2018