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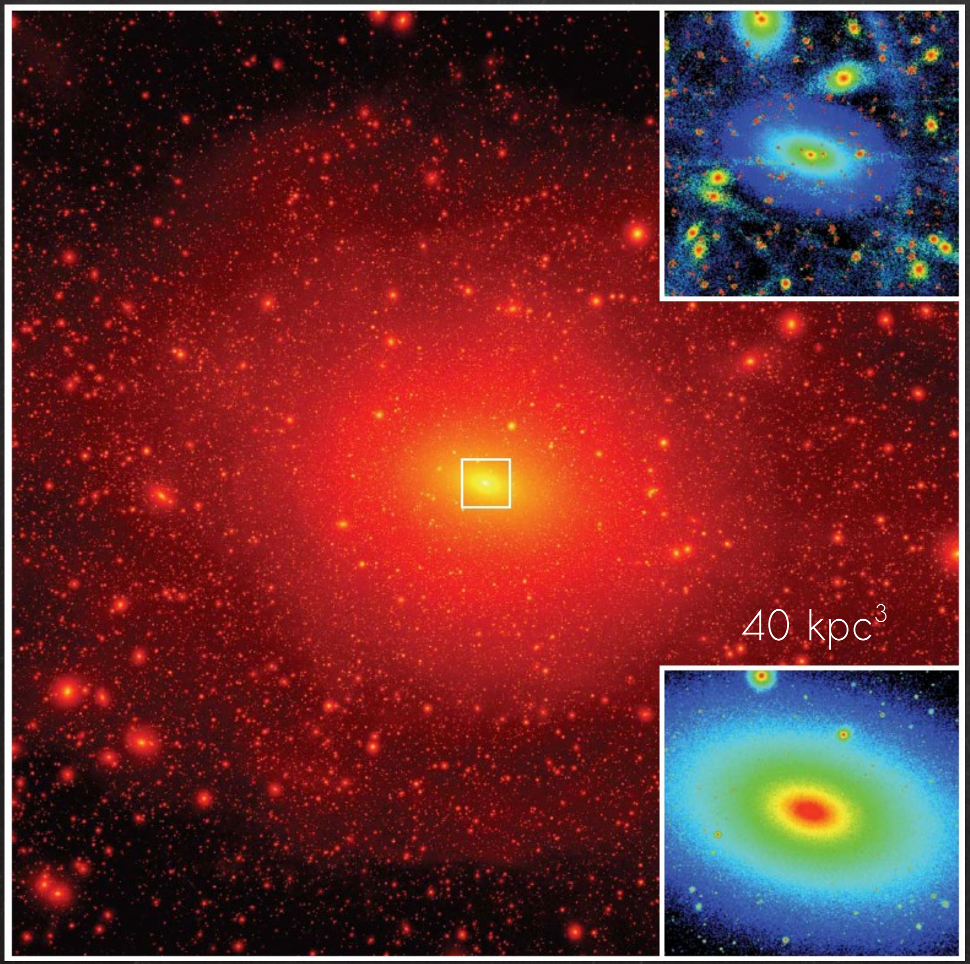
Electron Anisotropy:
A tool to discriminate dark matter in cosmic rays

Based on
Borriello, Maccione, and Cuoco
arXiv:10120041

DM galactic substructures

N-body simulations

Diemand et al. arXiv:0805.1244
Springer at al. arXiv:0809.0898



800 kpc^3

Numerical simulations: **smooth** and **homogeneous** Universe (z ~ 100)

The tiny **fluctuations** of the matter distribution began to **collapse** because of gravity.

The first objects to form are planet-mass dark-matter **subhaloes.**

Stable against gravitational disruption: over **10^{17}** clumps survive.

Rough e**quipartition** in mass among the smooth halo and the subhaloes distri_ bution.

Current **numerical resolution**:

$10^{4.5}\ M_\odot$ Via Lactea II

$10^4\ M_\odot$ Aquarius

DM galactic substructures

Detectability at γ-rays energies

Pieri et al. arXiv:arXiv:0908.0195

DM particle: **Neutralino**

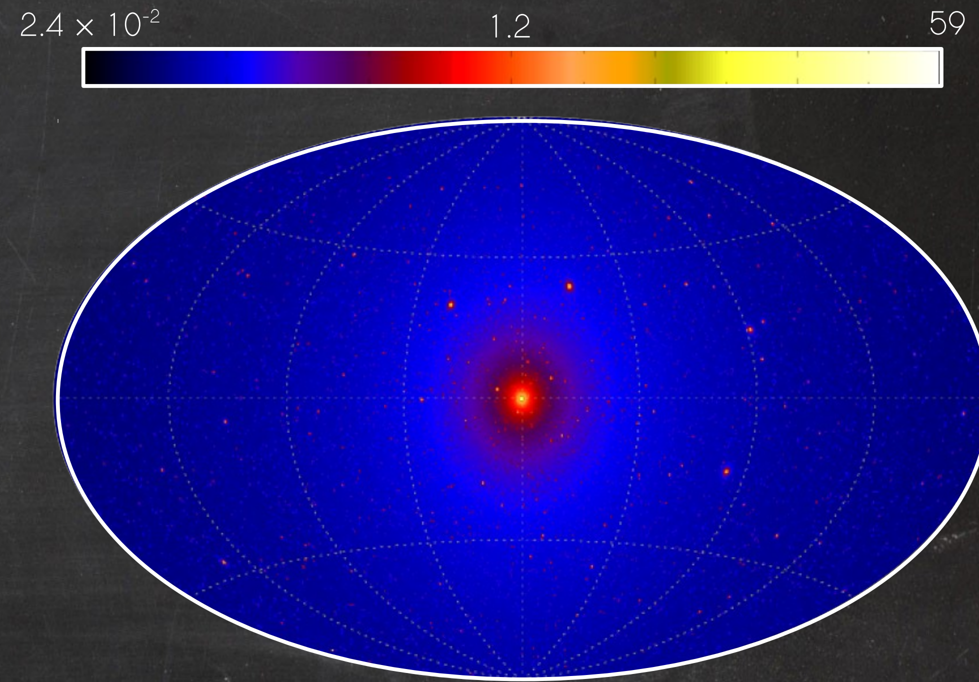
DM mass: 40 GeV

Annihilation rate: 3×10^{-26} cm^3 s^{-1}

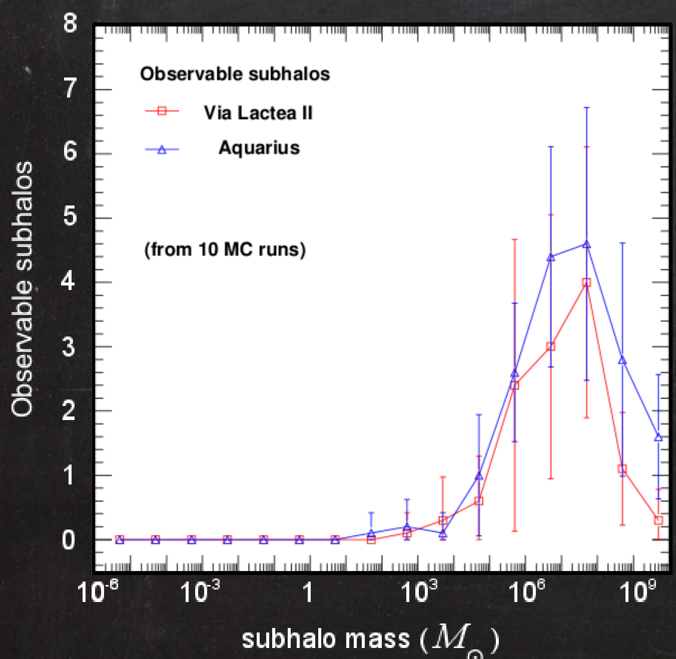
Energy treshold: 3 GeV

Annihilation channel:

$\chi + \chi \rightarrow b$ quarks $\rightarrow \pi^0 \rightarrow \gamma + \gamma$



Full sky map of the **number of photons** produced by DM annihilation



Observable clumps:

Via Lactea II 9.2 ± 2.6 at $3\ \sigma$

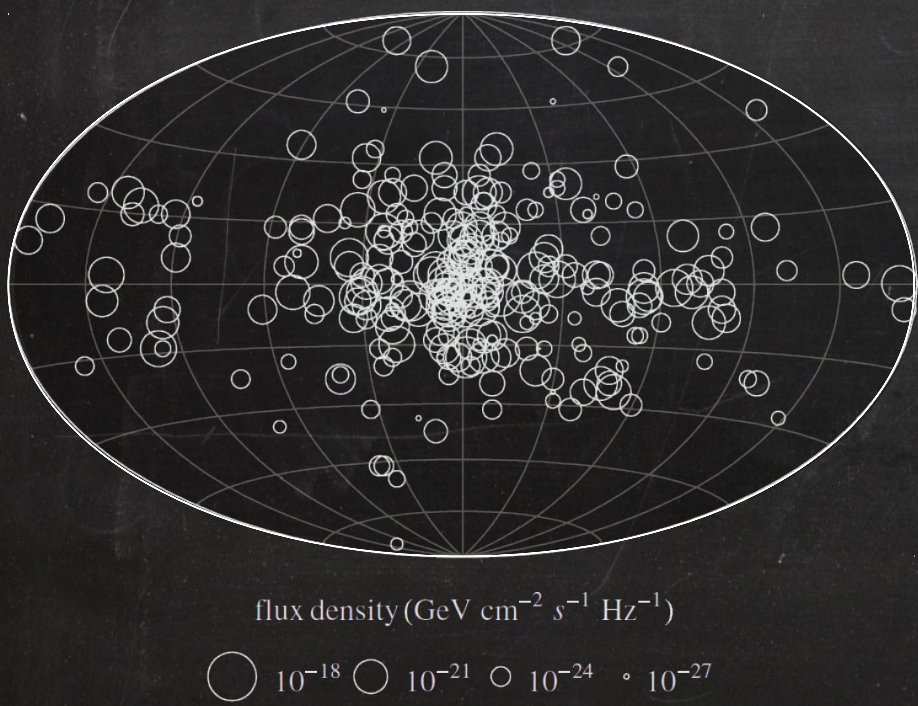
DM galactic substructures

Detectability at radio wavelenghts

Borriello et al. arXiv:arXiv:0809.2990

clump #	distance kpc	scale rad. kpc	density par. $\mathrm{GeV\,c^{-2}cm^{-3}}$	GMF μG	flux $\mathrm{GeV\,cm^{-2}s^{-1}Hz^{-1}}$
1	14.2	0.180	6.51	0.0962	1.70×10^{-25}
2	4.71	0.181	6.50	0.320	4.55×10^{-23}
3	5.50	0.188	6.40	3.08	2.66×10^{-21}

Clumps from 10^7 to $10^{10}\ M_{sun}$

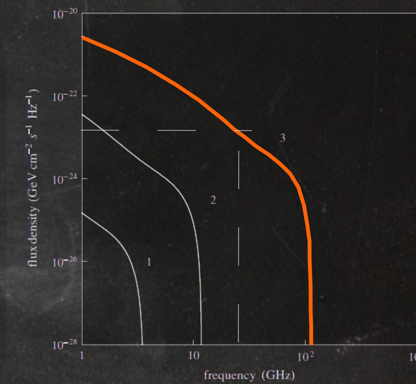


At $\nu \approx 23$ GHz (1st **WMAP** band) the flux is order $10^{-23}\ \mathrm{GeV\,cm^{-2}s^{-1}Hz^{-1}}$ (100 GeV $\tilde{\chi}_1$)

$e^{\pm}$ **diffuse** in a ~1 kpc radius sphere:

$\Omega \sim 0.1$ sr

(d ~ 5 kpc)

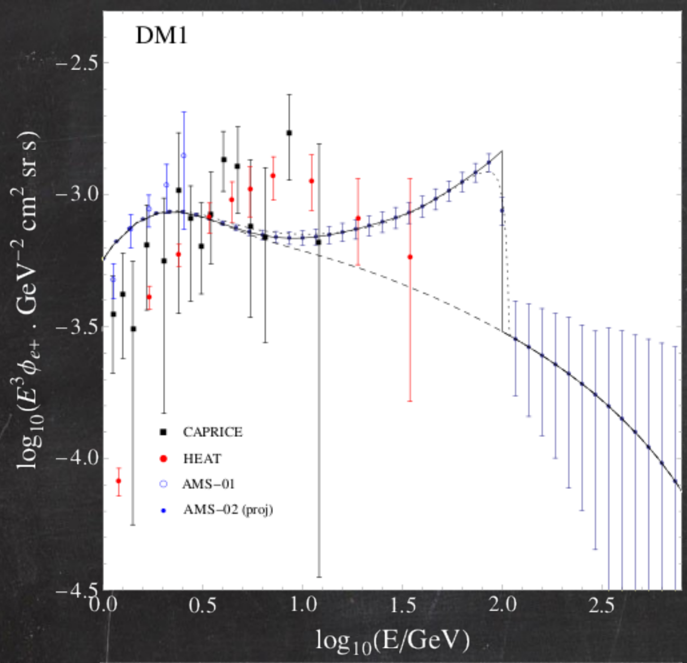


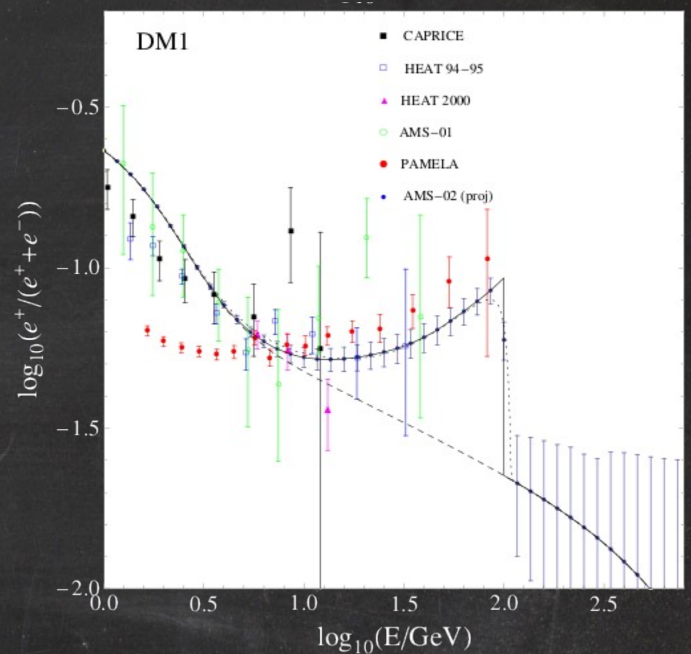
$\mathrm{Flux}/\Omega \sim 10^{-22}\ \mathrm{GeV\,cm^{-2}s^{-1}Hz^{-1}sr^{-1}}$

Experiment	Sensitivity $\mathrm{GeV\ cm^{-2}\ s^{-1}\ Hz^{-1}\ sr^{-1}}$
WMAP	10^{-18}
ALMA	10^{-19}

Electron and positron flux

Pato, Lattanzi & Bertone arXiv: 1010.5236





benchmark	Γ	E_{cut} [GeV]	N_1^{50}	N_1^{99}	N_2	N_3
DM1	1.3	1000	0	0	5	3
DM1	1.5	1000	0	0	5	5
DM1	1.7	1000	0	0	5	3
DM1	1.9	1000	0	0	1	1

ANTF and Fermi-LAT catalogues

It is always possible to find suitable pulsars that produce an electron-positron spectrum compatible, within the experimental uncertainties, with one produced by DM (an vice-versa).

Why electron anisotropy could be better?

A lot of uncertainty affects every attempt to detect the DM

Its nature (mass, rate of annihilation or decay, etc.)

Spiked or cored galactic mass density profile?

Smooth or clumpy distribution

etc...

$$\delta_{DM} = \frac{3\,D(E)}{v}\frac{|\vec{\nabla}\,\phi_{DM}|}{\phi_{DM}}$$

DM electron intrinsic anisotropy is defined in terms of a ratio in which the two term vary in a coherent way with respect to integrated unknowns. Any multiplicative factors is simplified.

Electrons and positrons can travel only few kpc. Almost no difference among spiked and cored profiles

Electron anisotropy

Limit cases

Total flux = Astrophysical flux + Dark Matter flux

$$\vec{\delta} = \frac{3D}{c} \frac{\vec{\nabla}(\phi_{AS}+\phi_{DM})}{\phi_{AS}+\phi_{DM}} \qquad \delta_{min} \leqslant \delta \leqslant \delta_{max}$$

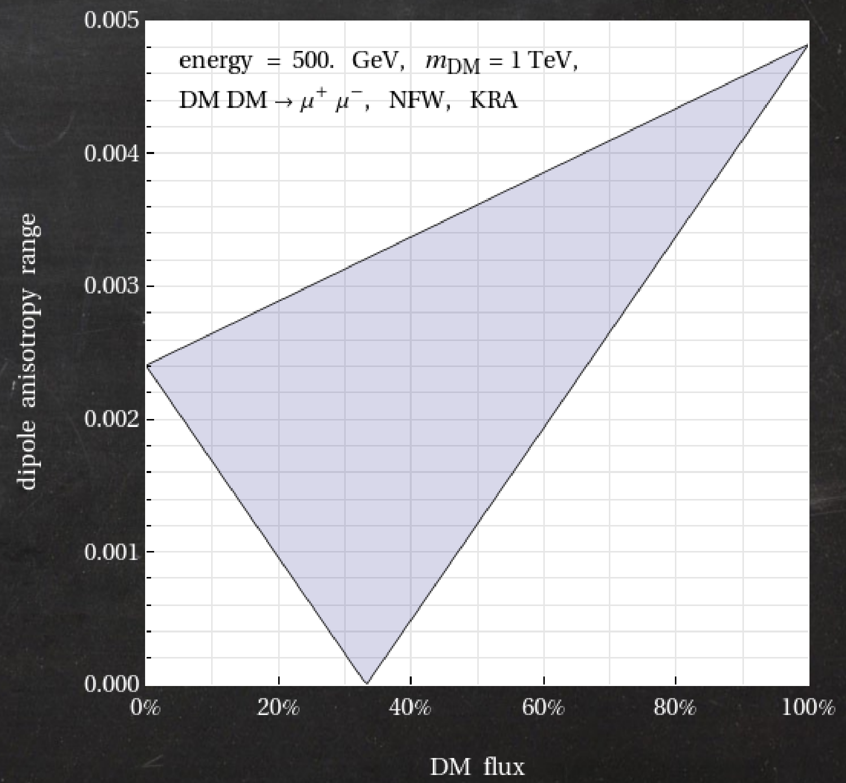
Intrinsic degree of anisotropy:

$$\delta_i = \frac{3D}{v} \frac{|\vec{\nabla}\phi_i|}{\phi_i}$$

$$\delta_{\substack{min\\max}} = \left| \left(1-\frac{\phi_{DM}}{\phi_{TOT}}\right)\delta_{AS} \mp \frac{\phi_{DM}}{\phi_{TOT}}\delta_{DM} \right|$$

Standard assumptions about UHECR: e^- accelerated by SNR, secondary e^+

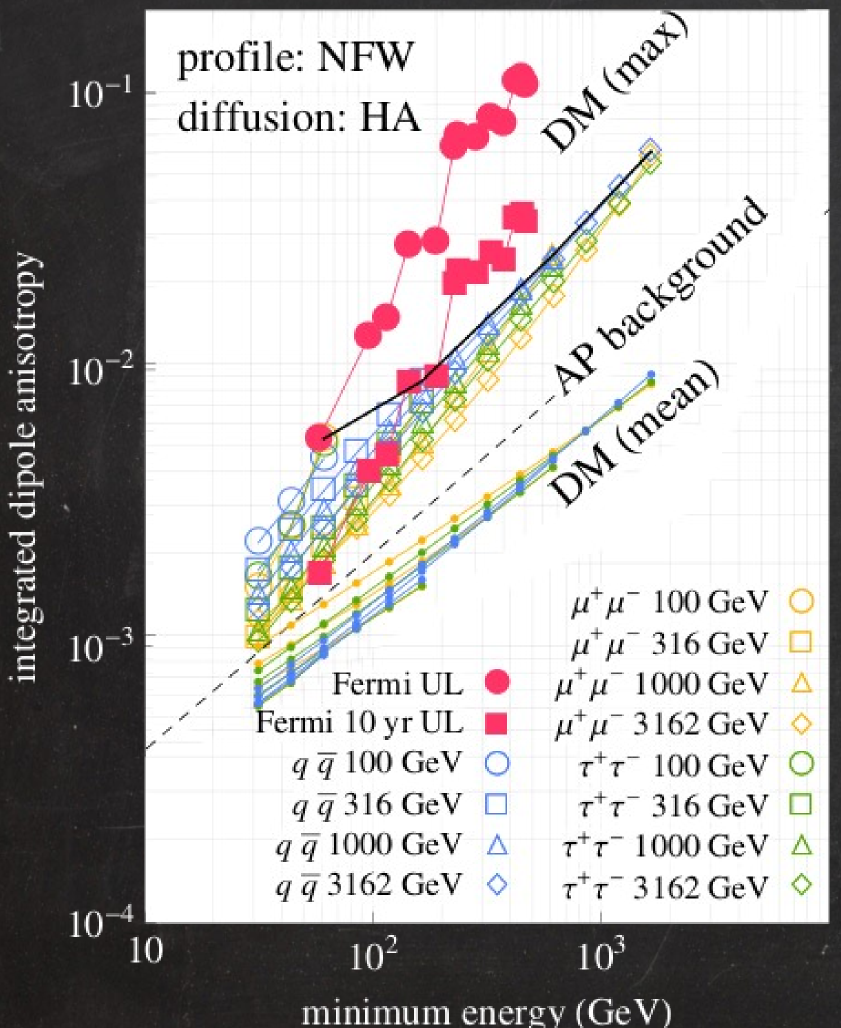
The shielding flux from small substructures prevents unreasonably high values of the Anisotropy.



Electron anisotropy

Universality of the DM electron anisotropy upper limit

Borriello et al. arXiv:arXiv:1012.0041



$$\delta_{DM} = \frac{3\,D(E)}{v}\frac{|\vec{\nabla}\,\phi_{DM}|}{\phi_{DM}}$$

Mass:
From 100 to 3500 GeV

Annihilation models:
- quark pairs
- muon pairs
- tau particle pairs

DM mass density profile:
- NFW (spiked)
- Burkert (cored)

Annihilation rate:
Independent (by def.)

Local DM density:
Independent (by def.)

Propagation model:
- Kraichnan
- Kolmogorov
- HA (α = 0.7)

100 MC realization of the distribution of the clumps with

$m \in 10^2 \div 10^{10}\ M_\odot$

for each model.

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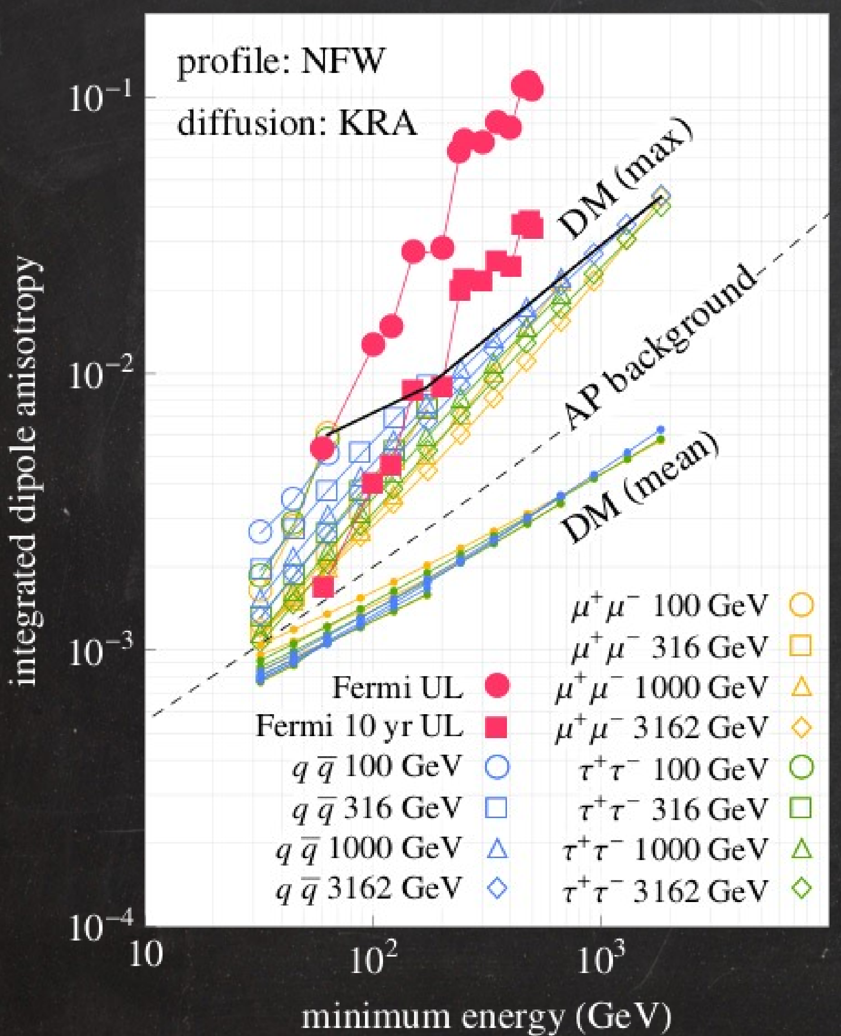

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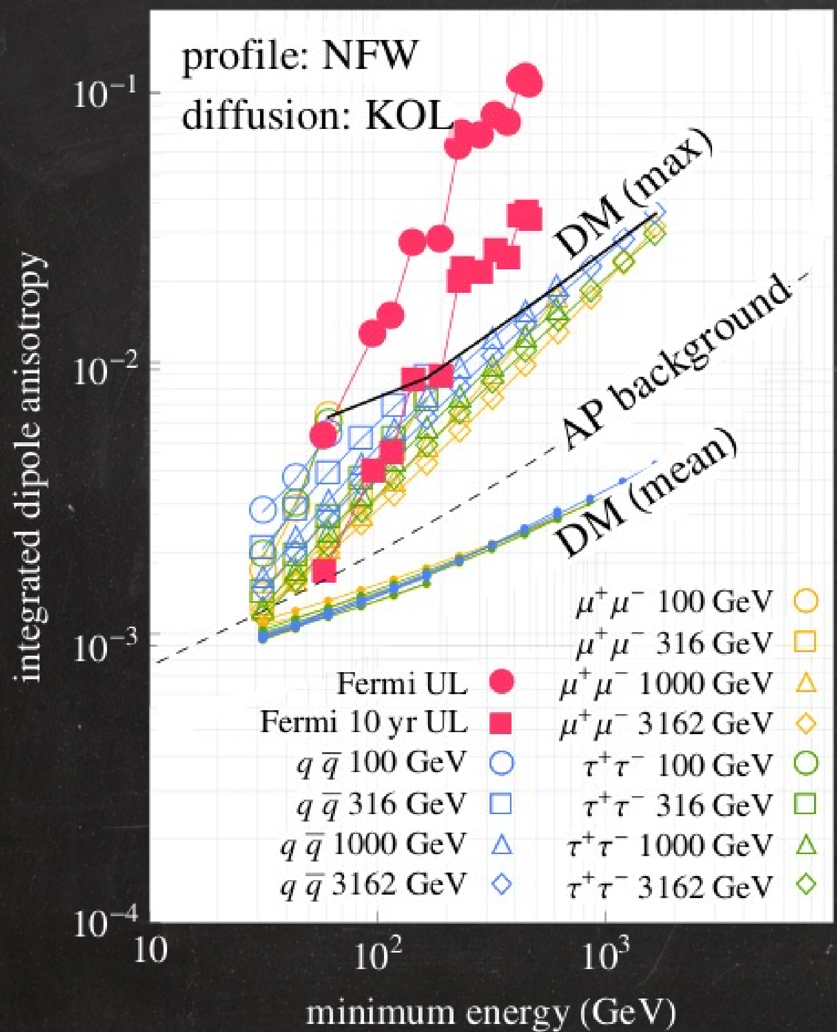

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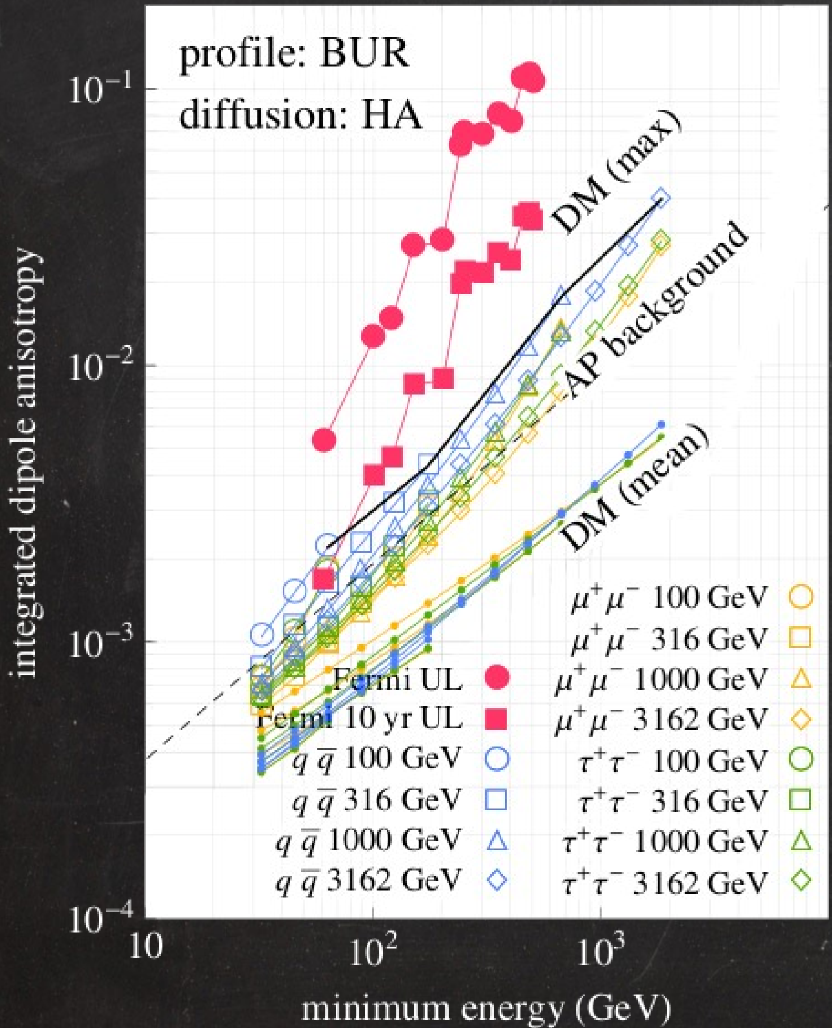

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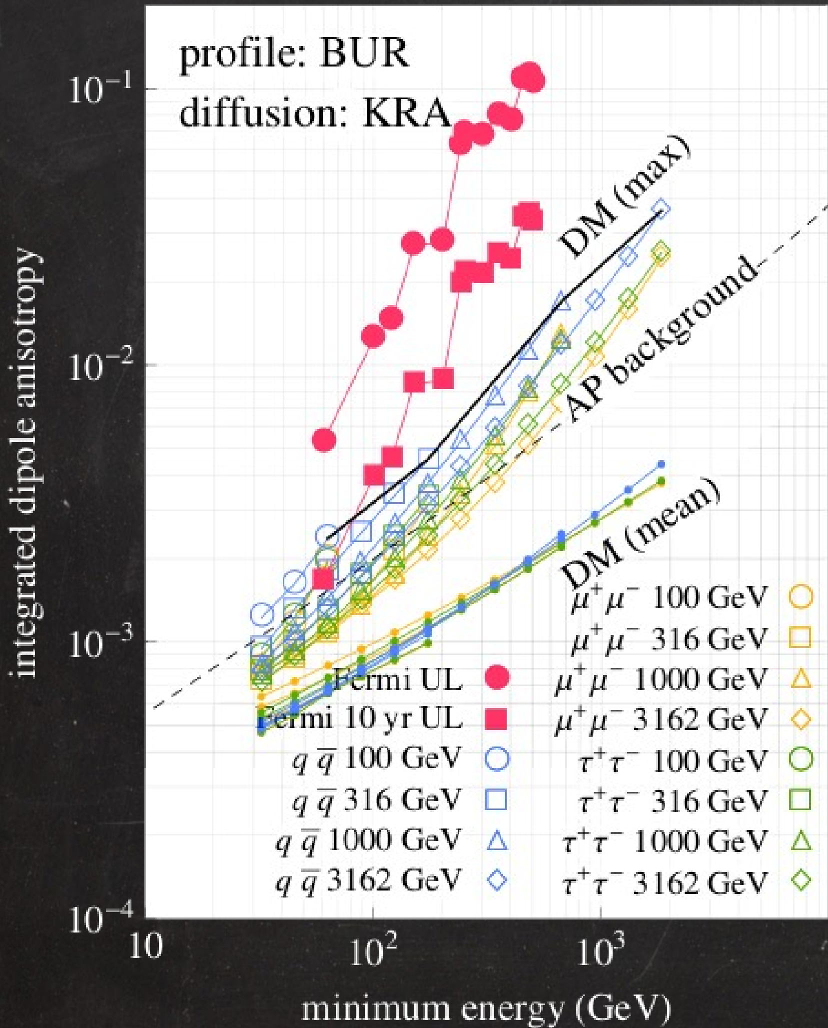

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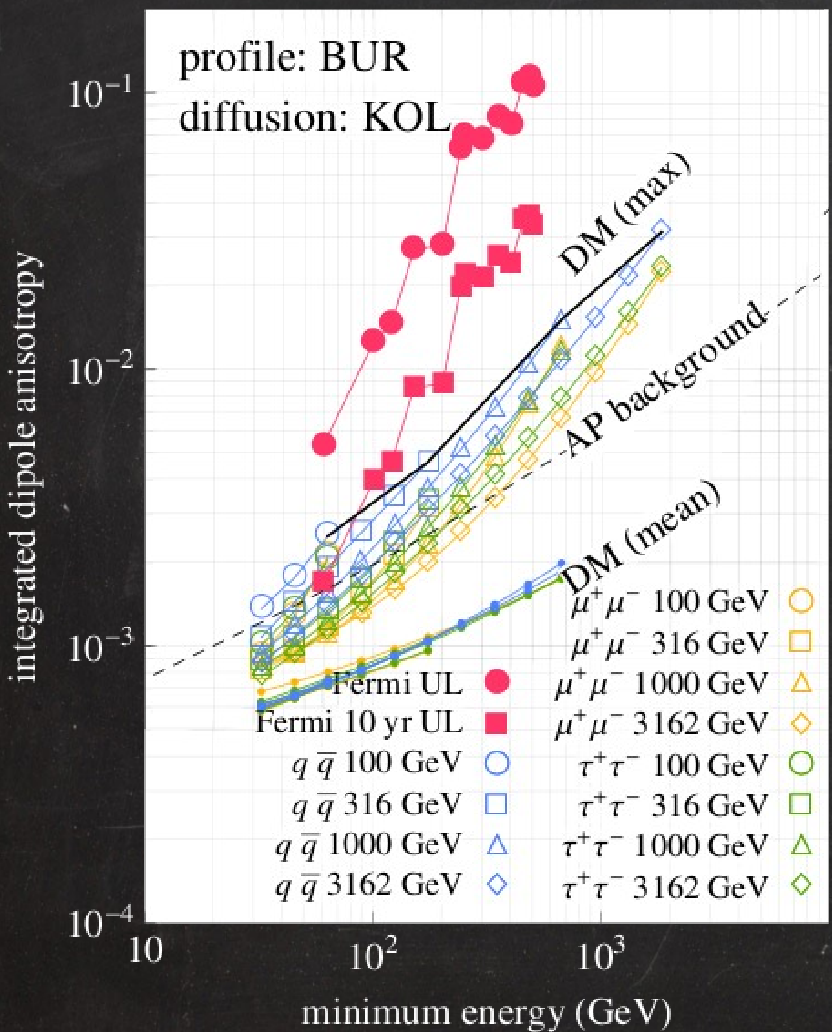

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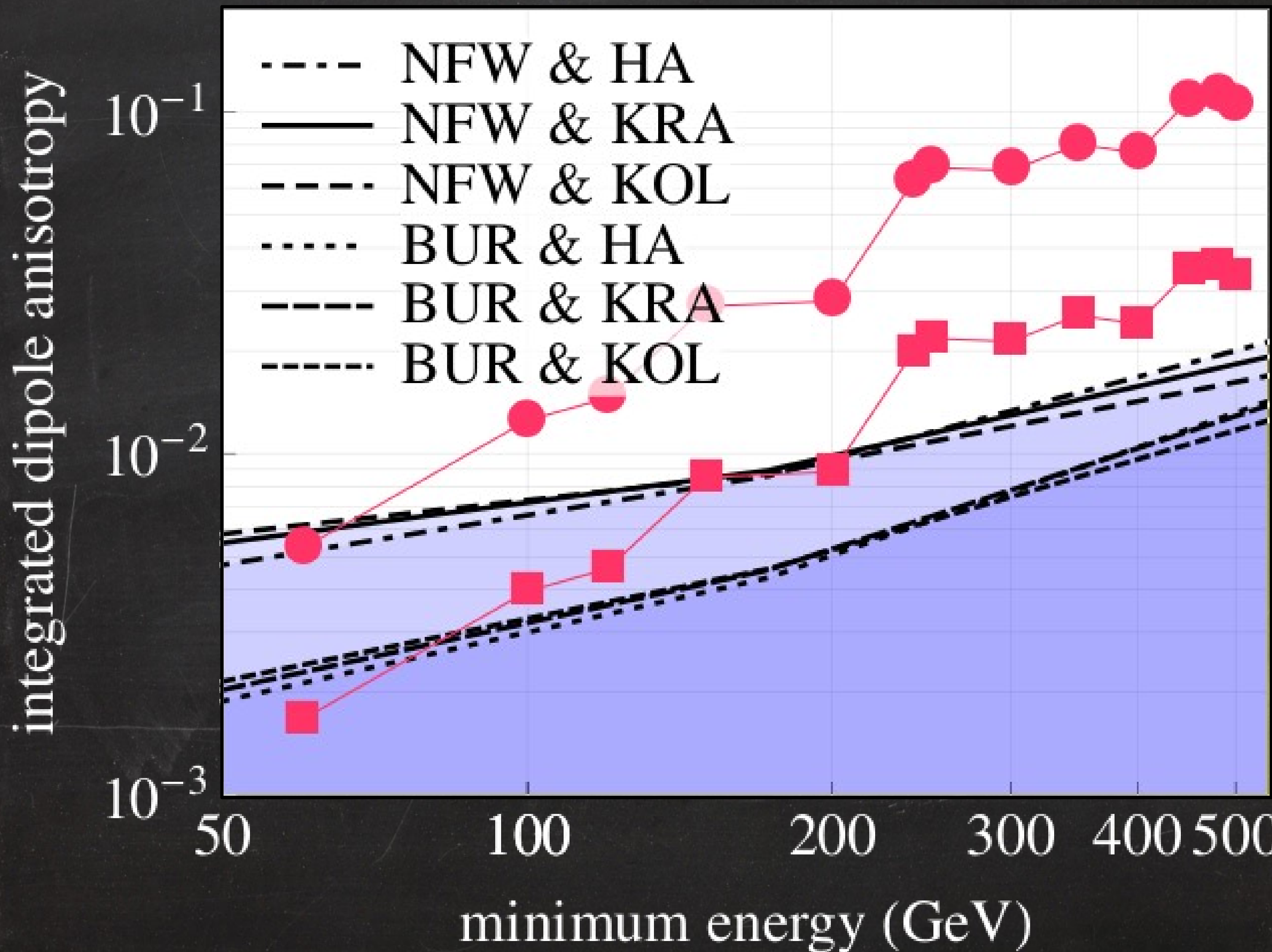
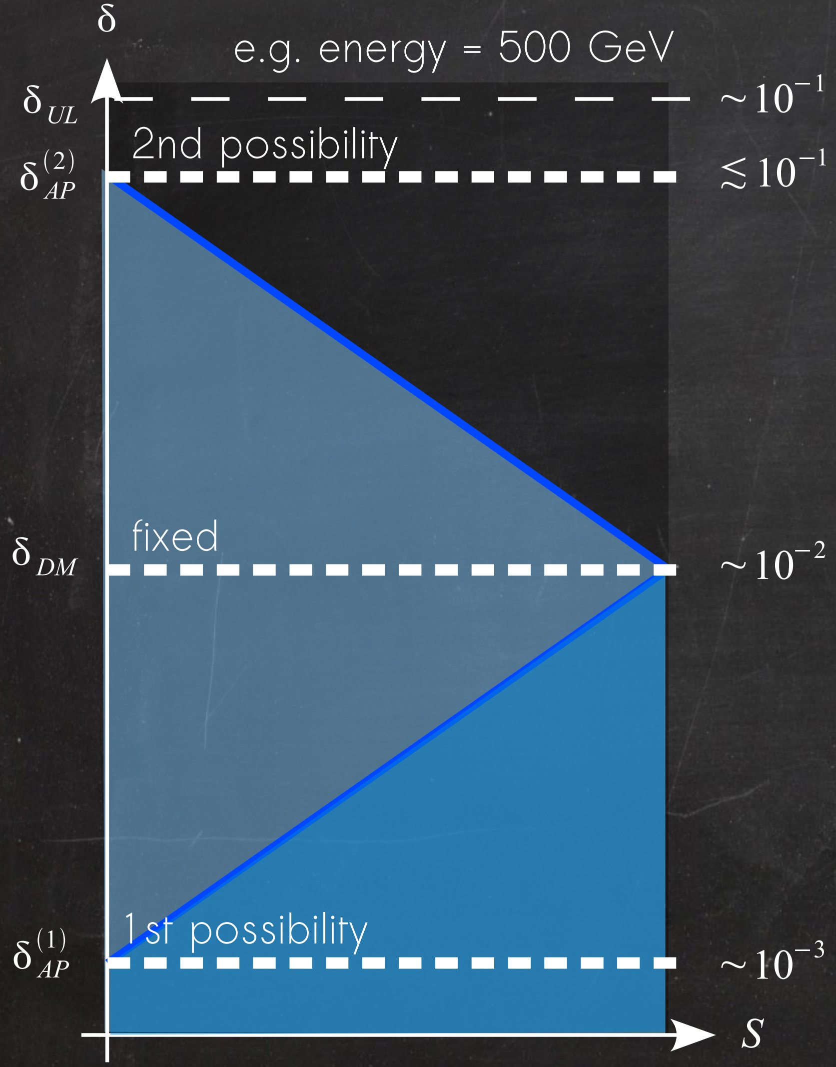


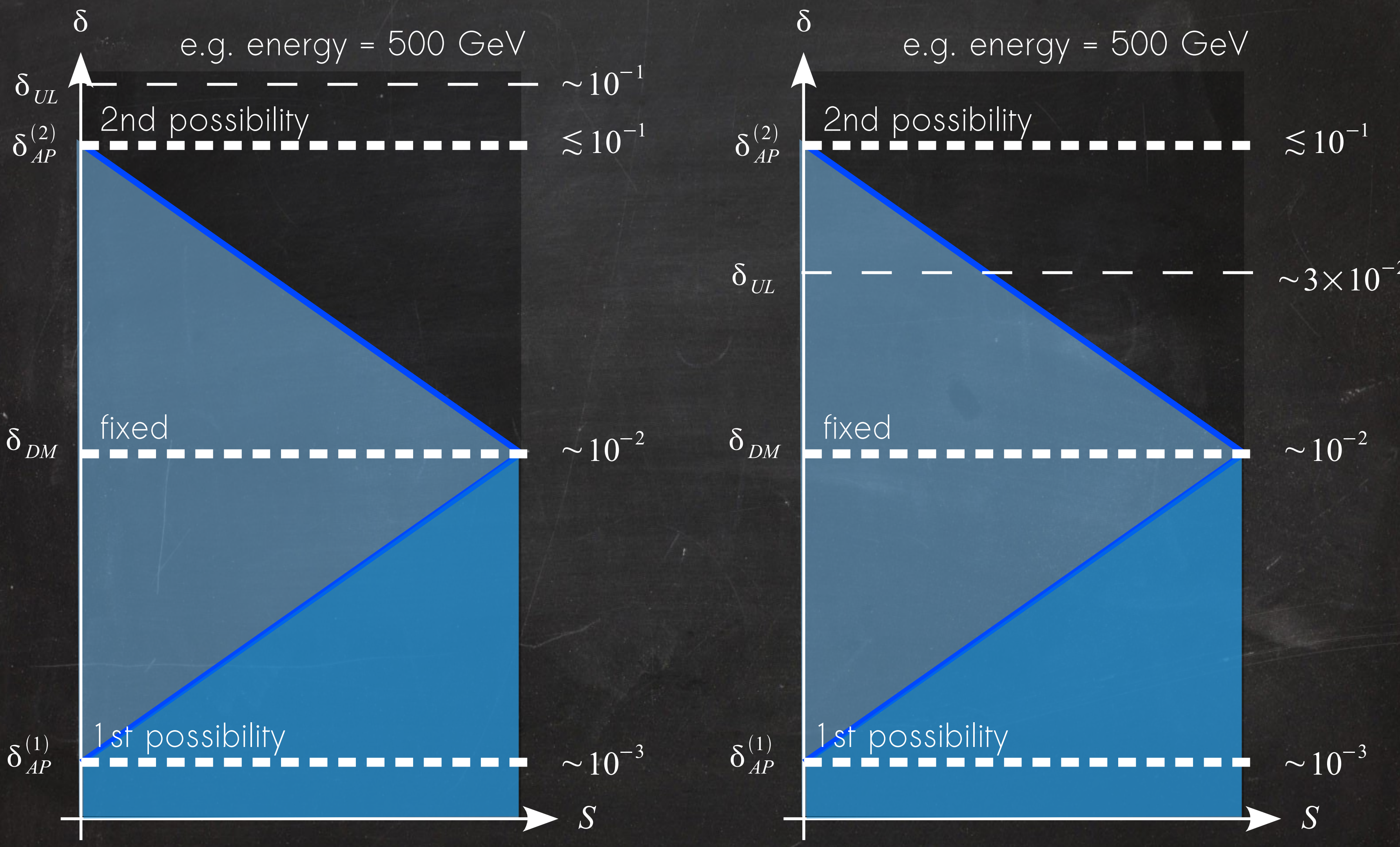
Astrophysical implications

AP anisotropy dominated scenario



Astrophysical implications

Excluding the DM interpretation of a forthcoming anisotropy detection



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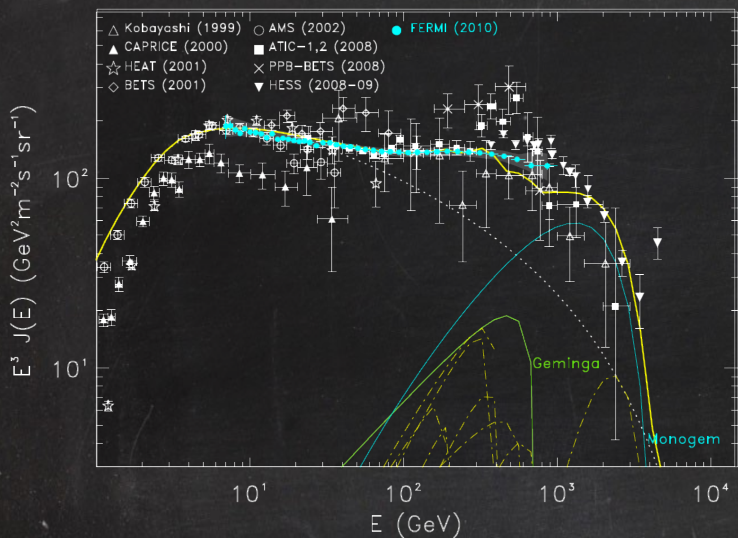
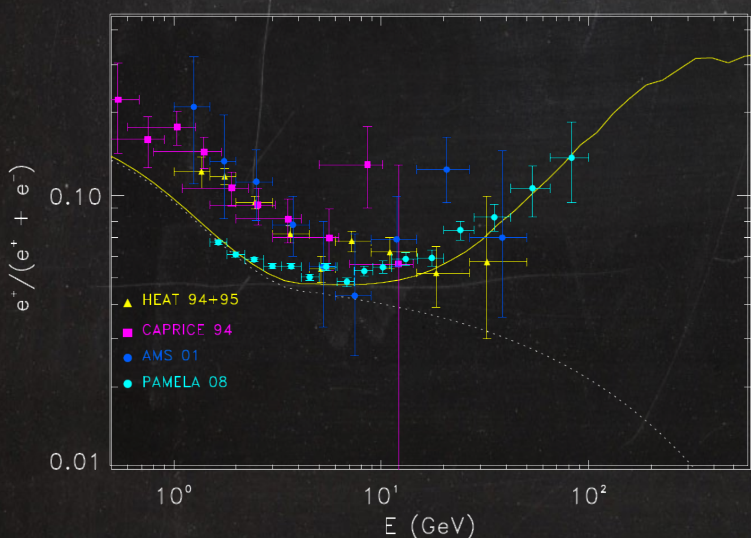
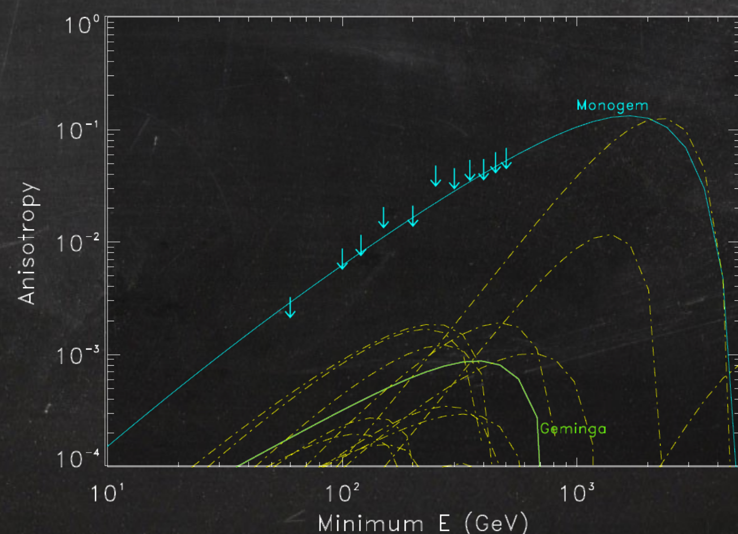


$\delta_{AP} > \delta_{DM}$

Nearby pulsars (within 2 kpc, KRA diffusion setup) contribution is able to explain the excess seen by Fermi LAT with respect to a standard electron and positron astrophysical background.

The same model is able to perfectly reproduce the positron fraction observed by Pamela.

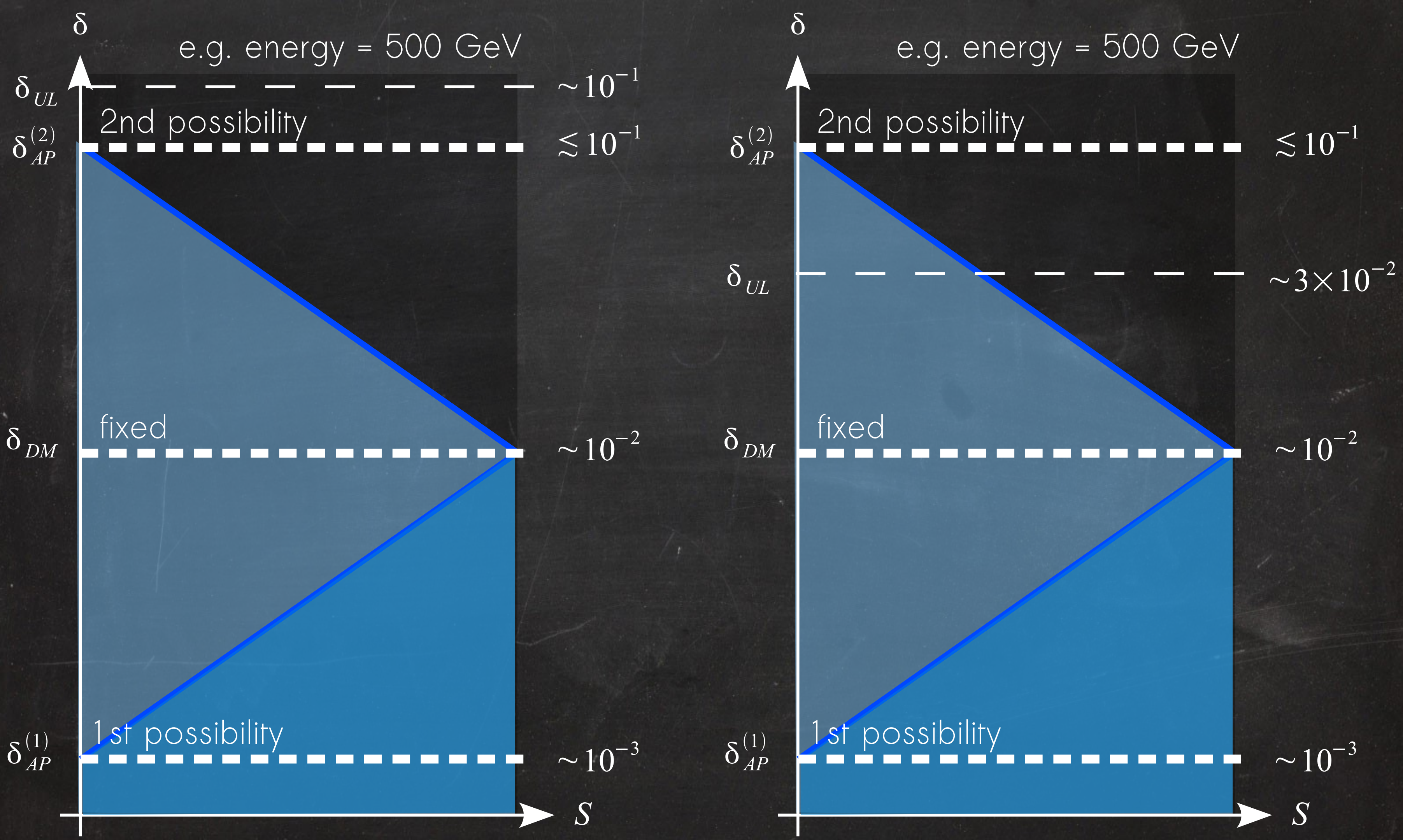




The associ_ated electron anisotropy would be on the verge of being dete_cted by Fermi LAT.

Astrophysical implications

Excluding the DM interpretation of a forthcoming anisotropy detection



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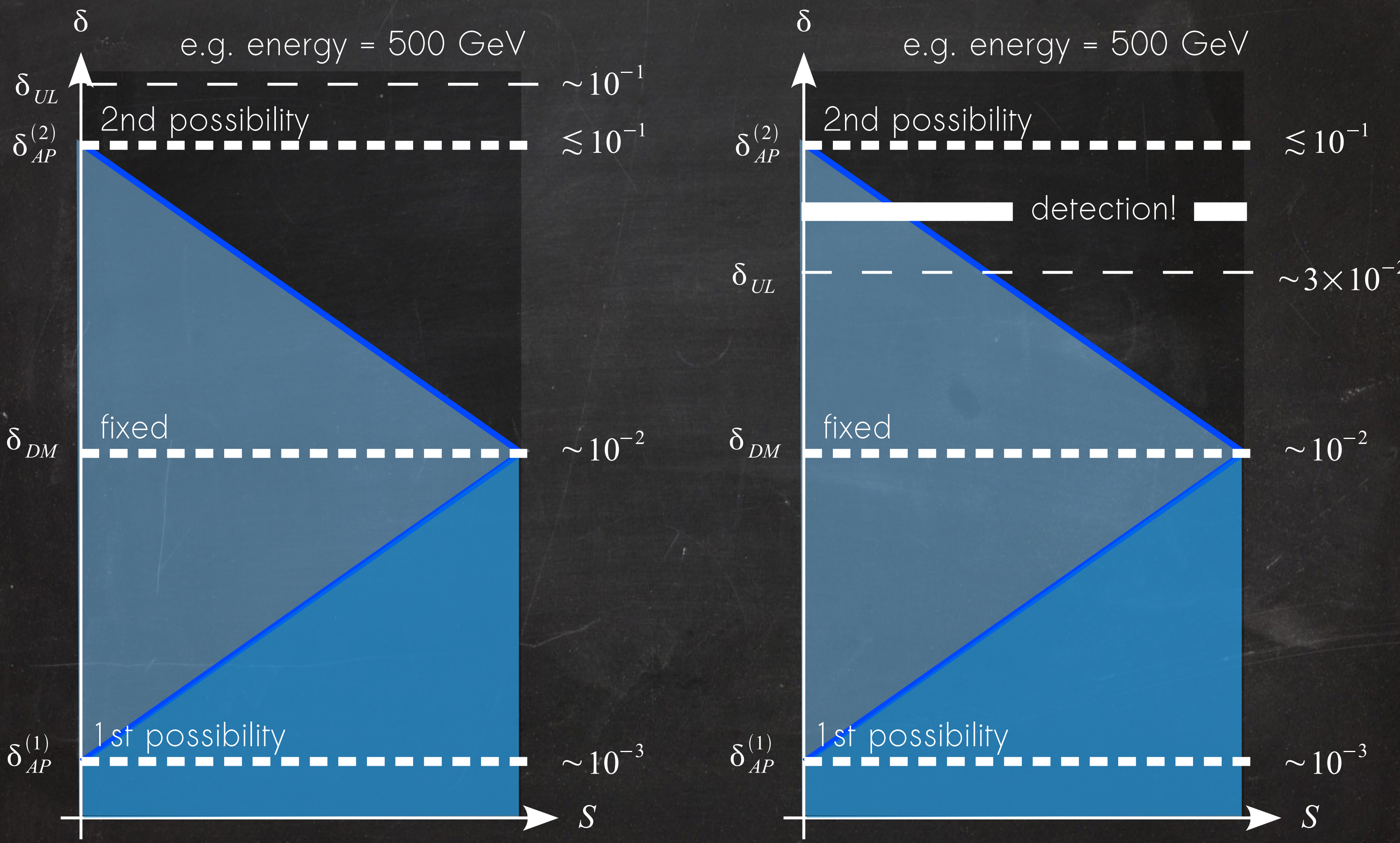
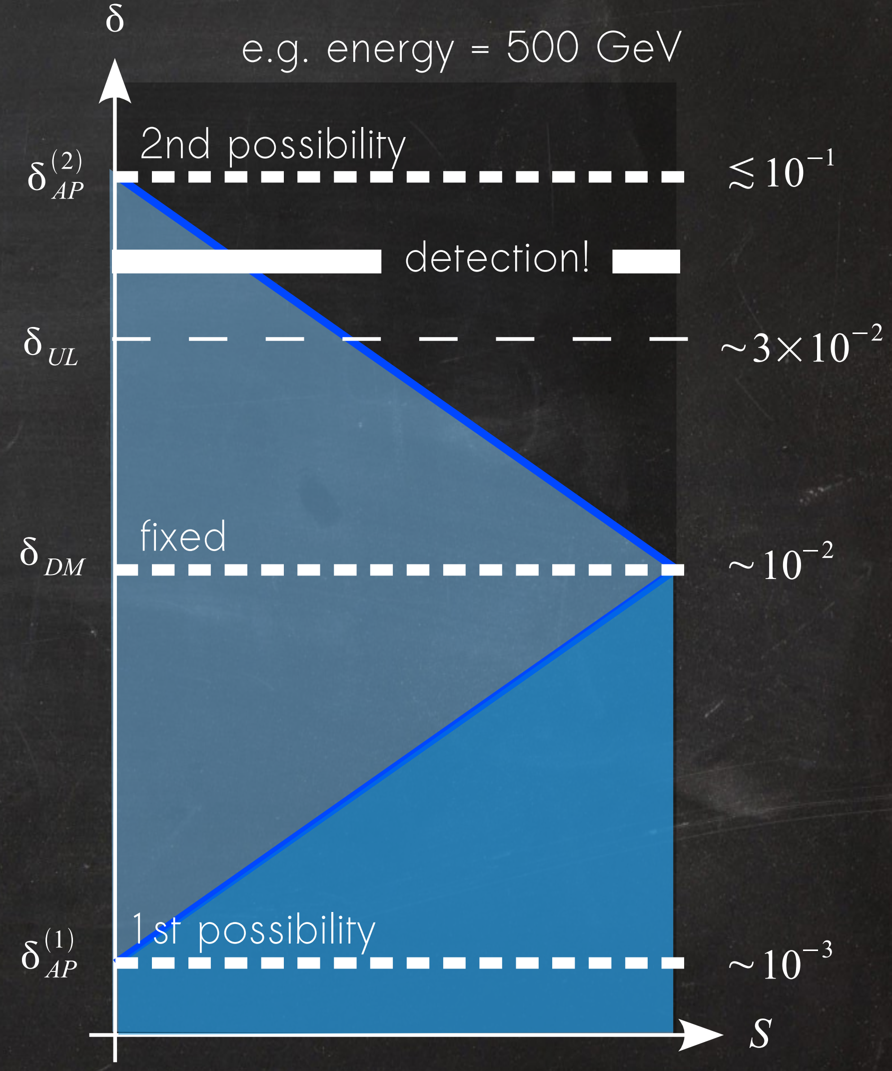


Astrophysical implications

Excluding the DM interpretation of a forthcoming anisotropy detection

Conclusions:

- Dipole anisotropy can exceed the DM intrinsic upper limit only thanks to the contribution of non-standard astrophy_ sical sources.
- If a detection will be made by Fermi LAT in the next ten years, then this argument could be used as a criterion to deduce the presence of exotic astrophysical sources.
- Electron anisotropy can be use as a tool to rule out a dominant DM cotribution to the flux.



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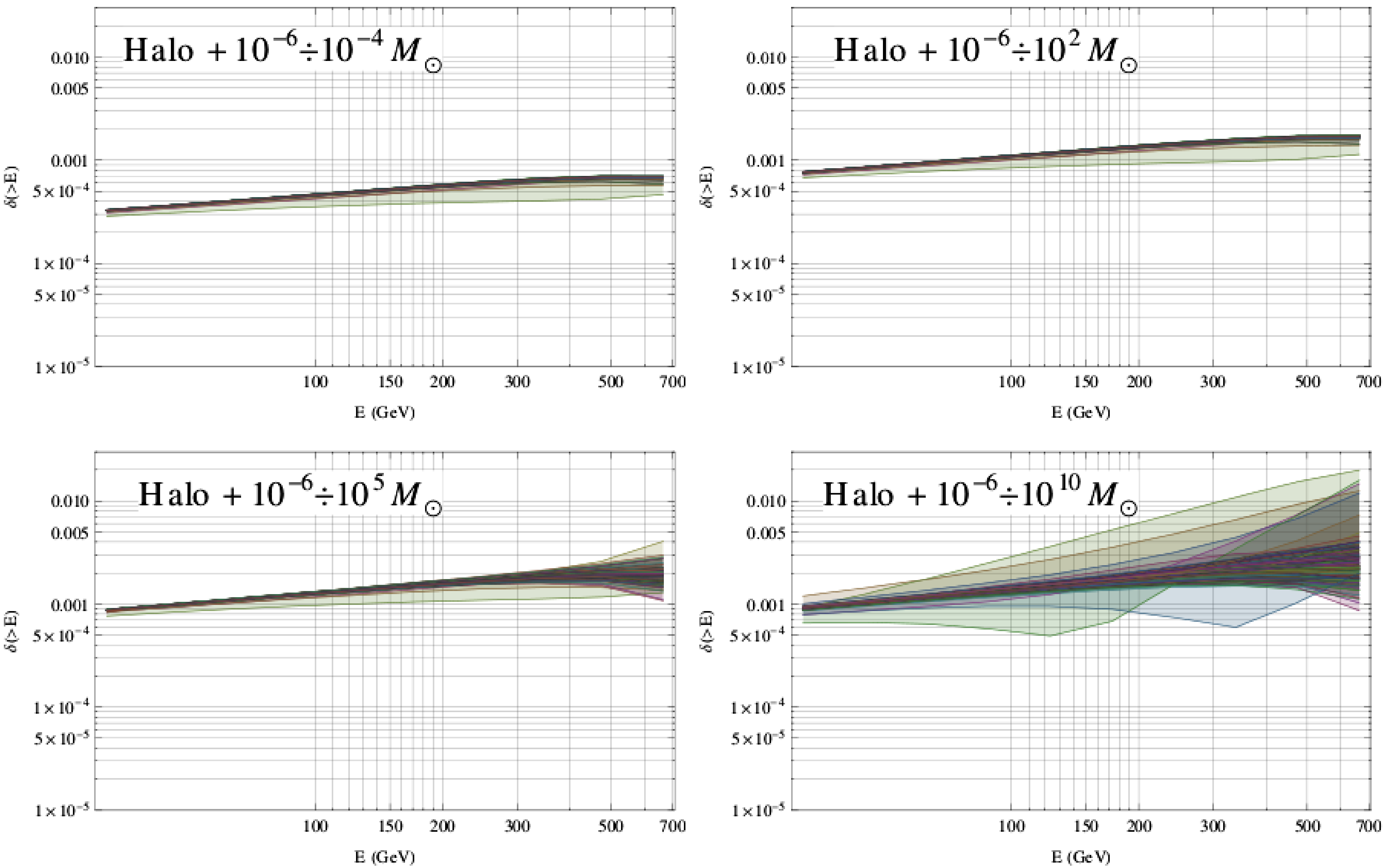
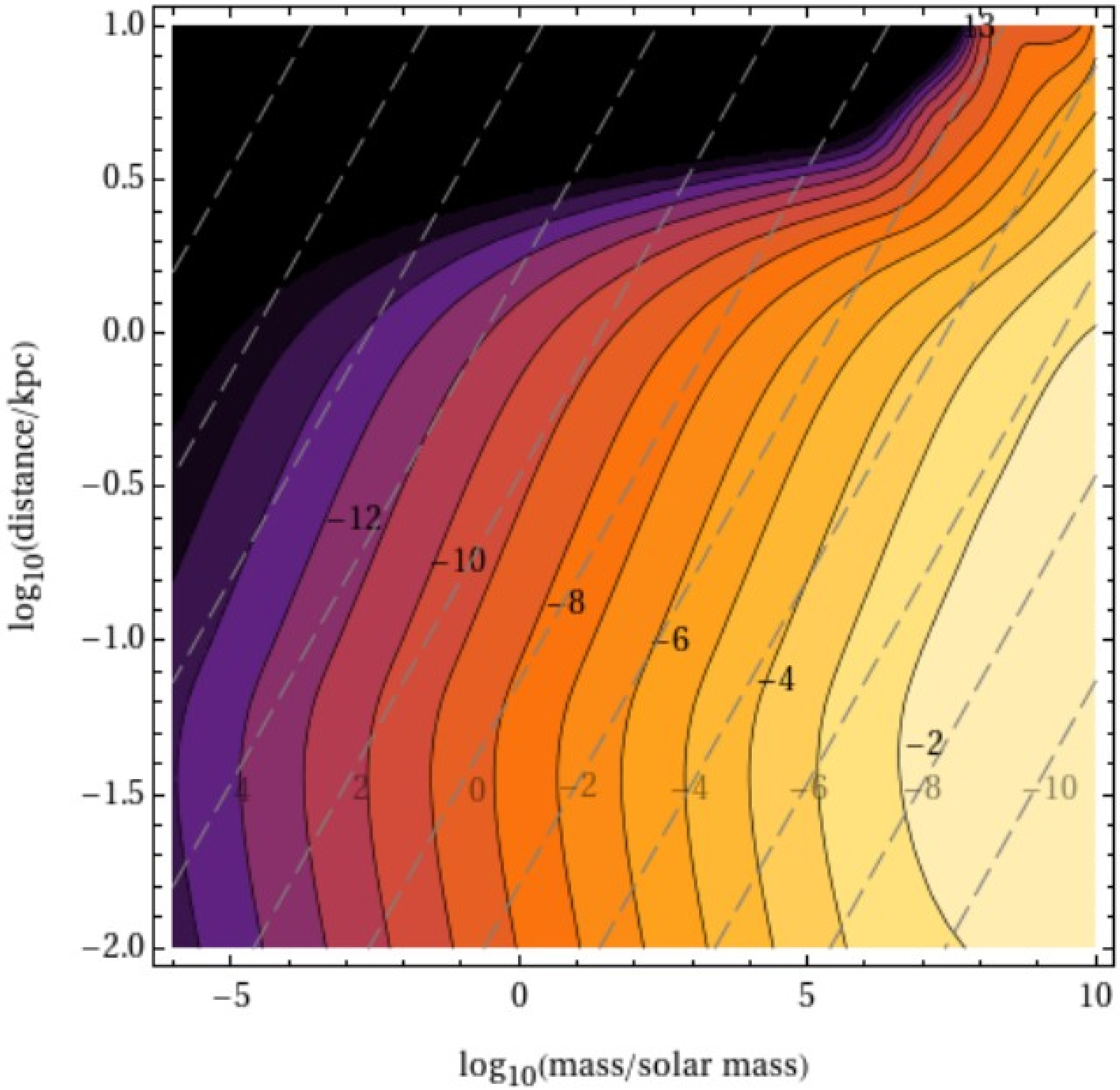


DM anisotropy contributed by substructures in different mass ranges for 100 different realizations.



log10(distance/kpc)
log10(mass/solar mass)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−5
0
5
10
−12
−10
−8
−6
−4
−2
−13
4
2
0
−2
−4
−6
−8
−10