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Gamma rays from Dark Matter in light of CMB constraints

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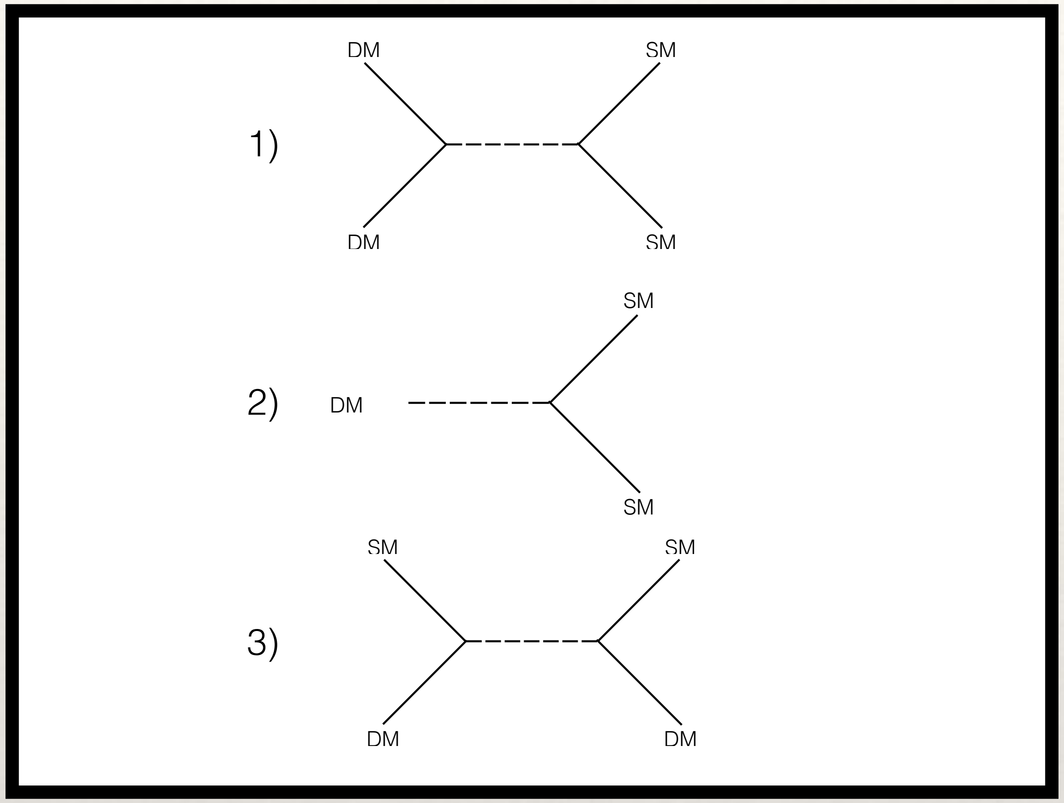
Introduction

Introduction



Targets !

Galactic Center

Dark Matter is key in the Lambda CDM model, roughly 26% of the Universe

yet we do not have non-gravitational signals

one way to search for such signals is through indirect detection

Fermi - GeV

- Searches for gamma rays as DM probe have been extensively pursued (Fermi-LAT) [1-3]

[1] A. A. Abdo et al., Phys. Rev. Lett. 104, 091302 (2010), 1001.4836.

[2] A. A. Abdo et al. (Fermi-LAT), JCAP 1004, 014 (2010), 1002.4415.

[3] M. Ackermann et al. (Fermi-LAT), Phys. Rev. D86, 022002 (2012), 1205.2739.

Introduction

- New generation of gamma ray detectors have been proposed to explore the low MeV and overlap some of the Fermi energy regime such as the e-ASTROGAM [4], GRIPS [5], PANGU[6], ACT[20], and others

[4] V. Tatischeff et al., Proc. SPIE Int. Soc. Opt. Eng. 9905, 99052N (2016), 1608.03739

[5] J. Greiner, K. Mannheim, F. Aharonian, M. Ajello, L. G. Balasz, G. Barbiellini, R. Bellazzini, S. Bishop, G. S. Bisnovatij-Kogan, S. Boggs, et al. (2011), 1105.12
URL https://arxiv.org/abs/1105.1265.

[6] X. Wu, M. Su, A. Bravar, J. Chang, Y. Fan, M. Pohl, and R. Walter (2014), 1407.0710, URL https://arxiv. org/abs/1407.0710.

[7] S. E. Boggs et al. (Larger ACT), New Astron. Rev. 50, 604 (2006), astro-ph/0608532.

Introduction

- In this work we focus on the possibility of having a 5σ detection in the $\langle \sigma v \rangle$ m_χ plane considering CMB constraints

Targets

Galactic center

Dwarf Galaxy Draco

Gamma-rays from DM

Gamma-rays from DM

$$m_{\pi^0} \lesssim m_\chi \lesssim 1\ \mathrm{GeV}$$

- 6 annihilation channels:

$$\chi\chi \to \gamma\gamma$$
$$\chi\chi \to \gamma\pi^0$$
$$\chi\chi \to \pi^0\pi^0$$
$$\chi\chi \to \bar{l}l \quad (l = e, \mu)$$
$$\chi\chi \to \pi^+\pi^-$$

- With energy spectra:

$$\frac{dN}{dE}_{\gamma\gamma} = 2\delta(E - m_\chi)$$

$$\frac{dN}{dE}_{\gamma\pi^0} = \delta\left(E - \left(m_\chi - \frac{m_{\pi^0}^2}{4m_\chi}\right)\right) + \frac{2}{m_\chi - \frac{m_{\pi^0}^2}{4m_\chi}}$$

$$\frac{dN}{dE}_{\pi^0\pi^0} = \frac{4}{\sqrt{\frac{s}{4} - m_{\pi^0}^2}}$$

$$\frac{dN}{dE}_{\bar{l}l} = \frac{\alpha}{\pi}\left(\frac{1 - (1-y)^2}{y}\right)\left(\ln\frac{s(1-y)}{m_l^2}\right)$$

The spectra for charged pions was provided by [8] !

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[8] D.-F. M. L. Coogan, A and S. Profumo (2017), Private Communication, In Preparation.

Thermal history and CMB constraints

Thermal History and CMB constraints

- DM particle annihilation can inject energy in the IGM

Energy injected !

$$\frac{dE}{dtdV} = \rho_c^2 c^2 \Omega_\chi^2 (1+z)^6 \frac{\langle \sigma v \rangle}{m_\chi}$$

- Account for the absorbed energy

$$\frac{dE}{dtdV}_{\text{absorbed}} = f(z) \frac{dE}{dtdV}_{\text{injected}}$$

- Efficiency function $f(z)$

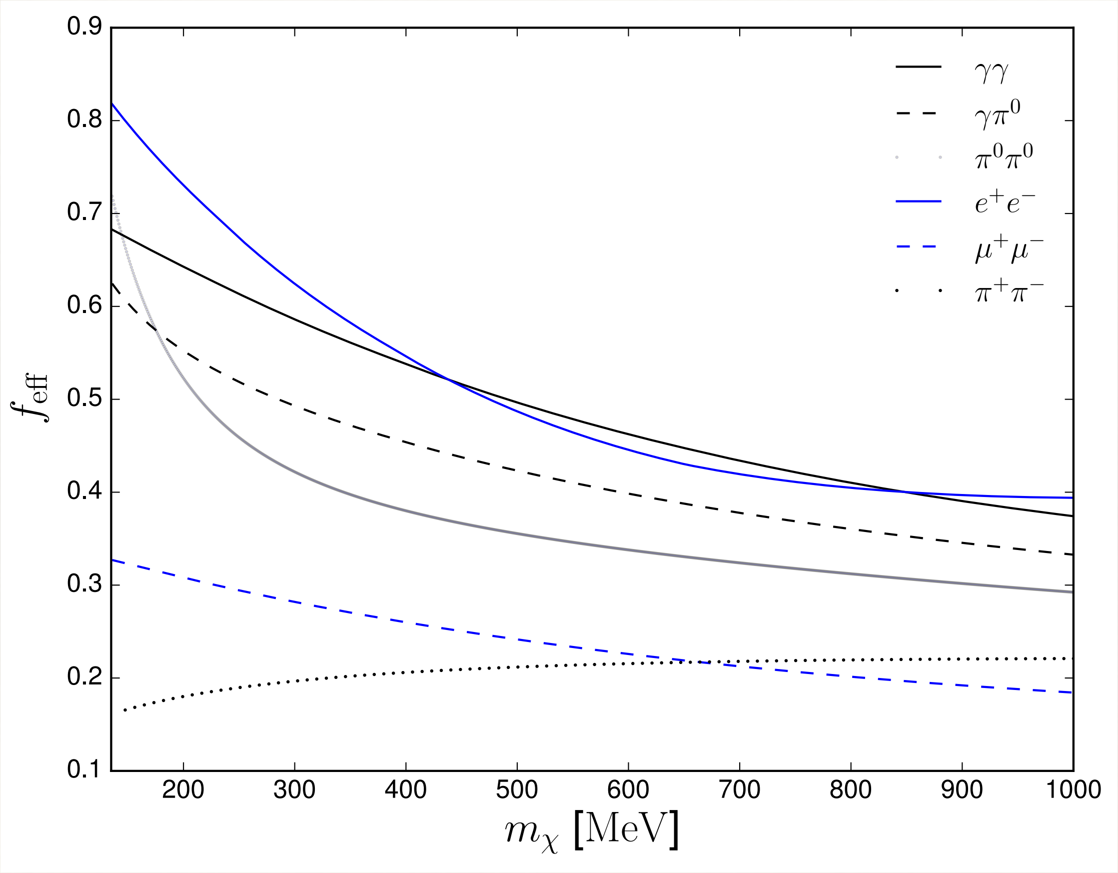
Mathematica: http://nebel.rc.fas.harvard.edu/epsilon

Python: https://github.com/JavierReynoso/feff.git

. T. R. Slatyer, Phys. Rev. D93, 023527 (2016), 1506.03811.

Thermal history and CMB constraints

DM annihilation channels $\longrightarrow$ $\dfrac{dN^{e^-(e^+)}}{dE}$ $\dfrac{dN^{(\gamma)}}{dE}$ $\xrightarrow[\text{Input in the code}]{}$ $f_{\rm eff}$



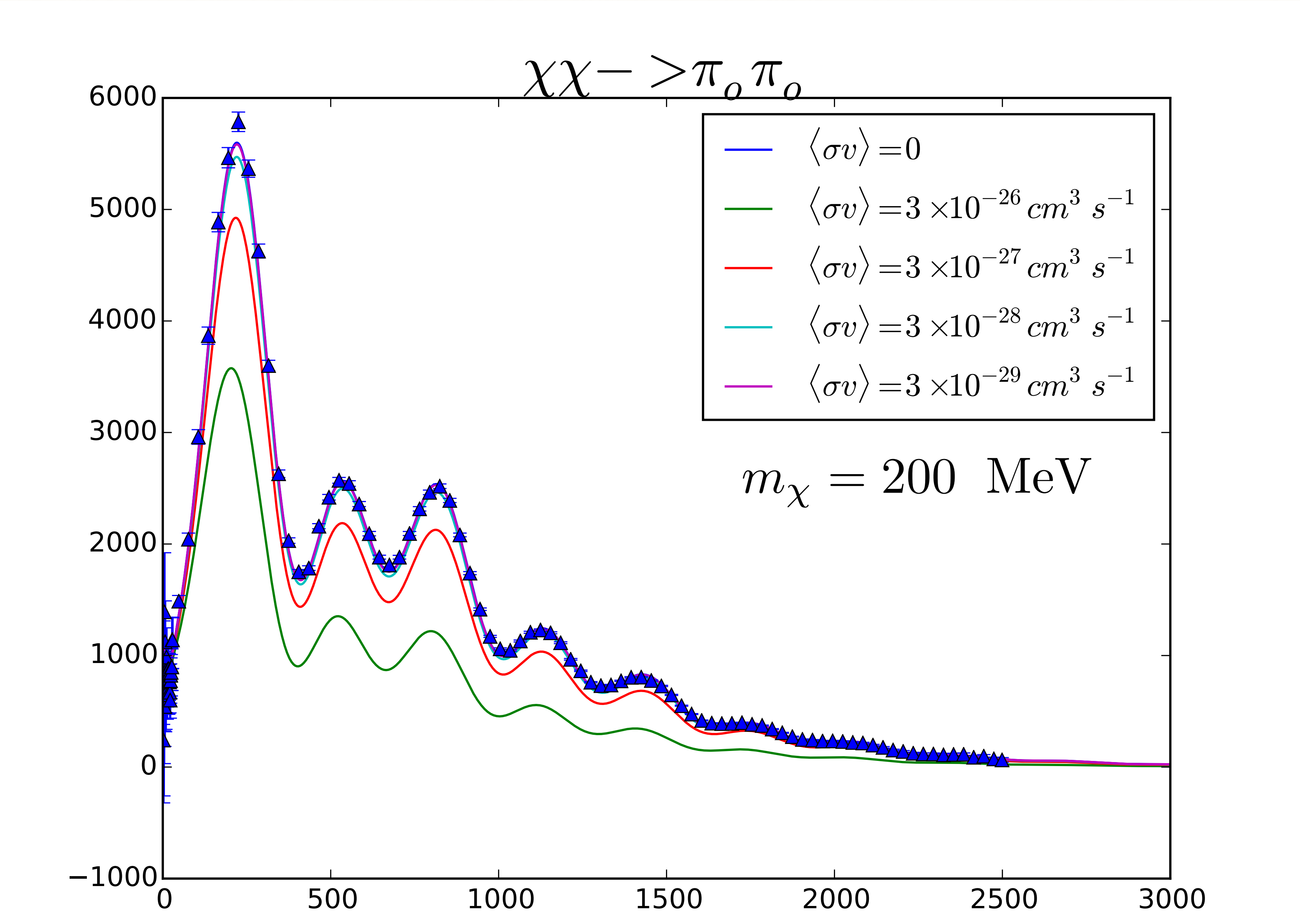
$$P_{\rm ann} \equiv f_{\rm eff}\frac{\langle\sigma v\rangle}{m_\chi}$$

$$\boxed{\langle\sigma v\rangle < \frac{m_\chi}{f_{\rm eff}} P_{\rm ann}}$$

$$P_{\rm ann} < 4.1 \times 10^{-28} {\rm cm}^3 {\rm s}^{-1} {\rm GeV}^{-1}$$

P. A. R. Ade et al. (Planck), Astron. Astrophys. 594, A13 (2016), 1502.01589.

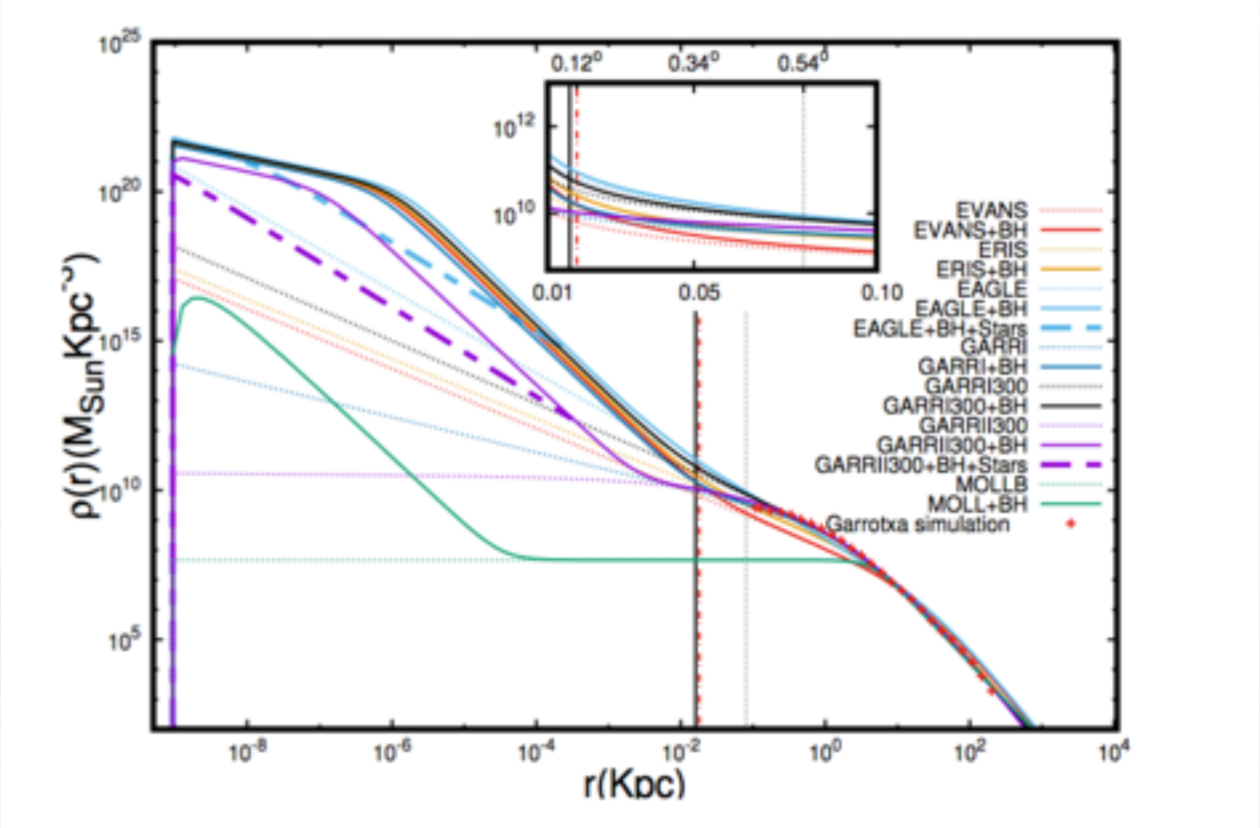
Thermal History and CMB constraints



Gamma-ray detection

Gamma-ray detection

- Photon flux from DM annihilation



$$\phi = J(\Delta\Omega)\cdot\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\int dE\frac{dN}{dE}_\gamma$$

$$\log_{10}(J_{\rm Draco}/{\rm GeV}^2{\rm cm}^{-5}) = 19.05^{+0.22}_{-0.21}[10]$$

$$\log_{10}(J_{\rm GC}/{\rm GeV}^2{\rm cm}^{-5}) \sim 19 - -23[9]$$

[9] V. Gammaldi, V. Avila-Reese, O. Valenzuela, and A. X. Gonzales-Morales, Phys. Rev. D94, 121301 (2016), 1607.02012.

[10] K. K. Boddy, K. R. Dienes, D. Kim, J. Kumar, J.-C. Park, and B. Thomas, Phys. Rev. D94, 095027 (2016), 1606.07440.

Gamma-ray detection

$$N_s \sim N_\sigma \sqrt{N_b} \qquad N_\sigma = 5$$

we built an hypothetical detector
~ eASTROGAM

$$N_s = \phi \cdot T_{\rm obs} \cdot A_{\rm eff} \qquad N_b \propto \int dE \frac{d\phi_b}{dE}$$

$$\boxed{\langle \sigma v \rangle > 10\sqrt{N_b}\frac{1}{\int_{E^-}^{E^+} dE\,\frac{dN}{dE}}\frac{4\pi}{A_{\rm eff}T_{\rm obs}J}m_\chi^2}$$

- To have a 5 sigma detection !

Gamma-ray detection

$$\frac{d\phi}{d\Omega dE} = (2.74) \times 10^{-3} \left(\frac{\mathrm{MeV}}{E}\right)^{-2.0} \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{MeV}^{-1}$$ Draco [10]

$$E^2 \frac{d\phi}{dE} \sim 1.1 \times 10^{-2} E^{0.23} \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{MeV}$$ GC [11]

Analysis → Optimize energy range of observation

[10] K. K. Boddy, K. R. Dienes, D. Kim, J. Kumar, J.-C. Park, and B. Thomas, Phys. Rev. D94, 095027 (2016), 1606.07440.

[11] A. W. Strong, I. V. Moskalenko, and O. Reimer, Astro- phys. J. 613, 962 (2004), astro-ph/0406254

Gamma-ray detection

$$\int_{\Delta E - m_\chi}^{m_\chi} dE \frac{dN}{dE} \longrightarrow \Delta E$$ maximizes the detection

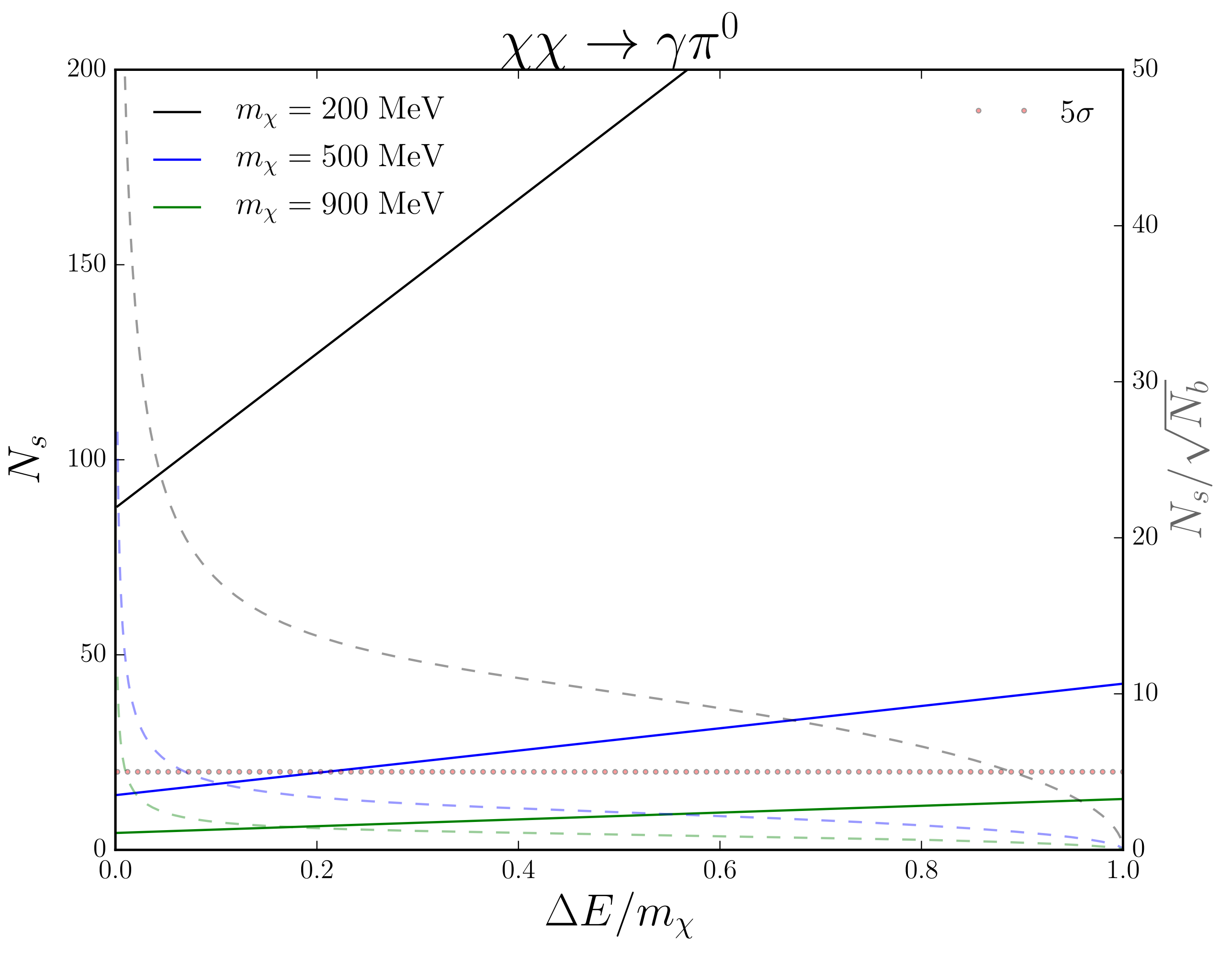
$$\frac{N_s}{\sqrt{N_b}} \propto f(\langle \sigma v \rangle_o, m_{\chi_o}, \Delta E) > 5$$

$$\gamma\pi^0 \to \Delta E / m_\chi \sim 0.01$$

$$\gamma\gamma \to \Delta E / m_\chi \sim 0.01$$

$$\pi^0\pi^0 \to \Delta E / m_\chi = \sqrt{\frac{s}{4} - m_{\pi^0}^2}$$

$$l\bar{l}, \pi^+\pi^- \to \Delta E / m_\chi \sim 0.95$$



Results

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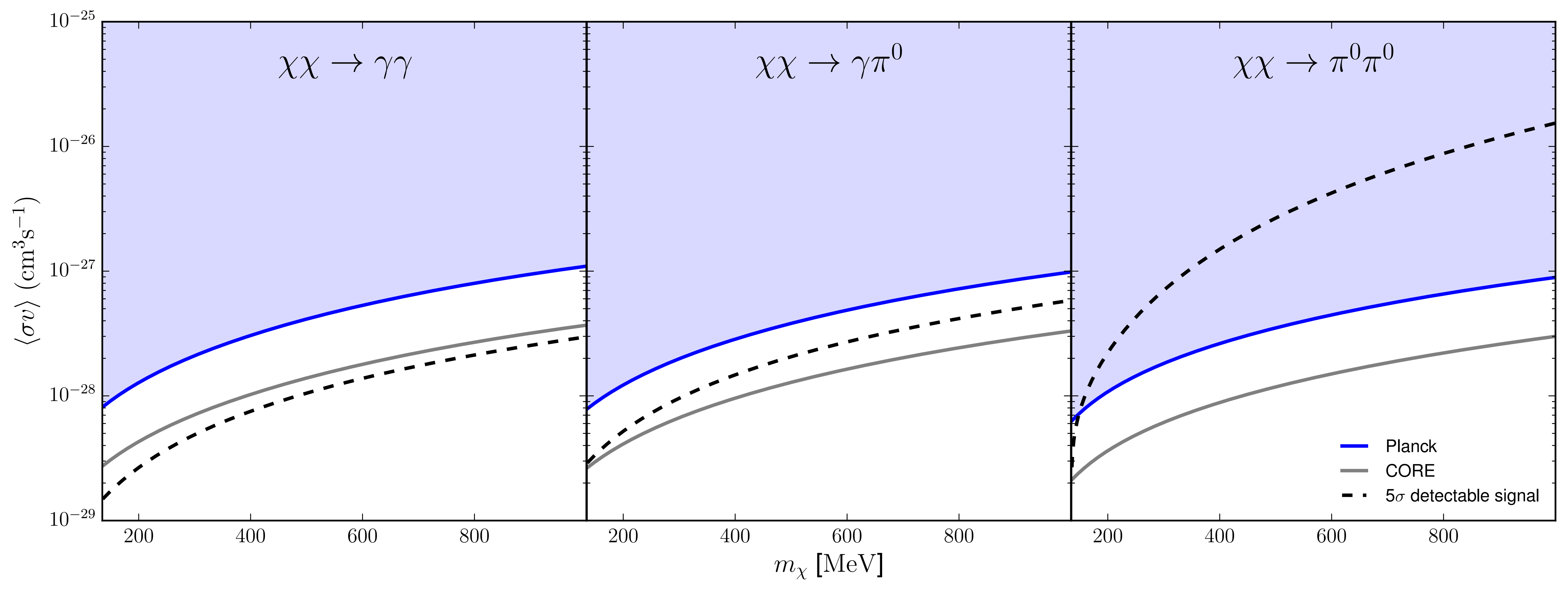
Projected constraint from CORE+ [12] $P_{\text{ann}} < 1.38 \times 10^{-28} \text{cm}^3\text{s}^{-1}\text{GeV}^{-1}$

Planck [13] $P_{\text{ann}} < 4.1 \times 10^{-28} \text{cm}^3\text{s}^{-1}\text{GeV}^{-1}$



[12] E. Di Valentino et al. (CORE) (2016), 1612.00021.

[13] P. A. R. Ade et al. (Planck), Astron. Astrophys. 594, A13 (2016), 1502.01589.

Draco

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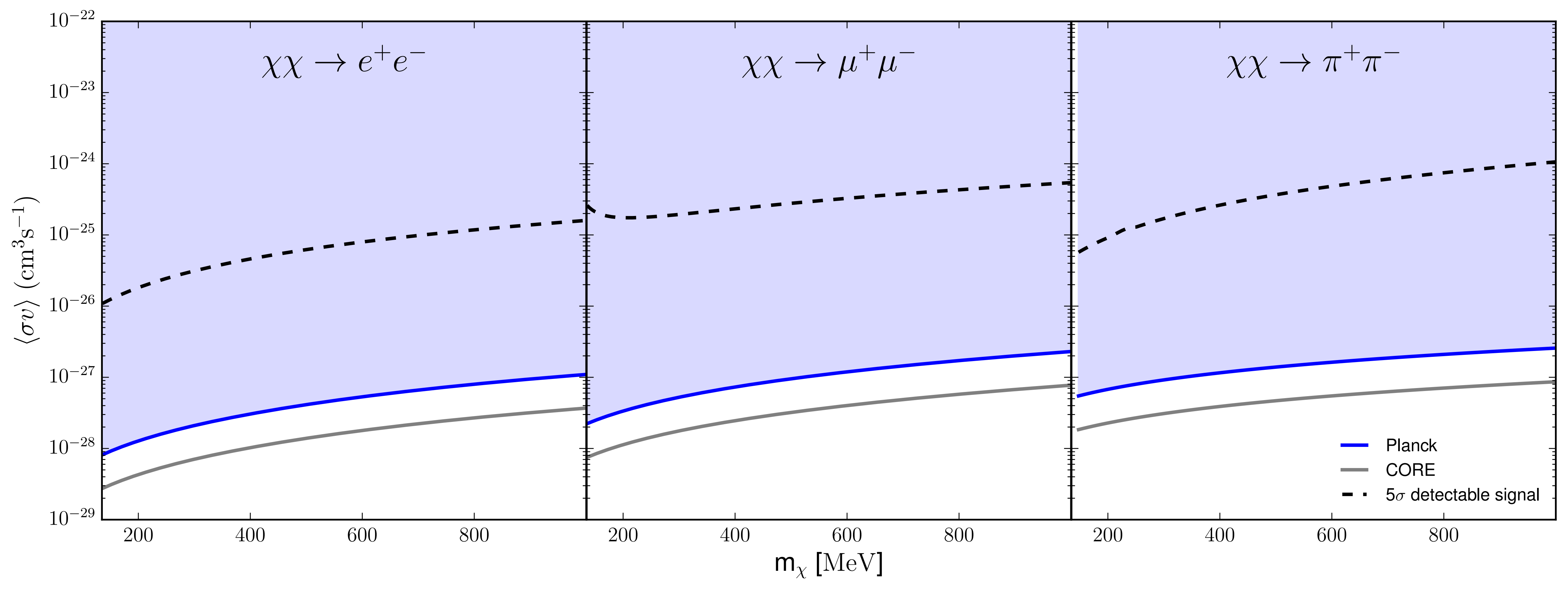

[12] E. Di Valentino et al. (CORE) (2016), 1612.00021.

[13] P. A. R. Ade et al. (Planck), Astron. Astrophys. 594, A13 (2016), 1502.01589.

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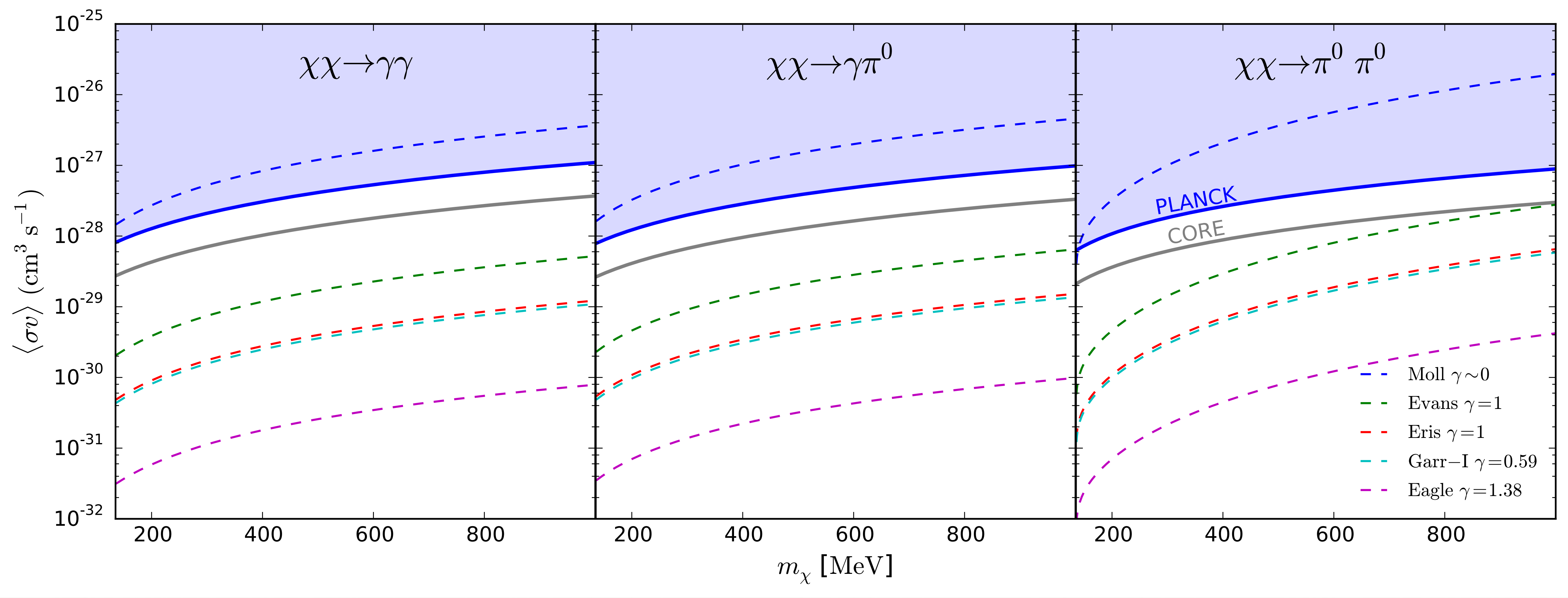

[12] E. Di Valentino et al. (CORE) (2016), 1612.00021.

[13] P. A. R. Ade et al. (Planck), Astron. Astrophys. 594, A13 (2016), 1502.01589.

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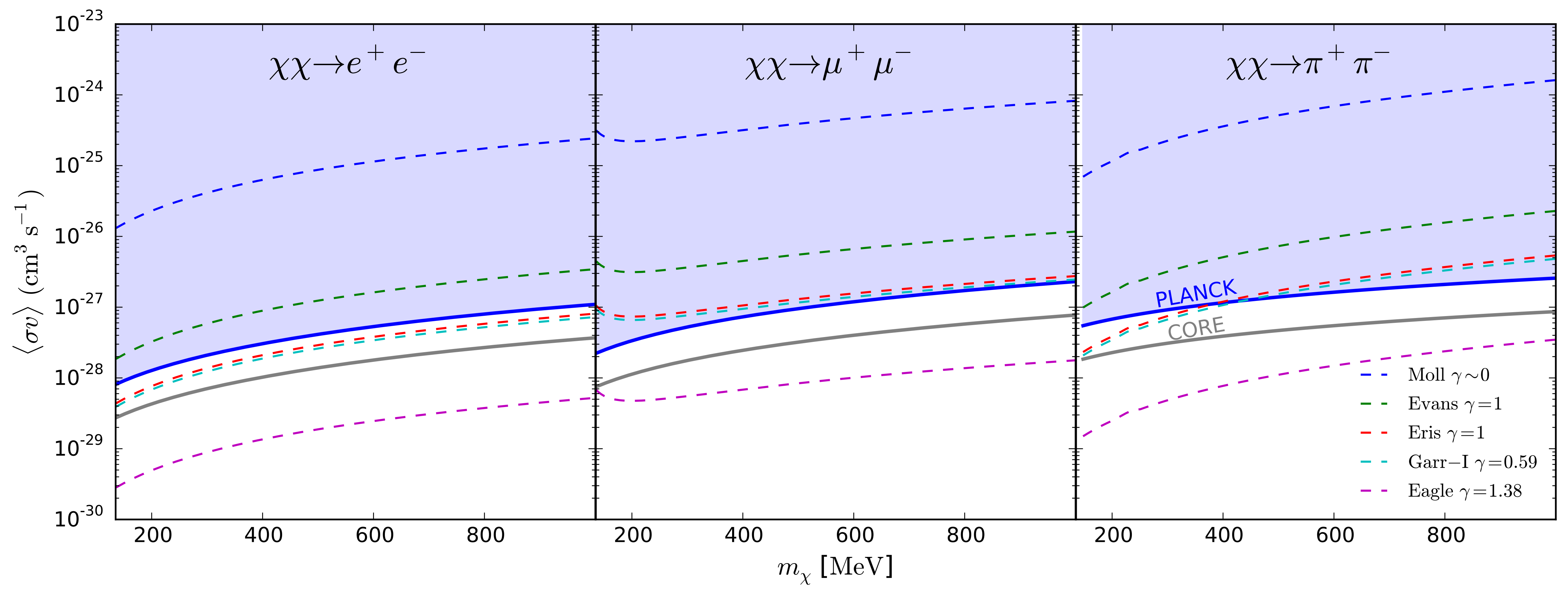


[12] E. Di Valentino et al. (CORE) (2016), 1612.00021.

[13] P. A. R. Ade et al. (Planck), Astron. Astrophys. 594, A13 (2016), 1502.01589.

GC

Discussion

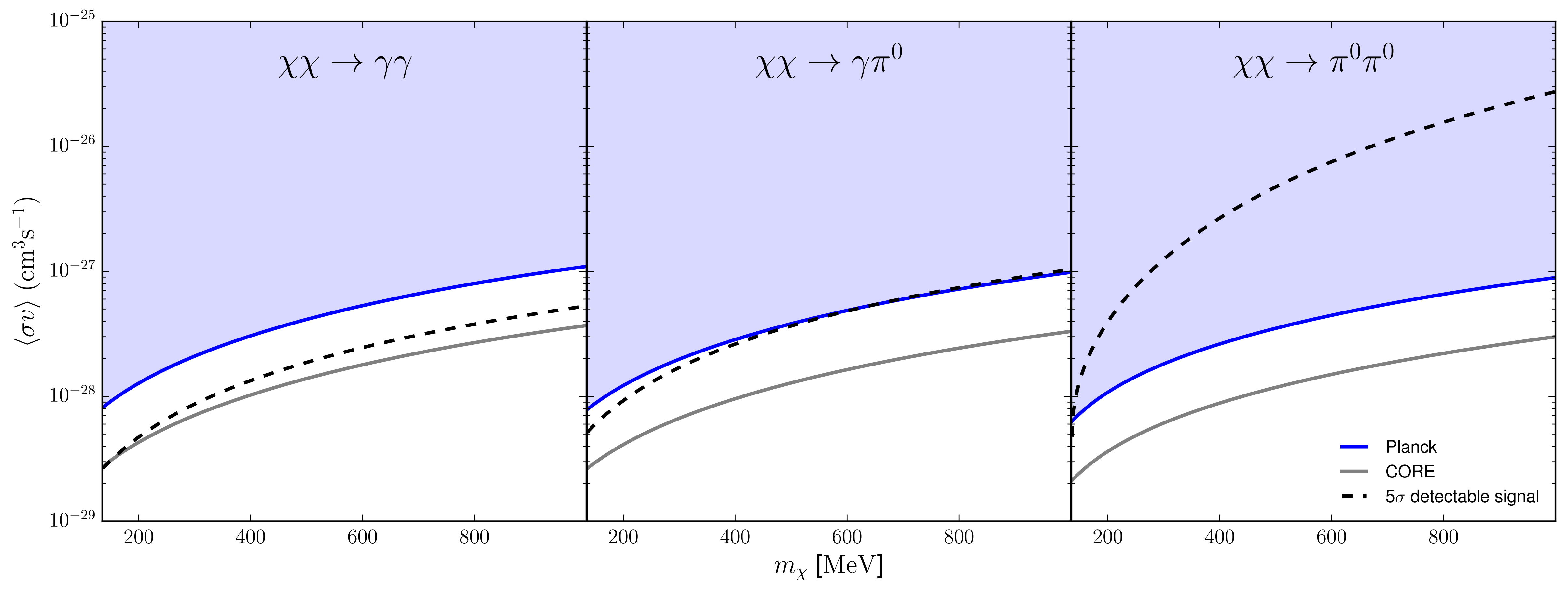
Discussion

- We investigated the possible detection of DM annihilation in the MeV regime
- 6 annihilation channels
- Compared constraints and detection limits
- For Draco 3 channels are totally excluded and the neutral pions channel have a small window of possible detection
- The GC detection depends strongly on the DM density profile used to compute the astrophysical factor "J", still more optimistic

Thanks!

Support material

$$\log_{10}(J_{\mathrm{Draco}}/\mathrm{GeV}^2\mathrm{cm}^{-5}) \sim 18.8[13]$$



[13] A. Geringer-Sameth, S. M. Koushiappas, and M. Walker, Astrophys. J. 801, 74 (2015) [arXiv:1408.0002 [astro- ph.CO]].

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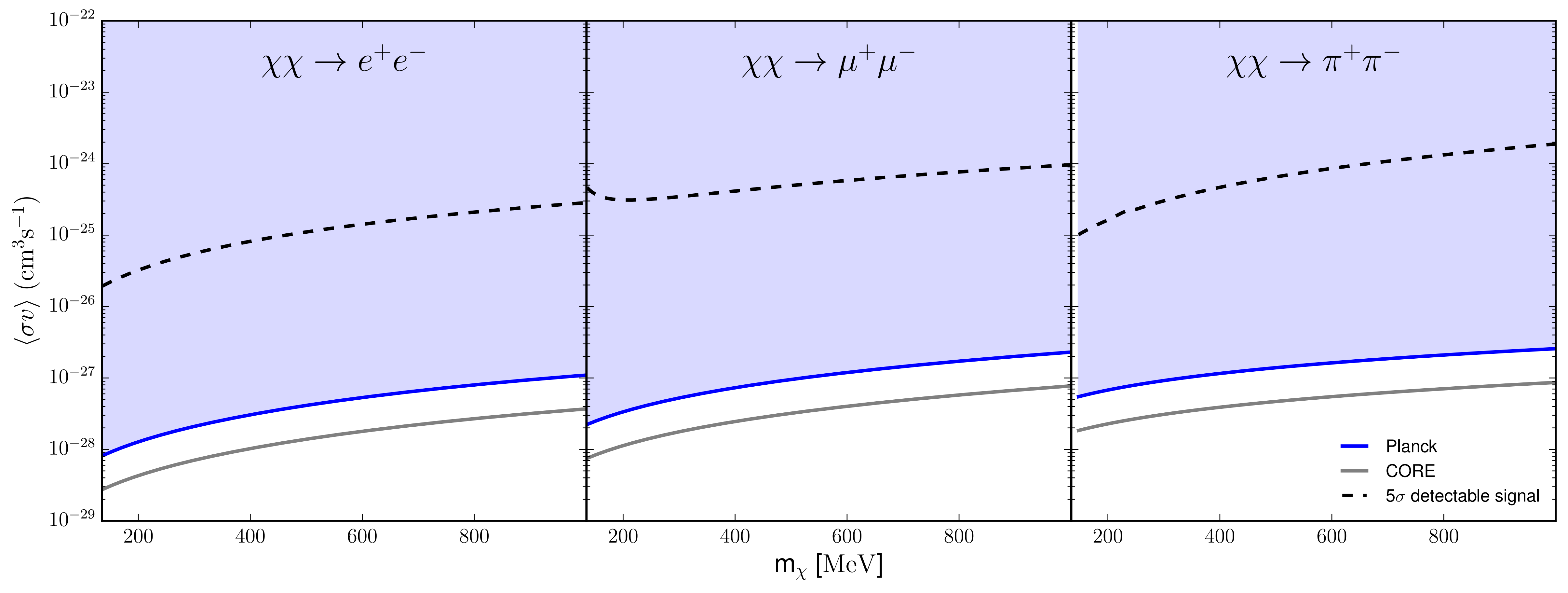


[13] A. Geringer-Sameth, S. M. Koushiappas, and M. Walker, Astrophys. J. 801, 74 (2015) [arXiv:1408.0002 [astro- ph.CO]].

Support material

$$f_{\rm eff} = \frac{1}{2m_\chi} = \int_0^{m_\chi} dE\; E \left(f_{\rm eff}^{\gamma}(E) \frac{dN}{dE}_{\gamma}(E) + 2 f_{\rm eff}^{e^{-(+)}}(E) \frac{dN}{dE}_{e^{-(+)}} \right)$$

http://nebel.rc.fas.harvard.edu/epsilon

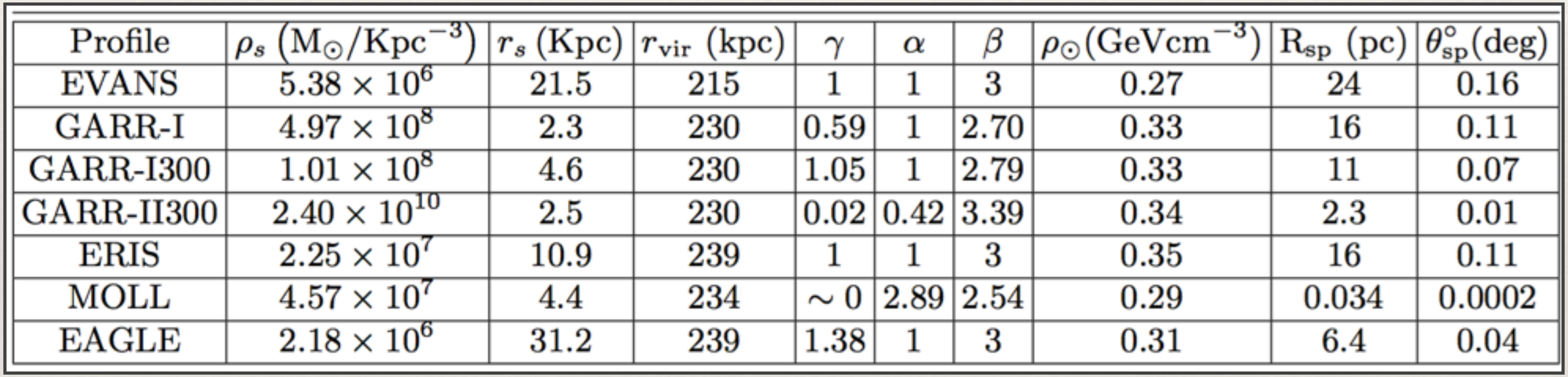
$$f(z) \to f_{\rm eff}$$

$$E^- = \frac{m_{\pi^0}^2}{4m_\chi} \qquad E^+ = \frac{m_\chi}{2}$$

$$\frac{dN}{dE} = \frac{4}{E^+ - E^-} \theta(E_\gamma - E^-)\theta(E^+ - E_\gamma)$$

Support material

$$\rho_h(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)^{\gamma}\left(1+\frac{r}{r_s}^{\alpha}\right)^{\frac{\beta-\gamma}{\alpha}}}$$

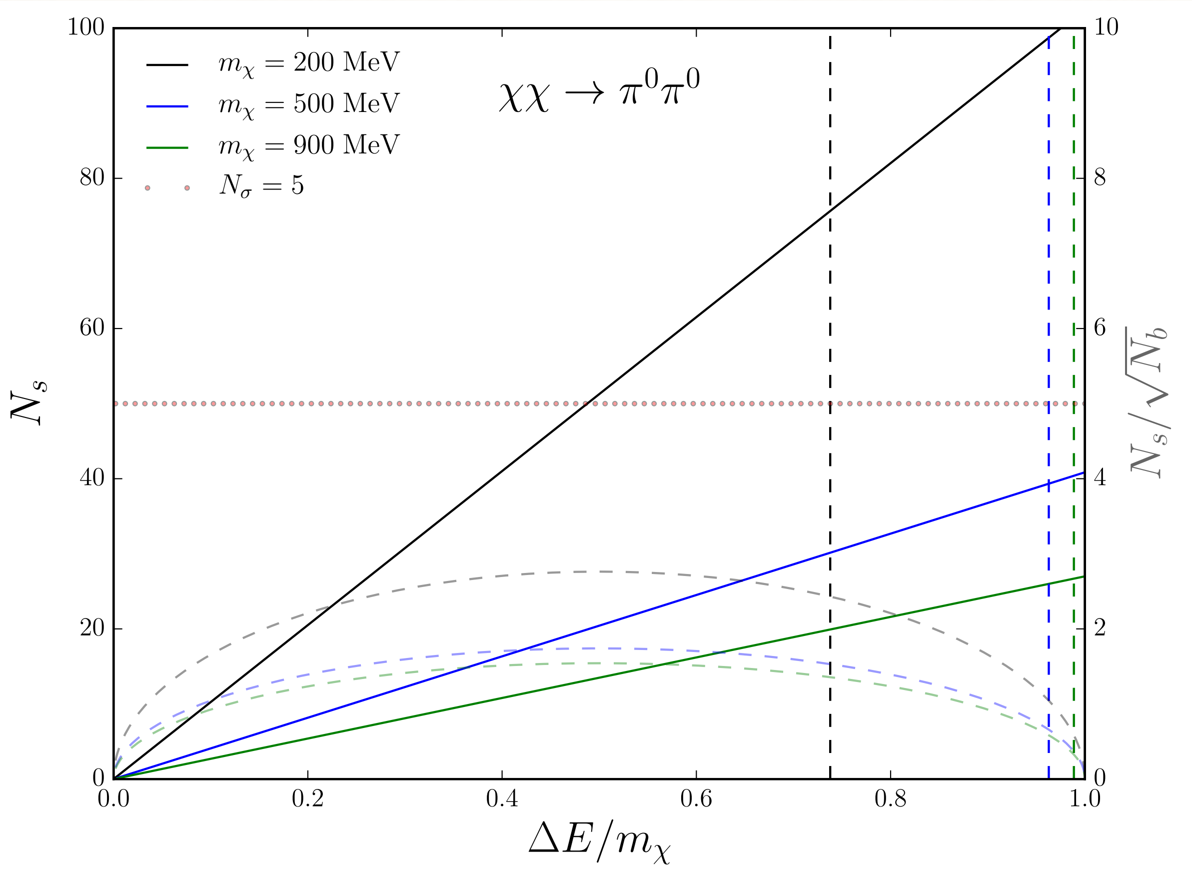


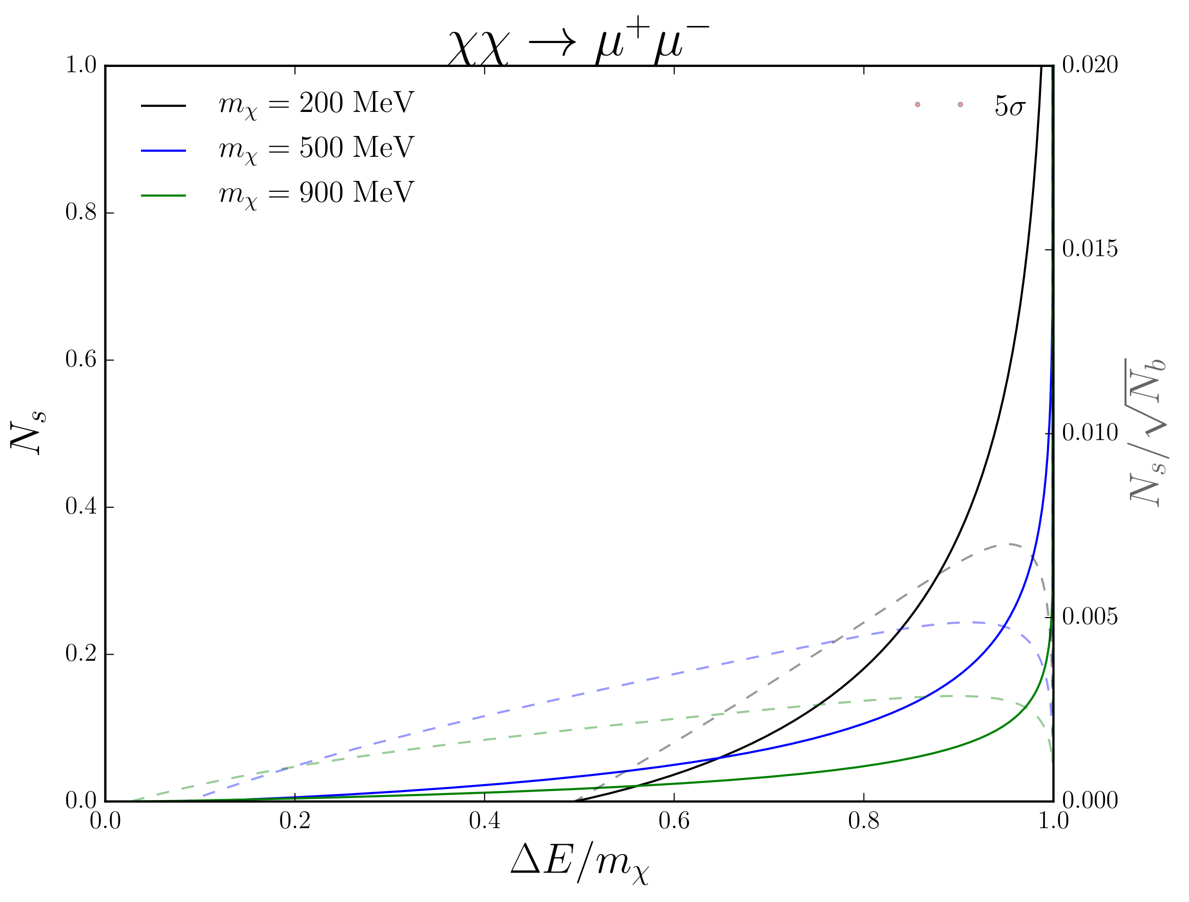
Profile	ρ_s $(\mathrm{M}_\odot/\mathrm{Kpc}^{-3})$	r_s (Kpc)	r_{vir} (kpc)	γ	α	β	$\rho_\odot(\mathrm{GeVcm}^{-3})$	R_{sp} (pc)	$\theta^\circ_{\mathrm{sp}}$(deg)
EVANS	5.38×10^6	21.5	215	1	1	3	0.27	24	0.16
GARR-I	4.97×10^8	2.3	230	0.59	1	2.70	0.33	16	0.11
GARR-I300	1.01×10^8	4.6	230	1.05	1	2.79	0.33	11	0.07
GARR-II300	2.40×10^{10}	2.5	230	0.02	0.42	3.39	0.34	2.3	0.01
ERIS	2.25×10^7	10.9	239	1	1	3	0.35	16	0.11
MOLL	4.57×10^7	4.4	234	~ 0	2.89	2.54	0.29	0.034	0.0002
EAGLE	2.18×10^6	31.2	239	1.38	1	3	0.31	6.4	0.04

$$J(\Delta\Omega) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_0^{l(\hat{\theta}_{\mathrm{max}})} \rho^2(r(l))dl(\theta)$$

[9] V. Gammaldi, V. Avila-Reese, O. Valenzuela, and A. X. Gonzales-Morales, Phys. Rev. D94, 121301 (2016), 1607.02012.

Support material





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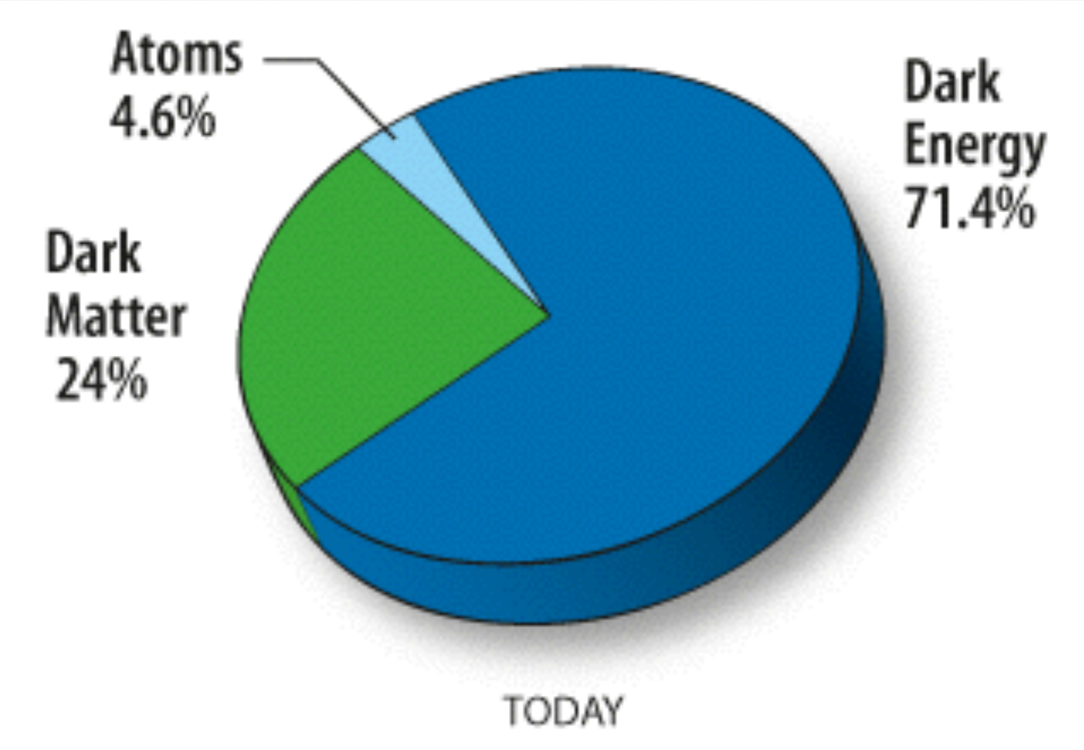
Introduction

- Dark matter is key in the ΛCDM model, consistent with most cosmological observations



https://map.gsfc.nasa.gov/universe/uni_matter.html