Two-mediator DM models and cosmic electron excess

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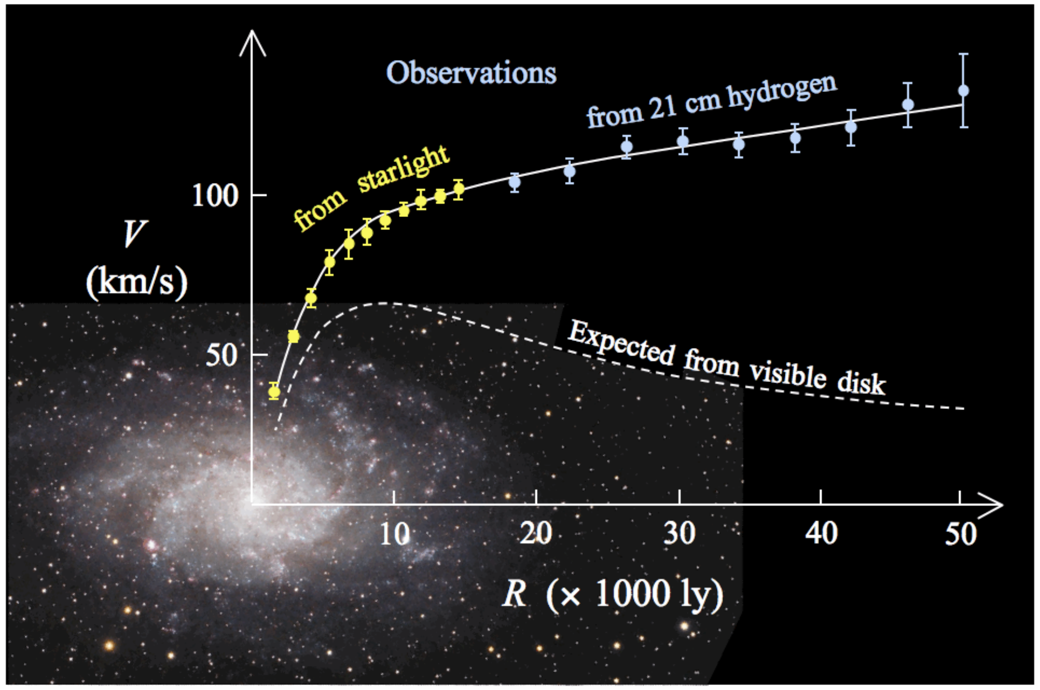
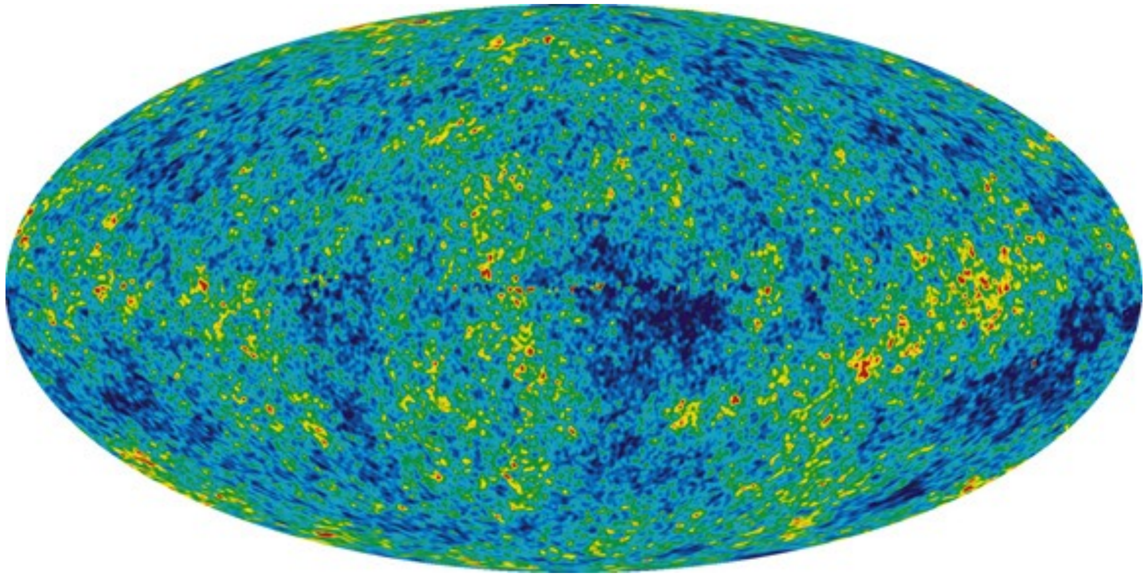
2019年2月28日

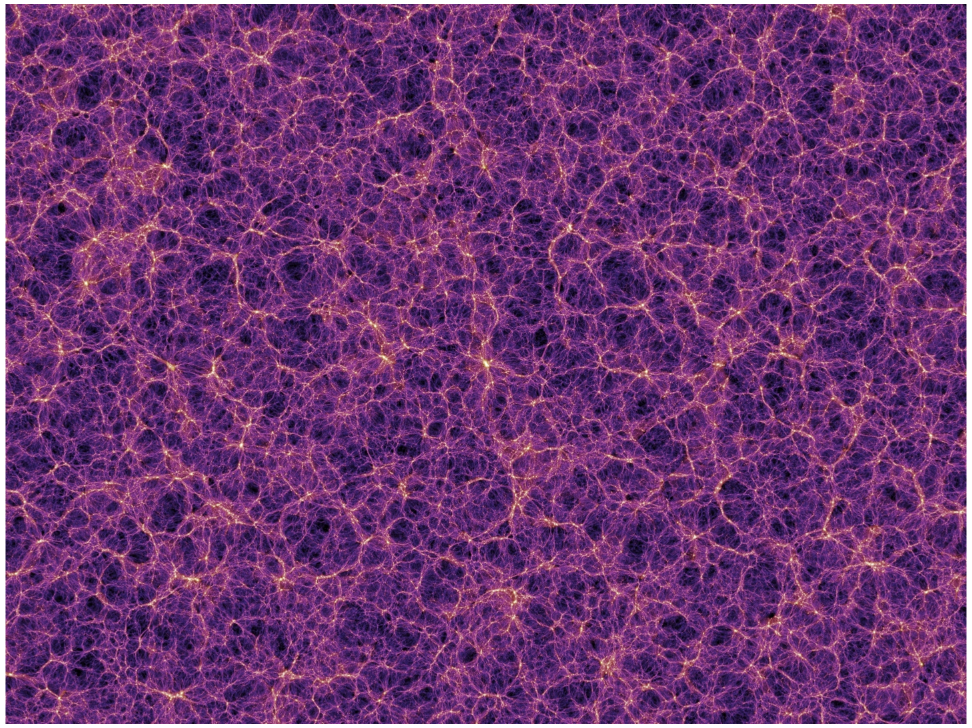
Rotation curve



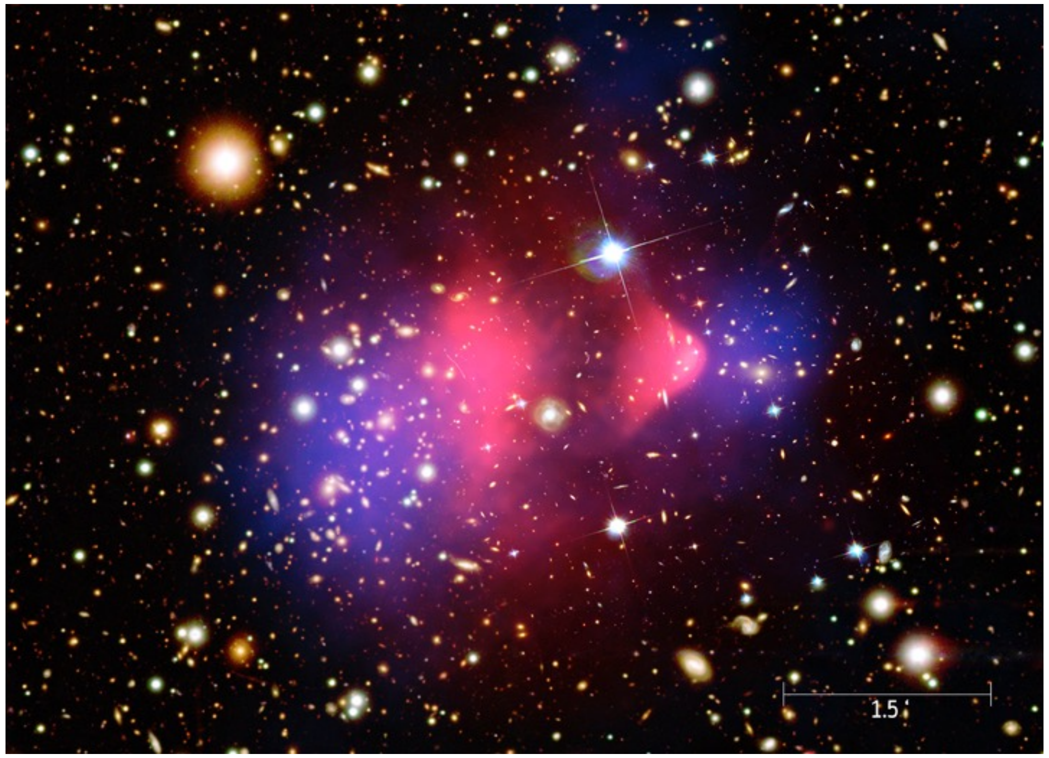
CMB

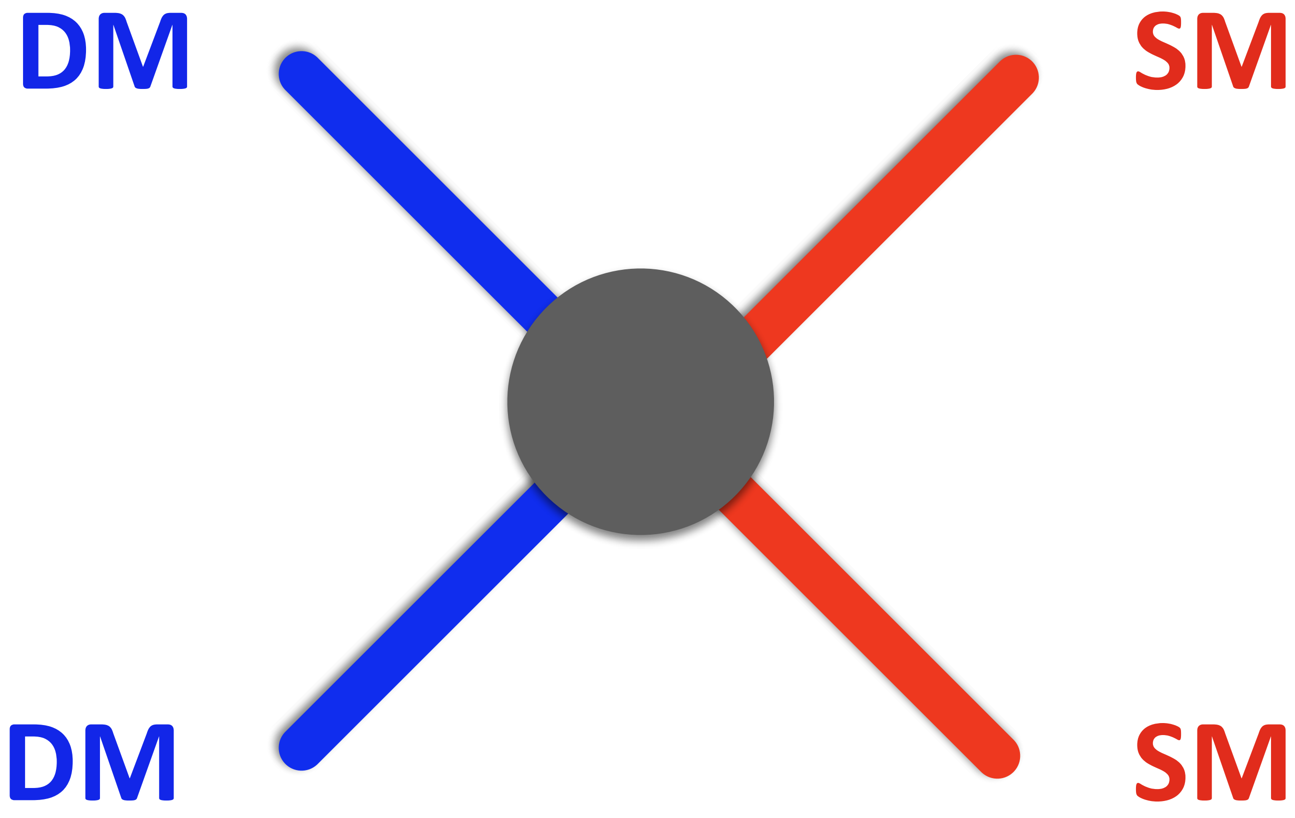


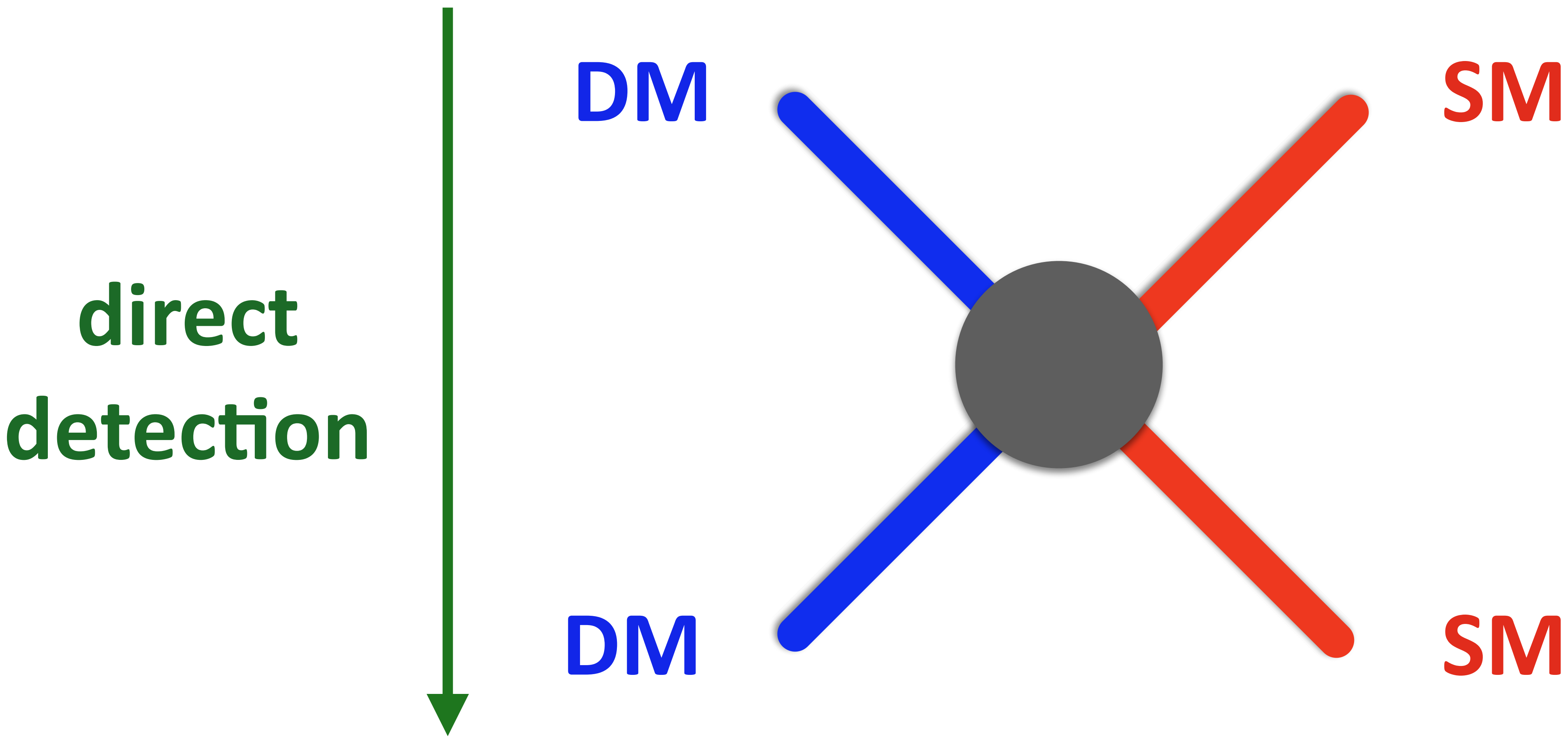
LSS

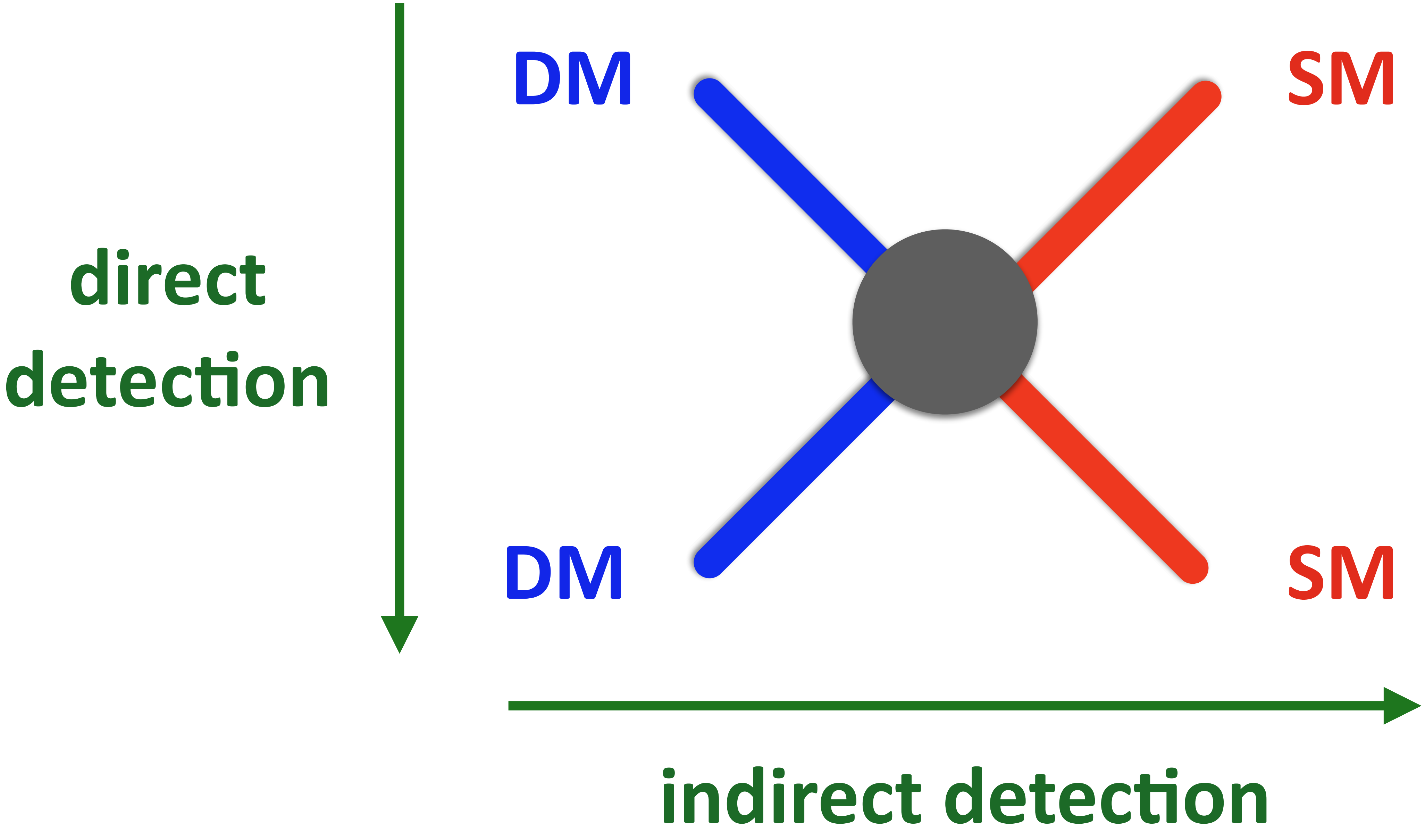


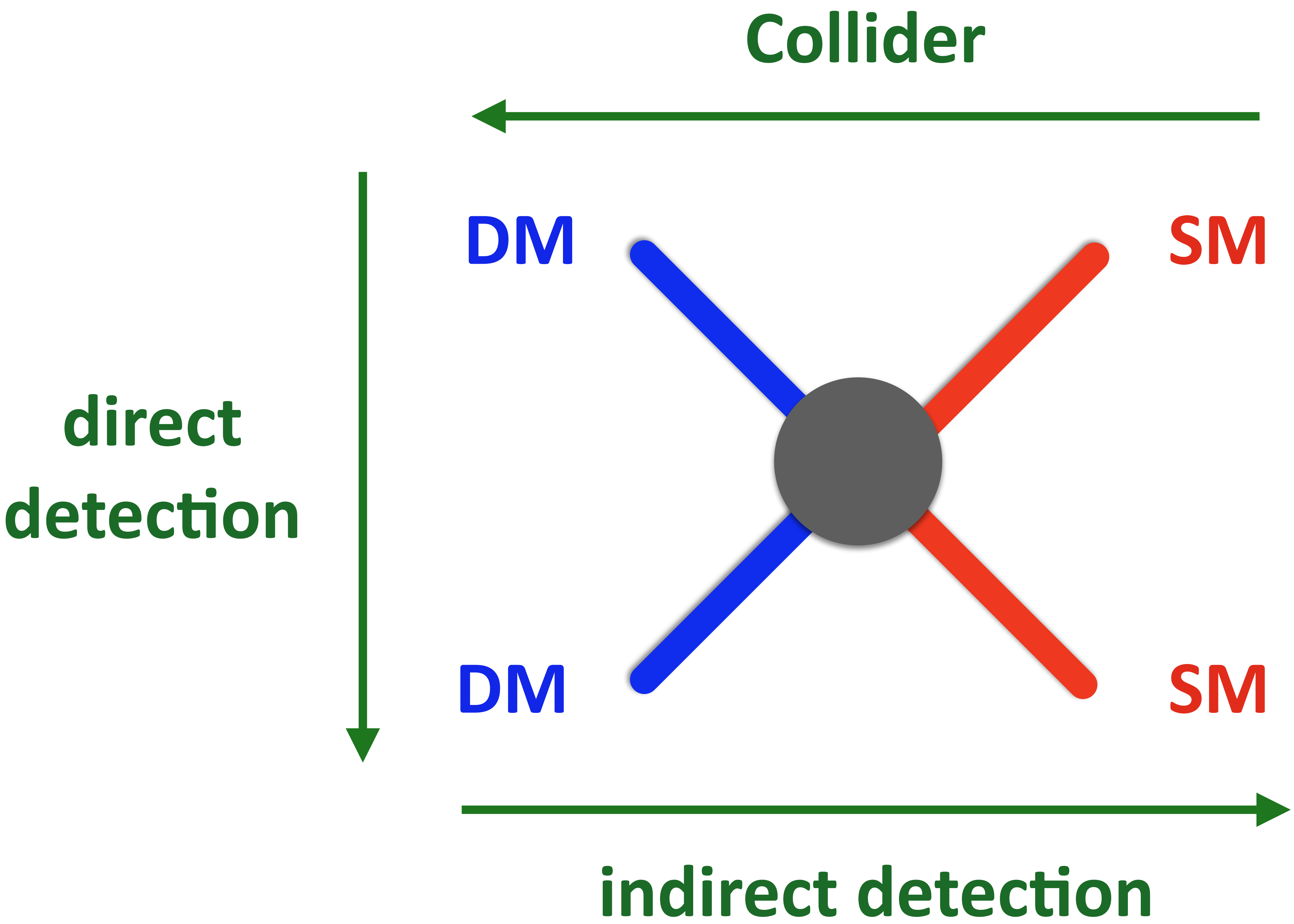
Bullet cluster

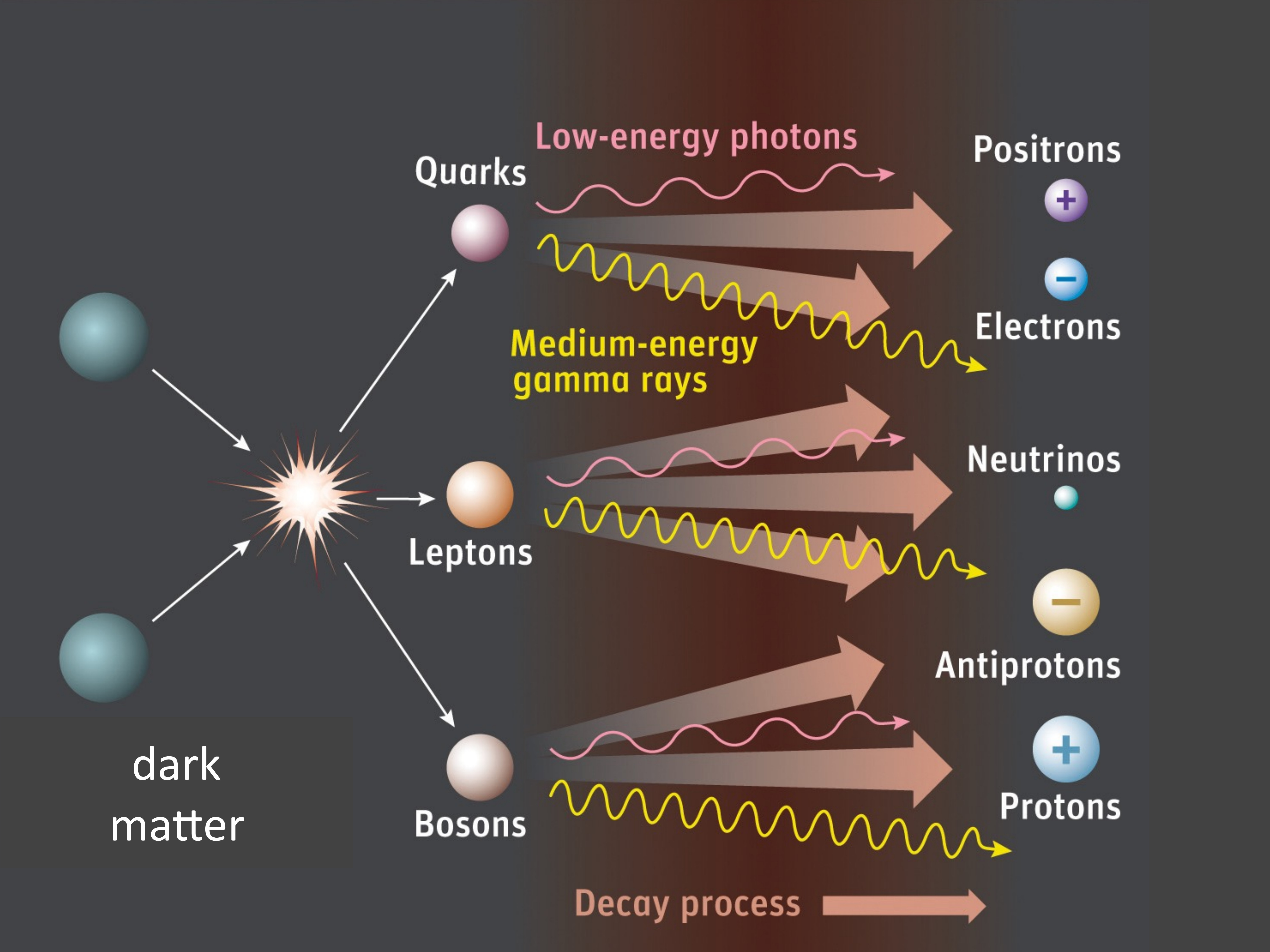


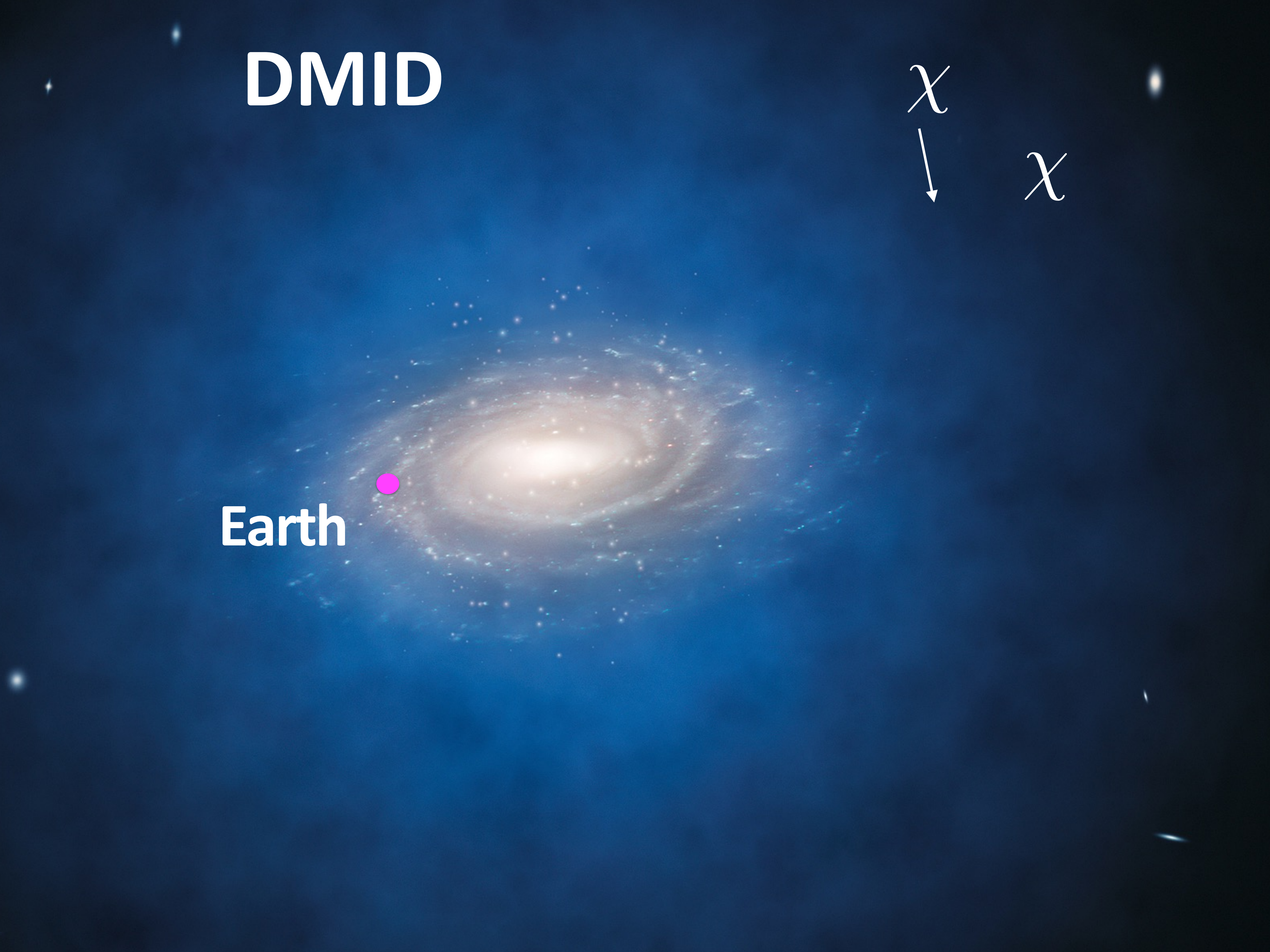

DM
SM
DM
SM

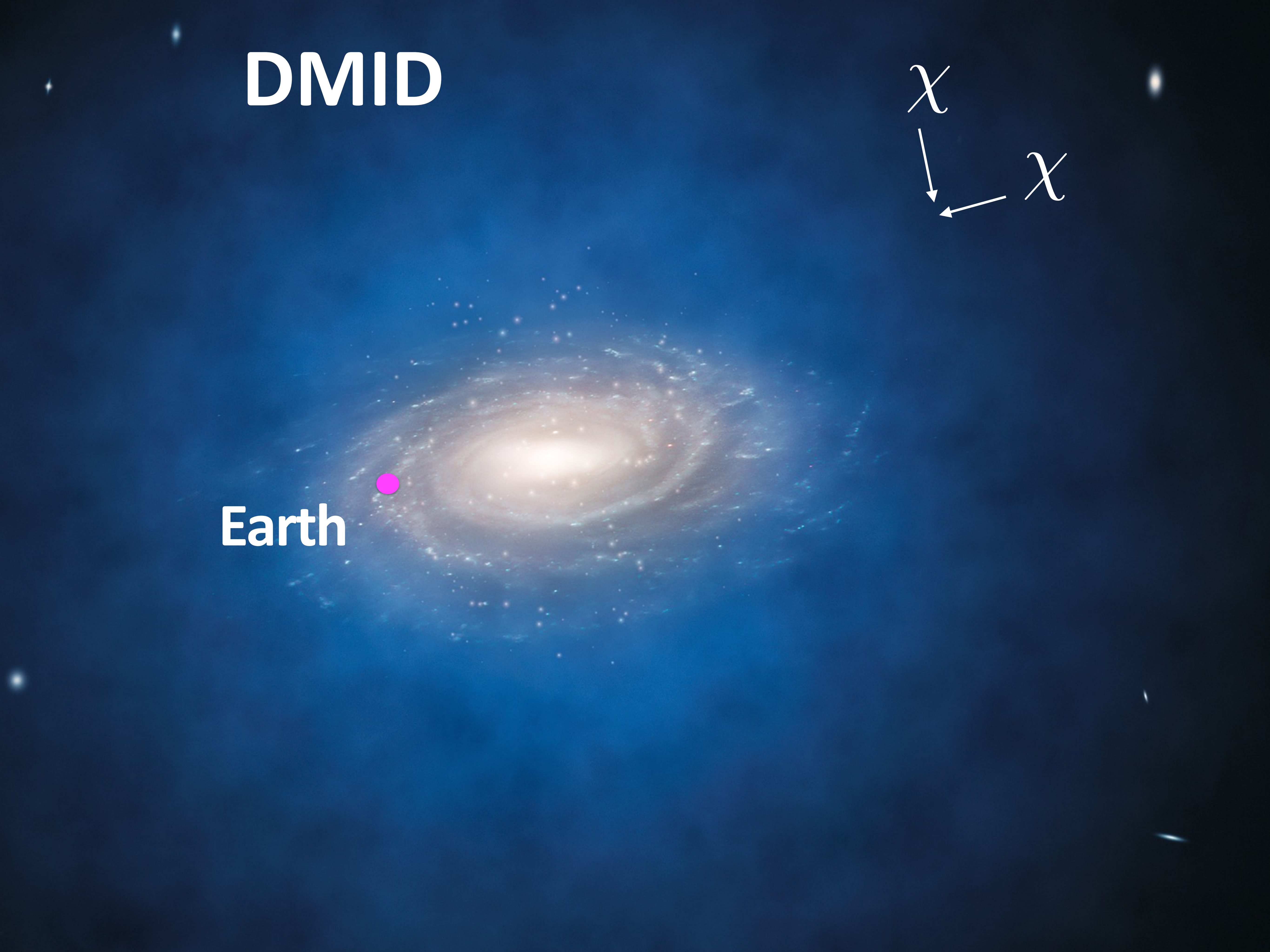

DM
SM
direct
detection
DM
SM


DM
SM
direct
detection
DM
SM
indirect detection

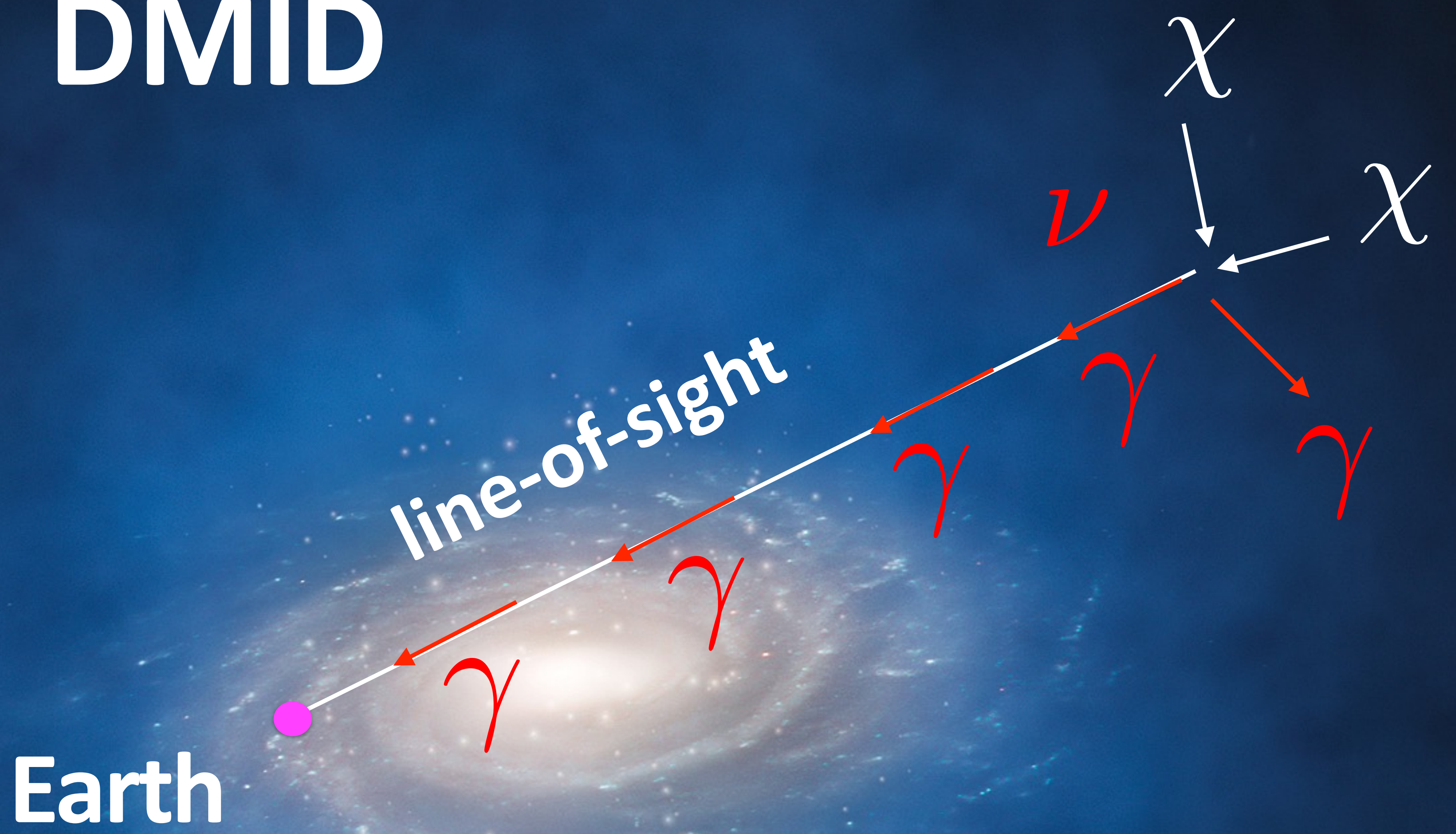

Collider
DM
SM
direct detection
DM
SM
indirect detection


Low-energy photons
Quarks
Positrons
Electrons
Medium-energy
gamma rays
Neutrinos
Leptons
Antiprotons
Protons
Bosons
dark
matter
Decay process


DMID
χ
χ
Earth

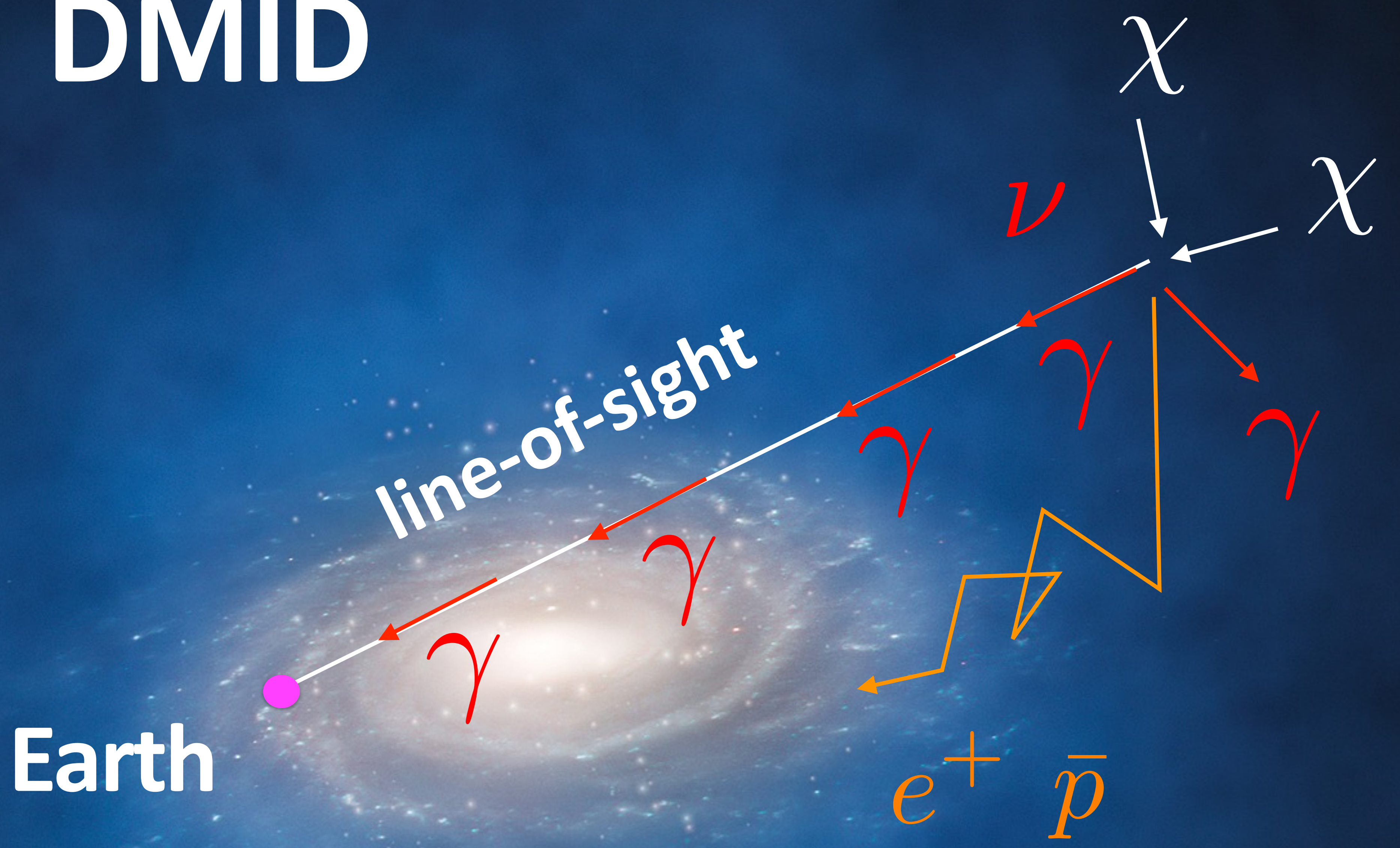

DMID
χ
χ
Earth

DMID



Gamma and neutrino are neutral; line-of-sight integral.

DMID

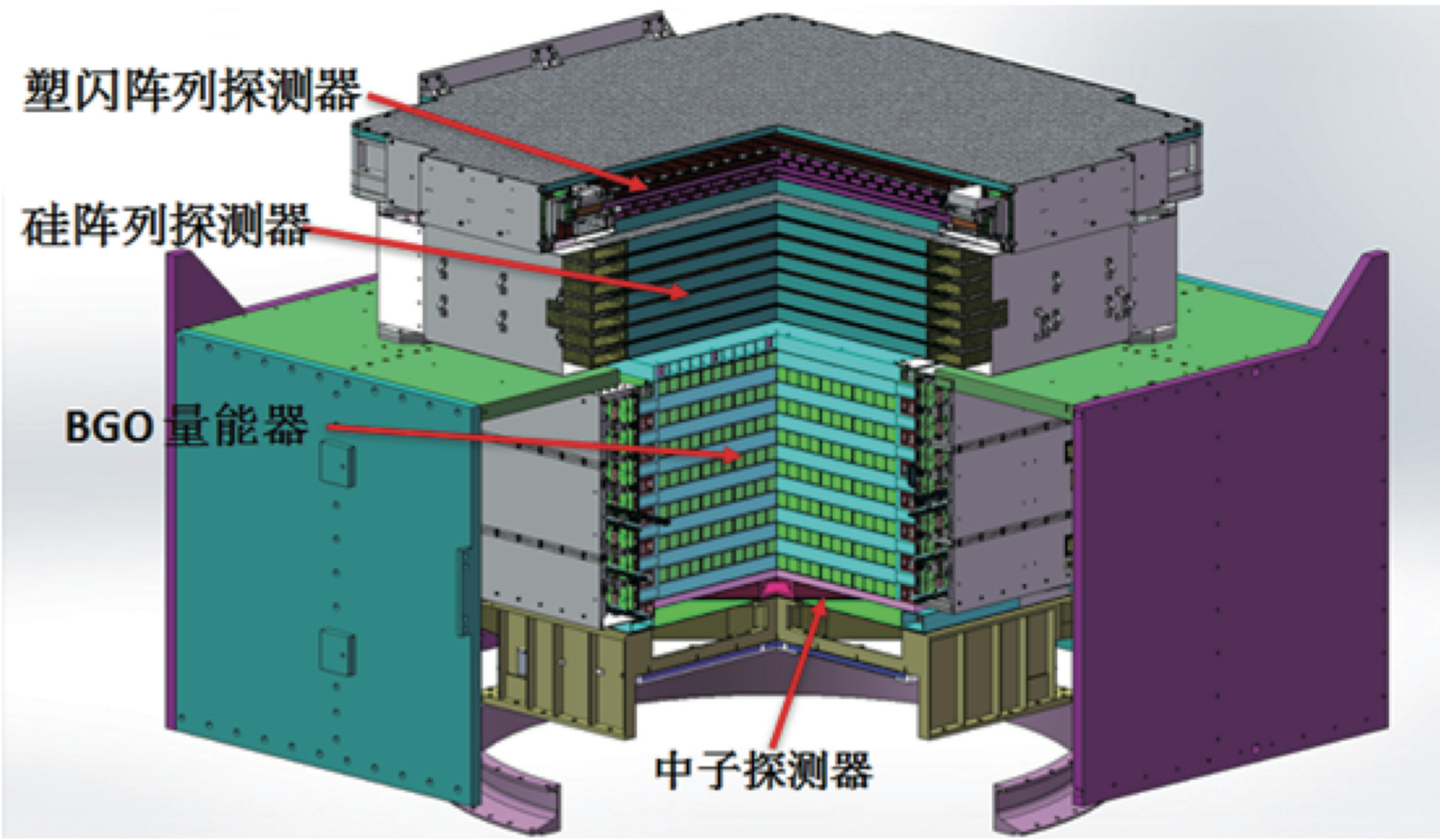


Gamma and neutrino are neutral; line-of-sight integral.

Cosmic ray (CR): energy & direction loss due to B-field

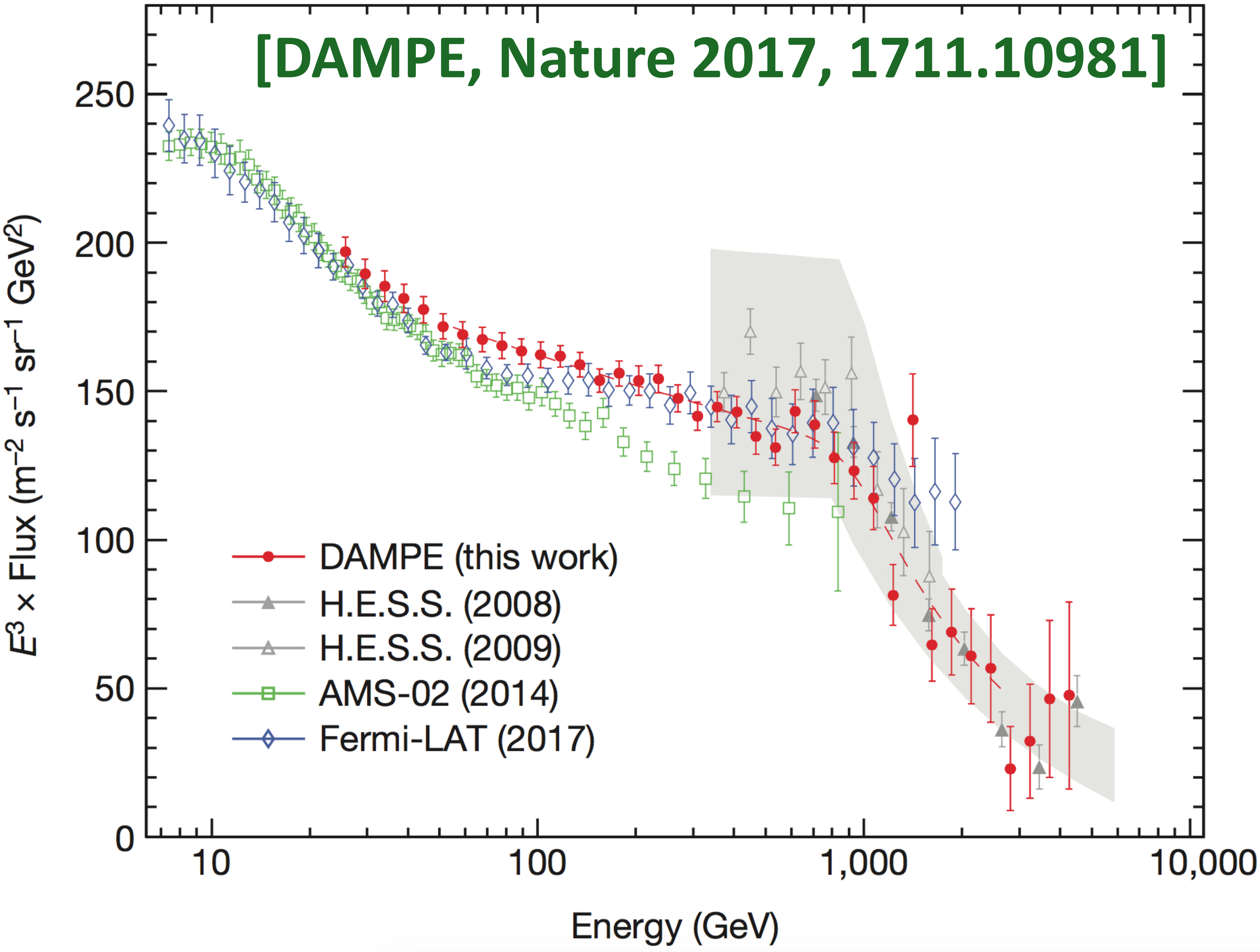
DAMPE satellite

2015年12月27日，悟空暗物质卫星发射升空

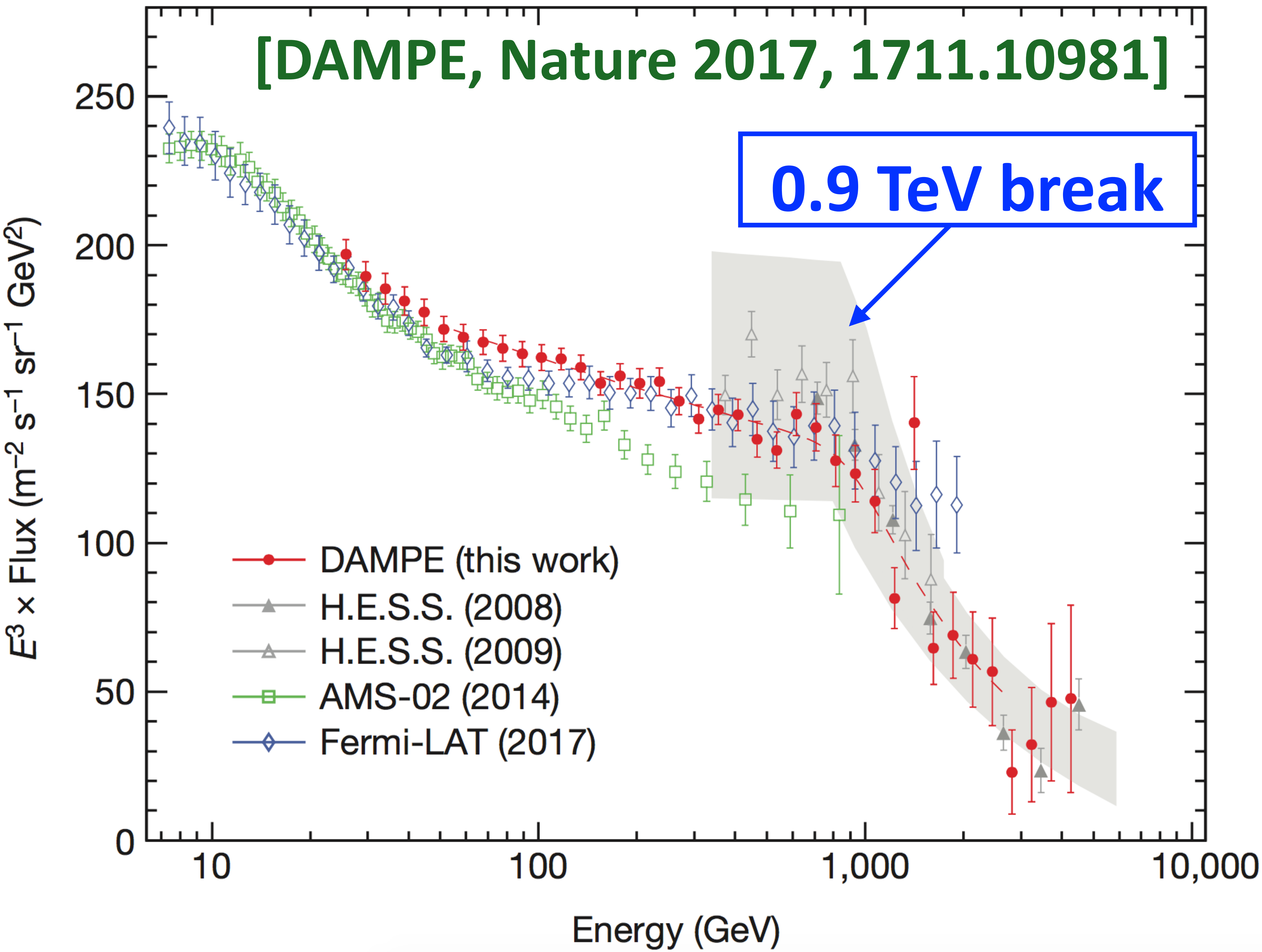


能量分辨率高(1%), 测量能量范围大(10 TeV)

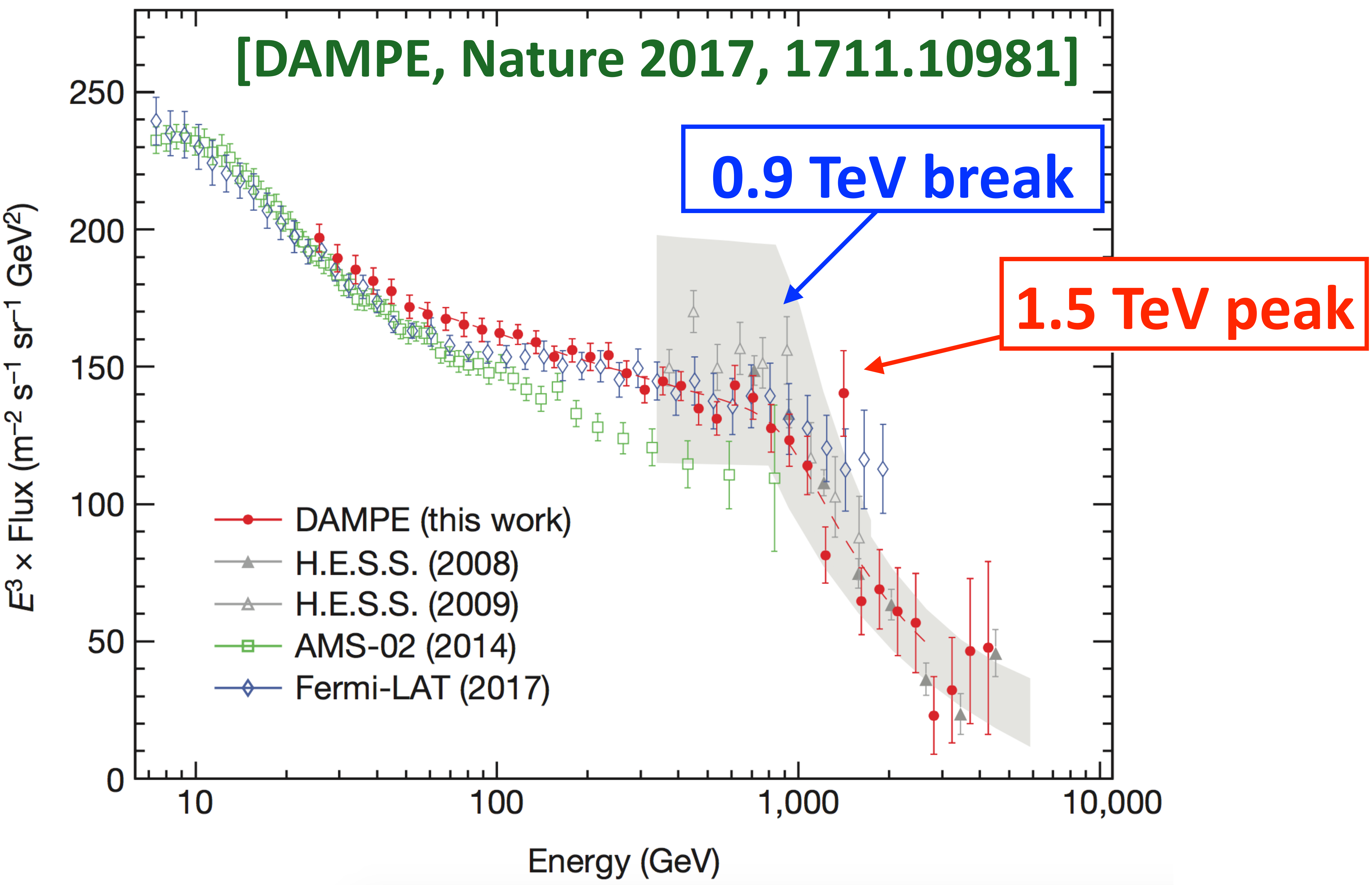
DAMPE electron excess



DAMPE electron excess



DAMPE electron excess



Outline

- DAMPE electron excess
- 1.4 TeV excess & DM

  [Xuewen Liu, ZL, PRD, 1711.11579]
- 0.9 TeV break & 1.4 TeV peak

  [Xuewen Liu, ZL, Yushan Su, 1902.04916]
- Summary

TeV DM model

$$\mathcal{L} = -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{1}{2}M_X^2 X_\mu X^\mu + X_\mu J^\mu$$

$$J_\mu = g_f \bar{f}\gamma_\mu f + g_\chi \bar{\chi}\gamma_\mu \chi$$

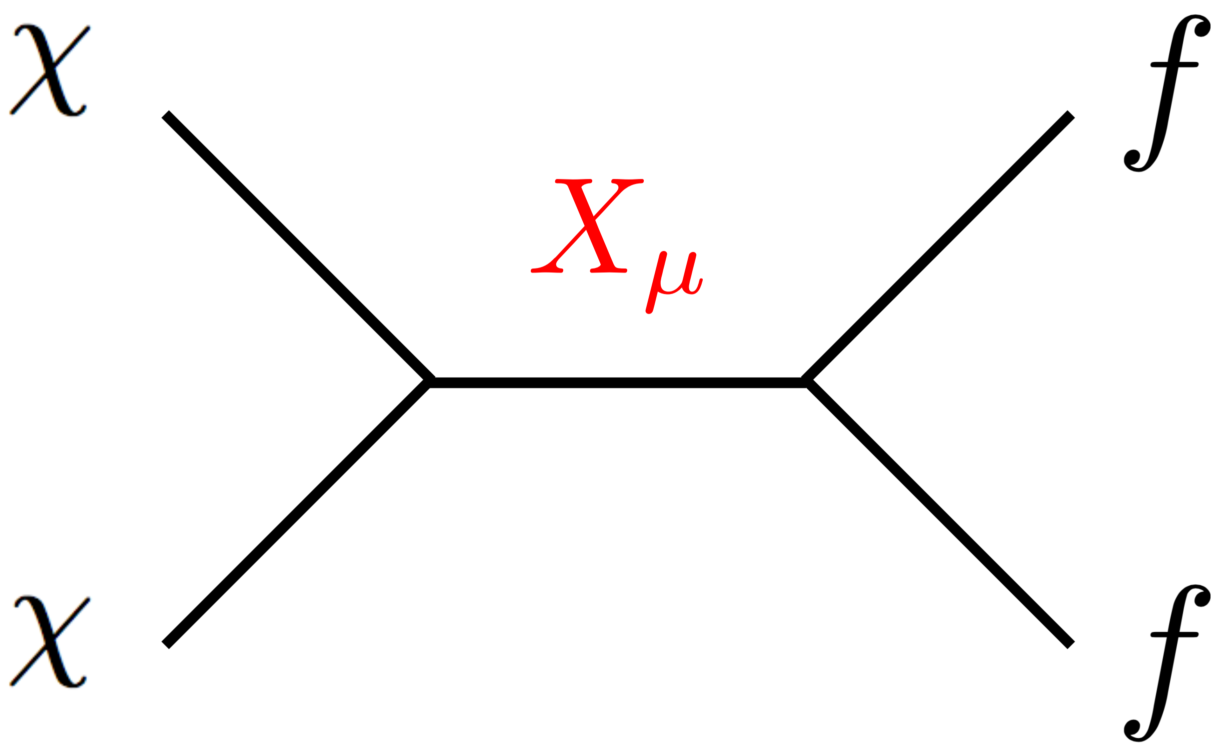
X_μ **New gauge boson**

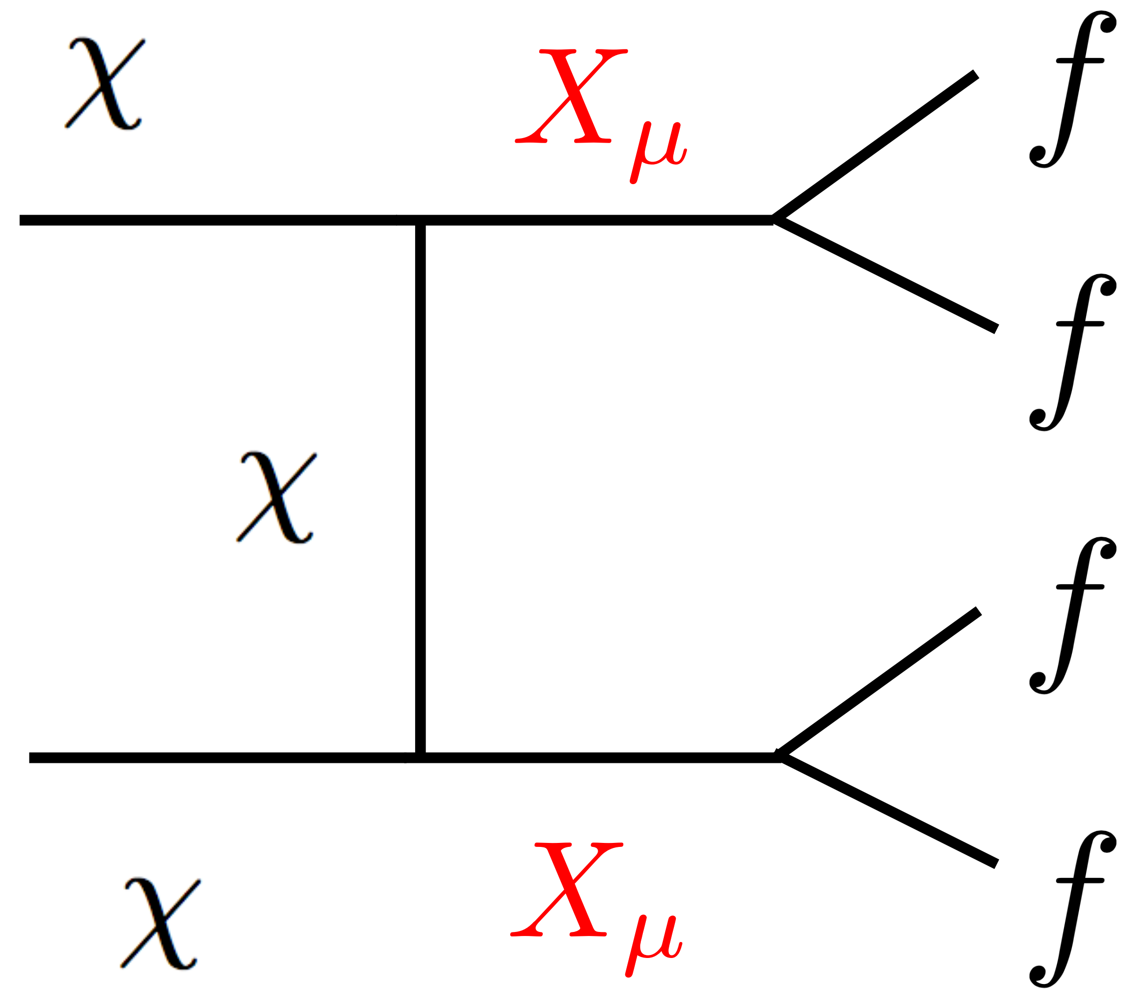
χ **Dirac DM**

Vector current interaction

[Xuewen Liu, ZL, PRD, 1711.11579]

DM annihilation channels





1.5 TeV DM

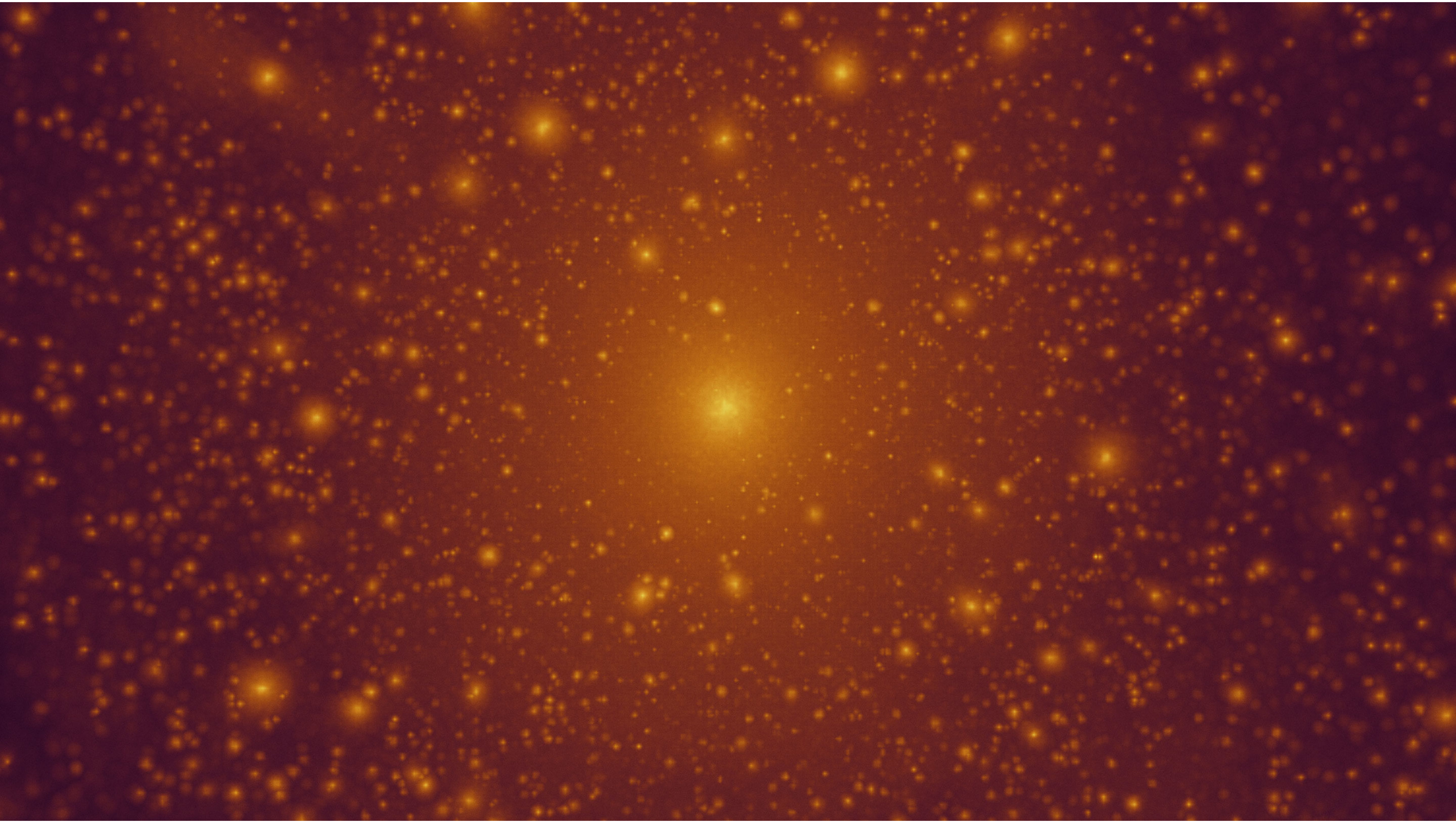
(A) f=e only

(C) f =all SM fermions

3 TeV DM

(B) f=e only

Smaller clumps in a galactic halo



Nearby Subhalo profile

NFW profile $$\rho(r) = \rho_s \frac{(r/r_s)^{-\gamma}}{(1 + r/r_s)^{3-\gamma}}$$

d_s **distance to us in kpc**

ρ_s **in GeV/cm³**

r_s **in kpc**

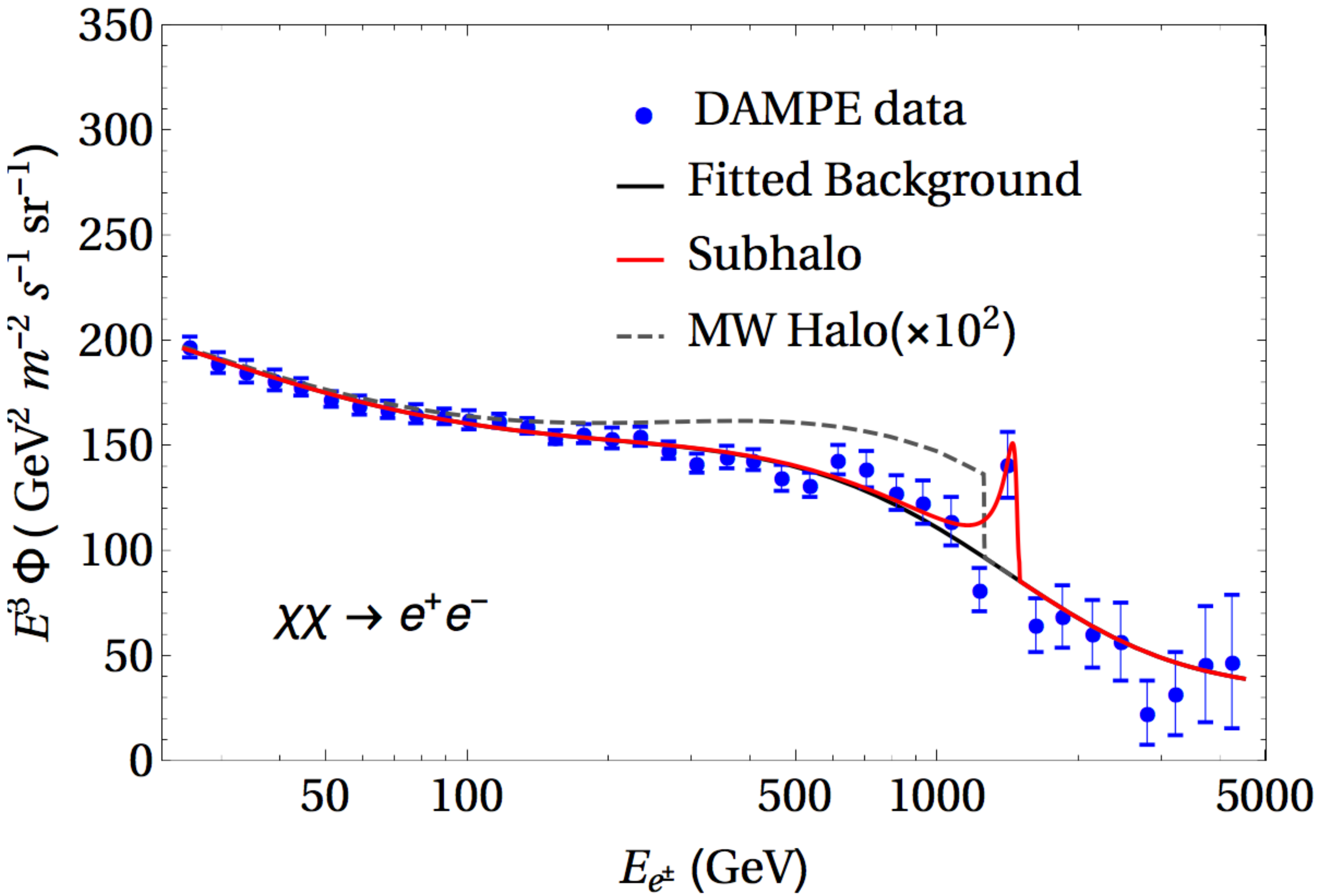
SHA $(\gamma, \rho_s, r_s, d_s) = (1, 1, 1, 1)$

SHB $(\gamma, \rho_s, r_s, d_s) = (0.5, 100, 0.1, 0.3)$

SHB fit DAMPE w/ thermal σv

SHA is 100 times smaller

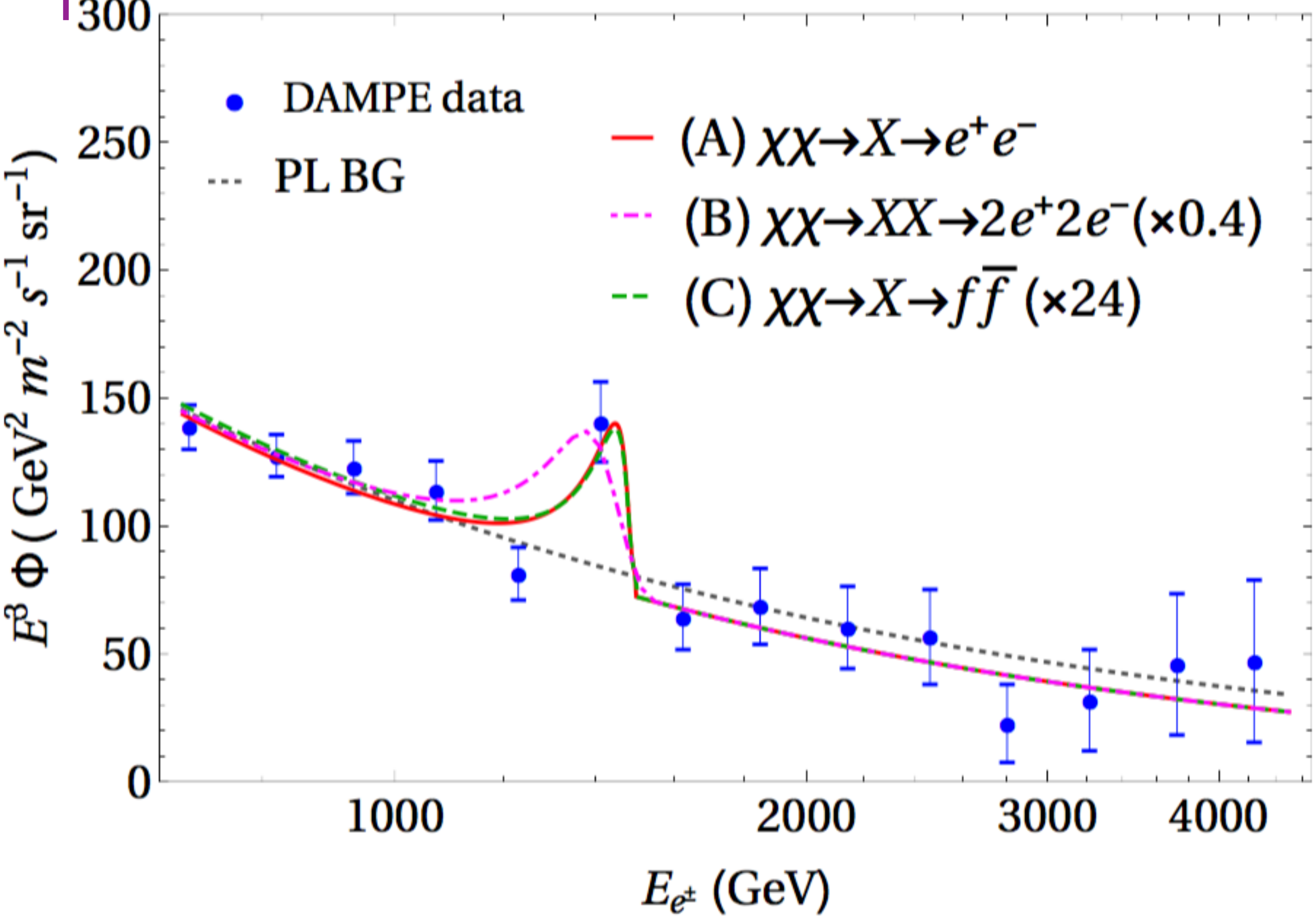
Nearby Subhalo vs MW halo



MW halo is flat & smaller

λ ~ 0.3 kpc for a 1.5 TeV electron to lose 100 GeV

different annihilation channels



PLBG

$$\Phi_B = CE^{-\gamma}$$

$$\chi^2 = 20.4$$

$$(A)\Delta\chi^2 = 11.4$$

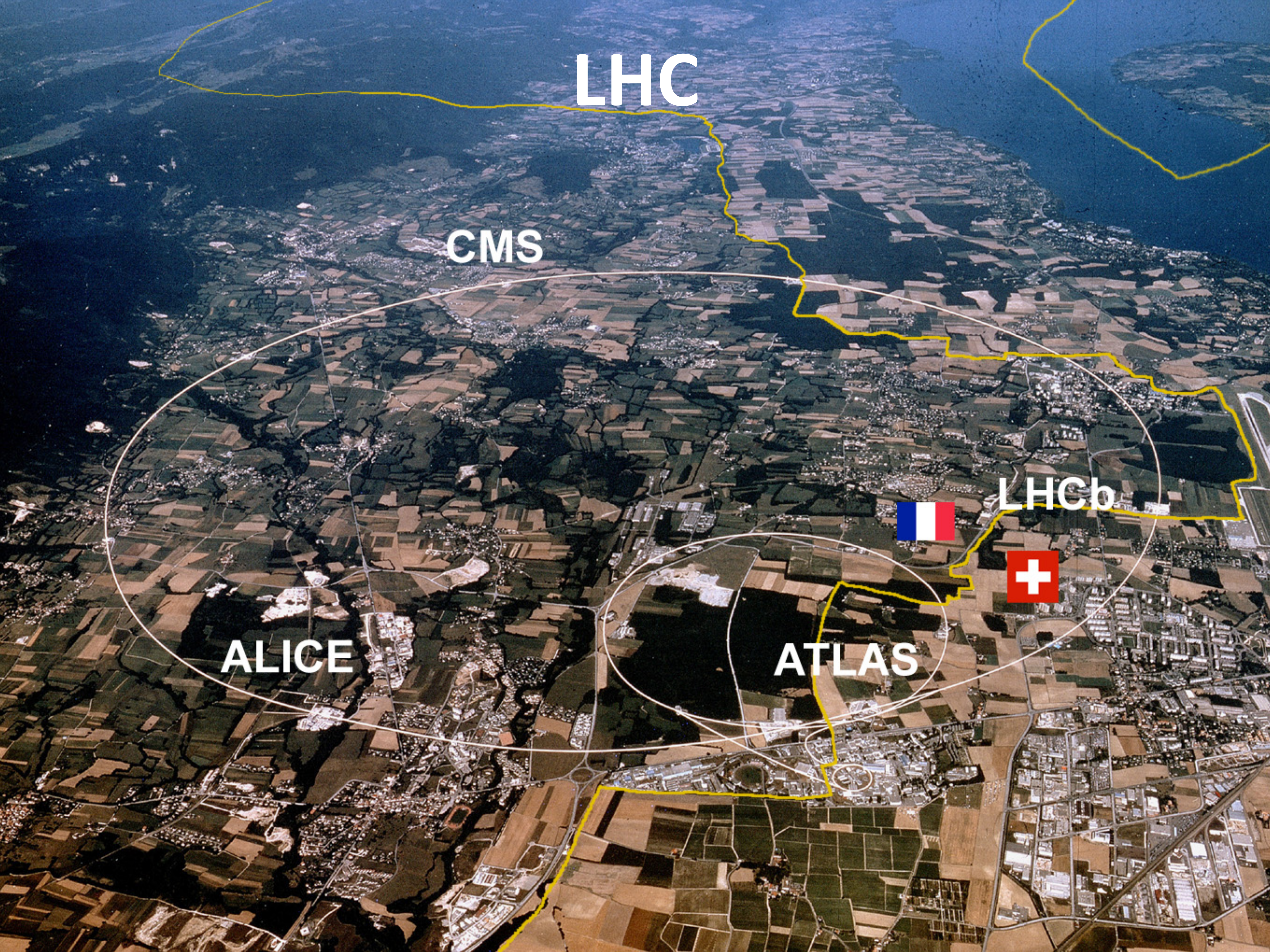
$$(B)\Delta\chi^2 = 5.1$$

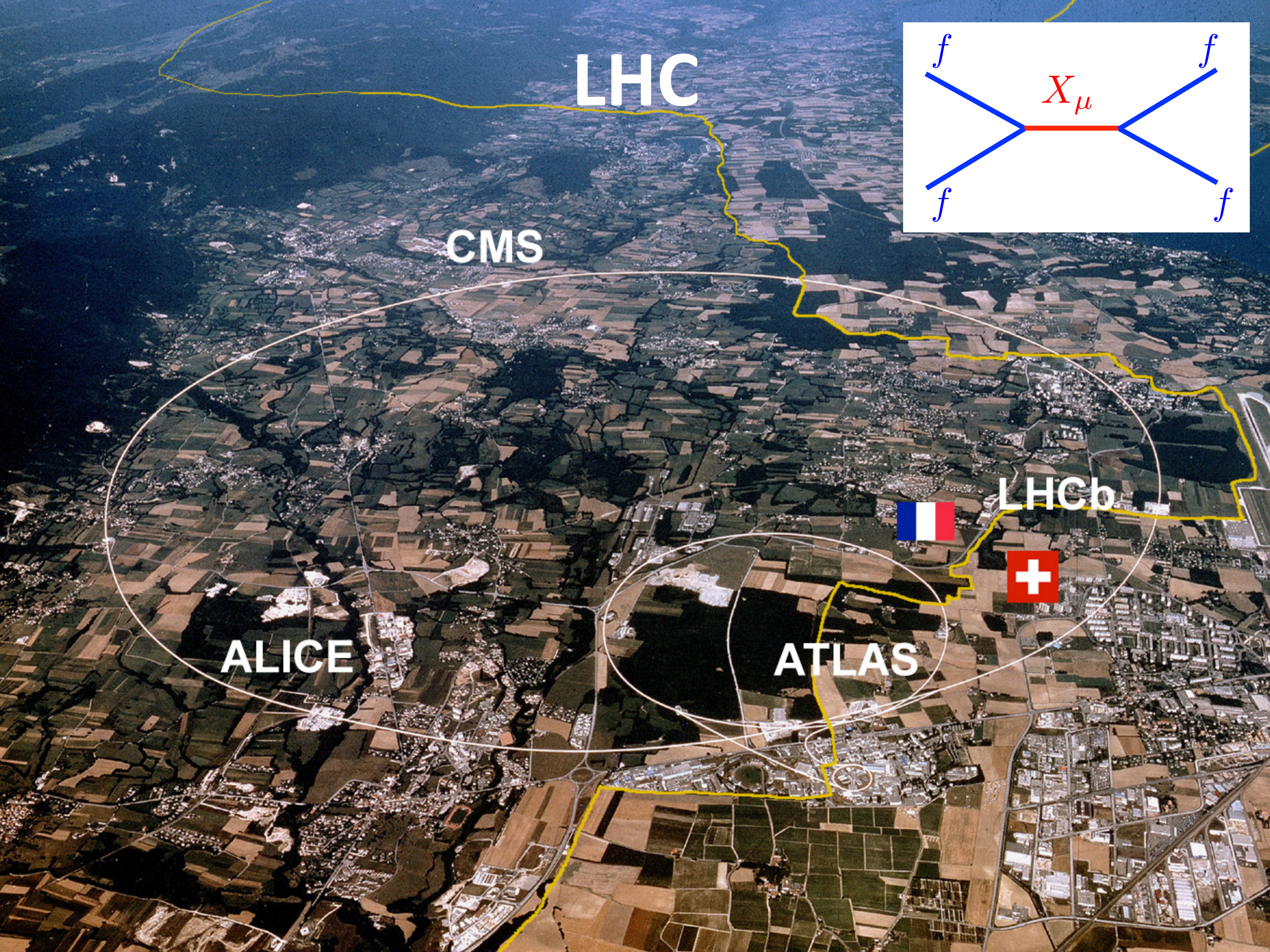
$$(C)\Delta\chi^2 = 11$$

small mass gap in (B)

$$\text{(B)}\ m_\chi - M_X = 2\ \text{GeV}$$

thermal σv for all cases


LHC
CMS
LHCb
ALICE
ATLAS


LHC
CMS
LHCb
ALICE
ATLAS
f
f
X_μ
f
f

Collider Constrains

ATLAS

1707.02424

$$\mathcal{L} = \frac{4\pi}{\Lambda^2}\eta_{ij}(\bar{q}_i\gamma^\mu q_i)(\bar{\ell}_j\gamma^\mu \ell_j)$$

$\Lambda > 40\ \mathrm{TeV}$ for LL and ℓ ℓ

$$\sqrt{|g_q g_\ell|} < 0.09(M_X/\mathrm{TeV})$$

LEP

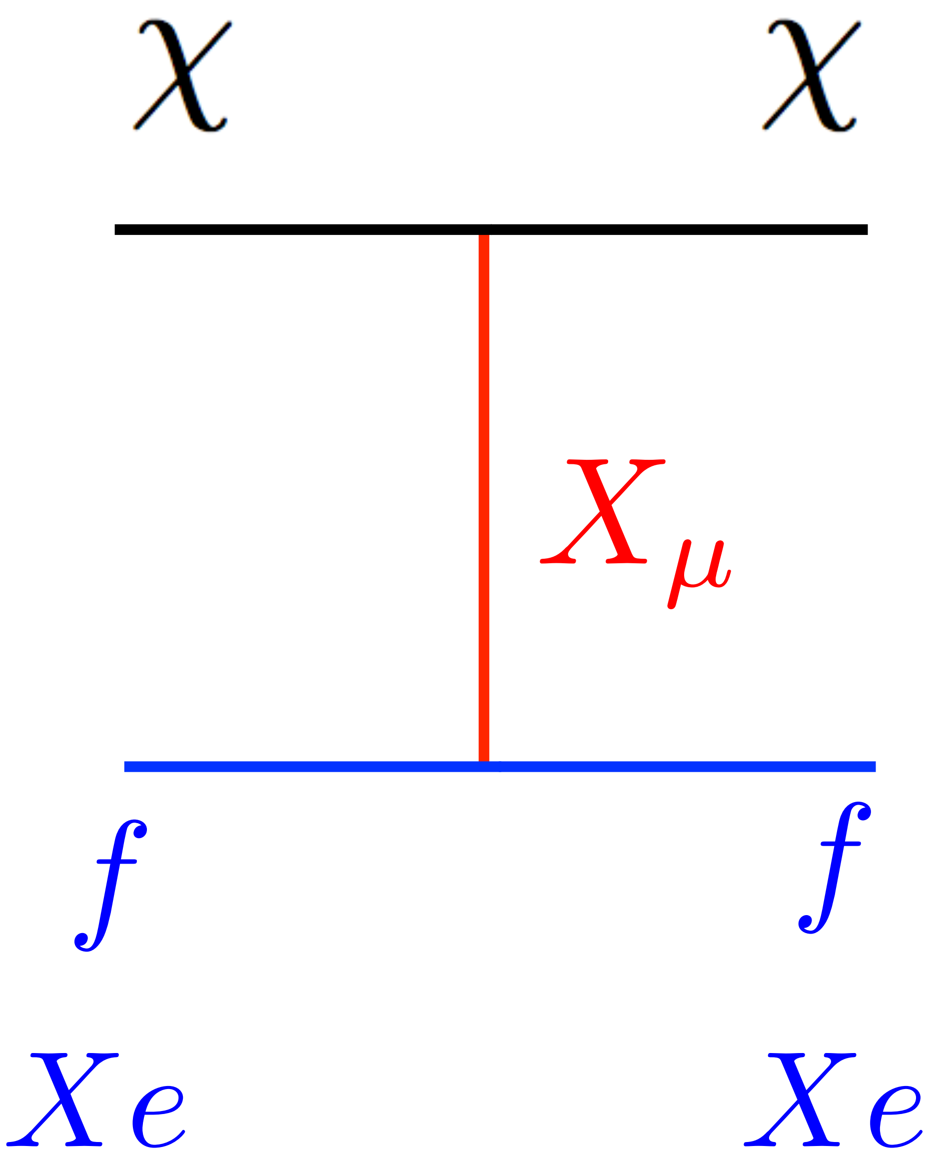
hep-ex/0312023
hep-ex/0609051

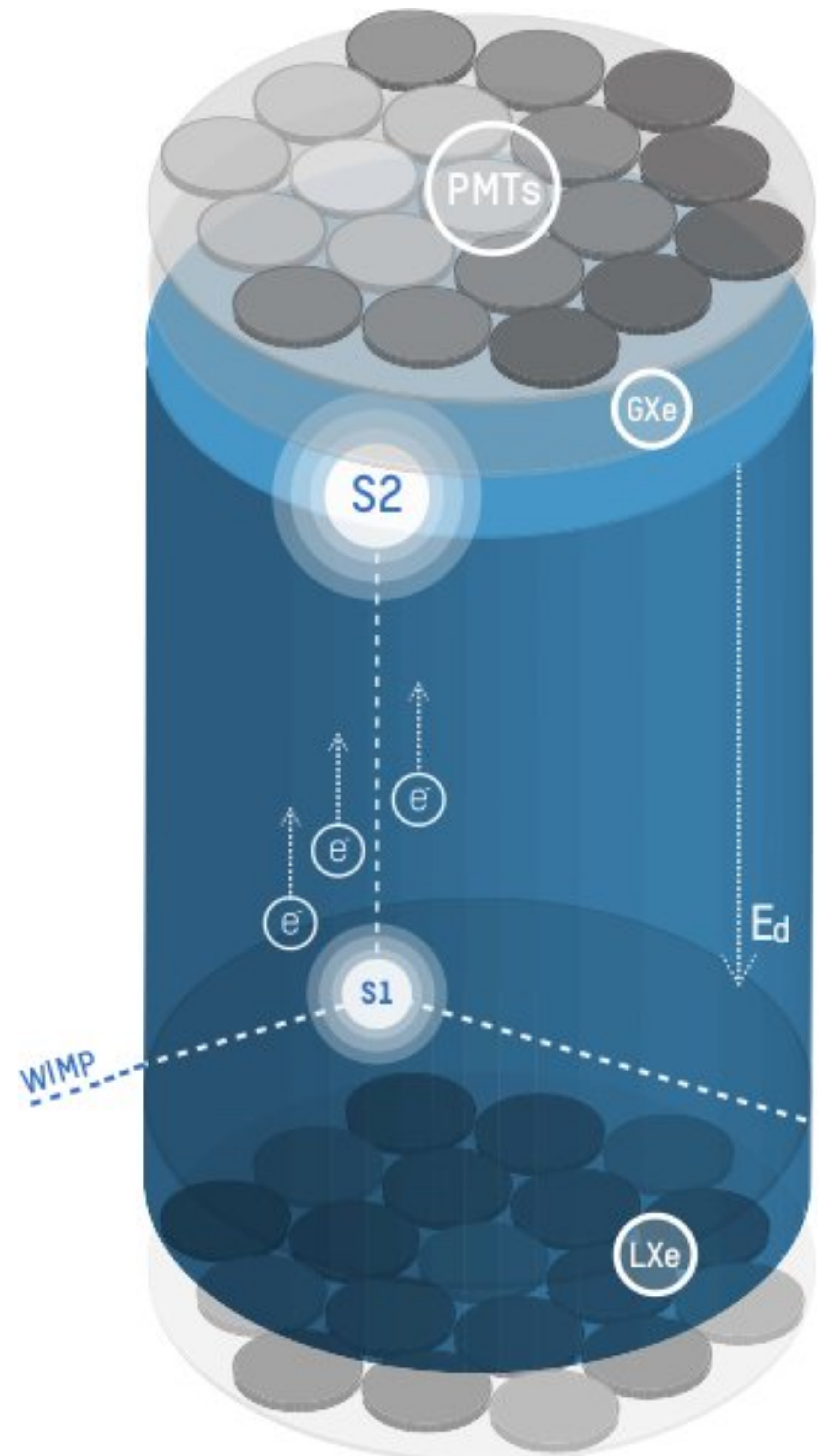
$$\Lambda_{VV} > 15.9\ \mathrm{TeV}$$

for ee → ee

$$g_e \lesssim 0.11(M_X/\mathrm{TeV})$$

DM direct detection





DM direct detection constraints

PandaX

1708.06917

$$\sigma_{\chi p}^{\rm SI} \lesssim 1.7 \times 10^{-45}\ {\rm cm}^2$$

$$\sigma_{\chi p} = \mu_{\chi p}^2 g_\chi^2 g_p^2/(\pi M_X^4)$$

$$\sqrt{|g_\chi g_p|} \lesssim 6 \times 10^{-2} (M_X/{\rm TeV}).$$

Essig et al.

1703.00910

Xenon10 & Xenon100

$$\sigma_{\chi e} < 3 \times 10^{-38}\ {\rm cm}^2$$

$$\sigma_{\chi e} = \mu_{\chi e}^2 g_\chi^2 g_e^2/(\pi M_X^4)$$

$$\sqrt{|g_\chi g_e|} \lesssim 1.8 \times 10^{2} (M_X/{\rm TeV}).$$

DM indirect detection constraints

HESS

1607.08142

$\langle \sigma v \rangle < 2(6) \times 10^{-26}\ \mathrm{cm}^3/s$

for the $\tau^+\tau^-$ (W^+W^-) channel

from GC w/ Einasto profile

Profumo et al

1711.03133

for the $\chi\chi \to XX \to 4e$ channel

$\langle \sigma v \rangle < 6(20) \times 10^{-25}\ \mathrm{cm}^3/s$

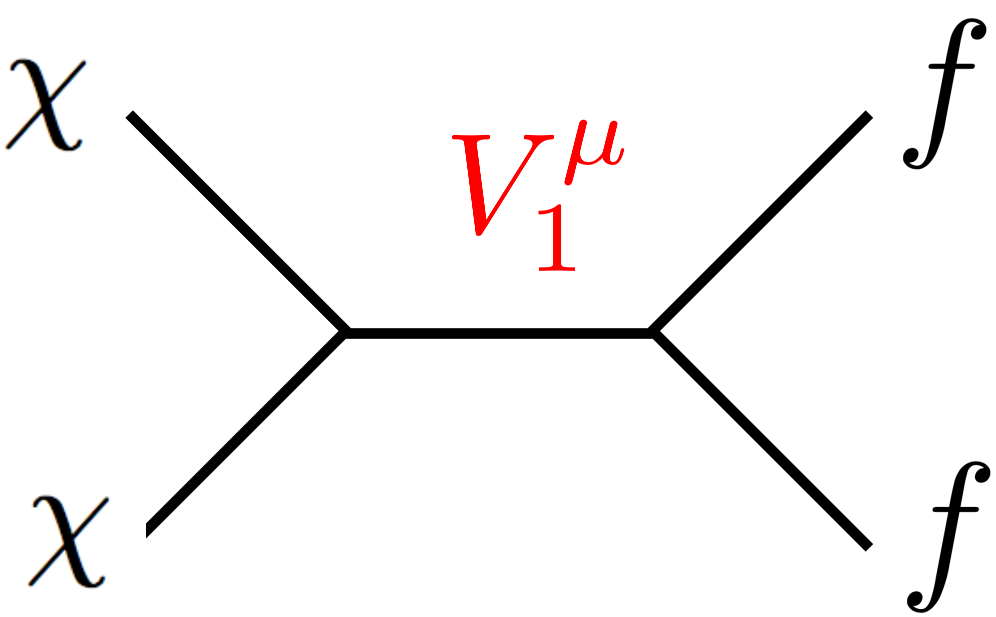
in the $m_\chi \sim M_X$ $(m_\chi \gg M_X)$ case

DM explains both break & peak

Two-mediator DM model

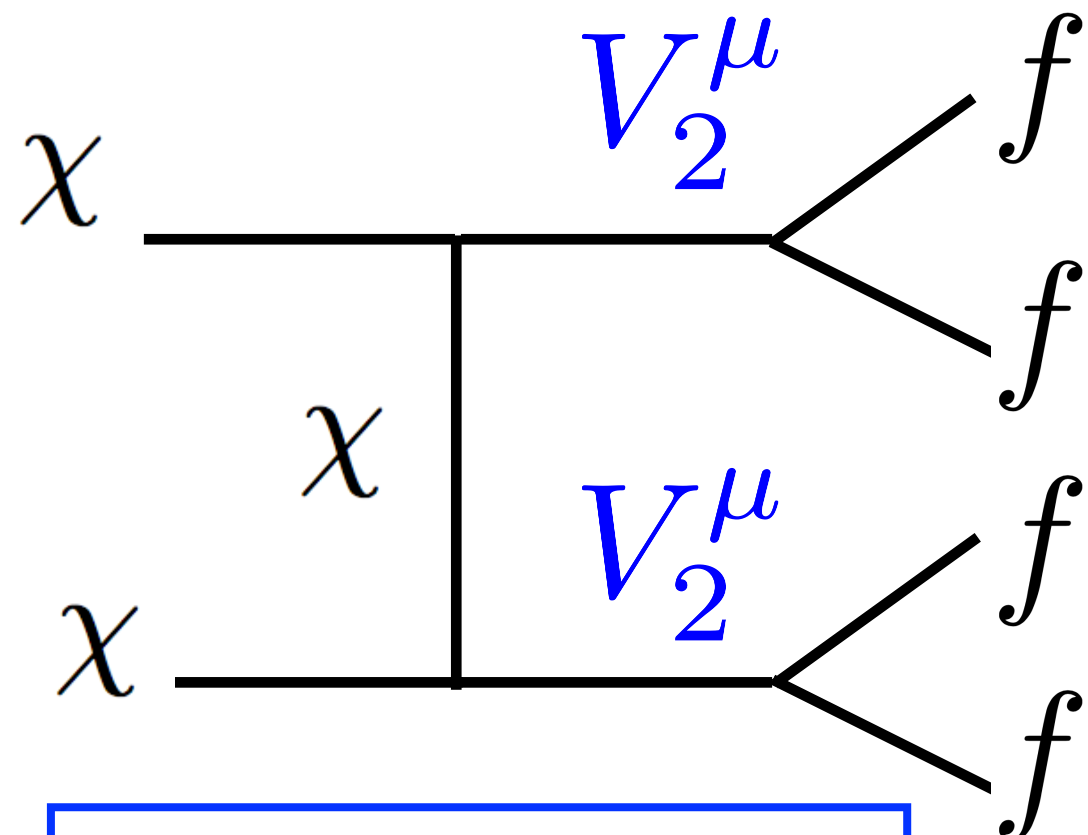
[Xuewen Liu, ZL, Yushan Su, 1902.04916]

annihilation 1



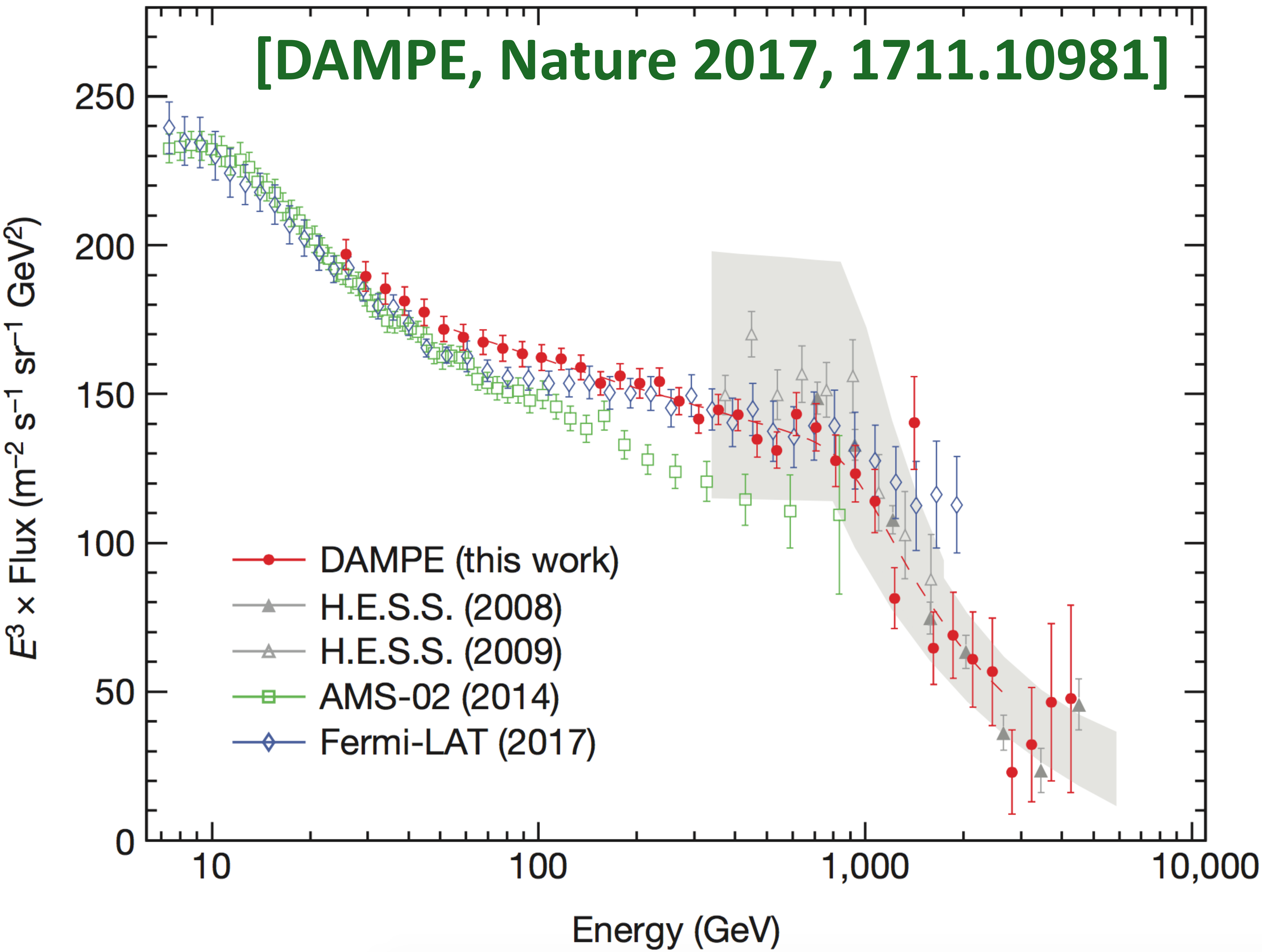
1.5 TeV peak

annihilation 2

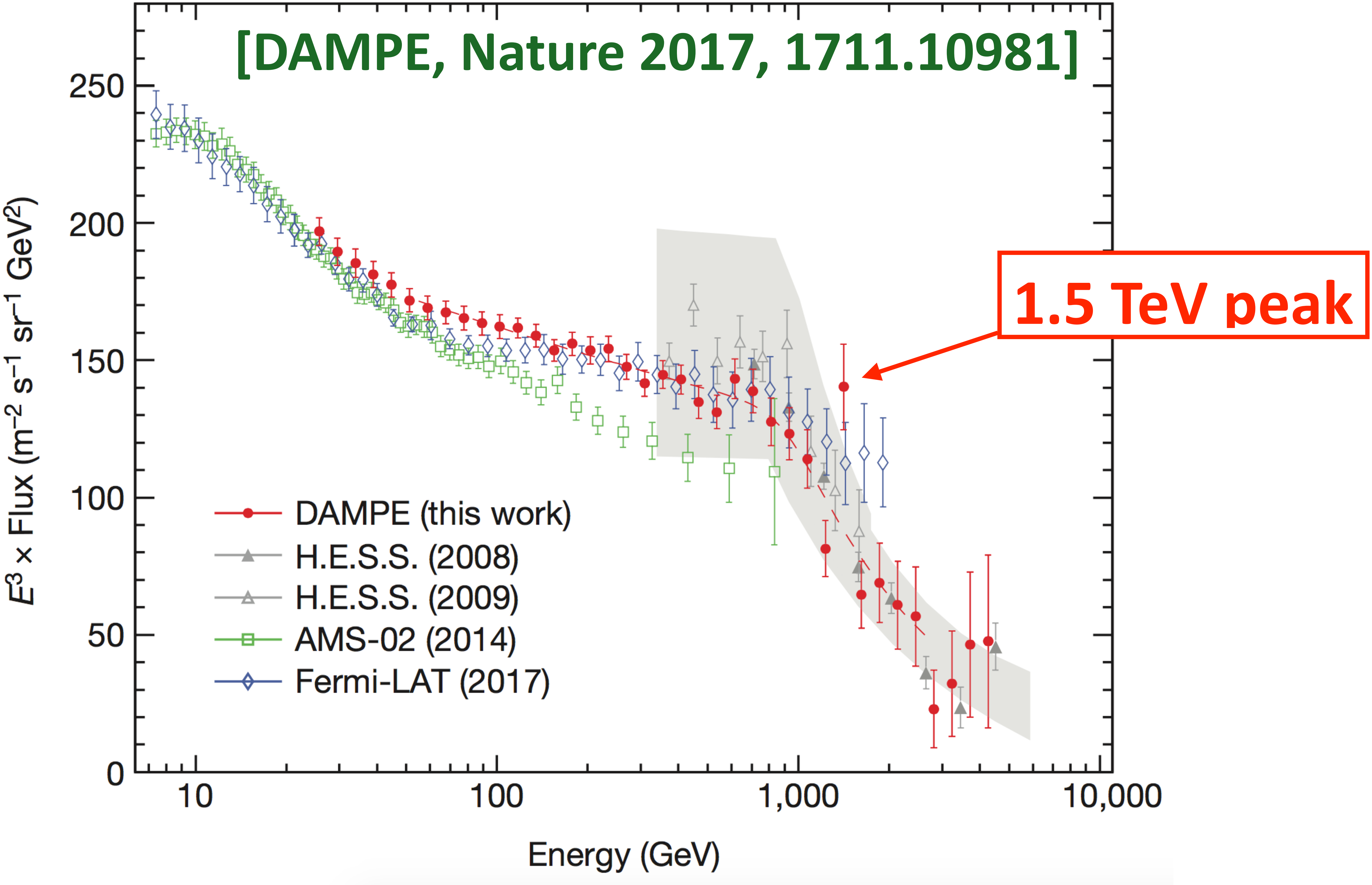


0.9 TeV break

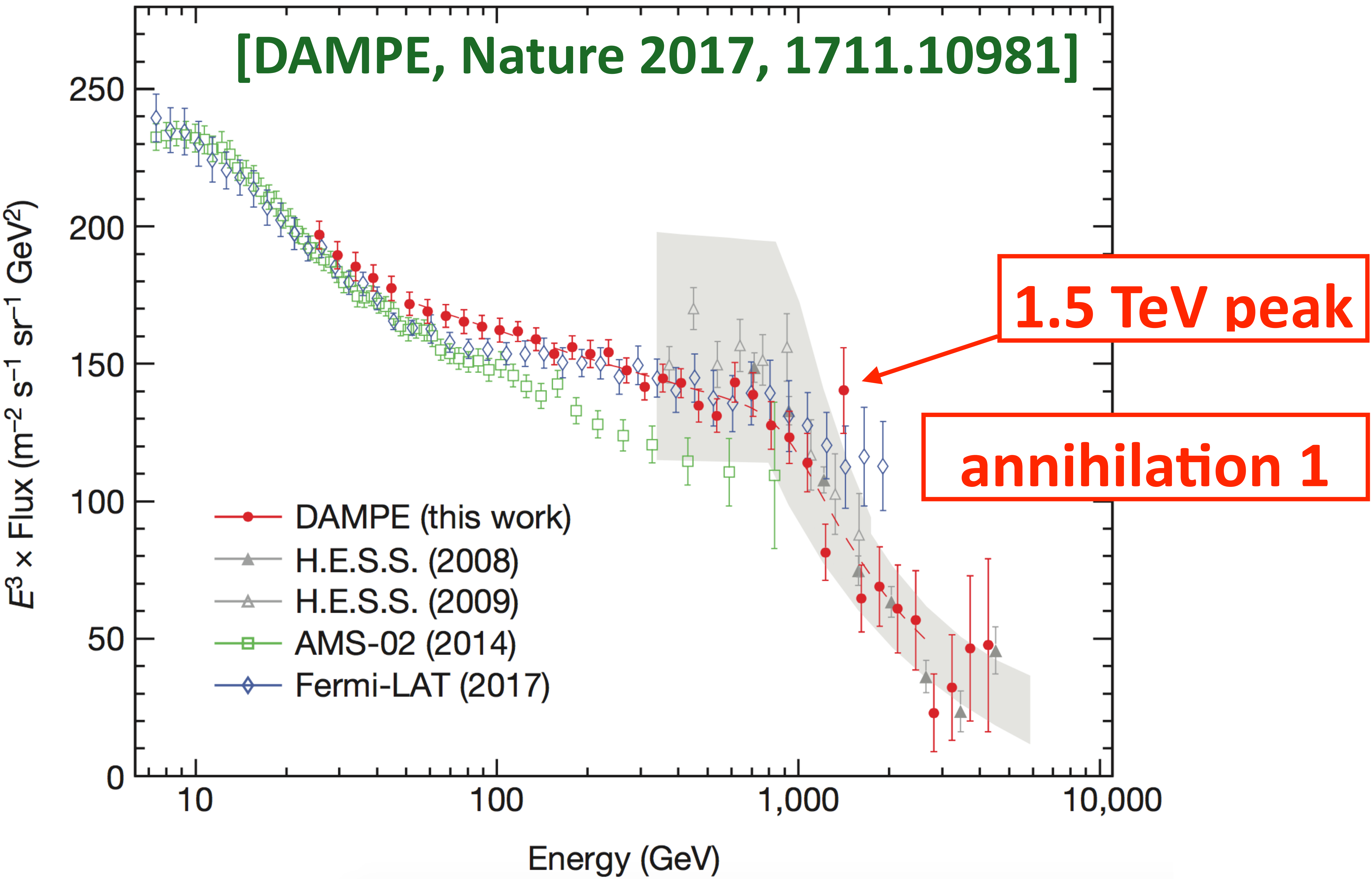
DAMPE electron excess



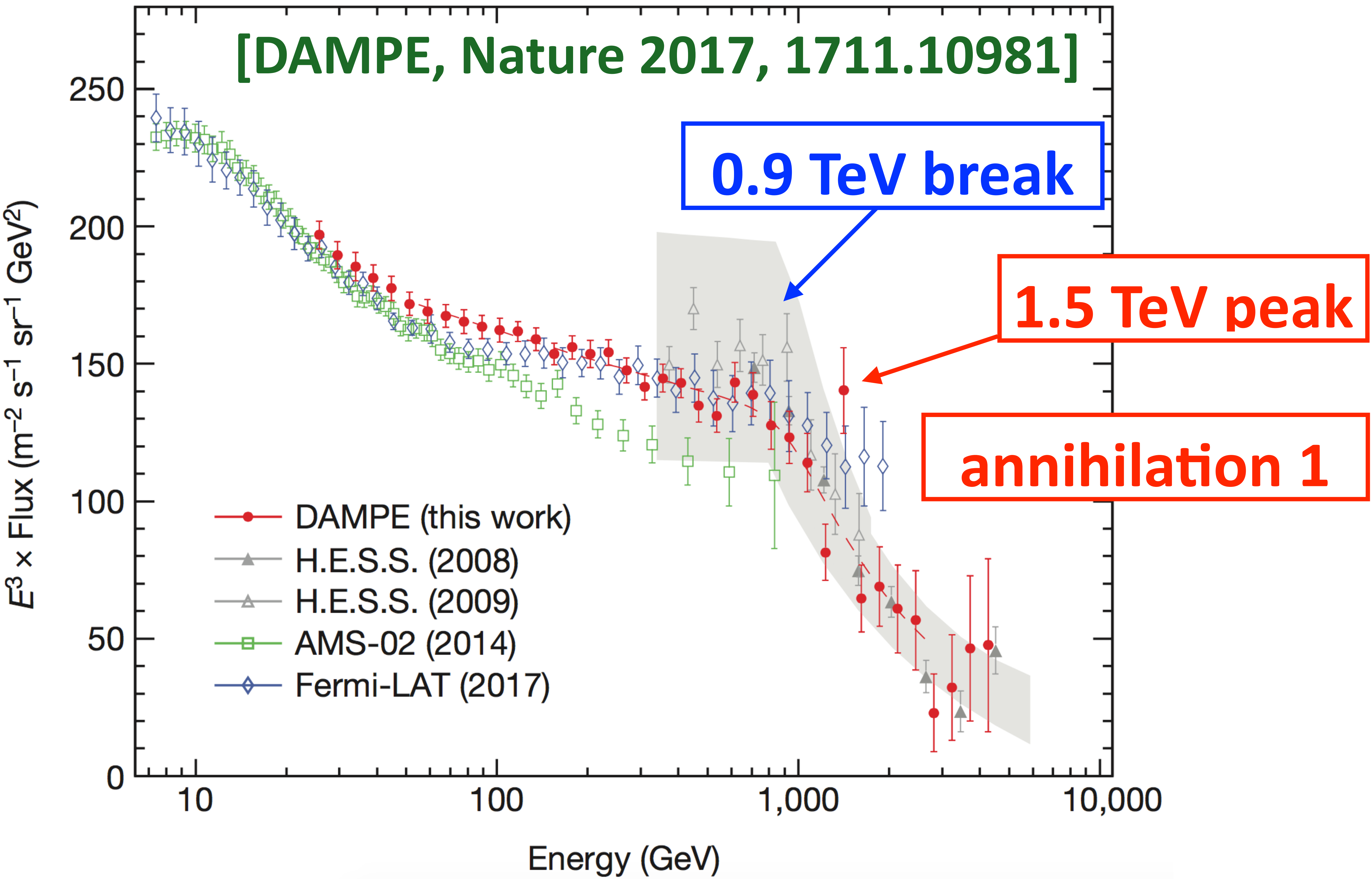
DAMPE electron excess



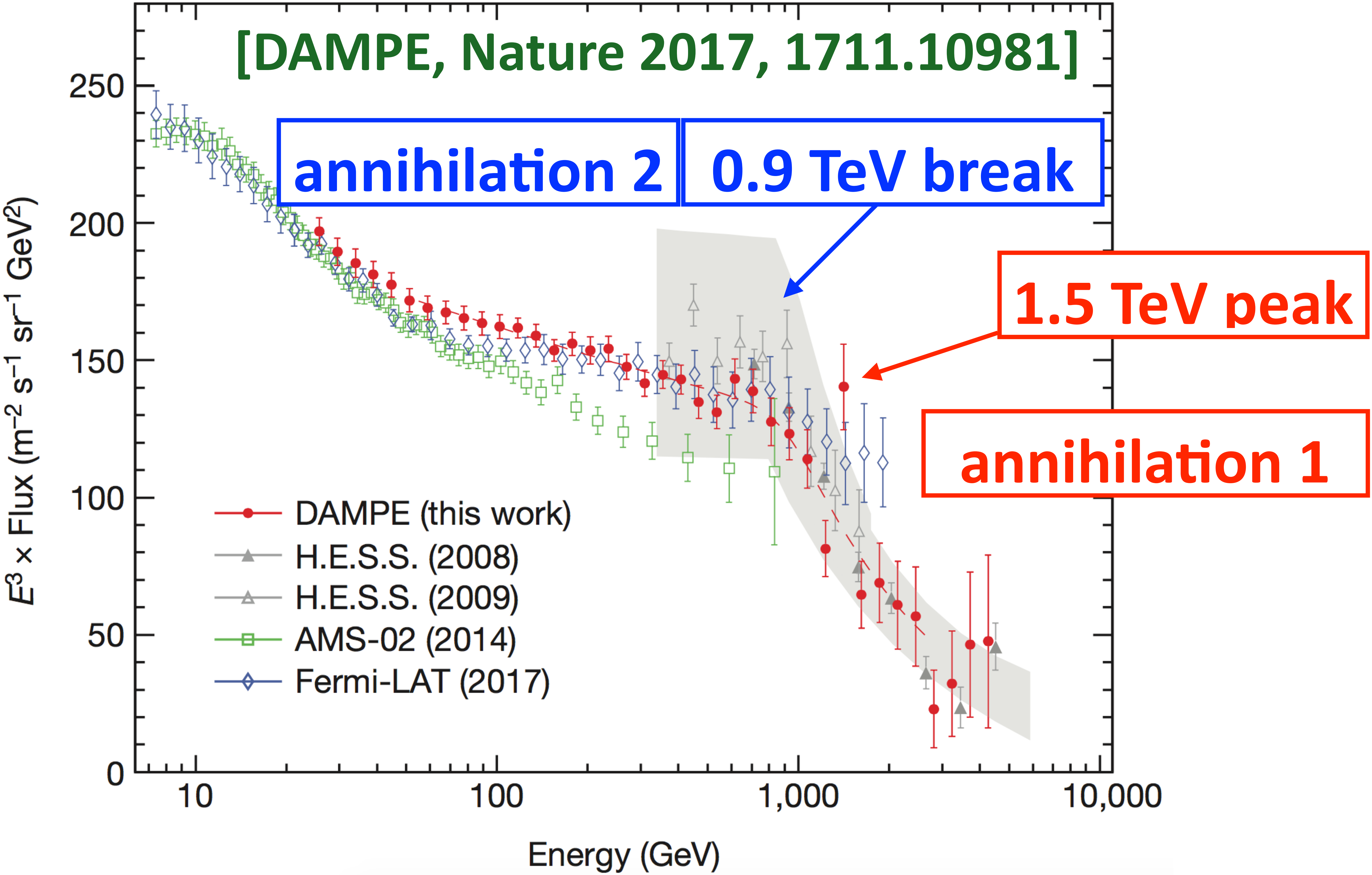
DAMPE electron excess



DAMPE electron excess



DAMPE electron excess



Two different models

	annihilation 1	annihilation 2
	V_1^μ	V_2^μ
1	electrophilic	$L_\mu - L_\tau$
2	kinetic mixing (KM)	$L_\mu - L_\tau$

Cosmic ray BG

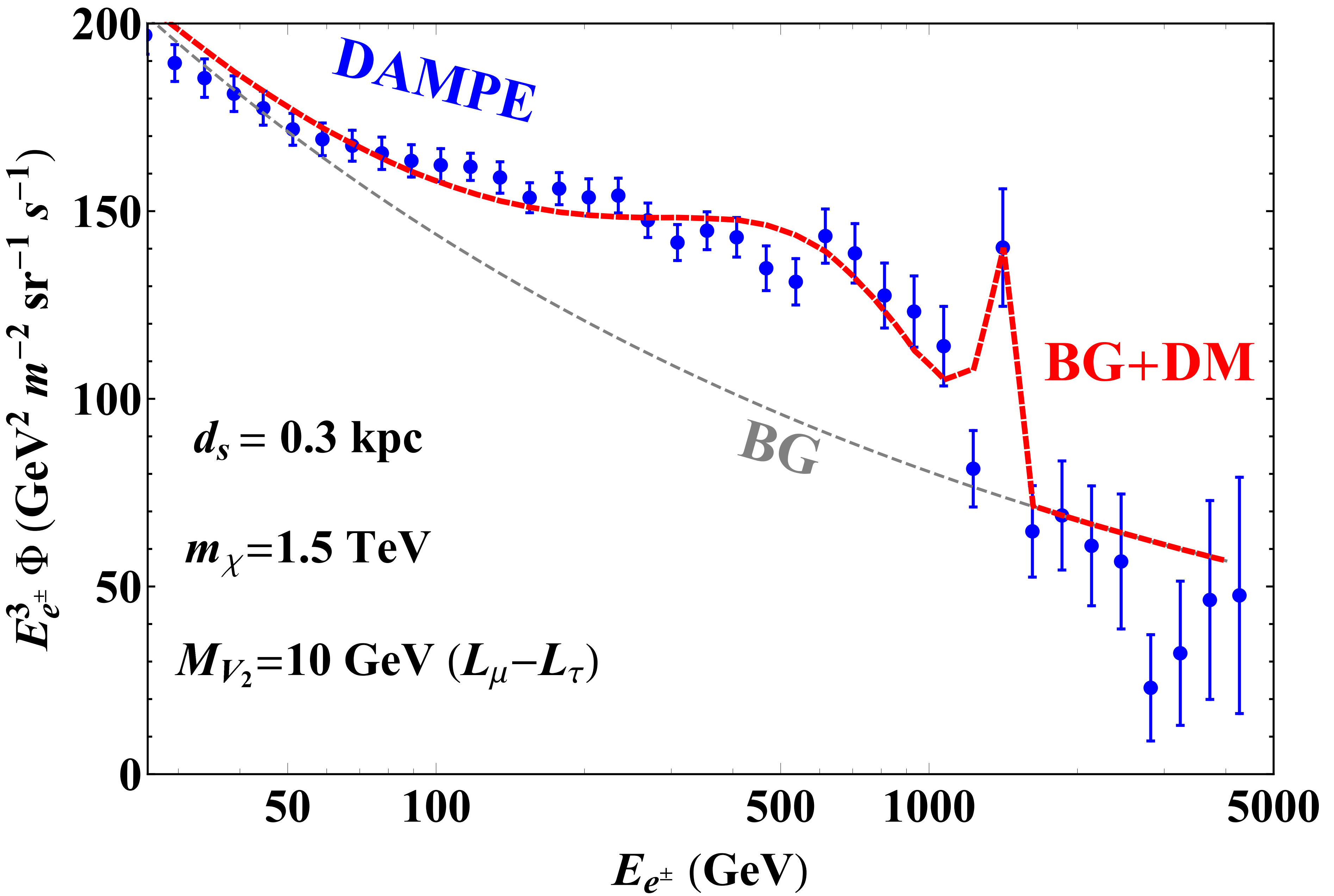
simple BG function w/ only 2 parameters

$$\Phi_{e^\pm} = CE^{-\gamma}$$

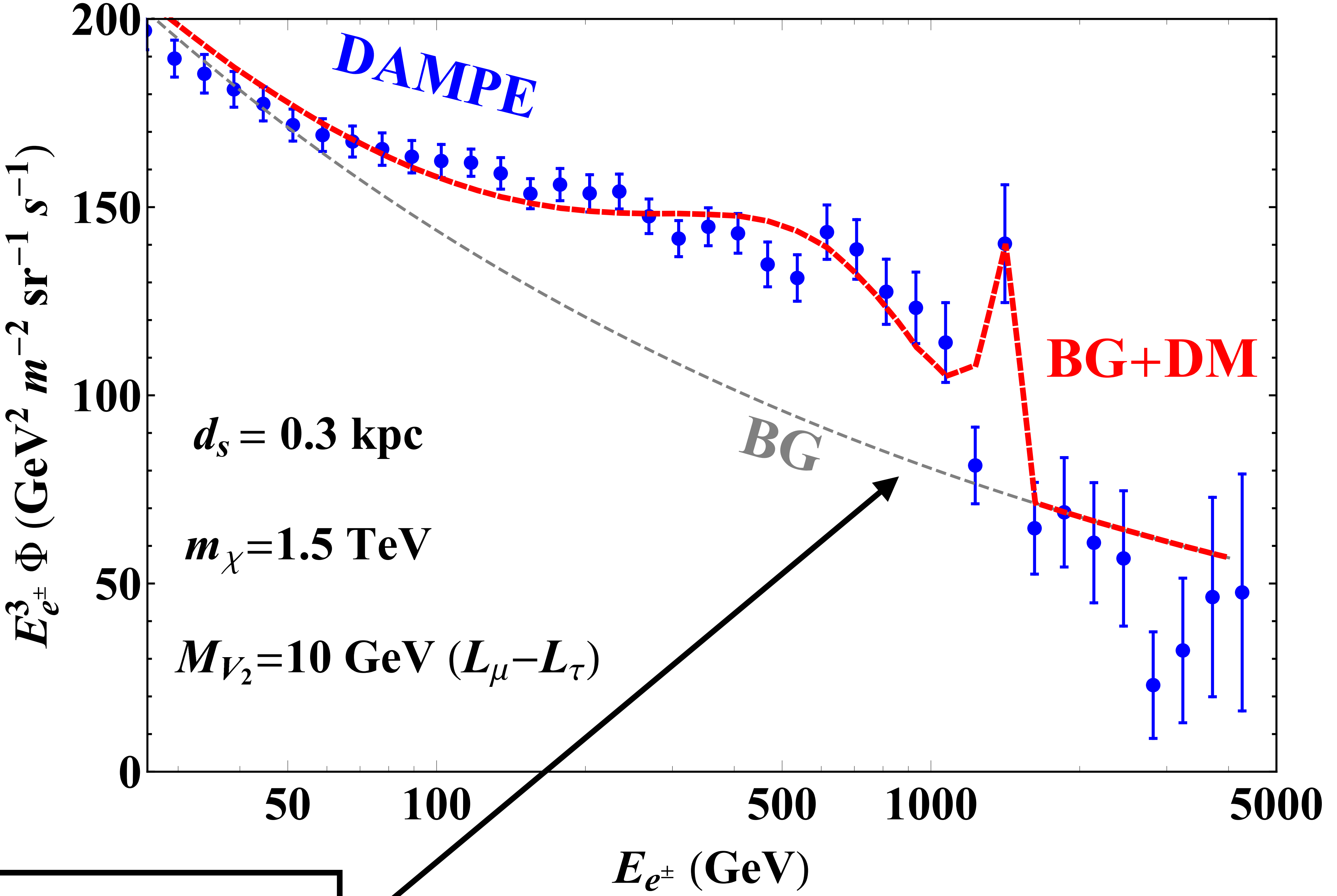
DAMPE data points <72.4 GeV or > 1.514 TeV (first & last 8 points)

$$C = 458\ (\mathrm{GeV\ m^2\ s\ sr})^{-1}$$
$$\gamma = 3.25$$

electrophilic V_1 & L_μ - L_τ V_2



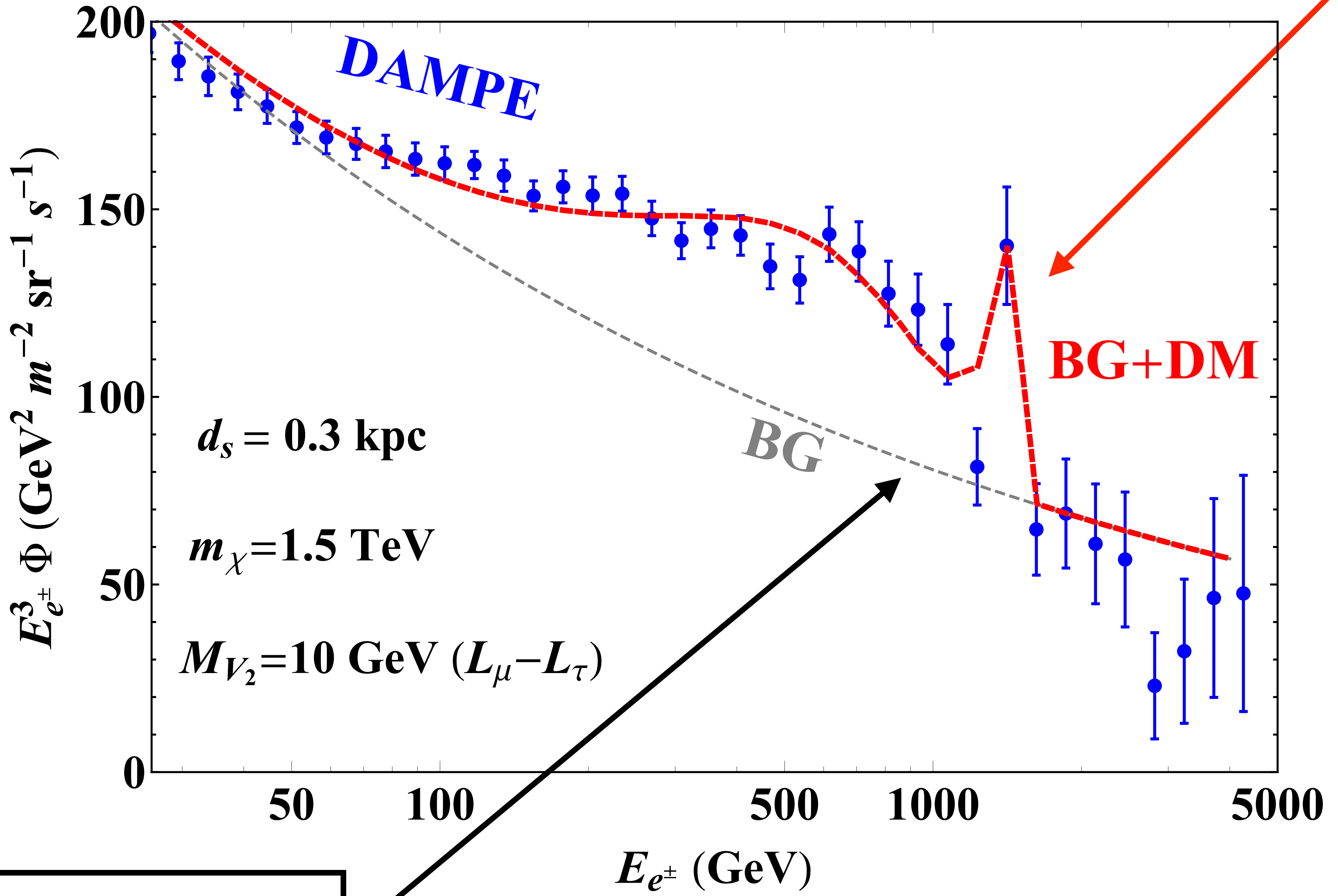
electrophilic V_1 & L_μ - L_τ V_2



simple BG

electrophilic V_1 & L_μ - L_τ V_2

e-philic V1

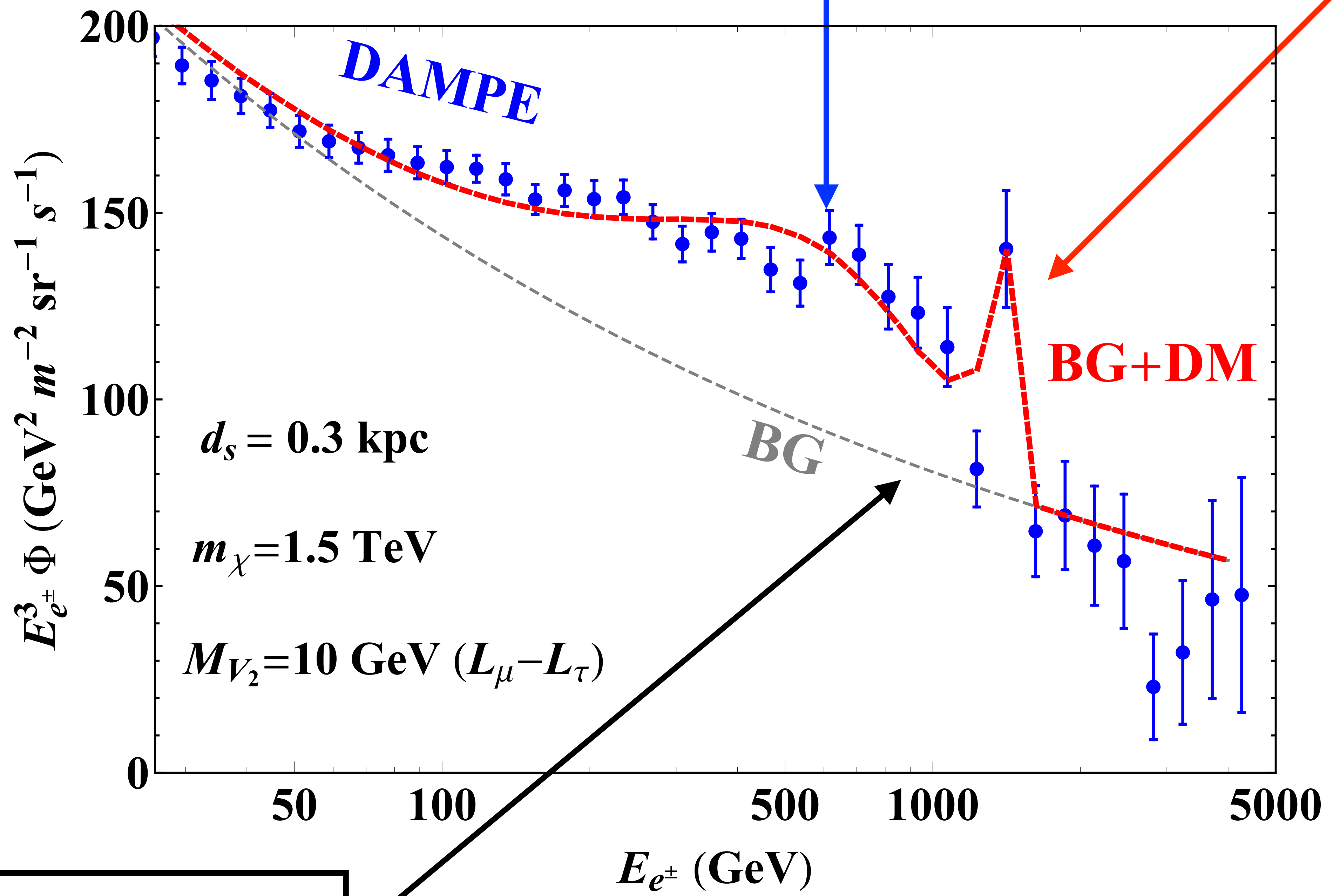


simple BG

electrophilic V_1 & L_μ - L_τ V_2

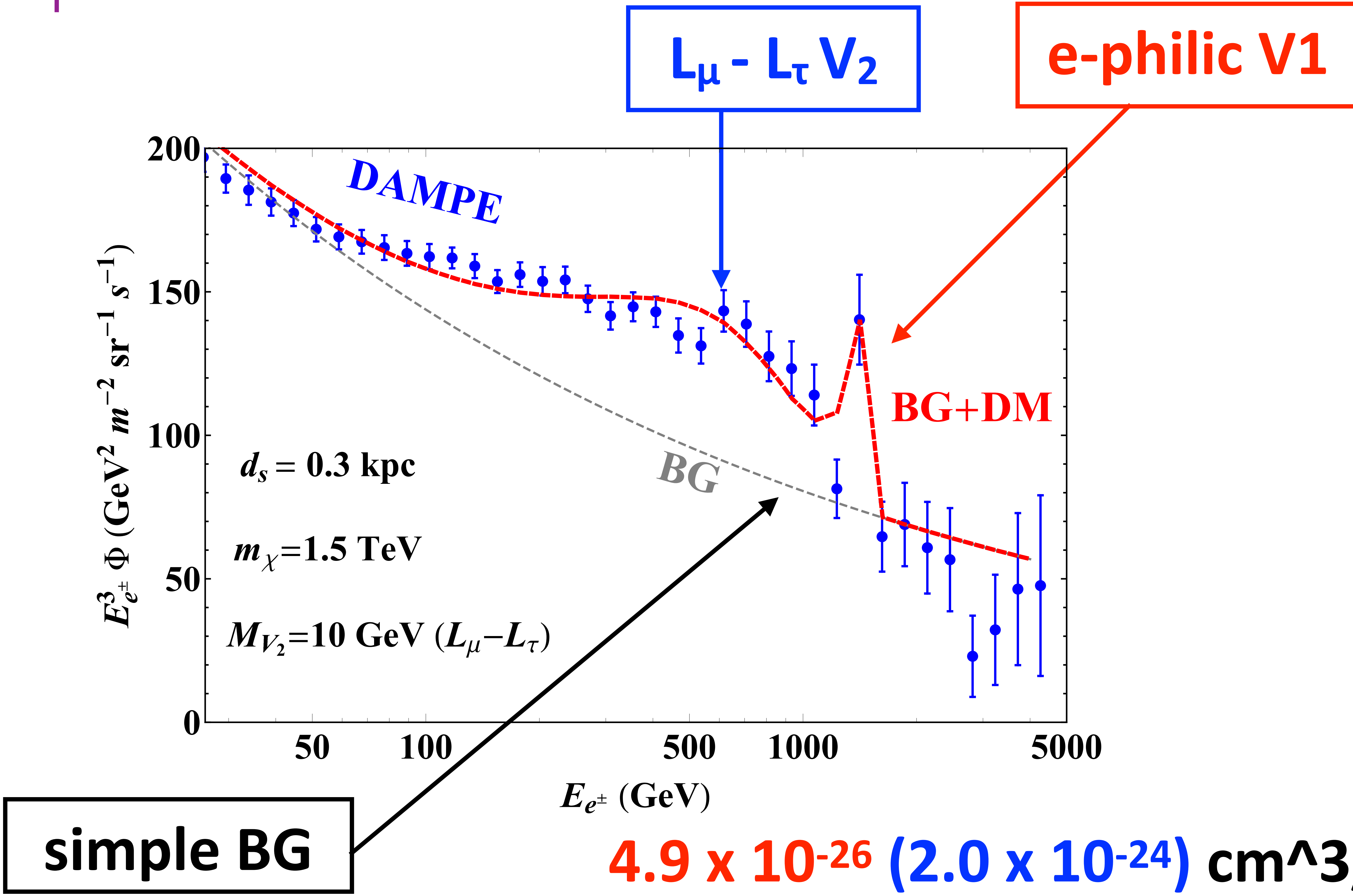
L_μ - L_τ V_2

e-philic V1



simple BG

electrophilic V_1 & L_μ - L_τ V_2

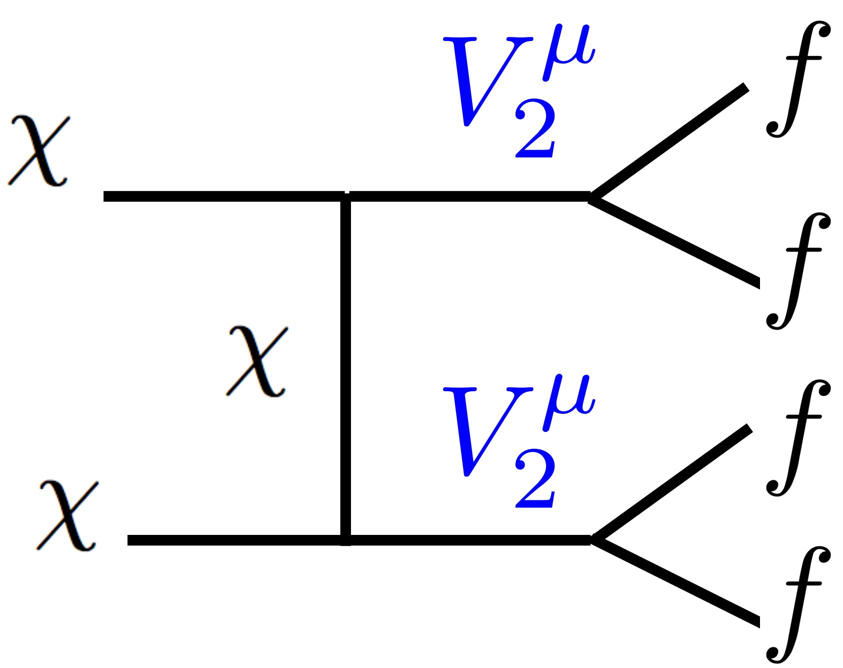


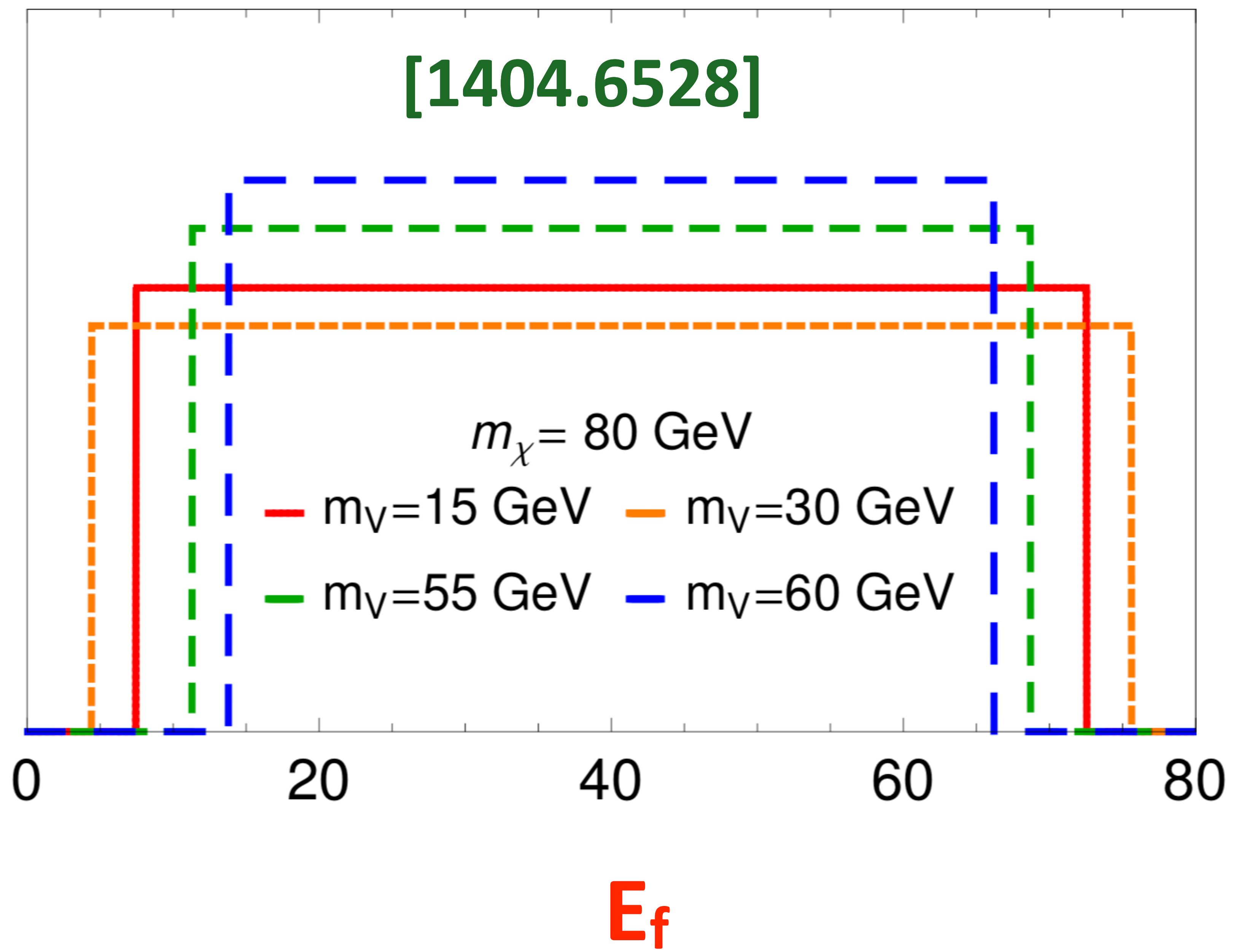
4.9×10^{-26} (2.0×10^{-24}) cm^3/s

Box-shape energy spectrum

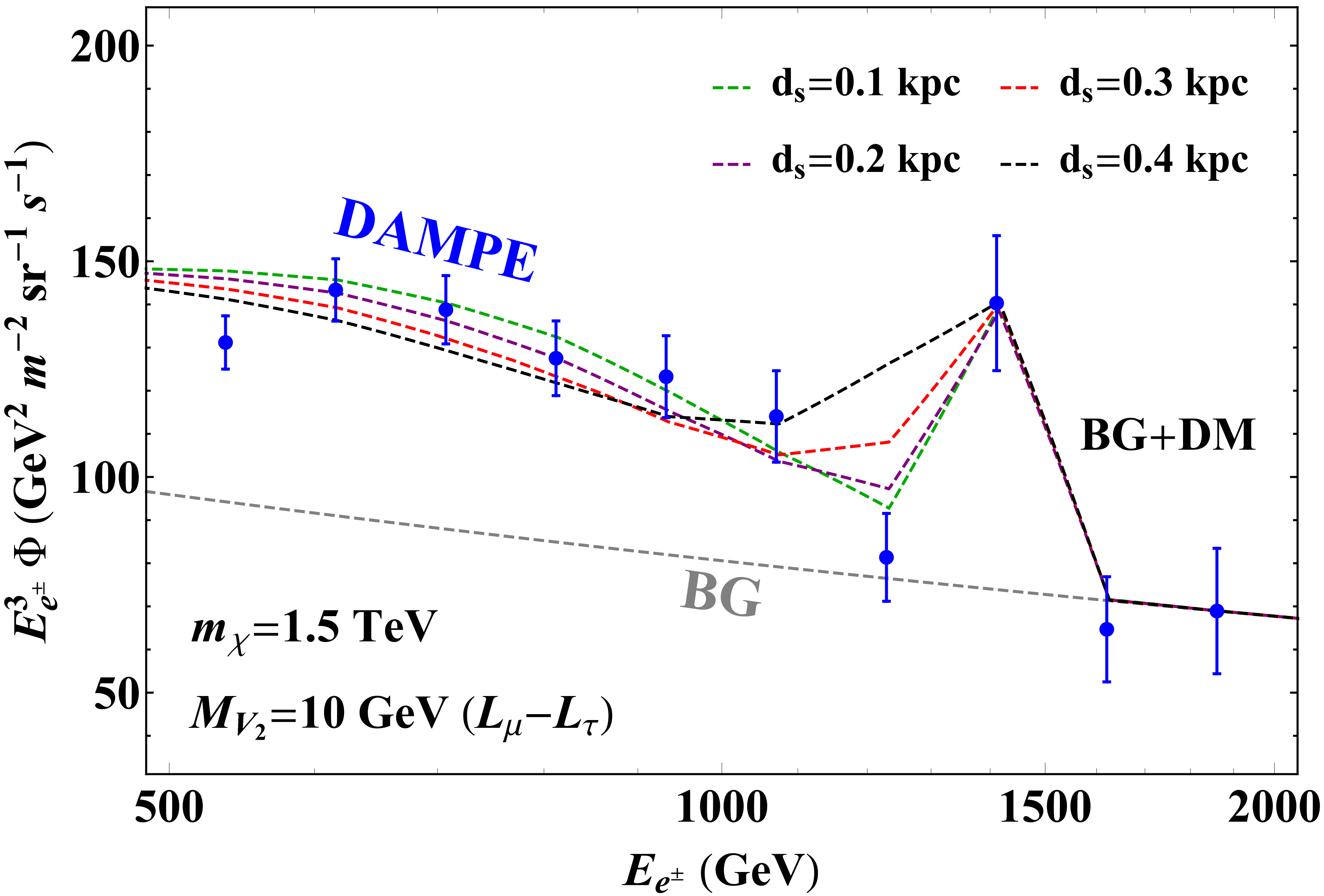
extended energy spectrum

$$\chi\chi \to VV \to 4f$$



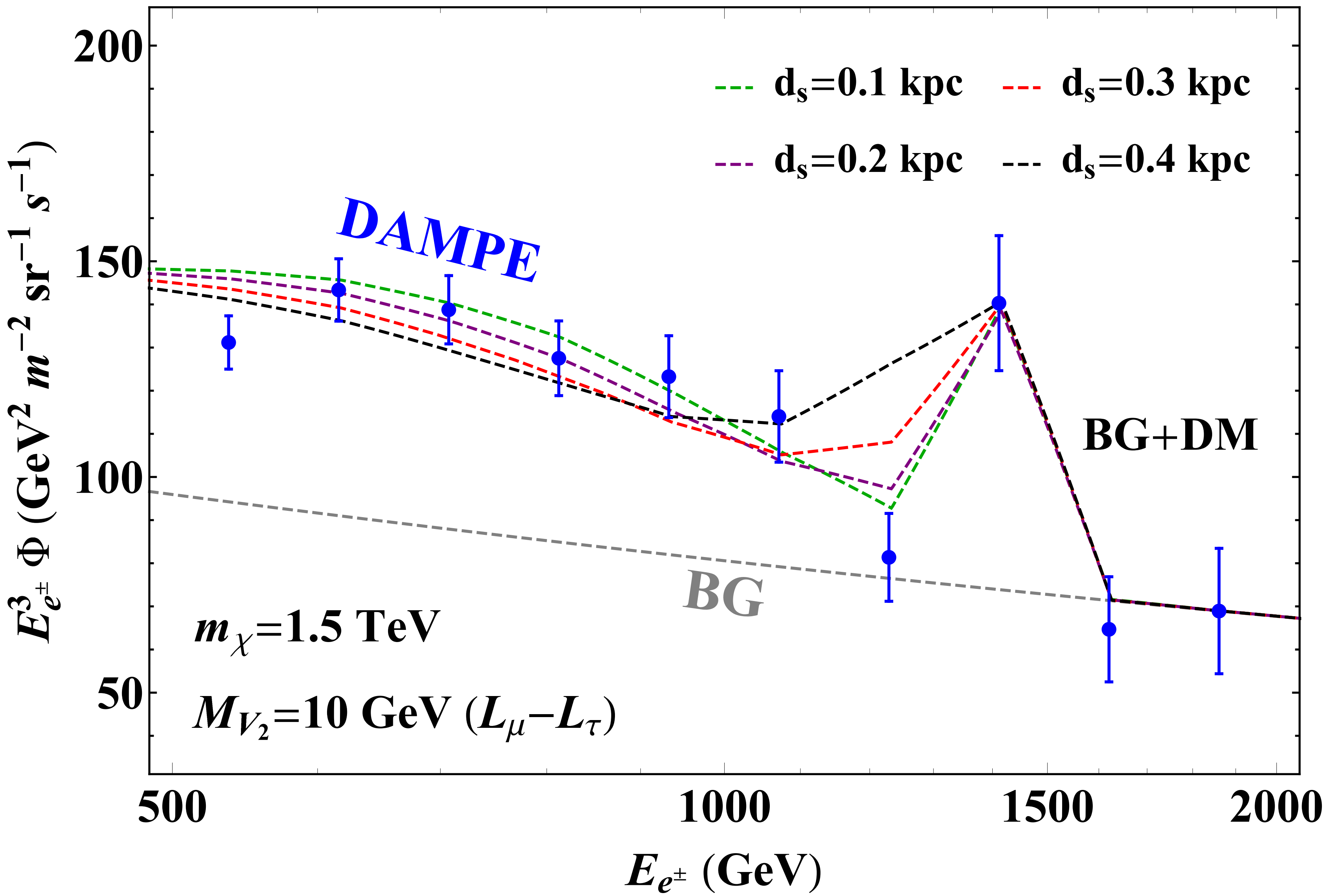


electrophilic V_1 & L_μ - L_τ V_2



d_s (kpc)	0.1	0.2	0.3	0.4
$\sigma v(\chi\chi \to e^+e^-)(\mathrm{cm}^3/\mathrm{s})$	7.9×10^{-27}	2.1×10^{-26}	4.9×10^{-26}	1.1×10^{-25}
$\sigma v(\chi\chi \to V_2V_2)\ (\mathrm{cm}^3/\mathrm{s})$	6.5×10^{-25}	1.3×10^{-24}	2.0×10^{-24}	2.8×10^{-24}

electrophilic V_1 & L_μ - L_τ V_2



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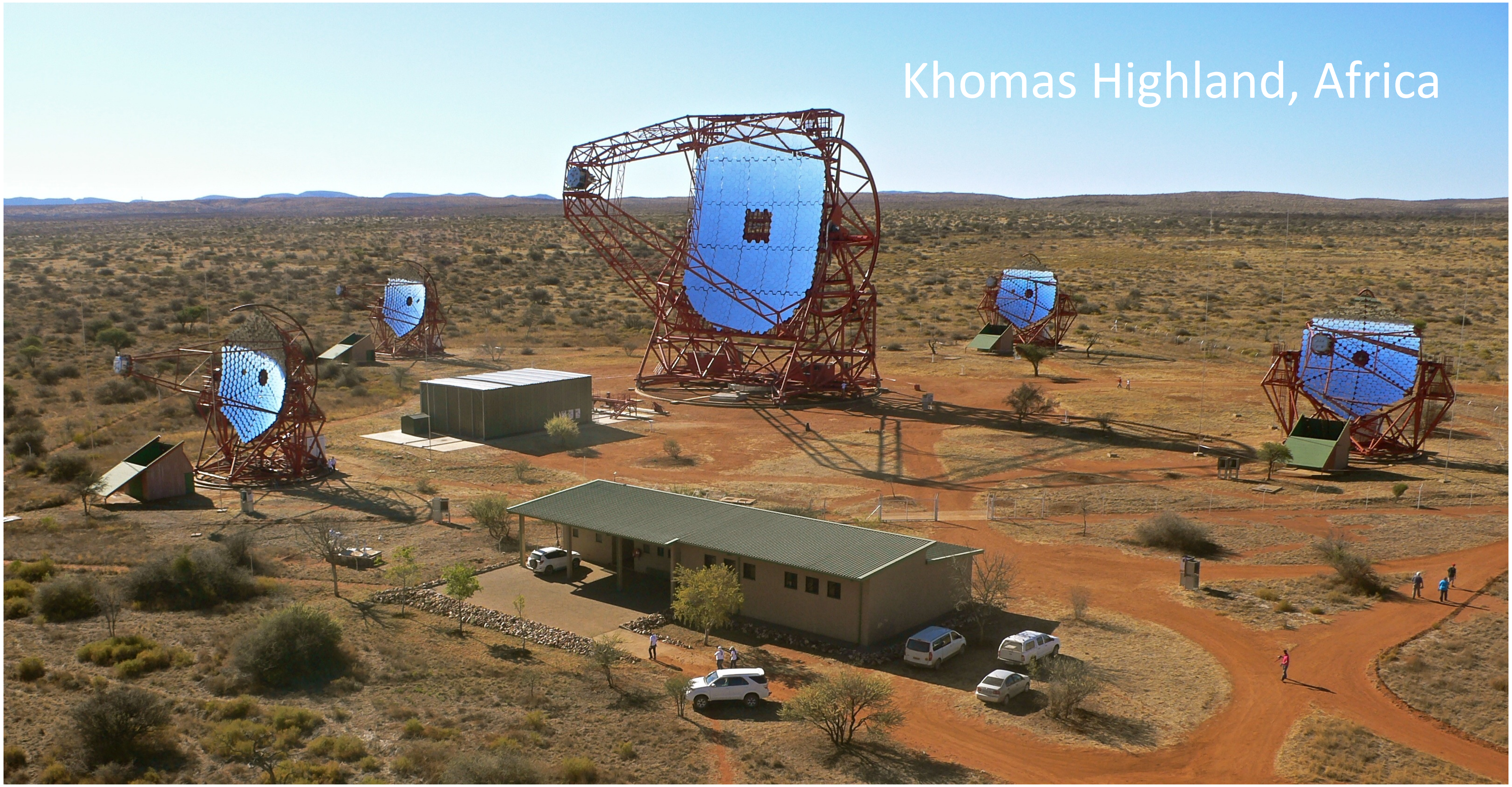
$\sigma v(\chi\chi \to V_2V_2)$ $(\mathrm{cm}^3/\mathrm{s})$	6.5×10^{-25}	1.3×10^{-24}	2.0×10^{-24}	2.8×10^{-24}

HESS experiment

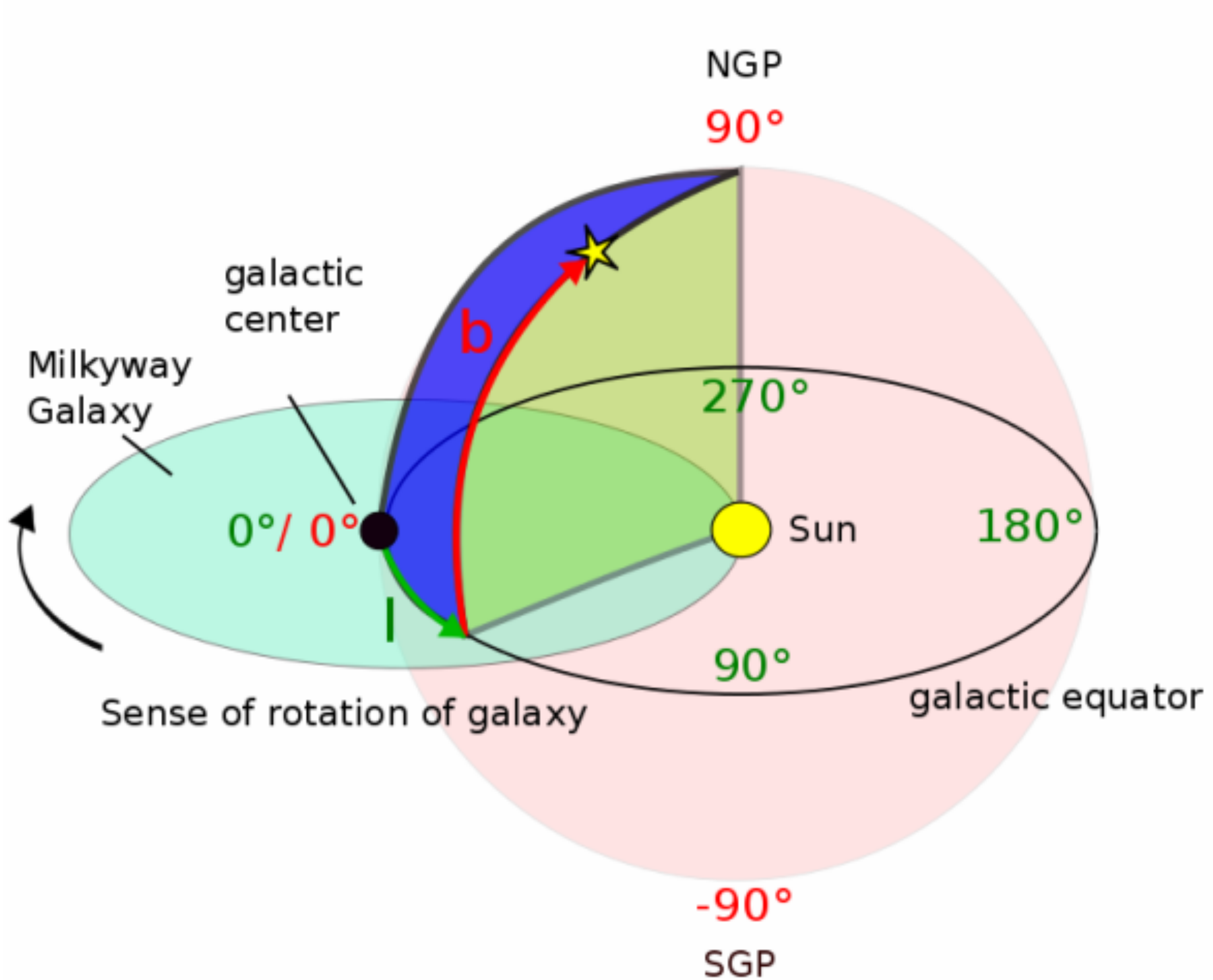


High Energy Stereoscopic System (H.E.S.S.)

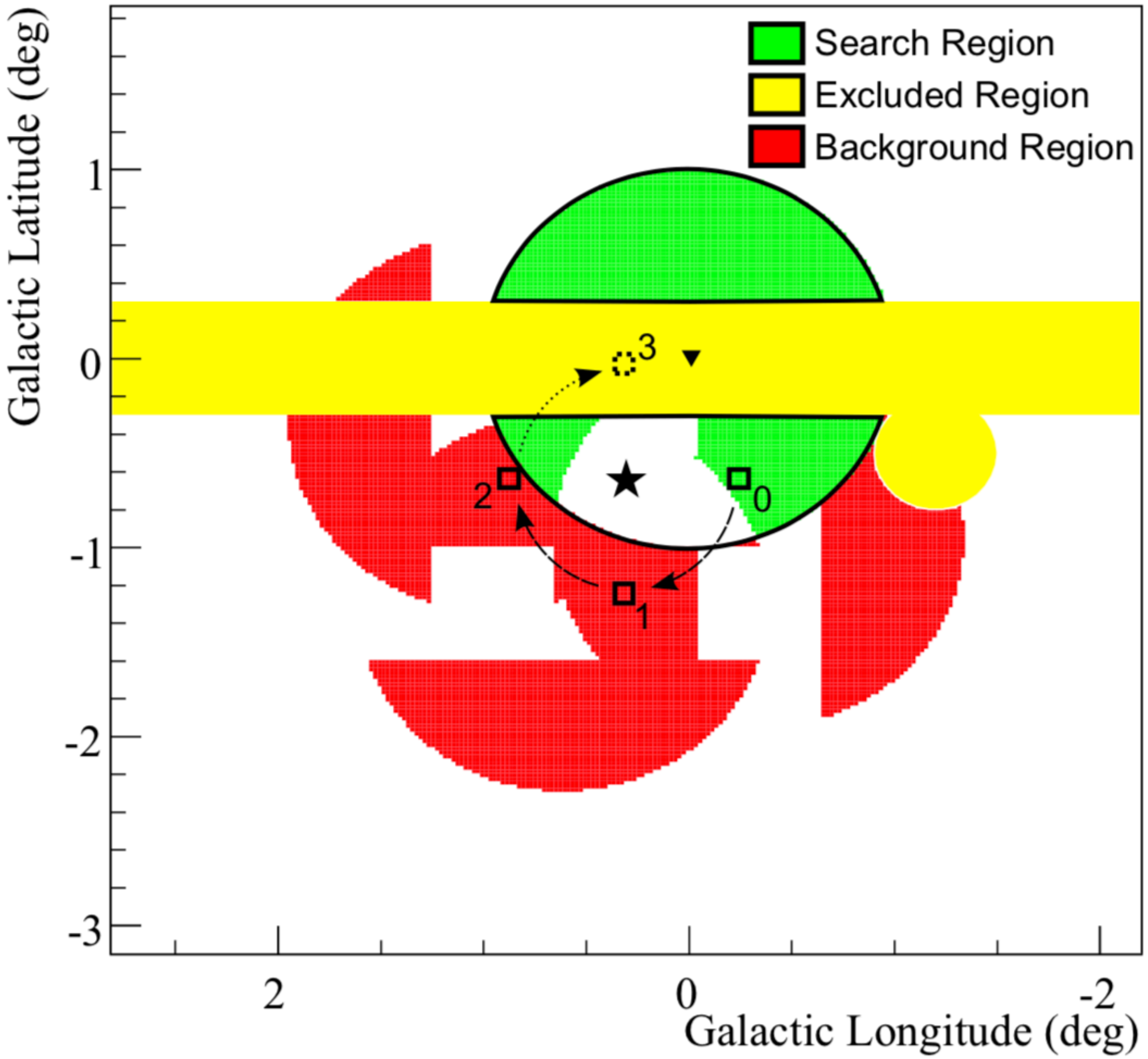
Imaging Atmospheric Cherenkov Telescopes

cosmic gamma ray 30 GeV - 100 TeV

galactic coordinates



HESS search region

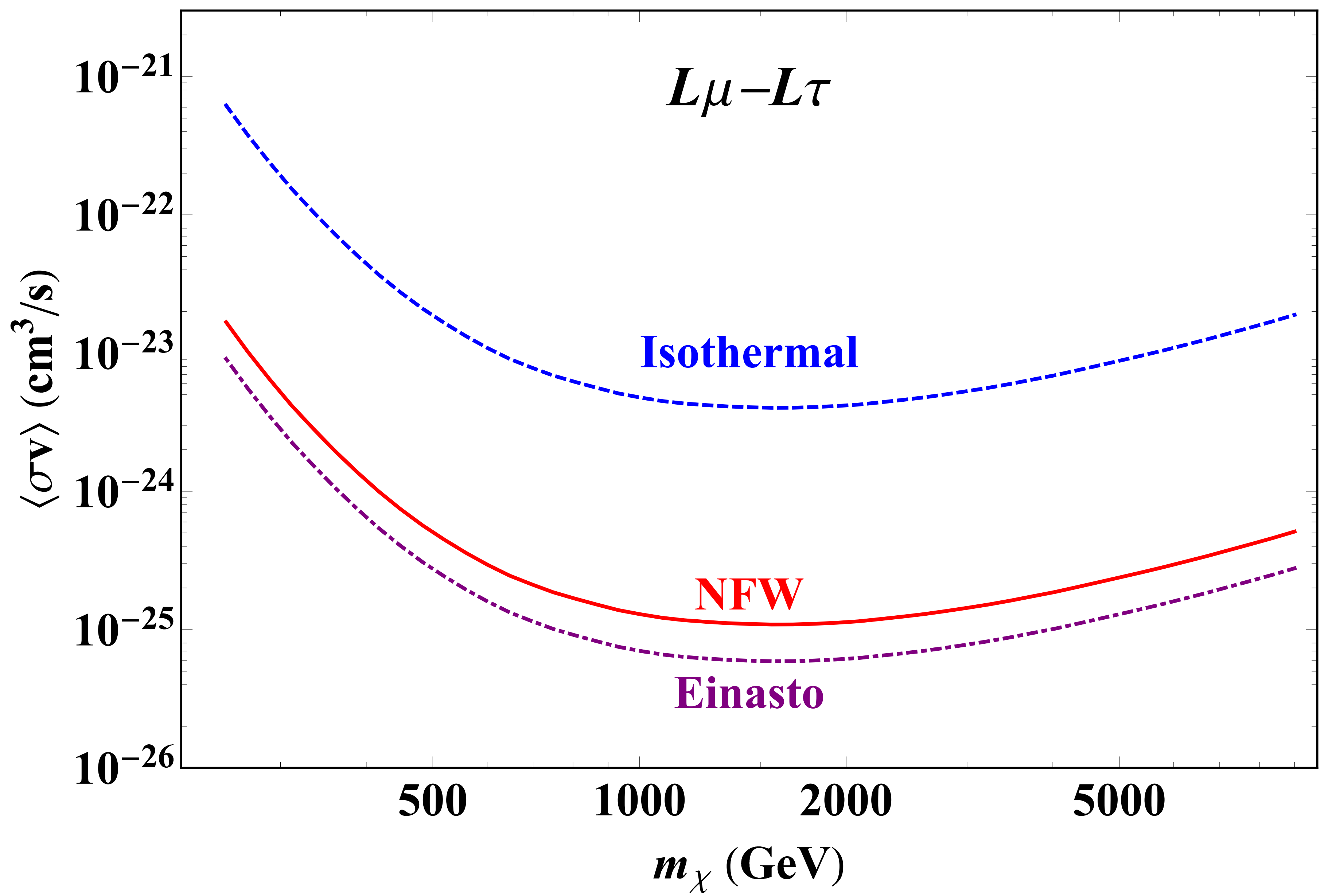


HESS
1607.08142

circular region $r = 1^\circ$ w/ $|b| < 0.3^\circ$ masked

HESS constraints on L_μ - L_τ V_2

[HESS 254-h data, 1607.08142]



circular region $r = 1^\circ$ w/ $|b| < 0.3^\circ$ masked

Fermi experiment

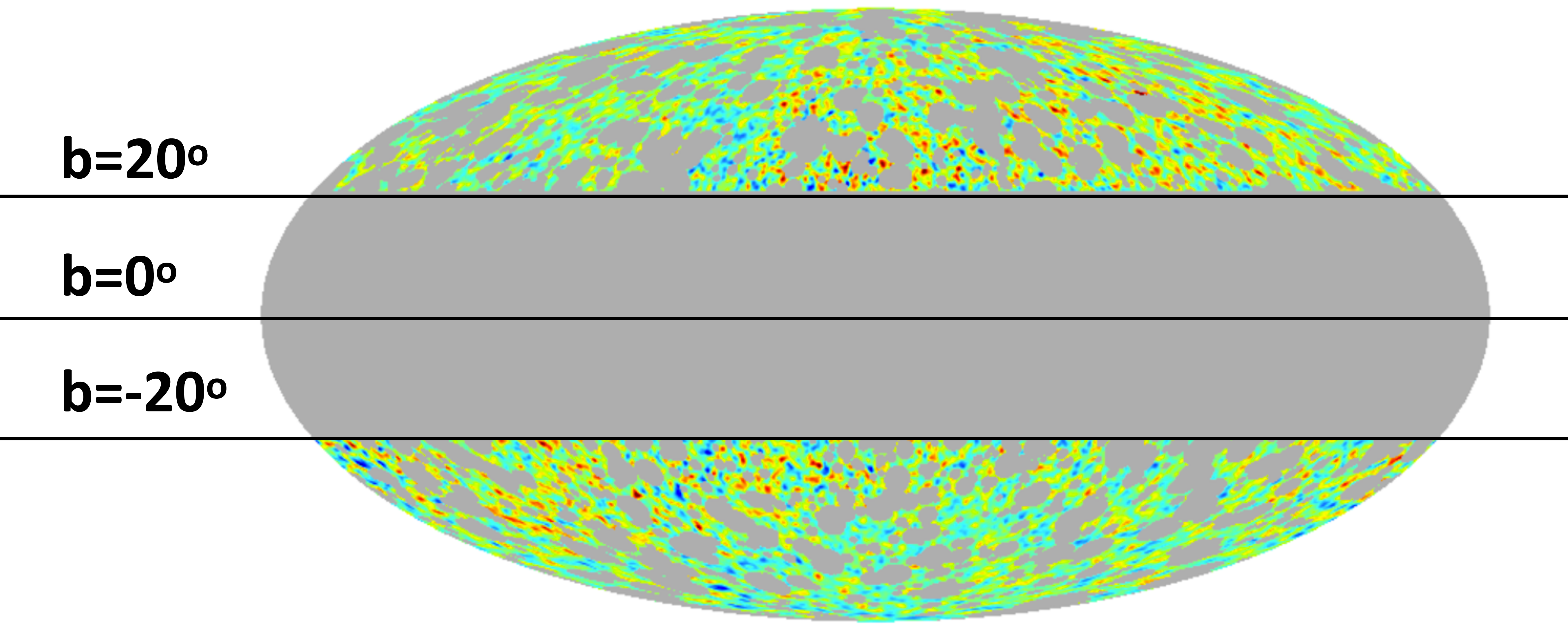
launched on June 11, 2008

Fermi-LAT

LAT (large area telescope)

Fermi isotropic gamma ray background

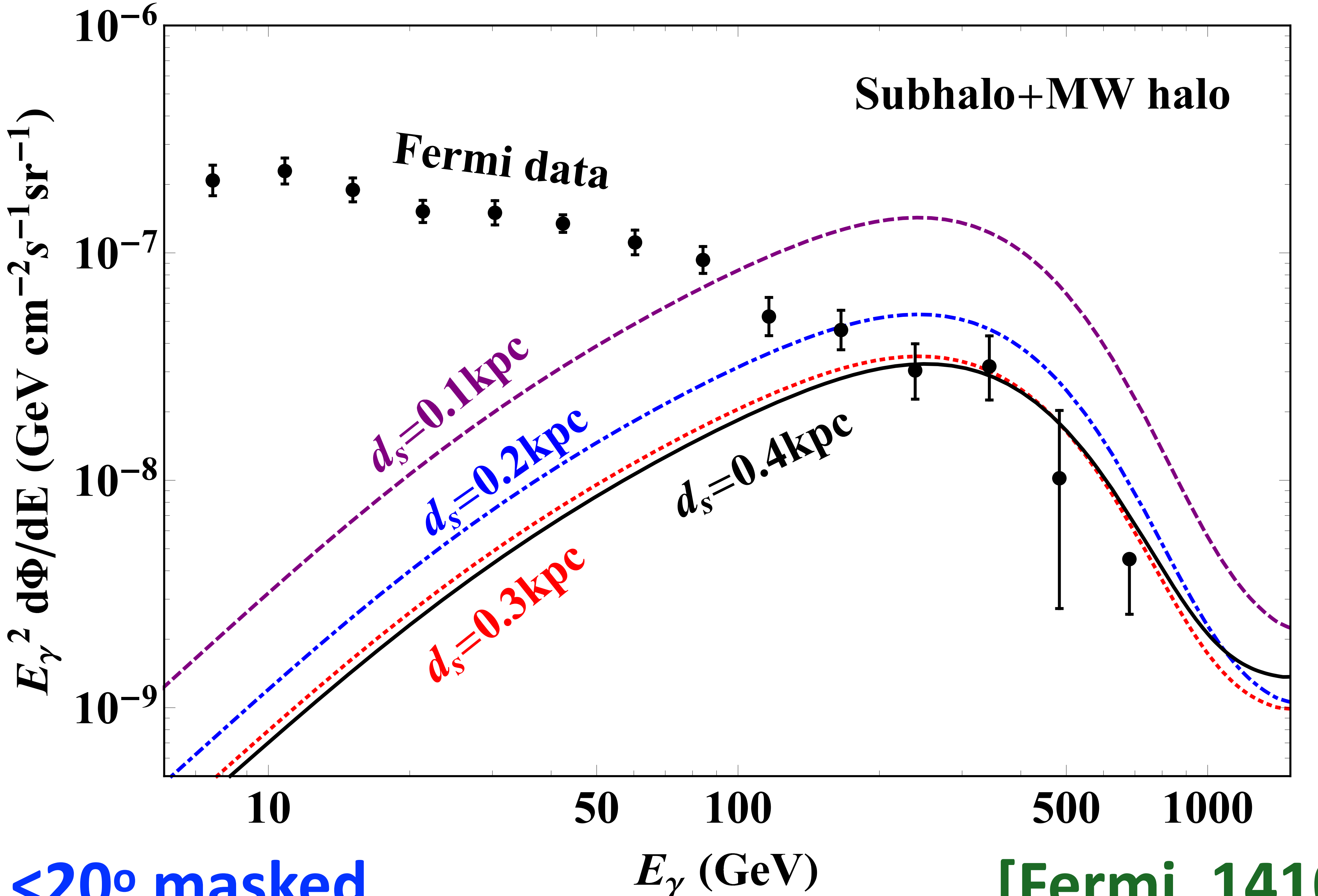
isotropic gamma ray background (IGRB)



|b|<20° masked

Fermi IGRB as a function d_s

electrophilic V_1 & L_μ - L_τ V_2

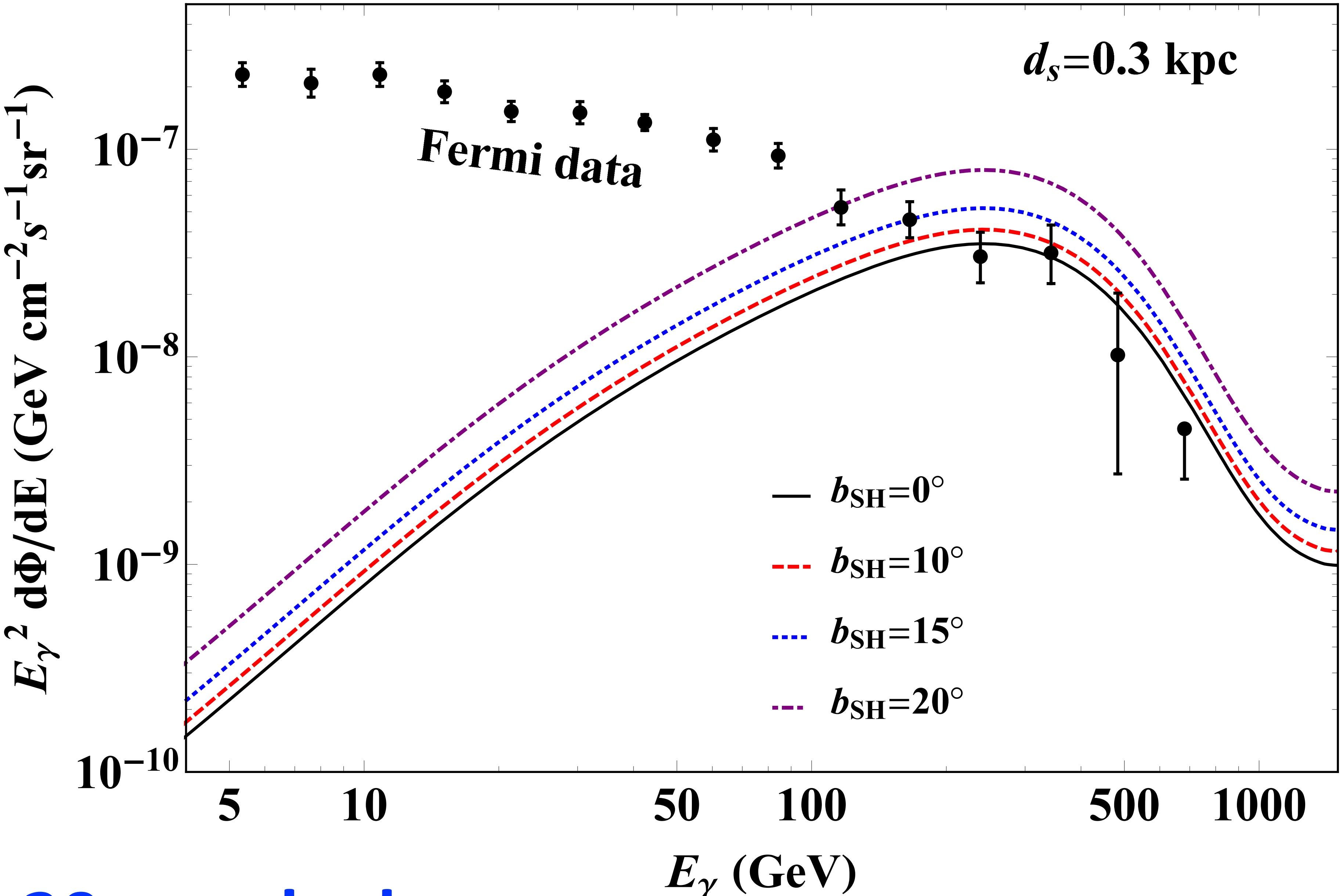


|b|<20^o masked

[Fermi, 1410.3696]

Fermi IGRB as a function b_{SH}

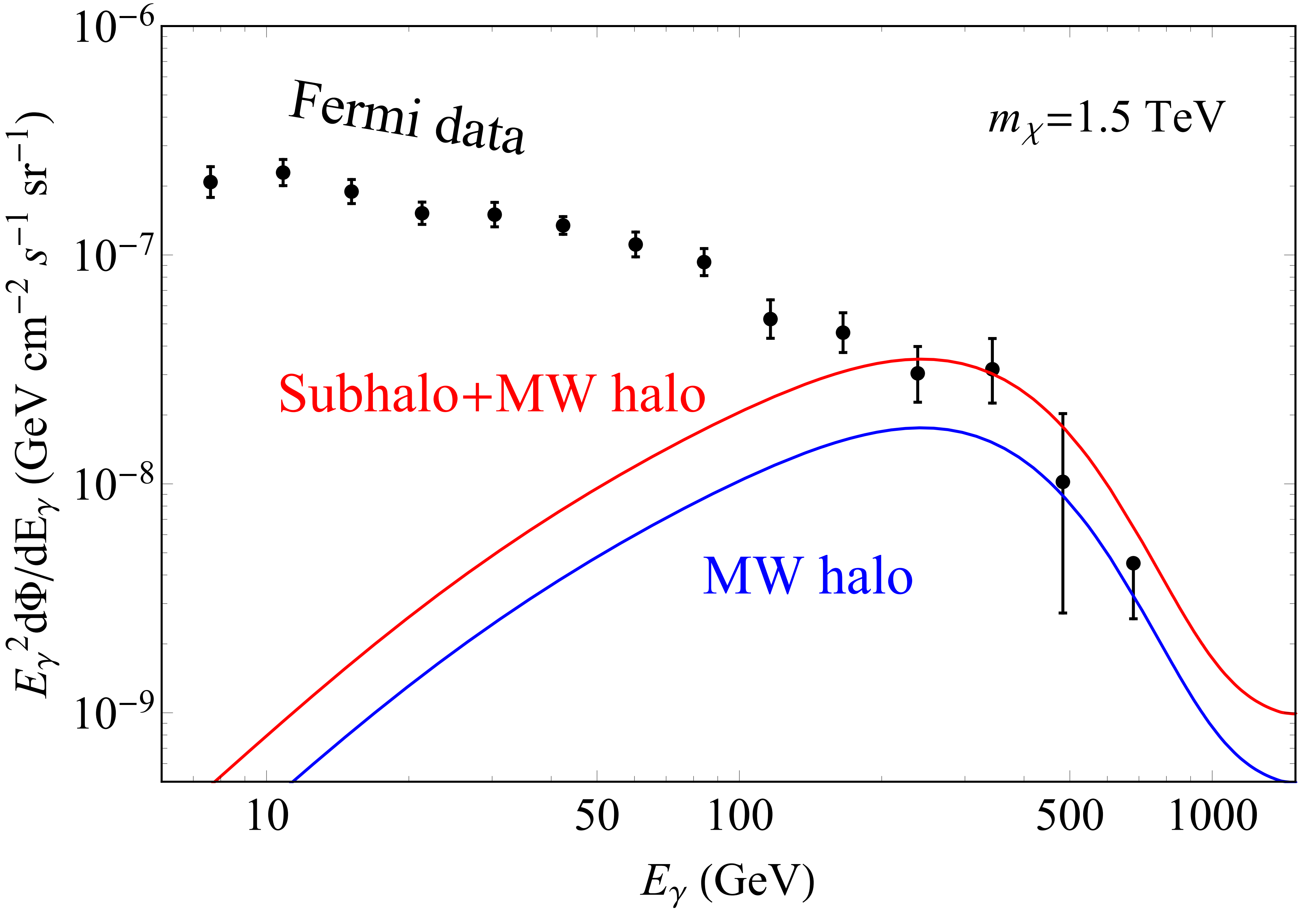
electrophilic V_1 & L_μ - L_τ V_2



|b|<20° masked

Fermi isotropic gamma ray BG

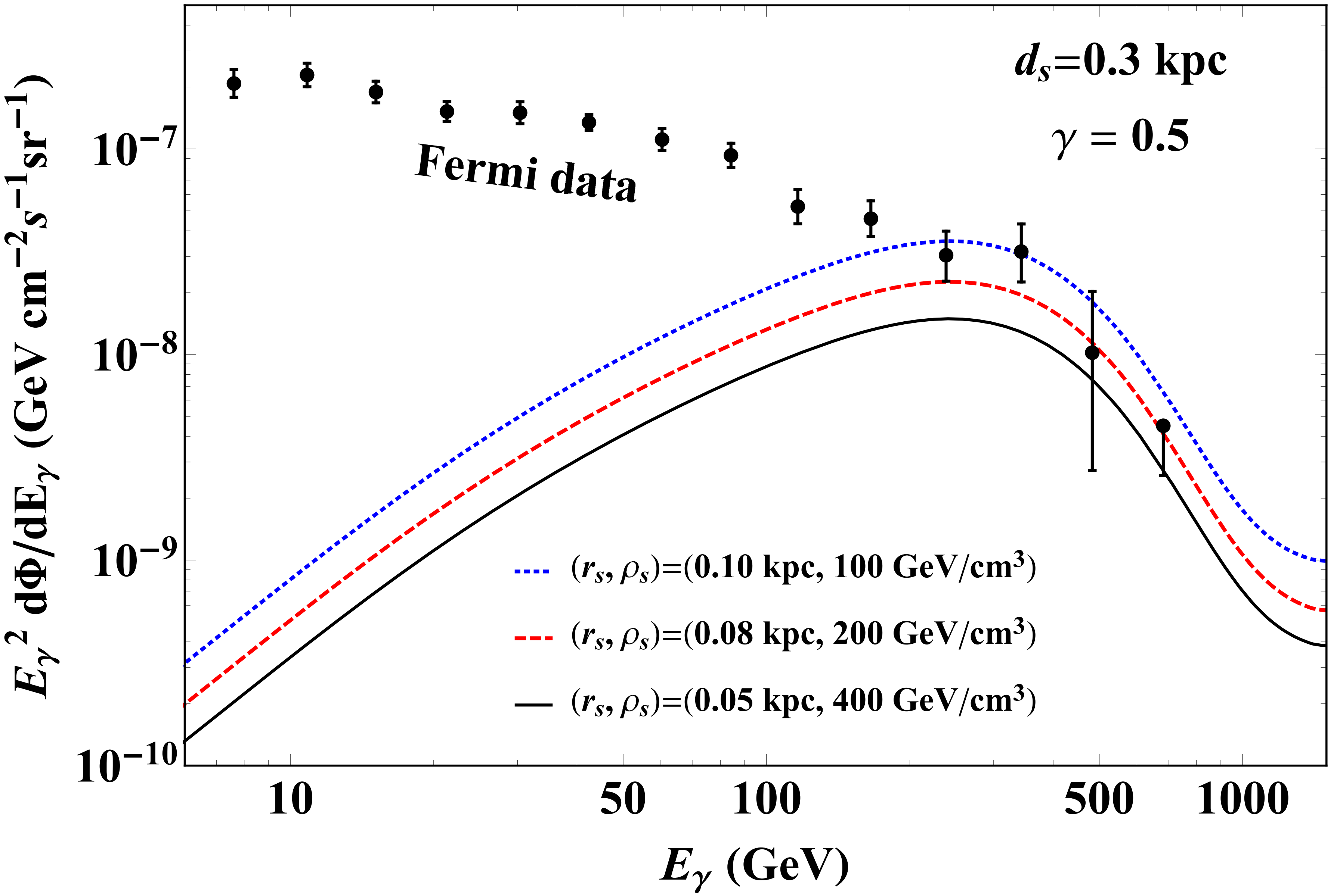
electrophilic V_1 & L_μ - L_τ V_2 **ds=0.3 kpc**



|b|<20º masked **[Fermi, 1410.3696]**

Fermi IGRB for diff subhalos

electrophilic V_1 & L_μ - L_τ V_2



|b|<20^o masked

KM V_1 & L_μ - L_τ V_2

$$\mathcal{L} \supset -\frac{1}{4} V_1^{\mu\nu} V_{1\mu\nu} + \frac{\epsilon}{2} V_1^{\mu\nu} B_{\mu\nu} + g_1 \bar{\chi} \gamma_\mu \chi V_1^\mu$$

$$-\frac{1}{4} V_2^{\mu\nu} V_{2\mu\nu} + g_2 \bar{\chi} \gamma_\mu \chi V_2^\mu$$

$$+g_2 (\bar{\mu} \gamma_\mu \mu + \bar{\nu}_\mu \gamma_\mu P_L \nu_\mu) V_2^\mu$$

$$-g_2 (\bar{\tau} \gamma_\mu \tau + \bar{\nu}_\tau \gamma_\mu P_L \nu_\tau) V_2^\mu$$

KM V_1 & L_μ - L_τ V_2

V_1: kinetic mixing (KM)

$$\mathcal{L} \supset -\frac{1}{4}V_1^{\mu\nu}V_{1\mu\nu} + \frac{\epsilon}{2}V_1^{\mu\nu}B_{\mu\nu} + g_1\bar{\chi}\gamma_\mu\chi V_1^\mu$$

$$-\frac{1}{4}V_2^{\mu\nu}V_{2\mu\nu} + g_2\bar{\chi}\gamma_\mu\chi V_2^\mu$$

$$+g_2(\bar{\mu}\gamma_\mu\mu + \bar{\nu}_\mu\gamma_\mu P_L\nu_\mu)V_2^\mu$$

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KM V_1 & L_μ - L_τ V_2

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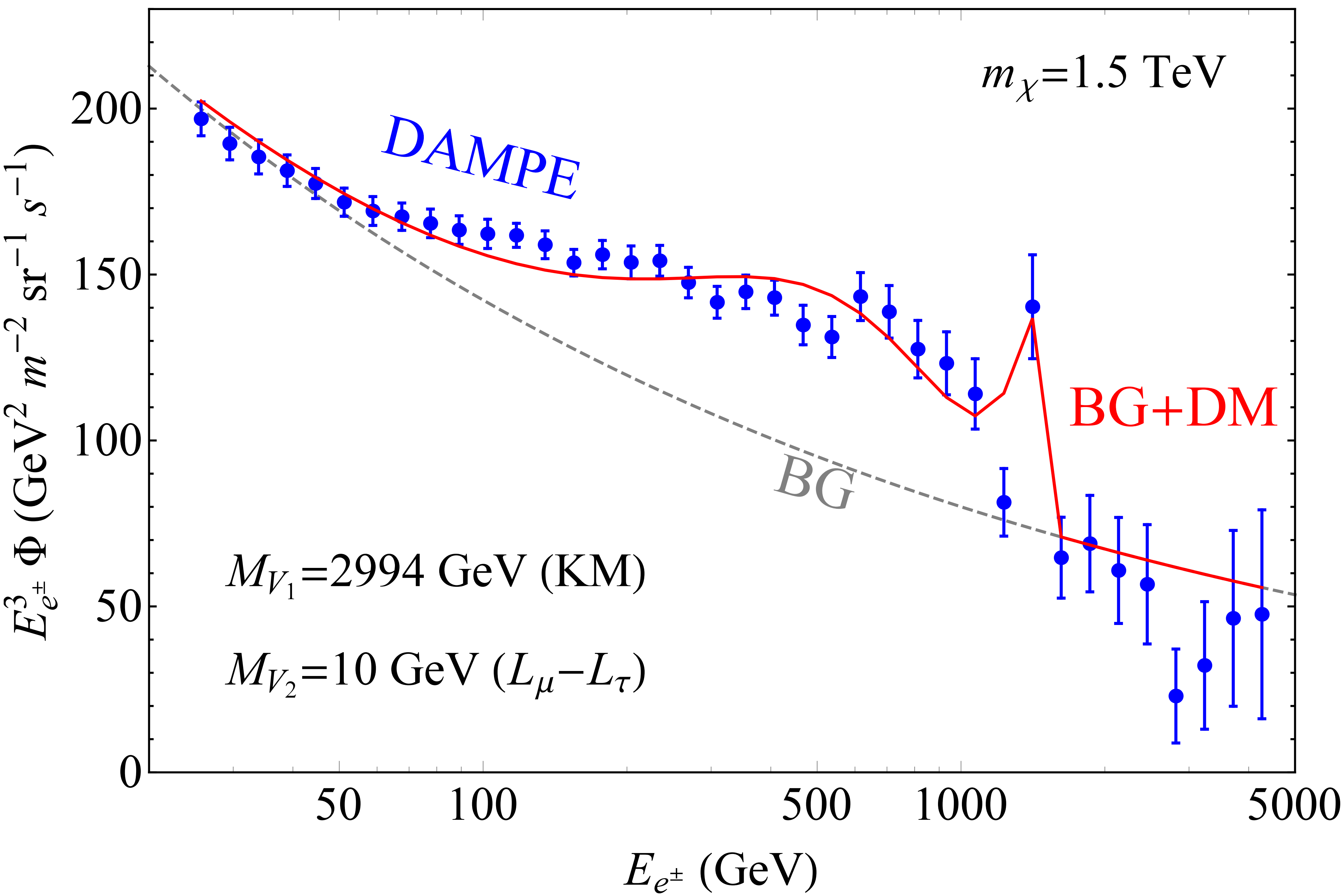
$$-g_2(\bar{\tau}\gamma_\mu \tau + \bar{\nu}_\tau \gamma_\mu P_L \nu_\tau) V_2^\mu$$

V_2: L_μ - L_τ

KM V_1 & L_μ - L_τ V_2

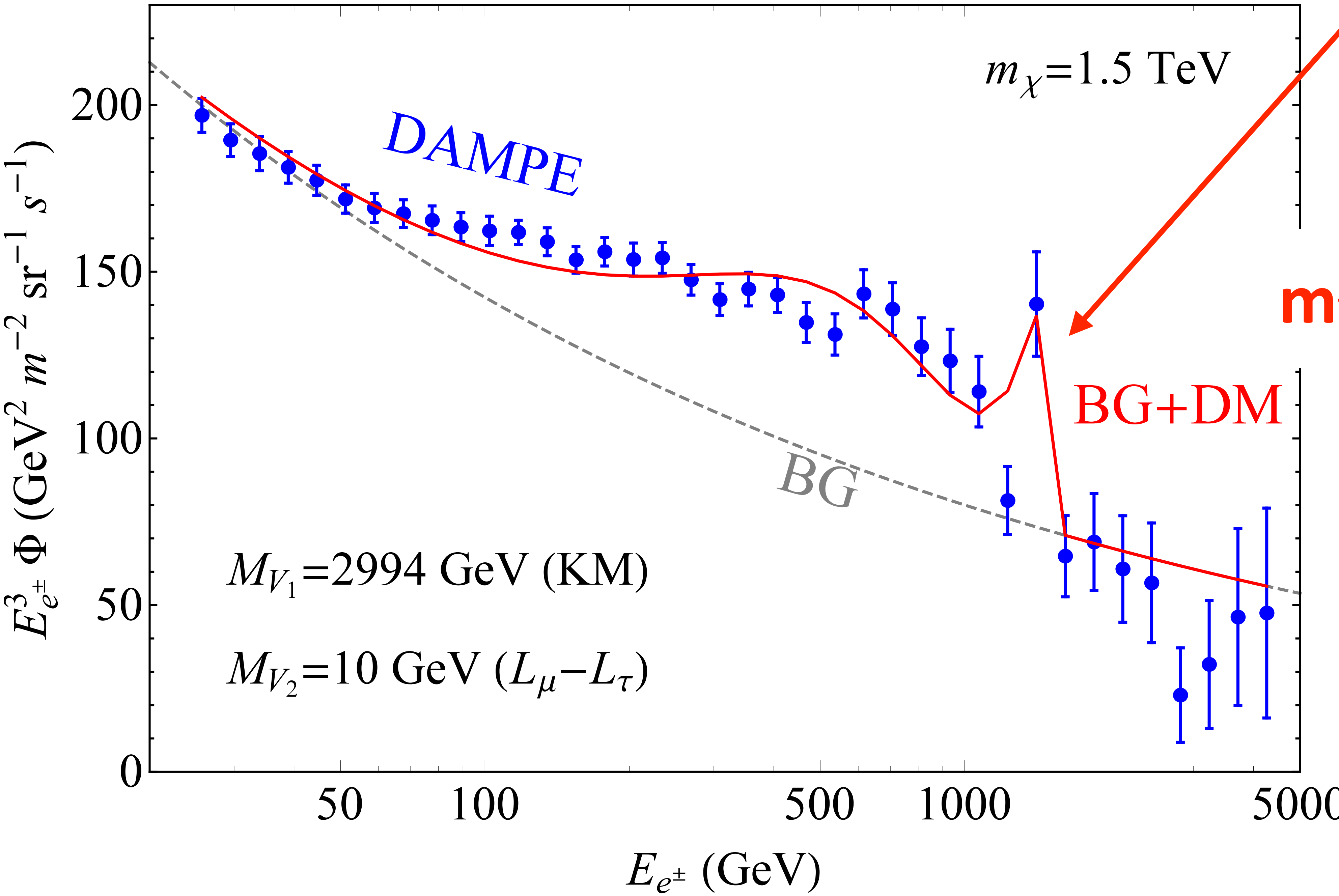


KM V_1 & L_μ - L_τ V_2

KM V1

$g_1 = \varepsilon = 0.1$

m_{V1} = 2994 GeV



KM V_1 & L_μ - L_τ V_2

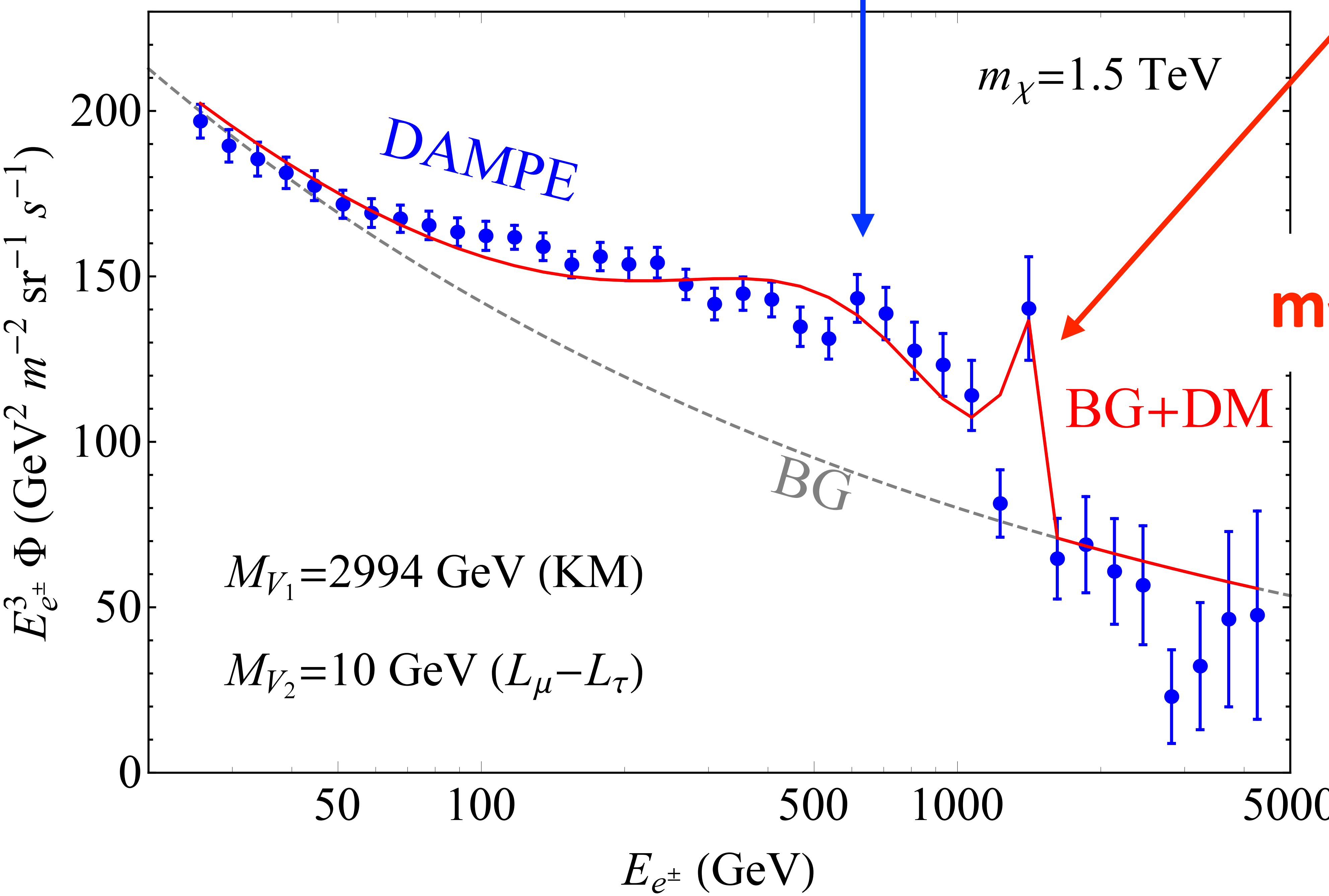
m_{V2} = 10 GeV

L_μ - L_τ V_2

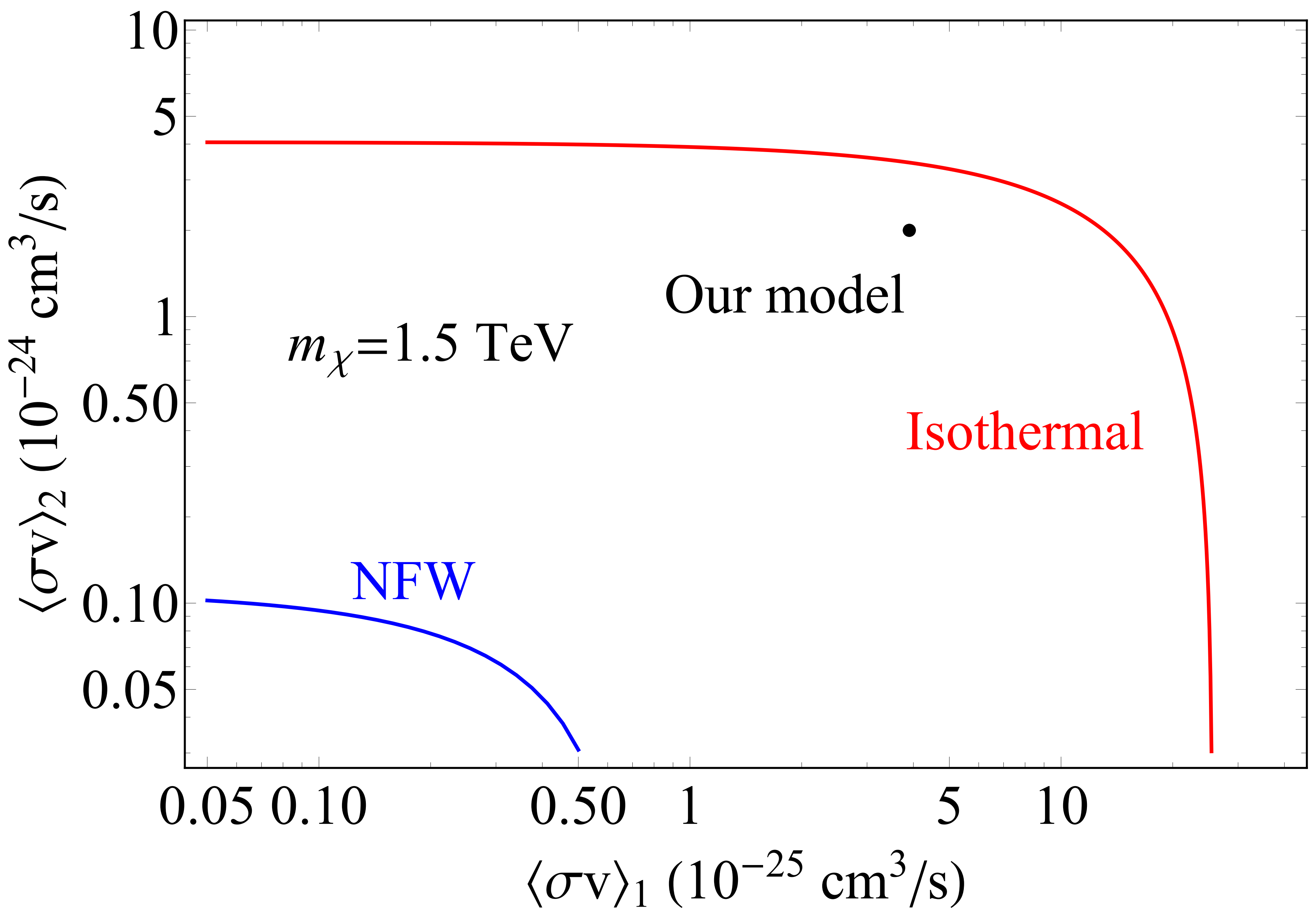
KM V1

g_1=ε=0.1

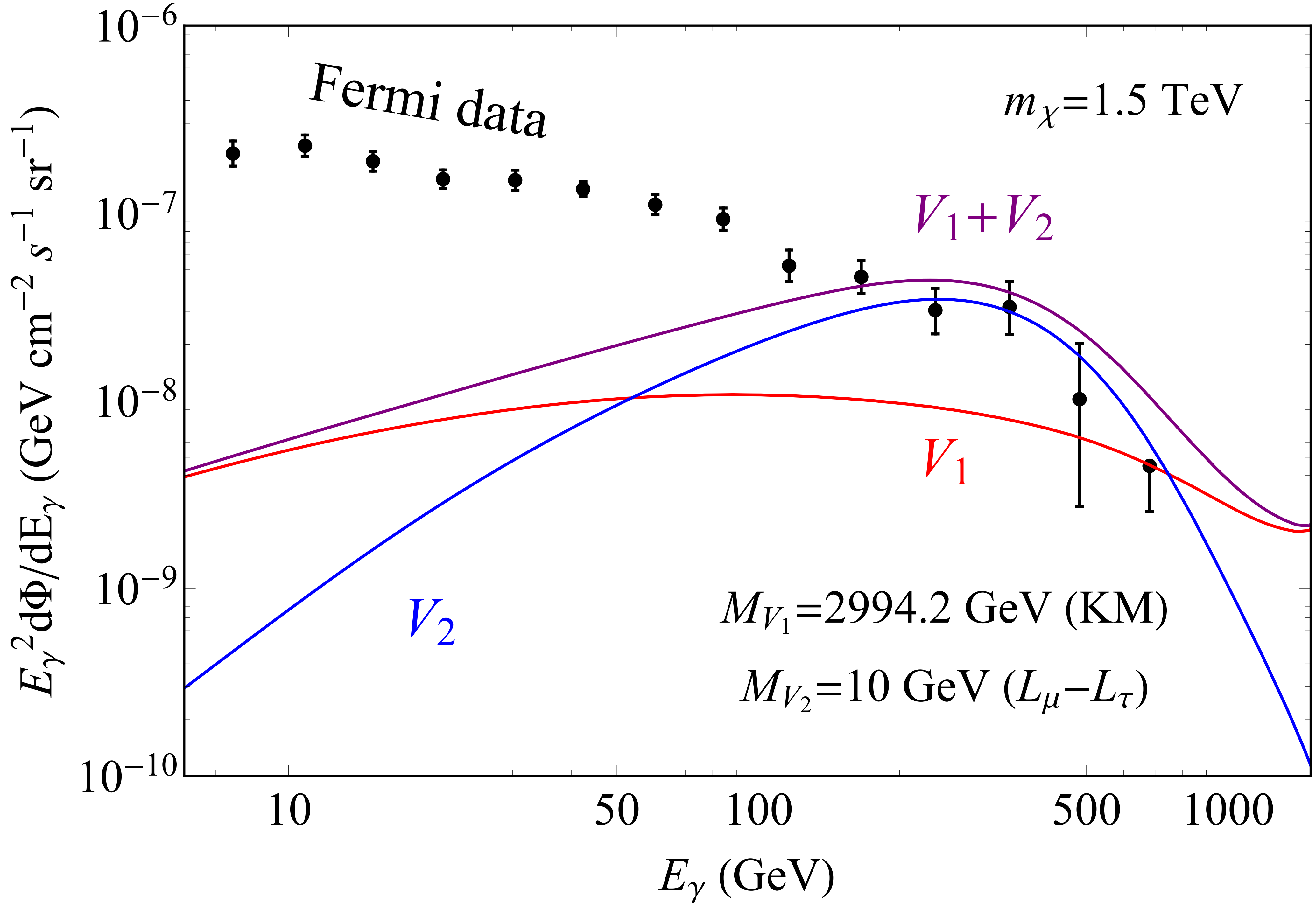
m_{V1} = 2994 GeV



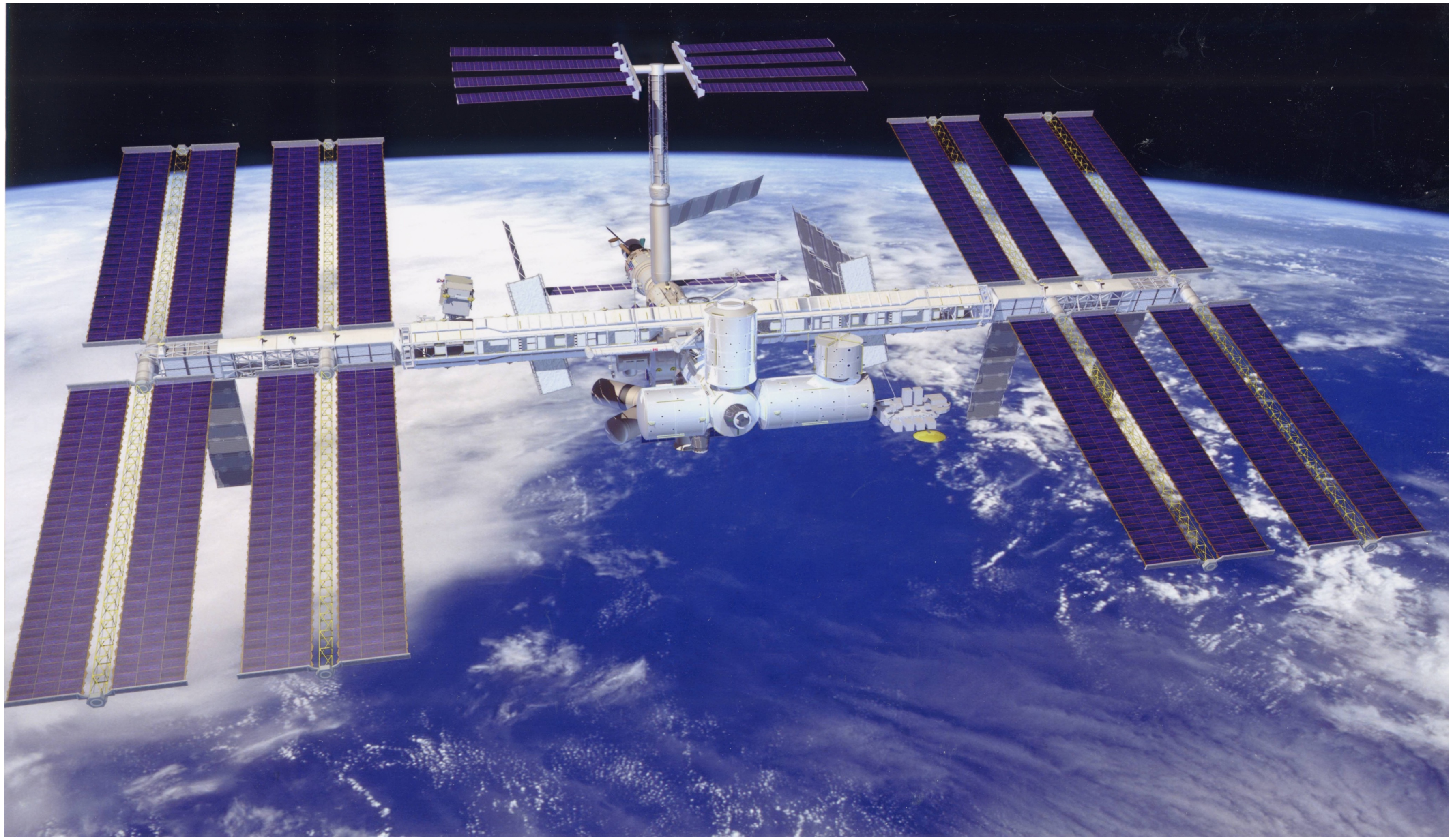
HESS constraints on KM V_1 & L_μ - L_τ V_2



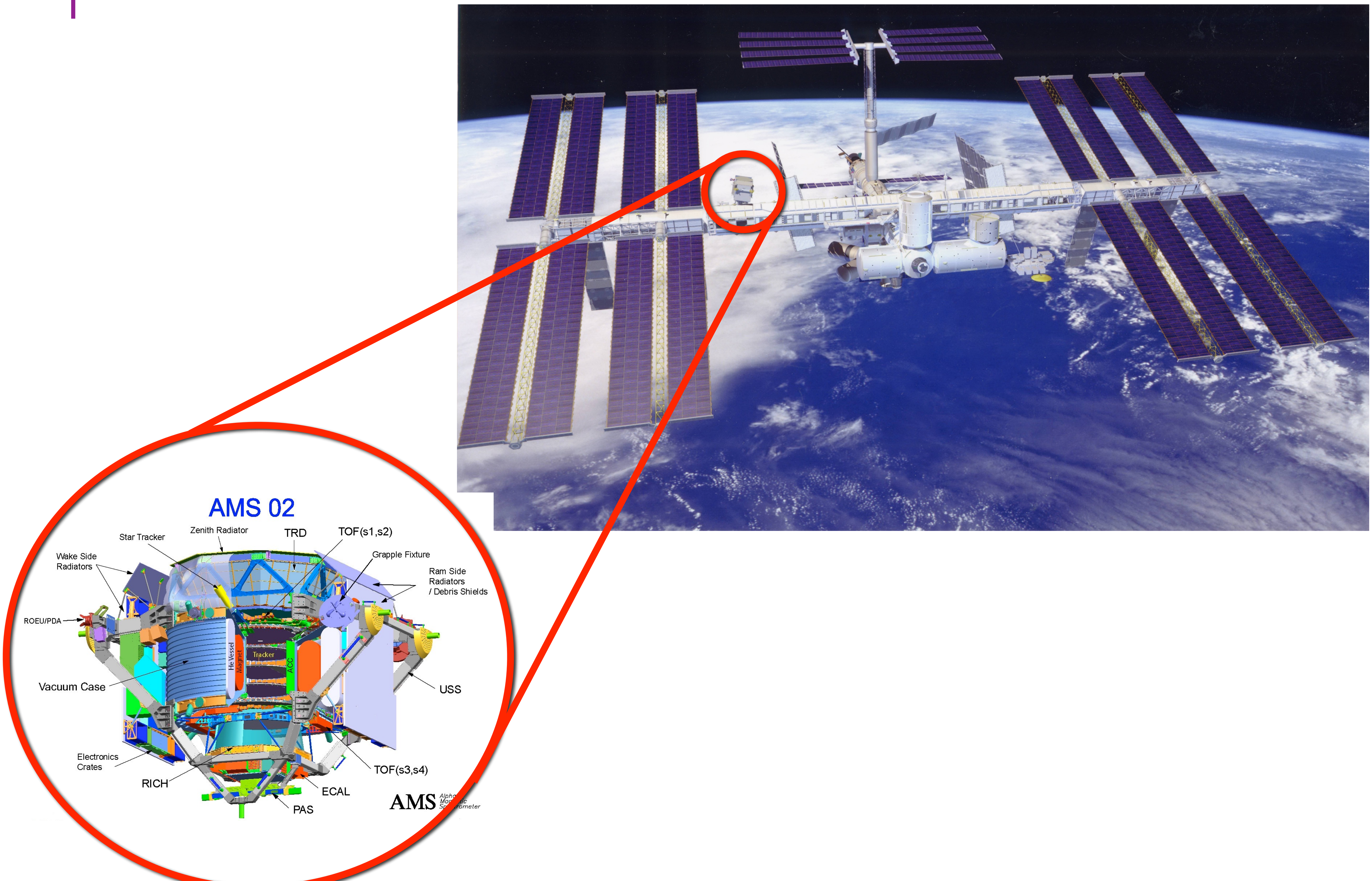
Fermi constraints on KM V_1 & L_μ - L_τ V_2



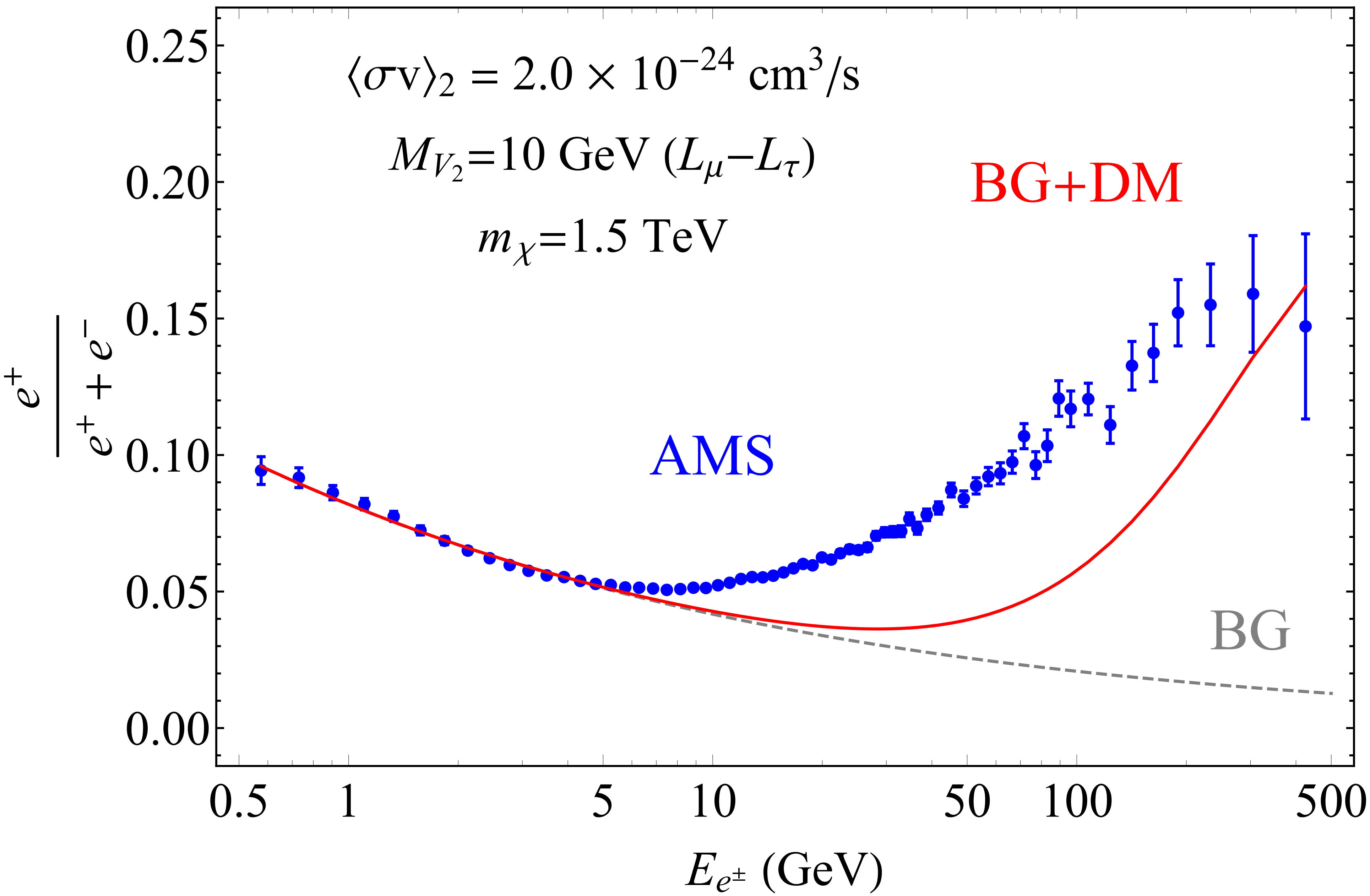
AMS experiment



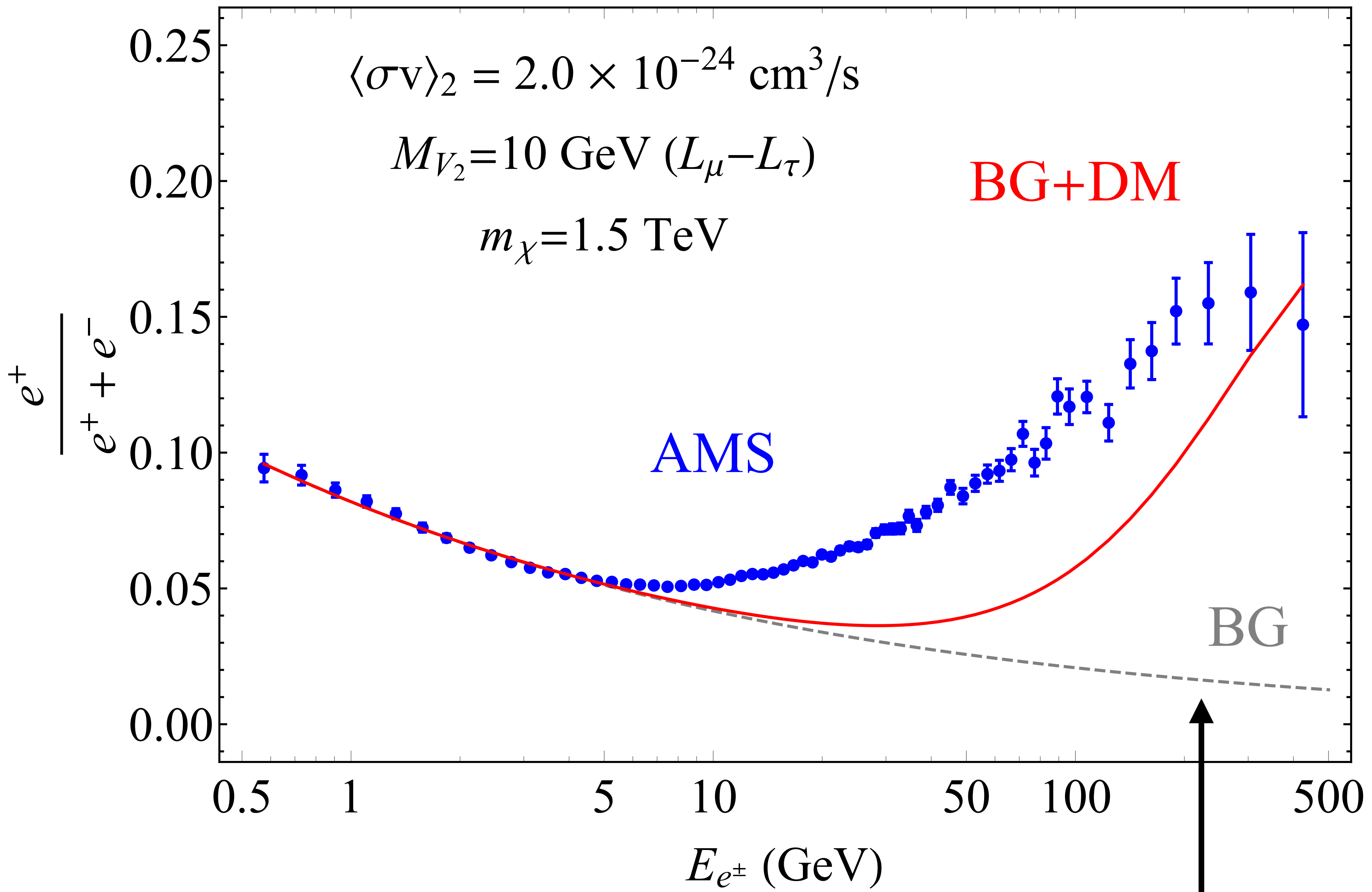
AMS experiment



AMS positron fraction



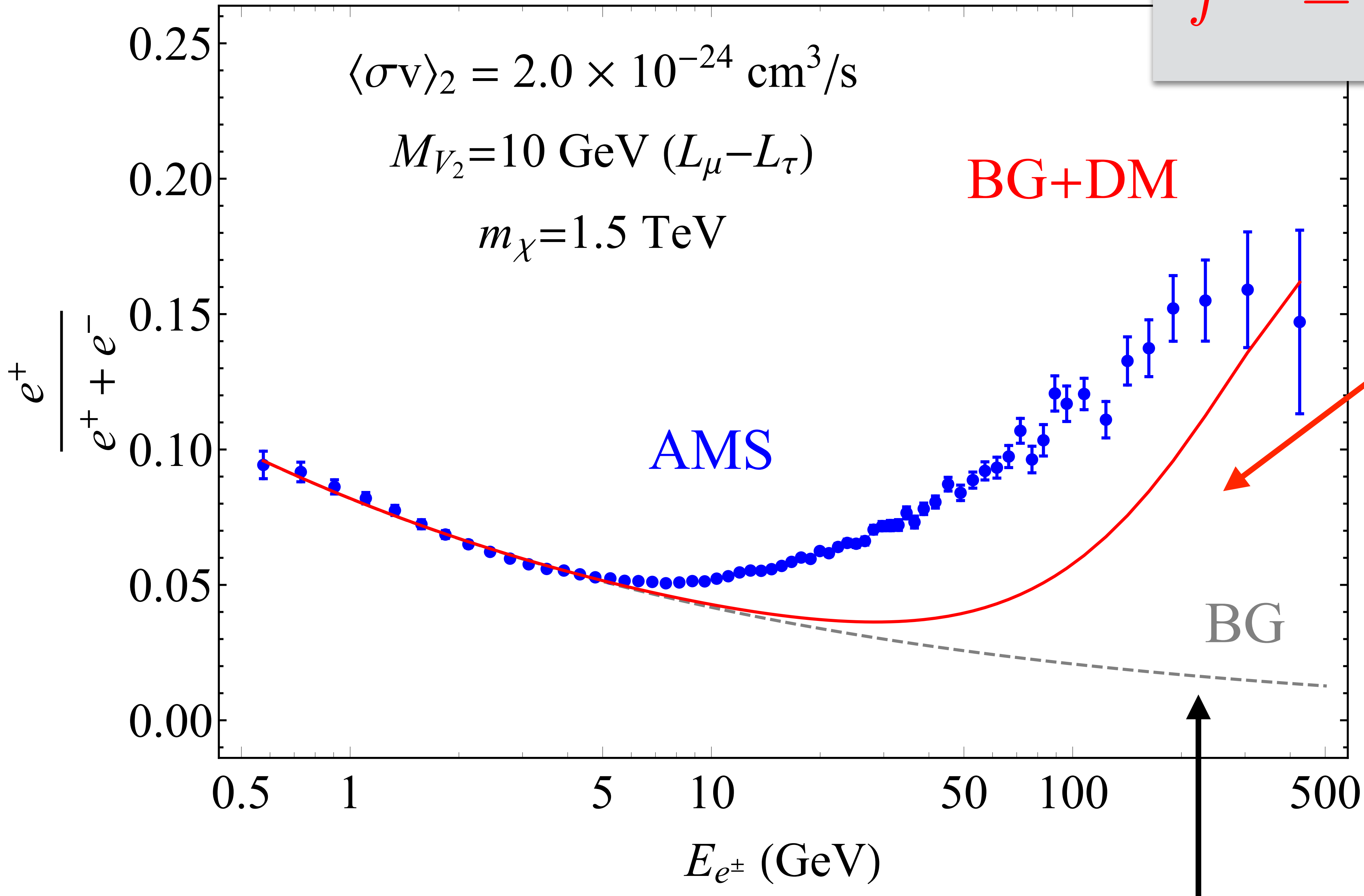
AMS positron fraction



$$f^{\rm BG} = 1/(C_f E^{\gamma_f} + 1) \text{ w/ } C_f = 11.2, \gamma_f = 0.31 \text{ (first 15 points)}$$

AMS positron fraction

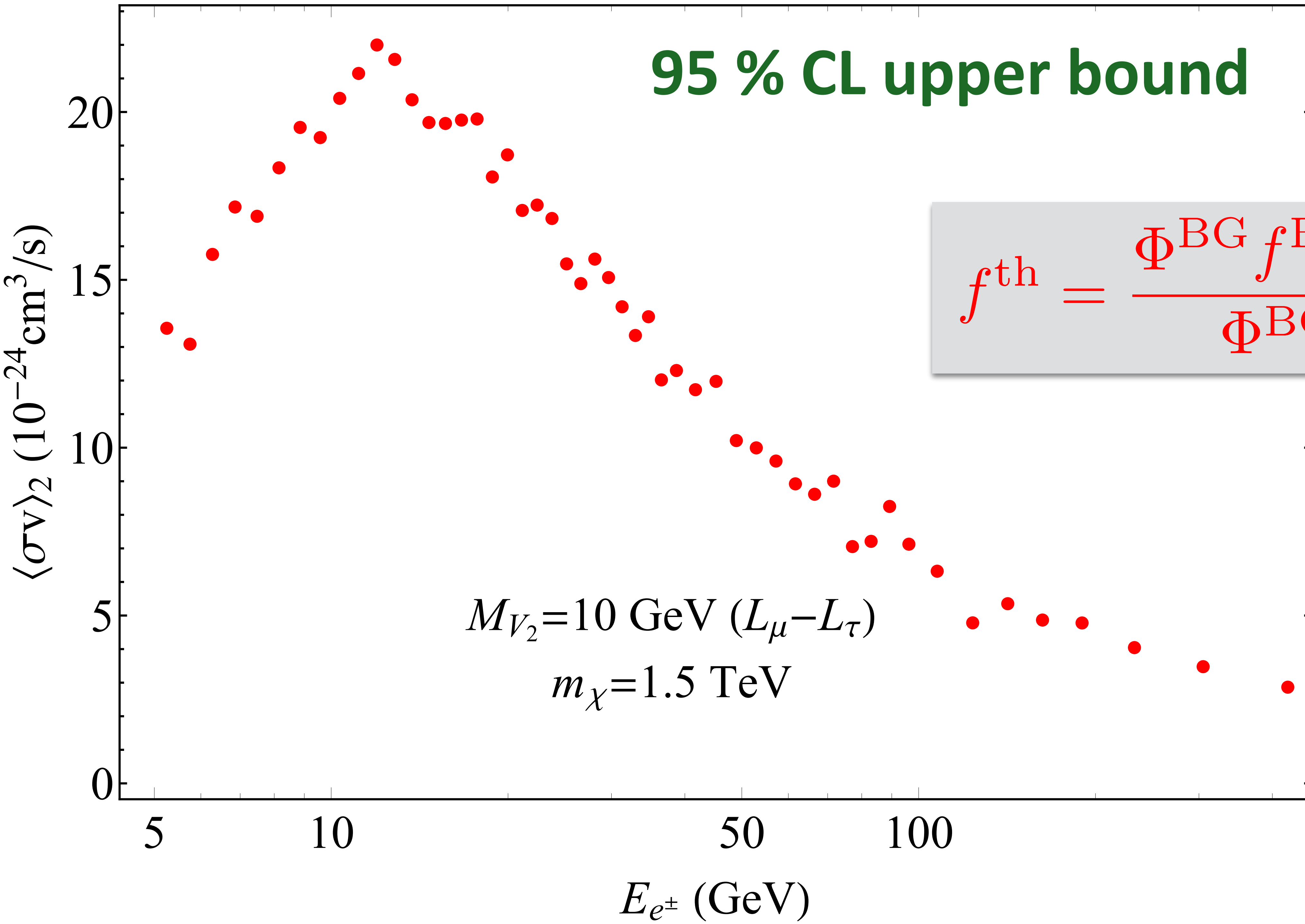
$$f^{\rm th} = \frac{\Phi^{\rm BG} f^{\rm BG} + \Phi^{\chi}/2}{\Phi^{\rm BG} + \Phi^{\chi}}$$



$$f^{\rm BG} = 1/(C_f E^{\gamma_f} + 1) \text{ w/ } C_f = 11.2, \gamma_f = 0.31 \text{ (first 15 points)}$$

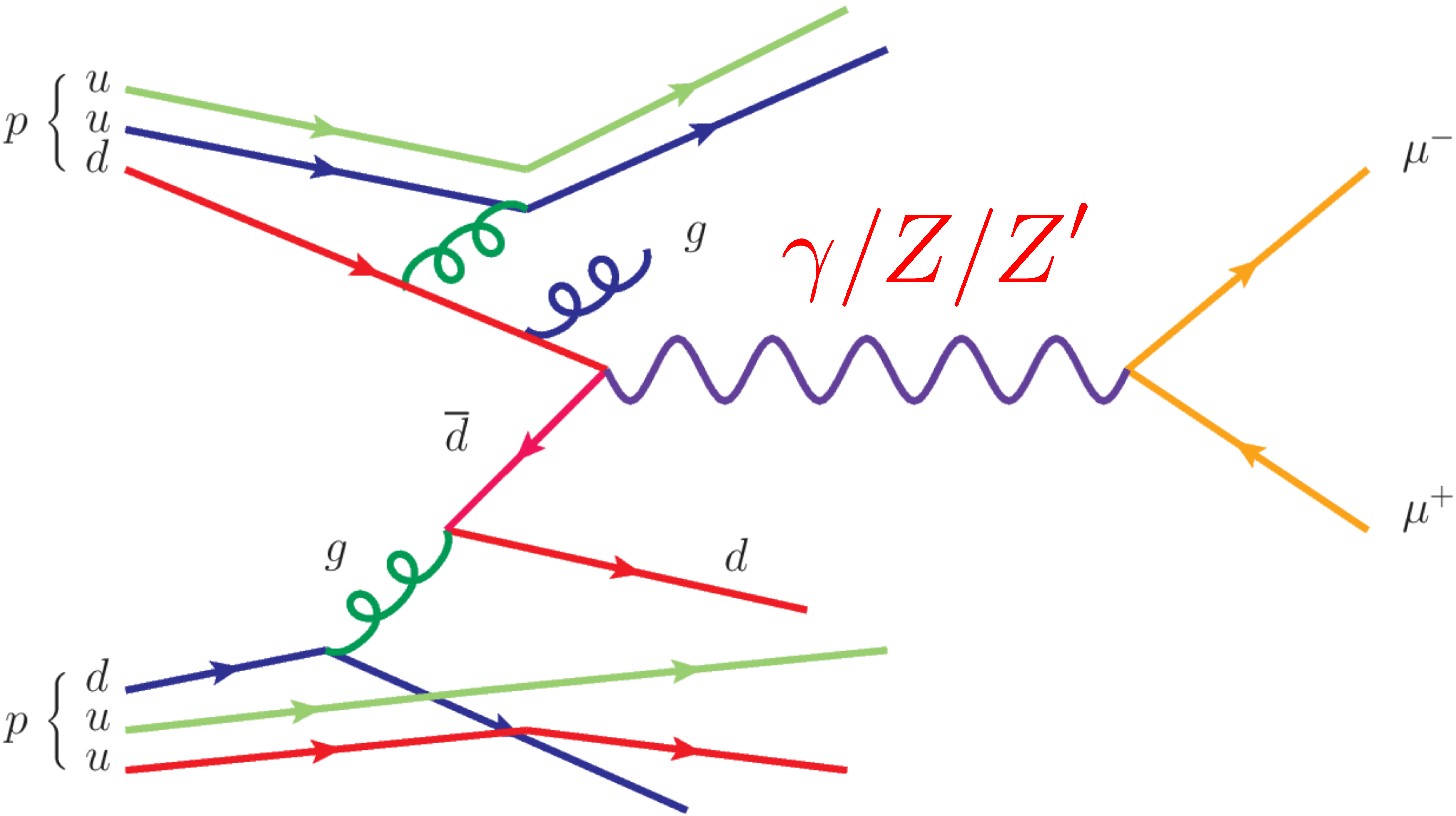
AMS constraints (upper bound)

$$f_i^{\rm AMS} + 1.64\,\delta f_i^{\rm AMS}$$



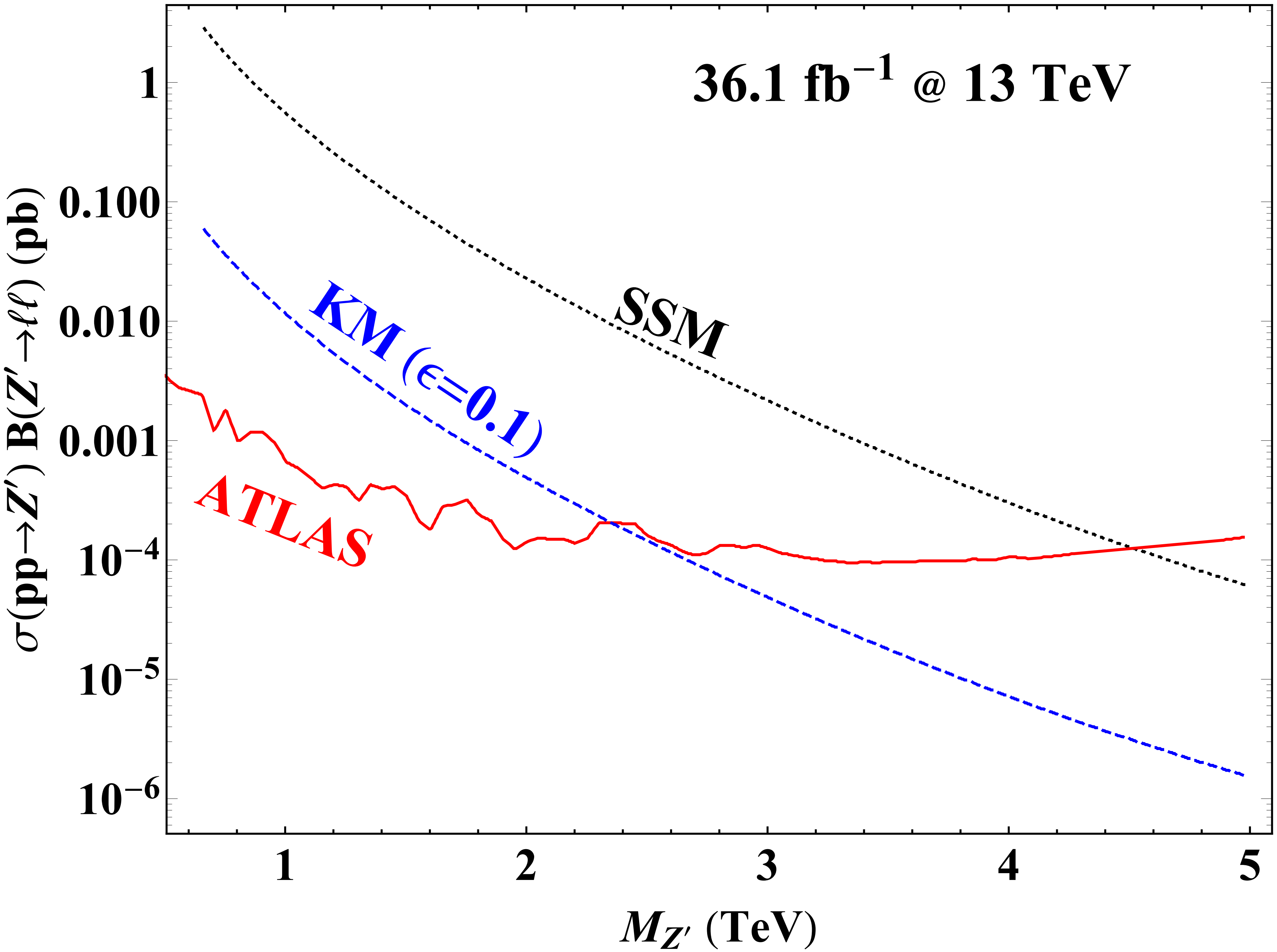
$$f^{\rm th} = \frac{\Phi^{\rm BG} f^{\rm BG} + \Phi^\chi/2}{\Phi^{\rm BG} + \Phi^\chi}$$

Drell-Yan process @ LHC



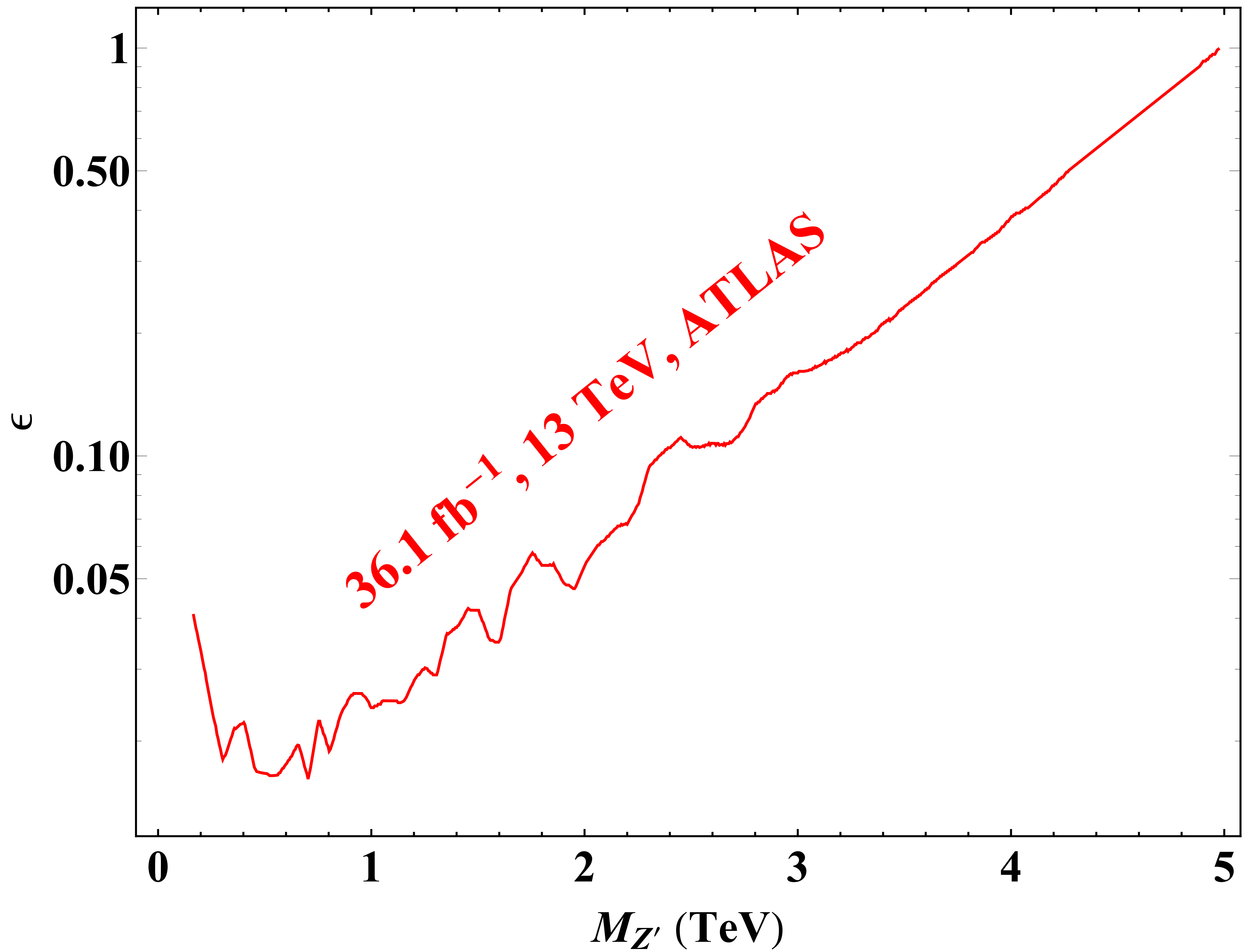
dilepton @ ATLAS

[ATLAS, 1707.02424]



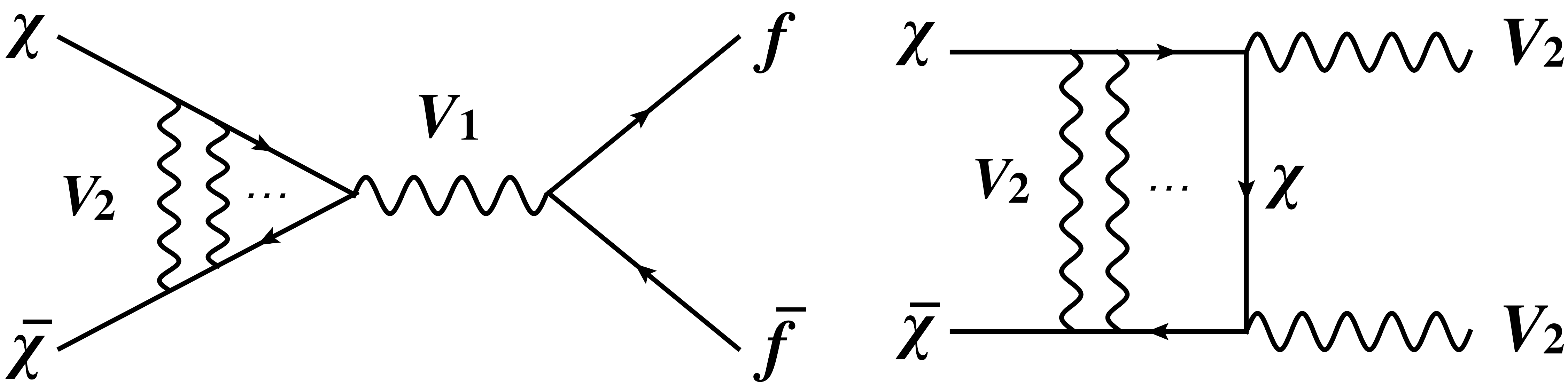
ATLAS constraints on KM

[ATLAS, 1707.02424]



Sommerfeld enhancement

nonperturbative enhancement due to the lighter mediator

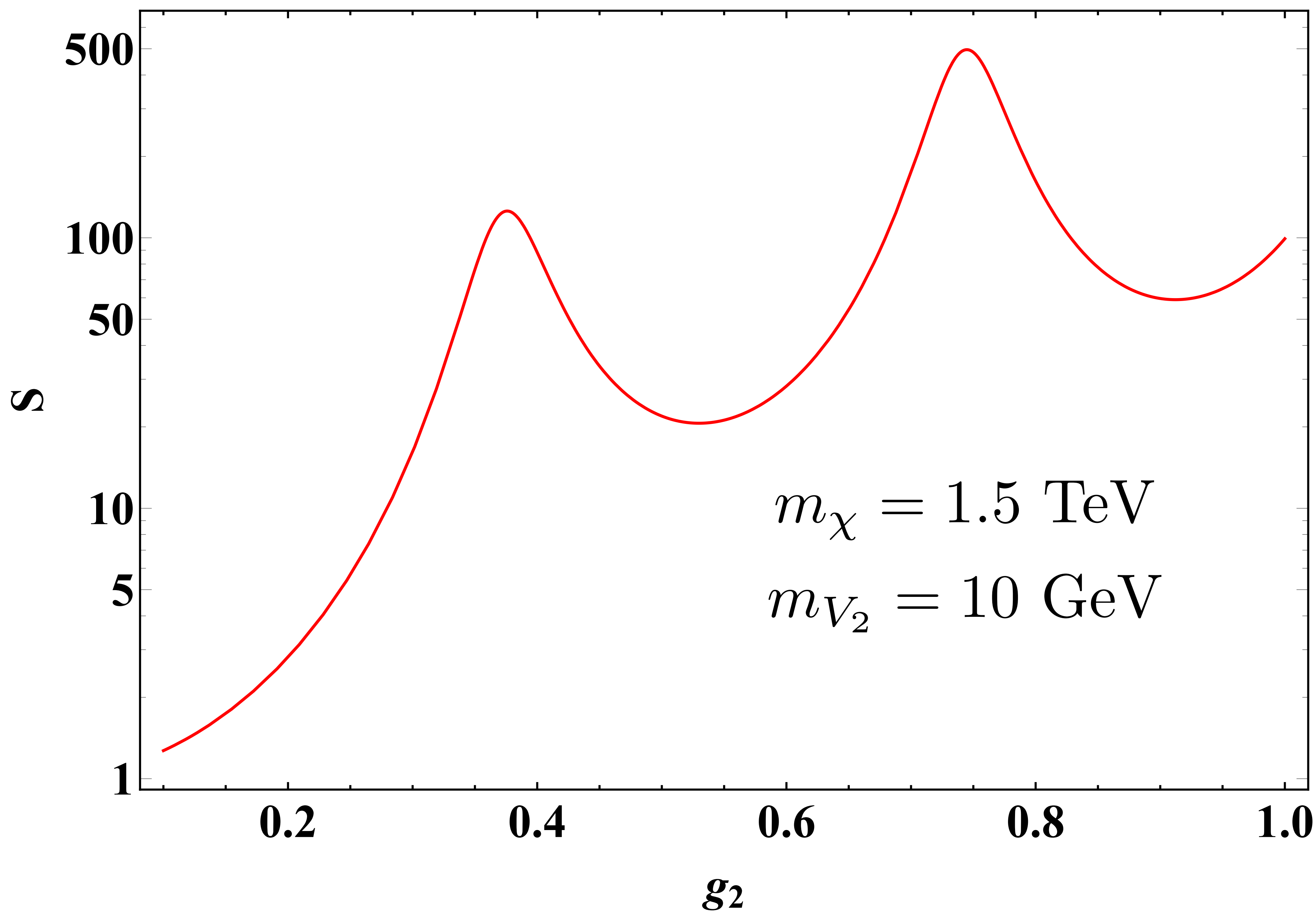


$$S = \left(\frac{\pi}{\epsilon_v}\right) \frac{\sinh X}{\cosh X - \cos\sqrt{(2\pi/\bar{\epsilon}_2) - X^2}}$$

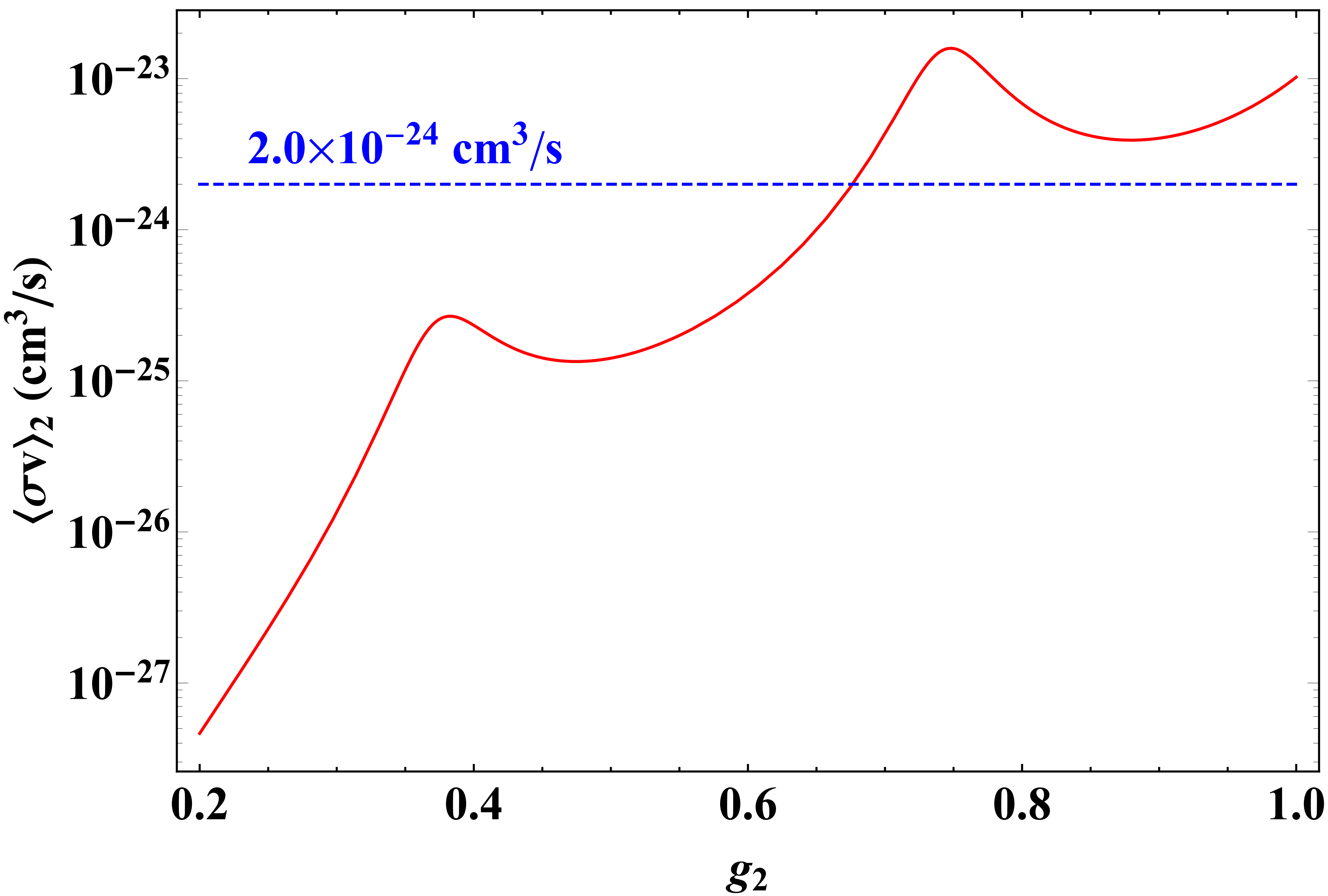
$$\bar{\epsilon}_2 = (\pi/12)\epsilon_2,\ X = \epsilon_v/\bar{\epsilon}_2,\ \epsilon_2 = m_{V_2}/(\alpha_2 m_\chi),$$
$$\epsilon_v = v/\alpha_2 \text{ with } \alpha_2 = g_2^2/(4\pi),\ v = 10^{-3}.$$

[0903.5307, 0910.5713]

Sommerfeld enhancement

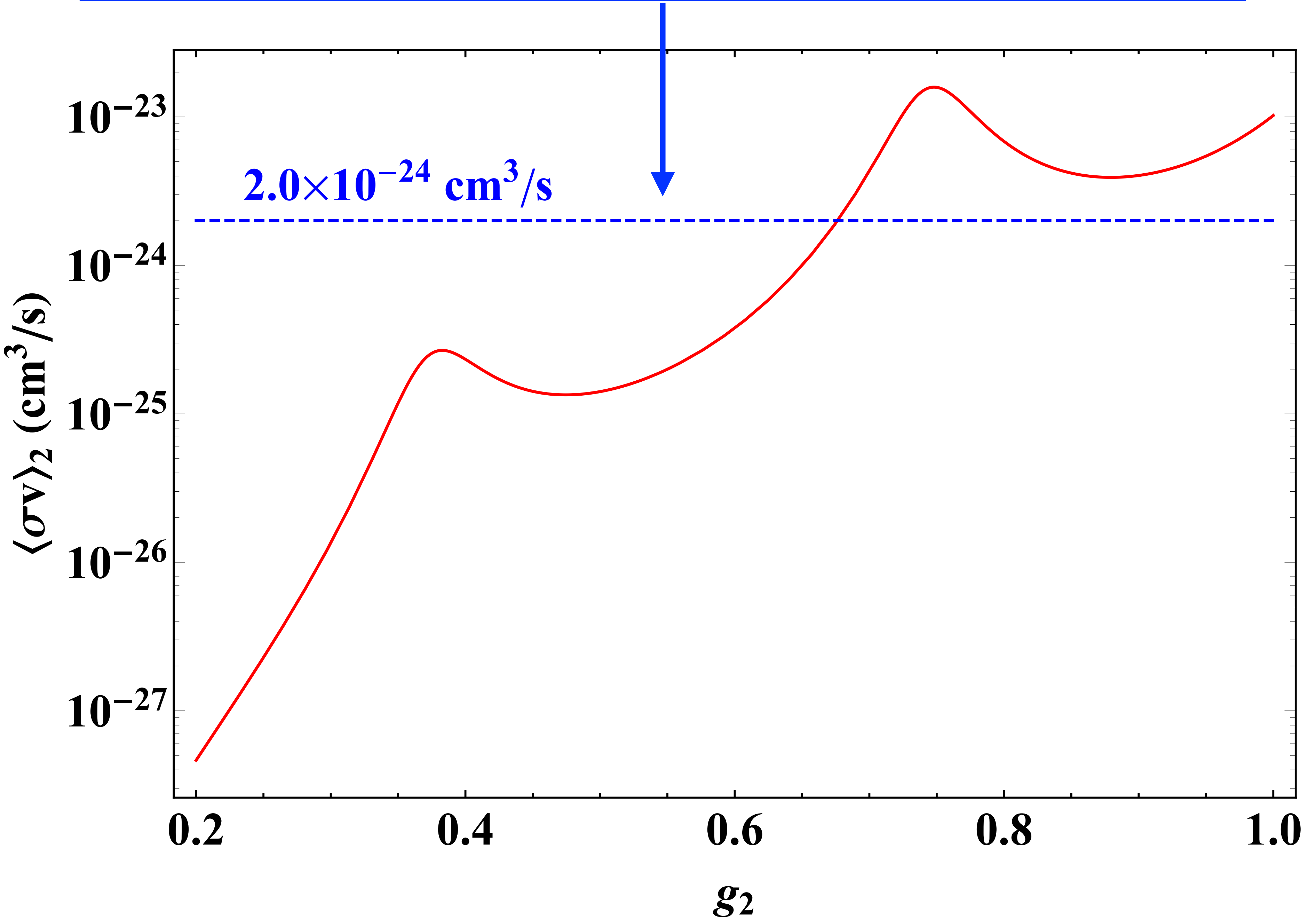


‘Correct’ annihilation cross section

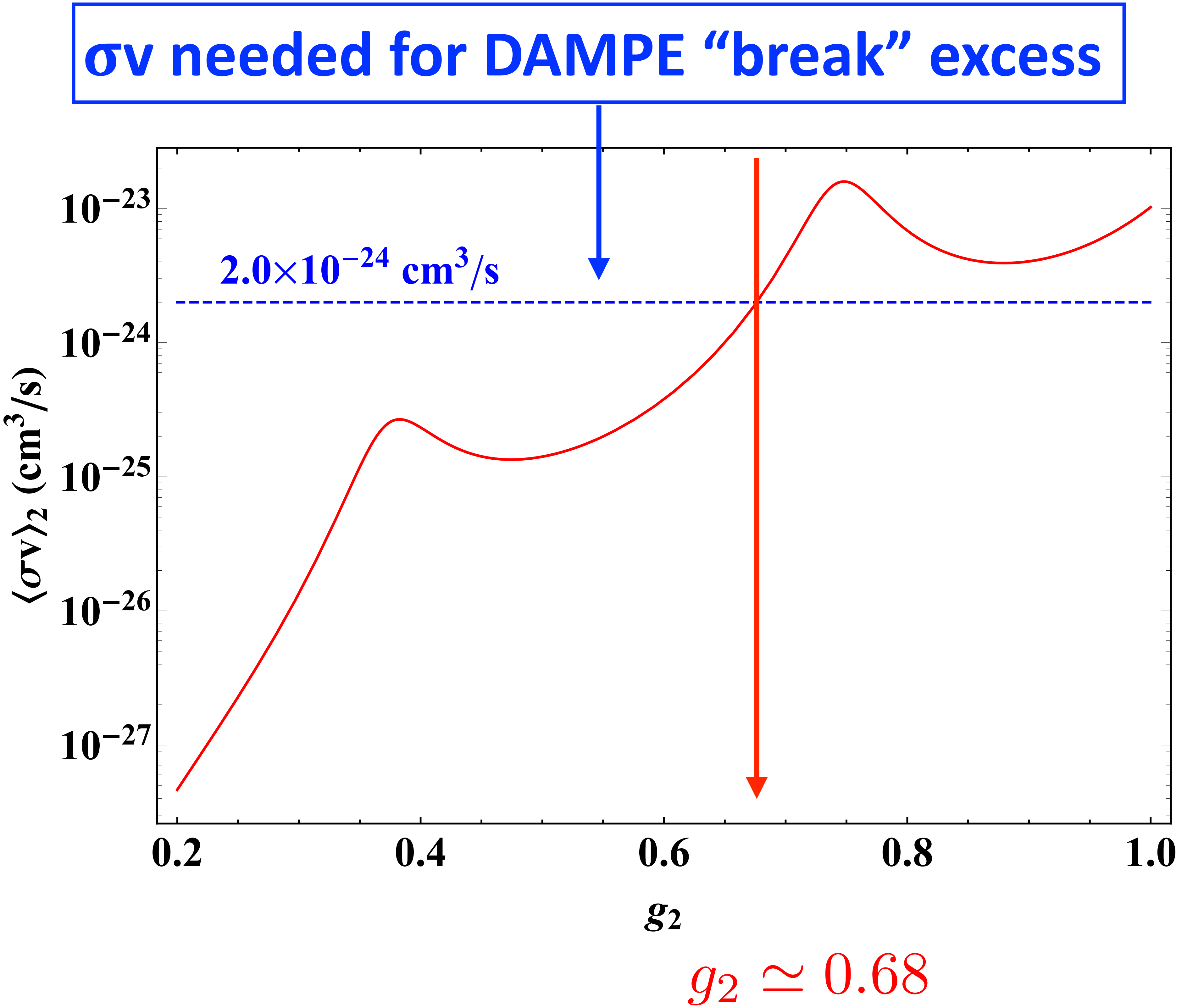


'Correct' annihilation cross section

σv needed for DAMPE "break" excess



'Correct' annihilation cross section



Relic density

	Galaxy today	Early Universe
$\langle \sigma v \rangle_1$	$3.9 \times 10^{-25}\ \mathrm{cm}^3/\mathrm{s}$	$1.0 \times 10^{-28}\ \mathrm{cm}^3/\mathrm{s}$
$\langle \sigma v \rangle_2$	$2.0 \times 10^{-24}\ \mathrm{cm}^3/\mathrm{s}$	$2.2 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$

$$(\epsilon,\ g_1,\ m_\chi,\ M_{V_1}) = (0.01,\ 0.1,\ 1500\ \mathrm{GeV},\ 2994.2\ \mathrm{GeV})$$

Relic density

further Breit-Wigner suppression

	Galaxy today	Early Universe
$\langle \sigma v \rangle_1$	$3.9 \times 10^{-25}\ \mathrm{cm}^3/\mathrm{s}$	$1.0 \times 10^{-28}\ \mathrm{cm}^3/\mathrm{s}$
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$$(\epsilon,\ g_1,\ m_\chi,\ M_{V_1}) = (0.01,\ 0.1,\ 1500\ \mathrm{GeV},\ 2994.2\ \mathrm{GeV})$$

Summary

- 1.5 TeV DM annihilation in a nearby subhalo can explain the excess electrons in the DAMPE data

- To explain both the 1.5 TeV peak and the 0.9 TeV break in DAMPE electron data, we propose a two-mediator DM model in which DM annihilates via two different channels.

- DM annihilation via an s-channel mediator produces the 1.5 TeV peak; DM annihilates into on-shell mediators leading to the 0.9 TeV break.