Two-mediator DM models & cosmic electron excess

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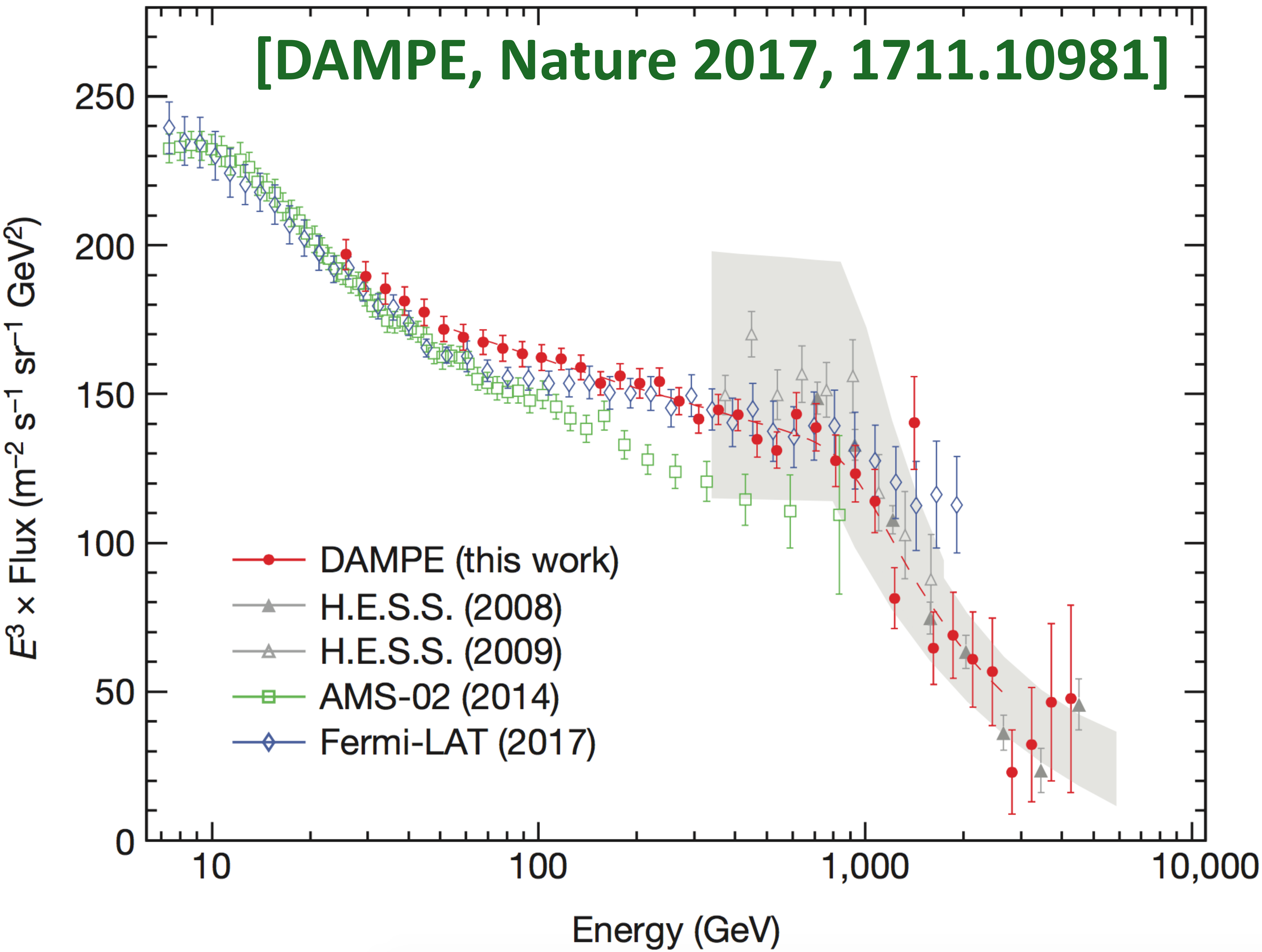
April 21th, 2019, Nanjing, TeV workshop

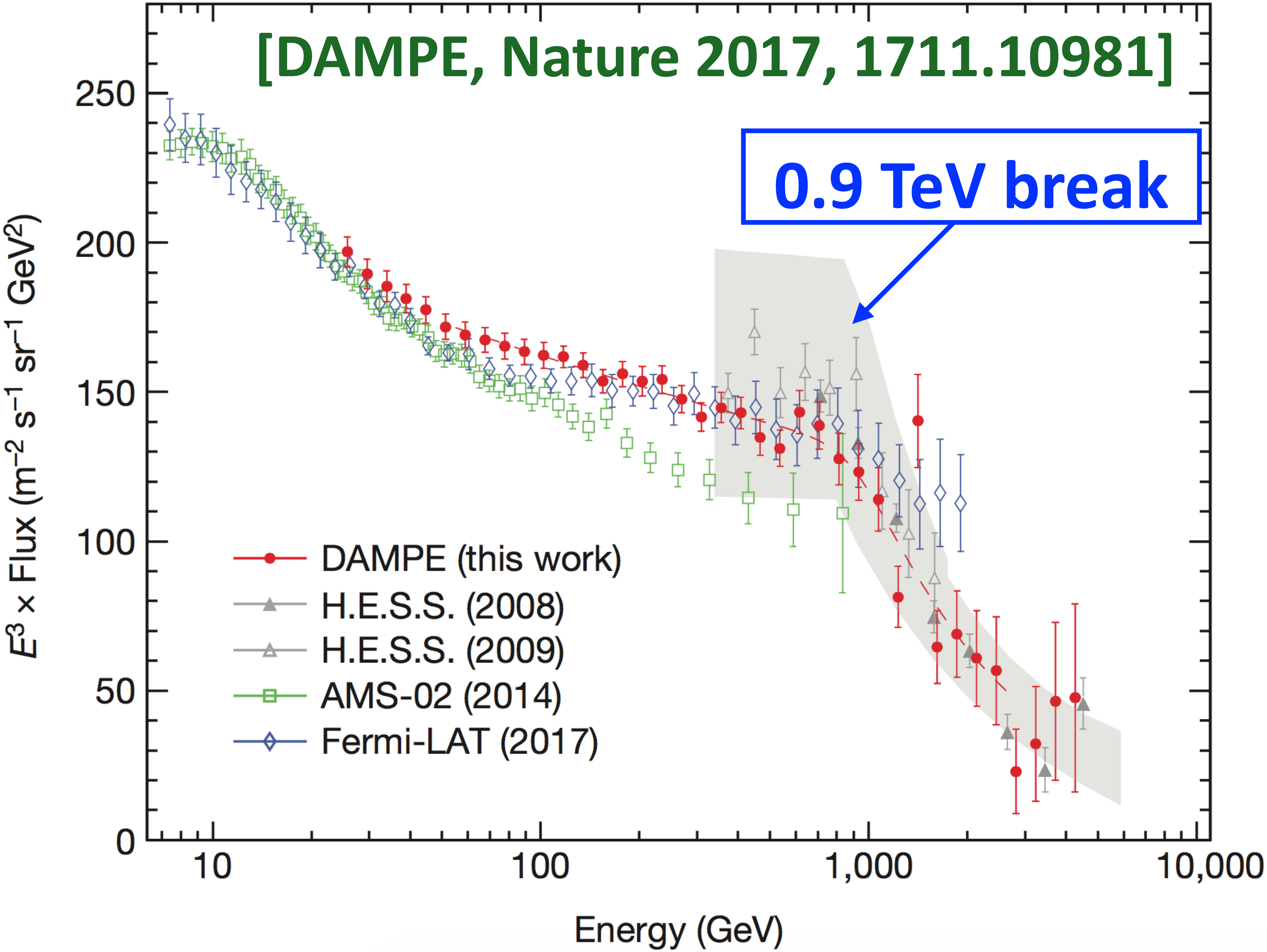
Outline

- 2 electron excess features in DAMPE
  - 0.9 TeV break & 1.4 TeV peak
- 2 mediator DM model (2MDM)
  - on-shell & s-channel annihilations
- Experimental constraints
- Summary

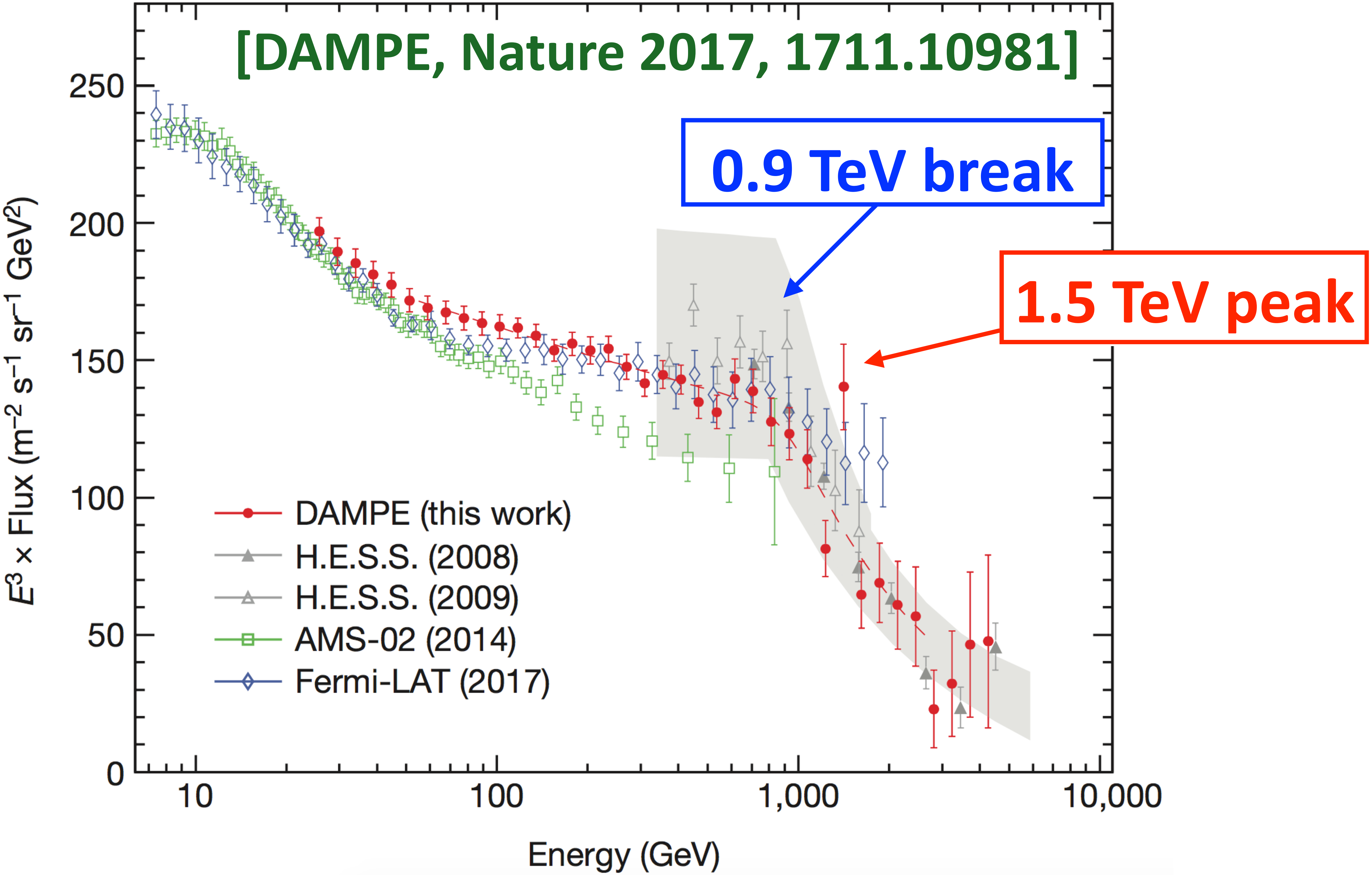
DAMPE electron excess



DAMPE electron excess



DAMPE electron excess



A nearby subhalo is assumed

High-E CR has short diffusion length, ~kpc

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**

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

fit DAMPE 1.4 TeV peak excess w/ thermal σv

Simple power-law BG for cosmic e±

simple power-law BG w/ only 2 parameters

$$\Phi_{e^\pm} = C E^{-\gamma}$$

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

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

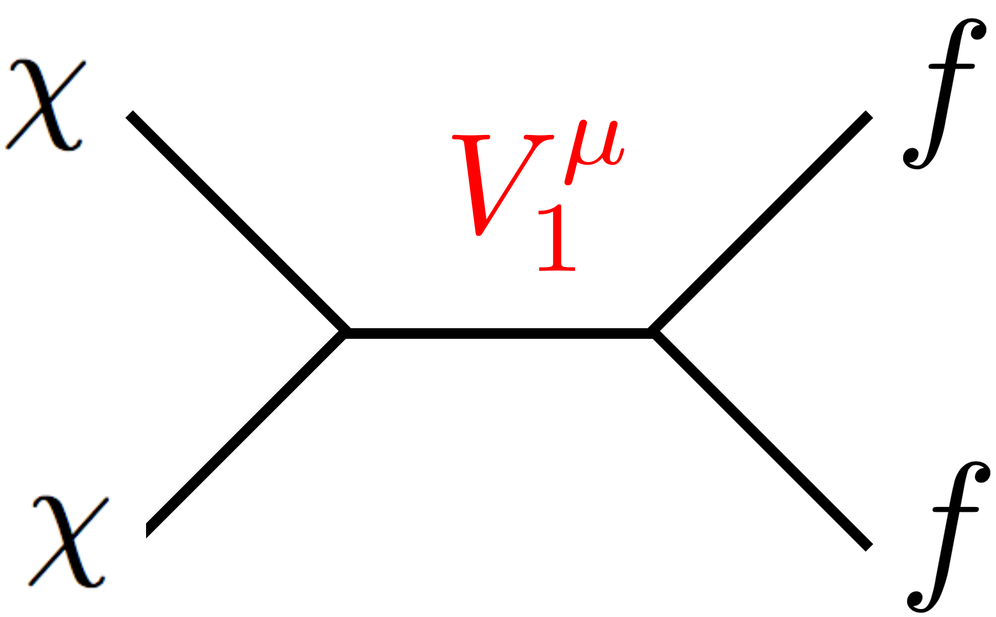
$$\gamma = 3.25$$

DM explains both break & peak

Two-mediator DM model (2MDM)

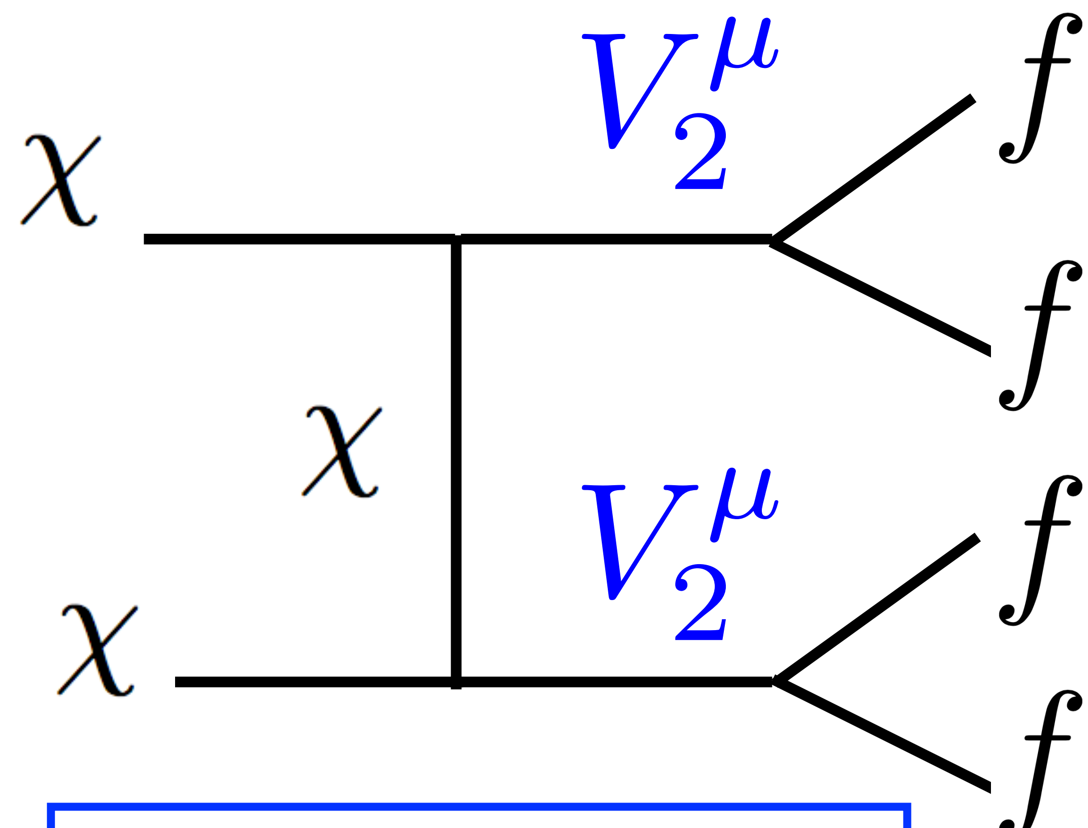
[Xuewen Liu, ZL, Yushan Su, 1902.04916]

annihilation 1



1.5 TeV peak

annihilation 2

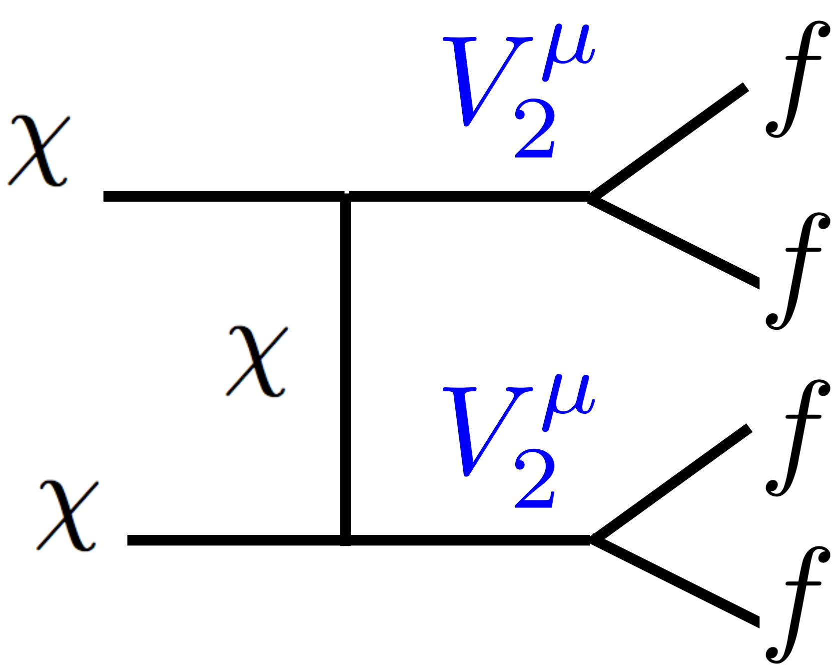


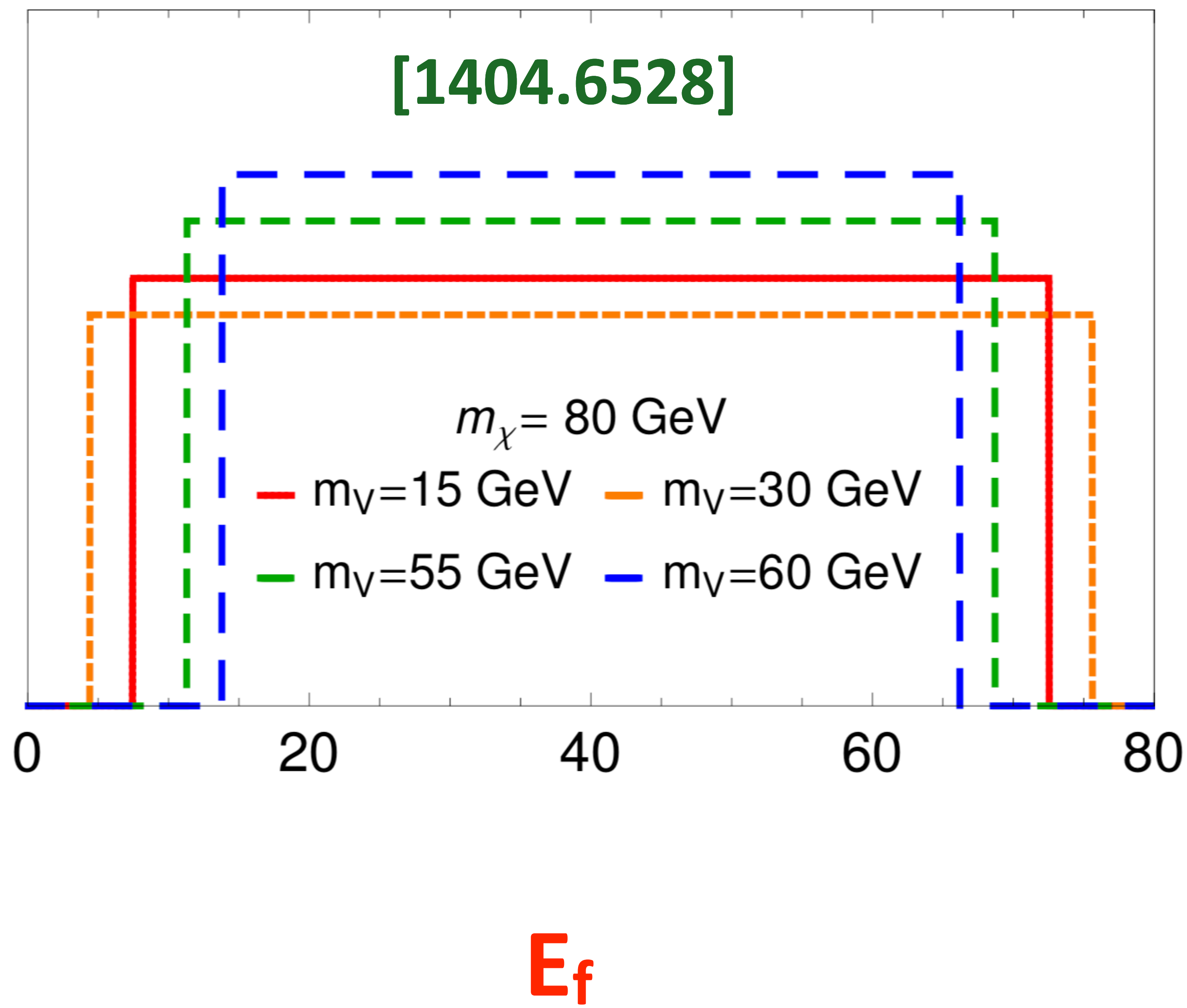
0.9 TeV break

Box-shape energy spectrum

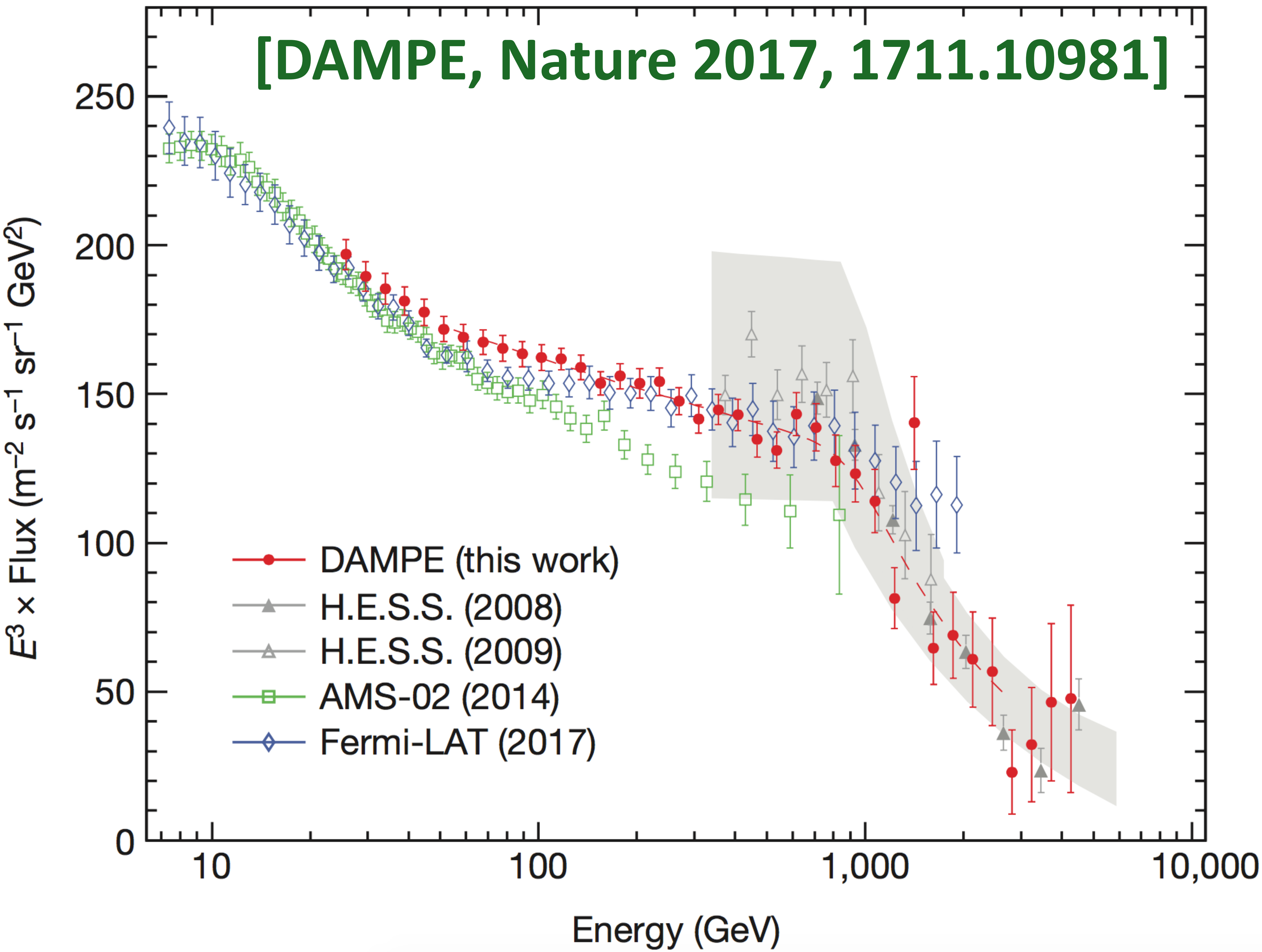
on-shell annihilation → **extended spectrum**

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

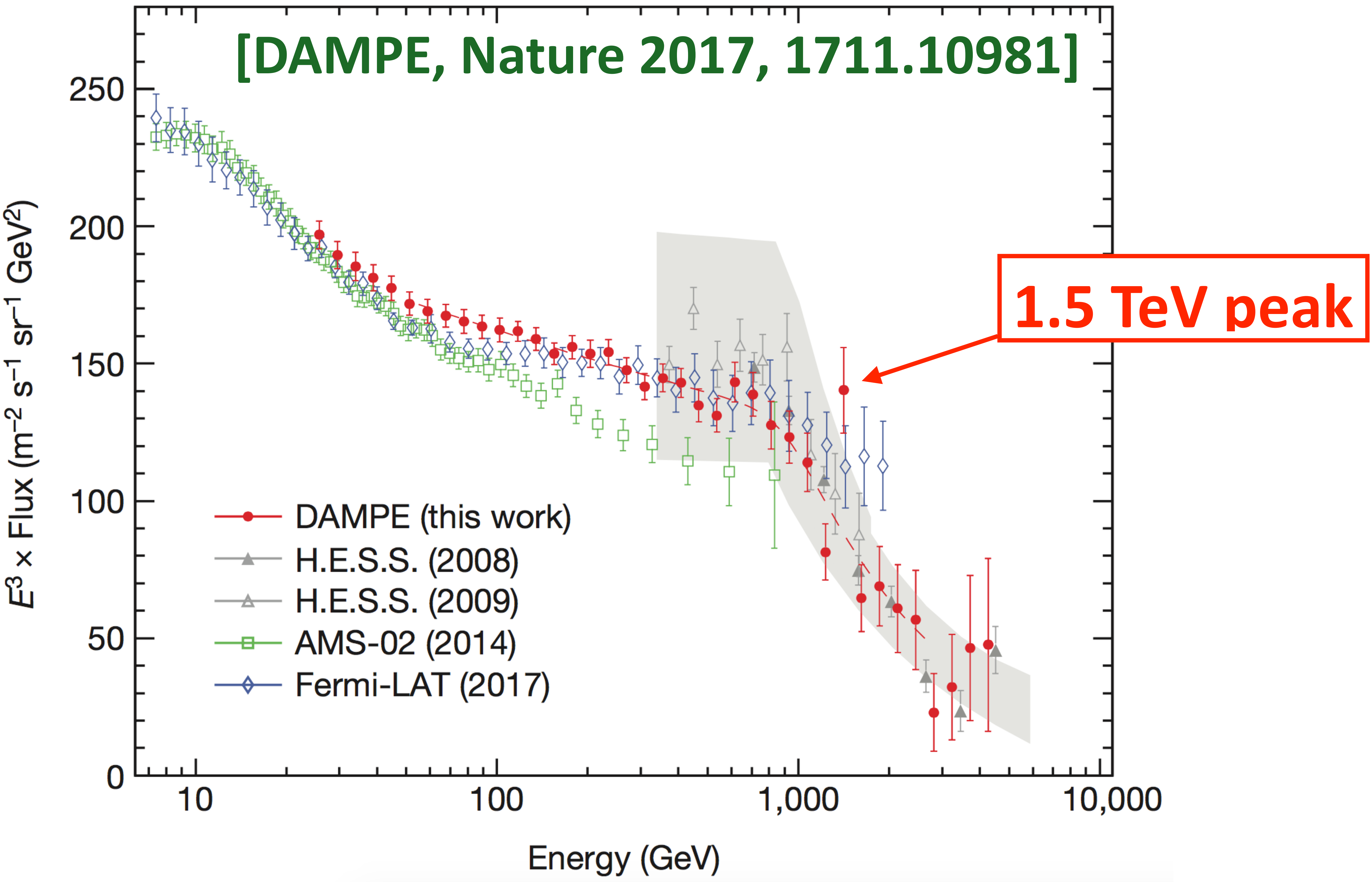




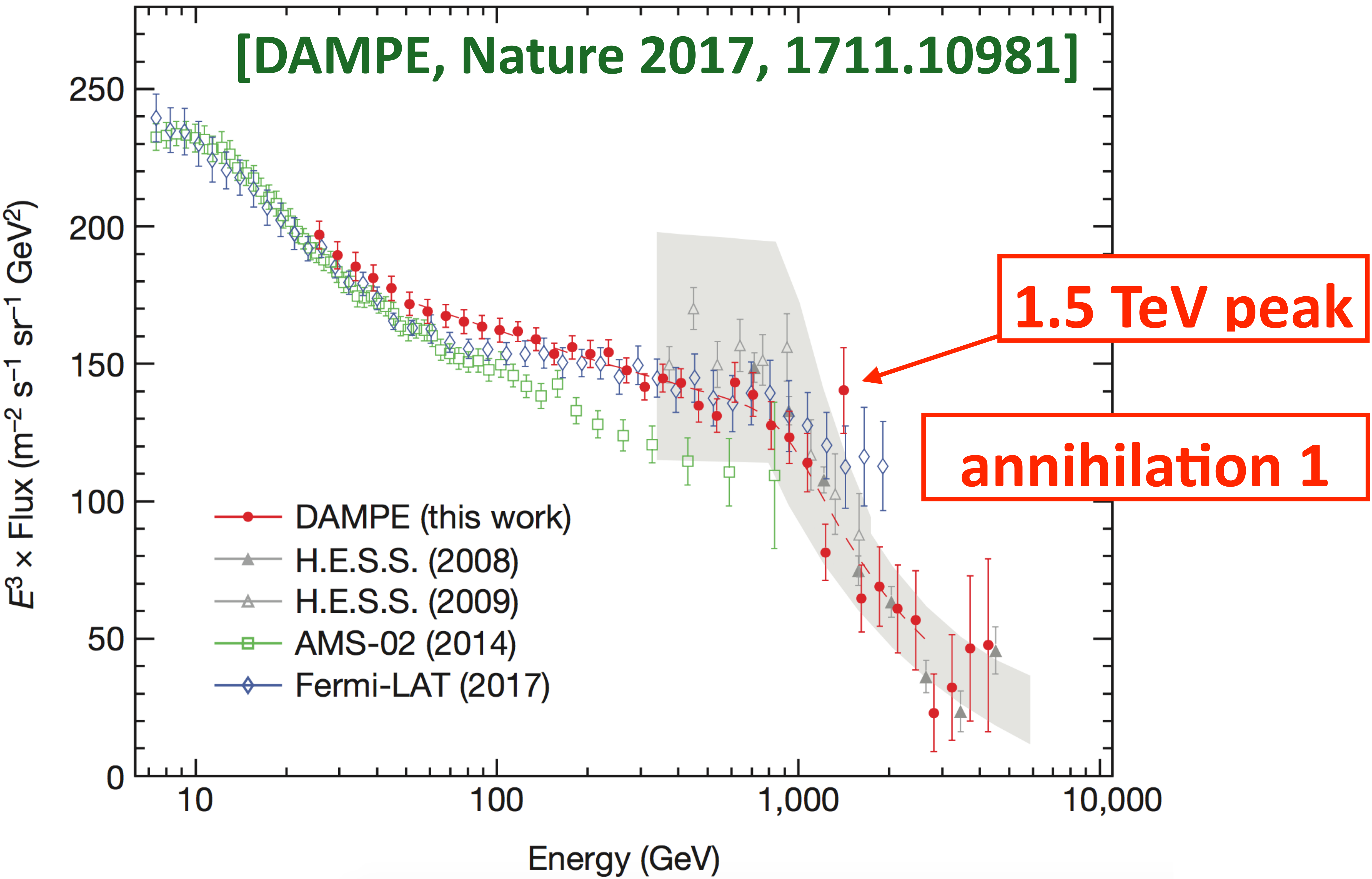
DAMPE electron excess



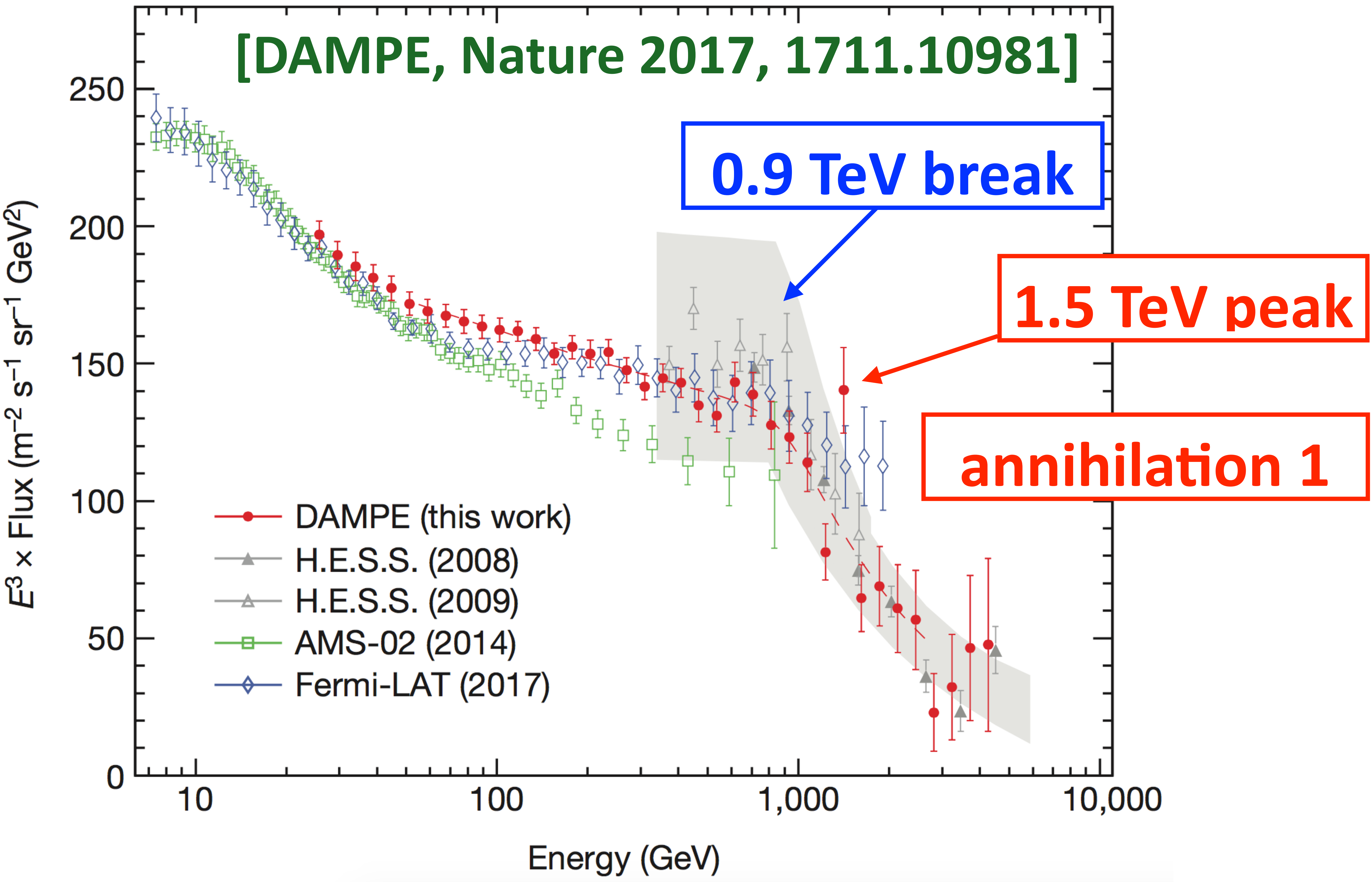
DAMPE electron excess



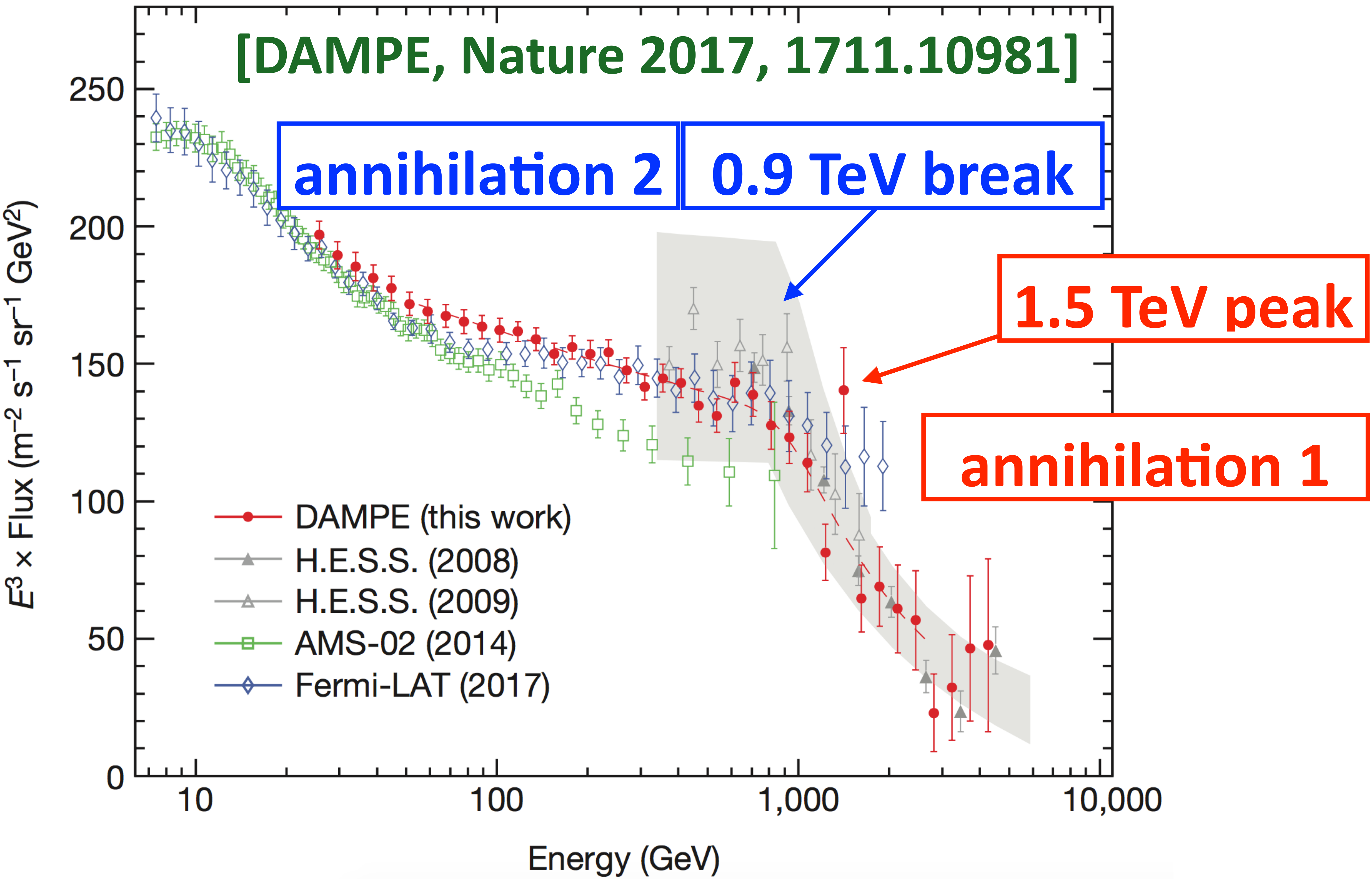
DAMPE electron excess



DAMPE electron excess



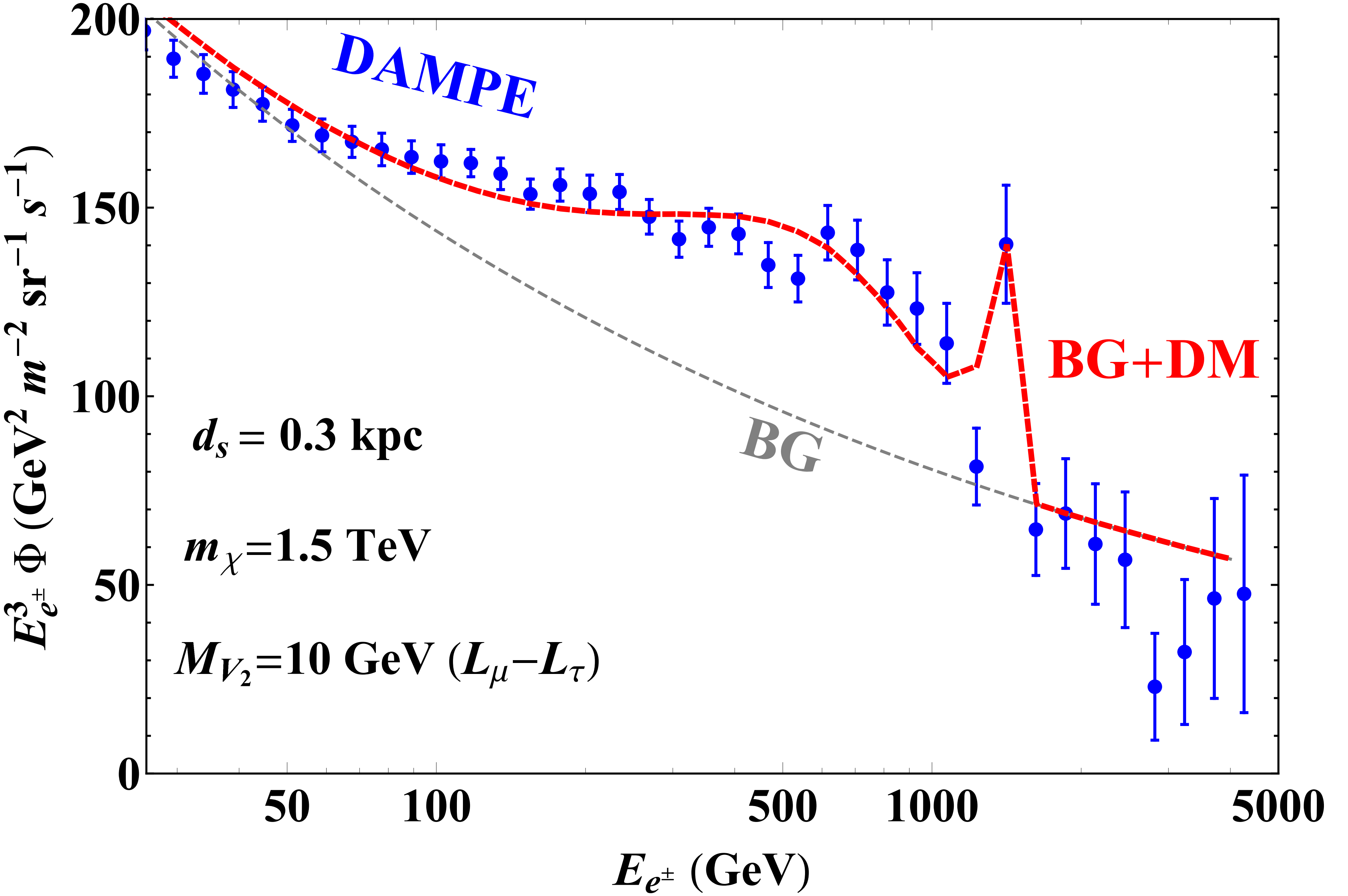
DAMPE electron excess



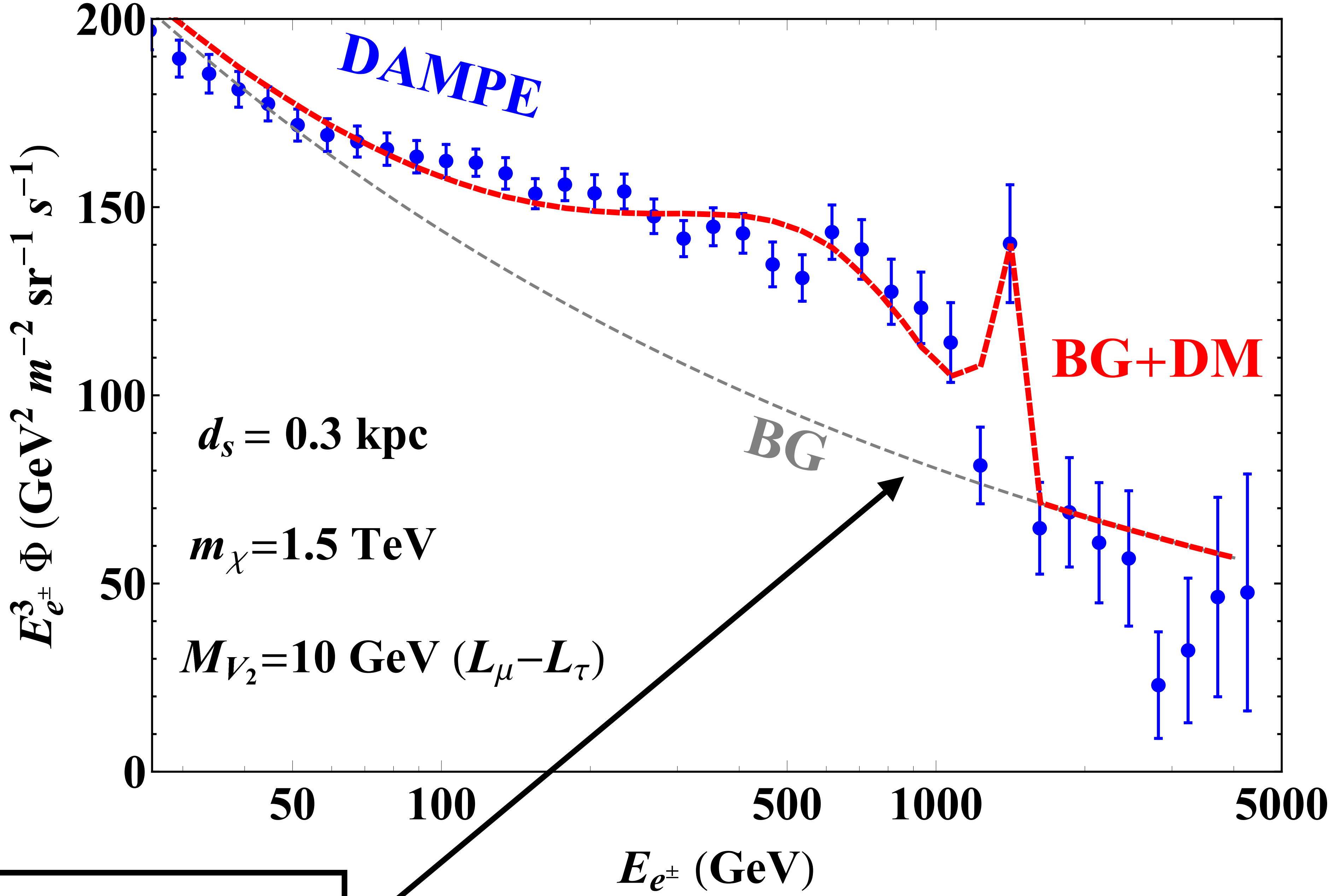
Two different models

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

electrophilic V_1 & L_μ - L_τ V_2



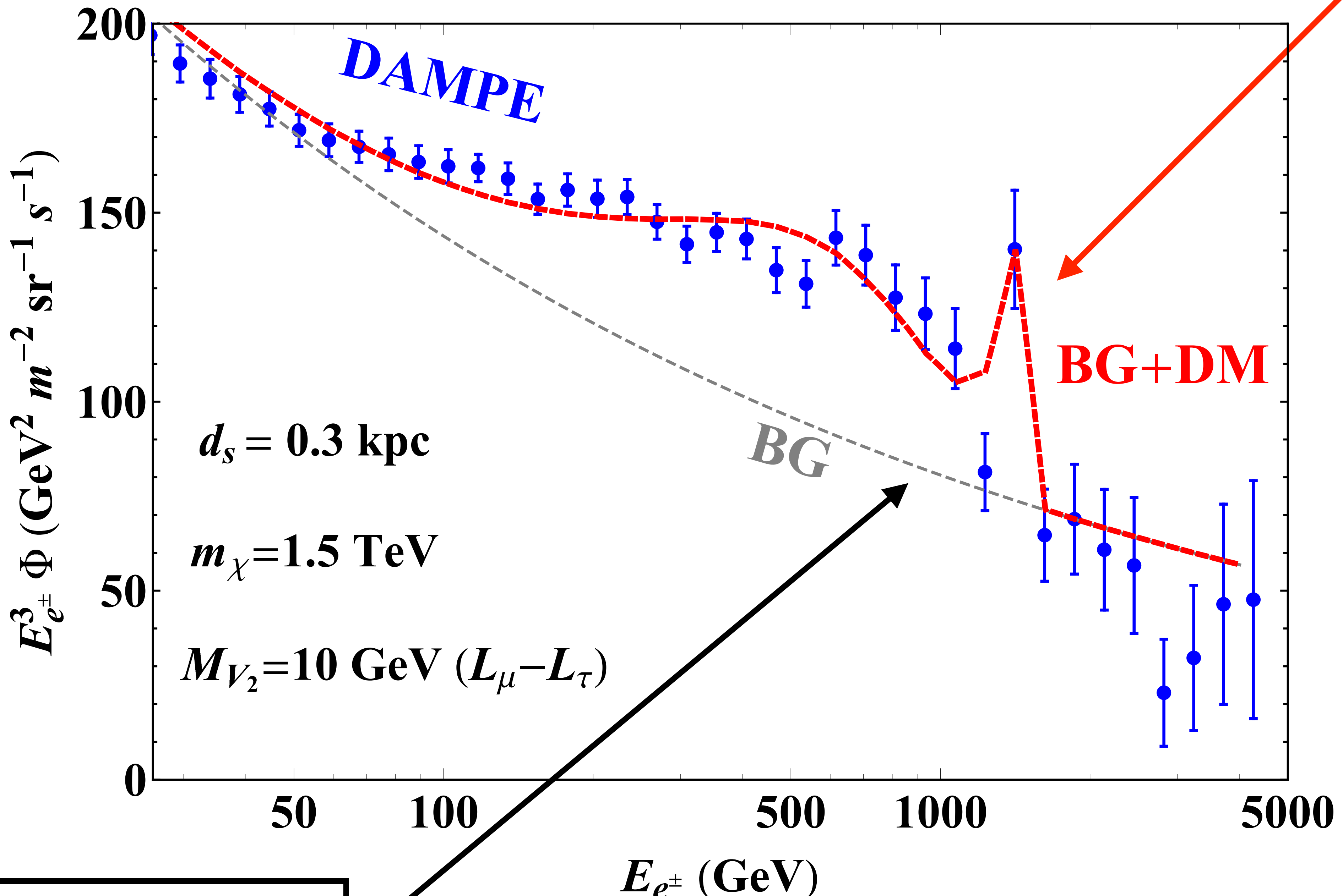
electrophilic V_1 & L_μ - L_τ V_2



simple BG

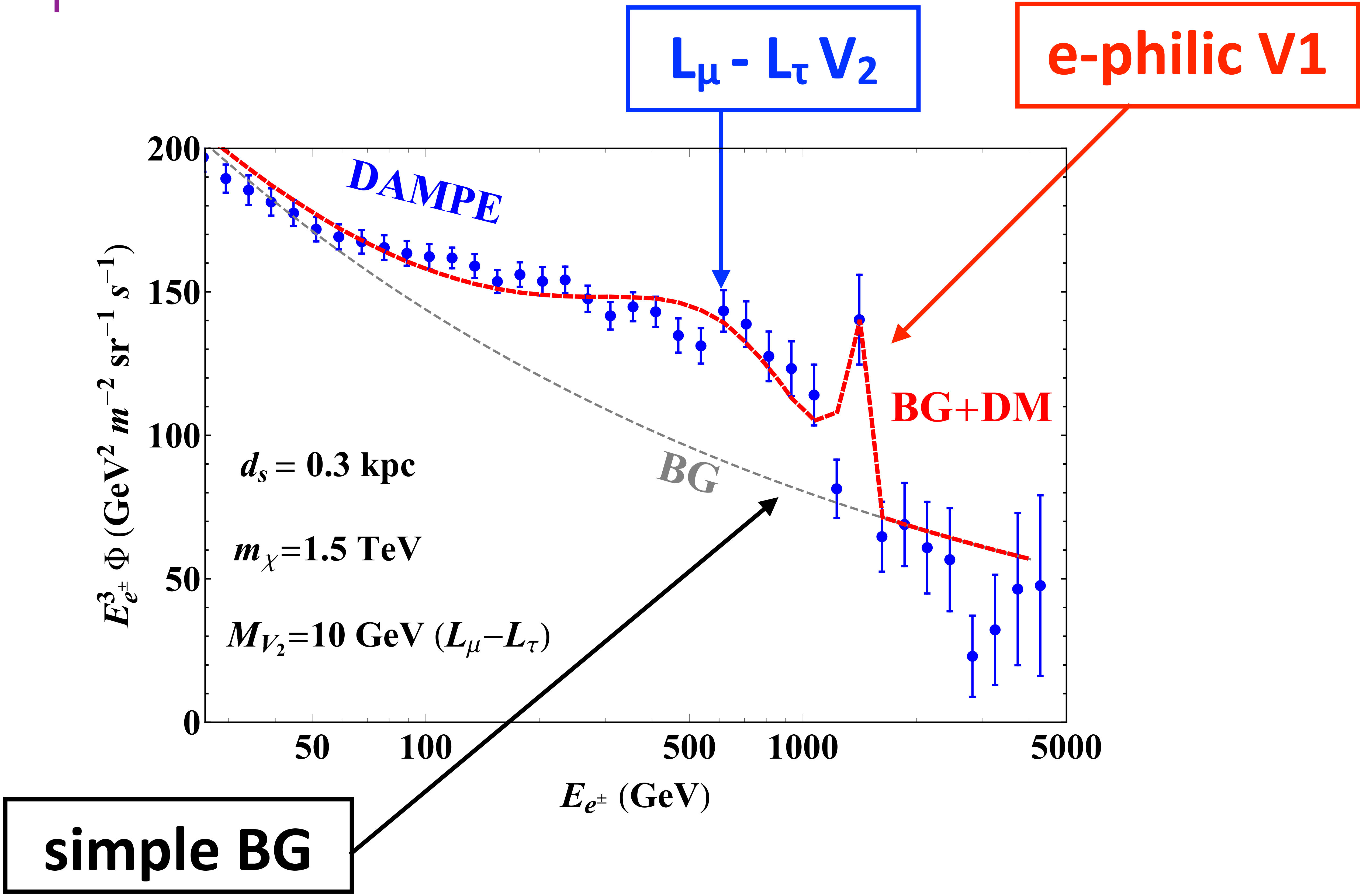
electrophilic V_1 & L_μ - L_τ V_2

e-philic V1



simple BG

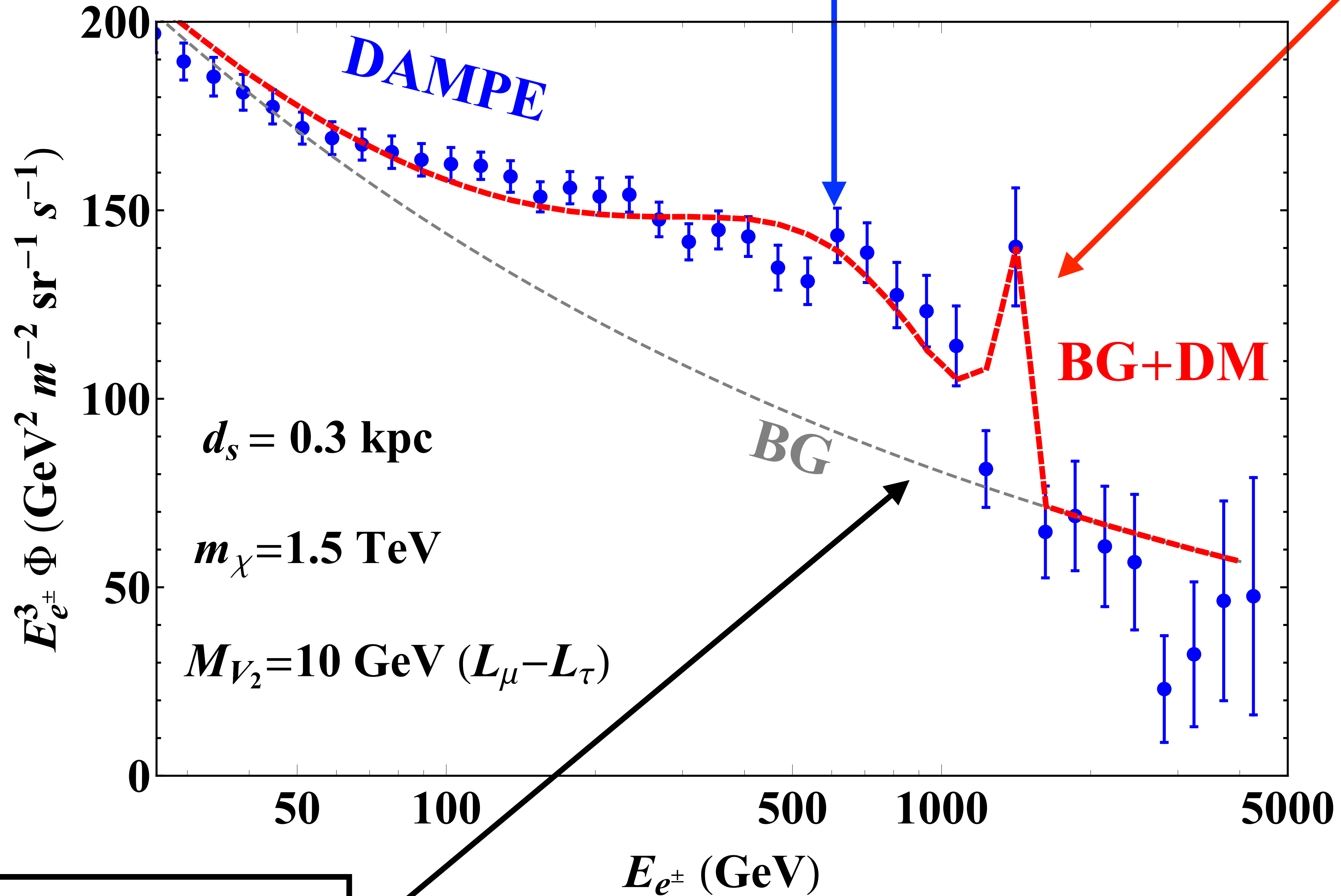
electrophilic V_1 & L_μ - L_τ V_2



electrophilic V_1 & L_μ - L_τ V_2

L_μ - L_τ V_2

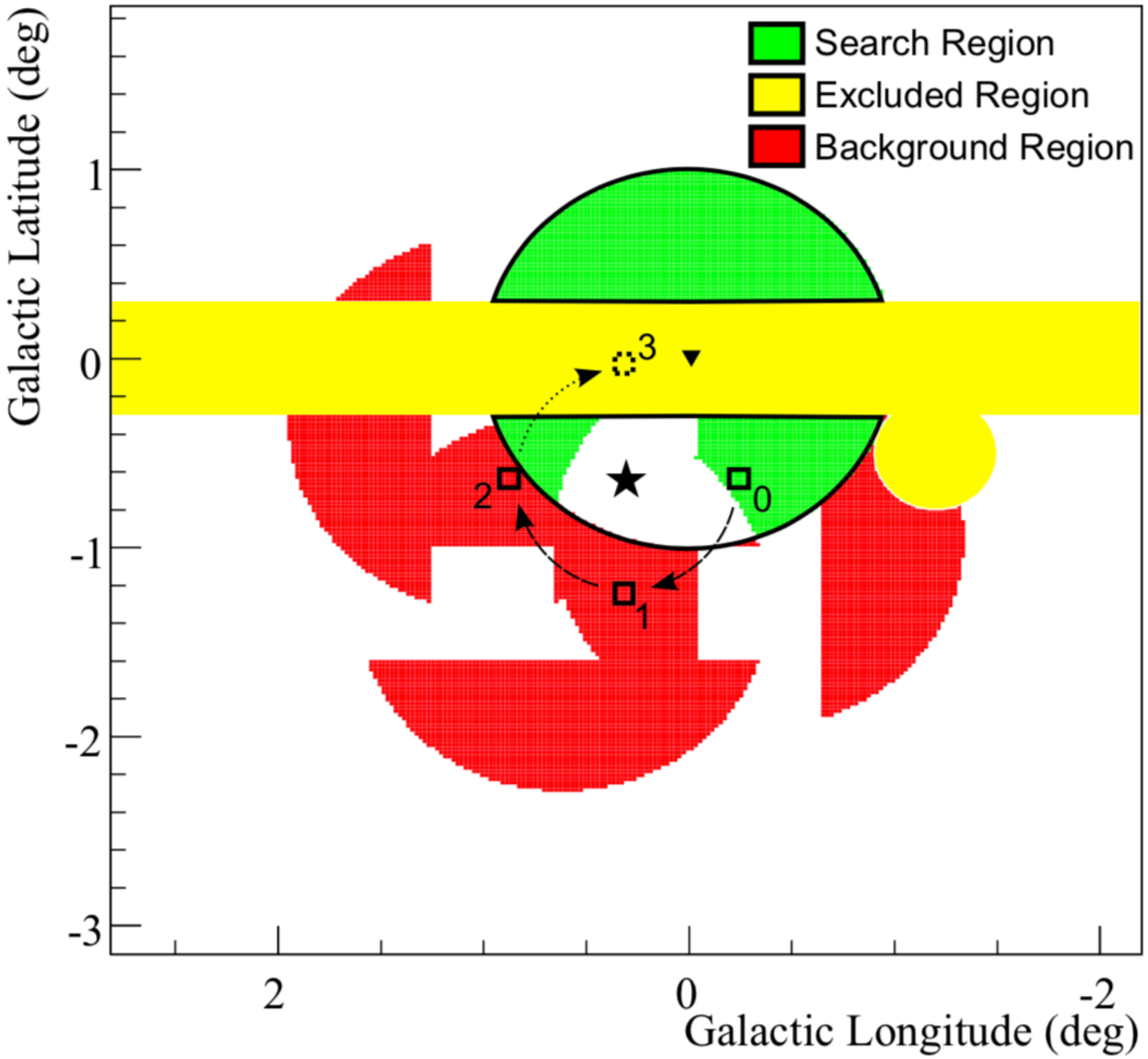
e-philic V1



simple BG

4.9×10^{-26} (2.0×10^{-24}) cm^3/s

HESS search region

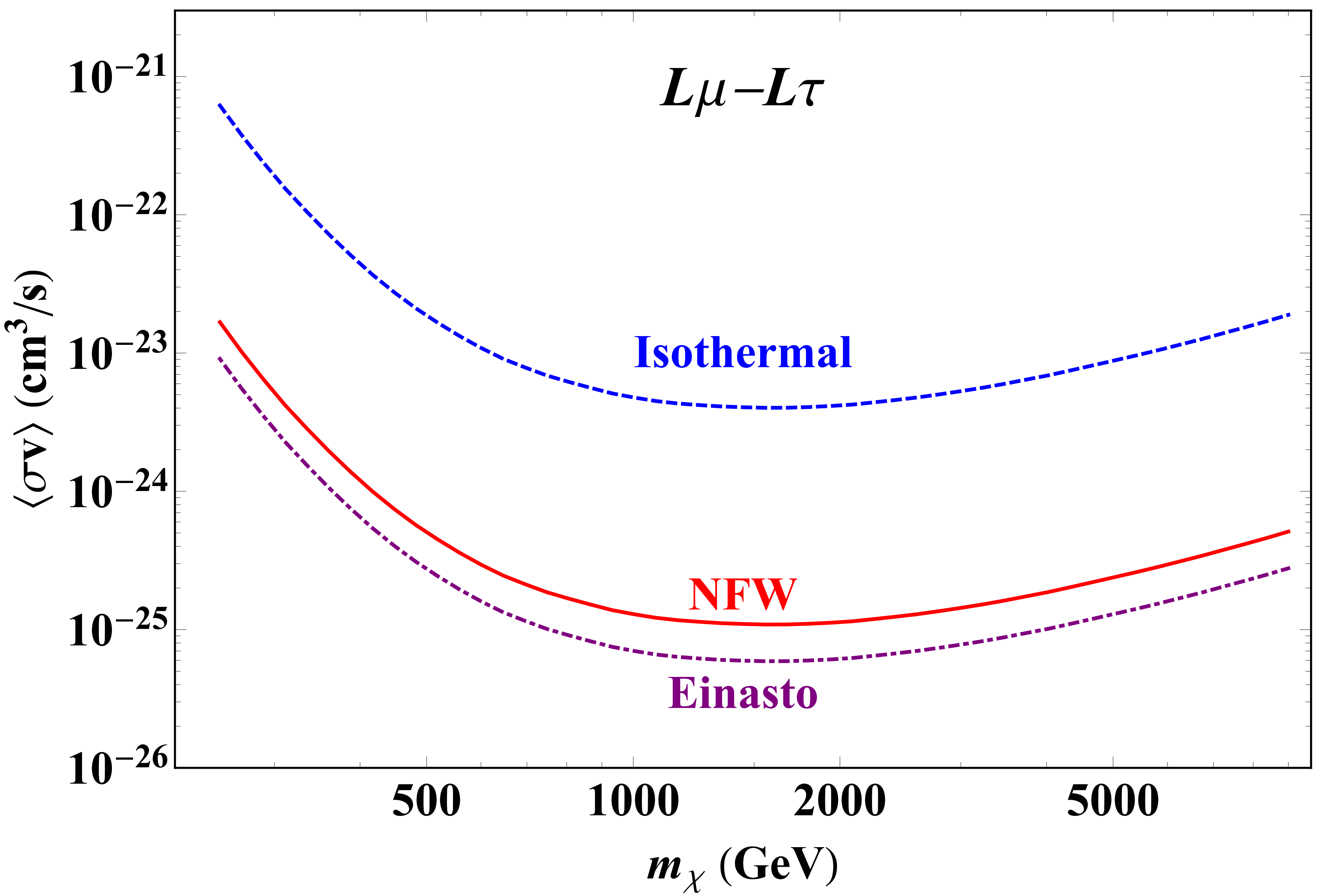


HESS
1607.08142

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

HESS constraints on L_μ - L_τ V_2

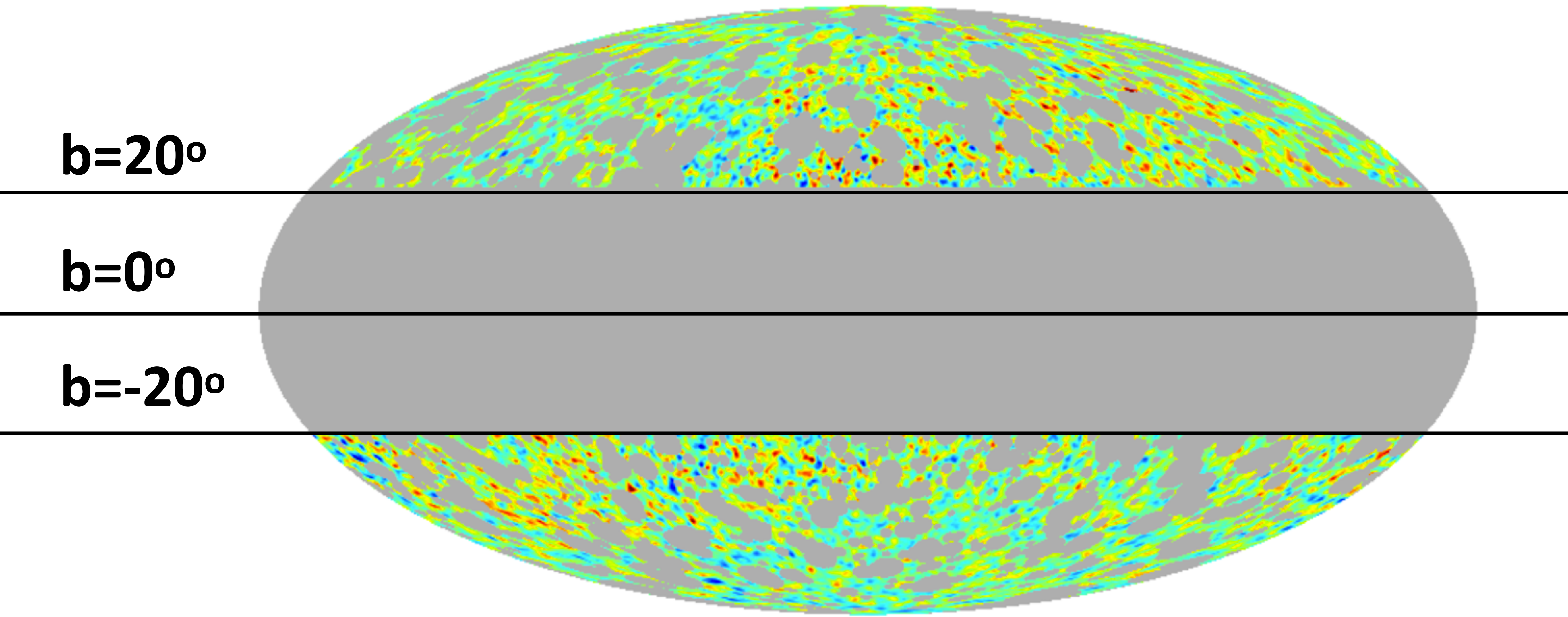
[HESS 254-h data, 1607.08142]



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

Fermi isotropic gamma ray background

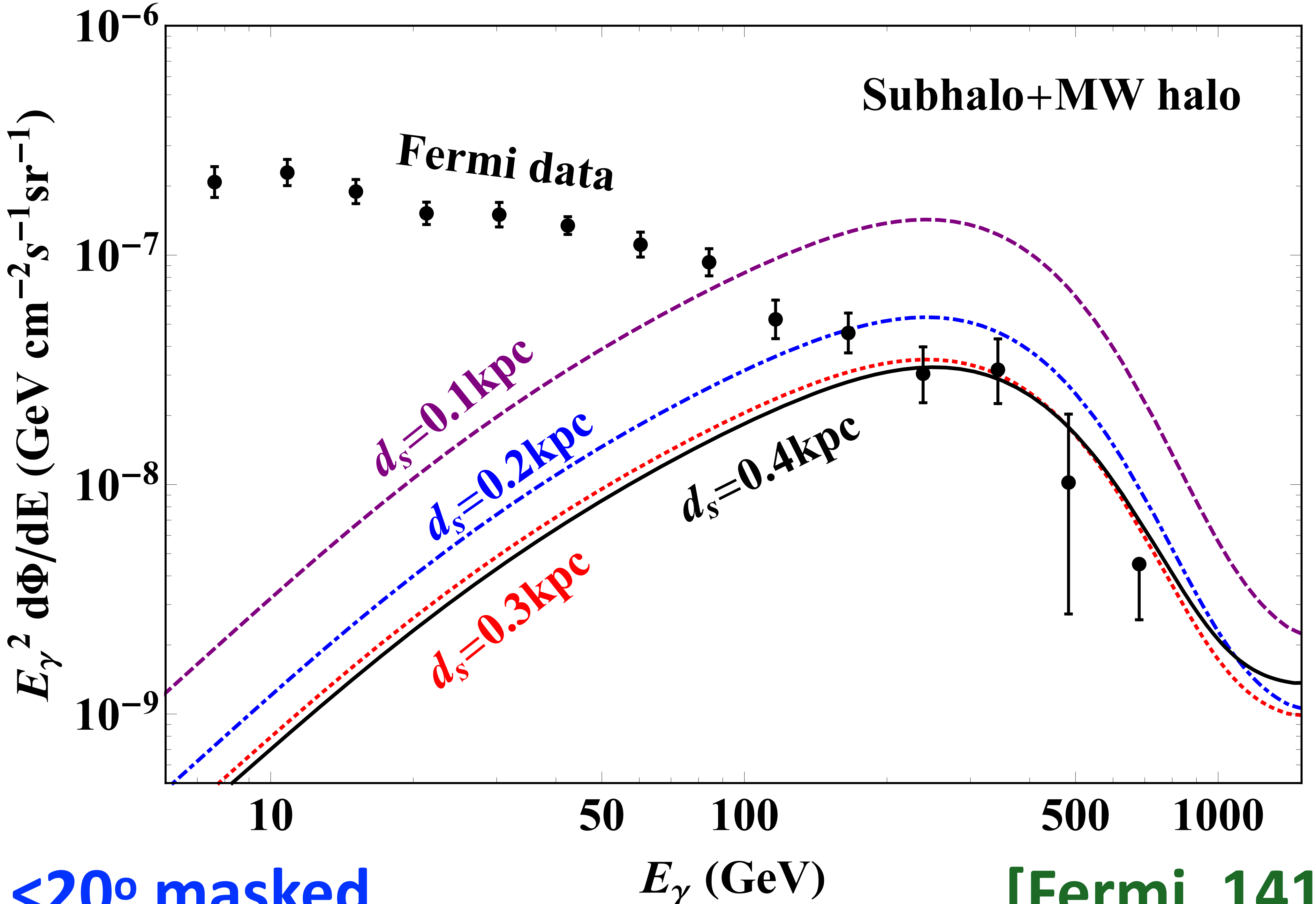
isotropic gamma ray background (IGRB)



$|b|<20^{o}$ masked

Fermi IGRB as a function d_s

electrophilic V_1 & L_μ - L_τ V_2



|b|<20° masked

[Fermi, 1410.3696]

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)

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

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

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

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

KM V_1 & $L_\mu - L_\tau$ V_2

V_1: kinetic mixing (KM)

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

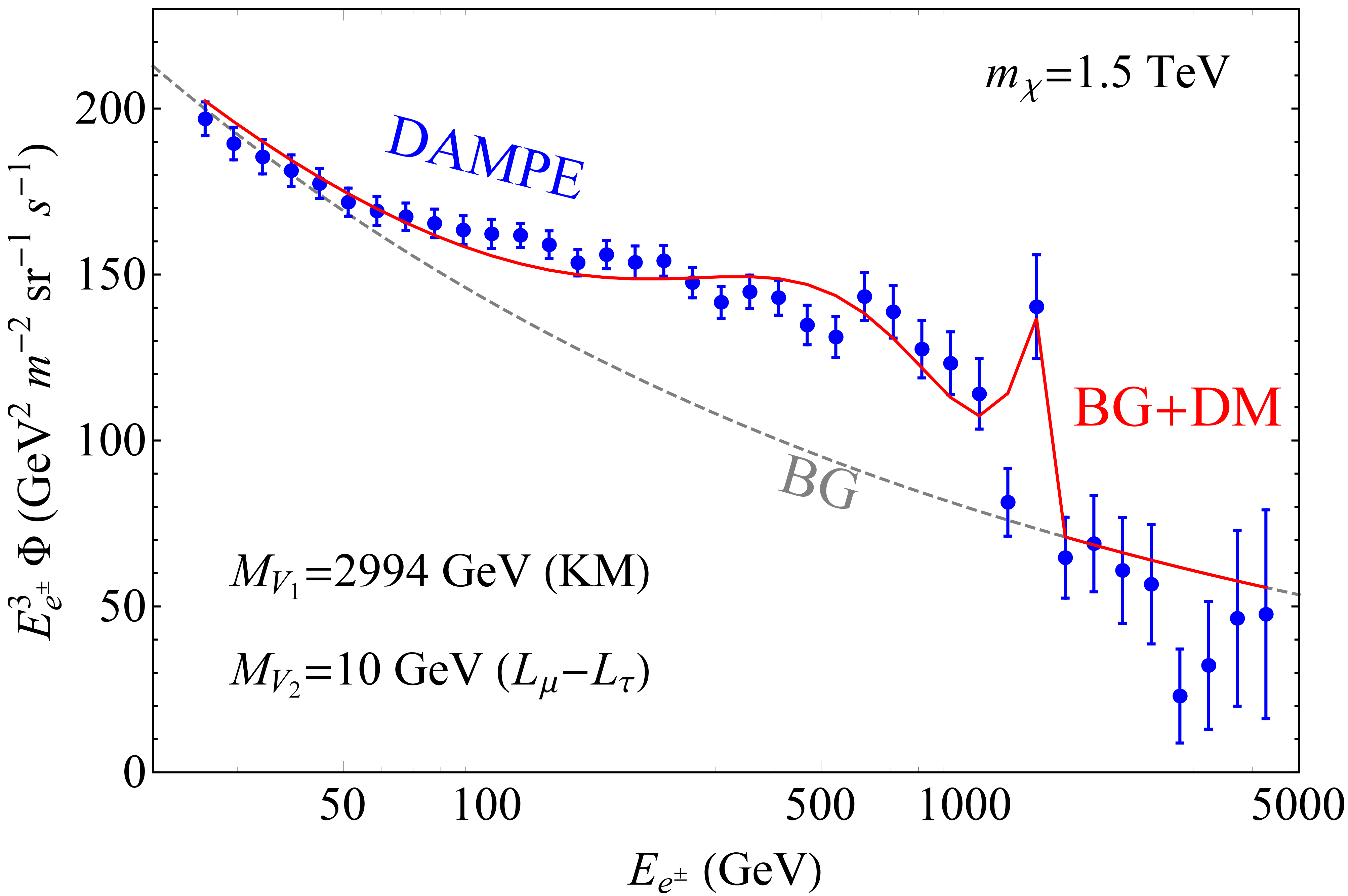
$$-\frac{1}{4} V_2^{\mu\nu} V_{2\mu\nu} + g_2 \bar{\chi} \gamma_\mu \chi V_2^\mu$$

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

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

V_2: $L_\mu - L_\tau$

KM V_1 & L_μ - L_τ V_2

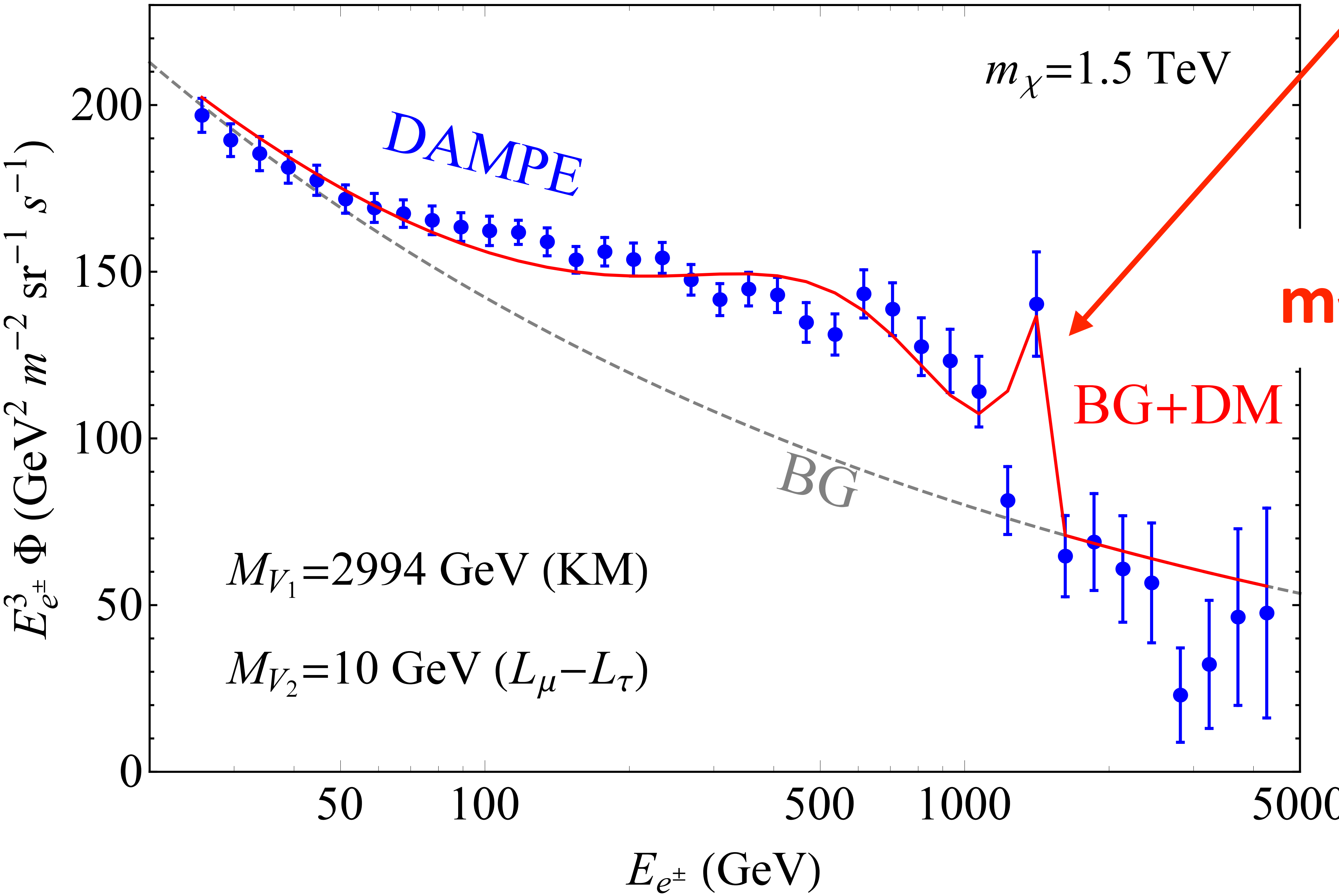


KM V_1 & L_μ - L_τ V_2

KM V1

$g_1=\varepsilon=0.1$

m_{V1} = 2994 GeV

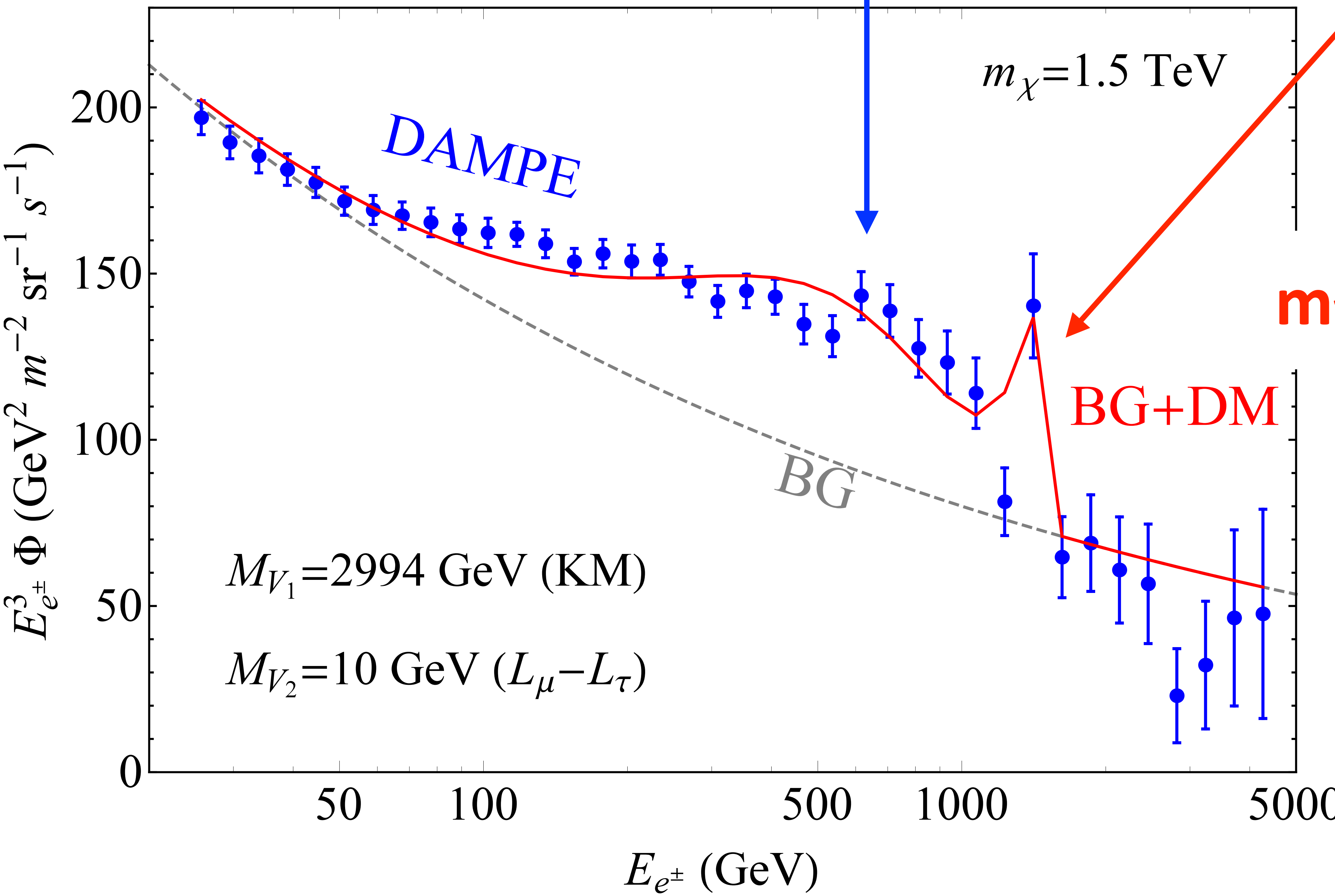


KM V_1 & L_μ - L_τ V_2

m_{V2} = 10 GeV

L_μ - L_τ V_2

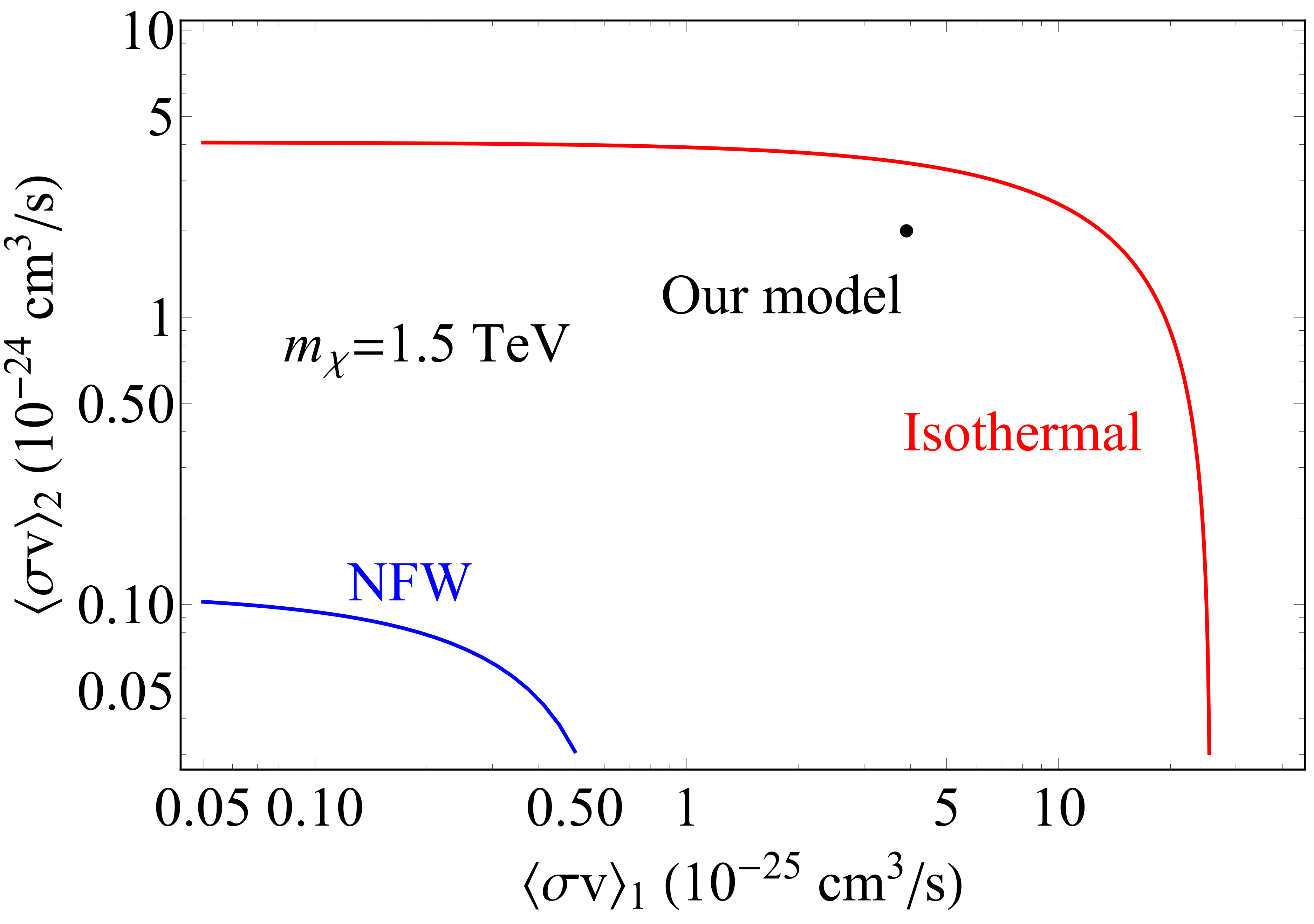
KM V1



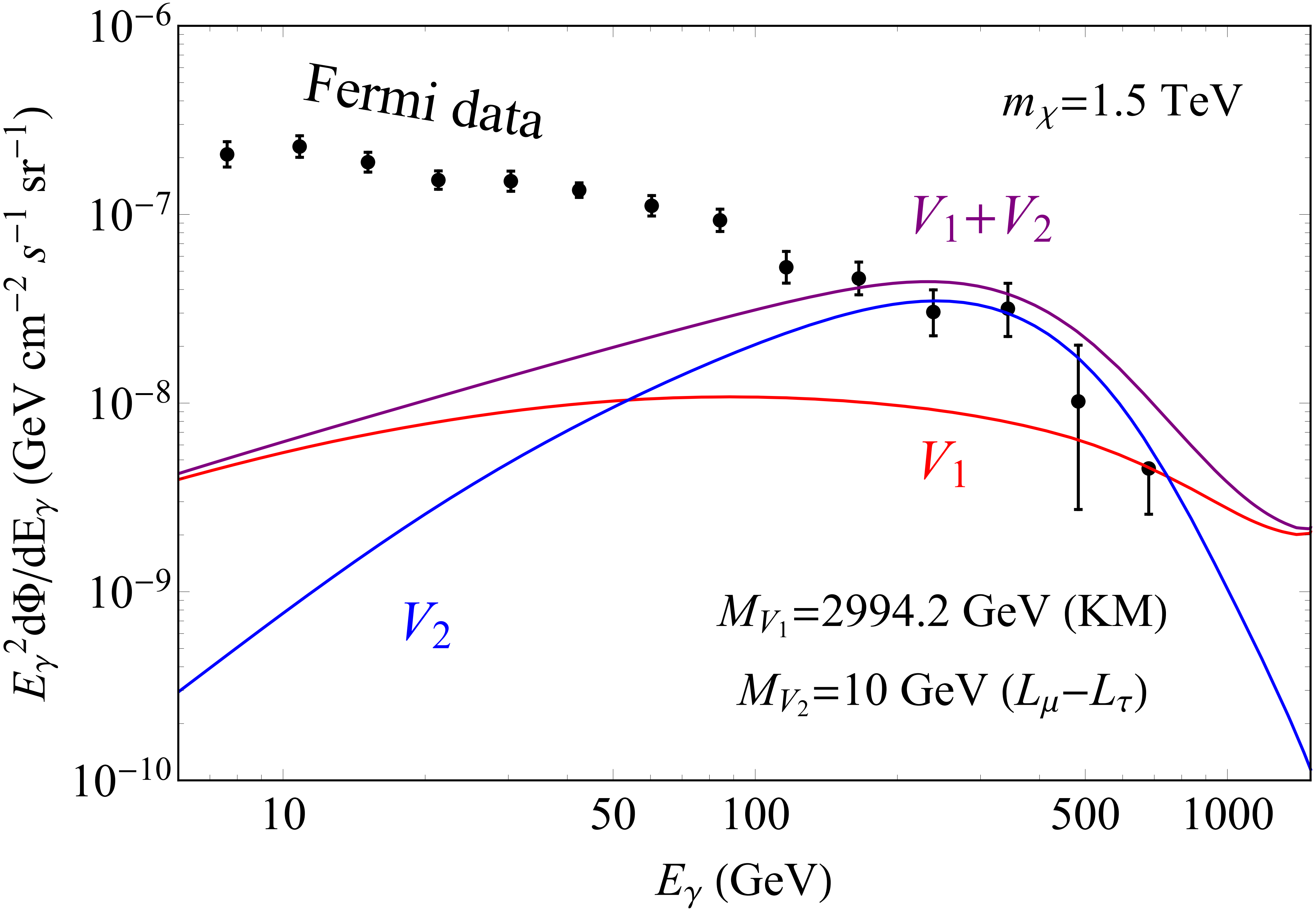
g_1=ε=0.1

m_{V1} = 2994 GeV

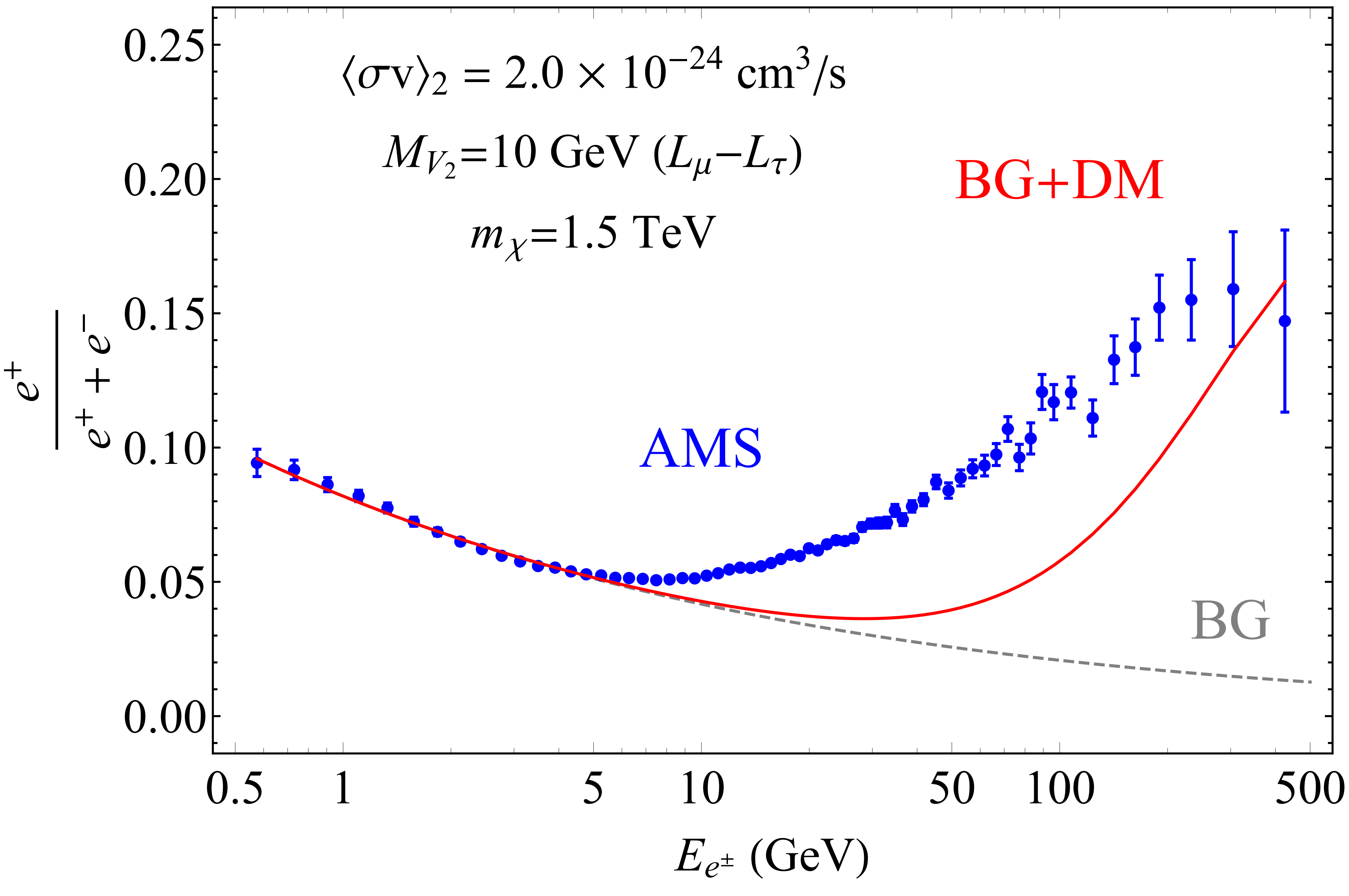
HESS constraints on KM V_1 & L_μ - L_τ V_2



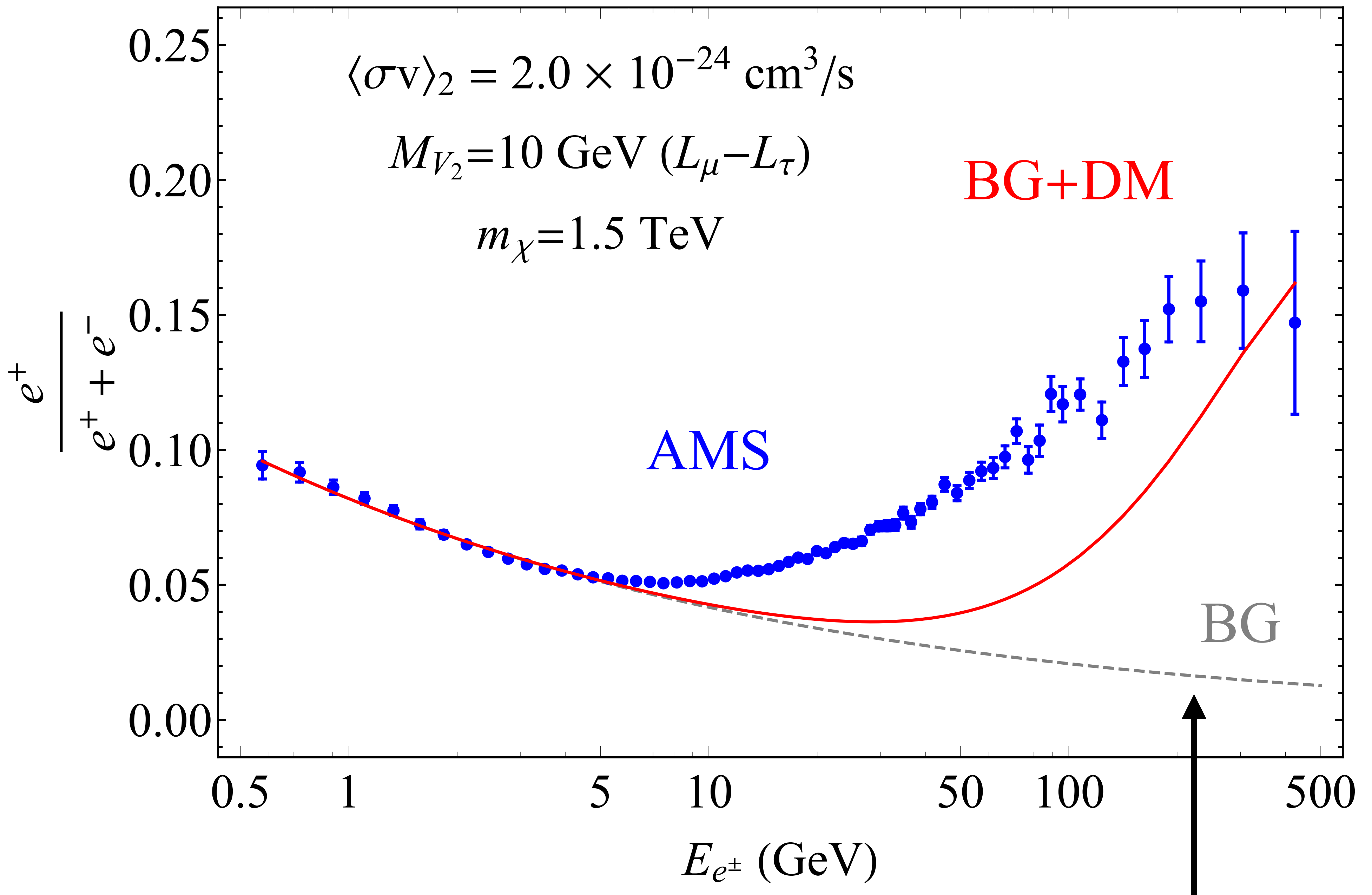
Fermi constraints on KM V_1 & L_μ - L_τ V_2



AMS positron fraction



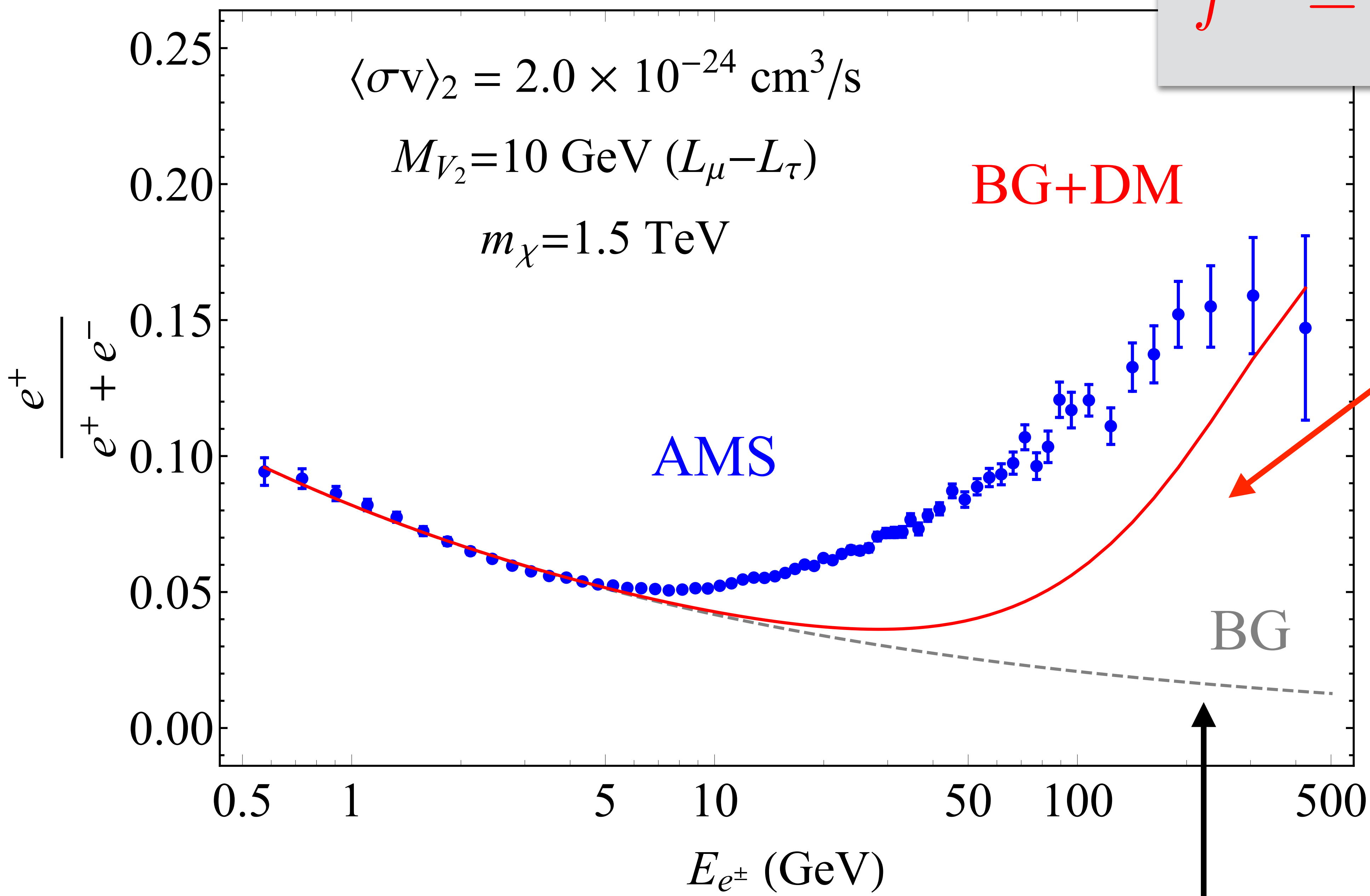
AMS positron fraction



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

AMS positron fraction

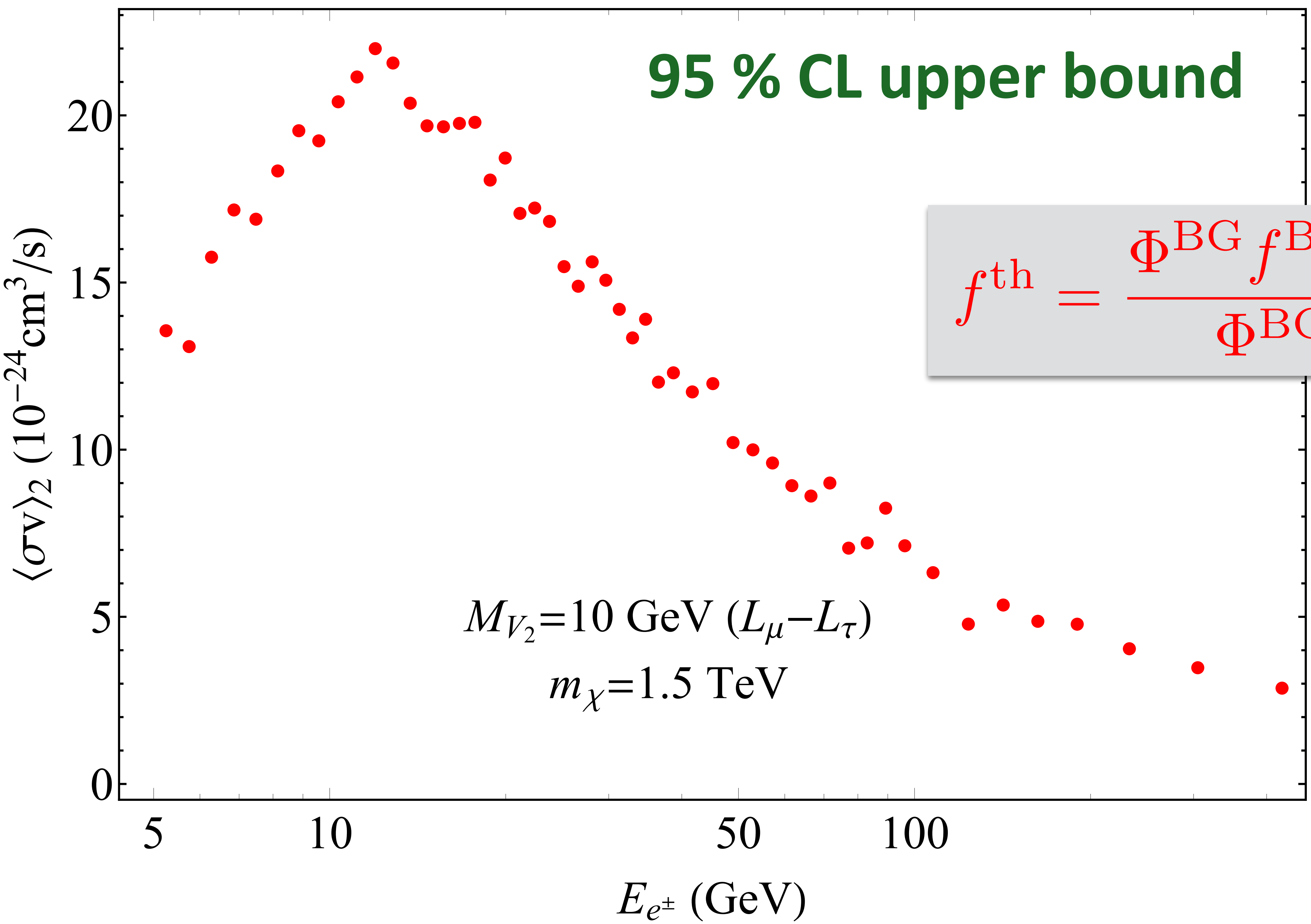
$$f^{th} = \frac{\Phi^{BG} f^{BG} + \Phi^{\chi}/2}{\Phi^{BG} + \Phi^{\chi}}$$



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

AMS constraints (upper bound)

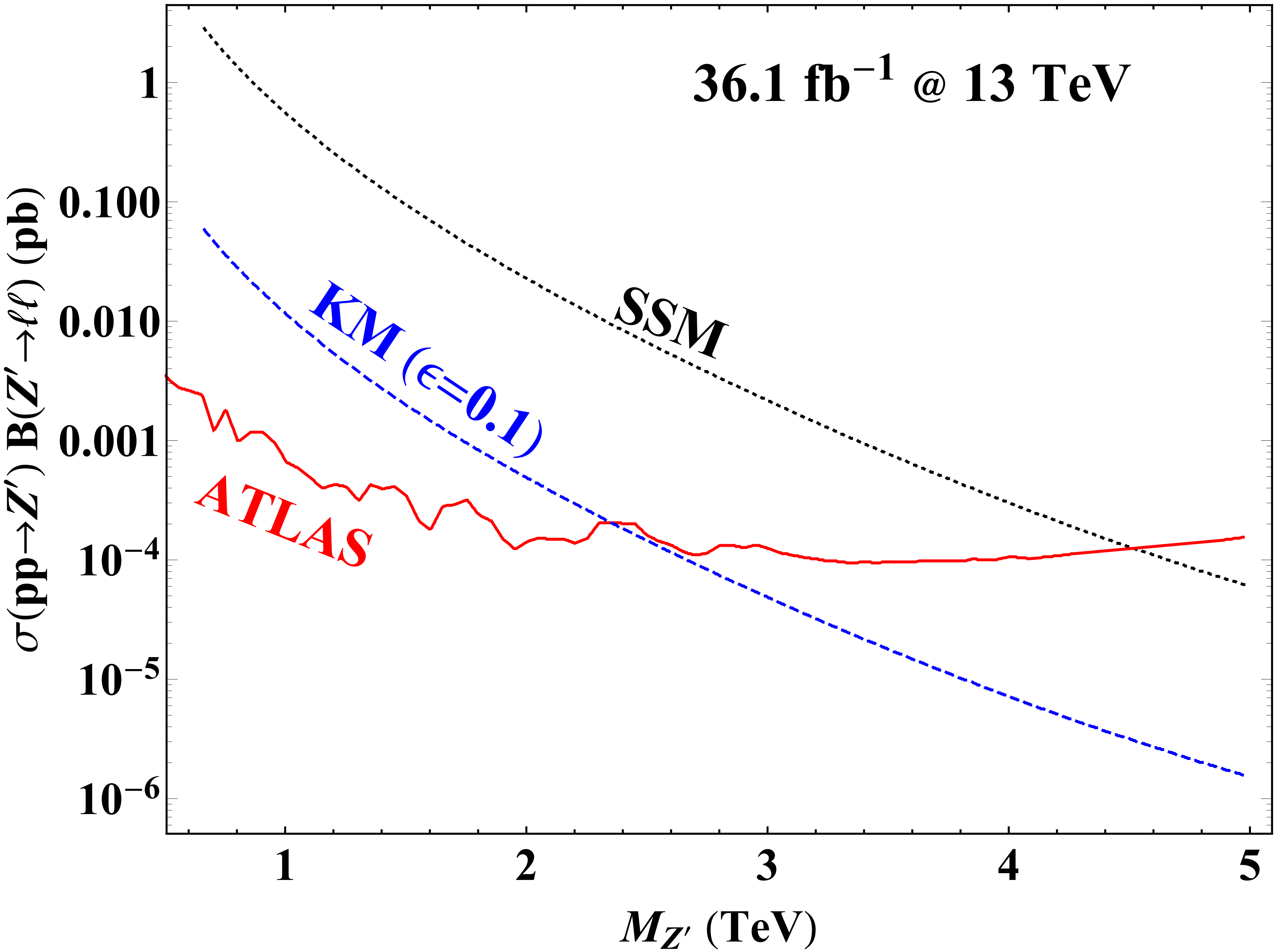
$$f_i^{\mathrm{AMS}} + 1.64\,\delta f_i^{\mathrm{AMS}}$$



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

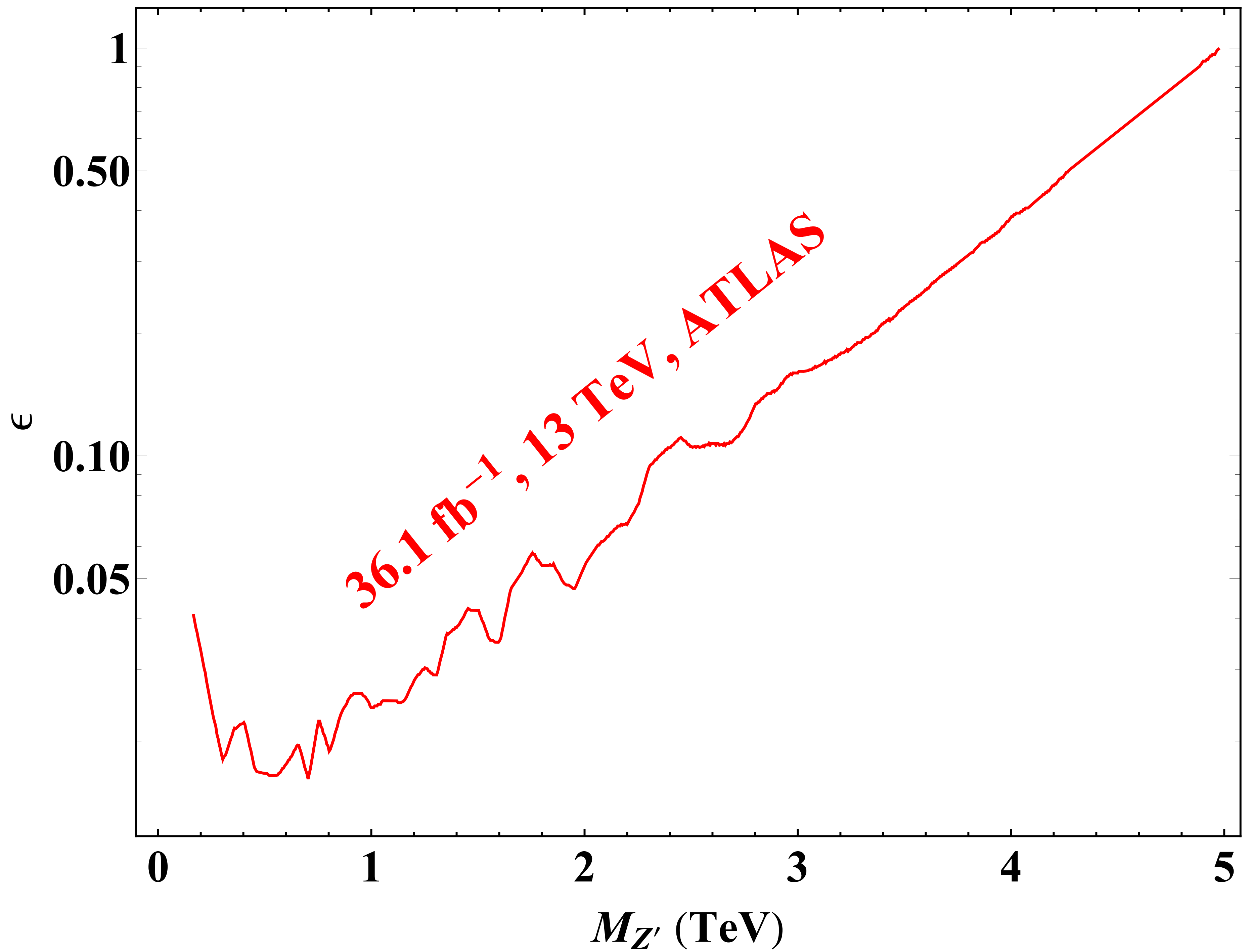
dilepton @ ATLAS via Drell-Yan

[ATLAS, 1707.02424]



ATLAS constraints on KM

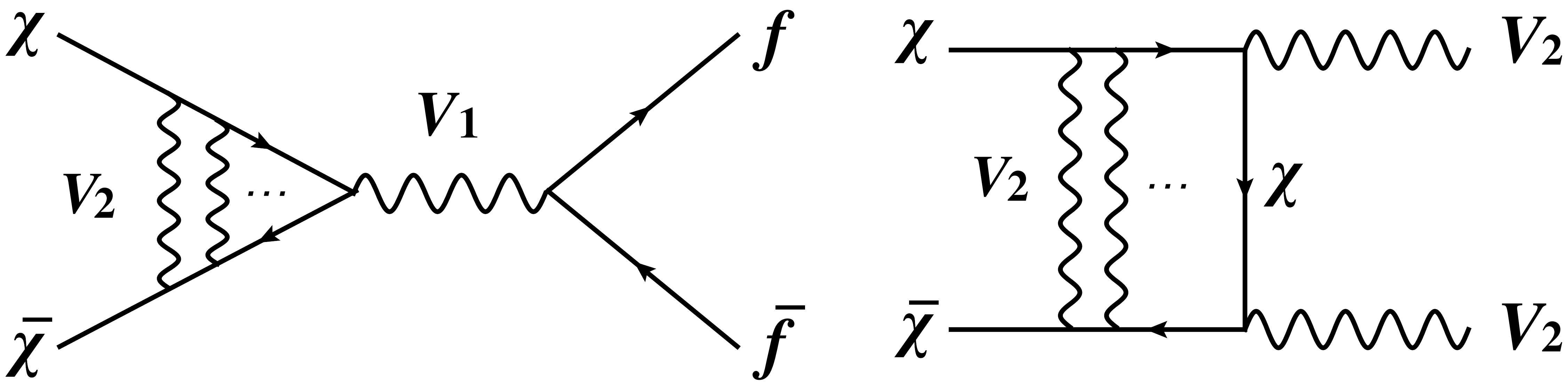
[ATLAS, 1707.02424]



Sommerfeld enhancement

nonperturbative enhancement due to the lighter mediator

present in both annihilation channels

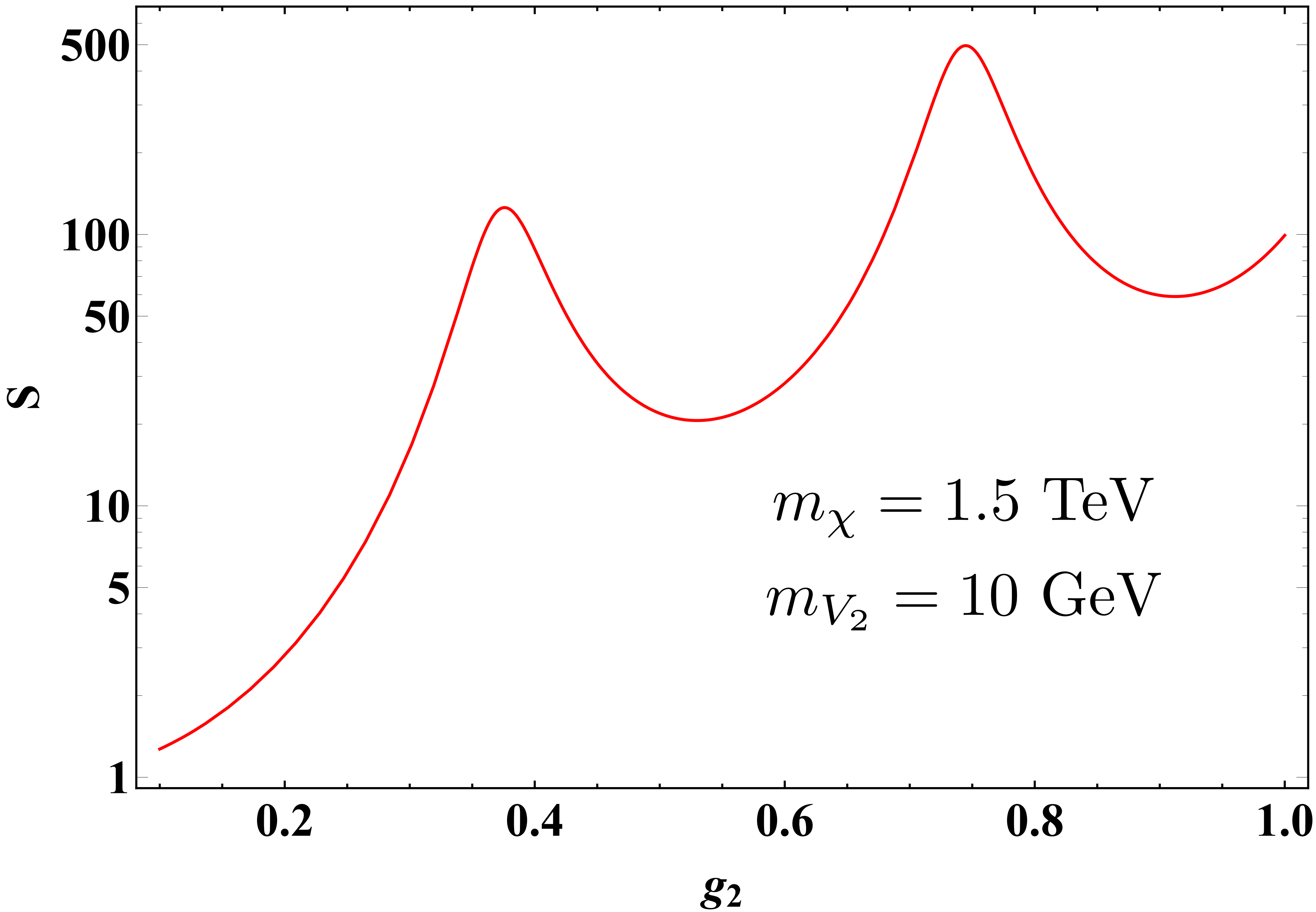


$$S = \left(\frac{\pi}{\epsilon_v}\right)\frac{\sinh X}{\cosh X - \cos\sqrt{(2\pi/\bar{\epsilon}_2) - X^2}}$$

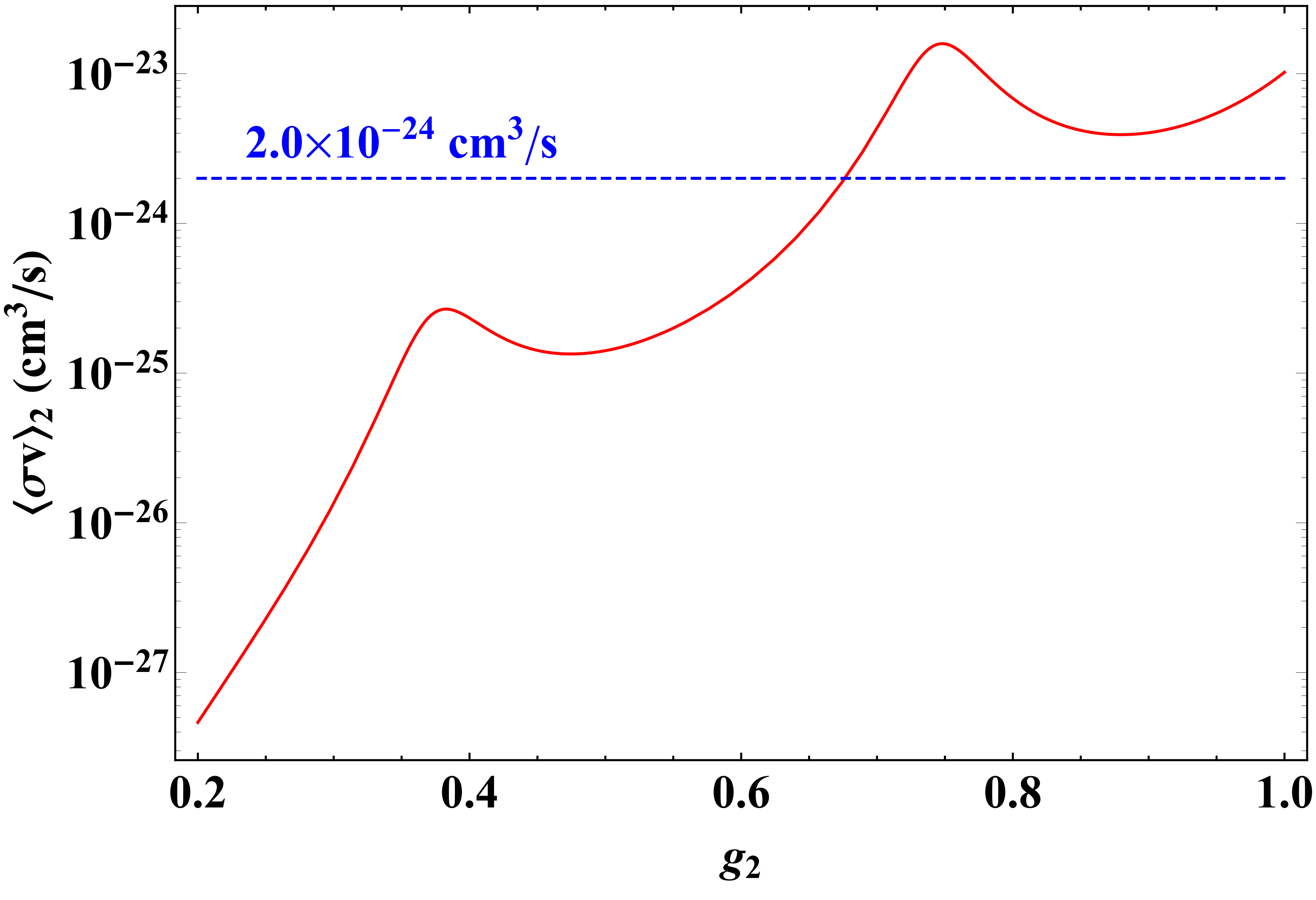
$$\bar{\epsilon}_2 = (\pi/12)\epsilon_2,\ X = \epsilon_v/\bar{\epsilon}_2,\ \epsilon_2 = m_{V_2}/(\alpha_2 m_\chi),$$
$$\epsilon_v = v/\alpha_2 \text{ with } \alpha_2 = g_2^2/(4\pi),\ v = 10^{-3}.$$

[0903.5307, 0910.5713]

Sommerfeld enhancement

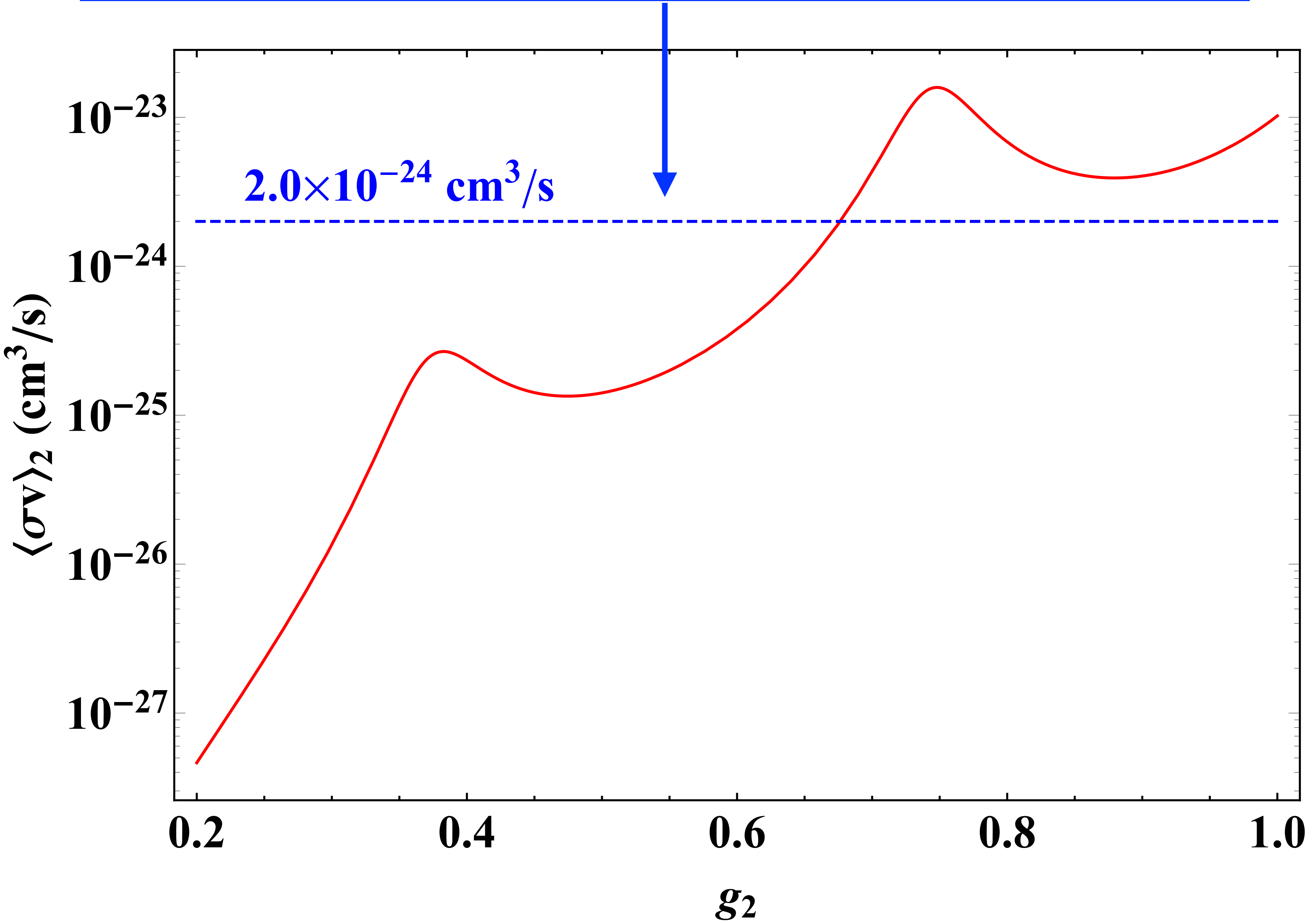


'Correct' annihilation cross section



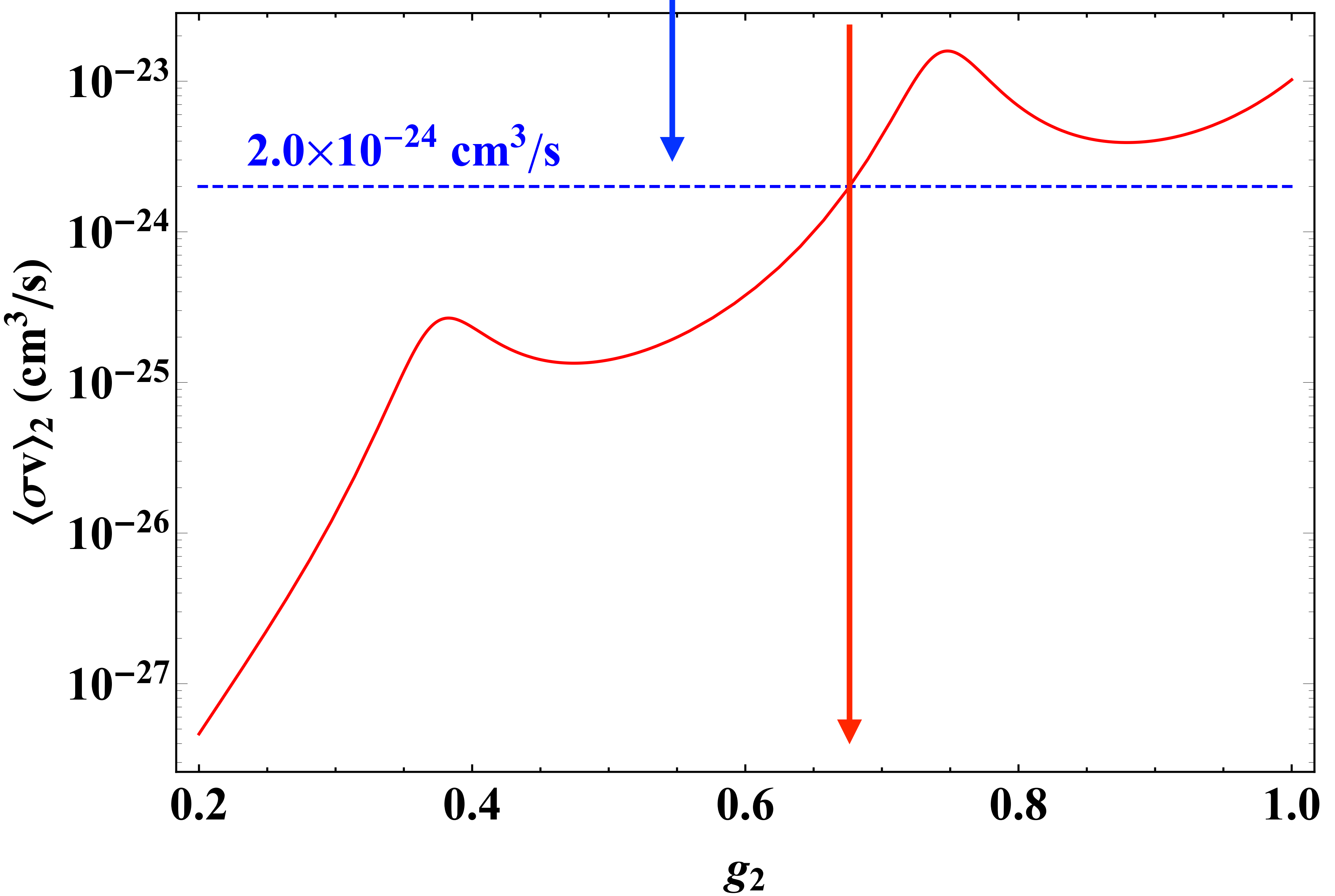
'Correct' annihilation cross section

σv needed for DAMPE "break" excess



'Correct' annihilation cross section

σv needed for DAMPE "break" excess



$g_2 \simeq 0.68$

Relic density

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

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

consistent w/ relic density requirement

Relic density

further Breit-Wigner suppression

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

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

consistent w/ relic density requirement

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.