AMS-02による反陽子宇宙線観測と暗黒物質

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(University of Tokyo)

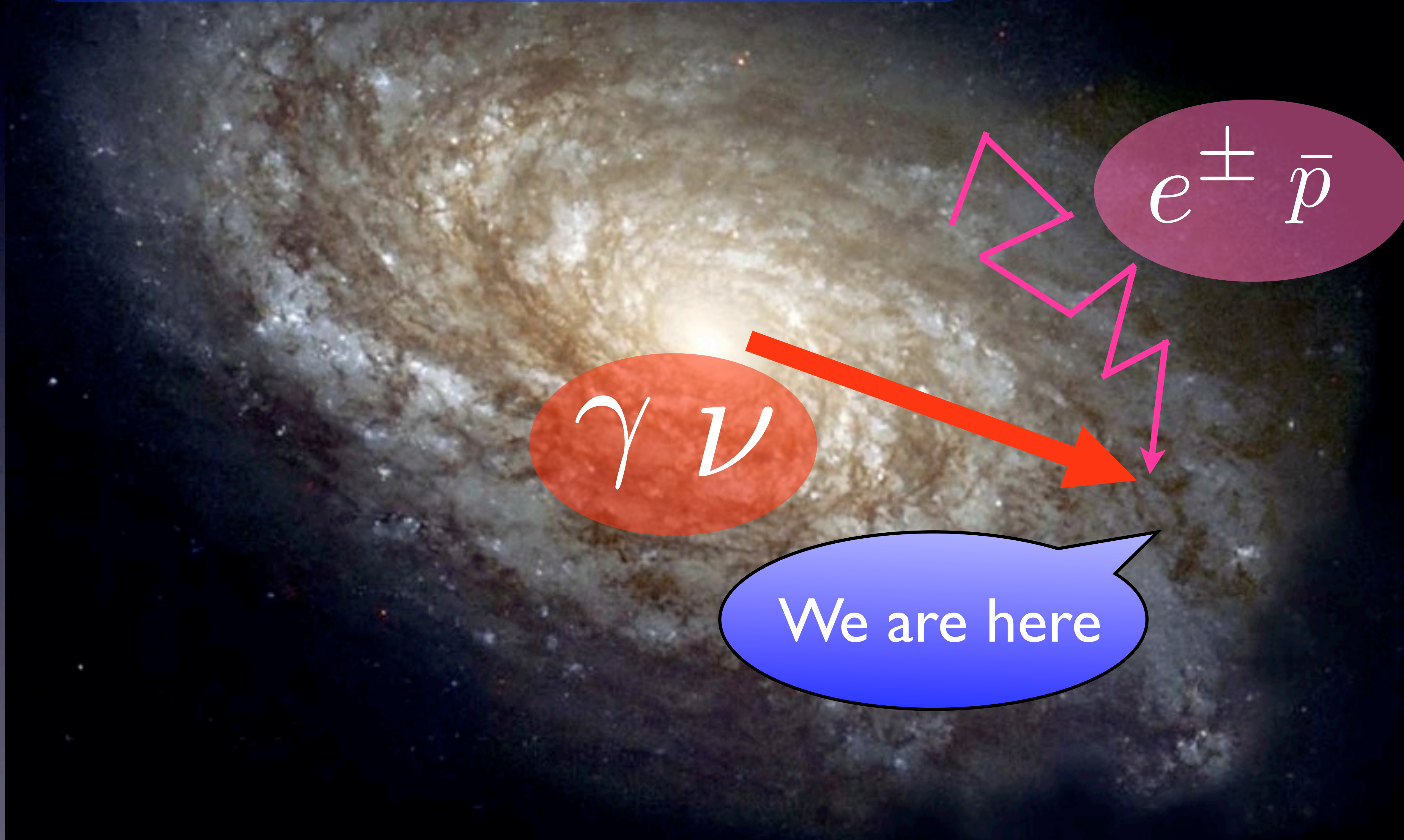
2015/5/16, 神戸大学

Current situation

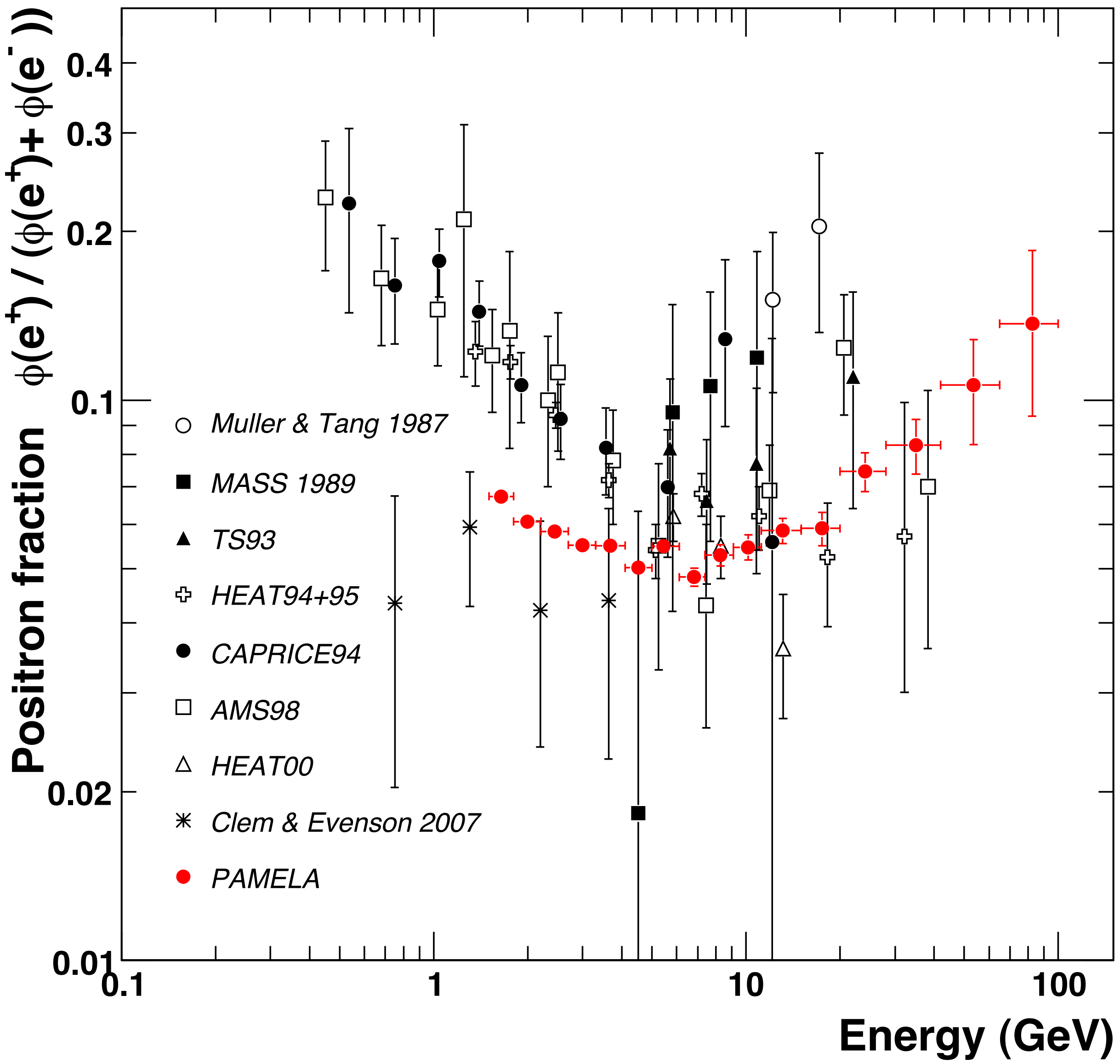
- Excess in Positron and Electron flux : PAMELA/AMS-02 and Fermi
- No excess in gamma-rays : Fermi, HESS, ...
- No excess in neutrinos : SK, IceCube
- Strong constraint from CMB and BBN
- Excess in Anti-Proton ? : AMS-02

Indirect detection of dark matter

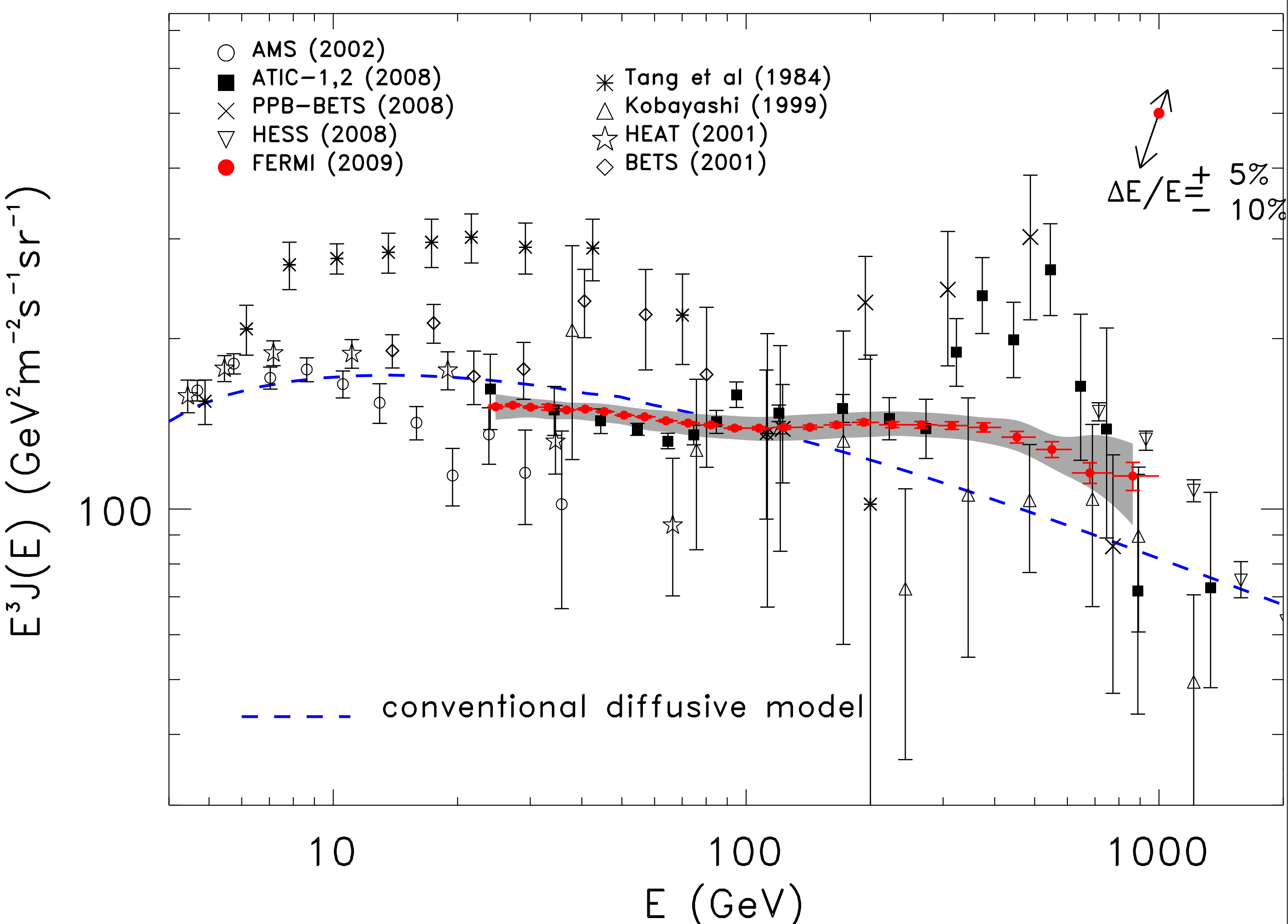
$$\mathrm{DM} + \mathrm{DM} \to e^{\pm}, \gamma, \bar{p}, \nu, \ldots$$



Positron/electron Excess

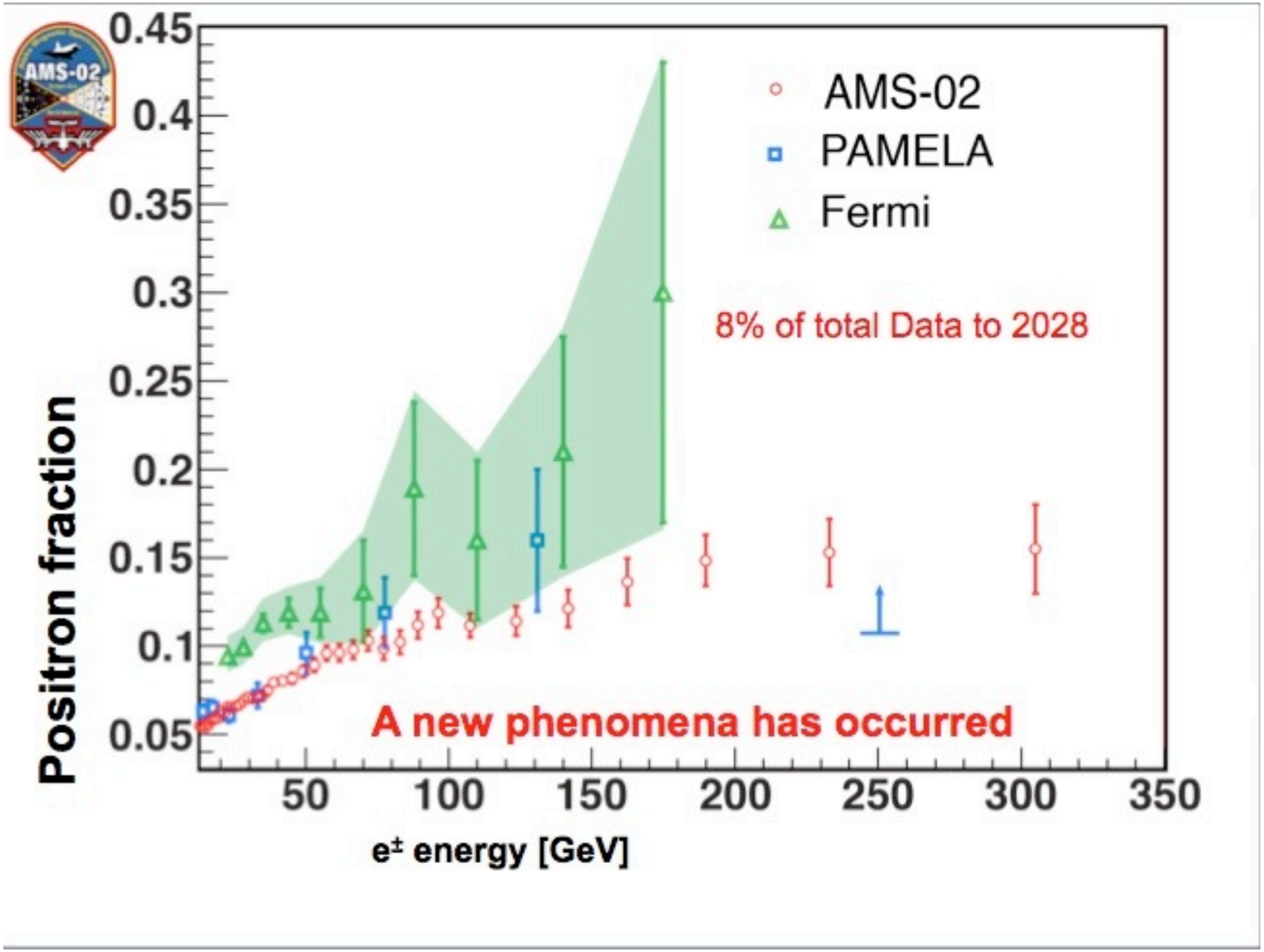


PAMELA

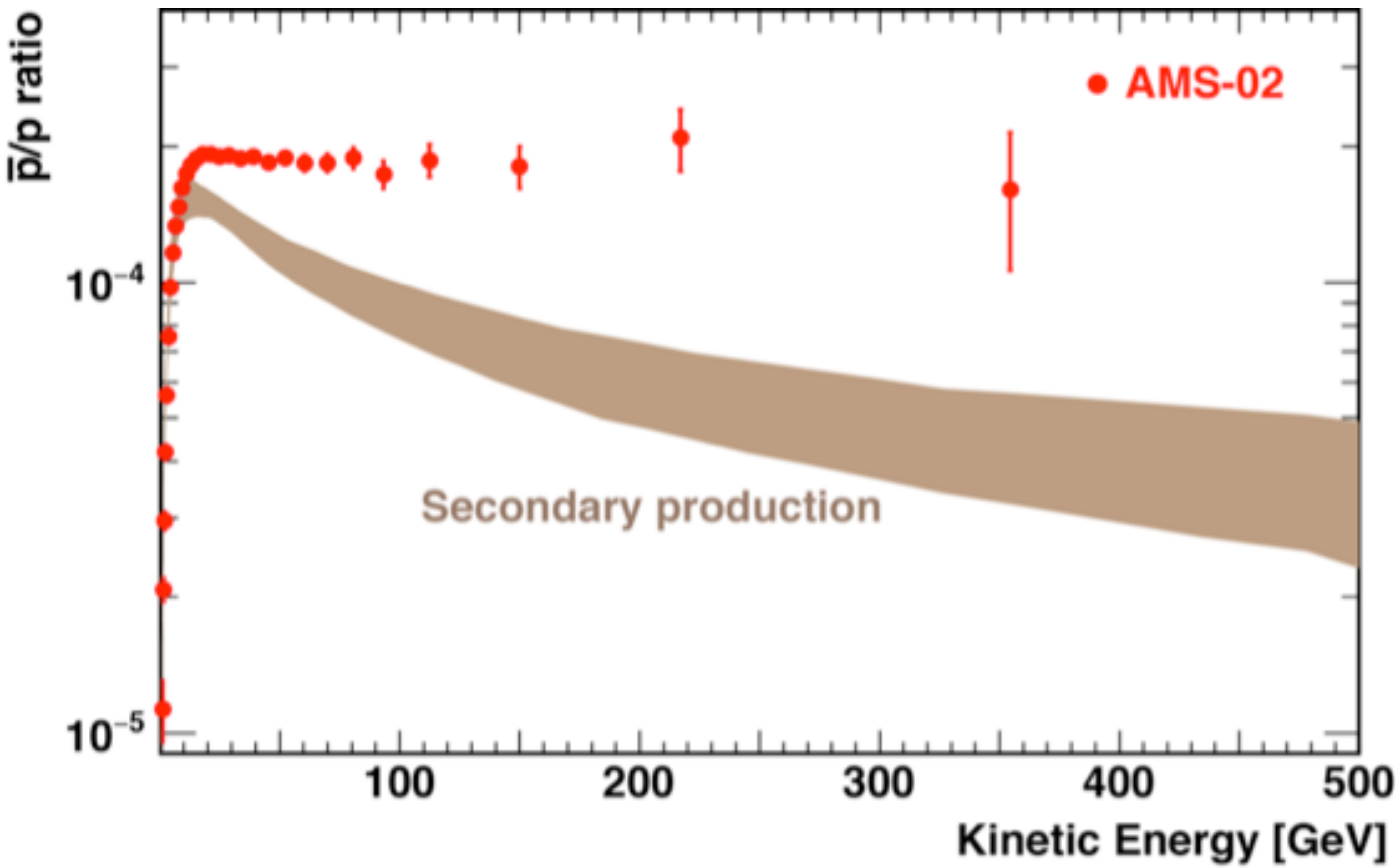


Fermi

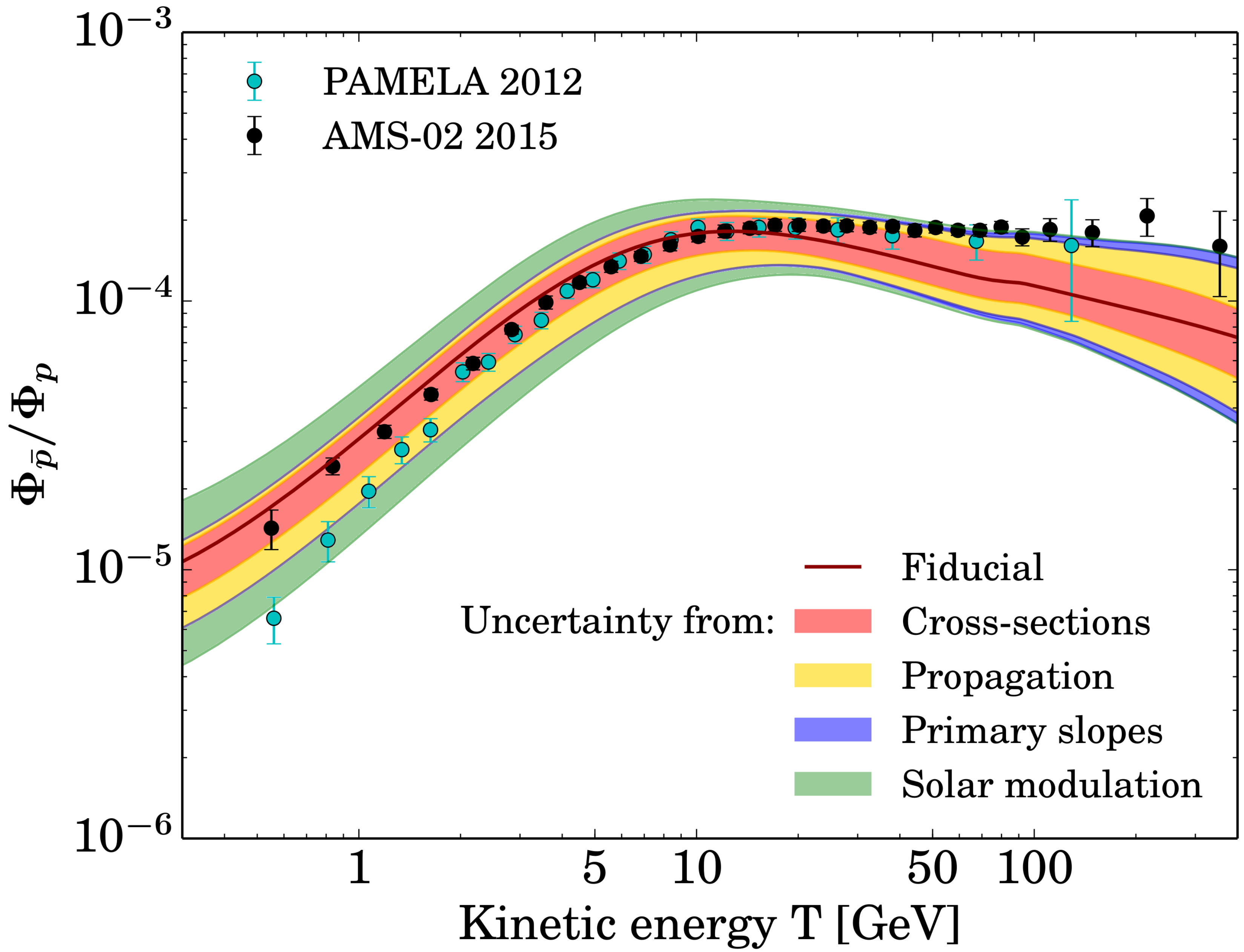
Positron by AMS-02



Anti-proton by AMS-02

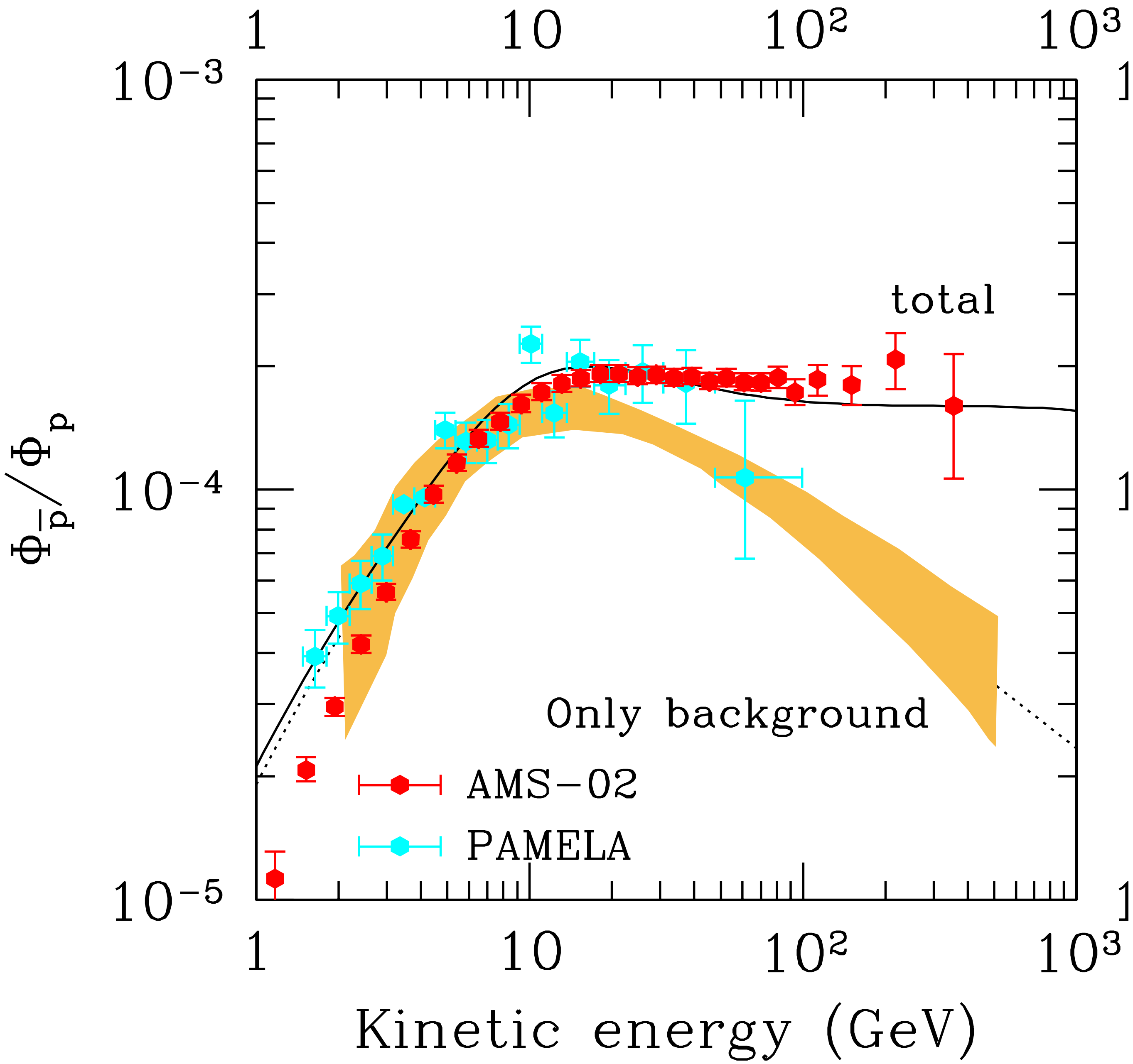


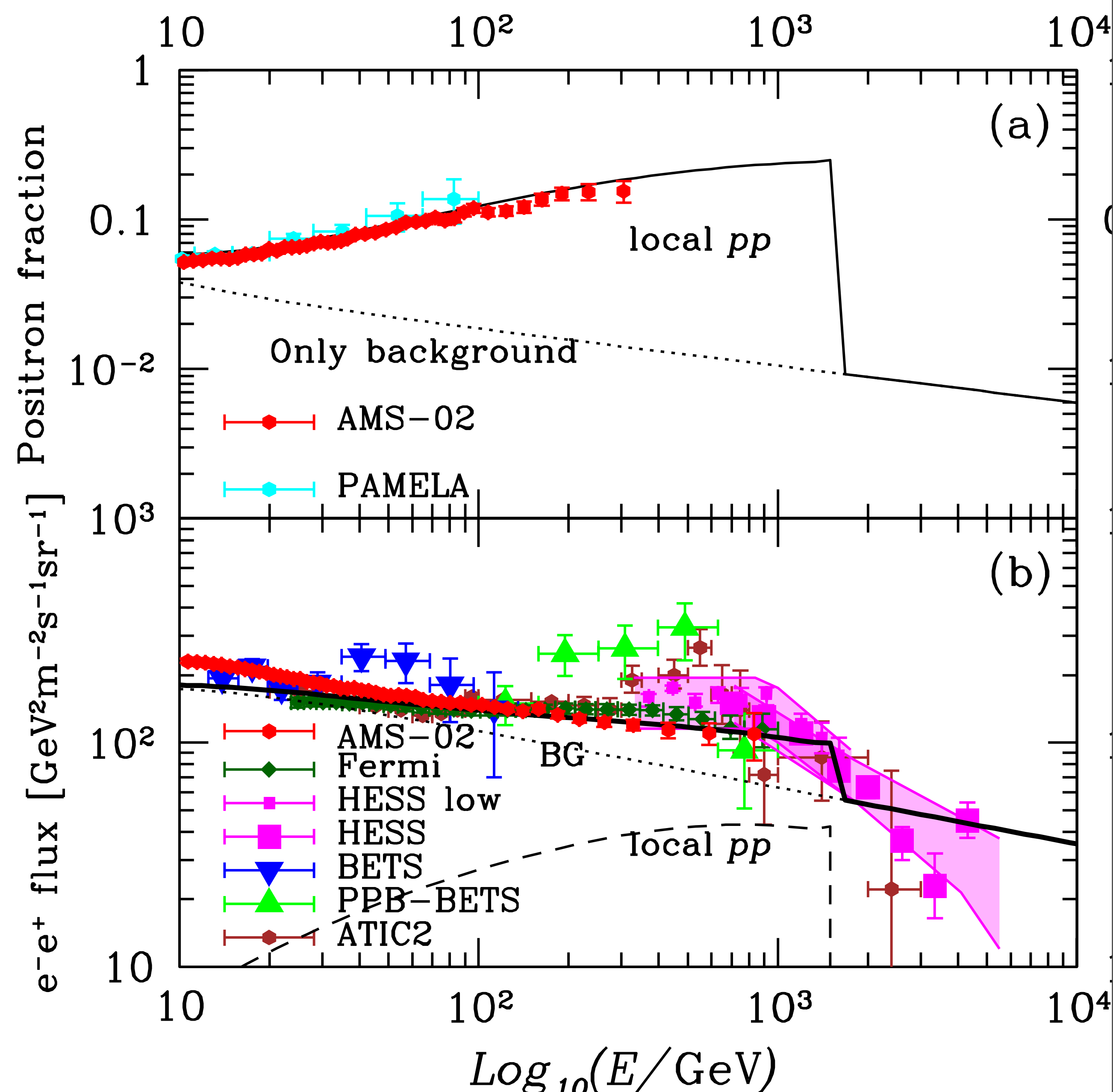
Astrophysics ?



G.Giesen et al, 1504.04276

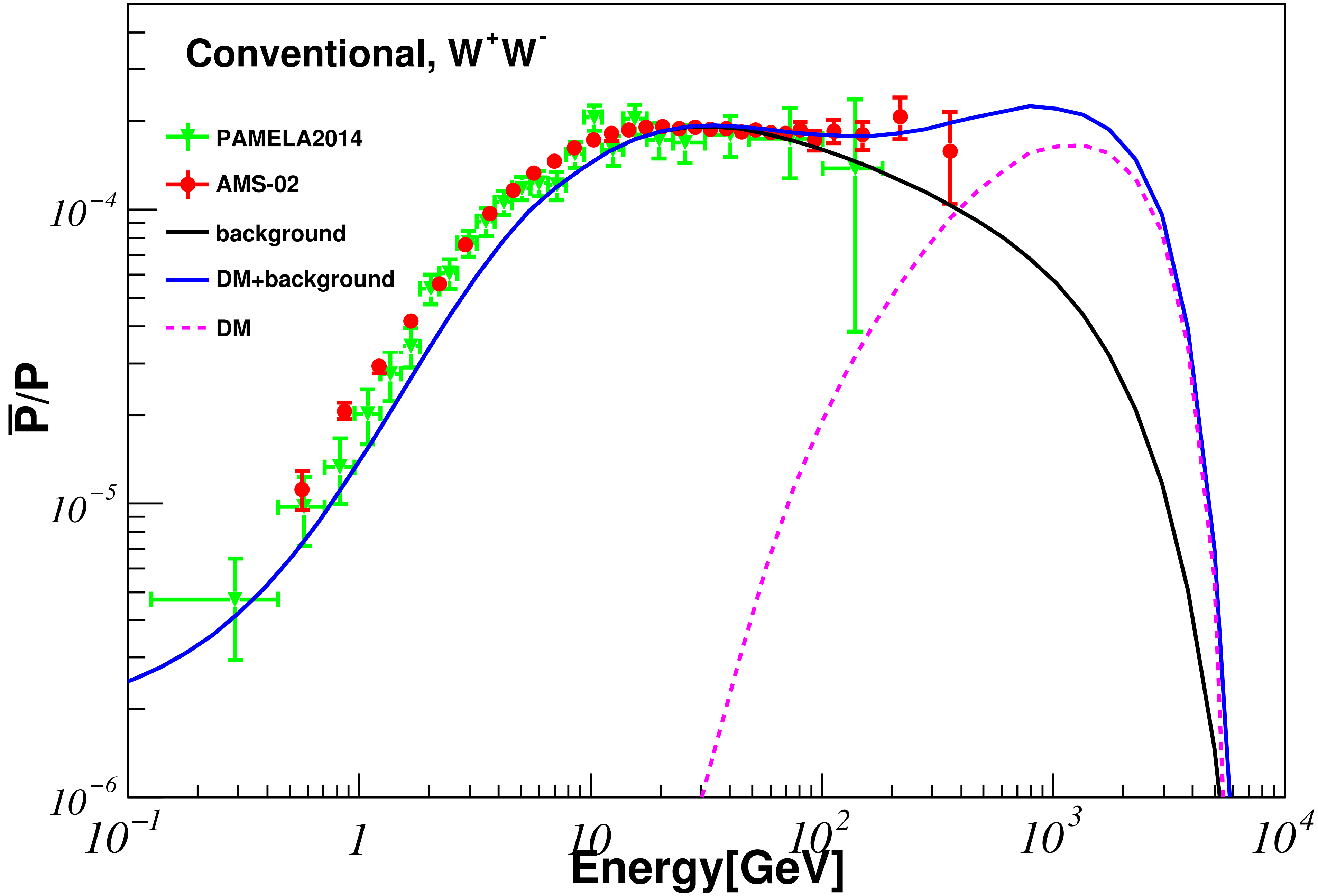
Astrophysics ?





Kohri, Ioka, Fujita, Yamazaki, 1505.01236

Dark Matter ！？

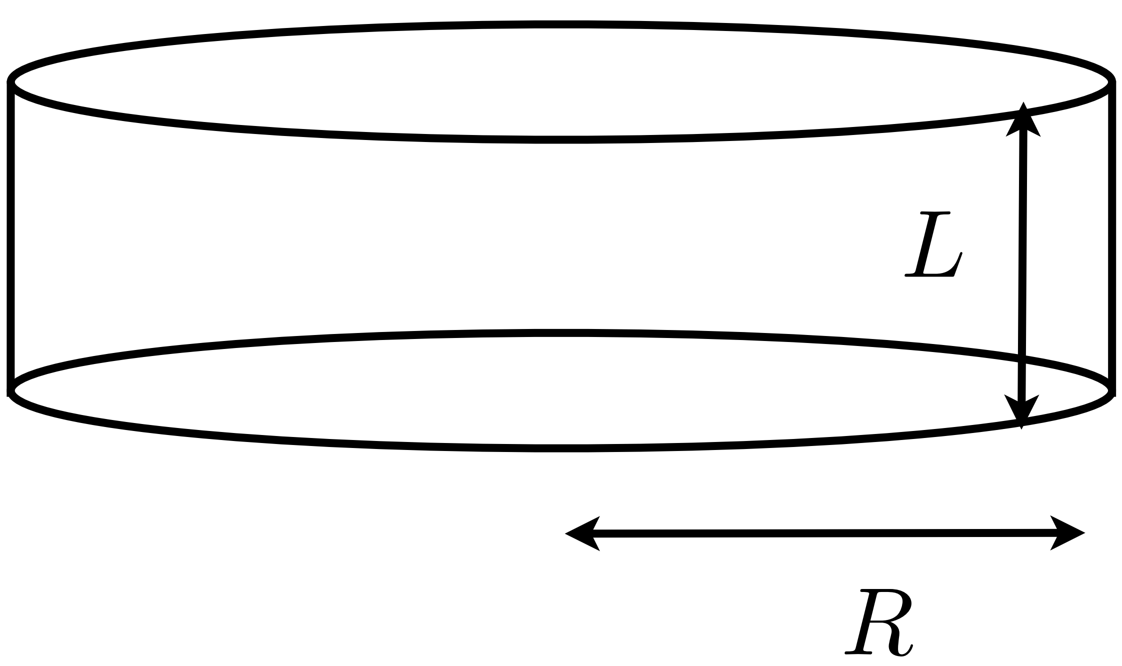


Jin, Wu, Zhou, 1504.04604

• Diffusion Equation

$$\frac{\partial}{\partial t} f_i(E,\vec{x}) = K(E)\nabla^2 f_i(E,\vec{x}) + \frac{\partial}{\partial E}[b(E) f_i(E,\vec{x})] + Q_i(E,\vec{x}) - \frac{\partial}{\partial z}[V_c(z) f_i(E,\vec{x})] - \frac{f_i(E,\vec{x})}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} f_j(E,\vec{x}),$$

$f_i(E,\vec{x})$: Distribution function of species i



Model	R(kpc)	L(kpc)	K_0(kpc^2/Myr)
MIN	20	1	0.0016
MED	20	4	0.0112
MAX	20	15	0.0765

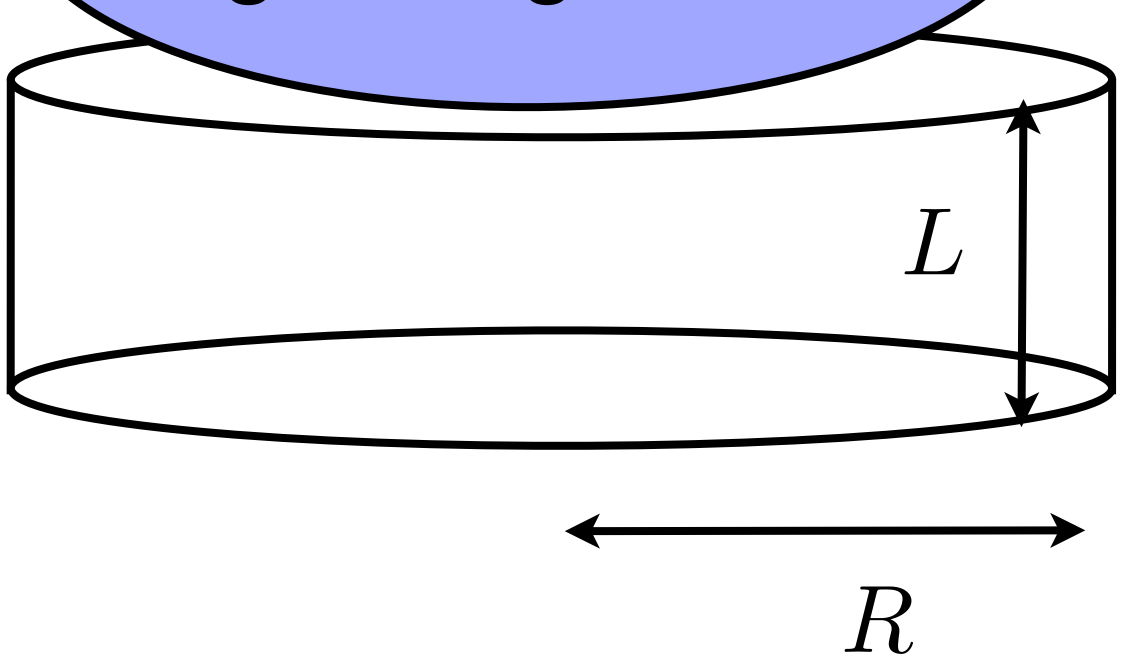
δ	V_c(km/s)
0.85	13.5
0.70	12
0.46	5

• Diffusion Equation

$$\frac{\partial}{\partial t} f_i(E,\vec{x}) = K(E)\nabla^2 f_i(E,\vec{x}) + \frac{\partial}{\partial E}[b(E) f_i(E,\vec{x})] + Q_i(E,\vec{x}) - \frac{\partial}{\partial z}[V_c(z) f_i(E,\vec{x})] - \frac{f_i(E,\vec{x})}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} f_j(E,\vec{x}),$$

$f_i(E$ … function of species i

Diffusion due to tangled magnetic field



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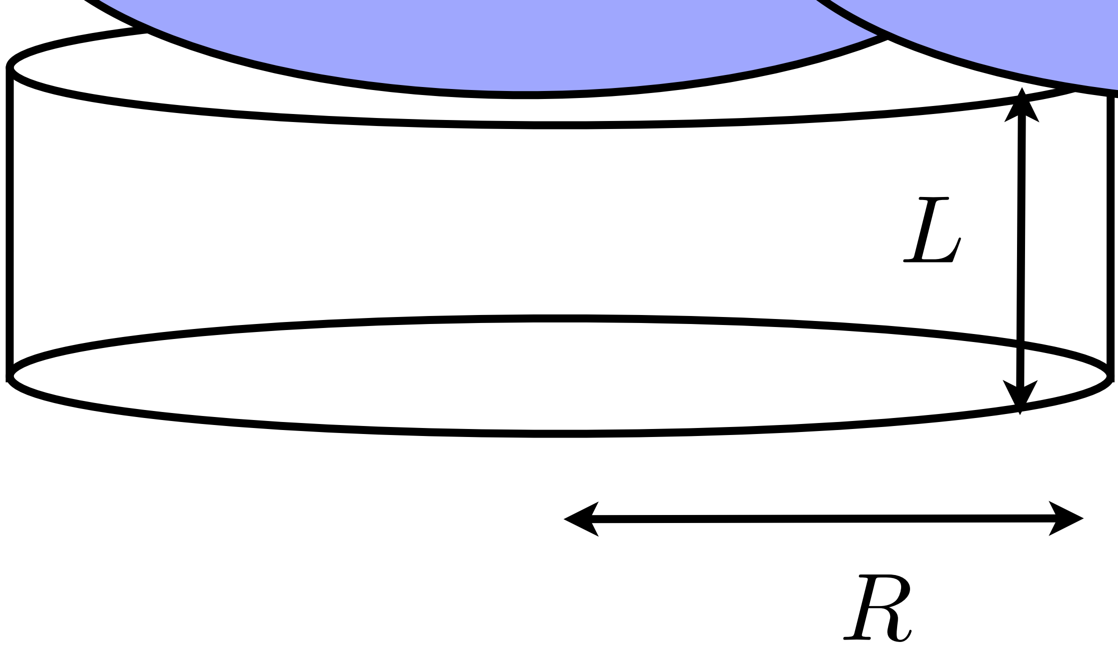
Diffusion due t[illegible] tangled magnetic [illegible]

Energy loss due to I.C. and synchrotron

$f_i(E$ [illegible] ies i



		L(kpc)	K_0(kpc^2/Myr)
[illegible]	20	1	0.0016
MED	20	4	0.0112
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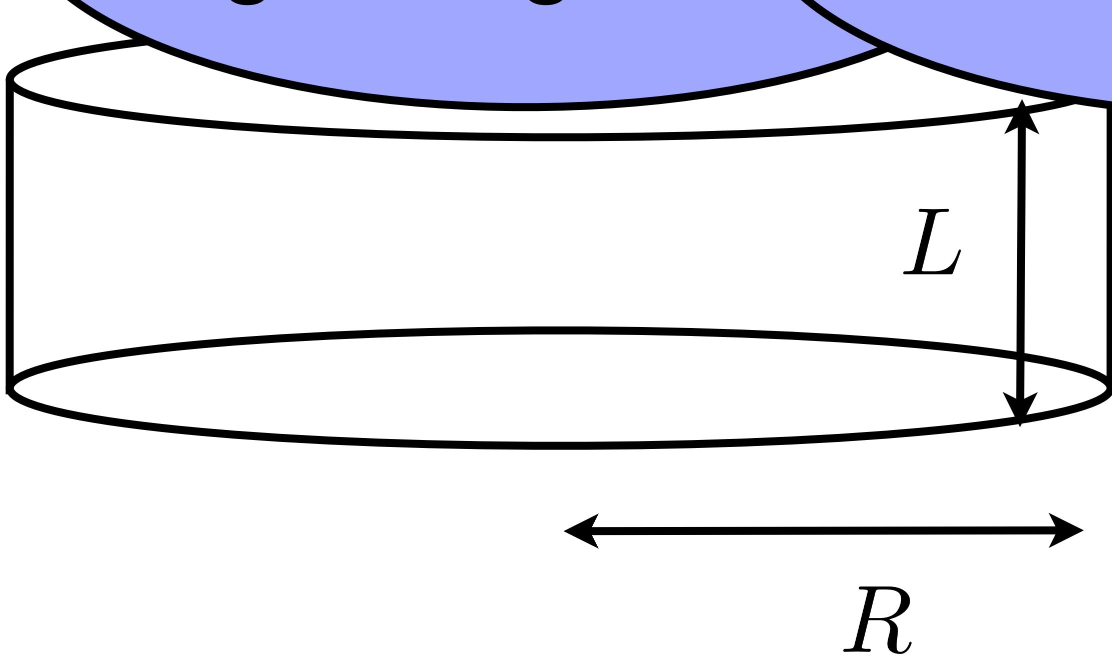
Diffusion due t
tangled magnetic

Energy loss du
I.C. and synchro

Source (Supernova,
Dark Matter)

$f_i(E$



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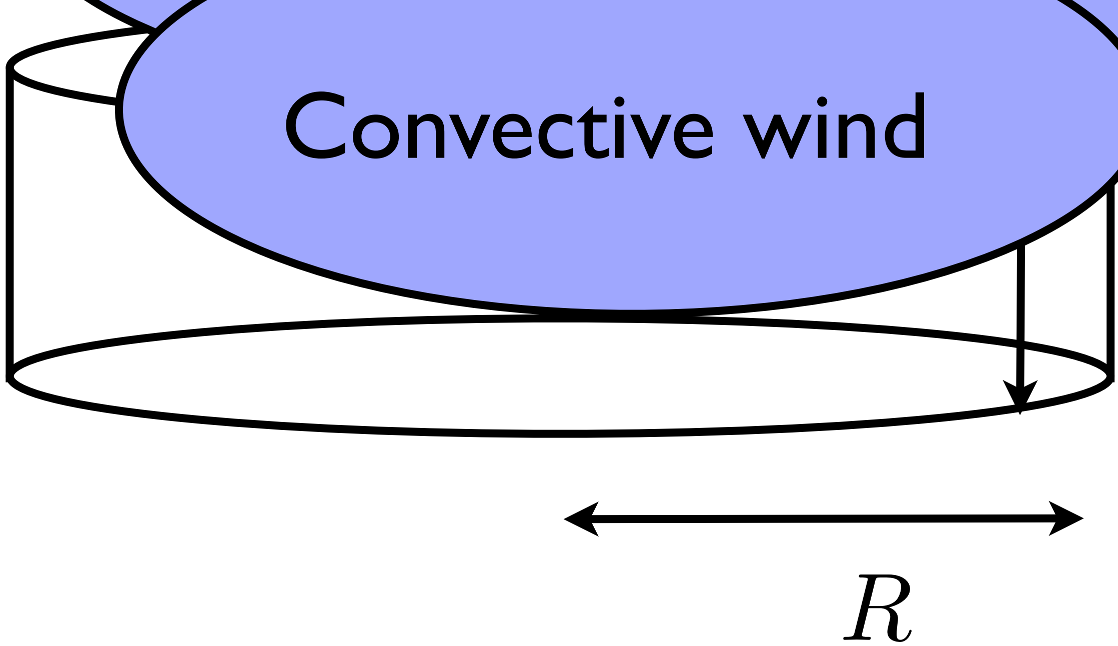
Diffusion due t… tangled…

Energy loss du… …IC and synchro…

Source (Supernova, Dark Matter)

Convective wind



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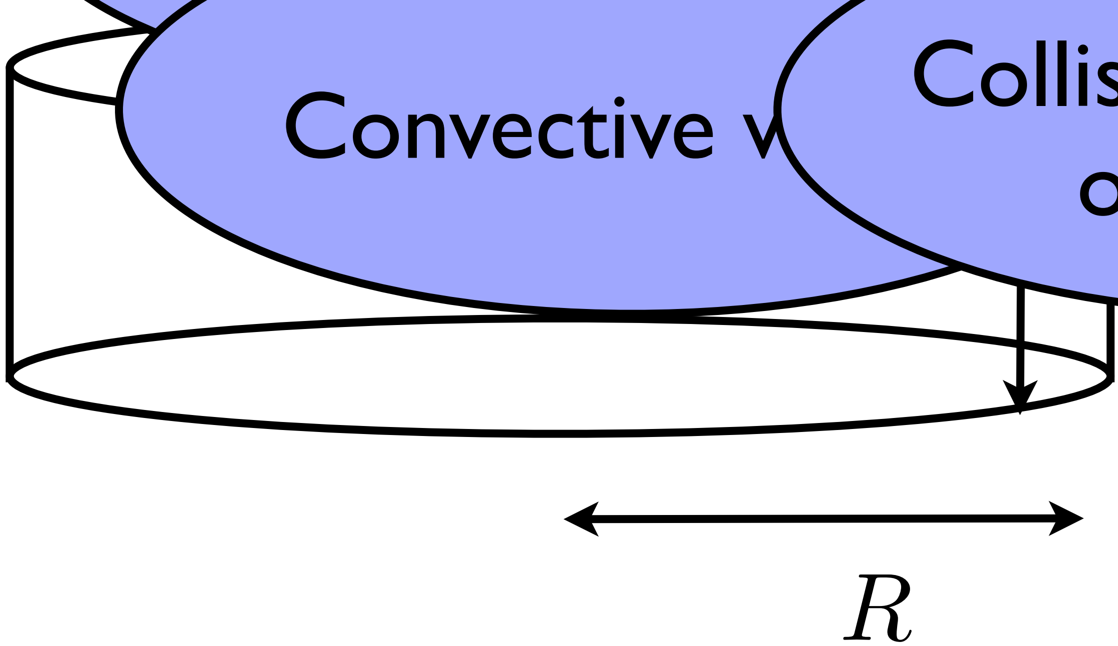
Diffusion due t
tangled

Energy loss

Source (Supernova,
Dark Matter)

Convective v

Collision of nucleus
of i species



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Diffusion due t
tangled

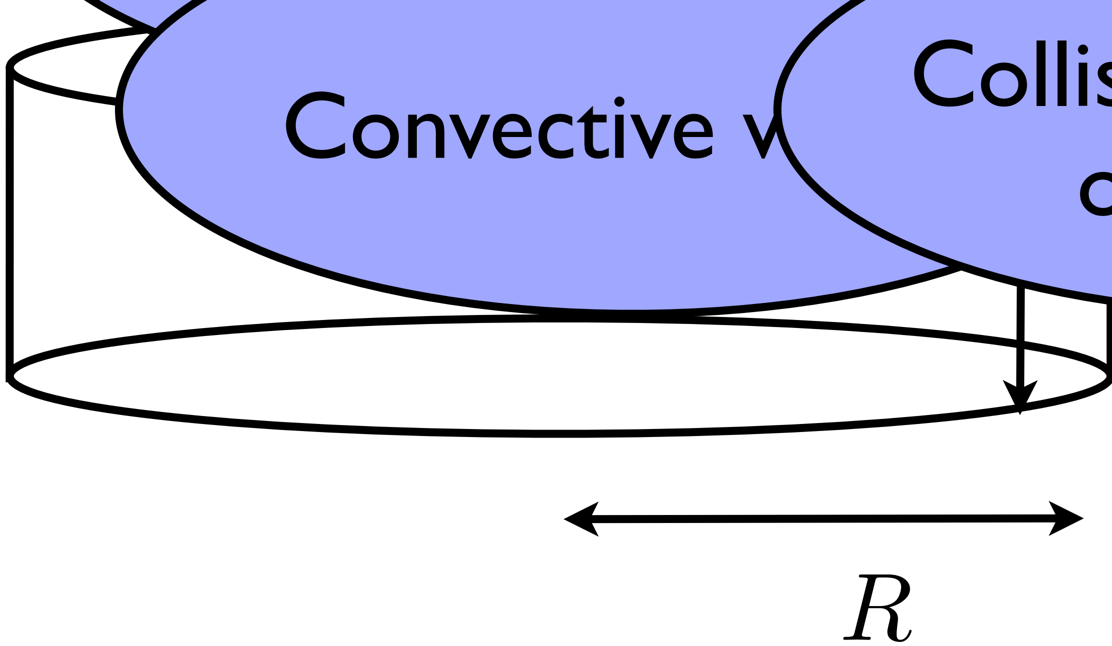
Energy loss du

Source (Sup rnova,

Convective w

Collision of nuc
of i species

Production of i
from collision of j



δ	V_c(km/s)
0.85	13.5
0.70	12
0.46	5

- Diffusion Equation for Positron

$$\frac{\partial}{\partial t} f_i(E,\vec{x}) = K(E)\nabla^2 f_i(E,\vec{x}) + \frac{\partial}{\partial E}[b(E) f_i(E,\vec{x})] + Q_i(E,\vec{x})$$
$$- \frac{\partial}{\partial z}[V_c(z) f_i(E,\vec{x})] - \frac{f_i(E,\vec{x})}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} f_j(E,\vec{x}),$$

Diffusion due t

tangle

Energy loss du

Source (Sup rnova,

Convective v

Collision of nuc
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Production of i
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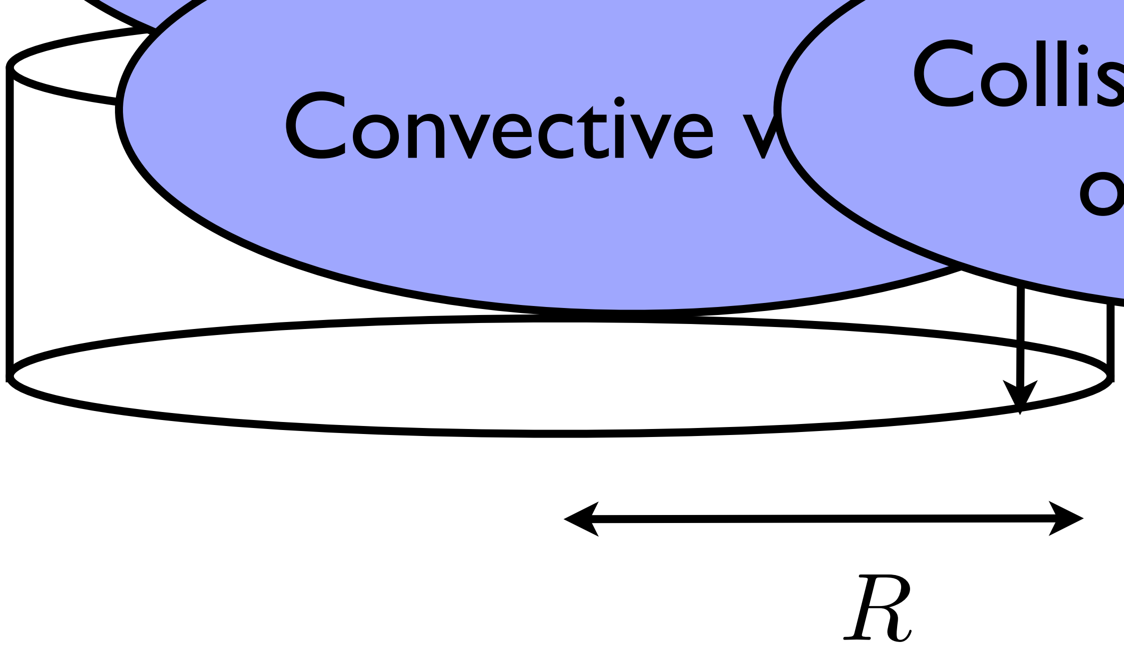

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Diffusion due t
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Energy loss due

Source (Sup rnova,

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Collision of nuc
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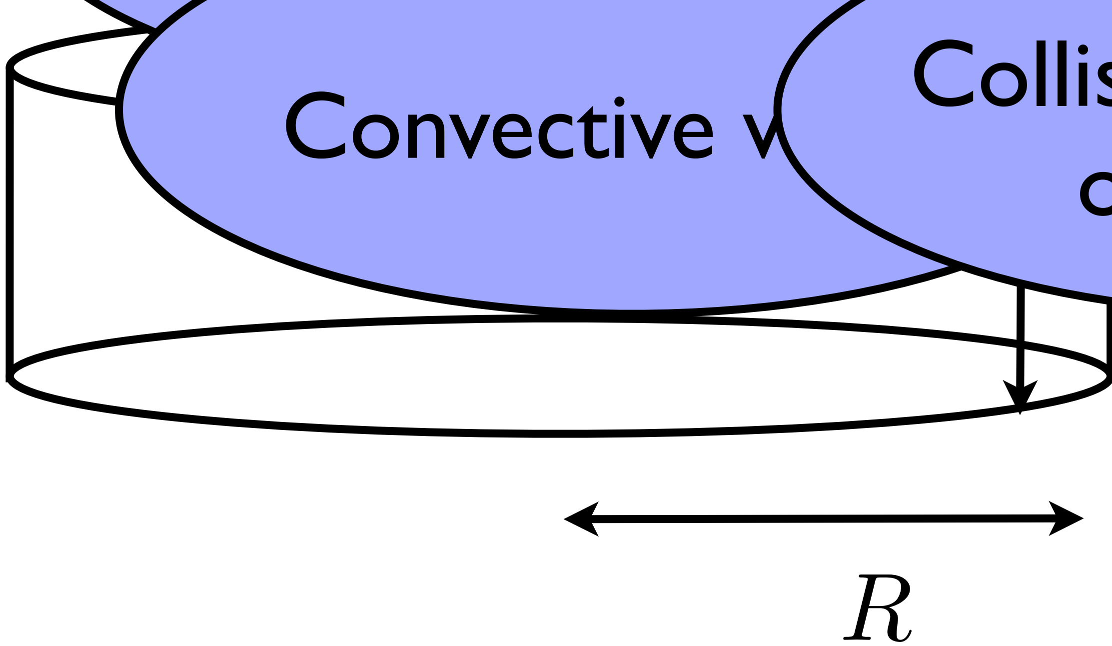

δ	V_c(km/s)
0.85	13.5
0.70	12
0.46	5

- # Diffusion Equation for Anti-Proton

$$\frac{\partial}{\partial t} f_i(E,\vec{x}) = K(E)\nabla^2 f_i(E,\vec{x}) + \frac{\partial}{\partial E}[b(E) f_i(E,\vec{x})] + Q_i(E,\vec{x}) - \frac{\partial}{\partial z}[V_c(z) f_i(E,\vec{x})] - \frac{f_i(E,\vec{x})}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} f_j(E,\vec{x}),$$

Diffusion due t
tangled

Energy loss du

Source (Sup rnova,

Convective v

Collision of nuc
of i species

Production of i
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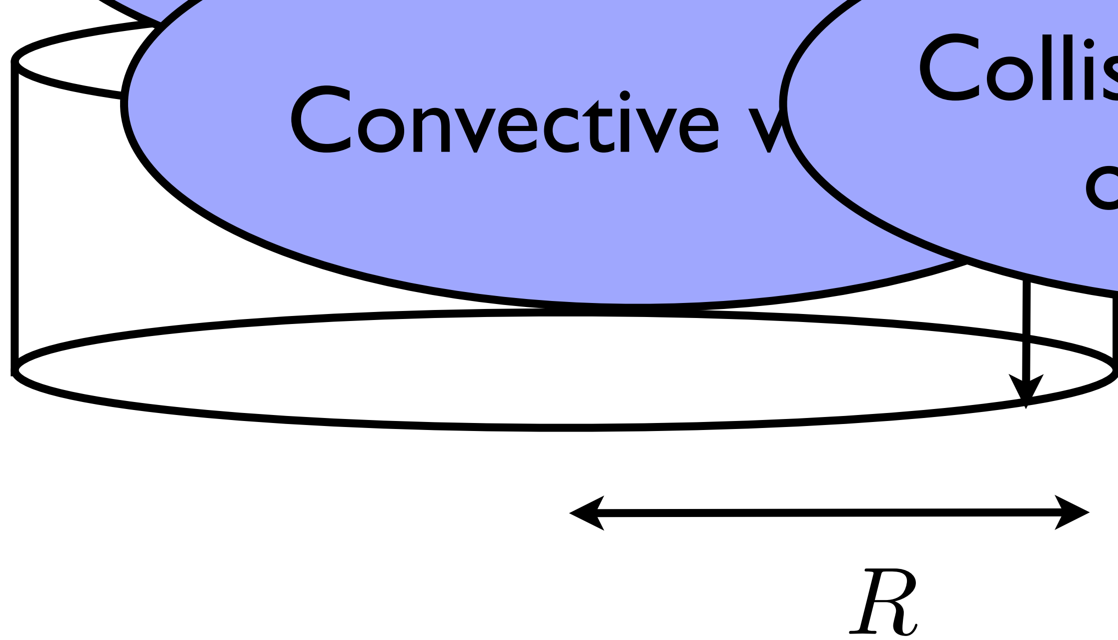


δ	V_c(km/s)
0.85	13.5
0.70	12
0.46	5

- # DM source term

$$Q(T,\vec{r}) = q(\vec{r})\frac{dN_{\bar{p}}(T)}{dT}$$

$$q(\vec{r}) = \frac{1}{2}\langle\sigma v\rangle\left(\frac{\rho_{\rm DM}(|\vec{r}|)}{m_{\rm DM}}\right)^2 \qquad \text{for annihilating DM}\,,$$

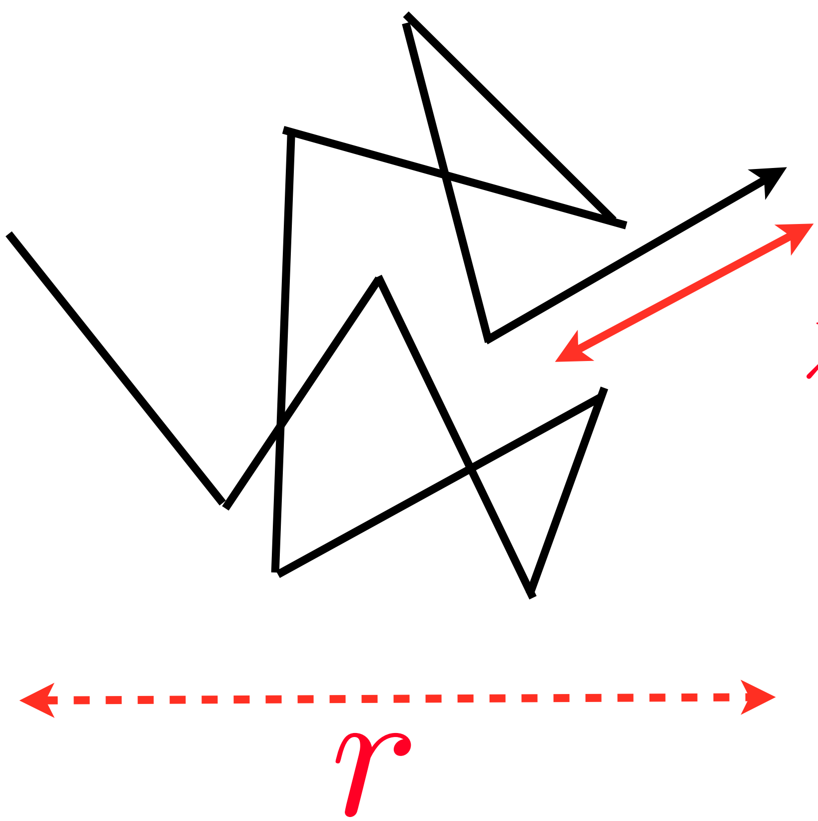
$$q(\vec{r}) = \frac{1}{\tau_{\rm DM}}\left(\frac{\rho_{\rm DM}(|\vec{r}|)}{m_{\rm DM}}\right) \qquad \text{for decaying DM}\,.$$

$\frac{dN_{\bar{p}}(T)}{dT}$: energy spectrum of anti-p from DM decay

$\langle\sigma v\rangle$, $\tau_{\rm DM}$: DM annihilation cross section, lifetime

$\rho_{\rm DM}(|\vec{r}|)$: DM density profile in the Galaxy

- Propagation of charged particle in tangled magnetic field



$$\lambda = \frac{K(E)}{c} \sim 10^{17}\mathrm{cm}\left(\frac{E}{1\mathrm{GeV}}\right)^{\delta} \sim 0.1\mathrm{pc}$$

$$r \sim \sqrt{K(E)t} \sim 1\mathrm{kpc}\left(\frac{t}{10^8\,\mathrm{yr}}\right)^{\frac{1}{2}}\left(\frac{E}{1\mathrm{GeV}}\right)^{\frac{\delta}{2}}$$

Charged particle escapes from diffusion zone after 10^7~10^8 yr.

$$\equiv t_{\mathrm{esc}}$$

- Electron/positron loses energy before escape due to inverse Compton and synchrotron:

$$r_{\mathrm{loss}} = \sqrt{\frac{EK(E)}{b(E)}} \sim 1.8\,\mathrm{kpc}\left(\frac{1\,\mathrm{GeV}}{E}\right)^{(\delta-1)/2}$$

- Primary/Secondary ratio

Primary: Produced at Source (Proton, Carbon, ...) $f_{\rm prim}$

Secondary: Produced by primary CR-intersteller medium interaction (Anti-proton, Boron, ...) $f_{\rm sec}$

$$\frac{f_{\rm sec}}{f_{\rm prim}} \sim \frac{t_{\rm int}}{t_{\rm esc}}$$

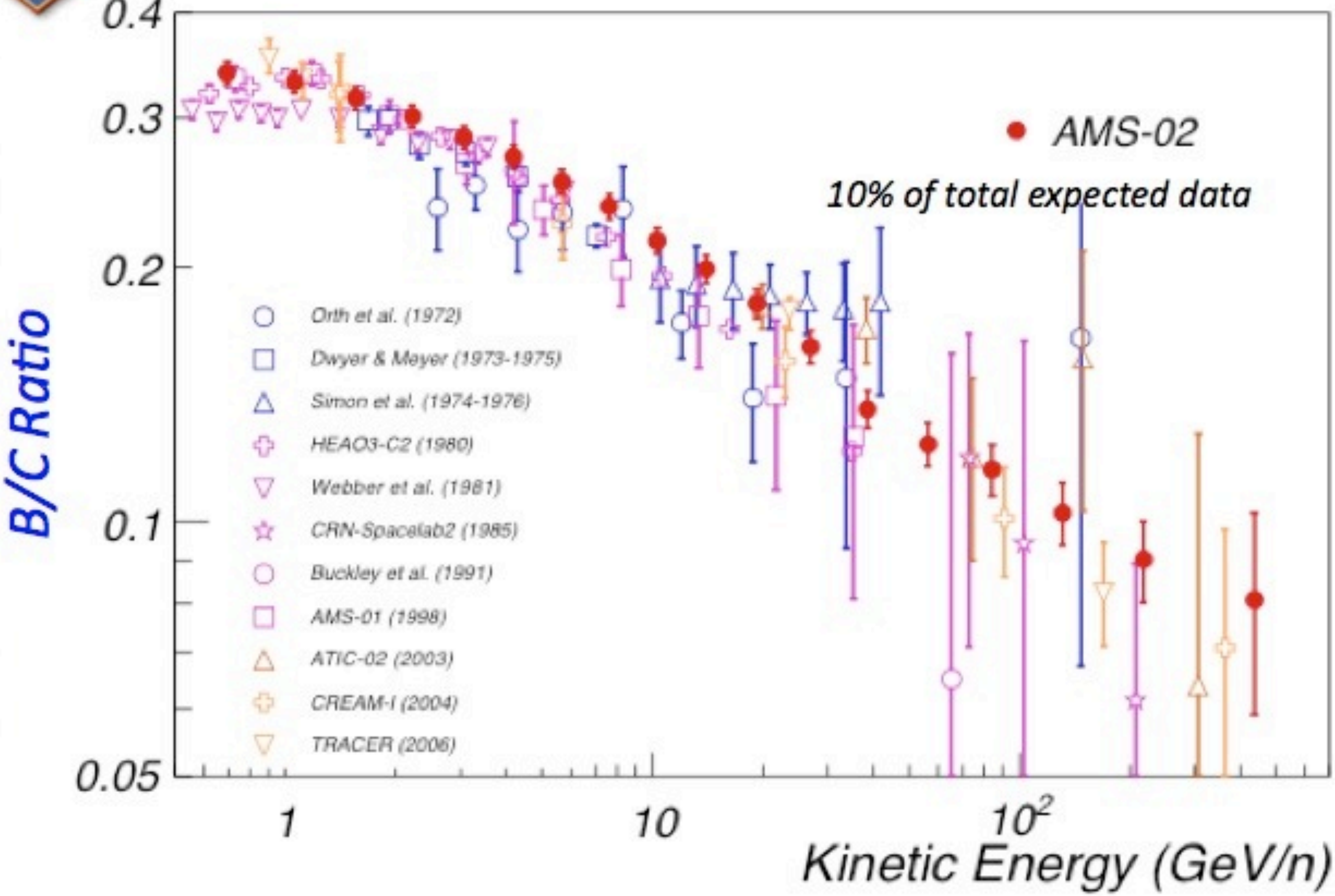
Prim/Sec ratio determines escape time, but there is a degeneracy on K and L.

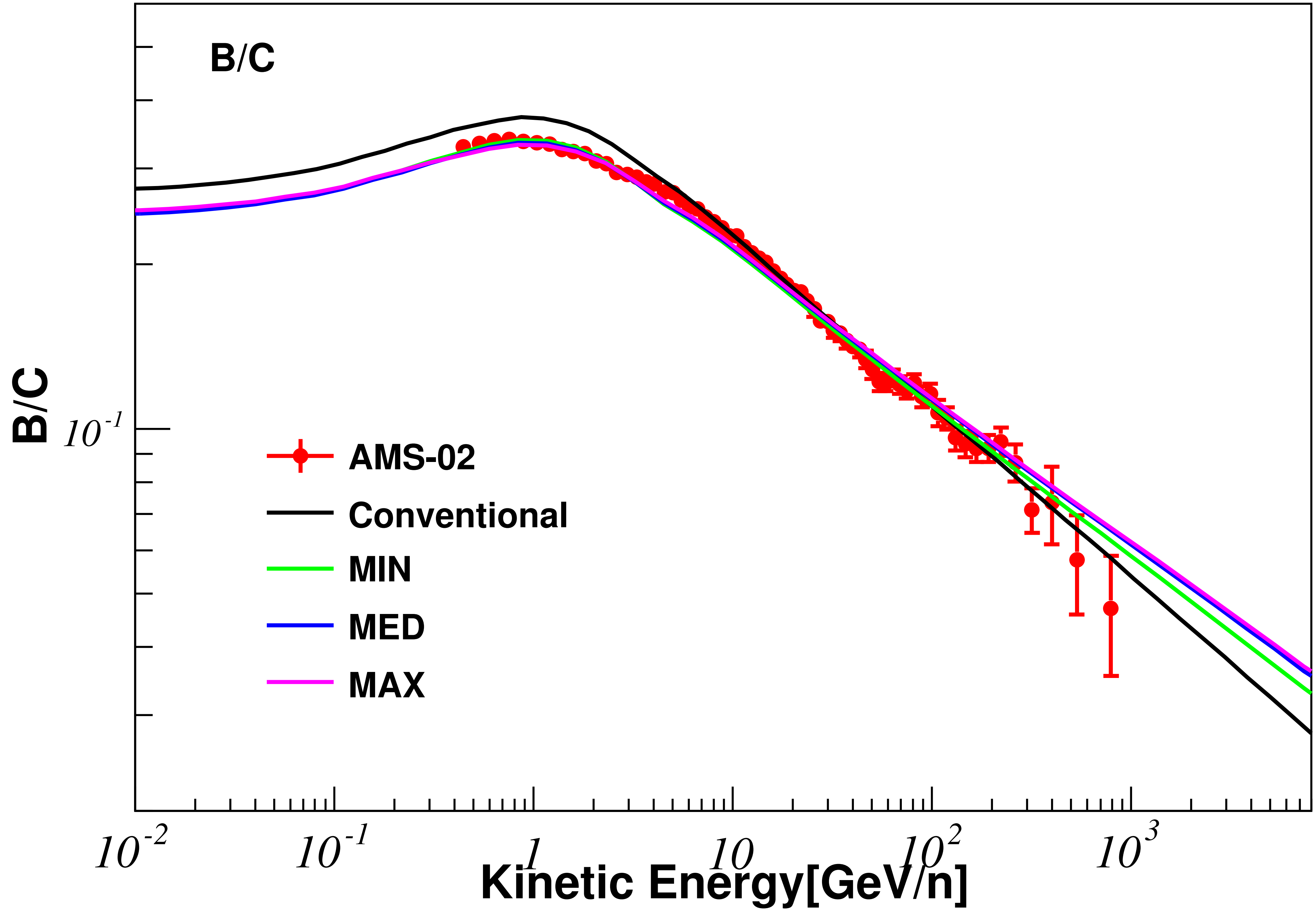
	R [kpc]	L [kpc]	δ	K_0[kpc^2/Myr]	K_0[cm^2/s]	V_c[km/s]
MAX	20.0	15	0.46	0.0765	2.31×10^{28}	5
MED	20.0	4	0.70	0.0112	3.38×10^{27}	12
MIN	20.0	1	0.85	0.0016	4.83×10^{26}	13.5

Donato et al. (2004)

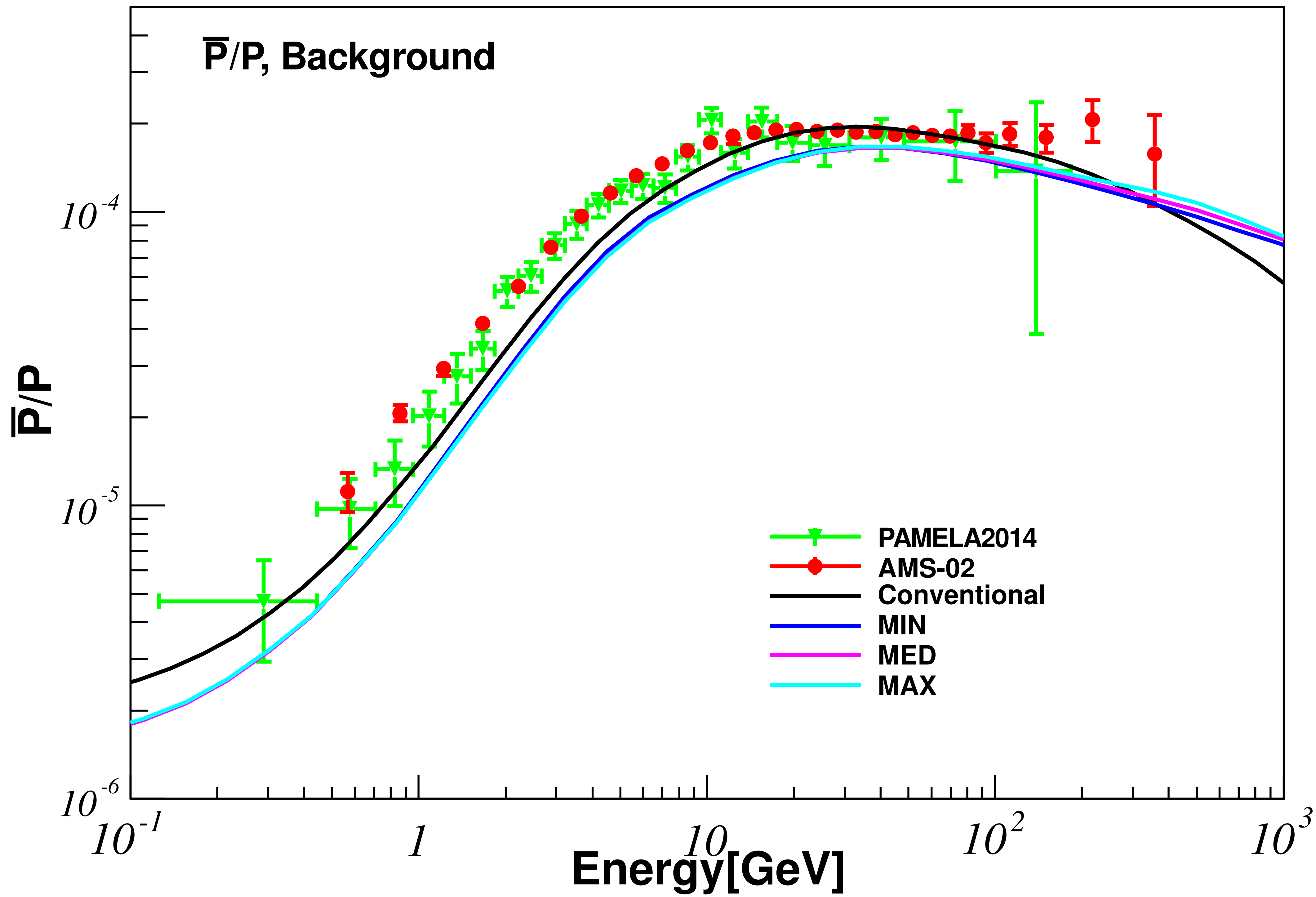
Anti-p of DM origin is Primary, not Secondary, hence anti-p flux of DM origin significantly depend on L.

Boron-to-Carbon ratio compared with previous data



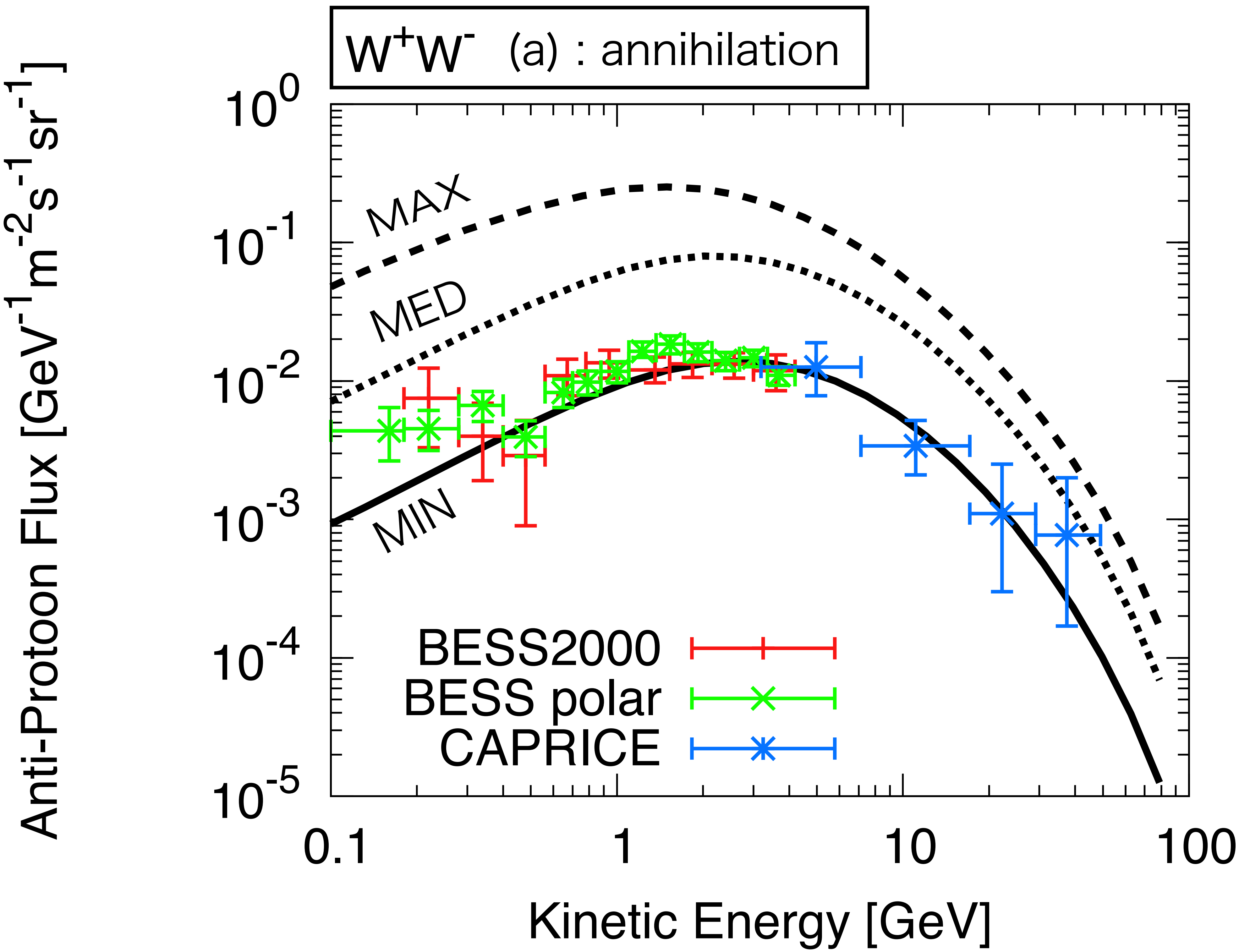


Jin, Wu, Zhou, 1504.04604

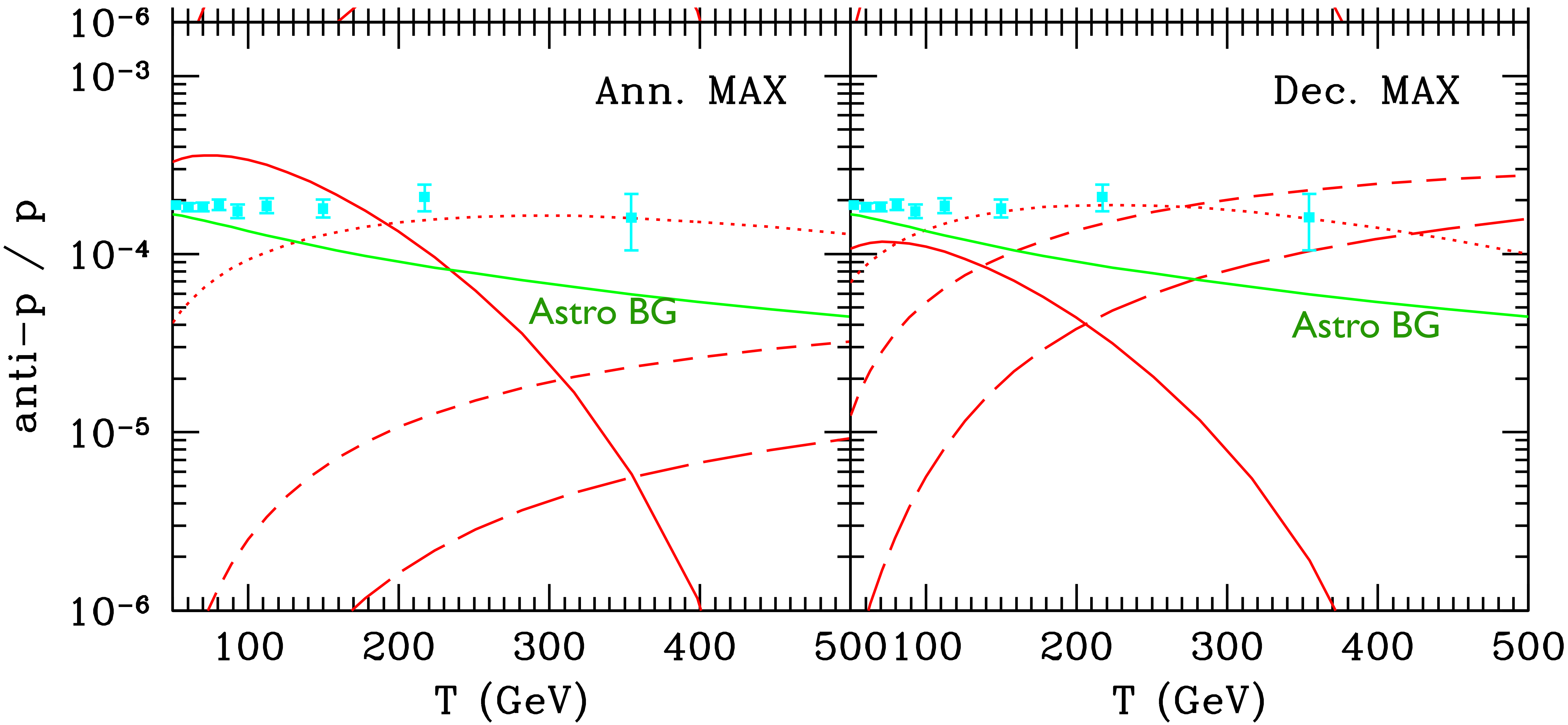


Jin, Wu, Zhou, 1504.04604

- Anti-proton flux from DM : diffusion model dependence



- Comparison with AMS-02 data



$\langle \sigma v \rangle = \ 6 \times 10^{-25}\ \mathrm{cm^3/sec}$

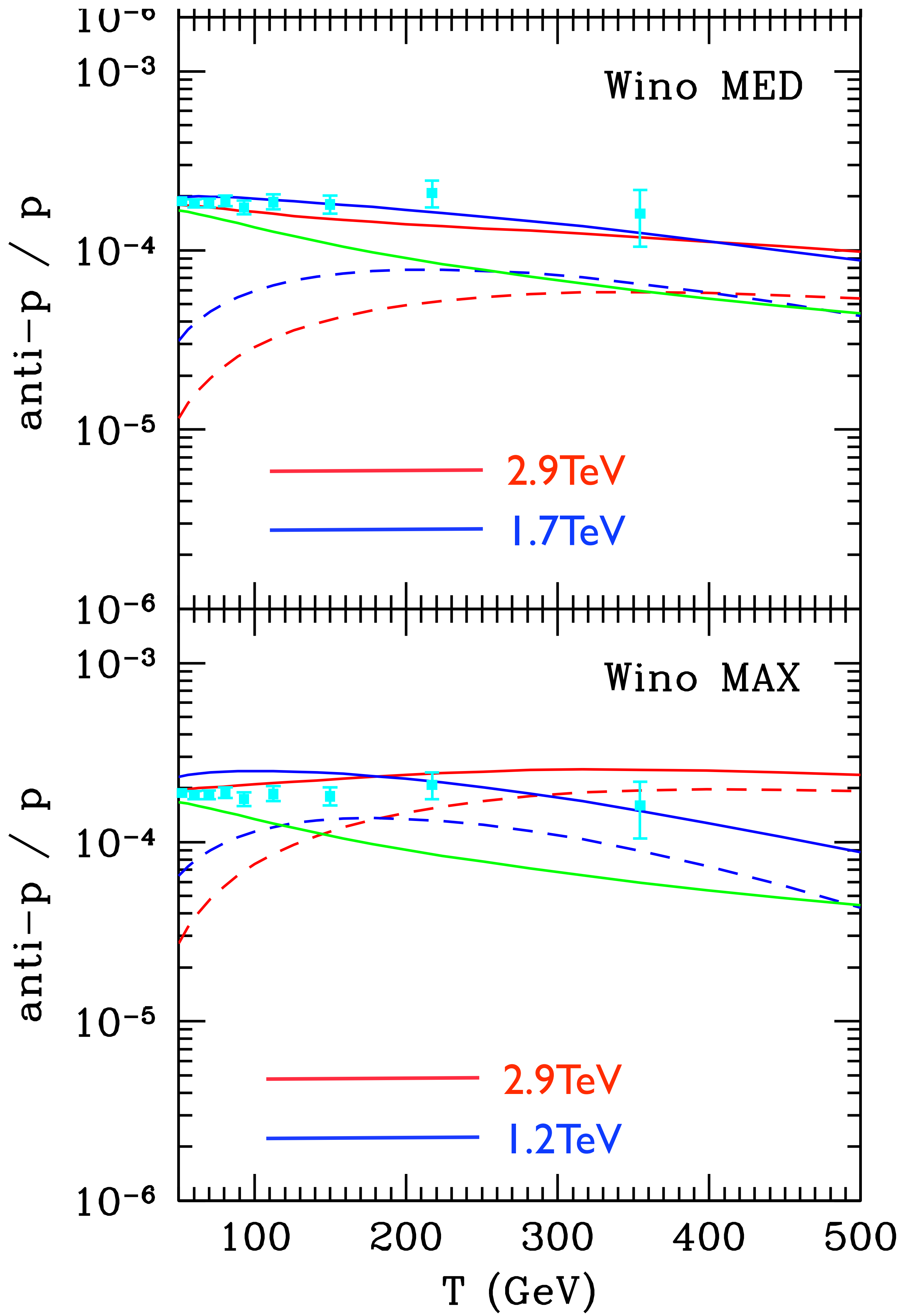
$m_{\mathrm{DM}} = 0.5,\ 1,\ 2,\ 10\mathrm{TeV}$

$\tau_{\mathrm{DM}} = 2 \times 10^{27}\ \mathrm{sec}$

$m_{\mathrm{DM}} = 1,\ 3,\ 10,\ 30\mathrm{TeV}$

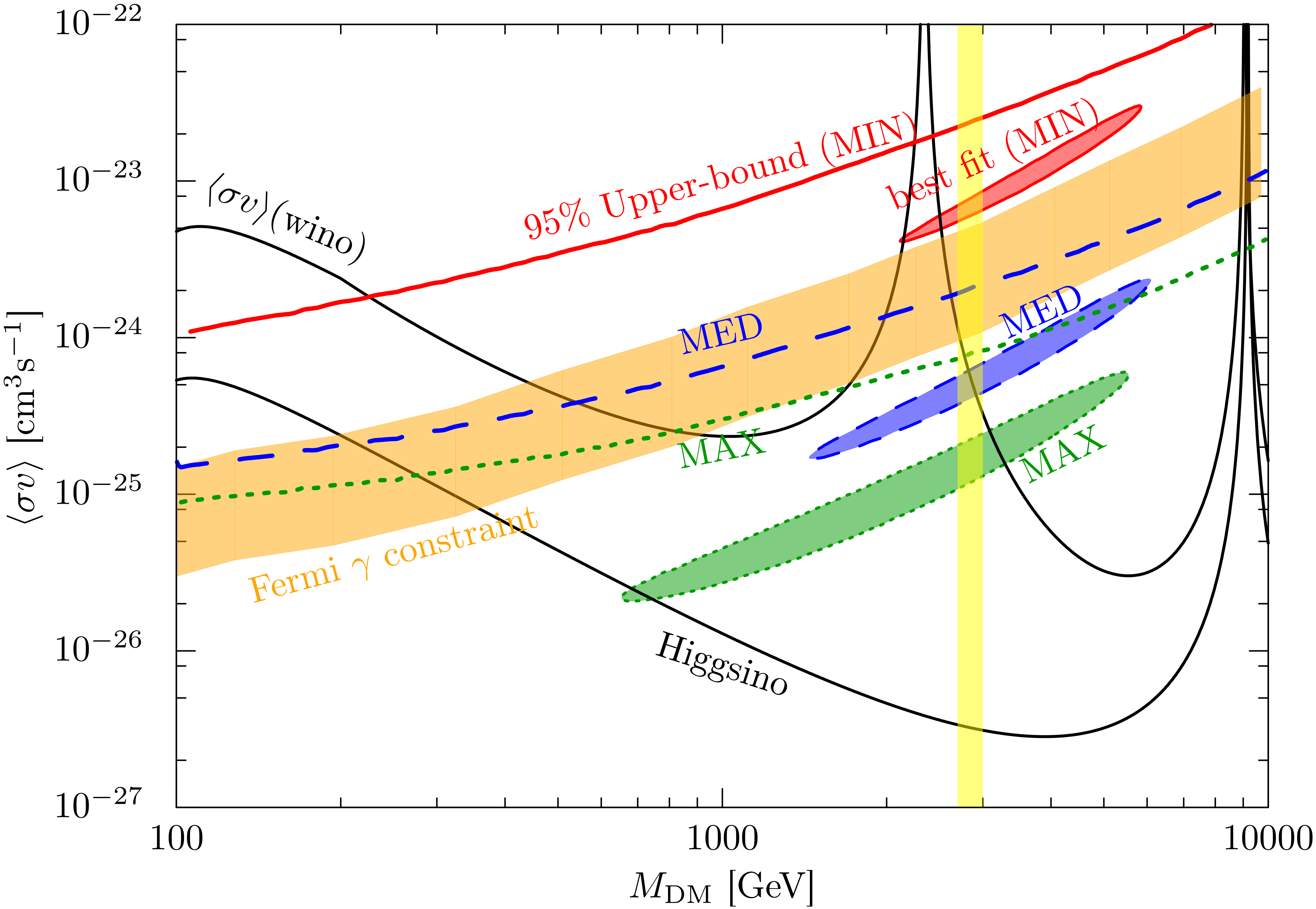
Hamaguchi, Moroi, KN, 1504.05937

- Wino Dark Matter
  - Wino : Superpartner of W boson.
  - Lightest SUSY particle in anomaly-mediation or pure gravity mediation.
  - Most attractive DM candidate after discovery of 125GeV Higgs.
  - It can reproduce AMS-02 result with thermal relic DM scenario!!



Ibe,Matsumoto,Shirai,Yanagida, 1504.05554
Hamaguchi, Moroi, KN, 1504.05937

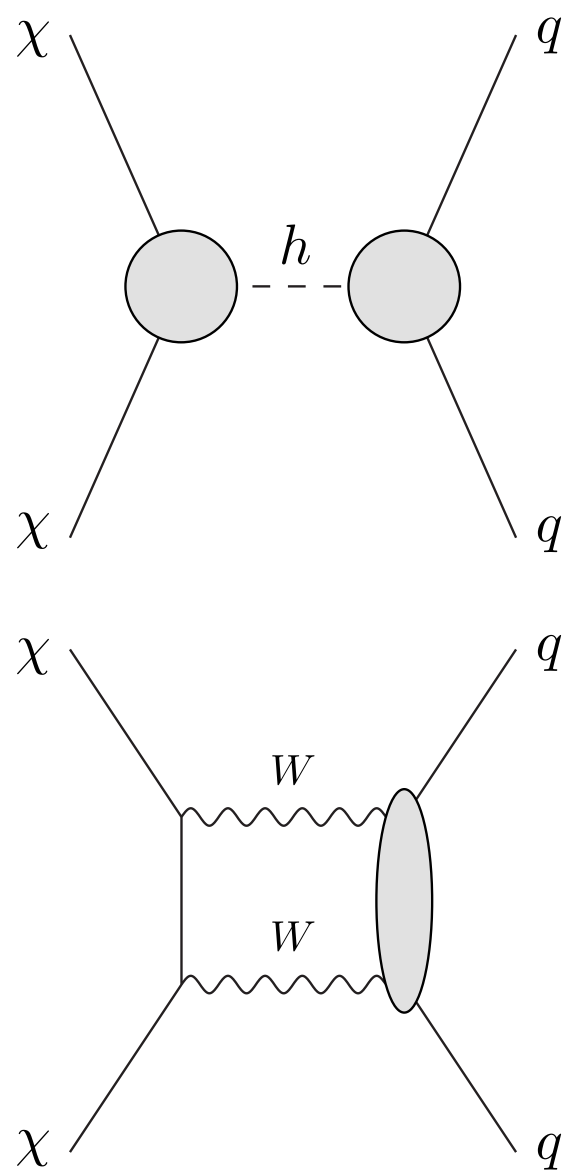
Wino Dark Matter

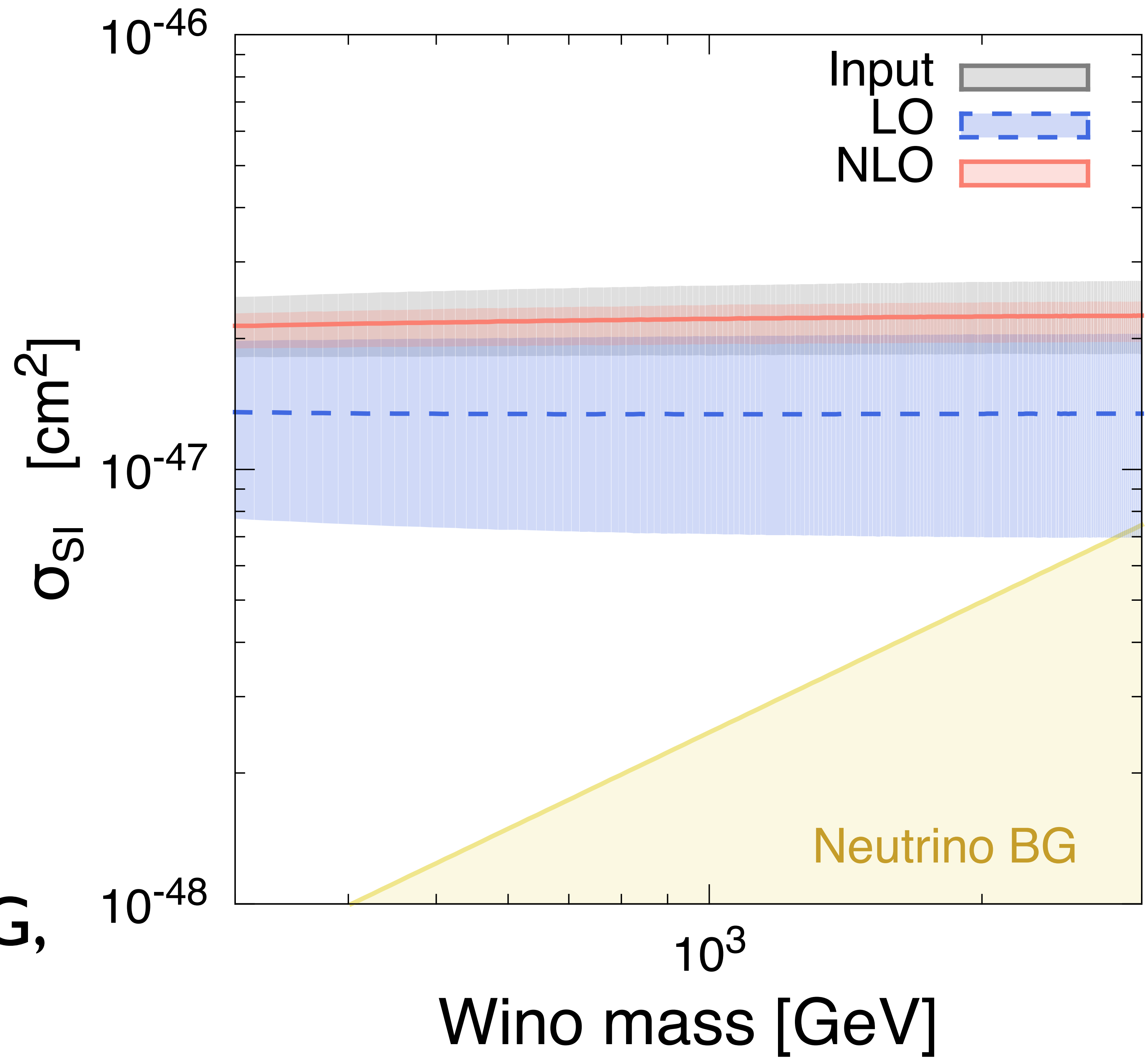


(a) Constraints

Ibe, Matsumoto, Shirai, Yanagida, 1504.05554

- Direct detection of Wino Dark Matter

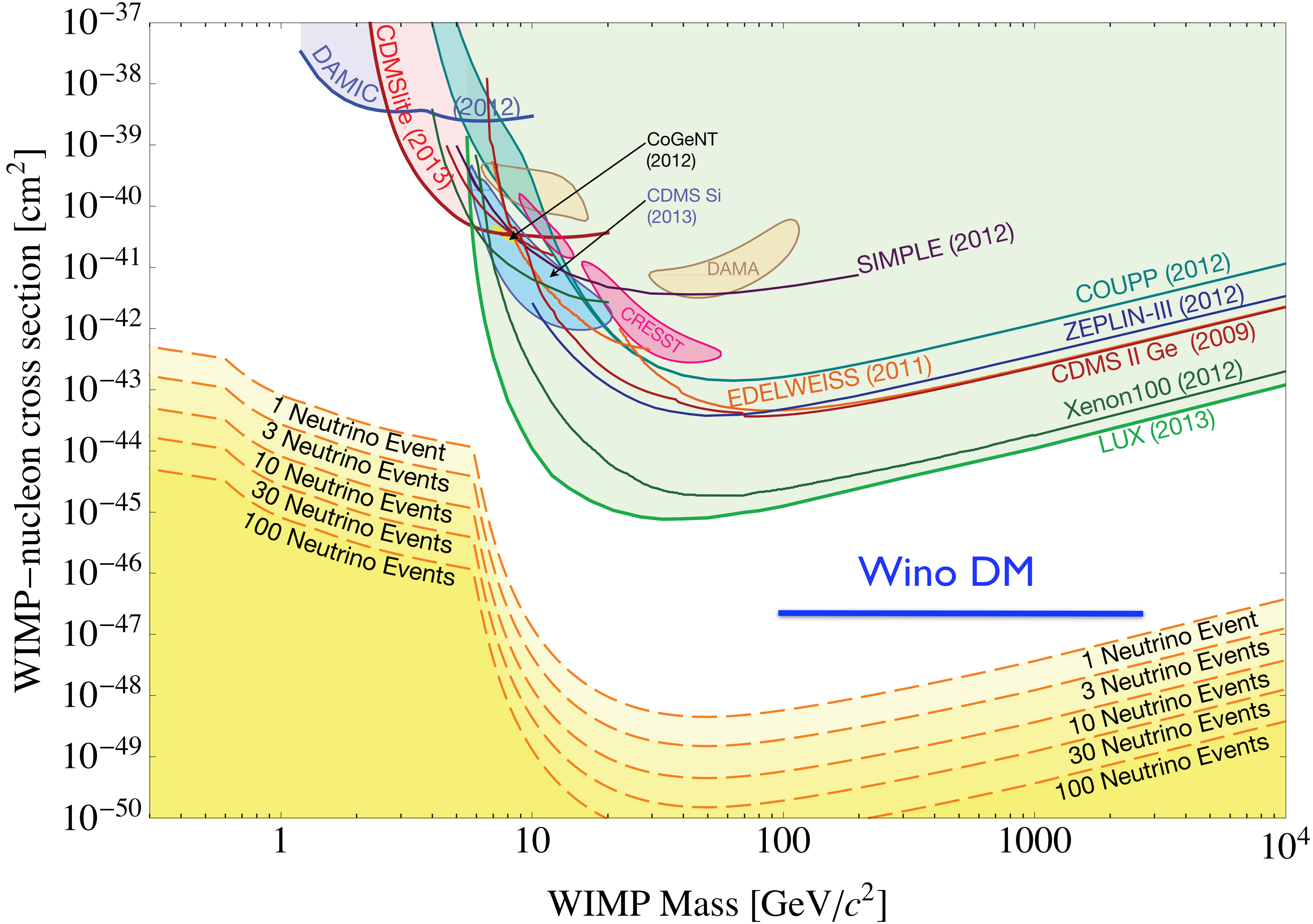




Well above neutrino BG, but still challenging.

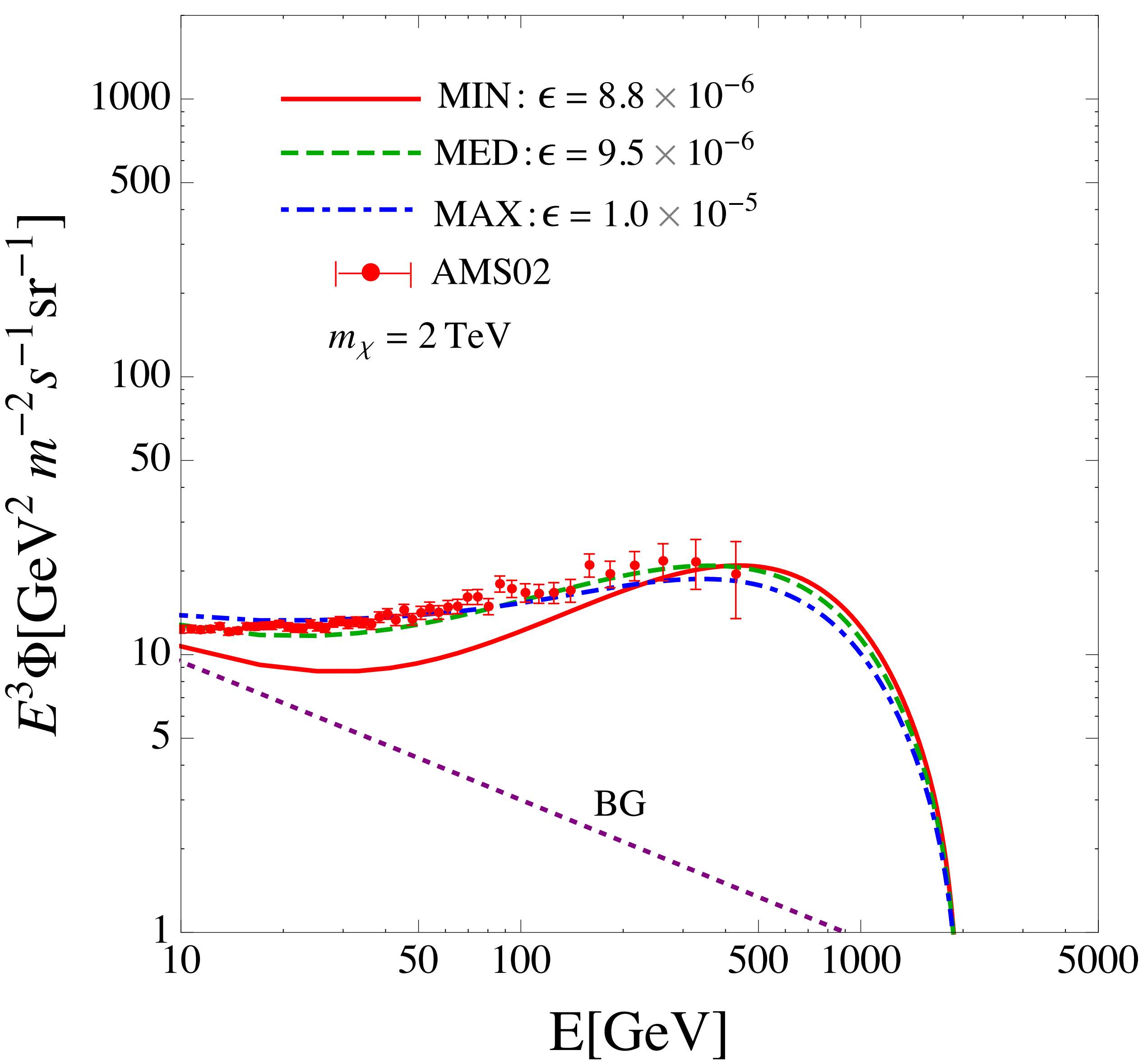
~2orders of magnitude below LUX level.

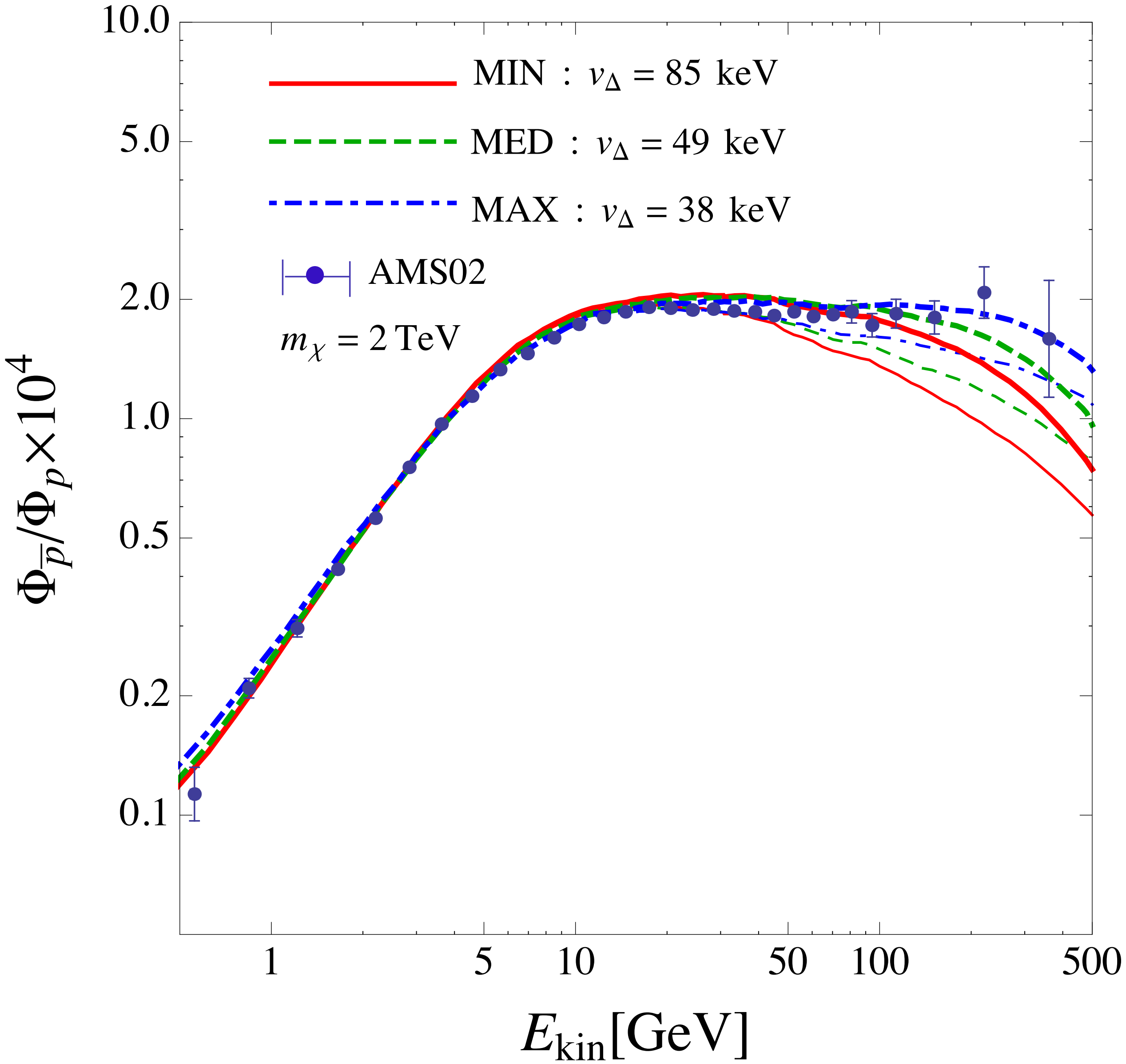
Hisano, Ishiwata, Nagata, 1504.00915



Billard, Figueroa-Faliciano, Strigari, 1307.5458

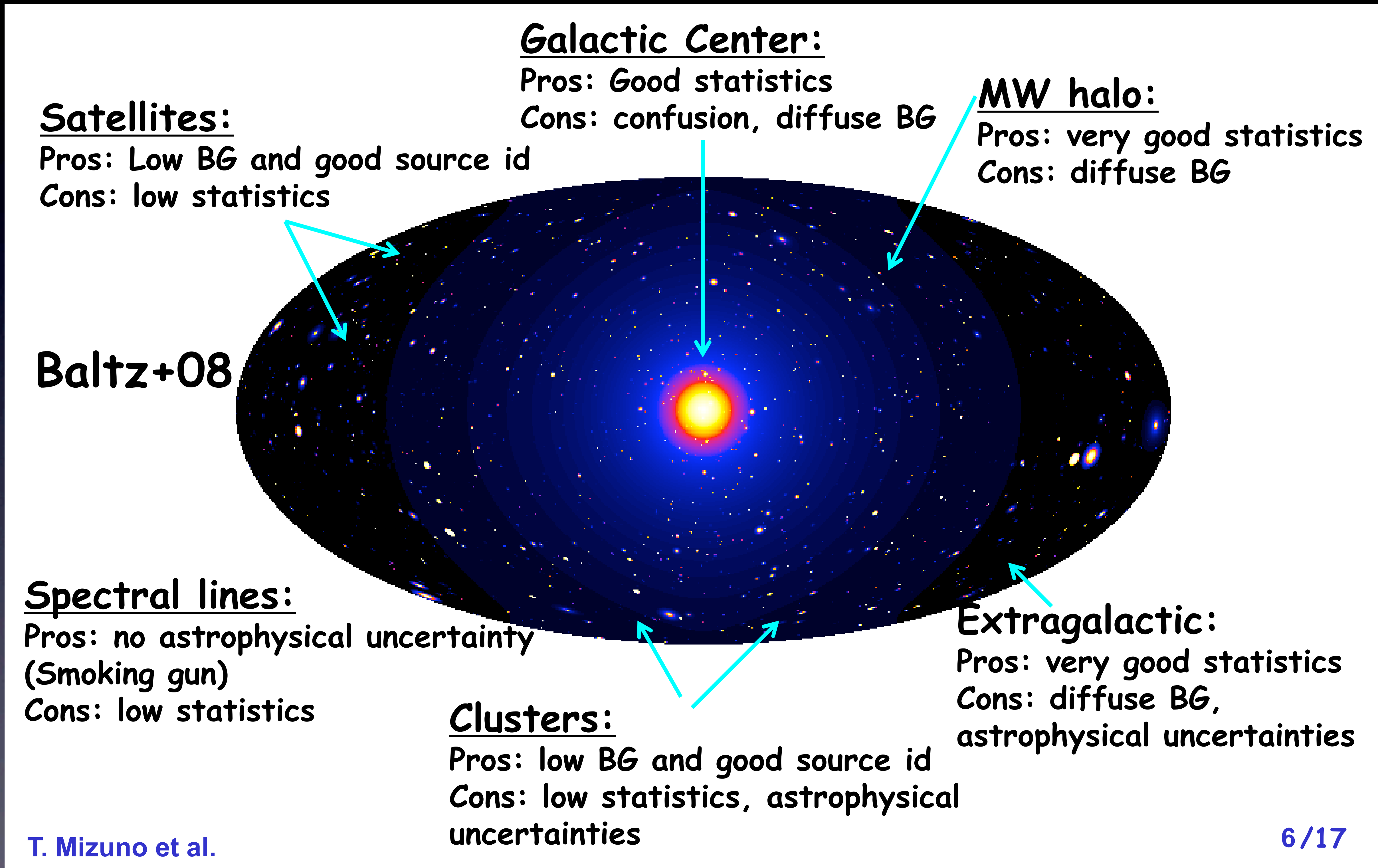
Positron and Anti-proton excess can be simultaneously explained by some DM model.





Chen, Chiang, Nomura, 1504.07848

Gamma-ray sky



Slide from Talk by Tsunefumi Mizuno

Gamma-rays from dwarf Spheroidals (dSph)

$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\rm DM}^2}\int_{E_{\rm min}}^{E_{\rm max}}\frac{{\rm d}N_\gamma}{{\rm d}E_\gamma}{\rm d}E_\gamma}_{\text{particle physics}} \times \underbrace{\int_{\Delta\Omega}\int_{\rm l.o.s.}\rho_{\rm DM}^2(\boldsymbol{r}){\rm d}l{\rm d}\Omega'}_{\text{J-factor}} .$$

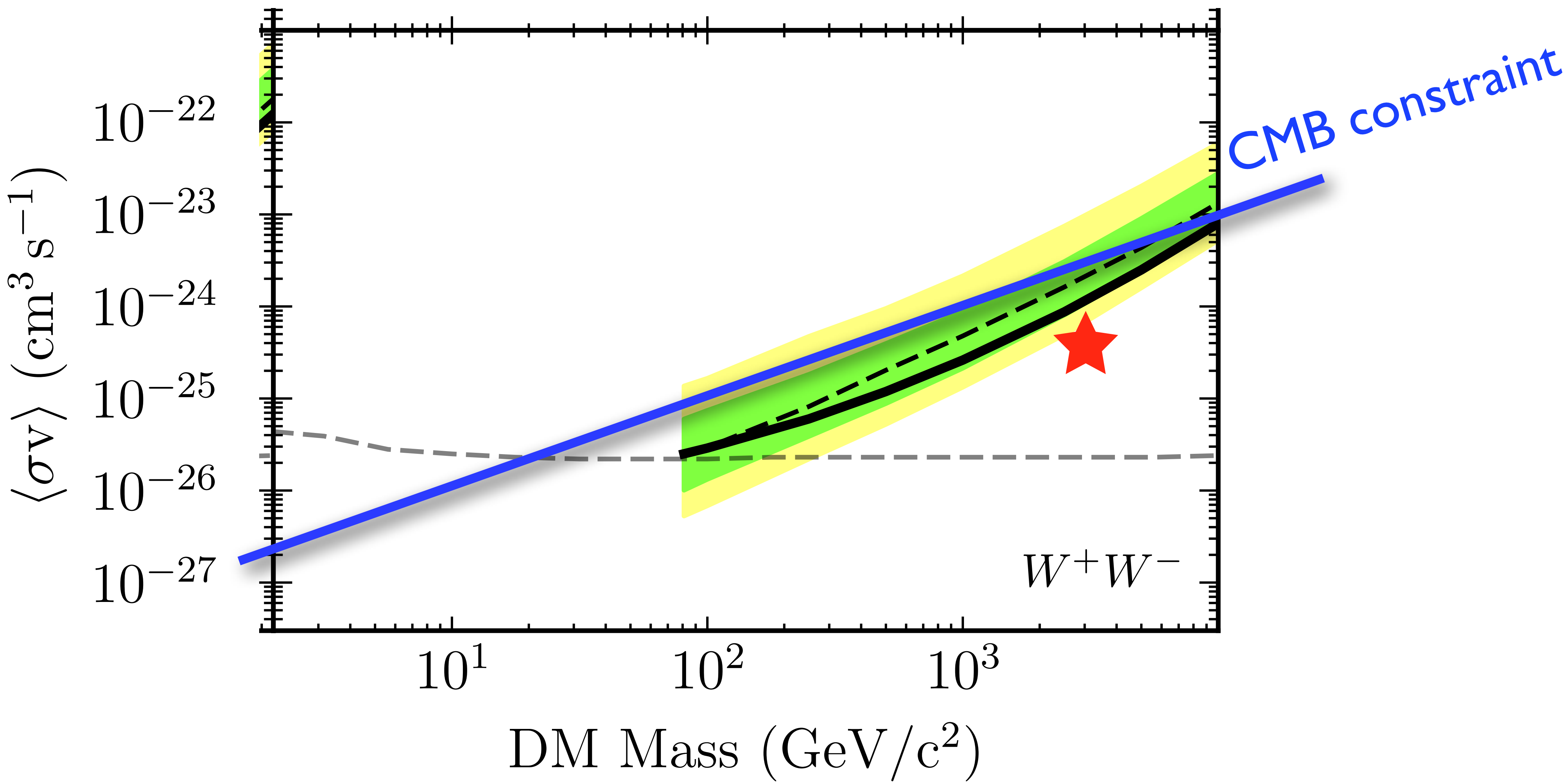
TABLE I. Properties of Milky Way dSphs.

Name	$\ell^{\rm a}$ (deg)	$b^{\rm a}$ (deg)	Distance (kpc)	$\log_{10}(J_{\rm obs})^{\rm b}$ ($\log_{10}[\,{\rm GeV}^2\,{\rm cm}^{-5}]$)
Bootes I	358.1	69.6	66	18.8 ± 0.22
Canes Venatici II	113.6	82.7	160	17.9 ± 0.25
Carina	260.1	−22.2	105	18.1 ± 0.23
Coma Berenices	241.9	83.6	44	19.0 ± 0.25
Draco	86.4	34.7	76	18.8 ± 0.16
Fornax	237.1	−65.7	147	18.2 ± 0.21
Hercules	28.7	36.9	132	18.1 ± 0.25
Leo II	220.2	67.2	233	17.6 ± 0.18
Leo IV	265.4	56.5	154	17.9 ± 0.28
Sculptor	287.5	−83.2	86	18.6 ± 0.18
Segue 1	220.5	50.4	23	19.5 ± 0.29
Sextans	243.5	42.3	86	18.4 ± 0.27
Ursa Major II	152.5	37.4	32	19.3 ± 0.28
Ursa Minor	105.0	44.8	76	18.8 ± 0.19
Willman 1	158.6	56.8	38	19.1 ± 0.31
Bootes II [c]	353.7	68.9	42	–
Bootes III	35.4	75.4	47	–
Canes Venatici I	74.3	79.8	218	17.7 ± 0.26
Canis Major	240.0	−8.0	7	–
Leo I	226.0	49.1	254	17.7 ± 0.18
Leo V	261.9	58.5	178	–
Pisces II	79.2	−47.1	182	–
Sagittarius	5.6	−14.2	26	–
Segue 2	149.4	−38.1	35	–
Ursa Major I	159.4	54.4	97	18.3 ± 0.24

M.Ackerman et al., 1503.02641

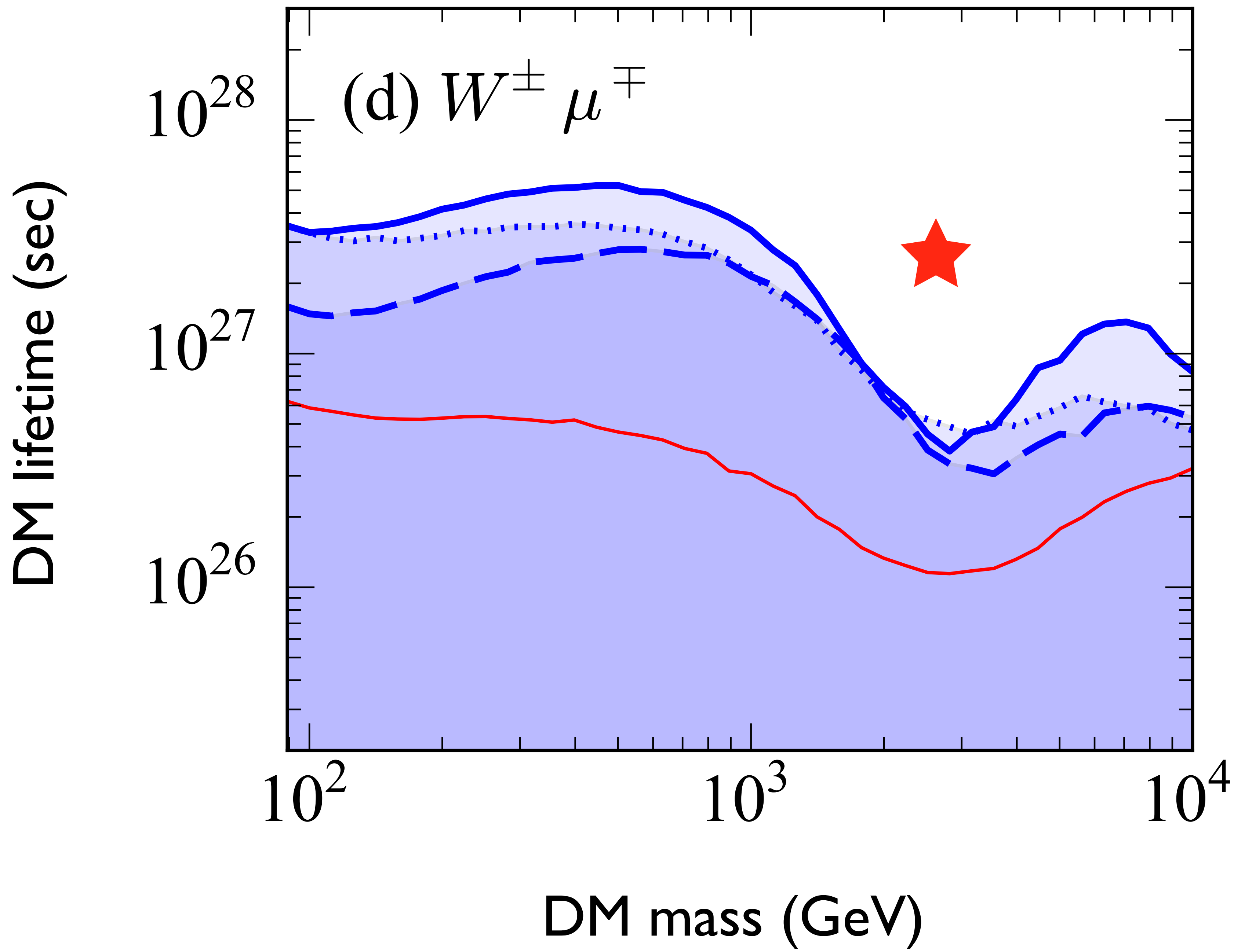
- Fermi constraint on DM ann. from dwarf spheroidal galaxies

dSph : DM dominated system,
Small uncertainty from DM density profile



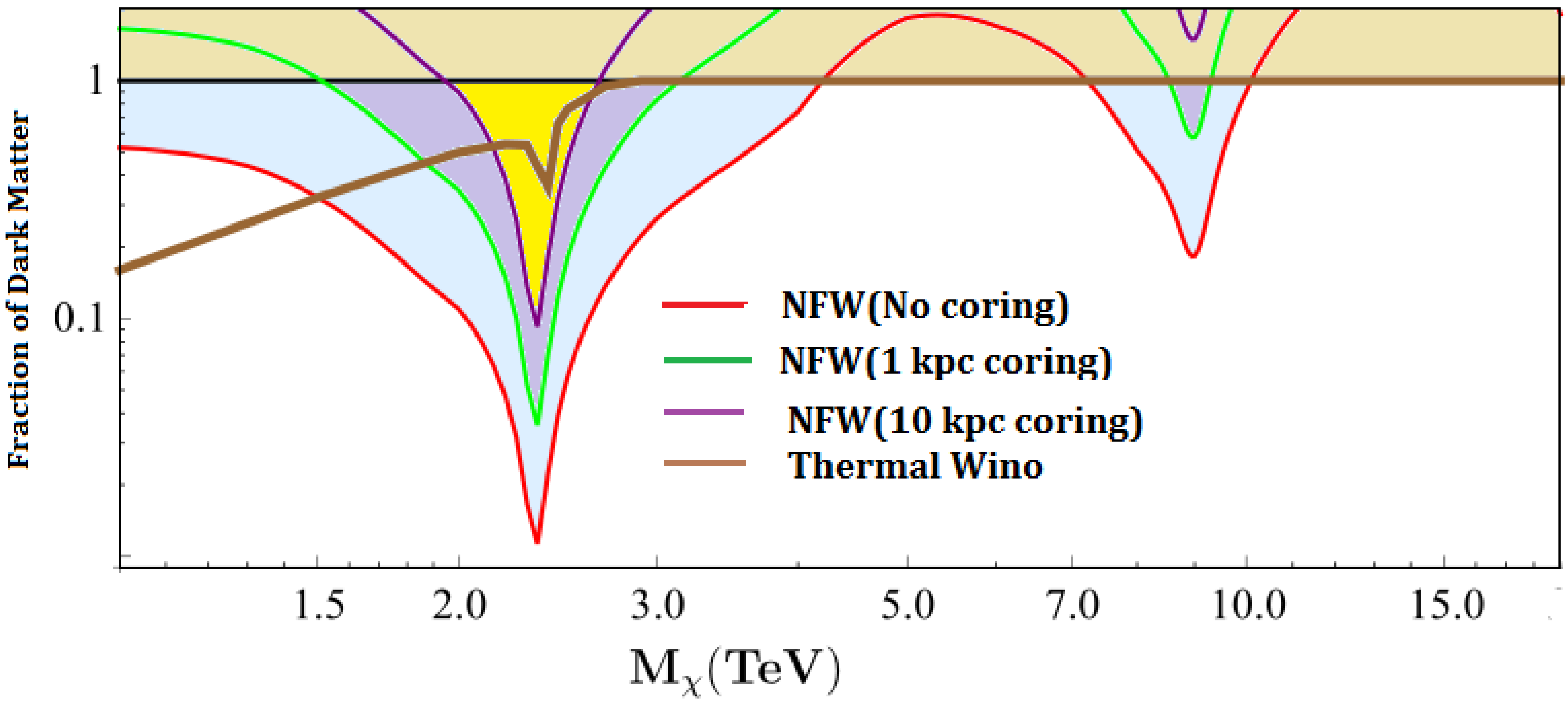
M.Ackerman et al., 1503.02641

- For decaying DM, extragalactic gamma-rays gives severe constraint.



Ando, Ishiwata, 1502.02007

- Constraint on Wino DM from HESS gamma-ray line search

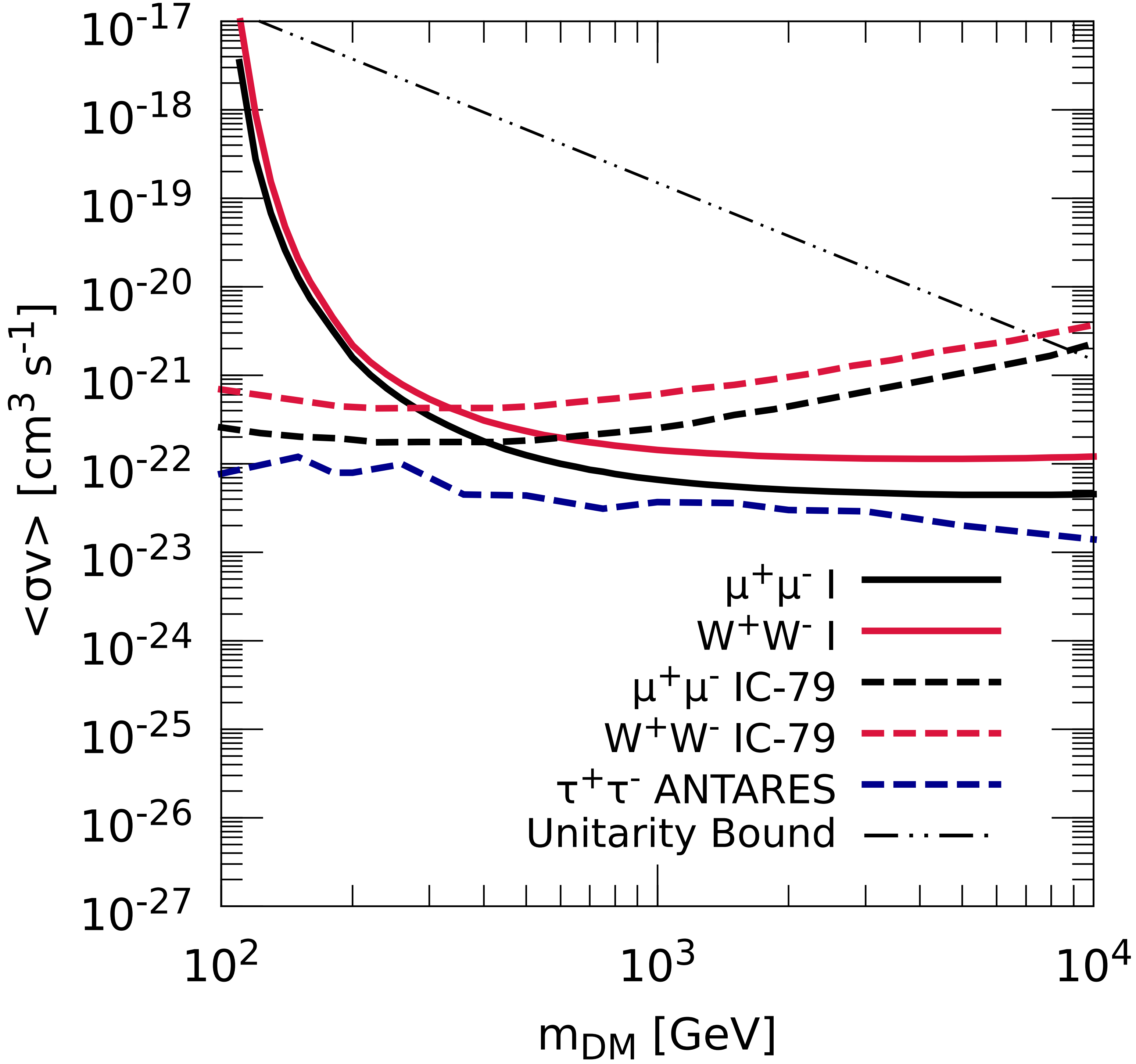


Baumgart, Rothstein, Vaidya, 1412.8698

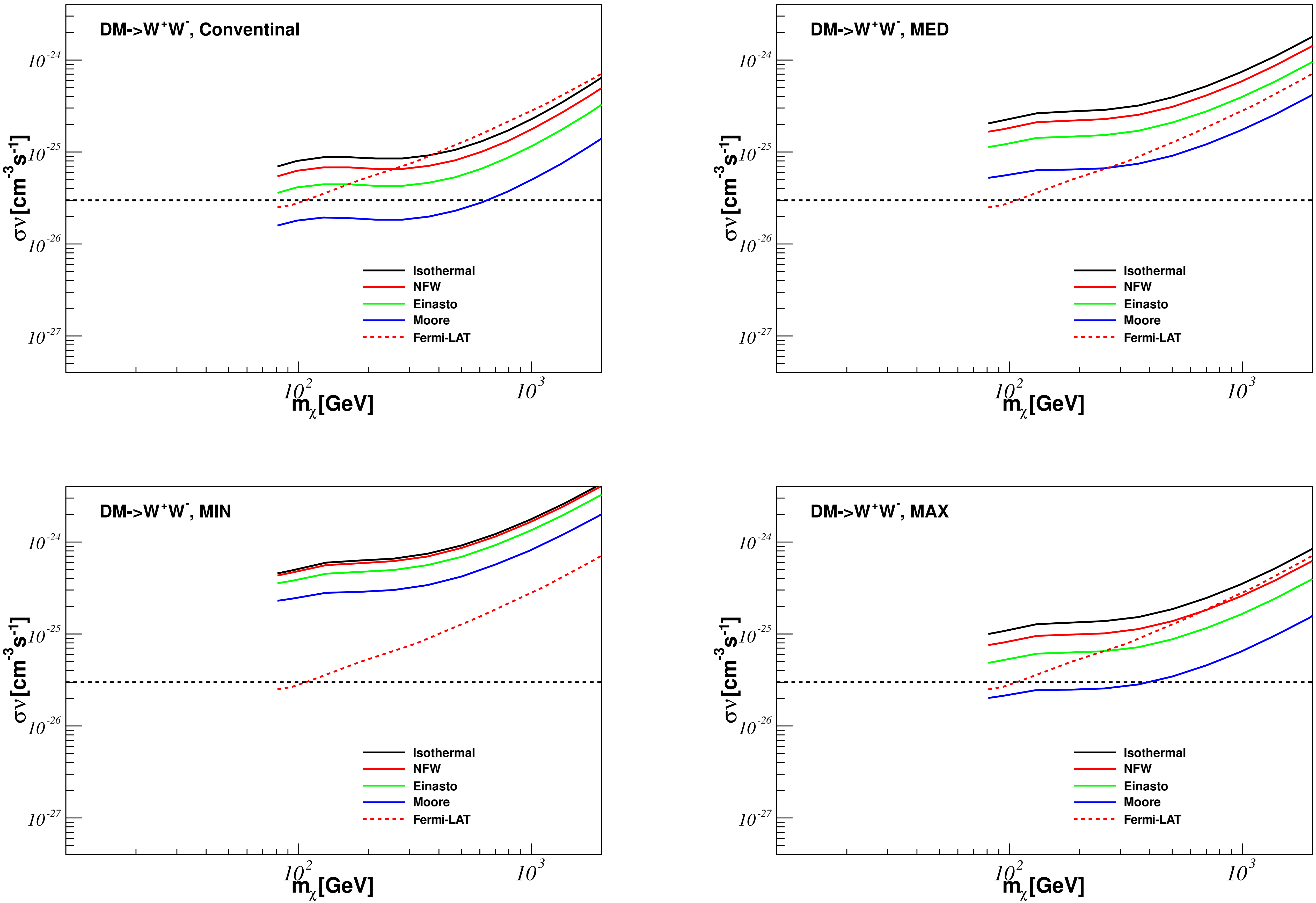
Summary

- AMS-02 reported excess of Anti-Proton flux
- It can be explained astrophysical sources
- It can also be explained Dark Matter annihilation/decay
- Wino Dark Matter is a good candidate

- Constraint from Neutrino



Moline, Ibarra, Palomares-Ruiz, 1412.4308



Jin, Wu, Zhou, 1504.04604