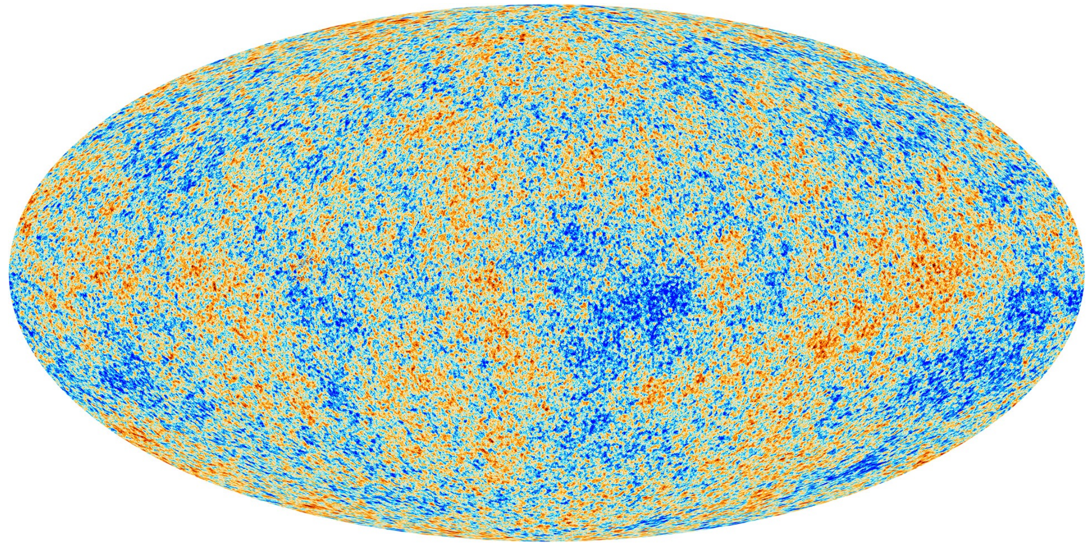
Constraints on Dark Matter annihilations coming from the CMB

An update using Planck 2015 data

Vivian Poulin
LAPTh and RWTH Aachen University

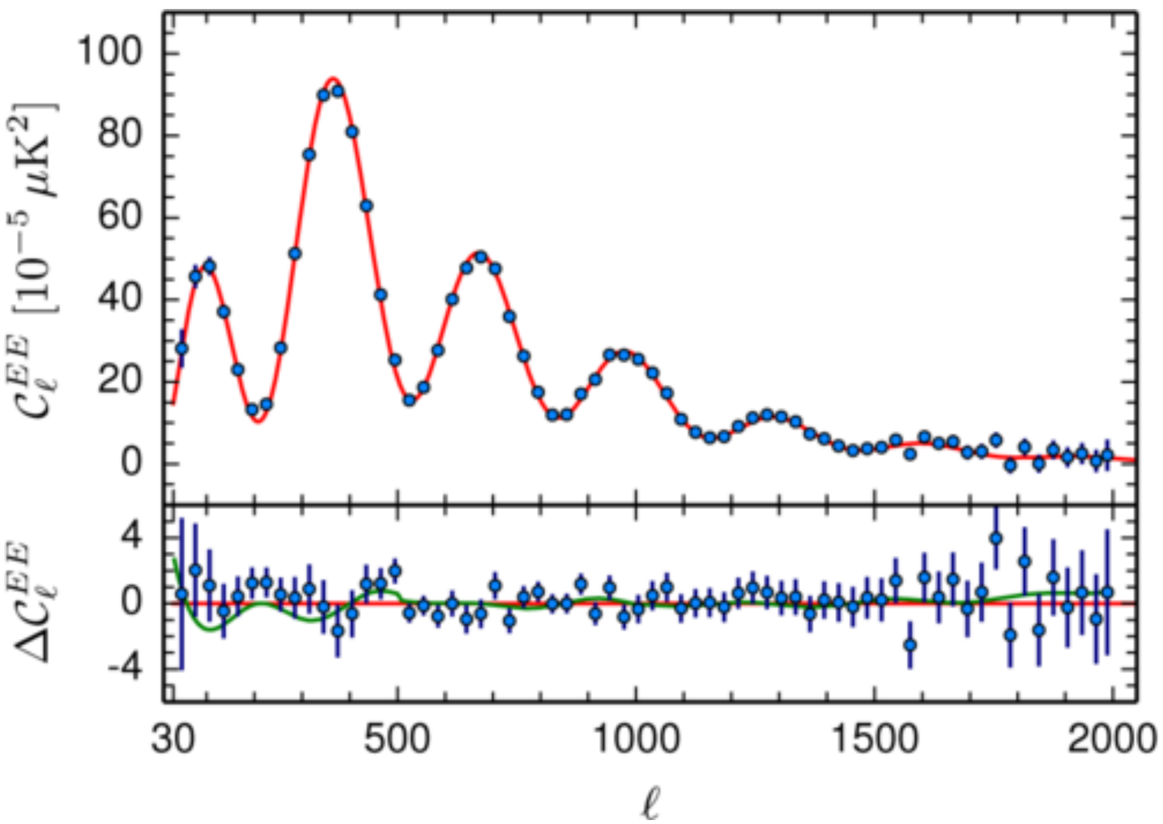
Talk based on
Planck 2015 [arXiv:1502.01589]
Poulin et al. [arXiv:1508.01370] (JCAP 1512 (2015) 12, 041)
In collaboration with
P. Serpico (LAPTh) and J. Lesgourgues (RWTH)

Texas Symposium, Geneva
december 16, 2015

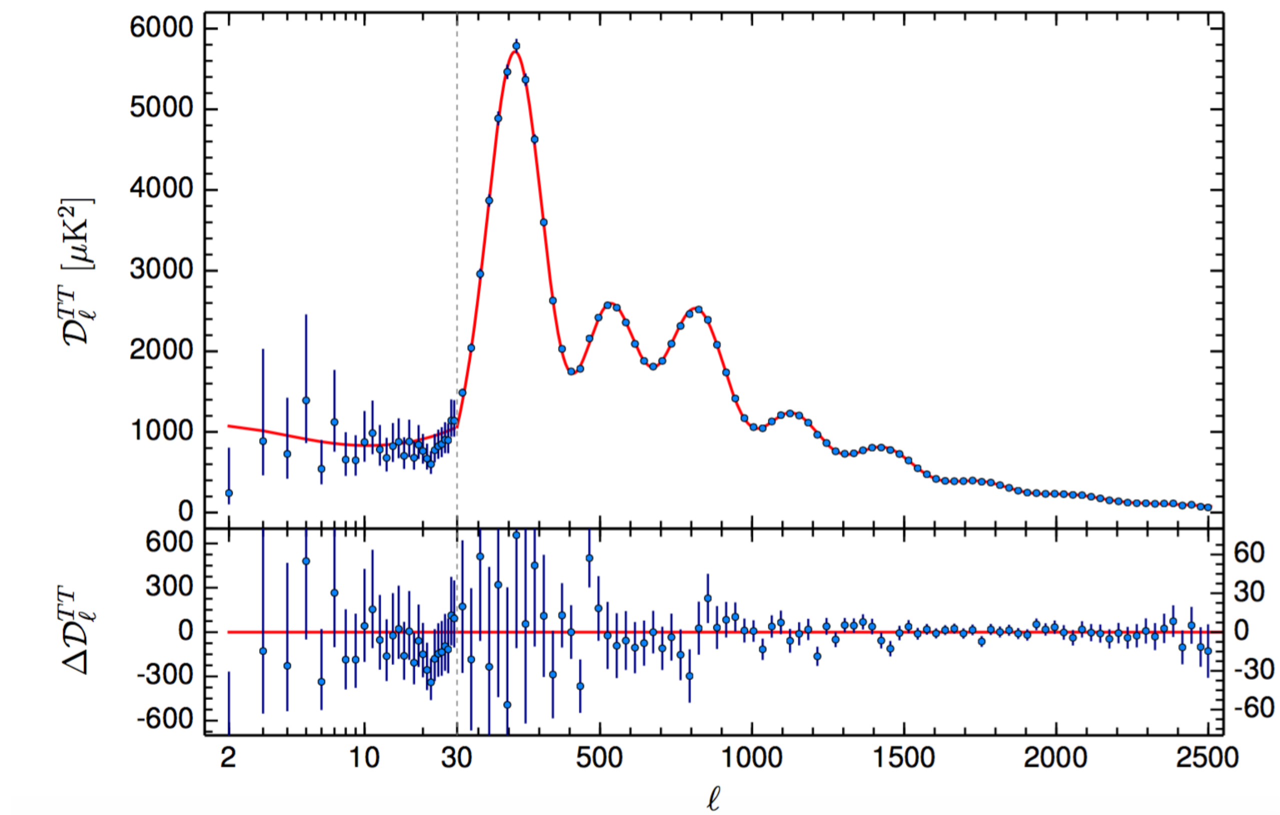


CMB as measured by Planck

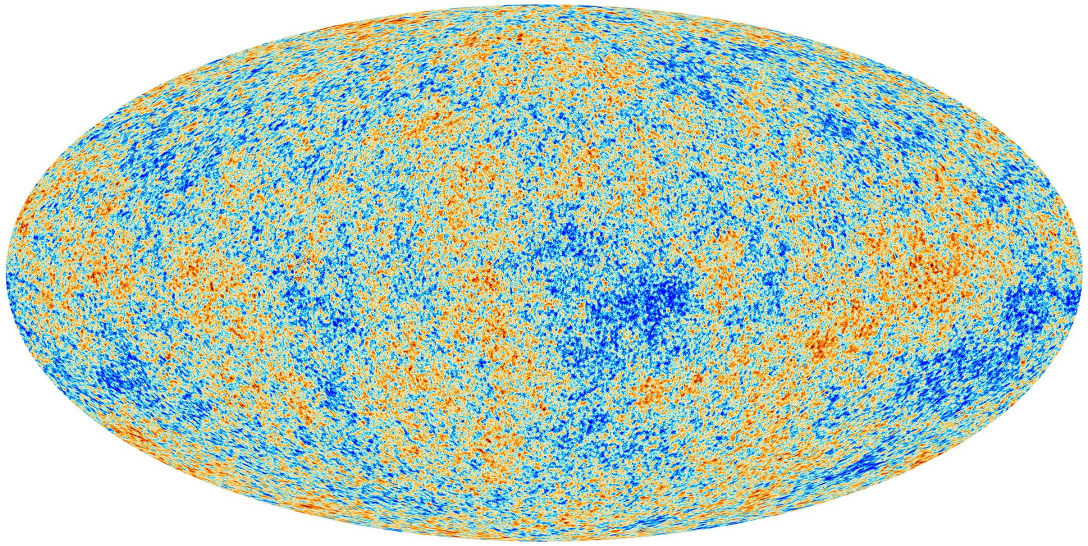
Planck 2015 [arXiv:1502.01589]



EE power spectrum



TT power spectrum



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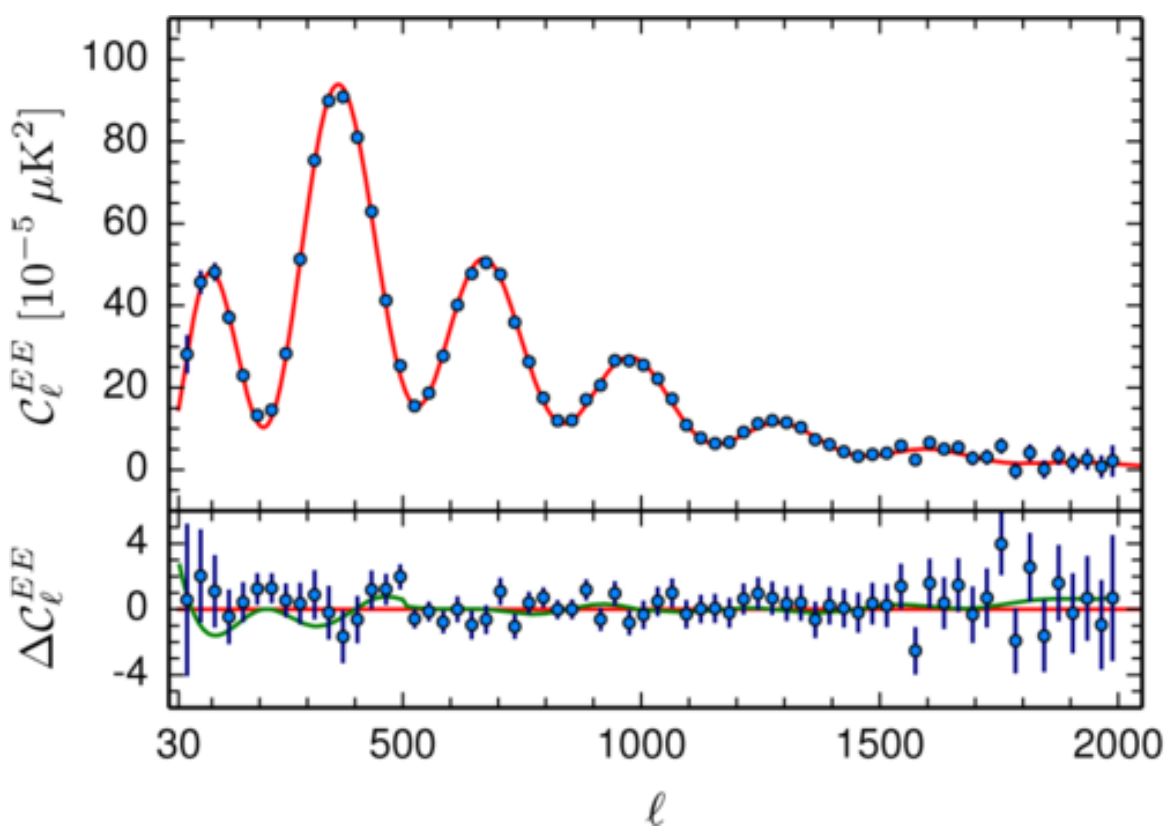

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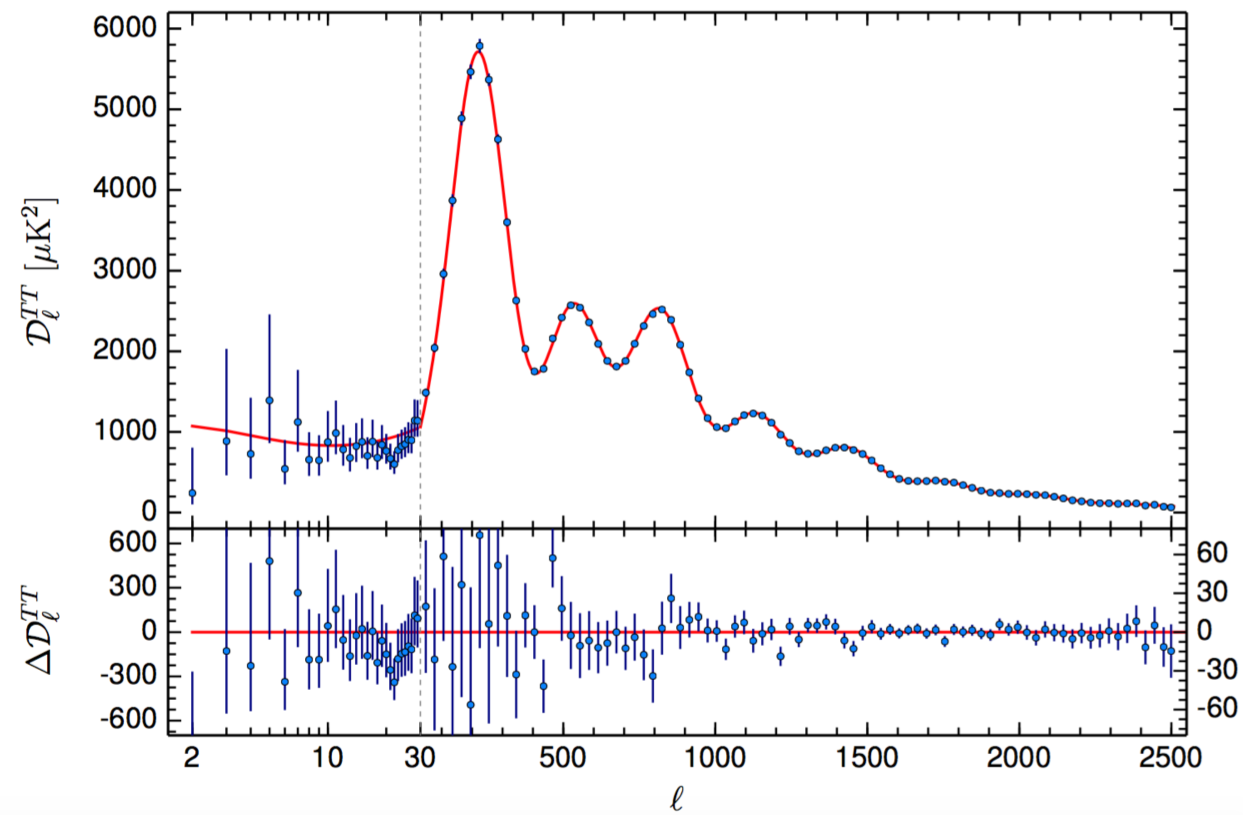


TT power spectrum

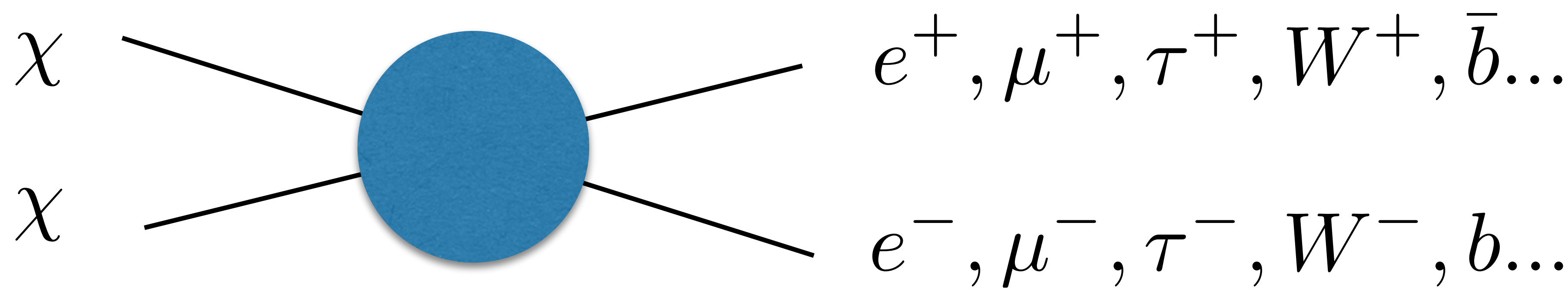
DM interacts only gravitationally in the standard Cosmology
=> Constraints can be derived

About 40 papers in 10 years

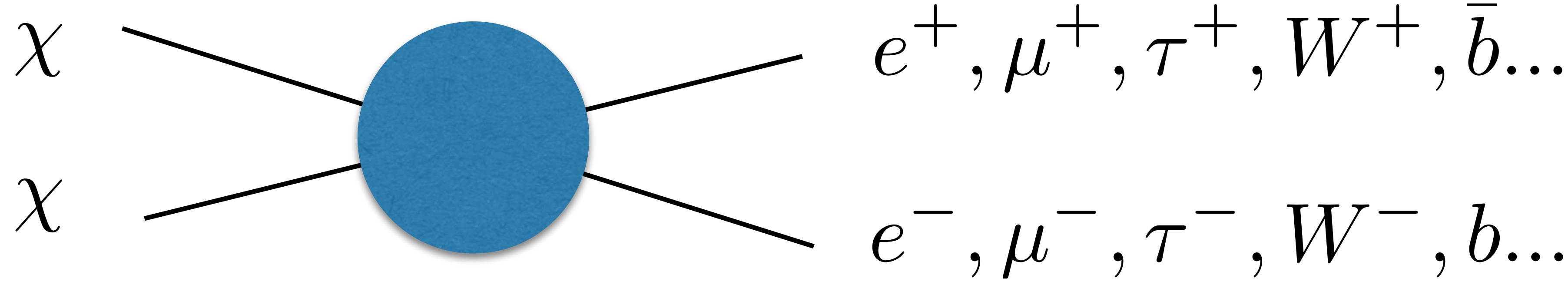
Very well documented subject

a non-exhaustive sample

- X.-L. Chen and M. Kamionkowski, Phys.Rev., vol. D70, p. 043502, 2004.
- S. Kasuya and M. Kawasaki, JCAP, vol. 0702, p. 010, 2007.
- L. Zhang, X. Chen, M. Kamionkowski, Z.-g. Si, and Z. Zheng, “Phys.Rev., vol. D76, p. 061301, 2007.
- A. V. Belikov and D. Hooper, Phys.Rev., vol. D80, p. 035007, 2009.
- M. Cirelli, F. Iocco, and P. Panci, JCAP, vol. 0910, p. 009, 2009.
- G. Huetsi, A. Hektor, and M. Raidal, Astron. Astrophys., vol. 505, pp. 999–1005, 2009.
- T. R. Slatyer, N. Padmanabhan, and D. P. Finkbeiner, Phys.Rev., vol. D80, p. 043526, 2009.
- A. Natarajan and D. J. Schwarz, Phys.Rev., vol. D81, p. 123510, 2010.
- C. Evoli, M. Valdes, and A. Ferrara, PoS, vol. CRF2010, p. 036, 2010.
- S. Galli, F. Iocco, G. Bertone, and A. Melchiorri, Phys.Rev., vol. D80, p. 023505, 2009.
- G. Hutsi, J. Chluba, A. Hektor, and M. Raidal, Astron.Astrophys., vol. 535, p. A26, 2011.
- D. P. Finkbeiner, S. Galli, T. Lin, and T. R. Slatyer, Phys.Rev., vol. D85, p. 043522, 2012.
- G. Giesen, J. Lesgourgues, B. Audren, and Y. Ali-Haimoud, JCAP, vol. 1212, p. 008, 2012.
- T. R. Slatyer, Phys.Rev., vol. D87, no. 12, p. 123513, 2013.
- S. Galli, T. R. Slatyer, M. Valdes, and F. Iocco, Phys.Rev., vol. D88, p. 063502, 2013.
- L. Lopez-Honorez, O. Mena, S. Palomares-Ruiz, and A. C. Vincent, JCAP, vol. 1307, p. 046, 2013.
- T. R. Slatyer, arXiv:1506.03812, 2015.
- T. R. Slatyer, arXiv:1506.03812, 2015.
- …



What happens to the annihilation products ?



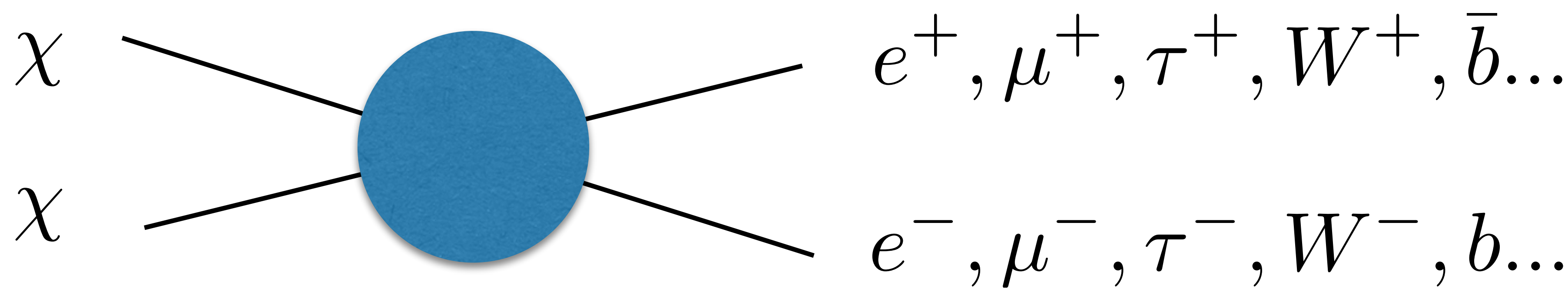
What happens to the annihilation products ?

Only $e^{\pm}, \gamma$ interact with the intergalactic medium (IGM) and CMB. They can :

i) Lose their energy through interaction with CMB and redshifting

$$e\gamma_{\rm CMB} \rightarrow e\gamma \qquad \gamma\gamma_{\rm CMB} \rightarrow \gamma\gamma \qquad \gamma\gamma_{\rm CMB} \rightarrow e^+e^- \ ;$$

ii) ionize, excite or heat the IGM.



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Main impact of DM annihilations : modification of the recombination

Peebles « case-b » recombination

$$\frac{dx_e}{dz} = \frac{1}{(1+z)H(z)}[R_s(z) - I_s(z) - I_X(z)]$$

$$x_e \equiv \frac{n_e}{n_H}$$

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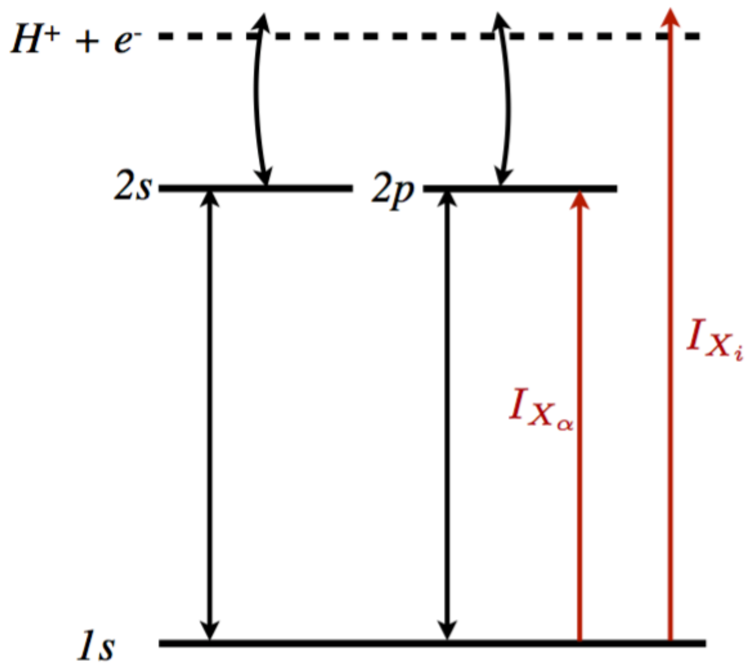

$$I_X(z) = I_{X_i}(z) + I_{X_\alpha}(z)$$

$$I_{X_i}(z) = \frac{\chi_i(z)}{n_H(z)E_i}\frac{dE}{dVdt}\bigg|_{\mathrm{dep}}$$

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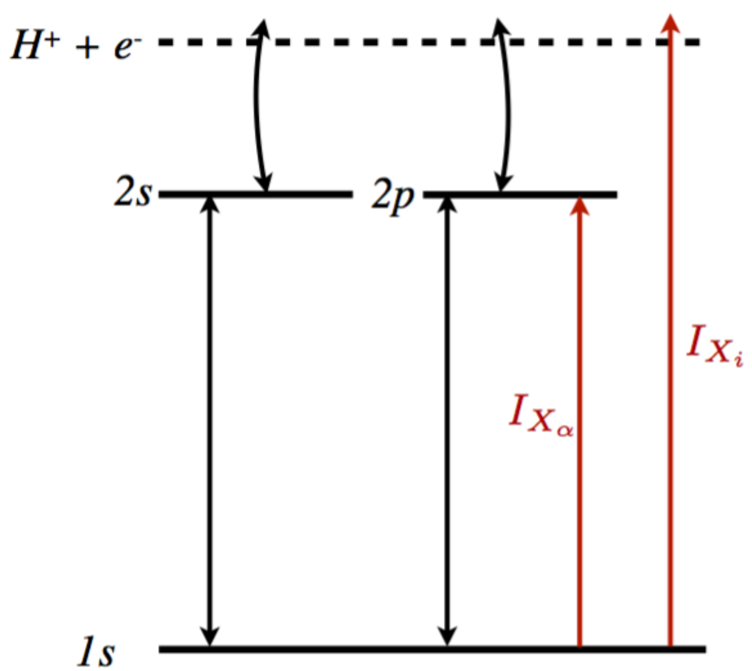

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$$\frac{dT_{\rm M}}{dz} = \frac{1}{1+z}\left[2T_{\rm M} + \gamma(T_{\rm M} - T_{\rm CMB}) + K_h\right]$$

$$K_h = -\frac{2\chi_h(z)}{H(z)3k_b n_H(z)(1+f_{He}+x_e)}\frac{dE}{dVdt}\bigg|_{\rm dep}$$

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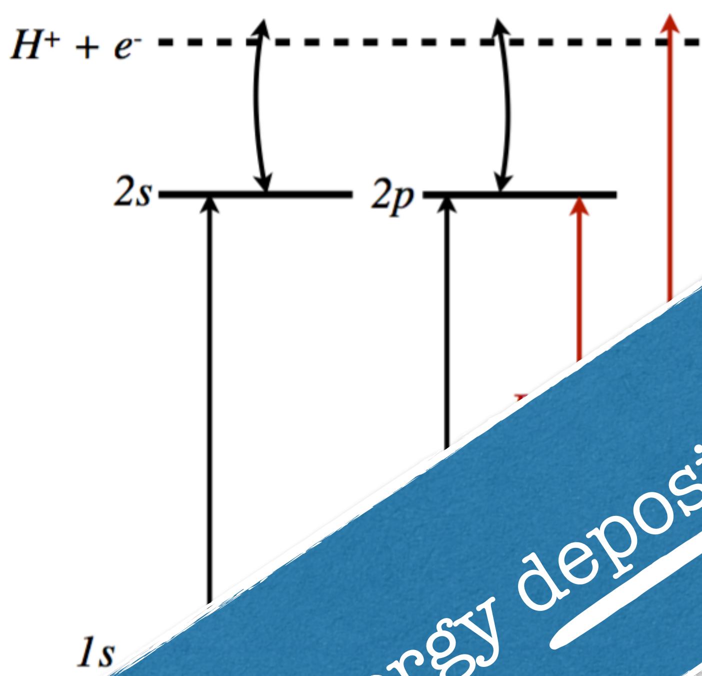

The energy deposited by the DM

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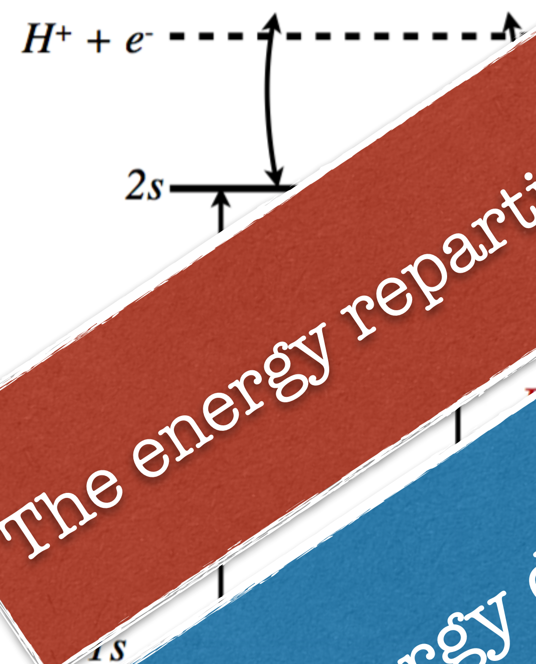

The energy repartition functions

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$$\left.\frac{dE}{dV\,dt}\right|_{\rm inj}(z) = \left(n_{\rm pairs} = \kappa\frac{n_{\rm DM}}{2}\right)\cdot\left(P_{\rm ann} = \langle\sigma_{\rm ann}v\rangle n_{\rm DM}\right)\cdot\left(E_{\rm ann} = 2m_{\rm DM}c^2\right)$$

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number density
of pairs

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In the smooth background :

$$\left.\frac{dE}{dV\,dt}\right|_{\rm inj,smooth}(z) = \kappa\rho_c^2c^2\Omega_{\rm DM}^2(1+z)^6\frac{\langle\sigma_{\rm ann}v\rangle}{m_{\rm DM}}$$

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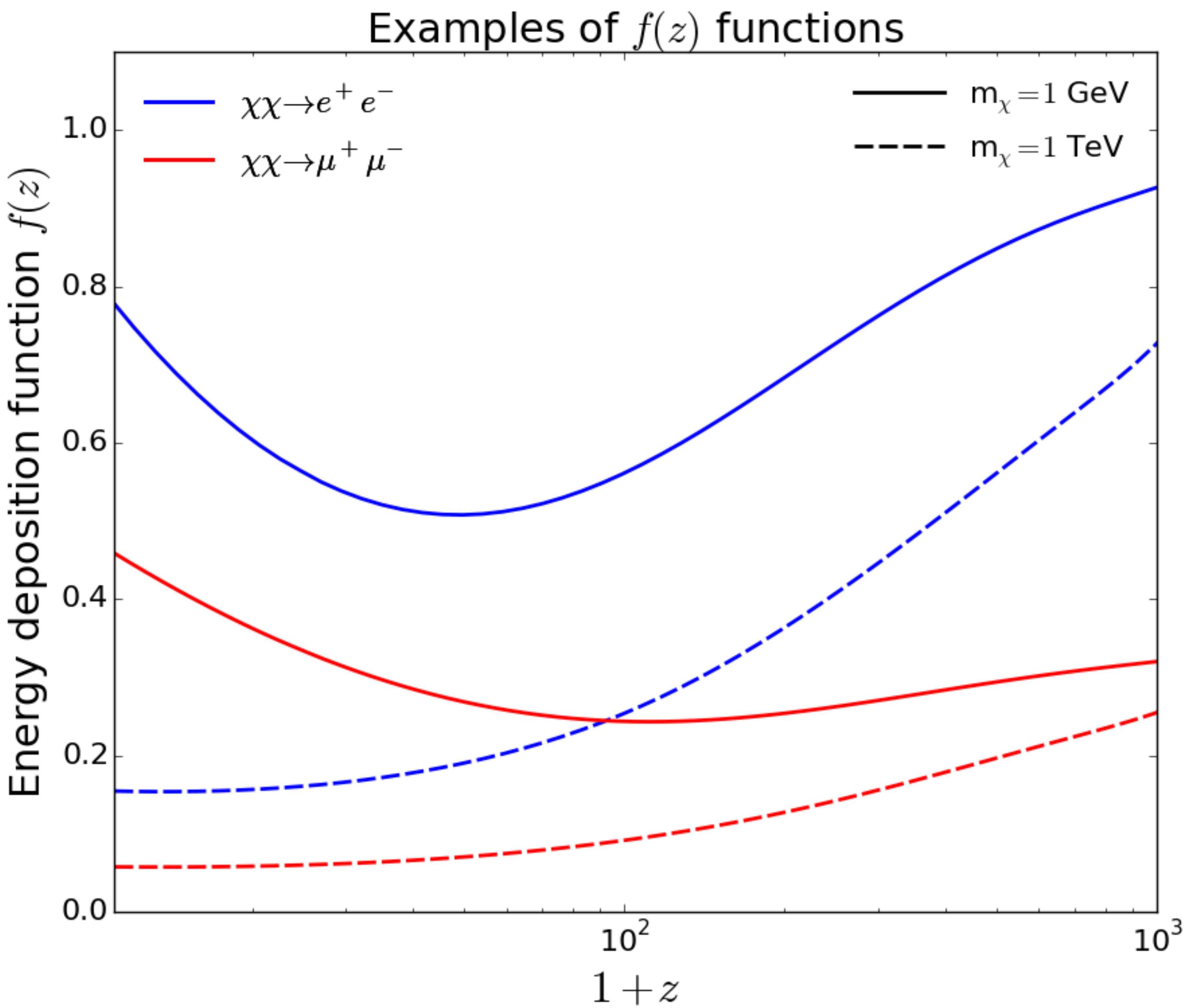
Typical parameterization through the $f(z)$ functions :

$$\left.\frac{dE}{dV\,dt}\right|_{\rm dep}(z) = f(z)\left.\frac{dE}{dV\,dt}\right|_{\rm inj}(z)$$


Examples of $f(z)$ functions
$\chi\chi \to e^+ e^-$
$\chi\chi \to \mu^+ \mu^-$
$m_\chi = 1$ GeV
$m_\chi = 1$ TeV
Energy deposition function $f(z)$
1.0
0.8
0.6
0.4
0.2
0.0
10^2
10^3
$1+z$

In practice, for annihilations in the smooth background, it has been found that the CMB is only sensitive to

$$p_{\rm ann} \equiv f_{\rm eff} \frac{\langle \sigma_{\rm ann} v \rangle}{m_{\rm DM}} \qquad \text{where} \qquad f_{\rm eff} \equiv f(z = 600) \ .$$

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Hence, we usually write

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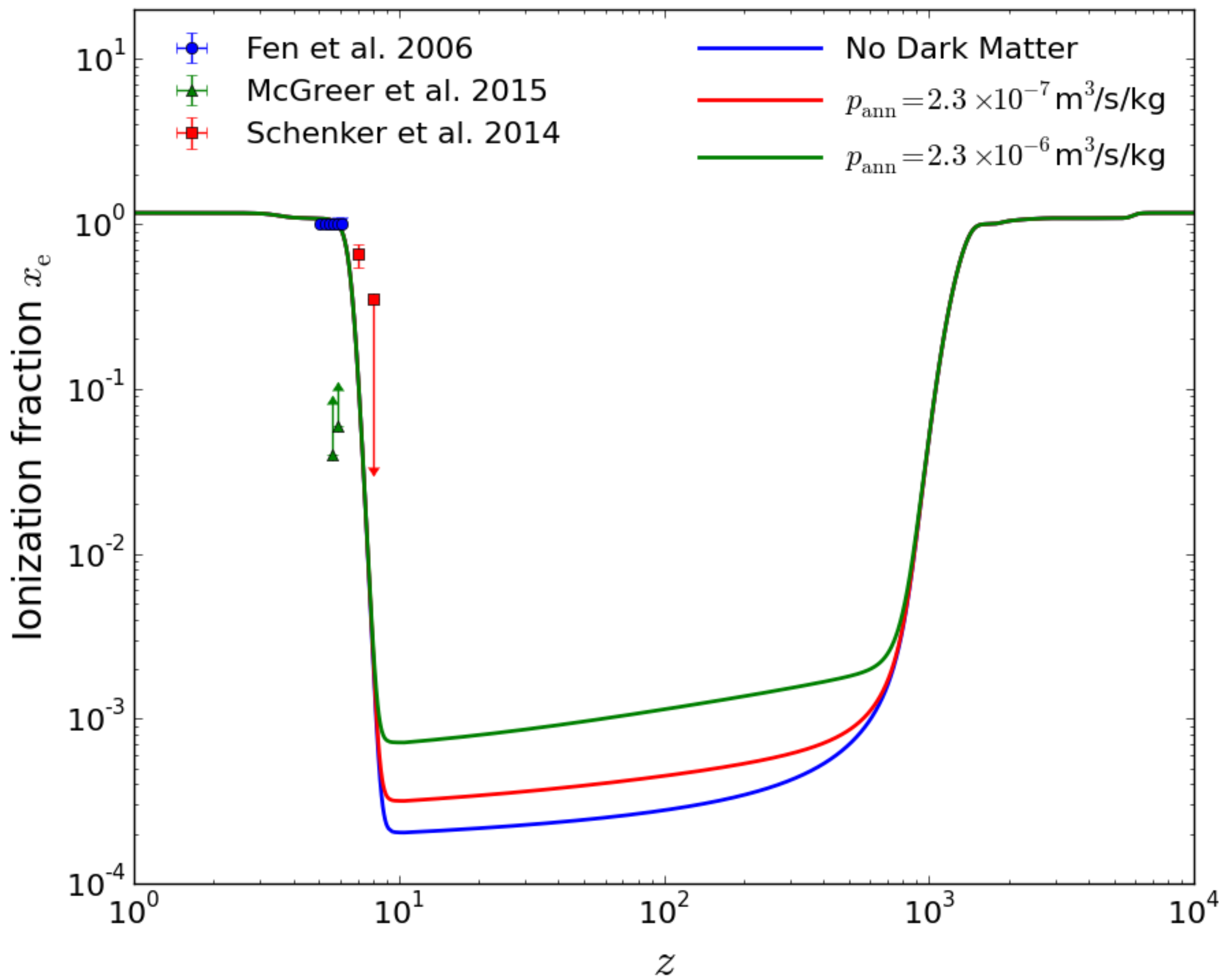
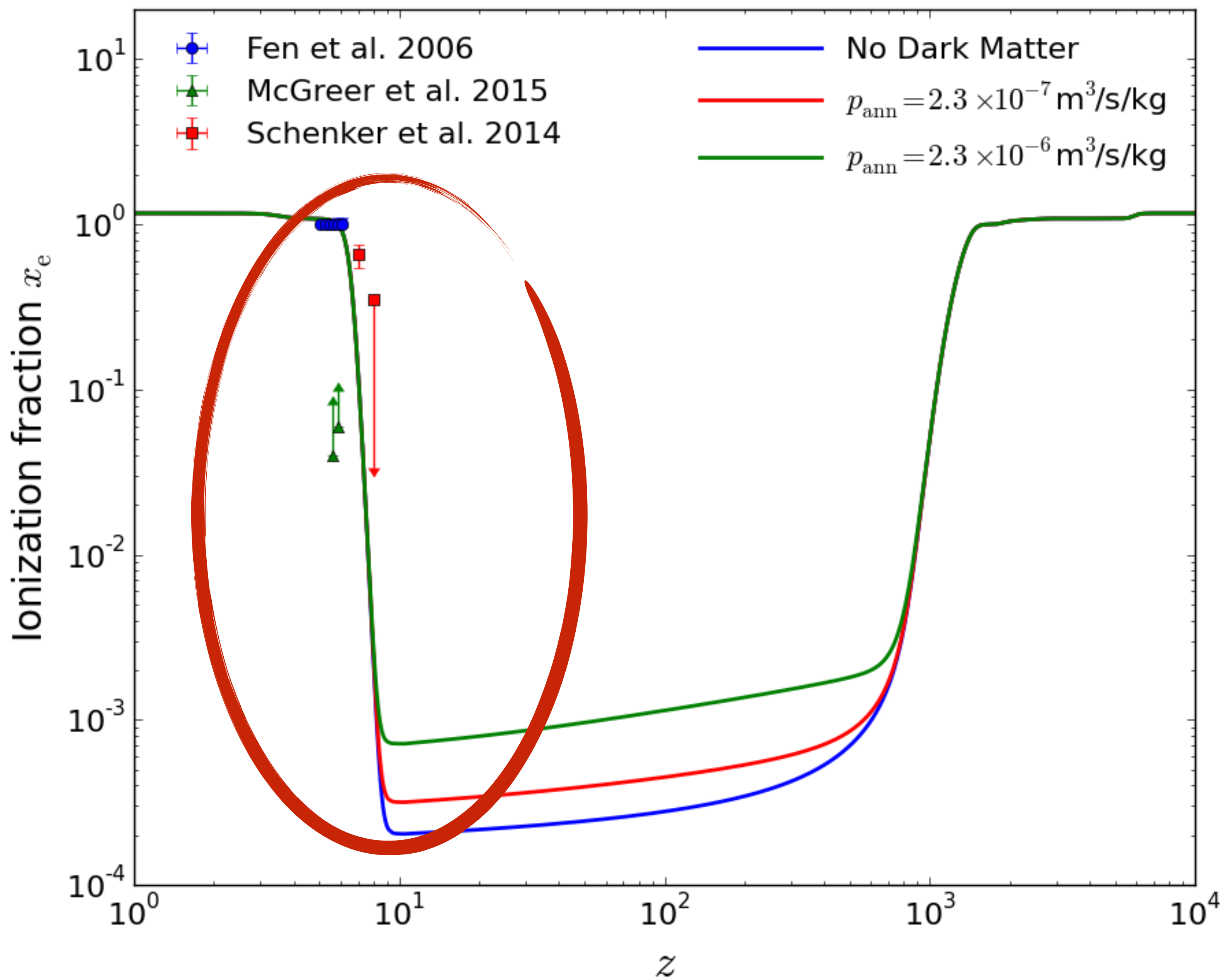
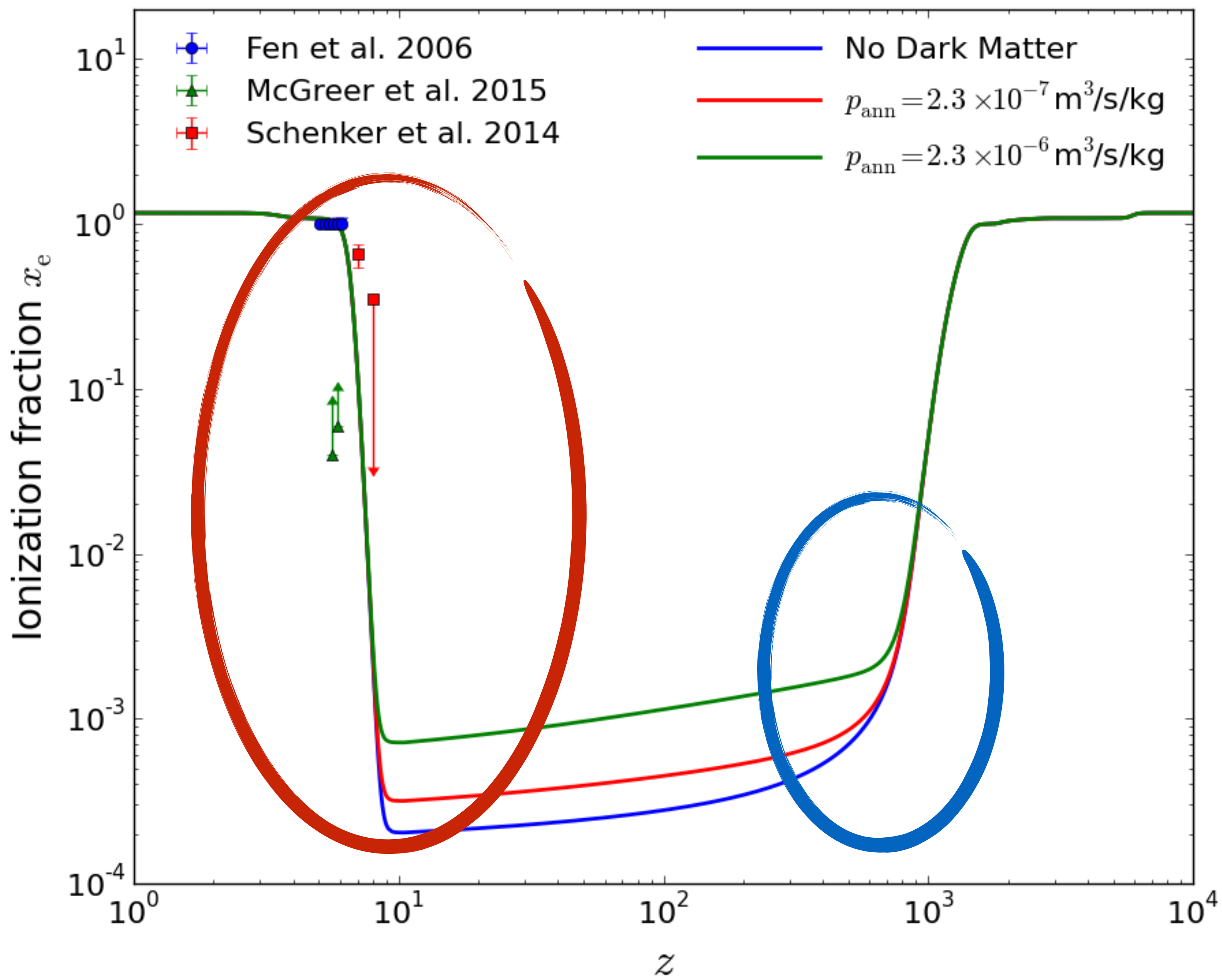
$$\left. \frac{dE}{dV\,dt} \right|_{\rm dep} (z) = p_{\rm ann} \cdot \kappa \rho_c^2 c^2 \Omega_{\rm DM}^2 (1+z)^6$$

This is the quantity really constrained by CMB power spectra analysis !


Fen et al. 2006
McGreer et al. 2015
Schenker et al. 2014
No Dark Matter
$p_{ann} = 2.3 \times 10^{-7}$ m^3/s/kg
$p_{ann} = 2.3 \times 10^{-6}$ m^3/s/kg
Ionization fraction x_e
z
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}



Reionization : put by hand !
Mostly due to star formation.
Still to understand.



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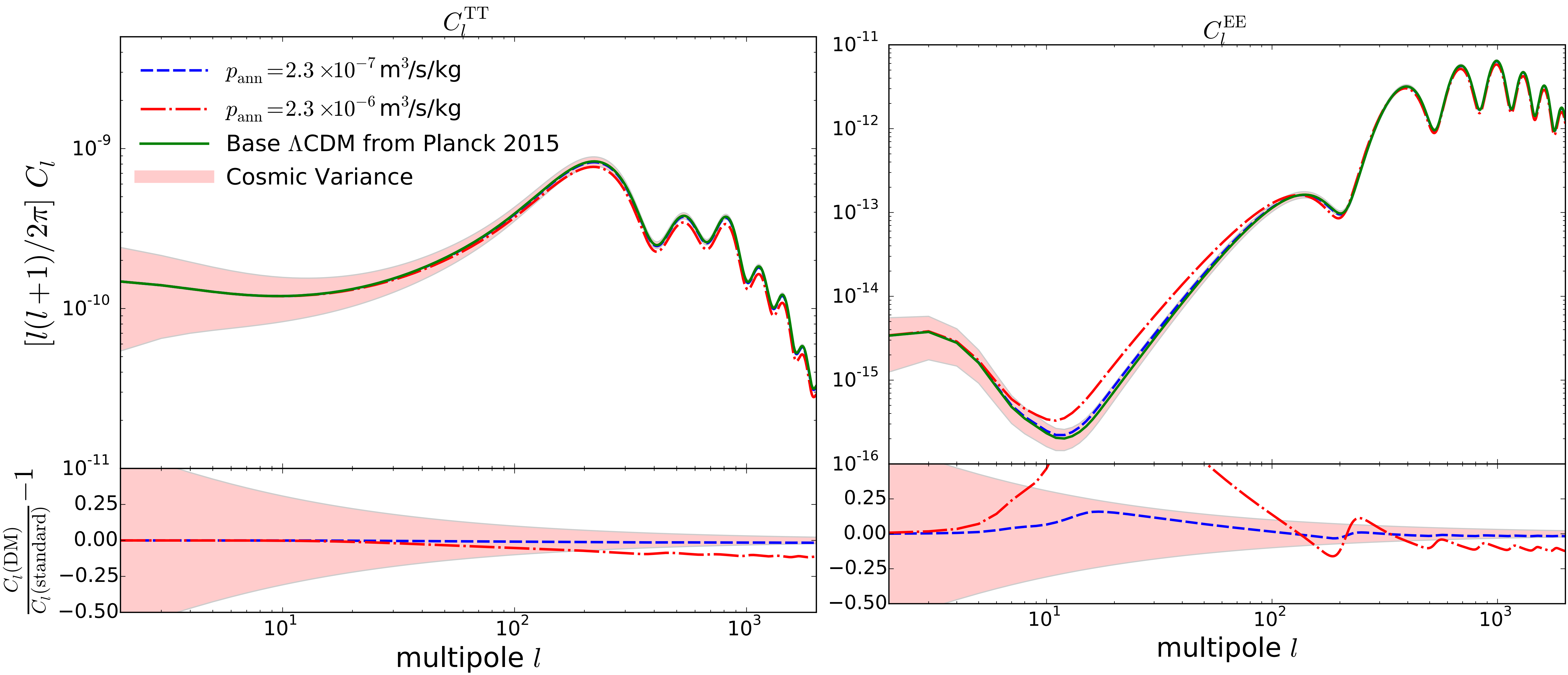
DM annihilations delay the recombination and enforce the free electron fraction to freeze-out (z=600) at higher values.

Modification of the ionisation fraction will in turn affect the CMB power spectra through CMB scattering with free electrons.



Recombination delay implies :

1) Shift of the peaks
2) More diffusion damping

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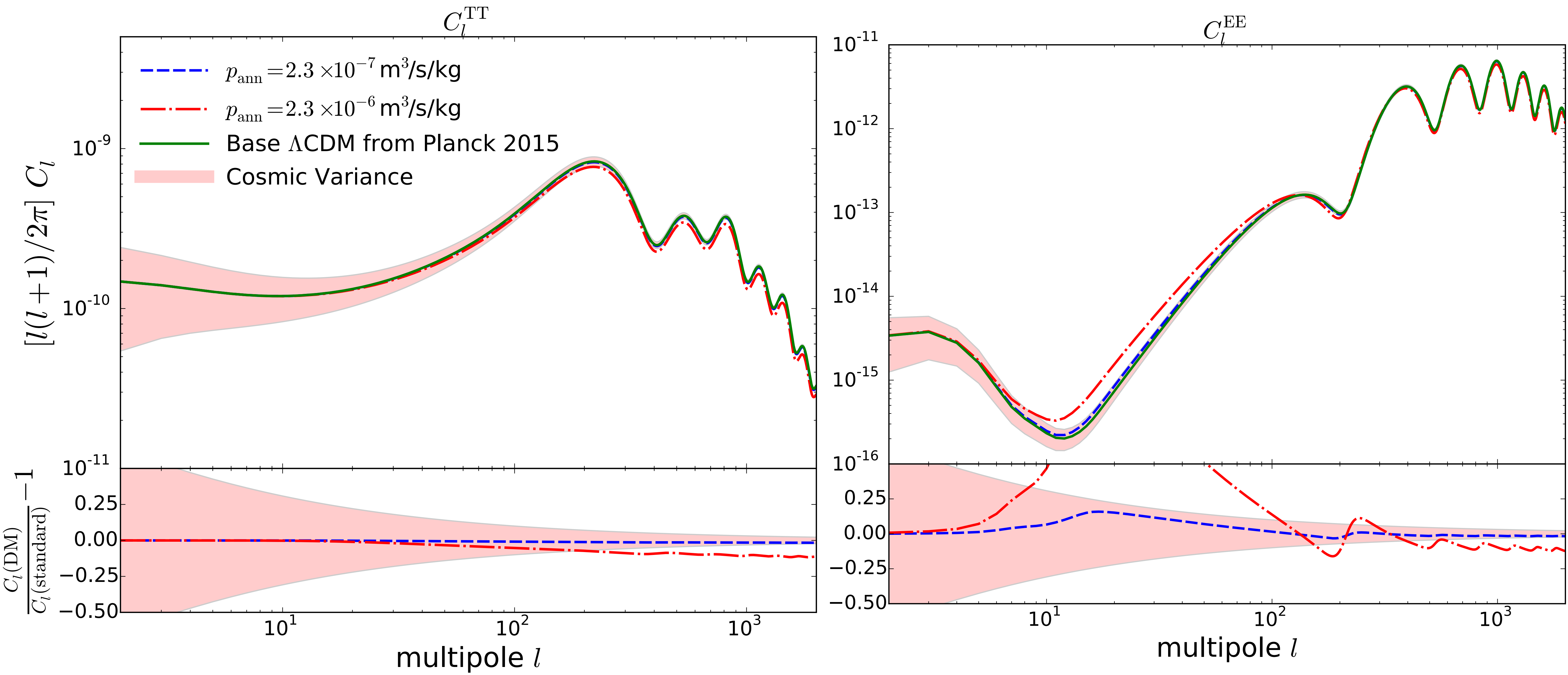
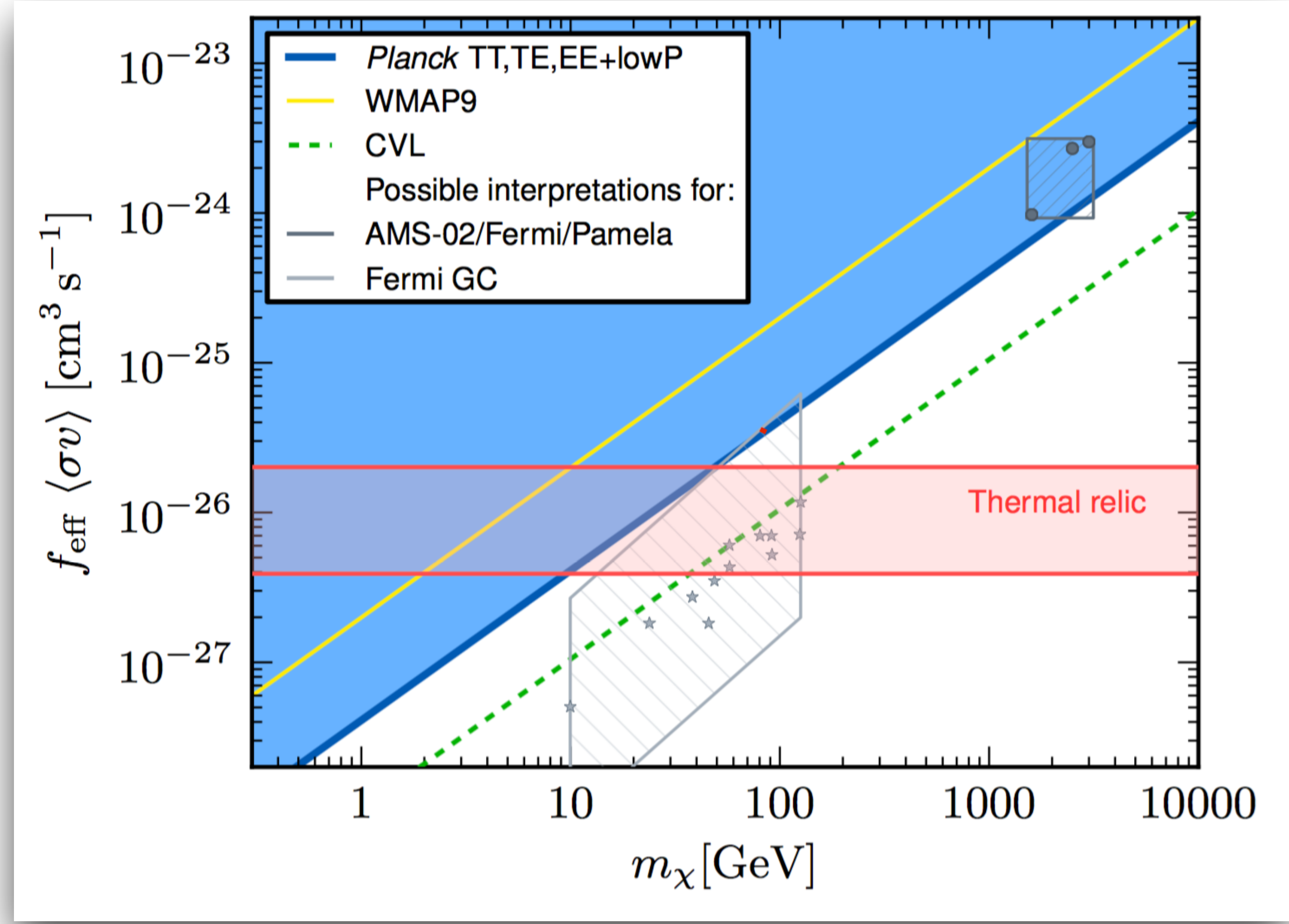


More scattering implies :

1) Suppression of power on all scales with $\ell > 200$

2) Regeneration of power in the polarization spectrum



$$p_{\rm ann} \equiv f_{\rm eff}\frac{\langle\sigma_{\rm ann}v\rangle}{m_{\rm DM}} < 3.4\times10^{-28}{\rm cm}^3{\rm s}^{-1}{\rm GeV}^{-1}$$

TT, TE, EE + lowP + lensing

Planck 2015 [arXiv:1502.01589]

Results obtained from annihilation in the smooth background only
Is it possible to improve over it by taking into account Dark Matter halo formation?

As time goes by, virialized structures of DM starts to form, the so-called « DM halos ».

Universe globally homogeneous

$$\langle\rho\rangle^2\big|_{\rm smooth} = \langle\rho\rangle^2\big|_{\rm smooth+halos}$$

however

$$\langle\rho^2\rangle\big|_{\rm smooth} \leq \langle\rho^2\rangle\big|_{\rm smooth+halos}$$

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=> More energy injected => Better constraints.

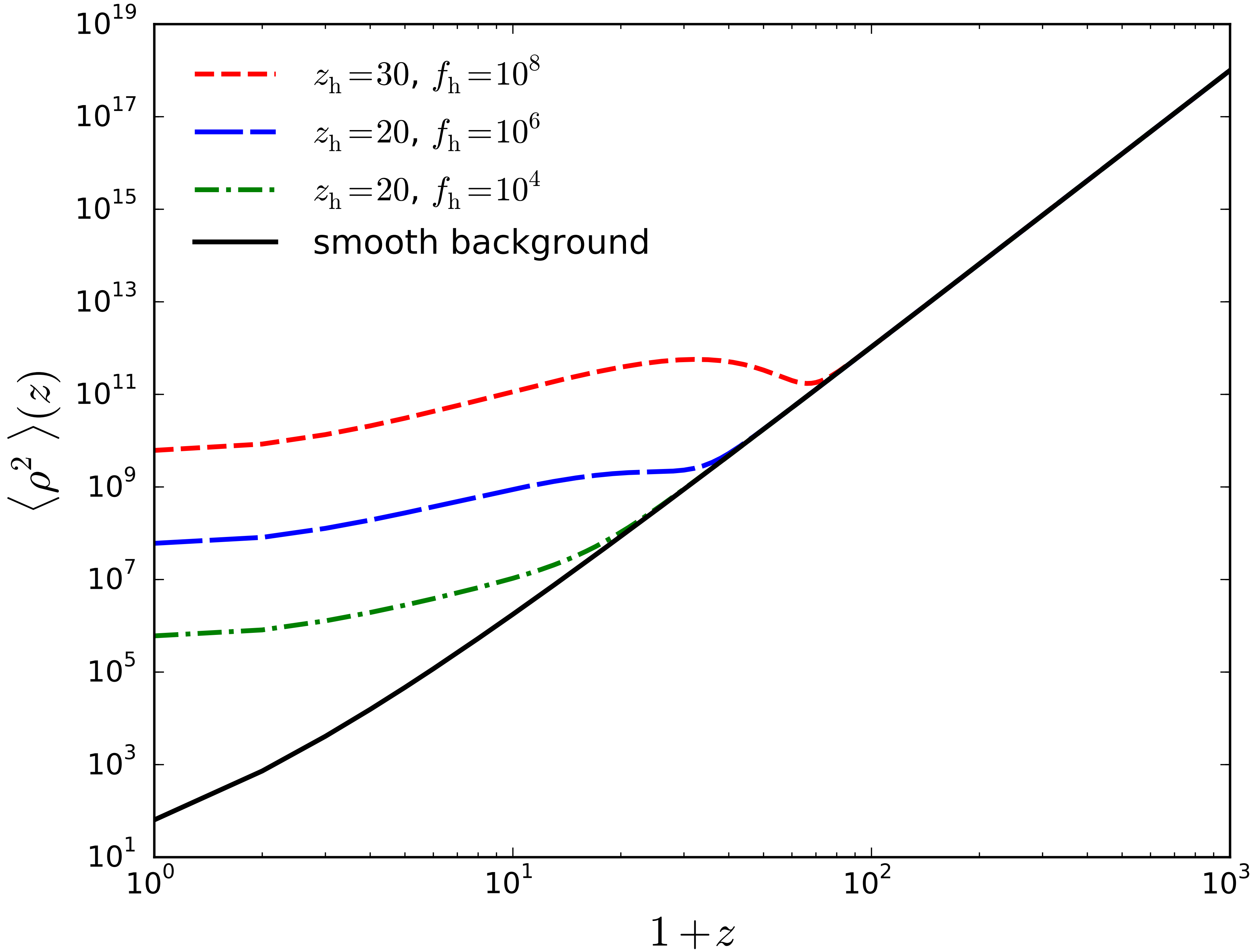
But, is it very so easy ? unfortunately, no !

Useful parameterization

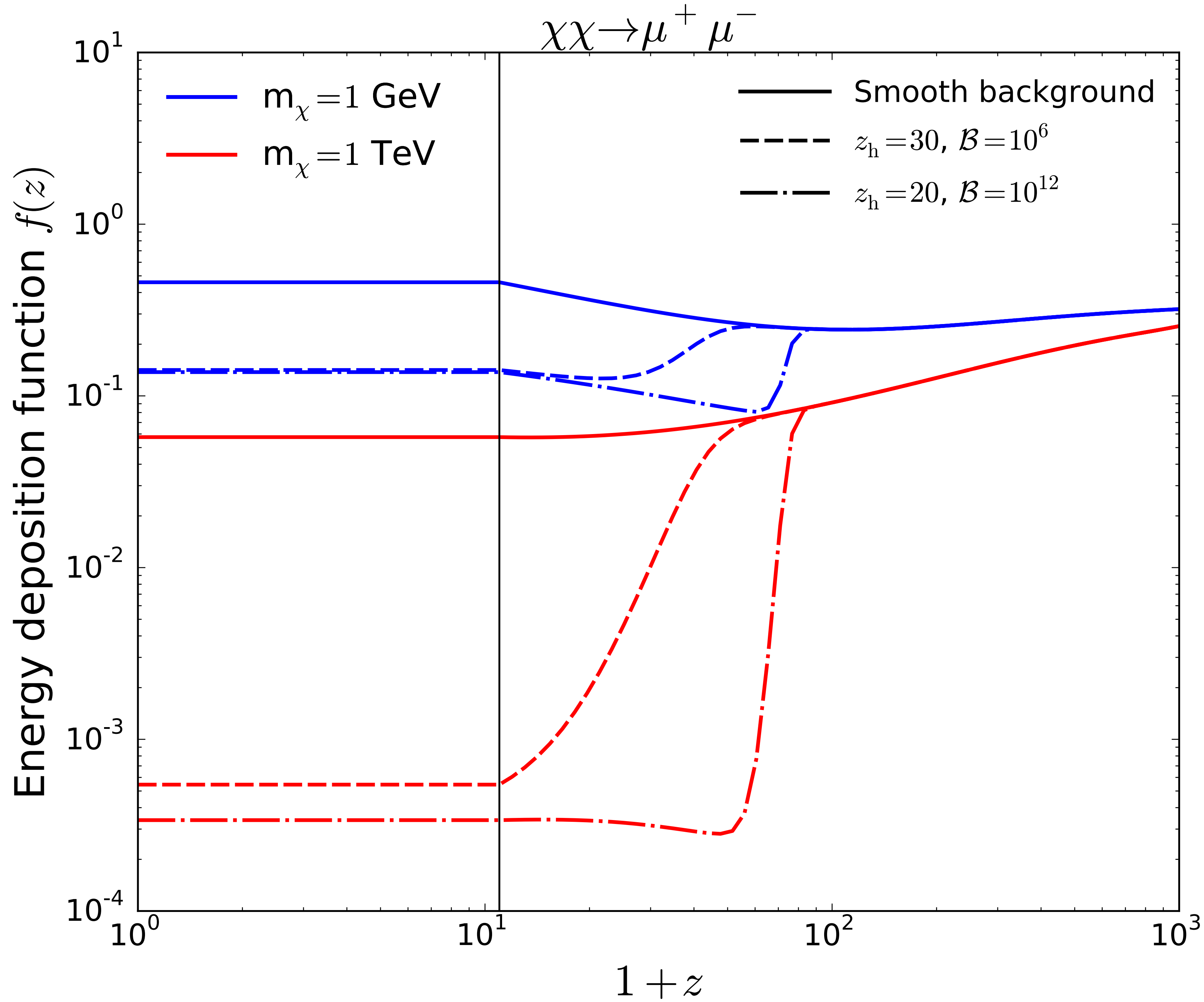
$$\langle \rho^2 \rangle(z) = (1 + \mathcal{B}(z))\langle \rho^2 \rangle$$

In the « Press-shechter formalism »

$$\mathcal{B}(z) = \frac{f_{\rm h}}{(1+z)^3}\,{\rm erfc}\left(\frac{1+z}{1+z_{\rm h}}\right)$$



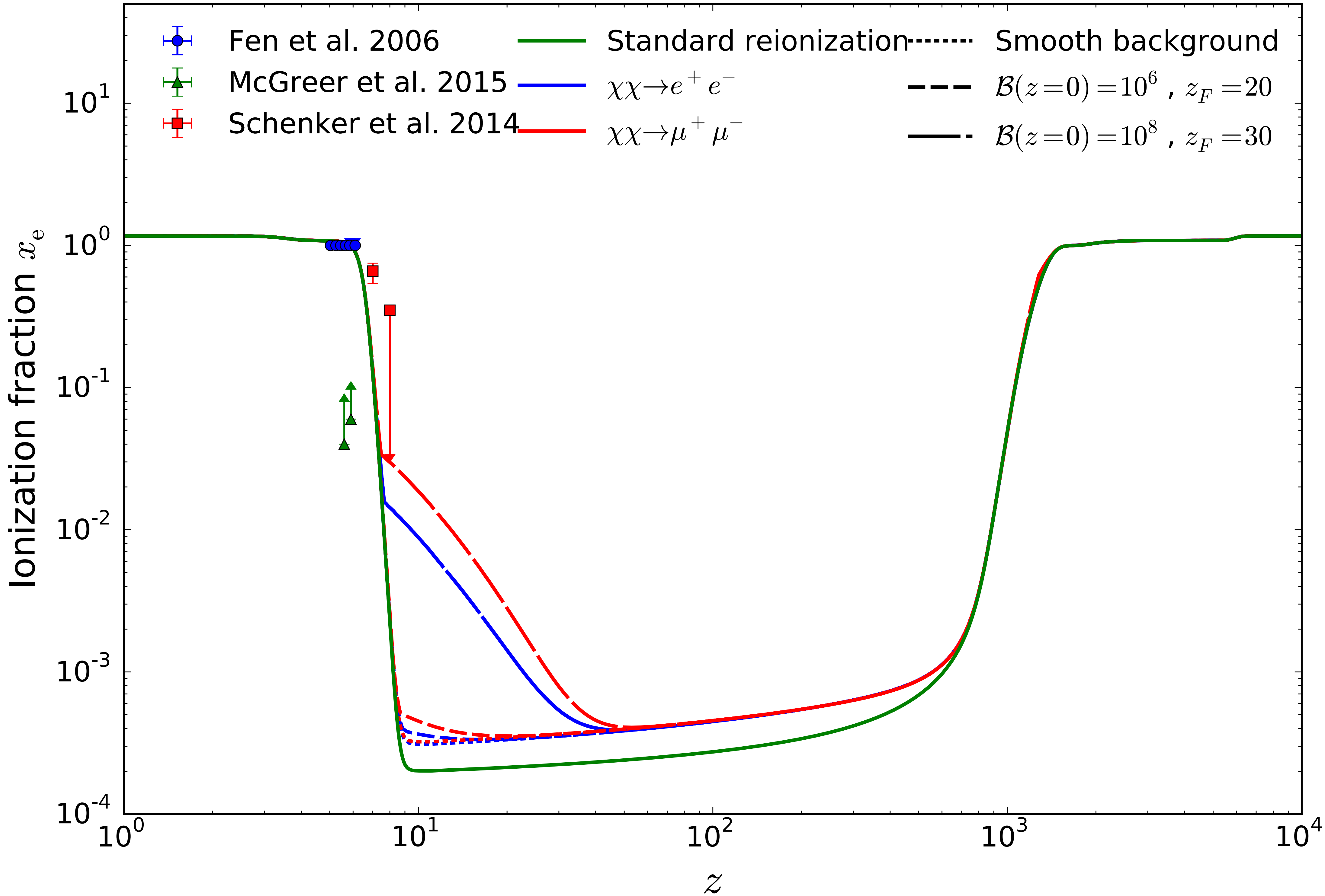
We need to recompute the $f(z)$ functions !



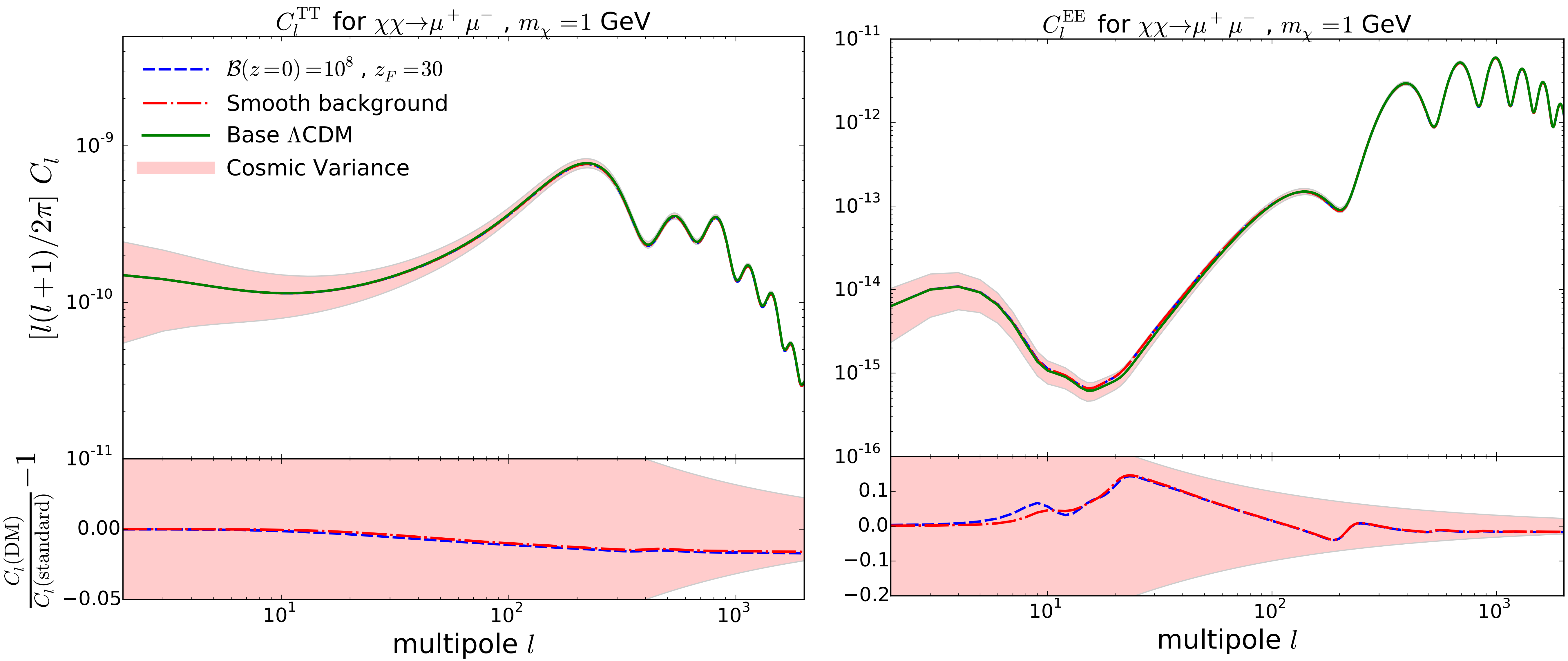
$f(z)$ decreases but it will be multiply by $(1+\mathcal{B}(z))$

see also [arXiv:1303.5094]

Impact of halos is similar to reionization



Impact of « standard halos » not distinguishable by the CMB



at low l : Effect well below cosmic variance.

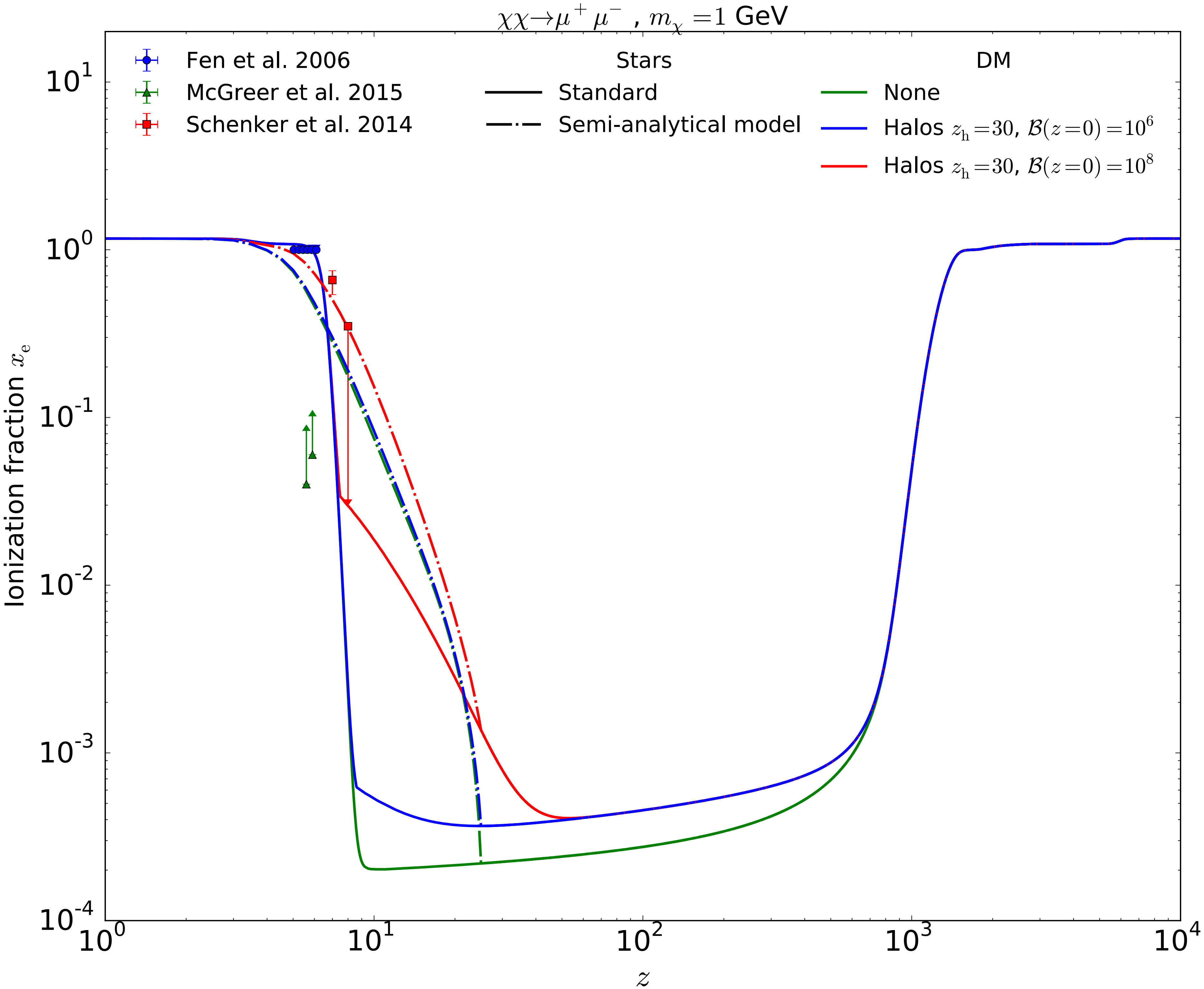
at high l : not distinguishable from background annihilations.

[arXiv:1508.01370]

UV sources in star-forming galaxies reionize the IGM

Standard :
tanh parameterization centered on « z_{reio} »

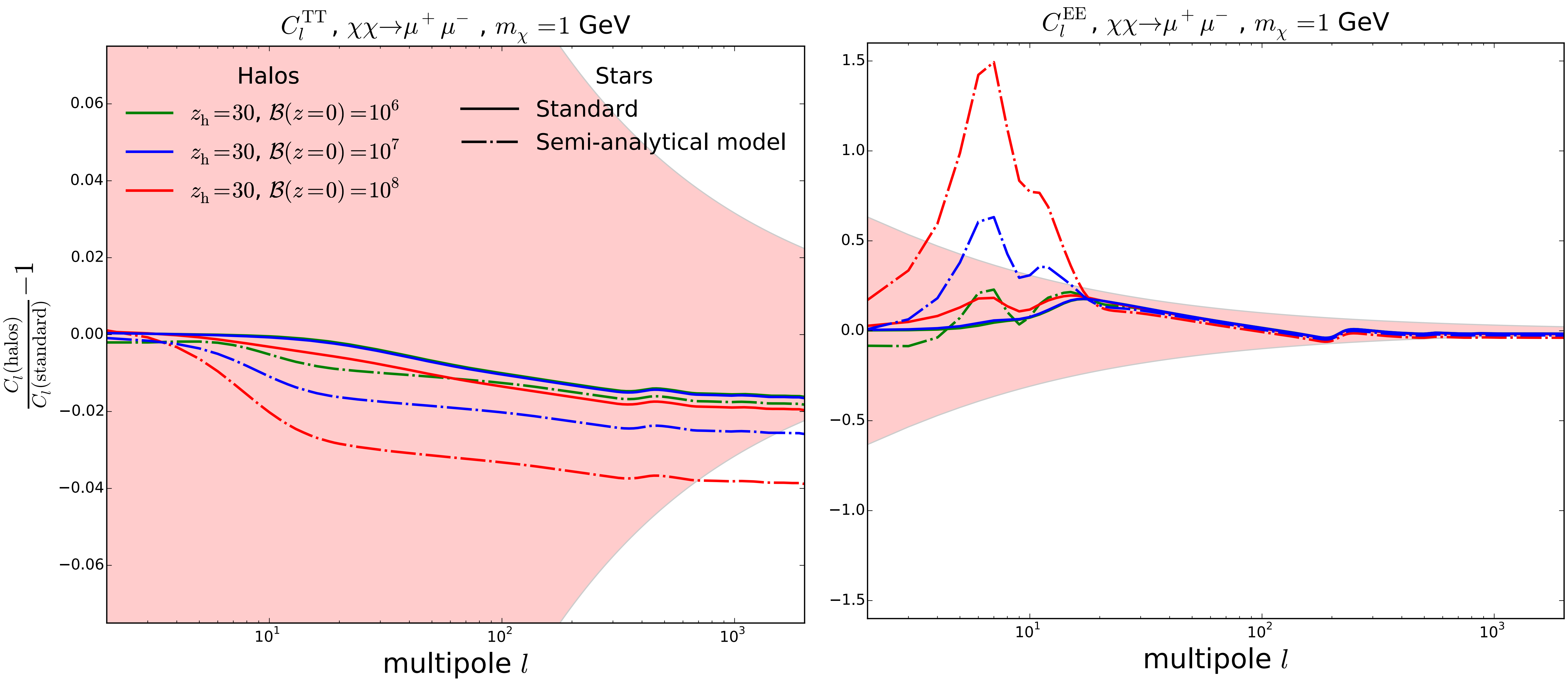
Semi analytical-model :
add a source term prop. to the star formation rate, itself prop. to UV luminosity.



$$\left.\frac{1}{E}\frac{dE}{dV\,dt}\right|_{\rm dep} = A_* f_{\rm esc}\xi_{\rm ion}\rho_{\rm SFR}(z)(1+z)^3$$

see also [arXiv:1502.02024]

Two different treatments of star reionization will lead to different conclusions !



A more realistic treatment might indicates that impact of halos is non-negligible. Caveat : Only for « big halos », disfavored by numerical simulations.

In a nutshell :

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From annihilations in the smooth background only, Planck

- improved bounds on $\langle \sigma v \rangle$ up to 1 order of magnitude;
- ruled out thermal relics below 10 GeV whatever annihilation channels;
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From annihilations of standard DM models in halos :

- optical depth cannot be significantly increased by realistic halos;
- impact on CMB power spectra depends on reionization modeling :
  - too small to improve bounds for the standard parameterization;
  - non-negligible for « big halos » in a more realistic modelization of stars.

Thanks for your attention !