Dark matter annihilations and decays after the AMS-02 positron measurements

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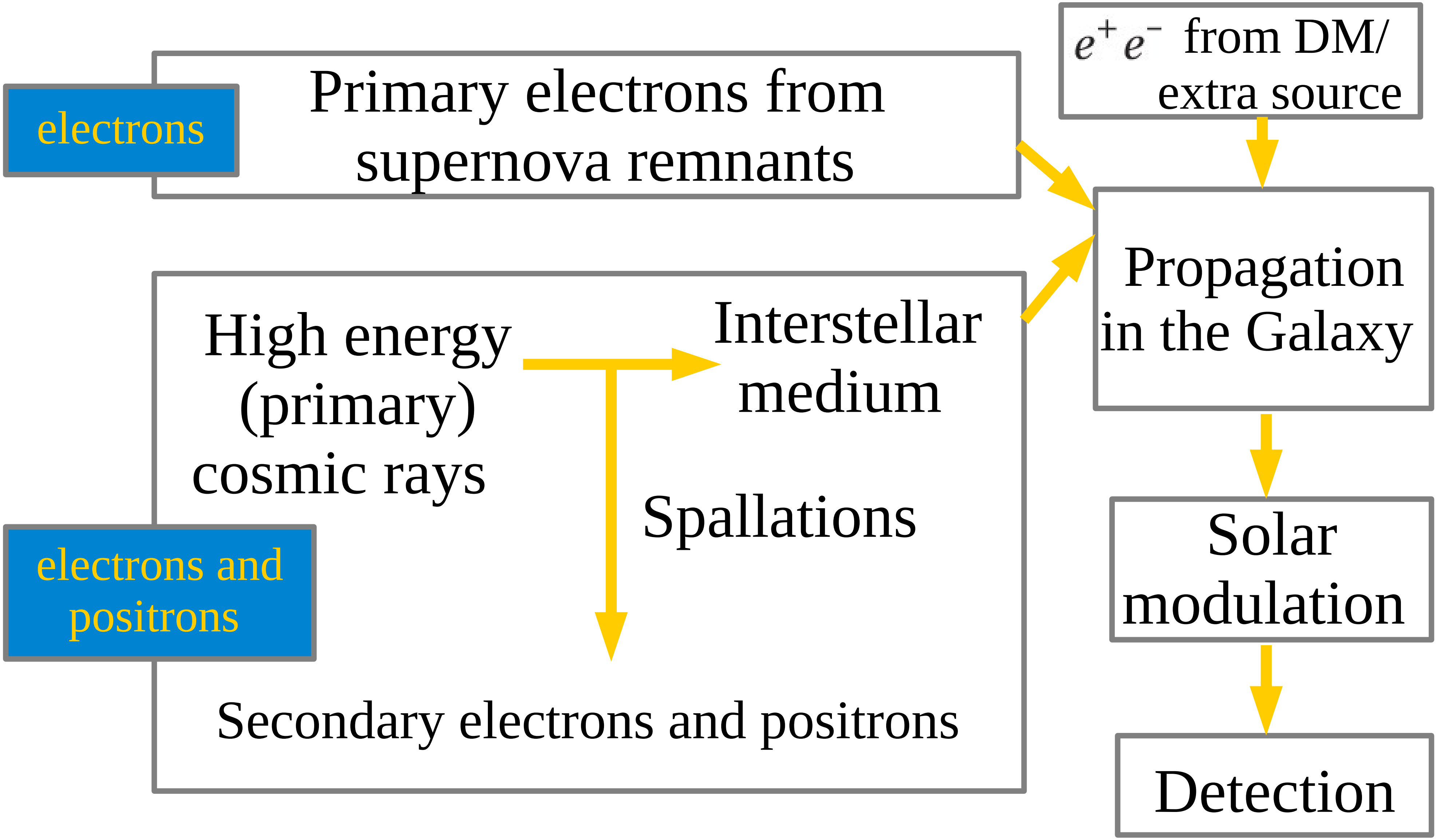
Based on arXiv:1309.2570 (Phys. Rev. D 89, 063539 (2014)),
in collaboration with Alejandro Ibarra and Joseph Silk

Objective

- Obtain limits for dark matter annihilations and decays for the first time from positron flux, but also from the positron fraction (see also arXiv:1306.3983 Bergström et al.)
  - Contrary to the fraction the electron flux is not needed → cleaner from theoretical point of view
  - Use well-motivated physical background model
  - Take the best limit from various energy windows
- Compare to limits from
  - the positron fraction
  - PAMELA and HEAT positron flux measurements
  - Fermi-LAT gamma rays

Electrons and positrons: from production to detection



electrons

Primary electrons from supernova remnants

e^+e^- from DM/ extra source

Propagation in the Galaxy

High energy (primary) cosmic rays

Interstellar medium

Spallations

electrons and positrons

Secondary electrons and positrons

Solar modulation

Detection

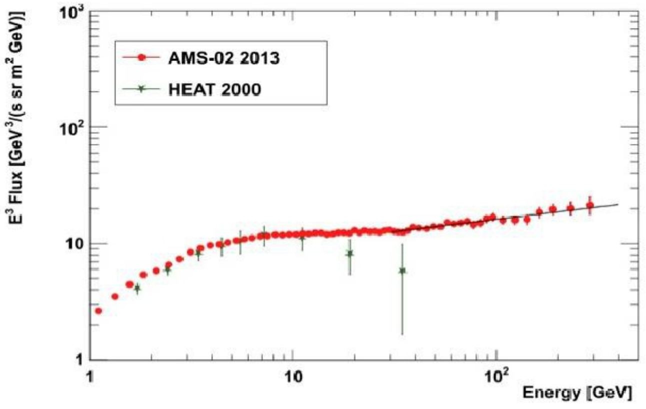
Approach

- Need parameterization for positron flux:

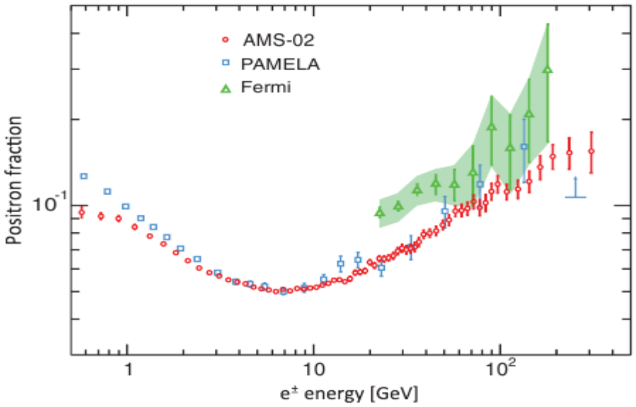
$$\phi_{e^+} = \boxed{\phi_{\mathrm{sec}}} + \boxed{\phi_{\mathrm{source}}} + \boxed{\phi_{\mathrm{DM}}}$$

- Perform χ^2 fit to the positron flux and fraction data measured by AMS-02 to obtain the limits

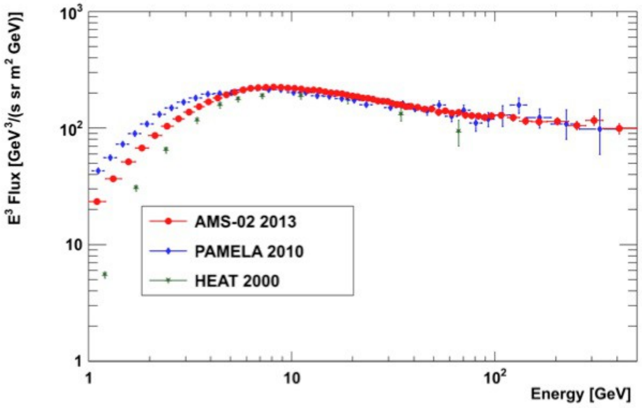
ICRC 2013 Positron Spectrum



Phys. Rev. Lett. 110, 141102 (2013)



ICRC 2013 Electron Spectrum



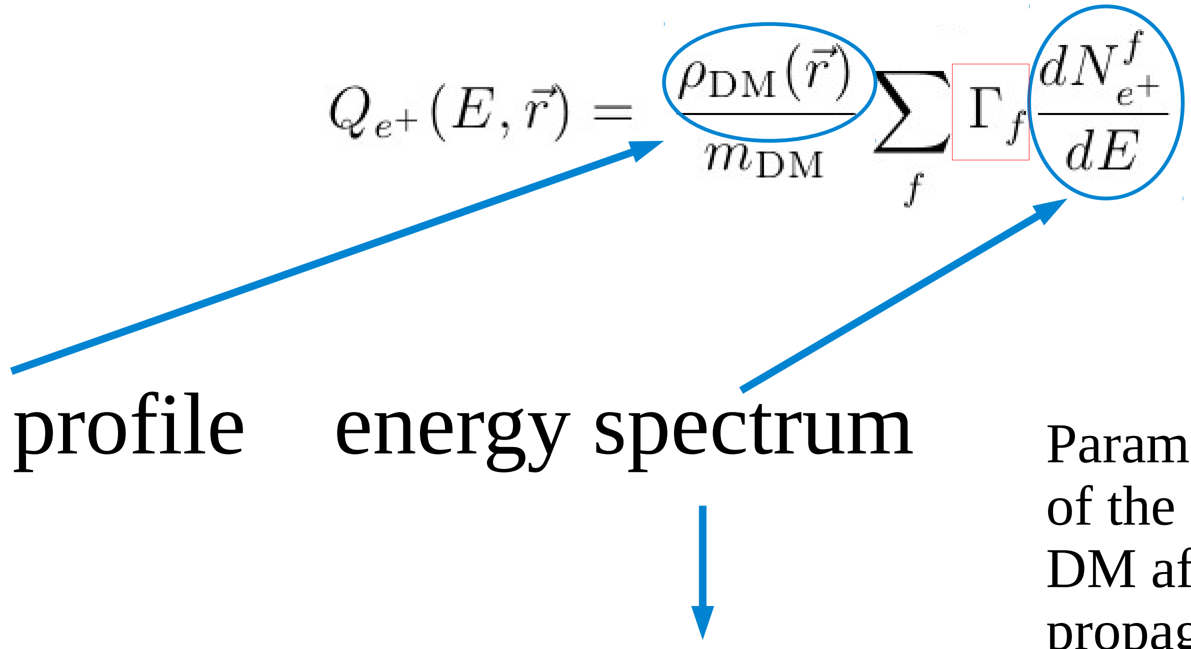
Primary positrons

- Annihilations:

$$Q_{e^+}(E,\vec{r}) = \frac{1}{2}\frac{\rho^2_{\rm DM}(\vec{r})}{m^2_{\rm DM}}\sum_f \boxed{\langle\sigma v\rangle_f}\frac{dN^f_{e^+}}{dE}$$

- Decays:

$$Q_{e^+}(E,\vec{r}) = \boxed{\frac{\rho_{\rm DM}(\vec{r})}{m_{\rm DM}}}\sum_f \boxed{\Gamma_f}\boxed{\frac{dN^f_{e^+}}{dE}}$$



dark matter profile

energy spectrum

Einasto profile

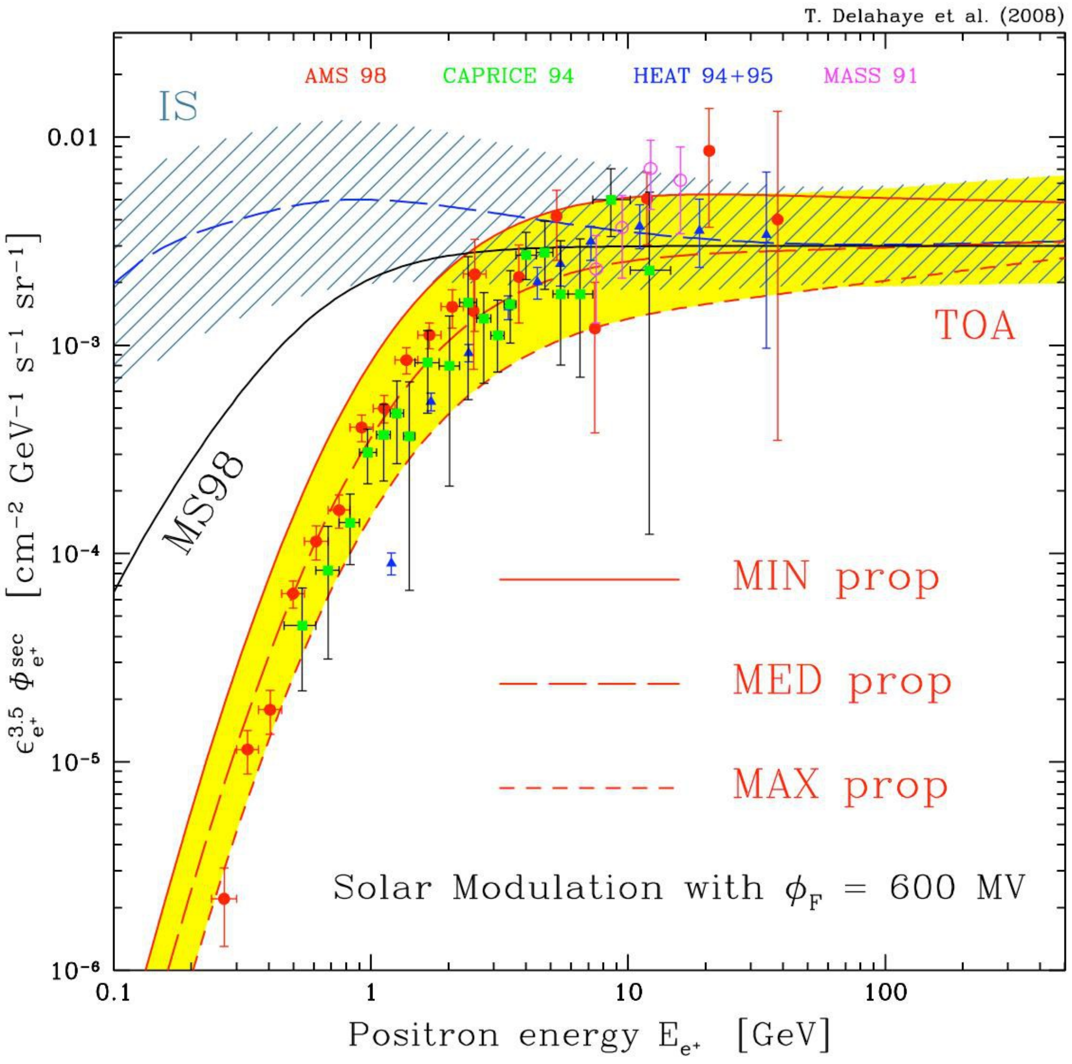
different channels

$$\rho_{\rm DM}(r) = \rho_0 \exp\left[-\frac{2}{\alpha}\left(\frac{r}{r_s}\right)^{\alpha}\right]$$

$$e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^-,\ b\bar{b},\ W^+W^-$$

Parameterizations of the fluxes from DM after propagation are given in 1012.4515 by M. Cirelli et al.

Secondary positrons: spallations



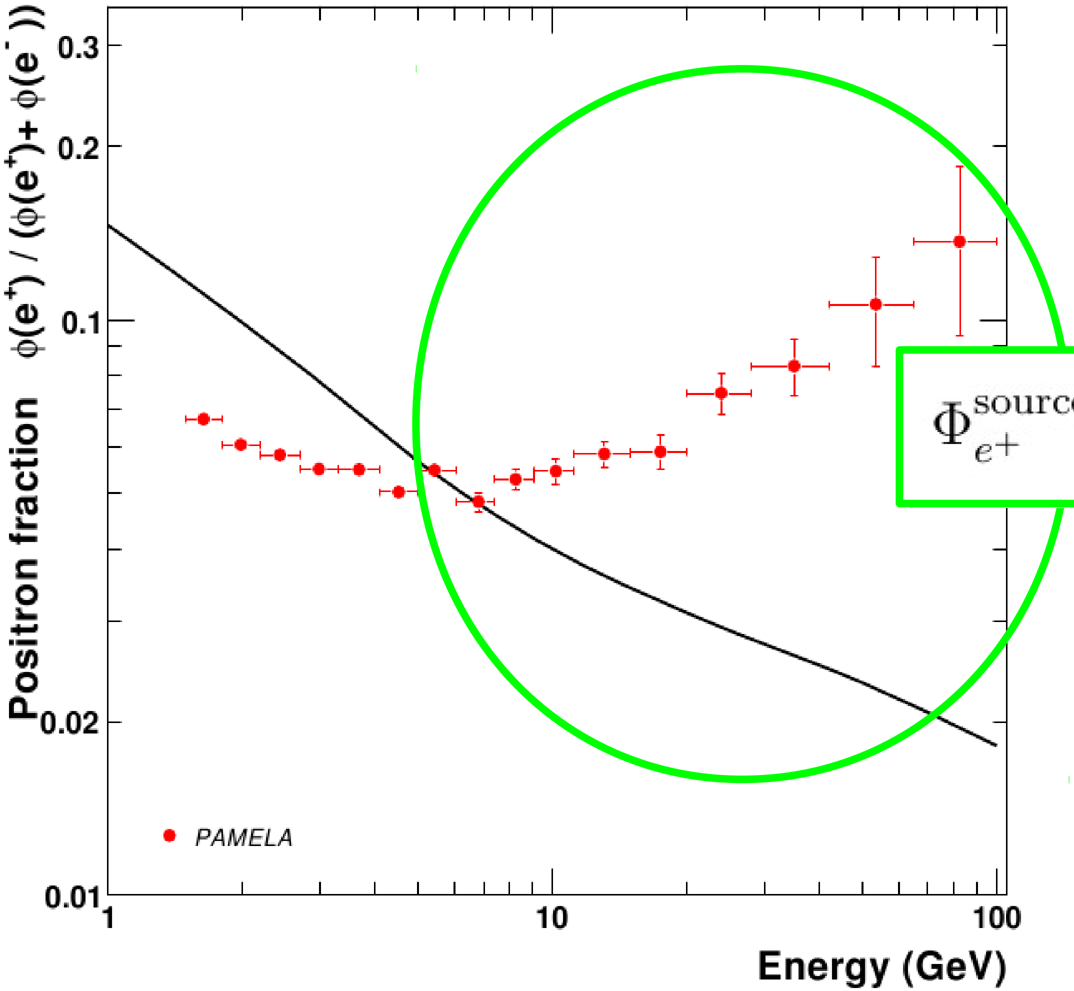
T. Delahaye et al. (2008)

- Power law above 2 GeV
- Index: 3.3 < γ_{e+} < 3.7

$$\Phi_{e^+}^{\mathrm{sec,IS}}(E) = C_{e^+} E^{-\gamma_{e^+}}$$

Positron background - possible additional source

arXiv:0810.4995, Adriani et al.



$$\Phi_{e+}^{\text{source,IS}}(E) = C_s E^{-\gamma_s} \exp(-E/E_s)$$

$$\gamma_{e+} > \gamma_s$$

Parametrization of background: positron flux

$$\Phi^{\mathrm{IS}}_{e^+}(E) = \boxed{\begin{array}{c} C_{e^+} E^{-\gamma_{e^+}} \\ \text{secondary positrons} \end{array}} + \boxed{\begin{array}{c} C_s E^{-\gamma_s} \exp(-E/E_s) \\ \text{additional source} \end{array}}$$

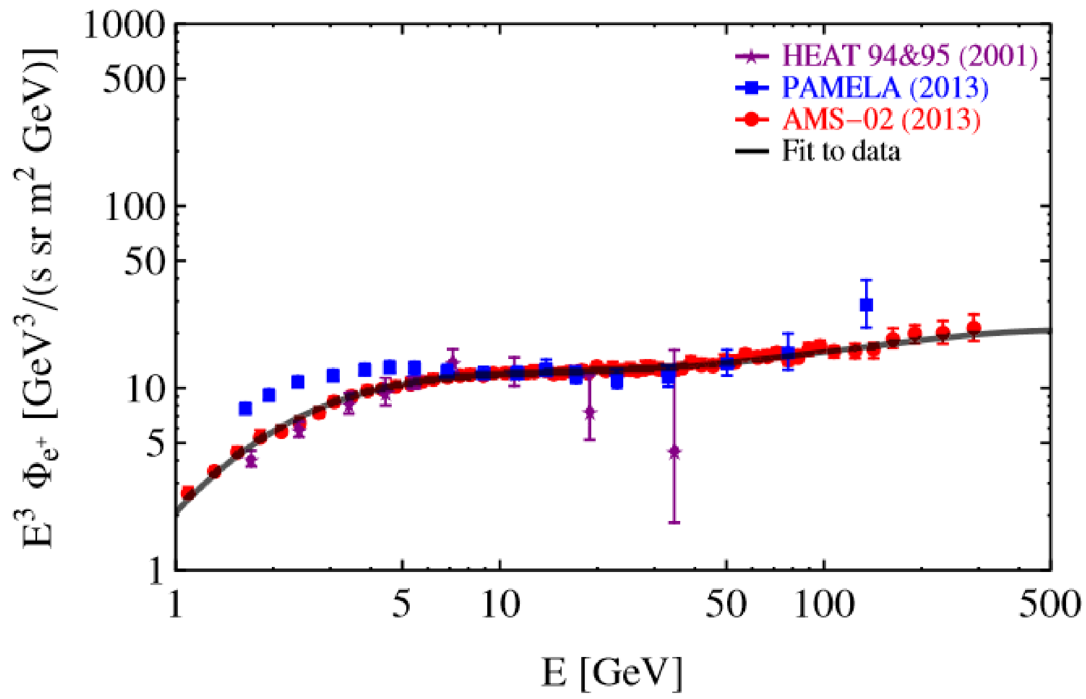
Parametrization of background: positron flux

$$\Phi^{\mathrm{IS}}_{e^+}(E) = \boxed{C_{e^+}}\, E^{-\boxed{\gamma_{e^+}}} + \boxed{C_s}\, E^{-\boxed{\gamma_s}} \exp(-E/\boxed{E_s})$$

Solar modulation:
0.5GV < ϕ < 1.3GV

$$\Phi^{\mathrm{TOA}}_{e^+}(E) = \frac{E^2}{(E+\boxed{\phi_{e^+}})^2}\,\Phi^{\mathrm{IS}}_{e^+}(E+\boxed{\phi_{e^+}})$$

Fit to AMS data



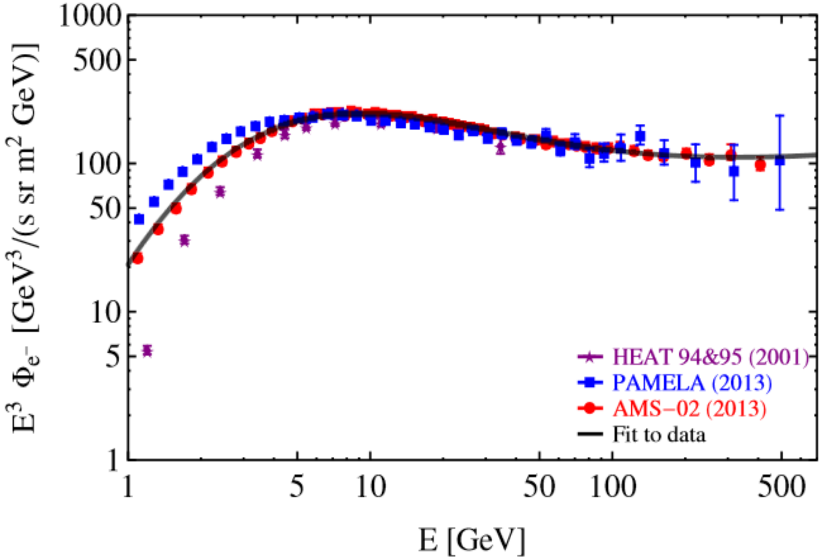
Parametrization of background: positron fraction

$$\frac{\Phi_{e^+}^{\mathrm{TOA}}}{\Phi_{e^+}^{\mathrm{TOA}}+\Phi_{e^-}^{\mathrm{TOA}}}$$

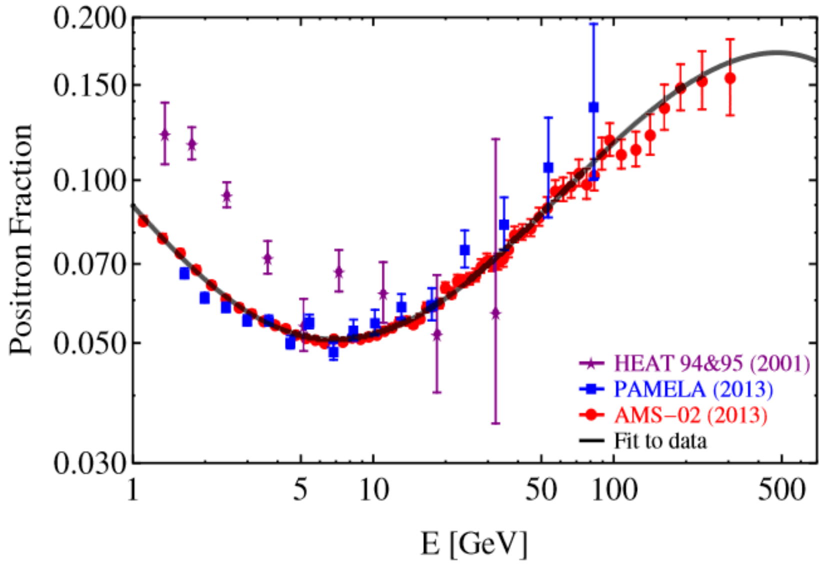
Electrons: use measured flux

$$\Phi_{e^-}^{\mathrm{TOA}}(E)=\frac{E^2}{(E+\phi_{e^-})^2}\left[C_1(E+\phi_{e^-})^{-\gamma_1}+C_2(E+\phi_{e^-})^{-\gamma_2}\right]$$

Fit electron parameters to electron flux



Fit positron parameters to the fraction



Limits: fit

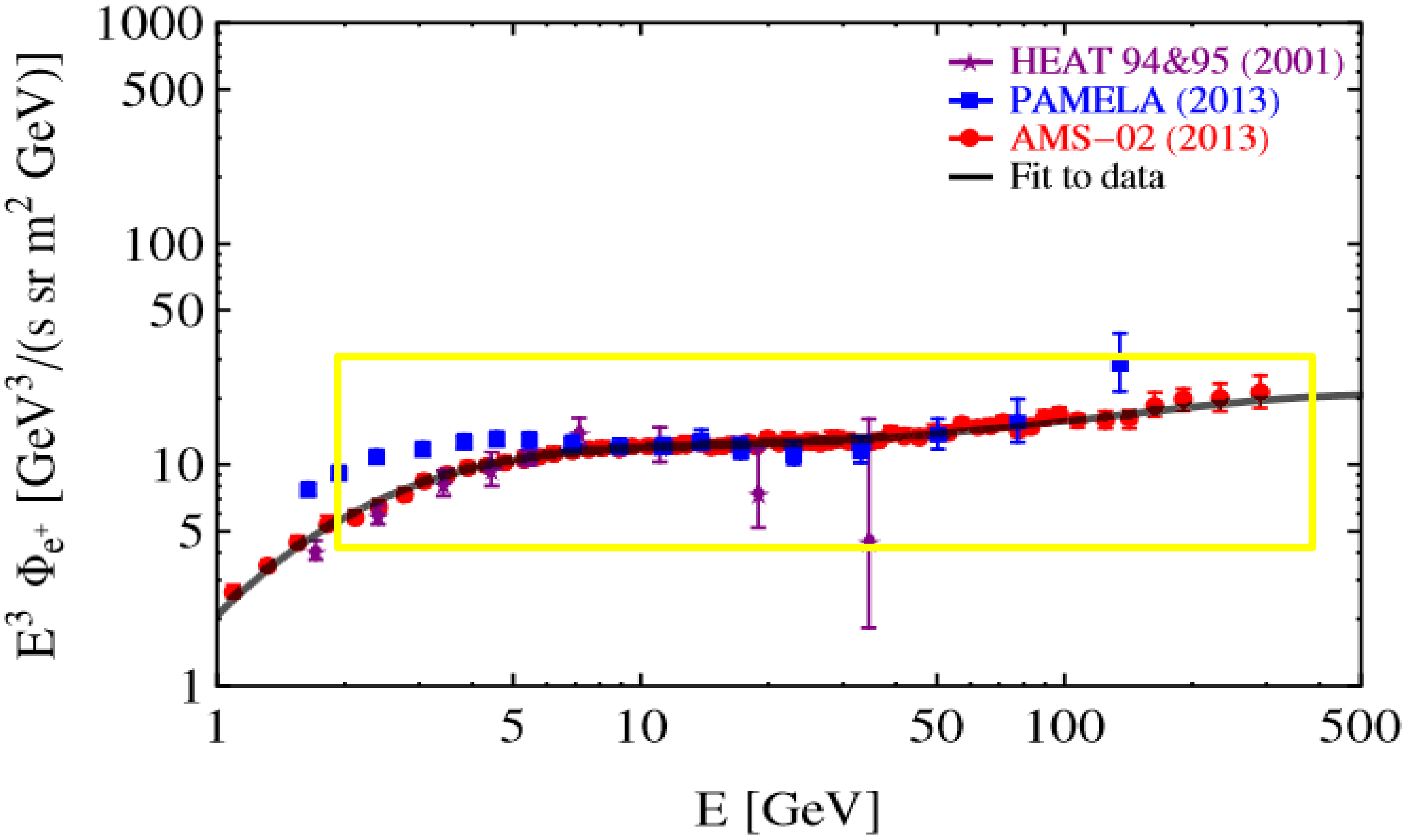
$$\Phi_{e^+}^{\mathrm{bkg,TOA}}(E) = \Phi_{e^+}^{\mathrm{sec,TOA}}(E) + \Phi_{e^+}^{\mathrm{source,TOA}}(E)$$

2σ limit corresponds to $\Delta\chi^2 > 4$

$$\Phi_{e^+}^{\mathrm{TOA}}(E) = \Phi_{e^+}^{\mathrm{bkg,TOA}}(E) + \boxed{\Phi_{e^+}^{\mathrm{DM,TOA}}(E)}$$

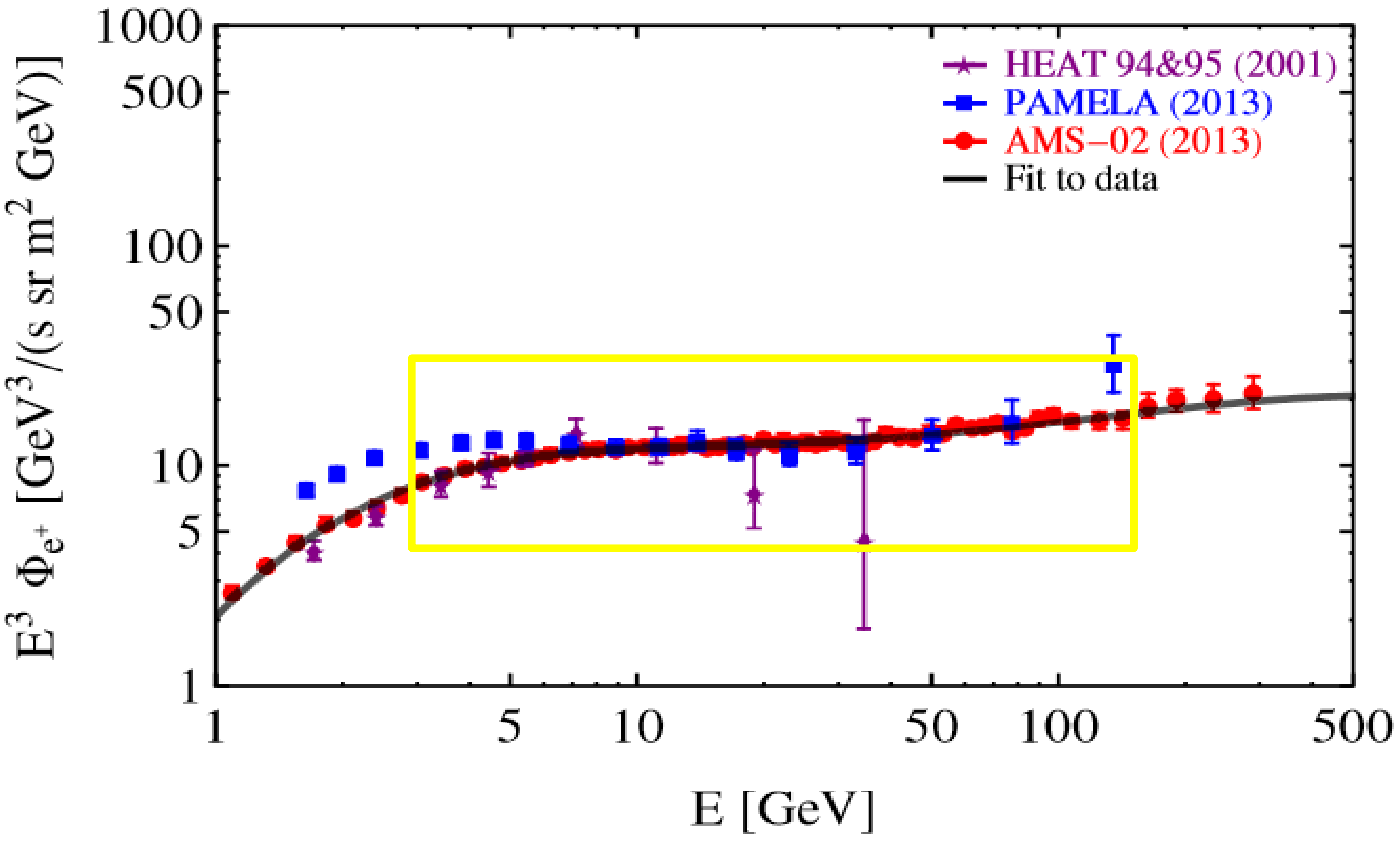
increase

Limits: energy windows



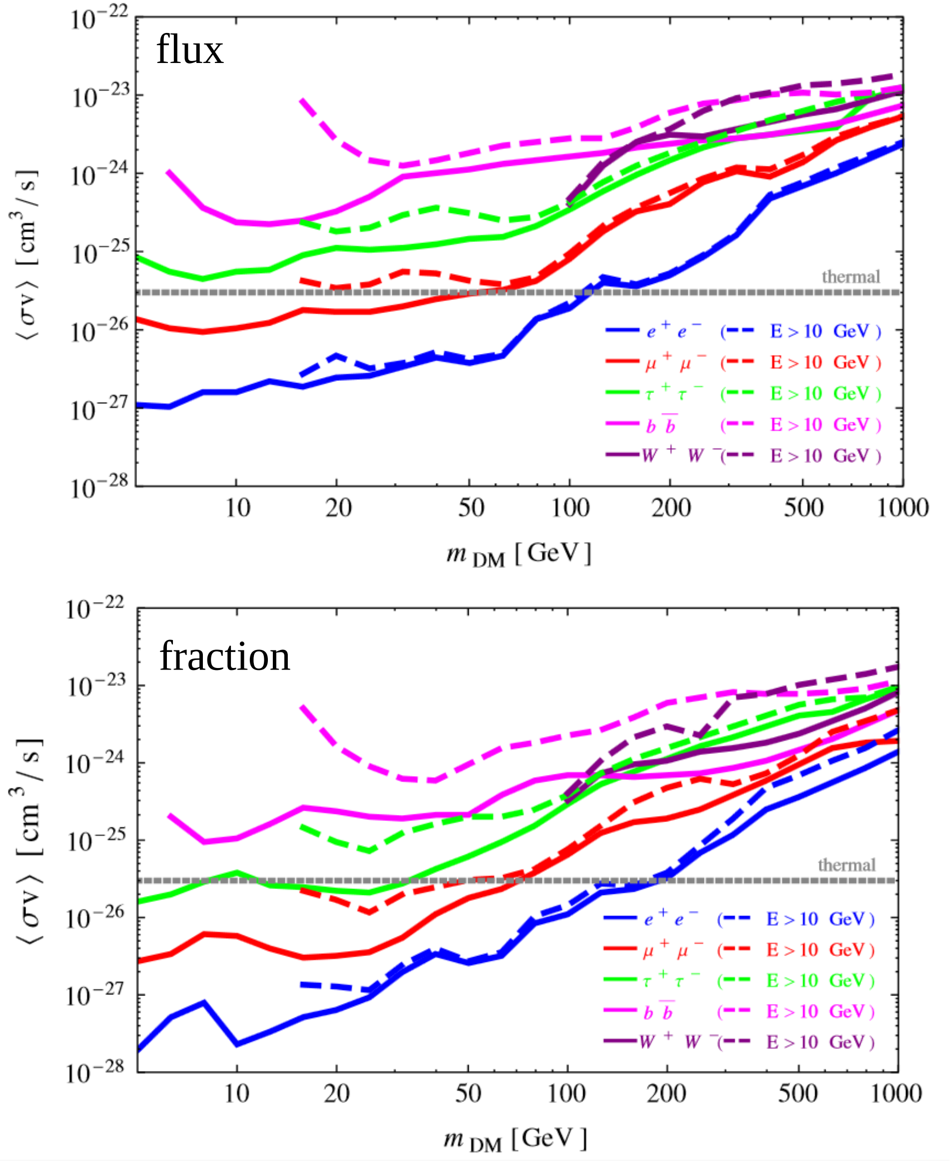
Select strongest limit from sampling over various energy windows

Limits: energy windows



Select strongest limit from sampling over various energy windows

Limits: Competitive results from flux and fraction



- Final states:

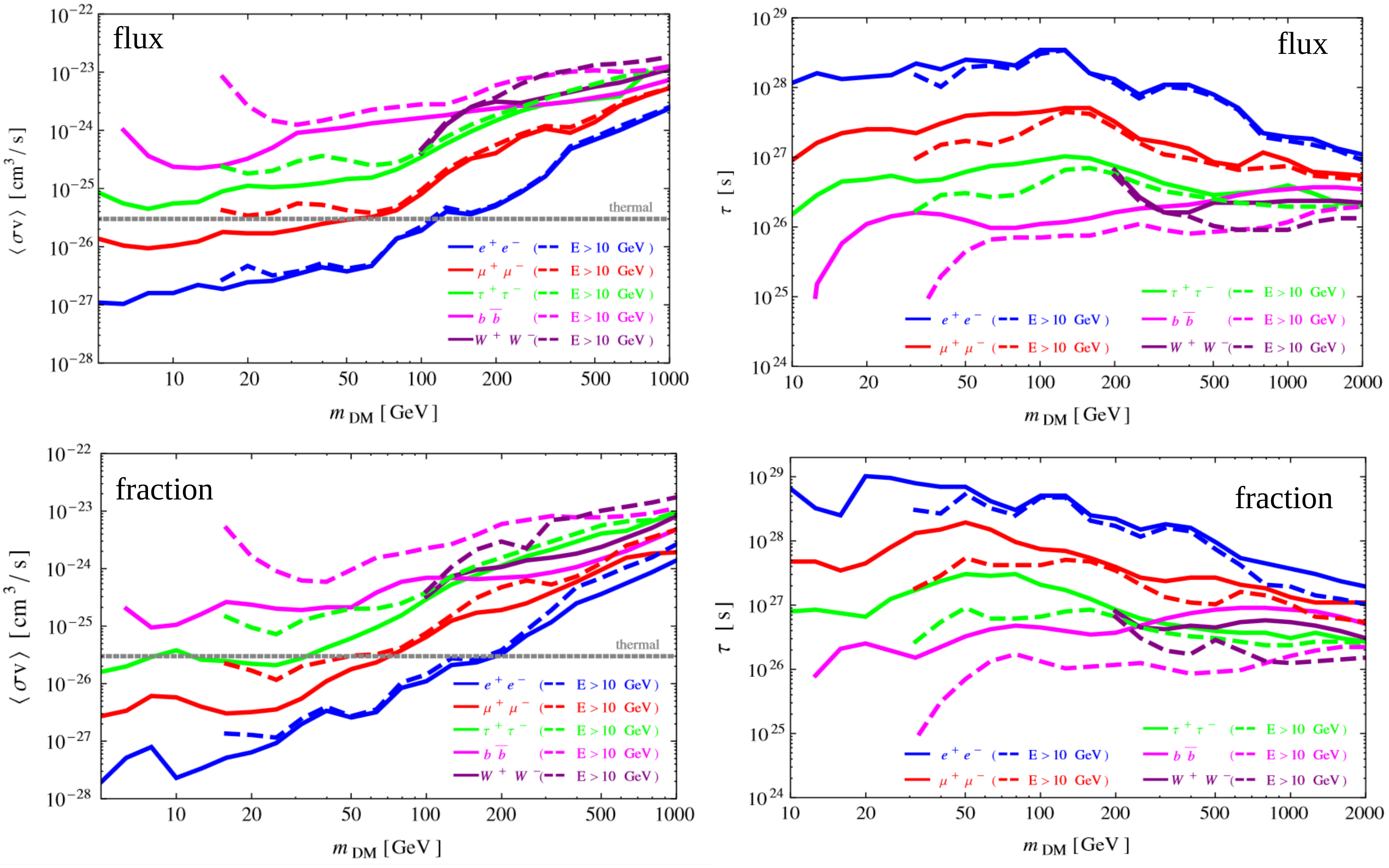
  $e^+e^-, \mu^+\mu^-, \tau^+\tau^-, b\bar{b}, W^+W^-$

- Limits using data points above 10 GeV insensitive to solar modulation

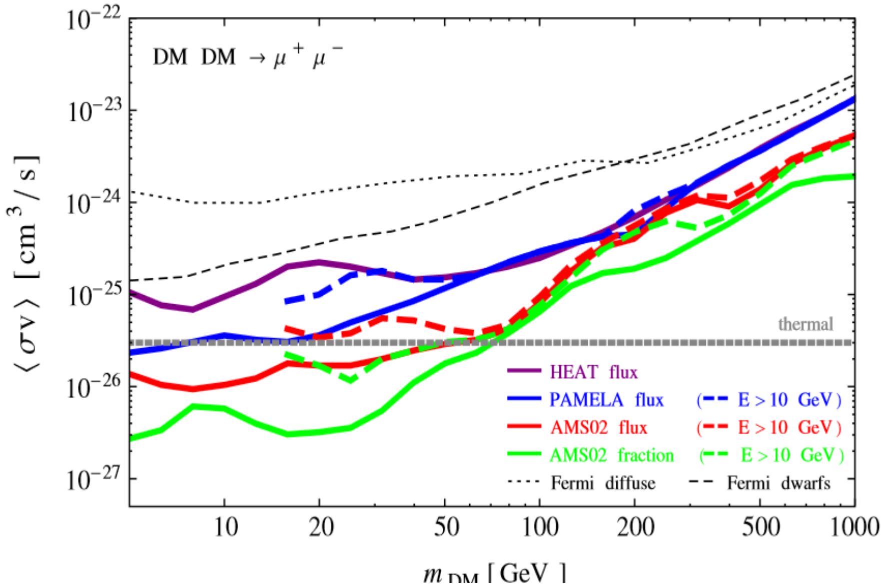
- Probe thermal cross section for dark matter masses smaller than 100 GeV in the e^+e^- final state and for masses smaller than 60 GeV in the $\mu^+\mu^-$ final state

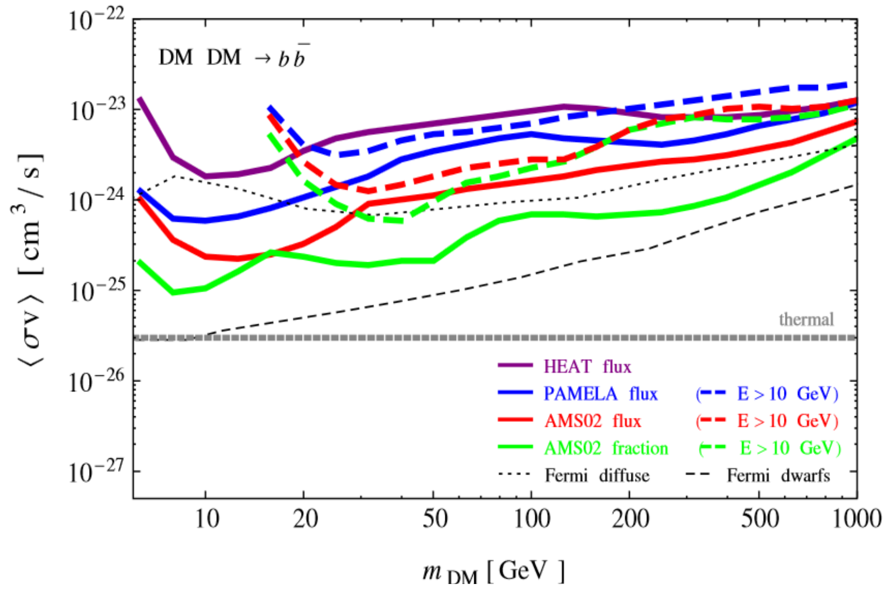
- Limits competitive with the one from the positron fraction, though slightly worse

Limits: Competitive results from flux and fraction



Limits: Comparison for muon and b channels





- Limits from AMS-02 positron flux are best, but PAMELA and HEAT positron fluxes give also strong limits

- Limits from the positron fraction are better than the ones from the positron flux

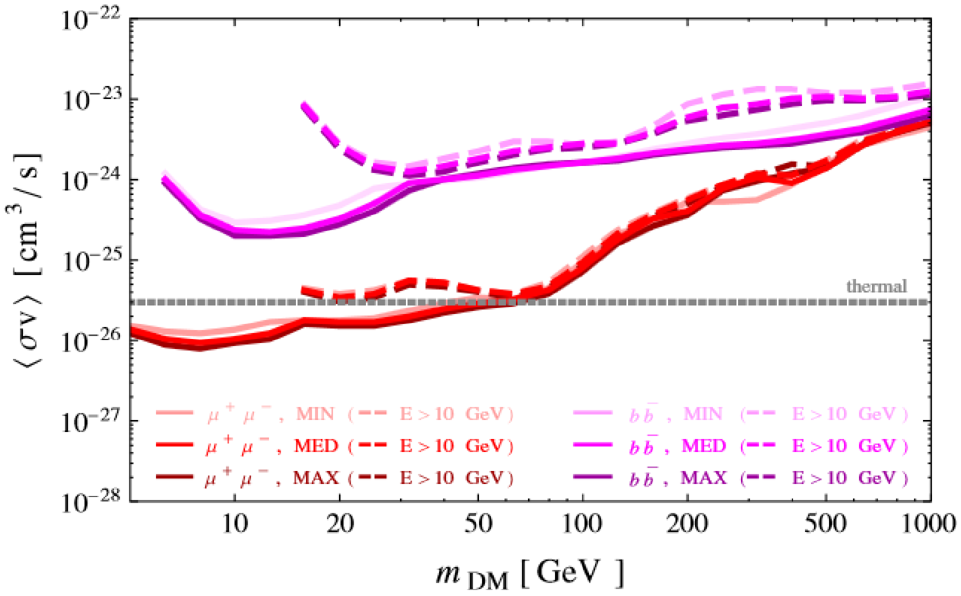
- In some channels, the limits from the positron flux are better than the ones from the diffuse gamma-ray flux reported by the Fermi-LAT collaboration (Ackermann et al. arXiv:1205.2739, and arXiv:1310.0828)

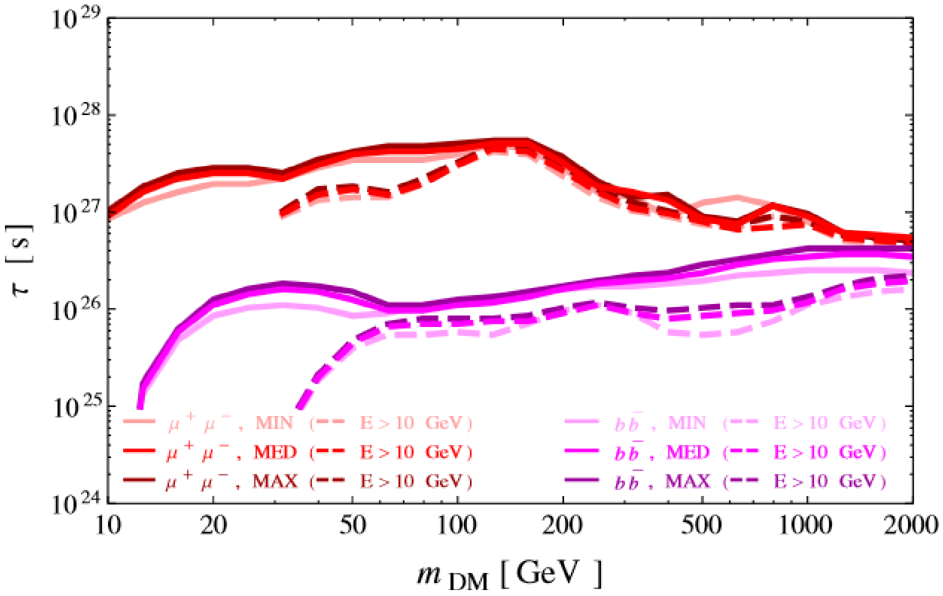
Conclusions

- AMS positron measurements allow to severely constrain dark matter parameters
- Optimization of limits by choosing the best limits from using various energy windows
- Limits from the positron flux are competitive with the ones form the positron fraction and in some cases better than the limits reported by the Fermi-LAT collaboration

Thank you for your attention!

Propagation: MIN, MED and MAX parameters





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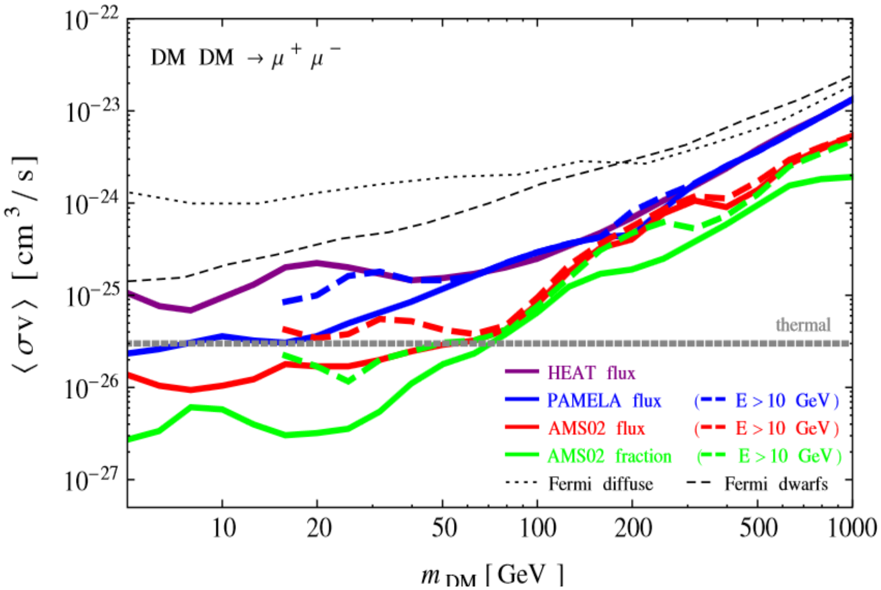
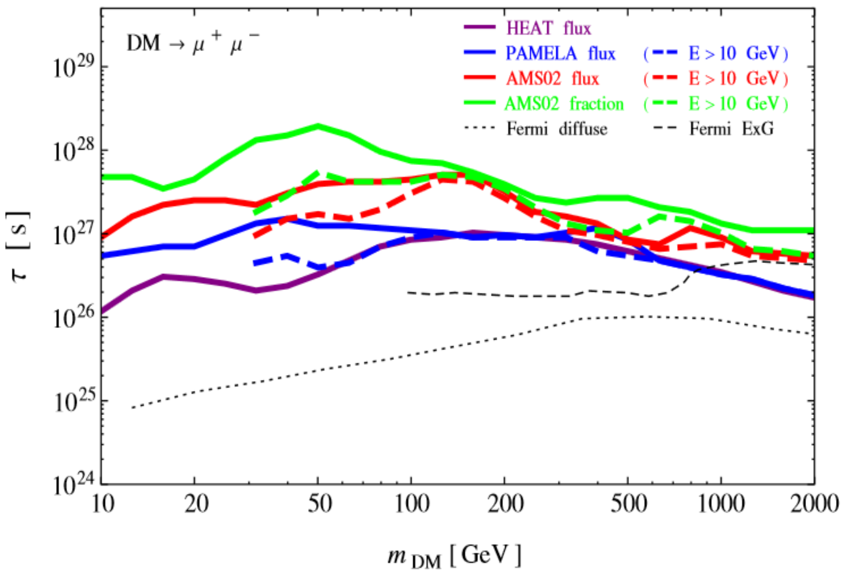
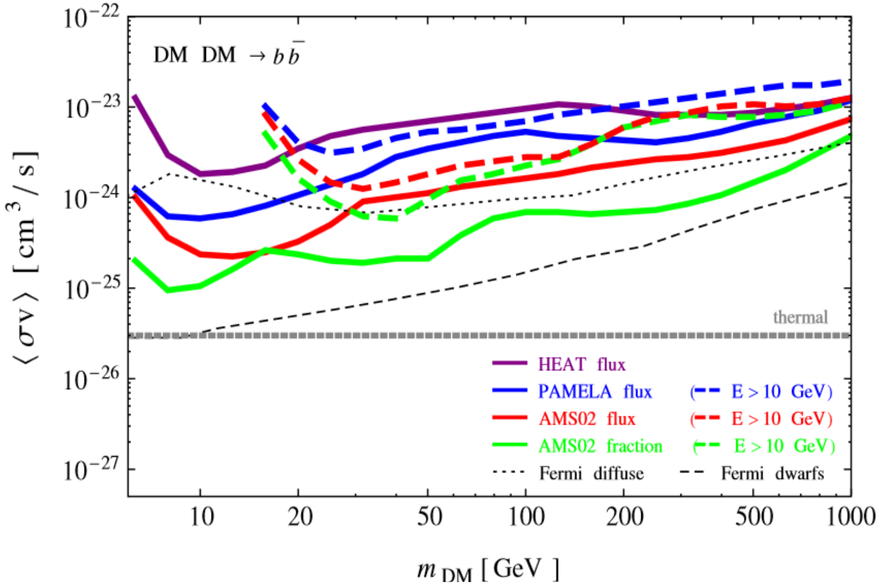
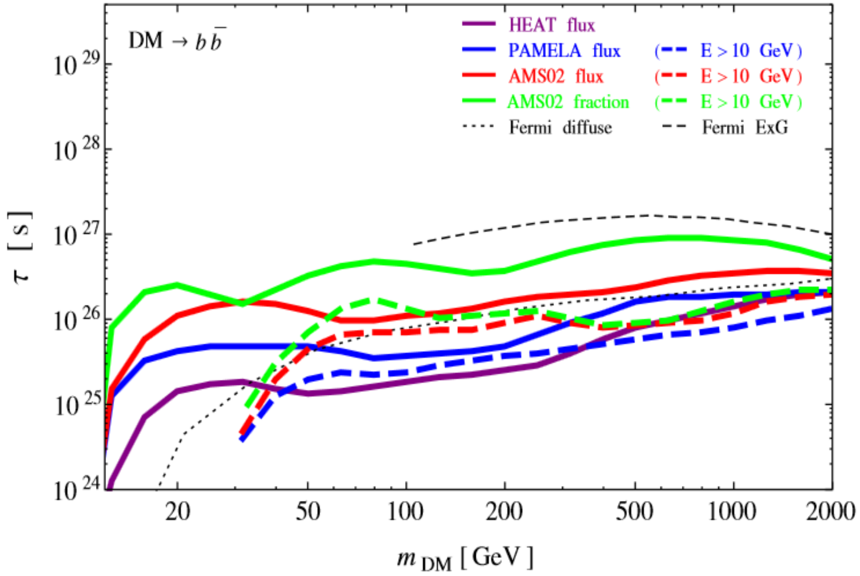


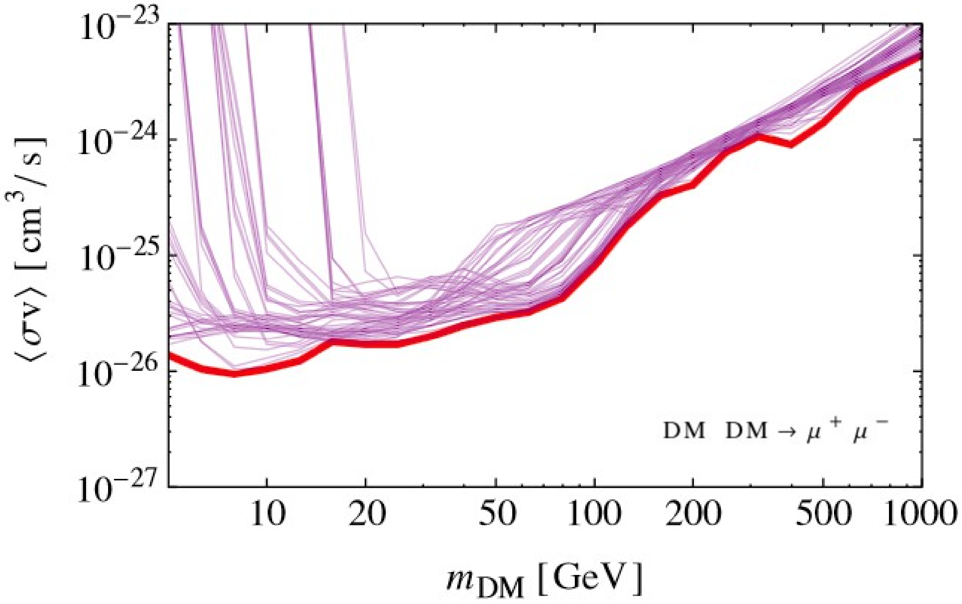


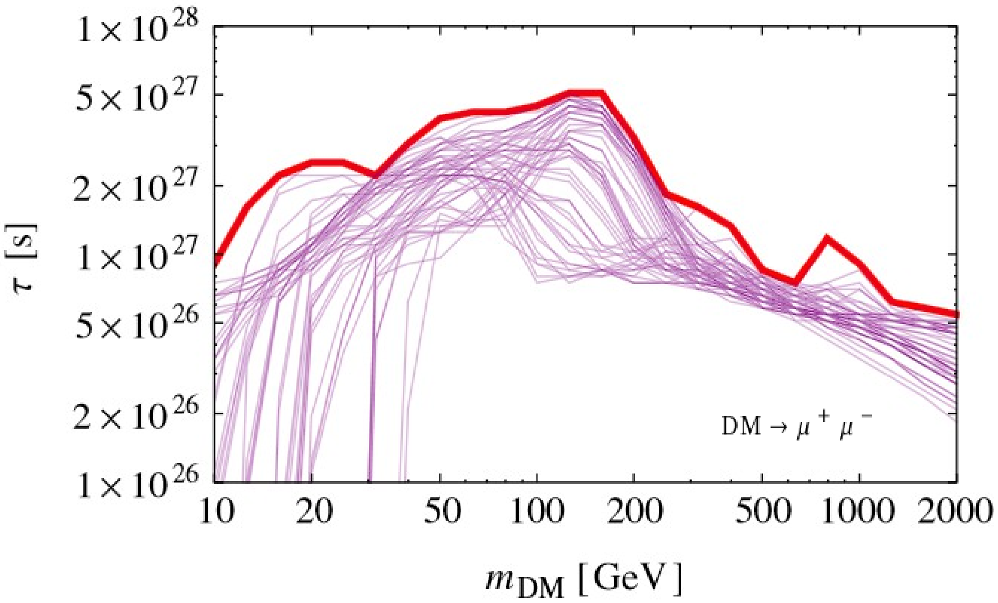




Limits: energy windows

Select strongest limit from sampling over various energy windows





Propagation in the Galaxy

The diffusion loss equation for positrons:

$$0 = \frac{\partial f_{e^+}}{\partial t} = \nabla \cdot [K(E,\vec{r})\nabla f_{e^+}] + \frac{\partial}{\partial E}[b(E,\vec{r}) f_{e^+}] + Q(E,\vec{r})$$

- Consider stationary case
- Diffusion coefficient describes scattering off random component of galactic magnetic fields
- Energy losses for positrons: synchrotron radiation, inverse Compton scattering
- Source term from dark matter annihilations and decays

Useful parameterization of the positron fluxes at Earth is given in arXiv:1012.4515 by M. Cirelli et al.