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

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in collaboration with Alejandro Ibarra and Joseph Silk

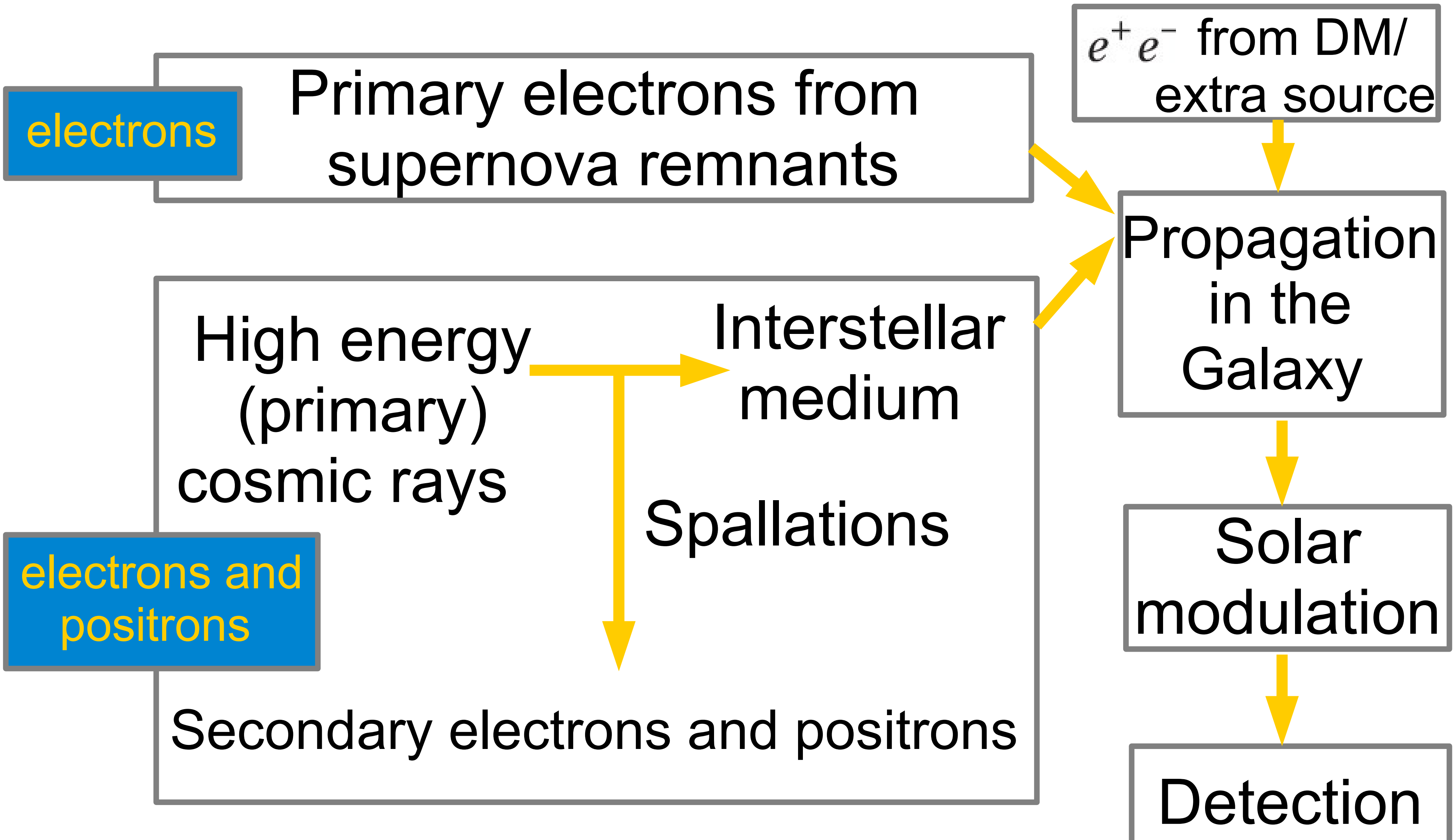
Outline

- Objective: Use positron measurements to calculate limits on dark matter parameters
- Approach:
  - Treatment of primary and secondary positrons
  - Calculation of the limits
- Obtain limits in different channels and from different measurements
- Conclusions

Objective

- Obtain limits for dark matter annihilations and decays for the first time from positron flux
  - Contrary to the fraction the electron flux is not needed → cleaner from theoretical point of view
  - Use well-motivated physical background model
- Compare to limits from
  - the positron fraction
  - PAMELA and HEAT positron flux measurements
  - Fermi-LAT gamma rays

Electrons and positrons: from production to detection



Approach

- Need expression for positron flux: Background positrons plus primary positrons from dark matter annihilations and decays
- Perform χ^2 fit to the positron flux and fraction data to obtain the limits

Primary positrons

- Annihilations:

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

- Decays:

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

dark matter profile → Einasto profile

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

energy spectrum → different channels

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

Propagation in the Galaxy

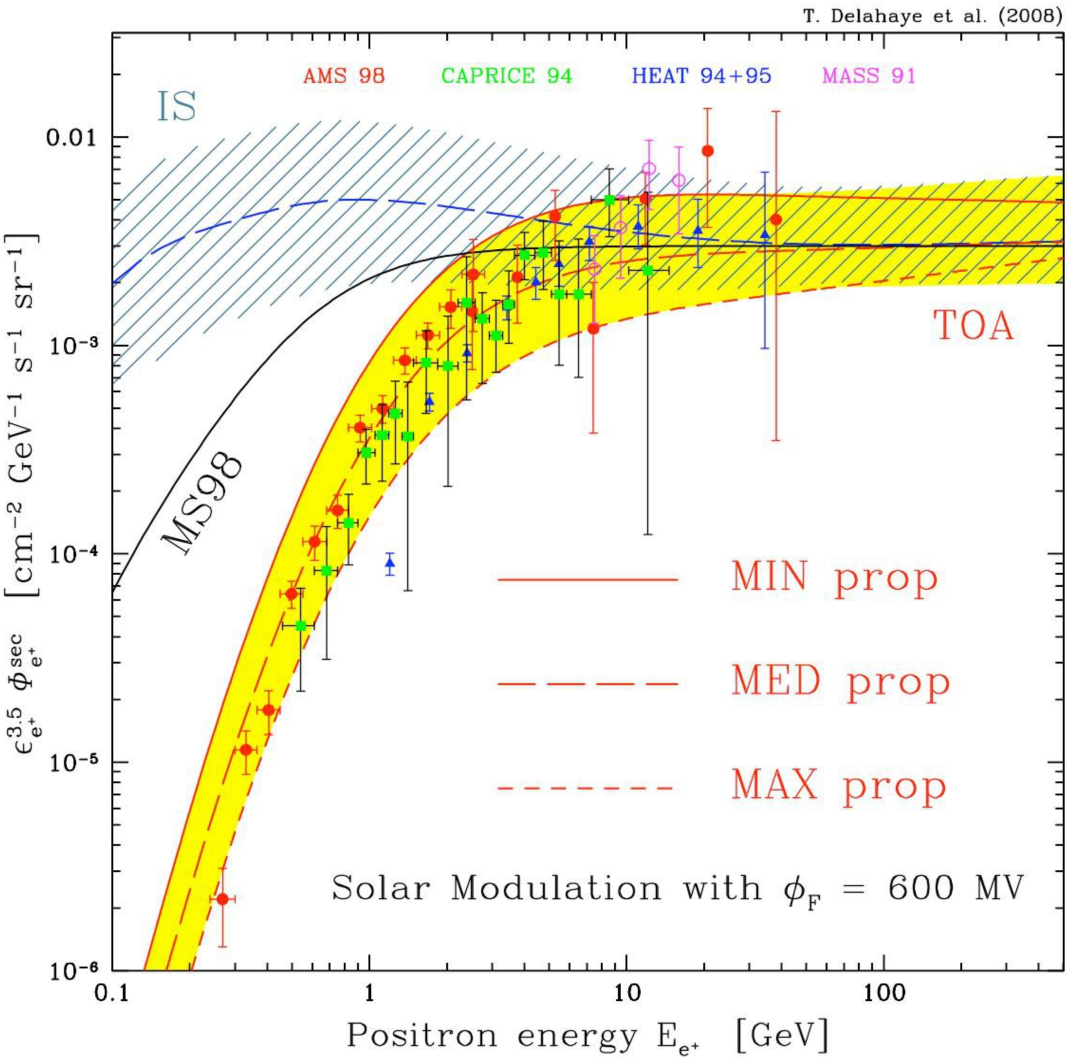
The diffusion loss equation for positrons:

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

- 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.

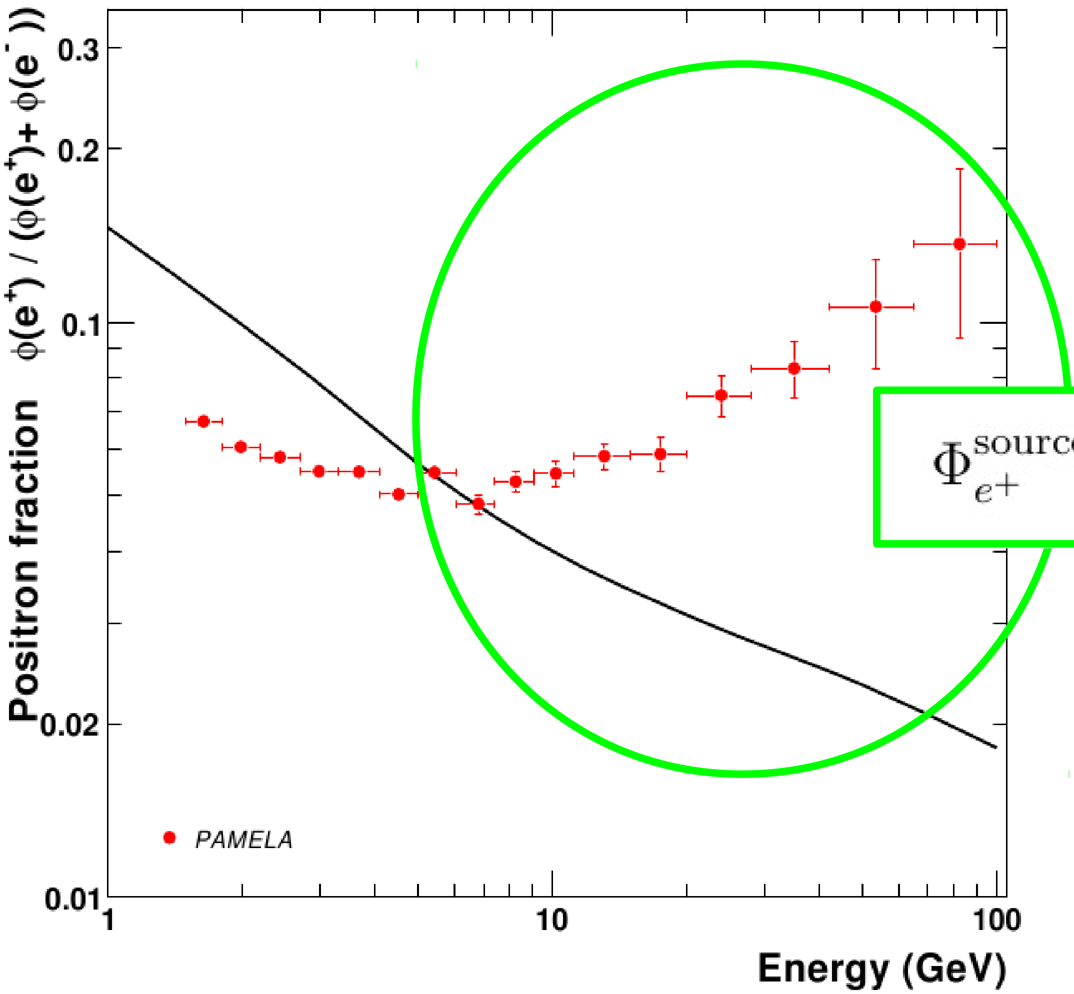
Secondary positrons: spallations



- Power law above 2 GeV
- Index: $3.3 < \gamma_{e+} < 3.7$

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

Positron background - possible additional source



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

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

Parametrization of background: positron flux

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

secondary positrons

additional source

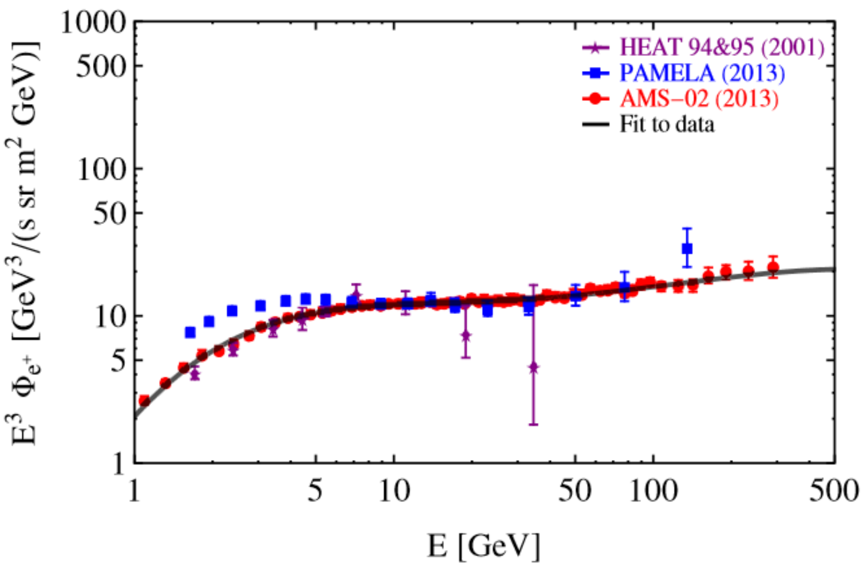
Parametrization of background: positron flux

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

Solar modulation:
0.5GV < ϕ < 1.3GV

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

Fit to AMS data



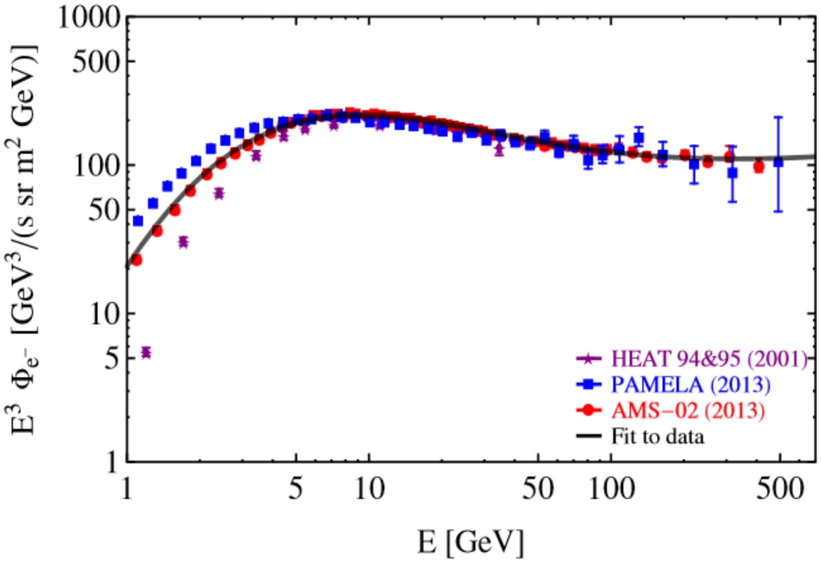
Parametrization of background: positron fraction

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

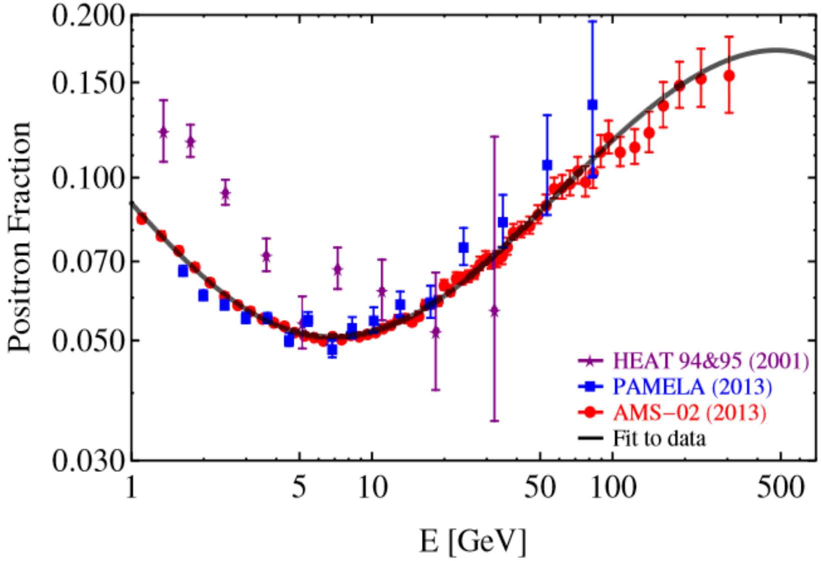
Electrons: use measured flux

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

Fit electron parameters to electron flux



Fit positron parameters to the fraction



Limits: fit

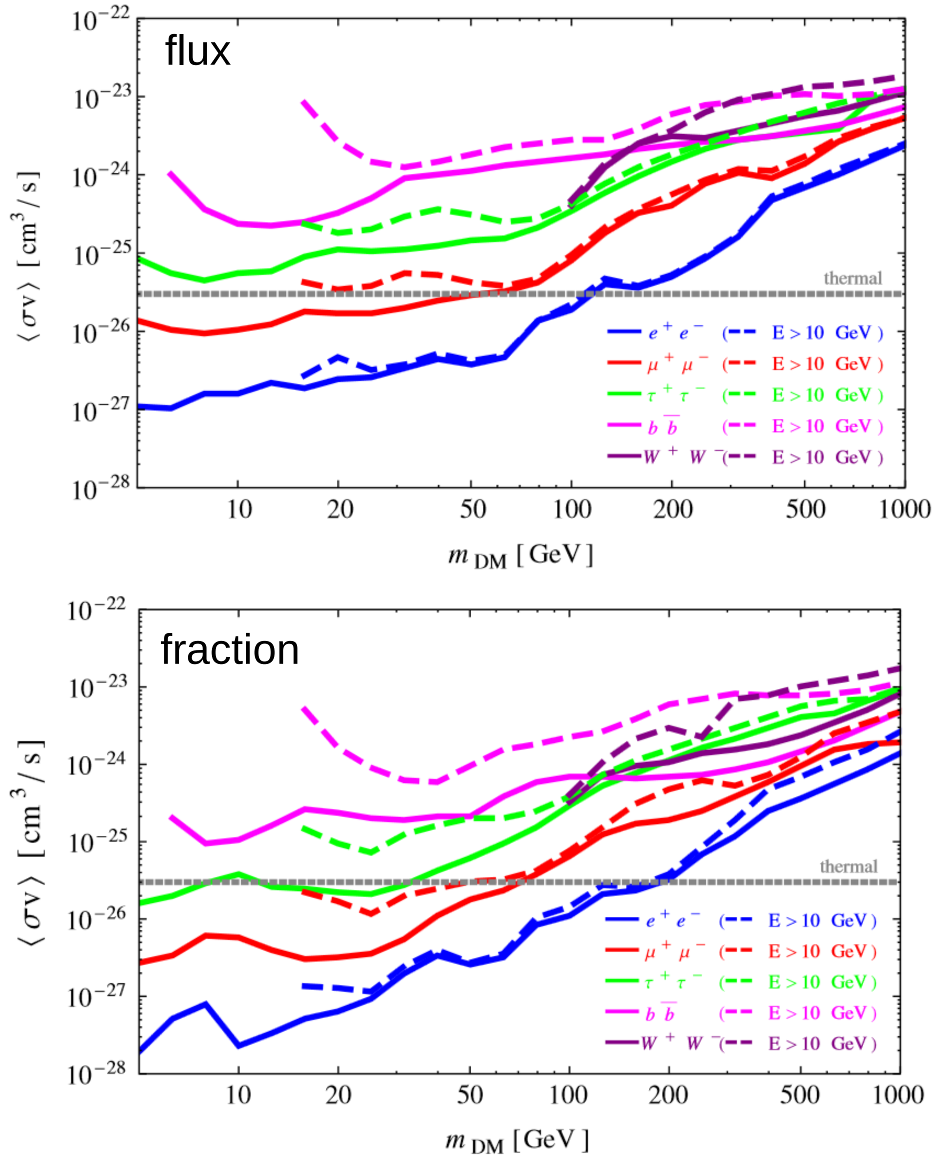
$$\Phi_{e^+}^{\mathrm{bkg,TOA}}(E) = \Phi_{e^+}^{\mathrm{sec,TOA}}(E) + \Phi_{e^+}^{\mathrm{source,TOA}}(E)$$

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

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

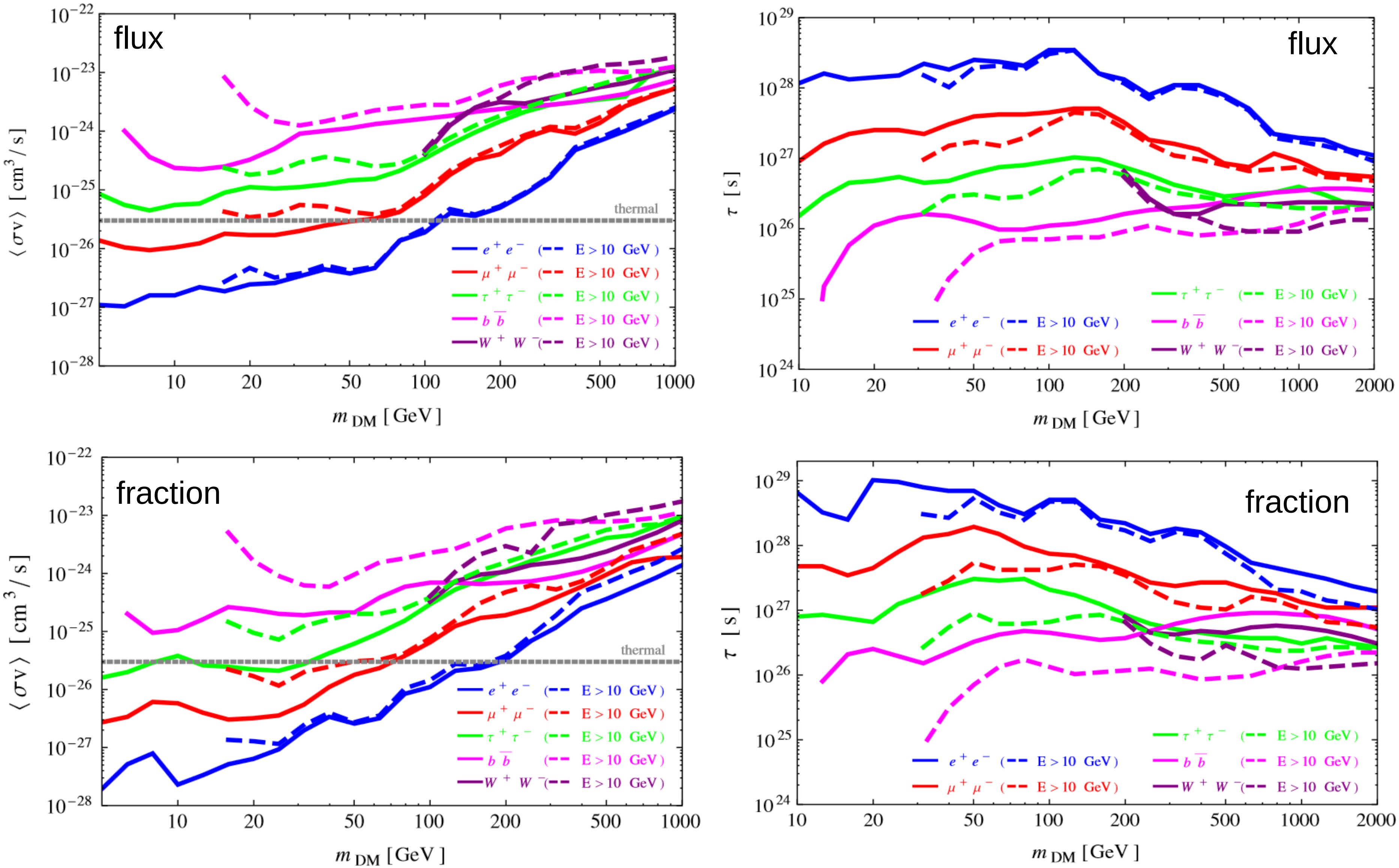
increase

Limits: Competitive results from flux and fraction

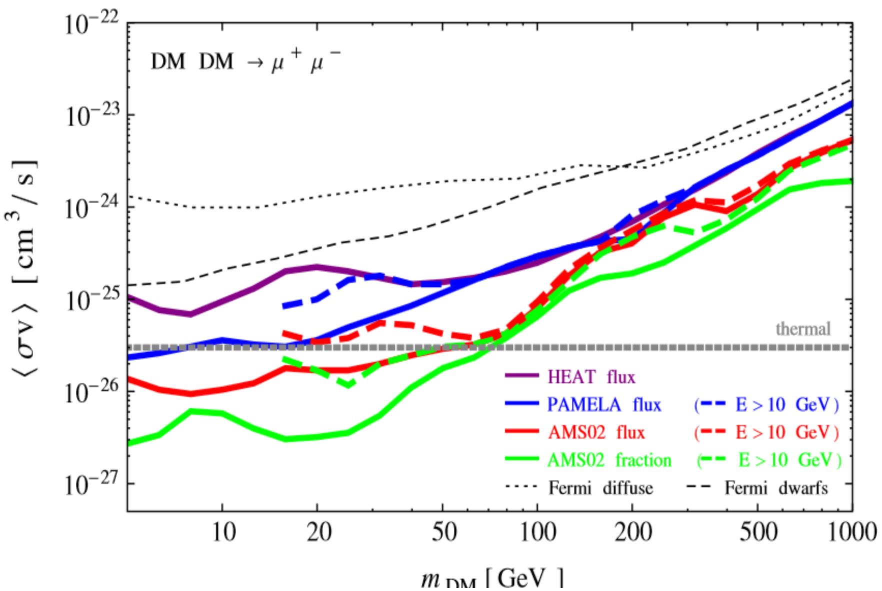


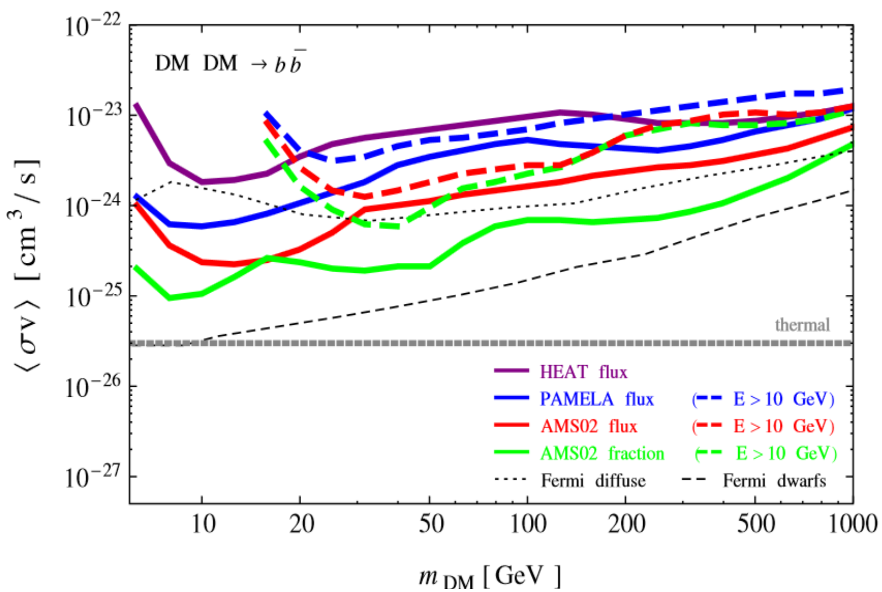
- Final states: $e^+e^-, \mu^+\mu^-, \tau^+\tau^-, b\bar{b}, W^+W^-$
- Limits using data points above 10 GeV insensitive to solar modulation
- Probe thermal cross section for dark matter masses smaller than 100 GeV in the e^+e^- final state and for masses smaller than 60 GeV in the $\mu^+\mu^-$ final 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





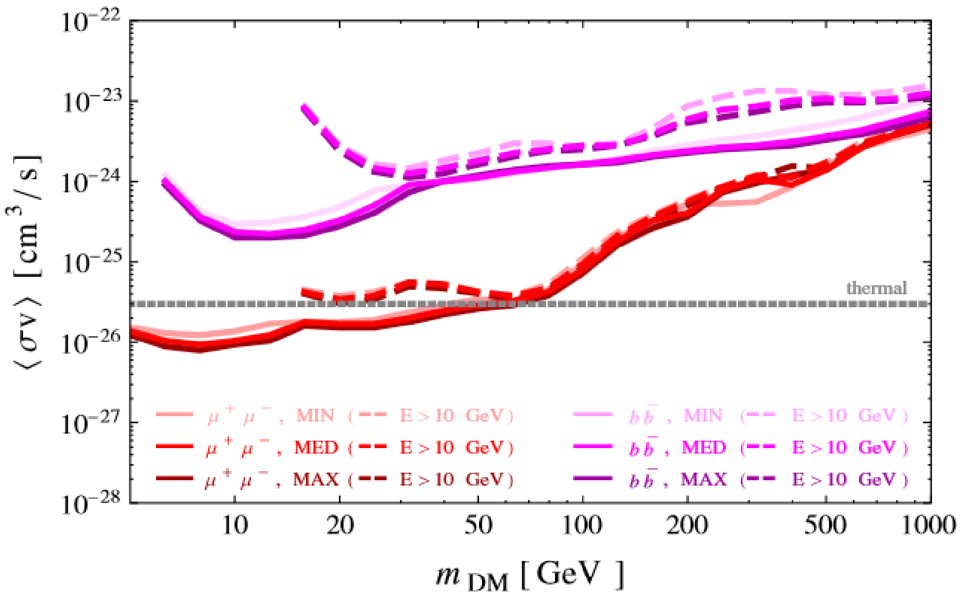
- Limits from AMS-02 positron flux are best, but PAMELA and HEAT positron fluxes give also strong limits
- Limits from the positron fraction are better than the ones from the positron flux
- In some channels, the limits from the positron flux are better than the ones from the diffuse gamma-ray flux reported by the Fermi-LAT collaboration in arXiv:1205.2739 and arXiv:1310.0828

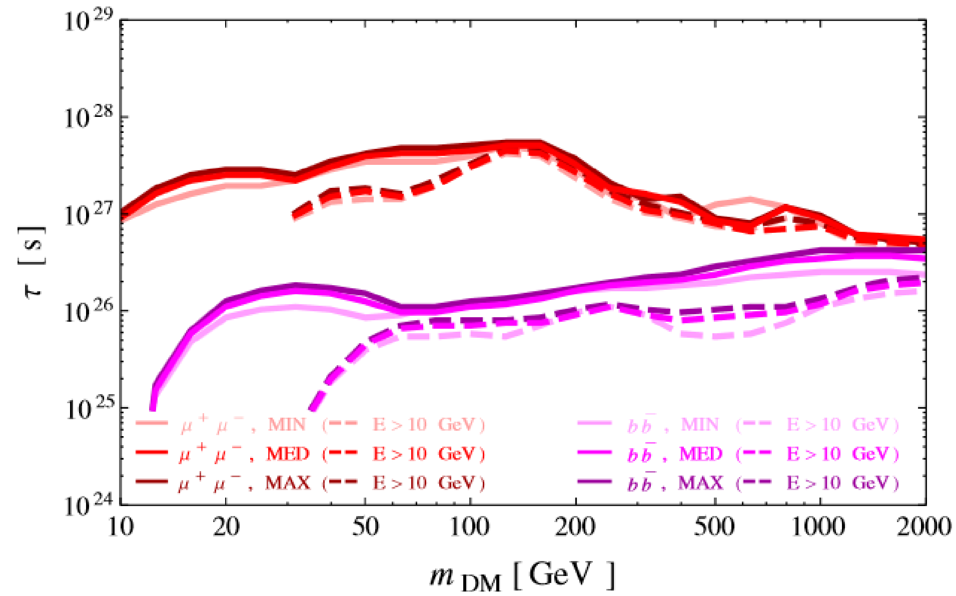
Conclusions

- AMS positron measurements allow to severely constrain dark matter parameters
- 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

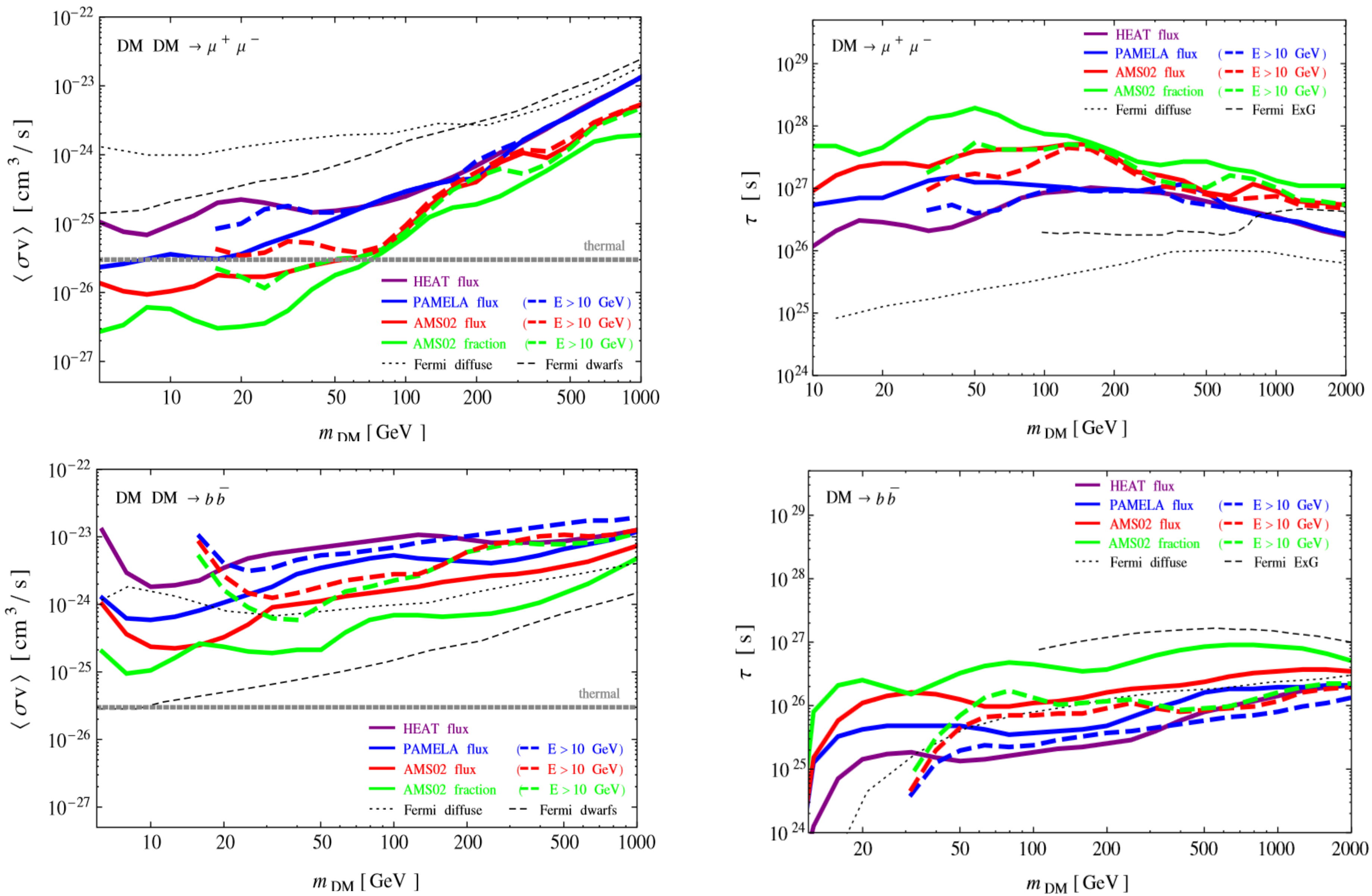
Thank you for your attention!

Propagation: MIN, MED and MAX parameters

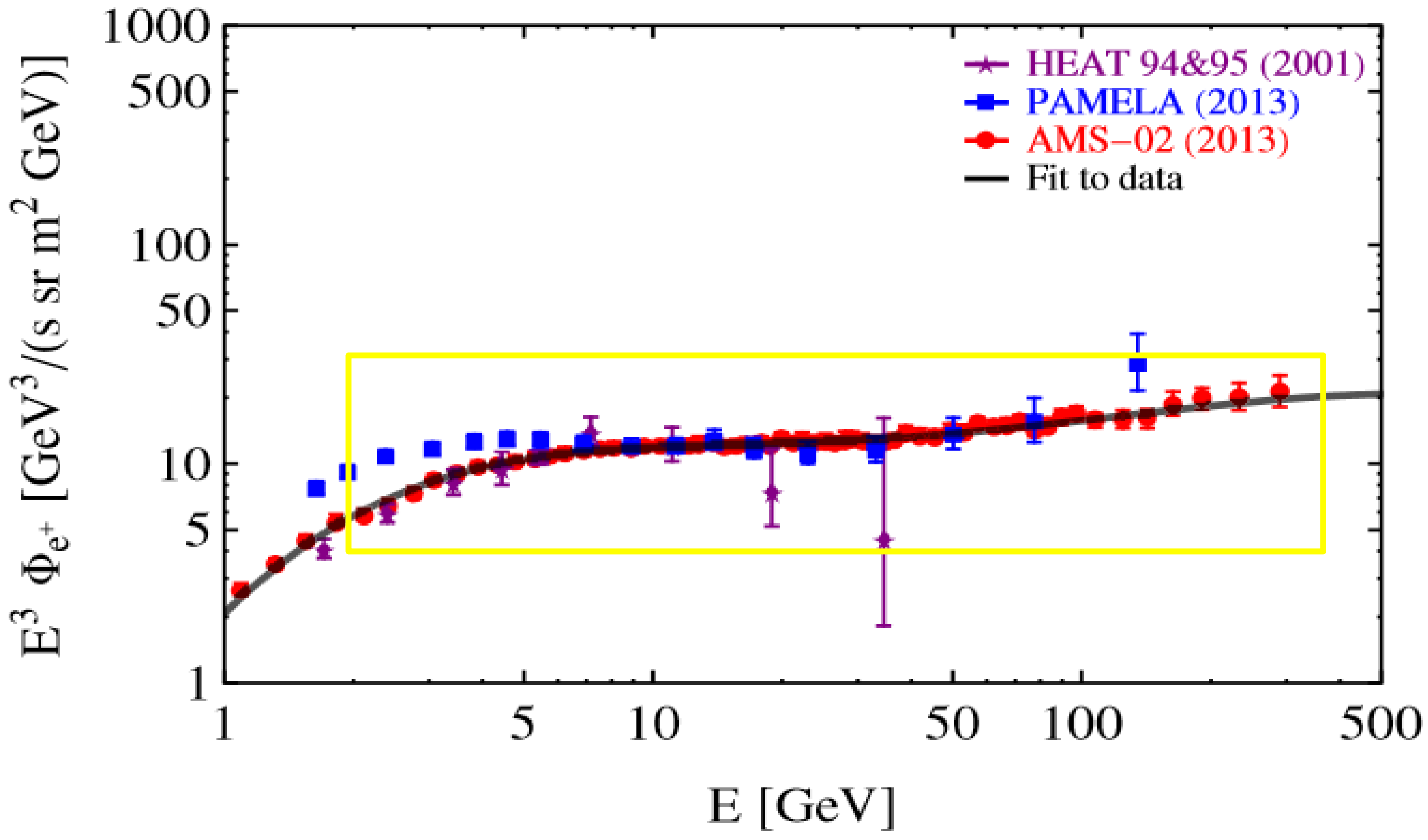




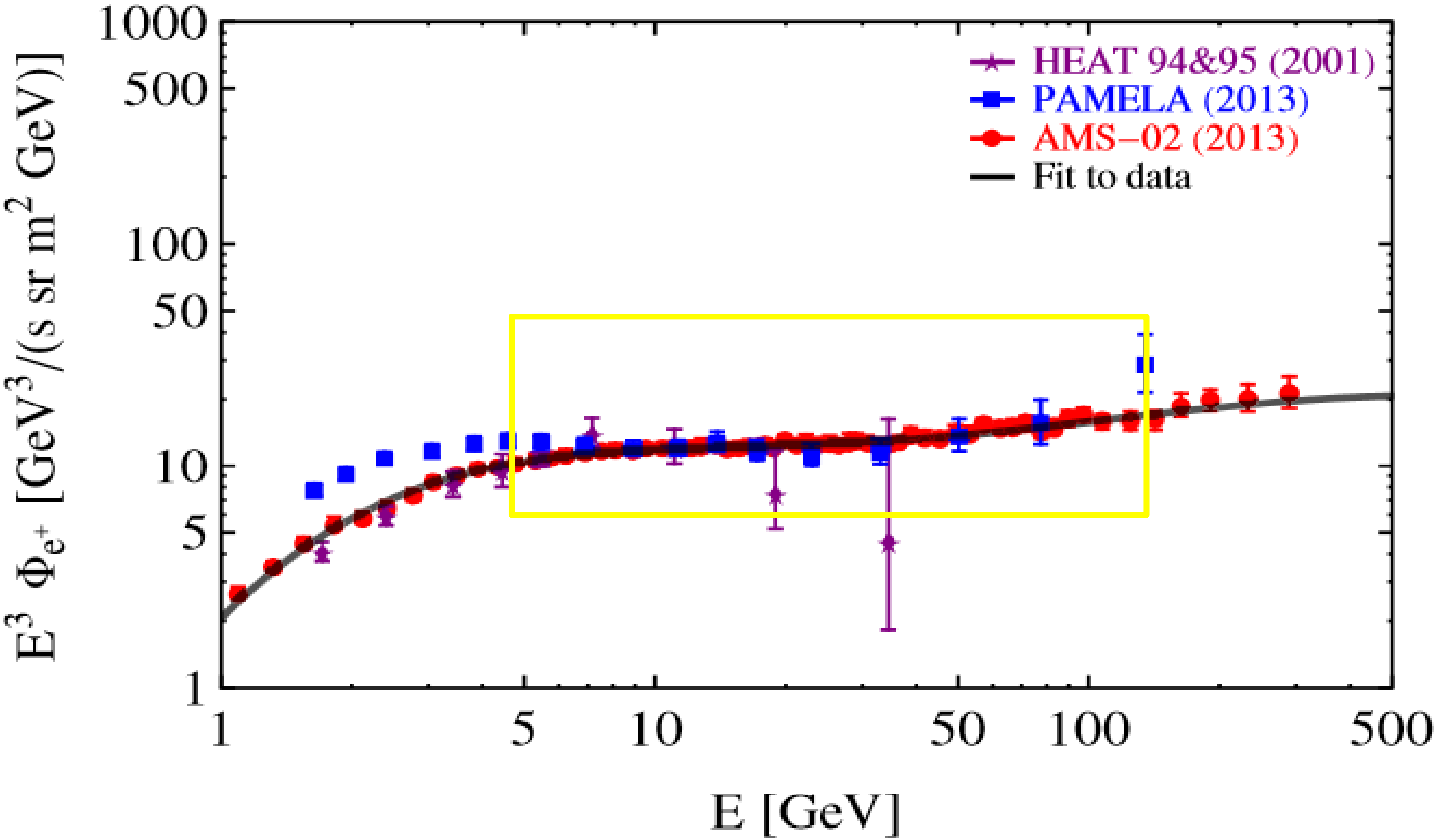
Limits: Comparison for muon and b channels



Limits: energy windows



Limits: energy windows



Limits: energy windows

Select strongest limit from sampling over various energy windows