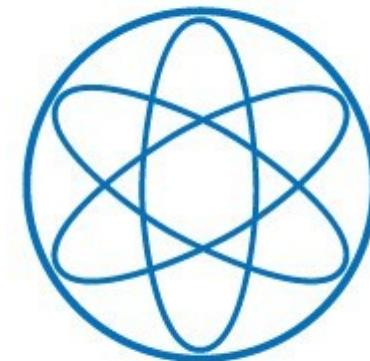


# Dark matter annihilations and decays after the AMS-02 positron measurements

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15 April 2014



Based on arXiv:1309.2570, 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

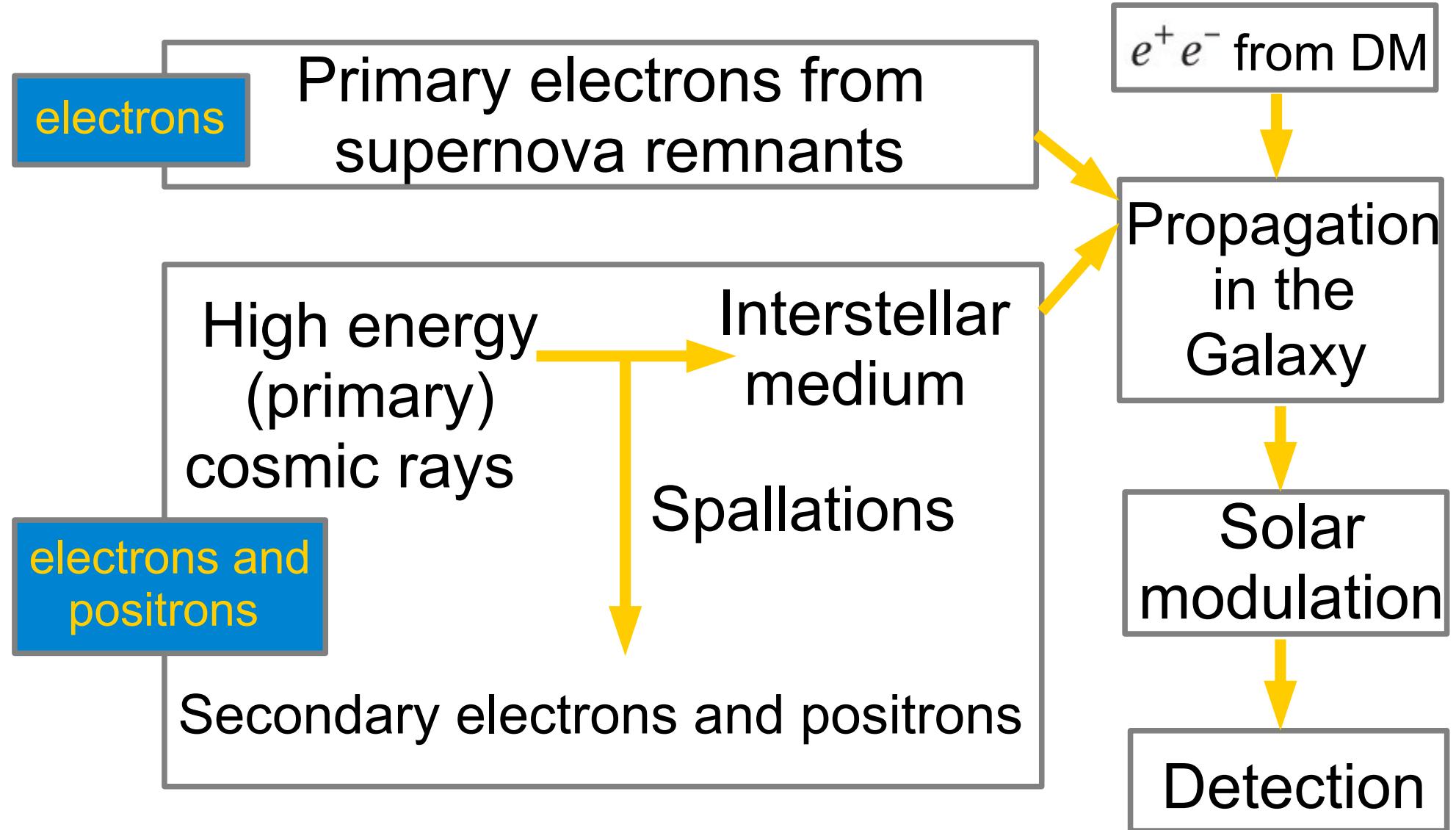
# Objective

- 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

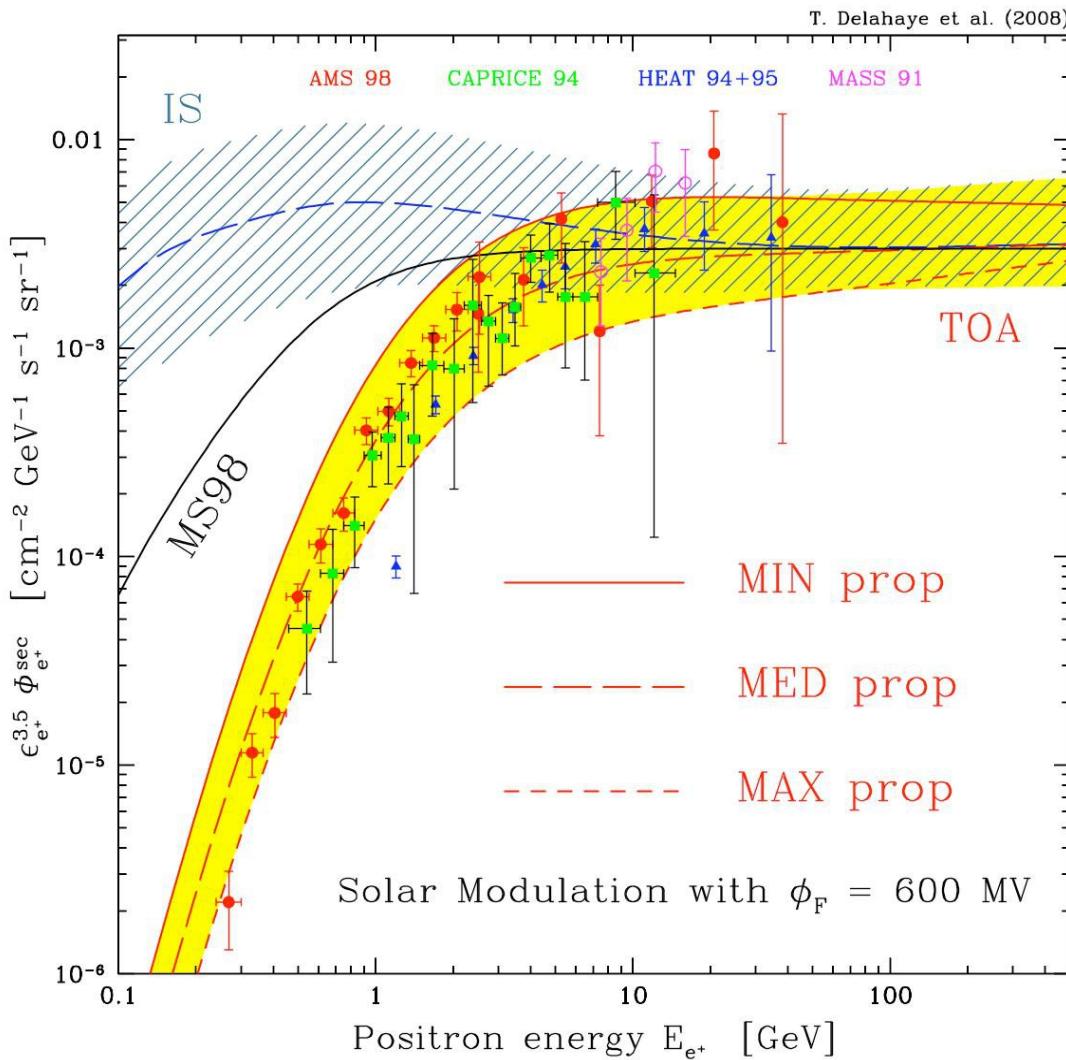
# Approach

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

# Electrons and positrons: from production to detection



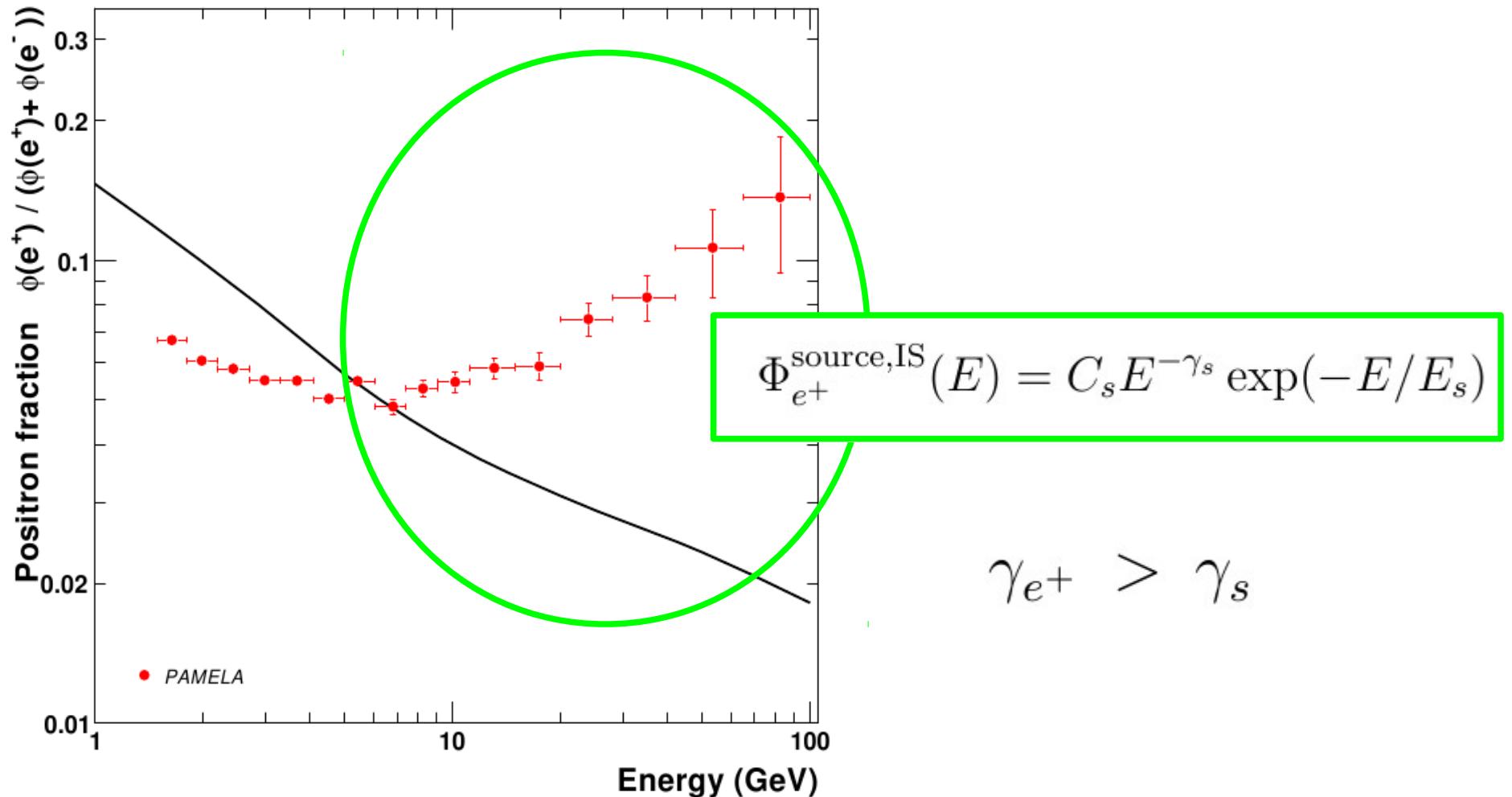
# Secondary positrons: spallations



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

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

# Positron background - possible additional source



# Parametrization of background: positron flux

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

secondary positronsadditional source

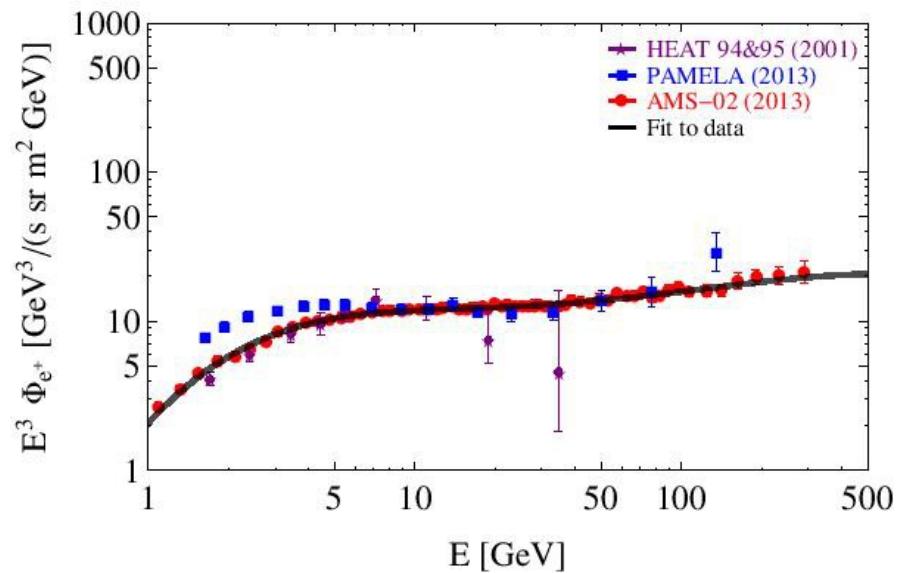
# Parametrization of background: positron flux

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

Solar modulation:  
 $0.5\text{GV} < \phi < 1.3\text{GV}$

$$\Phi_{e^+}^{\text{TOA}}(E) = \frac{E^2}{(E + \phi_{e^+})^2} \Phi_{e^+}^{\text{IS}}(E + \phi_{e^+})$$

Fit to AMS data



# Limits: fit

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

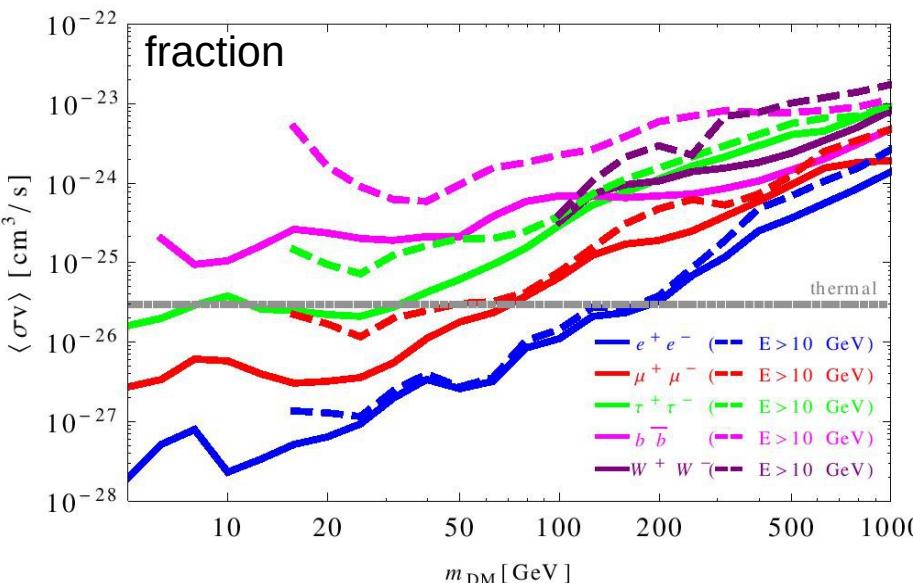
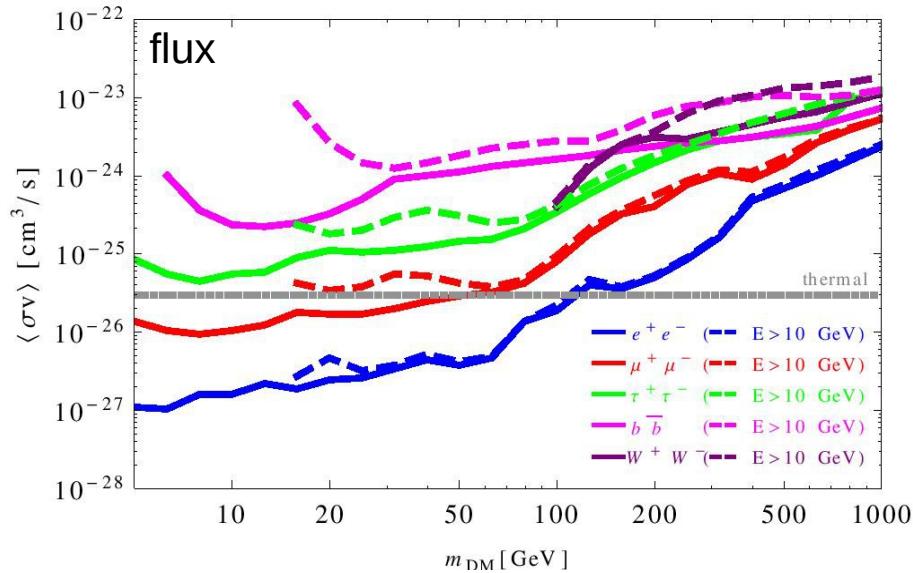


$2\sigma$  limit corresponds to  $\Delta\chi^2 > 4$

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

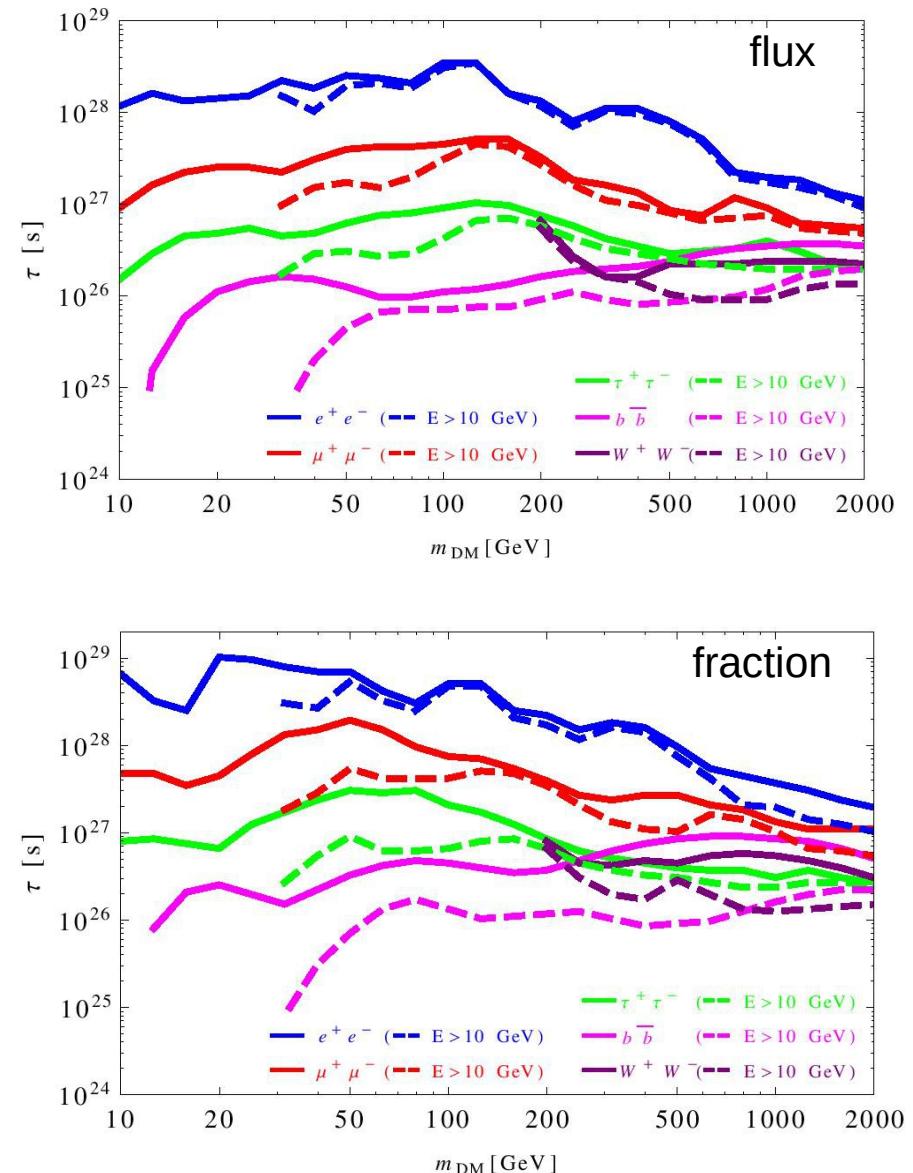
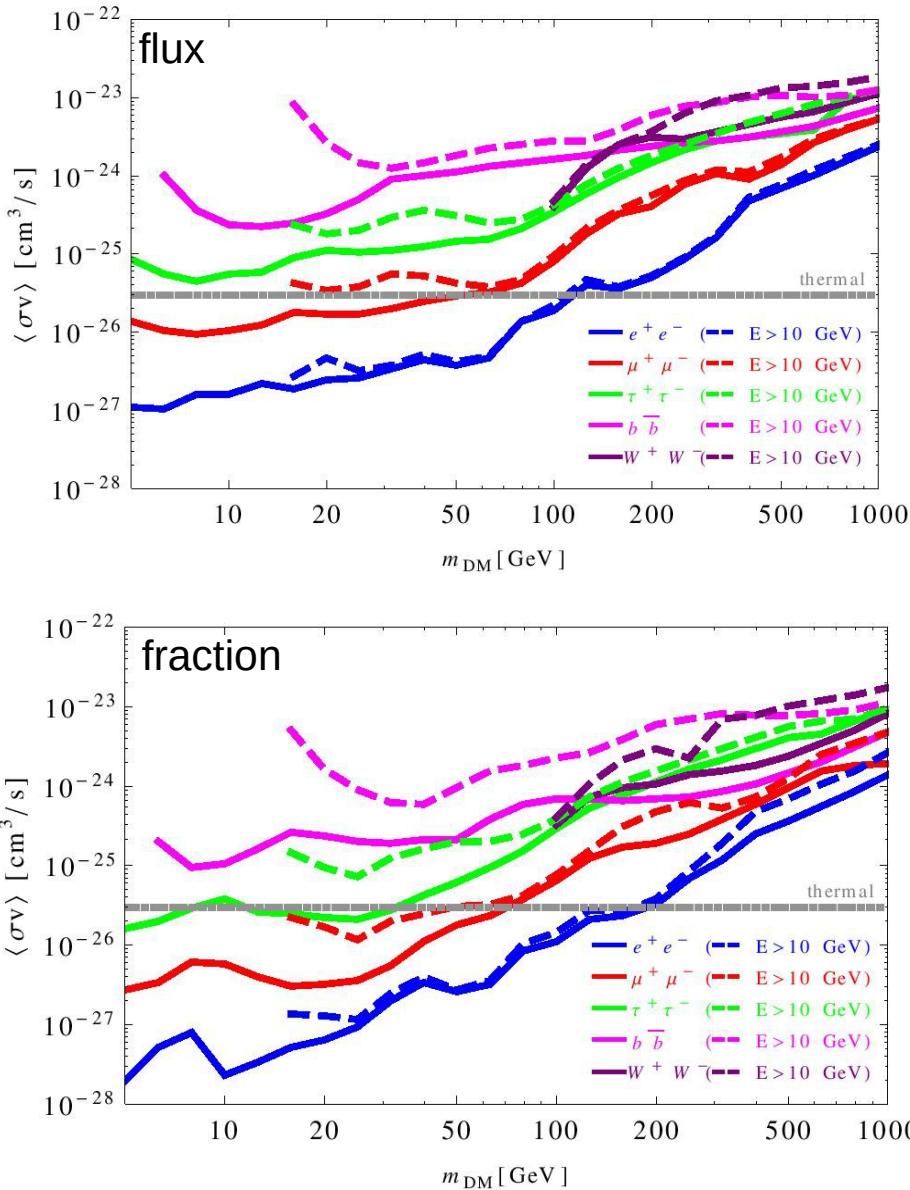
increase

# Limits: Competitive results from flux and fraction

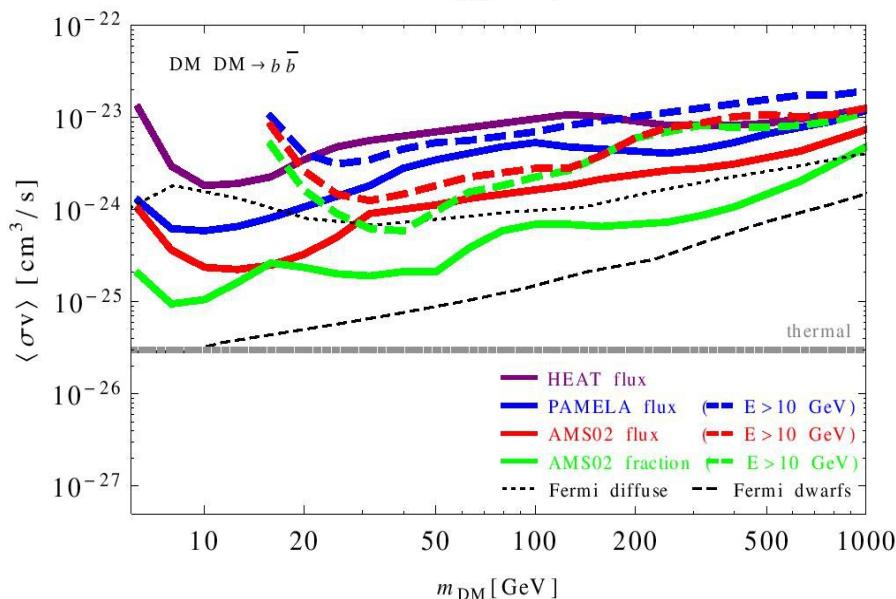
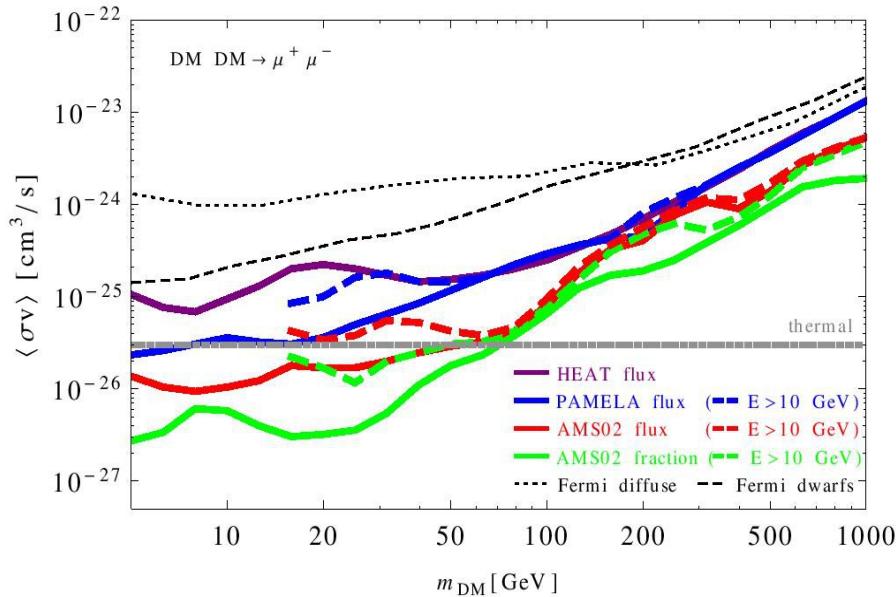


- Final states:  
 $e^+e^-$ ,  $\mu^+\mu^-$ ,  $\tau^+\tau^-$ ,  $b\bar{b}$ ,  $W^+W^-$
- Limits using data points above 10 GeV insensitive to solar modulation
- Probe thermal cross section for dark matter masses smaller than 100 GeV in the  $e^+e^-$  final state and for masses smaller than 60 GeV in 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 from the positron fraction and in some cases better than the limits reported by the Fermi-LAT collaboration

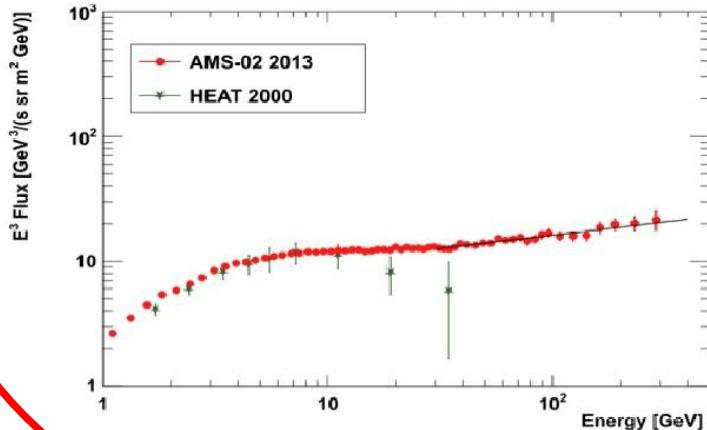
Thank you for your attention!

# AMS-02 electron and positron measurements

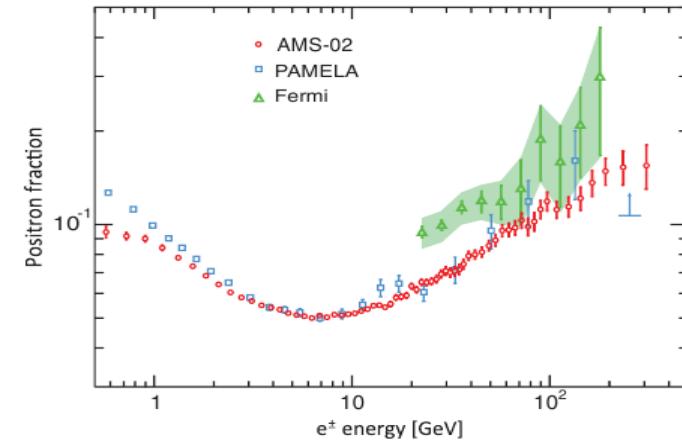
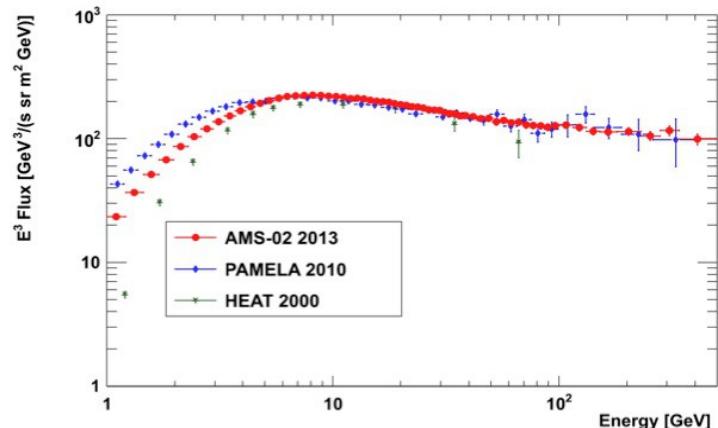
- Positron flux
- Electron flux
- Positron fraction



ICRC 2013 Positron Spectrum



ICRC 2013 Electron Spectrum



# Primary positrons

- Annihilations:

$$Q_{e^+}(E, \vec{r}) = \frac{1}{2} \frac{\rho_{\text{DM}}^2(\vec{r})}{m_{\text{DM}}^2} \sum_f \langle \sigma v \rangle_f \frac{dN_{e^+}^f}{dE}$$

- Decays:

$$Q_{e^+}(E, \vec{r}) = \frac{\rho_{\text{DM}}(\vec{r})}{m_{\text{DM}}} \sum_f \Gamma_f \frac{dN_{e^+}^f}{dE}$$

dark matter profile



Einasto profile

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

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.

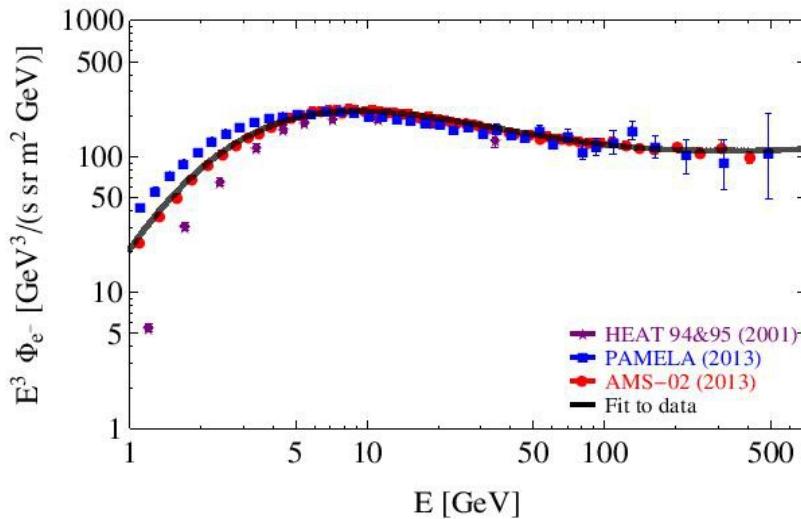
# Parametrization of background: positron fraction

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

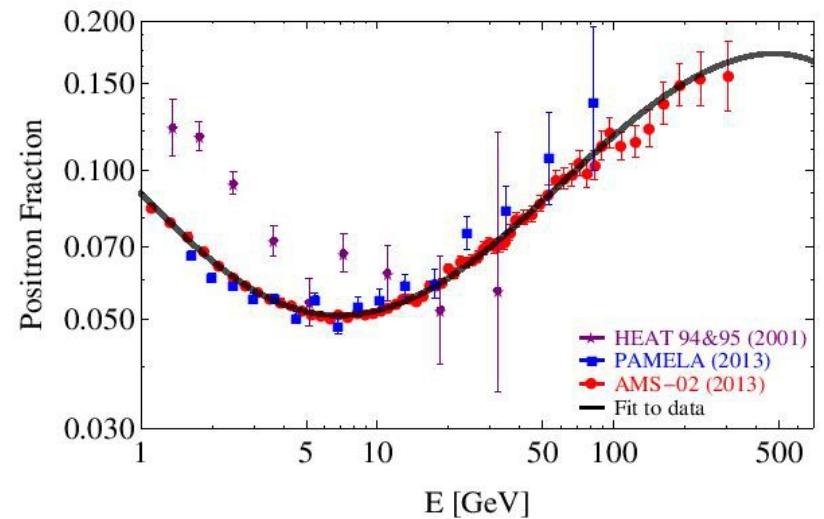
Electrons: use measured flux

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

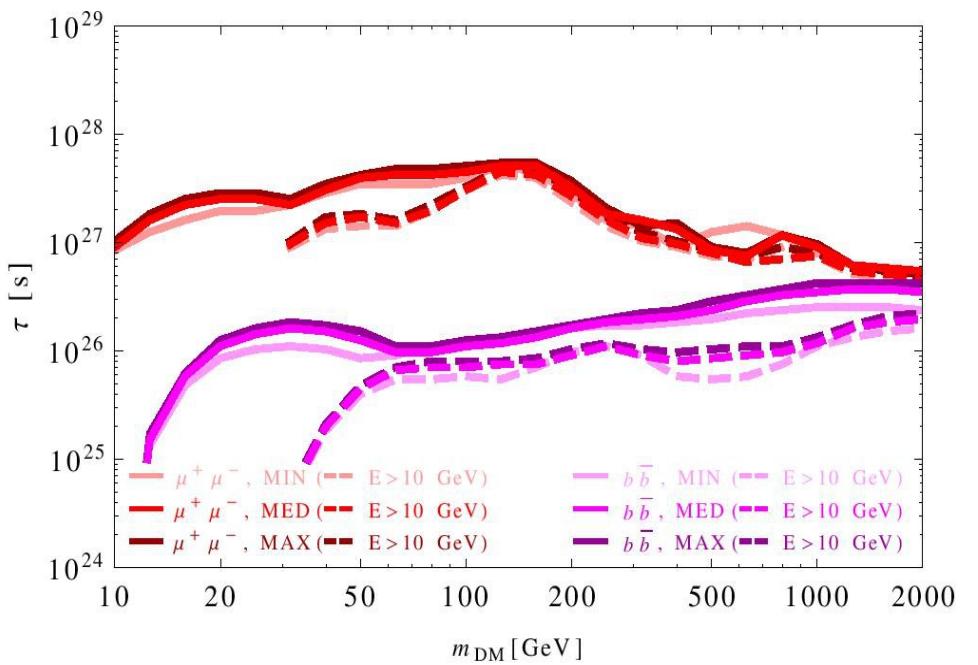
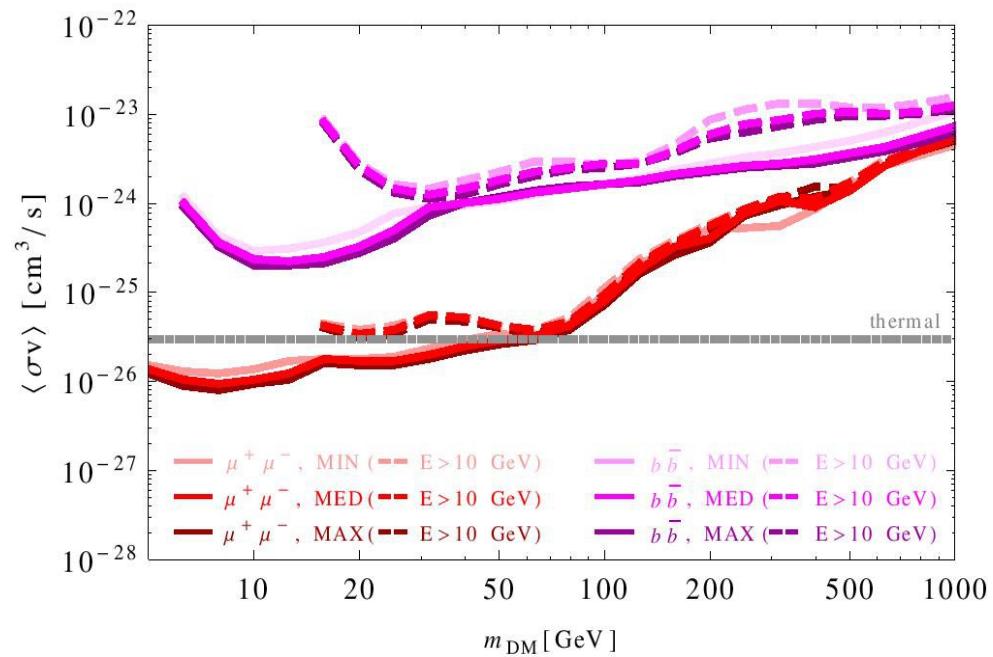
Fit electron parameters to electron flux



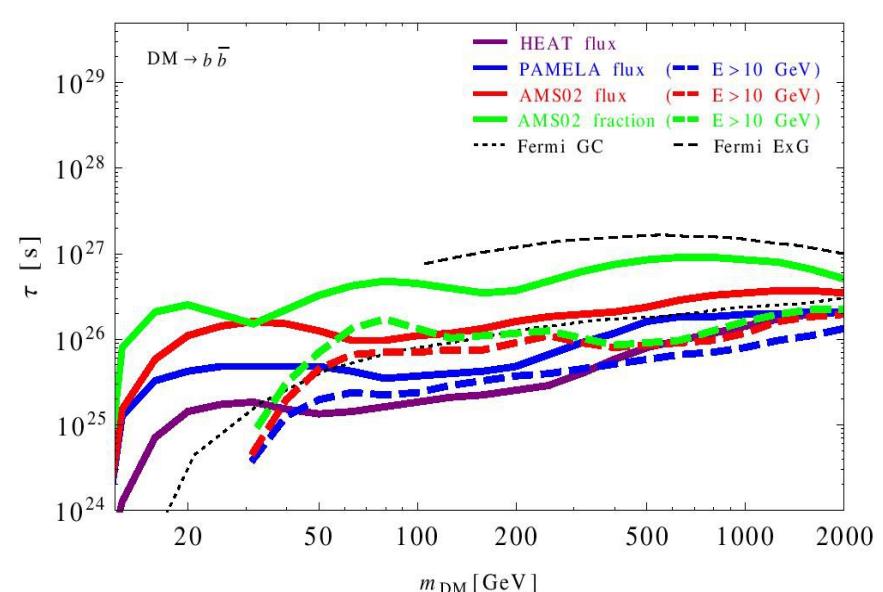
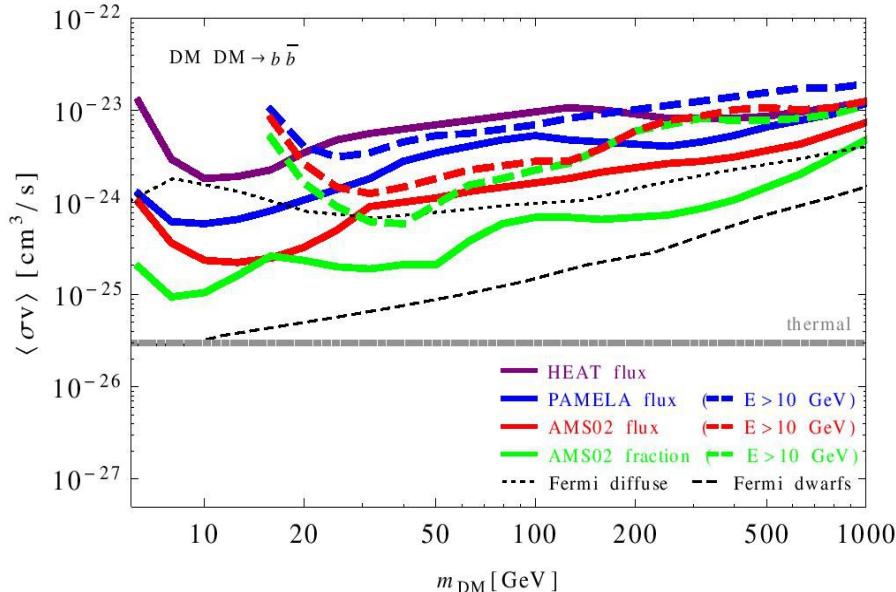
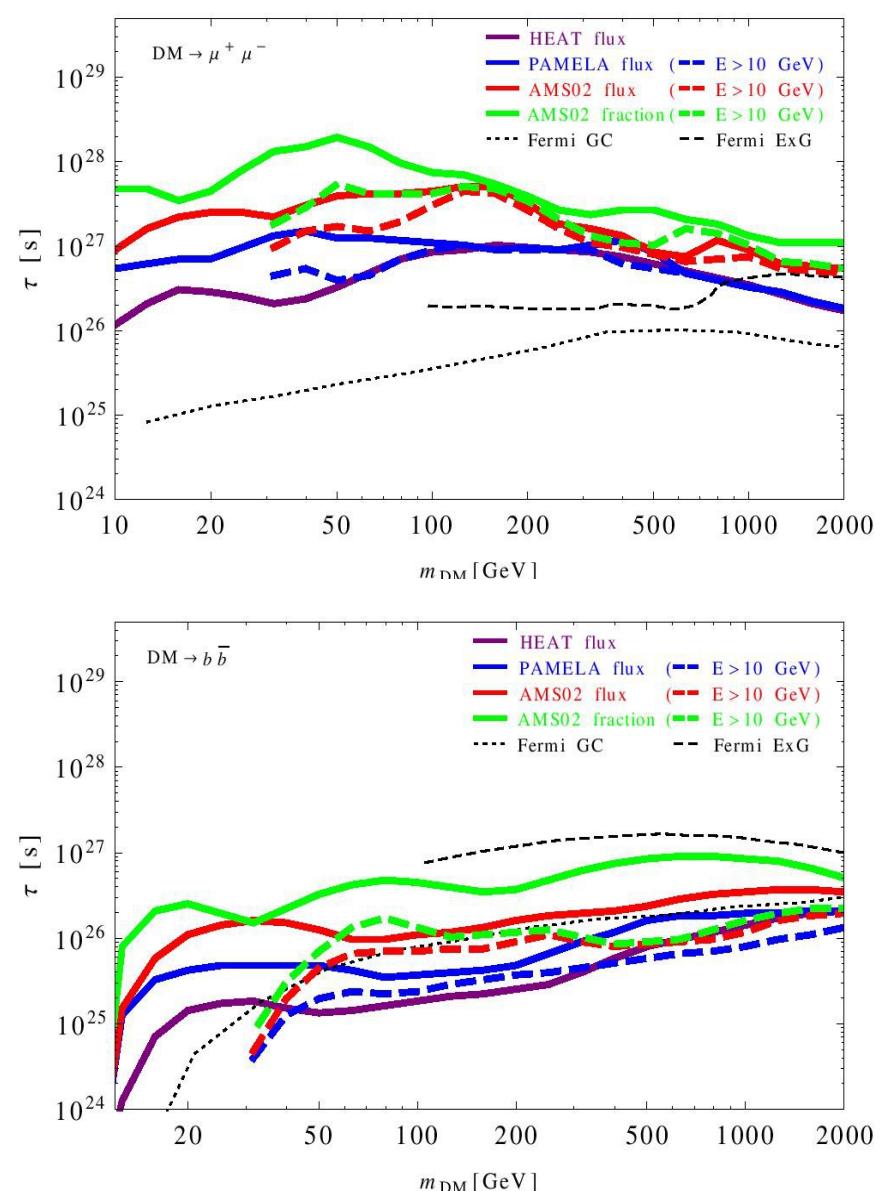
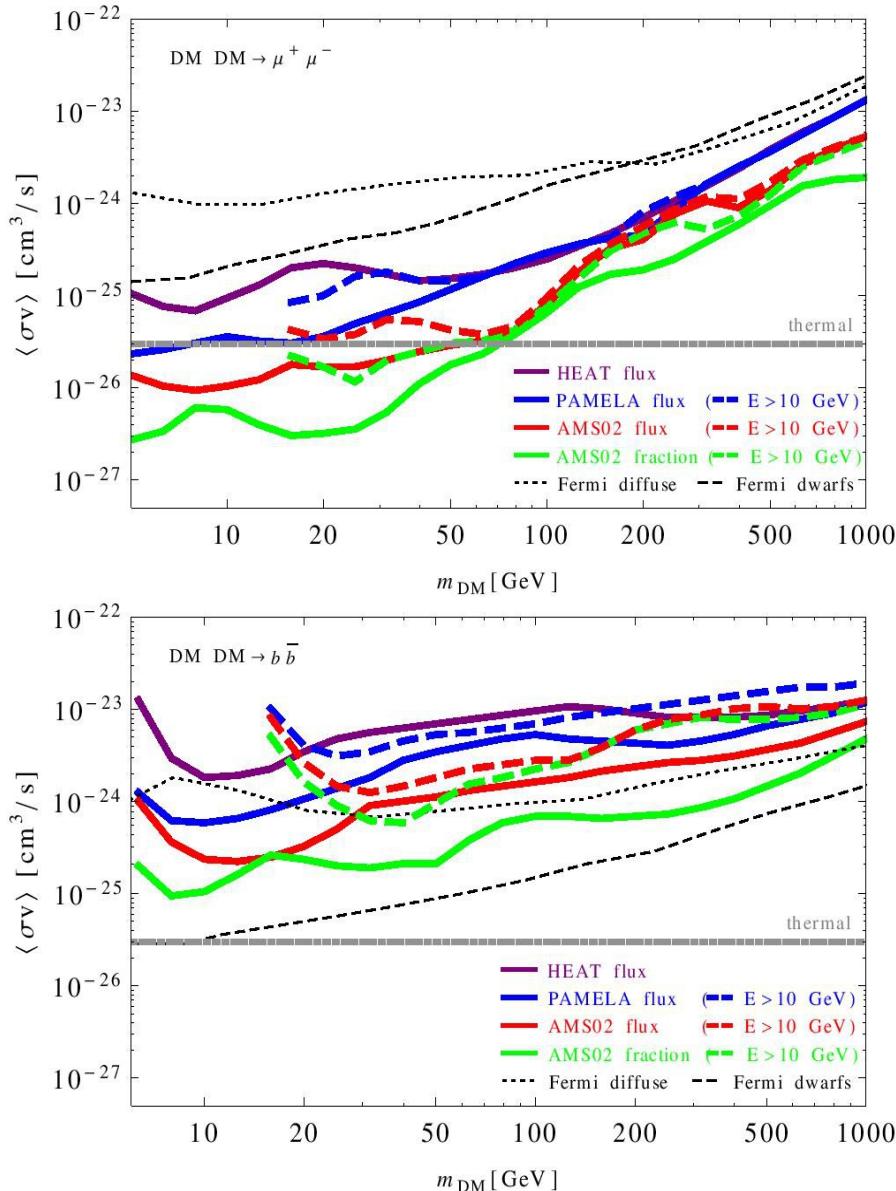
Fit positron parameters to the fraction



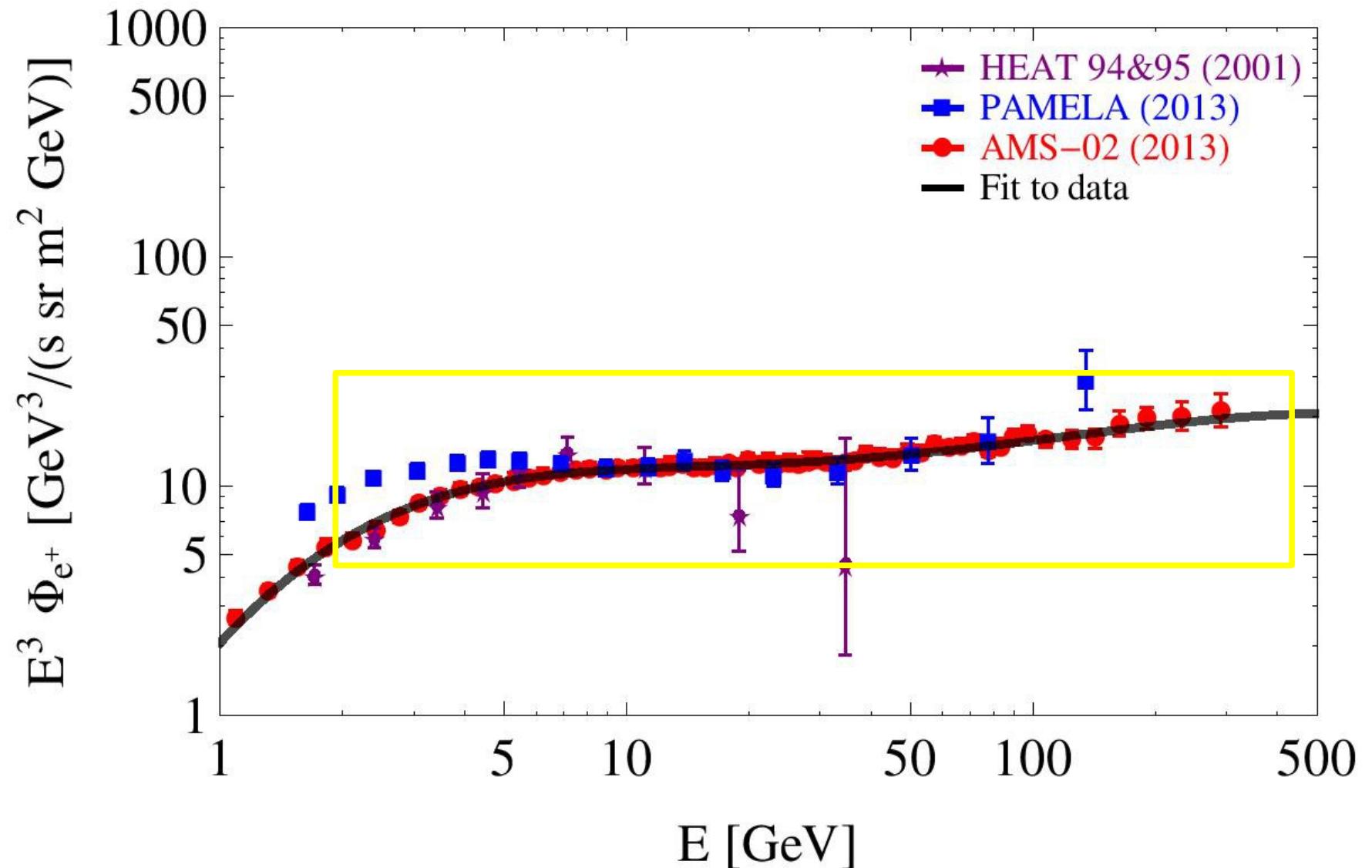
# Propagation: MIN, MED and MAX parameters



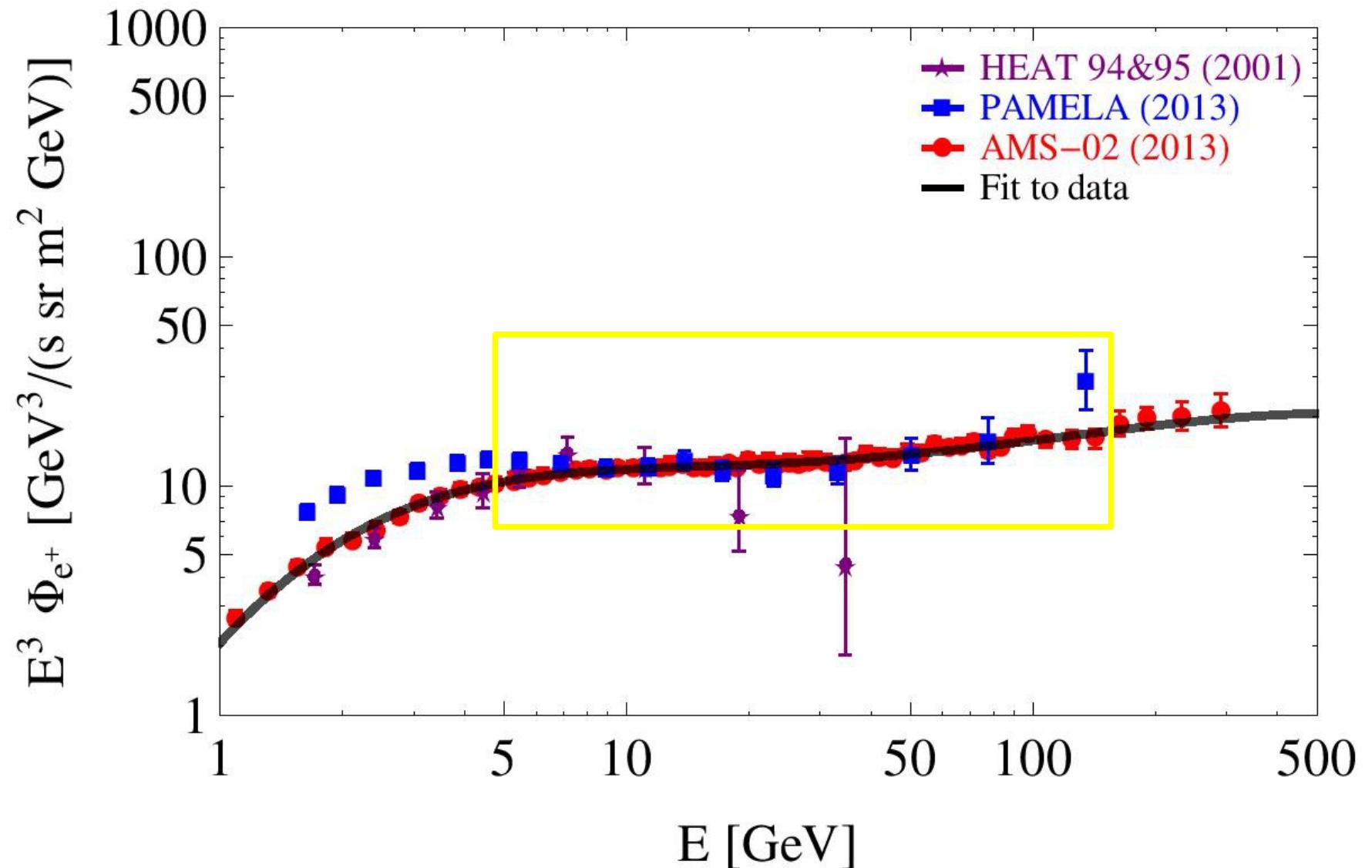
# Limits: Comparison for muon and b channels



# Limits: energy windows



# Limits: energy windows



# Limits: energy windows

Select strongest limit from sampling over various energy windows

