Cosmic Ray Positrons from Dark Matter

General remarks & current limits

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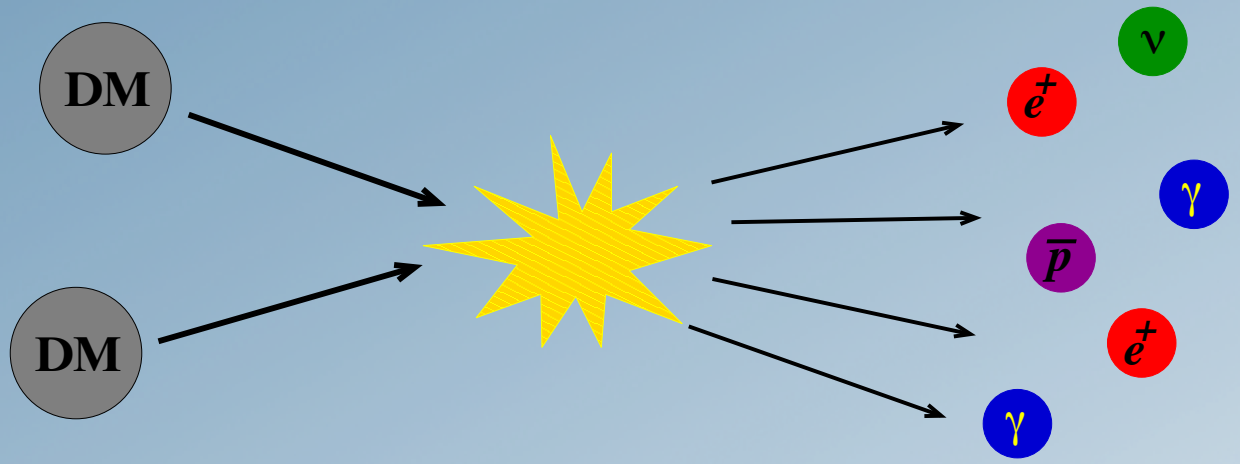
Indirect detection of WIMPs

- The basic idea:



- Different messengers probe different parts of the halo:

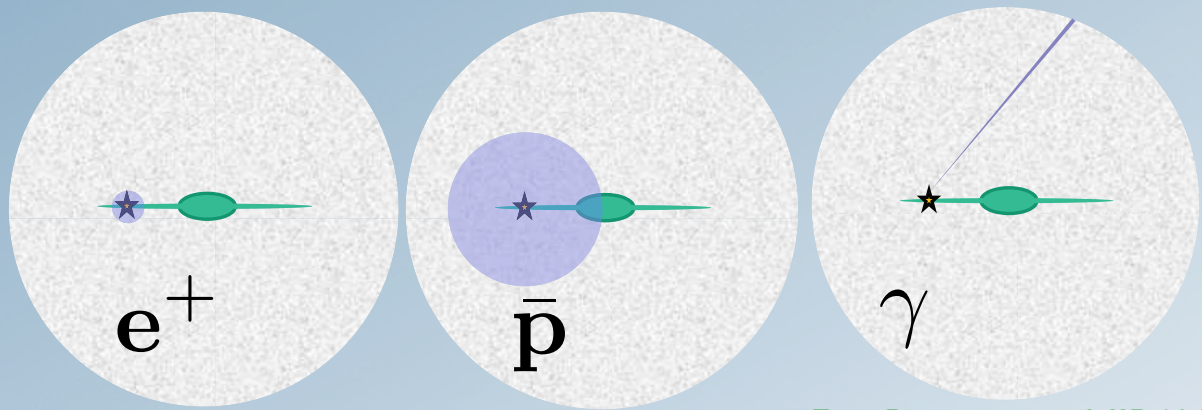
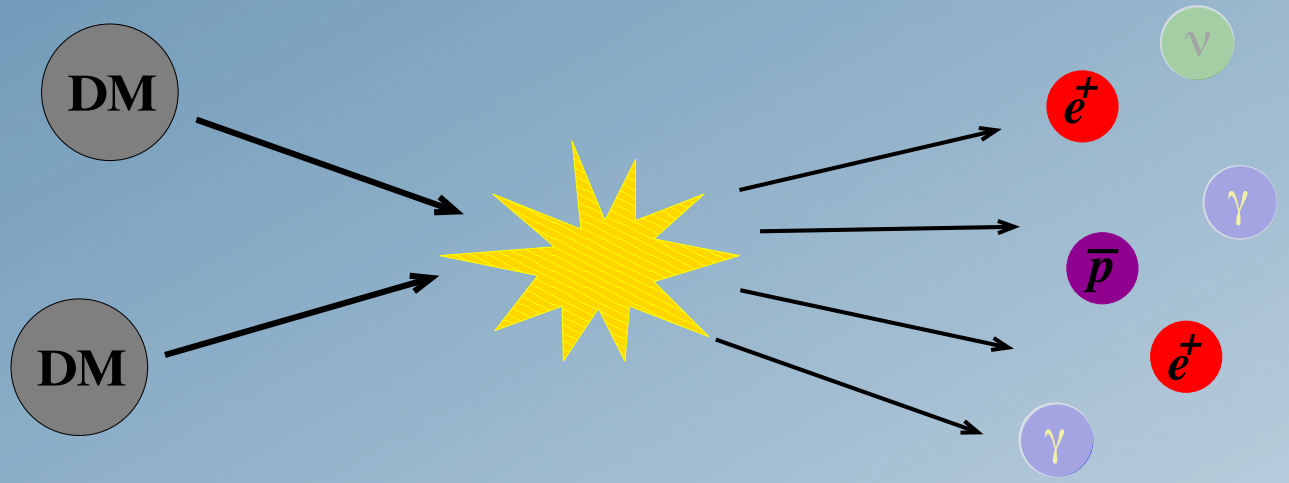


Fig.: Bergström, NJP '09

Total flux:

$$\Phi_{\rm SM} \propto \langle \rho_\chi^2 \rangle = (1 + {\rm BF}) \langle \rho_\chi \rangle^2$$

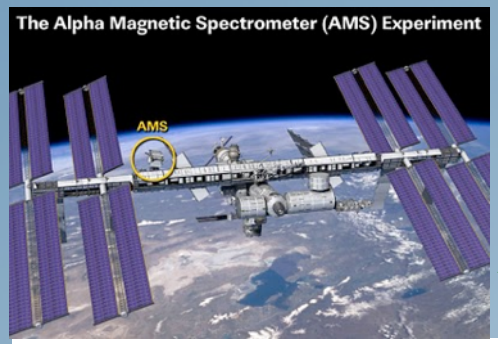
Charged cosmic rays



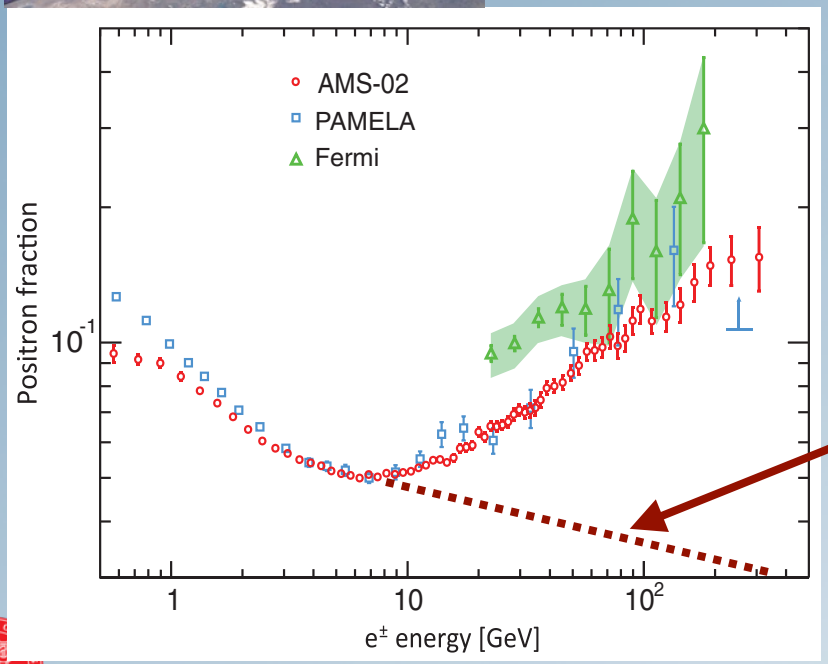
- GCRs are confined by galactic magnetic fields
- Random distribution of field inhomogeneities
  ⇝ propagation well described by diffusion equation
- After propagation, no directional information is left
- Also the spectral information tends to get washed out
- Equal amounts of matter and antimatter
  ⇒ focus on antimatter (low backgrounds!)

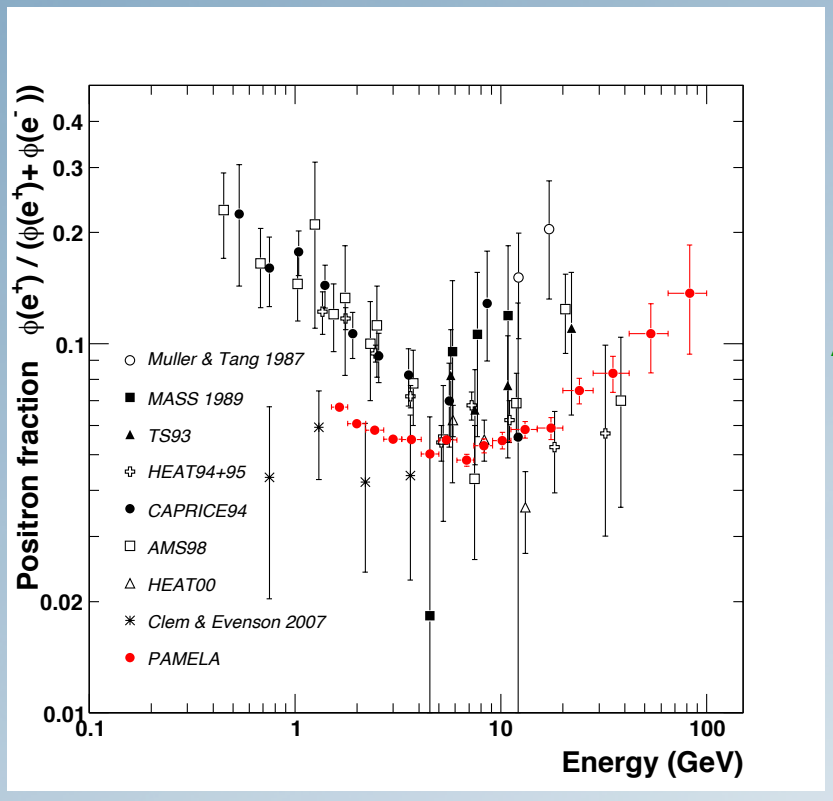
Positrons

Excess in cosmic ray positron data has triggered big excitement:

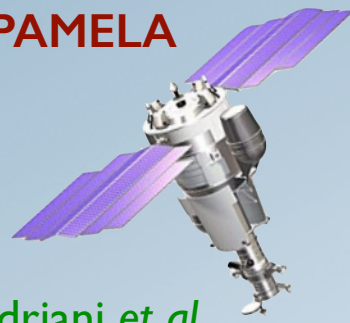


Aguilar *et al.*, PRL '13





PAMELA



Adriani *et al.*, Nature '09

~expected for secondary positron production

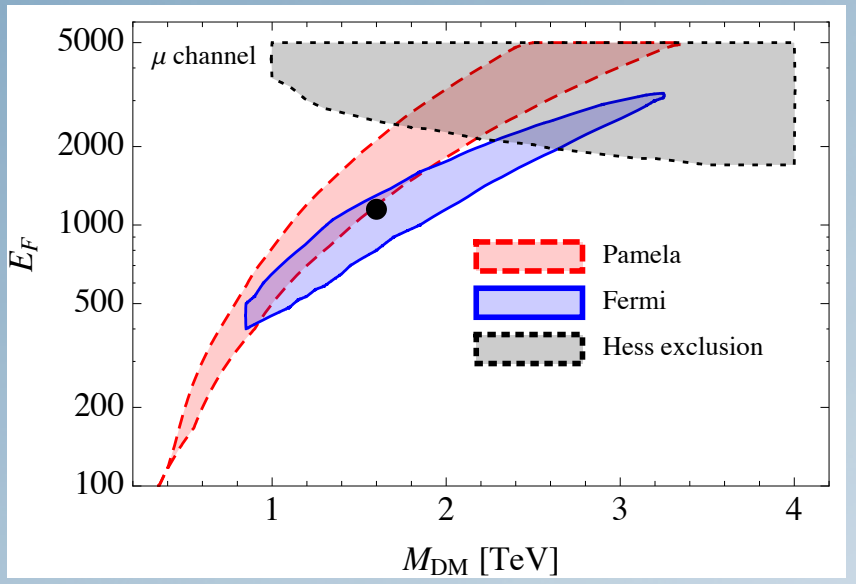
⇨ Are we seeing a DM signal ???

DM explanations

- Model-independent analysis:
  - strong constraints on hadronic modes from $\bar{p}$ data
  - $\chi\chi \to e^+e^-$ or $\mu^+\mu^-$ favoured
  - large boost factors *generic* – $\mathcal{O}(10^3)$

➡ highly non-conventional DM!

+ significant radio/IC constraints…



Bergström, Edsjö & Zaharijas, PRL '09

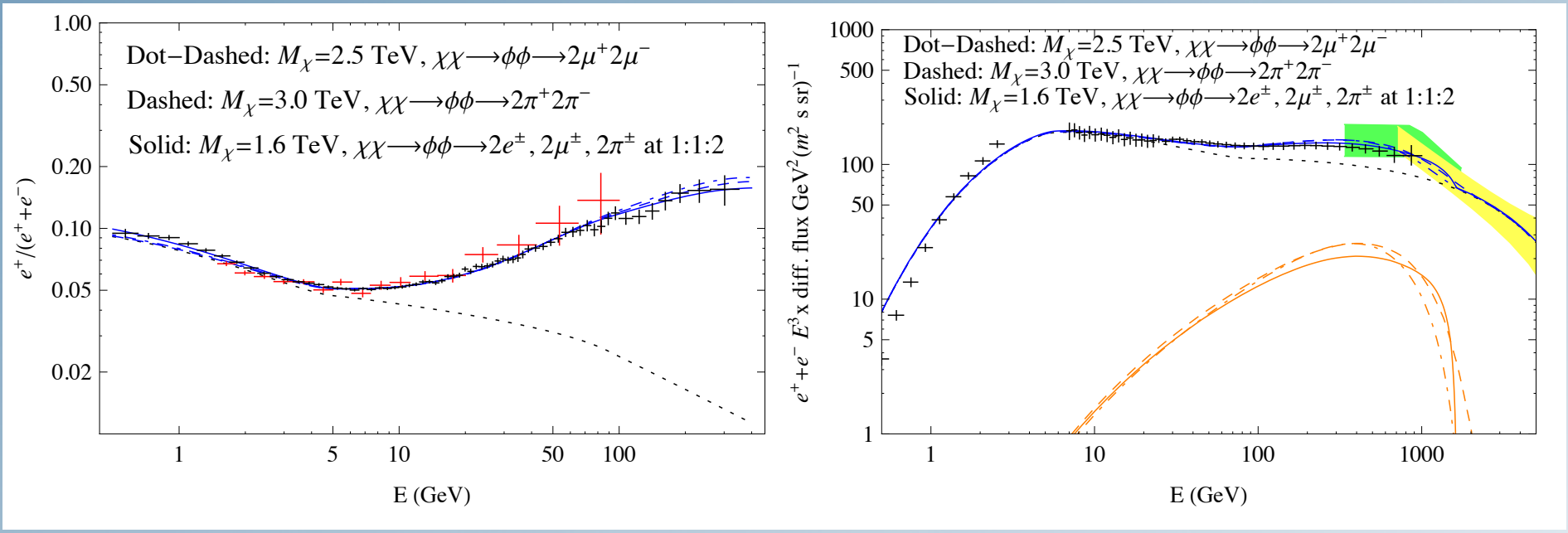
- *and*: many good astrophysical candidates for primary sources in the cosmic neighbourhood:
  - pulsars Grasso *et al.*, ApP '09; Yüksel *et al.*, PRL '09; Profumo, 0812.4457
  - old SNRs Blasi, PRL '09; Blasi & Serpico, PRL '09
  - and further proposals...

➡ *Very challenging to probe DM with positrons…*

Update after AMS

- Direct annihilation to leptons gives no longer a sufficiently good fit: need softer spectra

[required annihilation rate still $10^2 - 10^3 \times \langle \sigma v \rangle_{\rm therm}$ …]

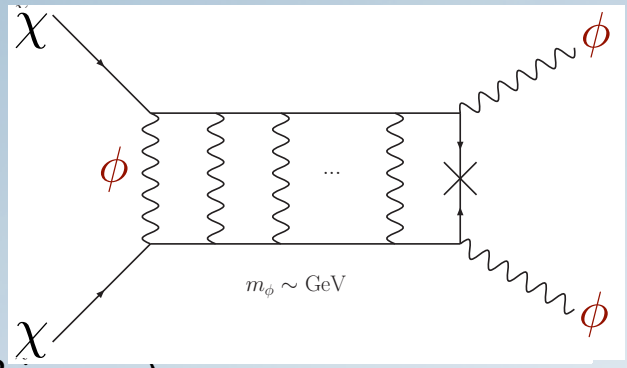


Cholis & Hooper, PRD '13

➡ Sommerfeld-type models!?

Arkani-Hamed, Finkbeiner, Slatyer & Weiner, PRD '09

…

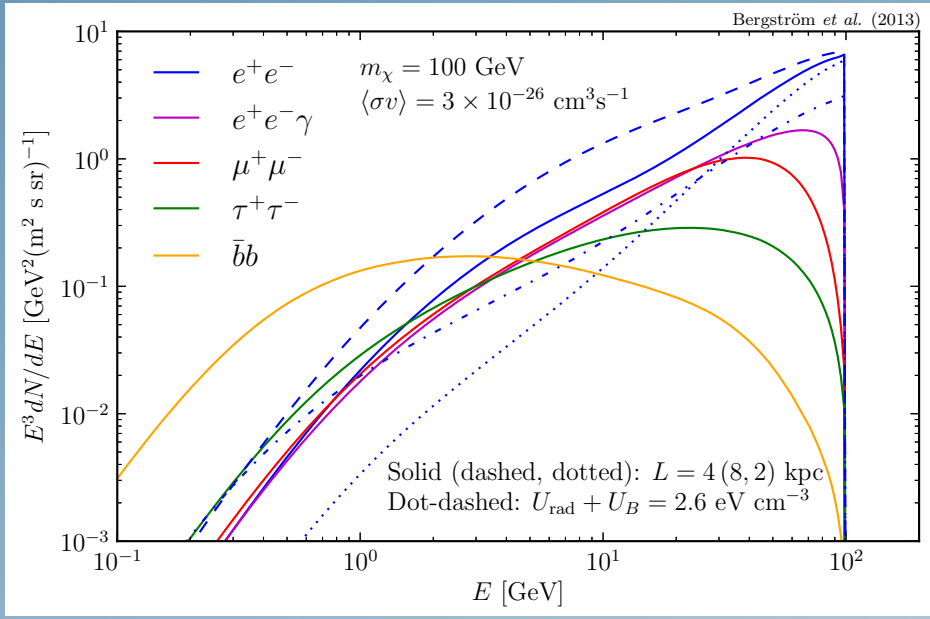


- ***but***: strong constraints e.g. from gamma (IB) and radio (synchroton)!

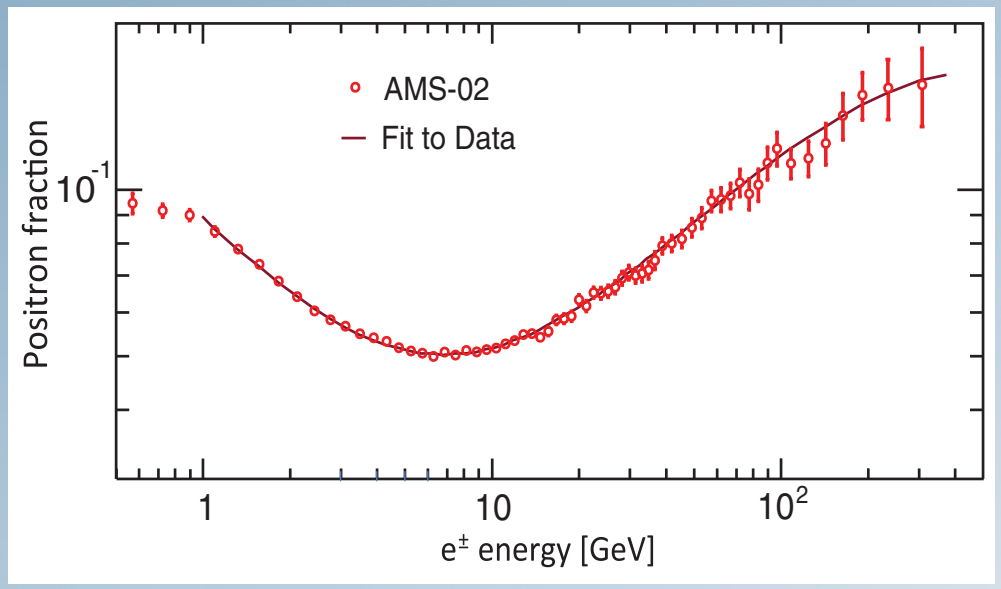
Bertone, Bergström, TB, Edsjö & Taoso, PRD '09

Re-assessing the e^+ channel

- Fact #1:



- Fact #2:



Sharp spectral features do exist, for leptonic channels, even after propagation!

AMS provides data
i) with extremely high statistics
ii) for which a simple (5 param) smooth BG model provides an excellent fit

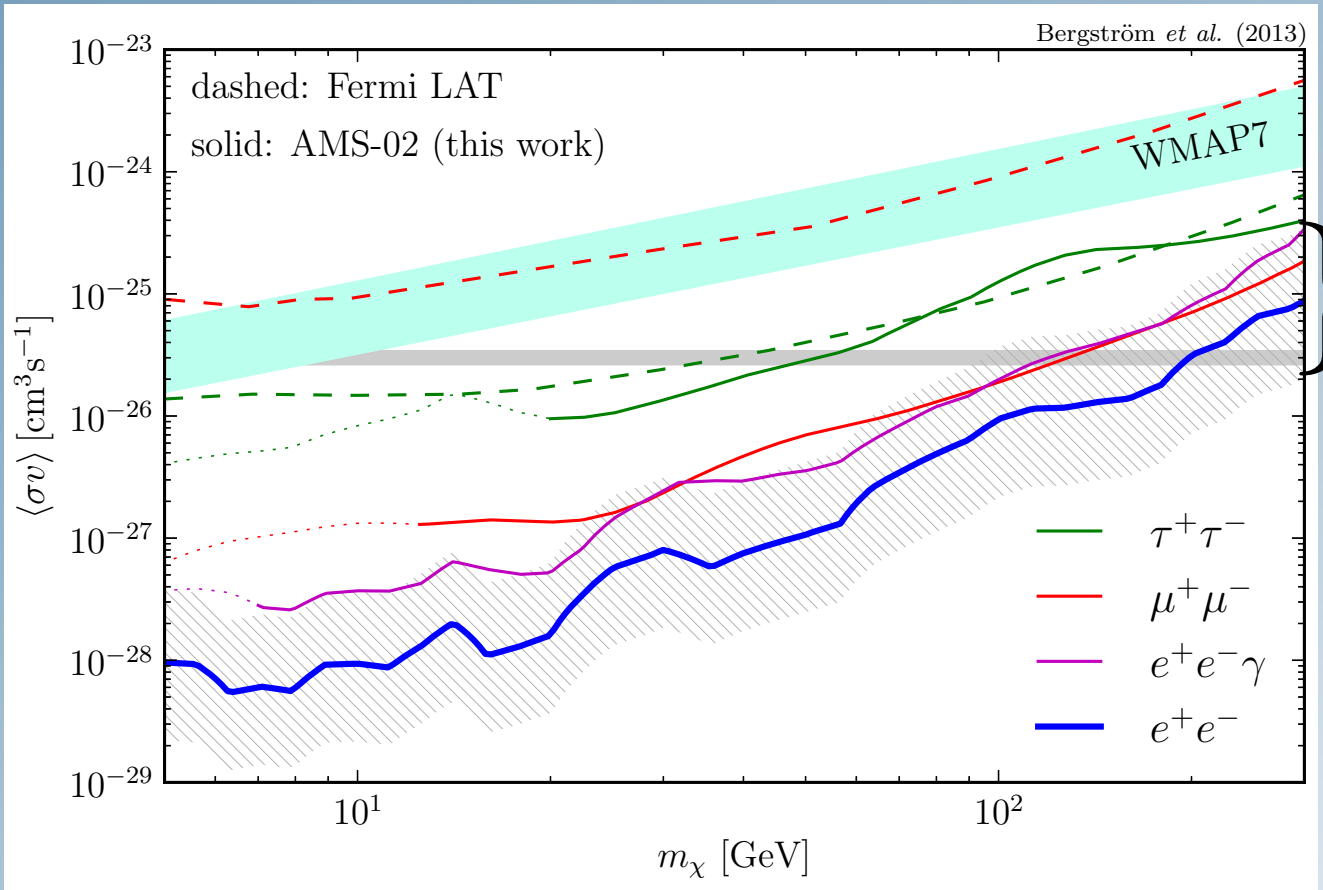
Let's do a spectral fit!

Spectral fit with positrons

Bergström, TB, Cholis, Hooper & Weniger, PRL '13

- ~same procedure as for gamma rays...

  [profile likelihood; *no* sliding energy window, 5 params for BG instead of 2 for gamma lines]



represents uncertainty in
i) local DM density
ii) local radiation density

NB: this method gives very robust limits – but only for spiky spectra!

➡ *Most stringent existing limits on (light) leptonic states!*

(and no signal…)

see also Ibarra, Lamperstorfer & Silk, PRD'14 !

Some comments

- Agnostic approach: NO assumption about origin of BG!

$$f = \frac{\Phi_{e^+}}{\Phi_{e^-} + \Phi_{e^+}}$$

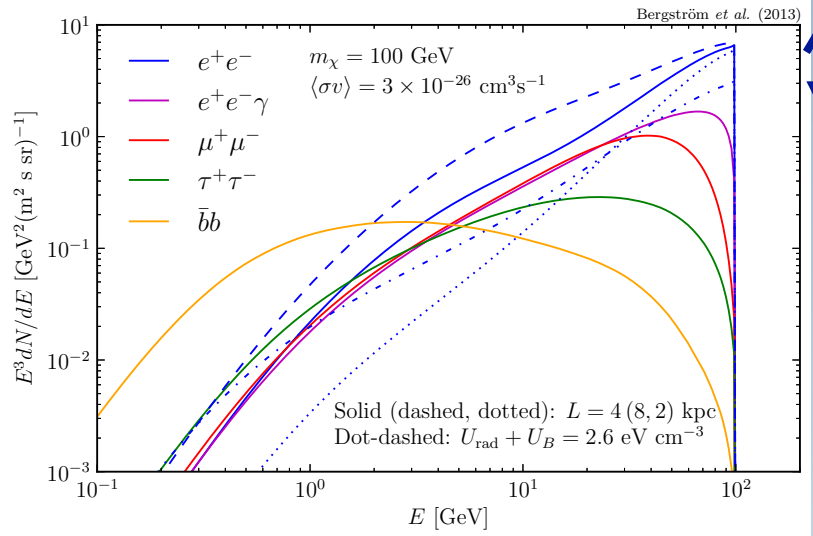
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

[same as in Aguilar+, PRL '13]

- Propagation dominated by energy losses

➡ mainly affects signal normalisation



$$\frac{dN}{dE}_{\rm peak} \propto \frac{1}{b}$$

$$b_{\rm syn}(E_e) = \frac{4}{3}\sigma_{\rm T}\gamma_e^2\frac{B^2}{2}$$

$$b_{\rm ICS}(E_e) = \frac{4}{3}\sigma_{\rm T}\gamma_e^2 \underbrace{\int_0^\infty d\epsilon\, \epsilon f_{\rm CMB}(\epsilon)}_{\equiv \rho_{\rm CMB}}$$

$$\frac{\partial f}{\partial t} - \nabla\left(\mathcal{K}(E,\vec{x})\nabla f\right) - \frac{\partial}{\partial E}\left(b(E,\vec{x})f\right) = Q(E,\vec{x}$$

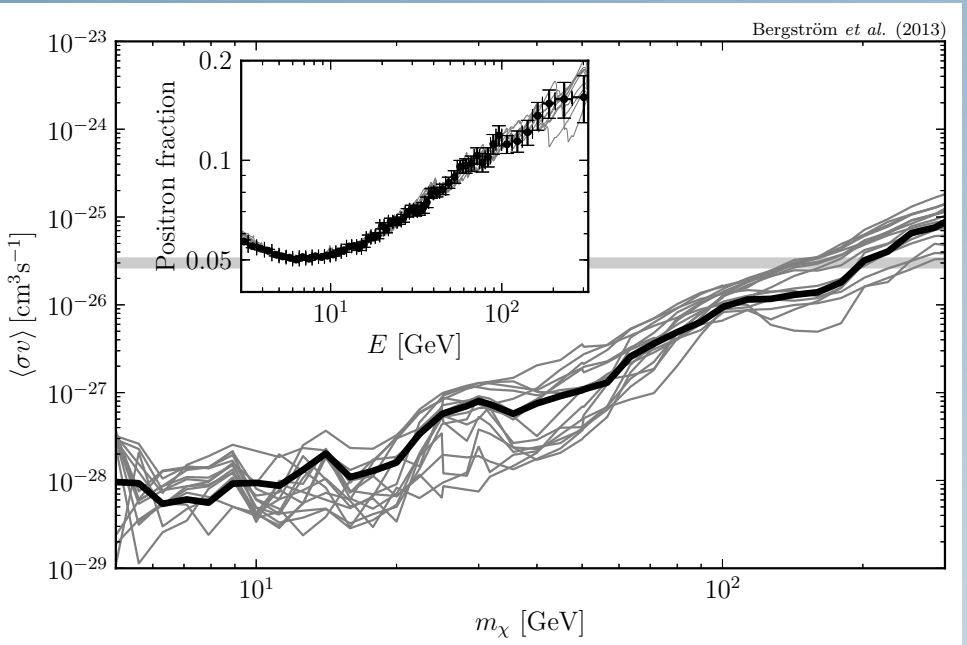
- Solar modulation: Force field very good for E>5 GeV

***NB**: even at lower energies no characteristic spike-like features expected!*

Physical background models

- Still need to fit the data
  - ➡ no big effect expected for limits!
- Worst case: "conspiracy scenario"

(DM signal hides between two pulsar bumps)



limits could in principle worsen by a factor of up to ~3…

➡ ***Bottom line:*** *these limits are both stringent, robust and `model-independent'!*