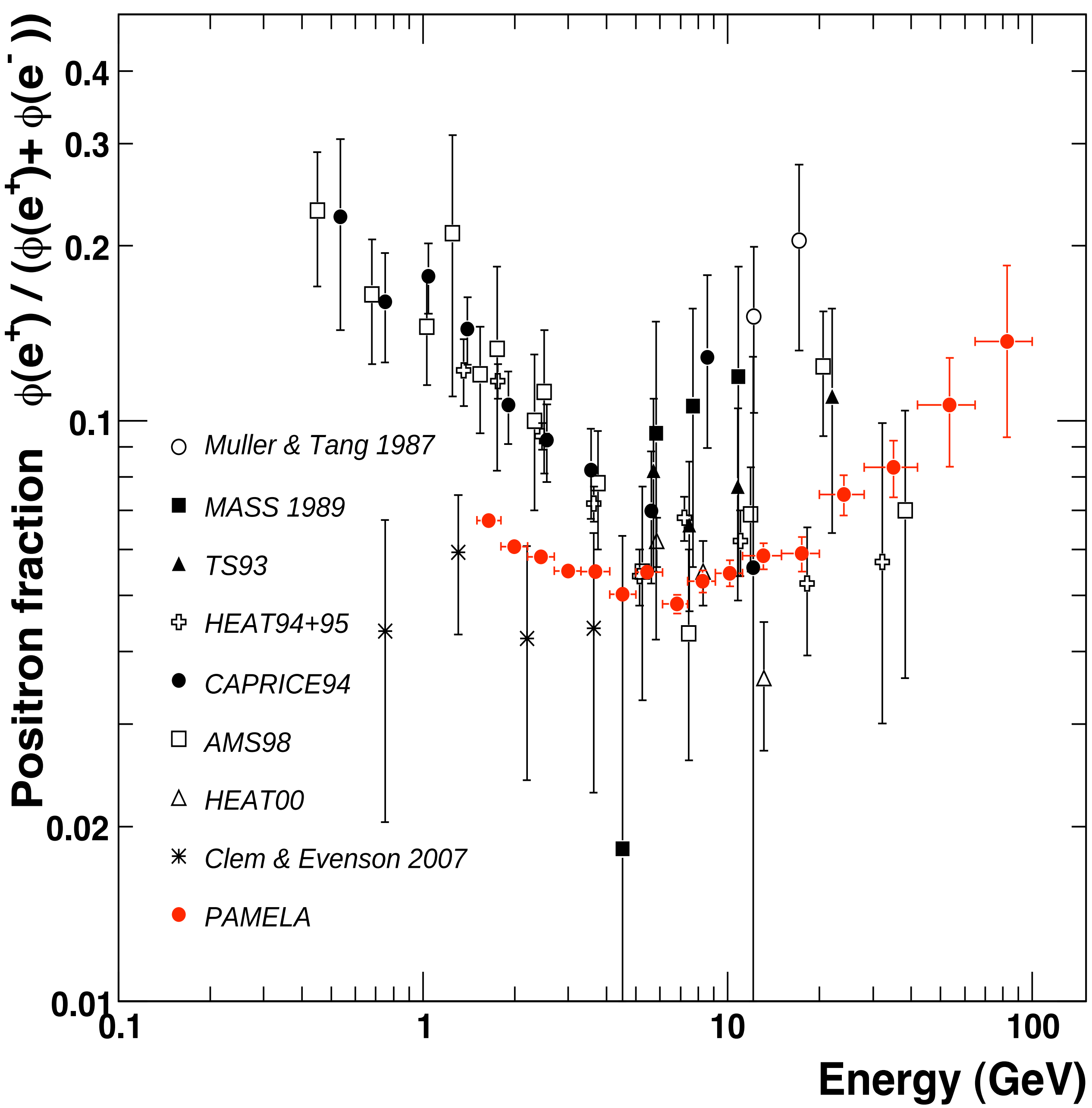
Discussion: Experimental Anomalies as New Dark Matter Physics

Graham Kribs

U Oregon

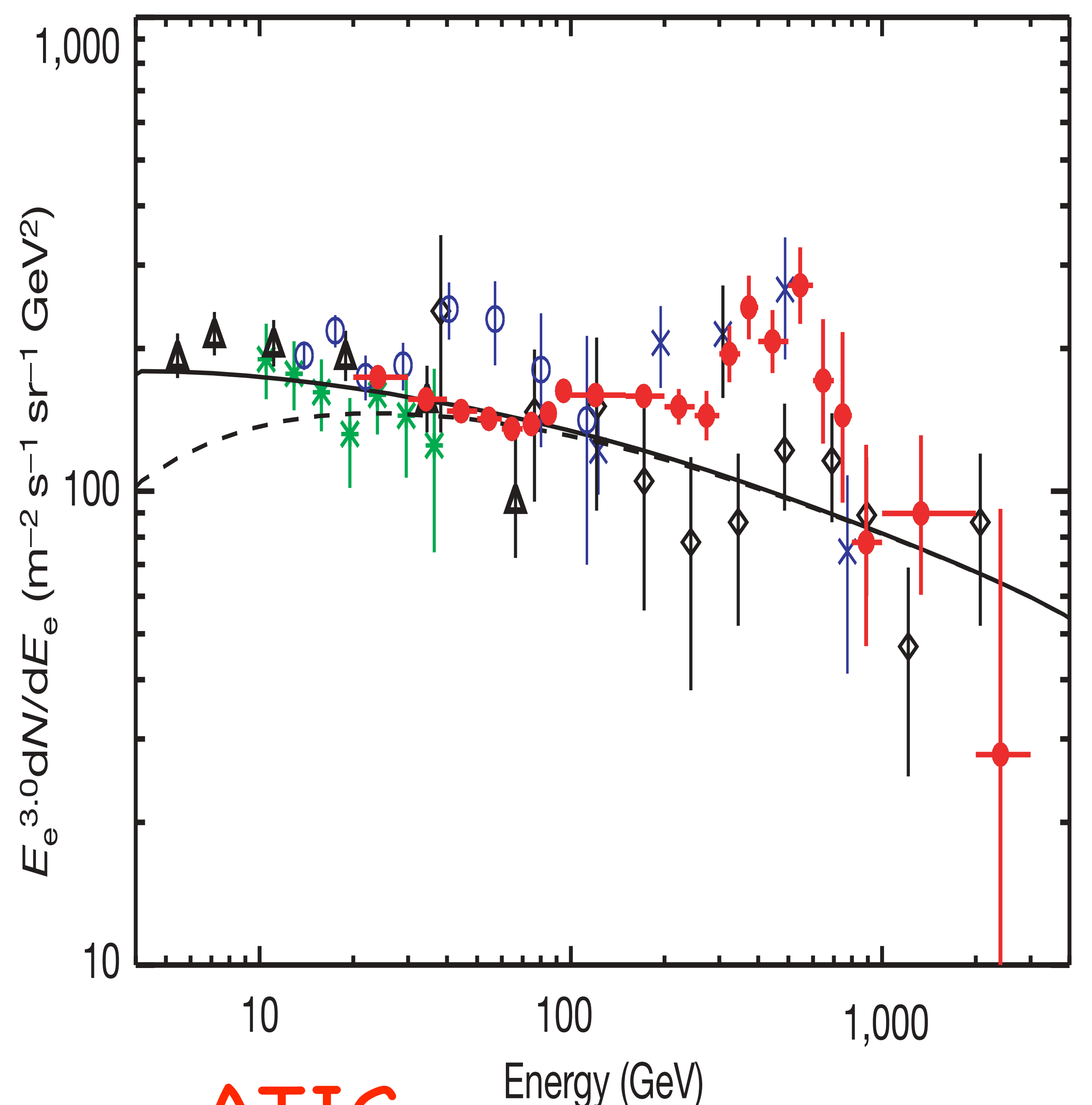
New Paradigms for Dark Matter, UC Davis

Positron fraction



PAMELA

e⁺+e⁻ spectrum



ATIC

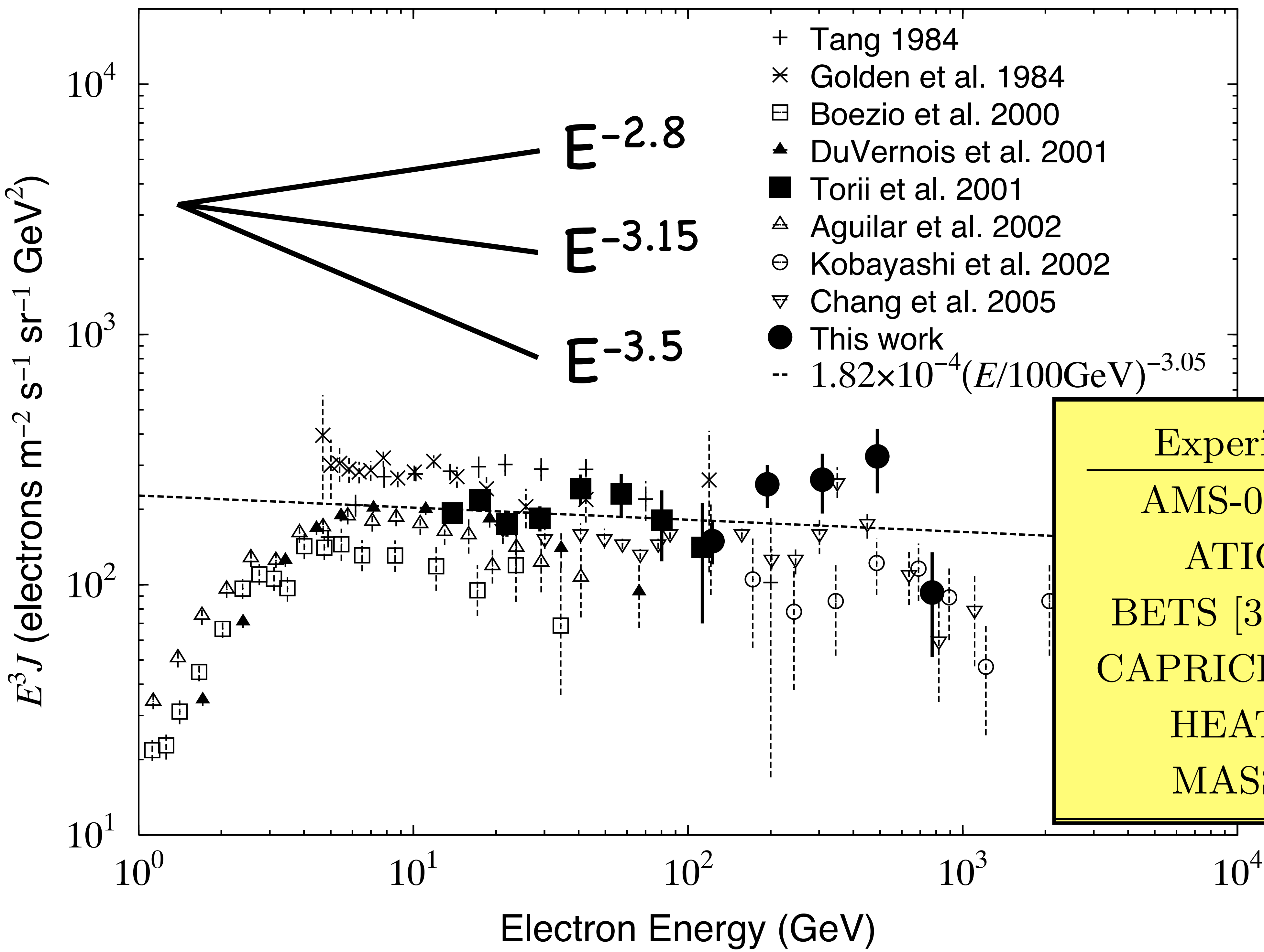
BETS

Positron Excess or Electron Deficit?

We don't know yet.

But, we do know that if it is an electron deficit, PAMELA sees far fewer electrons than any other experiment that has measured the same energy range.

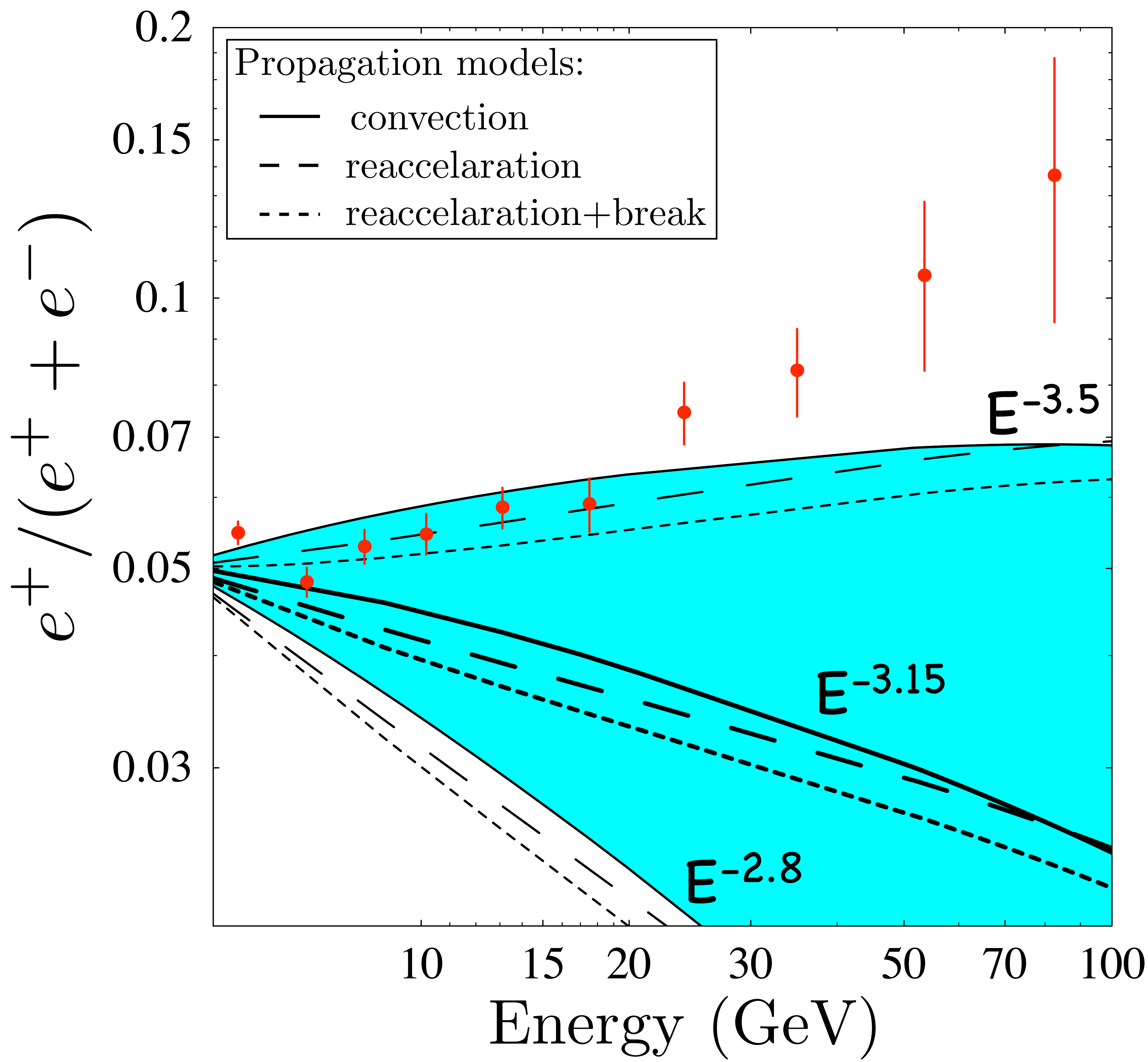
Existing electron data from other experiments (5-100 GeV only) can be used to determine the shape of electron flux.



Experiment	power law index α
AMS-01 [29]	3.15 ± 0.04
ATIC [30]	3.14 ± 0.08
BETS [31, 32]	3.05 ± 0.05
CAPRICE [33]	3.47 ± 0.34
HEAT [34]	2.82 ± 0.16
MASS [35]	2.89 ± 0.10

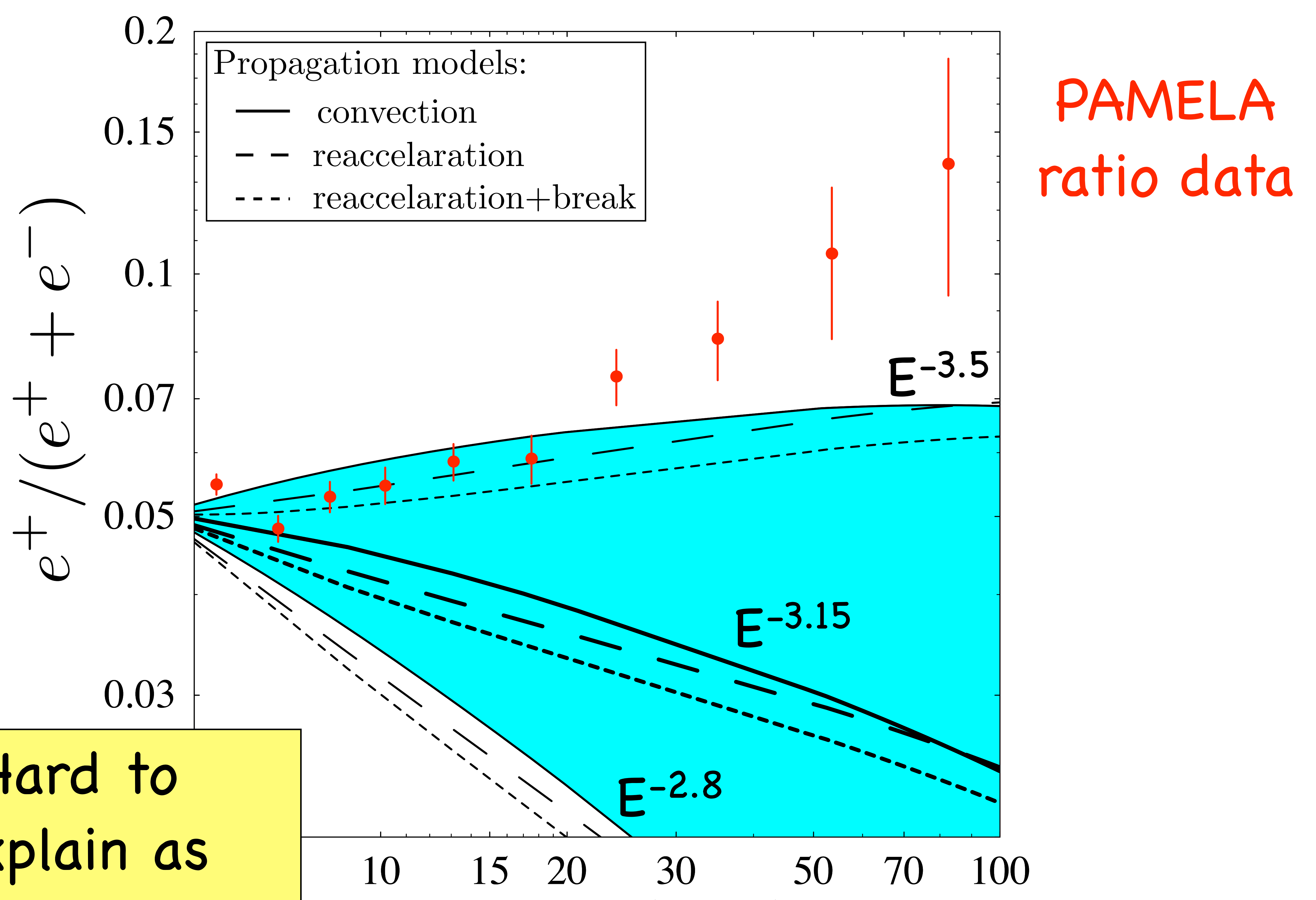
Harnik, GK

No dark matter:



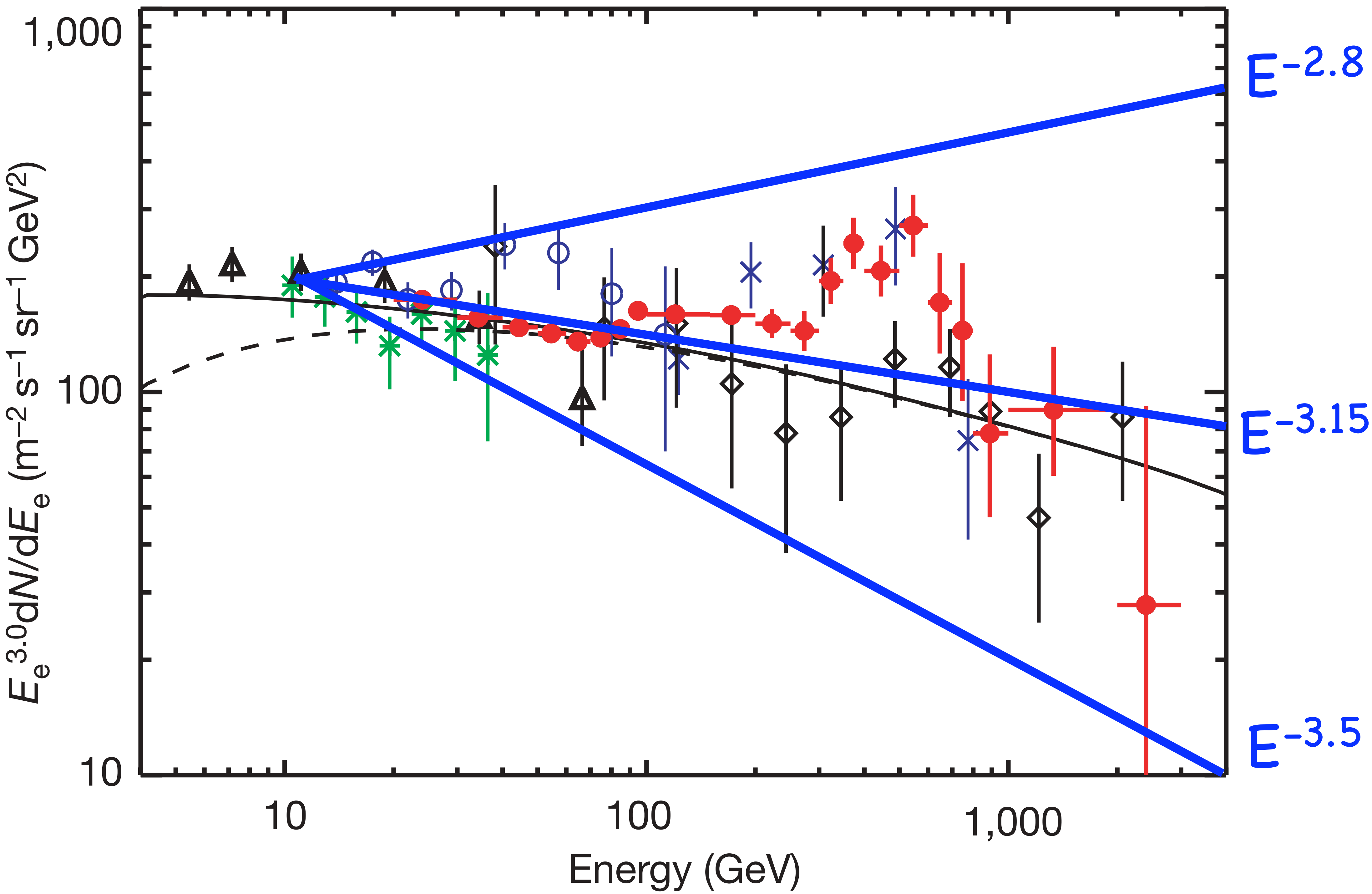
PAMELA
ratio data

No dark matter:



Hard to explain as electron deficit

PPB-BETS, ATIC, and the High Energy $e^+ + e^-$ Spectrum



Observation: Minimizing the discrepency using solely the electron flux...

PAMELA prefers a steeper slope

ATIC/BETS prefers a shallower slope.

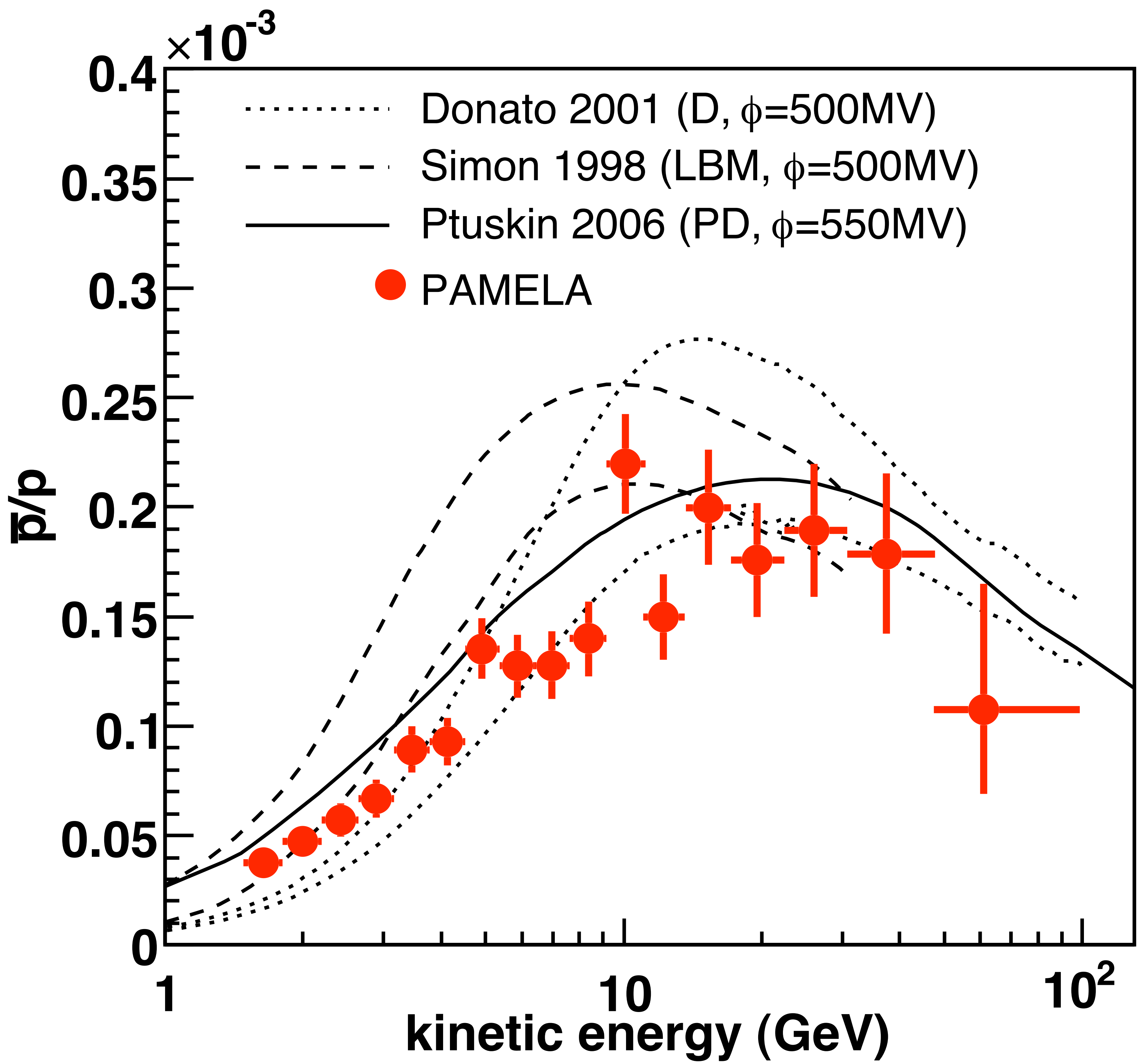
Annihilating Dark Matter

Annihilation channel(s)

Cross section enhancements

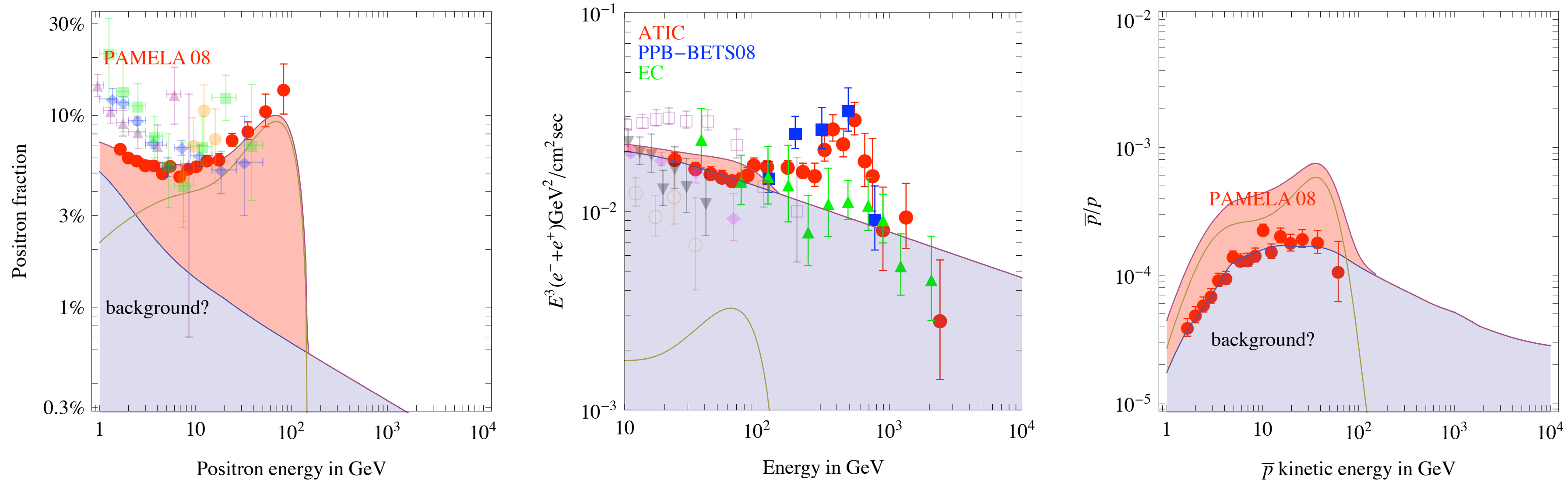
Constraints & Predictions

Why not annihilate to quarks, h, W's?

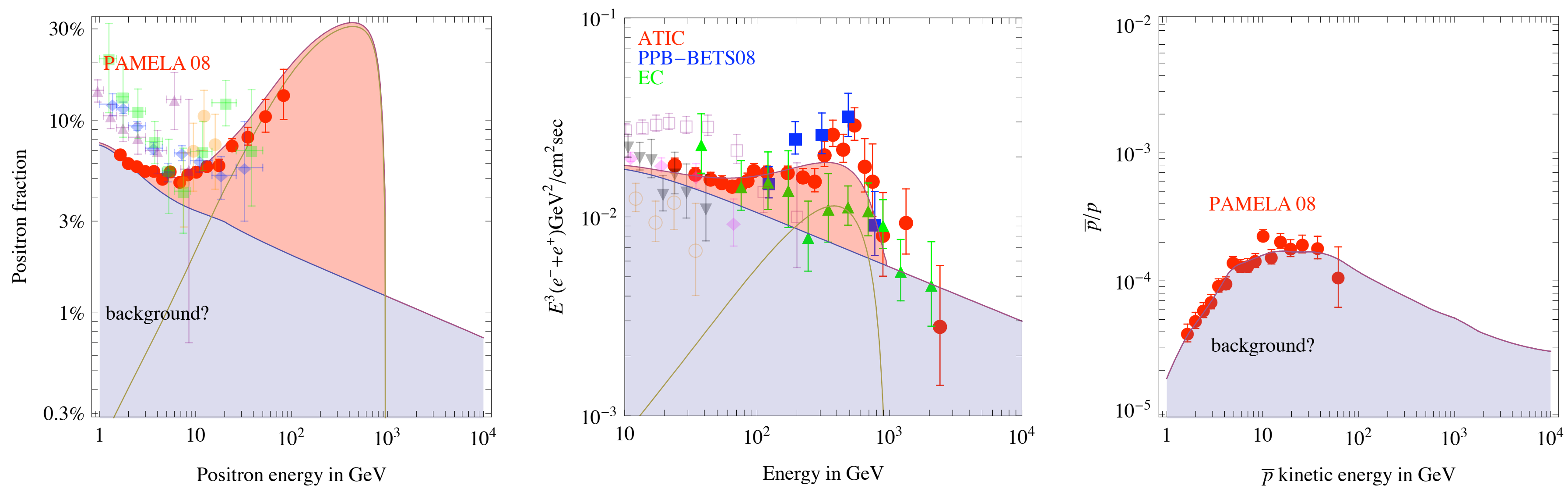


PAMELA

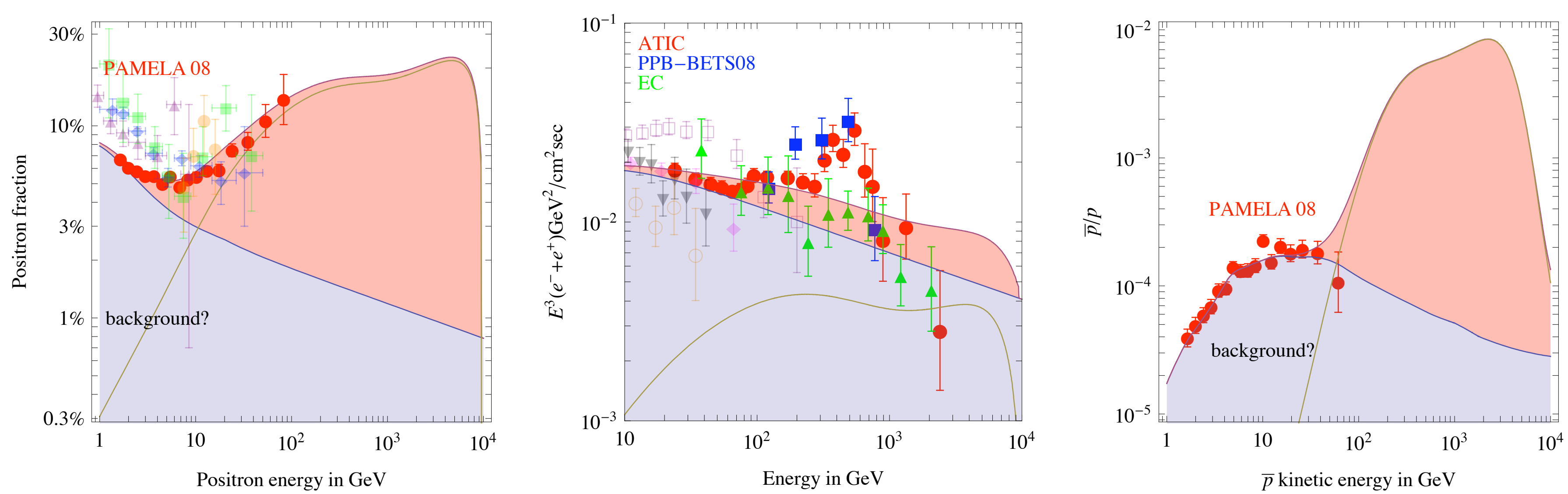
DM with M = 150 GeV that annihilates into W^+W^-



DM with M = 1 TeV that annihilates into $\mu^+\mu^-$



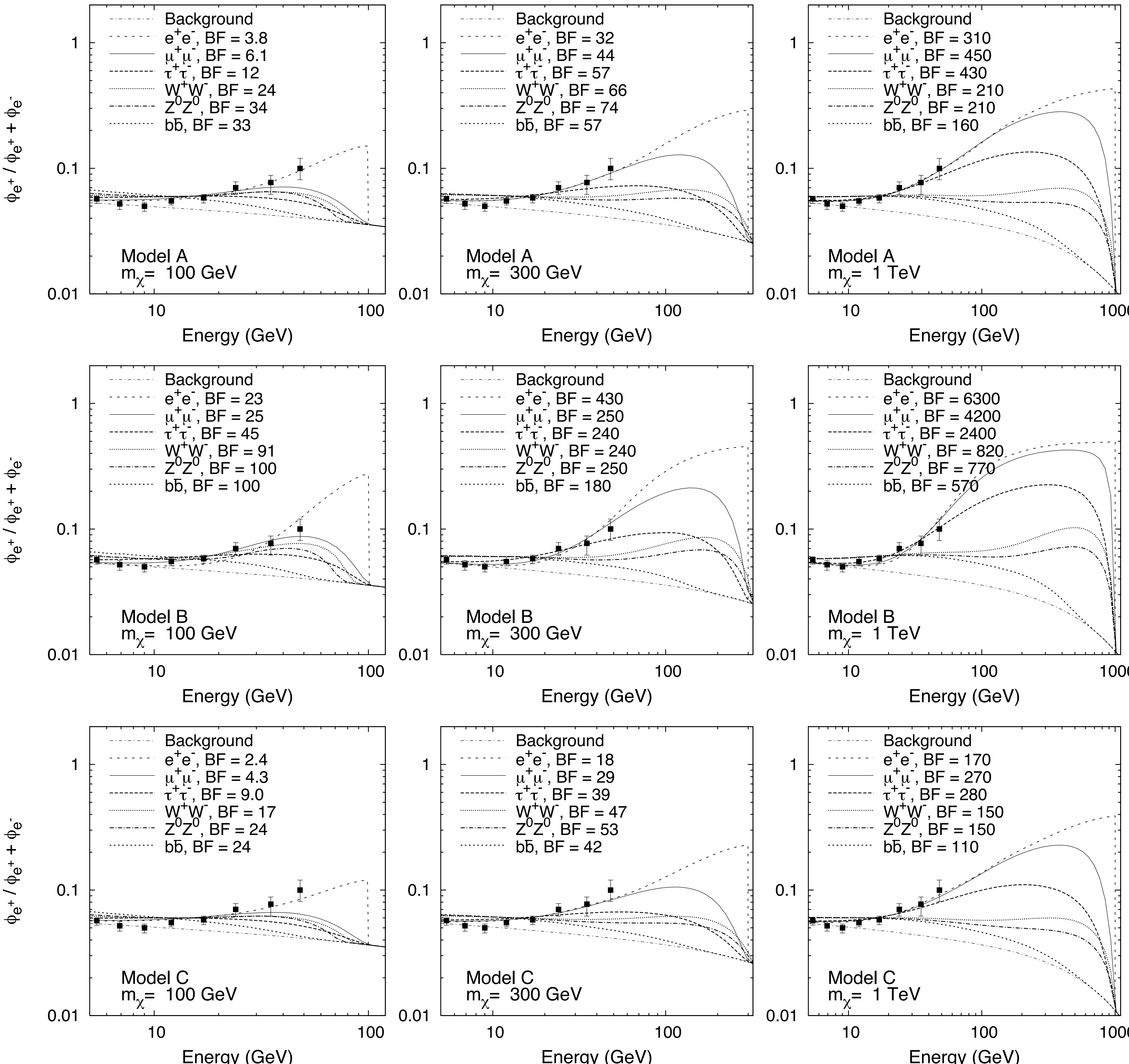
DM with M = 10 TeV that annihilates into W^+W^-



Cirelli et al

W's suck.

Too many anti-protons.



Background
e+e-, BF = 3.8
μ+μ-, BF = 6.1
τ+τ-, BF = 12
W+W-, BF = 24
Z0Z0, BF = 34
bb̄, BF = 33
Model A
mχ= 100 GeV
Background
e+e-, BF = 32
μ+μ-, BF = 44
τ+τ-, BF = 57
W+W-, BF = 66
Z0Z0, BF = 74
bb̄, BF = 57
Model A
mχ= 300 GeV
Background
e+e-, BF = 310
μ+μ-, BF = 450
τ+τ-, BF = 430
W+W-, BF = 210
Z0Z0, BF = 210
bb̄, BF = 160
Model A
mχ= 1 TeV
Background
e+e-, BF = 23
μ+μ-, BF = 25
τ+τ-, BF = 45
W+W-, BF = 91
Z0Z0, BF = 100
bb̄, BF = 100
Model B
mχ= 100 GeV
Background
e+e-, BF = 430
μ+μ-, BF = 250
τ+τ-, BF = 240
W+W-, BF = 240
Z0Z0, BF = 250
bb̄, BF = 180
Model B
mχ= 300 GeV
Background
e+e-, BF = 6300
μ+μ-, BF = 4200
τ+τ-, BF = 2400
W+W-, BF = 820
Z0Z0, BF = 770
bb̄, BF = 570
Model B
mχ= 1 TeV
Background
e+e-, BF = 2.4
μ+μ-, BF = 4.3
τ+τ-, BF = 9.0
W+W-, BF = 17
Z0Z0, BF = 24
bb̄, BF = 24
Model C
mχ= 100 GeV
Background
e+e-, BF = 18
μ+μ-, BF = 29
τ+τ-, BF = 39
W+W-, BF = 47
Z0Z0, BF = 53
bb̄, BF = 42
Model C
mχ= 300 GeV
Background
e+e-, BF = 170
μ+μ-, BF = 270
τ+τ-, BF = 280
W+W-, BF = 150
Z0Z0, BF = 150
bb̄, BF = 110
Model C
mχ= 1 TeV
φe+ / φe+ + φe-
Energy (GeV)
0.01
0.1
1
10
100
1000

Cholis et al

W's, b's, Z's suck.
Too many low energy positrons;
bad "fit" to PAMELA data.

Conclusion: annihilate to leptons.

How to get leptons

* Hypercharge

* Kinematics

* New symmetries

* (new ideas?)

My personal favorite: hypercharge

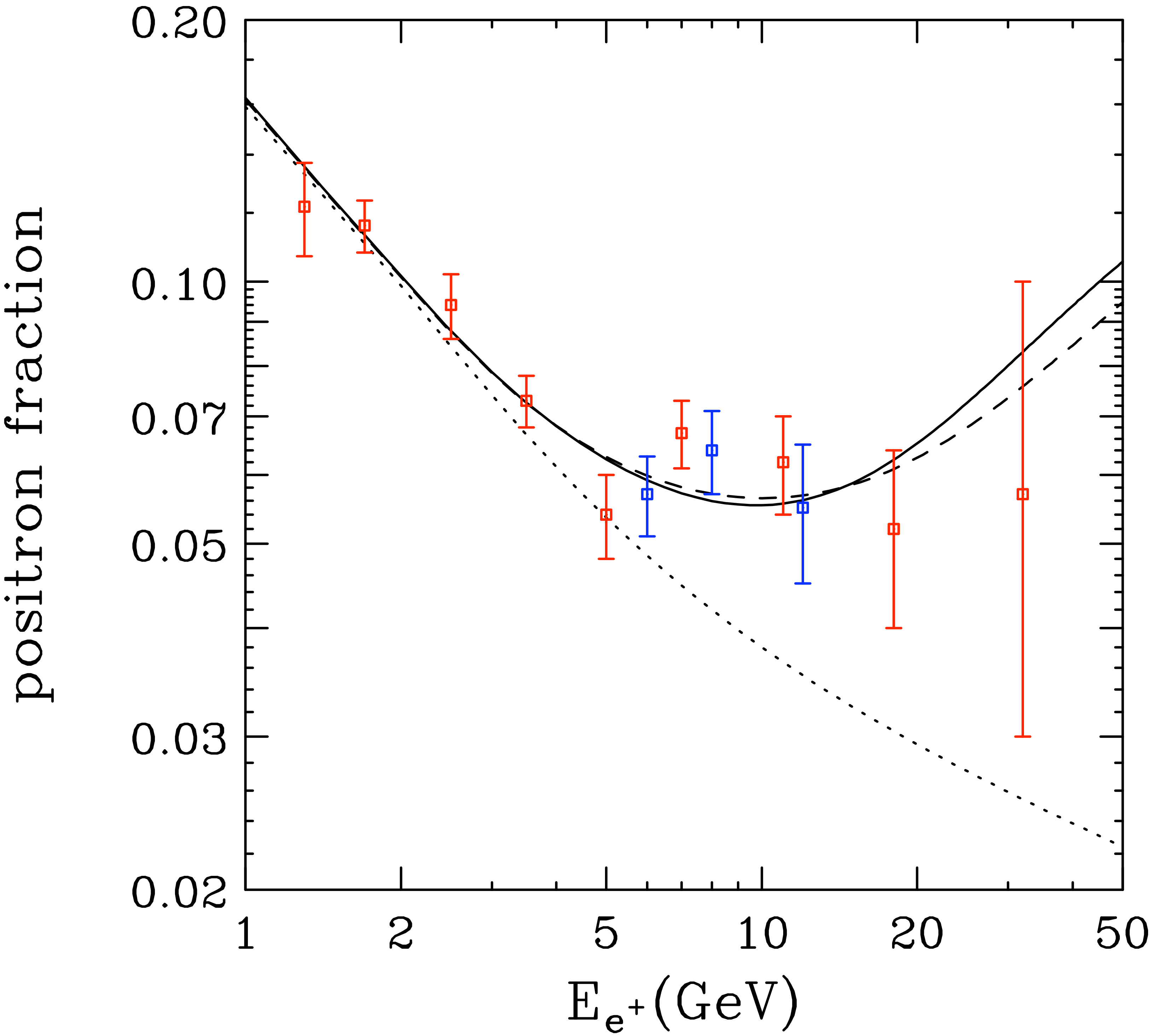
If $\langle\sigma v\rangle$ proportional to Y^4, automatically dominantly annihilate to (RH-)leptons.

Expect roughly
80% to RH leptons
15% to RH up-type quarks
5% rest...

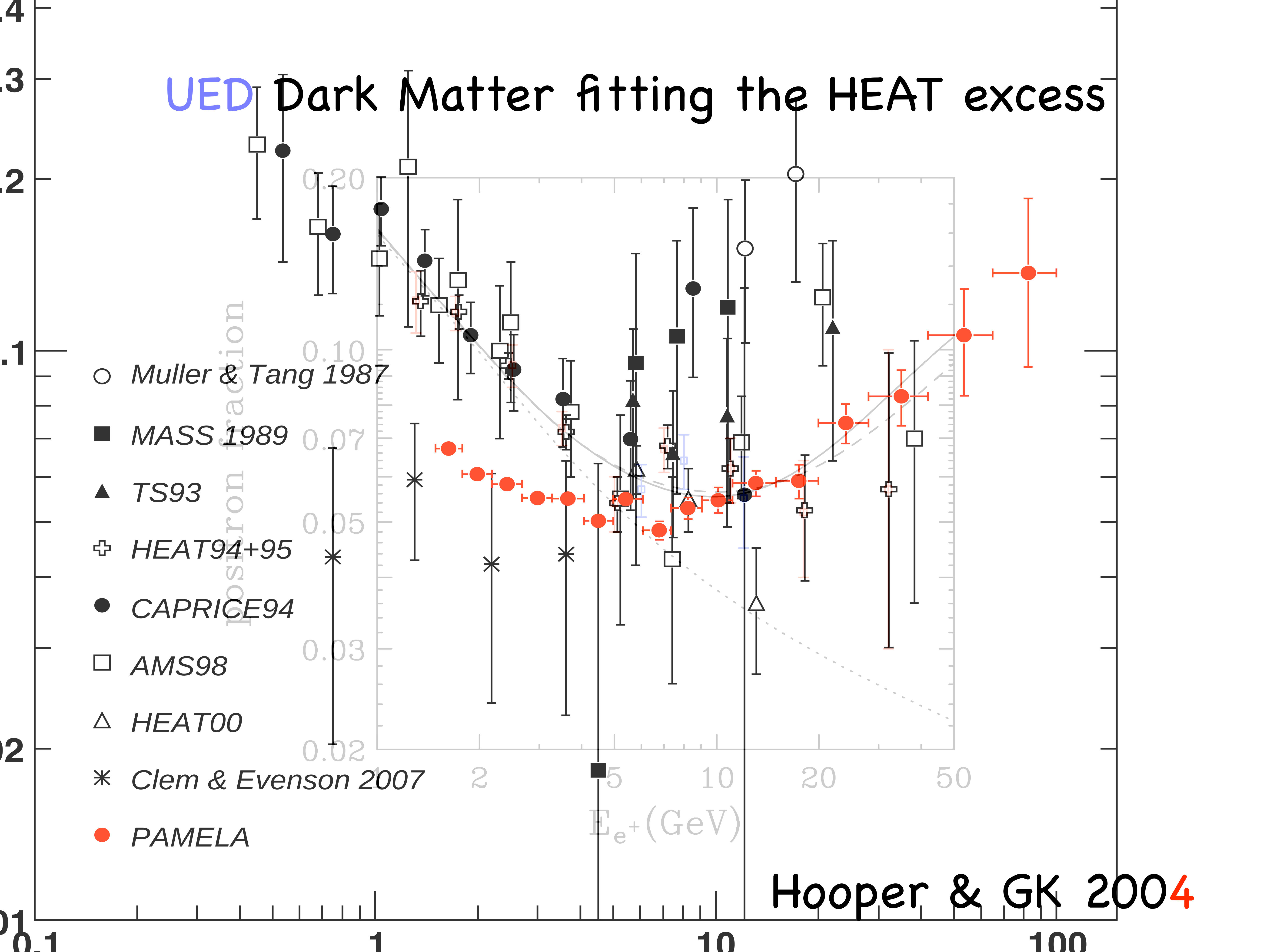
Models utilizing this: UED; Dirac Bino; ...

Interesting Question: Is this good enough to satisfy antiproton signal?

UED Dark Matter fitting the HEAT excess

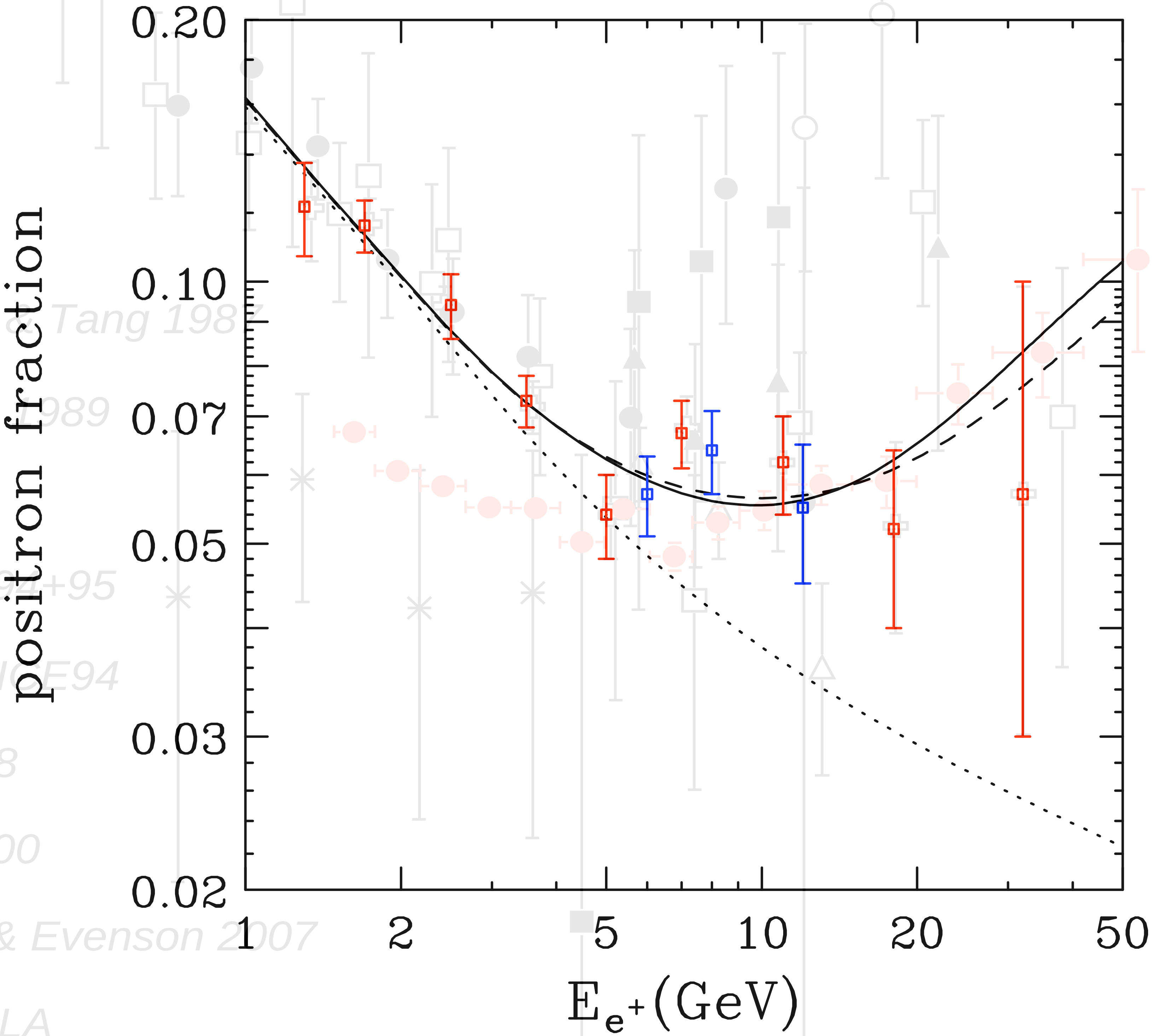


Hooper & GK 2004



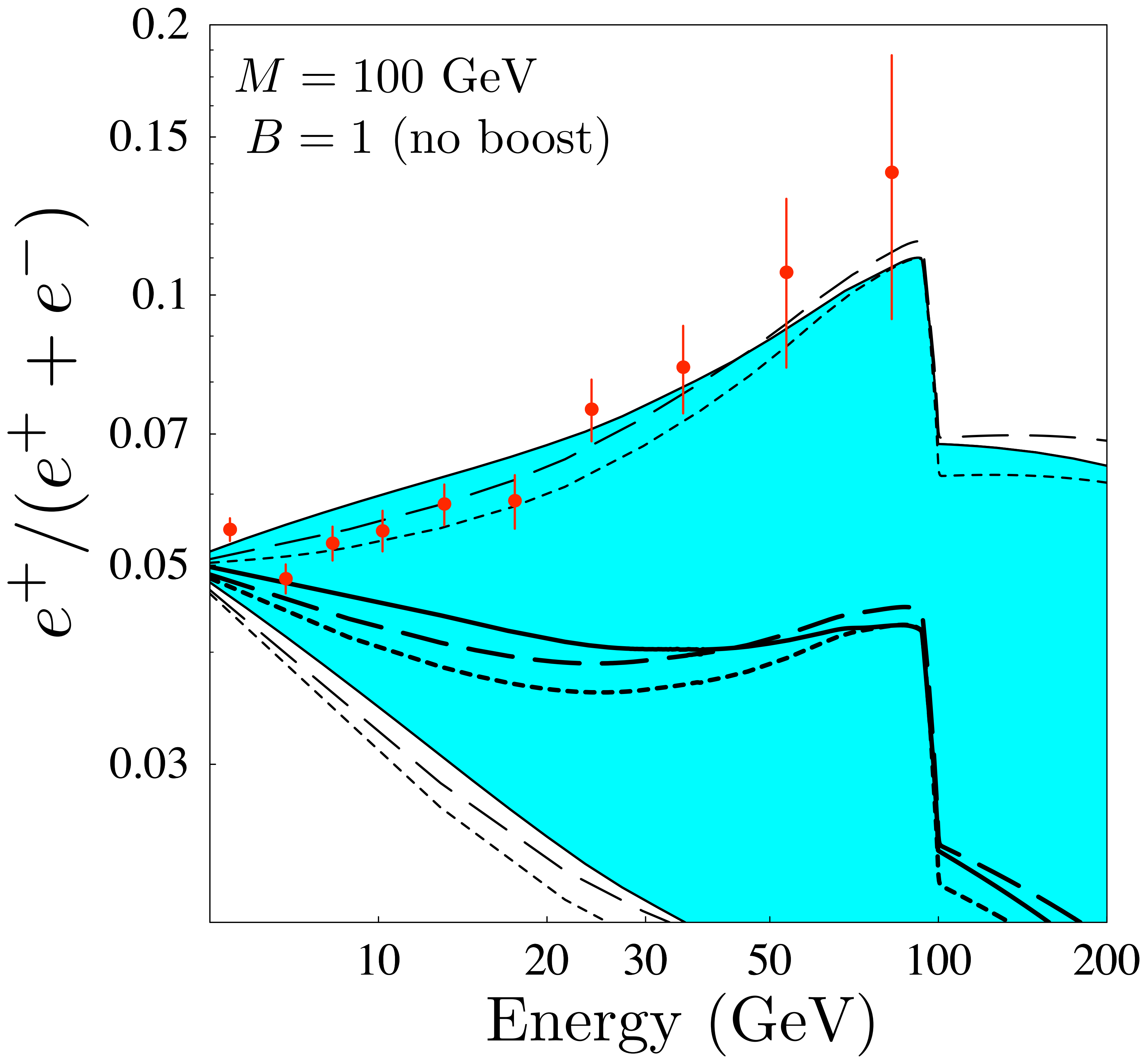
UED Dark Matter fitting the HEAT excess
Muller & Tang 1987
MASS 1989
TS93
HEAT94+95
CAPRICE94
AMS98
HEAT00
Clem & Evenson 2007
PAMELA
Positron fraction
E_{e^+}(GeV)
Hooper & GK 2004

UED Dark Matter fitting the HEAT excess



Hooper & GK 2004

Dirac Dark Matter

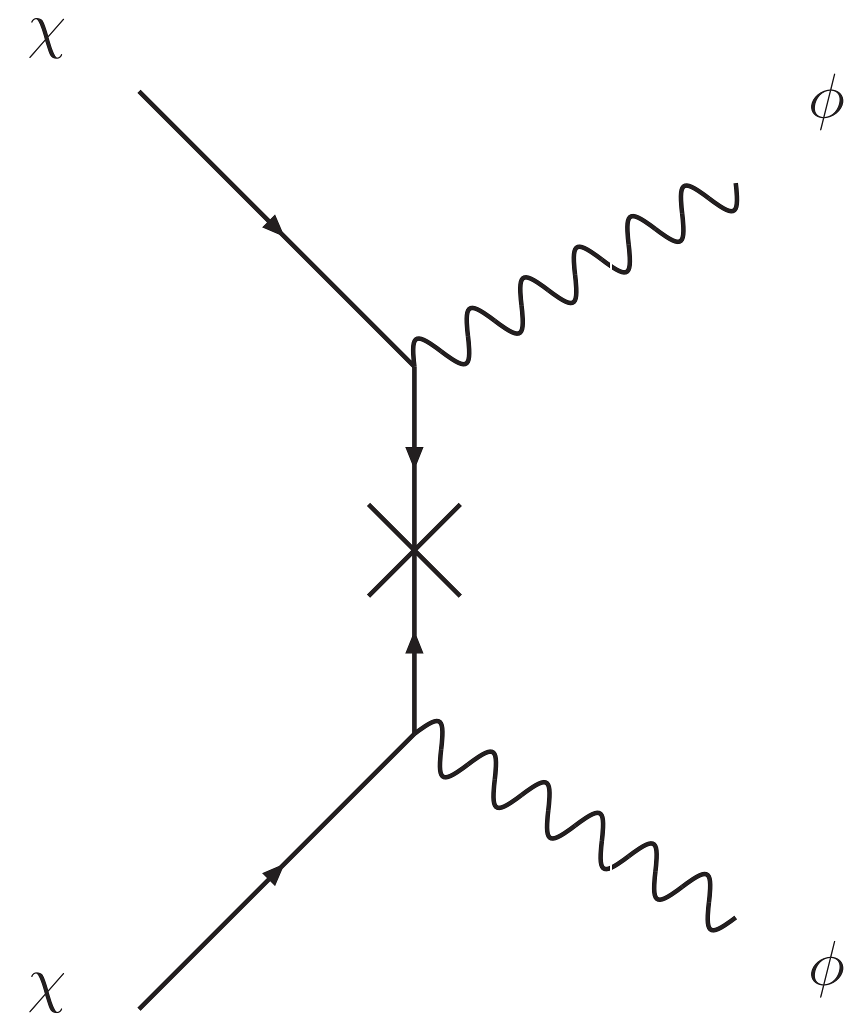


Annihilation to e^+e^- only

Harnik, GK

* Kinematics

Annihilation into a mediator φ light enough such that it decays dominantly into leptons.



To avoid anti-protons, typically
m_φ < 1 GeV.

To get leptons,
m_φ < few-200 MeV.

To avoid BBN, m_φ > MeV.

Arkani-Hamed et al
Pospelov et al
Nomura et al
...

* New symmetries

U(1) model of Fox & Poppitz

$U(1)_{B-L}$ model of Chen, Takahashi, Yanagida

$U(1)_{\mu-\tau}$ model of Baek, Ko

Others?

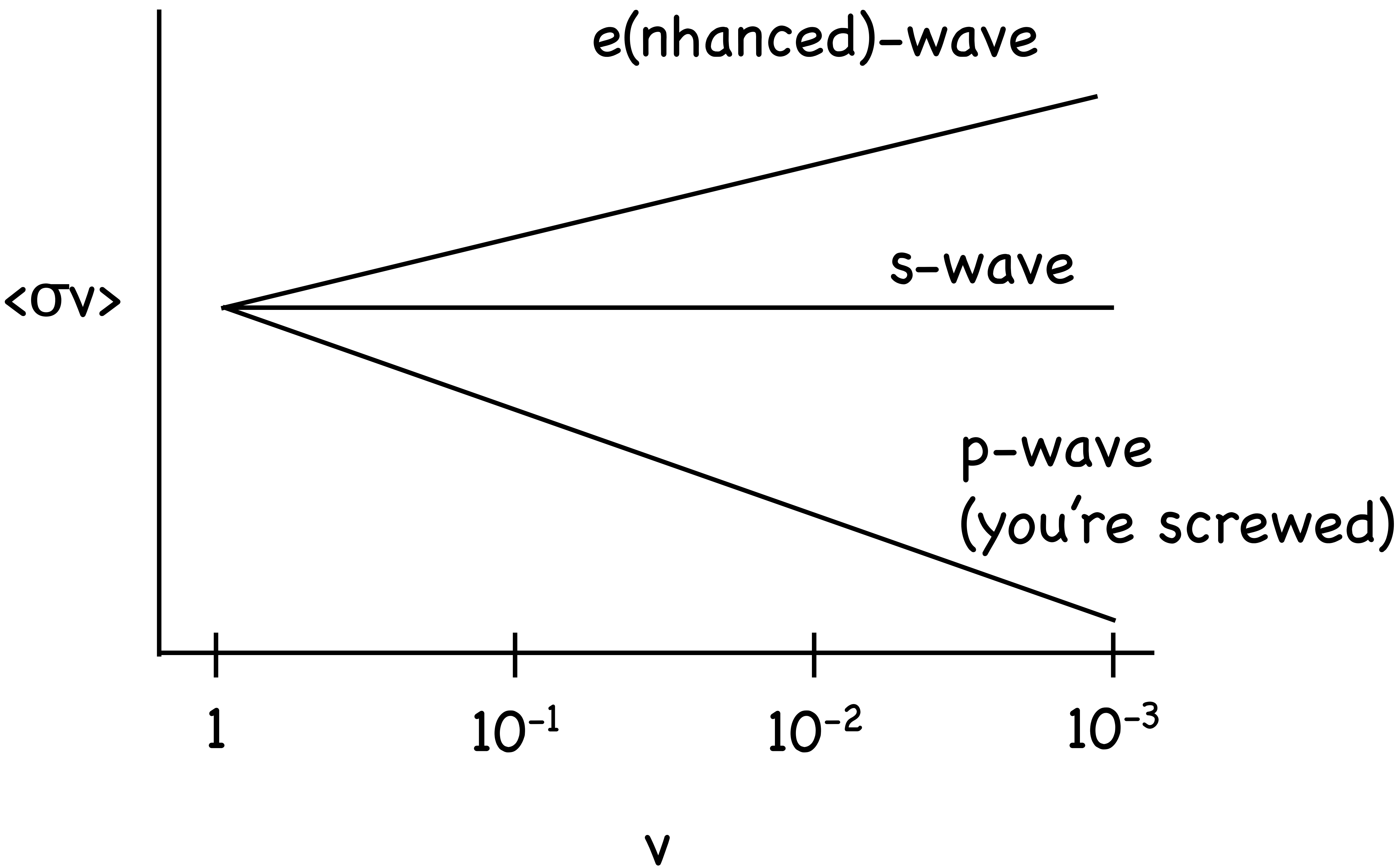
What cross section?

Thermal relic abundance:

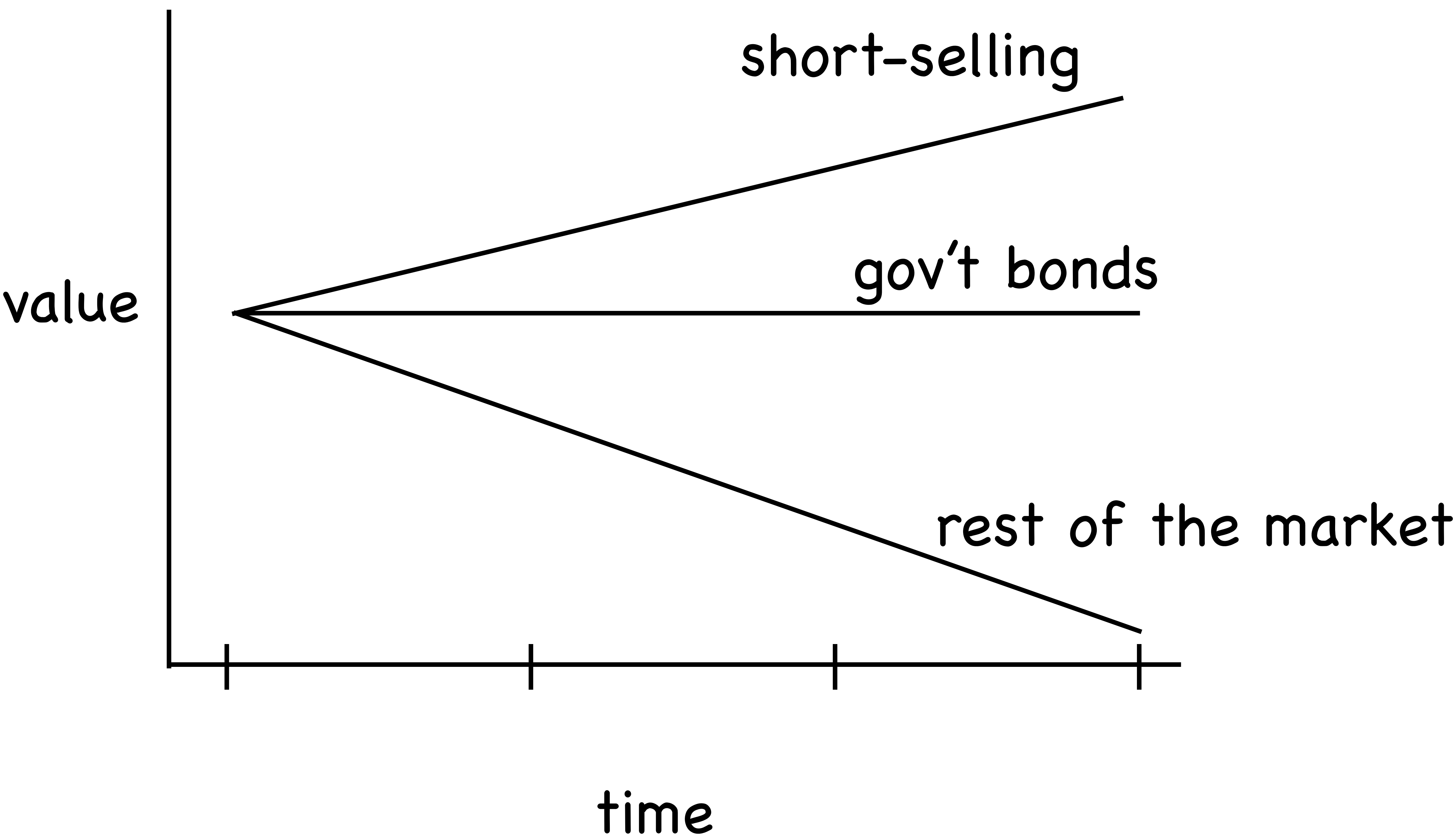
$$\Omega h^2 = 0.1 \frac{1\ \text{pb}}{\langle \sigma v \rangle}$$

("s-wave"; no velocity suppression)

Model plot

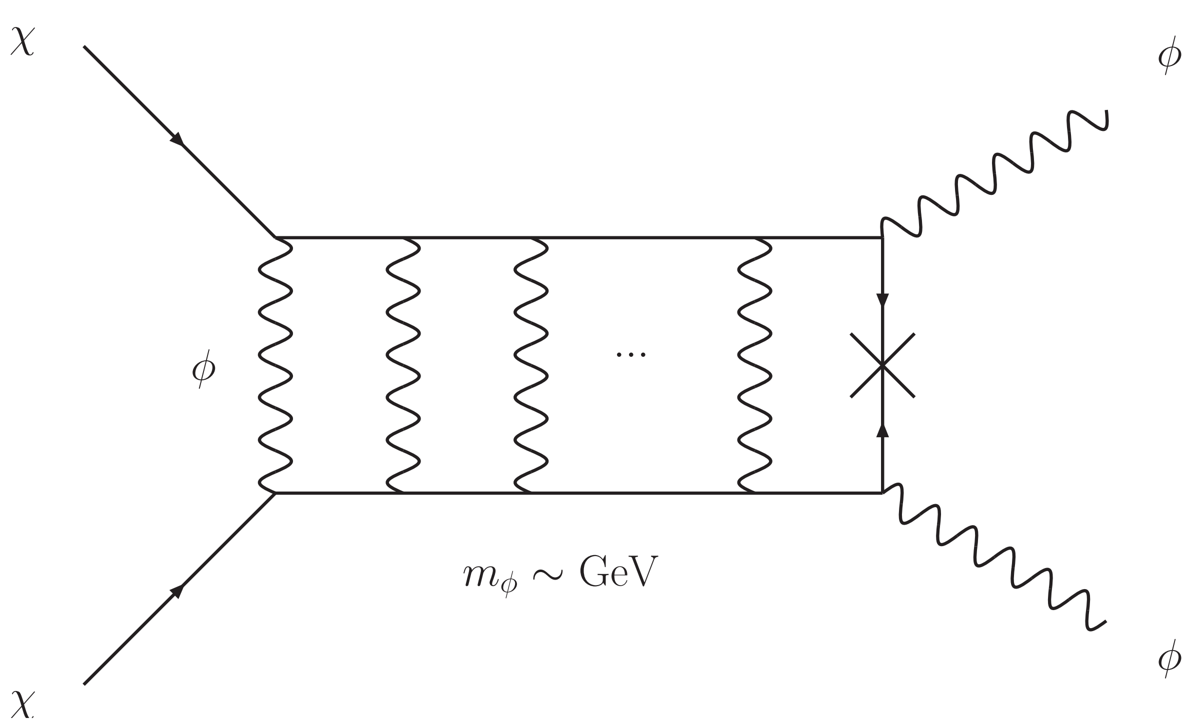


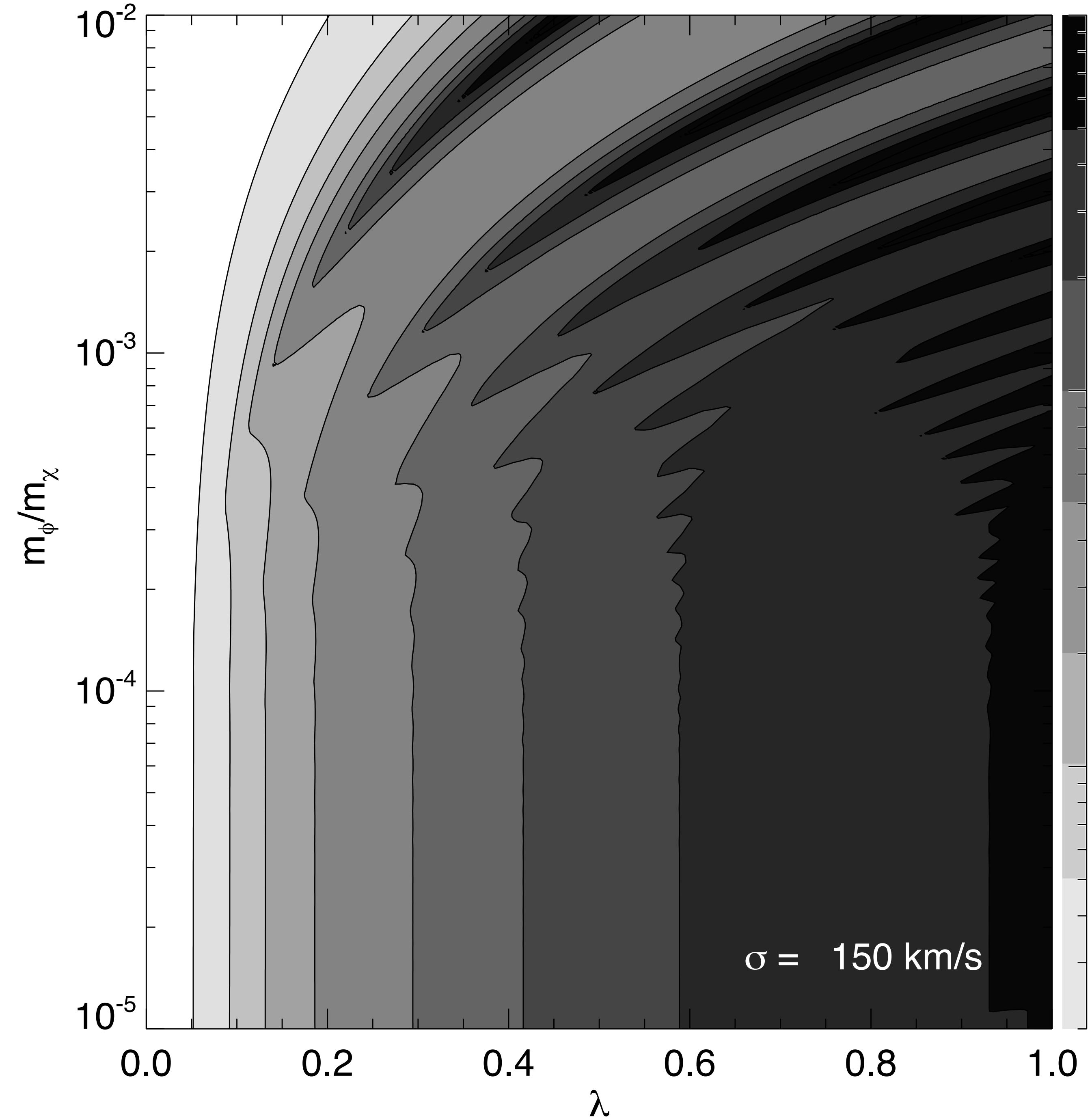
Financial plot



Size of cross section?

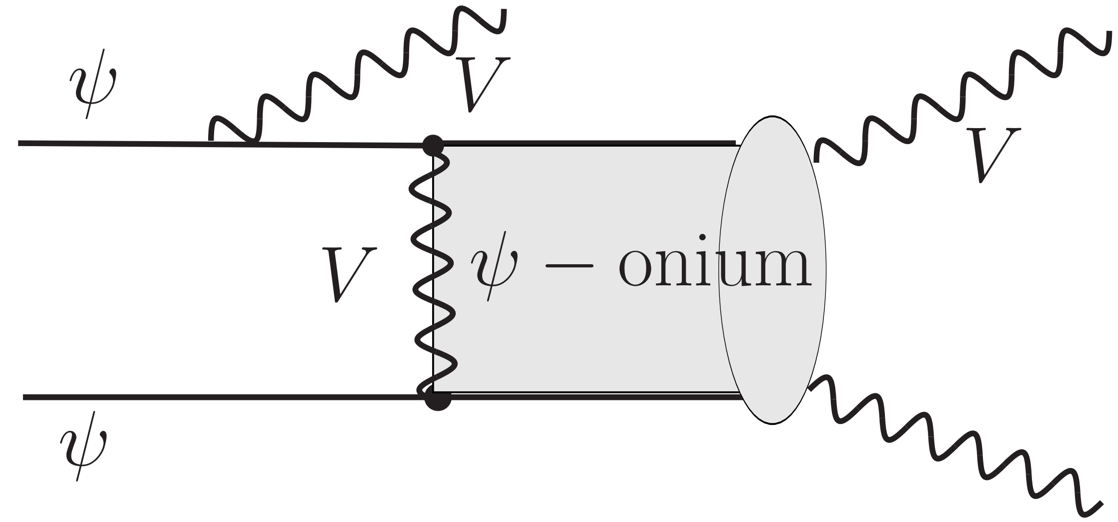
Sommerfeld:





Arkani-Hamed et al

WIMPonium



- C: *New annihilation channels.* While the two previous mechanisms have already been discussed at some length in the literature [20, 21], a third possibility - namely the enhancement due to new annihilation channels - has not been widely noticed.[1] Specifically, we refer to the new recombination process (see Fig. 1),

$$\text{recombination}: \ \psi + \psi \to (\psi - \text{onium}) + V, \tag{17}$$

(and similarly for ϕ) which is kinematically open even in the limit $E_\psi \to 0$ if the condition (2) is satisfied. The subsequent fate of the ψ-onium state is very different within the early Universe during freeze-out as compared to the galactic environment. In the halo, every ψ-onium that is formed via the process (17) decays further to two or three V-bosons. During freeze-out, however, the annihilation rate of ψ-onium into V's is strongly inhibited by thermal break-up, ψ-onium + V $\to 2\psi$. One can easily show that in the latter case the efficiency of annihilation, $\text{Br} = \Gamma_{\text{annih}}/(\Gamma_{\text{annih}} + \Gamma_{\text{break-up}})$, is much smaller than one. Thus, effectively only when the temperature drops below the binding energy does the process (17) serve as a new annihilation channel and, as we are going to see shortly, indeed dominate the annihilation rate in the galactic halo.

Pospelov et al

Nelson-Spitzer mechanism: Early Decoupling

In our scenario this is modified by a factor of

$$\sigma v \approx \frac{F(T^4_{\mathrm{hid},XY} + g_{*,XY} T^4_{\gamma,XY})^{\frac{1}{2}}}{g^{\frac{1}{2}}_{*,XY} T^2_{\mathrm{hid},XY}} 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{sec}} \ . \quad (18)$$

Note that F is largest when $T_{\gamma,XY}$ can be neglected relative to $T_{\mathrm{hid},XY}$. The factor $F/g^{\frac{1}{2}}_{*,XY}$ has an upper bound of about 5 so the upper bound on the annihilation cross section is approximately

$$\sigma v < 1.5 \times 10^{-25} \frac{\mathrm{cm}^3}{\mathrm{sec}} \ . \quad (19)$$

Decaying Dark Matter

Models:

Neutralino with R-parity violation (Yin et al)

Hidden sector gauge boson decays via kinetic mixing with $U(1)_{B-L}$ (Chen et al)

SuperWIMP -> SuperWIMP transition (Pospelov et al)

More to come...

Lifetime?

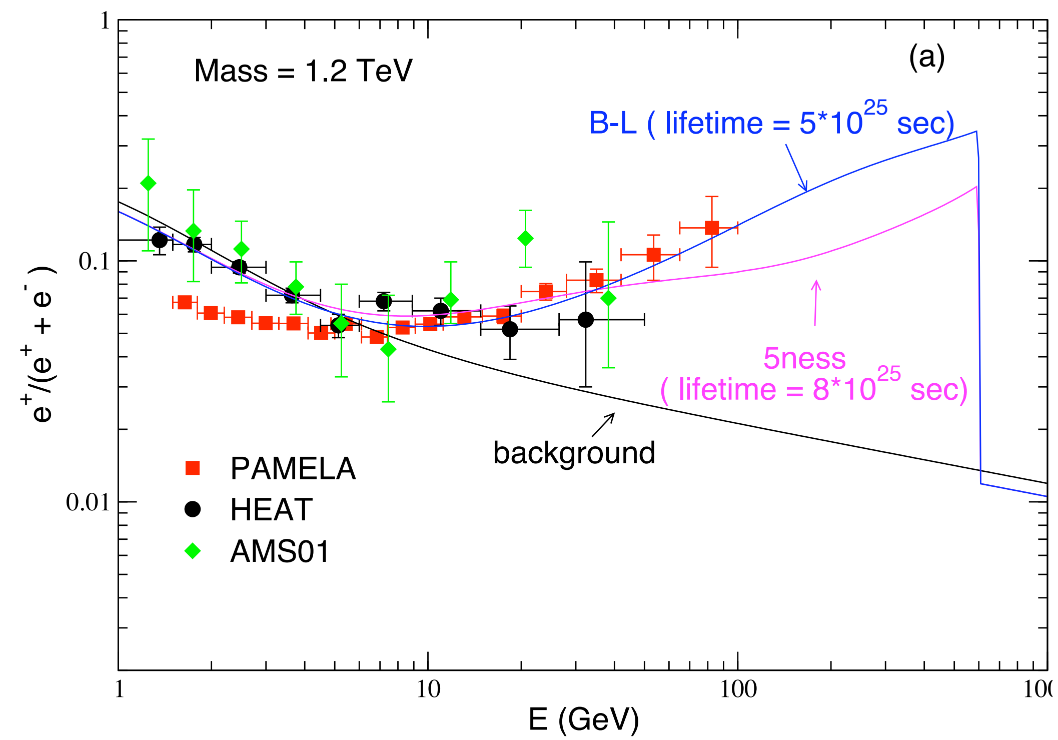
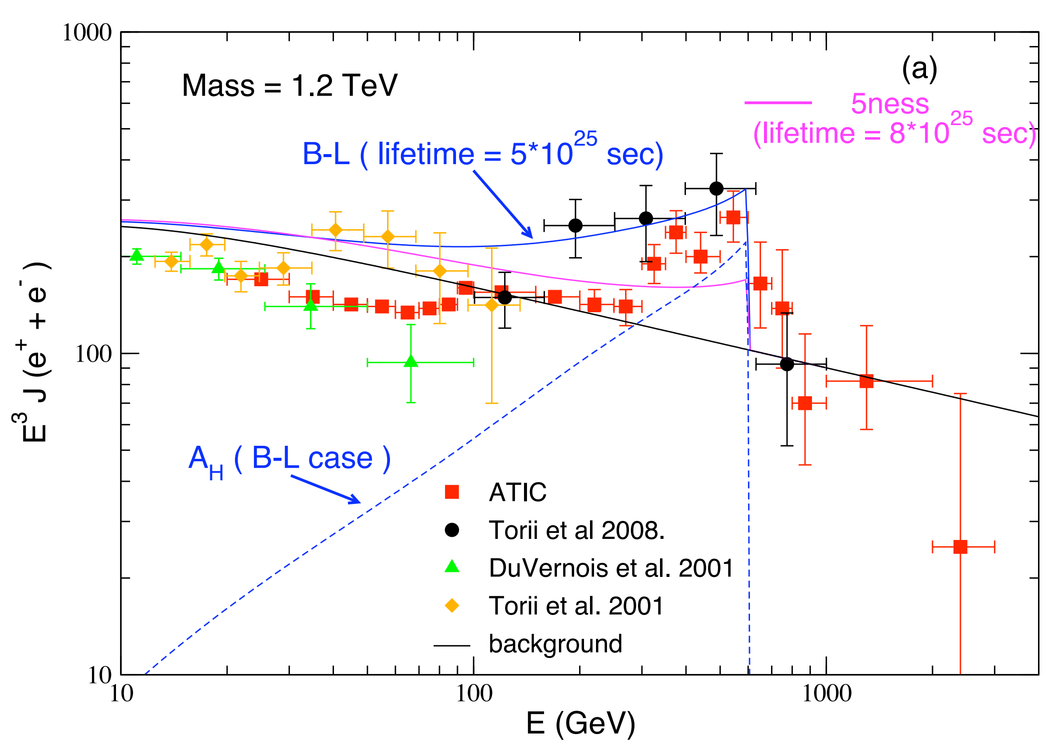
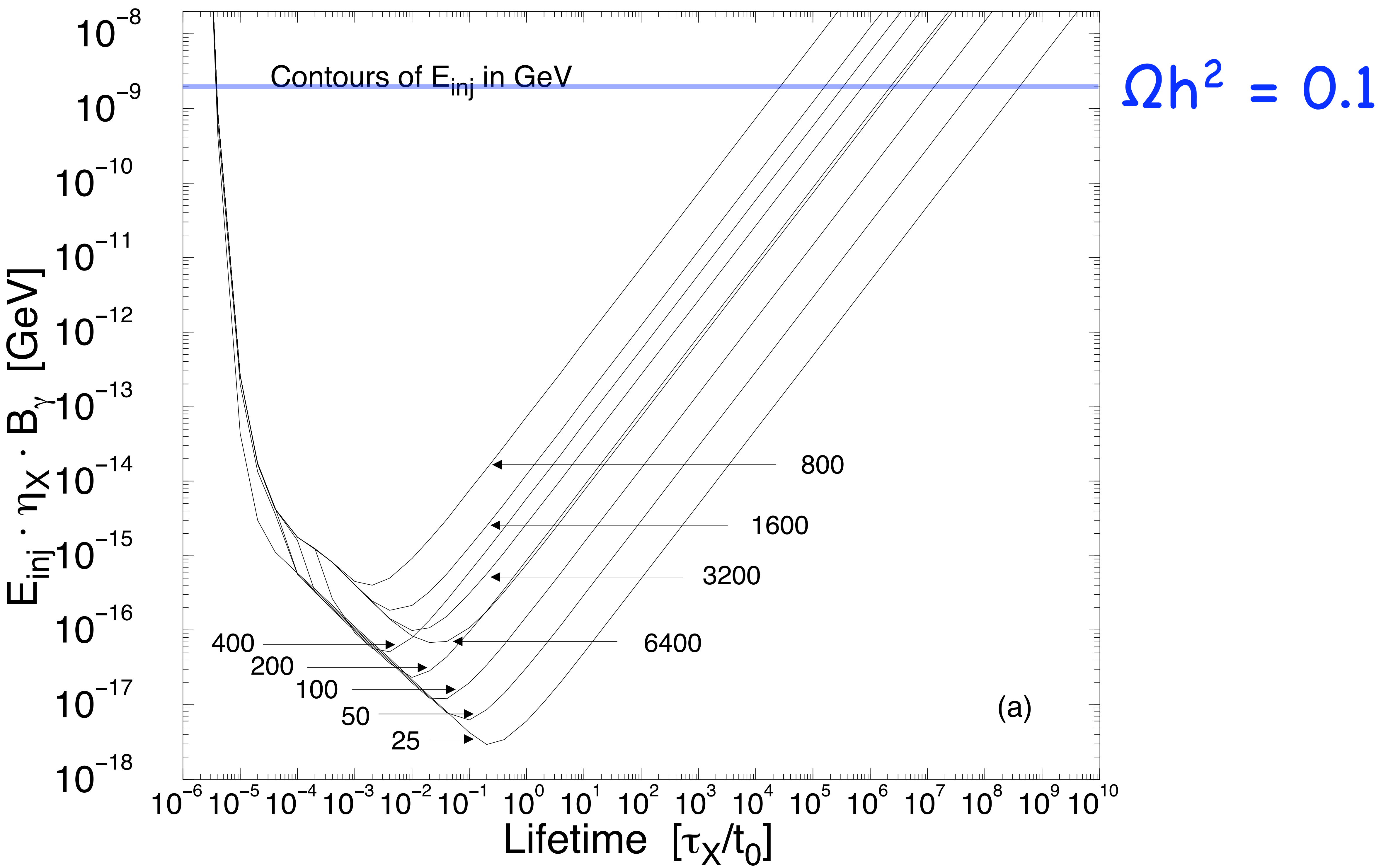


FIG. 1: (a) The predicted positron fraction from (blue line) and $U(1)_5$ (magenta line), compared w recent PAMELA results [1]; (b) For $U(1)_{B-L}$ case

(Bounds on long-lived DM from diffuse background photons were set long ago... Rothstein, GK)



Chen et al



Contours of E_{inj} in GeV
$\Omega h^2 = 0.1$
800
1600
3200
6400
400
200
100
50
25
(a)
$E_{inj} \cdot \eta_X \cdot B_\gamma$ [GeV]
Lifetime $[\tau_X/t_0]$
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10}

No LHC data is a boon for speculative theory!

What will survive?

(Next Davis workshop?)