A cautionary tale of dark matter indirect searches

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Latsis Symposium, Zürich
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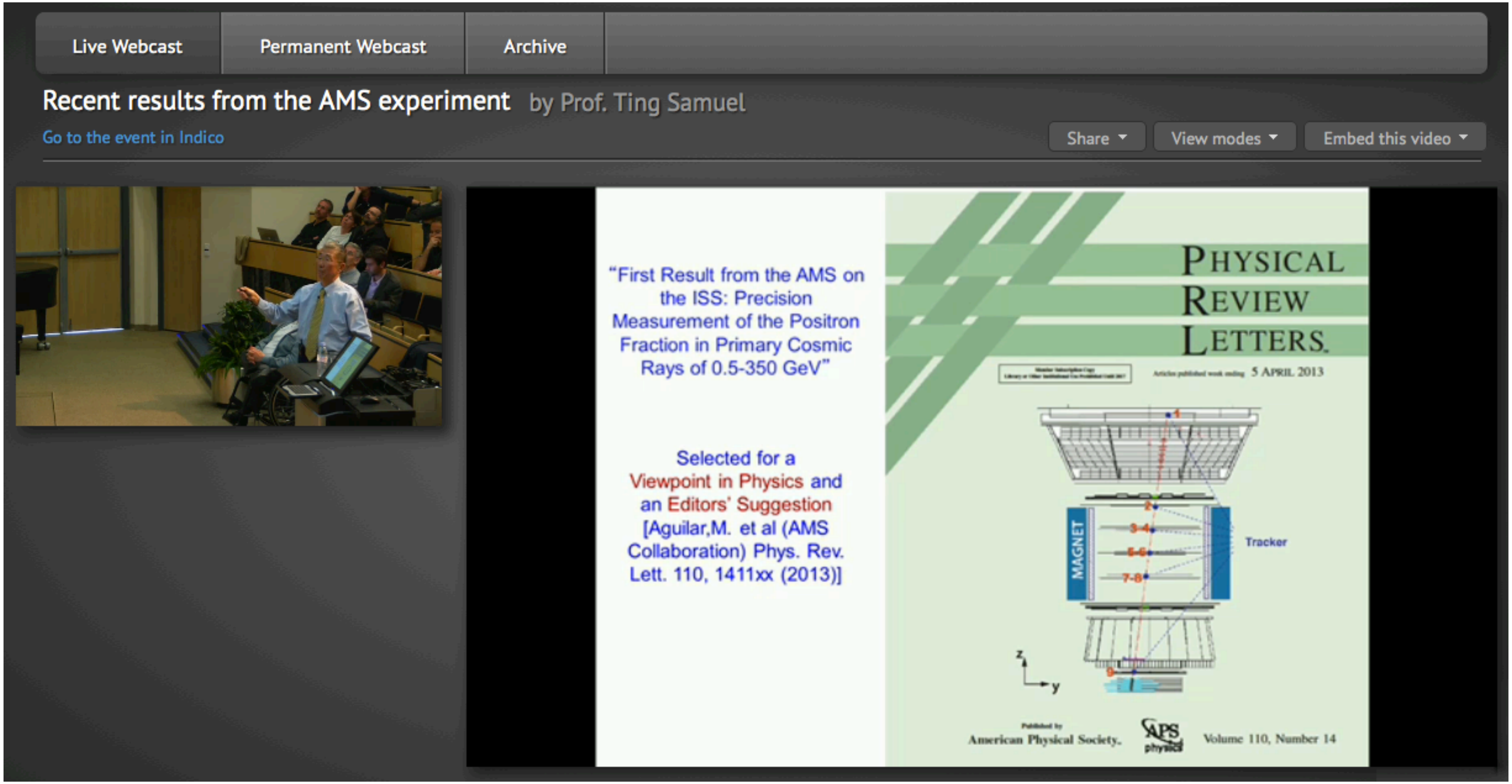
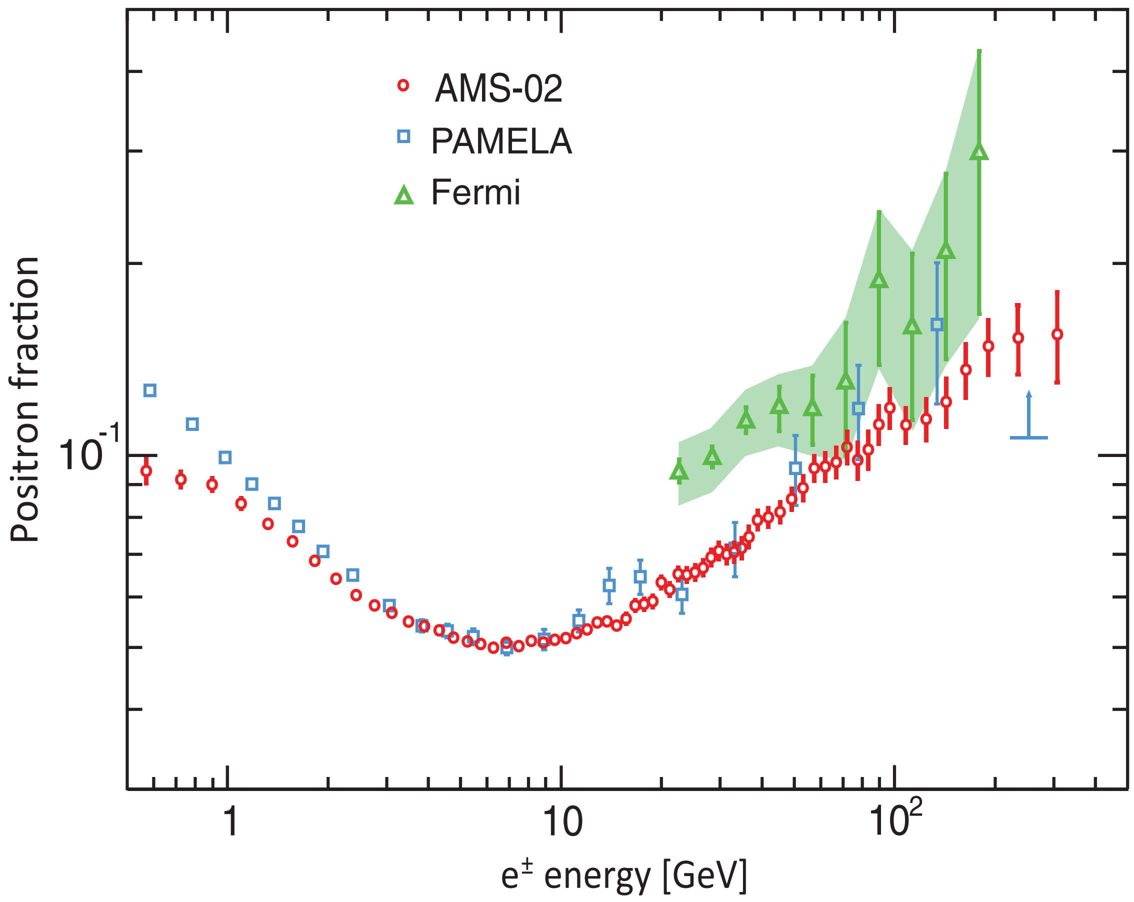
New AMS results



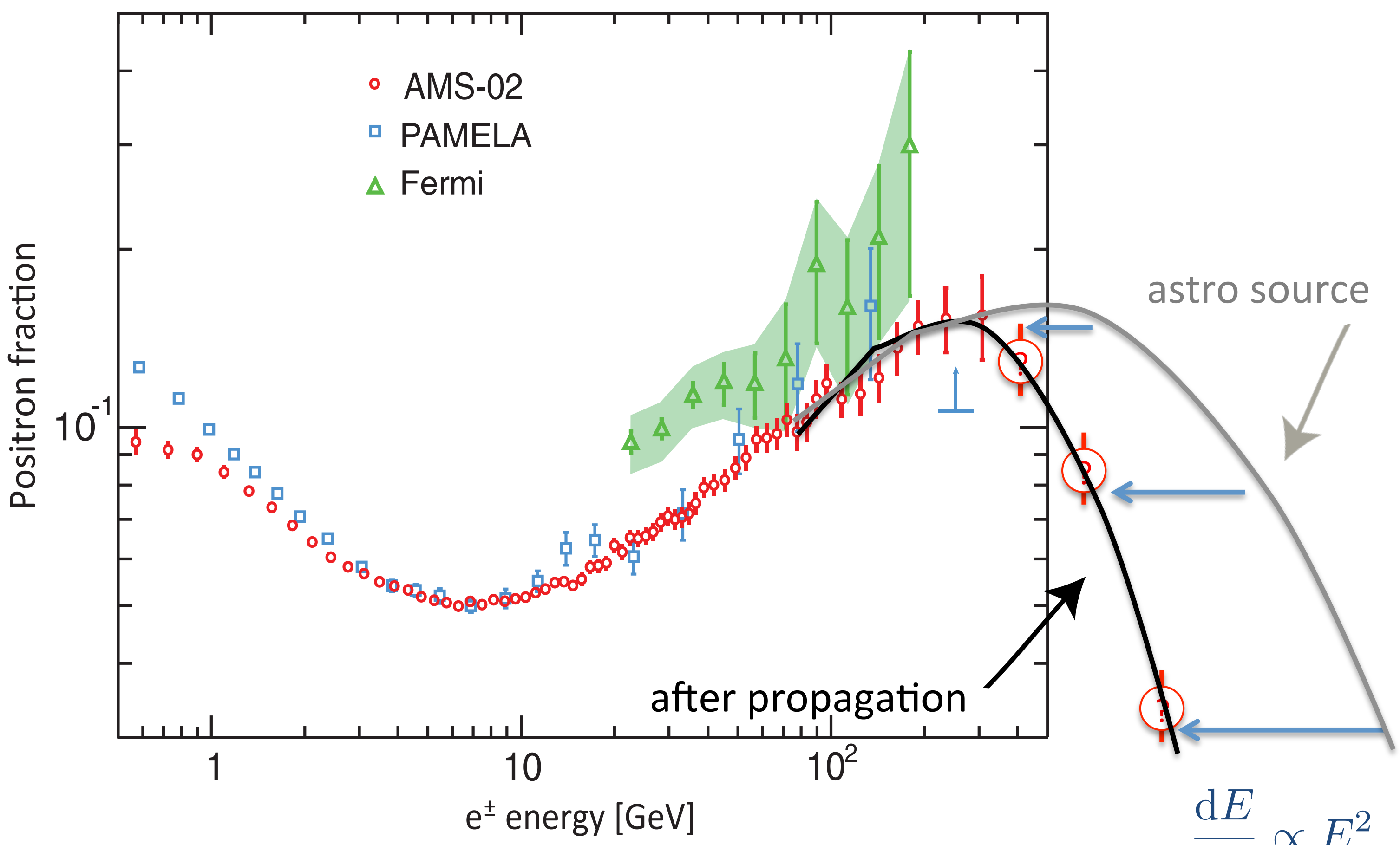
"There's no such thing as disappointing."
(Sam Ting)

New AMS results



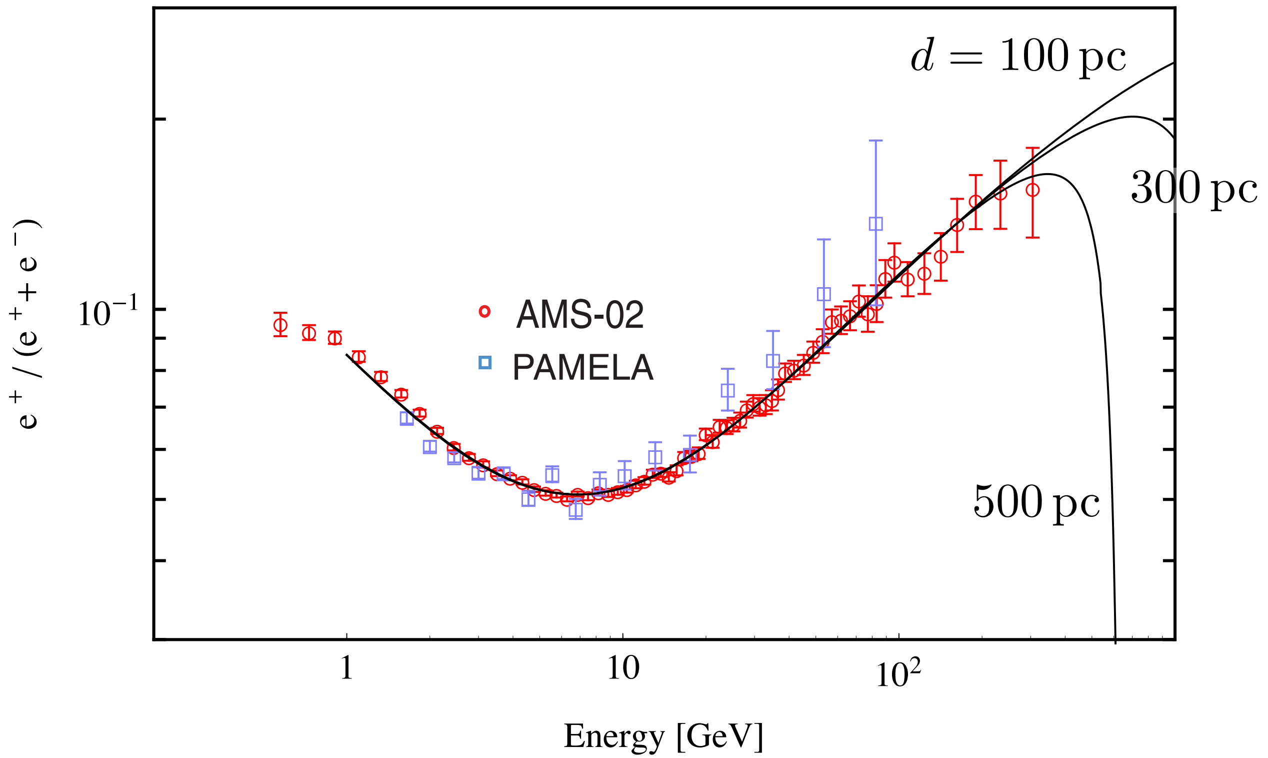
“The positron fraction is turning over,
so it must be dark matter.”

"It's turning over, so it must be DM."



$$\frac{\mathrm{d}E}{\mathrm{d}t} \propto E^2$$

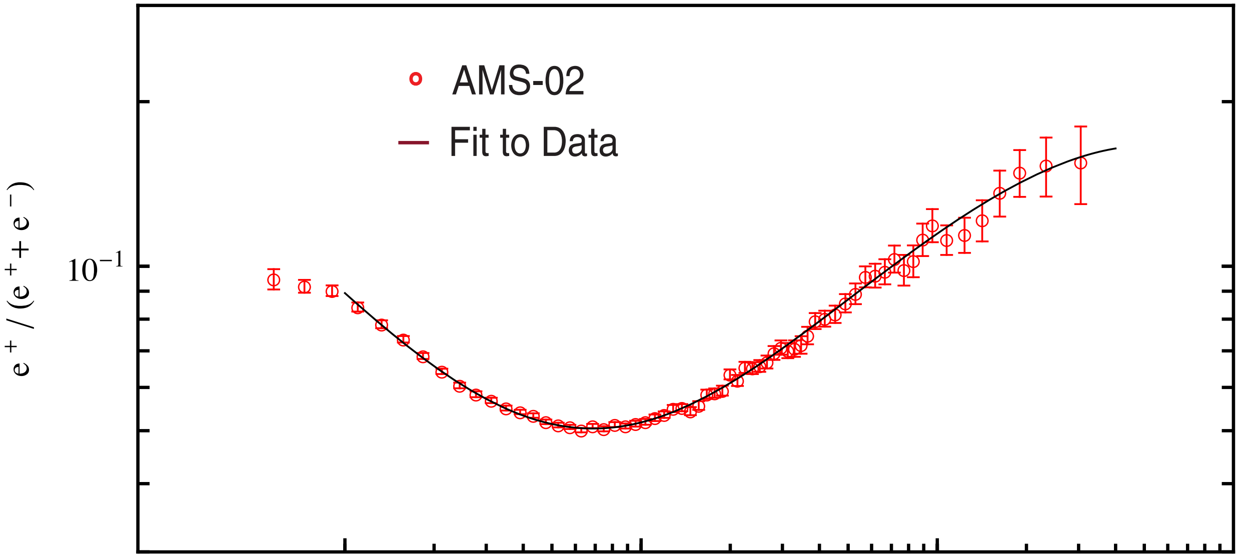
"It's turning over, so it must be DM."



- power law spectrum with spectral index $\Gamma \sim 1.7$
- exponential cut-off at $3\,\mathrm{TeV}$
- impulsive injection $20,000 \ldots 500,000\,\mathrm{yr}$ ago

"The positron fraction has substructure, so it must be dark matter."

“There’s substructure, hence DM.”



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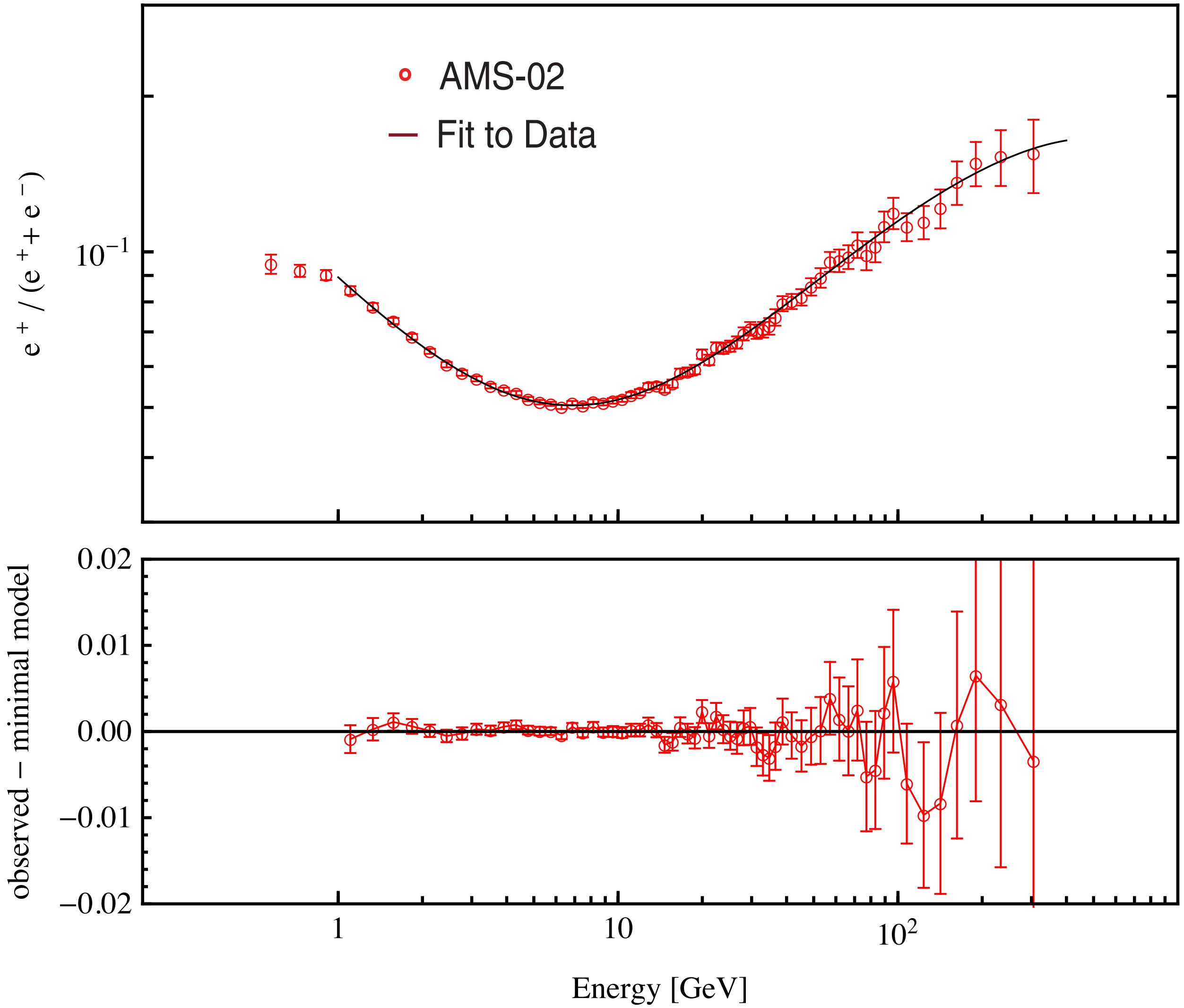

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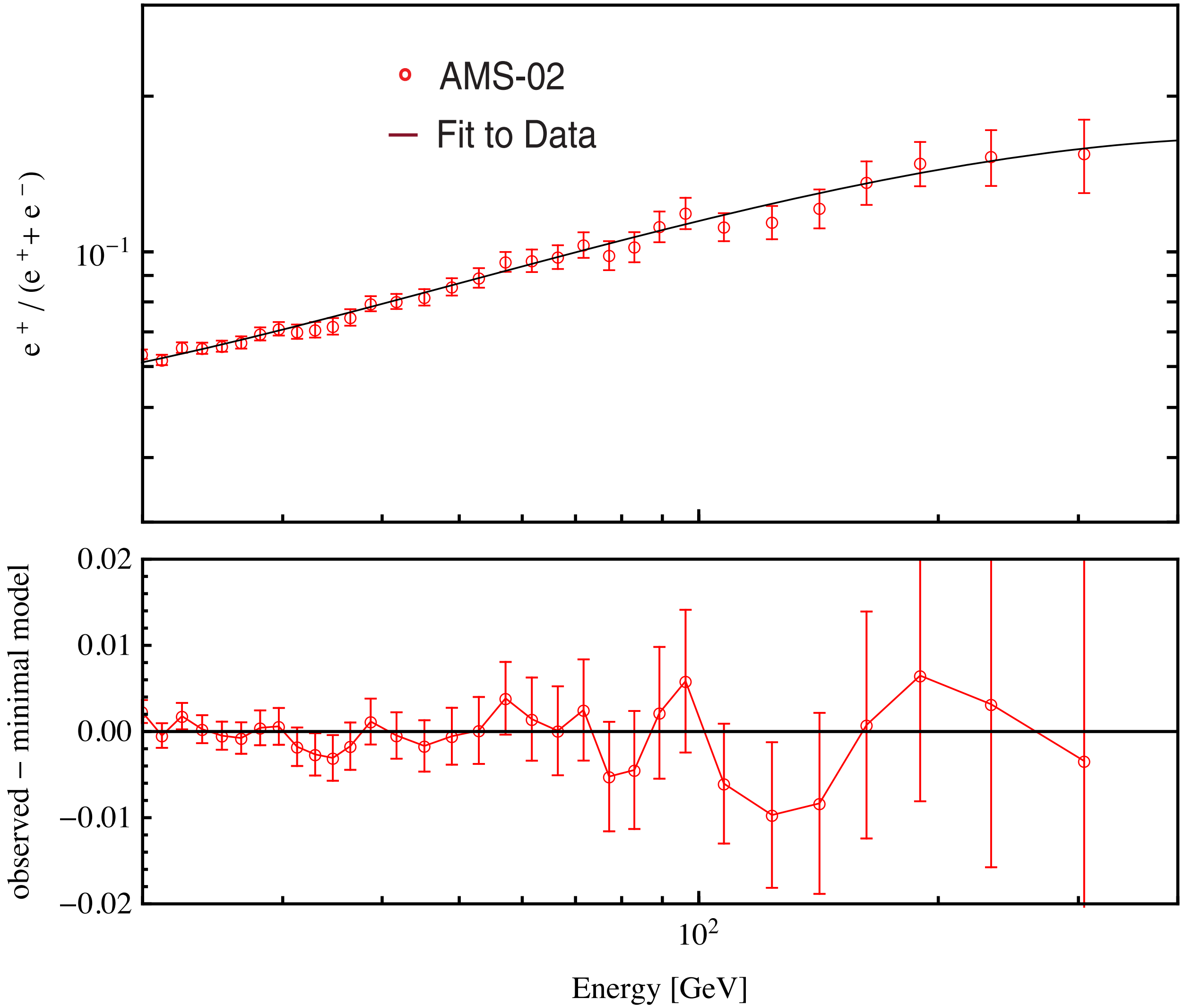

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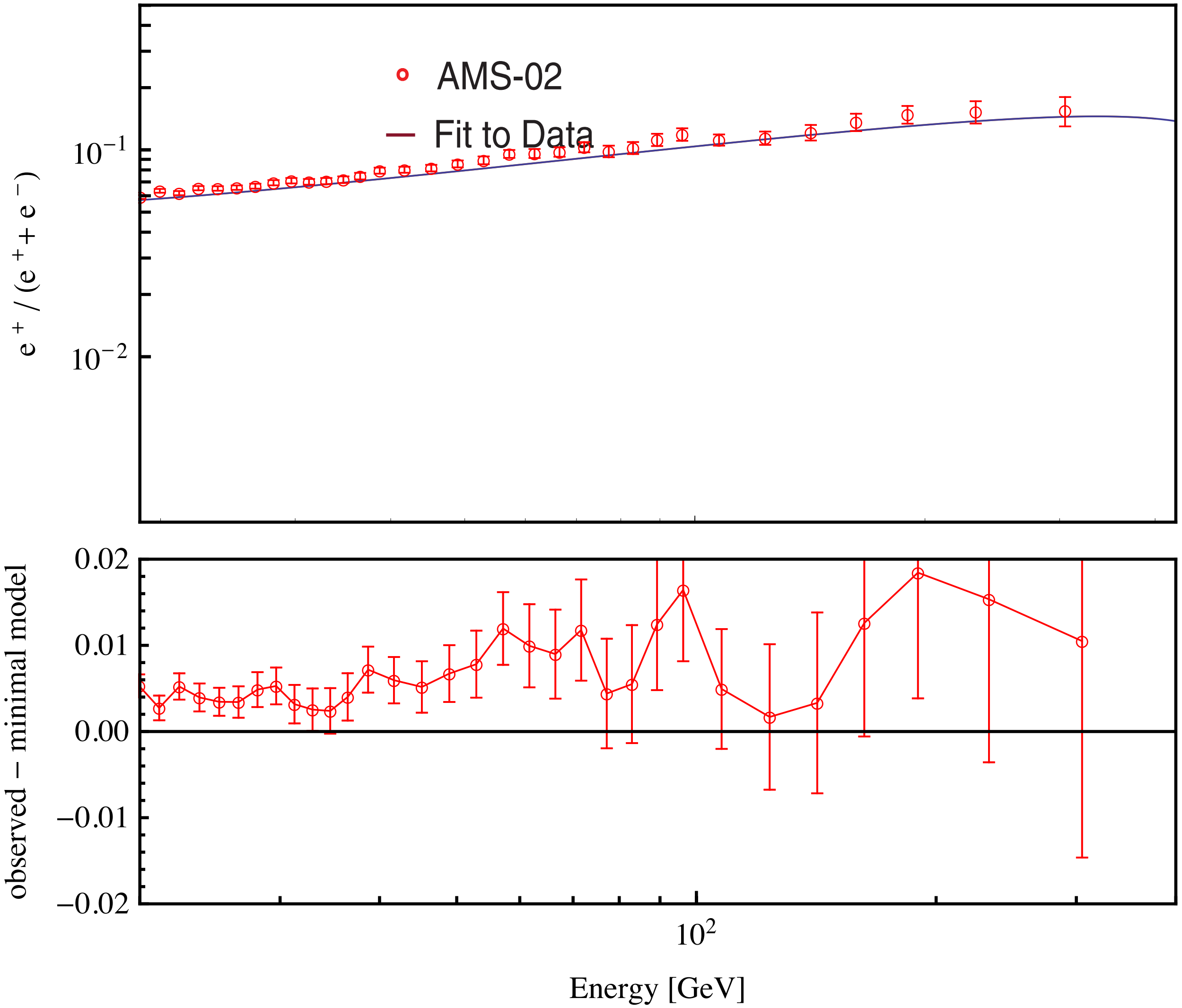

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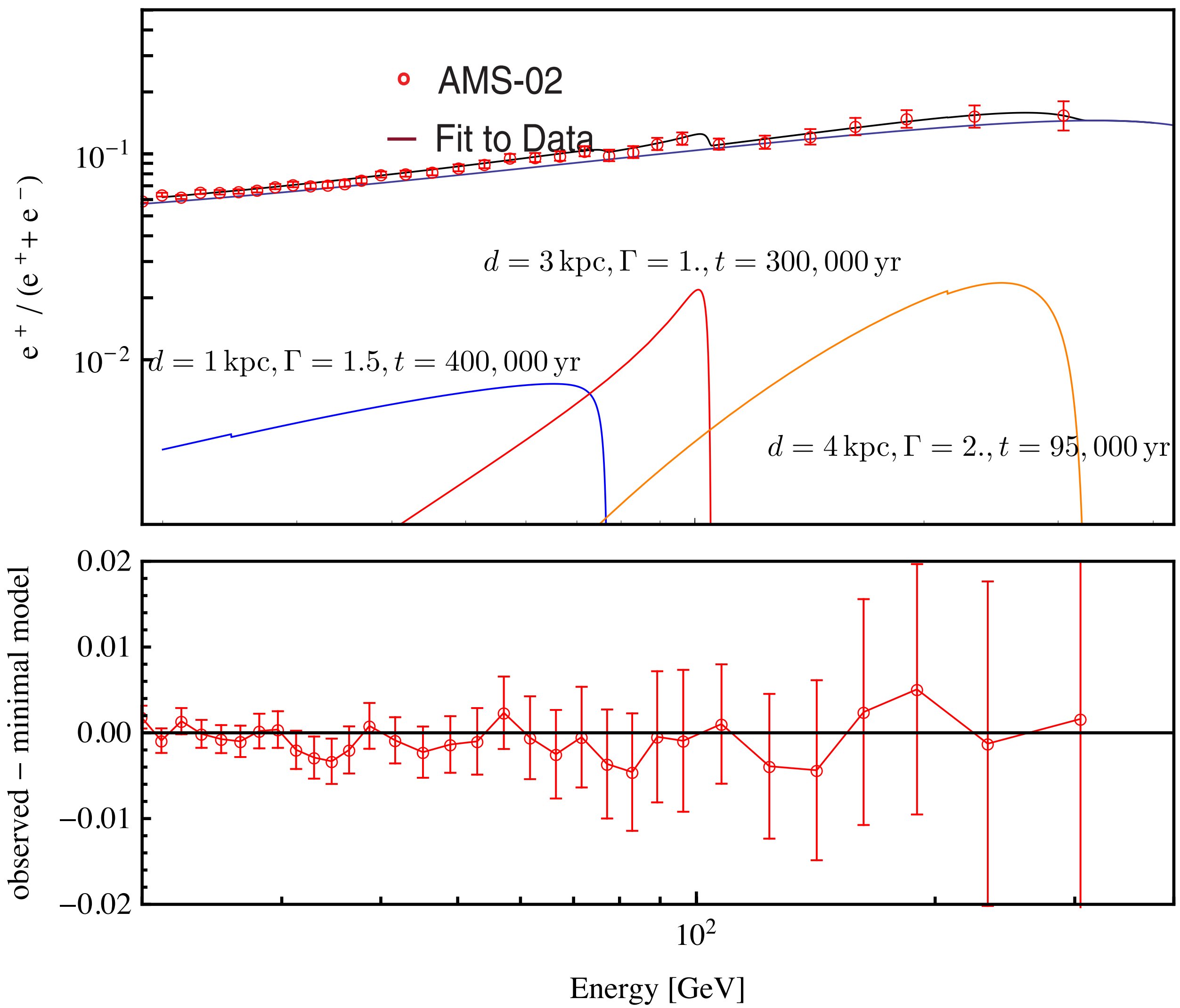

“It’s either dark matter or pulsars.”

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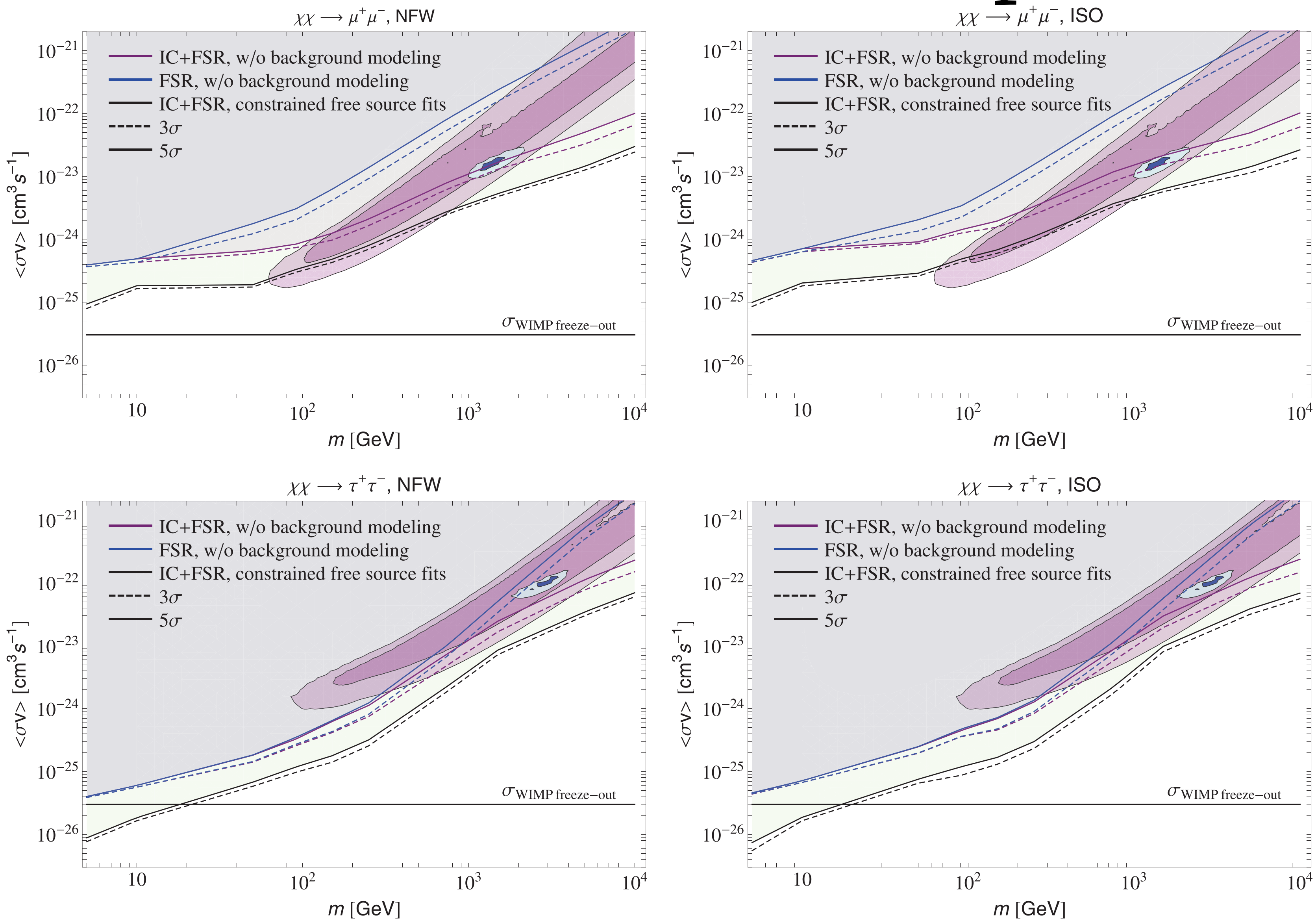
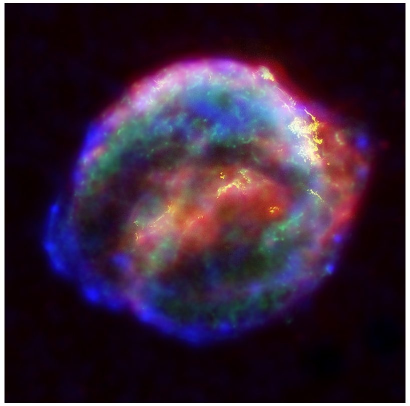


Ackermann *et al.*, ApJ **761** (2012) 91

Secondaries from the Source?

Common belief: secondaries from propagation dominate since the grammage in the ISM is larger than in the source



$$\langle \tau_{\mathrm{src}} \rangle \lesssim \tau_{\mathrm{SNR}} \approx 10^{4\ldots5}\,\mathrm{yr}$$

$$n_{\mathrm{src}} \lesssim 10\,\mathrm{cm}^{-3}$$

$$\Rightarrow \lambda_{\mathrm{src}} \approx 0.2\,\mathrm{g\,cm}^{-2}$$

$$\langle \tau_{\mathrm{ISM}} \rangle \sim \tau_{\mathrm{esc}} \approx 10^{7}\,\mathrm{yr}$$

$$n_{\mathrm{ISM}} \approx 0.1\,\mathrm{cm}^{-3}$$

$$\Rightarrow \lambda_{\mathrm{ISM}} \approx \mathrm{few\,g\,cm}^{-2}$$

However, the secondaries from the source can have a much harder spectrum!

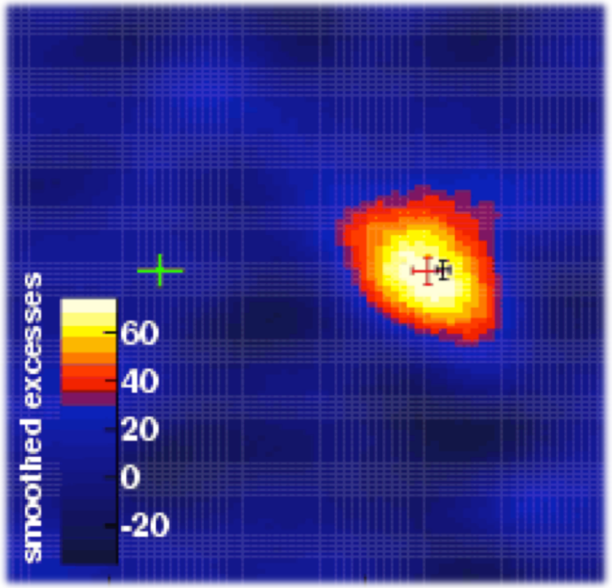
Secondary Origin of $e^{\pm}$

Rise in positron fraction could be due to secondary positrons produced during acceleration and accelerated along with primary electrons

Blasi, PRL **103** (2009) 051105

Assuming production of galactic CR in SNRs, positron fraction can be fitted

This effect is guaranteed, only its size depends on normalisation and one free parameter that needs to be fitted from observations



Cas A in γ-rays from MAGIC

DSA – Test Particle Approximation

Acceleration determined by compression ratio:

$$r = \frac{u_1}{u_2} = \frac{n_2}{n_1}, \qquad \gamma = \frac{3r}{r-1}$$

Solve transport equation,

$$u\frac{\partial f}{\partial x} = D\frac{\partial^2 f}{\partial x^2} + \frac{1}{3}\frac{\mathrm{d}u}{\mathrm{d}x}p\frac{\partial f}{\partial p}$$

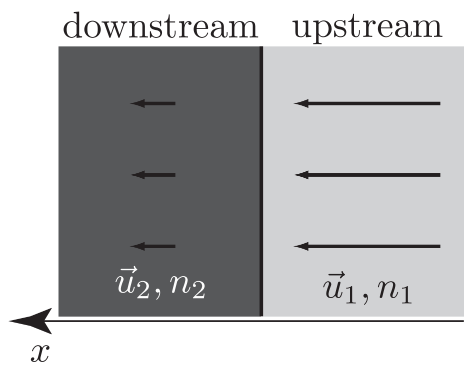
$$f \xrightarrow{x\to-\infty} f_{\mathrm{inj}}(p), \qquad \left|\lim_{x\to\infty} f\right| \ll \infty$$

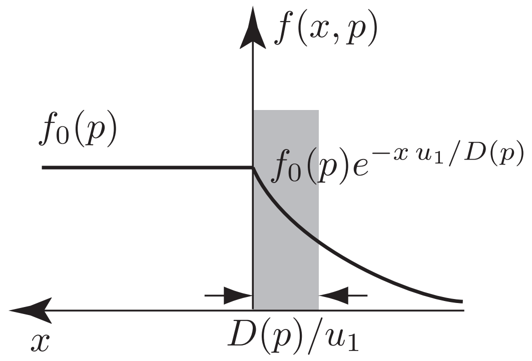
Solution for $x < 0$:

$$f = f_{\mathrm{inj}}(p) + (f^0(p) - f_{\mathrm{inj}}(p))e^{-x\,u_1/D(p)}$$

where

$$f^0(p) = \gamma\int_0^p \frac{\mathrm{d}p'}{p'}\left(\frac{p'}{p}\right)^\gamma f_{\mathrm{inj}}(p') + Cp^{-\gamma}$$





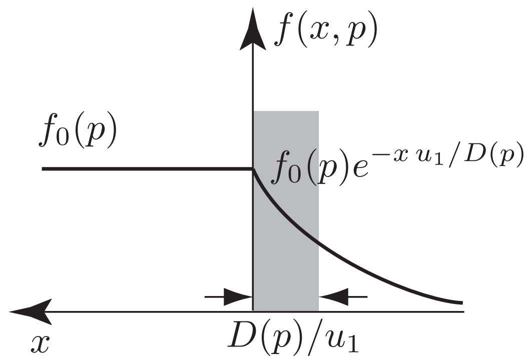
As long as $f_{\mathrm{inj}}(p)$ is softer than $p^{-\gamma}$, at high energies:

$$f(x,p) \sim p^{-\gamma}$$

DSA with Secondaries

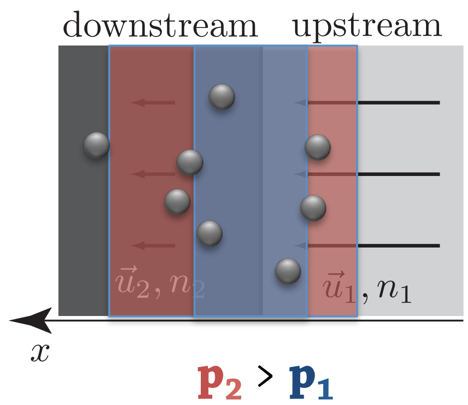
- Secondaries get produced with primary spectrum:

$$q_{e^\pm} \propto f_{\rm CR} \propto p^{-\gamma}$$



- Only particles with $|x| \lesssim D(p)/u$ can be accelerated

- Bohm diffusion: $D(p) \propto p$

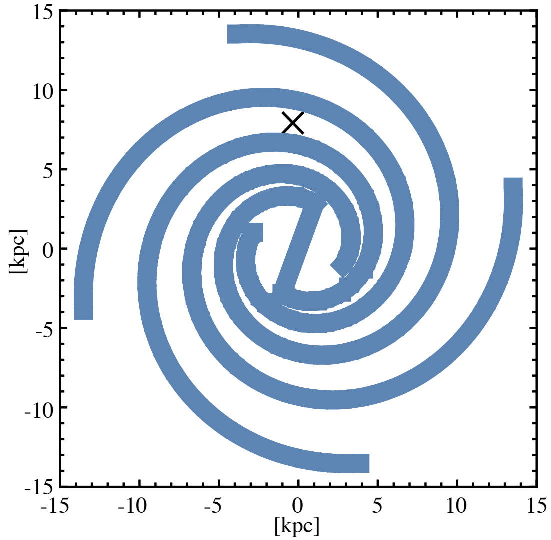


- Fraction of secondaries that go into acceleration $\propto p$

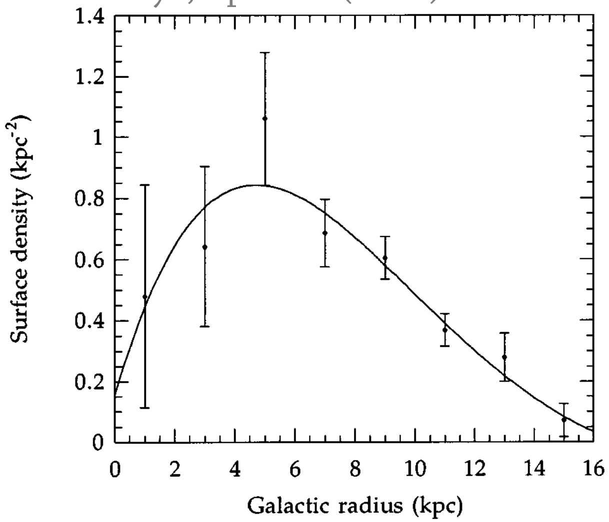
- Equilibrium spectrum

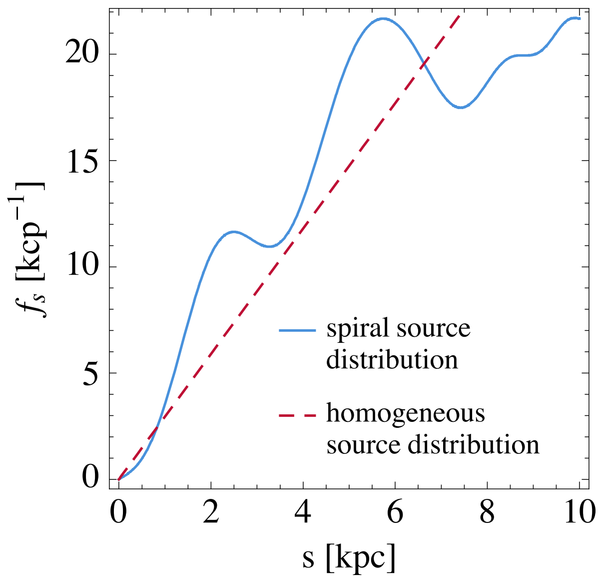
$$n_{e^\pm} \propto q_{e^\pm}\left(1 + \frac{p}{p_0}\right) \propto p^{-\gamma} + p^{-\gamma+1}$$

Statistical Distribution of Sources



Case, Bhattacharya, ApJ 504 (1998) 761



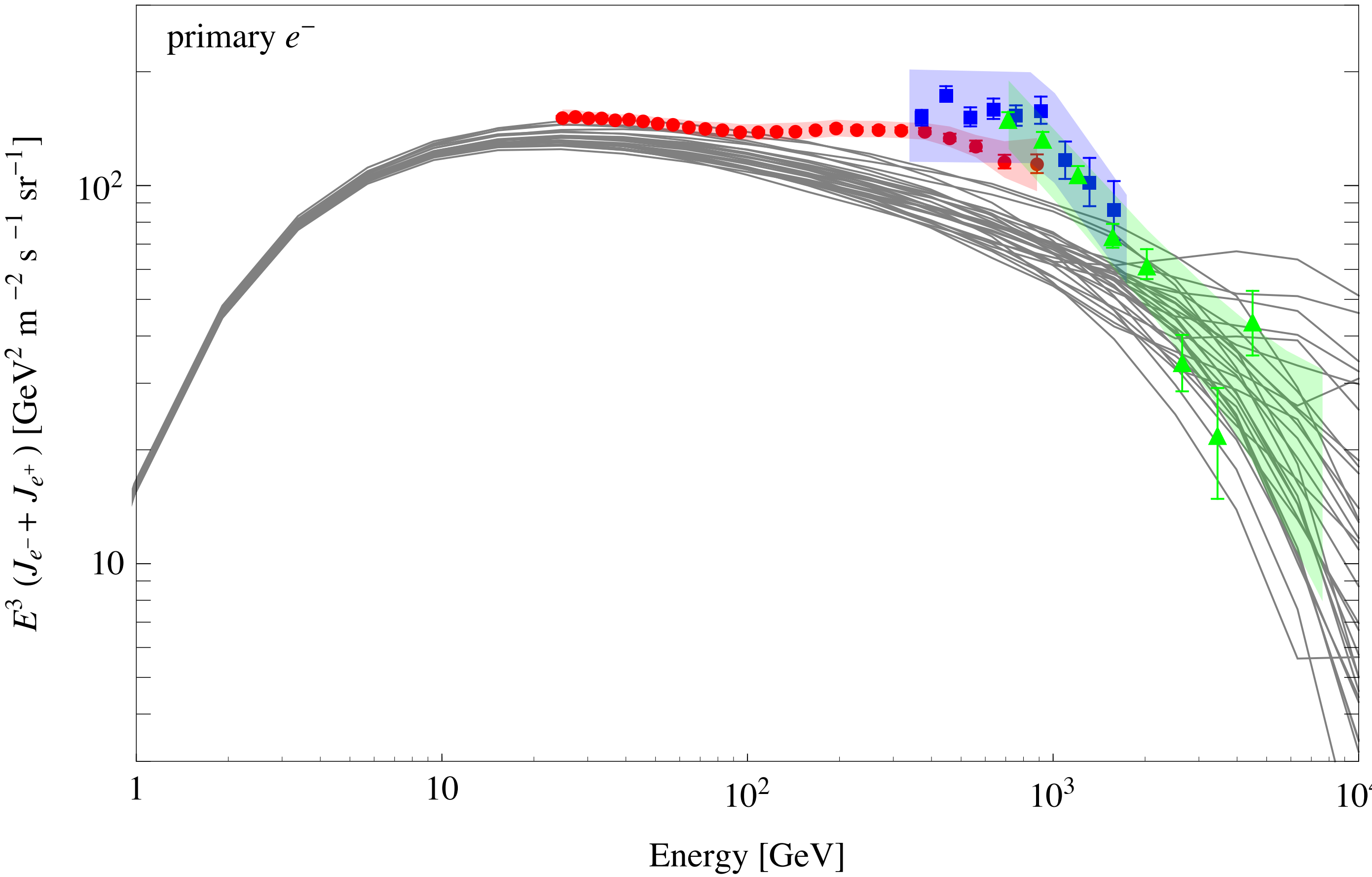


probability density for distances, $f_s(s)$

probability density for ages, $f_t(t) = \mathrm{const.}$

Ahlers, Mertsch, Sarkar, PRD **80** (2009) 123017

The Total $(e^+ + e^-)$ Flux



Ahlers, Mertsch, Sarkar, PRD **80** (2009) 123017
Mertsch & Sarkar, *in preparation*

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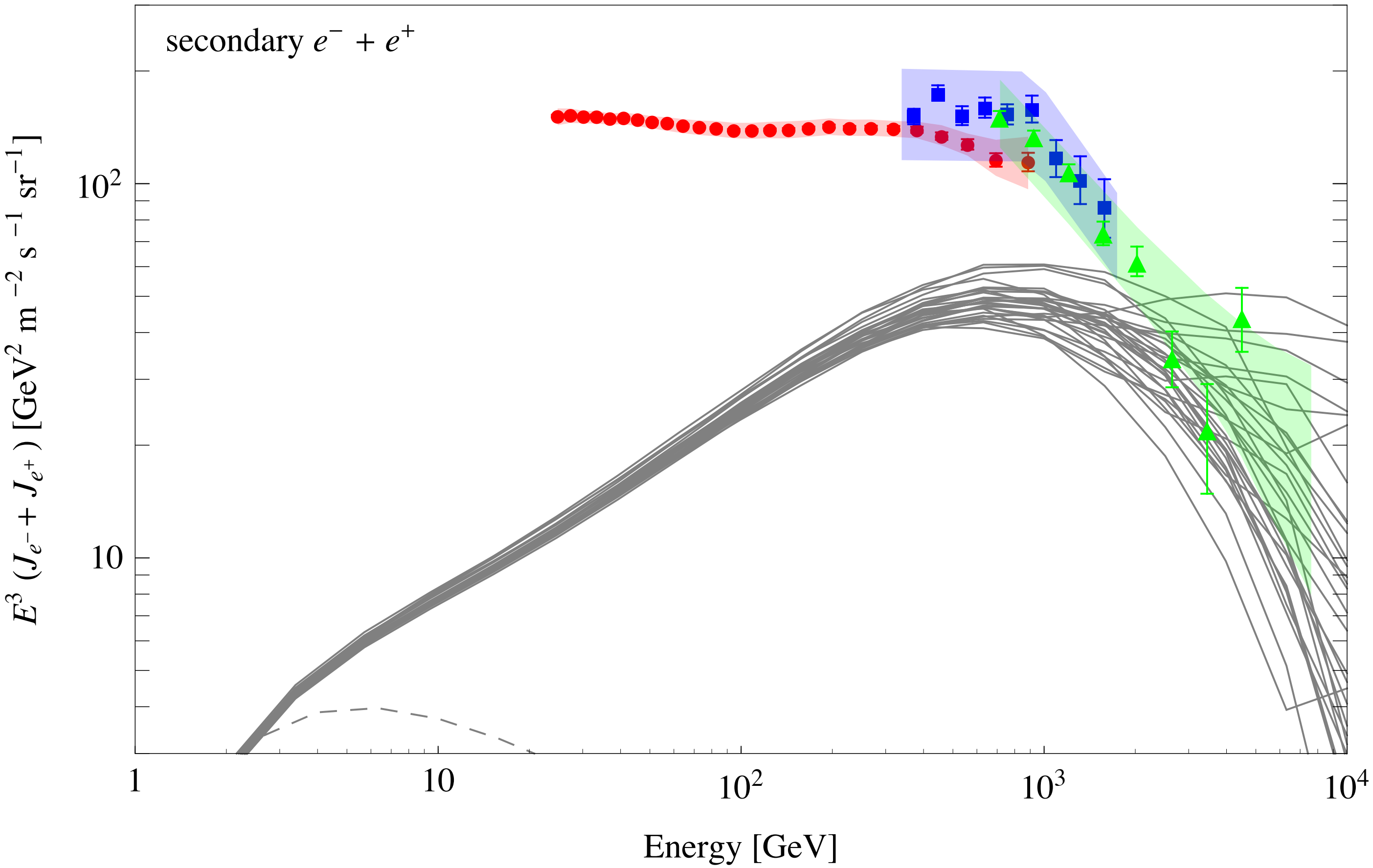

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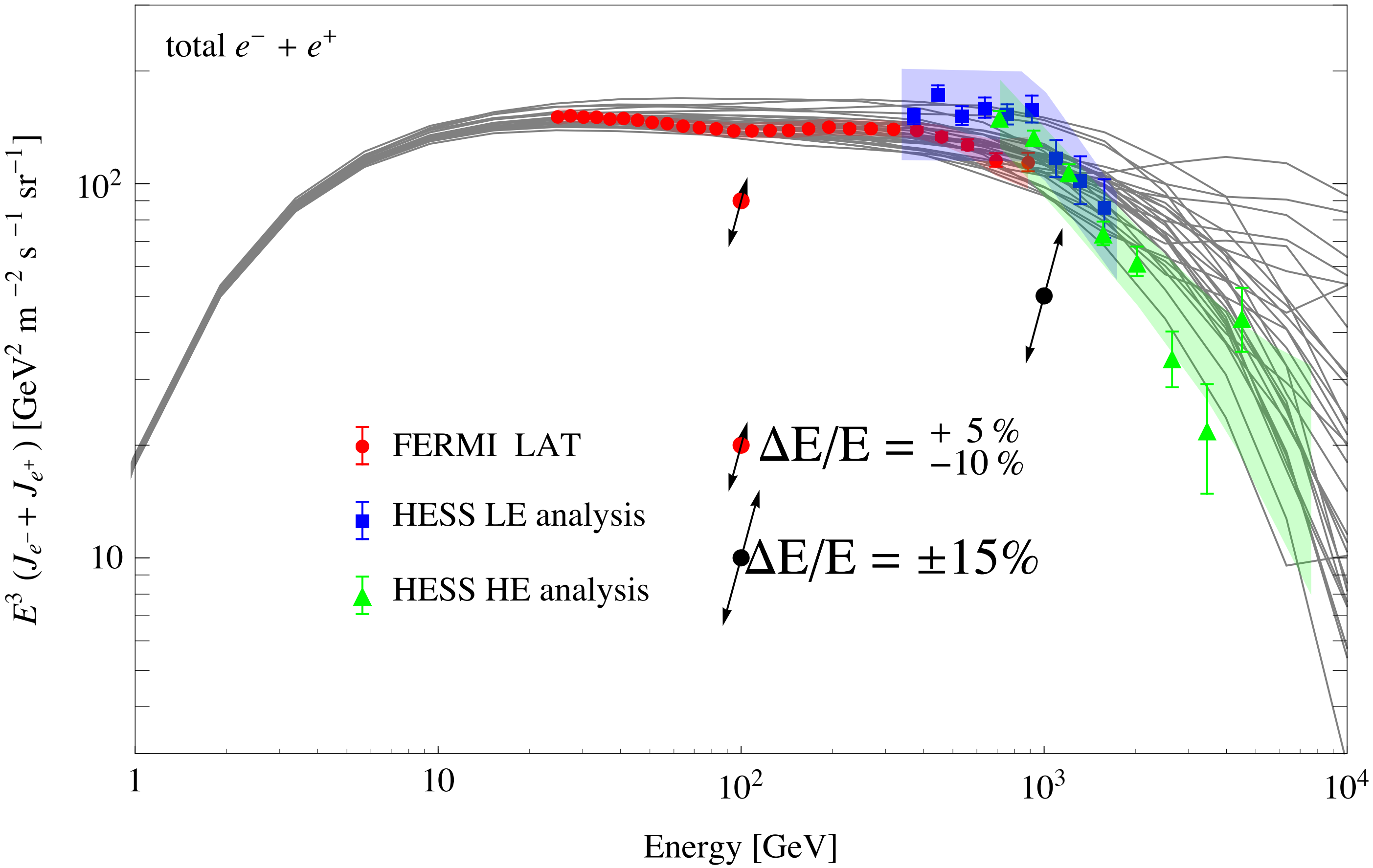

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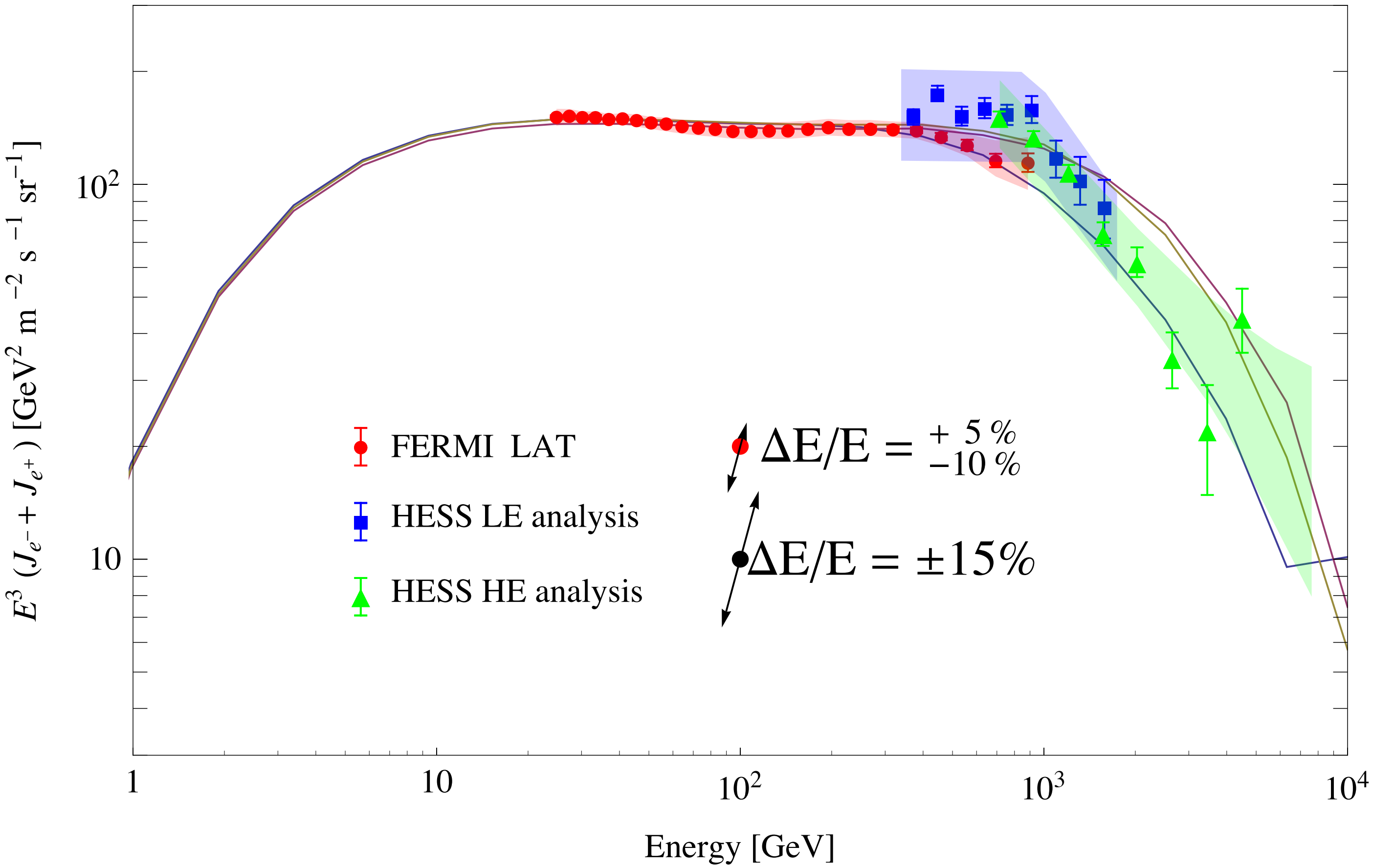
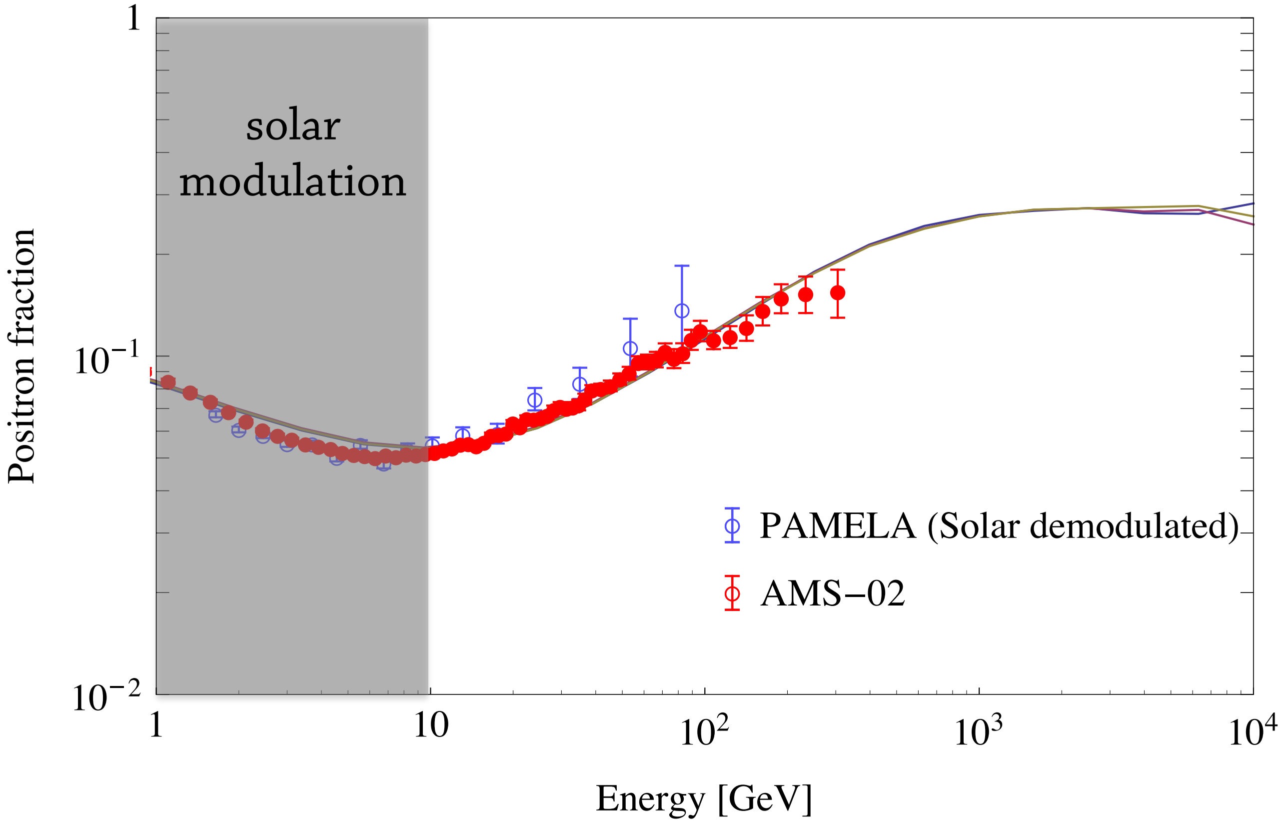


Ahlers, Mertsch, Sarkar, PRD **80** (2009) 123017
Mertsch & Sarkar, *in preparation*

The Positron Fraction

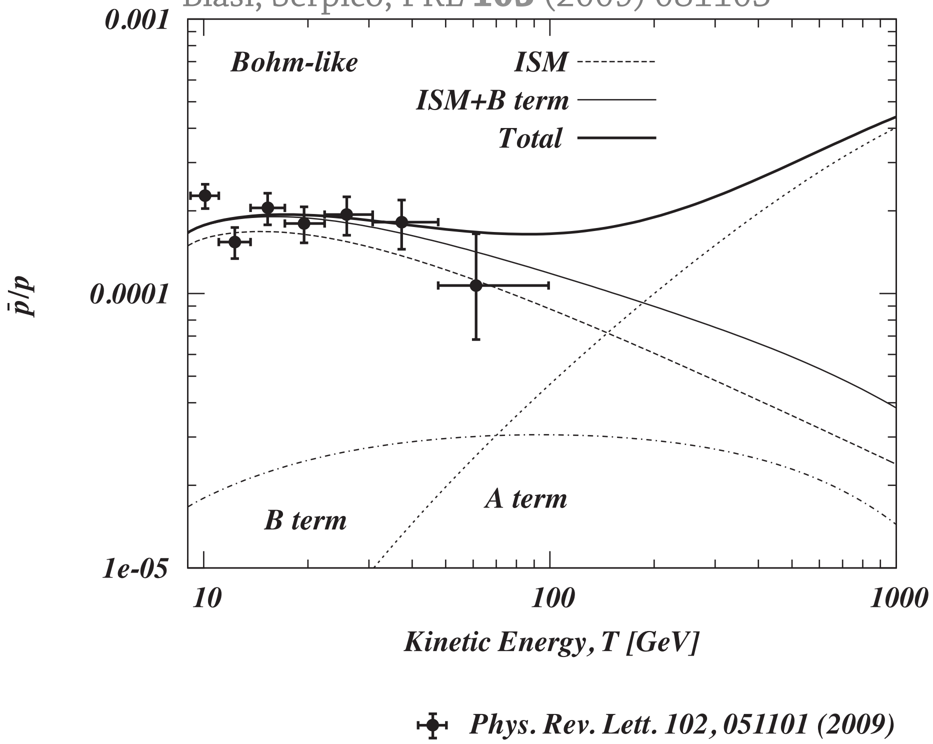


Ahlers, Mertsch, Sarkar, PRD **80** (2009) 123017
Mertsch & Sarkar, *in preparation*

Antiproton-to-proton Ratio

rise in...	$\bar{p}/p$
DM	(✓)
Pulsars	✗
Acceleration of Secondaries	✓

Blasi, Serpico, PRL **103** (2009) 081103



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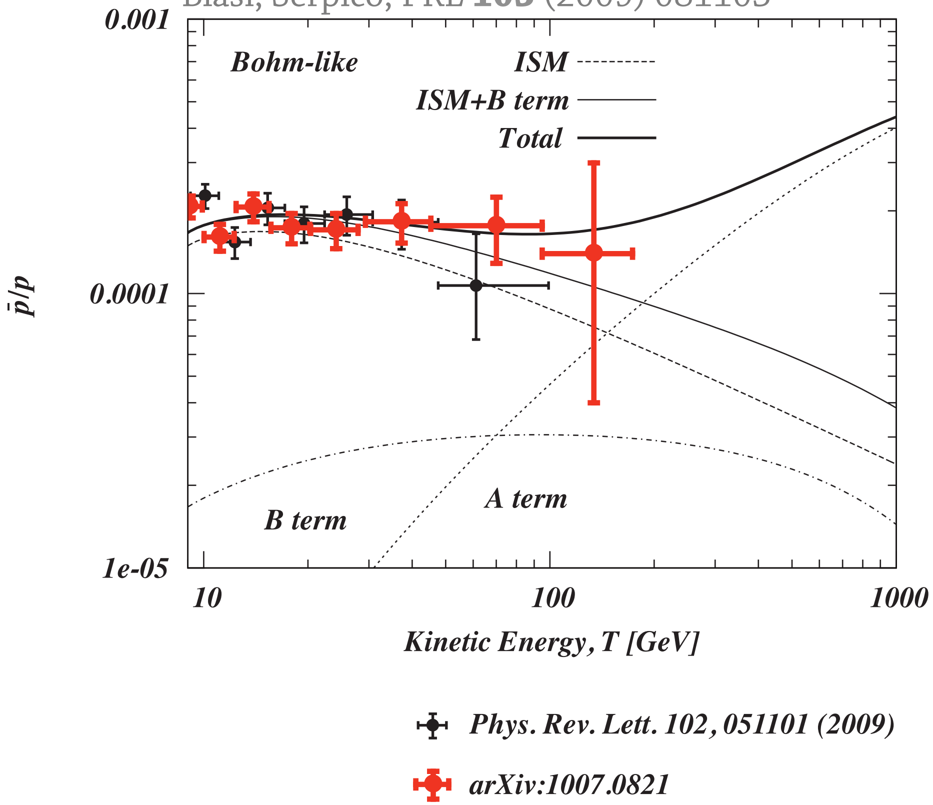
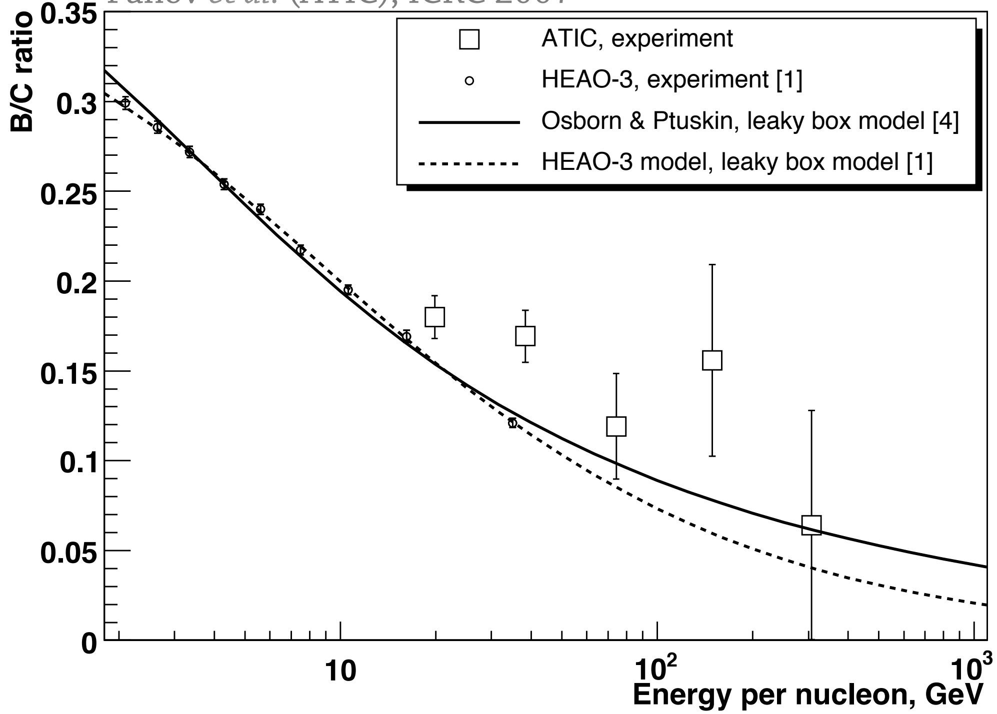


Nuclear Secondary-to-Primary Ratios

rise in...	nuclei
DM	✗
Pulsars	✗

Nuclear secondary-to-primary ratios used for testing and calibrating propagation models

Panov *et al.* (ATIC), ICRC 2007



DM and pulsars do not produce nuclei!

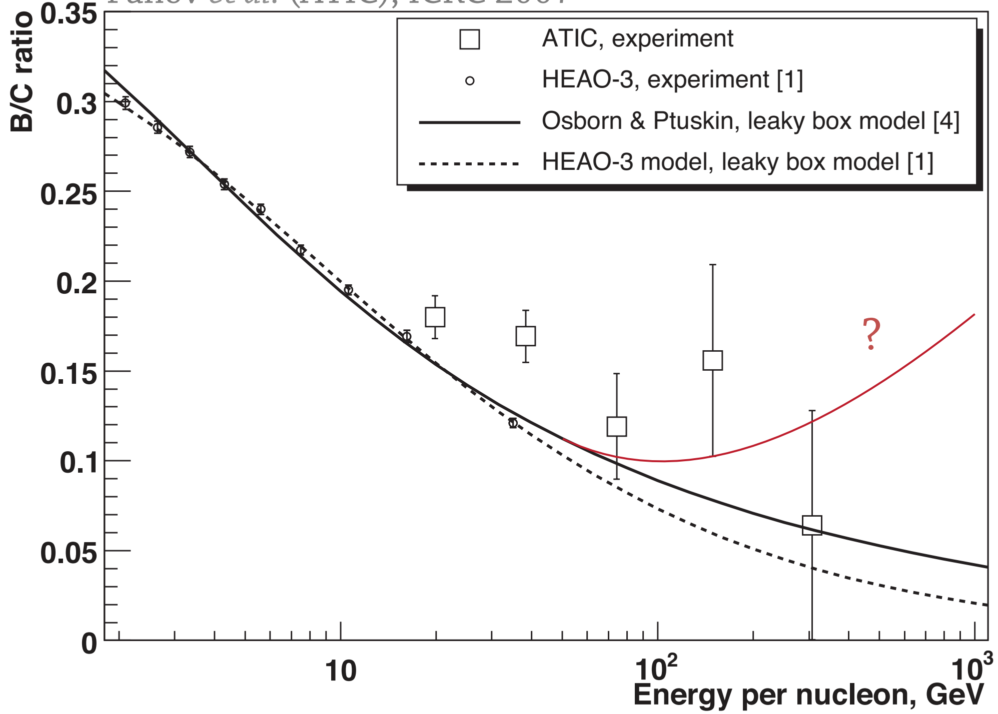
Nuclear Secondary-to-Primary Ratios

rise in...	nuclei
DM	✗
Pulsars	✗
Acceleration of Secondaries	✓

This would be a clear indication for acceleration of secondaries!

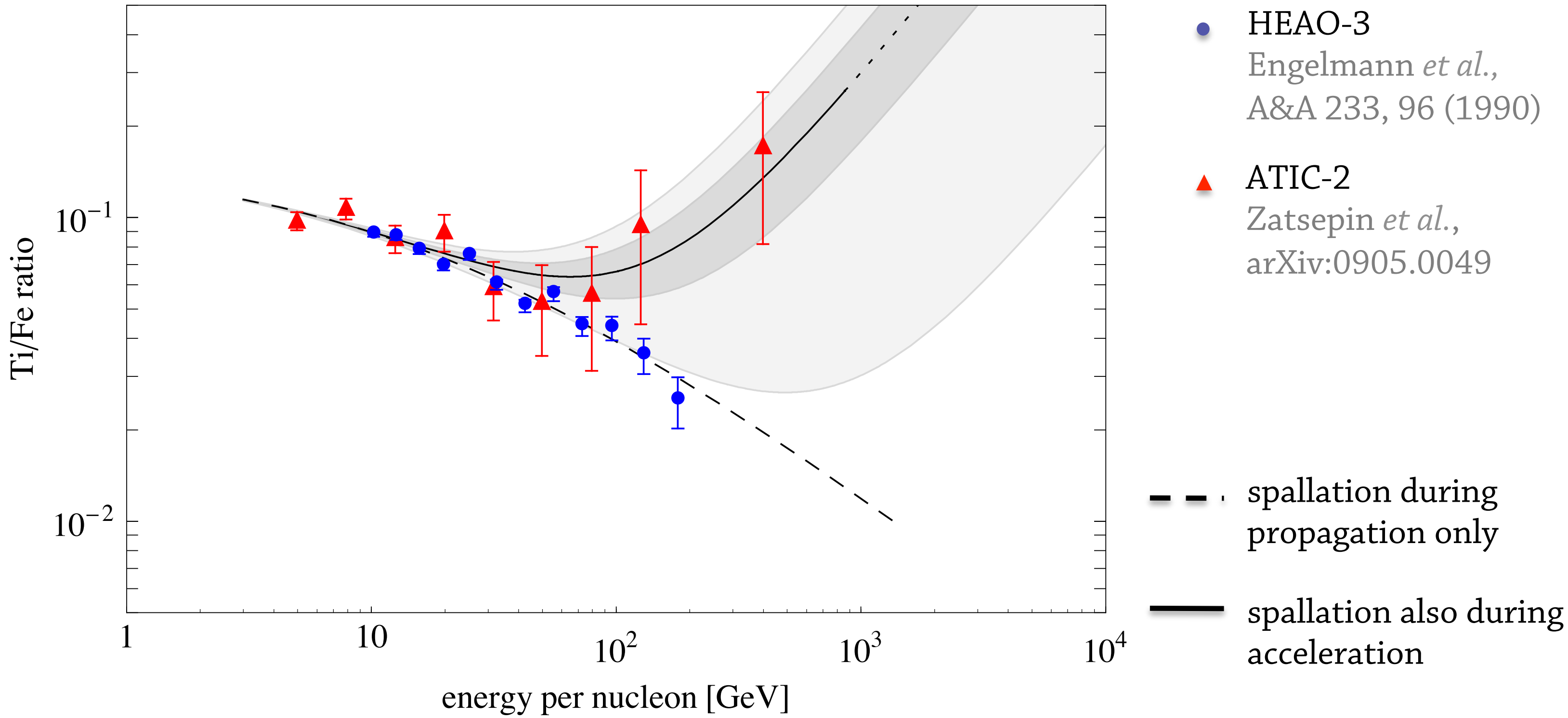
If nuclei are accelerated in the same sources as electrons and positrons, nuclear ratios *must* rise eventually

Panov *et al.* (ATIC), ICRC 2007



Titanium-to-Iron Ratio

PM and Sarkar, PRL **103** (2009) 081104

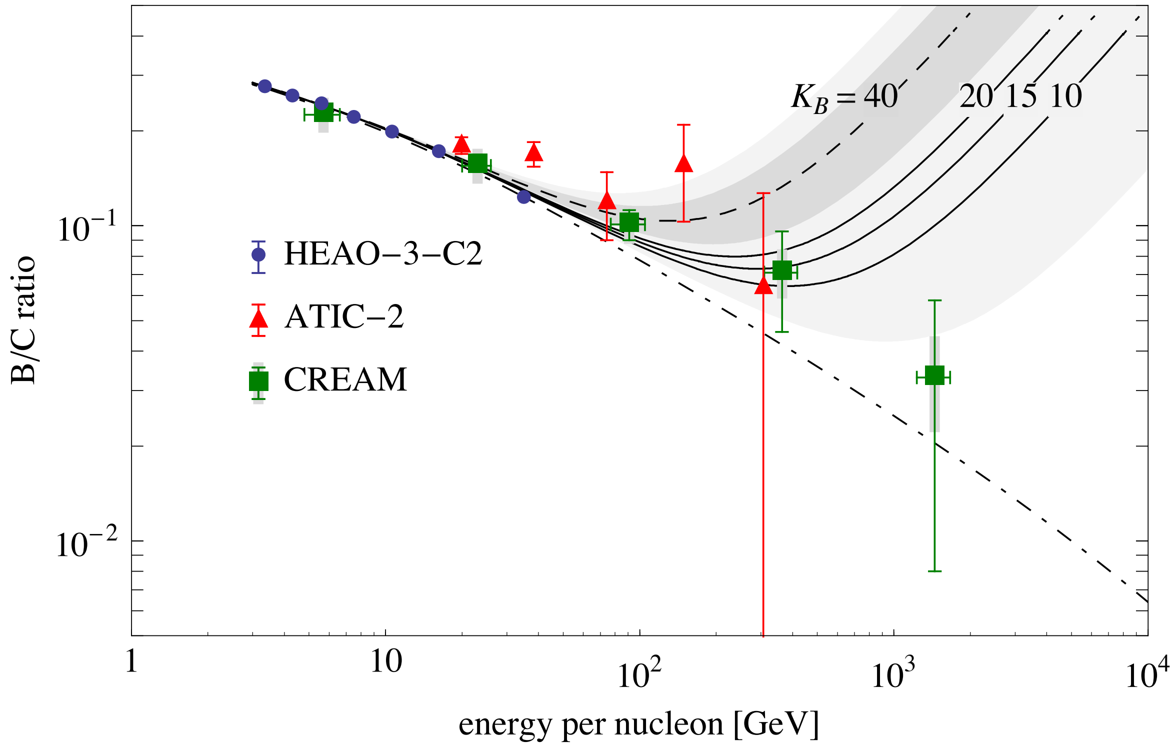


Titanium-to-iron ratio used as calibration point for diffusion coefficient:

$$K_{\rm B} \simeq 40$$

Boron-to-Carbon Ratio

PM and Sarkar, PRL **103** (2009) 081104; Ahlers *et al.*, PRD **80** (2009) 123017



HEAO-3
Engelmann *et al.*, A&A 233, 96 (1990)

ATIC-2
Panov *et al.*, ICRC 2007

CREAM
Ahn *et al.*, Astropart. Phys. 30, 133 (2008).

spallation during propagation only

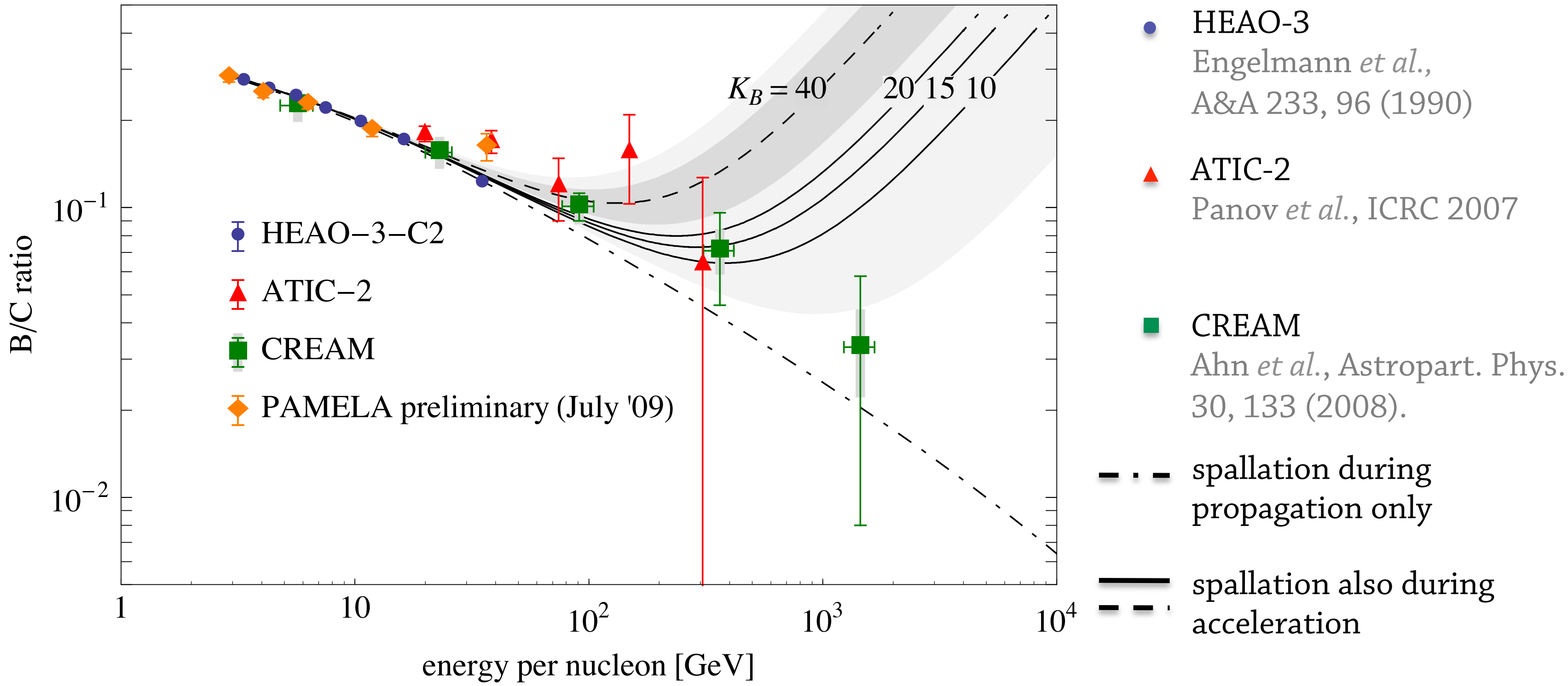
spallation also during acceleration

PAMELA is currently measuring B/C with unprecedented accuracy

A rise would rule out the DM and pulsar explanation of the PAMELA e^+/e^- excess.

Boron-to-Carbon Ratio

PM and Sarkar, PRL **103** (2009) 081104; Ahlers *et al.*, PRD **80** (2009) 123017



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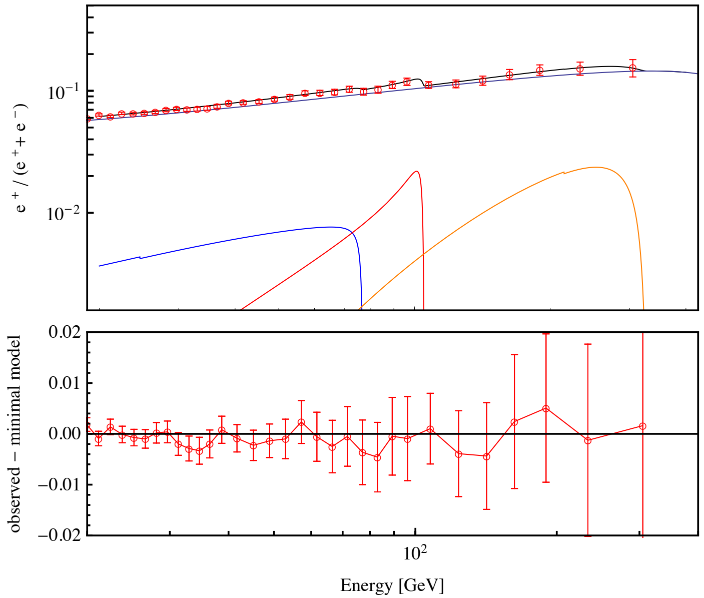
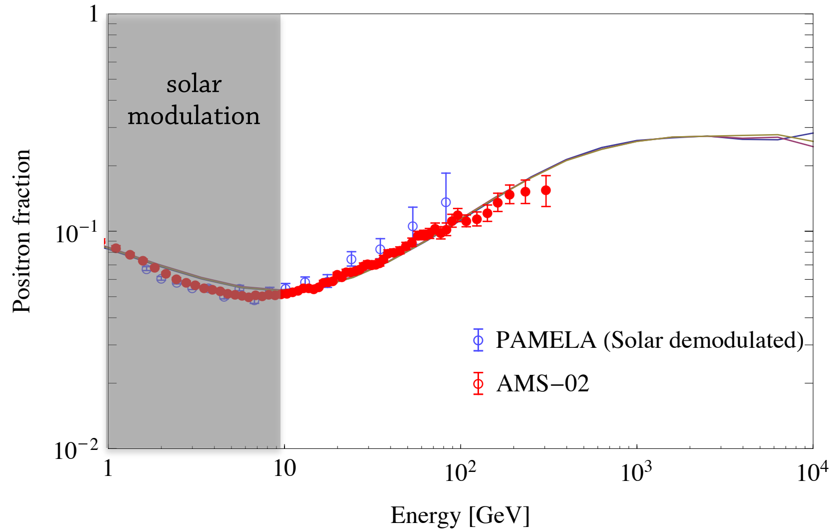
Conclusions





Positron fraction is a bad place to look for DM:

astrophysical sources are always (more) flexible

There are attractive and very testable astrophysical explanations,

e.g. secondary positrons from supernova remnants