Stefano Profumo

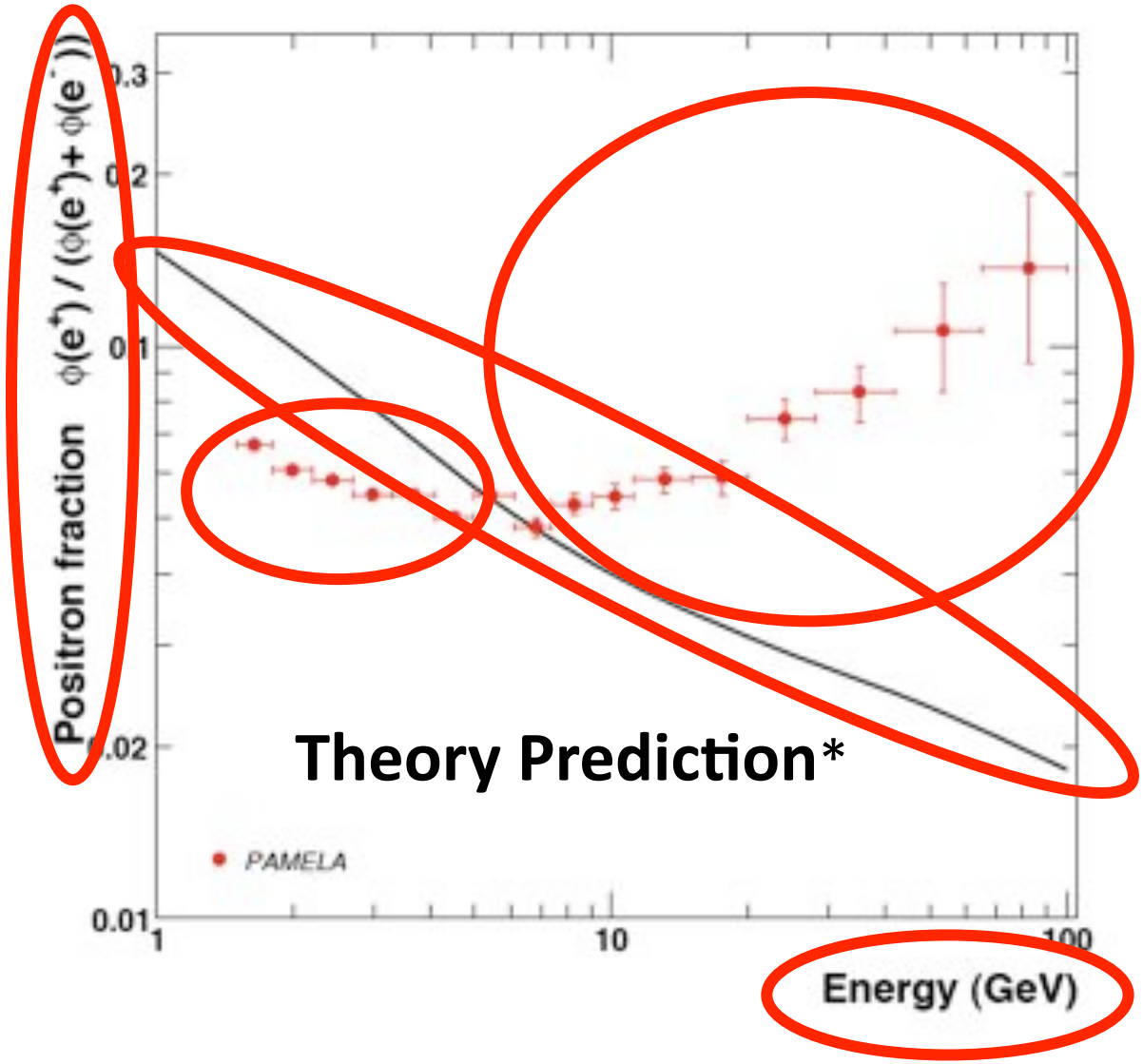
University of California, Santa Cruz

Santa Cruz Institute for Particle Physics

Cosmic Rays and Fermi

Fermi Symposium

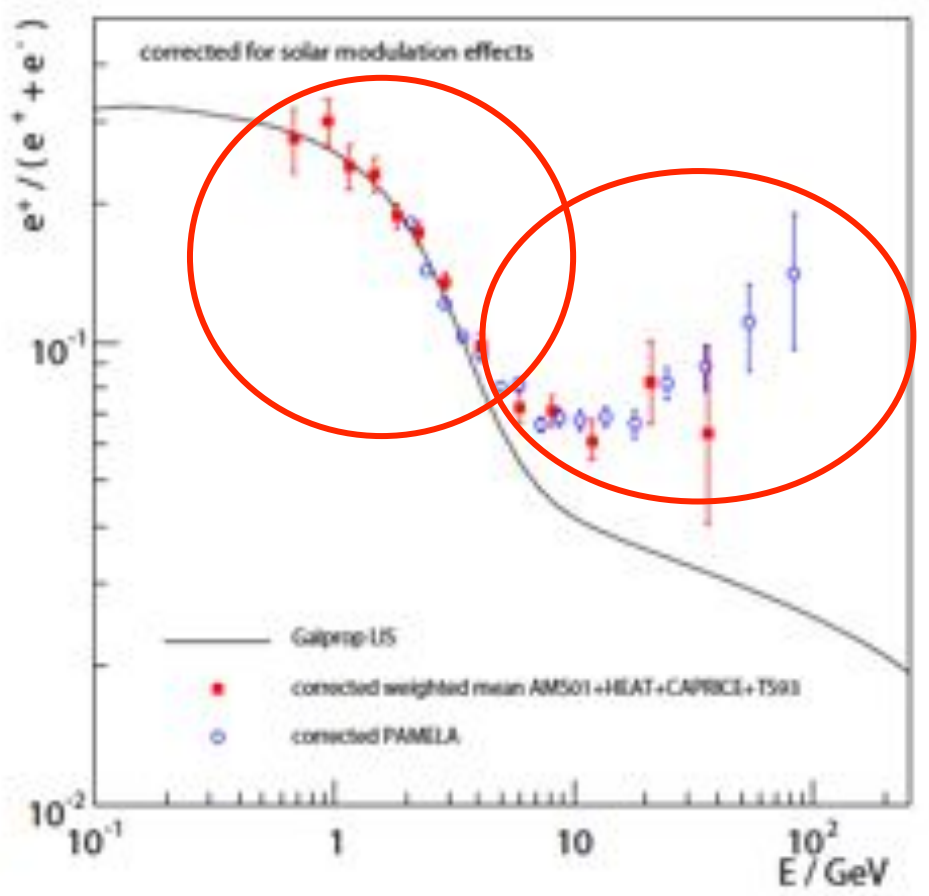
Tuesday October 30, 2012, Monterey, CA



Adriani et al, Nature 458 (2009) 607, arXiv 0810.4995

*I.V. Moskalenko and A.W. Strong Astrophys. J. 493, 694-707 (1998).

Low-Energy: correct for (charge-dependent) **solar modulation**



22 years full cycle (max every 11 years, with **polarity reversal**)
previous data: solar polarity favored positively charged particles, opposite for PAMELA

Gast & Schael, ICRC Conference, Lodz, 2009

Cosmic Ray **Secondary-to-Primary** ratio

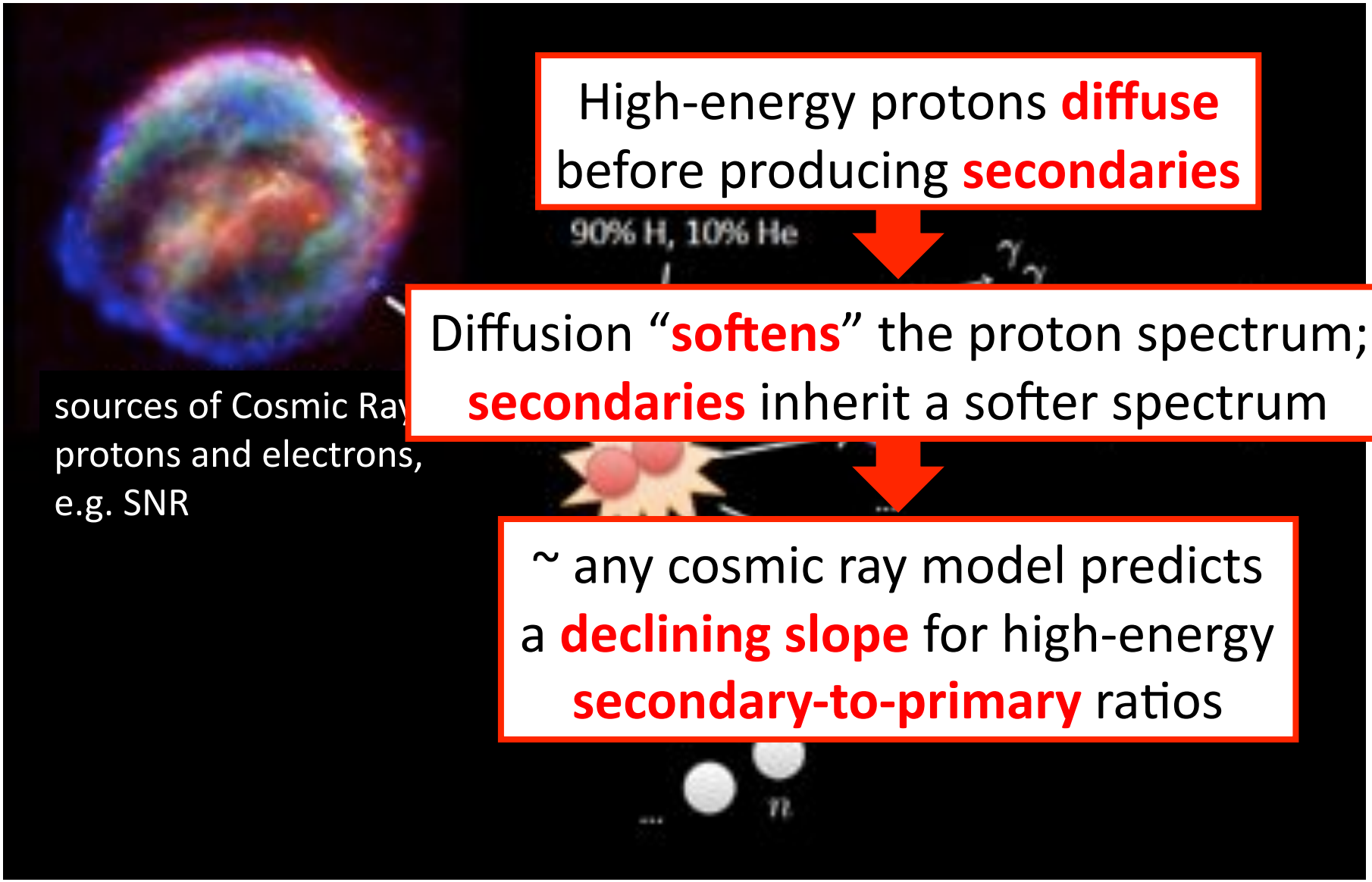
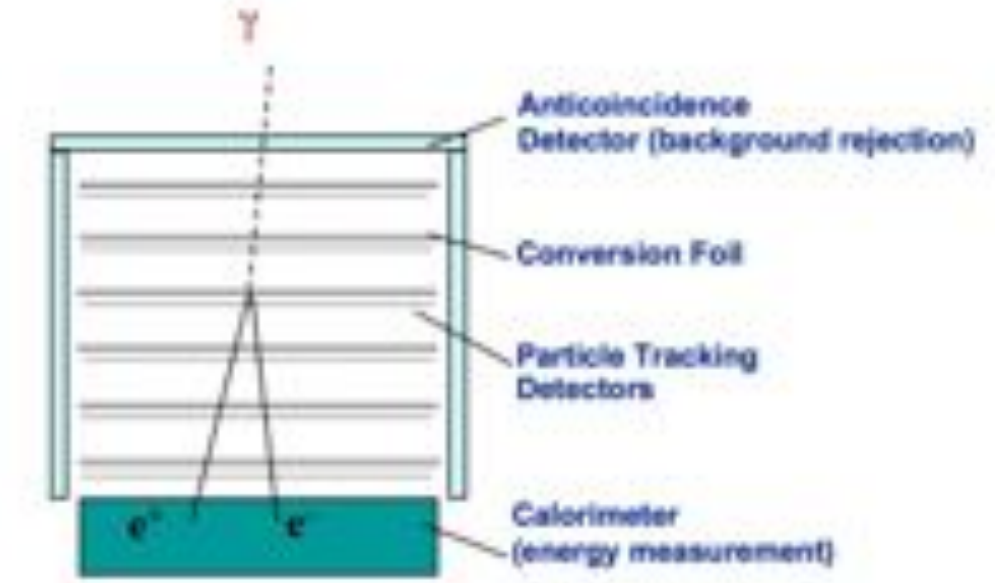


image credit: Philip Mertsch

First contribution from **Fermi-LAT**:
measure the "denominator" (**e+e-** flux)!

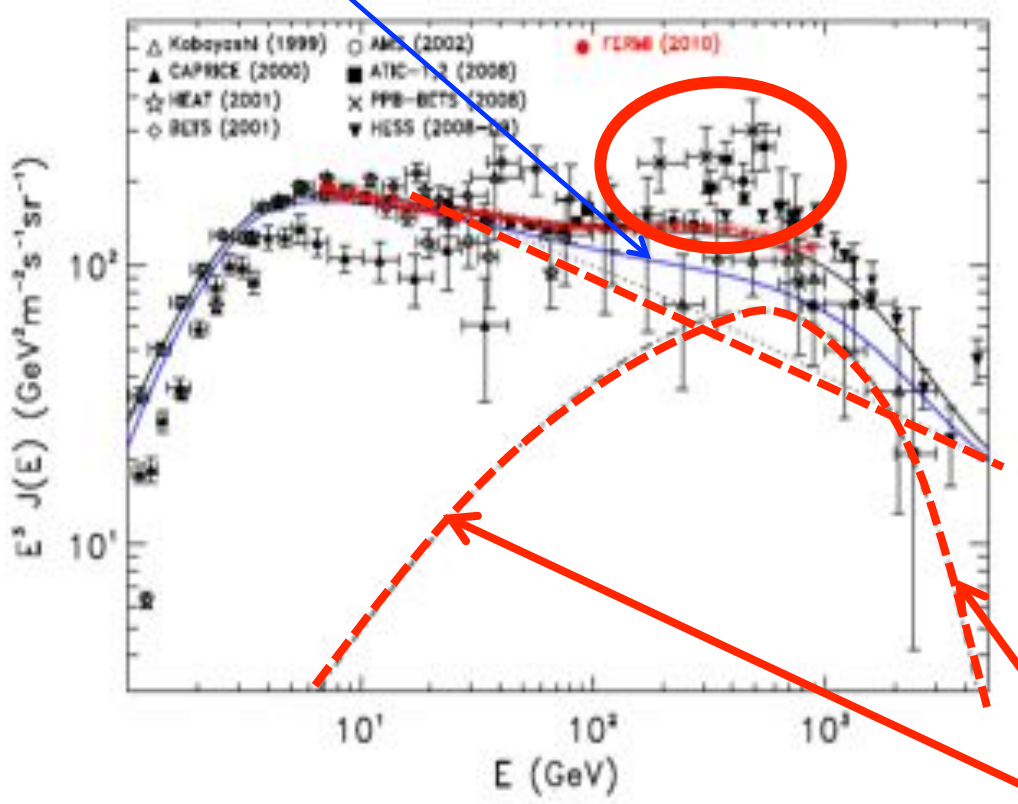


Fermi-LAT Collaboration, Phys.Rev.Lett. 102 (2009) 181101

First contribution from **Fermi-LAT**:
measure the denominator (**e+e-** flux)!

Kudos to the (pre-PAMELA)
perseverance of **Alex Moiseev**!

Electron plus Positron spectrum from Fermi-LAT



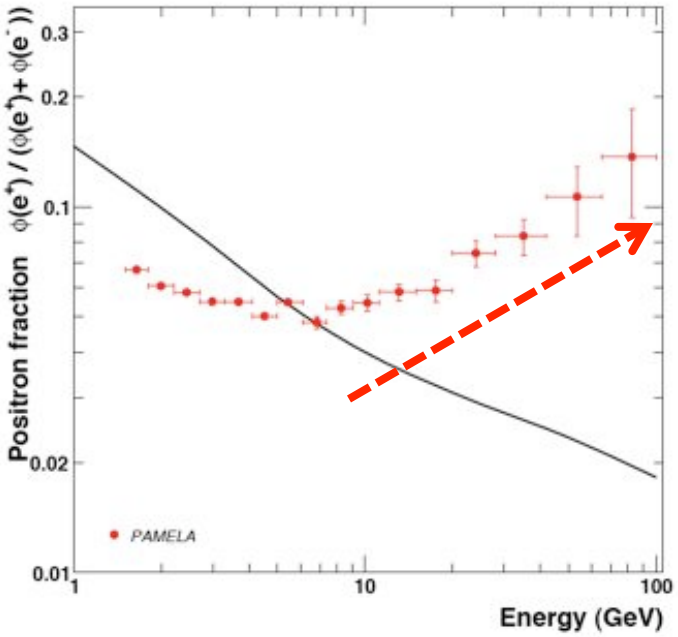
Galactic Cosmic Ray **acceleration** should produce a **power-law** e+e- injection spectrum

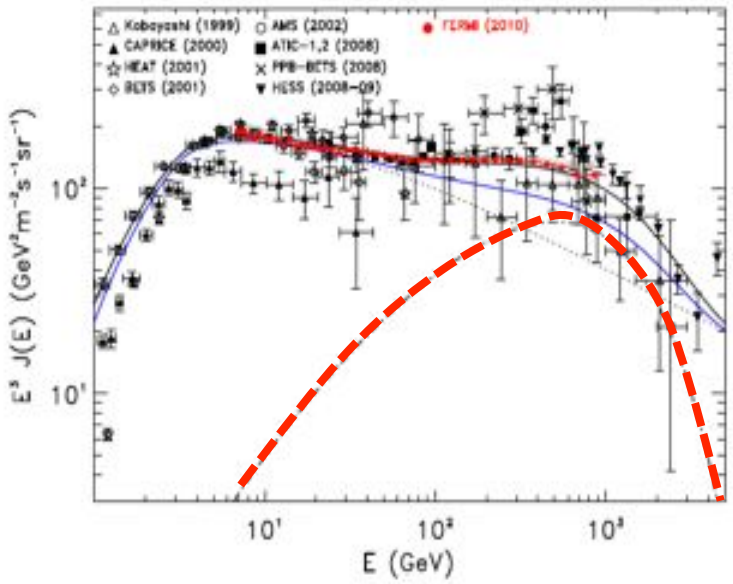
No **ATIC** excess!

Fermi data **compatible** with **additional** high-energy source

Fermi-LAT Collaboration, Phys.Rev.Lett. 102 (2009) 181101 (**topcite 600+**)

Solution: postulate **additional source**
of (high-energy) electrons and positrons:





What is the nature of this
new powerful electron-positron **source**??

Exciting!

It could be New Physics:

Dark Matter Annihilation!

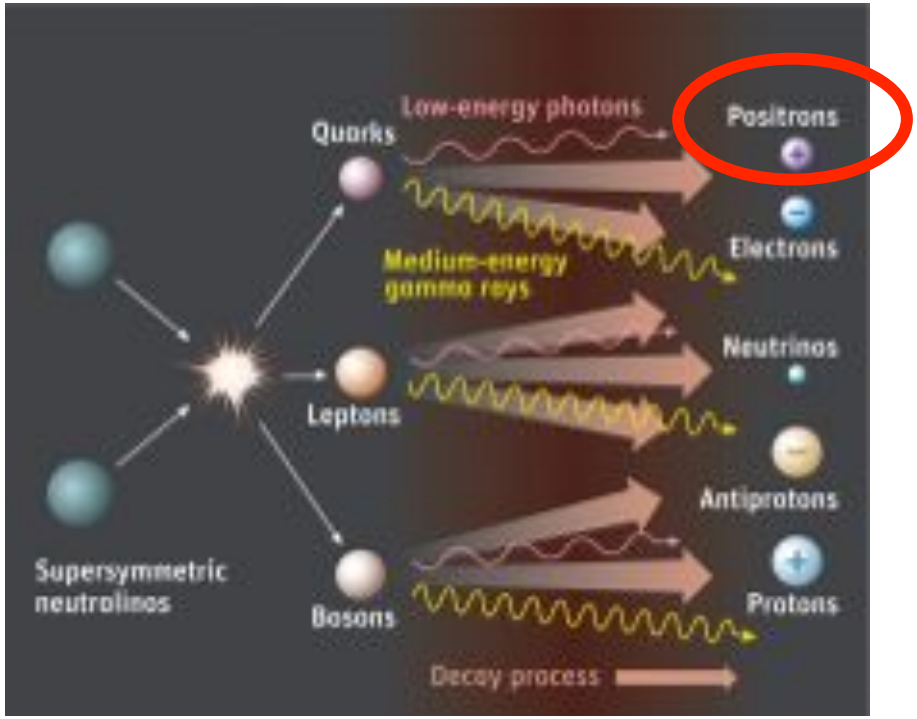


Image Credit: NASA/GLAST collaboration

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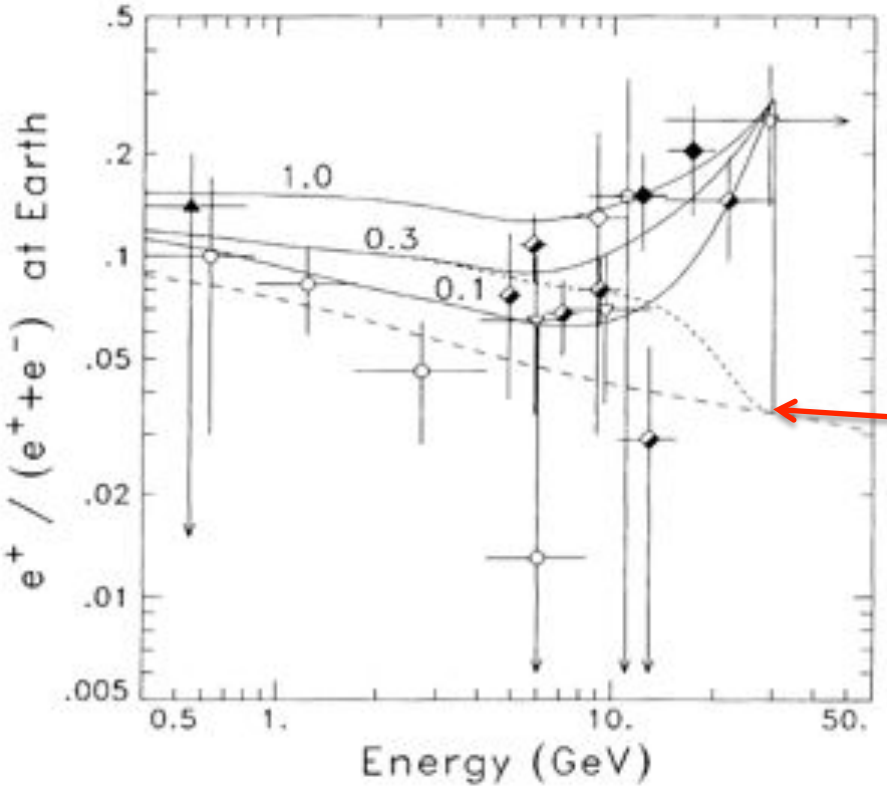


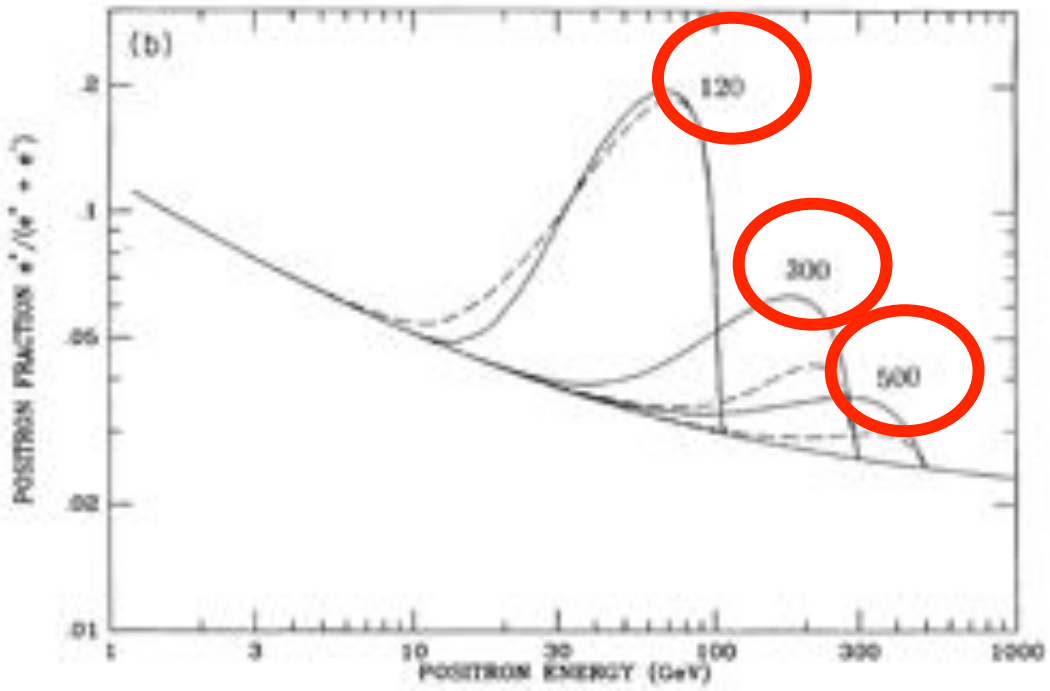
Dark Matter particle **mass**

A. Tylka, Phys. Rev. Lett. 63, 840-843 (**1989**). [Erratum-ibid. 63, 1658 (1989)]

Exciting!

It could be New Physics:

Dark Matter Annihilation!



M. Kamionkowski and M. Turner, Phys. Rev. D 43, 1774-1780 (1991)

Exciting!

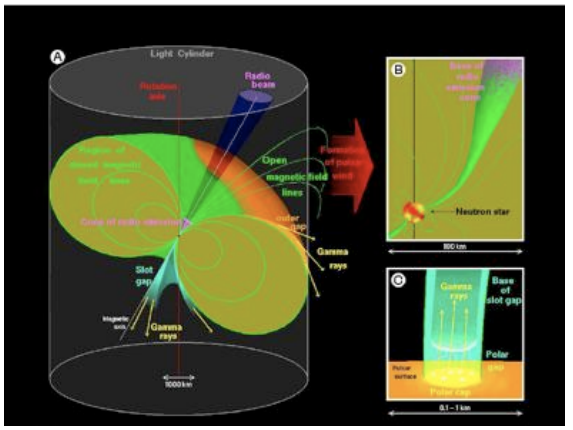
It could be New Physics:

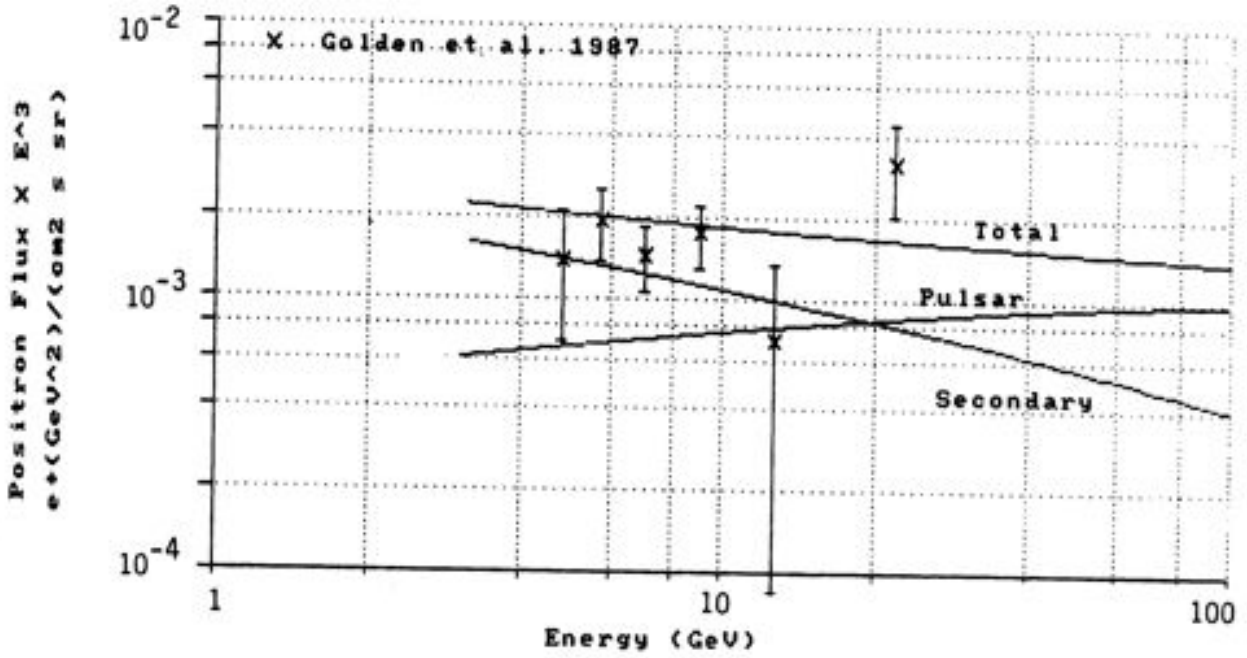
Dark Matter Annihilation!

…or it could **not**…

Pulsar Magnetosphere

Rotation-powered Neutron Stars produce e+e- pairs, injected in ISM when out of Pulsar Wind Nebula

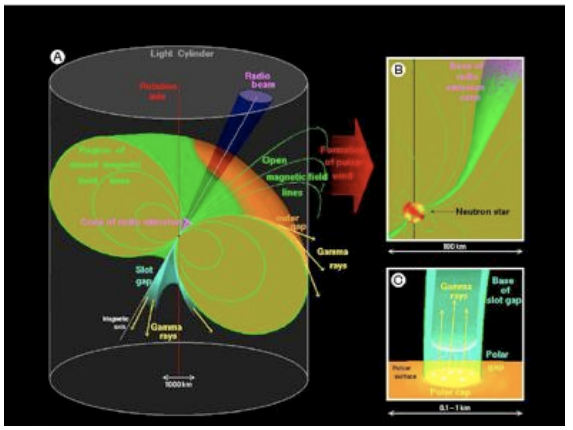


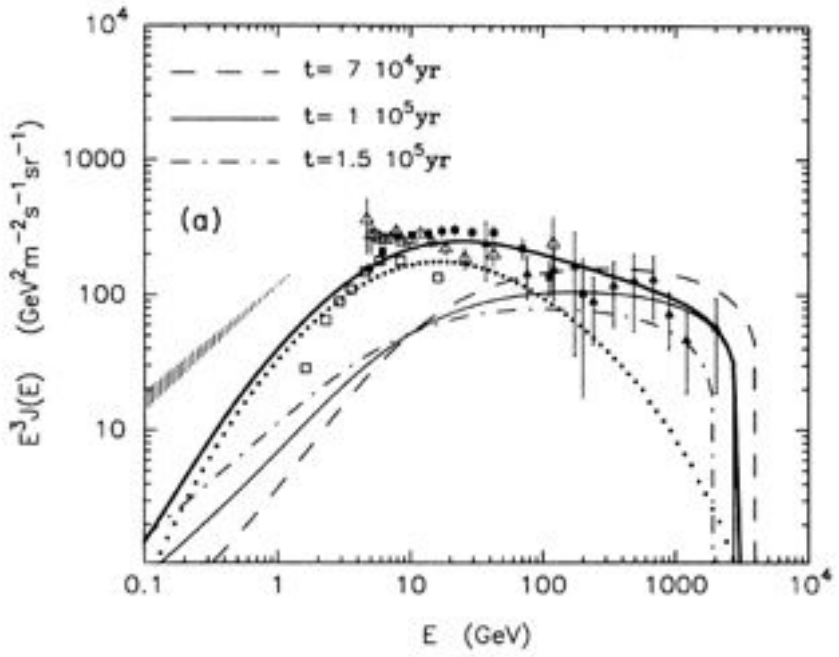


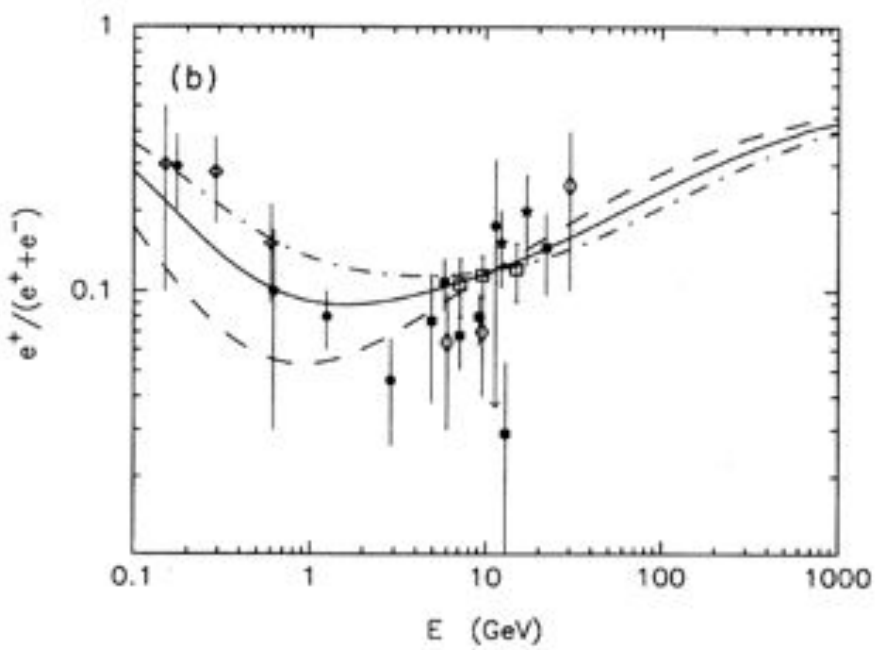
Harding, A. K. & Ramaty, R. The pulsar contribution to galactic cosmic-ray positrons. Proc. 20th ICRC, Moscow 2, 92-95 (**1987**).

Pulsar Magnetosphere

Rotation-powered Neutron Stars produce e+e- pairs, injected in ISM when out of Pulsar Wind Nebula







Atoian, A. M., Aharonian, F. A., & Volk, H. J. Electrons and positrons in the galactic cosmic-rays. Phys. Rev. D 52, 3265-3275 (1995).

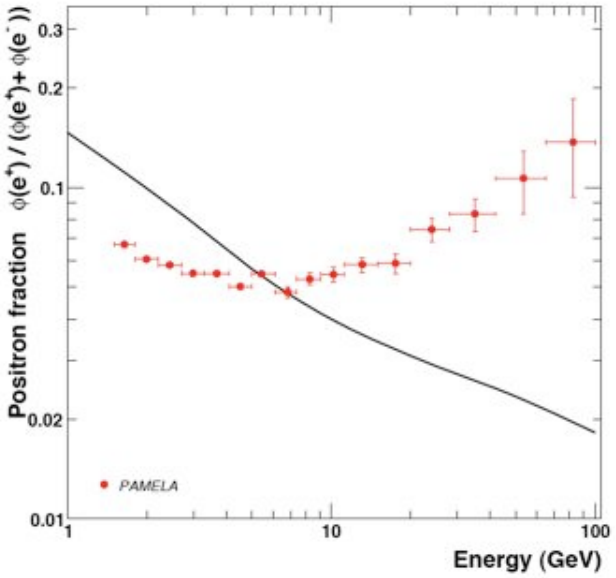
Two Key Questions

1. is the **positron** excess **real**?

2. can we discriminate
   pulsars vs **dark matter**?

Fermi-LAT key to both!

1. is the **positron** excess **real**?



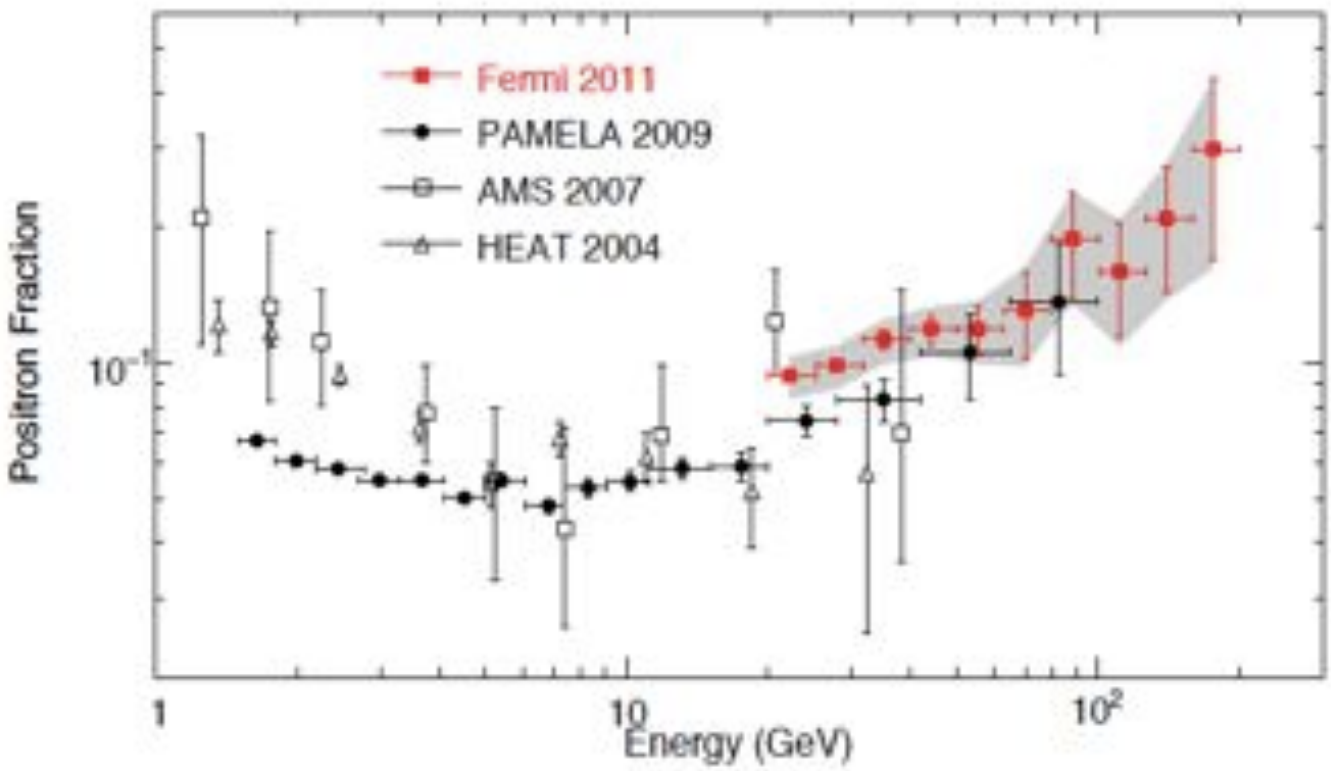
…almost **1,000** citations!

Experimentalists get ignored if they are right,
and **hugely cited** if they are **wrong**.

Theorists get ignored if they are wrong,
but a **Nobel** Prize if they are **right**.*

Superluminal Neutrinos @ OPERA:
>200 theory papers

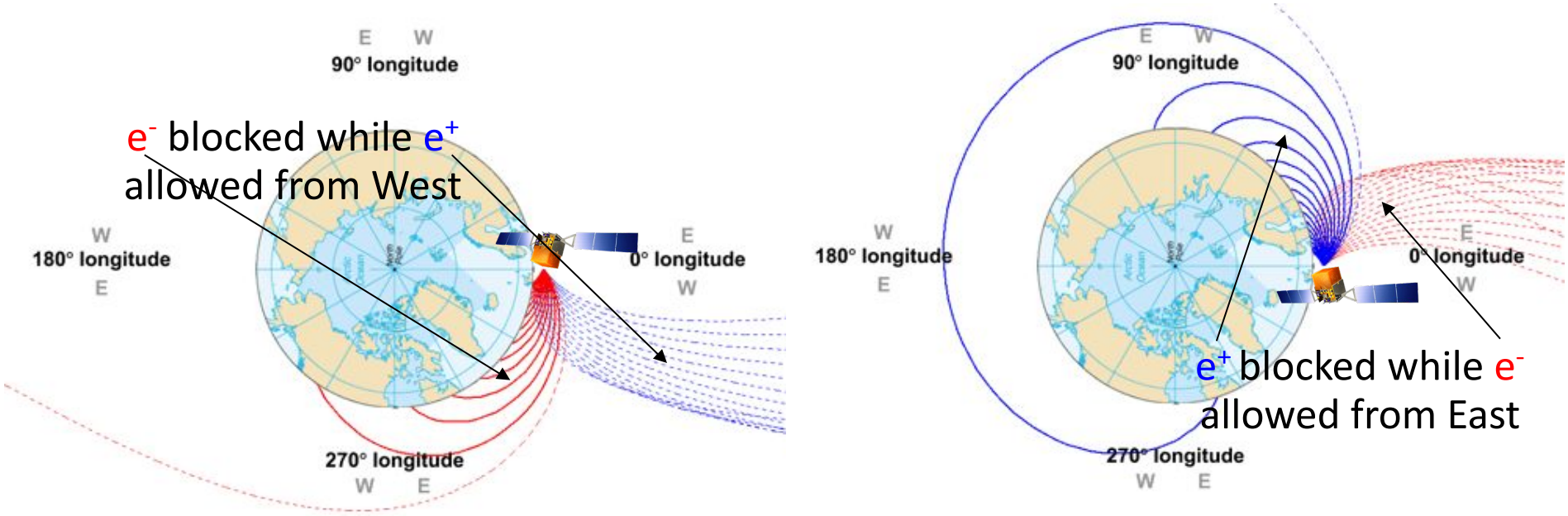
* quoted from the Guardian



How does **Fermi** tells e^+ apart from e^-?

Fermi-LAT Collaboration, 1109.0521, Phys.Rev.Lett. 108 (2012) 011103

Geomagnetic field + solid **Earth** shadow = directions from which only electrons or **only positrons** are allowed



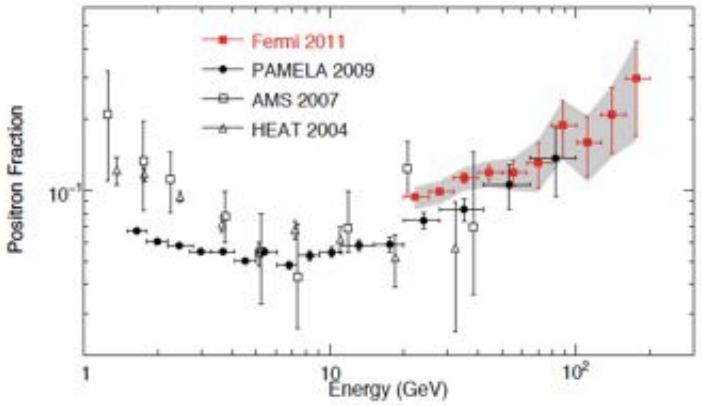
For particular directions, electrons or positrons are completely forbidden

Pure e^+ region looking West and pure e^- region looking East

Regions vary with **particle energy** and **spacecraft position**

Slide concept: Justin Vandenbroucke

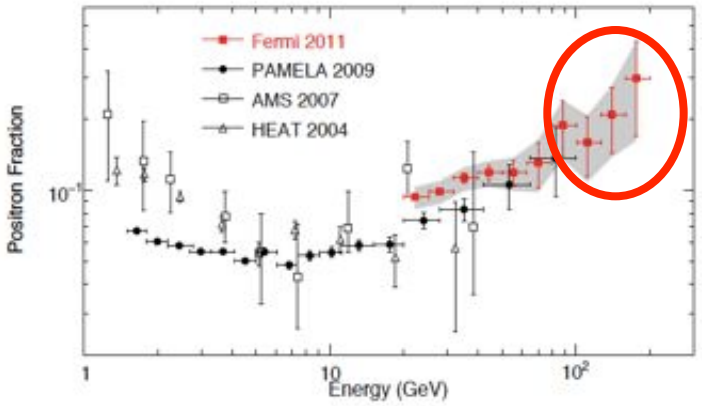
Why is this measurement **important**?



(i) For **every** (50 GeV) **cosmic-ray positron**,
10 electrons and **10,000 protons**!

important confirmation that the extra positrons measured by Pamela are ***not mis-ID protons****!*

Why is this measurement **important**?



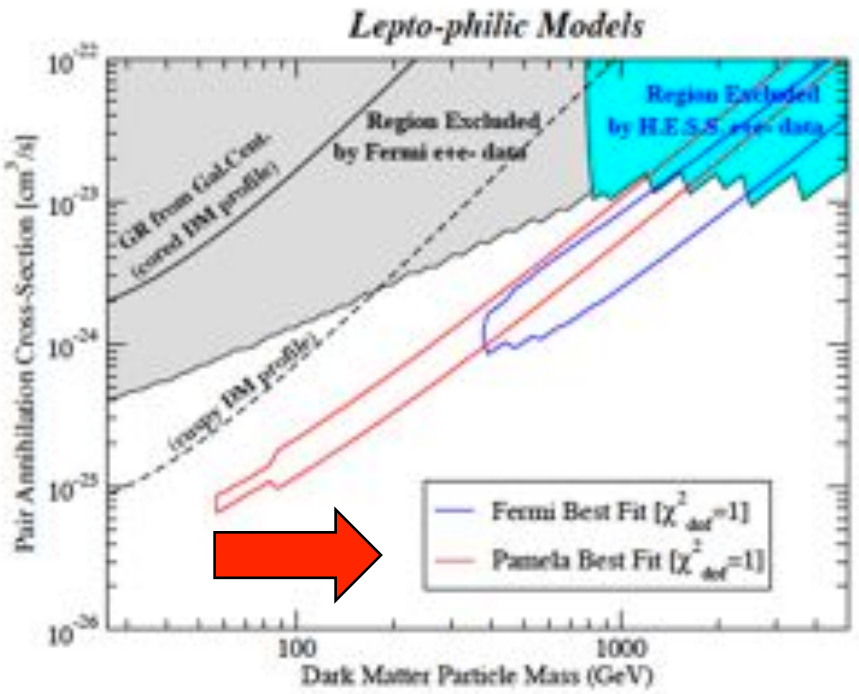
(ii) Extends Pamela results

to **higher energy**, E=200 GeV

consistent spectrum, no turnover

What do we learn from **Fermi e+/(e+e-)** about the **source** of high-energy **positrons**?

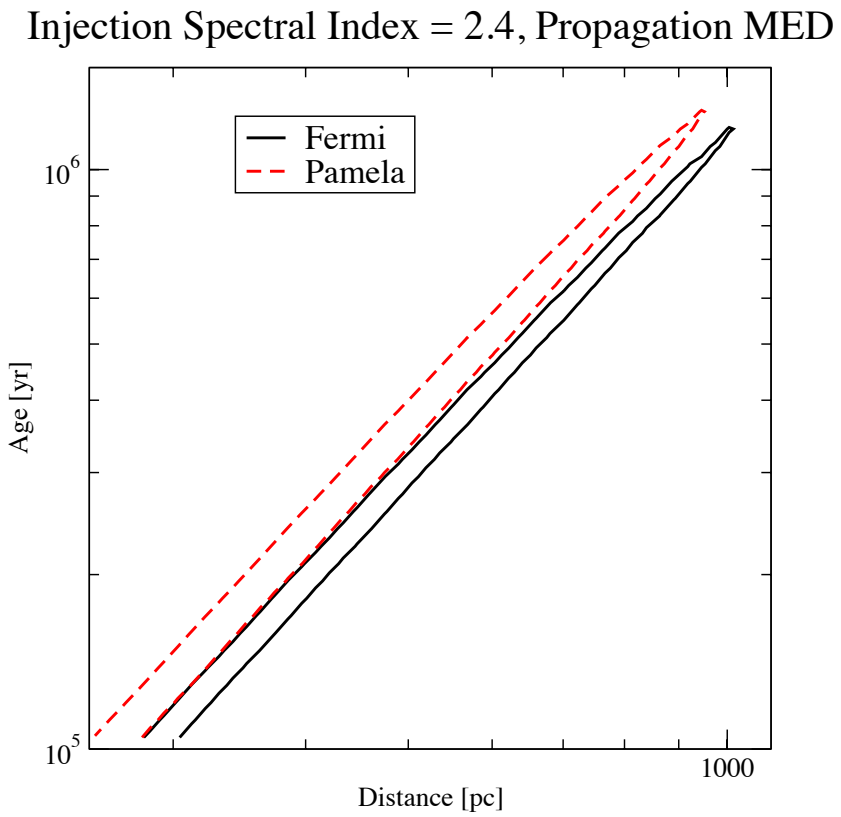
if it is **Dark Matter**, must be heavier than 200 GeV



Grasso, Profumo et al, 0905.0636

What do we learn from **Fermi e+/(e+e-)** about the **source** of high-energy **positrons**?

if it is **a pulsar**, slightly different **age-distance** correlation



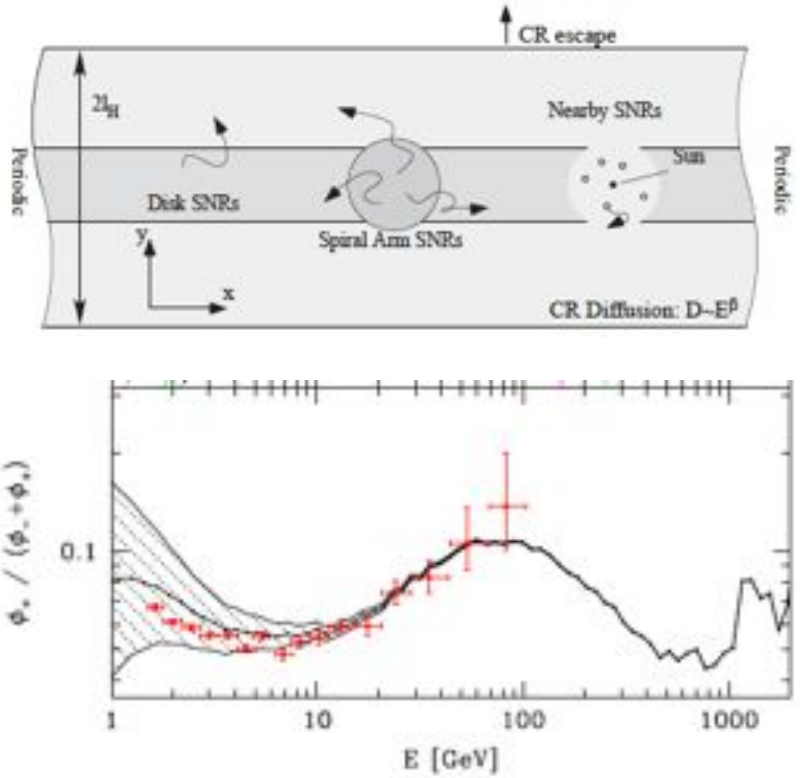
What do we learn from **Fermi e+/(e+e-)** about the **source** of high-energy **positrons**?

some explanations

ruled out

(e.g. **SNR** distribution

inhomogeneities)



Shaviv et al, 0902.0376

better **take seriously**
the excess of **HE positrons**…

2. Can we determine the **source?**

750/900 papers advocate Dark Matter

…**despite** some obvious and significant **issues**:

(i) Need very **large annihilation rates**
($\langle\sigma v\rangle \sim 10^2$-$10^3 \times 10^{-26}\ cm^3/s$)

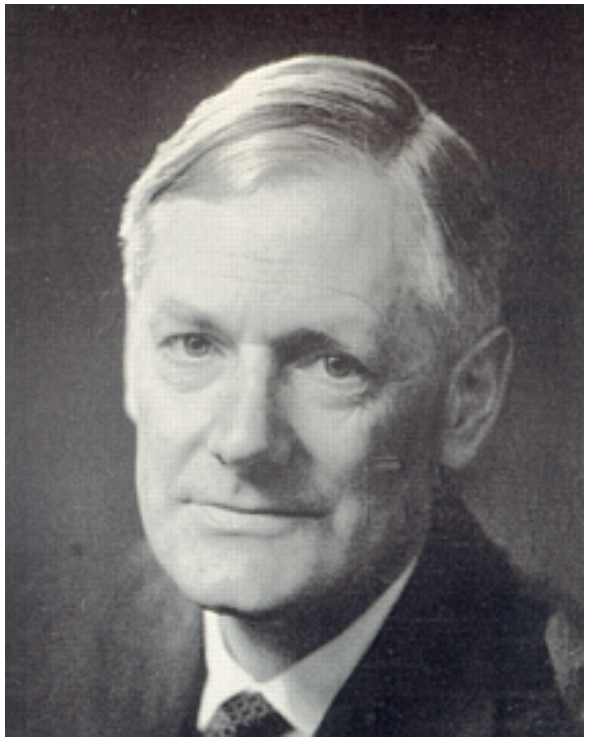
(ii) Need rather **large masses** (~TeV)

(iii) Need special annihilation or decay modes
(suppress **antiprotons** + have a hard spectrum)
e.g.: $\mu^+\mu^-$, or 4μ

interesting **riddle** to test a **theorist's creativity**!

Redman's Theorem

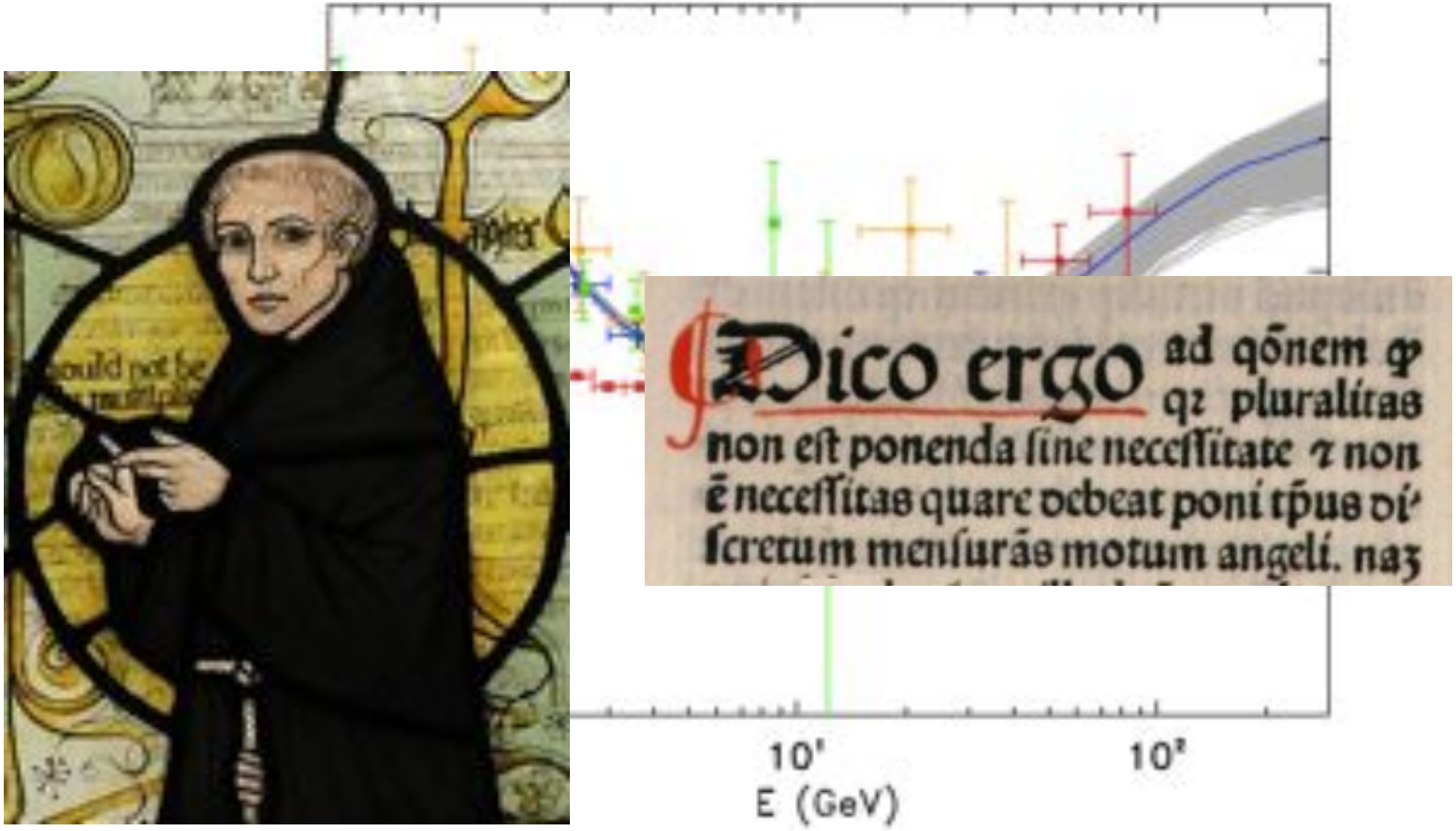
"Any competent theoretician can fit any given theory to any given set of facts" (*)



Roderick O. Redman
(b. 1905, d. 1975)
Professor of Astronomy
at Cambridge University

(*) Quoted in M. Longair's
"High Energy Astrophysics", sec 2.5.1
"The psychology of astronomers and astrophysicists"

"Dissecting Pamela with **Occam's Razor**:
existing, well-known Pulsars naturally account for the
"anomalous" Cosmic-Ray Electron and Positron Data"



Profumo, 0812.4457; Grasso, Profumo, 0905.0636

…plus, radio-quiet **gamma-ray** pulsars!

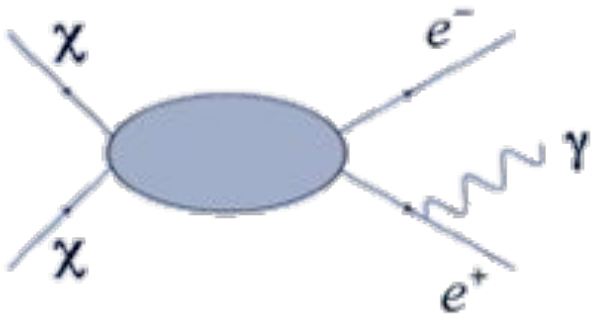
Gendelev, SP and **Dormody**
JCAP 1002 (2010) 016

Dark Matter: a "**Universal**" Phenomenology

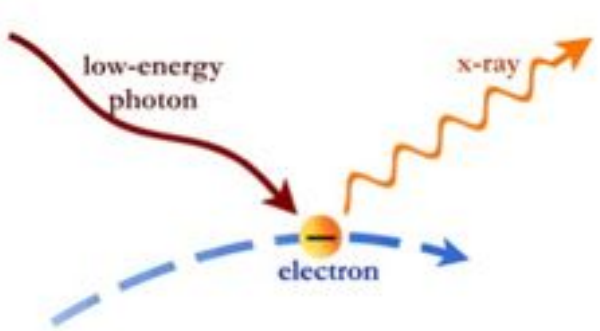
Large **annihilation rates**

Large **masses**

Hard **charged leptons**



Final State Radiation

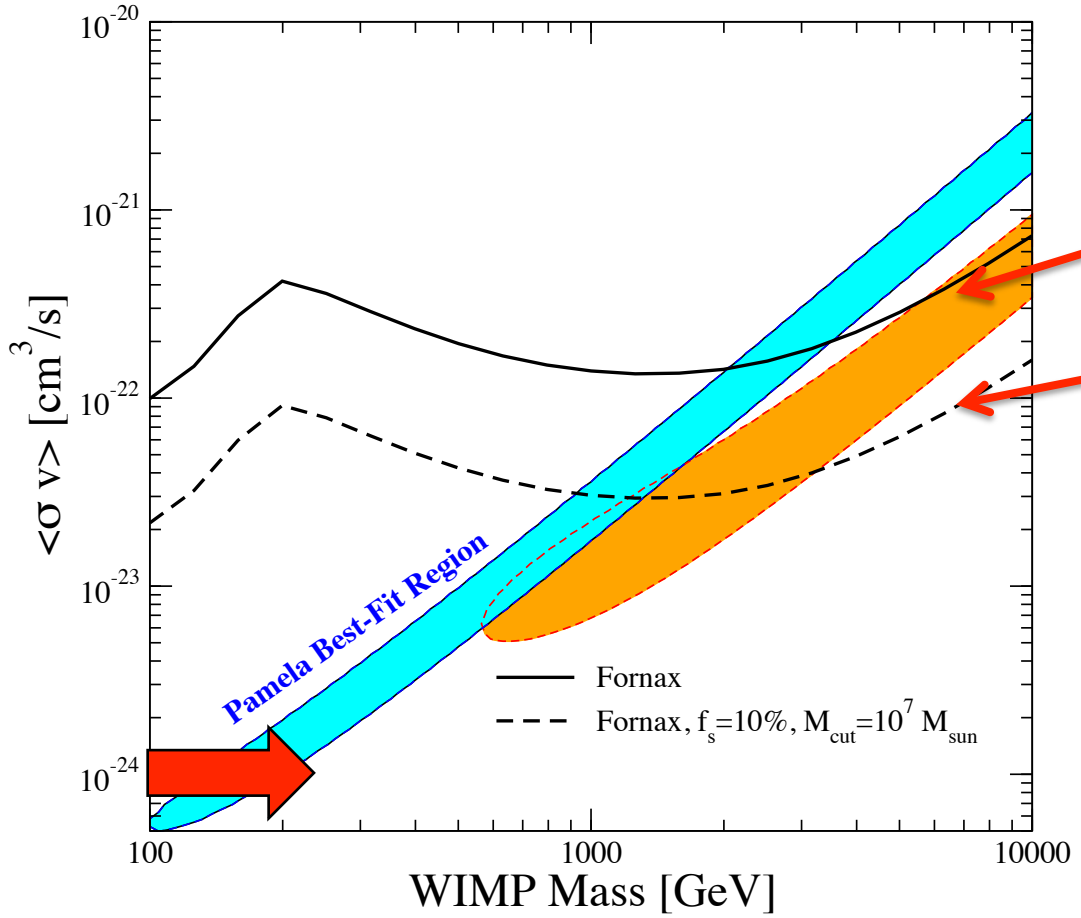


Inverse Compton

Gamma-Ray Searches from **Galaxy Clusters**

Jeltema, Profumo & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4531

Gamma-Ray Searches from **Galaxy Clusters**

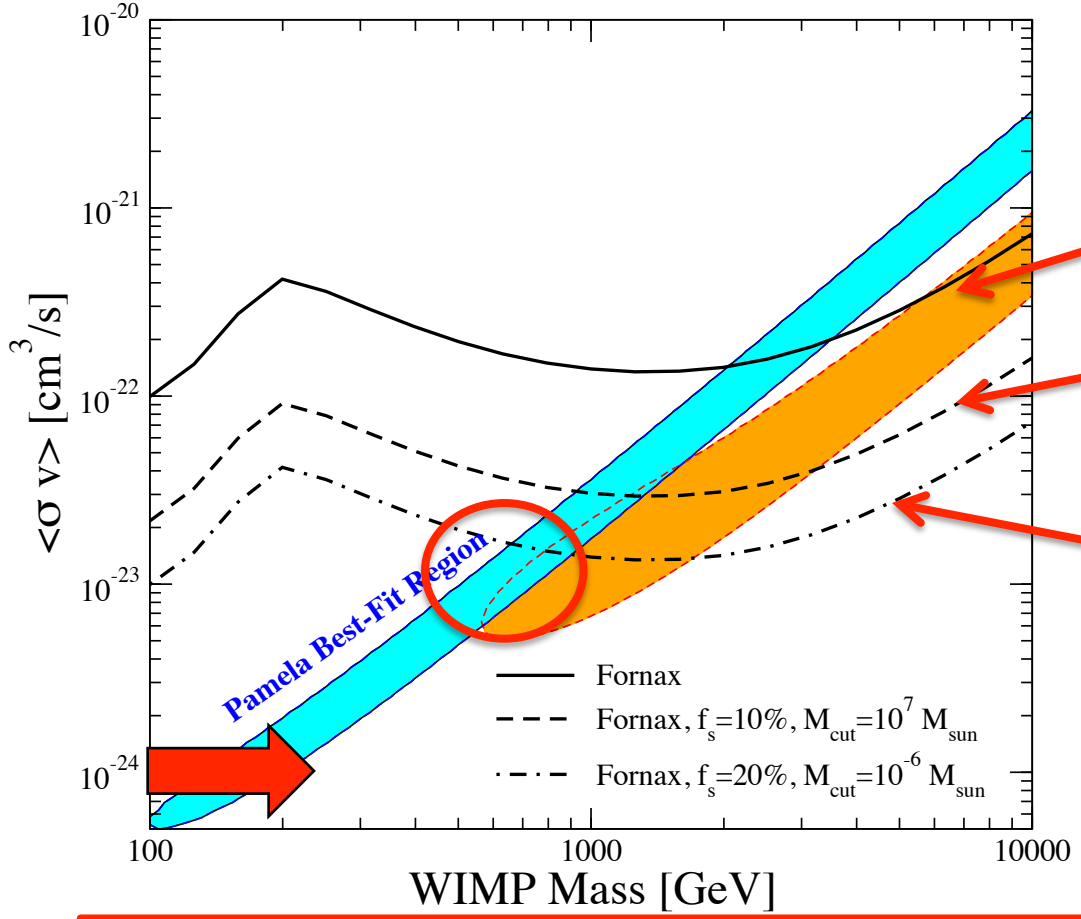


no substructure

galaxies only

Jeltema, Profumo & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4531

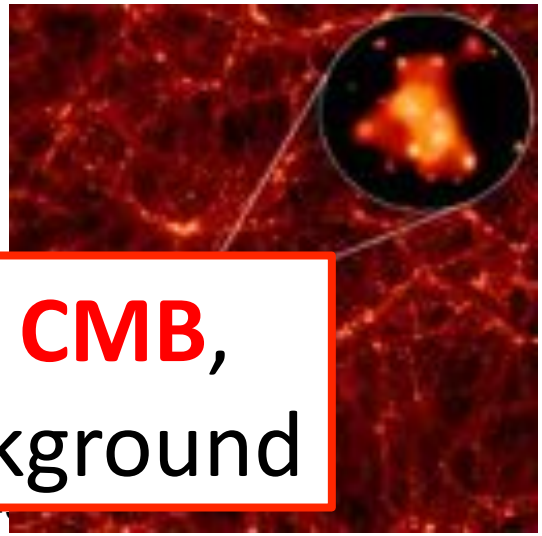
Gamma-Ray Searches from **Galaxy Clusters**



no substructure

galaxies only

substructure with M > 10^{-6} M_{Sun}



Additional constraints from **CMB**, extragalactic **gamma-ray** background

Jeltema, [illegible] & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4[illegible]

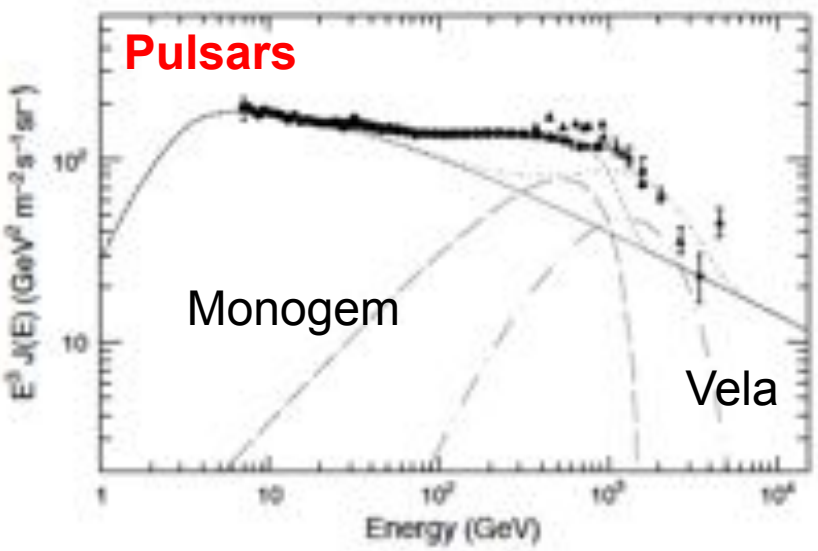
Is there an “**experimentum crucis**” to **discriminate** between **dark matter** and **pulsars**?

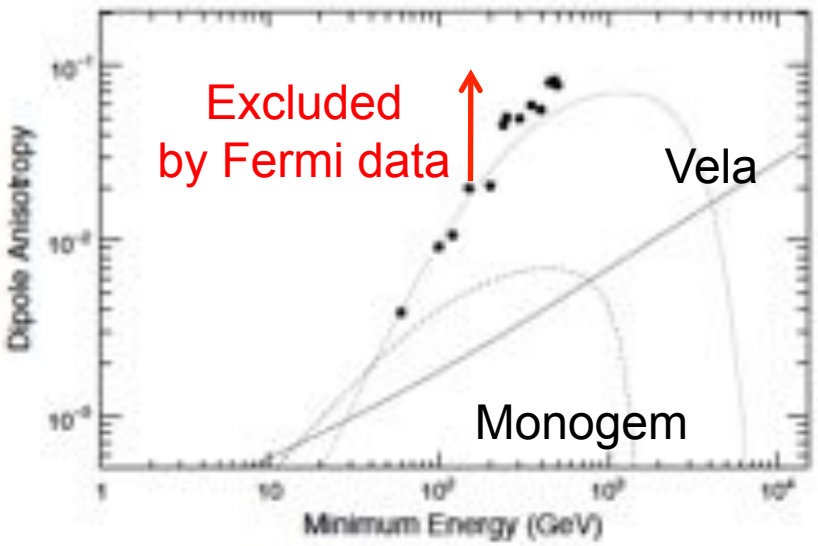
Nearby **Pulsar** → Anisotropy in the arrival direction *(sufficient, not necessary)*

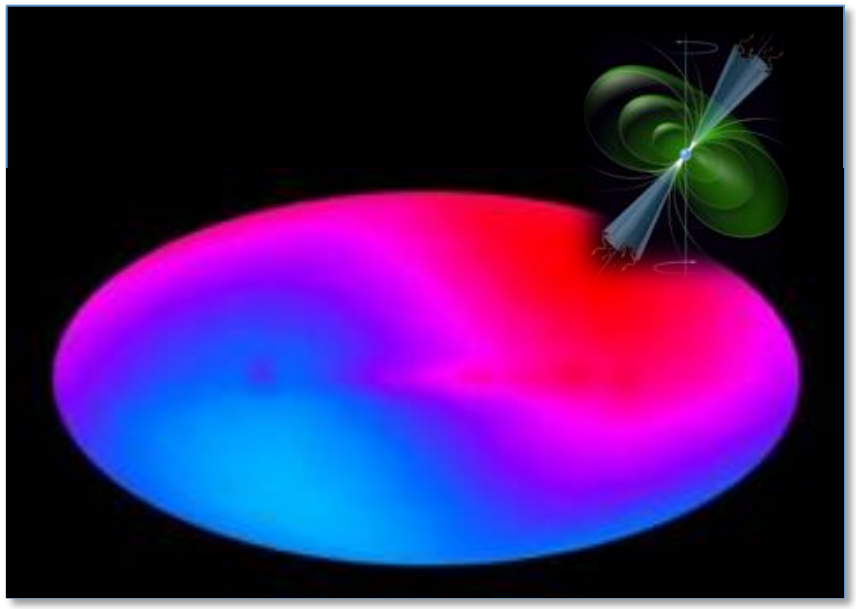
Dark Matter → Diffuse secondary component *(observationally tricky)*

Nearby **Pulsar** → Anisotropy in the arrival direction

(sufficient, not necessary)



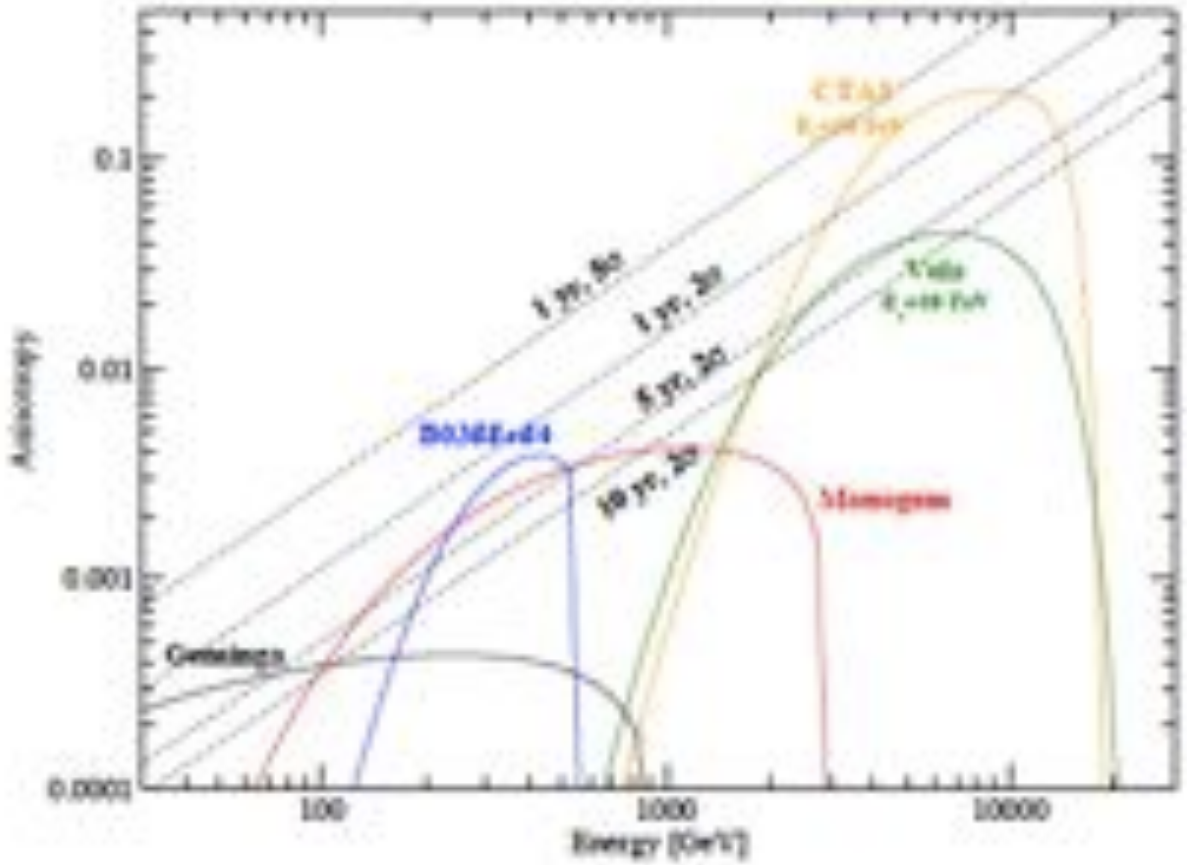




No Anisotropy observed in the Fermi e+e- E>60 GeV data

Pulsar interpretation entirely **consistent** with **all data**

Fermi-LAT Collaboration, PRD, 1008.5119

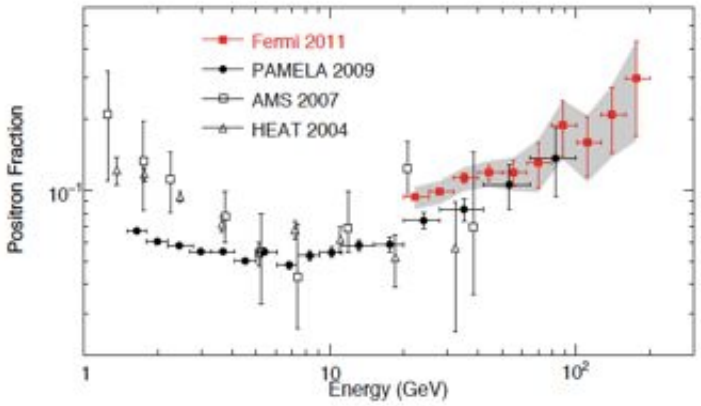


5 yr statistics might be **crucial**

to detect **anisotropy** signal

S. Profumo, arXiv 0812.4457

The origin of the **positron excess** is still unsettled



Pulsars explanation is **fine**;
Dark Matter is a **viable**,
though highly **constrained**, option

What Next?

Update on **AMS**

Launched 5/16/2011
Installed on ISS 5/19/2011

- Ongoing **Calibration** & Alignment
- **Jan 2013**: $e^+/(e^+ + e^-)$; analysis by two independent groups within Collaboration*
- Next priority: **antiprotons**; then, high-Z
- **B/C** and **^{10}Be/^{9}Be** for propagation models

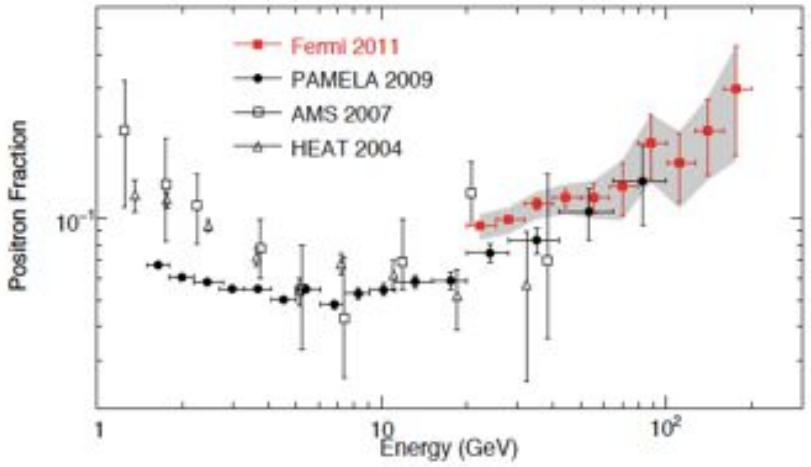
* Iris Gebauer, private communication

Opportunities for **Fermi**-LAT

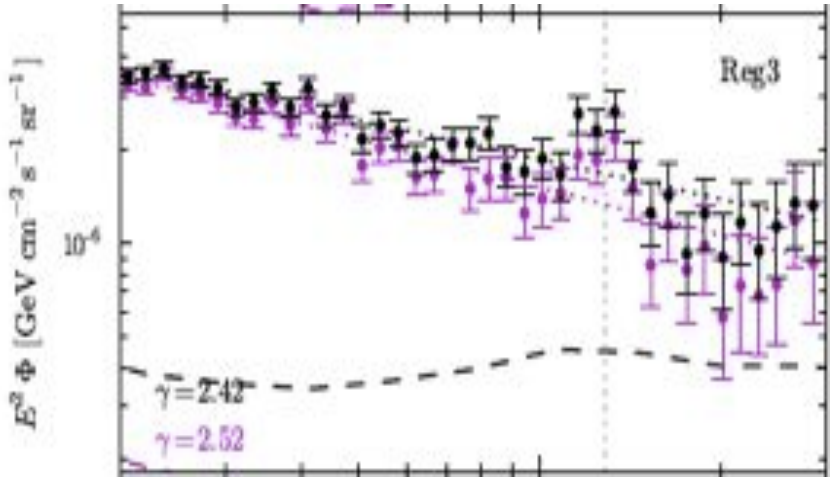
- Search for **Anisotropy** with **4 yrs** vs 1
- Cross-calibration of **AMS** electron and proton fluxes
- Extend **e+e- spectrum** to low energies, greater statistics

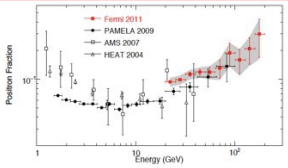
New Physics and Fermi

Cosmic-Ray Positron Excess



the 130 GeV line





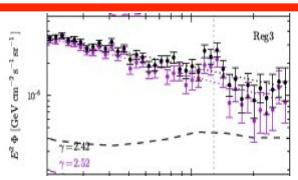
Positron Excess

Likely **not** instrumental

Likely **not** New Physics

If New Physics, **weird** kind of New Physics!

- ✓ **AMS-02** e+ fraction
- ✓ Fermi 4 yrs Anisotropy



130 GeV line

Maybe instrumental??

Likely **New Physics**

If New Physics, **weird** kind of New Physics!

- ✓ **Pass-8**
- ✓ **HESS**-II

ATIC: **excesses** at high-energy in every cosmic ray species!!