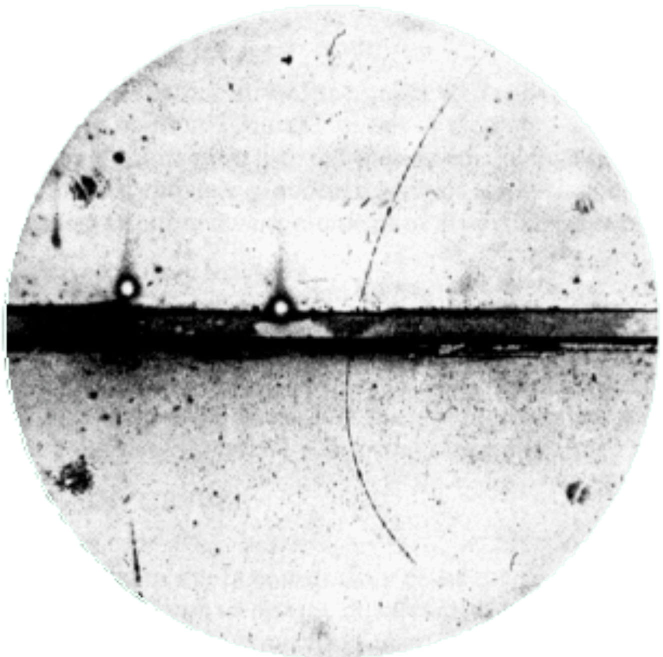
Cosmic ray “anomaly” in positron fraction: from data to sources

Pasquale D. Serpico

CERN



C.D. ANDERSON → Nobel Prize 1936
Phys. Rev. 43, 491 (1933)

PAMELA → ?!

Annecy, 02/06/2009

"I study … [your field]: Why should I bother?"

- When no (or only poor) man-made accelerators available, particle physics was born out of Cosmic Ray studies: New particles discovered (e^+, μ, π, K, Λ, '30-'50) as secondaries induced by CRs in the atmosphere

- In the '50-'80, emphasis mostly on astrophysics ("decoupling era")

- Starting in the '90, with atmospheric/solar neutrinos, dark matter searches & UHECR puzzles, new emphasis on particle-physics applications (already led to major discovery, ν-oscillations): a synergy is possible & present with "the Lab" (both accelerator & non-accelerator, both theoretically & experimentally)

- In the search for signatures of BSM Physics Nature may help providing for free extreme astrophysical sources and even the detector media. In order to exploit the "low-luminosity / high energy" beams Nature provides we must understand "the beam", i.e. astrophysics. (Think of solar ν-oscillations, impossible to assess without a "Standard Solar Model"!)

- In the 21st century, we will be facing more and more technological challenges in creating in the Lab the (often extreme) conditions needed to have a glimpse of Physics Beyond the SM (ν-mass, baryogenesis, dark matter, dark energy, inflation, strong gravity regime…)

Outline of the talk

- Setting the Stage

→ Generalities on Dark Matter & indirect searches

→ The data

→ Some notions on Galactic Cosmic Rays

- Recent Positron Data: “Model-independent” interpretation

→ I’ll argue that this points to the existence of a primary source!

- Models for the interpretation & way to distinguish between

→ Astrophysical explanations (Pulsars?)

→ Dark Matter explanations

- Conclusions

Dark Matter has been detected (and it's blue)

So… much ado about nothing?

News Release Number: STScI-2007-17

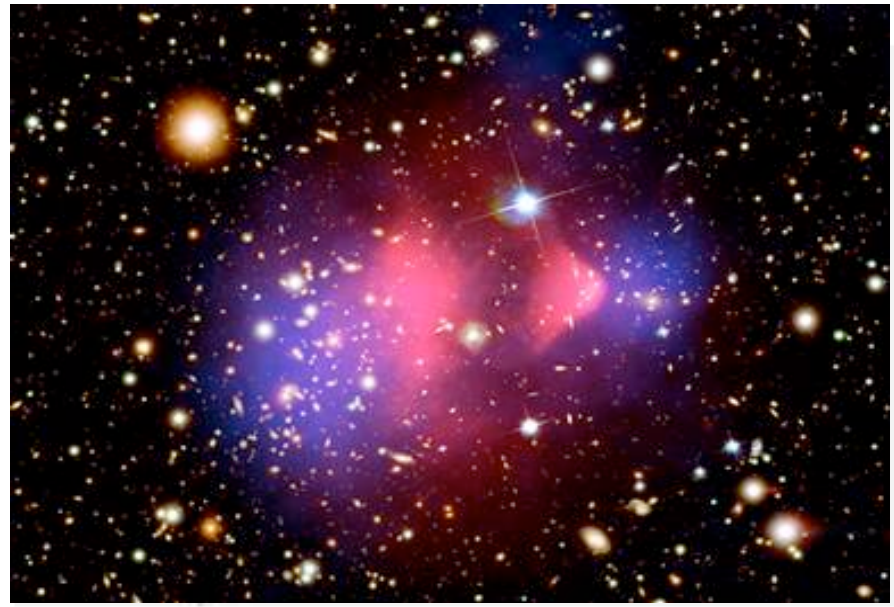
May 15, 2007 *01:00 PM (EDT)*

Hubble Finds Ring of Dark Matter

Press Release 06-120

Astronomers 'See' the Invisible

First 'direct observation' sheds new light on dark matter

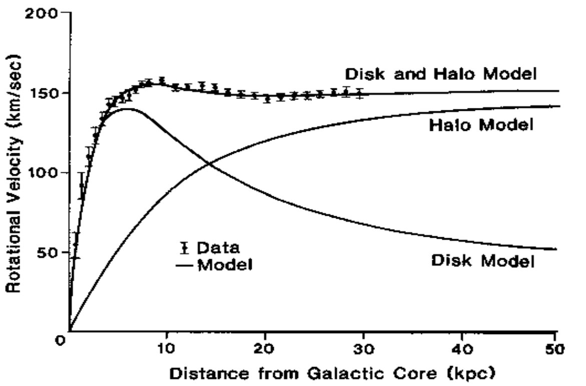


The separation of luminous gas appears red, and dark matter appears blue.
Credit and Larger Version

August 21, 2006

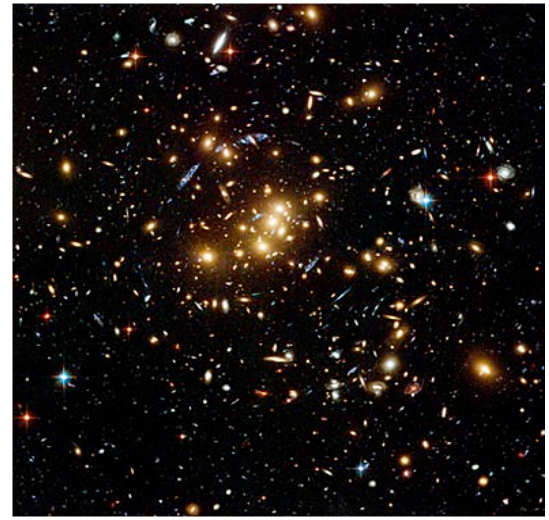
Dark Matter detected… only gravitationally!

Rotation curves of Galaxies



Galaxy Clusters

Lensing

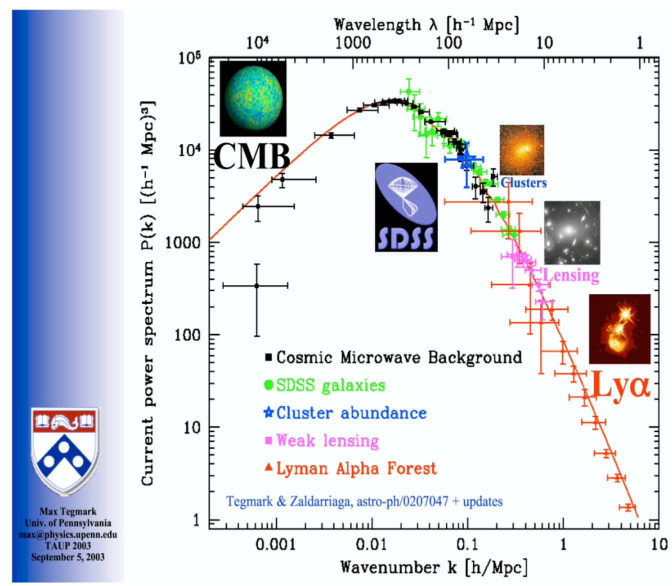


Discovery via gravity

F. Zwicky, 1933

V. Rubin, 1970

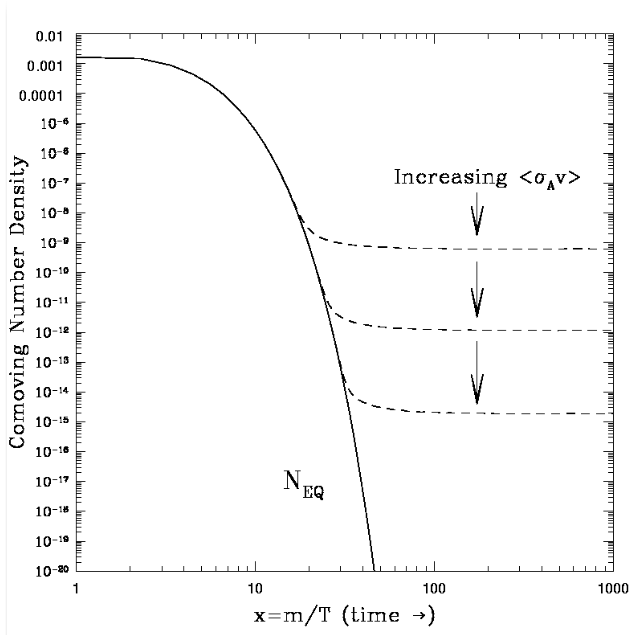
Large scale structures



But gravity is “universal”, does not permit particle identification: a discovery via electromagnetic, strong or weak probes is needed

What is DM? WIMPs? A reasonable bet

- ✓ It's cold (maybe a little warm…)
- ✓ It's dark (<u>at most</u> weakly interacting with SM fields)
- ✓ It's non-baryonic (New Physics!)



❖ The Weakly Interacting Massive Particle "miracle"
thermal relic with EW gauge couplings & $m_X \approx 0.01 - 1$ TeV matches cosmological requirement, $\Omega_X \approx 0.25$

$$\Omega_{wimp} \sim 0.3 / <\sigma v> (pb)$$

❖ EW scale may be related with DM!
Stability ↔ Discrete Symmetry ↔ Only pair production at Colliders?
(SUSY R-parity, K-parity in ED, T-parity in Little Higgs)
Also would ease agreement with EW observables, Proton stability…

❖ EW-related candidates have a rich phenomenology
Higher chances of detection via collider, direct, and indirect techniques

➢ *Warning: keep in mind other possibilities!*
(Axions, SuperHeavy DM, SuperWIMPS, MeV DM, sterile neutrinos…)
They have peculiar signatures and require ad hoc searches

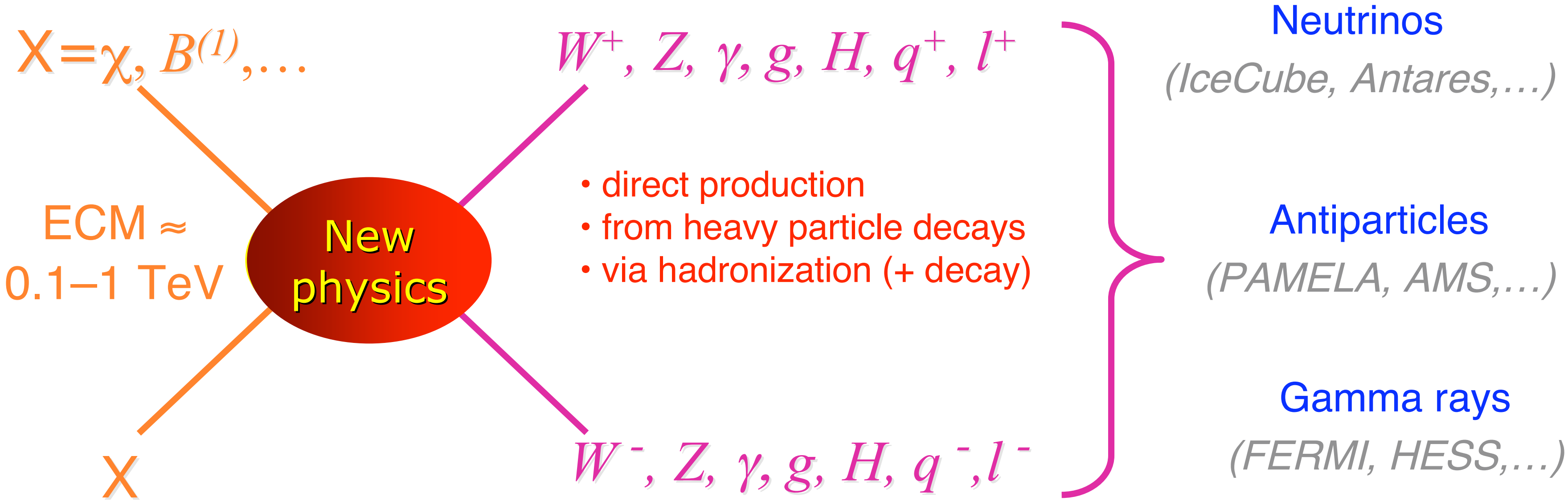
Strategies & Desiderata towards detection of DM

Experiment	*Source*	*Interaction*	*Channel*
Direct	Local (crossing Earth)	WIMP-nucleus scattering	Phonons
Indirect	Earth, Sun, Galaxy, Cosmos	WIMP decay/ annihilation	γ,ν, Antimatter
Collider	Controlled production	WIMP pair production	$\not{E}$

✓demonstrate that Gal. DM made of particles (locally- direct det.; remotely indirect det.)

✓ Possibly, create DM candidates in the controlled environments of accelerators

✓ Find a consistency between properties of the two classes of particles (ideally, we would like to be able to calculate abundance and direct/indirect signatures)



Rationale behind indirect DM search program

As a discovery tool

Search for peculiar signatures, which cannot be easily mimicked by astrophysical objects (HE ν from Sun/Earth; γ lines & angle/spectrum features; edge in CR(anti)matter spectra…). This is no different from particle physics, where one looks for new particles in the "best channels"!

If no signal is found

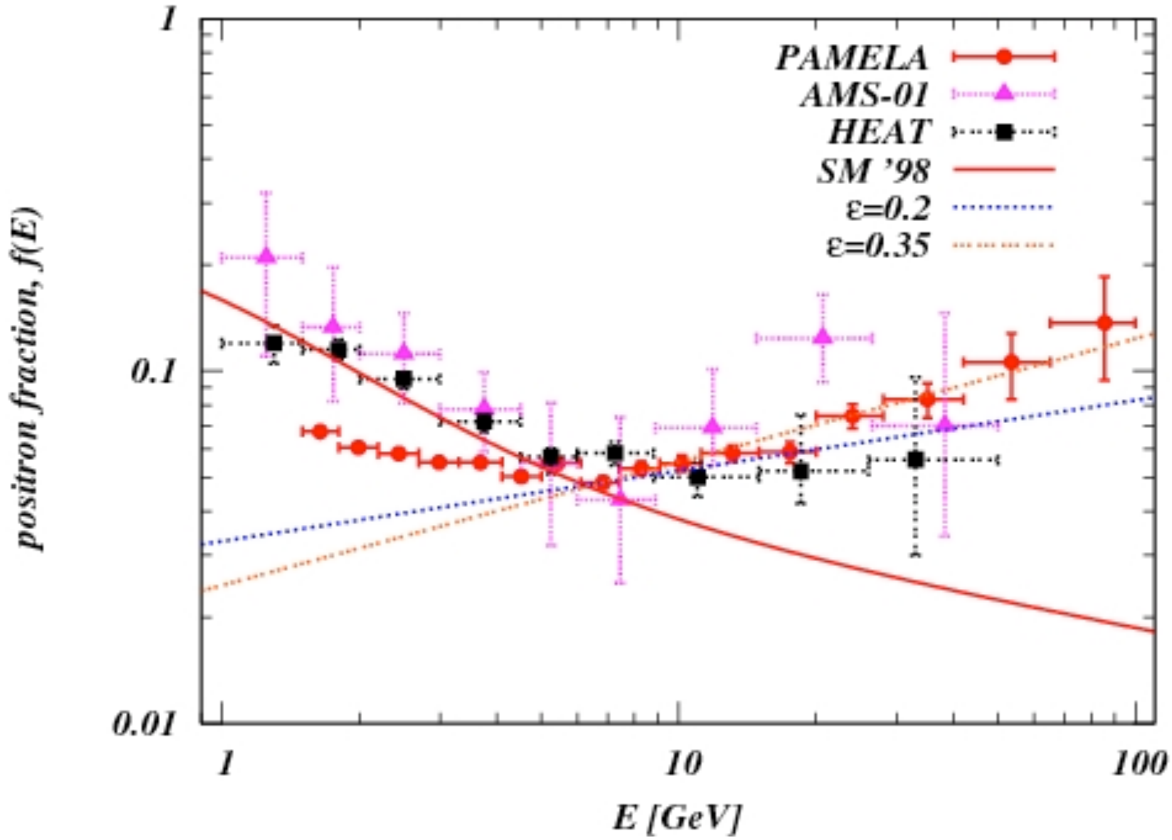
One can used indirect constraints (complementary to accelerators) to "motivated particle physics models" (e.g. SUSY in its MSSM incarnation)

If a signal is found in other chanels (accelerator/direct detection)

We still *need* indirect detection:

- ✓ To confirm that whatever we find in the Lab is the same "dark stuff" responsible for astrophysical and cosmological observations.
- ✓ To access particle information not otherwise available in the Lab (annihilation cross section or decay time, b.r.'s)
- ✓ to infer cosmological properties of DM (e.g. power spectrum of DM at very small scales) not accessible otherwise.

e^+ fraction measurements reveal the following:



- Is this the long-awaited hint from DM? Not really: Edge missing!
- Still, this is “unexpected/puzzling/exciting”: what do we mean? See following…

Diffusion

Source term (time, space, momentum dep.)
Includes dec./frag. for heavier nuclei

Diffusion

Energy loss

$$\frac{\partial \Phi}{\partial t} = Q + \vec{\nabla} \cdot (D_{sp} \vec{\nabla} \Phi) - \frac{\partial}{\partial p}(\dot{p} \Phi) +$$

Convection velocity

$$+ \frac{\partial}{\partial p}\left[p^2 D_{mom} \frac{\partial (p^{-2} \Phi)}{\partial p} \right] - \vec{\nabla} \cdot (\vec{V} \Phi) + \frac{\partial}{\partial p}\left[\frac{p}{3} (\vec{\nabla} \cdot \vec{V}) \Phi \right] +$$

$$- \frac{\Phi}{\tau_{frag}} - \frac{\Phi}{\tau_{decay}}$$

Adiabatic flow term

Fragmentation and decay terms
(negligible/vanishing for protons)

Diffusive reacceleration

world experts in the audience, I won't spend much time… but the basic argument is simple

Diffusion → Leaky box: hadrons

$$\frac{\partial \Phi}{\partial t} = Q - \frac{\Phi}{\tau_{esc}} - \frac{\partial}{\partial p}(\dot{p}\Phi)$$

❖ For Protons, fair to neglect energy losses and one gets

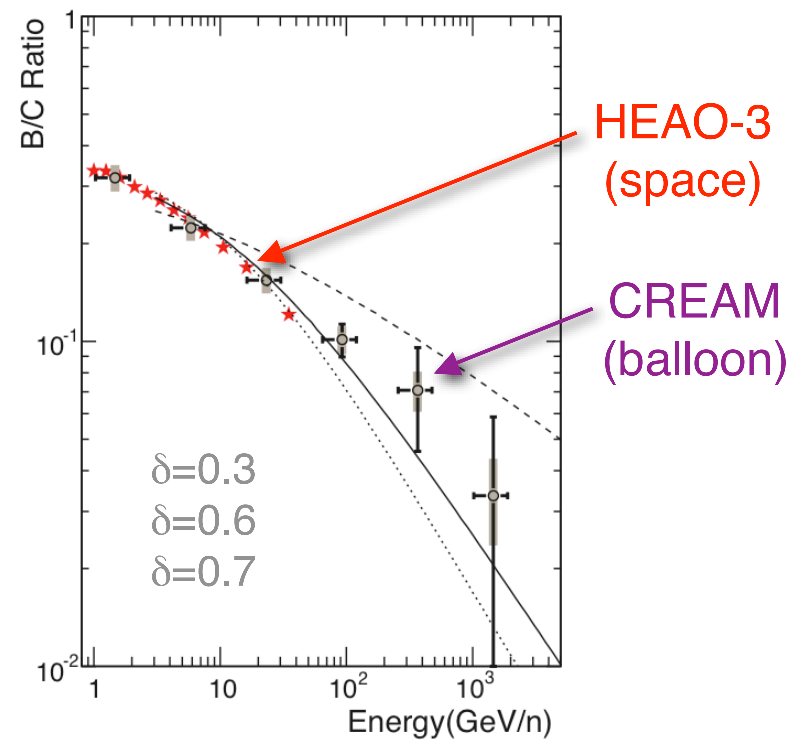
$$Q_p(E) \propto E^{-\gamma_p} \Rightarrow \Phi_p(E) \propto E^{-\gamma_p}\tau_{esc}(E)$$

❖ For pure secondary nuclei (as Boron, produced from Carbon) one gets

$$Q_{\sec}(E) \propto \sigma\,\Phi_{prim}(E) \Rightarrow \Phi_{\sec}(E) \propto \sigma\,\Phi_{prim}(E)\tau_{esc}(E)$$

$$\tau_{esc}(E) \propto D(E)^{-1} \propto E^{-\delta}$$

δ~0.6 e.g. from B/C (and other s/p data).
Non-linear theory & simulations predict δ~0.3-0.6



Diffusion → Leaky box: leptons & positron fraction

$$\frac{\partial \Phi}{\partial t} = Q - \frac{\Phi}{\tau_{esc}} - \frac{\partial}{\partial p}(\dot{p}\Phi)$$

- For primary electrons, one can deduce by analogy

$$Q_-(E) \propto E^{-\gamma_-} \Rightarrow \Phi_-(E) \propto E^{-[\gamma_- + \ell(E)]}$$

- Similarly, for secondary positrons (if cross section~E-independent)

$$Q_+(E) \propto \Phi_p(E) \Rightarrow \Phi_+(E) \propto E^{-[\gamma_p + \delta + \ell(E)]}$$

If energy-loss time negligible wrt escape time $\ell(E) \approx \delta$

When radiative energy loss dominate (high energy):
But continous source approximation can break down… $\ell(E) \approx 1$

$$f(E) \equiv \frac{\Phi_+}{\Phi_+ + \Phi_-} = \frac{1}{1 + (\Phi_- / \Phi_+)} \approx \frac{1}{1 + kE^{\rho}}$$

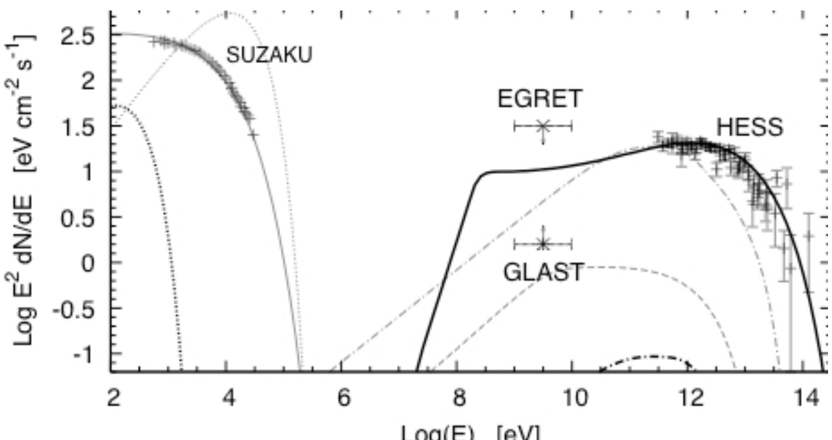
$$\rho = \delta + \gamma_p - \gamma_-$$

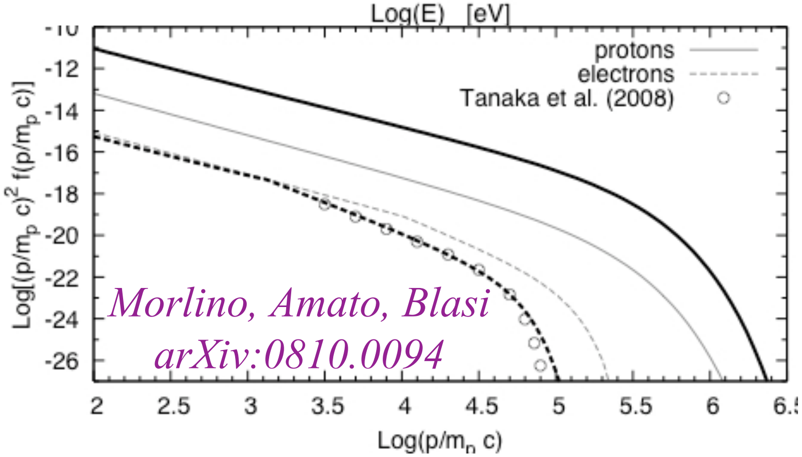
Evidence? The Supernova Remnant Paradigm

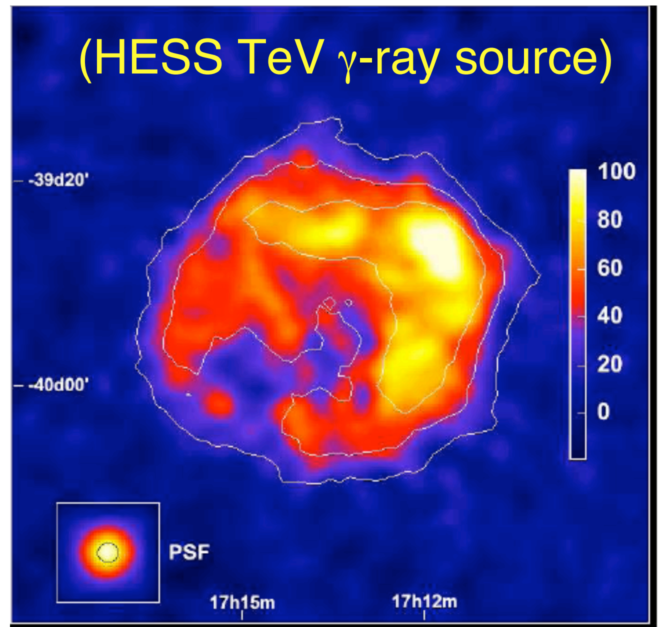
- Galactic Cosmic Rays produced by 1st order Fermi acceleration at SNR shocks ($L_{CR} \approx 0.1 E_{kin,SNR} R_{SN}$, SNR known TeV γ-sources…)
- Power laws $\sim E^{-\gamma}$ generated naturally with $\gamma=2+\varepsilon$

(strong/supersonic non-relativistic shock, no-backreaction, perfect gas EOS)

- Spectra observed at the Earth modified by diffusive propagation in the Galaxy (which also isotropizes the flux) : $\gamma+\delta\sim 2.7 \rightarrow \gamma\sim 2.1$, OK!







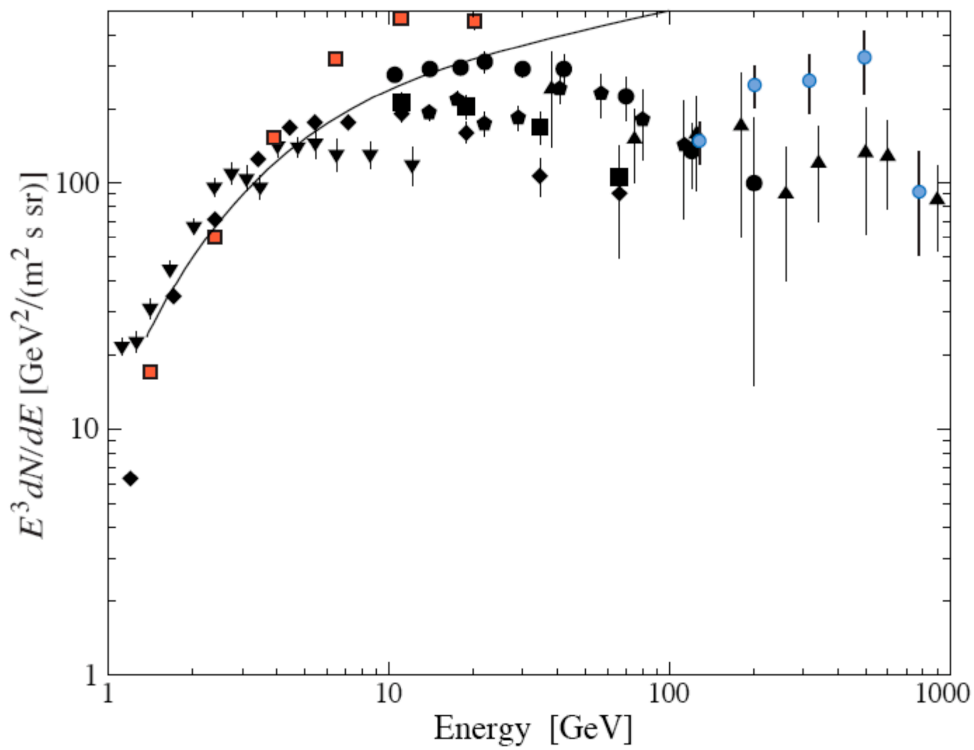
Consistent multiwavelength fits with hadronic models, here RX J1713.7-3946. Soon FERMI data… then final word from neutrinos?

Can we have $\gamma_- > \gamma_p + \delta$? Theoretical argument

As far as we know (e.g. from low-energy data and SNRs phenomenology) most *e* undergo similar acceleration (same site?) as *p.*
For example, when both are subject to diffusion only,

$$\Phi_-(E) \propto \Phi_p(E) \;\; at \;\; E \leq 10 \;\; GeV$$

In this case, $\gamma_- = \gamma_p$ and secondaries have a spectrum harder than primary electrons



Can we have $\gamma_{-} > \gamma_{p}+\delta$? Empirical argument

Assume we know nothing about *e* but the observed spectrum (note: this moves the problem to explaining the *e* -spectrum: a new mechanism is now required for *e* !), while we trust secondary calculations because *p* are better measured (and featurless). Even in this case, there is a conflict between *f(E)* and overall *e*-flux.

Hardest self-consistent secondary e+ spectrum

$$\Phi_{+}(E) \propto E^{-3.33} \quad at \;\; E \geq 10 \;\; GeV$$

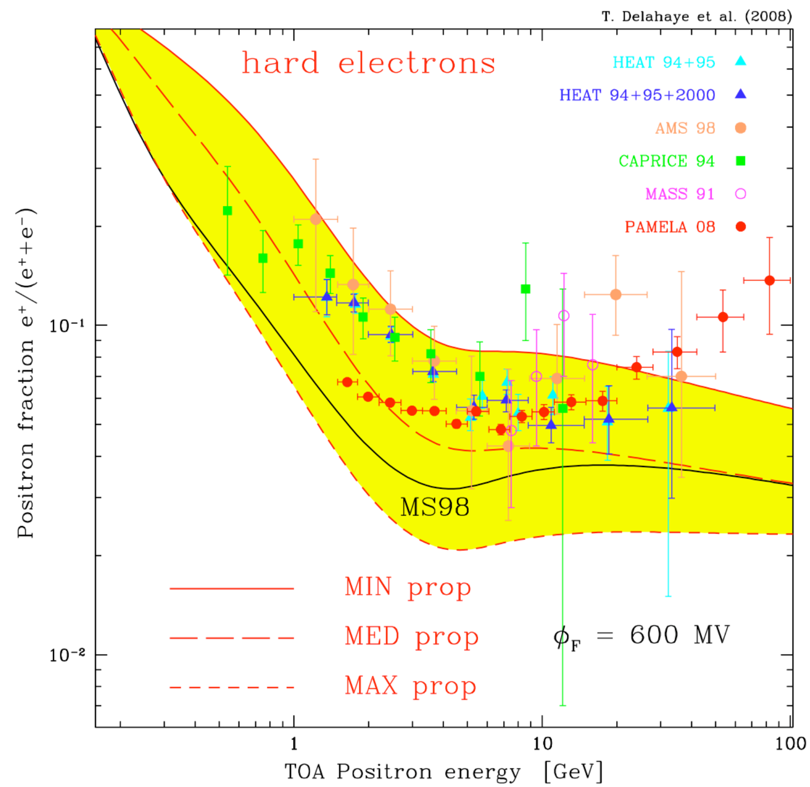
Softest possible spectrum fitting at 3 σ $e^{-}(+e^{+})$ data (not explaining them!)

$$\Phi_{e}(E) \propto E^{-3.54} \quad at \;\; E \geq 10 \;\; GeV$$

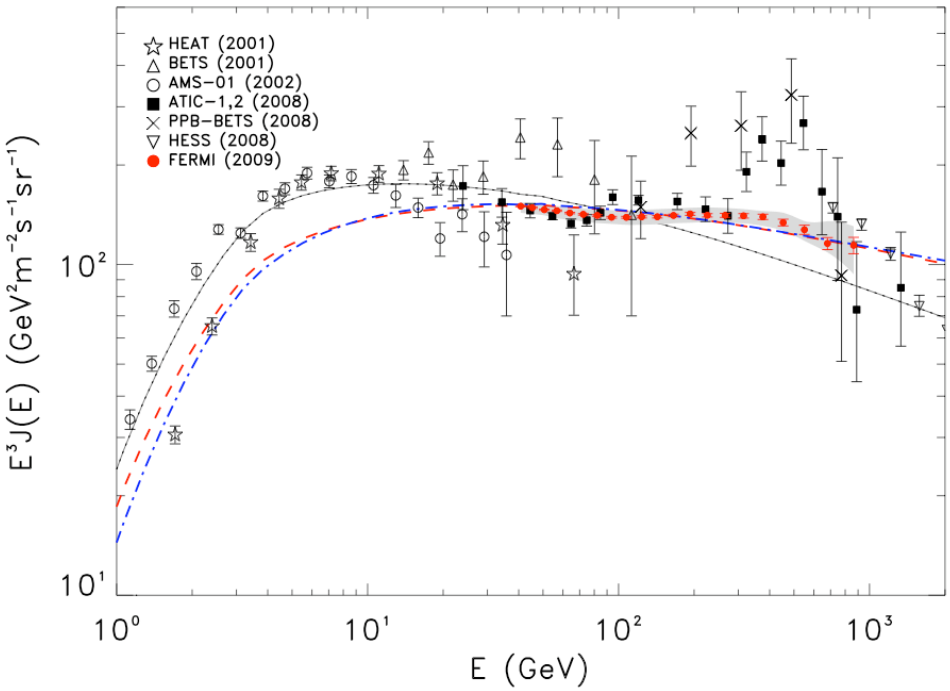
$$\rho > -0.2 \;\; (\rho \approx -0.35 \;\; required)$$

PAMELA preliminary result $\Phi_{(e-)} \propto E^{-3.25}$
Fermi results in the same range $\Phi_{(e-+e+)} \sim E^{-3.0}$

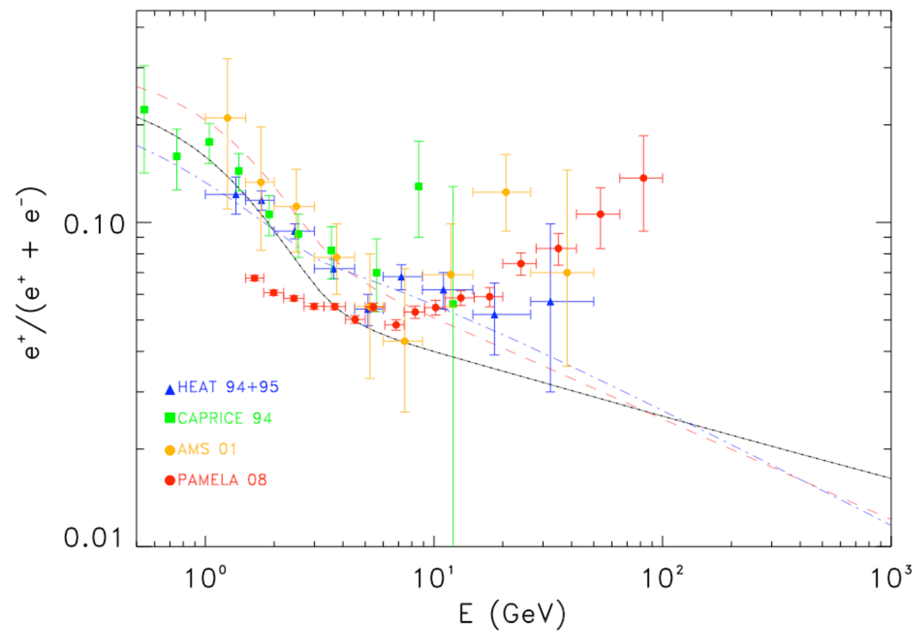
Delahaye et al. arXiv:0809.5268



Overall $e^- + e^+$ Spectrum

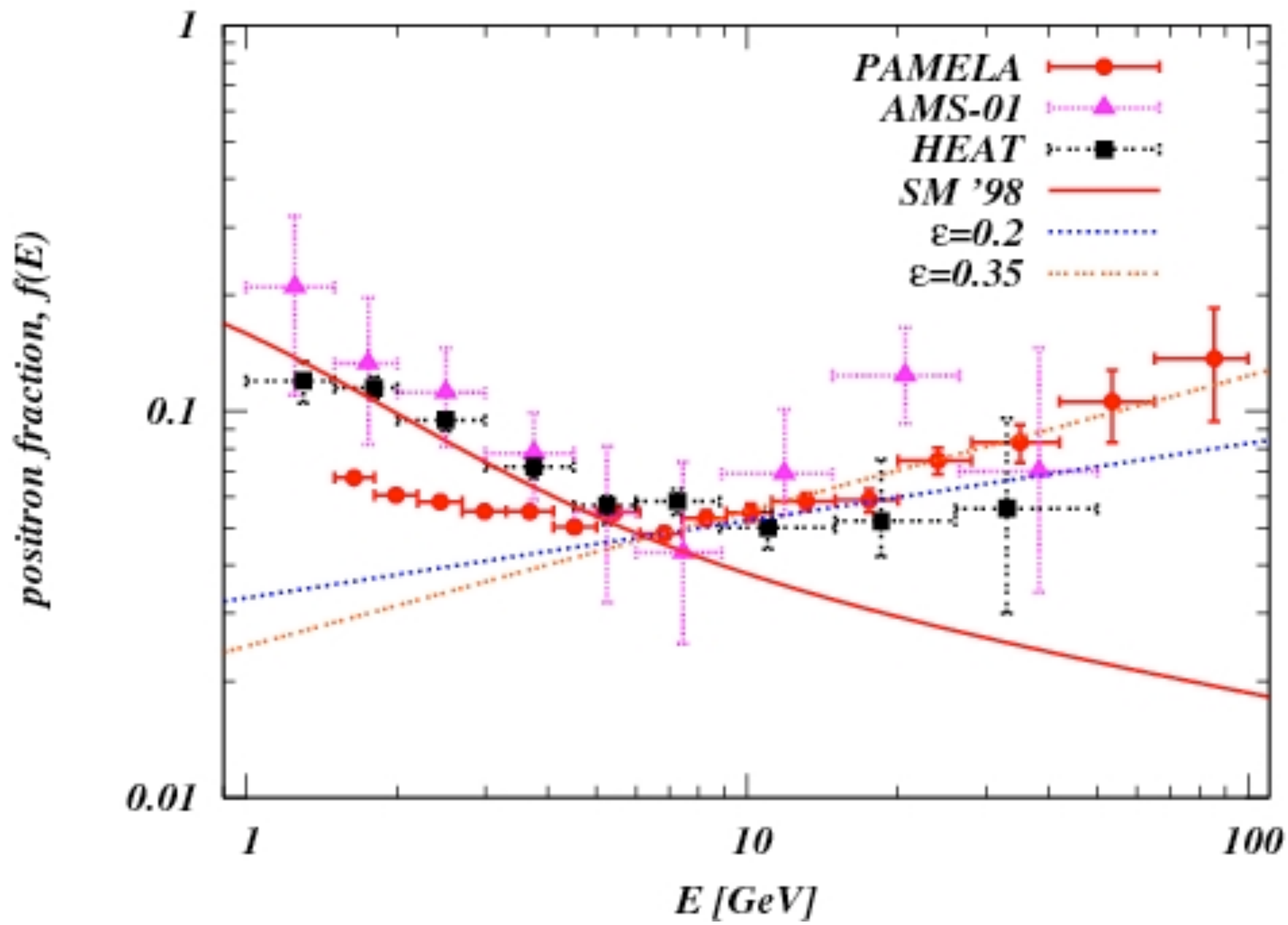


Positron Fraction data



Abdo et al. arXiv:0905.0025, PRL
Grasso et al. arXiv:0905.0636

The conclusion is:



$$\rho = \delta + \gamma_p - \gamma_- \approx -0.35 < 0 \;\; at \;\; E \geq 7 \;\; GeV$$

Rather than "the excess" over a (more or less robustly estimated) background, it is the slope seen in *f(E)* which seems to imply a new class of e^+ (or more likely e^+e^-) CR "accelerators"!

Possible Loopholes in the previous arguments

- ✓ Rising cross section at high energy.
- ✓ High energy behavior of the e^+ excess over e^- in secondaries of *pp* collisions.
- ✓ Spectral feature in the proton flux responsible for the secondaries.
- ✓ Role of Helium nuclei in secondary production.
- ✓ Difference between local and ISM spectrum of protons.
- ✓ “Anomalous” energy-dependent behaviour of the diffusion coefficient.

Short answer:
None of them capable of explaining the feature

P.S. arXiv:0810.4846 - PRD 79, 021302(R) (2009)

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Astroparticle Physics 11 (1999) 429–435

Astroparticle Physics

www.elsevier.nl/locate/astropart

Cosmic-ray positrons: are there primary sources?

Stéphane Coutu [a,*], Steven W. Barwick [b], James J. Beatty [a], Amit Bhattacharyya [c], Chuck R. Bower [c], Christopher J. Chaput [d,1], Georgia A. de Nolfo [a,2], Michael A. DuVernois [a], Allan Labrador [e], Shawn P. McKee [d], Dietrich Müller [e], James A. Musser [c], Scott L. Nutter [f], Eric Schneider [b], Simon P. Swordy [e], Gregory Tarlé [d], Andrew D. Tomasch [d], Eric Torbet [e,3]

Very, very likely the answer is: Yes

What causes the rise?

Whatever you think of, it is crucial it does not to violate other CR constraints!
(better if it can also account for some other “anomaly”)

Pulsars

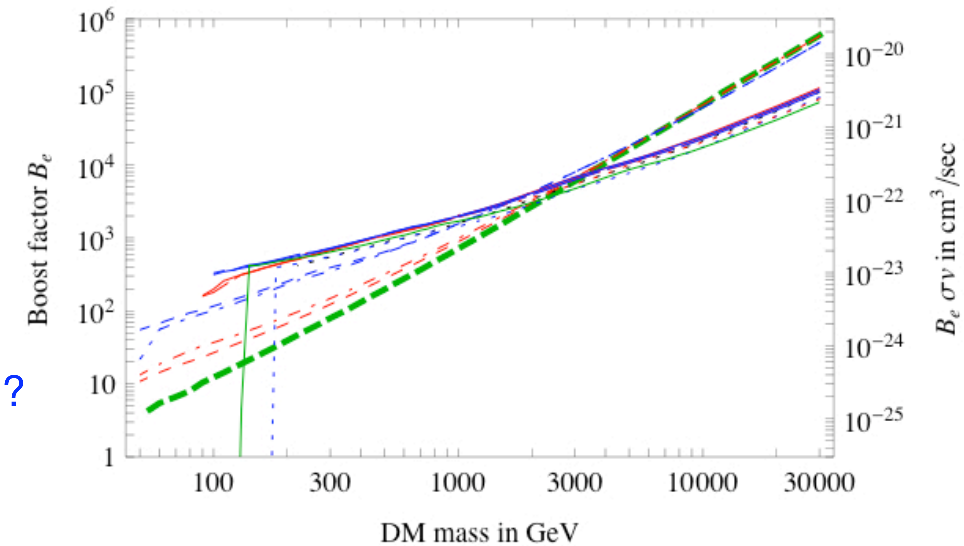
- Complex astrophysics, no “robust predictions”
- “Natural” normalization & shape of the signal
- Purely e.m. cascade, explains why no p-bar

Dark Matter

- For a given model, spectra “easily” predicted
- Signal requires large enhancement
(non-th.? Decay? Sommerfeld? Clumps?):
in all cases, ready to give up the “WIMP miracle”?
- Constraints from anti-p, ν and γ-ray data

A dark horse: mature SNRs?

- In situ production is certain at some level.
- How large hard to calculate reliably a priori,
most likely must be answered observationally.
- Prediction of high-energy feature in p-bar



M. Cirelli et al. arXiv:0809.2409

Pulsars

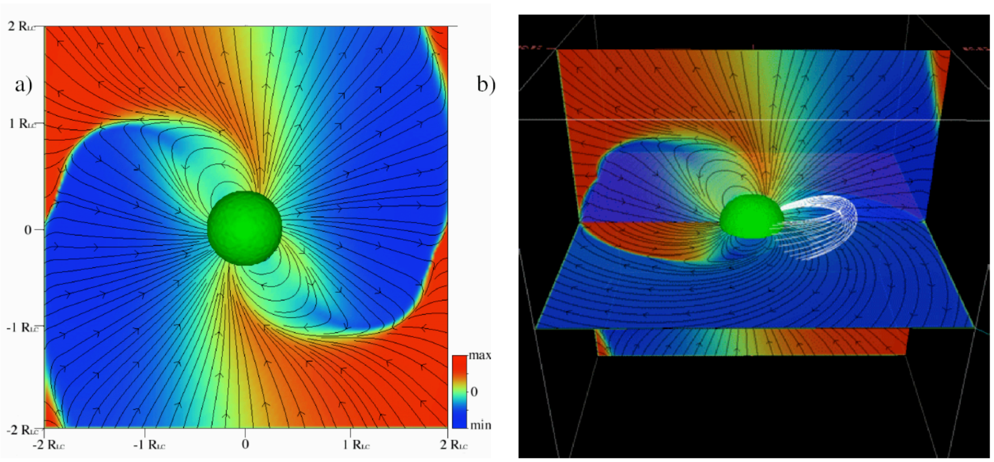
➢ Magnetized NS with non-aligned rotation and magnetic axes: *Pacini, Gold 1967-68.*

➢ They lose rotational energy and spin-down through e.m. torques due to large-scale currents in their magnetospheres.

➢ Only qualitative ideas on their structure: analytic expression exists for the vacuum rotator but real pulsars are not in vacuum since e^{+-} e^{-} are copiously produced due to the high surface electric fields induced by rotation

➢ One must rely on numerical solutions, which present several challenges.
Very active field in astrophysics:

- First consistent solution axisymmetric case: *Contopoulos, Kazanas & Fendt (1999)*
- First time-dependent simulations in 3D: *Spitkovsky (2006).*

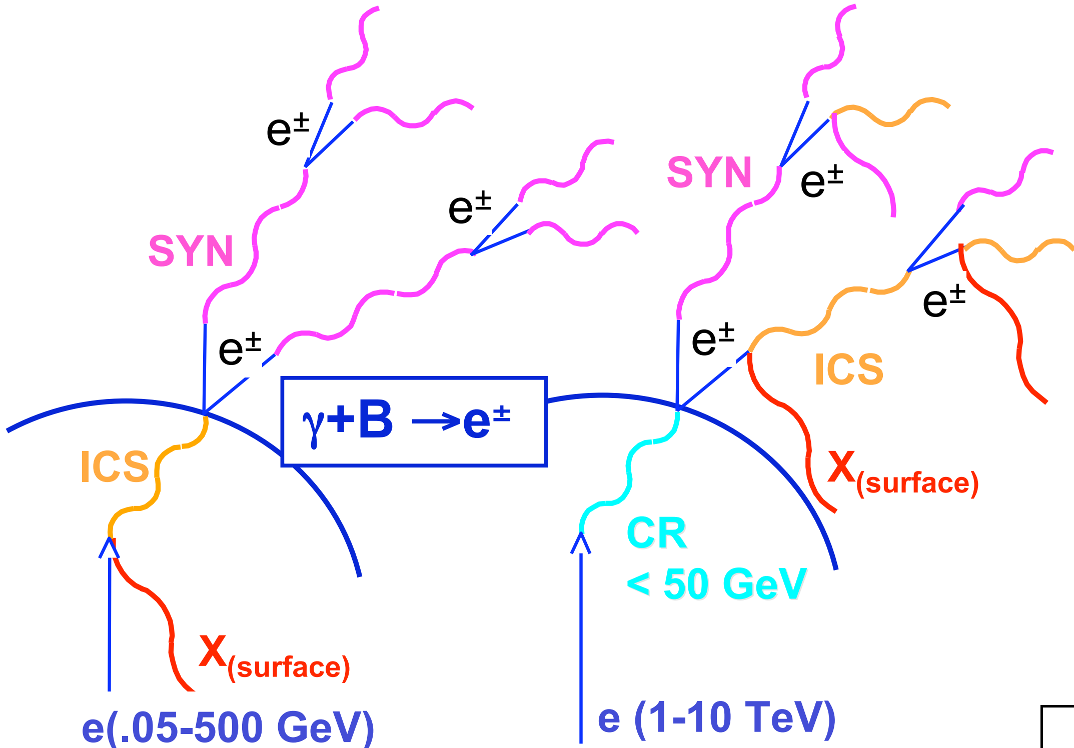


Force-free electrodynamics:

$E \cdot B = 0$ everywhere

No accelerator gaps!

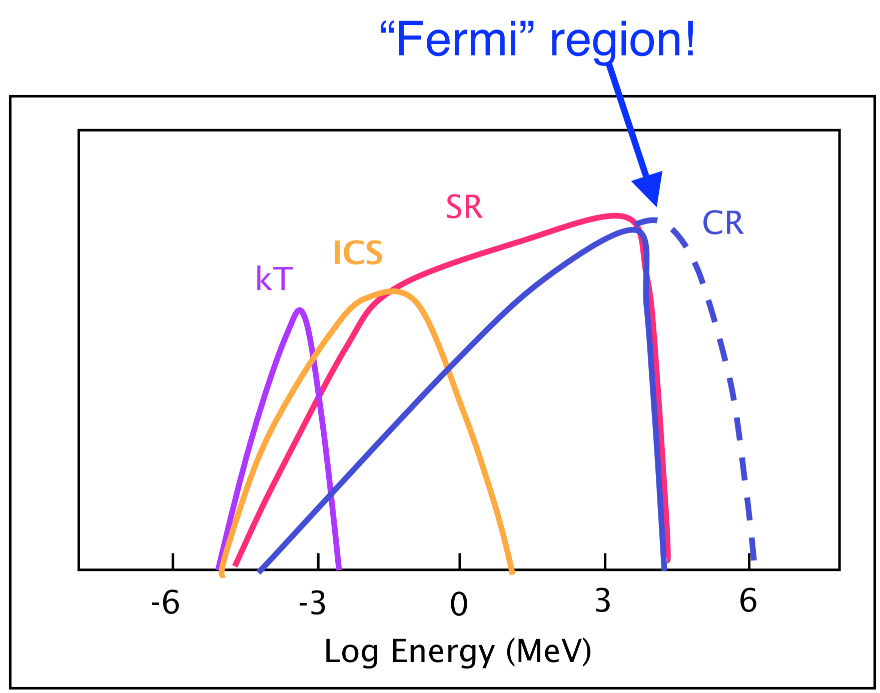
Pulsars: Basic of pair cascade mechanism



e^+ and e^- are accelerated by $E_{||}$

Relativistic e^+/e^- emit γ-rays via synchro-curvature, and IC

γ-rays collide with soft photons/B producing pairs in the accelerator

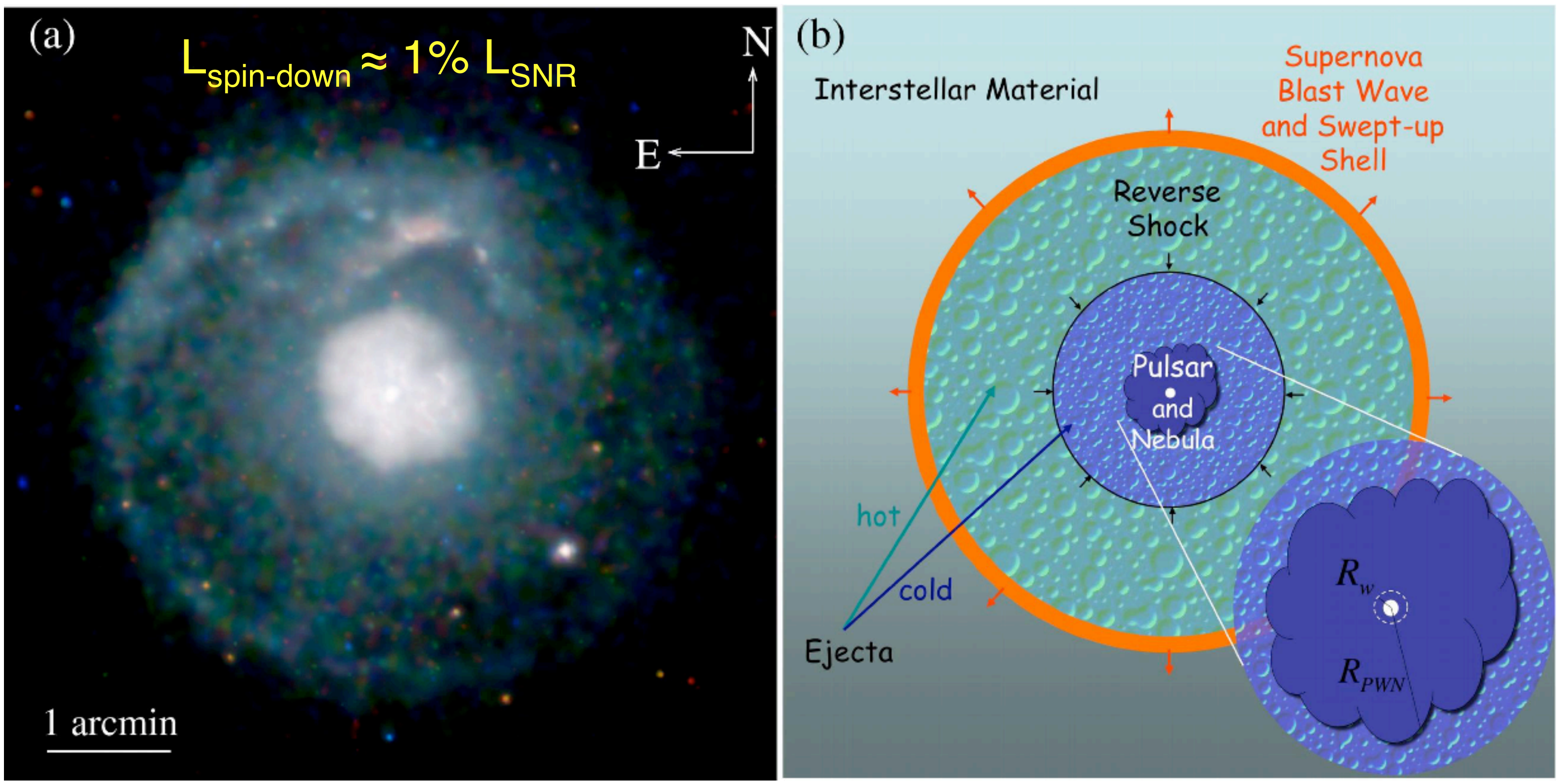


Different models exist depending on location & geometry of "gaps" (where $E.B \neq 0$)

Constrained via γ-ray spectra (possibly high-energy cutoff!), phase-profile, multi-wavelength (radio to γ) constraints.

Emission at magnetosphere is not the whole story…

- ✓ Production at magnetosphere: dependence on B,Ω,geometry…
- ✓ Propagation in the PWN, then circumstellar environment: shock reacceleration!
- ✓ Escape in the ISM after the PWN breaks-up, after ~10^5 years



X-ray Chandra image of "composite" SNR G21.5-0.9
(here, no reverse shock of ejecta deceleration moving inward, yet)

Gaensler & Slane
astro-ph/061081

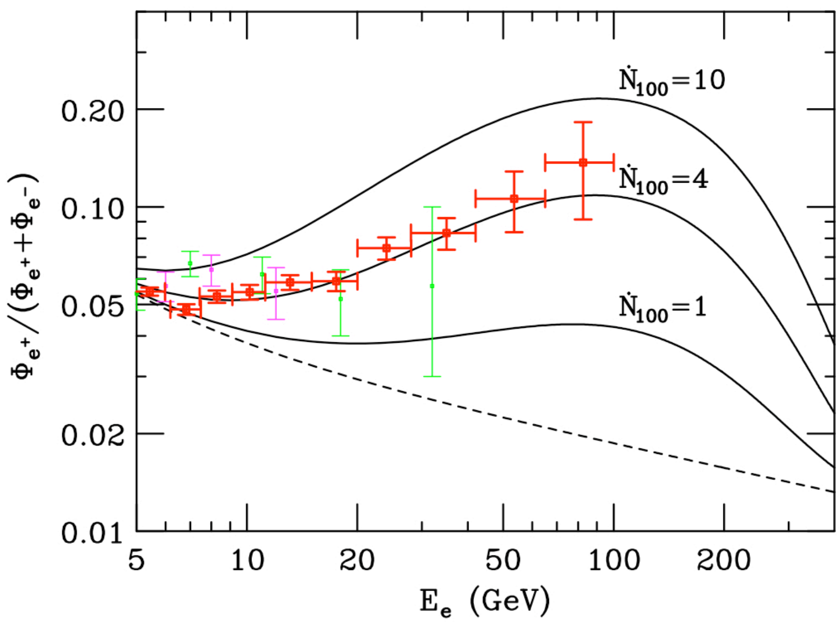
Prediction of a 'population model' of pulsars

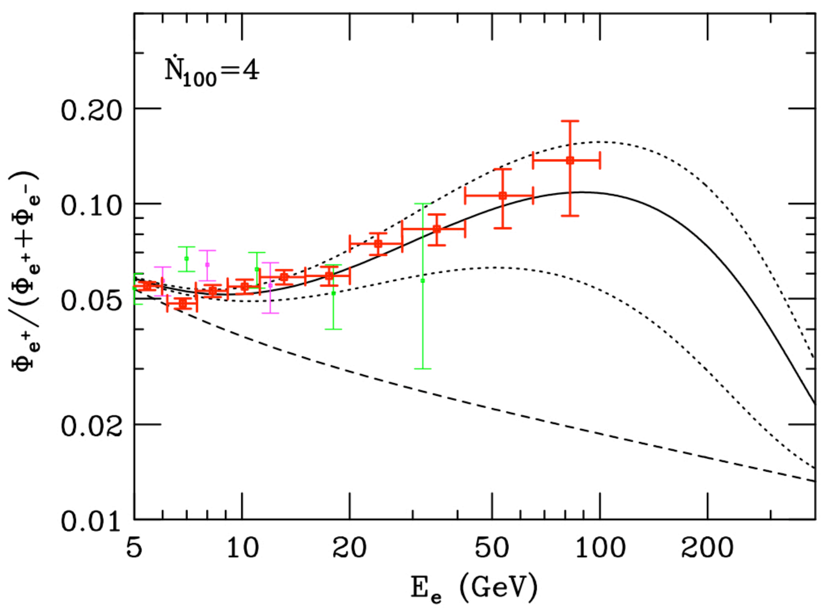
Once fixed a model for the emission (dependence on B, age…) a population study with Galactic population of Pulsars is needed

$$Q(E,\vec{x}) \approx 8.6\times 10^{38}\ p(\vec{x})\ \dot{N}_{100}\ E_{GeV}{}^{-1.6} Exp(-E_{GeV}/80)\ GeV^{-1}\ s^{-1}$$

For example: L. Zhang and K. S. Cheng, Astron. Astrophys. 368, 1063-1070 (2001)

Account for Propagation/Energy losses…

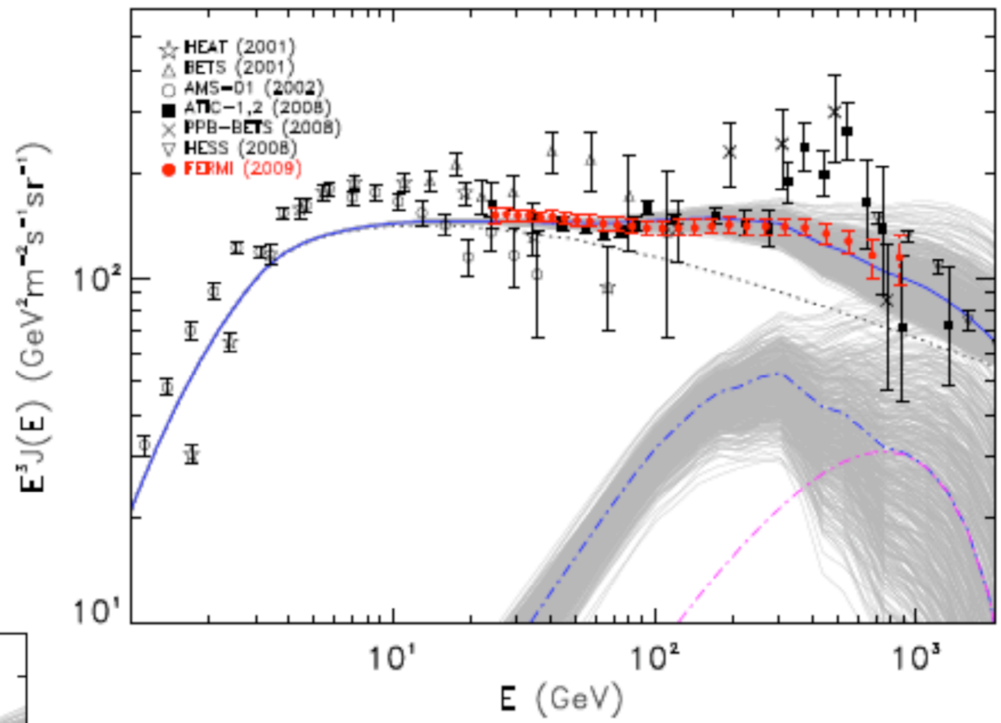


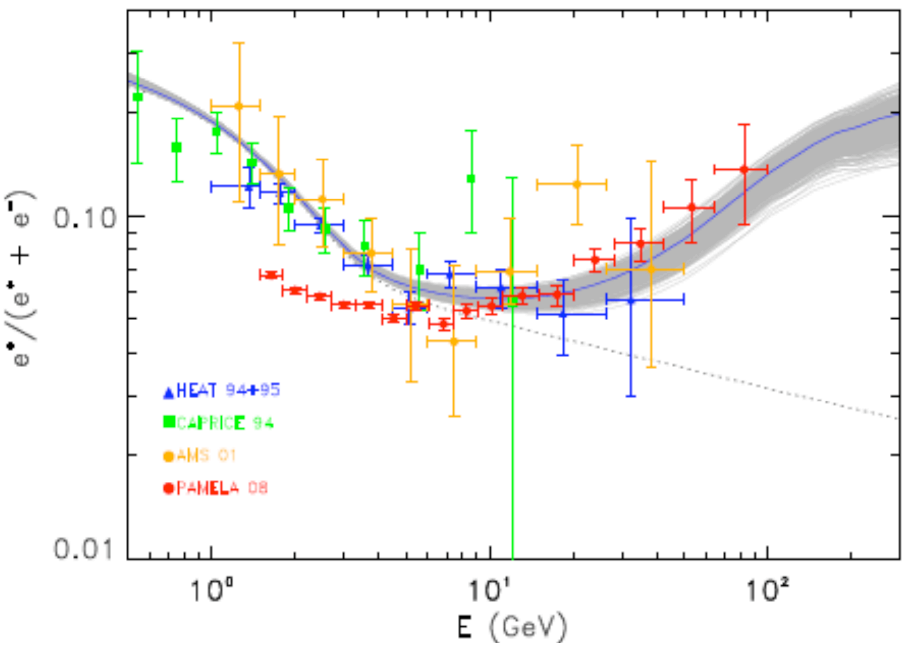


For details: D. Hooper, P. Blasi, PS, JCAP 0901:025 (2009) [arXiv:0810.1527]

Contribution of local sources

Especially at High Energy (E>50-100 GeV) few prominent nearby sources should give dominant contributions (Monogem,Geminga,…)





D. Grasso et al.
arXiv:0905.0636 (and refs. therein)

Issues with DM interpretation

A large "enhancement" with respect to S-wave thermal relic is required

$$B \sim 10 \left(\frac{m_X}{100\,\mathrm{GeV}}\right)^{1.7}$$

Might be due to astrophysics?

In principle, local clump (Hooper, Stebbins, Zurek 0812.3202) but theoretically very unlikely:
Requires fine tuning & γ-rays should have been seen (Bringmann, Lavalle, Salati 0902.3665)

Might be due to "Particle Physics"?

- Sommerfeld enhancement (large m & light mediator of long-range forces, some fine-tuning)
- Non-thermal relic? Add another parameter and gives up WIMP miracle!!!
  - If annihilating, usually excluded by other considerations
  - Decaying? Possible, requires careful modeling (e.g. trilinear RPV rather than bilinear)

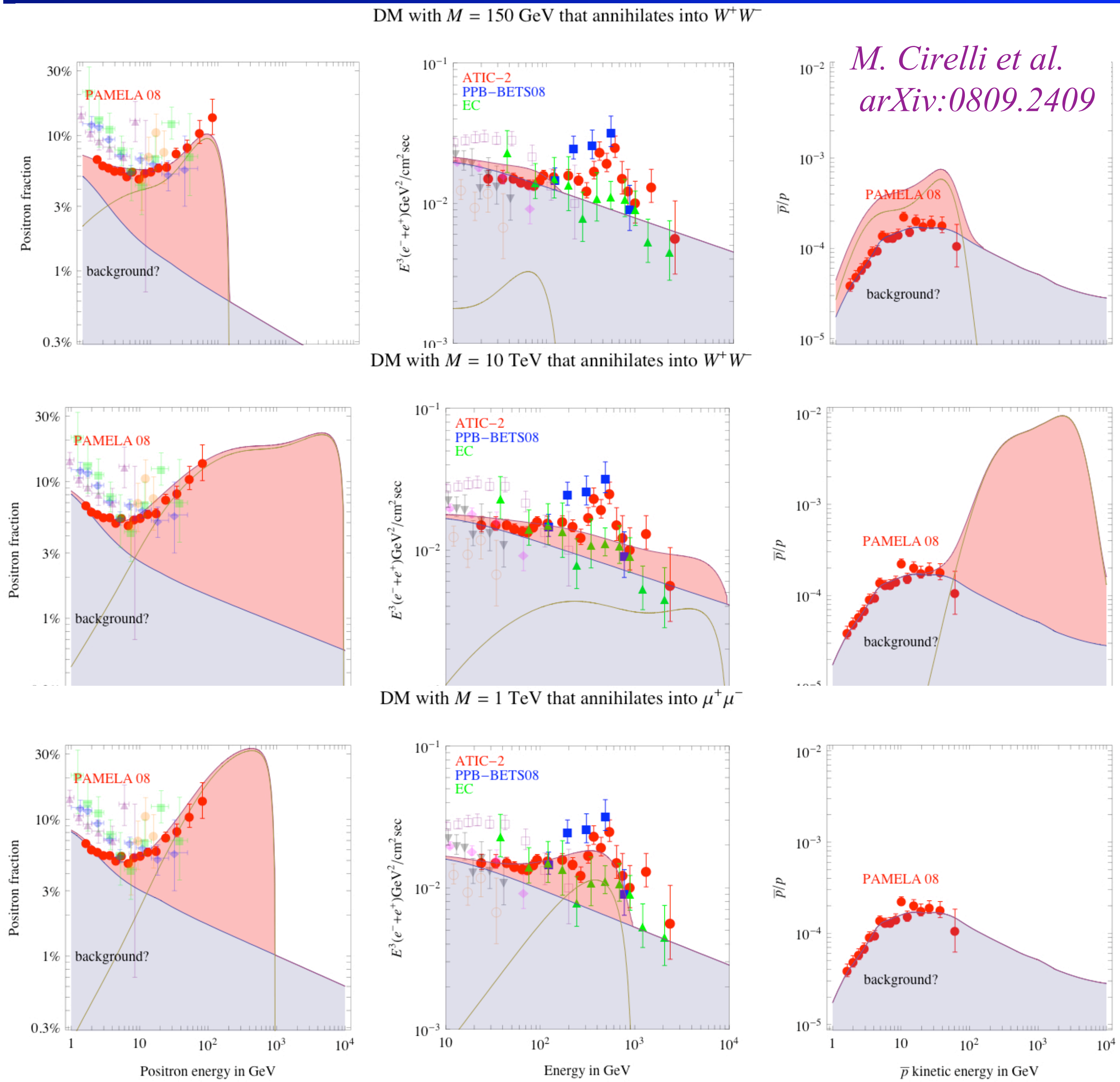
Other constraints require a dominant b.r. in leptonic final states.

- Requires some level of "model-engineering"

After some remarks I'll focus on the main issue:

How to disentangle from astrophysics?
Are there specific signatures?

Some general consideration on annihilating DM



M. Cirelli et al. arXiv:0809.2409

$$Q = \frac{\rho^2(\vec{x})}{m^2}\frac{<\sigma v>}{2}\frac{dN}{dE}$$

- *Heavy particles (≥TeV)*
- *Large normalizations*
- *Must suppress p-bar*
- *Cored Halo to avoid γ (& SK ν!) constraints*
- *…*

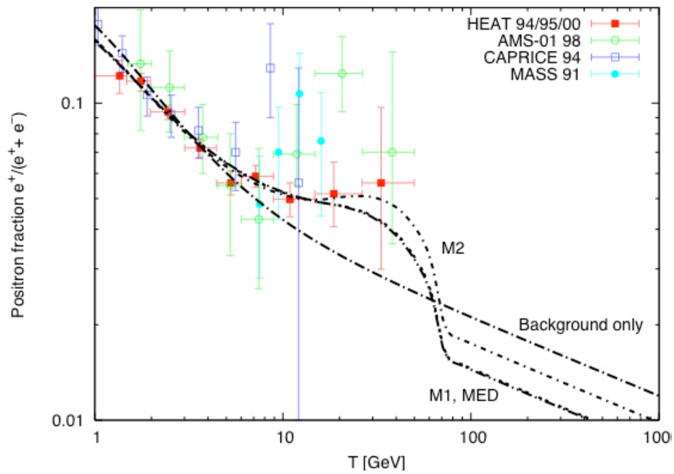
Decaying DM

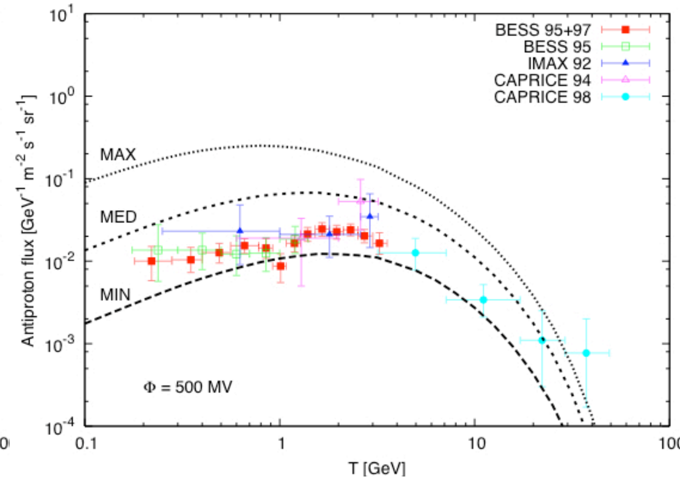
A. Ibarra and D.Tran, arXiv:0811.1555

Gravitino in R-parity violating SUGRA. p-bar problem?

$$\psi_{3/2} \to W\,\ell\,/\;Z\,\nu$$

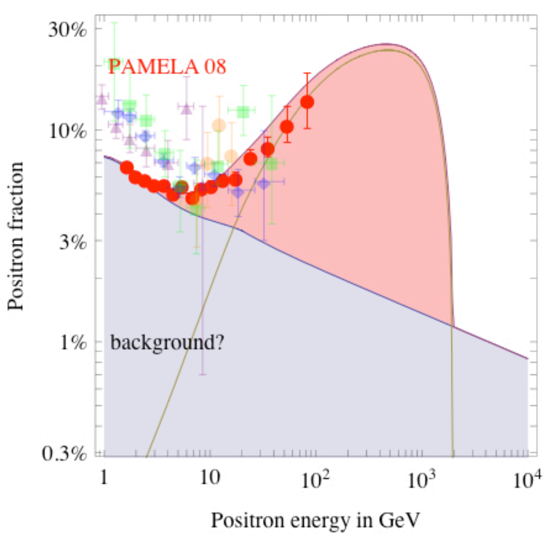
$$m_{3/2} \approx 150\;GeV,\;\; \tau_{3/2} \approx 10^{26}\,s$$



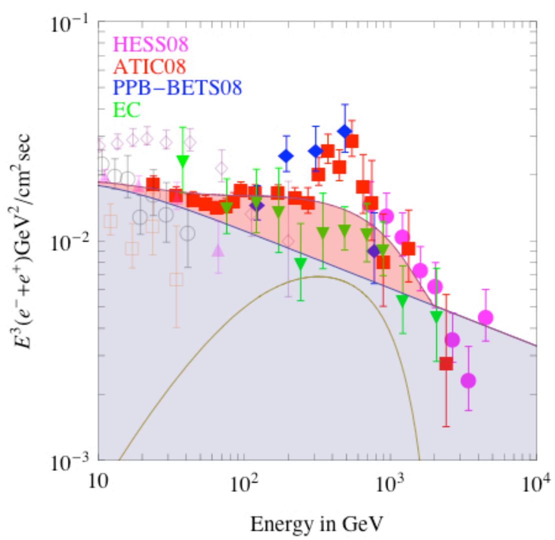


$$Q(E,\vec{x}) = \rho(\vec{x})\;\frac{\Gamma}{m}\frac{dN}{dE}$$

No "vanilla-model candidate", No "obvious" fit either…

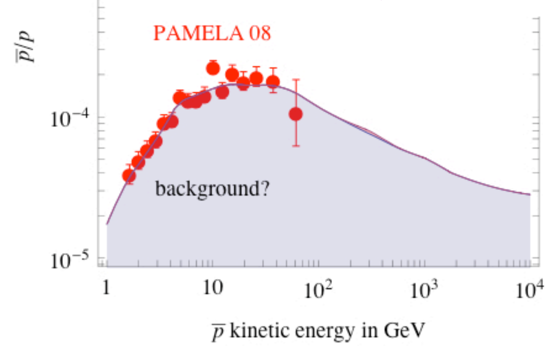


DM with $M = 4$ TeV that decays into $\tau^+\tau^-$



Quasi-stable composite particle with a baryon-like matter asymmetry. (Technicolor-inspired model)

E. Nardi, F. Sannino and A. Strumia, arXiv:0811.4153



Decaying DM: who ordered it?

Fitting data with DDM gives up the "WIMP" miracle argument

A (meta)stable particle has a long lifetime due to some symmetry:

- The electron is stable due to electric charge conservation
- A DM candidate is assumed to be stable due to some new discrete symmetry (R-parity…)

- ➢ The proton is stable due to baryon number conservation, but not true in GUT!
- ➢ Same operators mediating "rare" p-decays might be involved in the DM decay?!

Naïve estimate for the lifetime:

$$\tau_{DM} \approx 8\pi \frac{M_{GUT}^2}{m_{DM}^3} \approx 7\ s \left(\frac{TeV}{m_{DM}}\right)^3 \left(\frac{M_{GUT}}{2\times 10^{16}\,GeV}\right)^2$$

From Dim 5 Operator
Related to metastable particles decaying at BBN epoch?
Solves perhaps "Lithium problems"?

$$\tau_{DM} \approx 8\pi \frac{M_{GUT}^4}{m_{DM}^5} \approx 3\times 10^{27}\,s \left(\frac{TeV}{m_{DM}}\right)^5 \left(\frac{M_{GUT}}{2\times 10^{16}\,GeV}\right)^4$$

From Dim 6 Operator
Explains PAMELA/ATIC results?

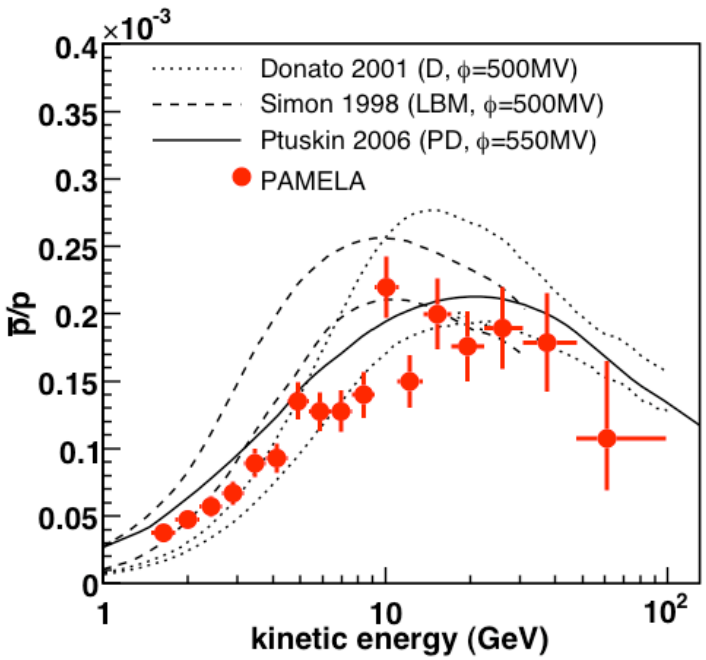
For further considerations along these lines: *Arvanitaki, Dimopoulos, Dubovsky, et al. arXiv:0812.2075*

Disentangling Pulsars from DM (I)

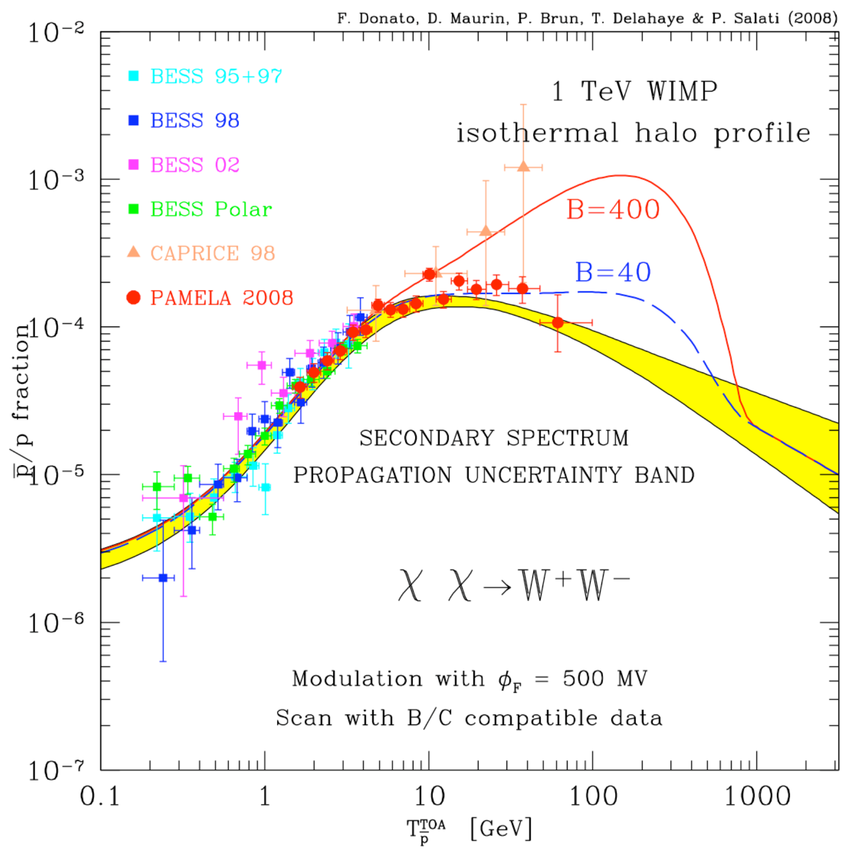
- ✓ *Antiprotons (& anti-D)*
- ✓ *Possible anisotropy*
- ✓ *Shape of the cutoff in e-flux feature (IACTs?)*
- ✓ *γ-rays: Fermi should find high-latitude diffuse excess vs. unresolved/unidentified point-sources*
- ✓ *Often, new (meta)stable particle at colliders (but troubles for ~TeV hadrophobic particles…)*
- ✓ *Improved ν-bounds from Galactic Center, …*

- Antiprotons consistent with pure CR spallation background
- Exclude "universal" BF ~ needed to fit e^+
- Fraction for "typical" WIMP annihil. modes

(astro-sources typ. predict no pbar excess)



O. Adriani et al. [PAMELA collab] PRL 102 051101 (2009)

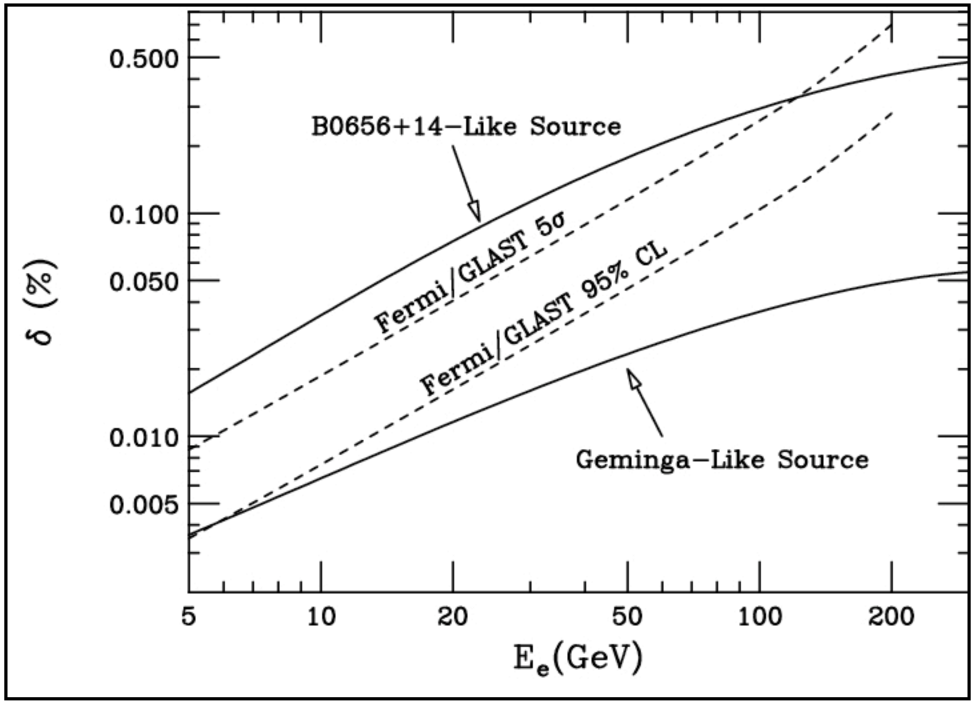


Disentangling Pulsars from DM (II)

- ✓ *Antiprotons (& anti-D)*
- ✓ *Possible anisotropy*
- ✓ *Shape of the cutoff in e-flux feature (IACTs?)*
- ✓ *γ-rays: Fermi should find high-latitude diffuse excess vs. unresolved/unidentified point-sources*
- ✓ *Often, new (meta)stable particle at colliders (but troubles for ~TeV hadrophobic particles…)*
- ✓ *Improved ν-bounds from Galactic Center, …*

- Anisotropy in the total e-flux at ~0.1% level towards Galactic plane for nearby astro sources
- DM could mimic if from "clump", but unlikely oriented towards GP

D. Hooper, P. Blasi, PS, JCAP 0901:025 (2009)
I. Bueschling et al. arXiv:0804.0220 (APJL)



Disentangling Pulsars from DM (III)

✓ *Antiprotons (& anti-D)*

✓ *Possible anisotropy*

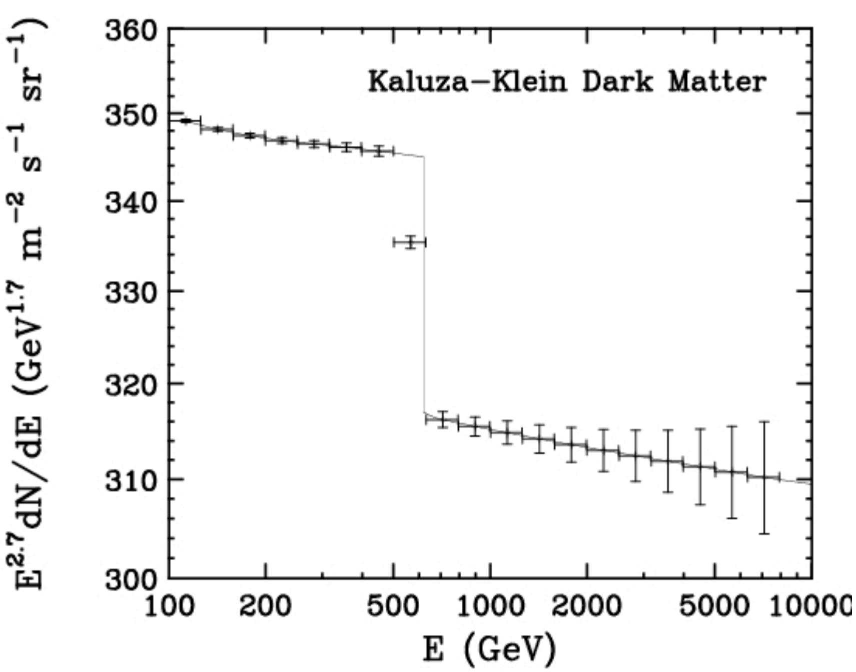
✓ *Shape of the cutoff in e-flux feature (IACTs?)*

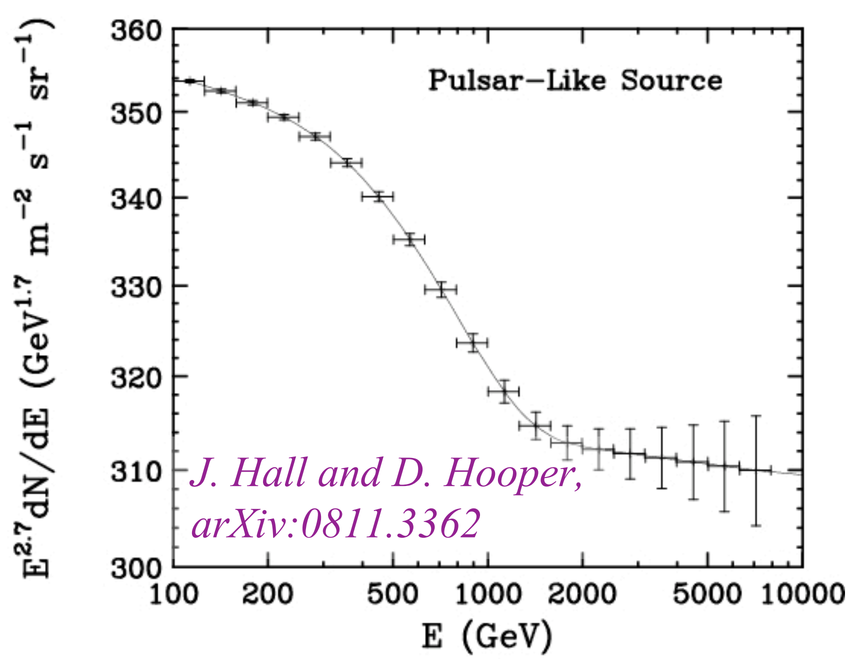
✓ *γ-rays: Fermi should find high-latitude diffuse excess vs. unresolved/unidentified point-sources*

✓ *Often, new (meta)stable particle at colliders (but troubles for ~TeV hadrophobic particles…)*

✓ *Improved ν-bounds from Galactic Center, …*

• In some DM models (e.g. KK) sharper cutoff, Harder to achieve for astrophysical models. (But the feature can be spoiled by propagation effects, see *M. Pohl, arXiv:0812.1174*)



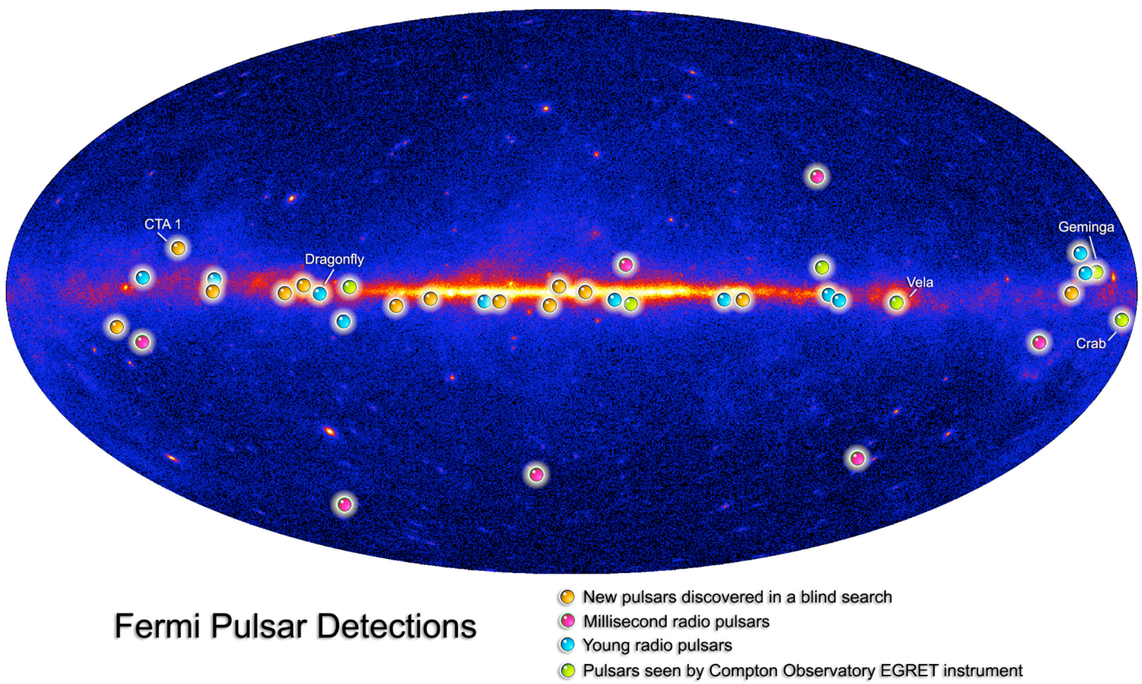


J. Hall and D. Hooper, arXiv:0811.3362

Disentangling Pulsars from DM (IV)

- ✓ *Antiprotons (& anti-D)*
- ✓ *Possible anisotropy*
- ✓ *Shape of the cutoff in e-flux feature (IACTs?)*
- ✓ *γ-rays: Fermi should find high-latitude diffuse excess vs. unresolved/unidentified point-sources*
- ✓ *Often, new (meta)stable particle at colliders (but troubles for ~TeV hadrophobic particles…)*
- ✓ *Improved ν-bounds from Galactic Center, …*

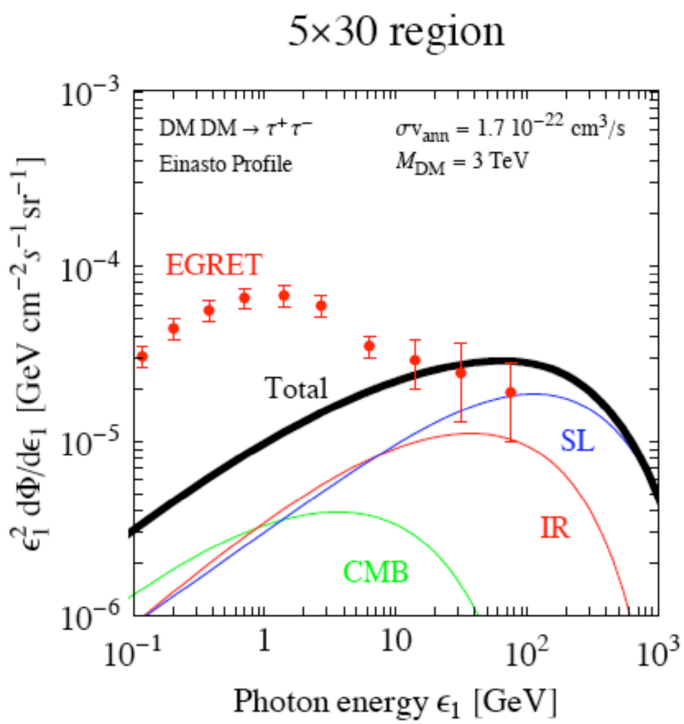
- Only the youngest and/or nearest pulsars were detectable by EGRET
- Yet ~53 radio pulsars in error circles of EGRET unidentified sources! (~20 plausible counterparts)
- First major Fermi discoveries already in this direction! CTA-1, arXiv:0810.3562; http://www.nasa.gov/mission_pages/GLAST/news/dozen_pulsars.html



Fermi Pulsar Detections

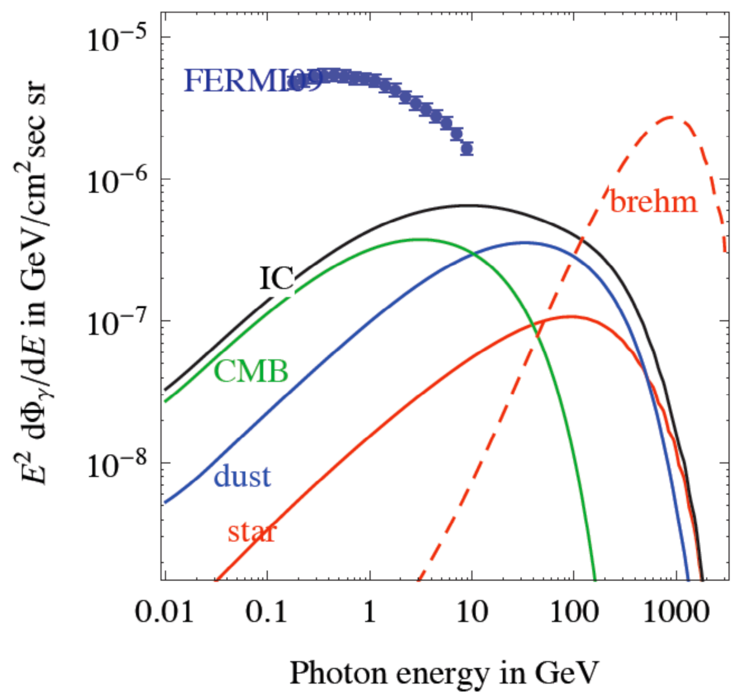
Disentangling Pulsars from DM (IV), cnt'd

- ✓ *Antiprotons (& anti-D)*
- ✓ *Possible anisotropy*
- ✓ *Shape of the cutoff in e-flux feature (IACTs?)*
- ✓ *γ-rays: Fermi should find high-latitude diffuse excess vs. unresolved/unidentified point-sources*
- ✓ *Often, new (meta)stable particle at colliders (but troubles for ~TeV hadrophobic particles…)*
- ✓ *Improved ν-bounds from Galactic Center, …*



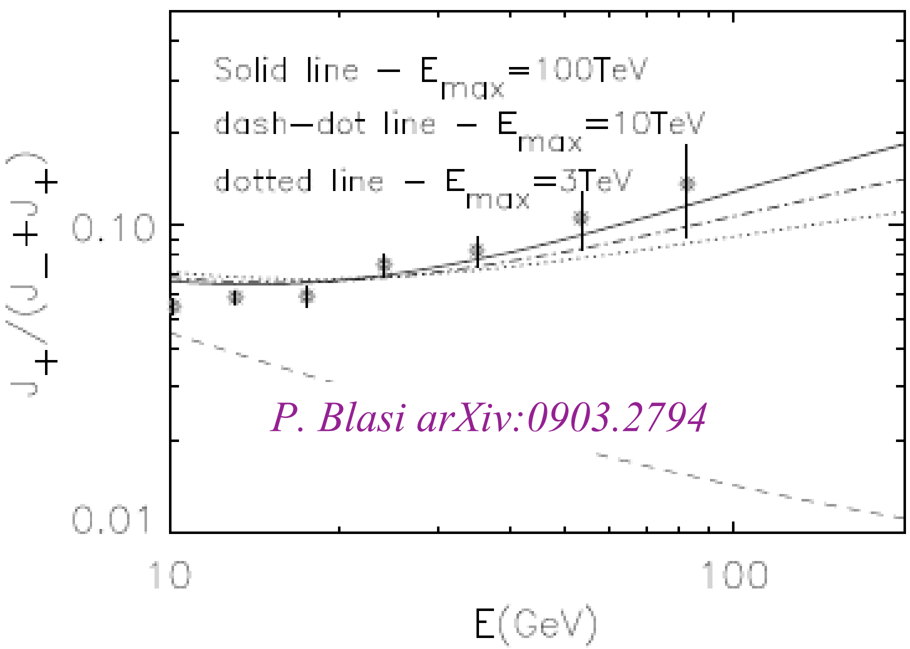
- The fact that DM is distributed in the halo (rather than just in the disk) unavoidably predicts an 'excess' of ICS & Brehm. Radiation from high-Galactic Latitudes

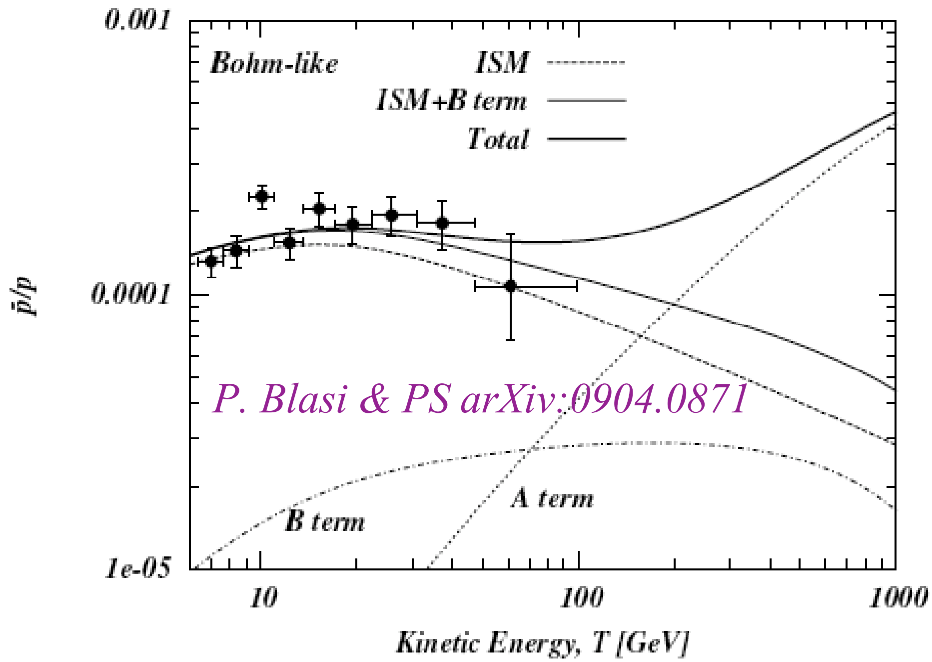
Borriello et al. arxiv:0903.1852;
Regis & Ullio, arXiv:0904.4645;
Cirelli & Panci arXiv:0904.3830;
Meade et al. arXiv:0905.0480



The dark horse: the good, old SNRs

e^+ created in *pp* interactions inside mature SNRs, standard source of sub-TeV CRs.
Crucial physics ingredient: production in the same region where CRs are accelerated.
Secondary e^+e^- have a very flat spectrum.
(Missed) universal effect! But strength depends on environmental parameters in mature SNRs
Might be disproved by antiproton observations.

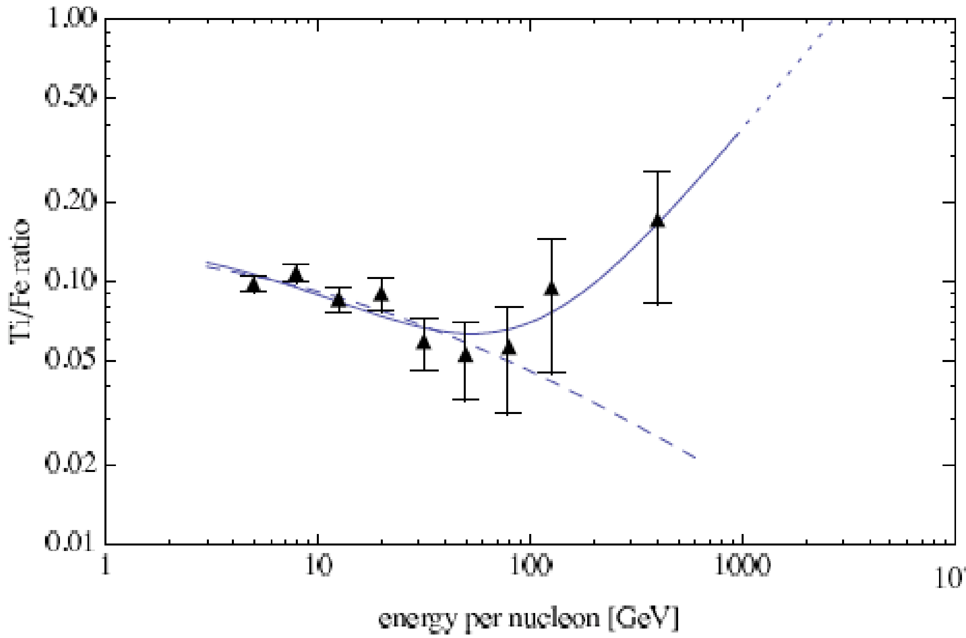




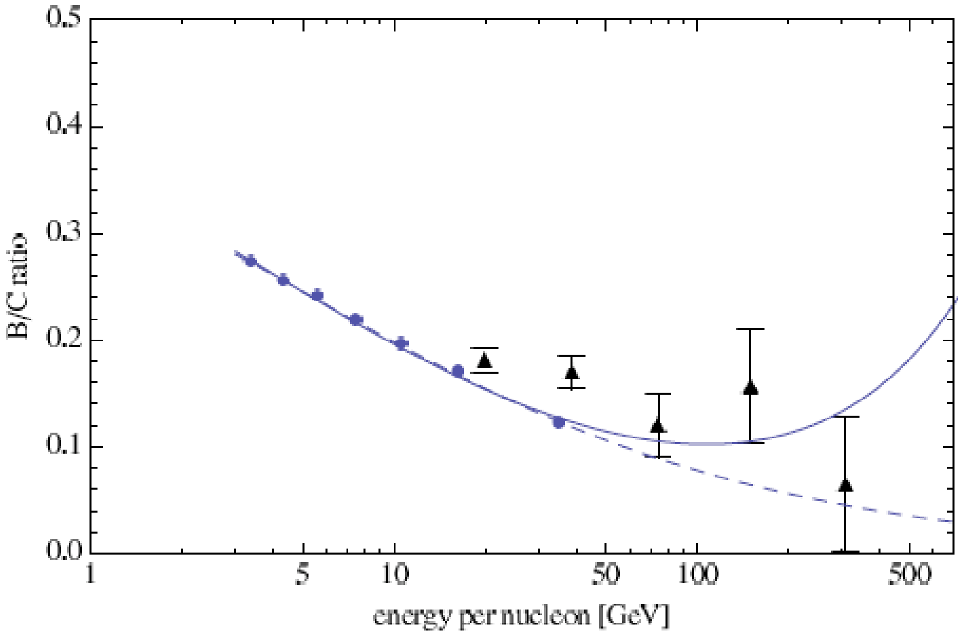
Caveat: astrophysical "backgrounds" to CR antimatter might be less trivial than originally thought! Should we rethink the viability of antimatter for DM searches?

Already some hint? Jury still out!

Mertsch & Sarkar arXiv:0905.3152



Warning I:
from some CR nucleosynthesis data, some HE astrophysicists argue that the bulk of nuclei and the bulk of p are not exactly accelerated in the same medium.



Warning II:
Clearly we need better measurements and over a larger dynamical range

Summary: a new era in High Energy astrophysics

- ❑ Wealth of (multi-wavelength) data ⇒ identification of accelerators & their features! *(X-ray detectors…ACTs, MILAGRO, Fermi…PAMELA, Balloons…ν Telescopes)*

- ❑ Feedback in CRs-Background field is being understood (e.g. in SNRs): validation of the Standard Model of Galactic Cosmic Rays in Progress!

- ❑ Important 'applications' to particle physics: atmospheric ν's, Dark Matter…

- ❑ Barring systematics, I argued that recent positron data suggest a class of energetic pair-producers. Both astrophysical & DM explanations possible.

→ The combined data (p-bar, gammas, electrons, etc.) point likely to astrophysical explanations. Alternatively, to quite exotic DM properties (exciting?!)

→ Further astrophysical data as well as info from colliders & direct detection experiments important to discriminate between possibilities

- ✓ *Info from other messengers: anti-p, ν, γ*
- ✓ *Spectral shapes of e^-+e^+, e^+, e^-, f_{e+} over larger energy range*
- ✓ *Anisotropies*
- ✓ *Refined astro models especially from Fermi*
- ✓ *Info from colliders & Direct detection (more model dependent)*

The power of vision: From Hess Nobel Lecture, 1936

[…] It is likely that further research into "showers" and "bursts" of the cosmic rays may possibly lead to the discovery of still more elementary particles, neutrinos and negative protons, of which the existence has been postulated by some theoretical physicists in recent years.

…and don't forget that the exact sources of CRs are still unidentified, one century after Viktor Hess' discovery: clarifying that would be exciting as well!