Spectra of Cosmic Rays

Flux of relativistic charged particles

$$\phi_a(E, \Omega)$$

[nearly exactly isotropic]

$$a = p, \quad \mathrm{He}, \quad \mathrm{Li}, \quad \mathrm{Be}, \quad \mathrm{B}, \quad \mathrm{C},$$

$$e^-, \quad e^+, \quad \overline{p}$$

Particle density

$$n_a(E) = \frac{4\pi}{\beta\, c}\, \phi_a(E)$$

Power-Law Energy spectra

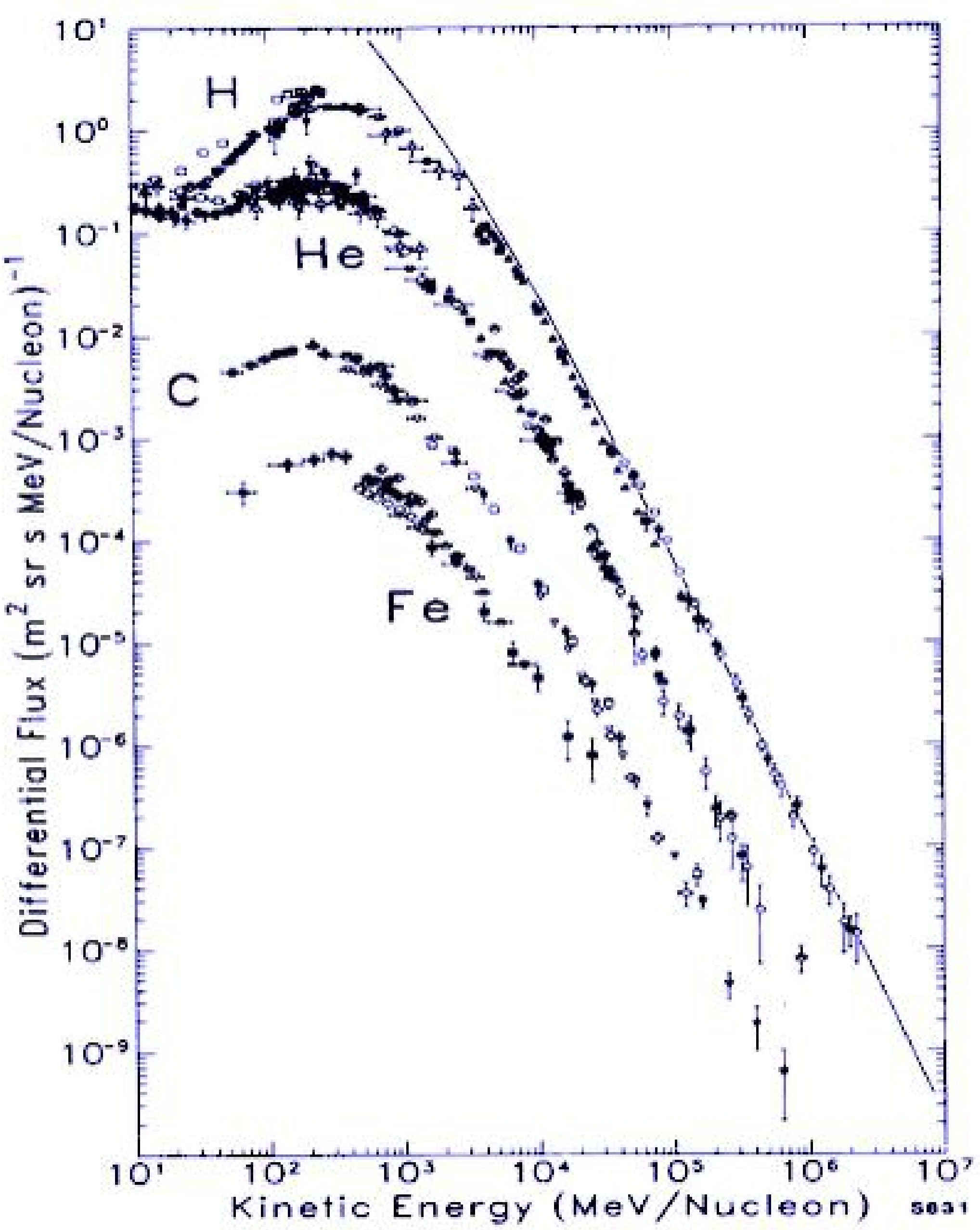


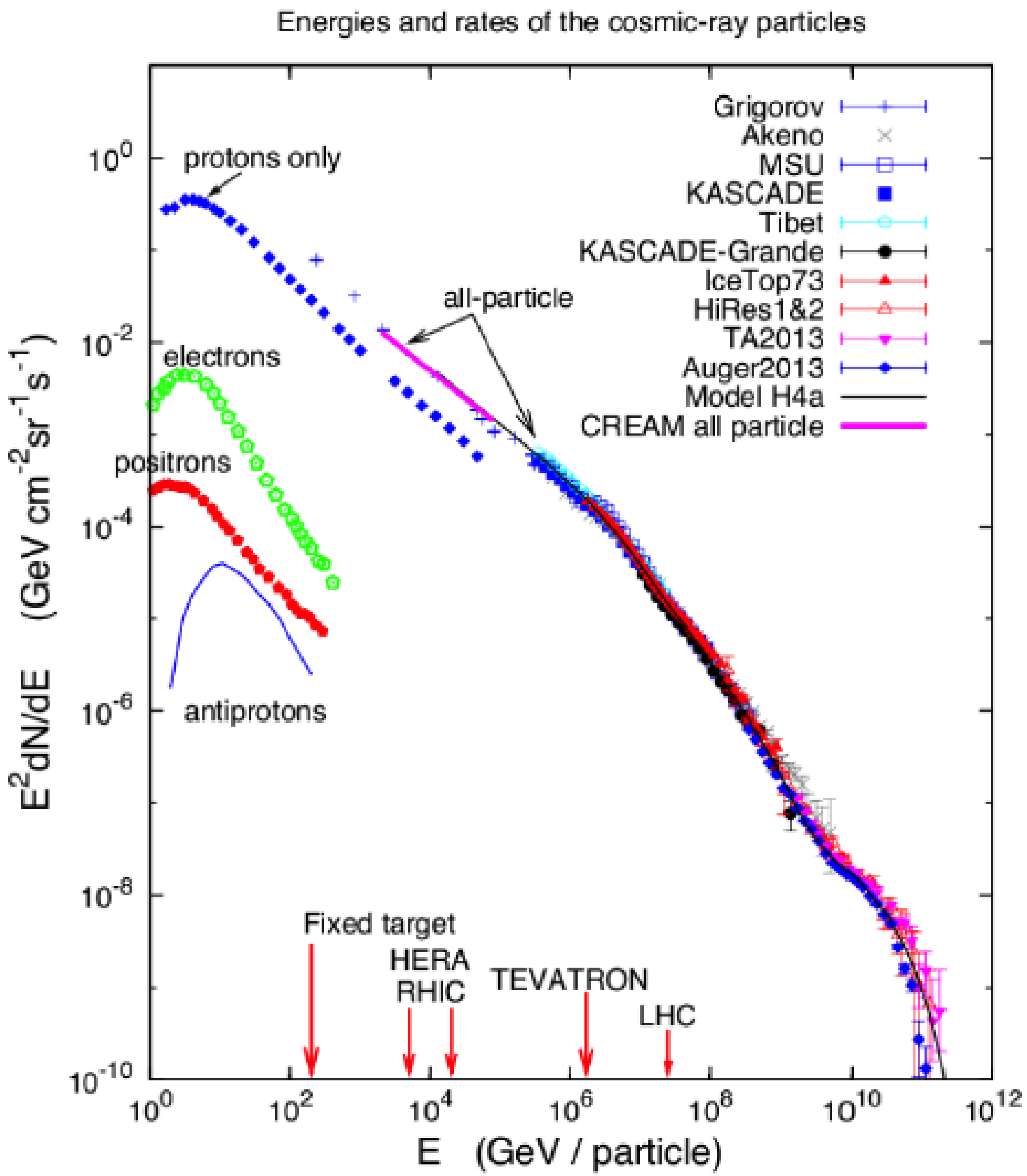
Figure 2. The differential energy spectra of the primary cosmic ray H, He, C, and Fe at Earth. [*Reproduced with permission from J. A. Simpson (1983). Ann. Rev. Nucl. Part. Sci.* **33** *by Annual Reviews, Inc.*].

Exponent (p, Nuclei) :

$$\alpha \simeq 2.7$$

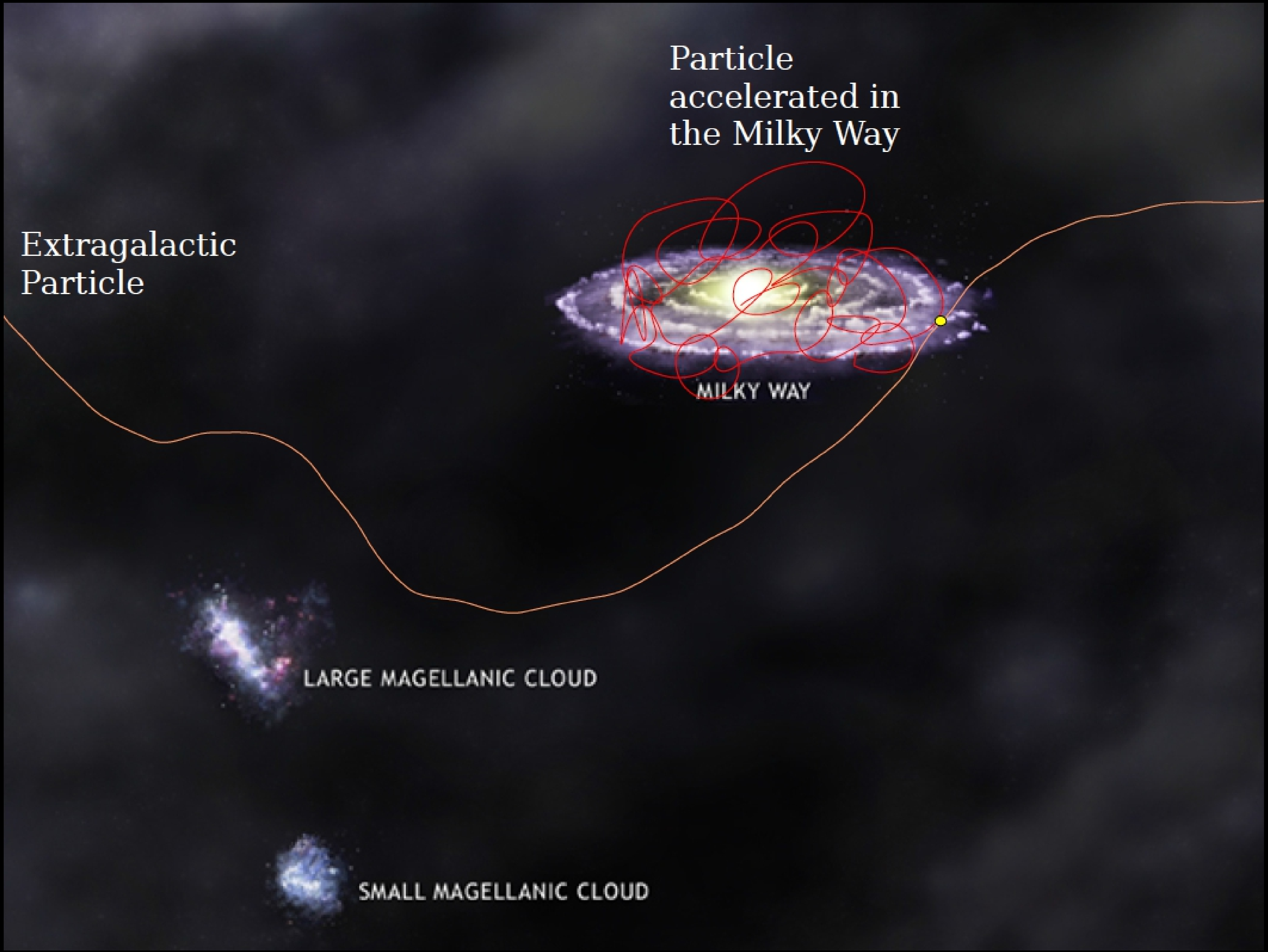
Why power laws ?

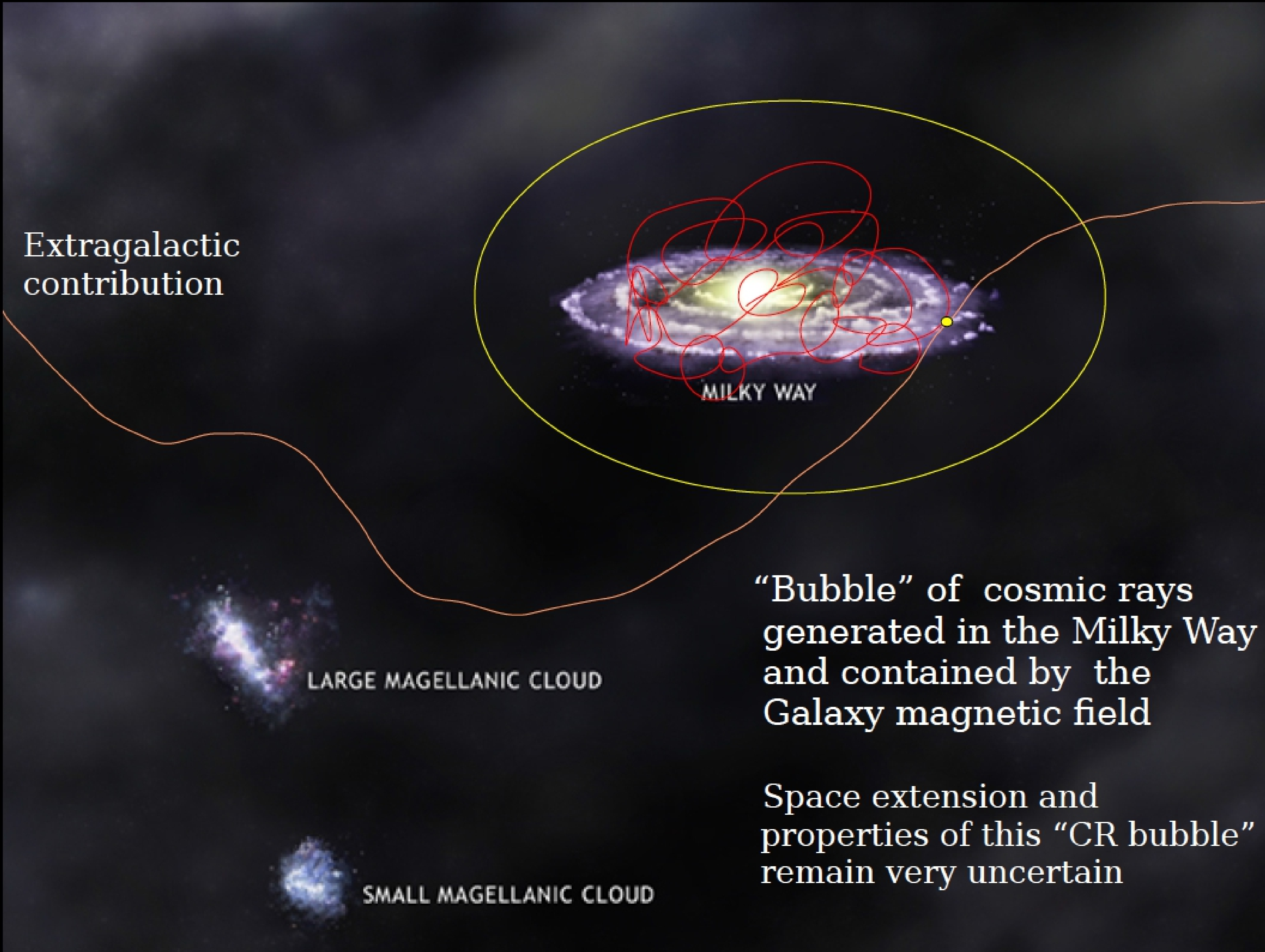
(constraint on the dynamics of the accelerators and propagation)



Electron flux is smaller and *softer* than the proton flux.

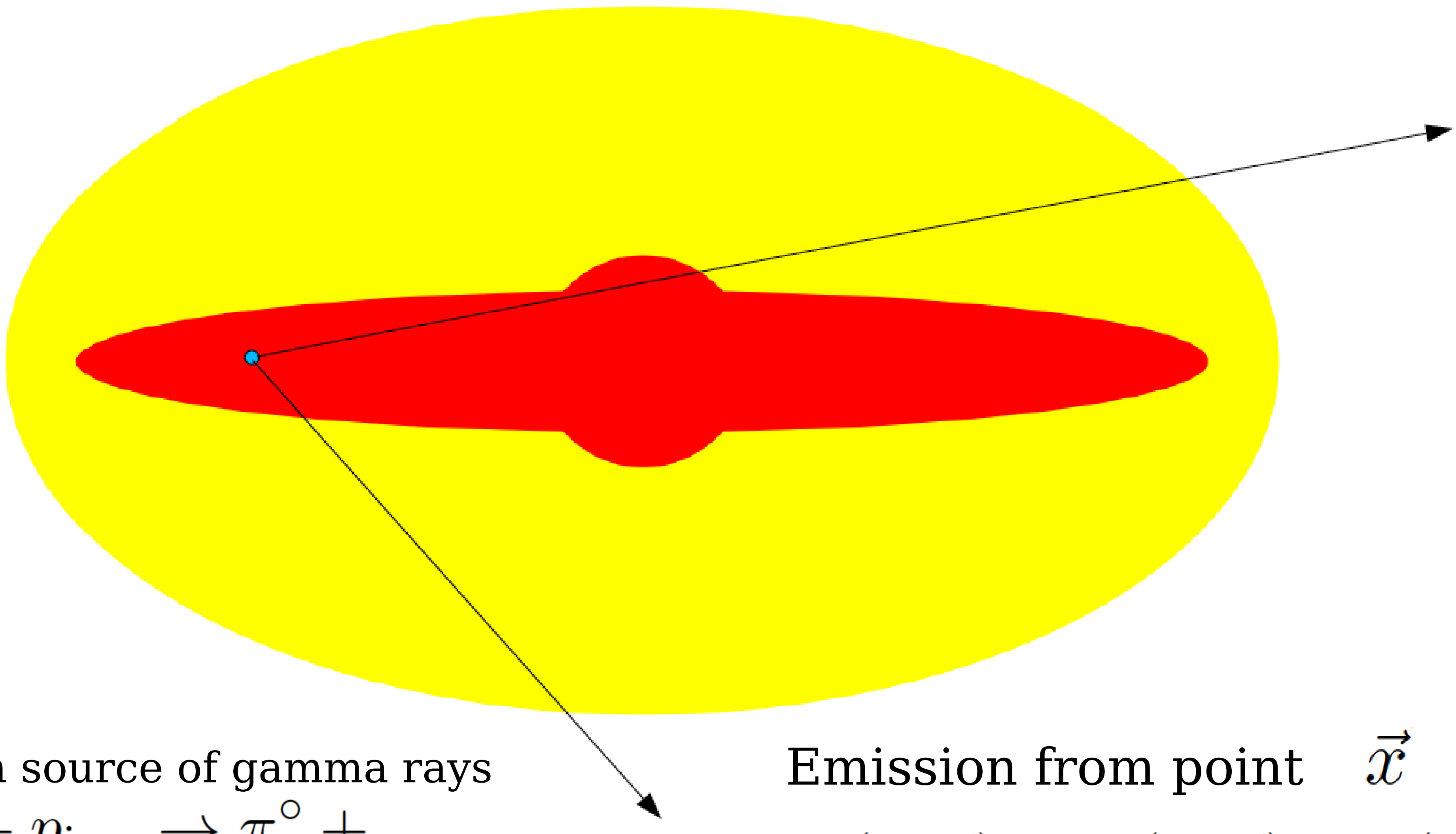
Smaller contributions of positrons and antiprotons


Particle
accelerated in
the Milky Way
Extragalactic
Particle
MILKY WAY
LARGE MAGELLANIC CLOUD
SMALL MAGELLANIC CLOUD


Extragalactic contribution
MILKY WAY
LARGE MAGELLANIC CLOUD
SMALL MAGELLANIC CLOUD
“Bubble” of cosmic rays generated in the Milky Way and contained by the Galaxy magnetic field
Space extension and properties of this “CR bubble” remain very uncertain

Study of cosmic rays
inside the Galaxy (at different positions)

via Gamma Astronomy

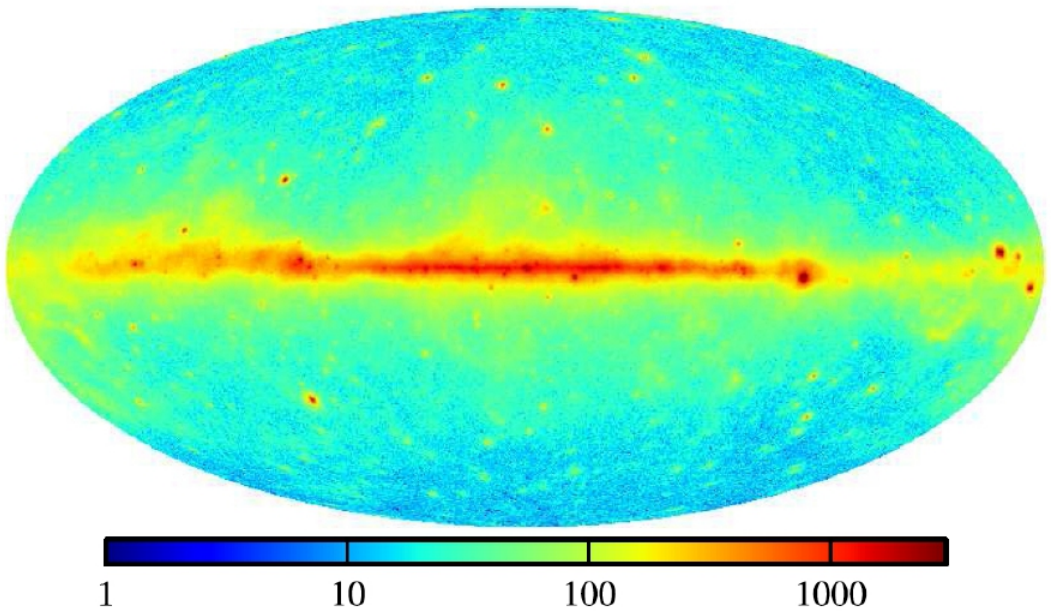


Main source of gamma rays

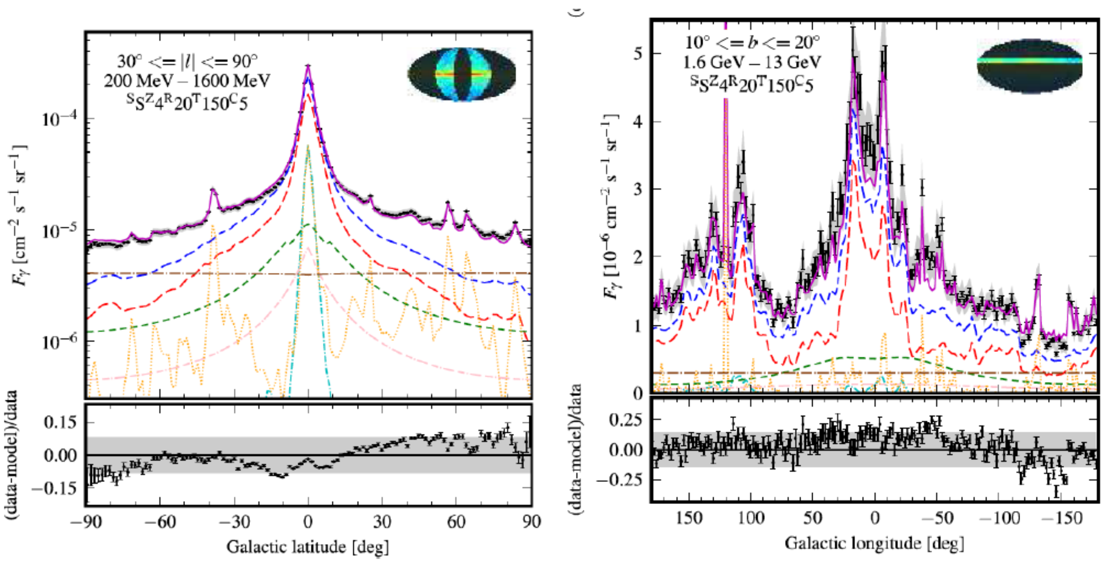
$$p + p_{\rm ism} \to \pi^\circ + \ldots$$
$$\hookrightarrow \gamma \;\; \gamma$$

Emission from point $\vec{x}$

$$q_\gamma(E, \vec{x}) \propto n_p(E, \vec{x}) \; n_{\rm ism}(\vec{x})$$



Map of Fermi-LAT counts (200 MeV – 100 GeV)



Examples of angular distribution

Cosmic rays near the disk of the Galaxy have a spectrum with a position independent shape (and only a small spatial gradient)

Cosmic Ray in the Milky Way:

Injection :

Sources release relativistic charged particles in interstellar space.

Propagation :

The charged particles are (temporarily) trapped by magnetic fields and can travel from the injection point to the Earth.

Flux observed "here"
(near the Sun)
and "now"

$$\phi_a(E)$$

$$\phi_a(E, \vec{x}_\odot, t_{\rm now})$$

$$q_a(E, \vec{x}, t)$$

Injection of Cosmic Rays
(of type a)

$$n_a(E, \vec{x}, t)$$

Density of cosmic rays
(of type a)

$$q_a(E, \vec{x}, t)$$

Injection of Cosmic Rays
(of type a)

↕ Propagation

$$n_a(E, \vec{x}, t)$$

Density of cosmic rays
(of type a)

[density and injection
(after averaging over an appropriate time)
are very likely stationary]

Galactic Cosmic Rays

Dimensional analysis

$$N_j(E) = Q_j(E) \times T_j(E)$$

Different particles

$p, \quad \text{nuclei}(Z, A)$

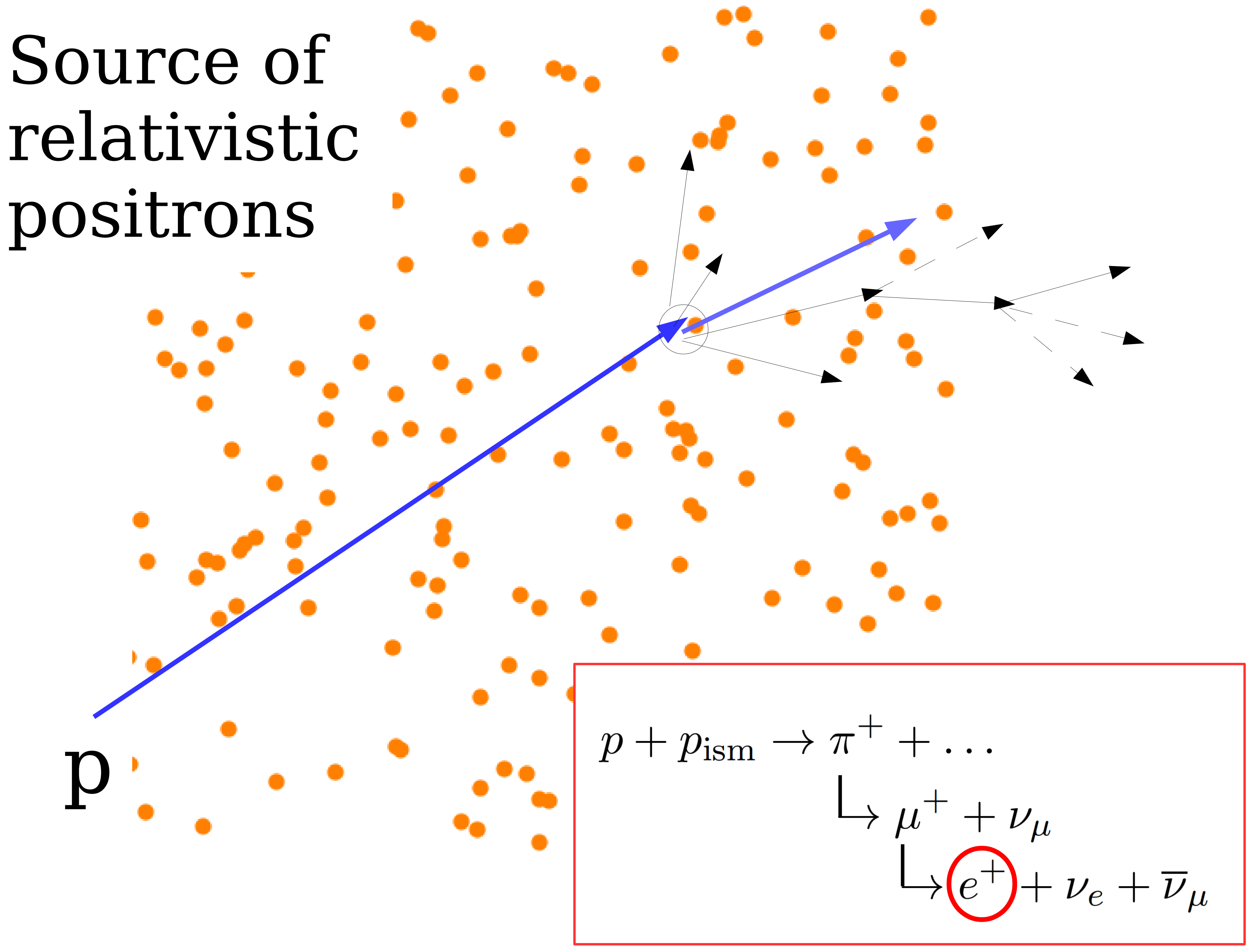
$\overline{p}, \quad e^-, \quad e^+$

Injection
of cosmic rays

Containment
time

$$N_j(E) = \int d^3x \; n_j(E, \vec{x})$$

$$\phi_j(E) = \frac{c}{4\pi} \, n_j(E)$$



Source of relativistic positrons
p
$p + p_{\rm ism} \rightarrow \pi^+ + \ldots$
$\hookrightarrow \mu^+ + \nu_\mu$
$\hookrightarrow e^+ + \nu_e + \overline{\nu}_\mu$

$$q_{e^+} = q_{e^+}^{\text{standard}} + q_{e^+}^{\text{DM}} + q_{e^+}^{\text{astro}}$$

Possible additional sources of relativistic positrons in the Milky Way

1. Dark Matter annihilation (or decay)

2. Astrophysical sources that accelerate positrons.

$$q_{e^+} = q_{e^+}^{\mathrm{standard}} + q_{e^+}^{\mathrm{DM}} + q_{e^+}^{\mathrm{astro}}$$

Possible additional sources of relativistic positrons in the Milky Way

1. Dark Matter annihilation (or decay)

2. Astrophysical sources that accelerate positrons.

Observations:

$$\phi_{e^+} = \phi_{e^+}^{\mathrm{standard}} + \phi_{e^+}^{\mathrm{DM}} + \phi_{e^+}^{\mathrm{astro}}$$

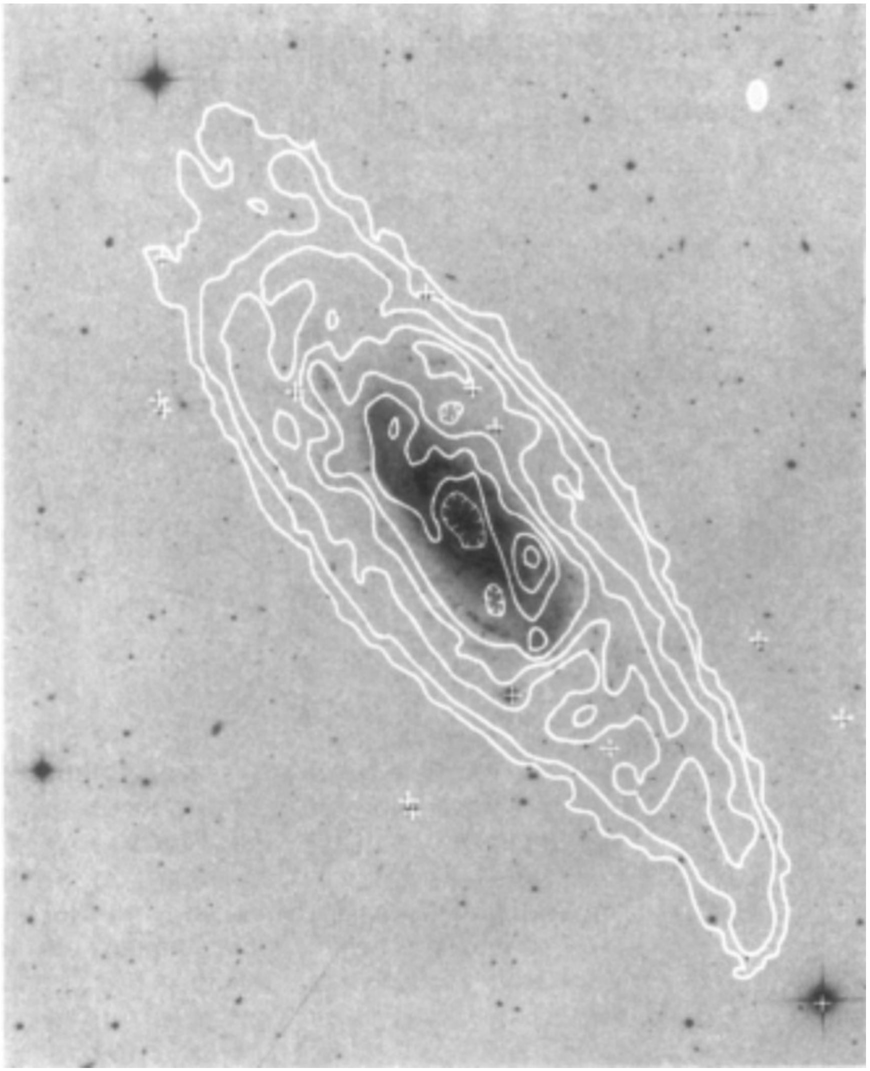
Cold Dark Matter

Cornelia Parker. (Tate Gallery, London)

Dynamical evidence
for Dark Matter
at different length-scales
[Galaxies,
Clusters of Galaxies,
the entire universe]

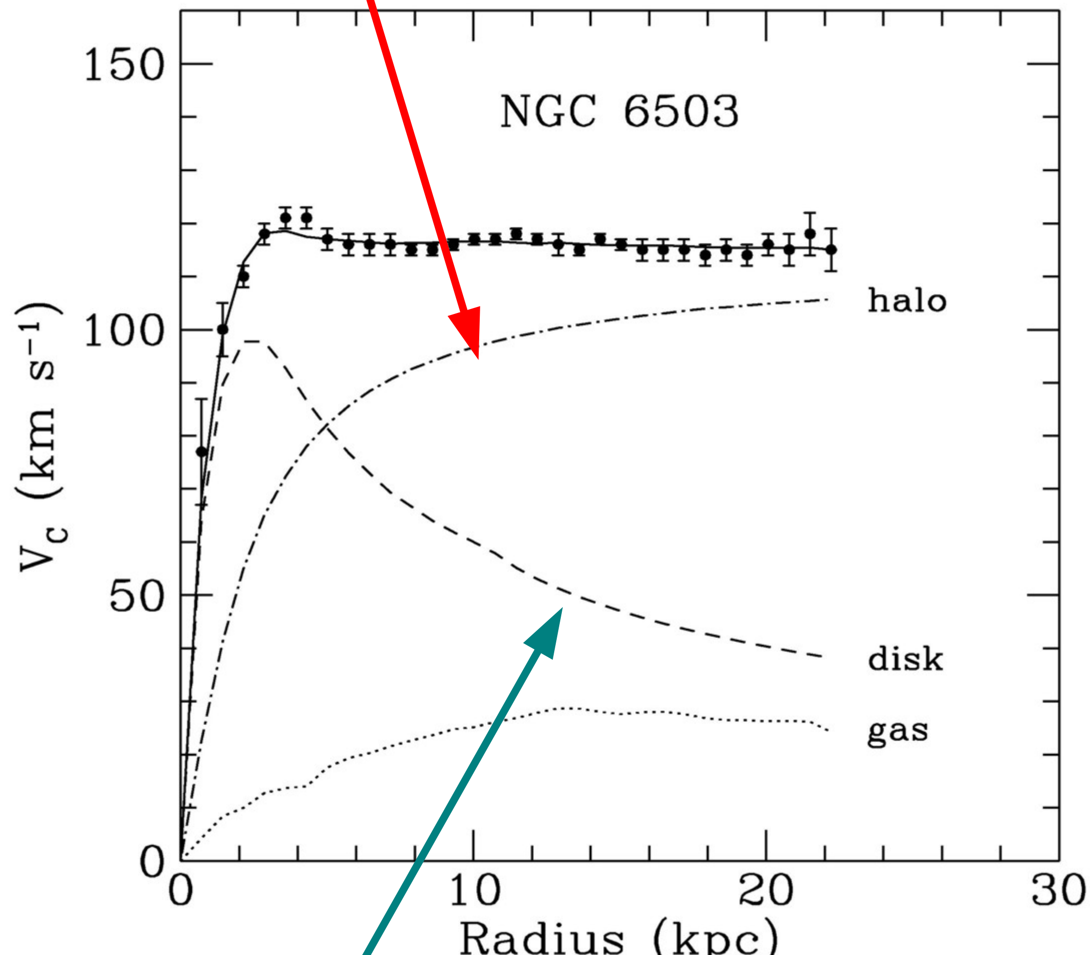
What is the nature
of the Dark Matter ?

Dark Matter Halo in spiral Galaxies



Spiral galaxy NGC 3198 overlaid with hydrogen column density [21 cm] [ApJ 295 (1995) 305

Extra "invisible" component



Expected from luminous Matter in the disk (Keplerian 1/Sqrt[r])

The “thermal relic” or WIMP paradigm for Dark Matter

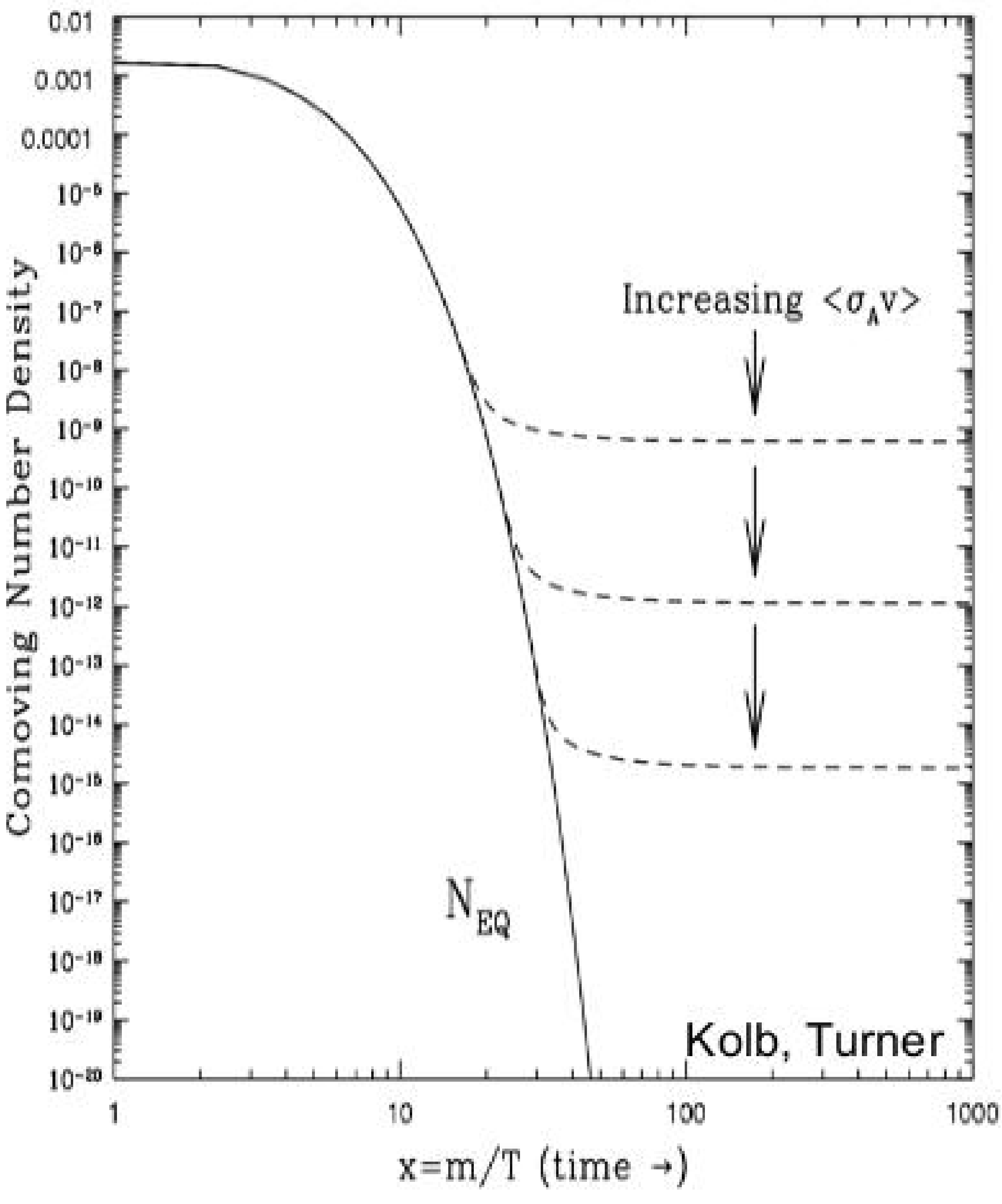
Hypothesis that the Dark Matter is formed by a (yet undiscovered) *elementary particle*

This particle was in thermal equilibrium in the early universe when the temperature was $T \gg m_\chi$

The “relic abundance” of this particle is determined by (and is inversely proportional to) its (velocity averaged) annihilation cross section.

$$\rho_\chi \propto \frac{1}{\langle \sigma v \rangle}$$

Concept of thermal relic [WIMP] :



$$\chi + \chi \leftarrow f + \overline{f}$$

$$\chi + \chi \rightarrow f + \overline{f}$$

Annihilation cross section
Determines the
"relic abundance"

$$\Omega_j^0 \simeq 0.2 \left[\frac{3 \times 10^{-26}\ \mathrm{cm}^3\,\mathrm{s}^{-1}}{\langle \sigma\, v \rangle}\right]$$

“Relic abundance” estimate in standard Cosmology (simplest treatment)

$$\Omega_\chi \simeq \left(\frac{16\,\pi^{5/2}}{9\,\sqrt{\pi}}\right)\ \frac{G^{3/2}\,T_0^3}{H_0^2\,(\hbar c)^{3/2}\,c^3}\ \frac{\sqrt{g^*}}{\langle\sigma\,v\rangle}$$

$$\Omega_\chi \simeq 0.2$$

$$\langle\sigma\,v\rangle \simeq 3\times 10^{-26}\ \frac{\mathrm{cm}^3}{\mathrm{sec}}$$

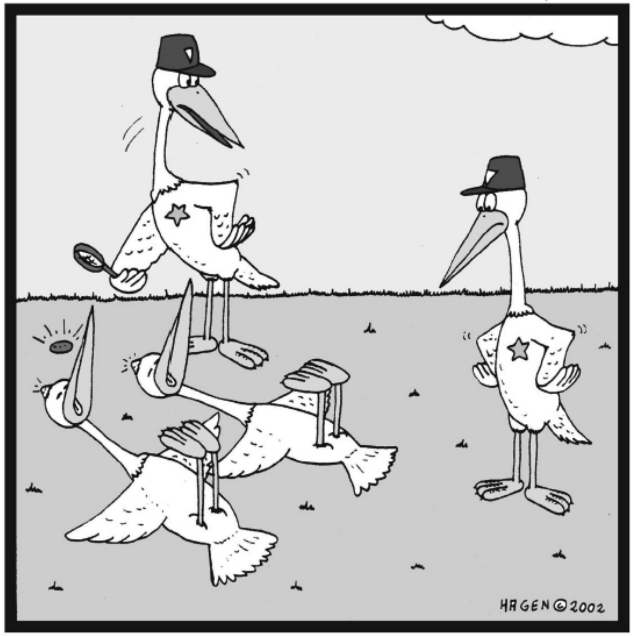
$$\sigma \simeq \frac{\alpha^2}{M^2}$$

$$M \simeq \frac{\hbar\,c}{\sqrt{\sigma/\alpha^2}} \simeq 140\ \mathrm{GeV}$$

Connection with
Weak (Fermi) scale ?!
[and perhaps supersymmetry]

The “WIMP's Miracle” ?

the WIMP's "miracle"



Unbelievable! It looks like they've both been killed by the same stone...

"Killing two birds with a single stone"

"Dark Matter Particle"

Direct observational puzzle

New particles are predicted in "beyond the Standard Model" theories, (in particular Supersymmetry) that have the DM particle properties.

Theoretical motivations (hierarchy problem)

Supersymmetry

Fermionic degrees of freedom

Bosonic degrees Of freedom

All "internal quantum numbers" (charge, color,…) must be identical

$q \quad \tilde{q}$ squark

$e^{\pm} \quad \tilde{e}^{\pm}$ selectron

$g \quad \tilde{g}$ gluino

…………………………

	Standard Model fields	Super-symmetric extension	
fermions	quarks	Squarks	New bosons (scalar) spin 0 S-
	leptons	Sleptons	
	neutrinos	Sneutrinos	
bosons	photon	photino	New fermions spin 1/2 -ino
	W	Wino	
	Z	Zino	
	gluons	gluinos	
	Higgs	Higgsino	
2 Higgs →	H h	$\tilde{H}$ $\tilde{h}$	

Weak (~100 GeV) Mass scale ?

1 stable New Particle (R-parity conserved)

$$|\chi\rangle = c_1\,|\tilde{\gamma}\rangle + c_2\,|\tilde{z}\rangle + c_3\,|\tilde{H}\rangle + c_4\,|\tilde{h}\rangle$$

Three roads to the discovery of DM
in the form of thermal relics (WIMP's)

$$\chi + \chi \rightarrow q + \overline{q}$$

Annihilation

$$q + \overline{q} \rightarrow \chi + \chi$$

Creation

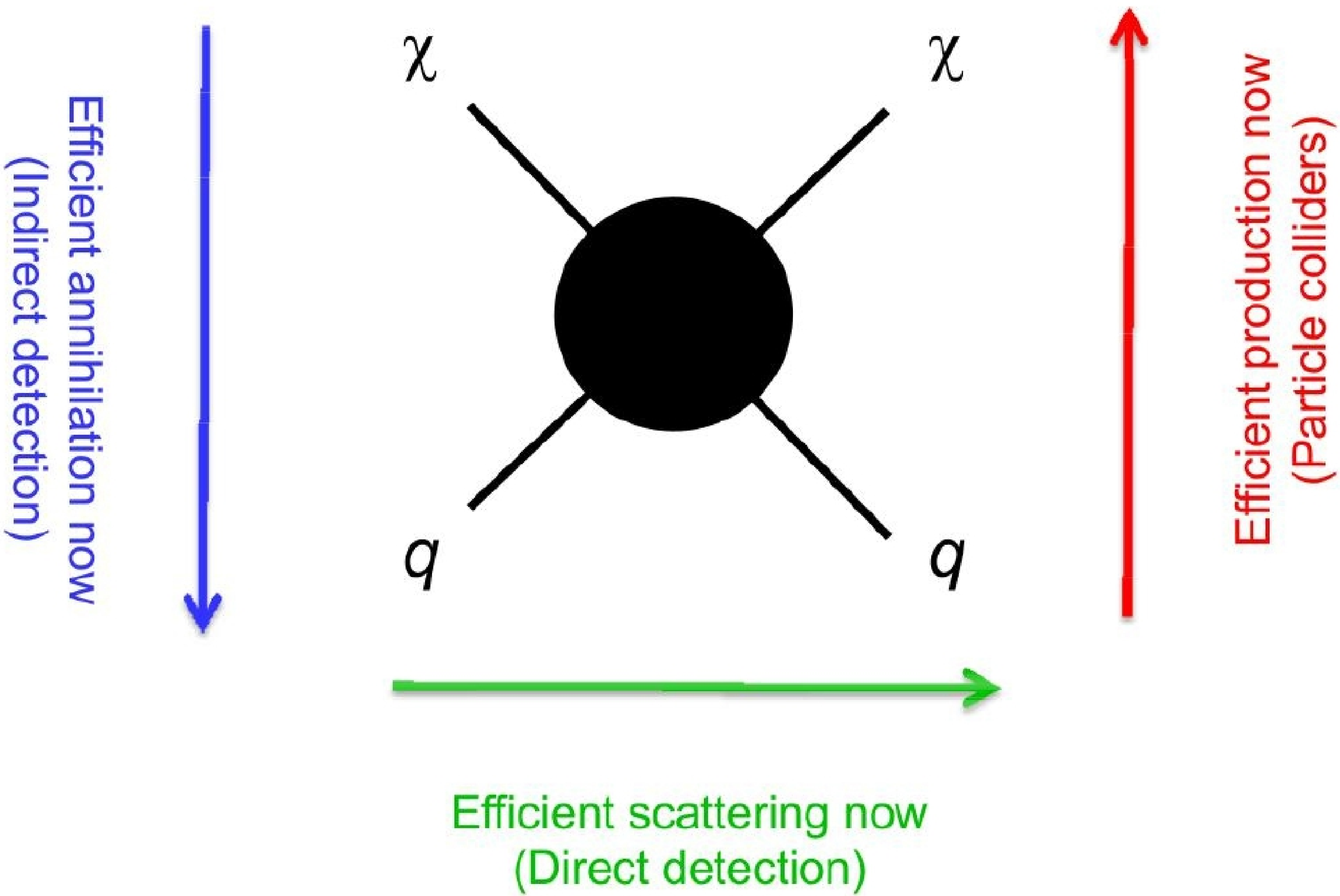
Time reversal

$$\chi + q \rightarrow \chi + q$$

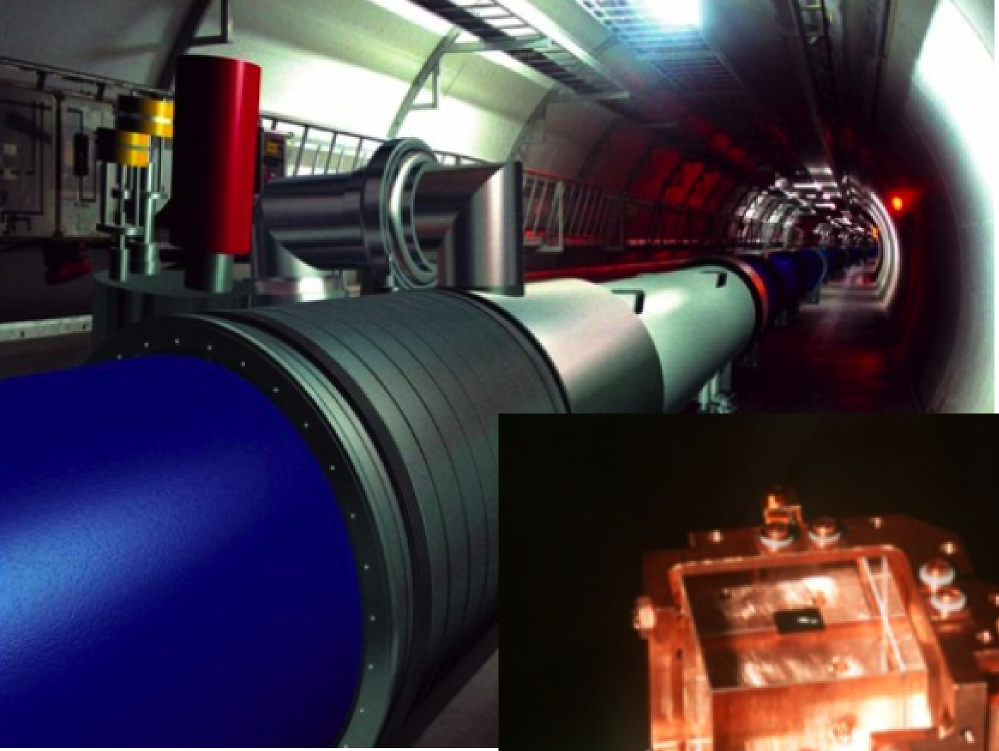
Elastic

Crossing symmetry

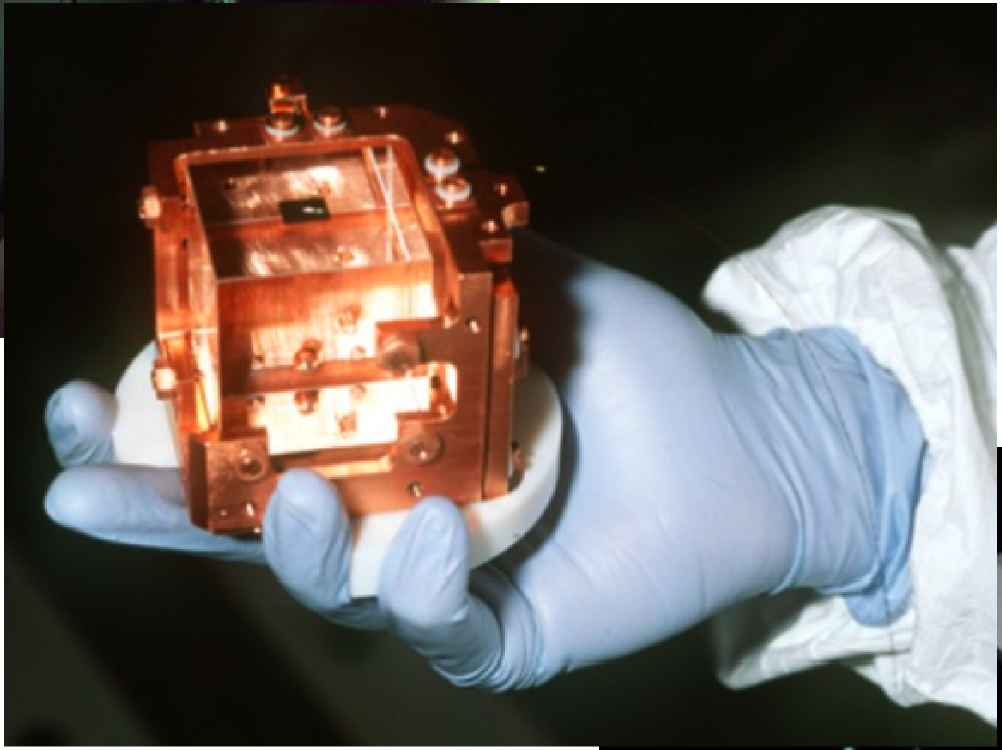
Three roads to the discovery of DM
in the form of thermal relics (WIMP's)



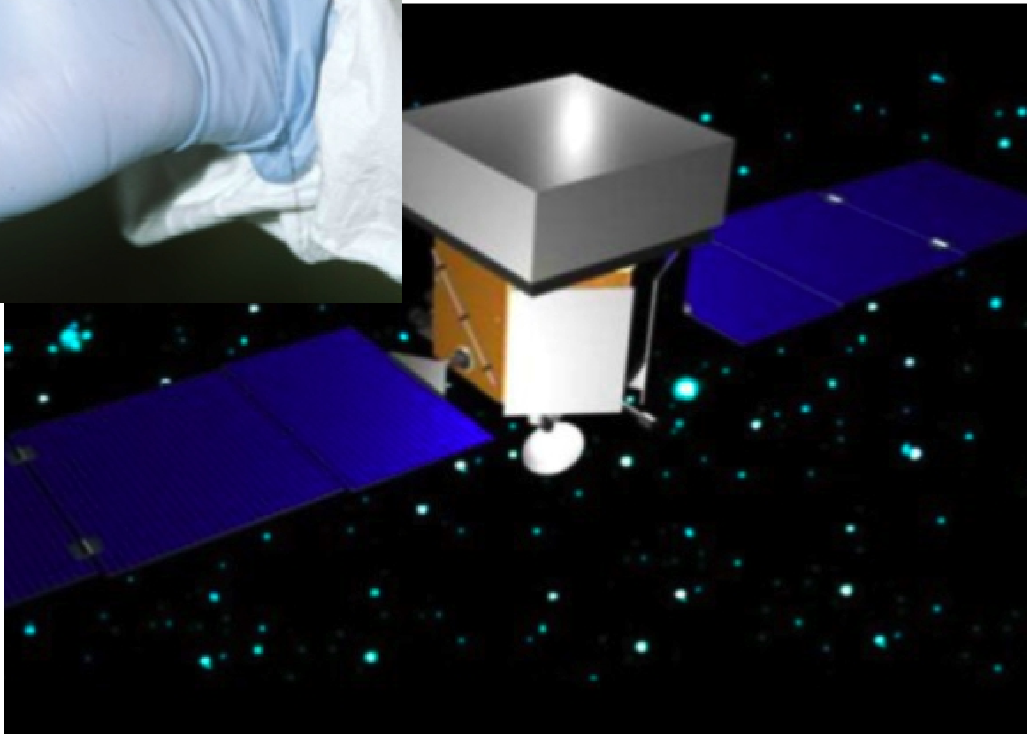
3 Roads to test the WIMP hypothesis



Accelerator Searches



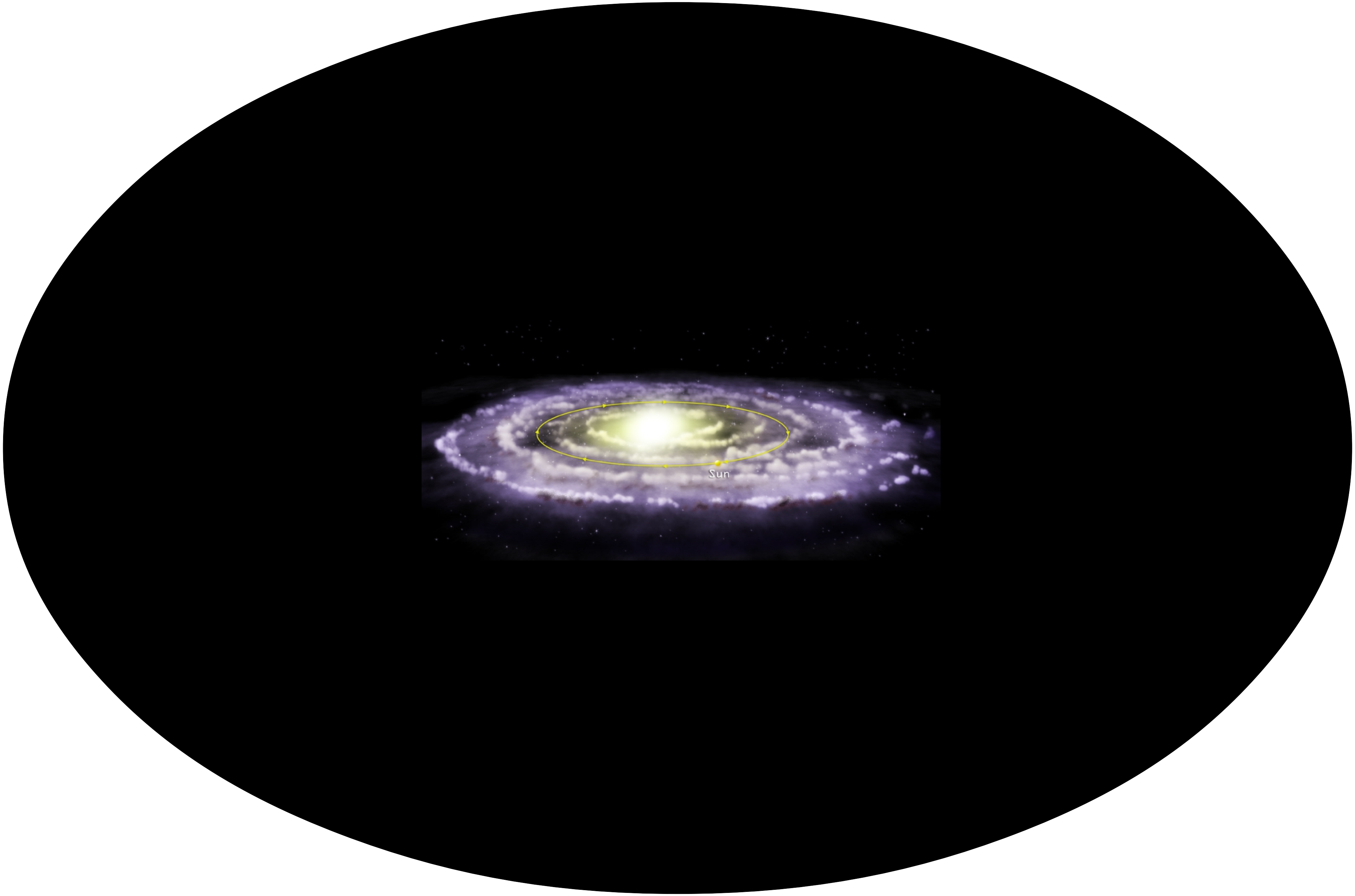
Direct searches
(elastic scattering)



Indirect searches

Indirect searches for DARK MATTER

Dark Matter Halo in our Galaxy.



In the “WIMP paradigm” Dark Matter is NOT really dark

Self-annihilation of the DM particles that form the halo

$$n_\chi(\vec{x}) = \frac{\rho_\chi(\vec{x})}{m_\chi}$$

Number density of Dark Matter particles

$$\frac{dN_{\chi\chi\to X}}{d^3x\, dt} = \frac{1}{2}\, n_\chi^2(\vec{x}) \;\; \langle \sigma\, v \rangle$$

Number of annihilations per unit time and unit volume

$$\frac{dL_{\rm DM}}{d^3x}(\vec{x}) = \frac{\rho^2(\vec{x})}{m_\chi} \; \langle \sigma\, v \rangle$$

Luminosity per unit volume

What is the energy output of the Milky Way in DM annihilations?

$$\frac{dL_{\rm DM}}{d^3x}(\vec{x}) = \frac{\rho^2(\vec{x})}{m_\chi}\langle\sigma\, v\rangle$$

We know
(at least approximately)
from cosmology

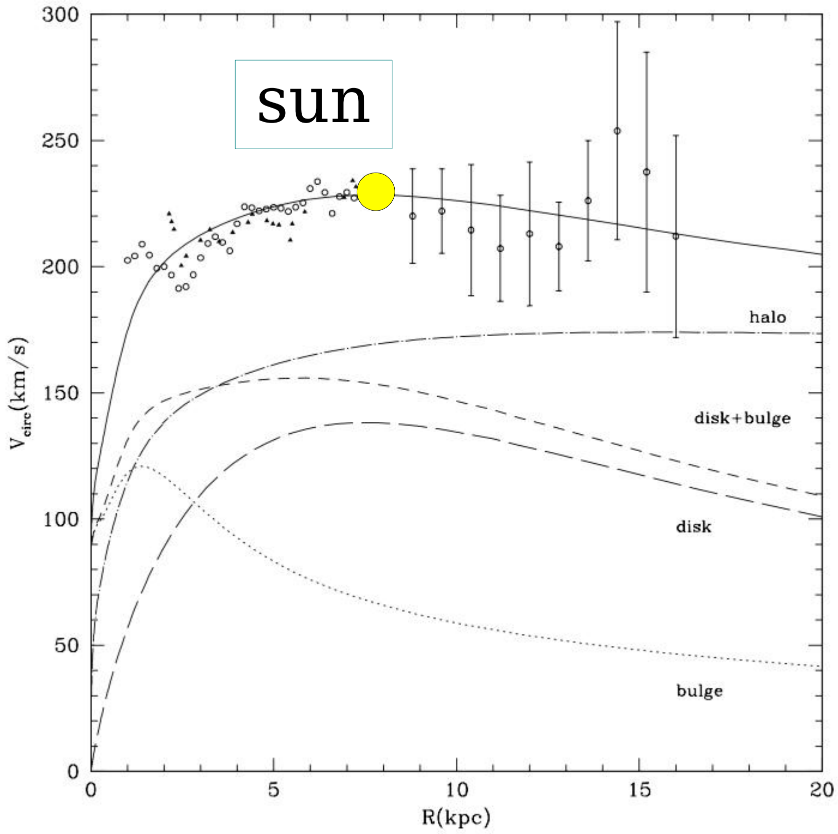
Astrophysical observations
(rotation velocity)
+ Modeling of galaxy formation
for the central part of the Galaxy

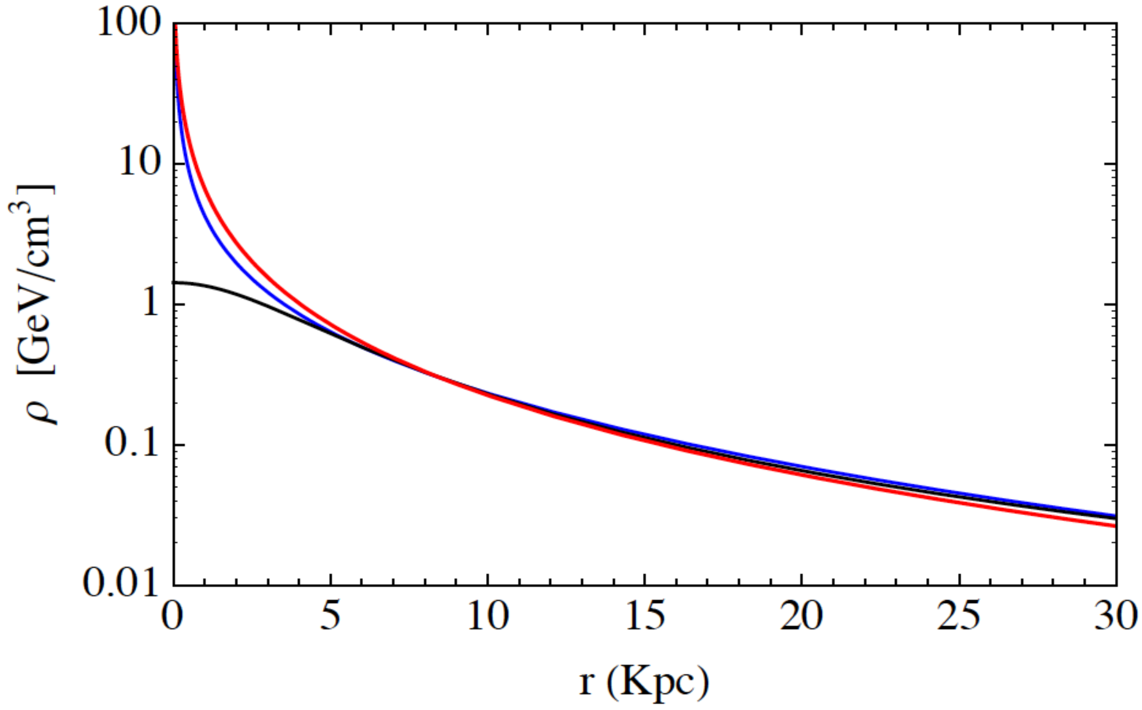
DM in the Milky Way

$$\rho_{\text{isothermal}}(r) = \frac{\rho_s}{1 + (r/r_s)^2}$$

$$\rho_{\text{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}$$

$$\rho_{\text{Einasto}}(r) = \rho_s \exp\{-(2/\alpha)[(r/r_s)^\alpha - 1]\}$$





Density distribution
determined by
Rotation velocity measurements

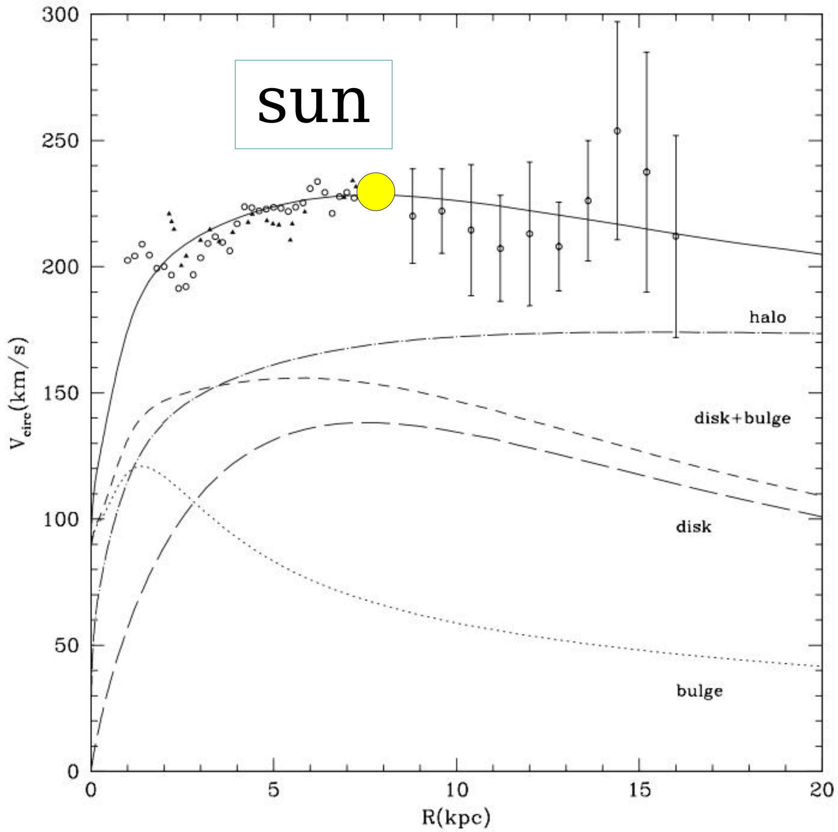
"Cusp" at GC
derived by N-body simulations

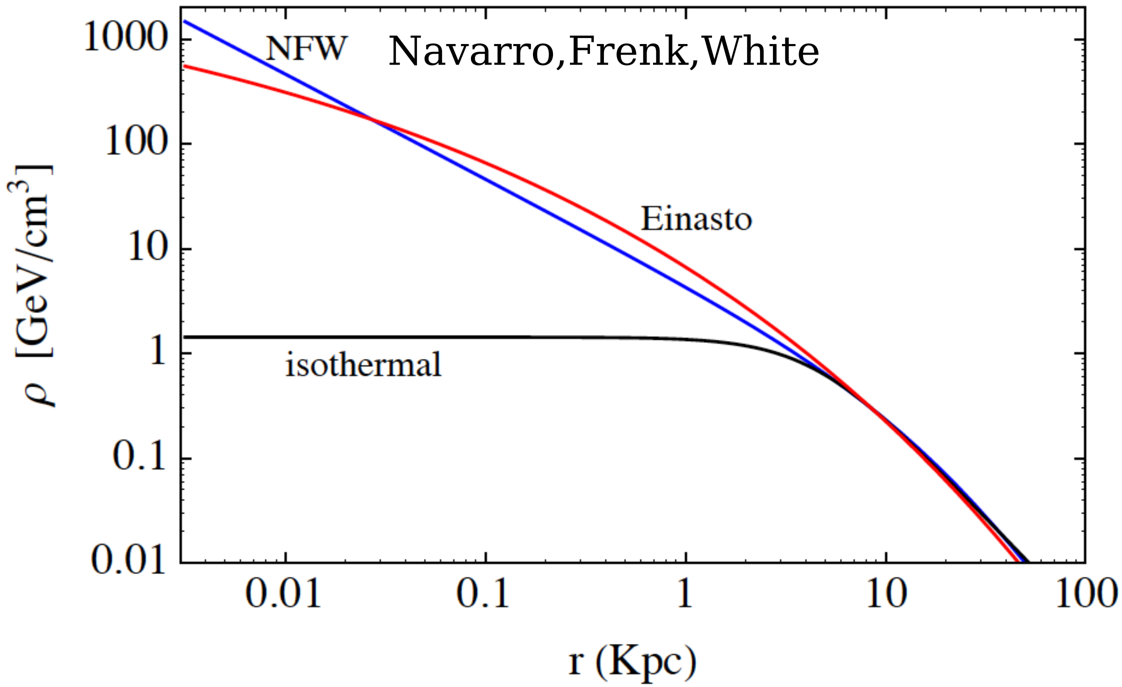
DM in the Milky Way

$$\rho_{\mathrm{isothermal}}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

$$\rho_{\mathrm{Einasto}}(r) = \rho_s \exp\{-(2/\alpha)[(r/r_s)^\alpha - 1]\}$$





Density distribution
determined by
Rotation velocity measurements

"Cusp" at GC
derived by N-body simulations

Power generated by DM annihilations in the Milky Way halo

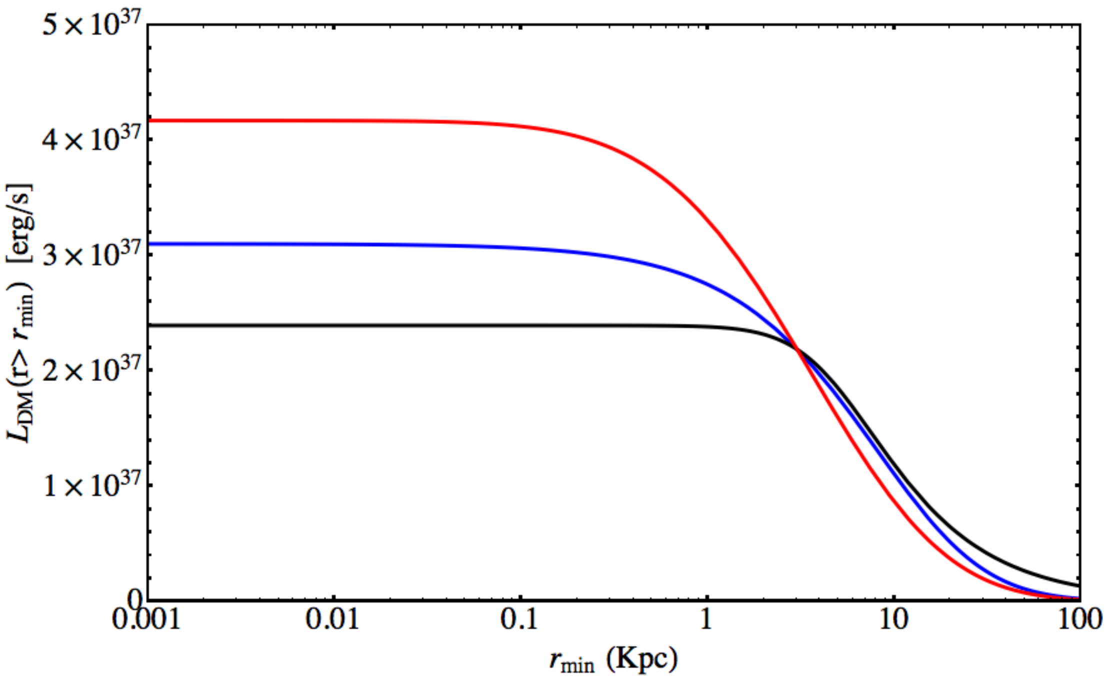
$$\frac{dN_{\chi\chi\to X}}{d^3x\,dt} = \frac{1}{2}\, n_\chi^2(\vec{x}) \;\langle \sigma\, v\rangle$$

$$\frac{dL_{\rm DM}}{d^3x}(\vec{x}) = \frac{\rho^2(\vec{x})}{m_\chi}\;\langle \sigma\, v\rangle$$

[Majorana particle]

$$L_{\rm DM} \propto \frac{\langle \sigma\, v\rangle}{m_\chi}$$

$$L_{\rm DM} \simeq 3\times 10^{37}\ {\rm erg\ s^{-1}}\ \left[\frac{\langle \sigma\, v\rangle}{3\times 10^{-26}\ ({\rm cm^3 s})^{-1}}\right]\ \left[\frac{100\ {\rm GeV}}{m_\chi}\right]$$



small effect of
“Cusp” on total luminosity

For comparison:
Power of the Cosmic Ray Accelerators in the Milky Way:

$$L_p \simeq 10^{41}\ \frac{\rm erg}{\rm s}$$

What is the final state of DM annihilations ?

… well we do not know, we have to build a model (for example supersymmetry).

But it is plausible that the Dark Matter particle will (or could) produce all particles (and anti-particles) that we know.

Most promising for detection:

$$\chi + \chi \rightarrow \gamma \quad e^{+} \quad \bar{p} \quad \nu_{\alpha}$$

photons

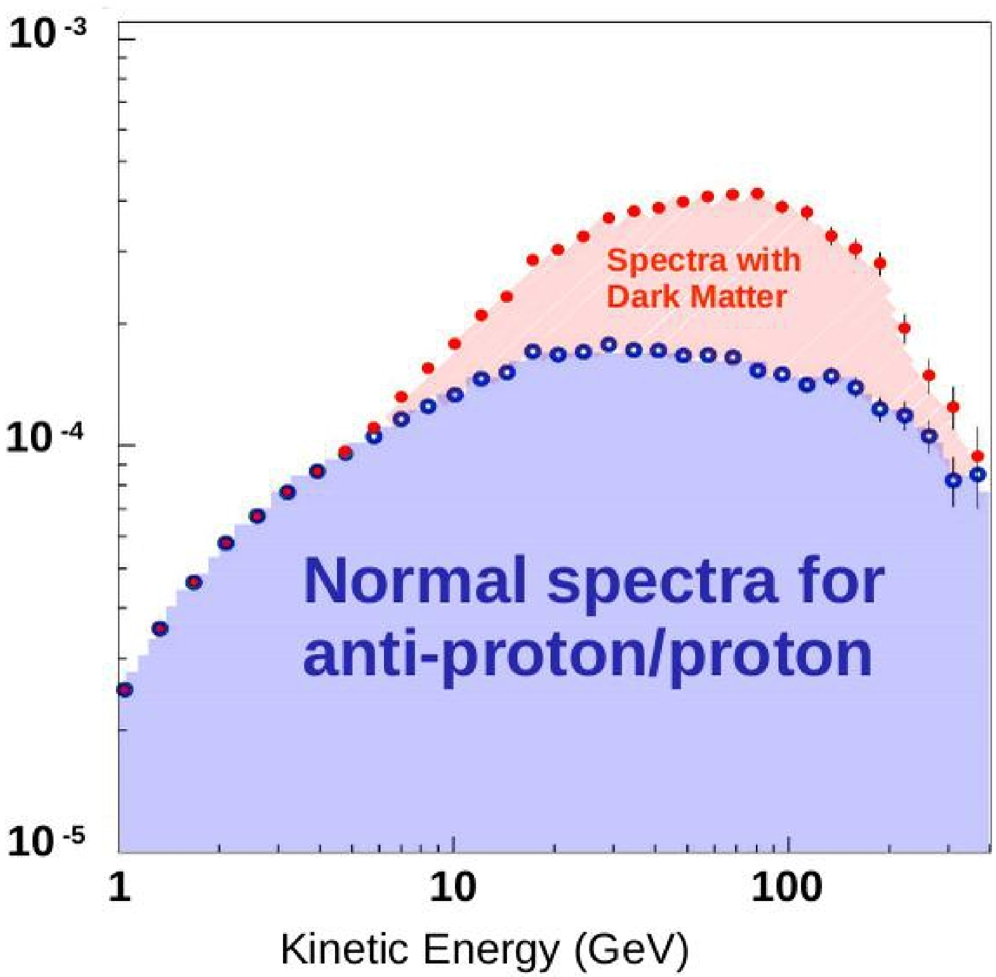
Charged (anti)particles

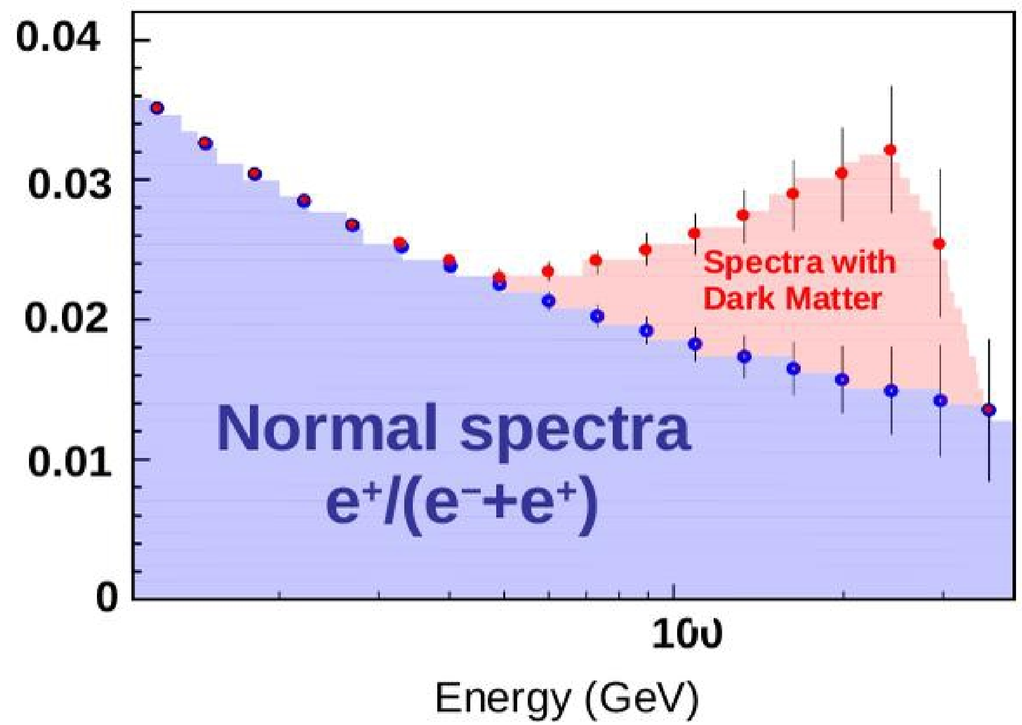
Neutrinos

Charged particles:
positrons and
anti-protons

Trapped by the
Galactic magnetic field

Extra contribution to
the cosmic ray fluxes





“Standard” source of Positrons :

Main expected contribution:
I*nteraction of cosmic rays propagating in the interstellar medium:*

$$p + p_{\text{ism}} \rightarrow \pi^+ + \ldots$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

$$p + \text{He}_{\text{ism}} \rightarrow \ldots$$

$$\text{He} + p_{\text{ism}} \rightarrow$$

$$\text{C} + p_{\text{ism}} \rightarrow$$

“Standard” source of Positrons :

Main expected contribution:
I*nteraction of cosmic rays propagating in the interstellar medium:*

$$p + p_{\rm ism} \to \pi^+ + \ldots$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

$$T_{\rm int} = \left[\sigma_{pp}\, c\, \langle n_{\rm ism}\rangle\right]^{-1} \simeq 30\ {\rm Myr}\ \left[\frac{{\rm cm}^{-3}}{\langle n_{\rm ism}\rangle}\right]$$

Injection of positrons by the standard mechanism

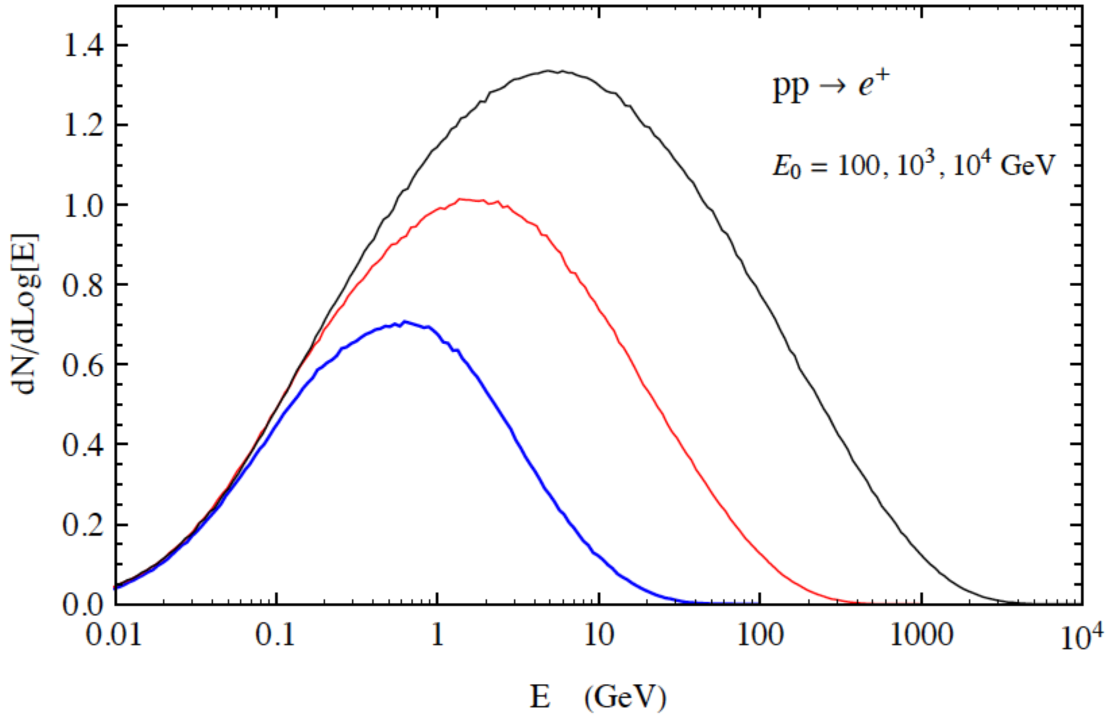
$$q_{e^+}(E, \vec{x}, t) =$$

$$\beta\, c \;\; n_{\rm ism}(\vec{x}) \; \int dE_0 \; n_p(E_0, \vec{x}, t) \; \sigma_{pp}(E_0) \;\; \frac{dN_{pp\to e^+}}{dE}(E, E_0)$$

$$E_p = 10^2,\; 10^3,\; 10^4 \;\; \mathrm{GeV}$$

$$\langle N_{e^+} \rangle \simeq$$

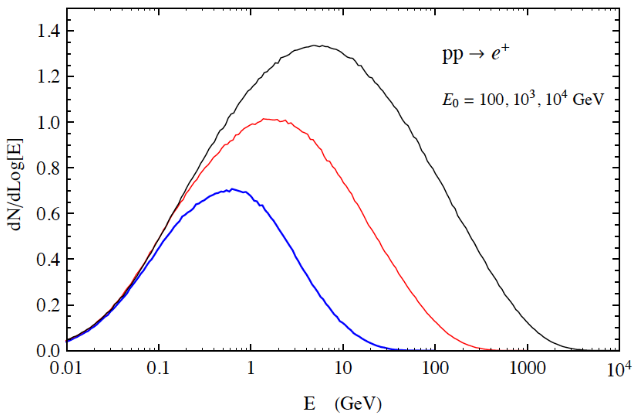
2.9, 5.5, 8.9



Positron energy spectra are approximately *"scaling"* in the projectile fragmentation region

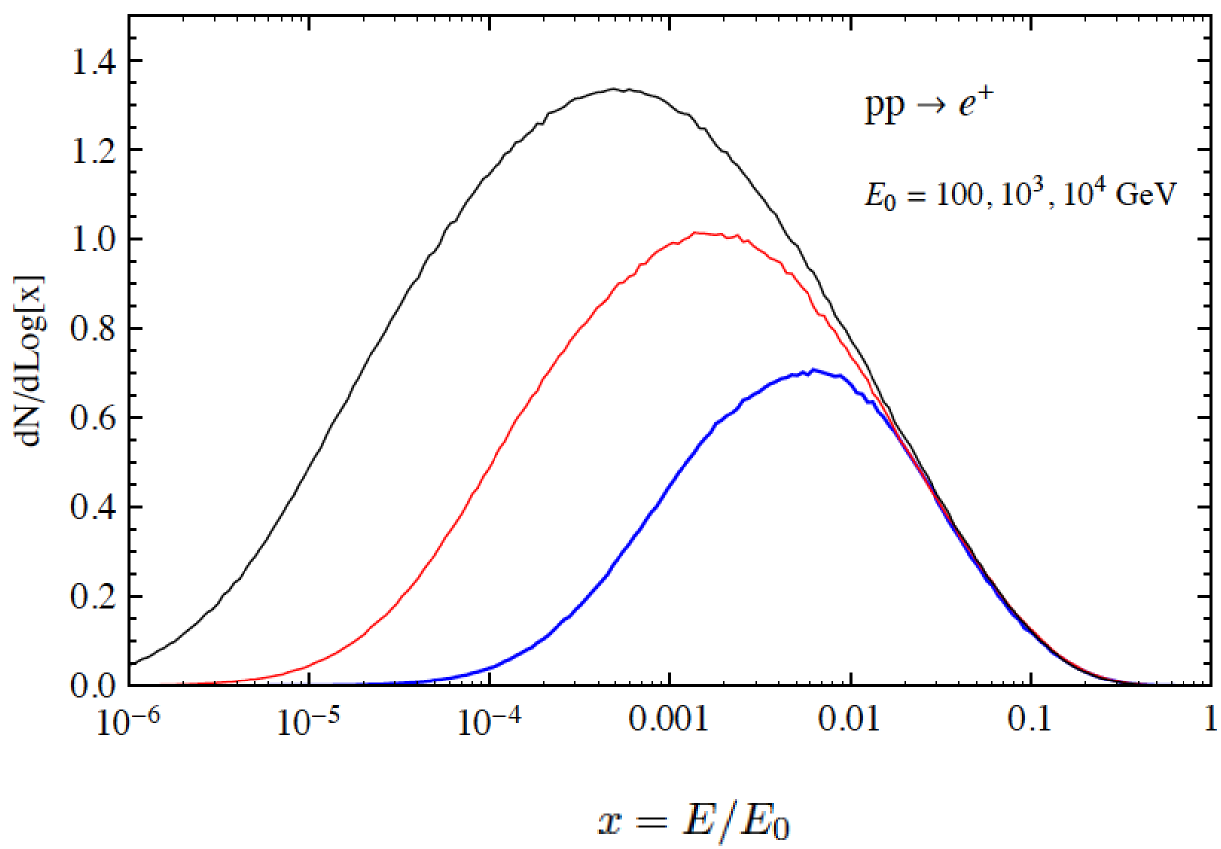
(reflection of approximate validity of Feynman scaling)

$$\frac{dN_{pp\to e^+}}{dx}(x, E_0) \simeq F(x)$$



positron spectra as function of

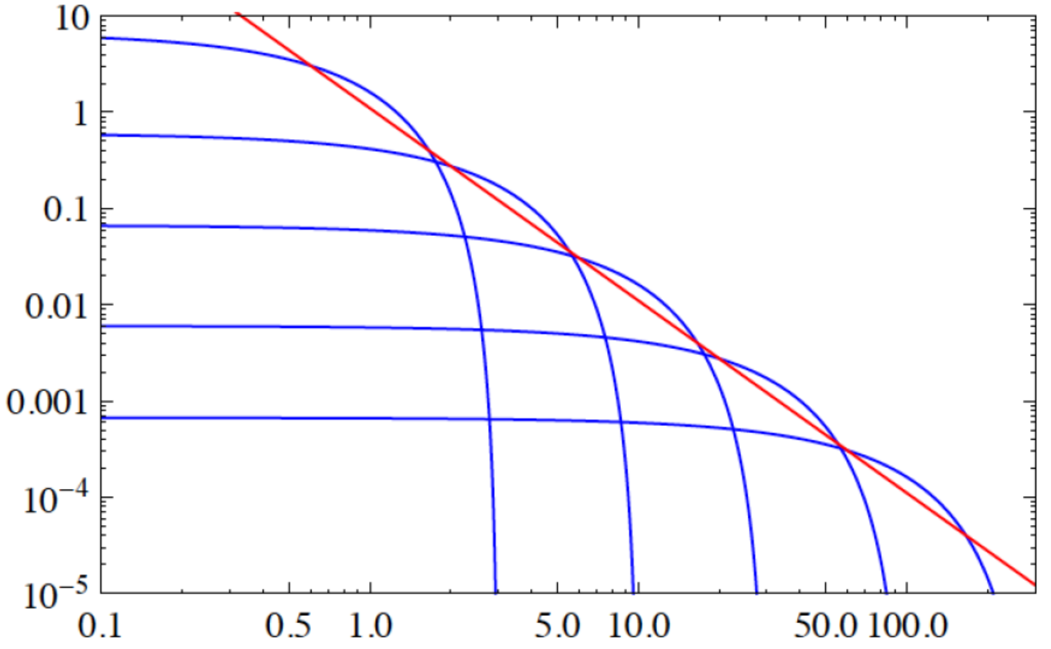
$$x = \frac{E}{E_0}$$



[Power Law spectrum] $\otimes$ [Scaling function] =

[Power Law spectrum]

(of same exponent)



Positron injection
(in the standard mechanism)
is in good approximation
a power law with the same
exponent as the proton flux

$$q_{e^+}(E) \propto E^{-2.7}$$

Relation between:

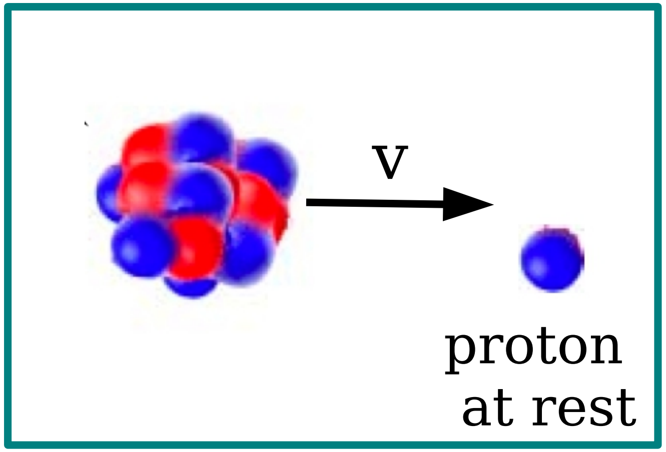
Injection spectrum

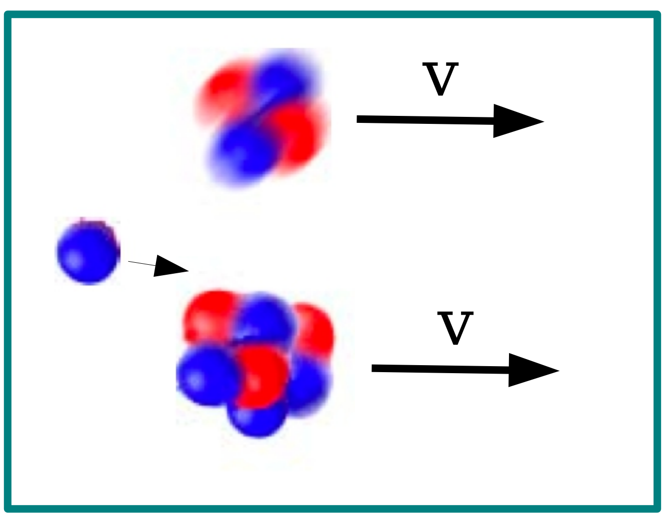
Observed spectrum

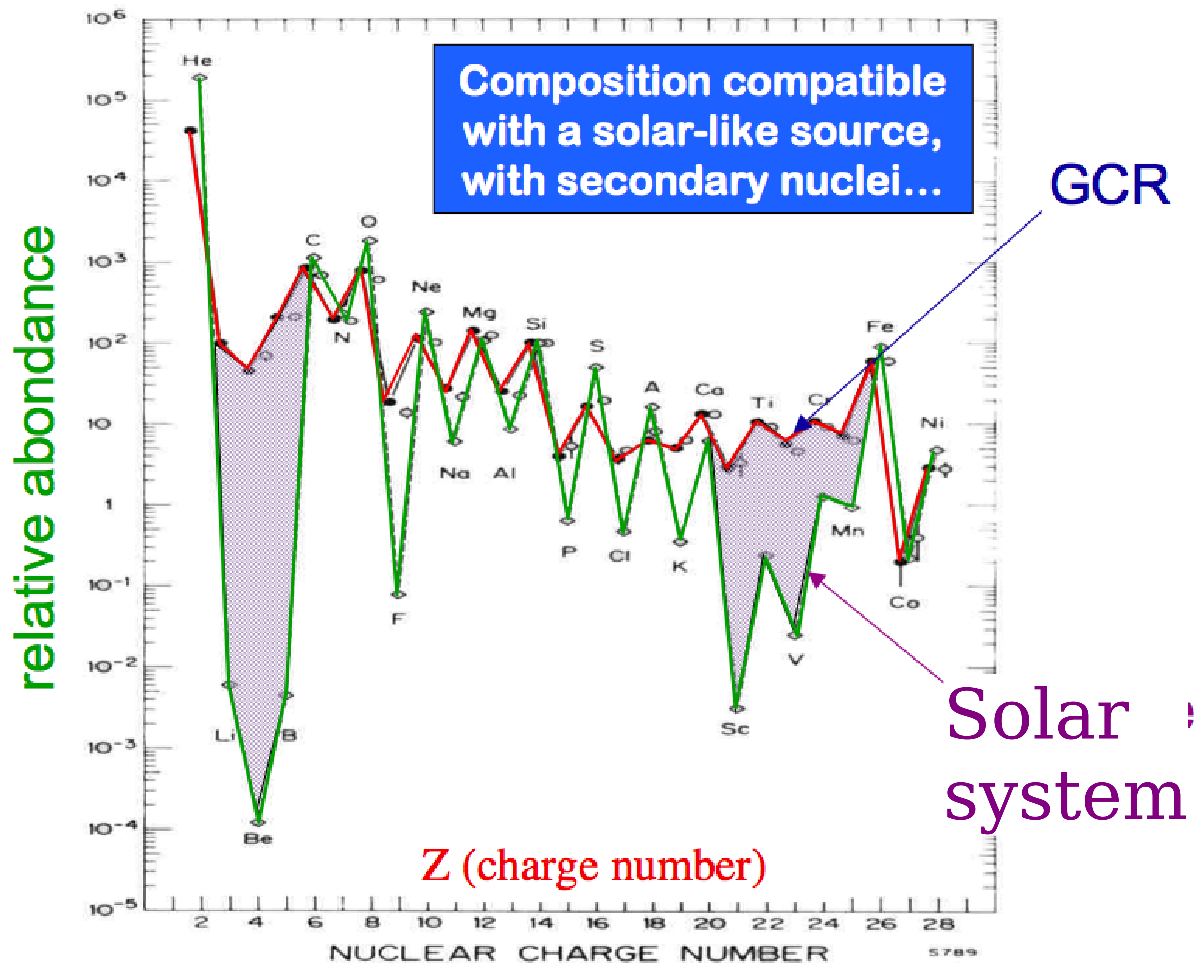
Study of *"Secondary Nuclei"*

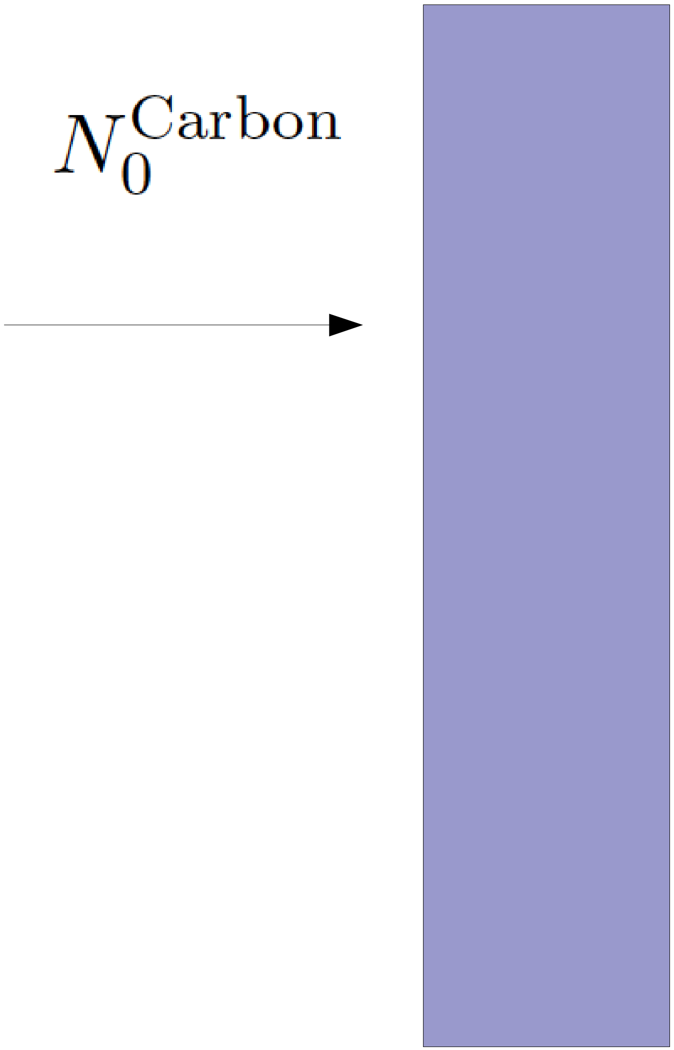
(Li, Be, B), (sub-iron group)

Nuclear Fragmentation
(collisions with the Inter Stellar Medium)









Layer of material
column density X

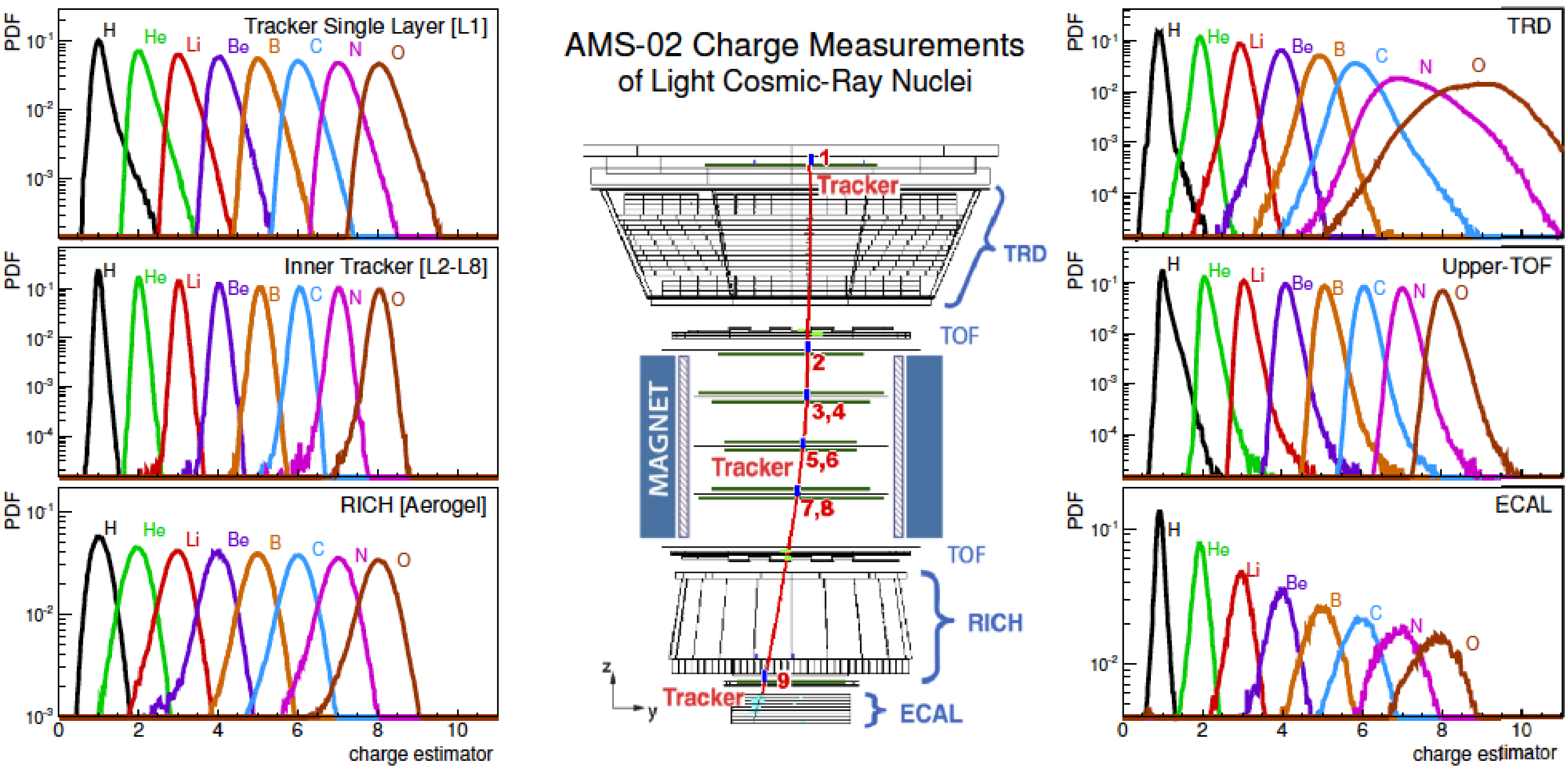
$$\lambda_{\mathrm{C}} \simeq \lambda_{\mathrm{B}} \simeq 8.4 \ \frac{\mathrm{g}}{\mathrm{cm}^2}$$

$$N_{\mathrm{C}} = \ N_0 \ e^{-X/\lambda_{\mathrm{C}}}$$

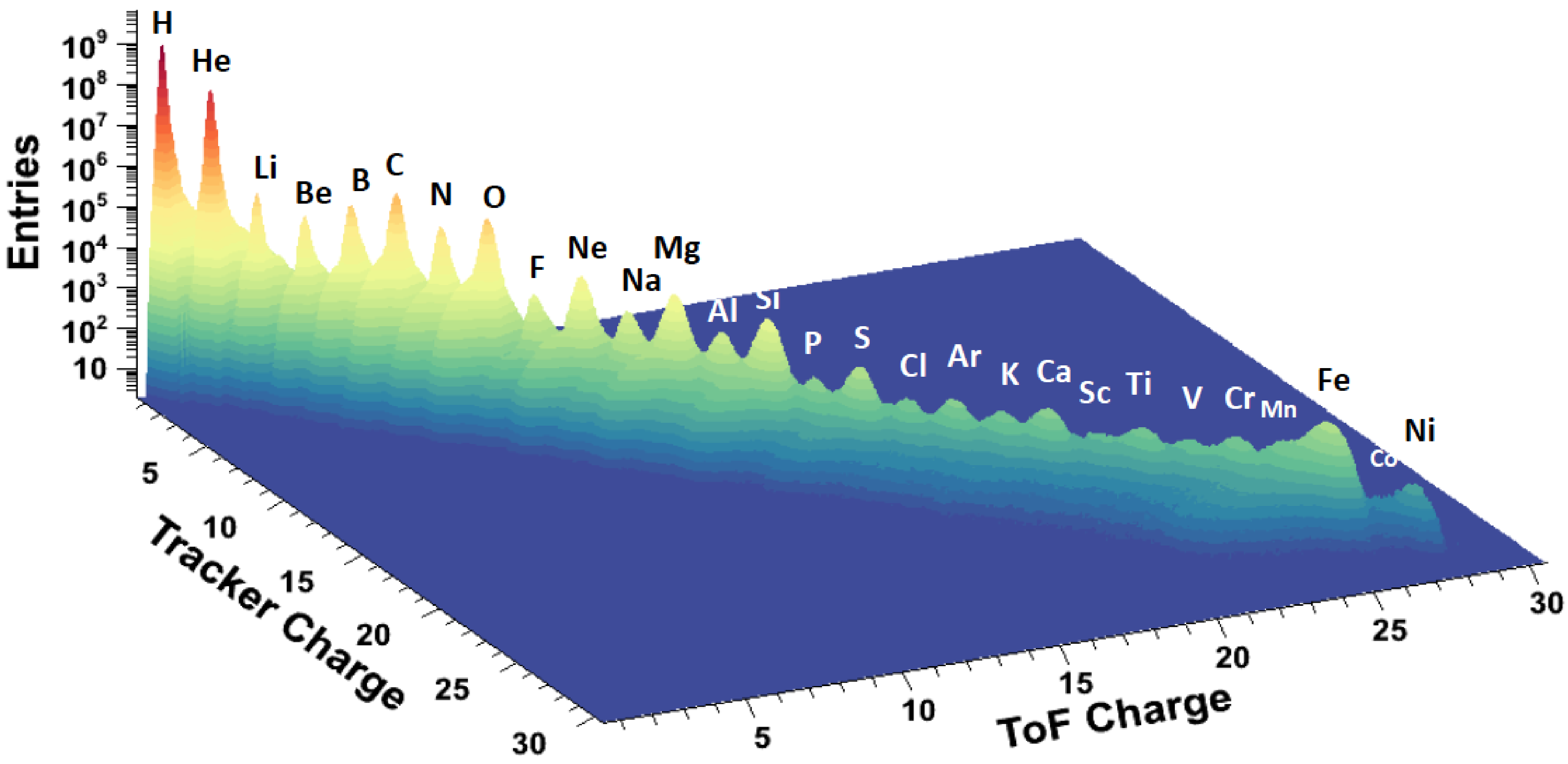
$$N_{\mathrm{B}} = \ N_0 \ B_{\mathrm{C}\to\mathrm{B}} \frac{X}{\lambda_{\mathrm{C}}} \ e^{-X/\lambda_{\mathrm{C}}}$$

$$\frac{n_B}{n_{\mathrm{C}}} \simeq B_{\mathrm{C}\to\mathrm{B}} \ \frac{\langle X \rangle}{\lambda_{\mathrm{C}} + \langle X \rangle}$$

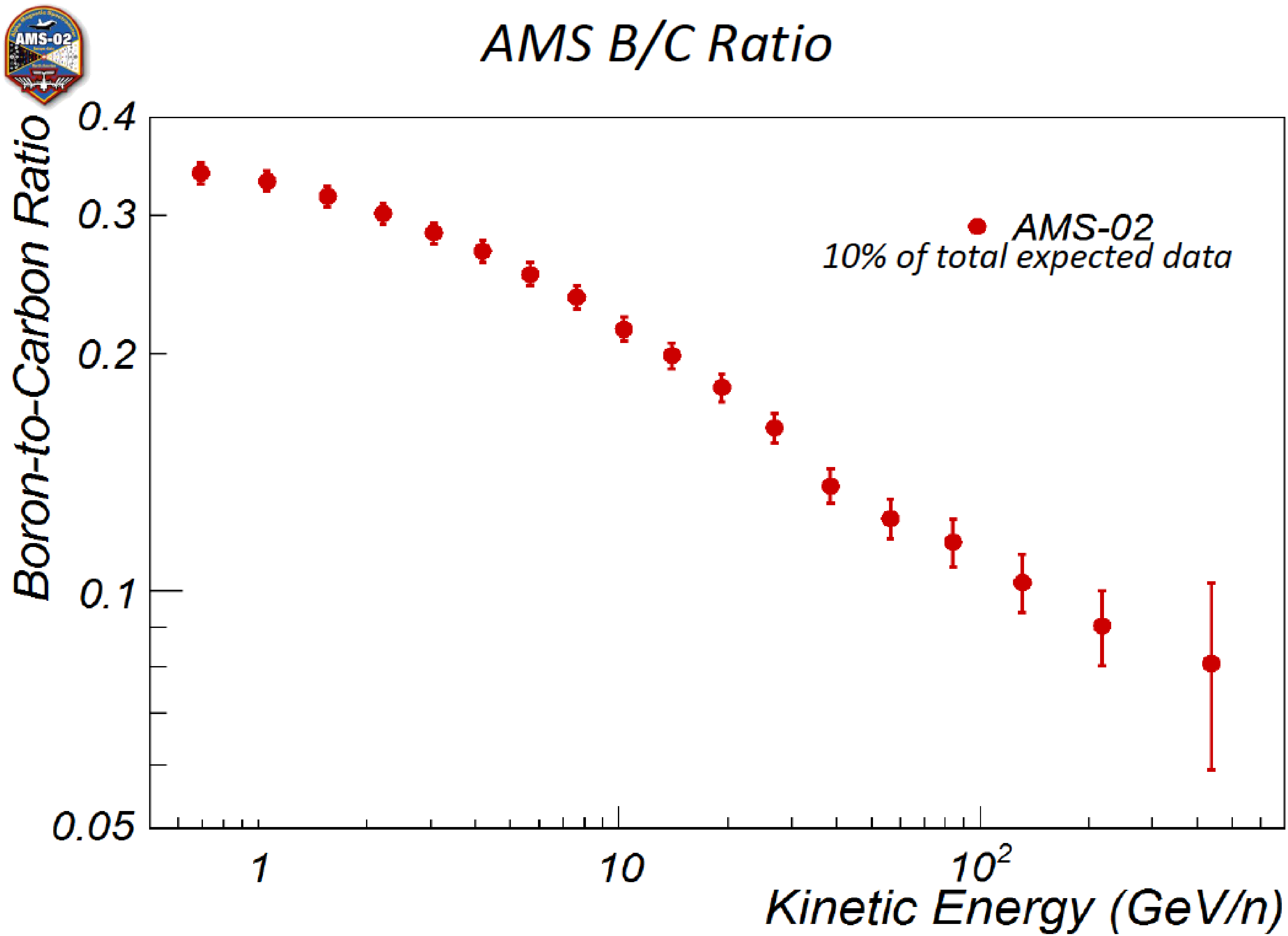
The Boron/Carbon ratio allows to estimate the average column density crossed by cosmic rays.

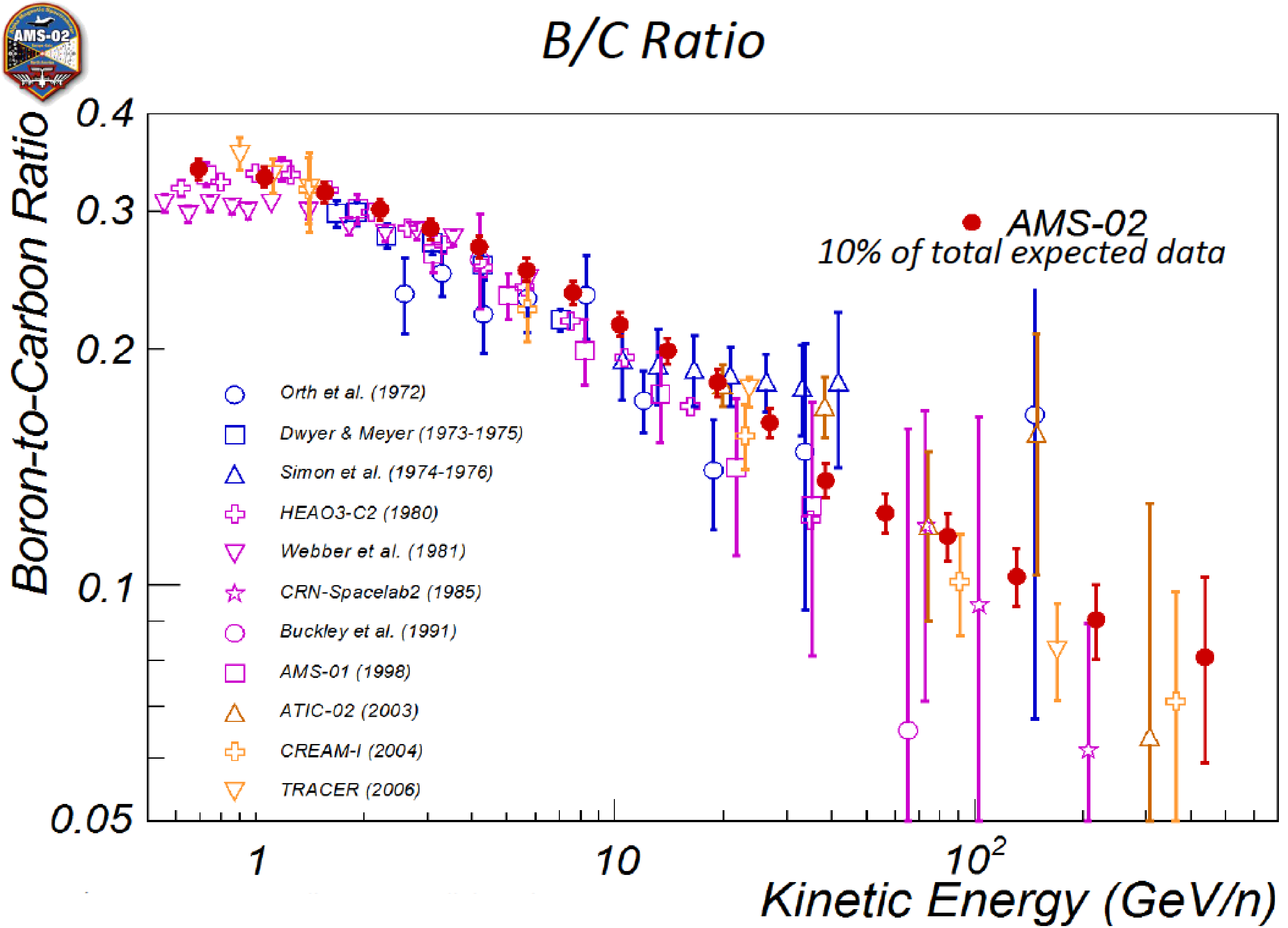

AMS-02 Charge Measurements
of Light Cosmic-Ray Nuclei
Tracker Single Layer [L1]
Inner Tracker [L2-L8]
RICH [Aerogel]
TRD
Upper-TOF
ECAL
PDF
charge estimator
H
He
Li
Be
B
C
N
O
Tracker
TRD
TOF
MAGNET
RICH
ECAL
1
2
3,4
5,6
7,8
9
z
y

Nuclei Identification in AMS



AMS B/C Ratio


AMS-02
Boron-to-Carbon Ratio
0.4
0.3
0.2
0.1
0.05
AMS-02
10% of total expected data
1
10
10^2
Kinetic Energy (GeV/n)

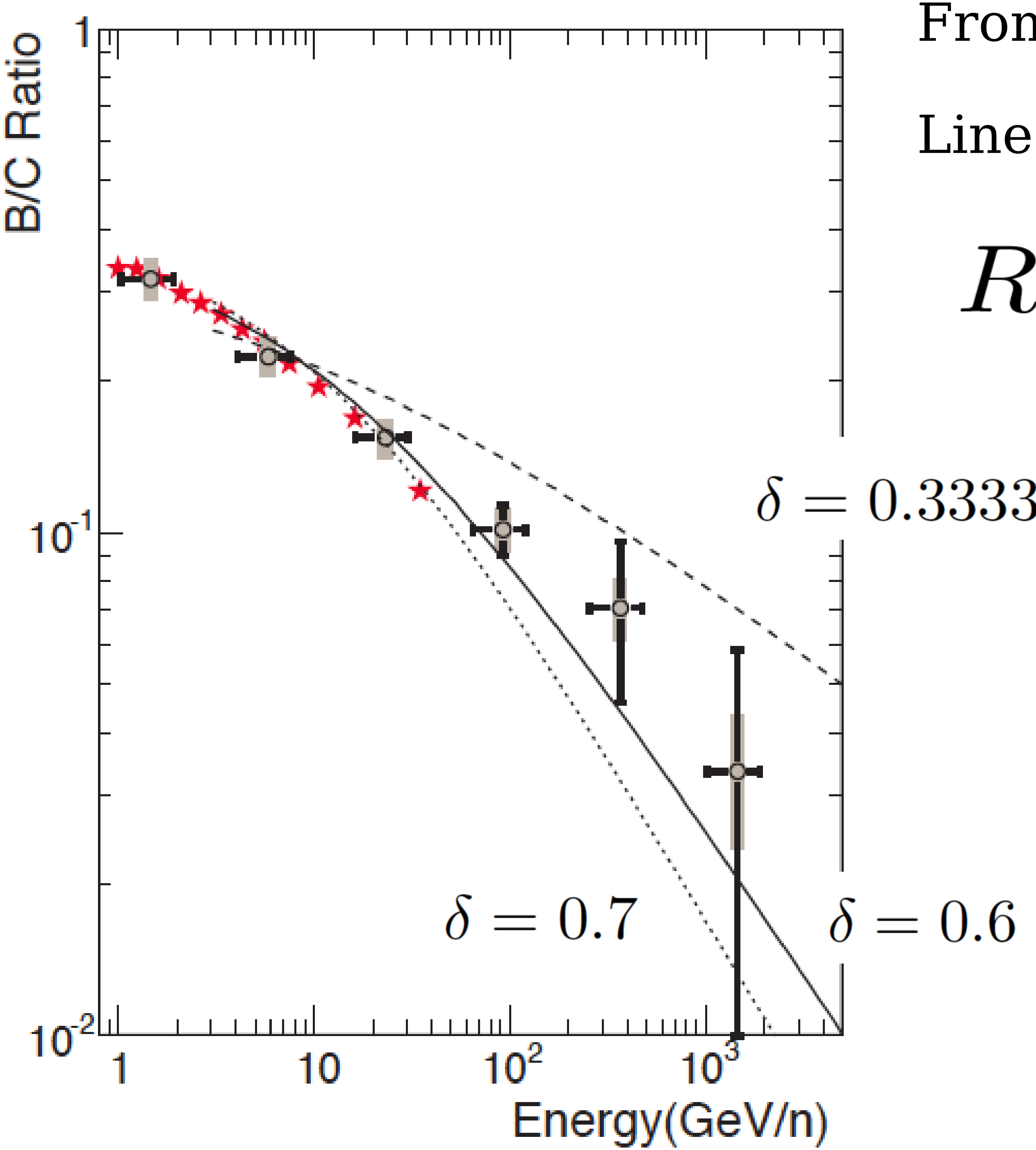


B/C Ratio
AMS-02
AMS-02
10% of total expected data
Boron-to-Carbon Ratio
0.4
0.3
0.2
0.1
0.05
1
10
10^2
Kinetic Energy (GeV/n)
Orth et al. (1972)
Dwyer & Meyer (1973-1975)
Simon et al. (1974-1976)
HEAO3-C2 (1980)
Webber et al. (1981)
CRN-Spacelab2 (1985)
Buckley et al. (1991)
AMS-01 (1998)
ATIC-02 (2003)
CREAM-I (2004)
TRACER (2006)

From CREAM

Lines of form: $R^{-\delta}$

R =rigidity



Interpretation of the result:

$$\langle X \rangle = T_{\rm escape} \; \langle n_{\rm ism} \rangle \; \beta \, c \;\; m_p$$

Column density corresponds to the confinement time of cosmic rays in the Galaxy

$$T_{\rm esc}(E/Z) \propto \left(\frac{E}{Z} \right)^{-\delta}$$

$$n_A(E) \simeq q_A(E) \; T_{\rm escape}(E/Z)$$

$$E^{-2.7} \simeq E^{-2.2} \times E^{-0.5}$$

Observed Spectrum of cosmic rays is *softer* than the injection spectrum

Propagation of *electrons (+positrons):*

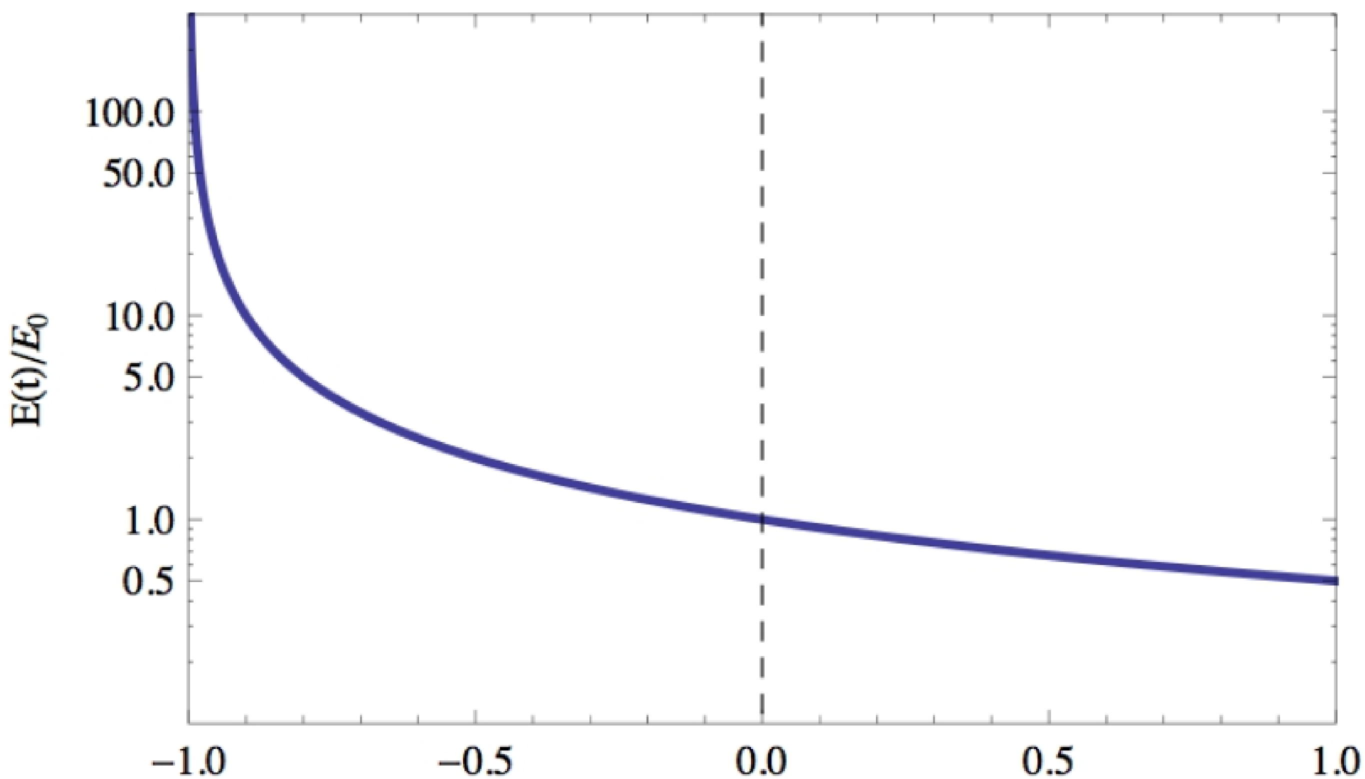
Energy Losses
[Synchrotron +
Compton scattering (on the radiation fields present in Galaxy)]

$$-\frac{dE}{dt} \simeq b\, E^2$$

$$b = \frac{4}{3}\,\sigma_{\rm Thomson}\, c \left[\frac{B^2}{8\pi} + \rho_\gamma\right] \frac{1}{m^2}$$

CMBR + stellar light

$$E(E_0, t) = \frac{E_0}{1 + b\, E_0\, t}$$



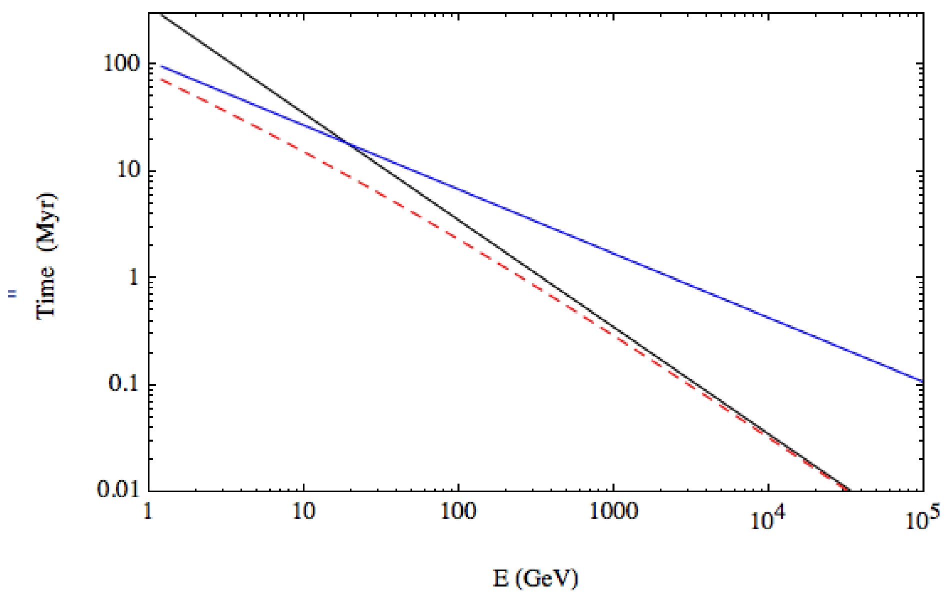
$$T_{\mathrm{loss}}(E) = \frac{1}{b\, E} \simeq\ 350 \times \left[\frac{6\ \mu\mathrm{Gauss}}{\langle B \rangle}\right]^2\ E_{\mathrm{GeV}}^{-1}\ \mathrm{Myr}$$

Combine the effects of Escape and Energy loss.

$$T_e \simeq \left[\frac{1}{T_{\rm loss}(E)} + \frac{1}{T_{\rm esc}(E)}\right]$$

$$T_{\rm loss}(E) \propto E^{-1}$$

$$T_{\rm esc}(E) \propto E^{-\delta}$$



$$n_{e^\pm}(E) = q_{e^\pm}(E) \times T_e(E)$$

Propagation effects softens the e+- spectrum more than for protons and nuclei

Electron flux

$$n_{e^-}(E) = q_{e^-}(E) \times T_e(E)$$

$$E^{-3.2} \simeq E^{-2.2} \times E^{-1}$$

[same shape of injection as protons and nuclei]

Positron flux

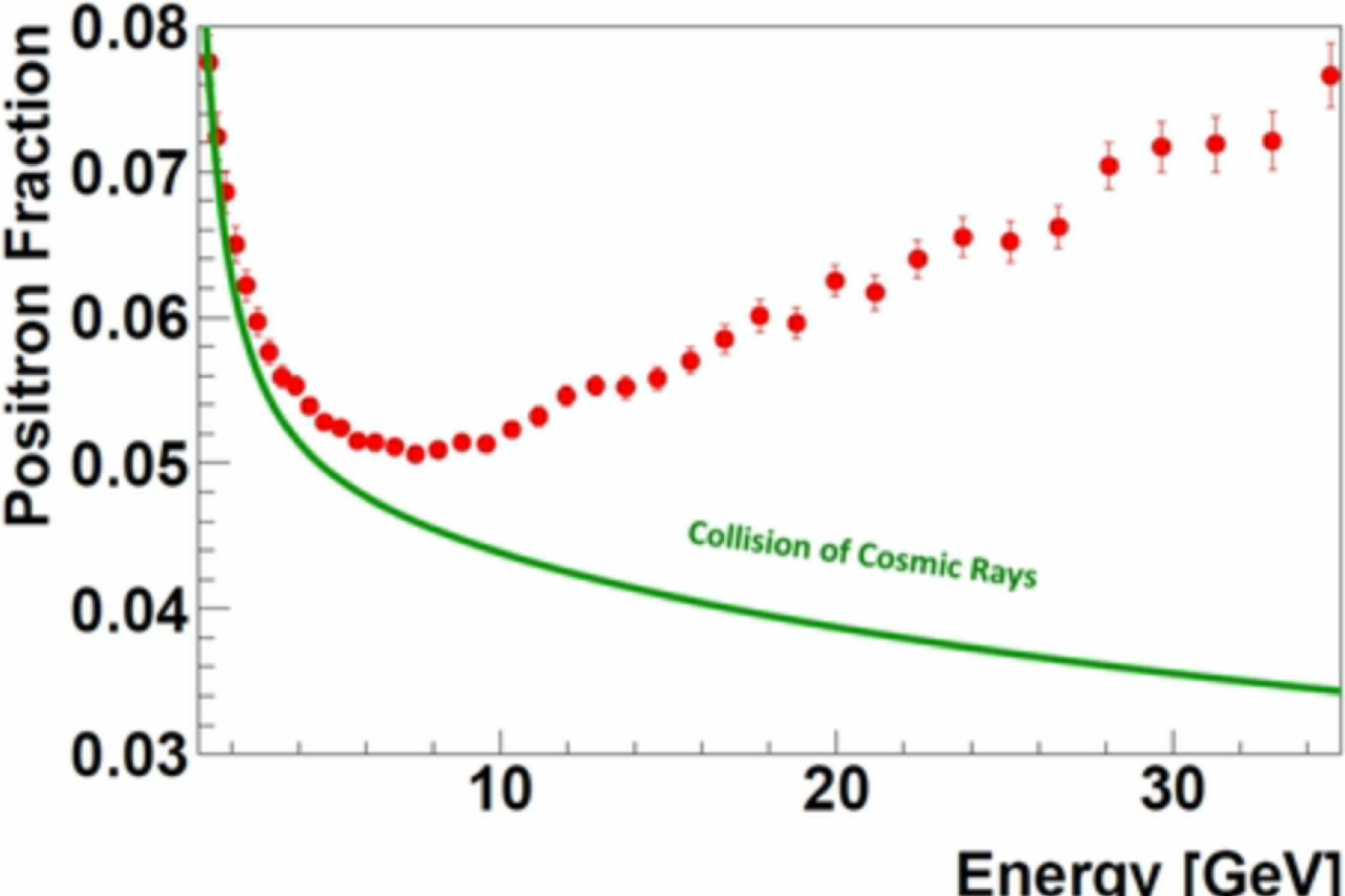
$$n_{e^+}(E) = q_{e^+}(E) \times T_e(E)$$

$$E^{-3.7} \simeq E^{-2.7} \times E^{-1}$$

Prediction : *softer*

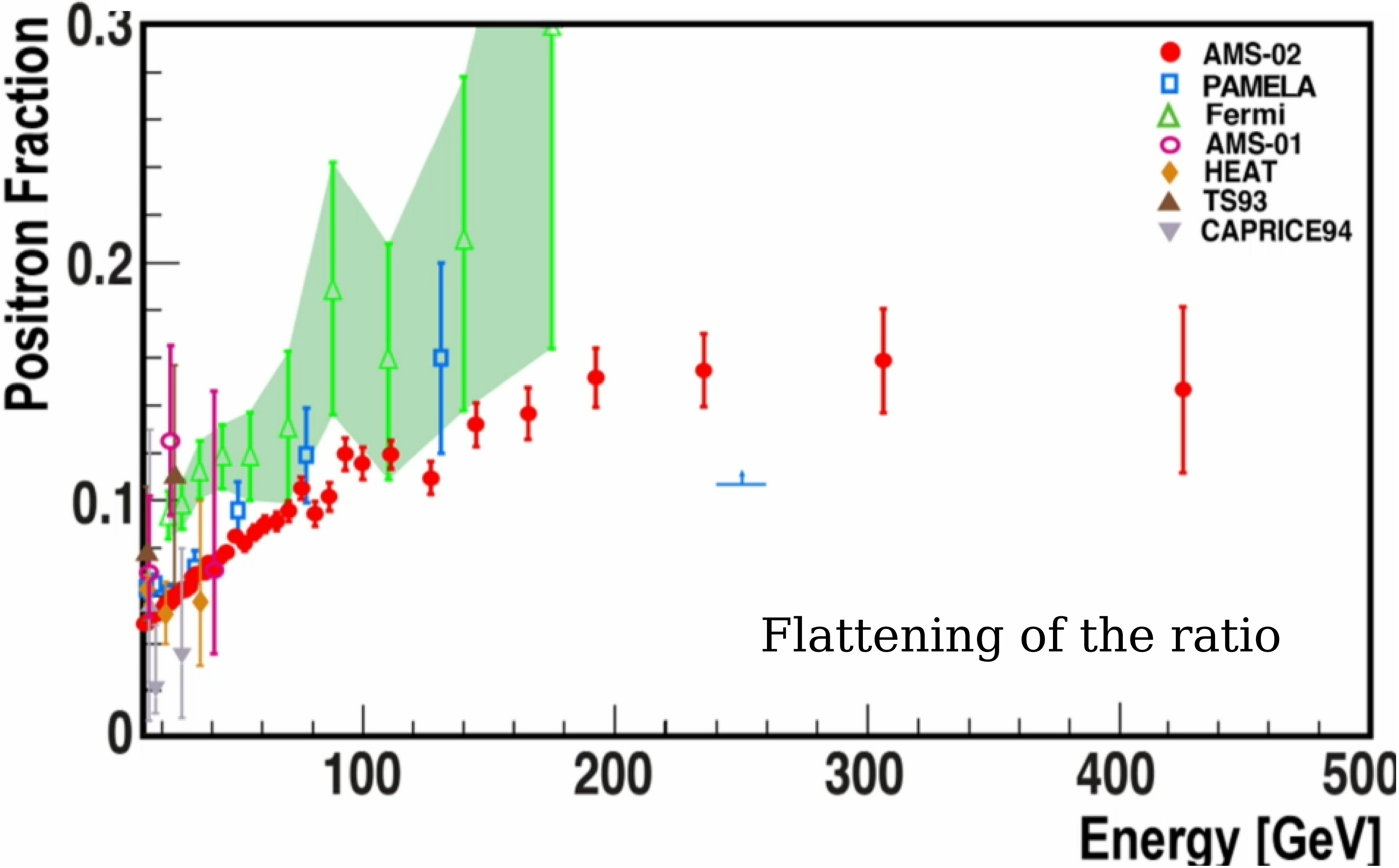
Positron Fraction

$$\frac{e^+}{e^+ + e^-}$$



Positron Fraction

$$\frac{e^+}{e^+ + e^-}$$



Flattening of the ratio

Minimal Model:

Diffuse Flux — Source Flux

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

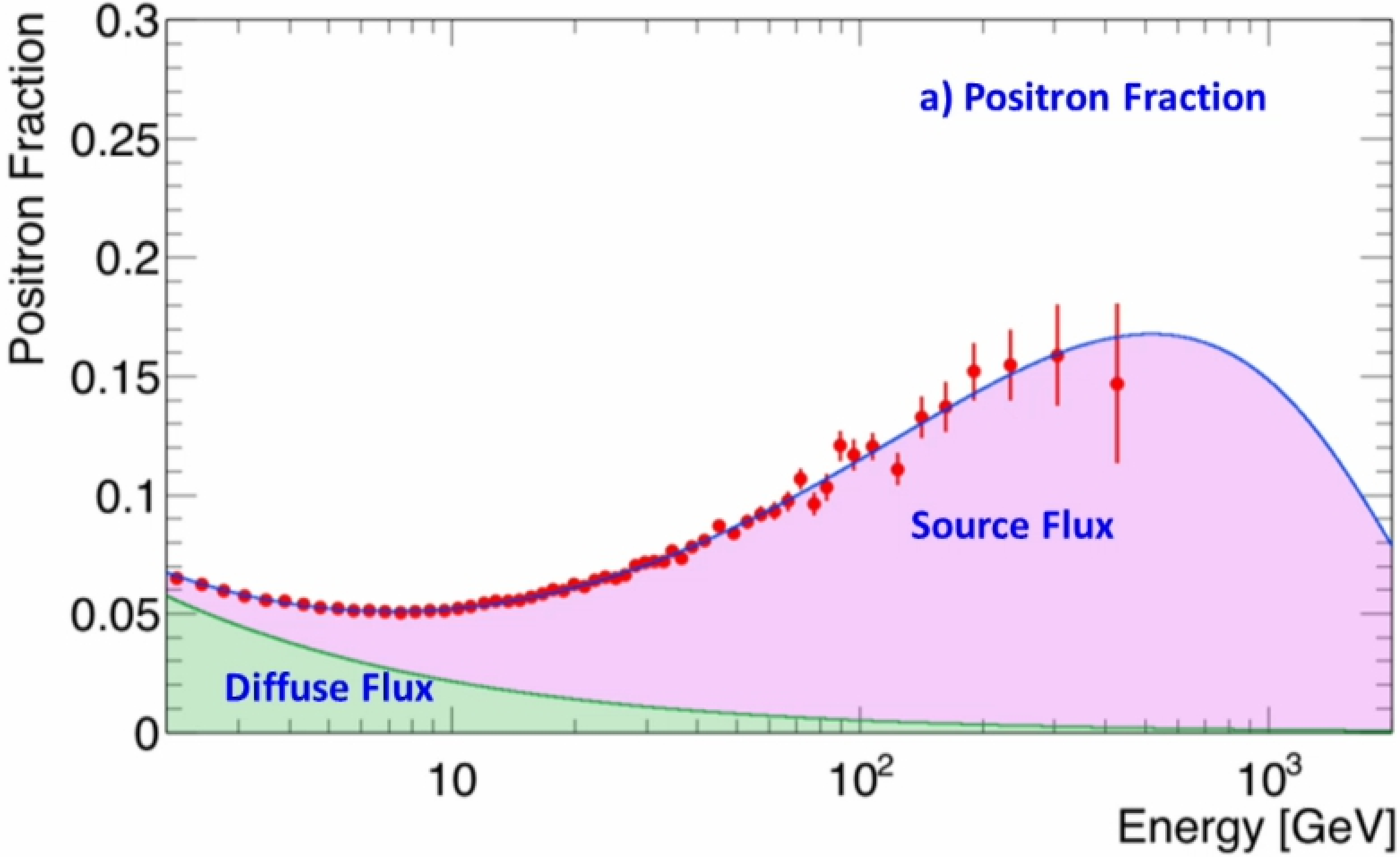
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Fit to a) Positron Fraction from 2 GeV determines the relations:

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.06$, $\gamma_{e-} - \gamma_s = 0.66 \pm 0.05$,

$C_{e+} / C_{e-} = 0.095 \pm 0.003$, $C_s / C_{e-} = 0.008 \pm 0.001$

$1/E_s = 1.3 \pm 0.6\ \mathrm{TeV}^{-1}$



Minimal Model:

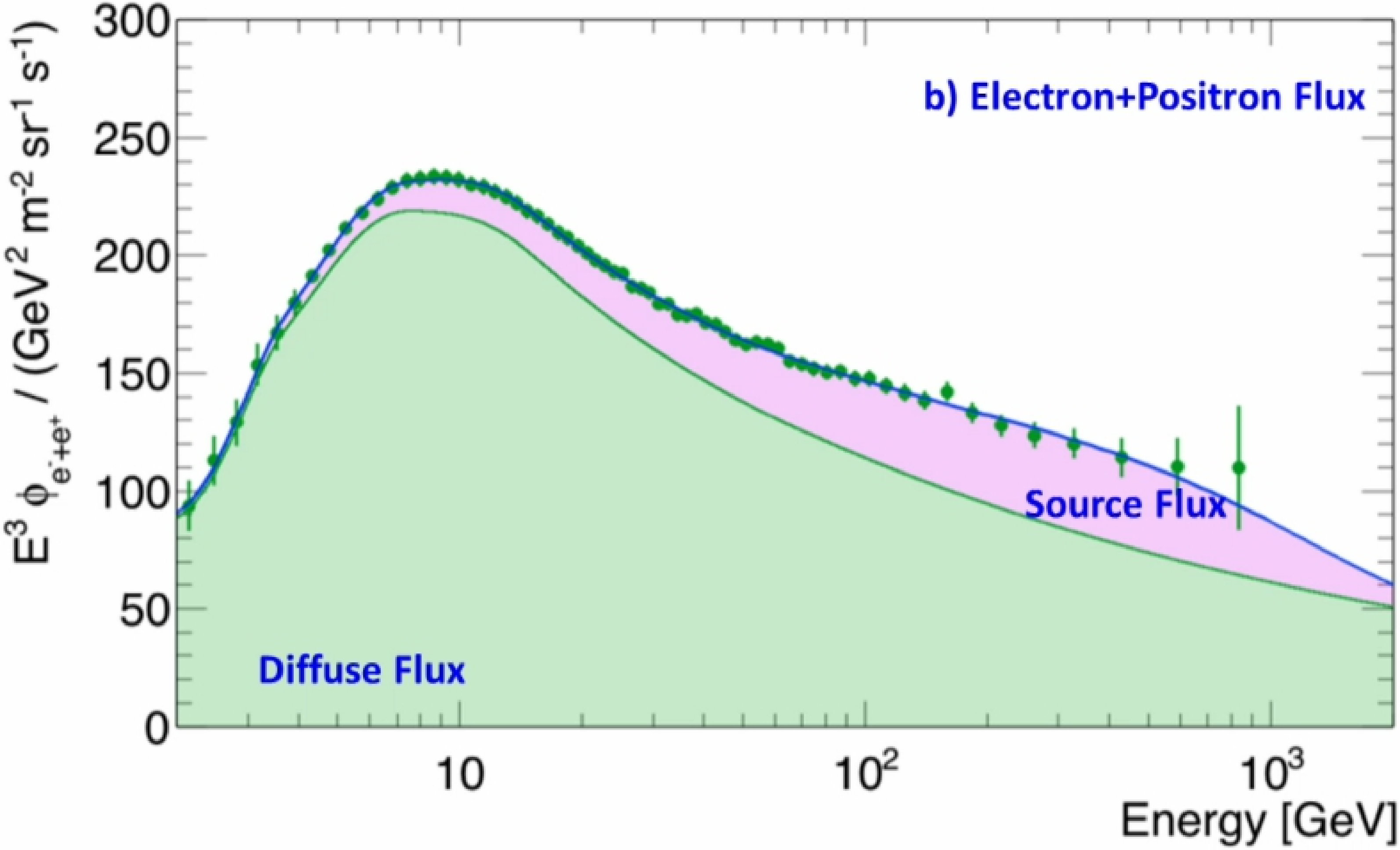
Diffuse Flux | Source Flux

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

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

Fit to b) Electron + Positron Flux from 2 GeV determines γ_{e-} and C_{e-}

γ_{e-} is energy dependent below ~15 GeV



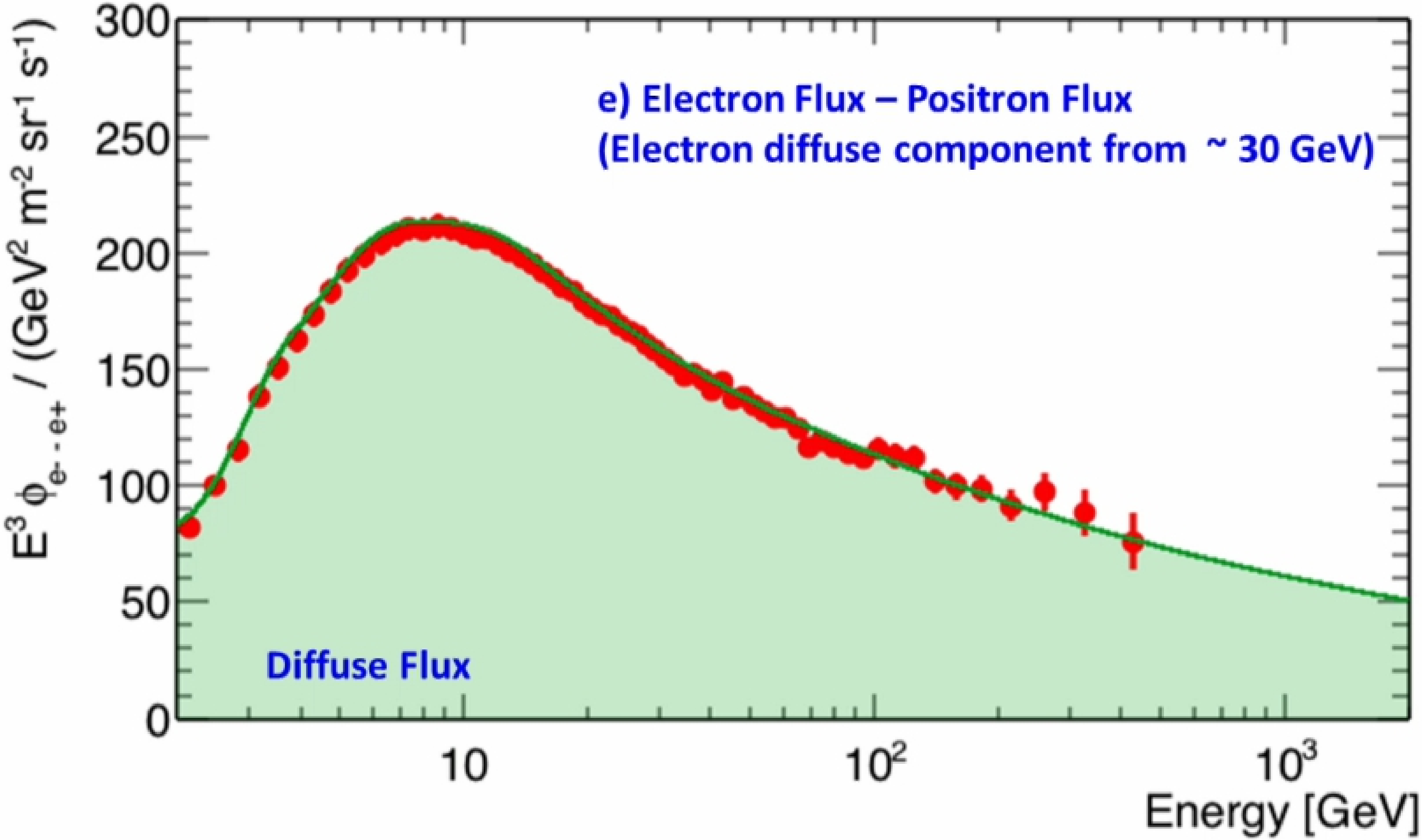
Minimal Model:

Diffuse Flux — Source Flux

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

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

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



Has the existence of an “extra-component”
In the positron flux established beyond doubt ?
(or it is somewhat “model dependent” ?)

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the propagation of cosmic rays in our Galaxy,
and can be considered as quite robust.

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(protons, nuclei, electrons, fail completely with positrons).

.... but there is no "universal" agreement on
the need of an extra positron component

First (clear) indication of the "positron excess" by PAMELA (september 2009)

An anomalous positron abundance in cosmic rays with energies 1.5-100 GeV
PAMELA Collaboration (Oscar Adriani (Florence U. & INFN, Florence) *et al.*). Oct 2008. 20 pp.
Published in **Nature 458 (2009) 607-609**
DOI: 10.1038/nature07942
e-Print: **arXiv:0810.4995 [astro-ph] | PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
CERN Document Server ; ADS Abstract Service
Detailed record - Cited by 1329 records 1000+

> 1300 references

First paper of AMS on the positron fraction (march 2013)

First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV
AMS Collaboration (M. Aguilar *et al.*). 2013.
Published in **Phys.Rev.Lett. 110 (2013) 141102**
DOI: 10.1103/PhysRevLett.110.141102
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
Interactions.org article; Link to SYMMETRY; Link to PRESSRELEASE
Detailed record - Cited by 272 records 250+

$\simeq 0.48$ papers/day

Some authors (3 groups) claim that the positron data are compatible with the “standard mechanism” of positrons production in cosmic ray collisions.
[At the “price” of an important modification of the properties of Cosmic Ray propagation in the Galaxy.]

[1] R. Cowsik and B. Burch,
“Positron fraction in cosmic rays and models of cosmic-ray propagation,”
Phys. Rev. D **82**, 023009 (2010).

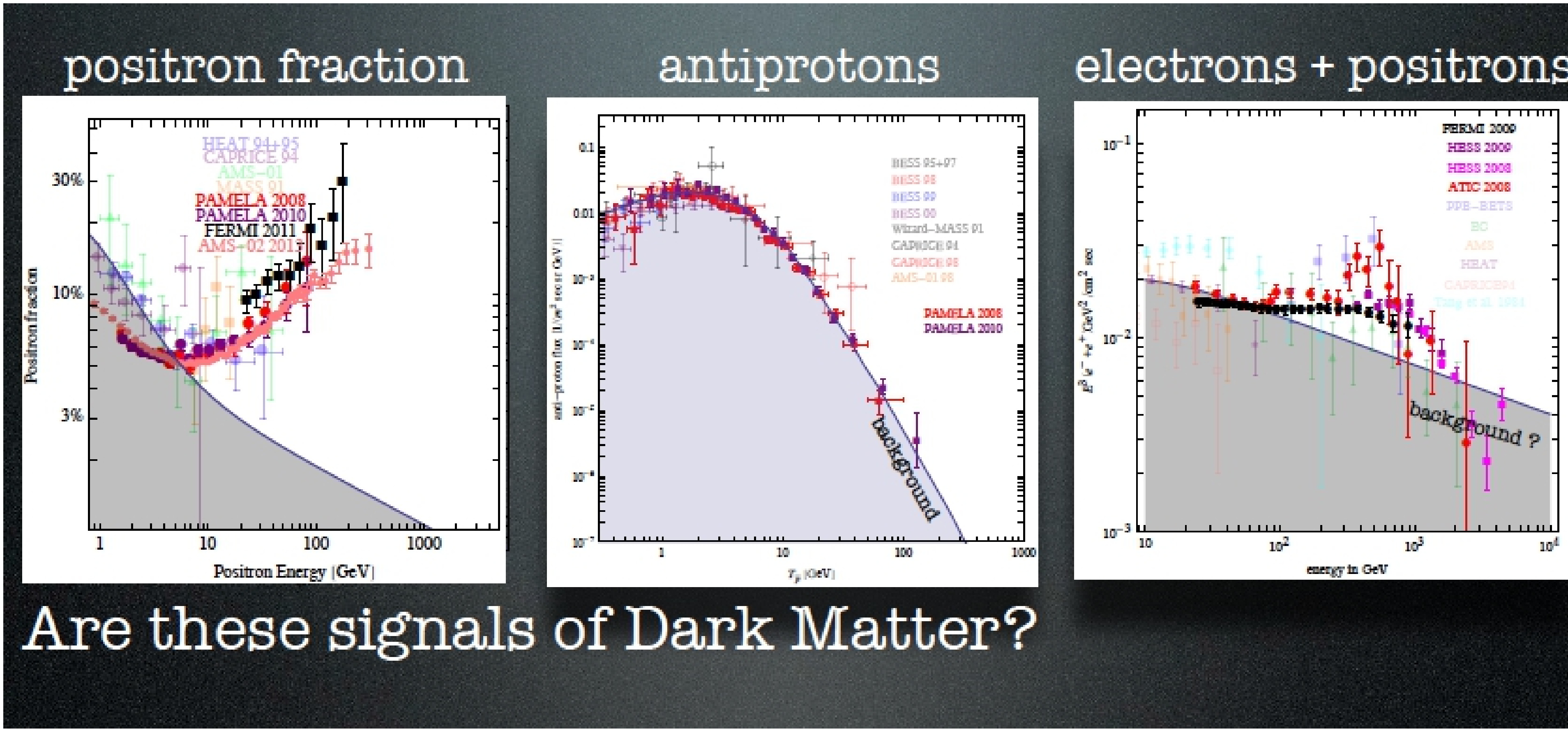
[2] R. Cowsik, B. Burch and T. Madziwa-Nussinov,
“The origin of the spectral intensities of cosmic-ray positrons,”
Astrophys. J. **786**, 124 (2014) [arXiv:1305.1242 [astro-ph.HE]].

[3] K. Blum, B. Katz and E. Waxman,
“AMS-02 Results Support the Secondary Origin of Cosmic Ray Positrons,”
Phys. Rev. Lett. **111**, no. 21, 211101 (2013) [arXiv:1305.1324 [astro-ph.HE]].

[4] S. P. Ahlen and G. Tarlé,
“Secondary Production as the Origin for the Cosmic Ray Positron Excess,”
arXiv:1410.7239 [astro-ph.HE].

Dark Matter interpretation

Marco Cirelli (Ricap-2014).



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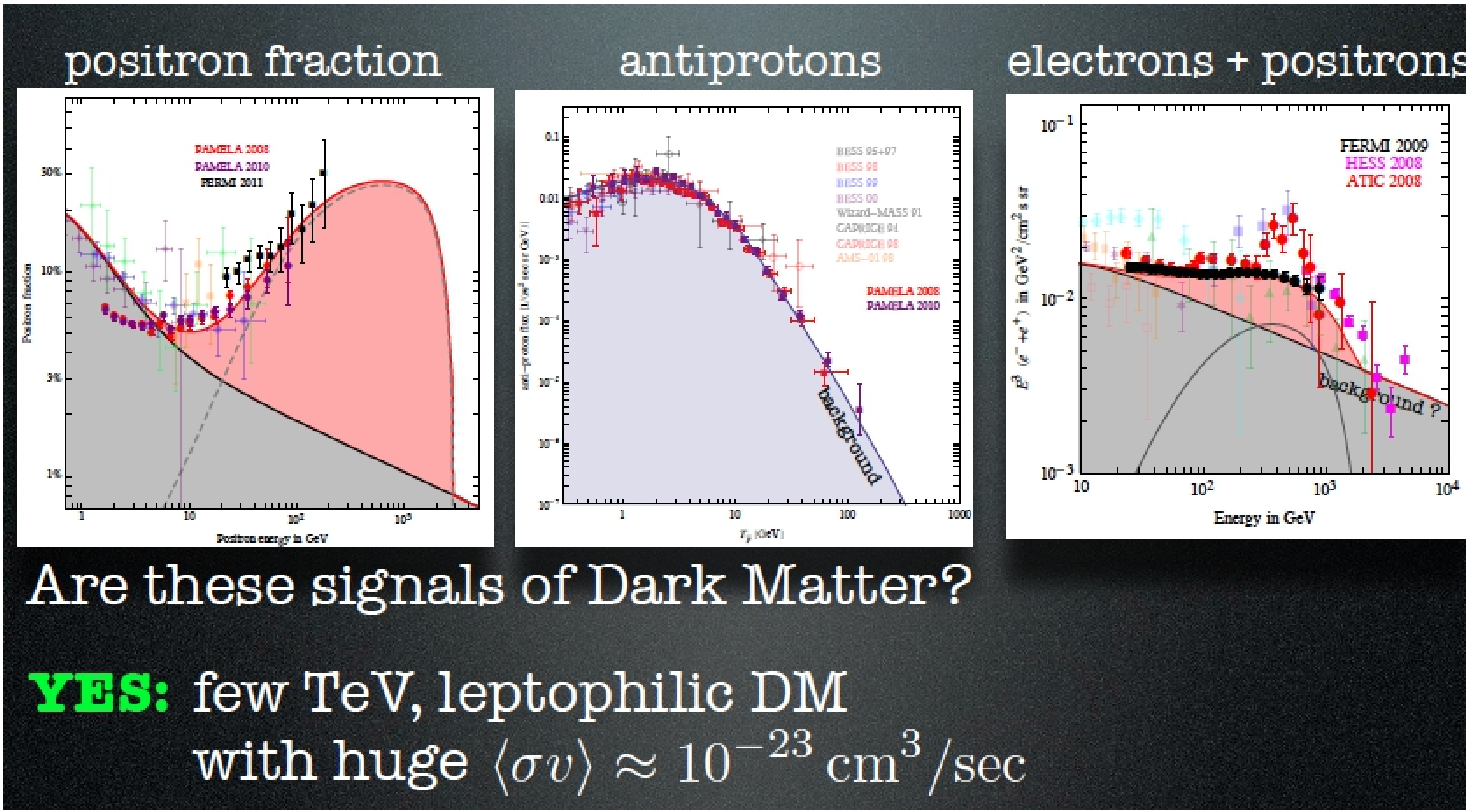
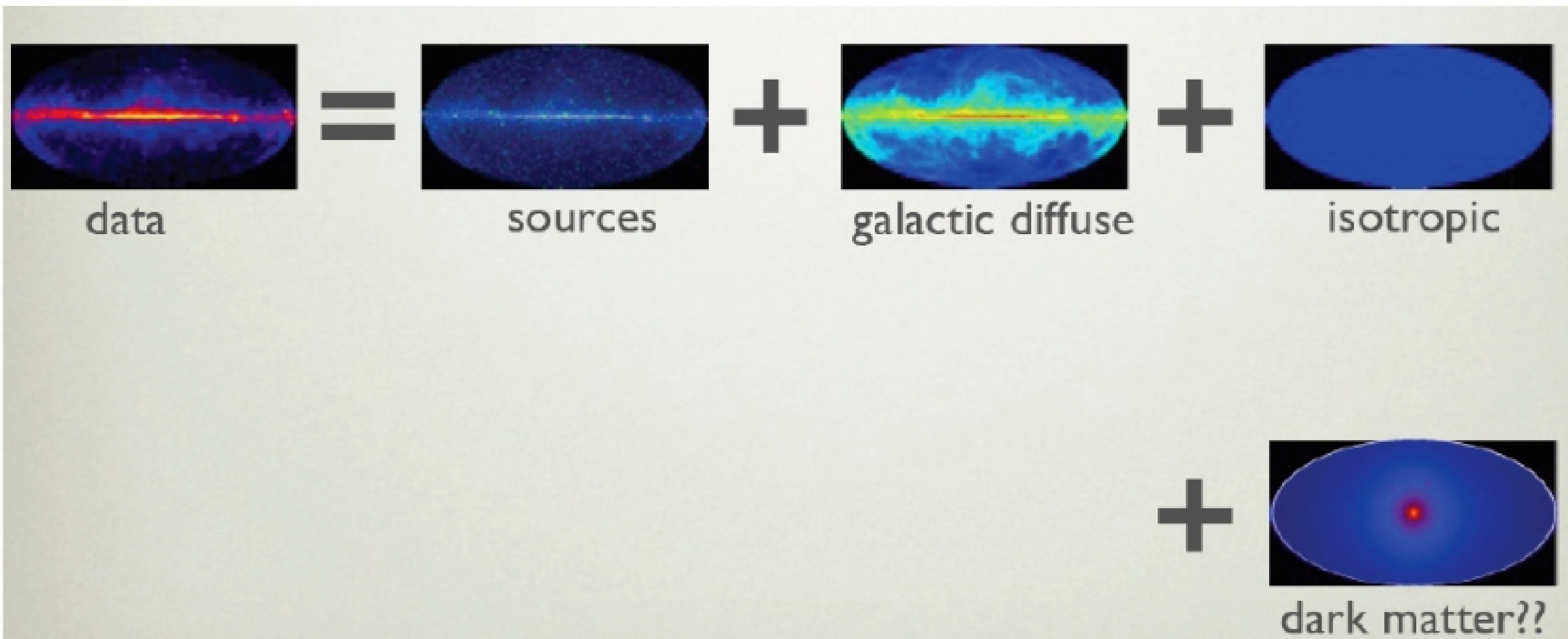
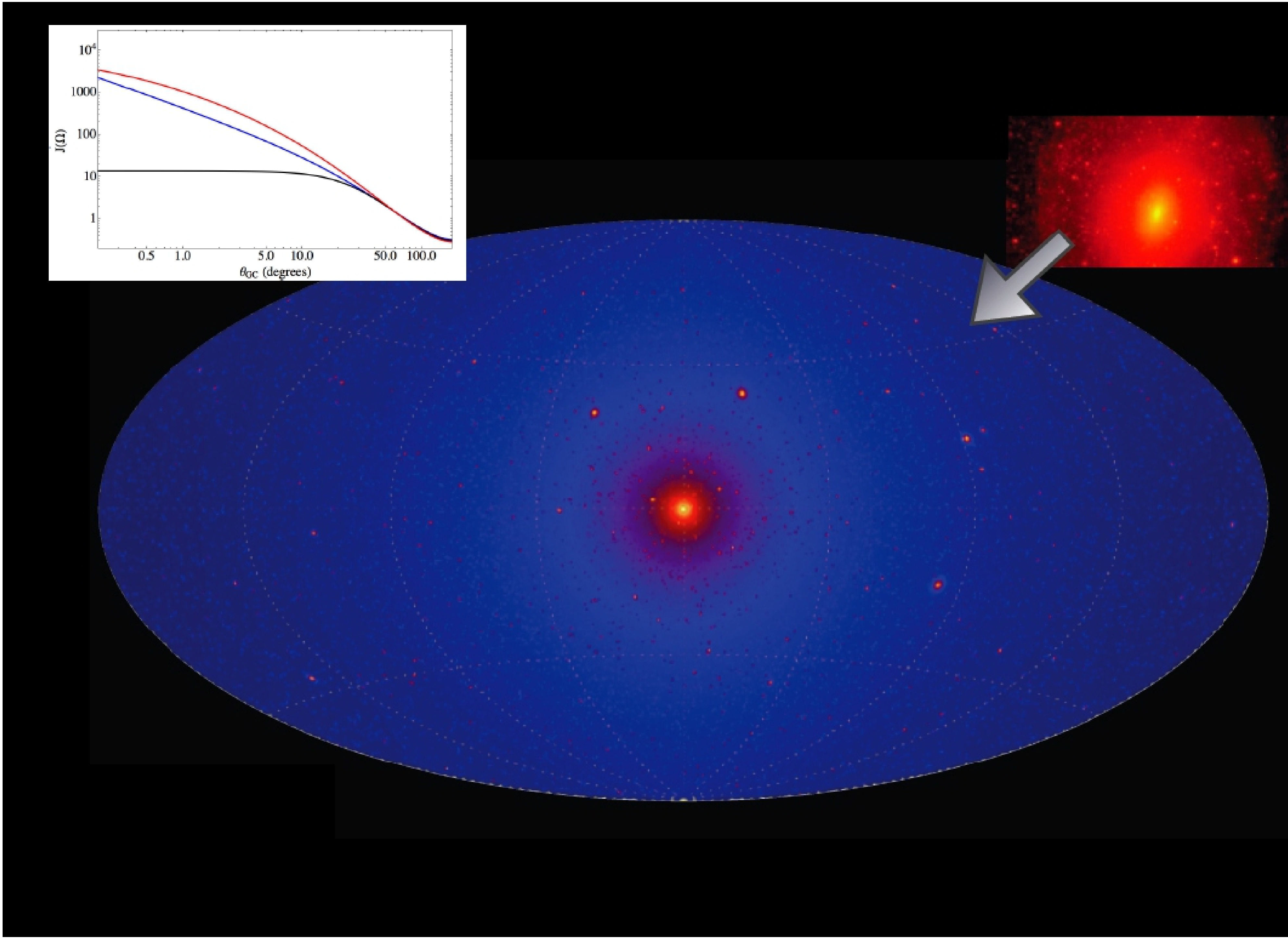
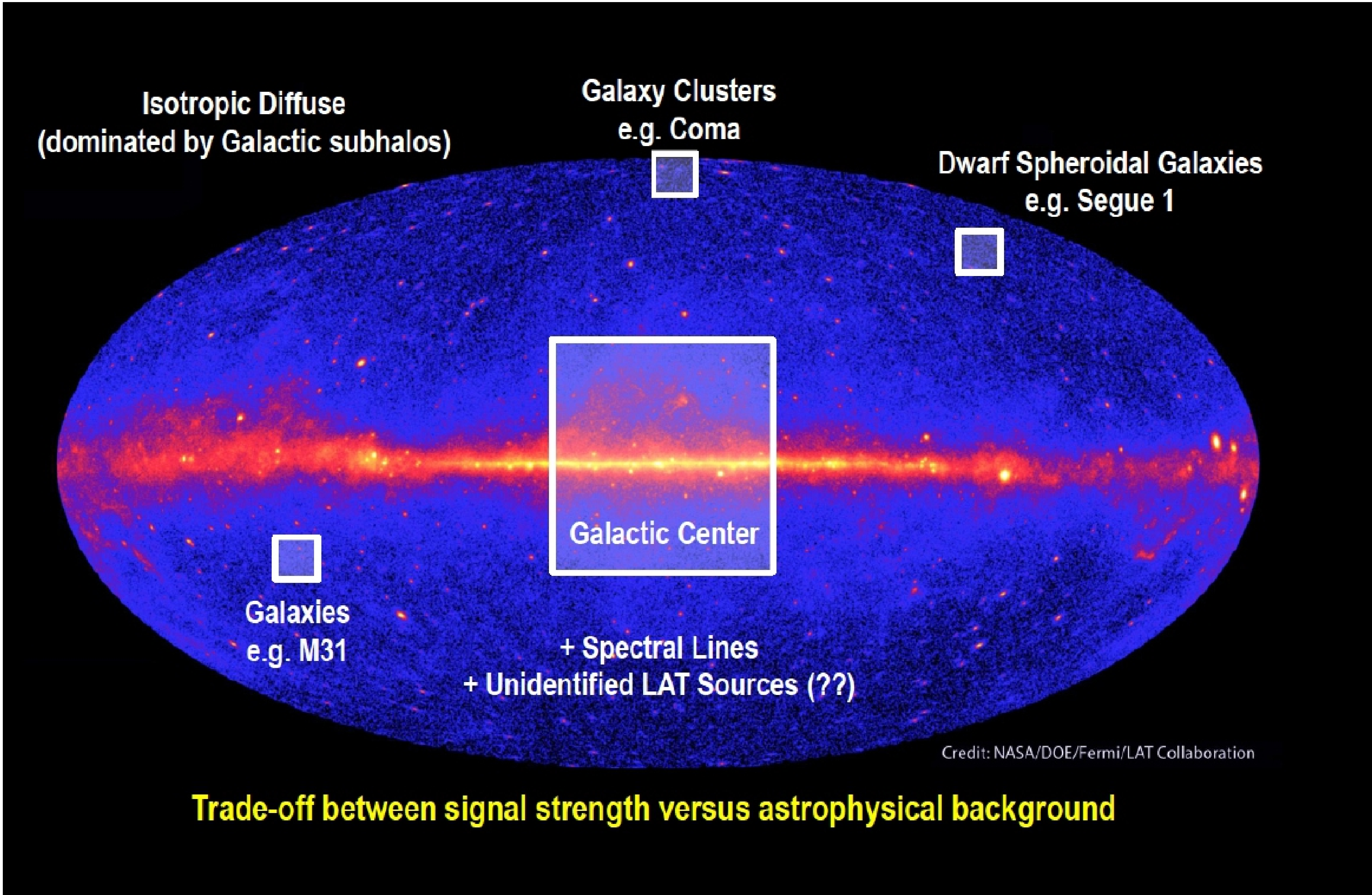


A Dark Matter interpretation of the positron excess can be tested with gamma-ray astronomy.

[and is is possible tension with existing data From FERMI (and Cherenkov telescopes)]




J(Ω)
θGC (degrees)
10^4
1000
100
10
1
0.5
1.0
5.0
10.0
50.0
100.0


Isotropic Diffuse
(dominated by Galactic subhalos)
Galaxy Clusters
e.g. Coma
Dwarf Spheroidal Galaxies
e.g. Segue 1
Galactic Center
Galaxies
e.g. M31
+ Spectral Lines
+ Unidentified LAT Sources (??)
Credit: NASA/DOE/Fermi/LAT Collaboration
Trade-off between signal strength versus astrophysical background

DM Related Symposium Contributions

Contribution	Topic
Non-detections of Gamma-rays from Galaxy Clusters with the Fermi-LAT: status and implications for cosmic ray and dark matter physics (**S. Zimmer**)	Galaxy Clusters
A modified likelihood procedure for dark matter searches (**A. Drlica-Wagner**) A Search for Dark Matter Annihilation in Dwarf Spheroidal Galaxies with Pass 8 Data (**B. Anderson**) Searching for Dark Matter Annihilation in the Smith High-Velocity Cloud (**G. Gómez-Vargas**)	Milky Way Satellites
Updated Spectral Line Search and Status of 135 GeV Feature with Pass 8 Data (**A. Albert**) Detailed Look at the 133 GeV Feature Comparing Pass 7 and Pass 8 Event Reconstructions (**R. Caputo**)	Gamma-ray Lines
Fermi LAT limit on evaporation of primordial black holes (**D. Malyshev**) Dark Matter Annihilation Cross Section Constraints from the Cross-correlation of Cosmic Shear and Extragalactic Gamma-ray Background (**M. Shirasaki**) Anisotropies in the Gamma-ray Sky (**F. Donato**) Composition of the Isotropic Diffuse Gamma-ray Background and Dark Matter Constraints (**M. Di Mauro**)	Isotropic Gamma-ray Background
Observations of High-Energy Gamma-Ray Emission Toward the Galactic Center (**S. Murgia**) The Characterization of the Gamma-Ray Signal from the Central Milky Way (**T. Linden**) Dark Matter Annihilation in the Galactic Center (**D. Hooper**) The GeV Excess Shining Through: Background Systematics for the Inner Galaxy Analysis (**F. Calore**) Robust Identification of the GeV Galactic Center Excess at Higher Latitudes (**C. Weniger**) The Inner Milky Way's Extended Gamma-ray Excess: Evidence of Self-annihilating Dark Matter? (**A. Kwa**) GeV Excess Electrons Upscattering the CMB: A Possible Resolution to the "Photon Underproduction Crisis" (**T. Daylan**)	Inner Galaxy/ Galactic Center

Alternative "Astrophysical" explanation:

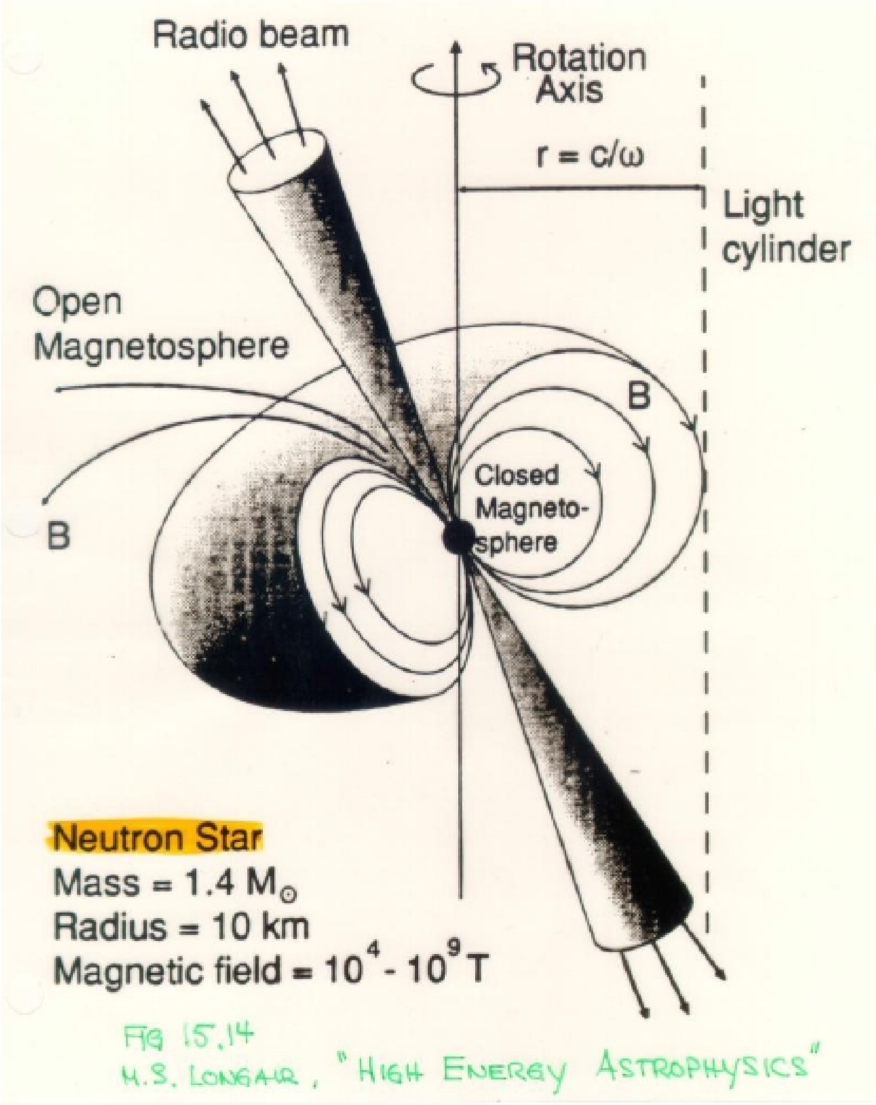
Existence of a new class of astrophysical sources that accelerate positrons

Injecting a very hard spectrum in interstellar space: $q_{e^+}(E) \simeq E^{-1.7}$

and sufficient power 10^{37} - 10^{38} erg/s

PULSARS

Proposed as possible Accelerators of e+ e-



CRAB Nebula

$$P_{\rm Crab} = 0.0334 \text{ s}$$

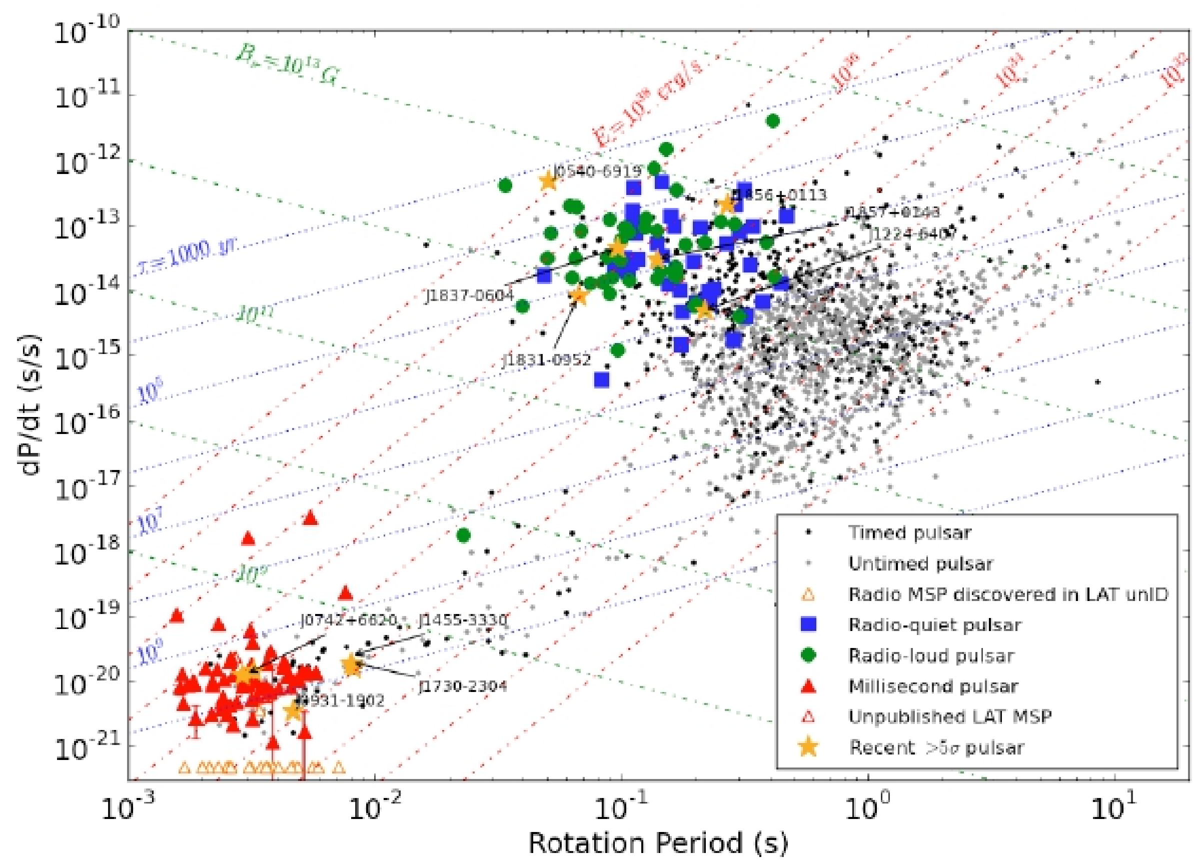
$$\dot{P}_{\rm Crab} = 4.2 \times 10^{-13} \text{ s}$$

$$(\Delta P_{\rm Crab})_{\rm year} = 13.2 \times 10^{-6} \text{ s}$$

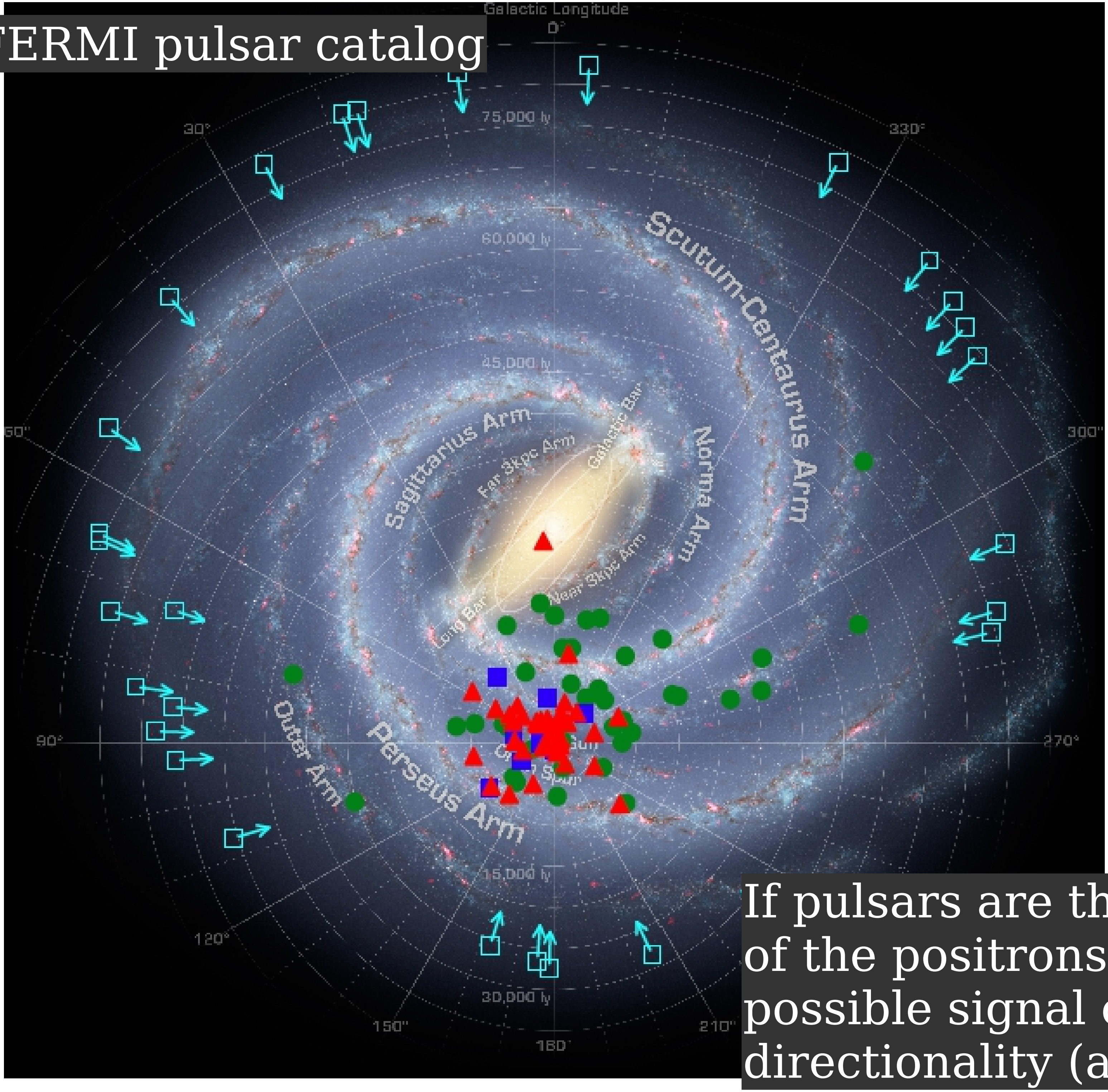
FERMI satellite measurement of pulsars.

- **Radio-loud young pulsars: 50***
- **Radio-quiet young pulsars: 40***
- **Fermi pulsar *Science* papers: 7**

- **Millisecond Pulsars: 71**
  - **Viva la revolution!**
  - **See EF's poster 7.02 and Anne Archibald talk.**
  - **But MSPs are *complicated.***



2nd FERMI pulsar catalog



If pulsars are the sources of the positrons, then possible signal of directionality (anisotropy)

Pulsars as the Sources of High Energy Cosmic Ray Positrons

Hooper, Blasi, Serpico 2008

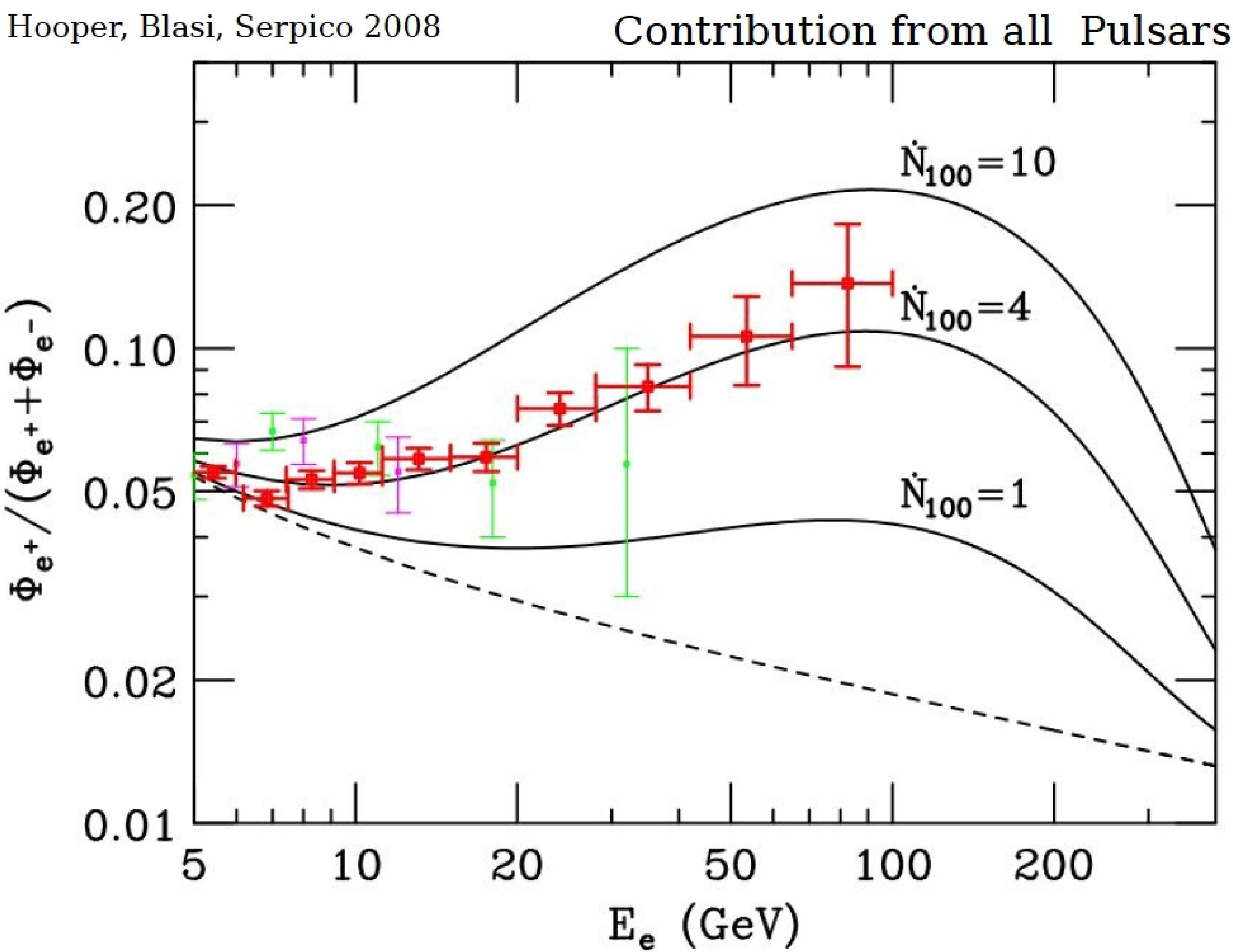
Energy is available
Dynamics of particle production?

$$\frac{dN_e}{dE_e} \approx 8.6 \times 10^{38} \dot{N}_{100} \, (E_e/\text{GeV})^{-1.6} \exp\left(-E_e/80\,\text{GeV}\right) \text{GeV}^{-1}\,\text{s}^{-1}$$

$$-\frac{dE}{dt} = \frac{2}{3\,c^3} \left|\ddot{M}\right|^2$$

$$|\ddot{\vec{M}}|^2 = \frac{B_p^2 R^6}{4} \Omega^4 \sin^2\alpha;$$

$$\frac{dE}{dt} = \frac{d}{dt}\left[\frac{1}{2}\,\Omega^2\right] = I\,\Omega\,\dot{\Omega}$$



Hooper, Blasi, Serpico 2008
Contribution from all Pulsars
$\dot{N}_{100}=10$
$\dot{N}_{100}=4$
$\dot{N}_{100}=1$
0.20
0.10
0.05
0.02
0.01
5
10
20
50
100
200
E_e (GeV)
$\Phi_{e^+}/(\Phi_{e^+}+\Phi_{e^-})$

Conclusions :

1. The AMS detector has obtained new measurements of the electron and positron fluxes of *unprecedented quality and precision.*

2. There are strong indications for the existence of an extra-source of positrons.
   (confirming the indications of Pamela, Fermi, ….)

3. A Dark Matter interpretation is consistent with the Observations, but requires:
   [a] A strong suppression of annihilation into p-pbar
   [or a revision of the present production estimates].
   [b] A large enhancement of the expected annihilation rate

4. Astrophysical solutions (such as emission from young pulsars) are a possibility.

5. New data soon [*anti-protons*],
   Protons, nuclei (for more stringent constraints on propagation).