Indirect Dark Matter search in cosmic rays

F.S. Cafagna, INFN Bari

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An experimentalist point of view

F.S. Cafagna, INFN Bari

With PAMELA experiment

Why Anti(particle)matter matters?

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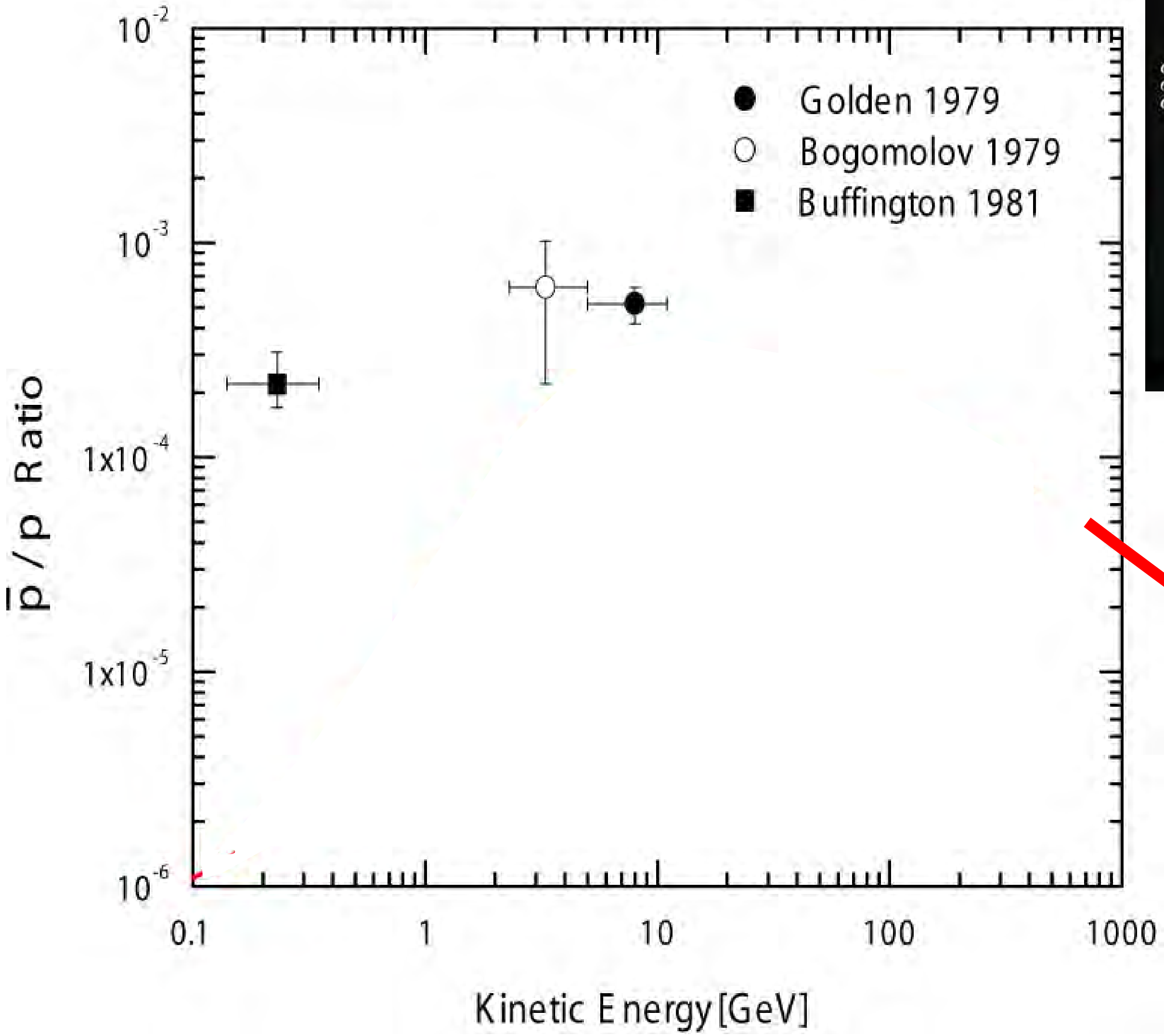
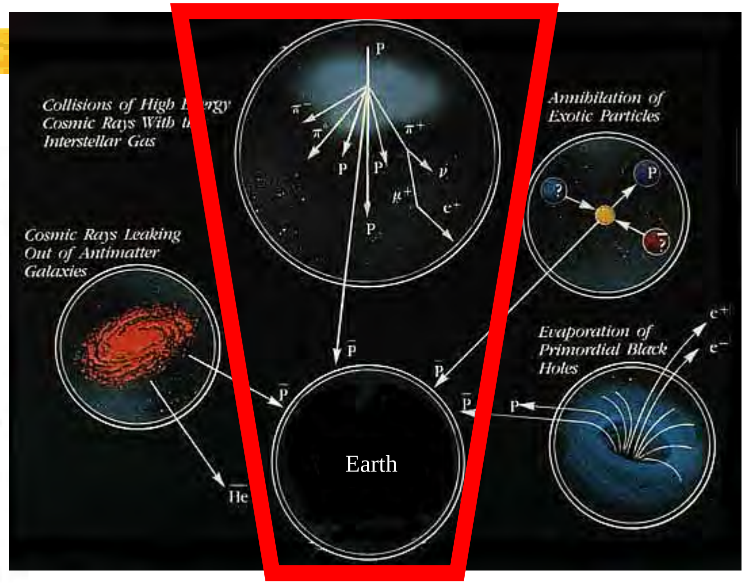
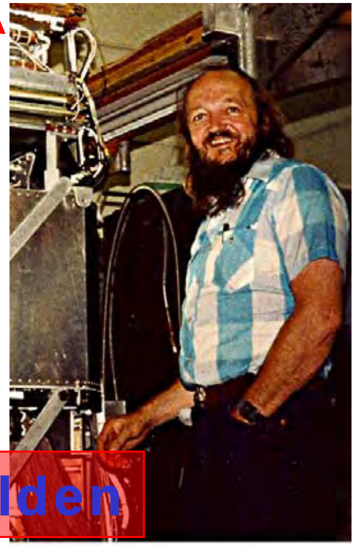
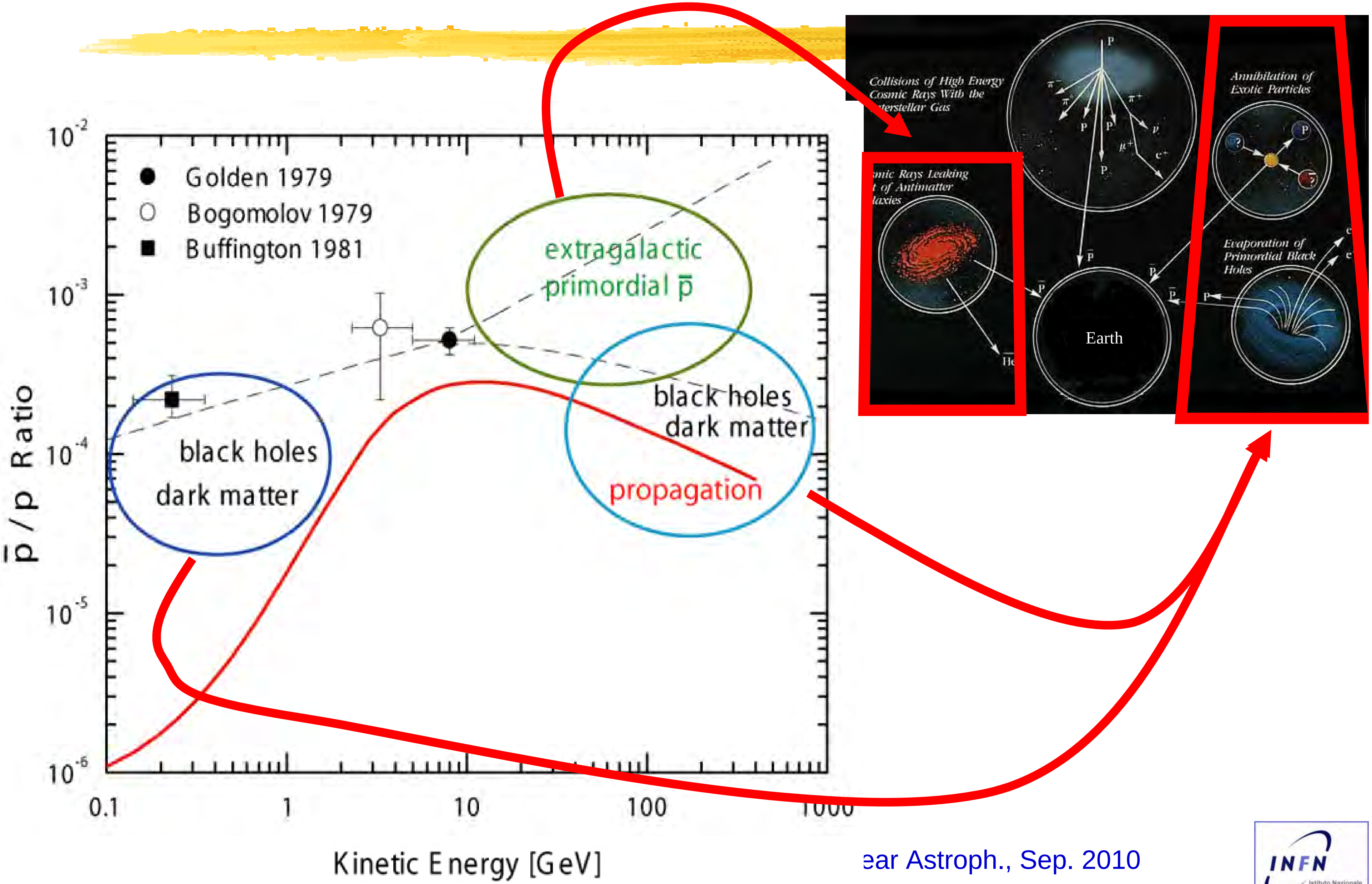






R.L. Golden

Why Anti(particle)matter matters?



ear Astroph., Sep. 2010

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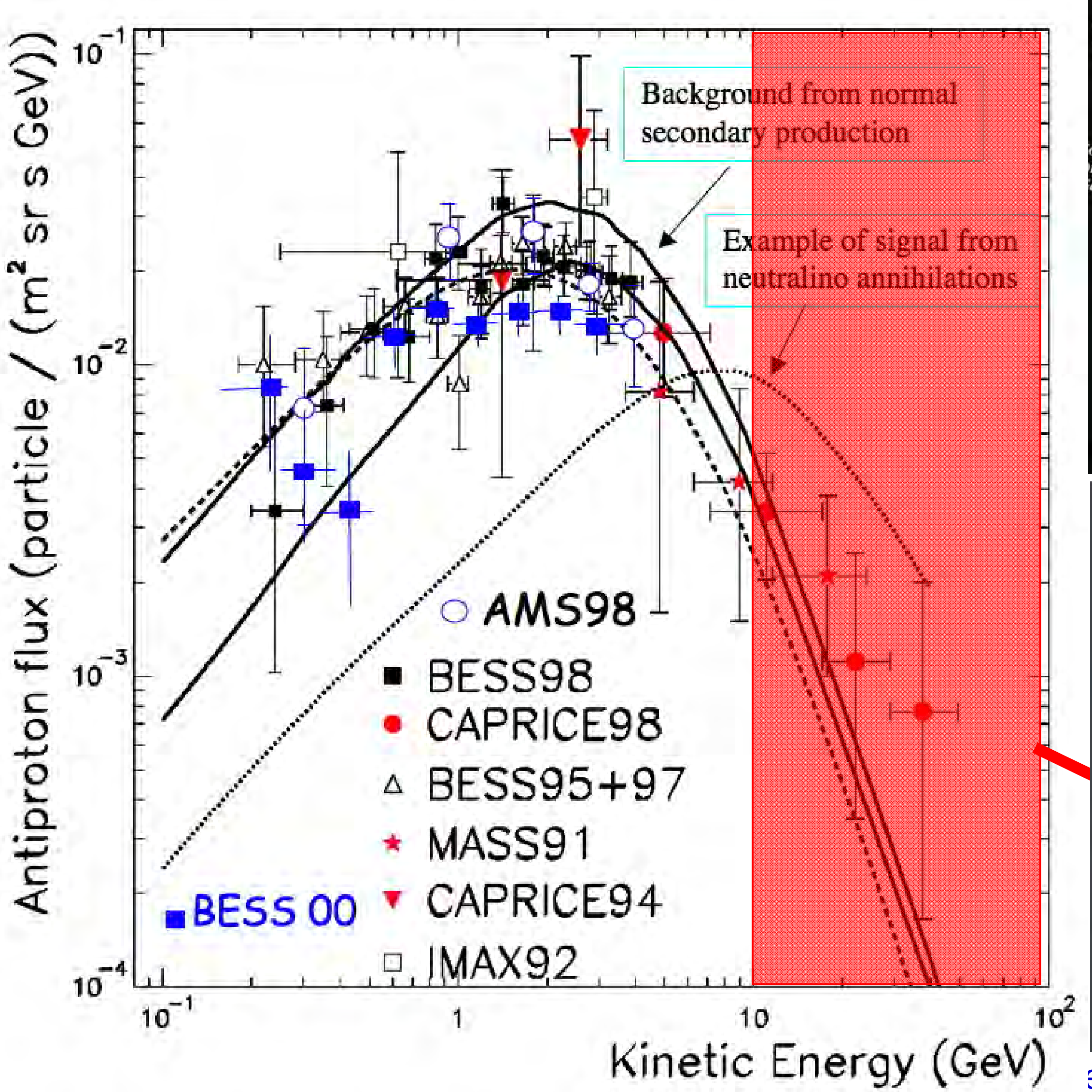

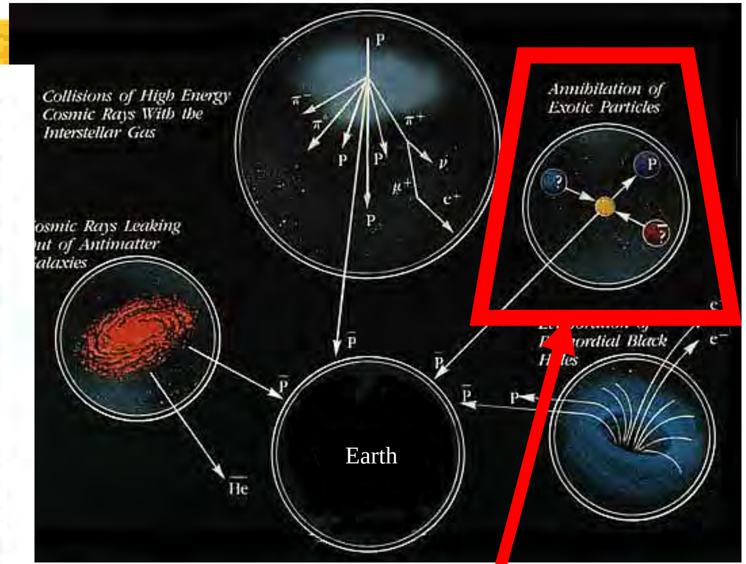

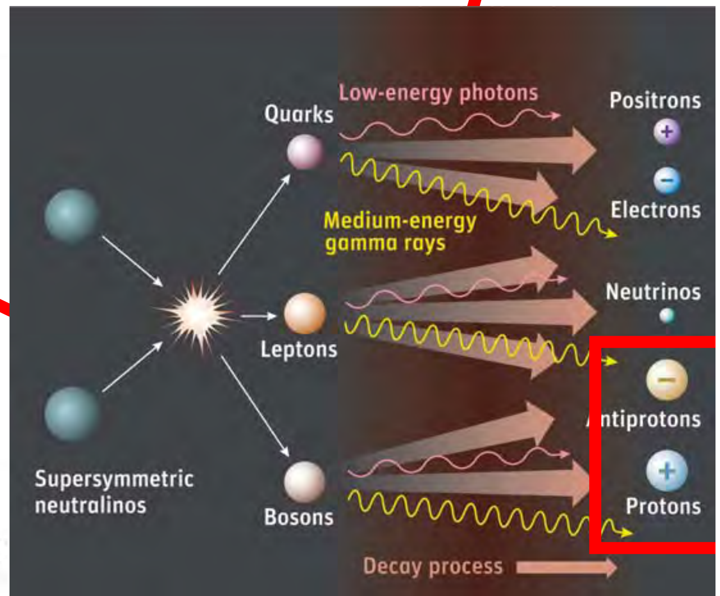

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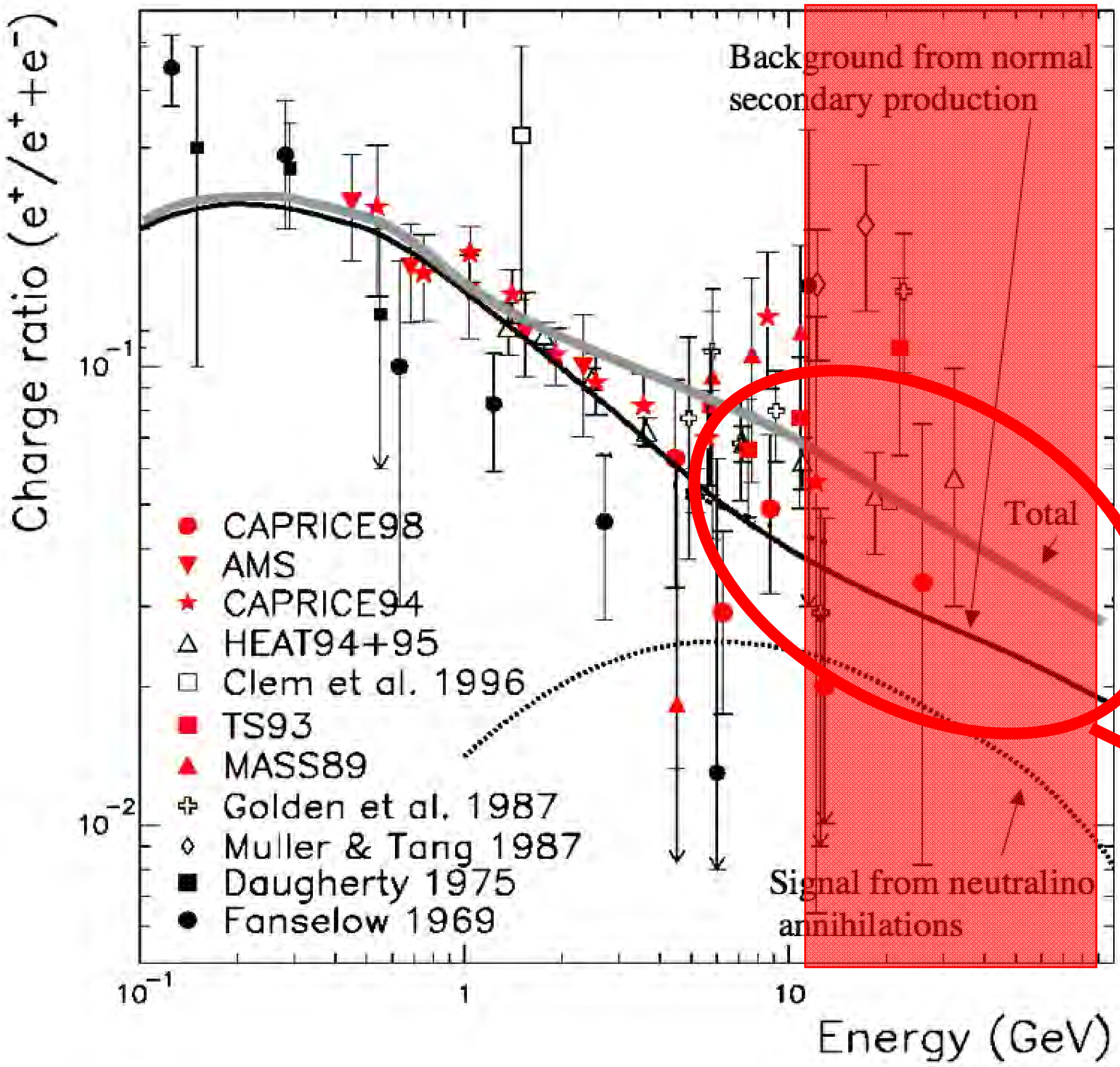
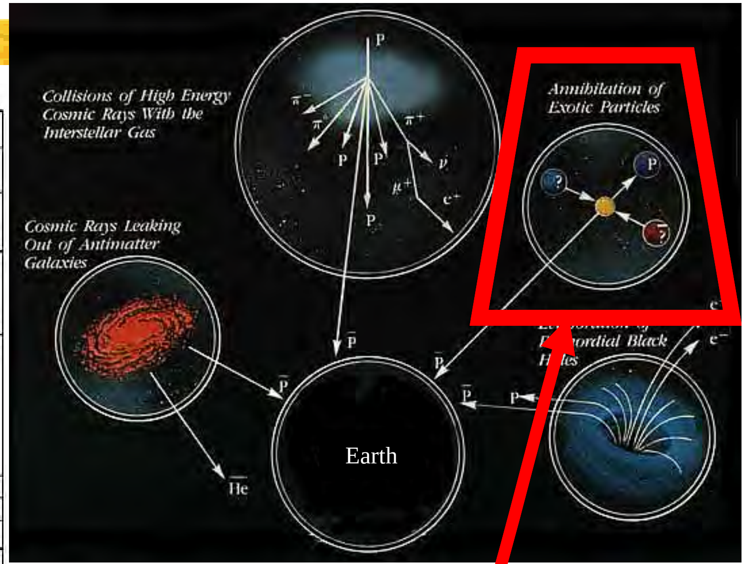
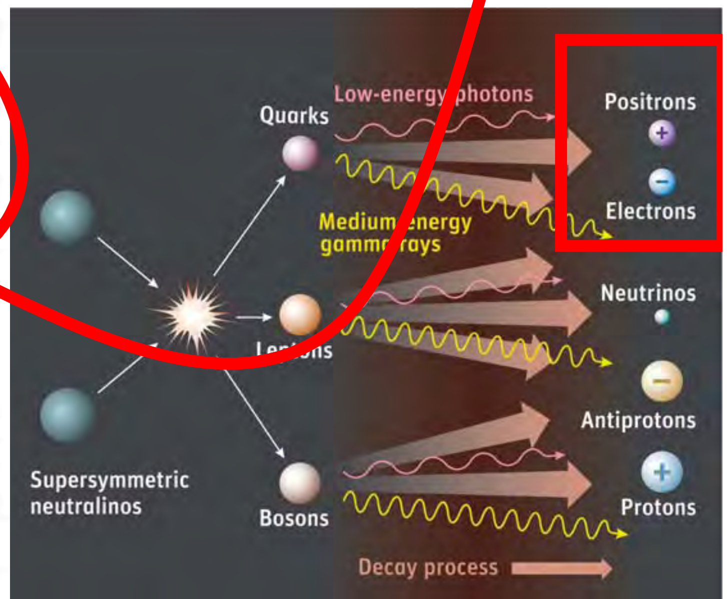




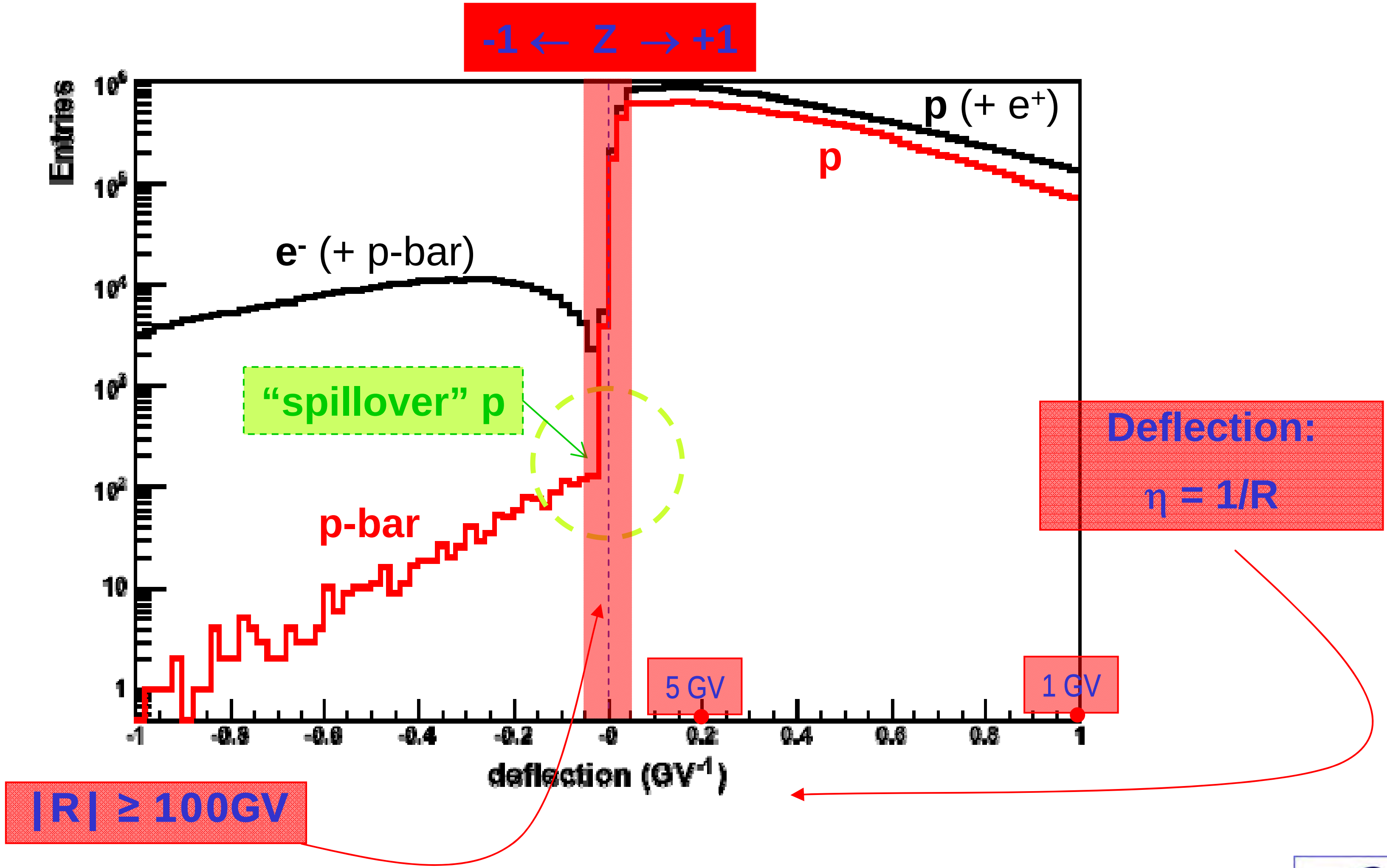


ear Astroph., Sep. 2010

CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)

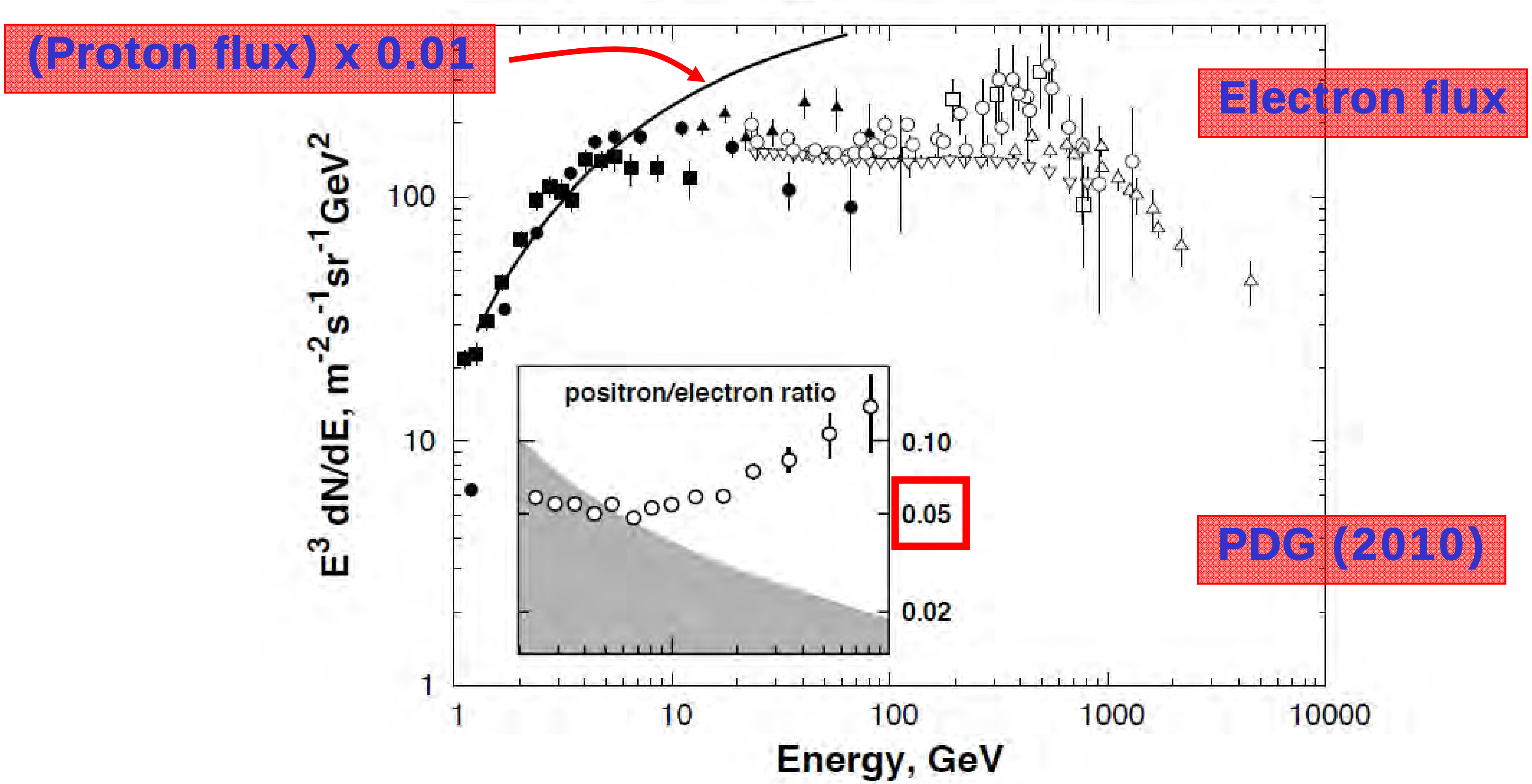
CR antimatter detector cookbook



CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)
- Good (*e/h* > 10^{-5}) particle identification (positron)

CR antimatter detector cookbook

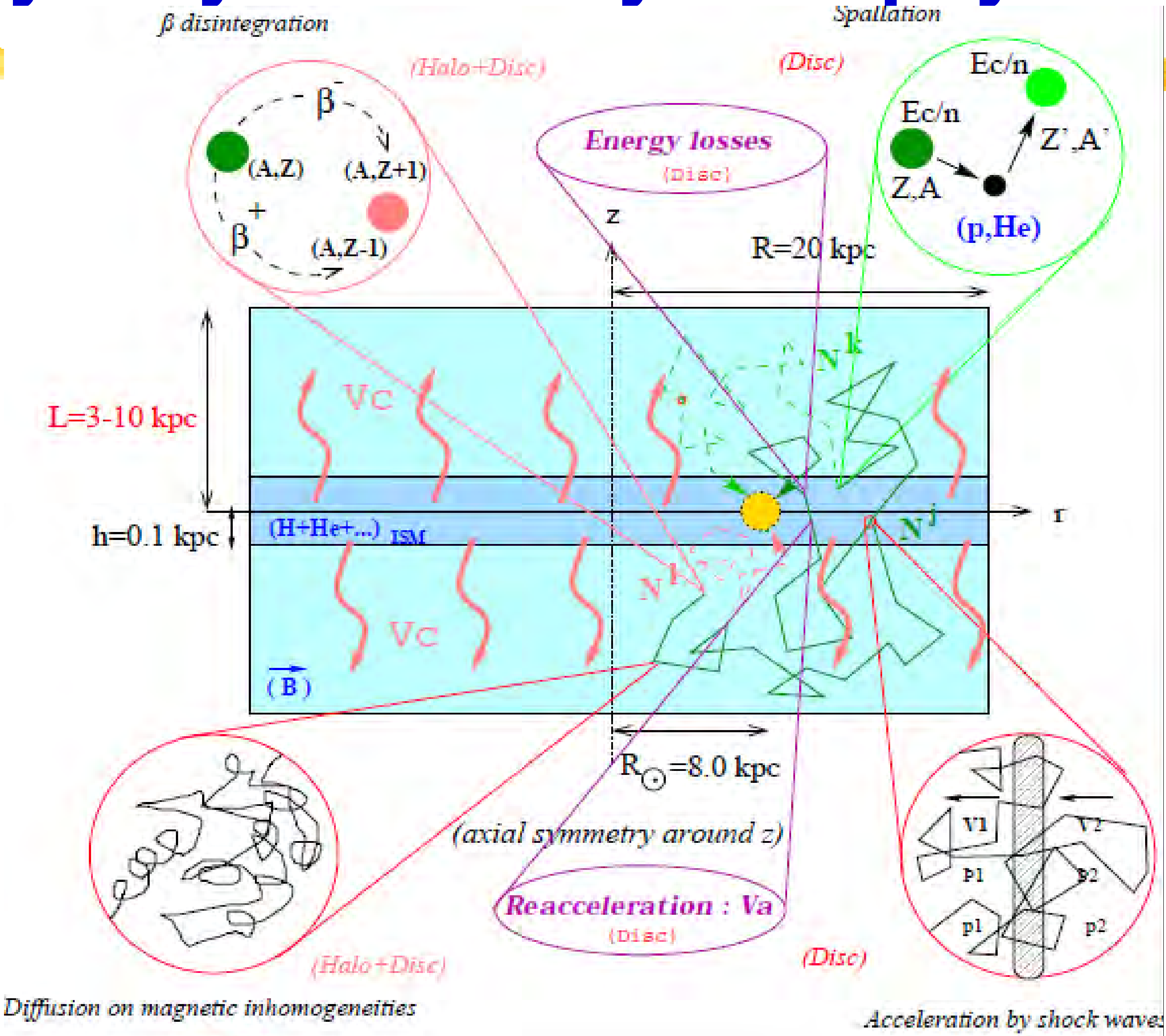


Positron/Proton rejection factor > 10^{-5}

CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)
- Good (*e/h* > 10^{-5}) particle identification (positron)
- Redundancy to calculate efficiencies and systematic in flight (absolute fluxes)
- All other useful detectors ...
- Very low secondary background -> SPACE

Milky Way as seen by a CR physicist



D. Maurin et al., arXiv:astro-ph/0212111

Antimatter from DM calculation

M. Cirelli, NOW 2010
http://www.ba.infn.it/~now/now2010/

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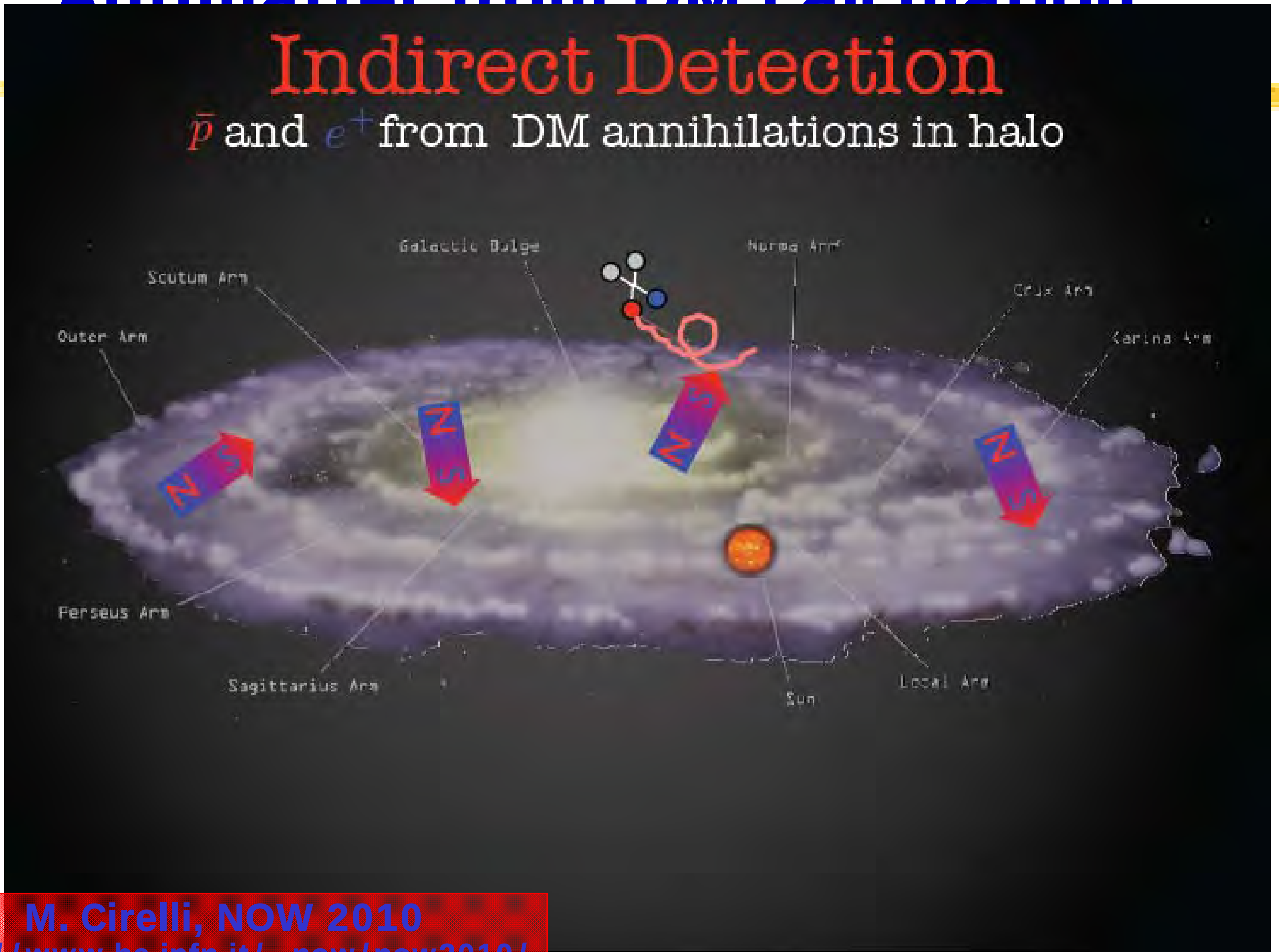

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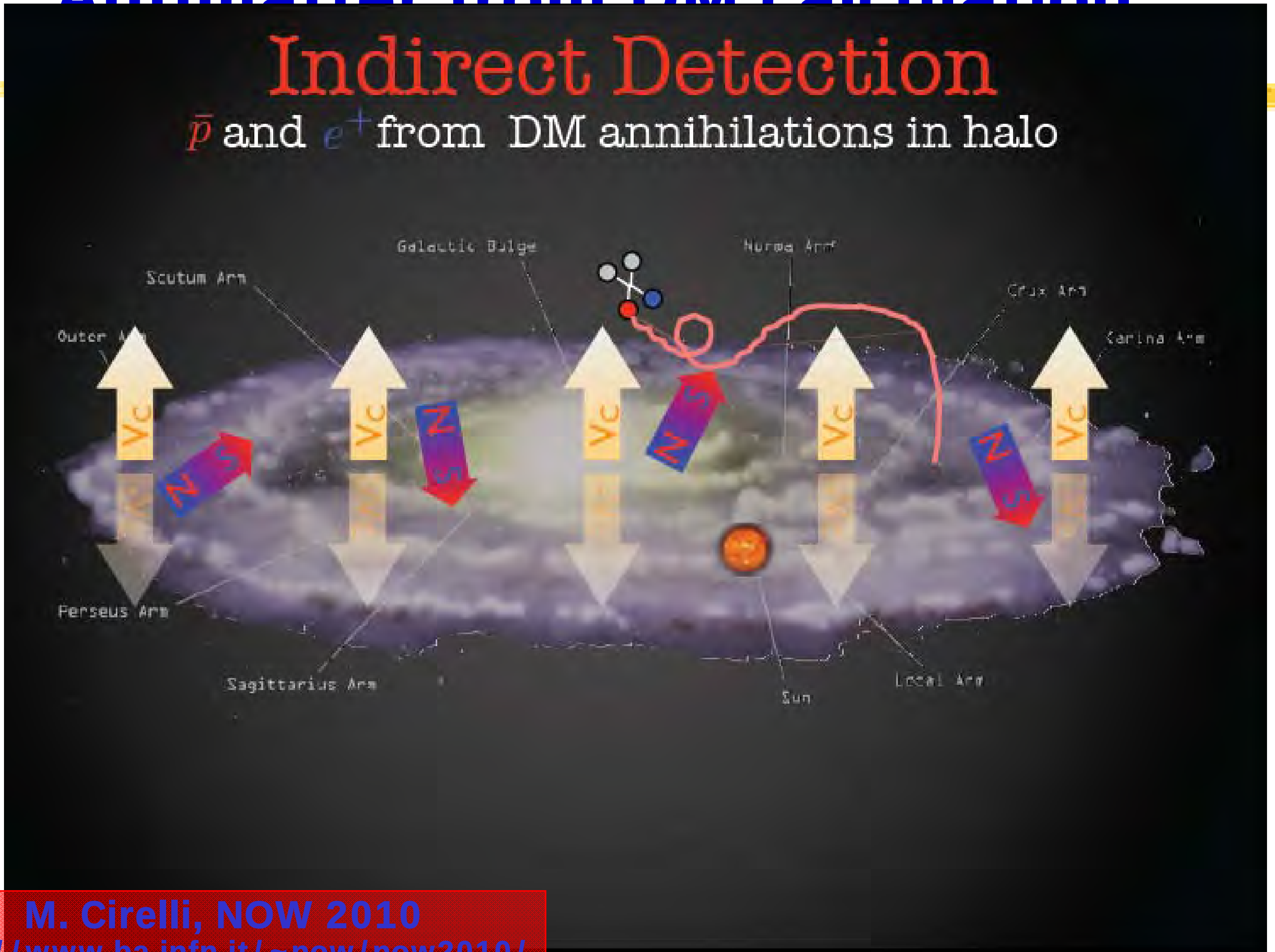

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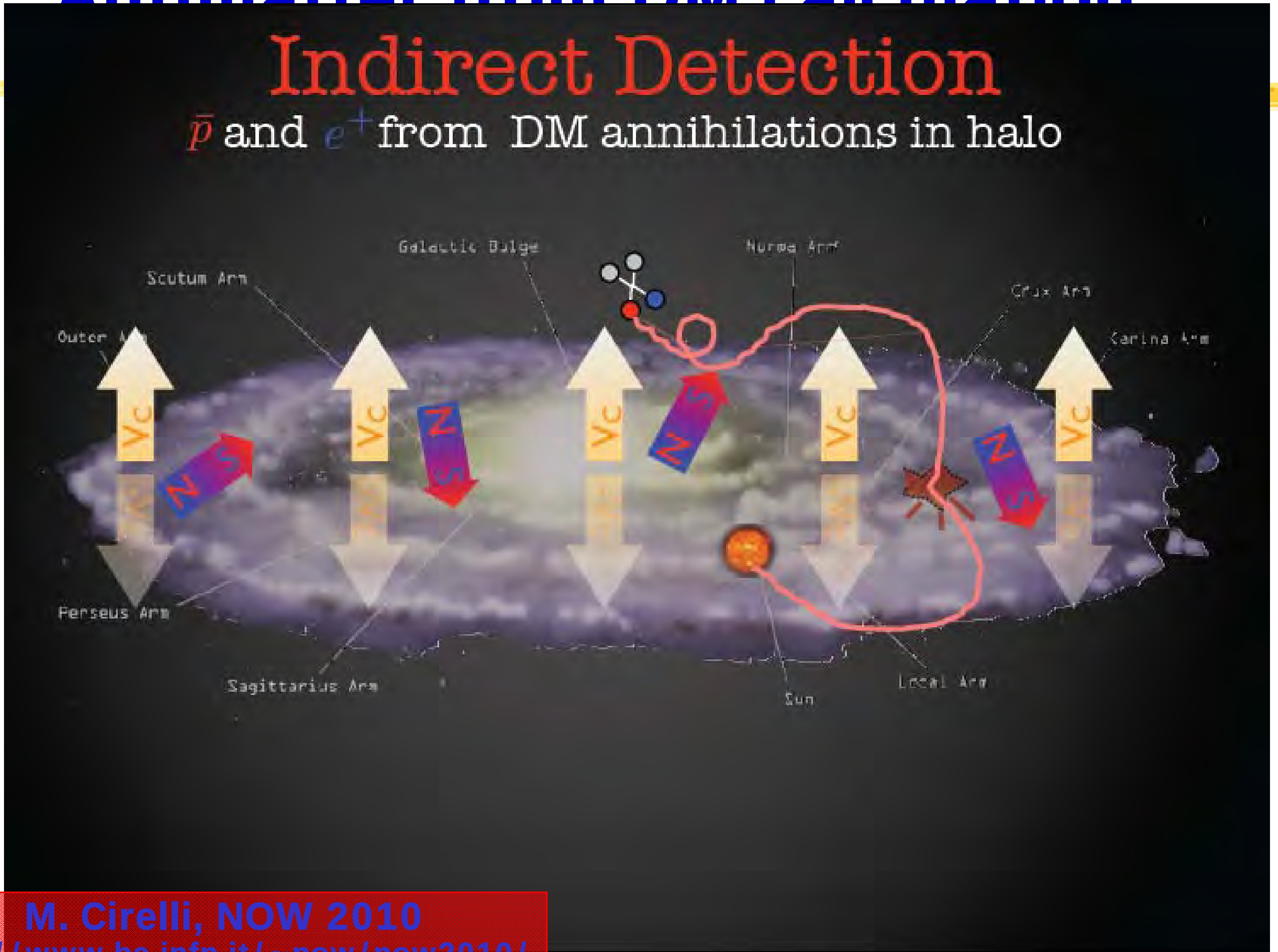

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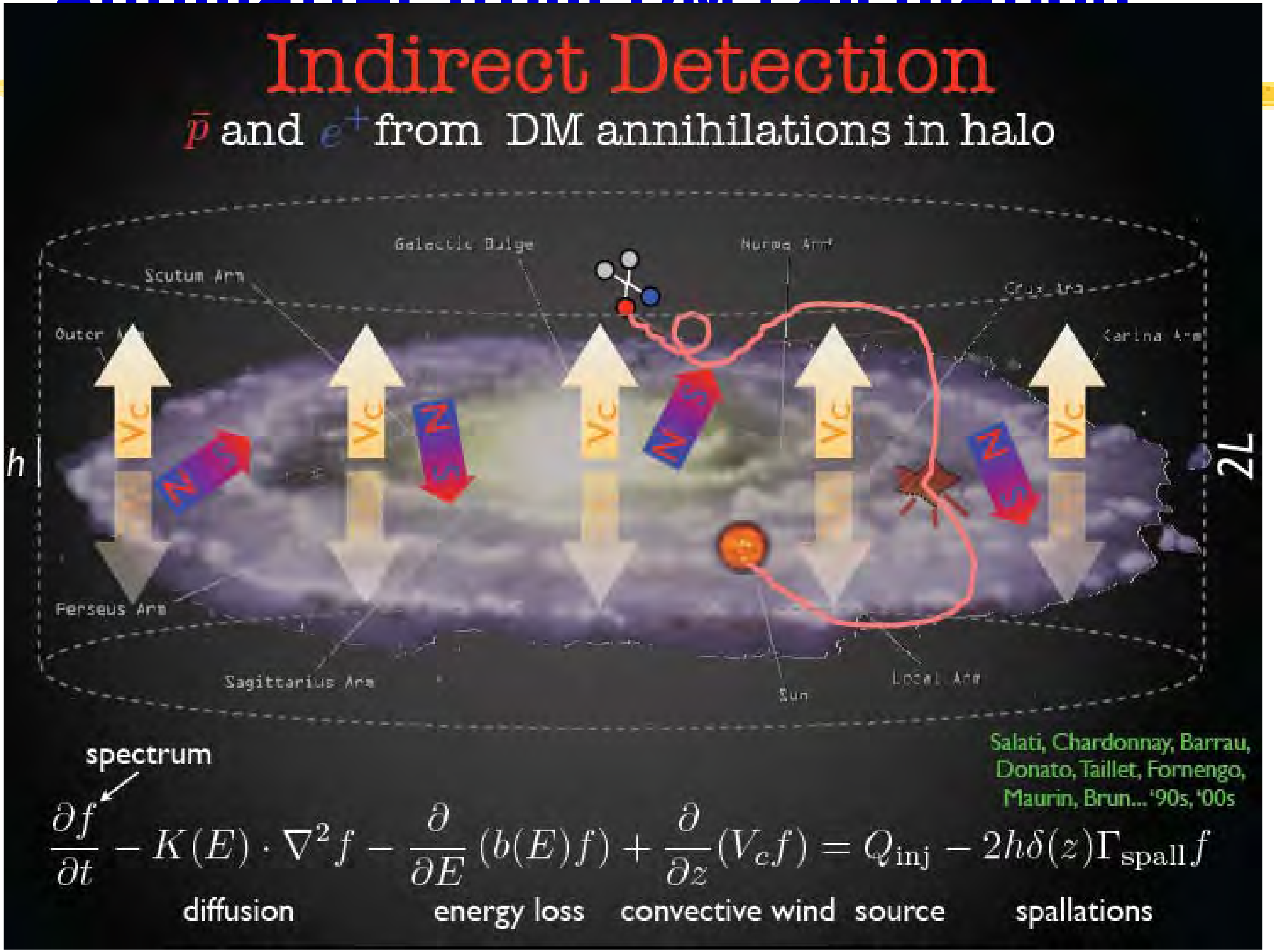

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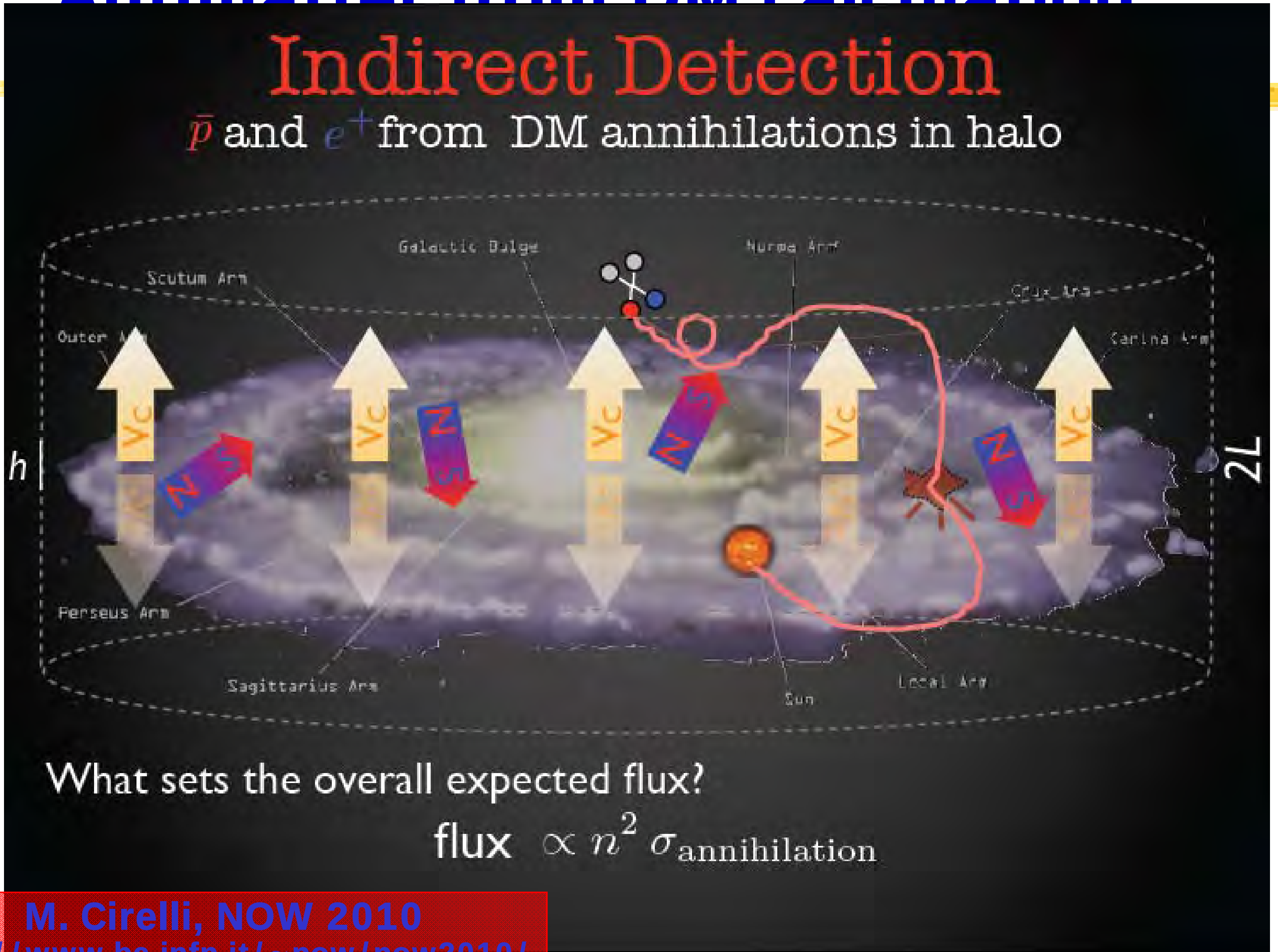

M. Cirelli, NOW 2010
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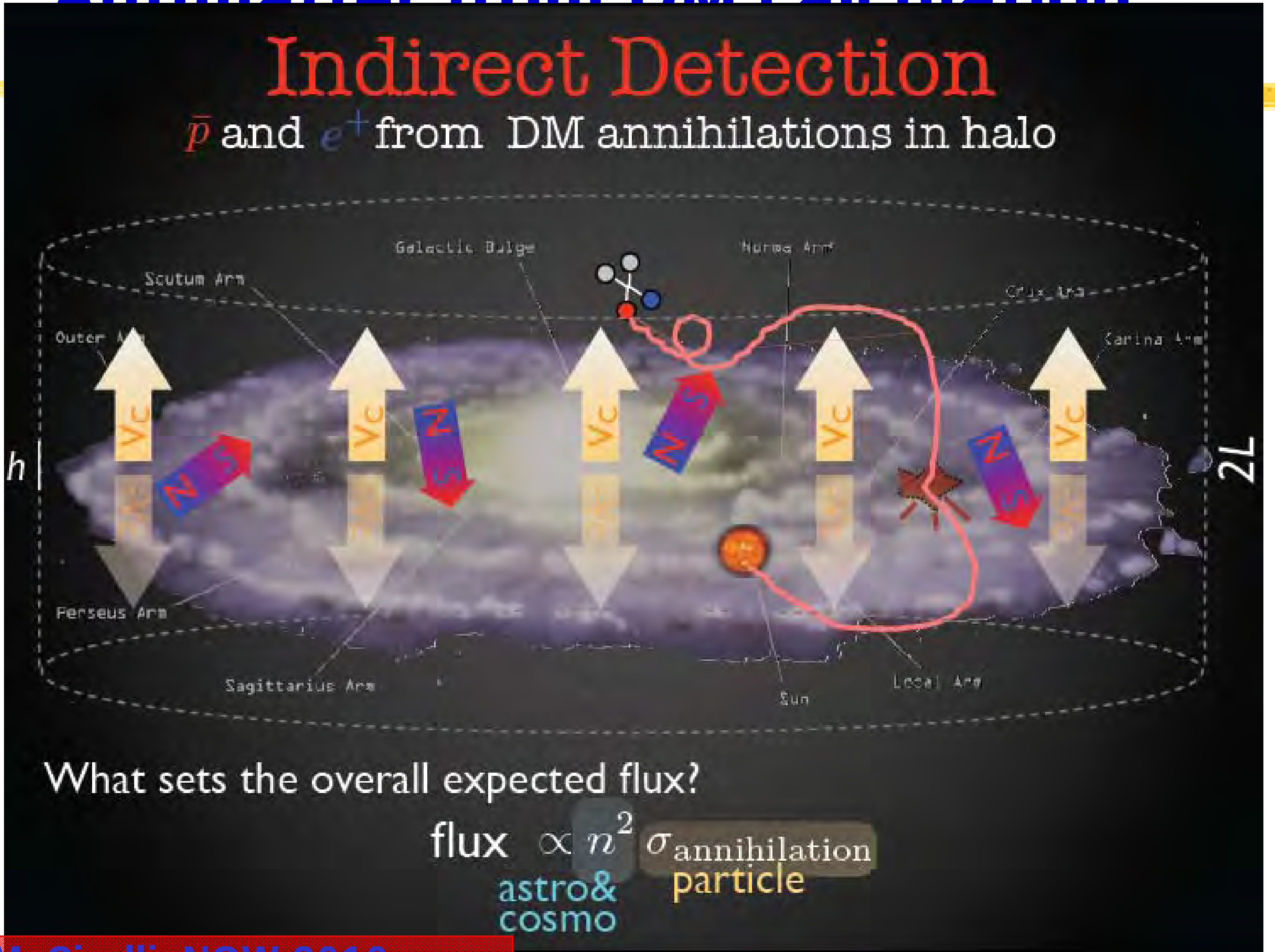

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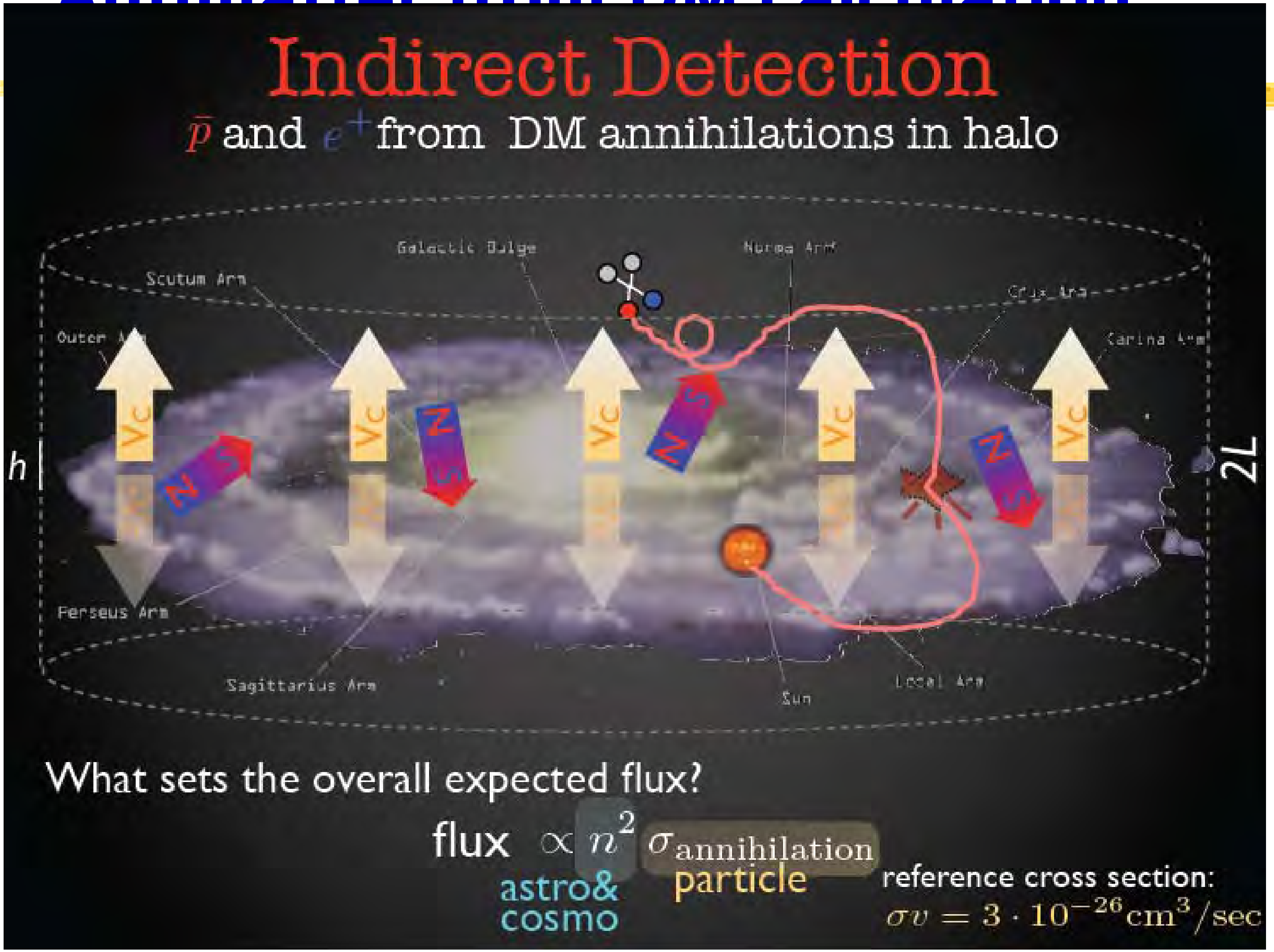

M. Cirelli, NOW 2010
http://www.ba.infn.it/~now/now2010/

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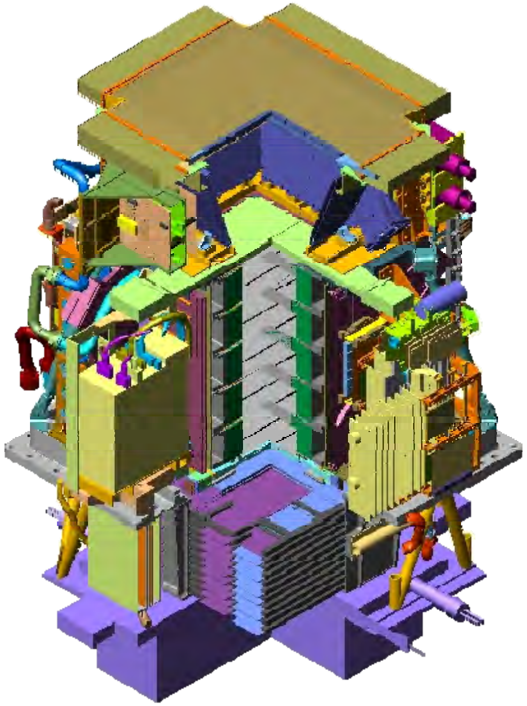
PAMELA Collaboration

PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure



GF:	21.5 cm^2 sr
Mass:	470 kg
Size:	130x70x70 cm^3
Power Budget:	360W

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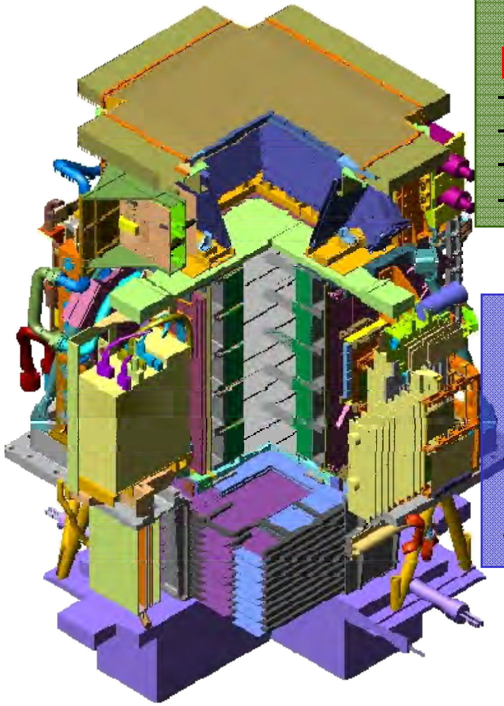
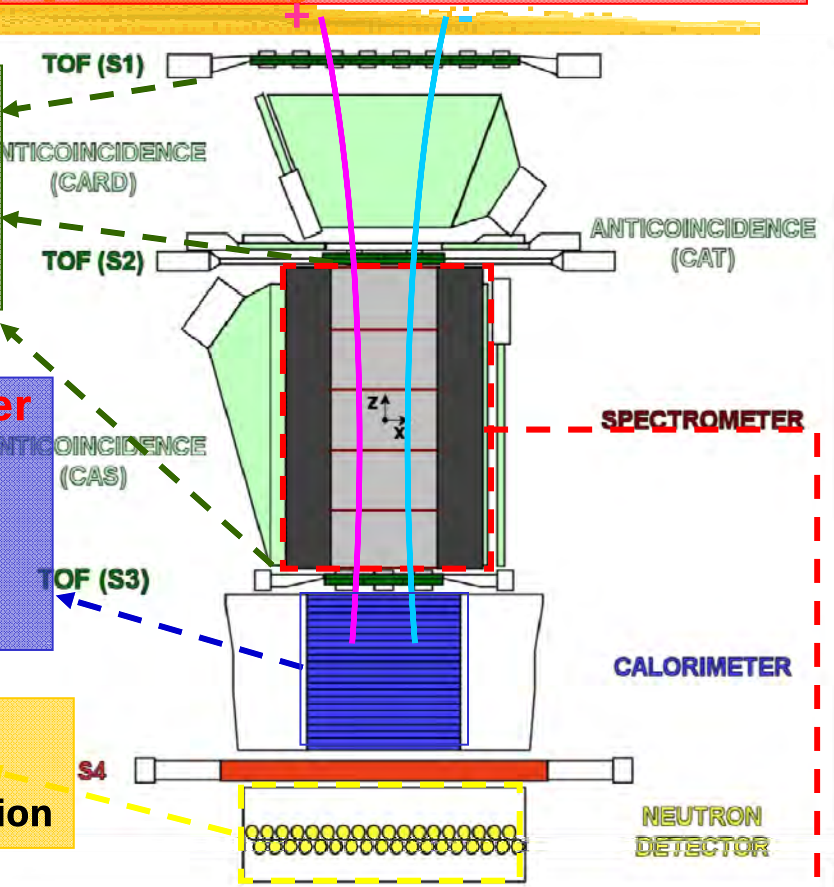


Time-Of-Flight
plastic scintillators + PMT
- Trigger;
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling
(16.3 X_0, 0.6 λ_I)
- Discrimination e^+ / p, pbar / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector &
Shower-tail catcher (S4):
- High-energy e/h discrimination



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Spectrometer microstrip silicon tracking system + permanent magnet
- Magnetic rigidity (R = pc/Ze)
- Charge sign
- Charge value from dE/dx

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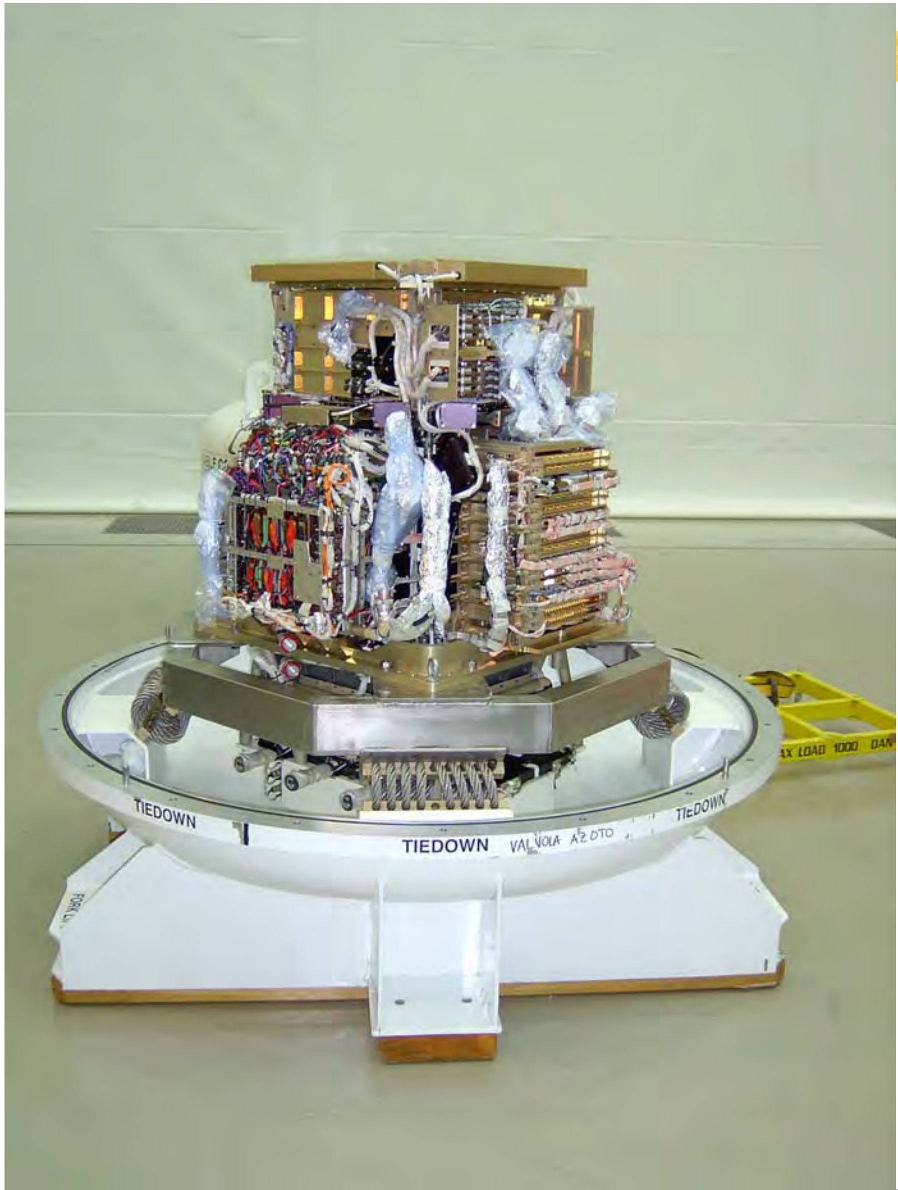
Design Performance

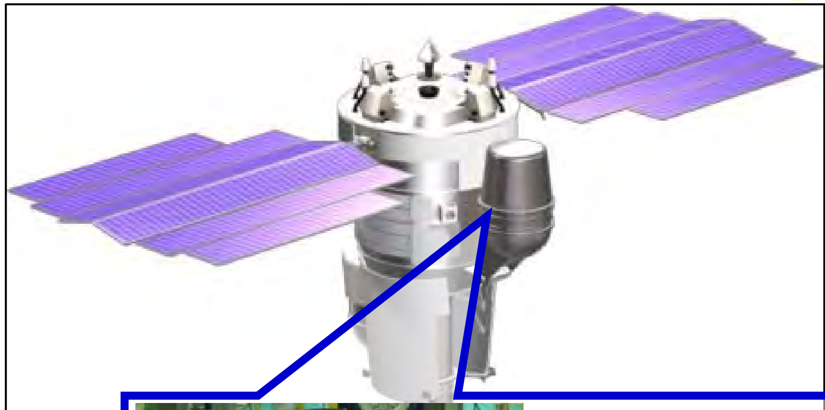
Antiprotons	80 MeV - 150 GeV
Positrons	50 MeV – 270 GeV
Electrons	up to 400 GeV
Protons	up to 700 GeV
Electrons+positrons	up to 2 TeV (calorimeter alone)
Light Nuclei (He/Be/C)	up to 200 GeV/n
AntiNuclei search	sensitivity of 3×10^{-8} in $\overline{He}/He$

→ Simultaneous measurement of many cosmic-ray species
→ New energy range
→ Unprecedented statistics

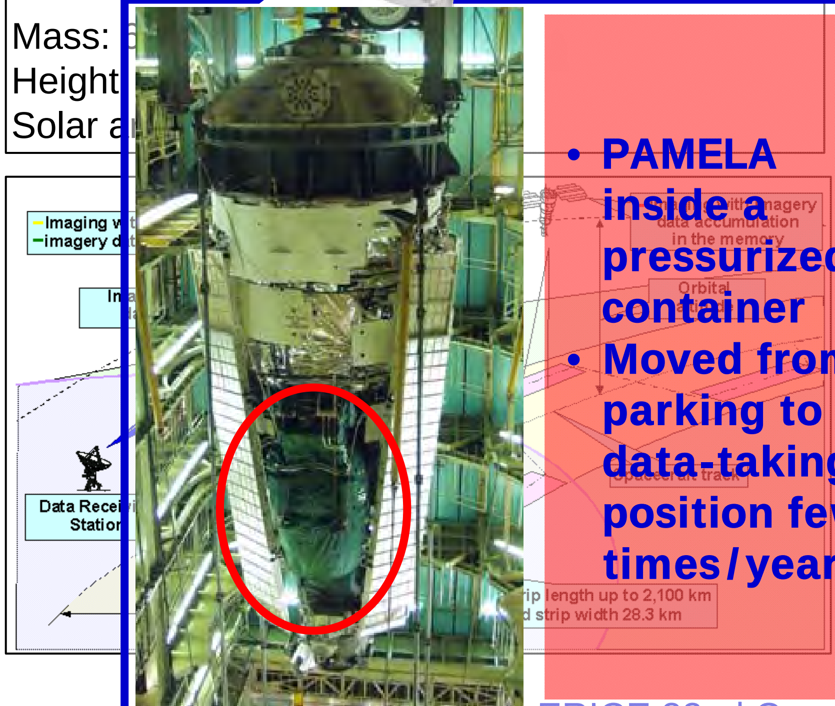
PAMELA: the integration



The Resurs DK-1 spacecraft



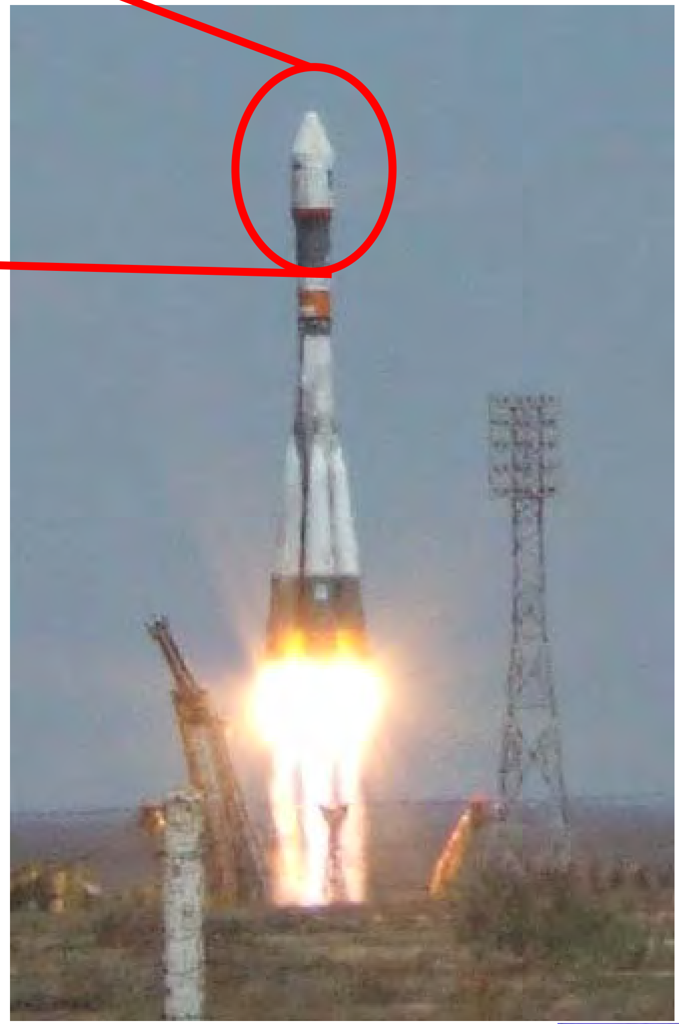
Mass:
Height
Solar a



- PAMELA inside a pressurized container
- Moved from parking to data-taking position few times/year

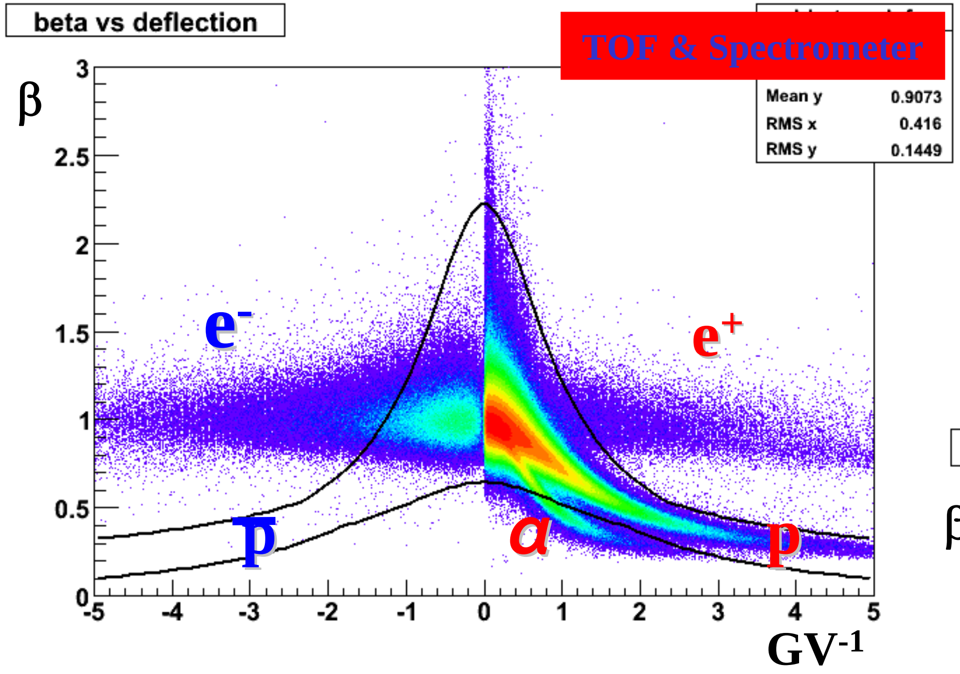
- Multi-spectral remote sensing of earth's surface
  - → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
  - inclination ~70º
  - altitude ~ 360-600 km (elliptical)
- Active life >3 years
- Data transmitted via Very high-speed Radio Link (VRL)

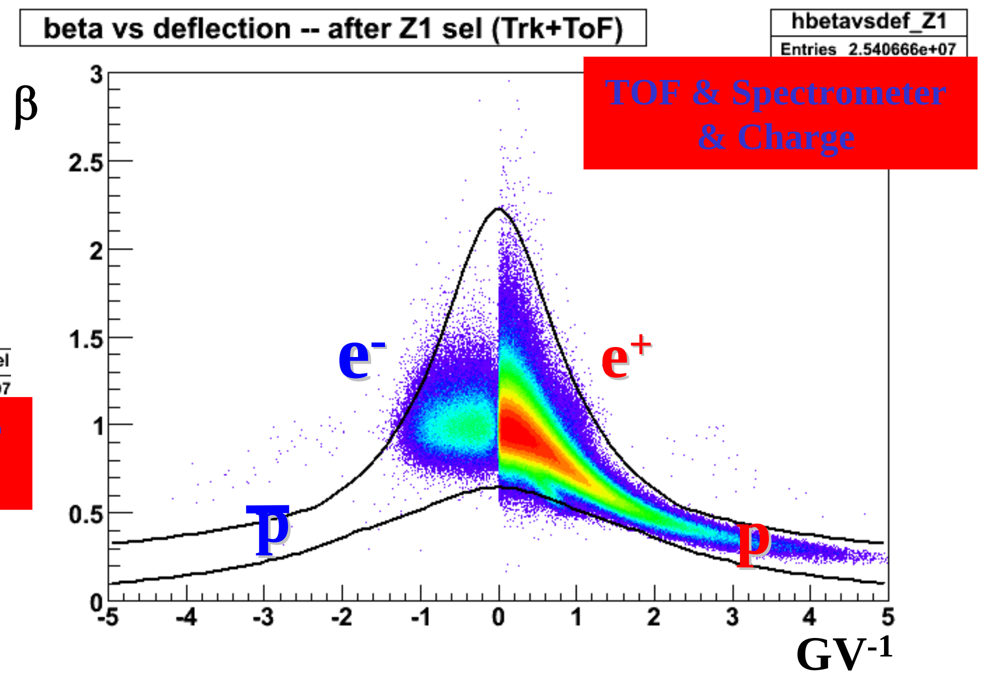
the satellite & launch

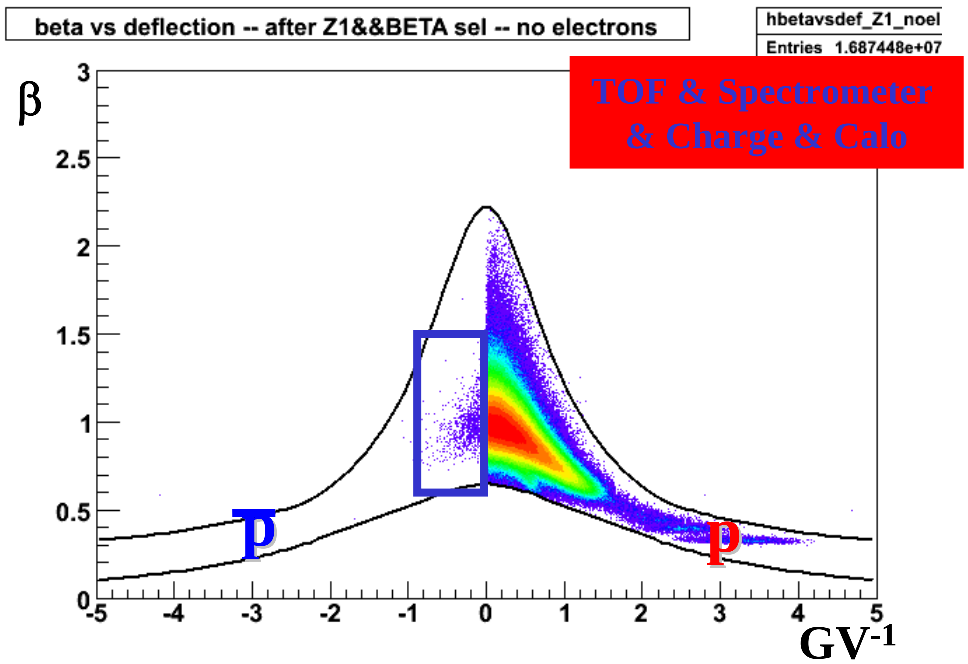


- Launch from Baikonur: June 15th 2006, 0800 UTC. Power On: June 21st 2006, 0300 UTC. Detectors operated as expected after launch
- PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006
  - ~1200 days of data taking (~73% live-time)
  - ~14 TByte of raw data downlinked
  - >1.4x10^9 triggers recorded and under analysis

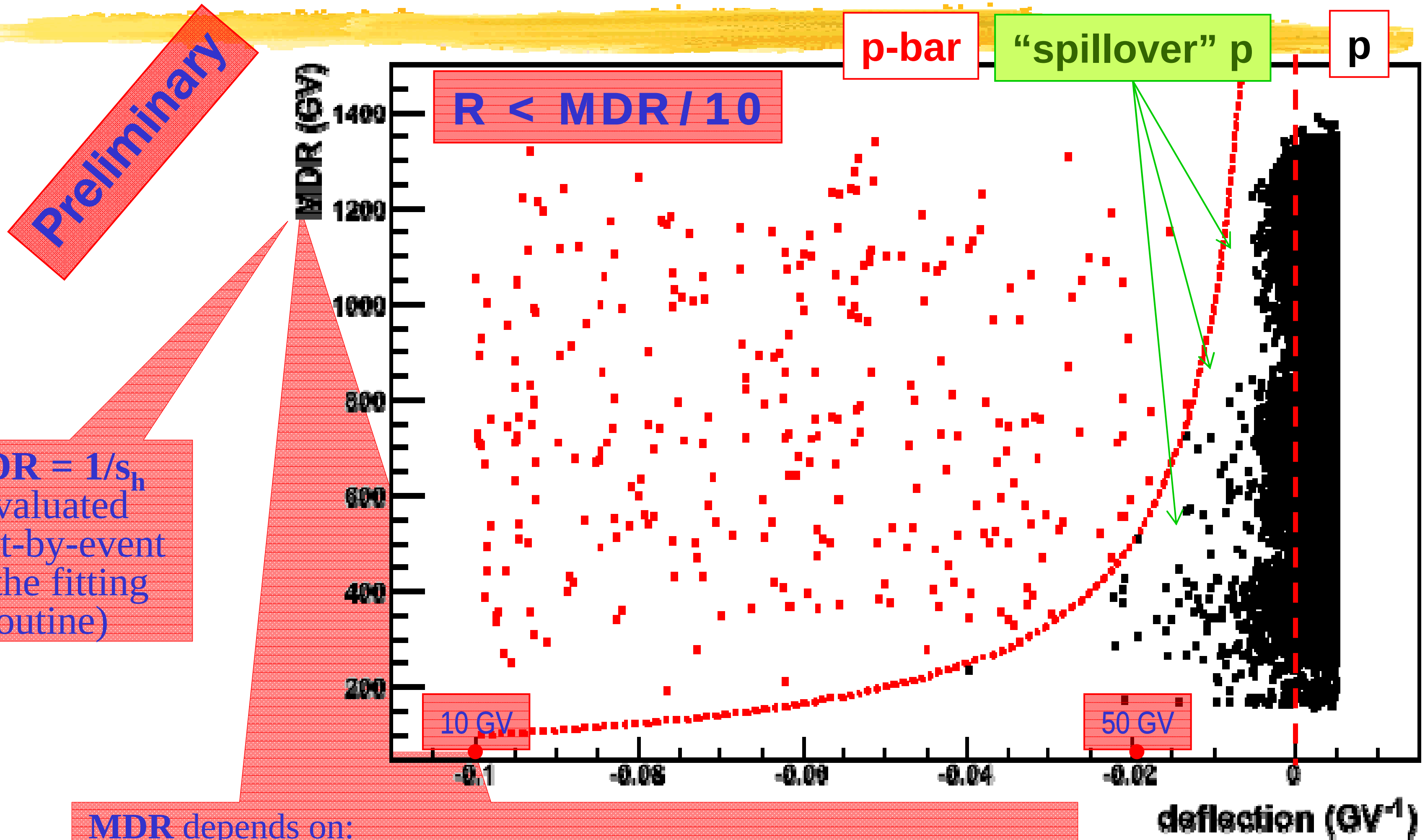
Antiproton Selection







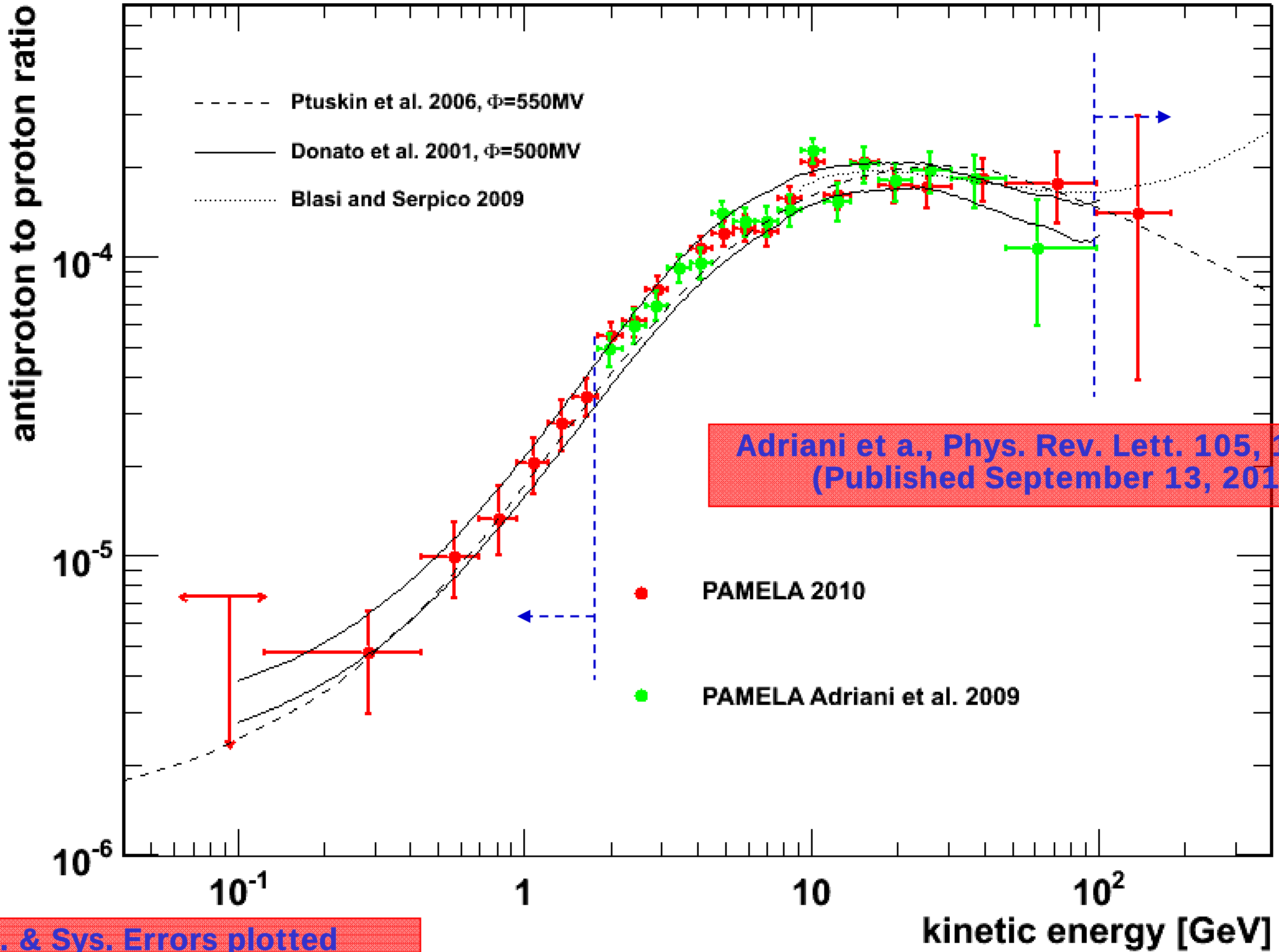
High-energy antiproton selection



MDR = $1/s_h$
(evaluated event-by-event by the fitting routine)

MDR depends on:
- number and distribution of fitted points along the trajectory
- spatial resolution of the single position measurements
- magnetic field intensity along the trajectory

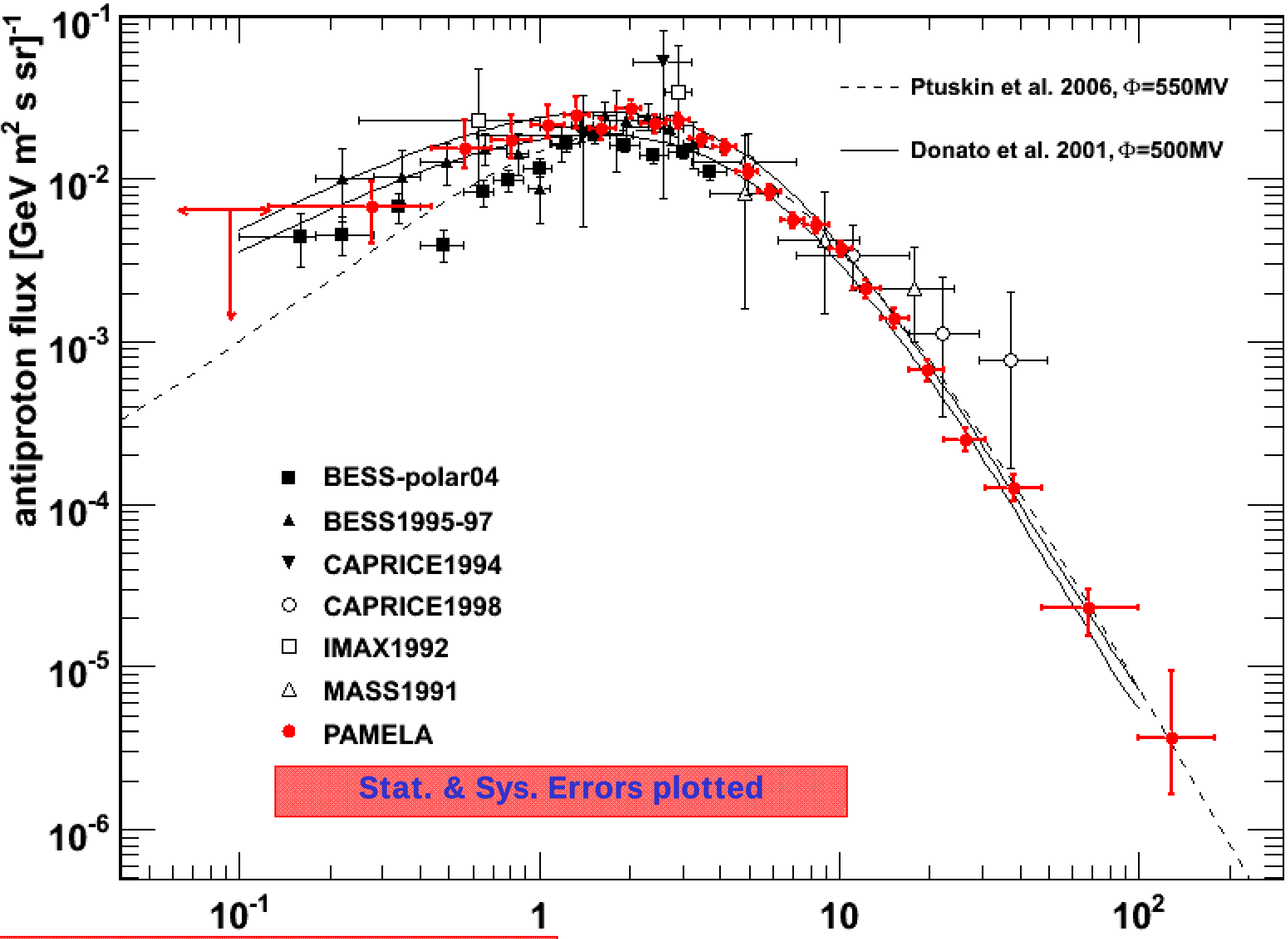
Antiproton to Proton Ratio



Adriani et a., Phys. Rev. Lett. 105, 121101 (Published September 13, 2010)

Stat. & Sys. Errors plotted

Antiproton Flux



Adriani et a., Phys. Rev. Lett. 105, 121101
(Published September 13, 2010)

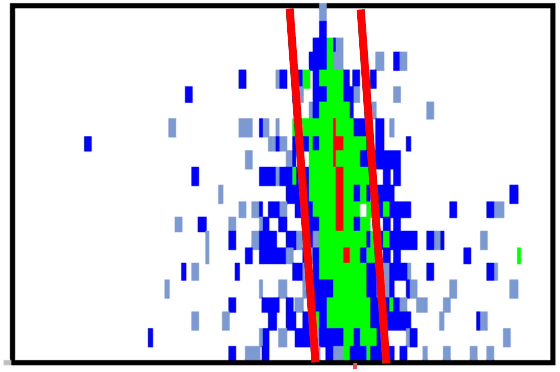
Positron selection with calorimeter

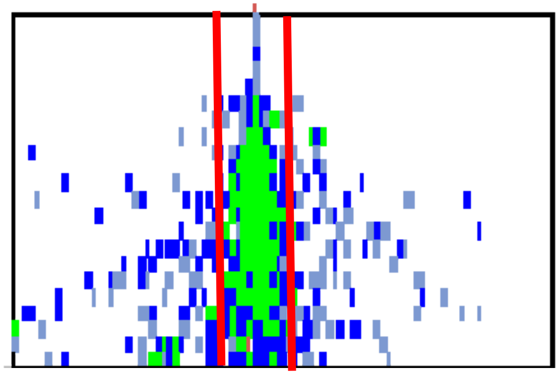
51 GV Positron

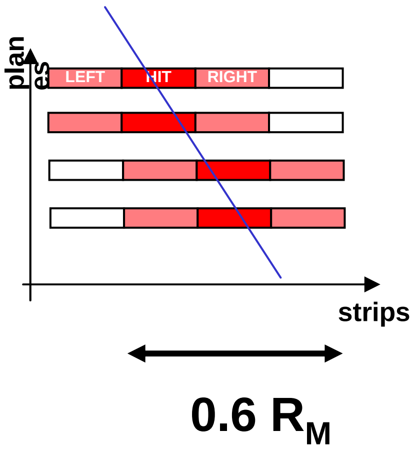
80GV Proton

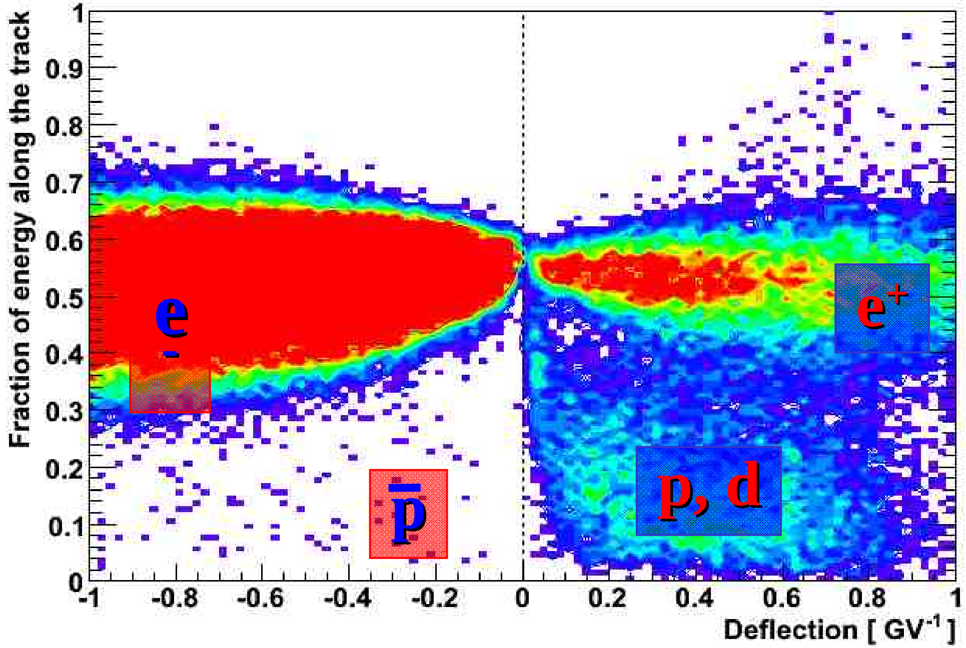
Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match



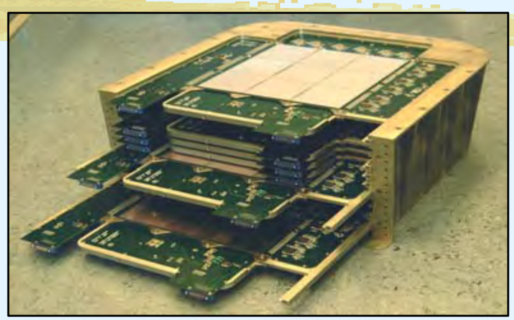






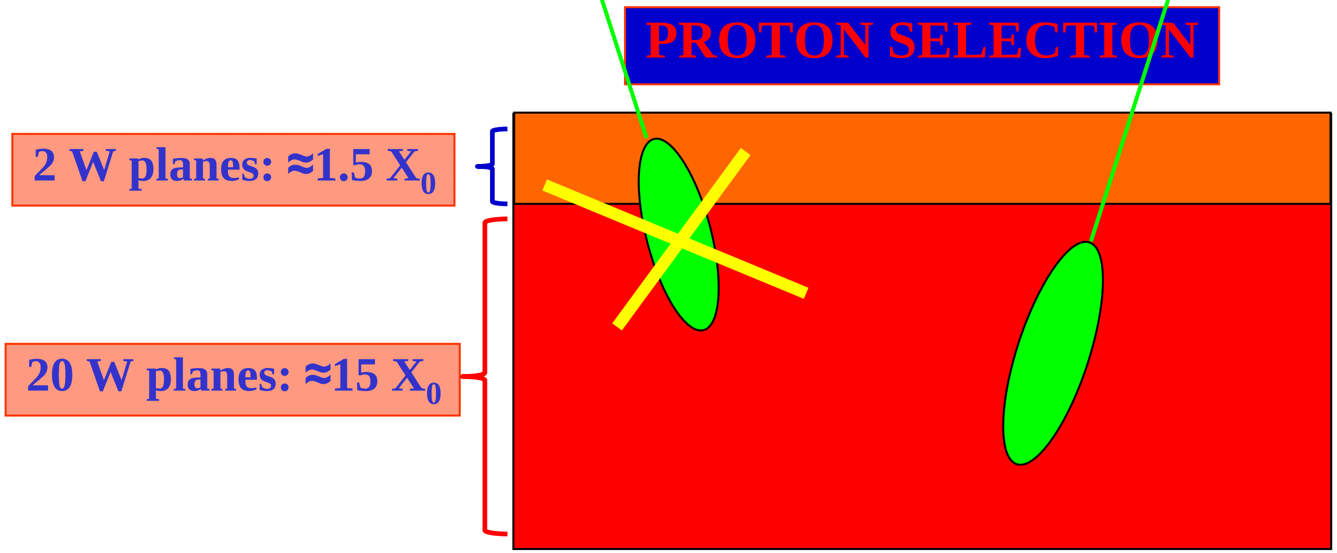
The "pre-sampler" method

The electromagnetic calorimeter



Characteristics:

- 44 Si layers (X/Y) +22 W planes
- 16.3 X_0 / 0.6 l_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)



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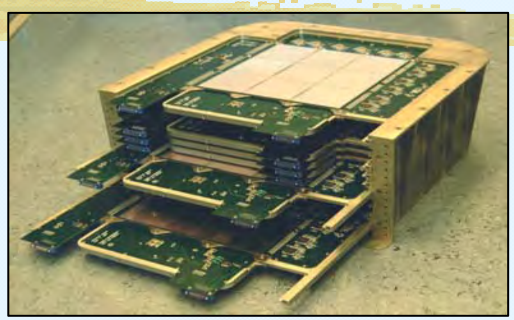

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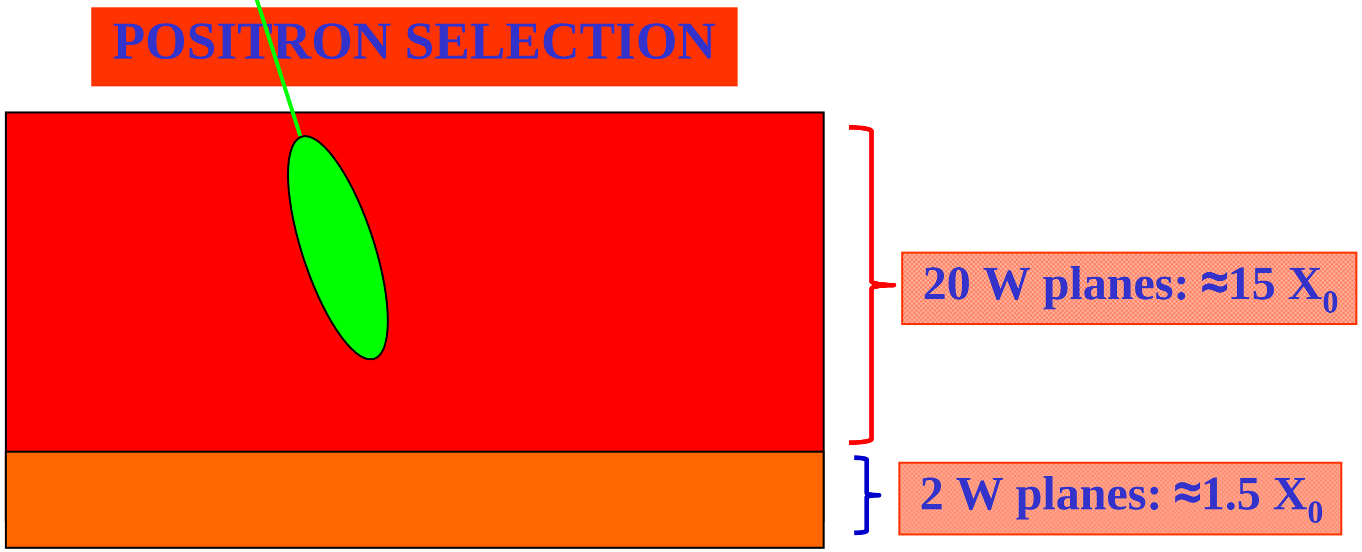
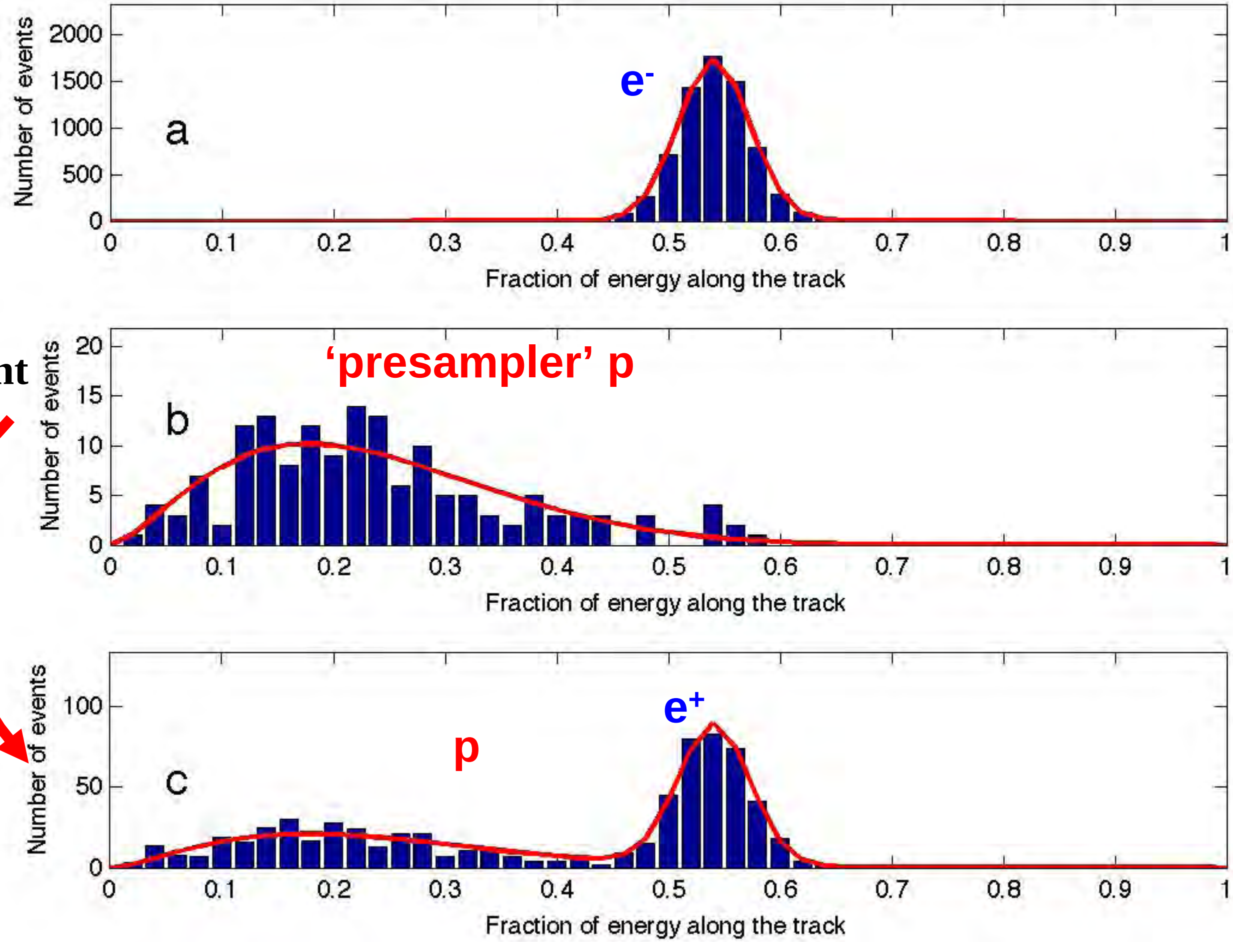


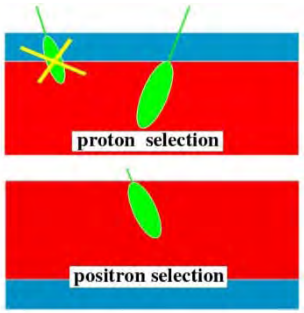
e$^+$ background estimation from data

Fraction of charge released along the calorimeter track

Constrains on:

- **Energy momentum match**
- **Shower starting-point**

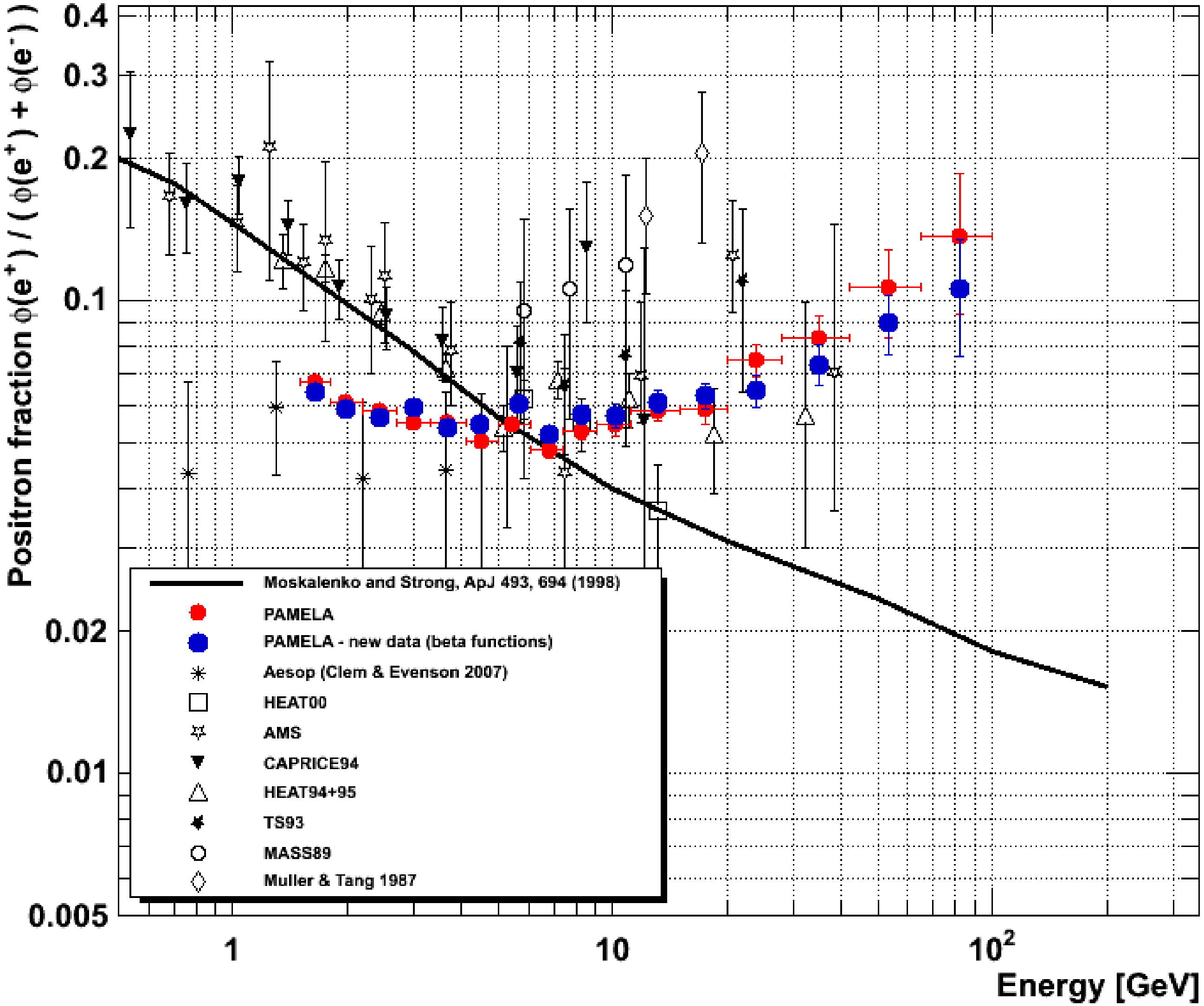




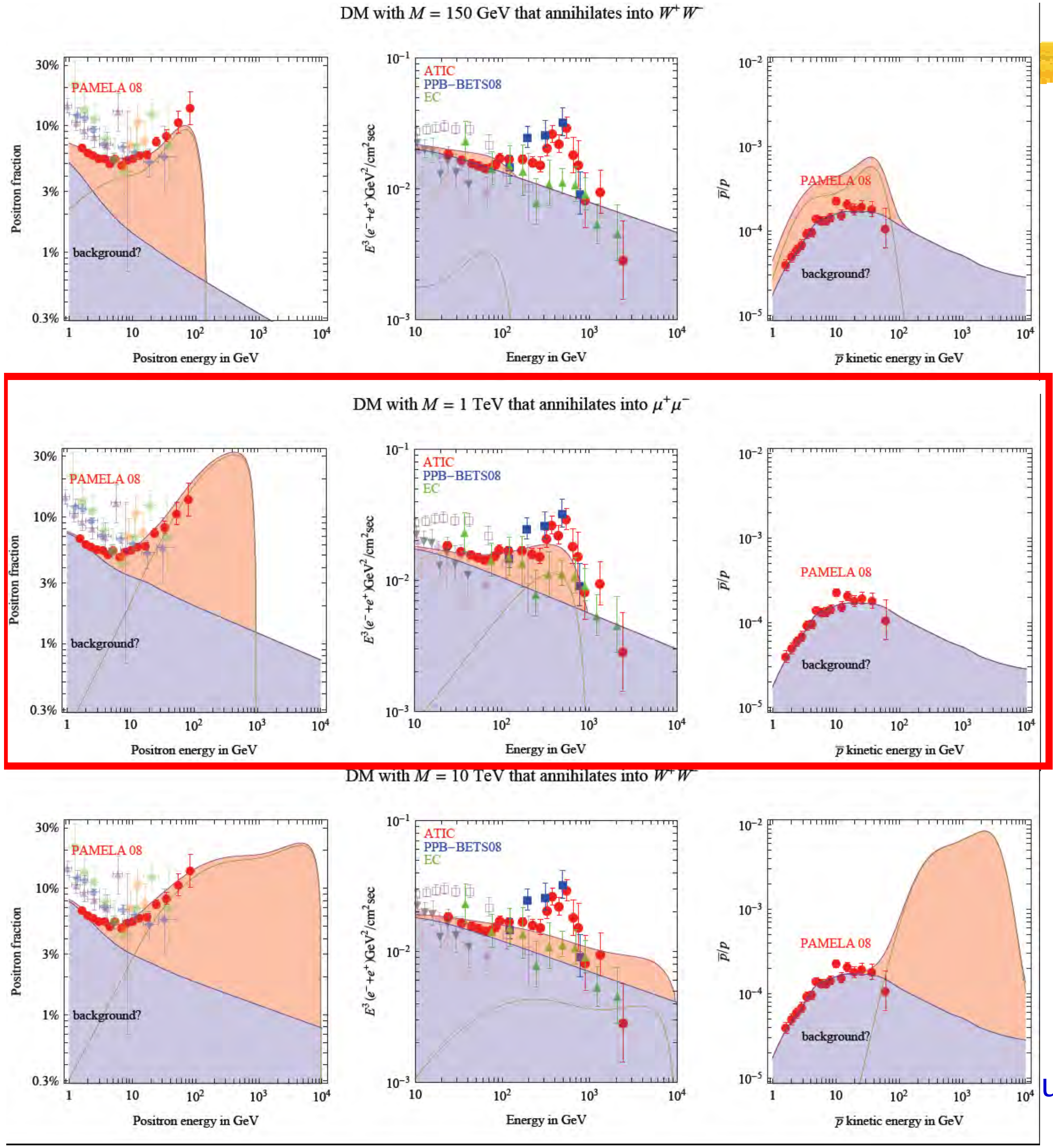
Rigidity: 20-28 GV

Positron to All Electron Fraction

Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522



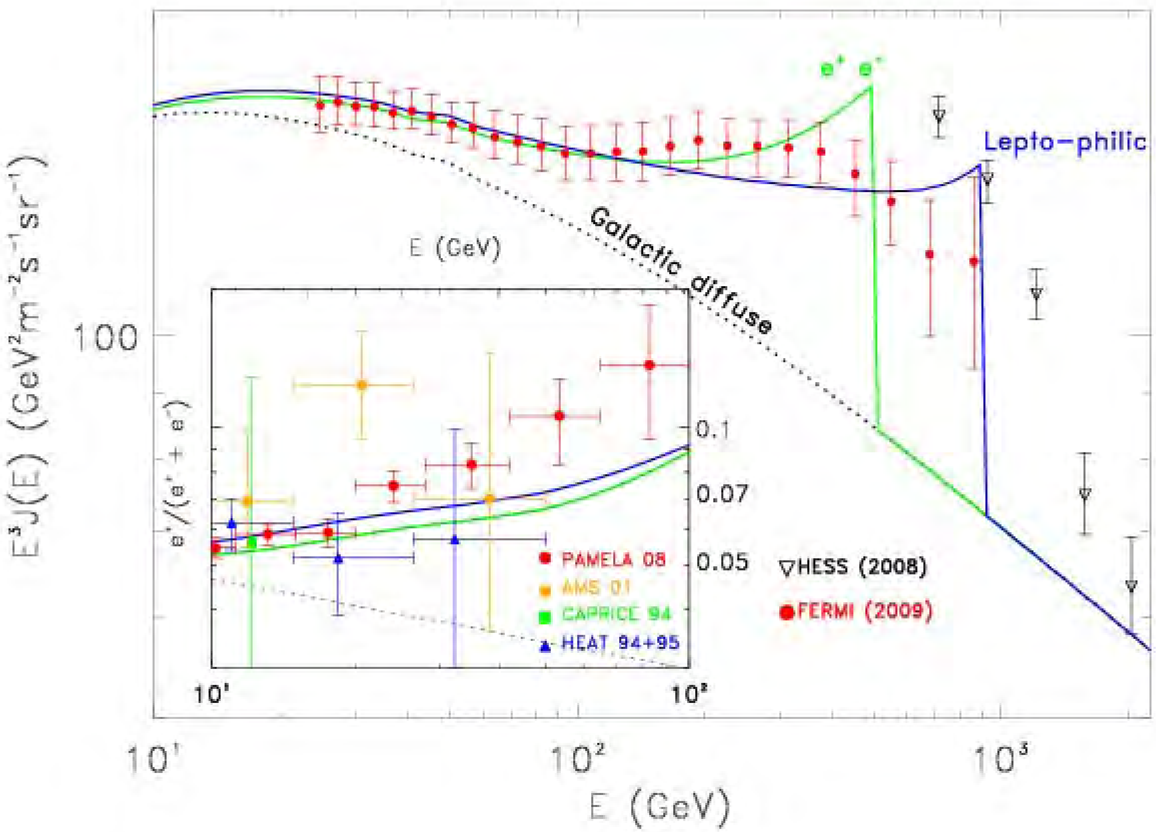
DM ?



- PAMELA ability of measuring both proton and electron charge ration, make it possible to put several constrains to the models

M. Cirelli, M. Kadastik, M. Raidal, A. Strumia arXiv:0809.2409v3

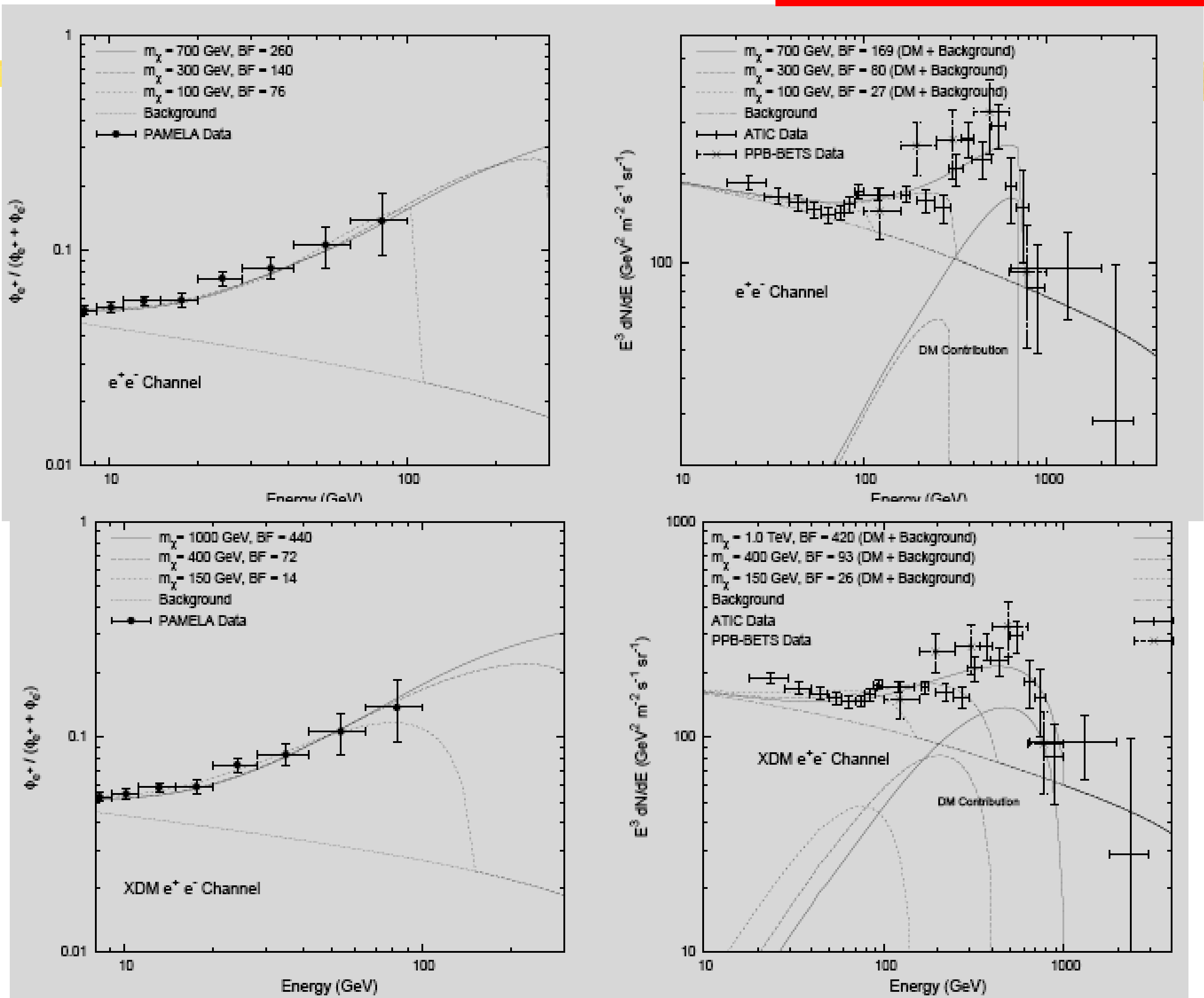
Leptophilic DM



- DM only annihilates into charged leptons. DM masses between 0.4 and 2 TeV, but boost factors on the order of 10^2.

D. Grasso *et al.* Astrop. Phys. 32 (2009), arXiv: 0905.0636v3

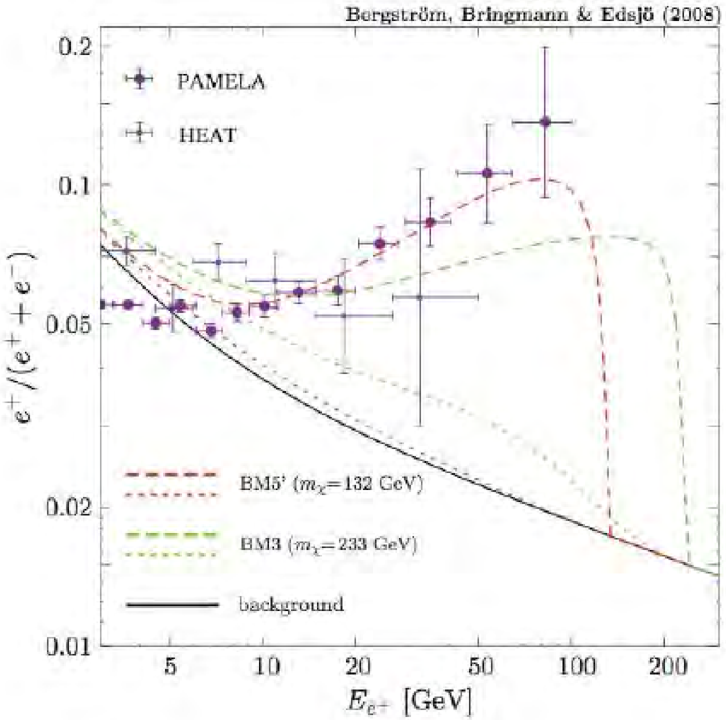
I. Cholis et al. arXiv:0811.3641v1



- Propose a new light boson ($m_\Phi \leq$ GeV), such that $\chi\chi \rightarrow \Phi\Phi$; $\Phi \rightarrow e^+e^-$, $\mu^+\mu^-$, ...
- Light boson, so decays to antiprotons are kinematically suppressed

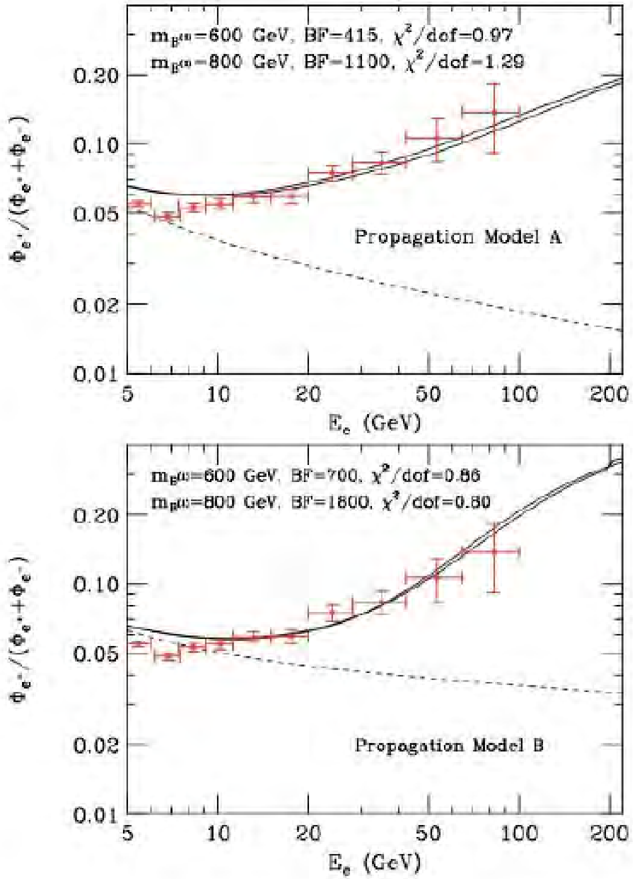
Example: Dark Matter

arXiv:0808.3725



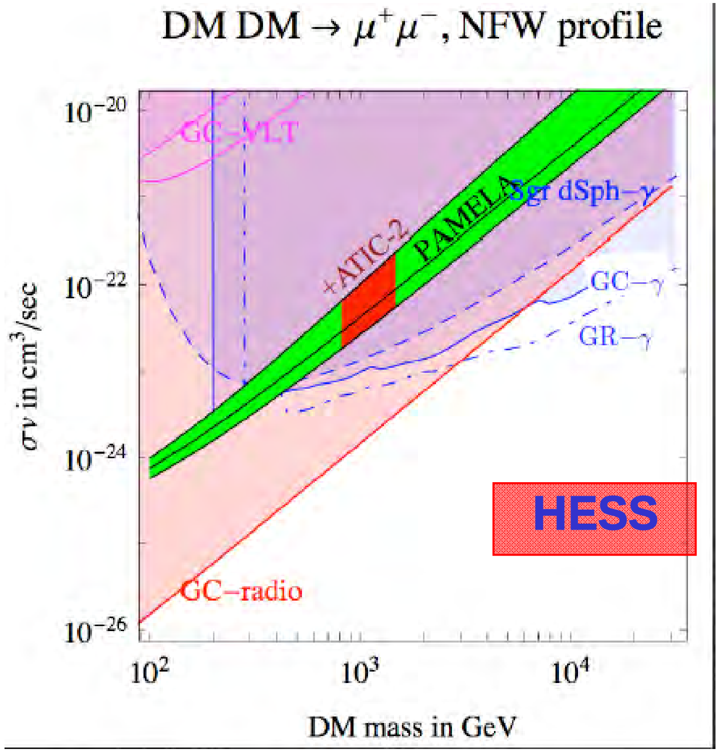
Majorana DM with **new** internal bremsstrahlung correction. NB: requires annihilation cross-section to be 'boosted' by >1000.

Hooper and Zurek
arXiv:0902.0593v1

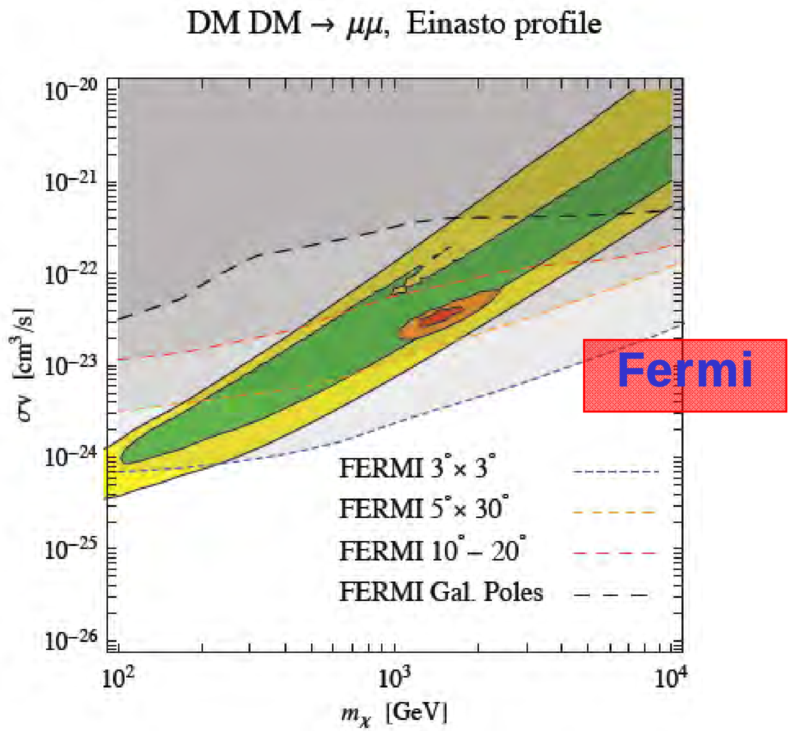


Kaluza-Klein dark matter

Gamma constrains



Bertone, Cirelli, Strumia, Taoso 0811.3744

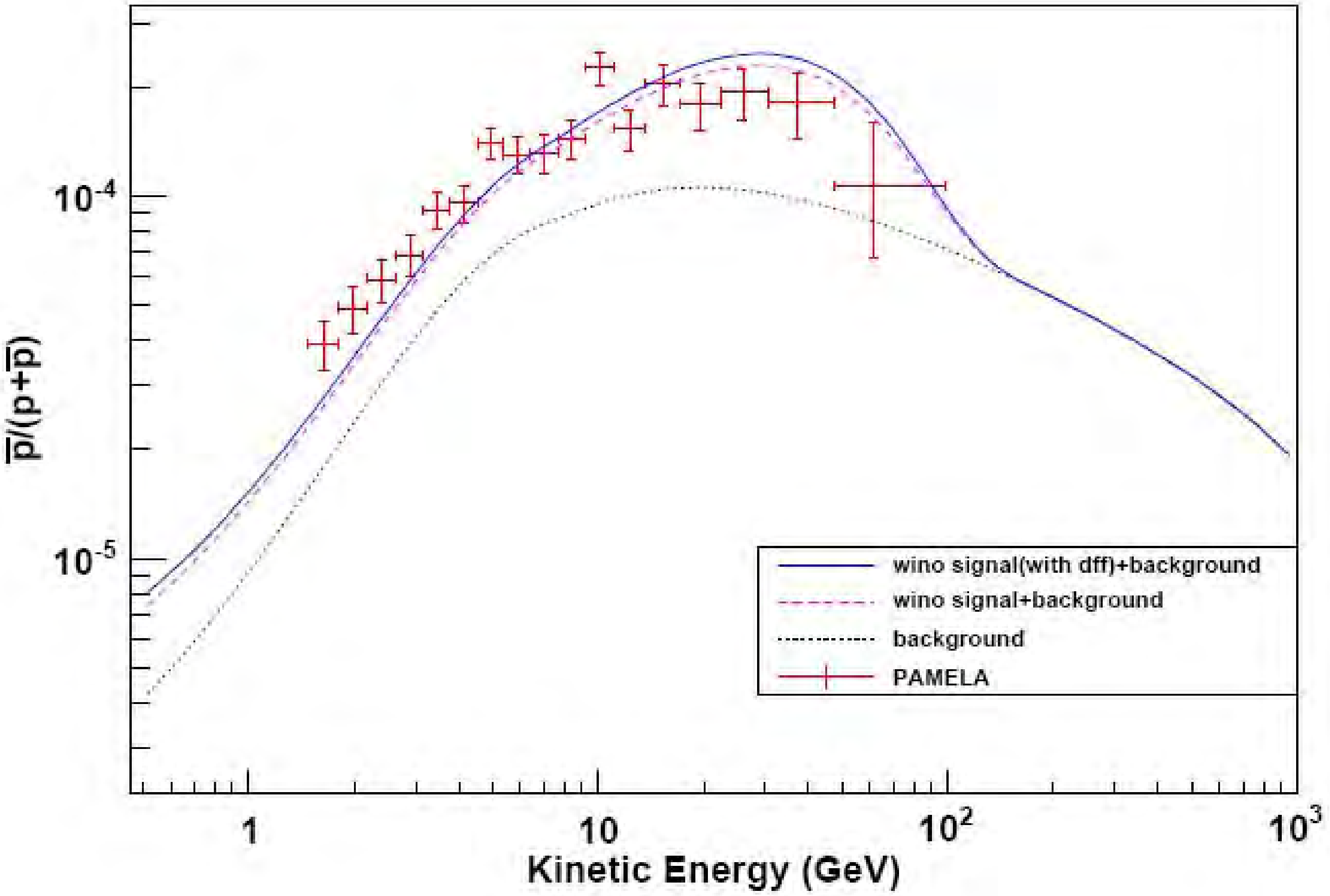


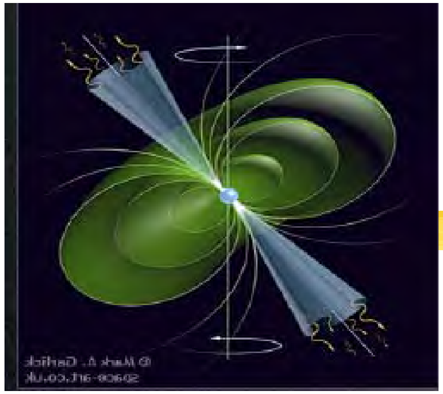
Cirelli, Panci, Serpico 0912.0663

- Decaying DM excluded, leptonic annihilation with "fine-tuned" parameter

Wino Dark Matter in a non-thermal Universe

G. Kane, R. Lu, and S. Watson
arXiv:0906.4765v3 [astro-ph]



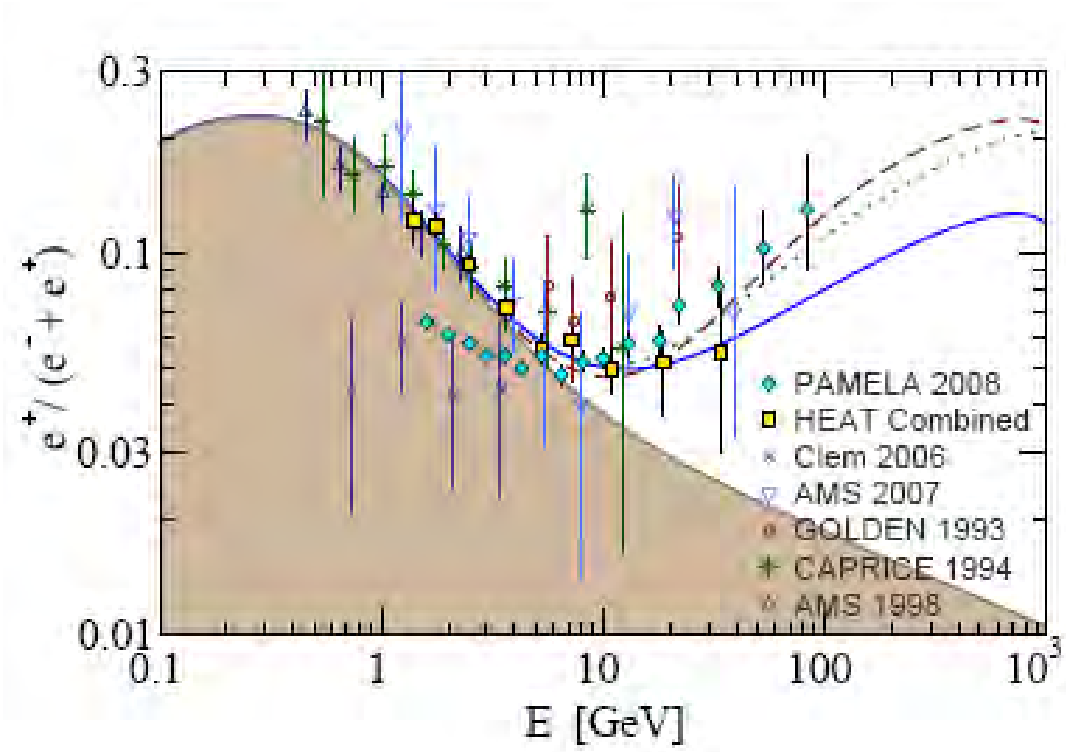


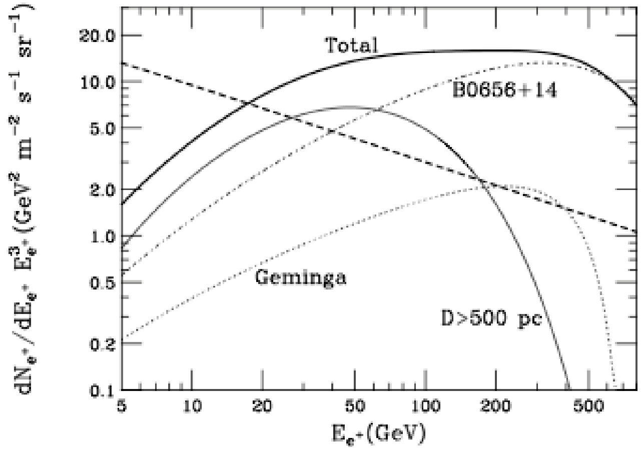
Astrophysical Explanation
Pulsars

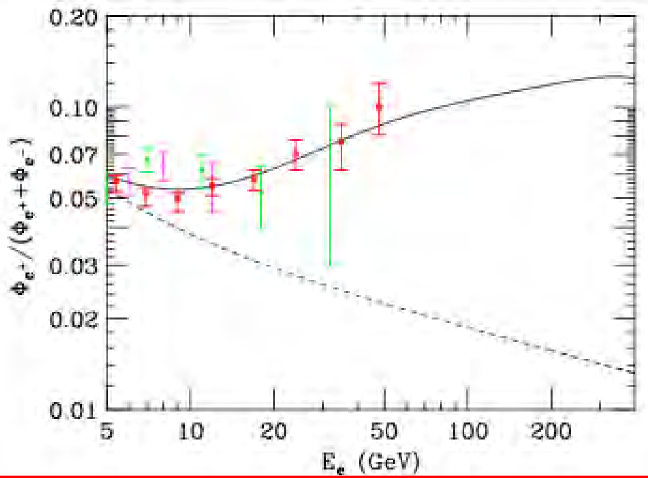
S. Profumo Astro-ph 0812-4457

- Mechanism: the spinning $\vec{\mathbf{B}}$ of the pulsar strips e^- that accelerated at the polar cap or at the outer gap emit γ that make production of $e^\pm$ that are trapped in the cloud, further accelerated and later released at $\tau \sim 10^5$ years.
- Young ($T \sim 10^5$ years) and nearby (< 1kpc) If not: too much diffusion, low energy, too low flux.
- Geminga: 157 parsecs from Earth and 370,000 years old
- B0656+14: 290 parsecs from Earth and 110,000 years old
- Many others after Fermi/GLAST
- Diffuse mature pulsars

Positrons from Pulsar





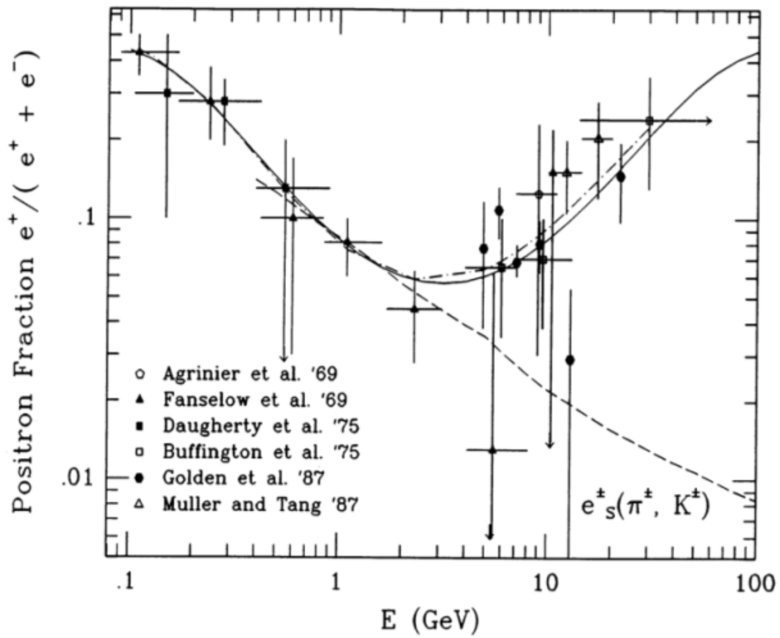


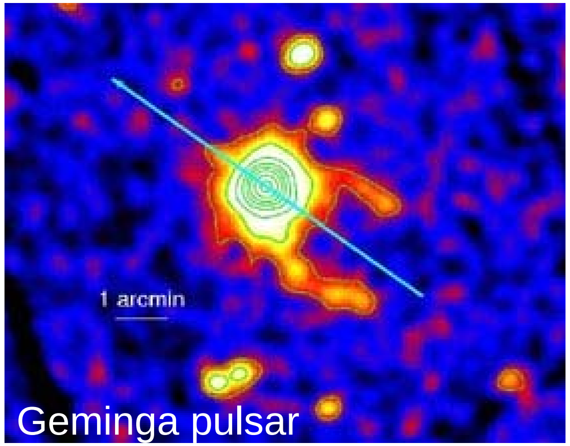
H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar

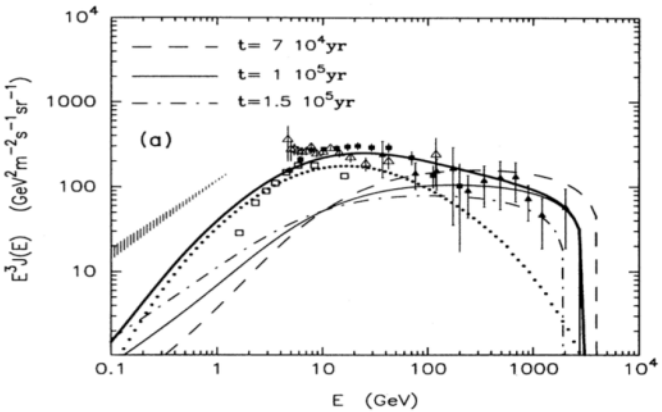
Diffuse mature & nearby young pulsars Hooper, Blasi, and Serpico arXiv:0810.1527

Astrophysical Explanation: Pulsars

Young, nearby pulsars

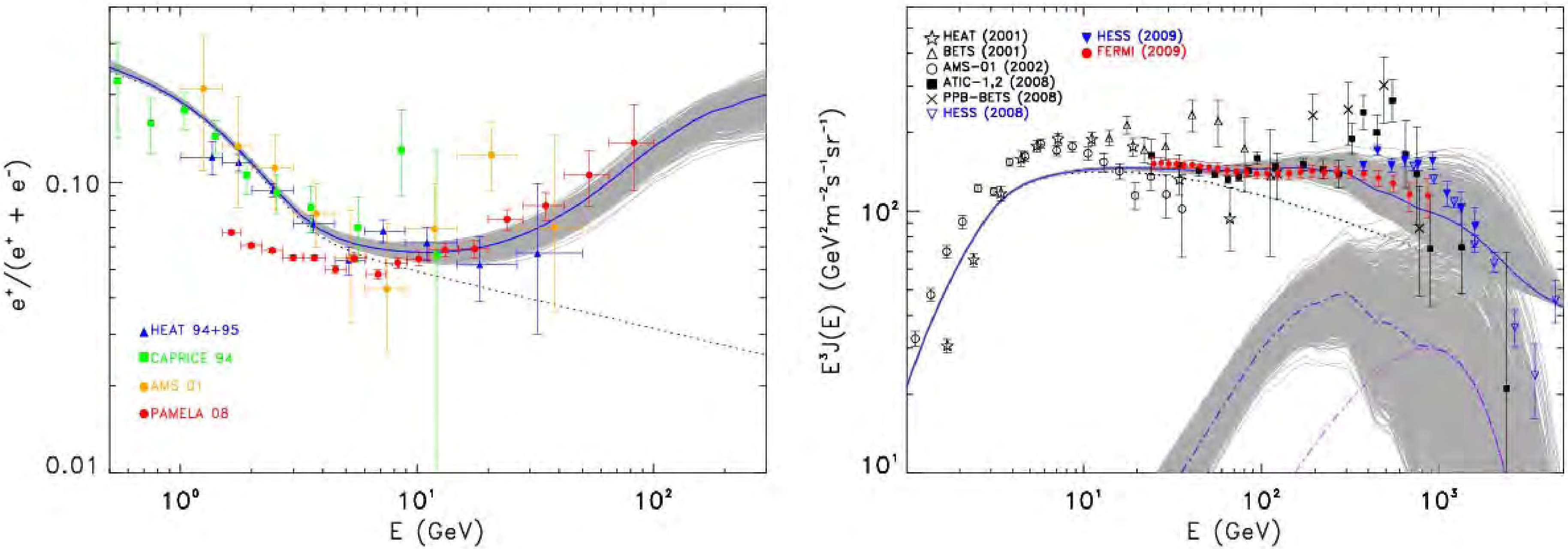






Not a new idea: Boulares, ApJ 342 (1989), Atoyan et al (1995)

Astrophysical Explanation: Pulsars

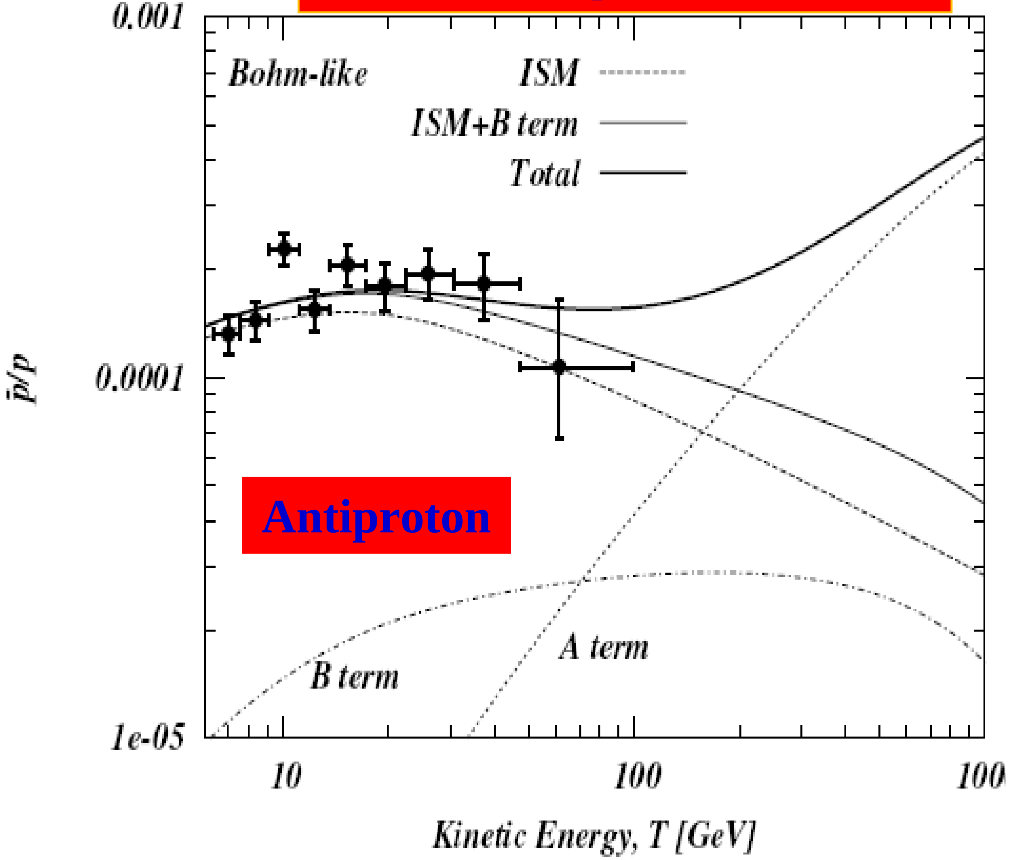


- contribution of all nearby pulsars in the ATNF catalogue (~150 pulsars) with d < 3 kpc with age 5 × 104 < T < 107 yr

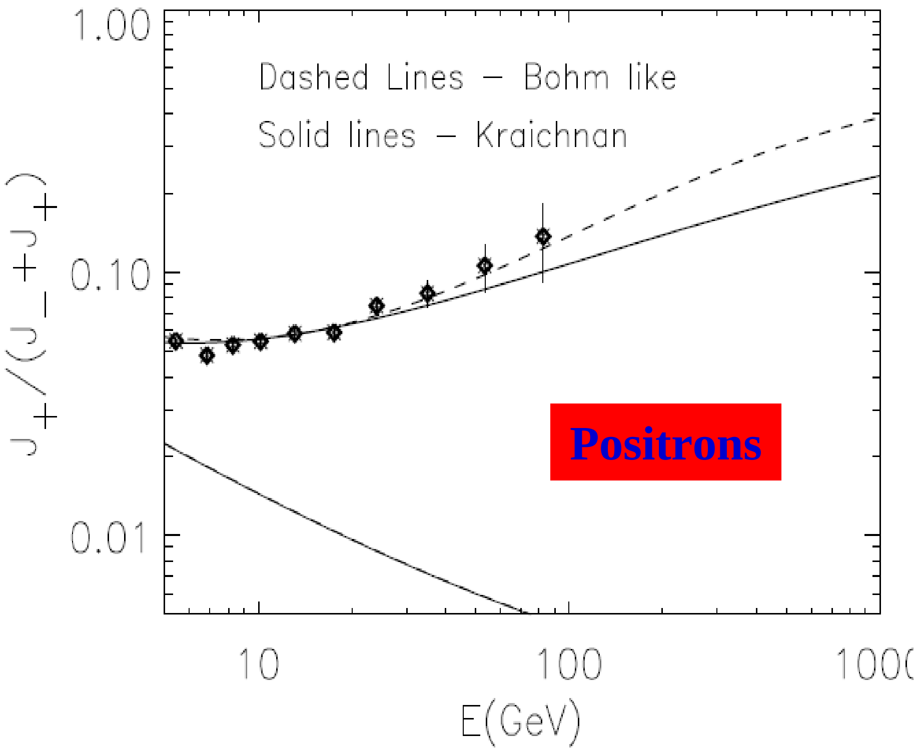
D. Grasso *et al.* Astrop. Phys. 32 (2009), arXiv: 0905.0636v3

Antiprotons & positrons from old SNR's

P.Blasi Astro-ph.HE 0904.0871

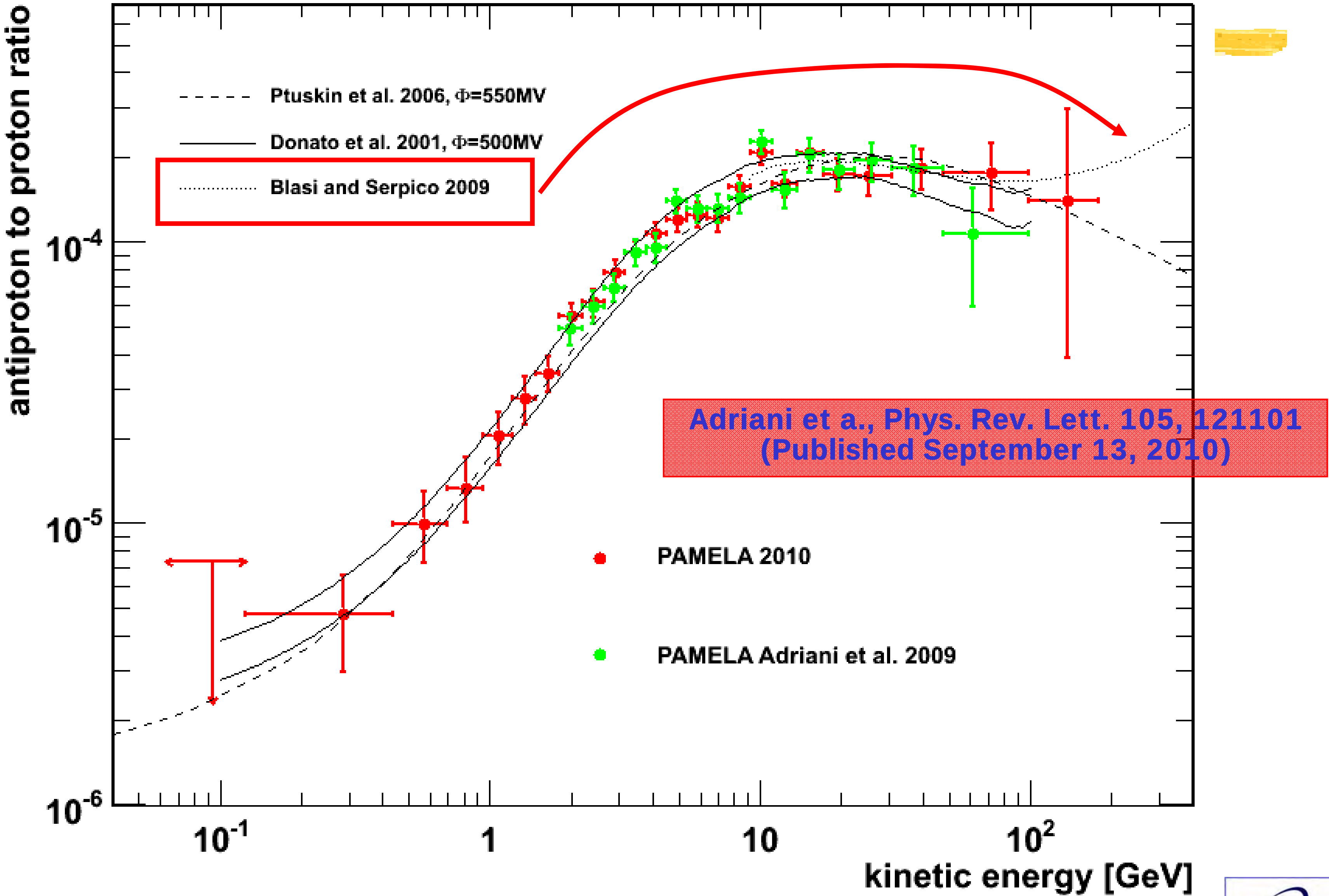


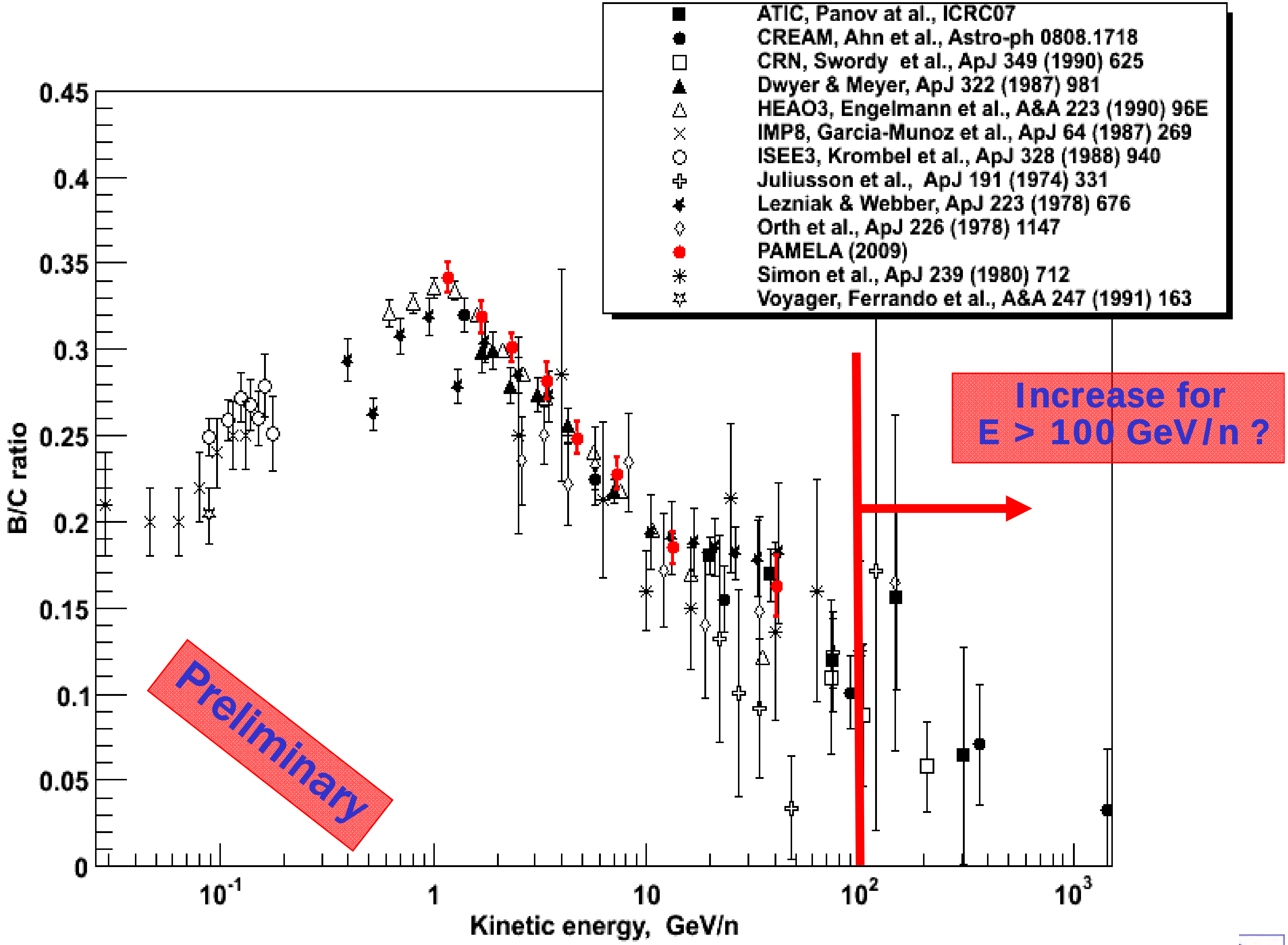
P. Blasi 0903.2794



- positrons created as secondary products of hadronic interactions inside the sources
- secondary production takes place in the same region where cosmic rays are being accelerated
- Antiproton/proton and B/C increase for E> 100GeV

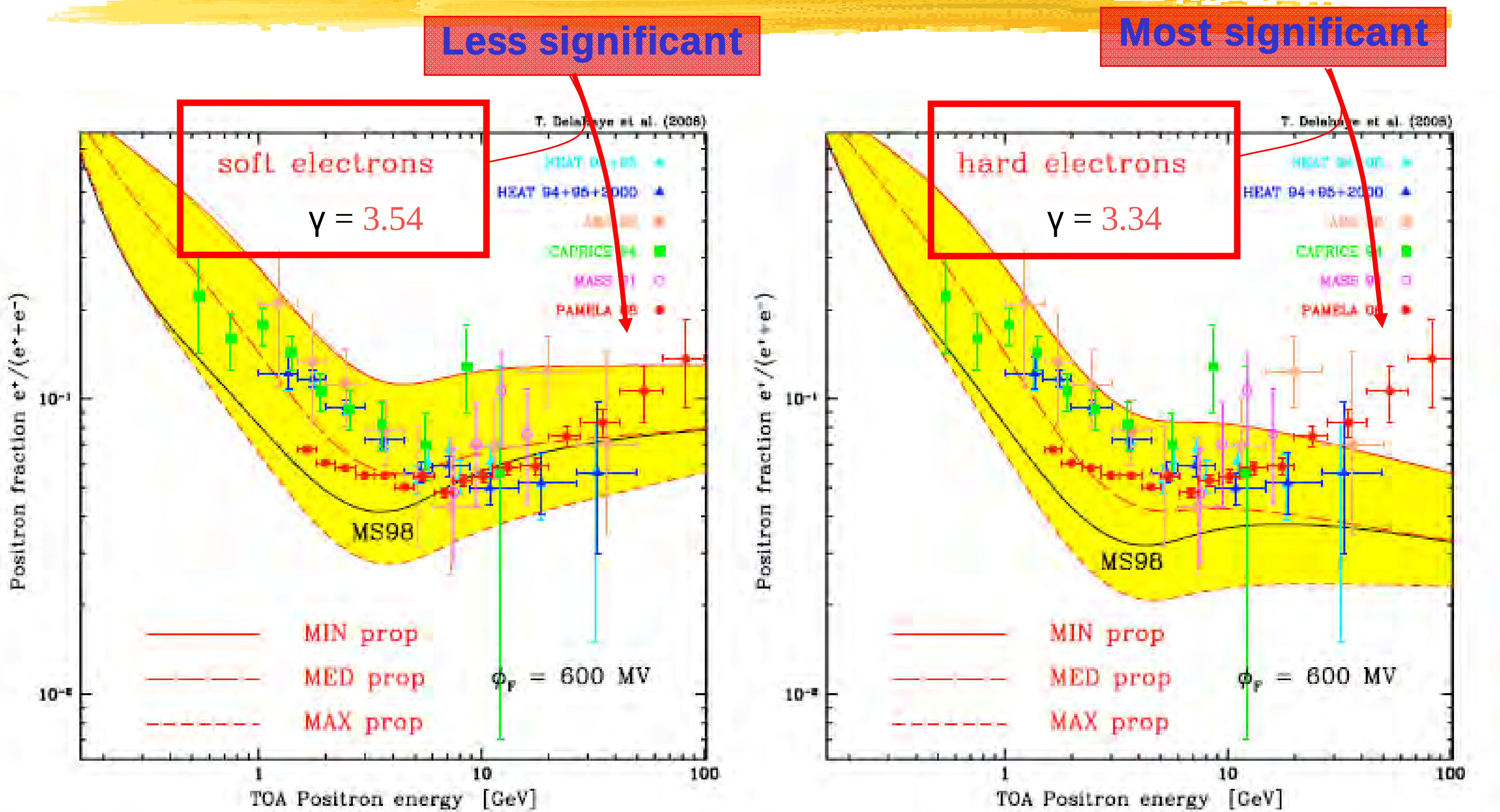
Antiprotons & positrons from old SNR's





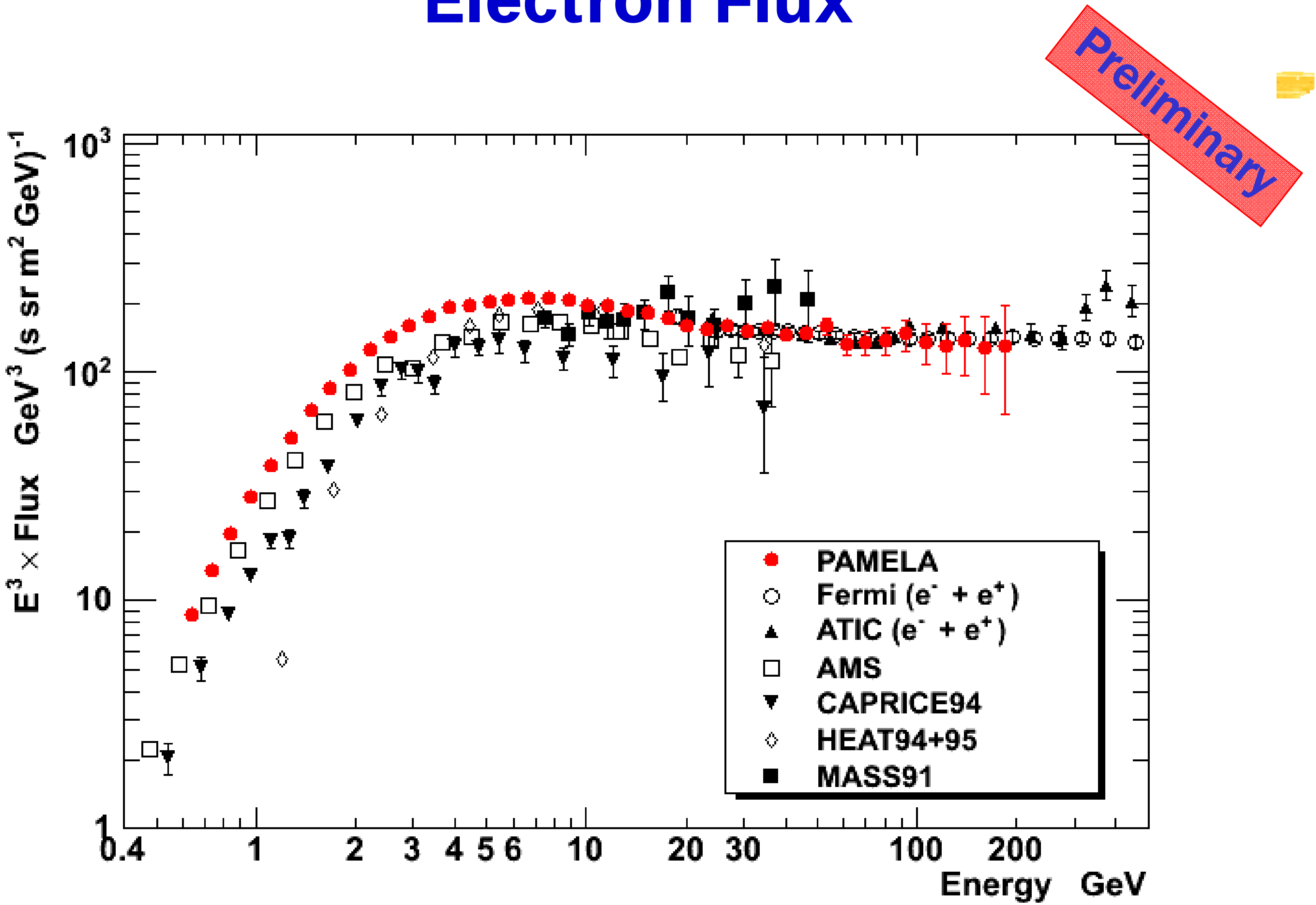
ATIC, Panov at al., ICRC07
CREAM, Ahn et al., Astro-ph 0808.1718
CRN, Swordy et al., ApJ 349 (1990) 625
Dwyer & Meyer, ApJ 322 (1987) 981
HEAO3, Engelmann et al., A&A 223 (1990) 96E
IMP8, Garcia-Munoz et al., ApJ 64 (1987) 269
ISEE3, Krombel et al., ApJ 328 (1988) 940
Juliusson et al., ApJ 191 (1974) 331
Lezniak & Webber, ApJ 223 (1978) 676
Orth et al., ApJ 226 (1978) 1147
PAMELA (2009)
Simon et al., ApJ 239 (1980) 712
Voyager, Ferrando et al., A&A 247 (1991) 163
Increase for
E > 100 GeV/n ?
Preliminary
B/C ratio
Kinetic energy, GeV/n
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10^{-1}
1
10
10^2
10^3

Positron Fraction Theoretical Uncertainties

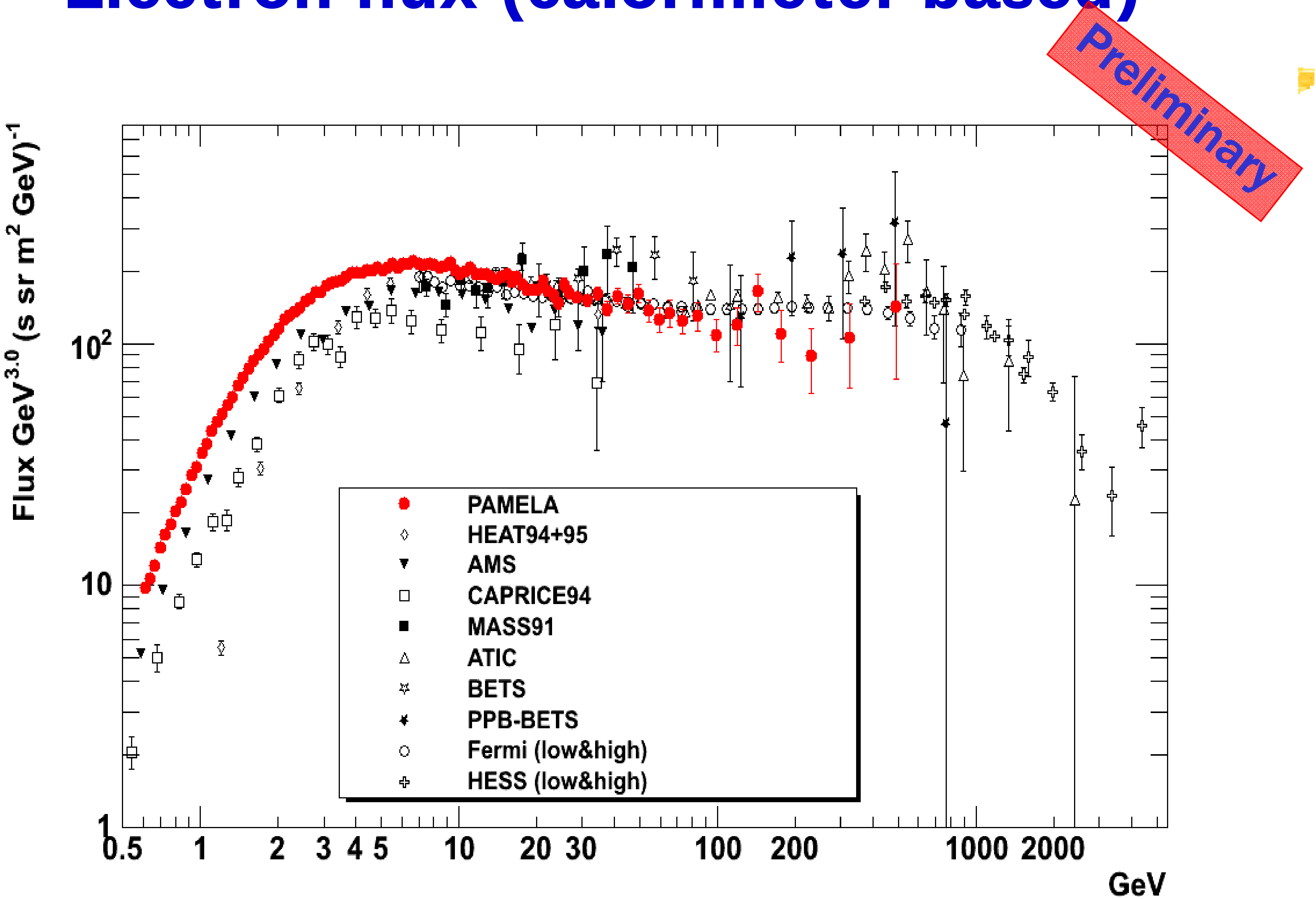


T. Delahaye et al., arXiv: 0809.5268v3

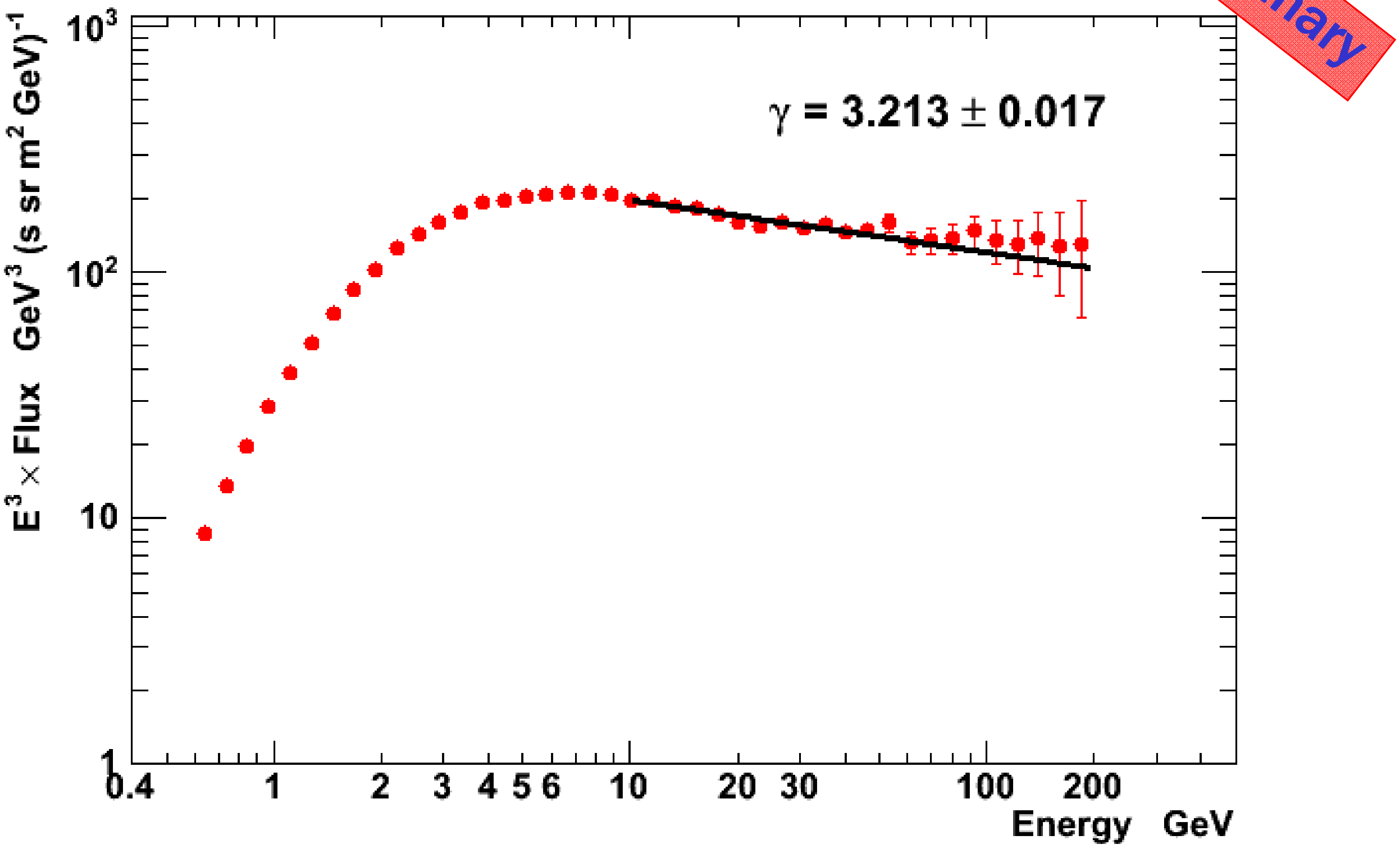
Electron Flux



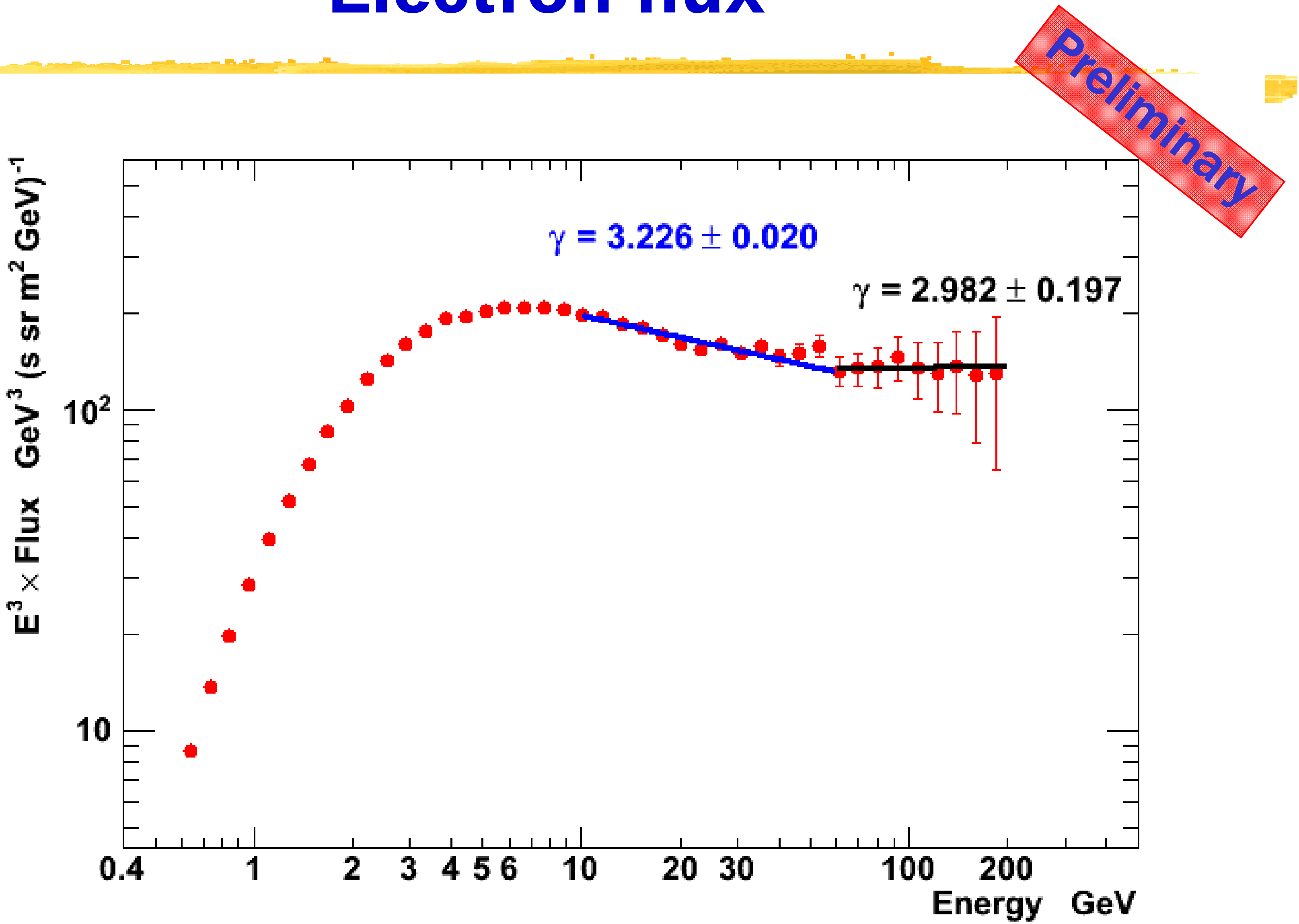
Electron flux (calorimeter based)

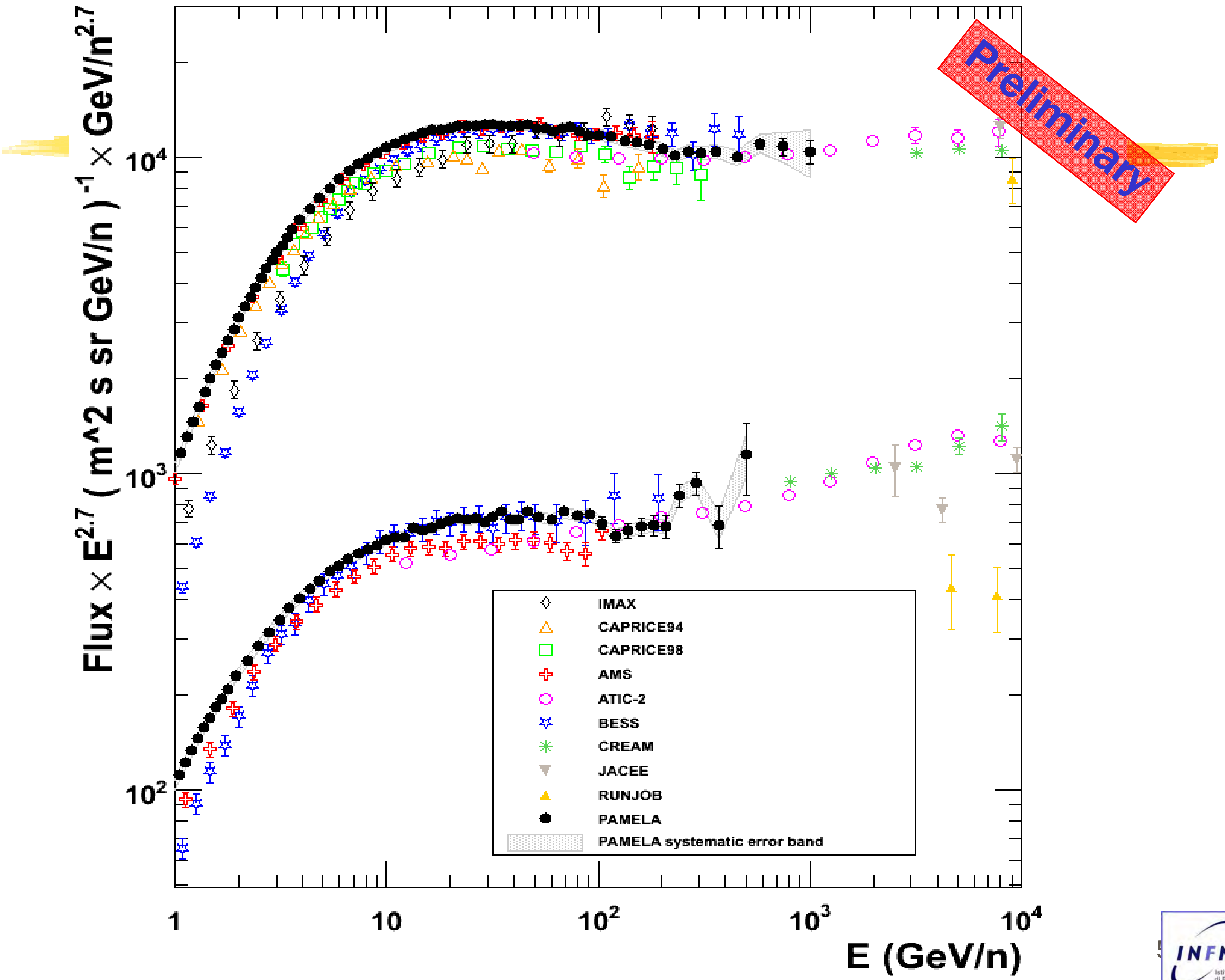


Electron Flux



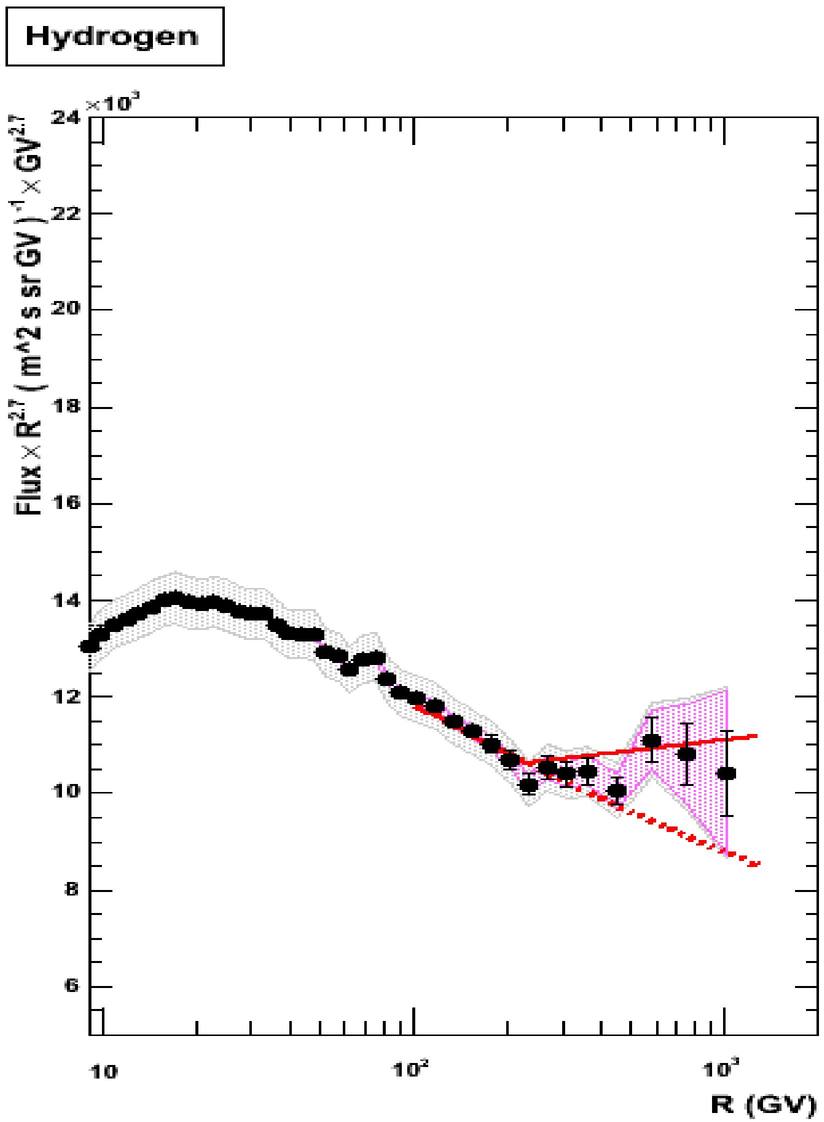
Electron flux

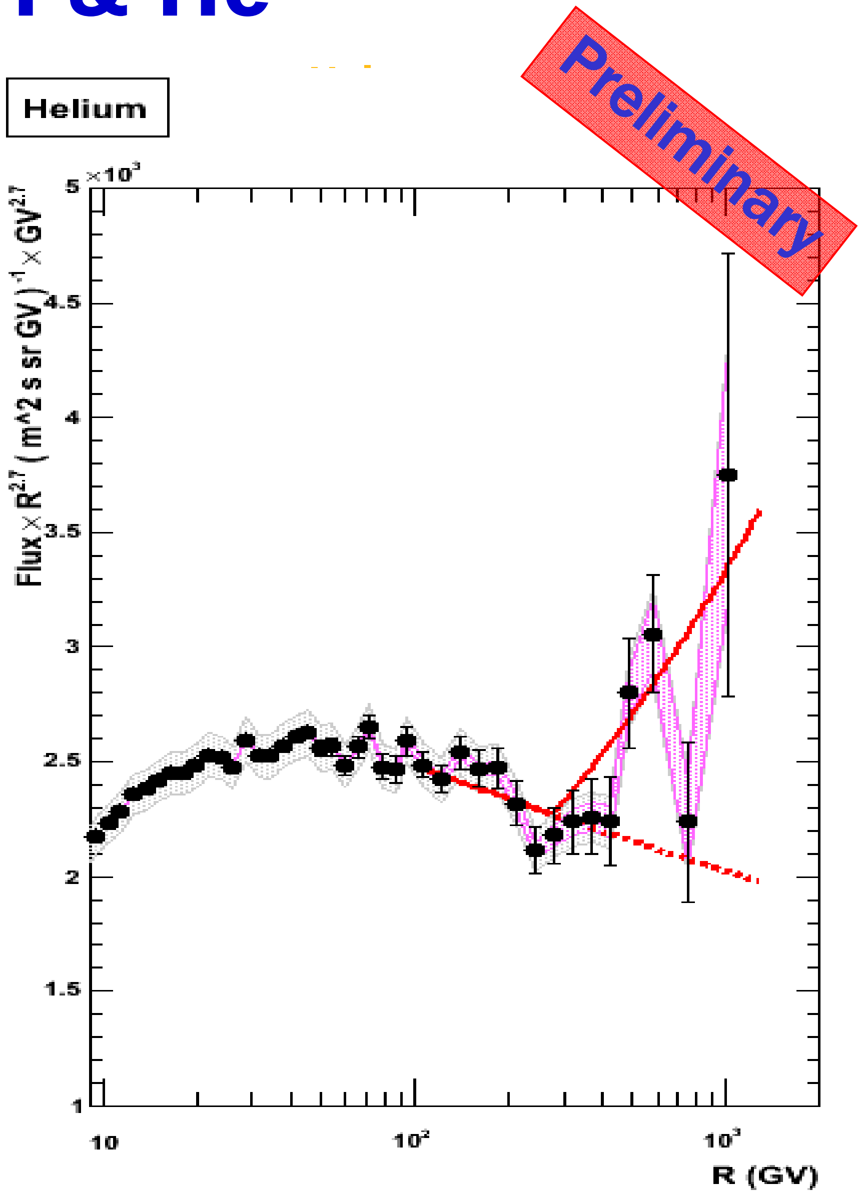




Preliminary
Flux × E^2.7 (m^2 s sr GeV/n)^-1 × GeV/n^2.7
10^4
10^3
10^2
1
10
10^2
10^3
10^4
E (GeV/n)
IMAX
CAPRICE94
CAPRICE98
AMS
ATIC-2
BESS
CREAM
JACEE
RUNJOB
PAMELA
PAMELA systematic error band

Galactic H & He





Conclusions

- We are entered in the new era of precision measurements of (anti)particle fluxes in CR.
- This opens new scenarios in indirect detection of DM but force us to improve our knowledge of the background investigating “standard” astrophysics.
- PAMELA data show anomalies only in the positron sector favoring a “lepthophilic” DM but ...
- ... combined analysis of PAMELA, FERMI and HESS put strong constraints on that DM model.
- The knowledge of background and particle fluxes must be improved, stay tuned for new PAMELA data on $e^{\pm}$, p & He, B & C fluxes!

THANKS !!!!