The PAMELA Space Mission for Antimatter and Dark Matter Searches in Cosmic Rays

F.S. Cafagna, INFN Bari
on behalf of the PAMELA Collaboration

PAMELA Collaboration

Italy: Bari, Florence, Frascati, Naples, Rome, Trieste, CNR, Florence

LNF

Tor Vergata

IFAC

Russia: Moscow, St. Petersburg

Физический Институт

Ioffe Physico-Technical Institute

МИФИ

INFN Istituto Nazionale di Fisica Nucleare

agenzia spaziale italiana

DLR

SNSB

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

Germany: Siegen

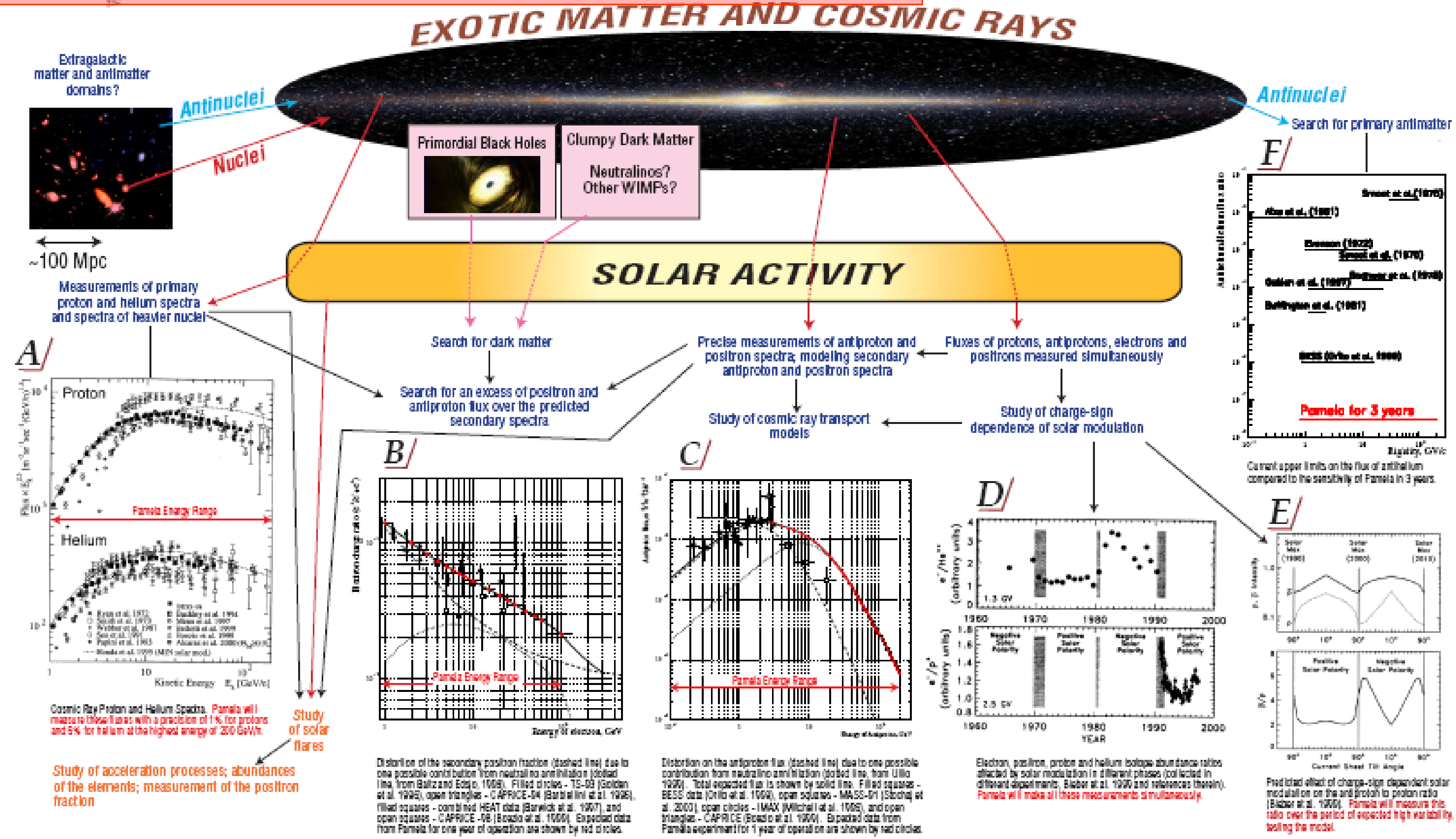
Universität Gesamthochschule Siegen

Sweden: KTH, Stockholm

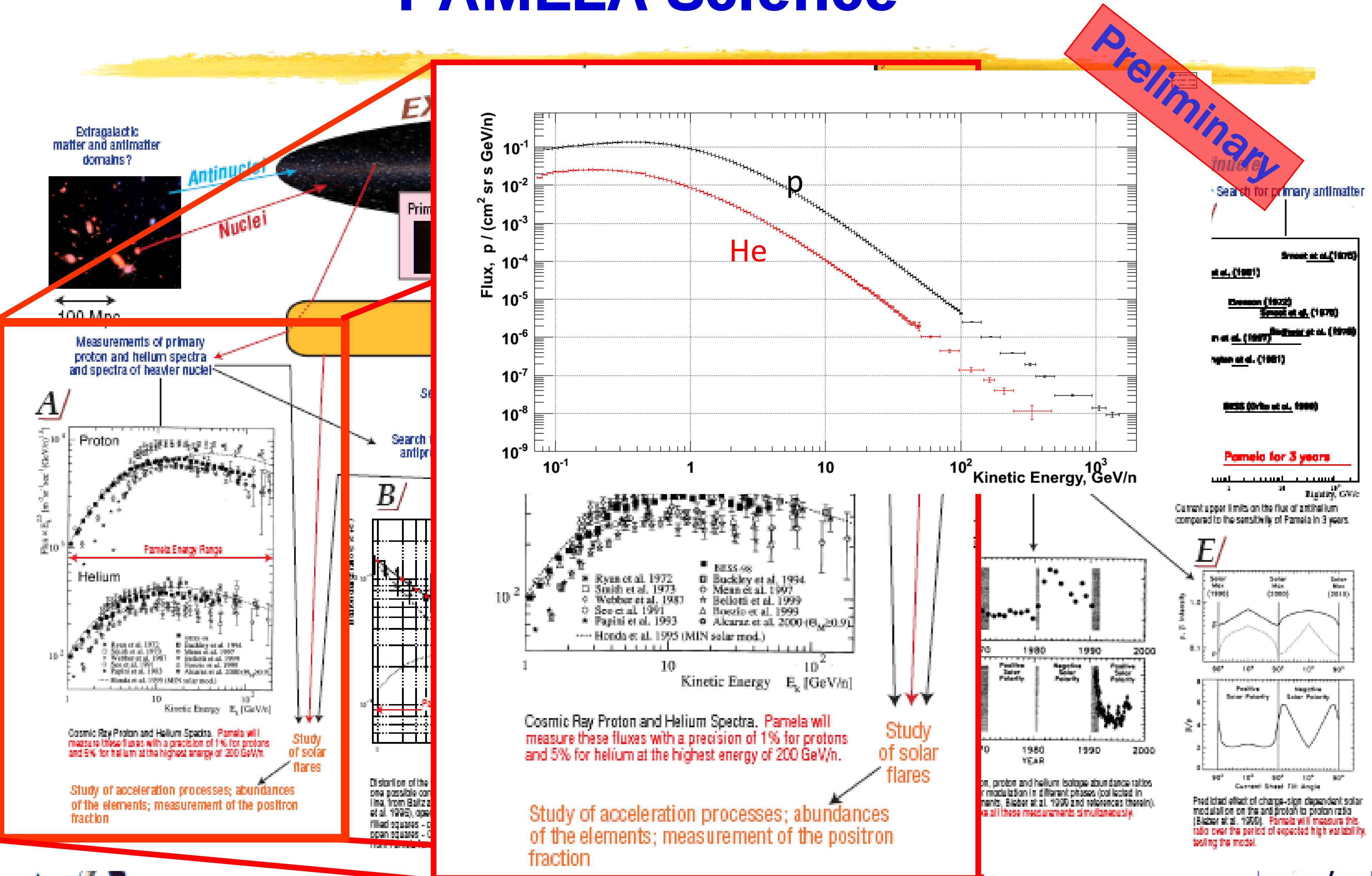
Kungl Tekniska Högskolan

PAMELA Science

PAMELA as a Space Observatory @ 1AU



PAMELA Science



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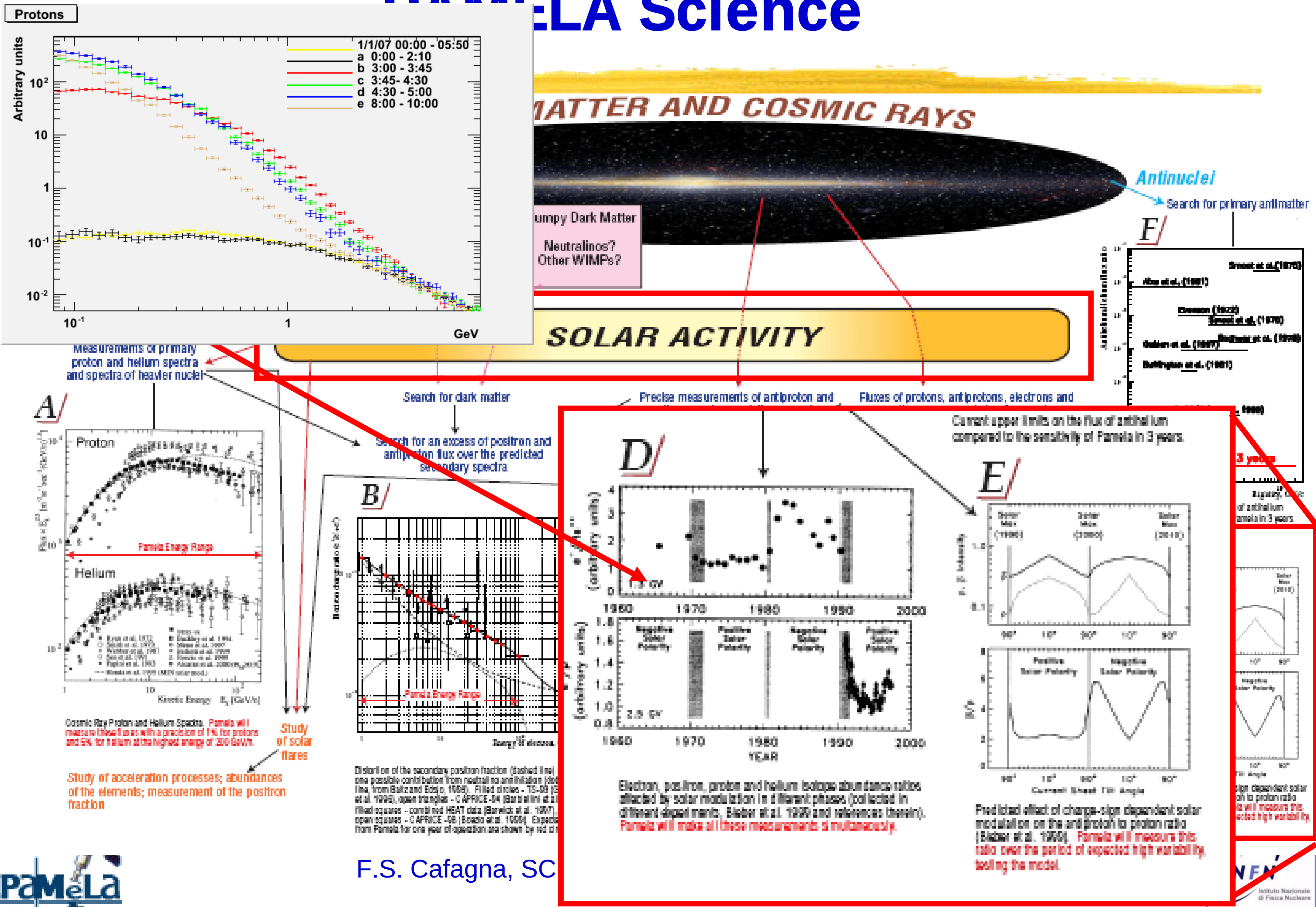

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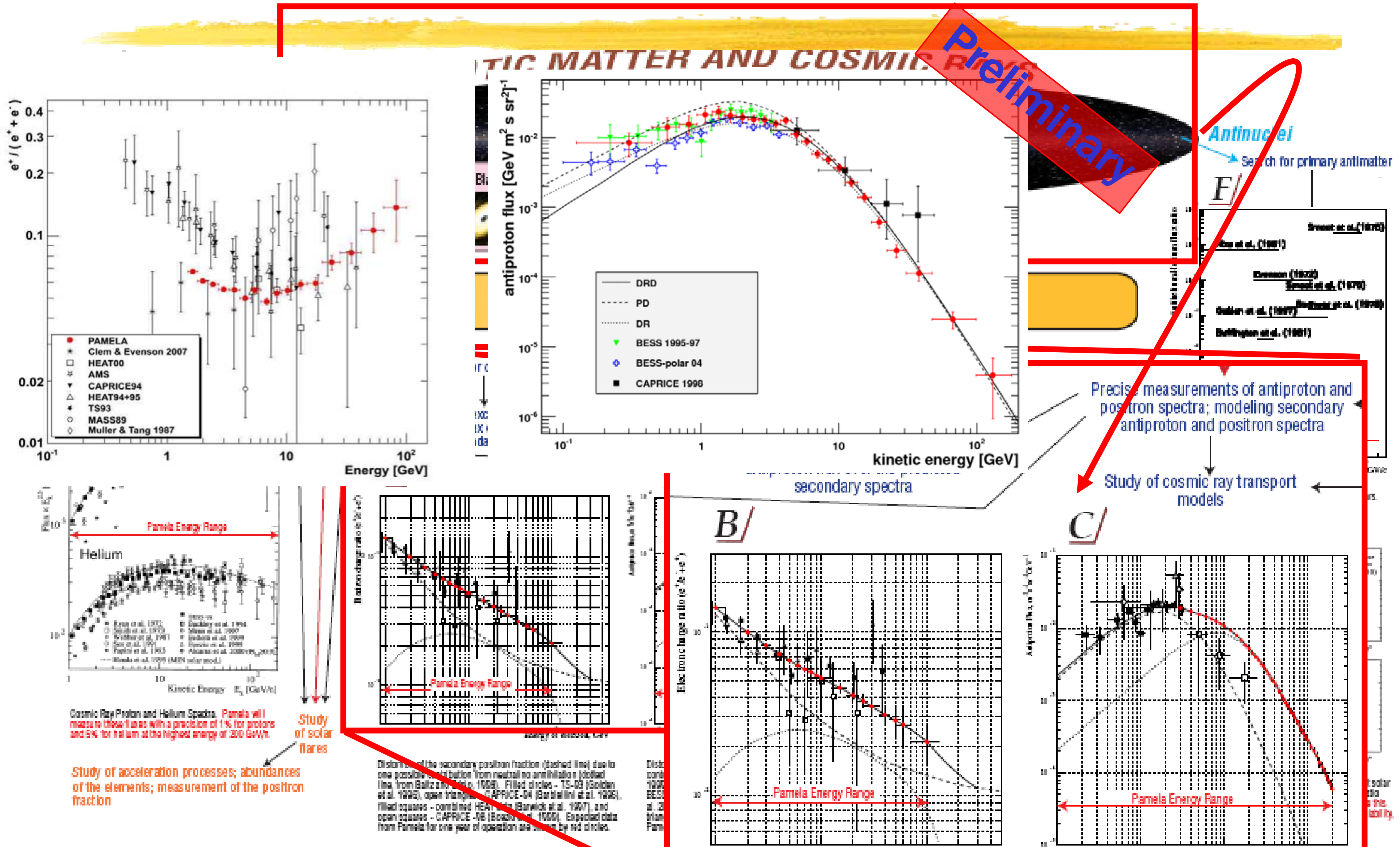
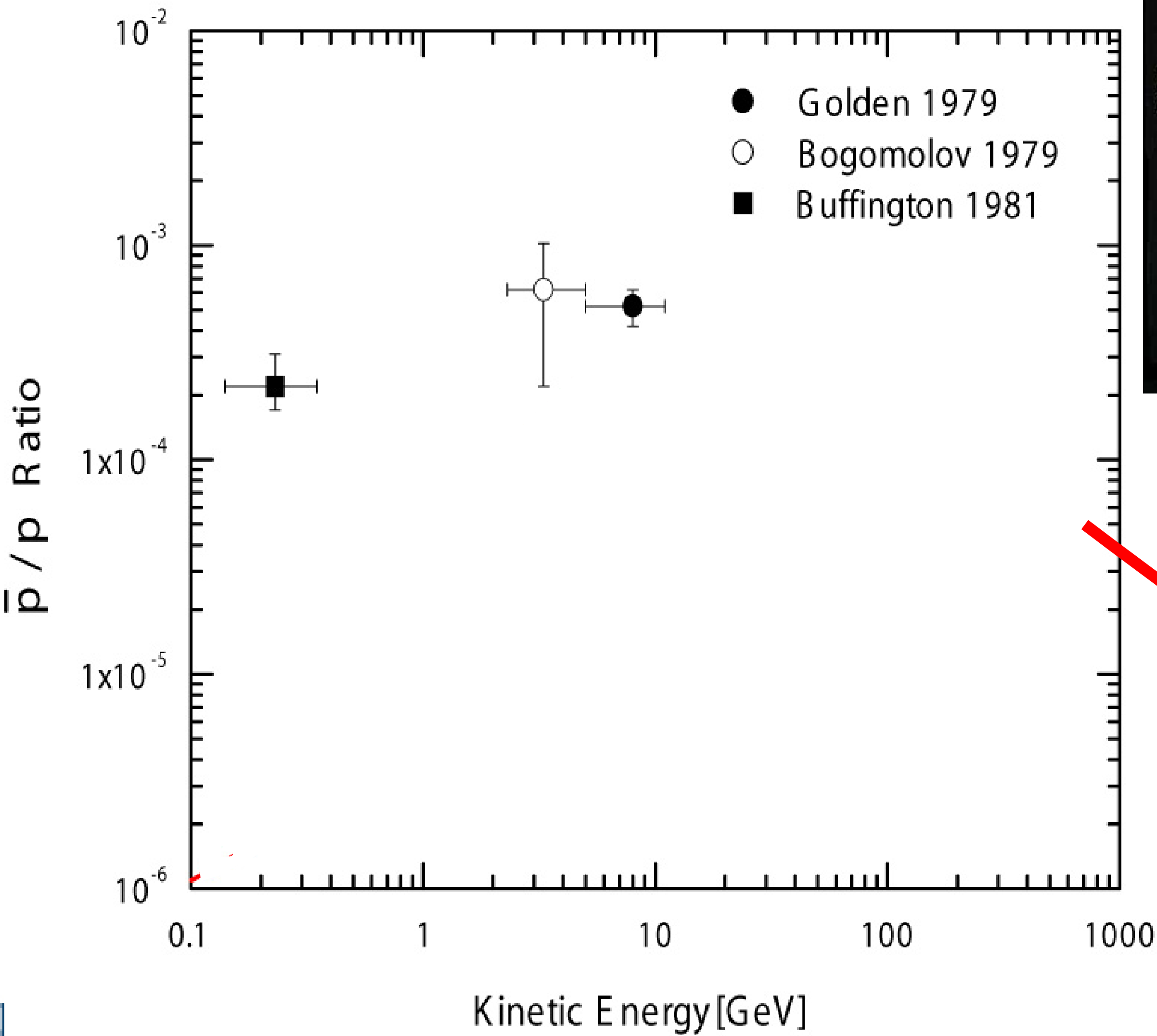
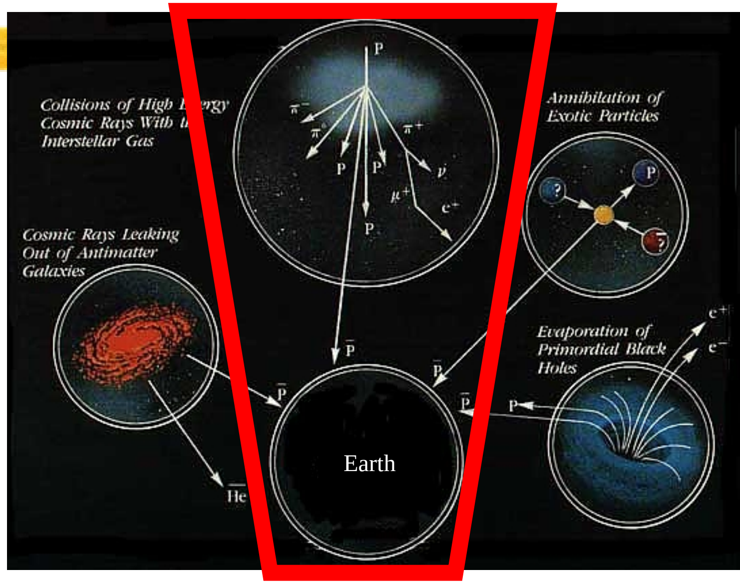
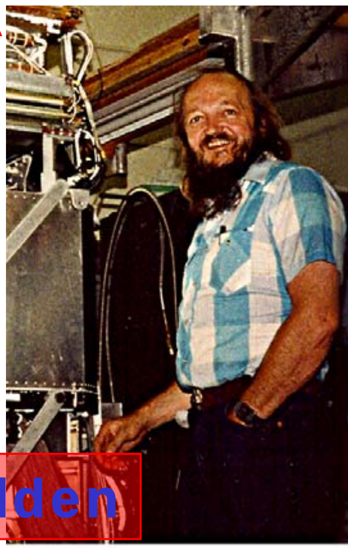


Why Anti(particle)matter matters?







R.L. Golden

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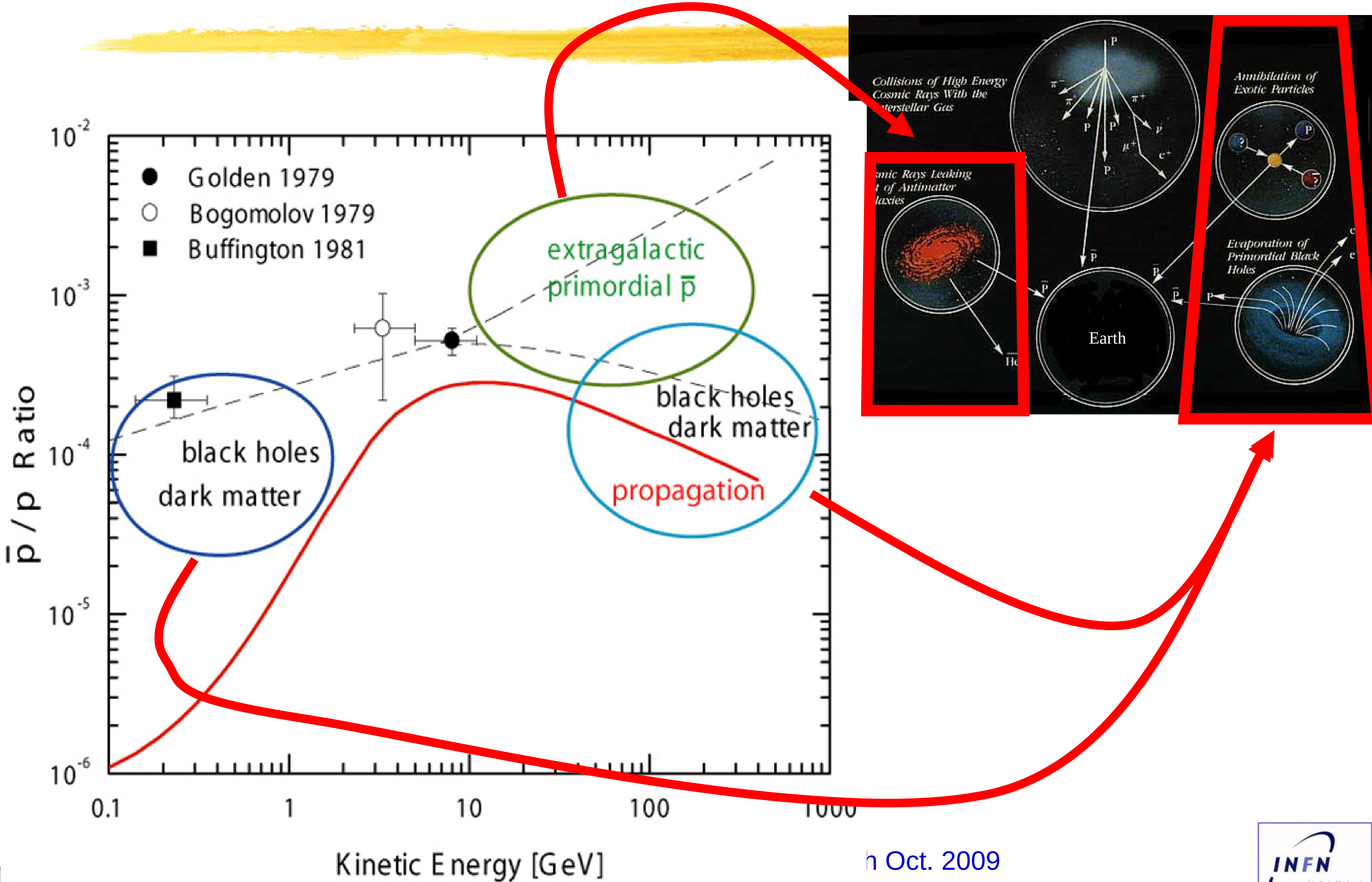

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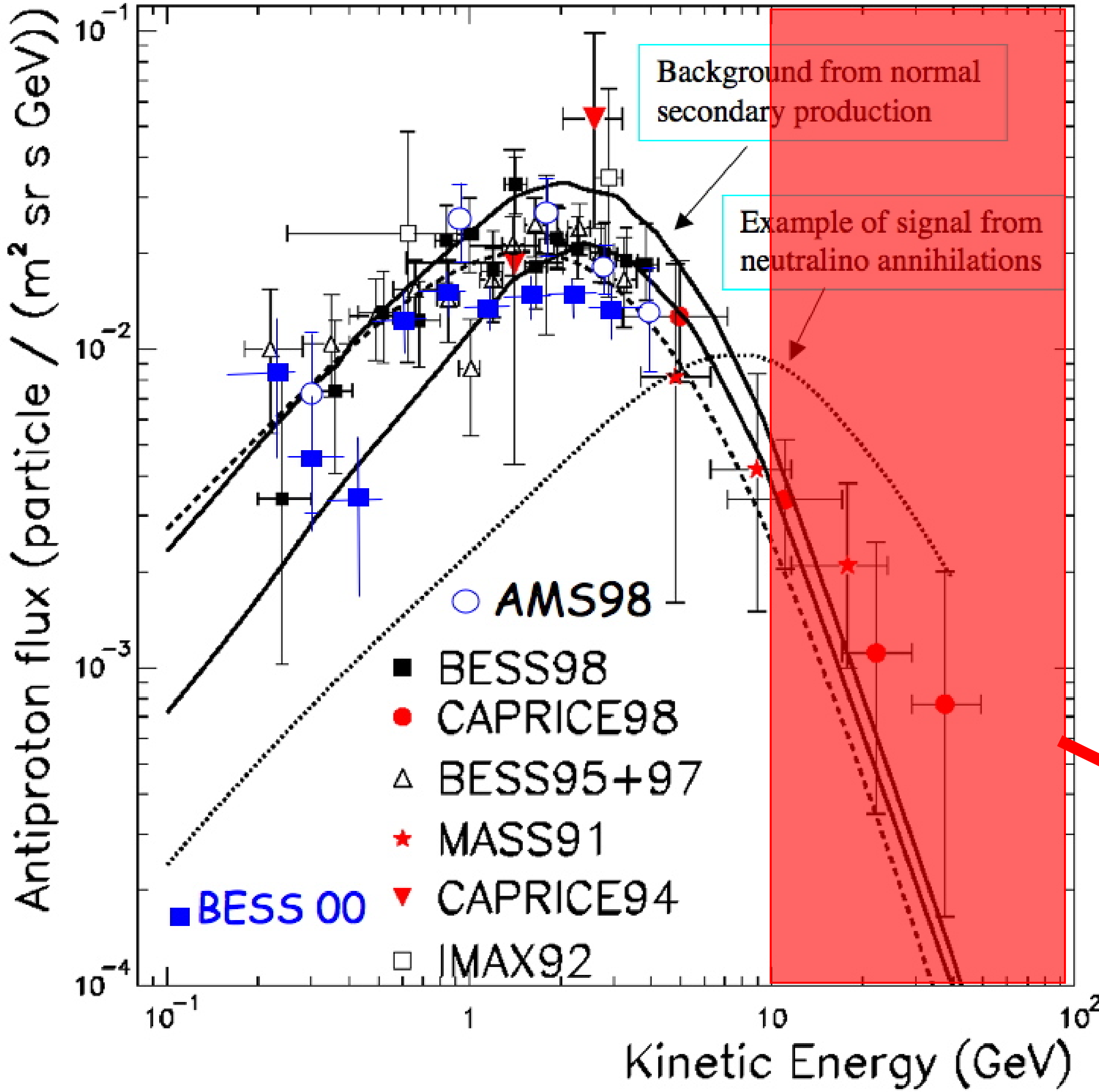

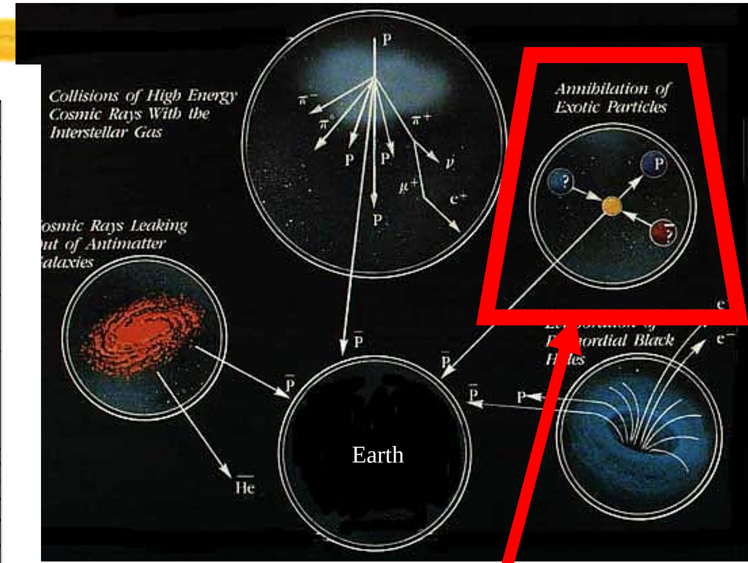

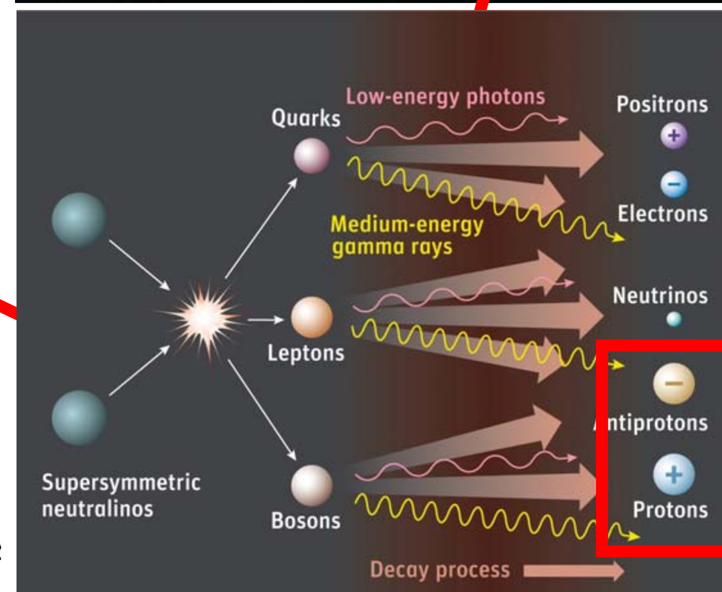

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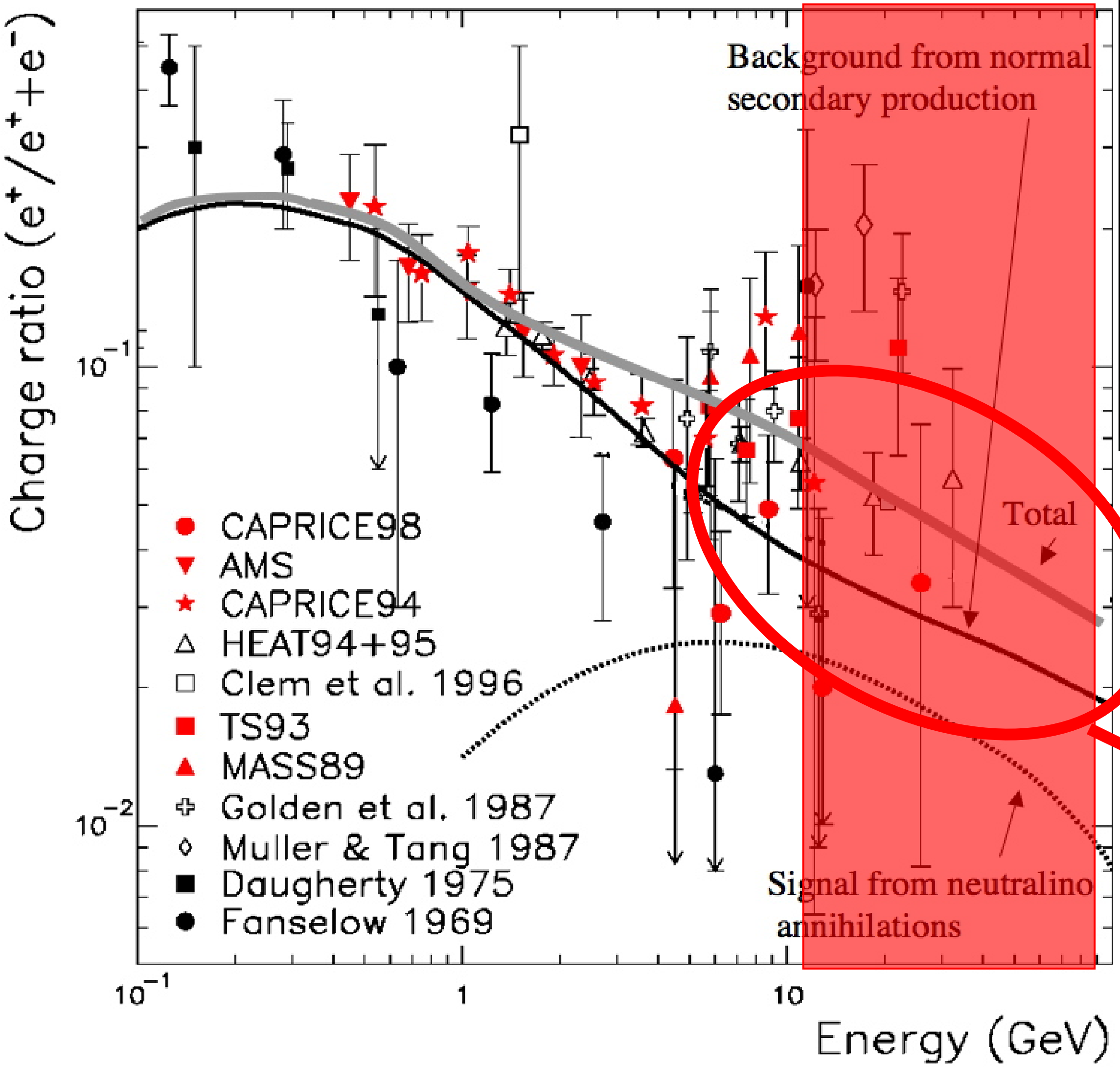
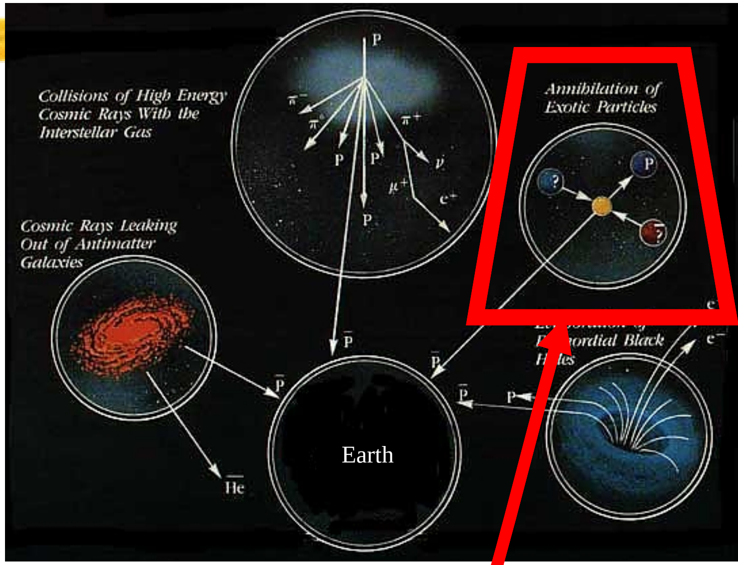
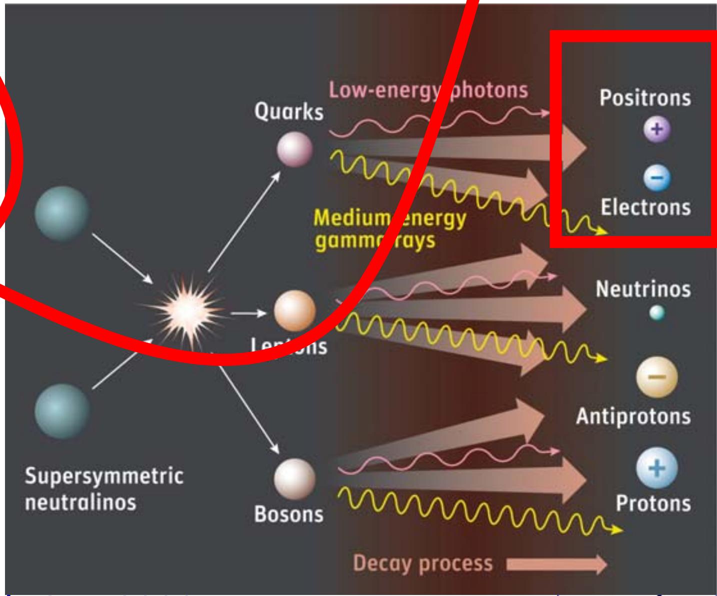
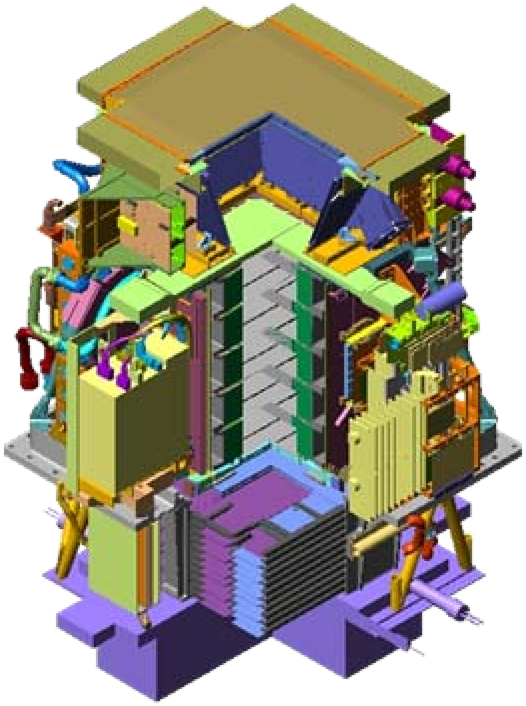






PAMELA detectors

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



GF:	**21.5 cm² sr**
Mass:	**470 kg**
Size:	**130x70x70 cm³**
Power Budget:	**360W**

PAMELA detectors

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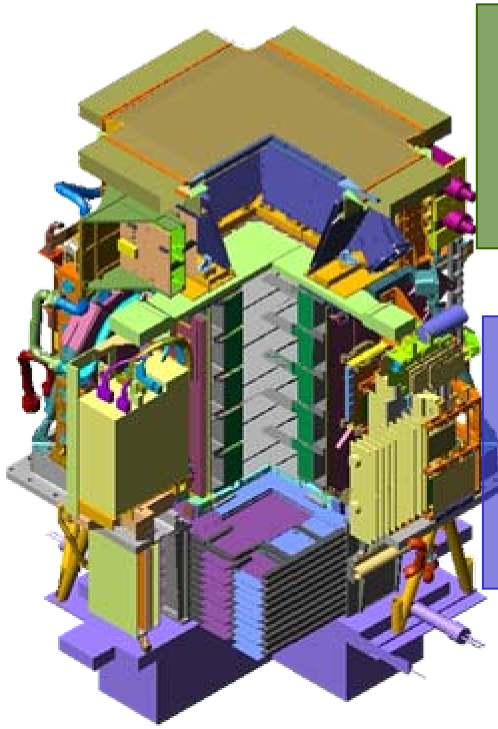
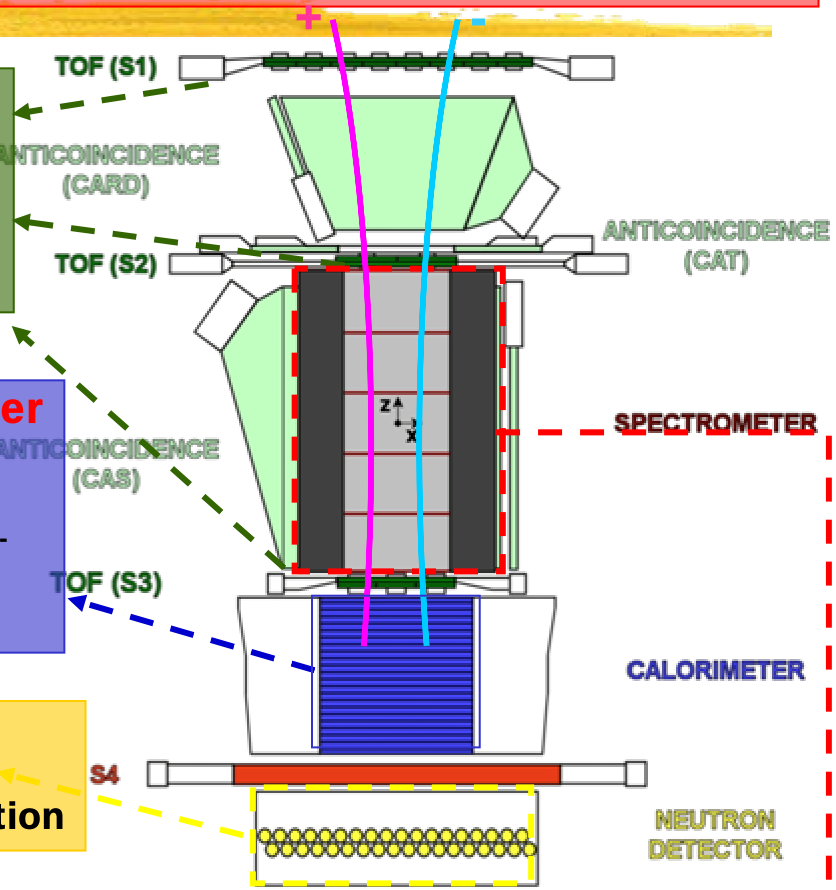


Time-Of-Flight
plastic scintillators + PMT
- -Trigger;
- -Albedo rejection;
- -Mass identification up to 1 GeV;
- -Charge identification from dE/dX.

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



GF:	21.5 cm² sr
Mass:	470 kg
Size:	130x70x70 cm³
Power Budget:	360W

Spectrometer
microstrip silicon tracking system + permanent magnet

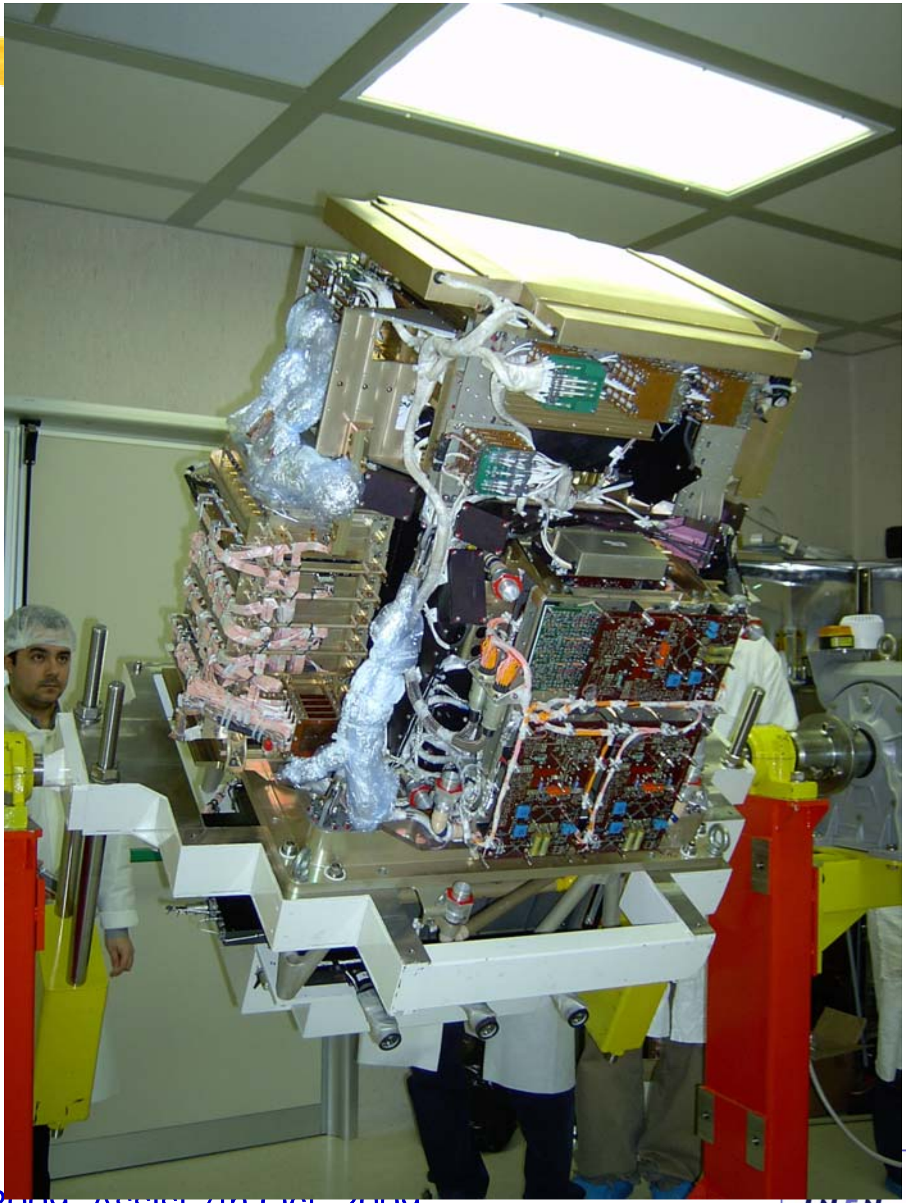
- Magnetic rigidity (R = pc/Ze)
- Charge sign
- Charge value from dE/dx

Design Performance

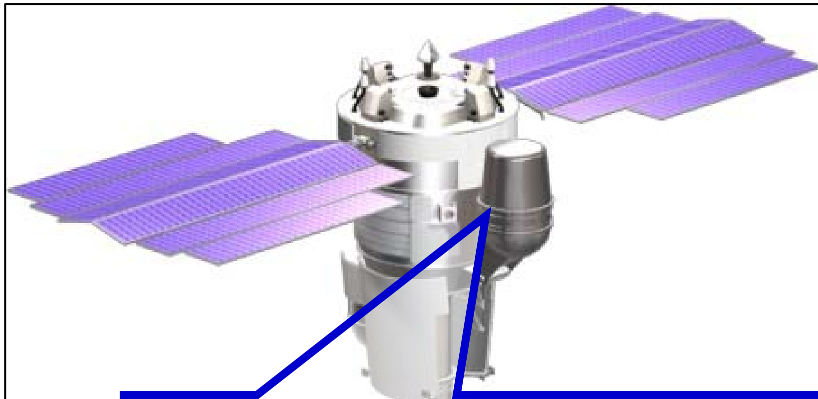
• Antiprotons	80 MeV - 150 GeV
• Positrons	50 MeV – 270 GeV
• Electrons	up to 400 GeV
• Protons	up to 700 GeV
• Electrons+positrons	up to 2 TeV (calorimeter alone)
• Light Nuclei (He/Be/C)	up to 200 GeV/n
• AntiNuclei search	sensitivity of 3×10^{-8} in $\overline{He}$/He

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

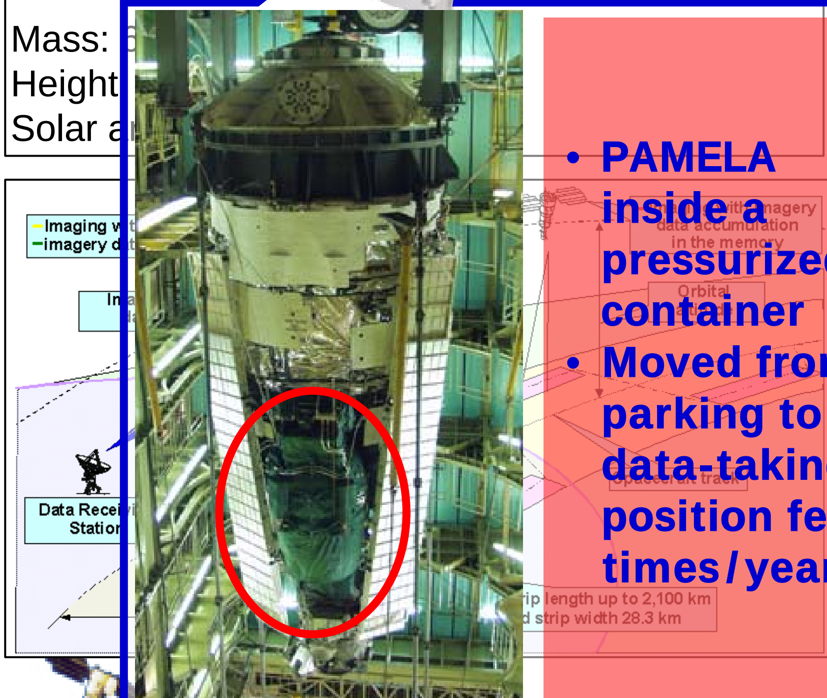
PAMELA: the integration



The Resurs DK-1 spacecraft



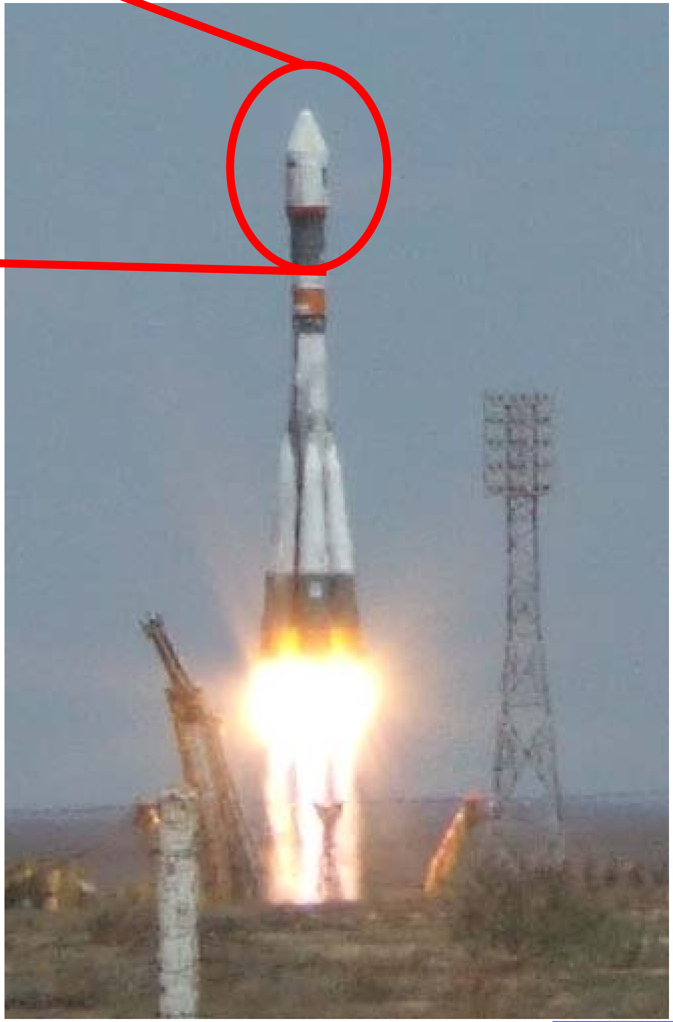
Mass:
Height
Solar a



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

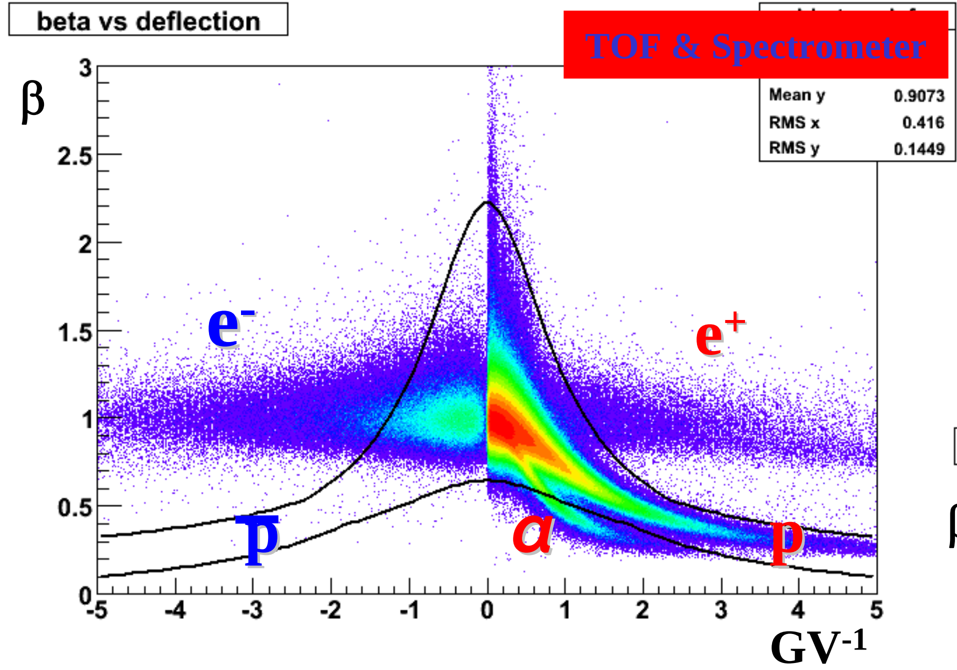
- Multi-spectral remote sensing of earth's surface
  → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
  - inclination ~70º
  - altitude ~ 360-600 km (elliptical)
- Active life >3 years
- Data transmitted via Very high-speed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

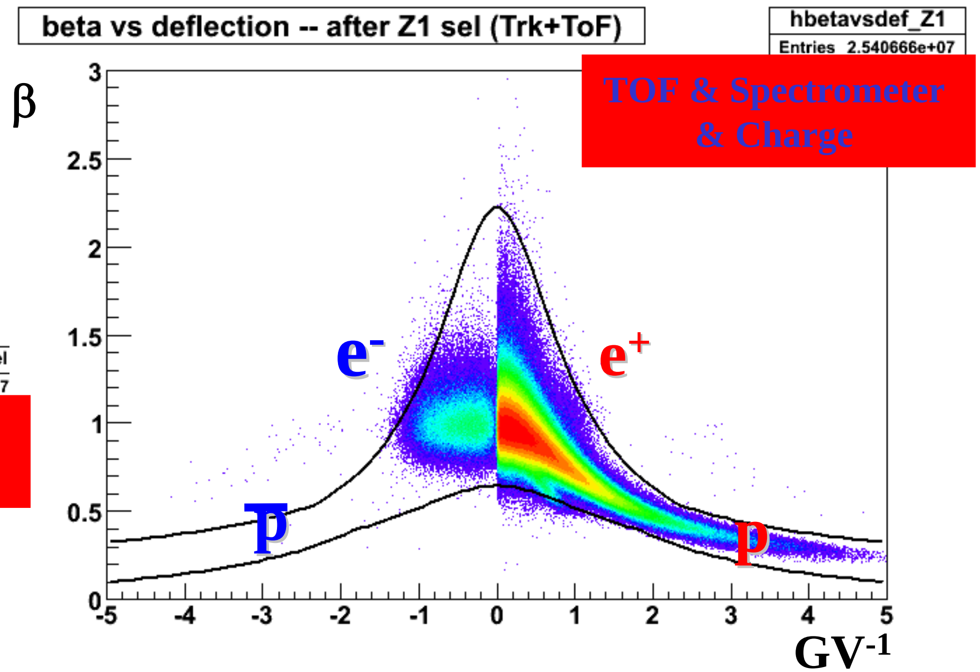
the satellite & launch

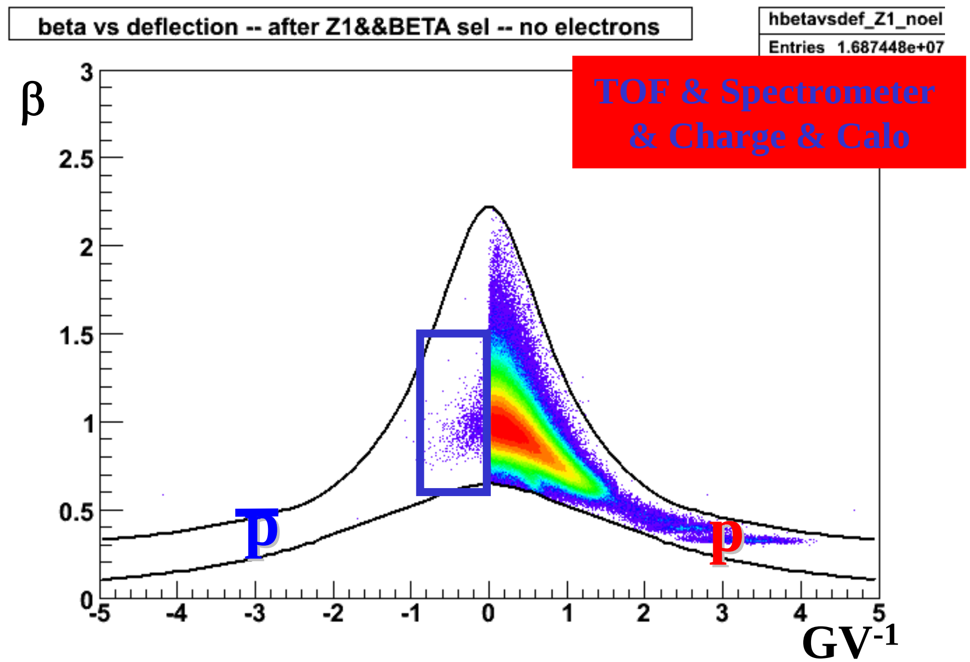


- Launch from Baikonur:
  June 15th 2006, 0800 UTC.
  Power On: June 21st 2006, 0300 UTC.
  Detectors operated as expected after launch
- PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006
  - ~1200 days of data taking (~73% live-time)
  - ~14 TByte of raw data downlinked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

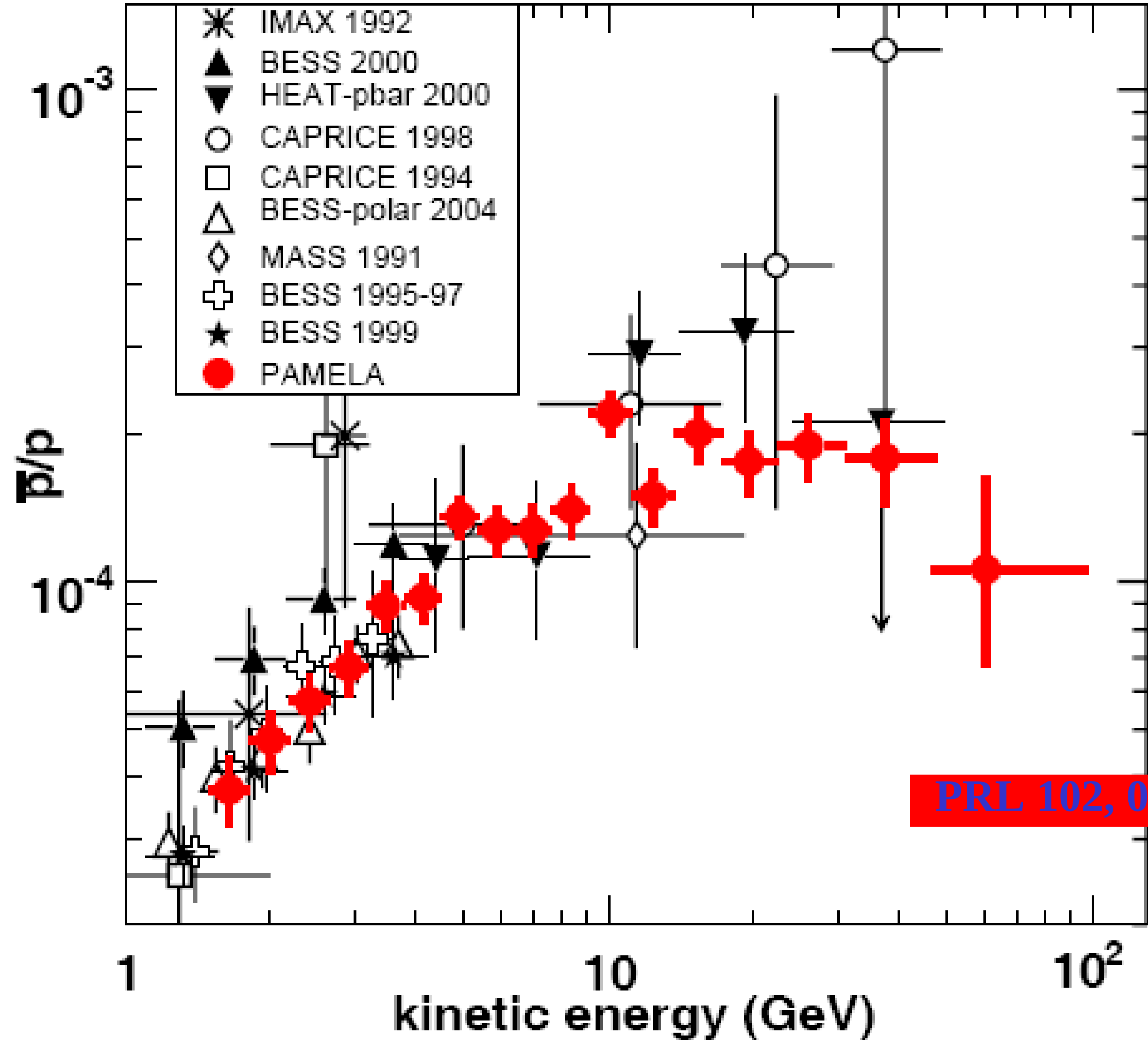
Antiproton Selection





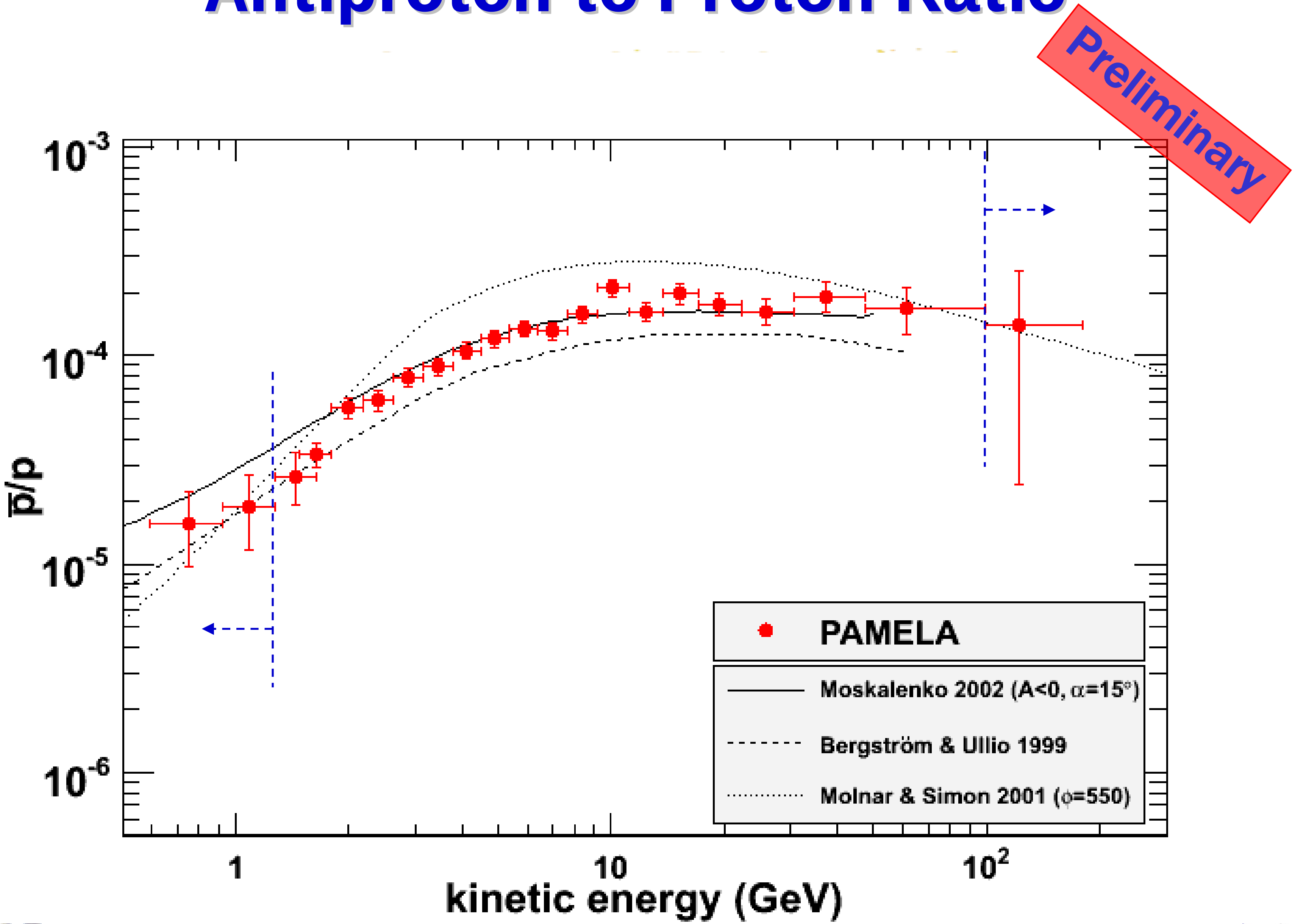


Antiproton to Proton Ratio

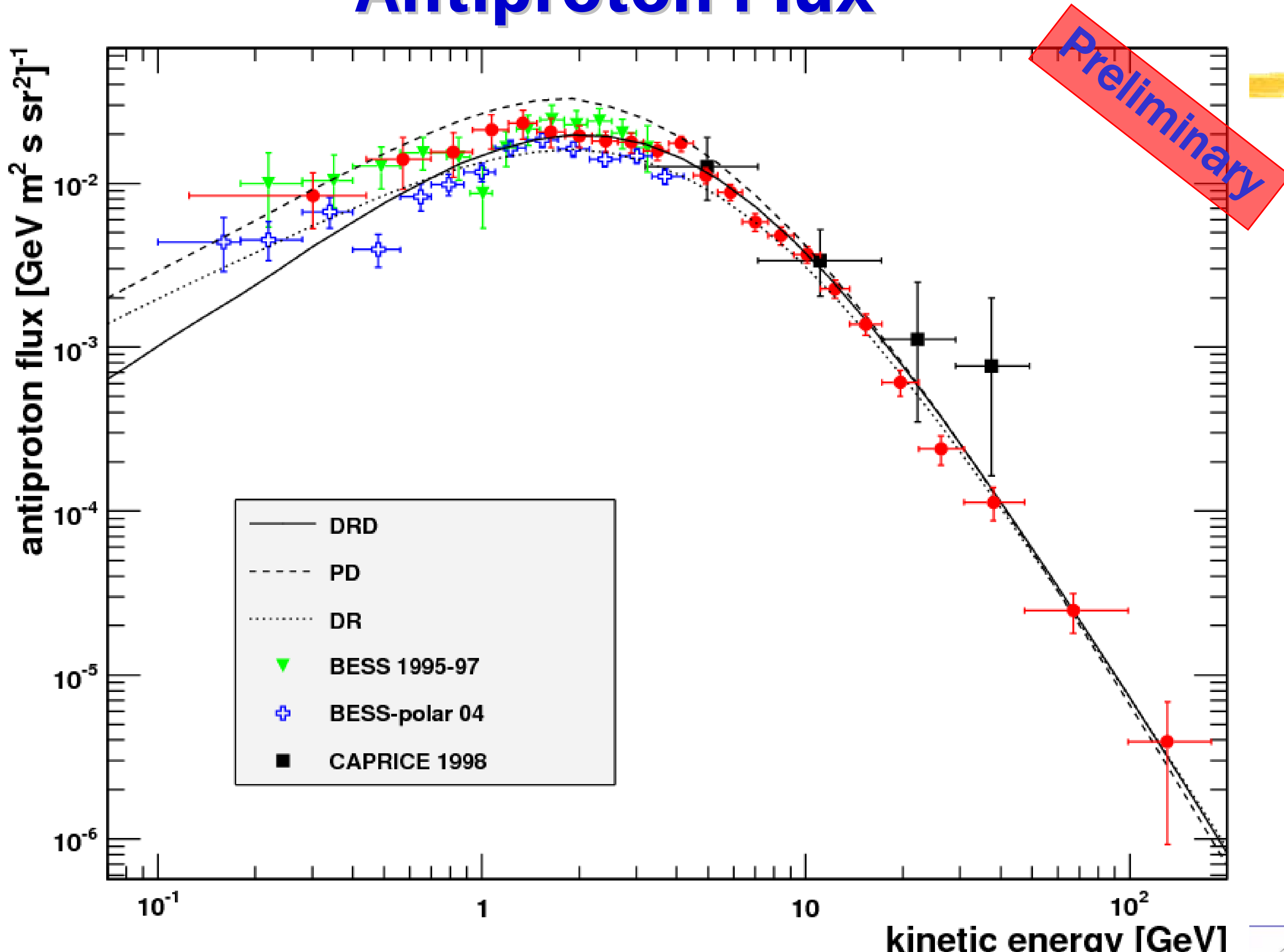


PRL 102, 051101 (2009)

Antiproton to Proton Ratio



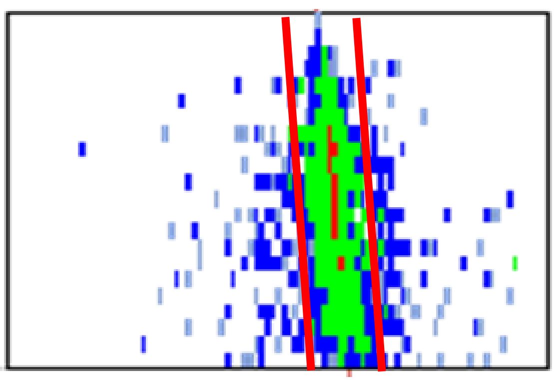
Antiproton Flux

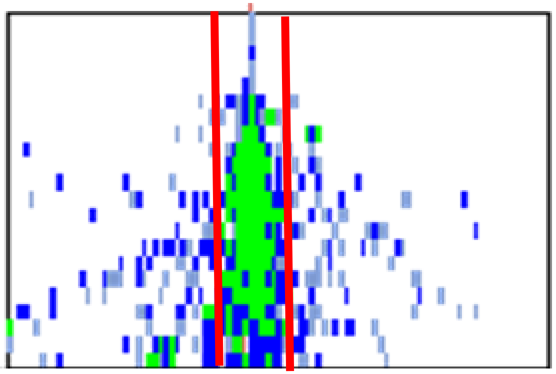


Positron selection with calorimeter

51 GV Positron

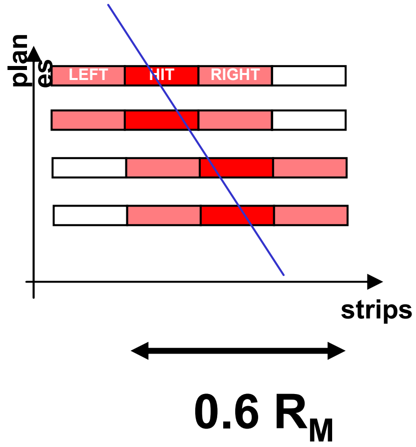
80GV Proton

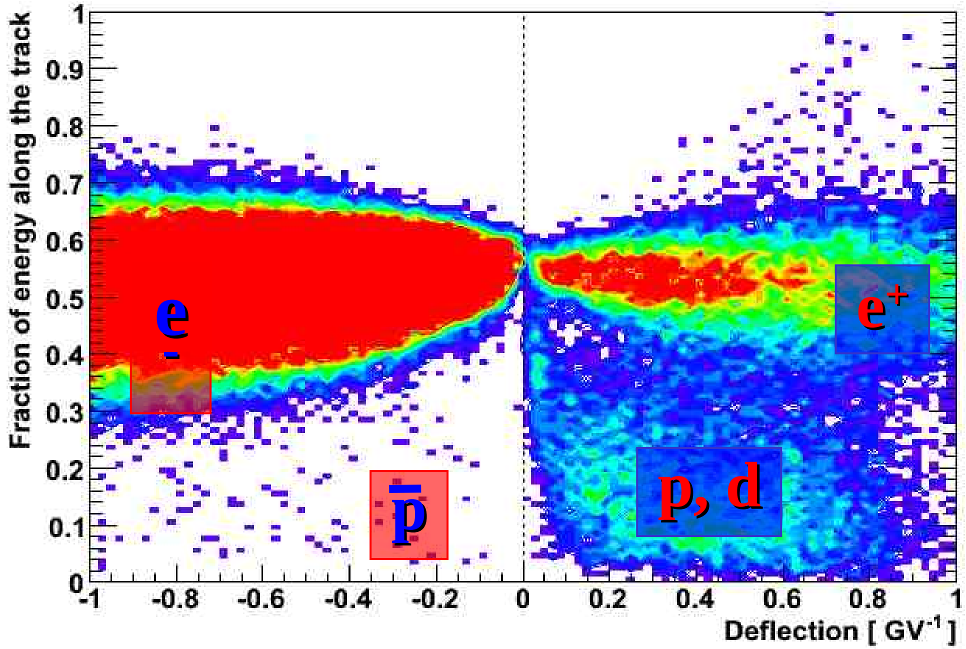




Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match





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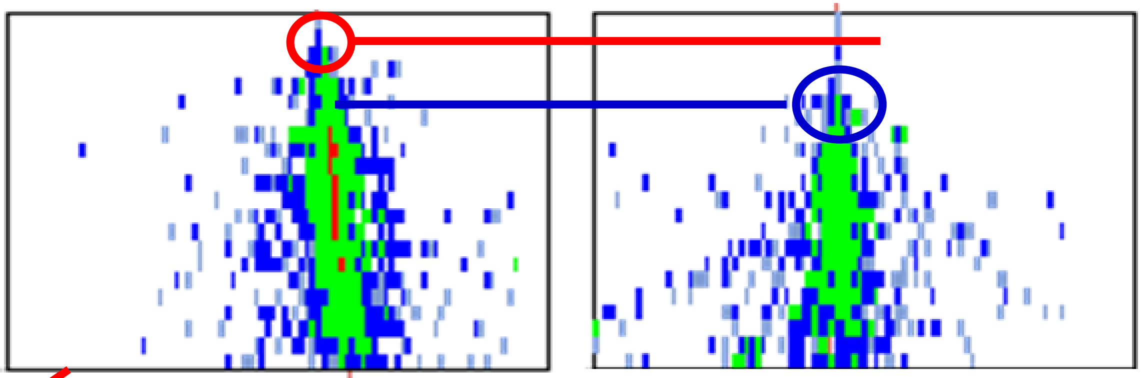
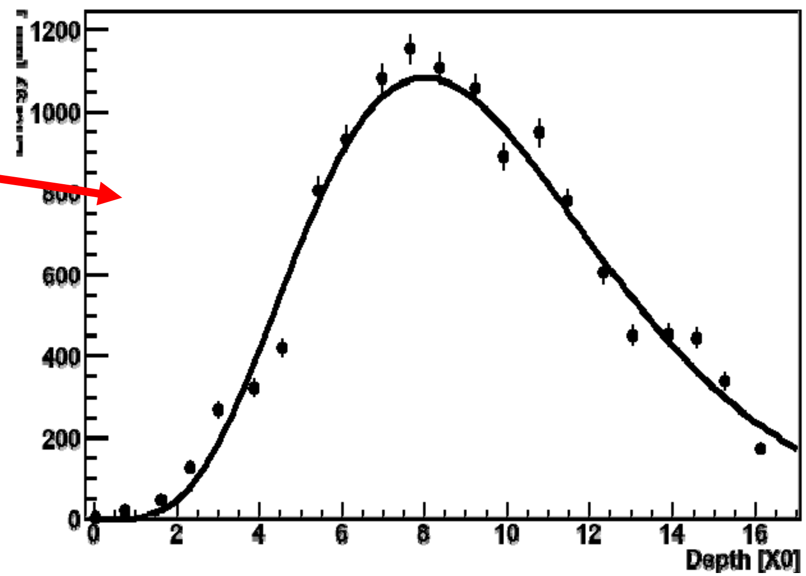


Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match

Shower starting point

Longitudinal profile



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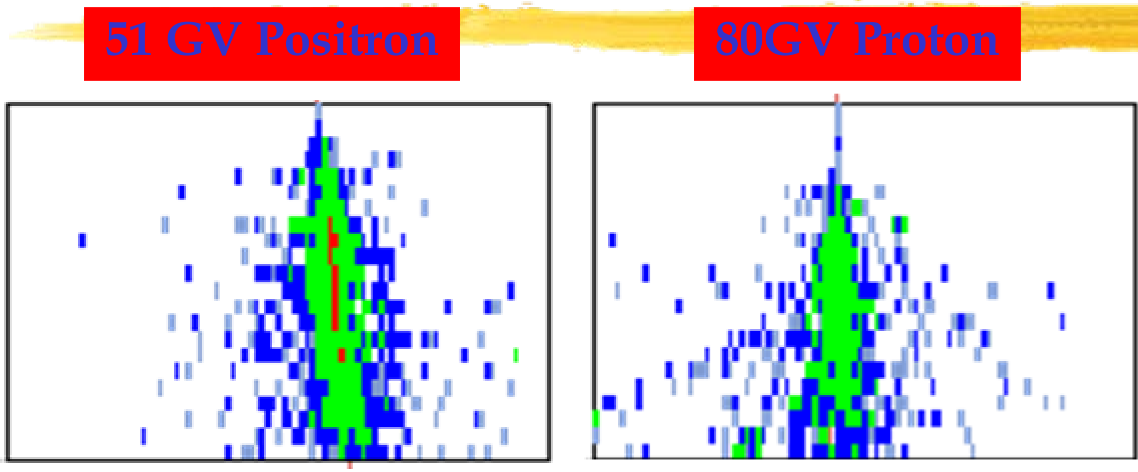


Fraction of charge released along the calorimeter track

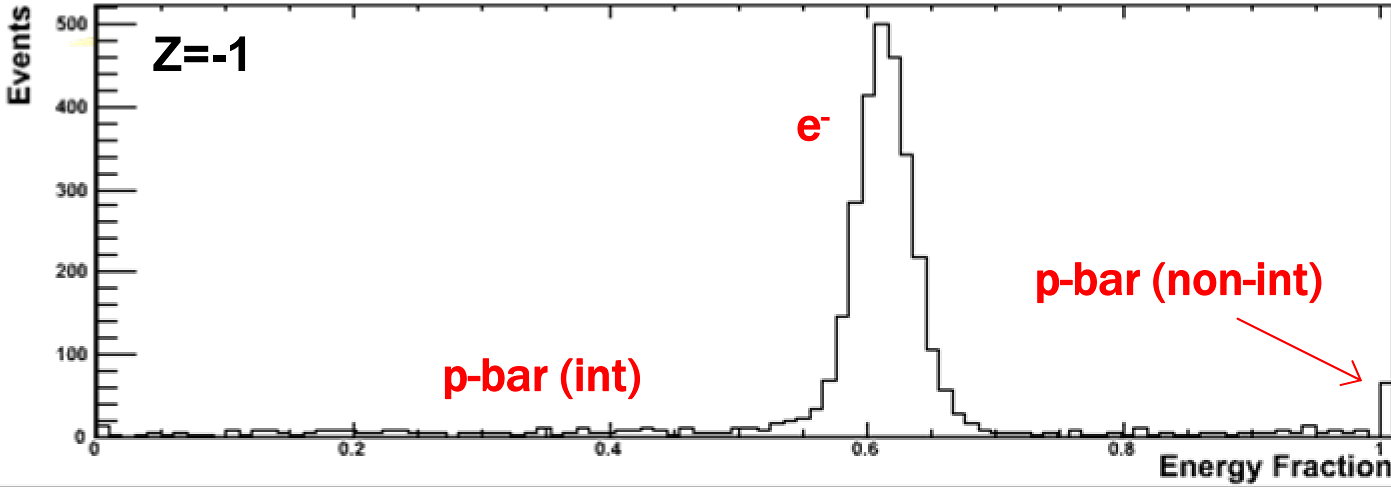
Energy (calo) – Momentum (spectrometer) match

Shower starting point

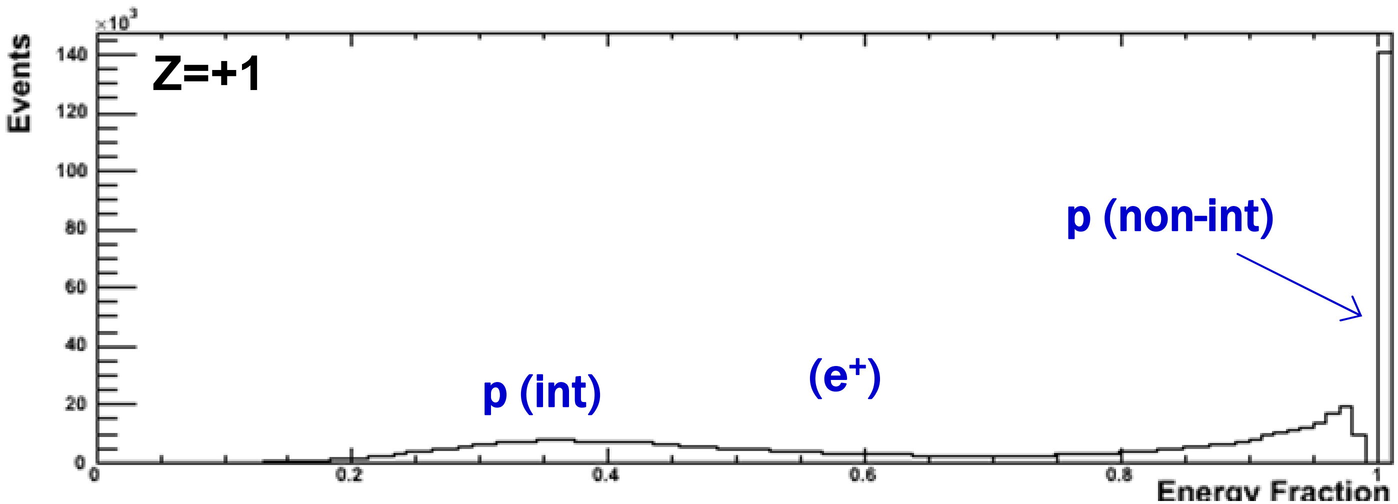
Longitudinal profile

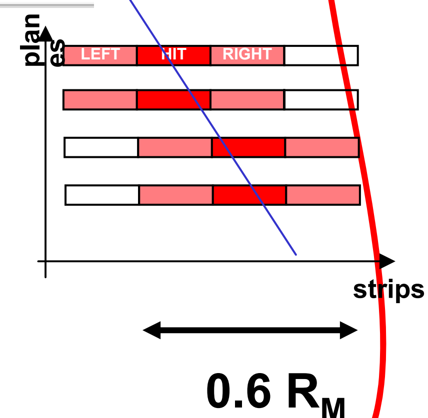
- Tuning/check of selection criteria using:
  - test-beam data
  - simulation
  - flight data: *dE*/ *dx* from spectrometer & neutron yield from ND
- Selection of pure proton sample from flight data ("pre-sampler" method):
  - Background-suppression method
  - Background-estimation method
- Final results DON'T MAKE USE of test-beam and/or simulation calibrations.

Positron selection with calorimeter



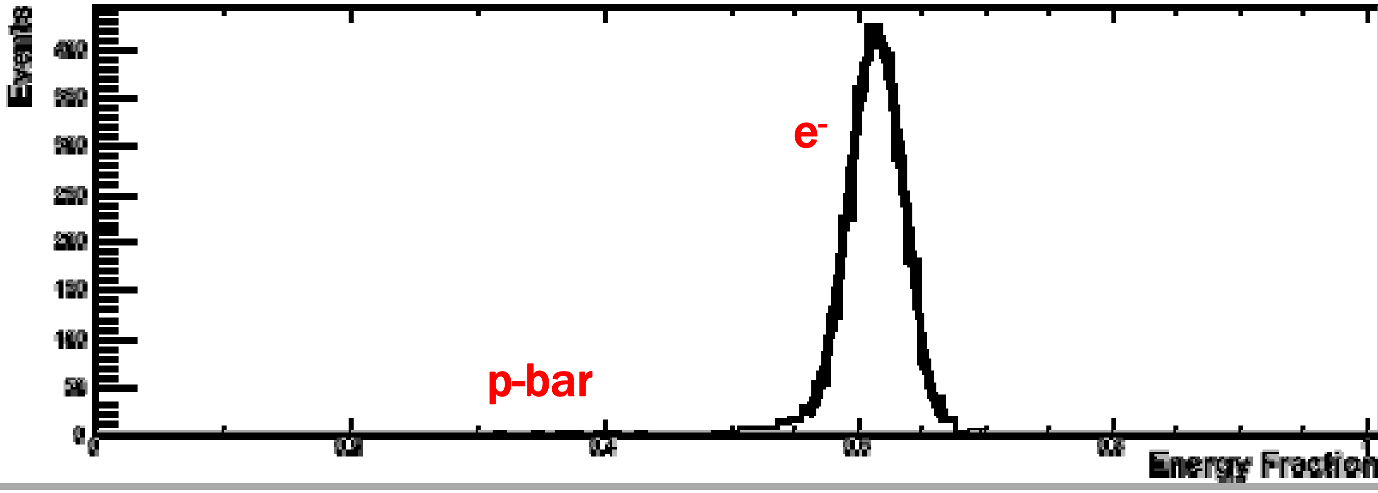
Fraction of charge released along the calorimeter track

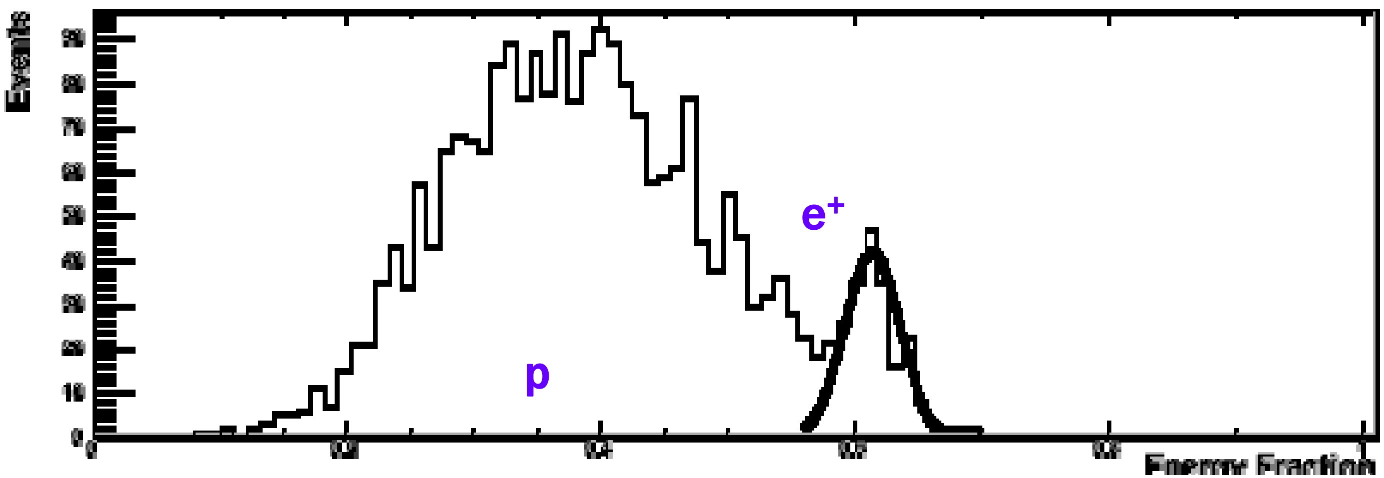




Rigidity: 20-30 GV

Positron selection with calorimeter





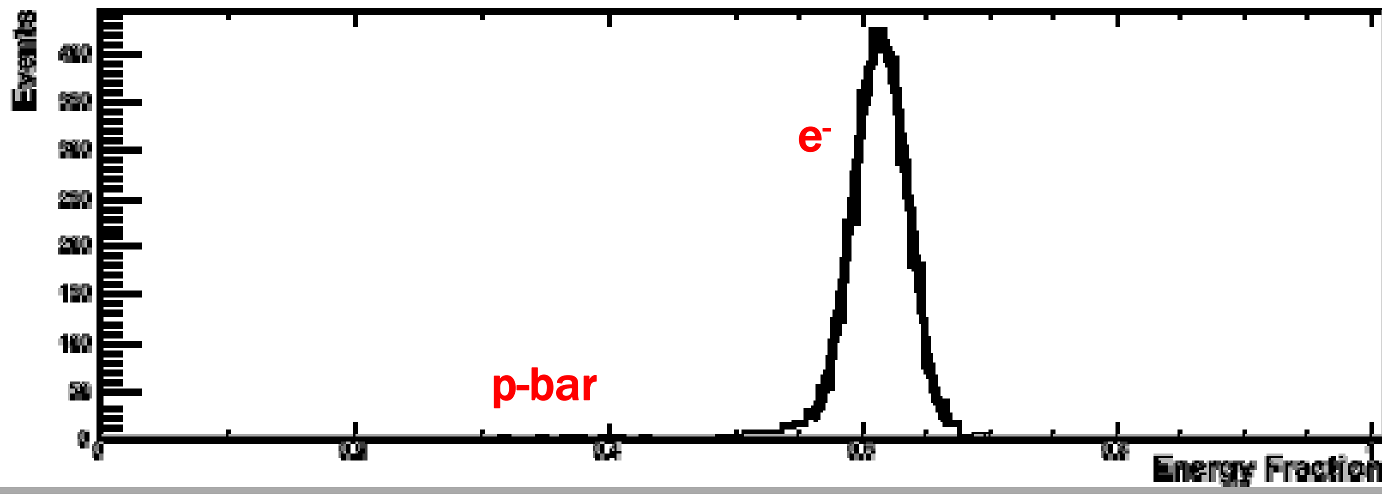
Fraction of charge released along the calorimeter track

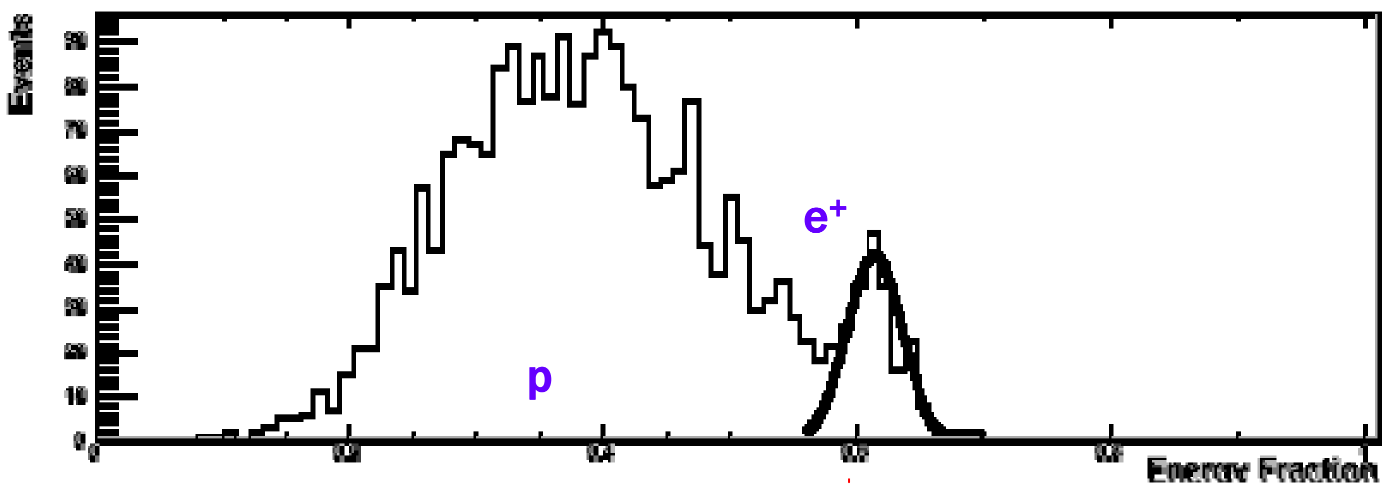
Constrains on:

- Energy momentum match

Rigidity: 20-30 GV

Positron selection with calorimeter





Fraction of charge released along the calorimeter track

Constrains on:

- Energy momentum match
- Shower starting-point
- Longitudinal profile

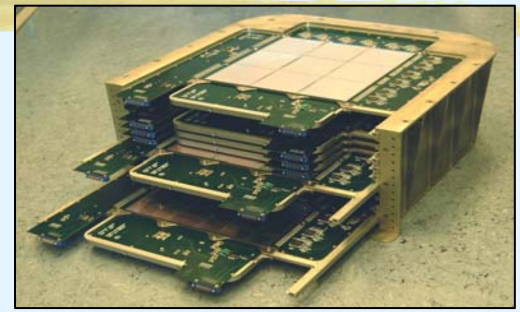
Cross check:

- Simulation
- Tracker dE/dX
- Neutron Detector

Rigidity: 20-30 GV

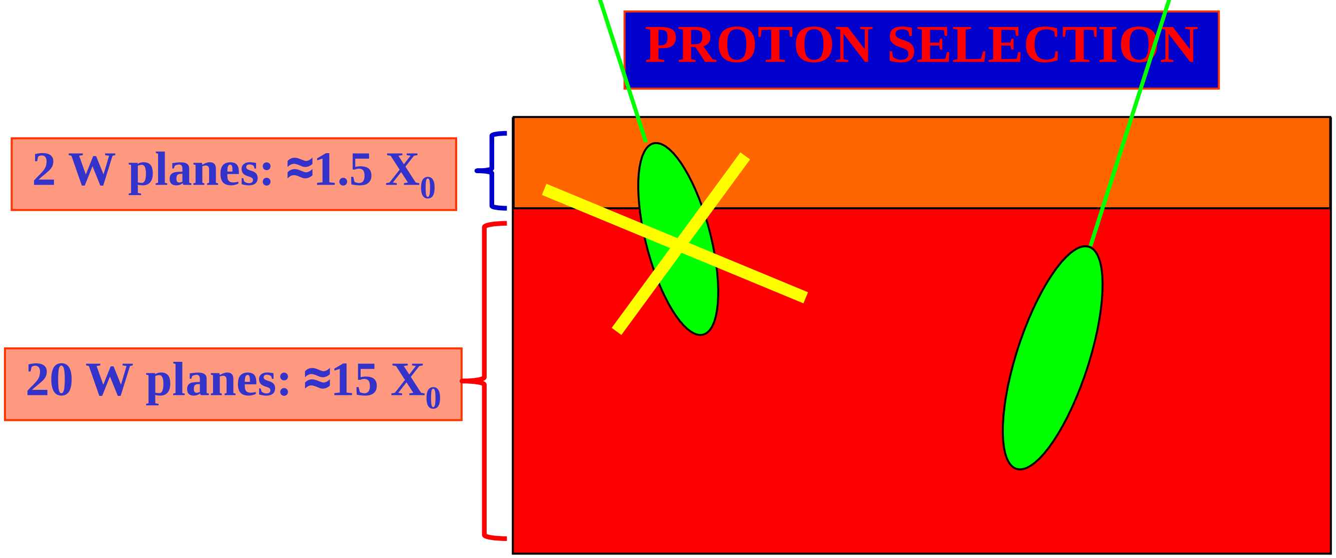
The “pre-sampler” method

The electromagnetic calorimeter



Characteristics:

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



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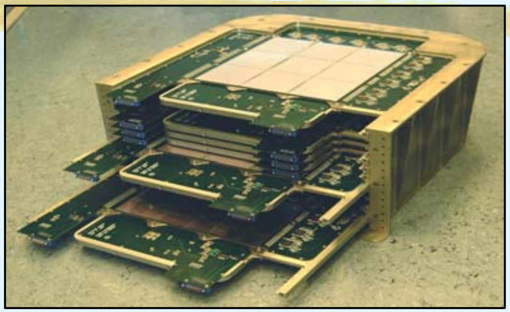

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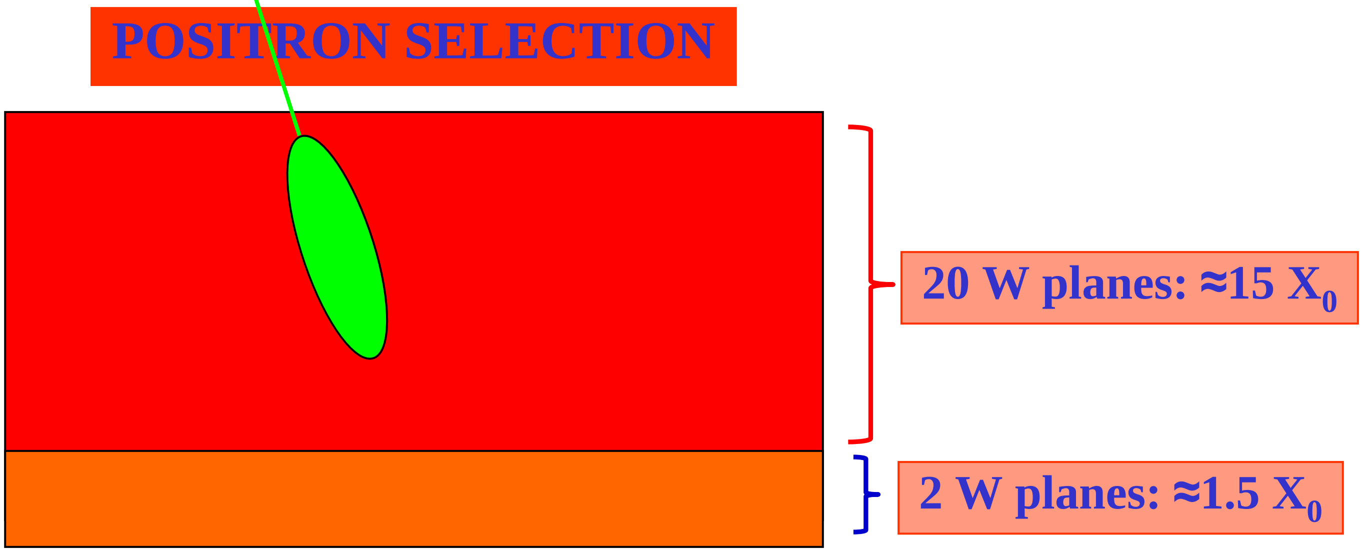
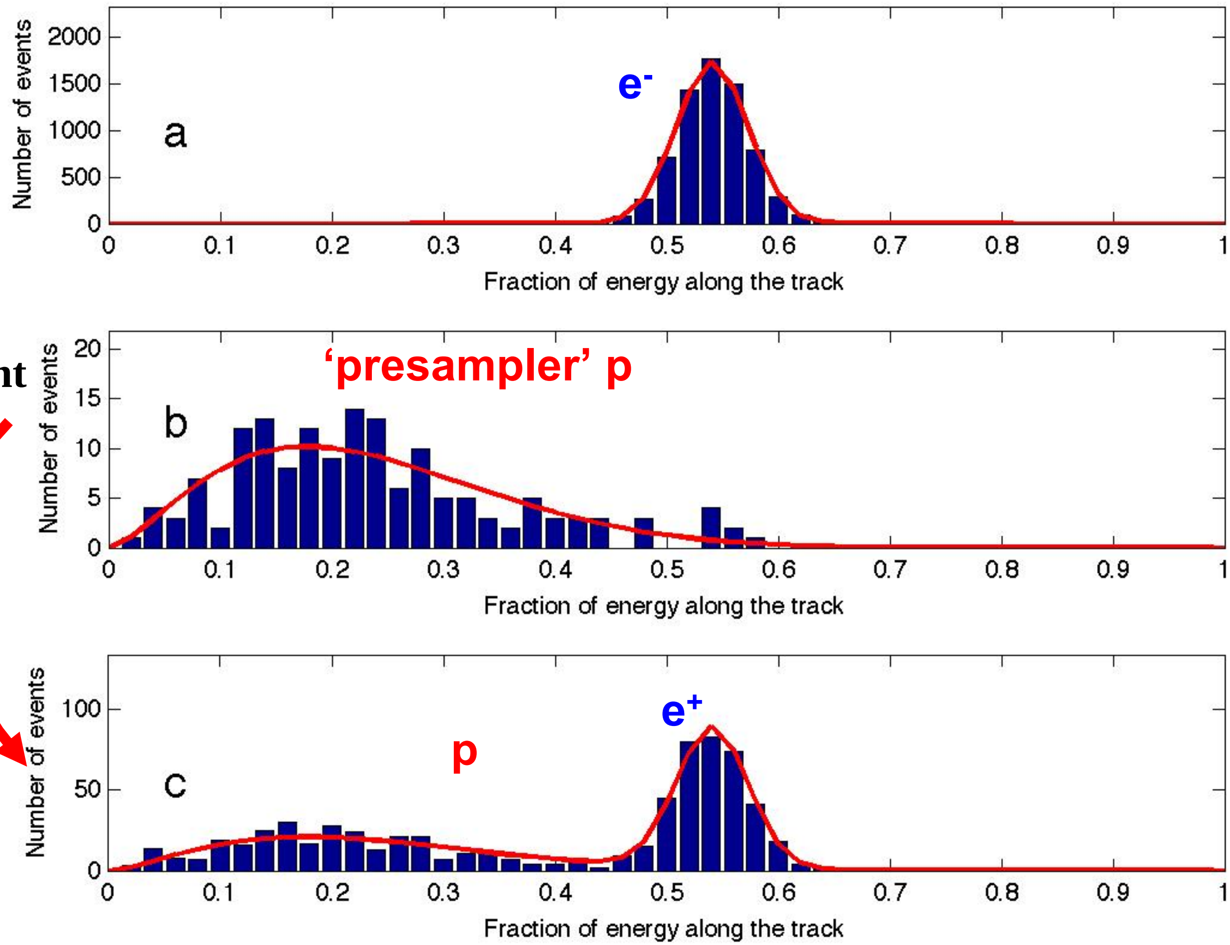


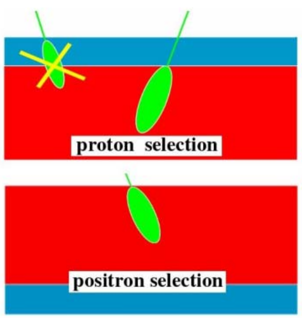
e^+ background estimation from data

Fraction of charge released along the calorimeter track

Constrains on:

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

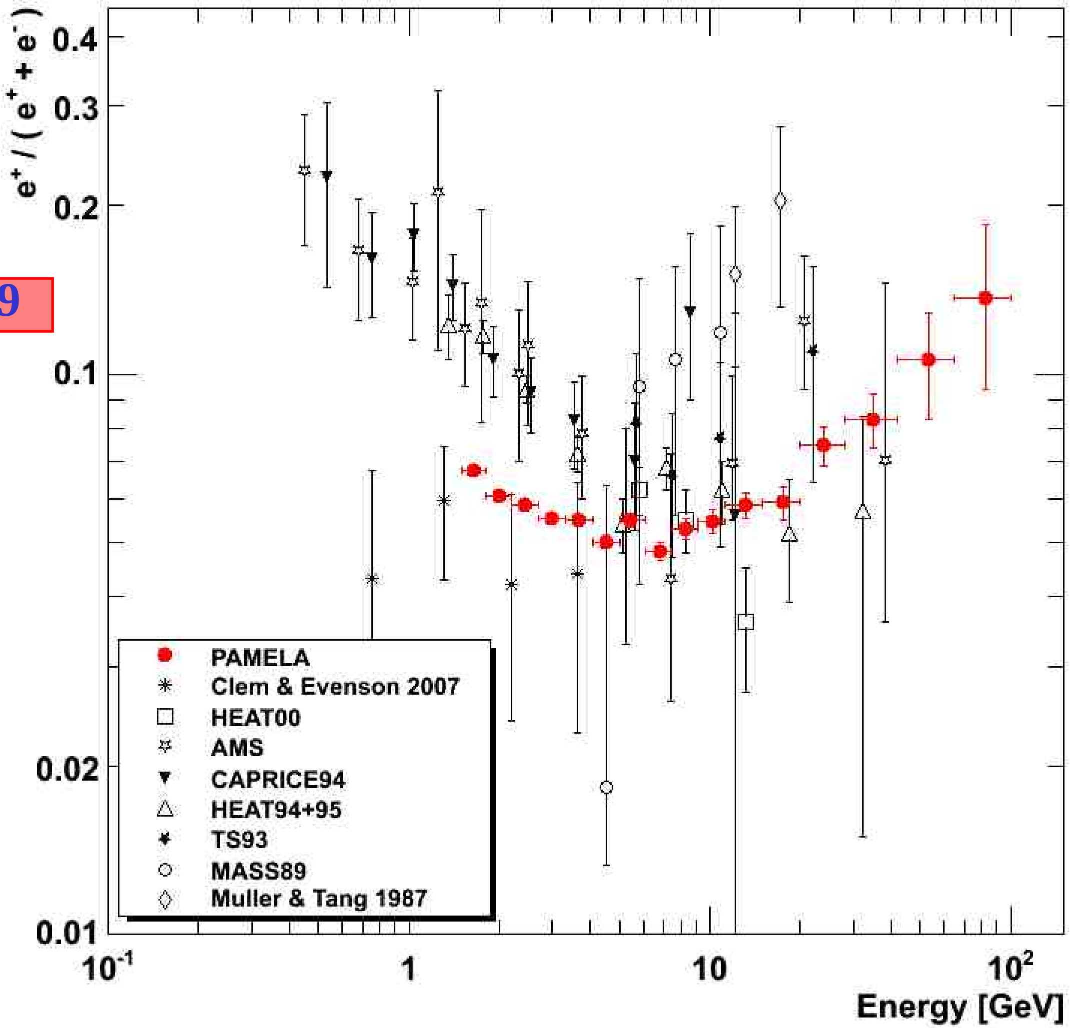




Rigidity: 20-28 GV

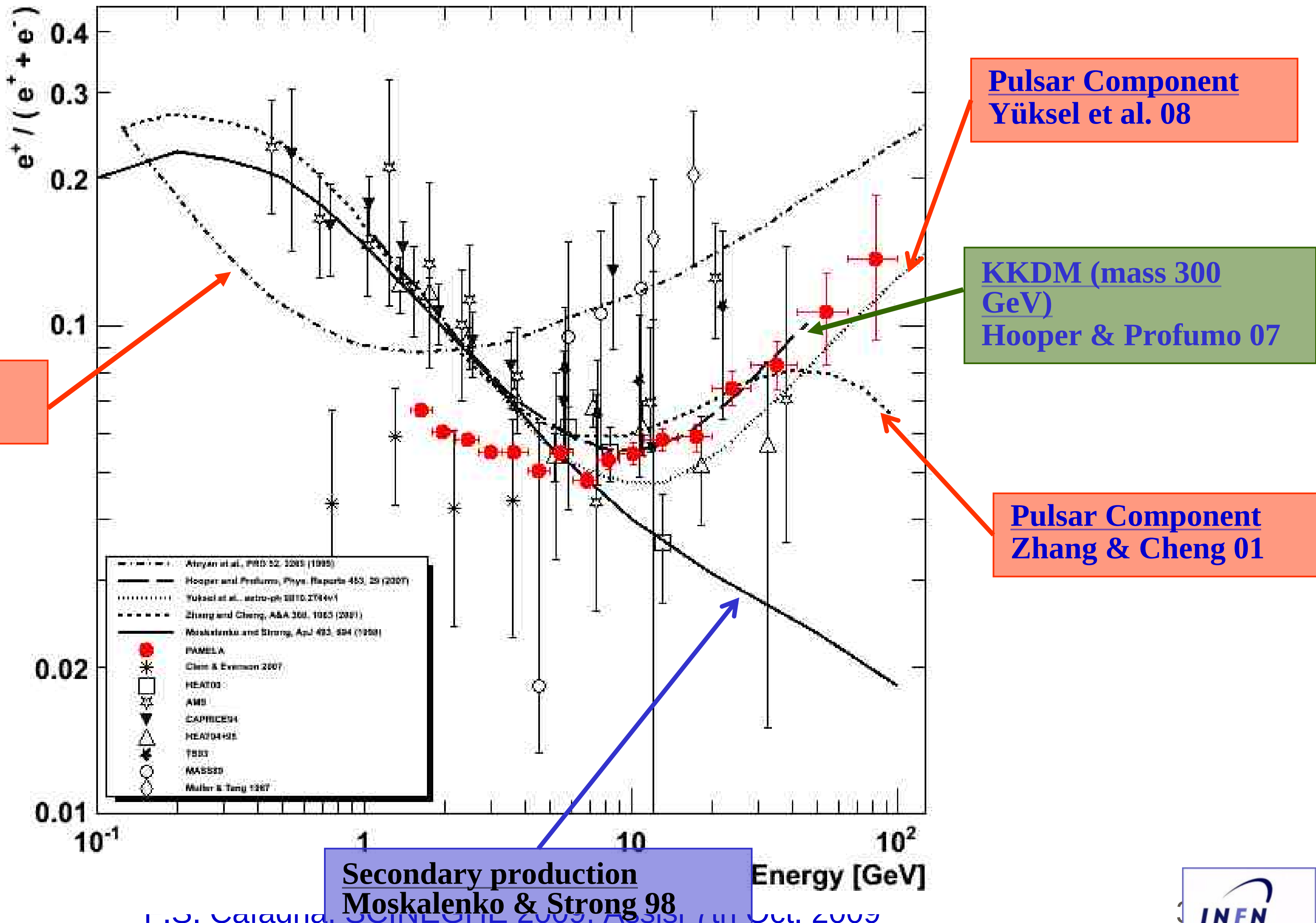
Positron to All Electron Fraction

Nature 458, 697, 2009

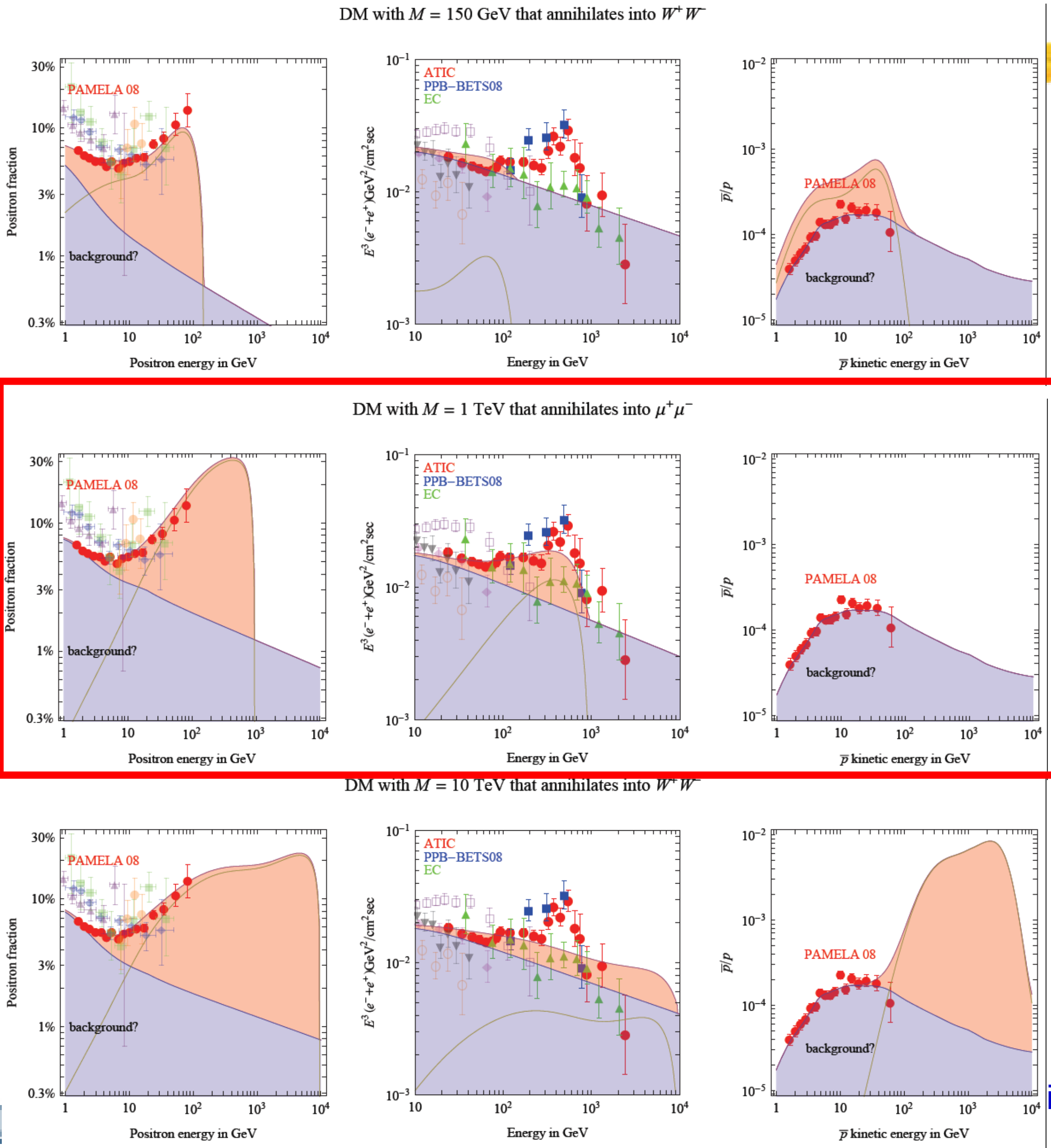


End 2007:
~10 000 e^+ >1.5GV
~2 000 e+> 5 GeV

Positron to Electron Fraction



DM ?

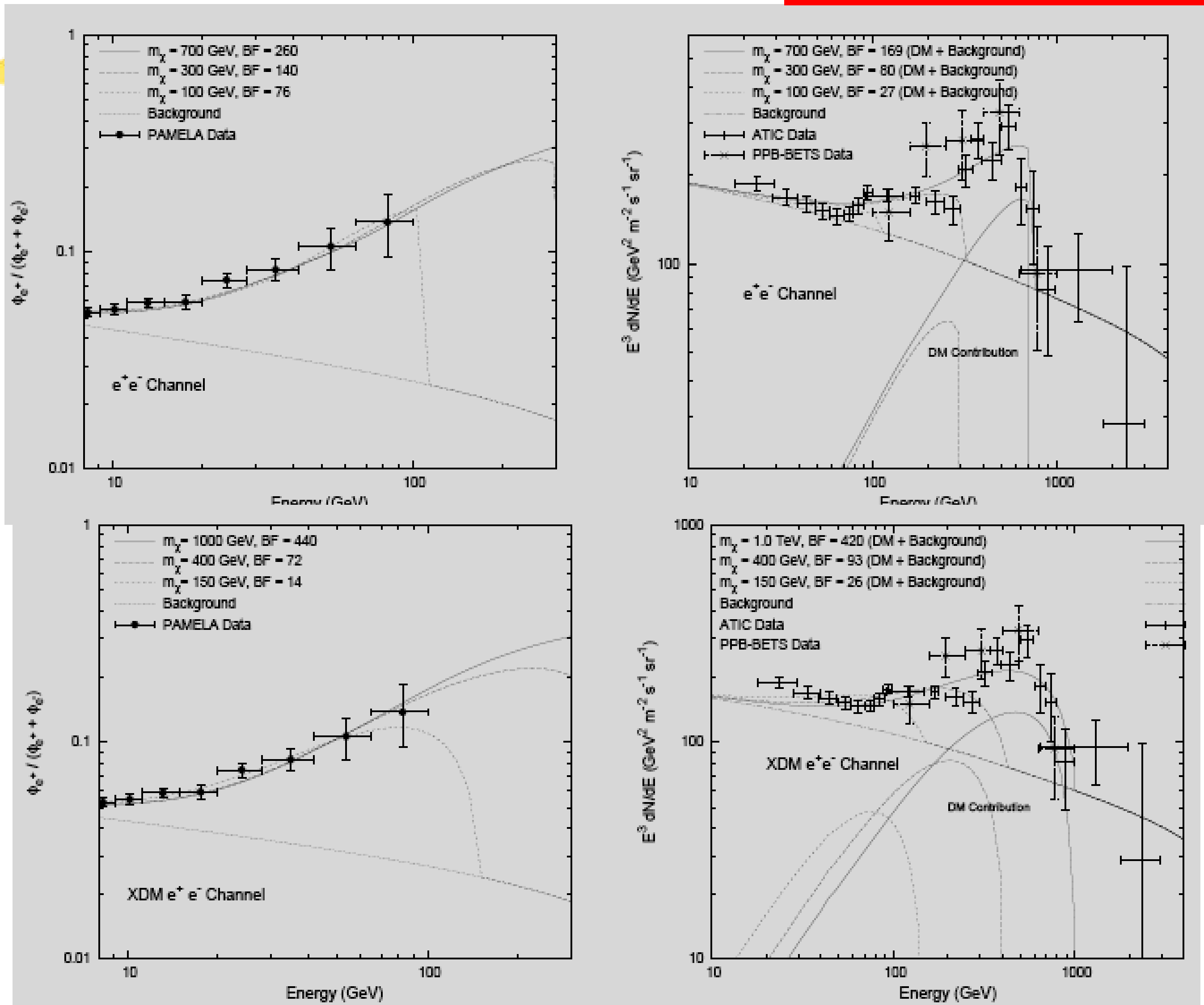


- PAMELA ability of measuring both proton and electron charge ration, make it possible to put several constrains to the models

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

DM ?

I. Cholis et al. arXiv:0811.3641v1

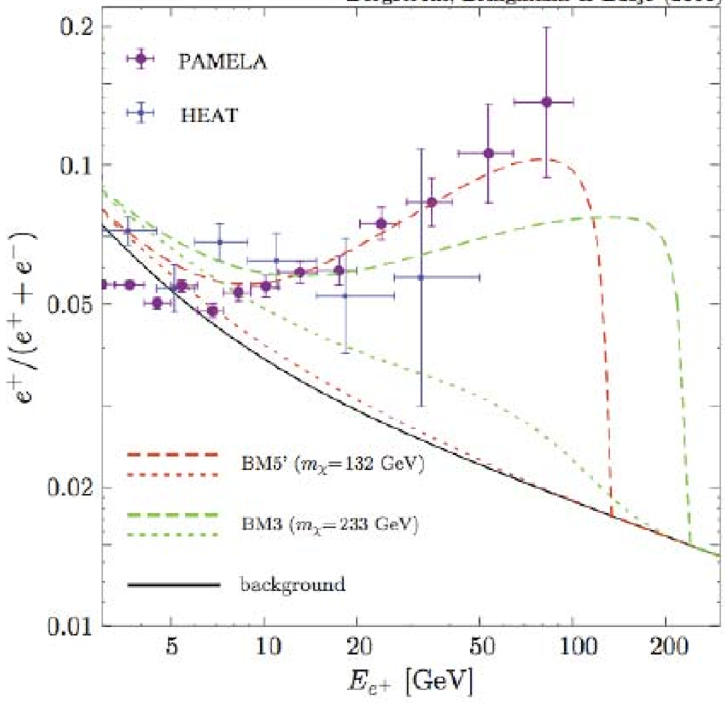


- Propose a new light boson ($m_\Phi \leq$ GeV), such that $\chi\chi \rightarrow \Phi\Phi$; $\Phi \rightarrow e^+e^-$, $\mu^+\mu^-$, ...
- Light boson, so decays to antiprotons are kinematically suppressed

Example: Dark Matter

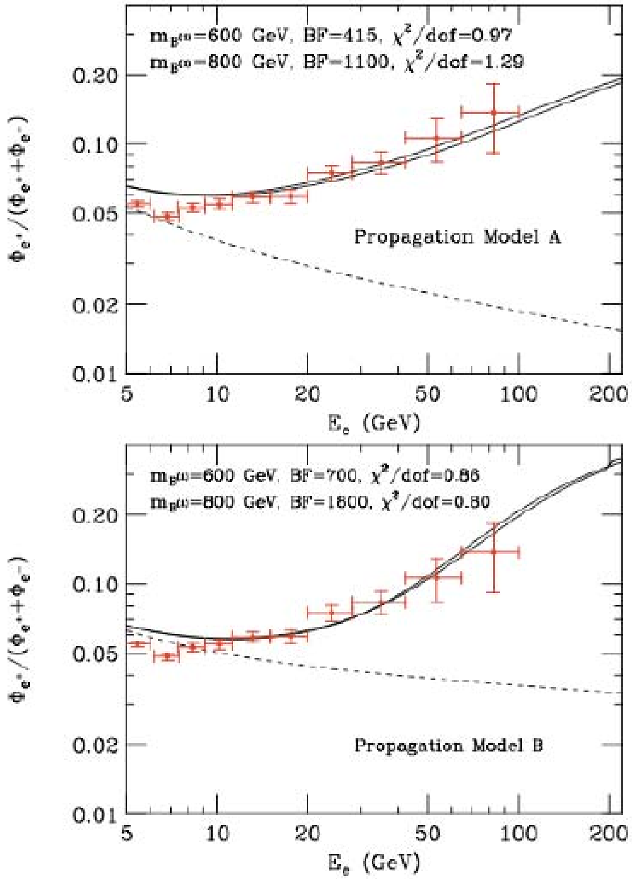
arXiv:0808.3725

Bergström, Bringmann & Edsjö (2008)



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

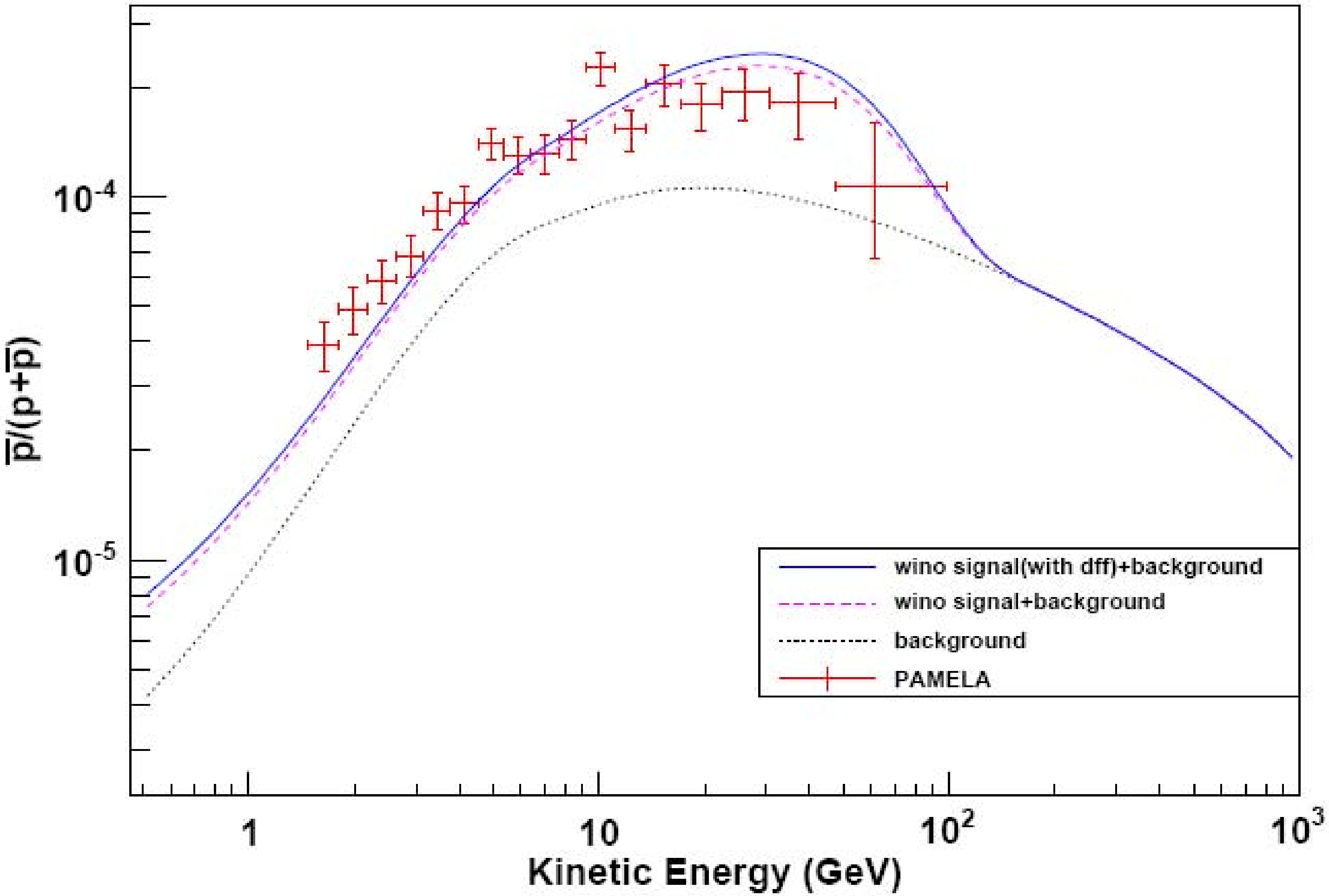
Hooper and Zurek
arXiv:0902.0593v1



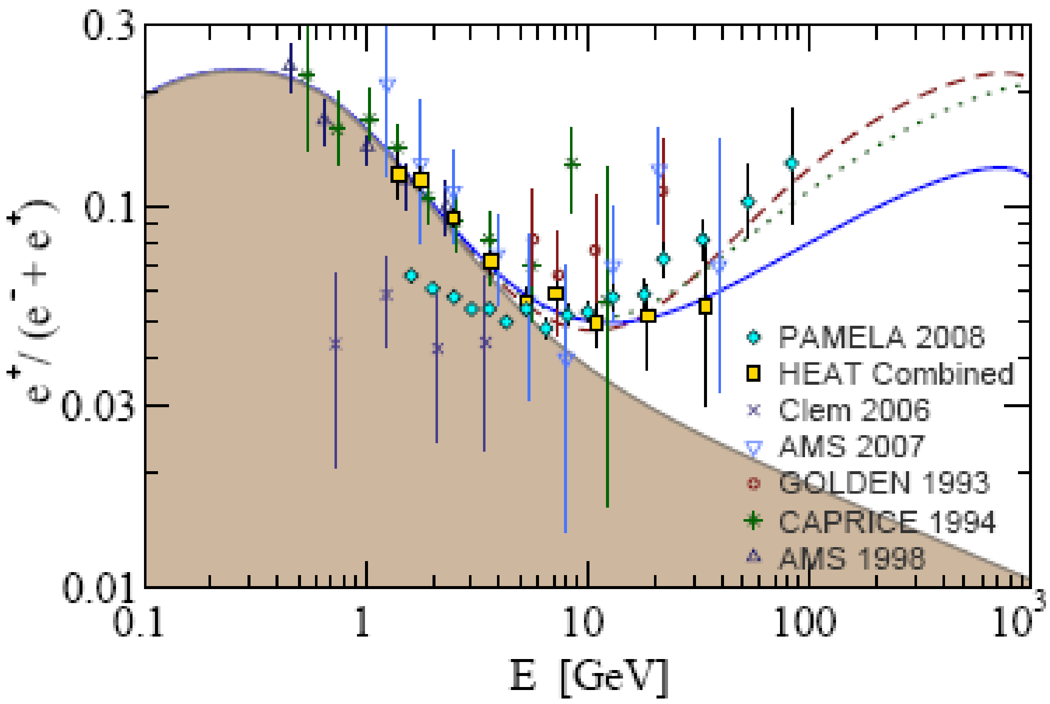
Kaluza-Klein dark matter

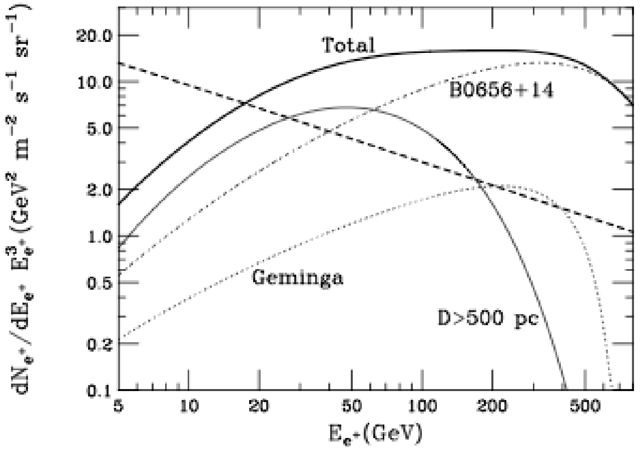
Wino Dark Matter in a non-thermal Universe

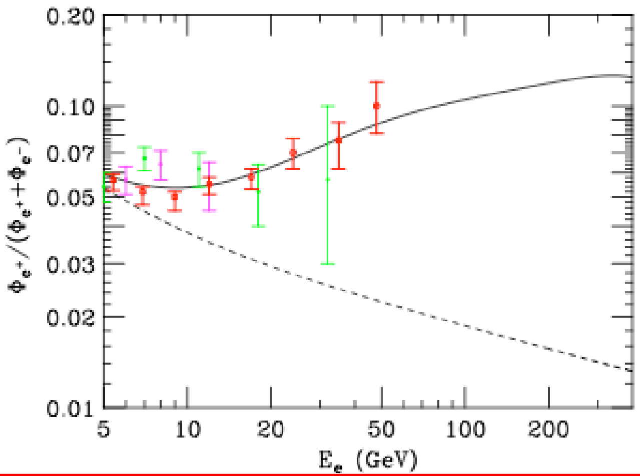
G. Kane, R. Lu, and S. Watson
arXiv:0906.4765v3 [astro-ph]



Positrons from Pulsar







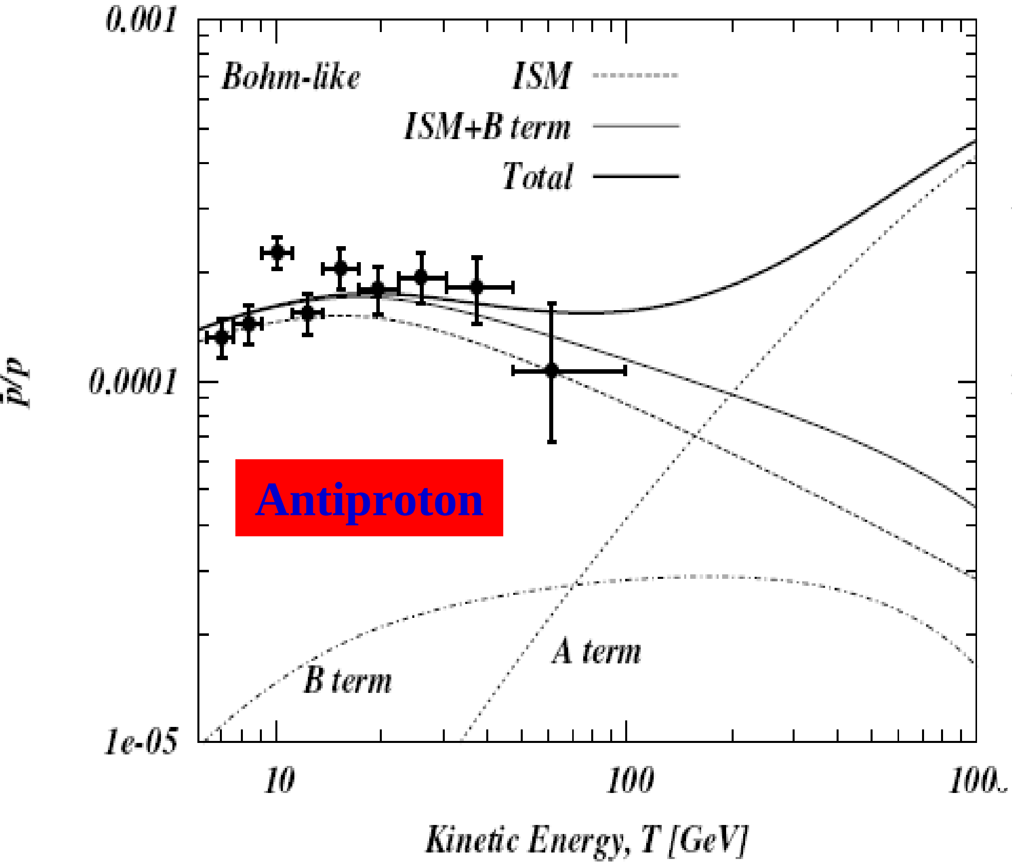
H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar

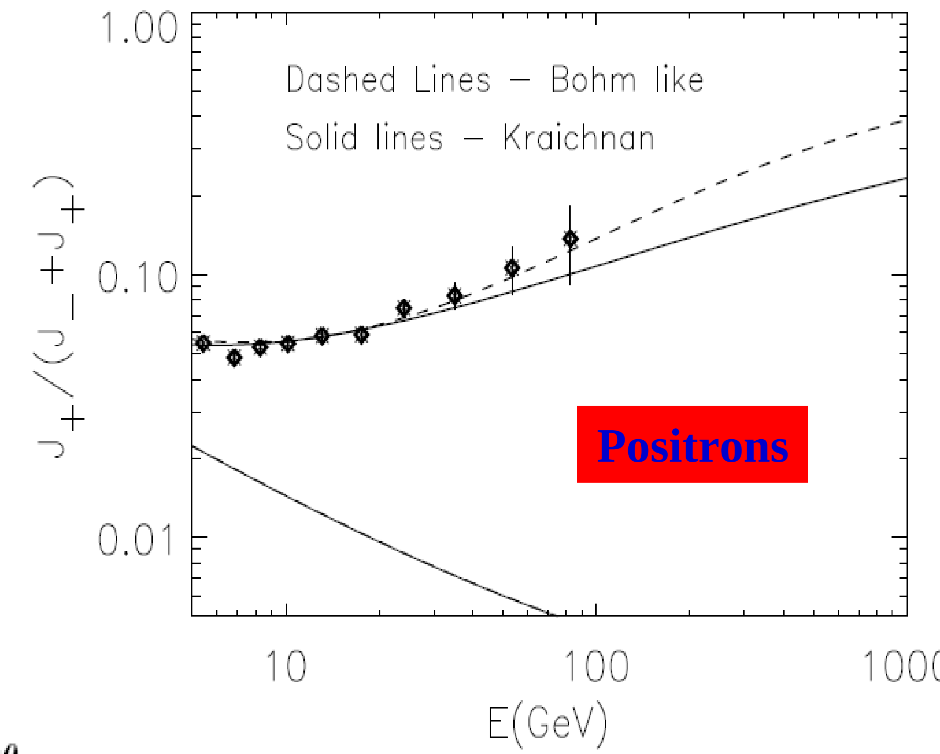
Diffuse mature & nearby young pulsars Hooper, Blasi, and Serpico arXiv:0810.1527

Antiprotons & positrons from old SNR's

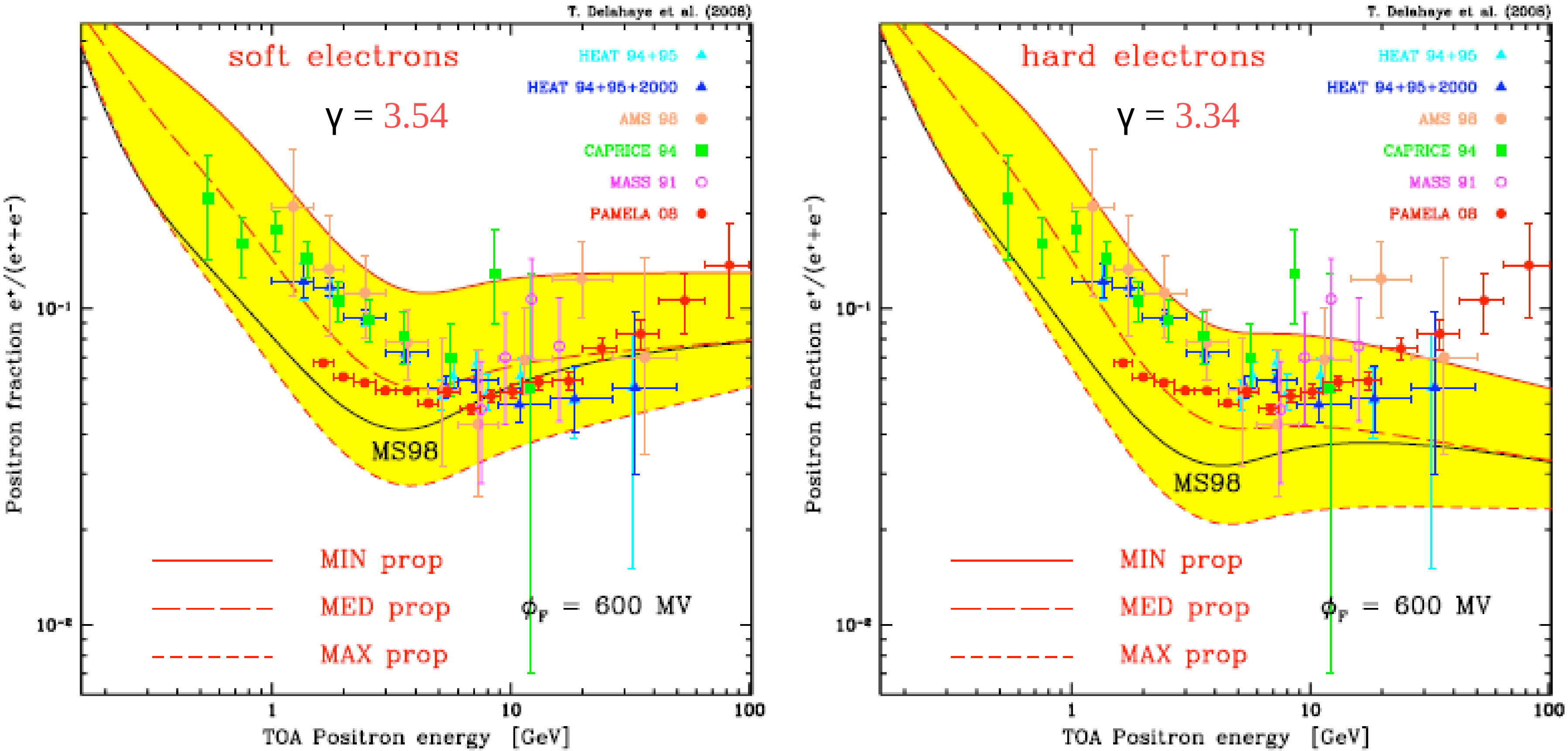
P.Blasi Astro-ph.HE 0904.0871

P. Blasi 0903.2794





Standard Positron Fraction
Theoretical Uncertainties



T. Delahaye et al., arXiv: 0809.5268v3

Conclusions

- PAMELA is a permanent cosmic ray space laboratory (a three year mission extension has been approved).
- PAMELA is the first space experiment which is measuring the antiproton and positron cosmic-ray components to the high energies (10^2GeV) with an unprecedented statistical precision.
- Antiparticle fluxes are an exciting tools to study DM characteristics. Stay tuned for fluxes … THANKS !!!!