

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

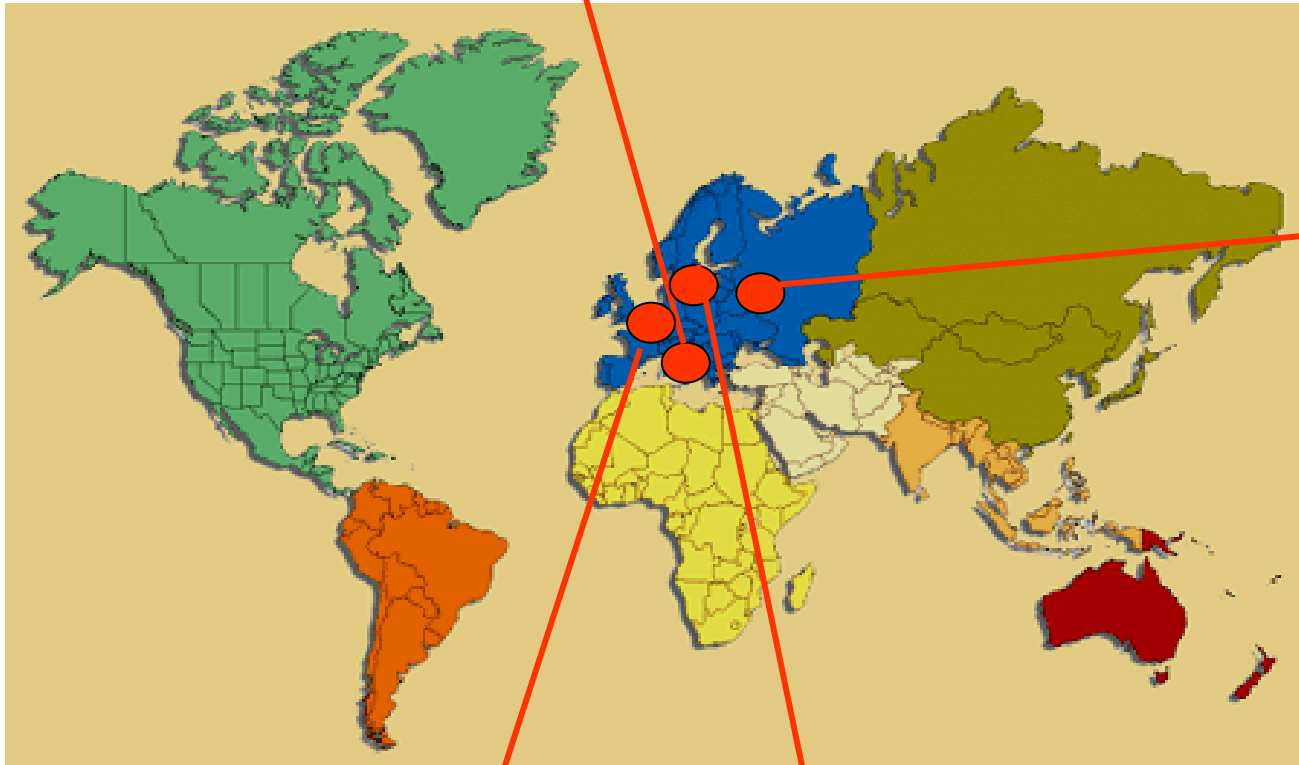


F.S. Cafagna, INFN Bari  
on behalf of the PAMELA  
Collaboration

# PAMELA Collaboration

**Italy:**

Bari	Florence	Frascati	Naples	Rome	Trieste	CNR, Florence



**Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics**

**Russia:**

Moscow St. Petersburg

**Germany:**

F.S. Car Siegen

**Sweden:**

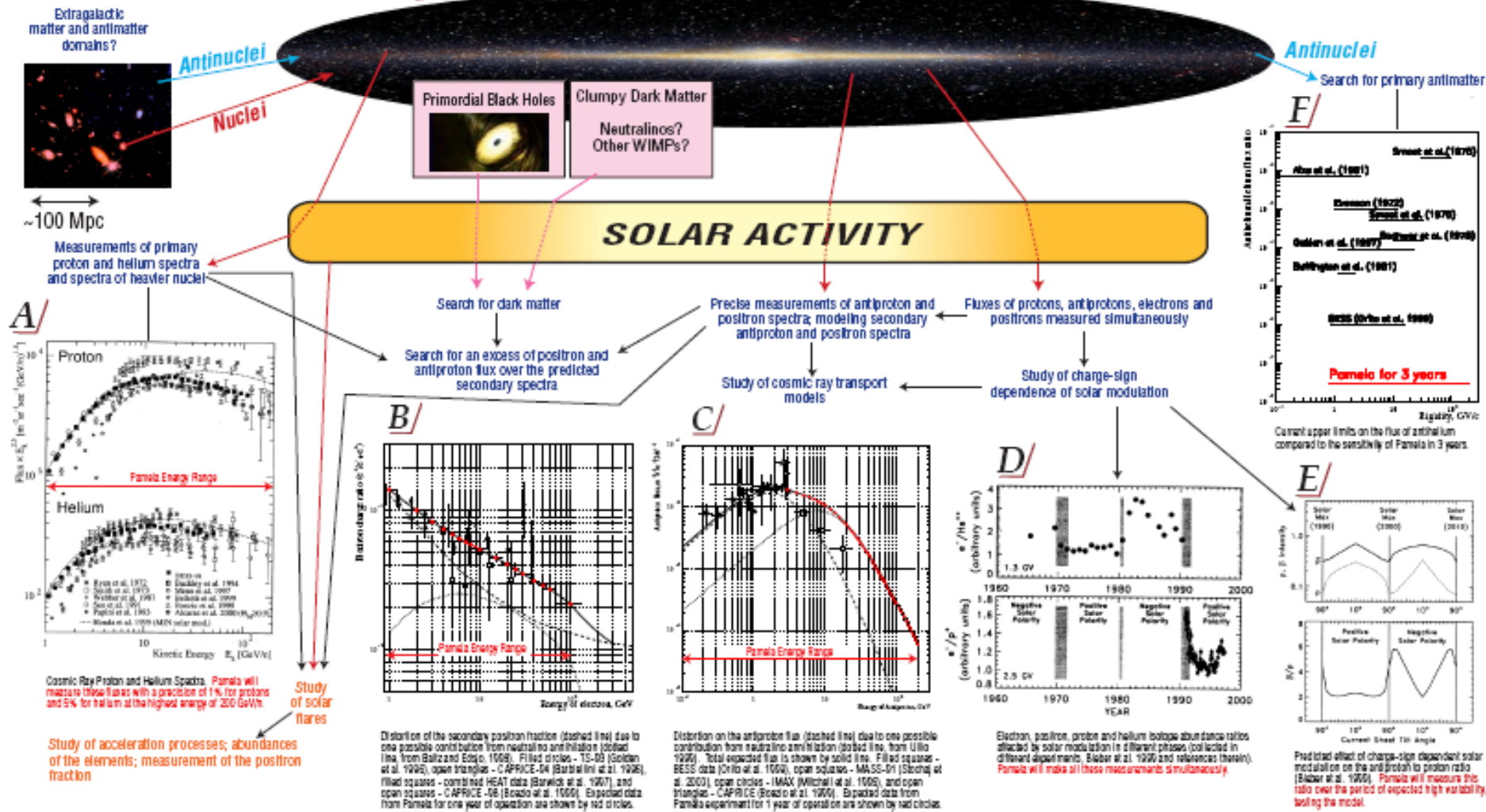
KTH, Stockholm



# PAMELA Science

## PAMELA as a Space Observatory @ 1AU

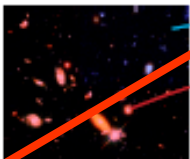
### EXOTIC MATTER AND COSMIC RAYS



# PAMELA Science

Preliminary

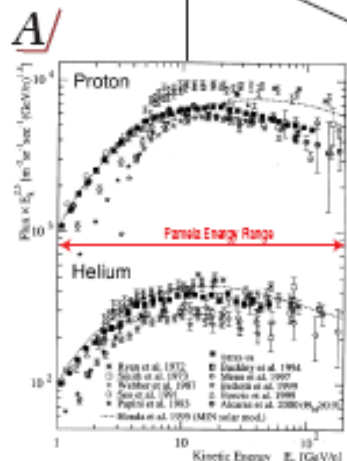
Extragalactic matter and antimatter domains?



Antinuclei  
Nuclei

100 Mpc

Measurements of primary proton and helium spectra and spectra of heavier nuclei



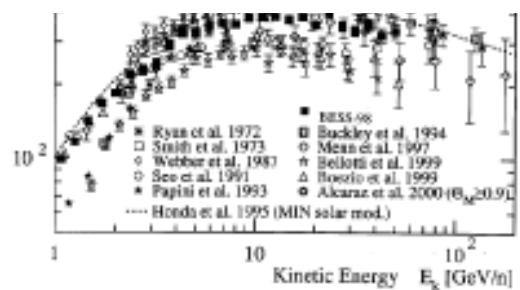
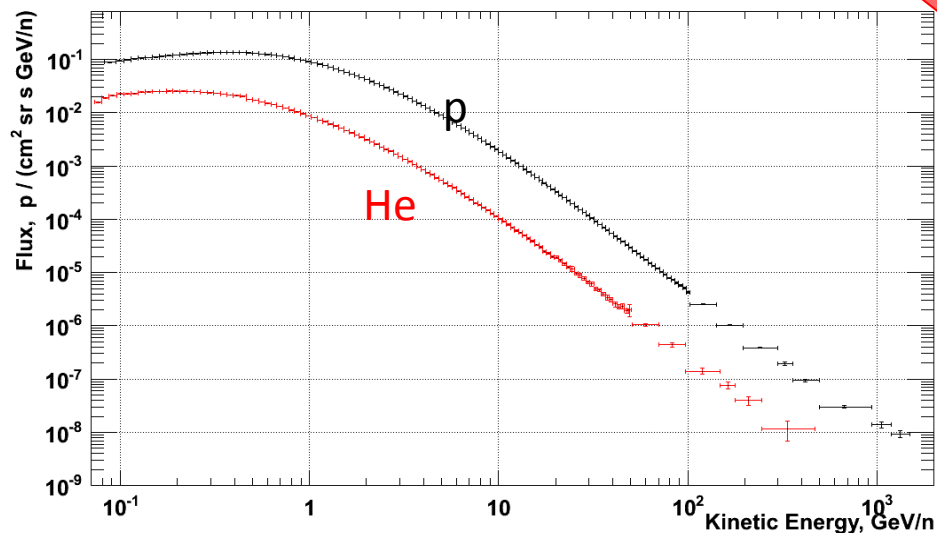
Study of solar flares

Study of acceleration processes; abundances of the elements; measurement of the positron fraction

Search antip



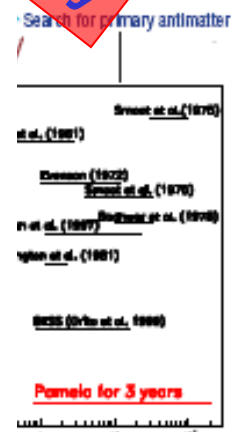
Distortion of the one possible con...  
filled squares - C...  
open squares - C...



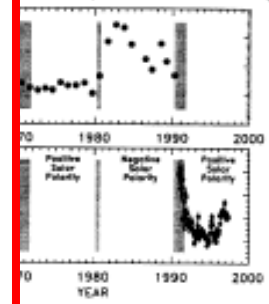
Cosmic Ray Proton and Helium Spectra. PAMELA will measure these fluxes with a precision of 1% for protons and 5% for helium at the highest energy of 200 GeV/n.

Study of solar flares

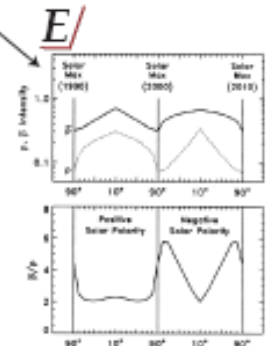
Study of acceleration processes; abundances of the elements; measurement of the positron fraction



Current upper limits on the flux of antihelium compared to the sensitivity of PAMELA in 3 years.



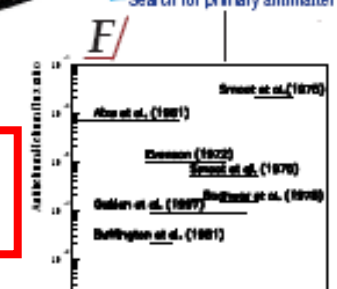
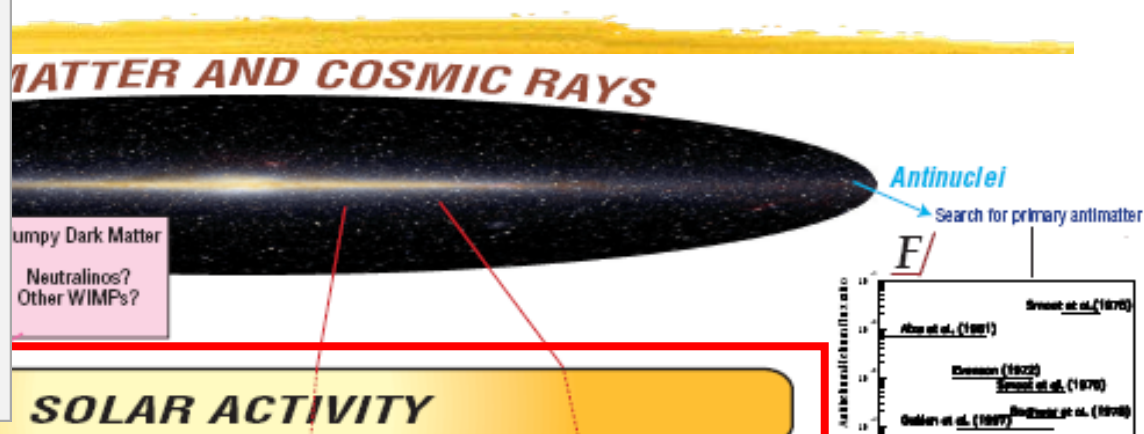
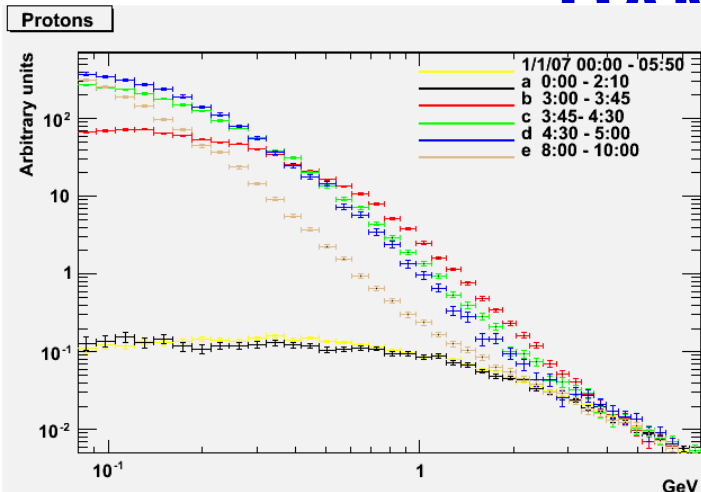
Solar proton and helium isotopic abundance ratios for modulation in different phases (collected in panels, Bladler et al. 1996 and references therein). All these measurements simultaneously.



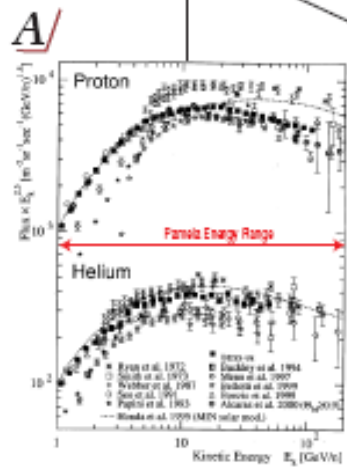
Predicted effect of charge-sign dependent solar modulation on the antiproton to proton ratio (Bladler et al. 1996). PAMELA will measure this ratio over the period of expected high variability, testing the model.



# PAMELA Science



measurements of primary proton and helium spectra and spectra of heavier nuclei

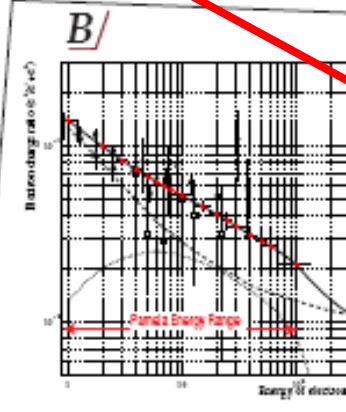


Cosmic Ray Proton and Helium Spectra. PAMELA will measure these fluxes with a precision of 1% for protons and 5% for helium at the highest energy of 200 GeV.

Study of acceleration processes; abundances of the elements; measurement of the positron fraction

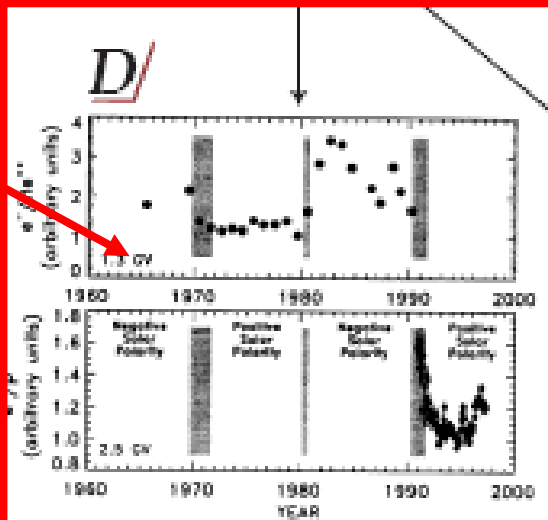
Search for dark matter

Search for an excess of positron and antiproton flux over the predicted secondary spectra



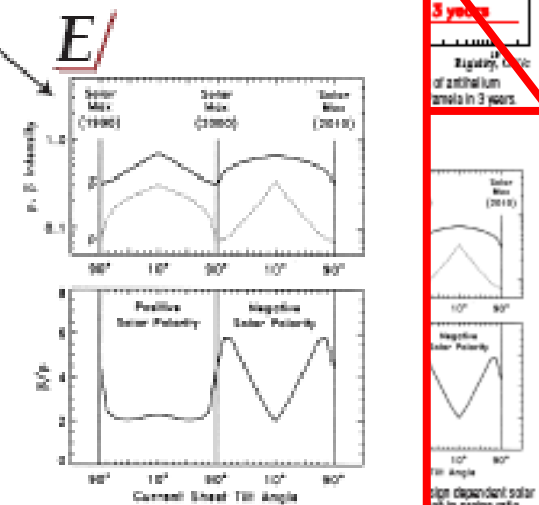
Distribution of the secondary positron fraction (dashed line) and one possible contribution from neutralino annihilation (solid line). From Balzano & Esposito, 1988. Filled circles - 15-09 (G. et al. 1996), open triangles - CAPRICE-04 (Barbiellini et al. 2007), filled squares - combined HEAT data (Barwick et al. 1997), open squares - CAPRICE-98 (Esposito et al. 1999). Expectations from PAMELA for one year of operation are shown by red dots.

Precise measurements of antiproton and



Electron, positron, proton and helium isotope abundance ratios affected by solar modulation in different phases (collected in different segments). Elsässer et al. 1999 and references therein. PAMELA will make all these measurements simultaneously.

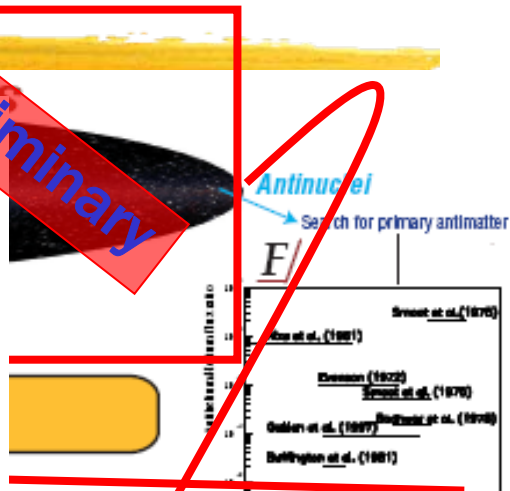
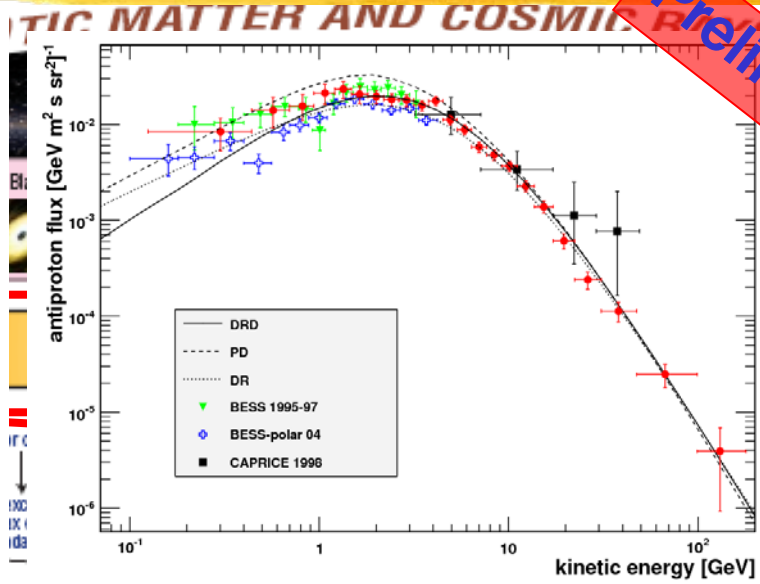
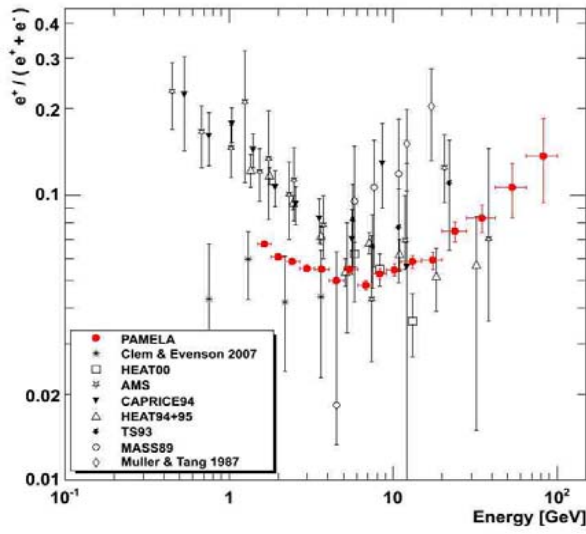
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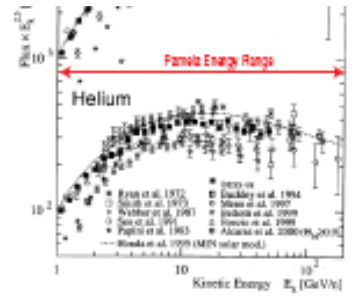
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# PAMELA Science

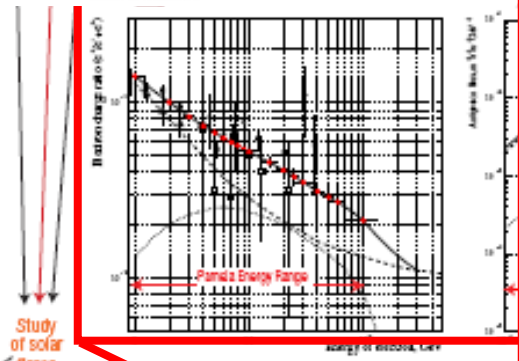
Preliminary



Precise measurements of antiproton and positron spectra; modeling secondary antiproton and positron spectra  
 Study of cosmic ray transport models



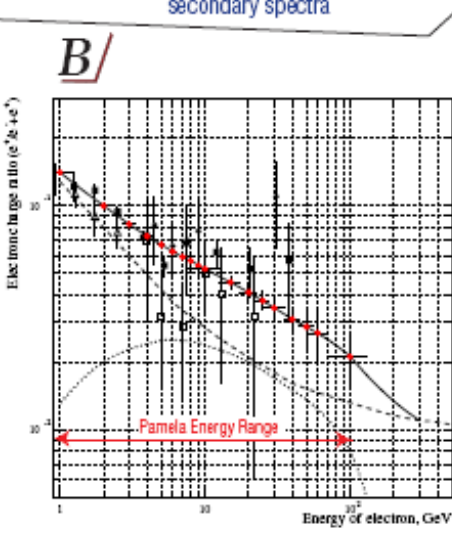
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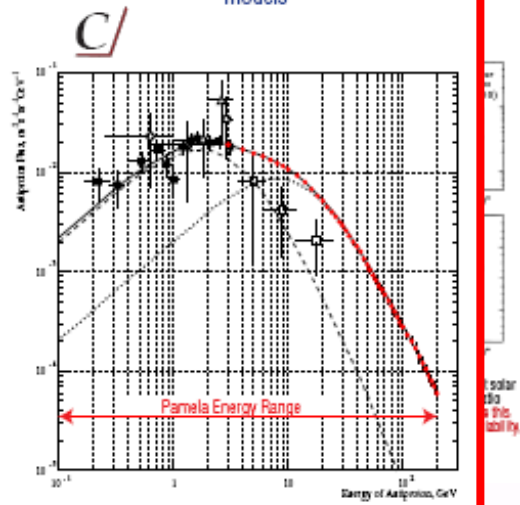
Study of solar flares

Study of acceleration processes; abundances of the elements; measurement of the positron fraction

Distribution of the secondary positron fraction (dashed line) due to one possible contribution from neutral to one ionization (solid line) from Balzard et al., 1968. Filled circles - TS-03 (Golden et al. 1998), open triangles - CAPRICE-04 (Barbiellini et al. 2006), filled squares - combined HEAT (Barbiellini et al. 1997) and open squares - CAPRICE-98 (Boccardi, 1999). Expected data from PAMELA for one year of operation are shown by red circles.

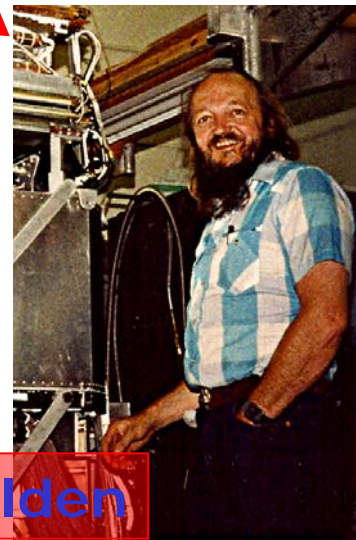
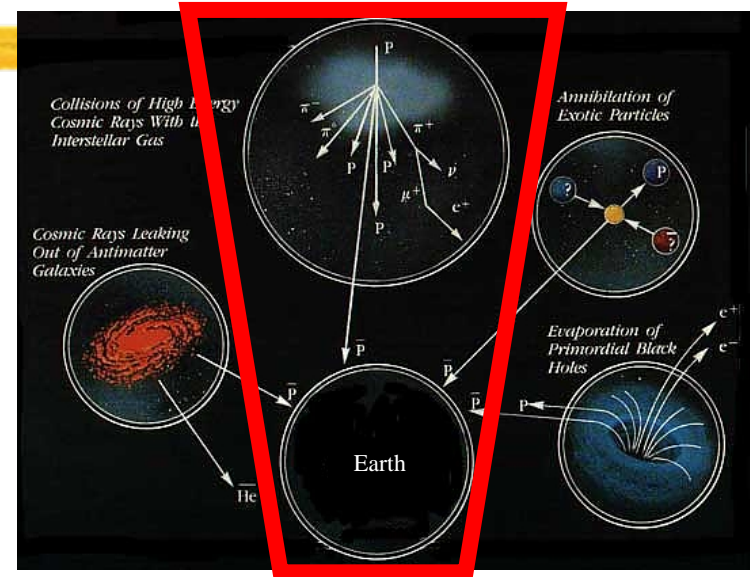
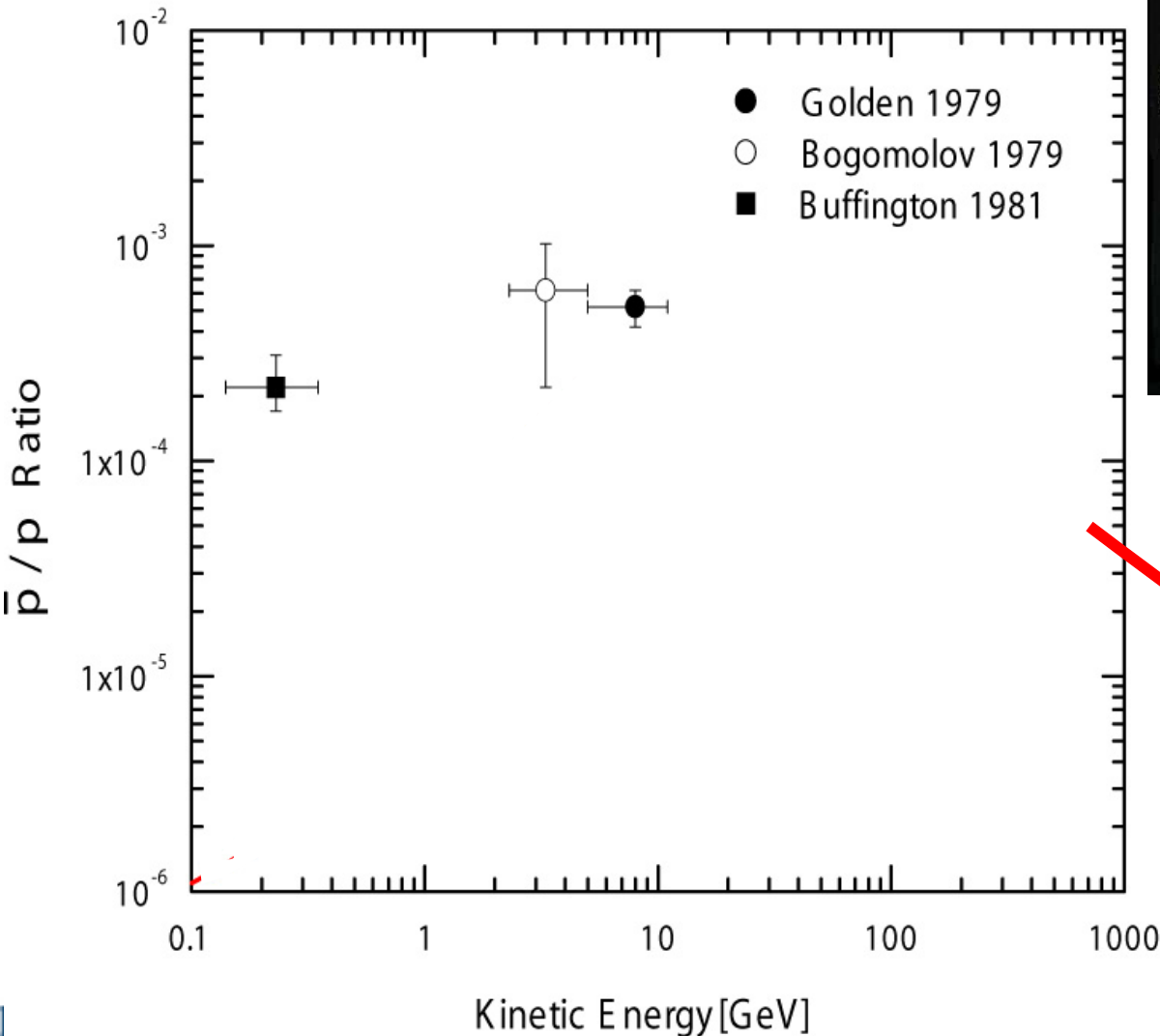


secondary spectra



F.S. Cafagna, SCINEGI

# Why Anti(particle)matter matters?

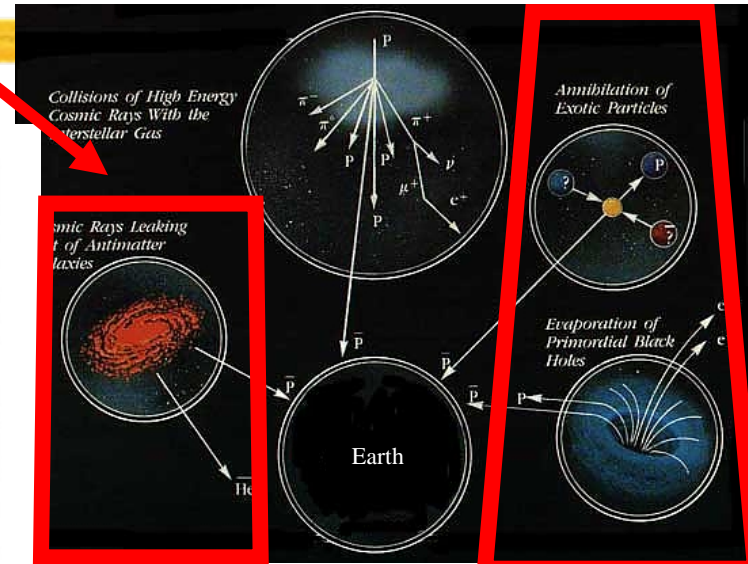
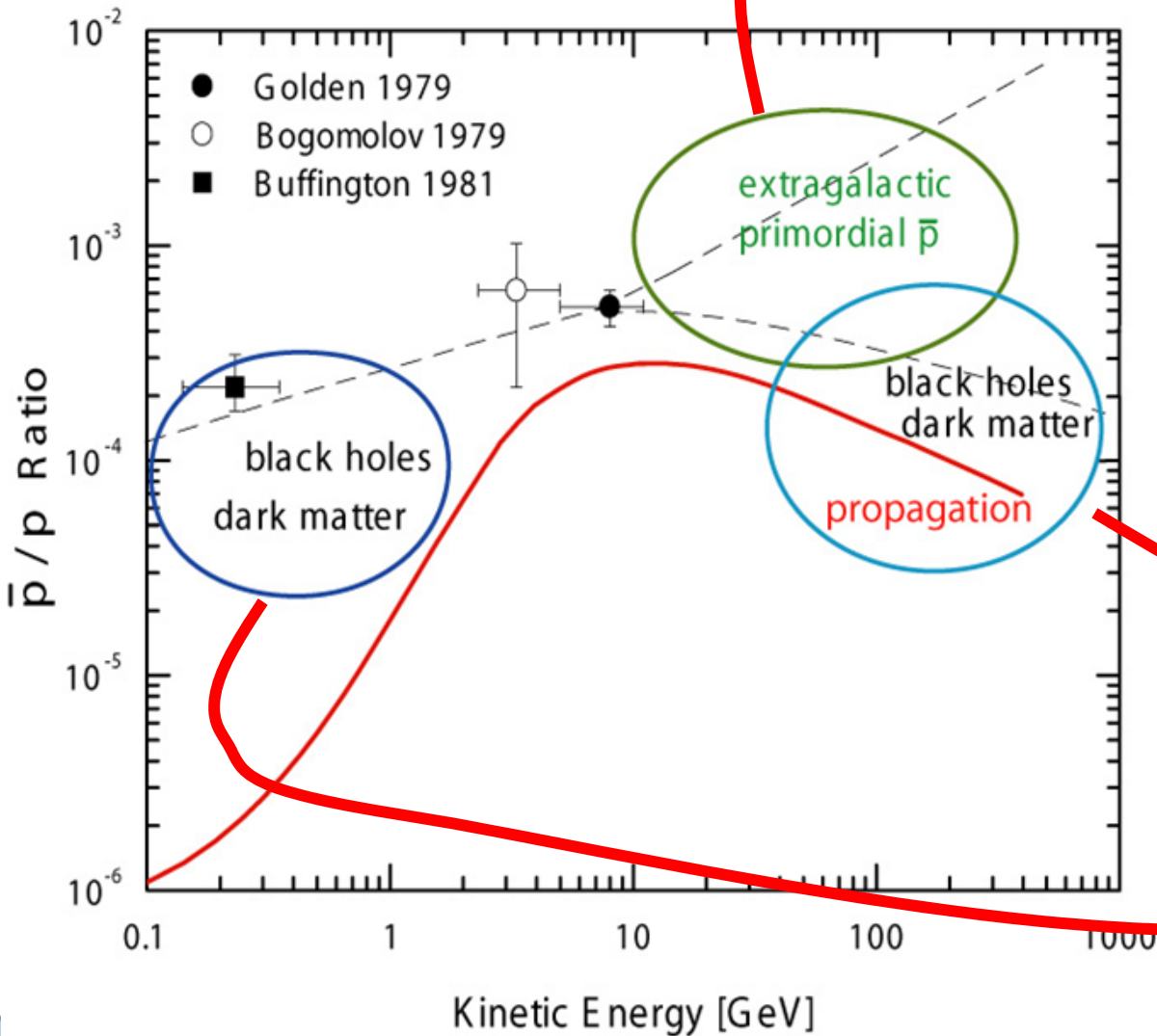


R.L. Golden

1 Oct. 2009



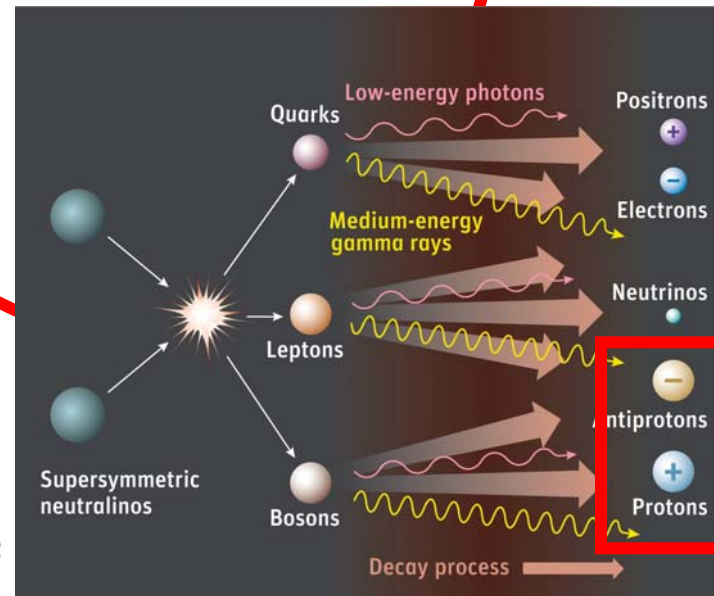
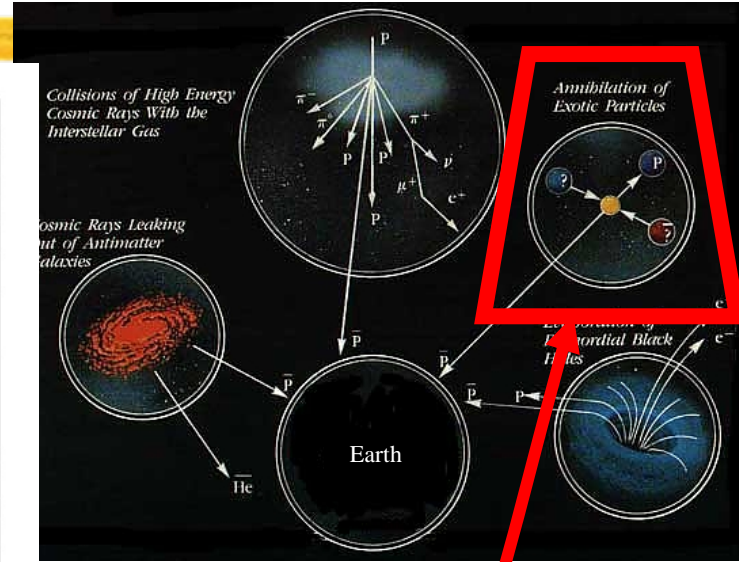
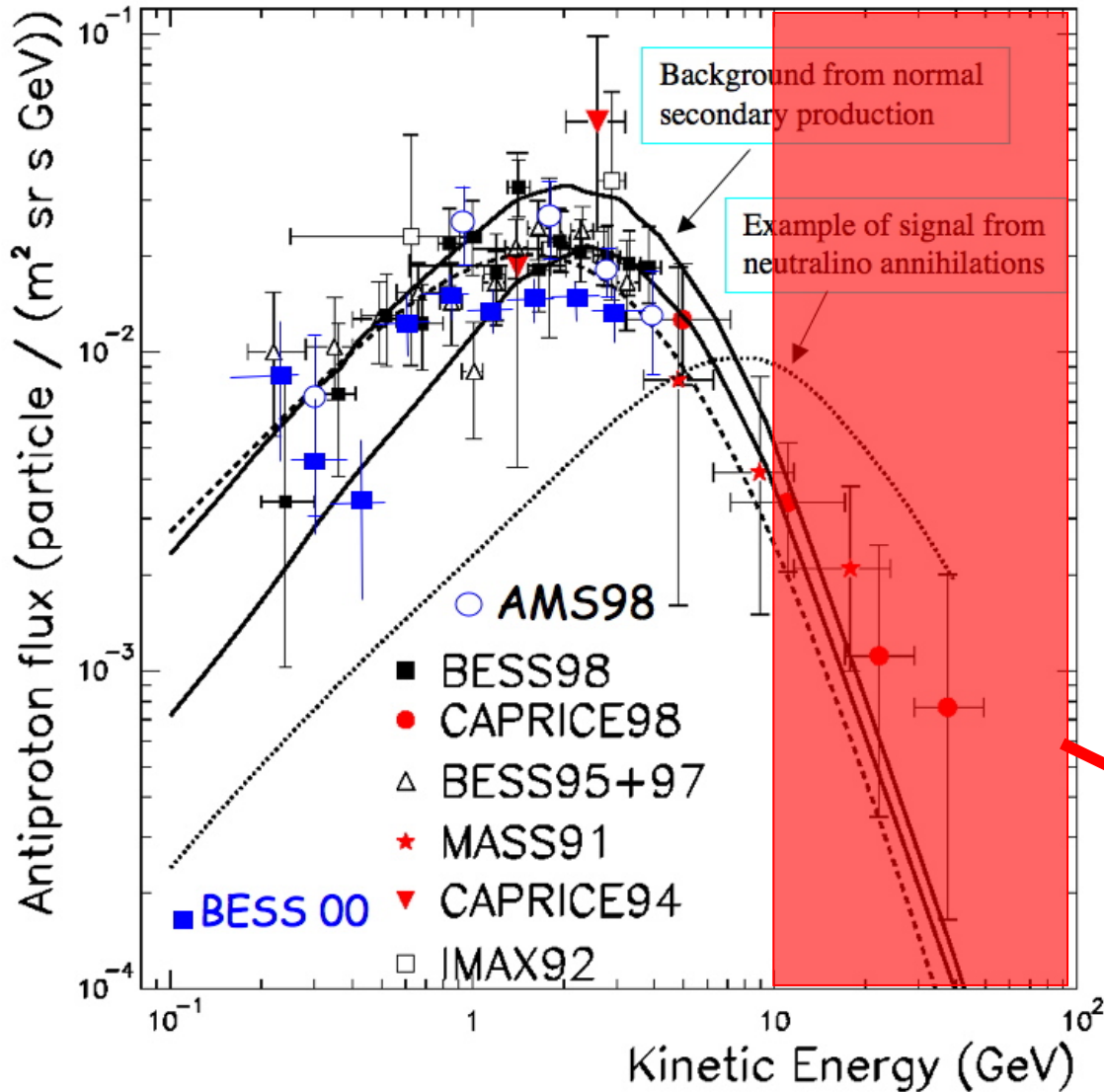
# Why Anti(particle)matter matters?



h Oct. 2009

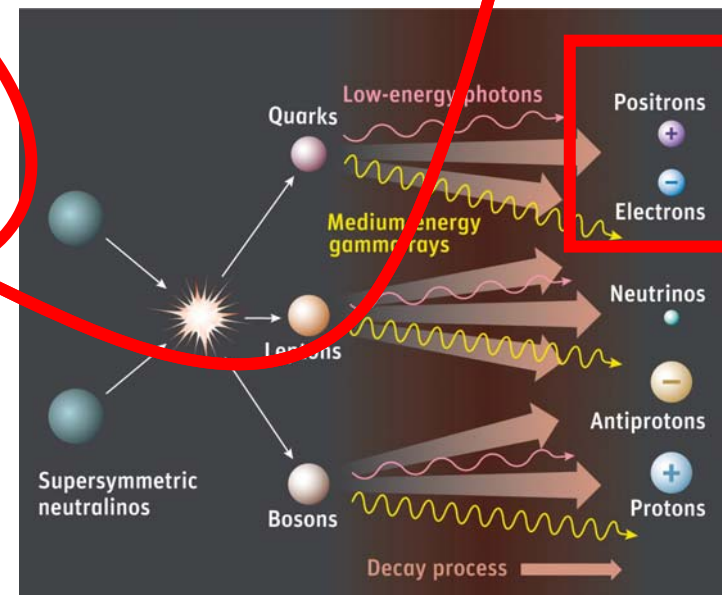
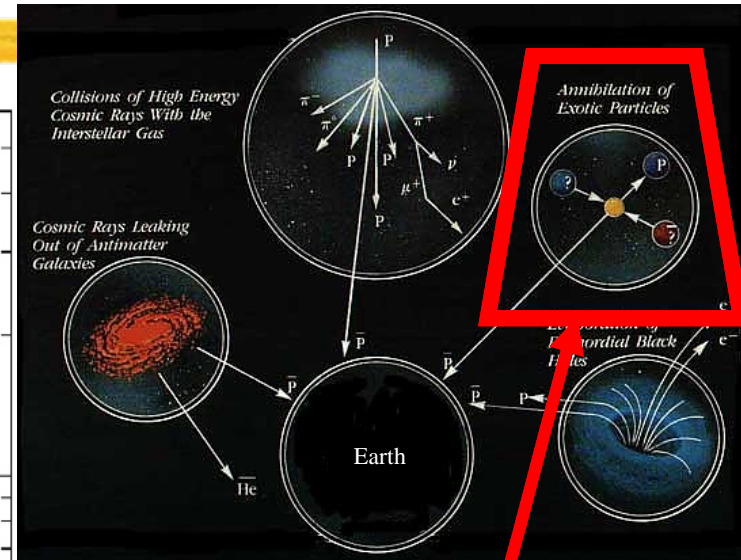
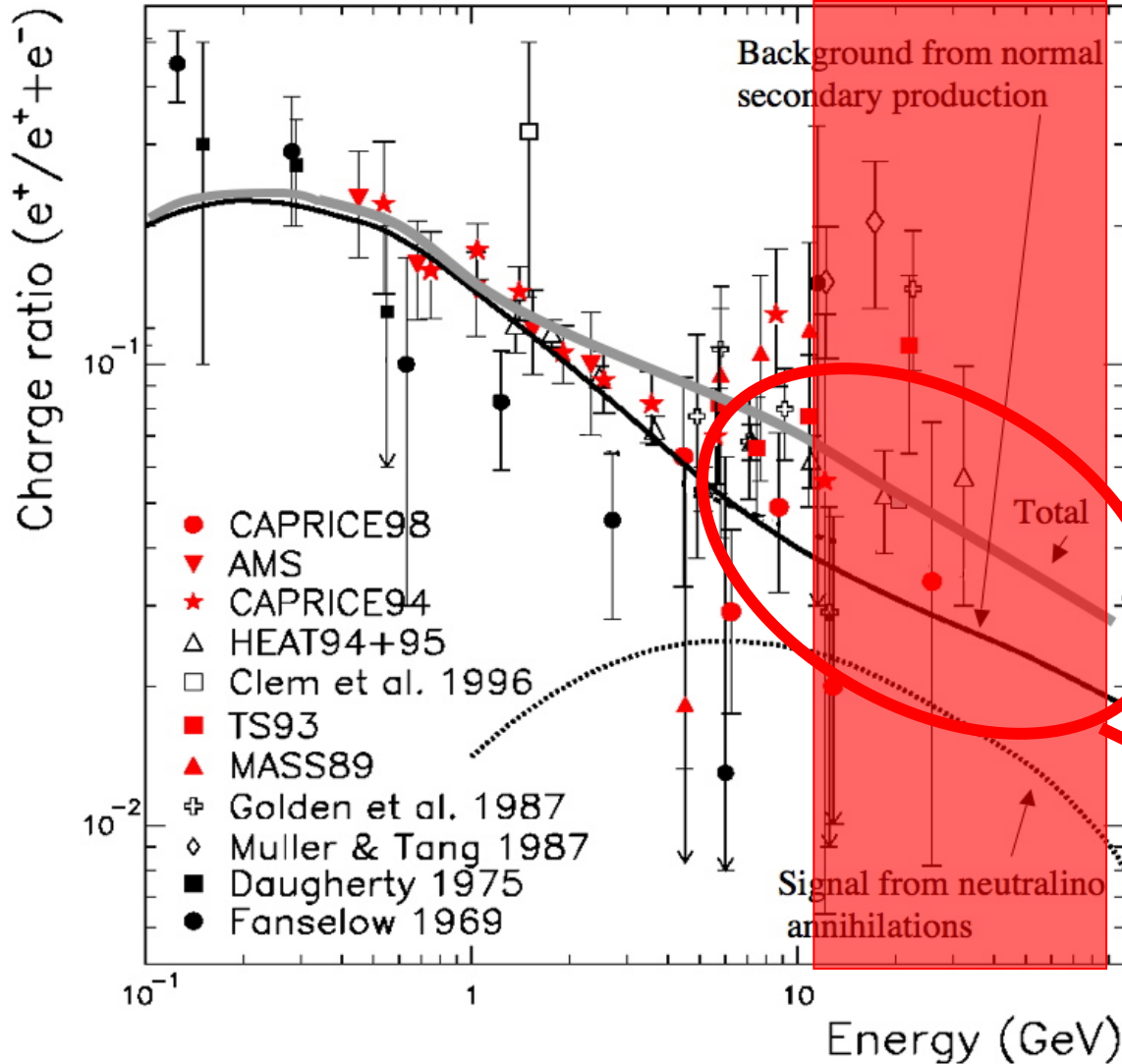


# Why Anti(particle)matter matters?



Oct. 2009

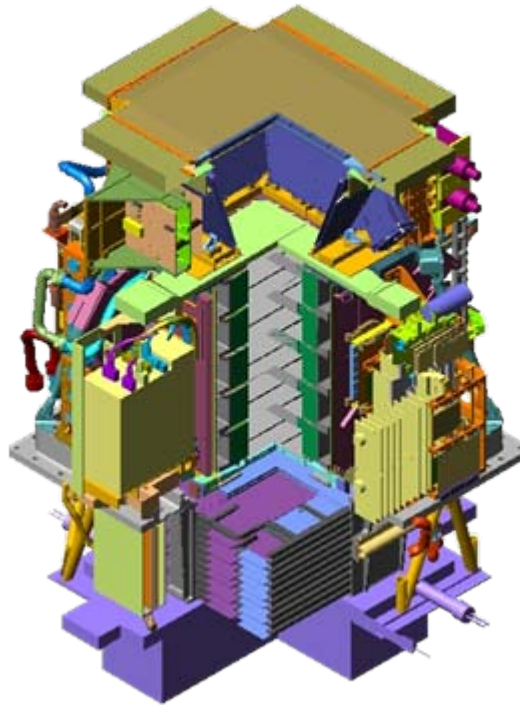
# Why Anti(particle)matter matters?



h Oct. 2009

# PAMELA detectors

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

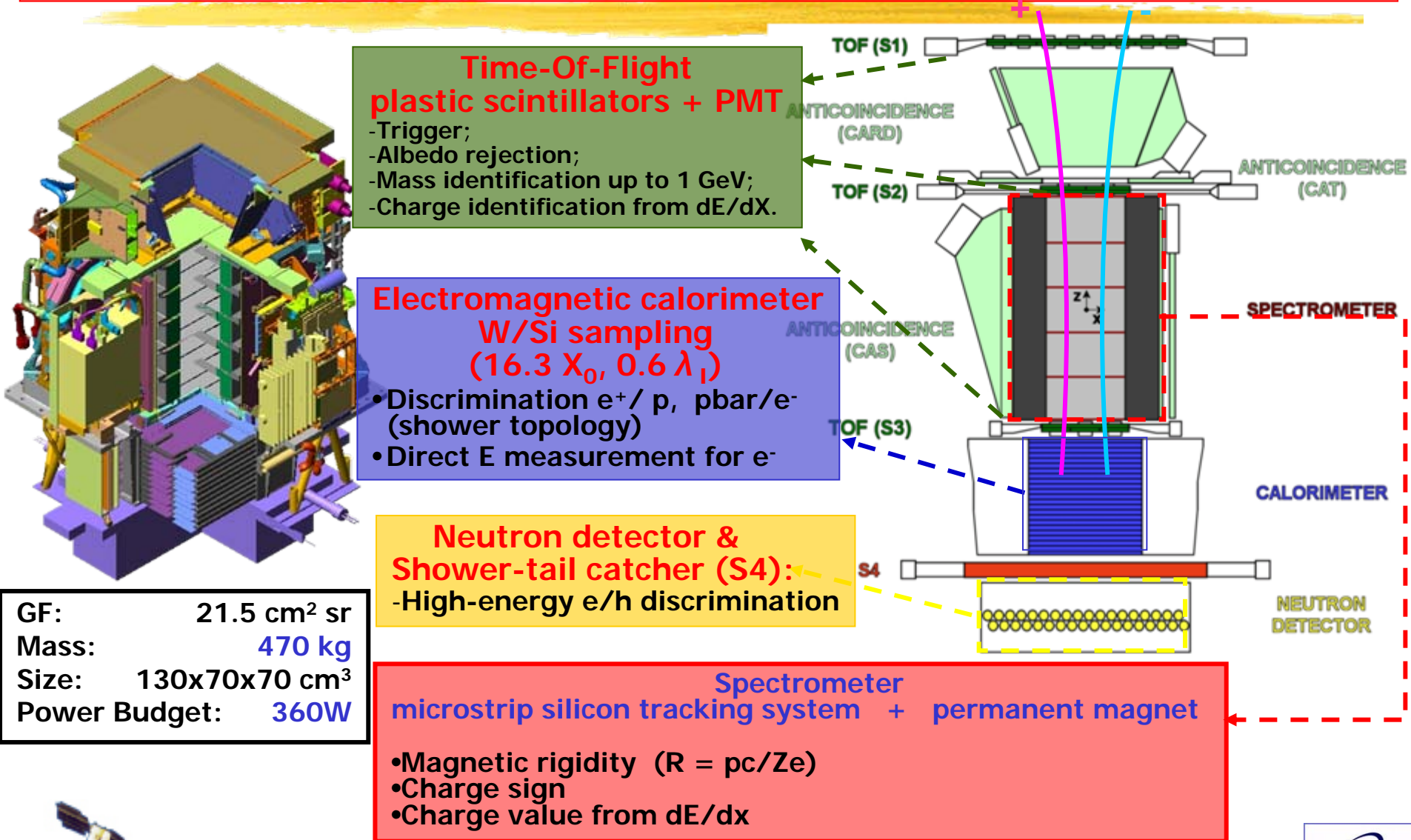


GF:	21.5 cm <sup>2</sup> sr
Mass:	470 kg
Size:	130x70x70 cm <sup>3</sup>
Power Budget:	360W



# PAMELA detectors

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



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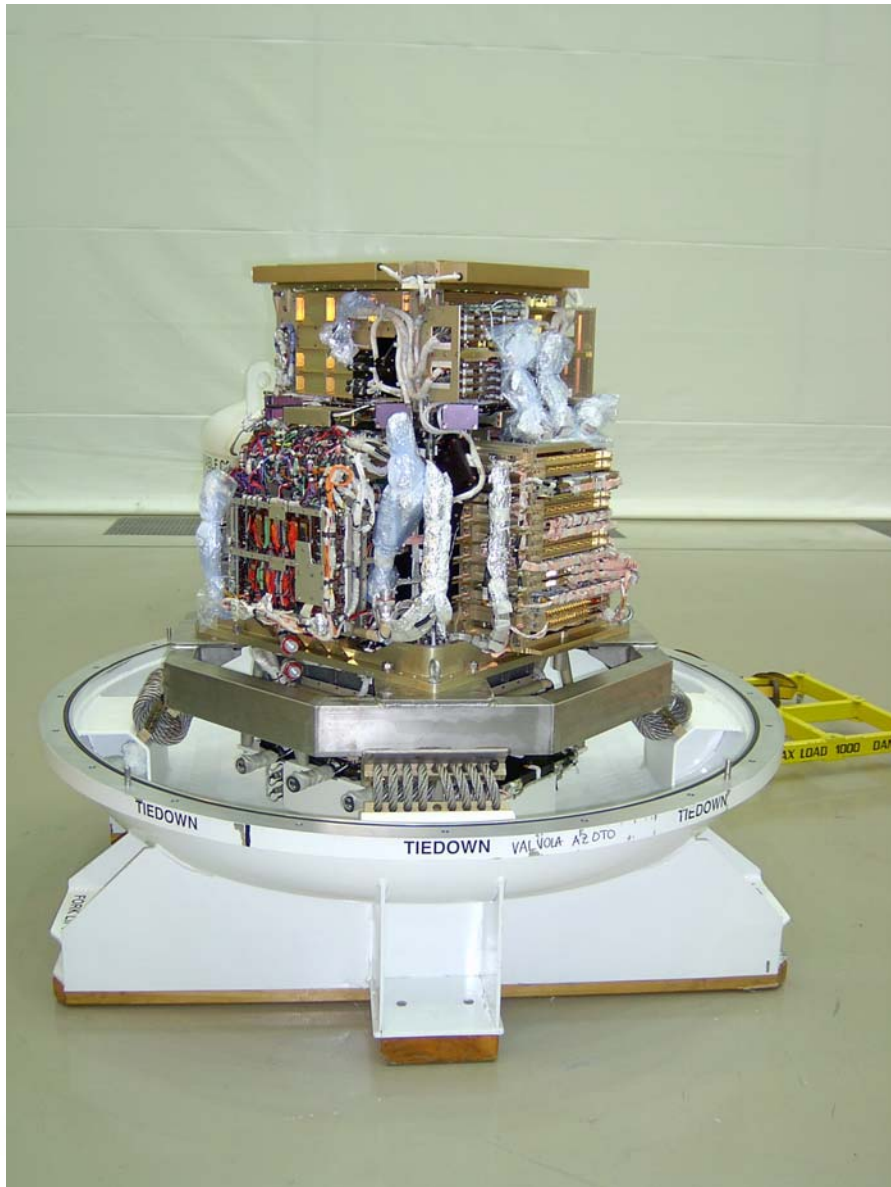


# Design Performance

- 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  $3 \times 10^{-8}$  in  $\bar{\text{He}}/\text{He}$

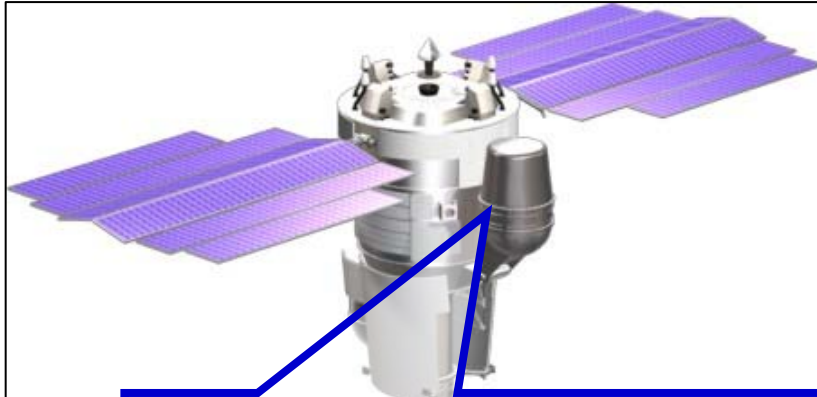
- Simultaneous measurement of many cosmic-ray species
- New energy range
- Unprecedented statistics

# PAMELA: the integration



F.S. Caragna, SCINEGHE 2009, Assisi 7th Oct. 2009

# The Resurs DK-1 spacecraft

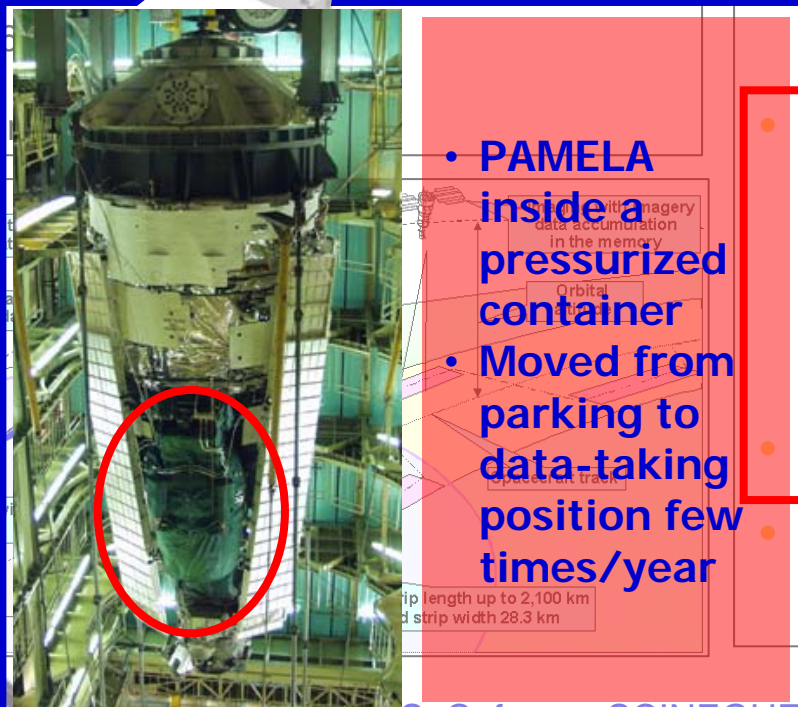


Mass:  
Height:  
Solar a

- Multi-spectral remote sensing of earth's surface
  - near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)

Imaging w  
-imagery d

Data Receiv  
Station

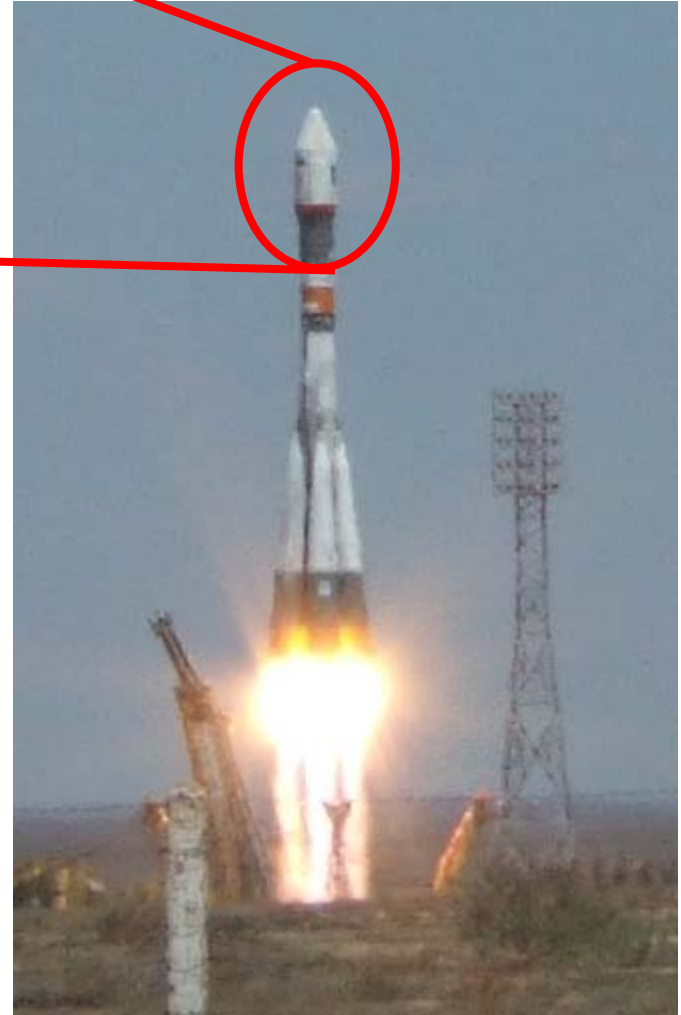


- **PAMELA inside a pressurized container**
- **Moved from parking to data-taking position few times/year**

- Operational orbit parameters:
  - inclination  $\sim 70^\circ$
  - altitude  $\sim 360-600$  km (elliptical)
- Active life  $> 3$  years
- Data transmitted via Very high-speed Radio Link (VRL)



# the satellite & launch



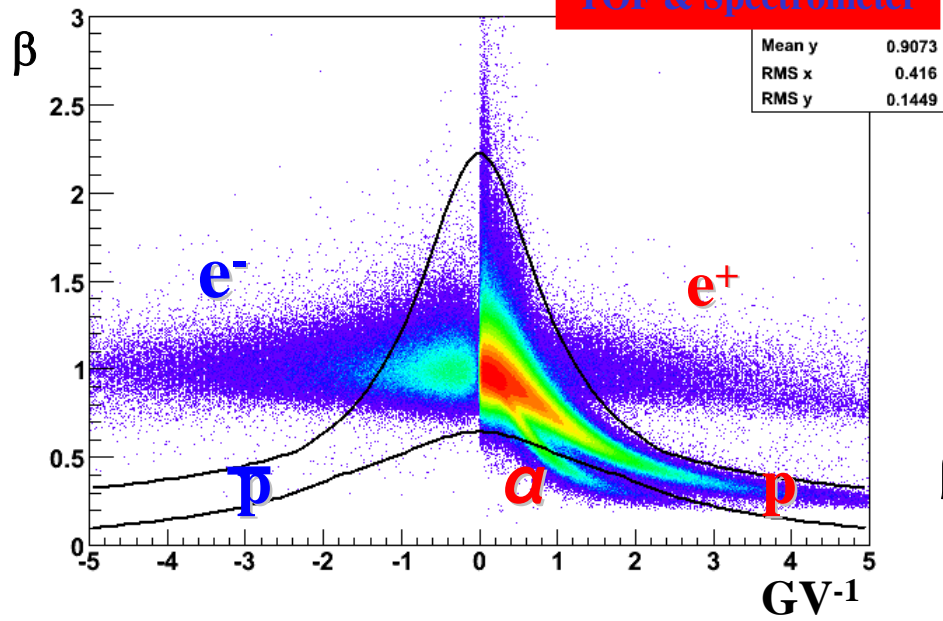
- Launch from Baikonur:  
June 15th 2006, 0800 UTC.  
Power On: June 21<sup>st</sup> 2006, 0300 UTC.  
Detectors operated as expected after launch
- PAMELA in continuous data-taking mode since commissioning phase ended on July 11<sup>th</sup> 2006

- ~1200 days of data taking (~73% live-time)
- ~14 TByte of raw data downlinked
- $>1.4 \times 10^9$  triggers recorded and under analysis

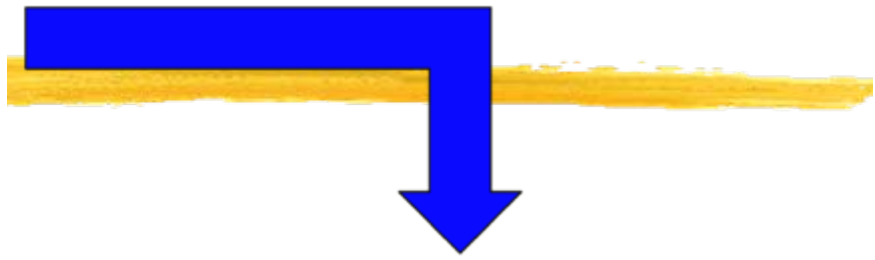


beta vs deflection

TOF & Spectrometer



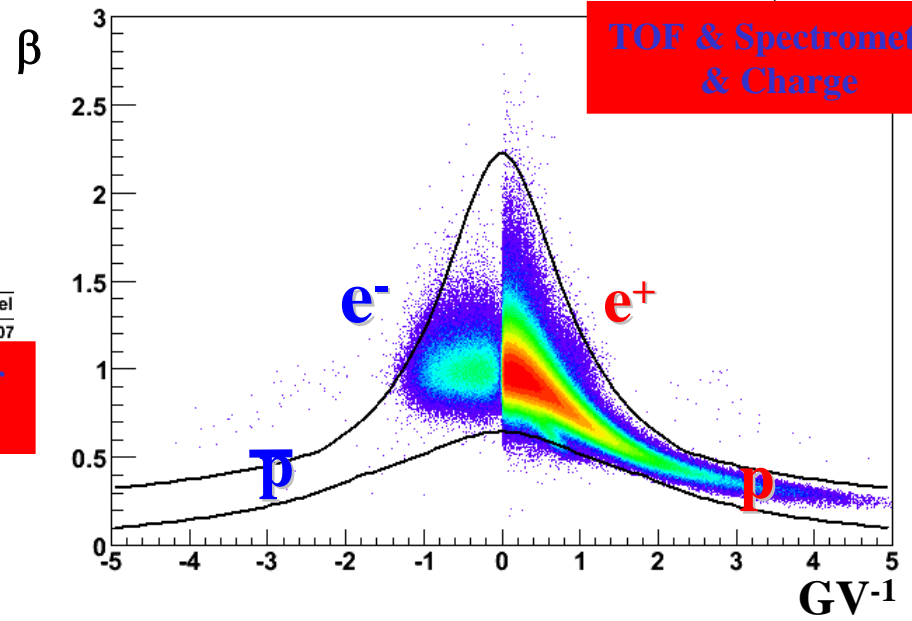
# Antiproton Selection



beta vs deflection -- after Z1 sel (Trk+ToF)

hbetavsdef\_Z1  
Entries 2.540666e+07

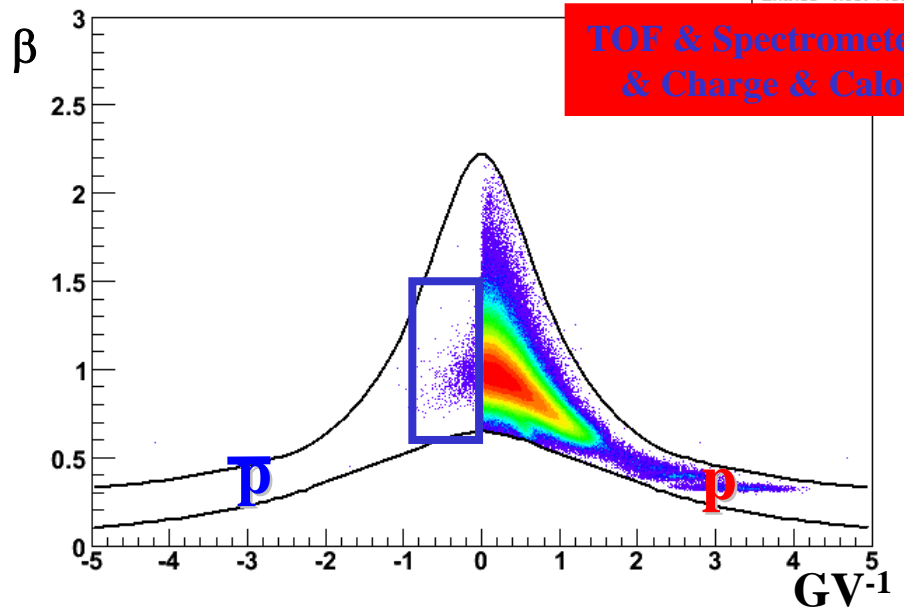
TOF & Spectrometer & Charge



beta vs deflection -- after Z1&&BETA sel -- no electrons

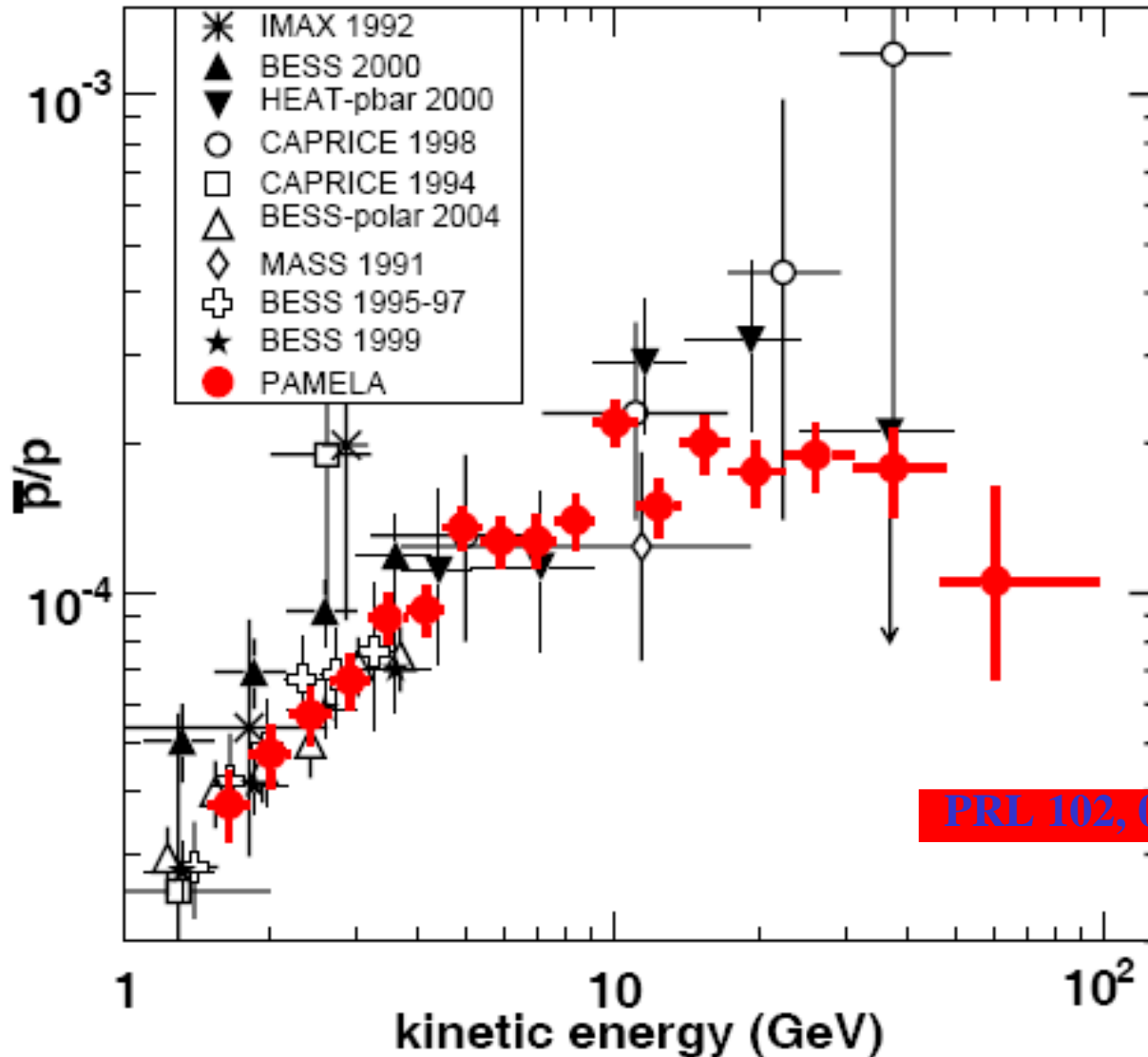
hbetavsdef\_Z1\_noel  
Entries 1.687448e+07

TOF & Spectrometer & Charge & Calo



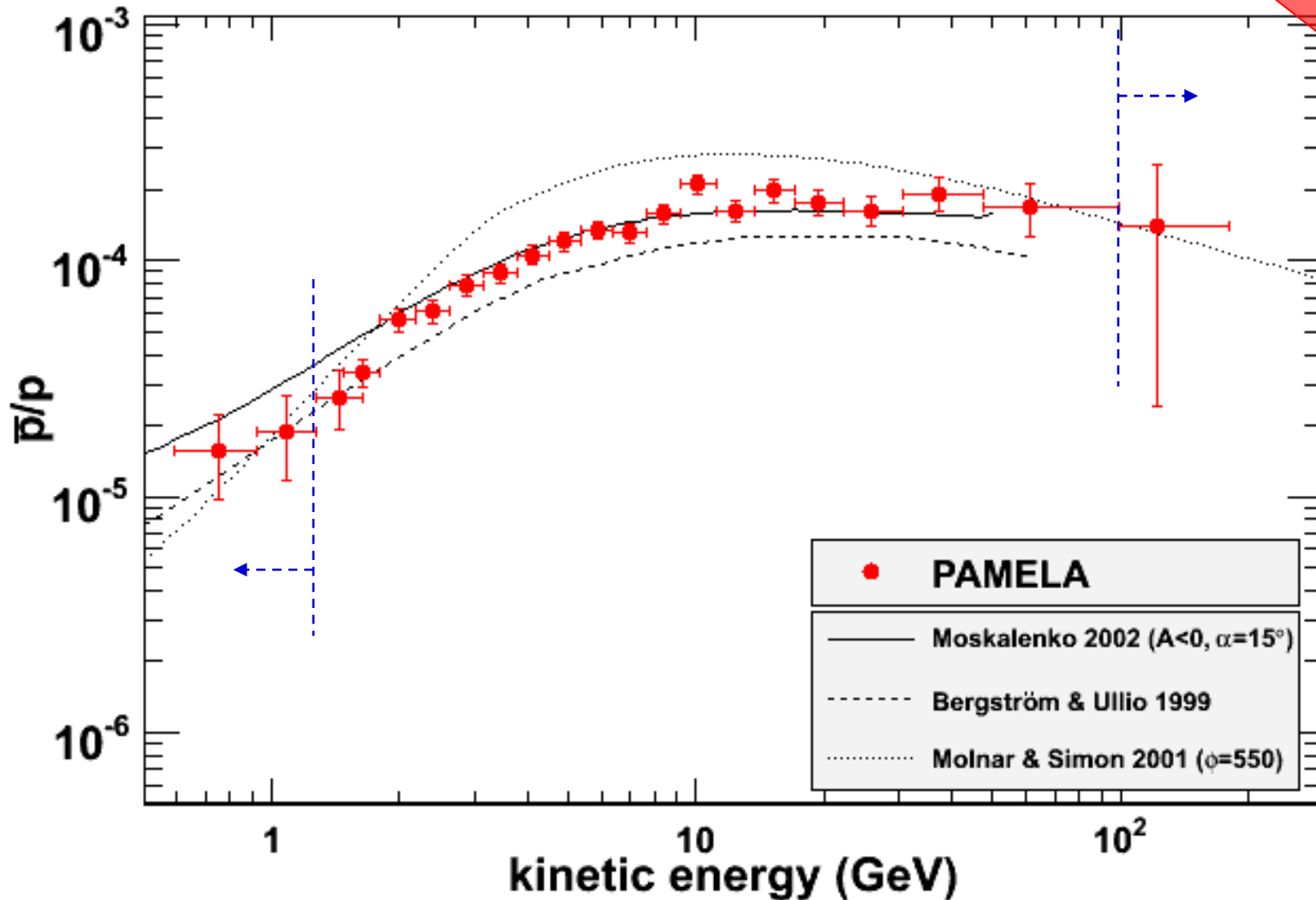
2009, Assisi 7th Oct. 2009

# Antiproton to Proton Ratio



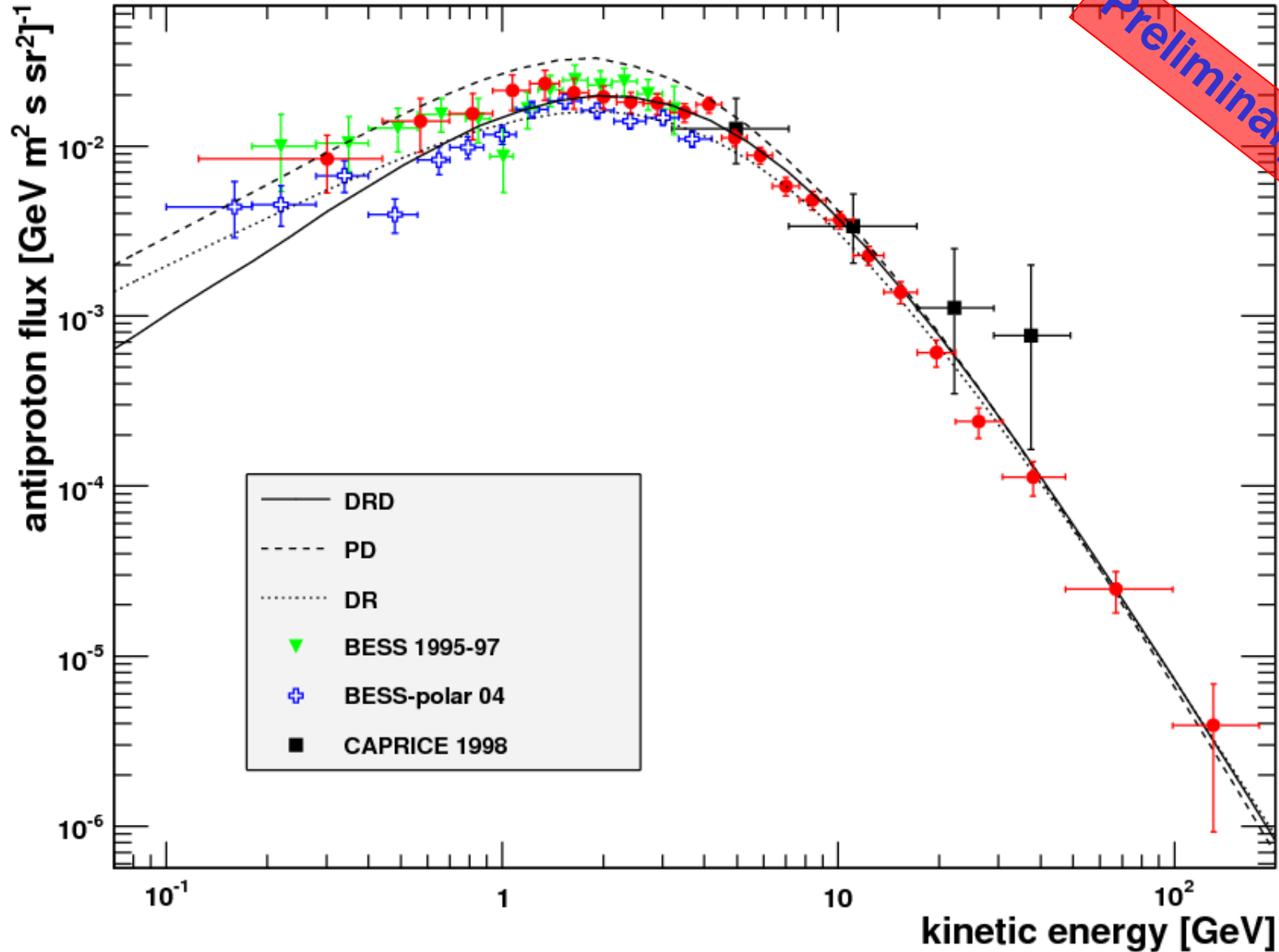
# Antiproton to Proton Ratio

Preliminary



F.S. Cafagna, SCINEGHE 2009, Assisi 7th Oct. 2009

# Antiproton Flux



Prof. Calagna, COSMIC 2000, ASSI, Fri Oct. 2000



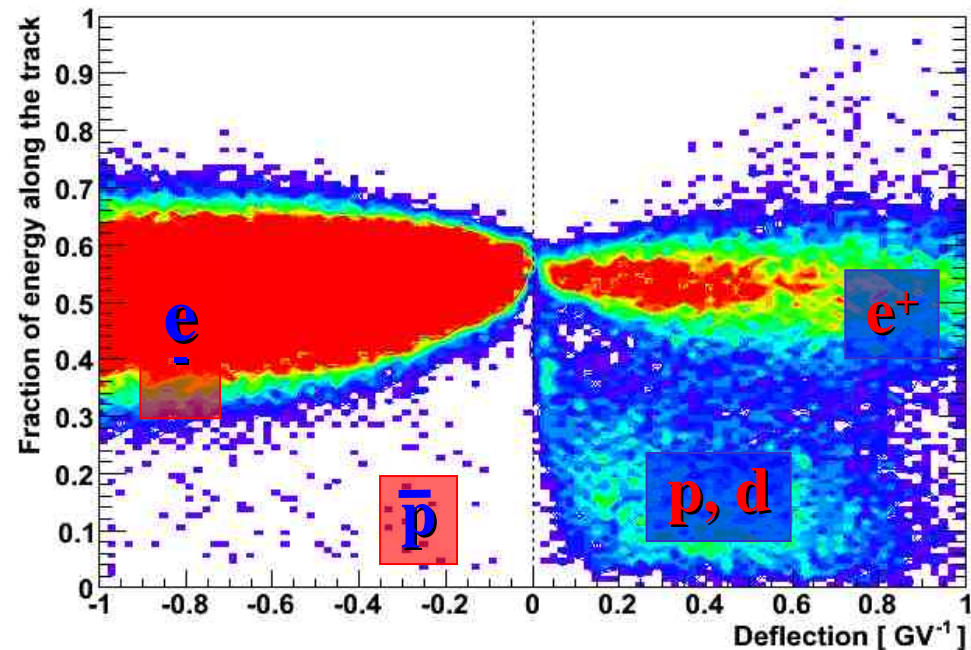
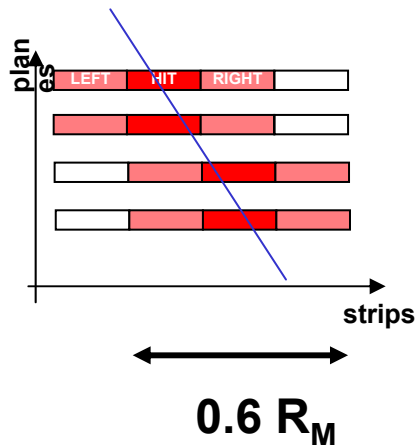
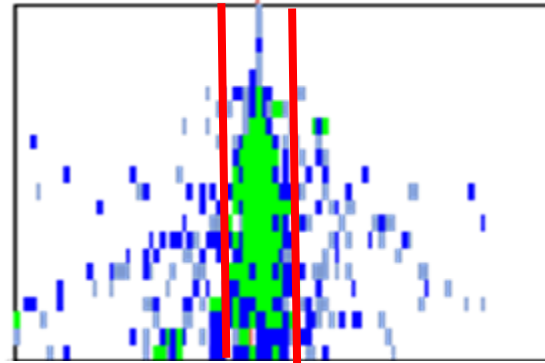
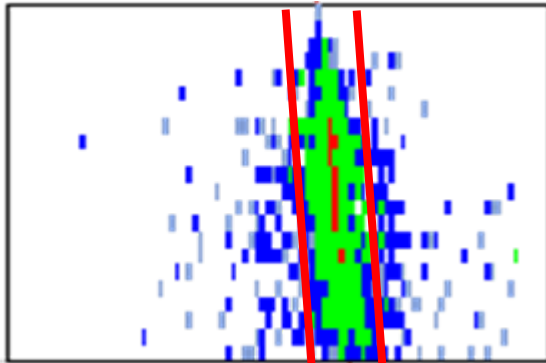
# Positron selection with calorimeter

51 GV Positron

80GV Proton

Fraction of charge released along the calorimeter track

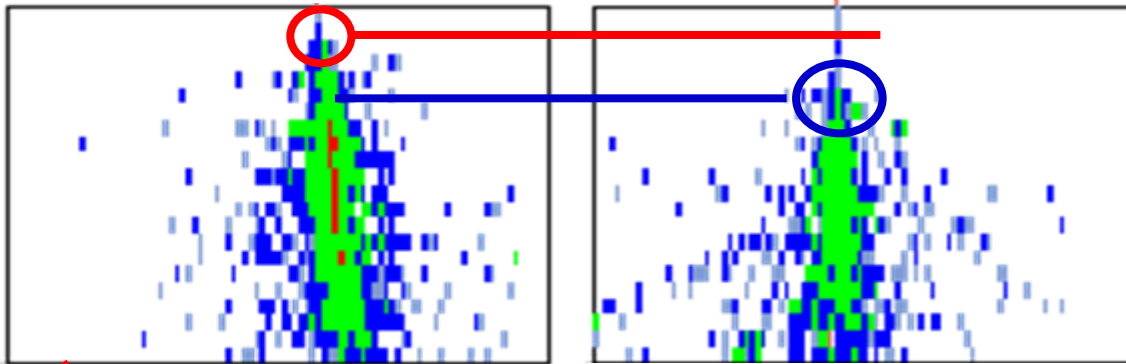
Energy (calo) –  
Momentum  
(spectrometer)  
match



# Positron selection with calorimeter

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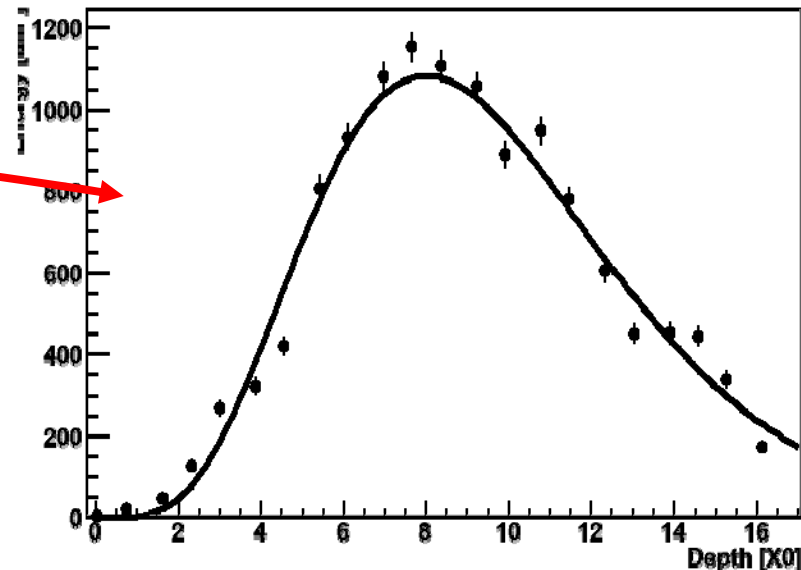


Fraction of charge released along the calorimeter track

Energy (calo) –  
Momentum  
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match

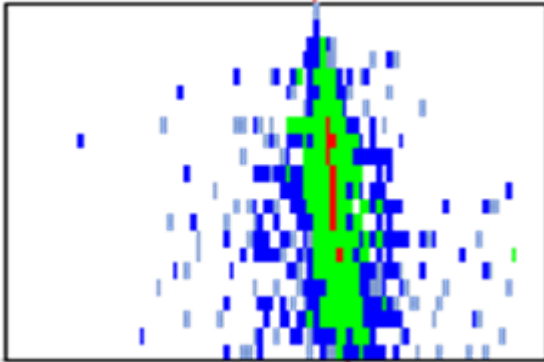
Shower starting  
point

Longitudinal profile

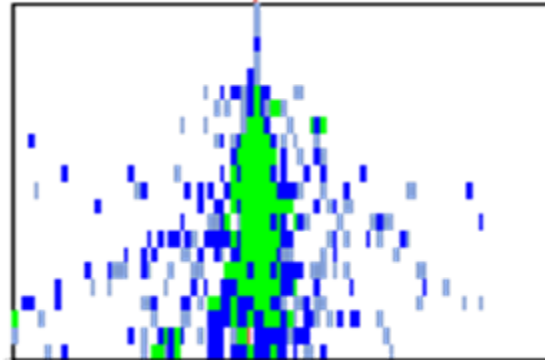


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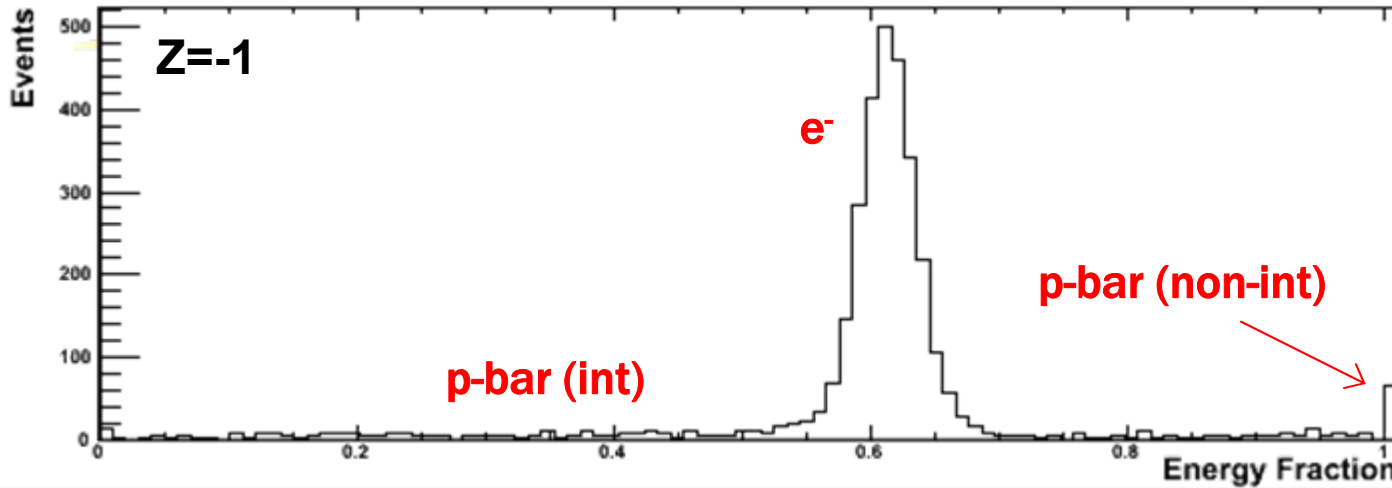
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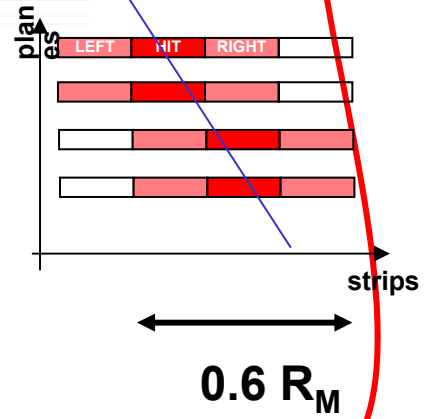
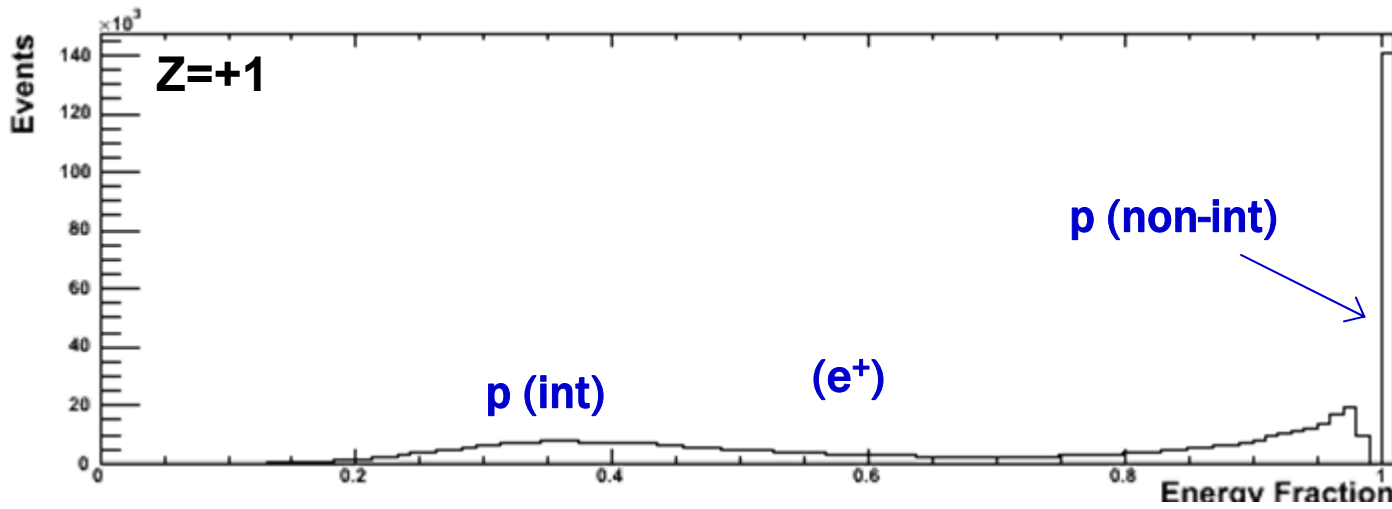
Longitudinal profile

- 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

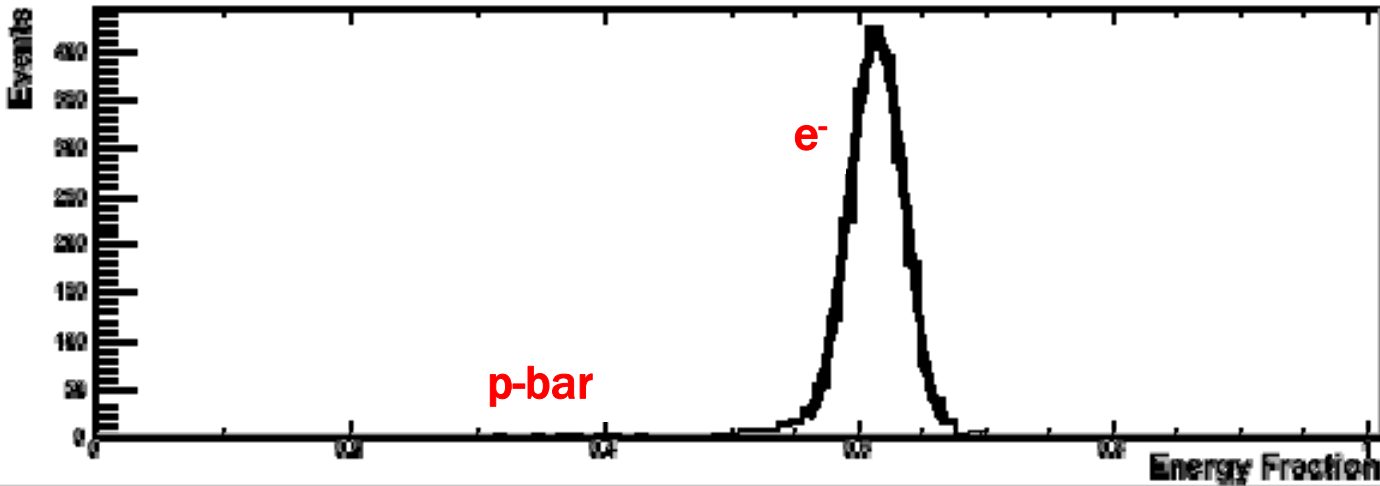


Rigidity: 20-30 GV



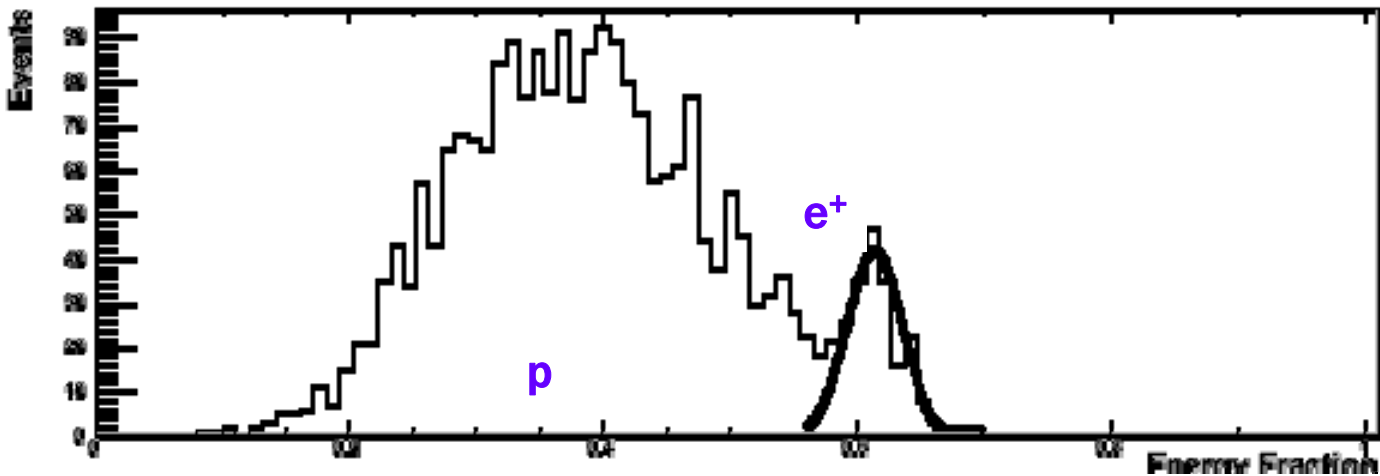


# Positron selection with calorimeter



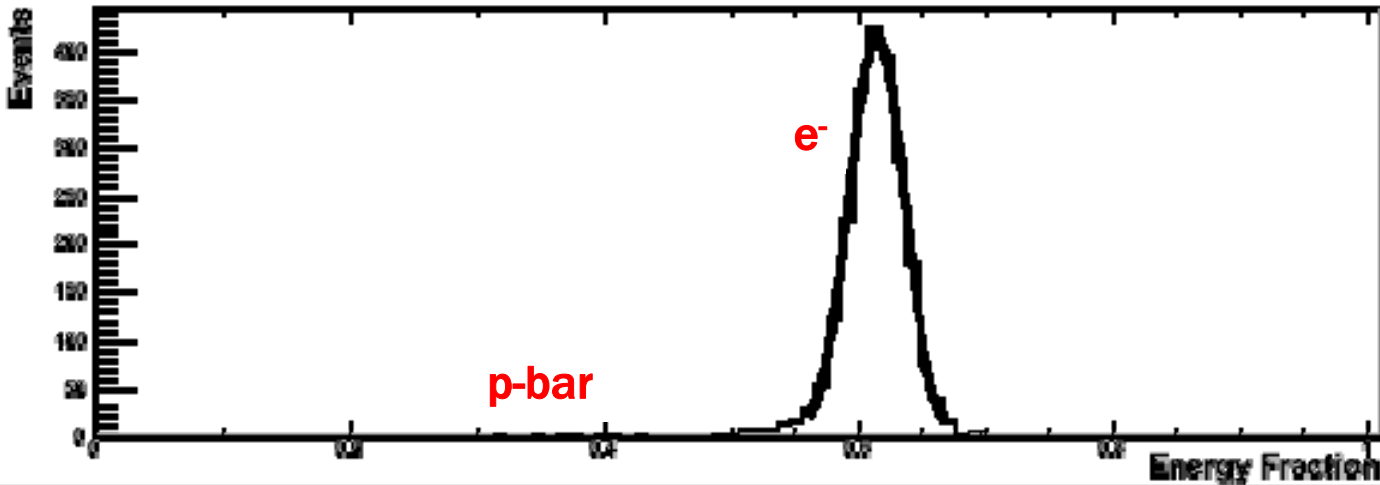
Fraction of charge released along the calorimeter track

- Constrains on:
- Energy momentum match



Rigidity: 20-30 GV

# Positron selection with calorimeter



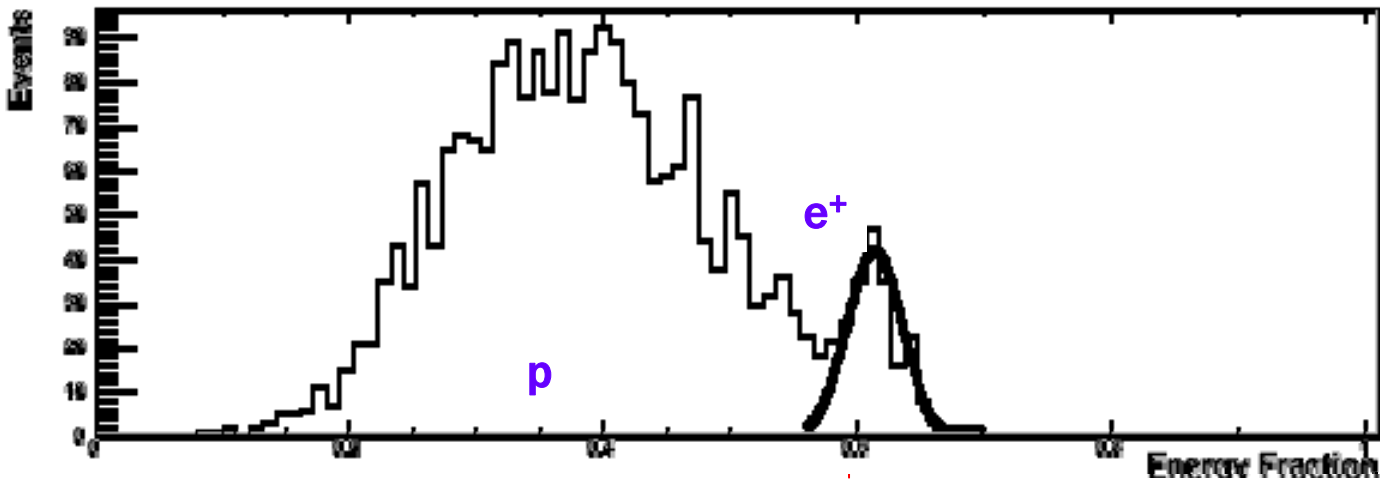
Fraction of charge released along the calorimeter track

Constrains on:

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

Cross check:

- Simulation
- Tracker  $dE/dX$
- Neutron Detector



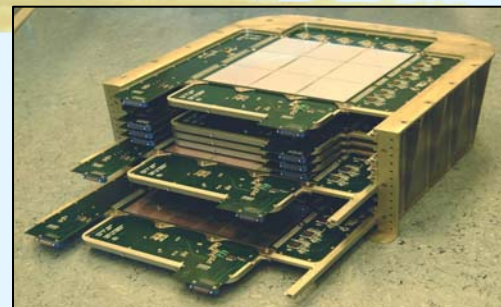
Rigidity: 20-30 GV

# The "pre-sampler" method

## The electromagnetic calorimeter

### Characteristics:

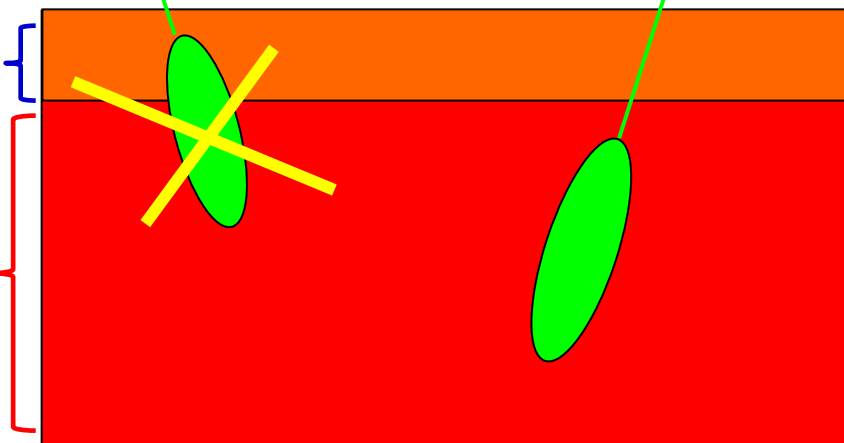
- 44 Si layers (X/Y) + 22 W planes
- $16.3 X_0 / 0.6 I_0$
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode ( $> 300 \text{ GeV GF} \sim 600 \text{ cm}^2 \text{ sr}$ )



### PROTON SELECTION

2 W planes:  $\approx 1.5 X_0$

20 W planes:  $\approx 15 X_0$

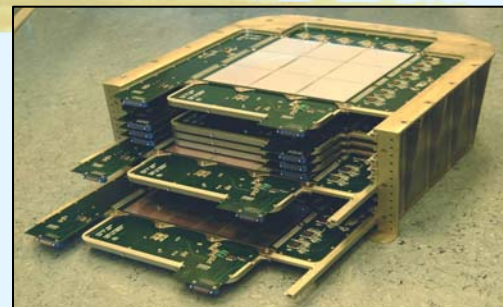


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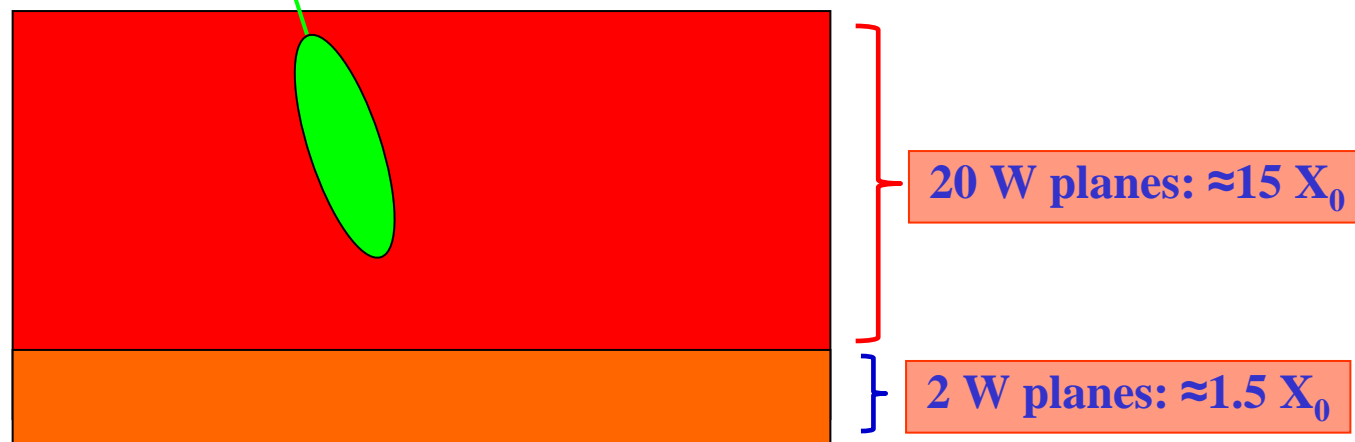
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- Self-trigger mode ( $> 300 \text{ GeV GF} \sim 600 \text{ cm}^2 \text{ sr}$ )



### POSITRON SELECTION



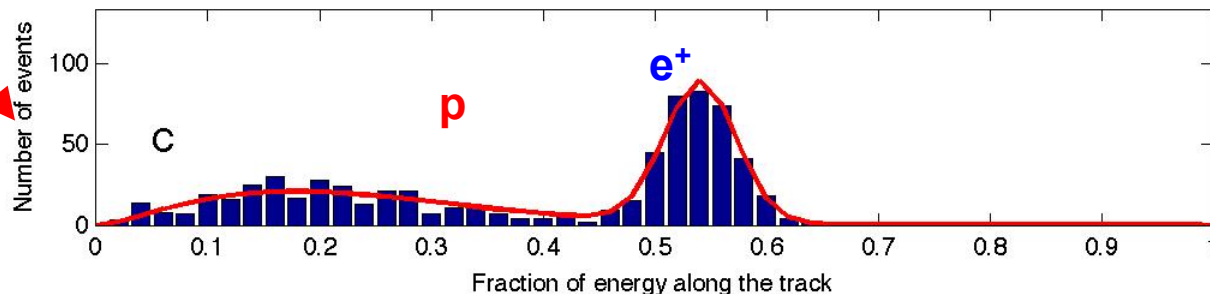
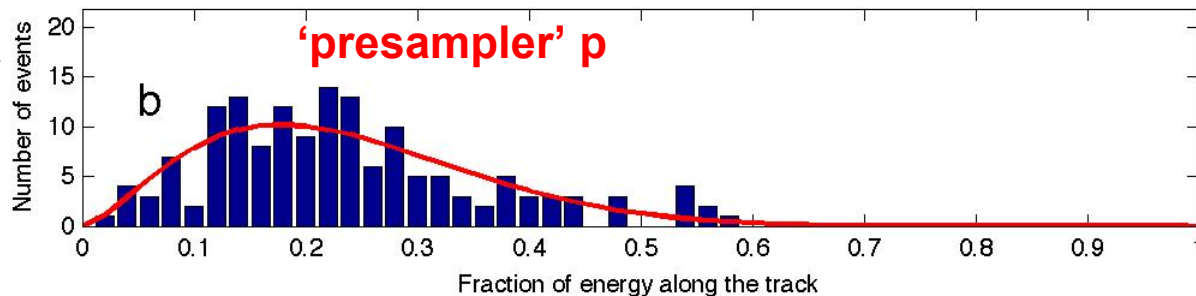
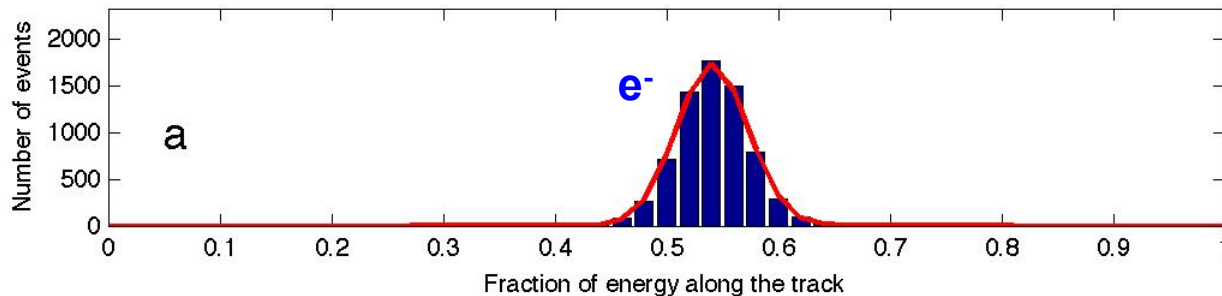
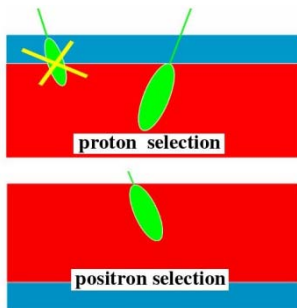


# $e^+$ background estimation from data

Fraction of charge released along the calorimeter track

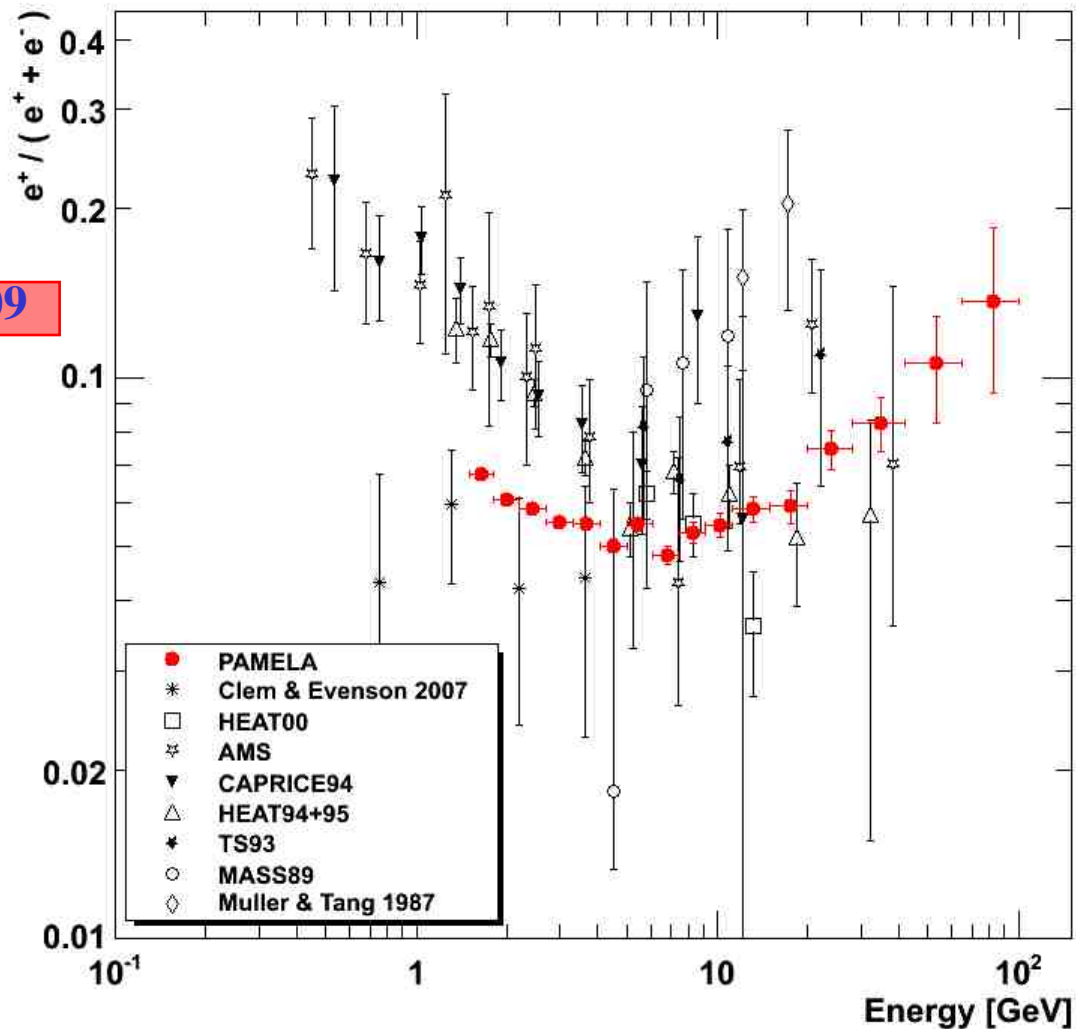
Constrains on:

- Energy momentum match
- Shower starting-point



Rigidity: 20-28 GV

# Positron to All Electron Fraction

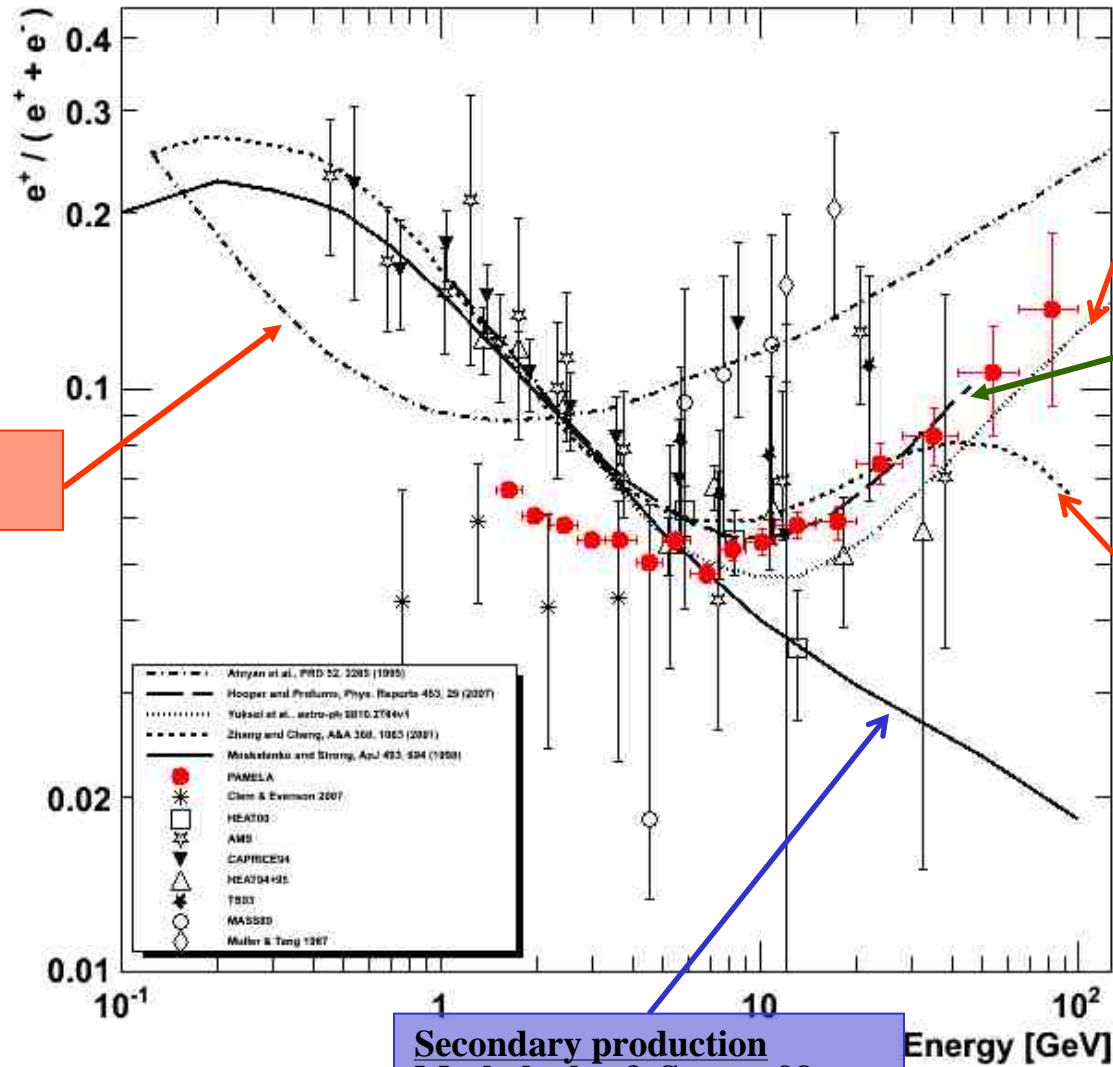


Nature 458, 697, 2009

End 2007:  
~10 000  $e^+ > 1.5\text{GV}$   
~2 000  $e^+ > 5\text{ GeV}$



# Positron to Electron Fraction



**Pulsar Component**  
Atoyan et al. 95

**Pulsar Component**  
Yüksel et al. 08

**KKDM (mass 300 GeV)**  
Hooper & Profumo 07

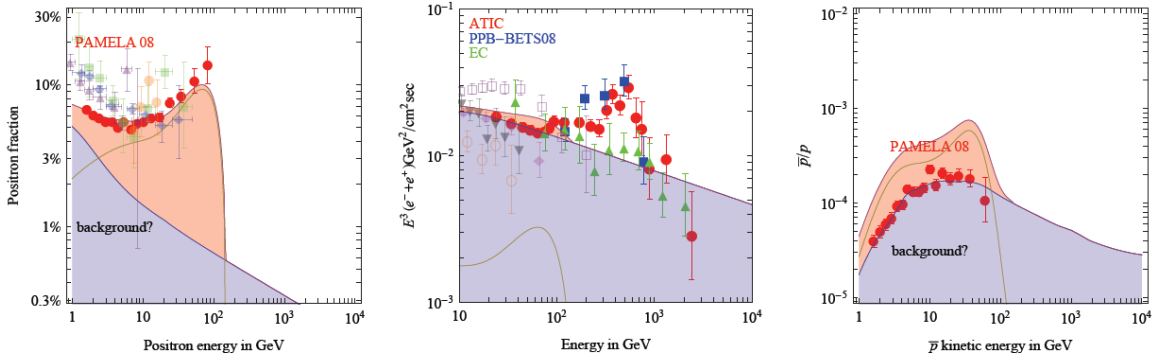
**Pulsar Component**  
Zhang & Cheng 01

**Secondary production**  
Moskalenko & Strong 98



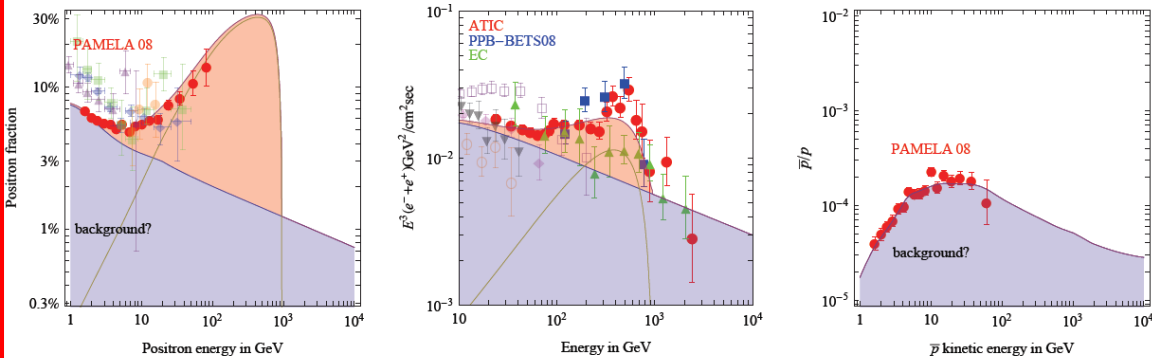
# DM ?

DM with  $M = 150$  GeV that annihilates into  $W^+ W^-$

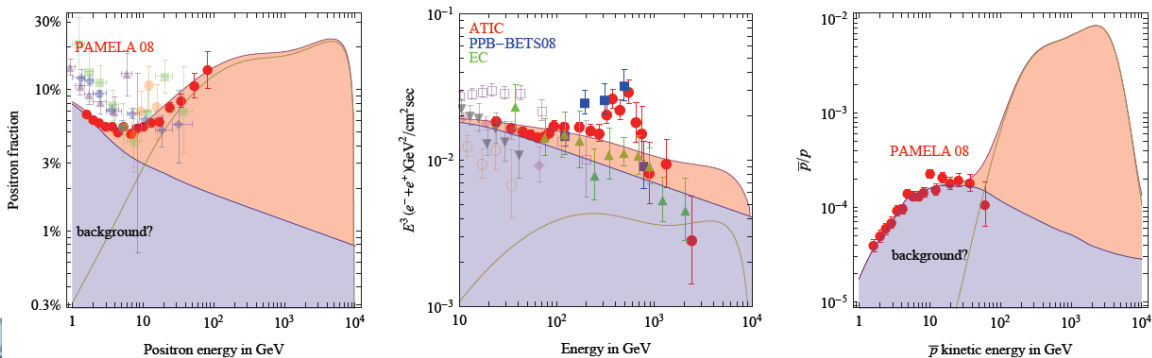


- PAMELA ability of measuring both proton and electron charge ration, make it possible to put several constrains to the models

DM with  $M = 1$  TeV that annihilates into  $\mu^+ \mu^-$



DM with  $M = 10$  TeV that annihilates into  $W^+ W^-$



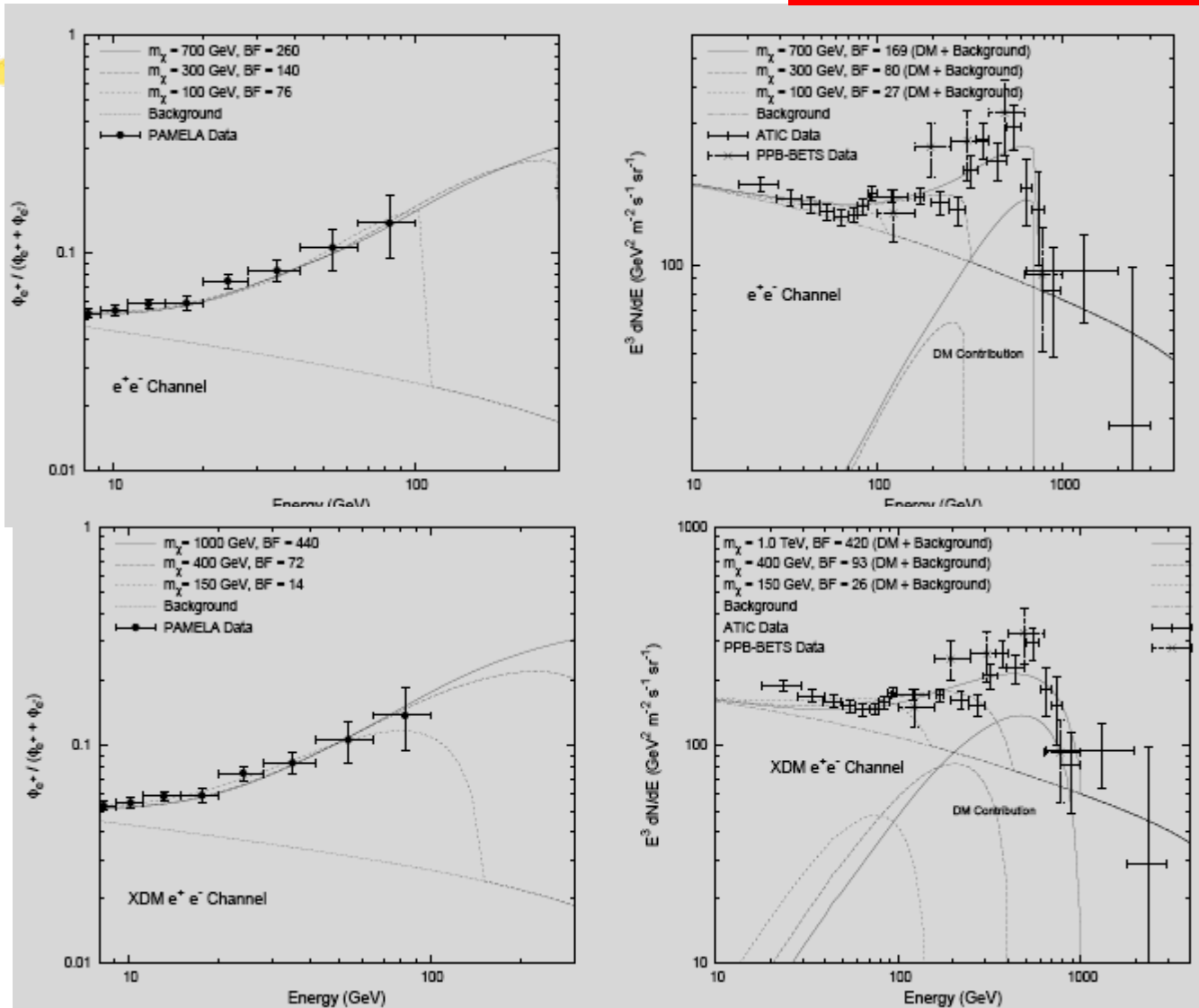
M. Cirelli, M. Kadastik,  
M. Raidal, A. Strumia  
arXiv:0809.2409v3

7th Oct. 2009



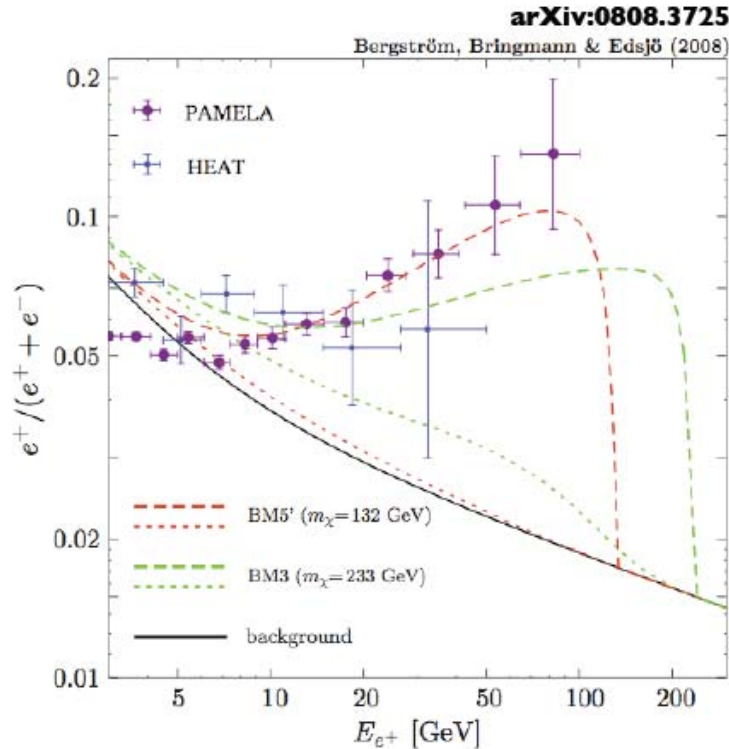
# DM ?

I. Cholis et al. arXiv:0811.3641v1



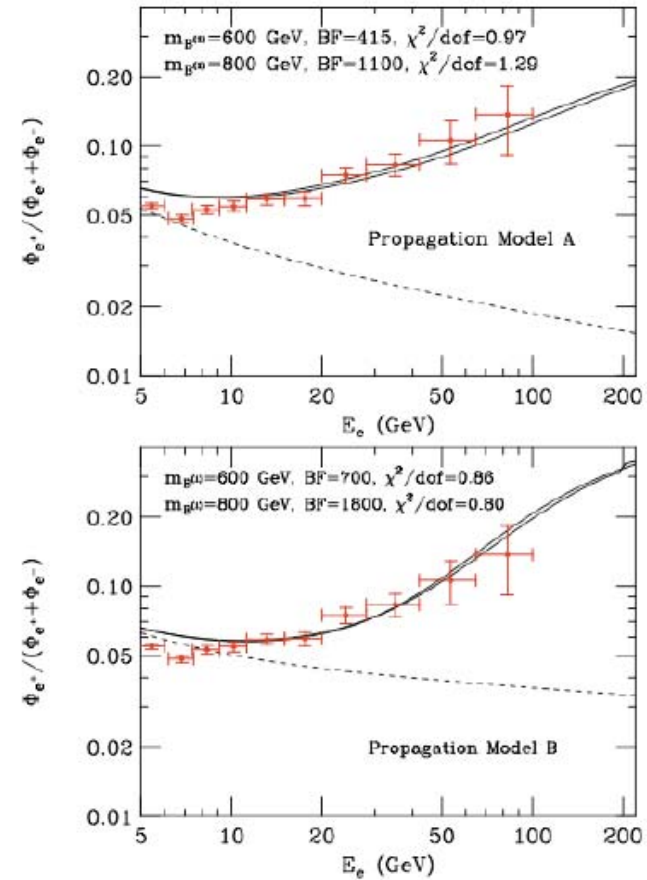
- Propose a new light boson ( $m_\Phi \leq \text{GeV}$ ), such that  $\chi\chi \rightarrow \Phi\Phi$ ;  $\Phi \rightarrow e^+e^-, \mu^+\mu^-, \dots$
- Light boson, so decays to antiprotons are kinematically suppressed

# Example: Dark Matter



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

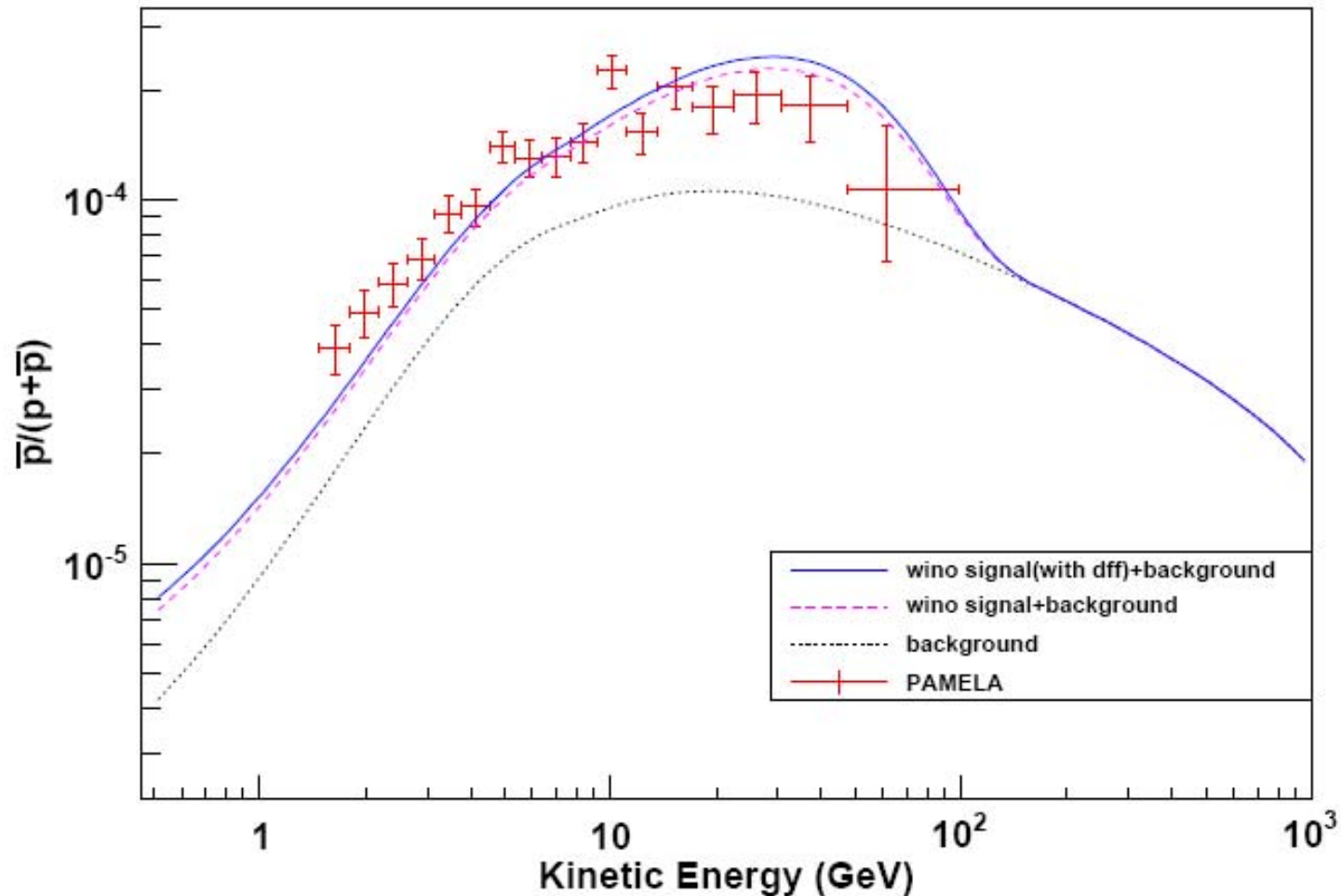
Hooper and Zurek  
arXiv:0902.0593v1



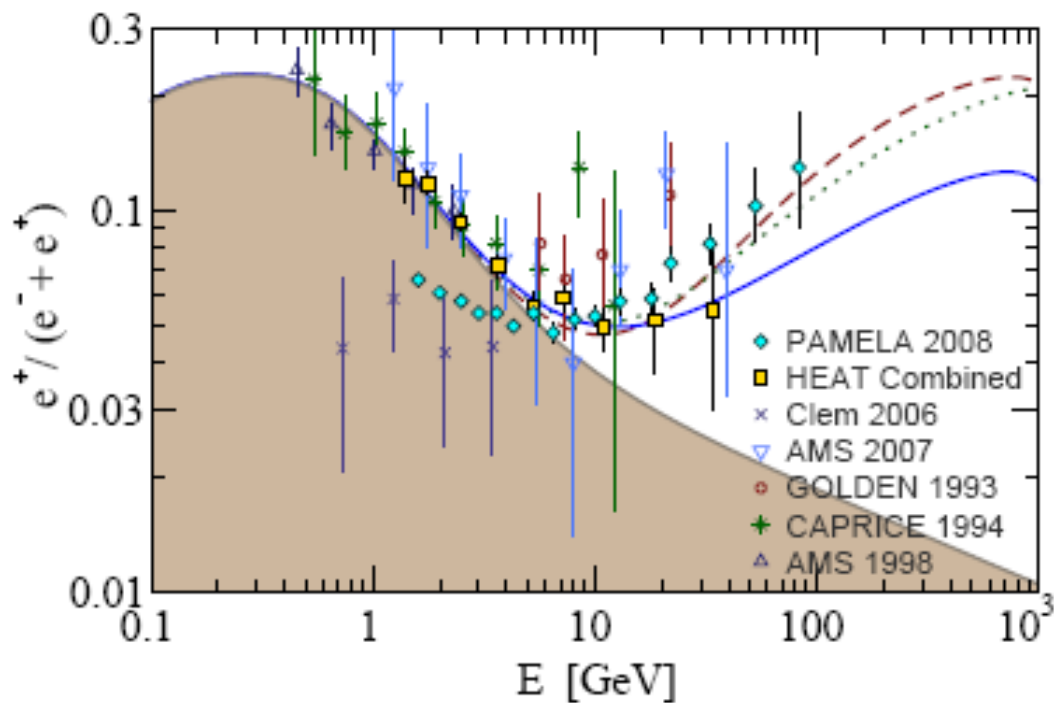
Kaluza-Klein dark matter

# Wino Dark Matter in a non-thermal Universe

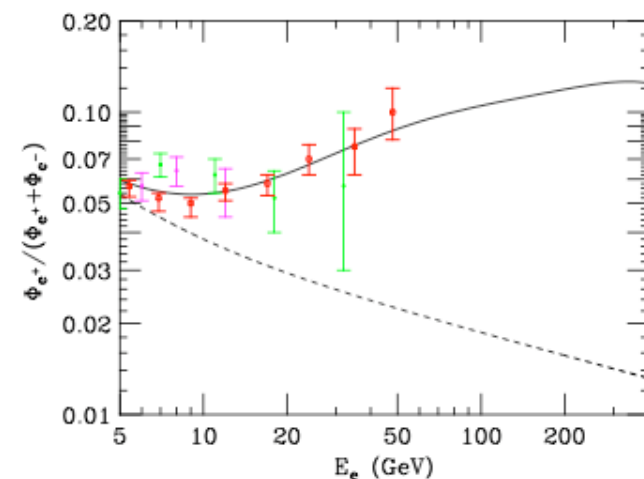
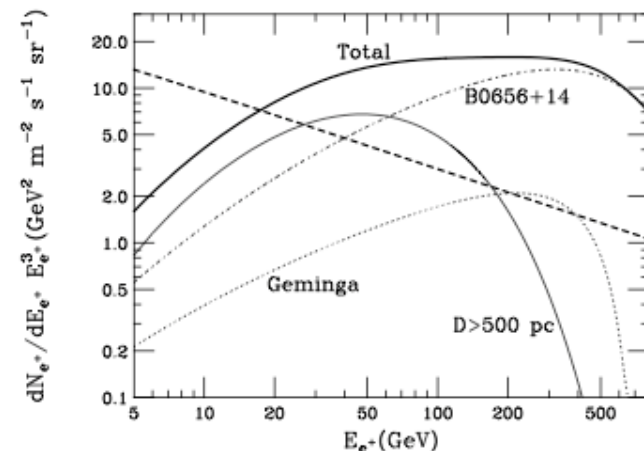
G. Kane, R. Lu, and S. Watson  
arXiv:0906.4765v3 [astro-ph]



# 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



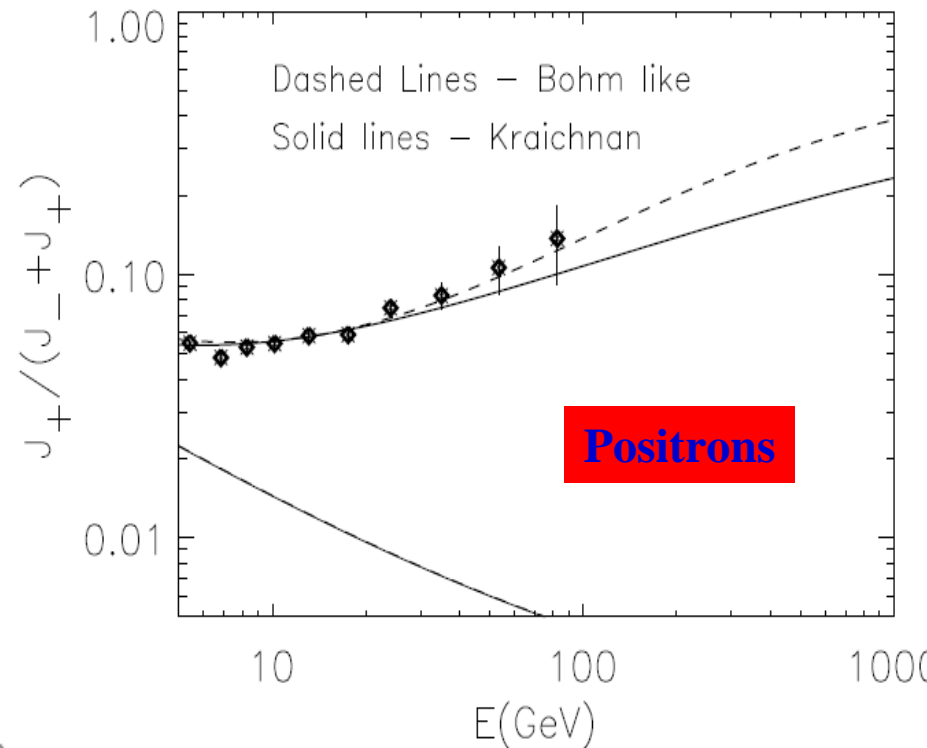
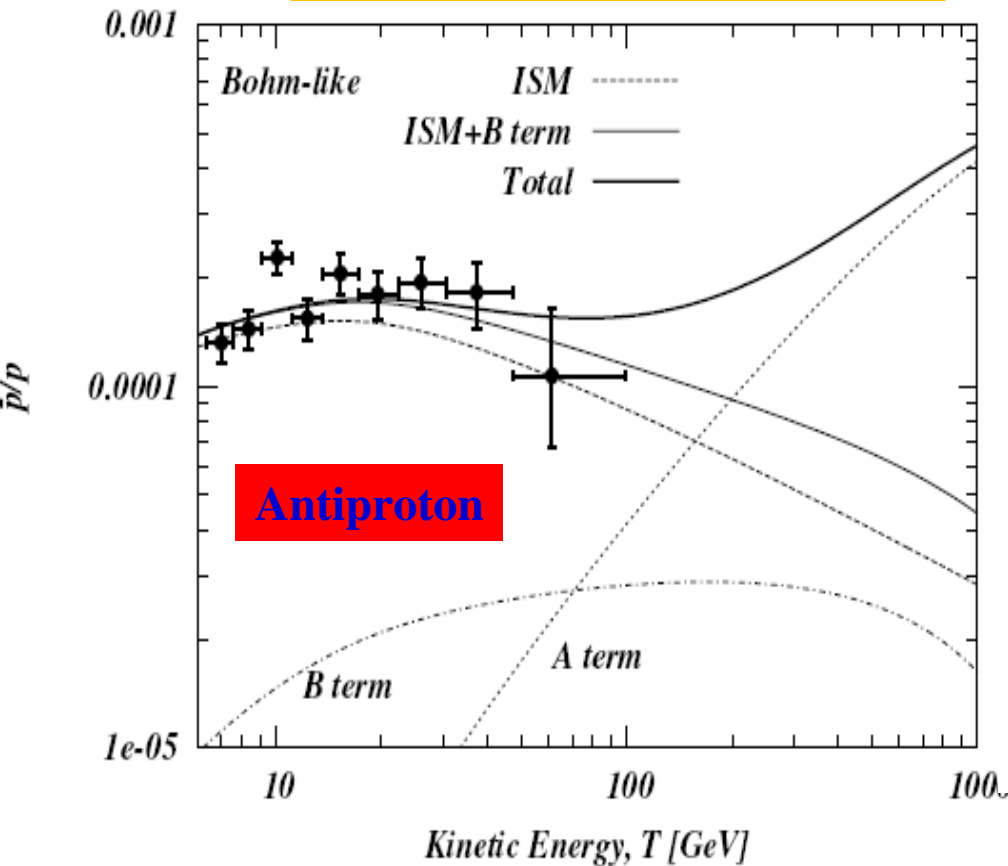
Diffuse mature & nearby young pulsars Hooper,  
 Blasi, and Serpico arXiv:0810.1527



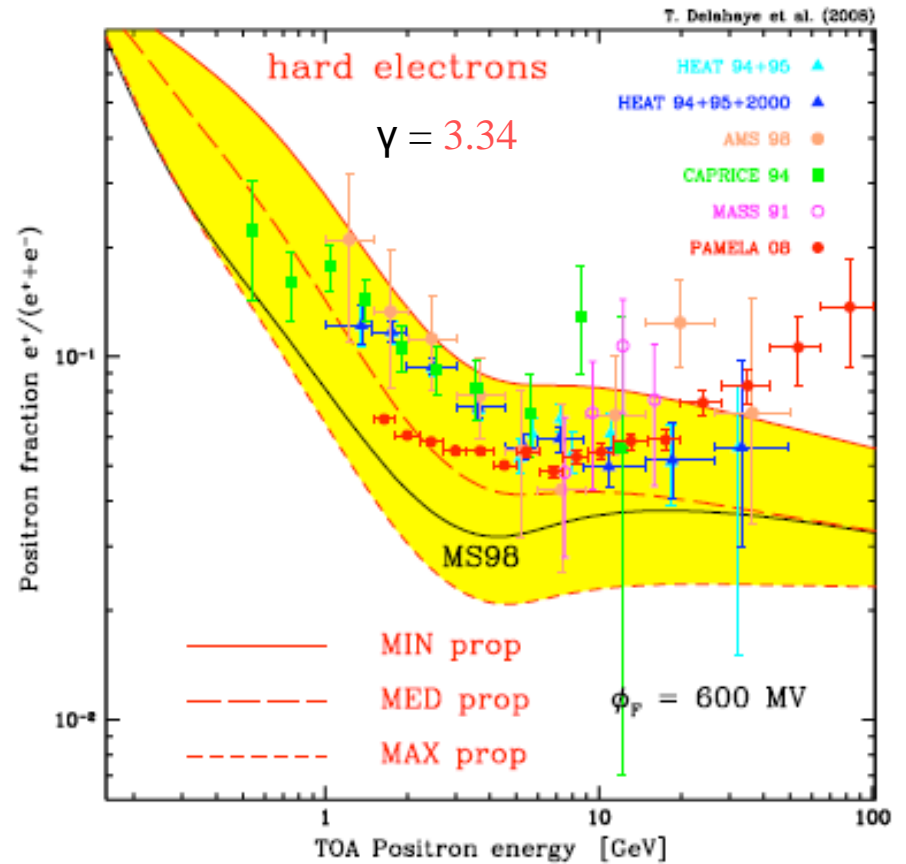
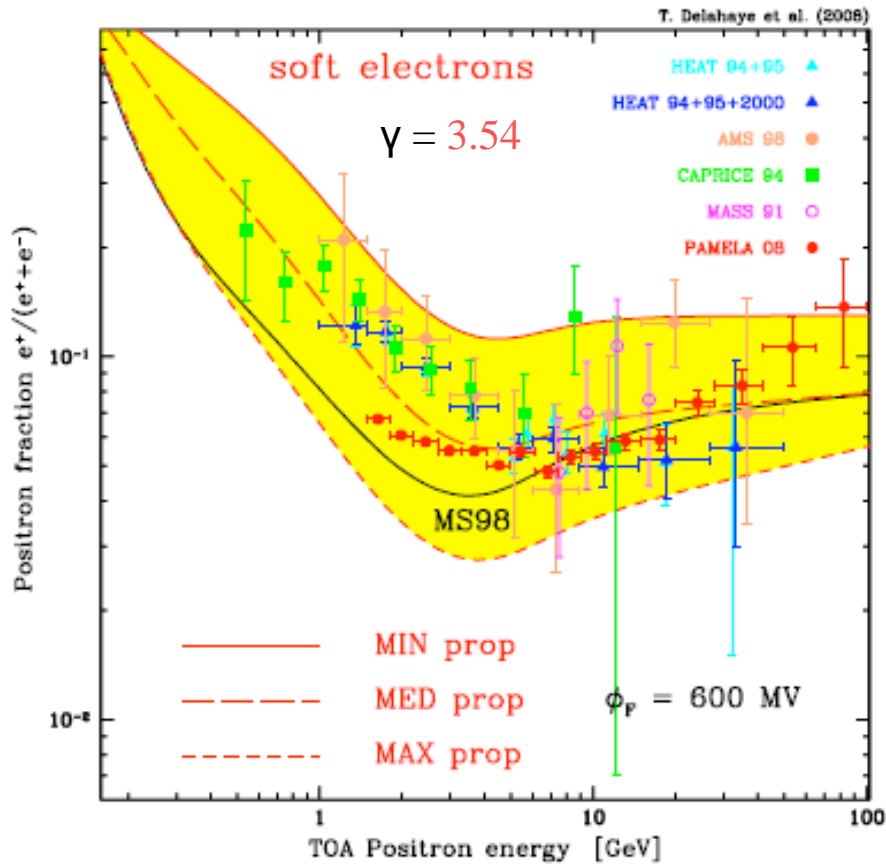
# Antiprotons & positrons from old SNR's

P. Blasi Astro-ph.HE 0904.0871

P. Blasi 0903.2794



# Standard Positron Fraction Theoretical Uncertainties



T. Delahaye et al., arXiv: 0809.5268v3

F.S. Cafagna, SCINEGHE 2009, Assisi 7th Oct. 2009



# 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 ( $10^2$  GeV) with an unprecedented statistical precision.
- Antiparticle fluxes are an exciting tools to study DM characteristics. Stay tuned for fluxes ... **THANKS !!!!**

