The PAMELA experiment for cosmic-ray measurements

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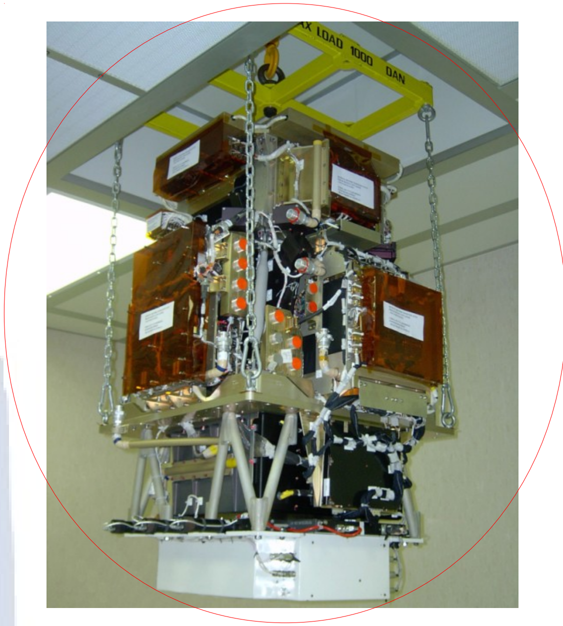
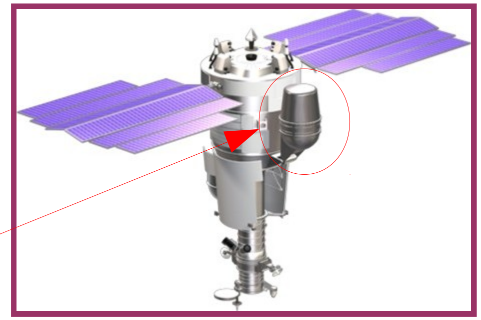
on behalf of the PAMELA collaboration

International Symposium on Neutrino Physics and Beyond, Shenzhen, 25th September 2012

The PAMELA experiment



Resurs DK1 satellite



Satellite-borne experiment
↓
No atmospheric effects

[The PAMELA collaboration]

Italy

Bari

Naples

Florence

Rome

Trieste

Frascati

Russia

Moscow

Ioffe Physico-Technical Institute

St. Petersburg

Sweden

Stockholm

Germany

Siegen

Technical data	**Mission details**
Mass ~ 470 kg Height ~ 1.3 m Power cons. ~ 355 W Downlink rate ~ 10 GB/day	Altitude: 360 – 600 km Orbit inclination: 70° Planned duration: 3 years Launch: 15th June 2006

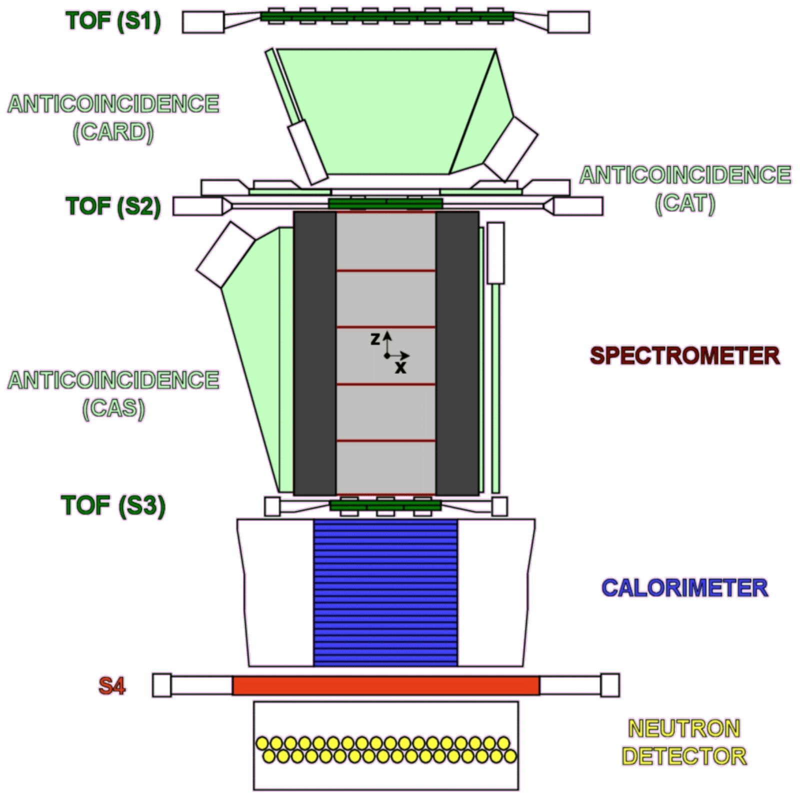
Current status

> 6 years in orbit
Data taking LT ~ 75%
> 20 TB of raw data
> 2x10^9 triggers

Aimed at light particles (up to oxygen)

Main focus on **antiparticles**

The detector



Time-Of-Flight (TOF)
Plastic scintillators + PMT
- Trigger
- Albedo rejection
- Mass identification up to 1 GeV
- Charge identification from dE/dX

Anticoincidence
Plastic scintillators + PMT
- Multi-particle and interacting event rejection

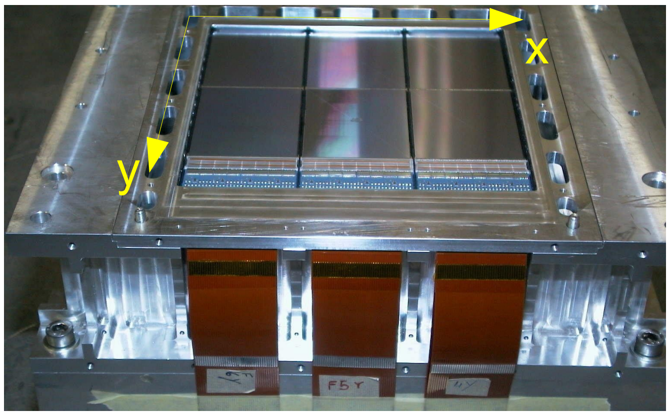
Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λ_I)
- e^+/p, $e^-/\bar{p}$ discrimination (shower topology)
- Direct energy measurement for $e^\pm$

Spectrometer
Microstrip silicon tracking system + perm. magnet
- magnetic rigidity R = pc/Ze
  - sign of charge
  - charge value from dE/dx

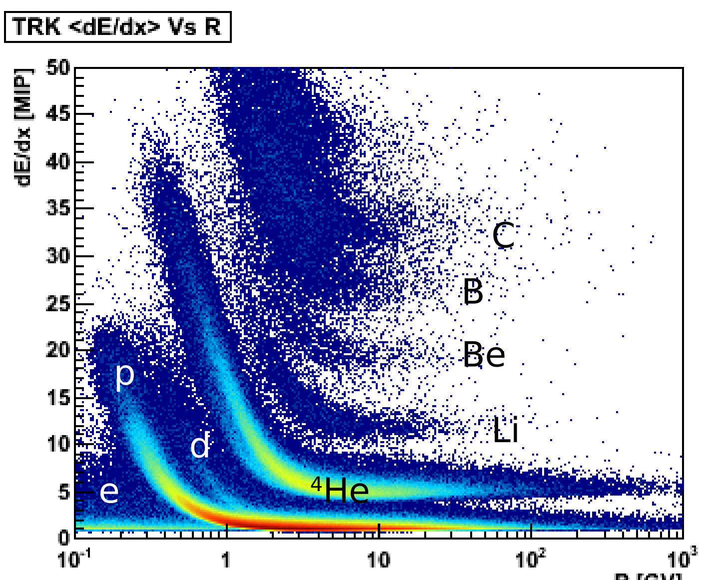
Neutron detector
36 ^3He counters
- High-energy e/h discrimination

The magnetic spectrometer

Provides, among other informations, the **sign of charge**, which is crucial to identify antiparticles



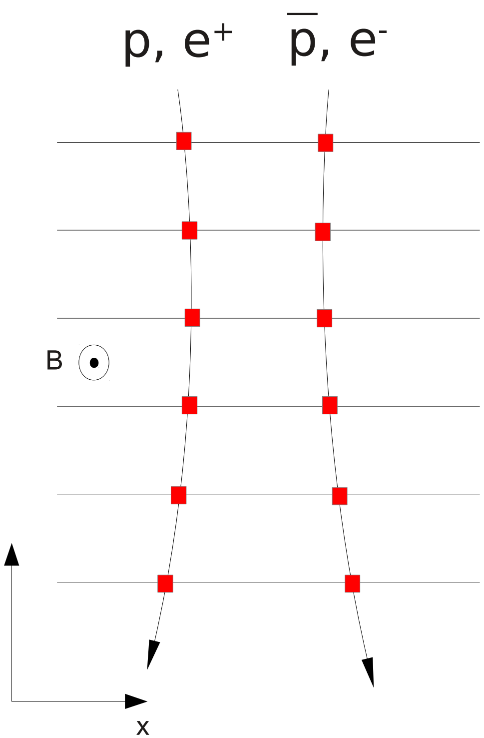
Tracker module

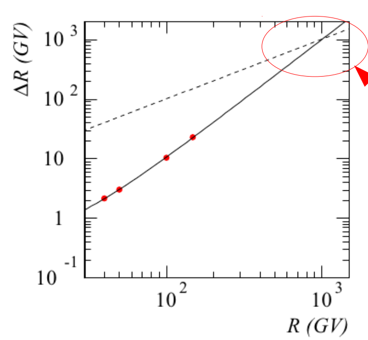


Particle identification with dE/dx

- ~ uniform magnetic field along Z, $\langle B \rangle_{center}$ = 0.43 T
- Magnetic cavity defines the whole PAMELA acceptance:
  GF = 21.5 cm^2 sr
  - Small variations with energy due to track curvature

- Position resolution:
  σ_x=3μm, σ_y=13μm
- Bending radius ρ is obtained by fitting points with trajectory and then:
  R α ρB
- Rigidity resolution worsening at high energy is due to finite position resolution:
  - $\Delta\eta_{res}$ ~ const (η=1/R)
- **M**aximum**D**etectable**R**igidity: σ_R ~ R
  - Spillover (wrong sign determination)

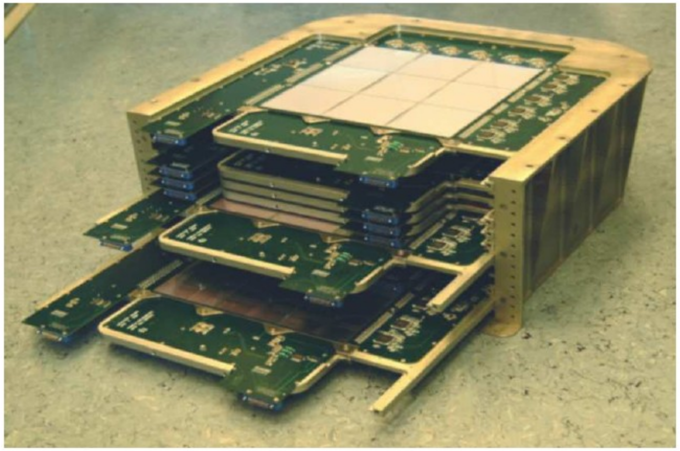




MDR ~ 1 TV

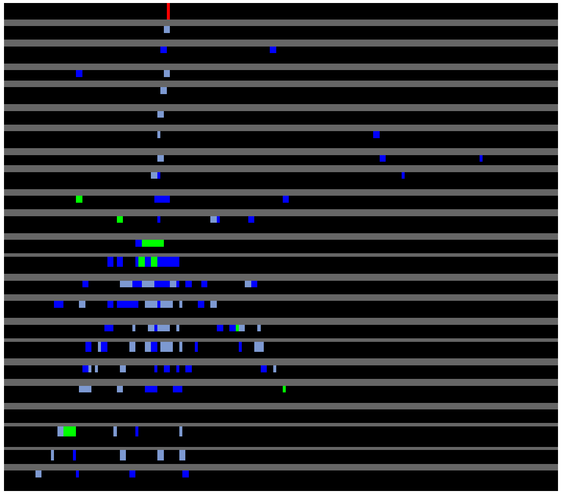
The e.m. calorimeter

Topological shower information is used to discriminate hadrons from leptons. Direct measurement of energy for $e^{\pm}$.

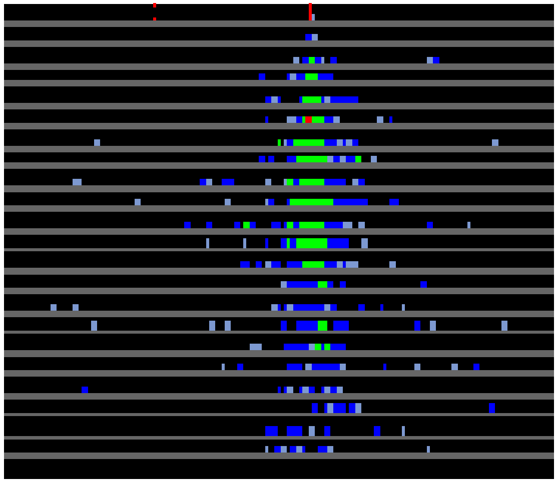


- 22 Si-W-Si layers
- Si strip pitch: 2.4 mm
  - Very good sampling of lateral shower development
- Depth: 16.3 X_0
  - Good longitudinal containment for $e^{\pm}$
  - Energy measurement for $e^{\pm}$
- Energy resolution for $e^{\pm}$:
  - ~ 8% @ 10 GeV → ~ 3% @ 100 GeV
  - Good containment required to exploit such performances

hadron (R=19GV)

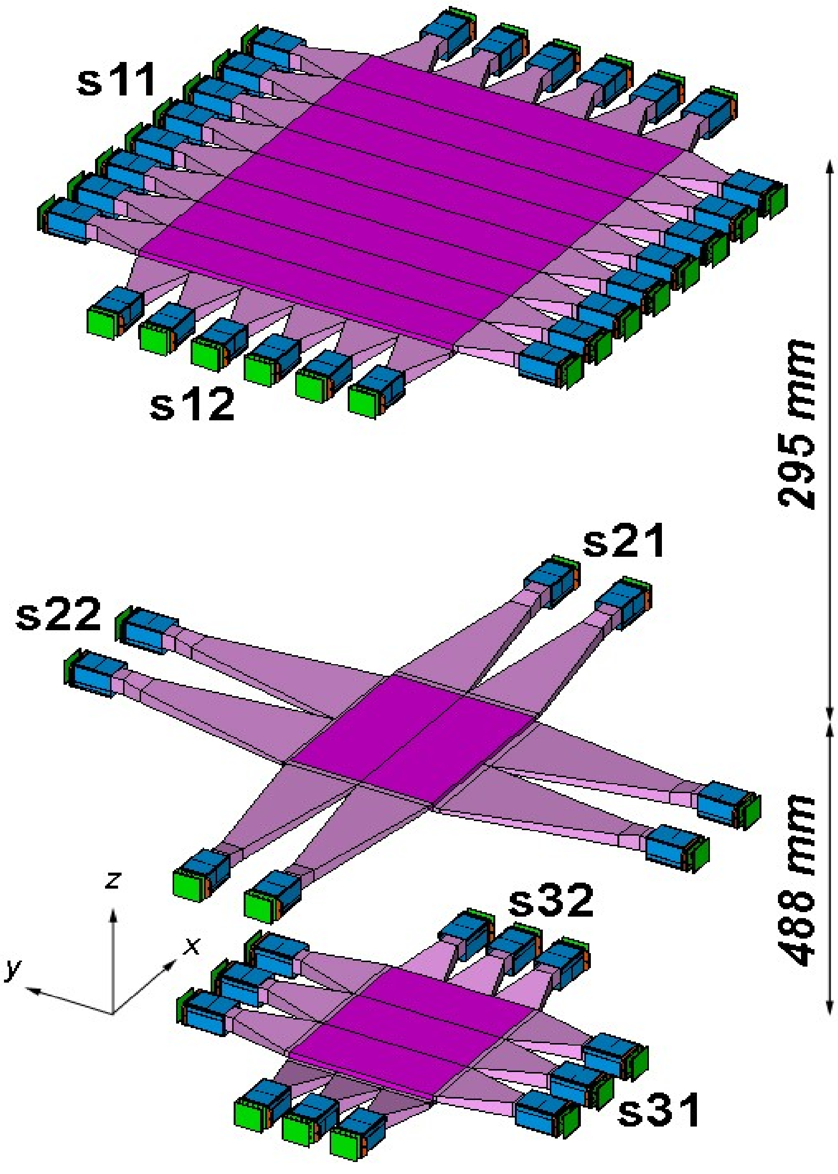


electron (R=17GV)

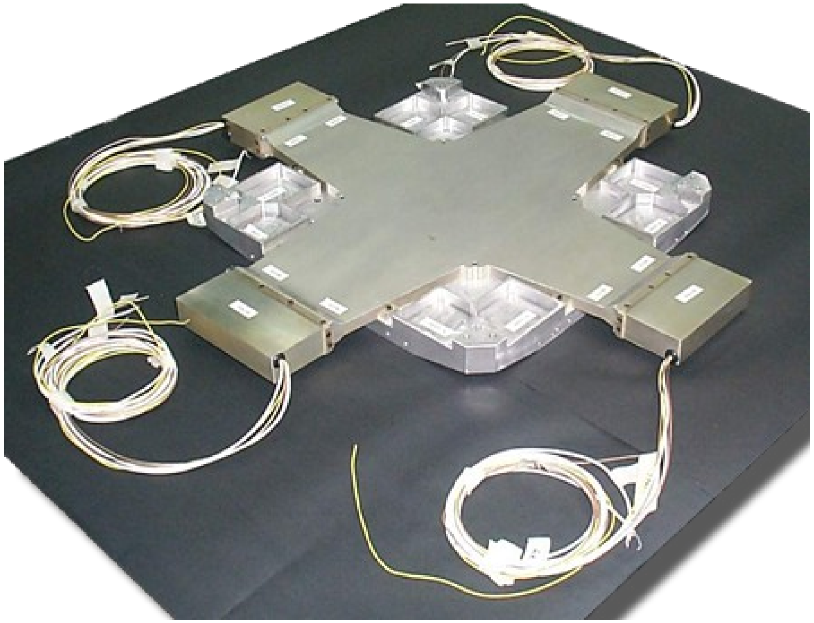


- Hadron/lepton rejection power ~ 10^5
  - From simulations & test beam

The Time-of-Flight system



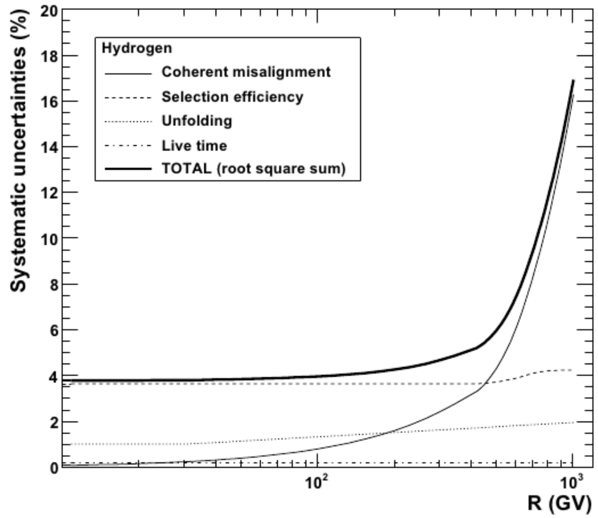
- 6 layers of plastic scintillators arranged in 3 XY planes
- It provides:
  - trigger
  - time-of-flight measurement
    - β
    - albedo rejection
  - ionization loss (dE/dx) measurement
- Resolution on time-of-flight measurement: 250 ps

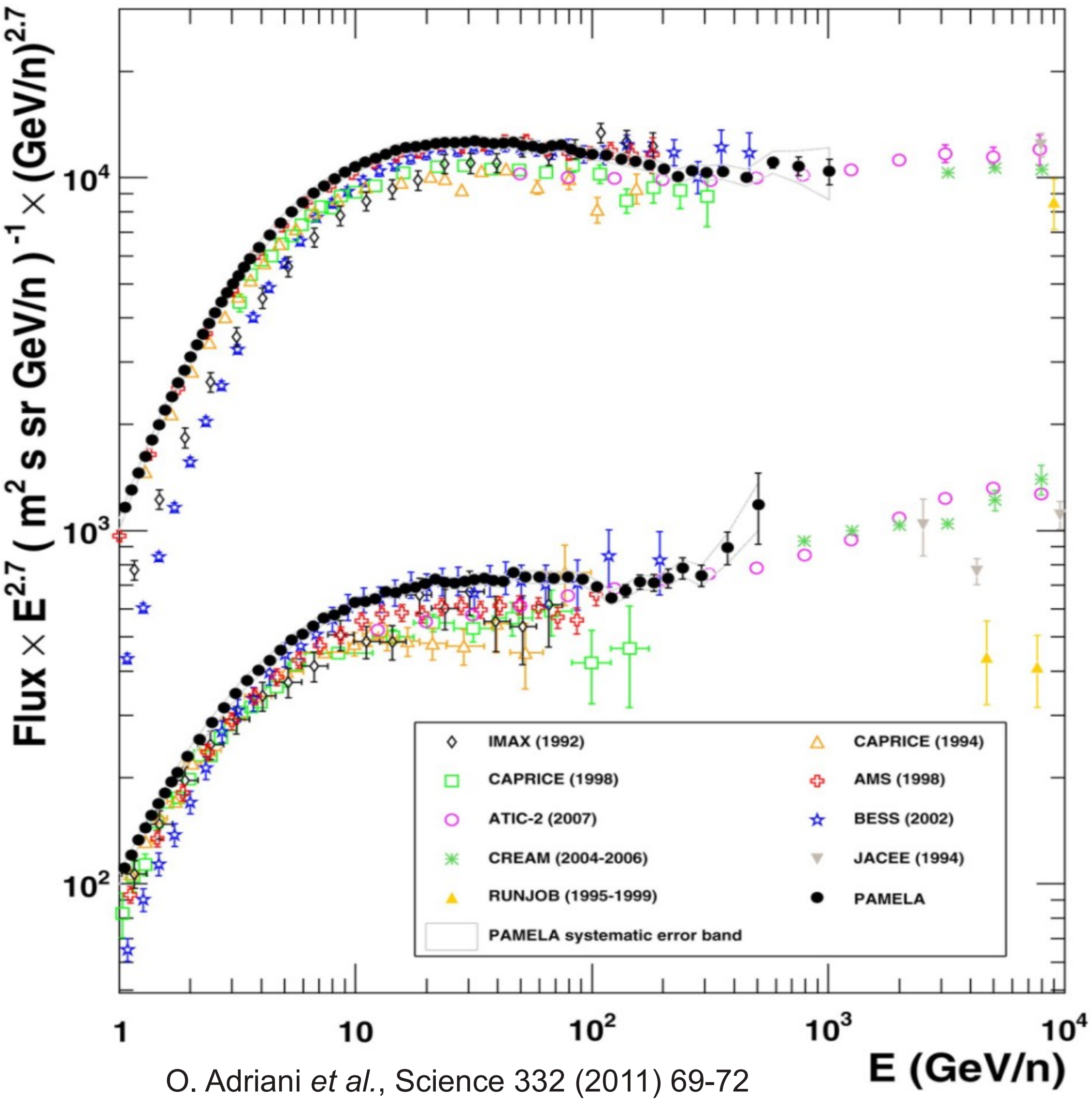


Protons, helium, antiprotons

Protons and helium

- Most abundant species
- Measure selection efficiencies using flight data
- Corrections from simulation
  - Cross-check with flight data
- No ground calibrations are used



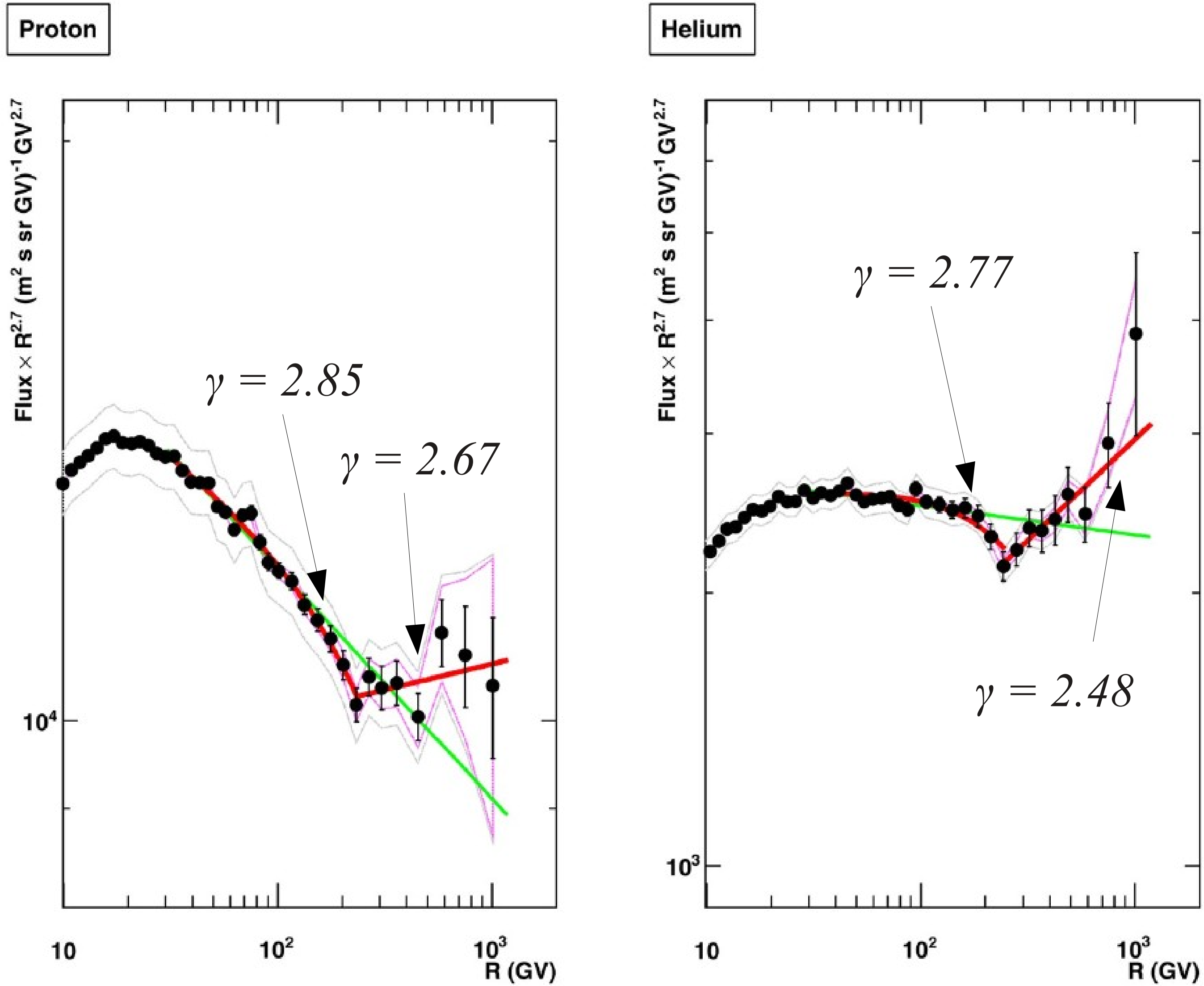


O. Adriani *et al.*, Science 332 (2011) 69-72

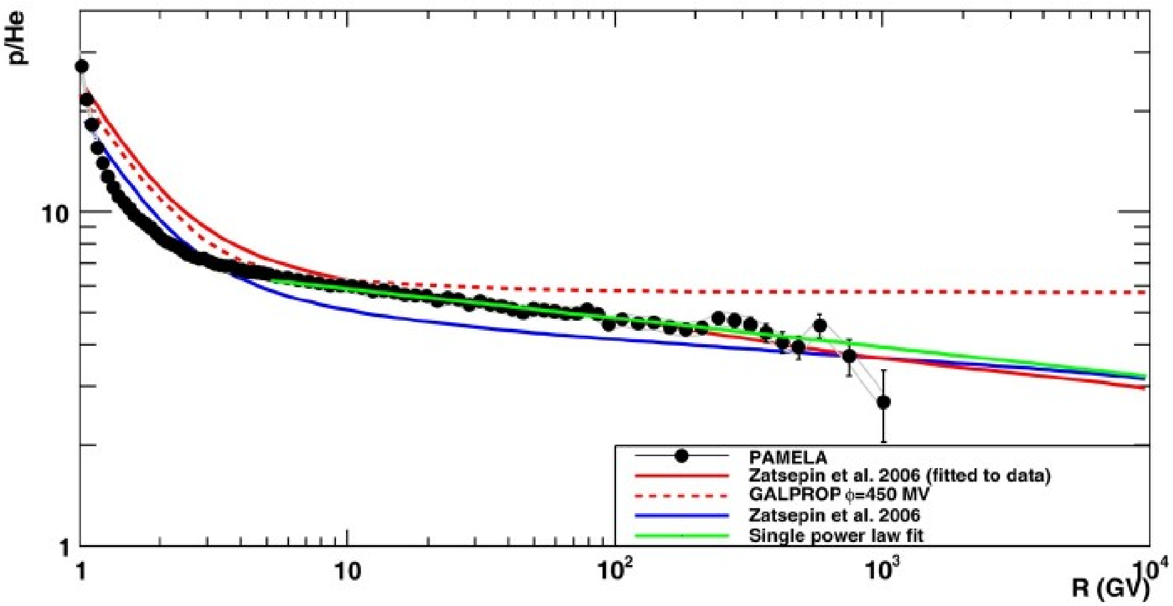
- New features in the spectra:
  - Gradual softening in rigidity range 30 – 230 GV

$$\varphi = A * R^{-\gamma - \alpha \frac{R - R_0}{R}}$$

  - Single power law (SPL) hypothesys is rejected at 95% c.l. (according to Fisher's and Student's *t* tests)
  - Sudden hardening around 235 GV
  - SPL hypothesys rejected at 95% c.l. for both protons and helium

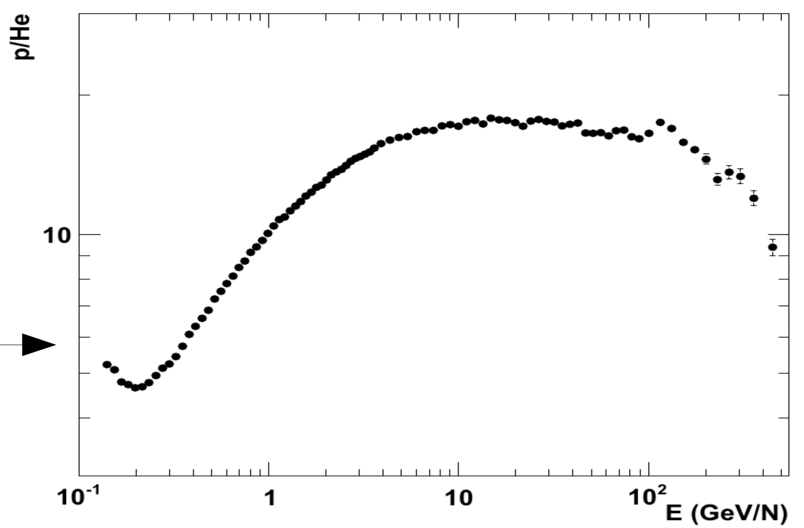


- Ratio of fluxes:
  systematics partially cancels out
- Solar modulation effects ~ negligible above 5 GV
- First strong experimental evidence of different p and He spectral index



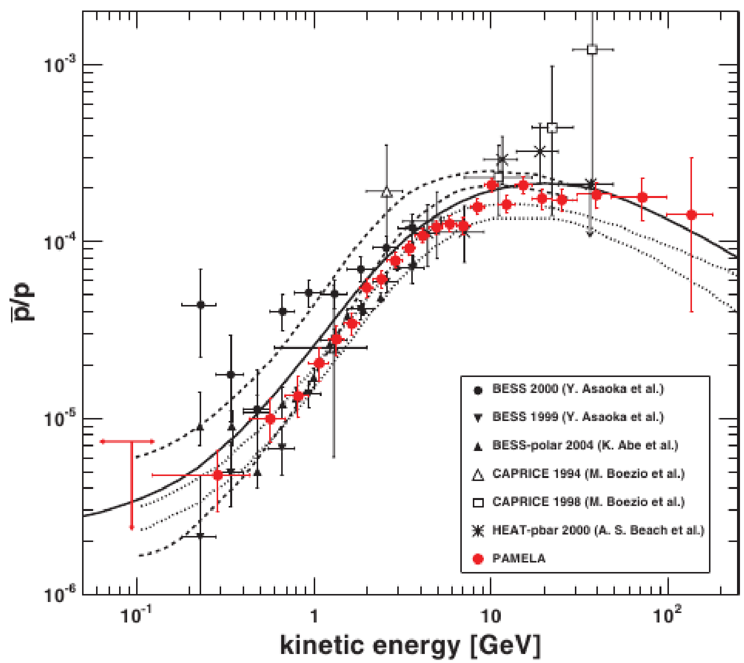
- p/He vs R is consistent with SPL above 5 GV, despite the many structures seen in single spectra
  - Consistent with SPL:

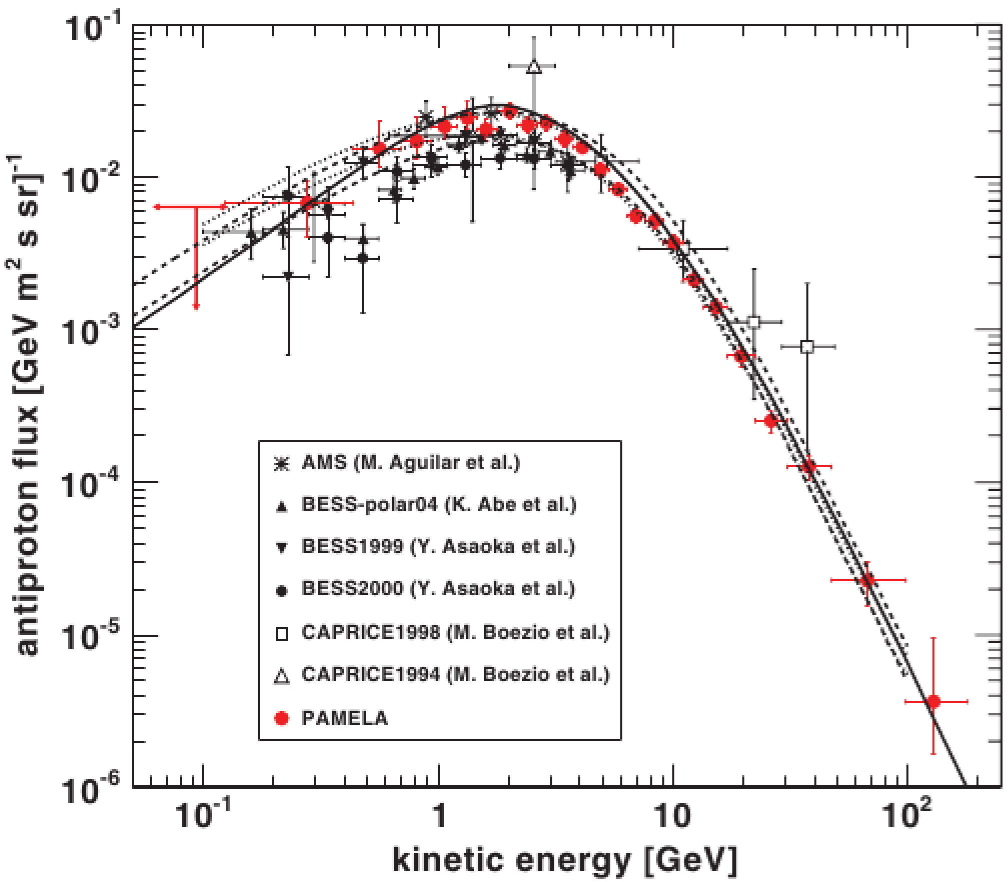
    $\Delta\gamma = \gamma_p - \gamma_{He} = 0.101 \pm 0.0014 \pm 0.0001$
- p/He vs energy does not show such a regular behavior



Antiprotons

- Far less abundant than protons and electrons
  - $\bar{p}/p \sim 2\times10^{-4}$ @ 10 GeV
- Strong calorimetr/spectrometer requirements to reduce contamination





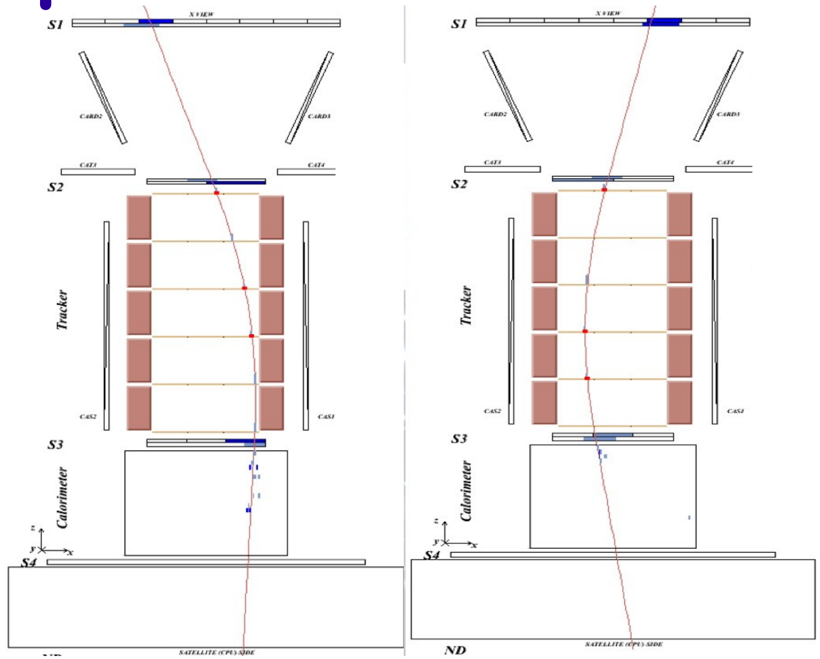
O. Adriani *et al.*, Physical Review Letters 105, 121101 (2010)

- Selection efficiencies can be measured using proton sample from flight data
  - Less dependence on simulations
  - Reduced systematics

Electrons and positrons

Electrons and positrons are identified by tracker and calorimeter:

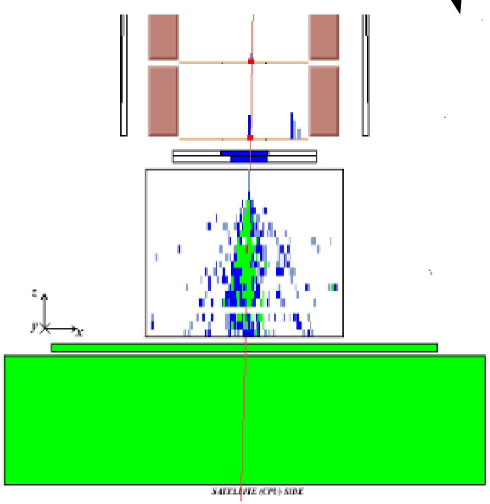
- Tracker can identify particle's charge
- Calorimeter can identify leptons and hadrons



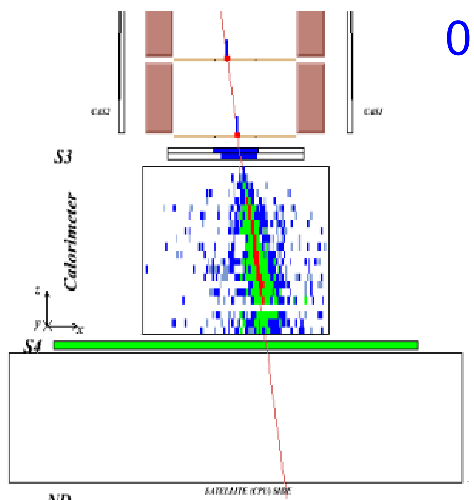
0.171 GV positron 0.169 GV electron

Most important contamination: <u>protons</u>

- Eg., spillover protons in e^- sample: ~% @ 100 GV → 1000% @ 500 GV
- Reduced to a negligible amount using calorimeter



proton

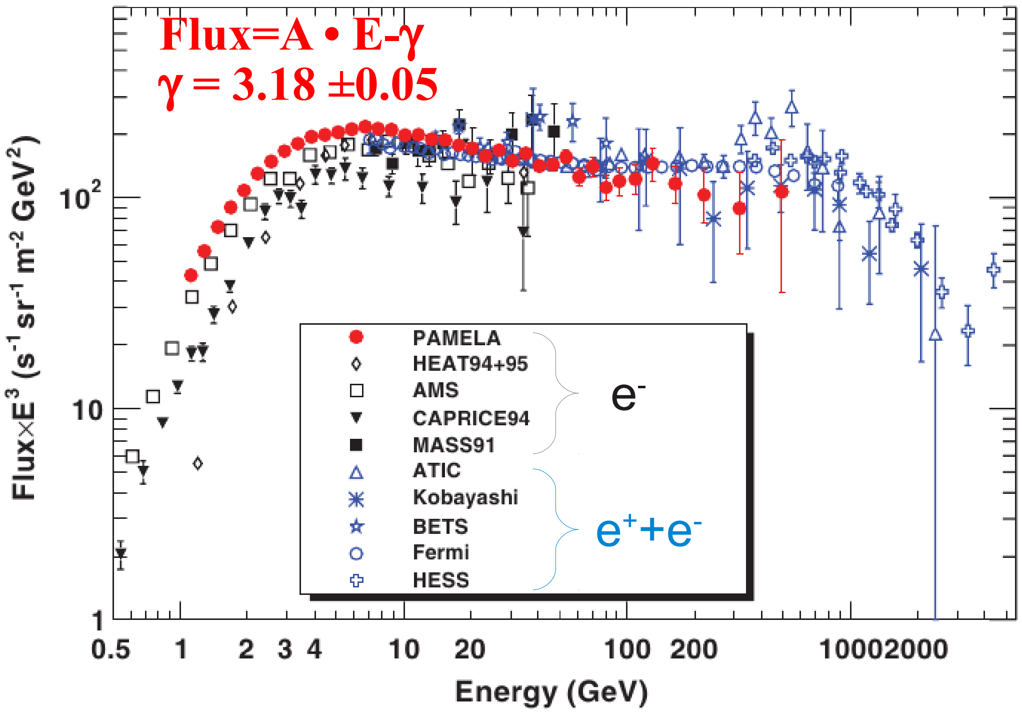


electron

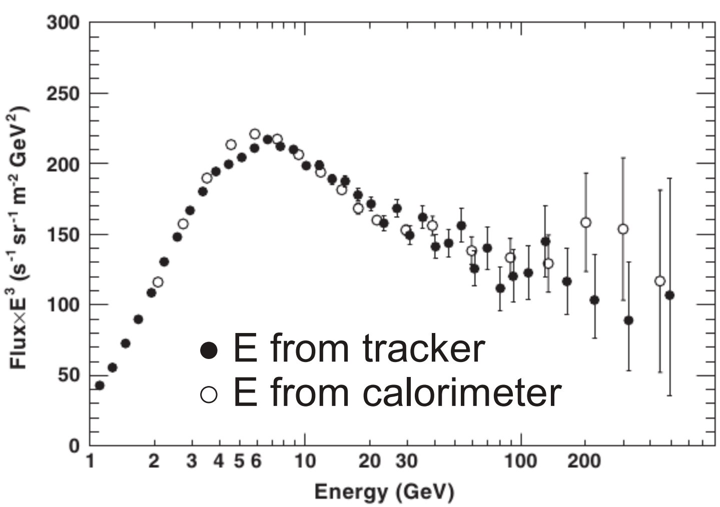
The tracker – segmented calorimeter combo is essential to obtain excellent lepton-hadron and charge separations

Electrons

- Highest energy currently available spectrometric electron flux
  - Calorimeters (eg. ATIC) cannot separate e^+ from e^-
  - Separate e^+ and e^- spectra by Fermi using the Earth's magnetic field



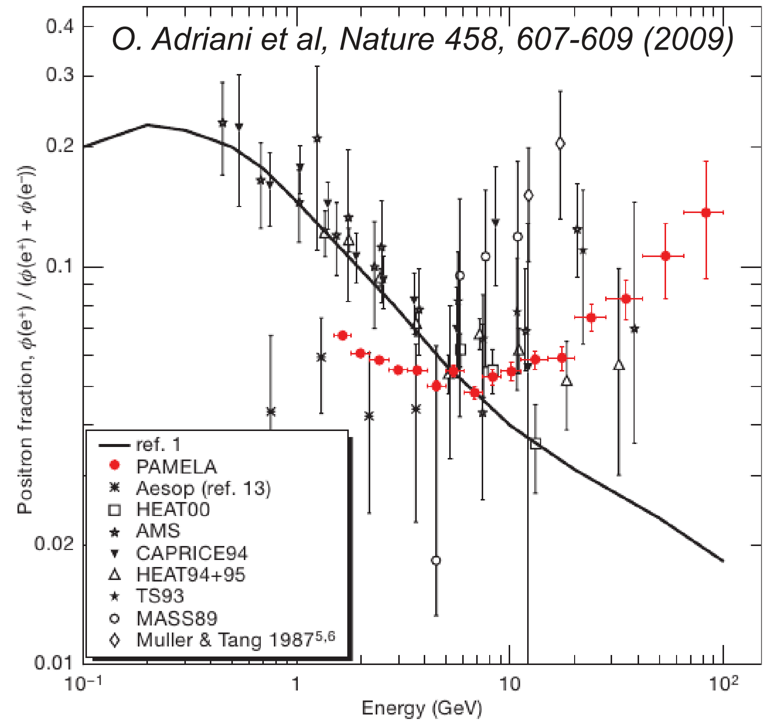
O. Adriani et al, Physical Review Letters 106, 201101 (2011)

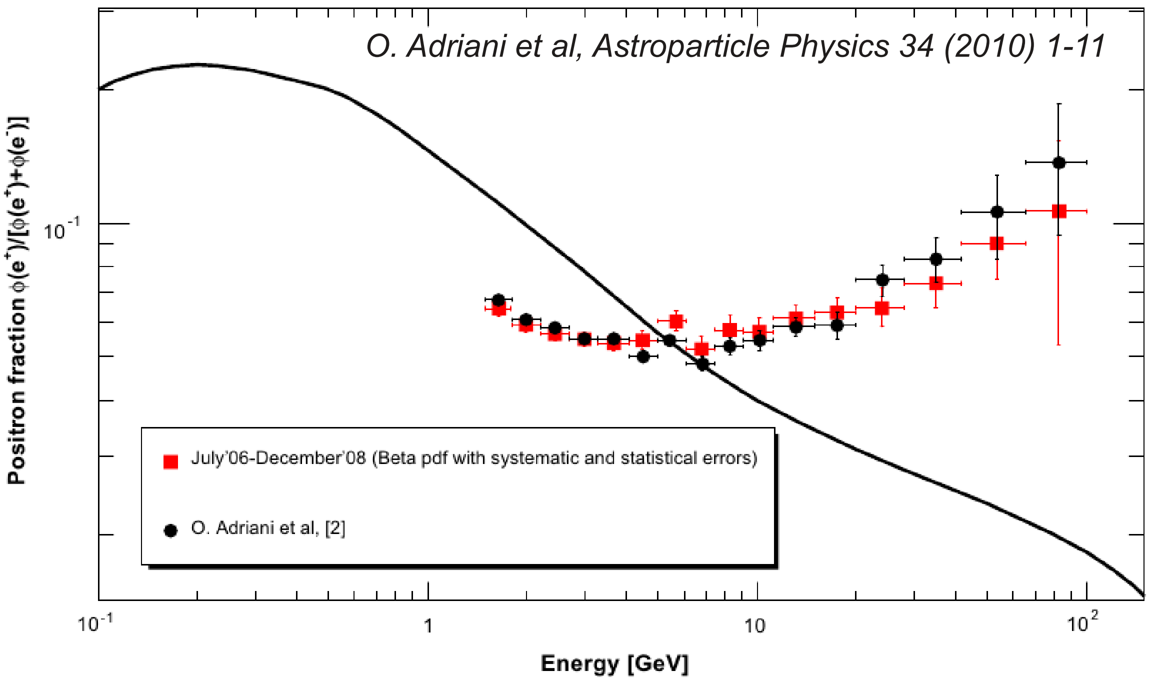


- Energy measurement can be done separately by tracker and calorimeter
  - Possibility to check instrumental effects and correction factors (eg. bremsstrahlung correction in tracker)

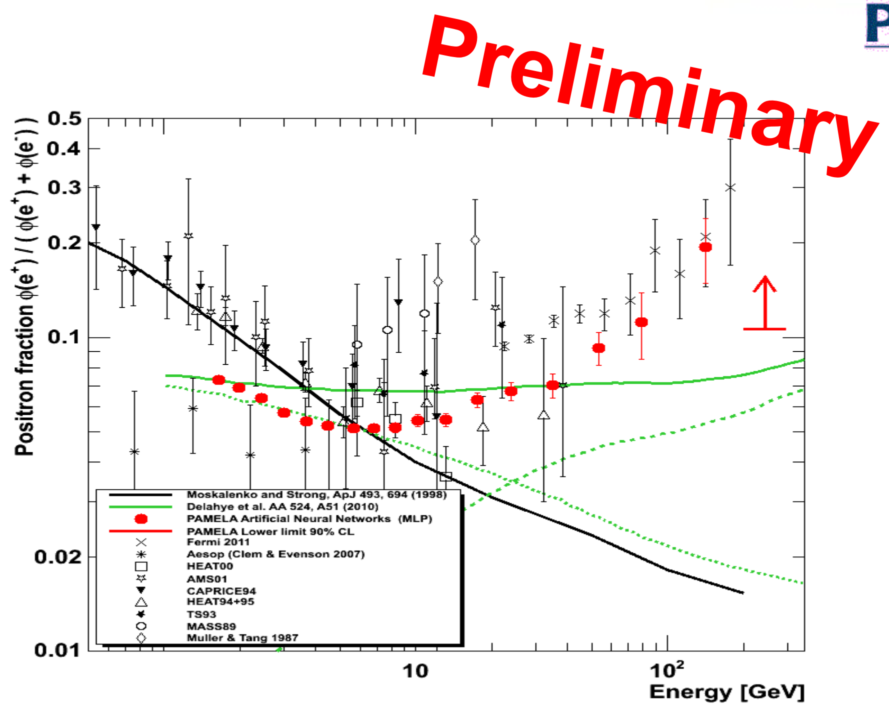
Positrons

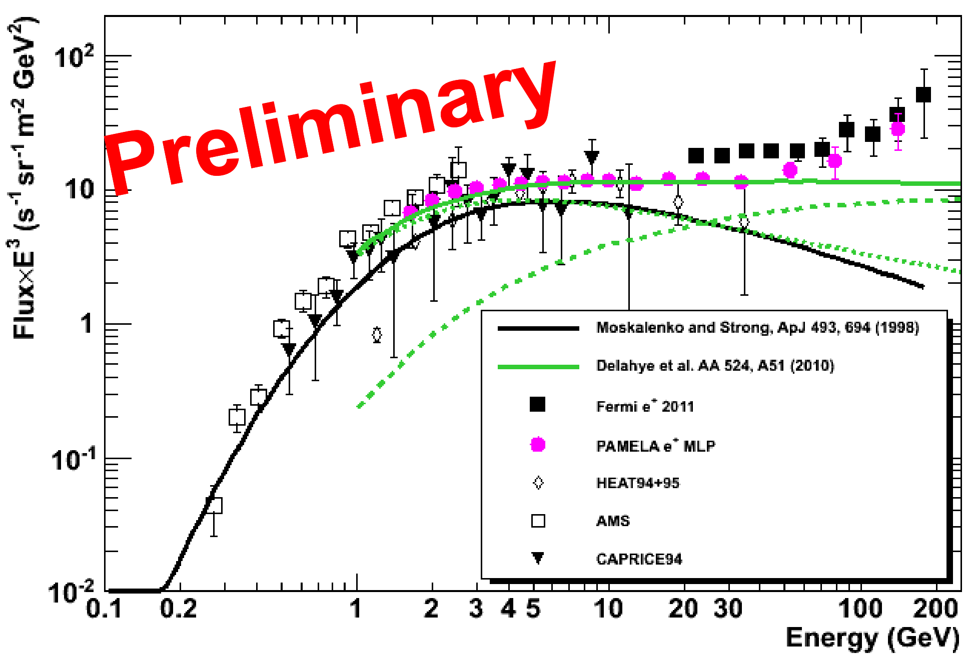
- Spectrometer alone can't help in separating relativistic protons from positrons
- First consistency criterion: energy-rigidity match
- Second criterion: shower topology
- Residual contamination estimated by statistical methods, using only flight data





- Work in progress to cross-check the results and extend energy range
  - Alternative approach based on artificial neural networks
  - Lower limit on flux up to 300 GeV





- Absolute positron flux
  - Obtained from neural network analysis based on Multi-Layer Perceptrons (MLP)

Interpretations

Rising positron fraction requires a primary positron component (Serpico, Phys.Rev. D79 (2009) 021302)

Astrophysical objects

- Pulsars (Hooper, Blasi & Serpico, JCAP 0901 (2009) 025)
- Secondary production in SNR (Blasi, Phys.Rev.Lett. 103 (2009) 051104)

Dark Matter annihilation/decay

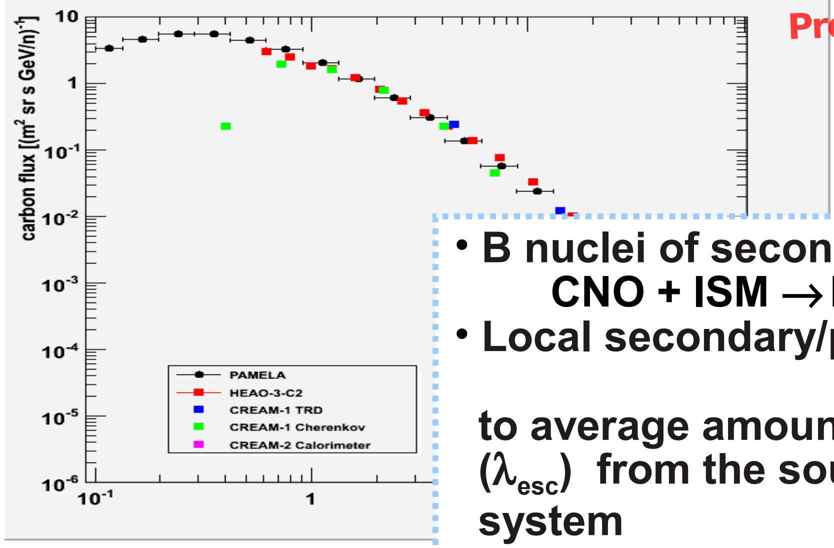
- Neutralino annihilation (Bergström, Bringmann & Edsjö, Phys.Rev. D78 (2008) 103520)
- Kaluza-Klein annihilation (Hooper & Zurek, Phys.Rev. D79 (2009) 103529)
- DM decay (Ibarra & Tran, JCAP 0902 (2009) 021)
- ...

Some tensions:

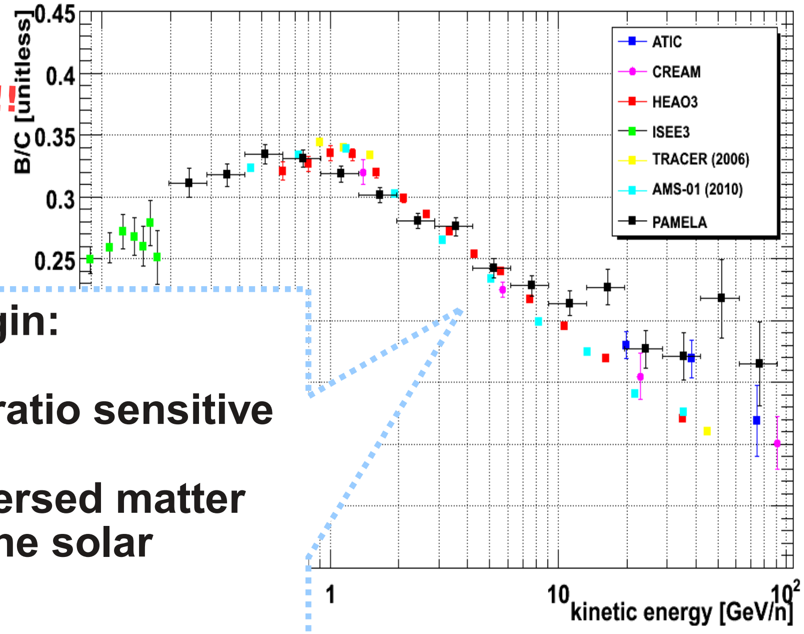
- Hard positron spectrum (very large CS, local DM clump, Sommerfeld enhancement...)
- No anomaly in antiproton spectrum ("leptophilic" DM)
- No DM signals in Fermi-LAT data yet...

Light nuclei

Carbon flux



Preliminary!!



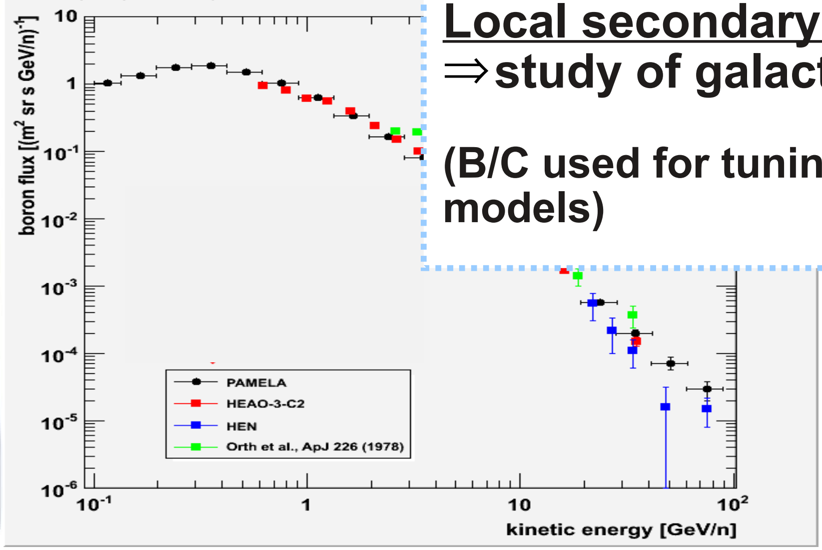
- B nuclei of secondary origin:
  CNO + ISM $\rightarrow$ B + …
- Local secondary/primary ratio sensitive

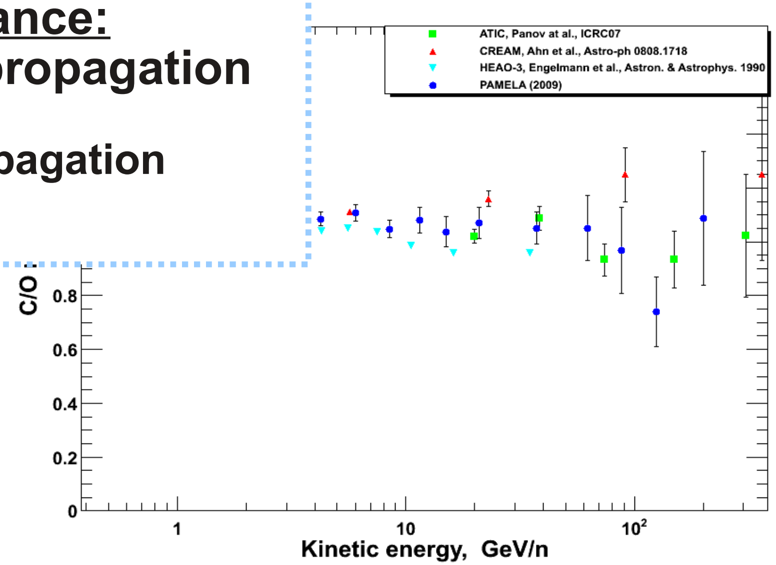
  to average amount of traversed matter (λ_{esc}) from the source to the solar system

<u>Local secondary abundance:</u>
$\Rightarrow$ study of galactic CR propagation

(B/C used for tuning of propagation models)

Boron flux





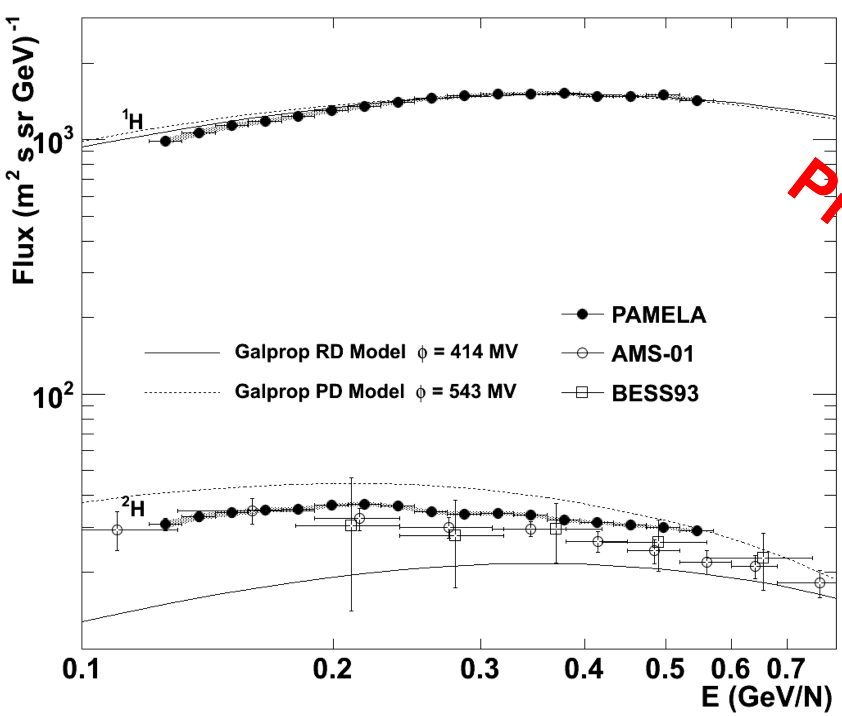
Isotopes

- Non-relativistic isotopes can be identified by means of a Time-of-Flight measurement:

$$R=\frac{p}{ze}=\frac{m\gamma\beta}{ze}=\frac{m\sqrt{\frac{1}{1-\beta^2}}\beta}{ze}$$

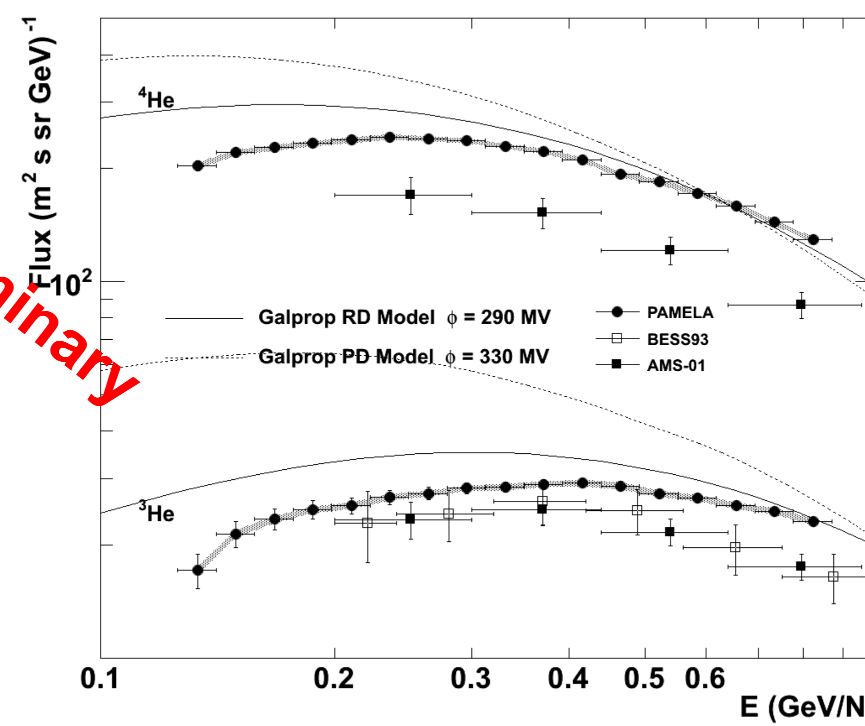
  - Independent measurements of R and β give the mass of the particle

Protons and deuterium



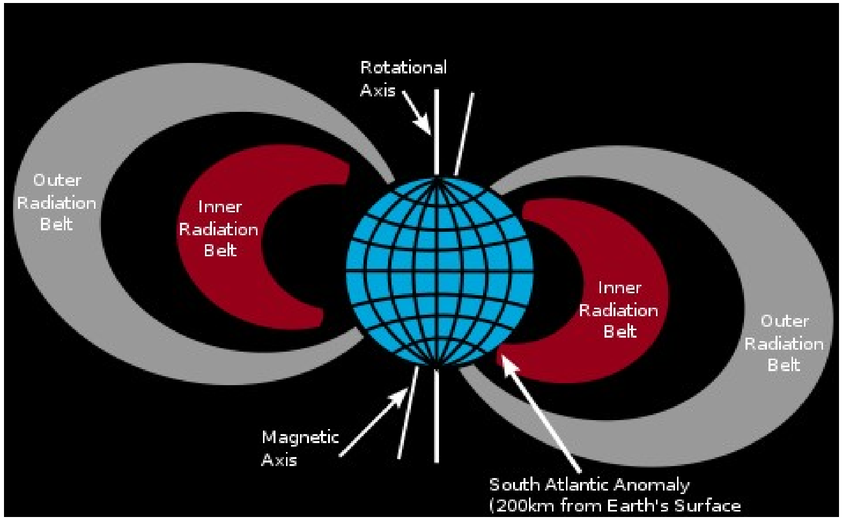
Preliminary

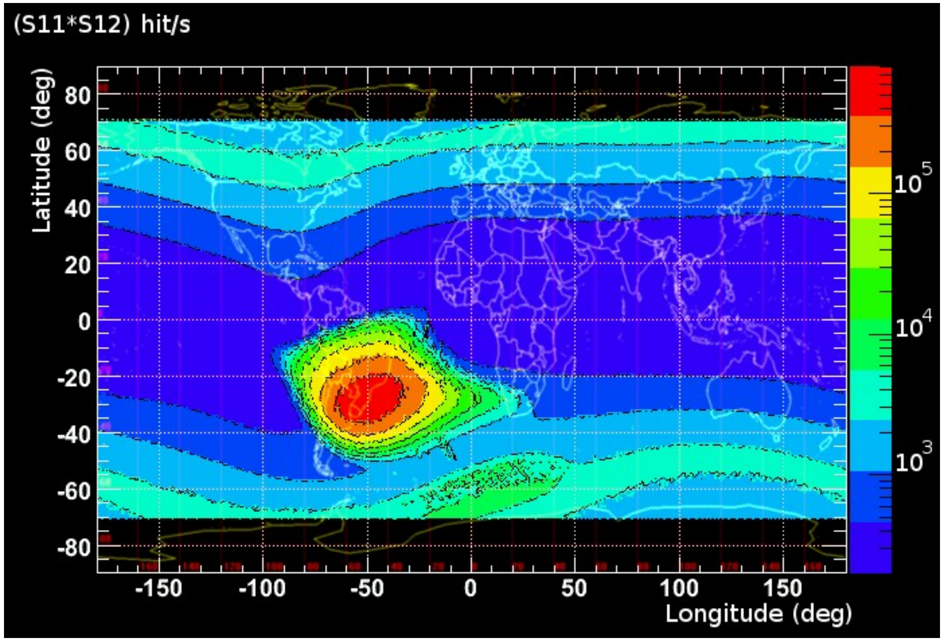
^{4}He and ^{3}He



Trapped particles

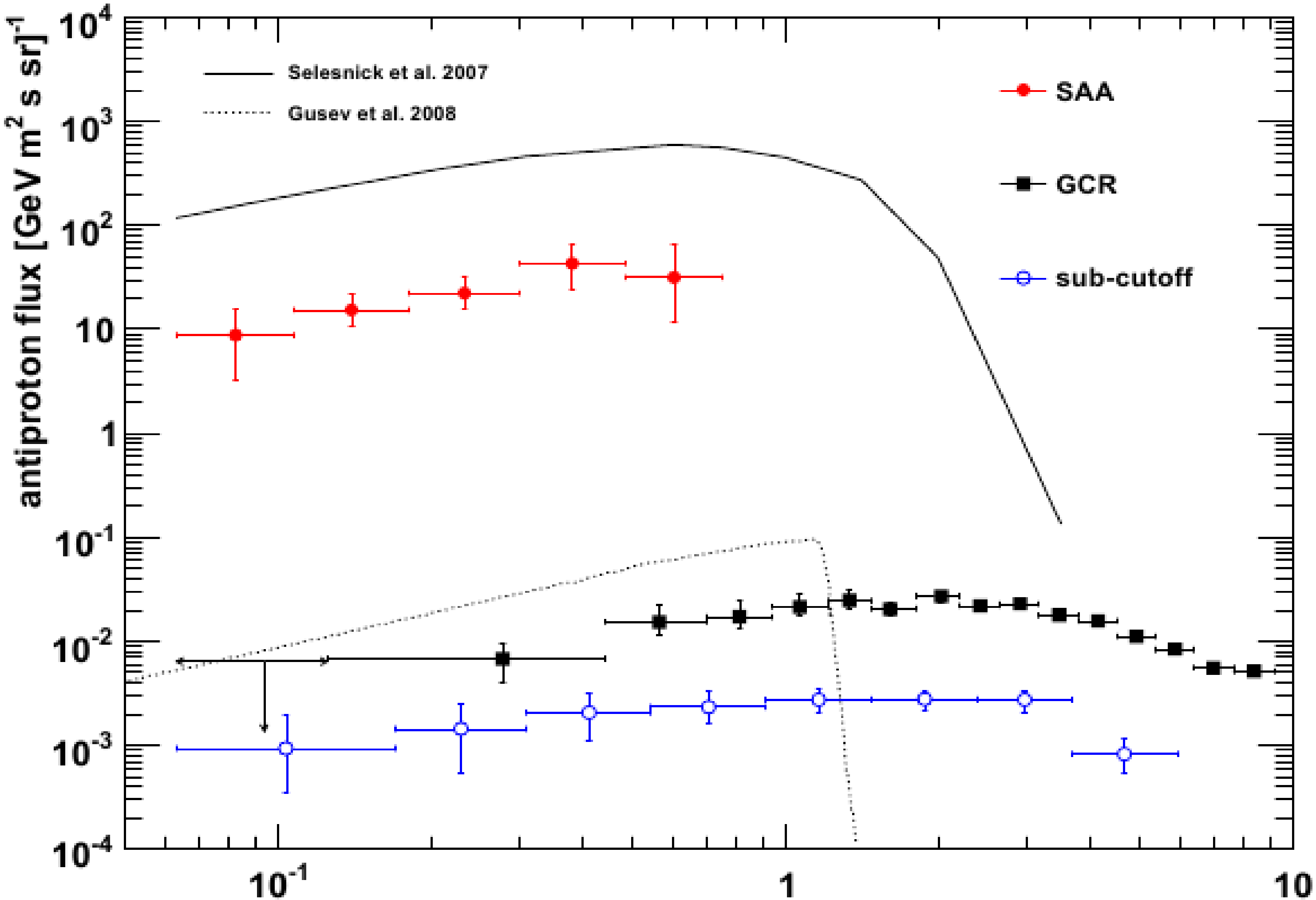
- The Earth's magnetic field can act as a “charged particles trap”
  - Van Allen's radiation belts
- Due to relative inclination of Earth's rotation and magnetic axes, radiation belt comes closer to Earth's surface ~ above Brazil
  - South Atlantic Anomaly (SAA)
- PAMELA's orbit height: 360 – 600 km





Trapped antiprotons

First evidence of the existence of trapped antiprotons

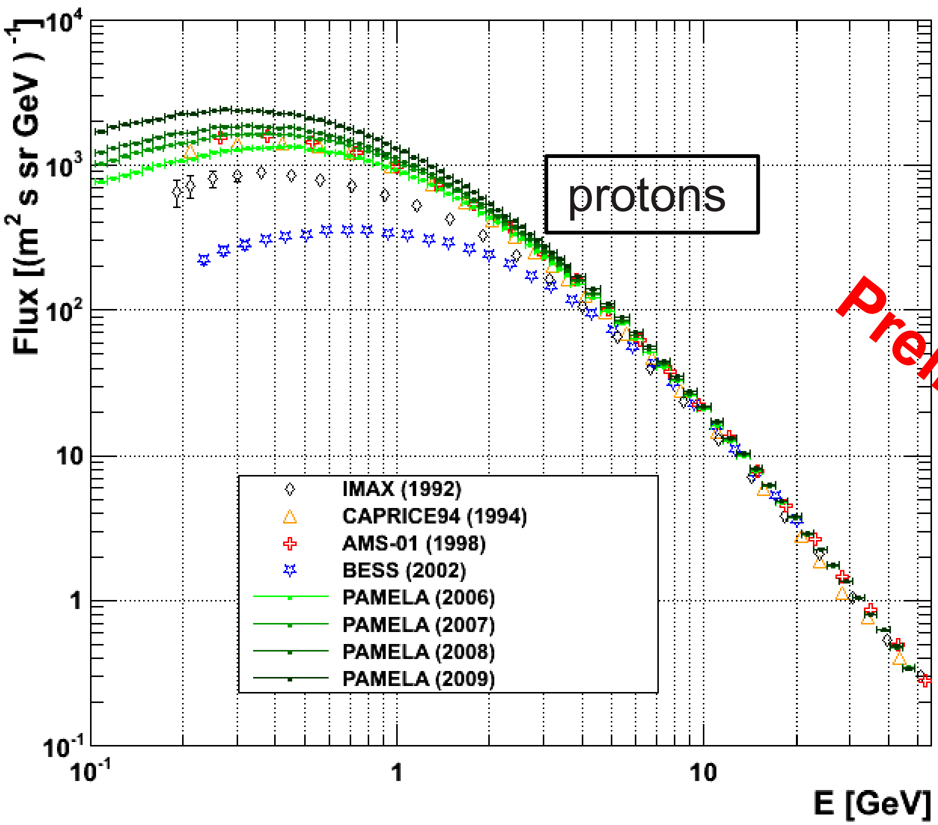


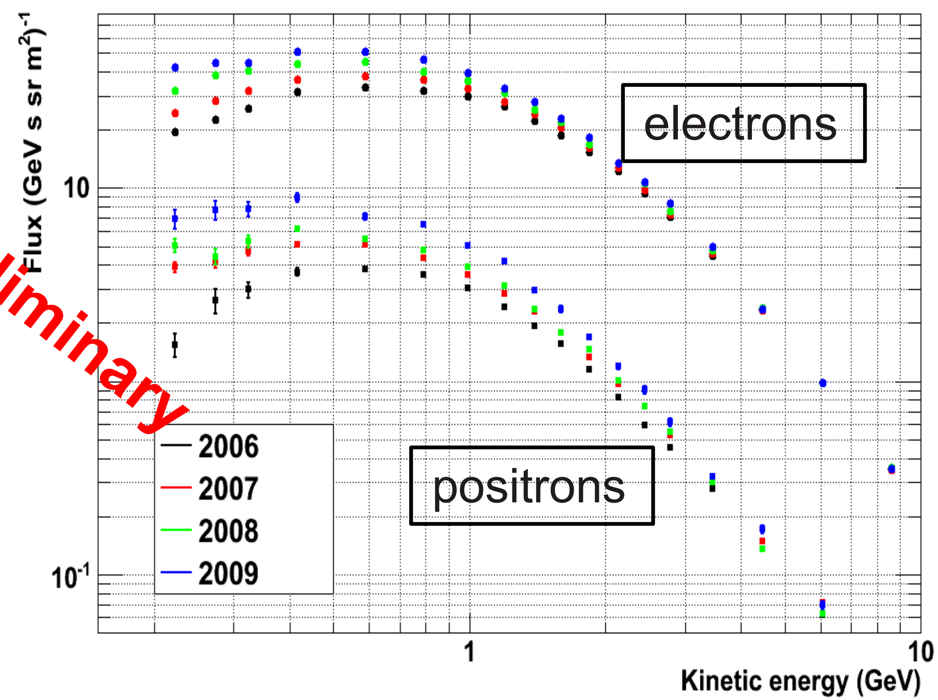
O. Adriani et al, Astrophysical Journal Letters 737 (2011) L29

Solar physics

Solar modulation

- Particles entering in the heliosphere from interstellar space interacts with solar magnetosphere and solar wind
- Time dependence of low energy fluxes, related to solar activity
- Modulation effects depends on sign-of-charge





Summary

- The PAMELA experiment has been taking data for more than 6 years, since June 2006
- Its capabilities make it possible to investigate many aspects of particle astrophysics, from dark matter to solar and geomagnetic physics
- Many new features discovered thanks to high precision, high statistics measurements, that raised interest and discussions in scientific community
- Analysis is going on to refine previous results and provide new ones

PAMELA in a shot!!