# Results from the PAMELA experiment

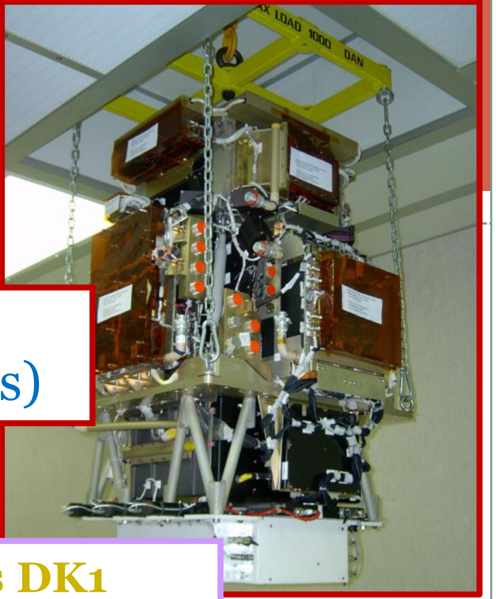
ELENA VANNUCCINI

ON BEHALF OF

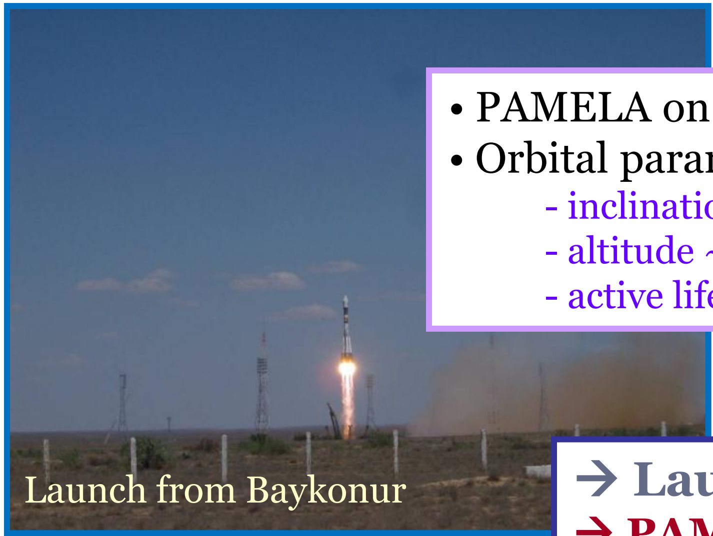
PAMELA COLLABORATION

# PAMELA

## Payload for Matter/antimatter Exploration and Light-nuclei Astrophysics

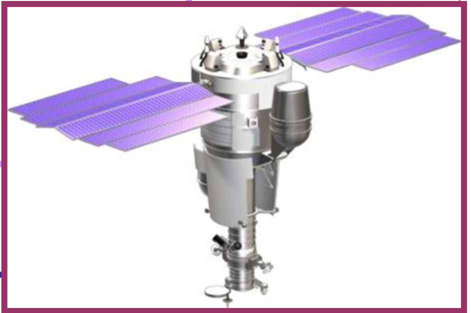


- **Direct** detection of CRs in space
- Main focus on **antiparticles** (antiprotons and positrons)



Launch from Baykonur

- PAMELA on board of Russian satellite **Resurs DK1**
- Orbital parameters:
  - inclination ~70° (⇒ low energy)
  - altitude ~ 360-600 km (elliptical)
  - active life >3 years (⇒ high statistics)



→ **Launched on 15th June 2006**

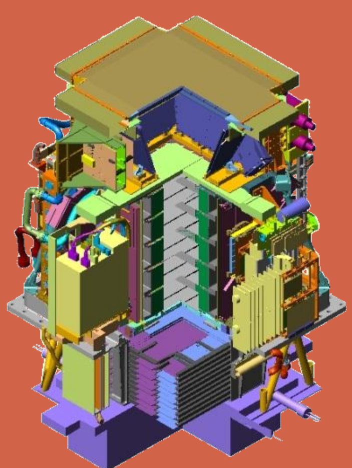
→ **PAMELA in continuous data-taking mode since then!**

# PAMELA detectors

Main requirements:

- high-sensitivity antiparticle identification

- precise momentum measure



**Time-Of-Flight**

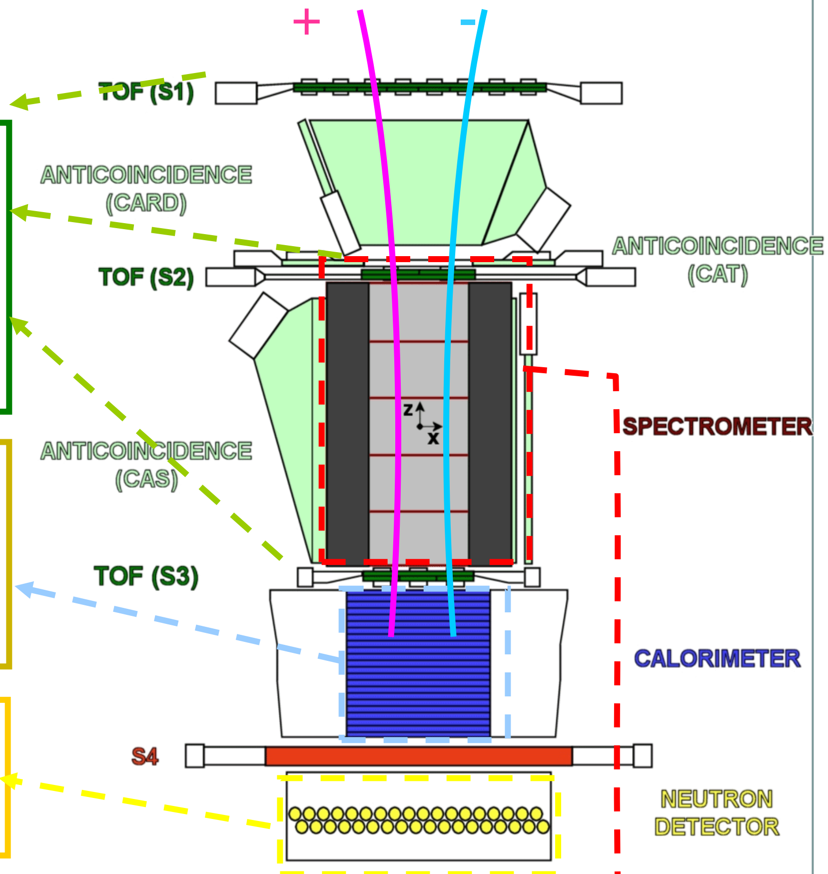
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

**Electromagnetic calorimeter**

W/Si sampling (16.3 X0, 0.6 λI)
- Discrimination e+ / p, anti-p / $e^-$ (shower topology)
- Direct E measurement for $e^-$

**Neutron detector**

plastic scintillators + PMT:
- High-energy e/h discrimination




**Spectrometer**

microstrip silicon tracking system + permanent magnet

It provides:
- *Magnetic rigidity* → $R = pc/Ze$
- *Charge sign*
- *Charge value from dE/dx*

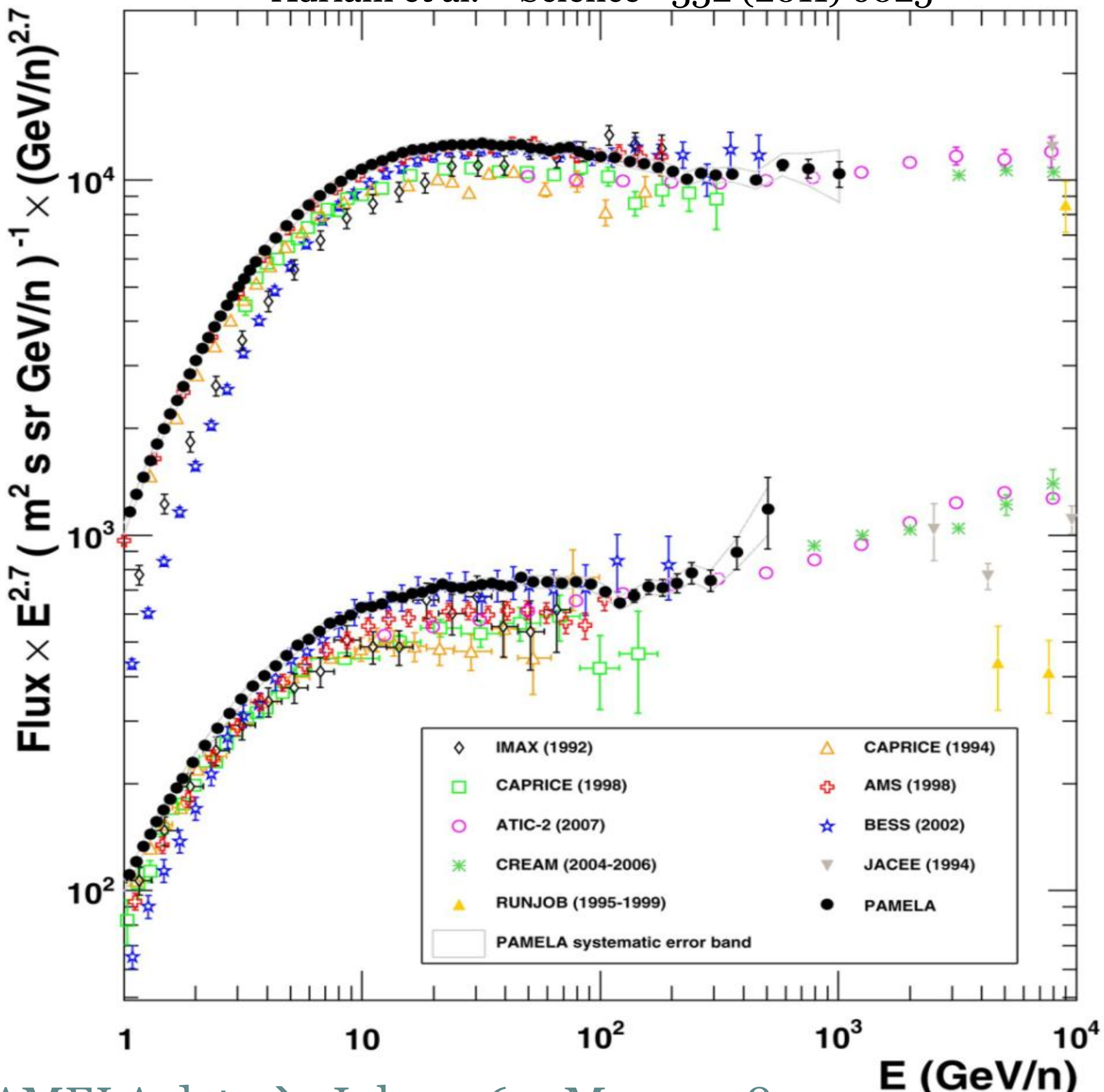
GF: 21.5 $cm^2$ sr
Mass: 470 kg
Size: 130x70x70 $cm^3$
Power Budget: 360W

# Absolute fluxes of primary GCRs

# H & He absolute fluxes

- First high-statistics and high-precision measurement over three decades in energy
- Dominated by systematics (~4% below 300 GV)
- Low energy → minimu solar activity ($\phi$ = 450÷550 GV)
- High-energy → a complex structure of the spectra emerges…

Adriani et al. - Science - 332 (2011) 6025




PAMELA data→ Jul 2006 ÷ Mar 2008

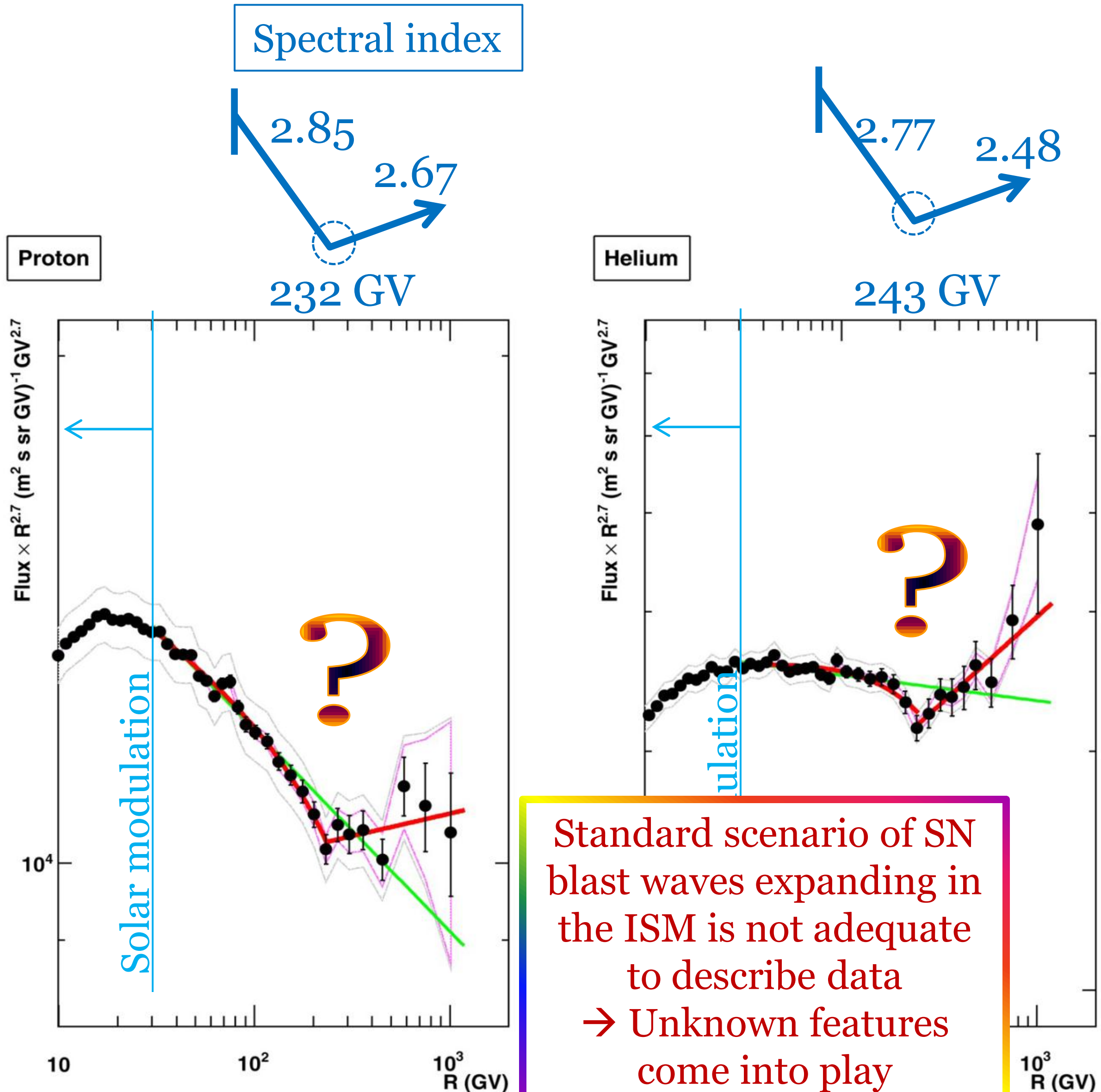
# P & He absolute fluxes @ high energy

Deviations from single power law (SPL):

- Spectra gradually soften in the range 30÷230GV
- Abrupt spectral hardening @ ~235GV

Eg: statistical analysis for protons

- SPL hp in the range 30÷230 GV rejected @ >95% CL
- SPL hp above 80 GV rejected @ >95% CL




Standard scenario of SN blast waves expanding in the ISM is not adequate to describe data
→ Unknown features come into play

# H/He ratio vs R

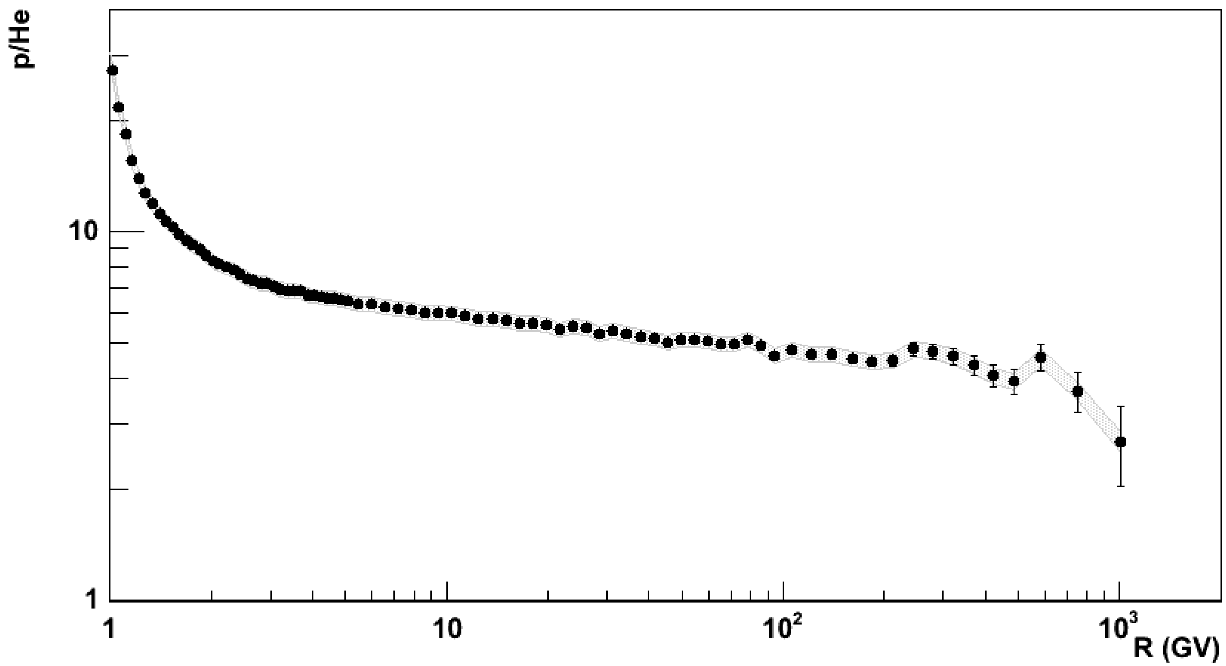
**Instrumental p.o.v.**

- Systematic uncertainties partly cancel out

**Theoretical p.o.v.**

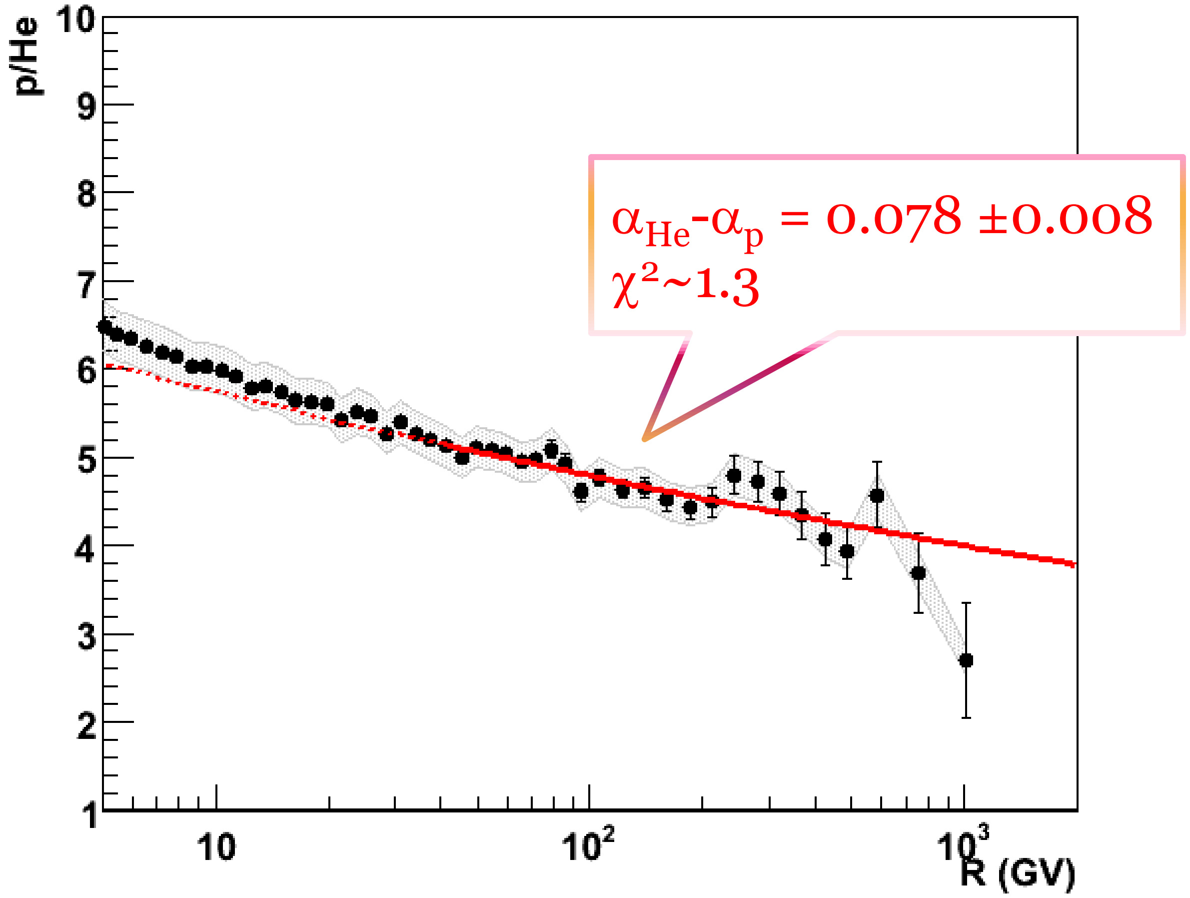
- Solar modulation negligible
  → information about IS spectra down to GV region
- Propagation effects (diffusion and fragmentation) negligible above ~100GV
  → information about source spectra

(Putze et al. 2010)



# P/He ratio vs R

- First clear evidence of different H and He slopes above ~10GV
- Ratio described by a single power law (in spite of the evident structures in the individual spectra)



# Electron energy measurement

Two independent way s to determine electron energy:

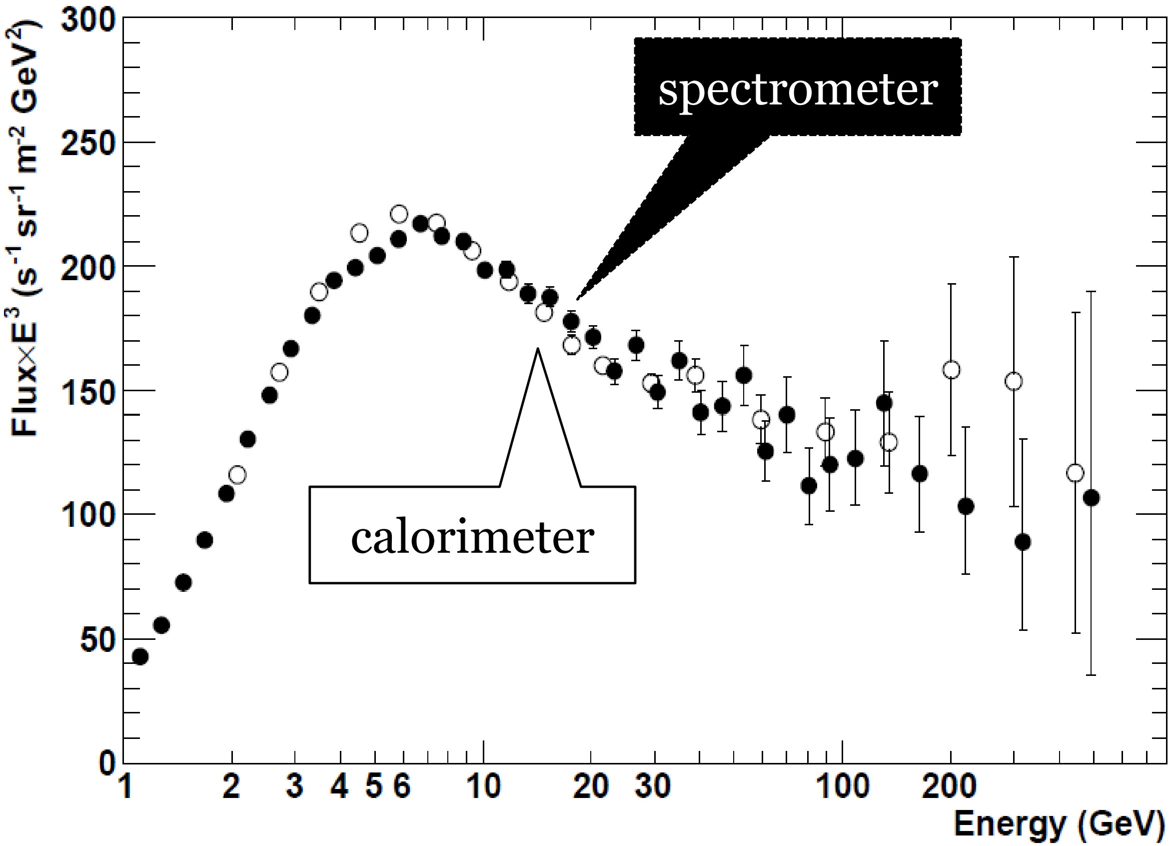
## 1. Spectrometer

- Most precise
- Non-negligible energy losses (bremsstrahlung) above the spectrometer → unfolding

## 2. Calorimeter

- Gaussian resolution
- No energy-loss correction required
- Strong containment requirements → smaller statistical sample

Adriani et al. - PRL - arXiv:1103.2880v1

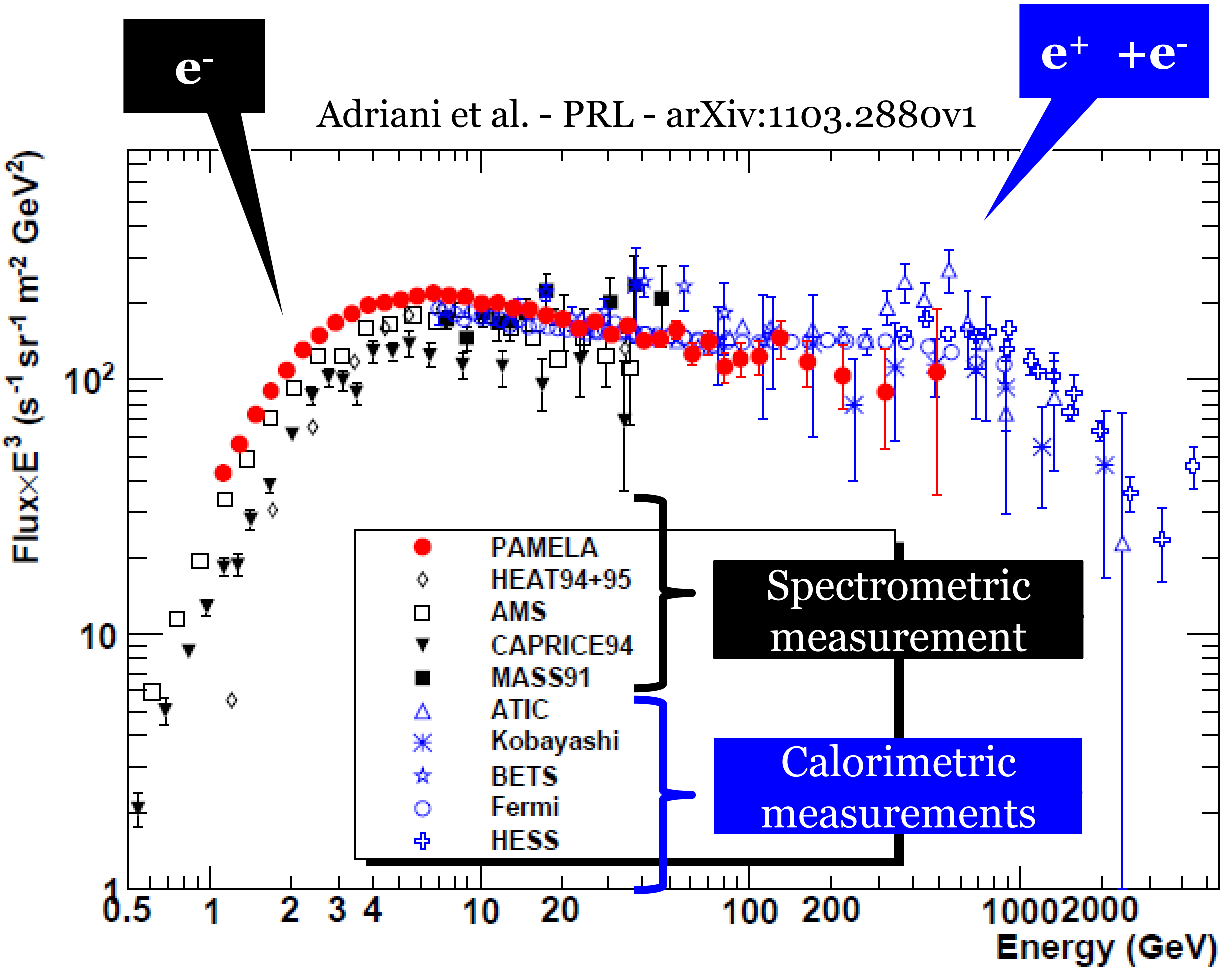



Electron identification:

- Negative curvature in the spectrometer
- EM-like interaction pattern in the calorimeter

# Electron absolute flux

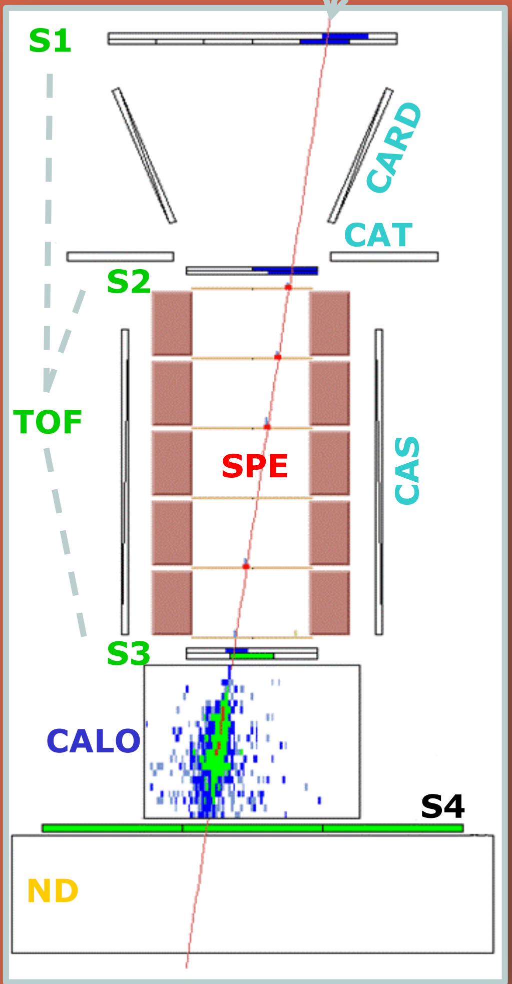
- Largest energy range covered in any experiment hitherto with no atmospheric overburden
- Low energy
  - minimum solar activity ($\phi = 450 \div 550$ GV)
- High energy
  - No significant disagreement with recent ATIC and Fermi data
  - Softer spectrum consistent with both systematics and growing positron component




PAMELA data → Jul 2006 ÷ Jan 2010

# Antiparticles

# Positrons




Positron/electron identification:

- Positive/negative curvature in the spectrometer
  → **$e^-/e^+$ separation**
- EM-like interaction pattern in the calorimeter
  → **$e^+/p$ (and $e^-/\bar{p}$) separation**

Main issue:

- **Interacting proton background**:
  - fluctuations in hadronic shower development: $\pi_0 \rightarrow \gamma\gamma$ mimic pure e.m. showers
  - $p/e^+$: ~$10^3$ @1GV ~$10^4$ @100GV

→ **Robust $e^+$ identification**

- Shower topology + energy-rigidity match

→ **Residual background evaluation**

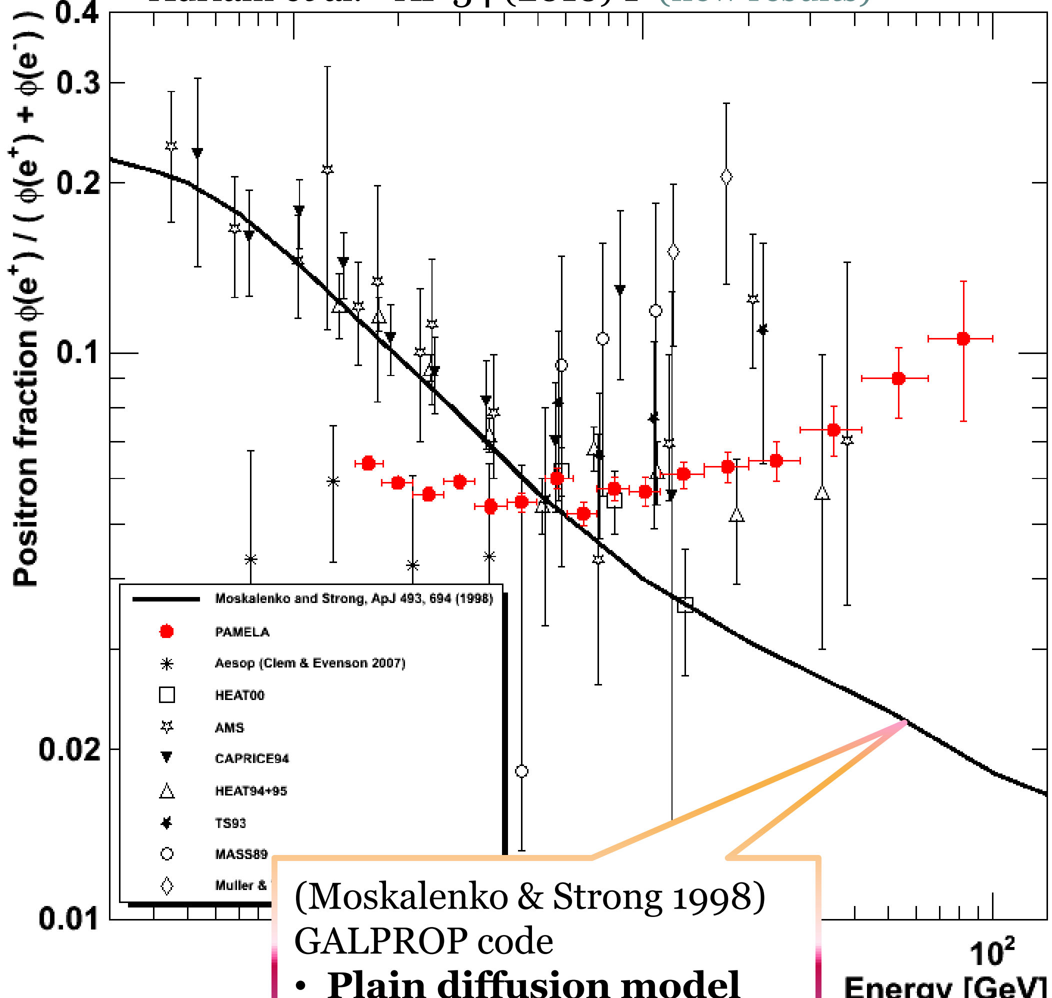
- Done with flight data
- No dependency on simulation

# Positron fraction

- Low energy
  → charge-dependent solar modulation
- High energy
  → (quite robust) evidence of positron excess above 10GeV

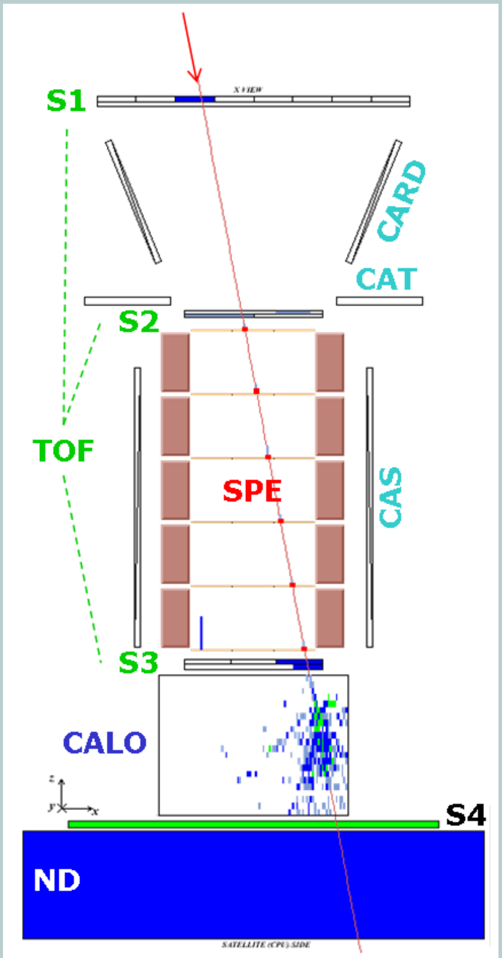
(see eg. Serpico 2008)

Adriani et al. – Nature 458 (2009) 607
Adriani et al. –AP 34 (2010) 1 (new results)




(Moskalenko & Strong 1998)
GALPROP code
- **Plain diffusion model**
- Interstellar spectra

# Antiprotons




Antiproton/proton identification:

- Negative/positive curvature in the spectrometer
  → **p-bar/p separation**
- Rejection of EM-like interaction patterns in the calorimeter
  → **p-bar/$e^-$ (and p/$e^+$ ) separation**

Main issue:

- **Proton "spillover" background**:
  wrong assignment of charge-sign @ high energy due to finite spectrometer resolution

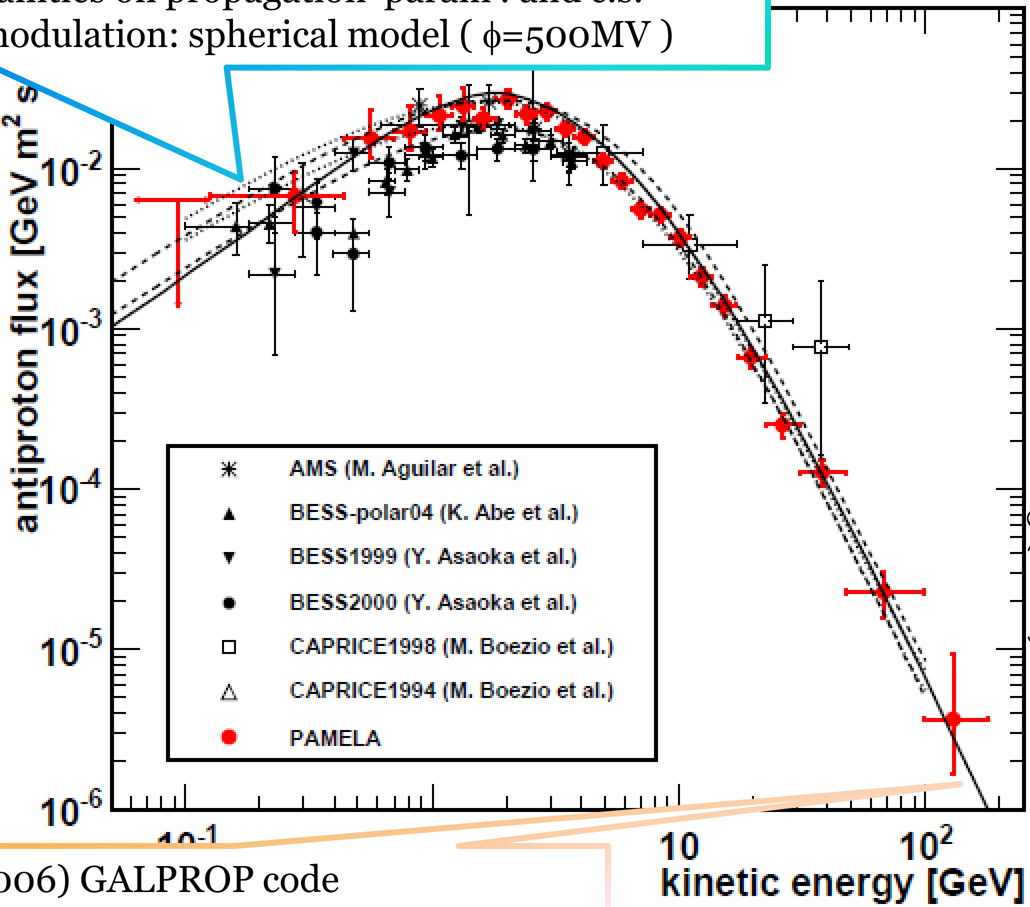
→ **Strong tracking requirements**
- Spatial resolution < 4μm
- R < MDR/6

→ **Residual background subtraction**
- Evaluated with simulation (tuned with in-flight data)
- ~30% above 100GeV

# Antiproton flux

- Largest energy range covered hiterto
- Overall agreement with pure secondary calculation
- Experimental uncertainty (stat⊕sys) smaller than spread in theoretical curves
  → constraints on propagation parameters

(Donato et al. 2001)
- **Diffusion model with convection and reacceleration**
- Uncertainties on propagation param . and c.s.
- Solar modulation: spherical model ( $\phi$=500MV )



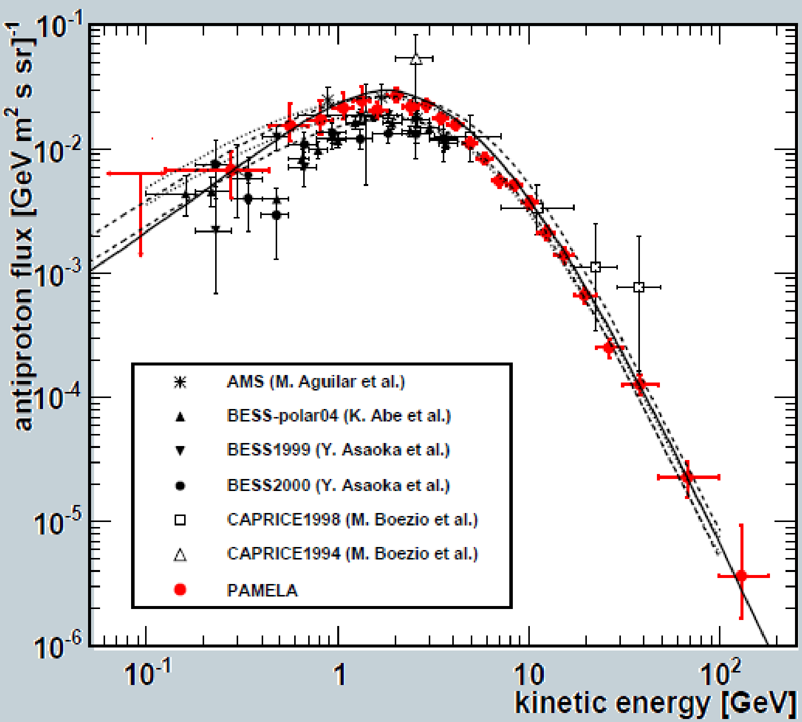

Adriani et al. - PRL 105 (2010) 121101

(Ptuskin et al. 2006) GALPROP code
- **Plain diffusion model**
- Solar modulation: spherical model ( $\phi$=550MV )

# A challenging puzzle for CR physicists

## Antiprotons

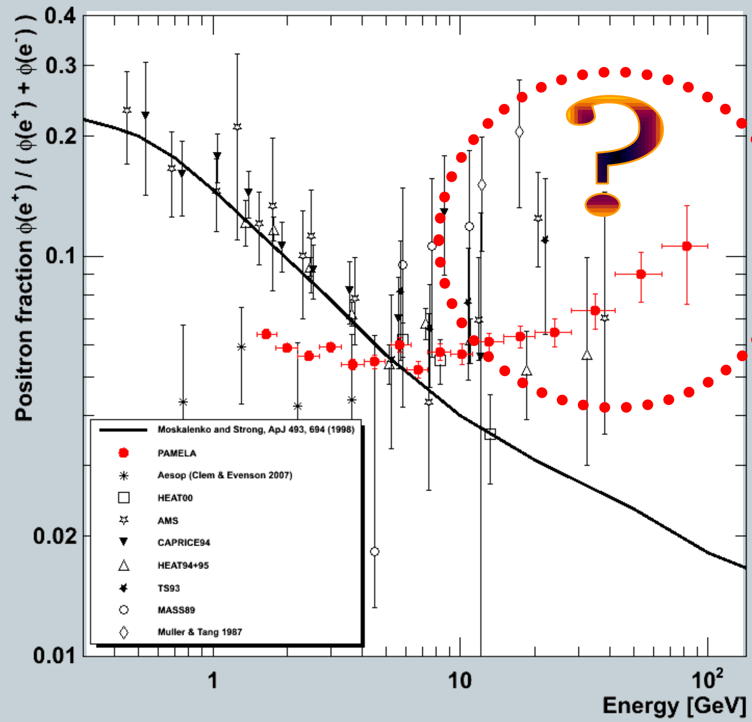
→ Consistent with pure secondary production




Adriani et al. –PRL 105 (2010) 121101

## Positrons

→ Evidence for an excess




Adriani et al. –AP 34 (2010) 1

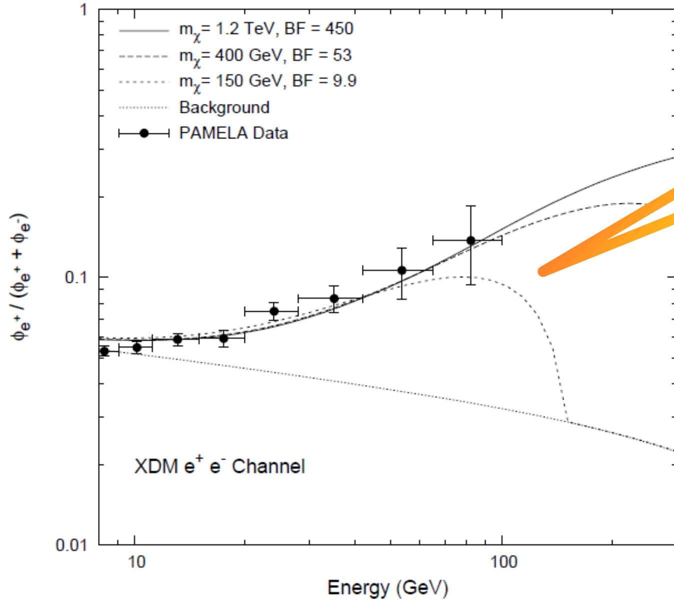
# Positron-excess interpretations

<u>**Dark matter**</u>

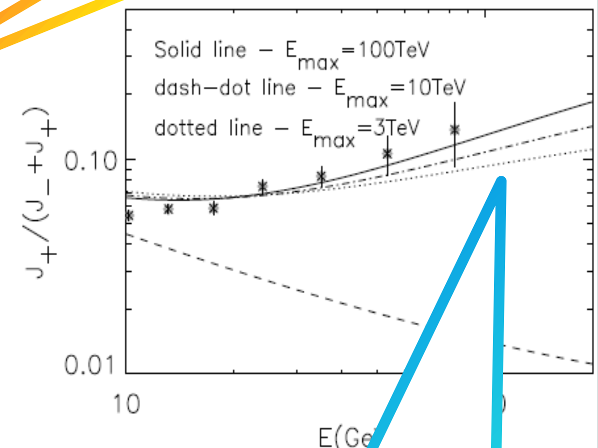
- boost factor required
- lepton vs hadron yield must be consistent with p-bar observation

<u>**Astrophysical processes**</u>

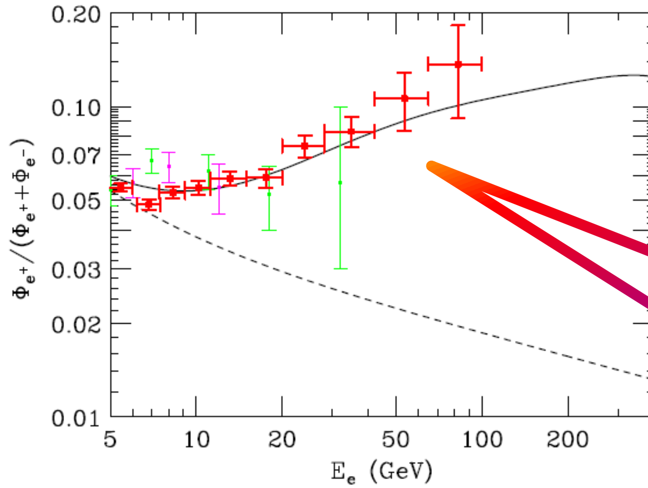
- known processes
- large uncertainties on environmental parameters




(Cholis et al. 2009)
Contribution from **DM annihilation**.




(Blasi 2009)
e+ (and e-) produced as **secondaries** in the CR acceleration sites (e.g. SNR)




(Hooper, Blasi and Serpico, 2009)
contribution from diffuse mature & nearby young **pulsars**.

# Positrons vs antiprotons

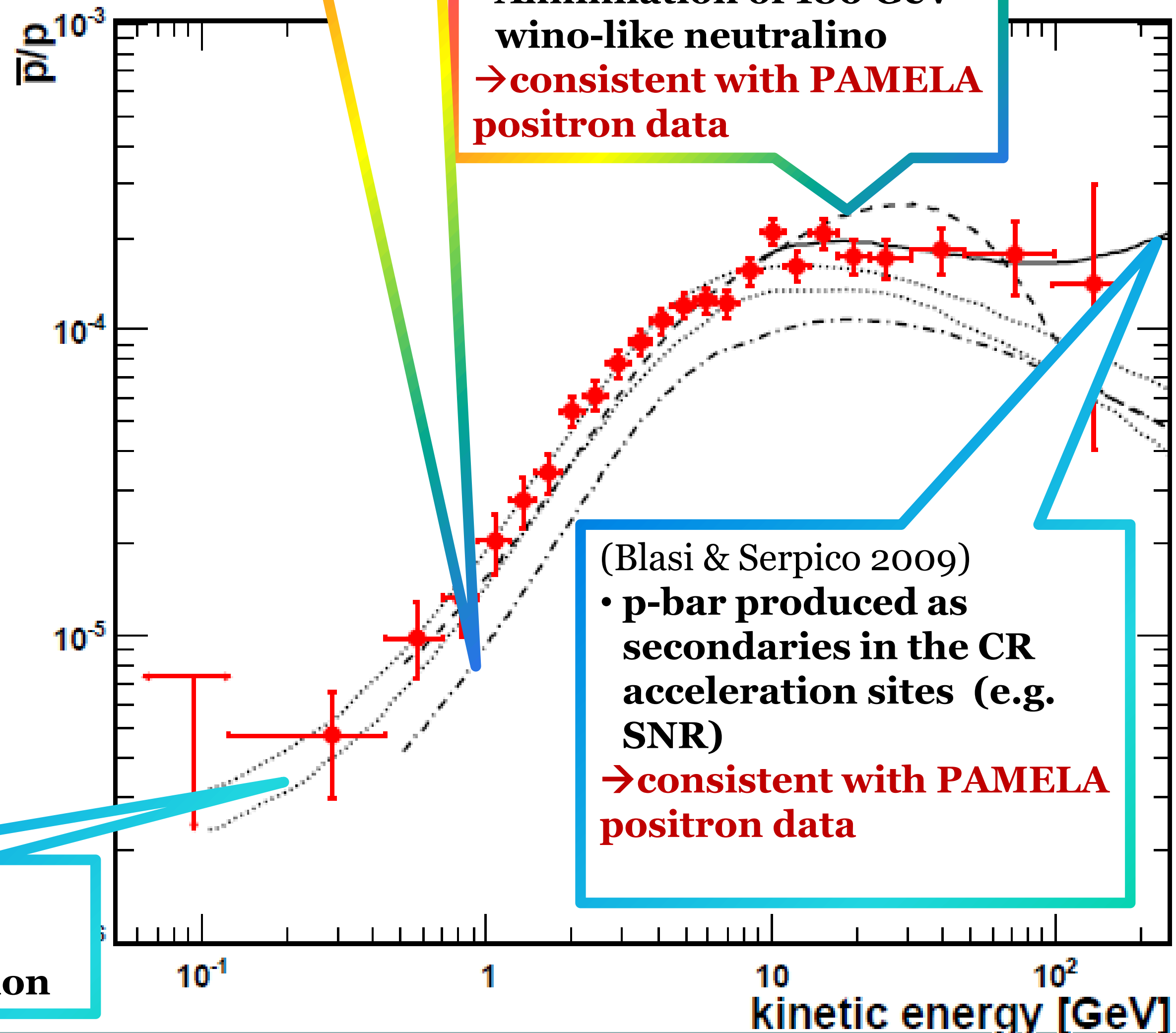
- Large uncertainties on propagation parameters allows to accommodate an additional component
- A p-bar rise above 200GeV is not excluded

(Strong & Moskalenko 1998)
GALPROP code

+

(Kane et al. 2009)
- **Annihilation of 180 GeV wino-like neutralino**

**→consistent with PAMELA positron data**




(Blasi & Serpico 2009)
- **p-bar produced as secondaries in the CR acceleration sites (e.g. SNR)**

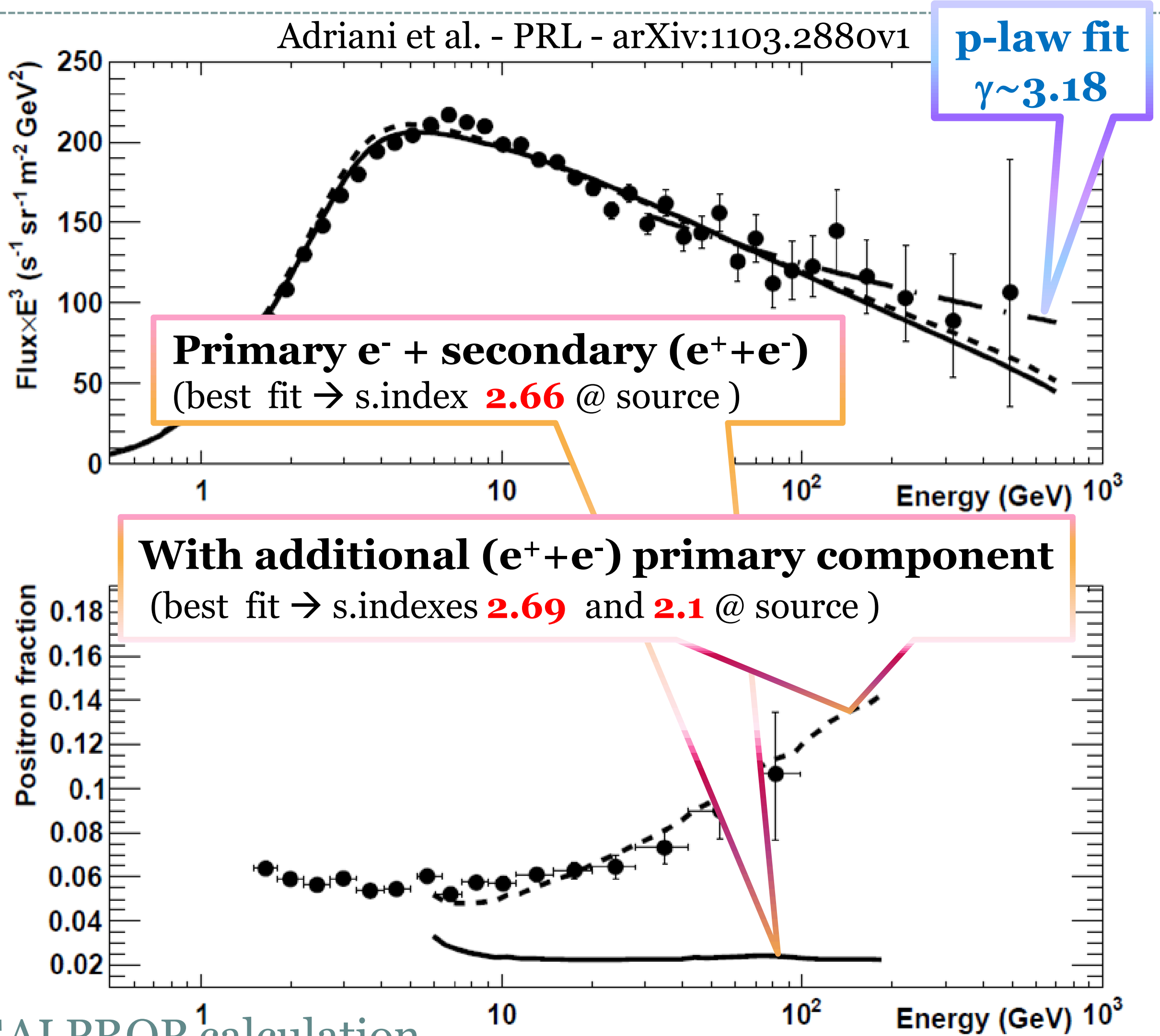
**→consistent with PAMELA positron data**

(Donato et al. 2009)
- **Diffusion model with convection and reacceleration**

Adriani et al. - PRL 105 (2010) 121101

# Positrons vs electrons

- Fit of electron flux
- Two scenarios:
  1. **standard** (primary+secondary components)
  2. **additional primary** $e^-$ (and $e^+$) component
- Electron data are not inconsistent with standard scenario, but…
- …an additional component better reproduce spositron data



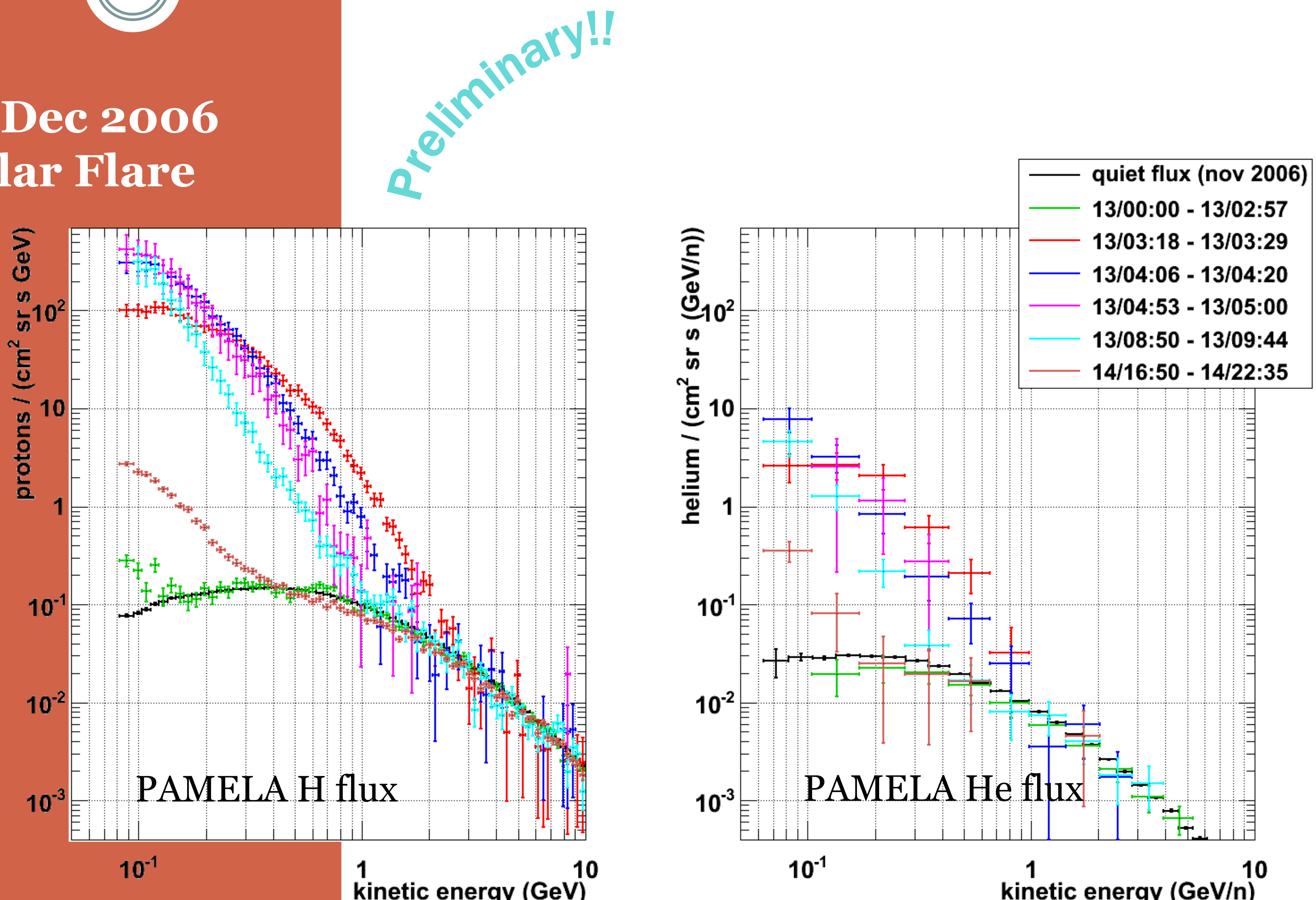

GALPROP calculation

diffusion + reacceleration (Ptuskin et al. 2006)

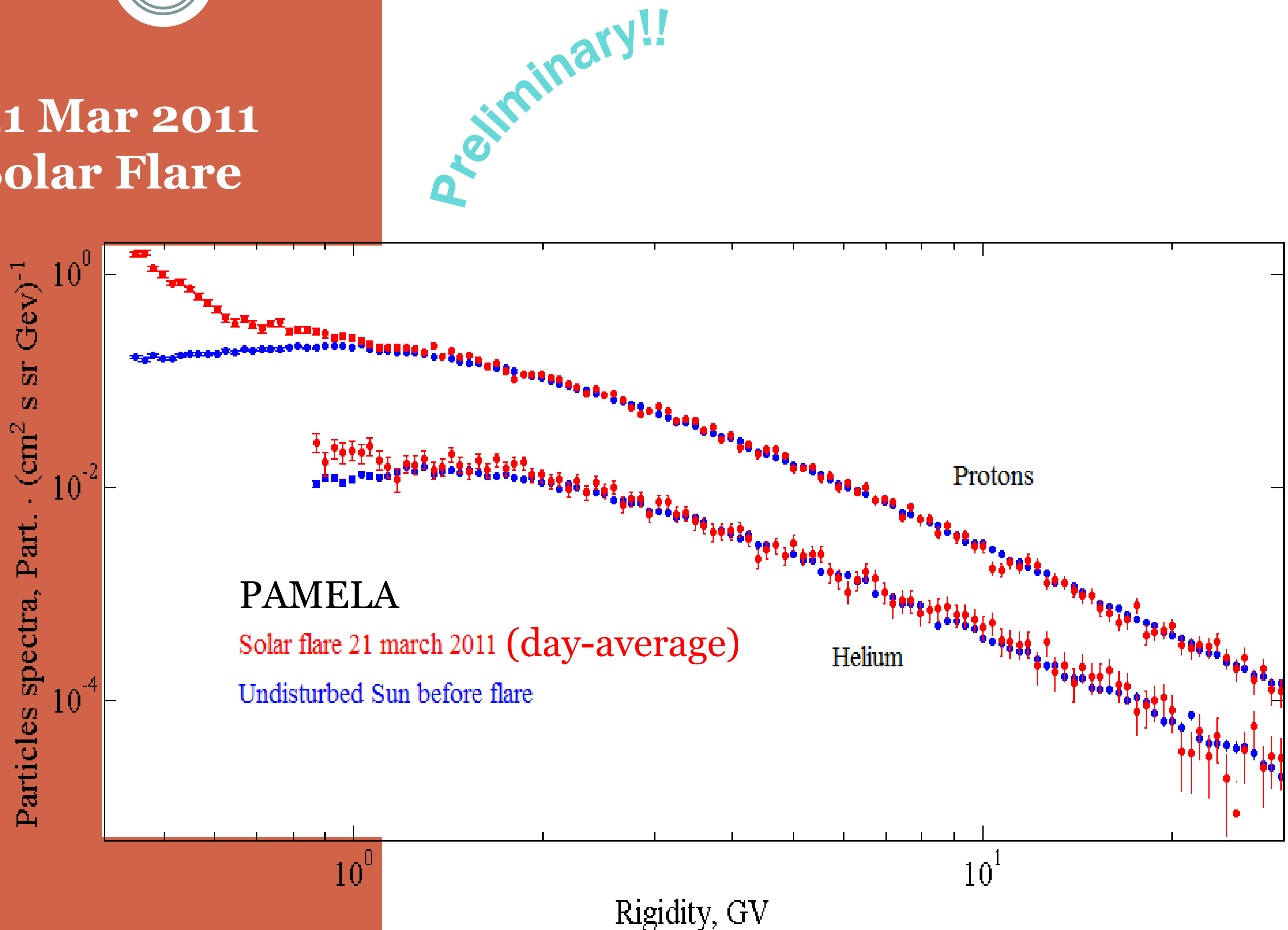
H and He primary spectra from best fit of propagated spectra to PAMELA results

# Solar and terrestrial physics

# 13 Dec 2006 Solar Flare

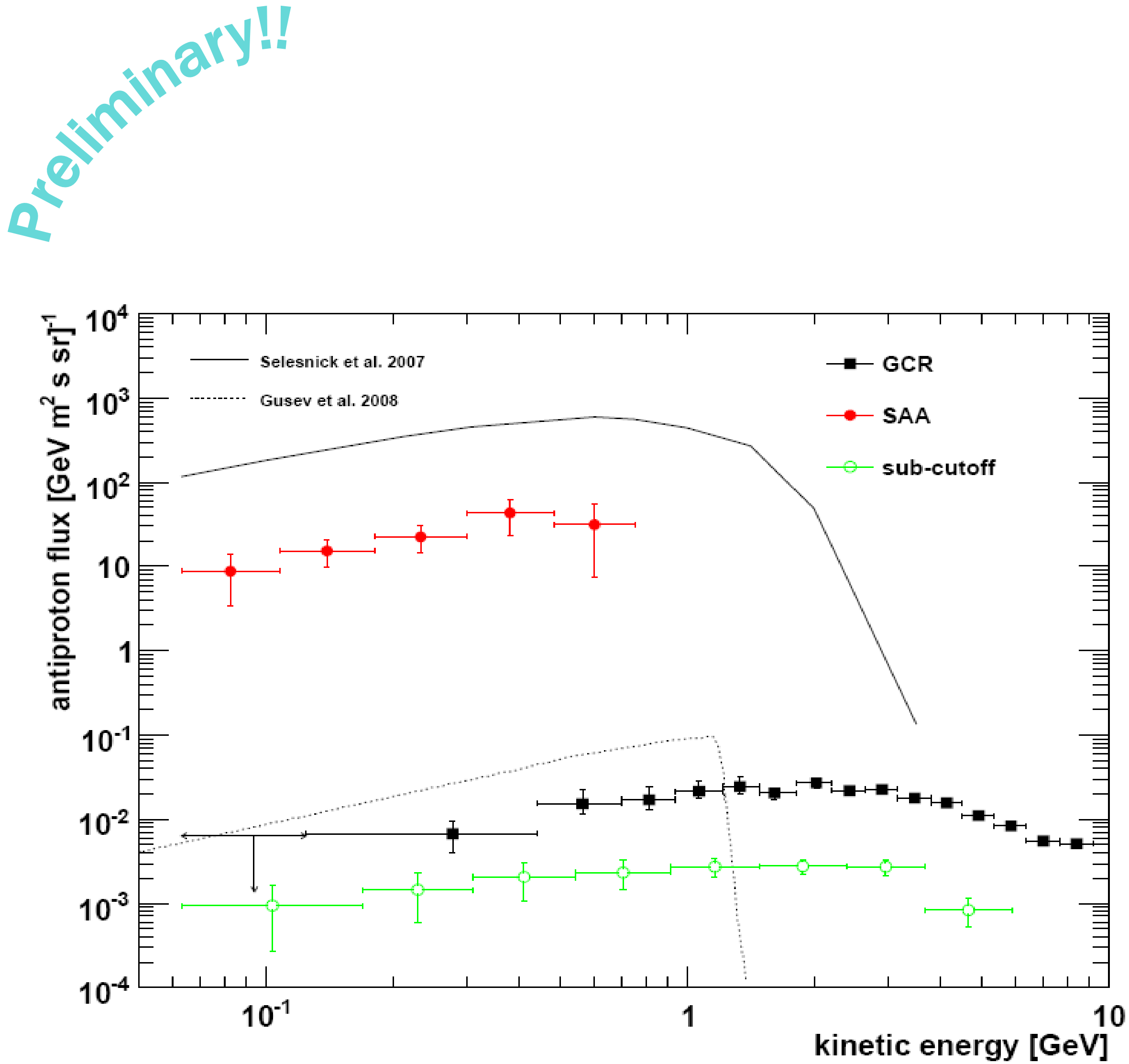


# 21 Mar 2011 Solar Flare



# Trapped antiprotons

First measurement of p-bar trapped in the inner belt.



# Summary and conclusions (1)

PAMELA has been in orbit and studying cosmic rays for ~4.5 years.

>$10^9$ triggers registered and >20 TB of data have been down-linked.

- **H and He absolute fluxes** → Measured up to ~1.2TV. Most precise measurement so far. Complex spectral structures observed (spectral hardening at ~200GV!) → Challenge the current paradigm of CR acceleration in SNRs!
- **Electron absolute flux** →Measured up to ~600GeV. No evident deviations from standard scenario, but not inconsistent with an additional electron component.
- **High energy positron fraction (>10 GeV)** → Increases significantly (and unexpectedly!) with energy. → Primary source?
- **Antiproton energy spectrum** → Measured up to ~200 GeV. No significant deviations from secondary production expectations.

- **Solar physics**: measurement of solar-flare particle spectra
- **Physics of the magnetosphere**: first measurement of trapped antiproton flux

# Summary and conclusions (2)

Other studies and forthcoming results:

- Upgrade of positron analysis (increased statistics, higher energy)
- Primary and secondary-nuclei abundance (up to Oxygen)
- H and He isotope abundance
- Solar modulation (long-term flux variation and charge-dependent effects)
- Upper limit to anti-he abundance

**Thanks!!**