PAMELA a Payload for Antimatter Matter Exploration and Light–nuclei Astrophysics

# Cosmic ray electrons and positrons over decade with the PAMELA experiment

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**PAMELA collaboration**

IV ICPPA , 26, October, 2018

# PAMELA Collaboration

Bari Florence Frascati Naples Rome Trieste CNR, Florence

Russia:

Moscow
St. Petersburg

Germany:

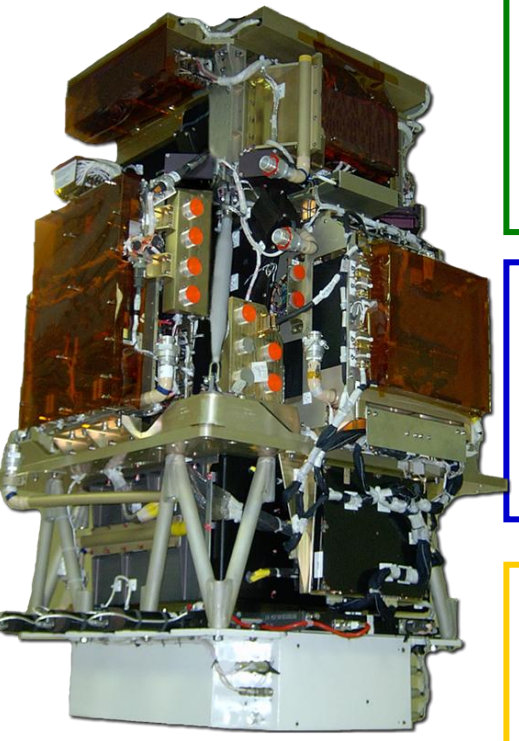
Siegen

Sweden:

KTH, Stockholm

# The PAMELA instrument

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



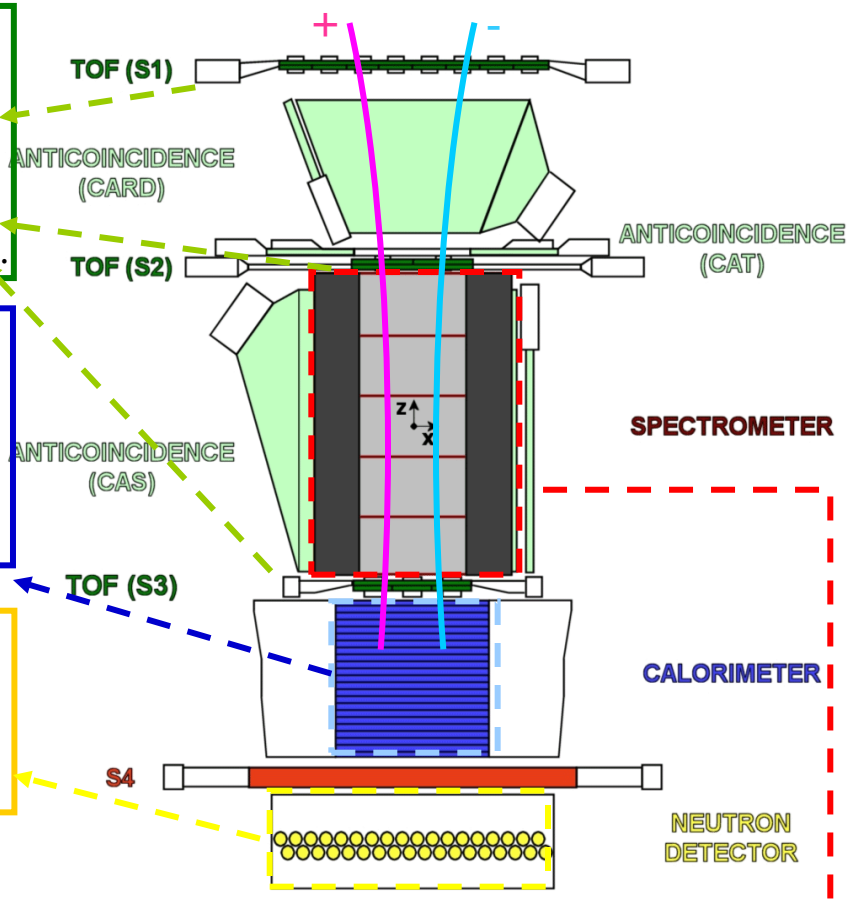
**GF: 21.5 cm² sr**
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W

**Energy range for e+, e- from ~50 MeV to ~1 TeV**

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

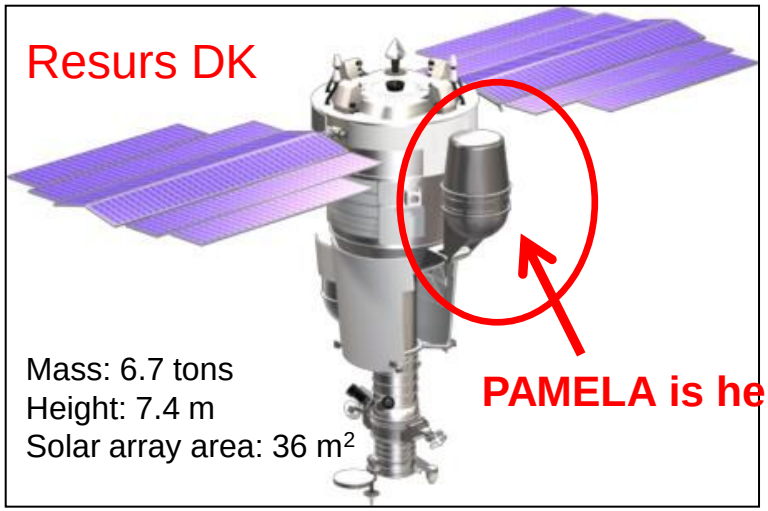
Electromagnetic calorimeter
W/Si sampling (16.3 $X_0$, 0.6 $\lambda I$)
- Discrimination e+ / p, anti-p / $e^-$ (shower topology)
- Direct E measurement for $e^-$

Neutron detector
$^3$He tubes + polyethylene moderator:
- 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*

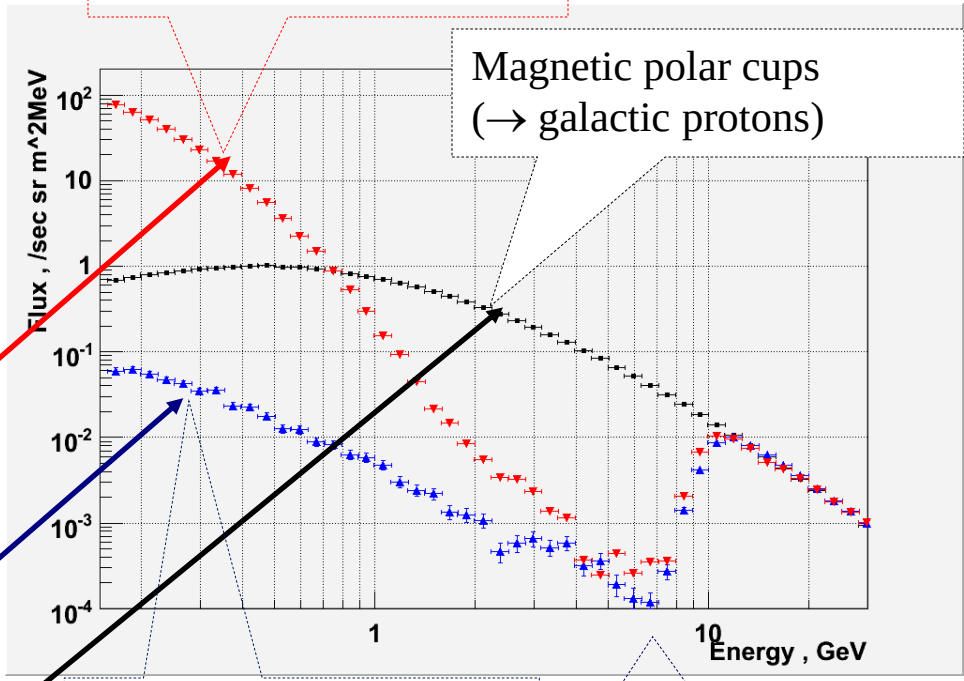
# The PAMELA Experiment




**The satellite was launched in 2006 on elliptical orbit : 350- 610 km with inclination ~70⁰ .**

Trapped protons in SAA.

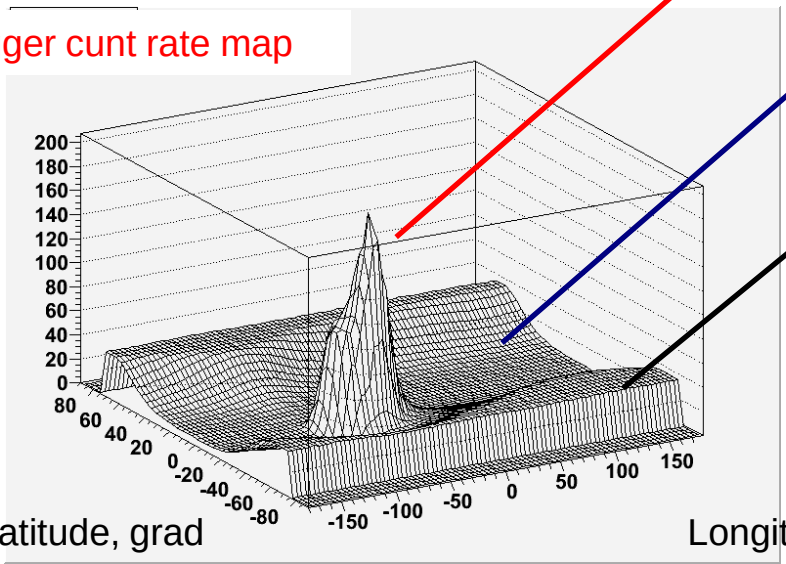
Magnetic polar cups
(→ galactic protons)




Secondary re-entrant-albedo protons

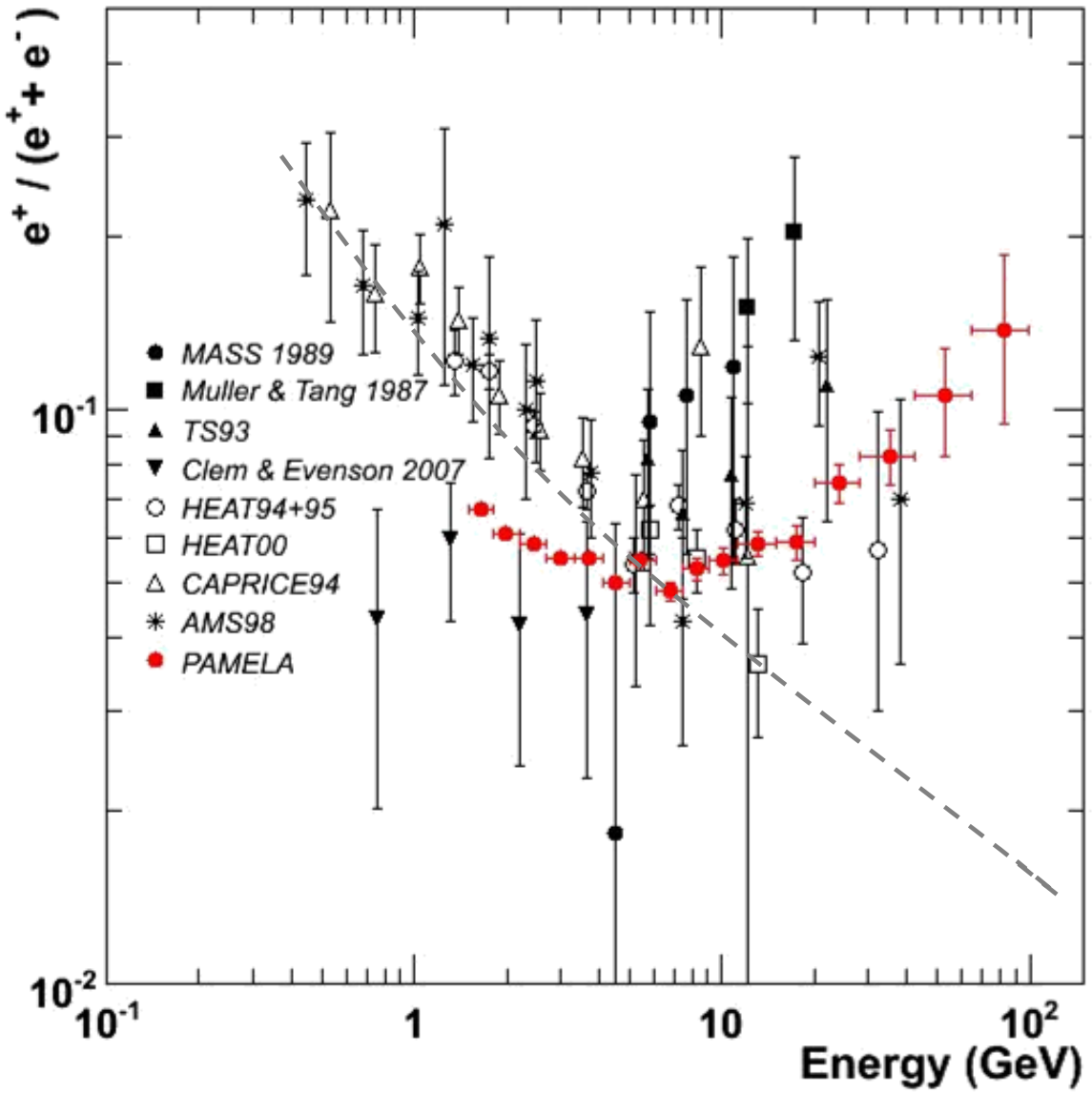
Geomagnetic cutoff

Trigger cunt rate map




**Since July 2006 till January 2018:**
**~3200 days of data taking (~80% )**
**~55 TByte of raw data downlinked**
**~9•10⁹ trigger events**

# The PAMELA discovery: rising positron fraction




Nature, 2009

TS93 (Golden+'96): flat positron fraction $0.078 \pm 0.016$ in the range 5-60 GeV

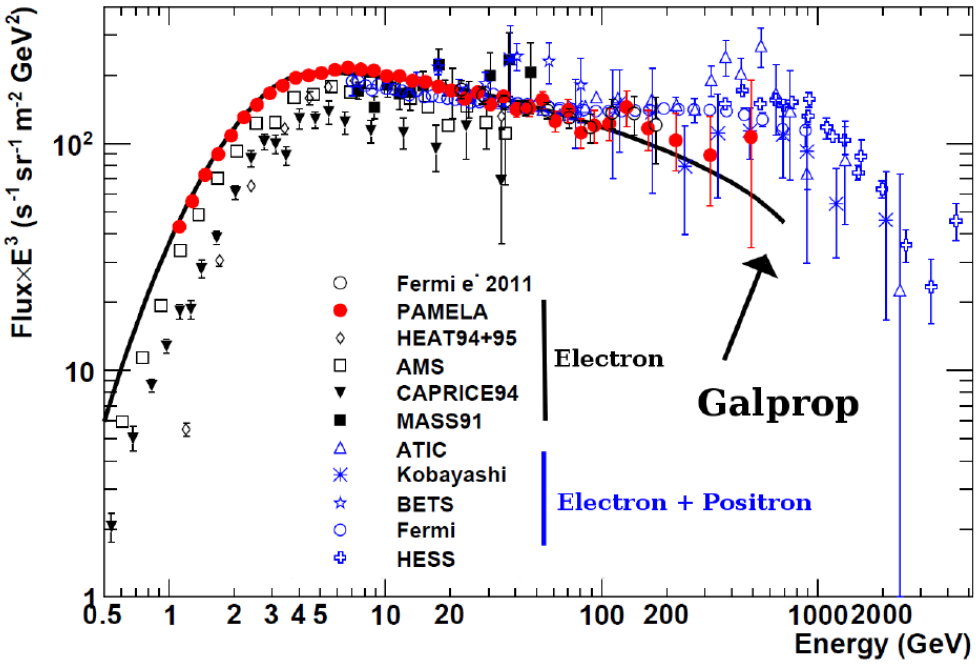
HEAT-94,95,00 (Beatty+'04): "a small positron flux of nonstandard origin"

PAMELA reported a clear and very significant rise in the positron fraction compared to the "standard" model predictions

"Standard" GALPROP model:

- Secondary production of positrons in the Interstellar Medium
- Diffusive CR propagation
- Smooth CR source distribution of p, N,e-
- Steady state

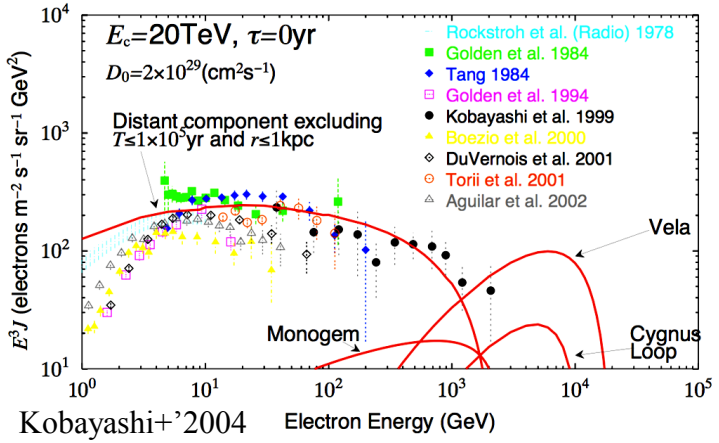
# Electron spectrum




Phys.Rev.Lett. 2011 (e-), Phys Pep. 2014 (e+)

- First electron measurement above 50 GeV;
- Both (e-) (e+) spectra show some structure (breaks and bumps)
- Above ~10 GeV flatter than extrapolated from low energies.
- Concave shape in both cases is clear indication of an additional component above ~10 GeV

- The fluxes of $e^+$ & $e^-$ tell more



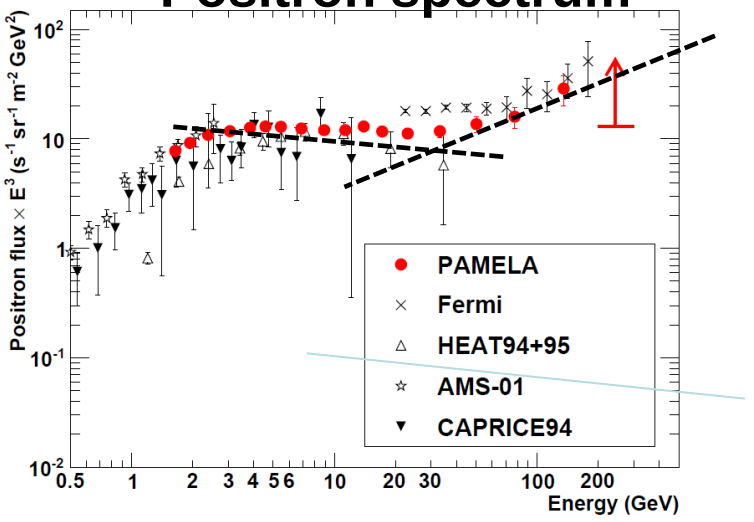

Kobayashi+'2004

- Cannot be reproduced with a single power-law injection spectrum
- Origin :

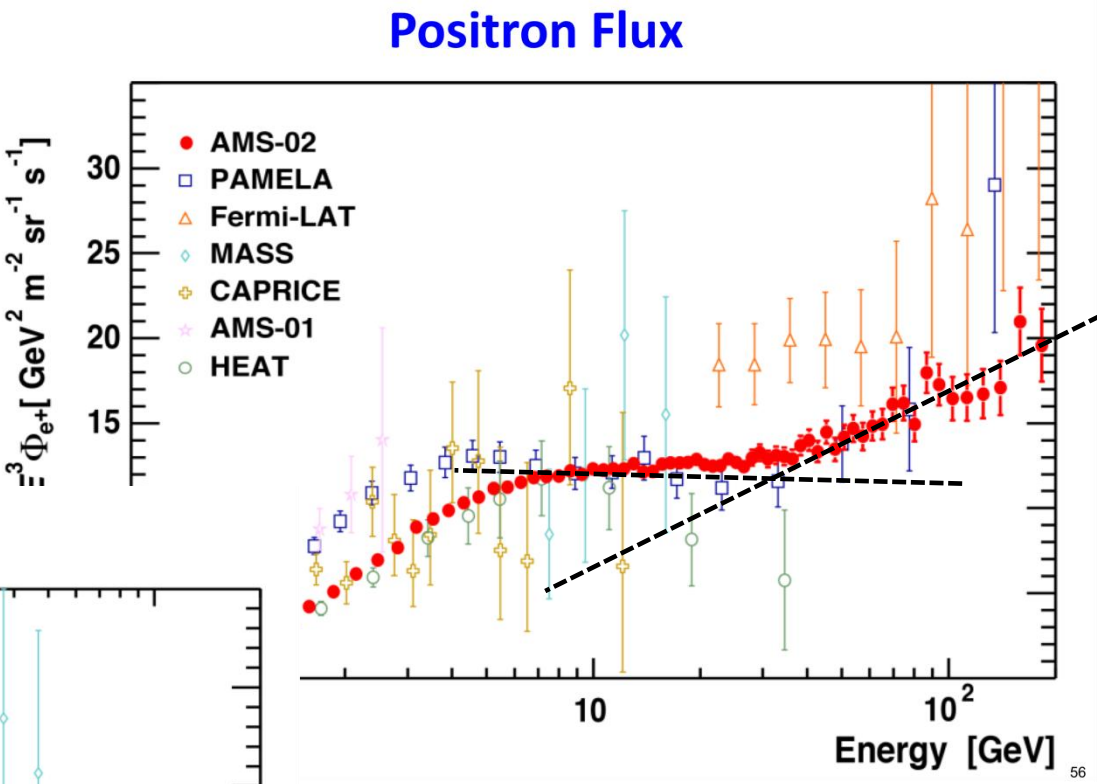
✓ Local astrophysical sources (pulsars)?

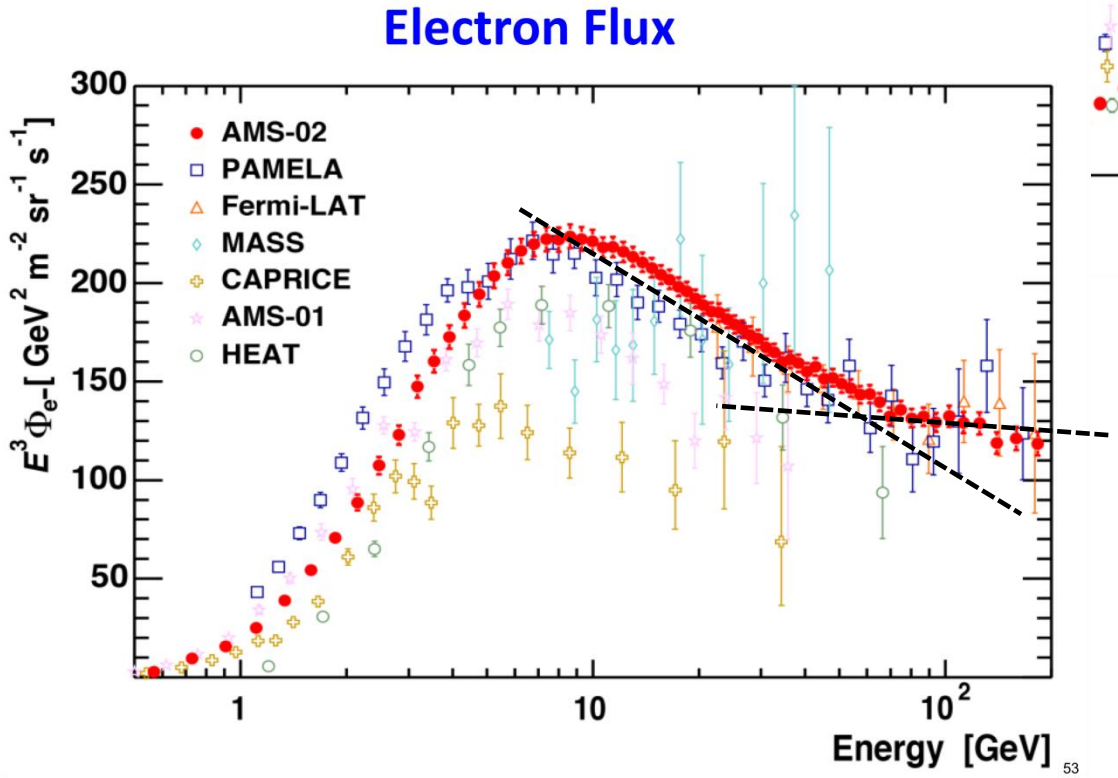
✓ Hard component?

## Positron spectrum



- AMS02 and Fermi-LAT confirmed results
- Measurements extended to ~800 GeV for e+ for very high statistic accuracy




e+
AMS-02 collaboration
Phys. Rev. Lett. 113 (2014) 121102
Fermi-LAT collaboration
Phys. Rev. Lett. 108 (2012) 011103

# Is here a bump in positron spectrum?

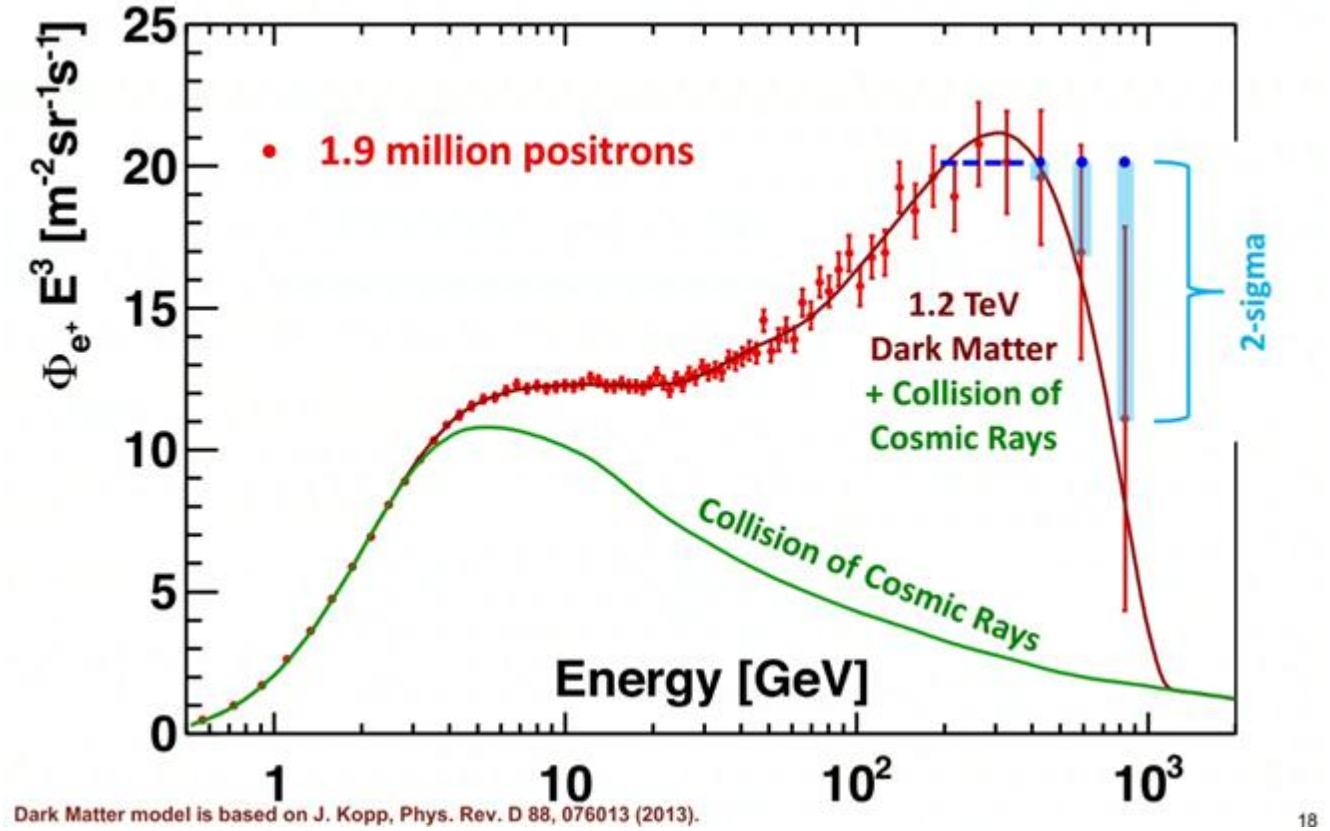
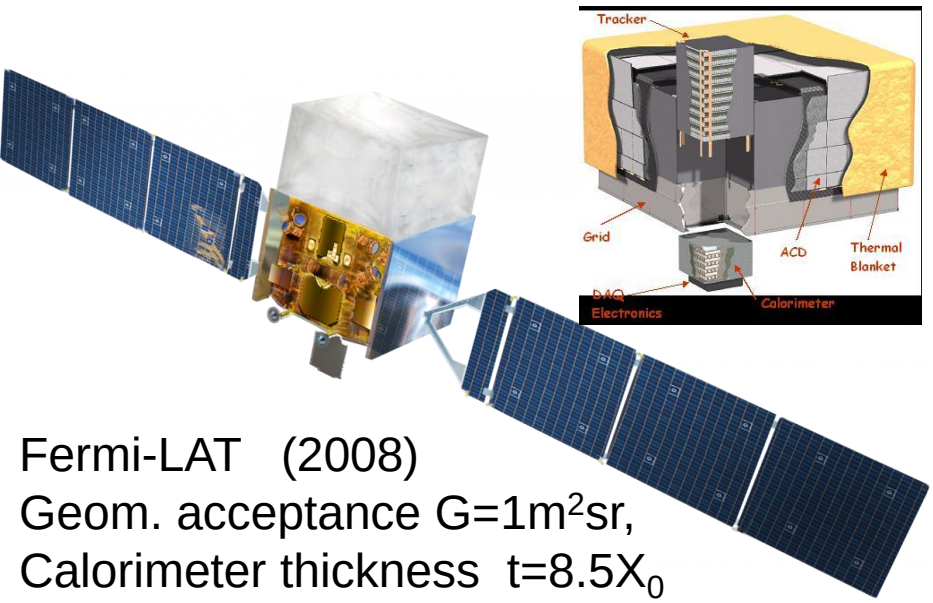



*Figure from S.Ting presentation in CERN, May 2018*

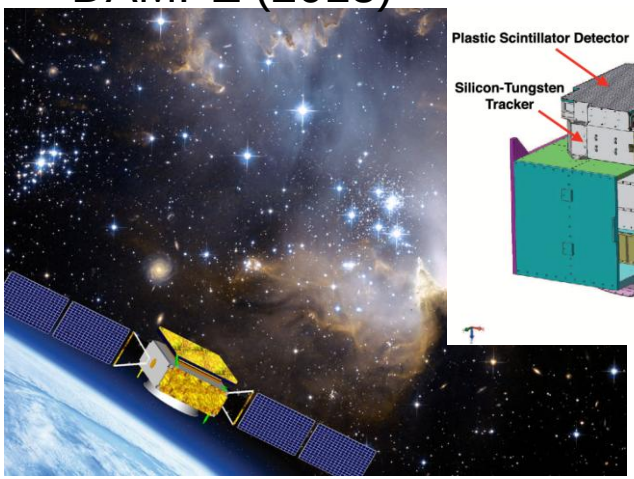
The feature should be visible both in e+ and e- spectra

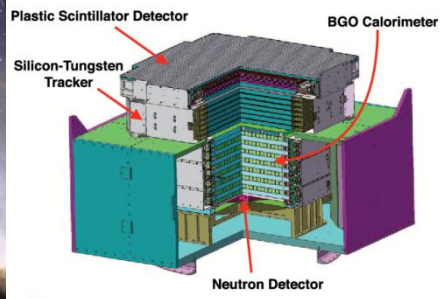
# New generation of space instruments



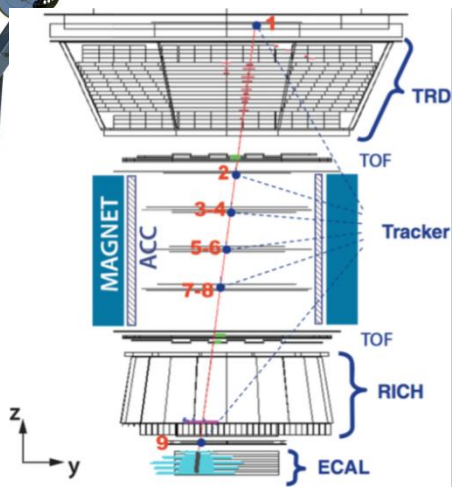

Fermi-LAT (2008)
Geom. acceptance G=1m$^2$sr,
Calorimeter thickness t=8.5X$_0$

DAMPE (2015)

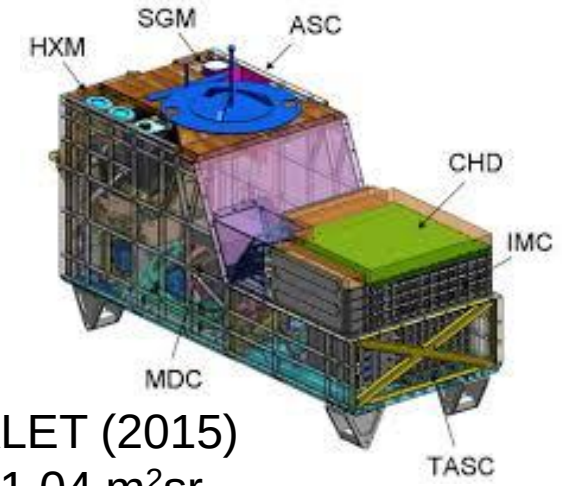





G=0.3 m$^2$sr
t=32X$_0$

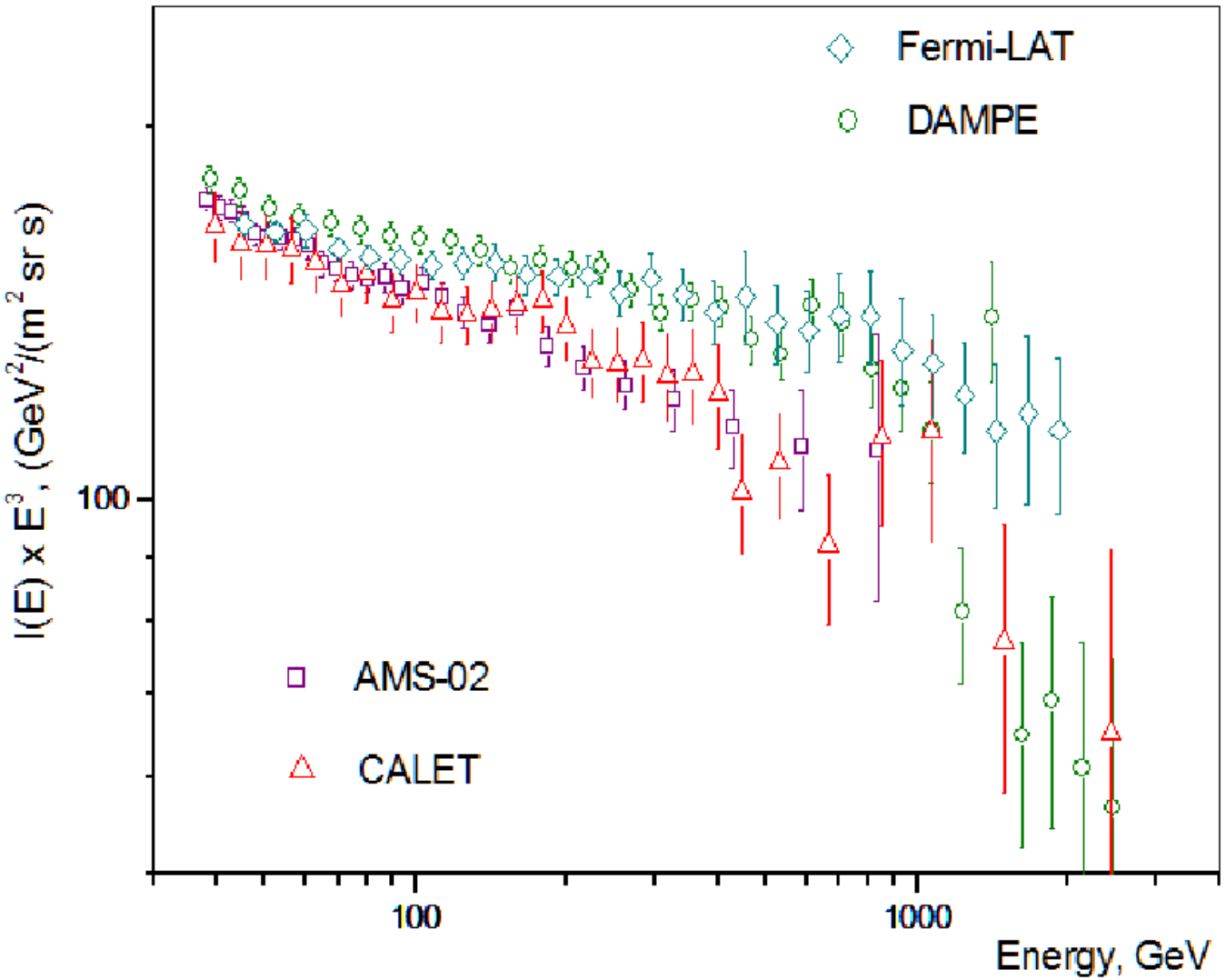



AMS-02 (2011)
G~0.5 m$^2$sr,
t=17X$_0$
MDR ~2 TV




CALET (2015)
G=1.04 m$^2$sr
t=30X$_0$

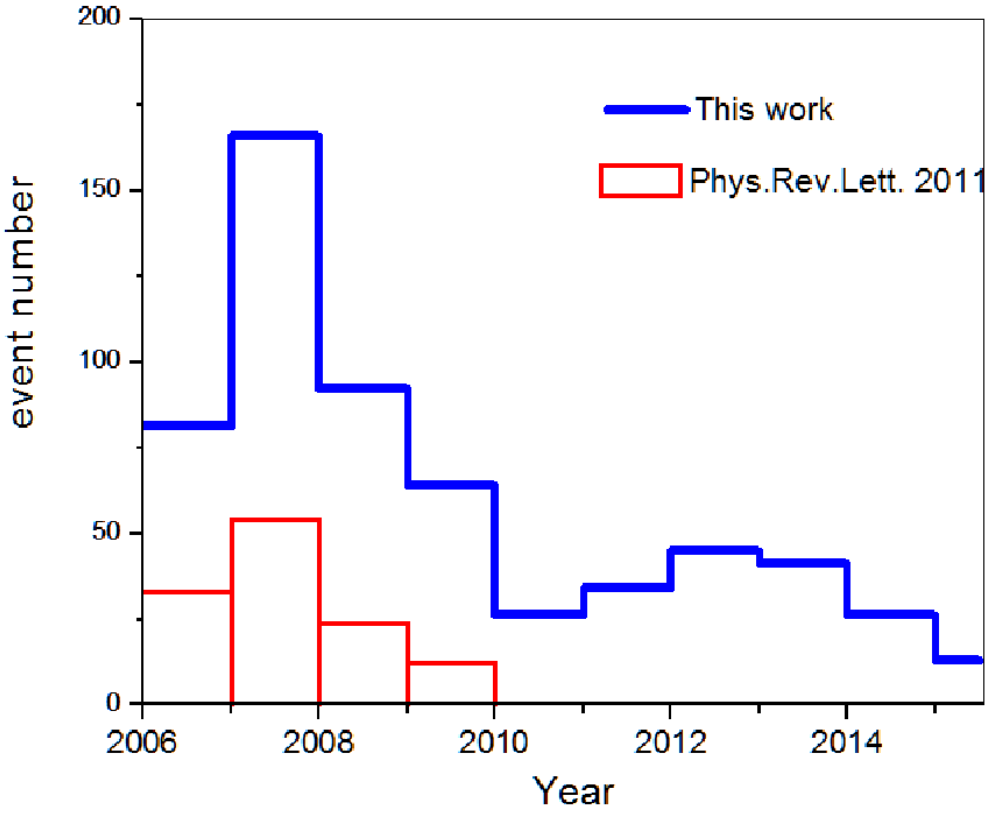
# All electron spectrum in 2017




Data from https://tools.ssdc.asi.it/CosmicRays/

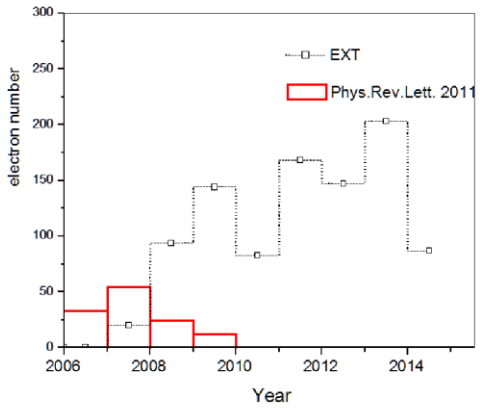
# New electron analysis

Event number with E>100 GeV



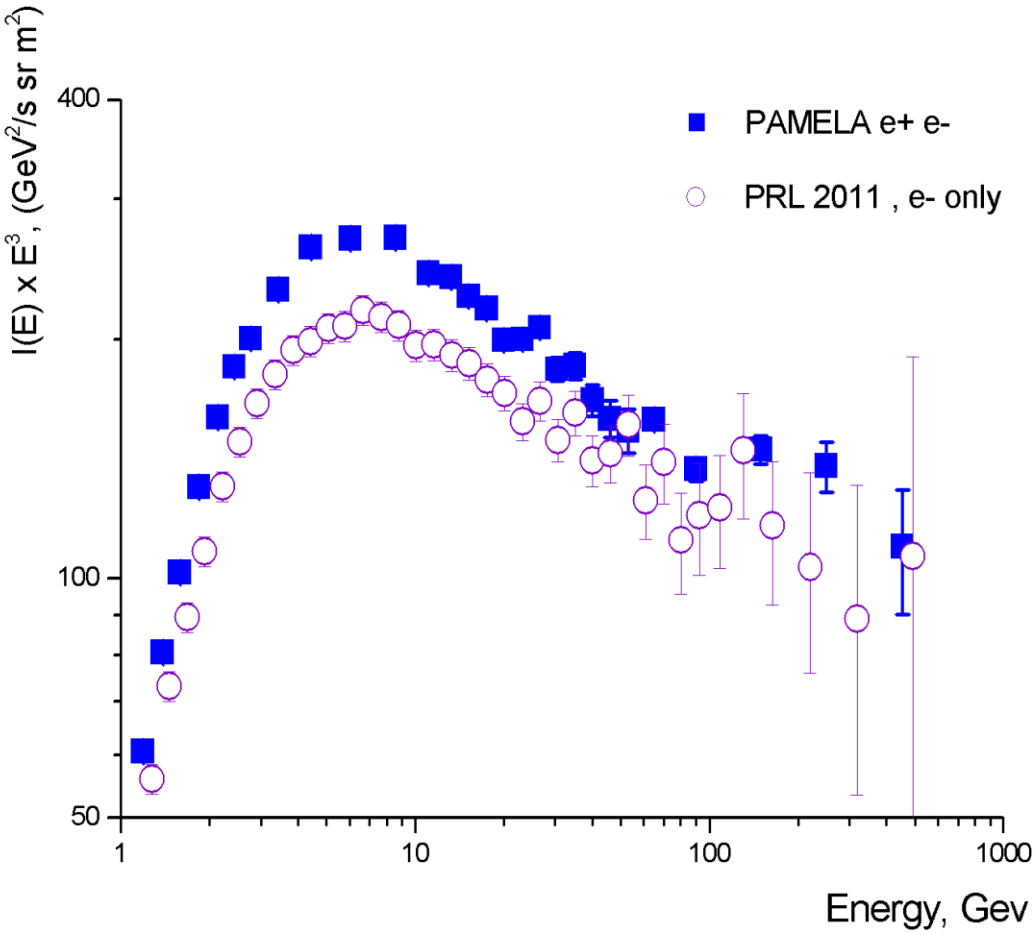

-New 10th data reduction
with "standard" track finding algorithm
of previous 9th reduction (to cross check)
-Soft tracker condition
- multiple hits in ToF
- No AC veto
- Proton rejection with CALO
-Energy reconstruction with CALO

Next step with EXTended tracks
of new 10th reduction




Above 100 GeV : ~120 events in (Ph.Rev.Lett. 2011), new selection ~600 events

# All electron ($e^+$+$e^-$) spectrum

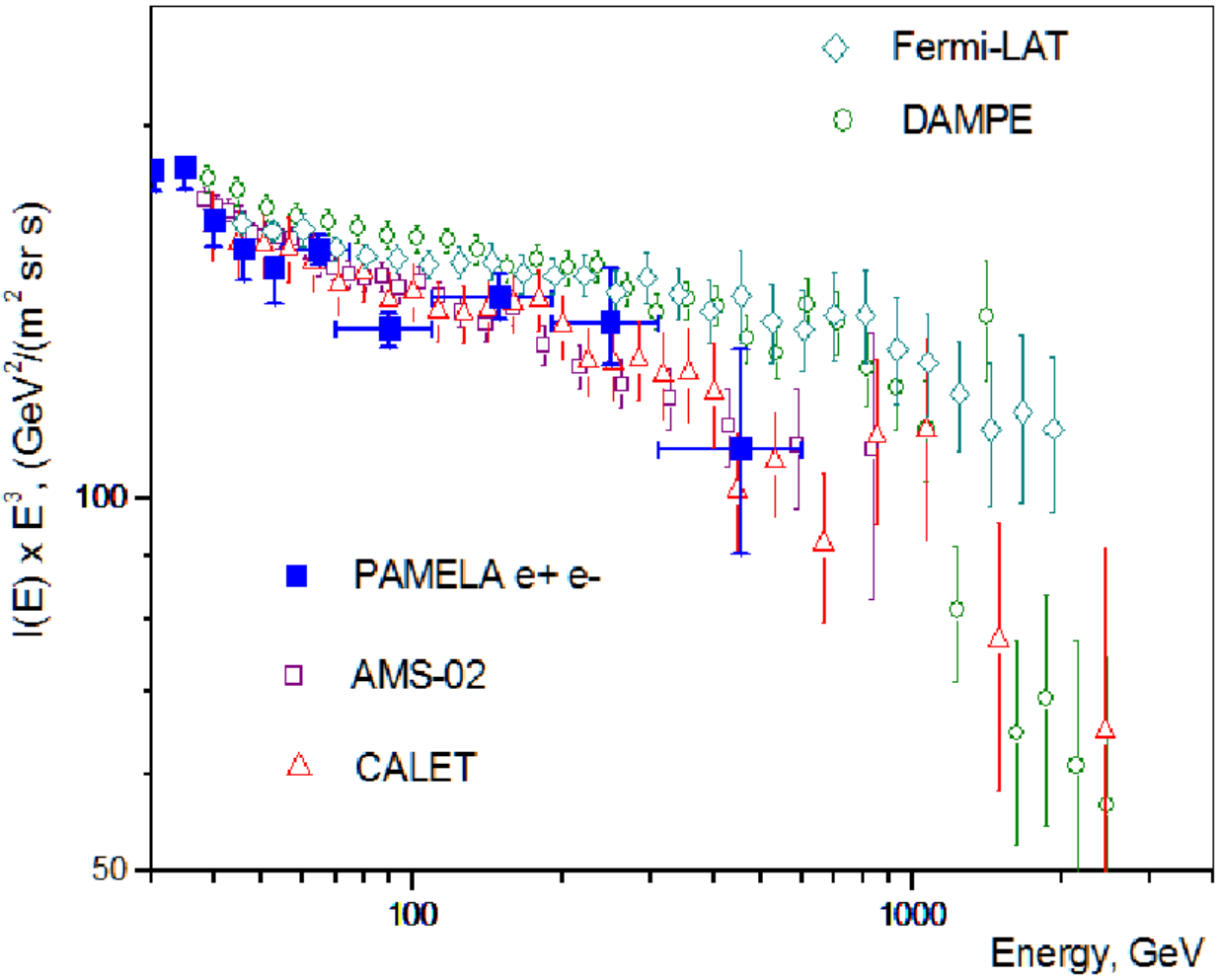



Energy spectra $\Phi$ (E) evaluated by

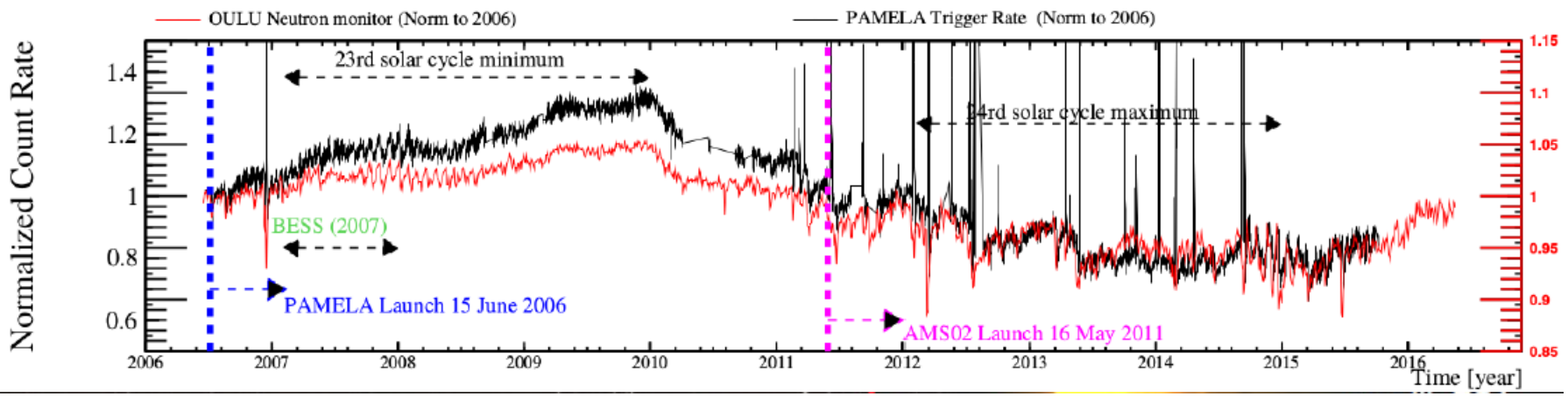
$$\Phi(E) = \frac{N(E) - Nb}{\Delta E \; T \; G(E) \; \varepsilon(E)}$$

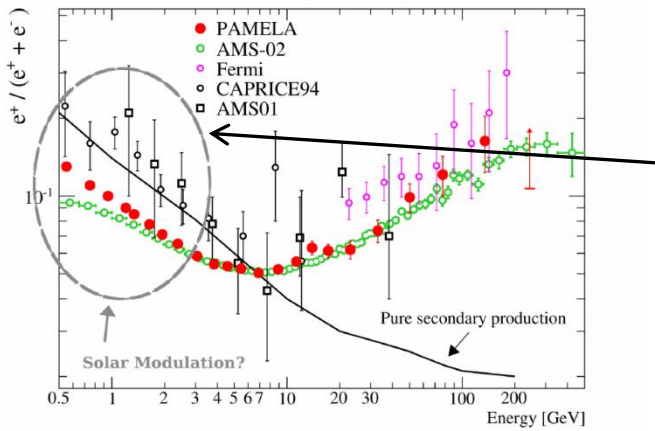
Where N(E) is number of events in energy bin $\Delta$E , Nb=0
T is exposure time,
G(E) and $\varepsilon$(E) are geometric factor and efficiency evaluated by MC simulations

# PAMELA all electron ($e^+$+$e^-$) spectrum



# Heliospheric propagation



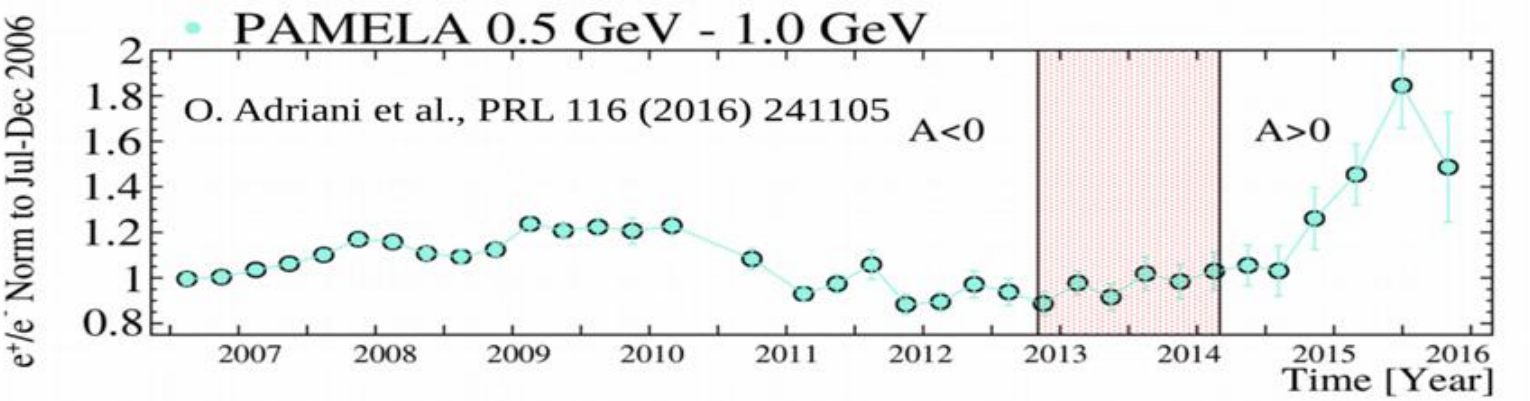

- Below ~30 GV heliosphere strongly affects CRs at Earth;
- Charge dependent solar modulation due to drift term (d); $V_D$ depends from heliospheric magnetic field polarity *A*. *A* changed in 2013-2014 from *A<0* to *A>0*

$$\underbrace{\frac{\partial f}{\partial t}}_{a} = -\underbrace{\mathbf{V}\cdot\nabla f}_{b} + \underbrace{\nabla\cdot(\mathbf{K_s}\cdot\nabla f)}_{c} - \underbrace{\langle\mathbf{v_D}\rangle\cdot\nabla f}_{d} + \underbrace{\frac{1}{3}(\nabla\cdot\mathbf{V})\frac{\partial f}{\partial \ln p}}_{e} + \underbrace{Q(\mathbf{x},p,t)}_{f}$$

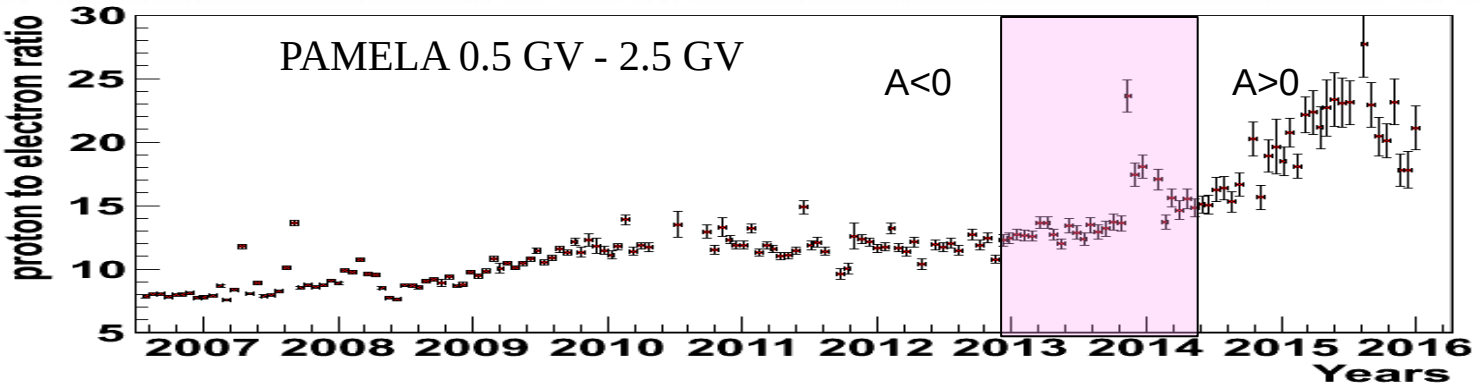
**(a)** $f(\mathbf{x},p,t)$, omnidirectional function distribution of CRs; **(b)** convection with solar wind $\mathbf{V}$; **(c)** diffusion by magnetic field irregularities; **(d)** drift, curvature and gradient in magnetic field; **(e)** adiabatic energy losses; **(f)** local sources (Jovian electrons);

# Charge sign dependence

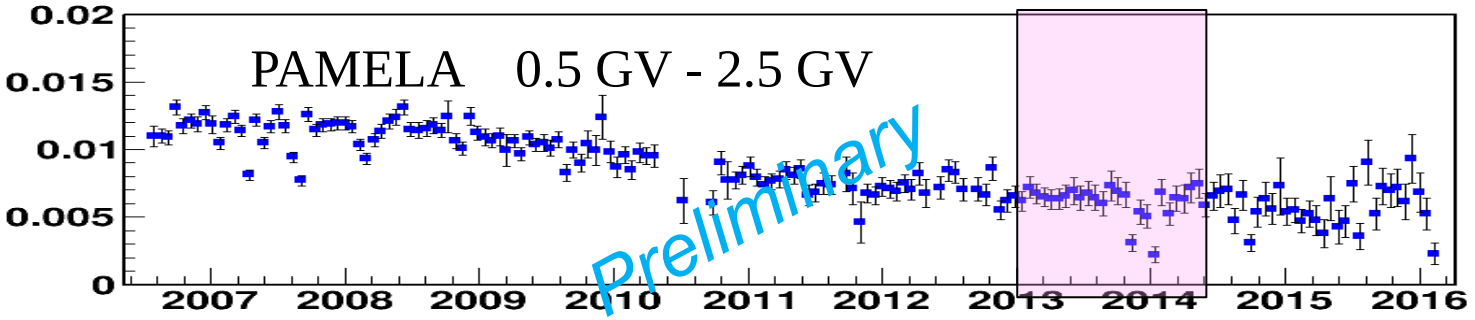
e+/e-




p/e-




e+/p



Thank you