

# The PAMELA Experiment: observations of solar modulation effects in cosmic ray proton and helium nuclei

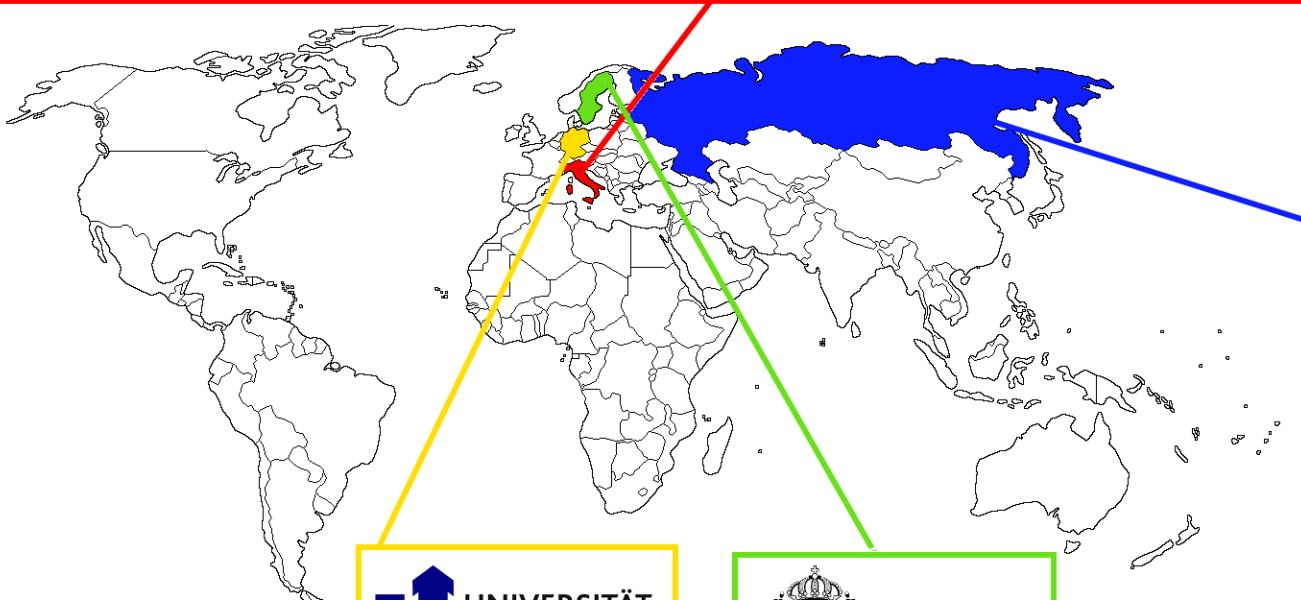
**Mirko Boezio & Matteo Martucci**  
*INFN Trieste-Roma2, Italy*

**On behalf of the PAMELA collaboration and  
M. Potgieter and J.L. Raath**

SEP, Solar Modulation and Space Radiation Workshop,  
Washington  
*April 24<sup>th</sup> 2017*






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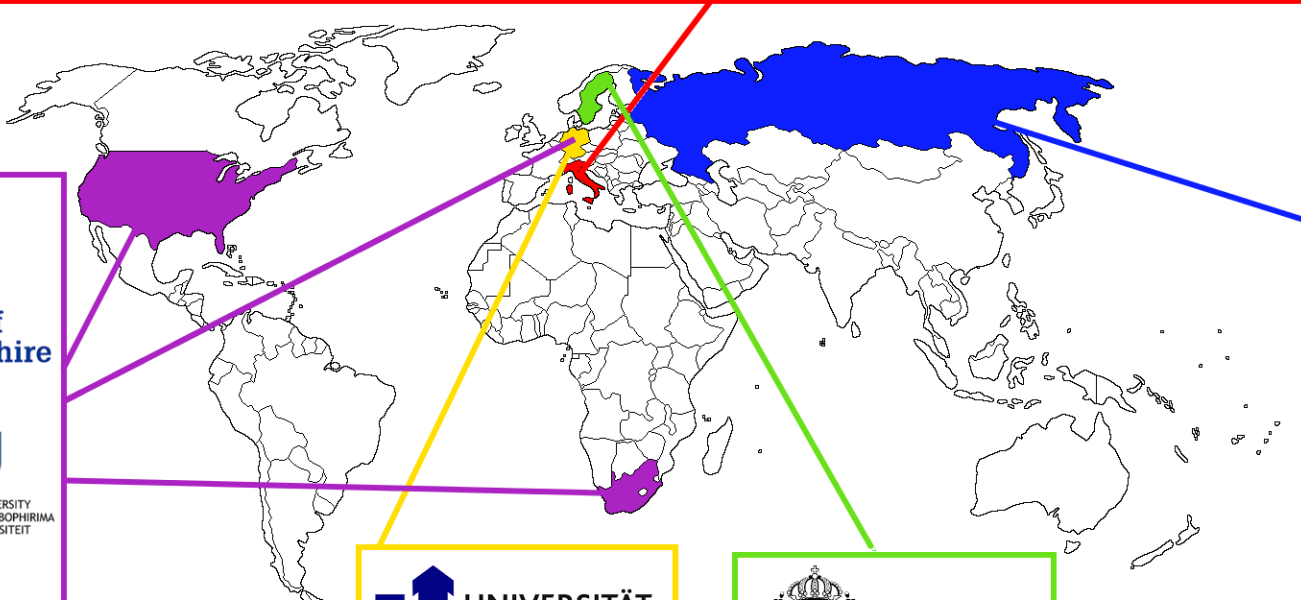


Mirko Boezio, SEP, Solar Modulation and Space Radiation Workshop, Washington, 24-04-2017





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**External collaboration**

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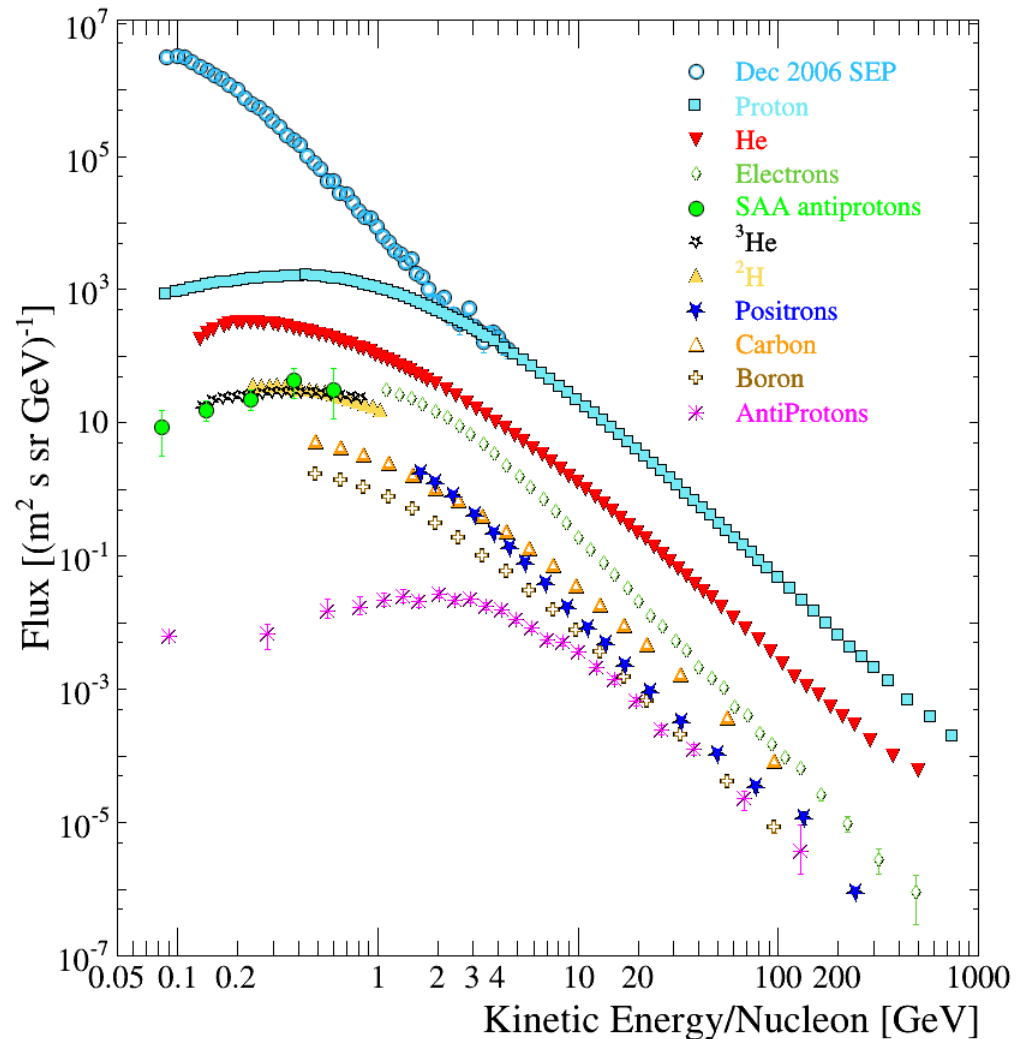


# PAMELA science case

1. Search for **signatures of exotic processes connected to the Dark Matter problem**;
2. Provide **new high precision data about CR primary and secondary fluxes**, to constrain on current acceleration and diffusion models of cosmic rays in the Galaxy;
3. Help solving the cosmological problem about the existence of the **apparent asymmetry between matter and antimatter**;
4. **Investigating the heliosphere and Earth magnetosphere.**

# PAMELA overall results

- Results span 4 decades in energy and 13 in fluxes



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# PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and 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  $X_0$ , 0.6  $\lambda I$ )**

- Discrimination  $e^+ / p$ , anti- $p / e^-$  (shower topology)
- Direct E measurement for  $e^-$

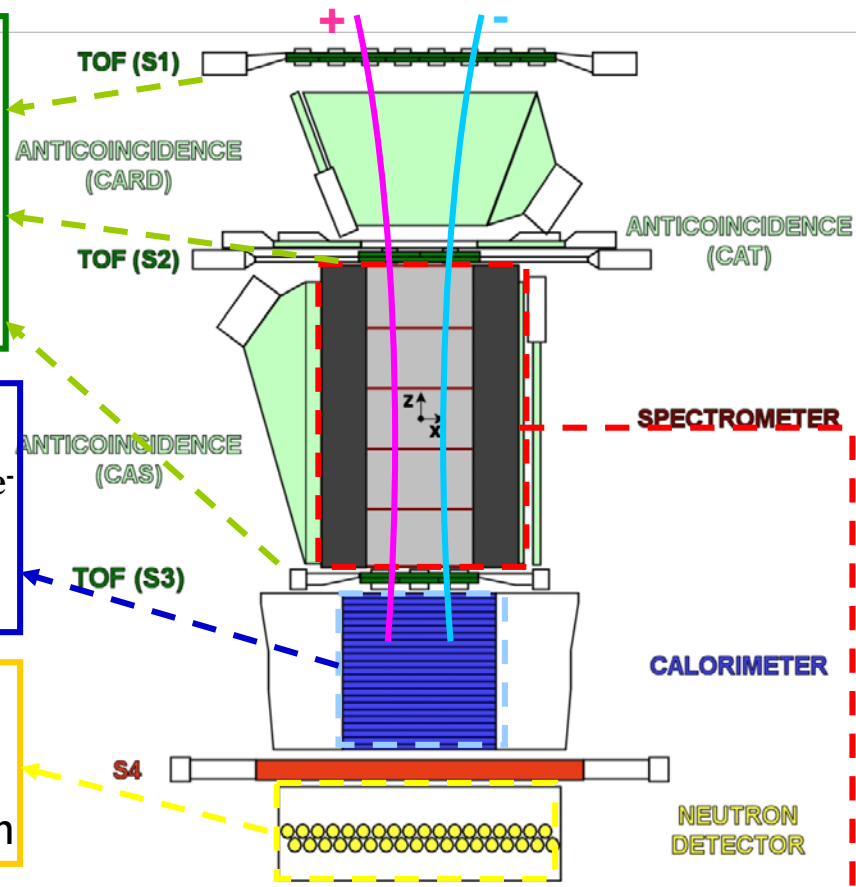
**Neutron detector**  
 **$^3\text{He}$  tubes + polyethylene moderator:**

- High-energy  $e/h$  discrimination

**Spectrometer**  
**microstrip silicon tracking system + permanent magnet**  
 It provides:

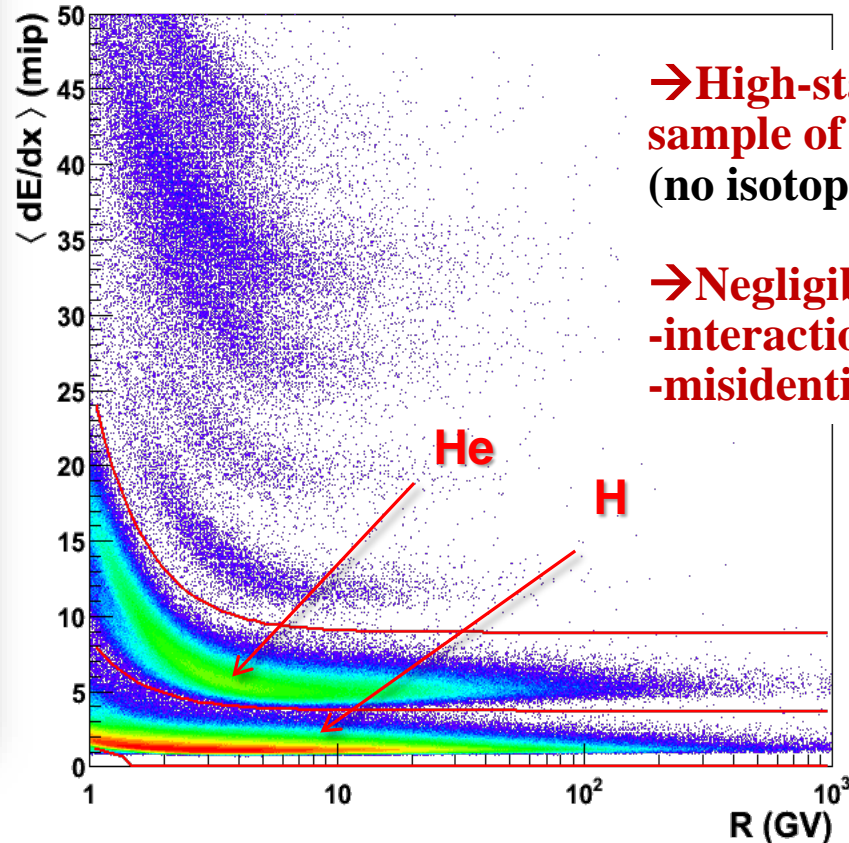
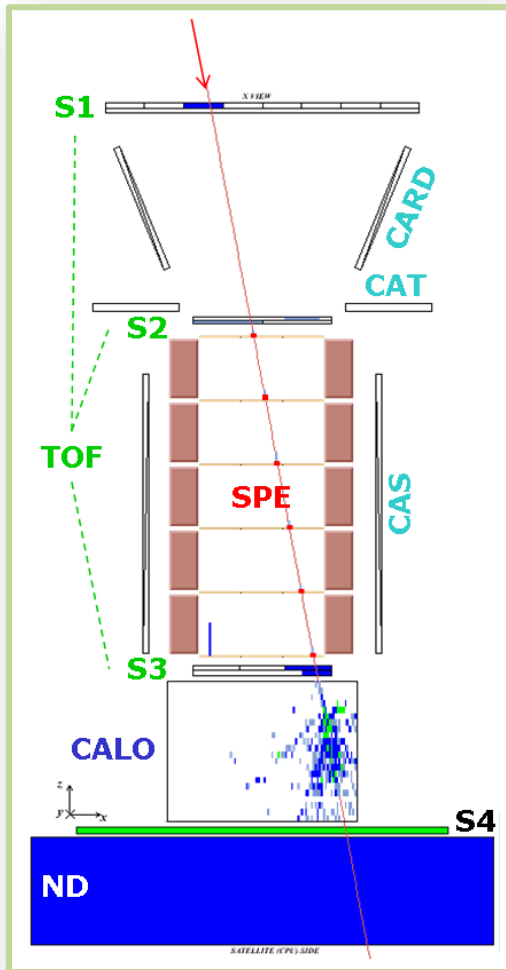
- *Magnetic rigidity* →  $R = pc/Z\beta$
- *Charge sign*
- *Charge value from  $dE/dx$*

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



# H/He Selection

- Single good-quality track in the spectrometer  
→ Particle rigidity ( $R = pc/Ze$ )
- Downward-going (velocity:  $\beta > 0$ ) & positive-curvature ( $R > 0$ ) trajectory  
→ Positive-charge particle from above
- Clean pattern through the apparatus  
→ Not an interaction product above or in the tracking system
- Energy deposits in the tracking system consistent with H and He nuclei

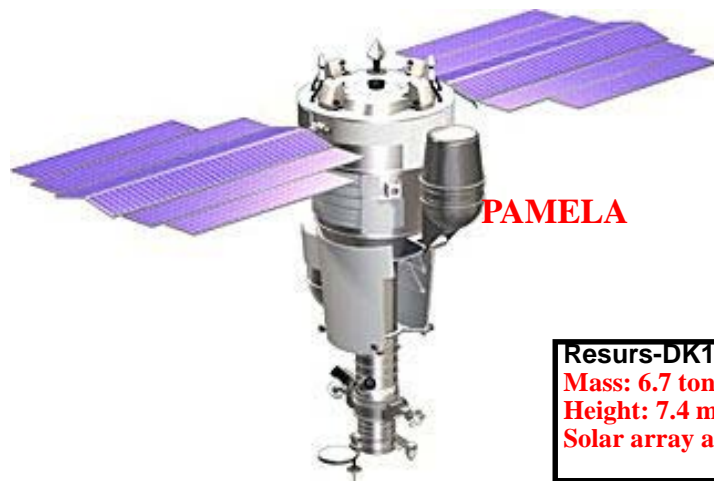


→ High-statistic ( $\sim 10^8$ ) sample of H and He (no isotope separation)

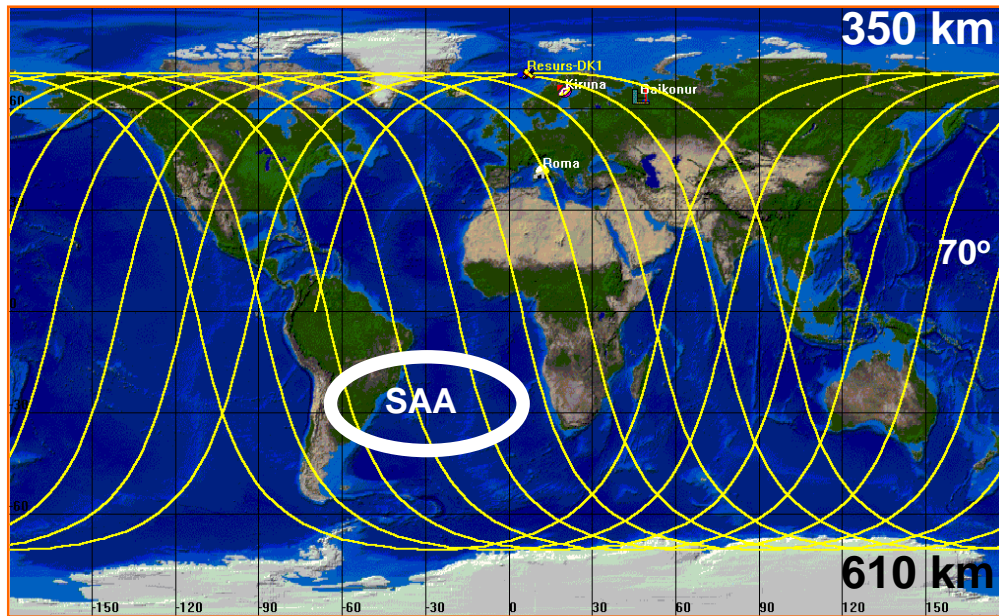
→ Negligible bk of -interaction products -misidentified particles



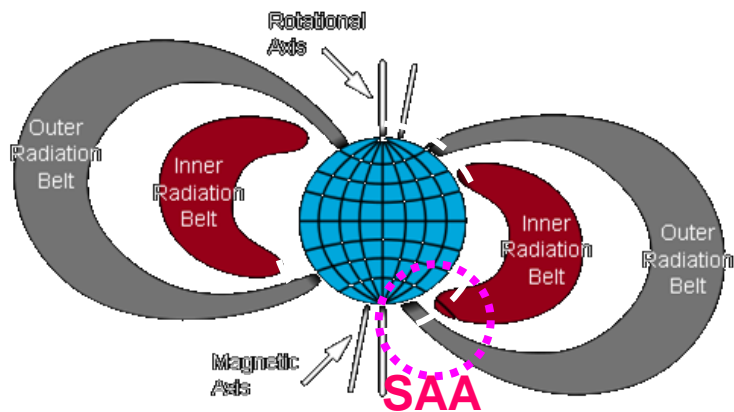
# Resurs-DK1 satellite + orbit



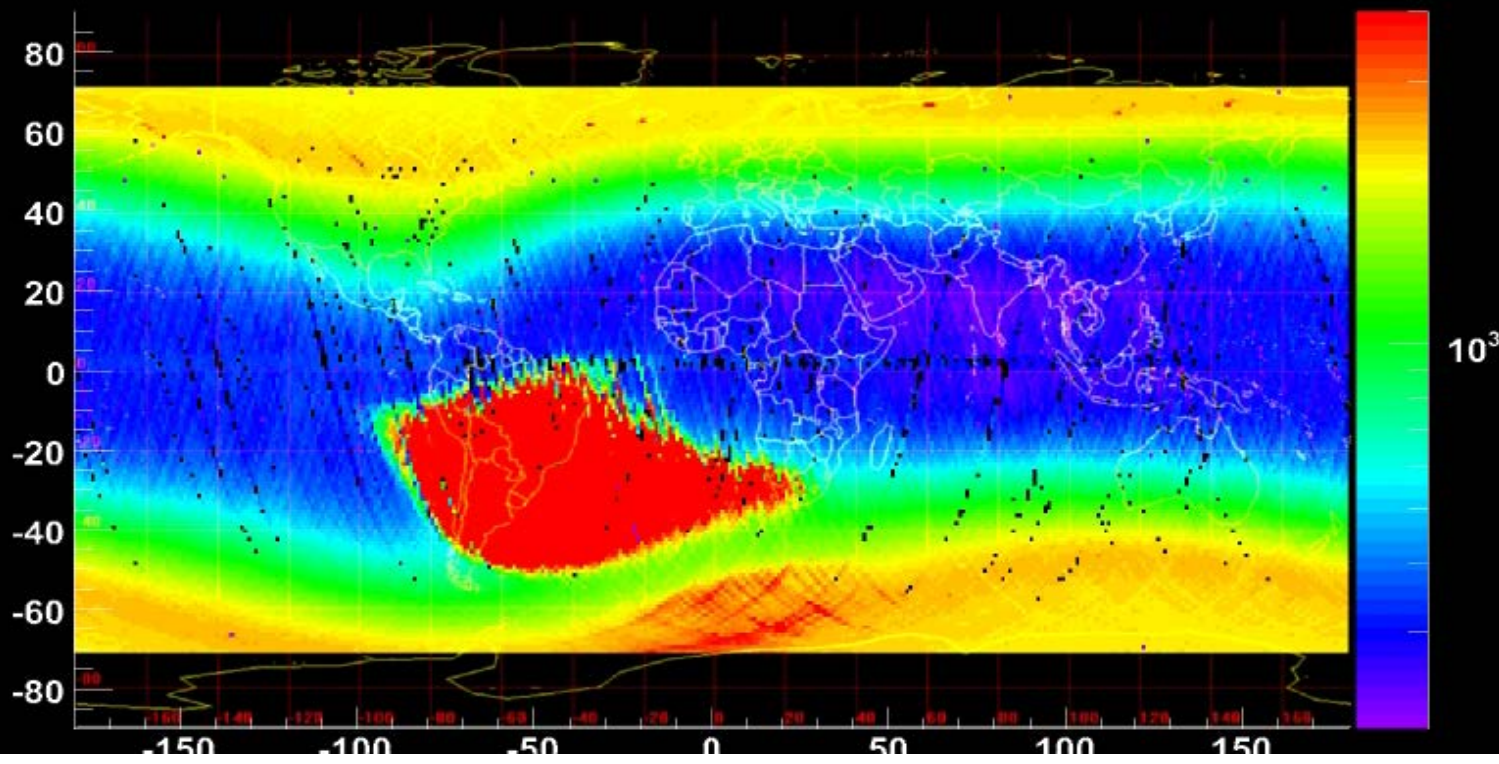
**Resurs-DK1**  
Mass: 6.7 tonnes  
Height: 7.4 m  
Solar array area: 36 m<sup>2</sup>



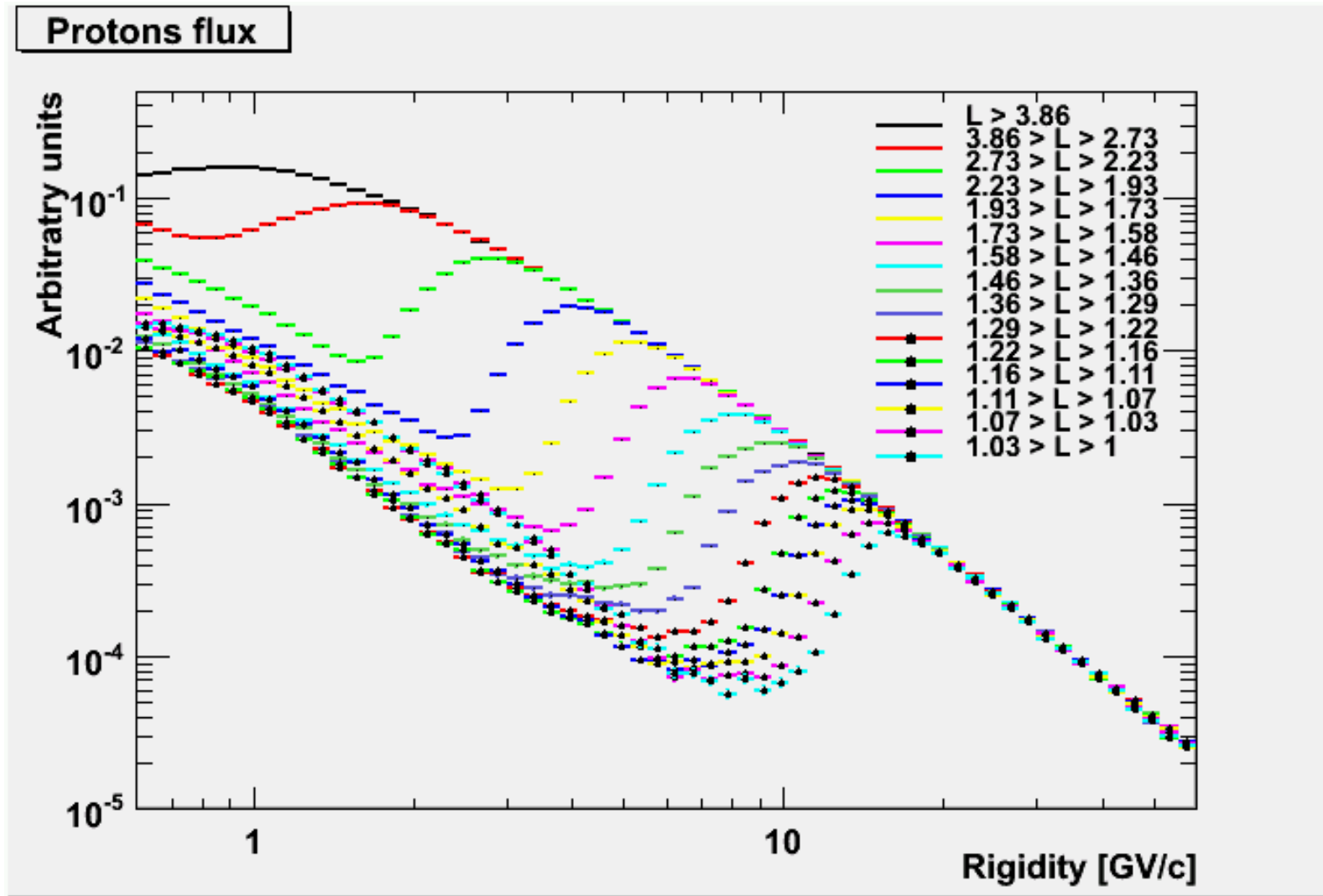
- Resurs-DK1: multi-spectral imaging of earth's surface
- PAMELA mounted inside a pressurized container
- Launched on 15th June 2006 PAMELA in nearly continuous data-taking mode since January 2016 when downlink operation were terminated
- Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day
- Quasi-polar and elliptical orbit (70.0° , 350 km - 600 km) – from 2010 circular orbit (70.0° , ~600 km)
- Traverses the South Atlantic Anomaly
- Crosses the outer (electron) Van Allen belt at south pole

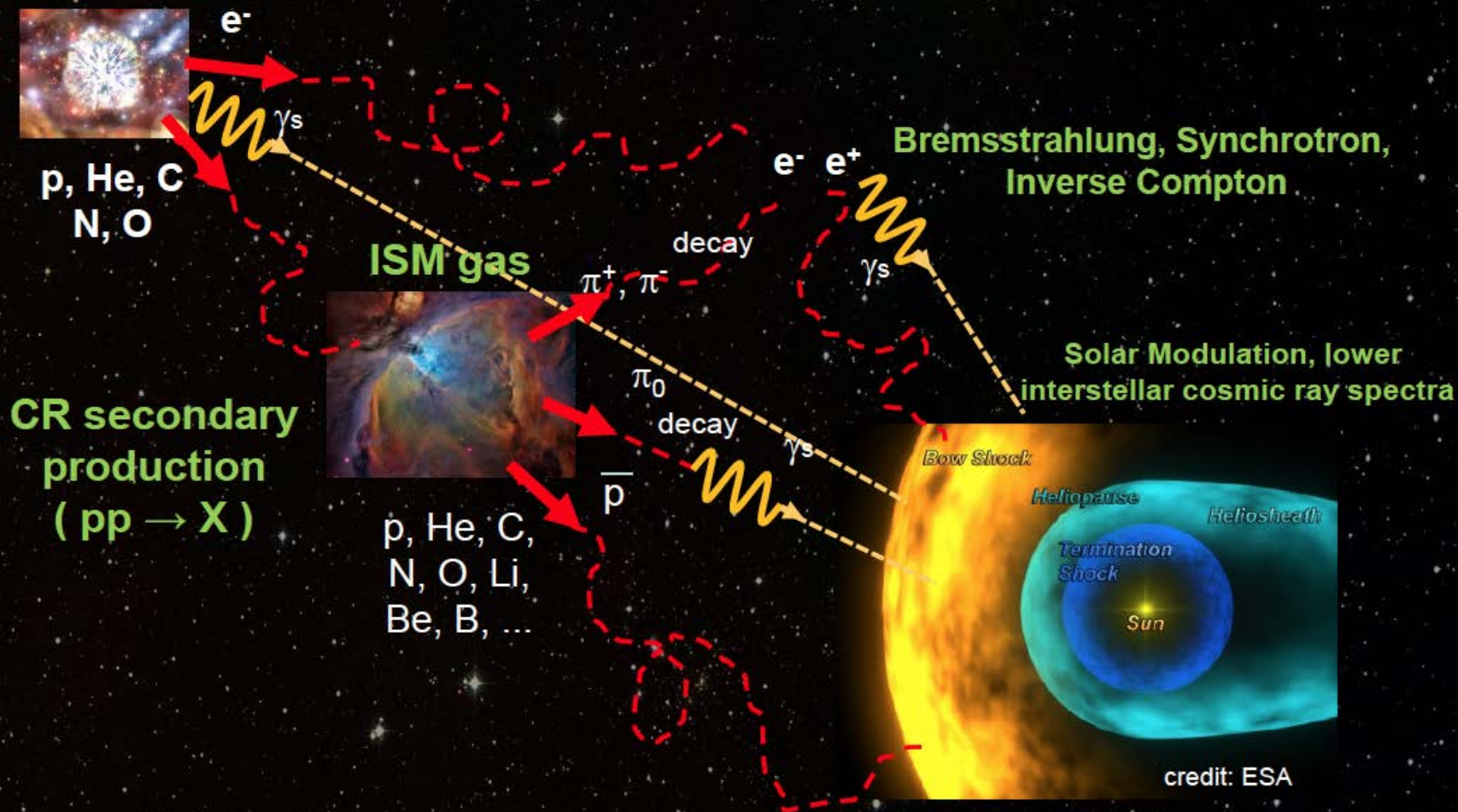


Latitude (deg)



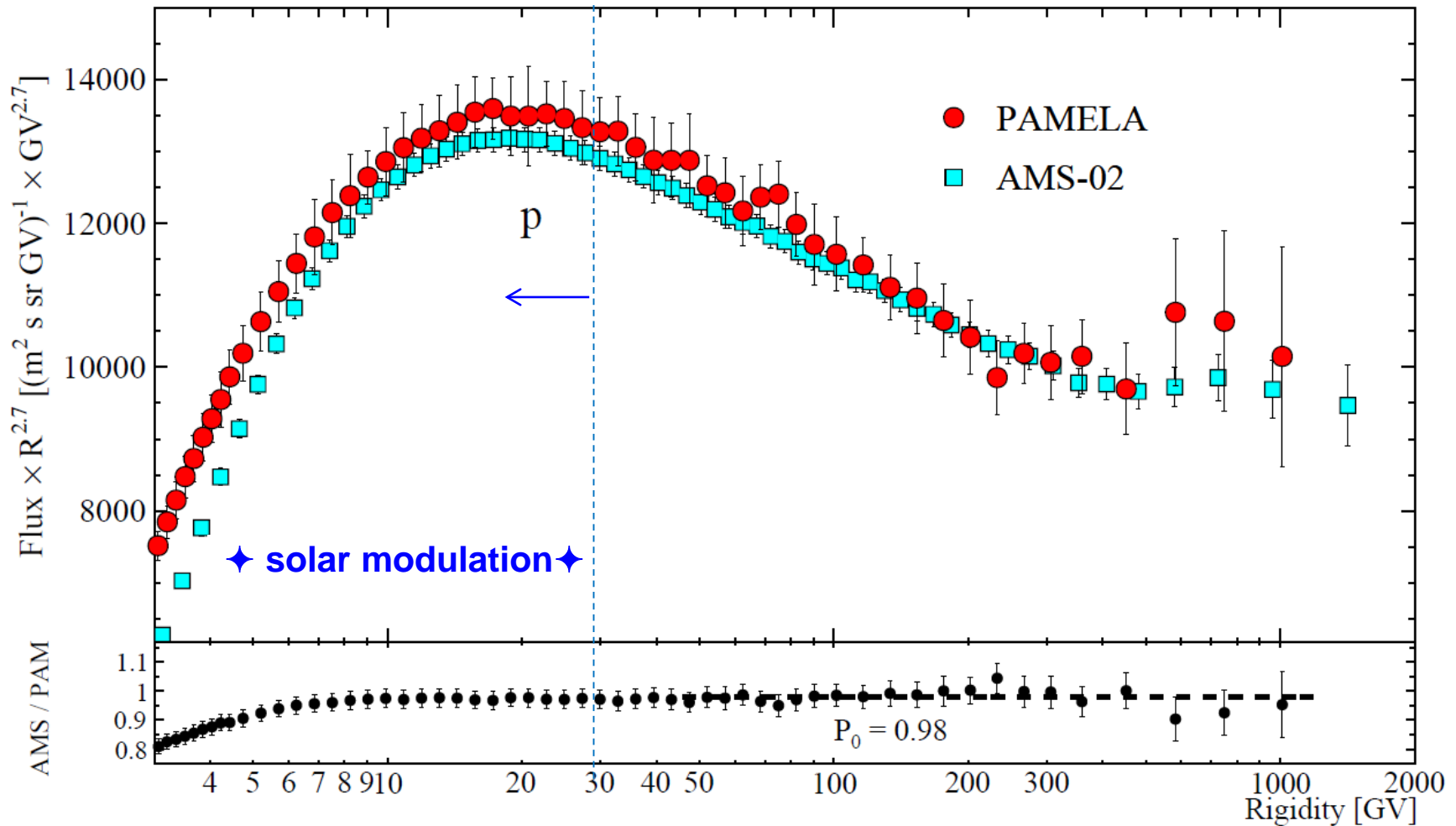
# Proton energy spectrum over PAMELA orbit



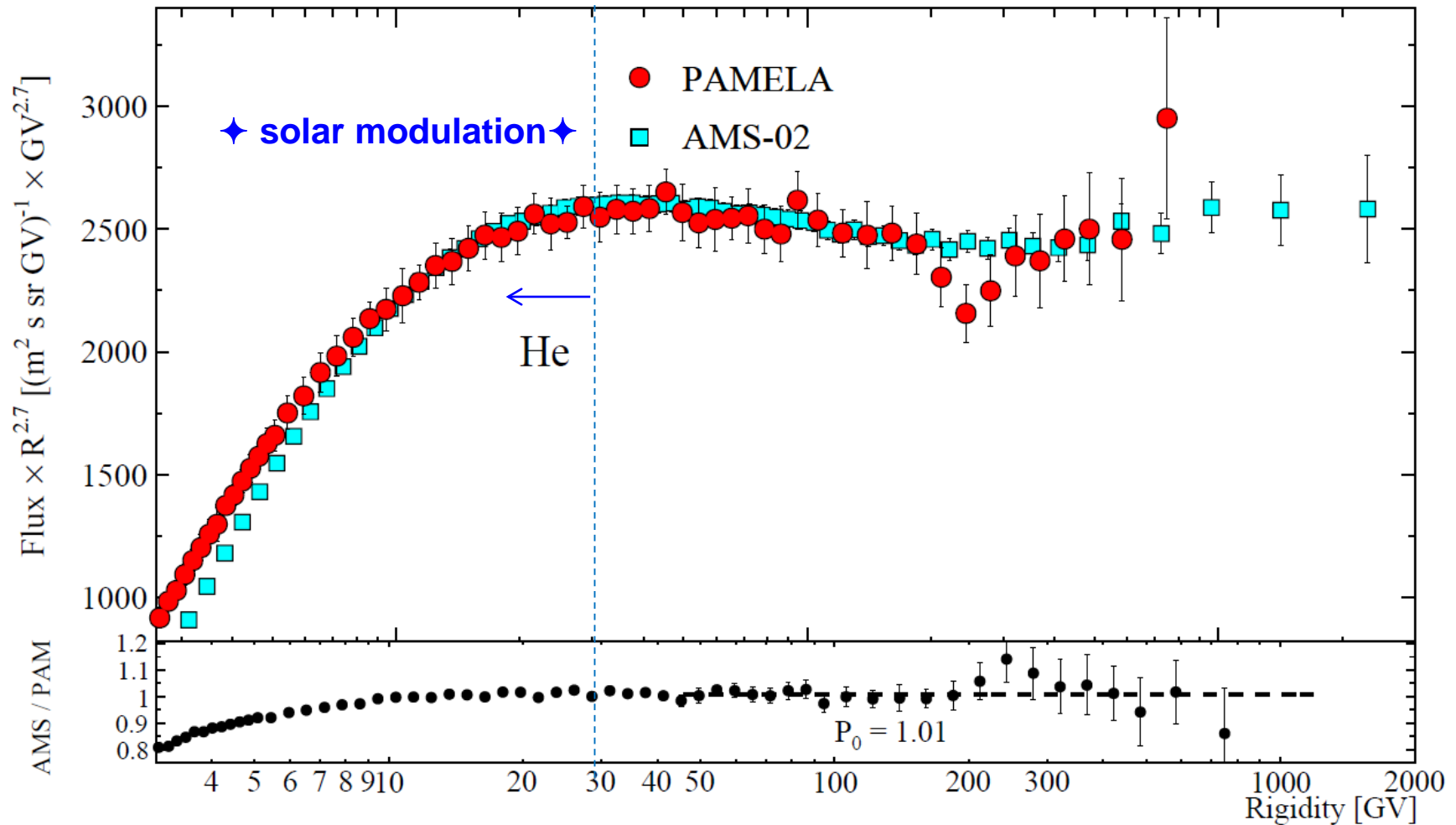


# Cosmic rays in the heliosphere

# PAMELA vs AMS-02: p



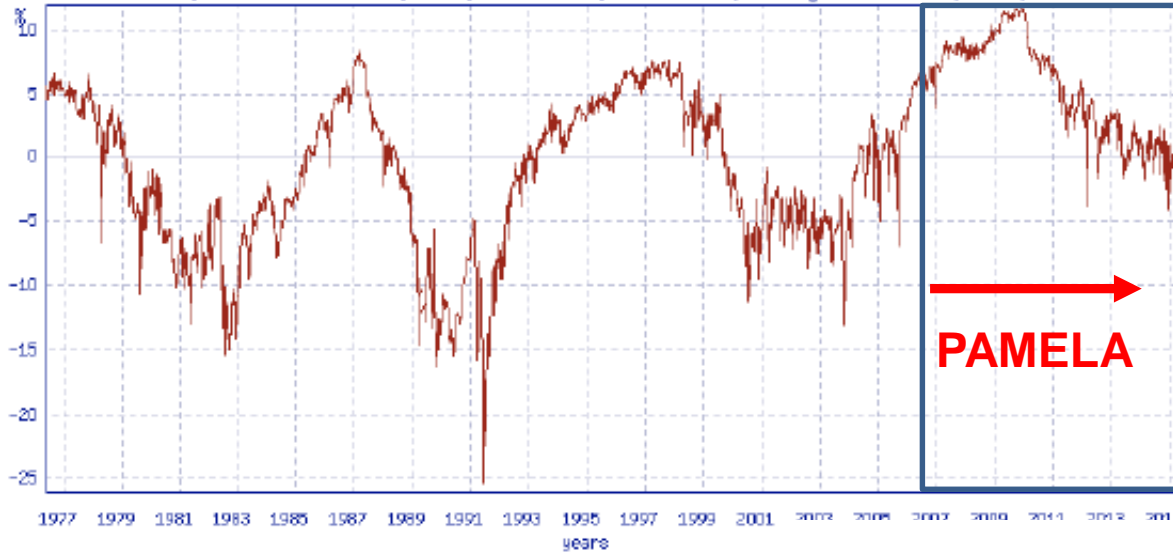
# PAMELA vs AMS-02: He



# Heliospheric conditions during PAMELA observations

## Oulu Neutron Monitor

1976-05-27 00:00 - 2015-05-21 23:59 UT, Resolution: 14400 mins, Average count rate: 6158.2



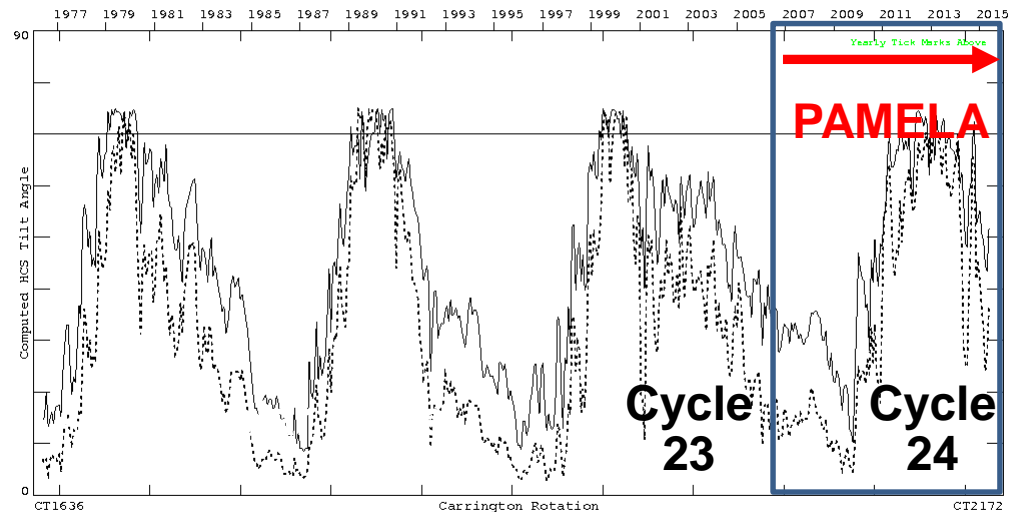
Neutron Monitor counts

Data from  
<http://cosmicrays oulu.fi/>

Computed HCS tilt angle

Data from <http://wso.stanford.edu/>

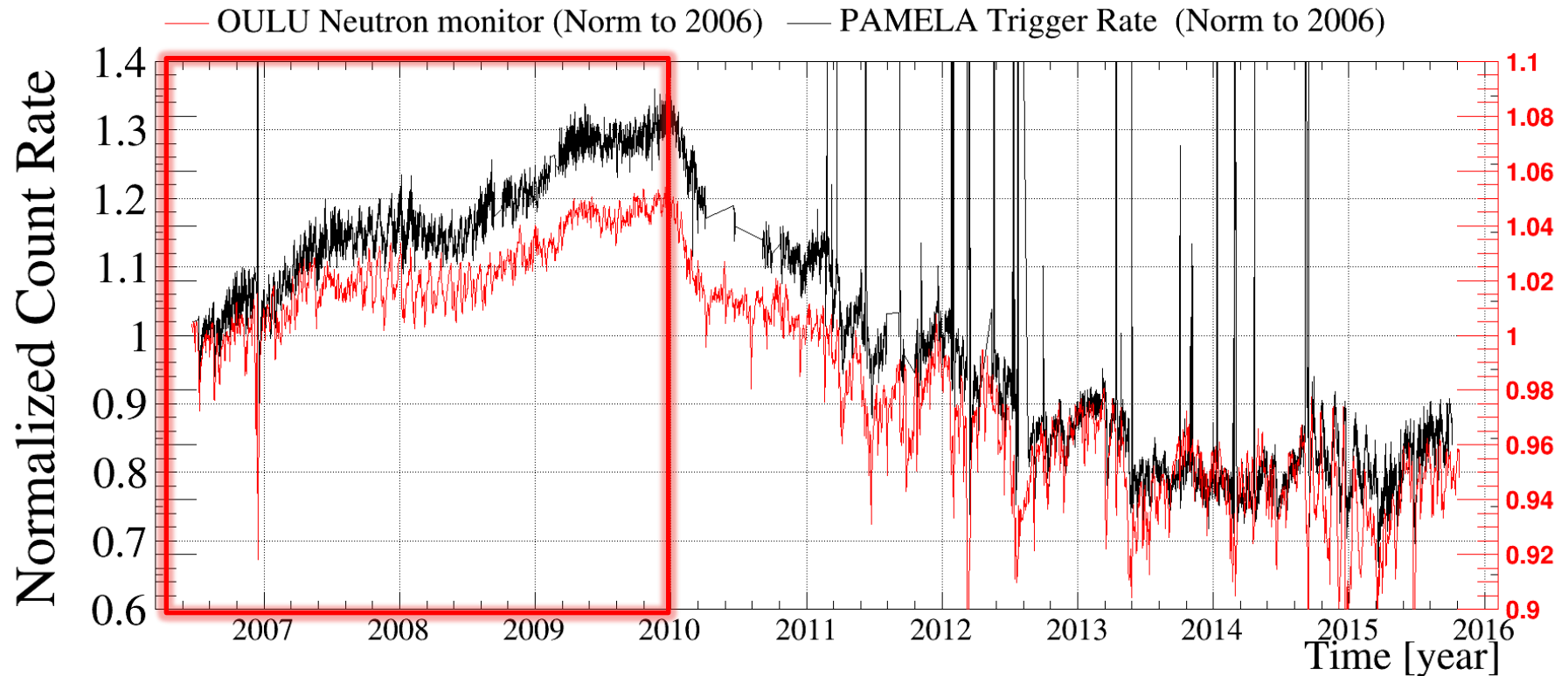
Maximum Inclination of the Current Sheet (N-S Mean): 1976-2015



Solid=Classic PFSS Model (preferred)

Dashed=Radial  $R_s=3.25$

# Heliospheric conditions during PAMELA observations



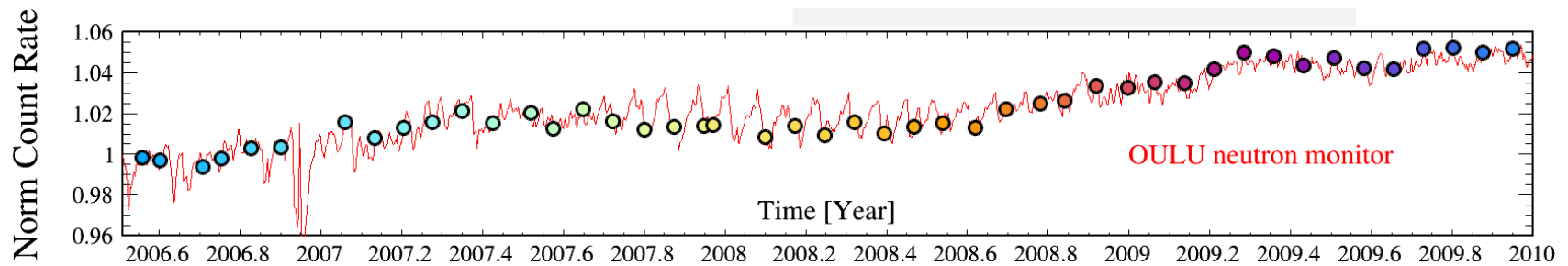
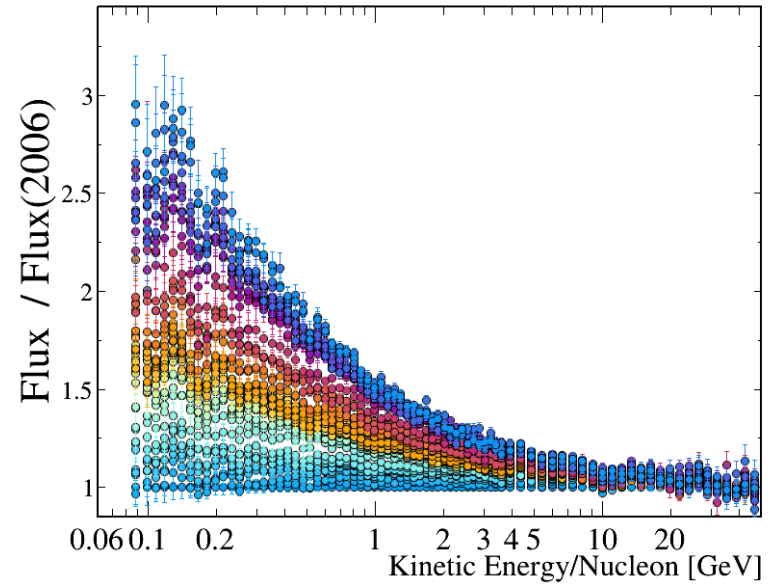
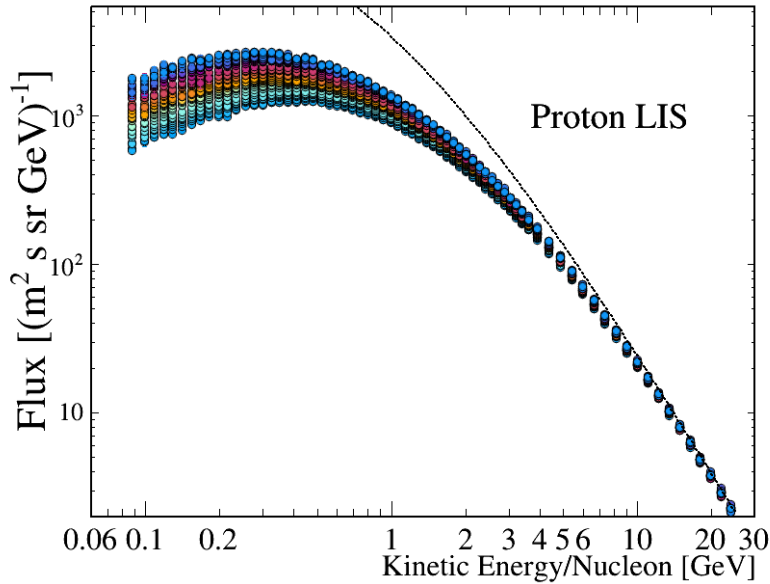
Neutron Monitor counts data from  
<http://cosmicrays oulu.fi/>

**PAMELA observations covers ~ one solar cycle**

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Washington, 24-04-2017



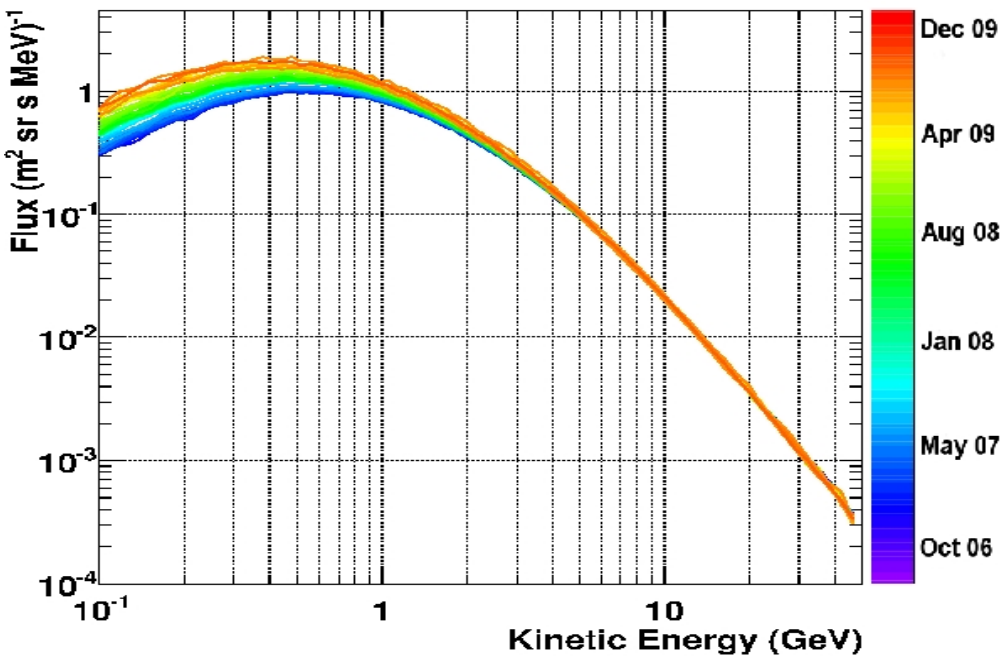
# Time dependence - Proton flux



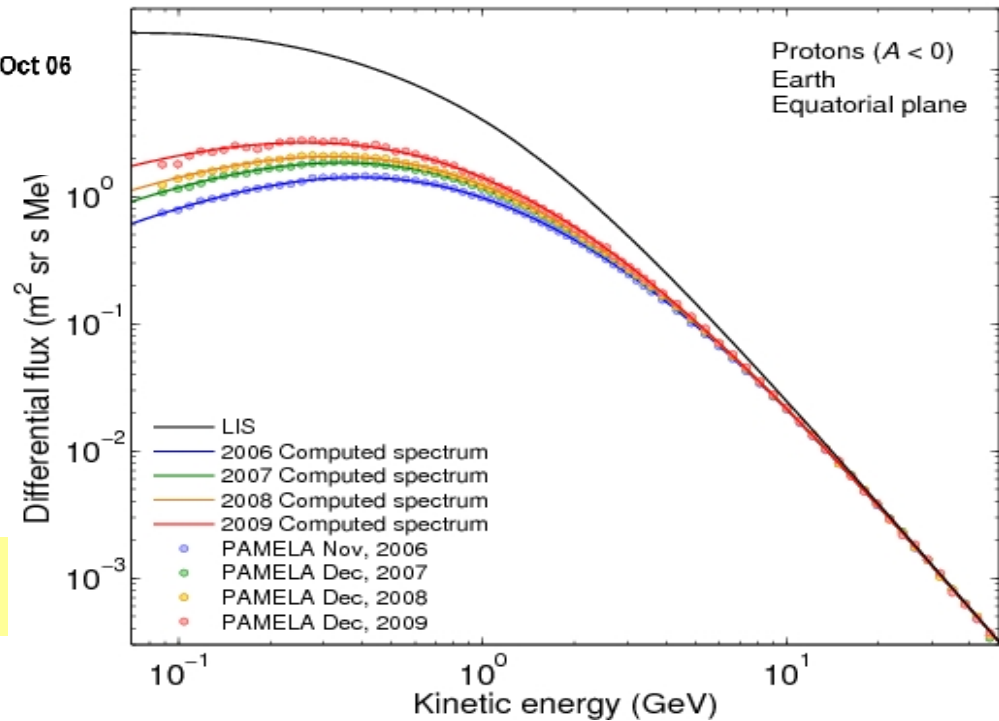
# Time Dependence of the Proton Flux

See M. Potgieter's talk  
See R. Munini's talk

Evolution of the proton energy spectrum from July 2006 to December 2009



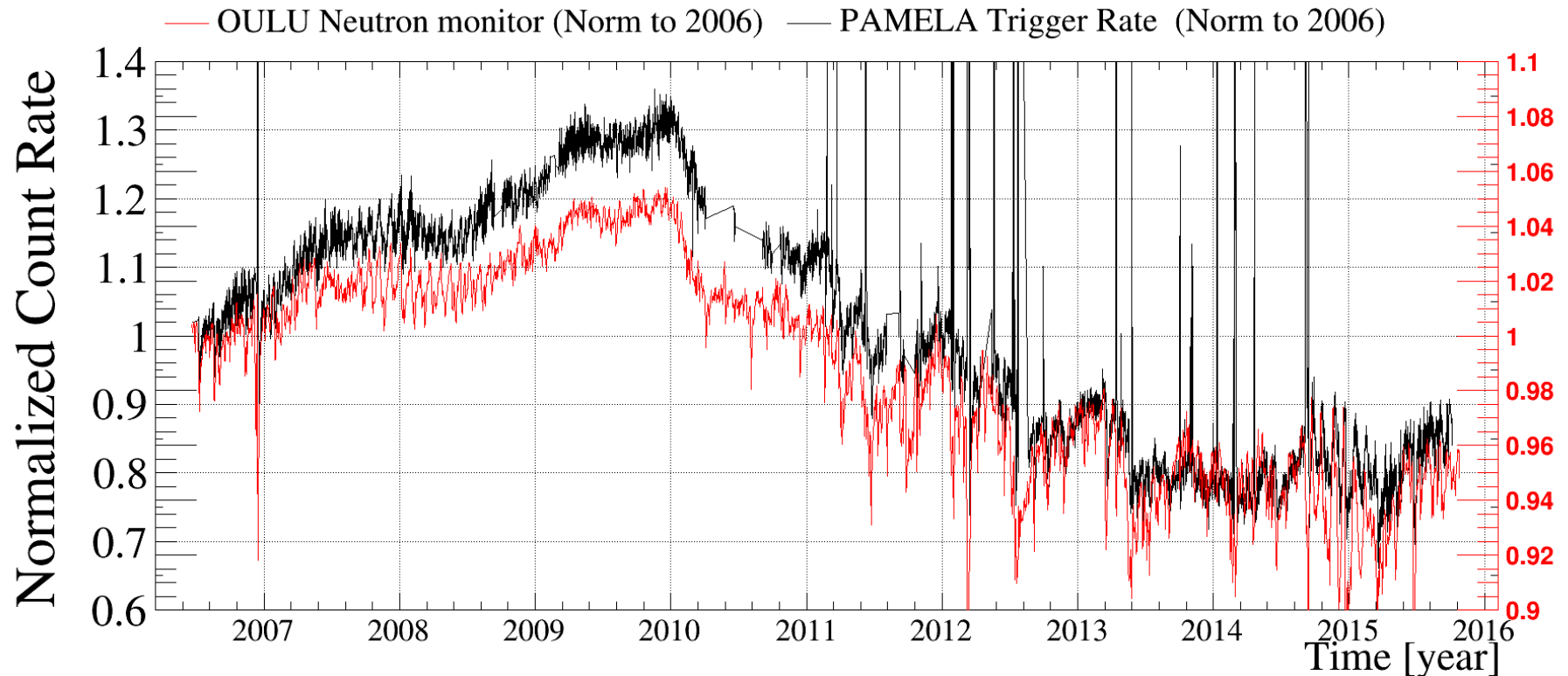
The PAMELA proton spectra over four months compared with the computed spectra



O. Adriani et al., ApJ 765 (2013) 91;  
M. S. Potgieter et al., Solar Phys. 289 (2014) 391

# Heliospheric conditions during PAMELA observations

See R. Munini's talk

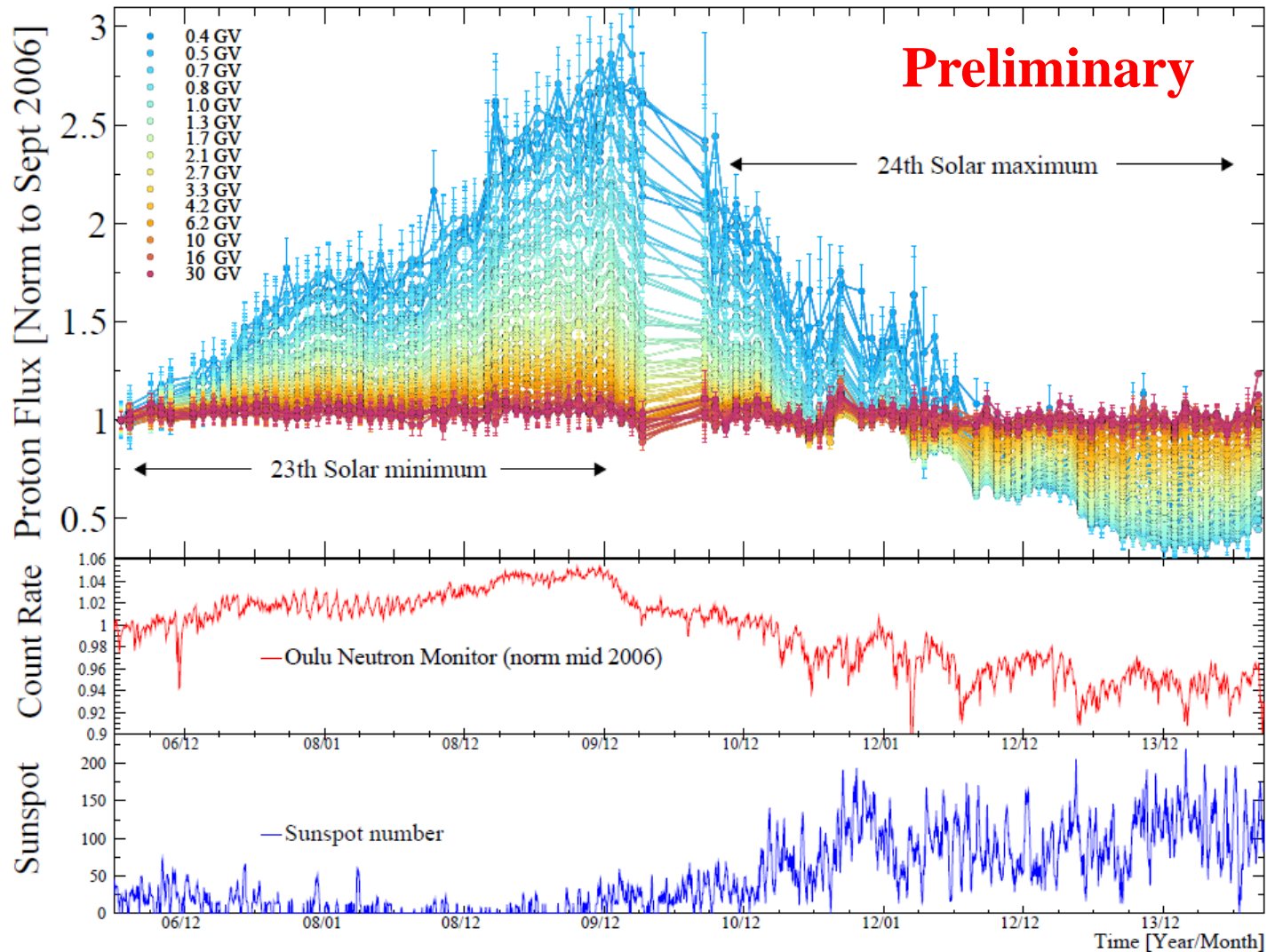


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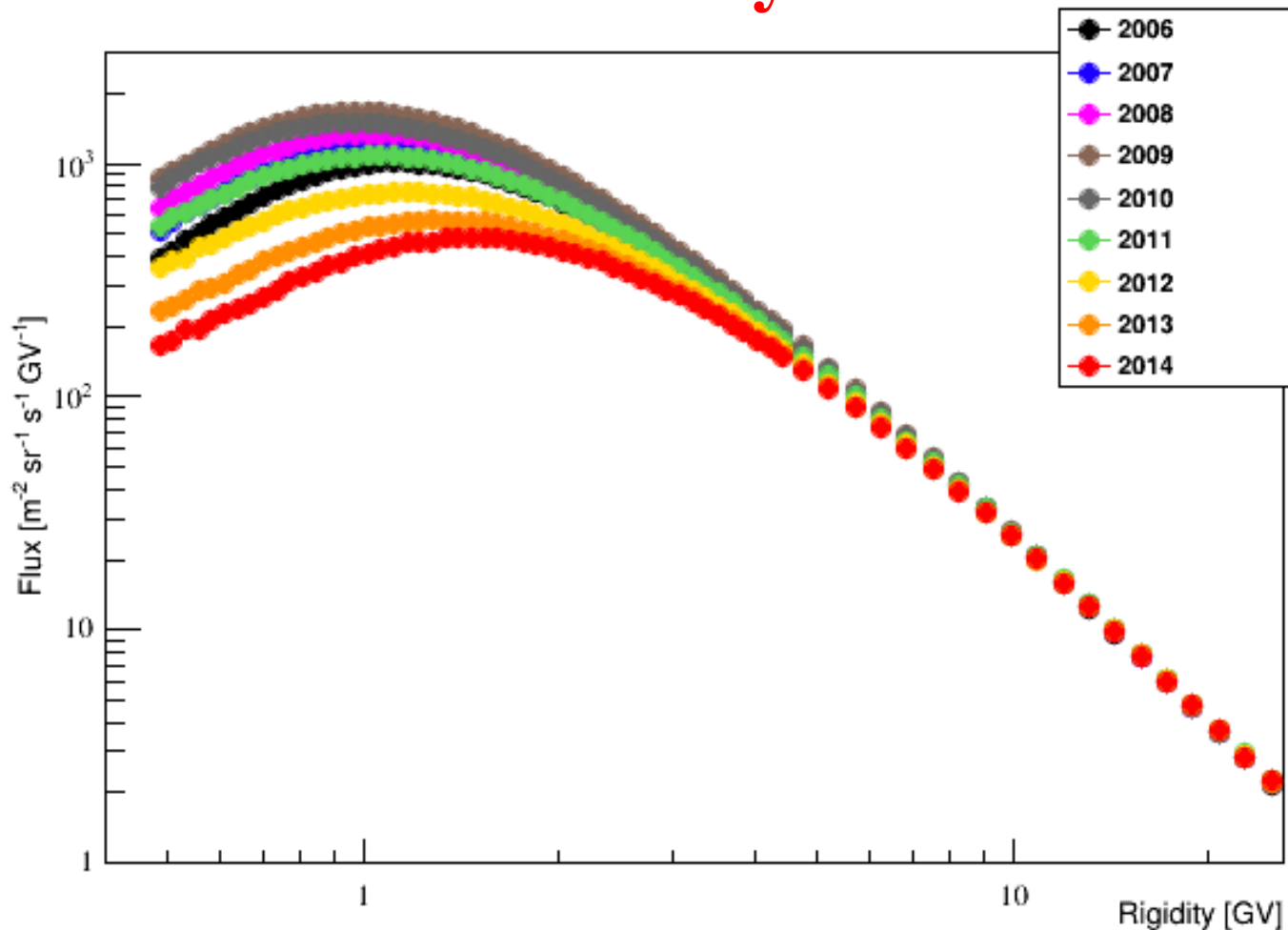
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# Time dependance of the proton flux July 2006-December 2014



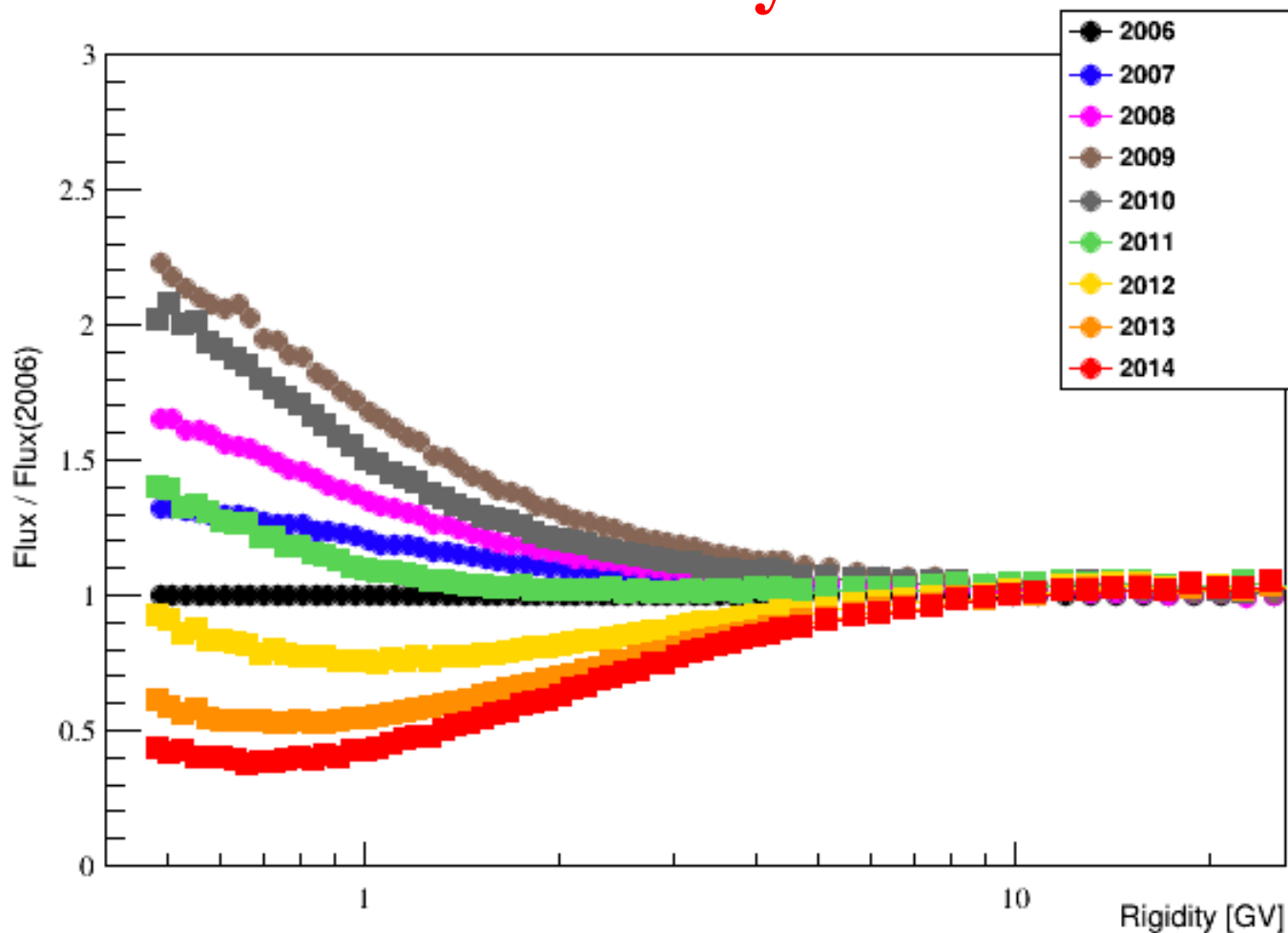
# Time dependance of the proton flux July 2006-December 2014

Preliminary!

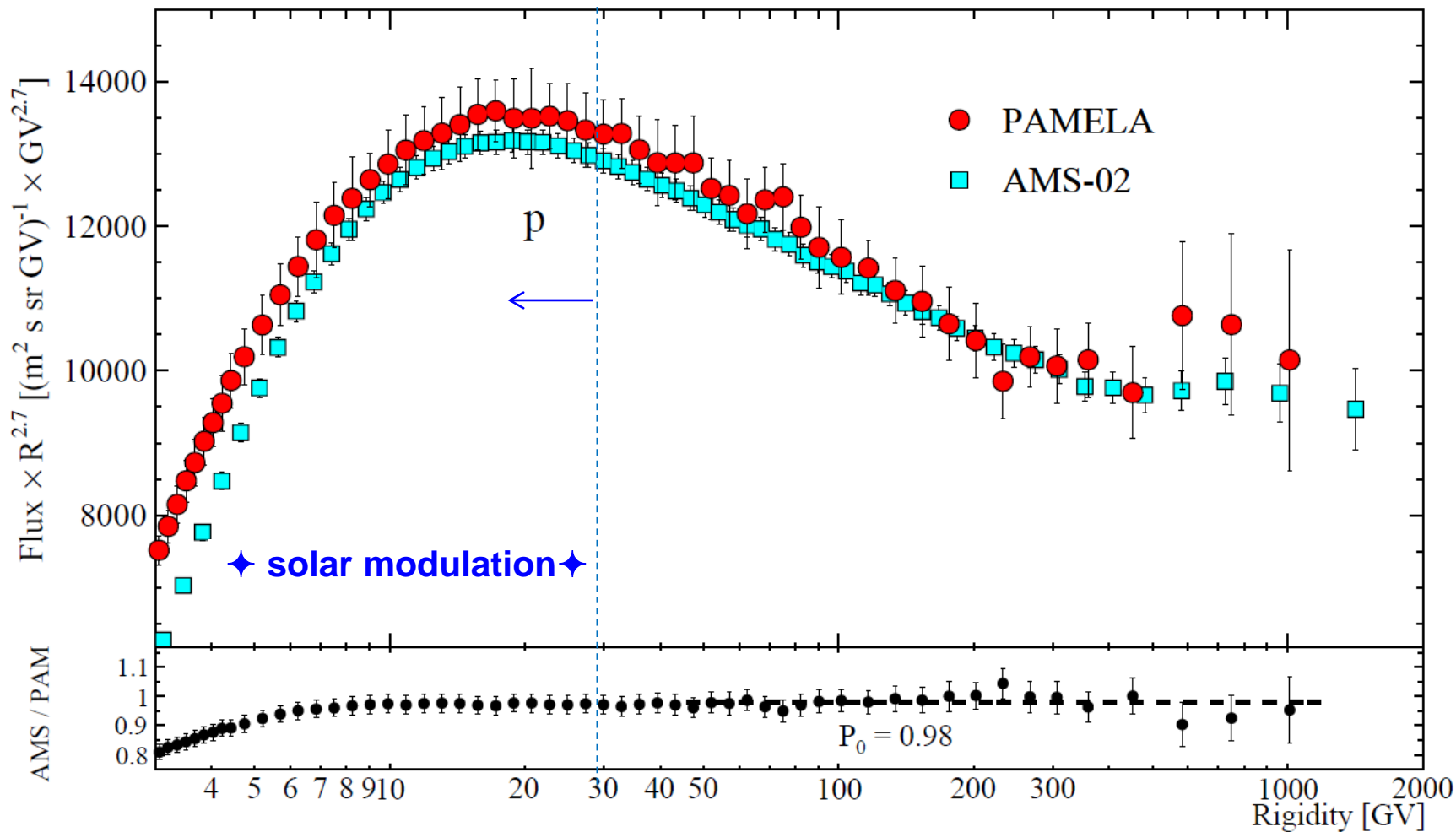


# Time dependance of the proton flux July 2006-December 2014

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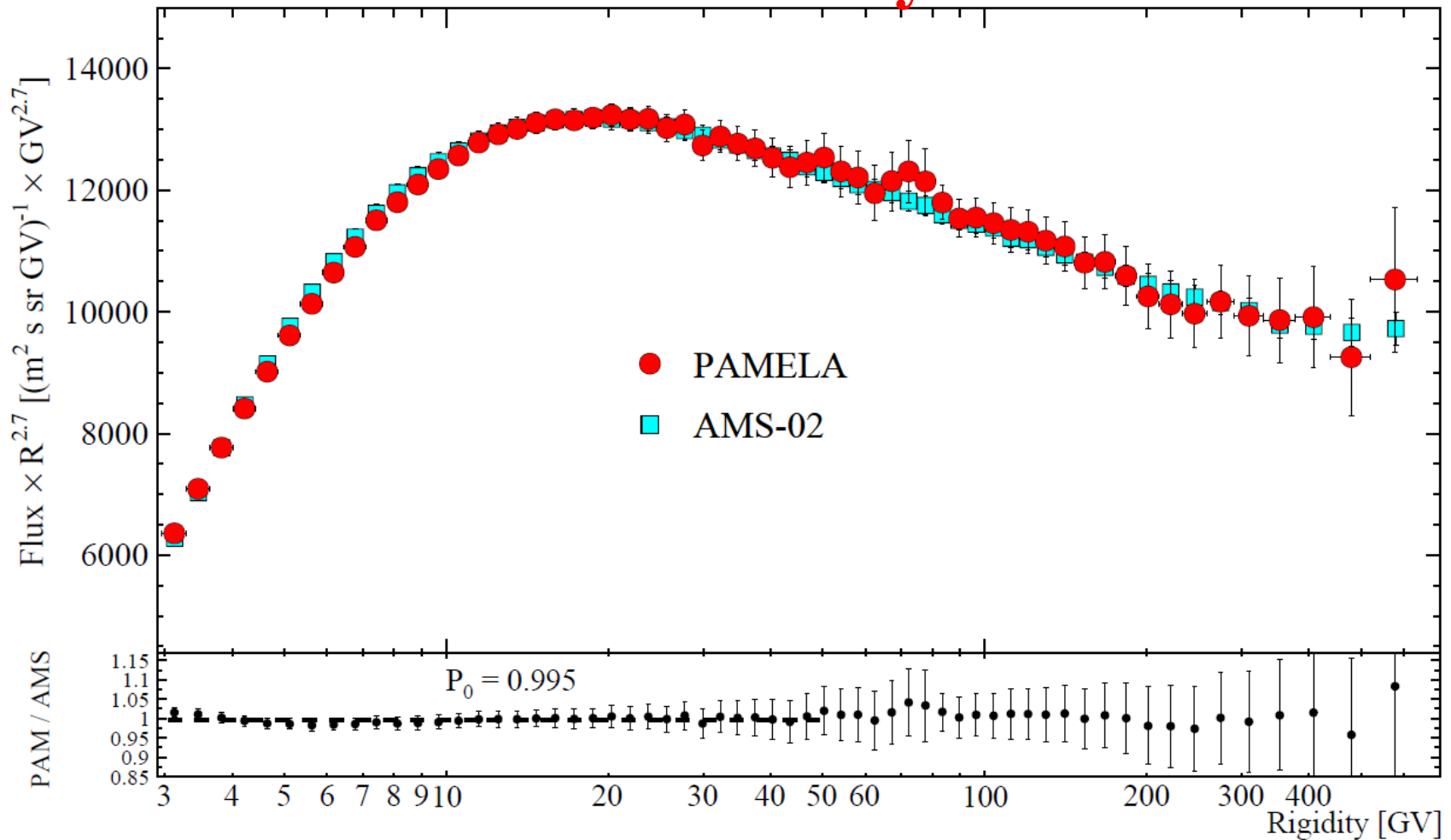


# PAMELA vs AMS-02: p



# PAMELA vs AMS-02: p 2011-2013

Preliminary!





Thanks!