PROCEEDINGS OF SCIENCE

Time dependence of the proton and helium flux measured by PAMELA

B. Panico*
INFN, Sezione di Napoli, I-80126 Naples, Italy
E-mail: beatrice.panico@na.infn.it

D. Campana, G. Osteria
INFN, Sezione di Napoli, I-80126 Naples, Italy

G. C. Barbarino
University of Naples 'Federico II', Department of Physics, I-80126 Naples, Italy
INFN, Sezione di Napoli, I-80126 Naples, Italy

O. Adriani, M. Bongi, P. Spillantini, N. Mori
University of Florence, Department of Physics and Astronomy, I-50019 Sesto Fiorentino,Florence, Italy
INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Florence, Italy

P. Papini, E. Vannuccini
INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Florence, Italy

G. A. Bazilevskaya, A. N. Kvashnin, Y. I. Stozhkov
Lebedev Physical Institute, RU-119991, Moscow, Russia

R. Bellotti, A. Monaco
University of Bari, Department of Physics, I-70126 Bari, Italy
INFN, Sezione di Bari, I-70126 Bari, Italy

A. Bruno
University of Bari, Department of Physics, I-70126 Bari, Italy

F. Cafagna
INFN, Sezione di Bari, I-70126 Bari, Italy

M. Boezio, V. Bonvicini, E. Mocchiutti, R. Munini, G. Zampa, N. Zampa
INFN, Sezione di Trieste, I-34149 Trieste, Italy

35th International Cosmic Ray Conference — ICRC2017
10–20 July, 2017
Bexco, Busan, Korea

*Speaker.

PoS(ICRC2017)173

A. Vacchi
INFN, Sezione di Trieste, I-34149 Trieste, Italy
University of Udine, Department of Mathematics and Informatics, I-33100 Udine, Italy

E. A. Bogomolov, S. Y. Krutkov, G. I. Vasilyev
Ioffe Physical Technical Institute, RU-194021 St. Petersburg, Russia

P. Carlson, M. Pearce
KTH, Department of Physics, and the Oskar Klein Centre for Cosmoparticle Physics, AlbaNova University Centre, SE-10691 Stockholm, Sweden

M. Casolino
INFN, Sezione di Roma Tor Vergata, I-00133 Rome, Italy
RIKEN, Advanced Science Institute, Wako-shi, Saitama, Japan

G. Castellini
IFAC, I-50019 Sesto Fiorentino, Florence, Italy

C. De Santis, L. Marcelli, M. Mergé, P. Picozza, R. Sparvoli
University of Rome Tor Vergata, Department of Physics, I-00133 Rome, Italy
INFN, Sezione di Roma Tor Vergata, I-00133 Rome, Italy

V. Di Felice
INFN, Sezione di Roma Tor Vergata, I-00133 Rome, Italy
Agenzia Spaziale Italiana (ASI) Science Data Center, Via del Politecnico snc I-00133 Rome, Italy

A. M. Galper,A. V. Karelin,S. V. Koldashov,S. Koldobskiy,Y. T. Yurkin,V. Malakhov,A. Leonov,A. G. Mayorov,V. V. Mikhailov,S. A. Voronov
National Research Nuclear University MEPhI, RU-115409 Moscow

M. Martucci
University of Rome Tor Vergata, Department of Physics, I-00133 Rome, Italy
INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati, Italy

W. Menn, M. Simon
Universitat Siegen, Department of Physics, D-57068 Siegen, Germany

M. Ricci
INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati, Italy

S. B. Ricciarini
INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Florence, Italy
IFAC, I-50019 Sesto Fiorentino, Florence, Italy

The energy spectra of galactic cosmic rays carry fundamental information regarding their origin and propagation, but, near Earth, cosmic rays are significantly affected by the solar magnetic field which changes over time. The time dependence of proton and electron spectra were measured from July 2006 to December 2009 by PAMELA experiment, that is a ballooon-borne experiment collecting data since 15 June 2006. These studies allowed to obtain a more complete description of the cosmic radiation, providing fundamental information about the transport and modulation of cosmic rays inside the heliosphere. In this talk the study of the time dependence of the cosmic-ray protons and helium nuclei from the unusual 23rd solar minimum through the following period of solar maximum activity is presented.

PoS(ICRC2017)173

1. Introduction

Although cosmic rays (CRs) have been discovered a long time ago, the mechanism of their propagation is still under study. During propagation thorough the interstellar medium to the Earth cosmic rays undergo interactions with gas atoms and suffered the solar wind interactions. The solar wind is a constant flow of charged particles emanates from the solar corona. The plasma extends up to the heliopause carrying also the heliospheric magnetic field. When cosmic rays encounter the plasma and the embedded magnetic filed, undergo a temporal variation in their intensity and in their energy as a function of the position inside the heliosphere. This process is known as the solar modulation of cosmic rays [1]. The solar activity modulates cosmic rays with its cycle which lasts 11 years on average. It starts from a minimum level when the Sun is quiet to a maximum when the number of sunspots, flares, prominences and other solar activities increase and then returning to a new minimum to repeat the cycle.

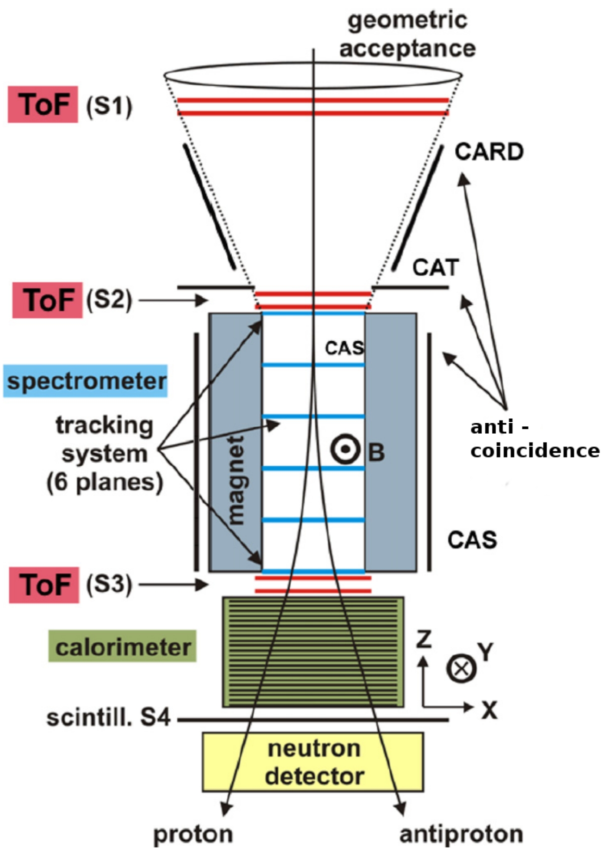
The modulation of cosmic rays is considered to happen from below ∼30 GV/nucleon. Direct cosmic-ray measurements above a few MeV have been performed from the inner to the outer heliosphere and at the Earth [2, 3]. They will provide fundamental data to understand the basic features of the heliosphere.
To have a complete description of the propagation effects, precise measurements of cosmic-ray spectra over a wide rigidity range and over a long period of time are needed. This gives the possibility to study the influence of the solar modulation in different conditions and also as a function of the rigidity up to a range where it is uneffective. PAMELA took data from June 2006 to the beginning of 2016, covering a long part of the last solar cycle which has been uncommon. It was expected that the new cycle would begin in 2008, but the minimum has finished only in the end of 2009. Therefore, it is possible with only one detector to cover a wide range of energy and a temporal period which goes from the solar minimum towards to the maximum.

2. The PAMELA experiment

PAMELA is a Payload for Antimatter-Matter Exploration and Light-nuclei Astrophysics. It is a space-based cosmic-ray detector hosted on the Russian Resurs-DK1 satellite. It was launched with a Soyuz-U rocket on June 15th of 2006 from the Baikonur cosmodrome (Kazakhstan) and it has taken data until the beginning of 2016. PAMELA orbit was elliptical with an inclination of about 70°, an altitude varying between 355 and 584 km and a period of about 90 minutes. In September 2010, the orbit was changed to a nearby circular one, at an altitude of about 570 Km [4].

PAMELA has different scientific objectives, with a special focus on antimatter, as:

- the study of antiproton spectrum up to 200 GeV;
- the study of electron and positron spectrum up to hundreds of GeV;
- the study of proton and helium spectrum up to the TeV;



(a) PAM

Figure 1: Pamela experiment

- the study of light nuclei spectra;
- the search of dark matter and antinuclei;
- the study of solar physics, like the emissions of Solar Energetic Particles;
- the study of solar modulation;
- the study of terrestrial magnetosphere.

Anyway, its layout was optimized for precision study of light particles and antiparticles in primary cosmic rays on a range of energy between tens of MeV and hundred of GeV.
A schematic view of PAMELA apparatus is showed in Fig.1. It is $\sim$1.3 m high with a mass of $\sim$470 kg and contains different detector, as explained below.

- A **Time of flight system** (ToF: S1, S2, S3). It is composed by 6 layers of plastic scintillators arranged into 3 planes; it provides the main experimental trigger and can determine particle charge up to Z<8 by measuring ionization energy loss. It measures the time of flight of particles passing between planes; this information is combined with track length information derived by the spectrometer to determine particle velocity. It allows the identification of albedo particles measuring the incoming particle direction.

- A **magnetic spectrometer**, composed by a permanent magnet equipped with six double-sided micro-strip silicon sensors, arranged in such a way to produce inside the cavity a quasi-dipolar magnetic field B with practically all the strength concentrated along the Y axis (the X and Z components are less than 10% of the Y component) and rather uniform. It allows the determination of the sign of the charge and the rigidity of particles up to 1 TeV/c. Also ionization losses are measured into the silicon planes, obtaining the absolute charge of the particle. Any stray magnetic field outside the cavity can potentially interfere with the satellite instruments and navigation systems; in order to attenuate it, the magnet is enclosed by a ferromagnetic shielding.

- An **anticoincidence system** (CARD, CAT, CAS), which consists of nine plastic scintillators. It acts as a veto shield, allowing the identification, during off-line data analysis, of the events originating fake triggers, mainly due to the interaction with the mechanical structure of the experiment.

- An **electromagnetic calorimeter**, composed by 44 silicon planes and 22 plates of tungsten for a total of 16.3 radiation lengths. It provides a direct measurement of the energy for electrons and positrons and, through the analysis of the shower topology, allows the discrimination between hadrons and leptons.

- A **neutron detector**, which improves the lepton/hadron discrimination measuring the neutron over-production that is present in case of hadronic showers respect to the electromagnetic ones.

3. Event Selection

A crucial point of this analysis is the selection of a sample of events to ensure an high statistic with a negligible contamination both for protons and helium. The analysis is based on data collected from June 2006 to September 2014. In the analysis on proton and helium spectum [5] the aim is to maximize the spectrometer performances and minimize the systematic uncertainties. In this paper we want to study the variation of the low energy particle flux in different periods. As a crucial role is played by statistics, the tracking requirements were relaxed and the fiducial volume was enlarged while the selection cuts were narrowed.

3.1 Tof cuts

To control the charge selection with the tracker, it is important to select a pure sample of events. Thanks to the different detectors which composed PAMELA, we have a redundancy of information. In Fig. 2 the dEdx for each layer of the Tof as a function of the β of the particle is reported for protons. In Fig. 2 the dEdx for each layer of the Tof as a function of the $1/\beta$ is reported for helium events. It can be clearly seen that protons and helium are well separated, allowing a good quality selection.

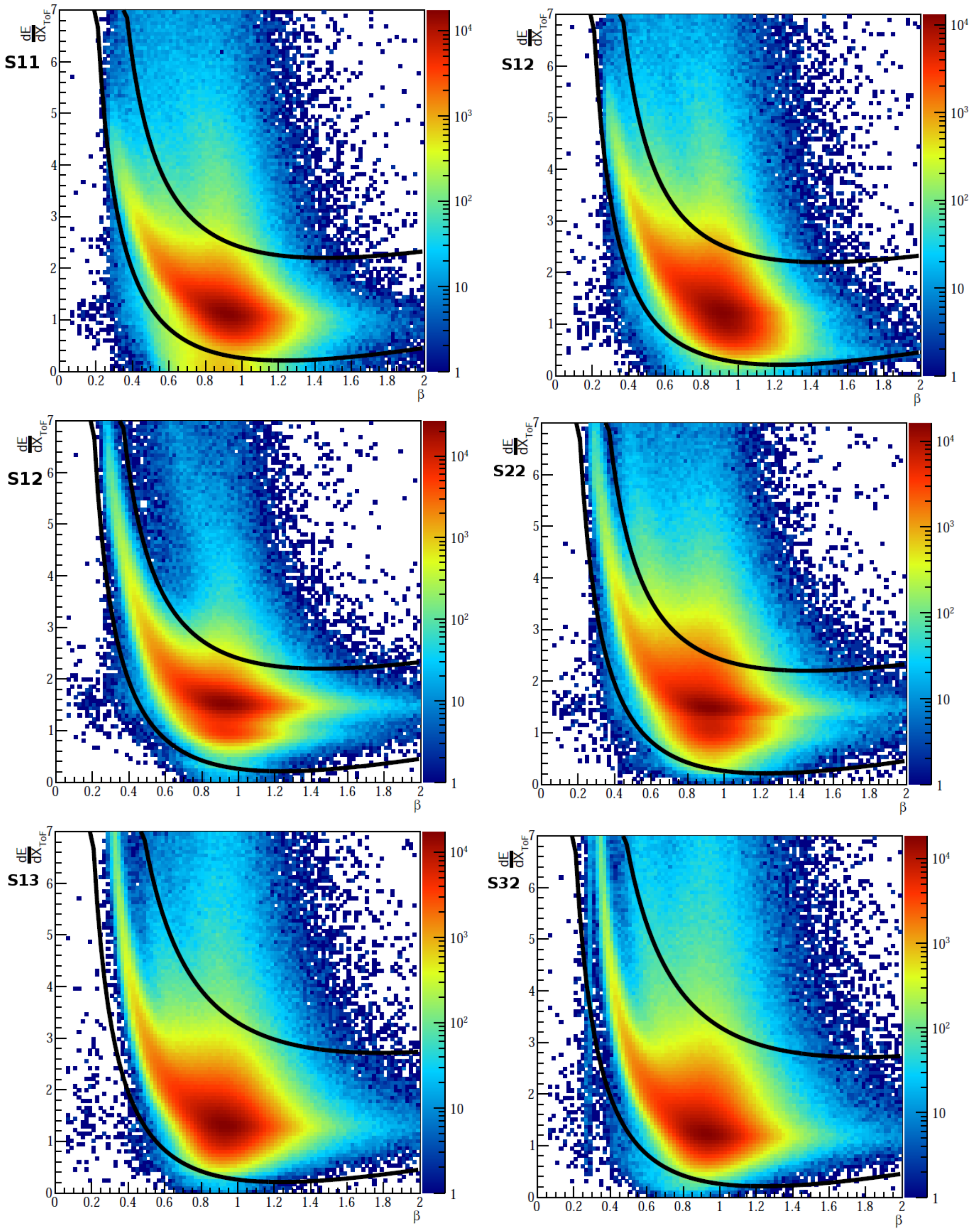


Figure 2: dEdx in the 6 planes of the TOF as a function of β. The lines represent the boundaries set to select proton events.

3.2 Tracker cuts

To increase the statistics, two choices have been done:

1. the fiducial area is bounded 1.5 mm from the magnet cavity walls;

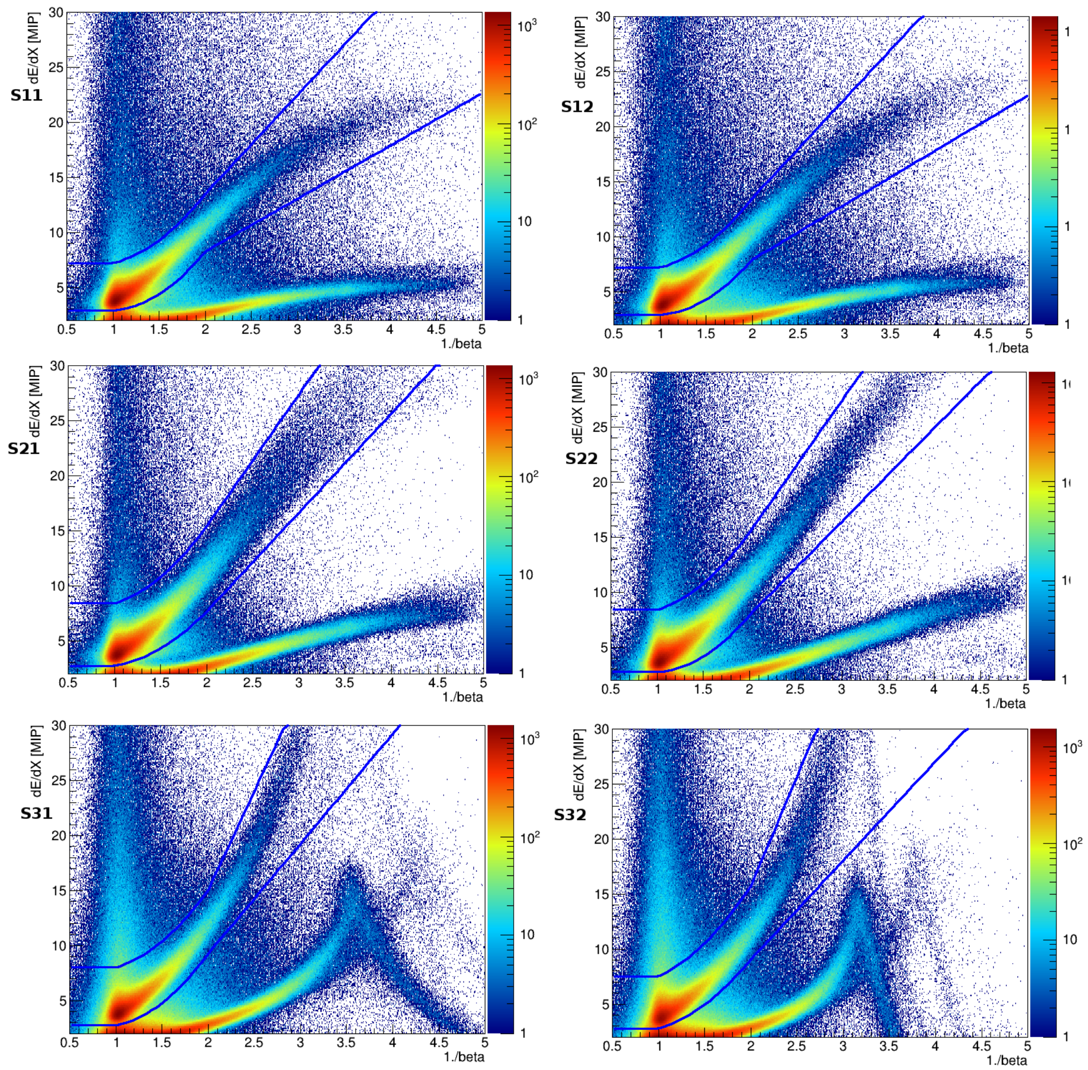
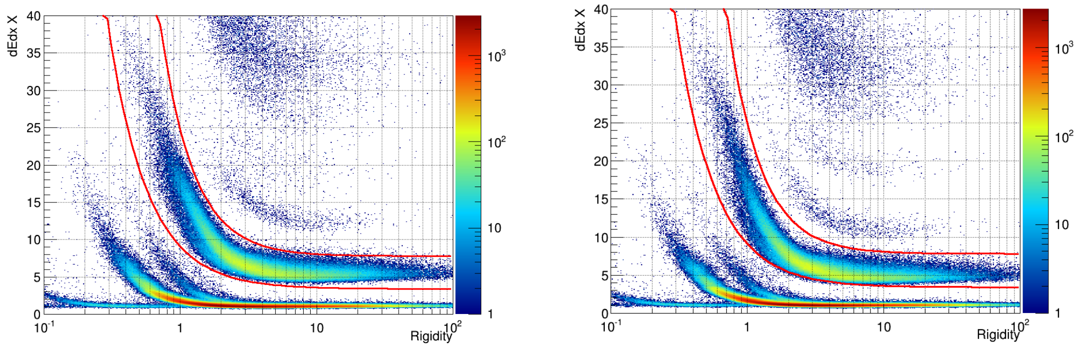


Figure 3: dEdx in the 6 planes of the TOF as a function of $1/\beta$. The lines represent the boundaries set to select helium events.

2. to obtain a good track quality at least 3 hits on both X and Y view and a track lever-arm of at least 4 silicon planes in the tracker are required.

Finally a cut based on the dEdx read by the silicon layers have been applied. The dEdx on the 6 layer have been summed, excluding the max value for each event. The resulting dEdx in the X and in Y view is reported in Fig. 4. The difference between the bands identified by different particles can be clearly seen. As an example the boundaries set to select helium are reported; in this case the contamination due to protons is less than $5 \cdot 10^{-4}$.



(a) X (b) Y

Figure 4: dEdx on the X (left) and Y (right) view in the tracker. As example the boundaries set to select helium are reported (red lines).

4. Conclusions

PAMELA has the possibility to study the solar modulation of proton and helium nuclei on a very long time from the unusual 23rd solar minimum through the following period of solar maximum activity. A preliminary analysis on the selection of events have been reported in this proceeding. More information will be given at the conference.

5. Acknowledgments

The Italian authors acknowledge the partial financial support from the Italian Space Agency (ASI) under the program 'Programma PAMELA - attività scientifica di analisi dati in fase E'.

References

[1] Potgieter, M.S., Living Rev. Sol. Phys. (2013) 10, 3, doi:10.12942/lrsp-2013-3

[2] Heber, B. & Potgieter, M.S., Space Sci Rev (2006) 127, 117, doi:10.1007/s11214-006-9085-y

[3] Webber, W. R., McDonald, F. B., Cummings, A. C. et al., Geophys. Res. Lett. (2012) 39, 6, doi:10.1029/2012GL051171

[4] Picozza, P., Galper A., Castellini, G., Astropart. Phys. (2007) 27, 296, doi:10.1016/j.astropartphys.2006.12.002

[5] Adriani, O., Barbarino, G.C., Bazilevskaya, G.A. et al., Science (2011) 332, 6025, doi:10.1126/science.1199172