Measurement of Deuterium and ^{3}He component in cosmic rays with PAMELA experiment

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Abstract: PAMELA is a satellite borne experiment designed to study with great accuracy cosmic rays of galactic, solar, and trapped nature, with particular focus on the antimatter component. The detector consists of a permanent magnet spectrometer core to provide rigidity and charge sign information, a Time-of-Flight system for velocity and charge information, a Silicon-Tungsten calorimeter and a Neutron detector for lepton/hadron identification. The beta and rigidity information allow to identify isotopes for $Z = 1$ and $Z = 2$ particles in the energy range 100 MeV/n to 1 GeV/n. In this work we will present observation of cosmic rays D and He isotopes at the 23rd solar minimum from 2006 to 2008. Specifically we will discuss the ratios D/H and ^{3}He/^{4}He as a function of time and compare the results with existing measurements and models.

Keywords: The keywords will be used to select your subject from all ICRC contributions.

1 Introduction

Hydrogen and helium isotopes in cosmic rays are generally believed to be of secondary origin, resulting mainly from the nuclear interactions of primary cosmic-ray protons and ^{4}He with the interstellar medium. A precise measurement of the isotopic composition of hydrogen and helium could provide important information about the propagation of cosmic rays in the interstellar space, since they offer better statistics than other secondaries. This can be crucial when analyzing positron and antiproton spectra, which is the primary goal of several current cosmic-ray experiments [1, 2].

The PAMELA experiment has been measuring since 2006 both hydrogen and helium isotopes over a wide range of time with reduced instrumental uncertainty and with no environmental systematics, such as - for instance - the residual atmosphere present in balloon experiments.

In this paper we present the isotopic composition of helium in the energy range from 0.1 to about 1 GeV nucleon^{-1} (corresponding to rigidities from ~ 800 MV to ~ 2.5 GV) obtained from the flight data recorded until December 2008.

2 Pamela detector

PAMELA [3] is constituted by a number of redundant detectors (see Fig. 1) capable of identifying particles providing charge, mass, rigidity ($\rho = p/Ze$) and velocity ($\beta = v/c$) over a very wide energy range. Its main scientific objective is the study of the antimatter component in CR, see [4]. The core of the instrument is a permanent magnet with six planes of silicon microstrip detectors for tracking particles. A three-scintillators system provides trigger, charge and time of flight information. A silicon-tungsten calorimeter is used for hadron/lepton separation with a shower tail catcher and a neutron detector at the bottom of the apparatus to help increase this separation. An anticounter system is used to reject spurious events in the off-line phase. The readout electronics, the interfaces with the CPU and all primary and secondary power supplies are housed around the detectors. All systems (power supply, readout boards etc.) are redundant with the exception of the CPU which is more tolerant to failures. The apparatus is enclosed in a pressurized container located on one side of the Resurs-DK1 satellite. Total weight of PAMELA is 470 kg; power consumption is 355 W. A more detailed description of the instruments and the data handling can be found in [3].

3 Analysis

The high inclination ($70°$) orbit of the Resurs-DK1 satellite and the long mission duration allow PAMELA to study low energy particles (down to 50 MeV) investigating several aspects of the solar and terrestrial environment.

To select the primary (galactic) component we evaluated the local geomagnetic cutoff G in the Störmer approximation [5]. The value of $G = 14.9/L^2$ - valid for vertically incident particles - is estimated using the IGRF magnetic field model along the orbit; from this the McIlwain

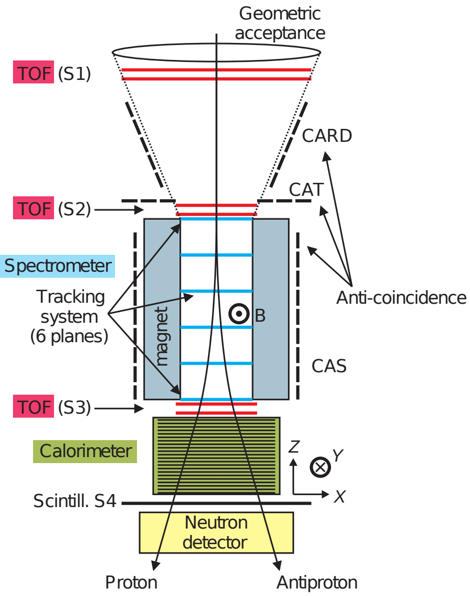

Figure 1: A schematic overview of the PAMELA satellite experiment. The experiment stands ~1.3 m high and, from top to bottom, consists of a time-of-flight (ToF) system (S1, S2, S3 scintillator planes), an anticoincidence shield system, a permanent magnet spectrometer (the magnetic field runs in the y-direction), a silicon-tungsten electromagnetic calorimeter, a shower tail scintillator (S4) and a neutron detector.

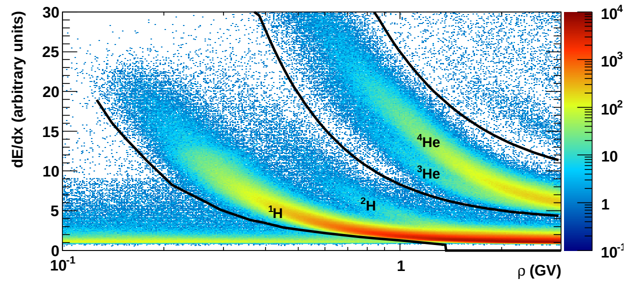

Figure 2: Energy loss in tracker (mean in all planes hit) vs tracker rigidity for positively charged particles. The Proton and Helium bands are clearly visible. The black lines represent cuts used to select H and He nuclei.

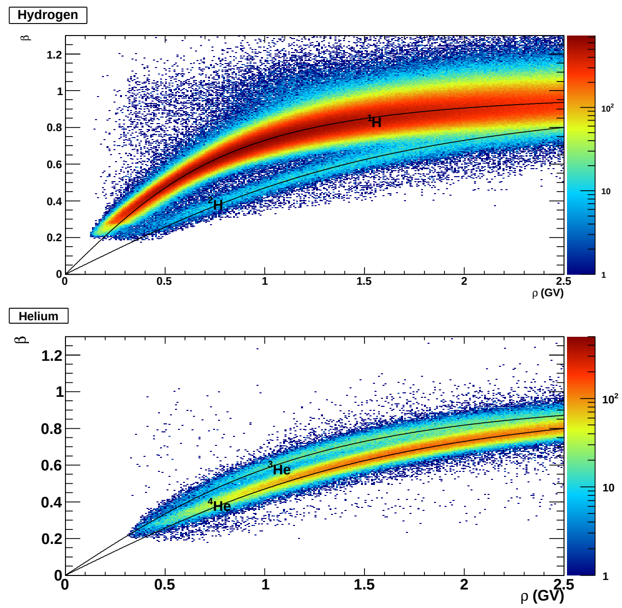

Figure 3: Mass separation for $Z = 1$ (*top*) and $Z = 2$ (*bottome*) particles with the β vs. rigidity method. The black lines represent the theoretical curves from Eq. 1

L shell is calculated [6]. Particles where selected requiring $\rho > 1.3\ G$ to remove any effect due to directionality in the detector and Earth's penumbral regions.

For the measurement of ratios as functions of kinetic energy the geomagnetic cutoff cut is applied considering the same geographical region for the two isotopes requiring $\rho^*(E) > 1.3G$, where $\rho^*(E)$ is the lowest rigidity between the two isotopes having kinetic energy E.

We have selected events that do not produce secondary particles by requiring a single track fitted within the spectrometer fiducial acceptance and a maximum of one paddle hit in the two top scintillators of the ToF system. The hits in the two scintillators must match the extrapolated trajectory from the tracker. Albedo particles are rejected requiring $\beta > 0$.

3.1 Hydrogen and Helium selection

The measurement of the average energy released in the tracker planes for a given event at a given rigidity can be used to discriminate between different particles since energy loss of a charged particle through matter follows the Bethe Block formula, $dE/dx \propto Z^2/\beta^2$ (neglecting logarithmic terms). In Fig. 2 is shown the energy loss in the tracker as a function of the particle rigidity. The top band is due to helium nuclei which have energy loss in the tracker $Z^2 = 4$ times the protons, identified in the central band. The band at the bottom left of Fig. 2 is due to positrons, relativistic also at low rigidities and the background of pion and secondary particles. The black lines show the energy dependent cuts used to select the helium sample.

Cuts in the energy loss (dE/dx) vs rigidity remove positrons, pions and particles with $Z > 2$ as shown Fig 2.

3.2 Isotope separation

To separate ^{2}H from ^{1}H and ^{3}He from ^{4}He we have taken the $1/\beta$ distribution (described by a Gauss function) at fixed rigidity. As shown in Fig. 3 the different masses of the isotopes guarantee a separation (decreasing with energy) in the $1/\beta$ distribution according to

$$\frac{1}{\beta} = \sqrt{1 + \frac{A^2}{Z^2}\frac{m_p^2}{\rho^2}} \quad (1)$$

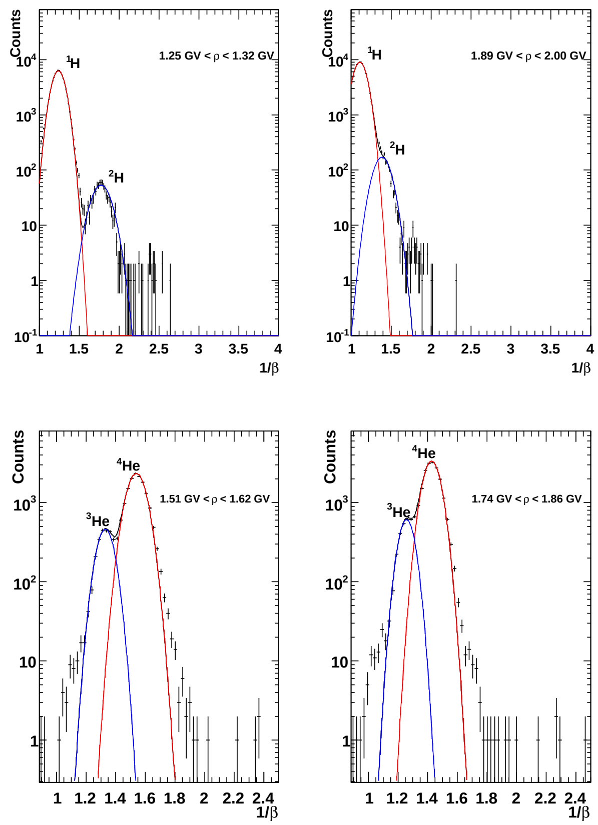

Figure 4: Examples of isotopic separation between ^{2}H and ^{1}H (*top*), and between ^{3}He and ^{4}He (*bottom*) at fixed rigidity range.

A simulation has shown that this method can be safely applied up to rigidities of 2.5 GV, where the peak of the ^{3}He (^{2}H) gaussian is still above the background from ^{4}He (^{1}H) events; below this value the systematic uncertainty is less than 5%.

Inside each bin we estimate the number of particles by fitting the total $1/\beta$ distribution using the sum of two Gaussian functions (Fig. 4)

$$f(x) = A \cdot \exp\left[\frac{(x-\mu_1)^2}{2\sigma_1^2}\right] + B \cdot \exp\left[\frac{(x-\mu_2)^2}{2\sigma_2^2}\right] \quad (2)$$

(where $x = 1/\beta$ at fixed rigidity) with the Maximum Likelihood method assuming the mean values of the two gaussians (μ_1 and μ_2) from equation 1. The ratio R is then evaluated as $R = A\sigma_1/B\sigma_2$.

In order to have isotopic ratios as function of kinetic energy we fix the kinetic energy bins of the final ratio and calculate the corresponding rigidity intervals for each species. Two different rigidity binning (one for each isotope) are selected in such a way that the n-th rigidity bin will always correspond to the same kinetic energy range.

In the rigidity dependent ratios the selection efficiency (which depends on the particle rigidity) is the same for all the isotopes of a given element. This assumption is no longer valid when measuring kinetic energy isotopic ratios since, due to the different mass, at a given kinetic energy value correspond different rigidities for the isotopes; thus the selection efficiency has been corrected by a factor equal to the ratio of the efficiencies estimated by the analysis on proton and helium absolute fluxes. This correction is less than 10% below 300 MeV nucleon^{-1} and less than 1% above 300 MeV nucleon^{-1}.

3.3 Contribution of Secondary Particles - Top of the Payload Correction

Helium and Hydrogen nuclei may be lost due to hadronic interactions in the 2 mm Al thick pressurized container and the top scintillator detectors; the correction to the ratio due to particles lost and the contribution of ^{2}H and ^{3}He from ^{4}He inelastic scattering has been estimated to be less than 1% and has been included in the systematic uncertainty of the measurement.

4 Results

The results on the ^{2}H/^{1}H and ^{3}He/^{4}He ratios will be presented during the conference.

5 Conclusions

In this work we have shown the capability of PAMELA to measure both the ^{2}H/^{1}H and the ^{3}He/^{4}He ratios at Earth. Such measurements will help to better understand the phenomena taking place in cosmic ray propagation.

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