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Measurements of cosmic-ray proton and helium spectra with the PAMELA calorimeter

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Abstract

We present a new measurement of the cosmic ray proton and helium spectra by the PAMELA experiment performed using the "thin" (in terms of nuclei interactions) sampling electromagnetic calorimeter. The described method, optimized by using Monte Carlo

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simulation, beam test and experimental data, allows the spectra to be measured up to 10 TeV, thus extending the PAMELA observational range based on the magnetic spectrometer measurement.

Keywords: Cosmic ray; Protons and helium; Calorimeter

1. Introduction

Despite of the long history of cosmic ray proton and helium measurements, few investigations have continuously covered the energy range from 1 to 10 TeV. Since the 1960s, when the first direct measurement was achieved by the PROTON satellite experiments (Grigorov et al., 1969), only a few balloon borne and only one satellite (SOKOL (Ivanenko et al., 1989)) experiments reported observations in that range. A new measurement of the cosmic ray proton spectrum up to 2 TeV and of the helium spectrum up to 300 GeV/nucleon, performed at balloon altitudes, was provided by Ryan et al. (1972) during November 1970. Almost 30 years after, the ATIC balloon experiment (Ahn et al., 2006) reported results for the energy spectra of protons and helium nuclei over the energy range from 100 GeV to 100 TeV. The first series of JACEE balloon flights (Asakimori et al., 1998) observed protons over the energy ranges 5–500 TeV and helium nuclei over 2–50 TeV/nucleon. Finally, the CREAM experiment (Seo et al., 2004) has recently published proton and helium data above 2.5 TeV (Ahn et al., 2010).

The measurements by the PROTON satellite series reported for the first time a steeping of the integral proton spectrum at an energy of about 1000 GeV. However, data from PROTON and from the Ryan group – where no steepening is visible – appear to be in agreement once the measurement uncertainties have been taken into account. The resulting spectral index is 2.75 ± 0.03 for 50 GeV–2 TeV protons and 2.77 ± 0.05 for helium nuclei in the range 20–600 GeV/nucleon. The Jacee flights 0, 1, 2 (Burnett et al., 1983) showed almost the same spectral indexes for both species as well ($\sim$2.8). From SOKOL measurements (Ivanenko et al., 1993) the power spectral index for protons was found to be -2.85 ± 0.14 for energy more 5 TeV and for helium -2.64 ± 0.12 for energy more 1 TeV/nucleon. The ATIC-2 results do indicate differences in spectral shape between protons and helium over the investigated energy range (Panov et al., 2009). The CREAM group (Ahn et al., 2010) confirmed the ATIC-2 results, showing that the proton and the helium spectra can be described by power-law fits with indexes of -2.66 ± 0.02 for protons and -2.58 ± 0.02 for helium, respectively, in the range from 2.5×10^3 GeV to 2.5×10^5 GeV. All these results are assembled in Table 1 including the PAMELA calorimetric results.

PAMELA published already the proton and helium absolute energy spectra in the in the rigidity range 1 GV to 1.2 TV (Adriani et al., 2011), by spectrometric measurements. These measurements showed that the spectral shapes of these two species are different and cannot be described well by a single power law. A new measurement of the cosmic ray proton and helium nuclei spectra made by PAMELA in a wider energy range might provide very important constraints on the shape and the spectral indexes.

2. PAMELA experiment

The PAMELA experiment (Picozza et al., 2007) was put into a space on board of the Resurs DK1 satellite from the Baikonur Cosmodrome in June 2006. It was designed to study the composition and energy spectra of cosmic ray particles in a wide energy range in near-Earth space. The PAMELA instrument (a total mass is 470 kg) consists of several specialized detectors as shown in Fig. 1: a permanent magnet equipped with the silicon tracking system, a time of flight (ToF) system made of three double planes, an anticoincidence system, a neutron detector, a bottom shower scintillator detector and a tungsten/silicon sampling electromagnetic calorimeter (Boezio et al., 2002). The total calorimeter thickness is 16.3 radiation lengths and 0.6 nuclear interaction lengths. The calorimeter (see Fig. 2) is composed of 44 silicon layers (SSD) interleaved by 22 tungsten plates with a thickness of 0.26 cm thick. Each silicon plane is 380 μm thick and segmented in 96 strips with a pitch of 2.4 mm. 22 Planes are used for the X view and 22 for the Y view in order to provide topolog-

Table 1
The indices reported in different experiments.

The experiment	The energy range	Protons	Helium
PROTON	0.07–0.8 TeV; 1–1000 TeV	2.65 ± 0.05	
SOKOL	5–100 TeV (p); 1–50 TeV/n (He)	2.85 ± 0.14	2.64 ± 0.12
Ryan	0.05–2 TeV (p); 0.02–0.6 TeV/n (He)	2.75 ± 0.03	2.77 ± 0.05
JACEE-1,2,3	5–500 TeV (p); 2–50 TeV/n (He)	2.81 ± 0.13	2.82 ± 0.20
CREAM	2.5–250 TeV	2.66 ± 0.02	2.58 ± 0.02
PAMELA CALO	0.05–15 TeV (p); 0.05–3.5 TeV/n (He)	2.70 ± 0.05	2.47 ± 0.07