

Measurements of Cosmic-Ray Hydrogen and Helium Isotopes with BESS-Polar I in 2004

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Abstract. The Balloon-borne Experiment with a Superconducting Spectrometer (BESS-Polar I) was flown successfully 13 - 21 December 2004 for the first time in Antarctica. A total number of 900 million cosmic-ray events were recorded from the 8-day, 13-hour flight. The polar region allowed for a reduction in the detectable rigidity to about 0.26 GV. The energy loss in the scintillators provided charge measurements to separate protons and helium nuclei. Particle trajectories in the magnetic field provided rigidity measurements. Time-of-Flight counters provided particle velocity measurements to identify isotopes. The data selection procedure for hydrogen and helium isotopes and the mass histograms of hydrogen isotope, ^2H , measured with the BESS-Polar I flight are presented in this paper.

Keywords: Cosmic Ray, Balloon Flight, Isotope

I. INTRODUCTION

It is generally believed that precise measurements of the isotopic composition of hydrogen and helium nuclei provide information on the cosmic-ray origin and propagation history in interstellar space. In the recently published BESS-2000 measurements, a distinctive \bar{p}/p ratio was reported [1]. The \bar{p}/p ratio did not change much from 1993 to 1999, but it increased dramatically

during the solar maximum period in 2000 following the solar magnetic reversal. It would be interesting to check other secondary/primary ratios such as $^2\text{H}/^1\text{H}$, $^2\text{H}/^4\text{He}$ and $^3\text{He}/^4\text{He}$, since ^2H and ^3He are mostly made from the same primary proton and helium interactions with the interstellar medium.

The Balloon-borne Experiment with a Superconducting Spectrometer (BESS) [2], [3], [4] has measured primary cosmic-ray hydrogen, helium and their secondary particles as well as antiparticles [5], [6], [7], [8]. The measurement of absolute fluxes of ^2H and ^3He with BESS-2000 spectrometer were reported in paper [9]. The BESS-Polar experiment was proposed as an advanced BESS program of long-duration balloon flights over Antarctica to investigate further with extended rigidity ranges and higher data statistics [10], [11], [12]. It was developed to enable measurements of lower-energy cosmic-ray particles by taking advantage of the lower geomagnetic cut off over Antarctica, and the much longer duration than the maximum one day exposure of the previous BESS experiments. BESS-Polar I was flown successfully 13 - 21 December 2004 in Antarctica with an average float altitude of 38.5 km (residual atmosphere of 4.3 g/cm²) [13]. A total number of 900 million cosmic-ray events were recorded from the 8-day, 13-hour flight. The polar region allowed for a reduction in the detectable rigidity to about 0.26 GV. In this paper, we present the data selection procedure for hydrogen and helium isotopes and the histograms of ^2H measured with the BESS-Polar I flight.

II. BESS-POLAR I INSTRUMENT

The BESS-Polar superconducting spectrometer was designed and constructed to search for antimatter in cosmic rays, and to make precise measurements of other cosmic-ray components over more extended rigidity ranges and with higher statistics than those of the previ-

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ous BESS spectrometer. BESS-Polar I was developed to reduce the material thickness along the particle trajectory and to meet the severe requirements for long duration balloon flights over Antarctica. The material inside the newly developed spectrometer was reduced down to 4.5 g/cm^2 , and a new detector called the middle Time-of-Flight (MTOF) was installed. With these changes, the lowest energy for proton detection was 0.1 GeV at the top of atmosphere. The spectrometer was also improved for long duration flight in the gas flow system and solar-battery power supply system. The liquid helium reservoir was extended and the payload weight was reduced to meet the requirements for the long duration flight. The detailed changes with the cross section view was published in paper [14].

The spectrometer consisted of three main detecting systems: Time-of-Flight (TOF) scintillating hodoscopes, JET chamber with superconducting solenoid and inner drift chamber, and an aerogel Čerenkov counter. All of the detector's components were assembled in a cylindrical configuration. A very low instrumental energy cutoff was achieved with a new thin-walled ($2.46 \text{ g/cm}^2/\text{wall}$ including cryostat) superconducting magnet [15], [16] using a new high-strength aluminum-stabilized superconductor. In addition, the outer pressure vessel was eliminated, and the detectors were reconfigured. The solenoid superconducting coil provided a uniform magnetic field of 0.8 Tesla which maintained its continuous operation for over 11 days with a 400-liter liquid helium reservoir. The particle's trajectory was measured by a tracking system composed of several detectors in the instrument.

There are three different TOF counters located at top (UTOF), middle (MTOF), and bottom (LTOF) of the spectrometer. TOF provides charge measurements from the particle energy loss to separate protons and helium nuclei, and particle velocity with other TOF counters to identify isotopes. The TOF hodoscopes consist of ten plastic scintillation counter paddles at the top and twelve at the bottom of the instrument. The hodoscopes provide the velocity ($\beta \equiv v/c$) and energy loss (dE/dx) measurements. The time resolution of each counter is 110 ps , which yields a $1/\beta$ resolution of 3.3% . A middle-TOF was installed on the lower surface of the solenoid bore to detect low energy particles, which cannot penetrate the magnet wall. The MTOF consists of 64 plastic scintillator bars with a cross section of 10 mm (width) \times 5 mm (thickness) read by multi-anode PMTs. The lower energy particles can be measured as a combination of top-middle TOF with a $1/\beta$ resolution of 4.5% . The data acquisition sequence was initiated by a first level TOF trigger, which was a coincidence of signals in the top and bottom scintillators. The JET chamber was surrounded by inner drift chamber and superconducting solenoid to measure particle trajectories in the magnetic field to provide rigidity measurements. The tracking system consisted of a central jet-type (JET) chamber and

two inner drift chambers (IDC), which were used to determine a particle's rigidity. The track positions in the $r\text{-}\phi$ plane and along the z -axis were measured by all three independent detectors: JET, IDC, and TOF. The Čerenkov counter with the silica aerogel radiator (ACC) was installed below the magnet, which was selected to have a refractive index of 1.02 in order to veto e^-/μ^- backgrounds up to 4.2 GeV .

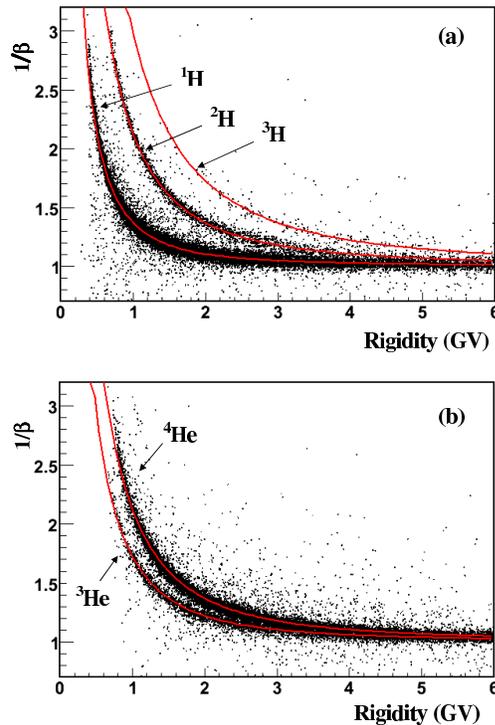


Fig. 1. $1/\beta$ versus rigidity plots. (a) shows clear separation of ^2H and ^1H particles and (b) ^3He and ^4He particles. The solid lines show the expected particle positions.

III. DATA ANALYSIS

Event selection proceeded mainly with five steps: pre-selection, fiducial selection, quality cuts, particle ID cut, and mass cut. Pre-selection included single-track (No. of track = 1, the number of allowed hits in TOF was 1 or 2, which were used to remove events either not passing the detection region of the JET chamber or having nuclear interactions within the instrument), positive velocity and positive track ($1/\beta > 0$ and rigidity > 0), TOF-track match in x and 2-D reconstructed track selection. Fiducial selection included fiducial volume in x (No. of expected hits in JET $\geq 32, 40, \text{ or } 48$), fiducial volume in z , zenith angle cut, TOF hit pattern selection, and Black-Hole cut (cut for bad quality in JET). Quality-cut selection included track-quality in x - y fit, track-quality in r - z fit, TOF-track mach in z , and hazard flag checking.

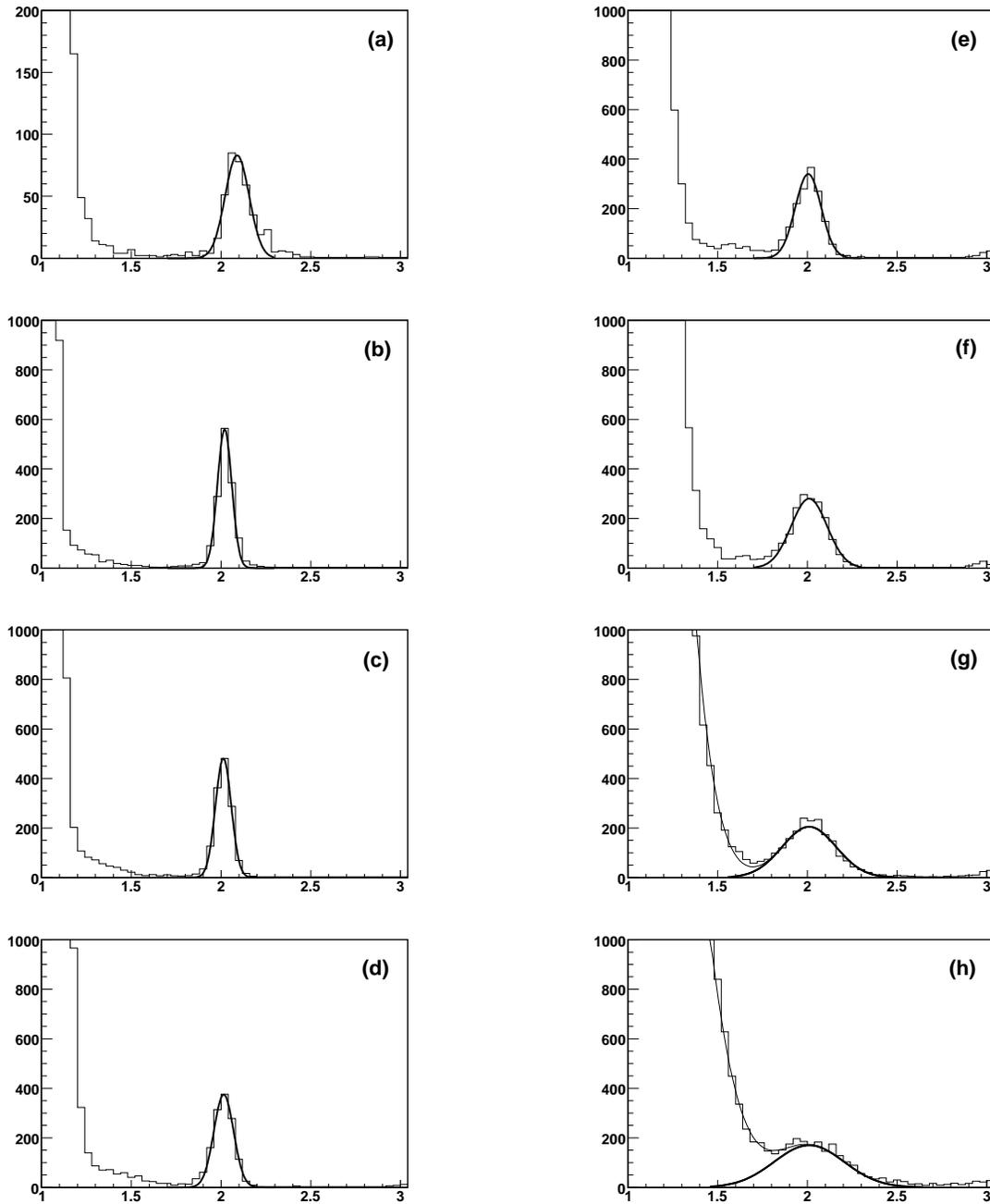


Fig. 2. The mass histogram for ^2H counting for energy bins in units of GeV/nucleon: (a) 0.10-0.13; (b) 0.13-0.18; (c) 0.18-0.24; (d) 0.24-0.32; (e) 0.32-0.42; (f) 0.42-0.56; (g) 0.56-0.75; (h) 0.75-1.00 GeV/n

Track-quality cuts ensure a particle's passing through the center of JET chamber, and the consistency of hitting in the TOF and IDC with JET track in both the $r-\phi$ and $r-z$ planes. Hazard flags are issued during the dead-time of switching in each analog-to-digital board for TOF [17]. Hazard cut rejected these events digitized during the dead-time. The particle ID cut selected charge +1 and +2 particles with energy loss (dE/dx) measurements. The charge identification was based on the ionization signals in both the top and bottom TOF

scintillation counters. From the data set passing the pre-selection, fiducial, and quality cuts, we selected the $Z = +1$ and $Z = +2$ particle candidates by applying a loose dE/dx cut. Finally, mass histograms were made for the remaining events to effectively separate ^2H from ^1H and ^3He from ^4He . Figure 1 shows (a) ^2H , ^1H and (b) ^3He , ^4He separation in the $1/\beta$ versus rigidity plots. The plots show that ^2H particles are well separated from ^1H and ^3He isotopes are separated from ^4He , as expected. Figure 2 shows the mass histograms of

^2H with ^1H at the top of atmosphere (TOA), which fit well with Gaussian functions. It shows that the ^2H particles with relatively smaller statistics are clearly separated from the ^1H particles. The area of the Gaussian function was used as a particle count for ^2H . At the higher energy above 0.56 GeV/n, we used the double Gaussian method to count ^2H particles. The ^2H data with the energy range from 0.10 to 0.13 GeV/n were successfully measured for the first time with BESS-Polar spectrometer due to higher statistics and reduced spectrometer material. The data with the energy range from 0.13 to 0.18 GeV/n were the lowest possible ones measured with the previous BESS spectrometer [5], [7], [18]. The mass histograms of ^3He with ^4He at the TOA are in process.

IV. SUMMARY

The cosmic-ray isotopes of hydrogen and helium have been measured with the BESS-Polar I flight data. Using the pre-selection, fiducial, quality cuts, and energy loss dE/dx cuts, good candidates of proton and helium isotopes were selected. Finally, the ^2H particles were selected from mass histograms due to their atomic mass differences from proton particles. The number of particles observed in the BESS-Polar I flight was much higher and the detectable energy ranges were lower than those observed in previous years. This was expected due to the longer flight and reduced spectrometer material, which gave us more precise measurements than those in previous experiments. The study of the energy spectra of the primary particles and their isotopes, and their comparison to theoretical propagation models [19], [20], [21] are in process.

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