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# Isotope Measurements of Cosmic-Ray Hydrogen and Helium during the 2000 Solar Maximum

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The isotopic composition measurements of cosmic-ray hydrogen and helium were made during the most recent period of solar maximum using the Balloon-borne Experiment with a Superconducting Spectrometer (BESS). The data selection procedure and the mass histograms for proton, helium and their isotopes of BESS-2000 are presented in this paper.

## 1. Introduction

It is generally believed that the precise measurements of the isotopic composition of hydrogen and helium nuclei provide information on the cosmic-ray origin and propagation history in interstellar space. The Balloon-borne Experiment with a Superconducting Spectrometer (BESS), which has been flown annually since 1993, has measured both the primary cosmic-ray hydrogen, helium and their secondary particles as well as antiparticles. In the recently published BESS-2000 measurements, a distinctive p̄/p ratio was reported [1]. It was reported that p̄/p ratio did not change much from 1993 to 1999, but the ratio was increased dramatically during the solar maximum period in 2000 following the solar magnetic reversal. It would be interesting to check other secondary/primary ratio such as $^{2}$H/$^{4}$He and $^{3}$He/$^{4}$He since $^{2}$H and $^{3}$He are mostly made from the same primary proton and helium interactions with the interstellar medium. In this paper, we present the data selection procedure and the histograms of hydrogen and helium isotopes, $^{2}$H and $^{3}$He, as measured during the most recent solar maximum with the BESS-2000 flight.

## 2. The BESS instrument

The BESS spectrometer was designed and constructed to search for antimatter in cosmic rays, and to make precise measurements of other cosmic ray components [2]. Figure 1(a) shows the cross sectional view of the BESS-2000 configuration. All of the detector's components are assembled in a cylindrical configuration

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with a superconducting solenoidal magnet. The solenoid provides a uniform magnetic field of 1 Tesla. The particle's trajectory is measured by a tracking system composed of several detectors in the instrument. The TOF hodoscopes consist of ten plastic scintillation counter paddles at the top and twelve at the bottom of instrument. The hodoscopes provide the velocity ($\beta \equiv v/c$) and energy loss ($\mathrm{d}E/\mathrm{d}x$) measurements. The time resolution of each counter is 55 ps, which yields a $1/\beta$ resolution of 1.4% [3]. The data acquisition sequence is initiated by a first level TOF trigger, which is a coincidence of signals in the top and bottom scintillators. The tracking system consists of a central jet-type (JET) chamber and two inner drift chambers (IDC), which are used to determine a particle's rigidity. The track positions in the r-$\phi$ plane and along the z-axis are measured by all three independent detectors: JET, IDC, and TOF. The plastic scintillators, a lead plate and the Acrylic Čerenkov Counter were placed at the bottom of the BESS-99 to improve accurate measurements for highly-charged particles and the $\mu$/e separation, but the plastic scintillators were removed for BESS-2000. The Čerenkov counter with the silica aerogel radiator, which is able to detect events at high energies, was not used in the current isotope analysis.

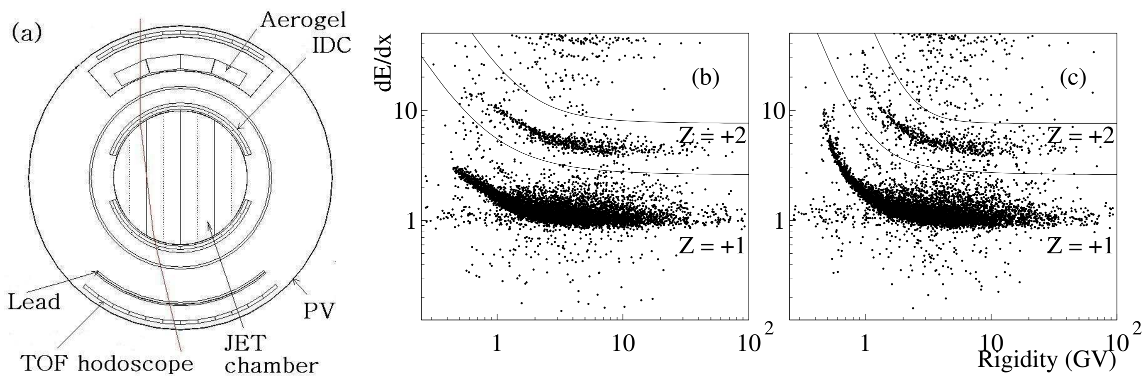



**Figure 1.** (a) The cross sectional view of the BESS-2000 configuration and ionization loss in (b) the top scintillation counter and (c) the bottom scintillation counter vs. rigidity. The solid curves show the selection criteria for Z = +1 and +2 particles.

## 3. Data analysis

The countdown data is an unbiased data set that is used in our data analysis to obtain the cosmic-ray particles with positive charge and positive velocity [4]. One of every 30 events passing the trigger system were processed and saved in the countdown data set. After removing the events with negative velocity and negative rigidity, single-track cuts were used to remove events either not passing the fiducial region of the JET chamber or having nuclear interactions within the instrument. The charge identification was based on the ionization signals in both the top and bottom TOF scintillation counters. From the data set passing the single-track cuts, we selected the Z = +1 and Z = +2 particle candidates by applying a loose $\mathrm{d}E/\mathrm{d}x$ cut (Fig. 1(b) and 1(c)). The lower solid curves in both Figures 1(b) and 1(c) show the upper limit used for the selection of Z = +1 particles. The regions defined by the pair of curves shown in Figures 1(b) and 1(c), respectively, were used to select Z = +2 particles. In order to achieve good measurements of the rigidity, track-quality and consistency cuts were applied to the Z =+1 and Z = +2 candidates. Track-quality cuts ensure particle's passing through the center of JET chamber, and the number of hits for trajectory fitting. The consistency cuts ensure the consistency of hitting in the TOF and IDC with JET track in both the r-$\phi$ and r-z planes.

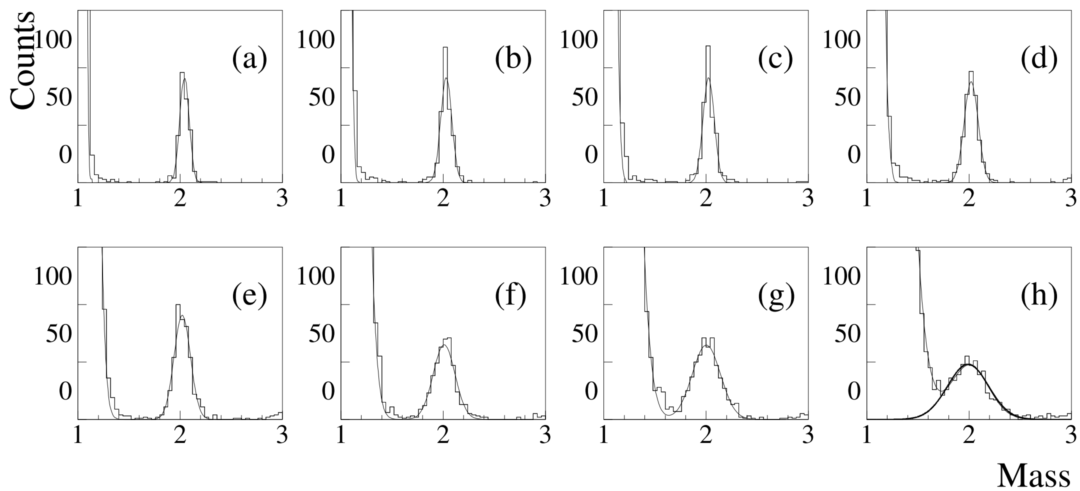



**Figure 2.** The mass histogram for $^2$H counting for energy bins in units of GeV/nucleon: (a) 0.13-0.18; (b) 0.18-0.24; (c) 0.24-0.32; (d) 0.32-0.42; (e) 0.42-0.56; (f) 0.56-0.75; (g) 0.75-1.0; (h) 1.0-1.3.

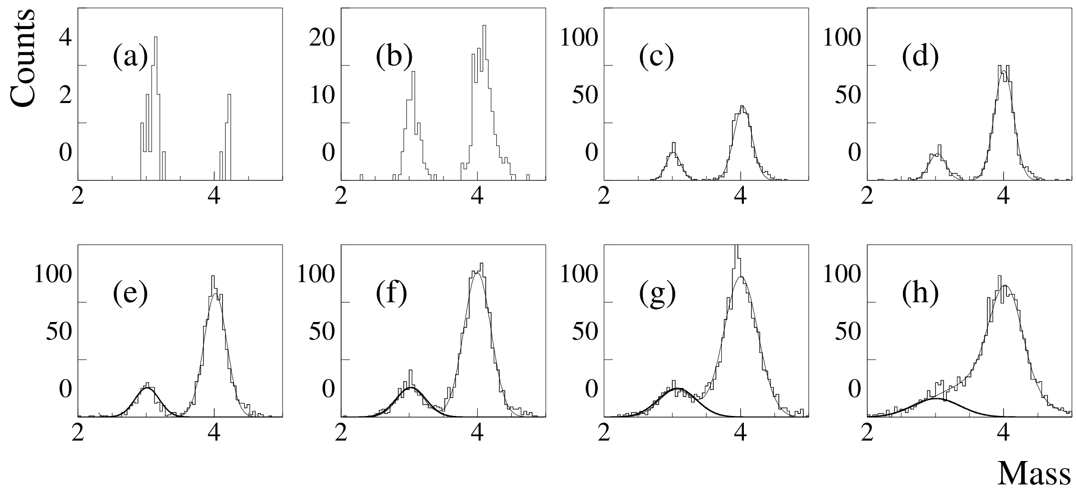
Mass histogram were made for the remaining events to effectively separate $^2$H from $^1$H and $^3$He from $^4$He. Figure 2 shows the mass histograms of $^2$H with $^1$H at the top of atmosphere (TOA), which fit well with Gaussian functions. It shows that the $^2$H particles with relatively smaller statistics are clearly separated from the protons. The area of the Gaussian function was used as a particle count for $^2$H. The overall rigidity interval for $^2$H was 0.83 GV to 4.1 GV.

Figure 3 shows the mass histograms of $^3$He with $^4$He at TOA which also fit well with Gaussian functions. The $^3$He and $^4$He particles are well separated. The overall rigidity interval to collect $^3$He particles was 0.53 to 3.8 GV. We do not need to apply Gaussian fitting to the first few energy bins, since the number of particles are relatively small and could be counted manually.

the BESS-2000 number of particles is much lower than those of the BESS-97 [5] and the BESS-98 [6] data despite of the longer live time. This was expected due to the higher activity of the Sun in 2000 (Solar maximum) [7].

## 4. Summary

The cosmic-ray isotopes of H and He have been measured with the BESS-2000 flight data. Using the single track cuts, energy loss $\mathrm{d}E/\mathrm{d}x$ cuts, track-quality and track-consistency cuts, good candidates of proton and helium isotopes were selected. Finally, the $^2$H and $^3$He particles were well separated from proton and $^4$He particles due to their atomic mass differences. The number of particles observed in the 2000 flight was much lower than observed particles in 1997, the solar minimum year, as was expected due to the solar modulation.

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The study of the energy spectra of the primary particles and their isotopes, and the comparison to theoretical propagation models are in progress.

## 5. Acknowledgments

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