# Cosmic Ray $^3$He and $^4$He Spectra from BESS 98

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## Abstract

The Balloon-borne Experiment with a Superconducting Spectrometer (BESS) has been flown annually for the past ten years to collect cosmic-ray data. In 1998, the instrument was launched from Lynn Lake Manitoba. During the 22-hour flight, the instrument gathered 38 GB of data, roughly $1.7 \times 10^7$ cosmic ray events. The helium isotopes were effectively separated for energies between 0.18 GeV/n and 1.78 GeV/n. Once accounting for atmospheric secondary corrections, the absolute fluxes for $^3$He and $^4$He were determined for this energy range. These results were compared with the results of previous measurements and theoretical calculations of different propagation models, namely, the Standard Leaky Box Model and the Reacceleration Model (SLBM). The $^3$He/$^4$He ratio provides information regarding the propagation history of cosmic-rays. Some implications of these results on cosmic ray propagation are presented in this paper.

## 1. Introduction

Cosmic-ray $^3$He nuclei are created from the nuclear interactions of primary cosmic-rays, mainly H and He, during their galactic propagation. The energy dependence of the ratio of the secondaries to primaries can distinguish among Galactic propagation models. Since BESS [1] was first launched in 1993, its annual flights have provided better and better results due to the continued improvements in the instrument's configuration [2,13]. The 1998 flight was launched on July 29th. With its improved timing resolution, the 1998 instrument was able to

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distinguish $^3$He isotopes from $^4$He primaries up to 1.78 GeV/n.

## 2. Data Analysis

Since the BESS instrument was designed to observe negatively charged antimatter of primary origin [10], a biased trigger was used to limit the number of positive events recorded at low energies, because the number of events with negative rigidity is very small in comparison. For charge one (Z = 1) and charge two (Z = 2) particles, respectively, one event out of 60 and one event out of 25 were triggered without a bias. These events comprised the "countdown data set" used in this analysis. The particle 'events' that the BESS instrument detected were first separated by charge. The Z = 1 and Z = 2 candidates were determined by the ionization energy loss ($dE/dx$) of each event in the top time-of-flight counter. Cuts were applied to ensure single track events inside the instrument. Further cuts were then applied to ensure track quality and consistency. Mass histograms were made for the remaining events to effectively separate $^3$He from $^4$He. Figure 1 shows the mass histograms of $^3$He that fit well with Gaussian functions. $^3$He is clearly separated from $^4$He between 0.18 GeV/n and 1.78 GeV/n. The area under the Gaussian function was used as the particle count.

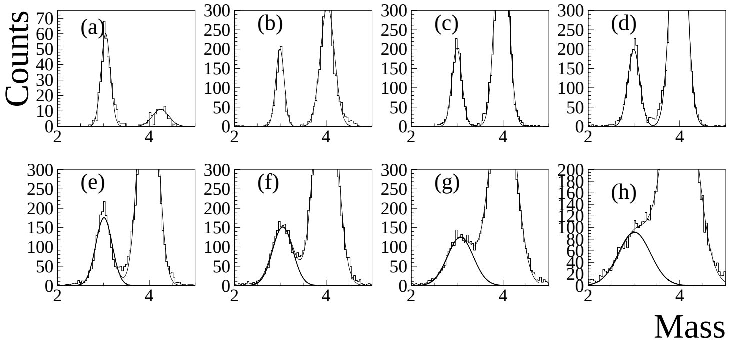

**Fig. 1.** The mass histograms of $^3$He from BESS 98 at the top of the atmosphere. The energy ranges are in units of GeV/nucleon and are as follows: (a) 0.18 - 0.24, (b) 0.24 - 0.32, (c) 0.32 - 0.42, (d) 0.42 - 0.56, (e) 0.56 - 0.75, (f) 0.75 - 1.00, (g) 1.00 - 1.33, (h) 1.33 - 1.78.

In balloon experiments, secondary particles produced by nuclear interactions in the atmosphere are measured along with the primary cosmic-ray events. The count spectra for $^4$He and $^3$He were corrected for atmospheric secondaries. Without correcting for these secondary particles the cosmic ray spectra at the top of the atmosphere cannot be correctly determined. Calculations for the atmospheric secondary cosmic-rays were reported in Wang et al.[15]. The same method was used for the BESS 98 data analysis. The absolute flux was determined by the following:

$$F_{TOA}(E) \ = \ \left( \frac{N(E)\, C_d}{E_{gf}(E)\, E_c T, \Delta E_{in}} \ - \ f_{sec}(E) \right) \frac{\Delta E_{in}}{\eta(E)\, \Delta E_{TOA}} \qquad (1)$$

where $C_d$ is the inverse of the countdown rate for Z=2 events (25), $E_{gf}$ is the effective geometry factor (calculated to be 0.22m$^2$sr), $E_c$ is the efficiency of the data selection cuts (calculated to be 83.3%), T is the live time (86.4% during the float time), $\Delta E_{in}$ is the energy bin size at the BESS float altitude and corresponds to $\Delta E_{TOA}$ at the top of the atmosphere, $f_{sec}(E)$ is the atmospheric secondary spectra, and $\eta(E)$ is the correction factor for the attenuation loss [14].

## 3. Results and Discussion

The absolute fluxes of $^4$He and $^3$He, and their ratio obtained by analyzing the BESS 98 data are shown in Fig. 2. The BESS 93 through BESS 98 spectra show annual variation that can be attributed to solar modulation. In the SLBM, the main parameter is escape length, $X_e$, which is the mean thickness of matter traversed by cosmic rays. The escape lengths used here are the same as in Webber et al.[18]: $X_e = 35.1\beta\mathrm{R}^{-0.6}$ gcm$^{-2}$ for R$\geq$ 3.3GV and $X_e = 17.2\beta$ gcm$^{-2}$ for R$\leq$ 3.3GV. The reacceleration model, requires the additional parameter $\alpha$, which determines the efficiency of reacceleration, but the escape length is a simple power law in rigidity that reduces the number of total free parameters. The reacceleration model used in this analysis of cosmic ray transport involved two parameters which are the same ones used by Seo and Ptuskin,[11]: 14(R)$^{-1/3}$ gcm$^{-2}$ for the power law escape length, and $\alpha = 10^{-3}$ (gcm$^{-2}$)$^{-2}$ for the reacceleration efficiency. The energy spectra for $^3$He and $^4$He as well as their ratios were measured with good precision over the energy range 0.18 - 1.78 GeV/n by analyzing the data from BESS 98. The $^3$He and $^4$He spectra are in reasonable agreement with both the reacceleration model and the SLBM. Both the $^3$He and $^4$He spectra are in close agreement with the 700 MV modulation curve for each model. The total He ($^3$He + $^4$He) spectrum (open circles) is in better agreement with the 600 MV modulation curve as is the total H spectrum from the same year [9,12]. The $^3$He/$^4$He ratio of the BESS data tends to be higher than previous data. While the ratio is consistent with both models, it is in slightly better agreement with the SLBM.

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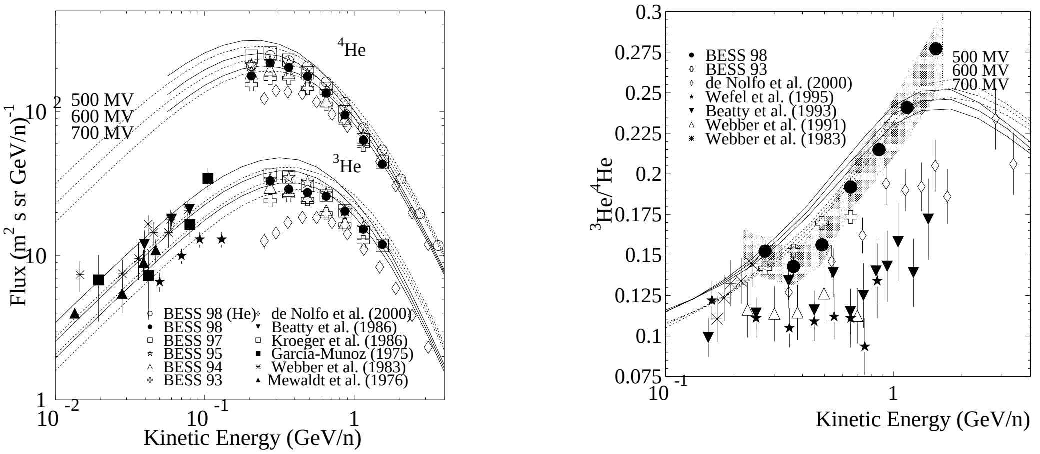

**Fig. 2.** Comparison of $^4$He and $^3$He BESS 98 fluxes and ratio with previous data and with theoretical predictions of both the reacceleration model and the SLBM. The solid and dashed curves represent the reacceleration model and SLMB respectively, (top to bottom, 500, 600, 700MV).

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