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A search for antihelium with the BESS spectrometer

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Abstract. We have searched for antihelium nuclei in cosmic rays using the data obtained from balloon flights of the BESS magnetic spectrometer, flown in 1999 and 2000 at Lynn Lake, Canada. The search was mainly based on track quality selection and rigidity analysis and on the time-of-flight and dE/dx measurements of the scintillation counter hodoscope. No events were observed in the energy range from 1 to 14 GV. Combined with the data collected in the previous flights since 1993, a new upper limit for the ratio of $\overline{\mathrm{He}}/\mathrm{He}$ at the top of the atmosphere has been obtained to be 7×10^{-7} after correcting for the interactions in the air and in the instruments.

1 Introduction

There is a small amount of antiprotons and yet no evidence that antimatter with $|Z| \geq 2$ exists in cosmic rays (Ormes et al., 1997; Saeki et al., 1998; Alcaraz et al., 1999). It is a direct evidence that our galaxy is made of matter and a baryon asymmetry is maximal. The question is that this asymmetry is global or local in the universe. The absence of annihilation γ-ray peaks shows that little antimatter is to be found within $\sim$ 20 Mpc, however, the possibility of existence of antimatter clusters in the universe is not completely precluded. If one antihelium were observed in cosmic rays, it would be a strong indication to the existence of antimatter clusters because the probability to produce antihelium in collisions of cosmic ray with the interstellar medium is too small. We have searched for antihelium in cosmic rays using the BESS detector in every summer, and a model-dependent upper limit (assume the $\overline{\mathrm{He}}$ energy spectrum coincide with the He spectrum) on the flux ratio $\overline{\mathrm{He}}/\mathrm{He} < 1 \times 10^{-6}$ had been reported (Nozaki et al., 1999). In this letter, we re-analysed all the data collected during 1993-2000 with a common analysis procedure and updated the previous results (Ormes et al., 1997; Saeki et al., 1998; Nozaki et al., 1999).

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2 Instrument

Figure 1 shows a cross-sectional view of the BESS spectrometer. It has wide-open geometry and large acceptance (0.3 m^{2}sr). Details of the detector were described elsewhere (Ajima et al., 2000). A particle traversing the apparatus went through a uniform field of 1 T produced by a thin superconducting coil. The trajectory was measured by the jet-type drift chamber (JET) and the inner drift chambers (IDC). The rigidity was determined by using the chamber hits up to 28 points and the maximum detectable rigidity (MDR) was 200 GV. The upper and lower scintillator hodoscopes (TOF) were used to measure the time of flight and dE/dx. An Aerogel Čerenkov counter (ACC) was installed from 1997 flight, but was not used in this letter. All these detector components were installed in a pressure vessel.

The trigger system was designed to detect negatively charged particles with high efficiency while sampling positively charged particles. It was composed of the T0 trigger and the T1 trigger. The T0 trigger, the basic instrument trigger, was provided by a simple coincidence between the TOF counters and initiated digitization of various electronics modules and event building processes. The T1 trigger was a hard-wired logic which determined the coarse track rigidity based on the IDC/TOF hit cell information and discarded the majority of positive low-energy particles. In order to determine the T1 trigger efficiency and the flux of positive charged particles, the sampled T0 triggers with sampling frequency, or count-down (CD) were recorded irrespective of T1 trigger.

3 Analysis

To search for antihelium, we have selected clear $|Z|$=2 events from all recorded data. Applied off-line selections were

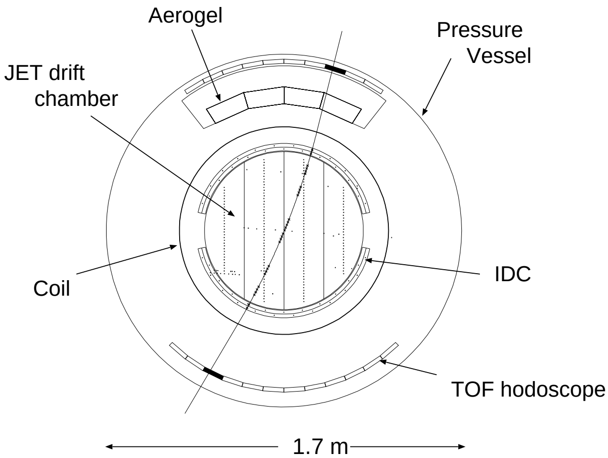

Fig. 1. Cross-sectional view of the BESS detector.

1. There was only one hit in each layer of the TOF, allowing for one additional hit in the bottom layer.
2. The number of tracks with 10 or more hits found in JET chamber should be one and only one.
3. The number of hits in the fiducial region expected from the trajectory was 16 or more.
4. The velocity, β, should be consistent with downward going (anti) heliums. Events outside a β band, shown in Figure 2, were rejected.
5. The dE/dx in the TOF and JET chamber should be consistent with $|Z|$=2 particles. Events in dE/dx bands, shown in Figure 3, were selected.
6. The number of hits used in the trajectory fitting $N_{r\phi-\text{fit}} \geq 16$, and the reduced chi-square had to be less than 5.
7. The number of hits used in the z-trajectory fitting $N_{z-\text{fit}} \geq 6$, and the reduced chi-square had to be less than 5.
8. The track should be extrapolated in the r-ϕ plane to the TOF hit counter.
9. The extrapolation of the track should match the good IDC hit.
10. A "missing" hit was a JET hit satisfying the following two conditions; (1) which was expected from the trajectory (2) while did not exist actually close to the expected position. We counted the number of "missing" hits (N_{missing}), which should be less 4 to avoid wrong reconstruction of the trajectory.

Cuts 1, 2 and 3 selected single track events. Cuts 6 - 10 assured the track fitting quality and to remove possible scattering in the detector (Data Quality Cut).

All the above off-line selections were applied irrespective of the charge sign. Figure 4 shows the 1/rigidity distribution

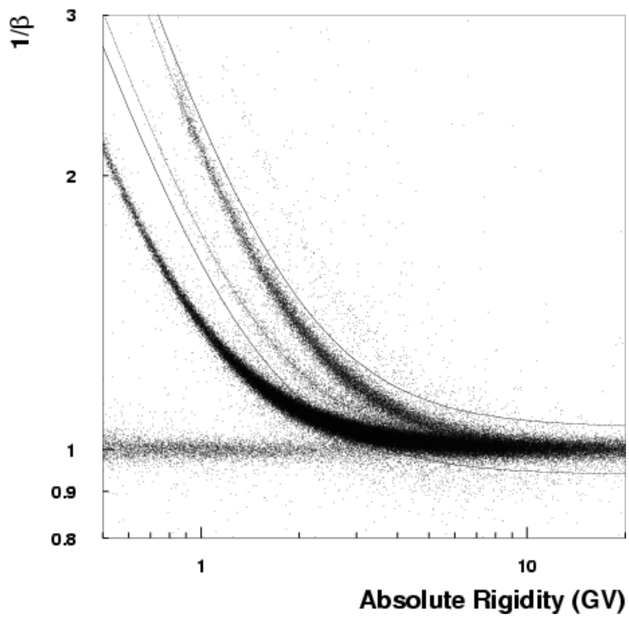

Fig. 2. The β^{-1} vs. absolute rigidity. The solid lines are applied for rejection and the dashed lines are the peak of ^{3}He and ^{4}He.

after all selections. No antihelium candidates were found in the rigidity region (1-14 GV). The resultant upper limit for the ratio of antihelium to helium in cosmic rays $R_{\overline{\text{He}}/\text{He}}$ at the top of the atmosphere (TOA) is

$$R_{\overline{\text{He}}/\text{He}} = \frac{\int N_{Obs,\overline{\text{He}}}/\overline{\epsilon}_{total} dE}{\int N_{Obs,\text{He}}/\epsilon_{total} dE} \quad (1)$$

$$\overline{\epsilon}_{total} = S\Omega \times \overline{\eta} \times \overline{\epsilon}_{sngl} \times \overline{\epsilon}_{trig} \times \overline{\epsilon}_{dE/dx} \times \overline{\epsilon}_{\beta} \times \overline{\epsilon}_{DQ} \quad (2)$$

$$\epsilon_{total} = S\Omega \times \eta \times \epsilon_{sngl} \times \epsilon_{trig} \times \epsilon_{dE/dx} \times \epsilon_{\beta} \times \epsilon_{DQ}, \quad (3)$$

where

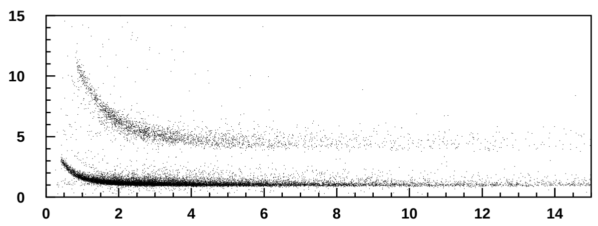

Fig. 3. The dE/dx vs. absolute rigidity measured by top and bottom TOF and JET. The solid lines are applied for selection.

1. N_{obs} is the number of observed He ($\overline{\mathrm{He}}$) events,
2. $S\Omega$ is a geometrical acceptance of the BESS detector,
3. $1-\eta(1-\overline{\eta})$ is a probability to lose by Air of He ($\overline{\mathrm{He}}$).
4. $\epsilon_{sngl}(\overline{\epsilon}_{sngl})$ is single track efficiency of He ($\overline{\mathrm{He}}$).,
5. $\epsilon_{trig}(\overline{\epsilon}_{trig})$ is trigger efficiency of He ($\overline{\mathrm{He}}$).
6. $\epsilon_{dE/dx}(\overline{\epsilon}_{dE/dx})$ is dE/dx cut efficiency of He ($\overline{\mathrm{He}}$),
7. $\epsilon_{\beta}(\overline{\epsilon}_{\beta})$ is β cut efficiency of He ($\overline{\mathrm{He}}$).,
8. $\epsilon_{DQ}(\overline{\epsilon}_{DQ})$ is Data Quality Cut efficiency of He ($\overline{\mathrm{He}}$).,

Numerator in (1) is the number of antihelium events which hits the TOA and denominator is that of helium. To determine the $S\Omega$, $\eta(\overline{\eta})$ and $\epsilon_{sngl}(\overline{\epsilon}_{sngl})$, we have developed a simulation model of the BESS instrument based on the GEANT/GHEISHA code. In the original code, the effects of energy loss, multiple scattering, bremsstrahlung, δ-rays and nuclear interactions in the detector media were taken into account. By fitting the accelerator data, nuclear cross sections of helium were modified as described elsewhere (Matsumoto , 1999; Sanuki et al., 2000). Interactions of antihelium nuclei were not taken into account on these code but easy to define except nuclear interactions. Nuclear interactions of antihelium nuclei were implemented in the simulation code with the following assumptions:

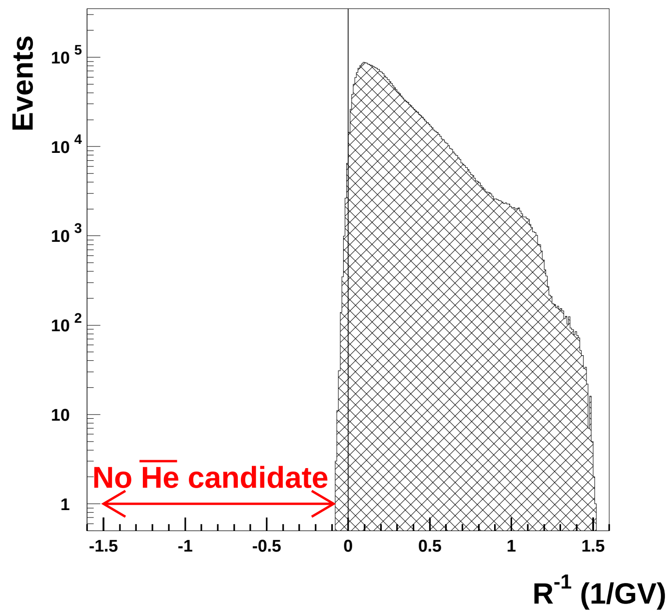

Fig. 4. 1/R distribution of selected He events.

– The inelastic cross sections of antihelium obey the empirical model of hard spheres with overlap (Bradt,H.L., & Peters, B. , 1950).

  $\sigma(A_i, A_t) \propto (A_i^{1/3}+A_t^{1/3}-0.71\times(A_i^{-1/3}+A_t^{-1/3}))^2,$

  where $\sigma(A_i, A_t)$ is the cross section of an incident particle with atomic weight A_i to a target with atomic weight A_t.

– The elastic cross sections of antihelium is the same as that of helium.

– Antihelium is broken without fail when inelastic interaction occurs.

While the geometrical acceptance of the BESS detector ($S\Omega$) slightly depended on the energy, it turned out to be almost constant in the relevant energy region. The dE/dx selection efficiency and β cut efficiency of He ($\overline{\mathrm{He}}$) were higher than 99 %. The other selection efficiencies were derived from the real data. The upper bound of the integral in Eqs. 1 was determined by the edge of the spillover in the negative rigidity region and the lower bound of integral was determined by the edge of the events in the positive rigidity regions which correspond to the event stopped in the bottom scintillator. They were 6.2 GeV/n and 0.14 GeV/n at TOA, respectively. In this analysis, however, we took 0.18 GeV/n as the lower bound of integral at TOA (the rigidity 1 GV at center of the detector) since some efficiencies were not high enough in low rigidity regions. Since we found no antihelium candidate with a rigidity below 14 GV, only the upper limit can be set using Eqs. 1 in this rigidity region. We take 3.1 as the number of antiheliums($\overline{\mathrm{He}}$) for the calculation of the 95 % confidence level upper limit. To integrate the numerators in Eqs. 1, we must assume the energy spectrum of antihelium, since the

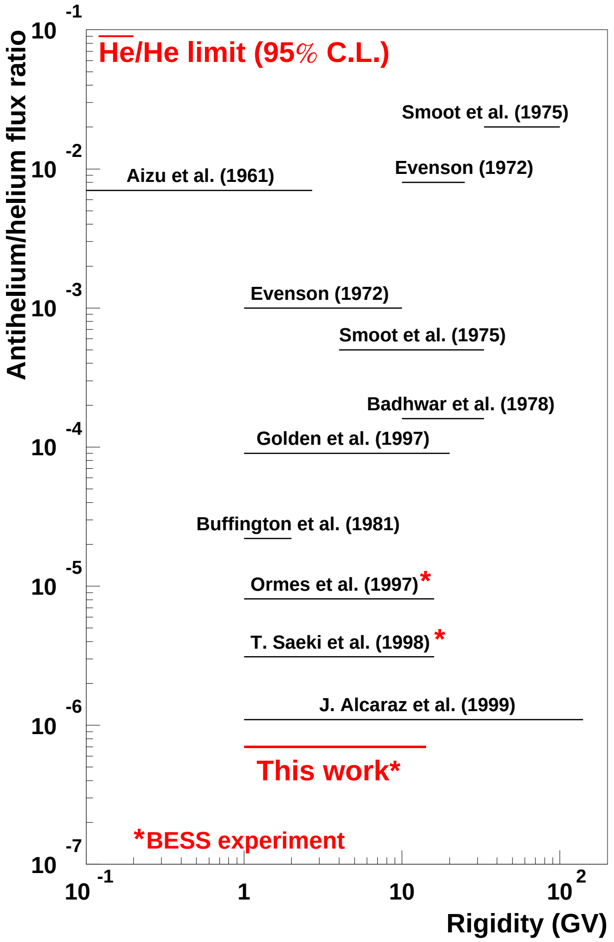

Fig. 5. New upper limit of $\overline{\mathrm{He}}/\mathrm{He}$ together with previous BESS results(BESS 1993-2000), and with other experiment results.

efficiencies were functions of energy. Here, we assume that the incident $\overline{\mathrm{He}}$ energy spectrum has a same shape as the He spectrum. Under this assumption, Eqs. 1 becomes

$$R_{\overline{\mathrm{He}}/\mathrm{He}} < \int \frac{3.1 \mathrm{d}E}{N_{Obs,\mathrm{He}} \times \overline{\eta} \times \overline{\epsilon}_{sngl} \times \overline{\epsilon}_{trig} / (\eta \times \epsilon_{sngl} \times \epsilon_{trig})}. \quad (4)$$

4 Results

We have searched for antihelium nuclei in cosmic rays using the BESS spectrometer. We re-analysed all the data collected during 1993-2000 with the common analysis procedure. The total number of helium nuclei observed by BESS 1993-2000 was $> 6.6 \times 10^6$ in the rigidity region from 1 GV to 14 GV. No antihelium candidate was found in the corresponding rigidity region. The resultant 95 % confidence level upper limit on the $\overline{\mathrm{He}}/\mathrm{He}$ flux ratio at the top of the atmosphere was 7×10^{-7} in the rigidity range from 1 to 14 GV with the model dependent assumption that the $\overline{\mathrm{He}}$ energy spectrum coincided with the He spectrum. This result is shown in figure 5 and is compared with previous limits (Smoot et al., 1975; Evenson et al., 1972; Aizu et al., 1961; Badhwar et al., 1978; Golden et al., 1997; Buffington et al., 1981; Ormes et al., 1997; Saeki et al., 1998; Alcaraz et al., 1999). As seen in the figure, this work has improved the previous result.

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