OG 1.1.23

A search for antihelium down to 10^{-6} relative to helium

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Abstract

A search for cosmic ray antihelium has been made using the data obtained with the BESS magnetic rigidity spectrometer during the '97 and '98 flights from Lynn Lake, Canada. The search is based on precise measurements of rigidity, time-of-flight and dE/dx. No antihelium candidate is observed in the rigidity range from 1 to 16 GV/c. By combining these data with the results from previous flights, a new upper limit of 1×10^{-6} is obtained on the $\overline{He}/He$ ratio at the top of the atmosphere after correcting for interaction losses in the air and the instruments.

1 Introduction:

Particle interactions are almost symmetric for matter and antimatter, and yet the matter dominance in our neighborhood is obvious. The feasibility of direct/indirect detection of antimatter in cosmic radiation has been studied by many authors. If we assume matter and antimatter were well mixed, only a small fraction of antimatter is allowed in a cluster of galaxies (Steigman 1976). Even if the antimatter domain is well separated from the matter domain, the separation scale is estimated to be larger than 1000 Mpc, requiring that the flux of radiation from boundaries should be consistent with the present observation of cosmic diffuse gamma rays (Cohen, DeRujula, and Glashow 1998). Cosmic ray diffusion through inter-glactic space is also problematic. If we take its mean free path to be 1 Mpc, it would require a Hubble time to diffuse 100 Mpc (Ormes et al. 1997). The accessibility to enter the Milky Way also suppresses the extra-galactic cosmic rays (Adams et al. 1997).

In spite of these difficulties, the direct detection of a single antihelium nucleus would provide a conclusive evidence for the existence of primordial antimatter or anti-star because the secondary production of antihelium nuclei is extremely small. The galactic antihelium abundance is estimated to be less than 10^{-12} (Chardonnet, Orloff, and Salati 1997).

In this paper, we report on a search for antihelium nuclei in cosmic rays at the top of the atmosphere by using the BESS (Balloon-borne Experiment with a Superocnducting magnet Spectrometer) detector.

2 Detector

The BESS detector is a compact cylindrical magnetic spectrometer. It has wide-open geometry and large acceptance (0.3 m^2sr). The details of the detector will be described elsewhere (Anraku et al.). An axial and uniform (±15%) magnetic field of 1 Tesla is generated by a thin (4.7 g/cm^2 per wall) superconducting solenoid of 1 m diameter. A jet type drift chamber (JET) and two pairs of arch-shaped inner drift chambers (IDCs) are located inside the solenoid. The JET provides up to 24 points measurements of particle trajectories at with flash ADC readout, allowing us to “visualize” whole events. Any interactions or large angle scatterings in the instrument can easily be identified. The IDCs are equipped with vernier cathode strips which provide precise axial position with 0.5 mm resolution. With a combination of these chambers we achieved maximum detectable rigidity (MDR) of ~200 GV.

A plastic scintillation counter hodoscope (TOF) is concentrically arranged at the outermost part of the apparatus. Each scintillation paddle has a size of $950 \times 100 \times 20$ mm^3 and is viewed by two PMTs at both ends. There are 10 counters in the top layer and 12 in the bottom. They measure time-of-flight and energy loss, and they generate the first level trigger. The time resolution per counter was measured to be 75 psec.

An aerogel Cherenkov counter located between the TOF and the cryostat showed excellent capability in distinguishing antiprotons, but was not used in this analysis.

3 Flight and Trigger

This analysis is based on the data set collected in two balloon flights performed in July, 1997 and July 1998. The apparatus was launched from Lynn Lake, Manitoba Canada, to an altitude of 36 km where the residual air thickness is 5 g/cm^2. The floating time was 17 (18) hours in the 1997 (1998) flight. The payload drifted westward and was recovered near Peace River area, 1000 km west of Lynn Lake. The cut-off rigidity varied during the flight from 0.4 to 0.6 GV/c.

The BESS data acquisition is triggered in two steps. The first step is a coincidence of the top and bottom TOF counters, T0. There are three threshold levels provided to each counter. The lowest one was set to a value well below minimum ionization (~1/3 of MIPs, T0-low), and the middle one was adjusted so that the double-charged particles are triggered with good efficiency (2.7 times MIPs, T0-high). The highest one, irrelevant to this analysis, was set to 10 MIPs to trigger heavier nuclei.

The second-level hard-wired trigger, track trigger (TT), was designed to enrich the event data with negative-charged particles, such as antiprotons and antihelium nuclei. Using a look-up-table memory addressed by the hit pattern of the TOF counters and IDC cells, the TT rejects events which are not consistent with clear single tracks; TT-pattern selection. It then makes a quick and coarse determination of track rigidity from the hit counter/cell positions; TT-rigidity selection. The majority of positive low-energy particles were discarded at this stage. However, a fraction of events bypassed the TT and were recorded irrespective of their track pattern or rigidity. This unbiased event sample is used in this analysis to evaluate trigger efficiencies and to derive flux normalization. The sampling frequency, or count down (CD) rate, was 1/60 for T0-low and 1/25 for T0-high.

We have collected 15,804,719 (15,105,758) events during the 1997 (1998) flight, including 493,532 (528,054) unbiased events.

4 Analysis

Prior to (anti) helium selection, all the events were processed to derive physical quantities. Rigidity was obtained by fitting the JET and IDC hits in the r-ϕ and r-z planes. Velocity was calculated from the time-of-flight and path length. Energy losses (dE/dx) in the TOF and JET were corrected for incident angles and hit positions and were normalized to MIPs. Since the CD events were not subject to the on-board TT analysis, an equivalent off-line TT-pattern selection was applied to these events. The following selection criteria were then imposed to search for antihelium and to select helium.

(1) There is only one hit in each layer of the TOF, allowing for one additional hit in the bottom layer.
(2) The number of tracks found in the JET should be one.
(3) The number of expected hits along the track should be larger than 19.

(4) The number of hits used in the r–ϕ (r–z) track fitting should be greater than 16 (6).

(5) The chi-square of the track fitting should be less than 5.0/dof.

(6) The track should be extrapolated in the r–ϕ plane to the TOF hit counter.

(7) The extrapolation of the track should match the IDC hit within 1mm.

(8) The dE/dx in the TOF and JET should be consistent with doubly charged particles. Events in dE/dx bands, shown in Figures 1-a, 1-b and 1-c, were selected.

(9) The velocity, β, should be consistent with downward going (anti) heliums. Events outside a β band, shown in Figure 2, were rejected.

Cuts (1) and (2) select single track events. Cut (3) requires the track to pass through the central fiducial region since the sidemost section of the JET has only 16 readout wires. Cuts (4) – (7) assure the track fitting quality and to remove possible scattering in the detector. These four cuts drops ~30% of the events, but they improve the confidence of the rigidity determination. Cut (8) removes most of the singly charged particles.

The number of surviving events after all of the above cuts in an absolute rigidity range between 0.7 and 16 GV/c is 676,629 (424,797) for the 1997 (1998) flight, including 64,439 (53,394) CD events (see Figure 3). The lower limit (0.7 GV/c), well above the magnetic cut-off, is determined so that the incident (anti) helium has enough energy to pass through the instrument. The upper limit (16 GV/c) was chosen so that the negative charged events are free of spillover from the overwhelming positive curvature events. After correcting for energy loss in the air and the detector, the corresponding rigidity range at the top of the atmosphere is 1 ~ 16 GV/c. We found no antihelium candidate and take 3.1 for a 95% C.L. upper limit. In determining the $\overline{He}/He$ ratio, we use only the unbiased CD events triggered by T0-high for normalization.

Since the off-line cuts, as well as the on-line TT-pattern selection, do not distinguish the sign of charge

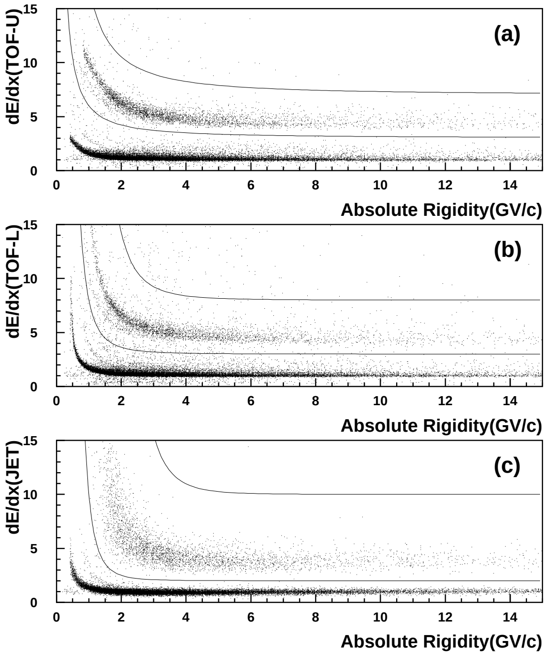

Figure 1: The dE/dx vs. absolute rigidity measured by (a) top and (b) bottom TOF and (c) JET. Because of the energy loss in the detector, the dE/dx in the bottom TOF is slightly higher in the low-rigidity region.

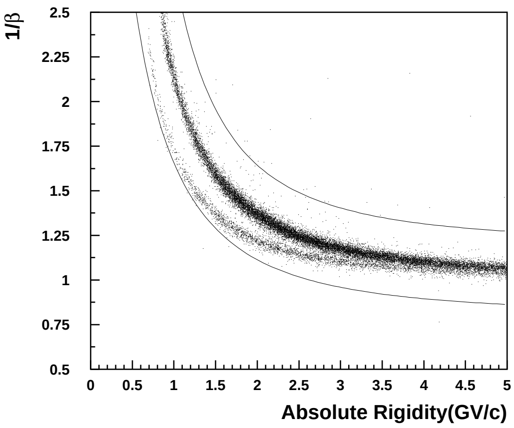

Figure 2:The β^{-1} vs. absolute rigidity.

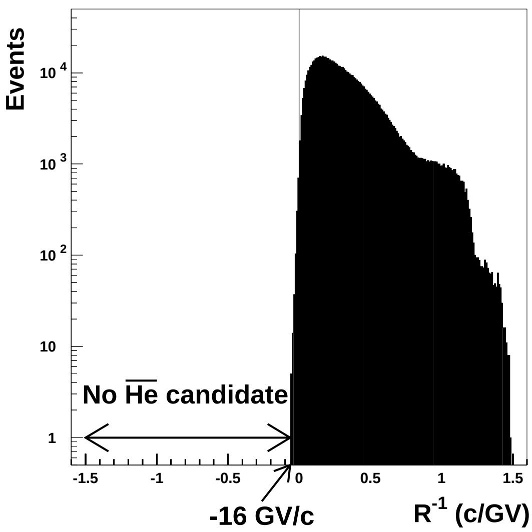

Figure 3: 1/R distribution of selected events.

(helium or antihelium), they both eliminate the same fraction of non-interacting events and they eliminate all of the interacting events. Thus these selection efficiencies are the same for helium and antihelium, and cancel if we take the $\overline{He}/He$ abundance ratio. We have only to correct for the efficiencies of the on-line TT-rigidity selection and the atmospheric and instrumental loss.

The TT-rigidity selection efficiency for each energy bin was obtained by using the negative curvature events in the CD-triggered event sample. To calculate the interaction loss, we need (anti) helium inelastic cross sections on various target nuclei. Since no experimental data for antihelium interaction is available and there exist relatively sparse data even for helium in the GeV region, the cross sections were estimated from the (anti) proton-nucleus collision data using "the hard sphere with overlap model" as in our previous work (Saeki et al. 1998). We estimated the interaction loss in the 5 g/cm^2 of air plus 15 g/cm^2 of detector material for each energy bin assuming the same energy spectrum for antihelium and helium.

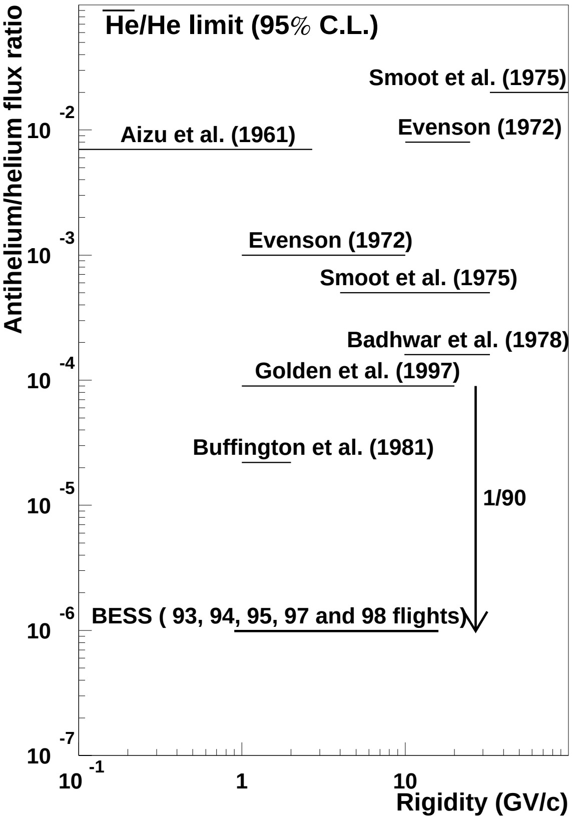

Figure 4: Our upper limit of $\overline{He}/He$ together with previous results.

5 Conclusion

We have searched for cosmic ray antihelium nuclei at the top of atmosphere by using the BESS magnetic spectrometer. No antihelium candidate was found in two scientific flights performed in northern Canada in 1997 and in 1998. Combining these data with our previous data, accumulated in 1993, 1994 and 1995, we can set an upper limit on the $\overline{He}/He$ abundance ratio in the rigidity range between 1 and 16 GV/c to be 1.0×10^{-6}, which is a factor 90 improvement compared with the previous work (see Figure 4).

Acknowledgement

We thank the NASA/GSFC/WFF Balloon office and the National Scientific Balloon Facility (NSBF) for the balloon expedition, and KEK and ISAS for various support. This work is supported in Japan by Grant-in-Aid for Scientific Research, Monbusho and by Heiwa Nakajima Foundation; and in USA by NASA grants NAGW-3526 and NAG 5-5061.

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