BESS AND ITS FUTURE PROSPECT FOR POLAR LONG DURATION FLIGHTS

BESS Collaboration

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ABSTRACT

The Balloon-borne Experiment with a Superconducting Spectrometer, BESS, aims to study elementary particle/antiparticle phenomena in the early history of the Universe. The instrument has a unique feature of a thin superconducting solenoid magnet enabling a large geometrical acceptance with a horizontally cylindrical configuration. Seven balloon flights have been successfully carried out since 1993. More than \(10^3\) cosmic-ray antiproton have been unambiguously detected, and the energy spectrum has been measured with the characteristic peak at 2 GeV. The search for cosmic-ray antihelium brought the upper-limit of the antihelium/helium ratio down to \(< 10^{-6}\). To extend the highly sensitive measurements, we are planning polar long duration flights in Antarctica focusing on the very low energy antiproton spectrum towards the solar-minimum in the next decade. © 2002 COSPAR. Published by Elsevier Science Ltd. All rights reserved.

INTRODUCTION

The Balloon-borne Experiment with a Superconducting Solenoid Magnet Spectrometer, BESS, has been carried out as a US-Japan scientific balloon program since 1993 (Orito, 1987, Yamamoto et al., 1994, Nishimura et al., 1997). It aims at studying elementary particle phenomena in the early history of the Universe through precise measurements of low-energy antiproton spectrum and search for antiparticle of cosmic origin. It also provides very precise measurements of absolute fluxes of cosmic rays as fundamental references in cosmic-ray physics.

The detection of cosmic-ray antiprotons was first reported in 1979 (Golden et al., 1979). Subsequent experiments have tried to understand the origin of the cosmic-ray antiprotons (reviewed by Yoshimura, 2000). The energy spectra measured by those experiments seem to be consistent with secondary particles produced in collisions of energetic cosmic-ray nuclei with ambient interstellar material.
However, in the energy region below 1 GeV, it is kinematically difficult to produce the secondary particles. Therefore, the low energy region is ideal to search for the cosmic-ray antiproton of the cosmic origin. It might be produced with novel primary sources such as the evaporation of primordial black holes (Hawking, 1975; Maki et al., 1996) or the annihilation of neutralino dark matters (Silk and Srednicki, 1984; Mitsui et al., 1996; Bergstroem et al., 1999). The BESS experiment is aiming at a highly precise measurement of the low energy antiproton spectrum to understand the origin of cosmic-ray antiprotons.

It is a fundamental question in cosmology whether matter and antimatter are asymmetric or symmetric in the Universe. If there was symmetry breaking in baryon numbers (CP violation) in the early history ($10^{-36}$ sec) of the Universe, baryon domination in the further history can be explained (Sakharov, 1967; Ormes and Streitmatter, 1992). Thus, antimatter may not be found in cosmic rays. Although antihelium might be produced in cosmic-ray interactions, their contribution to the antihelium/helium ratio should be much smaller than $10^{-12}$ (Brown & Stecker, 1979). Detecting antihelium at a level higher than this could therefore provide evidence of antimatter domain in the Universe. Therefore, the BESS experiment aims to search for antihelium at a sensitivity level of $< 10^{-6}$ in antihelium/helium ratio.

The absolute fluxes and spectra of primary cosmic-ray protons and helium nuclei are fundamental information as references in cosmic-ray physics. They are indispensable to calculate secondary antiprotons, positrons, and diffuse gamma radiation, which in turn provide important knowledge of particle propagation and matter distribution in interstellar space. Those are also indispensable as basic parameters for studying atmospheric neutrinos.

This report describes the scientific progress in the BESS experiment and its future prospect for long duration flights in Antarctica to extend the highly sensitive measurements.

**BESS SPECTROMETER**

The BESS detector is a high resolution spectrometer with a thin superconducting solenoid magnet (Yamamoto et al. 1988; Ajima et al., 2000). It features a large geometrical acceptance and a simple layout based on a horizontally cylindrical spectrometer configuration as the cross section shown in Figure. 1.

The horizontal configuration enables the spectrometer to be compact and to have wide open-angle geometry with an acceptance of 0.3 m$^2$ sr (Yamamoto et al., 1994). The solenoid magnet provides an axial and uniform magnetic field of 1 T (Makida et al., 1991, 1995) in which the rigidity of particles can be measured up to a maximum rigidity of 200 GV. Since the magnetic field is highly uniform inside the solenoid, a very sharp deflection resolution can be realized as shown in Figure. 2 (Sanuki et al., 2000). This enables the BESS experiment to provide high statistics and very precise energy resolution. Particle identification is made with a pair of Time-of-Flight (TOF) scintillation counters (Shikaze et al., 2000) combined with silica-aerogel Cherenkov counters for separating electrons/positrons from other heavier particles (Asaoka et al., 1999).

![Fig. 1. Cross section of the BESS-97 spectrometer.](image-url)
BESS and its Future Prospect

Fig. 2. Deflection resolution of the BESS spectrometer compared with previous experiments.

BALLOON FLIGHTS
The balloon experiment has been successfully carried out since 1993 (Anraku et al., 1996; Yamamoto et al., 1998; Ajima et al., 2000). The spectrometer was launched from Lynn Lake, Manitoba, Canada, every summer, and seven flights have been successful. It stayed at an altitude of 35 km with a residual pressure of ~5 mb. Those flight conditions are summarized in Table 1.

Table 1. Progress of the BESS balloon flights in Canada.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>17.5</td>
<td>14</td>
<td>4.0</td>
<td>4.5</td>
<td>300</td>
<td>1.032</td>
<td>6</td>
<td>0.18-0.5</td>
<td>2.2x10^3</td>
</tr>
<tr>
<td>94</td>
<td>17.0</td>
<td>15</td>
<td>4.2</td>
<td>6.5</td>
<td>300</td>
<td>1.020</td>
<td>2</td>
<td>0.18-0.5</td>
<td>4.3x10^6</td>
</tr>
<tr>
<td>95</td>
<td>19.5</td>
<td>17.5</td>
<td>4.5</td>
<td>8.0</td>
<td>100</td>
<td>1.020</td>
<td>43</td>
<td>0.18-1.5</td>
<td>2.4x10^6</td>
</tr>
<tr>
<td>97</td>
<td>20.5</td>
<td>18.3</td>
<td>16.2</td>
<td>31</td>
<td>75</td>
<td>1.020</td>
<td>41</td>
<td>0.18-3.6</td>
<td>1.4x10^6</td>
</tr>
<tr>
<td>98</td>
<td>22</td>
<td>20.0</td>
<td>19.0</td>
<td>38</td>
<td>75</td>
<td>1.020</td>
<td>41</td>
<td>0.18-4.2</td>
<td>1.0x10^6</td>
</tr>
<tr>
<td>99</td>
<td>34.5</td>
<td>20.0 (2.8*)+31.3 (2.5)+32.5</td>
<td>16.8</td>
<td>41</td>
<td>75</td>
<td>1.020</td>
<td>41</td>
<td>0.18-4.2</td>
<td>0.8x10^6</td>
</tr>
<tr>
<td>2000</td>
<td>44.5</td>
<td>31.3 (2.3*)+16.8 (2)+15</td>
<td>15</td>
<td>75</td>
<td>75</td>
<td>1.020</td>
<td>&gt; 650</td>
<td>0.18-4.2</td>
<td>TBD</td>
</tr>
</tbody>
</table>

* (data taking also during ascending)

EXPERIMENTAL RESULTS

Low Energy Antiproton Spectra
The mass-identified low energy antiprotons below 1 GeV were first detected in the BESS-93 flight (Yoshimura et al., 1995; Moiseev et al., 1997), and the antiproton events have been accumulated to be more than 10^3 in the subsequent flights as summarized in Table 1. The low energy antiproton spectrum in the energy range of 0.18 to 4.2 GeV has been measured in the subsequent balloon flights (J. Nishimura et al., 1997, Matsunaga et al., 1998; Orito et al., 2000; Maeno et al., 2000). Figure 3 shows (a) the energy spectrum and (b) the antiproton/proton ratio measured in BESS93, 95, 97, and in 98, in comparison with other experiments (Mitchell et al., 1996; Boezio et al., 1997). A clear peak of the energy spectrum was first observed at 2 GeV in BESS-97 (Orito et al., 2000) and it was confirmed in BESS-98 (Maeno et al., 2000). The slightly reduced numbers of antiproton events observed in BESS-98 may be explained with solar activity getting higher than in BESS-97. Our results in a higher energy region around the spectrum peak are consistent with a calculation for the energy spectrum of secondary origin indicated by the solid and dotted lines (Mitsui et al., 1996, Bergstroem et al., 1999; Bieber et al., 1999). This implies that the secondary antiproton is the dominant component of the cosmic-ray antiprotons and the propagation models are basically correct. It shows, however, a little excessive flux especially at the very low energy region. It is important to extend statistics to draw any conclusions on possible admixture of antiprotons from primary origin such as primordial black holes and annihilation of
nutrinos (Maki et al., 1996, Mitsui et al., 1996 and in preparation). The experiment is continued to accumulate statistics especially in the low energy region. The rapid increase of solar activity toward the year 2001 shall suppress the primary antiproton spectrum, while the spectrum of the secondary antiproton will be changed only modestly. The extended study of solar modulation dependence on the antiproton spectrum is becoming very important (Maeno et al., 2000).

Antihelium Search
The search for antihelium has been carried out since the BESS-93 flights (Ormes et al., 1997, Saeki et al., 1998, Nozaki et al., 1999). No antihelium candidate has been detected in 6 x 10⁴ observed helium events of with a rigidity range of 1 - 14 GV accumulated in six flights (Sasaki et al., 2000). Figure 4 shows the resultant upper limit of antihelium/helium flux ratio accumulated in the BESS experiments in comparison with previous/other experiments (Aizu et al., 1961; Smoot et al., 1975; Badhwar et al., 1978; Buffington et al., 1981; Golden et al., 1997, Alcaraz et al., 1999). The resultant upper limit of the antihelium/helium flux ratio at the top of the atmosphere has been decreased down to < 8 x 10⁻⁷ with a 95 % confidence level. The sensitivity of the antihelium search has been pushed nearly two orders of magnitude by the BESS experiment. The search for antihelium is to be extended to reach an upper limit of ~ 10⁻⁷ in the future BESS long duration flights.

Proton and Helium Spectra
Figure 5 (a) shows the proton and helium fluxes in the energy range of 1 - 120 GeV and 1 to 54 GeV per nucleon, respectively, measured in BESS-98 (Sanuki et al., 2000). These are compared with previous/other experiments (Ryan et al., 1972; Smith et al., 1973; Webber et al., 1987; Seo et al., 1991; Papini et al. 1993; Buckley et al., 1994; Bellotti et al.; 1999;
Boezio et al. 1999; Alcaraz et al., 2000; Menn et al., 2000). In BESS-98, a new trigger mode was implemented with a new silica-aerogel Cherenkov counter to record all energetic particles. This drastically improved statistics of proton and helium events above 6 GeV per nucleon. Filled squares show results of the BESS-98 experiment. Those spectra were determined within an overall uncertainty of 5% for protons and 10% for helium nuclei including statistical and systematic errors. Our results are more favorable to lower fluxes than the ones assumed in the atmospheric neutrino calculation (Honda et al, 1995), especially above a few tens of GeV per nucleon. This may suggest an importance of reconsideration for atmospheric neutrino flux predictions. The precise measurements of primary cosmic rays help to improve the accuracy in the atmospheric neutrino calculations. Upgrade of the BESS spectrometer is in progress to extend the proton and helium spectra up to a level of 500 GeV/nucleon or above, as shown in Figure 5 (b). Flights with the upgraded spectrometer are planned to be carried out in 2001 and 2002 (Sanuki et al., 2000).

Fig. 5 (a) Proton and helium spectra measured by BESS and by previous and other experiments. The solid lines are used in neutrino oscillation calculation. (b) The proton spectrum in wide energy range, and the BESS measurement to be extended in 2001-2002 (indicated by open squares).

**PLAN FOR POLAR LONG DURATION FLIGHTS**

**Scientific Objectives**

The BESS long duration flight in Antarctica, BESS-Polar, is being prepared to extend the BESS scientific objectives under ideal ballooning environment at Antarctica (Nishimura, 2000). It aims at extremely sensitive measurements of low energy antiprotons to search for any novel primary origin, and at the same time to study the cosmic-ray propagation model. The search for cosmic-ray anti-deuteron is anticipated with a similar objective. The search for anti-helium is the fundamental subject to study baryon asymmetry/symmetry in the Universe. The BESS experiment, having a high rigidity resolution and large geometrical acceptance, may maximize the advantage of long duration flights in Antarctica with a very low rigidity cut-off.

The BESS-Polar experiment is a unique and complementary program, even compared with two large-scale space experiments to be realized in the same time period, as summarized in Table 2 (Yoshimura, 2000). The PAMELA experiment is to be launched on a polar-orbit in 2002 (Adriani et al, 1999). It has a great advantage with the polar orbit passing over two polar regions. It has, however, a strong constraint in its sensitivity because of the relatively small geometrical acceptance of the instrument. The AMS experiment is to be carried out on the International Space Station and it has a great advantage of its long exposure time for three years (Ahlen et al., 1994). It has, however, a strong constraint in the flight profile of 0 - 57 degrees in latitude in comparison with the BESS profile staying at ~80 degrees as
shown in Figure. 6. Figure 7 shows the exposure sensitivity (defined by geometrical acceptance x exposure time) of the BESS-Polar experiment as a function of the energy in comparison with those for the PAMELA and AMS experiments. The BESS flight in Antarctica gives an exclusively high sensitivity in the low energy region below ~ 0.3 GeV, where we expect the best chances to detect antiprotons of primary origin. Figure 8 shows antiproton spectra in simulations with assuming a BESS-Polar flight of 20 days. The solid line indicates the secondary antiproton spectrum and the dotted line indicates a possible antiproton spectrum of primary origin from the evaporation of the primordial black holes (PBH). The dashed line indicates the summed spectrum of those secondary and primary antiprotons. The closed squares give the expected secondary spectrum with statistical uncertainty and the open circles indicate the same spectrum with statistical uncertainty in the case of the primary antiprotons existing. The discrepancy of the antiproton spectrum should be detectable with extremely high statistics during the long duration flights in Antarctica. It is emphasized that the BESS-Polar experiment is very much complementary with AMS in the energy range, while providing a common range for possible inter-calibration of the absolute flux around the specific spectrum peak at ~ 2 GeV.

Table 2. The BESS-Polar experiment in comparison with the PAMELA and AMS programs.

<table>
<thead>
<tr>
<th>Project</th>
<th>BESS-Polar</th>
<th>PAMELA</th>
<th>AMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical acceptance</td>
<td>~0.27 m(^2) sr</td>
<td>~0.0021 m(^2) sr</td>
<td>~0.3 m(^2) sr</td>
</tr>
<tr>
<td>Max. detectable rigidity</td>
<td>150–200 GV</td>
<td>385 GV</td>
<td>~1 TV</td>
</tr>
<tr>
<td>Flight duration</td>
<td>~ 20 days</td>
<td>~ 3 years</td>
<td>~ 3 years</td>
</tr>
<tr>
<td>Flight altitude</td>
<td>36 km</td>
<td>690 km</td>
<td>320–390 km</td>
</tr>
<tr>
<td>Residual air</td>
<td>&lt; 5 g/cm(^2)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flight latitude</td>
<td>~ 80 degrees</td>
<td>~ +/- 80 deg.</td>
<td>~ +/- 51.7 deg.</td>
</tr>
<tr>
<td>Energy region</td>
<td>0.1–4 GeV</td>
<td>&gt; 0.1 GeV</td>
<td>&gt; 0.5 GeV</td>
</tr>
<tr>
<td>Flight vehicle</td>
<td>Balloon</td>
<td>Satellite</td>
<td>Space Station</td>
</tr>
<tr>
<td>Launch (proposed)</td>
<td>2003/4</td>
<td>2002</td>
<td>2004</td>
</tr>
</tbody>
</table>

Fig. 6. Flight profiles of BESS-Polar, AMS on the Space Station and PAMELA on a polar orbit with rigidity cut-off distribution.

Fig. 7. Sensitivity of the BESS-Polar compared with AMS and PAMELA.

Fig. 8. Antiproton spectra expected in a 20-days flight in Antarctica.
BESS-Polar Spectrometer

The spectrometer for the BESS-Polar experiment is designed to meet the requirements of a science payload weight of 1400 kg in maximum, a spectrometer-wall material of < 5 g/cm² at the upper-half spectrometer, an electrical power balance of < 600 W, and a continuous operation time of over 20 days. Figure 9 shows a cross sectional view of the BESS-Polar spectrometer compared with the present BESS spectrometer. A compact spectrometer design is achieved with a geometrical acceptance of 0.27 m² sr, corresponding to 90 % of the present one. An extremely thin-walled solenoid magnet is developed as a key component to realize the total spectrometer wall transparency smaller than 5 g/cm². Also, the magnet cryostat is designed to function as a pressure vessel for the central tracking detector installed inside the warm bore of the solenoid coil. The general pressure-vessel is not provided, and further detector components of the TOF (time-of-flight) counters and the silica-aerogel Cherenkov counters are placed outside the cryostat where they will be operated in vacuum. The BESS-Polar spectrometer design parameters are summarized in Table 3.

Table 3. BESS-Polar spectrometer design compared with the present BESS spectrometer.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Present</th>
<th>BESS-Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical acceptance</td>
<td>0.3 m² sr</td>
<td>0.27 m² sr</td>
</tr>
<tr>
<td>Flight duration</td>
<td>~1 day</td>
<td>10 ~ 20 days</td>
</tr>
<tr>
<td>Integrated sensitivity</td>
<td>~ 0.3 m² sr.day</td>
<td>2.7 ~ 5.4 m² sr.day</td>
</tr>
<tr>
<td>Energy range for antiprotons (@TOA)</td>
<td>0.18 ~ 4.2 GeV</td>
<td>0.1 ~ 4.2 GeV</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>1 T</td>
<td>0.8 ~ 1 T</td>
</tr>
<tr>
<td>Distance between TOF counters</td>
<td>1.5 m</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Diameter of Central tracker (JET/IDC)</td>
<td>0.83 m</td>
<td>0.75 m</td>
</tr>
<tr>
<td>Maximum detectable rigidity</td>
<td>200 GV</td>
<td>150 ~ 200 GV</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1.2 kW</td>
<td>0.6 kW</td>
</tr>
<tr>
<td>Material in upper-half detector wall</td>
<td>9 g/cm²</td>
<td>4.5 g/cm²</td>
</tr>
<tr>
<td>Over-all payload size (x/y/z)</td>
<td>2m/2m/4m</td>
<td>1.5m/1.5m/3m</td>
</tr>
<tr>
<td>Weight</td>
<td>2.2 tons</td>
<td>1.4 tons</td>
</tr>
</tbody>
</table>

Development of an ultra-thin superconducting solenoid magnet is in progress to realize a magnetic field of 0.8 ~ 1.0 T in flight with a half wall-thickness of 2 g/cm². The recent development of high strength aluminum stabilized superconductor has enabled the coil design to be much thinner (Yamamoto et al, 1999; Wada et al, 2000). The aluminum stabilizer may be reinforced to get an yield strength of over 100 MPa at 4.2K by combining technology of micro-alloying with cold-work strengthening as shown in Figure 10(a). The cross section of the aluminum stabilized superconductor is shown in Figure 10(b). Table 4 gives the design parameters of the superconducting magnet for the BESS-Polar spectrometer in comparison with the present magnet parameters.
Fig. 10. (a) Strength of aluminum stabilizers as a function of residual resistivity ratio with dependence of the cold-work reduction ratio (indicated in parenthesis), (b) microscopic structure of Al-alloy with Ni (5000 ppm) precipitated to be Al3Ni (Wada et al., 2000), (c) cross section of the Al-Ni alloy stabilized superconductor (0.8 x 1.1 mm²) developed for the BESS-Polar superconducting solenoid to be wound in two layers.

Table 4. BESS-Polar solenoid design parameters compared with the present BESS design.

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<tr>
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<tbody>
<tr>
<td>Coil diameter</td>
<td>1 m</td>
<td>0.9 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central magnetic field strength</td>
<td>1.2 T</td>
<td>1.0 T</td>
<td>1.2 T</td>
<td>0.8 T</td>
</tr>
<tr>
<td>Current</td>
<td>520 A</td>
<td>433 A</td>
<td>642 A</td>
<td>430 A</td>
</tr>
<tr>
<td>Turns (Layers)</td>
<td>3383 turn (4, 8 layers)</td>
<td>2600 turns (2 layers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stored energy</td>
<td>820 kJ</td>
<td>600 kJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/M ratio in coil</td>
<td>6 kJ/kg</td>
<td>15 kJ/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material @ half-wall (coil+cryostat)</td>
<td>4 g/cm²</td>
<td>2 g/cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation thickness</td>
<td>0.2 Xo</td>
<td>0.1 Xo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHe Capacity</td>
<td>150 liter</td>
<td>400 liter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total weight</td>
<td>450 kg</td>
<td>380 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductor: Al stabilizer cross section</td>
<td>1.2 x 1.8 mm²</td>
<td>0.8 x 1.1 mm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NbTi/Cu diameter</td>
<td>0.76 mm</td>
<td>0.59 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ic @ 2.5 T, 4.2 K</td>
<td>1,270 A</td>
<td>&gt; 720 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y.S. (Al) @ 4.2 K</td>
<td>30 MPa</td>
<td>&gt; 100 MPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y.S. (overall) @ 4.2 K</td>
<td>&gt; 90 MPa</td>
<td>&gt; 250 MPa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The particle detector system consists of a JET type drift chamber as the central tracker and TOF counters and silica-aerogel Cherenkov counters for triggering and particle identification as shown in Figure 11. The central drift chamber is placed inside the warm bore of the solenoid. The TOF counters with 1-cm thick plastic scintillator paddles are placed at the top and bottom ends of the detector system to provide event triggering and particle identification. A set of very thin TOF counters are installed just under the JET chamber for enabling the bottom trigger even if the low energy particles are absorbed in the lower magnet-wall. The lowest energy of detectable antiprotons is expected to be 0.1 GeV (~0.45 GeV/c) at the top of the atmosphere (TOA). The antiproton energy (momentum) is reduced to ~0.07 GeV (~0.35 GeV/c) at the top of the instrument (TOI) after traveling through the residual air of ~5 g/cm². The energy is further reduced to ~0.02 GeV (~0.2 GeV/c) after passing through the upper-half spectrometer of ~4.5 g/cm². The thin TOF counter below the JET chamber provides triggering for the low energy particle before its stopping in the lower magnet wall. The silica-aerogel Cherenkov counters are placed under the lower magnet-wall for the particle identification in a higher energy region. The refractive
The index of the silica-aerogel radiator is chosen to optimize the antiproton identification in the higher energies. A shower counter consisting of thin lead and scintillator plates may be optionally provided to separate electrons and positrons from heavier particles. A large solar battery system is required to enable the particle detector system operation with a capacity of 600 W during a flight period of 20 days.

The new BESS-polar spectrometer is to be completed by 2003. The first flight in Antarctica is expected in 2003-2004, and the second flight is expected towards the solar-minimum period in 2006 ~ 2007.

SUMMARY

The BESS experiment has been carried out to investigate elementary particle/antiparticle phenomena in the early history of the Universe through precise measurements of cosmic-ray antiproton spectrum. The low energy cosmic-ray antiproton was first unambiguously detected with its mass identification in 1993, and an energy spectrum between 0.18 and 4.2 GeV has been measured with its characteristic peak at ~ 2 GeV in the subsequent flights. The primarily secondary nature of cosmic-ray antiproton has been understood especially around at the peak of the energy spectrum. It shows, however, an excessive flux especially at the very low energy region with remaining possibilities of exotic primary sources such as primordial black holes or annihilation of neutralino dark matters in lower energies. It is very important to extend the precise measurement of the low energy antiproton spectra to search for the possible novel primary sources and, at the same time, to study the cosmic propagation model. The solar modulation effects and the charge dependence will be studied in an ideal comparison between antiproton and proton for further understanding of the cosmic-propagation model. BESS has set the upper limit on the antihelium/helium ratio to below $10^{-6}$ in cosmic rays. This result suggests that our galaxy should be filled with matter. Further sensitive searches will extend to a further distance in the Universe.

The BESS-Polar long duration flight is planned to perform the ultimately sensitive measurement of low energy antiproton spectra, search for antihelium as well as very precise measurement of cosmic-ray spectra. The first flight in Antarctica is expected to be realized in 2003-2004.

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REFERENCES

Nishimura, J., a solicited paper in COSPAR-2000, PSB1-0001, Warsaw, and to be published in Adv. Space Res.
Sasaki, M., et al, to be published. Further analysis for all data in BESS 93-99 performed in the rigidity region of 1 —14 GV.