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# BESS-Polar: Long Duration Flights at Antarctica to Search for Primordial Antiparticles

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*Abstract* --- The BESS-Polar experiment with long-duration balloon flights at Antarctica aims at extremely sensitive measurement of low energy antiprotons to search for novel primary origins in the early Universe, and to study cosmic-ray propagation and solar modulation. The search for cosmic antimatter is a fundamental objective to study baryon asymmetry in the Universe. The BESS experiment with high rigidity resolution and large geometrical acceptance will maximize advantages of long duration flights at Antarctica where the rigidity cut-off is lowest. A very compact and thin superconducting magnet spectrometer is being developed to maximize the detector performance in low energies. The BESS-Polar project and progress of the development are described.

## 1. INTRODUCTION

The Balloon-borne Experiment with a Super-conducting Spectrometer, BESS, has been carried out with aiming at studying elementary particle phenomena in the early history of the Universe through precise measurements of low-energy antiproton spectrum and searching for antiparticles of cosmic origins [1–3].

The low energy cosmic-ray antiproton fluxes and the energy spectra have been precisely measured in northern Canada, since 1993 [5–9]. Figure 1 shows the energy spectra measured in BESS-93 to -98 compared with other experiments [8, 10,11] and with theoretical calculations [12-14]. The mostly secondary nature of cosmic-ray low energy antiproton has been understood especially with the characteristic peak around at 2 GeV. Some of energy spectra are, however, indicating a flatter antiproton spectrum than theoretical calculations especially at a very low energy region below 0.5 GeV. It might suggest exotic primary sources such as evaporation of primordial black holes [15, 16] or annihilation of neutralino dark matter [13]. It is very important to extend the precise measurement of the low energy antiproton spectra to search for the possible novel primary sources. At the same time, the cosmic ray propagation and solar modulation are to be studied by using a unique probe of secondary antiprotons only opposite in charge from protons.

The search for anti-helium has been progressed [17–19], and it is a fundamental objective to study baryon asymmetry in the Universe.

## 2. BALLOON FLIGHTS AT ANTARCTICA

BESS long duration flights in polar region, BESS-Polar, are being prepared to extend the BESS scientific objectives in ideal ballooning environments at Antarctica [20]. The thin superconducting solenoid magnet spectrometer having a high rigidity resolution and large geometrical acceptance may maximize the advantage of long duration flights in Antarctica.

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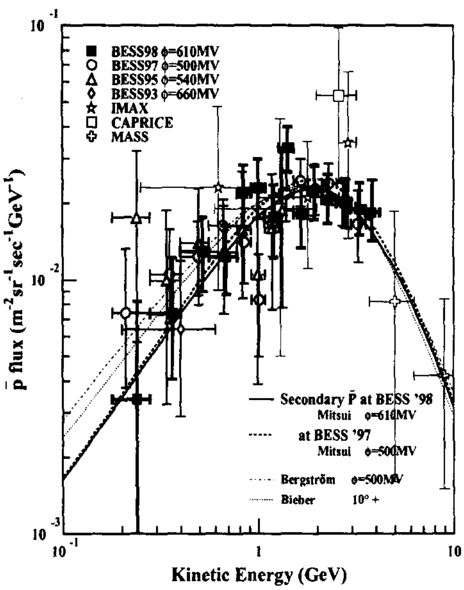


Fig. 1. Low energy antiproton spectra (@ TOA) measured by BESS compared with other experiments and theoretical calculations for secondary origins [8].

BESS-Polar has unique features compared with two large-scale space experiments, PAMELA [21] and AMS [22] as summarized in Table 1. Figure 2 shows the exposure sensitivity, defined by geometrical acceptance x exposure time, of the BESS-Polar experiment as a function of the energy in comparisons with those for the PAMELA and AMS experiments [23]. The BESS flight in Antarctica gives a uniquely high sensitivity in low energy regions below ~ 0.3 GeV, where we expect the best chance to detect antiprotons of the primary origins. PAMELA has an advantage of the polar orbit passing over two polar-regions. It has, however, a constraint in its sensitivity because of the relatively small geometrical acceptance of the instrument. AMS is to be realized on the International Space Station. It has a great advantage of a long exposure time of three years, but has a strong constraint in the flight orbit limited within < 52 degrees in latitude. The cut-off rigidity in the AMS experiment has to be higher because of the orbit. Figure 3 shows antiproton spectra in a simulation with assuming a BESS-Polar flight duration 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 alone with statistical uncertainty, and the

Table 1.
The BESS-Polar experiment in comparisons with the PAMELA and AMS experiments.

| Project | BESS-Polar | PAMELA | AMS |
|---|---|---|---|
| Acceptance (m$^2$•sr) | 0.3 | 0.002 | 0.3 |
| MDR (GV) | 150 | 740 | 1000 |
| Flight duration (days) | 20 | 1000 | 1000 |
| Flight altitude (km) | 36 | 690 | 350 |
| Residual air (g/cm2) | 5 | - | - |
| Flight latitude (deg.) | 80 | +/- 70 | +/-52 |
| Energy region (GeV) | > 0.1 | > 0.1 | > ~ 0.5 |
| Flight vehicle | Balloon | Satellite | Station |

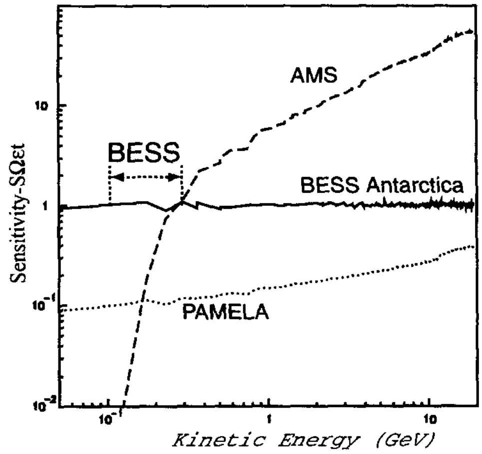


Fig. 2. Sensitivity of a BESS-Polar 20-day balloon flight compared with AMS and PAMELA [23].

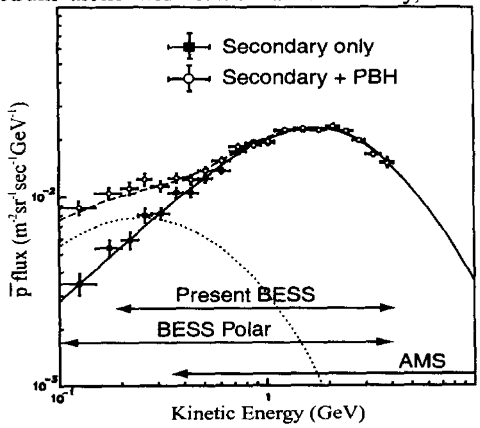


Fig. 3. Antiproton spectra in a simulation expected in a 20 days flight in Antarctica [23].

open circles indicate the spectrum with statistical uncertainty in the case of the primary antiprotons existing. The excessive antiproton spectrum because of the primary origin should be detectable with very high statistics during the long duration flights at Antarctica. BESS-Polar is complementary to AMS in focusing on the low energy range, while providing a common energy range at the characteristic secondary peak at ~ 2 GeV. It is very useful for inter-calibrations of the absolute flux in those two experiments.

### 3. BESS-Polar Spectrometer

The spectrometer for the BESS-Polar experiment is designed with a spectrometer wall material density of < 5 g/cm$^2$ at the upper-half spectrometer, a payload weight of < 1500 kg, an electrical power balance of 600 W, and with a continuous operation time of 20 days. Figure 4 shows a cross sectional view of the BESS-Polar spectrometer. Table 2 gives general design parameters. The compact spectrometer design is achieved with a geometrical acceptance of ~ 0.3 m$^2$•sr, as similar as that of the present BESS spectrometer. Figure 5 shows the detector components with the magnetic flux lines. A thin superconducting solenoid magnet is being developed to provide a magnetic field of 0.8 T (to 1.0 T maximum) in ballooning with a wall material density of 2.3 g/cm$^2$, including the cryostat wall [24]. The recent development of high strength aluminum stabilized superconductor has enabled the coil design to be much thinner and to be further transparent [25]. The warm bore of the cryostat acts as a pressure vessel for a central tracking detector (JET). No dedicated outer pressure-vessel is provided, and time-of-flight (TOF) counters and silica-aerogel Cherenkov counters (ACC) are placed outside the cryostat where they are operated in vacuum.

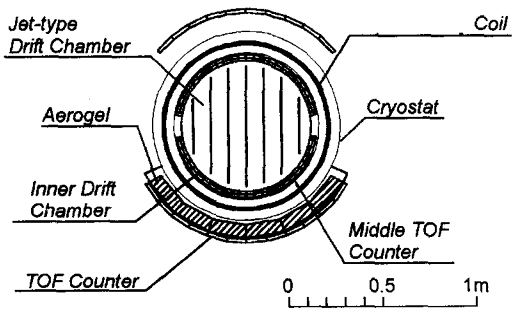


Fig. 4. Cross-section of the BESS-Polar Spectrometer with a thin superconducting solenoid.

Table 2.
BESS-Polar spectrometer design parameters.

| | |
|---|---|
| Geometrical acceptance | 0.3 m$^2$•sr |
| Flight duration | 10 ~ 20 days |
| Energy range for p-bar (@ TOA) | 0.1 ~ 4.2 GeV |
| Magnetic field | 0.8 (~ 1) T |
| Distance between TOF counters | 1.47 m |
| Diameter of Central tracker (JET/IDC) | 0.75 m |
| Maximum detectable rigidity | 150 GV |
| Power consumption | 600 W |
| Material in upper-half detector wall | 4.5 g/cm$^2$ |
| Over-all payload size (x/y/z) | 1.5/ 1.5/4 m |
| Weight | 1.5 ton |

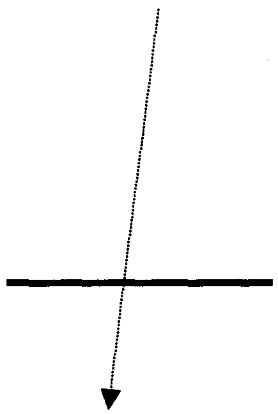


Fig. 5. BESS-Polar spectrometer configuration and magnetic flux lines.

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 thin middle-TOF counters are installed under the JET chamber for additional triggering for the very low energy particles before their stopping in the lower detector components. In this approach, the total material in the upper half of the detector is designed to be 4.5 g/cm$^2$. Taking into account of a residual air of ~ 5 g/cm$^2$ above the spectrometer, the minimum detectable energy of the antiproton is to be 0.1 GeV (0.45 GeV/c) at the top of the atmosphere (TOA). It has been also examined with a Monte-Carlo simulation as shown in Fig. 6.

The ACC counters are placed under the lower magnet cryostat to enable the particle identification in a higher energy region. The refractive index of the

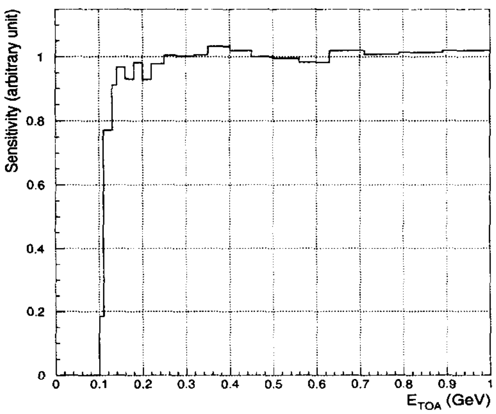


Fig. 6. Simulation for energy dependence of the BESS-Polar spectrometer sensitivity.

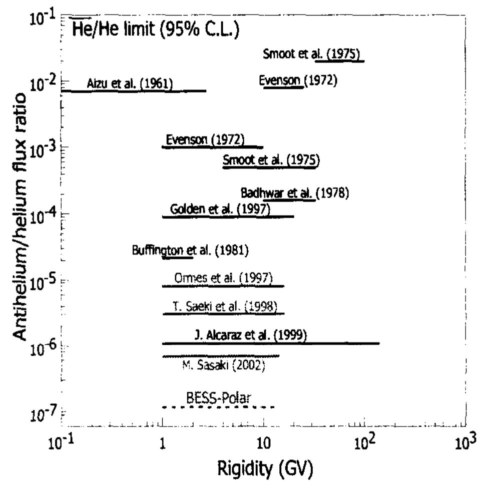


Fig. 7. Upper Limits of Antihelium to helium ratio. Progress and expected sensitivity in BESS-Polar [19].

silica-aerogel radiator is optimized to be 1.020 for the electron identification with vetoing antiprotons in a energy range below 4.2 GeV. A shower counter consisting of thin lead and scintillator plates may be a possible option to separate electrons and positrons from heavier particles in future. A large solar power system is being developed for the continuous detector system operation for 20 days with a power supplying capacity of 900 W. A technical balloon flight for the prototype solar power system has been successfully carried out at Sanriku Balloon Center, ISAS, Japan.

The first flight at Antarctica is planned in 2004 and the second flight is expected in the coming solar minimum period of 2006 ~ 2007. More than $10^3$ antiproton fluxes are to be observed below 1 GeV and ~ $10^4$ antiproton fluxes may be observed in an energy range of 0.1 ~ 4.2 GeV. In the search for antimatter, the upper limit of anti-helium to helium ratio may reach down to ~$10^{-7}$ with the flights at Antarctica, as shown in Fig. 7.

## 4. SUMMARY

The BESS-Polar long duration flight at Antarctica is being prepared to search for low energy antiproton of primary origin and search for anti-helium. At the same time, the study of comic ray propagation and the solar modulation is to be carried out by using a unique probe of secondary antiprotons only opposite in charge from the protons, as well as by using protons. More than $10^3$ antiproton fluxes are to be observed below 0.1 GeV. It will realize ultimately high sensitivity to search for the primary origins of low energy antiprotons such as evaporation of primordial black holes or annihilation of neutralino dark matters. BESS-Polar is complementary to AMS in the coverage of energy range, while partly providing a common energy range at the characteristic secondary peak at ~ 2 GeV for confirmation of the absolute flux in those two experiments. Those complementary measurements may provide a full scope of the comic ray antiproton spectrum with ultimate sensitivities. The search for anti-helium to study baryon asymmetry/symmetry in the Universe is to reach the upper limit of anti-helium to helium ratio down to be $10^{-7}$. The first BESS-Polar flight in Antarctica is expected in 2004.


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