BESS-Polar Long Duration Flights in Antarctica

A. Yamamoto[1], J. Mitchell[2], K. Abe[3], K. Anraku[2], Y. Asaoka[3], M. Fujikawa[3], H. Fuke[3], H. Haino[3], K. Izumi[3], T. Maeno[4], Y. Makida[1], S. Matsuda[3], N. Matsui[3], H. Matsumoto[3], A.Moiseev[2], J. Nishimura[3], M. Nozaki[4], H. Omiya[1,*] J. F. Ormes[3], M. Sasaki[1], E. S. Seo[5], Y. Shikaze[2], J. Suzuki[1], K. Tanaka[1], K. Tanizaki[4], J.Z. Wang[5], T. Yamagami[6], Y. Yamamoto[2], K. Yamato[4], T. Yoshida[1], and K. Yoshimura[1],

[1]High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan
[2]NASA Goddard Space Flight Center (NASA/GSFC), Greenbelt, Maryland, 20771, U.S.A.
[3]The University of Tokyo, Tokyo, 113-0033, Japan
[4]Kobe University, Kobe, Hyogo, 657-8501, Japan
[5]University of Maryland, College Park, Maryland, 20742, U.S.A.
[6]Institute of Space and Astronautical Science (ISAS), Sagami-hara, 229-8510, Japan

Abstract. A long-duration balloon flight in Antarctica is being prepared. Known as BESS-Polar, it aims at extremely sensitive measurement of low energy antiprotons to search for any novel primary origin and to study the cosmic-ray propagation and the solar modulation. The search for cosmic antimatter is a fundamental objective to study baryon asymmetry/symmetry in the Universe. The BESS experiment having an excellent rigidity resolution and large geometrical acceptance will maximize the advantage of long duration flights in Antarctica where the rigidity cut-off is very low. A very compact and thin superconducting magnet spectrometer is being developed to maximize the BESS-Polar scientific return. The progress and further plan is 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 search for antiparticle of cosmic origin (Orito, 1987; Yamamoto et al., 1994; Ajima et al., 2000). The low energy cosmic-ray antiproton fluxes and the energy spectra have been precisely measured in northern Canada, since 1993 (Yoshimura et al., 1995; Moiseev et al.; 1997; Matsunaga et al.; 1999, Orito et al.; 2000; Maeno et al.; 2001; Asaoka et al., 2001). Figure 1 shows the energy spectra measured in BESS-93 to -98 compared with other experiments (Mitchell et al., 1996; Boezio et al., 1997) and with theoretical calculations (Mitsui et al., 1996; Bergstoem et al., 1999; Bieber et al., 1999).

The primarily 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 slightly excessive antiproton fluxes 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 (Hoking, 1975; Maki et al., 1996) or annihilation of neutralino dark matter (Mitsui et al., 1996; Bergstroem et al., 1999) 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 cosmic ray propagation and solar modulation by using a unique probe of secondary antiprotons only opposite in charge from protons.

2. Polar long duration flights

The BESS long duration flight in Antarctica, BESS-Polar, is being prepared to extend the BESS scientific

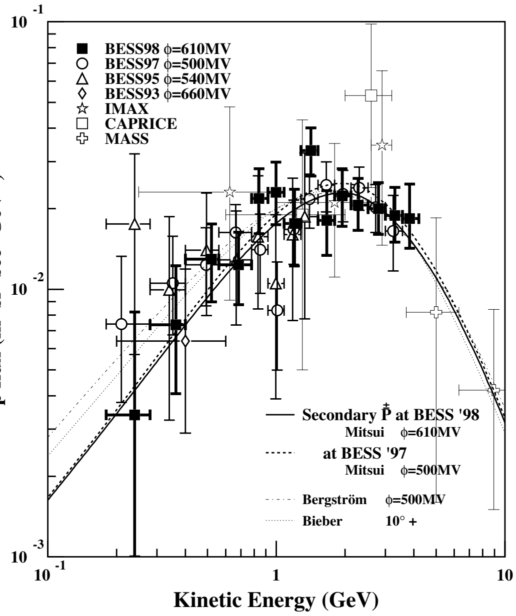

Fig. 1. Progress in low energy antiproton spectra (@ TOA) measured in BESS-93, -95, -97, and –98 compared with other experiments and theoretical calculations for the secondaries. (Maeno et al., 2001)

Correspondence to: Yamamoto (akira.yamamoto@kek.jp)

* fellow from Science University of Tokyo

objectives in an ideal ballooning environment in Antarctica (Yamamoto et al., 2000). It primarily aims at extremely sensitive measurements of low energy antiprotons as described above. The search for cosmic-ray anti-deuteron is anticipated with a similar objective. The search for anti-helium, progressed in BESS-1993 to -2000 (Ormes et al., 1997; Saeki et al, 1998; Nozaki et al., 1999; Sasaki et al., 2001), is extended to study baryon asymmetry/symmetry in the Universe. It is to reach the upper limit of anti-helium to helium ratio down to 10^{-7} in a flight period of 20 days. 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.

BESS-Polar has unique features compared with two large-scale space experiments, PAMLA and AMS as summarized in Table 1. PAMELA is to be launched in a polar-orbit (Adriani et al, 1999). It 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 (Ahlen et al., 1994). It has a great advantage of a long exposure time of three years, but has a strong constraint in the flight profile of 0 – 51.7 degrees in latitude. The cut-off rigidity in the AMS experiment may not be very low. 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 comparison with those for the PAMELA and AMS experiments (Yoshimura, 2000). The BESS flight in Antarctica gives a uniquely high sensitivity in the low energy region below ~ 0.3 GeV, where we expect the best chances to detect antiprotons of primary origin. Figure 3 shows antiproton spectra in a simulation with assuming a BESS-Polar flight duration of 20 days (Yoshimura, 2000). 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 excessive antiproton spectrum because of the primary origin should be detectable with the very high statistics during the long duration flights in Antarctica. BESS-Polar is complementary to AMS in the coverage of energy range, while providing a common energy range at the characteristic secondary peak at ~ 2 GeV. It is very much convenient for possible confirmation or inter-calibration of the absolute flux in those two experiments.

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

Project	**BESS-Polar**	PAMELA	AMS
Acceptance (m^2•sr)	0.27	0.0021	0.3
MDR (GV)	150-200	385	~1000
Flight duration (days)	20	1000	1000
Flight altitude (km)	36	690	320~390
Residual air (g/cm2)	< 5	-	-
Flight latitude (deg.)	> 70	~ +/- 80	<+/-51.7
Energy region (GeV)	0.1~ 4	> 0.1	>~0.5
Flight vehicle	Balloon	Satellite	Station
Launch (proposed)	2003/2004	2002	2003

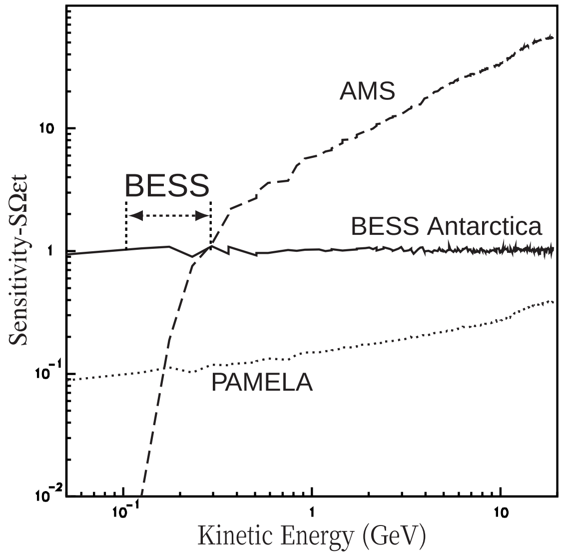

Fig. 2. Sensitivity of a BESS-Polar 20-day balloon flight compared with AMS and PAMELA

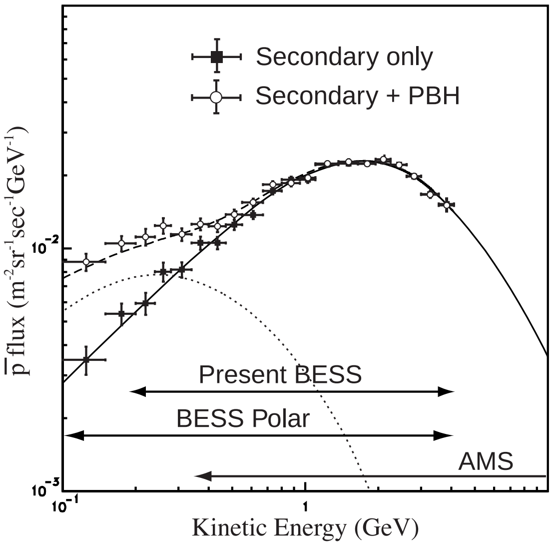

Fig. 3. Antiproton spectra in a simulation expected in a 20 days flight in Antarctica with and without primary origin of PBH.

3. BESS-Polar Spectrometer

The spectrometer for the BESS-Polar experiment is designed to meet constraints/requirements of a science payload weight of 1400 kg in maximum, a spectrometer wall material of

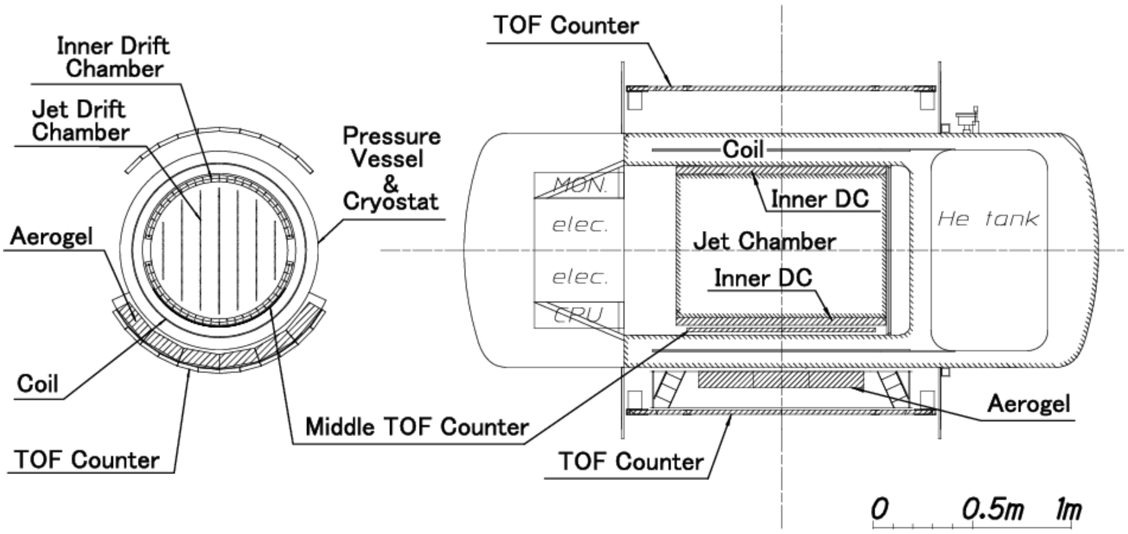

Fig. 4. Cross sections of the BESS-Polar spectrometer. The central tracker is placed inside the solenoid coil and others are placed outside the cryostat in vacuum.

< 5 g/cm^2 at the upper-half spectrometer, an electrical power balance of < 600 W, and a continuous operation time of over 20 days. Figure 4 shows cross sectional views of the BESS-Polar spectrometer, and Figure 5 shows the detector components with the magnetic flux lines. Table 2 gives general design parameters. The compact spectrometer design is achieved with a geometrical acceptance of 0.27 m^2•sr, corresponding to 90 % of the present BESS.

An extremely thin superconducting solenoid magnet is being developed to provide a magnetic field of 1.0 T with a wall material of 2 g/cm^2, including the cryostat wall. The recent development of high strength aluminum stabilized superconductor has enabled the coil design to be much thinner and further transparent (Yamamoto et al., 1999). The warm bore of the cryostat acts as a pressure vessel for the central tracking detector (JET). No dedicated outer pressure-vessel is provided, and other detector components of the time-of-flight (TOF) counters and the silica-aerogel Cherenkov counters (ACC) are placed outside the cryostat where they will be operated in vacuum.

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 as shown in Fig. 5. A set of thin middle-TOF counters are installed under the JET chamber for additional triggering for the very low energy particles before stopping in the lower detector components. In this approach, the total material in the upper half of the detector is designed to be 5 g/cm^2 or smaller. Taking into account of a residual air of 5 g/cm^2 above the spectrometer, the minimum detectable antiproton energy is expected 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 higher energy region. The refractive index of the silica-aerogel radiator is optimized for the antiproton/proton identification (vetoing) in the higher energies. A shower counter consisting of thin lead and scintillator plates may be optionally installed to

Table 2. BESS-Polar spectrometer design parameters

Geometrical acceptance	0.27 m^2•sr
Flight duration	10 ~ 20 days
Energy range for antiprotons (@ TOA)	0.1 ~ 4.2 GeV
Magnetic field	0.8 ~ 1 T
Distance between TOF counters	1.2 m
Diameter of Central tracker (JET/IDC)	0.75 m
Maximum detectable rigidity	150 ~ 200 GV
Power consumption	600 W
Material in upper-half detector wall	4.5 g/cm^2
Over-all payload size (x/y/z)	1.5m / 1.5m / 3m
Weight	1.4 ton

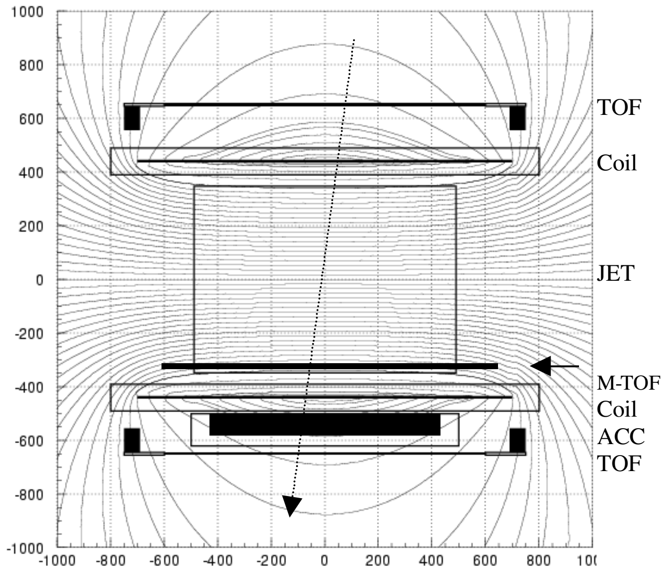

Fig. 5. Particle detector configuration with magnetic flux lines. The middle (M-) TOF is effective for low energy particle trigger.

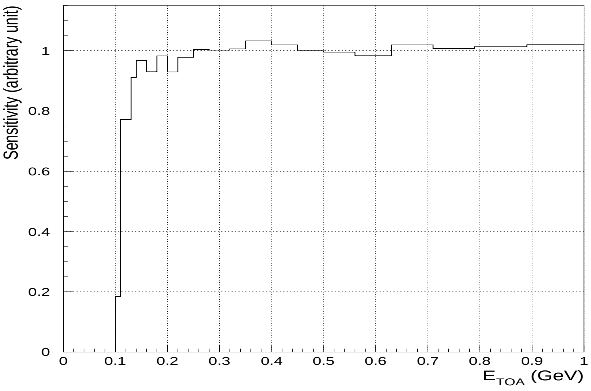

Fig. 6. Monte Carlo Simulation of the energy dependence of the spectrometer sensitivity. The lower limit of the detector sensitivity is evaluated to be ~ 0.1 GeV.

separate electrons and positrons from heavier particles. A large solar battery system is required for the continuous detector system operation for 20 days with an electrical generation capacity of ~ 1.2 kW including efficiencies.

The first flight in Antarctica is expected to be realized in 2003 ~ 2004 and the second flight in the coming solar minimum period. More than 10^3 antiproton fluxes are to be observed below 1 GeV and ~ 10^4 antiproton fluxes may be observed in a global energy range of 0.1 ~ 4.2 GeV.

4. Summary

The BESS-Polar long duration flight in 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 the ultimate sensitivity to search for the primary origins 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 2003/2004.

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