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# BESS-Polar

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**Abstract**

BESS-Polar is a balloon experiment being planned to be carried out at Antarctica and/or Arctic to study in detail low energy cosmic-ray anti-protons. After a brief review of anti-matter search and anti-proton measurements at the top of the atmosphere, the BESS-Polar project will be presented. The BESS-Polar instrument is a magnetic spectrometer using a superconducting solenoid, which is the third generation of the BESS detector. A new apparatus with better transparancy, extended energy coverage and longer lifetime to cope with the 10–20 day flight is being developed. The first flight is planned in 2004.


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## 1. Introduction

### 1.1. Cosmic-ray anti-matter

We know, from high energy experiments, that particles and anti-particles behave almost symmetrically. At the early Universe, particles and anti-particles are believed to be the same in number and they are in thermal equilibrium; pair creation and pair annihilation repeated in an ultra-high energy environment.

From astronomical observation, on the other hand, we have not found any condensed or clustered anti-matter. There has not been an established model that reconciles these conflicting observations. Among various possibilities that have been proposed, the most plausible scenario is to assume a tiny excess of particles over anti-particles due to CP violation at an early epoch and all the anti-particles had already annihilated.

From an experimental point of view, anti-helium nuclei can be unambiguously identified if they hit the detector. By using an apparatus like the BESS detector, which will be described below, doubly charged negative particles will be clearly separated from other singly charged or positive particles. Background from nuclear interaction is expected to be very small because any accelerator experiments ever performed have failed to detect any anti-helium nuclei.

### 1.2. Search for anti-matter

Search for cosmic-ray anti-matter has a long history. It started in 1961, soon after the discovery of anti-protons at Bevatron. The first limit was set

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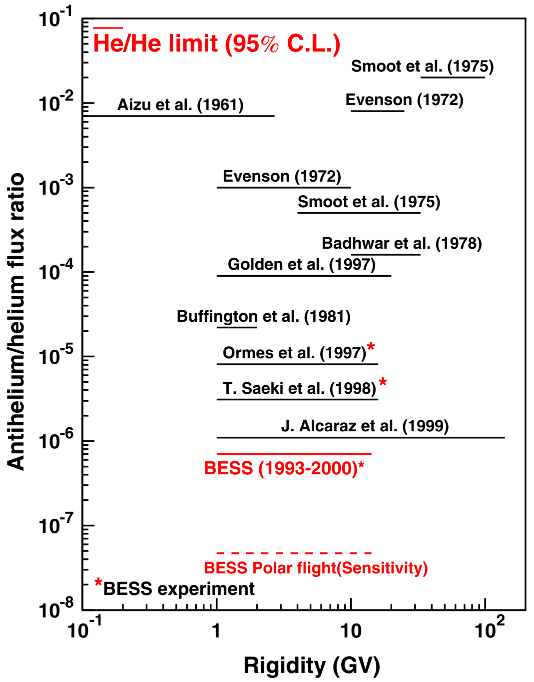


Fig. 1. Observational 95% CL upper limits of anti-helium to helium ratio obtained by various experiments.

by an emulsion experiment, although whose purpose was to measure heavy primaries; not anti-particles. The authors claimed that they detected 500 alphas, 300 CNOs and about 200 heavy particles, while no anti-particles were detected. They set an upper limit of $10^{-3}$ [1].

In 40 years, the limits have been improved by a factor of 10,000 by using larger and more sophisticated particle detectors (see Fig. 1). All the measurements have been performed at the top of or far above the atmosphere. For the time being, BESS is in the lead and gives an 95% CL upper limit at $\overline{\mathrm{He}}/\mathrm{He} < 8 \times 10^{-7}$ [2].

### 1.3. Cosmic-ray anti-protons

Since no anti-helium nuclei have been detected so far, the flux of relic anti-protons produced in the anti-nucleosynthesis in the early Universe is expected to be well below our sensitivity. On the other hand, "secondary" anti-protons are regularly produced in the galaxy by the interaction between primary cosmic-ray particles and interstellar medium, mainly hydrogen atom. The energy spectrum of the secondary anti-protons can be calculated according to a propagation model using the measured values of primary cosmic-ray fluxes, interstellar gas density, production cross-section and "tertiary" interaction cross-section. A peak in the spectrum around 2 GeV due to collision kinematics is a generic feature of the spectrum; since the threshold energy of the anti-proton production is high, about 7 GeV, and Lorentz boost suppresses low energy anti-protons.

In addition to the secondary production, some "exotic" sources of anti-protons have been proposed; the evaporation of primordial black holes (PBH) and/or the annihilation of neutralinos [3]. Since the particle emission from the PBH is thermal, the flux is expected to be "soft"; large flux at low energies. The spectrum of the anti-protons from neutralino annihilation is also expected to be relatively softer than the spectrum of secondaries because of the annihilation at rest. However, it depends largely on the SUSY parameters that determine the neutralino masses and decay channels. There seems to be some parameter space that gives detectable anti-proton flux [4].

The first measurement of cosmic-ray anti-protons was done by Golden's team at high energies [5]. In 20 years, several experiments have collected more than 2000 anti-protons in total from 200 MeV up to around 50 GeV (see Fig. 2) [6]. As shown in the figure, the spectrum on the whole is consistent with what is expected from the secondary production although the statistics below 1 GeV is poor. Considering the difference in the shape of the spectrum between "exotic" and "secondary" anti-protons, low energy region is the best place to search for exotic sources.

### 1.4. Solar modulation

As far as we measure cosmic-ray charged particles in the heliosphere, which extends up to about 100 AU, the cosmic-ray spectrum is deformed by solar activities. Incoming cosmic-ray particles are scattered by the outflowing irregularities of solar magnetic field accompanied by the solar wind. Although the modulation effect is generally large at low energies, it depends also on the original

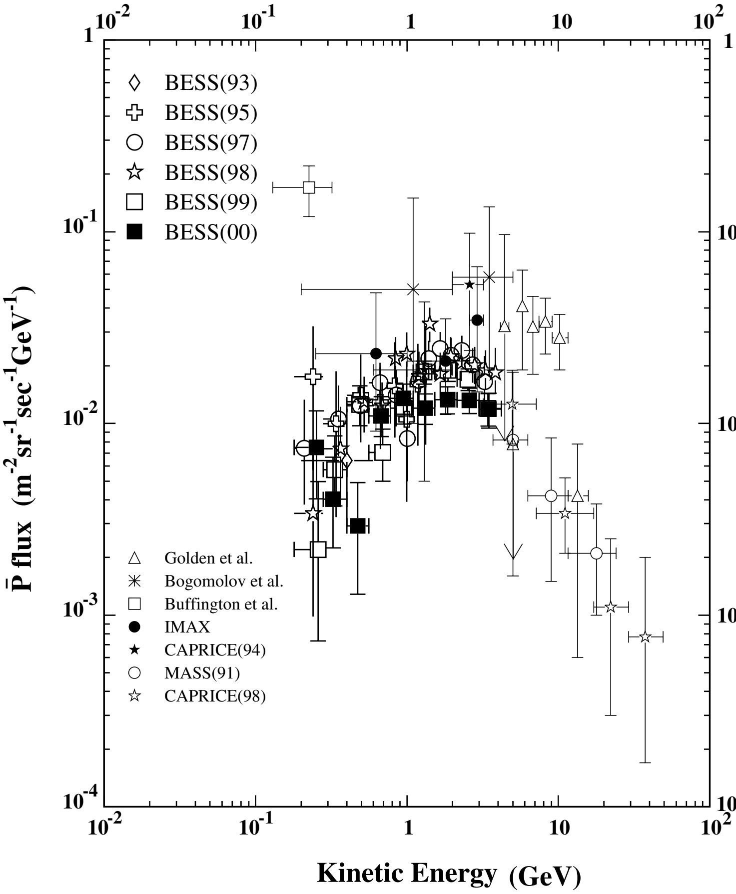


Fig. 2. Cosmic-ray anti-proton fluxes measured by BESS and other experiments.

spectrum shape. For example, while the flux of primary protons at 200 MeV is an order magnitude lower in the solar maximum period than in the solar minimum, the flux of anti-protons changes only by a factor 2 [7]. Therefore a better knowledge of the modulation effect is crucial to search for exotic phenomena in the low energy region by using the spectrum shape difference.

We should note also that the real period of the solar activity is 22 years rather than 11 years. The polarity of solar magnetic field flips every 11 years and consequently the global field pattern reverses. The path of positively charged particles is different from that of negative particles. We have observed the spectrum of protons and anti-protons in 1999 and 2000, just before and after the solar field reversal, and compared the effect of solar modulation. From these measurements, we have found that a model incorporating the charge dependent modulation describes our data better than simplified models without charge dependence.

### 1.5. The BESS-Polar experiment

BESS-Polar is a long-duration balloon experiment to measure low energy anti-protons [9]. The goal is to improve statistics by an order of magnitude and to extend the energy coverage; the minimum detectable energy will go down from 200 MeV to 100 MeV. Both requirements, lower energy and longer flight, will be realized by a polar flight. At polar regions, both the Antarctica and the Arctic, wind circulates around the pole and a long flight longer than a week is possible. Moreover the lower cut-off rigidity along the polar route allows us to measure lower energy particles. In order to make the most of the polar flight, the instrument should be more transparent.

## 2. The BESS-Polar instrument

A magnetic spectrometer to be used in the BESS-Polar experiment is the third generation of the BESS detector. The basic concept of the detector is inherited from the original BESS [8]; a cylindrical jet-type drift chamber sitting in an axial magnetic field generated by a thin superconducting solenoid measures the transverse rigidity (momentum/charge) and a pair of arch-shaped drift chambers equipped with vernier cathodes determine the hit coordinates along the magnetic field; in all, three-dimensional tracking is possible. The charge of the particles is measured by the energy deposit in the scintillation counter hodoscope and the mass is determined by the time-of-flight measurement. An auxiliary particle identification is provided by an aerogel Cherenkov counters. In the second phase of the BESS experiment, the BESS-TeV project, we added a pair of drift chambers outside the solenoid to improve the momentum resolution of higher energy particles.

Considering the requirements described in the previous section, an almost new detector system is being developed for the BESS-Polar project as illustrated in Fig. 3. The features of the apparatus are as follows: (1) the payload is compact with less weight (~1400 kg) to be safely launched and recovered, while keeping the geometrical acceptance at the same value as the present BESS, (2) using an ultra-thin (~2 g/cm$^2$) superconducting solenoid developed for this experiment [9], the wall thickness of the instrument is ~4 g/cm$^2$, less than half of the present BESS, (3) detectors are operated by solar cells instead of primary lithium batteries to cope with a long duration flight.

### 2.1. General layout

The size of the present BESS payload is too large to be recovered in Antarctica, where the surface transportation is not available. As the payload should be dismantled into small pieces at the impact point, we have abandoned the idea of installing all the detectors in a pressure vessel. Consequently, some detector components, a time-of-flight hodoscope and an aerogel Cherenkov counter, and related high voltage power supplies and readout electronics are exposed to a vacuum environment. The cryostat of the superconducting magnet serves as a pressure vessel for tracking chambers and their readout electronics.

The total weight of the payload will be reduced to be 1400 kg (the present weight of the BESS payload is 2200 kg) in order to meet a requirement imposed by the launcher available at the polar

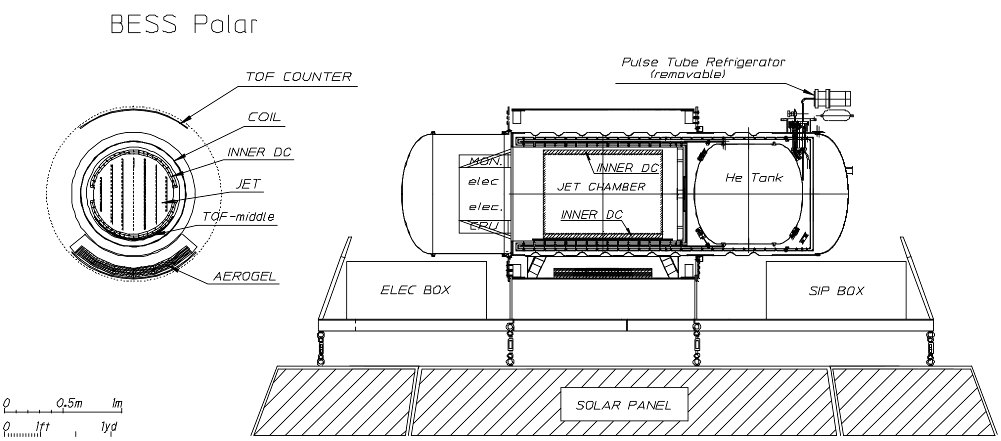


Fig. 3. A general layout of the BESS-Polar instrument.

flight. The major changes from the present BESS detector are described in the following sections.

### 2.2. Magnet

The key technology of the BESS-Polar magnet lies in the advances of aluminum stabilized superconductor. Higher strength of the stabilizer is achieved by optimizing the nickel content in aluminum [10]. This new material together with cold-work technique enabled us to fabricate a self-supporting ultra-thin coil, 3.4 mm with 1.0 g/cm$^2$. The coil is 0.9 m in diameter and 1.4 m in length and its weight is 41 kg. The total weight including the cryostat is 380 kg. We plan to operate the coil at 380 A to generate 0.8 T in a volume, 0.8 m in diameter and 1.4 m in length, where the tracking detectors are located.

### 2.3. Middle TOF counters

Thickness of the TOF scintillation counters should also be reduced from 20 to 10 mm to decrease the energy threshold for the incident particles to be triggered and detected. However, this reduction is not enough to detect particles with energy 100 MeV at the top of the atmosphere. Therefore a thin layer of scintillation counter hodoscope, middle TOF counter, is installed to trigger particles that have not enough energy to penetrate the lower wall of the coil. Since the space between the inner wall of the cryostat and the tracking chamber is limited, the thickness of the scintillator is 5 mm. The hodoscope is segmented into 64 scintillator bars, each 10 mm wide and 1.0 m long. The light is collected through clear fibers and measured by 2.5-inch. 8-channel multi-anode fine-mesh photomultiplier tubes (R6504MODX-M8ASSY), which is newly developed by Hamamatsu Photonics. The pulse height of each anode signal is digitized by a low-power ADC and the timing of a dynode signal, common to one PMT, is digitized by a TDC.

### 2.4. Solar panel

In order to cope with a long duration flight, the power supply system will completely be renewed. In the previous flights, we have used a $\sim$200 kg of primary lithium batteries to supply all the electric power needed for one day flight. If we extended the current system to the polar flight, we must carry unrealistically large amount of batteries. Therefore the solar cells are inevitable.

The solar cell we will use in BESS-Polar is commercially available (NT3436BD, SHARP) and has an efficiency of 16% [11]. A solar panel unit with an area of $40 \times 70$ cm$^2$ has 36 such cells connected in series and generates $\sim$48 V. As for the panel arrangement, there are two possibilities; one is to attach the panels to a frame that is fixed to the payload and the other is to rotate the frame with respect to the payload so that the panels always point to the direction of the sun. In the latter arrangement we need less number of panels while a sun-chasing mechanism is needed. We adopt the former mechanically simple arrangement with an octagonal frame to stabilize power generation. The frame size and thus the maximum number of panels that can be attached to the frame is limited by the size of the payload and the launch vehicle. We have optimized the layout and found that 96 panels can be installed. This number corresponds to a maximum power generation of 1200 W. Considering a 25% margin and efficiencies at DC–DC converters, we set an upper limit for the net power consumption of the apparatus at 600 W, which should be compared with the present power consumption of 900 W.

We have carried out a technical flight at Sanriku balloon base in May 2002 to study the performance of the solar power system and its aerodynamics. The size of the frame was similar to the final design but a quarter of real panels have been installed. Temperatures and output voltages at various points have been measured during the 4-h flight. The attitude of the payload was monitored by a onboard video camera. Thermal analysis of the system and the simulation of power generation have been compared and verified by measurements.

### 2.5. Data acquisition system

Because of the power limitation arising from the area of the solar panels that can be deployed around the payload, the maximum net power we can use is estimated to be 600 W. The most power consuming electronics are flash-ADCs to digitize chamber signals and TDCs for TOF measurement. We have developed a new readout system making the best use of currently available low-power electronics.

Storage device should also be updated. Although we have used two tape drives, 120 GB in total, for data storage in the previous one-day flights, it is not easy to increase the number by a factor 10 considering the size and weight of the drives. On the other hand, compact hard disk drives with large storage capacity are commercially available these days. Therefore, we will use a hard disk array with $\sim$1 TB capacity. Tolerance against shock and low temperature is now being investigated.

## 3. Future prospects

The construction of the BESS-Polar apparatus will be finished before summer 2003 and a technical flight to confirm communication between our payload and the system of NASA/NSBF is scheduled in autumn. The first flight of BESS-Polar is planned in 2004. More than 1000 antiprotons below 1 GeV will be detected in a 20-day flight.

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