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Progress of the BESS Superconducting Spectrometer

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Abstract

Balloon-borne Experiment with a Superconducting Spectrometer (BESS) is a balloon-borne spectrometer to study elementary particle phenomena in the early Universe as well as the origin and the propagation of cosmic radiation. The instrument has a unique feature of a thin superconducting solenoid which enables a large acceptance with a cylindrical configuration. Nine balloon flights have been successfully carried out since 1993. In 2002, the detector was upgraded as the BESS-TeV spectrometer to extend primary cosmic-ray spectra up to 1 TeV. For further studies of low-energy antiprotons, a new spectrometer, BESS-Polar, with a ultra-thin superconducting solenoid is being developed for long duration balloon flights in Antarctica.

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1. Introduction

The Balloon-borne Experiment with a Superconducting Spectrometer (BESS) has been carried out since 1993 to investigate elementary particle phenomena in the early Universe through sensitive searches for antiparticles of cosmic origin as well as the precise measurement of primary cosmic

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rays. The detection of cosmic-ray antiproton was first reported in 1979 [1], and the subsequent experiment [2] implied a large flux at a few hundred MeV where a secondary antiproton production by collisions of energetic cosmic-ray with interstellar material is kinematically suppressed. To investigate sources of such low-energy antiprotons with much higher statistics and confidence, BESS was proposed in 1987 [3].

We report here on the progress of this instrument since the first flight in 1993, the BESS-TeV upgrade in 2002 and the new BESS-Polar spectrometer in the near future.

2. BESS spectrometer

The BESS detector was designed and developed as a magnetic-rigidity spectrometer with a large geometrical acceptance owing to its simple cylindrical configuration using superconducting solenoid magnet [4,5]. Magnetic rigidity ($R \equiv pc/Ze$) of an incident particle is measured precisely from the deflection in the magnetic field. In the previous cosmic-ray experiments [1,2] a solenoid magnet was disfavored because of the unavoidable material along the particle passage. However, a thin superconducting solenoid developed at KEK [6] enabled us to adopt a concentric configuration with many advantages. A uniform rigidity resolution and a wide-open geometry acceptance ($0.3\,\mathrm{m}^2\,\mathrm{sr}$) are easily obtained while keeping the whole detector size compact.

The central jet-cell-type drift chamber (JET) is placed in the warm bore of the magnet together with two inner drift chambers (IDCs). The transverse magnetic rigidity is determined using up to 28 hit points with the position resolution of $200\,\mu\mathrm{m}$. A sharp deflection resolution with a maximum detectable rigidity (MDR) of 200 GV can be realized in the highly uniform magnetic field of 1 T. The upper and lower scintillator hodoscopes (TOF) provide the time-of-flight and two dE/dx measurements. Particle identification is performed by mass reconstruction according to the relation $m = ZeR\sqrt{1/\beta^2 - 1}$.

3. Progress of antiproton measurement

After the first mass-identified observation of cosmic-ray antiprotons achieved in 1993 [7], seven balloon experiments have been successfully carried out until 2000. The TOF resolution was improved from 280 to 110 ps in 1995 [8], followed by the further improvement down to 70 ps in 1997 [9]. A threshold-type aerogel Cherenkov counter [10] was introduced from the 1997 flight to eliminate the e^-/μ^- backgrounds for antiprotons. An accelerator beam test using low-energy antiprotons was performed in 1999 to directly measure the antiproton detection efficiency of the instrument [11]. The energy range of the antiproton detection was extended up to 4 GeV and 2000 antiprotons were totally accumulated [8,12–14].

4. Progress of primary cosmic-ray measurement

In the 1998 flight, signals from the aerogel Cherenkov counter were used as a trigger for the efficient detection of energetic primary cosmic-rays. The precise energy spectra of protons and helium nuclei were obtained with drastically improved statistics up to 120 GeV and 54 GeV/n, respectively [17]. In order to further extend the energy range of the measurement of precise primary cosmic-ray spectra up to several hundred GeV, the instrument was upgraded as the BESS-TeV spectrometer.

4.1. BESS-TeV spectrometer

Retaining the basic features of the BESS detector, the rigidity resolution was improved by the development of new drift chambers. JET/IDCs were upgraded with twice the measurement points and a better position resolution. Arc-shaped drift chambers called outer drift chambers (ODCs) were installed both on the top and bottom of the spectrometer and twice the long track as the previous BESS is obtained by four measurement points of each ODC (Fig. 1).

4.2. Reliable measurement of absolute rigidity

There are some specific issues for the balloon-borne cosmic-ray experiments different from the

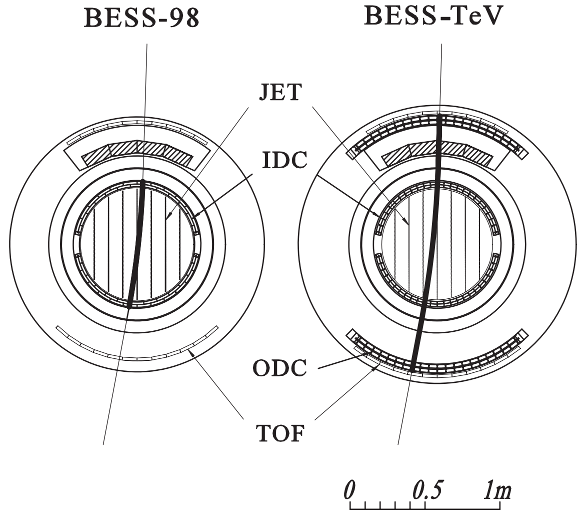

Fig. 1. Cross-sectional views of BESS-98 and BESS-TeV spectrometer. Thick lines represent the track length used in rigidity measurements.

accelerator experiments; large variation of pressure and temperature inside the pressure vessel during a flight, "slow gas" (CO_2 90% and Ar 10%) used as the chamber gas to keep low power consumption of read-out electronics and absence of absolute references such as beam timing, vertex position or invariant mass. In order to measure an absolute rigidity reliably up to 1 TV under such restrictions, reliable hit reconstructions of the drift chambers and of deep understanding of alignment of the chambers are required. So we developed a new chamber calibration procedure.

In this procedure, the consistency for all drift chambers is strictly required. The minimum number of parameters which should vary with the gas pressure during the flight, such as drift velocity and Lorentz angle, are calibrated. Since the gas volumes of the chambers are relatively small ($\phi 0.7\,\mathrm{m} \times 1\,\mathrm{m}$ for JET), the uniform temperature is assumed and the common calibration parameters are used for all the sense wires of each chamber. With redundant information up to 60 hit points measured by JET/IDCs and ODCs, calibrations and position reconstructions are confidently carried out.

In addition, a scintillating fiber counter system (SciFi) was installed to provide absolute position

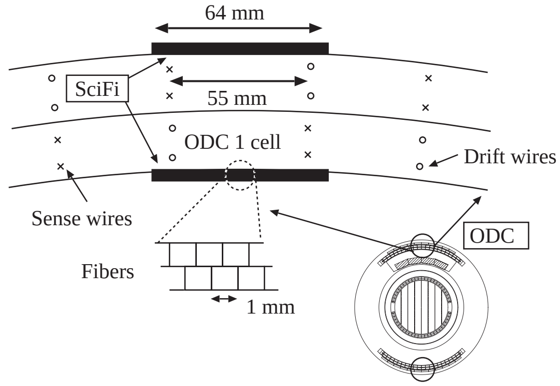

Fig. 2. Schematic view of SciFi mounted on ODC.

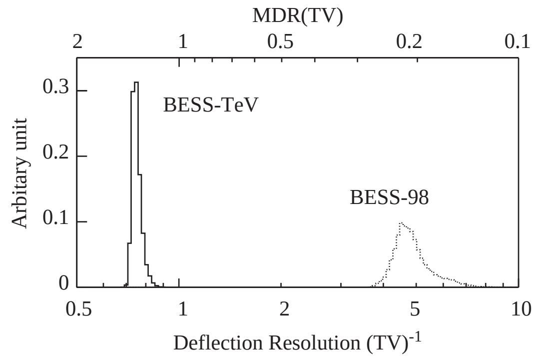

Fig. 3. Distribution of the deflection resolution. Each area of the histogram is normalized.

references for the calibration of ODCs. A set of SciFi consists of 2 layers of $1\,\mathrm{mm}^2$ square-shaped scintillation fibers which covers one central cell of each ODC (Fig. 2). Although SciFi can only measure hit positions in the accuracy of 0.5 mm, the center value of a distribution between an ODC track and hits of SciFi is an accurate position reference of an order of 10 μm when enough events are accumulated. The calibration parameters of ODCs are derived so that the center value becomes zero.

4.3. Performance during the balloon flight in 2002

Fig. 3 shows the distribution of the deflection resolution obtained from the flight data in 2002. A much higher MDR of 1.3 TV was achieved than that of previous BESS.

5. BESS-Polar spectrometer

Although the spectrum of antiprotons measured by the previous BESS flights [8,12–14] were almost consistent with the secondary particles, possible existence of some novel primary origin [15,16] has not been ruled out for energy below 1 GeV. Therefore, a long-duration balloon-borne experiment, BESS-Polar, was proposed for the highly sensitive measurement of low-energy antiprotons and the further study of their origin [18]. The BESS-Polar spectrometer is now being developed for this purpose. To measure antiprotons at the lowest possible energy, material thickness in the payload is reduced as low as possible. An extremely thin solenoid magnet with the thickness of 2.4 g/cm^2/wall including cryostat has been developed as a key component of the spectrometer. A high-strength aluminum stabilized superconductor was recently developed [19], which enables a very thin coil strong enough for self-supporting against the electromagnetic force [20]. There will be no pressure vessel outside the detector, and the cryostat of the solenoid will function as the pressure vessel. JET/IDCs which worked successfully in the BESS-TeV experiment will be placed inside the bore as a tracking system. TOF counters, aerogel Cherenkov counter and their front-end electronics will be operated in vacuum. To supply electric power continuously up to a few weeks to the electronics onboard, a new power supply system using solar cells is developed and tested by a technical flight performed in Japan.

The first scientific flight is planned to be conducted either at Fairbanks (Alaska), Karlsborg (Sweden) or Antarctica in 2004 after the technical flight at Fort Sumner, New Mexico, USA in September 2003. We expect to conduct the second long-duration flight over Antarctica during the coming solar minimum in the 2006/2007 Antarctic summer. The BESS-Polar experiment is ideal for the search for low-energy antiprotons of cosmic origin, since the long-duration balloon can stay at high-geomagnetic latitude. BESS-Polar will provide a very precise measurement of the cosmic-ray antiproton spectrum, focusing on the low-energy region, and complementary with the measurements of the space-based experiments such as AMS [21] and PAMELA [22].

6. Conclusions

The BESS experiment has been carried out to investigate elementary particle phenomena in the early Universe through precise measurements of the cosmic-ray antiproton spectrum since 1993. The precise energy spectra of primary cosmic rays were also measured and are to be extended up to a higher energy by the BESS-TeV spectrometer. Further studies of low-energy antiprotons will be carried out in the near future using BESS-Polar spectrometer by the long-duration balloon flights in Antarctica.

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