The second Antarctic Flight of BESS-Polar Experiment: Flight Summary and Detector Performance

K. Yoshimura*, K. Abe*,[1], H. Fuke†, S. Haino*,[2], T. Hams‡,[3], M. Hasegawa*, A. Horikoshi*, K. C. Kim§ A. Kusumoto¶, M-H. Lee§, Y. Makida*, S. Matsuda*, Y. Matsukawa¶, J. W. Mitchell‡, J. Nishimura† M. Nozaki*, R. Orito¶,[4], J. F. Ormes‖, K. Sakai, F. San Sebastian‡, M. Sasaki‡,[4], E. S. Seo§, R. Shinoda** R. E. Streitmatter‡, J. Suzuki*, N. Thakur‖, K. Tanaka*, T. Taniguchi*, T. Yamagami†, A. Yamamoto* and T. Yoshida†**

**High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, 305-0801 Japan*
†Institute of Space and Astronautical Science (ISAS/JAXA), Sagamihara, Kanagawa, 229-8510 Japan
‡NASA/Goddard Space Flight Center, Greenbelt, MD 20771 USA
§IPST, University of Maryland, College Park, MD 20742 USA
¶Kobe University, Kobe, Hyogo, 657-8501 Japan
‖University of Denver, Denver, CO 80208 USA
***The University of Tokyo, Bunkyo, Tokyo, 113-0033 Japan*

***Abstract*. The goals of the BESS-Polar experiment are precise measurements of the low-energy antiproton spectrum and search for cosmologically significant antimatter. After its first flight over Antarctica in 2004 (BESS-Polar I), we has developed a new spectrometer based on the feedback from the results. Most of the detector components were upgraded to improve their performance and to increase the data taking duration and capacity. The second flight (BESS-Polar II) was successfully carried out in December 2007– January 2008. We performed 24.5 days scientific observation just at the solar minimum. In flight all detectors operated nominally and exhibited expected performances despite of minor problems in some detectors.**

***Keywords*: BESS-Polar, long-duration balloon flight, solar activity**

I. Introduction

BESS-Polar[1][2], flown over Antarctica in a long-duration balloon flight, is the successor to the BESS experiment, which had been carried out 9 times in northern Canada in 1993 – 2001. The objectives of the BESS-Polar experiment are definitive measurements of various low-energy cosmic-ray phenomena with high statistics; particularly providing a firm answer on possible primary component of cosmic-ray antiprotons, searching for antinuclei down to an unprecedented level, and studying

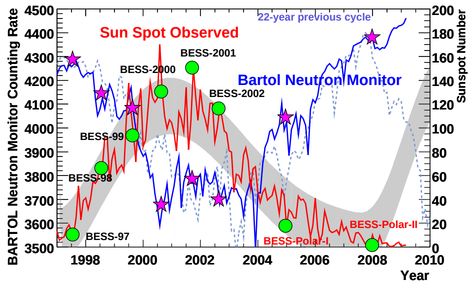


Fig. 1: Variation of neutron monitor and sunspot number together with the date of past and current BESS flight.

the origin and propagation of other galactic cosmic-ray species.

After its first successful flight in 2004 (BESS-Polar I)[3][4][5], the second flight of BESS-Polar (BESS-Polar II) has been prepared to be carried out at the solar minimum with an improved instrument and capability for an extended long-duration flight. We have built the new instrument for BESS-Polar II and successfully carried out the second Antarctic flight just at the present solar minimum as shown in Fig. 1.

In this paper, we describe BESS-Polar II instrument, flight summary, and detector performance based on the flight data.

II. BESS-Polar II Instrument

Figure 2 shows the general layout and a photo of the BESS-Polar II spectrometer. The following main features were inherited from the BESS-Polar I spectrometer

- Large geometrical acceptance: $\sim 0.3\mathrm{m}^2\mathrm{sr}$
- Ultra thin spectrometer: 4.5 $\mathrm{g/cm}^2$/wall
- Good rigidity measurement: MDR$\sim$230 GV
- Redundant particle identification: β, $\mathrm{d}E/\mathrm{d}x$
- Long duration capability: $10 \sim 20$ days

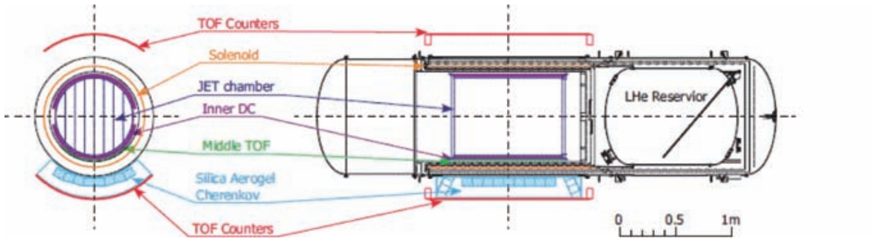
[1]Present address: Kamioka Observatory, ICRR, The University of Tokyo, Kamioka, Gifu 506-1205, Japan.

[2]Present address: Instituto Nazionale di Fisica Nucleare (INFN), Universitia degli Studi di Perugia, Perugia 06123 Italy

[3]Also at University of Maryland Baltimore County, Baltimore, MD, 21250. USA

[4]Also at University of Maryland, College Park, MD 20742, USA

[5]Present adress: Max-Plank-Institut für Physik, Fohringer Ring 6, 80805 München 80805, Germany



(a)

(b)

Fig. 2: Cross sectional view and photo of BESS-Polar II instrument.

Based on the feedback from the analysis of the BESS-Polar I data, various improvements were done and many of the detectors and systems were redesigned and re-fabricated both to improve performance and flight duration. A detailed description of the instrument was reported elsewhere [6][7]. Here major improvements and modifications from BESS-Polar I are highlighted and discussed.

- **Magnet[8]:**
  The longer life is achieved by installing a larger helium reservoir tank with a 520 ℓ capacity (400 ℓ previously) and an additional layer of radiation shield to improve the dewar's thermal insulation.
- **Middle Time of Flight (MTOF)[9]:**
  Both-end readout of the scintillators was realized for the new MTOF system by employing clear fiber-bundle as light guides and a splitable PMT attachment (cookie) as shown in Fig. 3a and 3b, respectively. The new system enabled axial position measurements using timing and amplitude differences of both scintillator ends, in addition to improving performance and efficiency.
- **Aerogel Cherenkov Counter (ACC)[10]:**
  The ACC was thoroughly redesigned and fabricated to increase rejection power against background for $\bar{p}$ measurements (Fig. 3c). We have optimized various parameters, e.g., height, PMT angle, and size of blocks, etc. We have also employed new, larger, aerogel blocks (190×280×20 mm^3, Fig. 3d) with refractive index of 1.03, previous blocks were 100×100×10 mm^3 with $n = 1.02$.
- **Time of Flight hodoscope (TOF)[11]:**
  In the BESS-Polar I flight, some of the TOF PMTs drew excessive current in the cold and low-pressure environment due to imperfections in the potted HV component encapsulation. To protect the PMTs from breakdown, a hermetic aluminum case has been adopted from the previous successful ACC use (Fig. 3e). The thickness of scintillator was increased from 10 mm to 12.7 mm as a compromise among material thickness, weight and performance(Fig. 3f).
- **Central Tracker (JET/IDC):**
  We added a thin layer of aluminum foil to eliminate noise caused by the DC-DC converters. A new gas flow control system was developed to improve stability of chamber gas pressure.
- **DAQ System:[12]**
  The data acquisition system has been upgraded to increase speed and capacity. Flash ADC performance has been improved by changing the readout configuration. The data storage and processor were also upgraded: total 16 TB hard disk drives (HDDs) and faster CPU (Intel Core Duo 1.66 GHz) were installed into the data vessel.

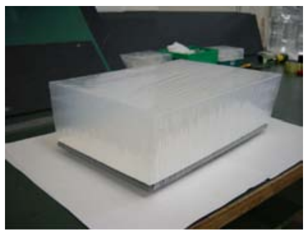
III. BESS-POLAR II FLIGHT

After integration of all detector components at NASA/Goddard Space Flight Center (GSFC) and the pre-deployment compatibility test at Columbia Scientific Balloon Facility (CSBF), the payload was transported

(a) MTOF fiber-bundled light guide

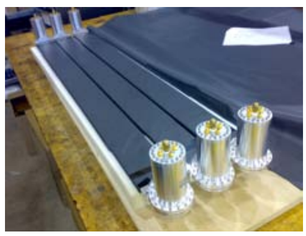
(b) MTOF Splittable cookie

(c) ACC counter box



(d) ACC block

(e) TOF PMT enclosed with an aluminum hermetic case



(f) TOF counters

Fig. 3: Newly developed detectors for BESS-Polar II

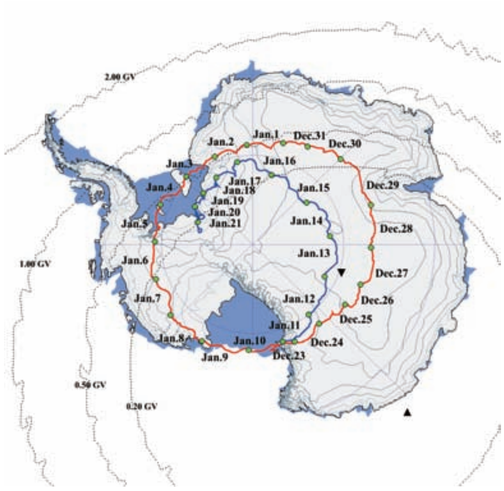


Fig. 4: BESS-Polar II trajectory. Contour lines indicate geomagnetic cutoff rigidity.

to Antarctica in the end of October 2007. After one month of onsite preparation at Williams Field near the U.S. McMurdo Station, the final compatibility test was performed on November 29 and BESS-Polar II payload was declared to be ready for the flight. After a waiting period for the sufficient weather condition, the BESS-Polar II payload was successfully launched from the Williams Field on December 23, 2007.

Figure 4 and 5 shows, respectively, the trajectory and pressure and altitude profile of the BESS-Polar II flight. The payload flew with one and 3/4 circumnavigation over Antarctica in 29.5 days. Science observation was successfully performed during the flight. Total observation time was 24.5 days, limited by the data storage capacity and the magnet cryogen life. The floating altitude was kept from 34 km to 38 km and average residual atmospheric pressure was 6 g/cm^2 during the flight. The magnetic rigidity cut-off did not exceed 0.6 GV and the majority of the flight was below 0.2 GV. The balloon flight was terminated on January 21, 2008 and the payload safely landed on the ice field located 370 nautical miles from the south pole. We had a first access to the payload by plane and recovered the data vessel and other important equipments. The rest of the payload will be recovered in the 2009/2010 season.

IV. Detector Performance

To observe the detector status and performance in flight event and house-keeping/monitor data were sampled and transmitted by down ink telemetry through the TDRSS and Iridium satellite. We could also send commands through the uplink communication during 15 minute window every hour. We could adjust various detector parameters, e.g. high voltage, threshold, and trigger condition. Actually some problems came up during the data taking period. However, we could detected the anomaly immediately from the monitor data and took appropriate actions to recover the detector performance

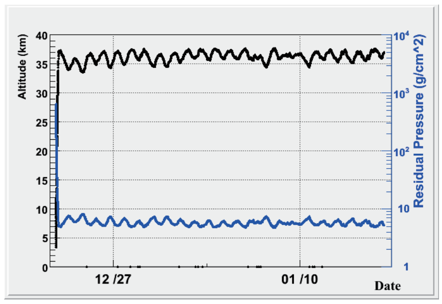


Fig. 5: Altitude and Residual atmospheric pressure during the flight.

as follows:

- Some of the PMTs for TOF became noisy. However, the signal amplitude of the noise pulses is small compared to a real CR events, and by raising discriminator threshold slightly, we could eliminate them without degradation of the TOF performance.
- JET-chamber high-voltage power supply (HV) became suddenly unstable and the voltage and the current started to fluctuate. Although we did not know what exactly happened to the power supply, we reduced the high voltage to 90 % of the nominal operating value. This intervention worked well and the chamber continued to function until the end of the science observation although small fluctuation of the voltage still remained as shown in Fig. 6

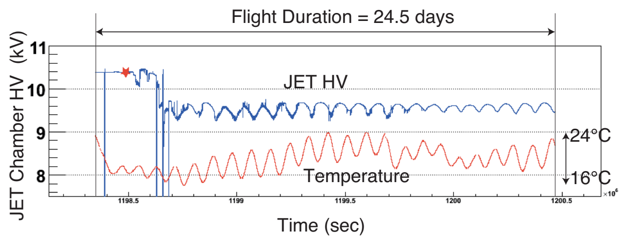


Fig. 6: Fluctuation of JET chamber High voltage, together with JET chamber gas temperature.

The other detectors worked perfectly and we gathered cosmic-ray events steadily. Trigger rate was about 3.1 $\sim$ 3.3 kHz ($\approx$2.4 $\sim$ 2.6 kHz if live-time fraction 0.77 was included). We had observed the slight deviation of the trigger rate, which was well correlated with solar wind speed and neutron monitor as shown in Fig. 7. We observed realtime solar modulation effect to the cosmic-ray measurement.

Data analysis of all flight data is now in progress. The whole data set was divided into 1171 runs (including 90 runs for initial detector tuning), each of which has 30 minute duration and includes online calibration data, e.g. pedestal and threshold for the detectors. Post-flight calibration of the all detectors were performed run by run using the flight data. For the JET chamber, further detailed calibration has been done to adjust drift velocity

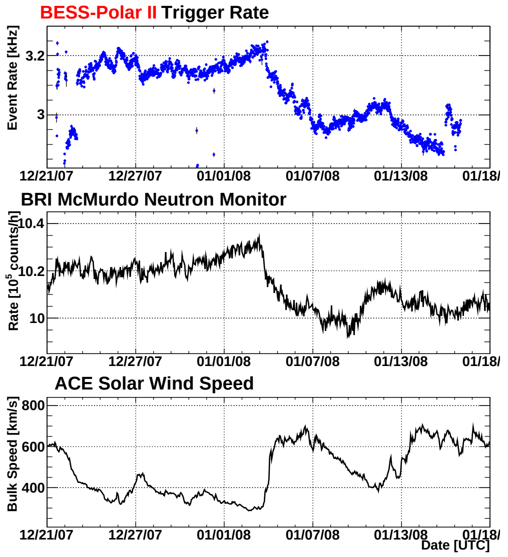
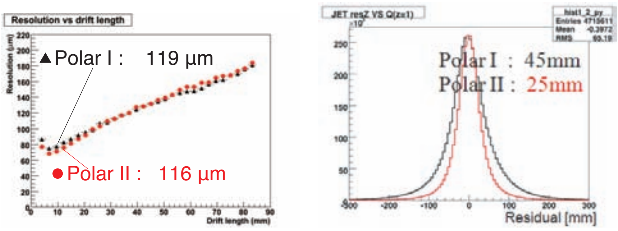


Fig. 7: Top: BESS-Polar II trigger rate, Middle: neutron monitor, Bottom: solar window speed



(a) $r\phi$ resolution vs drift length (b) z resolution

Fig. 8: (a) $r\phi$ and (b) z resolution of the JET chamber in comparison with those from BESS-Polar I.

according to the high voltage fluctuation. As a result, we obtained $r\phi$ position resolution comparable to BESS-Polar I for most of the run (Fig. 8a. Axial (z) position resolution of the JET chamber was greatly improved by noise reduction as shown in Fig. 8b. The other detectors, MTOF, ACC, and TOF showed also better performances than those in BESS-Polar I, due to above-mentioned improvements.

Now we have confirmed that more than 90% of total data, excluding runs in initial tuning ($\sim$7%) and JET HV instability ($\sim$2%), can be utilized for further physics analysis. The effective live time corresponds to 5 times of BESS-Polar I and 20 times of BESS97.

Table I summarize the BESS-Polar flight status and detector performance.

V. Summary

BESS-Polar II experiment was successfully flown in 2007/2008 season. About 4.7 billion cosmic-ray events were recorded onboard on the hard disks. The data are currently in the process of analysis. The BESS-Polar II instrument demonstrated the expected performance. We are now approaching physics analysis on cosmic-ray antiproton[13], antihelium[14], and other cosmic-ray species. In addition, the precision cosmic-ray data from BESS-Polar II would provide new opportunities such as a short-term and dinual variation of galactic cosmic ray due to solar activity[15] as suggested in Fig. 7.

TABLE I: BESS-Polar II flight summary and detector performance

	BESS-Polar I	BESS-Polar II
Total Float Time	8.5 days	29.5 days
Observation Time	8.5 days	24.5 days
Recorded Event	900 M	4700 M
Recorded Data Size	2.1 TB	13.5 TB
Trigger Rate	1.4 kHz	2.4 $\sim$ 2.6 kHz
Live Time Fraction	0.8	0.77
Altitude	37$\sim$39 km	34$\sim$38 km
Air Pressure	4$\sim$5 g/cm^2	4.5$\sim$8 g/cm^2
$r\phi$ resolution (JET)	119 μm	116 μm
z resolution (JET)	45 mm	25 mm
z resolution (IDC)	0.7 mm	0.6 mm
TOF resolution (UL-TOF)	156 ps	120 ps
TOF resolution (MTOF-TOF)	320–530 ps	34–420 ps
No. of photo electron (Acc)	6.7	11.3
Rejection power (ACC)	900	$>$ 10000

Acknowledgements

The authors thank NASA Headquarters for the continuous encouragement in this U.S.-Japan cooperative project. Sincere thanks are expressed to the NASA Balloon Programs Office at GSFC/WFF and CSBF for their experienced support. They also thank ISAS/JAXA and KEK for their continuous support and encouragement. Special thanks go to the National Science Foundation (NSF), U.S.A., and Raytheon Polar Service Company for their professional support in U.S.A. and in Antarctica. The BESS-Polar experiment is being carried out as a Japan-U.S. collaboration, and is supported by a KAKENHI(13001004 and 18104006) in Japan, and by NASA in U.S.A.

References

[1] A. Yamamoto, J. W. Mitchell, K. Abe, *et al.* BESS-Polar long duration flights in Antarctica. In *Proc. 27th Intl. Cosmic Ray conf. (Hamburg)*, pages 2135–2138, 2001.;
[2] T. Yoshida, A. Yamamoto, J. W. Mitchell, *et al.* BESS-Polar Experiment. *Adv. Space Res.*, 33:(10)1755–(10)1762, 2004.;
[3] K. Abe *et al.* Measurement of cosmic-ray low-energy antiproton spectrum with the first BESS-Polar Antarctic flight. *Phys. Lett. B* Volume 670, pages 103–108, 2008.;
[4] R. Orito for BESS collaboration (OG1.1)
[5] K.C. Kim for BESS collaboration (OG1.1)
[6] K. Yoshimura *et al.* BESS-Polar Experiment: Progress and Future Prospects. *Adv. Space Res.* Volume 42, Issue 10, pages 1664–1669, 2008.;
[7] K. Yoshimura *et al.* BESS-Polar Experiment–Progress and Future Prospect– *J. Phys. Soc. Jpn.* Volume 78 Supplement A, pages 29–39, 2009.;
[8] Y. Makida, T. Kumazawa, K. Tanaka, *et al.* Performance of an Ultra-Thin Superconducting Solenoid for Particle Astrophysics. In *IEEE Trans. Applied Superconductivity*, volume 15, pages 1248–1251, 2005.
[9] A. Horikoshi *et al.* (OG1.5)
[10] K. Sakai *et al.* (OG1.5)
[11] N. Thakur *et al.* (OG1.5)
[12] M. Sasaki *et al.* (OG1.5)
[13] J. W. Mitchell for BESS collaboration (Highlight Talk)
[14] K. Sasaki for BESS collaboration (OG1.1)
[15] T. Hams for BESS collaboration (SH3.2)