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Observation of low energy antiprotons at the 2004 BESS-Polar flight in Antarctica

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A flatter spectrum of low-energy cosmic ray antiprotons below 1 GeV measured by the BESS experiment in the last solar minimum period suggests the existence of possible novel and exotic sources of cosmic-ray antiprotons, such as evaporation of primordial black holes and annihilation of supersymmetric dark matter. In order to investigate these antiproton sources and to search for antimatter in the cosmic radiation, the BESS-Polar experiment was carried out with a NASA long duration balloon flight over Antarctica in December 2004. During this 8.5-day flight, the BESS-Polar superconducting spectrometer gathered 900 million cosmic-ray events. The data show that the newly developed particle detector system functioned well enough to observe the low energy antiprotons during the entire flight. Thus we can expect to derive a precise energy spectrum of the low-energy antiprotons with several-times higher statistics than that from the flight of the previous solar minimum period.

1. Introduction

The BESS experiment has measured the flux of cosmic-ray antiprotons in an energy range of 0.18 to 4.2 GeV with high statistics, and observed a characteristic peak around at 2 GeV in the energy spectrum [1]. This peak is well understood by the production model of ‘secondary’ antiprotons produced by cosmic-ray interactions with interstellar gas.

On the other hand, in the low energy region, observed spectrum at the last solar minimum period seems to be softer than that predicted by the secondary production models. Because the secondary spectrum should exhibit a steep decrease below 2 GeV kinematically, other possible ‘primary’ sources such as evaporation of primordial black holes, if they exist, could cause flattening of the spectrum. Though there are some uncertainties both in models and in measurements, we still cannot rule out the existence of these novel ‘primary’ sources.

Measurements of a more precise spectrum with much higher statistics in the low energy region is very important to search for these ‘primary’ origins. Therefore, the BESS-Polar experiment with newly developed spectrometer was carried out in 2004 to accumulate many more antiprotons through a long duration flight over Antarctica.

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2. BESS-Polar experiment

The BESS-Polar spectrometer was developed to realize a long duration flight over Antarctica [2]. Fig. 1 shows a cross sectional view of the BESS-Polar spectrometer. It consists of an ultra-thin superconducting solenoid magnet with a jet-type drift chamber (JET), two inner drift chambers (IDCs), time-of-flight counter hodoscopes (TOF), a silica aerogel Cherenkov counter (ACC), and a Middle-TOF (MTOF). Material thickness in this spectrometer was reduced and a new trigger system including MTOF for low energy incident particles was developed to achieve the lowest energy of 0.1 GeV for antiproton detection.

With this spectrometer, BESS-Polar 2004 campaign started since October 27 in Antarctica. The BESS-Polar payload was launched on December 13 from Williams Field near the US Mcmurdo station [4]. After reaching a floating altitude over 37 km, which corresponds to an atomospheric depth around 4 g/cm^2, 900 million events of cosmic-ray data without any event selections was accumulated through the 8.5-day flight. During the flight, geomagnetic cutoff rigidity was mostly below 0.1GV because the payload stayed at high latitude (83-85 degrees).

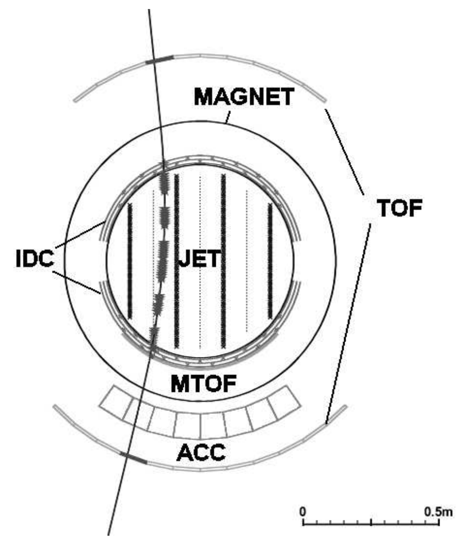

Figure 1. BESS-Polar spectrometer

The data storage and the particle detectors were recovered successfully.

3. Status of the particle detectors during flight

Throughout the flight, the central trackers (JET/IDC) worked well. Their spatial resolutions were evaluated from their residual distributions defined as the difference between the measured coordinate and the reconstructed track. In the BESS-Polar 2004 flight, spatial resolutions better than 140μm were achieved for both of

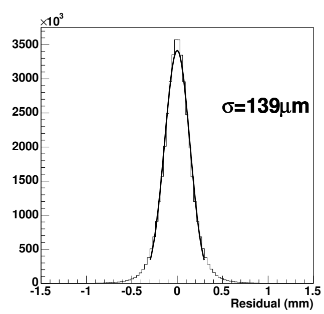

Figure 2. Residual distribution of JET

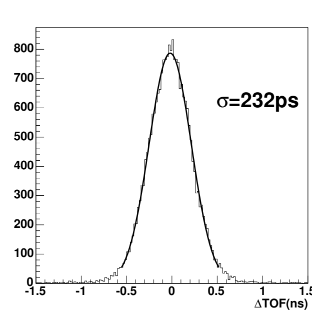

Figure 3. Overall resolution of TOF

JET and IDCs. Fig. 2 shows the residual distribution of the JET chamber. Some photomultipliers of TOF had sudden excessive leak current during the flight, and had to be turned off. We modified the trigger configuration immediately, and could keep geometrical acceptance up to 80 % of the full acceptance. Overall time-resolution of the TOF counter was 240 ps, as shown in Fig. 3, in spite of the single-end readout of several TOF counters. MTOF worked stably and the average trigger rate including the MTOF trigger was 1.7 kHz. Performance of ACC will be presented in other paper [3].

4. Particle identification

In the BESS-Polar experiment, we can identify antiprotons by mass reconstruction according to the relation,

$$m = ZeR\sqrt{1/\beta^2 - 1}.$$

The rigidity R ($R \equiv pc/Ze$), is precisely measured by the deflection of the reconstructed trajectory in JET/IDCs. Fig. 4 shows the distribution of the deflection resolution. This distribution has a sharp peak at 0.0042 GV^{-1}, and it indicates the maximum detectable rigidity (MDR) is 240 GV in the BESS-Polar spectrometer. The velocity β, defined as particle velocity divided by the speed of the light, is derived from the path length and the time-of-flight between the upper and the lower (or middle) TOF counters. The energy deposit in the TOF provides the magnitude of the charge Z.

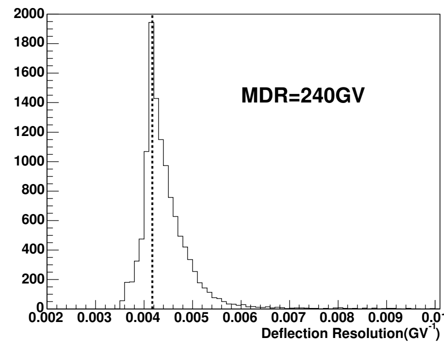

Figure 4. Deflection Distribution

The sign of charge is determined by the deflection and the particle direction, i.e., up-going or down-going, measured by TOF. The mass is finally reconstructed from these measurements. In addition to these measurements, in the high velocity region where antiprotons can be contaminated with enormous background of light particles (μ/e), we required no emission of the Cherenkov light in ACC. Fig. 5 shows the β^{-1} versus R plot for the surviving events. The band of antiprotons can be seen at the exact mirror position of protons, and in the energy region below 1 GeV, 375 antiproton candidates are observed. In Fig. 1, an antiproton candidate event is shown together with the BESS-Polar spectrometer cross section.

The events with valid TOF between the top and the bottom counters are considered in Fig. 5. Calculating a time-of-flight by the top TOF and MTOF, we will be able to identify the lowest energy antiprotons which cannot penetrate lower wall of the superconducting magnet. Thus, the lowest energy of antiprotons will be down to 0.1 GeV.

5. Summary

The BESS-Polar 2004 flight was successfully carried out over Antarctica in December 2004. Owing to the several-times higher statistics than that of the previous BESS flight in the last solar minimum period, we can expect to derive more accurate spectrum of the low energy antiprotons with the kinetic energy region down to 0.1 GeV. The result of this flight will do much contribution to the search for primary sources such as primordial black holes.

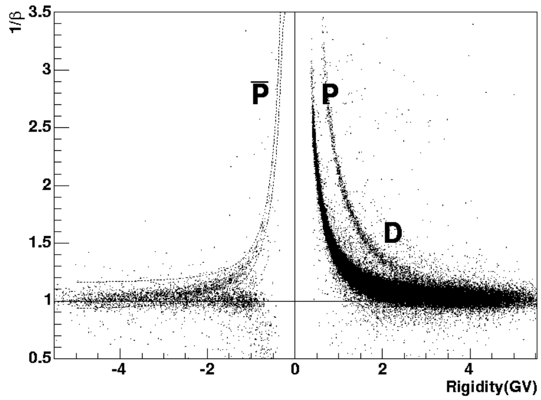

Figure 5. β^{-1} versus R plot. Only partial dataset are used for this plot.

6. Acknowledgements

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