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Results from BESS-Polar I 2004 Antarctica Flight

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Abstract: The Search for antimatter in the galactic cosmic radiation is one of the main scientific objectives of the Balloon-borne Experiment with a Superconducting Spectrometer (BESS). A flatter antiproton spectrum below the secondary production peak at 2 GeV might suggest possible novel antiproton sources, such as evaporating black-holes or decaying super symmetric particles. The BESS-Polar experiment is designed as a highly transparent magnetic rigidity spectrometer that can precisely detect antiprotons down to energies of 0.1 GeV were a potential excess of primary antiprotons over the secondary production might be more apparent. The BESS-Polar instrument had its first successful balloon flight in December 2004, from McMurdo Station in Antarctica. During the 8.5-day long flight 900 million events were recorded. In this paper, we report antiproton and proton spectra as well as the search for antihelium.

Introduction

A major scientific objective of the BESS-Polar balloon program is the search for antimatter in the cosmic radiation. BESS-Polar is the current effort of the ongoing BESS program [1][2]. Cosmic-ray antiprotons ($\bar{p}$) are expected as secondaries from the interaction of high energy cosmic rays with the interstellar medium. The secondary $\bar{p}$ spectrum peaks at $\sim$2 GeV and falls rapidly to both sides. The BESS-Polar instrument can precisely measure $\bar{p}$ down to 0.1 GeV and is sensitive to potential primary $\bar{p}$, which might result in a $\bar{p}$ excess above the secondary component. A potential primary $\bar{p}$ source might be evaporating primordial black holes (PBH) (see Ref. in [2]).

The BESS-Polar Instrument

The BESS-Polar experiment is a magnetic-rigidity spectrometer comprised of a thin-walled superconducting solenoidal magnet and a set of high-resolution detector systems: a time-of-flight (TOF) measuring the charge, Z, and velocity, β, a spectrometer measuring the magnetic rigidity (momentum over charge), $R = p/Z$, and charge sign of incident particles. An aerogel-Cherenkov Counter (ACC) is used as a threshold detector to reject the

e and μ background. These measurements allow mass-resolved particle identification. A more detailed discussion of the instrument can be found elsewhere [1][3].

BESS-Polar I 2004 Flight

BESS-Polar I had its first scientific flight in Dec. 2004 from Williams Field near the U.S. McMurdo Station in Antarctica. The instrument was launched on 13 December 2004 and remained at float (>37 km) for 8.5 days. During the flight the detector systems, the magnet, solar-cell power system, and the data acquisition system worked as designed, except for a few TOF PMTs, which had HV breakdown problems when exposed to low temperature and low pressure. In flight, over 180 hours of data were recorded with an 80% instrument livetime fraction, which amounted to 9×10^8 cosmic-ray events. The recorded data volume stored onboard was 2.14 terabytes. A discussion of the 2004 BESS-Polar I expedition can be found in [4].

Data Analysis

The following analysis uses the BESS-Polar I data at float with the instrument under stable conditions. The $p(\bar{p})$ analysis presented here is similar to that used for previous BESS flights[5][6]. From the float data, only non-interacting single-track events in the tracking detector were selected, which have at most two paddle hits in each of the upper and middle or lower TOF counters, which penetrate the instrument from top to bottom, and which are fully contained in the fiducial volume of all detector systems. In addition, quality cuts are applied and a consistency cut is imposed on the reconstructed trajectory by the tracker and the TOF hits.

For particle identification, charge is determined with dE/dx cuts in the TOF and a mass band is selected with a cut on the $1/\beta$ vs. R plot. The charge sign of the particle is determined by the sign of R. The ACC is used to reject the lighter component (e, μ) from the $p(\bar{p})$ band up to 4.2 GeV. For protons with energies above the ACC threshold of 4.2 GeV, the combined contamination from μ^+, e^+, was studied with a Monte Carlo simulation. It was found that the contamination is of the same magnitude as the statistical error on the proton flux of a few percent and could be ignored. The identified $p(\bar{p})$ events are converted into a top-of-instrument (TOI) flux by accounting for the different cut efficiencies, effective exposure time and instrument aperture as well as the energy loss in the instrument. This TOI flux is measured with an atmospheric overburden of ~5 g/cm^2. The technique to correct the TOI flux to one at top-of-atmosphere (TOA) is discussed in [5] and is used for this analysis as well. For the analysis on the antihelium search, refer to [7].

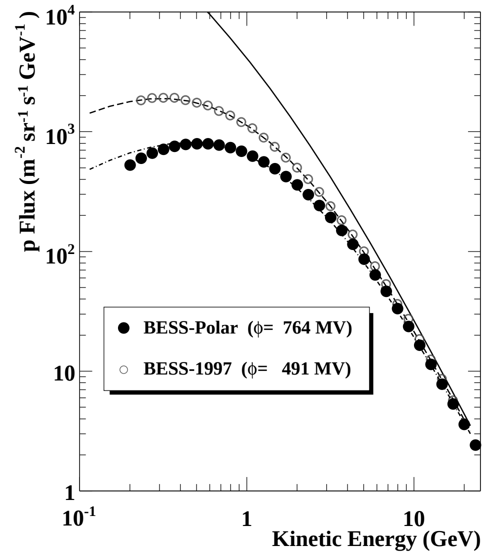

Figure 1: BESS-Polar I proton flux compared with the proton flux of BESS(97) (lines see text).

Results

Figure 1 shows the TOA proton flux measured by BESS-Polar I [8] and for comparison the proton flux measured during the last Solar minimum (BESS(97), [5]). The BESS-Polar I results include statistical errors only. The solid line is the interstellar (IS) energy spectrum obtained with BESS(98) proton data using a Force Field approximation with a modulation parameter of $\phi \sim 600$ MV. The other lines use this IS proton spectrum and fit the Solar modulation parameter ϕ. For the BESS-Polar I spectrum a modulation parameter of $\phi \sim 764$ MV is found. A detailed discussion on the effects of Solar modulation on the BESS data collected dur-

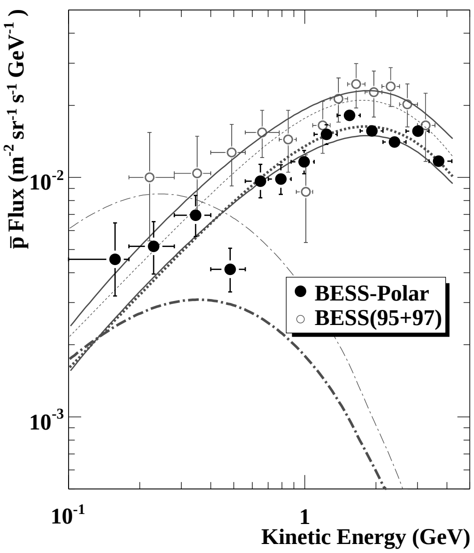

Figure 2: Antiproton spectrum measured in BESS-Polar I compared with BESS(95+97) results (lines see text).

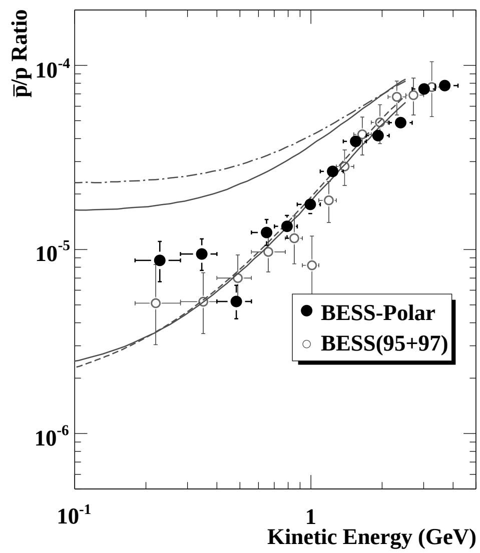

Figure 3: $\bar{p}/p$ ratio measured by BESS(95+97) and BESS-Polar I (2004) compared with drift model calculations at various Solar magnetic field tilt angles (top to bottom at 0.7 GeV: $A < 0$ and 65^o (dash-dotted), $A < 0$ and 25^o. (solid), $A > 0$ and 65^o. (dashed), and $A > 0$ and 15^o (solid) [10].

ing 1995-2004 can be found in these proceedings [9].

Figure 3 shows the $\bar{p}$ energy spectrum measured in BESS-Polar I [11] (statistical errors only) compared with BESS(95+97) results [12] measured during the last Solar minimum. Theoretical calculations of secondary antiprotons based on the standard leaky box model modulated by a spherically symmetric model are shown at the modulation parameter $\phi = 550$ MV (thin dotted curve) during the last Solar minimum period (1995+1997) and 841 MV (thick dotted curve) for BESS-Polar I (2004) ([13][14][15]). Theoretical calculations of the antiproton flux from evaporation of primordial black holes (thin dash-dotted curves for $\phi \sim 550$ MV and thick dash-dotted curve for 841 MV) are shown with the same modulation parameters [16]. Theoretical calculations of secondary antiprotons using the code GALPROP are based on a diffusion and convection model [10], tuned to the BESS(95+97) data, and a three dimensional drift model for the heliospherical modulation at a Solar magnetic field tilt angle of 25^o (upper solid curve), and on a reacceleration model with the tilt angle of 25^o in heliospherical modulation (lower solid curve) [17]. Figure 3 shows the $\bar{p}/p$ ratio as measured by BESS-Polar I and BESS(95+97). BESS-Polar I has also placed a stringent upper limit for the antihelium to helium ratio ($\overline{\mathrm{He}}/\mathrm{He}$) of 4.4×10^{-7} in the rigidity range of $1 - 20$ GV [7]. And when combining all BESS data the upper limit for $\overline{\mathrm{He}}/\mathrm{He}$ is 2.7×10^{-7} in the rigidity range $1 - 14$ GV (see Figure 4).

Summary

The first BESS-Polar flight, conducted in a transient period preceding Solar minimum, has demonstrated the capabilities of the instrument and has provided a high-statistics $\bar{p}$ spectrum to low energies. The $\bar{p}$ data of BESS-Polar I did not show a statistically significant excess and are consistent with the secondary production only as might be expected at this level of Solar modulation. In the planned 20-day flight scheduled for later this year, during Solar minimum, BESS-Polar II will continue its measurements with better statistics and higher sensitivity. Detailed discussion of the

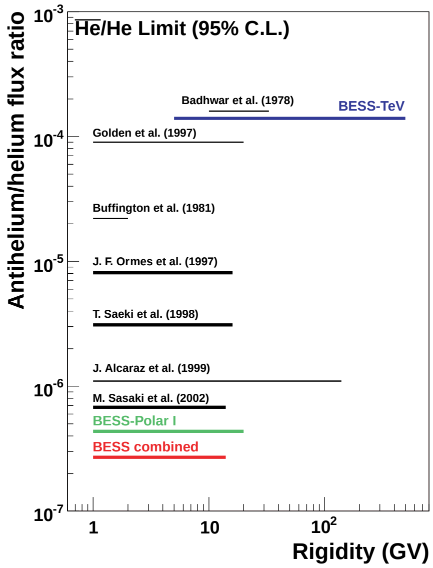

Figure 4: Antihelium flux limits from BESS-Polar I, see [7] and Ref. therein.

planned BESS-Polar II can be found elsewhere in these proceedings [18].

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