Measurement of cosmic-ray antiproton spectrum at solar minimum with BESS-Polar II

BESS Balloon-borne Experiment with a Superconducting Spectrometer

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Presented by K. Sakai (NASA/GSFC/UMBC) for BESS collaboration
BESS-Polar II collaboration

7 Institutes
(PI, Japan A. Yamamoto, KEK
PI, US J.W. Mitchell, NASA/GSFC)

High Energy Accelerator Research Organization (KEK)
The University of Tokyo
Kobe University
National Aeronautical and Space Administration
Goddard Space Flight Center
University of Maryland
University of Denver (Since June 2005)
Institute of Space and Astronautical Science/JAXA
BESS-Polar II collaboration

7 Institutes
(PI, Japan A. Yamamoto, KEK
PLUS US J.W. Mitchell, NASA/GSFC)


1Kobe University, Kobe, Hyogo 657-8501, Japan
2Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), Sagamihara, Kanagawa 229-8510, Japan
3High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0001, Japan
4NASA-Goddard Space Flight Center (NASA-GSFC), Greenbelt, MD 20771, USA
5IPST, University of Maryland, College Park, MD 20742, USA
6The University of Tokyo, Bunkyo, Tokyo 113-0033, Japan
7University of Denver, Denver, CO 80208, USA

Kobe University
University of Denver (Since June 2005)
Institute of Space and Astronautical Science/JAXA
Cosmic-ray Antiprotons

Antiproton Sources

1. Secondary antiproton:
   Energetic collision of Galactic Cosmic rays with interstellar matter

2. Primary antiproton:
   Primordial Black Hole
   SUSY darkmatter

Objectives of the antiproton spectrum measurement

1. Understanding of Propagation and Solar modulation
2. Search for Primary origin
Motivation of BESS-Polar II

Previous solar minimum period (BESS95+97)

- Distinctive Peak around 2 GeV
- Slightly flatter in low energy
- The existence of novel processes for production of cosmic-ray antiproton

More Statistic necessary
→ Polar long duration flight
Magnet Spectrometer

BESS-PolarII

Run: 095 Event: 4200488 (5A) Size: 2897 FADC: 1944 FEND: 904
Trigger: 001001011 JET: 71 IDC: 4 UTOF: 1 MTOF: 1 LTOF: 1

Trigger condition
UTOF+LTOF coincidence or
UTOF+MTOF coincidence

Detectors
Superconducting Solenoid (MAG):
Uniform magnetic field of 0.8T

Central Tracker (JET/IDC):
Track deflection (rigidity R), dE/dx(Charge Z)

Time-of-Flight (UTOF/MTOF/LTOF)
velocity β, dE/dx(Charge Z)

Silica Aerogel Cherenkov Counter (ACC)
Background Veto

\[ m = ZeR \sqrt{1/\beta^2 - 1} \]
**Flight summary**

<table>
<thead>
<tr>
<th>Flight Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch date</td>
<td>Dec. 23(^{rd}), 2007</td>
</tr>
<tr>
<td>Observation time</td>
<td>24.5 day</td>
</tr>
<tr>
<td>Cosmic-ray observed</td>
<td>(4.7 \times 10^9) event</td>
</tr>
<tr>
<td>Data size</td>
<td>13.5Tb</td>
</tr>
<tr>
<td>Flight altitude</td>
<td>(~36\text{km}(6\text{~5g/cm}^2))</td>
</tr>
<tr>
<td>Recovery (data/detector)</td>
<td>Feb. 3(^{rd}) 2008 / Jan. 16(^{th}) 2010</td>
</tr>
</tbody>
</table>

BESS-Polar II flight was carried out at Solar minimum.

Total no. of antiprotons \(~ 10000\)
Antiproton ID

No. of Antiprotons = 7886

Acceptance loss: 20%

TOF quality: Only both readout

\[ \times \frac{1}{300} \text{ for positive rigidity} \]

7886 Antiprotons

No. of Antiprotons = 7886
Comparison with BESS95+97

BESS-Polar II
Antiproton flux

In low energy region below 1.0 GeV, statistics of Polar-II
\(\sim 14 \times\) statistics of BESS95+97
(at previous Solar minimum)

BESS95+97 reported by
S. Orito et al.
In low energy region below 1.0 GeV, statistics of Polar-II ~ 28 x statistics of PAMELA (2006 Jul. – 2008 Dec.)

BESS-Polar II Antiproton flux

Comparison with secondary models

Secondary $\bar{p}$ calculation = Propagation model \times Solar modulation

The antiproton spectrum measured by BESS-Polar II generally shows good consistency with Secondary antiproton spectra calculated for solar minimum conditions.
Spectral shape analysis

Normalization near peak region (>1 GeV)

<table>
<thead>
<tr>
<th>ID</th>
<th>Model</th>
<th>$\chi^2$ (&lt;1.0 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mitsui (600 MV)</td>
<td>0.57</td>
</tr>
<tr>
<td>2</td>
<td>Bieber</td>
<td>0.56</td>
</tr>
<tr>
<td>3</td>
<td>Bergstrom</td>
<td>1.24</td>
</tr>
<tr>
<td>4</td>
<td>Donato</td>
<td>1.59</td>
</tr>
<tr>
<td>5</td>
<td>Galprop (PD)</td>
<td>0.63</td>
</tr>
</tbody>
</table>

The shaded band is a possible Solar modulation range at this time.

Models w/o low energy enhancement were favored.
Evaluation of Primary Antiproton

PBH antiproton flux

= Observation (Polar-II or 95&97)
- Secondary $\bar{p}$ calculation
  (Mitsui model: SLB+Force-Field)

Most probable
PBH evaporation rate (R):

<table>
<thead>
<tr>
<th>ID</th>
<th>Data</th>
<th>$R$ (1/pc³/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>BESS-PolarII</td>
<td>$5.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>B</td>
<td>BESS95+97</td>
<td>$4.2 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

No evidence of PBH antiprotons

Upper limit
$1.2 \times 10^{-3}$/pc³/yr (90% C.L.)
Summary

1) 7886 antiprotons in BESS-Polar II.

2) With the improved precision of antiprotons based on 14 times statistics of BESS95+97 below 1 GeV, the antiproton flux has been determined.

3) New antiproton spectrum observed at Solar minimum is well consistent with secondary calculations.

4) BESS-Polar II result shows no evidence of PBH antiprotons originated from the evaporation of PBH within statistics.

http://arxiv.org/abs/1107.6000
Appendix
BESS-Polar II Antiproton/proton ratio

BESS-Polar II Antiproton/proton ratio with PAMELA
(2006 Jul.– 2008 Dec.)

PAMELA reported by
O. Adriani et al.
105. 121101 (2010)
Constraints on PBH

Probability density function for Evaporation rate of PBH (R)

Top : Mitsui
Middle : Bieber
Bottom : Bergstrom

In all three cases, evaporation rate which could explain antiproton flux in BESS95+97 was not observed.

Upper limit

$1.2 \times 10^{-3}/\text{pc}^3/\text{yr}$ (90% C.L.)
Secondary Antiprotons

Collision origin

\[ p_{\text{cosmic-ray}} + p_{\text{gas}} \rightarrow \bar{p} + X \]

Secondary \( \bar{p} \) calculation =

Propagation model

\[ \times \] Solar modulation
Primary Antiprotons

Primary origin
1. Evaporation of PBH
2. Annihilation of SUSY DM

Primary $\bar{p}$ calculation =
Total $\bar{p}$ (observation) – Secondary $\bar{p}$ calculation