Search for Cosmic-Ray Antideuterons with BESS-Polar II

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For BESS collaboration
BESS is US-Japan collaborative program.

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University of Denver (Since June 2005)
BESS-Polar I & II flights were carried out over Antarctica.

<table>
<thead>
<tr>
<th></th>
<th>BESS-Polar I</th>
<th>BESS-Polar II</th>
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<tbody>
<tr>
<td><strong>Launch date</strong></td>
<td>Dec. 13(^{th}), 2004</td>
<td>Dec. 23(^{rd}), 2007</td>
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<tr>
<td><strong>Observation time</strong></td>
<td>8.5 days</td>
<td>24.5 days</td>
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<tr>
<td><strong>Cosmic-ray observed</strong></td>
<td>$9 \times 10^8$ events</td>
<td>$4.7 \times 10^9$ events</td>
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<tr>
<td><strong>Flight altitude</strong></td>
<td>37<del>39km (5</del>4g/cm(^2))</td>
<td><del>36km (6</del>5g/cm(^2))</td>
</tr>
</tbody>
</table>
Event display with reconstructed proton track is shown.

**Rigidity (MDR: 200 GV)**

**Solenoid**: Uniform field ($\phi=0.9\,\text{m}, B=0.8\,\text{T}$)

Thin material (2.4 g/cm$^2$/wall)

**Drift chamber**: Redundant hits

($\sigma \sim 150\,\mu\text{m}, 32\sim48+4\text{hits}$)

**Charge, Velocity**

**TOF, Chamber**: $dE/dx$ measurement

($Z = 1, 2, \ldots$)

**TOF**: $1/\beta$ measurement ($\sigma \sim 1, 2\%$)

$$m = ZeR \sqrt{1/\beta^2 - 1}$$
Why does antideuteron search probe possible exotic sources?

<table>
<thead>
<tr>
<th>Antiproton</th>
<th>Antideuteron</th>
</tr>
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<tbody>
<tr>
<td>BESS-Polar II</td>
<td>BESS 97-00</td>
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</table>

Flux (m²·sr⁻¹·s⁻¹·GeV⁻¹) vs. Kinetic energy (GeV)

- BESS-Polar II
- BESS95+97
- PAMELA
- AMS-02

Antiproton flux (m³·s⁻¹·sr⁻¹·GeV⁻¹):
- Mitsui et al.
- Bieber et al. (interpolated)
- Bergström et al.
- Donato et al.
- GALPROP
- Bieber et al.

Leaky Box Force field φ=600 MV
Leaky Box Force field φ=500-1000 MV
Leaky Box Drift model TA=15°(A<0)
Simplified 2-zone diffusion
Leaky Box Drift model TA=10°(A>0)

Flux (m²·sr⁻¹·s⁻¹·GeV⁻¹) vs. Kinetic Energy (GeV/n):

- BESS95+97 p
- secondary p
- neutralino p
- PBH p
- PBH d (included in this paper)
- secondary d

This work

Antiproton Flux (BESS-Polar II) vs. Antideuteron Flux (BESS 97-00)

1.9 x 10⁻⁴ (95% C.L.)

Upper limit (97 - 00)
Antideuteron Analysis

5  Particle identification

\[ \frac{dE}{dx} \]

\[ \frac{1}{\beta} \]
**Antideuteron search**

The $1/\beta_{UL}$ VS rigidity plot

- Signal region for antideuteron

Excluding 3.5σ region from antiproton center to prevent antiproton contamination.
Antideuteron search

The 1/$\beta_{UL}$ VS rigidity plot

- Signal region for antideuteron
- No antideuteron candidate in BESS-Polar II data

Excluding 3.5$\sigma$ region from antiproton center to prevent antiproton contamination
Upper limit calculation

\[ \Phi \bar{d} \ dE = \frac{N_{obs}}{S \Omega \cdot T_{live} \cdot \varepsilon_{single} \cdot \varepsilon_{Q-ID} \cdot \eta (1 - \delta_{sys})} \]

- \( N_{obs} \): Number of Observed candidate = 3.1
- \( S \Omega \): Geometrical acceptance
- \( T_{live} \): Live time
- \( \varepsilon_{single} \): Single track efficiency
- \( \varepsilon_{Q-ID} \): Detector selection efficiencies
- \( \eta \): Survival fraction through atmosphere
- \( \delta_{sys} \): Systematic error

- Since no antideuteron was found, 3.1 was taken as the number of the observed antideuteron events for the calculation of 95% C.L. upper limit.
- In order to obtain the most conservative limit, the minimum value of the effective exposure factors \( (S \Omega \cdot T_{live} \cdot \varepsilon_{single} \cdot \varepsilon_{Q-ID} \cdot \eta) \) was used.
Detector efficiencies

\[ \Phi_{\bar{d}} \, dE = \frac{N_{\text{obs}}}{S \Omega \cdot T_{\text{live}}} \, \varepsilon_{\text{single}} \cdot \varepsilon_{\text{Q-ID}} \cdot \eta \cdot (1 - \delta_{\text{sys}}) \]
Antideuteron Analysis

10 Geometrical acceptance $\times \varepsilon_{\text{single}}$

\[
\Phi dE = \frac{N_{\text{obs}}}{S\Omega \cdot T_{\text{live}} \cdot \varepsilon_{\text{single}} \cdot \varepsilon_{Q-1D} \cdot \eta \cdot (1 - \delta_{\text{sys}})}
\]
Upper limit on antideuteron flux measured by BESS-Polar II together with earlier published BESS97-00 antideuteron upper limit

\[ J(d) < 5.5 \times 10^{-5} \quad \text{m}^2 \text{sr sec GeV/n}^{-1} \quad (95\% \text{C.L.}) \]

- Compared with the data taken in the solar minimum (BESS97), order of magnitude improvement has been achieved.
Antideuteron search

• No antideuteron candidate in BESS-Polar II.

• New upper limit \( J(d) < 5.5 \times 10^{-5} \text{ (m}^2\text{sr sec GeV/n)}^{-1} \) (95% C.L.)
  o 3.1 was taken as the number of the observed antideuteron events for the calculation of 95% C.L. upper limit.
  o In order to obtain the most conservative limit, the effective exposure factors was reduced by using with the systematic error (dsys = \(\sim\)4%).

• Compared with the data taken in the solar minimum (BESS97), order of magnitude improvement has been achieved.