Present and Future prospect of 
BESS-Polar

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(KEK)  
for the BESS collaboration

at KEKPH2006  
KEK, Mar. 2-4, 2006
BESS Collaboration
As of Feb. 2006

High Energy Accelerator Research Organization (KEK)

The University of Tokyo

Kobe University

Institute of Space and Astronautical Science (JAXA)

National Aeronautical and Space Administration
Goddard Space Flight Center

University of Maryland

University of Denver (Since June 2005)
Outline

BESS and BESS-Polar Experiment
Detector Progress in Observation
BESS Polar I Campaign
Physics and BESS-Polar II
Summary
**BESS**

Balloon-borne Experiment with a Superconducting Spectrometer

**Search for**

Primordial Antiparticle

- **antiproton**: Novel primary origins (PBH, DM)
- **antihelium**: Asymmetry of matter/antimatter

**Precise Measurement of Cosmic-ray flux:**

highly precise measurement at < 1 TeV
Progress of BESS Experiment

1993~ 2000, BESS, North Canada
2002, BESS-TeV
1999, 2001, BESS-Ground, Japan
2001, BESS-TeV, Fort Sumner
2004, BESS-Polar I, Antarctica

10 scientific balloon flights during 1993-2004
Low Energy Cosmic-ray Spectra
Precisely Measured by BESS

Rigidity Measurement

Precise spectra
- proton (0.2~500 GeV)
- helium (0.2~250 GeV/n)
- antiproton (0.2~4 GeV)

Anchor the spectrum in the lowest energy region.
BESS Detector

Rigidity measurement
SC Solenoid (L=1m, B=1T)

Min. material (4.7g/cm²)
Uniform field
Large acceptance
Central tracker

(Drift chamber
δ ~200µm

Z, m measurement

\[ R, \beta \rightarrow m = ZeR \sqrt{\frac{1}{\beta^2-1}} \]
\[ dE/dx \rightarrow Z \]
BESS Deflection Resolution 1993~1998

BESS:
Max. Det. Rigidity: 200 GV

Sharp peak of resolution

Strong and uniform field

\[ \frac{dR}{R} \propto \frac{1}{R} \left( \frac{B}{L^2} \right) \]
Central Tracker (JET/IDC) improvement
\[ \delta = 200 \rightarrow 150 \, \mu m \]
\[ N = 28 \rightarrow 52 \]

New detector (ODC) installed
\[ L = 0.8 \rightarrow 1.6 \, m \]

MDR:
BESS-TeV Deflection Resolution

MDR 1.4 TV

Normalized

Deflection resolution $\Delta R^{-1} (GV)^{-1}$

BESS-98
MDR 200 GV

BESS-TeV ($\times 1/10$)
BESS
LEAP
MASS
IMAX
Primary Cosmic-ray Spectra
(~1990)
Primary Cosmic-ray Spectra
(1998: Bess-98, AMS-I, Caprice)

Error: < +/-5 %
@ 100 GeV

1135
Primary Cosmic-ray Spectra (BESS-TeV)

Flux \times E_{k}^{2.5} (m^{-2}sr^{-1}sec^{-1}GeV^{1.5})

Error: < +/-15% @ 500 GeV

Proton

Helium

BESS-TeV 2002
BESS 1998

BESS-TeV Result Anchor the P and He Spectra in Low Energy (< TeV)

\[ F = \phi E_k^{-\gamma} \]

Proton \((E_k > 30 \text{ GeV})\)
\[ \phi = (1.37 \pm 0.12) \times 10^4 \]
\[ \gamma = 2.732 \pm 0.022 \]

Helium \((E_k > 20 \text{ GeV})\)
\[ \phi = (7.06 \pm 1.15) \times 10^2 \]
\[ \gamma = 2.699 \pm 0.059 \]
Correlation of cosmic-ray flux with solar modulation

![Graph showing correlation of cosmic-ray flux with solar modulation](image)

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Solar Modulation Effect on p-bar/p ratio

$p/p$ ratio: sudden change
Charge dependence clearly observed

Maeno et al. AP 16 (2001) 121
Asaoka et al. PRL 88 (2002) 051101
Haino et al. ICRC 2005
Mostly secondary particles with specific peak at 2 GeV

**Study:**

- Propagation model
- Solar modulation

**Search for:**

- Novel Primary Origin? (PBH, DM)

*Flatter spectrum in low energy*

More Statistics necessary ->> Long-duration Flight
BESS-Polar Experiment

Very precise measurement
Low energy Antiprotons

Around south-pole, Antarctica
Long duration flight
High latitude
Solar minimum

With a new spectrometer
Ultimately small material
Ultra-thin superconducting solenoid
Feature of BESS-Polar Spectrometer

- Minimize material in spectrometer
- New detector (Middle TOF)
- Energy range extended down to 0.1 GeV
- Low power electronics
- Solar Power System, Longer life of cryogen, LHe
- Long duration flight
<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Feb</td>
<td>Preparation start</td>
</tr>
<tr>
<td>2002</td>
<td>Mar</td>
<td>Superconducting magnet complete</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>Engineering Flight of solar battery system (ISAS/JAXA)</td>
</tr>
<tr>
<td>2003</td>
<td>Jun</td>
<td>Detector beam test @ KEK</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>Technical flight @ Ft.Sumner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General Integration start @ GSFC/NASA</td>
</tr>
<tr>
<td>2004</td>
<td>Aug</td>
<td>General integration complete</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>Compatibility test with NSBF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Preparation @ Antarctica start</td>
</tr>
</tbody>
</table>
Integration in GSFC

2003 Oct - 2004 Aug

JET/IDC & MTOF

Upper TOF

Aerogel Cherenkov Counter

Integration complete!
Compatibility test with NSBF

Final Compatibility test with National Scientific Balloon Facility was achieved at Palestine, TX, USA

Establishment of
- Mechanical compatibility
- Operations & communication in the Magnetic field

2004 Aug
BESS-Polar Campaign 2004

Oct 27
Stuff arrived McMurdo station in Antarctica

**Preparation start @ Williams Fields**

Dec 3
Preparation complete
Compatibility test with NASA/NSBF
**Flight ready**

Dec 13
**Launch!**

21 Landing after 8.5 days flight

23 Recovery Work start

29 **Recovery complete**

2005 Jan 4
**Complete BESS-Polar 2004 campaign**
Preparation at Williams Field

Final preparation for BESS-Polar 1st flight done in building called ‘Weatherport’.

- Detector check
- Integration of Solar battery system
- Installation of SIP
- Thermal insulation

Pig Barn

Weatherport
Weather in Antarctica

Weather changes drastically in Antarctica

Preparation has been carried under critical weather conditioned at Antarctica.
Hang test prior to flight was successfully done.

Full configuration of spectrometer, solar battery system, and communication systems.
Weather Condition

- 10 days after flight ready, 3rd flight chance came
  (1st and 2nd chance were postponed due to the bad weather)

Wind map of flight day

Date: 41213
Level: 127 Kft
Knots (Latitude Corrected)
Flight day (Assembly)
Launched from Williams Field, McMurdo, in Antarctica, (S77-51, E-166-40), 5:56(UTC), Dec. 13, 2004
Data communication systems

- 1 RS-232C (19.2 kbps)
- 2 RS-232C (1200 bps)
- 28 Digital O.C. output
- 1 Timed-gate O.C. output
- 32 Analog input
- 16 Digital input

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<table>
<thead>
<tr>
<th>Link</th>
<th>TDRSS</th>
<th>Iridium</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink</td>
<td>Scheduled</td>
<td>Backup</td>
<td></td>
</tr>
<tr>
<td>Downlink</td>
<td>6 kbps</td>
<td>255 bytes / 15 min.</td>
<td>83.33 kbps</td>
</tr>
</tbody>
</table>

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**Event data**

- **BESS-Polar**
  - Event: 011833 (D3)  Size: 1918  FADC: 1156  FEND: 730
  - Trigger: 000111111  JET: 44  IDTC: 4  UTOF: 1  MTOF: 1  LTOF: 1

---

**Link options**

- **TDRSS**:
  - **Upplink**: Scheduled
  - **Downlink**: 6 kbps

- **Iridium**:
  - **Uplink**: Backup
  - **Downlink**: 255 bytes / 15 min.

- **LOS**:
  - **Uplink**: 83.33 kbps
Flight Trajectory

**Launch**

**Landing**

- **Flight ~8.5 days**

- **Float**

- **Termination**
Landing

Impacted the ground at (S-83-06, W-155-35), at 22:56(UTC), Dec. 21
First quick access to the data vessel
Data vessel was successfully recovered.

Transported to the base camp @ siple dome.
Recovery (2)

Due to the capacity of the airplane.

All detectors were disassembled.

Magnet and frame were cut to several pieces.

After 1 week recovery work, all detectors and magnet were recovered successfully.

No serious damage to each components.

Detectors and magnet will come back to the U.S.A in this April.
Low Energy Antiproton Observed in BESS Polar I (in 2004)

- ~2000 antiproton candidate observed

Preliminary

Antiproton Candidates
Lowest Energy Events Observed

Limit by BTOF Trigger

Limit by MTOF Trigger

Antiproton event

★ Kinetic Energy $\sim 0.11\text{GeV} (@ \text{TOA})$

★ Multi-track events to be further studied
Cosmic-ray Antiprotons Observed by BESS

- More than 4000 antiprotons (candidates) observed
Antiprotons Observed (Preliminary)

<table>
<thead>
<tr>
<th>KineticEnergy(@TOA)</th>
<th>BESS-97</th>
<th>Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1- 0.18 (GeV)</td>
<td>-</td>
<td>In Analysis</td>
</tr>
<tr>
<td>0.18-0.28</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>0.28-0.40</td>
<td>9</td>
<td>39</td>
</tr>
<tr>
<td>0.40-0.56</td>
<td>16</td>
<td>63</td>
</tr>
<tr>
<td>0.56-0.78</td>
<td>31</td>
<td>123</td>
</tr>
<tr>
<td>0.78-0.92</td>
<td>19</td>
<td>90</td>
</tr>
<tr>
<td>0.92-1.08</td>
<td>16</td>
<td>92</td>
</tr>
<tr>
<td><strong>Total (below 1.08 GeV)</strong></td>
<td><strong>95</strong></td>
<td><strong>432</strong></td>
</tr>
</tbody>
</table>

Statistics *4~5 times* larger than 1997,

with the effectively limited acceptance of \(~0.2 \text{ m}^2\text{sr (60\%)}~\)
First BESS-Polar experiment was successfully carried out and gather about 900 M events without any online selection.

4 times as many antiprotons were obtained compared with data taken during last solar minimum, i.e.,
- ~ 400 events below 1 GeV and
- ~ 2000 below 4.2 GeV

Analysis to extend lower energy region by using MTOF are now in progress.
Further Plan for BESS-Polar II

- Solar minimum in 2006~07
- Realize further long duration flight of 20 days with two circle around the pole, 4~5 x BESS-Polar I statistics
BESS-Polar realize the best sensitivity in low energy

<table>
<thead>
<tr>
<th></th>
<th>Acceptance (m$^2$sr)</th>
<th>Flight Time</th>
<th>Latitude</th>
<th>Altitude (km)</th>
<th>Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>0.5</td>
<td>3 years</td>
<td>&lt; 51.7</td>
<td>690</td>
<td>2008</td>
</tr>
<tr>
<td>PAMELA</td>
<td>0.0021</td>
<td>3 years</td>
<td>&lt; 70.4</td>
<td>320–390</td>
<td>2006</td>
</tr>
<tr>
<td>BESS-Polar2</td>
<td>0.3</td>
<td>20 days</td>
<td>&gt; 75</td>
<td>36</td>
<td>2007</td>
</tr>
</tbody>
</table>
## Improvement toward BESS-Polar II

<table>
<thead>
<tr>
<th>Subject</th>
<th>(BESS-Polar I)</th>
<th>(BESS-Polar II)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet Cryogen Life</td>
<td>~ 11 days</td>
<td>&gt; 25 days</td>
</tr>
<tr>
<td>Track detector (JET) gas quality</td>
<td>~ 10 days</td>
<td>&gt; 20 days</td>
</tr>
<tr>
<td>TOF-PMT housing</td>
<td>Resin potting</td>
<td>Pressurized housing</td>
</tr>
<tr>
<td>ACC Particle ID</td>
<td>Rejection ~ 630</td>
<td>&gt;&gt; 1000</td>
</tr>
<tr>
<td>Solar-power gen.</td>
<td>4 stage 900 W</td>
<td>3 stage 675 W</td>
</tr>
<tr>
<td>Effective Acceptance</td>
<td>0.2 m2sr</td>
<td>0.3 m2sr</td>
</tr>
<tr>
<td>Observation time</td>
<td>8.5 days</td>
<td>&gt; 20 days</td>
</tr>
<tr>
<td>Statistics</td>
<td>4 x BESS97 2 of 3.6 TB (recorded)</td>
<td>20 x BESS97 12 ~ 16 TB</td>
</tr>
<tr>
<td>Data storage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ultimate sensitive search for Primordial Anti-particles

**Antiprotons**
- Dark matter, primordial black hole, and unknown sources
- Solar modulation (charge dependent)

**Antideuterons**
- Dark matter, primordial black hole, and unknown sources

**Antimatter**
- Matter/antimatter asymmetry

**Ultimate precision measurement of cosmic-ray Propagation**
- Solar modulation
- Daily variation

Expectated Physic from BESS-Polar II
Secondary collision origin (background)

\[ p + p, \, N \rightarrow \bar{p} + X \]

kinematically suppressed at low E

but...

low E flux is larger than expected

Tertiary interaction of pbar

p-nucleus collision at production

Bergstrom, Edjo, Ullio, 1999

Gaisser et al., 1999

Still we believe there are rooms for primary origin.
Atmospheric Antiprotons at various altitude

BESS measurements at
- Top of the atmosphere: 4~26 g/cm²
- Mountain altitude: 742 g/cm²
- Ground level: 994 g/cm²

Test two interaction models
- Box Approx.
- delta Approx

Observed data
- not totally consistent with both
- could be used for model tuning

References:
Yamato et al., astro-ph/0509577
Indirect search for dark matter with antiproton

**SUSY**

- $\chi^2$: 6.5/12
- $\chi^2$ (bg only): 27.4/13

- Boostfaktor: 1
- $m_\chi = 14.8\,\text{GeV}$
- $m_0 = 500\,\text{GeV}$
- $m_{1/2} = 350\,\text{GeV}$
- $\tan \beta = 50$

**Kaluza-Klein**

- $M_{KK} = 3\,\text{TeV}$

W. de Boer EPS 867

Barrau astro-ph/0506389
Positron
Measurement at high energies is very promising by PAMELA, AMS2
Need for hard component

Gamma ray
Diffused gamma ray
GLAST will shed light on this field

Single evidence is not enough
need for different measurements to clarify the source
The strongest constraint is probably the antiproton flux, which would be far above the flux measured by BESS.
PBH may have been formed via:
- Initial density fluctuation
- Phase transition
- Collapse of cosmic string

Soft spectrum can be distinguished from secondary antiproton

BESS93 antiproton data
- More stringent upper limit
- \( R < 1.7 \times 10^{-2} \text{ pc}^{-3} \text{ yr}^{-1} \)
Secondary antideuteron strongly suppressed physics background free!

Flux can be measured down to $1.9 \times 10^{-4}$

$0.17 \sim 1.15 \text{ GeV/n}$

Antiproton is main background

Even single event give a great impact on physics.
BESS-Polar II will search

\[ \frac{\text{He}}{\text{He}} \sim 10^{-8} \]

If we were to observe one He, it should have fly from anti-domain.

High Risk and High (NO)Return
Long duration flight would shed light on new field ex. Daily variation of solar activity ex. We may have chance to see solar flare during flight

Observation of solar modulation during more than half solar cycle Important information on charge dependent modulation
Summary

BESS-Polar I:
Demonstrate reality long duration flight
Intermediate progress in science

BESS-Polar II:
Preparation has already started
to realize ultimately sensitive search for primordial antiparticle with the long duration flight (> 20 days) in solar minimum period (in 2007), and

Extend fundamental cosmic-ray measurement, in a complemental approach to PAMELA and AMS.