Search for Antihelium with the BESS-Polar Spectrometer


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Introduction

• BESS means “the Balloon-borne Experiment with a Superconducting Spectrometer”.
• BESS-Polar is the experiment to search for antiparticle.
• BESS-Polar was launched from Williams Field near McMurdo Station at Antarctica.
Introduction

Why was this launched?
• To reduce the effect by an interaction with the atmosphere.

Why was this conducted in Antarctica?
• To reduce the cutoff by geomagnetic effect.
• A solar battery is available due to the midnight sun. (Li battery is too heavy.)
• A balloon can move around Antarctica by the wind.
Introduction

BESS-Polar I
2004/12/13 ~ 12/22

BESS-Polar II
2007/12/23 ~ 2008/1/21
Introduction

Launch

BESS-Polar II
2007/12/23 ~ 2008/1/21

[Map of Antarctic region with launch trajectory marked]

[Image of launch site and balloon in sky]
Introduction

Recovery (2 years later)

BESS-Polar II
2007/12/23 ~ 2008/1/21

2 years later ...
The universe around us is composed of the matter. One of the sources of this asymmetry is CP-violation. The CP-violation which is measured is not enough to explain the asymmetry. The anti-matter dominant domain may exist in this universe. 

Motivation:

To detect anti-particles from such domains.

- Anti-proton $p^-$ is produced by the interaction of cosmic radiations.
- Anti-Helium is not produced.

Search for $He$
Detectors

**Time Of Flight Counters (UTOF & LTOF)**

- The TOF is composed from 10 upper TOF (UTOF) scintillators and 12 lower TOF (LTOF) scintillators.
- Measure flight time ($\sigma \sim 120$ps) and energy deposit ($dE/dx$).
- Determine the axial position of trajectories initially.
- Trigger events by the UTOF in coincidence with LTOF.

FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.
Solenoid

- Provide a uniform magnetic field (0.8 T) which is parallel to the axis of cylinder.
- The magnetic field bend trajectories of incident particles for the measurement of the charge and the momentum.
- The solenoid is kept at superconducting state using liquid He.
Jet-cell type drift chamber (JET)  Inner Drift Chamber (IDC)

- The central drift chamber is composed from JET & IDC.
- Used Gas is CO$_2$.
- Particle trajectories are fitted using up to 52 points ($\sigma \sim 140\mu$m).
  Measure the magnetic-rigidity ($\sigma \leq 0.4\%$).
- JET measure $dE/dx$ also.
These figure show BESS detector. There is no outer drift chamber (ODC) in BESS-Polar detector.
Middle TOF (MTOF)

- MTOF is to detect low energy particles that cannot penetrate the lower magnet wall (and LTOF).
- Low energy events are triggered by the UTOF in coincidence with MTOF.
- MTOF is not used for the anti-He search.

FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.
Detectors

Aerogel Cherenkov Counter (ACC)

- ACC is a detector for particle identification by checking whether a particle emit Cherenkov light.
- This ACC can separate $p^-$ events from $e^-$ and $\mu^-$ background.
- ACC is not used for the anti-He search.
Event selection

\[ He(\overline{He}) \text{ are identified by } M^2 = R^2 Z^2 \left( \frac{1}{\beta^2} - 1 \right) \]

\( M : \text{mass} \quad \text{The mass of } He \text{ is understood precisely.} \)

\[ R \equiv \frac{p}{Z} : \text{magnetic-rigidity} \quad \rho : \text{momentum, } Z : \text{electric charge} \]

\( R \) is measured as the radius of particle trajectories.

\[ R = \frac{p}{Z} = Br \quad B : \text{magnitude of magnetic field} \]

\[ r : \text{radius of particle trajectory} \]

\( \beta : \text{velocity} \quad \beta \text{ is determined by TOF.} \)

\( Z : \text{electric charge} \quad |Z| \text{ is determined by } \beta \text{ and } dE/dx. \)

Bethe-Bloch Formula

\[ -\left\langle \frac{dE}{dx} \right\rangle = \frac{K Z^2}{A} \frac{Z}{\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{I^2} - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right] \]
Event selection

• Events have single track are chosen.

• Trajectory fits with $\chi^2 \leq 2.5$, detected track $\geq 500$ mm.

• $1/\beta$ and $dE/dx$ band cuts are used to select $He$ ($\overline{He}$).

• A similar cut is applied to $dE/dx$ measured by the JET.

• $1.0 < R < 20$ GV (BESS-Polar I)
  $1.0 < R < 14$ GV (BESS-Polar II)
Result & Consideration

Observed $|Z| = 2$ events

BESS-Polar I : $8.4 \times 10^6$ events
BESS-Polar II : $4.0 \times 10^7$ events

No anti-He candidates were found.

$R^{-1}$ distribution of the BESS-Polar II

$|Z| = 2$ data with all selections applied.

due to differing $^4\text{He}$ and $^3\text{He}$.

due to miss-id of high rigidity He.
The ratio of $\overline{He}/He$ is calculated as follows.

$$R_{\overline{He}/He} = \frac{\int N_{\text{Obs,He}/He}/(S\Omega\bar{\eta}\bar{\epsilon}_{\text{sngl}}\bar{\epsilon}_{dE/dx}\bar{\epsilon}_{\beta}\bar{\epsilon}_{DQ})dE}{\int N_{\text{Obs,He}/He}/(S\Omega\eta\epsilon_{\text{sngl}}\epsilon_{dE/dx}\epsilon_{\beta}\epsilon_{DQ})dE}$$

$N_{\text{Obs,He}(\overline{He})}$ : differential intensity of observed $He(\overline{He})$.

$S\Omega$ : geometric acceptance

$\eta(\bar{\eta})$ : survival probability of $He(\overline{He})$ traversing the atmosphere.

$\epsilon_{\text{sngl}}(\bar{\epsilon}_{\text{sngl}})$ : single track efficiency

$\epsilon_{dE/dx}(\bar{\epsilon}_{dE/dx})$ : $dE/dx$ selection efficiency

$\epsilon_{\beta}(\bar{\epsilon}_{\beta})$ : $\beta$ selection efficiency

$\epsilon_{DQ}(\bar{\epsilon}_{DQ})$ : data quality selection efficiency

In this search, there are no anti-He candidates ($N_{\text{Obs,He}} = 0$).

It is necessary to calculate the upper limit.

The energy dependent efficiencies for anti-He is needed.
Two different assumptions are considered for anti-He energy spectrum.

(i) *Same spectral shape for anti-He as for He.*

The energy spectrum of anti-He is the same as for He.

- $\int N_{\text{Obs,He}} dE < 3.1$ (at 95% confidence with a null detection and no background)
- $\epsilon_d E / dx / \bar{\epsilon}_d E / dx$, $\epsilon_\beta / \bar{\epsilon}_\beta$, and $\epsilon_{DQ} / \bar{\epsilon}_{DQ}$ are canceled.

$R_{\text{He/He}} < \frac{3.1}{\int N_{\text{Obs,He}} \bar{\eta} \bar{\epsilon}_{\text{snegl}} / (\eta \epsilon_{\text{snegl}}) dE}$

- $\eta, \bar{\eta}, \epsilon_{\text{snegl}}, \bar{\epsilon}_{\text{snegl}}$ are determined by Monte Carlo simulation.

Bess-Polar I: $R_{\text{He/He}} < 4.4 \times 10^{-7}$ (1.0 < $R$ < 20)
Bess-Polar II: $R_{\text{He/He}} < 9.4 \times 10^{-8}$ (1.0 < $R$ < 14)
Combined: $R_{\text{He/He}} < 6.9 \times 10^{-8}$ (1.0 < $R$ < 14)
Result & Consideration

(ii) *No assumed anti-He spectrum.*

The most conservative upper limit is obtained.

- The energy spectrum of anti-He is not assumed.
- The lowest efficiency within the search range is used.
- Only $S\Omega$ is canceled.

$$R_{\text{He}/\text{He}} < \frac{3.1 / [\bar{\eta} \bar{\epsilon}_{\text{e}} \bar{\epsilon}_{dE/dx} \bar{\epsilon} \bar{\epsilon}_{DQ}]_{\text{MIN}}}{\int N_{\text{Obs,He}} / (\eta \epsilon_{\text{e}} \epsilon_{dE/dx} \epsilon \epsilon_{DQ}) dE}$$

Bess-Polar I : $R_{\text{He}/\text{He}} < 5.3 \times 10^{-7}$ ( $1.5 < R < 20$ )
Bess-Polar II : $R_{\text{He}/\text{He}} < 1.2 \times 10^{-7}$ ( $1.6 < R < 14$ )
Combined : $R_{\text{He}/\text{He}} < 1.0 \times 10^{-7}$ ( $1.6 < R < 14$ )

Only about 25% higher than assumption (i).
Conclusion

- BESS-Polar is the experiment to search for antiparticle.
- Anti-He was searched to investigate whether there are anti-matter dominant domain in the universe.
- $4.8 \times 10^7$ He(anti-He) candidates were detected.
- No anti-He candidates were found.
- The upper limit of ratio of anti-He/He was obtained as $6.9 \times 10^{-8}$. 
Back up
Event selection

$\text{He}(\text{He})$ are identified by

$$M^2 = R^2 Z^2 \left( \frac{1}{\beta^2} - 1 \right)$$

$M$ : mass, $p$ : momentum, $Z$ : electric charge, $\beta$ : velocity, $R \equiv p/Z$ : magnetic-rigidity

Absolute charge ($|Z|$) is determined from $\beta$ and $dE/dx$.

Bethe-Bloch Formula

$$\left[ -\langle \frac{dE}{dx} \rangle = K z^2 Z \frac{1}{A \beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{I^2} - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right] \right]$$

1/$\beta$

dE/dx (UTOF)

dE/dx (LTOF)