Paper reading seminar

Search for Antihelium with the BESS-Polar Spectrometer

K. Abe, H. Fuke, and S. Haino *et al.*, Phys. Rev. Lett. 108, 131301 (2012)

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Zenmei Suzuki

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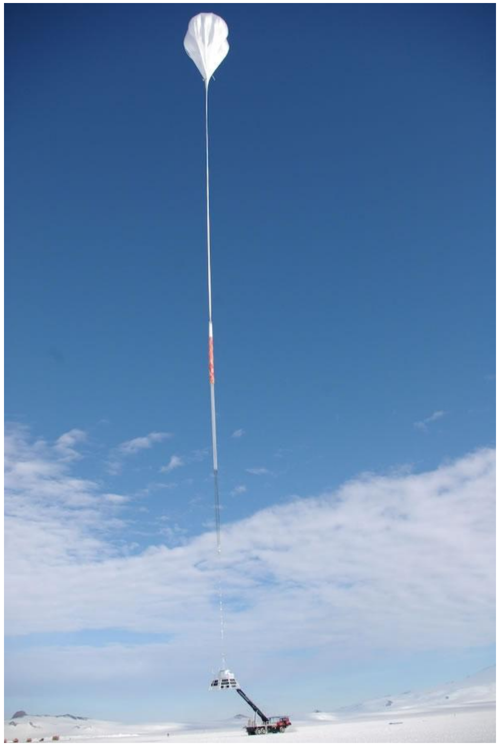
Introduction

- 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.



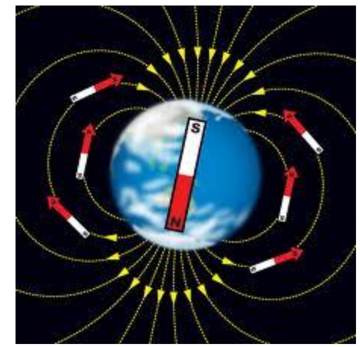
Introduction

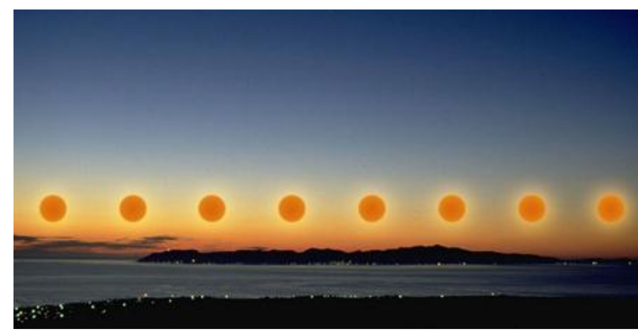
Why was this launched?

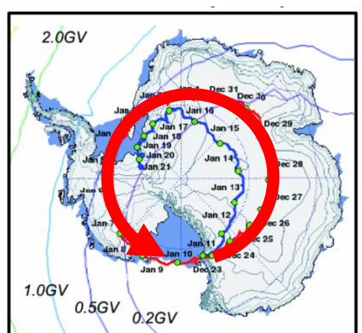
- To reduce the effect by an interaction with the atmosphere.

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.

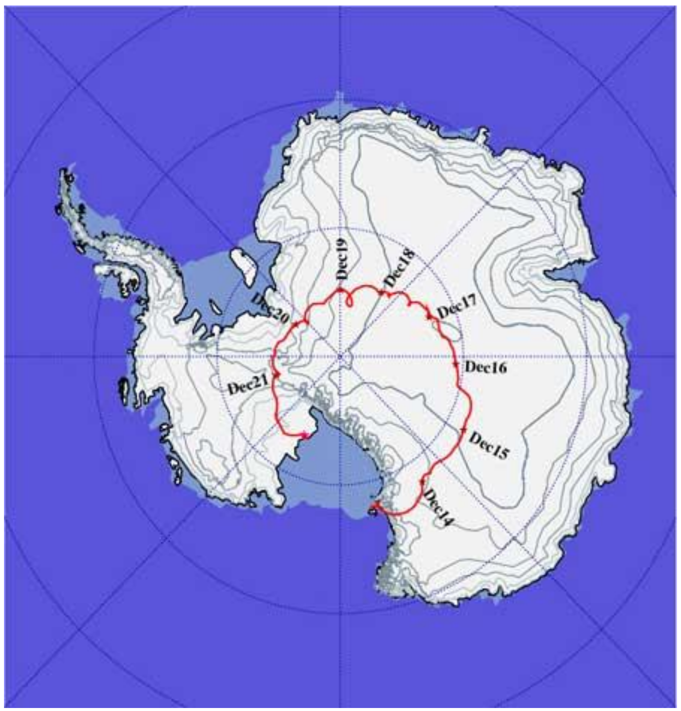




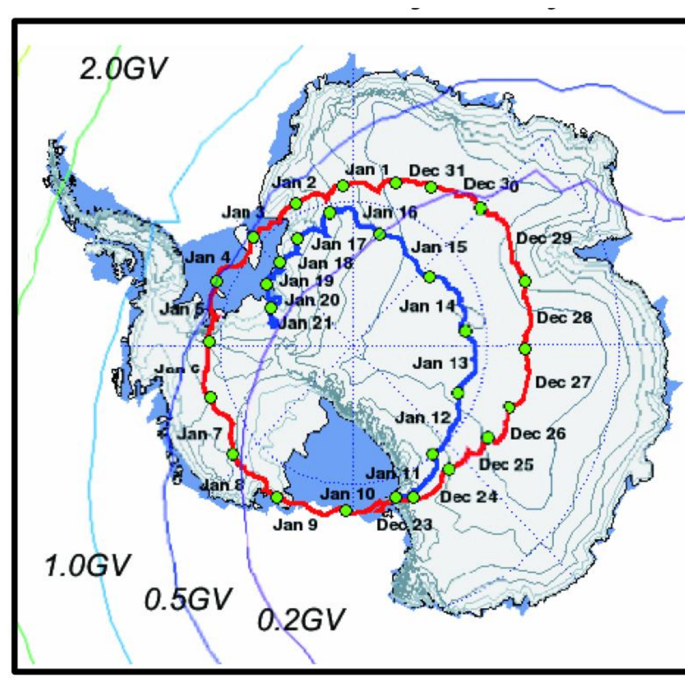


Introduction

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

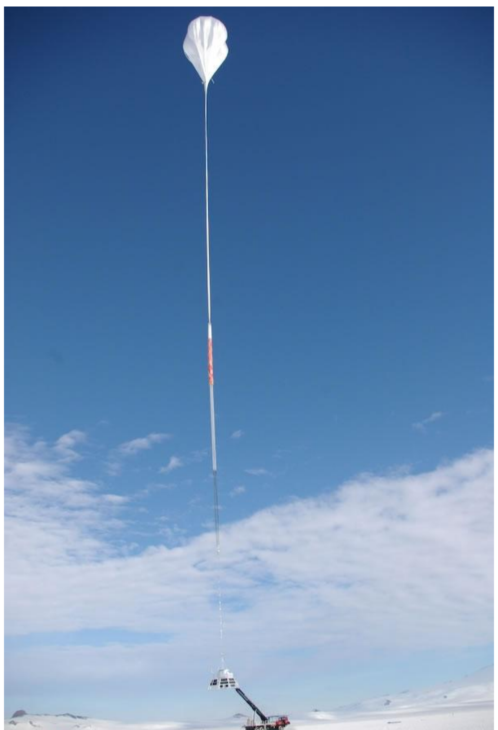


BESS-Polar II
2007/12/23 ~ 2008/1/21

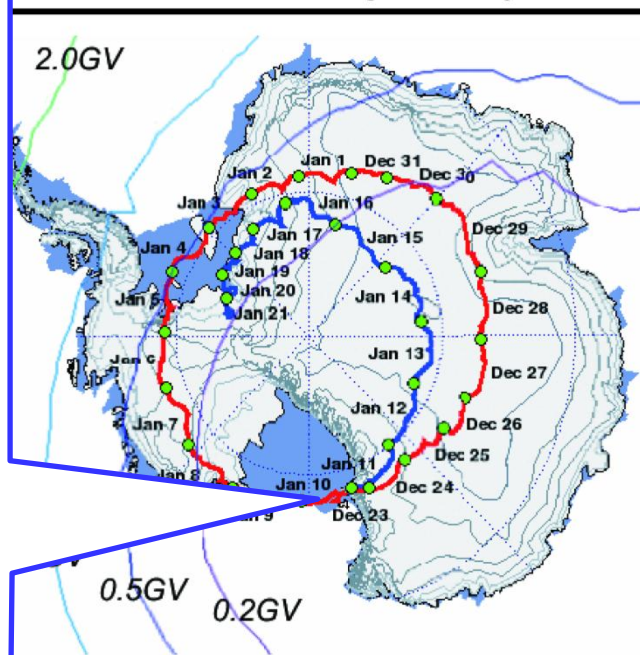


Introduction

Launch



BESS-Polar II
007/12/23 ~ 2008/1/21



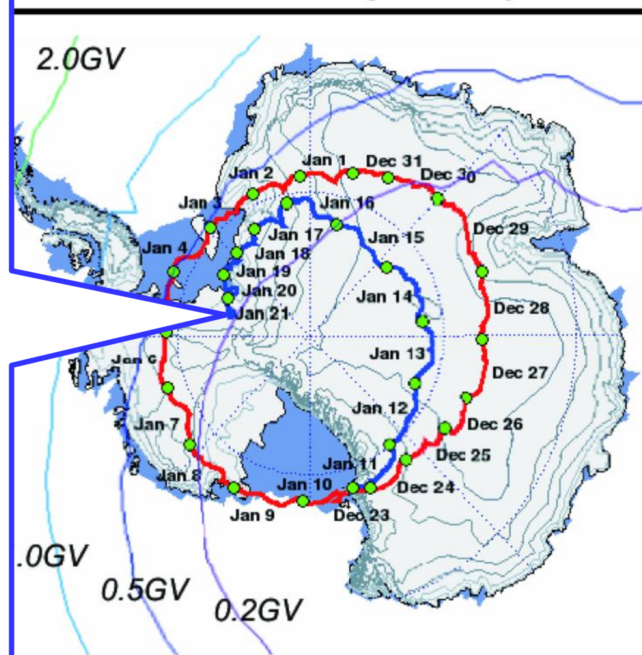
Introduction

Recovery (2 years later)

2 years later …

BESS-Polar II

007/12/23 ~ 2008/1/21



Motivation

The universe around us is composed from the matter.

One of the source of this asymmetry is CP-violation.

but …

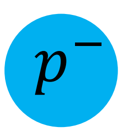
The CP-violation which is measured is not enough to explain the asymmetry.

The anti-matter dominant domain may exist in this universe.

Motivation :

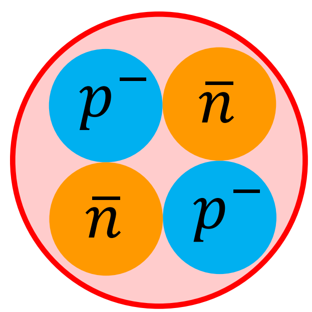
To detect anti-particles from such domains.

anti-proton



is produced by the interaction of cosmic radiations.

anti-Helium



is not produced.

Search for $\overline{He}$

Detectors

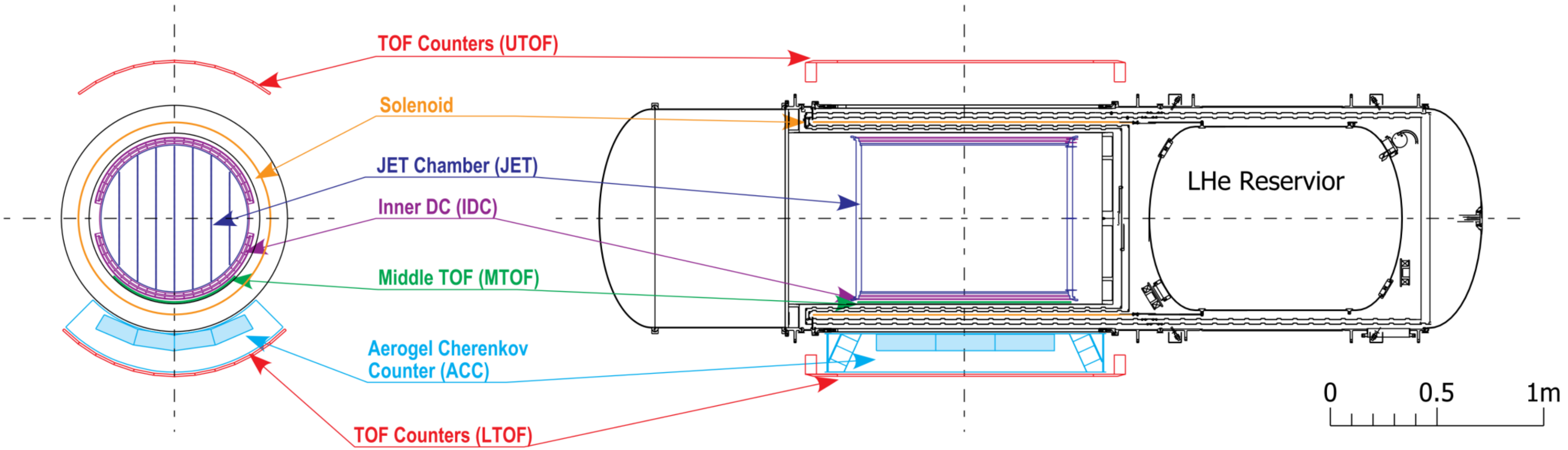


FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.

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 (σ~120ps) and energy deposit (*dE/dx*).
- Determine the axial position of trajectories initially.
- Trigger events by the UTOF in coincidence with LTOF.

Detectors

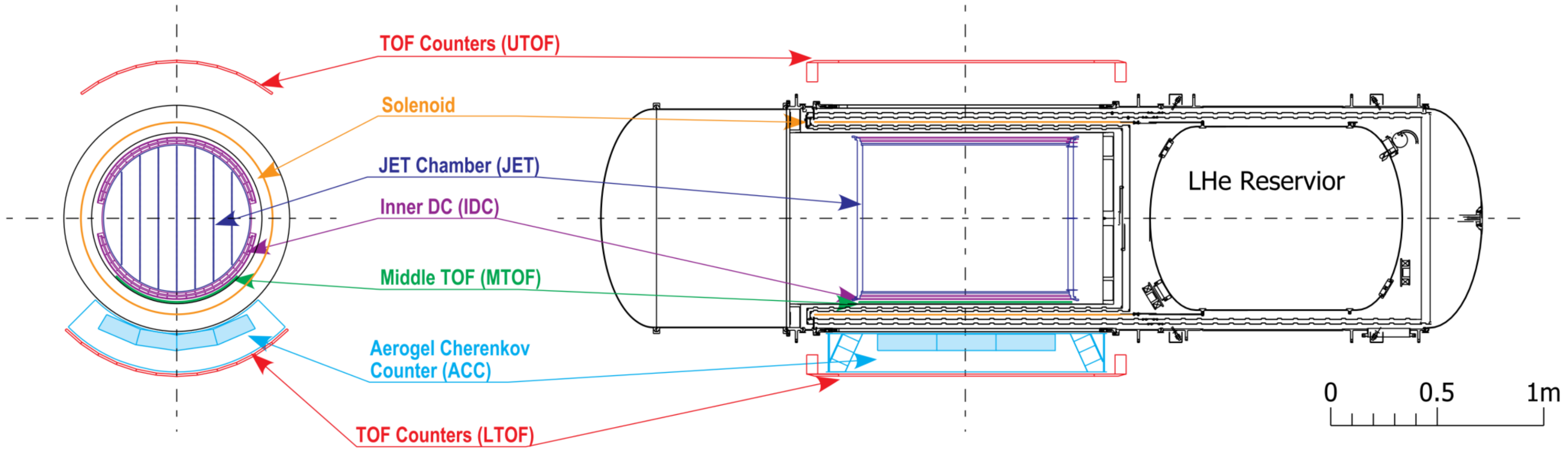


FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.

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.

Detectors

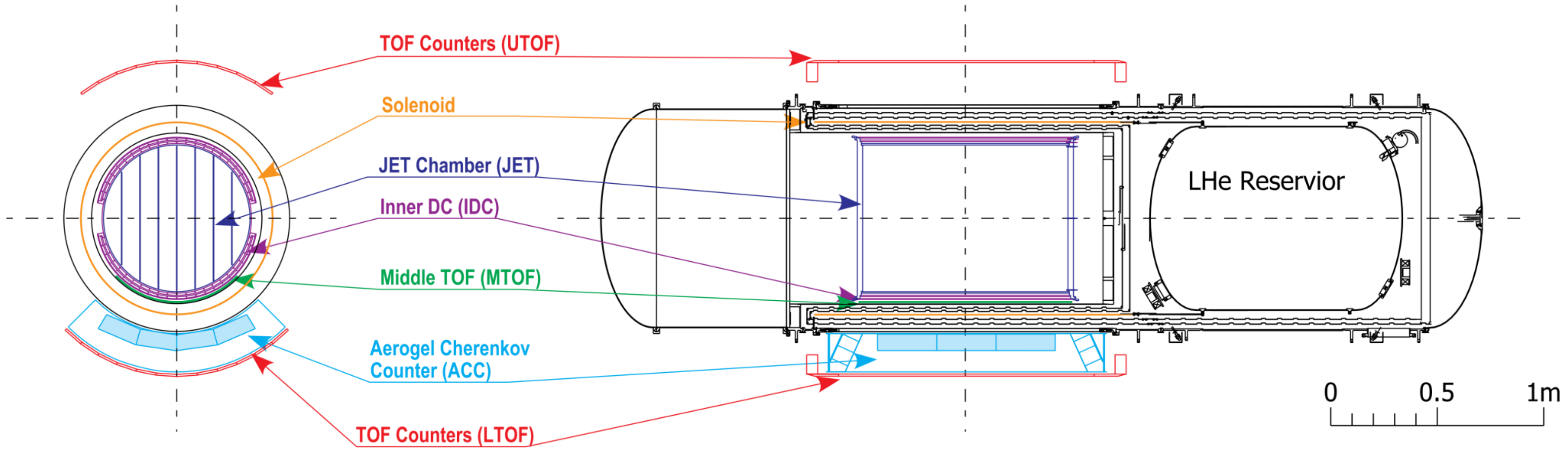


FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.

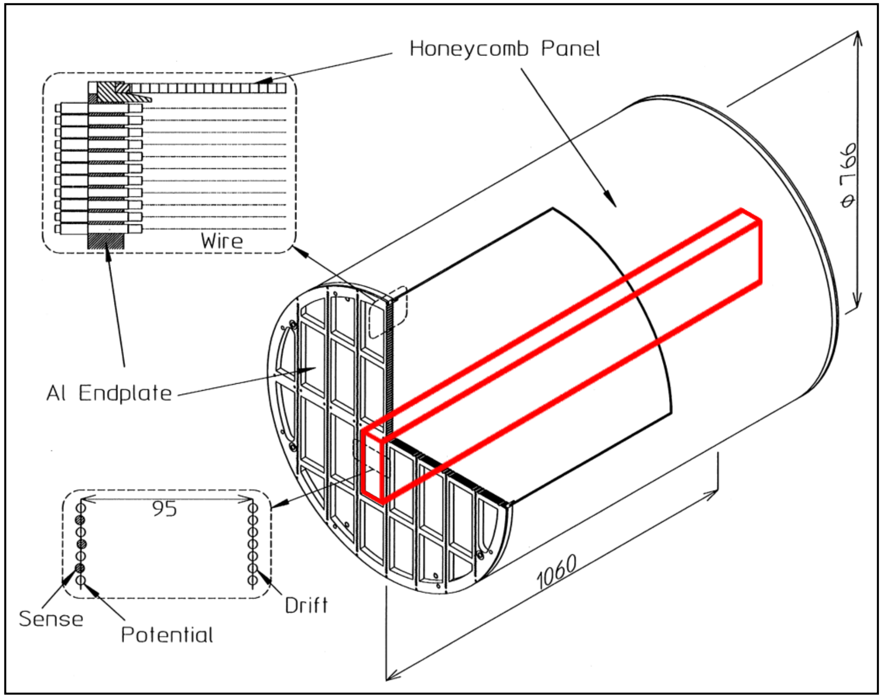
Jet-cell type drift chamber (JET)	Inner Drift Chamber (IDC)

- The central drift chamber is composed from JET & IDC.
- Used Gas is CO_2.
- Particle trajectories are fitted using up to 52 points (σ~140μm).

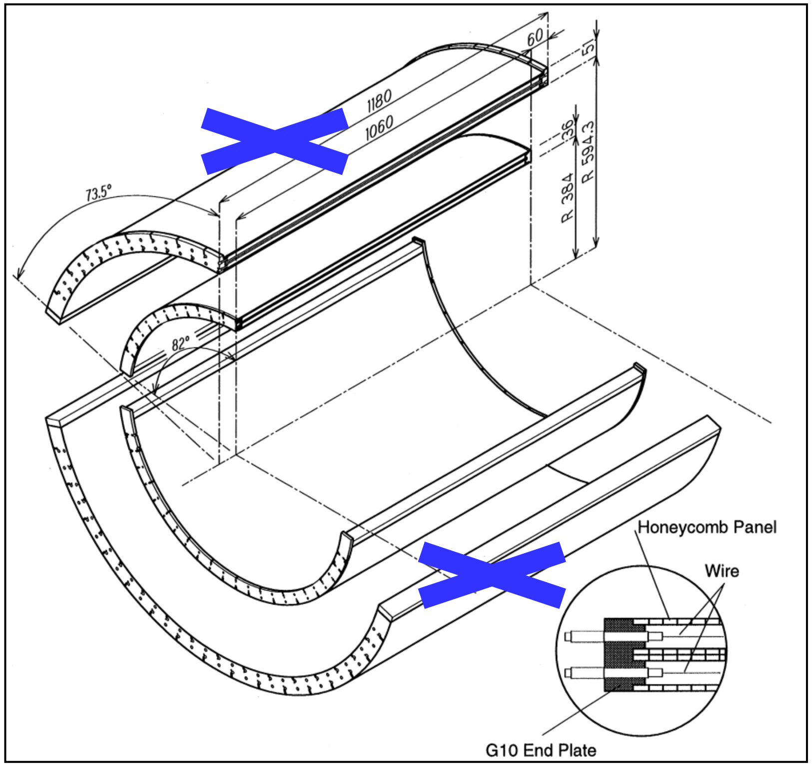
  ➡ Measure the magnetic-rigidity ($\sigma \leq 0.4\%$).
- JET measure *dE*/*dx* also.

Detectors

JET chamber



IDC chamber



These figure show BESS detector.

There is no outer drift chamber (ODC) in BESS-Polar detector.

Detectors

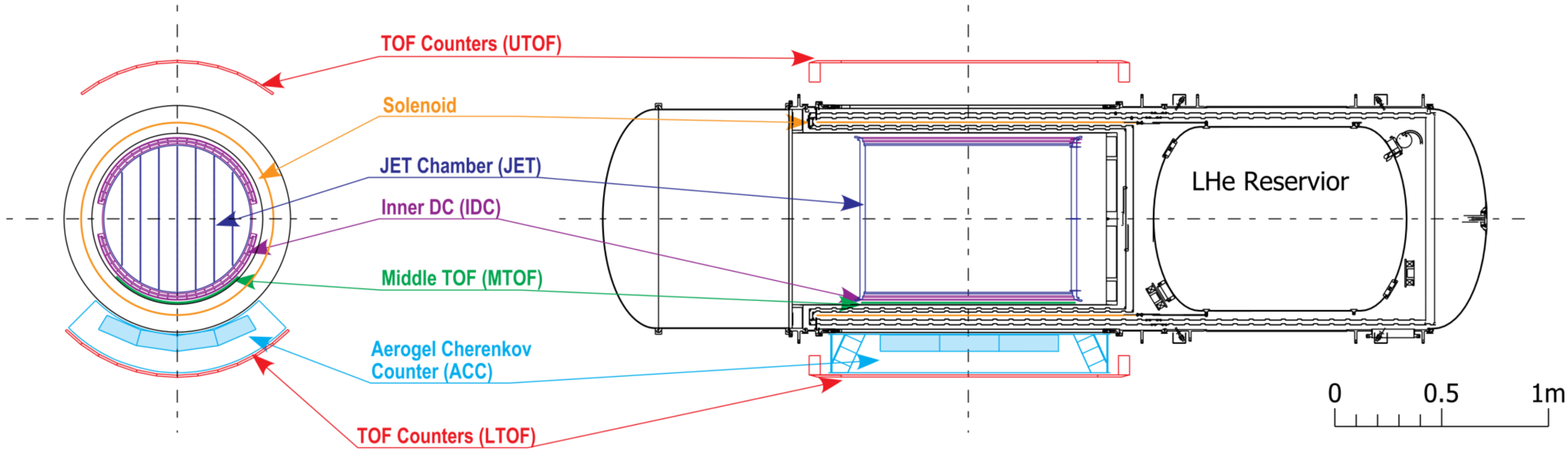


FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.

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.

Detectors

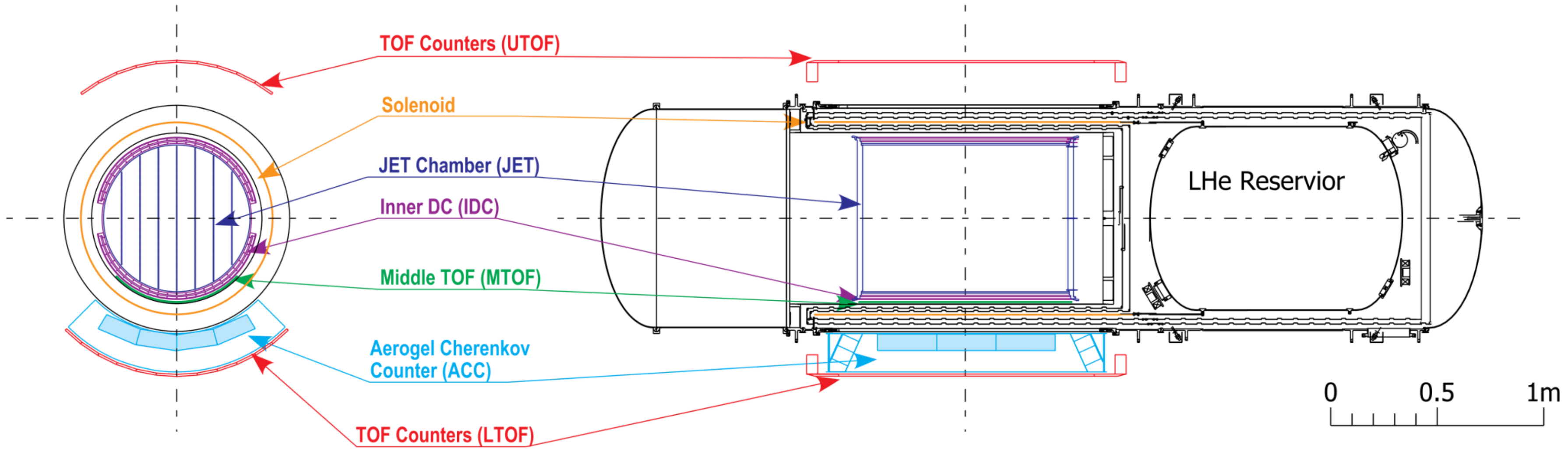


FIG. 1 (color online). Cross-sectional and side views of the BESS-Polar II Spectrometer.

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 μ^- background.
- ACC is not used for the anti-He search.

Event selection

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

M : mass — The mass of *He* is understood precisely.

$R \equiv p/Z$: magnetic-rigidity — p : momentum, Z : electric charge

R is measured as the radius of particle trajectories.

$R = p/Z = Br$ — B : magnitude of magnetic field, r : radius of particle trajectory

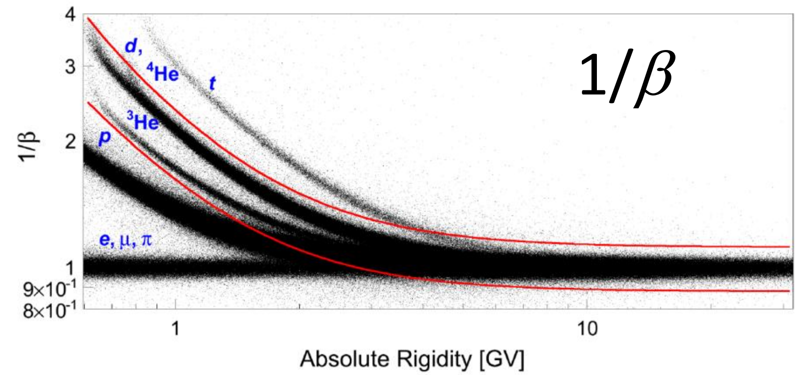
β : velocity — β is determined by TOF.

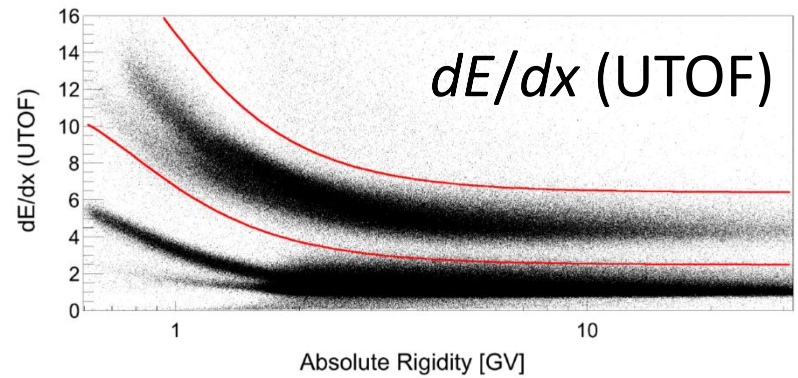
Z : electric charge — $|Z|$ is determined by β and dE/dx.

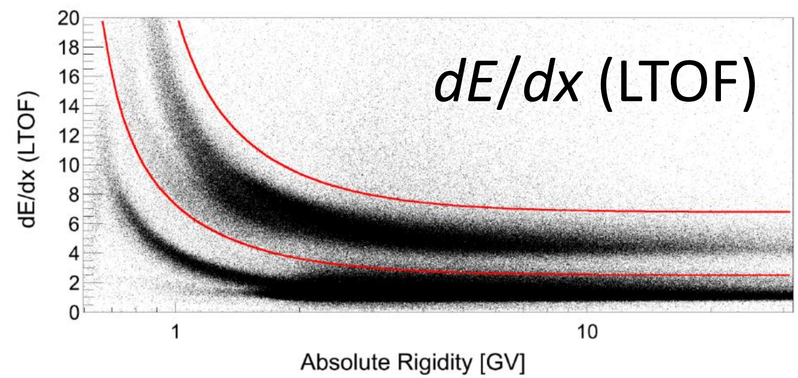
Bethe-Bloch Formula $$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Event selection

- Events have single track are chosen.
- Trajectory fits with $\chi^2 \leqq 2.5$, detected track $\geqq$ 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)







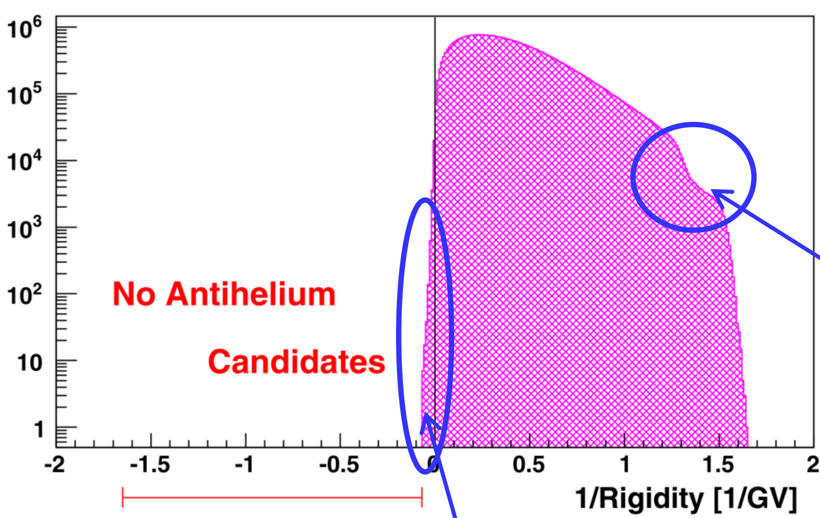
Result & Consideration

Observed $|Z| = 2$ events

BESS-Polar I : 8.4×10^6 events
BESS-Polar II : 4.0×10^7 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}He and ^{3}He.

due to miss-id of high rigidity He.

Result & Consideration

The ratio of $\overline{He}/He$ is calculated as follows.

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

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

$S\Omega$: geometric acceptance

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

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

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

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

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

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

➡ It is necessary to calculate the upper limit.
The energy dependent efficiencies for anti-He is needed.

Result & Consideration

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.

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

$$\boxed{R_{\overline{\mathrm{He}}/\mathrm{He}} < \frac{3.1}{\int N_{\mathrm{Obs,He}}\,\bar{\eta}\bar{\epsilon}_{\mathrm{sngl}}/(\eta\epsilon_{\mathrm{sngl}})dE}}$$

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

Bess-Polar I : $R_{\overline{He}/He} < 4.4 \times 10^{-7}$ (1.0 < R < 20)
Bess-Polar II : $R_{\overline{He}/He} < 9.4 \times 10^{-8}$ (1.0 < R < 14)
Combined : $R_{\overline{He}/He} < 6.9 \times 10^{-8}$ (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 SΩ is canceled.

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

Bess-Polar I : $R_{\overline{He}/He} < 5.3 \times 10^{-7}$ (1.5 < R < 20)

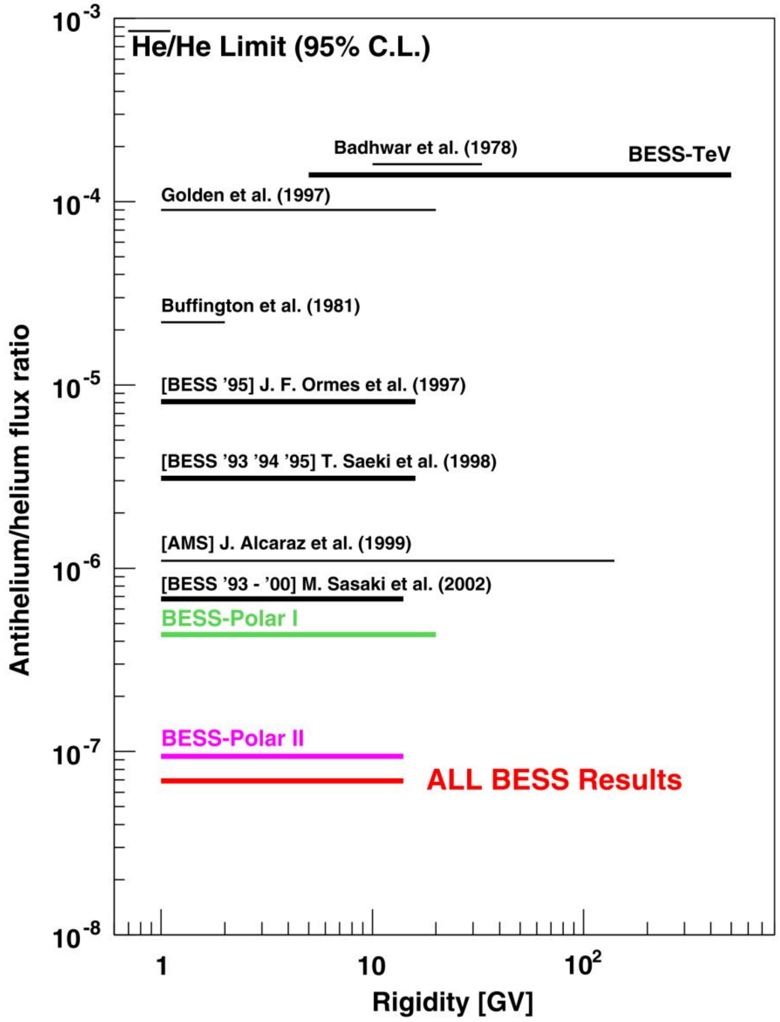
Bess-Polar II : $R_{\overline{He}/He} < 1.2 \times 10^{-7}$ (1.6 < R < 14)

Combined : $R_{\overline{He}/He} < 1.0 \times 10^{-7}$ (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.
- 4.8×10^7 He(anti-He) candidates were detected.
- No anti-He candidates were found.
- The upper limit of ratio of anti-He/He was obtained as 6.9×10^{-8}.



Back up

Event selection

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

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

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

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

Bethe-Bloch Formula

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