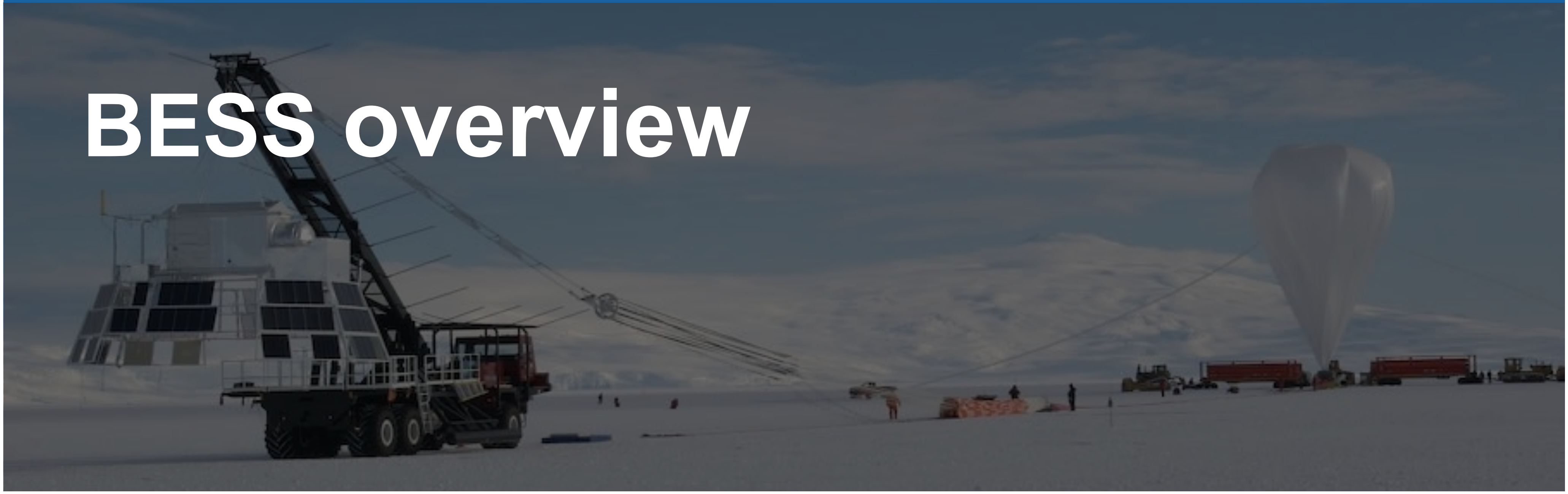


BESS overview

Speaker: **Kenichi Sakai*** for BESS collaboration

NASA-GSFC, U-Maryland, U-Denver,
KEK, U-Tokyo, Kobe-U., and ISAS-JAXA

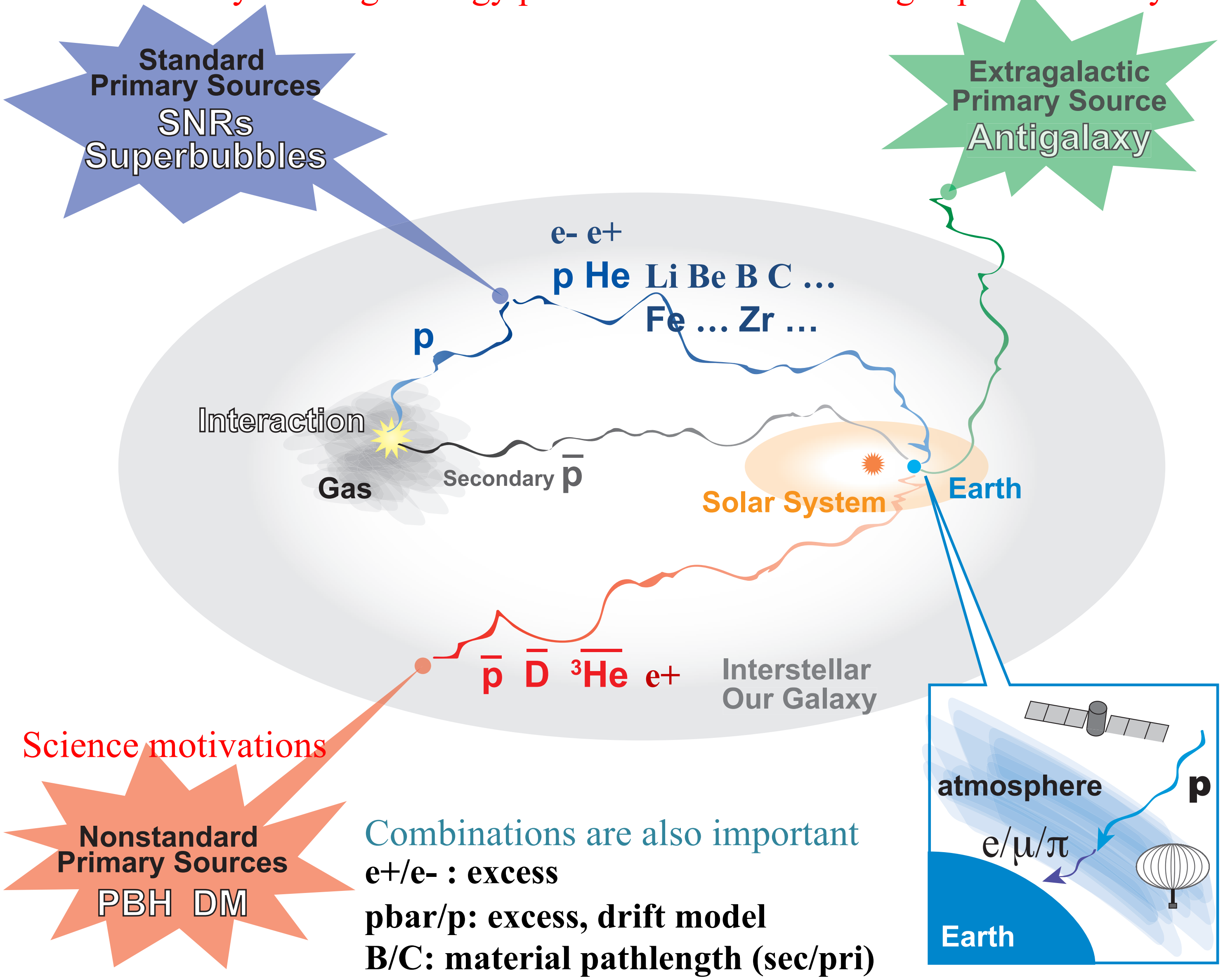
* Currently at Enrico Fermi Inst., Univ. of Chicago

JENAA workshop on Nuclear Physics at the LHC and connections to astrophysics

Aug 19 – 20, 2024
CERN
Europe/Zurich timezone

1 Fundamental science being explored by using the balloon or ISS

Cosmic rays are high energy particles that move through space at nearly the speed of light.



Science motivations

Combinations are also important

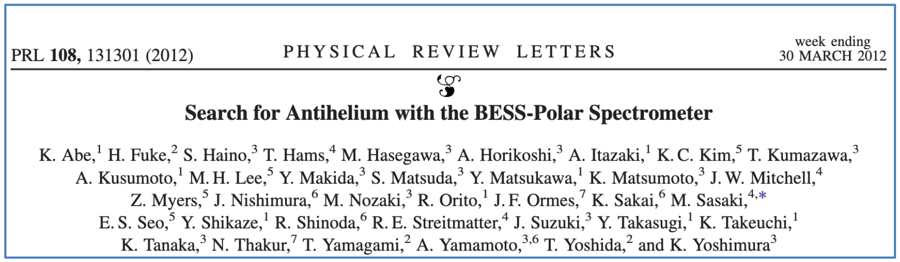
e+/e- : excess

pbar/p: excess, drift model

B/C: material pathlength (sec/pri)

Be10/Be9: the lifetime of cosmic ray (radioactive isotopes)

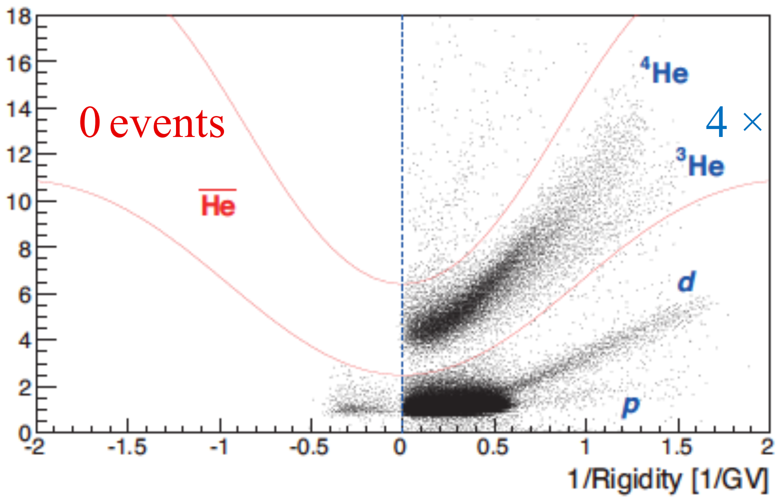
2 The most stringent upper limit to the ratio antihelium/helium



PRL **108,** 131301 (2012) PHYSICAL REVIEW LETTERS week ending 30 MARCH 2012

Search for Antihelium with the BESS-Polar Spectrometer

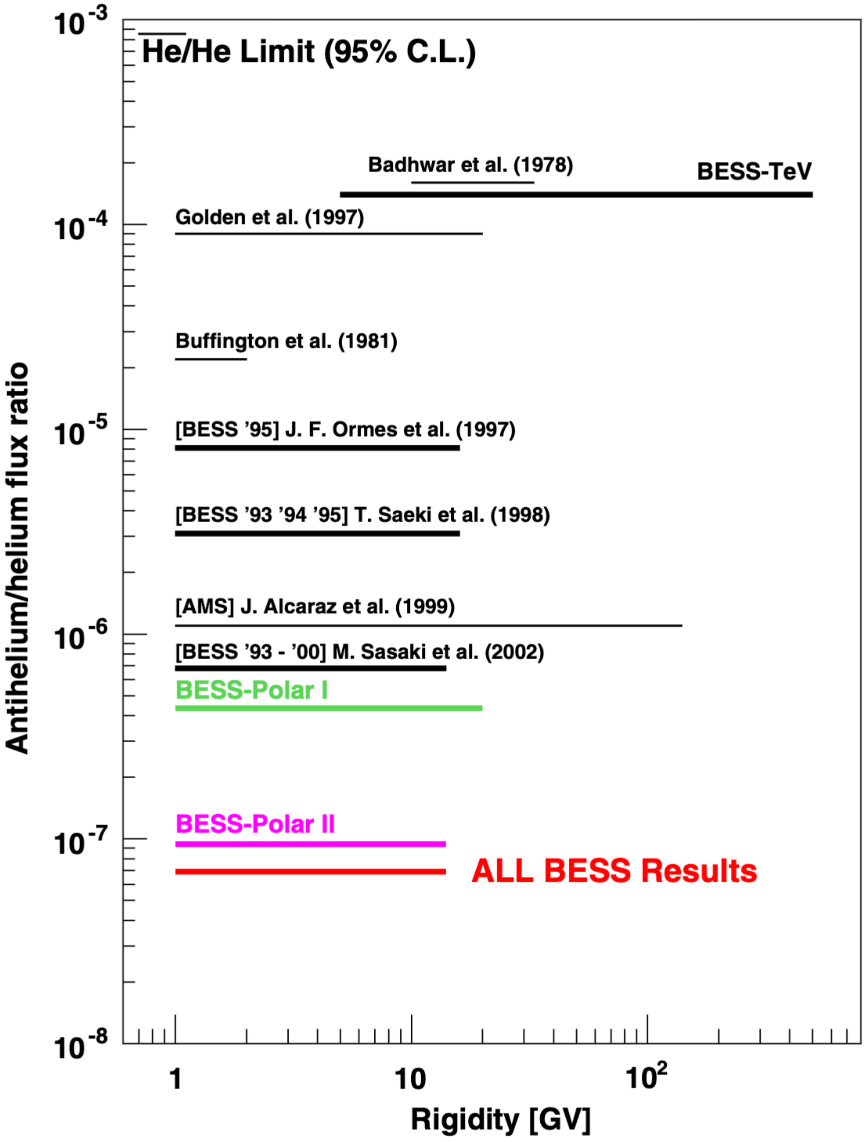
K. Abe,[1] H. Fuke,[2] S. Haino,[3] T. Hams,[4] M. Hasegawa,[3] A. Horikoshi,[3] A. Itazaki,[1] K. C. Kim,[5] T. Kumazawa,[3]
A. Kusumoto,[1] M. H. Lee,[5] Y. Makida,[3] S. Matsuda,[3] Y. Matsukawa,[1] K. Matsumoto,[3] J. W. Mitchell,[4]
Z. Myers,[5] J. Nishimura,[6] M. Nozaki,[3] R. Orito,[1] J. F. Ormes,[7] K. Sakai,[6] M. Sasaki,[4,*]
E. S. Seo,[5] Y. Shikaze,[1] R. Shinoda,[6] R. E. Streitmatter,[4] J. Suzuki,[3] Y. Takasugi,[1] K. Takeuchi,[1]
K. Tanaka,[3] N. Thakur,[7] T. Yamagami,[2] A. Yamamoto,[3,6] T. Yoshida,[2] and K. Yoshimura[3]



0 events

4×10^7 events

A series of BESS flights has resulted in the most stringent upper limit of 1.0×10^{-7} to the ratio Antihelium/He in the rigidity range from 1.6 to 14 GV.



3 Antihelium detected in AMS-02?

To date we have observed

a few events

with Z = -2 and

with mass around ^{3}He.

Antihelium

AMS-02
Riv. Nuovo Cimento 43, 319 (2020)

Very recently, tantalizing hints of ^{3}Hebar and ^{4}Hebar candidates have been observed by the AMS-02 magnetic spectrometer.

The analysis of these events and of the associated background is ongoing and will continue, while accumulating more data to increase the statistical significance of the sample.

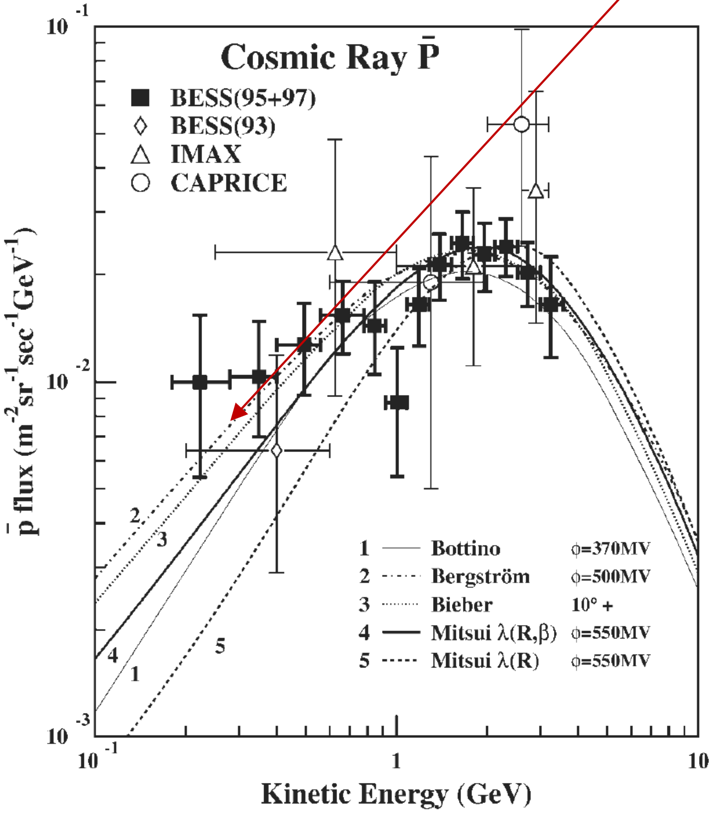
↓

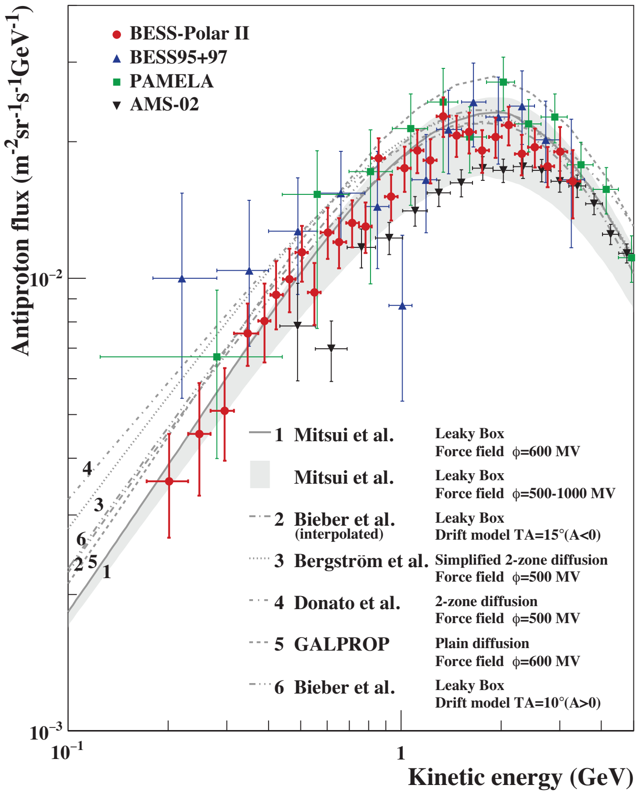
No clear evidence or results have yet been reported for antihelium.

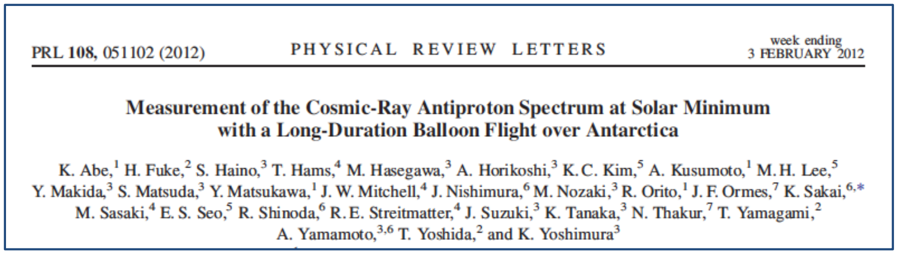
4 What precise measurements of low-energy antiprotons can tell us

Motivation:
Slightly flatter in low energy
At solar minimum period
(BESS95+97)

Result:
Showing good consistency with
Secondary antiproton spectra
(BESS-Polar II)







PRL 108, 051102 (2012) PHYSICAL REVIEW LETTERS week ending 3 FEBRUARY 2012

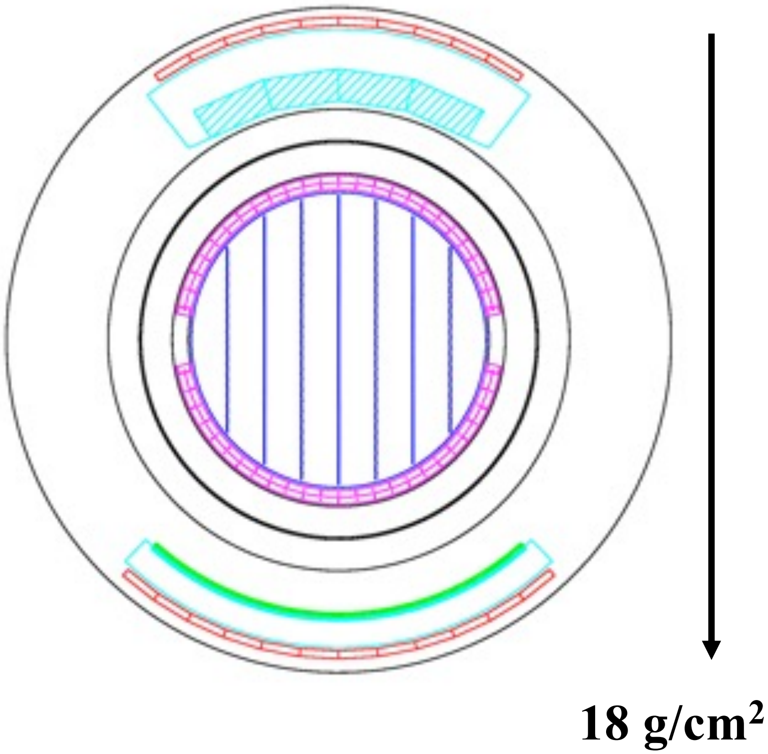
Measurement of the Cosmic-Ray Antiproton Spectrum at Solar Minimum with a Long-Duration Balloon Flight over Antarctica

K. Abe,[1] H. Fuke,[2] S. Haino,[3] T. Hams,[4] M. Hasegawa,[3] A. Horikoshi,[3] K. C. Kim,[5] A. Kusumoto,[1] M. H. Lee,[5] Y. Makida,[3] S. Matsuda,[3] Y. Matsukawa,[1] J. W. Mitchell,[4] J. Nishimura,[6] M. Nozaki,[3] R. Orito,[1] J. F. Ormes,[7] K. Sakai,[6,*] M. Sasaki,[4] E. S. Seo,[5] R. Shinoda,[6] R. E. Streitmatter,[4] J. Suzuki,[3] K. Tanaka,[3] N. Thakur,[7] T. Yamagami,[2] A. Yamamoto,[3,6] T. Yoshida,[2] and K. Yoshimura[3]

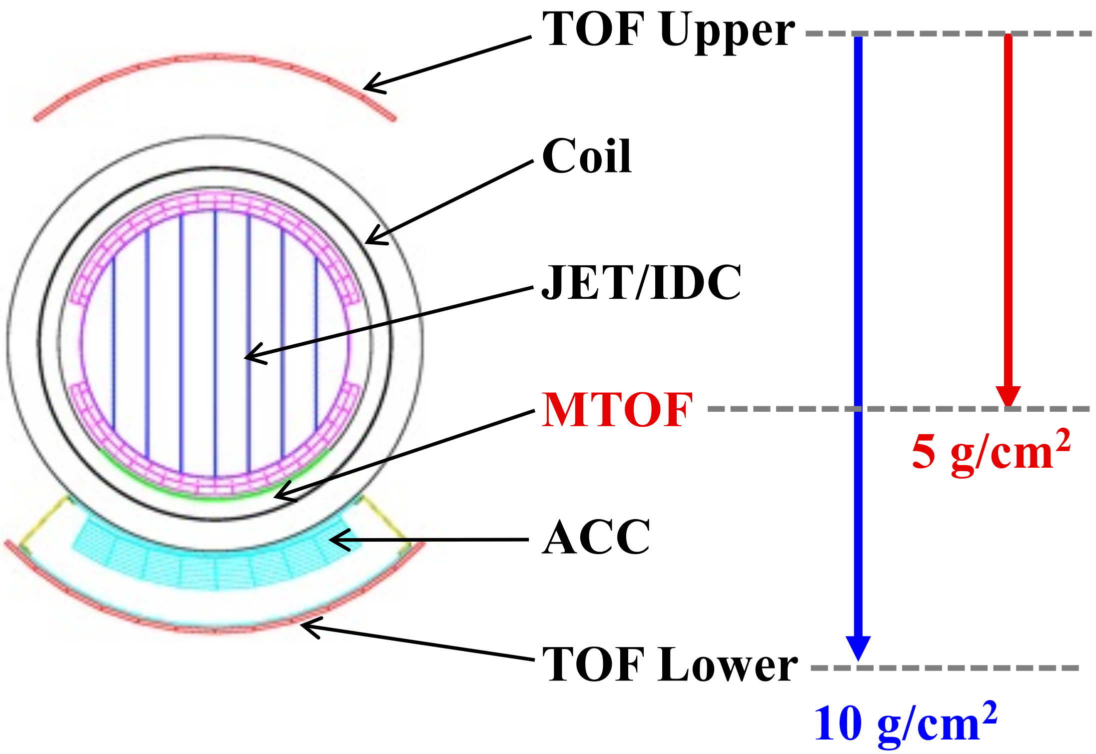
5 Let's go lower energy

To minimize material in spectrometer: New detector (Middle TOF)

BESS-2000

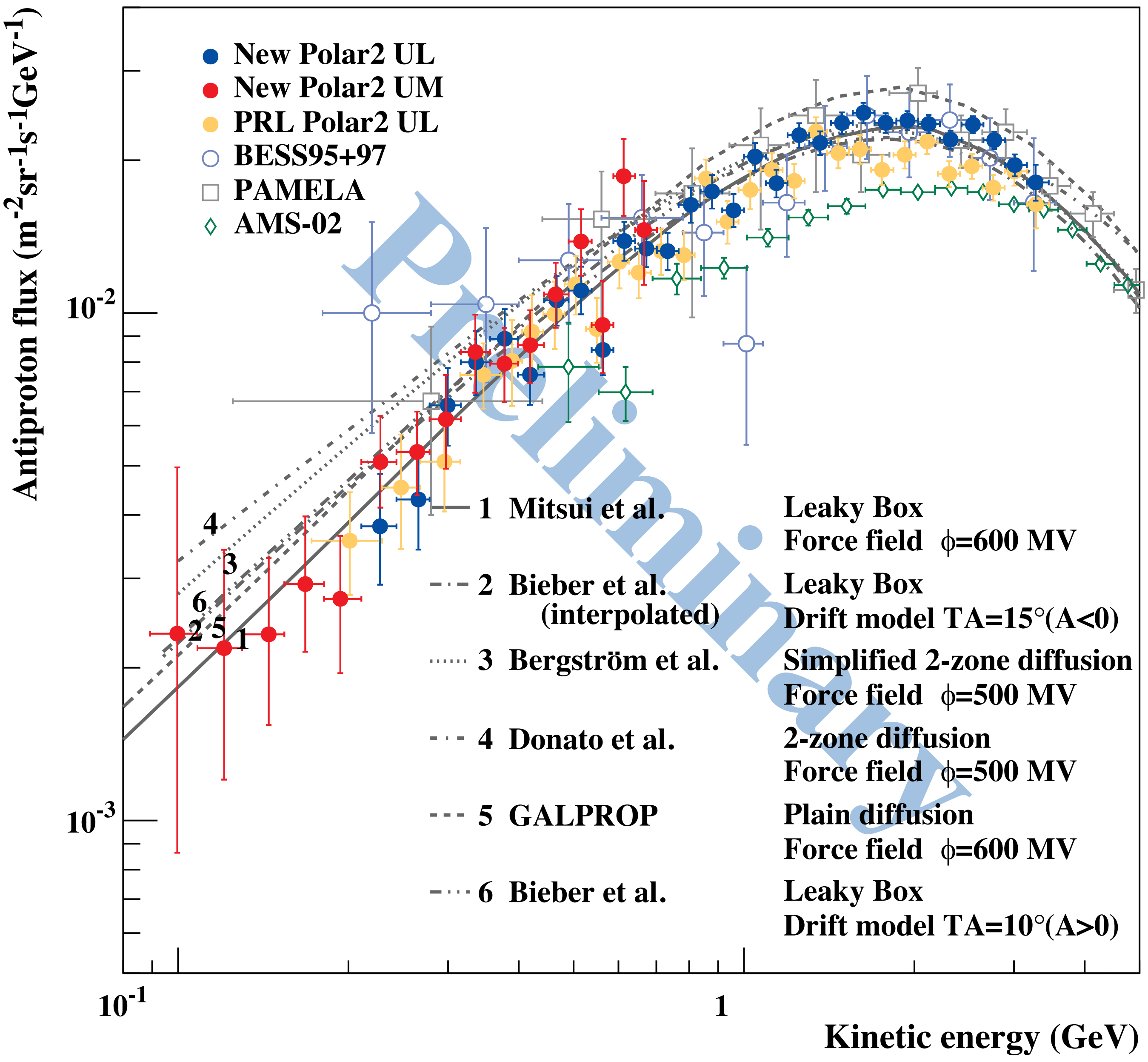


BESS-Polar



MTOF extends the energy range down to about 0.1 GeV.

6 Lower energy antiproton flux by using Middle TOF trigger



New UM and UL absolute differential energy spectra of antiprotons measured by BESS-Polar II together with earlier published BESS-Polar II UL antiproton spectrum

- UL antiproton flux: 0.2-3.5 GeV
- UM antiproton flux: 0.1-0.7 GeV

A systematic shift in antiproton flux was introduced by modified acceptance of Geant3 to Geant4.

Particles study

- Antihelium from BESS-Polar II (published)
- Antiprotons from BESS-Polar II (published)
- Lower-energy Antirptorons from BESS-Polar II

Isotopes study

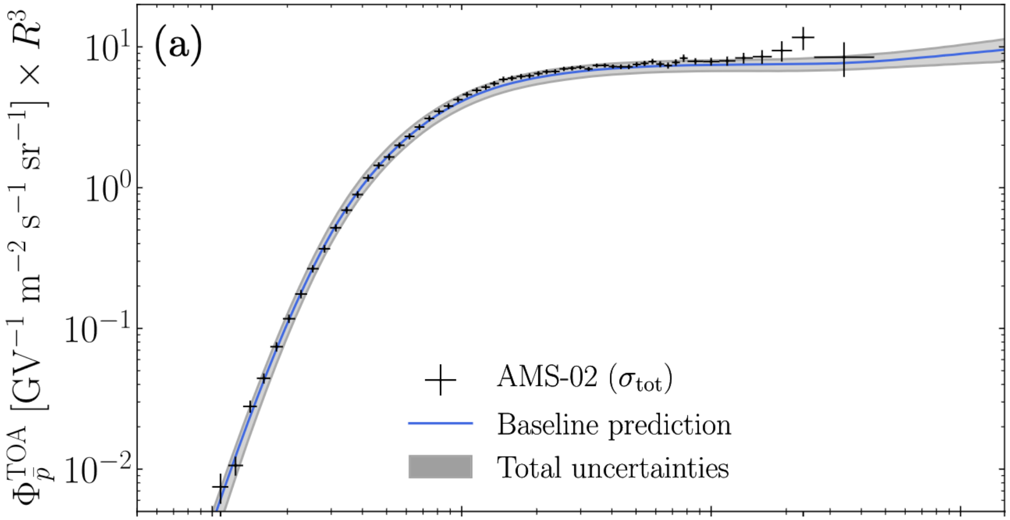
- **Antideutron from BESS-Polar II (published)**

- **^{10}Be/^{9}Be ratio from BESS-Polar II**
- **^{10}Be/^{9}Be ratio from HELIX**

7 Difficulty in searching for primary origins using antiprotons

Antiproton	
PAMELA **PRL 105, 121101 (2010)**	The measurements are consistent with purely secondary production of antiprotons in the Galaxy. (From abstract)
BESS-Polar II **PRL 108, 051102 (2012)**	This shows good consistency with secondary antiproton calculations. (From abstract)
AMS-02 **PRL 117, 091103 (2016)**	New observations of the properties of elementary particles in the cosmos. (From abstract)

Theory
Boudaud et al. **Phys. rev. res. 2, 023022 (2020)**



We underline that CR antiprotons are one of the most sensitive astroparticle probes of annihilating and decaying DM in the GeV–TeV range, and any constraint on DM candidates depends on how well the astrophysical background is controlled.

Why the antideuteron?

ALICE @ LHC

Phys. Rev.C 97, 024615 (2018)

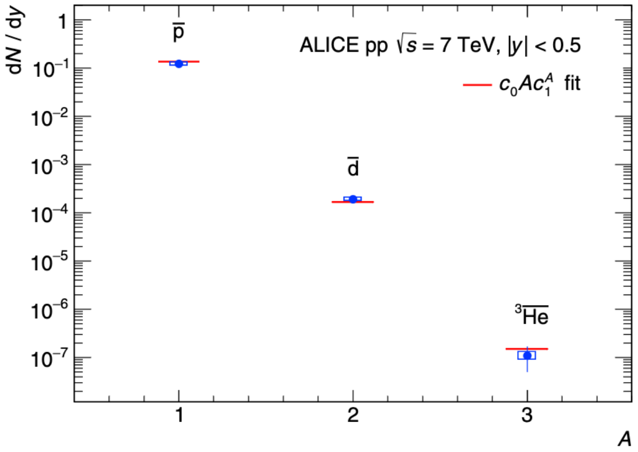
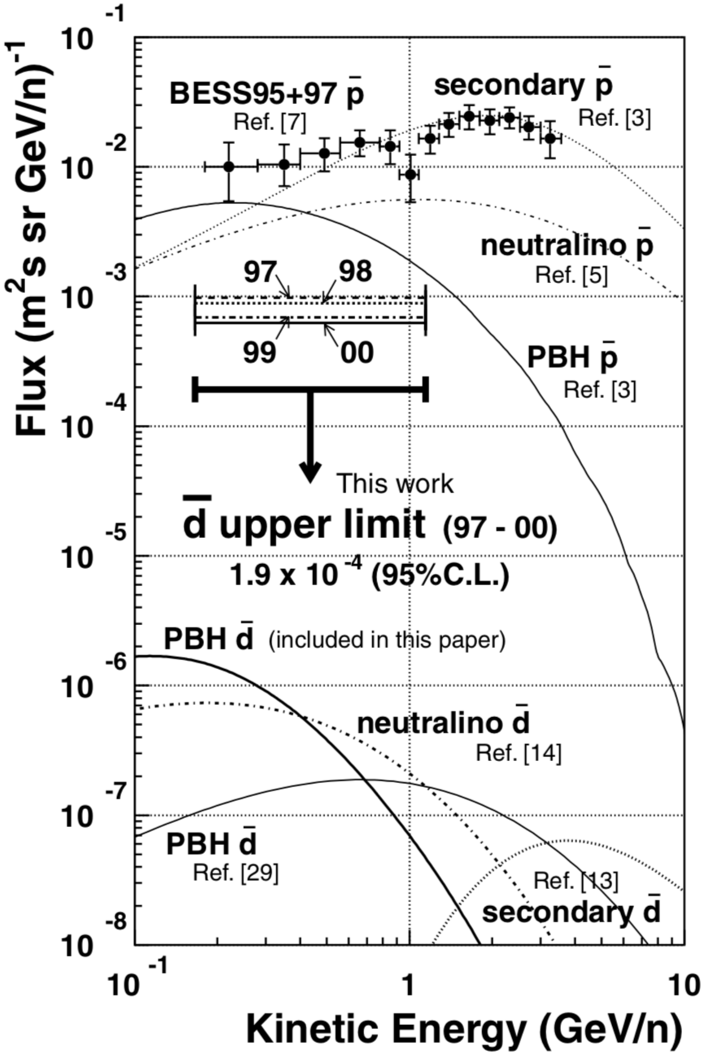


FIG. 12. Integrated yields (dN/dy) of antiprotons, antideuterons and $^3\overline{\text{He}}$ nuclei as a function of the number of antinucleons in inelastic pp collisions at $\sqrt{s} = 7$ TeV. The horizontal lines represent a fit with the function $c_0 A c_1^A$ based on Eq. (1).

Antideuteron

BESS 97-00
PRL 95, 081101 (2005)



Antideuterons have the extremely low astrophysical background. Therefore, the discovery of the antideuteron is directly related to the search for the primary origin.

No antideuteron has been reported in the peer-reviewed literature.

[Next/Future] AMS-02, GAPS, GRAMS, ADHD, ...

Why do we need superconducting magnets for isotope research?

$$(\frac{\delta m}{m})^2 = (\frac{\delta R}{R})^2 + \gamma^4 (\frac{\delta \beta}{\beta})^2$$

$$R\ [GV] = 0.3 B\rho\ [Tm]$$

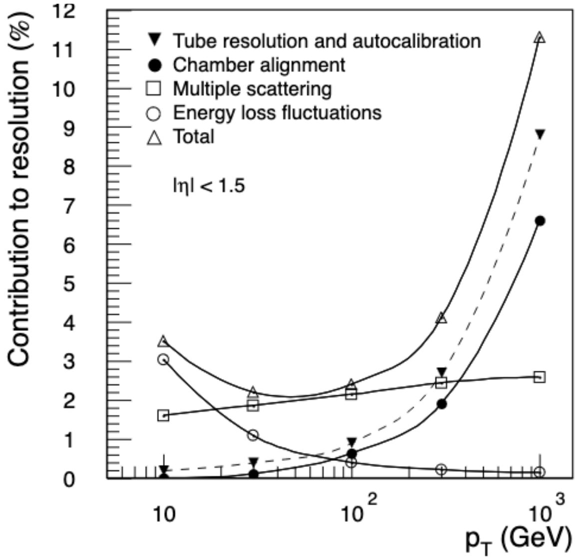
For low-energy regions, the rigidity resolution is limited by multiple scattering.

↓

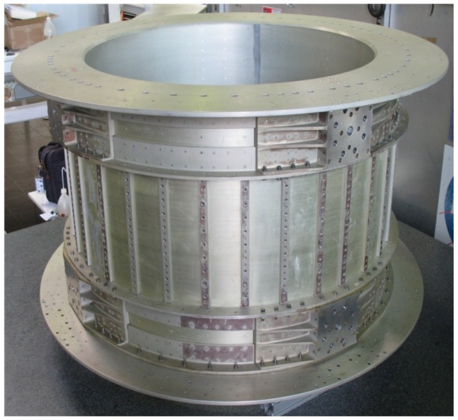
A strong magnetic field is essential for mass resolution.

Drift Chamber

Werner Riegler
CERN-THESIS-1998-001



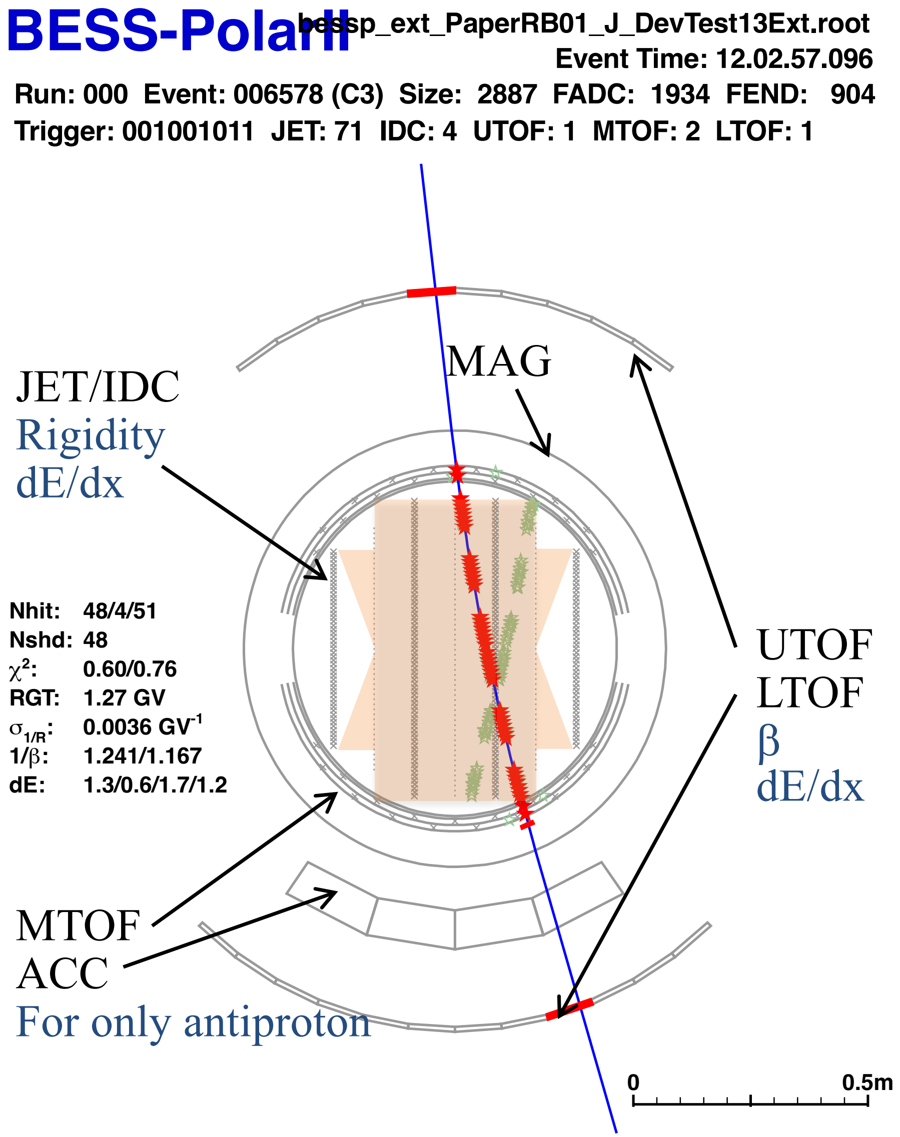
AMS-02: 0.14T



BESS-Polar II: 0.8T

HELIX: 1.0T

10 BESS superconducting magnetic spectrometer



JET/IDC
Rigidity
dE/dx

MAG

UTOF
LTOF
β
dE/dx

MTOF
ACC
For only antiproton

Event display with reconstructed proton track is shown.

Rigidity (MDR:200GV)

Superconducting solenoid: @ 4.4 K
Uniform field (ϕ=0.9m, B=0.8T)
Thin material (2.4 g/cm^2/wall)

Drift chamber: Redundant hits
(σ~150μm, 32~48+4hits)

Charge, Velocity

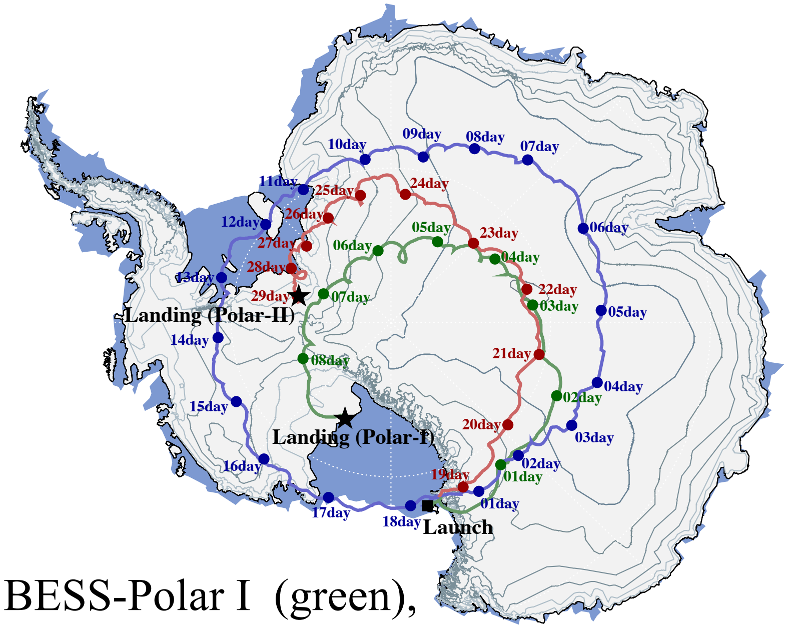
TOF, Chamber: dE/dx measurement
(Z = 1, 2, ...)

TOF: $1/\beta$ measurement (σ~1,2%)

$$m = ZeR\sqrt{1/\beta^2 - 1}$$

11 BESS-Polar I and II experiment

BESS-Polar I & II flights were carried out over Antarctica.

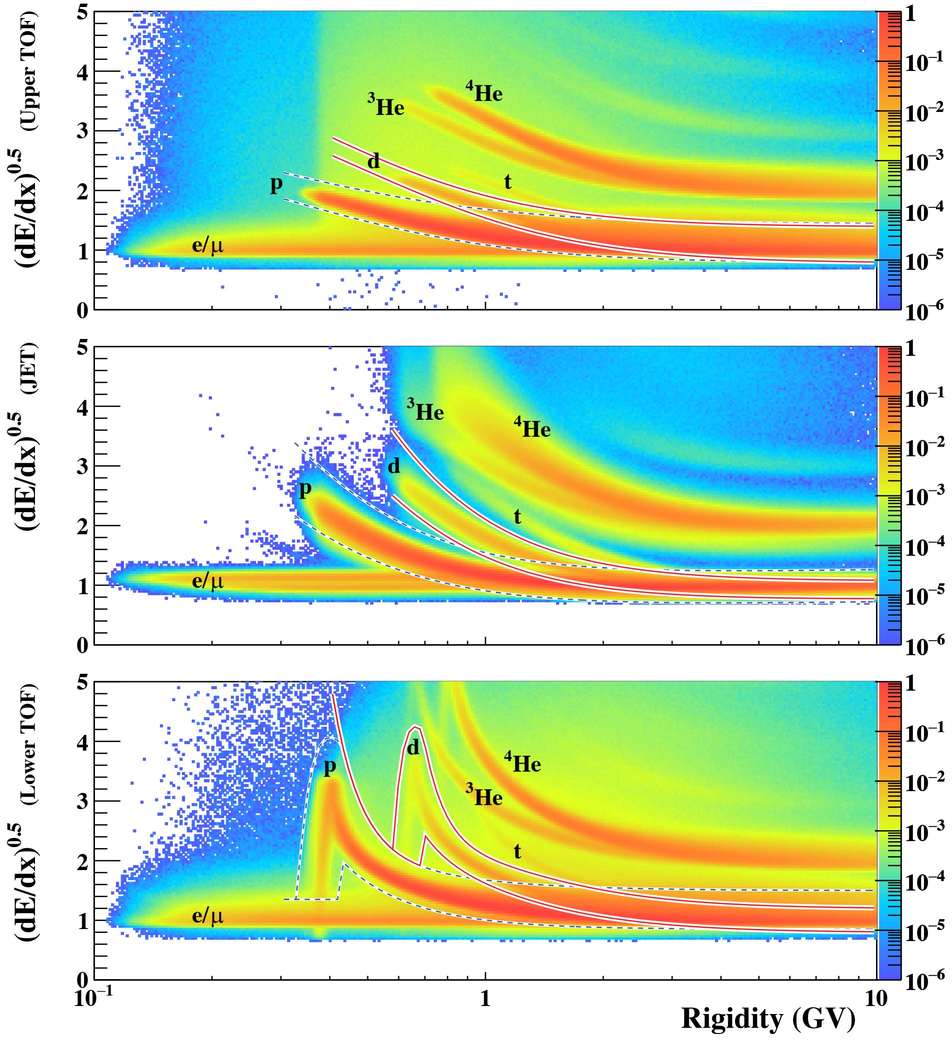


BESS-Polar I (green),
BESS-Polar II (1st :blue, 2nd :red)

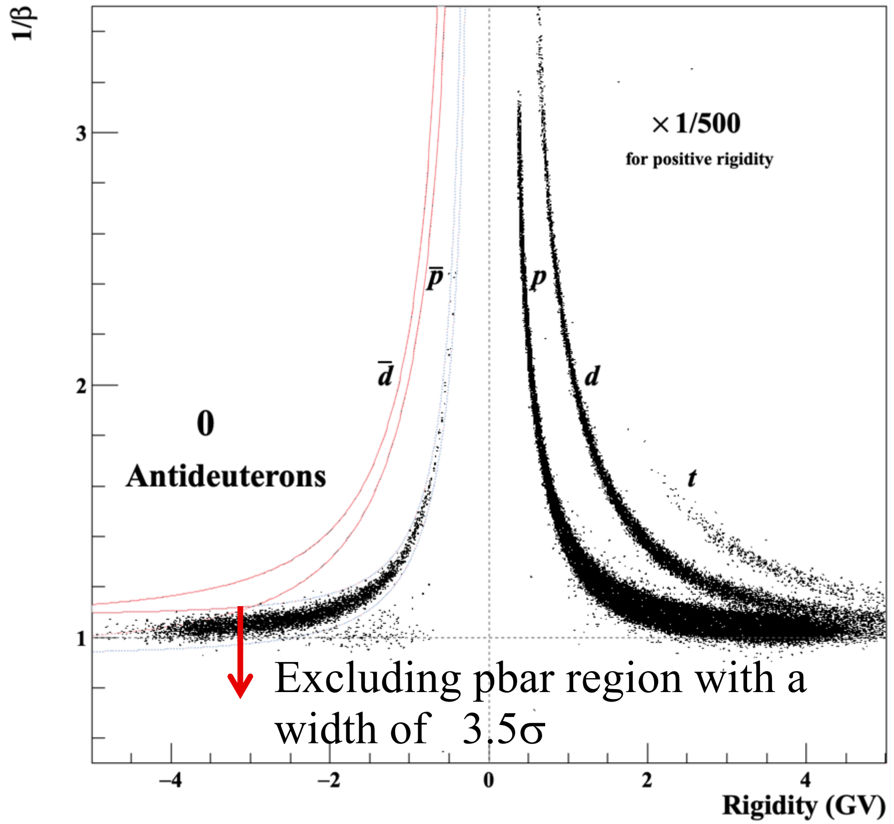
	BESS-Polar I	BESS-Polar II
Launch date	Dec. 13th ,2004	Dec. 23rd , 2007
Observation time	8.5 days	24.5 days
Cosmic-ray observed	9 x 10^8 events	4.7 x 10^9 events
Flight altitude	37~39km (5~4g/cm^2)	~36km (6~5g/cm^2)

12 No cosmic-ray antideuterons were found with BESS-Polar II

dE/dx



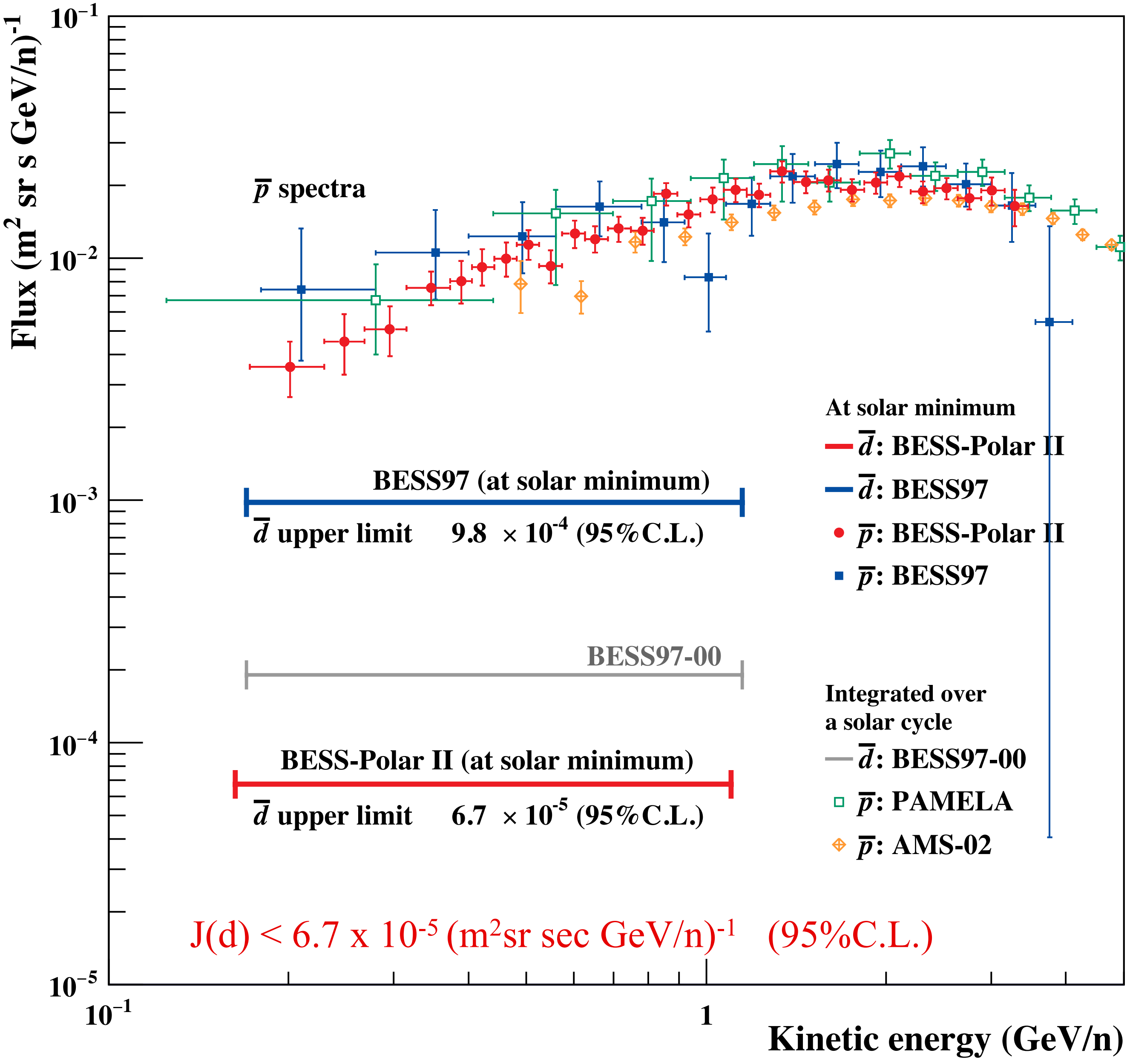
1/β



Excluding pbar region with a width of 3.5σ

- No antideuteron candidate in BESS-Polar II data

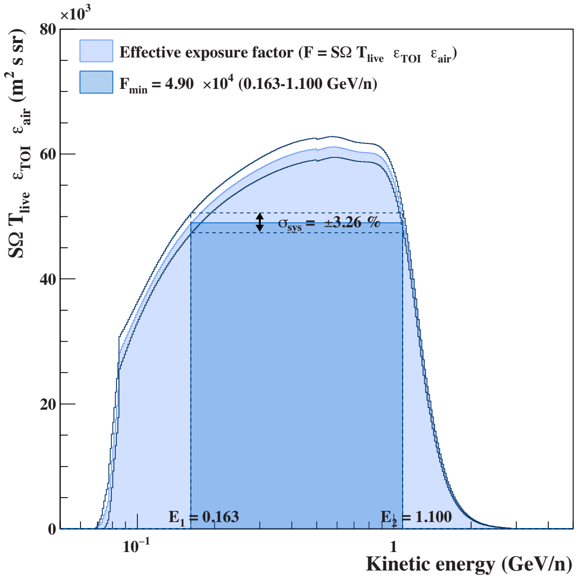
Upper limit on the antideuteron flux



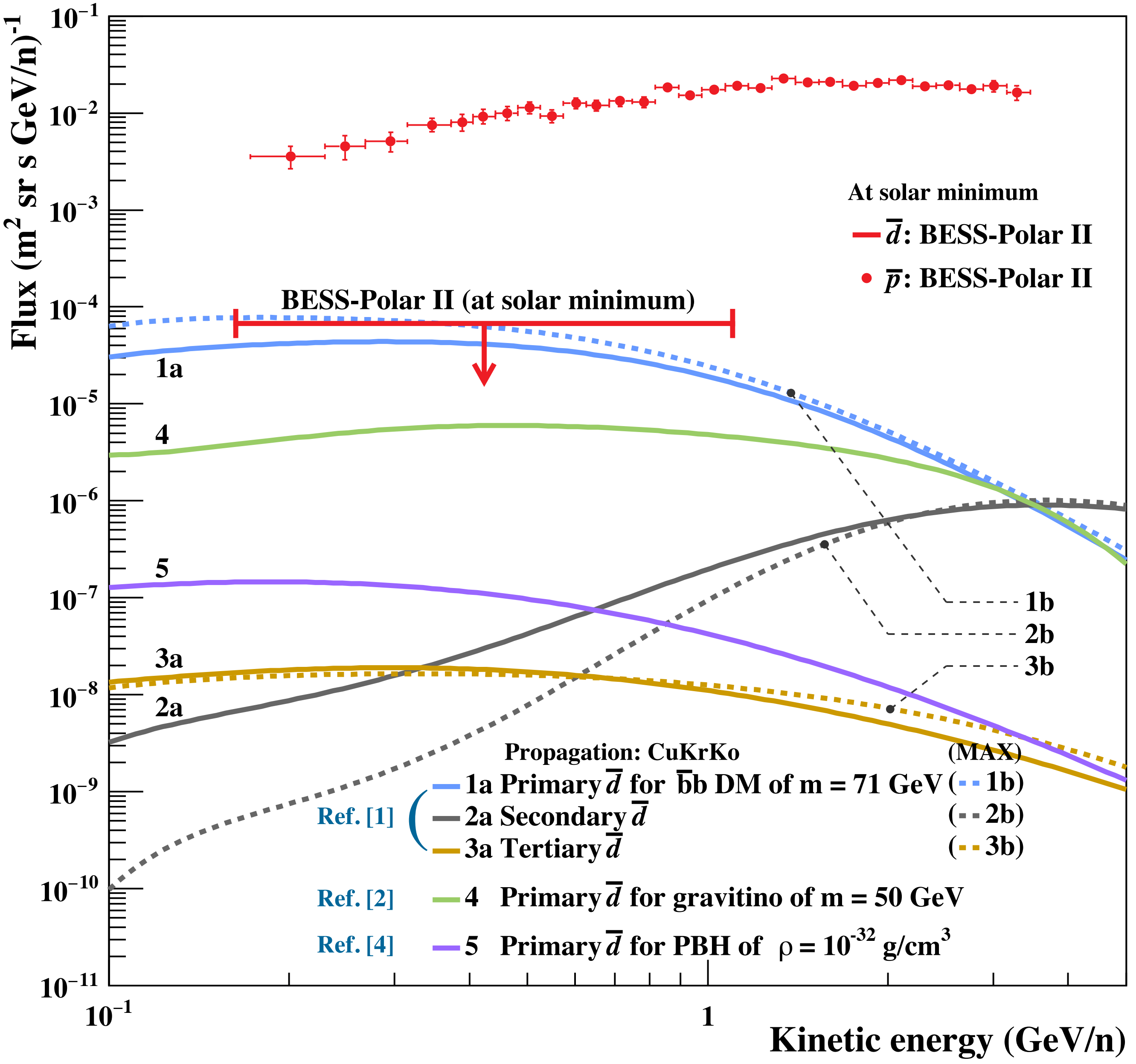
J(d) < 6.7 x 10^{-5} (m^{2}sr sec GeV/n)$^{-1}$ (95%C.L.)

The upper limit on antideuteron flux measured by BESS-Polar II

- With ε_{noint} being 69.2% and ε_{air} being 80.6%, calculated using FTFP_BERT in Geant4.10.07.p03
- The combined systematic uncertainty σ_{sys} is 3.26%



14 Upper limit on the antideuteron flux

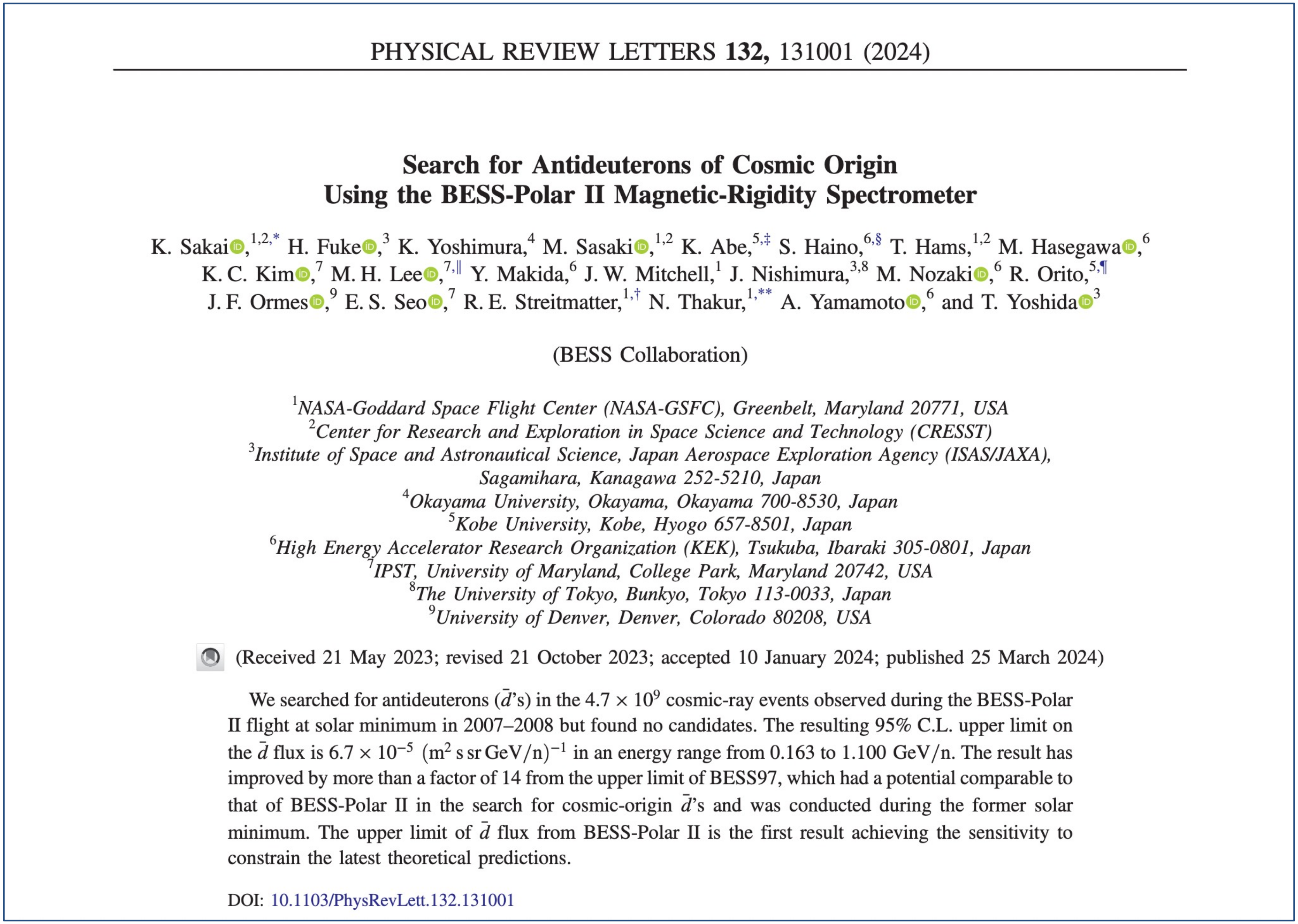


The upper limit on antideuteron flux measured by BESS-Polar II compared with the possible solar-minimum antideuteron flux curves derived from theoretical calculations.

$J(\bar{d}) < 6.7 \times 10^{-5}$
(m^{2}sr sec GeV/n)$^{-1}$
(95%C.L.)

- The upper limit on antideuteron flux from BESS-Polar II is the first result to achieve the sensitivity to constrain the latest theoretical predictions.

15 If you are interested, please read it



PHYSICAL REVIEW LETTERS **132,** 131001 (2024)

Search for Antideuterons of Cosmic Origin Using the BESS-Polar II Magnetic-Rigidity Spectrometer

K. Sakai,[1,2,*] H. Fuke,[3] K. Yoshimura,[4] M. Sasaki,[1,2] K. Abe,[5,‡] S. Haino,[6,§] T. Hams,[1,2] M. Hasegawa,[6]
K. C. Kim,[7] M. H. Lee,[7,∥] Y. Makida,[6] J. W. Mitchell,[1] J. Nishimura,[3,8] M. Nozaki,[6] R. Orito,[5,¶]
J. F. Ormes,[9] E. S. Seo,[7] R. E. Streitmatter,[1,†] N. Thakur,[1,**] A. Yamamoto,[6] and T. Yoshida[3]

(BESS Collaboration)

[1]*NASA-Goddard Space Flight Center (NASA-GSFC), Greenbelt, Maryland 20771, USA*
[2]*Center for Research and Exploration in Space Science and Technology (CRESST)*
[3]*Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), Sagamihara, Kanagawa 252-5210, Japan*
[4]*Okayama University, Okayama, Okayama 700-8530, Japan*
[5]*Kobe University, Kobe, Hyogo 657-8501, Japan*
[6]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[7]*IPST, University of Maryland, College Park, Maryland 20742, USA*
[8]*The University of Tokyo, Bunkyo, Tokyo 113-0033, Japan*
[9]*University of Denver, Denver, Colorado 80208, USA*

(Received 21 May 2023; revised 21 October 2023; accepted 10 January 2024; published 25 March 2024)

We searched for antideuterons ($\bar{d}$'s) in the 4.7×10^9 cosmic-ray events observed during the BESS-Polar II flight at solar minimum in 2007–2008 but found no candidates. The resulting 95% C.L. upper limit on the $\bar{d}$ flux is 6.7×10^{-5} $(\mathrm{m^2\,s\,sr\,GeV/n})^{-1}$ in an energy range from 0.163 to 1.100 GeV/n. The result has improved by more than a factor of 14 from the upper limit of BESS97, which had a potential comparable to that of BESS-Polar II in the search for cosmic-origin $\bar{d}$'s and was conducted during the former solar minimum. The upper limit of $\bar{d}$ flux from BESS-Polar II is the first result achieving the sensitivity to constrain the latest theoretical predictions.

DOI: 10.1103/PhysRevLett.132.131001

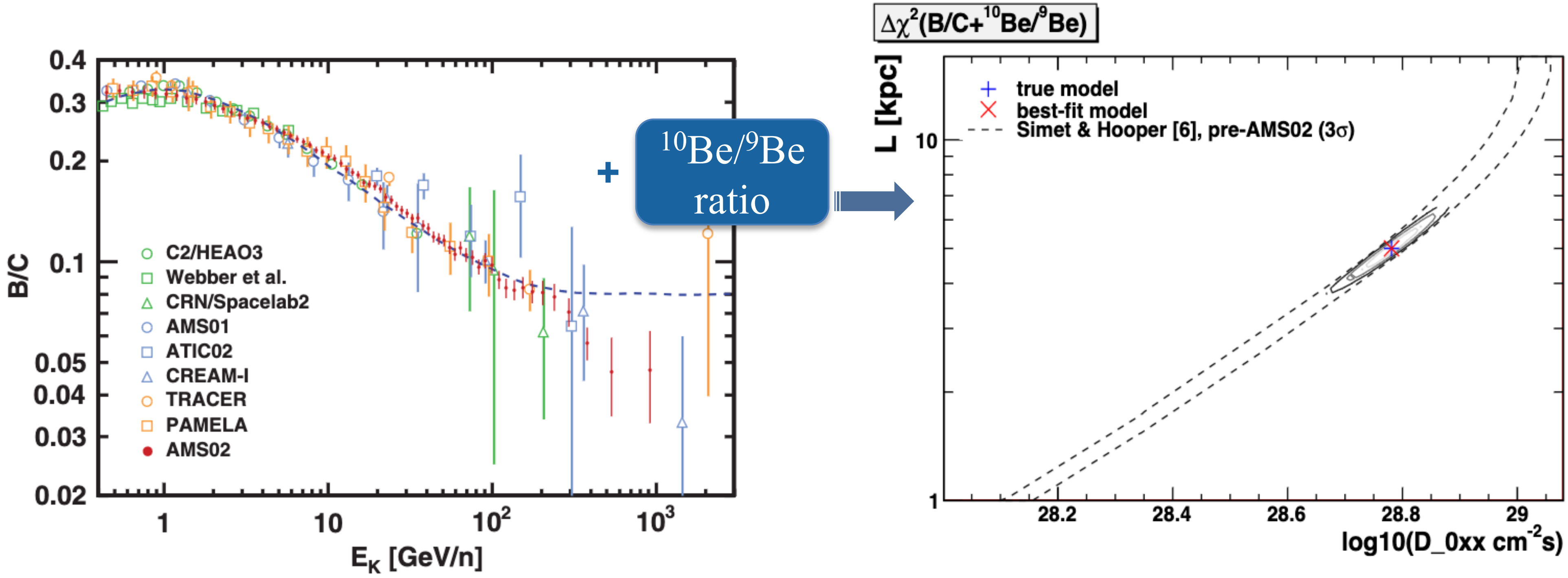
Why is the ^{10}Be/^{9}Be ratio interesting?

Boron to Carbon Flux Ratio

AMS-02
PRL 117, 231102 (2016)

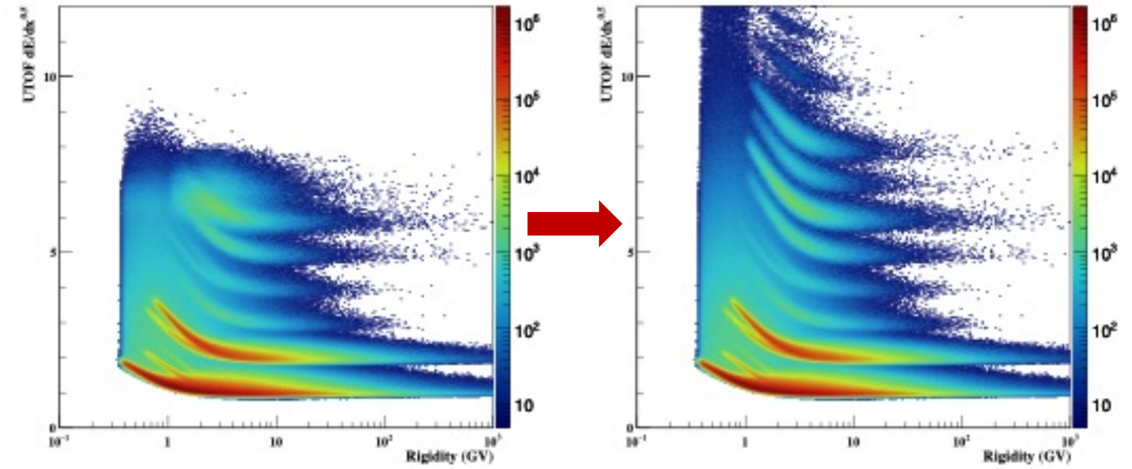
Propagation

Miguel Pato et al
JCAP06(2010)022



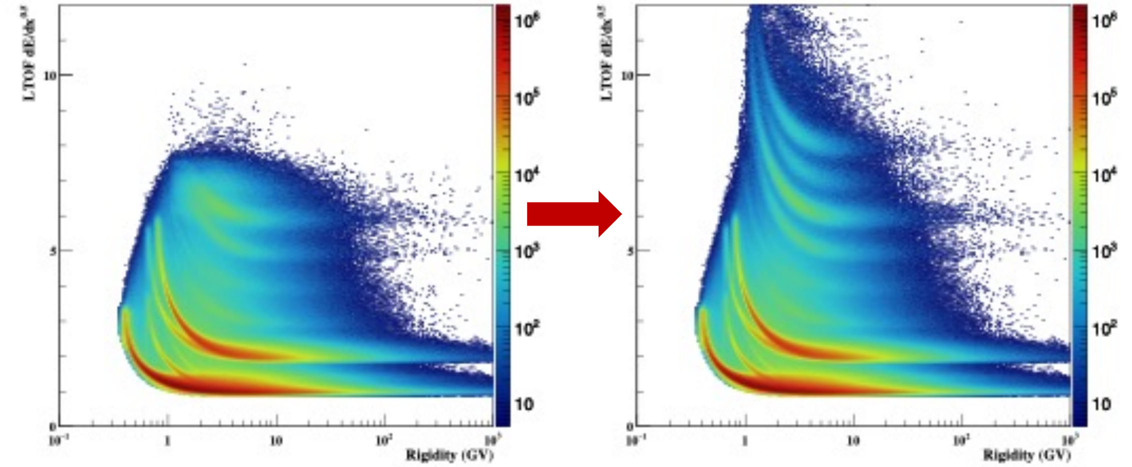
Within more realistic diffusion halo models, the ^{10}Be/^{9}Be ratio can be used, together with constraints from stable secondary-to-primary ratios, to estimate values for the diffusion coefficient and the Galactic halo size.

17 For analyzing Be with BESS data



(a) UTOF dE/dx calcualted by using only 18th dynode

(b) UTOF dE/dx calcualted by using gain stitch from 18th dynode to 13th dynode



(c) LTOF dE/dx calcualted by using only 18th dynode

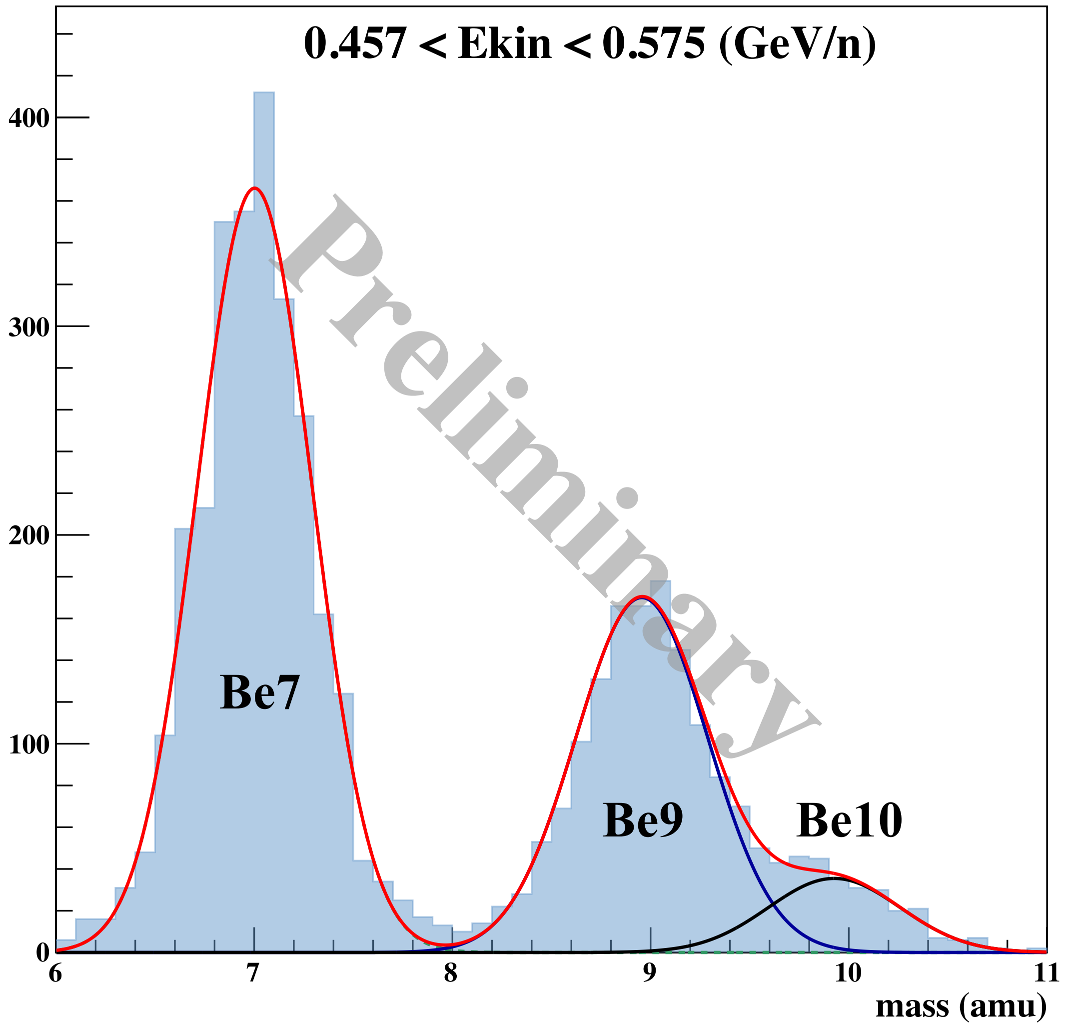
(d) LTOF dE/dx calcualted by using gain stitch from 18th dynode to 13th dynode

The JET chamber is saturated, but TOF identifies particles well up to Z=8.

Since BESS had targeted |Z|= 1 and 2, high-charge particles had never been explored as a possibility for analysis.

It was found that the low gain channel of the PMT in the TOF can be used to identify particles up to higher charges.

Analysis for ^{10}Be/^{9}Be ratio



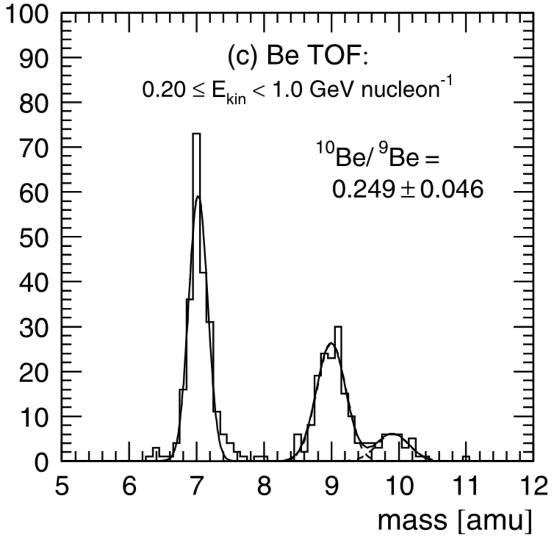
Be analysis in BESS-Polar II data

In the figure, the mass resolution is about 3.5%.

Slightly lower than the resolution of ISOMAX, but with more statistics.

^{10}Be/^{9}Be

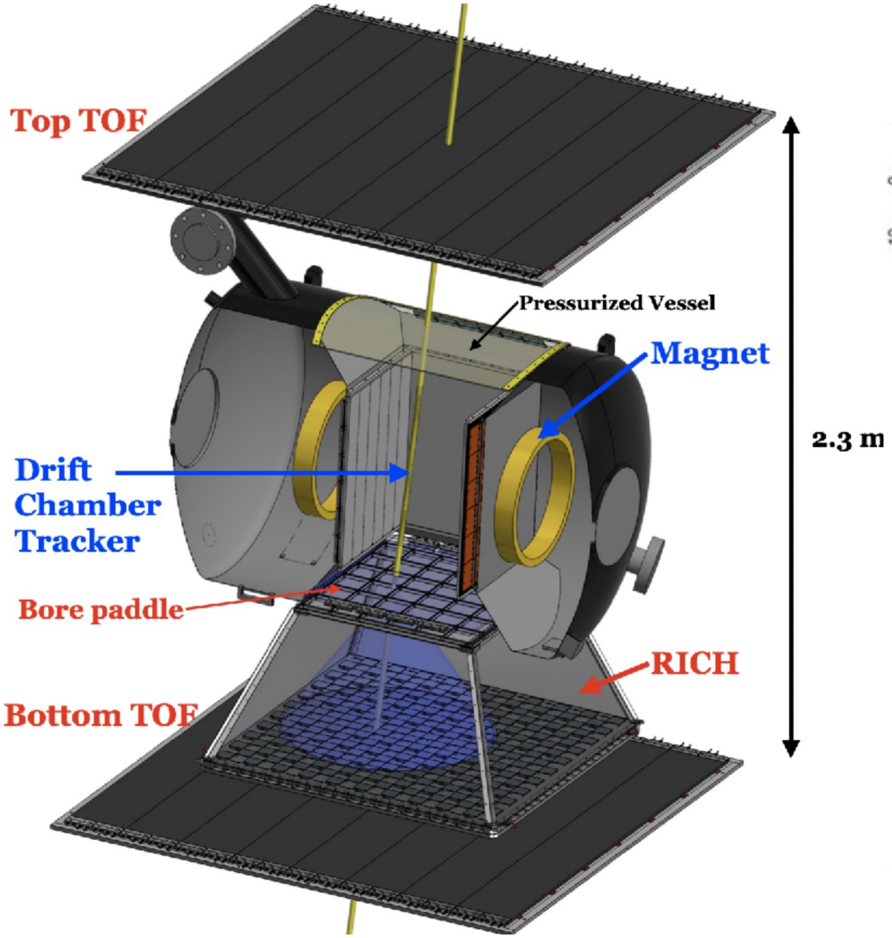
ISOMAX
APJ 611:892–905, 2004 August 20

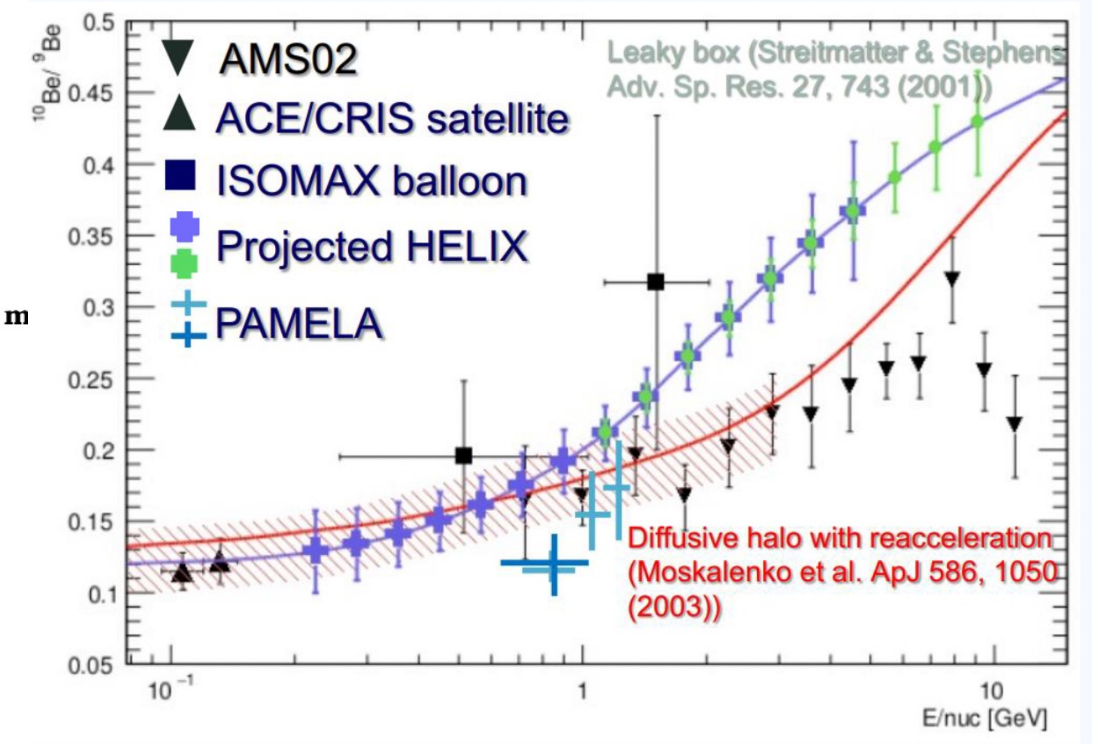


HELIX experiment (I am now a member of UChicago)

HELIX - High-Energy Light Isotope Experiment

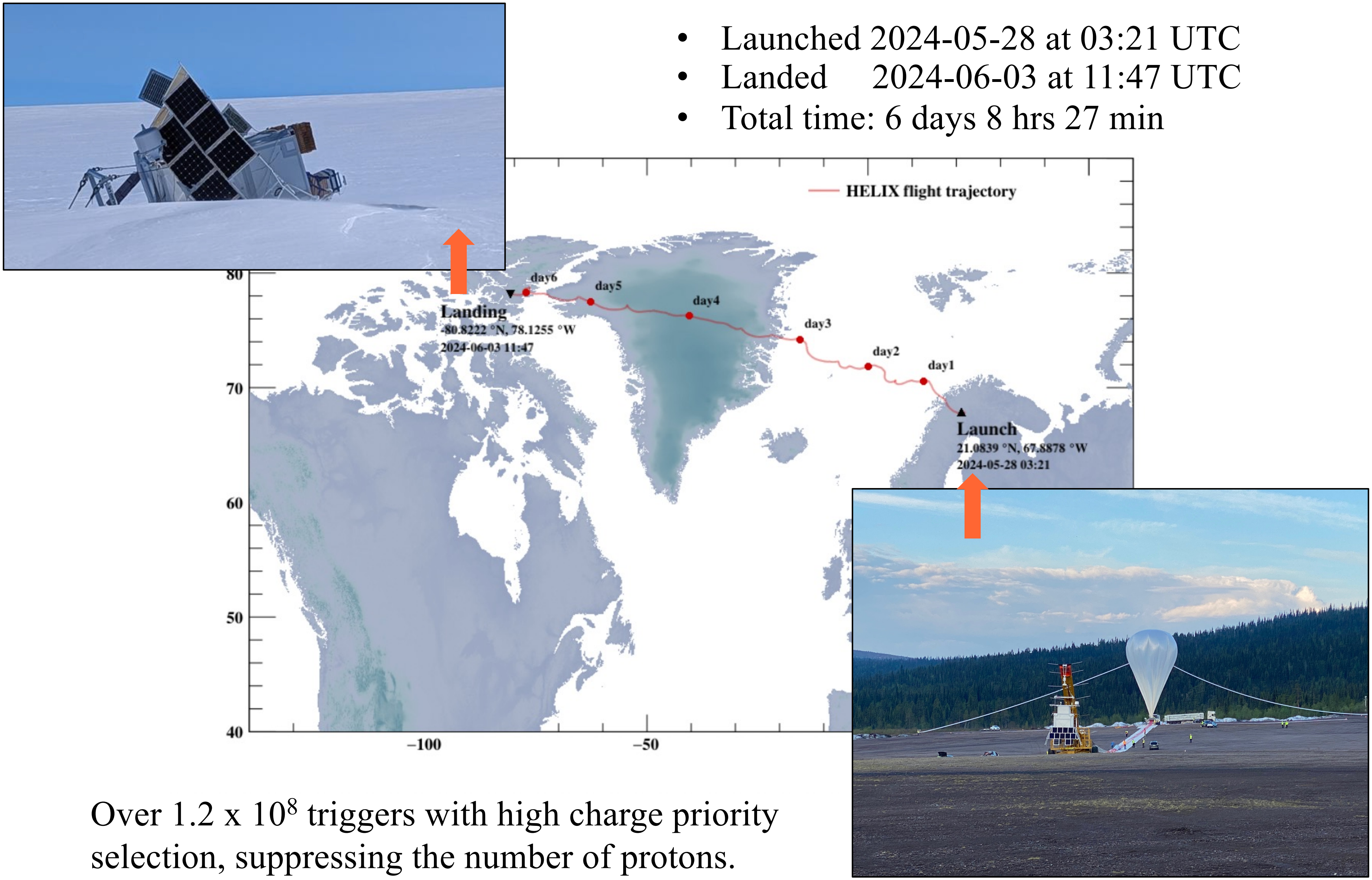
- A superconducting magnet spectrometer, like BESS, with a gas tracker and ring-imaging RICH
- The purpose of employing a RICH is to achieve high-precision β measurements at high energy.
- Aimed at measuring light chemical and isotopic composition, especially the ^{10}Be/^{9}Be ratio





HELIX flight 2024

- Launched 2024-05-28 at 03:21 UTC
- Landed 2024-06-03 at 11:47 UTC
- Total time: 6 days 8 hrs 27 min

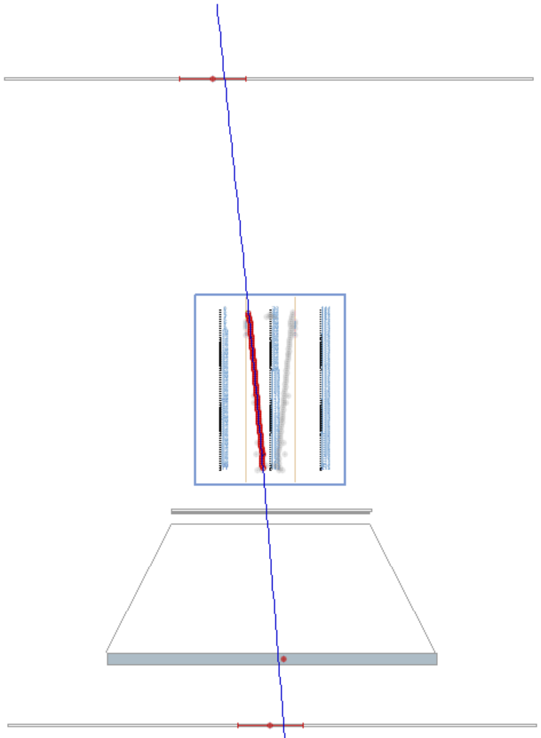


Over 1.2 x 10^8 triggers with high charge priority selection, suppressing the number of protons.

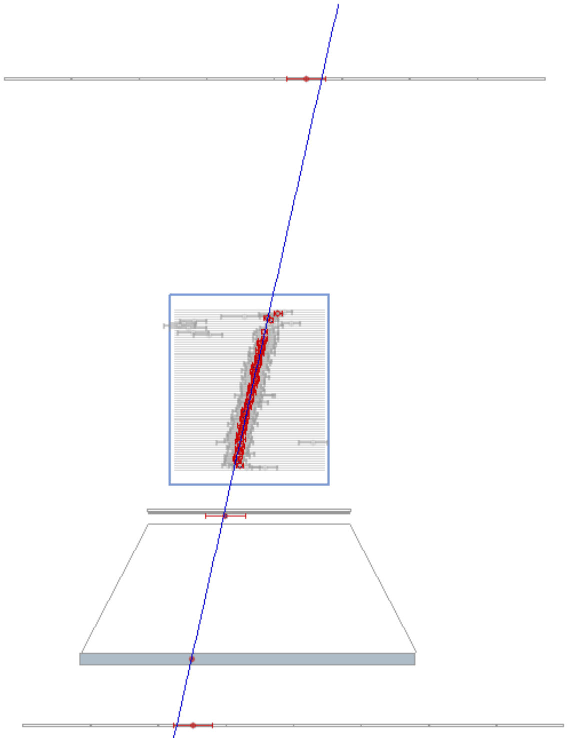
Be candidates in HELIX

- A payload recovery was performed, and the data disk was retrieved.
- Basic functionality of systems confirmed.
- Be candidate selected by dE/dx of Top TOF, Bottom TOF and DCT is shown below.
  - The ring imaging Cherenkov detector (RICH), which reads 12,800 channels on the balloon, was the first challenge but was confirmed to work properly.

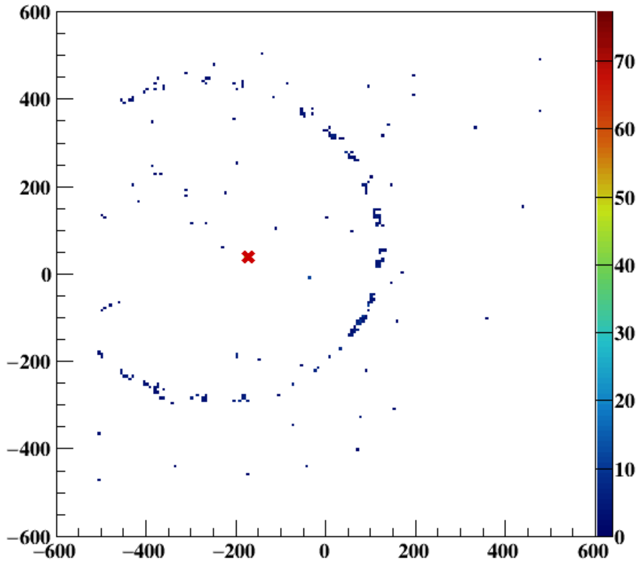
Be candidate



Y-Z view (Bending plane)



X-Z view (Non-bending plane)



RICH

Summary

Antideuteron search in BESS-Polar II: PRL 132, 131001 (2024)

- No antideuteron candidate in BESS-Polar II.
- New preliminary upper limit $J(\bar{d}) < 6.7 \times 10^{-5}$ $(m^2 sr\ sec\ GeV/n)^{-1}$ (95%C.L.)
    - Compared with the data taken in the solar minimum (BESS97), order of magnitude improvement has been achieved.
    - The upper limit is the first result to achieve the sensitivity to constrain the latest theoretical predictions.

Possible Future Results

- Lower energy antiproton flux by using Middle TOF trigger in BESS-Polar II
- $^{10}Be/^{9}Be$ ratio in BESS-Polar II
- $^{10}Be/^{9}Be$ ratio covering higher energy in HELIX

Backup

A BESS collaboration

BESS is US-Japan collaborative program.

J. W. Mitchell (PI, US, NASA/GSFC)

National Aeronautical and Space Administration / Goddard Space Flight Center (NASA/GSFC)

University of Maryland

University of Denver
(Since June 2005)

A. Yamamoto (PI, Japan, KEK)

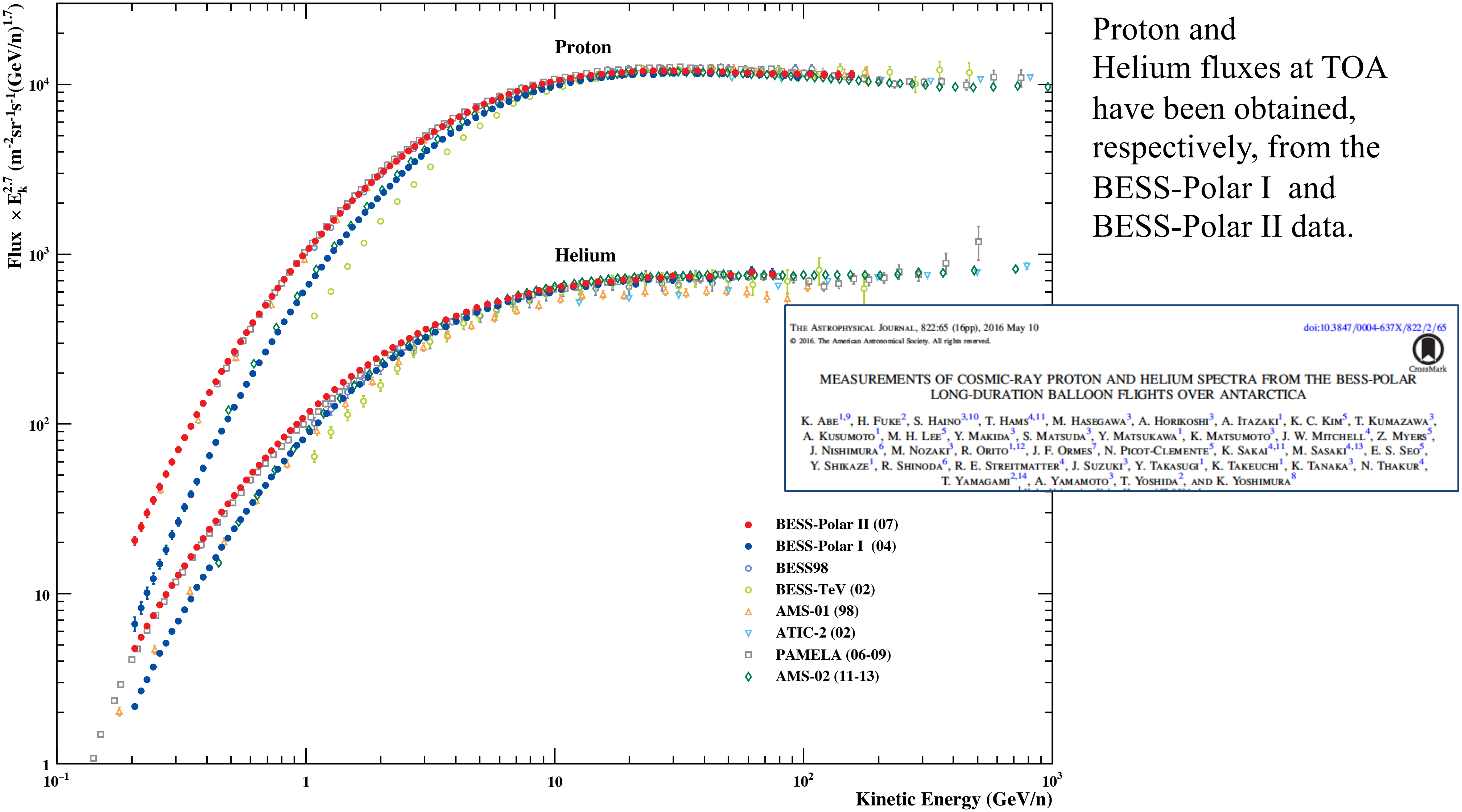
High Energy Accelerator Research Organization (KEK)

The University of Tokyo

Kobe University

Institute of Space and Astronautical Science/JAXA

B Proton and Helium spectra with BESS-Polar



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MEASUREMENTS OF COSMIC-RAY PROTON AND HELIUM SPECTRA FROM THE BESS-POLAR LONG-DURATION BALLOON FLIGHTS OVER ANTARCTICA

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Proton and Helium fluxes at TOA have been obtained, respectively, from the BESS-Polar I and BESS-Polar II data.

C Upper limit calculation

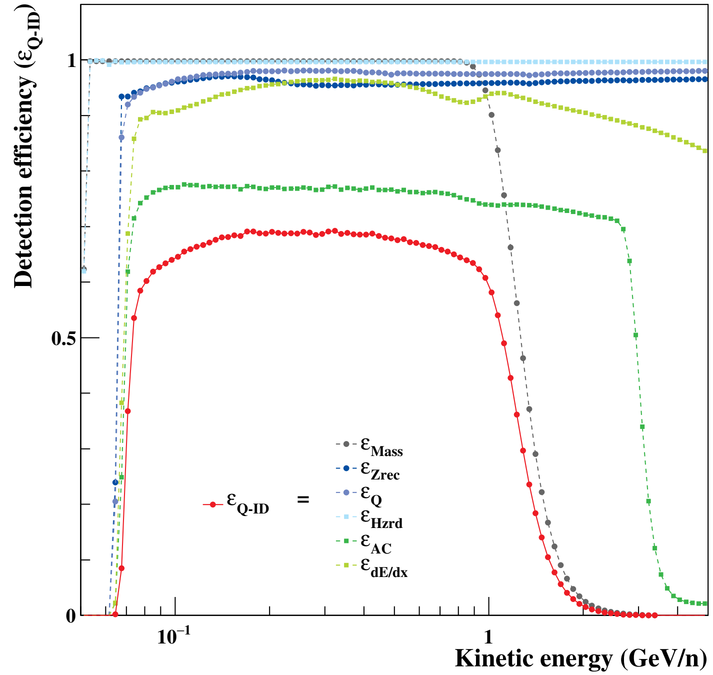
$$\Phi_{\bar{d}} = \frac{N_{poisson}}{F_{min} \cdot (E_2 - E_1)}$$

$$F_{min} = S\Omega \cdot T_{live} \cdot \varepsilon_{TOI} \cdot \varepsilon_{\mathrm{air}}$$

$$\varepsilon_{TOI} = \varepsilon_{\mathrm{Q-ID}} \cdot \varepsilon_{\mathrm{other}} \cdot \varepsilon_{\mathrm{noint}}$$

$N_{poisson}$: The 95% C.L. upper limit (=3.00)
F_{min} : Minimum effective exposure factor
E_1, E_2 : The lower-end, the upper-end E2 of one bin
$S\Omega$: Geometrical acceptance
T_{live} : Live time
ε_{TOI} : The total efficiency
$\varepsilon_{\mathrm{air}}$: Survival fraction through atmosphere
$\varepsilon_{\mathrm{Q-ID}}$: Detector selection efficiencies
$\varepsilon_{\mathrm{other}}$: The other efficiencies
$\varepsilon_{\mathrm{noint}}$: The non-interaction efficiency

$\varepsilon_{\mathrm{TOI}}$: total efficiency



$S\Omega \cdot \varepsilon_{\mathrm{noint}}$