22nd European Cosmic Ray Symposium

The BESS experimental astroparticle physics program

Makoto Sasaki, John W. Mitchell

for the BESS Collaboration

<u>Outline:</u>

- Overview of the BESS Program
- BESS-Polar Program
- New Results from BESS-Polar II

Overview of the BESS Program

BESS Collaboration

Balloon-borne Experiment with a Superconducting Spectrometer

High Energy Accelerator Research Organization(KEK)

National Aeronautical and Space Administration Goddard Space Flight Center

The University of Tokyo

University of Maryland

BESS Collaboration

Kobe University

University of Denver

Institute of Space and Astronautical Science/JAXA

BESS Program

- Balloon-borne Experiment
  - Steady improvement
    - Continuously upgrade and modify detector components
    - Various new scientific subjects
  - Long period of successive observations
    - Cover more than full cycle (11 years) of solar activity
  - Education/Training
    - Young people can be responsible for essential parts of the experiment (20 students/engineers awarded with Ph.D)

with a

- Superconducting Spectrometer
  - Large acceptance
    - High statistics
  - Uniform magnetic field
    - High resolution MDR 200 – 1400 GV
  - Transparent
    - Thin Solenoid 4.4 g/cm^2 (2.2 g/cm^2)
  - Definitive mass ID

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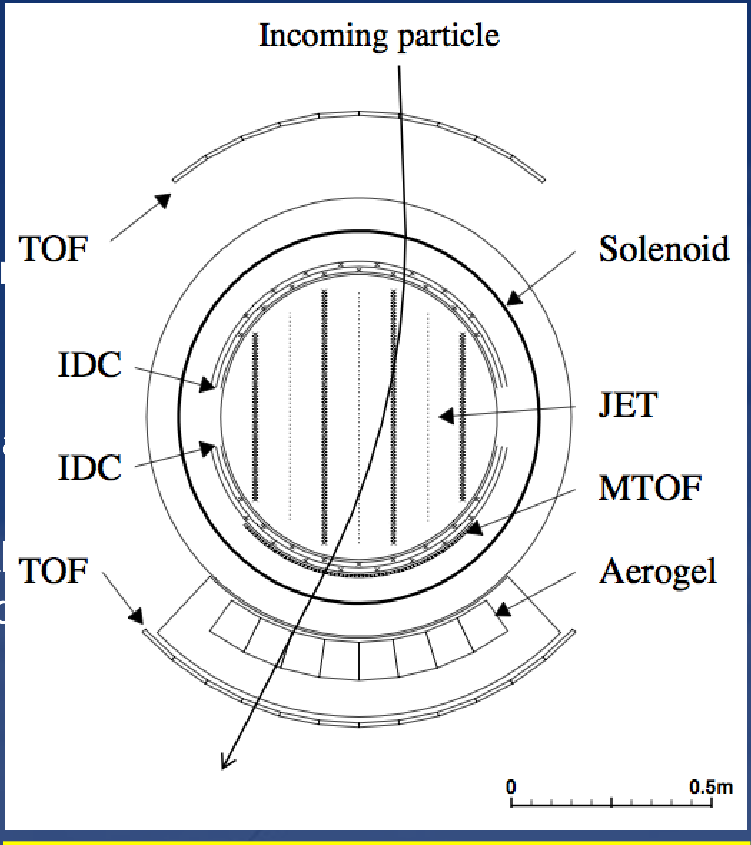
with a

- **S**uperconducting **S**pectrometer
  - Large acceptance
    - High Statistics
  - Uniform magnetic field
    - High, uniform resolution (MDR ~ 200 GV)
  - Transparent
    - Thin Solenoid 4.4 g/cm^2 (2.2 g/cm^2)
  - Definitive mass ID

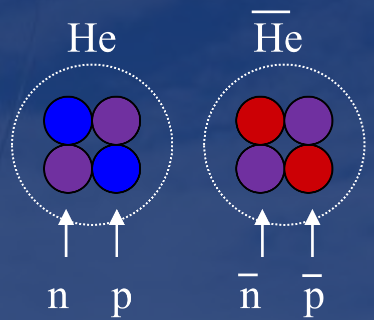
$$m = ZeR\sqrt{1/\beta^2 - 1}$$



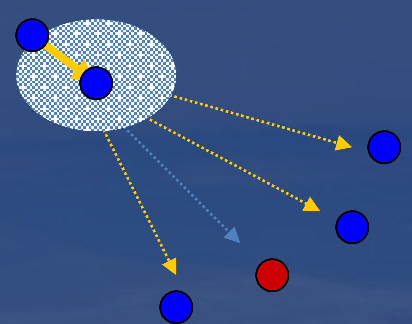
- JET, IDC drift chambers: rigidity
- Time-of-flight system (TOF): velocity and charge
- Aerogel Cherenkov detector (ACC, n=1.02/1.03): background rejection

Science Objectives

- Measure cosmic-ray particles and antiparticles as a probe to study the early Universe
  - Antinuclei:
    - Antihelium/antiduteron; none observed in cosmic rays by any instrument
      - Fundamental question: symmetry of matter and antimatter
  - Antiprotons:
    - **$\bar{p}/p$ ~ 10^{-5} @ 1 GeV**
      - Mainly secondary origin; cosmic ray interactions with ISM
      - Possible small primary component;
        - Evaporation by Hawking radiation of primordial black holes (PBH) initially near ~5×10^{14}g?
        - Annihilation of super-symmetric particles?



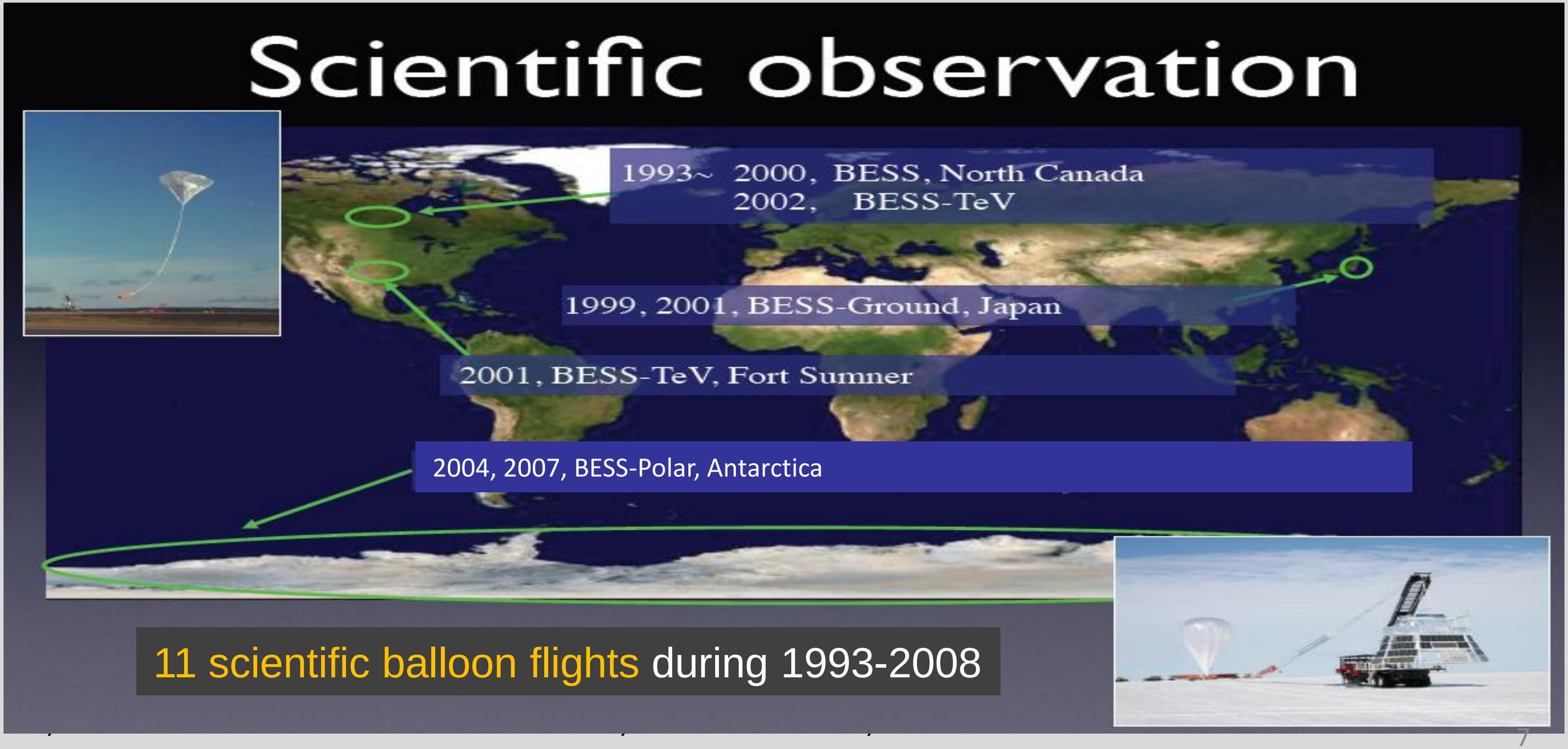
- Quantify charge-sign dependent Solar modulation
- Measure cosmic ray spectra and composition
  - p, He, Li, Be isotopic and elemental spectra
  - B, C, N, O elemental spectra
  - Atmospheric muons



$p+p \rightarrow p+\bar{p}+p+p$

BESS Flight History

- **Nine northern latitude BESS flights (1+ days) 1993-2002**
- **Two Antarctic BESS-Polar flights (8.5 & 24.5 days) 2004, 2007**



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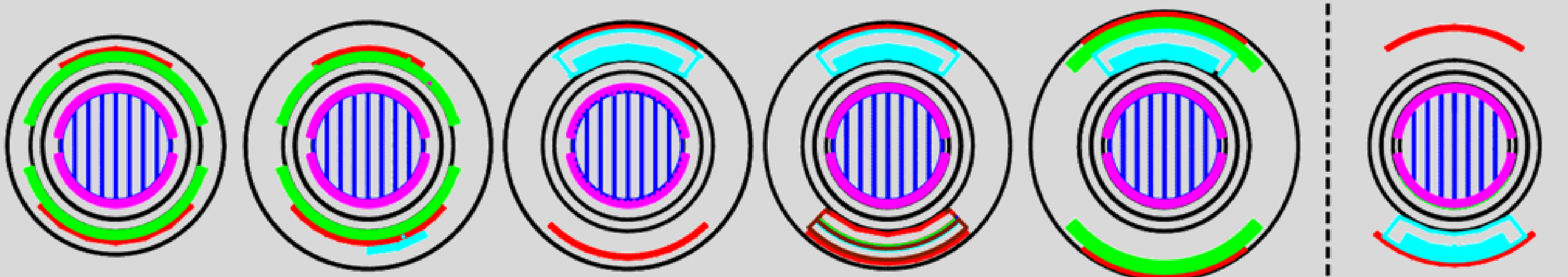

BESS-93,94	BESS-95	BESS-97,98	BESS-99,00	BESS-TeV (2001-2002)	BESS-Polar (2004, 2007)
	Larger Vessel			Larger Vessel	No Vessel
σ_{TOF} =300 ps	σ_{TOF} =110 ps	σ_{TOF} =70 ps Aerogel C 97 n=1.03 $\bar{p}$ 0.2-3.5 GeV 98 n=1.02	Shower Counter $2X_0$ Lead e/μ sep.	New ODC's New JET/IDC's p/He up to 1 TeV	New Mag (ultra thin)
$\bar{p}$ 0.2-0.6 GeV	$\bar{p}$ 0.2-1.4 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.1-4.2 GeV
6, 2	43	415, 398	668, 558	147	1512, > 8000

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				2001-2002	**2004, 2007**
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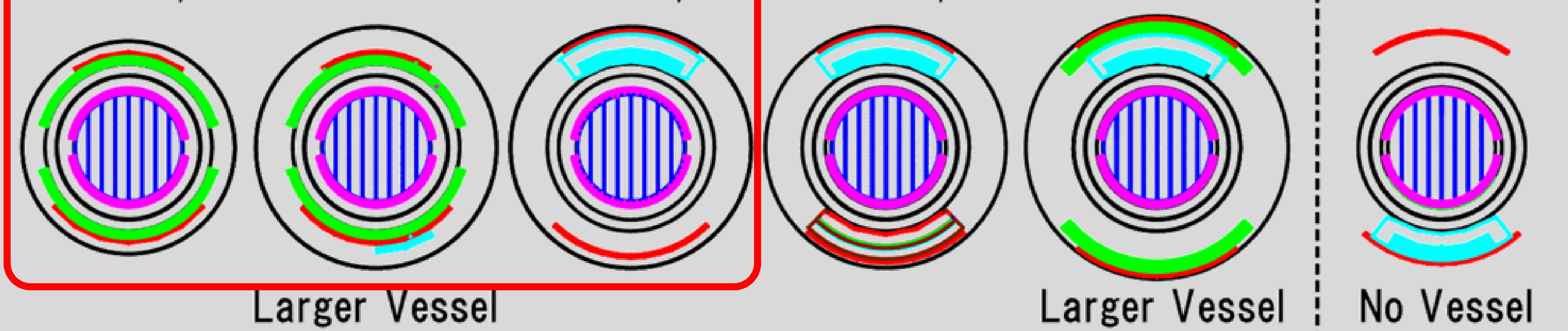

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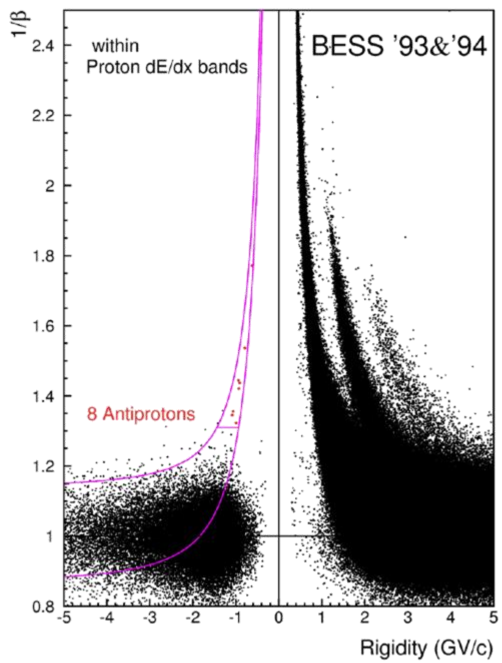
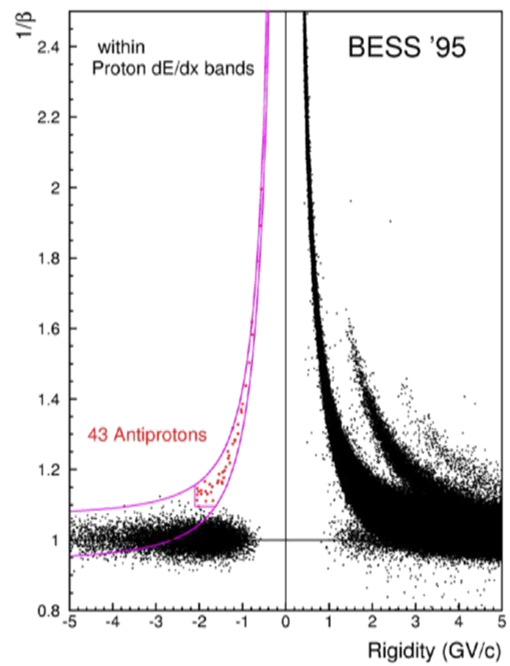
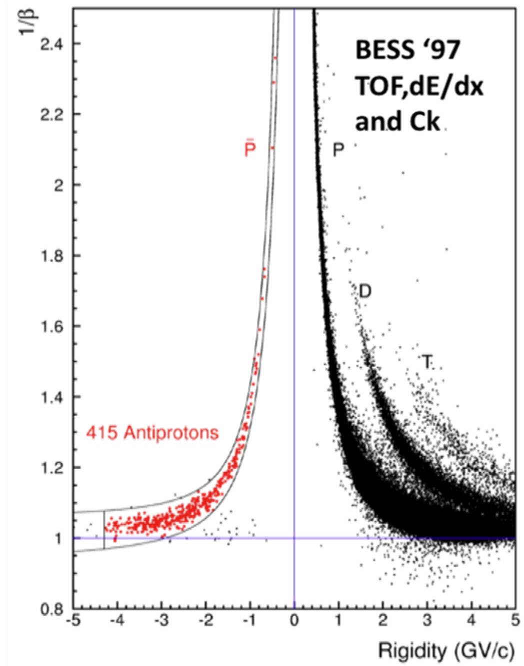
Evolution of the BESS Instrument

<table>
<tr><th></th><th>1993 +1994</th><th>1995</th><th>1997~</th></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>σ_{TOF}</td><td>300 psec</td><td>110 psec</td><td>70 psec</td></tr>
<tr><td>N_{obs}</td><td>8</td><td>43</td><td>~500/year</td></tr>
<tr><td>$E_{\bar{p}}$</td><td>0.2 ~ 0.6 GeV</td><td>0.2 ~ 1.4 GeV</td><td>0.2 ~ 4.2 GeV</td></tr>
<tr><td></td><td>**First mass-ID**</td><td>**New TOF**</td><td>**Cherenkov Veto**</td></tr>
</table>

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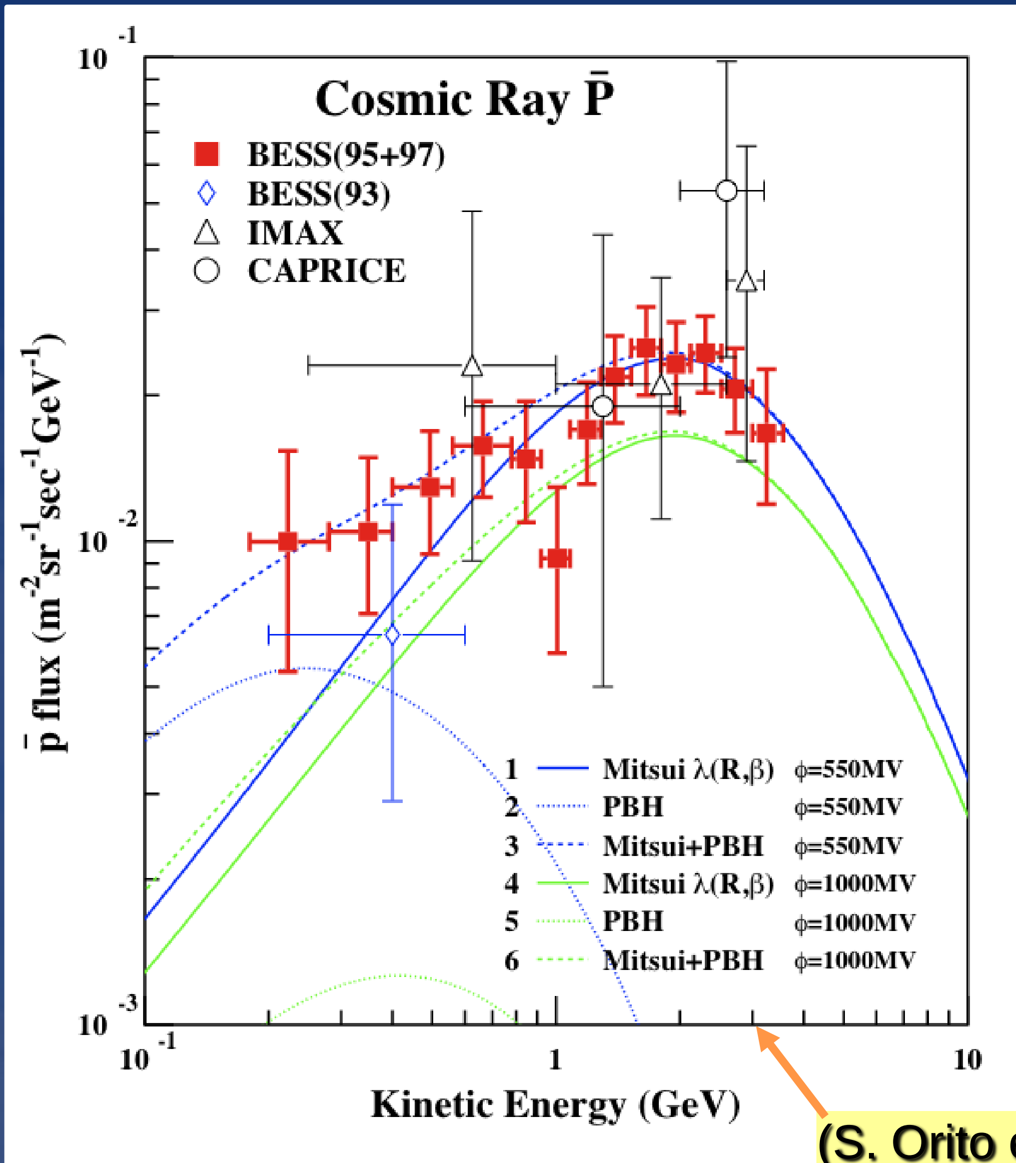
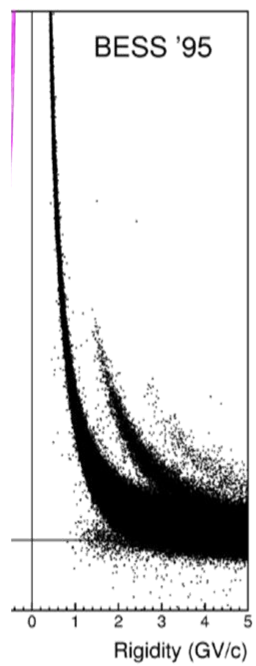
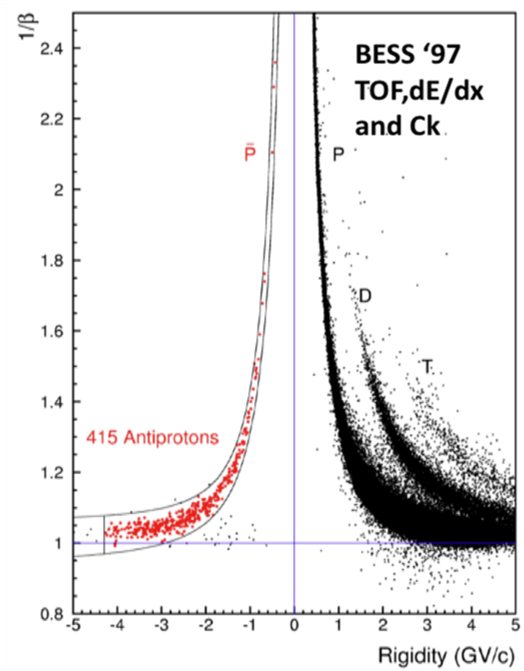
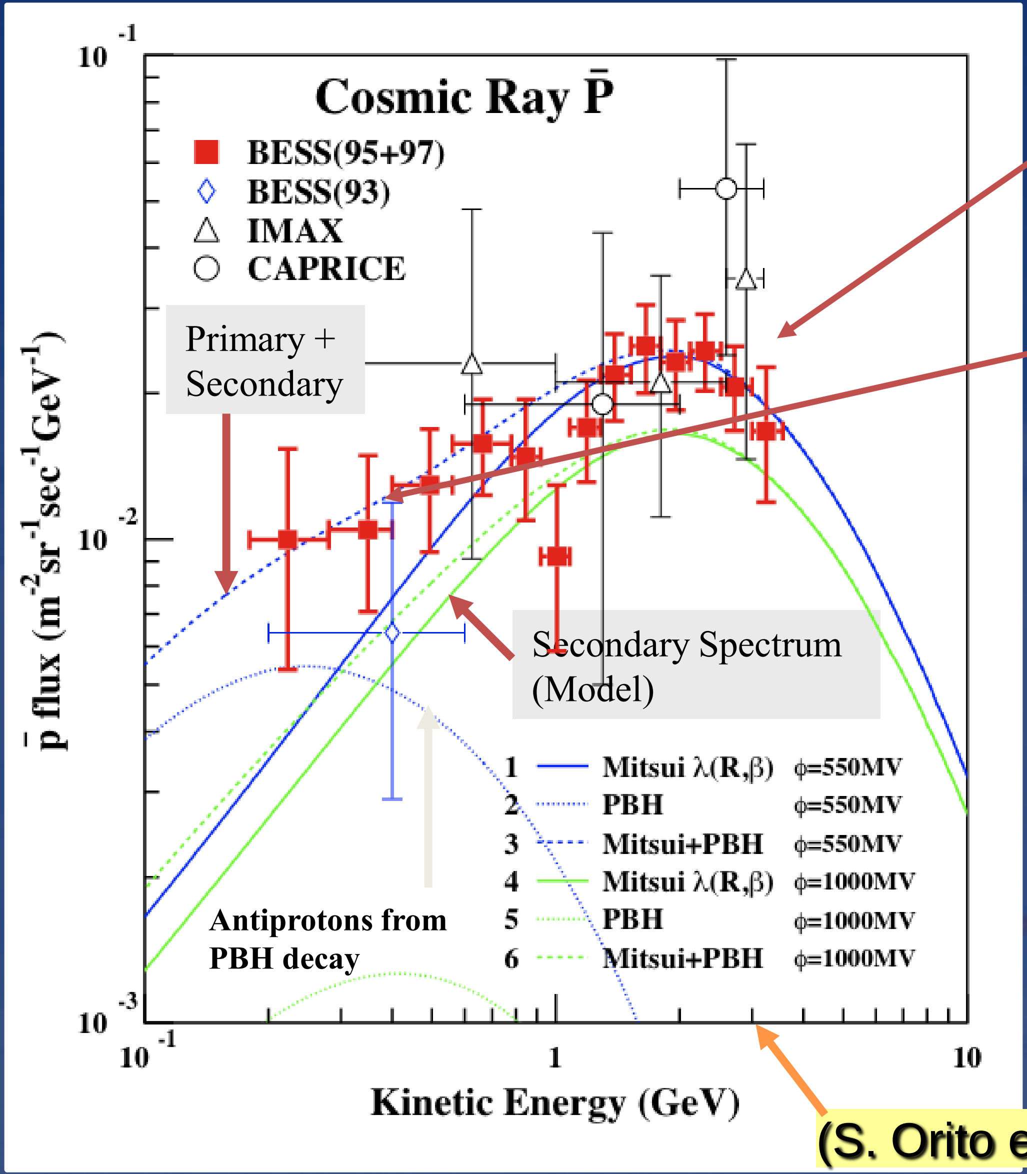


95	1997~
	
sec	70 psec
3	~500/year
4 GeV	0.2 ~ 4.2 GeV
TOF	Cherenkov Veto

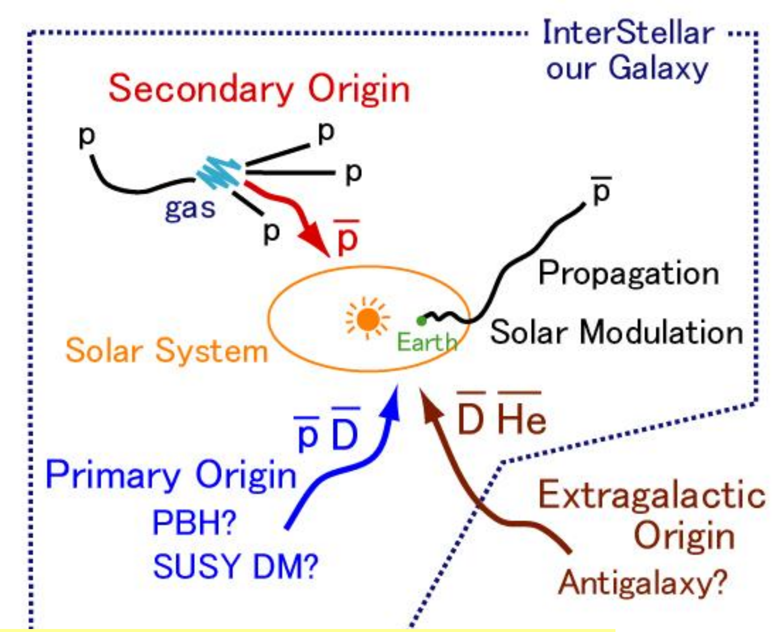
(S. Orito et al. PRL, Vol. 84, No. 6, 2000)

Antiproton Measurement



Most antiprotons are nuclear secondaries - characteristic spectral peak ~2 GeV

Some indication of additional component in low energy Solar minimum data!



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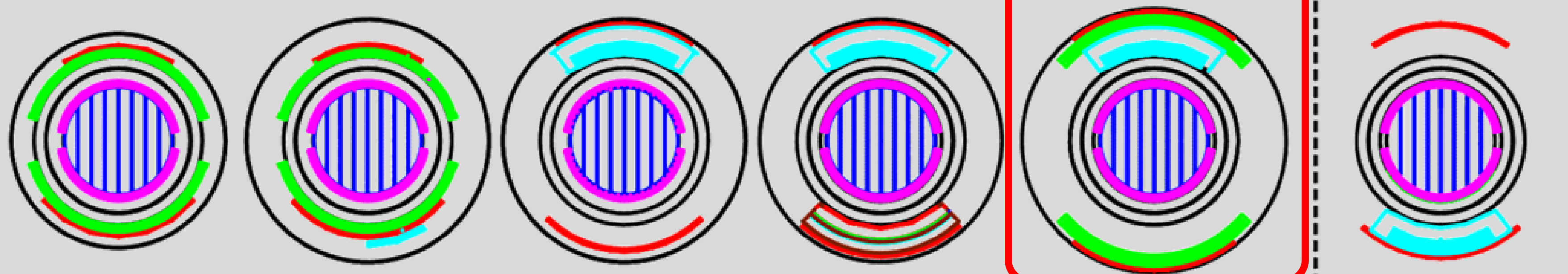

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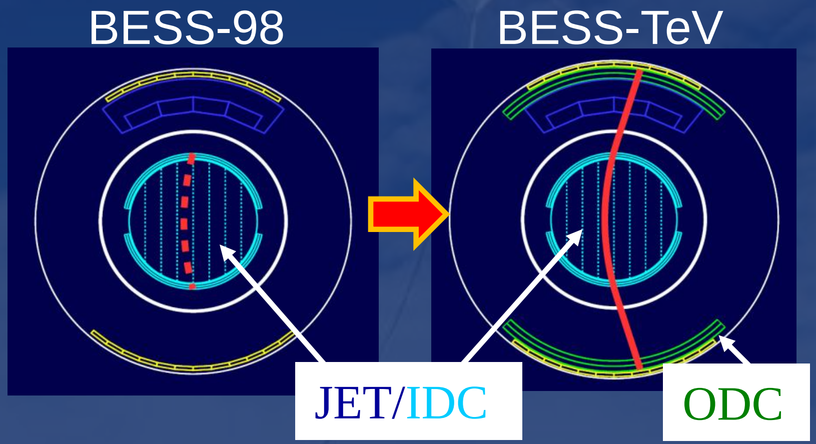
BESS-TeV Flight

$\text{p} + \text{p} \;\text{-->}\; \text{p} + \bar{\text{X}}$

$$\text{p} + A \rightarrow \pi + \pi + \cdots$$
$$\pi \rightarrow \mu + \nu_\mu$$
$$\mu \rightarrow e + \nu_e + \nu_\mu$$

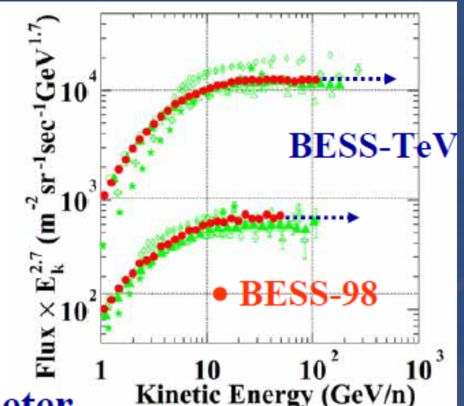
Fundamental Data for
- Cosmic-ray physics
- Atmospheric Neutrino Calculation

	BESS-98	BESS-TeV
JET/IDC; **N**-track(δx)	24 (200 μm)	52 (150 μm)
JET/IDC/ODC; **L**-track	0.8 m	1.6 m
MDR	**200 GV**	**1400 GV**



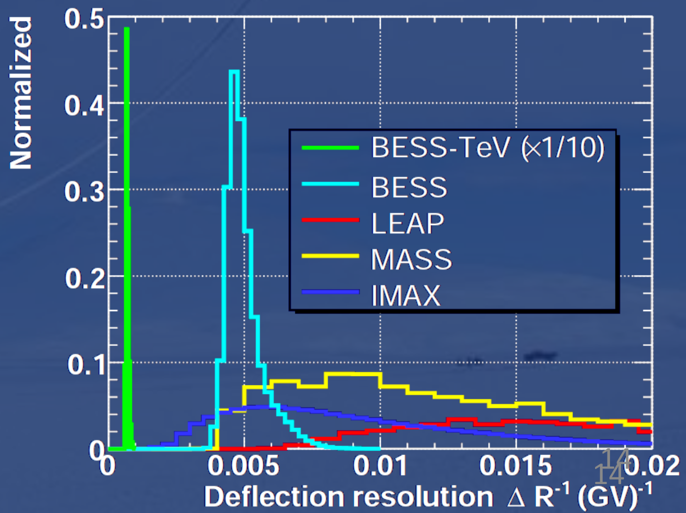
Measurements with BESS

Proton up to 100 GeV
→ **> 500 GeV**
Helium up to 50 GeV/n
→ **> 200 GeV/n**



Upgrade of the BESS spectrometer

Improvement of rigidity resolution
(Maximum Detectable Rigidity, MDR)



BESS-TeV Flight

$p + p \to p + \bar{X}$

$$p + A \to \pi + \pi + \cdots$$

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BESS-98

BESS-TeV

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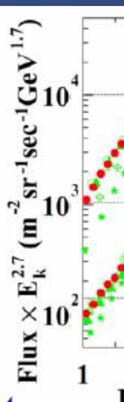

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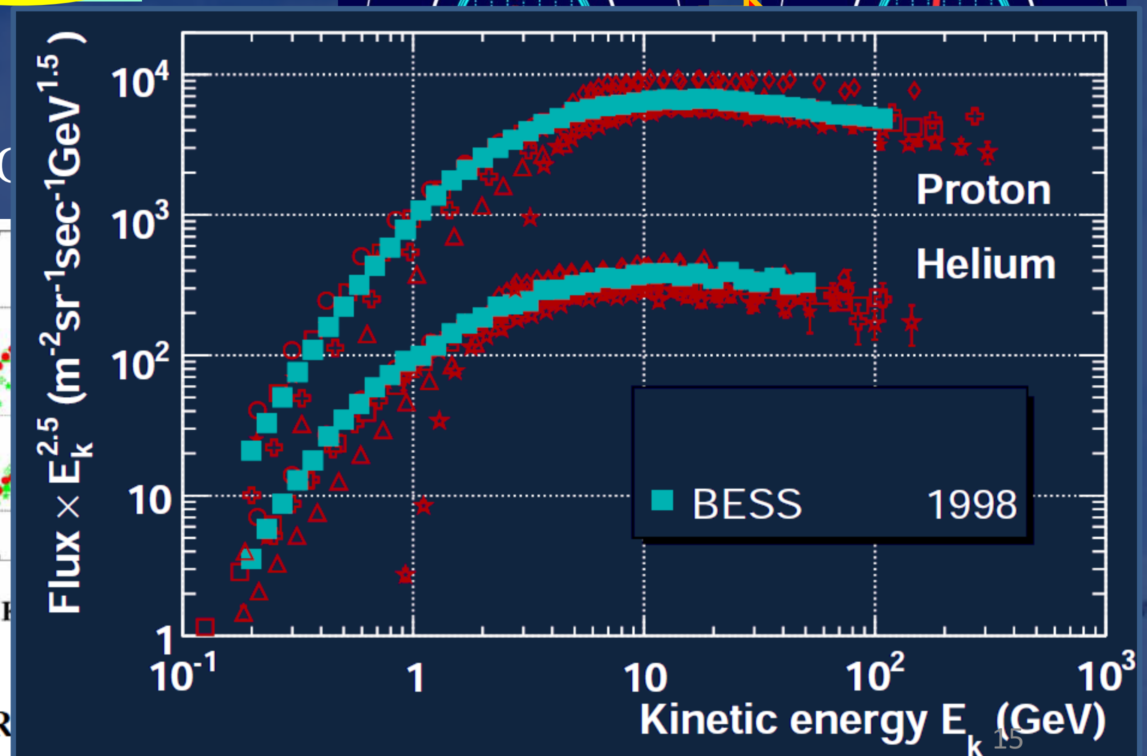

BESS-TeV Flight

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BESS-98

BESS-TeV

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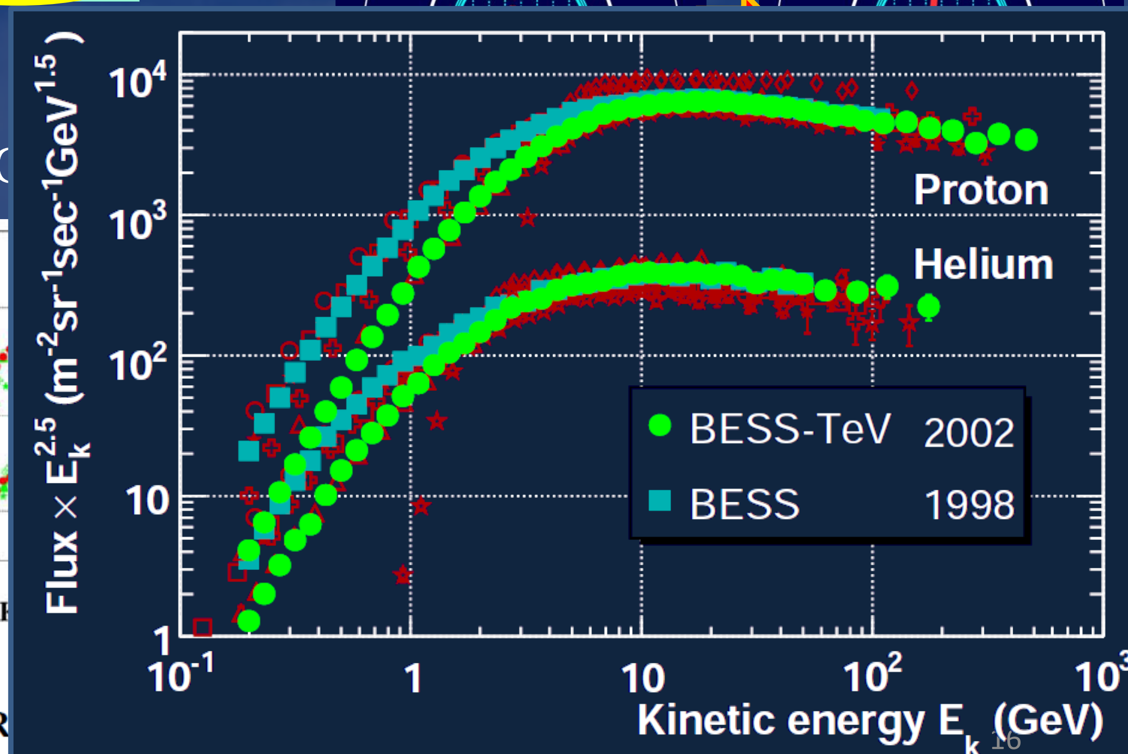

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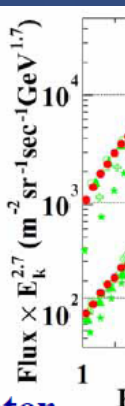

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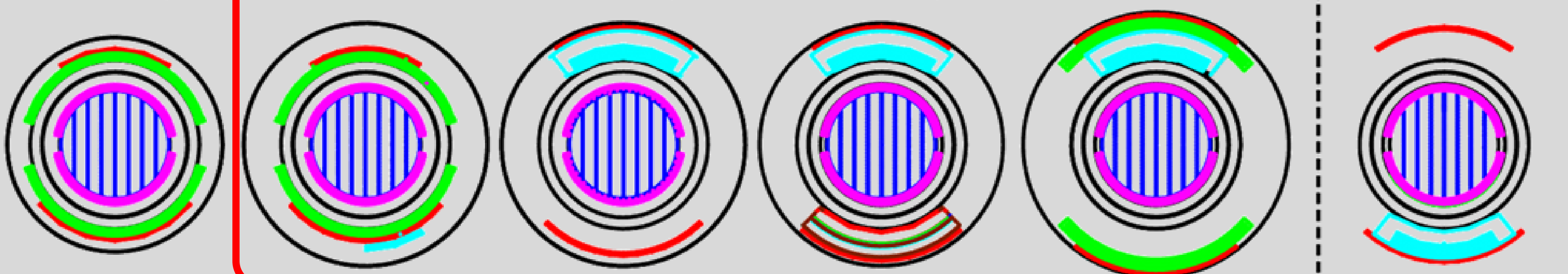

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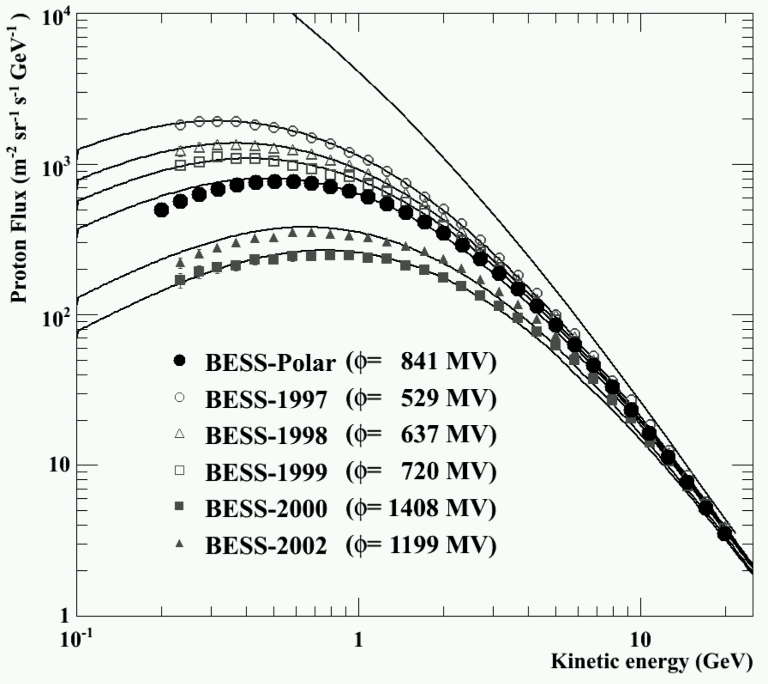
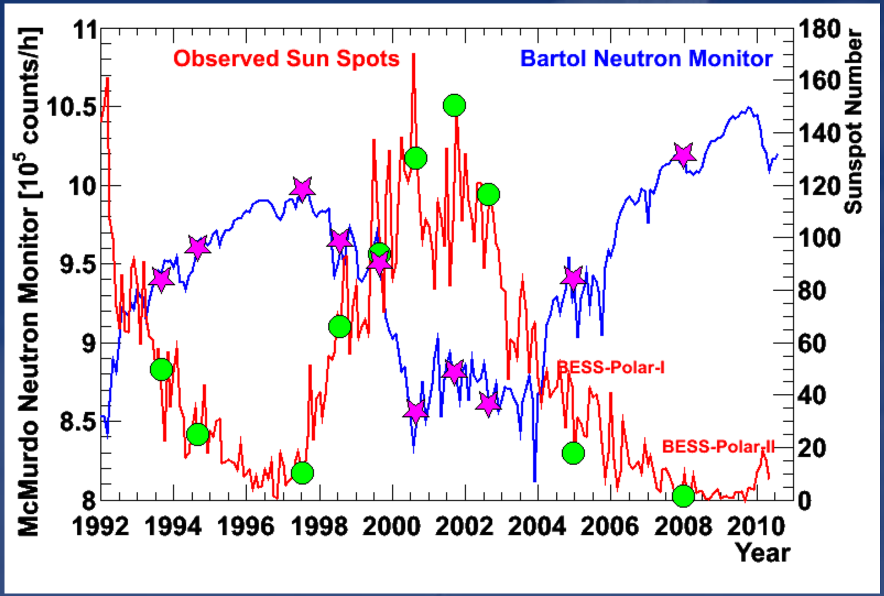
Proton Flux Modulation

Proton Flux

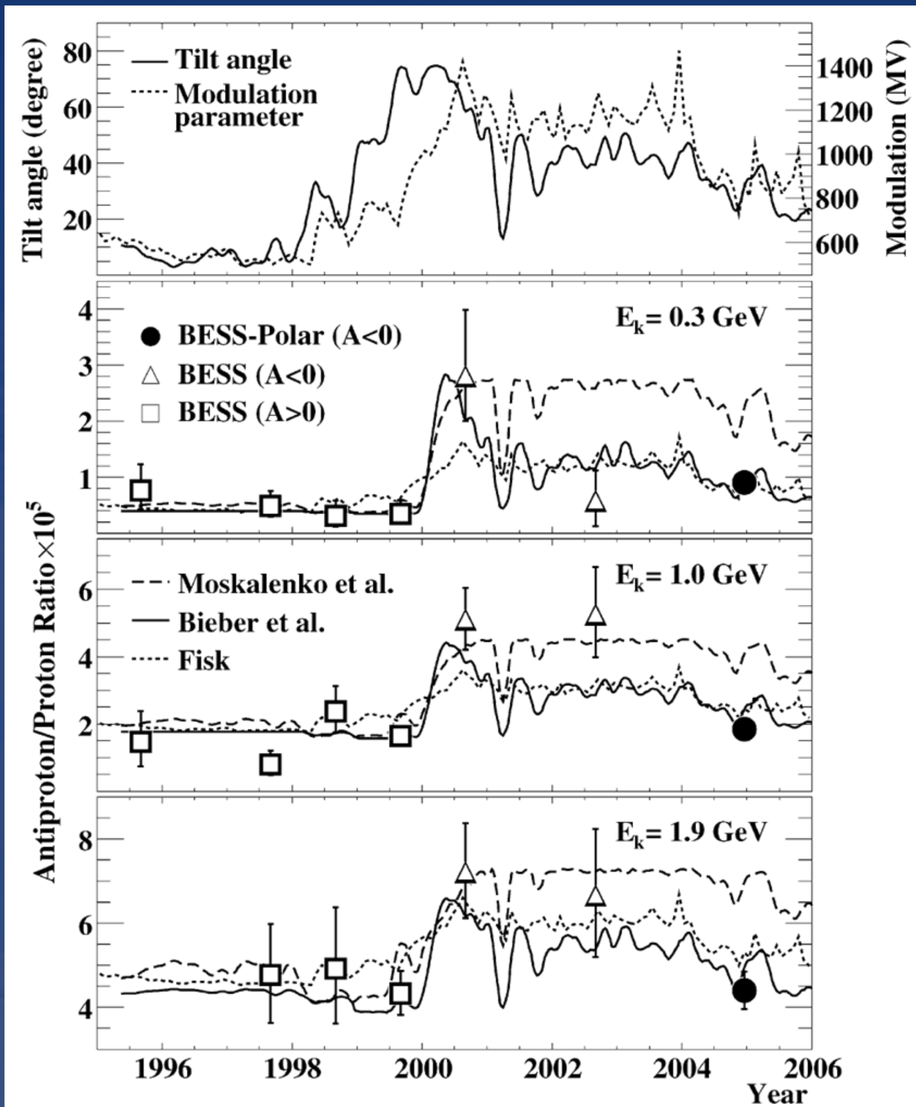




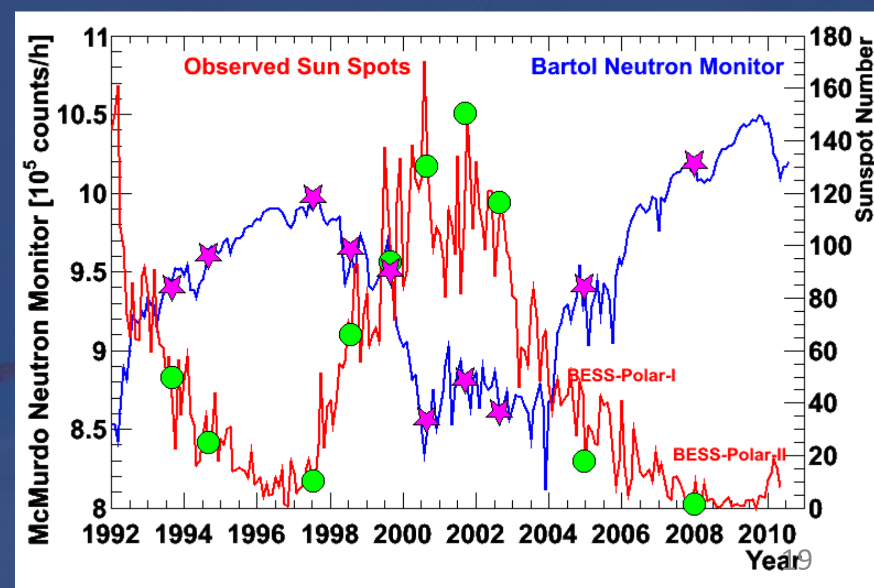
- Proton spectra measured to ~500 GeV
- Proton spectra to 100 GeV measured for full solar cycle
- Upper solid line shows local interstellar (LIS) proton spectrum from best fit to BESS data (spectral index 2.76)
- Lower curves show the variation with time (Solar modulation) of the measured proton spectra extrapolated to the top of the atmosphere

Solar Modulation

Antiproton/Proton Ratio

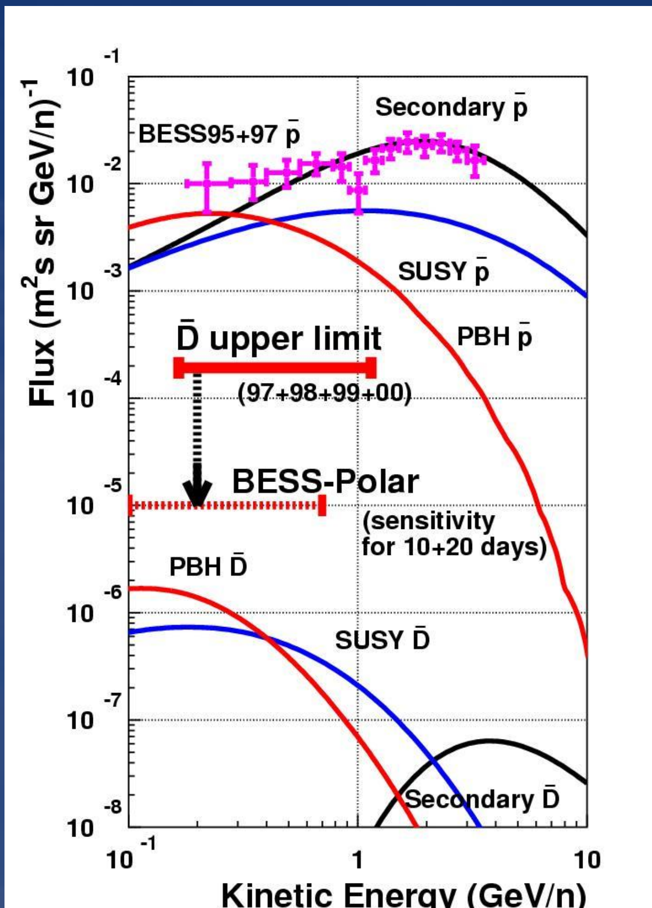


- Antiprotons and protons differ only in charge-sign
- Simultaneous measurements of proton and antiproton spectra provide a powerful test of models of charge-dependent Solar modulation of cosmic-rays (protons are most sensitive)
- More work is required in the interpretation

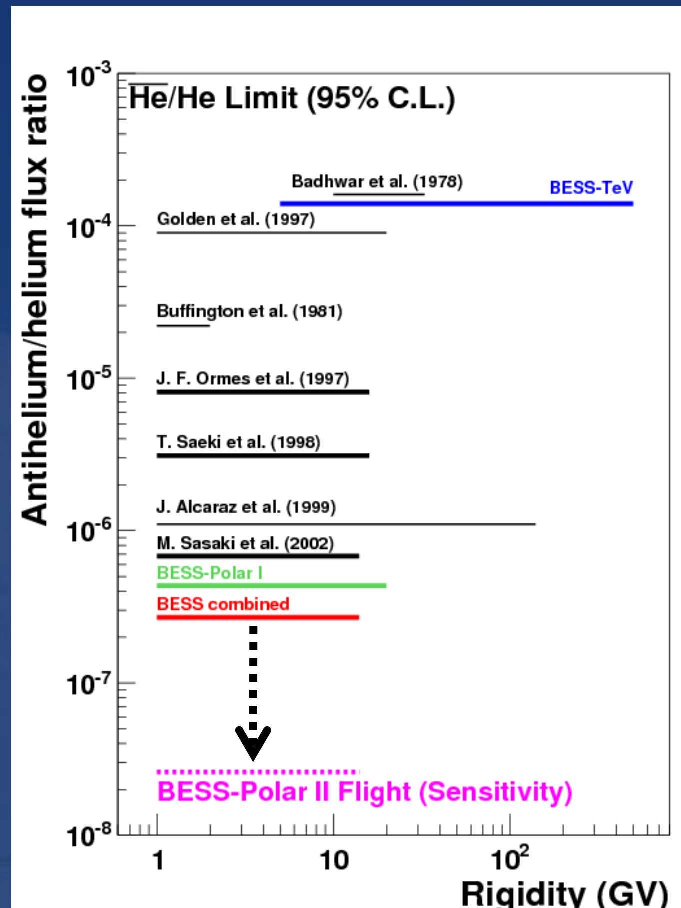


Antimatter Search

(Expected from BESS-Polar)



Antideuteron Search
(Search for PBH)



Antihelium Search
(Search for antimatter domain)

- Secondary $\bar{D}$ probability is negligible at low energies due to kinematics
- Any observed $\bar{D}$ almost certainly has a primary origin!
- $\bar{D}$ 95% C.L. upper limit (first reported) 1.92×10^{-4} (m^2 s sr GeV/n)$^{-1}$
- $\overline{He}$ 95% C.L. upper limit
  - BESS-TeV
    - 1.4×10^{-4} (5 – 500 GV)
  - BESS-Polar I
    - 4.4×10^{-7} (1 – 20 GV)
  - Combined data
    - 2.7×10^{-7} (1 – 14 GV)

BESS-Polar II flight in 2007 with a sensitivity 3×10^{-8}

BESS-Polar Program

BESS-Polar Program

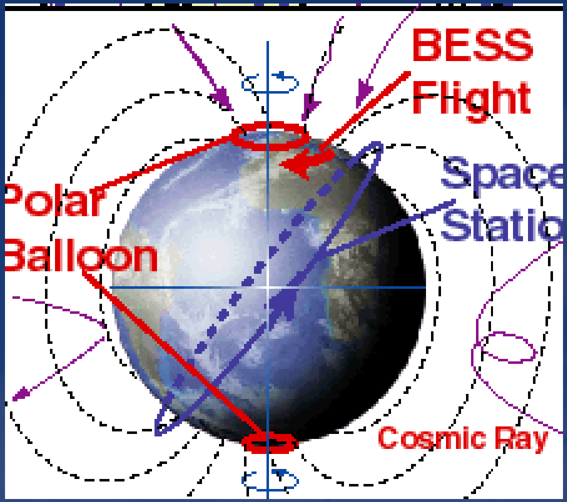
Very precise measurement

Antiprotons to lower energy

Around south pole, Antarctica

Long duration flight

High latitude



With a new spectrometer

Maintain large acceptance

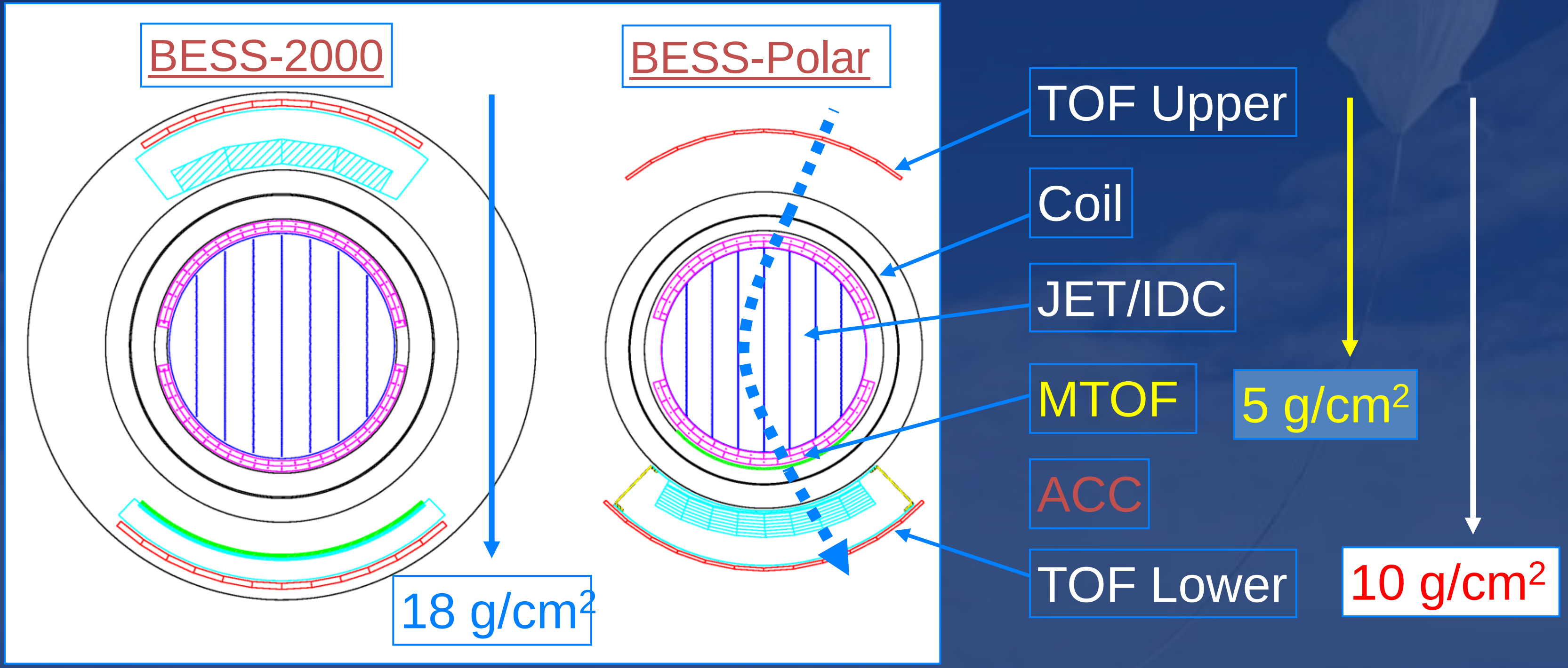
Minimum material in particle path

Flown Twice

BESS-Polar I (2004)

BESS-Polar II (2007/2008)

BESS-Polar Program



Minimize material in spectrometer
New detector (Middle TOF),
No pressure vessel

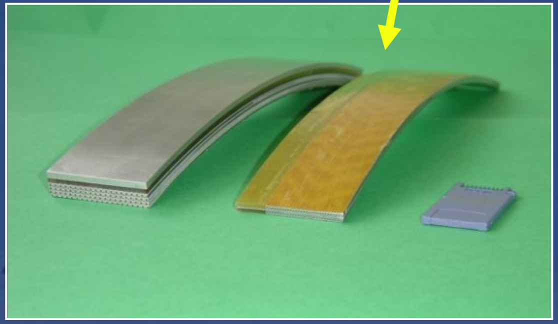
→ Energy range extended
down to 0.1 GeV

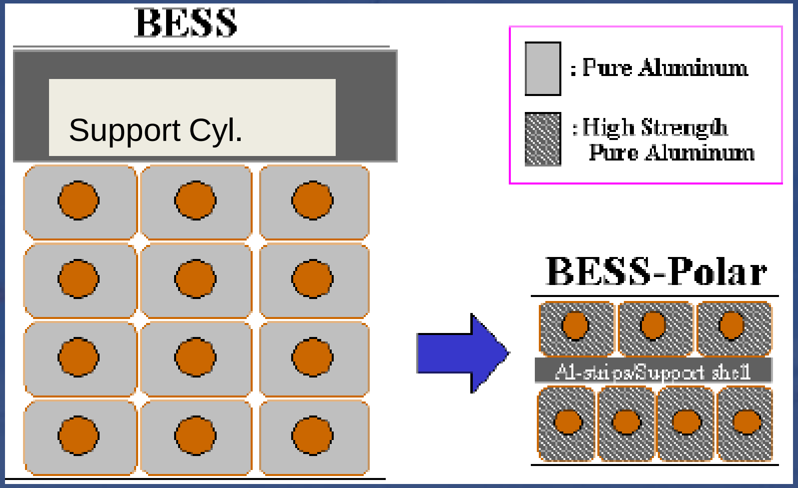
Low power electronics
Solar power system, Longer cryogen life, LHe

→ Long duration flight

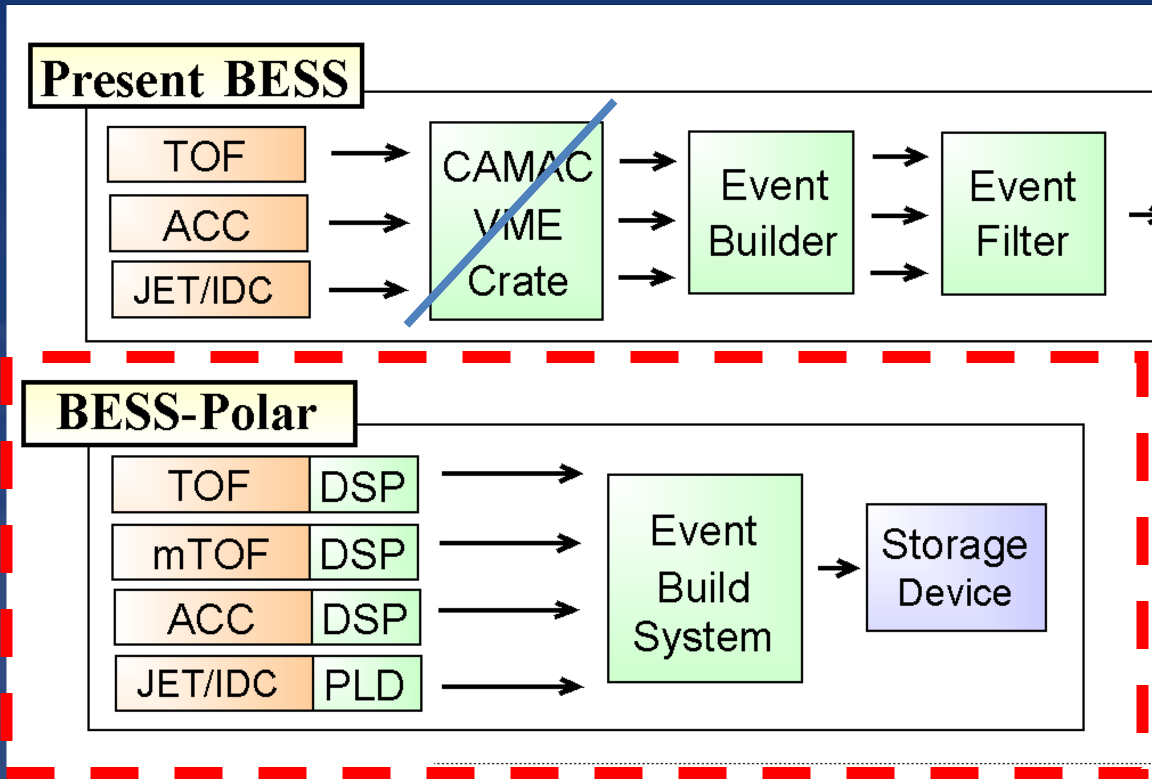
BESS-Polar Program

After assembly





BESS-Polar Program



- Digital events directly transfer to Event Builder for DAQ
  >> compact, Fast and Power Saved

BESS-Polar Program

	BESS	BESS-Polar
Geom. Acceptance:	0.3	0.3 $m^2 \cdot sr$
Material for trigger:	18 g/cm^2	4.5 g/cm^2
Magnetic field	1.0 T	0.8 T
Weight	2.2	2.0 tons
Power	Battery	Solar-panel
Comsumption	1.2 kW	450 W
Cryogen life	5.5	20 days

BESS-Polar I Flight

BESS-Polar I Flight

Status of the BESS-Polar I Flight

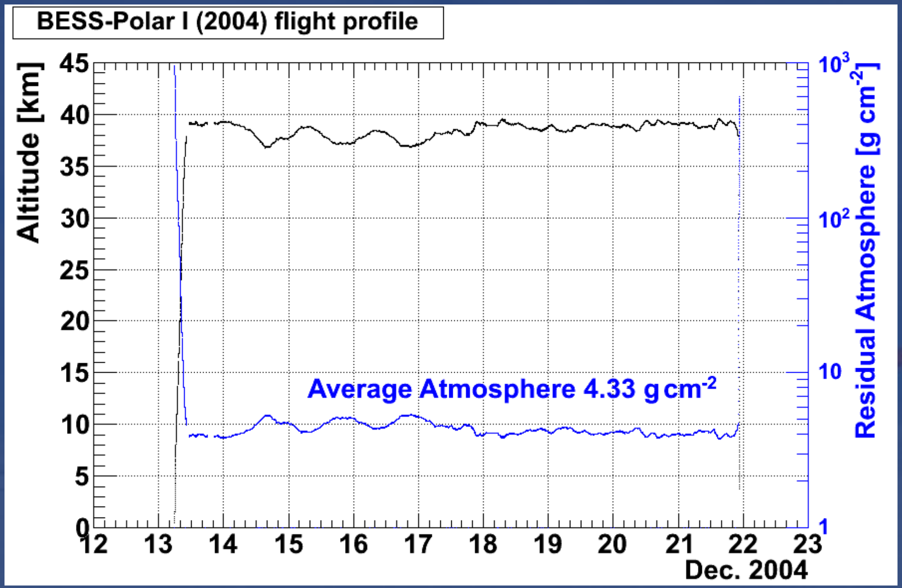
Observation Time: 8.5 days

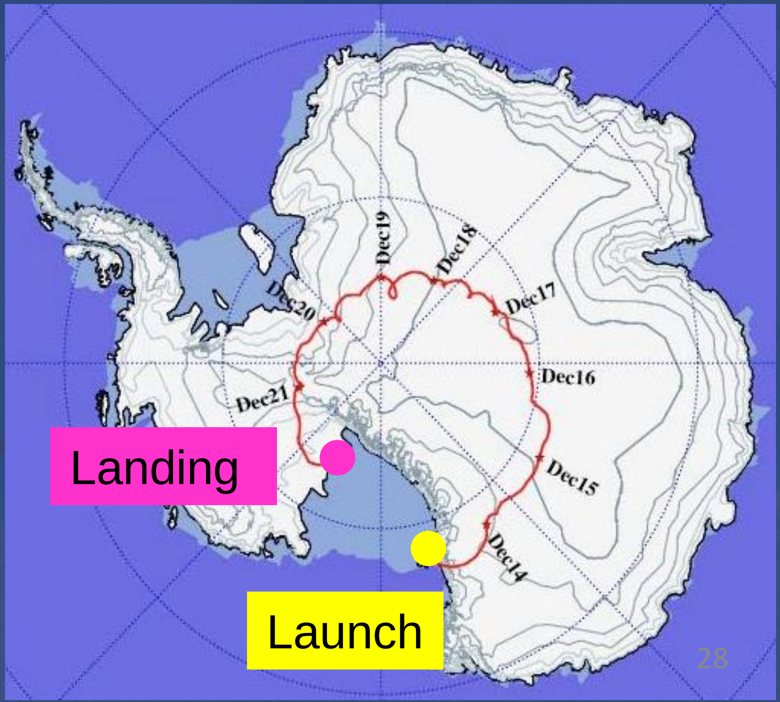
Float Time: 8.5 days (12/13/2004-12/21/2004)

Events recorded: > 9×10^8

Data volume: ~ 2.1 terabytes

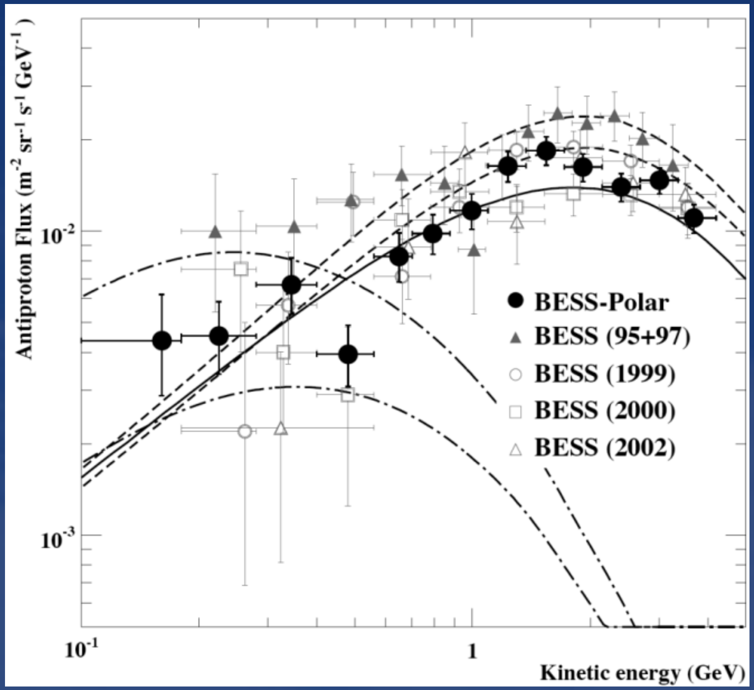
Data recovery: **completed** 2004
Payload recovery: **completed** 2004



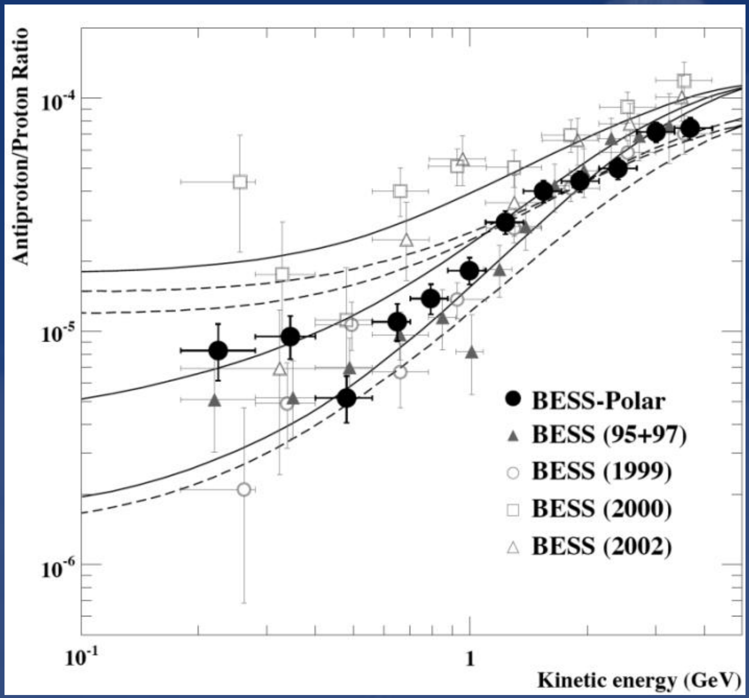


BESS-Polar I Results

Antiroton Flux



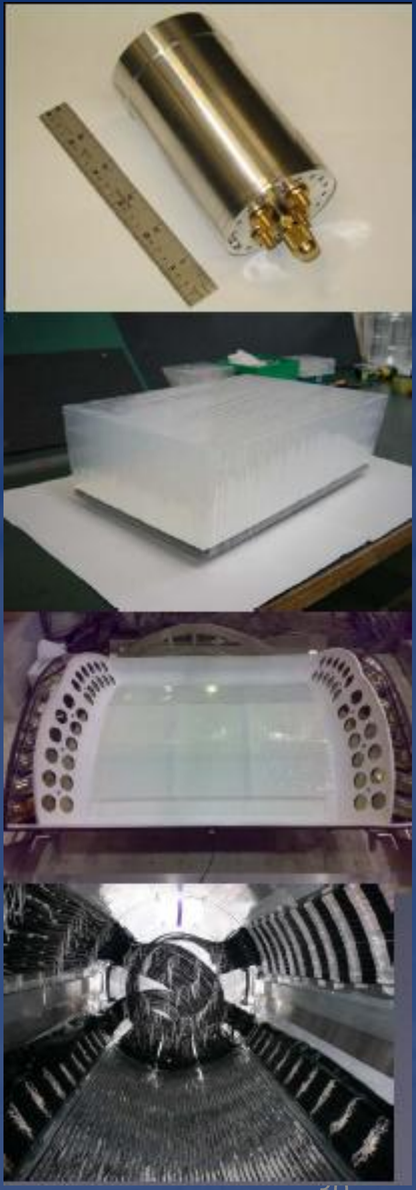
Antiroton/Proton Ratio



- Upper dashed curve is leaky box calculation with spherically symmetric modulation @ 550 MV to fit BESS (95+97) data.
- BESS-Polar I data at higher solar activity (851 MV - lower dashed curve) are consistent with secondary production.
- Solid curve is diffusive reacceleration with break for 30˚ Solar tilt angle

BESS-Polar II

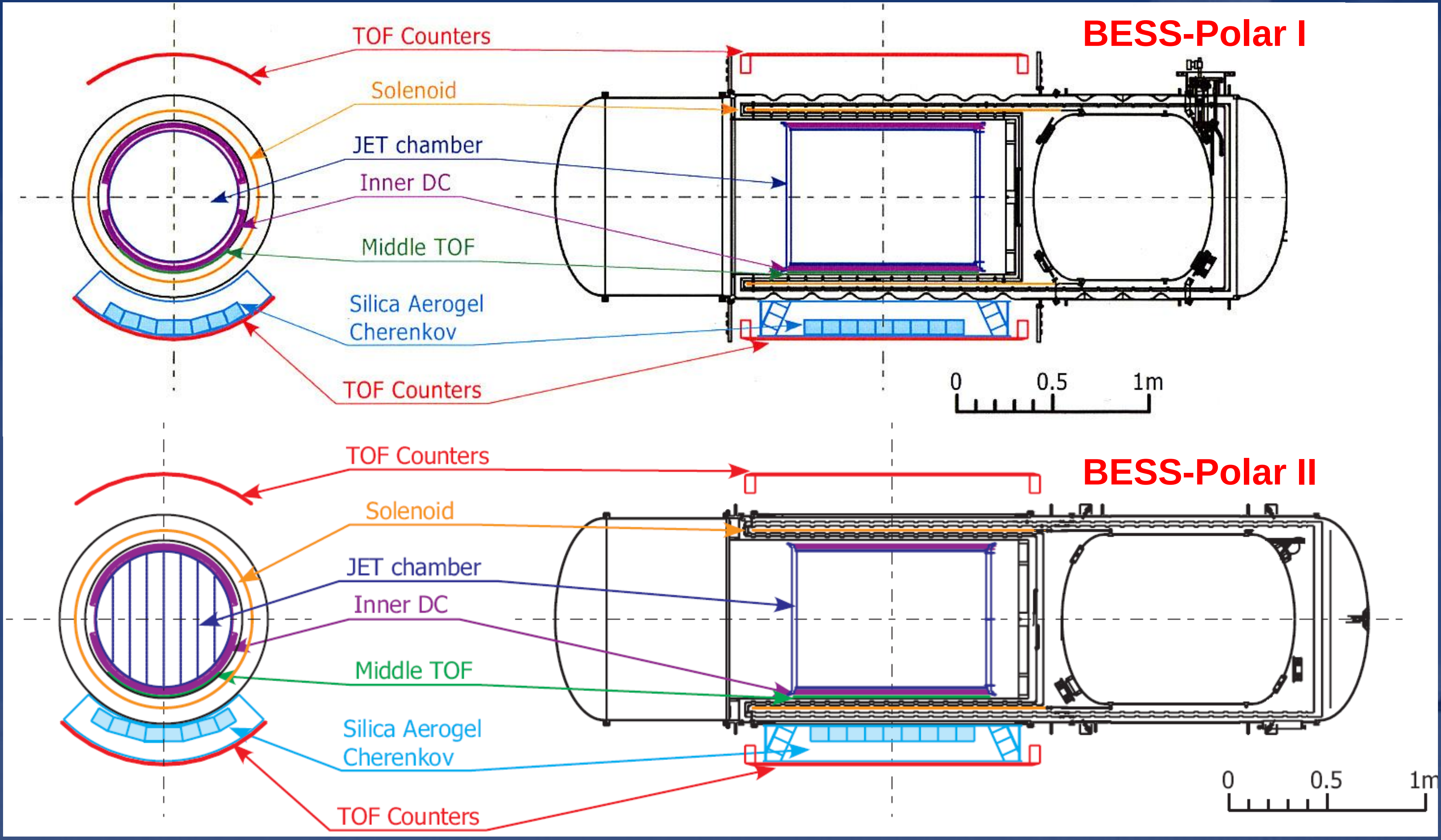
BESS-Polar II Spectrometer improvement



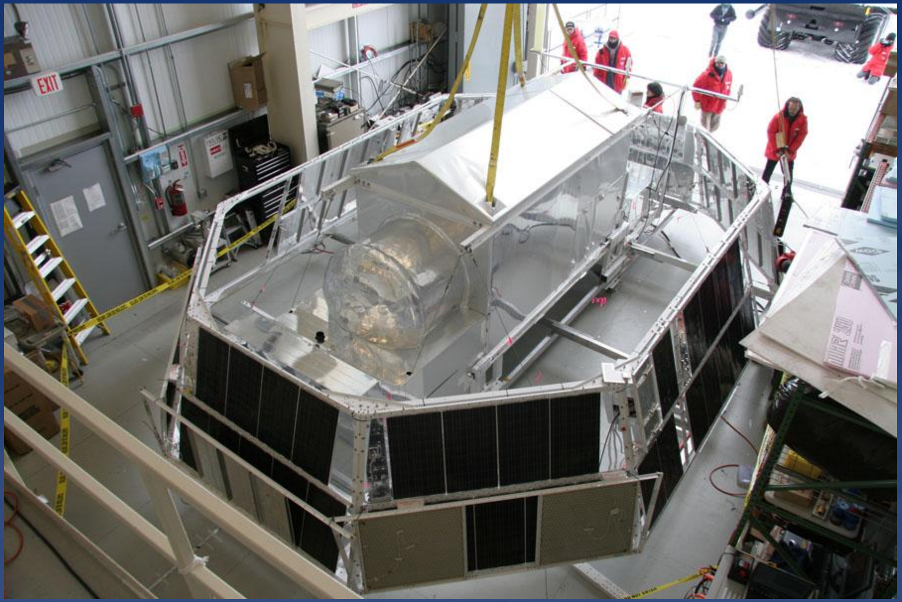
- Longer observing time (10 days → 20 days)
  - New magnet with new cryostat
    - Larger tank, third radiation shield
  - Increase gas bottle for chamber gas
  - Increase storage size (3.6 Tbyte → 16 Tbyte)
- Detector improvement
  - Pressurized TOF PMT units
  - ACC rejection power
  - MTOF resolution
  - JET noise reduction

BESS-Polar II

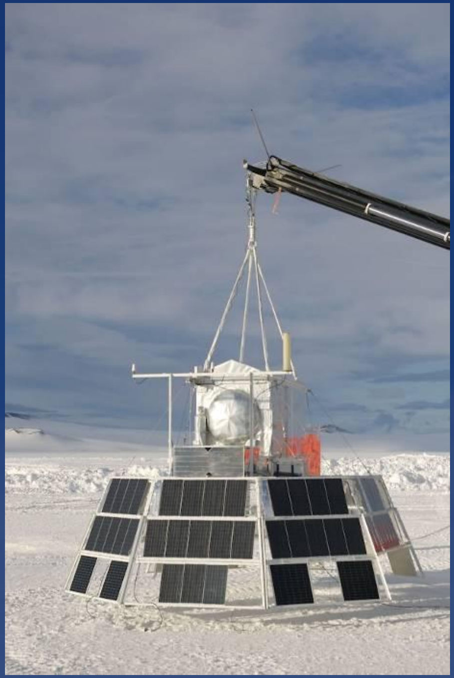
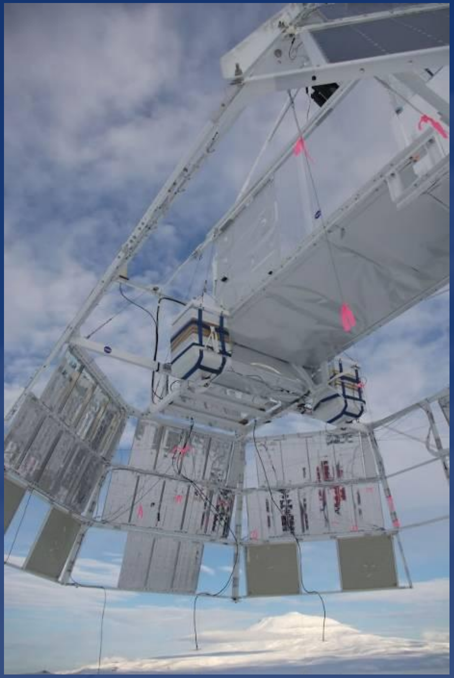
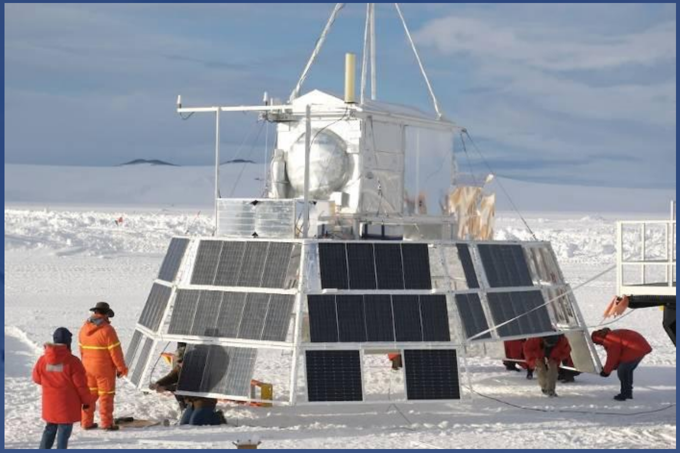
BESS-Polar II Spectrometer improvement



BESS-Polar II Flight



BESS-Polar II Flight


BESS-Polar II Flight

BESS-Polar II Flight

Status of the BESS-Polar II Flight

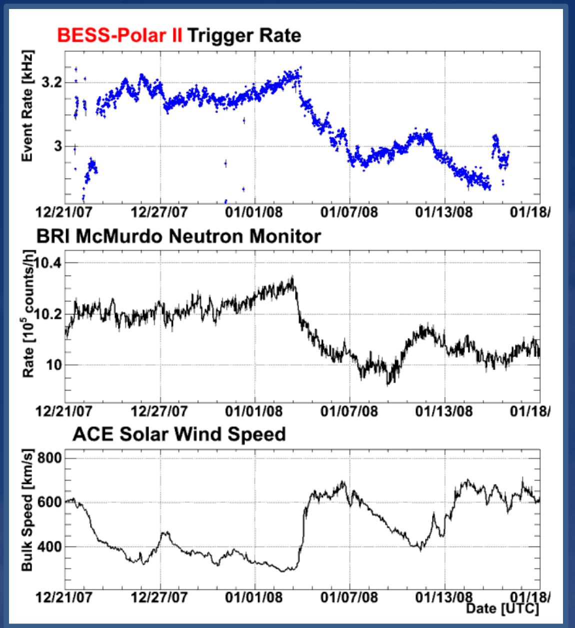
Observation Time: 24.5 days

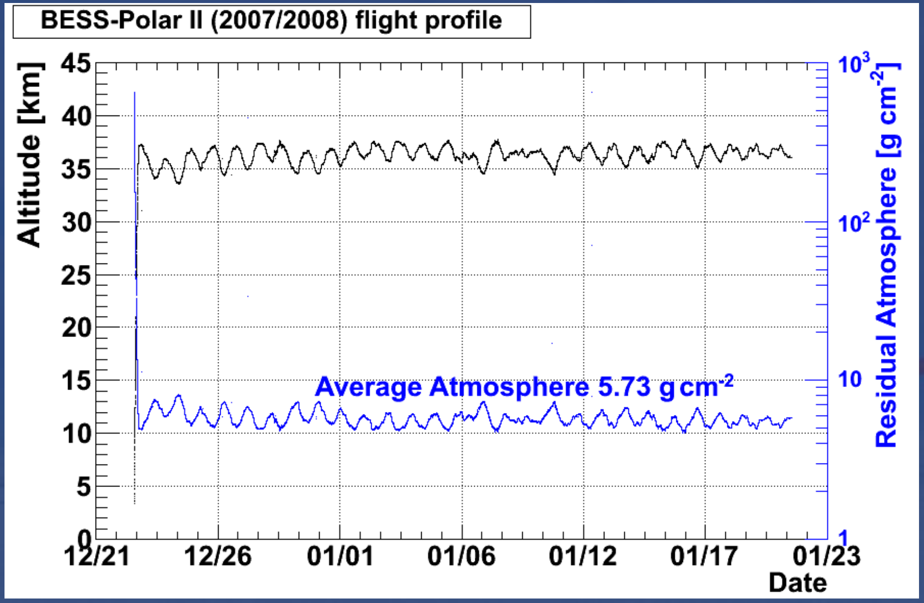
Float Time: 29.5 days (12/23/2007-01/21/2008)

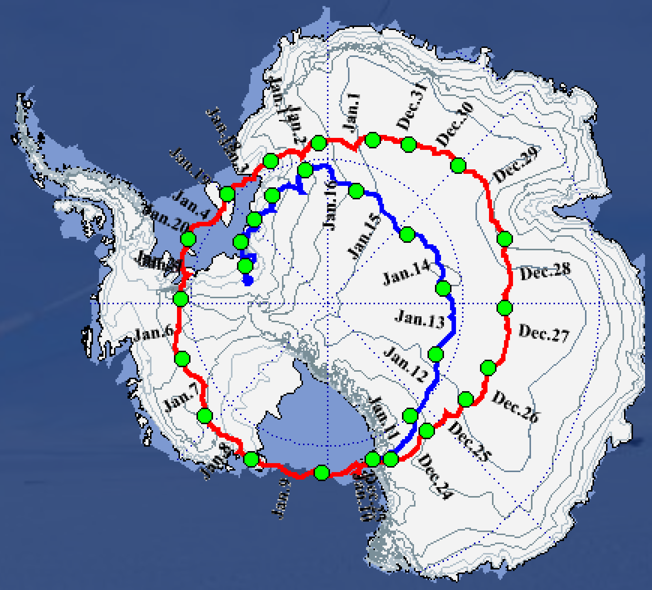
Events recorded: > 4.7 x 10^9

Data volume: ~ 13.5 terabytes

Data recovery: **completed** Feb 3, 2008
Payload recovery: **completed** Jan 16, 2010







BESS-Polar II Flight

BESS-Polar II Flight Termination

- Location 83 ° 51.23’ S, 73° 5.47’ W
- Instrument landed upright, with minimal damage
- Data successfully recovered February 3, 2008!

BESS-Polar II Flight

BESS-Polar II Recovery

- Staged from WAIS Divide/Byrd Surface Camp
- Camped on site 13 days for disassembly
- Basler (turboprop DC-3) used due to range and instrument size

BESS-Polar II Flight

BESS-Polar II Spectrometer Status

- Detectors are in good condition
- No additional damage incurred during recovery process and shipping
- Currently the magnet is being refurbished and reassembled in Japan
- Basic functionality test of the TOF and Cherenkov Counter indicate almost all PMTs are still operational.
- Basic functionality test of the JET chamber and IDC conducted. Applied full HV and no wire broken.

Magnet refurbish @ TOSHIBA, Japan

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Magnet refurbish @ TOSHIBA, Japan

Future Science Objectives

- Be isotope measurement
- e^+/e^- measurement
- Continuation of current science objectives

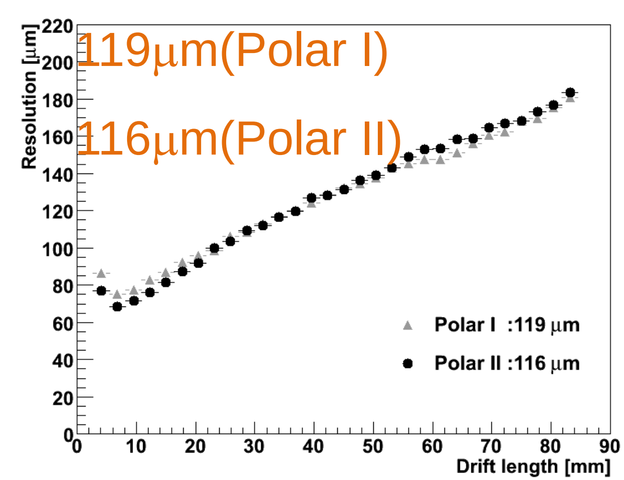
BESS-Polar Program

Flight Summary

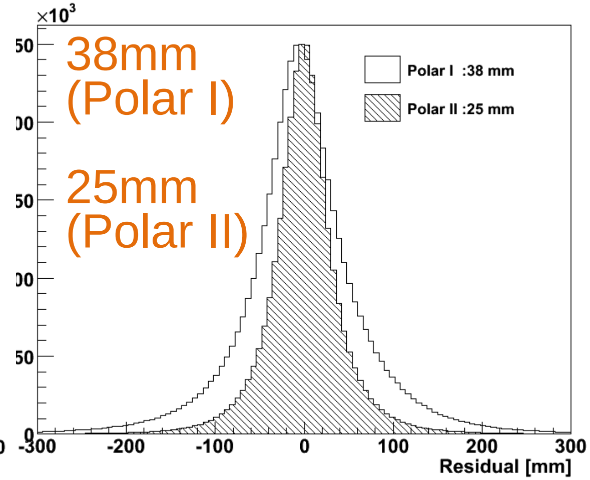
	BESS-Polar I	BESS-Polar II
Total Floating Time	8.5 days	29.5 days
Observation Time	8.5 days	24.5 days
Recorded Event	900 M	4700 M
Recorded Data Size	2.1 TBytes	13.5 TBytes
Trigger Rate	1.4 kHz	2.4 kHz
Live Time Fraction	0.8	0.82
Altitude	37 ~ 39 km	34 ~ 38 km
Residual Air Pressure	4 ~ 5 g/cm^2	4.5 ~ 8 g/cm^2

New Results from BESS-Polar II

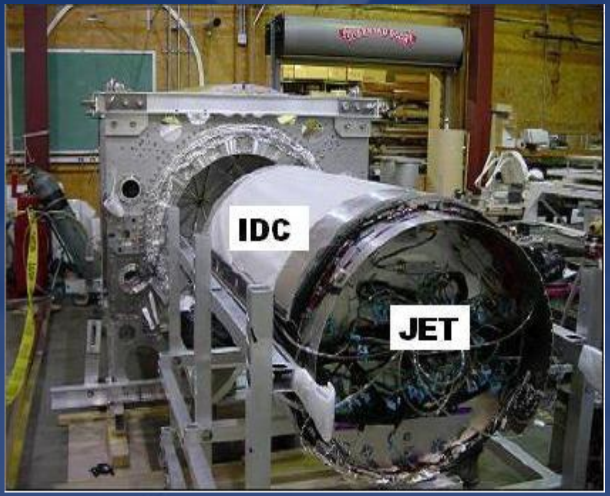
BESS-Polar II Spectrometer Performance



JET position resolution in r-ϕ plane @ each drift length



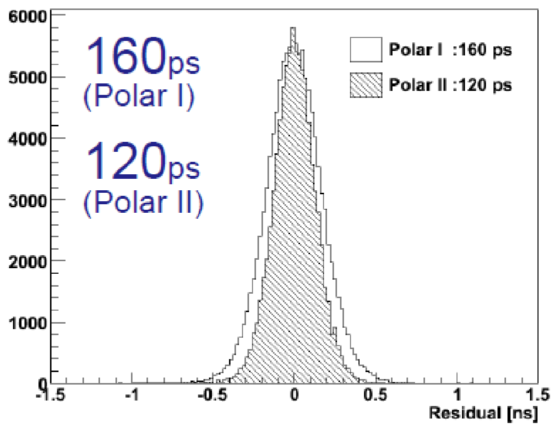
JET position resolution in z plane



Acceptance

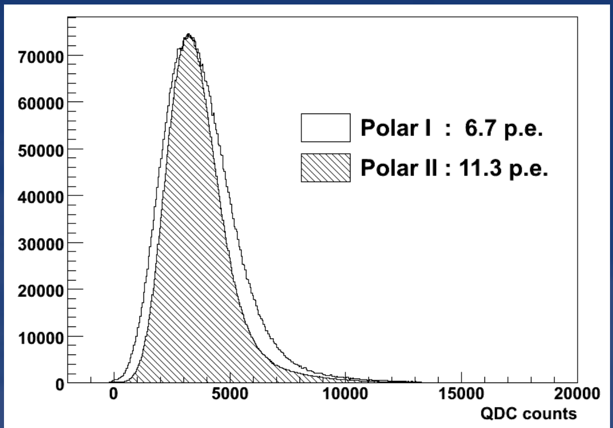
	BESS-Polar I	BESS-Polar II
Both-side	8/22	20/22
Single-side	10/22	2/22
Dead	4/22	0/22
Acceptance	66%	100%

List of survival TOF PMTs during Flight

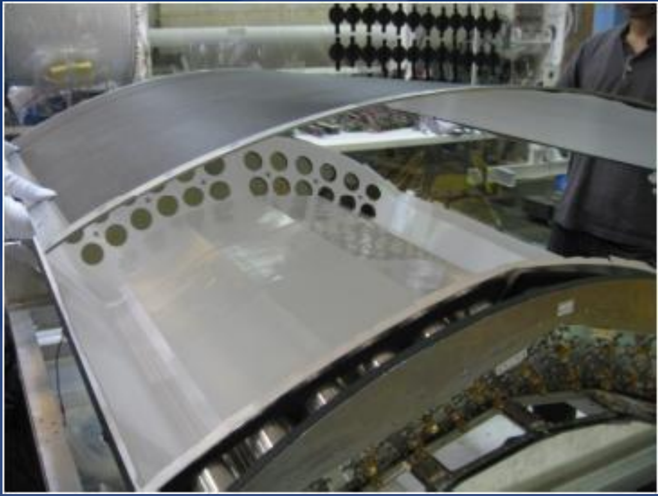


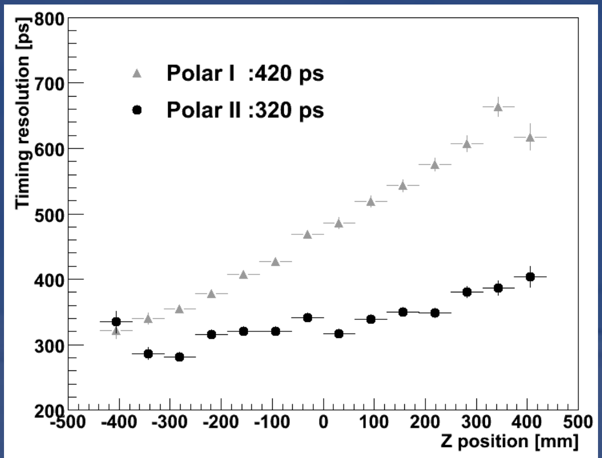
TOF timing resolution

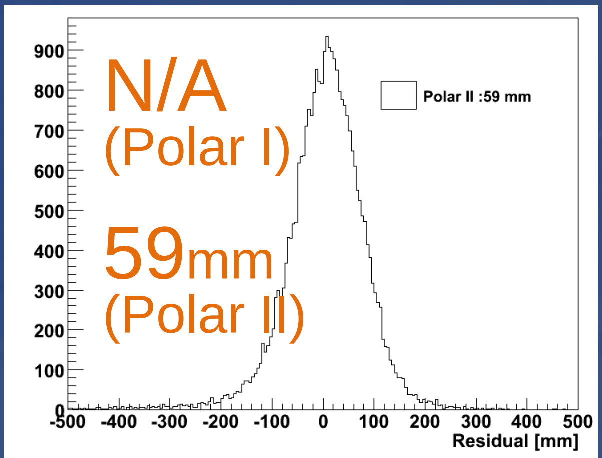
BESS-Polar II Spectrometer Performance



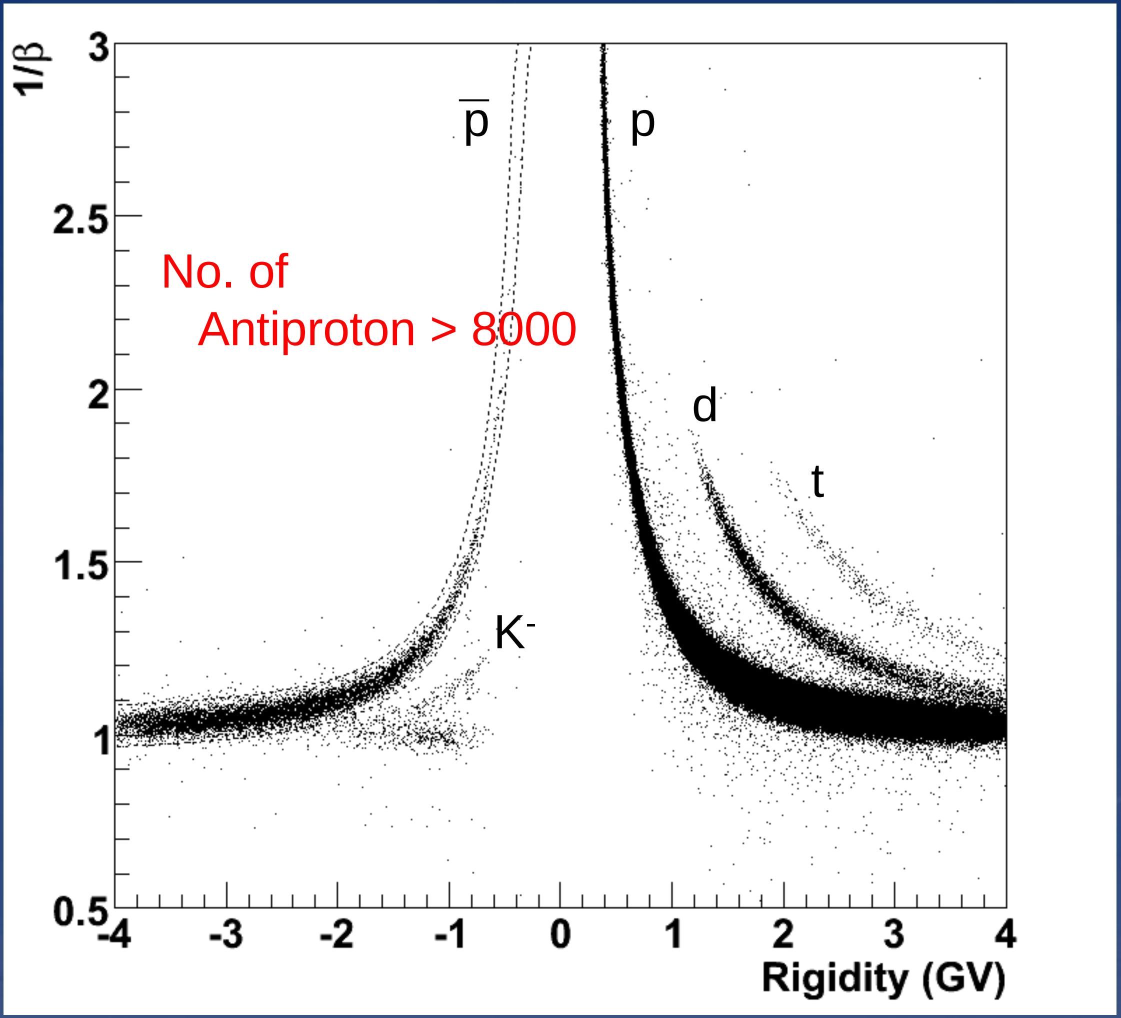
	BESS-Polar I	BESS-Polar II
Efficency	92%	97%
Rejection power	1500	6800



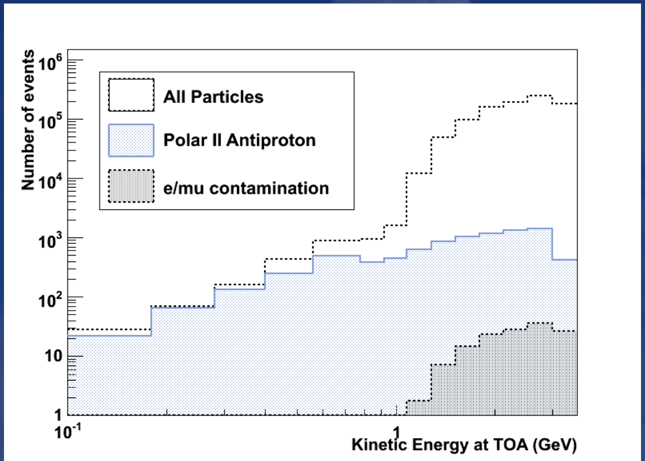


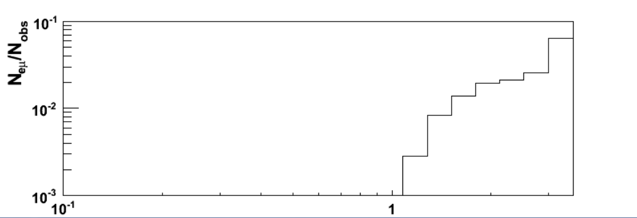


Antiproton Measurement



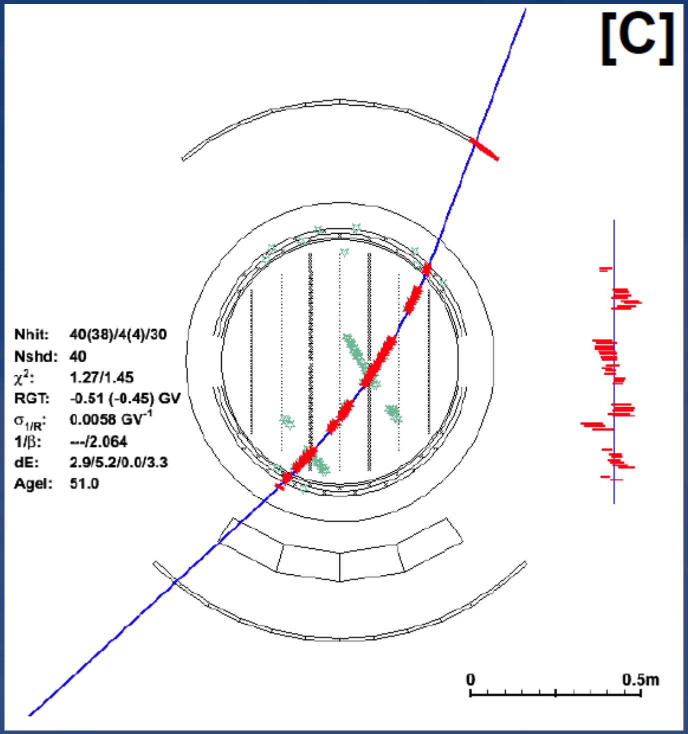
β-1 vs Rigidity plots in BESS-Polar II

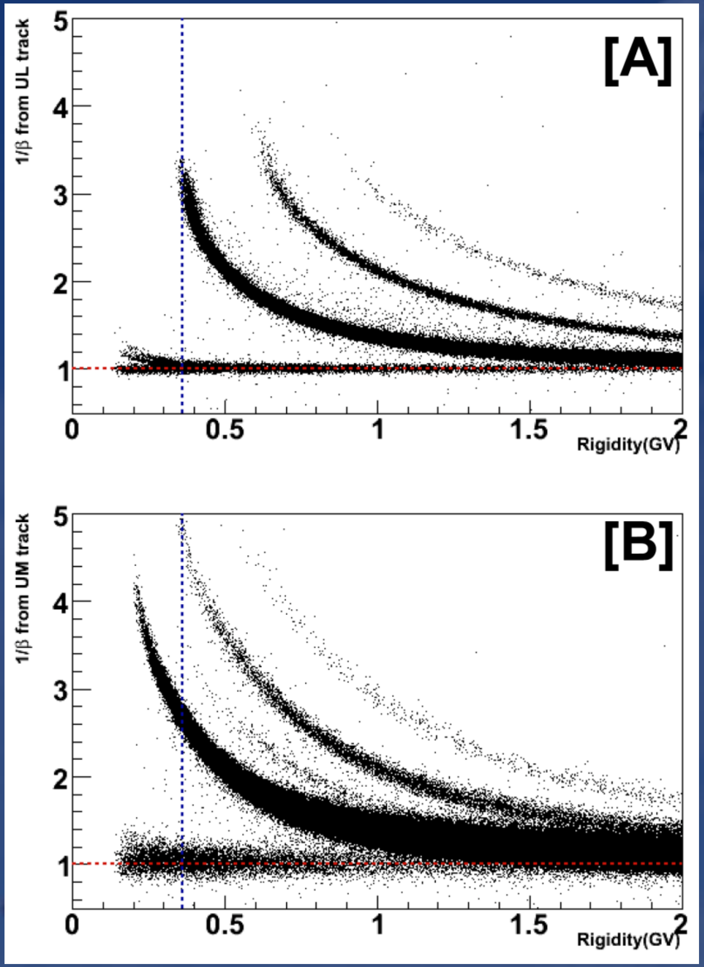




There is no background contamination below 1 GeV!

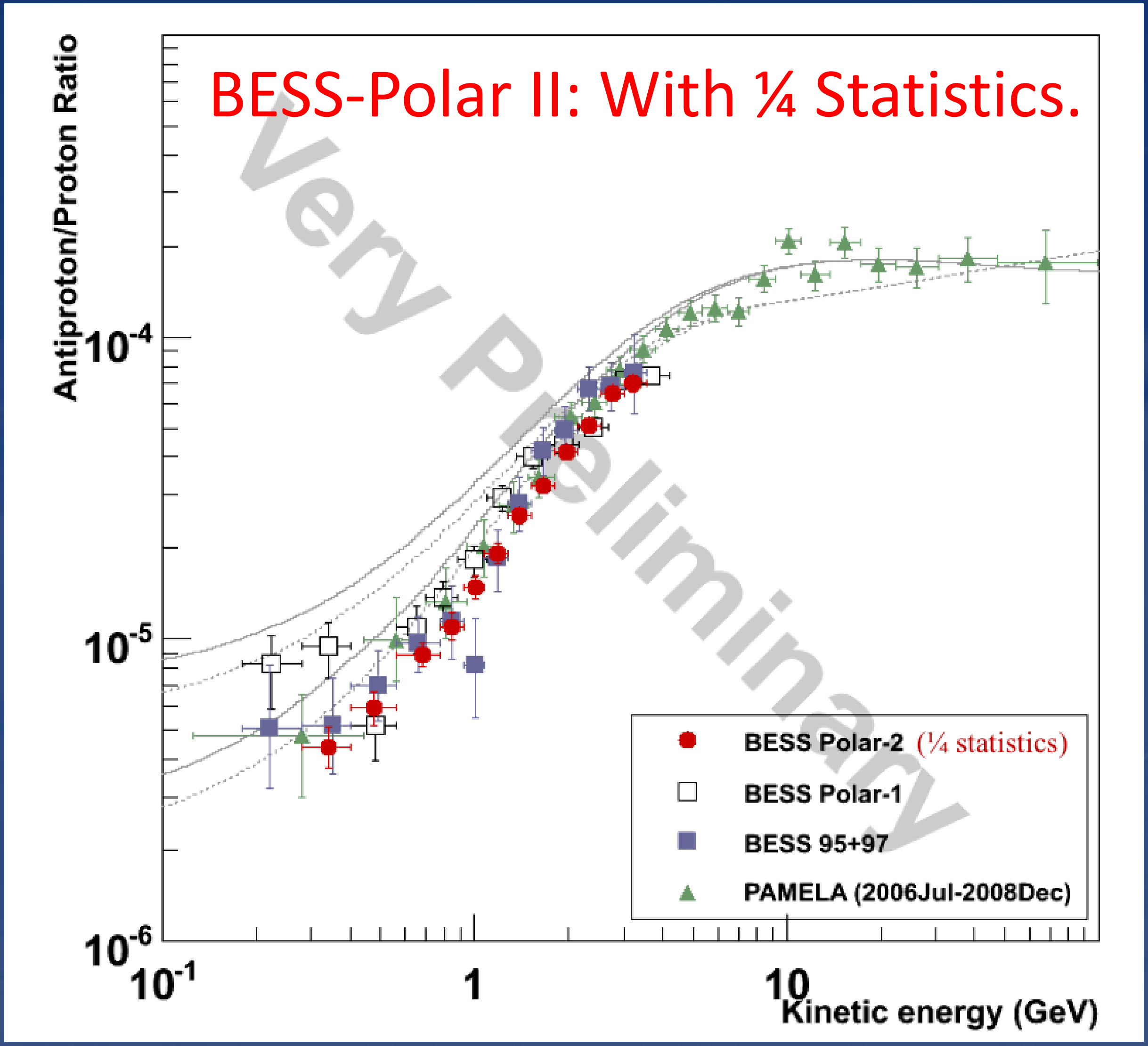
Low Energy Antiproton with Middle TOF





The antiproton observation was extended to lower energy by using the Middle TOF. We are now finalizing this analysis.

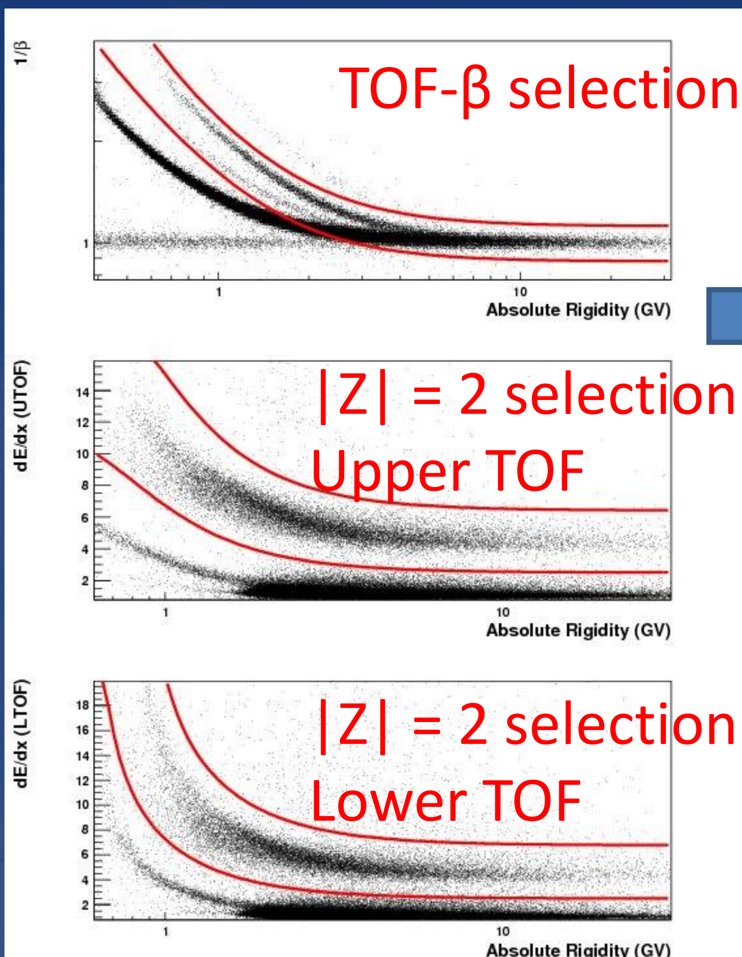
Antiproton/Proton Ratio



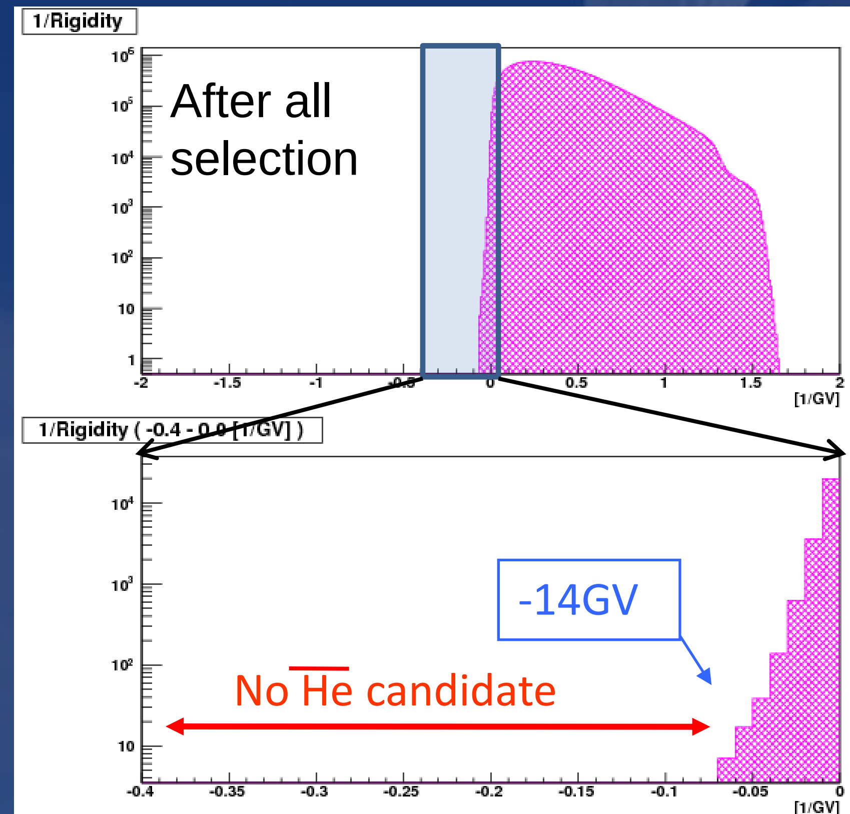
- Agree with the PAMELA data.
- We are now finalizing calibration and including MTOF information for full BESS-Polar II flight data.
- Antiproton flux will be coming soon.

Antihelium Search

Particle Identification using the TOF information

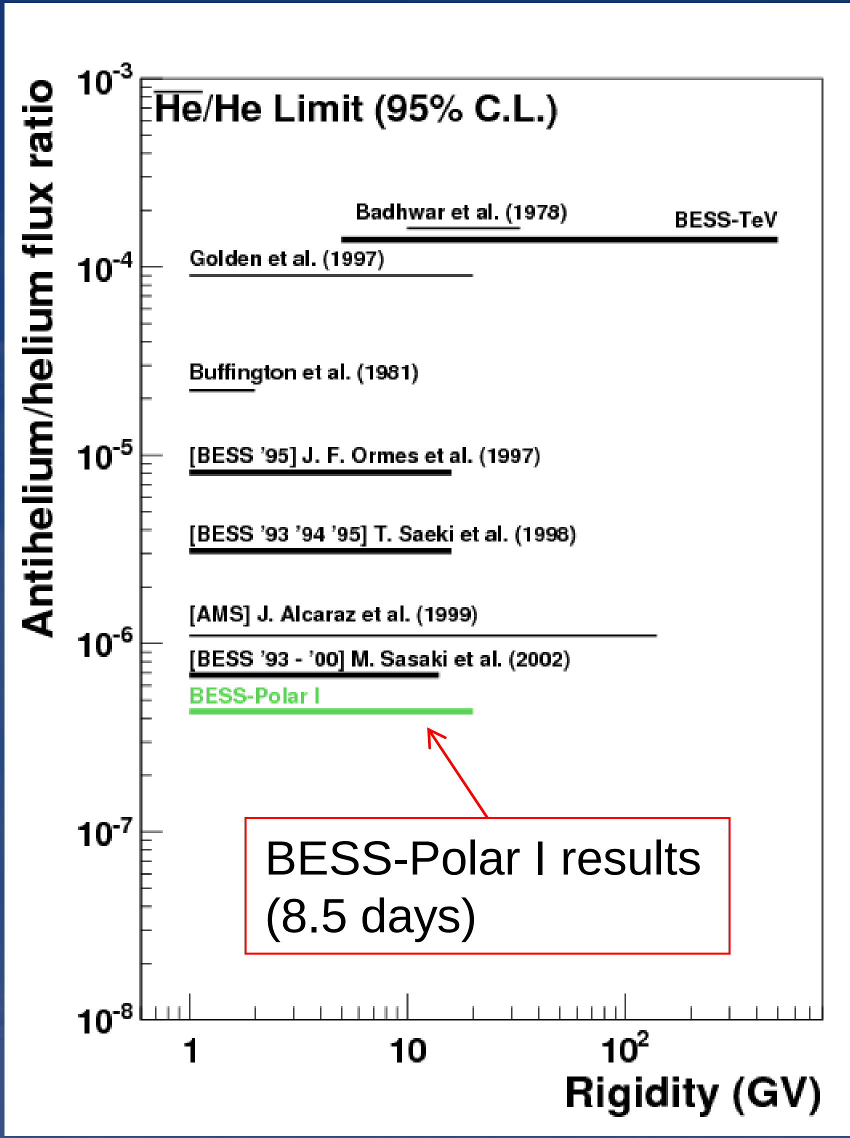


The figure below shows remaining events after all selections applied.



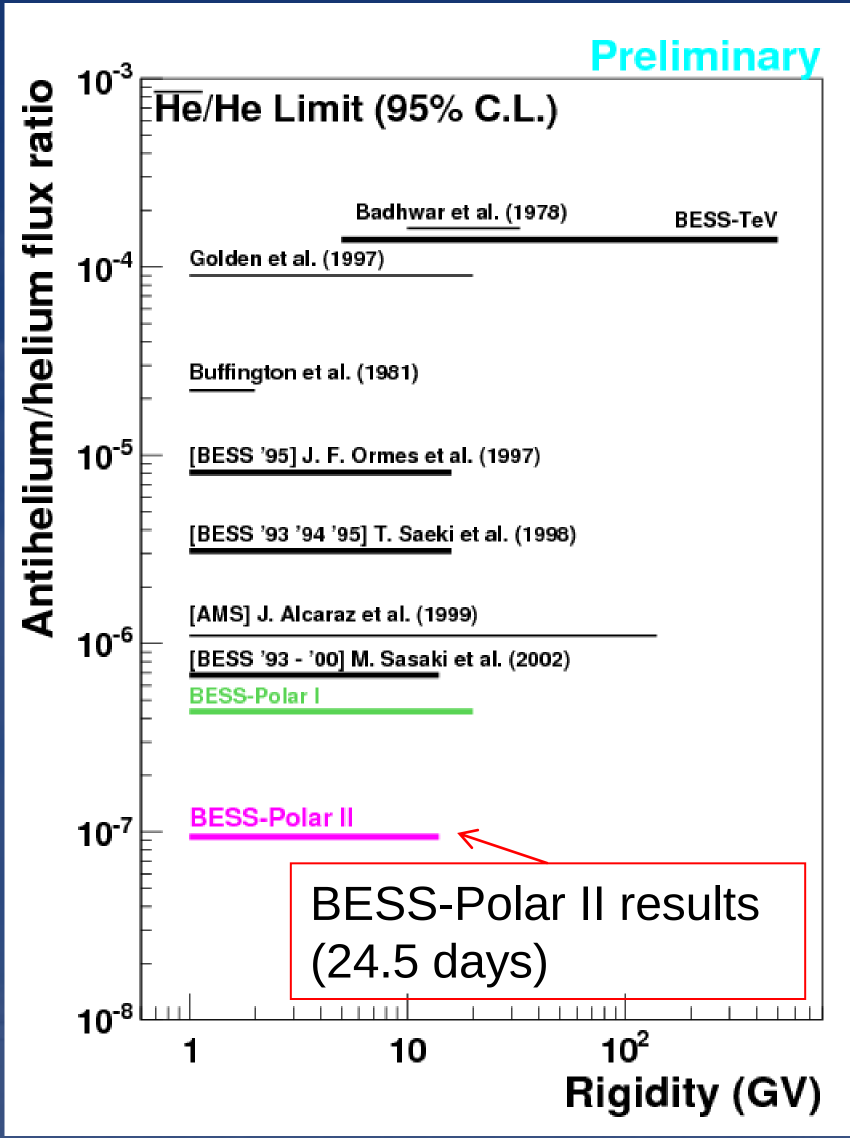
No antihelium candidate was found between -14 and -1 GV after all selection among 4×10^7 Helium events.

Antihelium Limit



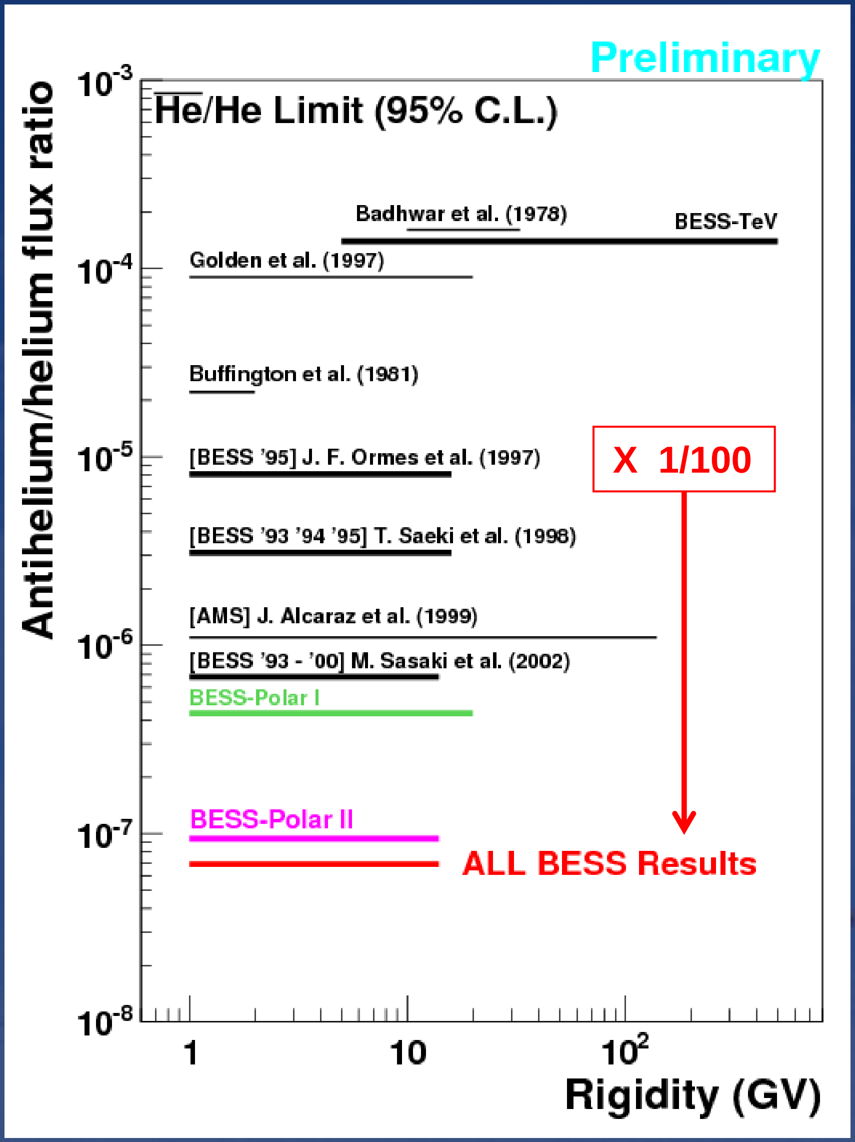
- BESS-Polar I antihelium upper limit 4.4×10^{-7}.

Antihelium Limit



- BESS-Polar I antihelium upper limit 4.4×10^{-7}.
- We set the upper limit of 9.4×10^{-8} by using the BESS-Polar II flight data.

Antihelium Limit



- BESS-Polar I antihelium upper limit 4.4×10^{-7}.
- We set the upper limit of 9.4×10^{-8} by using the BESS-Polar II flight data.
- We set the upper limit of 6.9×10^{-8} by using all BESS flight data, which is improved by two orders of magnitude since our first report.

Summary

- BESS-Polar II successfully gathered cosmic-ray data in the solar minimum period with 10 times statistics of the previous solar minimum (’95 + ‘97) at low energy.
- BESS-Polar II Spectrometer was recovered from Antarctica and magnet is now being refurbished. Detector components are still in good shape after two winters on ice in Antarctica.
- Antiproton/proton ratio was reported using ¼ of BESS-Polar II data. Analysis for full flight data is being finalized.
- We searched for antihelium in the BESS-Polar II data. No antihelium candidate was found and we set a stringent upper limit on antihelium/helium.

End of the presentation

Appendix

BESS swam the Canadian Lake