Search for Antiparticle in Cosmic Rays with BESS

Akira Yamamoto (KEK)

for the BESS Collaboration

RESCEU symposium, held at U. Tokyo, Nov. 11-14, 2008

BESS Collaboration

High Energy Accelerator Research Organization(KEK)

National Aeronautical and Space Administration Goddard Space Flight Center

The University of Tokyo

University of Maryland

Kobe University

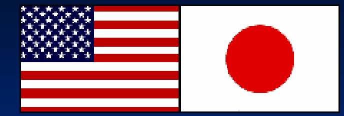
University of Denver (Since June 2005)

Institute of Space and Astronautical Science/JAXA

Balloon-borne Experiment with a Superconducting Spectrometer

BESS Collaboration

(as of Nov., 2008)

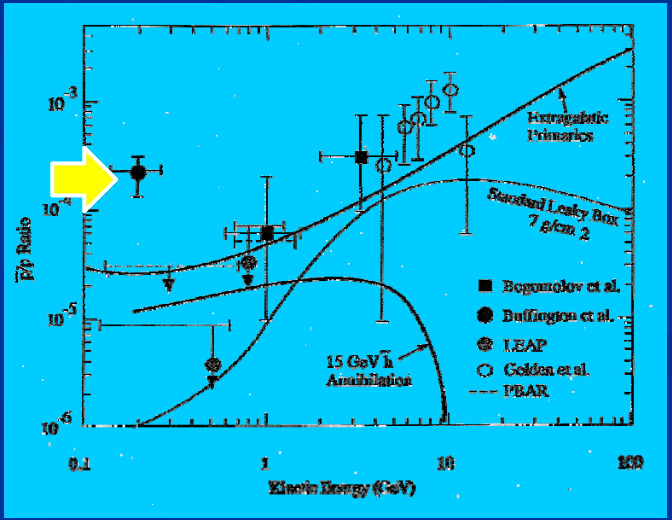


- **KEK**
  M. Hasegawa, A. Horikoshi, Y.Makida, M. Nozaki, R. Orito, J.Suzuki, K.Tanaka, A. Yamamoto*, K.Yoshimura, S. Haino
- **NASA/Goddard Space Flight Center**
  T. Hams, J.W .Mitchell*, M. Sasaki, R.E. Streitmatter
- **The University of Tokyo**
  J.Nishimura, K. Sakai
- **Kobe University**
  A. Kusumoto
- **Univ. of Maryland**
  K. Kim, M.H. Lee, E.S. Seo
- **ISAS/JAXA**
  H. Fuke, T. Yoshida, T. Yamagami
- **University of Denver**
  J. Ormes, N. Thakur

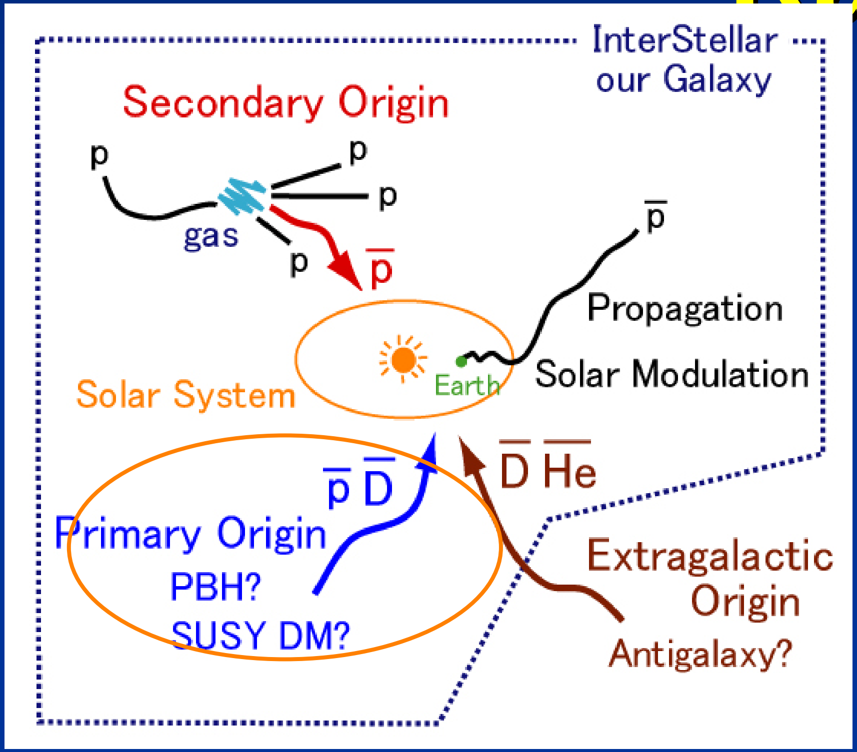
Cosmic-Ray Antiproton Chronology

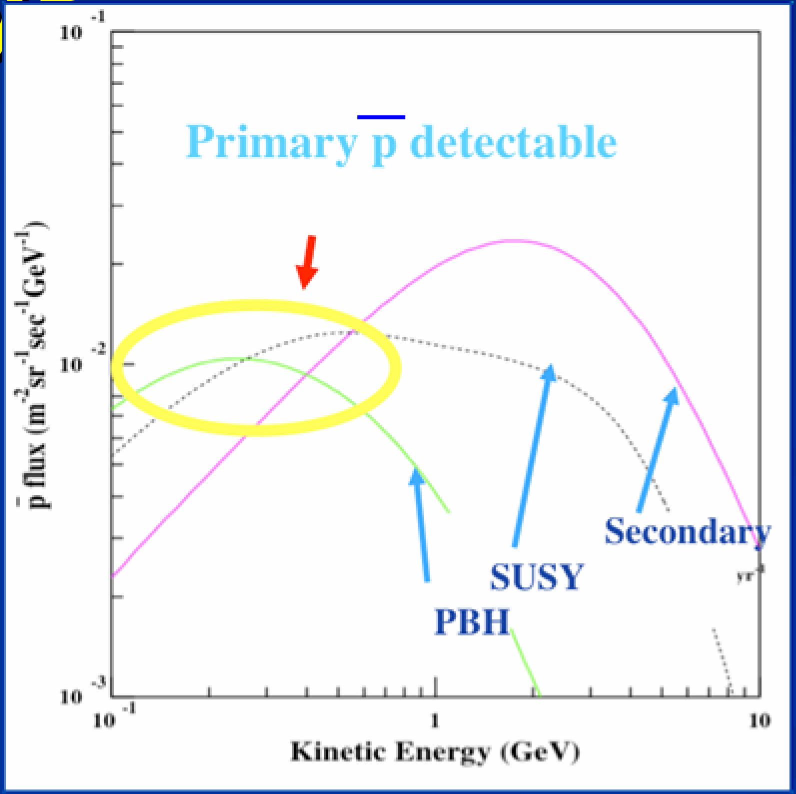
1979: First Antiproton Report (Golden et al.)
1979: Russian PM (Bogomolov et al.)
1981: Low-energy excess (Buffington et al.)
1985: ASTROMAG Study Started
1986: HEAO Antinucleus upper limits
1987: LEAP, PBAR (upper limits)
BESS proposed (by Orito)
1991: MASS
1992: IMAX (16 mass-resolved antiprotons)
1993: BESS (6 mass-resolved antiprotons)
1994: CAPRICE94
1998: CAPRICE98, AMS-01
2000: HEAT-pbar

2004: BESS-Polar I
2006: PAMELA
2007: Solar minimum
BESS-Polar II
2010+: AMS-02



Search for Primordial Antiparticles in Cosmic Rays

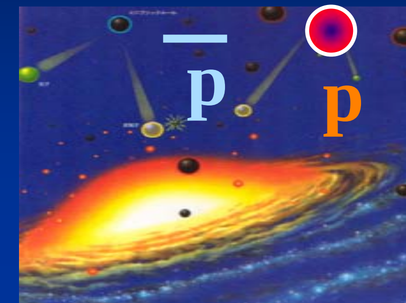




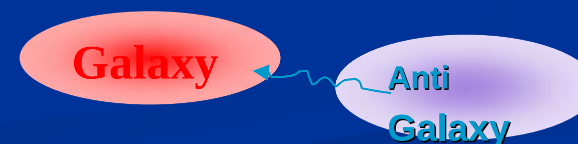
- Primary origins relatively enhanced at < 1 GeV,
- **Low energy antiproton** is an **ideal probe**.

BESS Objectives

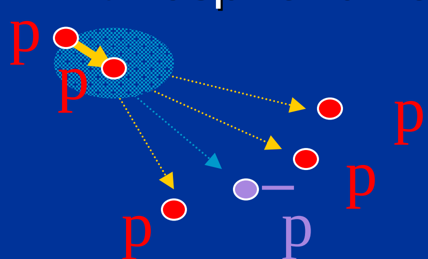
Balloon-borne **E**xperiment with a **S**uperconducting **S**pectrometer



- **Antiparticle/Antimatter**
  - **$\bar{p}$, $\bar{D}$** Novel cosmic origins
    - Evaporation of Primordial Black Holes
    - Annihilation of super-symmetric particles
  - **$\overline{He}$** Baryon Asymmetry in Universe



- **Fundamental Cosmic-ray Data**
  - **Precise spectra**
    - Propagation, solar modulation, charge-sign dependence, atmospheric secondaries,
    - Atmospheric neutrinos



$$
\begin{aligned}
p + A &\rightarrow \pi + \pi + \cdots \\
\pi &\rightarrow \mu + \nu_\mu \\
\mu &\rightarrow e + \nu_e + \nu_\mu
\end{aligned}
$$

BESS Spectrometer: Concept

Rigidity measurement

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

Transparent

Min. material (4.7g/cm^2)

Uniform field

Large acceptance

Central tracker

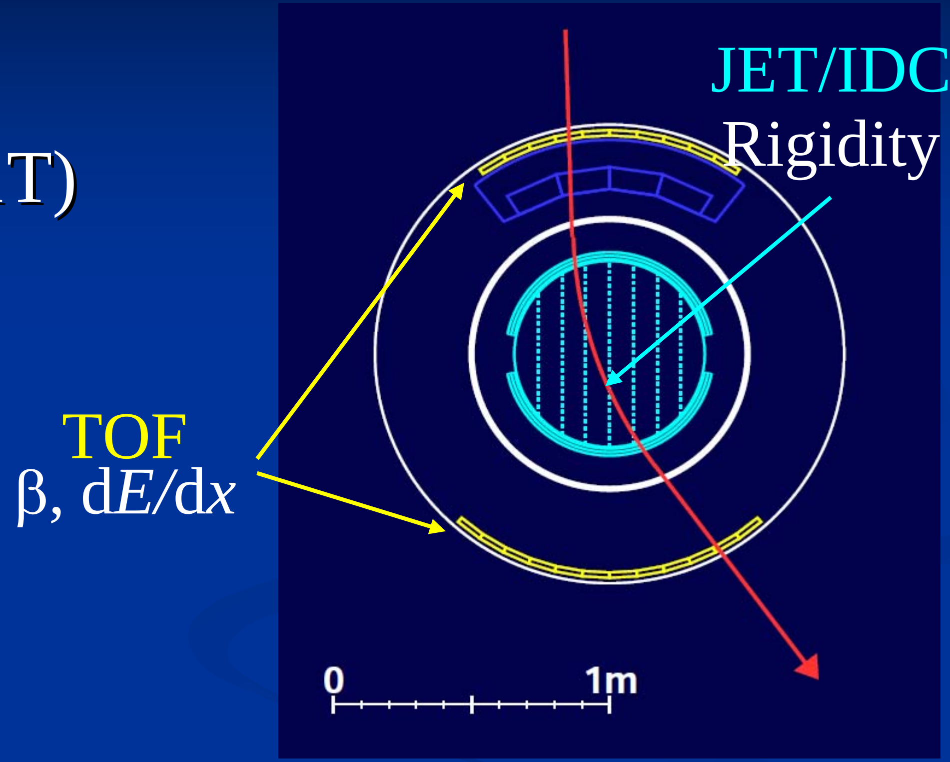
Drift chamber

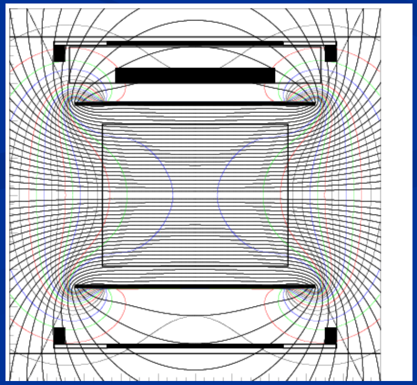
δ ~200**μm**

***Z, m* measurement**

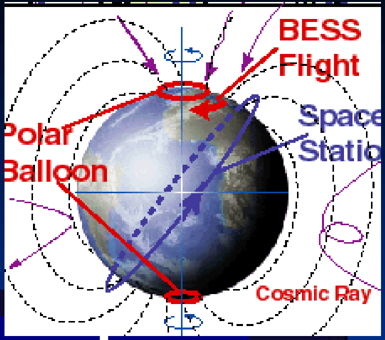
R, β --> $m = ZeR\sqrt{1/\beta^2 - 1}$

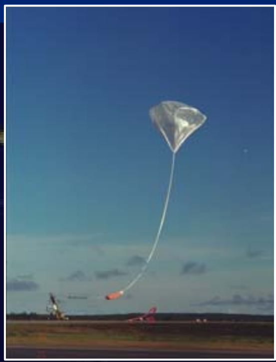
dE/dx --> Z





BESS Ballooning





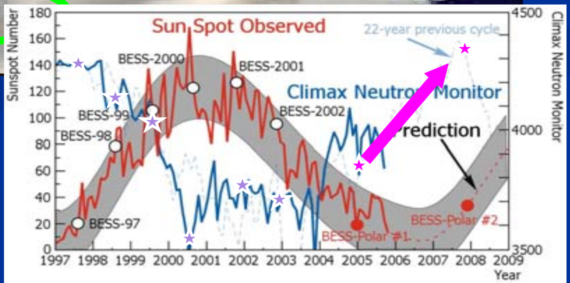
1993~ 2000, BESS, North Canada
2002, BESS-TeV

1999, 2001, BESS-Ground, Japan

2001, BESS-TeV, Fort Sumner

2004, BESS-Polar I, Antarctica

10 scientific balloon flight



Summary of BESS Observation

	1993	1994	1995	1997	1998	1999	2000	2001	2002	2004
Program	BESS							BESS-TeV		**Bess-P**
Data Taking Time (hrs)	14.0	15.0	17.5	18.3	20.0	2.8 +31.3	2.5 +32.5	2.5 +11.0	4.0 +16.0	**200**
Event Numbers (M Events)	4.0	4.2	4.5	**16.2**	19.0	2.3 +16.8	2 +15	15	13.0	**~900 w/o track trigger**
Antiprotons (below 1.1 GeV)	**6**	**2**	**43**	**415 (90)**	**384**	**668**	**558**	NA	TBD	**1520 (246)**
Antiproton Ident. Range (GeV)	0.18~0.5		0.18 ~1..5	0.18 ~3.6	0.18~4.2			0.18~4.2		**0.1-4.2**
He/He	2.2×10^{-5}	4.3×10^{-6}	2.4×10^{-6}	1.4×10^{-6}	8.8×10^{-7}	6.7×10^{-7}		--		**2.7×10^{-7}**

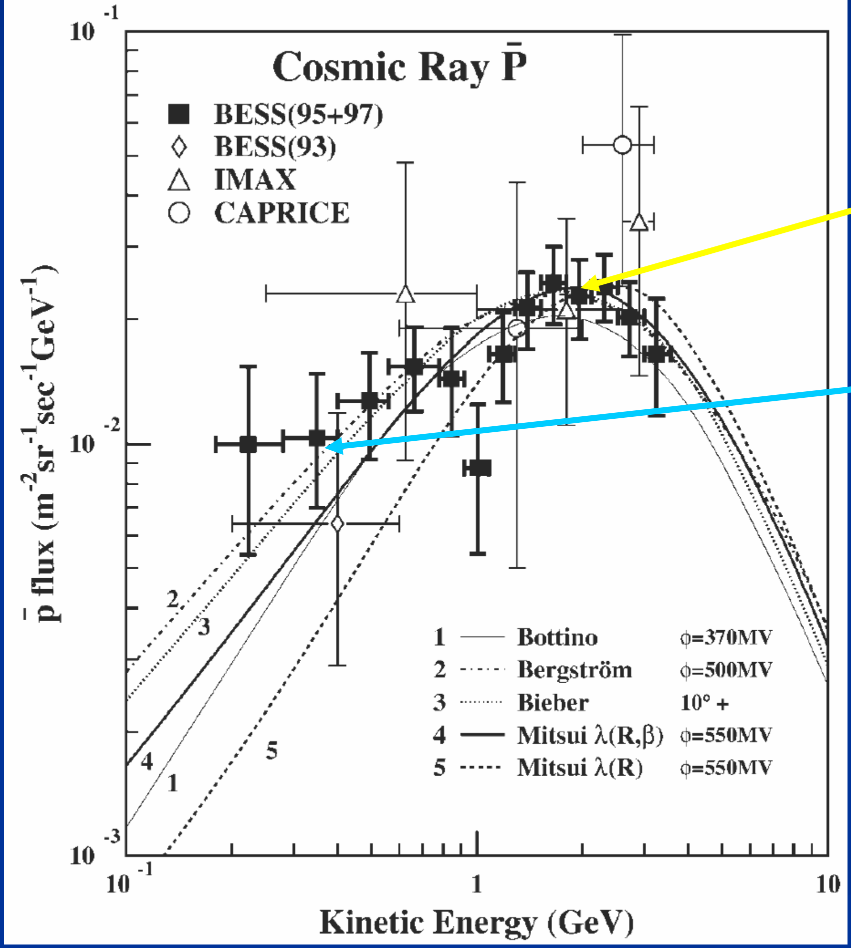
Conventional one-day flight : 10 ~ 20 M events w/ on-line event selection

Bess-Polar I flight for 8 days : 900 M events w/o on-line event selection

Acceptance: 0.3 --> 0.1 m2sr (due to TOF-PMT problem)

Antiproton Spectrum measured in last Solar Minimum Period in 1995 - 1997

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

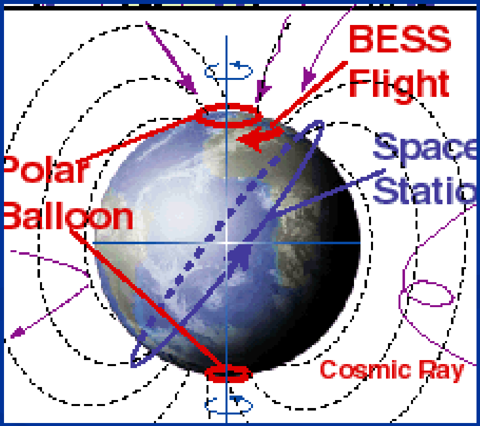


- Peak for Secondary
- Flatter in low energy?
  - Primary Origin?
- More statistics necessary
  - Next solar minimum (06~07)

BESS-Polar Experiment

Very precise measurement

Low energy Antiprotons



Around south-pole,

Antarctica

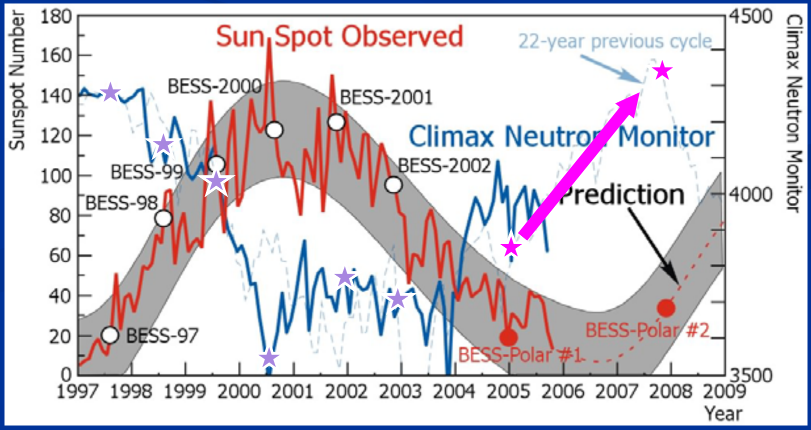
Long duration flight

High latitude

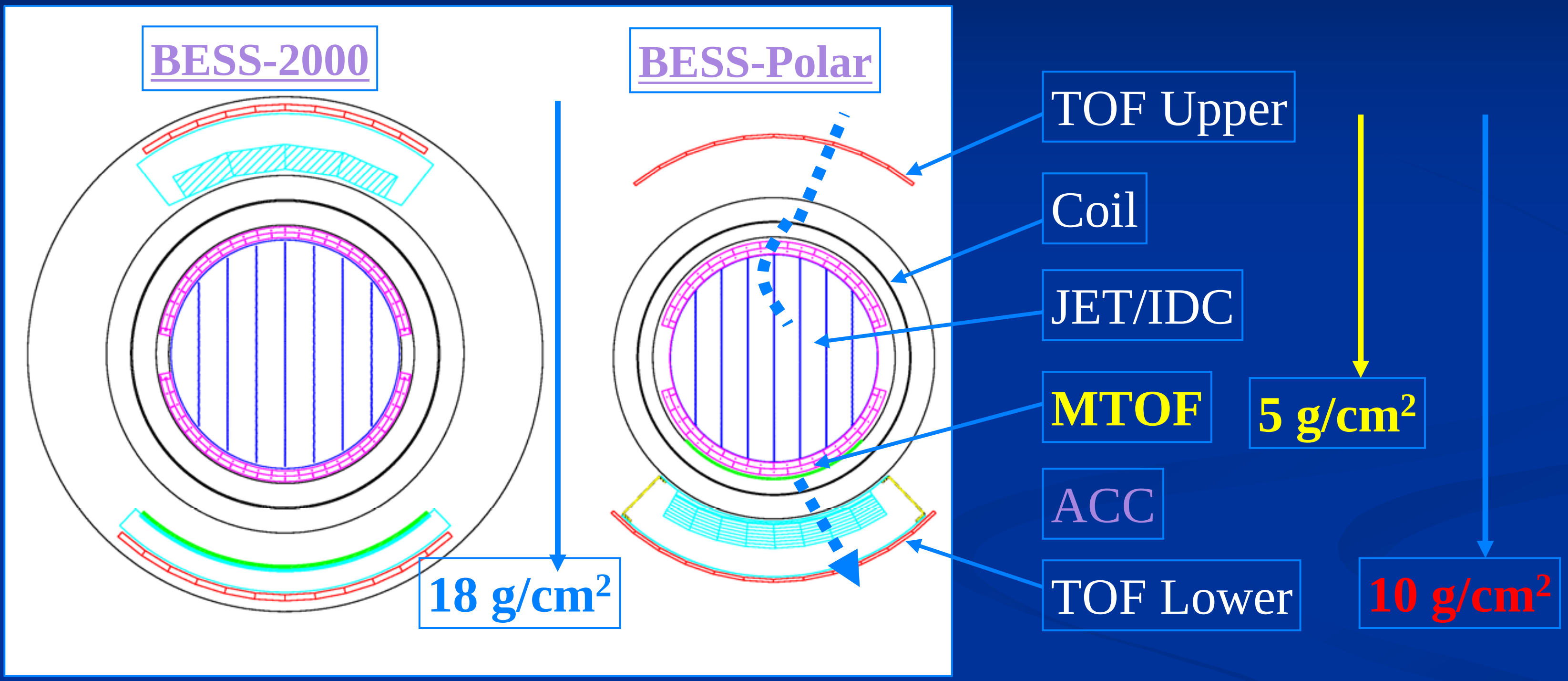
With a new spectrometer

Large Acceptance

Ultimately small material



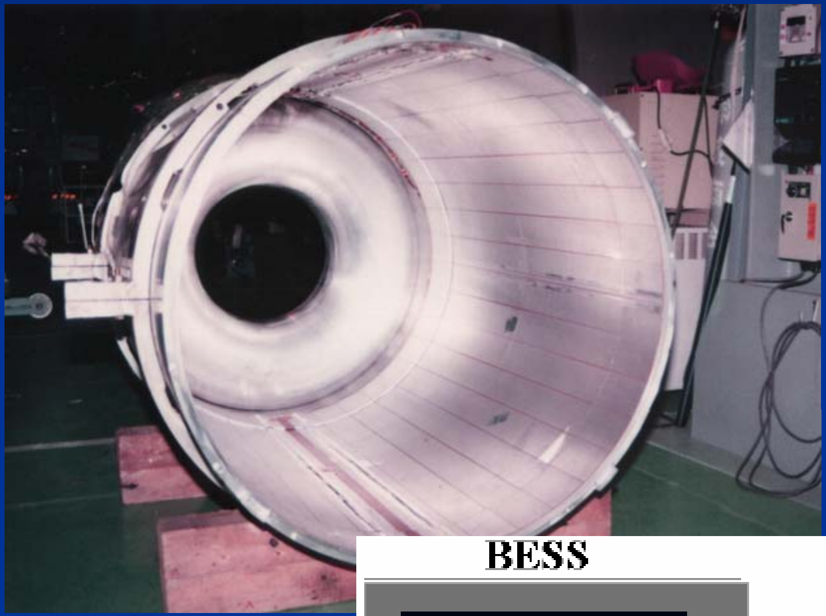
BESS-Polar Spectrometer with Minimizing Material in Detectors

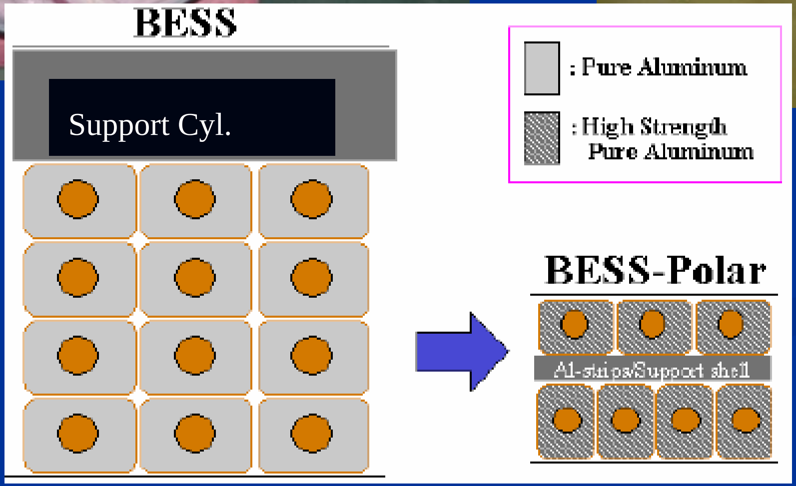


Minimize material in spectrometer
New detector (Middle TOF) ⇒ **Energy range extended down to 0.1 GeV**

Low power electronics
Solar Power System, Longer life of cryogen, LHe ⇒ **Long duration flight**

BESS-Polar：Superconducting Magnet



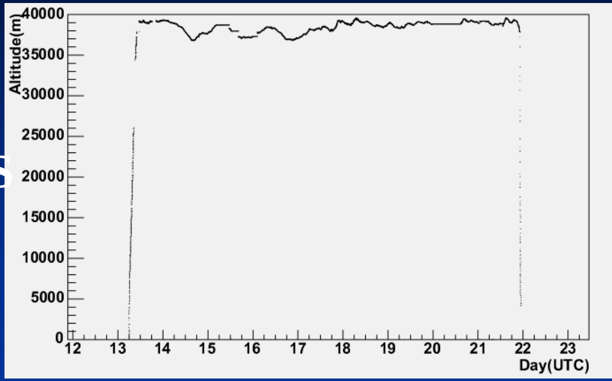


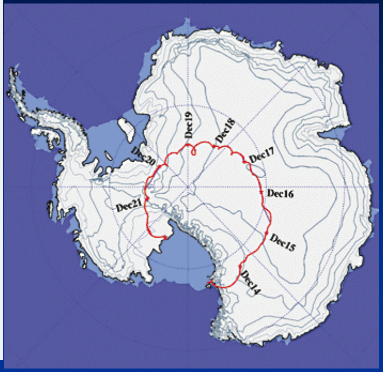
BESS-Polar I Spectrometer

	BESS	BESS-Polar
Geom. Acceptance: $m^2 \cdot sr$	0.3	0.3
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 Source	Battery	Solar-panel
Power Consumption	1.2 kW	450 W
Cryogen life	5.5	10 ~ 20 days

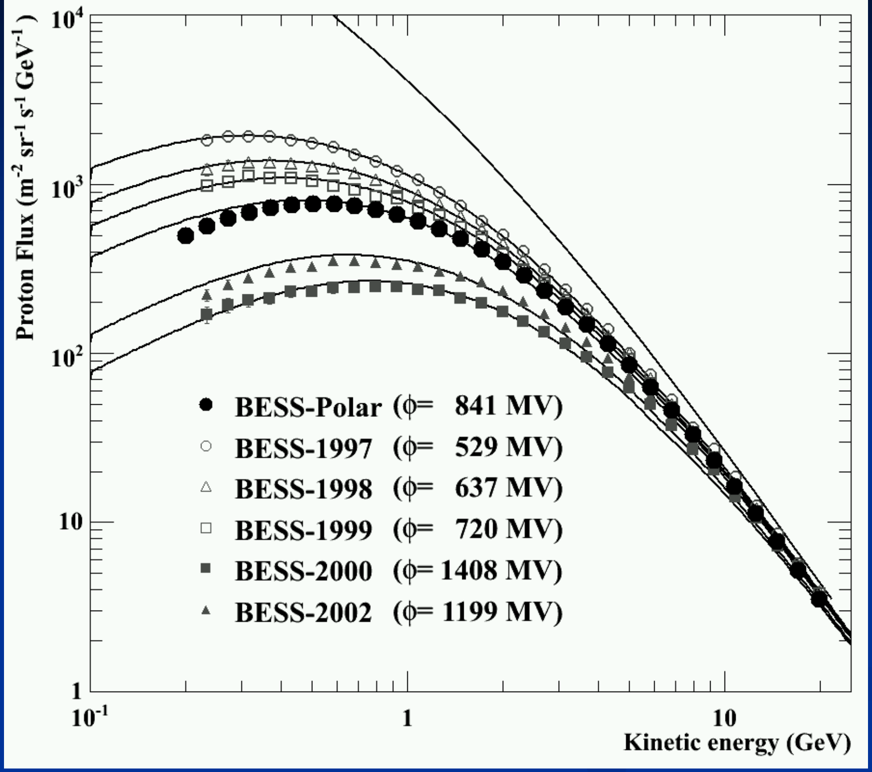
BESS-Polar I Flight

- •Duration: 8 days, 17 hours (December 13-22 2004)
- •Altitude: 120 - 129 kft (37 - 39 km)
- •Trajectory: circumpolar 77.9° - 86° S
- •Events recorded: > 9 x 10^8
- •Data volume: ~ 2 terabytes



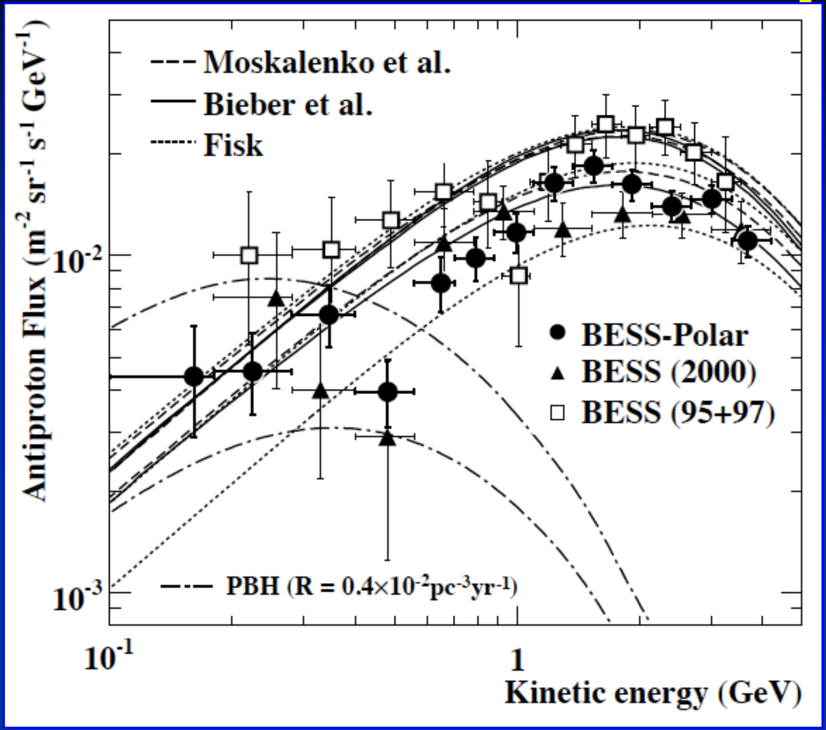


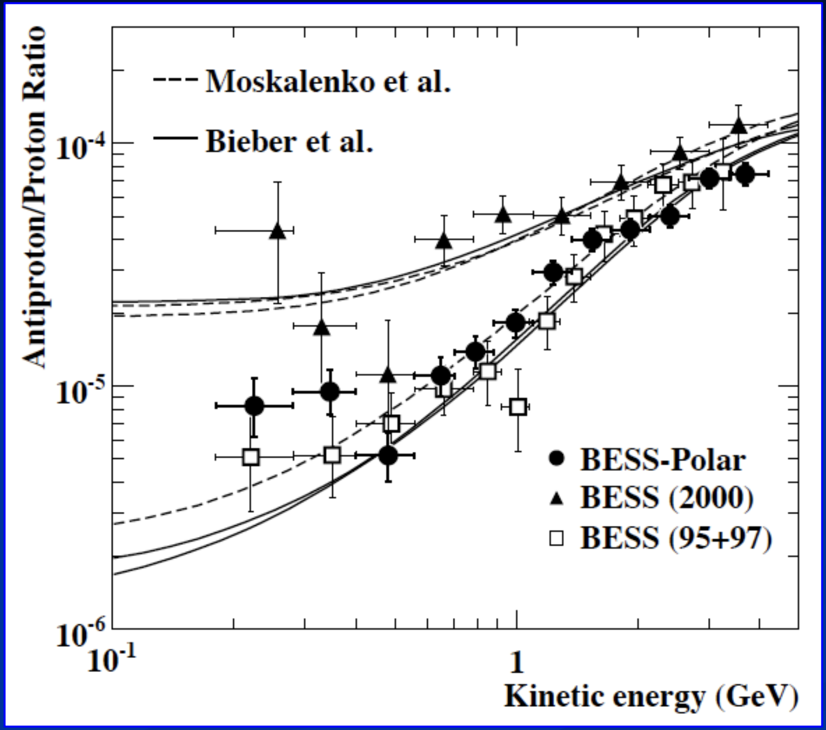
Protons



- **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**
- **Lower curves show the variation with time (Solar modulation) of the measured proton spectra extrapolated to the top of the atmosphere**

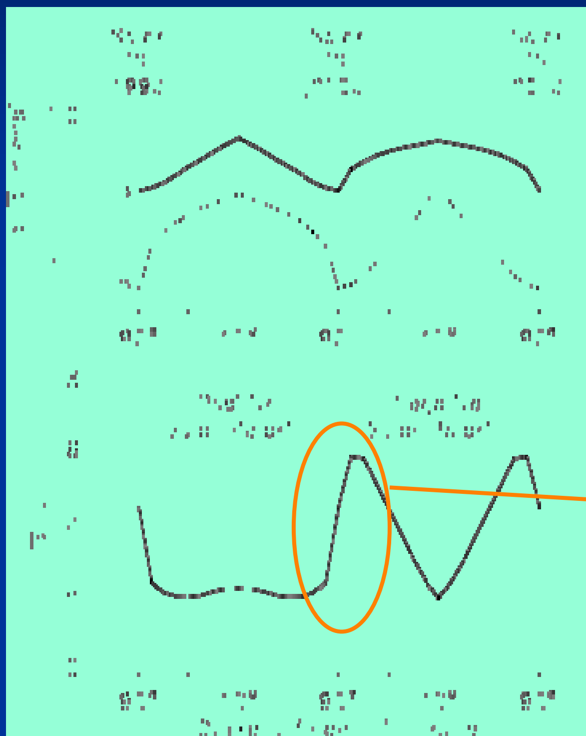
Antiprotons

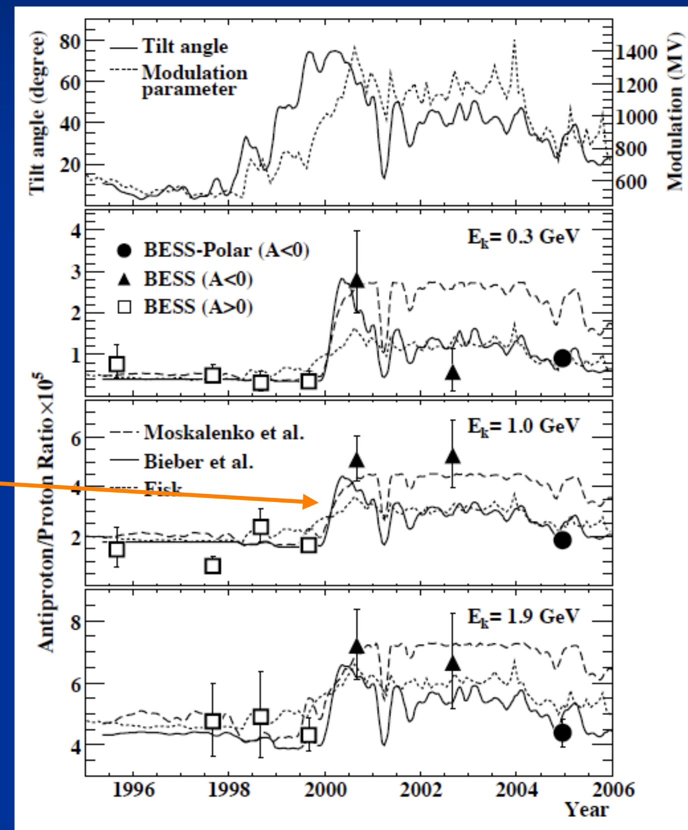




- BESS (95+97) Solar-min data show a possible *flattening of the antiproton spectrum at lower energies* compared to secondary production.
- BESS-Polar I data taken at higher solar are consistent with secondary production, as expected.
- Primary source suppressed at higher modulation levels.
- Results to be published in Physics Letters B arXiv:0805.1754

Charge-Sign Dependence of Solar Modulation with p-bar/p Ratio





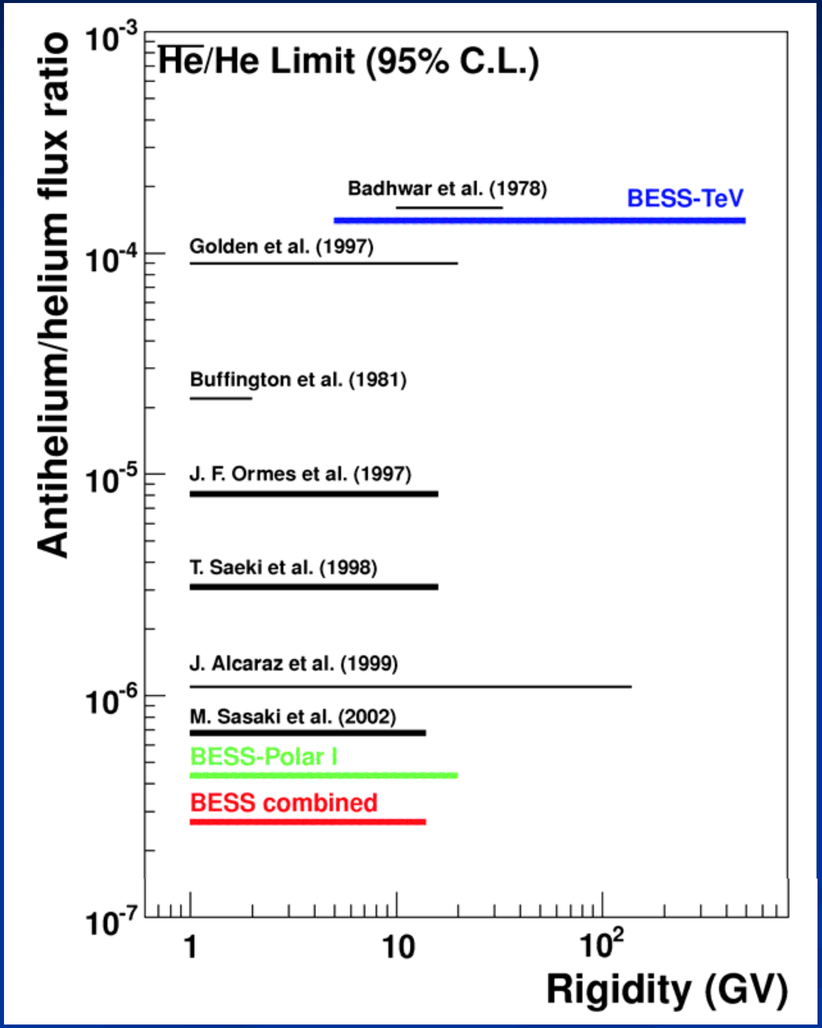
Bieber et al. PRL, 88, 4, 8 (1999) 674.

Moskalenko et al., APJ, 565 (2002) 280.

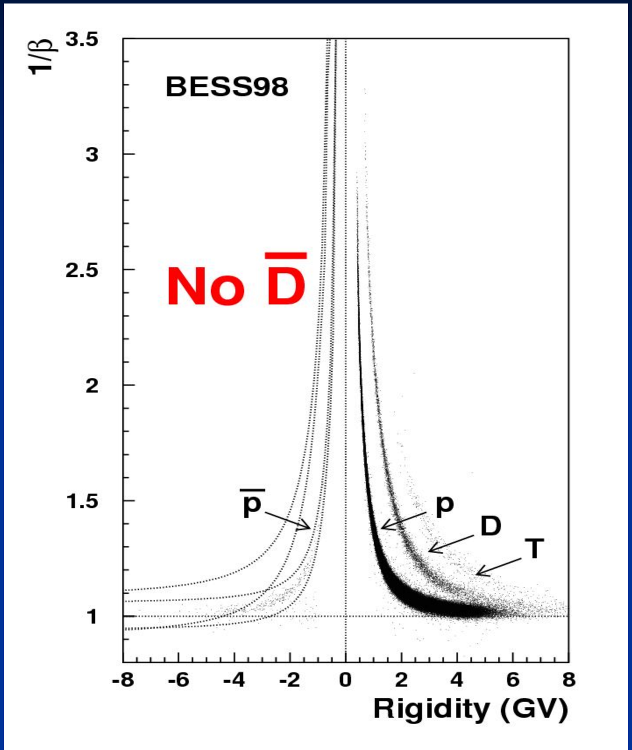
- Drift models and the charge-sign dependence in solar modulation is better consistent with BESS results

Antihelium

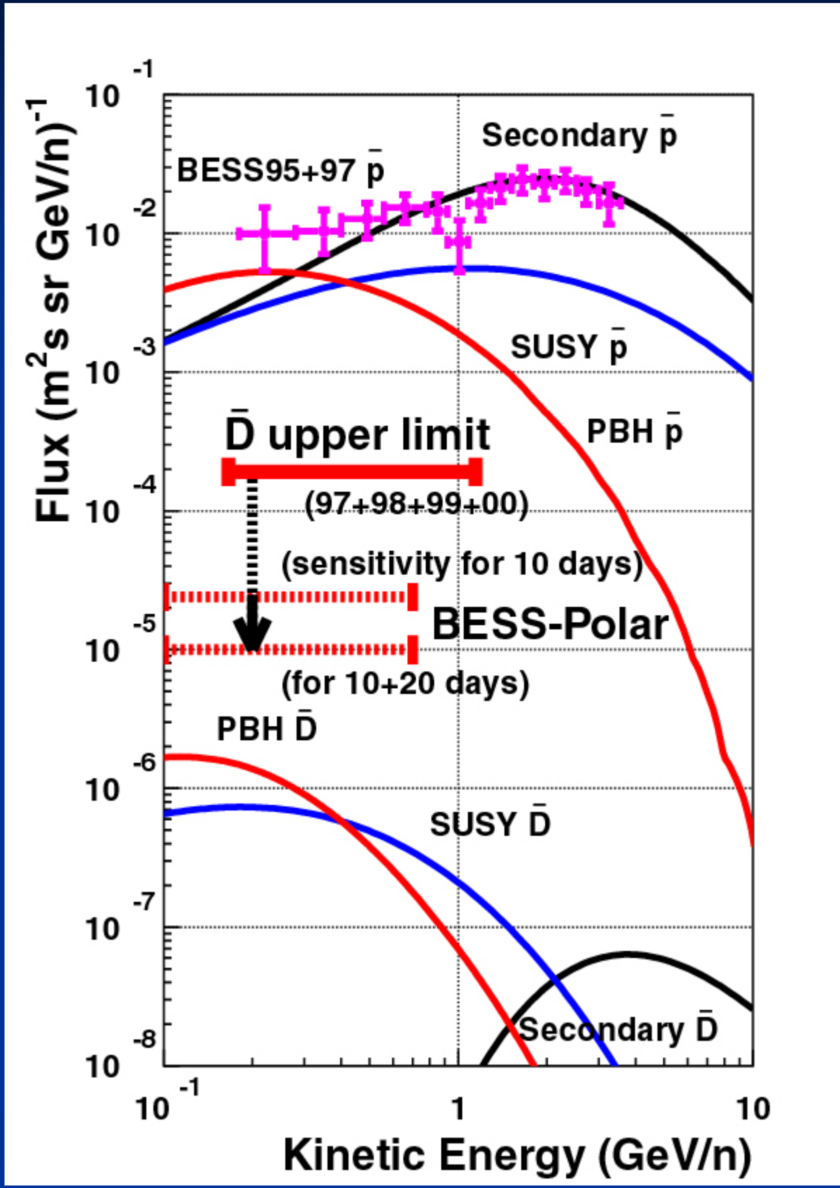
- No antihelium candidate has been found by any investigation
- BESS-TeV
  1 - 500 GV, 7 x 10^4 He events
- BESS-Polar I
  0.6 - 20 GV, 10^6 He events
- BESS combined upper limit for the Antihelium to Helium flux ratio
  2.7 x 10^{-7}
- 24.5-day flight of BESS-Polar II will give sensitivity <3 x 10^{-8}.
- Science News article May 12, 2007



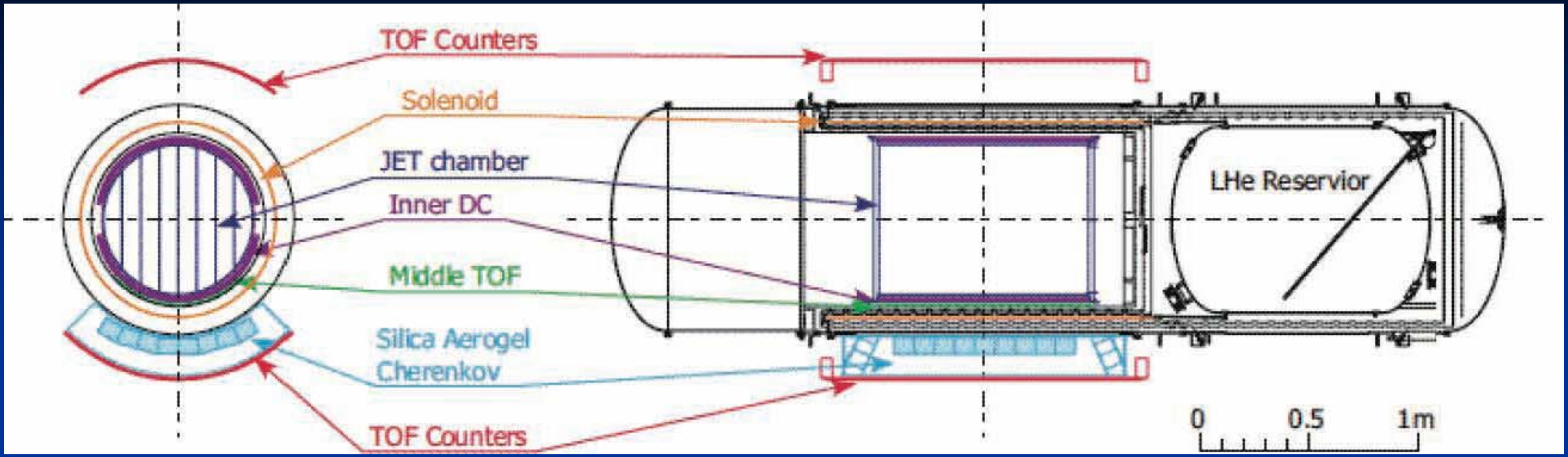
Antideuteron



- Secondary $\bar{D}$ probability is negligible at low energies due to kinematics
- Any observed $\bar{D}$ almost certainly has a primary origin !
- D upper limit (first reported), 1.92 x 10^{-4} $(m^2\ s\ sr\ GeV/n)^{-1}$



BESS-Polar II



- Longer Observing Time
  - Increased **magnet cryogen life***
  - Enlarged **data storage volume***
- Improved Reliability
  - Pressurized enclosure for the TOF PMT
  - Improved electronics efficiency
- Improved Performance
  - ACC rejection power *
  - Middle TOF resolution/position determination
  - Outer TOF resolution

* Specially supported by RESCEU

- Payload Size:
  - Spectrometer 1.5 x 1.5 x 5 m^3
  - Solar-cell arra 6 x 8 x 2.5 m^3
- Payload weight 2130 kg

Superconducting Magnet

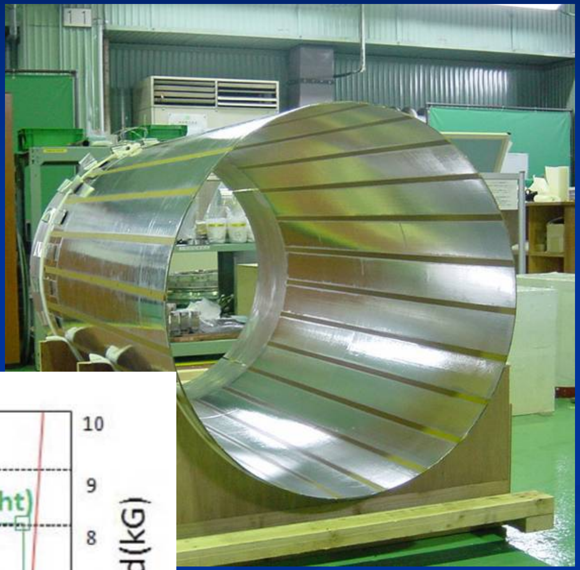
Coil: 0.9 m dia. x 1.4 m long

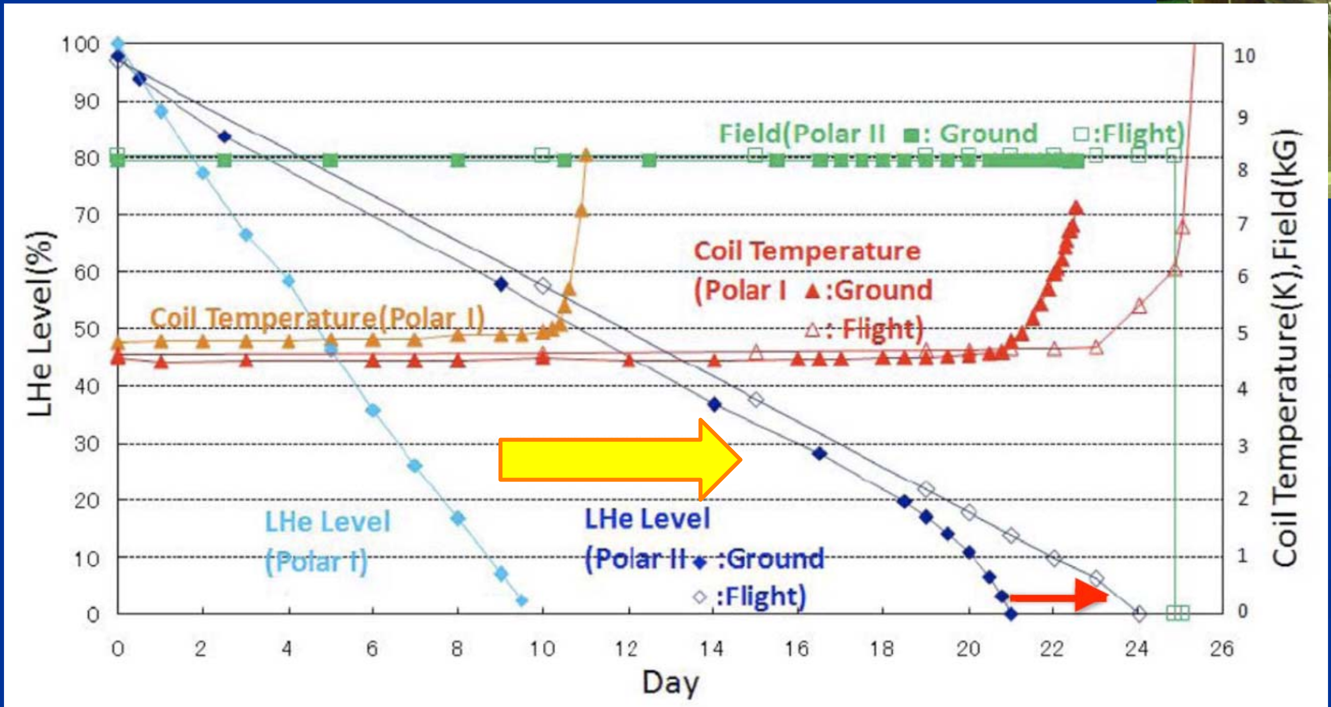
Very uniform magnetic field

Field Strength 0.8 Tesla (flight)

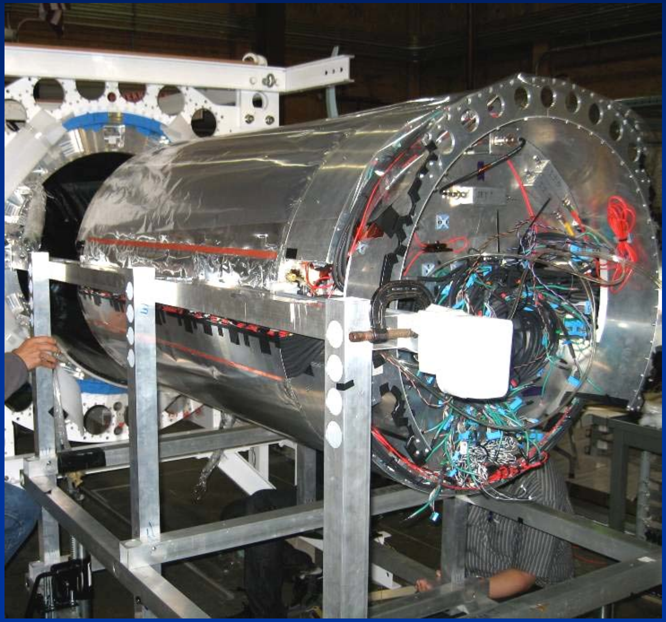
2.2 g/cm^2 wall thickness including cryostat

In flight 25 days persistent mode with 520 l LHe





Drift Chamber

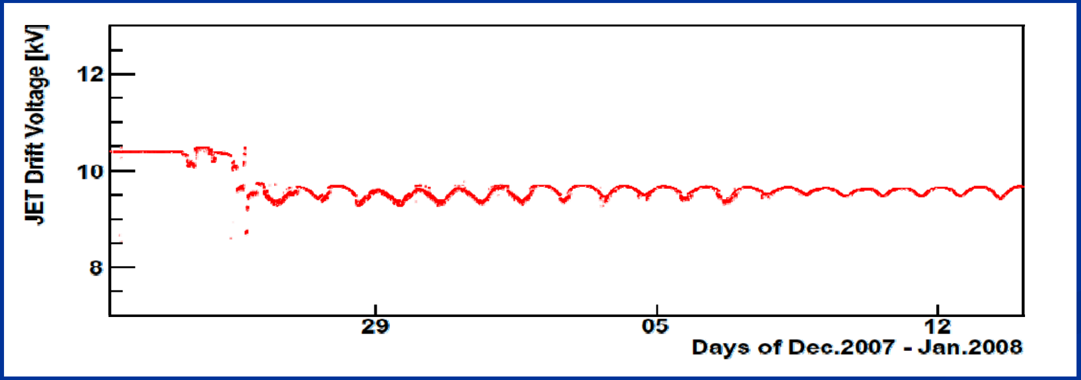


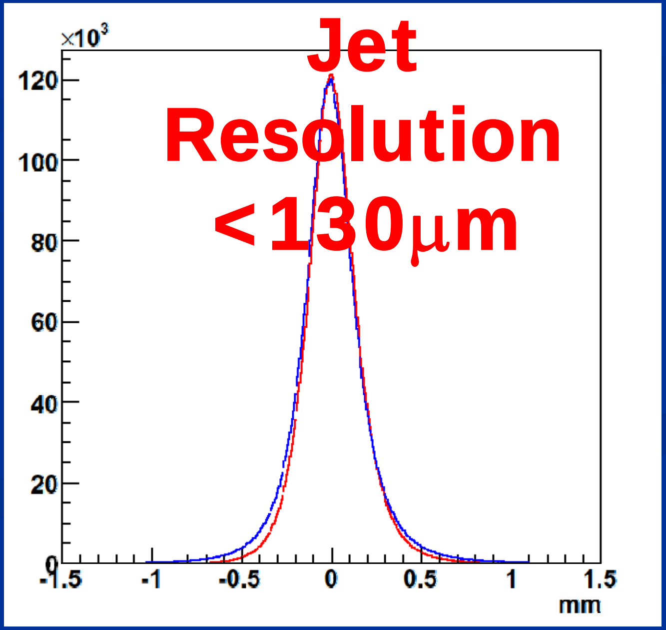
Jet-type Drift Chamber

Up to 52 track positions

With a spatial resolution < 130 um

ΔR/R = R/MDR   MDR=240 GV/c





Outer Time-of-Flight

Outer Time of Flight Counter

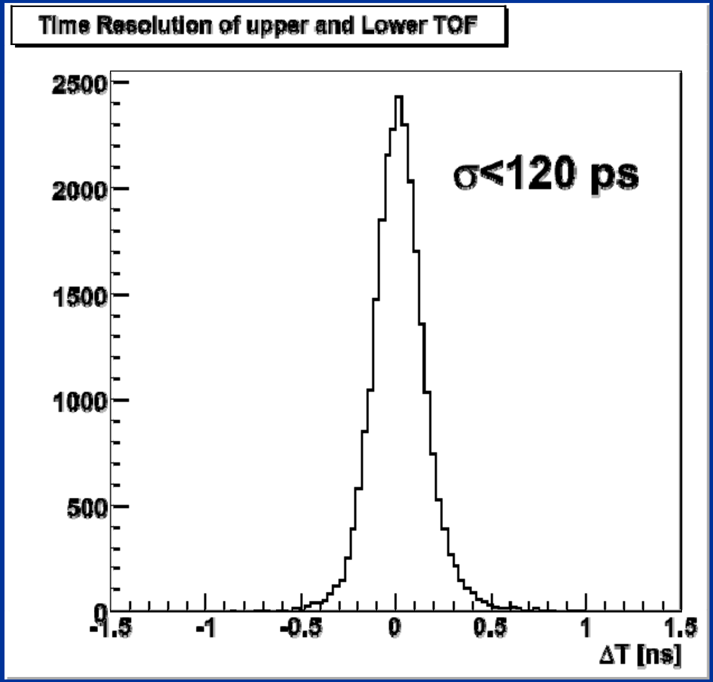
10 paddle upper plane

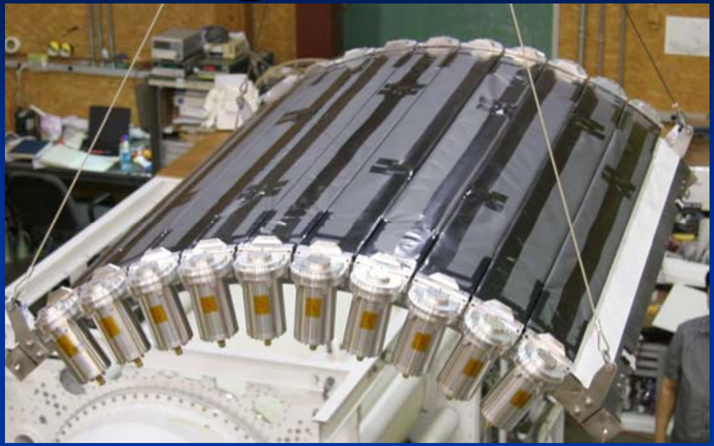
12 paddle lower plane

active area each 0.95 x 0.1 m^2

Trigger aperture 0.3 m_2 sr

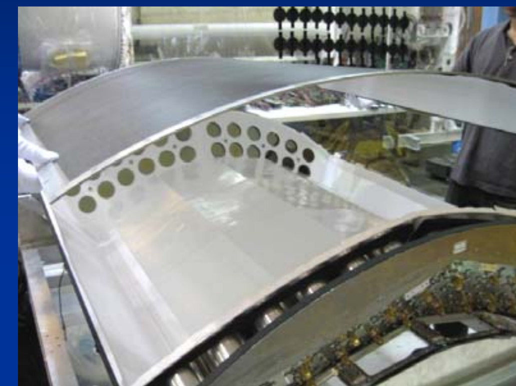
Outer TOF resolution <120 ps

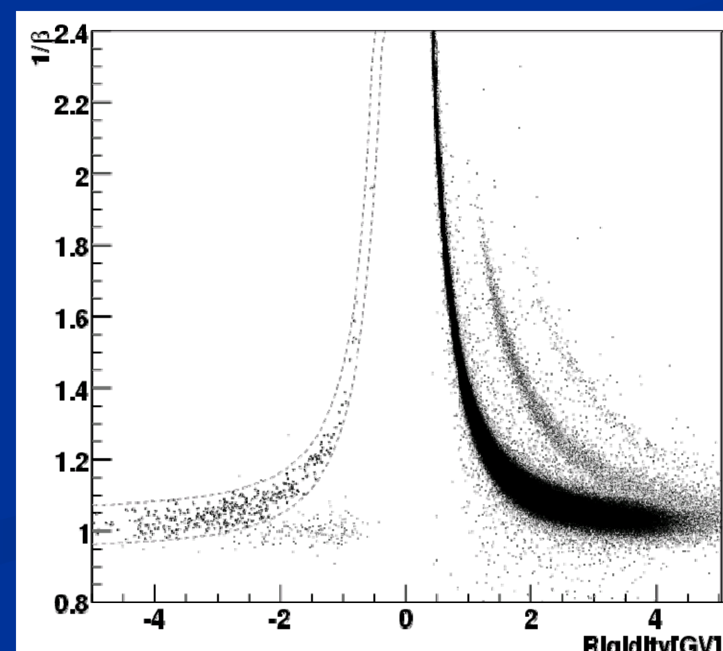




Aerogel Cherenkov Counter

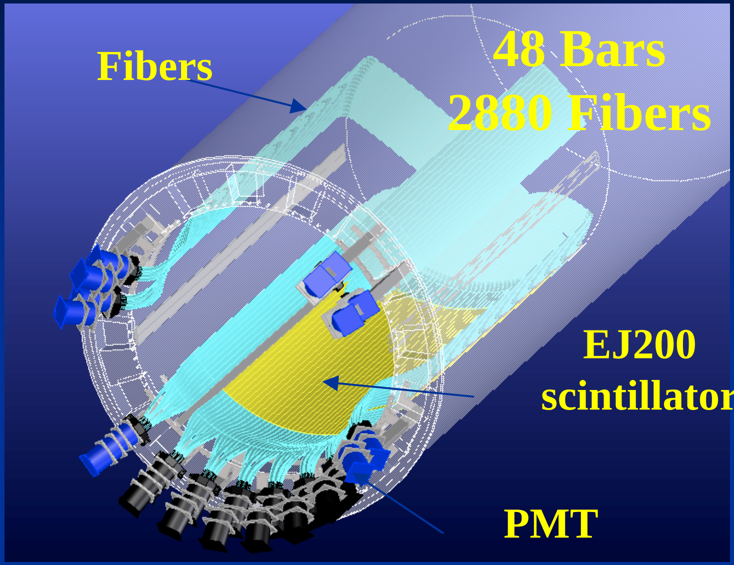
- BESS Cherenkov is a light diffusion Cherenkov Counter.
- 48 R6504 PMT view ACC
- Index-of-refraction n=1.03
  β_{ck}= 0.971; γ = 4.174
  $E_{kin,\,ck}$ = 0.333 GeV (μ), 2.9 GeV (p)
- It is used a Threshold counter
  binary test: is particle faster β_{ck}
  allows to suppress lighter e/μ
- Light Yield Npe = 12
- Rejection factor ~1/6000



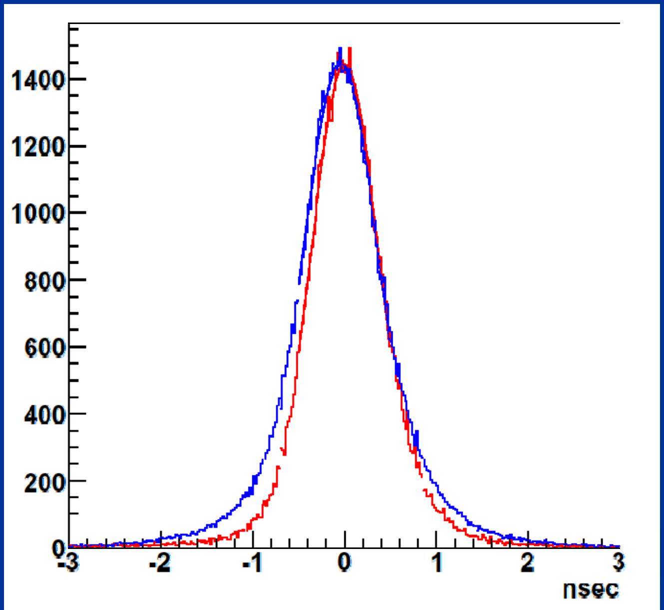


Middle Time-of-Flight

- Middle TOF is part of low energy trigger.
- Needs less stringent time resolution
- Can serve a backsplash veto
- 48 Scintillator strips read from both ends by R6504 multi-anode PMT



Polar-II UM TOF ~370ps

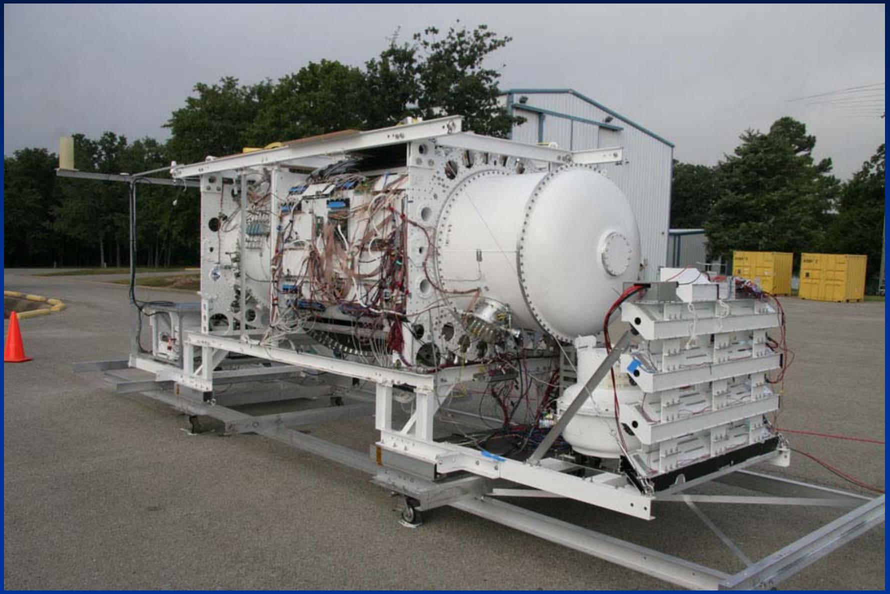


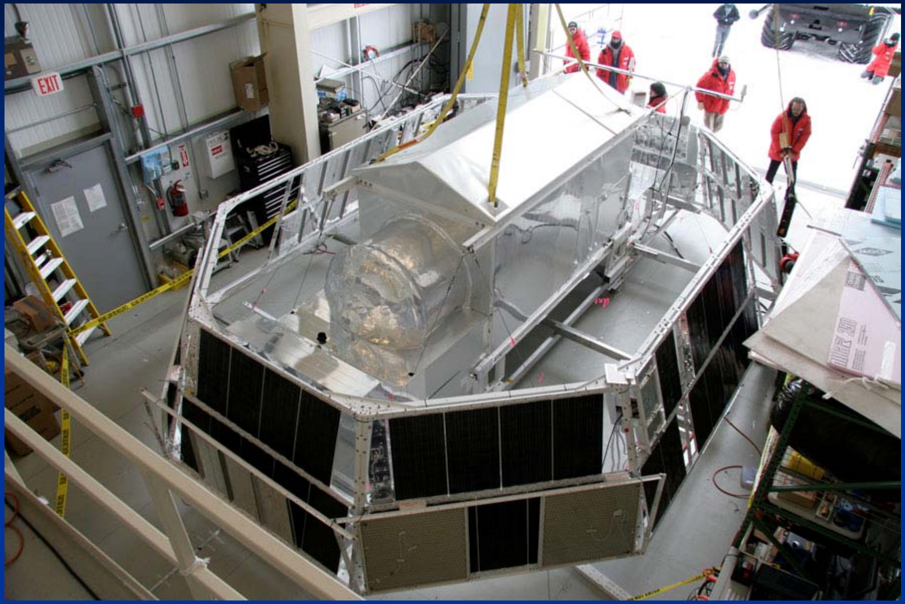
BESS-Polar II Improvements

Subject	(BESS-Polar I)	(BESS-Polar II)
Magnet Cryogen Life	~ 11 days (400 l LHe)	>25 days (520 l LHe)
Track detector (JET) gas quality	~ 10 days	> 20 days
TOF-PMT housing	Resin potting	Pressurized housing*
ACC particle Identification	Rejection: 1/600	<< 1/1000*
Solar-power system	4 stage 900 W	3 stage 675 W
Effective Acceptance	~0.11m^2sr	0.3 m^2sr
Observation time	8.5 days	> 20 days
Statistics Data storage	4 x BESS97 3.6 TB (2.1 recorded)	20 x BESS97 16 TB (13.5 recorded)*

*** Supported by RESCEU**

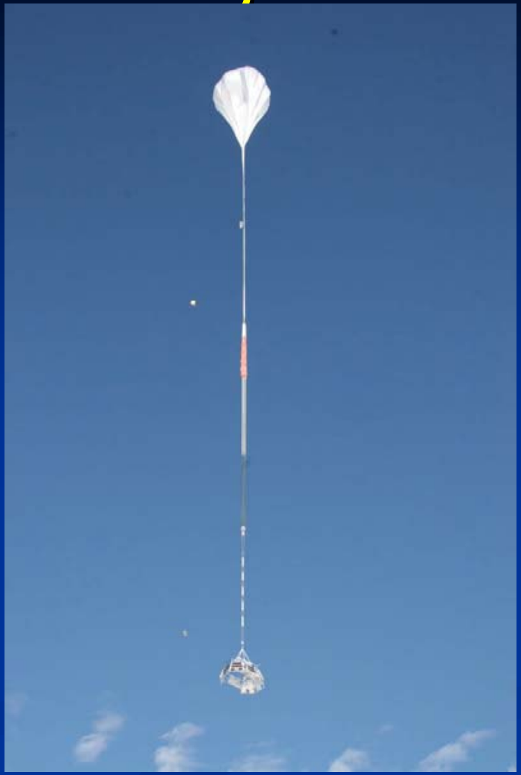
BESS-Polar II - 2007



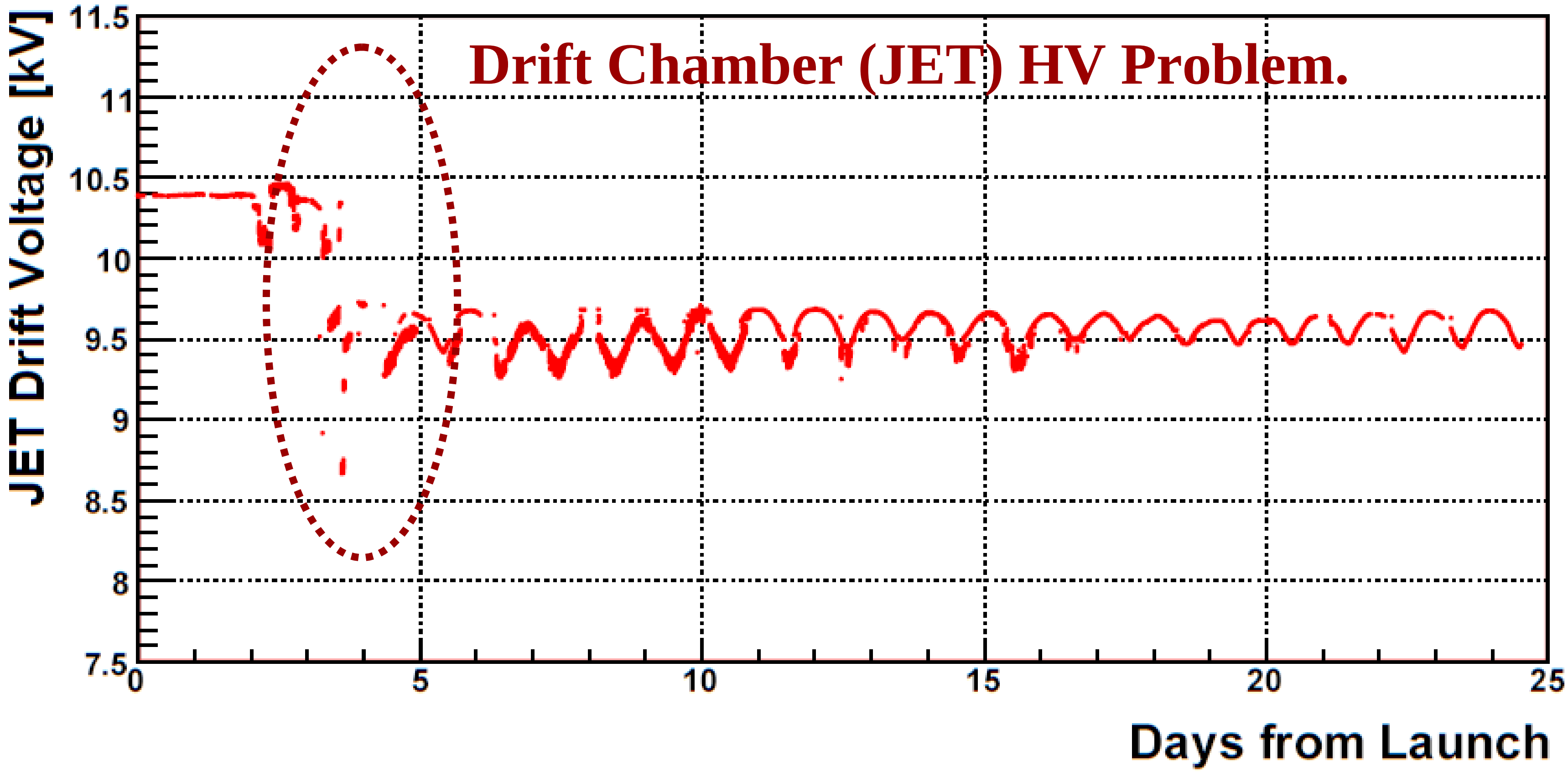


BESS-Polar II Launch - December 22, 2007

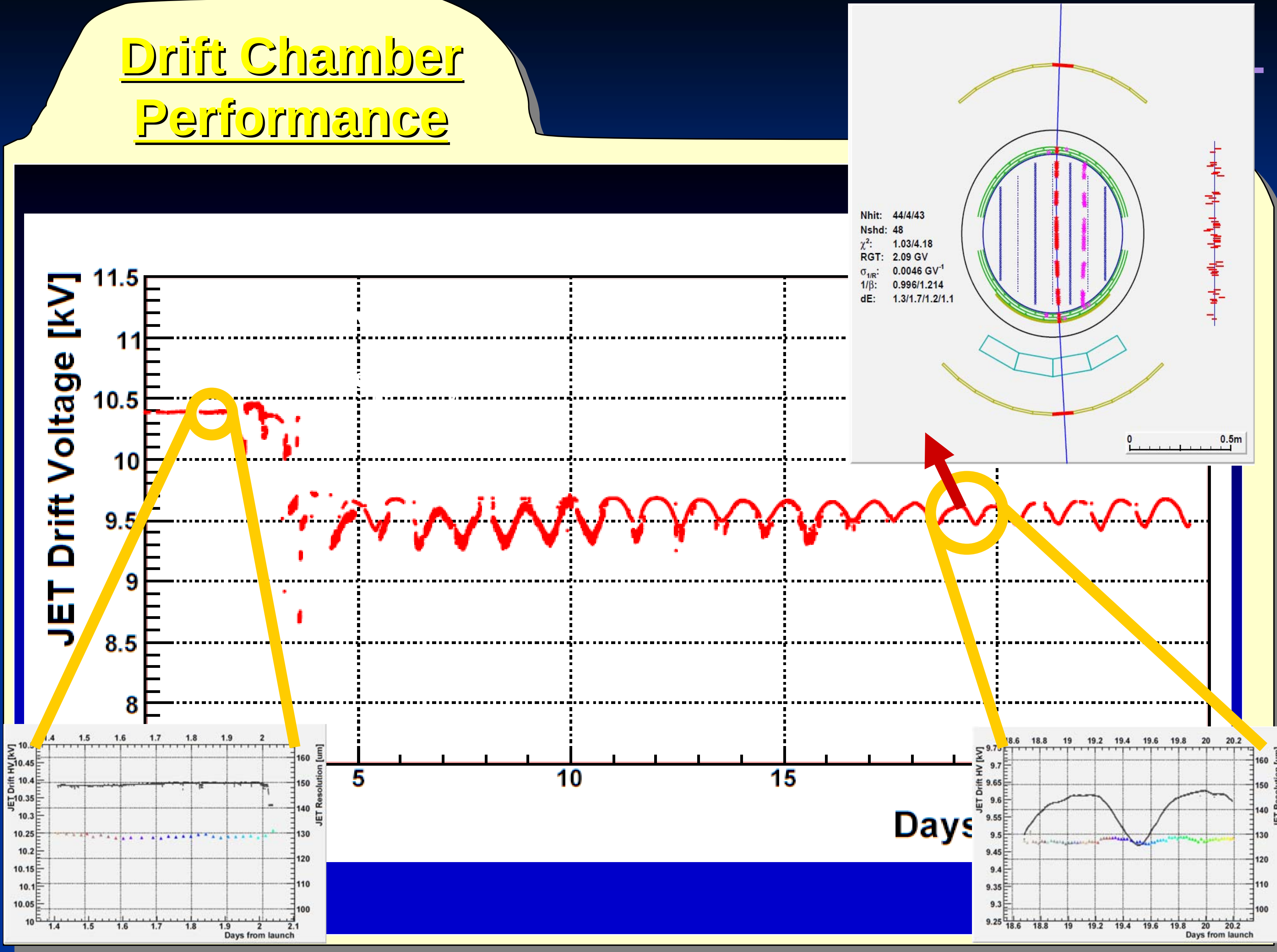
BESS-Polar II Launch - December 22, 2007



Drift Chamber Performance



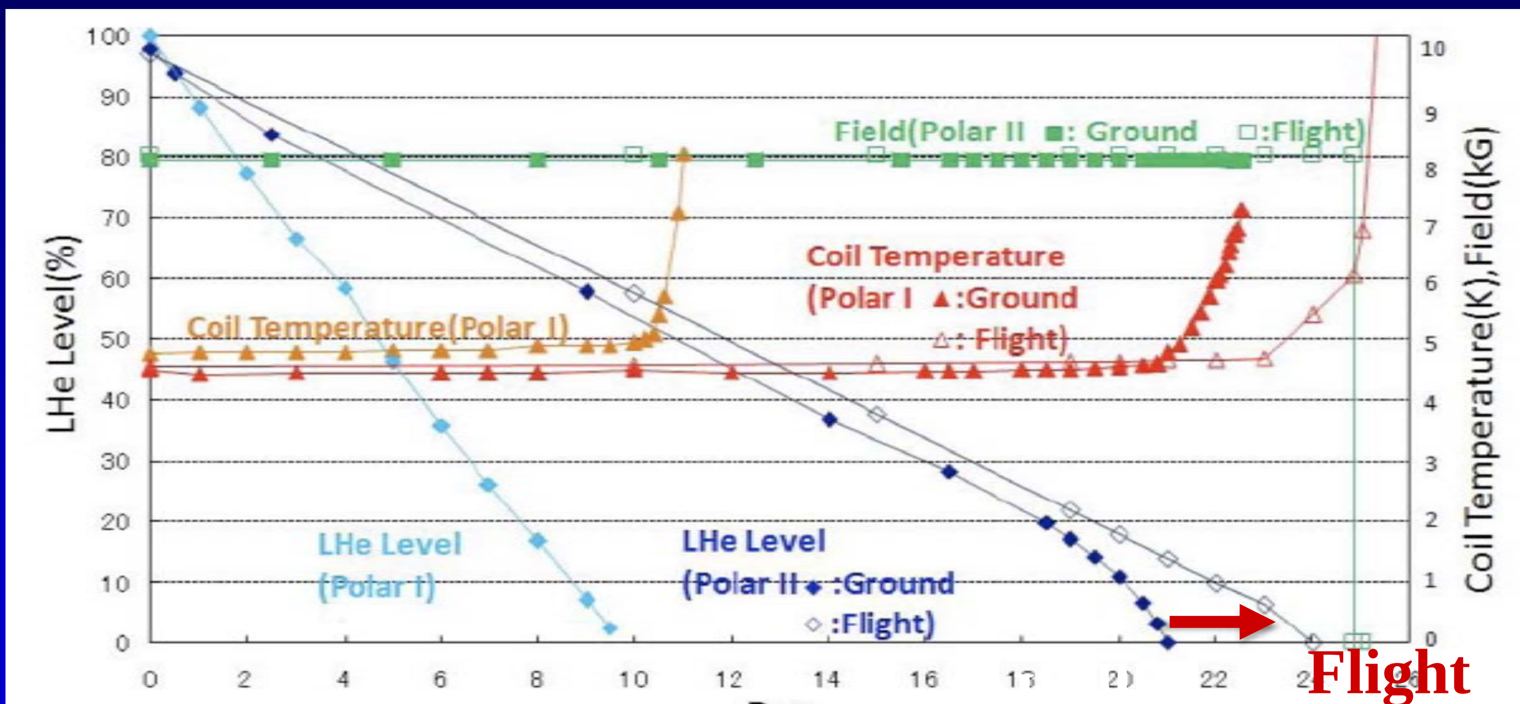
Drift Chamber Performance



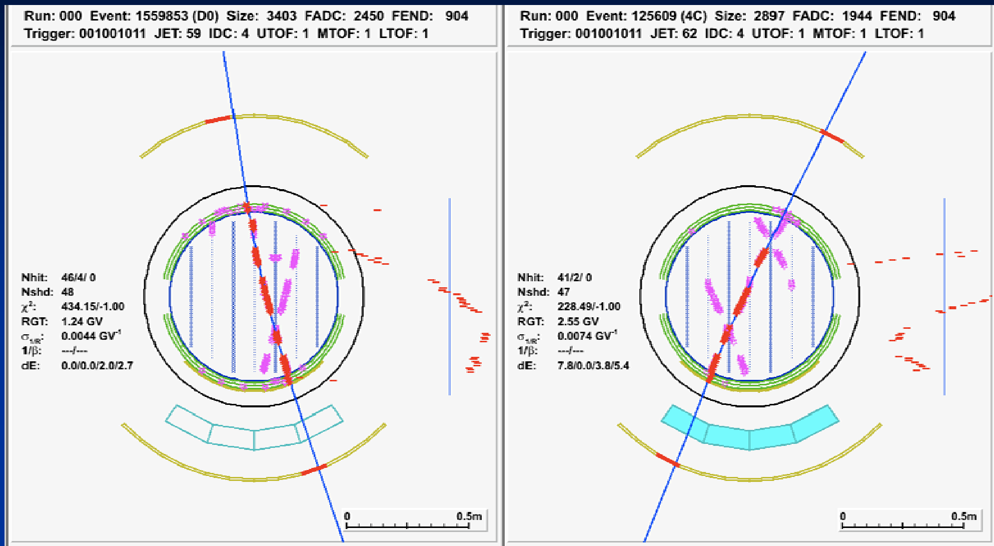
BESS-Polar II Magnet Status

Magnet life 22.5 days in ground -> ~ 25.5 days in flight

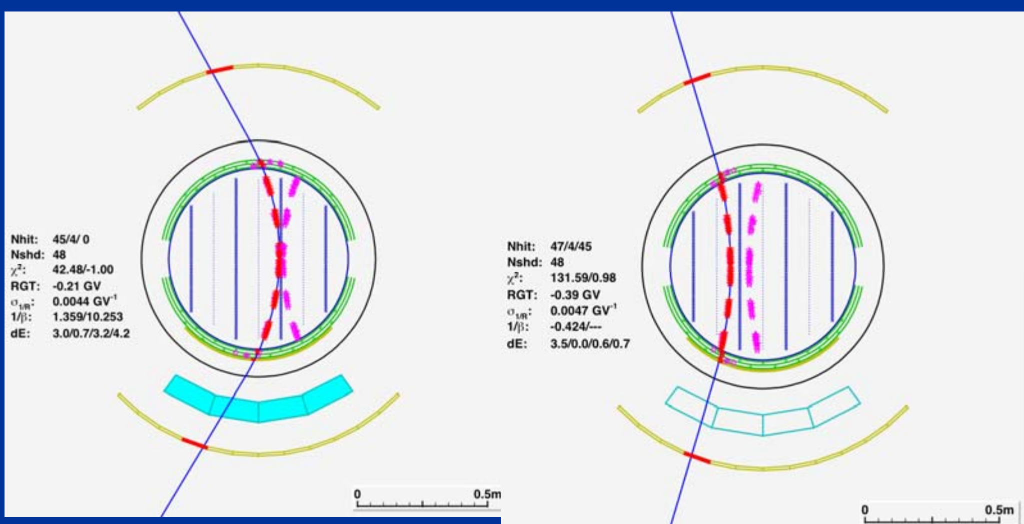
24.5 days science run with B-field was achieved!



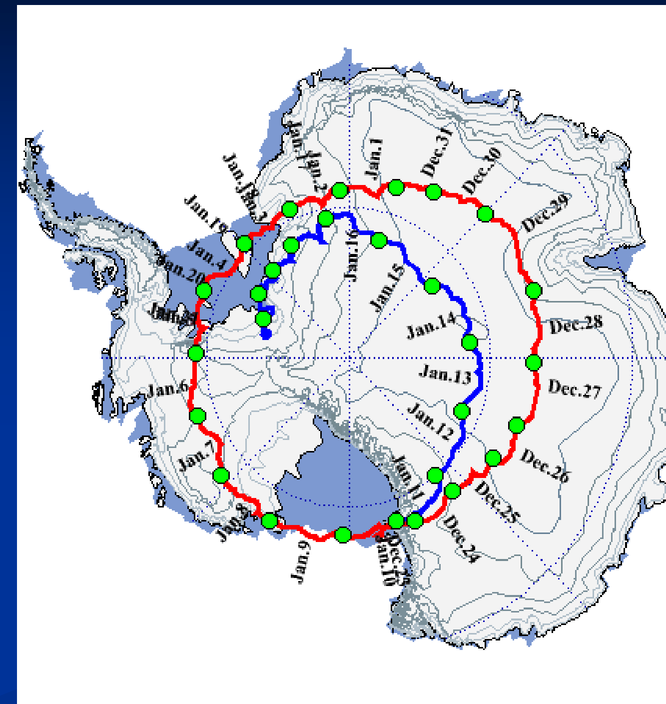
BESS-Polar II Flight



Positive Events

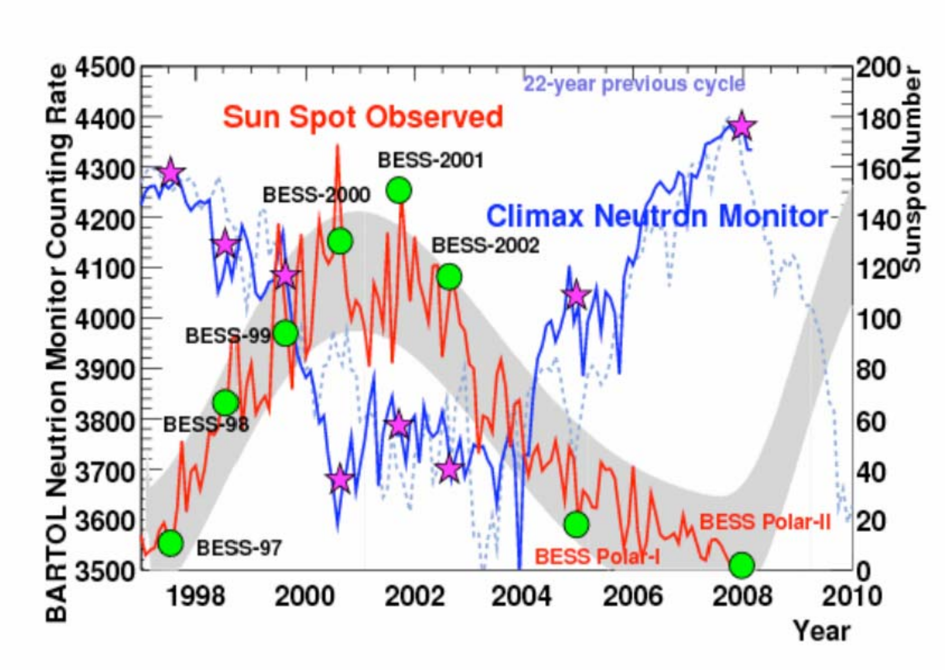


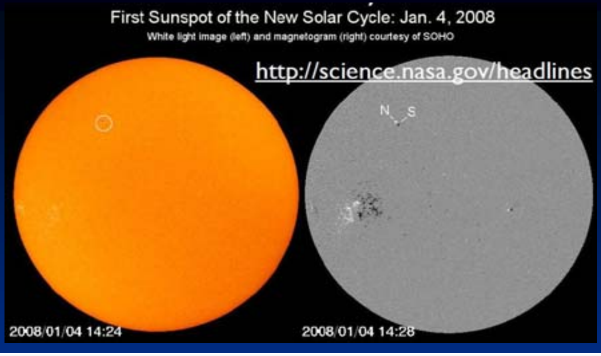
Negative Events

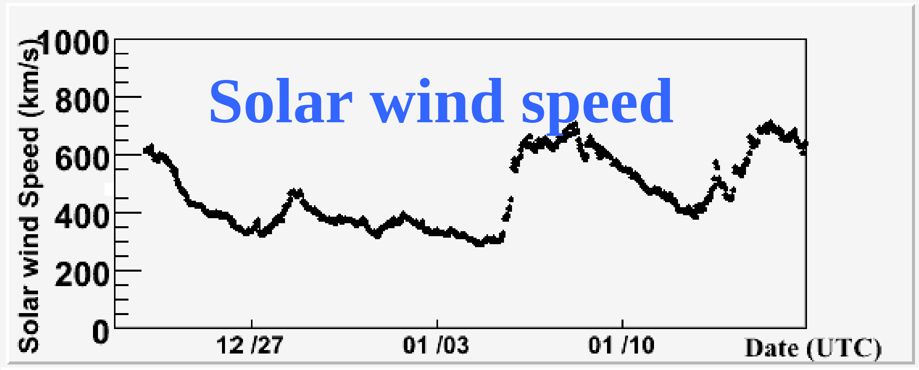


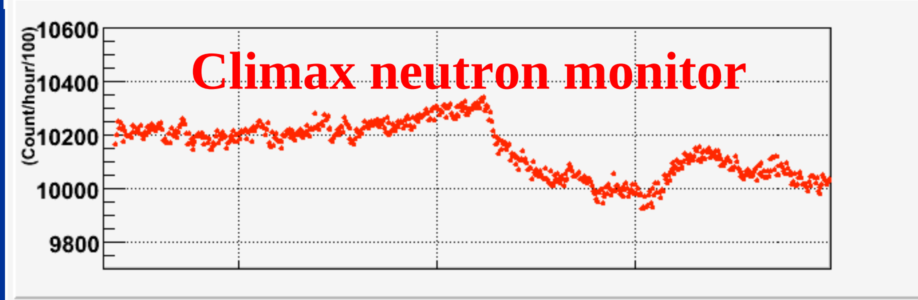
- Launch 12/22/07 17:30 UTC
- Science Termination 1/16/08 2:00 UTC
- Observation time - 24 days 10 hours
- Average altitude ~36 km (118,000 ft)
- Latitude 77.9° - 83° South

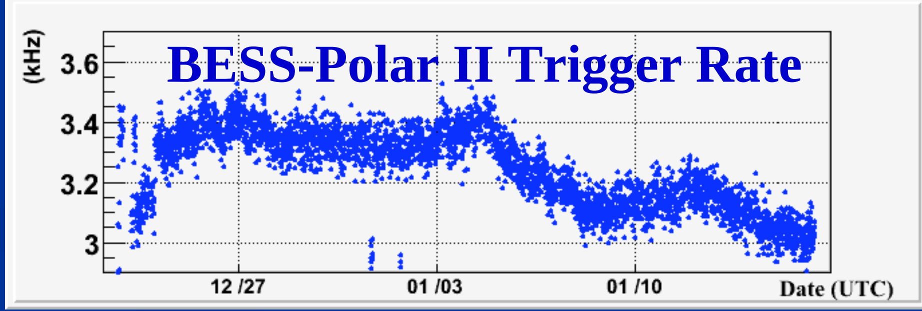
Solar Conditions











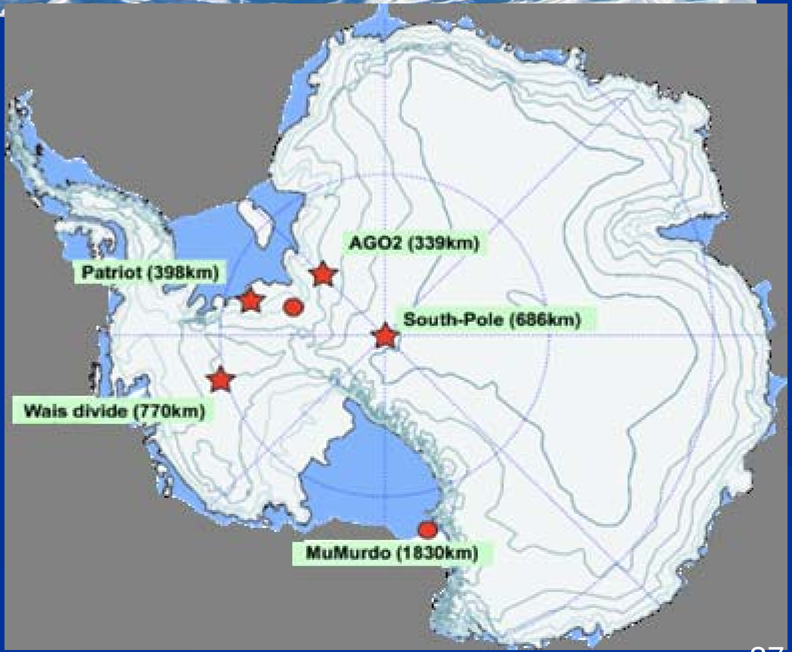
- Flight at true Solar minimum
- Sunspot resulted in high-speed stream in solar wind
- Variation in rate clearly correlates with solar wind and neutron monitor
- Daily variation of proton spectrum and antiproton/proton ratio important for further study

End of BESS-Polar II Flight

- Flight termination January 20, 2008 ~30 days
- Location 83 ° 51.23’ S, 73° 5.47’ W
- On West Antarctic ice sheet - 225 nm from Patriot Hills Camp, 185 nm from AGO-2, 357 nm from South Pole
- Data successfully recovered February 3!

BESS-Polar II Recovery Plan

- Planned for Winter 2008-2009
- Staging from South Pole baselined
- Camp on site ~1-2 weeks for disassembly
- Bassler (mod DC-3 turboprop) planned due to range and instrument size

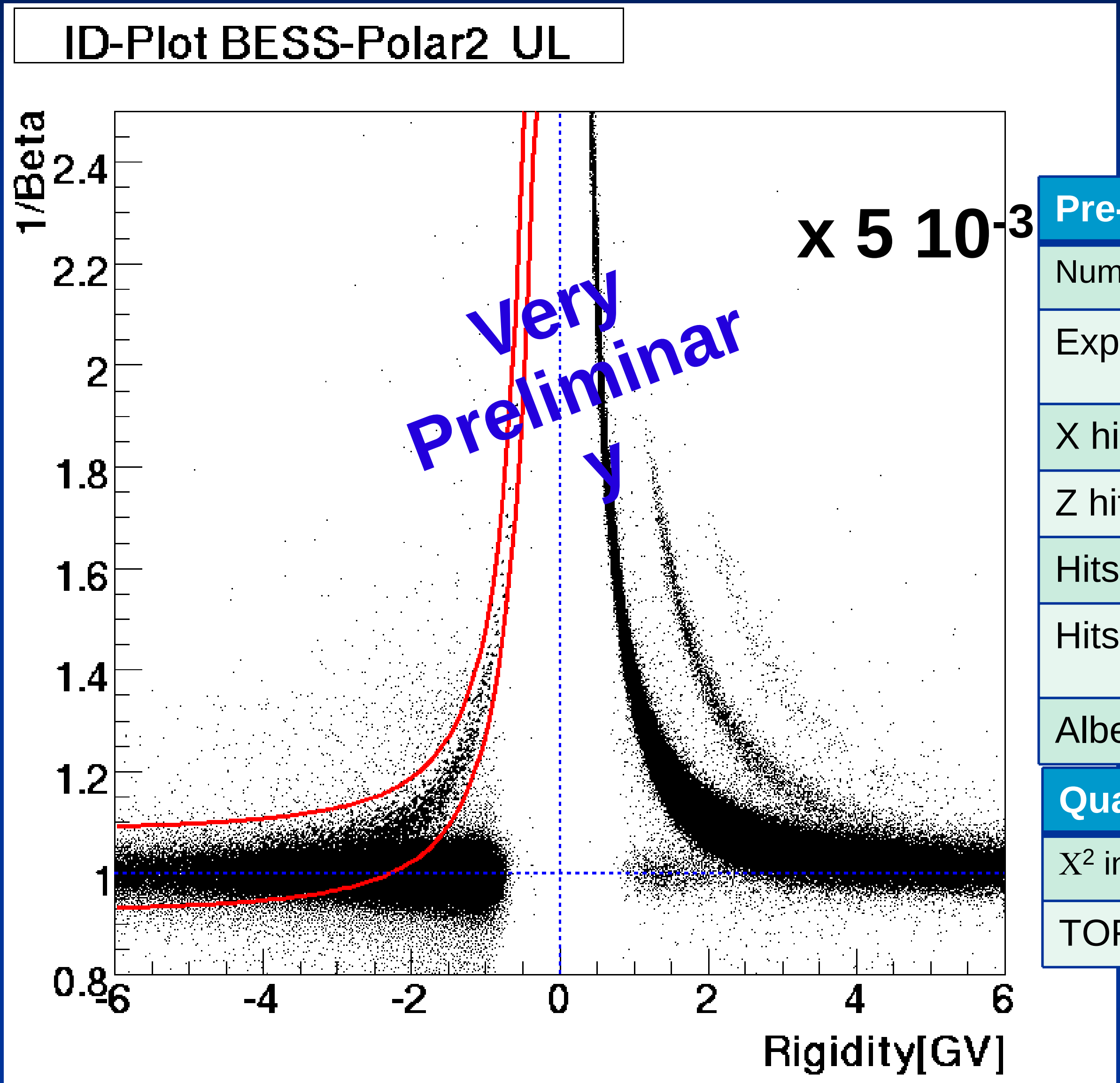


Performance Summary

Flight Status	BESS-Polar I	BESS-Polar II
Total Float time	8.5 days	29.5 days
Observation Time	8.5 days	24.5 days
Recorded Event	900M	4700M
Recorded Data size	2.1TB	13.5TB
Trigger rate	1.4kHz	2.4kHz
Live time Fraction	0.8	0.77
Altitude	37~39 km	34~38km
Air Pressure	4~5 g/cm^2	4.5~8 g/cm^2
Total Weight	1950kg	2200kg
Balloon	40-Light	37-Heavy

Detector performance		BESS-Polar I	BESS-Polar II
JET	r-f resolution(mm)	126	128
	z resolution(mm)	45	25
TOF	Timing resolution U-L(ps)	156	118
ACC	N.pe.	6.7	11.3
MTOF	Timing resolution U-M(ps)	320-530	260-360

ID-plot (BESS-Polar II)

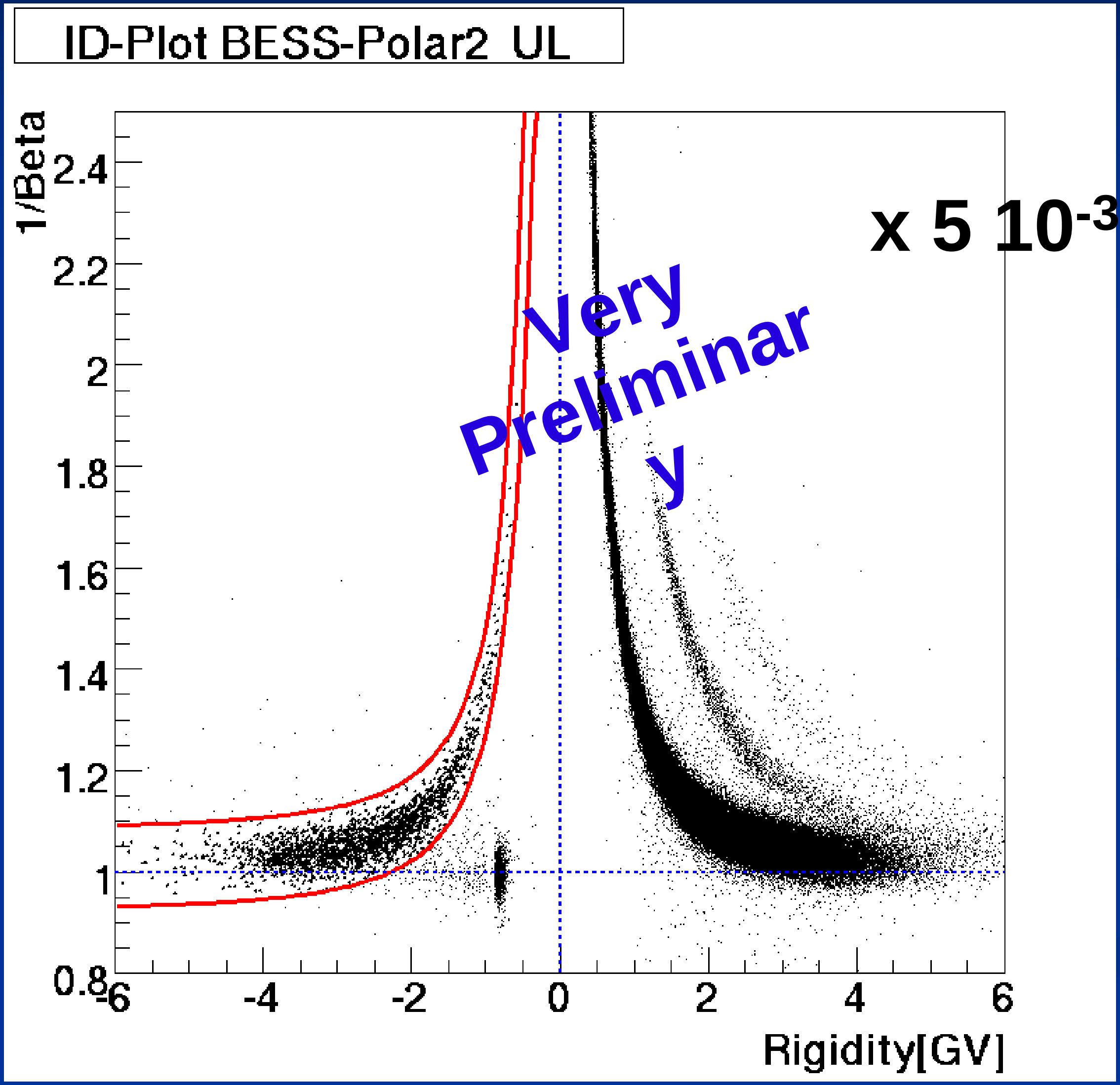


Event Selection Criteria

Pre-selection	UL
Number of long track	$N_{longTK} = 1$
Expect hits in JET	$N_{expect} \geqq 32$, $N_{center} > 0$
X hit position in TOF	$\lvert X_{TRU,L} \rvert < 75mm$
Z hit position in TOF	$\lvert Z_{TKU,L} \rvert < 450mm$
Hits other than track	$N_{JET} < 100$
Hits in TOF	$N_{TOFU} = 1$, $N_{TOFL} = 1$ or 2
Albedo rejection	$\beta > 0$

Quality cut	UL
X^2 in trajectory fitting	$C_{r\phi}^2 < 5$, $C_{yz}^2 < 20$
TOF hit consistency	$\lvert Z_{trk} - Z_{TOF} \rvert < 50mm$

ID-plot (BESS-Polar II)



P-bar Identification

[1] dE/dx-band cut

dE/dx band cut

Still to be investigated

[2] Aerogel Ch. cut

Improved with ACC

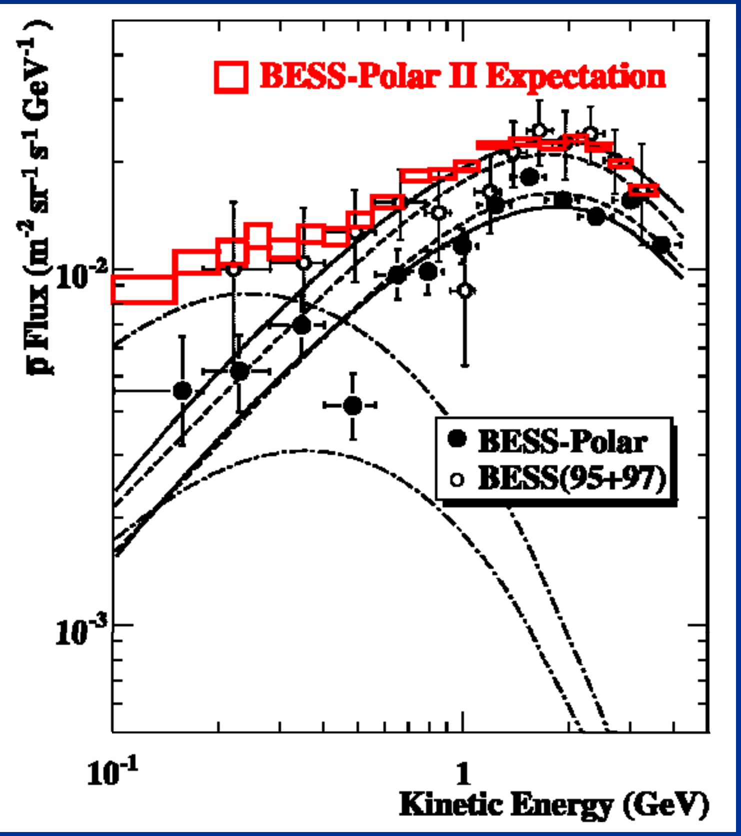
Rejection power

[3] β-band cut

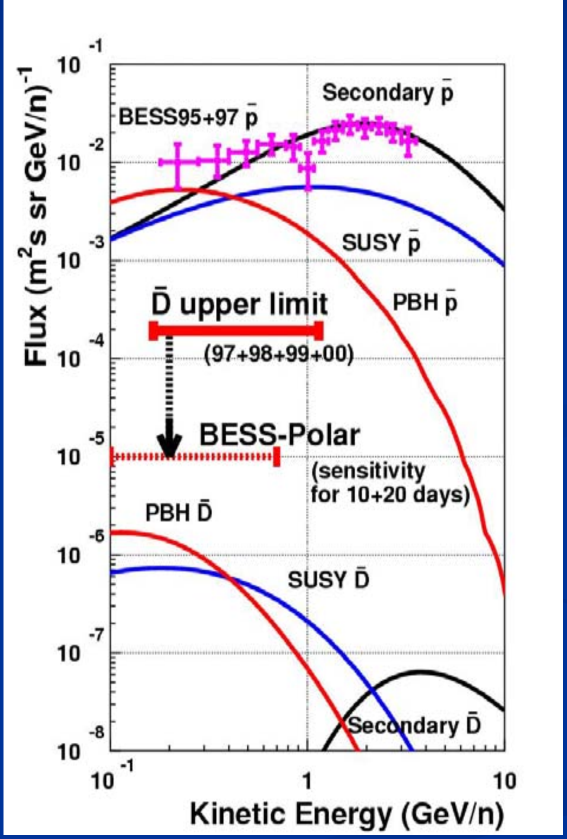
Improved with TOF

BESS Polar II Observations/Expectations

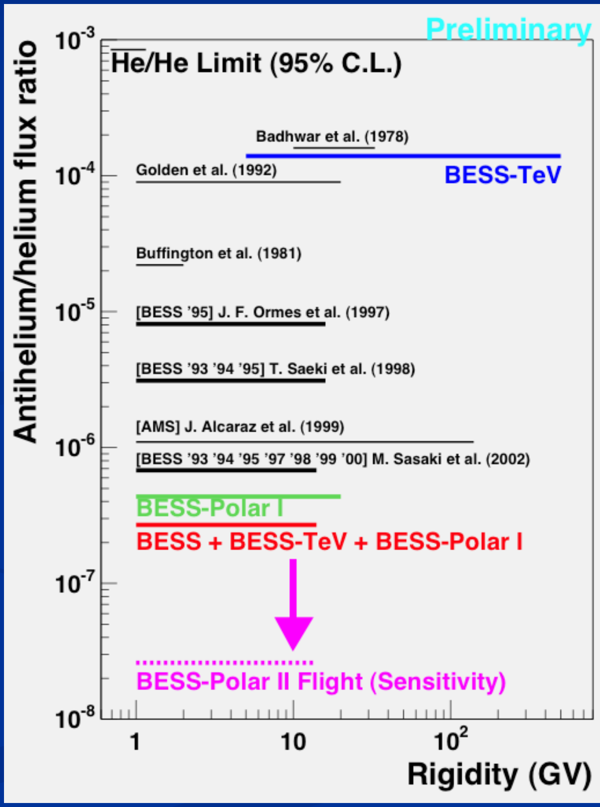
- Event rate ~2.5 kHz; Total events ~4.7 x 10^9
- Total data volume 13.5 TB (3.07 kB/event)
- Expected antiprotons ~10,000 10-20 times previous Solar minimum dataset



Antiproton
(Search for PBH)

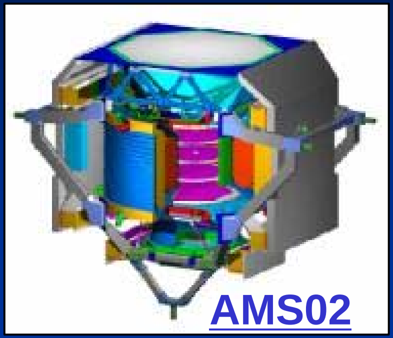


Antideuteron
(Search for PBH)

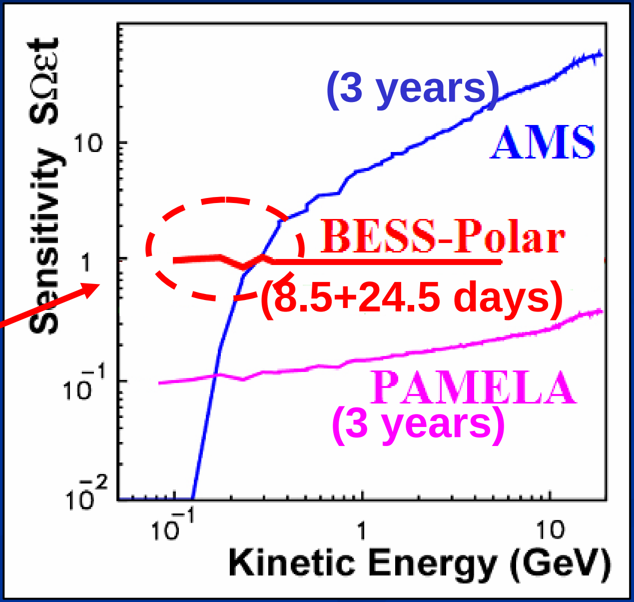


AntiHelium
(Search for Antimatter)

BESS-Polar Sensitivity



- BESS-Polar II has higher sensitivity than PAMELA or AMS at low energy
- Especially true at Solar minimum



	Acceptance (m^2sr)	Flight Time	Latitude	Altitude (km)	Launch
AMS	0.5	3 years	< 51.7	280~500	2010+
PAMELA	0.0021	3 years	<70.4	350-600	2006
BESS-Polar II	0.3	24.5 days	> 75	36	2007

Summary

- BESS experiment carried out since 1993, proposed by late Professor Orito (in 1987) and supported by RESCUE.
  - BESS. Canada/US: 9 successful flights and observations
  - BESS-Polar, Antarctica: 2 successful flights and observations
- BESS-Polar I - high-statistics antiproton and proton spectra and increased sensitivity in search for antihelium
- **BESS-Polar II** successful with observation during the period of solar minimum, in Dec., 2007 through Jan., 2008
  - BESS-Polar II performed well and analysis is underway
  - 24.5 days of BESS-Polar II data increase the statistics on low-energy antiprotons at Solar minimum ~10 (95+97) - 20 (97) fold
- Definitive results expected for PBH search with antiprotons
- *Many thanks for the strong support and encouragement by RESCEU*