Balloon-borne and Space-based Particle Measurements with Magnetic Spectrometers

John W. Mitchell NASA GSFC

XVI International Symposium on Very High Energy Cosmic Ray Interactions (ISVHECRI 2010)
FNAL June 29, 2010
Magnetic-Rigidity Spectrometers

Measure magnetic rigidity – $R = \frac{pc}{Ze}$

Instrument Components

• Magnetic field
  – Superconducting magnet; permanent magnet; Earth’s magnetic field

• Particle tracking / momentum measurement
  – Gas chambers; spark chambers; emulsion

• Charge measurement
  – Scintillator; Emulsion (early work)

• Auxiliary detector(s)
  – Velocity - Lorentz factor - energy deposit
  – TOF, Cherenkov, TRD, shower counter, calorimeter

Unique Measurement Capabilities

• Charge sign
• Mass at energies above $dE/dx$-total E, $dE/dx$-Cherenkov
• Energy measurement with minimal mass in beam
Space: No Atmosphere, Long Duration

HEAO: used geomagnetic cutoff

$F_{AN} Z > 9, 1.5 \times 10^{-4}, \approx 2 - 11 \text{ GeV/n}$


Fig. 1. The detector configuration of the danish-french cosmic ray spectrometer on HEAO-3. Four neon flash-tube hodoscope elements (FTT1–FTT4) are interposed between five Cerenkov counters (C1 – C5). A time-of-flight system between C1 and C5 determines the travel direction for each detected particle.
Isotopes: Isotope Magnet Experiment (ISOMAX)

- Clock isotope $^{10}\text{Be}$ probes storage of GCR in Galaxy
- $^{10}\text{Be}$ to $^{9}\text{Be}$ ratio to relativistic energies provides test of diffusive halo model

Single-paddle time resolution

$B=0.8 \text{ T, MDR}=1.2 \text{ TV (Be)}$
Isotope Magnet Experiment (ISOMAX)

- Mass resolution vs. kinetic energy for $^4\text{He}$ and $^{10}\text{Be}$.
- Mass spectra for Li, Be, and B.

(a) Li TOF: $0.15 \leq E_{\text{kin}} < 1.3$ GeV/nucleon
$^7\text{Li}/^6\text{Li} = 0.985 \pm 0.061$

(b) B TOF: $0.20 \leq E_{\text{kin}} < 0.9$ GeV/nucleon
$^{10}\text{B}/^{11}\text{B} = 0.553 \pm 0.081$

(c) Be TOF: $0.20 \leq E_{\text{kin}} < 1.0$ GeV/nucleon
$^{10}\text{Be}/^{9}\text{Be} = 0.249 \pm 0.046$

(d) Be CK: $1.10 \leq E_{\text{kin}} < 2.0$ GeV/nucleon
$^{10}\text{Be}/^{9}\text{Be} = 0.35 \pm 0.13$
ISOtope MAgnnet eXperiment
Beryllium Results

Time-of-Flight Energy Range

Cherenkov Energy Range

0.20 < $E_{\text{kin}}$ < 1.00 GeV/nucleon
$\varphi = 0.153$ amu

$\varphi = 0.205$ amu
$\varphi = 0.228$ amu

1.1 < $E_{\text{kin}}$ < 2.0 GeV/nucleon
$\varphi = 0.259$ amu
AESOP – positron/electron
Anti-Electron Sub Orbital Payload
University of Delaware/Bartol Research Institute

- Charge-sign dependent solar modulation.
- Permanent magnet and digital optical spark chambers
- ~6GV MDR
- Frequent flights 1995-2009
BESS Collaboration

Balloon-borne Experiment with a Superconducting Spectrometer

National Aeronautics and Space Administration
Goddard Space Flight Center

University of Tokyo

High Energy Accelerator Research Organization (KEK)

University of Maryland

Kobe University

Institute of Space and Astronautical Science/JAXA

University of Denver
BESS/BESS-Polar Science Reach

- Cosmic-ray particles and antiparticles probe the early Universe
  - Antinuclei test symmetry of matter and antimatter
  - Antiprotons:
    - Mainly secondary origin - cosmic ray interactions
    - Possible small primary component;
      - Evaporation of primordial black holes (PBH) initially near \( \sim 5 \times 10^{14} \) g?
      - Decay of super-symmetric particles?
- Cosmic ray spectra and composition
  - \( p \), \( He \), \( Li \), \( Be \) isotopic and elemental spectra
  - \( B \), \( C \), \( N \), \( O \) elemental spectra
  - Atmospheric muons
- Heliospheric influence on Galactic cosmic rays
  - Charge-sign dependent Solar modulation
  - Short-term transients and diurnal variation
- Future program
  - High-energy positrons
  - Radioactive \( ^{10}Be \) to high velocity (time dilation)

BESS antiproton measurements from 1995-1997 Solar minimum suggest possible excess at low energy.
BESS Instrumentation

- Measures charge, charge-sign, mass, and energy
- Superconducting magnetic spectrometer: momentum from magnetic rigidity
  - Thin solenoidal superconducting magnet
  - Fully active “JET” and “IDC” drift chambers with 54 points on trace, \( \sigma <130 \, \mu m \)
  - MDR: 200 GV BESS; 1400 GV BESS-TeV; 280 GV BESS-Polar
- Time-of-flight system (TOF): velocity and charge
- Silica-aerogel Cherenkov detector (ACC, \( n=1.02/1.03 \)): background rejection

\[
m = \frac{RZe}{\gamma \beta c}
\]
Evolution of BESS

- Nine northern latitude flights (1+ days) 1993-2002 and two Antarctic flights in 2004 (8.5 days) and 2007 (24.5 days)
- Including BESS-Polar I 3757 antiprotons reported 0.2 - 4.2 GeV

### BESS-93,94
- Larger Vessel
- $\sigma_{\text{TOF}} = 300$ ps
- $\bar{p}$ 0.2-0.6 GeV
- 6,2

### BESS-95
- Larger Vessel
- $\sigma_{\text{TOF}} = 110$ ps
- $\bar{p}$ 0.2-1.4 GeV
- 43

### BESS-97,98
- Aerogel C
- 97 $n = 1.03$
- $\bar{p}$ 0.2-3.5 GeV
- 98 $n = 1.02$
- $\bar{p}$ 0.2-4.2 GeV
- 415, 398

### BESS-99,00
- New ODC's
- New JET/IDC's
- 2X0 Lead e/$\mu$ sep.
- $\bar{p}$ 0.2-4.2 GeV
- 668, 558

### 2001-2002 BESS-TeV
- New Mag (ultra thin)
- 2X0 Lead e/$\mu$ sep.
- $\bar{p}$ 0.2-4.2 GeV
- 147

### 2004, 2007 BESS-Polar
- No Vessel
- 2X0 Lead e/$\mu$ sep.
- $\bar{p}$ 0.2-4.2 GeV
- $\bar{p}$ 0.1-4.2 GeV
- 1,512, ~8,000
• Minimum material in path of particle (4.5 g/cm\(^2\))
  • Thinner magnet (2.2 g/cm\(^2\) with cryostat ~1/2 BESS)
  • Middle TOF (MTOF) - low energy TOF/trigger
  • No pressure vessel - TOF, ACC in near-vacuum
  • Total material in path 1/4 of BESS
• No in-flight data selection
• 3.6 TB hard disk array
• High speed data acquisition - 2.5 kHz event rate
• Cryogen lifetime ~11.5 days - 400 liters Lhe
• 8.5 day flight
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 (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
Light Isotopes

- dE/dx vs rigidity gives charge
- $1/\beta$ vs rigidity gives mass
- Isotopes of hydrogen and helium isotopes are well separated to >0.5 GeV/nucleon with TOF
• BESS (95+97) Solar min data show a possible flattening of the antiproton spectrum at lower energies compared to secondary production. (Upper dash curve leaky box with spherically symmetric modulation @ 550 MV.)

• BESS-Polar I data at higher solar activity (851 MV - lower dashed curve) are consistent with secondary production, as expected.

• Primary source suppressed at higher modulation levels.

• Solid curve diffusive reacceleration with break at 30° Solar tilt angle
Antihelium Search

- No antihelium candidate found by any investigation
- 95% confidence level He/He upper limits set, assuming He spectrum same as He
- BESS-TeV - $1.4 \times 10^{-4}$
  1 - 500 GV, 7 $\times$ 10$^4$ He events
- BESS-Polar I - $4.4 \times 10^{-7}$
  0.6 - 20 GV, 10$^6$ He events
- BESS combined - $2.7 \times 10^{-7}$
  1 - 14 GV
Antideuteron Search

- 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% upper limit (first reported) $1.92 \times 10^{-4}$ $(m^2 \text{s sr GeV/n})^{-1}$
Antiproton/Proton Ratio - Solar Modulation

- 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)
BESS-Polar I Proton Spectrum - Solar Effects

- General trend of BESS-Polar I proton flux tracks the neutron monitor
- BESS-Polar I observes diurnal variation in the proton flux (work in progress)
  - First direct measurement of this effect (requires large collecting area)
- Transient and diurnal variation investigation continues with BESS-Polar II
BESS-Polar II

- Longer Observing Time
  - Magnet cryogen life: >25 days
    - 520 liters LHe
    - 16 TB data storage
- Improved Reliability
  - Pressurized TOF PMT units
  - Improved electronics efficiency
- Improved Performance
  - ACC rejection power
  - Middle TOF resolution
  - Outer TOF resolution
BESS-Polar II Flight

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

Positive Event

Negative Event
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, 2008!
BESS-Polar II Recovery 2009-2010

- 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 Recovery
BESS-Polar II Performance

- Spectrometer - <130 μm resolution, B=0.8 T, MDR 266 - 281 GV
- Outer TOF - 120 ps
- Middle TOF - 280-380 ps
- Aerogel Cherenkov - 11.3 pe, ~6000 background rejection factor
- Data Acquisition - 2.5 kHz event rate, no onboard event selection, 82% live
BESS Polar II Observations/Expectations

- Total events $\sim 4.7 \times 10^9$
- Total data volume 13.5 TB (3.07 kB/event)
- Antiprotons 8,000 - 10,000 10-20 times previous Solar minimum dataset
PAMELA Scientific goals

- Search for dark matter annihilation
- Search for antihelium (primordial antimatter)
- Search for new Matter in the Universe (Strangelets?)
- Study of cosmic-ray propagation (light nuclei and isotopes)
- Study of electron spectrum (local sources?)
- Study solar physics and solar modulation
- Study terrestrial magnetosphere
# Design Performance

<table>
<thead>
<tr>
<th>Particle Type</th>
<th>Energy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antiprotons</td>
<td>80 MeV - 190 GeV</td>
</tr>
<tr>
<td>Positrons</td>
<td>50 MeV – 300 GeV</td>
</tr>
<tr>
<td>Electrons</td>
<td>up to 500 GeV</td>
</tr>
<tr>
<td>Protons</td>
<td>up to 700 GeV</td>
</tr>
<tr>
<td>Electrons+positrons</td>
<td>up to 2 TeV (from calorimeter)</td>
</tr>
<tr>
<td>Light Nuclei (He/Be/C)</td>
<td>up to 200 GeV/n</td>
</tr>
<tr>
<td>AntiNuclei search</td>
<td>sensitivity of $3 \times 10^{-8}$ in He/He</td>
</tr>
</tbody>
</table>

- Simultaneous measurement of many cosmic-ray species
- New energy range
- Unprecedented statistics
**PAMELA detectors**

Main requirements ➔ high-sensitivity antiparticle identification and precise momentum measure

**Time-Of-Flight**
- plastic scintillators + PMT:
  - Trigger
  - Albedo rejection
  - Mass identification up to 1 GeV
  - Charge identification from dE/dX

**Electromagnetic calorimeter**
- W/Si sampling (16.3 $X_0$, 0.6 $\lambda_I$)
  - Discrimination $e^+ / p$, anti-p / $e^-$ (shower topology)
  - Direct E measurement for $e^-$

**Neutron detector**
- plastic scintillators + PMT:
  - High-energy $e/h$ discrimination

**Spectrometer**
- microstrip silicon tracking system + permanent magnet
It provides:
  - **Magnetic rigidity** ➔ $R = pc/Ze$
  - **Charge sign**
  - **Charge value from dE/dx**

GF: 21.5 cm$^2$ sr
Magnetic Field: 0.43 T
MDR: ~1 TV
Mass: 470 kg
Size: 130x70x70 cm$^3$
Power Budget: 360W
The Launch: 15th June 2006
Resurs-DK1 satellite + orbit

• Resurs-DK1: multi-spectral imaging of earth’s surface
• PAMELA mounted inside a pressurized container
• Lifetime > 4 years

• Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day

• Quasi-polar and elliptical orbit (70.0°, 350 km - 600 km)

• Traverses the South Atlantic Anomaly

• Crosses the outer (electron) Van Allen belt at south pole

Resurs-DK1
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 m²

PAMELA

~90 mins

350 km

610 km

J.W. Mitchell NASA Goddard Space Flight Center
Magnetic Spectrometers

ISVHECRI June 29, 2010
Flight data:

0.169 GV electron

Flight data:

0.171 GV positron
Flight data: 0.763 GeV/c antiproton annihilation
Antiproton / positron identification

Time-of-flight: trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer: sign of charge

Ionisation energy loss (dE/dx): magnitude of charge

Interaction pattern in calorimeter: electron-like or proton-like, electron energy

Antiproton (NB: $e^-/\bar{p} \sim 10^2$)

Positron (NB: $p/e^+ \sim 10^{3-4}$)
Antiproton to proton flux ratio
Antiproton Flux

![Graph showing antiproton flux vs kinetic energy]

- AMS (M. Aguilar et al.)
- BESS-polar04 (K. Abe et al.)
- BESS1999 (Y. Asaoka et al.)
- BESS2000 (Y. Asaoka et al.)
- CAPRICE1998 (M. Boezio et al.)
- CAPRICE1994 (M. Boezio et al.)
- PAMELA
Proton / positron discrimination

Time-of-flight:
- trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer: sign of charge

Ionisation energy loss (dE/dx):
magnitude of charge

Interaction pattern in calorimeter: electron-like or proton-like, electron energy

Proton

Positron
In Nature article published data acquired till February 2008

New data reduction: data till end of 2008. With same approach of Nature paper ~30% increase in statistics better understanding of systematics.

Astrophysical Explanation: SNR

N.J. Shaviv et al., arXiv: 0902.0376v1
Are there “standard” astrophysical explanations of the PAMELA data?

**Young, nearby pulsars**

![Graph showing positron fraction (e^+/(e^- + e^-)) vs. energy (E) for various experiments.](image)

Interpretation: DM

Which DM spectra can fit the data?

DM with $m_\chi \simeq 150$ GeV and $W^+W^-$ dominant annihilation channel (possible candidate: Wino)

- positrons: Yes!
- antiprotons: No!
Which DM spectra can fit the data?

DM with $m_\chi \simeq 10$ TeV and $W^+W^-$ dominant annihilation channel (no “natural” SUSY candidate)

But $B \approx 10^4$
Interpretation: DM

DM with $m_\chi \simeq 1\,\text{TeV}$ and $\mu^+\mu^-$ dominant annihilation channel

Example: Dark Matter

Majorana DM with **new** internal bremsstrahlung correction. NB: requires annihilation cross-section to be ‘boosted’ by >1000.

Kaluza-Klein dark matter
Interpretation: DM

**Interpretation: DM**

**Antiproton Flux Ratio With Density Enhancement**

- $L = 4$ kpc
- $K_0 = 4.5 \times 10^{28}$ cm$^2$ s$^{-1}$
- $\delta = 0.54$
- $v_{\text{conv}} = 5$ km s$^{-1}$ kpc$^{-1}$
- $v_{\text{Alfven}} = 32$ km s$^{-1}$
- $\tau = 2$
- $f = 0.7$

**Positron Flux Ratio With Density Enhancement**

- $L = 4$ kpc
- $K_0 = 4.5 \times 10^{28}$ cm$^2$ s$^{-1}$
- $\delta = 0.54$
- $v_{\text{conv}} = 5$ km s$^{-1}$ kpc$^{-1}$
- $v_{\text{Alfven}} = 32$ km s$^{-1}$
- $\tau = 2$
- $f = 0.7$


Non-thermal wino-like neutralino
Varying propagation model, no boost factor
PAMELA Electron ($e^-$) Spectrum
PAMELA Electron (e⁻ + e⁺) Spectrum

\[ A = 200 \pm 32 \quad \gamma = -3.06 \pm 0.05 \]

\[ A = 194 \pm 21 \quad \gamma = -3.07 \pm 0.03 \]
Secondary nuclei

- B nuclei of secondary origin:
  \[ \text{CNO + ISM} \rightarrow \text{B} + \ldots \]
- Local secondary/primary ratio sensitive to average amount of traversed matter (l_{esc}) from the source to the solar system

Local secondary abundance:
\[ \Rightarrow \text{study of galactic CR propagation} \]

(B/C used for tuning of propagation models)
Solar Modulation of galactic cosmic rays

- Study of charge sign dependent effects
  J. Clem et al. 30th ICRC 2007
Solar modulation

A$^+$ A$^-$ A$^+$ A$^-$

Annual Variation of P/P Ratio

Bieber et al, 1999

10°, (+) - 1997 solar min. at positive phase

70°, (+) - 1999 solar max. at positive phase

70°, (-) - 2000 solar max. at negative phase

Kinetic Energy (GeV)

PAMELA

Thule, Greenland, Neutron Monitor
Bartol Research Institute, University of Delaware
27-day Averages - data through August 2008

Counts/ Hour/ 100

Smoothed Sunspot Number
Monthly Averages

~ 11 y

Increasing flux

Decreasing solar activity

Positron fraction (e$^+$ / (e$^+$ + e$^-$))

Positron fraction (e$^+$ / (e$^+$ + e$^-$))

PAMELA

Amsop 2007 (Chen & Emerson 2007)
Amsop 2000 (Chen & Emerson 2001)
Amsop 1996 (Chen & Emerson 2001)
AMS
CAPRICE94
HEAT94+53

Energy [GeV]
95% of the ~$2.0B to build AMS has come from international partners.
Alpha Magnetic Spectrometer
First flight, STS-91, 2 June 1998 (10 days)

AMS-01

Construction of AMS-01

\[ p = mv \]

- \( p \):
  - Silicon \( \Delta x = 10 \mu \)
- Magnet
  - \( BL^2 = 0.14 \text{ TM}^2 \)
- Electronics
  - 70,000 channels

V: Scintillators

V: Aerogel
The AMS-01 Detector
Flew 10 days on STS-91 June 1998

6 planes of Silicon Tracker: 3.2 % $X_0$, 10 $\mu$m.
$BL^2 = 0.14 \text{Tm}^2$, $\Delta P/P = 7\%$ at 10 GeV
Fig. 4.40. The AMS antiproton flux measurement in comparison with BESS [70] data.
AMS: A TeV precision, multipurpose spectrometer

Particles and nuclei are defined by their charge ($Z$) and energy ($E \sim P$).

Z, $P$ are measured independently from Tracker, RICH, TOF and ECAL.

Z, P are measured independently from Tracker, RICH, TOF and ECAL.
Test Beam Results of integrated detector

Velocity measured to an accuracy of 1/1000 for 400 GeV protons

$\sigma = 10\mu$

Electron Energy Resolution: 2.5-3%

TRD:

$\frac{e^+}{p} = 10^{-6}$

J.W. Mitchell NASA Goddard Space Flight Center

Magnetic Spectrometers

ISVHECRI June 29, 2010
Layers 1 and 9 are far away from the magnet.
With 9 tracker planes, the resolution of AMS with the permanent magnet is equal (to 10%) to that of the superconducting magnet. For helium, the MDR for the permanent magnet is 3.75 TV.

AMS-02 SC (MDR, 2.18 TV)
AMS-02 (MDR, 2.14 TV)
Sensitivity in Dark Matter searches: large acceptance, long duration
\( \chi^0 \chi^0 \rightarrow e^+ , e^- \) for \( m\chi^0 = 200 \) GeV

I.Cholis et al, astro-ph 30 Apr 2009

\[ \frac{e^+}{e^+ + e^-} \]

\[ \frac{e^-}{e^+ + e^-} \]

\[ \text{Energy [GeV]} \]

AMS-02 (18 Yrs)

AMS-02 SC (3 Yrs)

AMS-02 (10 Yrs)

J.W.Mitchell NASA Goddard Space Flight Center

Magnetic Spectrometers

ISVHECRI June 29, 2010
AMS – search for DM:
1. Large acceptance and long duration
2. $e^+/p \sim 10^{-6}$
We present four studies based on four models to highlight AMS sensitivity.

AMS-02 (10 Yrs)

- $m_\chi = 800$ GeV
- $m_\chi = 400$ GeV
- $m_\chi = 200$ GeV


$m_\chi = 100$, $200$, $400$, $800$ GeV

Energy (GeV)
Kaluza-Klein Bosons are also Dark Matter candidates

**case 3 TeV Scale Singlet Dark Matter**

*Eduardo Pontón and Lisa Randall*

\[ E_{\text{Energy}} (\text{GeV}) \]

\[ E_{\text{Energy}} = 10^{-1} \quad 10^{-2} \quad 10^{-3} \]

\[ e^+/(e^+ + e^-) \]

\[ B \times \langle \Sigma e^+ e^- \rangle/c = 1 \text{ pb} \]

\[ M_{\epsilon^+} = M_{\Phi} \]

\[ 500 \text{ GeV} \quad 2 \text{ TeV} \]

**Fig. 5**

[Graph showing positron fraction vs. energy (GeV)]

*sdm_500_18Yb*
Dark Matter Searches
normalized to the sensitivity of AMS with superconducting magnet on ISS for 3 years

As seen, the permanent magnet upgrade of AMS has a 600-200% improvement in sensitivity in the search for Dark Matter.
The overall height, including the lower crush pads, is 2.7 m and the overall width is 3.3 m. The total weight of the instrument is 2000 kg.
The magnetic spectrometer has a geometrical acceptance of 1300 cm$^2$ sr for electrons.

The most important contributions to the overall weight are the magnet weight and the weight of the calorimeter with 890 kg and 650 kg, respectively.

The power consumption is dominated by the 250 W needed for the tracker which has roughly 60,000 individual readout channels.

The lower detector combination of TRD and ECAL, which is used for the measurement of the combined electron positron spectrum at high energies, has an acceptance of 6000 cm$^2$ sr.
Final polishing of the PERDAIX permanent magnet which is constructed in the same way as the PEBS magnet. An aluminum matrix is used to support the 72 NdFeB cylinders to form the permanent magnet.

Weight 892 kg, B-Field 0.34 Tesla, 
\[ r_{\text{Inner}} = 0.32 \text{ m}, \quad r_{\text{Outer}} = 0.44 \text{ m}, \quad \text{Height} = 50.0 \text{ cm} \]
The expected statistics from a single 20 day flight of PEBS shown as blue circles assumed to conform to Galprop model plus a nearby pulsar (blue dashed line) or dark matter annihilation (red dashed line) as an additional electron and positron source.
The expected statistics for the combined electron+positron spectrum from a single 20 day flight of PEBS shown as blue circles assumed to conform to Galprop model plus a nearby pulsar (blue line) as an additional electron and positron source.
PEBS Summary

• A dedicated balloon experiment could provide a competitive measurement of the cosmic ray electron & positron flux.

• The spectrometer is based on a scintillating fiber tracker with SiPM readout in a permanent magnet.

• The proton rejection of $\sim 10^6$ can be achieved by a combination of ToF, TRD, ECAL and Tracker.

• Key parameters:
  Acceptance: $\sim 1300 \text{ cm}^2 \text{ sr}$
  Weight: $\sim 2000 \text{ kg}$
  Power: $\sim 900 \text{ Watt}$

• R&D Phase:
  2006 – 2010, first test flight of a small prototype (PERDAIX) in October 2010

• Construction Phase: 2010 - 2013

• First PEBS Flight: 2014
Summary

• Magnetic-rigidity spectrometer techniques have been applied with great success to positron, antiproton, and isotope measurements as well as to the search for cosmic antimatter.
• The current generation of instruments, BESS-Polar II and PAMELA, have achieved exceptional sensitivity.
• The upcoming flight of AMS-02 will greatly improve statistical sensitivity in the measurement of positrons and antiprotons and in the search for cosmic antihelium and heavier antinuclei.
• Future magnetic-spectrometer balloon experiments include PEBS and future flights of BESS-Polar. PEBS will measure positrons and antiprotons. BESS-Polar will be configured to measure positrons and antiprotons or light isotopes.