Antiproton Flux and Properties of Elementary Particles Fluxes in Primary Cosmic Rays Measured with Alpha Magnetic Spectrometer on the ISS

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AMS is a space version of a precision detector used in accelerators.

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

$Z$ and $P$ are measured independently by the Tracker, RICH, TOF, and ECAL.
AMS is a unique magnetic spectrometer in space

AMS is able to pick out 1 positron from 1,000,000 protons;
unambiguously separate positrons from electrons up to a trillion eV;
and accurately measure all cosmic rays to trillions of eV.

In 8 years, the detectors have performed flawlessly, collected more than 140 billion cosmic rays.
Silicon Tracker and Magnet

1.4 kG

Continuously monitor and calibrate the position of Tracker with 2 micron accuracy.

L1 to L9: 3 m level arm; single point resolution: 10micron MDR: 2TV
$e^\pm$ and $p, \bar{p}$ separation in AMS

- Separation power is $10^3$ to $10^4$ with TRD

- Separation power is above $10^4$ with ECAL and tracker

- TRD and ECAL is separated by magnet, they have independent particle separation
Calibration of the AMS Detector

Test beam at CERN SPS:
- $p, e^\pm, \pi^\pm, 10-400$ GeV

Computer simulation:
- Interactions, Materials, Electronics

2000 positions

Measurement - Prediction
Elementary Particles in Cosmic Rays

There are only four elementary particles which are long lived particles and could travel through the galaxy.

- Protons
- Antiprotons
- Positrons
- Electrons

They carry information of the origin and propagation history of cosmic rays.

Especially, antiprotons and positrons are anti-particles, it is particularly interesting to find new phenomena because of the low backgrounds.

The latest AMS measurement of these elementary particles will be presented. These results are in agreement with previous AMS publications, and extend to higher energy with better accuracy.
On the Origins of Cosmic Antiprotons and Positrons

New Astrophysical Sources: Pulsars, ...

Supernovae

Protons, Helium, ...

Interstellar Medium

Positrons from Pulsars

Positrons, Antiprotons from Collisions

Dark Matter

Electrons, ...

Positrons, Antiprotons from Dark Matter

Dark Matter
AMS Measurement of the Proton Flux

Latest results – 1 billion protons
The result shows progressive hardening above 200GV
and in agreement with previous publication

See Q.Yan's talk for details (CRD7a)
AMS Measurement of Electron and Positron Flux

Latest results – 28.1M electrons and 1.9 M positrons

See W.Xu's and Z.Weng's talk for details (CRD2b & CRD2h)
Antiproton Analysis

The Antiproton Flux is $\sim 10^{-4}$ of the Proton Flux.

A percent precision experiment requires background rejection close to 1 in a million.

- **TOF & RICH**: select down going particle and measure velocity
- **ECAL**: reject electron background
- **TRD**: provide proton/electron separation $\Lambda_{TRD}$, the ratio of the log-likelihood probability of the $e^{\pm}$ hypothesis to that of $p, \bar{p}$ hypothesis
- **Tracker**: Measure rigidity and reject misidentified proton with charge confusion estimator $\Lambda_{cc}$, the boosted decision tree value combines multiple information from tracker and TOF
Antiproton identification at intermediate rigidity

\[ 5.4 < |R| < 6.5 \text{ GV} \]
Antiproton identification at High Energy

- Number of antiprotons are obtained by a fit to data sample in $(\Lambda_{TRD} - \Lambda_{CC})$ plane
- Precision determination of Signal and Background from Data:
  - Antiproton Signal are clearly identified in the signal region
  - Electron: identified by TRD estimator $\Lambda_{TRD}$
  - Proton Charge Confusion: identified by Charge Confusion estimator

In first 6.5 years, $\sim 0.56M$ antiprotons are analyzed in the rigidity range $1<|R|<525$ GV.

More than 3500 antiprotons above 100GV.
AMS observed for the first time that above 60 GeV, $p$ and $\bar{p}$ have identical behavior.
Antiproton-to-Proton Flux Ratio

Show no rigidity dependence above 60GV

Fit to a power law in the range \([60,525]\) GV shows that the difference between the power law index of proton and antiproton is \(0.05 \pm 0.06\), consistent with 0.

- AMS  Preliminary data, refer to upcoming AMS publication
- PAMELA

\[ \frac{\bar{p}}{p} \]
The Spectra of Protons and Electrons

Electron flux decrease with energy much faster than proton

Preliminary data, refer to upcoming AMS publication
The Spectra of Protons and Positrons

- Protons and positrons have very different origin and propagation history:
  - Secondary positrons: softer than proton due to diffusion and energy loss

- From ~60 GV, Positron and Proton have very similar rigidity dependence
- Starting from ~280GV, positron flux shows drop-off
- New source of high energy positron with energy cut-off.

Preliminary data, refer to upcoming AMS publication
The spectra of antiproton and positron

At high energy Antiprotons have very similar trends with Positron

Antiprotons can not come from pulsar
Antiprotons and Positrons to 2028

By continue taking data, AMS will improve the accuracy of these measurements and extend to higher energies.
1. The latest AMS measurement of elementary particles are presented.
2. The spectra of positrons, antiprotons, and protons are nearly identical in a large energy range and positron show drop-off at ~280GV.
3. Electron spectrum decrease faster than other three species.
4. By collecting data through the lifetime of ISS, AMS will greatly improve the accuracy of these measurements and reach to higher energy.
AMS Publications in PRL

1. First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV (2013)
2. Electron and Positron Fluxes in Primary Cosmic Rays Measured with the AMS on the ISS (2014)
3. High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the AMS on the ISS (2014)
4. Precision Measurement of the $e^+ + e^-$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the AMS on the ISS (2014)
5. Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the AMS on the ISS (2015)
6. Precision Measurement of the He Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the AMS on the ISS (2015)
8. Precision Measurement of the B to C Flux Ratio in Cosmic Rays from 1.9 GV to 2.6 TV with the AMS on the ISS (2016)
11. Observation of Fine Time Structures in the Cosmic Proton and Helium Fluxes with AMS on the ISS (2018)
12. Observation of complex time structures in the cosmic-ray electron and positron fluxes with the AMS on the ISS (2018)
13. Precision measurement of cosmic-ray nitrogen and its primary and secondary components with AMS on the ISS (2018)

... “Helium Isotopes in the Cosmos”
... “Rigidity Dependence of Ne, Mg, and Si Cosmic Rays”
AMS Presentations in ICRC

- CRD1a: Antiproton Flux and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the ISS, C. Zhang
- CRD2a: Observation of Complex Time Structures in the Cosmic-Ray Electron and Positron Fluxes by the Alpha Magnetic Spectrometer on the ISS, M. Duranti
- CRD2b: Towards Understanding the Origin of Cosmic-Ray Electrons, W. Xu
- CRD2h: Towards Understanding the Origin of Cosmic-Ray Positrons, Z. Weng
- CRD4a: Anisotropy of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the ISS, I. Gebauer
- SH5f: Solar Energetic Particles measured by the Alpha Magnetic Spectrometer on the International Space Station during solar cycle 24, C. Light
- CRD6b: Properties of Secondary Cosmic Rays Lithium, Beryllium and Boron Measured by the Alpha Magnetic Spectrometer on the International Space Station, A. Oliva
- CRD6c: Cosmic-Ray Helium Isotopes with the Alpha Magnetic Spectrometer, C. Delgado
- CRD6d: Cosmic-Ray Lithium Isotopes with the Alpha Magnetic Spectrometer, L. Derome
- CRD7a: Properties of Primary Cosmic Rays Neon, Magnesium and Silicon Measured with the Alpha Magnetic Spectrometer on the ISS, Q. Yan
- CRD8a: Precision Measurement of the Monthly Carbon and Oxygen Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station, F. Donnini
- CRD8b: Properties of Primary Protons, Helium, Carbon and Oxygen Nuclei Measured with the Alpha Magnetic Spectrometer on the ISS, Q. Yan
- CRD8c: Precision Measurement of the Daily Proton and Helium Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station, C. Consolandi
- CRD8d: Precision Measurement of the Monthly Proton and Helium Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station, N. Tomassetti
Antiproton identification

• The number of antiprotons is determined from template fit.
• To maximize the measurement accuracy, different templates are used in three rigidity region

1. Low rigidity region: Electron, pion background
   1.00-4.02 GV The mass calculated from TOF and Tracker

2. Intermediate region: Electron and small amount of pion background
   3.67-18.0 GV RICH and The TRD estimator

3. High rigidity region: Electron and charge confusion proton background
   16.6-525 GV 2D template in (∧_{TRD} - ∧_{CC}) plane

In 6.5 years, >5.6 \times 10^5 antiprotons are selected in the rigidity range 1<|R|<525 GV
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More than 3500 antiprotons above 100 GV

**Systematic Errors Study**

- Affect the antiproton counting $\sigma_N$
  - Geomagnetic cutoff
  - Event selection
  - Charge confusion templates

- Affect the acceptance, $\sigma_A$
  - Inelastic cross sections
  - Limited MC statistics
  - Migration matrix

- Rigidity scale, $\sigma_R$