The Alpha Magnetic Spectrometer on the International Space Station
Fundamental Science on the International Space Station (ISS)

There are two kinds of cosmic rays traveling through space

1- Chargedless cosmic rays (light rays and neutrinos): Light rays have been measured (e.g., Hubble) for over 50 years. Fundamental discoveries have been made.

2- Charged cosmic rays: An unexplored region in science. Using a magnetic spectrometer (AMS) on ISS is the only way to measure high energy charged cosmic rays.
Professor Samuel Ting  
Massachusetts Institute of Technology  
Laboratory for Nuclear Science  
Cambridge, MA  02139

Dear Professor Ting:

Thank you for your May 9, 1994, presentation on a concept to search for the origin of mass using a magnetic spectrometer on the Space Station. The detection of antinuclei, heavier than hydrogen from cosmic sources, would indeed have a fundamental impact on science and the way we view the universe.

This letter is to inform you that we are taking some initial steps to assess the accommodations for fundamental physics experiments as external attached payloads on the Space Station using your concept as a model. We are assuming that your research group would provide the experimental package with non-NASA, primarily Department of Energy (DOE) funding, and that NASA would provide transportation to the Station and on-orbit accommodations including electrical power, operations, and delivery of data tapes or equipment.

Sincerely,

Wesley T. Huntress, Jr.
Associate Administrator for Space Science
FINAL of 3 SCIENTIFIC REVIEWS of AMS by the U.S. DOE (Sept 25, 06) by the DOE AMS committee:

Barry C. Barish, Chair, Caltech

Elliott D. Bloom, Stanford University

James Cronin, University of Chicago

Steve Olsen, University of Hawaii

George Smoot, L.B.N.L.

Paul J. Steinhardt, Princeton University,

Trevor Weekes, Harvard University
AMS is an international collaboration of 16 countries, 60 institutes (10 U.S.) and 600 physicists.
Acknowledgement

The CERN cryogenics, magnet, vacuum and accelerator groups have provided outstanding technical support which has kept AMS on schedule.

Many theoretical physicists at CERN, John Ellis, Alvaro De Rujula and others, have kept a continuous interest in AMS. They have contributed greatly in the formation of our data analysis framework.
There has never been a superconducting magnet in space due to the extremely difficult technical challenges.

**STEP ONE: AMS-01**
A Permanent Magnet to fly on the Shuttle

1- Minimum torque from Earth’s magnetic field
2- Minimum field leakage
3- Minimum weight: no iron

**STEP TWO: AMS-02**
A Superconducting Magnet with the same field arrangement
First flight AMS-01
Unexpected results from first flight:
There are many more positrons ($e^+$) than electrons ($e^-$)

"Helium in Near Earth Orbit"

(Mass of He$^4 = 3.7$ GeV; He$^3 = 2.8$ GeV)


AMS-01 results were not predicted by any cosmic ray model
AMS on ISS

Particles are identified by their mass, charge and energy.

TRD
Electrons

Silicon Tracker
Mass, Charge, Energy

ECAL
Electrons, Gamma-rays

TOF
Mass, Charge, Energy

Magnet
Mass, Charge, Energy

RICH
Mass, Charge, Energy
The Superconducting magnet

2,500 liters of Superfluid Helium (1.8K)
Duration: 3-5 years
For AMS-02, two Magnets were built:
One for Space Qualification Tests in Germany and Italy
Testing of the flight magnet

Once charged, the magnetic field will decay \(~5\%\) in 5 years. It will require no additional charge.

\[
\begin{align*}
L &= 49.2 \, \text{H} \\
R &= 17 \, \text{n}\Omega \\
T_0 &= 94.6 \, \text{years} \\
\text{(Field decay 1.1\% per year)}
\end{align*}
\]
Transition Radiation Detector (TRD) Identifies electrons

5248 tubes filled with Xe/CO₂, 2m length centered to 100 μm
Life time ~ 21 years
Veto System rejects random cosmic rays

AMS-02 Magnet with Veto Counters

Measured veto efficiency better than 0.9999
Silicon Tracker

Resolution: 10 \( \mu \)m

Test results: measure all nuclei simultaneously

8 planes, 200,000 channels
In space, the tracker alignment of 3 μm will be continuously monitored by 40 Laser beams.
Ring Imaging Cerenkov Counter (RICH)

Particle: Velocity(θ), Charge(Intensity)

Radiator

Reflector

10,880 Photodetectors
Tests with Accelerator at E=158 GeV/n

RICH has no consumables: AMS on ISS can study high energy cosmic ray spectra indefinitely.
A precision 3-dimensional measurement of the directions and energies of light rays and electrons

10,000 fibers, $\phi = 1$ mm
distributed uniformly
Inside 1,200 lb of lead

e\pm, $\gamma$

proton
We gained extensive experience, adjusted all the cables and the integration sequence by integrating AMS in 2008.
Simultaneous measurement of all nuclei

Test results from accelerator

\[ \Delta v/v = 0.001 \]

\[ \Delta x = 10 \mu m \]

\[ \Delta t = 160 \text{ ps} \]
The astronauts strongly urged us to study the on-orbit refill capability so that AMS will continue to produce unique science.
Flight Integration of AMS: installation of the Veto system
Flight Integration of AMS: cabling of the inner tracker
Flight Integration of AMS: mounting of the TRD and TOF
Flight Integration of AMS: installation of the TOF, RICH & ECAL

All of the detectors have been re-integrated and functionally tested
The AMS Science Operation and Data Analysis Center at CERN

USA
- Florida A&M Univ.
- Johns Hopkins Univ.
- MIT - Cambridge
- NASA Goddard Space Flight Center
- NASA Johnson Space Center
- NASA Kennedy Space Center
- Florida State University
- Texas A&M University
- University of Florida
- University of Maryland
- University of Texas
- Yale Univ. - New Haven

FLORIDA A&M UNIV.
FLORIDA STATE UNIVERSITY
JOHNS HOPKINS UNIV.
MIT - CAMBRIDGE
NASA GODDARD SPACE FLIGHT CENTER
NASA JOHNSON SPACE CENTER
NASA KENNEDY SPACE CENTER
UNIVERSITY OF FLORIDA
UNIVERSITY OF MARYLAND
UNIVERSITY OF TEXAS
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- UNAM

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FRANCE
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- CNRS - IN2P3
- CNRS - LAPP
- LAPP - ANNECY
- LPSC - GRENOBLE

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- RWTH II
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- UNIVERSITY OF KARLSRUHE

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- CARSO TRIESTE
- IROE FLORENCE
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- INFN & Università di Milano
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- ETH Zürich
- University of Bern

SWITZERLAND

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- Kyung Pook Nat. University

KOREA

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- AIDC (Taiwan)
- CSIST (Taiwan)
- NCKU (Tainan)
- NCU (Chung-Li)
- NSPO (Hsinchu)
- NCTU (Hsinchu)
- Savannah State University (Savannah, GA)

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- IEE (Beijing)
- IHEP (Beijing)
- SJTU (Shanghai)
- SEU (Nanjing)
- SYSU (Guangzhou)
- SDU (Jinan)
- University of Science and Technology Beijing
- University of Science and Technology of China
- Tsinghua University

CHINA

PORTUGAL
- Lab. of Instrumentation, Lisbon

PORTUGAL

UK
- University of Oxford
- University of Cambridge
- University of Warwick
- University of Manchester
- University College London
- Imperial College London

UK

JAPAN
- University of Tokyo
- University of Kyoto
- University of Tokyo
- University of Osaka
- University of Nagoya

JAPAN

CHINA
- University of Science and Technology Beijing
- University of Science and Technology of China
- Tsinghua University

CHINA

THE AMERICAN SCIENCE OPERATIONS CENTER AT CERN
Physics example

Search for Cold Dark Matter: $\chi^0$

Collisions of $\chi^0$ will produce excesses in the spectra of $e^+, e^-, \bar{p}$ different from known cosmic ray collisions

The spectra of all types of cosmic rays will be measured by AMS simultaneously.
AMS spectra with $M_\chi = 840$ GeV (not accessible to LHC)

AMS is sensitive to very high SUSY masses

From normal cosmic ray collisions

From Dark matter collisions
Physics examples
Search for the existence of Antimatter in the Universe

The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning.
AMS-02 Antihelium Limits

Current antimatter searches are limited

AMS-01

AMS-02

(a) Buffington et al. 1981
(b) Golden et al. 1997
(c) Badhwar et al. 1978
(d) Sasaki et al. 2001
AMS Physics example

Study of high energy (0.1 GeV – 1 TeV) diffuse gammas

1. Pointing precision of 2 arcsec
2. UTC time (from GPS, μsec accuracy) allows to relate AMS measurements with other missions
Pulsars in the Milky Way:

**Pulsar:**
Neutron star sending radiation in a periodic way, *currently measured with millisec accuracy.* Emission in radio, visible, X- and gamma rays *currently measured up to ~1 Gev.*

**AMS:** pulsar periods measured with µsec time precision and energy spectrum for pulsars measured to 1 TeV (a factor of 1,000 improvement in time and energy).

Similar studies can be made for Blazers and Gamma Ray Bursters.
There are six types of Quarks found in accelerators \((u, d, s, c, b, t)\).

All matter on Earth is made out of only two types \((u, d)\) of quarks. “Strangelets” are new types of matter composed of three types of quarks \((u, d, s)\) which should exist in the cosmos.

AMS will provide a definitive search for this new type of matter.
Strangelet candidate from AMS-01

Observed 5 June 1998 11:13:16 UTC
Lat/Long= -44.38°/+23.70°, Local Cutoff 1.95±0.1 GV, Angle= 77.5° from local zenith

Front view

Side view

Rigidity = 4.31 ± 0.38 GV
Charge $Z = 2$
$\beta_1 = \beta_2 = 0.462 ± 0.005$
Mass = 16.45±0.15 GeV/c$^2$
$Z/A = 0.114 ± 0.01$
Flux ($1.5 < E_K < 10$ GeV) = $5 \times 10^{-5}$ (m$^2$ sr sec)$^{-1}$

Background probability < 10$^{-3}$
## Discoveries in Physics

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*Exploring a new territory with a precision instrument is the key to discovery.*
The Cosmos is the Ultimate Laboratory.
Cosmic rays can be observed at energies higher than any accelerator.

The issues of antimatter in the universe and the origin of Dark Matter probe the foundations of modern physics.

The most exciting objective of AMS is to probe the unknown; to search for phenomena which exist in nature that we have not yet imagined nor had the tools to discover.