The Alpha Magnetic Spectrometer (AMS)

ISS: 108x80m 420T 240KW 400km
AMS: 5x4x3m 7.5T 2.4KW

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Scientific goals of AMS on the International Space Station

- Direct search of primordial antimatter:
  Anti-nuclei: He, C
- Indirect search of Dark Matter:
  e+, antiprotons, \( \Upsilon \), ... simultaneous observation in several signal channels
- New forms of matter:
  strangelets
- Identification of local sources of high energy photons (~TeV):
  SNR, Pulsars, PBH
- Measuring CR spectra up to the iron– refining propagation models;
- Solar modulation on CR spectra over 11 year solar cycle
AMS is a US DOE led International Collaboration
Spokesperson: Nobel laureate Prof. Dr. S. Ting from MIT
16 Countries, 60 Institutes and 600 Physicists

The detectors and the electronics were built all around the world and assembled in CERN, Switzerland
AMS is designed with the same precisions as the CERN LHC detectors. The technology has been miniaturized and upgraded to work on space.
AMS consists of 5 sub-detectors which provide redundant information for particle identification.

- **TRD**
  - Identify e+, e-

- **TOF**
  - Z, E

- **Silicon Tracker**
  - Z, P

- **ECAL**
  - E of e+, e-, γ

- **Magnet**
  - ±Z

- **RICH**
  - Z, E

Particles and nuclei are defined by their charge (Z) and energy (E ~ P). Z, P are measured independently by the Tracker, RICH, TOF and ECAL.
A TeV precision, multipurpose spectrometer

**Magnet**

± Z

same of AMS-01

B ~ 0.14 Tesla uniform along x

no field leak outside

no torque outside
A TeV precision, multipurpose spectrometer

- **TOF**
- **Z,E**
- 4 layer scintillators
- acceptance 0.4 m² sr
- 144 photomultipliers
A TeV precision, multipurpose spectrometer

Silicon Tracker
Z, P
9 layers silicon
192 readout channels
resolution of 10 µm in bending direction
A TeV precision, multipurpose spectrometer

TRD
Identify $e^+$, $e^-$
20 layers of radiators and 6mm straw tubes
Xe/CO$_2$ (80%/20%) gas
5248 channels
A TeV precision, multipurpose spectrometer

RICH
Z, E
Areogel and NaF radiators
conical reflector
10880 photosensors
A TeV precision, multipurpose spectrometer

**ECAL**

- $E$ of $e^+$, $e^-$, $\gamma$
- 3D sampling calorimeter
- 17 $X_0$
- 50000 fibers 1mm thick
- $e/p$ separation $10^4$
AMS electronics on ISS

650 computers, 300,000 channels. A ten year effort by 75 engineers 400% redundancy
AMS in the ESA

EMI and TVT tests
Tests at CERN
AMS in accelerator test beams Feb 4-8 and Aug 8-20, 2010
Test Beam Results

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

Bending Plane Residual (cm)

Reconstructed Velocity

e± Energy Resolution: 2.5-3%

TRD: 400 GeV protons
A US-AirForce C-5 Galaxy has been used for transport from Geneva to KSC - August 25th 2010
AMS in Endeavour’s Payload Bay
Launch of the Space Shuttle Endeavour
May 16, 2011 @ 08:56 AM
Temperatures and slow-control data monitoring started 2.5 h after the launch.
May 19: AMS installation completed at 5:15 AM.
Data taking started at 9:35 AM
AMS installed on ISS @ 16:15 Geneva time
AMS start data taking @ 16:35 Geneva time
AMS Operations

AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

White Sands Ground Terminal, NM

ISS

Astronaut at ISS AMS Laptop

TDRS Satellites

Flight Operations

Ground Operations

Ku-Band
High Rate (down):
Events: 10Mbit/s

S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s
Orbital DAQ parameters

Acquisition rate [Hz]

Time at location [s]

DAQ efficiency

Particle rates vary from 200 to 2000 Hz per orbit

Average DAQ efficiency 85%
Average DAQ rate ~700Hz
In 10 - 20 years AMS will collect from 160-320 billion events.

This will provide unprecedented sensitivity and statistic.
1.03 TeV electron

AMS Event Display  Run/Event 1315754945 / 173049  GMT Time 2011-254.15:31:15

Tracker and Magnet: measure momentum

ECAL: identifies electron and measures its energy

RICH: charge of electron

TRD: identifies electron

front view

side view
120 GeV Photon

17 $X_0$, 3D ECAL, measure γ to 1 TeV, time resolution of 1µsec
Nuclei in the TeV range

- $Z = 7$ (N), $P = 2.088$ TeV/c
- $Z = 10$ (Ne), $P = 0.576$ TeV/c
- $Z = 13$ (Al), $P = 9.148$ TeV/c
- $Z = 14$ (Si), $P = 0.951$ TeV/c
- $Z = 15$ (P), $P = 1.497$ TeV/c
- $Z = 16$ (S), $P = 1.645$ TeV/c
- $Z = 19$ (K), $P = 1.686$ TeV/c
- $Z = 20$ (Ca), $P = 2.382$ TeV/c
- $Z = 21$ (Sc), $P = 0.390$ TeV/c
- $Z = 22$ (Ti), $P = 1.288$ TeV/c
- $Z = 23$ (V), $P = 0.812$ TeV/c
- $Z = 26$ (Fe), $P = 0.795$ TeV/c
On-orbit thermal control

The thermal environment on ISS is constantly changing due to:
• Solar Beta Angle (beta)
• Position of the ISS Radiators and Solar Arrays
• ISS Attitude

Over 1,100 temperature sensors and 298 heaters are monitored to assure components stay within thermal limits and avoid permanent damage.
On orbit performance

TRD alignment

Due to temperature variations the TRD is moving on top of the inner tracker by up to 1 mm.

Cosmic protons are used for alignment to an accuracy of 0.04 mm for each straw module.
On orbit performance

**TRD gain calibration**

Due to temperature, pressure, gas composition and HV changes, the TRD detector response is changing.

Cosmic ray protons are used to calibrate the detector response to 3% accuracy.
On orbit performance

Tracker works as expected

Tracker alignment stability

1 MIP = 30 ADC

stability $\sigma \sim 0.003$ mm
On orbit performance

Proton Rejection

Electron Efficiency (%)

Proton Rejection = 10376 @90(%) efficiency

TRD

Tracker

TOF
Redundant charge identification capability
He rate

![Graph showing the rate of events per second versus rigidity for different values of $\Theta_M$.]

- $\Theta_M < 0.2$
- $0.4 < \Theta_M < 0.6$
- $0.6 < \Theta_M < 0.8$
- $1.0 < \Theta_M$
He rate and Solar Flare

Polar region

Equatorial region

Solar Flare, 24/1/2012
Quiet period
Conclusions

The Cosmos is the ultimate Lab: cosmic rays can be observed at energies higher than any accelerator

- AMS02 is in orbit since May 16th 2011
- All the detectors are properly functioning with DAQ in nominal conditions since May 19th 2011
- Ground operations (POCC and SOC) run smoothly
- Detector calibration (alignment, e/p rejection, charge id, etc.) are well advanced
- 10+ years on board the ISS at 16 $10^9$ events/year: great discovery potential

Science coming soon!!
Back-ups
Evolution of the beta angle through 2012, with dates of extreme values. At large positive values, the port side of AMS is hot and the starboard side cold. Vice-versa for large negative beta angles.
Solar Constant: illumination by the sun

Varies from 1326W/m² to 1418W/m² as the distance of the earth from the sun changes. Can cause differences of AMS temperatures on the order of 5°
Scientific goals
γ rays astrophysics up to TeV energies

Energy spectrum for pulsars in the 100 MeV – 1 TeV and pulsar periods measured with µsec time precision.

Similar studies can be made for Blazers and Gamma Ray Bursters.
γ rays astrophysics up to TeV energies

The diffuse gamma-ray spectrum of the Galactic plane
Tracker and Ecal Performances

Acceptance

Effective Area

Energy Resolution

Angular resolution
Search for New Matter in the Universe

After many years, the question of the existence of strange quark matter still remains without a definitive answer.

_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._

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**Carbon Nucleus**

Z/A ~ 0.5

**Strangelet**

Z/A ~ 0.1

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Strangelets

Jack Sandweiss (Yale) is leading the AMS search.

Candidate observed with AMS-01 5 June 1998 11:13:16 UTC

Rigidity = 4.31 ± 0.38 GV
Charge Z = 2
β_1 = β_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) = 5x10^{-5} (m^2 sr sec)^{-1}
Strangelets

\[ \Phi_{\text{strangelets}} = 5 \times 10^{-10} \text{(cm}^2\text{s sr)}^{-1} \]
Antimatter search

- Buffington et al. 1981
- Golden et al. 1997
- Badhwar et al. 1978
- Alcaraz et al. 1998
- Sasaki et al. 2001

Graph showing Antiproton/He Flux Upper Limit 95% CL vs. Rigidity (GV).
Dark Matter search: positron channel

AMS will explore the indirect detection of dark matter, measuring the dark matter annihilation and collision products. Combining searches in several different channels as:

- $e^+$
- Photons
- $p$
- Antideuterons

The leading candidate for Dark Matter is a SUSY neutralino ($\chi^0$)

Collisions of $\chi^0$ will produce excess in the spectra of $e^+$ different from known cosmic ray collisions.

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### AMS-02 (10 Yrs)

**$e^+/(e^+ + e^-)$**

- **AMS-01**
- **HEAT**
- **PAMELA**

**Collision of Cosmic Rays**

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**positrons current results**

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

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**$e^+$ Energy [GeV]**

**$m_{\chi^0}=800$ GeV**

**$m_{\chi^0}=400$ GeV**

**$m_{\chi^0}=200$ GeV**
Electron 901 GeV

Hadron Shower 919 GeV
- Use the AMS Tracker and Electromagnetic Calorimeter to define a clean Electron and Proton sample.

- Study the TRD response in Space and determine the particle identification power from space data directly!
Electron vs. Proton

$$N_e = 232286 \quad N_p = 18693730$$

- $\ln(L)$ of 90% electron eff. = 0.54
- $\ln(L)$ of 90% proton eff. = 0.85
TRD Proton Rejection at 90% Electron Efficiency

Proton Rejection

Momentum (GeV/c)

AMS on ISS 2011
Alignment
Stability of the Inner Tracker is monitored by the Tracker Laser Alignment System.

Laser Diodes
\(\lambda=1080\) nm

10 Laser rays
AMS Data on ISS

Stability of the Inner Silicon Tracker of AMS
(not corrected for the pointing stability of the laser beams!)

\[ \Delta X - 0.1L \ (\text{mm}) \]

\[ \begin{align*}
\Delta X - 0.1L & \quad 06/07 \quad 02:00 \\
0.0 & \quad +L=2 \\
0.0 & \quad +L=3 \\
0.0 & \quad +L=4 \\
0.0 & \quad +L=5 \\
0.0 & \quad +L=6 \\
0.0 & \quad +L=7 \\
0.0 & \quad +L=8 \\
\end{align*} \]

\[ \sigma_x = 6 \mu m \]

1 set of measurements every 30 minutes

\[ \Delta Y - 0.1L \ (\text{mm}) \]

\[ \begin{align*}
\Delta Y - 0.1L & \quad 06/07 \quad 02:00 \\
0.0 & \quad +L=2 \\
0.0 & \quad +L=3 \\
0.0 & \quad +L=4 \\
0.0 & \quad +L=5 \\
0.0 & \quad +L=6 \\
0.0 & \quad +L=7 \\
0.0 & \quad +L=8 \\
\end{align*} \]

\[ \sigma_y = 6 \mu m \]
Typical stability of an inner tracker plane is 0.1 μm as measured with Protons on the ISS.
Stability of Layer 1 with respect to the Inner Tracker (bending plane)

- Entries: 352
- $\chi^2$/ndf: 21.16/20
- Constant: 41.07 ± 2.99
- Mean: -0.682 ± 0.185
- Sigma: 3.217 ± 0.155

Stability

$\sigma = 0.003$ mm
Magnet
Magnets Comparison

Superconducting Magnet Scenario

\[ \frac{\Delta R}{R} \propto \frac{1}{B_{scm}l^2} \]

Permanent Magnet Scenario

\[ \frac{\Delta R}{R} \propto \frac{1}{B_{pm}lL} \]

\[ B_{scm} \sim 0.87 \, T \]
\[ l \sim 1 \, m \]
\[ B_{pm} \sim 0.14 \, T \]
\[ L \sim 4 \, m \]
Test Beam Results– 8-20 Aug 2010

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

Energy Resolution: 2.5-3%

Reconstructed Velocity

TRD: 400 GeV protons

Measured combined rejection power at 400 GeV: $e^+/p = 10^{-6}$
Test Beam Results of detector with superconducting magnet

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

Feb 4-8, 2010

Bending Plane Residual (cm)

Energy

Electron Energy Resolution: 2.5-3%
With 9 tracker planes, the resolution of AMS with the permanent magnet is equal (to 10%) to that of the superconducting magnet.
Rigidity resolution

AMS with:
- Superconducting Magnet
- Permanent Magnet
Lifetime
A. The lifetime of consumables – TRD Leak rate

Caused by CO$_2$ Diffusion
CO$_2$ Storage at Launch: 5 kg
Leakrate of 5 µg / s corresponds to a

**TRD Lifetime of 30 Years**
AMS-02 data flow
AMS Data/MC Volumes Projected

DATA

Per Year Of Operation:

- $1.6 \times 10^{10}$ Events
- 35 TB Raw Events
- 130 TB Reconstructed Ev.

MC

Per Year Of Operation:

- $\sim 2 \times 10^{10}$ Simulated Events
- $\sim 200$ TB Simulated Data Volume