Alpha Magnetic Spectrometer Experiment

Andrei Kounine / MIT on behalf of AMS collaboration

PANIC, 27 July 2011, Cambridge
Support of MIT School of Science, Physics Department and Laboratory for Nuclear Science is greatly appreciated!
5m x 4m x 3m
7.5 tons
300,000 electronic channels
650 processors

Silicon layer
TRD
TOF 1, 2
TOF 3, 4
Magnet
~1500 Gauss
RICH
Radiators
ECAL
RICH
7 Silicon layers
11,000 Photo Sensors
Silicon layer
AMS: A TeV precision, multipurpose particle physics spectrometer in space.

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

- **TRD** Identify $e^+$, $e^-$
- **Silicon Tracker** $Z$, $P$
- **ECAL** $E$ of $e^+$, $e^-$, $\gamma$
- **TOF** $Z$, $E$
- **Magnet** $\pm Z$
- **RICH** $Z$, $E$

$Z$, $P$ are measured independently from Tracker, RICH, TOF and ECAL.
In 12 years the field has remained the same to <1%

The detailed 3D field map (120000 locations) was measured at CERN on 25-27 May 2010
Transition Radiation Detector: TRD
Identify e\(^+\), reject P

Leak rate: CO\(_2\) ≈ 5 \(\mu\)g/s
Storage: 5 kg – 30 years lifetime

Prof. Becker, MIT
Prof. Fisher, MIT
Time of Flight (TOF)

Measures the time of relativistic particles to 160 picoseconds

Provides trigger for charged particles

Trigger time is synchronized to UTC time to 1µs

4 scintillator planes

\[ \Delta t/t = 160\text{ps} \]
Silicon Tracker

10 mil pitch; 200,000 channels; alignment 3 μm

Test beam 158 GeV/n

Test beam

σ ~ 8.5 μm
Ring Imaging Cherenkov Detector (RICH)

Intensity $\propto Z^2$

$\Theta \propto V$

Radiator
detectors
Reflector

NaF Aerogel

10,880 photosensors

Single Event Displays

RICH test beam E=158 GeV/n
Calorimeter (ECAL)

A precision, $17 \times X_0$, 3-dimensional measurement of the directions and energies of light rays and electrons

\[
\frac{\sigma (E)}{E} = \frac{10.6 \pm 0.1}{\sqrt{E}} (1.25 \pm 0.03)\%
\]

Test Beam Results

Lead foil (1mm)

Fibers ($\phi 1$mm)

50,000 fibers, $\phi = 1$ mm
distributed uniformly
Inside 1,200 lb of lead
AMS-02 Electronics

AMS electronics, designed by MIT group, is based on conventional accelerator physics technologies. It is ~10 times faster than commercial space electronics.

The level of redundancy is shown in parenthesis.
AMS in the ESA Electromagnetic Interference (EMI) Chamber, March 2010, ESTEC, Noordwijk, Netherlands
AMS in the ESA TVT Chamber, April 2010, ESTEC

Duration 330 hours
P < $10^{-6}$ mbar

Ambient temperature from -90°C to +40°C
Velocity measured to an accuracy of 1/1000 for 400 GeV protons

Bending Plane Residual (cm)

$\sigma \approx 10 \mu m$

Energy Resolution: 2.5-3%

Reconstructed Velocity/c

TRD: 400 GeV protons
Arrival of the AMS C5 at Geneva – 25 Aug 2010
Vol spécial pour l’aimant chasseur d’antimatière

PHYSIQUE Assemblé au CERN, l’AMS quitte Coitnur pour la Floride d’où il doit être lancé dans l’espace en février.


Le chargement dans la soute a eu lieu hier. Le mastodontique devait décoller ce matin entre 6 et 7 heures, en direction du Centre spatial Kennedy en Floride. C’est de là que le précieux instru-vrier, pour sa destination finale, la Station spatiale internationale, y sera amené. Principal et unique instrument de physique sur l’ISS, AMS devrait y fonctionner durant une vingtaine d’années. Les données recueillies seront transmises, via Houston, au CERN où se trouve le centre de contrôle du détecteur.

Scolant universités et institus-tuts, dont l’Université de Genève et l’EPFZ en Suisse, ont contribué à la réalisation de ce détecteur de 7,5 tonnes, haut de 4 mètres et large de 5, qui ne rentre pas dans des avions-cargos standard. Sa valeur totale atteint 2 milliards de dollars.

Bouquet de surprises

Le Spectromètre magnétique Alpha (AMS). Il tiraera, depuis l’espace, l’antimatière et la matière noire soupçonnée de constituer 90% de la masse de l’univers. (LAURENT GIRAUD)

OÙ l’antimatière primordiale, AMS analysera la composition des rayons cosmiques galactiques et extragalactiques, et recherchera également la matière noire.
22 October 2010
AMS in the Rotation Stand and mated with a Payload Attach System simulator (A) during interface verification testing with ISS
AMS Performance with Cosmic Rays at KSC

Mass measurement for sea level CR

\[ M_\mu = 105 \pm 1 \text{ MeV} \]
\[ M_p = 935 \pm 5 \text{ MeV} \]
AMS Transfer to the Shuttle, 26 March 2011
Counting down to the launch of STS-134
AMS is grappled by the Shuttle Remote Manipulator System (SRMS) May 19, 2011
AMS installed on the ISS Truss at 5:15 CDT and taking data since 9:35 CDT May 19, 2011
Two astronauts working on the Space Station near AMS
AMS Science Data Flow

During testing at KSC, on the launch pad and on the ISS

AMS

AMS

NASA channels

MSFC POIC, AL

AMS GSC

KSC, FL

AMS POCC
(August 2010 to May 2011)

JSC, TX

AMS POCC,
(February-June 2011)
and backup POCC
for CERN POCC

CERN

AMS POCC
Main operations centre
(from June 23, 2011)
AMS Payload Operation and Control Center for ISS

1. Management
2. Shift Leader
3. Commander
4. DAQ+Trigger +RunControl
5. Data Handling
6. Tracker+Laser Align.+Cooling
7. TRD+TRD Gas
8. TOF+ACC
9. RICH
10. ECAL
11. Thermal
12. NASA Liaison
13. Consultants
14. On call

Science Operation Center

The Wall

12 persons per shift for AMS on ISS

AMS GSC

POIC, MSFC
store all AMS data
POCC at CERN in control of AMS since 19 June 2011
Operational Experience of AMS on ISS

TRD

Silicon Tracker

ECAL

TOF

Magnet

RICH
Orbital DAQ parameters

**Acquisition rate [Hz]**

**Time at location [s]**

**DAQ efficiency**

Particle rates vary from 200 to 2000 Hz per orbit

On average:

- DAQ efficiency 85%
- DAQ rate ~700Hz
AMS collected over 3 billion events

First 2 months of AMS operations
Particle rates – two components

\[ \theta = (-50^\circ, -48^\circ), \text{ closest to pole} \]

\[ \theta = (-40^\circ, -38^\circ) \]

\[ \theta = (-30^\circ, -28^\circ) \]

\[ \theta = (-20^\circ, -18^\circ) \]

\[ \theta = (-10^\circ, -8^\circ) \]

\[ \theta = (-2^\circ, 0^\circ), \text{ equator} \]

Rate (s\(^{-1}\))

\[ |\text{Rigidity}| \]

Cosmic proton flux

Under-cutoff trapped particles
Geomagnetic cutoff

Model

Upper rigidity cutoff $R_u$ [GV]

AMS Data

latitude

longitude

latitude

longitude
Experience from the AMS operation on the ISS:

1. All AMS subsystems are fully operational with the performance expected from ground measurements;

2. AMS trigger was fine-tuned during the first week of data taking to improve purity of collected data for an average event acquisition rate of 700Hz and average DAQ efficiency of 85%;

3. The gas leak rate of the TRD is identical to the one measured at KSC;

4. Dynamically changing running parameters (data downlink bandwidth, distribution of available electrical power, rotation of ISS solar panels near AMS, ...) are constantly followed by the AMS shifts;

5. Variation of ambient conditions (temperature in first place) will be accounted for with proper calibrations and alignments;

6. Intensive calibration work for all detector systems is ongoing in order to maximize the accuracy of the measurements.
Cosmic ray studies with AMS

Goals:

- **Searches for primordial antimatter:**
  - Light anti-nuclei: D, He, ...
  - $\overline{p}/p$ ratio

- **Dark Matter searches:**
  - $e^+, e^\pm, \overline{p}, ...$
  - simultaneous observation of several signal channels.

- **Searches for new forms of matter:**
  - strangelets, ...

- **Measuring CR spectra – refining propagation models;**

- **Identification of local sources of high energy CR (~TeV):**
  - SNR, Pulsars, PBH, ...

- **Study effects of solar modulation on CR spectra over 11 year solar cycle**

  ...
The Origin of Dark Matter

~ 90% of Matter in the Universe is not visible and is called Dark Matter

Search for the origin of Dark Matter:
Collisions of Dark Matter will produce additional e+ These characteristics of additional e+ can be measured very accurately by AMS
The leading candidate for Dark Matter is a SUSY neutralino.
Detection of High Mass Dark Matter

Events from the first week of operations on ISS

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

$\chi_m = 400 \text{ GeV}$

$\chi_m = 200 \text{ GeV}$

$\chi_m = 800 \text{ GeV}$

AMS-02
AMS data on ISS

Electron 240 GeV, 22 May
Calorimeter (ECAL)  3D Sampling of Showers

Lead foil (1mm)

Fibers (1mm)

18 longitudinal samplings (9 groups of 2 layers)
Readout cell dimensions: Z (9 mm), X (9 mm), Y (9 mm)
240 GeV Electron, 3D Sampling of Shower

AMS data on ISS

Longitudinal profile, energy 240 GeV
Identifying $\gamma$ Sources with AMS

Example: Pulsars in the Milky Way

Neutron star sending radiation in a periodic way.

Currently measured to energies of $\sim$ GeV with precision of a millisecond.

AMS: energy spectrum up to 1 TeV and pulsar periods measured with $\mu$sec precision

A factor of 1,000 improvement in Energy and Time

Unique Features:
17 $X_0$, 3D ECAL, Measure $\gamma$ to 1 TeV,
AMS data on ISS

Photon 40 GeV, 23 May

Direction reconstructed with 3D shower sampling
Gamma 40 GeV, 3D Sampling of Shower

AMS data on ISS

Longitudinal profile, energy 40 GeV
The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very beginning.
Experimental work on Antimatter in the Universe

Direct search

- AMS
  - Increase in sensitivity: $x 10^3 - 10^6$
  - Increase in energy to $\sim$TeV

Search for Baryogenesis

- Proton decay
  - Super K
    - $T_p > 6.6 \times 10^{33}$ years

- New CP
  - BELLE
  - BaBar
    - $(\sin 2\beta = 0.672 \pm 0.023)$ consistent with SM
  - FNAL KTeV
    - $(\text{Re}(\epsilon'/\epsilon) = (19.2 \pm 2.1) \times 10^{-4})$
  - CERN NA-48
  - CDF, D0

- LHC-b
  - ATLAS
  - CMS

Increase in sensitivity: $x 10^3 - 10^6$
AMS data on ISS

Nuclear charge Z=14, Si
P = 136 GeV/c
AMS data on ISS

Nuclear charge $Z=8$, $P = 119$ GeV/c
AMS data on ISS
May 19 to 24, 2011
AMS on the ISS for two decades

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

Since the world's most advanced cosmic-ray detector took 16 years and $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse, NASA directed to finish building the space station and allow the space shuttle by the end of 2010, said: it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle Endeavour is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and what knows what—the list category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Lumps of the stuff in our galaxy might occasionally release showers of particles that would set the detectors afire. Some physicists also speculate that our planet might be peppered with the odd antimatter coming from distant galaxies made not of matter but of evil antimatter.

The spectrometer’s claim to fame is this: it can tell the ordinary from the extraordinary, which otherwise are easily confused. No other instrument has the combination of detectors that can sort out all the properties of a particle mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotic matter because it lacks the ability to distinguish a low-mass antimatter, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbolic way, it and the space station have come to justify each other’s existence. The station supplies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully photograph the station's energy spectra, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plunges the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit.