In 10 years, over 170 billion charged cosmic rays with energies up to multi-trillion eV have been studied by AMS-02 on the ISS.
AMS-02: Alpha Magnetic Spectrometer

Launch: 16/5/2011 (Endeavour)
Construction: 1999-2010
Dimensions: $3 \times 4 \times 5 \text{ m}^3$
Weight: 8.5 t
Power: 2500 W

Alpha Magnetic Spectrometer (AMS-02)

Specifications:
- Construction: 1999-2010
- Launch: May 16, 2011
- Power: 2,500 W
- Mass: 8,500 kg (18,739 lb)
- Press. Volume: 64 m$^3$ (2,260 ft$^3$)
Fix of the Cooling system 2019/20

4 EVAs by
• Luca Parmitano
• Andrew Morgan
AMS “tomography” using rare nuclear interaction events

The gray scale is proportional to the number of found vertices

Z = 178.5 cm
Precision Measurement of Cosmic Nuclei

Charge determined from scintillators

Charge determined from silicon tracker

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Continuous Calibration at TeV (above CERN 0.4 TeV test beam)

By comparing proton data and simulation from

the upper spectrometer
(L1 to L8)

and

the lower spectrometer
(L2 to L9)

By comparing proton data and simulation from

the upper spectrometer
(L1 to L8)

and

the lower spectrometer
(L2 to L9)
In AMS, the largest systematic error in the determination of the fluxes at the highest energies is due to the uncertainty in the absolute momentum scale.

In space continuous outgassing of the carbon fiber supporting structure can affect the position of the tracker sensors at the sub-micron level.

A shift in the central tracker planes of 0.5 microns is sufficient to create a momentum shift of 10% at 1 TeV and bias flux measurements.
Momentum Scale Verification

By matching the momentum determined by the tracker and magnet with the energy measured in the ECAL for both $e^+$ and $e^-$

The accuracy of the momentum is determined to be $1/(30,000 \text{ GeV})$; i.e., at 1 TeV the uncertainty is 3%
Precision measurement of cosmic-ray spectra requires an determination of **nuclear interactions** in the detector material

Define \((P, Z)\) of nuclei with the central spectrometer

Use right-to-left nuclei to measure **nuclear interactions** in the TRD+TOF

Use left-to-right nuclei to measure the **nuclear interactions** in the TOF+RICH
AMS Measurement of He-C Interaction Cross Section as a function of rigidity

\[ \sigma_{\text{inE}} \]

\[ \text{He Rigidity [GV]} \]

AMS Measured Cross Section
- Ableev 1977
- Jaros 1985
- Tanihata 1985
Oxygen ($Z = +8$)

Fluorine ($Z = +9$)

Neon ($Z = +10$)

Magnesium ($Z = +12$)
Silicon (Z = +14)

Sulfur (Z = +16)

Iron (Z = +26)

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Primary elements (H, He, C, ..., Fe) are produced during the lifetime of stars. They are accelerated by the explosion of stars (supernovae).
Surprisingly, above 60 GV, the primary cosmic rays have identical rigidity (P/Z) dependence.

AMS

Helium 125 Million
Carbon 14 Million
Oxygen 12 Million
Heavier primary cosmic rays Ne, Mg, Si: have their own identical rigidity behavior but different from He, C, O. Primary cosmic rays have at least two classes.
Iron is a very important element in cosmic ray theories because it is the heaviest element produced during stellar evolution. Iron has a large interaction cross section with the interstellar medium whereas helium has the smallest cross section.
Iron is in the He, C, O primary cosmic ray group
Secondary cosmic nuclei (Li, Be, B, ...) are produced by the collision of primary cosmic rays and interstellar medium.
Secondary Cosmic Rays also have two classes above 30 GV.

![Graph showing flux vs rigidity for different elements.
He/140, C/4.7, Ne×1.2, Mg, O/5.1, Si×1.1, Li×1.4, Be×2.8, Be×2.8, F×12.8, B.](image)
AMS Light nuclei comparison with Voyager-1
The ratios are independent of solar activity

Voyager
outside the solar system

AMS-02

inside the solar system

C/O

He/O

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Flux of Protons above 100 MeV

Average 2011-2018

Highest Radiation

Lowest Radiation

Highest Radiation
South Atlantic Anomaly Region

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AMS Radiation Flux ofHeavy Nuclei He(Z=2) to Zinc(Z=30)

Average 2011-2018

Highest Radiation

Lowest Radiation
Daily Variations in the Proton Flux

- [1.16-1.33] GV
- [1.92-2.15] GV
- [2.67-2.97] GV
- [4.02-4.43] GV

Preliminary
please refer to our forthcoming publication in PRL
Daily Variations in the Helium Flux

- [1.92-2.15] GV
- [2.97-3.29] GV
- [4.02-4.43] GV
- [5.37-5.90] GV

Preliminary please refer to our forthcoming publication in PRL
Conclusions

• AMS-02 is measuring with high accuracy the nuclei spectra up to Iron (and possibly just above)

• The AMS-02 measurements reveal new features

• AMS-02 can also study CR flux time dependence and its correlation with sun activity

AMS-02 Beyond 2021

• Positrons and anti-protons as probes for exotic signals

• Complete the CR spectra measurement

• Complete the CR fluxes study over a full solar cycle

• Search for heavy antimatter (few candidates observed) and anti-deuterons