Observation of the Identical Rigidity Dependence of the Primary Cosmic Rays Helium, Carbon and Oxygen fluxes by the Alpha Magnetic Spectrometer on the International Space Station

F. Donnini on behalf of the AMS Collaboration
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AMS-02 is a large-acceptance high-energy magnetic spectrometer able to perform precision measurements of particles in the GeV-TeV energy range. AMS-02 recorded more than 120 billion CR triggers in ~7 years of operation.
Cosmic rays in the Galaxy

Primary

$p, \text{He}, C, O \ldots$

Secondary

$Li, Be, B \ldots$

AMS
CR Primaries before AMS

AMS-02 is a large-acceptance high-energy magnetic spectrometer capable of accurately measuring particles in the GeV-TeV energy range.

Since May 19, 2011, AMS-02 has been operating on the International Space Station (ISS).

AMS recorded >117 billion CR triggers in ~7 years of operation.

AMS is expected to take data during the whole ISS lifetime (extended to 2024).

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

\(Z, P\) are measured independently by the Tracker, RICH, TOF and ECAL.
Chemical composition measured by AMS-02
Chemical composition measured by AMS-02

Covered in this talk

To be measured by 2024
Charge Measurement in AMS-02

Tracker L1 - 6.2
$\Delta Q \approx 0.3 \text{ c.u.}$

Tracker L9 - 5.8
$\Delta Q \approx 0.3 \text{ c.u.}$

TRD - 5.6
$\Delta Q \approx 0.33 \text{ c.u.}$

Upper ToF - 6.0
$\Delta Q \approx 0.16 \text{ c.u.}$

Inner Tracker - 6.0
$\Delta Q \approx 0.1 \text{ c.u.}$

Lower ToF - 5.7
$\Delta Q \approx 0.16 \text{ c.u.}$

ECAL - 6.0

Tracker, $R = p/Z$

Full Span MDR ($Z=6$)
$\approx 3.5 \text{ TV}$

TOF, $\beta$

$\Delta \beta (\beta=1, Z=2) \approx 0.02$

$\Delta \beta (\beta=1, Z=5, 6) \approx 0.01$
With the track defined by the inner tracker (L2-L8), examine the charge distribution on the tracker L1. The high redundancy of charge measurements allows to keep under control interactions in the upper part of the detector (between Tracker L1 and L2).
Cross-section and materials

Measurement of nuclear cross sections / accurate check of the materials when AMS is flying in horizontal attitude

First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, Li, Be, B, ...

Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.
The measured “Survival probabilities” are then compared with the corresponding predictions from the MC simulation. The relevant cross-sections are then estimated from this procedure and corrected in the MC simulation.
The cross-sections are studied at the level of the single nuclear branching-factor thanks, again, to the high redundancy in the charge measurements in AMS.
Another important source of systematic uncertainties is the knowledge of the rigidity measurement. This affects both the energy scale of the AMS spectrometer and the bin-to-bin migrations due to the spectrometer resolution.

On protons the resolution function has been measured on the 400GV SPS beam. For heavier nuclei it can be validated with the MC simulation by examining the spatial resolution of the silicon sensors.
Fluxes measured using events passing through L1-L9 divided by the ones measured using events passing through L1-L8 (or L2-L8).

The observed agreement verifies:

**acceptance**: the amount of material traversed is different

**unfolding**: bin-to-bin migration is different due to different resolution
Primary fluxes: Helium

Flux \times R^{2.7} [ m^{-2} \cdot s^{-1} \cdot sr^{-1} (GV)^{1.7} ]

Helium

AMS
PAMELA

He flux measurement: 90 million events
Primary fluxes: Carbon and Oxygen

C flux measurement: 8.4 million events
O flux measurement: 7 million events

M.Aguilar et al. PRL 119 (2017) 251101
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Conclusions

- Knowledge of the behavior of the primary cosmic ray nuclei is important for the understanding of the CR production, acceleration, and propagation.

- AMS is providing precision measurements of CRs primary elements (protons, helium and heavier nuclei fluxes) with a few percent precision.

- He, C, and O fluxes show a change of spectral index at around 200 GV, following the same rigidity dependence.

- AMS will continue taking data for the entire duration of the ISS, continuing the search for dark matter, primordial antimatter and a more detailed description of cosmic rays fluxes.
Flux Measurement

Isotropic Differential Flux \((m^2 \text{sr s GV})^{-1}\)

\[
\Phi_i^Z = \frac{N_i^Z}{T_i A_i^Z \varepsilon_i^Z \Delta R_i}
\]

Number of particles subtracted for backgrounds and corrected for bin to bin migration

Exposure Time \([s]\)
1.23x10^8 s, \(R > 30 \text{ GV}\)

Bin width \([\text{GV}]\)
67 bin between 1.9 GV and 3.3 TV

Trigger Efficiency
\(\varepsilon > 98\%\) over entire R range

Effective Acceptance \((m^2 \text{sr})\)
from MC Simulation, validated from Data
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