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AMS-02 on the International Space Station: Recent results and perspectives

V. Formato
INFN, Sezione di Perugia - Perugia, Italy

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Summary. — The AMS-02 (Alpha Magnetic Spectrometer) is a magnetic spectrometer built for the precision study of the energy spectrum and chemical composition of cosmic rays (CRs) in the GeV to TeV energy range. AMS-02 was installed on the ISS on May 19th 2011, and has been collecting data since then, collecting 17 billion CR triggers every year. With its large acceptance, long exposure time and excellent subdetector performance, AMS-02 can measure CRs fluxes with unprecedented precision in a wide energy range. In this contribution the main results achieved by AMS-02 in 5 years of operations will be presented and discussed.

1. – Introduction

Cosmic rays (CRs) are charged particles coming isotropically from outer space to the Earth atmosphere with an energy range spanning from the GeV to the TeV range. It is still unclear where and how CRs are accelerated in the Galaxy, as well as how they propagate through the interstellar medium (ISM), and both these aspects are subjects of current research. Another fundamental aspect in CR physics is the search for any signal of new physics in the antimatter component of CRs that could be linked to the decay of dark matter (DM) particles or to the existence of primordial antimatter. The bulk of cosmic rays is made of protons ($\sim$88%) and helium nuclei ($\sim$9%), while the remaining fraction is composed mostly of electrons ($\sim$2%) and heavier nuclei ($\sim$1%) with small traces of antimatter (positrons and antiprotons). Depending on wheter a cosmic ray reaches the solar system after being accelerated at its source or after being created in an anelastic interaction of other CRs with the ISM, it is labelled a *primary* or a *secondary* cosmic ray. Examples of primary species are protons, ^{4}He nuclei, carbon and oxygen nuclei, and electrons, while typical examples of secondary species are ^{2}H, ^{3}He, lithium, beryllium and boron nuclei.

Being created directly during the propagation of primary CRs in the Galaxy, secondary CRs carry important information on how the transport process modifies the original CR energy spectrum after the acceleration at the source. This is important for the theoretical prediction of the amount of secondary antimatter produced by CR propagation in the Galaxy, since this represents the natural background in the search for new physics in the antimatter channel. This aspect of CR physics gained importance after the observation, in 2008, by the PAMELA experiment [1] of an anoumalous rise in the positron fraction starting from a few GeV up to 100 GeV in energy, which is unexplained in terms of the current understanding of CR propagation. These findings were later confirmed by the Fermi satellite [2], and by the AMS-02 experiment [3]. Since high energy leptons lose energy very quickly due to bremmstrahlung radiation the higher their energy, this anomalous excess points to a source relatively close to the solar system for this excess of positrons, either in the form of a DM overdensity or in the form of pulsars/SNRs. Precise measurement of the CR hadronic component and of the antiproton flux as well as a detailed measurement of the positron flux spectral features can provide a way to discriminate between possible sources of the positron excess.

2. – The AMS-02 experiment

AMS-02 is a general-purpose high-energy physics particle detector operating onboard the International Space Station (ISS) since May 2011. The instrument will be active for the entire ISS lifetime which is currently foreseen to last until 2024. With such a long exposure time and its large geometrical acceptance ($\sim$0.5 m^2 sr), AMS-02 is capable to provide high-quality data on CR fluxes at the TeV energy scale with unprecedent precision and sensitivity. The AMS-02 detector is described in details in ref. [3]. It is composed by several sub-detector systems that allow precise particle identification as well as redundant measurements of the main characteristics of CR particles, such as arrival direction, charge and magnetic rigidity ($R = pc/Ze$). The particle trajectory in the AMS-02 magnetic field is reconstructed from the position measurements along the 9 silicon layers of the tracking system, which provides a spatial resolution of 10 μm in the y (bending) view and 30 μm in the x (non-bending) view. From the reconstructed trajectory the particle direction and rigidity can be measured. The velocity $\beta = v/c$ can be determined from the transit time between the upper and lower TOF scintillator planes (with a resolution, for $Z = 1$, $\Delta\beta/\beta^2 \sim 2\%$), or more precisely using the RICH sub-detector (with a resolution, for $Z = 1$, $\Delta\beta/\beta \sim 10^{-3}$). The central part of AMS-02 is surrounded by an anti-coincidence system (ACC). The detector is completed with a Transition Radiation Detector (TRD), which is located between the first layer of the silicon tracker and the upper TOF, and a 18 layer electromagnetic calorimeter (ECAL), which is placed at the bottom.

3. – Results

3·1. *Leptons and antiprotons.* – The positron fraction and the antiproton-to-proton ratio are both shown in fig. 1 as a function of energy [3, 4], also compared with results from previous experiments [1, 2, 5, 6]. It can be seen that, in the low energy range ($\sim$ 0.5–10 GeV), the positron fraction decreases with energy as naively expected from standard models of secondary production. However, for energies above $\sim$10 GeV, the AMS-02

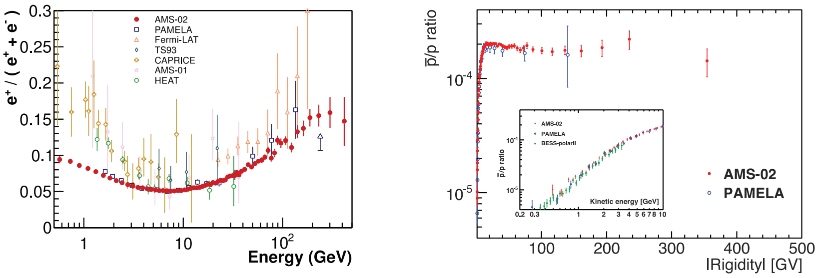

Fig. 1. – Left: the positron fraction measured by AMS-02, compared with previous measurements. Right: the $\bar{p}/p$ ratio measured by AMS-02, compared with previous measurements.

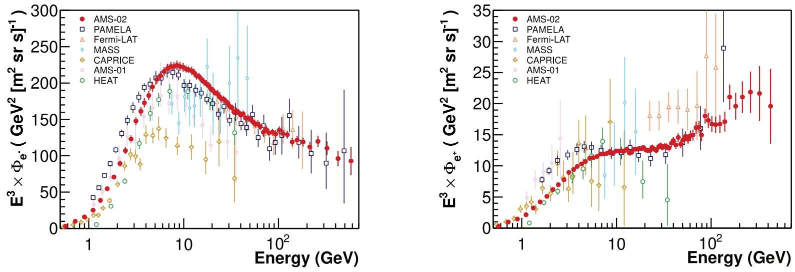

Fig. 2. – Left: the electron flux measured by AMS-02, compared with previous measurements. Right: the positron flux measured by AMS-02, compared with previous measurements. Both fluxes are multiplied by E^3.

data show an increase of the fraction up to 200 GeV, although the rise is flattening at $E \sim 200$–400 GeV. This behavior is in clear contrast with what expected by conventional CR propagation models [7] where positrons are only produced as secondary products of interactions of (mainly) high energy protons with the ISM. The separate e^+ and e^- fluxes are shown in fig. 2. The AMS data clearly highlights the different energy dependence of the two species, where the positron flux exhibits a significantly harder spectrum. This observation hints that the high-energy rise of the positron fraction is due to an excess of positrons and not to a deficiency of high energy electrons. More detailed studies on the $e^\pm$ spectral shapes are provided in ref. [8]. On the other hand the $\bar{p}/p$ ratio measured by AMS-02 shows no significant structure in energy, assuming an almost constant value above $\sim$40 GeV. The observed flatness of the $\bar{p}/p$ ratio is nevertheless very difficult to reproduce in the context of the conventional CR propagation models and could be a symptom of new physics as well as the rise in the positron fraction. It must be noted, however, that the theoretical predictions for the $\bar{p}/p$ ratio suffer from two large sources of systematic uncertainty: one is the limited knowledge of the $\bar{p}$ production cross-section at energies above 1 TeV, the other being the ability of CR propagation model to accurately model the CRs journey through the Galaxy. Although the latter problem can be solved by exploiting the simultaneous measurements of the CR hadronic species being performed by AMS-02, efforts are now beginning to appear from the collider experiments aiming to address the former problem as well [9].

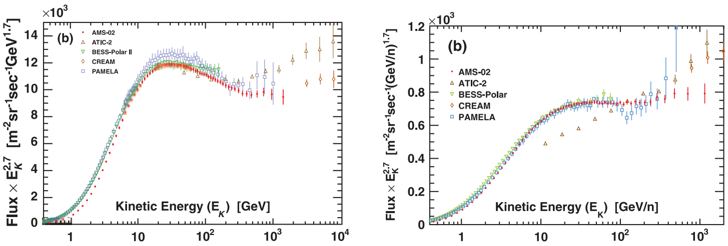

Fig. 3. – Left: the proton flux measured by AMS-02, compared with previous measurements. Right: the helium flux measured by AMS-02, compared with previous measurements. Both fluxes are multiplied by $E_k^{2.7}$

3˙2. *CR hadrons*. – The hadronic component of CRs holds valuable information on how CRs are accelerated and on how their energy spectrum is affected by the propagation in the galactic magnetic field. The most abundant species in CRs are hydrogen and helium, both of primary origin. The p and He fluxes measured by AMS-02 are shown in fig. 3 in the rigidity range from 1 GV to 1.8 TV and from 2 GV to 3 TV respectively [10, 11]. Similarly to what observed in the leptonic component, the hydrogen and helium fluxes show a unexpected and smooth change of the spectral index around ∼300 GV. Moreover hydrogen and helium have different spectral indexes, with a difference in value of $\Delta\gamma \sim 0.077$ with helium having a harder spectrum. Three kinds of interpretations have been suggested for these phenomena: diffusive shock acceleration mechanisms, propagation effects, or superposition of local and distant sources [12-14]. The origin of the CR spectral hardening (and its connection with the p/He spectral index difference) is an open question that may be resolved with high-energy data on light CR nuclei.

By measuring also secondary species, important information can be obtained about CR propagation, especially when the flux of a secondary species is divided by the flux of a primary species, preferably one of its progenitors. The most common example of such secondary-to-primary ratios is the B/C ratio, as measured by the AMS spectrometer in the energy range from 1.9 GV to 2.6 TV [15]. Unlike any of the other measurements presented in this contribution the B/C ratio does not show any significant spectral feature, but rather presents a smooth and continous power-law behaviour up to the highest energy with a spectral index of $\Delta = -0.333 \pm 0.014 \pm 0.005$.

Moreover the AMS Collaboration is currently working on the measurement of other primary (such as C, N, O) and secondary species (Li, Be, B) fluxes. Preliminary results shown at this conference indicate that the unexpected change of spectral index of p and He could be a feature shared by all primary species and by lithium as well.

4. – Conclusions

The main results from the AMS-02 experiment in the first 6 years of operation have been presented. AMS is adding to the already existing CR measurements a large amount of high precision data, improving in both accuracy and energy range with respect to its predecessors. Accurate multi-channel measurements of the CR energy spectrum are being performed by the Collaboration, with the future possibility of providing a deeper understanding of the Galactic CR physics.

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