IL NUOVO CIMENTO **42 C** (2019) 174
DOI 10.1393/ncc/i2019-19174-x

Colloquia: IFAE 2018

Measurements of the ^{3}He and D components in cosmic rays with the AMS-02 experiment

F. Dimiccoli(1), L. Basara(1), K. Kanishchev(1), F. Nozzoli(1)
and P. Zuccon(1)(2)

(1) *INFN-TIFPA, Trento Institute for Fundamental Physics and Applications Trento, Italy*

(2) *UNITN, Università degli studi di Trento, Dipartimento di Fisica - Trento, Italy*

received 31 January 2019

Summary. — The ^{3}He/^{4}He and D/p flux ratios in cosmic rays (CR) are two of the most valuable tools for understanding the propagation of CR in the galaxy and constrain the models that describe it. In this work, two new preliminary measurements of ^{3}He/^{4}He and D/p flux ratios are presented, each obtained from the data of the AMS-02 experiment.

1. – Light isotopic components in CR

The importance of the measurement of light isotopic components in CR like ^{3}He and D resides in their production by spallation reactions of primary CR protons and ^{4}He nuclei on the protons of the Inter Stellar Medium (ISM). The measurement of these components with respect to their respective primary particle can provide important constraints about the CR residence time within galaxy and their propagation history [1, 2]. Light isotopes originate from the spallation of heavier ones, for example ^{3}He nuclei are produced by the spallation of primary ^{4}He nuclei, and D from ^{3}He and ^{4}He. Another source of deuterons in CR is the p-p fusion in the CR collision with the ISM at extremely low energies (below $1\,\mathrm{GeV}/n$). The relative, secondary to primary, abundances provide additional and complementary information with respect to the commonest tool used for propagation studies, the B/C flux ratio. Given the smaller interaction cross-sections the two light isotopes probe different propagation distances and, in the deuteron case, the low energy threshold of the p-p fusion reaction makes the D/p ratio measurement useful to constrain propagation models at very low energies.

2. – The instrument: AMS-02

The Alpha Magnetic Spectrometer (AMS-02) [3-12] is a particle detector installed on the International Space Station, whose components include a solid-state Tracker for the determination of charge sign, charge value and rigidity, defined as $R = p/Z$ (where p is the particle momentum), a Time-of-Flight detector (ToF) and a Cherenkov detector (RICH) for particle velocity, a Transition Radiation Detector (TRD) and an Electromagnetic CALorimeter (ECAL) for hadron/lepton discrimination. The Tracker is composed by 7 layers inside the magnetic volume (inner Tracker), plus two external layers, one above the TRD and one in face of ECAL (respectively, L1 and L9). Thanks to its wide acceptance and privileged position above the Earth's atmosphere, AMS-02 has been providing compelling science, having collected more than 120 billions of charged CR since 2011. Data from published AMS-02 results are stored online in the ASI/SSDC cosmic-ray database [13].

3. – Light isotope distinction with AMS-02

The identification of D and ^{3}He isotopes from the respective dominant components (p, ^{4}He) is performed in AMS-02 with the concurrent measurement of rigidity and velocity, which, when combined, provide a mass measurement through the relativistic relation

$$m = ZR/\gamma\beta. \tag{1}$$

This mass separation is performed starting from $Z = 1$ and $Z = 2$ samples, obtained with charge identification at different levels within the detector. Additional selections have been implemented to reject most of the events suffering from interactions within the detector. The rigidity is measured by the inner Tracker, while the velocity by ToF and RICH. The resolution of ToF ($\sim$2%) allows isotopic distinction up to 0.85 GeV/n. At higher energies, AMS-02 RICH is used. This detector is equipped with two different radiators, sodium fluoride (NaF) and Aerogel (Agl), with different values of thresholds and resolutions, allowing isotopic distinction in the kinetic energy per nucleon range from 0.7 to 3.2 GeV/n and from 2.7 to 9 GeV/n for NaF and Agl, respectively.

In the combined range 0.2–8.9 GeV/n, the rigidity measurement has a resolution of 8%, which dominates the overall mass resolution. Such limited resolution prevents the event-by-event identification of isotopes and makes a template fit approach on the reconstructed mass distribution necessary for both analyses. In both cases, the separation is performed dividing each range into narrow bins of measured β, to exploit the higher precision of the velocity measurement and minimize migration effects. The results will be presented in kinetic energy per nucleon, obtained from β through this relation: $E_{kin}/n = (\gamma - 1)\frac{mass}{n}$, with $\gamma = \sqrt{\frac{1}{1-\beta^2}}$ and assuming as a constant the average nucleon mass, $\frac{mass}{m}$.

3·1. *Isotope separation.* – The templates for the separation of ^{3}He from ^{4}He have been fitted to the data using an analytical function describing the mass distribution obtained from the MC simulation. The analysis was performed in the RICH energy ranges. For the deuteron case, the templates have been obtained from MC simulations, tuned on both test beam and flight data to reproduce the mass distributions of the two isotopes. A selection based on multivariate analysis using Boosted Decision Trees (BDT) was developed to improve the signal-to-noise ratio in the mass region of interest. Both ToF and RICH energy mass distributions have been considered.

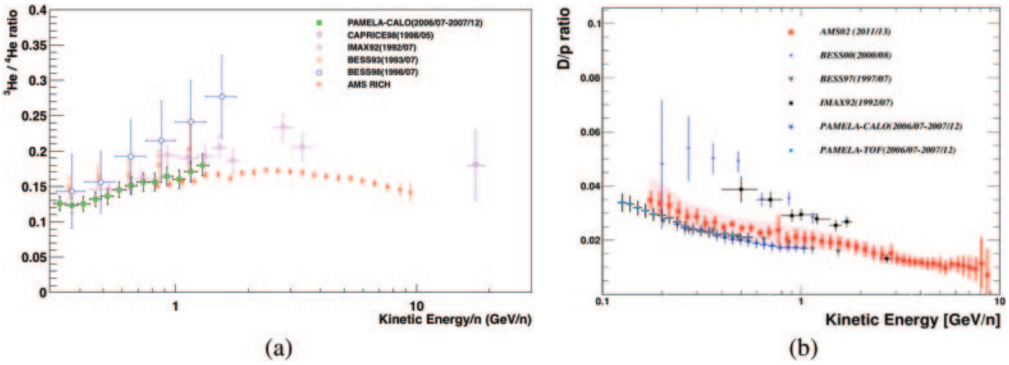

Fig. 1. – Preliminary measurements of ^{3}He/^{4}He (a) and D/p (b) flux ratios measured by the AMS-02 experiment, compared with previous measurements. The shaded area in (b) represents the preliminary (cautious) evaluation of the systematic error.

3˙2. *Evaluation of energy loss and fragmentation effects.* – These two effects have to be carefully evaluated to obtain the correct ratios at the Top Of Instrument (T.O.I.). The energy loss is caused by ionization within the detector before the inner tracker, mostly in TRD and ToF, and affects the measured energy dependence. The fragmentation regards the production of secondary nuclei of ^{3}He and D from the fragmentation of primary ^{4}He, mostly due to interactions in the external material of AMS-02. Each of the two effects was evaluated on MC simulations and then validated and cross-checked on flight data.

4. – Conclusions

The ^{3}He/^{4}He and D/p flux ratios in CR measured by the AMS-02 experiment extend in energy regions substantially uncharted by the previous observation, and present an accuracy of the order of few percent (fig. 1). The ^{3}He/^{4}He ratio was measured using AMS-02 RICH and covers the range 0.8–9 GeV/n, while for the D/p ratio also the AMS-02 ToF was used, covering the range 0.2–8.9 GeV/n. A study aimed to the reduction of the systematics related to the fragmentation within the AMS-02 detector is currently undergoing.

REFERENCES

[1] Coste B. *et al.*, *Astron. Astrophys.*, **539** (2012) A88.
[2] Tomassetti Nicola and Feng Jie, *Astrophys. J. Lett.*, **835** (2017) L26.
[3] Aguilar *et al.*, *Phys. Rev. Lett.*, **110** (2013) 141102.
[4] Accardo *et al.*, *Phys. Rev. Lett.*, **113** (2014) 121101.
[5] Aguilar *et al.*, *Phys. Rev. Lett.*, **113** (2014) 121102.
[6] Aguilar *et al.*, *Phys. Rev. Lett.*, **113** (2014) 221102.
[7] Aguilar *et al.*, *Phys. Rev. Lett.*, **114** (2015) 171103.
[8] Aguilar *et al.*, *Phys. Rev. Lett.*, **115** (2015) 211101.
[9] Aguilar *et al.*, *Phys. Rev. Lett.*, **117** (2016) 091103.
[10] Aguilar *et al.*, *Phys. Rev. Lett.*, **117** (2016) 231102.
[11] Aguilar *et al.*, *Phys. Rev. Lett.*, **119** (2017) 251101.
[12] Aguilar *et al.*, *Phys. Rev. Lett.*, **120** (2018) 021101.
[13] ASI/SSDC cosmic ray database `https://tools.ssdc.asi.it/CosmicRays/` (2018).