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Measurement of beryllium isotopic composition in cosmic rays with the AMS-02 experiment on the International Space Station

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Summary. — Cosmic rays are a powerful tool for the investigation of the structure of the magnetic fields in the galactic halo and of the properties of the Inter-Stellar Medium. Two parameters of the cosmic rays propagation models, the galactic halo (half-) thickness, H, and the diffusion coefficient, D, are loosely constrained by current cosmic rays flux measurements, in particular a large degeneracy exists being only H/D well measured. The ^{10}Be/^{9}Be isotopic flux ratio (thanks to the 2 My lifetime of ^{10}Be) can be used as a radioactive clock providing the measurement of cosmic rays residence time in the galaxy. This is an important probe to solve the H/D degeneracy. Past measurements of ^{10}Be/^{9}Be isotopic flux ratio in CR are scarce, limited to low energy and affected by large uncertainties. In this work, new preliminary measurements of ^{10}Be/^{9}Be and complementary ^{7}Be/Be flux ratios are presented, both obtained from the data of the AMS-02 experiment.

1. – Introduction

Cosmic Rays (CRs) are a powerful tool for the investigation of physics/astrophysics phenomena: high-energy CRs composition provides information on the galactic PeVatrons and the small anti-matter component in CR could reveal Dark Matter (DM) annihilations in our Galaxy.

Moreover, the structure of the magnetic fields in the galactic halo and the properties of the Inter-Stellar Medium can be probed by detailed CRs flux measurements. In particular the ratio of secondary CRs (as Li, Be, B) over the primary CRs (as He, C, O) allows to determine the *grammage*, that is the amount of material crossed by CRs in their journey through the Galaxy.

Two parameters of the CRs propagation models, the galactic halo (half-) thickness, H, and the diffusion coefficient, D, are loosely constrained by the *grammage* measurement, in particular a large degeneracy exists being only H/D well measured [1].

The uncertainties on D and H parameters (the latter is known to be in the range of 3–8 kpc) also reflects on the accuracy of the theoretical predictions for secondary antiproton and positrons fluxes that are the background for the DM or exotic (astro-)physics searches [2-4].

Abundances of long-living unstable isotopes in CRs can be used as a radioactive clock providing the measurement of CRs residence time in the Galaxy. This time information is complementary to the crossed *grammage*, thus the abundance of radioactive isotopes in CRs is an important tool to solve the existing H/D degeneracy in CR propagation models.

Only few elements in cosmic rays, namely Be, Al, Cl, Mg, Fe, contain long-living radioactive isotopes. Among them the beryllium is the lighter, thus the most promising for a measurement of isotopic composition in the relativistic kinetic energy range.

Three beryllium isotopes are found in cosmic rays:

- ^{7}Be: stable as bare nucleus in CRs. It decays by electron capture ($T_{1/2} = 53$ days).
- ^{9}Be: stable.
- ^{10}Be β-radioactive nucleus ($T_{1/2} = 1.39 \times 10^6$ y).

In the following, a preliminary measurement of beryllium isotopes with the Alpha Magnetic Spectrometer (AMS-02) on the International Space Station (ISS) is presented.

2. – The identification of beryllium isotopes with AMS-02

The AMS-02 detector (fig. 1, left) includes a permanent magnet (0.14 T) surrounding a microstrip silicon Tracker for the determination of charge sign, charge value, and rigidity $R = p/Z$ (where p is the particle momentum); a Time-of-Flight detector (ToF) and a Cherenkov detector (RICH) for particle velocity measurement; a Transition Radiation Detector (TRD) and an Electromagnetic CALorimeter (ECAL) for hadron/lepton discrimination. The inner Tracker consists of 7 layers within the magnetic bore and

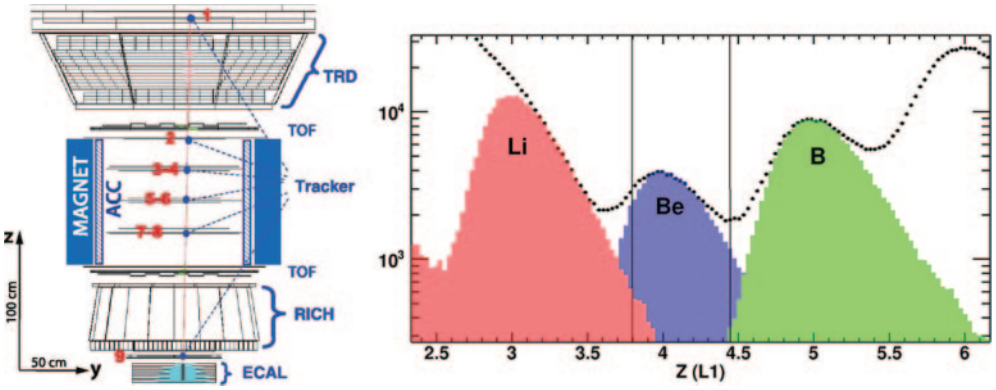


Fig. 1. – Scheme of the AMS-02 detector. From the top, tracker first layer (1), TRD, upper ToF, inner tracker layers (layer 2 to layer 8), lower ToF, RICH, tracker layer 9 and ECAL. Sixteen curved scintillator panels (AntiCoincidence Counters, ACC) surround the inner tracker inside the 0.14T magnet bore. On the right plot: example of the charge distribution measured by Tracker layer 1. Vertical lines represent the applied selection on this variable.

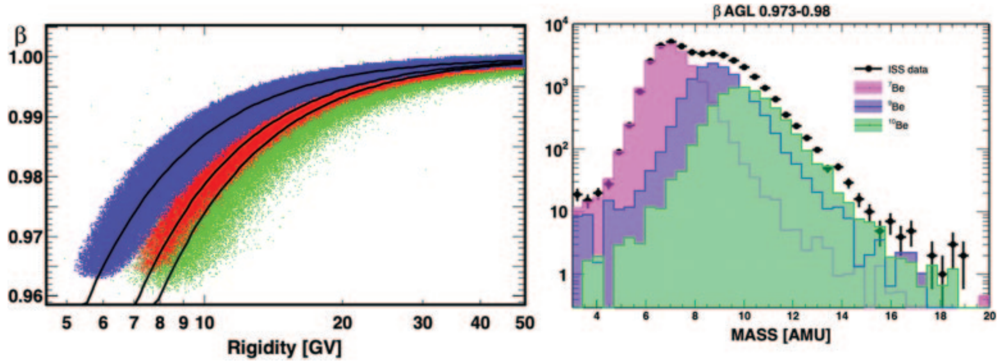
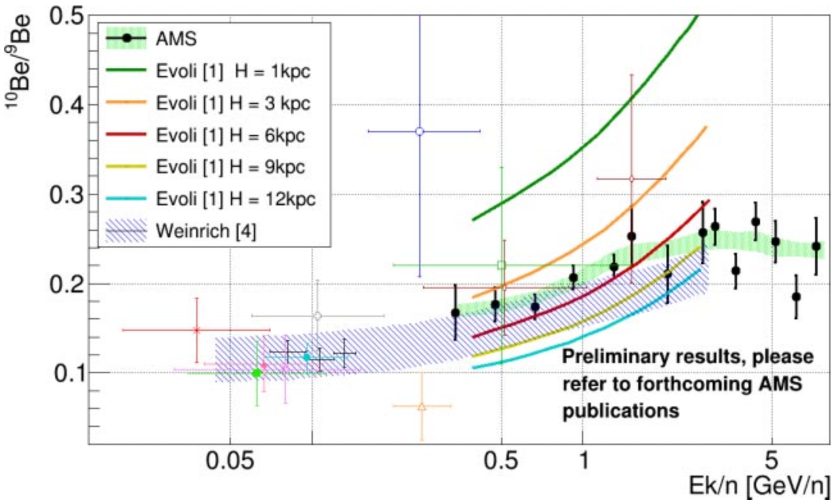


Fig. 2. – Left panel: distribution of reconstructed β *vs.* R for RICH-Agl for the three Monte Carlo samples (^{7}Be in blue, ^{9}Be in red and ^{10}Be in green) while the solid black lines are the theoretical curves. Right panel: result of one template fit procedure for the 0.973–0.98 β-bin of the Agl detector. This plot shows the isotope templates, obtained by the MC simulation, scaled according to the fit results. Black points are the beryllium mass distribution obtained from flight data.

of two outermost layers placed one above the TRD and one above the ECAL (L1 and L9, respectively). The identification of beryllium isotopes is performed in AMS-02 with the combined measurements of R and velocity ($\beta = v/c$) (see fig. 2), which provide a mass measurement through the relativistic relation: $m = ZR/(\gamma\beta)$. The identification of beryllium is performed starting from a sample of $Z = 4$ nuclei (see fig. 1, right), obtained with redundant charge measurement performed by all the inner Tracker layers plus layer 1, and by the ToF planes. By applying all the charge selections the contamination within AMS-02 of the Be sample is below 0.1%. Additional selections were implemented to reject most of events undergoing interactions within the detector. The rigidity is measured by the inner Tracker, while the velocity by the ToF and the RICH. The resolution of the ToF ($\sim 2\%$) allows isotopic separation up to 1.6 GeV/n. At higher energies, the AMS-02 RICH system is used. This detector is equipped with two different radiators, sodium fluoride (NaF) and aerogel (Agl), with different thresholds and resolutions, allowing isotopic separation in the range of kinetic energy per nucleon (E_k/n) from 1.3 to 2.9 GeV/n and from 2.4 to 8.4 GeV/n for NaF and Agl, respectively. In the combined 0.3–8.4 GeV/n range, the rigidity is measured with a $\sim$10% resolution, which dominates the overall mass resolution. Such limited resolution does not allow the event-by-event identification of isotopes, thus a template fit approach on the reconstructed mass distribution (fig. 2, right) is applied. For Be isotopes, the mass templates have been obtained from Monte Carlo (MC) simulations which were tuned on test beam and flight data. The analysis is performed in narrow bins of measured β to exploit the higher precision of the velocity measurement and minimise bin migration effects. The results are presented in terms of E_k/n, obtained from β through the relation: $E_k/n = (\gamma - 1)\frac{M}{n}$, with $\gamma = \sqrt{\frac{1}{1-\beta^2}}$ and assuming the average nucleon mass, $\frac{M}{n} \simeq 0.9315$ GeV, as a constant.

3. – Result and conclusions

A sample of 490k Be events from 7 years of AMS-02 data was selected. As a consequence of small acceptance differences for ^{7}Be, ^{9}Be and ^{10}Be isotopes a correction, based



Preliminary results, please refer to forthcoming AMS publications

Fig. 3. – Preliminary measurement of ^{10}Be/^{9}Be flux ratio *vs.* nucleus kinetic energy compared with previous experiments and theoretical predictions [1,4]. The green band indicates the overall systematic uncertainty.

on Monte Carlo simulation, must be applied to the template fit results. In particular, a correction of $\sim$ 8% of ^{7}Be/Be is necessary to account for the relatively larger acceptance of ^{7}Be in the measured kinetic energy range: this is mainly due to the relatively smaller nucleus cross section. Conversely, the effect of the acceptance correction in the ^{10}Be/^{9}Be flux ratio is negligible in the measured kinetic energy range. The effect of the residual contamination due to fragmentation of heavier elements yielding beryllium nuclei in the material above Tracker L1 was estimated with a realistic MC sample of B, C, N and O nuclei. This effect was accounted for by applying a correction of $\sim$ 10% to ^{10}Be/^{9}Be and $\sim$ 2% to ^{7}Be/Be flux ratios. The preliminary measurement of ^{10}Be/^{9}Be flux ratio is shown in fig. 3 and compared with the previous experiments and theoretical expectations. The green band represents the systematic uncertainty conservatively evaluated as 50% of the applied corrections to the flux ratio. In conclusion, with the large exposure and acceptance provided by the AMS-02 experiment it is possible to extend the measurement of ^{10}Be/^{9}Be up to 10 GeV/n with a sizeable reduction of uncertainties. This will allow a more refined knowledge of CR propagation parameters, in particular of the halo thickness.

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