PROCEEDINGS OF SCIENCE

Cosmic-Ray Beryllium Isotopes with AMS02

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Beryllium nuclei are expected to be mainly produced by the fragmentation of primary cosmic rays (CR) during their propagation. Therefore, their measurement is essential in the understanding of cosmic ray propagation and sources. In particular, the ^{10}Be/^{9}Be ratio can be used as a radioactive clock providing the measurement of CR residence time in the Galaxy. In this contribution, the measurement of the ^{7}Be, ^{9}Be, and ^{10}Be fluxes and ratios based on data collected by AMS are presented.

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1. Overview

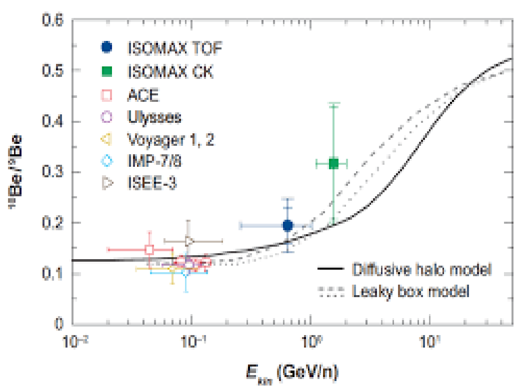
Cosmic rays (CR) can be divided into two categories: primary species, which arrive at us directly from their acceleration sites, and secondary species, which originate from reactions of heavy primaries (C,N,O) with the inter-stellar medium (ISM), which is mainly composed by p and He ([1], [2]).

In the standard picture, th CRs are originated from SuperNovae (SN) explosions and successively they gain energy through Fermi acceleration mechanism [1] whereas their propagation in the galaxy occurs through a diffusion-like mechanism on the irregularities of the magnetic field within the Galaxy where they interaction with the particles of the ISM takes place, along with the production of secondary species. The CR transport is often described in terms of the grammage, χ, that is a measurement expressing the amount of material that the particle goes through in its propagation during the confinement time of CR in the Galaxy.

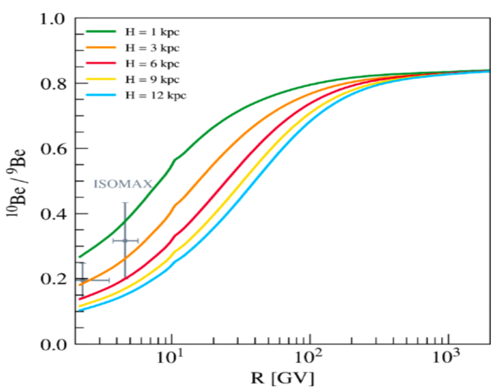
A very powerful probe for the grammage measurement is the secondary-to-primary ratio in CR. Indeed, since they are generated by spallation interactions during the propagation, the abundance of secondaries over the relative primaries from which they descend is sensible to the ISM composition and to the amount of interactions suffered in their journey and therefore to the total material path length they covered before they reach the Earth. For such reason, the abundance of secondary particles to primary particles is uniquely connected to propagation processes and thus the flux ratios B/C,Be/C, B/O,$^3He/^4He$, d/p have become standard tools over the past years to study propagation models and determining the key parameters of those models (Strong et al. 2007).

In CR we expect the presence of three Beryllium isotopes: ^{7}Be, ^{9}Be and ^{10}Be. The first decays only by electron capture (half-life 53 days), thus the half-life in space depends on the electron density and the galactic CR lifetime. ^{9}Be is stable, but ^{10}Be β-unstable and it decays to ^{10}B with a half-life of 1.39My. Thanks to its lifetime it is possible to exploit the measurement of the abundance of this last isotope as a radioactive clock.

Since ^{9}Be and ^{10}Be are produced in the ISM with more or less the same cross section, the ratio



(a)



(b)

Figure 1: Prediction of ^{10}Be/^{9}Be ratio from popular propagation models (a) and its sensibility to H parameter (b), along with current measurements

of ^{10}Be to stable ^{9}Be is entirely determined by the propagation history of the cosmic rays. This can provide important orthogonal information with respect to the tools commonly used for such studies, like Be/B, Be/C and Be/O ratios. A direct measurement of ^{10}Be/^{9}Be as a function of kinetic energy would be a fundamental further constrain parameter to discriminate between propagation models, but so far very sparse measurements at extremely low energy are available (fig. 1).

Another important motivation regards the indirect search for Dark Matter (DM) studies. The rise in the positron fraction measured by several experiments including AMS-02 [3] can be interpreted as a very promising signature for DM annihilation, but so far this rise can be explained by the production of antimatter from exotic sources like nearby pulsars, even without considering the uncertainty on the propagation parameters that still persists. For this reason, a precise and independent knowledge of the propagation parameters that can be obtained from the isotopic study of Be flux is needed for identifying new physics effects or ruling out wrong models. The right panel of fig. 1 shows the sensitivity of the ^{10}Be/^{9}Be measurement to a particular parameter, the width of the DM galactic halo (H). That is a very important parameter since it is closely related to the diffusion coefficient D. The ratio H/D is proportional to the grammage, which means that with common measurements of ratios like B/C we can only constrain the ratio of these two key parameters that are thus degenerate in many propagation models. Allowing to measure independently the residence time of CR in the Galaxy, radioactive clocks like ^{10}Be/^{9}Be can give the chance of a direct measurement of the spatial dimension H, giving the opportunity of disentangling H and D, which would be of capital importance in the general knowledge of the propagation of CRs.

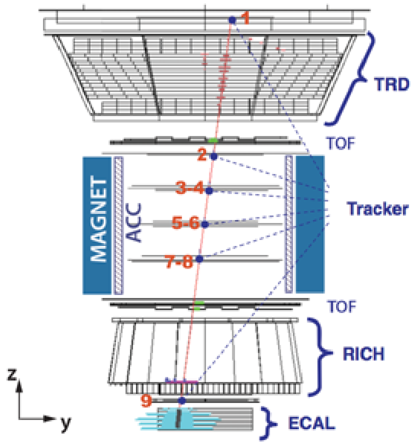


Figure 2: Scheme of the AMS spectrometer: the Tracker system measures R; ToF, RICH-NaF and RICH-Agl measure β

2. AMS-02

The AMS-02 magnetic spectrometer has proven to be one of the best instruments for the precision measurement of the CR and it is providing compelling science since its installation on ISS on May 2011 [4].
In fig. 2 a scheme of the Alpha Magnetic Spectrometer and the sub-detectors is shown. The rigidity R, which is defined as the ratio between the momentum and the electric charge, is measured by the Silicon Tracker, made up by 9 layers, 7 of which inside the magnetic volume forming the so-called Inner Tracker. The particle velocity (β) is measured independently by a Ring Imaging CHerenkov Counter (RICH) made up by NaF and Aerogel (AgL) radiators and by the Time of Flight detector (ToF), which also provide the main trigger for th whole experiment.

A Transition Radiation detector (TRD) and an electromagnetic Calorimeter (ECAL) allow high energy e-p discrimination.

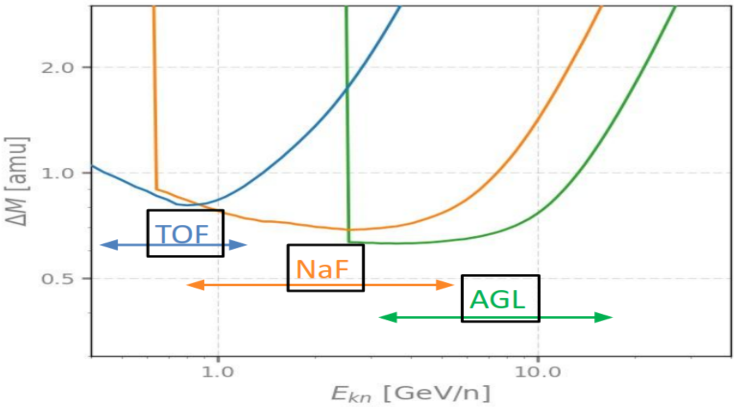


Figure 3: AMS-02 Mass resolution for Beryllium nuclei, using its different velocity-measuring sub-detectors.

3. The Analysis

The purpose of this analysis is the measurement the isotopic composition in the Beryllium flux as a function of kinetic energy.

In a magnetic spectrometer like AMS-02 isotopic distinction is obtained through the calculation of mass from measurement of R and β following the relativistic relation

$$m = \frac{qR}{\beta\gamma} \Rightarrow \frac{\Delta M}{M} = \sqrt{(\frac{\Delta R}{R})^2 + \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2} \tag{1}$$

The β-measuring sub-detectors cover different (partially overlapping) energy ranges with different resolutions. A preliminary work was carried out to determine such resolutions, aimed to establish which energy ranges guarantee the best mass measurement. Rigidity resolution is instead pretty constant towards the range in which velocity can be measured with good resolution. A key point in the analysis is to achieve a mass resolution optimization by applying quality selections that ensure good reconstruction of the track, out of which velocity and rigidity are reconstructed. The total amount of Beryllium in cosmic rays is very small, therefore the optimization of selections had to take into account an optimal compromise between efficiency and precision, even if the long duration of AMS mission and the high acceptance of the detector makes this task easier. In figure 3 the global mass resolution obtained after the data selection devised for this analysis is shown. it stands out that mass resolution for Beryllium is always $\gtrsim$1 AMU, preventing the event-by-event identification and making necessary a template-fit type analysis in order to extract the isotopic composition from the Be mass distribution in each range.

The mass Templates are obtained through a dataset created by a GEANT4 simulation based on Monte Carlo algorithm available to AMS collaboration. To show the energy dependence of the Be isotopic composition as a function of CR energies, we divided both the actual and the simulated datasets in several kinetic-energy-per-nucleon intervals (bins) and fit the mass distribution for each bin.

Building the mass template from the simulation is convenient because on the simulated dataset the "true" (generated) rigidity is accessible, thus one can take into account bin-to-bin migration due to rigidity and β responses and build them in directly in the template.

From simulated templates also detector acceptance can be deduced since is possible to count how many simulated events actually end up in the template and compare that number with the number of generated ones. Such "MC" acceptance was then validated and corrected using real Berillium datasets obtained with different selection sets without distinguishing between isotopes. The selections were chosen to be at first approximation independent to each other, so it was possible to obtain multiplicative correction factors to the acceptance for each of them. All the corrections obtained in this data-driven way are at the percent level. Acceptance corrections are believed to be the same for every isotope, while the "baseline" acceptance was calculated independently for the three isotopes, in order to take into account the different fragmentation probabilities of the three within the detector. In fig. 4 a typical example of mass fit in a particular kinetic energy bin is shown, with its three isotopic contributions.

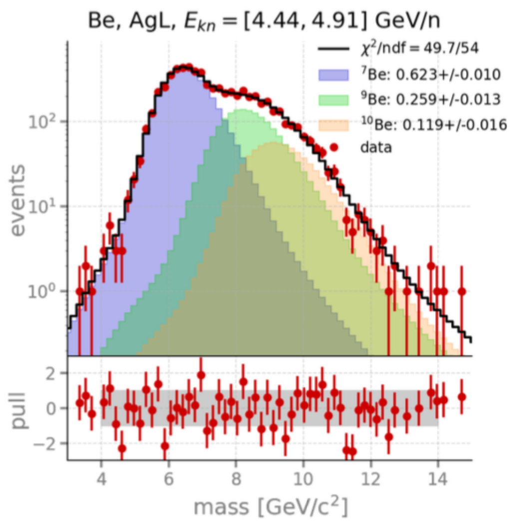
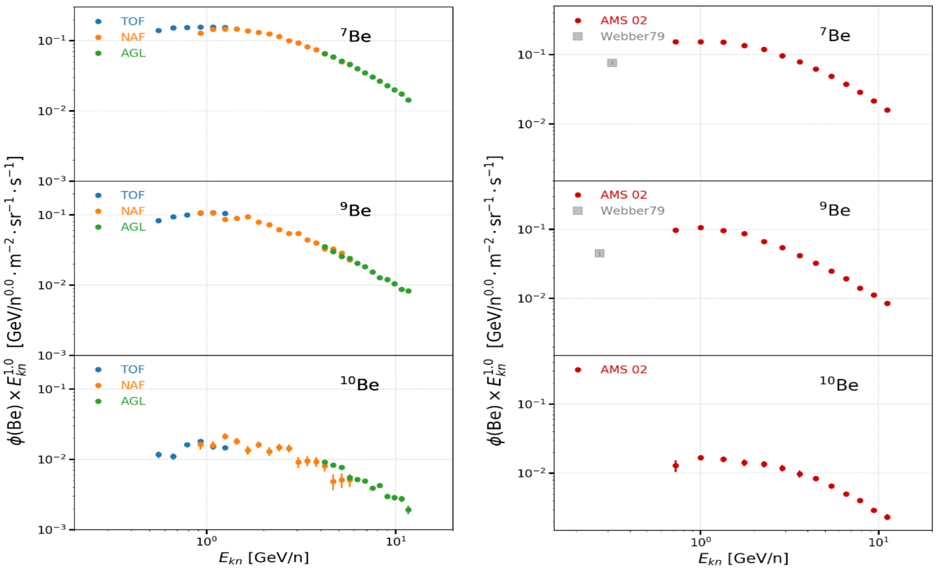


Figure 4: Typical fit of a Berillium slice distribution obtained in one slice of measured β

AMS-02 data are provided with a timestamp and an evaluation of the experiment "busy" status, from which is possible to calculate the livetime of the experiment to normalize the counts extracted from the fits and get the measured rate for every isotope. Dividing it by the corrected acceptance gives a measurement of the flux as a function of kinetic energy per nucleon.

The left plot of fig. 5 shows the fluxes of the three Beryllium isotopes measured in this way, using the data coming from the three different velocity-measuring sub-detectors. Statistical errors only were shown for these data. To evaluate a full estimation of systematic error, an analysis of the full covariance matrix was performed, important to describe the correlation between energy bins and different isotopes. Several sources of systematic uncertainty were considered: on acceptance correction, on mass fit, on higher charges background subtraction, and on survival probability of Be. For ^{10}Be, the most important ones are the uncertainties on survival probability, mass fit and background subtraction, reaching values of few percent (up to $\sim$ 10)and competing with statistical error as main source of uncertainty. For the other isotopes, every error is close to the percent level or below. The right plot of fig. 5 shows the final results with the complete estimation of error regarding the fluxes of the three Beryllium isotopes. The fluxes measured by the three sub-detectors were rebinned and merged to obtain a single estimation of the flux as a function of kinetic energy. In conclusion, fig. 6 shows the current status of ^{10}Be/^{9}Be and ^{9}Be/^{10}Be measurements compared with the results available in literature from precedent experiments. From the plots appears clear the fact that thanks to AMS-02 it is possible to chart completely un-explored energy regions for this measurement, with unprecedented precision.



(a) (b)

Figure 5: In the left panel, raw measurement of Be isotopes fluxes in each of the energy ranges selected for the analysis (stat. only error). In the right panel final merged result with complete error evaluation.

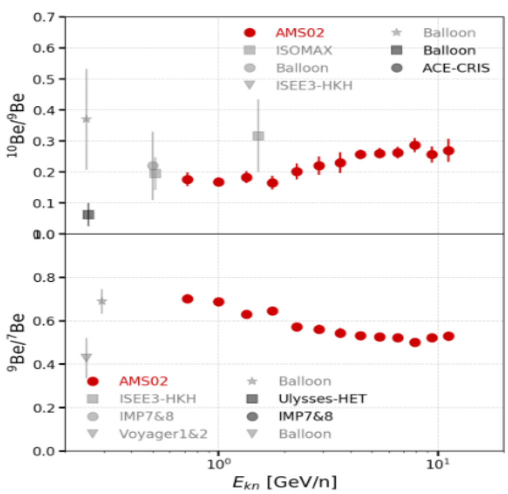


Figure 6: Measurements of Be isotope ratios as a function of kinetic energy compared with precedent experiments.

4. Conclusions

The isotopic composition of Beryllium in cosmic rays is a key measurement to understand the CR origin and propagation. in particular, the relative abundance of the slowly decaying ^{10}Be isotope can be used as a tool to estimate independently the residence time of CR in the Galaxy, and through this give important constraints on other fundamental parameters of the CR propagation models, like D and H. A Dedicated method based on simulated mass templates is used to fit the event rates vs mass to measure the isotopic fluxes. A measurement of Beryllium isotopic fluxes and ratios between 0.4 GeV/n and 11 GeV/n with systematic errors and associated covariance matrices has been presented, spanning over 9+ years of continuous data-taking by the AMS-02 experiment. Such measurement provides precise data, exploring uncharted energy range by previous experiments.

References

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