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Measurement of Lithium and Beryllium cosmic-ray abundances by the PAMELA experiment

E. Vannuccini[6], **N. Mori**[*5,6], **O. Adriani**[5,6], **G. C. Barbarino**[7,8], **G. A. Bazilevskaya**[9],**R. Bellotti**[10,11], **M. Boezio**[2], **E. A. Bogomolov**[12], **M. Bongi**[4,6], **V. Bonvicini**[2], **S. Bottai**[6], **A. Bruno**[10,11], **F. Cafagna**[11], **D. Campana**[8], **P. Carlson**[13], **M. Casolino**[3,15], **G. Castellini**[16], **C. De Donato**[3], **C. De Santis**[14], **N. De Simone**[3], **V. di Felice** [3,4] **V. Formato**[1,2], **A. M. Galper**[17], **A. V. Karelin**[17], **S. V. Koldashov**[17], **S. Koldobskiy**[17], **S. Y. Krutkov**[12], **A. N. Kvashnin**[9], **A. Leonov**[17],**V. Malakhov**[17], **L. Marcelli**[14], **M. Martucci**[14,18], **A. G. Mayorov**[17], **W. Menn**[16], **M Merge'**[3,14], **V. V. Mikhailov**[17],**E. Mocchiutti**[2], **A. Monaco**[10,11], **R. Munini**[1,2], **G. Osteria**[8], **F. Palma**[3,14], **B. Panico**[8] **P. Papini**[6], **M. Pearce**[13], **P. Picozza**[3,14], **M. Ricci**[18], **S. B. Ricciarini**[16], **R. Sarkar**[2], **V. Scotti**[7,8], **M. Simon**[19], **R. Sparvoli**[3,14], **P. Spillantini**[5,6], **Y. I. Stozhkov**[9], **A. Vacchi**[2], **E. Vannuccini**[6], **G. Vasilyev**[12], **S. A. Voronov**[17], **Y. T. Yurkin**[17], **G. Zampa**[2], **N. Zampa**[2], **M. S. Potgieter** [21], **E.E. Vos** [21].

[1] *University of Trieste, Department of Physics, I-34147 Trieste, Italy*
[2] *INFN, Sezione di Trieste I-34149 Trieste, Italy*
[3] *INFN, Sezione di Rome "Tor Vergata", I-00133 Rome, Italy*
[4] *Agenzia Spaziale Italiana (ASI) Science Data Center, I-00044 Frascati, Italy*
[5] *University of Florence, Department of Physics, I-50019 Sesto Fiorentino, Florence, Italy*
[6] *INFN, Sezione di Florence, I-50019 Sesto Fiorentino, Florence, Italy*
[7] *University of Naples "Federico II", Department of Physics, I-80126 Naples, Italy*
[8] *INFN, Sezione di Naples, I-80126 Naples, Italy*
[9] *Lebedev Physical Institute, RU-119991, Moscow, Russia*
[1]0 *University of Bari, Department of Physics, I-70126 Bari, Italy*
[11] *INFN, Sezione di Bari, I-70126 Bari, Italy*
[12] *Ioffe Physical Technical Institute, RU-194021 St. Petersburg, Russia*
[13] *KTH, Department of Physics, and the Oskar Klein Centre for Cosmoparticle Physics, AlbaNova University Centre, SE-10691 Stockholm, Sweden*
[14] *University of Rome "Tor Vergata", Department of Physics, I-00133 Rome, Italy*
[15] *RIKEN, Advanced Science Institute, Wako-shi, Saitama, Japan*
[16] *IFAC, I-50019 Sesto Fiorentino, Florence, Italy*
[17] *National Research Nuclear University MEPhI, RU-115409 Moscow*
[18] *INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati, Italy*
[19] *Universität Siegen, Department of Physics, D-57068 Siegen, Germany*
[20] *INFN, Sezione di Perugia, I-06123 Perugia, Italy*

E-mail: vannuccini@fi.infn.it mori@fi.infn.it

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The PAMELA experiment is collecting particles along a low Earth semi-polar orbit on board of Resurs-DK1 satellite since June 2006. The combined information of a silicon tracking system and a scintillator hodoscope provides redundant light-element identification capabilities, via multiple ionization energy-loss measurements. The instrument design is not optimized for nuclei detection, whose high ionization signal progressively saturates the detectors. However, Li and Be nuclei can still be identified by using the full set of information, which allows to efficiently select the two elements against the background of more abundant elements. The main issues of the analysis aiming to optimize the Li and Be selection are discussed in this paper. Preliminary results on the elemental abundances will be presented at the conference.

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*Speaker.

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1. Introduction

Li, Be and B in cosmic rays represent the lightest group of elements being of almost pure secondary origin. According to measurements, their relative abundance exceed that observed in ordinary matter by more than four order of magnitude and this is commonly interpreted as the effect of nuclear fragmentation of heavier nuclei during propagation from cosmic-ray sources to Earth. Among them, B is mainly produced by fragmentation of C, which instead originates almost entirely from the acceleration sites. This simple scheme of a single primary species going into a single secondary one makes the measured B/C ratio the strongest constrain to propagation parameters. Many measurements are available for the B abundance and propagation models are tuned to match the observed B/C ratio. Differently from B, a non-negligible fraction of Li and Be is of tertiary origin, being produced by further fragmentation of secondary Be and B. On one hand, this characteristic makes the knowledge of their abundance a complementary tool to tune propagation parameters, helping in removing parameter degeneracy and giving a more detailed description of the galactic propagation process. On the other hand, the interpretation of Li and Be abundances requires the knowledge of a complex chain of nuclear reactions, whose cross sections are still affected by large uncertainty. Thus, the constraint that the measurement of Li and Be abundances can provide to propagation models is still limited and as a matter of fact the available measurements of Li and Be species are scarce. The PAMELA experiment [2, 3] has recently measured the spectra of B and C, as well as the B/C ratio, in the kinetic energy range 0.44 - 129 GeV/n [1]. In this paper we present the analysis that is being carried out to measure the Li and Be absolu abundances. Preliminary results will be presented during the conference, while the measurement of the isotopic composition is described elsewhere in this proceeding collection [**?**].

2. The PAMELA instrument

The PAMELA main detector is a magnetic spectrometer made by a tracking system placed inside the magnetic field generated by a permanent magnet. The tracking system consists of six double-sided silicon microstrip tracking layers; the readout pitches for the X (bending) and Y views are 51 μm and 66.5 μm, respectively. The intensity of the magnetic fi

eld at the centre of the magnetic cavity is 0.46 T. The main aim of the tracking system is to measure the magnetic rigidity $R = pc/Ze$ of the impinging primary particle and the sign of the electric charge, from which antimatter can be discerned from matter. The instrument trigger is provided by the Time-Of-Flight (TOF) system. It is composed by six layers of plastic scintillating pads arranged in three X-Y layers, two of them (named S1 and S2) above the tracking system and the third (S3) below it. The TOF also measures the particle velocity, with a resolution of 250 ps for singly-charged particles and 70 ps for carbon. The six Si layers of the tracking system plus the six layers of TOF scintillators provide redundant information for electric charge determination, via multiple ionization measurements. The tracking system and the TOF are shielded by an anticoincidence system made by plastic scintillators, which allows interacting events producing secondary particles to be rejected during the off-line analysis. A silicon-tungsten sampling electromagnetic calorimeter is placed below S3. It is made of 22 modules, each composed by two single-sided silicon strip detectors encompassing a tungsten converter layer. The readout pitch of the strips is 2.44

mm and the total depth is 16.3 X0. The calorimeter provides a direct measurement of the energy of electrons and positrons. Due to its segmentation a lepton/hadron rejection power of about 105 by means of topological shower analysis can be achieved. The rejection power is further improved by a tail-catcher scintillator and a neutron detector, both placed below the calorimeter. For a detailed description of the PAMELA instrument and its performance see [2].

3. Data analysis

3.1 Track reconstruction

One of the main instrumental issue for the reconstruction of nuclei events by PAMELA instrument, which is specifically designed for singly-charged particle measurements, is the fact that tracking-system detectors saturate. This effect has two consequences: a degradation of the spatial resolution, and a degradation in the element separation based on multiple dE/dx measurements by the Si sensors. The former effect is accounted for by replacing the standard centre-of-gravity position-finding algorithm, used for low-Z particles, with an unweighted average over the saturated strips only (usually not more than two) and by assigning to saturated hits a consistently lower weight during the track fitting procedure. The net effect is a reduction of the MDR, which for Li is still consistent with the low-Z particle value, while for Be is reduced by about 50%. In order to reconstruct nuclei events, a dedicated track-finding algorithm is applied to data (see reference [1] for more details): first, all hits with energy deposit below 5 MIP are removed, hence the track-finding algorithm is applied to remaining hits. This procedure allows to efficiently recognize the tracks generated by high-Z particles, by cleaning the pattern from spurious hits generated by delta rays. Then, events with a single fitted track in the spectrometer are considered and standard quality cuts are applied: a minimum of 4 and 3 position measurements associated to the track, on the bending and non-bending views respectively, and a rigidity-dependent upper limit on the resulting χ^2. The tracking efficiency can be evaluated in flight by selecting clean samples of Li and Be on the basis of the independent TOF and calorimeter information, by requiring a reliable β measurement and by putting constraints on the energy deposits in S1, S2 and in the first Si plane of the calorimeter. From preliminary evaluation, the measured efficiencies for Li and Be resulted to be consistent within each other.

3.2 Charge identification

Due to different characteristics (e.g. strip layout) of the junction and ohmic sides of the Si sensors, the X and Y views of the tracking detectors manifest the saturation regime for different values of the energy deposit, having the latter a higher saturation threshold. Fig.1 shows the average ionization energy-deposit for the Y view, as a function of $1/\beta$, where β is measured by the TOF system, for a sample of events reconstructed with the nuclei tracking algorithm. The choice of a dE/dx-vs-β selection is dictated by the fact that (1) if the specific energy loss is expressed as a function of different isotopes of the same element populate the same bands and (2) has approximately a Gaussian spread. In order to maximize the element separation, quality constraints have been applied to the the reconstructed β (about 95%-efficiency cut). The two lower bands in Fig.1 are highly-ionizing low-energy protons and He nuclei, respectively, being the latter the most

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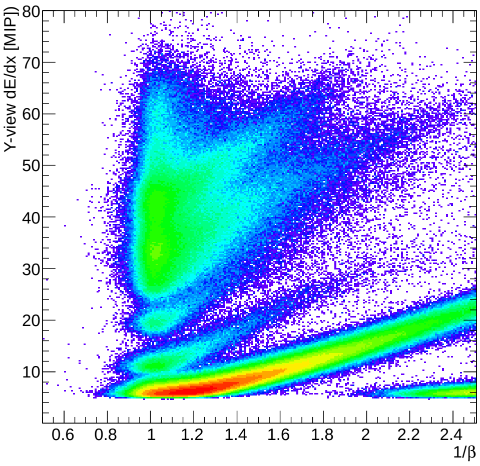

Figure 1: Average dE/dx in the tracking system evaluated by using hits from the ohmic side (Y view) of the Si sensors, as a function of the inverse of the velocity β measured by the TOF system, for a sample of tracks reconstructed by the nuclei tracking algorithm.

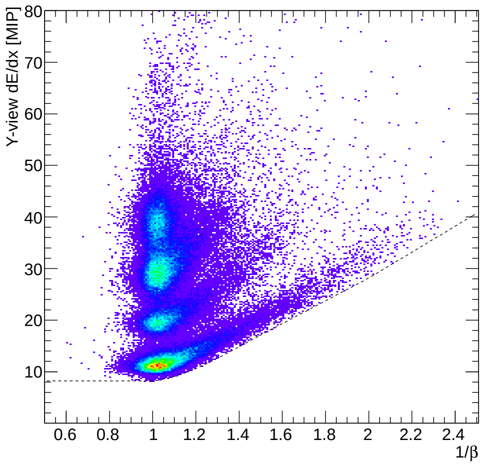

Figure 2: Same quantitities as in Fig.1, after the saturated hits are escluded from the average dE/dx evaluation and after a lower cut (dashed line) is applied on a hit-by-hit basis. The surviving events are distributed in bands that corresponds, from bottom to top, to Li, Be, B and C nuclei.

populated species, since most protons are removed from this sample by the 5 MIP cut described in section 3.1. The saturation progressively affects the dE/dx measurement for increasing energy deposits and practically prevents the identification of elements for values roughly above 25 MIP. For this reason, B and C analysis has been carried out by selecting the elements with the TOF scintillators only (see ref [1] for details). Li and Be are instead detected in an intermediate regime, where not all the hits are saturated, depending on fluctuations in the energy deposit, multiplicity of the cluster of hit strips and specific saturation threshold of the involved electronic channels. In order to minimize the effect of saturation in the ionization-energy measurement, the average dE/dx have been evaluated by excluding the saturated hits. An additional lower cut (dashed line) to the dE/dx has been also applied on a hit-by-hit basis, to cut down the He background. The resulting distribution is plotted in Fig.2. After the exclusion of saturated hits the number of surviving nuclei progressively reduces, but Li and Be can still be efficiently identified by defining proper selection bands in the dE/dx-vs-β plane. The Li and Be selection has been further constrained by applying cuts on the energy deposit measured in the lower layer of the top TOF scintillator (S1), aiming to clean the selected Li and Be samples from events where heavier nuclei interact in the material above the tracking system and are identified as Li and Be within the spectrometer and from residual background of misidentified nuclei due to fluctuation in energy deposits. The information from the upper S1 layer, from both the S2 layers and from the first Si plane of the calorimeter can instead be used to select pure samples of Li and Be traversing the apparatus without interacting, in order to cross-check the charge-selection and to measure efficiency and contaminations. From preliminary evaluation, the charge selection efficiency is of the order of 90% for both Li and Be above few GVs, for the combined constraints on the energy deposit in the S1 lower layer and in the tracking-system planes. In spite of the different ionization energy deposits for the two elements, the similar charge-selection efficiency found for Li and Be is due to two compensating requirements: the hit-by-hit He-suppressing lower cut on the energy deposits, which affects Li selection more than Be, and the exclusion of saturated hits from the dE/dx average, which affects Be more than Li.

4. Conclusions

The PAMELA identifcation capabilities for Li and Be has been illustrated. These nuclei species are detected by the tracking system in a partially-saturated regime. However, both the tracking resolution and the charge separation based on multiple dE/dx measurements by the tracker Si-sensors are good enough to measure their absolute abundances up to high energy. In particular, for Li and Be identification the full redundant set of dE/dx measurements provided by the PAMELA apparatus (TOF, tracking-system and calorimeter) can be used, with minor consequences due to tracking-system Si-detector saturation, to cleanly select these rare secondary elements against a large background of other particles. The analysis is still under progress. Preliminary results on Li and Be absolute abundances will be presented at the conference.

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