Abstract. Launched on the 15th of June 2006, the space experiment PAMELA is providing data showing interesting features in cosmic rays that might change our basic vision of the mechanisms of production, acceleration and propagation of cosmic rays in the galaxy. In addition, PAMELA measurements of cosmic antiproton and positron fluxes are setting strong constraints to the nature of Dark Matter. PAMELA is also testing cosmic rays acceleration mechanisms.
and propagation models through precise measurements of light nuclei and their isotopes. The determination of fluxes and secondary-to-primary ratios is possible for nuclei up to Oxygen in the energy range 200 MeV/n - 150 GeV/n. To investigate this important item, PAMELA can use measurements from three main detectors: the magnetic spectrometer, the calorimeter and the Time-of-Flight system. Analysis strategy and performance for nuclei studies using the detectors in stand-alone configuration will be discussed in this work.

1. Nuclei studies with PAMELA
The instrument PAMELA [1], in orbit since June 2006, is designed to study charged particles in the cosmic radiation, with a particular focus on antimatter and signals of dark matter annihilation. PAMELA is also looking for primordial antinuclei, measuring light nuclei energy spectra, studying the mechanisms of acceleration and propagation of the cosmic rays in the Galaxy, monitoring the solar activity and the radiation belts. The apparatus comprises several detectors: a Time-of-Flight system (ToF), a magnetic spectrometer, an anticoincidence system, an electromagnetic imaging calorimeter, a shower tail catcher scintillator and a neutron detector.

The relative abundances of elements and isotopes heavier than Helium are an essential piece of information to understand the origin and history of Cosmic Rays (CR) even if those particles only account for about few percent of the total flux. The study of the nuclear component of the cosmic radiation at energies higher than 200 MeV/n is therefore an important goal for PAMELA experiment. It is strictly connected to a better understanding of the propagation properties, which has great importance for the study of signatures of new physics in CR. For example, indirect signals of dark matter pairs annihilating in the halo of our Galaxy could be found in CR antiproton or positron but this search is limited by the uncertainties in the propagation parameters and fluxes of charged particles located in the whole diffusive halo. Galactic cosmic ray sources and propagation models can be studied measuring the primary and secondary nuclei in CR. It has indeed long been recognized that in CR the observed abundance ratio \((\text{Li} + \text{Be} + \text{B})/(\text{C} + \text{N} + \text{O})\) exceeds the value found in solar system material by a factor of about \(10^5\). This difference has been considered to be a measure of how much material CR have traversed since they were accelerated. Carbon, Nitrogen and Oxygen are considered primary cosmic rays, which means nuclei that are produced and accelerated by sources and reach Earth without undergoing fragmentation, while Lithium, Beryllium and Boron are secondary components resulting from fragmentation reactions in the interstellar medium. PAMELA contributes to this study measuring light nuclei fluxes and ratios with good accuracy, extending the measurement to unexplored energy. The nuclei charge identification is usually achieved by measuring the ionization losses in scintillators or silicon detectors. More challenging is the efficiency determination of the particles selection: nuclei can interact within the detector producing hadronic showers and also fragmenting into lighter nuclei. In the PAMELA instrument three different detectors (ToF [2], tracker [3] and calorimeter [4]) are able to identify light nuclei. Hence it is possible to perform a highly accurate charge measurement by selecting particles independently with the three detectors. In particular, below \(2\) GeV/n, three independent measurements from which the energy can be derived are available: the time of flight, the deflection of the particle in the spectrometer magnetic field and the Bragg’s peak of the nucleus stopping in the calorimeter. In this energy region is therefore possible to estimate the tracking system systematics uncertainties in the energy measurements. Moreover a cross-check of nuclei selection efficiencies as function of the nuclei energy can be used to account for systematics in the nuclei identification. Measurement of particle rigidity from the tracking system is used to extend the nuclei measurement to higher energies (hundred of GeV/n).

In this work independent nuclei measurements from ToF and calorimeter will be discussed.
2. Nuclei selection using ToF system
The Time-of-Flight (ToF) system of PAMELA is composed by 6 layers of scintillation counters arranged into 3 double-view \((x\) and \(y\) oriented) planes; there are 24 scintillators terminated at both ends by photomultipliers, for a total of 48 read-out channels. Particles of different \(Z\) (with \(1 \leq Z \leq 8\)) can be discriminate with a resolution up to \(\sim 4\%\) \([5]\) (up to \(\sim 2.5\sigma\) separation between B and C). In particular, a measurement from ToF system, in completely stand-alone configuration, of the B/C ratio can be done at energies below \(\sim 2.5\) GeV/n \([6]\): above this energy value, resolution in \(\beta\) measurements \([7]\) doesn’t allow a precise energy determination.

3. Nuclei selection using Calorimeter
The sampling calorimeter located at the bottom of PAMELA is composed of 44 silicon layers interleaved by 22 0.26 cm thick Tungsten plates; each plane is segmented in 96 strips per plane. Among the 44 active layers, 22 planes are used for the \(x\) view and 22 for the \(y\) view in order to provide topological and energetic information of the shower development in the calorimeter.

At low energy, up to about 1 GeV/n, non-interacting stopping nuclei can be selected and their energy release measured making use of calorimetry measurements. The main issues of this approach are the ability of the detector of selecting pure samples of non-interacting particles and the efficiency determination of this selection. A very good resolution in charge discrimination, shown for example in figure 1, allows a good quality estimation of selection efficiency and contamination of the sample at energies lower than \(\sim 0.6\) GeV/n, the same estimation becoming more and more challenging with increasing energy.

![Figure 1](image-url) \(\text{Figure 1.}\) In this plot of \(dE/dx\) versus the inverse square of the kinetic energy per nucleon, both measured by the PAMELA calorimeter in stand-alone configuration, for preselected stopping non-interacting nuclei, Boron (lower band) and Carbon (higher band) events are well separated below energies of \(\sim 0.6\) GeV/n \((E/n)^{-2} > 3\) on plot): above this energy a careful estimation of contamination is needed.

Efficiency calculation for calorimeter stand-alone selections can be studied by means of simulated data and cross-checking with ToF measurements. In the same energy range the time of flight system is used to determine the nucleus velocity and energy per nucleon, independently from its mass. Slow-down effects must be also taken into account and are a source of systematic uncertainties: the determination of such effects has been performed for light nuclei by means of simulation and an example is reported in figure 2. In particular, according to this estimation procedure, the nuclei energy before entering PAMELA has been calculated as a polynomial function of second degree of the reconstructed energy inside calorimeter.

4. Results
An independent measurement of B/C ratio from PAMELA calorimeter, obtained with selections and efficiency calculation described above, in the energy range \(0.25 - 1\) GeV/n is reported in figure 3, compared with independent measurement from PAMELA ToF and some measurements from previous experiment.
**Figure 2.** Input kinetic energy per nucleon of a simulated sample of $^{12}$C versus that reconstructed by the calorimeter: slow-down effect is clearly visible (comparing the trend to the red line which is the expected trend without slow-down) and well fitted by a polynomial of second degree (black line). Such slow-down trend remains stable also for other nuclei.

**Figure 3.** Preliminary B/C ratio measured independently by PAMELA ToF (red dots) and calorimeter (green triangles) in completely stand-alone configuration compared to some results from previous experiment HEAO [8], AMS-01 [9] and ACE [10]. Only statistical errors are shown in this plot; work is in progress for a careful evaluation of systematic errors.

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