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Cosmic ray abundance measurements with the CAKE balloon experiment

S. Cecchini[a,d], T. Chiarusi[b], G. Giacomelli[a], S. Manzoor,[a,c], E. Medinaceli[a],
L. Patrizii[a], V. Togo[a]
(a) Dip. Fisica dell'Università di Bologna and INFN, 40127 Bologna, Italy
(b) Dip. Fisica dell'Università "La Sapienza" di Roma, 00185 Roma, Italy
(c) PRD, PINSTECH, P.O. Nilore, Islamabad, Pakistan
(d) INAF/IASF Sez. di Bologna, 40129 Bologna, Italy
Presenter: T. Chiarusi (Chiarusi@roma1.infn.it), ita-chiarusi-T-abs1-og11-oral

We present the results from the CAKE (Cosmic Abundance below Knee Energy) balloon experiment which uses nuclear track detectors. The final experiment goal is the determination of the charge spectrum of CR nuclei with $Z > 30$ and the search for exotic heavy particles in the primary cosmic radiation. The detector, which has a geometric acceptance of ~ 1.7 m^{2}sr, was exposed in a trans-mediterranean stratospheric balloon flight. Calibrations of the detectors used (CR39 and Lexan), scanning strategies and algorithms for tracking particles in an automatic mode are presented. The present status of the results is discussed

1. Introduction

Precise measurements of cosmic ray (CR) nuclei abundances beyond Z>30 could allow to discriminate between two competing models [1] and [2] proposed for the composition at their sources. Especially ratios among heaviest elements appear to be the best discriminant for most current theories regardless of the propagation history of these particles [3]. In order to be able to measure these ratios, high charge resolution and high statistics are needed since the flux of heavy nuclei is very low (< 1 part/m^{2}h). Untill now, the largest statistics above the Fe threshold came from experiments of the HEAO-C3/Ariel-6 mission [4] [5], which unfortunately suffered from low charge resolution. Recently, the TIGER balloon experiment [6] published new results in the range of $30 < Z < 40$, after a flight of 31 days over Antarctica. The use of plastic nuclear track detectors (NTDs) onboard space vehicules to study the radiation environment is well know [7][8]. The use of NTDs makes possible to build experiments with large geometrical factors, and balloon flights of 20-40 day appear feasible from Antartica or in north circumpolar routes. These are good parameters for the study the Z range 30-40. We have proposed to the Italian Space Agency (ASI) an R&D programme with the final goal of using a large experiment (typically 8m^{2}sr) in a long duration balloon flight. CAKE is a prototype experiment, fully described in [9], which uses stacks of CR39 and Lexan passive nuclear track detectors exposed in a short balloon flight. It was flown for the first time in 1999 and preliminary results (in the range 5<Z<30) have been presented in [10][11]. In this paper we report on new approaches used for automatic scanning and new analys method of the recorded events. In particular we describe new algorithms implemented in the tracking and selection software. Preliminary results obtained with this technique are also presented.

2. The Test Flights

A first test flight was carried out in July 1999. The balloon was launched from the Trapani-Milo base (12°.50E, 32°.92N) of ASI and landed in central Spain after 22 hours. The plafond altitude was 37-40 km (3.5-3 g cm^{-2}) for 17.8 hours. Along the trajectory the average vertical rigidity cut-off was about 8 GV [12]. The gondola was not azimuthally controlled. The air temperature inside the cylinders that contained the NTD stacks was never higher than 34° C. A second flight was attempted from the same base in 2001 but the balloon was unable to reach the plafond after 4 hours, so the flight was interrupted.

3. The Calibrations

The calibrations used for the CR39 stacks are the ones described in [14]. In order to improve the contrast when using automatic scan a new set of calibrations were performed using 1 A GeV $^{26+}$Fe from the BNL AGS and 158 A GeV $^{49+}$In beams at the CERN SPS. Lexan detectors have been calibrated using 30 A GeV $^{82+}$Pb beams at the CERN SPS. We are also experiencing new etching conditions in order to avoid the formation of too many background tracks (low Z or end-of-range nuclei) and plastic surface defects.

4. Scanning strategy and track reconstruction algorithms

In order to distinguish heavy CR track candidates, which are very rare, from background in CR39 (which are sensitive to $Z/\beta > 5$) we need to develop an efficient data acquisition and data analysis strategy, possibly in automatic mode. In our standard procedure several (>3) consecutive CR39 foils belonging to the same stack are etched in a 6N NaOH solution at 70° for 40 hours. The plates are then scanned in automatic mode with the ELBEK Image Analyzer System [13]. During this step the position and major and minor axes size are measured on the top surface and stored. An off-line pre-selection of the recorded raw data was applied to remove those tracks having brightness and eccentricity outside prefixed fiducial bands. These band were determined from an independent set of ”good” data, measured with interactive scan sessions at the microscope. At present we are developing a Multilayer Perception neural network for implementing the off-line event filter.

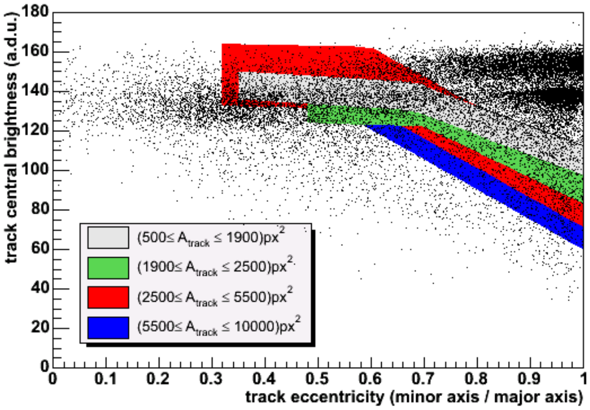

Figure 1. The off-line pre-selection fiducial belts (the coloured stripes) in the brightness versus eccentricity plot, with the measured raw data superimposed. It is apparent that the bulk of event with quasi unitary eccentricity are purely background.

Furthermore, in order to keep the alignment among the plates (during the scanning operations), to within ∼30 μm, we implemented a new microscope stage. A dedicated tracking algorithm was applied in order to select tracks crossing all the plates selected in the group, since CR nuclei are expected to be highly penetrating. Each candidate etch-pit was tracked individually, by means of a *fiducial area recursive method*. Starting from a track on the uppermost foil of the stack, and knowing the track inclination and orientation with respect to the plate,

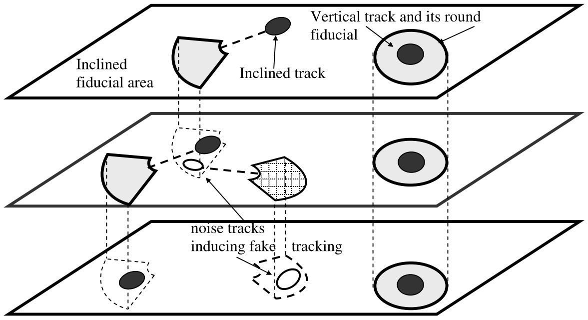

Figure 2. A sketch of the tracking procedure: according to the inclination and orientation of a first track on the uppermost foil, a fiducial area is determined where to look for a counterpart track on the lower foils. On the left, the inclined track originates a sector area, while, on the right, a circular area is set for a vertical track.. The tracking goes on recursively through all the scanned foils belonging to the same stack. Also a noise track falls in one fiducial area when tracking the inclined track. This event double the possible final trajectories. However, the wrong thread will be removed with the post-selection by requiring a linear trajectory for the impinging particles.

the algorithm defines a restricted area where to look for the counterpart track on the foil below. This procedure is made recursively through the foils of the stack. A full trajectory is determined when, for each scanned foils one track is linked with its upper and lower counterparts, yielding a *family* of tracks through the stack itself. The uncertainties on the size of each fiducial area arise from the uncertainties on the measured etch-pit base (± 10 μm) on the thickness of each foil (measured with a maximum error of $\pm$ 5μm) and on their mutual alignement in the stack. We have estimated a maximum shift of about 30 μm along the x-axis of the stage holding the NTD foils. The first scan usually produces more than 10000 raw tracks per foil. After tracking through 3 plates the selected events are reduced to roughly 1000 candidates.

5. Results and their comparison with simulations

The results here reported come from a scanned area of $\sim$870 cm^2, representing $\sim$15% of the total detector.

Fig. 3 shows the charge spectrum in the range $5 \leq Z \leq 40$ for events tracked through three consecutive plates compared to the MonteCarlo expectations [15]. The total number of reconstructed events is 1409. In the simulation we took into account the residual atmosphere and the detector's, scanning, tracking and selection efficiencies.

6. Conclusions

We are now in the process of completing the analysis of the remaining sheets of the CAKE experiment. The scanning and tracking automatic procedures that we have developed assure the possibility of making the measurements with large area NTDs with good efficiency in a reasonable time. For the present results we are confident that, with a single balloon flight of least 30 day duration or longer of an experiment of 8 m^{2}sr similar to CAKE, it will be possible to reach the sensitivity, charge resolution and statistics, needed for discriminating between the different scenarios of the origin of cosmic rays.

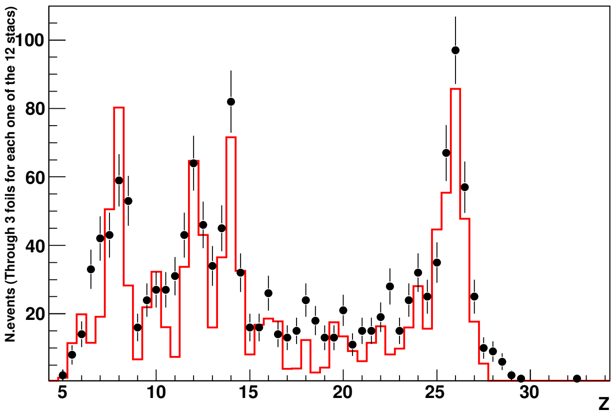

Figure 3. Charge spectrum of the 1409 events from the measurement of the 15% area of CAKE detector. Data (black dots) with statistical errors are compared to the MonteCarlo simulations (histogram).

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