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Experiments for light flash observation in space(*)(**)

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Summary. — Semiconductor detectors can be of great help for the study of radiation-induced effects on living objects and men in space. Here we present three projects: the Sileye 1 and 2 and ELFO. The Sileye detector series are the first particle detectors flown in space made by the Italian Institute of Nuclear Physics (INFN). The detectors consist of six silicon views made of a square ($6 \times 6\,\mathrm{cm}^2$) wafer of silicon, divided into 16 strips, each 3.6 mm wide. The first detector is on board MIR since October 1995; the second apparatus, Sileye2, was brought on MIR on October 1997 and it will be turned on in February 1998. Here we will present briefly the results obtained with Sileye1 and the performances of the second apparatus. The ELFO project is a much more ambitious one and it is planned for the International Alpha Station. Here we will review scheme and purpose

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1. – Introduction

The most important macro effect of the radiation in space on the men is the phenomenon of light flashes (LF) in cosmonauts' eyes during orbital flights. The first observation was reported by Aldrin during the Apollo 11 mission [1]. Other observations were later reported by Apollo-Soyuz [2] and cosmonauts on the MIR Space Station; the frequency of LF depends on orbit parameters, especially on the latitude and grows in polar areas and in the area of the South Atlantic Anomaly, but although many study and experiments in space and on earth were performed (for a review see [3] and references

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therein), the origin and nature of this phenomenon is far from comprehension. So to give a contribution to the study of this effect we prepared the SilEye detectors series.

2. – **The** SilEye **apparatus**

The SilEye detector is a unique device; it benefits from the technological developments made for the NINA calorimeter [4]. It can measure particle energy losses from 2.5 Minimum Ionizing Particles (MIPs) to 2500 MIPs (we take 1 MIP = 105 keV) and determine the coordinates of traversing particles with an accuracy of ±1.8 mm and an angular accuracy of 3.3 degrees. It can detect in real time the passage of particles which traverse the eyes and register on the on-board computer the six coordinates and energy depositions from which the direction and properties of the particles can be determined. Time of LF occurrence seen by the astronauts are also stored in a separate file for off-line correlation. The system monitors also astronaut's dark adaptation and reaction time and performs reliability controls on device performances. The astronaut uses a joystick to register light flashes in order to minimize reaction time. All the physical parameters of the detector (like gain or threshold) are completely software controlled. LEDs were added inside the astronaut's mask to check eye-detector alignment, minimum level of astronauts light sensitivity and readiness. The maximum acquisition rate is not lower than 60 Hz. The main body of our detector consists of six silicon views. A view is made of a square ($6 \times 6\,\text{cm}^2$) wafer of silicon, divided into 16 strips, each 3.6 mm wide. Two views, orthogonally attached, constitute a plane. We have three planes for a total number of 96 strips. The distance between the silicon planes is 14 mm. Each silicon strip is 380±15 μm thick, giving a total active thickness of 2.3 mm. The silicon strips act like completely depleted p-n junctions, and need to be supplied by a DC tension of 36V. The current signals coming from the silicon strips are very fast (less than 40 ns) and very weak (in electrons 1 MIP = $30400e^-$ = 4.86 fC). These signals go into charge preamplifiers and then into shaping amplifiers that prepare them for sample and hold.

The calibration of the device SilEye2 was carried out on a proton beam from the CELSIUS storage ring at TSL, Uppsala. The measurements were done at two different proton energies: 48 MeV and 70 MeV. The results and the performance of SilRye2 are reported in [5, 6].

As an example in fig. 1 the distribution of the total detected energy *vs.* the difference between the energy lost in the last plane and in the first view is plotted. It can be seen that the protons' energies are very well separated.

In fig. 2 and 3 it is shown a Monte Carlo study on the particle separation capabilities for several nuclei of interest, for impinging particles with low and high energy respectively. The incident energy range is chosen randomly between 50 MeV/n and 1 GeV/n. It should be noted that even in the region with $(E3 - E1) < 0.2$ MeV (corresponding to particles with high kinetic energy) it is possible to discriminate the nuclei (fig. 3), using E_{tot} as the only parameter.

Although with a weight of less than 5 kg and power consumption less than 7 W (at 27 V), the SilEye2 apparatus has demonstrated to be able to detect in real time the passage of particles which traverse the eyes and register on the on-board computer the six coordinates and energy depositions from which the direction and properties of the particles can be determined. The protons' energy resolution is better than 6 % for proton kinetic energies higher than 20 MeV and the nuclear discrimination will permit a better analysis of the total dose equivalent absorbed by the astronauts.

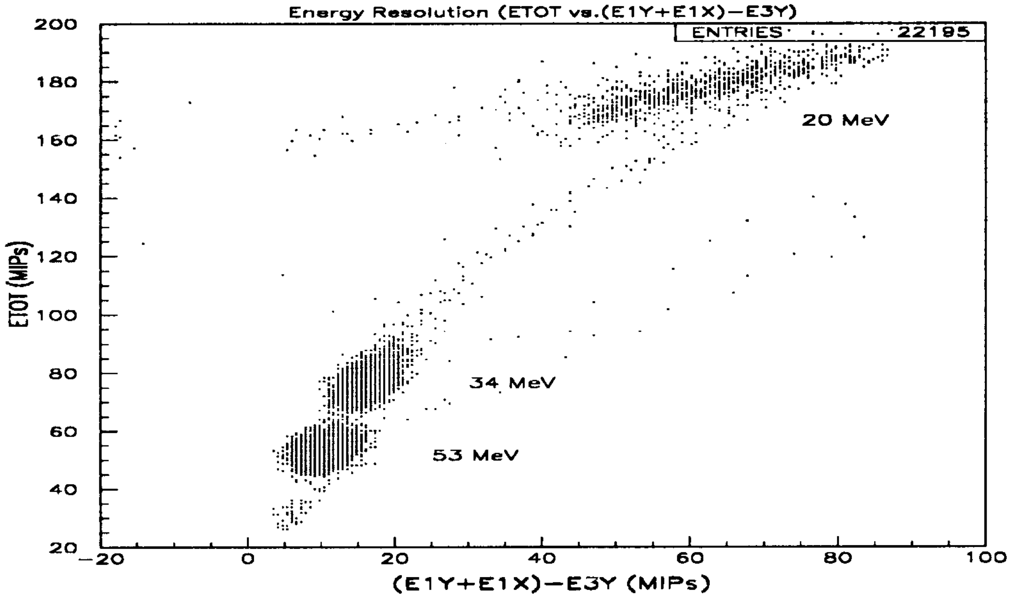

Fig. 1. – Distribution of the total detected energy versus the difference between the energy loss in the last plane and in the first view.

3. – The ELFO apparatus

In spite of the observed correlation between trajectory and transferred energy of particles flux at retinal level and the reported perceptual phenomena, the neurophysiological relevance and mechanisms of generation of these events have not been investigated and it is unclear whether the phenomenon is the result of the activation of physiological mechanisms of vision. Comparable transient visual alterations are in fact experienced by patients, *e.g.* during the first stages of retina detachment, at the beginning of migraine episodes, or in concomitance of simple partial epileptic seizures originating in primary visual cortex. Phosphenes of unknown origin are often reported by healthy subjects in the absence of any history or evidence of ocular, neurological or systemic disease. All these visual symptoms are, to a relevant extent, expression of enhanced/distorted function of those mechanisms which mediate visual information processing in physiological conditions. In particular, these perceptual events suggest a role of the basic mechanisms dedicated to the detection of simple physical characteristics of visual stimuli, such as luminance change, motion, contrast, etc. It is also known that X-rays at low doses can alter the light sensitivity threshold by acting at retinal level. It appears a practicable hypothesis that the particle flux may, in peculiar conditions, trigger (directly or indirectly) physiological mechanisms of the visual system or, in alternative, alter its functional status (*e.g.* sensitivity) so to change the effect of external events (*e.g.* particles). Retina and visual cortex are both putative sites of action of triggering particles.

In this case the approach must be both physical and electrophysiological with the collection of as much as possible correlated information on the status of the astronauts (for a complete reference see [7]) and the silicon detectors must be large enough to cover not only the eye but also the brain. Bounding together the basic $6\times6\,\text{cm}^2$ Sileye chips, we

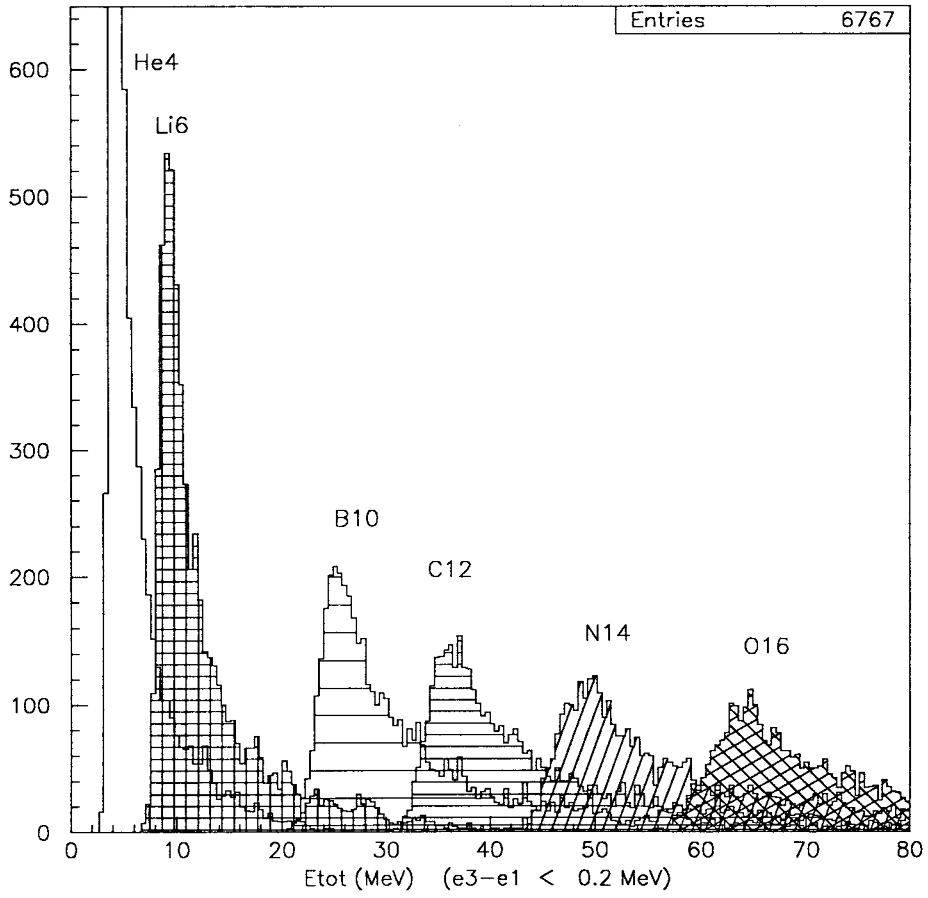

Fig. 2. – Discrimination of nuclei with low incident energy; Etot is the total energy released by the particles in the whole detector; $E3 - E1$ is the released energy difference between the third and the first plane.

can reach the desired measure (36 chips form a $32 \times 32\,\mathrm{cm}^2$ plane that is large enough). The technique to connect the x and y 3.6 mm strips is the same already experienced in our collaboration for the construction of the WiZard calorimeter [8], the PAMELA tracker and calorimeter [9], and proposed for the GILDA gamma-ray detector [10].

The planes of the helmet, in the baseline design, are nine; three stacked layers in the three Cartesian directions having the inside helmet as target. The distance between the inner and the outer planes is 61 mm. Each plane is constituted of

- seven ladders of seven detectors for the planes of the external layer, six ladders of six detectors each for the intermediate layer and five ladders of five detectors for the internal layer;
- the Front End (FE) electronics placed at the end of the related ladder.

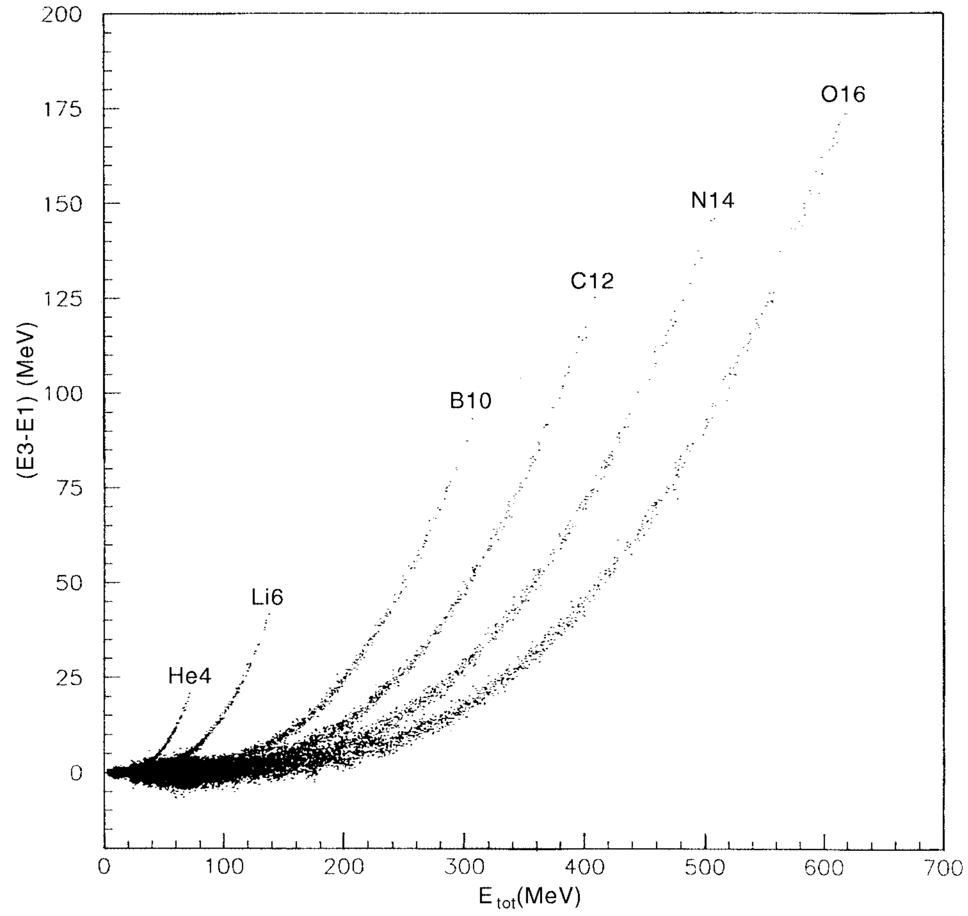

Fig. 3. – Discrimination of nuclei (HZE) with high incident energy ($E3 - E1 < 0.2$ MeV).

4. – Conclusion

In view of a permanent station in Earth orbit or on the Moon, radiation protection efforts must take into account that an increasing number of space workers, men and women of all age groups are expected to spend a substantial part of their time in space. Extravehicular activities will increasingly become a routine performance. Besides the proposed space station, special missions will bring workers to orbits of high altitude and high inclination up to polar orbits. Future perspectives of man's endeavour in space include voyages to the planets of our solar system with Mars being the first candidate. In an expedition to Mars, the High-Z Elements (HZE) of cosmic radiation and particles emitted during solar flares represent the major radiation hazard. Therefore, additional data on the biological effectiveness of HZE and an improved knowledge of the radiation situation inside space vehicles are urgently required, in order to secure man's safety in future long duration flights outside the Earth's magnetosphere or in high-inclination Earth orbits. Silicon detectors will play an important role in this fascinating adventure.

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