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# Application of Silicon-Detector Technology to Experiments in Space. An Option for the Astromag Facility.

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**Summary.** — Cosmic antimatter search needs transportation systems of the apparatus outside the atmosphere. The Astromag facility on the NASA space station will be a great opportunity for such a search in the next future. Here we discuss the advantages achievable from silicon-detector technology in space research and we propose a silicon calorimeter as an ideal option to work in connection with the Astromag facility itself.

PACS 07.90 – Other topics in specialized instrumentation.
PACS 29.40 – Radiation detectors.

## 1. – Introduction.

Astromag (¹) will be the NASA facility on the space station to provide a strong magnetic field for cosmic-ray experiments. On both sides of the magnet there will be two apparatus: one, MAS (Matter Antimatter Spectrometer), devoted to antimatter search and another, CRIS (Cosmic Rays Isotopes Search), devoted to the search for relative isotopic abundances. The MAS (¹) apparatus needs an efficient and reliable shower counter to work in connection with devices like transition radiation detectors, tracking chambers and time-of-flight counters. Here we present an option based on silicon-detector technique. Silicon detectors (SDs) have been used in nuclear physics for a long time (²). The typical field of application of SDs is the measurement of the energy loss ($\mathrm{d}E/\mathrm{d}x$) and of the total energy $E$ of highly ionizing particles. Recently, SDs have been introduced in elementary-particle physics for short-lifetime measurements (³) and for precision-tracking ($\Delta x \approx 5\,\mu\mathrm{m}$) determination. The fast development of very large-scale integration (VLSI) electronics now allows large solid-angle coverage ($\sim 4\pi$) for tracking with an accuracy of a few micrometres. More recently (⁴), SDs have been used in calorimeters that measure the electron or photon energy by counting the particles generated in the electromagnetic shower development. The first prototype of a hadron calorimeter is now being constructed by the SI-CA-PO Collaboration (⁵) to verify experimentally in a test beam the possibility of producing equal response (or equal energy deposited in the SD of the calorimeter) for hadrons or electrons of the same incident energy ($e/h = 1$).

Why are SDs interesting in general and particularly suitable for space research? Below some features are listed that make SDs attractive for use in particle physics.

i) The energy required for the separation of the charges in the detector is quite small: a minimum ionizing particle (MIP) produces 80 electron-hole pairs while crossing $1\,\mu\mathrm{m}$ of detector.

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(¹) *The Particle Astrophysics Magnet Facility*, Report of the Astromag Definition Team, edited by J. F. Ormes, M. Israel, M. Wiedenbeck and R. Mewaldt (May 1988).

(²) See, for example, *Proceedings of the Topical Meeting on Multiparticle Production on Nuclei, Trieste, 1970*, edited by G. Bellini, IAEA-SMR 21 (Wien, 1972), p. 505.

(³) G. Bellini, M. Conte, P. D'Angelo, P. F. Manfredi, D. Menasce, E. Meroni, L. Moroni, S. Sala and M. Szawlowski: *IEEE Trans. Nucl. Sci.*, NS-30, 415 (1983); B. Hyams, U. Koetz, E. Belan, R. Klanner, G. Lutz, E. Neugebauer, A. Wylie and J. Kemmer: *Nucl. Instrum. Methods*, **205**, 99 (1983).

(⁴) A. Nakamoto, H. Murakami, K. Nagata, J. Nishimura, T. Yamagami, T. Doke and J. Kikuchi: *IEEE Trans. Nucl. Sci.*, NS-27, 74 (1980); P. G. Rancoita: in *International Europhysics Conference on High Energy Physics, Brighton, July, 1983*, Contributed paper no. 102.

(⁵) S. Pensotti, P. G. Rancoita, A. Seidman and L. Vismara: *Nucl. Instrum. Methods A*, **265**, 266 (1988).

ii) The production of the charge is a linear process avoiding the typical instability of the high-gain charge amplification.

iii) Because of i) the longitudinal dimension of the SD can be small and the calorimeter can be very compact.

iv) The detectors are very uniform and do not suffer from saturation or the nonlinearity effect.

v) The low-voltage supply and the low dark current assure a small power consumption.

These properties of SDs have been well known to physicists for a long time. So what has changed? As mentioned before, the progress on VLSI electronics has brought as a consequence an important drop in the cost per channel of the detector readout (\$/ch ↓). The demand for large quantities of SDs has pushed industry to find economic solutions for the construction of SDs and now a few square metres of them quite reasonable cost.

## 2. – Possible applications of the SD in the space station era.

The very interesting physics program of Astromag requires a level of particle identification similar to the more sophisticated experiments carried out at accelerator. The SD can contribute to particle identification in the following ways:

i) by the measurement of $\mathrm{d}E/\mathrm{d}X$ ($\beta$ and charge);

ii) by the high-precision position measurement ($\mu$m) in a magnetic field (momentum);

iii) by measuring the total energy and at the same time the difference in the shower profiles of electrons and hadrons;

iv) by the antimatter annihilation in the calorimeter and by the measurement of the energy released in the annihilation:

$$E_{\mathrm{an}} = 2m_{\mathrm{p}}\,.$$

## 3. – Measurement of $\mathrm{d}E/\mathrm{d}x$.

To illustrate the possibilities of measuring $\mathrm{d}E/\mathrm{d}x$ with large-area detectors (of the order of square metres), we will give some recent results from the CERN UA2 Collaboration. This group has installed at the CERN-p-$\bar{\mathrm{p}}$ Collider 432 SDs of $(6.5\times 4.3)\,\mathrm{cm}^2$ area and $\sim 300\,\mu\mathrm{m}$ thickness for $\mathrm{d}E/\mathrm{d}x$ measurement and e, $\gamma$ separation. The SDs are made of $n$-type Si wafers of $(2\div 15)\,\mathrm{k}\Omega\,\mathrm{cm}$ specific resistivity. The capacity of each SD is $C_{\mathrm{D}} \simeq (120\div 130)\,\mathrm{pF}$ for full depletion. The

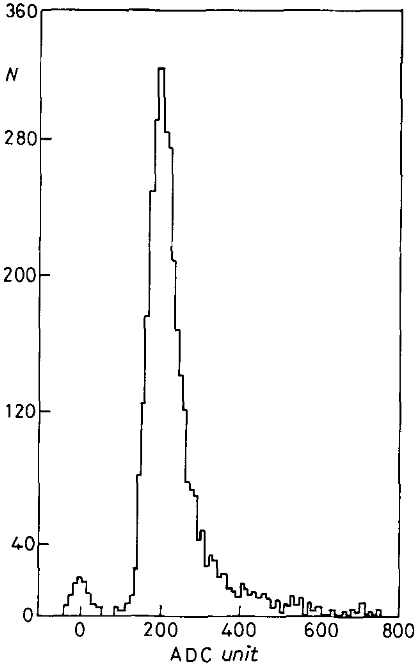

Fig. 1.

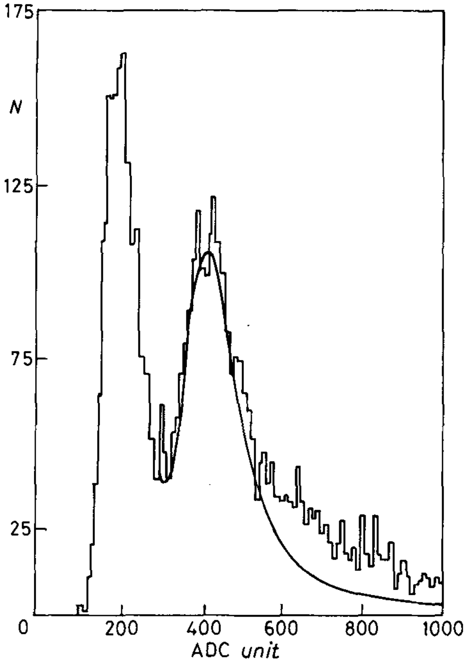

Fig. 2.

Fig. 1. – Response of a SD of the UA2 Collaboration to the energy loss by a 220 GeV $\mu^-$ crossing the detector.

Fig. 2. – Pulse-height distribution from a SD for one or two electrons traversing the counter.

average response of this relatively large sample of SDs is quite satisfactory, as seen in fig. 1 and 2. Figure 2 shows the separation obtained between the two peaks of the pulse-height distribution of the charge induced by 1 or 2 MIPs crossing the SD.

## 4. – Position measurement.

Silicon detectors for position measurement are typically built by printing conducting strips of a few micrometres with ~20 μm pitch on the Si wafer. Recently, two-dimensional wafers have been realized. An accuracy of ~5 μm is usually quoted for position measurements carried out by strip SDs. We would also like to mention here a recent development concerning position measurement with SDs, namely the semiconductor drift chamber (SDC). This position measurement device, proposed by Rehak *et al.* (6), seems to be very suitable for

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(6) P. Rehak, E. Gatti, A. Longoni, J. Kemmer, P. Holl, R. Klanner, G. Lutz and A. Wylie: *Nucl. Instrum. Methods A*, **235**, 224 (1985).

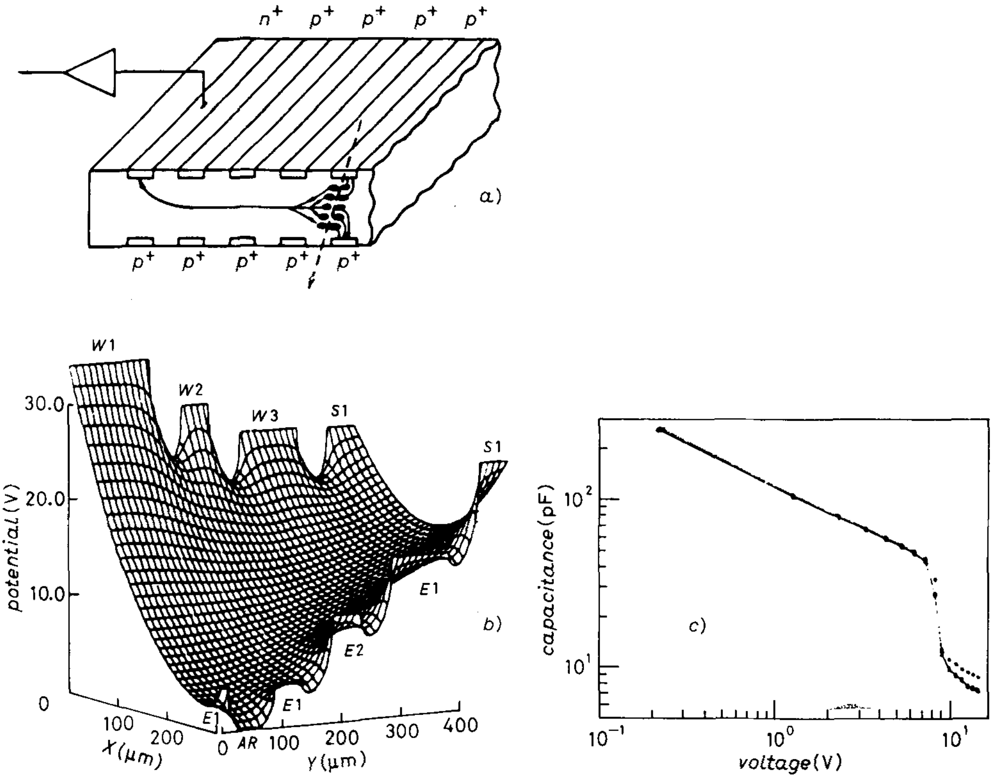

Fig. 3. – *a*) Voltage distribution applied to the SDC electrodes to obtain the drift field. *b*) Field line of the SDC obtained by applying the voltage of *a*). *c*) Anode-diode capacitance built in 0.2 V as a function of the voltage applied to the SDC. —●— device no. 1, ··●·· device no. 2.

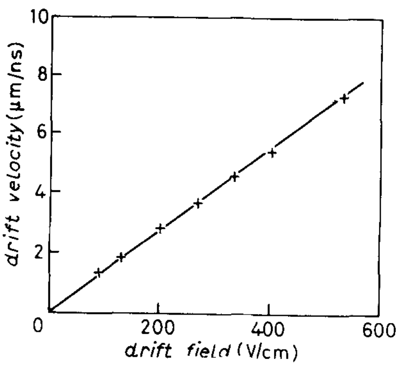

Fig. 4.

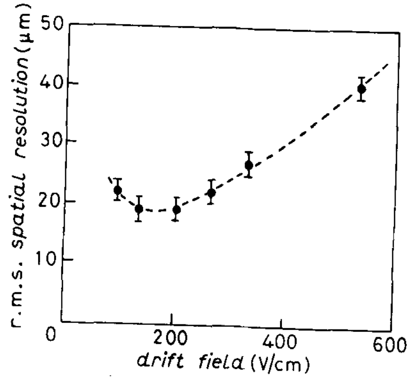

Fig. 5.

Fig 4. – Drift velocity in the SDC as a function of the applied field.

Fig. 5. – Space resolution as a function of the drift field.

space applications because the spatial accuracy of a few micrometres is obtained with a smaller number of electronic channels than in the strip detector. The working principle of the SDC is shown in fig. 3*a*), *b*) and *c*). The typical size of a SDC is $(6 \times 6)\,\text{cm}^2$. The drift velocity is a function of the applied field and is of the order of 1 cm/μs (see fig. 4). The SDC has been tested in a $\pi$ beam at CERN and has shown a spatial accuracy of 5 μm (see fig. 5). The pulse-height distribution is shown in fig. 6. A plane of the SDC in the middle of the deflected path of a charged particle in the magnetic field $B$ can improve the sagitta determination if multiple scattering introduced by 300 μm of Si is not a problem. A study of the improvements achievable with one or more SDC planes requires, of course, a detailed study.

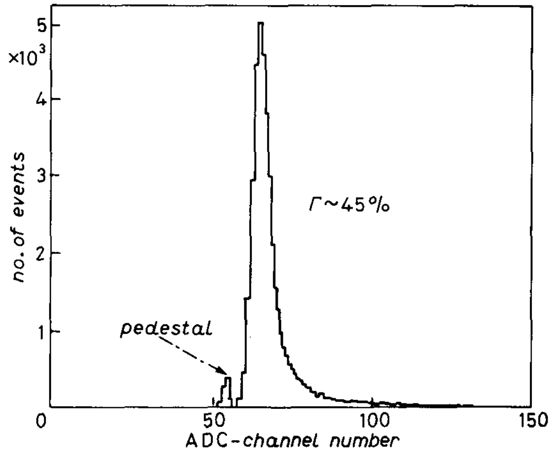

Fig. 6. – Pulse-height distribution of minimum ionizing particles crossing the SDC.

## 5. – Silicon calorimeter for Astromag.

The identification of positrons and their separation from protons and light nuclei requires a well-segmented calorimeter. The calorimetric measurement with tracking capability in order to give the annihilation pattern is also a powerful tool in the search for antimatter in space. Finally, a good energy resolution calorimeter extends the gamma-ray search to those $\gamma$ that have not been converted in the upper part of the magnetic telescope. The Astromag electromagnetic calorimeter has to cover an area of $\sim(1 \times 1)\,\text{m}^2$. The weight limitation ($\sim 1$ t) allows a maximum thickness of $\sim 10$ radiation lengths ($X_0$) using lead absorber. The SDs constitute the sensitive planes of the calorimeter. The planes are realized connecting the silicon strip wafer (SSW) in order to build $x$ and $y$ planes. The connection of the SSW is done through a kapton-printed board electrically connected by pressure to the strip in order to avoid delicate bounds. The optimization of the sampling layers and of the dimension of the strip is done on the basis of the power and readout constraints. The number of channels will be kept below $10^4$ to stay in the power limits. The dimension of the strip will vary from $\sim 2$ mm at the calorimeter entrance to $(3 \div 4)$ mm after the shower maximum ($\sim 5X_0$). Considering a sampling step of 1/3 of radiation length $X_0$ the SD planes will be 30 for the total thickness of $10X_0$. The $x$ and $y$ planes will be alternate every 1/3 of $X_0$. The first fifteen planes ($5X_0$) will be equipped with 2 mm strips and the remaining with $(3 \div 4)$ mm strips. The electronic readout will be done with VLSI preamplifer sampler and hold circuit available in chips of 128 channels. Zero suppression and logic decision before trasmission will be done with local intelligence realized with microprocessor. Silicon calorimeters are used in places where special conditions have to be fulfilled (presence of magnetic field, tight space requirement, vacuum, etc.). The feasibility and the advantages of a large Si calorimeter for future high-energy hadron machines, such as the large hadron collider (LHC) at CERN and the superconducting supercollider (SSC) in the USA, are under study, and experimental tests are being carried out by the SI-CA-PO collaboration. From this collaboration the data shown in

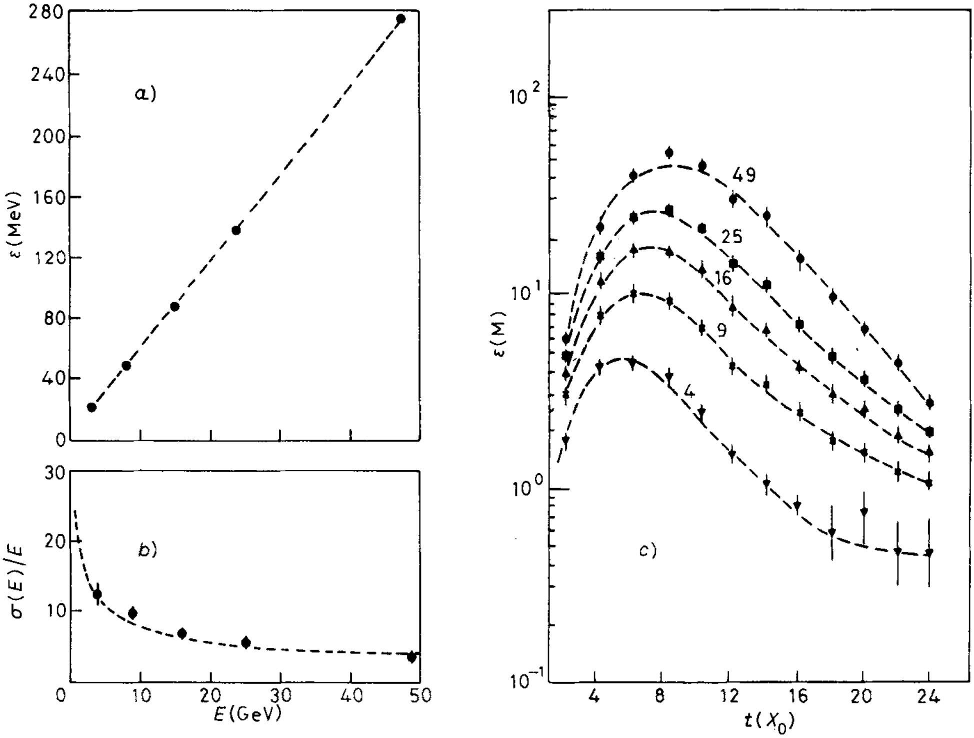

Fig. 7. – *a*) Linearity of the Si-U calorimeter response as a function of incident electron energy. *b*) Energy resolution of the Si-U calorimeter. *c*) Longitudinal shower development for different values of electron energy as a function of depth.

fig. 7*a*), *b*) and *c*) have been taken, which refer to the performance of a silicon-uranium (Si-U) calorimeter.

## 6. - Conclusions.

Silicon detectors and in particular the Si calorimeters seem to be ideal detectors for the Space Laboratory. The feasibility of large-area Si calorimeter has been proved. The problem of the cost of the SD will be solved firstly by its expected lowering with demand and time and, secondly, by comparison with the intrinsic high cost of expedition of technical equipment to the Space Laboratory.

## ● RIASSUNTO

La ricerca di antimateria cosmica necessita di sistemi di trasporto e di apparati al di fuori dell'atmosfera. La facility Astromag, posta sulla stazione spaziale della NASA, costituirà nel prossimo futuro una grande opportunità per questo tipo di ricerca. Si discutono qui i vantaggi che si possono ottenere dalla tecnologia dei rivelatori a silicio nella ricerca spaziale e si propone un calorimetro a silicio come opzione ideale per operare in connessione con la facility Astromag stessa.

## Применение технологии кремниевых детекторов к экспериментам в космосе. Экспериментальная установка для «АСТРОМАГ».

**Резюме** (*). — Поиски антивещества в космосе требуют транспортных систем для вывода экспериментальной аппаратуры за пределы атмосферы. Экспериментальная установка «АСТРОМАГ» на космической станции NASA представляет большие возможности для таких поисков. Мы обсуждаем преимущества технологии кремниевых детекторов в космических исследованиях. Предлагается кремниевый калориметр, как идеальный прибор для установки «АСТРОМАГ».

(*) *Переведено редакцией.*