Study of the Granularity for a Tracking Calorimeter with Optimal Rejection of Proton Background in Positron Detection.

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Summary. — In this paper we present a Monte Carlo study of a calorimeter response for an experiment to equip the magnetic facility of the USA space station. Main purpose in the design of such a calorimeter is the efficient discrimination between eloctromagnetic and hadronic showers. The estimated rejection power results to be better than $1 \cdot 10^{-3}$ p/e$^+$ for incident particles with energy between 10 GeV and 100 GeV.

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1. – Introduction.

NASA recommended to equip the USA space station with a magnetic facility (ASTROMAG) for cosmic-ray measurements (1). A study team was appointed to

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(1) *The particle Astrophysics program for 1985-1995*, Report of the NASA Cosmic Ray Program Working Group, Dec. 1985.

define the main features of such a facility and the proposed scheme ([2]) consisted of a zero net dipole superconducting coil system ([3-5]) equipped by two experiments. One of this (CRIS, namely cosmic-rays isotope spectrometer) should be devoted to isotopic separation of high-charge ($Z \geq 6$) nuclei, while the other one (MAS, namely matter antimatter spectrometer) to the study of elementary particles and low-charge nuclei.

2. – The WIZARD experiment for MAS.

The main physical goals of the WIZARD experiment are i) an accurate measurement of the energy spectrum of protons and helium up to a few TeV; ii) the measure of the energy spectrum of electrons and positrons up to 0.5 TeV; iii) the determination of the energy spectrum of the antiprotons; iv) the search for the presence of antinuclei (mainly antihelium); v) the isotopic separation of light nuclei; vi) a survey of intense γ-ray sources with wide acceptance and long exposure time.

To reach these goals the apparatus will include an accurate tracking system (32 wire chambers with 50 μm resolution), a precise time-of-flight measurement system (100 ps is the planned time resolution to attain), a TRD system and a tracking calorimeter (≈ 10 radiation lengths in depth). The whole apparatus shape will be a parallelepiped $(1.5 \cdot 0.75)$ m^2 in cross-section and 3.5 m in depth. The overall geometric acceptance will be 0.1 m^{2}sr, while the energy threshold—on the 28° inclined orbit of the space station—is about 4 GeV/a.m.u.

During three years of operation it is foreseen to collect about $3 \cdot 10^9$ protons, $4 \cdot 10^8$ helium nuclei, $2 \cdot 10^7$ electrons, $(1 \div 3) \cdot 10^6$ antiprotons and $(2 \div 3) \cdot 10^6$ positrons in the whole energy range from the threshold up to a few TeV.

In such a wide energy range, the problem is to identify positive particles, as they are flooded by the huge flux of protons. To reach an effective detection of the positrons, an optimal e^+/p discrimination in the calorimeter is needed (*i.e.* the calorimeter should have an enough narrow longitudinal segmentation and a sufficient transverse granularity to assist the TRD system in its task).

Moreover, the calorimeter must offer the same features either to guarantee the identification of the interaction vertex of the antiprotons annihilating inside

([2]) ASTROMAG: Report of the Study Team on the Particle Astrophysics Magnet Facility, May 1988.
([3]) M. A. GREEN, G. F. SMOOT, R. L. GOLDEN, M. H. ISRAEL, R. KEPHART, R. NIEMANN, R. A. MEWALDT, J. F. ORMES, P. SPILLANTINI and M. E. WIDENBECK: *IEEE Trans. Magn.*, MAG-23, 1240 (1987).
([4]) M. A. GREEN, G. BASINI, M. RICCI, A. CODINO, P. SPILLANTINI and F. ROSATELLI: *IEEE Trans. Magn.*, MAG-24, 1015 (1988).
([5]) M. A. GREEN: Report to the Astromag study team, Berkeley, Cal., Jan. 1988.

the volume or to give a self-trigger on the pattern of the showers initiated by γ-rays (the geometrical acceptance for γ-rays being a few $m^2 sr$).

3. – The calorimeter set-up.

In the calorimeter design we must take into account the mechanical constraints imposed to the whole system. The entrance surface will be $(1.5 \cdot 0.75)\, m^2$ in order to cover the whole cross-section of the WIZARD experiment; the maximum depth will be determined by the maximum allowed weight. This can be assumed of the order of 1000 kg—including mechanical structures and electronics—and the weight of the absorber cannot exceed 900 kg allowing a maximum of $80\, g/cm^2$.

To discriminate between positrons and protons we can take into account mainly indications: the starting point of the shower, the position of the maximum of the released energy, the shape of the longitudinal energy distribution and the dimension of the energy spread around the shower axis. However, these indications are not independent, so their accurate determination should be necessary.

To get the best discrimination, one must maximize the positron absorption and minimize the proton interactions, so a material with a high Z value should be used. Tungsten is appropriate and, furthermore, it shows good mechanical properties, well suited for a space experiment; however, also more traditional materials (*e.g.*, lead) could be used. In both cases about 11 radiation lengths will be the total depth at disposal. It seems to be enough conservative to have a sensitive layer every 1/3 radiation length to study the longitudinal shower development, with a spatial resolution of about 4 mm to obtain enough information about the transverse distribution of the energy.

To summarize, the tungsten calorimeter will consist of 26 identical stacks each one made by 1.5 mm of tungsten; the traditional lead calorimeter, instead, will be built by 33 stacks each one made by 1 mm Al, 1.7 mm Pb and 1 mm Al. In both cases each stack will be followed by two sensitive layers of 300 μm of silicon wafer (held in between of two printed boards, 1 mm thickness) with 4 mm strips—parallel to the sides of the calorimeter—printed on their surface. This detector allows us to determine, for each sample, the transverse energy distribution along two orthogonal axes parallel to the calorimeter edges, with a resolution adequate to obtain the e^+/p discrimination.

4. – Monte Carlo simulated performance.

To study the response of the calorimeter to both electromagnetic and hadronic showers, we use the program GEANT3 [6]. For the sake of simplicity we

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[6] R. BRUN, F. BRUYANT, M. MAIRE, A. C. MCPHERSON, P. ZANARINI: CERN DD/EE/84-1 (1987).

consider only particles impinging normally to the centre of the calorimeter entrance surface. To speed up the computation time, we also impose a lower limit of 10 MeV on the energy of the secondary electrons and gamma rays. This value for the energy cut arises from a compromise between the computation time and the accuracy in the determination of the transverse dimension of the shower.

We focus our attention mainly on the fluctuations either of the energy deposited in each sample or of the shower spread around its axis. In fact, even if the mean values of these quantities are well distinguished for positrons and protons, their fluctuations make it difficult to obtain a relevant rejection power together with an high detection efficiency.

In fig. 1 and fig. 2 the deposited energy and the estimated variance of the

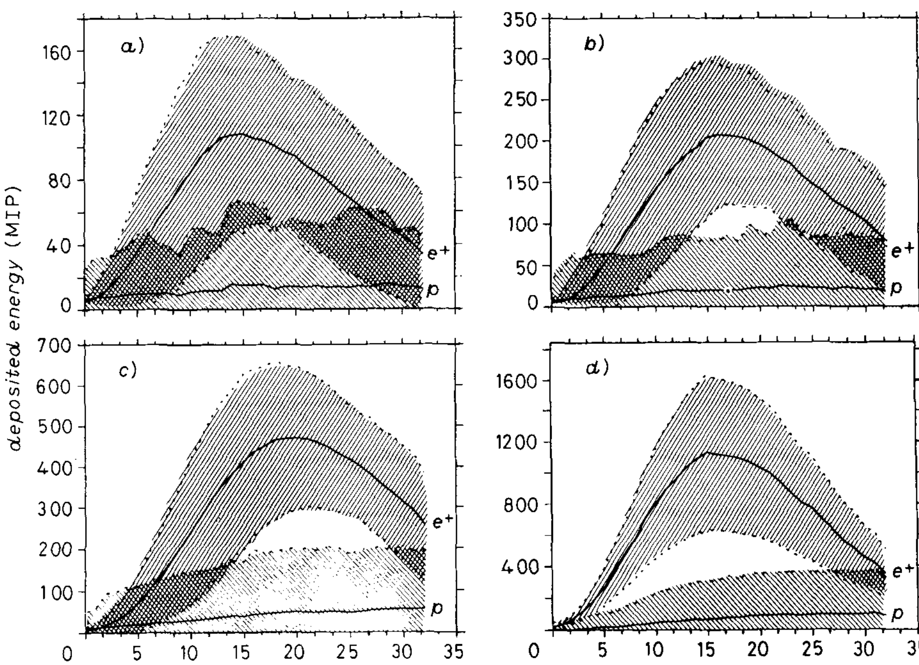

Fig. 1. – Deposited energy—in the sensitive layers of the calorimeter—as a function of the order number of the samples and for different energies, E_{inc}, of the incident particle. *a)* $E_{\text{inc}} = 10\,\text{GeV}$; *b)* $E_{\text{inc}} = 20\,\text{GeV}$; *c)* $E_{\text{inc}} = 50\,\text{GeV}$; *d)* $E_{\text{inc}} = 100\,\text{GeV}$. Solid lines represent the mean values for proton (p) and for positrons (e^+). Dashed areas represent the regions where 95% of the events are contained.

projected coordinate are shown as functions of the sample depth for positrons and protons and for various energies (10, 20, 50, 100 GeV) of the incident particle. The shaded areas represent the interval where 95% of the distribution is contained. As one can see—mainly for the protons—the areas above the mean values are much greater than the ones below; this corresponds to a lower event

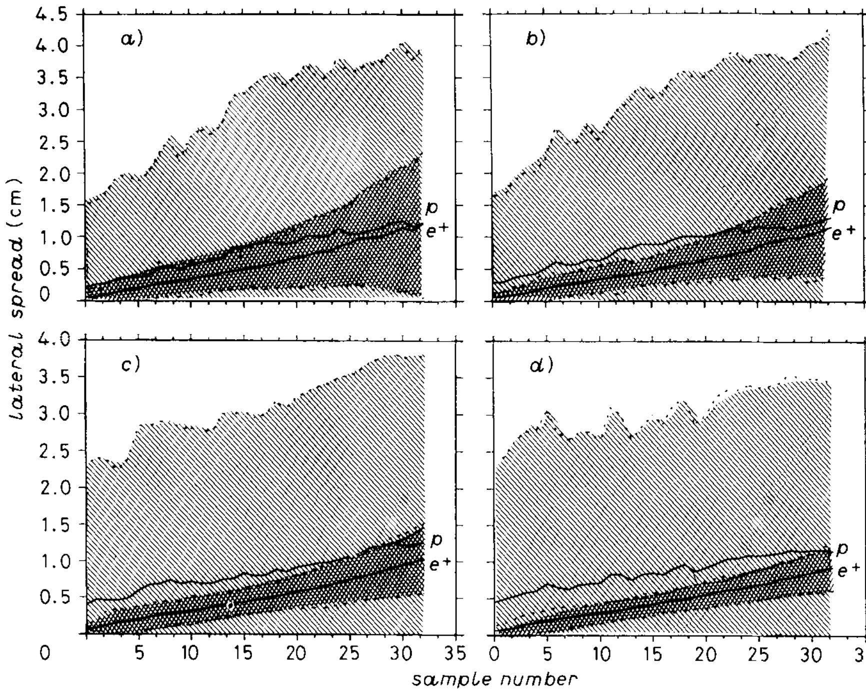

Fig. 2. – Estimated variance of the projected coordinate, as a function of the order number of the samples and for different energies, E_{inc}, of the incident particle. *a*) $E_{\text{inc}} = 10\,\text{GeV}$; *b*) $E_{\text{inc}} = 20\,\text{GeV}$; *c*) $E_{\text{inc}} = 50\,\text{GeV}$; *d*) $E_{\text{inc}} = 100\,\text{GeV}$. Solid lines represent the mean values for proton (p) and for positrons (e^+). Dashed areas represent the regions where 95% of the events are contained.

density in the upper region and reflects the long tailed shape of the proton distributions. Proton rejection is obtained combining indications from the deposited energy and the energy lateral spread. In fact, we observe that, when the hadronic shower does not develop, its spread is similar to an electromagnetic one, but it can be discriminated as the deposited energy is negligible—it is the energy of a minimum ionizing particle—. Moreover, when the deposited energy from a hadronic shower can be confused with that of an electromagnetic one, its spread is sensibly greater.

To achieve the e^+/p discrimination, we define «candidate positron in the i-th sample» an event with deposited energy, E_i, greater than a threshold value, E_i^{thresh}, and with estimated variance of the projected coordinate, S_i, less than a threshold value, S_i^{thresh}. These threshold values are properly chosen, from the Monte Carlo distributions, to maximize the proton rejection without relevant positron losses.

Then we state «candidate positron» an event that has been «candidate positron in the i-th sample» in at least 2/3 of all the samples. The effectiveness of

TABLE I. – *Proton rejection and positron losses.*

Energy (GeV)	Residual proton contamination (95% likelihood interval)	Positron losses (%)
10	$<1\cdot 10^{-3}$	2.5
20	$<1\cdot 10^{-3}$	0.5
50	$<1\cdot 10^{-3}$	1.5
100	$<1\cdot 10^{-3}$	<0.5

this procedure is summarized in table I. We notice that the rejection power can be increased allowing a decrease of positron detection efficiency; this should be useful in particular at 10 GeV.

5. – Conclusions.

The results presented here show that, in the case of the proposed calorimeter, it is possible to achieve a rejection power of the order of $(10^{-3} \div 10^{-4})\,\mathrm{p/e^+}$, combining the indications on the longitudinal and transverse shower shape. This value is suitable for the purposes of the WIZARD experiment.

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● RIASSUNTO

In questo lavoro presentiamo lo studio, realizzato con un metodo di Monte Carlo, della risposta di un calorimetro progettato per un esperimento da inserire nel magnete della stazione spaziale USA. Il principale obiettivo, considerato nel progetto di questo calorimetro, è l'efficiente discriminazione tra sciami elettromagnetici e adronici. Il potere di reiezione è stimato migliore di $1\cdot 10^{-3} p/e^+$ per energie delle particelle incidenti da 10 GeV a 100 GeV.

Исследование зернистости для трекового калориметра с оптимальным устранением фона протонов при детектировании позитронов.

Резюме (*). — В этой работе мы предлагаем исследование по методу Монте-Карло отклика калориметра, который сконструирован для экспериментов на космической станции США. Основная цель при конструировании такого калориметра заключается в эффективной дискриминации между электромагнитными и адронными ливнями. Оценивается степень устранения фона протонов, которая оказывается лучше, чем $1\cdot 10^{-3}$ p/e$^+$ для падающих частиц с энергиями между 10 ГэВ и 100 ГэВ.

(*) *Переведено редакцией.*