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Experimental results on stopping muons at 60 and 300 m.w.e.

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SEZIONE II

(Fisica, chimica, geologia, paleontologia e mineralogia)

Fisica. — *Experimental results on stopping muons at 60 and 300 m.w.e.* Nota di LAURA BERGAMASCO, CARLO CASTAGNOLI, M. CRISTINA TABASSO e PIO PICCHI, presentata (*) dal Socio G. WATAGHIN.

RIASSUNTO. — Si presentano i risultati sull'intensità dei muoni che passano e di quelli che s'arrestano decadendo in un rilevatore a scintillatore liquido a quattro profondità: 60, 110, 175 e 300 m.a.e. I dati così ottenuti vengono discussi e confrontati con quelli degli altri autori.

1. In these last years the stopping muon rate at moderate depths (10–60 m.w.e.) has been studied fairly extensively. There are however discrepancies between the values obtained with different techniques (emulsions and scintillator), and also between those obtained with the same method. For all these reasons we resolved to perform an experiment whose main features were to be: *a*) liquid scintillator rather than emulsions for the well known efficiency problems, *b*) detector of large volume and spherical symmetry to reduce the geometrical effects which often bias decay experiments.

TABLE I.

Experimental results on the traversing and stopping muon rate.

Zenithal angle θ	$0°$	$60°$	$60°$	$78°$
Depth x (m.w.e.)	60	110	175	300
E_0 (GeV)	12	23	40	70
Telescope factor (cm^2 sr) . . .	100	240	240	17
N_μ ($cm^{-2} s^{-1} sr^{-1}$)	$(6.299 \pm 0.009) \cdot 10^{-4}$	$(1.893 \pm 0.007) \cdot 10^{-4}$	$(1.186 \pm 0.025) \cdot 10^{-4}$	$(6.705 \pm 0.073) \cdot 10^{-5}$
S_μ ($cm^{-2} s^{-1} sr^{-1}$)	$(1.805 \pm 0.065) \cdot 10^{-3}$	$(5.522 \pm 0.147) \cdot 10^{-6}$	$(2.568 \pm 0.449) \cdot 10^{-6}$	$(1.688 \pm 0.486) \cdot 10^{-6}$

2. The muonic flux is identified by telescopes of two plastic scintillators $30 \times 30 \times 3$ cm^3 in twofold coincidences which give information on the muon intensity in the various directions (depth and zenithal angle). The volume available for the $\mu - e$ decay consists of 500 litres of NE liquid scintillator (decay time $\tau = 2.7 \cdot 10^{-9}$ s, density $\rho = 0.88$ gr $\cdot$ cm^{-2}, atomic number $Z = 5.72$) watched by eight photomultipliers. The scintillator signals in which two pulses are separated by a time interval between 40–250 ns or

(*) Nella seduta dell'11 aprile 1970.

0.6–10.6 μs are photographed on a dual beam oscilloscope and the $\mu - e$ events are identified through their temporal sequence. Table I reports our experimental results on the muon intensity I_μ and on the stopping muon rate S_μ relative to four different depths, whose threshold energy E_0 has been derived from the energy-range relation of Castagnoli *et al.* [1]. For the irregularities in the hill pattern, the spread on the depth in the vertical direction is $\sim 20\%$, while that on the other depths is less than 15 %. The random events due to the background during the 10^{-5} s gate have been estimated and amount to less than 1 % of the registered events.

3. We shall first discuss briefly the results on the traversing muon intensity I_μ. It is well known that the intensity measured at a depth h in a direction θ is related to the vertical intensity at the corresponding depth (h sec θ) by [2]:

$$I_\mu (h \sec \theta , 0) = I_\mu (h , \theta) \frac{(1 + \varepsilon^{-1}) E \cos \theta + E_0}{(1 + \varepsilon^{-1}) - E + E_0} \tag{1}$$

where E is the mean energy in the direction (x , θ) and $\varepsilon = 1.65 + 1/6 \log E/10$ is the exponent of the pion spectrum. Our data converted with eq. 1 to the vertical direction are shown in fig. 1*a* and there is a good agreement with the experimental results of the other authors reviewed by Barton [3] and the Durham spectrum [4].

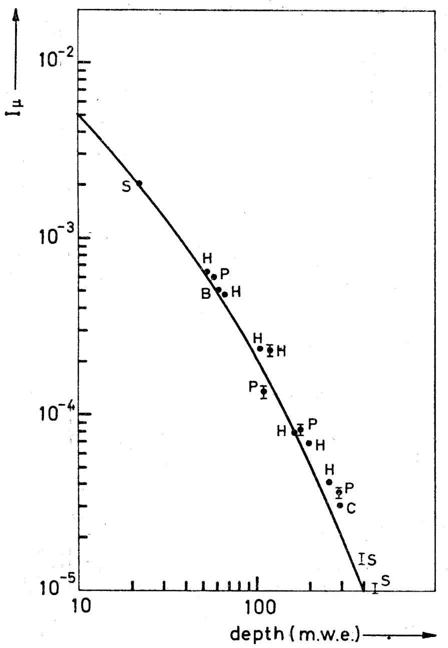

Fig. 1 *a*. – Experimental results on the traversing muon intensity. The curve is the Durham spectrum [4]. Experimental data: B) Barton; H) Higashi; S) Shreekantan; P) Present work.

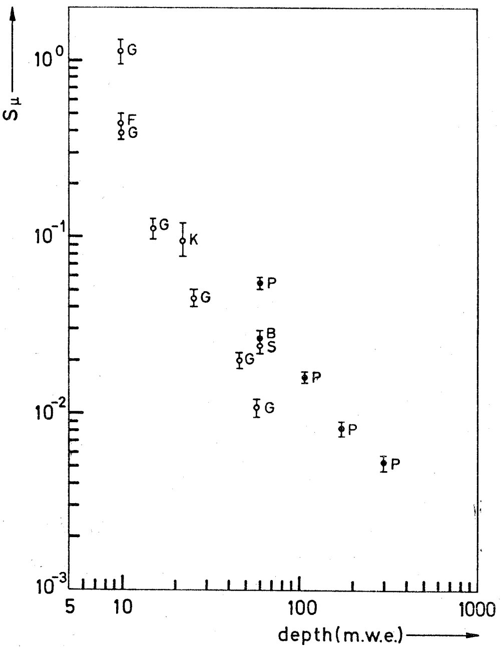

Fig. 1 *b*. – Experimental results on the stopping muon rate. Emulsions: F) Fotino [7]; G) George and Evans [5]; K) Kaneko *et al.* [6]; S) Short [8]. Scintillator: B) Barton *et al.* [9]; P) Present work.

Let us now consider our results on the stopping muon rate, shown in fig. 1 *b* together with those of other authors [5–9]. Only our result at 60 m.w.e. is directly comparable, for there are no results at greater depths. Our value turns out to be higher by a factor 2 than those given in [9] working with liquid scintillator and in [2] with emulsions. The observations which may be made on the emulsion results are obviously connected with the above-stated efficiency problems of these experimental techniques. It must yet be observed that also with scintillators we have to face some efficiency problems, an accurate " cleaning up " of the P. M. signals being important for the identification of the second pulse ($e^{\mp}$) out of the signal background in the photographic registration. We have been able to check experimentally in the first run of our measurements that this inefficiency may rise as high as 50% unless particular care is given to this point.

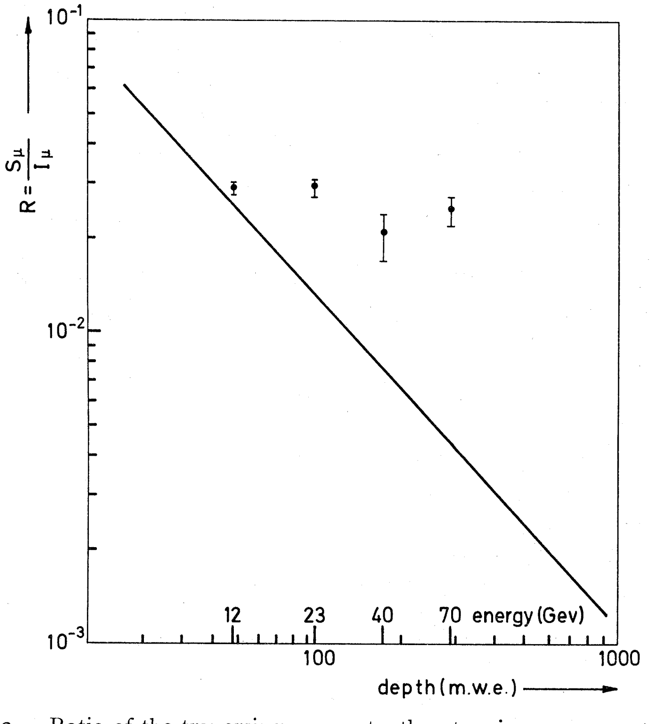

Fig. 2. – Ratio of the traversing muons to the stopping muons rate. The curve is calculated with eq. (3). The points are our experimental results.

4. An interesting figure in this process is the ratio R of the stopping muons to the traversing muons rate. The muons stopping in our detector must have an energy $\Delta E < 0.18$ GeV. At depth x, threshold energy E_0, the differential spectrum of muons is usually given by

$$F_x(E)\,dE = K\,(E_0 + E)^{-\gamma-1}\,dE \tag{2}$$

where γ is fairly well known in our energy range ($\bar{\gamma} = 2.1 \pm 0.1$).

We then obtain:

$$R = \frac{\int_{E_0}^{E_0+\Delta E} F_x(E)\, dE}{\int_{E_0}^{\infty} F_x(E)\, dE} = \frac{\gamma \Delta E}{E_0} . \tag{3}$$

At these energies the effect of the straggling is negligible. Fig. 2 shows the experimental results on R obtained in our experiments compared with eq. (3).

As it may be seen, there is a discrepancy between our experimental results and the expected values according to eq. (3), especially at the highest energies.

The effects of pions generated in rock which decay in air in μ which then stop in our detector seem to be excluded as the stopping pion rate has been measured experimentally [10] in the Station, and is lower than S_μ by two orders of magnitude. Also the production of a $n \rightarrow \pi \rightarrow \mu \rightarrow e$ chain in the scintillator seems to be negligible, as checked experimentally in the Station around that apparatus [10]. The discrepancy of fig. 1 *b*, seems to be effective and suggests the opportunity of carring on a similar experiment at a greater depth, particularly if connected with a neutrino induced production.

The experiment has been carried out in the Cappuccini Station (Torino) of Laboratorio di Cosmo-geofisica del C.N.R.

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