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Muon flux measurement in the Gran Sasso laboratory

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ABSTRACT. – Cosmic muon flux has been measured in the underground Gran Sasso Laboratory B and in the bypass n.12 of the tunnel. The experimental results are compared with the calculated flux.

Cosmic muons penetrating down to the Gran Sasso underground laboratory are a potential source of background, mainly for experiments in wich no signature of the muon induced events is available. We measured the muon flux in the main laboratory B and in the bypass n.12 which is situated at 5.6 Km from the end of the tunnel towards L'Aquila, about 0.5 Km far from the main laboratory.

The experimental set up (fig. 1) was an hodoscope of Resistive Plate Counters [1].

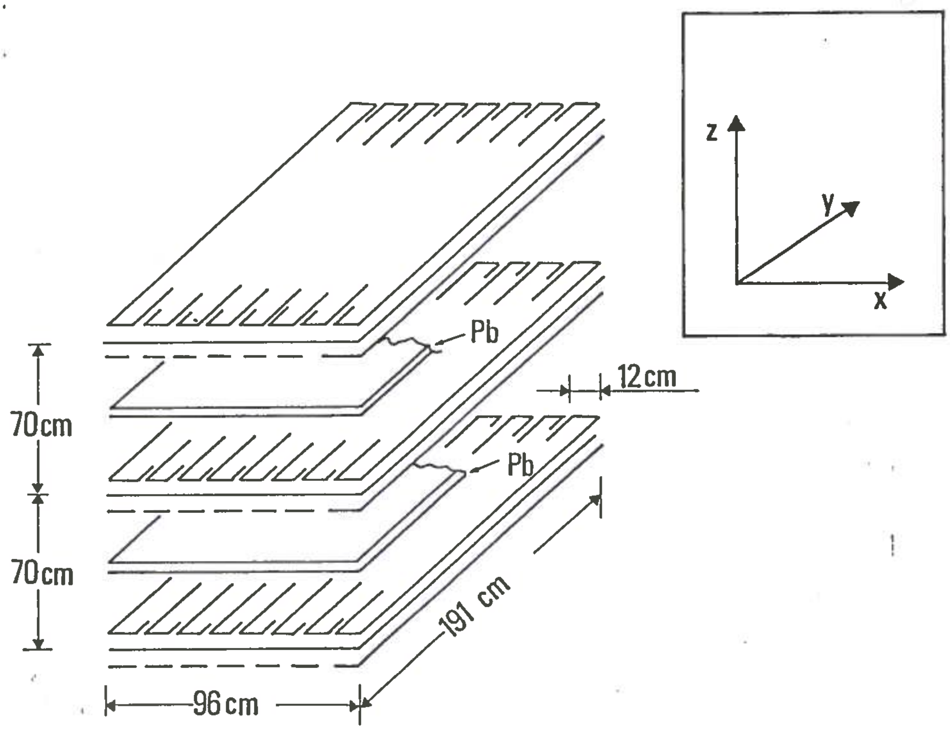

Figure 1 — Schematic view of the experimental set-up. The insert shows the coordinate system: the x-axis is parallel to the tunnel.

These are detectors of ionizing particles whose sensitive element is a layer of gas (Argon, Butane and a small amount of Freon), 2 mm thick, under a uniform electric field produced by two parallel electrode plates of phenolic polimers with a bulk resistivity of about $10^{11}\,\Omega$ cm. We used modulus containing two independent counters of 48×191 cm^2 useful area superposed in a single mechanical structure. Six moduli were assembled to realize a set-up of three pairs of horizontal sensitive planes of 96×191 cm^2 useful area. The distance between the highest and the lowest plane was 140 cm. Pick-up strips, 3 cm wide, allowed the signal read-out. Four contigous strips were grouped in the same read-out channel to localize a particle within an interval of 12 cm. Two lead plates, 3 mm thick, were interspaced between the counters to eventually absorb soft photons from environmental radioactivity. The whole system was installed on a van which acted as a movable laboratory.

Data acquisition through a CAMAC system controlled by a stand-alone microprocessor was triggered at the occurrence of a coincidence — within 80 ns — of at least four among the six sensitive planes. Two measurement sets of 60 and 102 hours were carried out in the main laboratory and in the bypass respectively. In both cases the experimental set-up was oriented with the read-out strips perpendicular to the tunnel direction. In the analysis only tracks crossing all the three counters were accepted. Fig. 2 shows the

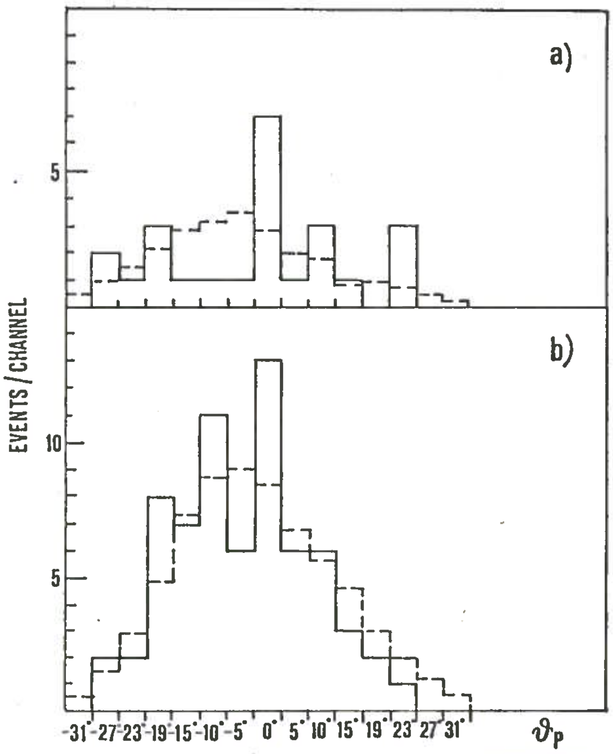

Figure 2 — Solid histogram represents the experimental data, dashed one represents Monte Carlo evaluations: a) main laboratory; b) bypass n.12. θ_p is defined to be negative for muons coming from L' Aquila side.

distributions of θ_p — the projected zenit angle on the xz plane — for 24 events collected in the main laboratory (fig. 2a) and 67 events collected in the bypass (fig. 2b). The muon counting rate over our set-up turns out to be: $R = (0.40 \pm 0.08)$ μ/h in the main laboratory and $R = (0.66 \pm 0.08)$ μ/h in the bypass.

The deep underground muon intensity at the slanted depth h and zenith angle θ can be factorized as:

$$I_\mu(h,\theta) = I(h) \times G(h,\theta)$$

where $I(h)$ represents the "vertical intensity" and $G(h,\theta)$ accounts for the "angular enhancement" [2,3]. We parametrize $I(h)$ as

$$I(h) = Ah^{-\alpha} \exp[-\beta h] \qquad cm^{-2}\ sterad^{-1}\ s^{-1}$$

where h is measured in hg·cm^{-2} of standard rock. Following ref. 3 we assume $A = 108.5$, $\alpha = 2.51$ and $\beta = 7.177 \times 10^{-4}$. According to usual approximations [2,3] the function $G(h,\theta)$ can be assumed to be independent from h and given by:

$$G(h,\theta) \simeq G(\theta) \simeq 1/cos\theta.$$

To avoid computational divergences we parametrize $G(\theta)$ as:

$$G_0(\theta) = \begin{cases} 1/\cos(\theta) & 0^\circ \leq \theta \leq \theta^* \\ \cos(\theta)/\cos^2(\theta^*) & \theta^* \leq \theta \leq 90^\circ, \end{cases}$$

however the final results are not critically dependent on θ^* value.

The rock depth travelled by a muon coming from a given (θ,ϕ) direction — namely the slanted depth $h(\theta,\phi)$ — was estimated using a map of the Gran Sasso region [4] covering an area of 20×20 Km^2 and giving the constant altitude lines in steps of 200 m (300 m steps are used in the interval 1000-1600 m). In the calculations, we assumed $\rho = 2.81$ g/cm^3 and $Z_{av} = 9.4$ for the Gran Sasso rock. The muon flux $I_\mu(\theta,\phi)\Delta\Omega$ was then evaluated in steps of $\Delta\phi = 5°$ and $\Delta\cos\theta = 0.05$ to form a 72×20 matrix covering the interval $0° \leq \phi \leq 360°$ and $0 \leq \cos\theta \leq 1$.

A comparison between experimental and calculated values is reported in table I. Here are quoted the values of: the muon flux in 2π solid angle, the fraction accepted by our set-up, the calculated and experimental muon counting rate.

TABLE I

	θ*	μ *flux* $(m^{-2}h^{-1})$	*accepted flux*(%)	*calculated rate* (h^{-1})	*experimental rate* (h^{-1})
lab B	60°	.91	.22	.37	$.40 \pm .08$
	80°	.91	.20	.36	
by-pass	60°	1.33	.35	.85	$.66 \pm .08$
	80°	1.36	.34	.85	

In fig. 2 dashed lines show Monte-Carlo distributions normalized to the experimental number of muons. The agreement between evaluated and measured values seems to be fairly good, the main source of systematic errors being the assumed value for the rock density.

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References

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[2] A. Castellina, B. D'Ettorre Piazzoli, G. Mannocchi, P.Picchi, S. Vernetto and M. Bilokon: *Nuovo Cim.* **C8**(1985),93.

[3] L. Bergamasco, A. Castellina, B. D'Ettorre Piazzoli, G.Mannocchi, P.Picchi, S. Vernetto: *Nuovo Cim.* **C6**(1983),569.

[4] A digitized copy of the Gran-Sasso map was kindly provided by the INFN, sezione di Bari.