

**PRELIMINARY RESULTS ON UNDERGROUND MUON BUNDLES  
OBSERVED IN THE "FREJUS" PROTON-DECAY DETECTOR**

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1. Introduction. The proton-decay detector installed in the "Modane Underground laboratory" (4400 mwe) <sup>(1)</sup> in the Fréjus tunnel (French Alps) has recorded 80 880 single muon and 2 322 multi-muon events between March '84 and March '85 (6425 hours of active time). During this period, a part of this modular detector was running, while new modules were being mounted, so that the detector size has continuously increased. The final detector has been completed in May '85.

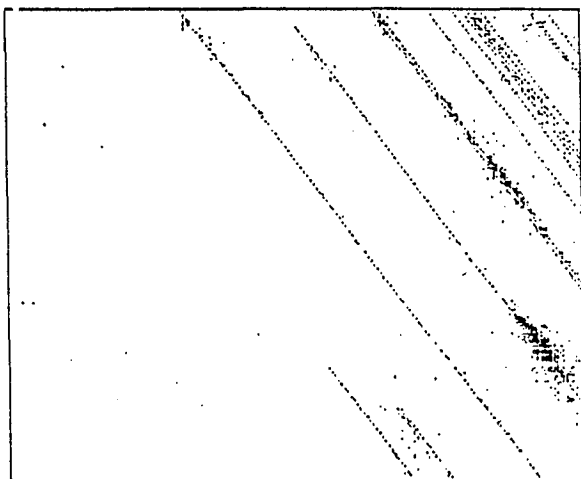


Figure 1

The experimental set-up is described in another paper presented at this Conference <sup>(2)</sup>. We just recall here the features which are relevant for underground muon studies. The final size of the apparatus is  $6 \times 6 \times 13 \text{ m}^3$  corresponding to an apparent detection area averaged over all muon directions of  $96 \text{ m}^2$ . This surface is reduced to  $60 \text{ m}^2$  for the data presented here which were taken with a part of the modules. The "Fréjus" detector thus combines a rather large detection area with a

high spatial resolution (flash-tube size  $5 \times 5 \text{ mm}^2$ ). Both qualities are needed in order to be sensitive to high muon multiplicities at the depth of 4400 mwe, which reflect, at least partially, the composition of primary cosmic rays in the range  $10^5 - 10^8 \text{ GeV}$ . The importance of the spatial resolution is illustrated in figure 1, showing a bundle of 15 muons observed in the Fréjus detector.

2. Results Figure 2 shows the observed multiplicity distribution. For those bundles including 3 muons or more, the following characteristic distances have been calculated:

- the smallest distance between muons;
- the average distance of all muons pairs;
- the radius of the smallest circle surrounding all muon impacts in the plane perpendicular to the shower direction.

The following table displays the average values of the preceding distances obtained in the present data sample. The average distance between muons in di-muon events is also shown.

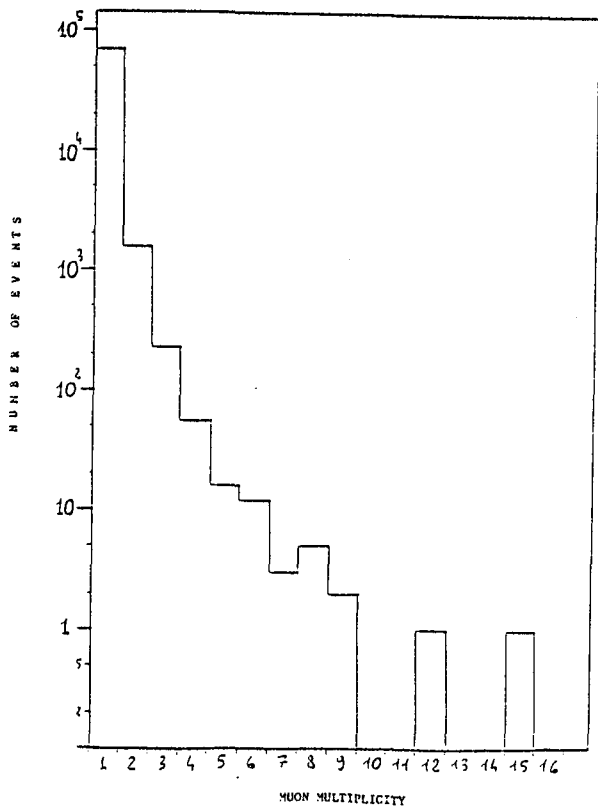


Figure 2

Average smallest distance ( $N_{\mu} \geq 3$ )	$1.30 \pm 0.06 M$
Average distance ( $N_{\mu} \geq 3$ )	$2.75 \pm 0.07 M$
Average circle radius ( $N_{\mu} \geq 3$ )	$2.08 \pm 0.06 M$
Average distance muons in di-muon events	$2.78 \pm 0.05 M$

### 3. Interpretation

These experimental data can only be interpreted by means of Monte-Carlo calculations simulating extensive air showers producing muons with energies greater than several TeV. The comparison with the data presented here is however not straightforward since the size of the detector has been regularly increased. The following analysis is very preliminary.

A Monte-Carlo simulation was developed and calibrated using ISR and collider data<sup>(3)</sup>. Violations of KNO scaling for multiplicity distributions as well as violations of Feynman scaling for rapidity and transverse momentum distributions were taken into account. The  $K/\pi$  ratio was assumed to increase linearly with charged multiplicity. The muons were propagated in the Fréjus rock (average density 2.75)

simulating all kinds of energy losses (ionisation, pair production, bremsstrahlung and nuclear collisions), then the detector acceptance was taken into account. The calculations show that the contribution of heavy nuclei essentially comes from primaries with energies greater than  $10^6$  GeV. In order to compare with protons or light nuclei in the same energy range, it is convenient to consider events with at least 4 muons. As a matter of fact, events with a lower multiplicity are dominated by primaries in the range  $10^4$ - $10^6$  GeV, and a normalization to such events would lead to additional uncertainties in the ratio of primary fluxes at different energies.

If  $N$  is the number of detected muons, the ratio

$$\rho = \frac{\text{Number of events with } N_{\mu} \geq 7}{\text{Number of events with } 4 \leq N_{\mu} \leq 6}$$

is very sensitive to primary composition, ranging from several percent for proton primaries, up to 30% - 50% (depending upon the spectral index) for iron nuclei. Our experimental result

$$\rho_{\text{exp}} = (14 \pm 4)\%$$

is consistent with the value expected from the so-called "low energy" composition<sup>(4)</sup>, on the basis of our Monte-Carlo program. Similarly, the characteristic distances displayed in Table 1 are accounted for with this composition.

#### References

1. A. Rousset, P. Delcros, M. Levy and J.M. Demorieux (Fev. 1983), in "Travaux" p. 9
2. AOPSW Collaboration, Contribution to this Conference.
3. W. Thome et al. (1977) Nucl. Phys. B 129, 365  
G. Arnison et al. (1982) Phys. Lett. 118 B, 167  
K. Alpgard et al. (1983) Phys. Lett. 121B, 209  
G. Arnison et al. (1983) Phys. Lett. 123B, 108.
4. J.W.Elbert, T.K. Gaisser and T. Stanev, (1983) Phys. Rev. D27, 1448.