PRIMARY COSMIC RAY SPECTRUM IN THE $10^{[illegible]}-10^{[illegible]}$ eV ENERGY RANGE FROM THE NUSEX EXPERIMENT

G. Battistoni[1], E. Bellotti[2], C. Bloise[1], G. Bologna[3], P. Campana[1], C. Castagnoli[3], A. Castellina[3], V. Chiarella[1], A. Ciocio[1], D. Cundy[4], B. D'Ettorre Piazzoli[3], E. Fiorini[2], P. Galeotti[3], E. Iarocci[1], C. Liguori[2], G. Mannocchi[3], G. Murtas[1], P. Negri[2], G. Nicoletti[1], P. Picchi[3], M. Price[4], A. Pullia[2], S. Ragazzi[2], M. Rollier[2], O. Saavedra[3], L. Satta[1], S. Vernetto[3] and L. Zanotti[2].

[1] Laboratori Nazionali dell'INFN, Frascati, Italy.
[2] Dipartimento di Fisica dell'Università and INFN, Milano, Italy.
[3] Istituto di Cosmogeofisica del CNR, Torino, Italy.
[4] CERN, European Organization for Nuclear Research; Geneva, Switzerland.

INTRODUCTION

The single muon intensity has been measured in the NUSEX experiment at various depth up to 10,000 hg/cm² s.r..

These intensities have been converted to a sea-level muon energy spectrum which is used to derive the primary all-nucleon flux.

From these data we are able to determine the slopes of the primary proton and helium spectra, which are thus used in a model for the primary composition producing the observed multiple muon rates.

DATA REDUCTION AND PRIMARY SPECTRUM

The NUSEX detector is located in the Mt. Blanc tunnel at a vertical depth of about 5000 hg cm^{-2} s.r. It consists of a cube of 150 t mass and 3.5 side, made of 136 horizontal planes 1 cm thick, interleaved with planes of tubes of 1 cm x 1 cm cross section, operating in the limited streamer mode. More details are reported elsewhere [1].

20429 muon events crossing at least 10 layers were recorded in a zenith angle range 0° - 75° during an effective working time of 18,946 hours from June 1982 to December 1984. The number of events for different multiplicities are reported in table 1.

The single muon intensity at different depths has been found using the procedure of Ref. 2. The general relation

$$I(h,\theta) = I_\mu^{\pi,K}(h)\cdot G^{\pi,K}(h,\theta) + I_\mu^{p}(h)\cdot G^{p}(h,\theta) \qquad (1)$$

has been fitted to the data. Here the π and K superscripts refer to conventional muons from π and K decay, the p superscript to prompt muons from charmed particle decays.

The angular enhancement functions have been calculated in Ref. 3 . The intensity of prompt muons is found < 4% on the considered range of depths, so that the second term in (1) has been neglected. The muon intensity is reported in Fig. 1. together with the intensity points measured with the spark chamber apparatus located in the Mt. Blanc tunnel, garage 27. The agreement is excellent, so giving a unique intensity-depth set of measurements from 3900 to 10000 hg/cm² s.r. very well represented by the relation

$$I_{\mu}^{\pi,K}(h) = (7.63\pm.48)\cdot 10^{-7}\exp[-h/(810.44\pm.84)]\,cm^{-2}s^{-1}sr^{-1}$$

Following the procedure of Ref. 2 we derive the primary all-nucleon spectrum in the relevant energy range $10^{13} \div 2\cdot 10^{14}$ eV :

$$\frac{dN}{dE_0} = (4.8\pm.2)E_0^{-2.79\pm.03}\ cm^{-2}s^{-1}sr^{-1}GeV^{-1}$$

The rates of events with exacty n muons have been calculated following the procedure described in Ref. 4.

$$\phi_n = \sum_i K_i(A) \int E_0^{-\gamma_i(A)} P_n(E_0,A)dE_0$$

where P_n (E_0,A) is the probability to sample n muons of a shower resulting from the interaction of a primary with energy E_0, and mass A, and the primary spectrum is described as a superposition of single power spectra

$$\frac{dN}{dE_0} = \sum_i k_i(A)\ E_0^{-\gamma_i(A)} \qquad (i=p,\alpha,CNO,Mg,Fe)$$

Inputs to P_n (E_0,A) come from the energy and radial muon distributions calculated by Gaisser and Stanev (Ref. 5) for our experimental site. We assume a value of -2.79 for the spectral index of proton and helium nuclei as determined from our data and normalize the flux at 10 TeV to the JACEE data. The spectral index for CNO and Mg groups is chosen slighty flatter as suggested by direct measurements to which we refer for relative normalization. The iron spectrum is normalized to a flux of 2.42 10^{-5} nuclei/(m²•sr•s•GeV/nucleon) at 100 GeV/nucleon, while its spectral index is considered as a free parameter.

Beyond a rigidity $R_c = 2\ 10^6$ GeV/c, all spectra steepen to $\gamma = 3.0$. The breaks for nuclei different from protons are at a total energy $(A/2)R_c$.

Fig. 2 shows that the measured rates are well described by an iron spectral index in the range 2.6 - 2.7.

This model describes very well both the all-nucleon flux in the range 10^{13} - 10^{14} eV and the all-particle flux between 10^{13} - 10^{16} eV (see for exemple the compilation of Hillas in Ref. 6). Normalization coefficients, slopes and breaking points or all components are summarized in table 2.

CONCLUSION

We have determined a primary cosmic ray spectrum fitting both our experimental multiple muon rates and the all-nucleon flux derived from the single muon intensities underground.

In the frame of the interaction model developped by Gaisser, Elbert and Stanev, we are able to reproduce NUSEX muon data with a primary composition in which the iron spectrum is only slightly flatter than the proton one.

This result rules out the popular idea that the primary composition varies drastically with increasing energy, leading to the dominance of heavier nuclei at energies 10^{15} - 10^{16} eV.

References

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Figure Captions

Fig. 1 - Muon intensity underground at Mt. Blanc.
Fig. 2 - Comparison between experimental rates and the predictions of our model of primary composition for different values of the iron group spectral index.

Table 1

Rate of multiple muons

Multiplicity	# events	Time
1	20429	
2	211	
3	29	18946 hours
4	4	
5	2	
6	1	

Table 2

Group	K_i ($m^{-2}s^{-1}sr^{-1}GeV^{-1}$)	γ_i	Points of change of slope, E(GeV)
p	$3.28\ 10^4$	2.79	$2\ 10^6$
He	$1.75\ 10^4$	2.79	$4\ 10^6$
CNO	$6.20\ 10^3$	2.71	$1.4\ 10^7$
Mg	$9.20\ 10^3$	2.71	$2.6\ 10^7$
Fe		2.6÷2.7	$5.2\ 10^7$