LATERAL DISTRIBUTION OF HIGH ENERGY MUONS IN EAS OF SIZES $N_e \simeq 10^5$ and $N_e \simeq 10^6$.

Bazhutov Yu.N., Ermakov G.G., Fomin Yu.A., Isaev V.I., Jarochkina Z.V., Kalmykov N.N., Khrenov B.A., Khristiansen G.B., Kulikov G.V., Motova M.V., Proshkina I.P., Rukovichkin V.P., Solovjeva V.I., Sulakov V.P., Shkurenkov A.V. Trubitsyn A.V. and Vashkevich V.V.

Institute of Nuclear Physics, Moscow State University, Moscow, 119899, USSR.

Muon energy spectra and muon lateral distribution in EAS are investigated with the help of the underground magnetic spectrometer working as a part of the Moscow State University EAS array [1,2,3]. Before going to new results on EAS muons a general concept of the measurement shold be mentioned. For every registered muon the data on EAS are analysed and the following EAS parameters are obtained: size N_e, distance r from the shower axis to muon, age parameter s. So the number of muons with energy over some threshold E_μ associated to EAS of fixed parameters are measured: I_{reg}. To obtain traditional characteristics-muon flux densities as a function of the distance r and muon energy E_μ, i.e. muon lateral distribution and energy spectra which are widely discussed in terms of hadron-nucleus interaction model and composition of primary cosmic rays one should use the equation:

$$\frac{\Delta I_{reg}}{\Delta N_e \Delta r \Delta s} = t \cdot 2\pi r \int_0^{\theta_1(\varphi)} \int_0^{2\pi} d\cos\theta \, d\varphi \, I(\theta,\varphi) \cdot \mathcal{F}(N_e,s) \, W_{reg}^{EAS}(N_e,r,s,\theta) \cdot W_{reg}^{\mu}\left[E_\mu, N_e, r, s, \sigma(E_\mu,\theta,\varphi)\right] \quad (1)$$

where $\mathcal{F}(N_e,s)$ is known spectrum of EAS, $W_{reg}^{EAS}(N_e,r,s,\theta)$ is probability to register the EAS of specified parameters, W_{reg}^{μ} is probability to register muon of energy over E in magnetic spectrometer with effective area $\sigma(\theta,\varphi,E_\mu)$, $I(\theta,\varphi)$ is angular distribution of EAS, $\theta_1(\varphi)$ is spectrometer geometry limit on zenith angle θ, t is operation time. In our case probability is equal

$$W_{reg}^{\mu} = \{1 - \exp[-\rho_\mu(E_\mu,N_e,r,s,\theta) \cdot \sigma(\theta,\varphi,E_\mu)]\} \simeq \rho_\mu(E_\mu,N_e,r,s,\theta) \cdot \sigma(\theta,\varphi,E_\mu) \quad (2)$$

where $\rho_\mu(E_\mu,N_e,r,s,\theta)$ is muon flux density.

For final analysis only showers with $W_{reg}^{EAS} \geq 0,9$ ($0,9 \leq s \geq 1,6$) are selected. In this case the densities ρ_μ derived from experimental data are unbyased on age parameter. So equation (1) transforms to

$$\frac{\Delta I_{reg}}{\Delta N_e \Delta r \Delta s} = t \cdot 2\pi r \cdot \mathcal{F}(N_e,s) \cdot \rho_\mu(E_\mu,N_e,r,s,\bar{\theta}) \cdot \sigma'(E_\mu); \; E_\mu, \text{Gev} \quad \bar{\theta} = 9^\circ \quad (3)$$

where σ' equal to $\sigma' = \int_0^{\theta_1(\varphi)} \int^{2\pi} I(\theta,\varphi) \cdot \sigma(\theta,\varphi,E_\mu) \, d\cos\theta \, d\varphi$ is geometry factor $\sigma'(\geq 15) = .14 \, m^2$. In Table 1 the numbers of registered muons for threshold energies E =10,200 and 500 Gev are presented. EAS size ranges are: N_e 1- $3.10^4 - 10^5$ ($\langle N_e \rangle = 6.10^4$), N_e 2- $10^5 - 3.10^5$ ($\langle N_e \rangle = 1,6.10^5$) N_e 3- $3.10^5 - 10^6$ ($\langle N_e \rangle = 5.10^5$) N_e 4- $\geq 10^6$ ($\langle N_e \rangle = 3.10^6$).

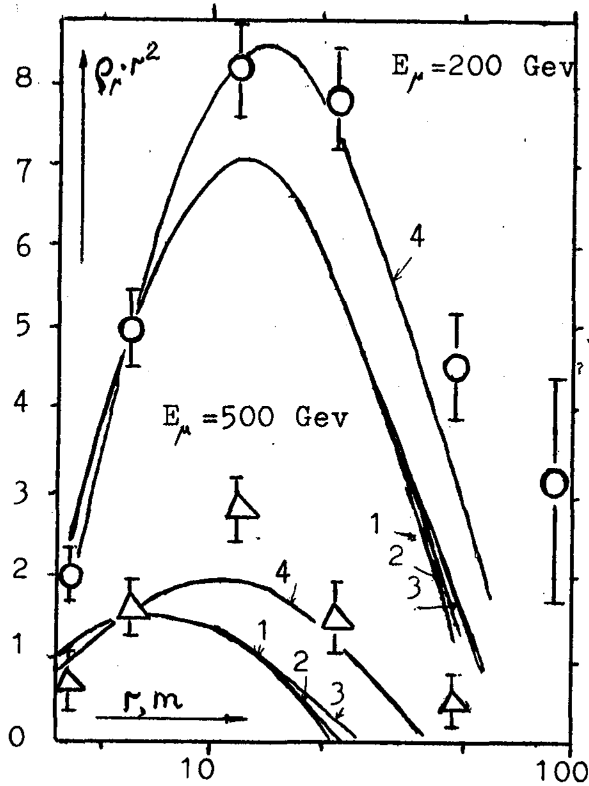

Fig.1 a

The data for muon threshold energies E_μ=200 and 500 Gev are corrected for MDM as in [1]. Muon lateral distribution (LD) shows weak dependance on EAS size. The following formula approximates the obtained data

$$\rho_\mu = K \cdot \left(\frac{N_e}{10^6}\right)^{\alpha} \cdot r^{-n} \cdot exp[-r/r_0(N_e)]$$

where parameter α is equal

E_μ Gev	50	100	200	500
α=	0,78	0,77	0,76	0,77
±	0,04	0,05	0,06	0,1

and

$$k = 1{,}3 \cdot 10^4 / (E_\mu + 250)^{1,4}$$

$$n = 0{,}55 \cdot \left(\frac{E_\mu + 2}{12}\right)^{0,1}$$

$$r_0 = \begin{cases} 30 \cdot \left(\frac{E_\mu+2}{12}\right)^{-0,62} \cdot \left(\frac{N_e}{10^6}\right)^{0,05 \pm 0,05} & 50 \le E_\mu \le 200 \\ 10 \pm 3 \text{ m} & E_\mu = 500 \end{cases}$$

In Fig.1a the average LD of muons with E_μ=200 and 500 Gev are presented for $\langle N_e \rangle = 2 \cdot 10^5$.

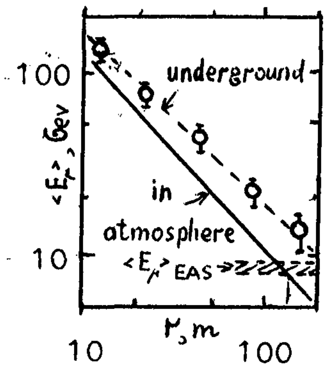

Fig.1 b

The mean muon energy as a function of distance r is presented in Fig.1b. Experimentally measured underground muon energy spectra were transformed to muon spectra in atmosphere. Solid line in Fig.1b presents mean muon energy in atmosphere at sea level. At the distance r=120±12m mean muon energy is equal to mean over EAS energy of muons, $\langle E_\mu \rangle$= 8±1 Gev,[3]. The ratio of positive and negative muon numbers was analysed for various distances r. Numbers of muons in differential ranges of energy are presented in Table2. It is seen that the ratio I_+/I_- does not deviate from 1 in statistical errors.

Table 1. Numbers of registered muons.

	r=0-8 m			r=8-16 m			r=16-32 m			r=32-64 m			r=64-128			r≥128	
E_μ,Gev	10	200	500	10	200	500	10	200	500	10	200	500	10	200	500	10	200
All	359	94	35	556	92	30	980	87	21	952	29	5	301	3	1	55	0
W0,9	359	94	35	484	81	28	625	46	10	508	12	2	112	2	0	10	0
N_e-1	224	60	22	259	42	14	177	18	5	-	-	-	-	-	-	-	-
N_e-2	84	23	12	131	19	7	273	18	3	207	3	1	-	-	-	-	-
N_e-3	41	8	1	77	17	5	139	7	2	205	5	1	33	1	0	-	-
N_e-4	10	3	0	17	3	2	36	3	0	96	4	0	79	1	0	10	0

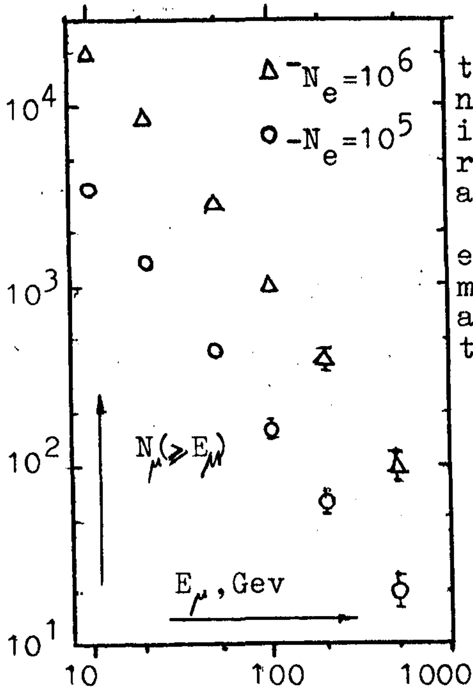

Fig. 2 a.

Comparison of LD of muons registered in E-W sectors of earth magnetic field and of muons registered in N-S sectors does not show difference in statistical errors (of about 10-20 %)for muon densities. It proves that for vertical showers deflection of muons in earth magnetic field is much less than angular spread of muon parent particles in acts of their generation.

Full numbers of muons $N_\mu(\geq E_\mu)$ in EAS of size $N_e=10^5$ and $N_e=10^6$ are presented in Fig.2a. The dependence $N_\mu(N_e)$ for the range of muon threshold energies E_μ=10-500 Gev and EAS of sizes $N_e=6.10^4-3.10^6$ can be presented in form

$$N_\mu(N_e) \sim N_e^\alpha$$

with α=0,78 in experimental errors presented above.

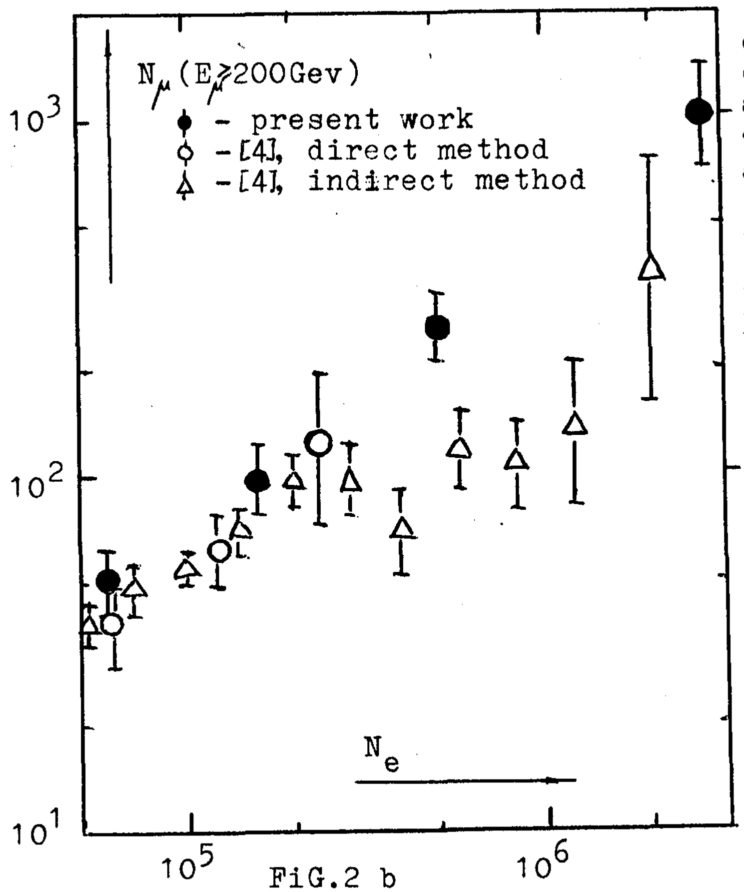

FiG.2 b

In Fig.2b our data on muons of threshold energy E_μ=200 Gev are compared to the data[4] of Indian group. The data[4] is recalculated to sea level taking the dependance N_e on depth x in atmosphere as

$$N_e \sim \exp(-x/180)$$

where x is in g/cm^2

One can see that our data do not confirm the change of the exponent α in $N_\mu(N_e)$ dependance obtained by indirect method in[4].

Table 2. Numbers of positive I_+ and negative I_- muons.

	E_μ Gev	10-50	50-100	100-200	200-500	500-1000
r < 16 m	I_+	161	97	77	57	9
	I_-	164	91	82	56	9
r=16-32m	I_+	174	75	51	18	4
	I_-	159	68	43	15	0
r ⩾ 32 m	I_+	224	69	16	6	0
	I_-	206	61	15	6	1

Experimental results presented above were compared to results of Monte-Carlo calculations based on the quark-gluon string theory of hadron-nucleon interactions[5]. This theory explains accelerator data including recent SPS collider data. In[6] this theory was applied to hadron-nucleus interactions. Calculations of EAS were carried out for muon production throughpion and kaon decays for primary protons and various primary nuclei in assumption of "superposition" model of nucleus-nucleus interactions. The composition of primaries was suggested as follows

A	1	4	14	21	56
%	40	15	15	15	15

Results of the calculations are presented in Fig.1a curves 1. One can see that for the highest measured muon threshold energies E_μ=200 and 500 Gev the theory does not agree with the experiment. To make agreement better there were carried out calculations taking into account muon production through decays of charm particles. Cross-section of charm production was taken as in[7]. Curves 2 present the results of this calculations. Soft jet production[8] was also checked as a reason for additional spread of muons. (curves 3 in Fig.1a). Both processes do not change LD of muons of threshold energies E_μ=200-500 Gev in the range of distances r close to median radius as is experimentally measured. Muon LD proved to be more sensitive to the model of nucleus-nucleus interaction. The "fragmentation" model in which nucleons not included in heavy fragments interact with target nucleus gives better agreement with the experimental data. In Fig1a curves 4 present results of the calculations taking into account this "fragmentation" model. Primary composition is as before.

Refrences.

1. Khrenov B.A., et al ,ICRC-16, Kyoto, 8,351, 1979.
2. Grishina N.V.,et al ,ICRC-17, Paris, 6, 3 , 1981.
3. Atrashkevich V.B., et al,ICRC-18,Bangalore,11,229,1983.
4. Rao M.V.S., ICRC-18, Rapp. paper, 1983.
5. KaidalovA.B.& Ter-Martirosjan K.A., Jadernaja Phys., 39,1514, 1983 and 40,211,1984 .
6. Kalmykov N.N.& Khristiansen G.B., ICRC-18,Bangalore, 11, 330, 1983.
7. Slavnov D.A., Jadernaja Phys., 41, 213, 1985.
8. Gribov L.V.,Levin E.M.,Ryskin M.V., Phys.Lett.,121B;65, 1983.