

Investigation of delaying penetrating particles with an underground device at Tien-Shan station

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Experimental data on penetrating particles delaying with respect to EAS front are obtained at Tien-Shan station using an underground (20 m.w.e.) scintillator device (MUON-T) with larger statistics than in our previous data. The results confirm the presence in the EAS with the energy higher than $\sim 10^{15}$ eV the penetrating particles delaying by more than 60 ns relative to the shower front. The probability of registration of these particles for our installation is $\cong 6 \times 10^{-3}$ whereas the calculation in terms of the QGS model gives the value $\sim 10^{-6}$ under an assumption that the delaying penetrating particles are the muons of ordinary origin. We also point at the possibility to obtain additional information on nature of delaying particles by studying the dependence of the frequency of their registration relative to the vector of a geomagnetic field (North-South effect).

1. Introduction

The investigation of particles delaying relative to the shower front, in particular the muons, was carried out in a large number of works [1].

The presence of delaying particles in the EAS indicates the existence of a delaying shower disc, and may be associated with long-life heavy particles [1] (H.Sakuyama et al., 1983). In the previous experiments performed at Lebedev Physical Institute at the underground installation (MUON-T) of Tien-Shan mountain station the results were obtained, which show the presence, in a small part of the EAS ($\leq 1\%$), of the muons delaying relative to EAS front by more than 60 ns [2].

The nature of these muons is not known at the present time. In this report the data on the delaying penetrating particles obtained with MUON-T device in 2001-2005 with larger statistics than in our previous data are presented. To reveal possible influence of a geomagnetic field on the registration of the delaying penetrating particles (probably the muons) we supplemented the MUON-T device with a chronotron in order to determine the EAS direction.

Experimental installation

The MUON-T installation, destined for measuring the EAS muon delay relative to the arrival of the first muon (assumed as the moment of the shower front arrival), was placed in the underground room of Tien Shan station (20 m.w.e.). The device consists of twelve plastic scintillators positioned for a reliable muon registration in two rows: one above the other. The sensitive area for each of the rows is 3.6 m^2 .

The scintillator light flashes were registered by a photomultiplier FEU-65.

The system of time registration (STR) allows one to register the delay within the time interval of 0-1280 ns with a bin of 20 ns. The system consists of 12 channels with an amplifier-former and the "time-code" transformers with the memory cells.

The registration of muon delay time was performed with a PC using a CAMAC creit. The registration condition was the appearance of the pulses from six or more scintillators in two rows within the interval of time resolution of 300 ns. This corresponds to muon density in the EAS at the MUON-T device area $\sim 1 \text{ m}^{-2}$.

More details about MUON-T device see in [2].

The chronotron device has four scintillator points with the two bases spaced by 40 meters in perpendicular directions.

To register the chronotron pulses we used four channels of the time device not used earlier. In connection with time delay (820 ns) on coaxial cable, for the possibility to simultaneously register the pulse delays of the underground counters and chronotron pulses the bin of time registration system was increased from 10 to 20 ns. The total range of the STR became 1280 ns. The time resolution of 20 ns permits to define the zenithal and azimuth angles with an accuracy of $\sim 10^\circ$.

2. Results

The installation MUON-T supplemented by a chronotron operated in 2001-2005 during 10043 hours, and during this period there were registered 223014 EAS.

Figure 1 illustrates the distribution of distances R between the axis of a registered EAS and MUON-T device. Figure 2 show number of particles (N_e) and primary energy E_0 corresponding to our registration conditions calculated by the Monte Carlo method, taking into account the experimental data on the spectrum over N_e , lateral distribution of muons and the dependence of muon number (N_μ) (the muon energy ≥ 5 GeV) on N_e [3].

The experimental data on temporal distribution of the penetrating particles obtained with MUON-T device in 2001-2005 and statistical reliability of the effect are given in Table 1.

Table 1.

	Delay Interval		
	60 ns \leq t \leq 100 ns	100 ns $<$ t \leq 140 ns	140 $<$ t \leq 180
n_t	1050	361	108
n_b	553	156	53
n_{ef}	497	205	55
Statistical reliability	12.4 σ	9 σ	4.3 σ

Here n_t is a total number of delaying events including the background ones; n_b , the number of background events; n_{ef} , the quantity of the effect events. The values n_b (background) were calculated by the method described in our paper [2] (R.U.Beisembaev et al., 1997). The method takes into account the dominant background from an accidental single muon, as well as spurious pulses from the photo multipliers. Figure 3 presents the temporal dependence of n_{ef} cases.

This dependence may be expressed by an exponential law:

$$N(t) \propto e^{-t/t_0} \quad (1)$$

where $t_0 \cong 30$ ns. If we assume that the law (1) works within the interval of time delays less than 60 ns up to zero delay, then t_0 is an average delay value.

The average probability of registration of the delaying penetrating particle calculated for all the exposition time with no account for the probability of muon registration is $p=3,4 \cdot 10^{-3}$. If we take into account this probability ($\cong 0.5$) for two rows of scintillators (in one row $p=0.7$), then we get the full probability of registering the penetrating particle delay: $6.8 \times 10^{-3} \cong 7 \times 10^{-3} \sim 10^{-2}$.

The calculation on the basis of QGS model under the assumption that the delaying penetrating particles are muons of ordinary origin gives for this value: $p \cong 10^{-6}$ [4].

3. Discussion

Assume the delaying penetrating particles be the products of a decay of heavy particles, which are moving with the velocity v less than c but near to c , where c is the velocity of light. The velocity of registered particles is assumed to be c . Then the delay time of penetrating particles will be defined by the delay of their parents on the way through the decay mean length l . The delay average time will be:

$$\bar{t} = t_0 = \frac{l}{v} - \frac{l}{c} \cong \frac{l}{2\gamma^2 c} = \frac{\tau_0 \gamma c}{2\gamma^2 c} = \frac{\tau_0}{2\gamma}$$

From Fig.3 for an average delay t_0 we have: $\bar{t} = t_0 \cong 30$ ns. The value t_0 differs by approximately twice from t_0 in [1] obtained by Japanese physicists (16 ns) with much better accuracy than in our experiment. Probably, an insufficient time resolution is responsible for the inaccuracy in t_0 in our case, and, so, this is not a contradiction between our and the Japanese data.

Assuming $\gamma \cong 10\div 30$, as it is in [1] (H.Sakuyama et al., 1983), then we have $\tau_0 \cong 30 \times 2(10\div 30)$ ns $\cong 1$ μ s in accordance with [1].

4. Conclusions

1. The experimental data obtained at Tien Shan station show that in an EAS with the primary energy $\geq 10^{15}$ eV the delay penetrating particles with the delay time more than tens of nanoseconds are present. The frequency of their registration is $\cong 6 \times 10^{-3}$, and this is several orders of magnitude higher than the one calculated for ordinary muons in the EAS ($\cong 10^{-6}$).
2. Probably, the nature of delay events at 20 m.w.e. is the same as for the delaying particles, which produce small showers in a dense substance in the experiments of Japanese physicists: [1] the delaying particles are created in the decay of heavy long-life particles with the lifetime ~ 1 μ s.
3. Further analysis of North-South effect for the EAS with delaying particles might give additional information about the nature of the delaying heavy particles, namely, about the charge of the particles.

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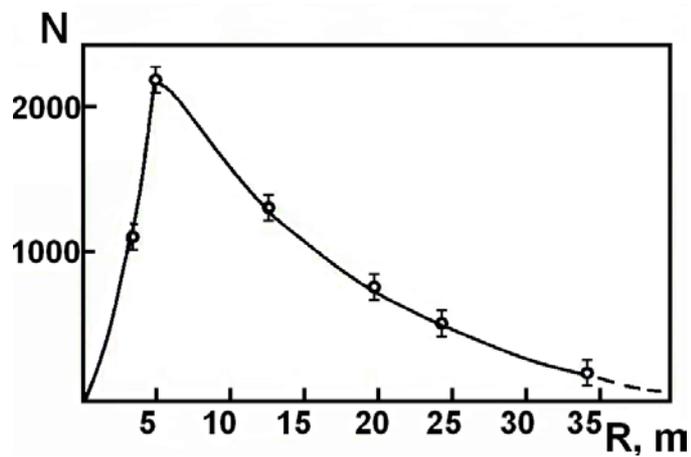


Figure 1. The distribution the distances (R) between EAS Axes and MUON-T device.

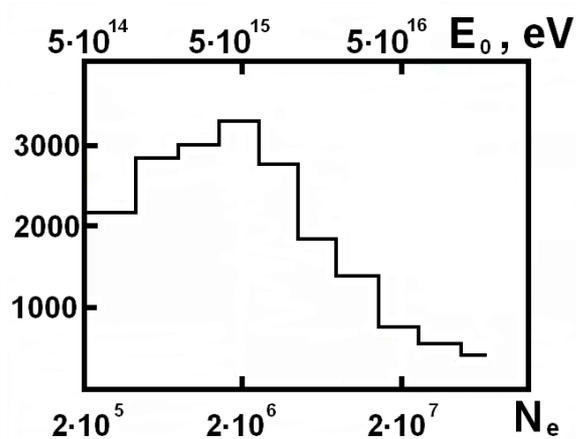


Figure 2. The distribution of EAS over N_e and primary energy E_0 .

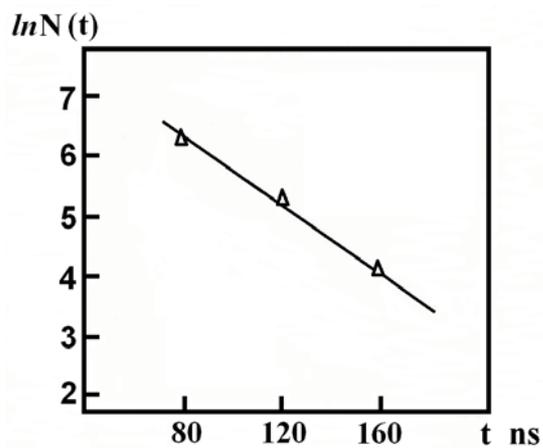


Figure 3. The dependence of the number of delaying particles from delay time.