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TIEN-SHAN EFFECT AND CHARMED PARTICLES.

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Abstract

It is shown that the Tien-Shan effect of long-flying component can be explained as a consequence of charmed particles production with high enough production cross-section (about 5 mb/nucleon at 100 TeV).

The investigation of attenuation peculiarities of EAS hadronic component energy flux in the calorimeter with lead absorber has shown /1,2/ that energy dependence of hadronic component energy attenuation length L(E) has a peak-type behaviour (see fig.1 in /1/). This phenomenon, named as "Tien-Shan effect", we'll account for as a consequence of generation and following decay of particles with charmed quarks. The most important conclusion from the comparison of theory and experiment is that charmed particles have to be produced in the fragmentational region and their production cross-section at energies about 100 TeV must be equal (5±2) mb/nucleon.

For a qualitative analisis of influence of particles with heavy quarks on the hadronic cascade we use as the first approach only one sort of particles called conventionally as charmed ones. It simplifies the system of kinetic equations for processes investigated:

$$\left\{\begin{aligned} &\frac{dS_c}{dz} = -\gamma S_c\,; \quad \frac{dS_N}{dz} = -\beta S_N + \delta S_c\,; \\ &\frac{dS_{\pi^\pm}}{dz} = -\alpha S_{\pi^\pm} + \frac{2}{3}\beta S_N + \frac{2}{3}(\gamma-\delta) S_c \end{aligned}\right. \qquad (1)$$

with initial conditions

$$\left\{\begin{aligned} &S_c(0) = \langle X \rangle \sigma_c/\sigma_N\,; \quad S_N(0) = 1 - K_N\,; \\ &S_{\pi^\pm}(0) = 2/3\,(K_N - \langle X_c \rangle \sigma_c/\sigma_N) \end{aligned}\right. \qquad (2)$$

Here S - are the fractions of primary energy transferred into charmed (C), nucleon (N) and pion ($\pi^\pm$) components;

Z is the coordinate along the axis of cascade developing; σ_c/σ_N -is a probability of charmed particle production. Eqs (1) show energy variation of charmed, nucleon and pion components because of their decay and interaction. Coefficients in (1) are :

$$\alpha=\frac{1}{3\lambda_\pi};\quad \beta=\frac{K_N}{\lambda_N};\quad \gamma=\frac{1}{\lambda_d}+\frac{K_c}{\lambda_c};\quad \delta=\frac{1-B}{\lambda_d} \qquad (3)$$

where λ_i, K_i are mean free paths and inelasticities of i-th component. B is the energy fraction transferred into pions by the particle decay into nucleons and pions (kaons have interaction properties close to those of pions). The complete solution of the system of equations is given in /3/. In particular case B = 1; K = 1, the total energy of pions is written in the form :

$$\frac{2}{3}S_{\pi\pm}=e^{-\alpha z}+\frac{\sigma_c}{\sigma_N}\frac{\langle X_c\rangle}{\gamma-\alpha}\left[\alpha e^{-\alpha z}-\gamma e^{-\gamma z}\right] \qquad (4)$$

It is seen that "the standard cascade" $\exp(-\alpha z)$ acquires additional contribution from the charmed component. At the small depths it is negative that corresponds to cascade damping because some energy is kept by charmed particles. After decay of those particles the energy is added to the cascade so that at the depth $Z_0=(\ln\gamma/\alpha)/(\gamma-\alpha)$ the transferred into pions energy becomes just the same as the energy in standard cascade. The maximum contribution from the charmed particles is achieved at the depth $Z_{max}= 2Z_0$, after that the cascade decreases along the same exponent as a standard one, but with an enlarged coefficient. So the charmed particles in the beginning of cascade start to "eat up" the standard cascade, then supply the additional "bump" which transforms into the usual decrease at the tail of the cascade.

More comprehensive system of kinetic equations for distributions of particle multiplicity F_i (index i means the particle's sort) of energy E along depth Z :

$$\left(\frac{d}{dz}+\frac{1}{\lambda_i}+\frac{m_i}{E_i\tau_i c\rho}\right)F_i(E,z)=\sum_j\frac{1}{\lambda_j}\int_E^{E_0}F_j(E',z)W_{ij}(E,E')dE'+\sum_j R_{ij} \qquad (5)$$

The dump of particles i because of interaction (λ_i) and decay (τ_i) is compensated by their production in the inelastic interactions (W_{ij}) and decays (R_{ij}) of particles j. The pion production spectrum has been chosen of CKP type, but for Λ_c it was admitted to be independent of X /4,5/ with $\bar{X}$ = 0,5. The D meson's spectrum is soft, but harder for primary pions to take into account the leading effect. Mean free paths have been taken as λ_N=192 g/cm^2; $\lambda_{\pi\pm}$ = 210 g/cm^2 /7/, and inelasticities are equal to K_N=0,63; $K_{\pi\pm}$ = 0,7 /7/; K_c=0,1 /8/. The hadronic mode of decay only has been taken into account. Charmed particles production cross-section is assumed to increase starting from FNAL energy, passing through ISR energy and achieving the constant value at an energy 100 TeV. Cascade curves in the depth's interval 374-924 g/cm^2 (as in experiment) were fitted by exponents, which determined attenuation lengths of cascades. The results are shown in fig.1. L(E) dependence for a standard cascade is shown by a dotted line. Numbers mark corresponding asympthotical cross-section values equal 1,2,5,10 mb at 100 TeV. One can see that 5 mb value corresponds to the best agreement with the experiment. The energy fraction carried out of the calorimeter by charmed particles grows with a primary energy (fig.2). It means that we use in the experiment another energy scale because we group all events according to the energy released in the calorimeter. Accounting this fact leads us to the unexpected effect i.e. narrowing of peaks and moving them to lower energies (fig.3).

For a detailed comparison with the experiment we are performing now the Monte-Carlo calculations.

Thus sufficiently effective charmed particles production in the fragmentational region leads to the energy dependence of cascade's attenuation lengths with clear maxima. It describes well qualitatively the main peculiarities of the Tien-Shan effect.

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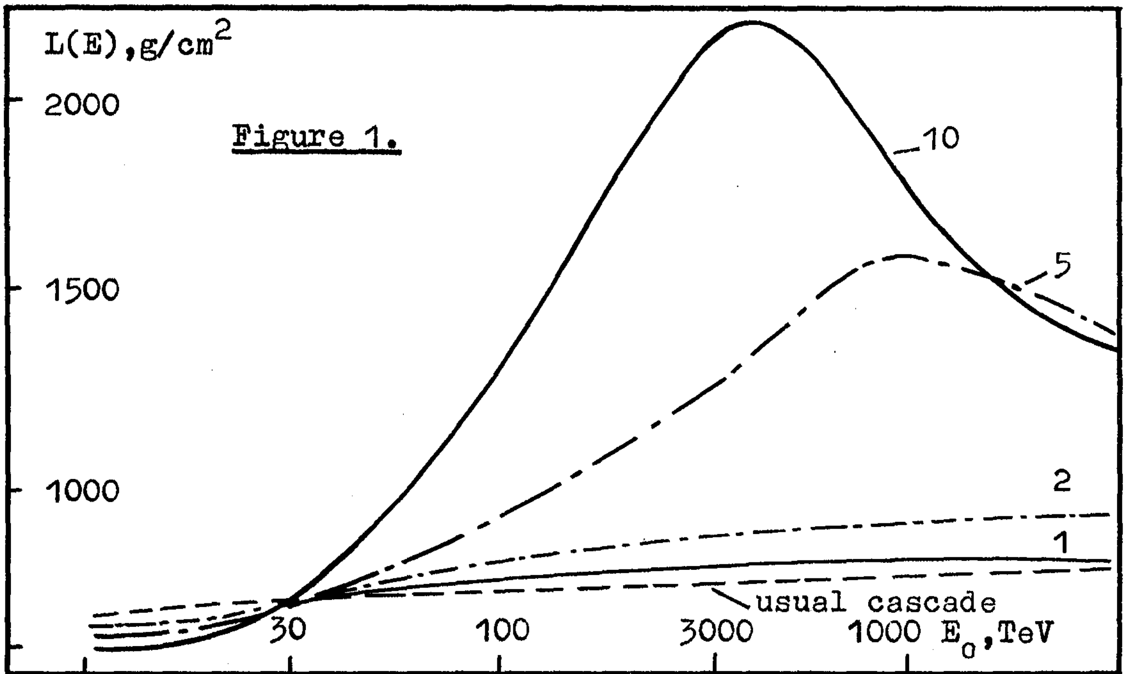

Figure 1.

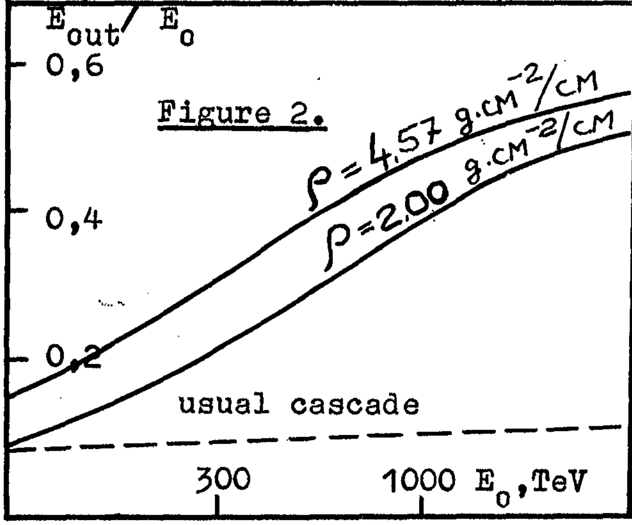

Figure 2.

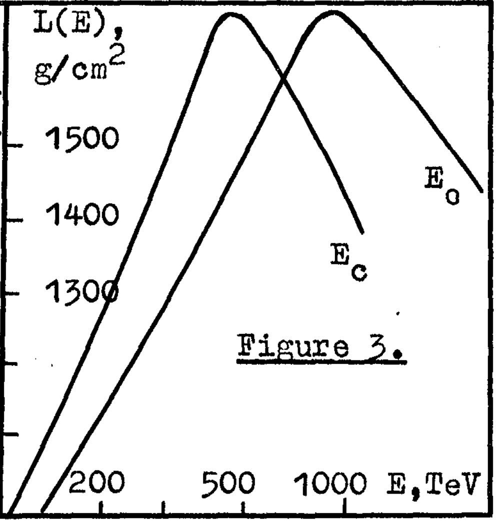

Figure 3.

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