

Cross-section of inelastic interaction of hadrons with iron nuclei.

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Abstract

Experimental data, obtained on the Tskhra-Tskaro installation in 1975-1977, 1987 and 1991 are analyzed in the work. The results of the analysis indicate the fact of the generation of particles creating electron-nuclear cascades with anomalously large length of absorption L in the iron absorber of the calorimeter.

The cross-section of the generation of unstable particles responsible for such behavior of cascades is measured. The obtained magnitude of path on the hadron interaction $\lambda=(420\pm 50)$ g/cm² corresponding to the generation cross-section $\sigma=(240\pm 40)$ mb. The comparison with the magnitude of similar cross-section, obtained on lead is made.

1 Introduction:

In the 1986-1991 experiment on Tskhra-Tskaro installation the observation on discrete Cygnus X-3 source was carried out. Ionization calorimeter (I.C) of the installation was used for separate the showers with small hadron content. In the calorimetric material obtained at this time, as well as in the material obtained on the installation[1] in 1975-1977 two types of electron-nuclear cascades were discovered sharply differing from each other in shape and length of avalanche absorption in the calorimeter which we called normal and anomalous.

Normal cascades are those having three ionization peaks distributed in the range of absorber depth from 0 to 500 g/cm² and ended at depth not lower than 560 g/cm². This situation is observed for all average normal cascades with the cascade energy from 0.2 to 10 TeV. Anomalous are the cascades in which the increase of ionization was observed at the depth of $x \geq 423$ g/cm². Contribution of such cascades to the whole statistics was, on the average, 0.25.

It was found out that the similar behavior of cascades created by the core of extensive air showers (EAS) was observed in the Tian-Shan lead calorimeter in 8% of cases [2]. Analytical calculation performed by Monte-Karlo method showed, that such behavior of hadron EAS component mainly can be explained by associative formation of Λ_c^- baryon and D-meson and their subsequent decay in EAS core [3]. For such explanation it was necessary cross-section of generation of such particles to be sufficiently large (4-5 mb/nucleon) at the energy higher than 10 TeV and particles to be generated with hard energy spectrum [4]. Thus, the particles containing heavy quarks can lead to the noticeable effect in the showers in cosmic rays if they are generated in rather large amount, particularly the generation and subsequent decay of such particles lead to the increase of the length of cascade absorption and increase of ionization at the depth of $x \geq 400$ g/cm².

1. Cascade shape in the calorimeter:

To analyze the shape of electron-nuclear cascades it was necessary that they don't fall outside the limits of the calorimeter area and don't cross its lateral sides. Hadron energy, forming cascades was determined by the equation:

$$E_h^c = (\beta/t) \sum_{i=1}^8 I_i \Delta x_i \quad (1).$$

where β and t are the critical energy and cascade units for iron.

The value of the energy of electron-nuclear cascades is the sum of two values - E_h and the energy carried away by secondary particles beyond the limits of calorimeter.

$$\dot{A}_h = E_h^c + \Delta E, \quad (2)$$

For normal cascades the ΔE value was calculated by eq.:

$$\Delta E = (\beta/t) I_8 \exp(-x/L) dx \quad (3)$$

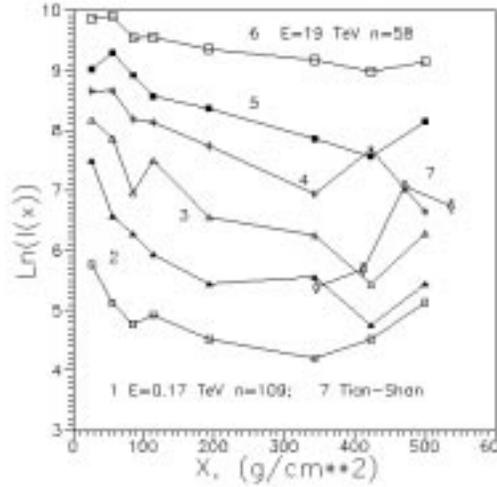


Figure 1: The shape of electron nuclear cascade curves

Here I_8 is the total ionization of last layer of ionization chamber, L is the absorption length determined from the curves of averaged cascades. For anomalous cascades the term of cascade energy is the energy released in calorimeter as the correct determination of ΔE is not possible. Fig 1 shows the cascade curves obtained in our and Tian-Shan experiment. Curve 4 is the example of normal cascade. The other curves are the cascades with anomalous length of absorption. Curve 7 - the Tian-Shan data - is the example of increasing cascade N2953-713 $E_a = 40$ TeV. The scale ionization axis for these curves is changed for comparison. Our attention is attracted by the similarity of the shapes of cascades generated by single hadrons in the calorimeter of Tskra-Tskaro installation and by the shape of cascade generated by EAS core obtained in Tian-Shan installation. Such anomalous behavior of averaged cascades can be explained only by one way. At interaction of the particles of EAS core unstable particles are formed having the less cross-section of inelastic interaction and/or coefficient of inelasticity as compared to the usual hadrons. In case of generating similar unstable particles due - to the sharp Lorentz-factor first the particles with lower energy will decay and then those with higher energy, resulting in regular increase of ionization with the depth.

In order to manifest themselves these unstable particles should have the decay path of the order of 1 m.

Table 1 [2].

Particle	Mass, (MeV)	Life time, sec.	Energy, eV.
Λ_c	2282	$1.1 * 10^{-13}$	$6.9 * 10^{13}$
D^0	1865	$4.8 * 10^{-13}$	$1.3 * 10^{13}$
D^\pm	1869	$9.1 * 10^{-13}$	$6.85 * 10^{12}$

The distinguished peculiarity of the effect observed in Tian-Shan calorimeter is its threshold character, i.e. it begins to manifest itself above the certain energy[5,6]. Curve 1 in Fig 1 obtained on Tskhra-Tskaro

installation has the averaged cascade energy $E=0.170$ TeV and by the shape and by ionization behavior at the depth of $x \geq 420 \text{ g/cm}^2$ can be classified as cascades with anomalously large absorption length.

3 Determination of the cross-section of particle generation:

For treatment the cascades satisfying the following requirements were selected:

1. The direction of the cascades should be pronounced. For anomalous cascades the total ionization of the 8-th layer should exceed the ionization of the 7-th layer .
2. The particles should pass through the upper calorimeter side.
3. The angle between the cascade axis and vertical direction should not be more than 60° . As a result of such selection not more than 500 events were included in the subsequent treatment.

The depth λ_1 of the particle generation point was determined according to the slope of the individual cascade curve at the absorber depth $423\text{-}500 \text{ g/cm}^2$. Then on the basis of obtained λ_1 values the generation cross-section was determined by the method of similarity maximum using Bartlett S-function [7]. As a result, the path value of hadron interaction $\lambda=(420 \pm 50)$ was obtained, corresponding to the cross-section of generation $\sigma=(240 \pm 40)$ mb. The generation cross-section , obtained on Tian-Shan installation [2] at energies above 10 TeV equals 1800 mb.

4 Dependence of the cascades of anomalous events of observation time:

In 1987 a run of 24 hour observation was carried out for 3 weeks. The data on the material obtained during this period are presented in Table 2.

Table 2.

N	Data of observation. (Oct.1987)	Event number obtained in this per.	Numb. of anomalous events.	Time of observation. (hour)	Contribution of anomalous events.	Number of anomalous. events/hour
1	1 - 3	246	66	48	0.27	1.38
2	3 - 5	192	39	48	0.20	0.81
3	5 - 7	139	59	48	0.42	1.23
4	7 - 9	132	65	48	0.49	1.35
5	9 - 11	137	57	48	0.42	1.19
6	11- 13	150	88	48	0.59	1.83
7	13- 15	164	99	48	0.60	2.06
8	15- 17	162	110	48	0.68	2.29

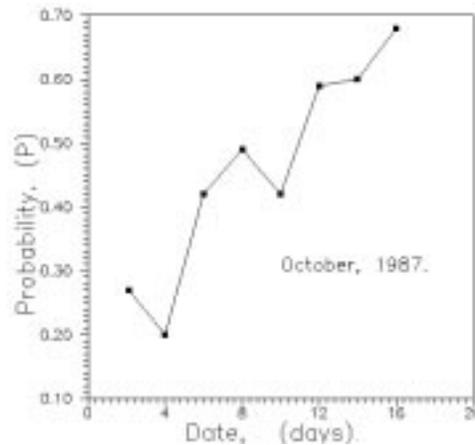


Figure 2: Dependence of the contribution of anomalous events on the observation time

Fig. 2 shows the dependence of the contribution of anomalous events on the time of observation. As it is seen in Fig.2 this dependence is of periodical nature.

Approximation of the obtained dependence by parabola with the subsequent determination of the position of the curve maximum has shown that the expected maximum contribution of anomalous events falls at (21-22).10.1987.

5. Conclusion:

In the ionization calorimeter of Tskra-Tskaro installation normal and anomalous electron-nuclear cascades, generated by single hadrons were observed. The shape of cascade curves repeats the form of cascade events created by EAS cores in Tian-Shan lead calorimeter.

Such behavior of cascade curves means that in the calorimeter absorber the unstable particles take the significant part of energy of hadrons generating them. Such particles can be Λ_c - barions and D-mesons generated associatively with hard energy spectrum.

The cross-section of the generation particles $\sigma=(240\pm 40)$ mb or 4.2 mb/nucl. was obtained. In Tskra-Tskaro calorimeter the anomalous cascades with average cascade energy $\langle E \rangle = 170$ GeV were observed.

In the experiment of 1987 the dependence of the contribution of anomalous events on the exposure time of the installation. This dependence is of periodical character and the maximum of contribution of anomalous events falls at (21-22).10.1987.

6. Acknowledgments:

The author expresses his gratitude to the staff of the Alpine Station of Tskra-Tskaro for their assistance in the exploitation of the installation and collection of experimental data used in the given work.

References

- [1]. Berdzenishvili O.L. et. al. Proc. 16th ICRC (Kyoto) **6** (1979) L337
- [2]. Yakovlev V.I. et.al. VANT, TPhE, **3**(20) 1984, P. 1
- [3]. Dremin I.M. Madigojin D.T. and Yakovlev V..I. Izvestia AN SSSR **50**(1986) P2116
- [4]. Dremin I.M. et.al. VANT, TPhE, **4**(25), 1985, P. 13
- [5]. Yakovlev V.I., Nikolsky S.I. Proc. 15 th ICRC (Plovdiv) **7**(1977) L115
- [6]. Yakovlev V.I., Nikolsky S.I. Proc. 16 th ICRC (Kyoto) **6** (1979),L59
- [7]. Bartlett M. Phil. Mag., **44** (1953), L249