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Possible reasons why LFC has not been found in the KASCADE calorimeter

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The long flying component (LFC) of the EAS hadronic component was detected in Tien Shan (3340 m.a.s.l.) ionization calorimeter (TSIC) with lead absorber. On the contrary, the KACADE group claimed that LFC has not been detected in the huge ionization calorimeter with iron absorber. Below we discuss the possible reasons of this contradiction.

1. Tien-Shan Ionization Calorimeter

TSIC had an area of 36 m^2 and consisted initially of 15 rows (19 finally) of copper ionization chambers of sizes 5.5×24×300 cm^3. Each row contained 48 ionization chambers. The total thickness of lead absorber (including the thickness of the chamber walls and steel carcass recalculated to lead) was equal to 850 g/cm^2 (1000 g/cm^2 finally). Each chamber had its own ADC with a dynamical range of $2 \cdot 10^4$. The signal measurement accuracy was better than 10% over the total range. The signal from a chamber was memorized in the diode-capacitor cell, whereupon the series of growing pulses was fed to all ACD inputs. Each next pulse in the series was 10% greater than previous one. The first pulse with an amplitude being 10% greater than that of the memorized one passed through the diode-capacitor cell, and its number n was fixed. All ADC's were calibrated in such a way after each trigger pulse. The signal amplitude at the ACD input was calculated by the formula $V_n = V_0 \cdot 1{,}1^n$ where V_0 is minimal detected value, n is number of the pulse stored. All information was recorded on magnetic tape.
The calorimeter-operation control has included the daily statistical analysis of functioning of each channel: its amplitude spectrum was compared with a spectrum derived by averaging over all the chambers of the given ionization-chamber row.

2. Investigation of hadron cascades attenuation

The shower array selected EAS's with sizes of $N_e > 1.3 \cdot 10^5$ particles. We selected EAS's for our analysis whose axes did not cross the calorimeter sides. Then the hadronic component's energy E_h released in the calorimeter at depths of 133 to 850 g/cm^2 was estimated. In fig.1 averaged over 765 events cascade at energy E_h=37,6 TeV is shown. It is seen that at the depths of absorber less than 133 g/cm^2 the electron-photon component of EAS core is dominated.

In Fig. 2 a distribution of $E_h/E_{e\text{-}ph}$ ratio, where $E_{e\text{-}ph}$ is the energy of electron-photon component of EAS core, is shown for cascades with a fixed value of the total energy release in the calorimeter, $E_c = E_{e\text{-}ph} + E_h = 80$ TeV. As is seen, the E_h value fluctuates strongly if events were selected by E_c value. To damp the E_h-value dispersion, we classified events by the E_h-value.

The ionization attenuation length, λ_i, was determined for each cascade by using the least-squares method in the depth interval 344 – 850 g/cm^2 (where hadronic component is not distorted by the EAS-core electron-photon component). The averaged attenuation length $<\lambda>$ value for cascades with a fixed energy E_h (in a narrow energy interval) was evaluated from equation: $<1/\lambda>=(\Sigma 1/\lambda_i)/n$, where n is the number of cascades.

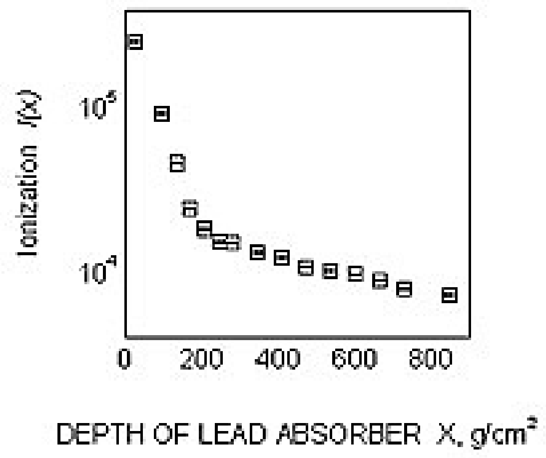

Figure 1. Averaged cascade produced by EAS core at $E_h = 37{,}6$ TeV

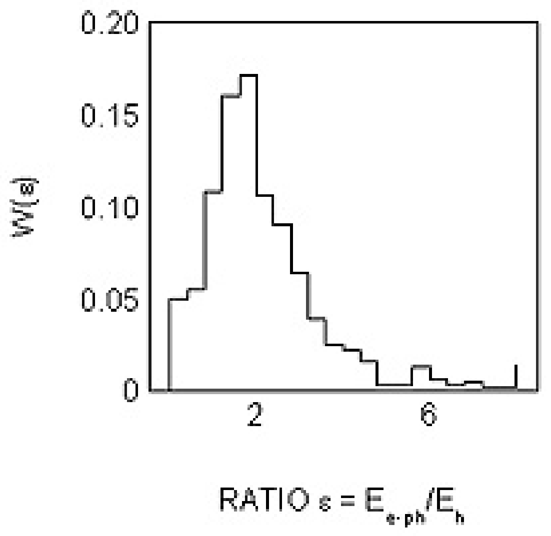

Figure 2. Distribution of $\varepsilon = E_{e\text{-}ph} / E_h$

On the other hand, the ionization attenuation lengths, $\bar{\lambda}$, were determined for averaged cascades. The energy dependence of $<\lambda(E)>$ and $\bar{\lambda}(E)$ is shown in Fig.3. A reasonable agreement between two approaches of attenuation length estimation is seen. A small difference is accounted for by some underestimation of value $<\lambda>$ in comparison with the accurate calculated value. Thus, to derive the attenuation length λ, we used finally the formulae: $\lambda = (<\lambda> + \bar{\lambda})/2$, which possibly slightly understates the λ value. $\lambda(E_h)$ energy dependencies for two runs of measurements separated by a period of 6 years are shown in Fig.4. Fully coincided results indicate the first-rate calorimeter operation.

3. Procedure of LFC searching in TSIC

It was shown by Murzin [1] that for the estimation of hadronic cascade attenuation length $\lambda=\lambda_{att}$ in the calorimeter at reasonable absorber depths the formulae $\lambda = \lambda_{int} / k_\gamma$ can be used, where λ_{int} is the particle's mean free path for interaction and k_γ is the partial inelasticity coefficient for all γ-ray generation channels in π meson interactions. Then, for lead absorber $\lambda \approx 192/0.3 = 640$ g/cm^2. More complete analytical [2] and Monte-Carlo calculations [3] give $\lambda = 780$ g/cm^2 for a cascade initiated by a single proton at $E_p = 500$ TeV, but only $\lambda = 620$ g/cm^2 for a proton at E_p=10 TeV.

The question arises: what is the reason for such difference with experimental data shown in Fig.4 ? We had analyzed the correlation between the λ value and X_{max} position of the absolute cascade maximum (ACM) in the depth interval, where λ was measured. The result derived is presented in Table 1. It demonstrates the inner consistency of data under analysis: the deeper position of ACM - the greater attenuation length. As the appearance of any cascade's local maximum is connected with an interaction of the leading particle, we can conclude that just such particles carry the energy deep into the cascade.

The component carrying the energy deep into cascade concentrates in the cascade's very central part. Let denote as $C(x)$ the concentration at the absorber depth x, which is the ratio of ionization released in the cascade center (in the circle with r=36 cm) to that released in the circle with r=300 cm.

If $C(x) = a + b_c x$, then value of $b_c = \partial C(x)/\partial x < 0$ corresponds to dissipation of energy flow from the cascade center vs. absorber depth, while $b_c > 0$ corresponds to its concentration.

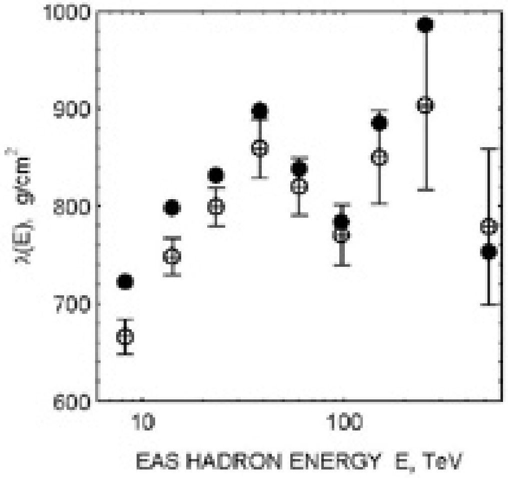

Figure 3. Energy dependence of $\langle\lambda\rangle$ - crosses in circle and $\bar{\lambda}$ - points

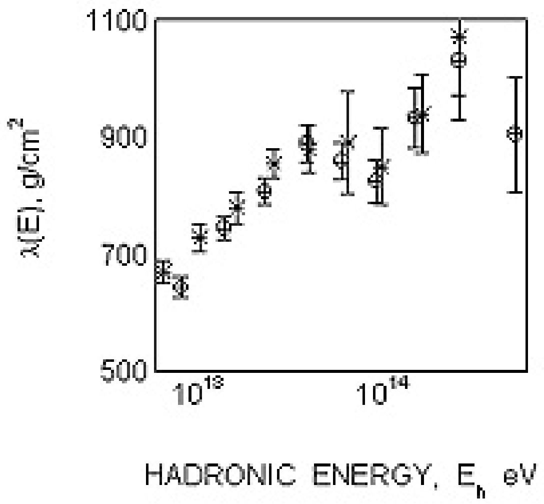

Figure 4. Points –1975 year; crosses - 1981

Table 1

X_{ACM}, g/cm²	$\lambda(X_{ACM})$, g/cm²
374	667 ± 15
600	$847 \pm^{60}_{58}$
>600	$2196 \pm^{267}_{214}$

We investigated the dependence of $b_c(\lambda)$. The result is presented in Fig. 5. It is seen that for cascades with $\lambda > 800$ g/cm², in average, $b_c > 0$, that means that the central part of such cascades attenuates slower than its periphery.

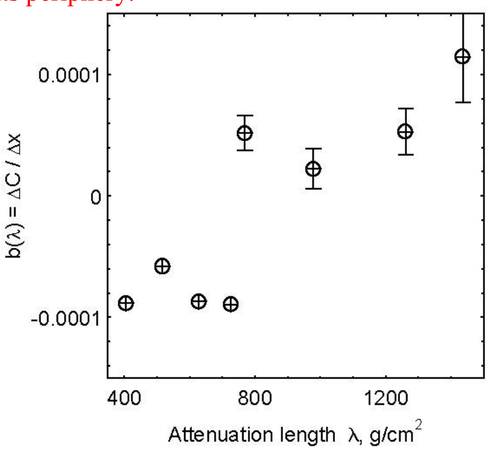

Figure 5. Dependence of concentration derivative $b = \Delta C/\Delta x$ on attenuation length

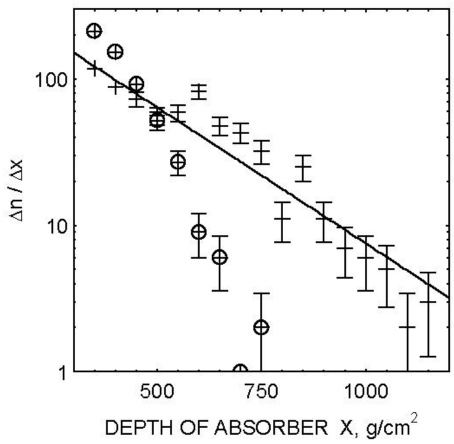

Figure 6. Distribution of ACM: $\lambda < 800$ g/cm² –circles; $\lambda > 800$ g/cm² – crosses. $E_h = 20\text{-}50$ TeV

Slow attenuated cascades have quite different distribution of ACM that is seen from fig.6 where distributions of ACM for 687 events with $\lambda > 800$ g/cm^2 and 606 events with $\lambda < 800$ g/cm^2 for cascades at E_h = 20-50 TeV are shown. It is seen, that the first distribution consists of two components. The attempt to fit this distribution by single low gives the value of $P(\chi^2) << 10^{-3}$.

THEREFORE, THERE IS THE COMPONENT IN SUCH SHOWERS WHICH JAMS THROUGH THE ENERGY DEEP INTO CASCADE !!! To distinguish this component from the penetrating muon component we entitled it as the LONG FLYING COMPONENT.

Averaged over 687 events with $\lambda > 800$ g/cm^2 cascade practically does not attenuated ($\bar{\lambda}$=2383 g/cm^2, taking into account $\langle\cos\theta\rangle$=0,92) at the depths of lead absorber 344-850 g/cm^2. The fraction of events at $\lambda > 800$ g/cm^2 is equal to 0,53±0,035.

The LFC contains the essential part of cascade energy. Let assume, that LFC contains the fraction ***a*** of the total flux of energy realized at the depth x=344 g/cm^2 and attenuates according to λ_1=2380 g/cm^2, while usual component attenuates according to λ_2=800 g/cm^2 and contains the fraction *(1-a)* of total flux of energy.

Then the value of $a = 0,3$ that can be estimated from the next correlation: $a / \lambda_1 + (1-a) / \lambda_2 \approx 1/\lambda$, where λ=1000 g/cm^2 - is the attenuation length of the whole cascade.

4. Possible reasons why the LFC has not been found in the KASCADE calorimeter

We don't familiar with the methodic of hadronic component investigation with the KASCADE calorimeter. Thus we only could assume some reasons why the LFC was not found there. Let enumerate them.

1. KASCADE calorimeter is located at the sea level. Thus the energy of the most energetic hadrons is dispersed in comparison with those at the mountain level.
2. KASCADE calorimeter uses the iron as absorber. For iron the ratio of mean free path λ_{int} to the cascade unit β is 3 times less in comparison with lead, that increases influence of fast attenuated electron-photon component of EAS rather deep in the absorber.
3. If averaged cascade was plotted according to the total energy released in the calorimeter then such cascade consists of the mixture of hadrons with very different energy that provides decreasing of the cascade attenuation length λ.
4. If averaged cascade was plotted according to the energy released by hadronic component in the whole calorimeter then (because of huge calorimeter area) the main part of released energy was provided by low energy hadrons. This can reduce attenuation length essentially.

We could recommend for KASCADE group to reanalyze their data and use for the analysis the information in the small radius around the EAS axis and select events according to the energy of hadronic component. Attenuation length should be measured at the absorber depths where the influence of electron-photon component is excluded all-out.

5. Acknowledgement

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