SCALING VIOLATION IN FRAGMENTATION REGION AT ENERGIES ABOVE 10^{15} EV BASED ON THE DATA ON COSMIC RAY HADRON COMPONENT

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The ratio of intensity of energetic hadrons, having no visible accompaniment, to the total flux of hadrons of the same energy at 4380m above sea level is given. The ratio is much more than expected for scaling model with proton primaries. This result could not be explained by complex chemical composition of primary cosmic ray and indicates the scaling violation in fragmentation region.

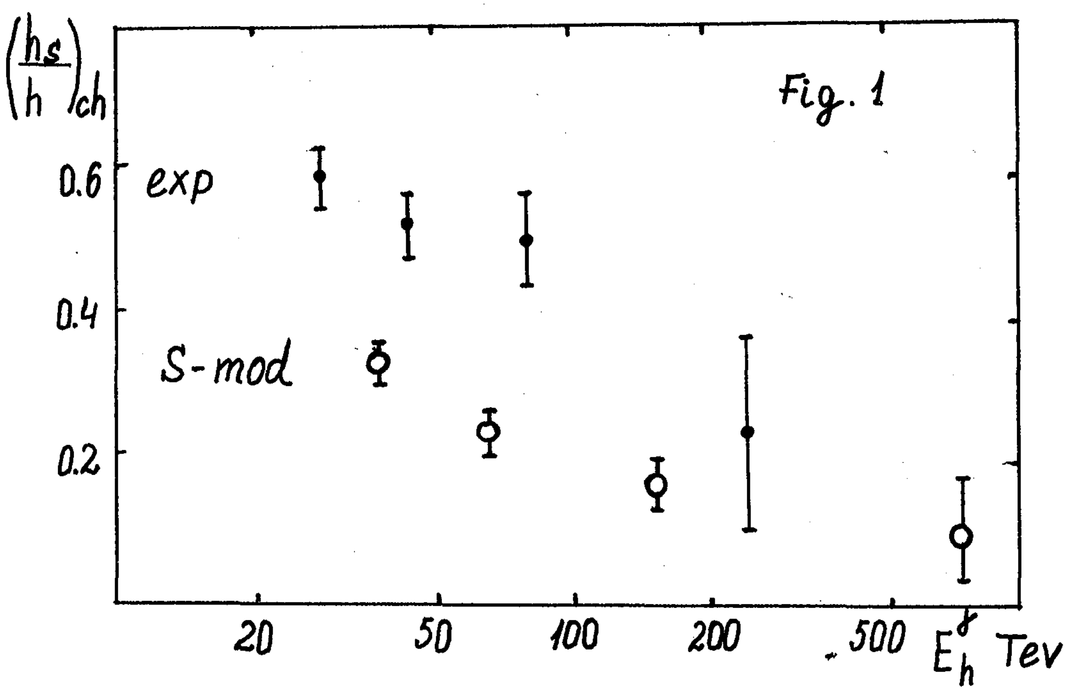
1. Experimental procedure. A special search of high energy hadrons in thick carbon type X-ray chambers [1] was made for investigation of hadron fraction having no accompaniment. 5 most energetic spots were selected in each X-ray sheet having 0.5 m^2 area. For them energy $E^{\pm}$ was determined by means of darkness dependence on E for e^+e^--pair. Then energy transferred by hadrons into electromagnetic component $E_h^{(\gamma)}$ was estimated using method described in [2]. For this procedure effective coefficient $K_{eff} = E_h^{(\gamma)}/E_h \simeq 0.35$ [2]. Only hadrons having $E_h^{(\gamma)} \geq 25$ TeV (we call them leaders) are including in the following analysis. The scanning efficiency for such hadrons is very good, since their average number of them is approximately 1 per 1 m^2 and beforehand selected one was 10 times higher.

A search of hadron accompaniment for each leader was made on the same X-ray sheet in a circle with R = 30 cm. Energy threshold for accompaniying particles was $E_h^{(\gamma)} = 3$ TeV.

Total area treated by the described method was 615 m^2, 608 leaders were found and among them 332 were single one*.

*Note that here single hadron means that it has no visible accompaniment. Only part of them are primaries which did not interact in the atmosphere.

2. Results. Energy dependence of single hadron fraction $(h_s/h)_{ch}$ is shown in Fig.1. Up to $E_h^{(\gamma)} \sim 100$ TeV it is



rather weak. The average value for $E_h^{(\gamma)} \geq 25$ TeV $(h_s/h)_{ch} = 0.55 \pm 0.03$. Sign ch-marks the value h_s/h determined for the given type of chambers. To estimate the corresponding value for incident hadrons one needs to take into account interaction probability in the chamber and restore total energy of leaders and accompaniying particles.

Correction for interaction probability ($\omega \simeq 0.6$) was made in the following way. It was supposed that multiplicity distribution of accompaniying hadrons is $(n+1)^{-\alpha}$. Constant α was found from experimental value $(h_s/h)_{ch} = \frac{\sum_0^{\infty}(n+1)^{-\alpha} C_n (1-\omega)^n}{\sum_0^{\infty}(n+1)^{-\alpha}} = 0.55 \pm 0.03$. It turns out to be $\alpha = 1.6 \pm 0.1$.

To check hypothesis about n distribution experimental distribution N_m of accompanying particle multiplicity m was compared with expected at $\alpha = 1.6$:

$$N_m = \sum_m^{\infty}(n+1)^{-\alpha} C_n^m (1-\omega)^{n-m} \omega^m \Big/ \sum_0^{\infty}(n+1)^{-\alpha}$$

The experimental and expected distribution were in good agreement. This was the argument for estimation of incident single hadron fraction as $h_s/h = 1/\sum_{0}^{\infty}(n+1)^{-\alpha} = 0.45 \pm 0.05$.

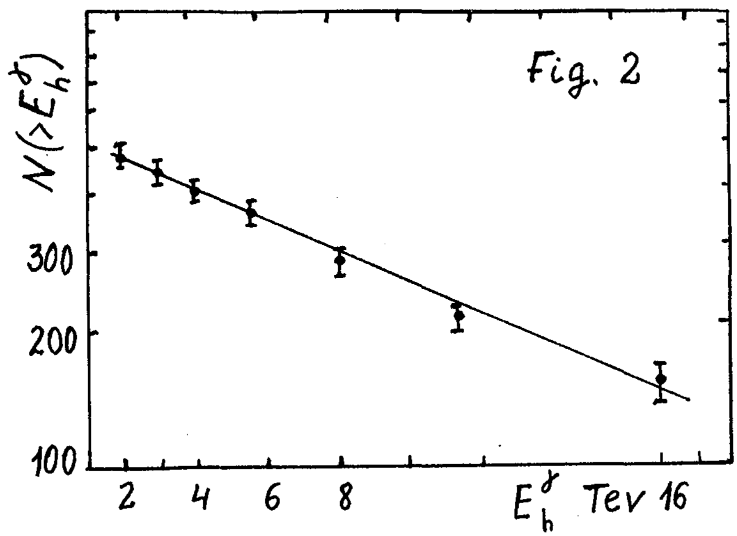
It was mentioned that effective coefficient connected total energy of a hadron $E_h^{(\gamma)}$ with measured $E_h^{(\gamma)}$ is equal to $\sim$ ~ 0.35. Therefore investigated energy ($E_h^{(\gamma)}$) interval of leaders corresponds to E_h interval (60 - 400)TeV, and threshold energy of accompanying hadrons is approximately (10 + 15) TeV.

3. <u>Comparison with the calculation.</u> Results of the scaling type S-model [3] for proton primaries simulation are shown in Fig.1 by open circles. Interaction probability in the chamber, size of X-ray sheet and K_γ distribution ($\overline{K_\gamma} = 0.17$, $\sigma = 0.12$ for nucleons, and $\overline{K_\gamma} = 0.23$, $\sigma = 0.13$ for pions has been taken into accounted in calculations.)

As it is seen, experimental value $(h_s/h)_{ch}$ up to $E_h^{(\gamma)} = 100$ TeV is essentially larger than simulated one.

Two methodical effects have to be analysed before final conclusions. The first is possible systematical error in $E_h^{(\gamma)}$. No exact correspondence of $E_h^{(\gamma)}$ in the experiment and simulation could lead to false disagreement between them due to $(h_s/h)_{ch}$ dependence on $E_h^{(\gamma)}$. But Fig.1 shows that overstimation of $E_h^{(\gamma)}$ in the experiment has to be too large to explain observed discrepancy.

The second effect is the influence of bad correspondence between energy threashold of accompanying particles in the experiment and calculation. It turns out that change of $E_h^{(\gamma)}$ from 3 TeV to 7 TeV in the simulation increases $(h_s/h)_{ch}$ from $0.30 \pm 0\ 02$ to 0.36 ± 0.02 only. The experimental situation looks rather interesting. Integral spectrum of accompanying particles is shown in Fig.2, It has exponential form without any threshold effect up to 2 TeV. About 33% of particles has $E_h^{(\gamma)}$ less than 7 TeV. But they practically do not influence on $(h_s/h)_{ch}$ value. While one changes threshold energy from 3 to 7 TeV it increases only by 0.01. This is



because most of the low energy particles are in groups of accompanying hadrons with multiplicity more than 1 or even 2.

4. Conclisions.

a. The experimental data on single hadron fraction are in disagreement with S-model prediction.

b. This disagreement could not be explained by experimental inaccuracy.

c. As it is shown in [4] , an account for interaction cross-section increase leads to the decrease of $(h_s/h)_{ch}$, i.e. to the increase of contradiction between the experiment and the model.

d. An account for complex chemical composition of primary cosmic ray leads to the same effect. This was shown in a small set of simulation for Fe primaries.

Thus an agreement between experimental data and calculation can be found only in the frame of models with scaling violation in the fragmentation region, in which either number of secondaries with large X is essentially less or (and) inelasticity coefficient is significantly larger than in scaling type models.

REFERENCES

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