EXTENSIVE AIR SHOWERS AND HIGH ENERGY INTERACTIONS

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Abstract

The most actual problem for the nuclear aspect of cosmic ray physics is now in what field could cosmic rays contribute to our knowledge of high energy interactions. In the study of the primary mass composition at high energies there are some problems, which could be referred to properties of AA-interactions. In this light the probability to find some additional electromagnetic energy losses in high energy AA-collisions is discussed. The other highlight problem is the behaviour of the inelasticity at high energies. The need to incorporate the study of the EAS longitudinal development complementary to the multivariate analysis of EAS on the observation level is emphasized.

There is a wide spread opinion that the nuclear aspect of cosmic ray physics is now dead due to the successful offensive of accelerators. I am not going to disprove it, since regard myself as its supporter. Nevertheless, there are some questions in my mind, which don't let me to become the complete, 100% supporter. As for me I prefer instead of the word "dead" to use another word "the death-bed", which gives the sick person a chance to recover.

In this point I think that the Organizing Committee was completely right inviting me to give the talk on "Extensive Air Showers and High Energy Interactions". Doubts of the potential opponent are usually more valuable, than claims of the passionate supporter. Besides that if the Organizing Committee didn't suggest me to give this invited talk, I never had an opportinity to see such an original and beautiful region of the world like Tibet. I thank all the members of the Organizing Committee with all my heart.

Now I'll tell you about these doubts. First of all, I should like to draw your attention to the observation, which seems to me relates to the subject of this talk. My favourite problem during a few latest years is the mass composition of cosmic rays, because it has the straightforward relevance to the cosmic ray origin. I spent some efforts to study it, especially in the "knee" region. Because direct measurements of the mass composition didn't reach this energy domain, we study it by means of EAS. The methods applied are based on the difference in the development of atmospheric cascades, induced by different primary nuclei. At the fixed primary energy E_0 heavier nuclei of the mass A have less value of the energy per nucleon E_0/A. At the same rate of the energy loss they produce pions and kaons of lesser energies. Their electromagnetic cascades develop and attenuate faster, than similar cascades of proton induced showers. Similarly, lower energy pions and kaons decay more often and give more muons. If the showers are observed beyond the maximum of their development, then nuclei induced showers of the same energy have more muons and less electrons, than the average shower. On the contrary, proton induced showers have less muons and more electrons. So if we select showers by their total electron number N_e, we select preferencially proton induced showers. The selection of EAS by their total muon number N_μ gives an advantage to nuclei induced showers.

The mass composition of cosmic rays is usually studied by the analysis of EAS N_e and N_μ distributions. The shape of experimental $N_{\mu(e)}$ distribution of showers, selected in the fixed interval of $N_{e(\mu)}$, is compared with the theoretical one, obtained by simulations for the superposition of showers induced by different primary nuclei. The best fit partial fractions of such showers give the so called "observed" mass composition. It is the mass composition of particles, which induce EAS, observed at the fixed atmospheric depth and selected by one of their classification parameters. The "observed" mass composition is : a) different from the primary mass composition and b) different for different classification parameters. For example, observed mass composition for N_e - selected showers in the knee region has to be lighter than that for N_μ - selected showers. After the necessary correction they both should coincide and give the same primary mass composition.

However from the very beginning, when such an cross-check analysis has been made /1/, it was noticed, that the observed mass composition of N_{μ} - selected showers was not heavier than that of N_e - selected ones. Within the errors they gave the same result. Unfortunately errors of fitting integrated one-dimensional $N_{e(\mu)}$ histograms by theoretical 5 nuclei group distributions were large. Neither in /1/, nor in our later re-analysis /2/ of the same experimental data we could say anything definite. We preferred just to keep this observation in our minds.

This summer we completed the analysis of the new experimental material, obtained at our Tien-Shan "Hadron" array. Now it was not the analysis of separate one-dimensional histograms, but of the two-dimensional distributions within so called triangle diagrams /3/. This technique is applicable to arrays with the large calorimeter area. By means of this area we measured directly the energy of the electromagnetic $E_{e\gamma}$ and hadron E_h component of the shower. Our underground muon array permitted us to measure the energy E_{μ} of the muon component. If we sum up these three energies we obtain the energy of the shower at the observation level E_{690} (690 g/cm^2 is the depth of our observation level at Tien-Shan) :

$$E_{e\gamma} + E_{\mu} + E_h = E_{690} \qquad (1)$$

The energy of neutrinos is not measured and not included into the definition of E_{690}. If we divide both parts of the expression (1) by E_{690}, we obtain:

$$\delta_{e\gamma} + \delta_{\mu} + \delta_h = 1 \qquad (2),$$

where $\delta_i = E_i/E_{690}$ is the energy fraction, carried by i - component at the observation level. The idea is that each individual shower is indicated as a point inside the equilateral triangle with the height equal to 1. The distances of this point from three sides of the triangle should be equal to energy fractions carried by electromagnetic $\delta_{e\gamma}$, muon δ_{μ} and hadron δ_h components of the shower at the observation level. We know that in this case sum of δ_i must be equal to 1.

Observed showers were selected by their electron size N_e and their energy at the observation level E_{690}. Because E_{690} is the considerable part of the primary energy E_0, we expected that the mass composition derived from this subset of EAS, had to be close to the primary mass composition. It means that it would be heavier than for showers selected by N_e.

The result nevertheless was similar to the case when showers were selected by N_μ. Observed mass composition for E_{690} - selected showers was not heavier, but close to that for N_e - selected showers (Fig.1). I am sure that this similarity is due to the muon component because E_μ is the essential part of E_{690} (δ_μ = 0.25-0.35). Hadron component has less influence due to its less magnitude of δ_h = 0.16-0.18.

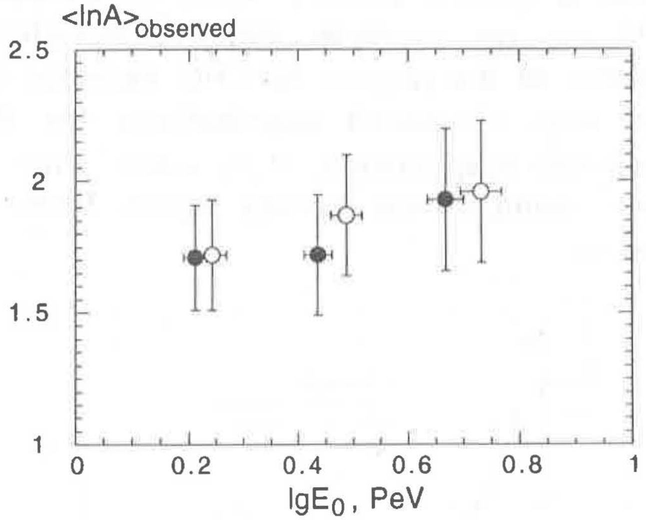

Fig.1. Values of $\langle \ln A \rangle_{observed}$ for EAS, selected by N_e (full circles) and by E_{690} (open circles)

This surprising observation looks as if nuclei induced showers have less muons than expected from our theoretical models. The deficit of muon-rich showers transforms into a lighter mass composition especially for N_μ or E_{690} selected showers.

Our observation is confirmed by another set of experiments. Here I mention the analysis of the cosmic ray mass composition, based on high energy electromagnetic and muon components of the shower. I mean so called gamma-families and underground muon groups. The latest analysis of X-ray emulsion chamber data, obtained at Mt's. Norikura and Fuji in Japan and here in China at Mt. Canbala, favours the heavy primary mass composition /4,5,6/. It follows mostly from the low absolute intensity of gamma-families. Pamir results don't contradict to japan-china conclusions. Their intensities are also low, although they prefer to explain them by the high inelasticity /7,8/. Their upper limit of iron nuclei fraction is relatively high: Δ_{Fe} < (0.24 - 0.32) at E_0 > 10 PeV /9/.

On the contrary, results of the high energy muon data support the so called "light" or normal mass composition. Multiplicity spectra for muon groups, detected at Baksan /10/, NUSEX /11/, KGF /12/, Frejus /13/, MACRO /14/, Homestake /15/, Soudan /16/ arrays agree with a normal primary mass composition at energies of 1 - 10 PeV. As an example, Fig.2 demonstrates the muon multiplicity spectrum of the largest MACRO detector in Gran Sasso, Italy, compared with simulated expectations for the "light" and "heavy" compositions respectively. It is seen, that the conclusion about the "light" composition comes again from the deficit of muon-rich showers.

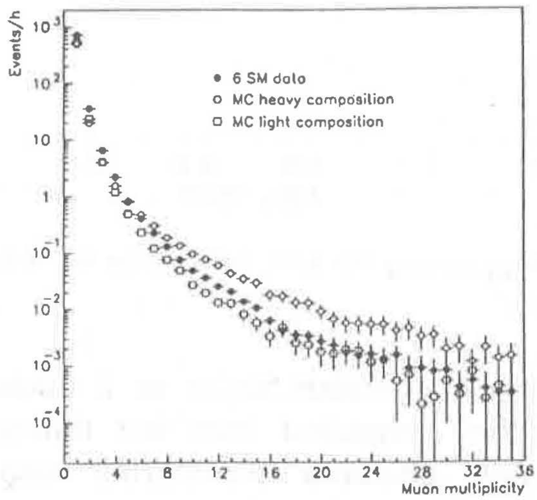

Fig.2. High energy muon multipliciy spectrum, obtained in MACRO experiment (full circles), compared with spectra, simulated for light primary mass composition (open squares) and heavy composition (open circles) /14/.

Here I can just suggest some qualitative explanation. It is highly speculative, but could have a relevance to the subject of my talk - high energy interactions in EAS. Suppose, that the iron nucleus Z_1 with the energy in the vicinity of the knee encounters the air nucleus Z_2. In all our simulation models we examine just the strong interaction of these nuclei. However, it should be mentioned that the electromagnetic interaction during this encounter is also strong: $Z_1 Z_2 \alpha > 1$, where α is the electromagnetic constant. The electric field of the projectile nucleus with $Z_1 = 26$ and the lorentz-factor $\gamma > 10^5$ has the dense virtual photon field, which could be the source of additional bremsstrahlung and electron-positron pairs during its reformation in the head-on collision. So I suppose that high energy nuclei lose their energy not only due to multiple pion and kaon production, but also due to electromagnetic processes (Fig.3). Their partial inelasticity K_γ is higher than we usually adopt. This energy loss is highly fluctuating, because the strength of the electromagnetic interaction depends on the impact parameter. Finally, this electromagnetic energy loss has to be via the production of pretty soft bremsstrahlung photons and electron-positron pairs.

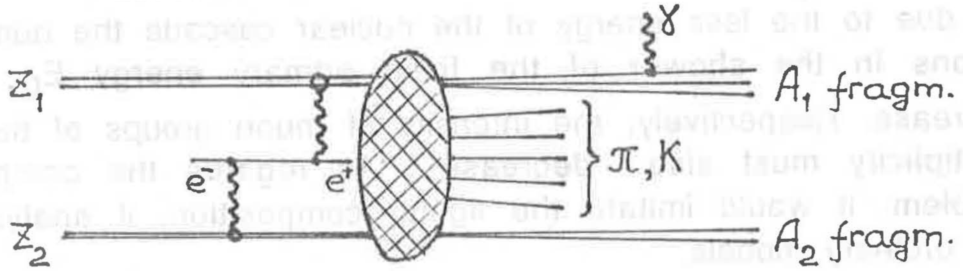

Fig.3. Proposed schematic view of AA - collisions at high energies.

What are the consequences of this idea ?

* $\langle K_\gamma \rangle_{AA}$ for high energy AA interactions has to grow with the primary energy, even if $\langle K_\gamma \rangle_{pA}$ doesn't essentially grow ;

* due to the additional electromagnetic energy loss and the soft spectrum of produced electron-positron pairs and bremsstrahlung gamma-quanta, the intensity of EAS in the stratosphere has to increase (Fig.4);

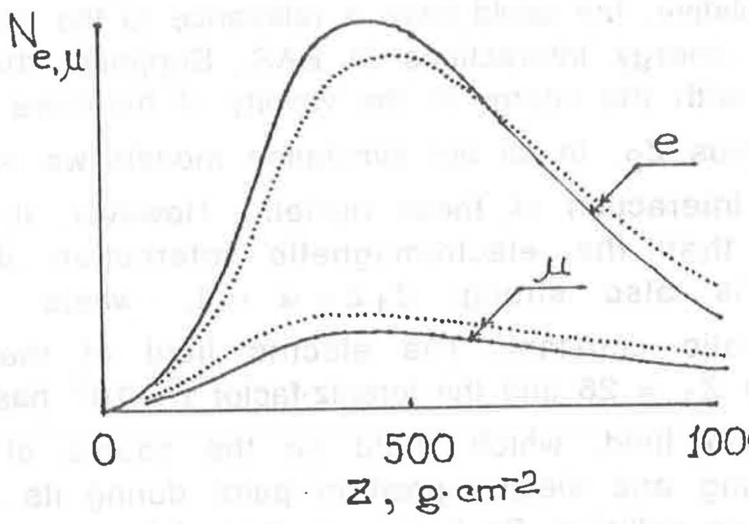

Fig.4. Longitudinal development of electromagnetic and muon components of the nucleus induced cascade in the ordinary (dotted lines) and proposed model with the increased electromagnetic energy loss (full lines).

* at the same time due to the soft spectrum of the electromagnetic component and less energy, preserved for the development of the nuclear cascade, the attenuation of the EAS in the lower part of the atmosphere has to increase. The number of electrons beyond the shower maximum must decrease ;

* due to the less energy of the nuclear cascade the number of muons in the shower of the fixed primary energy E_0 has to decrease. Respectively, the intensity of muon groups of the fixed multiplicity must also decrease . As regards the composition problem, it would imitate the lighter composition, if analysed by the ordinary models.

* it is difficult to predict, how $N_\mu(N_e)$ - dependence will be modified. It is because in the lower atmosphere both N_e and N_μ would decrease. However, because the attenuation of N_e is exponential, its decrease is expected to be stronger, than the decrease of N_μ. So $N_\mu(N_e)$ - dependence can become steeper ;

* because the entire development of EAS shifts to the upper atmosphere, the Q/N_e - ratio of the amount of Cherenkov light, normalized to the EAS size, should increase for the large showers.

It looks usually well in our institute, if the author of the speculative idea indicates himself the possible experiment, which might kill this idea. Of course, the most direct experiment is the observation of interactions of PeV nuclei with the high Z in the emulsions. There is a hope that the GOAL program of LDBF - long duration balloon flights will be able to look into this energy region /17/. Also RHIC - relativistic heavy ion collider will give an opportunity to check the energy balance among secondaries produced in high energy AA - collisions /18/ It is desirable to select for this purpose central collisions with the small impact parameter. I should like to mention that JACEE - collaboration which studied the interactions of TeV - nuclei with emulsions noticed the surprisingly large amount of electron-positron pairs, produced by soft photons in the close proximity of the vertex /19/ (Fig.5).

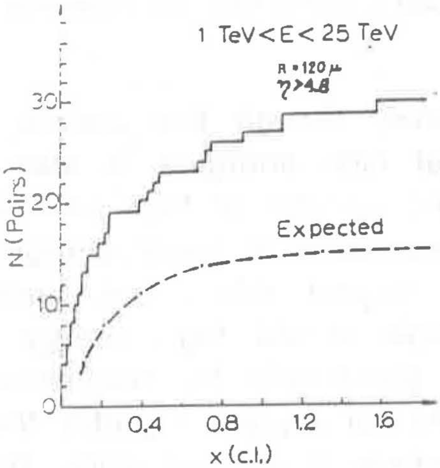

Fig.5. Number of electron-positron pairs as the function of distance from the interaction vertex in high energy JACEE events /19/.

Usually the defence of the nuclear aspect of cosmic rays is based on the statement that they are complementary to accelerator studies. They can study the so called fragmentation region of the secondaries inclusive spectra (Fig.6). In contrast, for example, at the future LHC secondaries with $x > 0.1$ won't escape the vacuum tube of the collider and cannot be studied nearer than hundreds of m from the interaction point. FAD - the project of the full acceptance detector for the former SSC is an example of such a hard attempt /20/. Colliders are mostly adjusted for the study of the central region of inclusive spectra.

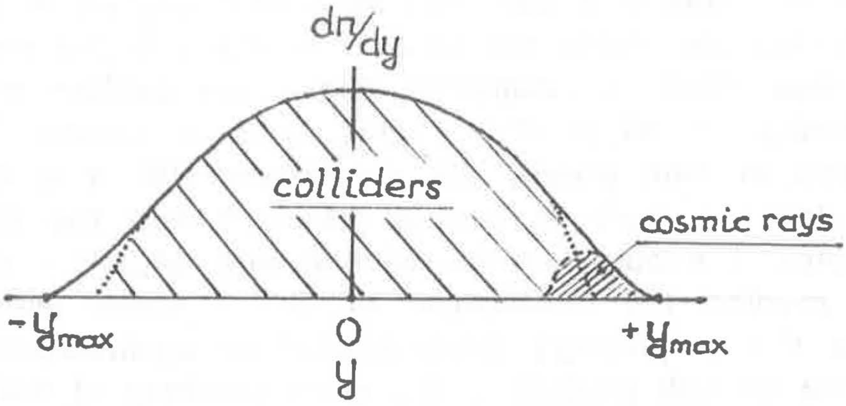

Fig.6. Inclusive rapidity spectrum of secondaries. Central and fragmentation regions studied at colliders and in cosmic rays, are marked by light and dense hatching respectively

This statement is true, though the cosmic ray study of the fragmentation region at high energies is also extremely difficult. All the variations of the spectra at high energies are masked by multiple production processes at lower energies. As a proof of this difficulty I can remind that even such a general and fundamental characteristic of the high energy interaction, as the inelasticity, which is dominated by fragmentation particles, is still discussed /21/. As for myself, I prefer the large and slowly rising inelasticity. However I am not sure, that if the Minijet model is indeed correct, that there is no gluon spectators and the scattered constituent quark as a dressed quark doesn't preserve its former gluon environment after the collision. In this case the inelasticity, being large at moderate energies, could begin decreasing. It is due to that the projectile hadron interacts with progressively lower x - partons and can preserve the larger part of its initial energy. It will carry this energy down the atmosphere and release it closer to the observation level.

In this connection I should like to mention the recent result obtained at Tien-Shan /22/. It relates to the flattening of the EAS size spectrum at $N_e > 10^8$ (Fig.7).

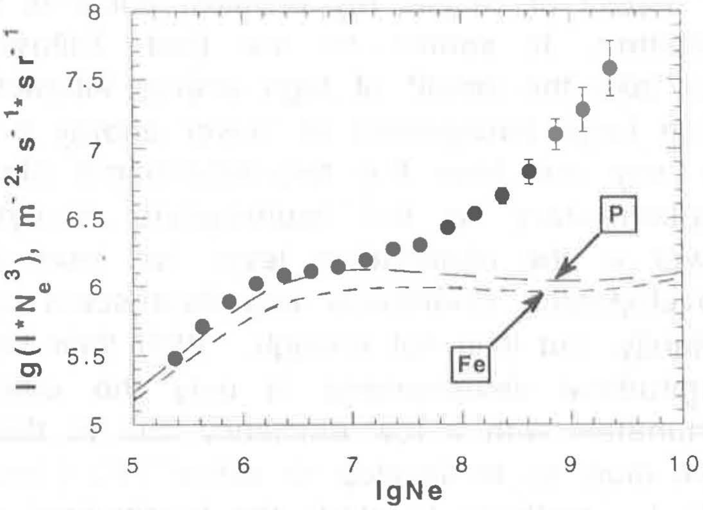

Fig.7. The size spectrum of EAS, observed at Tien-Shan /22/.

The effect is too strong to be explained by increasing fluctuations of the EAS development before the maximum. An increasing contribution of extragalactic protons wouldn't give such a strong increase of the intensity too, because the difference between iron and proton induced showers shouldn't be very big at this energies in the framework of conventional models. Besides that the increasing contribution of protons in the primary flux should be seen as the similar flattening at other altitudes in the atmosphere : for larger EAS at higher and for smaller EAS - at lower altitudes. In fact, observations indicate just the opposite picture : high intensity and the flat size spectrum of EAS at $N_e > 10^6$ in the stratosphere and the flattening at $N_e > 10^9$ at the sea level. Most of the showers in the excess observed at Tien-Shan are very young. It means that the bulk of the energy is indeed released close to the observation level. Could it be due to the decreasing inelasticity or it is the indication of the increasing role of charmed particles with the high x in the fragmentation region, which carry their energy down the atmosphere and release it there by the decay ? In both explanations we refer to the fragmentation region of secondaries spectra.

I mentioned here some effects, which could have the relation to the nuclear aspect of cosmic ray physics, but it is not easy to prove this relation. It seems to me that, following R.Kolb terminology, "to take the smell" of high energy interactions in the conditions of the large background of "lower energy pollution", we must find the way out from the two-dimentional picture of the shower. Complementary to the multivariate analysis of the individual shower at the observation level, we have to study its longitudinal development. Cherenkov and fluorescent light give us such an opportunity, but it is not enough. With their help we can study the longitudinal development of only the electromagnetic part, but unfortunately with a low efficiency due to the short duty cycle. I think we must try to develop so called TTC (track and time complementarity) - methods to study the longitudinal development of the muon component /23,24/. They are based on the same idea as the well known Fly's Eye experiment. However they use not optical photons, but another penetrating particles - muons as carriers of the information on the shower history. Using tracking and timing of muons it is principally possible to reconstruct their birth points in the atmosphere. Thus the development of the nuclear cascade could be "smelled" with no mediation of electromagnetic cascades with their intrinsic fluctuations. GeV muons are produced in average in the higher atmosphere than Cherenkov photons. Therefore, they are more sensitive to upper parts of atmospheric cascades, to the rate of the energy loss there and so, to the properties of high energy interactions. It is clear, that with TTC detectors you can work all along the day, so your duty cycle is not restricted by the night time and the good weather.

To conclude my talk I should say that we have to work a lot of, in order not to let our sick person die, but on the opposite, in terms of R. Moudi, to give him "life beyond the life".

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