SHORT REVIEW OF MODERN COSMIC RAY DATA.

V.I.Yakovlev
P.N.Lebedev Physical Institute, Russian Academy of Sciences
yakovlev@sgi.lpi.msk.su

INTRODUCTION.

"The most interesting in Cosmic Ray Physics (CRP) is discovery of new phenomena... In 30-40-th years of our century the main problem of CRP was the study of elementary particles and their interactions at high energies..."(S.Hayakawa in "Cosmic Ray Physics" Interscience Monographs and Texts in Physics and Astronomy, ed. by R.E.Marshak, v XXII, 1969.).

In fact, many elementary particles were discovered in cosmic rays. Between them e^+, μ (Andersen 1932, 1937), $\pi^\pm$ (Perkins 1947), strange particles (Leprince-Ringuet 1948), π^0 (Carlson, Hooper, King 1950), charmed particles (Niu 1970).

Such interesting phenomena as electron-photon cascades, nuclear-cascade process, near constancy of transverse momentum, Centauro, Long Flying Component (LFC), halo-events, alignment of energetic centres in gamma-ray families and some others were discovered in CRP investigations. First measurements of inelasticity and mean free paths at high energies were also performed in CRP.

Many important methodics that are now widely used in high energy physics were elaborated by cosmic ray physicists: nuclear emulsions, multy-coincident systems, ionization calorimeter, strimer chambers and other.

Below we will describe shortly some rather recent results received in CRP at Tien-Shan and Pamir mountains, which need more comprehensive analysis by using of new generation of accelerators. Most of them are related to fragmentation region of secondary particles spectrum, thus they could be investigated in the frames of FELIX project at LHC.

I. DATA RECEIVED BY USING OF TIEN-SHAN IONIZATION CALORIMETER AND EAS ARRAY.

I.1. Calorimeter and EAS array.

Many years the big ionization calorimeter had operated at TIEN-SHAN Mountain Station of P.N.Lebedev Institute /1/. The area of calorimeter was equal to 36 m^2 and it had from 15 up to 19 rows of ionization chambers in different periods of operation. Chambers had the sizes: $5{,}5 \times 24 \times 300$ cm^3. They were filled by pure argon up to the pressure 5 atmospheres. One chamber row contained 48 ionization chambers. The calorimeter absorber was lead with total vertical thickness from 850 up to 1053 g/cm^2 in different periods. Each ionization chamber had own ADC with the dynamical range equal to

2.10^4. The pulses detected were measured with the accuracy better than $\pm$ 10 % in the total dynamical range. The threshold of registration in individual channel was equivalent to energy 5 (2,5) GeV deposited in 2,5 cm layer of lead.

EAS array /1/ consisted of 64 scintillator counters 0,25 m^2 each controlled the area 10 $\times$ 10 m^2 and placed above the calorimeter. 10 scintillators (1 m^2 each) - 2 in center and other in 4 points at distances 20 meters from array center were used in timing system to measure the zenith and azimuthal angles. 20 m^2 of scintillators were placed at distance 73 meters from array center. Hodoscopical array with Geiger counters (10 m^2) was distributed between central scintillators. 10 m^2 of hodoscopical counters was placed at distance 70 m, and 2 m^2 at distances 10, 20, 40 and 55 meters from array center. Muons with E_μ > 5 GeV were detected by hodoscopical counters with total area of 53 m^2 distributed along the tunnel up to 54 meters from array center.

I.2. Long Flying Component in EAS cores.

The first indication for existence of any LFC was received by E.Murzina /2/ investigated in 1955 the ionization bursts under different layers of lead absorber at Pamir. But this result was not understood and explained.

Starting from 1972 we had investigated attenuation of energy flow deposited by hadronic component of Extensive Air Shower's (EAS) cores in the calorimeter /3/. In this case installation was triggered by showers. Unbiased threshold of the trigger corresponded to $N_e \geq 1{,}3.10^5$ particles. Showers which axises had not crossed the back sides of calorimeter had been selected for the analysis. Then events were combined according to the value of energy deposited by hadronic component at depths X $\geq$ 132 g/cm^2 where the influence of electron-photon component arise in the atmosphere was negligible. The attenuation length of hadronic component energy flow was measured by using of 8 (9) ionization chamber layers in the depth's interval (344-850) g/cm^2, common for all periods of calorimeter operation. The cosine value was took into account. It was assumed exponential behaviour of measured ionization attenuation: $I(x) \sim \exp(-x/ L)$. To get nonshifted value of L in each energy interval averaging was made according to values $\kappa_i = 1 / L_i$.

The results received for two array runs separated by the period of 6 years are shown in fig.1. It is seen excellent agreement between two sets of data that justify high reliability of calorimeter operation. Here also data of Monte-Carlo /4/ calculations in which production of pions and contribution of strongly ionized particles in detected ionization was taken into account are presented. It is seen that this calculations can not be coordinated with the experimental data: $P(\chi^2) < 10^{-4}$. The real attenuation is slower. Analysis of slow attenuated component was done. It is necessary to point out rapid increasing of energy fraction deposited deep in the absorber (with the increasing of cascade's energy) as it is possible to see from fig.2. This component is the leading component. It is possible to conclude from the correlation of attenuation length value with the parameter of concentration C that is the ratio of ionization in 3 central ionization chambers (respectively to shower axis) to those detected in total row of ionization chambers. If one approximate this value in the form $C = a + b_c \times Z$, where Z is the vertical depth of absorber, then negative meaning of b_c corresponds to dissipation of energy from the cascade centre with increasing of absorber depth, but its positive meaning corresponds to concentration of energy in cascade centre with absorber depth. The dependence of b_c (L) is presented in fig.3. It is seen the component carrying the energy deep into absorber is present mostly in the cascades with $L > 800$ g/cm^2 (for our geometry of calorimeter). This component was named as the LONG FLYING COMPONENT (LFC) /5/. The fraction of cascades contained LFC was estimated in the next way. We have plotted the distributions of attenuation lengths L for two groups of events : with $b_c < 0$ and $b_c \geq 0$ normalised each to other at the $L = 500$-600 g/cm^2 (see fig. 4). It is seen that the left part of these distributions at $L < 600$ g/cm^2 coincides, but at $L > 800$ g/cm^2 there is a big excess of cascades with $b_c \geq 0$. As we have seen from the previous analysis the component carrying the energy deep in the absorber have been present in such events. If we assume that LFC is produced only in the cascades with $b_c \geq 0$ and $L \geq 800$ g/cm^2 , then we can receive the lower estimation of LFC production cross-section: σ^{prod}(LFC) = (0,16±0,023) × σ^{in}(p-Pb). This estimation is the lower one because if long flying particles are unstable they can disintegrate in the cascade's beginning generating cascades with $L < 800$ g/cm^2 and $b_c < 0$. The upper estimation of LFC production cross-section gives /3/ the value of σ^{prod}(LFC) = (0,32 ± 0,072) × σ^{in}(p-Pb). Both estimations concern to leading particles with energies 10-20 TeV /3/.

I.3. The nature of LFC.

To account for the appearance of LFC it was assumed the big role of unstable particles with heavy quark /3/. Because of heavy quark presence such particles keep the momentum after interaction and thus carry the energy deep into cascade (up to its disintegration). In our opinion from particles known the most proper candidates are the charmed particles. In fact at energy ~ 7 TeV the decay length of $D^{\pm}$ mesons is equal to ~ 100 cm that is compatible with 266 cm vertical size of our calorimeter. From another side Λ_c and $\bar{D}$ being produced associatively take off the overwhelming fraction of interacting proton energy /6/, providing the presence of leading unstable particles in the cascade.

The Monte-Carlo calculations taking into account the big role of charmed particles was performed /4/. The production cross-section of charmed particles was assumed to be independent on the particle type and going through the points (0,4 TeV, 30 μb), (1,8 TeV, 0,5 mb) and (100 TeV, 5 mb). It was assumed that $\sigma_c(p\text{-}A) \sim A^1$. The production spectra of charmed particles were assumed in forms: $d\sigma(\Lambda_c) / dx \approx$ const by <x> = 0,5 (where x - Feinman variable) and $d\sigma(D_c) \sim (1 - x)$ by <x> = 0,33. In accordance with /7/ it was assumed that pions interacting with nuclei of lead had produced D-mesons with hard spectrum. Inelasticity of charmed particles (according to /8/) were assumed $K(\Lambda_c) = K(D) = 0,1$ and for usual hadrons: $K(N) = 0,585$; $K_\gamma(N) = 0,17$ and $K(\pi) = 0,68$. Interaction lengths of hadrons with lead nuclei were $\lambda(\Lambda_c) = \lambda(\pi) = 210$ g/cm^2; $\lambda(D) = 420$ g/cm^2 and $\lambda(N) = 192$ g/cm^2. It were taken into account the energy losses for disintegration of nuclei of lead: $E_{n.d.} = 1,5$ GeV. The results received are shown in fig.5 together with our experimental data. It is seen reasonable agreement: $P(\chi^2) = 0,16$.

The world survey of dependence of charmed particles production cross-sections on energy is presented in fig.6. It is seen rather good agreement of our estimations with total bulk of data.

I.4. Proton initiated cascades in the calorimeter.

We have analysed /9/ also cascades initiated in the calorimeter by single protons at energies above 4 TeV. It were selected cascades with starting points distributed in limits $34 \le x$ (g/cm^2) ≤ 590 of lead absorber and not crossed the back sides of calorimeter. Such selection criteria permitted as to select proton initiated cascades, so to measure cascade energy with appropriate accuracy. Examples of cascades with initial energies $E \ge 15$ TeV are shown in figures 7-9. It is seen extremely big fluctuations in cascade's forms. It is rather surprising, because of expected big multiplicity of secondary particles (> 50) that has to provide the smooth cascade's development.

Event N 2980-712 represents especial interest as the possible example of Anti Centauro-like event in which after the first proton interaction the energy was deposited only in electro-magnetic component. It is clear that Anti Centauro-like event can be easy investigated in the frames of FELIX project by using of simple calorimeter. Examples of possible Anti-Centauro like events in EAS will be described in section I.5.

The averaged cascades with detected energies 4,5 and 17,5 TeV are shown in fig 10. It is seen the fast change of cascade form with increasing of energy: less energy is deposited in the cascade beginning. This phenomenon is not connected with logarithmic shifting of cascade maximum in the theory of electron-photon cascades (including LPM effect), but with cascade leading particles. This point is supported by the increasing fraction of cascades in which the main cascade maximum overwhelms the first one as it is possible to see from fig.11. It was also investigated for averaged cascades the ratio of energy deposited by protons at the cascade depth 895 g/cm^2 to those deposited at the cascade maximum in dependence on the energy of cascades for which starting point was fixed in the second calorimeter row. This dependence is shown in fig.12. One is possible to conclude that fast increasing of energy fraction deposited deep in the absorber is started at energies above 5 TeV (for our geometry of calorimeter). Data presented strongly indicate on the production in proton interactions with lead nuclei of any LFC which carry the energy deep into absorber in agreement with data of previous section.

It is very important to stress out, that this effect has to be seen in the frames of FELIX project using of p-A type experiment especially with more dense (per unit of length) than our calorimeter.

We had also possibility to measure production cross-section for protons with average initial energy E = 25 TeV using the distribution of cascade's starting points. It turns out to be equal $\lambda_{p\text{-}Pb}$ = (159,3 + 20,2 - 27,9) g/cm^2.

1.5. Anti Centauro-like events in EAS.

Using the possibilities of calorimeter and EAS array we have searched showers initiated by high energy ($E \geq 10^{15}$ eV) gamma rays /10/. It were selected those showers which axis crossed the calorimeter but had no detected hadrons at all (or detected energy of hadrons was less than 5 % of average). In addition the number of muons in these 5 showers (detected in the period of 12900 hours) was less than 10 % of average.
Averaged cascade initiated inside the calorimeter by these 5 showers together with cascade averaged over the all showers of the same average EAS size are presented in figure 13.

The main reason why it is difficult to admit that this showers were initiated by primary gamma rays is that all these showers were much younger than average showers. Opposite, EAS initiated by primary gamma ray should be older than those initiated by primary proton or even by nuclei. We assume that these showers were started deep in the atmosphere after interaction of primary proton with nuclei of air and thus they are the clear examples of ANTI CENTAURO-like events.

II. PAMIR DATA.

II.1. Excess of gamma initiated cascades in deep lead-X ray emulsion chamber (XEC).

To check our conclusion on the big role of LFC special experiment was performed by PAMIR collaboration /11/. They used the 100 cm block of lead absorber interleaved with X-ray emulsions. It was founded out the big excess of cascades initiated by gamma quanta with $E_\gamma \geq 8$ TeV at depths X > 80 cascade units (fig.14). The results were explained /11 / by the assumption about big production cross-section of charmed particles : $\sigma(p\text{-}Pb \rightarrow c) \geq 1{,}6$ mb/nucl in the assumption that σ_c (p-A) ~A^1. It was assumed also another possible explanation by appearance of particle with properties close to Bjorken's globe of matter /12/ coming from the outer space.

II.2. Alignment in high energy gamma-hadronic families.

Alignment in high energy gamma-hadronic families was discovered firstly in multi-halo events (fig.15) by the naked eye oversight of X-ray films /13/. Later the presence of alignment was confirmed for high energy cascades in gamma-hadronic families with $\Sigma E_\gamma \geq 30$ TeV /14/. In difference with some other phenomena in cosmic rays this one (so as LFC) could not be accounted for by the increasing of primary cosmic ray atomic weight. Opposite, for heavier chemical composition this effect would decrease or even disappear at all. Different possibilities to account for the alignment were analysed in paper /15/. For ideal alignment the parameter of alignment $\lambda_i = 1$, (where index i- is the number of energy centers in family) that means that all energetic cascades are displaced along the straight line. The value of $\lambda_i = 0$ corresponds to azimuthally symmetrical events. In the analysis performed events for which $\lambda \geq 0,8$ were admitted as aligned. Experimental fraction of aligned events with $\Sigma E_\gamma \geq 700$ TeV were equal to $0,47 \pm 0,12$ for lead chambers /16/ and $0,26 \pm 0,10$ for carbon chambers /17/. For lower energies this value is equal to $0,059 \pm 0,003$ in good agreement with expected background /15 /. It was analysed the role of fluctuations as the possible source of aligned events. From 500 and 250 simulated examples of families in lead and carbon XEC with correspondent number of gamma-quanta in each family it were founded out no family coincided with experimental. Influence of Earth magnetic and electric fields were also analysed. It was shown magnetic field can't provide alignment, but vertical electric field with parameters 1 GV per the layer 10 km could increase the fraction of aligned events with $W(\lambda_4 \geq 0,8)$ up to $0,16 \pm 0,02$ and $0,25 \pm 0,03$ in the cascades from primary nuclei and gamma quanta. However it is difficult to assume constant presence of such electrical fields.

From the models of interactions it were investigated several euristical approaches. It was shown /15/ that cascade development destroys alignment rather fast, but the penetrating particles (say such as B_6-pairs /16/) have the greater potential to produce alignment. The next processes can influent on the azimuthal parameters of families: 1) coplanar production of several B_6 -barion pairs through the tension and rupture of the string and 2) coplanar generation of several triplet of hadrons by B_6 -barion. Nucleons can generate effectively n of B_6-pairs in diffractive processes only at $E_0 \geq n^2 \times 7$ PeV. But because of the greater penetrating ability B_6-barions gives increasing of alignment probability at $E \geq 1$ PeV (see fig.16).

III. SOME PROBLEMS AT AROUND $E \sim 3.10^{15}$ eV.

III.1. Results from HADRON array.

HADRON array /17/ had included Tien-Shan EAS array; 160 m^2 of X-ray emulsion chamber and 4 layers of ionisation chambers with crossed axis's interleaved with lead and carbon for detection of high energy cascades initiated by γ-rays and hadrons (fig.17).

In our opinion the main result received /18/ with this installation is the sharp softness of the gamma ray spectra in gamma families selected according to EAS size at $N_e > 10^7$ particles as it is seen from figure 18. It was made several attempts to explain the results received, particularly by scaling violation in the fragmentation region accompanied by production with big cross-section of very massive (M > 400 GeV/ c) particles which consumed the main fraction of primary energy /19/, though such the assumption would contradict to the well known rule for point-point interactions: $\sigma(M) \sim 1 / M^2$.

III.2. Other results from Tien-Shan EAS array.

One could be also proposed other explanation : the sharp change of the primary CR chemical composition - escaping of protons from the cosmic rays flux. At the first glance such the assumption could be supported by other data received at Tien-Shan. In addition to pointed 1) sharp softness of gamma families spectrum we have in the mind: 2) the sharp increasing of muon content /20/ in showers (fig.19) ; 3) the sharp decreasing of total flux of energy contained in hadronic component of EAS cores /21/ (see fig.20); 4) the sharp decreasing of ratio ρ_{50} / ρ_{150} /22/ (that are Cherenkov photon densities at distances 50 and 150 meters from EAS axis and reflect the distance from observation level to shower maximum / 23 /) indicating on the sudden shifting of shower's maximum to the upper atmosphere (see fig. 21); 5) the sharp decreasing of EAS size N_e in dependence on value of the Cherenkov light flux Q /22/ (see fig.22).

All pointed phenomena happen at the same interval of $N_e = 10^6 - 10^7$ particles, all indicate on the possible escaping of protons from primary cosmic rays flux and only the question is how to provide such sharp escaping of protons.

III.3. The Young EAS.

The very important data were recently received by Danilova e.a. /24/ who have analysed Tien-Shan data on the dependence of EAS size spectra form on their age S. The results of this analysis are shown in fig. 23. Authors have analysed the EAS with S in the intervals : 0,35-0,75; 0,75-0,95; 0,95-1,35 and > 1,35. It is seen a very fast rejuvenation of EAS with its size, that could means not only the presence of big fraction of protons in primary cosmic rays at least up to the energies of about 10^{17} eV but even possible increasing of its fraction in contradiction with above pointed (see III.2) data on sharp decreasing of proton fraction.

IV. DISCUSSION.

We have seen that a number of very interesting results were received recently by using of the big complex arrays. Different data indicate on the appearance of any LFC after interaction of high energy hadrons (E > 5 TeV) with nuclei of lead.

At energies E > 10^{15} eV one set of data indicate on rapid escaping of protons, other - on increasing of their fraction in primary flux of cosmic rays. In our opinion this set of data could be coordinated if one to assume the big role of unstable particles with heavy quarks produced in the interactions of high energy hadrons. Such particles have the mean free path close to those of usual hadrons, but because of the heavy quark presence they keep the momentum up to the disintegration and thus carry the energy deep into absorber. Even the production of such particles only in the first (but not in the consequent) interaction has to bring the delay in the cascade development because they have to decay and after that interact once more before the cascade starts to develop. If disintegration length l of such particles overwhelms the vertical size of the absorber L in which cascade develops, they carry the energy away and escape from the registration at the investigation level. At l = 0,5 L only 14 % of unstable particles would escape from registration, but with energy increasing in 4 times l = 2 L and this fraction increases up to 61 % . In the case discussed above parameters of detected showers have to change abruptly demonstrating the imaginary escaping of protons as it was established experimentally .

V. CONCLUSION.

The total bulk of data presented strongly indicate on the big role of unstable particles produced in the fragmentation region with rather big production cross-section. Particles with properties close to those of charmed can be easily detected in frames of FELIX experiment (p-A version) using calorimeter with heavy absorber (lead, uranium, wolfram) and scintillators. Such calorimeter could have more dense (than our) per unite of length absorber, thus some above presented results (see figures 10-12) would manifest itself even at lower energies.

Anti Centauro-like events also can be easy investigated by using of the same array.

We are ready to build such calorimeter and we have the lead for it.

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