Revista Mexicana de Física 24 (1975) 119-135

HIGH ENERGY INTERACTIONS: OLD WINE IN NEW BOTTLES?

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(Recibido: marzo 13, 1974)

ABSTRACT [*]: Almost all basic discoveries in particle physics came from cosmic ray research and the proudest recent achievements of high energy theories are mere refinements of models of thought developed from cosmic ray results. Very much can be achieved with the methods introduced by the hypothesis of scaling or limited fragmentation. However, they are not the ultimate solution to all the riddles of particle physics. Moreover, the crude models deduced from cosmic ray experiments have essentially the same physical content as the new hypotheses. We shall thus be well advised to give due appreciation also to other ideas derived from cosmic ray interaction studies, now and in the future.

I.

The discovery based on the theoretical work of Vallarta that cosmic radiation is of corpuscular nature also immediately permitted an estimate of the minimum energy of its primary particles. This turned out to be some three orders of magnitude higher than the largest energies then available in our labo-

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[*] Supplied by the Editor.

ratories. An entirely new field which we now call high energy physics or physics of fundamental particles was thus opened up, and proved fruitful very soon. Let us not forget that apart from the identification of the two types of neutrinos, all basic discoveries in particles physics came from cosmic ray research.

This fact alone, I believe, would justify a contribution on high energy interactions at a Symposium in honour of Professor Vallarta. Surely all of us who belong to the old guard of cosmic ray workers see in that field an essential, a vital part of our research efforts. And we hold this belief despite the obituaries which we have heard many a time during the past twenty years or so, whenever a new generation of accelerators was put in operation.

To prove that it does not belong as a dead body to the history of science but is still alive and kicking, I shall attempt today to show that the proudest recent achievements of high energy theories, the ultimate wisdom which serves as guiding beacon and as probestone in accelerator experiments these days, are mere refinements of models of thought developed from cosmic ray results. They are, of course, much more sophisticated and more elaborate in many aspects, but also more restricted in others - and again cosmic ray data expose their limitations. I refer to the hypotheses of scaling,[1] and of limited fragmentation.[2]

Surely there is no need to spell out in this address the basic ideas or the mathematical methods of the scaling hypothesis. Besides, not to exceed the proper scope of this contribution we can only give attention to two of its consequences. They concern the multiplicity of secondary production in nucleon-nucleon interactions, and the angular distribution of these secondaries. These are also the aspects about which cosmic ray experiments give us some evidence up to very high energies.

Recall, then, that in terms of the longitudinal and transverse momenta, $p_{\parallel}$ and p_T, of the incident particle in the centre-of-momentum (CM) system, with p_0 the maximum possible CM-momentum of a pion secondary, and introducing the dimensionless variable $x = p_{\parallel}/p_0$, under the scaling hypothesis the differential cross section for the production of a pion at (x, p_T) takes the form

$$d^2\sigma/dx\,dp_T = f(x, p_T)/\left[x^2 + (m^2 + p_T^2)\,p_0^{-2}\right]^{\frac{1}{2}}.$$

An immediate consequence is that the average *total* multiplicity $\langle n_s \rangle$, obtained by integration over all values of x, should increase logarithmically with the laboratory primary energy E_L: $\langle n_s \rangle \propto \ln p_0 \approx \ln E_L$. However, the situation is different with regard to *energetic* secondaries. Restricting the integration to values of $x \geqslant x_0 = (m^2 + p_T^2)\,p_0^{-2}$ one finds that in the high energy limit the average number $\langle n_s \rangle_0$ of these pions no longer depends on E_L: $\langle n_s \rangle_0 \rightarrow$ const. In other words, the hypothesis predicts that in interactions of highly energetic nucleons a quite small, and very nearly energy- independent, number of secondaries carries off a large fraction of the available energy.

It also follows that these groups of "fast" particles emitted forward and backward in the CM-system should be distinguishable as a narrow "forward" and a wide "backward" cone of secondaries when observed in the laboratory (L) system. This distribution of the laboratory angles θ_L is conveniently plotted in the parameter $\lambda = -\ln \tan \theta_L$, and since

$$dn_s(p,E_L) \approx dx/x \approx d\lambda,$$

the experimental λ-distribution is expected to have two smoothed-out rectangular regions at both ends, with an undetermined central part. The features of the more numerous low-energy secondaries cannot be described with similar certitude.

In a different language, very much the same results can be deduced from the concepts of limited fragmentation, eloquently and forcefully advocated by C.N. Yang in particular. From simple arguments based on his theory of a "droplet" structure of the nucleons he deduces that as the result of an energetic collision both hadrons will emerge in a highly excited state which is largely independent of the primary energy. The final decay of these excited bodies takes place only after the particles have separated, again giving rise to a practically constant number of secondaries, and to a logarithmically increasing total multiplicity of the secondaries. The emission of the bulk of the low-energy pions is seen as an additional process about which no definite prescriptions can be given. In their essential features therefore, both these hypotheses resemble the earlier "shaking-off" theories of secondary production, a point to which we shall return later.

But first we shall confront these theoretical results with experimental data in a range beyond the energies at present available in accelerator work. A word of warning is appropriate at this stage. Many so-called tests of scaling or limited fragmentation at cosmic ray energies are inadequate because they are founded on data which reflect, wholly or predominantly, the properties of the most energetic secondaries only. But the primary energy spectrum of the cosmic radiation falls off very rapidly, so that, for instance, a calculation of the atmospheric muon spectrum, or of the muon charge ratio, is not an unbiased test for the overall multiplicity. It will lead to nearly identical results for any theory or model which distinguishes a group of "fast" secondaries from a main ("pionisation") group of low-energy pions. To carry out a fair test we must choose data to which both groups contribute their share. The average multiplicity of secondary production observed in cosmic ray jets or showers, and the angular distribution of jet secondaries, satisfy that condition.

However, with the first of our examples we encounter another difficulty. The cosmic ray interactions from which we can take our data -mostly jets in nuclear emulsions and extensive air showers- are not nucleon-nucleon collisions but interactions of energetic nucleons with target nuclei. Yet a meaningful test is possible for two good reasons. It is known from careful accelerator experiments that the mean multiplicity rises only very slightly with the atomic number A of the target nucleus, and that this dependence does not vary appreciably with the incident particle energy (both provided that E_L is high enough). Thus, selecting for our survey only data from jets presumably originating in light emulsion nuclei (number of heavy prongs $N_h \leqslant 5$), or in other light material (LiH, C and hydrocarbons), and data derived from the study of extensive air showers (*EAS*), the points of our plot must be expected to lie systematically above the proper p-p multiplicities but differ from these only by an almost constant factor. Therefore they will still exhibit the correct energy dependence of the multiplicity.

In the case of emulsion jets another correction was necessary. In general an experimental bias is introduced by an arbitrary cutoff procedure demanding a certain minimum number of relativistic tracks, for instance $n_s \geqslant 5$. This would lead to an overestimate of the multiplicity, in particular at lower primary energies, and accordingly yield a somewhat flattened multiplicity spectrum. Whenever necessary the raw data were, therefore, corrected under the assumption that the *fractional* distribution $f(n_s/\langle n_s\rangle)$ is independent of the primary energy. This has been verified in the range of accelerator energies[3]; beyond it the deviations diminish rapidly. Details of the procedures and references to the experimental work from which the data up to $E_L \lesssim 10^{14}$ eV are taken, were given in an earlier paper.[4]

In the *EAS* energy range we have, of course, no direct evidence on the multiplicities of the individual high energy collisons. Indeed it may be believed that because of the enormous complexity of these events -in which only the summary result of many generations of interactions can be observed- a reliable analysis cannot be carried out. However, just this complexity also permits measurements covering a variety of features related to all *EAS* components. Elaborate and systematic cascade calculations, in particular due to Grieder,[5] Hillas,[6] and Turver,[7] have demonstrated that in order to attain consistency with all the known *EAS* features, at the very least certain limits can be set for a multiplicity law. Results obtained from their work, taken from a paper of Wdowczyk and Wolfendale,[8] provide the data pertaining to energies above a few 10^{14} eV.

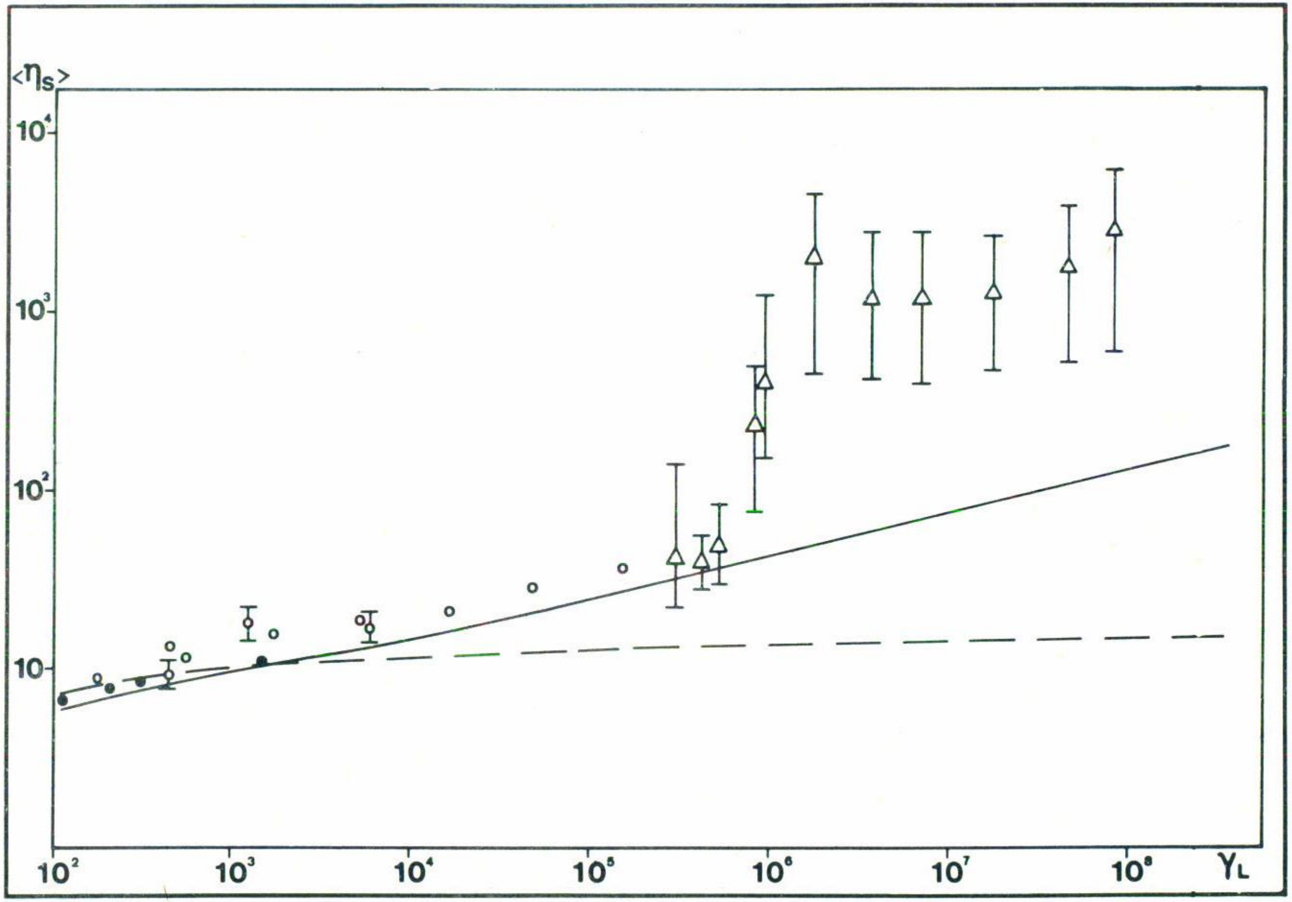

Fig. 1. Average multiplicity $\langle n_s \rangle$ of charged secondaries as a function of the L-system Lorentz factor γ_L of the primaries. Black circles: accelerator data; open circles: cosmic ray data from interactions in light target nuclei (error bars are shown in a few examples only); triangles: data derived from *EAS* studies[8]. The full line represents $\langle n_s \rangle$ calculated with an *IF* model[4,19]; the broken line, "scaling" predictions[9].

Both sets are shown in Fig. 1 together with the predictions of the scaling law derived from *ISR* data by Morrison,[9] represented by the broken line. Even taking into account that the presence of heavy primary nuclei in the cosmic radiation will increase the "scaling multiplicity" by a small factor the wide discrepancy at high energies is evident. Indeed Wdowczyk and Wolfendale argue that in order to achieve some degree of consistency, one would have to postulate a most unlikely rapid increase with energy of the mean mass of the primary radiation, reaching $A_{eff} \approx 200$ at $E_L \approx 10^{17}$ eV. Even then an adequate description of the shower development would necessitate the assumption of uncommon fragmentation features. The conclusion appears unescapable that, at least in the region of extremely high energies, the "scaling" multiplicity is significantly exceeded.

With regard to the angular distribution of jet secondaries, problems about its interpretation arise from the fact that the primary energy of the initiating particles is not known but must be deduced - very often from that distribution. Nevertheless several important features have been established, particularly by the extensive and careful work of the Cracow group.[10] Here we must draw attention to the following three observations:

(i) Quite frequently one finds that groups of particles can be distinguished which appear to be ejected isotropically from an "emission centre". In this case a simple relation is easily derived between the fraction $F(\theta)$ of secondaries emitted within an opening angle θ from the collision axis, and the Lorentz factor γ_e of the emission centre. In the extreme relativistic approximation one has

$$F(\theta)/[1-F(\theta)] = \gamma_e^2 \tan^2\theta$$

In a graph of $\ln[F/(1-F)]$ vs $\ln\tan\theta$ isotropy is therefore exhibited by data lying on a straight line of slope 2. This is the Duller-Walker "F-plot" method,[11] already a classic in the analysis of angular distributions.

(ii) Especially for events most likely to represent the results of nucleon-nucleon collisions ($N_h \leqslant 5$, $n_s < 20$) the differential angular distribution tends to divide into two groups of more or less equal size; it has a "double-hump" structure. Usually the individual F-plots demonstrate isotropic emission from two centres. In Fig. 2 we reproduce as an example the distribution obtained for jets of primary energies around 1 TeV in the Cracow laboratory, taken from the review of Miesowicz.[10]

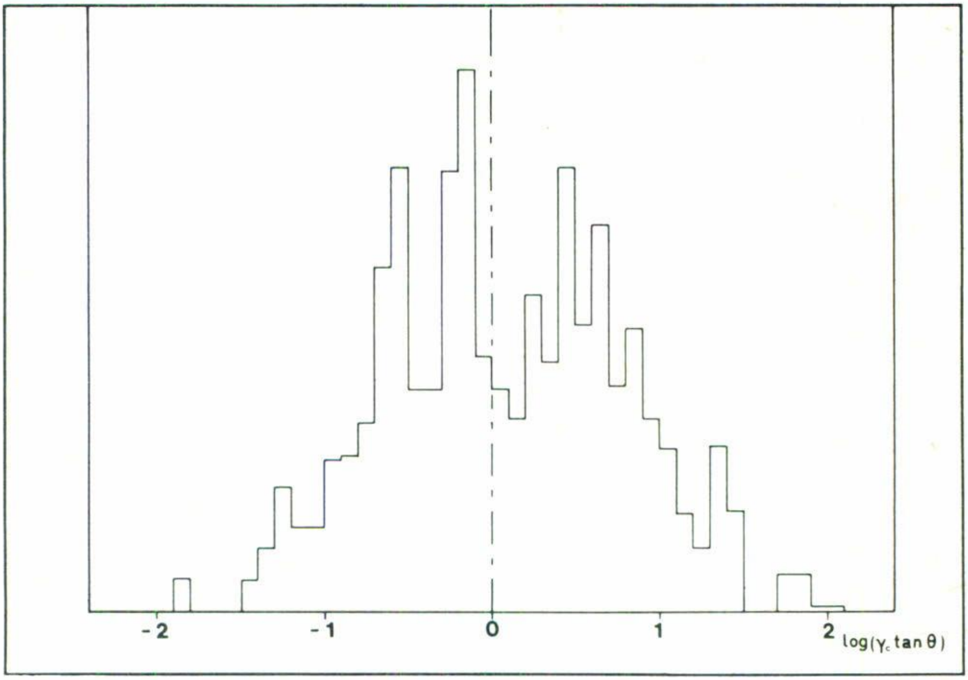

Fig. 2. Composite histogram of the differential angular distribution of jets with $N_h \leqslant 5$, $n_s < 20$ (after Miesowicz[10]).

(iii) Frequently however, some deviations from the isotropy occur, characterized by the emission of a small group of particles forward and backward in the CM system. Evidently the few "forward" particles will carry off a large fraction of the transferred primary energy, a feature which has been observed in experiments using quite different techniques as well. Naturally this is not clearly illustrated in a composite graph like that of Fig. 2. We take a better example from the work of Koshiba[12] in which a "beam" of monenergetic cosmic ray particles was obtained by an ingenious trick. The analysis was performed on jets initiated by nucleons which emerge by fragmentation from an incident heavy primary nucleus. Apart from insignificant fluctuations they therefore carry identical energies. In Fig. 3 we reproduce the angular distribution in the *CM* system obtained for pions and for kaons (which are easily identified at backward emission). The dashed histogram and the full line of the upper graph indicate the contribution of the "diffuse cone", the pionisation secondaries. Two facts are quite evident from his data: first, distinct small groups of particles are emitted in "narrow" forward and backward cones, well separated from the rest, and second, also the composition of these groups differs significantly from that of the others. A higher K/π ratio, and a larger fraction of γ-rays well above the $\frac{1}{3}$ expected at charge independence could be established beyond doubt. (From these results Koshiba concluded that in practically *all* high energy interactions one particular "aleph" isobar of distinct mass between about 1960 and 2100 MeV is created, with well defined decay properties. A more likely interpretation is that many "isobar states" in approximately that mass region, and with complex decay schemes, contribute their share.)

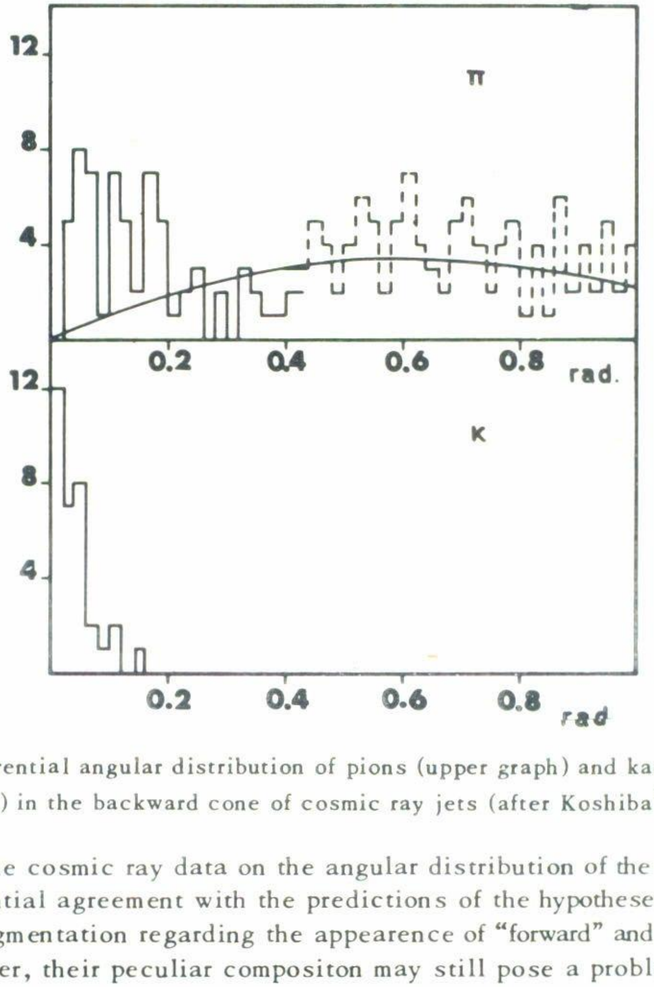

Fig. 3. Differential angular distribution of pions (upper graph) and kaons (lower graph) in the backward cone of cosmic ray jets (after Koshiba[12]).

Thus the cosmic ray data on the angular distribution of the secondaries show a substantial agreement with the predictions of the hypotheses of scaling and limited fragmentation regarding the appearence of "forward" and "backward" groups. However, their peculiar compositon may still pose a problem, but they also suggest that the process of pionisation which is largely neglected in these hypotheses, is neither simple nor of little consequence. A really satisfactory theory must account for its features as well.

II.

Except for the results on the secondary multiplicity derived from *EAS* studies, all the cosmic ray evidence mentioned above has been known for several years. Naturally, therefore, attempts have been made to interpret it long before the advent of the new hypotheses. That had to be done in terms of simple models, in the hope that they might find an explanation in a later theory. Let us briefly discuss how they were developed and where they lead us.

Shortly after the discovery of the "double-hump" structure of the angular distribution a "two-fireballs" model of pionisation was proposed independently by Cocconi,[13] Niu,[14] and Zatsepin.[15] It was suggested that from the interaction two bodies of excited hadronic matter - the fireballs - emerge, moving forward and backward in the *CM* system and decaying isotropically, predominantly into pions. This assumption allowed a satisfactory representation of the angular distribution of the pion component of most jets. It could not explain the fact that a large part of the transferred energy tends to be taken up by a few secondaries, that is, the existence of the narrow cones.

For that, a clue was taken from earlier accelerator work in which it had been shown that frequently the colliding nuclei emerge in an excited state as isobars. Hence an isobar-fireball (*IF*) model was formulated, assuming the creation of fireballs to account for the pionisation secondaries, and also, more or less independently, excitation of the collision partners in general. Thus we have *four* bodies as the immediate result of the interaction. Subsequently both isobars and fireballs were thought to decay isotropically in their respective rest systems.

The most comprehensive quantitative treatment of an *IF* model was given by Pal and Peters.[16] However, they suggest that only a *single* fireball is produced in the interaction, at rest in the *CM* system. That permits a unique description of the kinematics of the process without further assumptions. But it also requires a pionisation multiplicity rising as $E_L^{1/2}$. With this model they proceeded to calculate the absolute intensities of all the various cosmic ray components in the atmosphere. Their results are in quite satisfactory agreement with the experimental data.

Nevertheless their model has not been generally accepted. It predicts unduly high multiplicities, and can account for the "double-hump" structure only by ascribing implausibly large angular momenta to the fireballs. Most authors preferred a two-fireballs *IF* model from which an equally good description of the atmospheric development of the cosmic radiation can be obtained. That simply follows from the fact that the isobar component, common to both, is by far more effective in the propagation of the radiation than its pionisation counterpart. But the drawback of these models is - or was thought to be, as we shall see presently– that in order to obtain a unique definition of the kinematics, an additional assumption concerning the fireball mass, or the multiplicity, must be introduced. In general $\langle n_s \rangle \propto E_L^{1/4}$ was postulated.

Why this choice? Originally it stemed from the wish to relate the fireball model to a thermodynamical theory. It was always felt that fireballs should "behave" statistically, and the more recent definition given by Hagedorn[17]:

> → "A fireball is a statistical equilibrium (a hadronic black–body radiation) of an undetermined number of all kinds of fireballs, each of which in turn considered as — "

expresses precisely that general opinion. (With that remark we do not wish to make Hagedorn responsible for the $E_L^{1/4}$ law which is not an implicit consequence of his theory.) Still, an *IF* model with a different multiplicity can be formulated, and has been used for instance by Grieder.[5]

One further remark concerning the importance of the fireball process, and hence of the pionisation component. It also appears related to Hagedorn's definition. It has been established, in particular by the work of the Tata Institute group,[18] that as much as 10–15% of the secondaries produced in interactions at *EAS* energies are nucleon pairs. This is by far more than the amount expected from pair creation in the *CM* system according to the cross section measurements at accelerator energies. Likewise the energy distribution of the nucleons suggests that they originate in the fireballs. Obviously, therefore, the "pionisation" component provides us not only with pions but also with other particles, and presumably compounds –further fireballs– which in turn decay.

And now let us take a fresh look at the situation as it is presented by the data and by the general predictions of the theory, adding to it just one experimental result which we have not explicitly introduced so far. Theories and data tell us that the final outcome of the interaction is not established at the instance of the encounter. Rather, highly excited bodies are created which only subsequently decay into the ultimate secondaries. Experimental evidence proves that the incident nucleon retains, largely independent of the primary energy, about one–half of its initial energy when it finally emerges from the collision. We shall show that on this foundation alone a complete quantitative treatment of the *IF* model can be built.

Out of the "black box" of the original collision volume *two* "black boxes" are set free, and at least at sufficiently high energies separate beyond further interaction. Of their mass M and Lorentz factor γ_M we know that on the average they will have to satisfy the relation

$$\gamma_M M = \gamma_c ;$$

nothing else is needed. Their decay is subject to a very stringent condition: in the end the nucleon must still carry off half of the incident energy E_L. Allowing that it first emerges in an excited state of mass M_i – whose energy $E_i = \gamma_i M_i$ still must remain proportional to E_L or the Lorentz factor γ_L of the incident particle – a mere application of the relativistic transfromation laws immediately yields for the mass M_f of the "fireball" which is split off[4]

$$M_f \propto \gamma_c^{\frac{1}{2}} \propto E_L^{\frac{1}{4}} \quad .$$

The value of the fireball mass depends, of course, on the isobar mass; M_f defines the pionisation multiplicity, and pionisation and isobar secondaries *together* take up the transferred energy. But contrary to earlier belief (including our own) that extraneous assumptions are needed for a quantitative description of a two-fireballs *IF* model, we see that in this form the model is fully self-consistent without them, and the $E_L^{\frac{1}{4}}$ multiplicity law, hitherto postulated, now appears as a necessary consequence of the model if the fireballs decay isotropically. If this assumption is replaced by a different one, another multiplicity law follows again as a necessary consequence.

In order to determine the absolute value of M_f – and hence the average total multiplicity – "calibration" consists merely in either ascribing to the interaction a certain mean four-momentum transfer q, or in fitting the multiplicity relation to one experimental point. $q^2 \approx \frac{1}{2}$ provides a fair representation. Moreover, it can be shown[19] that at lower primary energies on the average only small isobar masses can be attained, while around 1 TeV values of 2–3 GeV become accessible. But for "average" collisions (with an energy transfer of $E_L/2$) the restriction $M_i \lesssim 3.24$ is found.

The full line of Fig. 1 represents the mean multiplicity derived from this model under the assumption that all accessible isobar states are excited with equal probability. The agreement with the experimental data below 10^{14} eV, or $\gamma_L \approx 10^5$, seems quite satisfactory if we recall that our open circles represent data on collisions in light nuclei. No attempt was made to improve it further, for instance by imposing conditions concerning M_i.

As for the scaling data, there remains the discrepancy at *EAS* energies. The possibility cannot be ruled out that in this range entirely new unknown interaction modes take over, giving rise to an increased rate of secondary production. Alternatively the deviations may be only apparent, and due to an inappropriate assumption in the calculations. All *EAS* analyses have been carried out with the use of equal multiplicity relations for nucleon and pion interactions. This is not really firmly established. In our model, for instance, it would follow if pion collisions are equally "elastic" as those of nucleons, that is, if a "leading pion" always carries off a *constant* fraction of the primary energy. Taking the extremely opposite view that *no* leading pion can be distinguished and the emerging forward "black box" which results from a π-N collision decays into indistinguishable secondaries, the model leads to a multiplicity rising as $E_{\pi}^{1/2}$. It can be shown that in this case the *EAS* cascades develop almost exactly like those calculated with the "single fireball" multiplicity $n_s \propto E_L^{1/2}$. The data for the *EAS* region reproduced in Fig. 1 would thus represent essentially the *pion* multiplicity law. Evidently no definite conclusions can be drawn about the high energy range at this stage.

III.

Up to now we have discussed what might be called conventional data only, with the aim to demonstrate the consistency of the *IF* assumptions with the concepts of scaling or limited fragmentation. In the following we shall endeavour to show also that recent observations which, taken at face value, appear to demand revolutionary changes in our ideas about hadronic matter can perhaps be explained less dramatically in terms of that simple model. We refer to the claim of the Japanese-Brazilian emulsion chamber group to have discovered, in their experiment at the Chacaltaya high-altitude station, the existence of new fundamental states of matter which they call "*H*-quanta" and "*SH*-quanta".[20]

For several years they exposed very large emulsion chambers to the incident radiation which at that location is attenuated by only about one-half of the sea level atmosphere. Interactions originating in a light-material producer layer (C-jets) or in lead absorbers (Pb-jets) were recorded, and also "families" of γ-rays incident from the atmosphere (A-jets). Precise measurements were carried out on the development of the individual γ-cascades, so that their energy E_γ and the total energy ΣE_γ given to the photon component in the interaction could be determined. In addition the angular distribution of the initial γ-rays with respect to the shower axis was measured.

The most important results of the experiment can be summarized as follows:

(i) For $E_\gamma \lesssim 30$ TeV (mostly C-jets) the energy distribution of the γ-rays is well respresented by an exponential relation

$$f(E_\gamma, \Sigma E_\gamma) = N_\gamma \exp(-N_\gamma E_\gamma / \Sigma E_\gamma)$$

with $N_\gamma = (8 \pm 1)$. At higher ΣE_γ (mostly A-jets) the simple exponential gives a poorer fit, and extraploation yields $N_\gamma \approx 30$.

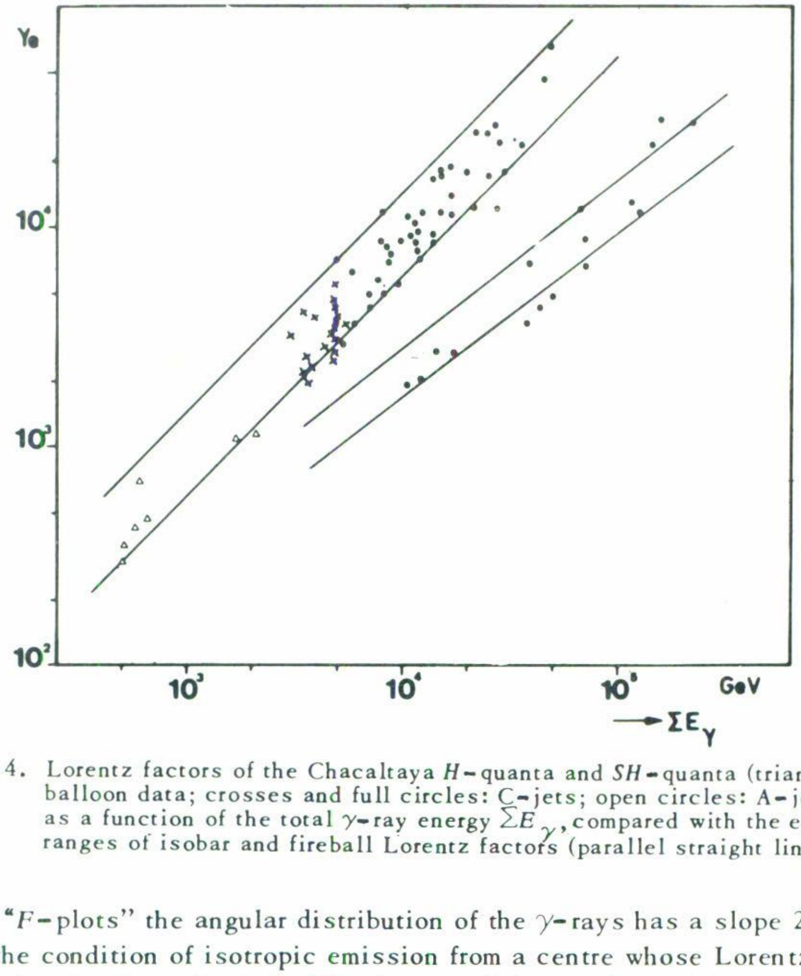

Fig. 4. Lorentz factors of the Chacaltaya *H*-quanta and *SH*-quanta (triangles: balloon data; crosses and full circles: C-jets; open circles: A-jets) as a function of the total γ-ray energy ΣE_γ, compared with the expected ranges of isobar and fireball Lorentz factors (parallel straight lines).

(ii) In "*F*-plots" the angular distribution of the γ-rays has a slope 2, satisfying the condition of isotropic emission from a centre whose Lorentz factor γ_e can thus be determined. In Fig. 4 some of the results on γ_e obtained by the Japanese-Brazilian workers are plotted against ΣE_γ. They also include a few earlier balloon measurements. For simplicity of presentation we have combined into single points some data at lower energies which lie very close together.

(iii) In the rest system of the emission centre the transverse momentum p_T of the γ-rays follows a distribution

$$f(p_T)\,dp_T = N_\gamma\,(p_T/p_0)\,\exp(-p_T/p_0)\;dp_T/p_0$$

with $p_0 = (82 \pm 15)$ MeV/c for C-jets, and again a higher p_0 for A-jets. Thus the emission is characterised by a low "temperature".

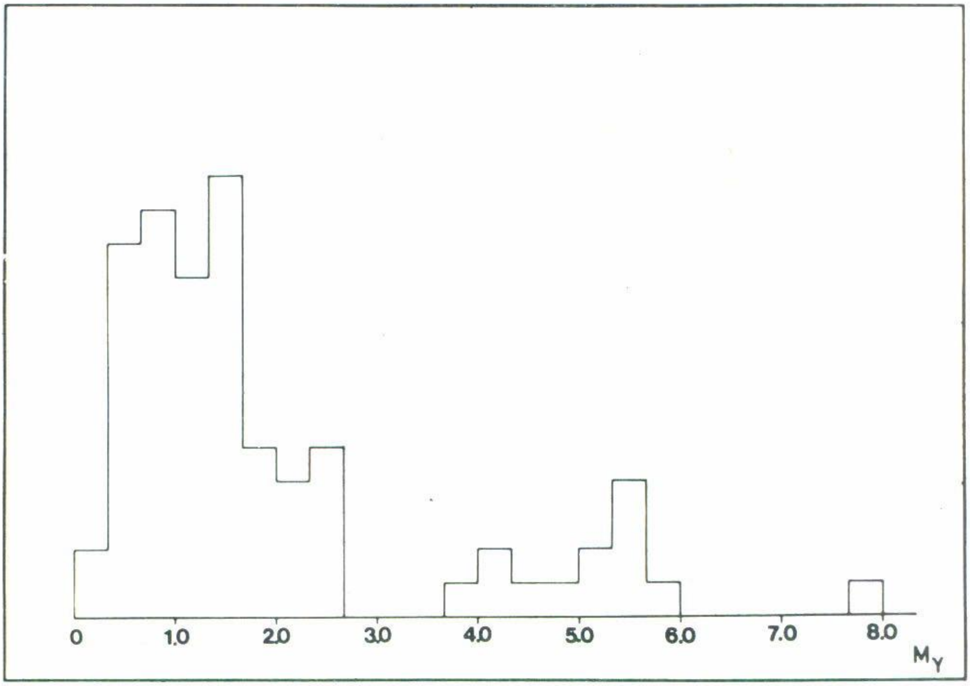

Fig. 5. Fireball mass spectrum of C-jets with $\Sigma E_\gamma \gtrsim 9$ TeV (ref. 20).

(iv) From the Lorentz factors γ_e of the emission system and the total energies ΣE_γ a "γ-ray mass" M_γ can be ascribed to the parent bodies. The distribution of these masses found in a recent analysis of C-jets with energies $\Sigma E_\gamma \gtrsim 9$ TeV is reproduced in Fig. 5. One notices two peaks for which mean γ-ray masses of $M_\gamma \approx 1.3$ GeV and $M_\gamma \approx 6$ GeV are deduced. In their earlier papers the Japanese-Brazilian authors derived values of $M_\gamma = (1.3 \pm 0.2)$ GeV for C-jets, and $M_\gamma \approx 8$ GeV for A-jets of $\Sigma E_\gamma \gtrsim 30$ GeV.

In view of the results of (i) - (iii) the Japanese-Brazilian workers call the parent bodies of their γ-ray groups "fireballs". But because of (iv) they assign to them very definite masses and the character of fundamental particles which they name "*H*-quanta" and "*SH*-quanta" (for heavy and superheavy). The terminology appears unfortunate since these quanta, possessing all the attributes of definite particles, have nothing but the name in common with the fireballs conceived in the earlier cosmic ray models, or in Hagedorn's theory. Taking into account the selection bias of the apparatus they derive masses of $M_H = (2.2 \pm 0.2)$ GeV and - from the A-jet data - $M_{SH} \approx (20 \pm 25)$ GeV for *H*-quanta and SH-quanta, respectively. A decay sequence $SH \to H \to \pi$ is postulated. H-quanta and SH-quanta are considered as elemental units of energy, fundamental in the multiple production of secondaries.

These are extremely important new results, and highly interesting conclusions. But before accepting them as convincing it seems prudent to carefully investigate whether an interpretation along more conventional lines is indeed impossible. What predictions can be derived from the IF model regarding the outcome of an experiment in the energy range around 10^{13} eV?

First of all, the model leads us to expect a spectrum of excitation reaching up to rather large isobar masses, though in general $M_i \lesssim 3.24$. Next, it states that according to the degree of excitation the larger fraction of the transferred energy can be carried off either by the isobar secondaries, or by the fireball particles. It is easily shown[19] that at high primary energies the isobar-carried energy dominates if $M_i > 1.67$, while for smaller isobar masses the fireball takes the larger share. In consequence an arrangement like that of the Chacaltaya emulsion chambers will "see" only the isobar part of the shower in the first case (in which the fireball gives only a minor diffuse background), while it will *not* see that part (in which merely one or two pions of all charges come from the isobar decay) in the second case where the fireball shower will be recorded; and isobar γ-rays, if any, add only a very few insignificant points to the F-plot.

Consider, now, the L-system Lorentz factors of *heavy* isobars ($1.67 \leq M_i \lesssim 3.24$ for an "average" collision) as a function of the total γ-ray energy ΣE_γ emitted in their decay. If the γ-rays take up between $\frac{1}{3}$ and $\frac{1}{2}$ of the total energy of the isobar secondaries - the former is the average value under the assumption of charge independence, the latter takes into account the experimental bias - the limits of the Lorentz factors shown by the straight lines of the upper branch of Fig. 4 are obtained. It is seen that practically all the Lorentz factors of the H-quanta fall into that region. Besides, one does expect a somewhat larger spread because we have neglected all fluctuations. Note, also, that the mass values derived from the Chacaltaya data are compatible with the isobar secondary masses in the large-M_i group. Therefore we believe that the H-quanta data give evidence not for the existence of a new species of elementary particle but for the important role of isobar excitation, using this term in a rather loose fashion for the "black boxes" emerging in forward direction.

Similarly we can evaluate the L-system Lorentz factors of the fireballs created in events of low isobar excitation, $M_i < 1.67$. The results of the calculation, again allowing for ΣE_γ values between $\frac{1}{3}$ and $\frac{1}{2}$ of the fireball energy, are reproduced by the straight lines of the lower branch of Fig. 4. Once more practically all SH-Lorentz factors lie inside the region allowed for our fireball masses. Moreover, the average fireball masses predicted from the IF model at values of ΣE_γ between 10^4 and 10^5 GeV rise slowly, ranging between about 10 GeV and 20 GeV, well in agreement with the mean $M_\gamma \approx 6$ GeV found for C-jets, and only slightly less than the *SH*-mass derived from the A-jets under the assumption of charge independence (about which one may have grave doubts).

The limits given here follow directly from the *IF* model as described above. No additional assumptions or adjustments were needed. Hence we believe that the *SH*-quanta are examples of pionisation fireballs, and altogether the Chacaltaya results are further testimony for the competence of the *IF* model.

IV.

In conclusion let it be stated quite explicitly that in extolling here the successes of the old model which has served us in cosmic ray physics, I do not wish for a moment to cast doubt on the merits of the new ideas. Very much can be achieved with the methods introduced by the hypotheses of scaling or limited fragmentation which we could never have done without their specific prescriptions. Very much more still can be learned by us in the cosmic ray field from the more exact accelerator-based work. However, the great advantages of the new theories must not make us forget two simple facts: one, that scaling or limited fragmentation are not, and cannot be, the ultimate solution to all the riddles of high energy and particle physics-they, too, have their limits, some of which we have pointed out; and two, that the crude models deduced from cosmic ray experiments, for all their immaturity compared with the sophisticated studies in the accelerator laboratories, nevertheless have essentially the same physical content as the new hypotheses - that these are indeed old wine in new bottles. Having recognized that on the examples presented above, we shall be well advised to give due appreciation also to other results and ideas derived from cosmic ray interaction studies, now and in the future. Like all the others, cosmic ray high energy physics, that offspring of Professor Vallarta's work, will still have a long and useful life.

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RESUMEN*

Casi todos los descubrimientos básicos en la física de partículas vinieron de la investigación de los rayos cósmicos, y los logros más recientes de las teorías de altas energías son meros refinamientos de modelos desarrollados a partir de resultados conectados con rayos cósmicos. Se puede lograr mucho con los métodos introducidos por la hipótesis de escalamiento o de fragmentación limitada. Sin embargo, no son la solución última de todos los problemas de la física de partículas. Además, los modelos crudos deducidos de los experimentos de radiación cósmica tienen esencialmente el mismo contenido físico que las nuevas hipótesis. Será entonces una buena sugerencia apreciar debidamente también otras ideas derivadas de los estudios de la radiación cósmica, ahora y en el futuro.

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* A cargo del editor.