and T. Yoneyama: Prog. Theor. Phys. **25** (1960) 670.
6) K. Niu: Proceedings of the Moscow Cosmic Ray Conferece **1** (1959) 234; INSJ-31, May 13, (1960); and the report presented to this conference.

Discussion

Yamaguchi, Y.: I would like to make a technical comment. Since the terminology of "fire-ball" has been extensively used in cosmic ray jets, I think the use of fire ball in your paper is not appropriate.

Mori, K.: Yes, the meaning of fire ball must be clearly defined.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-7-7. Summary Talk of Jet Sessions

C. F. POWELL

H. H. Wills Physical Laboratory, University of Bristol, U. K.

I want to attempt to describe very briefly some of the main features of high energy nuclear interactions, in so far as we have been able to elucidate them in the discussions on 'jets' during the past three days. If I make a mistake, some colleagues here will be kind enough to correct me.

I believe that one of the most important results of our discussions has been that we begin to see substantial progress in the very difficult field of high energy nuclear interactions. For a long time we have been very unsure of the energy of the primary particles which produce the interactions we observe in our expansion chambers or emulsions. We have been forced to use estimates that we knew to be rather unreliable. In particular, we have commonly assumed that in nucleon-nucleon collisions there is a forward-backward symmetry in the C-system of the collision, so that as many particles are emitted forward as backward. Under this assumption, we estimated the velocity of the C-system, and thence the primary energy. We knew this procedure was unreliable for several reasons; the number of secondary particles is small and we observe only the charged and not the neutral particles; and we are often dealing with collisions which are not between two nucleons but which involve a proton and a heavier nucleus. We also knew that, apart from statistical fluctuations, if there is any structure in a nucleon, the assumption of fore and aft symmetry, may break down in individual collisions; and that only for a statistically significant sample can we firmly rely upon a true forward and backward symmetry. So, we have been on very uncertain ground.

We are now beginning to get out of this difficult situation through the introduction of more powerful methods. First there are the pioneer experiments made in Moscow with what is called the ionization calorimeter. This apparatus allows the observation of the effects of collisions of the primary protons with light nuclei, lithium and protons, and the measurement of the momentum of the charged secondary particles thus produced in an expansion chamber. Secondly, the energy of the primary particle may also be estimated from the total release of ionization in a great assembly of lead and counters, the calorimeter. This has proved to be a very important instrument. As we have heard, the results obtained with it already demonstrate that, in proton-proton collisions, the secondary particles are not always distributed with fore and aft symmetry in the C-system. In about half of the collisions there is such a symmetry; in about a quarter, the particles tend to go forward in the C-system, and in about an equal number they tend to go backwards. This is a very rough summary of the position; Professor Dobrotin will no doubt give a more detailed account tomorrow.

We have similar information from the ICEF stack, where we take advantage of the fragmentation of primary particles of the heavy component. When heavy nuclei fragment in emulsion, they frequently give rise to pencils of nucleons and more complex nuclei all moving with the same, or very nearly the same, velocity. In a stack of sufficient size, we can see the interactions which these particles produce. An analysis of those favorable interactions of these particles of the same velocity, in which they appear to have made peripheral collisions, may be considered together. The angular distributions of the secondary particles from such an assembly of events are subject to much smaller statistical fluctuation than are the individual events. The results of such experiments also show us that the so-called "Castagnoli formula," which determines γ_c of the C-system, in the way I indicated, may lead us to estimates in individual cases which may be very seriously in error. The value indicated by application of the Castagnoli formula may be five times greater or smaller than the true energy. The extension of this work will be arduous; but important because we can rely on it. We are in a period where sound and reliable measurements are particularly valuable.

Now a second feature of our situation which seems to be generally agreed by most observers, is that the values of the transverse momentum of the secondary particles, the component of momentum normal to the direction of the primary particle producing the disintegration, are distributed with a peak at about 400 MeV/*c*. There is a 'tail' in the distribution which extends up to 2 or 3 GeV/*c*, but most of the values are grouped around 400 MeV/*c*.

The third feature is that about 75% of the secondary-particles are π-mesons, and the others must be attributed to baryons or to *K*-mesons.

The fourth point is that the multiplicity, the number of secondary particles created in nucleon-nucleon collisions, varies rather slowly with the energy E_p of the primary particles; something like $E_p^{1/4}$. Similarly from the analysis that has been made in the big stacks now becoming available, the indications are that when the secondary particles, mostly π-mesons, interact with nuclei, the number of mesons created also varies rather slowly with the energy of the incident particle. Some authors claim that there is no variation at all, and that the number created is independent of energy; some that the variation is similar to that for the protons, *vis*, $E^{1/4}$. I think, most workers would agree that we cannot yet reach a final decision on this point; but we ought to be able to do so in a year or so.

Fifthly, new and important technical advances are being made in studies of the γ radiation in the atmosphere; and of the total energy in the form of electromagnetic radiation which results from the nuclear interactions. The indications are that in proton-proton collisions about 50% of the energy of the primary can be expended in the creation of secondary particles. Between about 10 and 15% of the energy is commonly in the form of neutral π-mesons which give rise to γ-rays. If one assumes charge independence, this means that about 40% of the available energy goes into the π-mesons component charged and neutral.

These measurements with γ-rays have been reported by the Japanese group, and by some of the workers in Bristol. They allow the spectrum of γ-rays in the atmosphere to be measured. An important preliminary result is that it appears that the γ-radiation resulting from the high-energy collisions can be divided very roughly into two groups. Thus the Japanese physicists conclude that in the collisions of protons with energy above 10^{15} eV to 10^{16} eV, the γ-rays can be divided roughly into two groups, a low energy group and high energy group.

It is tempting to assume with Dr. Peters that the low energy group of γ-radiation can be attributed to what he calls the 'pionization' process, the evaporation of an excited meson cloud, and that the high energy γ-rays can be attributed to the decay of excited baryons; some possibly from the known hyperons, some from excited baryons of very short lifetime which decay with emission of γ-rays or π^0-mesons. The central point here is that whereas the energy available in the C-system goes up as roughly $E_p^{1/2}$ in the pionization process, it is proportional to the energy in the case of π^0 or γ-rays coming away from excited baryons. Another feature of interest which gives some support for this result is the observed spectrum of the γ-radiation in the atmosphere. If we assume that it arises from π^0-mesons, and that the penetrating component, μ-mesons, are similarly produced by the decay of charged π-mesons, then there should be a certain consistency between the spectrum of γ-ray radiation observed and the spectrum of the μ-meson component. According to some preliminary comparisons made here, there is indeed a satisfactory degree of consistency in this respect.

These seem to me to be the most important ones which have emerged from the discussion at the jet sessions. Perhaps I missed something out. But what I've said may provide the basis for discussions. I think that the really important thing is that we begin to get results of sufficient precision to allow a serious comparison between alternative theories of these high energy processes.

Discussion

Yamaguchi, Y.: I would like to know some experimental informations on the difference in the gross structures between nucleon-nucleon collisions and pion-nucleon collisions. I think you have said that the multiplicity in the pion-nucleon collisions seems to be independent of energies. Is it a fair statement?

Powell, C. F.: I don't know that we really should have an absolutely firm opinion about that at this time. As I think, I said some authors assert that if we confine ourselves to interactions of secondary π-mesons with the multiplicity greater than 7, then the mean value changes very little in going from 10 GeV to about 1000 GeV. I think that the mean value is of order of twelve and there are very few examples with the multiplicity above 20. This is the first point. And whereas in the case of nucleon-nucleon collisions there is an indication that the averages are considerably higher than that. Professor Fretter is better informed than I am on this point, I don't know if he care to comment.

Fretter, W. B.: The multiplicity of high energy nuclear interactions observed in emulsion or in air is probably not equal to the multiplicity in interactions with nucleons. Comparing the multiplicity of pion-nucleon events obtained at CERN at 16 GeV and the multiplicity of interactions of secondary particles of jets in the same energy range, we note that the pion-nucleon multiplicities are lower by a factor 2. Hence the interpretation of multiplicities measured in emulsion must be made with great caution, because of the possibility of cascades of nuclear interaction in the air or emulsion nuclei.

Yamaguchi: I would like to ask or point out the following features: if in some high energy regions there is some particular mode of pion production or dissociation process—may be it's more appropriate to call it—, namely if you have, for example, elastic or diffraction scattering due to nuclear interaction, or elastic Coulomb scattering, then the ground states of incoming particles may be gently excited by the external field, thereby these ground states suddenly jump to the excited states and then split to some number of pions or nucleon plus pions. This kind of process is called diffraction dissociations and I would like to know, if lucky enough, may be there are some experimental indication for such rare processes.

Powell: I may express opinion. It seems to me that precisely for the reason that Prof. Fretter has indicated, namely, precisely because of the possibility of secondary interactions—we are commonly striking heavier nuclei; we are not dealing, as in bubble chambers, with pure hydrogen targets—in most cases we would be very lucky to get evidence for such a process. But, of course, bearing rather closely on a similar point we will hear Prof. Miesowicz tomorrow on some of the conclusions which can be drawn from a detailed study of the angular distributions of these collisions. It seems to me that the kind of picture, which he puts forward to, appears in somewhat the same way as, I believe, your suggestion would lead us to.

Shapiro, M. M.: Is it yet possible to draw any firm conclusion about the structure of nucleons from jet studies?

Powell: Surely we cannot yet speak of firm conclusion. But the paper we shall hear tomorrow, in the plenary sessions on jets, from Professor Miesowicz and Professor Dobrotin, show that detailed studies of jets are very suggestive of structure within the nucleons.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-7-8. On the Character of Collisions of High Energy Nucleons*

G. T. ZATSEPIN

P. N. Lebedev Physical Institute, Academy of Sciences of the USSR

At present, there is a great amount of experimental materials on the nuclear collisions at high energies. Unfortunately, in spite of the progress in the mathematical aspects of the theory, the status of the theory of nuclear collisions as a whole cannot be considered to be satisfactory. To a great extent, this situation can be explained by the fact that, in experimental works, the results are usually presented in all their details so that it is often difficult to find out the fundamental characteristics of the phenomena. Therefore, we try to find out some characteristic features of the nuclear collisions at high energies.

Fundamental result of investigation of nuclear collisions is the confirmation of multiple production of mesons, which has been known for a long time. For consideration of nuclear collisions, it is convenient to divide the process into two stages: the stage of collision during which excited systems are produced, *i.e.*, the stage of essentially quantum character, and the second stage-the decay of the excited systems with emission of mesons and other particles. We can find the nature of the first stage only through the analysis of the second stage. The kinematics of the emission of particles gives us very important information. Kinematical aspect changes itself with the increase of energy, but it is possible to separate some invariant quantities.

Looking at the behavior of nucleons in a collision, we can conclude that the average rate of energy lost by nucleons does not change over a very wide energy range[1] ($3\cdot10^{10}$ eV $\sim 10^{14}$ eV, $\gamma_c = 4 \sim 250$), namely, during the collision, the Lorentz factor of a nucleon in the C-system changes by a factor independent of the initial value γ_c. On the logarithmic scale of γ_c, we find that the logarithm of Lorentz factor after collision differs from the initial value by a constant.

In the coordinate system in which one of the nucleons is at rest before collision, the target nucleon receives, usually, small momentum of the order of several hundred MeV, not increasing with energy[2].

It follows from kinematics of emission of particles also that, during the collision, the nucleons do not get excited or get a weak excitation which results in the emission of $1\sim2$ mesons. These mesons have large energy in the C-system. In the L-system, emission of mesons by a fast nucleon leads to production of a high energy meson moving

* Translated from Russian by Science Secretaries.