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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-6-8. International Cooperative Emulsion Flight*

ICEF COLLABORATING GROUPS

This is to report the present status of the ICEF collaboration project on high energy nuclear interactions and to give a brief account of the results that have already been obtained. The project has been initiated by the late Professor Marcel Schein of the University of Chicago with the support of National Science Foundation and of Office of Naval Research, U. S. A.. An account of the project up to August, 1960, was reported at the Rochester Conference 1960 and is already available in the published proceedings of the conference. During the last twelve months, the collaborating laboratories continued exchanging the information and the measured data. The data accumulated so far had been compiled through the three day meeting of ICEF just prior to this session into an unified body of systematic information on super-high energy nuclear interactions.

The collaborating laboratories are European Zone, coordinated by Professor C. F. Powell of University of Bristol and with the first 35% of the 80 litre emulsion stack, including the laboratories of ; the University of Bristol of England, the Universities of Hamburg and Kiel and the Max Plank Institute, Münich of Germany, Dublin Institute for Advanced Studies of Ireland, Weissmann Institute of Israel, the Universities of Bari, Genova, Padova, Parma, Roma, and Torino of Italy, the Universities of Krakow and Warsaw of Poland, and the University of Oslo of Sweden : Asia-Australia zone, with the middle 20% of the stack and coordinated by Prof. O. Minakawa of Kobe University, including the laboratories of ; the University of Sydney, Australia, Tata Institute of India and the Universities of Hirosaki, Kobe, Konan, Osaka City, St. Pauls, and the Institute for Nuclear Study of the University of Tokyo : American zone, with the last 45% of the stack, including the laboratories of ; the University of San Paulo of Brazil, National Research Council of Canada, and the Universities of Chicago, Louisiana, Rochester, Washington and the Naval Research Laboratory of U.S.A.. The complete list of the names of the physicists participating in this collaboration will be given in the final publication of the joint results.

Let us now look at the results so far accumulated. It represents slightly more than half the total available data expected in this collaboration. High energy events have been located by observing their dense cascades with the unaided eyes. Though some events with cascade energies of the order of a few hundred Bev have been detected, the results seem to indicate that the detection bias starts coming into play when the cascade energy goes below around 2000 Bev. Among the high energy cascades thus located, those of 2 mm or more per plate have, more than 450 events at present, been followed back to identify their origin.

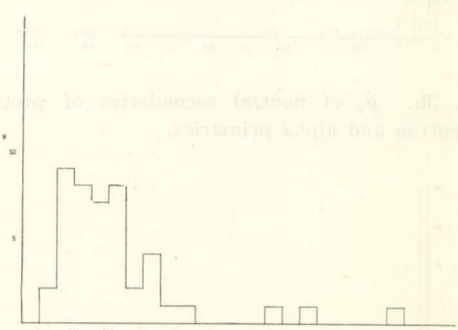

Fig. 1. Histogram showing the multiplicity of the primary jets produced by a single nucleon (41 from p and 4 from n)

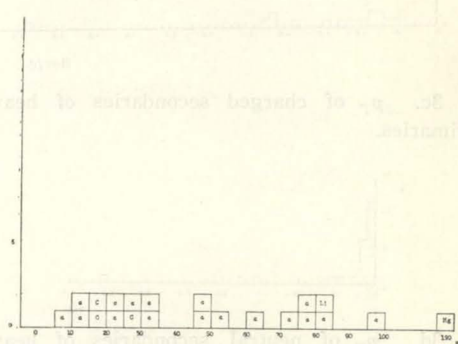

Fig. 2. n_s of multiply charged primaries

* This paper was read by M. Koshiba.

Fig. 1 shows the histogram of the multiplicities of the single nucleon, singly charged or neutral primaries, interactions so far observed, while Fig. 2 shows the same for the multiply charged primaries.

These high energy nuclear events have been subjected to the detailed analysis; *i. e.* scanning for secondary interactions within the cone of 2.5 milliradian half opening angle until the event goes out of the stack, the scanning for electron-positron pairs in the cone of 10 milliradian half opening angle for 3 cm, etc. Most of these events have been observed more than 35 cm from the initiating nuclear interactions.

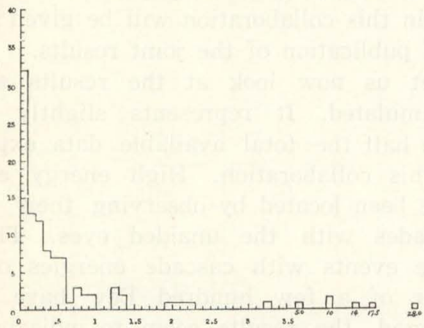

Fig. 3a. p_T of charged secondaries of proton, neutron and alpha primaries.

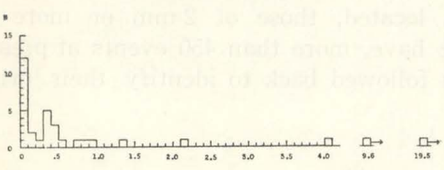

Fig. 3b. p_T of neutral secondaries of proton, neutron and alpha primaries.

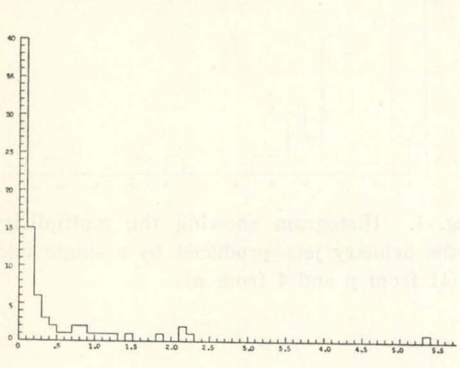

Fig. 3c. p_T of charged secondaries of heavy primaries.

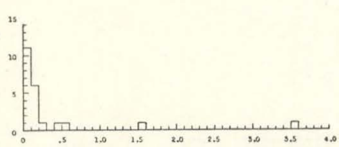

Fig. 3d. p_T of neutral secondaries of heavy primaries.

Figs. 3a to 3d show the historgram of the observed transverse momentum of the secondary particles. The energies of these secondary interactions have been estimated by applying the Castagnoli formula. The reason for showing the results separately for proton-alpha events and heavy primary events is that in the former one usually has to use the centre axis of the cascade as the reference axis in measuring the emission angle of the secondary particle in question while in the latter one usually observe the distinct center core of the primary interaction even after a large distance. That is, in the former the emission angle measurement involves additional error due to the emission angle of the high energy π^0's responsible for the main cascade. One can, however, observe that there is no detectable difference in the p_T distributions of neutral- and charged- secondary particles; in the heavy primary interactions, those secondary interactions occuring in the core, $<10^{-5}$ radian, have been omitted from Figs. 3c and 3d. This is very interesting, since it would imply the same average transverse momentum for nonpions and for pions. The same situation has already been observed at lower energies by accelerator experiments and by a cloud-

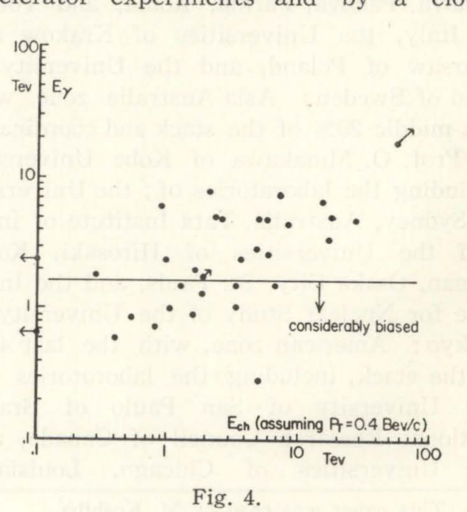

Fig. 4.

chamber experiment.

We shall now look at the partition of the energy between the charged secondary and the secondary π^0. The amount of the energy carried away in the form of charged secondary has been estimated by assuming p_T of 0.4 Bev/c for every charged secondary, pion or non-pion, an assumption consistent with the accelerator data and with our observation above. The energy carried away in the form of π^0 has been estimated by measuring the densities of the soft cascade at a number of places along the axis; *i.e.* by observing the transition curve of the cascade. Fig. 4 shows the results so far. Though it is suggestive of a linear relation between the two energies, one certainly need more statistics to make a meaningful conclusion.

We shall now look at the fraction of the primary energy going into π^0. The most serious difficulty here is the estimation of the primary energy itself. The straightforward application of the Castagnoli formula to the primary interaction gives the results as shown in Fig. 5. It gives the appearance of this fraction decreasing rather strongly with the increasing primary energy. However, in our large stack collaboration we can improve the estimate of the primary energy significantly by observing the secondary and the tertially interactions. Although the average length of observation is only about one interaction mean free path of the secondary particles, it is a vast improvement over a mere knowledge of the angular distribution of the primary event. The energies of the secondary interactions are estimated by the Castagnoli formula, the application of which is much safer for an ensemble of a large number of events. The sum of these energies can be corrected for the non-interacting particles by using the known interaction mean free path of 37 cm. In the case of heavy primary interactions, one can do still far better. The secondary interactions in the distinct core, presumably due to fragmentation nucleons and therefore of approximately the same energy per nucleon, can be regarded as the samples from the same intrinsic angular distribution. Disregarding for the moment the effect of the secondary nucleon cascade inside the target nucleus, we assume that the combined angular distribution of all those core interaction is symmetric, forward and backward, in the C. M. system of two colliding nucleons. This enables us to estimate the primary energy per nucleon. Furthermore, an addi-

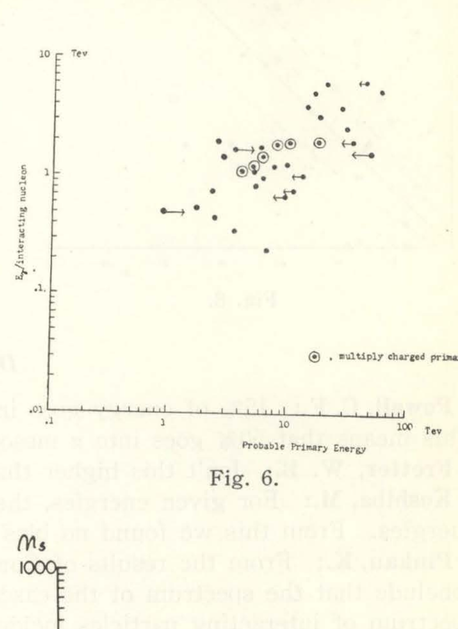

Fig. 6.

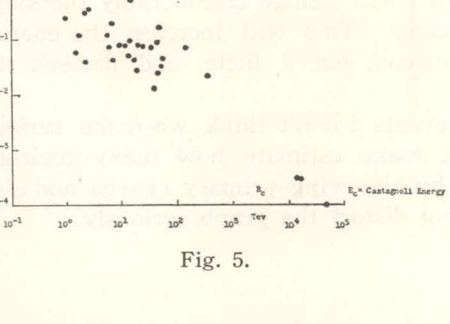

Fig. 5.

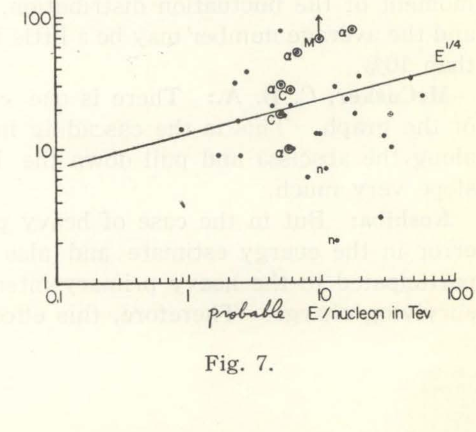

Fig. 7.

tional check can be made by using the Bradt-Peters-Kaplon formula for the fragmentation alpha particles whenever they are available. In this manner, we arrive at the most probable primary energy for each event. Using these estimate of the primary energy, we obtain the results shown in Fig. 6. The π^0 inelasticity is now constant, at around 16%, rather than decreasing rapidly with the primary energy. In Fig. 7 are plotted the multiplicity and the probable energy of the so far analysed events.

Finally, in Fig. 8 we show the appearance

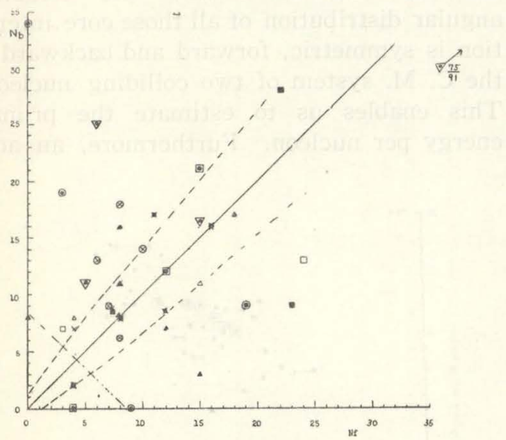

Fig. 8.

of the individual interactions in the assumed nucleon-nucleon center of mass system. Only the secondary interactions in the core of heavy primary interactions, as well as the primary heavy interactions themselves, have been used. The figure gives the numbers of charged particles emitted in the forward, n_f, and in the backward, n_b, in the C. M. system for each interactions. The dotted lines gives the statistical fluctuation from symmetric emission. It is quite clear that these are events which can not be described as symmetric. Certain number of events at the upper left region of the figure can be explained in terms of the secondary nucleon cascade inside the target nucleus, indeed the average N_h of these events is considerably larger than that of those at the lower right region. However, those at lower right in the figure have to be regarded as indicating the assymmetric, preferentially forward, emission of particles in the elementary act. A tentative estimate of the relative frequencies of occurrence gives 2/3 for symmetric, 1/6 for forward-preferential and 1/6 for backward-preferential. This result is quite analogous to that observed previously by Dobrotin and his collaborators at lower energy region of about 300 Bev.

Discussion

Powell, C. F.: 15% of energy goes into π^0 over the energy range 5×10^{12}–7×10^{15} ev. This means that 50% goes into π mesons, that is, Prof Peters' pionization process.

Fretter, W. B.: Isn't this higher than usually found?

Koshiba, M.: For given energies, the number of events was plotted against primary energies. From this we found no bias against low inelasticity.

Pinkau, K.: From the results of Comet Stack, which will be reported later, we can conclude that the spectrum of the cascade energy from nuclear interactions and the spectrum of interacting particles incident into the stack estimated from the primary spectrum by MIT group are shifted by a factor 0.15. This number is the γ-th moment of the fluctuation distribution, where γ is the power of the energy spectrum, and the average number may be a little bit smaller, but I don't think it is much lower than 10%.

McCusker, C. B. A.: There is one effect which will change considerably the slope of the graph. This is the cascading in the nucleus. This will increase the energy along the abscissa and pull down the E/int. nucleon, but a little, and flattens the slope very much.

Koshiba: But in the case of heavy primary events I don't think we make serious error in the energy estimate and also we can make estimate how many nucleons participated in the heavy primary interactions by observing primary charge and also surviving charge. Therefore, this effect will not distort the graph seriously.