MULTIPLE MESON PRODUCTION BY HEAVY PRIMARY NUCLEI OF COSMIC ORIGIN AND THEIR FRAGMENTATION PRODUCTS AT ENERGIES ABOVE 10^{12} PER NUCLEON *

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(Reported by J. GIERULA)

Purpose of the present investigation is the study of multiple meson production at $\sim 10^{12}$ eV using the detailed information obtained from the collisions of heavy primary nuclei of the cosmic radiation in a large nuclear emulsion block. In the collision with an emulsion nucleus, a primary heavy nucleus can dissociate into fragments and (or) single nucleons. The nuclear interactions of the latter can in turn be observed provided that the dimensions of the detector are large compared with the collision mean free path in nuclear emulsion (~ 37 cm). Thus a primary heavy nucleus initiates a family or a cascade of interactions, and it is plausible to expect that some of them can be caused by multiple charged fragments carrying the same per nucleon energy as the parent primary nucleus. Some of the nucleon fragments as well may emerge from the original fragmentation with an energy close to the per nucleon energy of the heavy primary. However, the remainder of the fragmentation products will be represented by surviving nucleons degraded in energy after having being involved in the production of mesons in the first collision. As a result, the break-up of a heavy primary nucleus is expected to originate a beam of fragments and nucleons, with some spread in energy but with a well defined upper edge of the per nucleon energy, equal to that of the primary heavy nucleus. The advantages of such

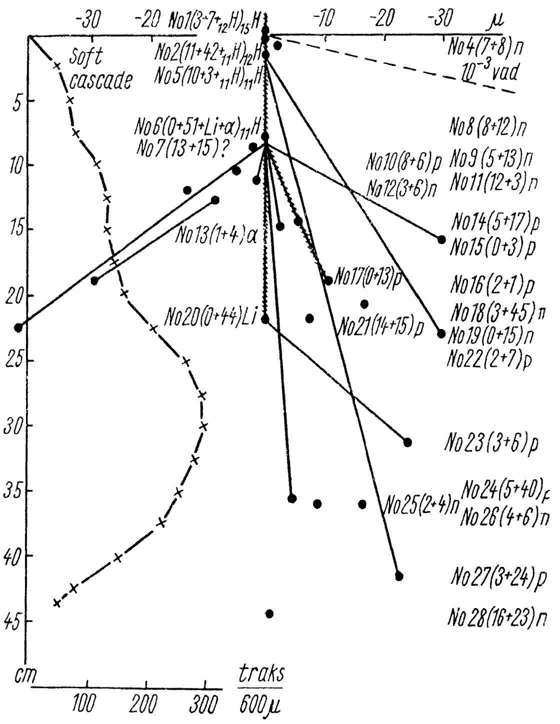

Fig. 1. The detailed picture of the event of nucleus-nucleus interaction. The charge of primary nucleus.

a situation are numerous and will be illustrated here [1].

Fig. 1 shows the detailed picture of the event which is the most informative one in our sample because of the great charge ($Z = 15$),

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and the great potential length in the stack ($\sim$47 cm). The cone of the opening angle 10^{-3} rad has been scanned along the tracks for charged secondary interactions and by area

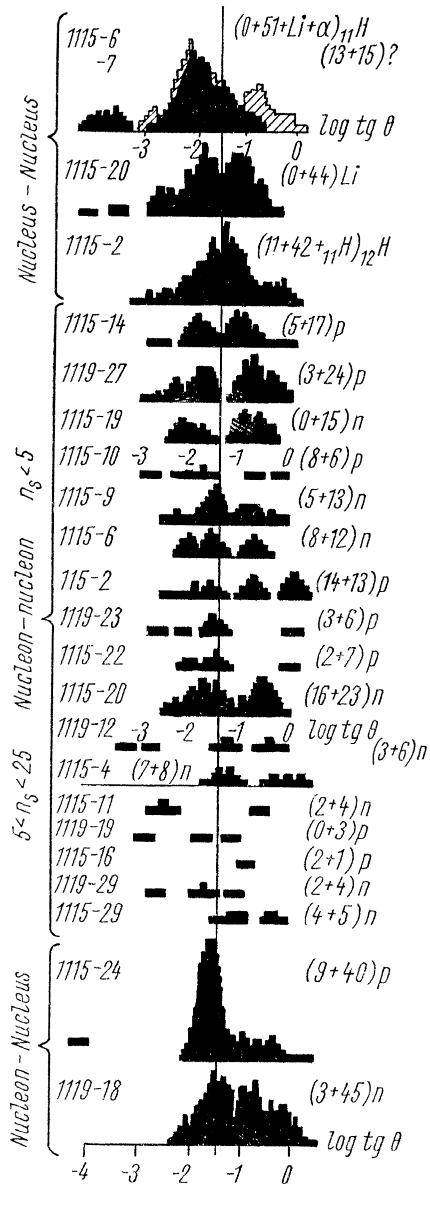

Fig. 2. The angular distributions for all primary and secondary interactions in the form of ideograms in log tan 0-variable.

scanning for neutral interactions. Fig. 2 shows the angular distributions for all primary and secondary interactions found, in the form of ideograms in log tan 0-variable. The small, angle group of particles has been identified as nucleons, by its composition (charged to neutral ratio equal to $\sim$1), by the number of charged tracks (nearly equal to the charge 15 of the primary nucleus), by a pronounced angular separation from other tracks (of produced particles), and from the general consistency of the energy dissipation in the whole family of interactions. This beam of nucleons has the well defined upper edge in energy spectrum equal to the per nucleon primary energy (1.4×10^{12} eV). (The angle corresponding to 90° in c. m. system of nucleon-nucleon collision of this energy is marked by the thick line along the Figure.) Consequently, such a well-defined beam of about 30 nucleons produces the sample of 19 interactions which is nearly monoenergetic and unbiased in its composition.

This pure sample of high energy jets shows without any doubt the strong bimodality of the angular distribution. This feature of high energy jets has been reported before in many papers by the Polish-Czek group [2]. The present observation is in contradiction with the modified statistical model of multiple meson production proposed recently by Czyzewski and Krzywicki [3]. The present sample deviated from the constant (rectangular) angular distribution predicted by this model by more than 3 standard devations. The average inelasticity coefficient estimated for nucleon-nucleon collisions in this sample is about 0.5. The degree of anisotropy in c. m. system increases in this sample with decreasing multiplicity. All these features can be easy understood on the basis of the fireball model which offers at present the best phenomenological description of nucleon-nucleon collisions at energies about 10^{12} eV.

Let us discuss now some features of collisions of primary nuclei. From the present experimental data we can calculate inelasticity K, transverse momenta P_T, and four momentum transfers Δ for single nucleons of the primary nucleus which emerge after interaction as the well separated group at small angles.

They are: average inelasticity $\langle K \rangle \approx 0.5$, average transverse momentum $\langle P_T \rangle \approx 0.4$ GeV/c (in any case not greater than 1 GeV/c) average four-momentum transfer $\langle \Delta \rangle \approx 0.5$ GeV/c.

The fact that some nucleons from the primary nucleus produced many mesons and then all the nucleons have been found in the very collimated beam can be treated as the final statistical confirmation that at energies 10^{12} eV the primary nucleons retain their individuality in the production process.

Some new features of the process of multiple production in nucleus-nucleus collisions, which have not been discussed up to now can be seen from Fig. 3. This Figure shows the angular distributions for events from the five remaining families found in the present investigation. Only collisions of nuclei are presented here.

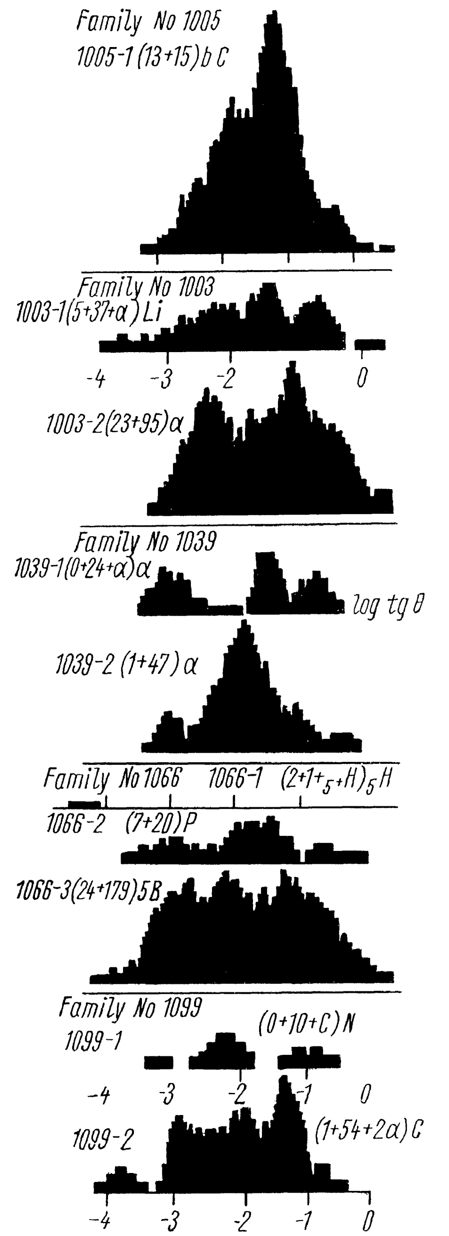

Fig. 3. The angular distributions for events from the five remaining families.

The characteristic features of these distributions are the large variety of shapes the high degree of symmetry which can be observed even in some details of the log tan θ ideograms.

All these features of nucleus-nucleus collisions could be understood on the basis of a simple model that the nucleus-nucleus collision is the summation of individual nucleon-nucleon collisions. The variety of shapes of angular distributions would correspond to what is observed in nucleon-nucleon collisions with the additional effect of a random occurance of several such elementary acts. However, the number of such elementary acts in one nucleus-nucleus collision is not large enough to produce a uniform average distribution. The high degree of symmetry may be explained by the fact that all nucleons of the primary nucleus have equal energy, and by the approximate equality in the numbers of nucleons engaged in meson production in both the incident and target nuclei.

CONCLUSIONS

The following conclusions can be drawn from the present work and some former investigations on jets with energy above 10^{12} eV:

A) Concerning nucleon-nucleon collisions:

1. The shape of the angular distributions are definitely bimodal in log tan θ variable. It deviates very significantly from the rectangular distribution expected by the modified statistical model.

2. The fire-ball model offers at present the best fit to the experimental data.

B) Concerning nucleus-nucleus collisions:

1. The experimental data (variety of shapes of angular distributions) are in contradiction with the hydrodynamical model of meson production.

2. The observed features of jets could be rougly understood as summation of independent nucleon-nucleon collisions.

REFERENCES

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DISCUSSION

Z. Koba

Remark and question on the report of Gierula. You have once again confirmed that the average four momentum transfer appearing in cosmic ray jets is fairly large (~ nucleon mass). This is very important for discussion of the models of high energy particle production (certain versions of the peripheral models, in particular). In this connection I would like to know whether you have further information on this quantity, that is its dependence on multiplicity and on energy such as discussed in the recent work of Kobayakawa and Nishikawa?

J. Gierula

I would like to stress that K, $p_\perp$ and Δ-values mentioned in this report correspond to nucleons of the primary nucleus which interacted producing some mesons. It is very probable that they interacted with a single free proton in the emulsion. Very less could be said about the distribution of these values or eventual correlations because the sample is very small. However, the absence of separated groups of tracks at small angles in central nucleus-nucleus collisions suggest that in such collisions $p_\perp$ and Δ of nucleons may be larger than the values given here.

K.D. Tolstov

In our studies on the interactions of protons of momentum 10 GeV/c with nuclei and the analysis of the analogous data for protons of momentum ~30 GeV/c, we deduced the validity of the mechanism of successive nucleon-nucleon collisions which coincides with your conclusions.

Up to which energy per nucleon of the fast nuclei do you consider this mechanism to be valid ?

J. Gierula

All the events discussed here are produced by nuclei having the energy 10^{12} —10^{13} eV per nucleon.

G.B. Zhdanov

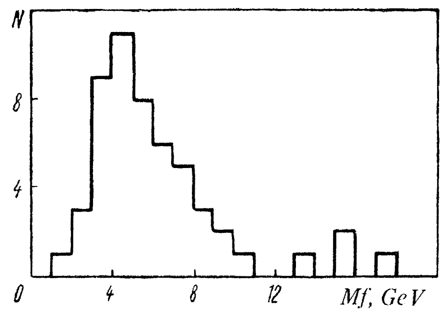
We examined the dependence of the four-momentum Δ^2 transferred by protons with an energy of 20 GeV on the number n_s of mesons generated. In the first approximation a linear dependence was obtained between lg Δ^2 and n_s-1.

S.A. Slavatinskii

We studied the nucleon-nucleon interaction at an energy of 300 GeV. These investigations led to the discovery of an assymmetric scattering of pions in the center-of-mass system of the colliding nucleons, about which was further reported at the Rochester Conference (1960). The following new results were obtained:

1. Both symmetric as well as asymmetric jets are well described by the model of one fireball moving relative to the C-system. The fireball mass $M = 1.5\ n_s < E_{\pi F} >$, whereby $< E_{\pi F} > = 0.5$ GeV and does not depend on energy. This relationship apparently represents the equation of state of the excited matter.

2. We obtained the distribution over the fireball masses M_F (see Figure).



Dependence of $N(M_F)$ on the fireball mass M_F.

Note that at energies of 10^{12} eV, according to the data of a group of Polish investigators, the fireball mass, as in the case of our energies (~ 10^{11} eV), is about 4–6 GeV. It is possible that the value of the fireball mass constitutes a new parameter of strong-interaction physics at ultra-high energies.