In conclusion, we are deeply grateful to G. A. Askar'yan for interest in the work and valuable discussion, and to V. B. Atrashkevich, G. V. Kulikov, and V. I. Boitsev for constant help. We are grateful to E. S. Shmatko, V. I. Kobizskoi, I. A. Borzhkovskii, and P. P. Matyash for help with the data reduction.

[1] G. A. Askar'yan, JETP 41, 616 (1961), Soviet Phys. JETP 14, 441 (1962).
[2] G. A. Askar'yan, JETP 48, 988 (1965), Soviet Phys. JETP 21, 658 (1965).
[3] F. D. Kahn and J. Lerche, Proc. Roy. Soc. 289, 206 (1966).
[4] J. V. Jelley, J. H. Fruin, N. A. Porter, T. C. Weekes, F. G. Smith, and R. A. Porter, Nature 205, 327 (1965).
[5] N. A. Porter et al., Proc. Int. Conf. on C. R. 706 (1965).
[6] J. V. Jelley et. al., ibid. 503 (1965).
[7] I. A. Borzhkovskii, V. D. Volovik, and E. I. Shmatko, Izv. AN SSSR ser. fiz. 30, 1705 (1966), transl. Bull. Acad. Sci.,Phys. Ser., in press.
[8] I. A. Borzhkovskii, V. D. Volovik, V. I. Kobizskoi, and E. I. Shmatko, JETP Letters 3, 186 (1966), transl. p. 118.
[9] S. N. Vernov, G. B. Khristiansen, A. T. Abrosimov, et al., Izv. AN SSSR ser. fiz. 28, 2087 (1964), transl. Bull. Acad. Sci., Phys. Ser., p. 1975.
[10] S. N. Vernov, A. T. Abrosimov, V. D. Volovik, I. I. Zalyuboskii, and G. B. Khristiansen, Izv. AN SSSR, ser. fiz. 31, No. 9 (1967), in press, transl. in press.
[11] A. T. Abrosimov, Dissertation, Moscow State University, 1965.

* The error does not exceed 3 - 4° in the zenith angle and 6 - 10° in the azimuthal angle; the error in the determination of the total number of mesons in the shower is not more than 35% of N_μ [11]; the relative error in the power flux of the radio signal from the EAS does not exceed 15% [10].

TRANSVERSE MOMENTA OF LEADING PARTICLES IN NUCLEON-NUCLEON INTERACTIONS WITH ENERGIES 10^{12} - 10^{14} eV

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The leading particle in a high-energy collision is defined as the particle that carries away the maximum energy. In this paper we discuss briefly results concerning leading particles in nucleon-nucleon interactions at energies in the range 10^{12} - 10^{14} eV.* These interactions were obtained in two large emulsion blocks in ICEF and in Brawley, in which a complete analysis of the "jets" was possible. We chose 24 events with $N_h \leq 5$ and $n_s \leq 20$, which apparently are for the most part nucleon-nucleon interactions.

To facilitate the scanning and to ensure a greater measurement accuracy, we considered only cases with track lengths not less than 2 mm per plate. The chosen events should furthermore have an approximate length > 30 cm in the accessible part of the block, so as to permit an almost complete analysis of the phenomenon. This analysis consisted of very accurate measurements of the angular distribution, a scanning along the tracks of particles in a narrow cone (we examined 131 tracks with angles $\theta \lesssim 10^{-2}$ on a total path of 22.93 m, and observed thereby 63 secondary interactions), searches for secondary interactions of neutral particles (of which 9 were found), searches for electron pairs (93 pairs were found, due to π^0-meson decays), and a study of the development of the electron cascades. In more than half of the cases we could estimate the energies of the individual π^0 mesons from the development of the cascades generated by them. The number of π^0 mesons (N_{π^0}) was determined from the number of the initial electron pairs.

As a result of this analysis we could attempt to determine the primary energy independently of the angular distribution of the particles of the primary jet. The most probable estimate of the primary energy E_0 was obtained in the following fashion:

1) If the energy of one of the secondary particles was much higher than the energy of the other particles (usually > 10^{12} eV), then we calculated the total energy of all the particles (together with the electron cascade and the neutral-particle interactions), ascribing to the non-participating particles an energy based on the constancy of the transverse momentum: $p_\perp = 0.4$ GeV/c. This total energy was taken to be the primary energy E_0. This could be done in 13 events. It turned out that for events with two maxima in the angular distribution the energy determined in this manner agrees with the relation $E_s = 2M\gamma_s^2$, where $\gamma_s = \sqrt{\gamma_1\gamma_2}$, and γ_1 and γ_2 were obtained by the Castagnoli method for the individual cones.

2) We therefore assumed for the three other cases having the same angular-distribution structure that $E_s = E_0$.

3) In the remaining seven cases with symmetrical angular distribution we assumed that $E_{Cast} = E_0$.

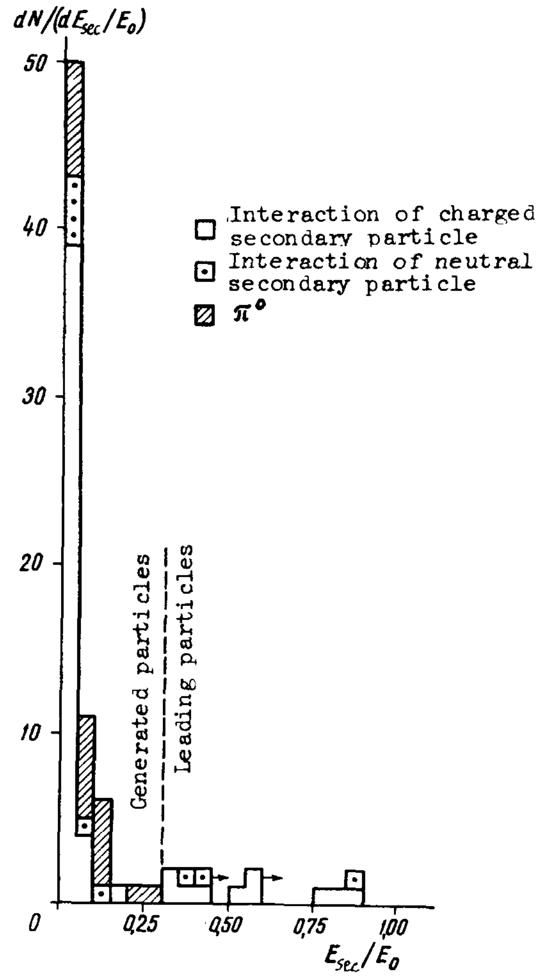

Fig. 1. Distribution of ratios of secondary particle energy (E_{sec}) to the primary particle energy E_0.

To study the energy distribution of the secondary particles, we calculated the ratios

E_{sec}/E_0 for 65 secondary interactions in which $n_s \geq 3$ (the energy E_{sec} was determined from the angular distribution of the secondary interactions), and for 22 π^0 mesons whose energy could be determined from the cascade development. The distribution of these ratios is shown in Fig. 1. A "tail" due to the particles that carry away a considerable fraction (> 0.30) of the primary energy is clearly seen. These particles can be identified as nucleons for the following reasons:

1) There is no more than one such particle in a given jet.

2) These particles include both neutral and charged particles.

3) The total number of such particles (13) agrees well with the number (14) expected by starting from the average interaction path and the scanned length, and assuming that one fast nucleon remains in each case.

4) No π^0 meson with a ratio $E_{sec}/E_0 > 0.30$ was observed in any of the 13 cases in which the cascades from individual π^0 mesons could be analyzed. For the remaining "jets," the value of $K_{\pi^0} = K_{casc}/E_0$ exceeded 0.30 only in six cases, but even in these cases we had $K_{\pi^0}/N_{\pi^0} < 0.20$. Thus, in this set the number of events with leading π^0 mesons turned out to be very small (and possibly zero). It must be emphasized that the method of recording the primary "jets" with the aid of electronic cascades, which we used here, gives preference to cases with large K_{π^0}.

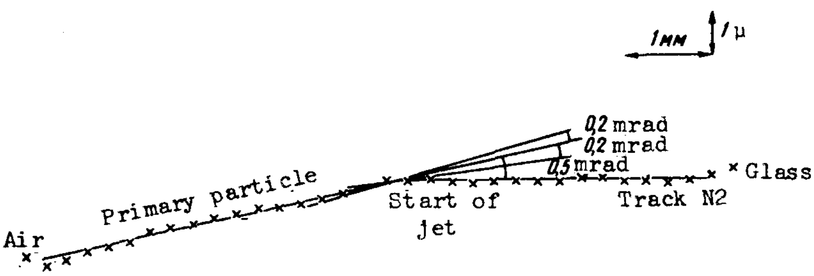

Fig. 2. Typical example of measurement of the angle between the directions of the primary and leading particles projected on the emulsion plane.

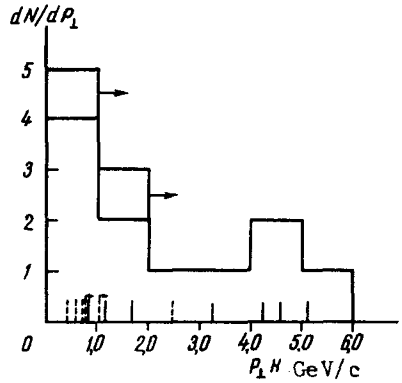

Fig. 3. Distribution of tansverse momenta of leading particles.

In investigations of the transverse nucleon momentum it is very important to know the angle of deflection of these nucleons from the primary direction. In favorable cases (in which local distortion is small and the lengths of the primary and secondary tracks in one plate are large) we can measure accurately the projection of this angle on the plane of the emulsion. Using a low-noise microscope we measured the position of the tracks in intervals of 250 μ. An example of such a measurement is shown in Fig. 2. The projection of the deflection angle is 0.5 ± 0.2 mrad. In other favorable cases the angles were larger, up to 2.0 ± 0.2 mrad. To calculate the transverse momentum, we assumed throughout a lower limit for the projection angle (which could be much smaller than the total angle). Cases in which the leading particle was outside the rectangle of the primary-direction errors are shown in

Fig. 3. Other transverse momenta (shown dashed in Fig. 3) were calculated relative to the center of gravity of the secondary particles, using statistical weights proportional to the corresponding energies. As seen from the figure, these transverse momenta are relatively small.

It seems to us that all the transverse momenta obtained in this manner can be regarded as realistic. Of course, they can be influenced by all the uncertainties connected with the errors in the determination of the primary energy and of the angular distribution, but this cannot change the overall picture of the transverse-momentum distribution. The average value of $p_\perp$ is $\langle p_\perp \rangle \approx 1 - 2$ GeV/c.

* A complete analysis of the interactions is described in the preprints of the Institute and has been submitted to Nuovo Cimento.

COLLECTIVE COULOMB EXCITATION OF NUCLEI IN A REGULAR CRYSTAL

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1. It has been shown that in resonant interaction of γ quanta or particles with nuclei situated in a crystal lattice, the resultant excited state (compound nucleus) has a collective character. In other words, the excited state is in this case not an excitation of an individual nucleus, but is "smeared" over the entire crystal.

It turns out that such a collective state can occur under certain conditions following Coulomb excitation of low-lying levels of nuclei which accompanies the scattering of fast charged particles in a regular crystal. When such an excited state decays, the angular distribution of the γ quanta has a unique character which differs greatly from the usual case.

2. Let the Coulomb excitation be realized by a beam of fast heavy particles (for concreteness, protons) with initial momentum p. As a result of the interaction, the nuclei of the crystal acquire a momentum q = p - p', where p' is the final momentum of the particles.

In an ideally rigid lattice, the γ radiation of the n-th nucleus will have a phase $\exp[i(q - \kappa)R_n]$ (κ - wave vector of the γ quantum). In a real crystal, such a phase is maintained only if no phonon excitation takes place, i.e., the process will have a "recoilless" character.

The phononless-transition probability depends on the setup of the experiment. We can visualize two types of experiments: a) an isomer level of the Mossbauer type is excited and only the γ quanta for which the Mossbauer effect takes place are registered; b) all the γ quanta are registered, regardless of their energy. A suitable analysis shows that in this case

$$\text{a)}\ f(q,\kappa) = \exp[-Z(q) - Z(\kappa)], \quad \text{b)}\ f(q,\kappa) = \exp[-Z(q-\kappa)], \tag{1}$$