SEARCHES FOR THE PROCESS OF FIREBALL GENERATION IN NUCLEAR INTERACTIONS OF PROTONS WITH ENERGIES 20 AND 23 GeV

G. B. Zhdanov, M. I. Tret'yakova, and M. M. Chernyavskii
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 3 October 1968
ZhETF Pis. Red. 8, No. 11, 659-665 (5 December 1968)

To assess the possibility of fireball formation, we analyzed the quasinucleon interactions of protons with energies 20 and 23 GeV, registered with the aid of emulsions exposed to the CERN accelerator in a pulsed magnetic field (180 kOe). By means of previously described criteria [1] we selected approximately 160 interactions of quasinucleon type with multiplicities n = 5 - 8, of which about 40 contained two protons in the final state. Besides the emission angles of all the charged secondary particles, we measured their momenta at the accuracies listed in Table 1, and determined the sign of the charge and the nature of the particle.

Table 1

Accuracy of measurement of the particle momentum

Measurement accuracy, $\Delta p/p$	$\leq$ 10%	11 - 20%	20 - 30%	30 - 50%	Remark
For fast particles (> 1.5 GeV/c)	~ 10%	65%	~ 20%	-	~ 5% unidentified
For slow particles (< 1.5 GeV/c)	~ 20%	20%	25%	~ 80%	~ 5% not measured

Selection of Three-particle Reactions

1. The first method used by us was based on finding in each investigated star a group consisting of at least three charged pions and which is kinematically uncorrelated with at least one of the secondary nucleons. This analysis was carried out on events of the type $2pk\pi^{\pm}m\pi^{0}$ (k = 3 - 6). A quantitative criterion for the absence of kinematic correlations between mesons and nuclei is a sufficiently large value of the effective masses of the system consisting of one nucleon and a specified number of pions. In particular, we assumed the condition

$$M_{ef}(p2\pi) > 1.8 \text{ GeV}/c^2 \qquad (A)$$

for all possible combinations of the protons and pions (inasmuch as formation of isobars with mass $M_{ef} > 1.8$ GeV/c^2 can be regarded as an event with low probability). Additional selection of three-pion clusters of small mass (particularly in the case of their asymmetrical emission in the c.m.s.) could be effected with the aid of the more complicated criterion

$$M_{ef}^2(p3\pi) - M_{ef}^2(3\pi) > 3.5\ (\text{GeV}/c^2)^2. \qquad (B)$$

2. An important confirmation (albeit not the only one) of the possibility of separating three-particle reactions can be the pion transverse momentum distribution shown in

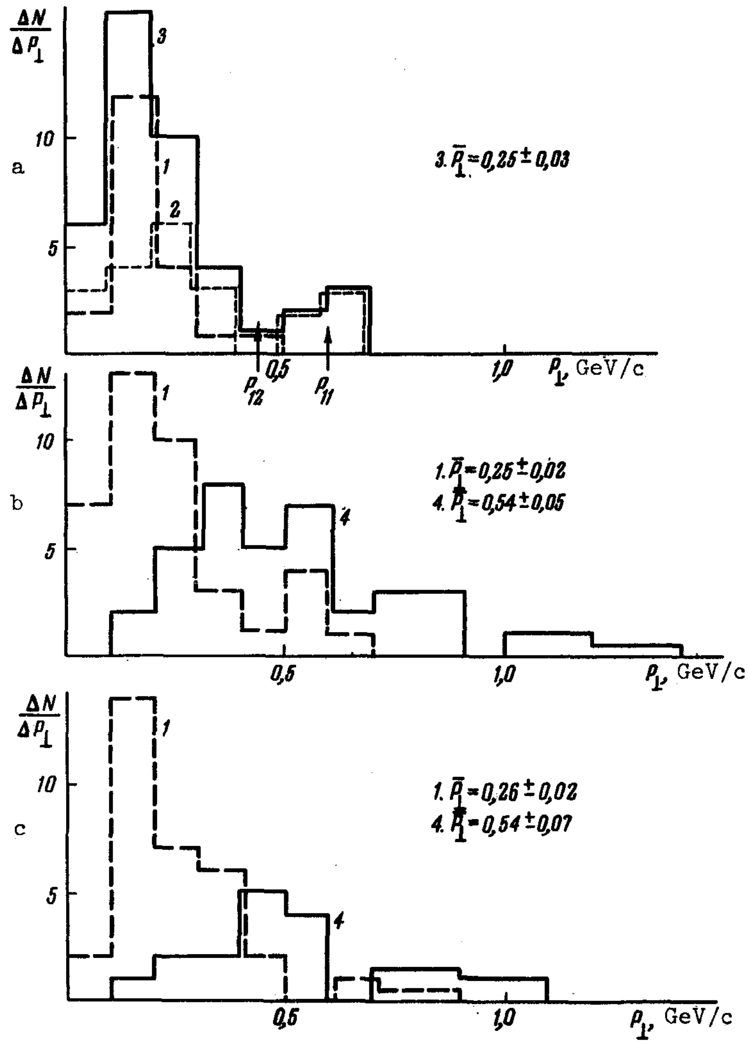

Fig. 1. Distribution of transverse momenta of pions for different reactions: a) $2p \to 2p\pi^+\pi^-$ (1 - $M_{ef}(p2\pi) \leq 1.8$ GeV/c^2, 2 - $M_{ef}(p\pi) \leq 1.8$ GeV/c^2, 3 - sum of 1 and 2; b) $pn \to 2p3\pi^\pm$ and $pp \to 2p4\pi^\pm$ (4 - $M_{ef}(p2\pi) > 1.8$ GeV/c^2; c) $pn \to 2p5\pi^\pm$ and $pp \to 2p6\pi^\pm$.

Fig. 1. It is seen that the mesons that are kinematically correlated with the nucleons have small transverse momenta ($p_\perp = 0.25$ GeV/c), characteristic of the process of decay of isobars with masses up to 1.8 GeV/c^2. At the same time, the pions that are genetically connected with the "third body," have also another form of distribution and a larger mean value of $p_\perp$ ($\bar{p}_\perp = (0.54 \pm 0.04)$ GeV/c). In the case of isotropic decay of the "third body" into four particles (see below) the value $\bar{p}_\perp = (0.54 \pm 0.04)$ GeV/c corresponds to a mass 2.75 ± 0.2 GeV/c^2.

Properties of Meson Clusters in Three-particle Reactions

1. The 15 pion triads of particles selected in accordance with criterion (A) turned out to be quite massive - the most probable value of the mass is approximately 1.8 GeV/c^2. An analysis of the angular distributions in the laboratory system (in a logarithmic scale, $\xi = \log \tan \theta$) has shown that they are close to isotropic - the probable variance per individual event is approximately 0.3.

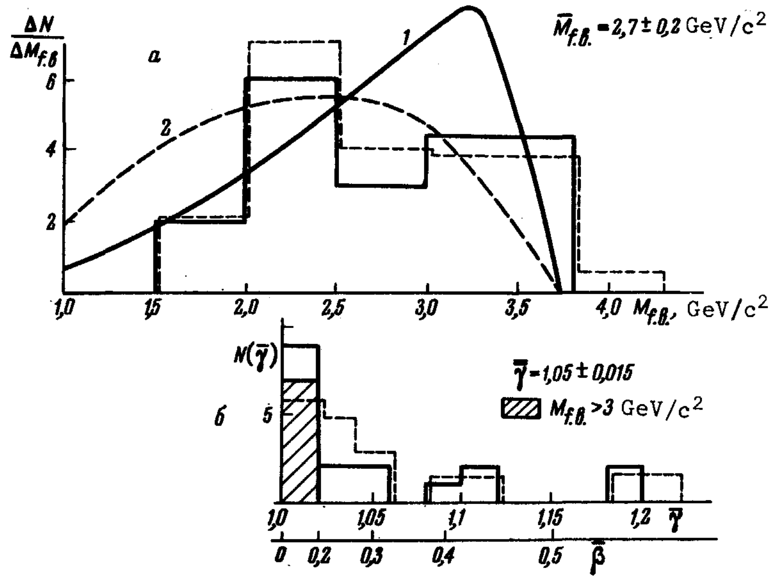

Fig. 2. Distribution of the masses (a) and Lorentz factors (b) of the "third body" in three-particle reactions. Curves 1, 2 - predictions of the theory [2] for the case of formation of the fireball and the fireball plus isobar, respectively.

2. An important property of the considered pion clusters is the appreciable value of their total transverse momentum, which corresponds approximately to the algebraic sum of the recoil momenta of the two nucleons (see Table 2).

Table 2

Distribution of transverse momenta $P_\perp$ of meson clusters and of the total momenta $|\Sigma p_{\perp p}|$ of the recoil nuclei (GeV/c)

	0 – 0.4	0.4 – 0.8	0.8 – 1.2	1.2 – 1.6
$P_\perp$	4	5	2	4
$\lvert \Sigma p_{\perp p} \rvert$	4	8	2	1

3. Another unique property of the meson clusters is that they include, with appreciable probability (on the order of 50%), triads of charged mesons that are complanar (within ±2 - 3°).

4. So far we have referred to charged pions emitted following the decay of the cluster. However, the inelasticity coefficients in the laboratory and "mirror" (connected with the incoming nucleon) coordinate systems, with allowance for the fraction of the pions having no relation to the "third body" (if such exists), makes it possible to determine three other important characteristics of the investigated three-particle reactions. From the energy and momentum conservation laws we can determine in each case the total mass of the meson cluster $M_{f.b.}$ (including the neutral pions). Figure 2a shows the distribution with respect to these masses (1) as well as the distributions predicted by one of the variants of the theory of

peripheral collisions [2] for fireballs produced by 20-GeV protons, both in pure form (1) and with excitation of one of the nucleons to the isobar state (2).

Figure 2b shows the distribution of the clusters with respect to the values of the Lorentz factors $\bar{\gamma}$ in the c.m.s., and the corresponding velocities $\bar{\beta}$. We see that only the heaviest clusters are produced almost immobile in the c.m.s. ($\bar{\gamma} \leq 1.02$).

The ensemble of events selected by us suffers from two shortcomings: first, a small admixture (~20%) of central interactions, which causes an excess of events in Fig. 2b in the region $\bar{\gamma} \leq 1.02$, and, second, failure to include all the three-particle reactions, as a result of the "overcaution" incorporated in the criterion (A). By introducing suitable changes and additions to the initial selection criteria (in particular, by using the criterion (B) in place of (A) we obtain the redistributions represented by the dashed lines in Figs. 2a and 2b, for which, however, the average values of $M_{f.b.}$ and $\bar{\gamma}$ remain practically unchanged.

5. By investigating the distribution of the ratios of the total mass of the cluster to the effective mass of the corresponding system of three charged pions, shown in Fig. 3, we can determine, in principle, how many neutral pions are contained (as a rule) in the same cluster. To this end it was sufficient to take into account principally the fluctuations in the ratio of the four-pion and three-pion masses, which could be taken from data on clusters of four charged pions. (The cluster contains as a rule only one neutral pion, and consequently the total number of pions in the cluster is 4, in accord with the expected result of the theory [2], which requires that the fireball decay only into an even number of pions.)

6. One of the characteristic properties of three-particle reactions in the presence of a sufficiently massive ($M_{f.b.} > 1.5$ GeV/c^2) meson cluster is a sufficiently frequent (probability 0.6 ± 0.2) appearance of a pion with a large (> 0.7 GeV/c) transverse momentum. In Table 3 are presented data which make it possible to determine both the fraction of such three-particle reactions among the interactions of different multiplicity, regardless of the presence in them of secondary protons, and the total cross section of such reactions. It turned out to be approximately 6 mb (accurate to ~30%). Here, too, there is satisfactory agreement with the theory [2], which predicts a fireball-generation cross section of approx-

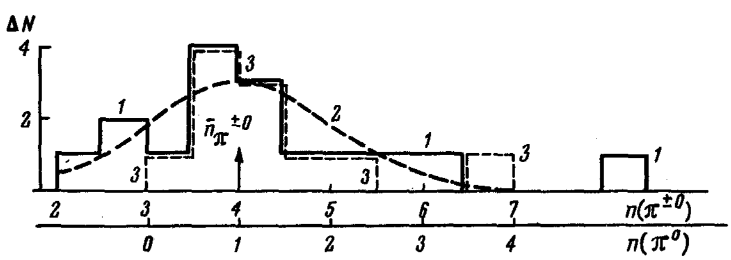

Fig. 3. Distributions with respect to the "missing" number of neutral pions $n(\pi^0)$ based: 1) on the analysis of the inelasticity coefficients and the effective masses of the three-pion systems, and 3) on the analysis of the masses of the $3\pi^{\pm}$ and $4\pi^{\pm}$ systems; 2) Gaussian curve with 25% variance.

Table 3

Fractions of interactions with large $p_{\perp\pi}$ and cross sections of 3-particle reactions

Number of charged pions	Number of observed interactions	Cross section, mb	Number of events with $p_{\perp} > 0.7$, GeV/c	With correction for observation probability	Cross section of 3-particle reactions, mb
$3\pi^{\pm}$	105	5.2	13	23	1.1
$4\pi^{\pm}$	117	4.5	23	41	1.6
$5\pi^{\pm}$	33	3.8	10	18	2.1
$6\pi^{\pm}$	20	1.9	9	16	1.5
Total	275	15.4	55	98	6.3

imately 8 mb at an initial energy 20 GeV.

7. For a more definite answer to the question of the nature of the meson clusters investigated in this paper it is absolutely necessary to have comparative data for much higher energies (at least to 70 GeV), since the theory [2] gives grounds for expecting that the masses and decay modes of the fireballs in three-particle reactions will change only weakly with change of initial energy.

An alternate explanation of the observed phenomena is to assume either generation of heavy boson resonances with various masses (with decay into three $\pi^{\pm}$ mesons), or cascade decay of the fireball with a final stage of decay into three particles.

The authors thank Dr. E. Dahl-Jensen for help in obtaining the emulsions from CERN, the laboratory group for high-grade microscope measurements, and I. I. Roizen, V. N. Akimov, G. T. Zatsepin, and A. E. Chudakov for fruitful discussions of the results.

[1] D. A. Galstyan, G. B. Zhdanov, M. I. Tret'yakova, M. N. Shcherbakova, and M. M. Chernyavskii, Zh. Eksp. Teor. Fiz. 51, 417 (1966) [Sov. Phys.-JETP 24, 280 (1967)].

[2] V. N. Akimov and I. I. Roizen, Preprint, Phys. Inst. Acad. Sci. No. 134, 1968.

ELECTROMAGNETIC EXCITATION OF SOUND IN TIN

Yu. P. Gaidukov and A. P. Perov
Moscow State University
Submitted 1 October 1968
ZhETF Pis. Red. 8, No. 11, 666 - 668 (5 December 1968)

We investigated the surface impedance of single-crystal tin in a magnetic field. The measurements were made at T = 4.2°K in a magnetic field up to 60 kOe, produced by a superconducting solenoid. We recorded the derivative of the real part of the impedance $\partial R/\partial H$ using a radiospectrometer with an autodyne of the Pound-Knight type [1]. Two samples in the form of discs of 18 mm diameters, with thicknesses 0.55 and 0.11 mm, were used. In both cases the [010] crystal axis was perpendicular to the sample plane.

We investigated the dependence of the amplitude of the quantum oscillations of the surface impedance on the frequency of the high-frequency field at $\vec{H} \parallel \vec{n}$, where $\vec{n}$ is the normal