A. A. Tyapkin. *Diffractive production of resonances and observation of two radially excited states of the pion.* The diffractive dissociation of hadrons by nuclei into more complex systems presents some unique opportunities for detecting and studying the resonance levels of excitation characteristic of the incident hadrons. The opportunities stem from the reliability with which such reactions can be identified as binary and from the lack of ambiguity in the corresponding analysis.

A study of the diffractive dissociation of negative pions into three-pion systems by nuclei at 40 GeV/c has been carried out with the help of the five-meter magnetic spark spectrometer at the Serpukhov accelerator in an experiment carried out jointly by the Joint Institute for Nuclear Research, Dubna, and the Instituto Nazionale di Fisica Nucleare, Milan and Bologna.[1] The reaction was studied by taking more than 700 000 stereo photographs of events with various targets with the spectrometer controlled by a special trigger system which effectively selected coherent inelastic interactions. This large amount of film information required a completely automatic analysis, which was carried out on NRD automated scanning systems at Bologna and Dubna with the help of large computers at Dubna, Milan, and Geneva.

This automatic analysis of the experimental data yielded 110 000 events in which three pions were produced which satisfied all the geometric and kinematic criteria. For each such event we determined the momentum transfer to the nucleus, the angles at which the mesons were emitted from the target, the momenta of the mesons, and the effective rest mass of the entire three-pion system. These data incorporated all the information required to analyze the characteristics of possible resonances produced during the dissociation of the pions. We selected for further analysis the events with a small momentum transfer in the region of the diffraction cone up to the first minimum. This choice reliably selected "pure" coherent events not involving the excitation of the target nucleus.

To detect possible resonance states for the entire three-pion system we used a partial-wave analysis of three-particle events; the contributions of different wave states in terms of spin and parity were taken into account separately. This analysis not only reveals the resonance behavior of the contribution of a certain wave but also makes it possible to prove the resonance nature of the observed peak on the basis of the change of the phase of this wave in the corresponding mass region. This circumstance is of decisive importance in a search for faint, broad resonances, since peaks of this sort may also arise from kinematic effects.

We turn now to the results of the analysis. First, rather intense peaks corresponding to the known resonances A_1 and A_3 with quantum numbers of 1^+ and 2^- were found. The results which are new on these peaks are the discovery of a significant change in the phases of the corresponding 1^+ and 2^- waves, conclusively proving the resonance nature of these peaks.

The most important results of the analysis dealt with the contribution of the 0^- wave, which has the same angular-momentum and parity quantum numbers as the incident pion. In the dependence of the contribution of this wave on the effective rest mass of the entire system we found some characteristic peaks near 1200 and 1800 MeV. The significant changes in the phase of the 0^- wave (about 80°) found in the same mass regions are convincing evidence of the resonance nature of these peaks.

The considerable width of the new resonances (300 and 200 MeV), their low intensity, and the overlap of the first of them with the more intense A_1 resonance has prevented the detection of these excited states in previous experiments. The large statistical base of events and the high measurement accuracy have made it possible to establish in this experiment the existence of some new excited states of the pion with average masses of 1240 ± 10 and 1770 ± 40 MeV.[2,3]

The fact that the masses of these new resonances are well above the mass of the incident pion and the fact that their total-angular-momentum and parity quantum numbers are the same signify the observation of the excitation of a radial degree of freedom in a quark-antiquark system. These resonances are thus of a special type which do not conform to the ordinary classification of hadrons on the basis of the theory of unitary symmetry. Such resonances furnish the most direct confirmation of the composite structure of the corresponding hadrons. An important aspect of these new resonances is that they directly prove the composite structure of the lightest hadron, which makes the basic contribution to the nuclear interactions of nucleons. The quantitative characteristics found in this experiment for these radially excited states of the pion can be used to test any theory that claims to describe the spectroscopy of the system of light quarks.

[1]G. Bellini, L. P. Chernenko, V. S. Datsko, M. di Carato, P. L. Frabetti, Yu. I. Ivanshin, P. Laurikanen, L. K. Kitkin, P. F. Manfredi, S. Micheletti, V. A. Moiseenko, V. I. Nikanorov, S. Otwinowiski, F. Palombo, J. Perneger, M. Pernica, M. Pimia, A. F. Pisarev, I. L. Pisarev, A. Sala, S. Sala, S. I. Sychkov, M. Szeptycka, A. A. Tyapkin, I. M. Vassilevski, G. Vegni, V. V. Vishniakov, O. A. Zaimidoroga, V. V. Antipov, A. G. Galperin, L. Moroni, and V. A. Petrov, Nucl. Phys. **B199**, 1 (1982).

[2]G. Bellini, M. di Carato, P. L. Frabetti, Yu. I. Ivanshin, L. K. Litkin, D. Menasce, S. Otwinowski, F. Palombo, J. Perneger, A. Sala, S. Sala, S. I. Sychkov, A. A. Tyapkin, I. M. Vassilevski, G. Vegni, V. V. Vishniakov, and O. A. Zaimidoroga (Dubna-Milano Collaboration), in: Proceedings of the Fourth Warsaw Symposium on Elementary Particle Physics, Kasimierz, May, 1981, Warsaw, 1981, p. 187.

[3]D. P. Bellini, I. M. Vasilevskiĭ, G. Vegni, V. V. Vishnyakov, M. di Carato, O. A. Zaĭmidoroga, Yu. I. Ivan'shin, L. K. Lytkin, F. Palombo, J. Perneyer, A. Sala, S. Sala, S. Ya. Sychkov, A. A. Tyapkin, and P. L. Frabetti, Pis'ma Zh. Eksp. Teor. Fiz. **34**, 511 (1981) [JETP Lett. **34**, 488 (1981)]; Phys. Rev. Lett. **48**, 1697 (1981).

Translated by Dave Parsons