Investigation of azimuthal correlations in $\pi^- p$ interactions at 40 GeV

S. A. Azimov, F. K. Aliev, N. N. Kulakhmedov, and T. S. Yuldashbaev

Physicotechnical Institute of the Uzbek Academy of Sciences
(Submitted 27 March 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 9, 530–533 (5 May 1978)

Investigation of the reactions $\pi^- p \to px^{-1}$ have revealed azimuthal correlations of dynamic origin in the missing-mass interval $3.6 < M_x \leq 4.8$ GeV.

PACS numbers: 13.85.Hd

The investigation of azimuthal correlations in the angular distribution of secondary particles is of great interest in the search for heavy multipion resonances.

The azimuthal correlations produced in the decay of such multipion "rotating" resonances can be easily observed with the aid of the sensitive criterion β proposed in[1]. The quantity $\beta = (\sum_{i \neq j} \cos 2\epsilon_{ij})/\sqrt{n_s(n_s - 1}$, which is a function of the period azimuthal angles $\epsilon_{ij} = \phi_i - \phi_j (i = 1, 2 ..., n_s; j = 1, 2, ..., n_s; i \neq j; 0 \leqslant \epsilon_{ij} \leqslant \pi, 0 \leqslant \phi < 2\pi, n_s$, and n_s is the number of secondary particles) does not depend on the direction from which the angles are reckoned and is bounded by the values $-\sqrt{n_s/(n_s - 1)} \leqslant \beta \leqslant \sqrt{n_s(n_s - 1)}$. In case of complete complanarity of n_s pulses of secondary particles in a plane perpendicular to the azimuthal plane, β reaches its maximum value. The value of β is minimal if the particles are uniformly distributed in $\phi_i (\Delta\phi_i = \phi_i - \phi_j = 2\pi/n_s, n_s \geqslant 3)$.

The quantity $\bar{\beta} = (\sum_{i=1} \beta_i)/N$ averaged over a large number N of events has an approximately normal distribution with zero expectation value and with a variance $1/N$. In the absence of azimuthal correlations, the inequality $|\bar{\beta}|\sqrt{N} < 2$ should then be satisfied with probability $\approx 95\%$.

Inelastic interactions of 17.2-GeV π^- mesons with free and quasi-free emulsion protons, accompanied by production of a slow (25–400 MeV) recoil proton and 3 and 5 fast charged particles, were investigated in[2]. Statistically reliable azimuthal correlations were observed in the missing-mass region $M_x = 2.9$–3.5 GeV ($\bar{\beta} = 0.37, N = 75$, $|\bar{\beta}|\sqrt{N} = 3.2$). There are no correlations in other missing-mass intervals.

However, the number of events analyzed in[2] is statistically small, and the complicated composition of the nuclear emulsions introduces an uncertainty in the value of M_x. Experiments with bubble chambers provide appreciable statistical material and more reliable information on the nature of the target particle.

We have therefore investigated in the present study the experimental data obtained by the collaboration with the JINR 2-meter propane bubble chamber exposed to a π^{-1}-meson beam of 40 GeV energy.

We used for the analysis 12 384 events satisfying the $\pi^- p$-collision selection criteria. From among these we selected stars with identified recoil proton and momentum $P_p \geqslant 140$ MeV/c and with $n_s = 3$ and 5 fast particles. A limitations was introduced on the inelasticity coefficient in the anti-laboratory (mirror) coordinate system

$$k_m = \frac{\Sigma(E_i - P_i \cos\theta_i)}{m_p} \leqslant 1.1 ,$$

where E_i, P_i, and θ_i are the energy, momentum, and emission angle of the charged particles in the laboratory frame. The summation is over all the charged particles, including the recoil proton. As shown in[3], the value $k_m \geqslant 1.1$ is due primarily to the contribution of the $\pi^- p$ collisions with the quasi-free protons of the carbon nuclei; these collisions can distort the measured value of the missing mass M_x.

The total number of events satisfying these selection criteria turned out to be 850. For each selected event we obtained the value of M_x and β. The missing mass M_x of all the secondary particles except the recoil proton was calculated from the relation

$$M_x^2 = m_\pi^2 + 2P_p P_0 \cos\theta_p - 2E_p(E_0 + m_p),$$

where m_π and m_p are the pion and proton masses, P_0 and P_p are the momenta of the primary pion and of the recoil proton, and E_p and θ_p are the kinetic energy and emission angle of the recoil proton.

The azimuthal angles were reckoned in a plane perpendicular to the Z axis, which was directed along the difference $(P_0 - P_p)$ of the momenta of the primary pion and the recoil proton, while the Y axis was directed along the vector product $P_p \times P_0$.

TABLE I.

Characteristic of stars	M_x, GeV	N	$\bar{\beta}$	$\lvert\bar{\beta}\rvert\sqrt{N}$
$E_0 = 40$ GeV	$\leqslant 3.6$	395	+0.07	1.5
	3.6 – 4.8	234	+0.27	4.2
$n_s = 3; 5$	> 4.8	221	+0.09	1.3
	all events	850	+0.13	3.9

The experimental results are listed in Table I, where the quantity $|\bar{\beta}|\sqrt{N}$ is a measure of the statistical reliability of the effect in units of standard deviation.

As seen from the results, in the mass interval $3.6 < M_x \leqslant 4.8$ GeV there are observed statistically reliable (at a level of 4.2 standard deviations) correlations, which do not appear at larger or smaller value of M_x. The correlations in the region $3.6 < M_x \leqslant 4.8$ GeV are separately observed both for events with $n_s = 3$ and for $n_s = 5$, so that to increase the statistics the table lists the combined experimental data.

The combined azimuthal distributions of the secondary shower particles, constructed for the M_x intervals indicated in the table, do not differ from the isotropic ones. The average value $\bar{\beta}$ is the same for the intervals $0<\phi_p\leqslant 180°$ and $180°<\phi_p\leqslant 360°$ of the azimuthal recoil-proton emission angles in the chamber, and is practically independent of the recoil-proton momentum P_p.

Calculations similar to those of[4] have shown that the experimentally observed nonmonotonic dependence of $\bar{\beta}$ on M_x can predict the models in which the azimuthal correlations are the result of the momentum conservation law, and thus indicate that the correlations in the missing-mass region $3.6<M_x\leqslant 4.8$ GeV are of nontrivial dynamic orgin.

A possible cause of the azimuthal correlations may be the formation, in the mass interval 3.6–4.8 GeV, of multipion resonances situated on infinitely growing Regge trajectories.[5] Since the spin of such resonances increases with increasing mass ($J_p \sim M^2$), the tendency of complanarity of the momenta of the secondary pions, which generates the azimuthal correlations, increases.

The cross section for the production of heavy resonances can be estimated by assuming that the azimuthal effects that arise in $\pi^- p$ interactions at 40 GeV are due to product ion of resonances in the mass interval $M_x=3.6$–4.8 GeV, while in the background events the average value is $\bar{\beta}=0$. The number of resonance events in the indicated mass interval then turns out to be $N_R=24.0\pm 5.6$, corresponding to a resonance production cross section $\sigma_p=60\pm 14$ μb.

Measurements made with the Serpukhov accelerator of the Institute of High Energy Physics with missing-mass spectrometer, at pion energies 25 and 40 GeV, gave no indication of the existence of such reasonances.[6]

It was shown in [7] that allowance for the effects of the centrifugal barrier leads to a rapid shrinking of the resonances located on linearly growing Regge trajectories, so that in the mass region $M\geqslant 3$ GeV their width tends to zero as $M\to\infty$. The shrinking of the resonance with increase of its mass can also be predicted within the framework of the Pomeranchuk model.[5]

It is possible that in the region $M_x>3.0$ GeV the distance between neighboring resonant peaks decreases enough to prevent their further resolution.

Thus, the analysis method based on the dependence of the azimuthal correlations on the missing mass of the particles can become very effective for the observation of closely-lying narrow resonances of large mass, $M>3$ GeV, when the resolution of the apparatus is insufficient for their separation in the usual manner.

The authors are deeply grateful to V.G. Grishin, A.A. Yuldashev, and V.M. Chudakov for a discussion of the work and for remarks.

[1]S.A. Azimov, Sh. Abduzhamilov, L.P. Chernova, G.M. Chernov, and V.M. Chudakov, Zh. Eksp. Teor. Fiz. **45**, 407 (1963) [Sov. Phys. JETP **18**, 281 (1964)].

[2]S.A. Azimov, I.V. Rechitsskiĭ, E.A. Til', and V.M. Chudakov, Yad. Fiz. **9**, 126 (1969) [Sov. J. Nucl. Phys. **9**, 77 (1969)].

[3]L.A. Didenko, V.S. Mursin *et al.*, Proc. Fifteenth Intern. Cosmic Ray Conf., Plovdiv, Bulgaria, 1977, vol. 7-HE, p. 79.

[4]S.A. Azimov, N.B. Eroshkina, and V.M. Chudakov, Izv. Akad. Nauk Uzb. SSR Ser. Fiz.-Mat. Nauk **4**, 56 (1975).
[5]S.A. Azimov, R.U. Beĭsembaev, E.Zh. Mullazhanov, V.M. Chudakov, and T.S. Yuldashbaev, Yad. Fiz. **11**, 1248 (1970) [Sov. J. Nucl. Phys. **11**, 694 (1970)].
[6]Yu.M. Antipov *et al.*, Yad. Fiz. **16**, 996 (1972) [Sov. J. Nucl. Phys. **16**, 550 (1973)].
[7]H. Goldberg, Phys. Rev. Lett. **21**, 778 (1968).