Possible exotic $\varphi\pi^0$ state with a mass of about 1.5 GeV

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New data have been obtained on a resonance in the $\varphi\pi^0$ system which forms in the charge-exchange reaction $\pi^- p \to Cn$, $C \to \varphi\pi^0$. The experiments were carried out on the 70-GeV accelerator at Serpukhov. The mass and width of the resonance are $M_c = 1490 \pm 25$ MeV and $\Gamma_c = 165 \pm 30$ MeV. The cross section has been determined at a momentum of 32.5 GeV/c: $\sigma(\pi^- p \to Cn)\mathrm{BR}(C \to \varphi\pi^0) = 35 \pm 15$ nb. The C state has an isospin $I = 1$, a spin $J \geqslant 1$, and a negative charge parity. It is strongly coupled to the $\varphi\pi^0$ channel and is regarded as a possible exotic meson.

In this letter we report the results of a new experimental study of the $\varphi\pi^0$ system which is formed in the charge-exchange reaction

$$\pi^- p \to \varphi\pi^0 n. \qquad (1)$$

As in the first study[1] of this reaction, the measurements were taken in a π^- beam with a momentum of 32.5 GeV/c of the Serpukhov accelerator by the composite Lepton-F spectrometer.[2,3]

This apparatus, which can effectively detect charged hadrons and γ rays, includes a wide-aperture magnetic spectrometer with wire proportional chambers and a GAMS-200 hodoscopic γ spectrometer.[4] The charged particles in both the initial and final states of the reaction are identified by means of gas-filled threshold Čerenkov counters.

During the exposure of the spectrometer to the beam, 4×10^{11} π mesons pass through the target. The sensitivity of the measurements is twice that of the first measurements.[1] In addition, substantial improvements were made in the background conditions; the acceptance of the spectrometer was increased; new proportional chambers were added; and the efficiency of the identification of the secondary K mesons was improved. While detecting the main exclusive process

$$\pi^- p \to K^+ K^- \pi^0 n, \tag{2}$$

which includes (1), we simultaneously detected the intense reaction

$$\pi^- p \to \pi^+ \pi^- \pi^0 n. \tag{3}$$

We used data on this reaction to normalize the cross sections, to calibrate the apparatus and to study the background.

For analysis we selected events with two charged particles in the final state with energies $E_{\pm} > 7.3$ GeV and with two γ rays with energies $E_{\gamma 1,2} > 0.5$ GeV, $E_{\gamma 1} + E_{\gamma 2} > 5$ GeV (see Ref. 1 for more details). The mass spectrum of the pairs of γ rays, $M_{\gamma\gamma}$, is dominated by a peak corresponding to the π^0 meson. Imposing the selection rules $100 < M_{\gamma\gamma} < 180$ MeV and $29 < (E_{\gamma 1} + E_{\gamma 2} + E_+ + E_-) < 35$ GeV made it possible to distinguish reactions (2) and (3) at the low background level.

In the mass spectrum of the K^+K^- system in reaction (2), we observe a clearly defined peak which corresponds to the production of a φ meson in reaction (1). The position of this peak ($\overline{M}_{K^+K^-} = 1020$ MeV) agrees with the tabulated value of the mass of the φ meson, while the width of the peak (9.6 MeV) is determined primarily by the instrumental resolution of the spectrometer. Events of reaction (2) were selected from the peak region ($1016 < M_{K^+K^-} < 1024$ MeV). The background contribution was taken into account by subtracting the number of events in the adjacent mass intervals (1002–1010 and 1030–1038 MeV).

The resulting mass spectrum of the $\varphi\pi^0$ system in reaction (1) is shown in Fig. 1. This spectrum is dominated by a resonant C state.[1]

In analyzing the data on reaction (2) and in identifying events of reaction (1), we varied the criteria for selecting events and we used various methods to subtract the background under the φ peak. The mass spectrum found for the $\varphi\pi^0$ system by the various methods agree well. The average characteristics of the C state are

$$M_c = 1490 \pm 25\,\text{MeV}, \quad \Gamma_c = 165 \pm 30\,\text{MeV}. \tag{4}$$

The cross section for the production of the C state is found to be

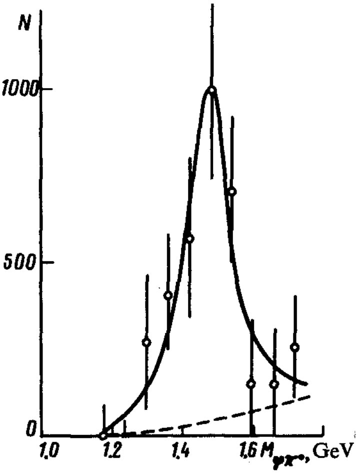

FIG. 1. Effective-mass spectrum of the $\varphi\pi^0$ system in the reaction $\pi^- p \to \varphi\pi^0 n$ at 32.5 GeV/c; the efficiency of the apparatus has been taken into account. The spectrum has been fitted by a resonant Breit-Wigner curve (the solid line) and by a polynomial background (the dashed line).

$$\sigma(\pi^- p \to Cn)\mathrm{BR}(C \to \varphi\pi^0) = 35 \pm 15 \text{ nb} . \qquad (5)$$

The uncertainties indicated here are due primarily to systematic errors.

The values in (4) and (5) agree with the values found previously.[1] These values are also supported by the data of Ref. 5, found in a study of charged $\varphi\pi^-$ states.

Resonant $\varphi\pi$ states have been studied theoretically.[6,7]

It follows from the scheme for the decay $C \to \varphi\pi^0$ that this state has an isospin $J = 1$ and a negative charge parity.[1)]

The limited acceptance of our spectrometer and the limited statistical base, attributable to the small cross section in (5), rules out a thorough analysis of the angular distributions for the decay $C \to \varphi\pi^0$. We can, however, study the distribution of events in the angle ($\theta_{K^- \pi^0}$) between the K^- meson and the π^0 meson in the center-of-mass frame of the φ meson. This distribution is essentially undistorted by the acceptance. The results of this analysis rule out an angular distribution $dN/d\cos\theta_{K^- \pi^0} \sim \cos^2\theta_{K^- \pi^0}$, which should occur in the case in which the C state has a spin $J = 0$. We can thus conclude that the spin of the C state is $J \geqslant 1$. It should be noted that this state, which forms near the kinematic threshold, could naturally be assigned the value $J^P = 1^+$ (corresponding to an orbital angular momentum $\iota = 0$). States with higher spins should be strongly suppressed by a barrier factor.

If the C state had a standard quark structure, $(u\bar{u}\text{-}d\bar{d})/\sqrt{2}(I = 1)$, the probability for the decay $C \to \varphi\pi^0$, which is forbidden by the Okubo-Zweig-Iizuka selection rule, should have been very small in comparison with the probability for $C \to \omega\pi^0$ ($< 1/100$). We analyze the mass spectrum of the $\omega\pi^0$ system from a series of experiments with the GAMS-2000 spectrometer.[8] This spectrum is dominated by peaks corresponding to the production of $B(1285)$ and $g(1680)$ mesons and their decays $B \to \omega\pi^0$ and $g \to \omega\pi^0$. In the region ~ 1.5 GeV in (4), on the other hand, we find no statistically significant structural features in the mass spectrum of the $\omega\pi^0$ system. We thus find the following limitation at a 95% confidence level:

$$\mathrm{BR}(C \to \varphi\pi^0)/\mathrm{BR}(C \to \omega\pi^0) > 1/2. \qquad (6)$$

This limit is two orders of magnitude higher than the value expected in the case of an ordinary $q\bar{q}$ structure of the C state.

The strong coupling of the C state with the $\varphi\pi^0$ channel is a strong argument in favor of its interpretation as a cryptoexotic state[6] with a possible four-quark structure $(u\bar{u} - d\bar{d})s\bar{s}/\sqrt{2}$. In this case we would have a natural explanation for the isospin of the state, $I = 1$, and for its strong coupling with the φ meson ($= s\bar{s}$). The further possibility of intense decays with s quarks for hybrid states (maketons) and quark-gluon mesons of the $q\bar{q}g$ type has also been discussed in the literature.[9]

[1)] The quantum numbers of the C state sharply distinguish it from its "neighbors" along the mass scale $E(1420)$, with $IJ^{PC} = 01^{++}$ and $\iota(1440)$, 00^{-+}.

[1] S. I. Bityukov *et al.*, Yad. Fiz. **38**, 1205 (1983) [Sov. J. Nucl. Phys. **38**, 727 (1983)].
[2] S. I. Bityukov *et al.*, Yad. Fiz. **39**, 1165 (1984) [Sov. J. Nucl. Phys. **39**, 735 (1984)].
[3] S. I. Bityukov *et al.*, Preprint IFVÉ 41-216, Institute of High-Energy Physics, Serpukhov, 1984.
[4] F. Binon *et al.*, Preprint IFVÉ 80-141, Institute of High-Energy Physics, Serpukhov, 1980; Nucl. Instrum. Methods **188**, 507 (1981).
[5] Yu. M. Antipov *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **38**, 356 (1983) [JETP Lett. **38**, 430 (1983)].
[6] F. E. Close and H. J. Lipkin, Phys. Rev. Lett. **41**, 1263 (1978).
[7] N. U. Barinov *et al.*, Yad. Fiz. **29**, 1357 (1979). [Sov. J. Nucl. Phys. **29**, 698 (1979)].
[8] F. Binon *et al.*, Preprint IFVÉ 85-62, Institute of High-Energy Physics, Serpukhov, 1985; Yad. Fiz. **38**, 934 (1983) [Sov. J. Nucl. Phys. **38**, 561 (1983)]; Nuovo Cimento **78A**, 313 (1983).
[9] M. S. Chanowitz, Preprint LBL-16653, Berkeley, USA, 1983.

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