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A NEW UPPER LIMIT FOR THE DECAY RATE $\Gamma(f' \to \pi\pi)$

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ABSTRACT

Data from an experiment on $\pi^- p \to K_S^0 K_S^0 n$ are used to compare the $K\bar{K}$ D-wave at the $f'(1516)$ mass with that at the $f(1270)$ mass. The ratio yields an upper limit for f' production by $\pi\pi$ scattering followed by decay into $K\bar{K}$. This limit can be expressed by $\Gamma(f' \to \pi\pi)/\Gamma(f' \to \text{all}) \lesssim 1\%$ or $\Gamma(f' \to \pi\pi)/\Gamma(f \to \pi\pi) \leq 1/400$; this indicates a suppression of the two-pion decay of the f', stronger than the well-known suppression of the $\phi(1019) \to \rho\pi$ decay.

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The 1^- and 2^+ meson nonets exhibit approximately "ideal" octet-singlet mixing[1], expressed by a mixing angle θ, where $\tan^2\theta = \frac{1}{2}$. In terms of quark content, this means that the isosinglets ω,f are composed of non-strange quarks, while ϕ,f′ are $\lambda\bar{\lambda}$. Within this simple picture it is nevertheless surprising that transitions from $\lambda\bar{\lambda}$ pairs to non-strange quark pairs are not induced by the strong interaction. No well-established conservation law is thereby violated. The hypothesis that such transitions cannot occur, known as the Zweig rule[2], has recently been discussed within the context of hidden charm in order to explain the narrow widths of the ψ and ψ' particles.

The result presented here on the $f' \to \pi\pi$ decay width indicates an inhibition stronger than that of the $\phi \to \rho\pi$ and contributes to our knowledge of decay mechanisms involving quark-pair annihilation.

We have analysed an experiment on $\pi^- p \to K^0_S K^0_S n$ at 8.9 GeV/c. The experiment was performed at the CERN Proton Synchrotron, using the CERN-ETH magnet spark chamber with a set-up similar to that used in an earlier experiment on the same reaction[3]. The full analysis of this experiment, where we discuss in detail the experimental procedure and the model which we use, will be published as a paper elsewhere. We analysed a sample of 6380 events. The detector's acceptance was fairly uniform and influenced mainly by K^0_S decays outside the fiducial volume. This acceptance was corrected by weighting each event. The weight is essentially the inverse of the detection probability averaged over the coordinate, along the beam trajectory, of the production vertex in the 41 cm liquid H_2 target. A comparison of the weighted and unweighted mass spectra (Fig. 1) shows how the weight increases slowly with the mass of the $K^0_S K^0_S$ system. The cross-section normalization for $\pi^- p \to K^0_S K^0_S n$, including the correction for unobserved K^0_S decay modes, is $(9.5 \pm 1.0) \times 10^{-35}$ cm^2 per weighted event.

We parametrize the $K\bar{K}$ production amplitudes in terms of a one-pion exchange model with absorption. Such models have successfully described the amplitudes for the similar process $\pi^- p \to \pi^+\pi^- n$ at small t [4]; furthermore, the t-dependence and the Treiman-Yang angular distribution of our data agree with the model. From all the amplitudes of the model which were included in the fit, the following ones dominate:

$$F^{\ell,m=0}_{+-} = F_\ell \frac{\sqrt{-t}}{\mu^2 - t} e^{-b_\ell(\mu^2-t)} + \text{cut terms}$$

$$F_\ell = \sqrt{2}\sqrt{\frac{g^2}{4\pi}} \frac{(4\pi)^2 M}{\sqrt{q_{\pi\pi} q_{KK}}} \sqrt{\frac{1}{3}} \sqrt{2\ell + 1}\, a_\ell .$$

The indices ℓ,m refer to the angular momentum of the $K\bar{K}$ state in the Gottfried-Jackson frame, +- are nucleon helicities, μ and M are the pion and $K\bar{K}$ mass, q's are c.m.s. momenta, b_ℓ is a slope parameter and $g^2/4\pi = 14.6$ is the π-nucleon coupling constant. The quantities a_ℓ (= S,D) are I = 0 $\pi\pi \to K\bar{K}$ partial-wave amplitudes normalized to the unitary condition $|a_\ell|^2 \leq 1$. The differential cross-section is then given by:

$$\frac{d^3\sigma(\pi^- p \to K^0 K^0 n,\ \ell \text{ even})}{dt dM d\Omega} = \frac{1}{(4\pi)^4} \frac{q_{KK}}{4p^2_{lab}M^2_p} \frac{1}{2} \sum_{\lambda_f \lambda_i} \left| \sum_{\ell,m} F^{\ell,m}_{\lambda_f \lambda_i} Y^m_\ell(\Omega) \right|^2 .$$

Only even values of ℓ contribute as the K^0_S in the final state are indistinguishable. In the mass region considered here $\ell \geq 4$ was found insignificant, as was A_2 production at small t ($\leq$ 0.2 GeV/c^2).

In Fig. 1 we show the unnormalized moments $\langle Y^0_L \rangle = \sum_i w_i Y^0_L(\Omega_i)$, where w_i is the weight of event i. A cut at $|t| \leq 0.2$ (GeV/c)^2 was applied. The results of the model fit are shown in Fig. 2. The magnitudes of the S- and D-waves, and the relative phase $\phi_S - \phi_D$, as obtained from different mass bins, are given. The f resonance is clearly seen in the mass distribution, in $\langle Y^0_4 \rangle$ and in $|D|^2$. The solid curves in Figs. 1 and 2 represent the result of an over-all (mass-dependent) fit of the model. The S-wave background is parametrized by a simple empirical formula. The D-wave is described by a Breit-Wigner amplitude of the f (m_f = 1.282, Γ_f = 0.159 GeV). The two mass-dependent partial widths $\Gamma^\pi_f(M)$ and $\Gamma^K_f(M)$ include barrier factors of the form $q^5/D_2(qR_f)$ [5] with $D_2(x) + 9 + 3x^2 + x^4$ and $R_f = 3.5$ (GeV)$^{-1}$. At the resonance mass M_R the magnitude of such a Breit-Wigner amplitude is given by

$$|D(M_R)|^2 = 4\Gamma^\pi\Gamma^K/\Gamma^2 . \tag{1}$$

We note from Figs. 1 and 2 the absence of a clear f$'$ signal. Since the dominant decay mode of f$'$ is into $K\bar{K}$, this implies a small coupling to the $\pi\pi$ channel; we can estimate an upper limit for this coupling if we assume $|D|^2$ at the f$'$ mass is due to f$'$ production by π exchange. Comparing this with $|D|^2$ at the f mass, we conclude

$$\frac{\Gamma^\pi_{f'}\Gamma^K_{f'}}{\Gamma^2_{f'}} \leq \frac{1}{3} \frac{\Gamma^\pi_f \Gamma^K_f}{\Gamma^2_f} . \tag{2}$$

The broken lines shown on the figures illustrate the effect that would be produced in our data if f$'$ production, corresponding to this upper limit, were included. The (+) and (-) refer to constructive and destructive interference between f-f'. The curves labelled (+) are clearly incompatible with the data; the (-) curves, although following the trend of $\langle Y_0^0 \rangle$, $\langle Y_4^0 \rangle$ and $|D|^2$, show a serious discrepancy for $\langle Y_2^0 \rangle$ and $\phi_S - \phi_D$ which depend on the S-wave phase ϕ_S. A linear rise of ϕ_S was used in the model. If the model had to accommodate f' production with an upper limit given by Eq. (2), a rapid variation of ϕ_S would be required. Since we do not know ϕ_S we have made a fit, disregarding $\phi_S - \phi_D$, of a f' contribution to $|D|^2$. It resulted in $\Gamma^{\pi}_{f'}\Gamma^{K}_{f'}/\Gamma^2_{f'} = (0.04\ ^{+0.05}_{-0.03})\Gamma^{\pi}_{f}\Gamma^{K}_{f}/\Gamma^2$. Considering all this evidence, we believe Eq. (2) yields a conservative upper limit.

We use the ratios $\Gamma^{\pi}_{f}/\Gamma_{f} = 0.83$, $\Gamma_{f'}/\Gamma_{f} = 0.235$ [6] and $\Gamma^{K}_{f'}/\Gamma_{f'} = 0.70$ [1] to give

$$\Gamma^{\pi}_{f'}/\Gamma^{K}_{f} \leq 0.093 ,$$

a result which is independent of our cross-section normalization. If we now use $\Gamma^{\pi}_{f}\Gamma^{K}_{f}/\Gamma^2_{f} = 0.018 \pm 0.005$, as determined in this experiment using the model described above [cf. the "world average" 0.033 ± 0.025 [6]], we compute

$$\Gamma^{\pi}_{f'}/\Gamma_{f'} \leq 0.0086 .$$

The previous experimental upper limit was given by $\Gamma^{\pi}_{f'}/\Gamma^{K}_{f'} < 20\%$ [6], a limit similar to that obtained in an SU(3) fit[1] of $\Gamma^{\pi}_{f'} = 0^{+7}_{-0}$ MeV.

Our result indicates a suppression of the decay $f' \to \pi\pi$ relative to $f \to \pi\pi$, which is stronger than that observed in the analogous case of $\phi(1019) \to \pi\rho$ relative to $\omega \to 3\pi$. The relative couplings in this latter case were estimated to be $g^2_{\phi\rho\pi}/g^2_{\omega\rho\pi} \sim 1/100$ [7]. We estimate the ratio:

$$\frac{g^2_{f'\pi\pi}}{g^2_{f\pi\pi}} = \frac{\Gamma^{\pi}_{f'}}{\Gamma^{\bar{K}}_{f}} \frac{m_{f'}}{m_f} \left(\frac{q_f}{q_{f'}}\right)^5 \leq 1/800 .$$

This experiment determines only the coupling of f' to two pions, and not other possible couplings to non-strange mesons. One may, therefore, speculate that the Zweig rule leads to a suppression similar to that observed for the ϕ and that the 2π decay mode is suppressed by some other mechanism [both $\rho'(1600)$ and g(1680) have dominant 4π decay modes].

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Figure captions

Fig. 1 : Unnormalized moments of the K_S^0 in the Gottfried-Jackson frame for the interval $0 \leq |t| \leq 0.2$ $(GeV/c)^2$. The ordinates are in units of events per 10 MeV $\left[\langle Y_0^0 \rangle = (1/\sqrt{4\pi}) \cdot (dN/dM)\right]$. The solid lines are the result of a fit of a model of pion exchange with absorption (see text); the broken lines were obtained by adding a f′ production amplitude with a strength corresponding to the upper limit discussed in the text. The choice of the relative sign is indicated by +,−. The histogram of Fig. 1a refers to the data without weight; note the change of scale in the ordinate.

Fig. 2 : Magnitudes of S- and D-wave, $|S|^2$ and $|D|^2$ and phase difference $\phi_S - \phi_D$, estimated from the data using the model described in the text. The points with error bars result from a mass-independent fit. The solid and broken lines have the same meaning as in Fig. 1.

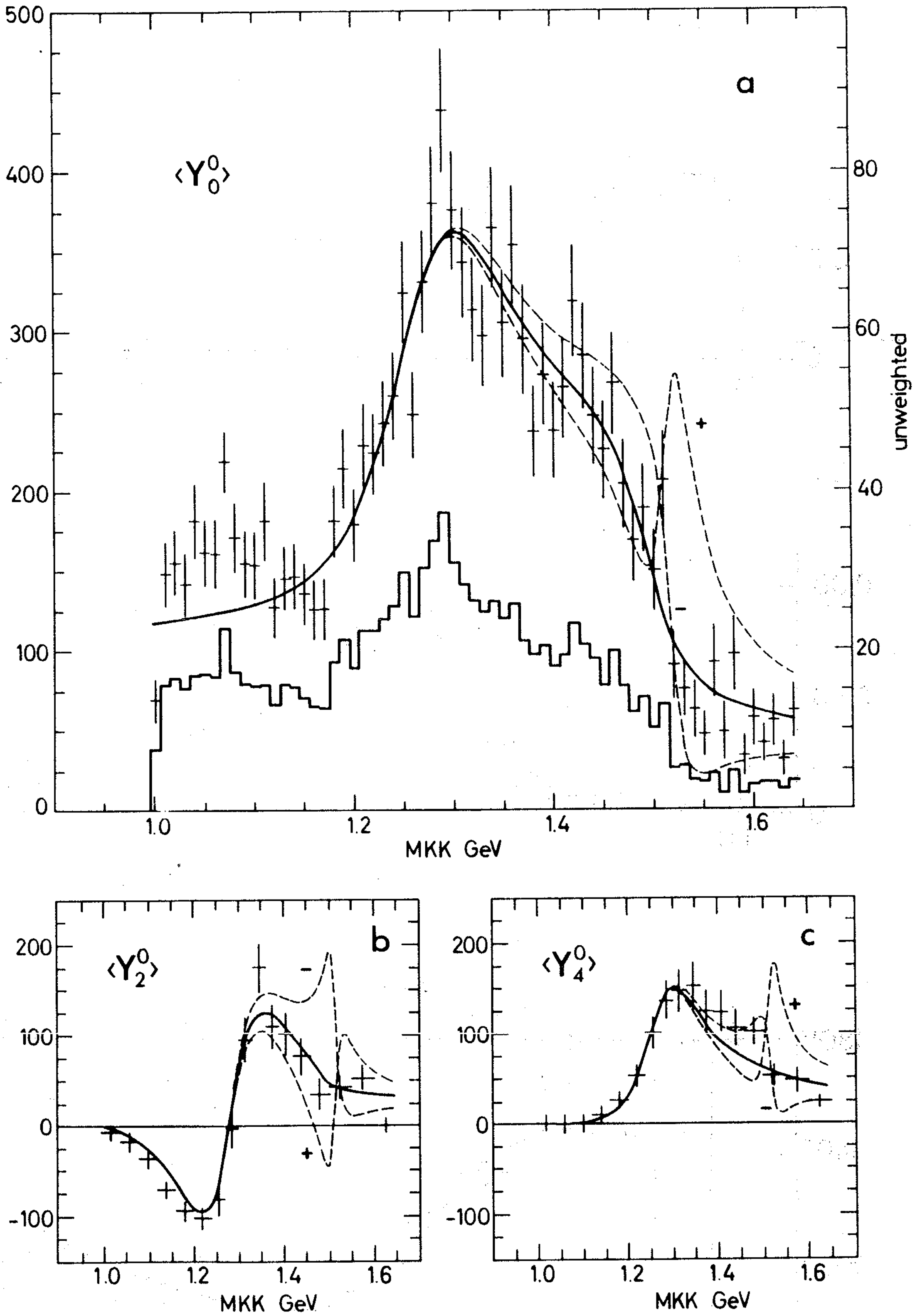
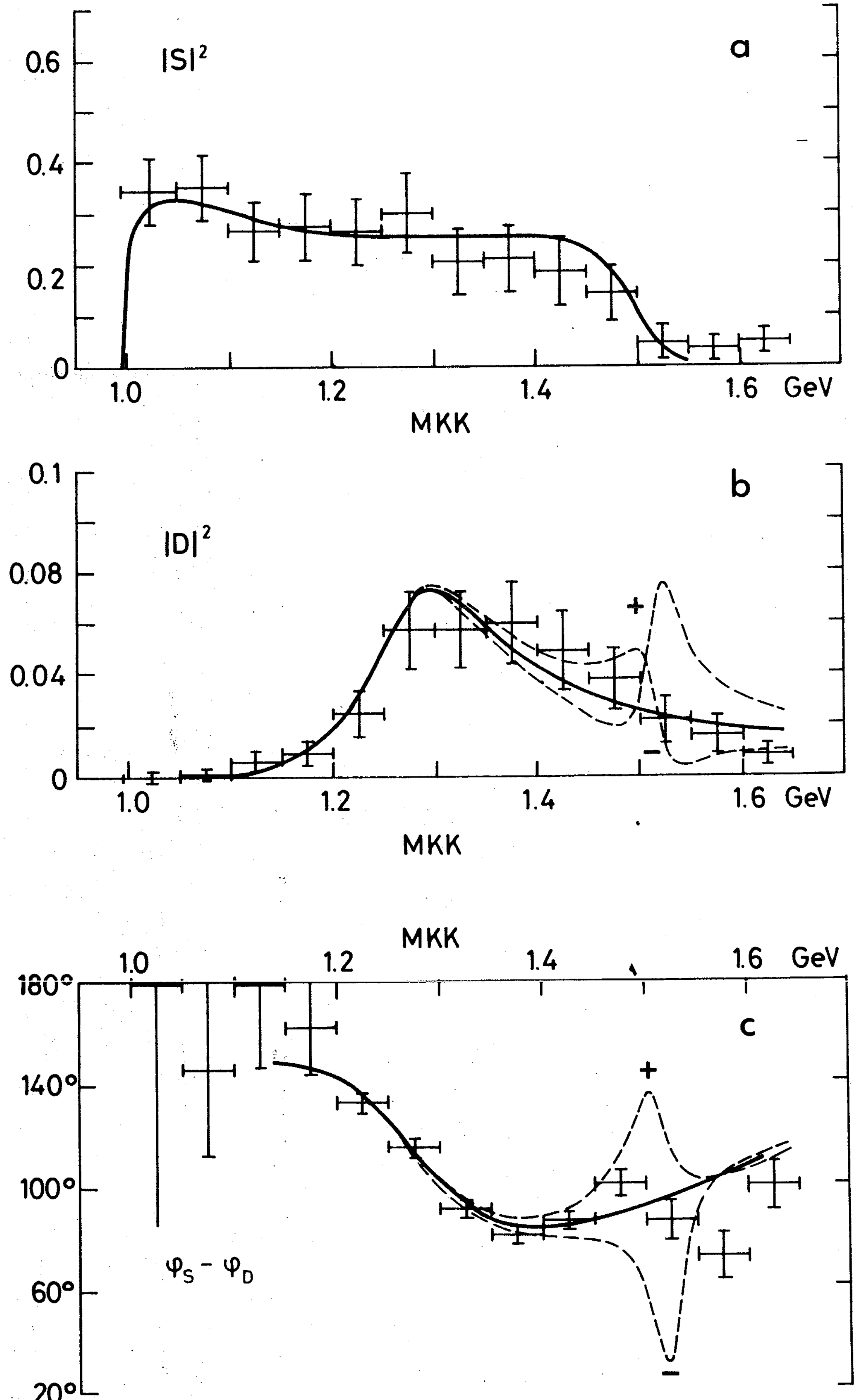


Fig. 1



a
|S|²
0.6
0.4
0.2
0
1.0
1.2
1.4
1.6 GeV
MKK
b
|D|²
0.1
0.08
0.04
0
+
-
1.0
1.2
1.4
1.6 GeV
MKK
MKK
1.0
1.2
1.4
1.6 GeV
180°
140°
100°
60°
20°
c
+
-
φS - φD

Fig. 2