Spin-Parity Analysis of the Centrally Produced $K_s^0 K^\pm \pi^\mp$ System at 800 GeV/c

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Results are presented from an analysis of a large sample of centrally produced mesons in the reaction $pp \to p_{slow}(K_s^0 K^\pm \pi^\mp) p_{fast}$ with 800 GeV/c protons on liquid hydrogen. Two resonances dominate the final state, the $f_1(1285)$, decaying into $a_0\pi$, and the $f_1(1420)$, decaying into K^*K. There is also evidence for a $J^{PG} = 1^{+-}$ resonance near 1400 MeV/c^2. All three mesons are produced with equal amounts of $|J_z| = 1$, $\eta = \pm 1$, and no $J_z = 0$.

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For many years, the classification of mesons decaying into $K\overline{K}\pi$ has been problematic. The observed spectrum depends dramatically on production mechanism, but not in a way which is easily understood. The confusing aspects of the spectrum have been called "the E/ι puzzle [1] [2]." In the mass region just above 1400 MeV/c^2, at least two pseudoscalars are seen in J/Ψ decays, and in a variety of hadronic interactions. This region also contains two 1^{++} mesons, the $f_1(1420)$ [3] [4], and the $f_1(1510)$ [5]. Since the $f_1(1510)$ is seen only in $K^- p$ interactions, it is commonly believed to be the $s\overline{s}$ partner of the $f_1(1285)$. This suggests that the $f_1(1420)$ is likely to be a non $q\overline{q}$ meson [1]. In this paper, we report the results of an analysis of the $K\overline{K}\pi$ system produced in a high statistics study of pp central production in the doubly diffractive reaction:

$$pp \longrightarrow p_{slow}(K_s^0 K^\pm \pi^\mp) p_{fast}, K_s^0 \to \pi^+\pi^- \qquad (1)$$

This study was motivated in part by the possibility that the production of non $q\overline{q}$ mesons may be favored in central production.

The results presented here are based on an analysis of 10% of the 5×10^9 events recorded by FNAL E690 during Fermilab's 1991 fixed target run. The E690 apparatus consisted of a high rate, open geometry multiparticle spectrometer (Figure 1) used to measure the target system (T) in $pp \to p_{fast}(T)$ reactions, and a beam spectrometer system used to measure the incident 800 GeV/c beam and scattered proton. A liquid hydrogen target was located just upstream of the multiparticle spectrometer [6]. The 96 cell Cherenkov counter located at the downstream end of the main spectrometer magnet used Freon 114 as a radiator and had a pion threshold of 2.57 GeV/c.

Reaction (1) was selected by requiring an interaction vertex in the LH_2 target with one positive track, one negative track, and a K_s^0. At least one of the two charged tracks originating at the interaction vertex was required to be identified by the Cherenkov counter (as either a π, or ambiguous K/p), and the other one was required to be compatible with the assumed identity. No direct measurement was made of the slow proton. The missing mass squared shown in Figure 2 has a clear proton peak for both charge states of reaction (1); this quantity was required to be between -1.0 and 2.2 (GeV/c^2)^2.

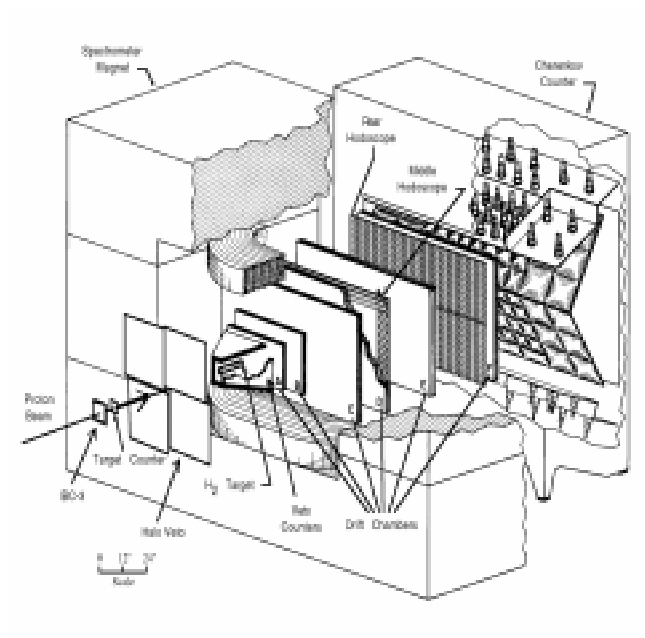

FIG. 1. E690 Multiparticle Spectrometer.

The detection efficiency and momentum resolution of the multiparticle spectrometer decreased rapidly for high energy particles produced in the forward direction in the pp center of mass system. Consequently, in all events selected by the cuts listed above, the forward proton, p_{fast}, was separated from the central mesons by at least 3.5 units of rapidity. A minimum gap of 1.8 units of rapidity was required between each individual meson and

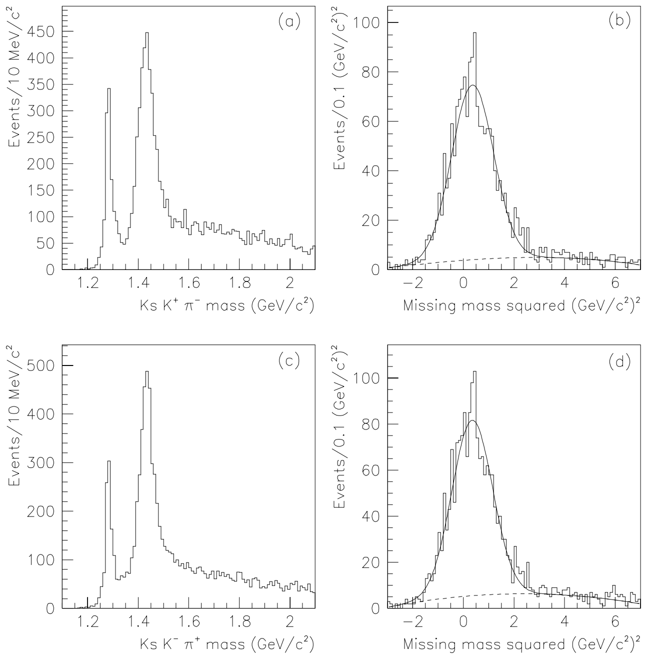

FIG. 2. a) Invariant mass, and b) Missing mass squared between threshold and 1480 MeV/c^2 for $K_s^0 K^+ \pi^-$. c) Invariant mass, and d) Missing mass squared between threshold and 1480 MeV/c^2 for $K_s^0 K^- \pi^+$.

p_{slow}. This ensured that there was no contamination of the final state from reactions in which p_{slow} was a decay product of a baryon resonance, such as Δ^{++} or $\Lambda(1520)$. Finally, in order to insure near uniform acceptance, the x_F of the meson system was required to be in the range $[-0.15, -0.02]$.

Figures 2.a and 2.c show the $K\overline{K}\pi$ invariant mass distributions for the selected data sample. In both charge states, the spectrum is dominated by two peaks. One of these is easily identified by its mass and width as the $f_1(1285)$. The second peak has a central value of approximately 1430 MeV/c^2. No obvious structure is seen at higher mass. In particular, the $f_1(1510)$ seen in K^-p interactions [5] is not evident.

Figures 3 and 4 show the Dalitz plots for the $K\overline{K}\pi$ mass range 1390-1480 MeV/c^2. Examination of these Dalitz plots shows that the peak at 1430 MeV/c^2 is almost certainly dominated by decays of a single 1^{++} meson, the $f_1(1420)$, into the final state K^*K. For both charge states, the Dalitz plots labelled "Data" show clear bands at the K^* mass, and an excess in the upper right corner. This indicates decay to K^*K, with the charged and neutral K^*'s interfering constructively, as required by even G parity.

In order to confirm the conclusions reached by inspection of the $K\overline{K}\pi$ invariant mass distributions and the Dalitz plots, and to reveal more subtle features of the spectra, a partial wave analysis was performed. The analysis assumed a two step process: the production step in

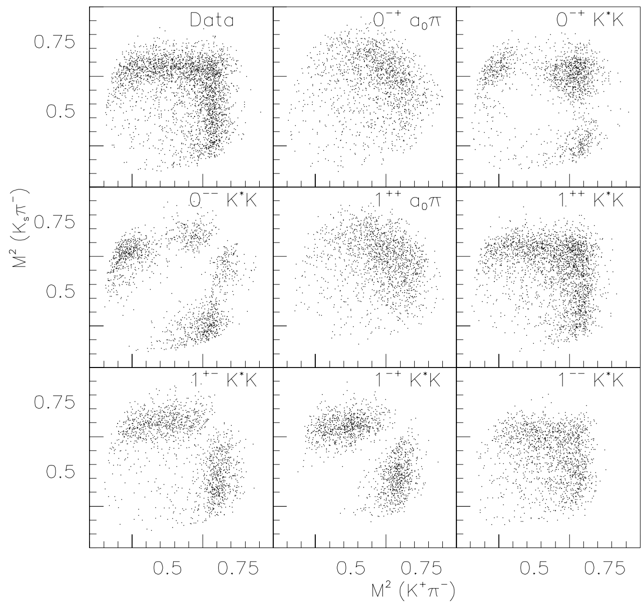

FIG. 3. Dalitz plots for both data and MC for the $K_s^0 K^+ \pi^-$ system.

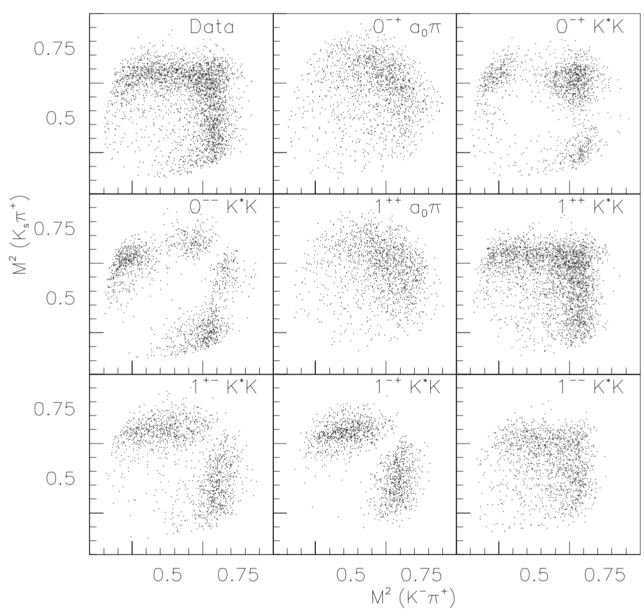

FIG. 4. Dalitz plots for both data and MC for the $K_s^0 K^- \pi^+$ system.

which a meson system was formed by the collision of two objects (from now on referred to as pomerons) emitted by the scattered protons, and the decay step in which the meson system decayed into $K\overline{K}\pi$. The decay was assumed to occur in two steps; a two body decay to either $a_0\pi$ or K^*K, followed by the decay of the isobar. The analysis was done using the BNL-MPS parameterization [7]. Waves were labelled with spin, parity, and G-parity J^{PG}, the isobar, and the absolute value of the spin projection and naturality $|J_z|^\eta$. All waves with spin 0 and 1 and isobars K^* and a_0 were tried. No background term was included in the fit. The $K^*(892)$ isobar was parameterized by a relativistic Breit-Wigner function, with mass and width as listed by the Particle Data Group [1]. The parameterization given in [7] was used for the $a_0(980)$.

The production coordinate system was defined in the center of mass of the $K\overline{K}\pi$, with the y-axis perpendicular to the plane of the two pomerons in the pp center of mass, and the z-axis in the direction of the beam pomeron in the $K\overline{K}\pi$ center of mass. The decay of the meson system was characterized by its isobar mass, the polar and azimuthal angles of the bachelor particle in the $K\overline{K}\pi$ center of mass, and similar decay angles for the $K^{\pm}$ produced in the isobar decay in a coordinate system defined by a Lorentz boost from the $K\overline{K}\pi$ center of mass to the center of mass of the isobar.

The wave amplitudes were determined by maximizing the log of the extended likelihood function [8], using a density matrix of rank one [9]. The analysis was done in 10 MeV/c^2 bins of $K\overline{K}\pi$ mass, from threshold to 1600 MeV/c^2, with x_F restricted to the range $[-0.15, -0.02]$, and integrated over p_t^2 for both protons, and over the angle between the two proton scattering planes in the $K\overline{K}\pi$ center of mass. Monte Carlo events were used to calculate acceptance integrals. These integrals were calculated for each mass bin using a flat x_F distribution. Events were generated using an $e^{-\alpha p_t^2}$ distribution for each scattered proton, with $\alpha = 6.5$ for p_{slow}, and $\alpha = 7.5$ for p_{fast} (to match the observed distributions).

The partial wave analysis was performed for each mass bin separately. First, each of the eighteen waves was tried one at a time. The single wave which maximized the likelihood was kept, and each of the remaining seventeen waves added to it one at a time. The two wave solution which maximized the likelihood was kept for the third iteration, and each of the remaining sixteen waves added one at a time. This process of adding one wave per iteration was continued until no significant improvement in the likelihood was observed. Below 1290 MeV/c^2, only the two 1^{++} $a_0\pi$ waves with $|J_z|^\eta = 1^{\pm}$ (the $f_1(1285)$) were required. Above 1290 MeV/c^2, four dominant waves were found: 1^{++} K^*K $|J_z|^\eta = 1^{\pm}$ (the $f_1(1420)$), and 1^{+-} K^*K $|J_z|^\eta = 1^{\pm}$ (probably the $h_1(1380)$). The final step of this procedure is illustrated in Figures 5 and 6. In these figures, the acceptance corrected intensities (normalized to the number of events) are shown for each set of waves. In each case, one additional wave was added to the dominant waves. For spin one, the figures show a sum of the $|J_z|^\eta$ components.

In order to determine the resonance parameters of the two dominant 1^{++} waves, the 1^{++} results from each mass bin were combined as shown in Figure 5.a and 6.a. A best fit to the data was performed using two non-relativistic Breit-Wigner functions plus a background parameterized as $a(m-m_{th})^b e^{(-cm-dm^2)}$ [3], where m is the $K\overline{K}\pi$

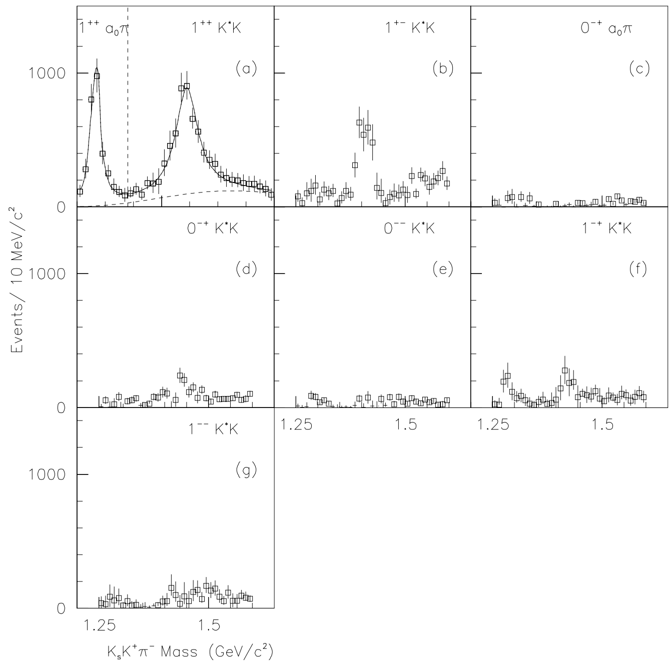

FIG. 5. Partial wave intensities for the $K_s^0K^+\pi^-$ system. The waves (c) to (g) where added one at a time to the waves (a)+(b). The fit in (a) is described in the text.

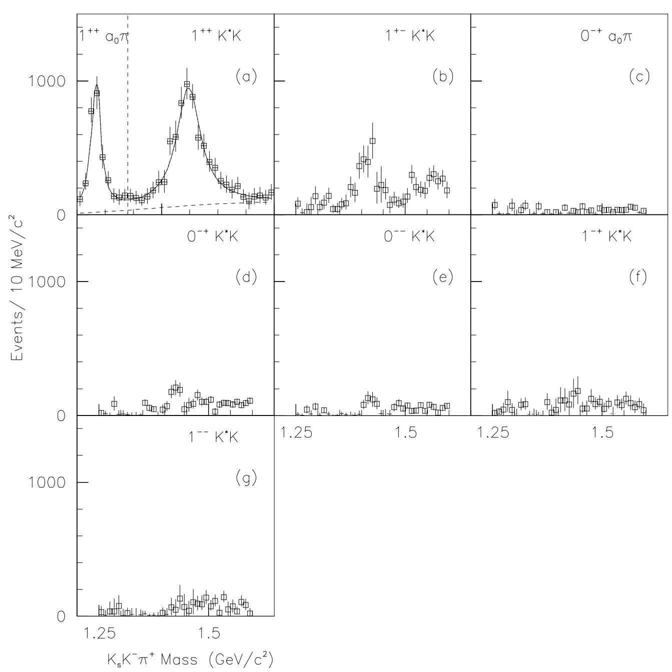

FIG. 6. Partial wave intensities for the $K_s^0K^-\pi^+$ system. The waves (c) to (g) where added one at a time to the waves (a)+(b). The fit in (a) is described in the text.

effective mass, m_{th} is the $K\overline{K}\pi$ threshold, and a,b,c, and d are fit parameters. The resulting masses and widths are shown in Table 1. The errors are statistical only.

As stated above, the data can be described completely using only waves with $|J_z|^\eta = 1^{\pm}$. This striking result is

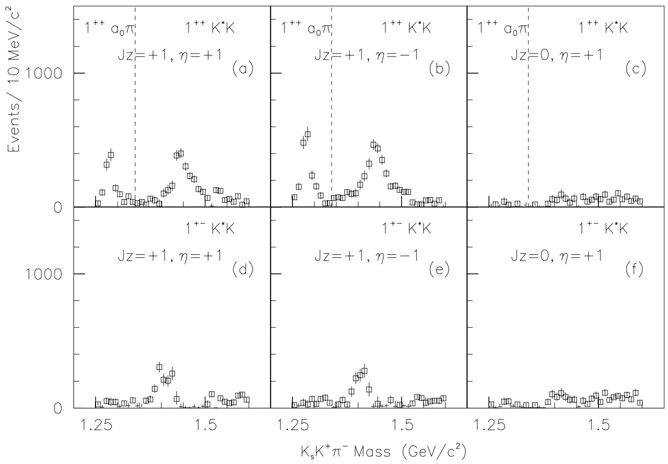

FIG. 7. Separate $|J_z|^\eta$ partial wave intensities for the $K_s^0 K^+ \pi^-$ system.

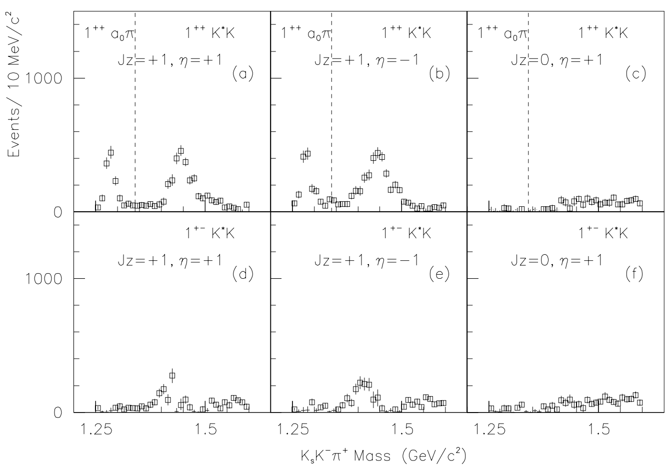

FIG. 8. Separate $|J_z|^\eta$ partial wave intensities for the $K_s^0 K^- \pi^+$ system.

illustrated in Figures 7 and 8. The figures show the intensities extracted using six waves in each mass bin. For all three states, the solution contains equal amounts of $|J_z| = 1$, $\eta = \pm 1$, and no $|J_z| = 0$. This result may be a consequence of the production mechanism [10]. If a meson of spin J is formed by the interaction of two identical particles of helicities λ_1 and λ_2, then the production amplitude $F^J_{\lambda_1 \lambda_2} = (-1)^J F^J_{\lambda_2 \lambda_1}$. Therefore $J = 1 \Rightarrow \lambda_1 \neq \lambda_2$ $\Rightarrow J_z = \lambda_1 - \lambda_2 \neq 0$.

Decay	Mass (MeV/c^2)	Width (MeV/c^2)
$K_s^0 K^+ \pi^-$	1282.5 ±5.6	23.7 ±2.6
	1443.2 ±11.3	59.7 ±6.8
$K_s^0 K^- \pi^+$	1283.6 ±5.6	26.9 ±3.2
	1447.2 ±11.2	63.2 ±6.1

Table 1. Masses and widths given by the fit.

In summary, results have been presented from a high statistics study of the $K\overline{K}\pi$ system produced in doubly diffractive pp interactions. Two resonances dominate the final state, the $f_1(1285)$, and the $f_1(1420)$. This confirms previous results that indicated that pseudoscalar states are not seen in central production of $K\overline{K}\pi$ [3]. There is also clear evidence of a 1^{+-} resonance near 1400 MeV/c^2. All three mesons are produced spin aligned; both $|J_z|^\eta = 1^\pm$ components are seen with equal strength, and in each case, the $|J_z| = 0$ component is absent. Resonance parameters for the two dominant states have been extracted from the results of a mass independent partial wave analysis. These results are well fit using a simple background parameterization and two non-relativistic Breit-Wigner functions.

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