FERMILAB-Pub-97/223-E
E690

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July 1997

Submitted to *Physical Review Letters*

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Partial Wave Analysis of the Centrally Produced K_sK_s System at 800 GeV/c

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(Received June 27, 1997)

Results are presented from a partial wave analysis of a sample of centrally produced mesons in the reaction $pp \rightarrow p_{slow}(K_sK_s)p_{fast}$, with 800 GeV/c protons incident on a liquid hydrogen target. The meson system is found to be predominantly S-wave in the mass range between K_sK_s threshold and 1.58 GeV/c^2. The $f_0(1500)$ is clearly observed in this region. Above 1.58 GeV/c^2 two solutions are possible, one with mainly S-wave and another with mainly D-wave. This ambiguity prevents a unique determination of the spin of the $f_J(1710)$ meson.

PACS numbers: 11.80.Et, 14.40.Cs, 12.39.Mk

Significant theoretical progress has been made recently with two separate lattice gauge calculations of the lowest lying scalar glueball [1]. The two calculated masses are 1550 ± 95 MeV/c^2 and 1740 ± 71 MeV/c^2. The leading experimental candidates are the $f_0(1500)$ and the $f_J(1710)$. The $f_0(1500)$ was first observed in K^-p interactions [2]. Its existence was beautifully confirmed, and several decay branching ratios measured, by the Crystal Barrel Collaboration [3]. Amsler and Close [4] have pointed out that the values of these branching ratios make it unlikely that the $f_0(1500)$ is a $q\bar{q}$ meson. If the $f_0(1500)$ is a glueball, then its production may be favored in doubly diffractive hadronic interactions. In this paper, we report the first observation of the $f_0(1500)$ in central production in the doubly diffractive reaction:

$$pp \rightarrow p_{slow}(K_sK_s)p_{fast}, \qquad K_s \rightarrow \pi^+\pi^- \tag{1}$$

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 $pp \rightarrow p_{fast}(T)$ 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. The target was surrounded by a segmented lead-scintillator "veto counter," which was used to detect the presence of charged or neutral particles outside the aperture of the multiparticle spectrometer [5].

Final state (1) was selected by requiring a primary vertex in the LH_2 target with two K_s, an incoming beam track, and a fast forward proton. No direct measurement was made of the slow proton p_{slow}, and no direct particle identification was used. The target veto system was used to reject events with more than a missing proton. Events were accepted when no veto counter was on, or only one veto counter was on, and the missing p_t pointed to it.

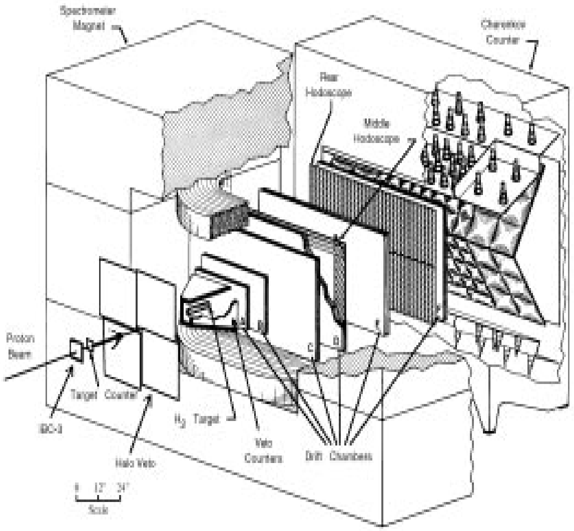

FIG. 1. E690 Multiparticle Spectrometer.

The missing mass squared seen in Figure 2.a shows a clear proton peak with little background; the arrows indicate the cuts used in the event selection. Figure 2.b shows the uncorrected x_F distribution for the K_sK_s system. The distribution is not symmetric about $x_F = 0$ because 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. The arrows in Figure 2.b indicate the cuts used in the event selection. With these cuts, the minimum rapidity gap between p_{slow} and the K_sK_s system is 1.2 units. The rapidity gap between the meson system and p_{fast} is greater than 3.7 units for all events.

The proton mass was assigned to the missing momentum in the events that passed the cuts, and the three momenta of p_{slow} and the longitudinal momentum of p_{fast}

were calculated using energy and momentum conservation.

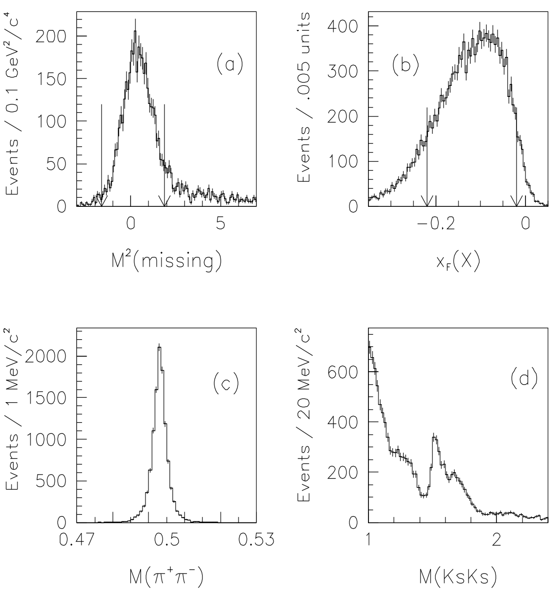

FIG. 2. a) Missing mass squared for $1.4 < M(K_sK_s) < 1.8$ GeV/c^2. b) Uncorrected x_F distribution. c–d) Measured $\pi^+\pi^-$ and K_sK_s invariant mass.

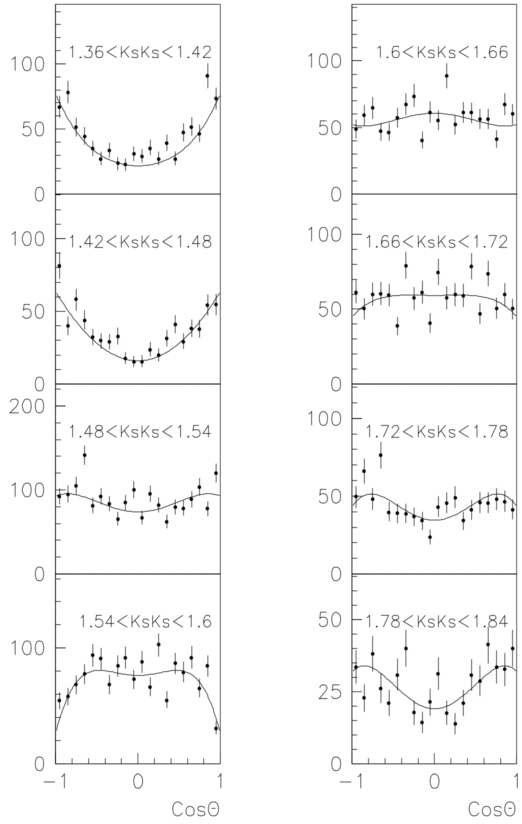

FIG. 3. Acceptance corrected $\cos\theta$ angular distributions in bins of the K_sK_s invariant mass, starting at 1.36 GeV/c^2 in steps of 60 MeV/c^2.

Figure 2.d shows the K_sK_s invariant mass for the events that passed the previous cuts. The current analysis was performed using 11182 events with K_sK_s mass between 1 and 2 GeV/c^2. The analysis was not continued to higher mass because the number of events is very low; but for $-0.22 < x_F < -0.02$ the K_sK_s invariant mass beyond 2 GeV/c^2 is smooth, with no evidence of the $\xi(2230)$ state seen by the BES Collaboration [6].

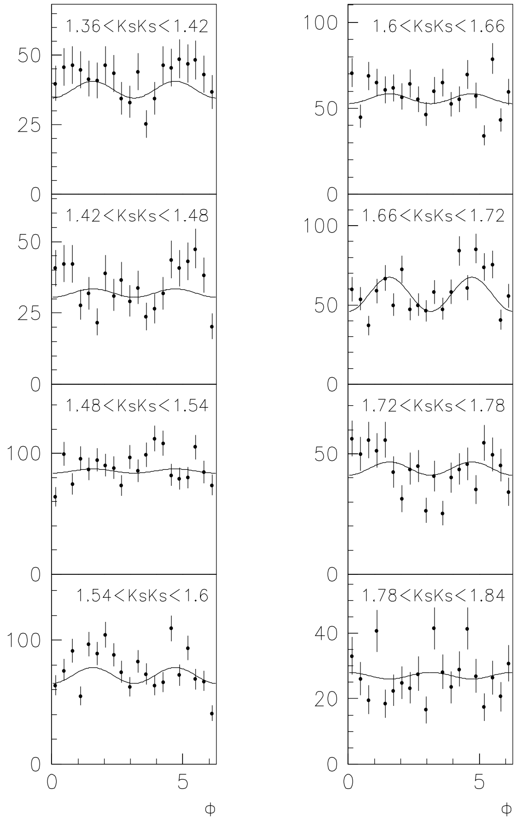

FIG. 4. Acceptance corrected ϕ angular distributions in bins of the K_sK_s invariant mass, starting at 1.36 GeV/c^2 in steps of 60 MeV/c^2.

The reaction studied here was analyzed as a two step process: the production step in which an (X) system is 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 object (X) decays into K_sK_s. The production coordinate system was defined in the center of mass of the (X) system, 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 (X) center of mass. The two variables needed to specify the decay process were taken as the polar and azimuthal angles (θ, ϕ) of one of the K_s (taken at random) in the production coordinate system. The acceptance corrected $\cos\theta$ and ϕ distributions are shown in Figures 3 and 4. The acceptance is flat in ϕ, and dips near $\cos\theta = \pm 1$. The solid lines represent the angular distributions obtained from the wave amplitudes of figures 6 or 7.

The five variables used to specify the production process were the transverse momenta of the slow and fast protons $(p^2_{t,s}, p^2_{t,f})$, the x_F and invariant mass of the K_sK_s system, and δ, the angle between the planes of the scattered protons in the K_sK_s center of mass. Although our 11182 events constitute a large sample, it is not large enough to bin the data in all five production variables. The analysis was done in bins of the K_sK_s invariant mass for the selected region in x_F, integrating over $p^2_{t,s}$, $p^2_{t,f}$ and δ.

The acceptance corrected moments, defined as

$$I(\Omega) = \frac{1}{\sqrt{4\pi}}\{\sum_l t_{l0} Y_l^0 + 2 \sum_{l,m>0} t_{lm} Re(Y_l^m)\} \qquad (2)$$

are shown in Figure 5, together with the measured mass distribution. The odd moments (not shown) are consistent with zero, as expected for a system of two identical bosons. The t_{00} moment is the acceptance corrected mass distribution. The error bars are statistical errors only.

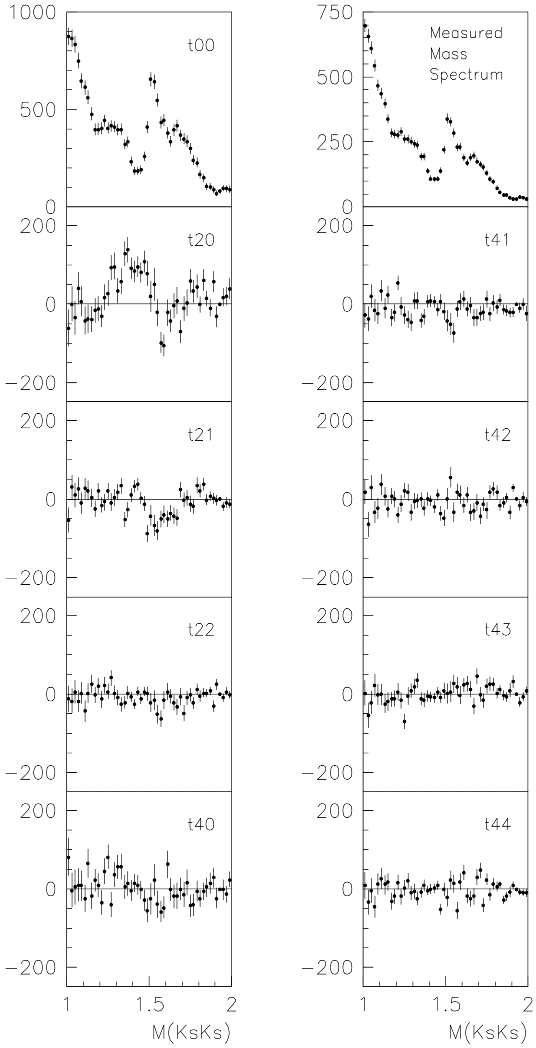

FIG. 5. Uncorrected mass distribution and acceptance corrected moments as a function of the K_sK_s invariant mass.

In the two step process considered here, the (X) system is formed by the interchange of two pomerons, whose momentum vectors lie in a plane in the pp center of mass system. Parity conservation in the strong interactions implies that reflection in this plane should be a symmetry of the system [7]. Therefore the amplitudes used for the partial wave analysis were defined in the reflectivity basis [8]. Since the t_{43} and t_{44} moments are consistent with zero (see Fig 5), only spherical harmonics with $l = 0, 2$ and $m = 0, \pm1$ were considered. The waves used were L^{ϵ}_m, with $L = S, D$, $m \geq 0$ and reflectivity $\epsilon = \pm1$:

$$S_0^- = Y_0^0 = 1/\sqrt{4\pi} \qquad (3)$$

$$D_0^- = Y_2^0 = \sqrt{5/16\pi}\,(3\,\cos^2\theta - 1) \qquad (4)$$

$$D_1^- = (Y_2^1 - Y_2^{-1})/\sqrt{2} = -\sqrt{15/16\pi}\ \sin 2\theta\ \cos\phi \qquad (5)$$

$$D_1^+ = (Y_2^1 + Y_2^{-1})/\sqrt{2} = -i\sqrt{15/16\pi}\ \sin 2\theta\ \sin\phi \qquad (6)$$

Waves with different reflectivity do not interfere.

The partial wave analysis was done in two different ways. First, the amplitudes were extracted from the moments shown in Figure 5. Second, the amplitudes were determined by maximizing the extended likelihood with respect to the four wave moduli and the two relative phases $\varphi(D^-_{0,1}) - \varphi(S^-_0)$. Within errors both analyses gave the same answer.

When using four waves the inherent ambiguities of a two body system are such that there are two solutions for each mass bin [8,9]. Both solutions give identical moments or identical values of the likelihood. In order to continue the solutions from one mass bin to the next, one follows the Barrelet zeros [8,9]. In general these zeros are complex and one lies above the real axis and the other lies below it. When the zeros cross the real axis the solutions bifurcate. In the analysis presented here, there is a bifurcation point at 1.58 GeV/c^2. Before this bifurcation point there are two solutions, one which is mostly S wave, and another that is mostly D wave. Since at threshold the K_sK_s cross section is dominated by the presence of the $f_0(980)$ [10] it is possible to eliminate the solution that has a very small S wave contribution at threshold. The remaining solution bifurcates at 1.58 GeV/c^2 into a solution that has a large S wave contribution (solution one), and another that has a large D wave component (solution two). The solutions obtained using maximum likelihood are shown in Figures 6 and 7. Solution one is shown in Figure 6, and solution two in Figure 7. The errors shown are statistical errors only.

A striking feature of both solutions is the large S wave peak observed at 1.52 GeV/c^2. The difference between this value and $f_0(1500)$ mass of 1.50 GeV/c^2 determined by the Crystal Barrel collaboration [3] could be due to interference with the S wave background. Beyond 1.58 GeV/c^2 solution one and solution two are equally valid.

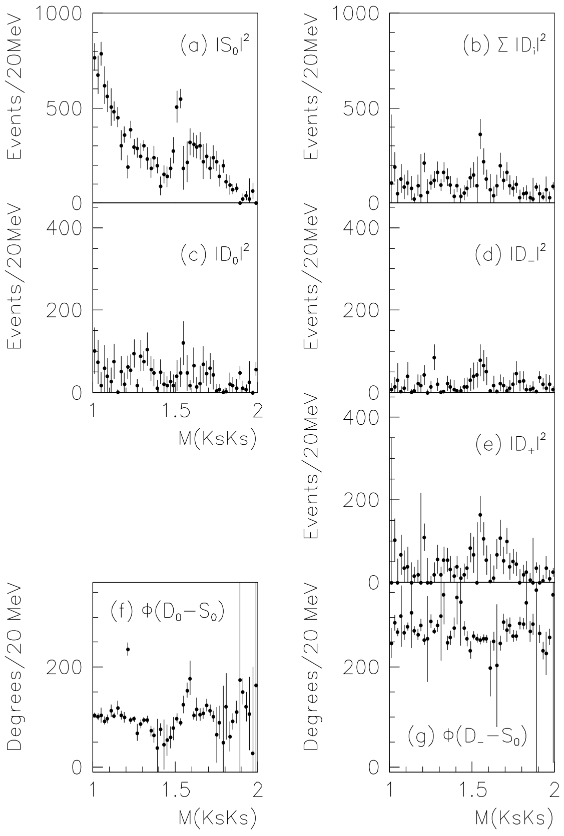

FIG. 6. Waves as a function of K_sK_s invariant mass for solution one. a) S and b) total D waves, c) to e) individual D wave, and f) and g) phases relative to the S wave.

In conclusion: a partial wave analysis of a sample of 11182 K_sK_s events centrally produced at 800 GeV/c has been presented. Two solutions have been found in the analysis. In both of them a clear $f_0(1500)$ has been observed. The ambiguity above 1.58 GeV/c^2 prevents a unique determination of the spin of the $f_J(1710)$ meson. Due to lack of statistics the analysis was not carried out beyond 2 GeV/c^2, but the K_sK_s invariant mass spectrum is smooth beyond that point and shows no sign of the $\xi(2230)$ meson seen by the BES Collaboration [6].

We wish to thank S.U. Chung and M. Albrow for useful discussions and advice. This work was funded in part by the Department of Energy under contract numbers DE-AC02-76CHO3000 and DE-AS05-87ER40356, the National Science Foundation under grant numbers PHY89-21320 and PHY90-14879, and CONACyT de México under grant numbers 1061-E9201, F246-E9207 and 3793-E9401.

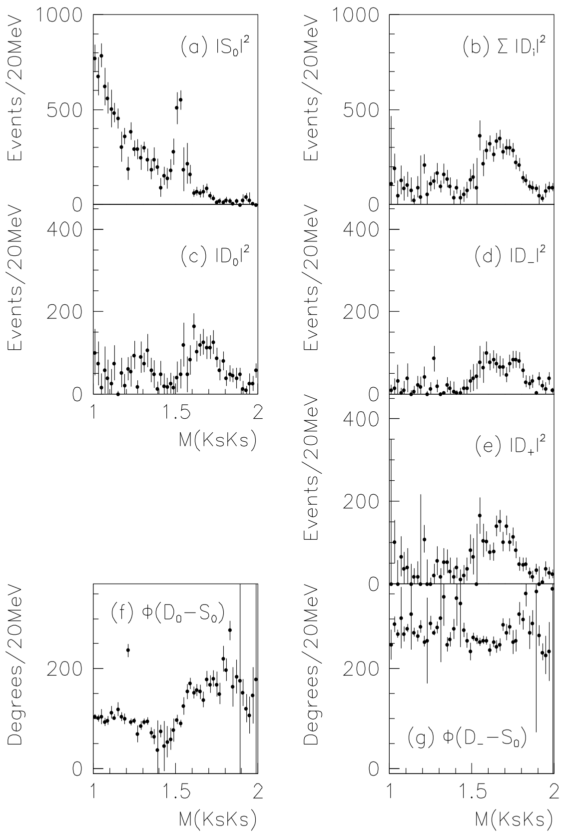

FIG. 7. Waves as a function of K_sK_s invariant mass for solution two. a) S and b) total D waves, c) to e) individual D wave, and f) and g) phases relative to the S wave.

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