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# $K_sK_s$ System at 800 GeV/c

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**Abstract.** 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.

Significant theoretical progress has been made recently with two separate lattice gauge calculations of the lowest lying scalar glueball [1]. The leading experimental candidates are the $f_0(1500)$ and $f_J(1710)$. 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 $q\overline{q}$ 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 observation of the $f_0(1500)$ in central production in the doubly diffractive reaction:

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

WA76 at CERN studied this process using charged kaons at two different beam energies [5]. From the observed angular distributions they identify the peak at around 1500 MeV/c$^2$ as the $f_2'(1525)$, and favor spin $J$=2 for $f_J(1710)$.

The results presented here are based on an analysis of 10% of the $5 \times 10^9$ events recorded by FNAL E690 during Fermilab's 1991 fixed target run. The E690 apparatus consisted of a high rate, open geometry multiparticle spectrometer 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 [6].

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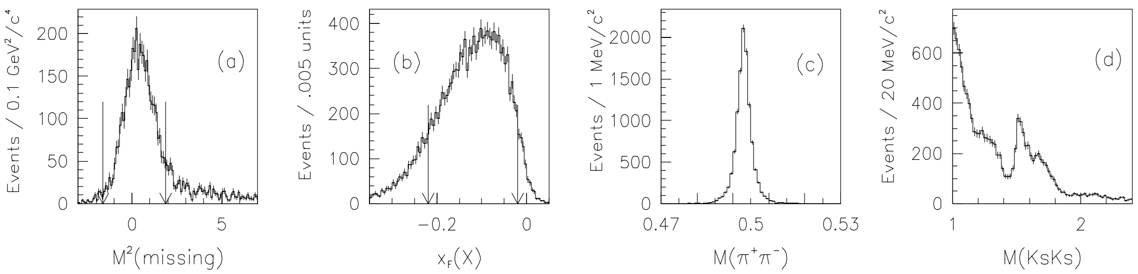

**FIGURE 1.** a) Missing mass squared for $1.4 < M(K_sK_s) < 1.8$ GeV/$c^2$. b) Uncorrected $x_F$ distribution. c–d) Measured $\pi^+\pi^-$ and $K_sK_s$ invariant mass.

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.

The missing mass squared seen in Figure 1.a shows a proton peak with little background. Figure 1.b shows the uncorrected $x_F$ distribution for the $K_sK_s$ system. The arrows in Figures 1.a,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.

Figure 1.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$^2$. 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 [7].

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 (referred to as pomerons) emitted by the scattered protons, and the decay step, when $(X)$ 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 $(\theta, \phi)$ of one of the $K_s$ (taken at random) in the production coordinate system. The acceptance corrected $\phi$ distribution is flat, and dips near $\cos\theta = \pm 1$ [8].

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 $\delta$, the angle between the planes of the scattered protons in the $K_sK_s$ center of mass. The present 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 $\delta$.

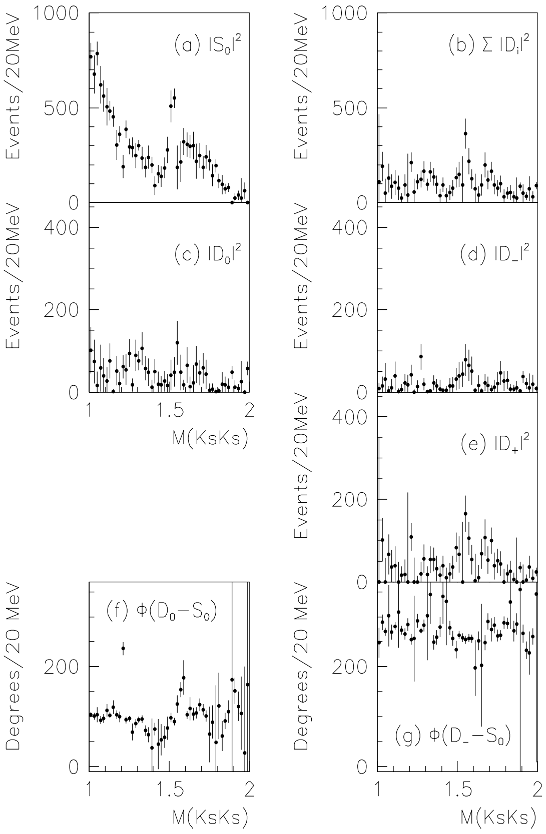

**FIGURE 2.** Waves as a function of $K_sK_s$ invariant mass for solution one. a) $S$ and b) total $D$ waves, c) to e) individual $D$ wave, and f) and g) phases relative to the $S$ wave.

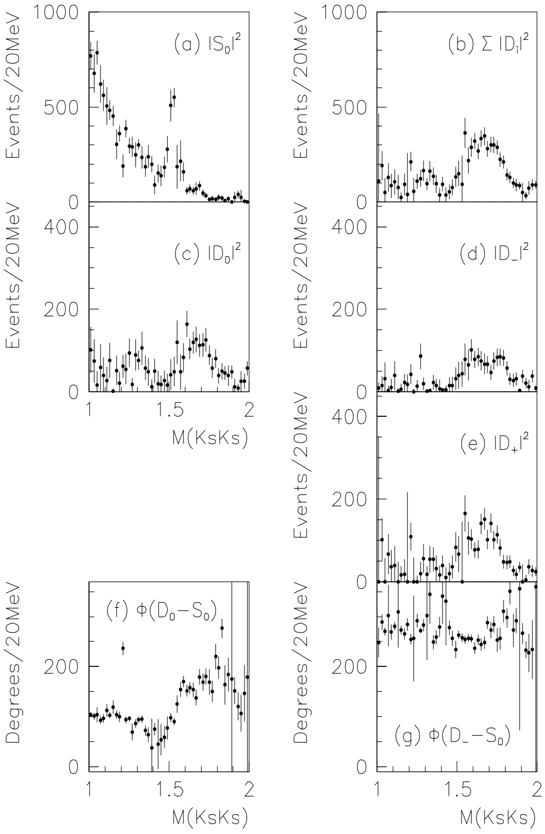

**FIGURE 3.** Waves as a function of $K_sK_s$ invariant mass for solution two. a) $S$ and b) total $D$ waves, c) to e) individual $D$ wave, and f) and g) phases relative to the $S$ wave.

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 [9]. Therefore the amplitudes used for the partial wave analysis were defined in the reflectivity basis [10]. The waves used were $L^{\epsilon}_{m}$, with $L = S, D$, $m \geq 0$ and reflectivity $\epsilon = \pm 1$:

$$L^{\epsilon}_{m} = \frac{1}{c}\left(Y^{m}_{l} - \epsilon Y^{-m}_{l}\right) \tag{2}$$

($c = 2$ if $m = 0$, $c = \sqrt{2}$ if $m \neq 0$). Only spherical harmonics with $l = 0, 2$ and $m = 0, \pm 1$ were considered. Waves with different reflectivity do not interfere.

The partial wave analysis was done in two different ways. First, the amplitudes were extracted from the acceptance corrected moments [8], defined by

$$I(\Omega) = \frac{1}{\sqrt{4\pi}}\{\sum_{l} t_{l0} Y^{0}_{l} + 2 \sum_{l,m>0} t_{lm} Re(Y^{m}_{l})\} \tag{3}$$

Second, the amplitudes were determined by maximizing the extended likelihood with respect to the four wave amplitudes. 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 [10,11]. 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 [10,11]. 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 $f_0(980)$ [12] 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 (Figure 2), and another that has a large $D$ wave component (Figure 3). The errors shown in the figures are statistical only. A striking feature of both solutions is the large $S$ wave peak observed at 1.52 GeV/$c^2$. Beyond 1.58 GeV/$c^2$ solution one and solution two are equally valid. The ambiguity prevents a unique determination of the spin of the $f_J(1710)$ meson.

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## REFERENCES

1. Bali, G., et al., *Phys.Lett.* **B309**, (1993) 378; Sexton, J., Vaccarino, A., and Weingarten, D., *Phys.Rev.Lett.* **75** (1995) 4563.
2. Aston, D., et al, *Nucl.Phys.* **B301** (1988) 525.
3. Amsler, C., et al, *Phys.Lett.* **B342** (1995) 433. For a review see Review of Particle Physics, *Phys.Rev.* **D54** (1996).
4. Amsler, C., and Close, F., *Phys.Rev.* **D53** (1996) 295.
5. Armstrong, T.A., et al, *Phys.Lett.* **B227** (1989) 186, and *Z.Phys.* **C51** (1991) 351.
6. The E690 multiparticle spectrometer was previously used at the Brookhaven National Laboratory in BNL E766 and is described in Uribe, J., et al, *Phys.Rev.* **D49** (1994) 4373. The beam chambers are described in Christian, D.C., et al, *NIMA* **345** (1994) 62–71. Details of this analysis may be found in Marco Reyes' Ph.D. thesis, CINVESTAV–IPN, Mexico, 1996.
7. Bai, J.Z., et al, *Phys.Rev.Lett.* **76** (1996) 3502.
8. Reyes, M.A., et al, *Nucl.Phys. B (Proc. Suppl.)* **56A**, (1997) 285–290.
9. Chung, S.U., BNL-QGS-94-23, and BNL-QGS-96-32.
10. Chung, S.U., and Truman, T.L., *Phys.Rev.* **D11** (1975) 633.
11. Barrelet, E., *Nuovo Cimento* **A8** (1972) 331.
12. Morgan,D., and Pennington, M.R., *Phys.Rev.* **D48** (1993) 1185.