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A study of the centrally produced $K^*(892)\bar{K}^*(892)$ and $\phi\omega$ systems in pp interactions at 450 GeV/c

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Abstract

A study of the reactions $pp \to p_f p_s (K^+K^-\pi^+\pi^-)$ and $pp \to p_f p_s (K^+K^-\pi^+\pi^-\pi^0)$ shows evidence for the $K^*(892)\bar{K}^*(892)$ and $\phi\omega$ channels respectively. The $K^*(892)\bar{K}^*(892)$ mass spectrum shows a broad distribution with a maximum near threshold and an angular analysis shows that it is compatible with having $J^P = 2^+$. The behaviour of the cross-section as a function of centre of mass energy, and the four momentum transfer dependence, are compatible with what would be expected if the $K^*(892)\bar{K}^*(892)$ system was produced via double Pomeron exchange. The dP_T behaviour of the $\phi\omega$ channel is similar to what has been observed for all the undisputed $q\bar{q}$ states. In contrast, the dP_T behaviour of the $K^*(892)\bar{K}^*(892)$ final state is similar to what has been observed for the $\phi\phi$ final state and for previously observed glueball candidates.

Experiment WA102 is designed to study exclusive final states formed in the reaction

$$pp \to p_f(X^0)p_s \qquad (1)$$

at 450 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory respectively and X^0 represents the central system that is presumed to be produced by double exchange processes. The experiment has been performed using the CERN Omega Spectrometer, the layout of which is described in Ref. [1]. In previous analyses of other channels it has been observed that when the centrally produced system has been analysed as a function of the parameter dP_T, which is the difference in the transverse momentum vectors of the two exchange particles [1,2], all the undisputed $q\bar{q}$ states are suppressed at small dP_T, in contrast to glueball candidates. In addition, it has recently been suggested [3,4] that this suppression could be due to the fact that the production mechanism is through the fusion of two vector particles. It is therefore interesting to make a study of the dP_T dependence of systems decaying to two vectors. In a recent publication we have performed a study of the centrally produced $\phi\phi$ final state [5], which was found to act like the glueball candidates that have been observed.

This paper presents a study of the $K^*(892)$-$\bar{K}^*(892)$ final state formed in the reaction

$$pp \to p_f(K^+K^-\pi^+\pi^-)p_s \qquad (2)$$

and the $\phi\omega$ final state formed in the reaction

$$pp \to p_f(K^+K^-\pi^+\pi^-\pi^0)p_s \qquad (3)$$

and represents a factor ten increase in statistics over previously published data samples [6].

Events corresponding to reaction (2) have been isolated from the sample of events having six outgoing charged tracks by first imposing the following cuts on the components of the missing momentum: |missing $P_x| < 14.0$ GeV/c, |missing $P_y| < 0.12$ GeV/c and |missing $P_z| < 0.08$ GeV/c, where the x axis is along the beam direction. A correlation between pulse-height and momentum obtained from a system of scintillation counters was used to ensure that the slow particle was a proton.

In order to select the $K^+K^-\pi^+\pi^-$ system, information from the Čerenkov counter was used. An event was accepted if a positive or negative particle was identified as a K/p and the other particle with the same charge was consistent with being a π. A modified method of Ehrlich et al. [7], has been used to compute the mass squared of the two highest momentum central particles assuming the other two particles to be pions. The resulting distribution is shown in Fig. 1a) where a clear peak can be seen at the kaon mass squared. This distribution has been fitted with Gaussians to represent the contributions from the $\pi^+\pi^-\pi^+\pi^-$ channel and the $K^+K^-\pi^+\pi^-$ channel. From this fit the number of $K^+K^-\pi^+\pi^-$ events is found to be 13950 $\pm$ 420. A cut on the Ehrlich mass squared of $0.16 \le M^2 \le 0.54$ GeV^2 has been used to select a sample of $K^+K^-\pi^+\pi^-$ events. The mass of the $K^-\pi^+$ pair is plotted against the mass of the $K^+\pi^-$ pair in Fig. 1b) and shows a strong $K^*(892)\bar{K}^*(892)$ signal.

The two possible $K\pi$ mass combinations are plotted in Fig. 1c). A clear $K^*(892)$ signal can be seen together with an enhancement at 1.4 GeV. A fit has been performed to this spectrum using two

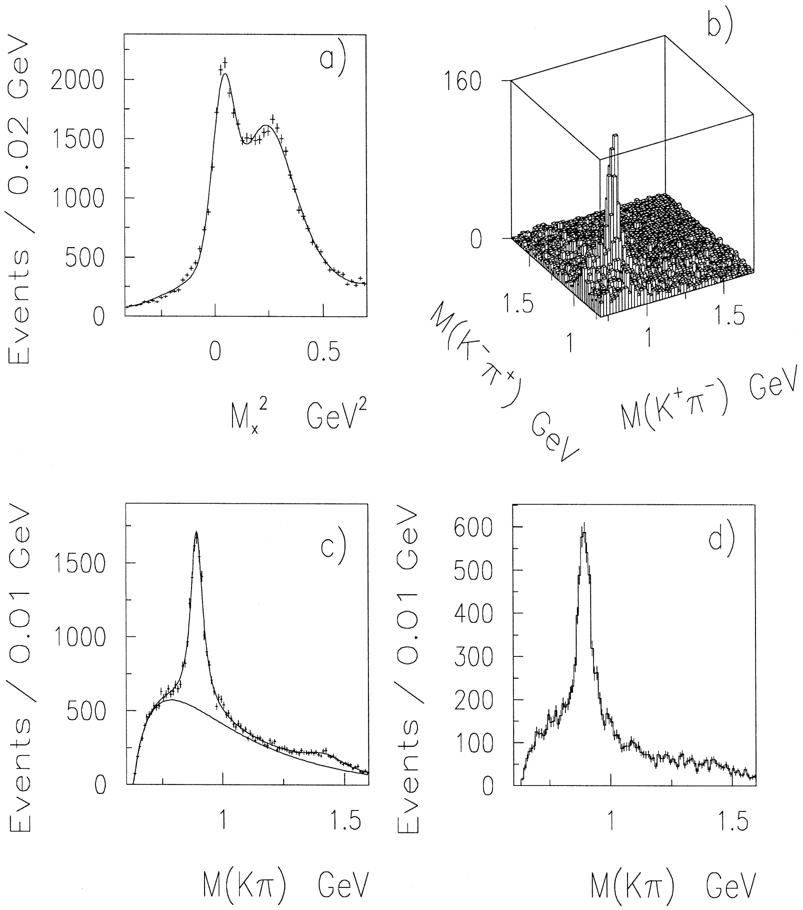

Fig. 1. For the $K^+K^-\pi^+\pi^-$ channel a) the Ehrlich mass squared distribution, b) the lego plot of $m(K^-\pi^+)$ versus $m(K^+\pi^-)$, c) the $K^\pm\pi^\mp$ mass spectrum and d) the $K^\pm\pi^\mp$ mass spectrum after selecting the $K^\mp\pi^\pm$ mass to lie in the $K^*(892)$ band.

Breit-Wigners to describe the $K^*(892)$ and the peak at 1.4 GeV, and a background of the form $(m - m_{th})^a \exp(-bm - cm^2)$ where m is the $K\pi$ mass, m_{th} is the threshold mass and a, b and c are fit parameters. The result of the fit gives $m_1 = 896 \pm 2$ MeV and $\Gamma_1 = 54 \pm 3$ MeV, compatible with the PDG values [8] for the $K^*(892)$ and $m_2 = 1436 \pm 8$ MeV and $\Gamma_2 = 196 \pm 45$ MeV, compatible with the PDG values for either the $K_0^*(1430)$ or the the $K_2^*(1430)$. By selecting one $K\pi$ mass to lie within a band around the $K^*(892)$ mass (from 0.73 - 1.06 GeV) and plotting the effective mass of the other pair, the spectrum of Fig. 1d) was produced. A strong $K^*(892)$ signal is observed confirming the presence of the $K^*(892)\overline{K}^*(892)$ final state. There is no evidence for $K^*(892)K^*(1430)$ production.

The number of events in nine regions around the $K^*(892)\overline{K}^*(892)$ position in the $K\pi$ scatter plot is shown in Fig. 2a). From these numbers and applying a correction for the tails of the $K^*(892)$ the total number of $K^*(892)\overline{K}^*(892)$ events is found to be 2027 ± 113 events. In order to compare the production rates for $K^*(892)K\pi$ and $K^*(892)\overline{K}^*(892)$, the number of $K^*(892)K\pi$ events has been estimated. This was done by subtracting twice the number of $K^*(892)\overline{K}^*(892)$ events from the total number of $K^*(892)$s observed in Fig. 1c), and this gives 6281 ± 340 $K^*(892)K\pi$ events.

The geometrical acceptance has been found to be similar for $K^*(892)\overline{K}^*(892)$ and $K^*(892)K\pi$ production. After correcting for unseen decay modes of the $K^*(892)$, the ratio of cross sections is estimated

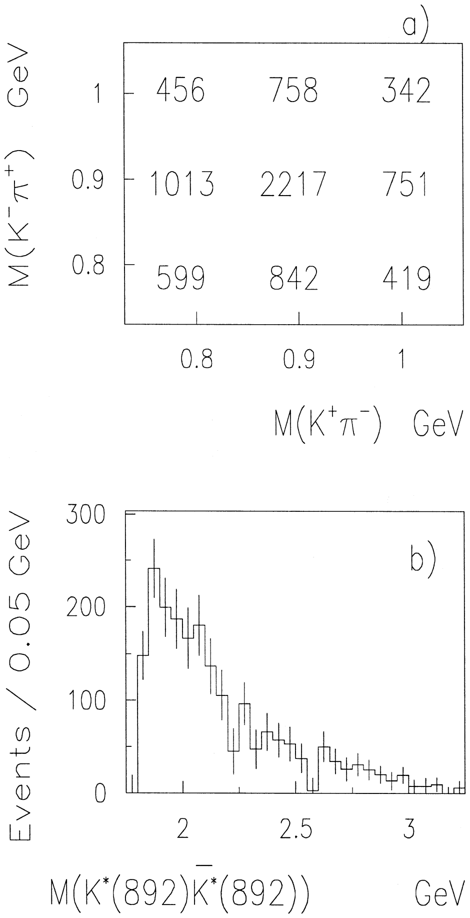

Fig. 2. For the $K^+K^-\pi^+\pi^-$ channel a) a scatter table of $m(K^-\pi^+)$ against $m(K^+\pi^-)$ in the $K^*(892)\bar{K}^*(892)$ region and b) the background subtracted $K^*(892)\bar{K}^*(892)$ mass spectrum.

to be $\sigma(K^*(892)K^{\pm}\pi^{\mp})/\sigma(K^*(892)\bar{K}^*(892)) = 2.06 \pm 0.13$. We can also calculate the number of $K^+K^-\pi^+\pi^-$ events that do not include a $K^*(892)$ using the fit to Fig. 1a) which gives 5642 ± 550 $K^+K^-\pi^+\pi^-$ events. Although the $K^*(892)$-$\bar{K}^*(892)$ final state is a major component of the $K^+K^-\pi^+\pi^-$ channel it is not the dominant component. In contrast, the $\phi\phi$ final state was found to be the dominant component of the $K^+K^-K^+K^-$ channel [5].

After correcting for geometrical acceptances, detector efficiencies, losses due to cuts, charged kaon decay and unseen decay modes, the cross-section for $K^*(892)\bar{K}^*(892)$ production at $\sqrt{s} = 29.1$ GeV in the x_F interval $|x_F| \leq 0.2$ is $\sigma(K^*(892)\bar{K}^*(892)) = 85 \pm 10$ nb. This can be compared with the cross-sections found in the same interval at $\sqrt{s} = 12.7$ and 23.8 GeV [6] of 67 ± 16 nb and 70 ± 14 nb respectively. This effectively constant cross-section as a function of energy is consistent with the $K^*(892)\bar{K}^*(892)$ system being produced by a Double Pomeron Exchange (DPE) mechanism which is similar to what was found for the $\phi\phi$ final state [5].

In the $K^+K^-\pi^+\pi^-$ channel we have also searched for associated $\phi\rho$ production but have found no evidence for this channel and can place an upper limit on the cross section of $\sigma(\phi\rho) < 0.7$ nb (95 % confidence limit).

In order to obtain a $K^*(892)\bar{K}^*(892)$ mass spectrum free from background we have used the nine bin method described above to calculate the number of $K^*(892)\bar{K}^*(892)$ events in 50 MeV mass intervals. The resulting $K^*(892)\bar{K}^*(892)$ effective mass spectrum is shown in Fig. 2b) and as can be seen shows a broad distribution with a maximum near threshold.

The angular distributions of the $K^*(892)$-$\bar{K}^*(892)$ system can be used to determine the spin-parity of the intermediate $K^*(892)\bar{K}^*(892)$ state using a method formulated by Chang and Nelson [9] and Trueman [10]. Three angles have to be considered: the azimuthal angle χ, between the two $K^*(892)$ decay planes and the two polar angles θ_1 and θ_2 of the Ks in their respective $K^*(892)$ rest frames relative to the $K^*(892)$ momenta in the $K^*(892)\bar{K}^*(892)$ rest frame.

Table 1
The β, ζ and chi-squared values for different spins of the $K^*(892)\bar{K}^*(892)$ system

J^P	L	S	β	ζ	chi-squared
0^+	0	0	2/3	0	54
0^+	2	2	1/3	1	175
0^-	1	1	−1	−1	314
1^-	1	1	0	1/2	68
1^+	2	2	0	1/2	68
2^+	0	2	1/15	0	18
2^+	2	0	2/3	0	54
2^+	2	2	2/21	3/14	30
2^-	1	1	−2/5	−1/10	64
2^-	3	1	−31/5	−2/3	139

For a $K^*(892)\bar{K}^*(892)$ sample of unique spin-parity and free of background the distribution of χ takes the form $dN/d\chi = 1 + \beta\cos(2\chi)$ where β is a constant which depends only on the spin-parity of the $K^*(892)\bar{K}^*(892)$ system and is independent of its polarisation. Similarly $dN/d\cos\theta = 1 + (\zeta/2)(3\cos^2\theta - 1)$. Values of β and ζ for different spin-parity states are given in Table 1 [11]. The χ and $\cos\theta$ distributions have been obtained by calculating the number of $K^*(892)\bar{K}^*(892)$ events from the nine bins in 9 intervals of χ and 10 intervals of $\cos\theta$. The resulting distributions are shown in Fig. 3a) and b) for χ and $\cos\theta$ respectively. A chi-squared fit has been performed to these spectra using the distributions expected for a single state with a given value of J^P. The results of the fit are given in Table 1 and as can be seen the lowest chi-squared is for a fit using $J^P = 2^+$ $(L=0, S=2)$ with $\beta = 1/15$ and $\zeta = 0$. As can be seen the $J^P = 0^+$ and 0^- hypotheses can be clearly ruled out. A free fit to the distributions has been performed and gives $\beta = 0.17 \pm 0.08$ and $\zeta = -0.13 \pm 0.09$. The spin analysis has been repeated in six slices in mass of the $K^*(892)$-$\bar{K}^*(892)$ system. The results found are similar to that for the total sample. The $\phi\phi$ final state was also found to have $J^P = 2^+$ [5].

A study of the $K^*(892)\bar{K}^*(892)$ system as a function of the parameter dP_T, which is the difference in the transverse momentum vectors of the two exchanged particles [1,2], has been performed. The fraction of $K^*(892)\bar{K}^*(892)$ production has been calculated for $dP_T \leq 0.2$ GeV, $0.2 \leq dP_T \leq 0.5$ GeV

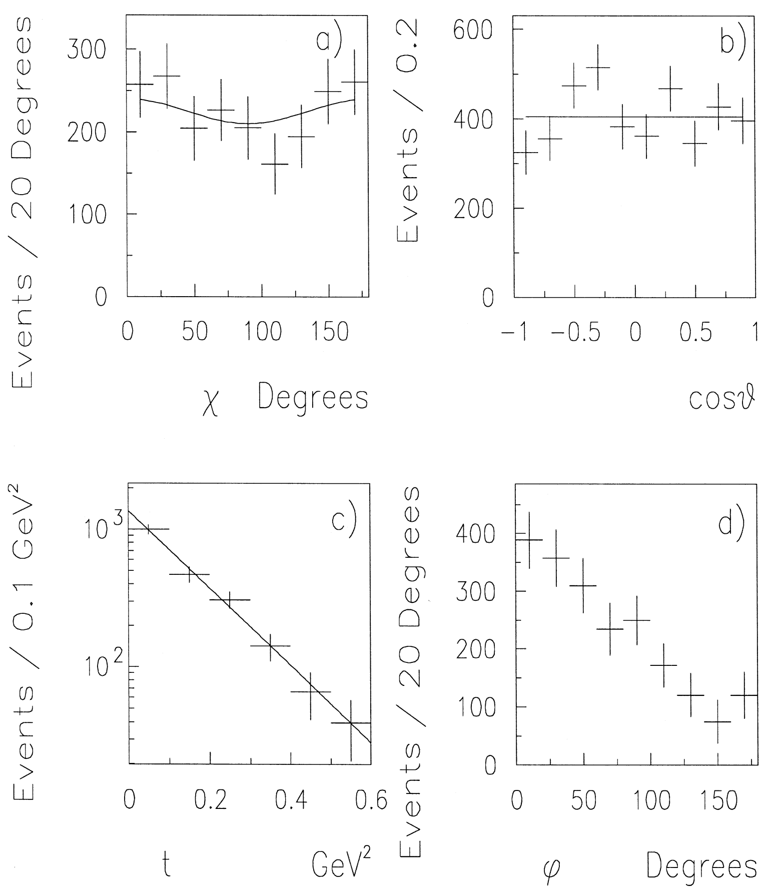

Fig. 3. For the $K^*(892)\bar{K}^*(892)$ channel a) and b) the χ and $\cos\theta$ distributions (the superimposed curve represents the 2^+ $(L=0, S=2)$ wave), c) the four momentum transfer squared ($|t|$) from one of the proton vertices and d) the azimuthal angle (ϕ) between the two outgoing protons.

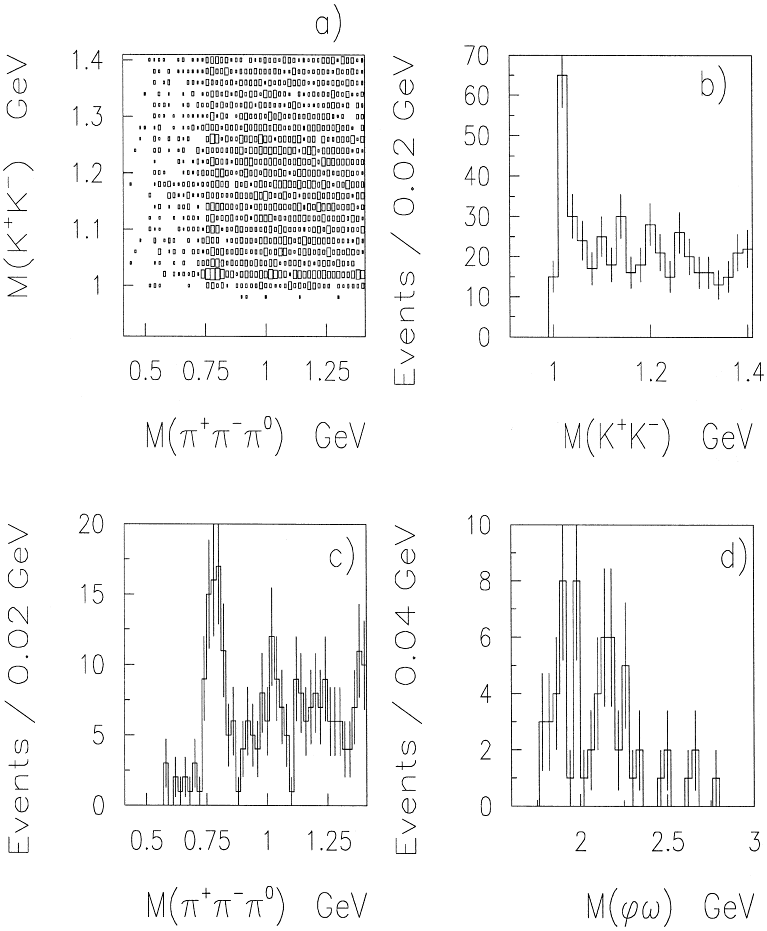

Fig. 4. For the $K^+K^-\pi^+\pi^-\pi^0$ channel a) the scatter plot of $m(K^+K^-)$ versus $m(\pi^+\pi^-\pi^0)$, b) the K^+K^- mass spectrum after selecting the $\pi^+\pi^-\pi^0$ mass spectrum to be in the ω region, c) the $\pi^+\pi^-\pi^0$ mass spectrum after selecting the K^+K^- mass spectrum to be in the ϕ region and d) the $\phi\omega$ mass spectrum.

and $dP_T \geq 0.5$ GeV and gives 0.23 $\pm$ 0.03, 0.54 $\pm$ 0.03 and 0.23 $\pm$ 0.02 respectively. This results in a ratio of production at small dP_T to large dP_T of 1.0 $\pm$ 0.16. This ratio is much higher than that observed [12] for the undisputed $q\bar{q}$ states, which typically have a value for this ratio of 0.1, but is similar to that found for glueball candidates and the $\phi\phi$ final state.

Fig. 3c) shows the four momentum transfer at one of the proton vertices for the $K^*(892)\bar{K}^*(892)$ system, obtained by calculating the number of $K^*(892)\bar{K}^*(892)$ events using the nine bin method in six intervals of t. The distribution has been fitted with a single exponential of the form $\exp(-b|t|)$ and yields $b = 6.4 \pm 0.5$ GeV which is consistent with what is expected from DPE [13]. The acceptance corrected azimuthal angle (ϕ) between the p_T vectors of the two protons is shown in Fig. 3d). This distribution is similar to that observed for the $\phi\phi$ final state [5], but differs significantly from that observed for the π^0, η, η' [14] and ω [15].

Reaction (3) has been isolated in a similar way to reaction (2) with the additional requirement of two γs reconstructed in the electromagnetic calorimeter [1].

[1] The showers associated with the impact of the charged tracks on the calorimeter have been removed from the event before the requirement of only two γs was made.

The mass of the K^+K^- pair is plotted against the mass of the $\pi^+\pi^-\pi^0$ system in Fig. 4a) and shows evidence for $\phi\omega$ production. Fig. 4b) shows the K^+K^- combination when the $\pi^+\pi^-\pi^0$ mass combination is required to be in the ω region (0.735 $< m(\pi^+\pi^-\pi^0) <$ 0.835 GeV) and Fig. 4c) shows the $\pi^+\pi^-\pi^0$ combination when the K^+K^- combination is required to be in the ϕ region (1.01 $<$ $m(K^+K^-) <$ 1.03 GeV). The resulting $\phi\omega$ mass distribution is shown in Fig. 4d). We have again used the nine bin method to determine the number of associated $\phi\omega$ events to be 42 $\pm$ 14. After correcting for geometrical acceptances, detector efficiencies, losses due to cuts, charged kaon decay and unseen decay modes, the cross-section for $\phi\omega$ production at $\sqrt{s} = 29.1$ GeV in the x_F interval $|x_F| \leq 0.2$ is $\sigma(\phi\omega) = 6 \pm 2$ nb.

A study of the $\phi\omega$ system as a function of the parameter dP_T has been performed in the three intervals $dP_T \leq 0.2$ GeV, $0.2 \leq dP_T \leq 0.5$ GeV and $dP_T \geq 0.5$ GeV and gives 0.00 $\pm$ 0.06, 0.48 $\pm$ 0.20 and 0.52 $\pm$ 0.20 respectively. This results in a ratio of production at small dP_T to large dP_T of 0.00 $\pm$ 0.18 compatible to what has been observed for undisputed $q\bar{q}$ states [12].

In conclusion, a study of the reactions $pp \to p_f p_s(K^+K^-\pi^+\pi^-)$ and $pp \to p_f p_s(K^+K^-\pi^+\pi^-\pi^0)$ show evidence for the $K^*(892)\bar{K}^*(892)$ and $\phi\omega$ channels respectively. The $K^*(892)$-$\bar{K}^*(892)$ mass spectrum shows a broad distribution with a maximum near threshold and an angular analysis shows that it is compatible with having $J^P = 2^+$. The behaviour of the cross-section as a function of centre of mass energy, and the four momentum transfer dependence, are compatible with what would be expected if the $K^*(892)$-$\bar{K}^*(892)$ system was produced via double Pomeron exchange. The dP_T behaviour of the $\phi\omega$ channel is similar to what has been observed for all the undisputed $q\bar{q}$ states. In contrast, the dP_T behaviour of the $K^*(892)\bar{K}^*(892)$ final state is similar to what has been observed for the $\phi\phi$ final state and for previously observed glueball candidates.

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References

[1] D. Barberis et al., Phys. Lett. B 397 (1997) 339.
[2] F.E. Close, A. Kirk, Phys. Lett. B 397 (1997) 333.
[3] F.E. Close, Phys. Lett. B 419 (1998) 387.
[4] P. Castoldi, R. Escribano, J.-M. Frere, Phys. Lett. B 425 (1998) 359.
[5] D. Barberis et al., hep-ex/9805018.
[6] T.A. Armstrong et al., Zeit. Phys. C 46 (1990) 405.
[7] R. Ehrlich et al., Phys. Rev. Lett. 20 (1968) 686.
[8] Particle Data Group, Phys Rev. D 54 (1996) 1.
[9] N.P. Chang, C.T. Nelson, Phys. Rev. Lett. 40 (1978) 1617.
[10] T.L. Trueman, Phys. Rev. D 18 (1978) 3423.
[11] G. Eigen, CALT 68-1483, 1987.
[12] A. Kirk, hep-ex/9803024.
[13] S.N. Ganguli, D.P. Roy, Phys. Rep. 67 (1980) 203.
[14] D. Barberis et al., Phys. Lett. B 427 (1998) 398.
[15] D. Barberis et al., Phys. Lett. B 422 (1998) 399.