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Inclusive $K^0_S K^0_S$ Resonance Production in ep Collisions

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Abstract

Resonant structure in the inclusive $K^0_s K^0_s$ mass spectrum is interpreted via interference between three tensor mesons plus the production of a glueball candidate state.

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1 Introduction and data set

We report on the $K_s^0K_s^0$ mass spectrum[1, 2], seen using the full HERA data set ($0.5\mathrm{pb}^{-1}$, 77% from HERA-II) with the ZEUS detector. The data sample of 672418 $K_s^0K_s^0$ pairs is 90% from photoproduction.

Recall that the $J^P = 1^-$ ϕ-meson decays to $K^0\overline{K}^0$ as $K_S^0K_L^0$ but never to $K_s^0K_s^0$ or to $K_L^0K_L^0$. This is an example of the non-local nature of quantum mechanics. The Bose symmetry of the $K_s^0K_s^0$ pair forces $J^P = 0^+, 2^+, 4^+$ etc. making this a good place to search for glueballs.

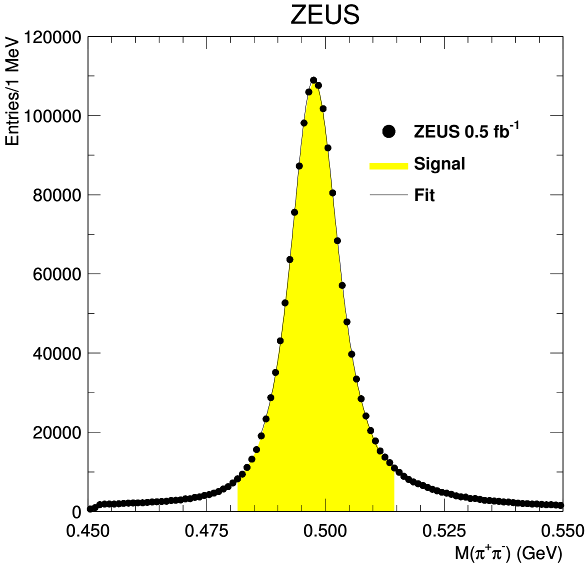

Figure 1: Measured $\pi^+\pi^-$ mass spectrum.

Quenched-approximation lattice gauge calculations [3] suggest the lightest glueball states are: $J^{PC} = 0^{++}$ at $1710 \pm 50 \pm 80$ MeV and $J^{PC} = 2^{++}$ at $2390 \pm 30 \pm 120$ MeV. Four states are found with $J^{PC} = 0^{++}$: $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$, consistent with three $q\overline{q}$ states and one gg state. The physical states can be mixtures of these. $q\overline{q}$ states are produced as leading hadrons in direct photoproduction or in fragmentation. gg states can be produced as leading hadrons in resolved photoproduction or in fragmentation.

The data were produced in the ZEUS detector, relying most on the central tracking (72 layers, B = 1.4T, $\sigma \simeq 160\mu$m) and the microvertex detector ($\sigma \simeq 25-35\mu$m) for reconstruction of the $K_s^0 \to \pi^+\pi^-$ decay. Both tracks from the same secondary decay vertex were assumed to be charged pions and the invariant mass, $M(\pi^+\pi^-)$, of each track pair was calculated. The K_s^0 candidates were selected by requiring: $M(e^+e^-) \geq 50$ MeV, where the electron mass was assigned to each track, to eliminate tracks from photon conversions and $M(p\pi) \geq 1121$ MeV, where the proton mass was assigned to the track with higher momentum, to eliminate Λ and $\overline{\Lambda}$ contamination to the K_s^0 signal.

We require $p_T(K_S^0) \geq 0.25$GeV and $|\eta(K_S^0)| \leq 1.6$; $\theta_{2D} < 0.12$ ($\theta_{3D} < 0.24$), where θ_{2D} (θ_{3D}) is the two (three) dimensional collinearity angle between the K_s^0 momentum vector and the vector defined by the interaction point and the vertex. (For θ_{2D}, the XY plane was used.) The cuts on the collinearity angles significantly reduced the non-K_s^0 background in the data during the 2004–2007 period, using microvertex detector information. After all these cuts, the decay length distribution of the resulting K_s^0 candidates peaks at $\approx$ 2cm.

Events with at least two K_s^0 candidates in the mass range of $481 \leq M(\pi^+\pi^-) \leq 515$MeV were accepted for further analysis. Figure 1 shows the $M(\pi^+\pi^-)$ distribution of these K_s^0 candidates. Figure 2 shows the $M(K_s^0K_s^0)$ distribution. The $K_s^0K_s^0$ mass resolution is typically 12 MeV.

2 Interpretation

The first $M(K_s^0K_s^0)$ fit (not shown) used a smooth background plus three incoherent Breit-Wigners. A health warning is in order: 'Breit-Wigner plus background' fits have strong correlations between the fitted BW intensity, the width and the background. There is a long history!

The χ^2/NDF is good (96/95) but the fit is poor near 1300 MeV and the width of the bump in the $f_2(1270)/a_2^0(1320)$ region is 61 ± 11 MeV, far too narrow for the f_2 and a_2^0 for which the PDG values are 176 ± 17 and 114 ± 14 MeV.

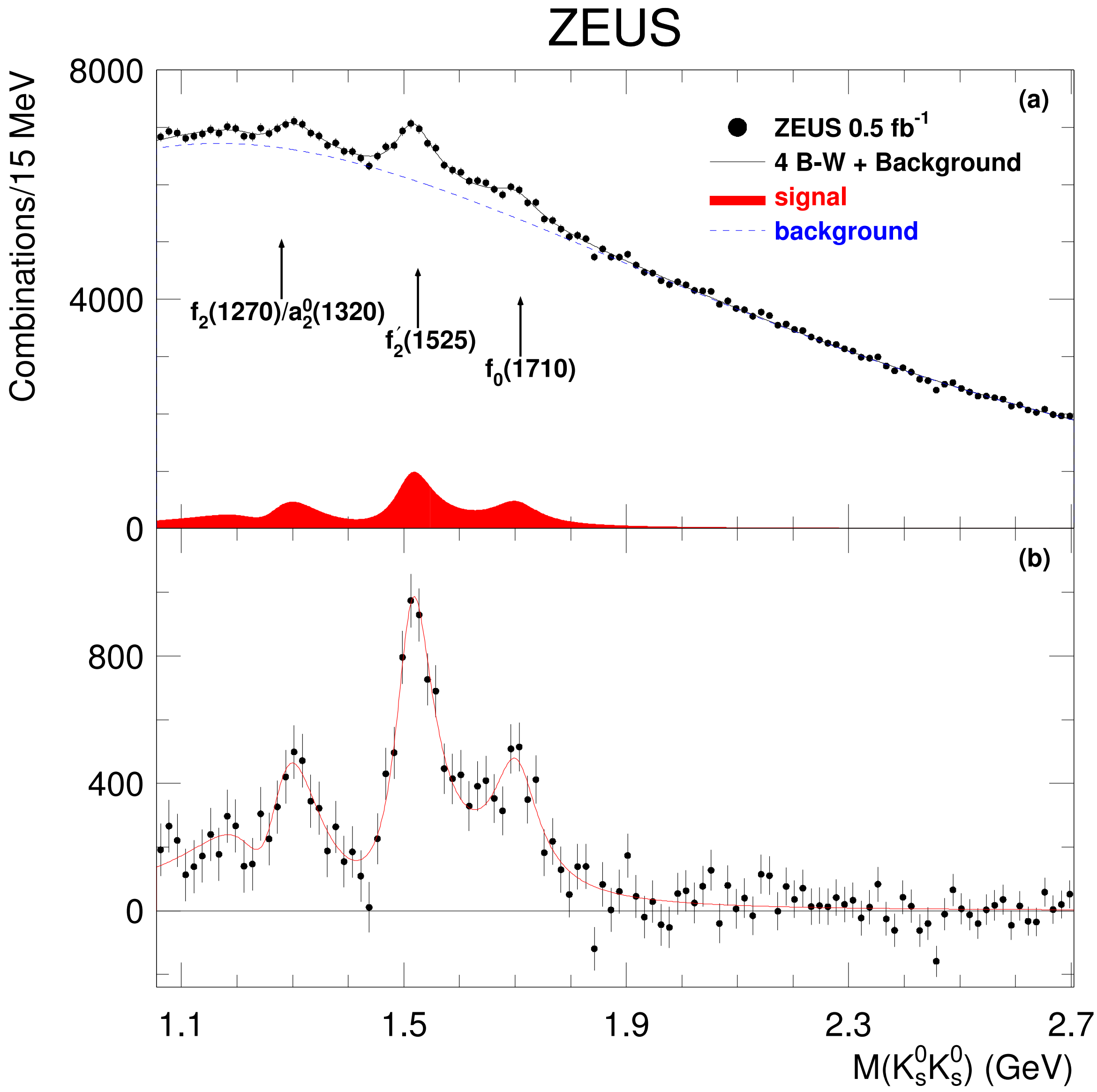

Figure 2: $K_s^0K_s^0$-mass (a) data and coherent fit (b) same with smooth background subtracted.

A similar result was obtained for the exclusive process $\gamma\gamma \rightarrow K_s^0K_s^0$ by the L3 collaboration [4]. The fitted mass spectrum is shown in Figure 3. Their fitted f_2/a_2^0 peak has a mass and width of 1239 ± 6 and 78 ± 19 MeV.

The TASSO collaboration measured the same process [5] and also measured $\gamma\gamma \rightarrow K^+K^-$. The $K_s^0K_s^0$ spectrum again shows an $f_2'(1525)$ signal but no trace of any enhancement around 1300 MeV. The K^+K^- result also shows a clear signal around 1525 MeV but has a major and broad enhancement in the f_2/a_2^0 region around 1300 MeV. (see Fig. 4).

Health warning 2: The $f_2(1270), a_2(1320)$ and $f_2'(1525)$ all have $J^p = 2^+$. In exclusive $\gamma\gamma$ production these must therefore interfere in the mass spectrum. Time reversal invariance makes the coefficients of their production amplitudes real.

The reaction $\gamma\gamma \rightarrow KK$ proceeds via electromagnetic coupling to the quark charges. Faiman, Lipkin and Rubinstein [6] use the quark structure of the resonant states. Thus for the $I = 0$ $f_2(1270)$ the quark content is $(u\overline{u} + d\overline{d})/\sqrt{2}$ giving a charge amplitude ratio factor $(2/3 \times 2/3 + 1/3 \times 1/3)/2 = 5/18$. For the $I = 0$ $f_2(1525)$ the content $s\overline{s}$ gives a factor 2/18, and the $I = 1$ $a_2^0(1320)$ the quark content is $(u\overline{u} - d\overline{d})/\sqrt{2}$ giving a charge amplitude ratio factor $(2/3 \times 2/3 - 1/3 \times 1/3)/2 = \pm 3/18$, where the + sign applies to the K^+K^- final state and the - sign to $K_s^0K_s^0$. Since the f_2 and a_2 are so close in mass we expect predominantly constructive interference between them in K^+K^- and predominantly destructive interference in $K_s^0K_s^0$, as observed by TASSO and L3.

The form used in the coherent fit to the ZEUS *ep* inclusive $K_s^0K_s^0$ mass spectrum, $f(m)$, is

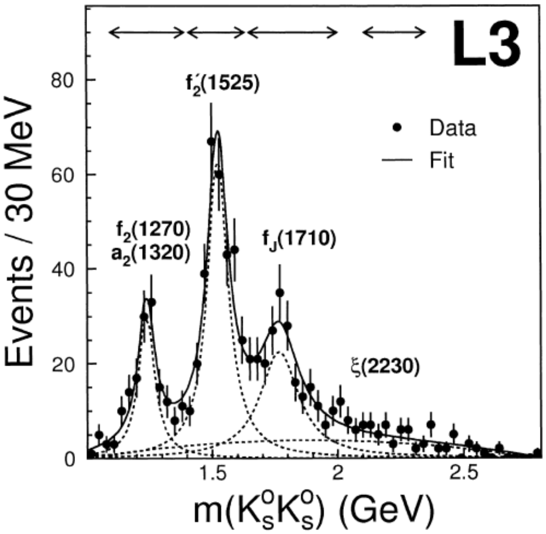

Figure 3: $\gamma\gamma \to K^0_s K^0_s$ results.

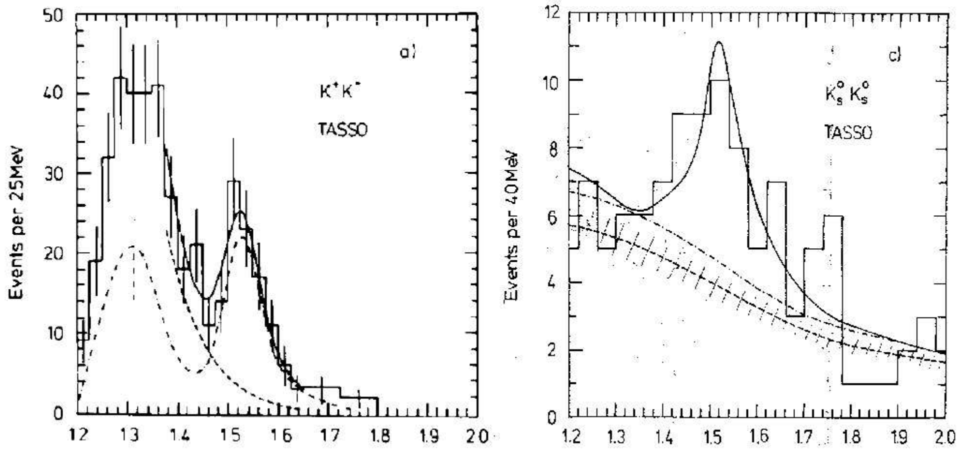

Figure 4: $\gamma\gamma \to K^+K^-$ and $K^0_s K^0_s$ results.

$$f(m) = a \times |5B_{f(1270)}(m) - 3B_{a(1320)}(m) + 2B_{f(1525)}(m)|^2 + b \times |B_{f(1710)}(M)|^2 + c \times U(m)$$

where $B_M(m)$ is the relativistic Breit-Wigner, $B_M(m) = M\sqrt{\Gamma}/(M^2 - m^2 - iM\Gamma)$, and $U(m)$ is a smooth background function.

3 Results

Figure 1 shows the resulting coherent fit, with the fitted background subtracted in figure 1(b). Compared to the no-interference fit the χ^2/NDF improves to 86/97, which can be viewed as a 3σ improvement. Note that in this fit the $J^P = 2^+$ states couple directly to the exchanged photon.

Fits without the $f(1710)$ are strongly disfavoured, with $\chi^2/NDF = 162/97$.

Table 1 compares the fitted parameters to Particle Data Group values. Mostly they are in good agreement. All the widths agree but the a_2 mass is still low. Figure 5 compares the $f_2'(1525)$ and $f_0(1710)$ results to previous measurements.

In conclusion, ZEUS have made a high-statistics study of the $K^0_s K^0_s$ system. Only $J^P = \text{even}^+$ states are possible. There is evidence for the coherent production of three $J^{PC} = 2^{++}$ states. Negative f_2/a_2 interference suggests coupling to the exchanged photon.

Production of the $f_0(1710)$ is clearly observed. This cannot be a pure glueball if it is the same state as the $f_J(1710)$ seen in $\gamma\gamma$ collisions.

State	M(fit)	Γ(fit)	M(PDG)	Γ(PDG)
$f_2(1270)$	1268 ± 10	176 ± 17	1275.4 ± 1.1	185 ± 3
$a_2^0(1320)$	1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1701 \pm 5^{+9}_{-2}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

Table 1: Coherent fit: camparison to PDG.

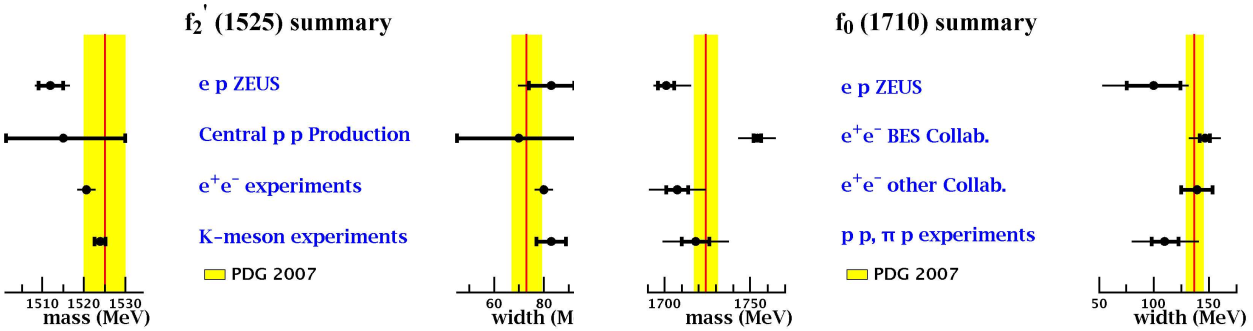

Figure 5: Comparisons to previous measurements

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