$K^0_S K^0_S$ Resonance Production at HERA

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on behalf of the
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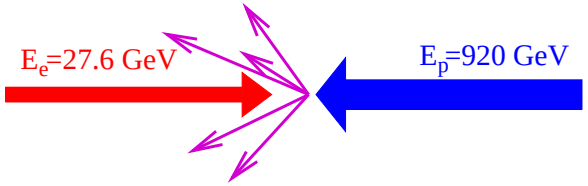
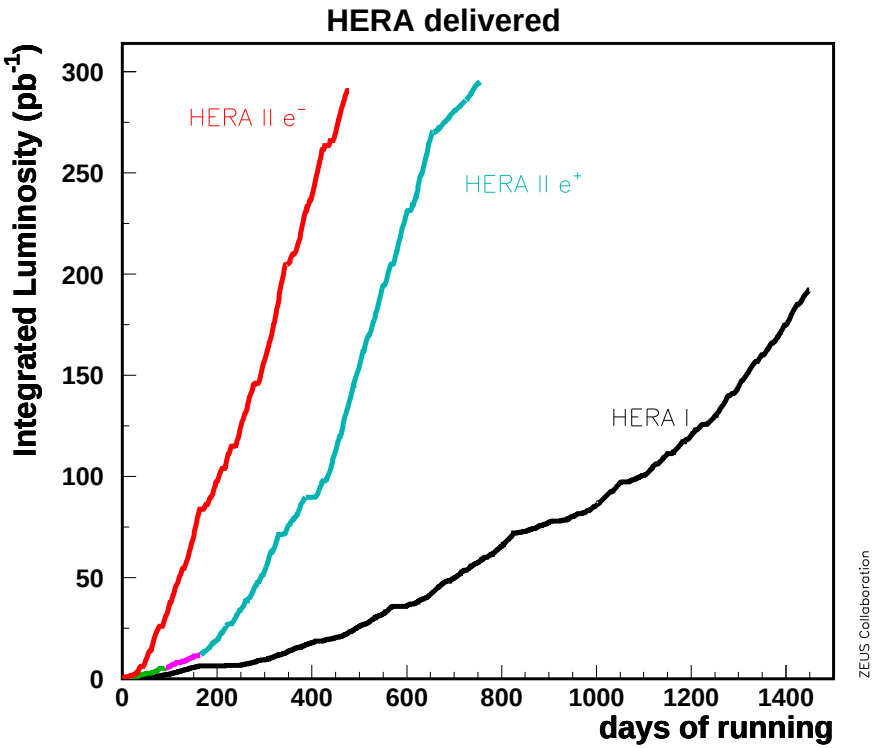
HERA Machine





	HERA I	HERA II
	1995-2000	2003-2007
$\sqrt{s}$	318 **(300)**	318 **GeV**
$\mathcal{L}$	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31}\, cm^{-2}\, s^{-1}$
$\mathcal{L}_{int}$	~ 120	$\sim 400\, pb^{-1}$

$$e(k) + p(P) \rightarrow e(k') + X \quad s = (P + k)^2$$

$$Q^2 = -q^2 = -(k - k')^2$$

Photoproduction $Q^2 \simeq 0\, GeV^2$

DIS $Q^2 > 1\, GeV^2$

Motivation

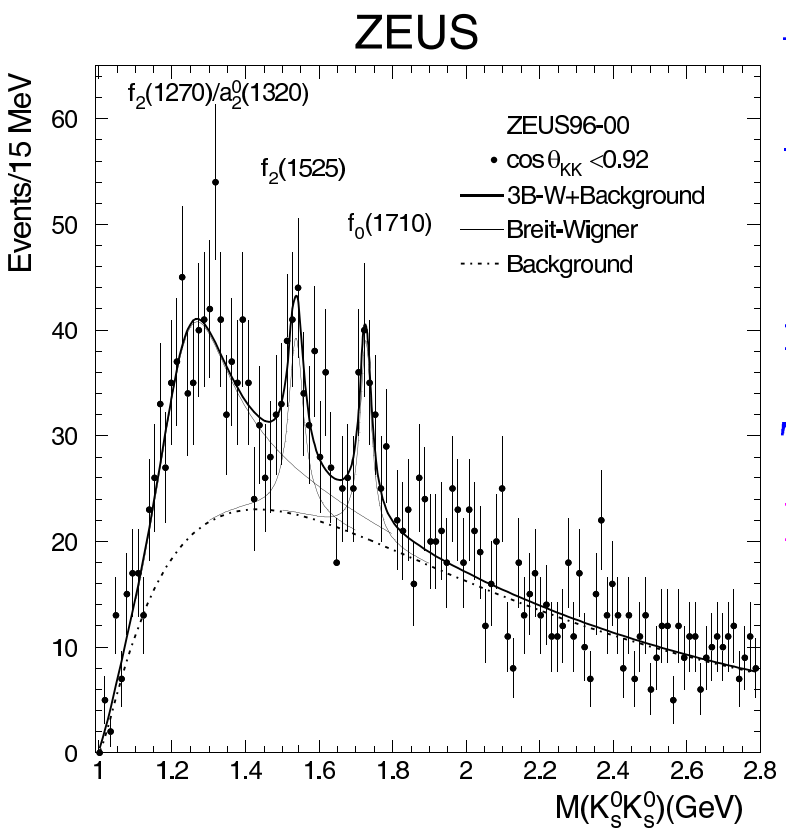
- The Standard Model (SM) describes hadrons via partons (mainly quarks)
- Mesons are usually described by spin-parity (J^P) multiplets of $q\bar{q}$
- The SM allows mesons with gluons, e.g. glueballs (gg) or hybrids (qqg)
- Scalar meson sector ($J^P = 0^+$) has too many established $I = 0$ states:
  $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$
  Only two can fit into the $q\bar{q}$ nonet
- Lattice calculations predict that lightest glueball has $J^{PC} = 0^{++}$ and mass in range $1550 - 1750$ MeV.
- It can mix with $q\bar{q}$ $I = 0$ states close in mass to the scalar meson nonet
- $f_0(1710)$ is considered to be a possible glueball candidate
- The $K^0_S K^0_S$ system can couple to $J^P = 0^+$ and 2^+

$\Rightarrow$ $K^0_S K^0_S$ is a good place to search for the lowest lying 0^+ glueball

Previous ZEUS $K^0_S K^0_S$ result

ZEUS observed indications of $f_2'(1525)$ and $f_0(1710)$ decaying into $K^0_S K^0_S$ in inclusive deep inelastic scattering (DIS) HERA I event sample (121 pb^{-1})

ZEUS Collab., S.Chekanov et al., Phys.Lett.B578,33(2004)



After applying strong cuts to the data sample, the statistical significance of each resonance was $\leq$ 3 s.d.

The $f_0(1710)$ width ($\approx$ 40 MeV) was much narrower than the PDG value ($\approx$ 130 MeV)

The present analysis was performed on the full HERA I + HERA II sample ($\approx$ 0.5 fb^{-1})

$$e^{\pm}p \to K^0_S K^0_S + X$$

The kinematic region included both photoproduction (PHP) ($Q^2 < 1$) and DIS ($Q^2 > 1$)

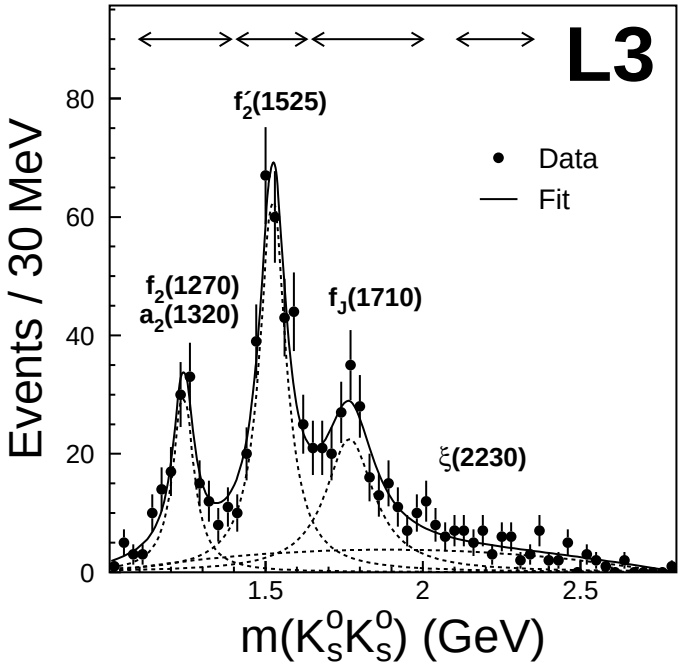
Sample dominated by PHP events

L3 $K^0_S K^0_S$ result

The L3 e^+e^- LEP experiment studied in two-photon collisions the exclusive reaction $\gamma\gamma \to K^0_S K^0_S$

L3 Collab., M.Acciarri et al., Phys.Lett.B501,173(2001)

They see 3 distinct peaks over a low background and attribute them to $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and $f_0(1710)$



Spectrum dominated by the formation of the $f_2'(1525)$ tensor meson

$f_0(1710)$ signal of $\approx$ 4 s.d. is seen

Maximum likelihood fit with 3 BW functions plus 2nd order polynomial

$f_2'(1525)$ parameters consistent with PDG

	$f_2(1270)/a_2(1320)$	$f_2'(1525)$	$f_0(1710)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Events	123 ± 22	331 ± 37	221 ± 55

Experimental details

The data were taken at the HERA e-p collider with the ZEUS detector

$E(e) = 27.5$ GeV; $E(p) = 820(920)$ GeV during 1996-97 (1998-2007)

Events with ≥ 2 V0 candidates were selected

No explicit trigger requirement applied for selecting $K^0_S K^0_S$ events

PHP sample dominated by low-E_T jet trigger ($E_T > 6$ GeV)

DIS sample triggered by requiring e^- or e^+ in the calorimeter

K^0_S mesons identified via $\pi^+\pi^-$ from secondary vertex

K^0_S candidates selected from $M(\pi^+\pi^-)$ by requiring:

- $M(e^+e^-) > 50$ MeV to eliminate photon conversions
- $M(p\pi) > 1121$ MeV to eliminate $\Lambda/\bar{\Lambda}$ contamination
- $p_T(K^0_S) > 0.25$ GeV; $|\eta(K^0_S)| < 1.6$
- $\theta_{2D} < 0.12$ rad θ_{2D} = angle in XY plane between K^0_S momentum vector and vector defined by interaction point and decay vertex

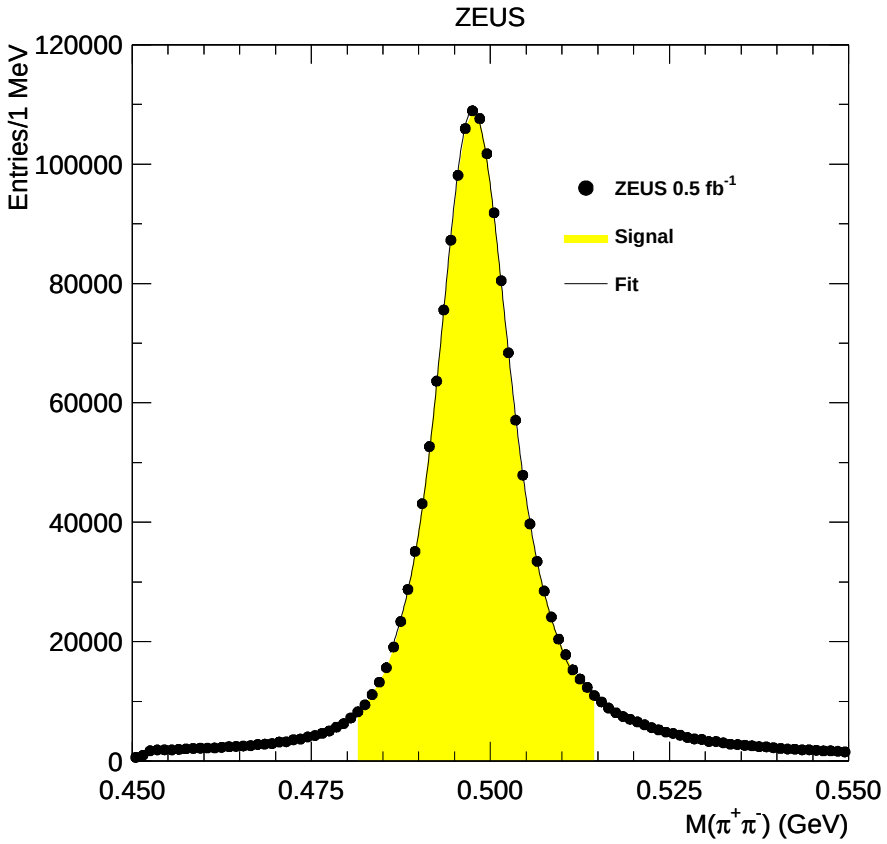
K^0_S mass distribution

$M(\pi^+\pi^-)$ distribution for events with $\geq 2 K^0_S$ candidates

Signal window for $M(K^0_S K^0_S)$ analysis: $481 \leq M(\pi^+\pi^-) \leq 515$ MeV

No. of K^0_S candidates in signal window $\approx 1,258,400$

Clean K^0_S signal; background $\approx 8\%$ (from 1st-order polynomial fit)



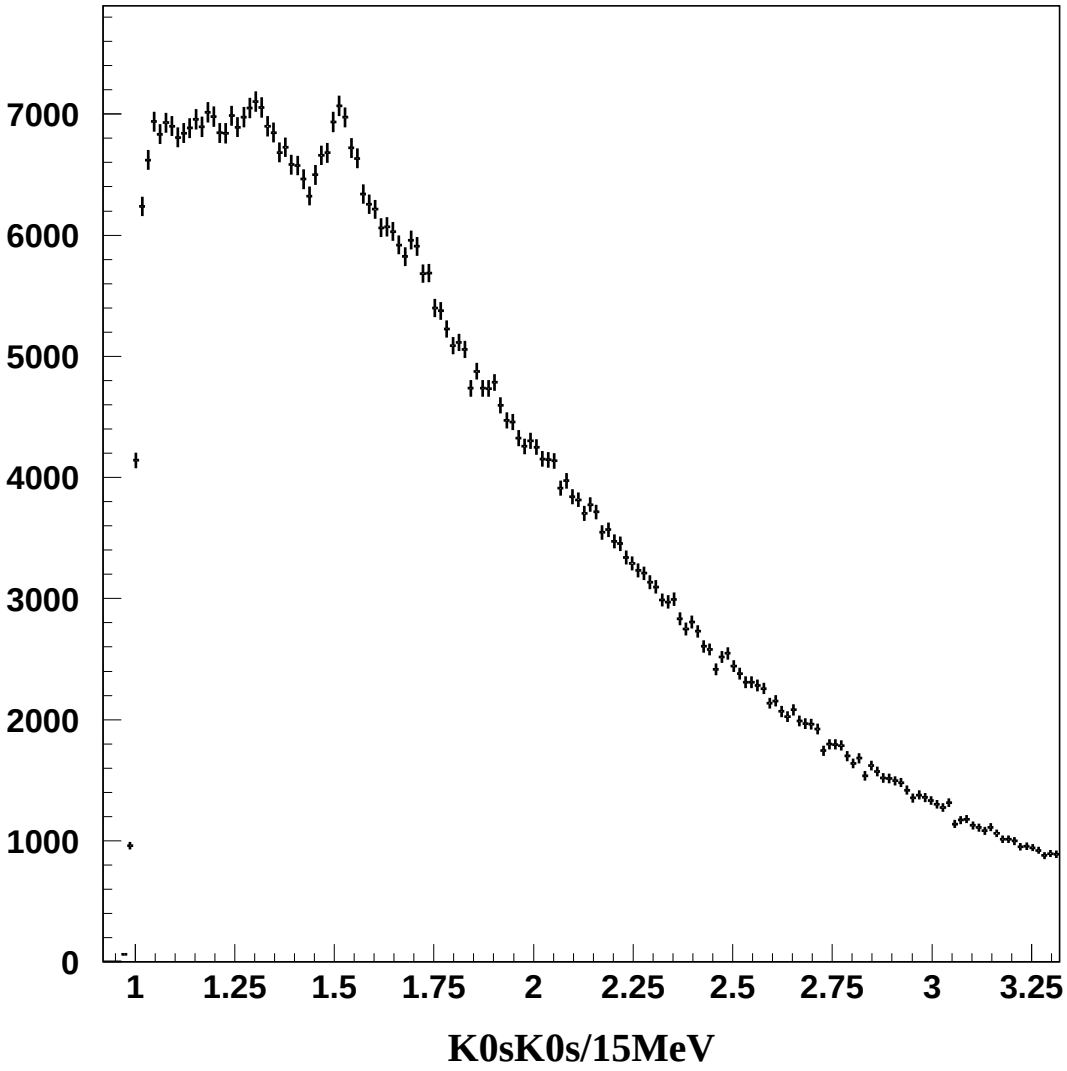
K^0_S mass and width determined by fitting central region with 2 Gaussians

M=497.49 MeV consistent with PDG

σ=4.1 MeV consistent with resolution

Fitting procedure

Two K^0_S candidates are combined to reconstruct the $K^0_S K^0_S$ invariant mass distribution



3 enhancements seen around

1.3, 1.5, 1.7 GeV

No state seen heavier than 1.7 GeV

Invariant mass distribution, m, fitted as sum of relativistic Breit-Wigner (RBW) resonances and smooth background

$$A(m-2M_{K^0_S})^B exp(-C(m-2M_{K^0_S}))$$

A,B,C are free parameters

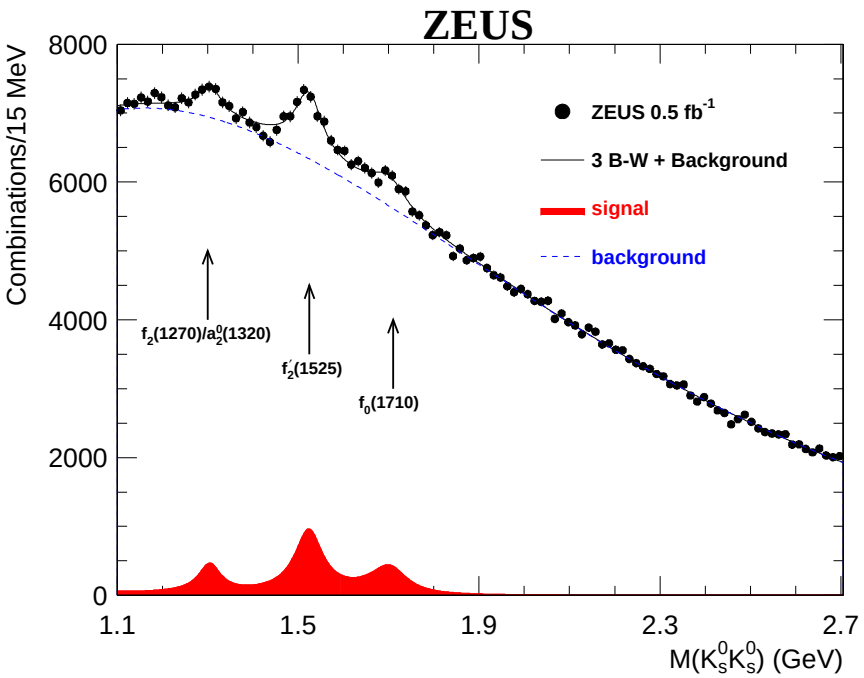
$M_{K^0_S}$ is the PDG K^0 mass

Mass resolution below 1.8 GeV

$\approx$ 12 MeV << resonance widths

$\Rightarrow$ not included in fit

$K^0_S K^0_S$ mass distribution + incoherent fit



Fit (as in L3) to background plus incoherent sum of 3 modified RBW resonances, R, of the form

$$F(m) = C_R\left(\frac{M_R\Gamma_R}{(M_R^2-m^2)^2+M_R^2\Gamma_R^2}\right)$$

representing the peaks

$f_2(1270)/a_2(1320)$, $f_2'(1525)$, $f_0(1710)$

C_R = Amplitude of resonance R

M_R = Mass of resonance R

Γ_R = Variable width of resonance R

$m = K^0_S K^0_S$ invariant mass

Goodness of fit is OK $\chi^2/ndf = 96/95$

Dip between $f_2(1270)/a_2(1320)$ and $f_2'(1525)$ not well reproduced

Fit without $f_0(1710)$ is bad $\Rightarrow$ $f_0(1710)$ is required

TASSO $K^0_S K^0_S$ result

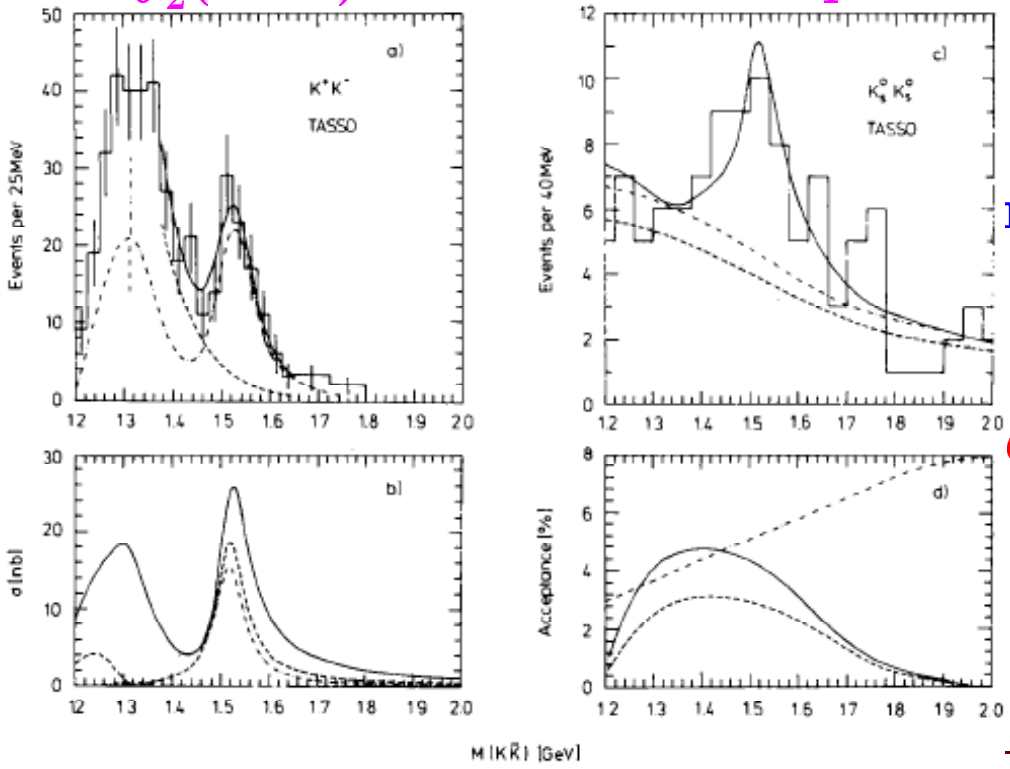
The old TASSO experiment at the PETRA e^+e^- collider studied in two-photon collisions the exclusive reactions $\gamma\gamma \to K^+K^-, K^0_S K^0_S$

TASSO Collab., M.Althoff et al., Phys.Lett.B121,216(1983)

A strong $f_2(1270)/a_2(1320)$ enhancement is seen in $M(K^+K^-)$

No $f_2(1270)/a_2(1320)$ signal is seen in $m(K^0_S K^0_S)$

The $f_2'(1525)$ is seen in both spectra



Results interpreted by interference effects between the 3 $J^P = 2^+$ resonances $f_2(1270), a_2(1320), f_2'(1525)$

For the same spin-parity, production amplitude is sum of 3 coherent BW's

$C_1 \cdot BW(f_2(1270)) \pm C_2 \cdot BW(a_2(1320)) + C_3 \cdot BW(f_2(1525))$

According to SU(3), sign of 2nd term is $+$ for K^+K^-; $-$ for $K^0_S K^0_S$

Faiman et al., Phys.Lett.B59,269 (1975)

$m(K^0_S K^0_S)$ fitting of coherent 2^+ states

	$f_2(1270)$	$a_2(1320)$	$f_2'(1525)$
Isospin I	0	1	0
Quark content	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$(u\bar{u}-d\bar{d})/\sqrt{2}$	$s\bar{s}$
Charge factor	$(\frac{2}{3}\cdot\frac{2}{3}+\frac{1}{3}\cdot\frac{1}{3})\frac{1}{2}$	$(\frac{2}{3}\cdot\frac{2}{3}-\frac{1}{3}\cdot\frac{1}{3})\frac{1}{2}$	$\frac{1}{3}\cdot\frac{1}{3}$
Amplitude ratio	$C_1 = 5$	$C_2 = -3$	$C_3 = 2$

$\Rightarrow$ The appropriate function to fit the $m(K^0_S K^0_S)$ spectra

for an electromagnetic production process assuming

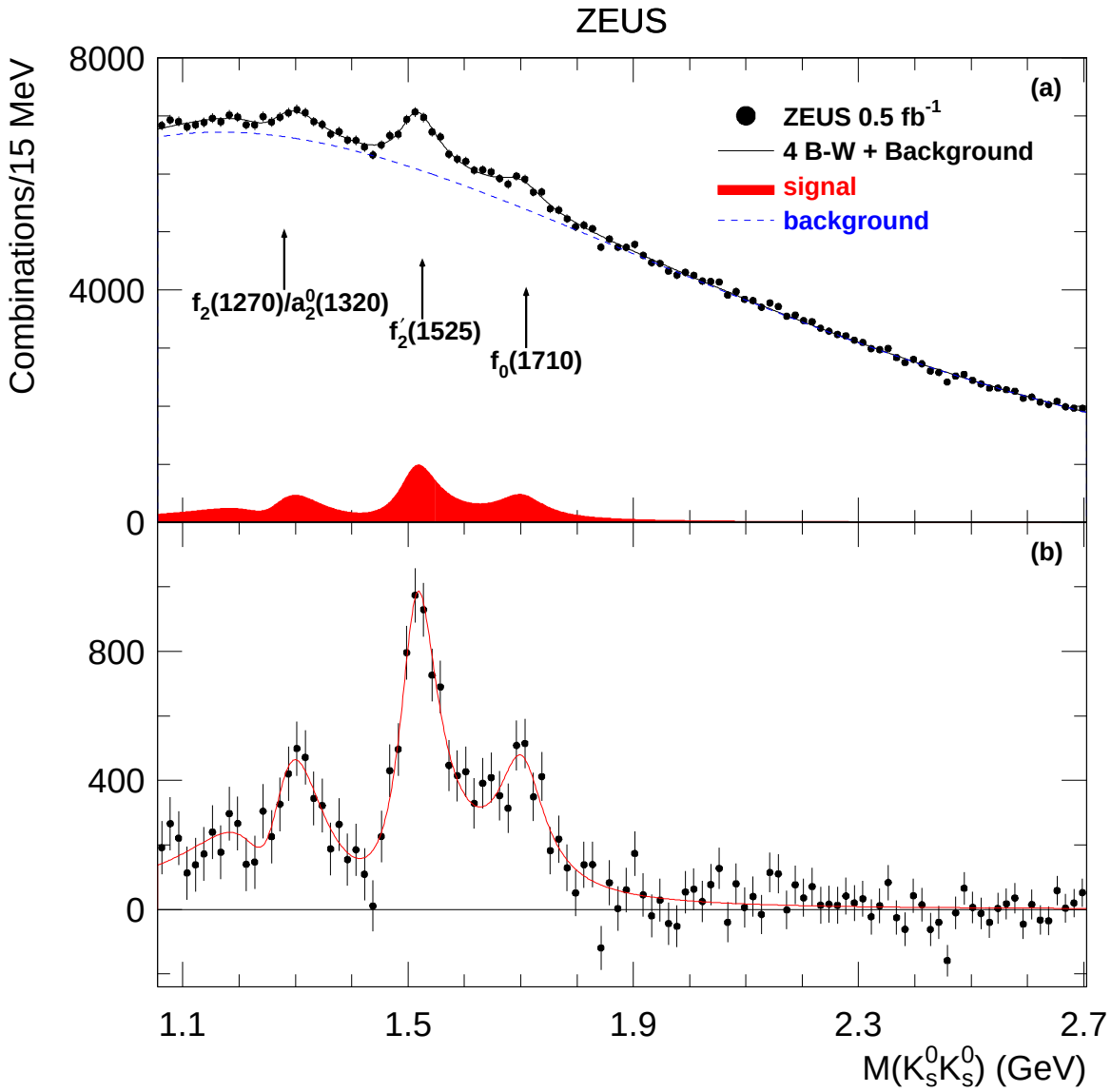
SU(3) symmetry is H.J.Lipkin, private communication

$$F(m) = a[5\cdot BW(f_2(1270)) - 3\cdot BW(a_2(1320)) + 2\cdot BW(f_2(1525))]^2 + b[BW(f_0(1710))]^2 + c\cdot \text{background}$$

a,b,c are free parameters

BW is a relativistic BW amplitude: $BW(R) = \frac{M_R\sqrt{\Gamma_R}}{M_R^2 - m^2 - iM_R\Gamma_R}$

$K^0_S K^0_S$ mass distribution + interference fit



M, Γ of all resonances - free parameters in the fit.

Bottom plot: background subtracted $M(K^0_S K^0_S)$ spectrum with fitted BW functions.

Good fit $\chi^2/ndf = 86/97$.

Peak around **1.3 GeV** suppressed due to destructive interference between $f_2(1270)$ and $a_2(1320)$.

Dip between $f_2(1270)/a_2(1320)$ and $f_2'(1525)$ is well reproduced.

No. of fitted $f_0(1710)$ events:

4058 ± 820 $\quad \approx 5\sigma$ significance

Fit without $f_0(1710)$ strongly disfavoured $\chi^2/ndf = 162/97$

Table of fit results

Fit	No interference		Interference		PDG 2007 Values	
χ^2/ndf	96/95		86/97			
in MeV	Mass	Width	Mass	Width	Mass	Width
$f_2(1270)$	1304 ± 6	61 ± 11	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$			1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+2}_{-0.6}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+5}_{-3}$	$100 \pm 24^{+8}_{-19}$	1724 ± 7	137 ± 8

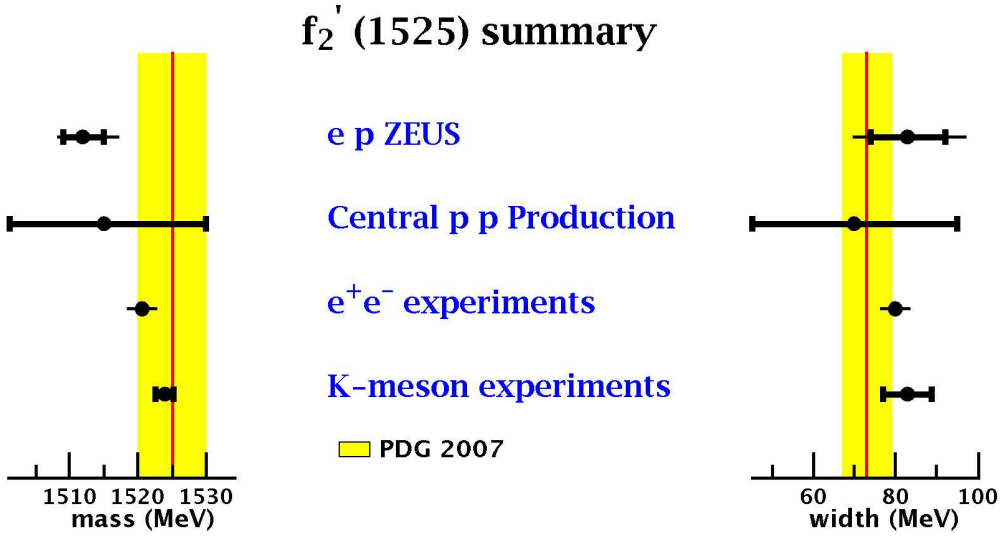
Incoherent fit yields narrow width for $f_2(1270)/a_2(1320)$: 61 ± 11 MeV

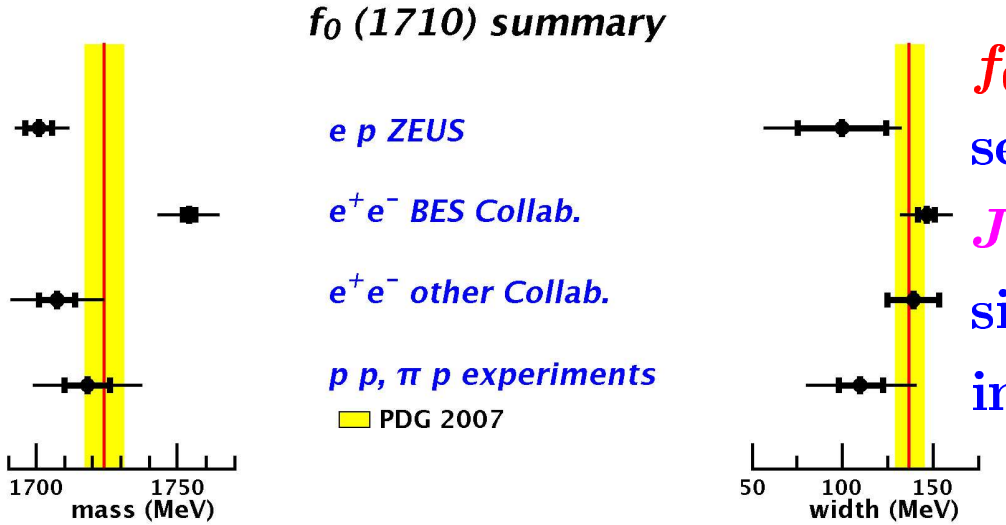
Similar to the L3 incoherent fit: $\Gamma(f_2(1270)/a_2(1320) = 78 \pm 19$ MeV

For fit with interference:

- **$a_2(1320)$ mass below PDG value. Similar shift, attributed to destructive $f_2(1270)/a_2(1320)$ interference, seen by Faiman et al.**
- **Widths of all observed resonances close to PDG values**
- **$f_2'(1525)$, $f_0(1710)$ masses below PDG; uncertainties compatible with PDG**
- **One of the best $f_0(1710)$ reported signals: 4058 ± 820 events ≈ 5 s.d.**
- **All resonances observed in DIS sample (much smaller than PHP one)**

Compilation of $f_2'(1525)$ and $f_0(1710)$ mass and width values





$f_0(1710)$ mass in BES experiment seen in quarkonium decays:

J/ψ or $\psi(2S) \to (\gamma$ or $\omega) + f_0(1710)$ significantly above other experiments including older J/ψ radiative decays

Conclusions

- $K^0_S K^0_S$ final states studied in ep collisions at HERA with ZEUS detector
- Observe 3 enhancements corresponding to $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and $f_0(1710)$
- No state observed heavier than $f_0(1710)$
- States fitted taking into account interference pattern predicted by SU(3) symmetry arguments
- M of $f_2'(1525)$, $f_0(1710)$ below PDG; all Γ consistent with PDG
- $f_0(1710)$ observed with 5σ significance
- $f_0(1710)$ has mass consistent with $J^P = 0^+$ glueball candidate
- If $f_0(1710)$ is same as seen in $\gamma\gamma \to K^0_S K^0_S$ (TASSO,L3) it is unlikely to be pure glueball since photons can couple in the partonic level only to charged quarks

Backup: systematic uncertainties

Systematic uncertainties of mass and width of the resonances determined from the fit evaluated by varying selection cuts:

- Minimum track p_T
- Track pseudorapidity range
- Track momenta by $\pm 0.1\%$
- Track angles by $\pm 0.5\%$
- Accepted $\pi^+\pi^-$ mass range around K^0_S peak
- Collinearity cuts

Fitting procedure changed: use maximum likelihood instead of χ^2 fit

Largest systematic uncertainties:

- Fitting with fixed M, Γ of $f_2'(1525)$ from PDG affects $f_0(1710)$ width by -19 MeV
- Variation of track momenta affects $f_0(1710)$ width by +7 MeV

Details in: C. Zhou, Ph.D. Thesis (unpublished), McGill University, Montreal, Canada, 2008.