

Inclusive $K_s^0 K_s^0$ resonance production in ep collisions

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Zeus Collab., Phys.Rev.Lett **101**, 112003(2008)

Full HERA data set (0.5 fb^{-1} , 77% from HERA II)

90% photoproduction ($Q^2 < 1 \text{ GeV}^2$), rest DIS

672418 $K_s^0 K_s^0$ pairs



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Quantum Mechanics of $K^0_s K^0_s$ pair

$\phi(1020)$ meson ($J^{PC} = 1^{--}$) decays 83% via $\phi \rightarrow K \bar{K}$
49% $\phi \rightarrow K^+ K^-$, 34% $\phi \rightarrow K^0 \bar{K}^0$ (strangeness eigenstates)

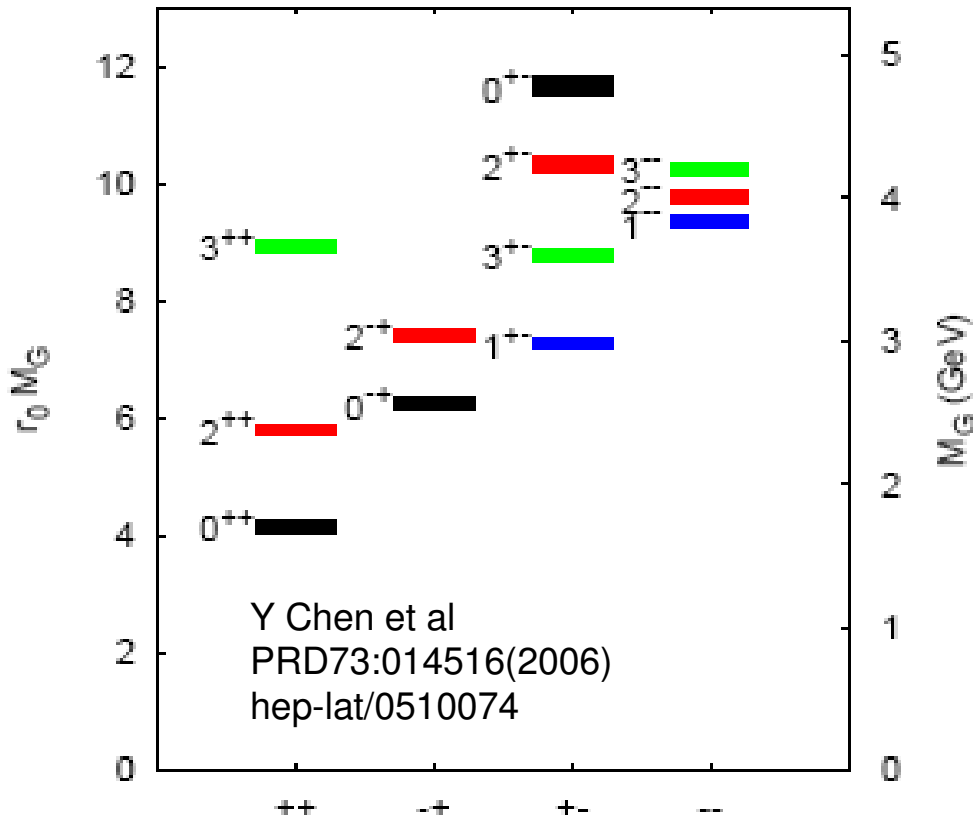
After 10^{-10} s one K^0 decays as K^0_s (CP eigenstate)

The other one **never** decays as K^0_s , always as K^0_L .

Needs non-local QM: EPR paradox

Reason: Bose Symmetry of $K^0_s K^0_s$ pair forces $J^{PC} = 0^{++}, 2^{++}, 4^{++}$ - use to investigate scalar and tensor mesons: $q\bar{q}$ or glueball (gg or ggg) or hybrid mixture or tetraquark ($qq\bar{q}\bar{q}$)

Lattice QCD predicts glueball spectrum: quenched approximation (no $q\bar{q}g$ coupling)



Lightest glueball predictions:

$$J^{PC} = 0^{++} \quad 1710_{\pm 50 \pm 80} \text{ MeV}$$

$$J^{PC} = 2^{++} \quad 2390_{\pm 30 \pm 120} \text{ MeV}$$

Four states found with $J^{PC} = 0^{++}$

$f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$

?? 3 $q\bar{q}$ + glueball or mixed

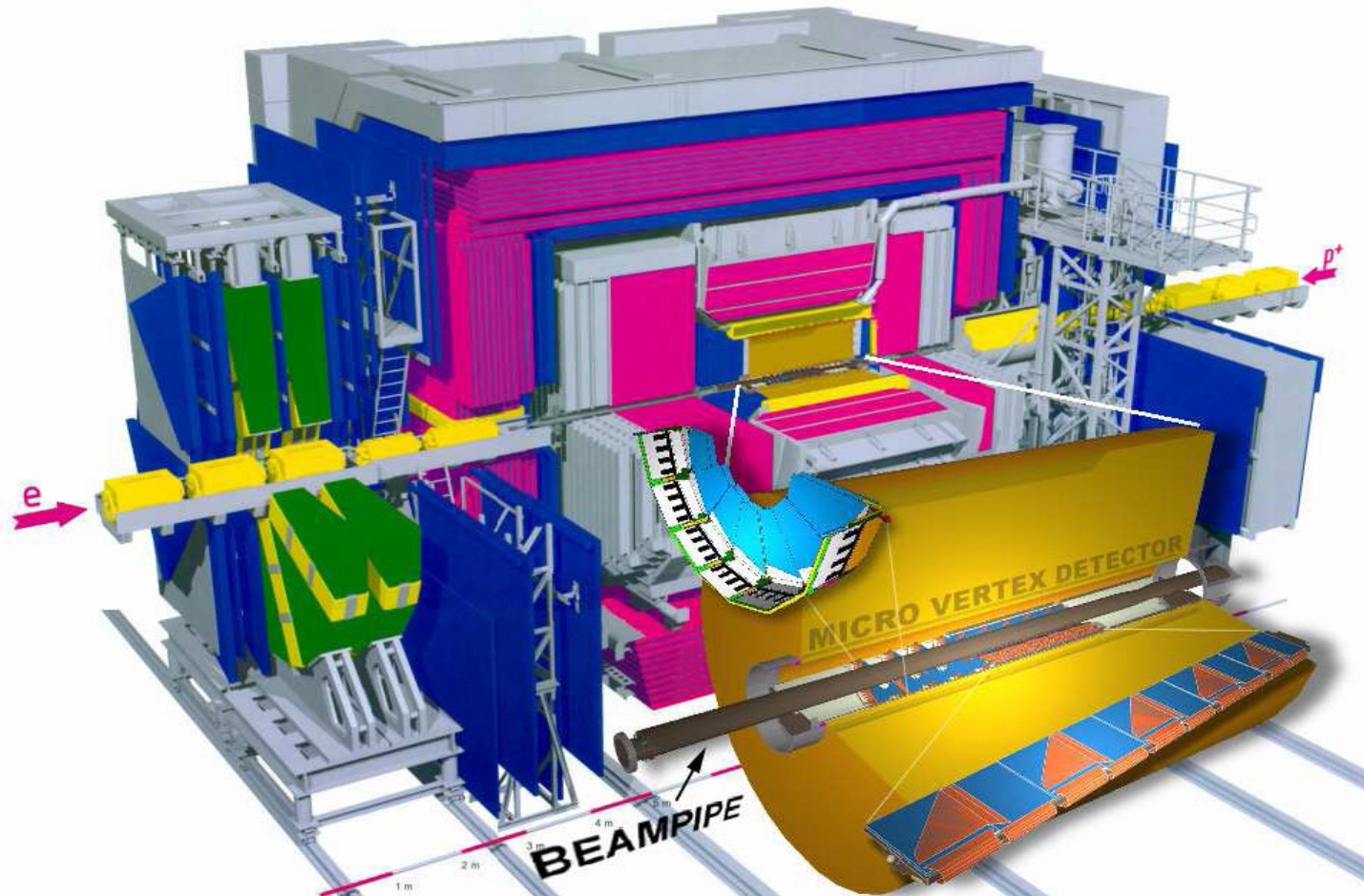
Produced as leading hadrons in
resolved photoproduction or in
fragmentation

$q\bar{q}$: Produced as leading hadrons
in direct photoproduction or in
fragmentation

Central tracking
to reconstruct
 $K_s^0 \rightarrow \pi^+\pi^-$

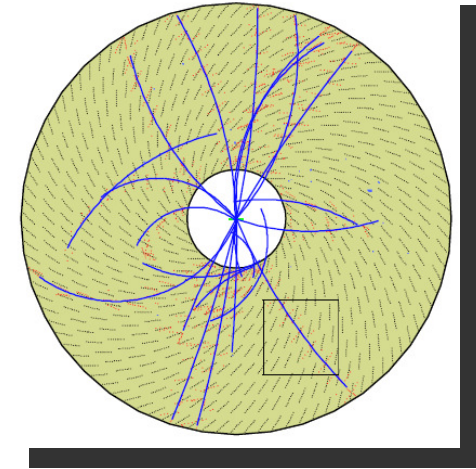
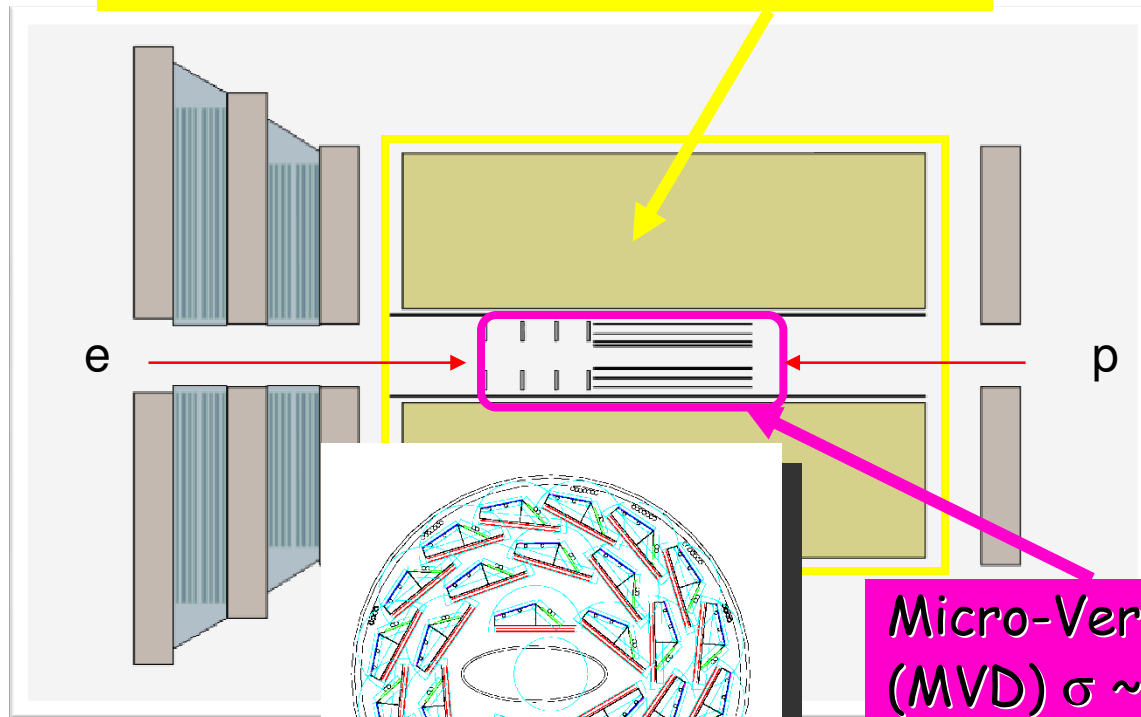
ZEUS at HERA

e^+p collider
 $\sqrt{s} = 300\text{-}318 \text{ GeV}$



Tracking Detectors

Central Tracking Detector (CTD)
72 layers, $\sigma \sim 160 \mu\text{m}$



$B = 1.4 \text{ T}$

Micro-Vertex Detector
(MVD) $\sigma \sim 25\text{-}35 \mu\text{m}$

$K_s^0 \rightarrow \pi^+\pi^-$ selection

Good primary event vtx, $|Z_{\text{vtx}}| < 50$ cm

$p_T(\pi^\pm) > 0.14$ GeV/c, $|\eta(\pi)| < 1.75$

$M(e^+e^-) > 50$ MeV

$M(p\pi^-, \bar{p}\pi^+) > 1121$ MeV/c

$p_T(K_s^0) > 0.25$ GeV/c, $|\eta(K_s^0)| < 1.6$

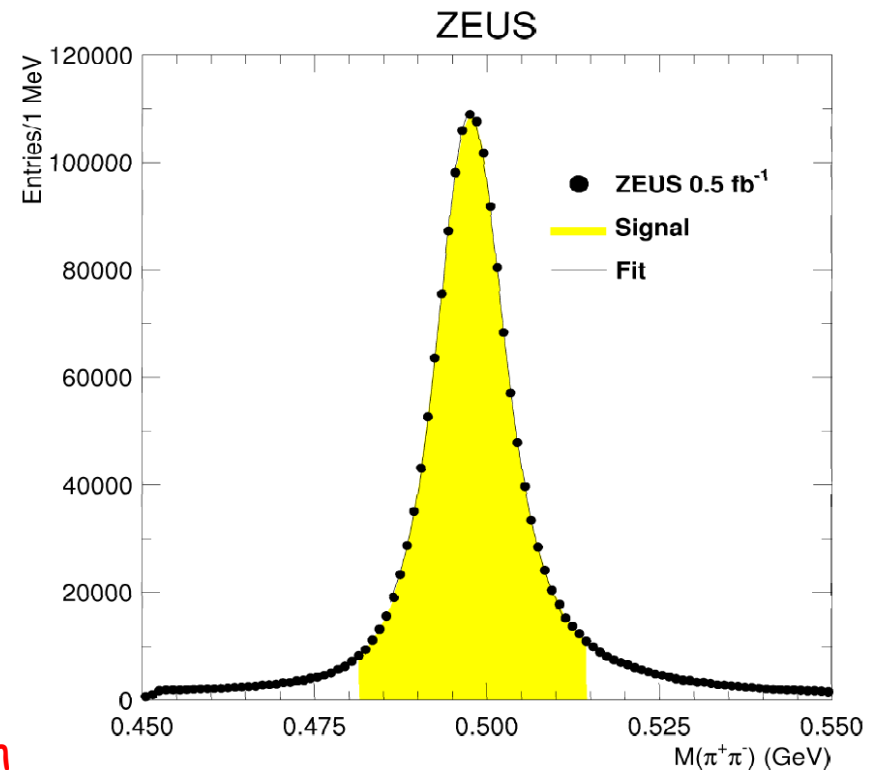
Decay colinearity < 0.12 (2d), 0.24 (3d)

Decay length < 30 cm (peak length 2 cm)

$481 < M(\pi^+\pi^-) < 515$ MeV

672418 $K_s^0 K_s^0$ pairs

Histogram shows $M(\pi^+\pi^-)$ for events with two or more $K_s^0 K_s^0$



Fit $M(K_s^0 K_s^0)$ by adding 3 Breit-Wigners + smooth background

Incoherent sum of 3 resonances, mass m_* , width Γ_d

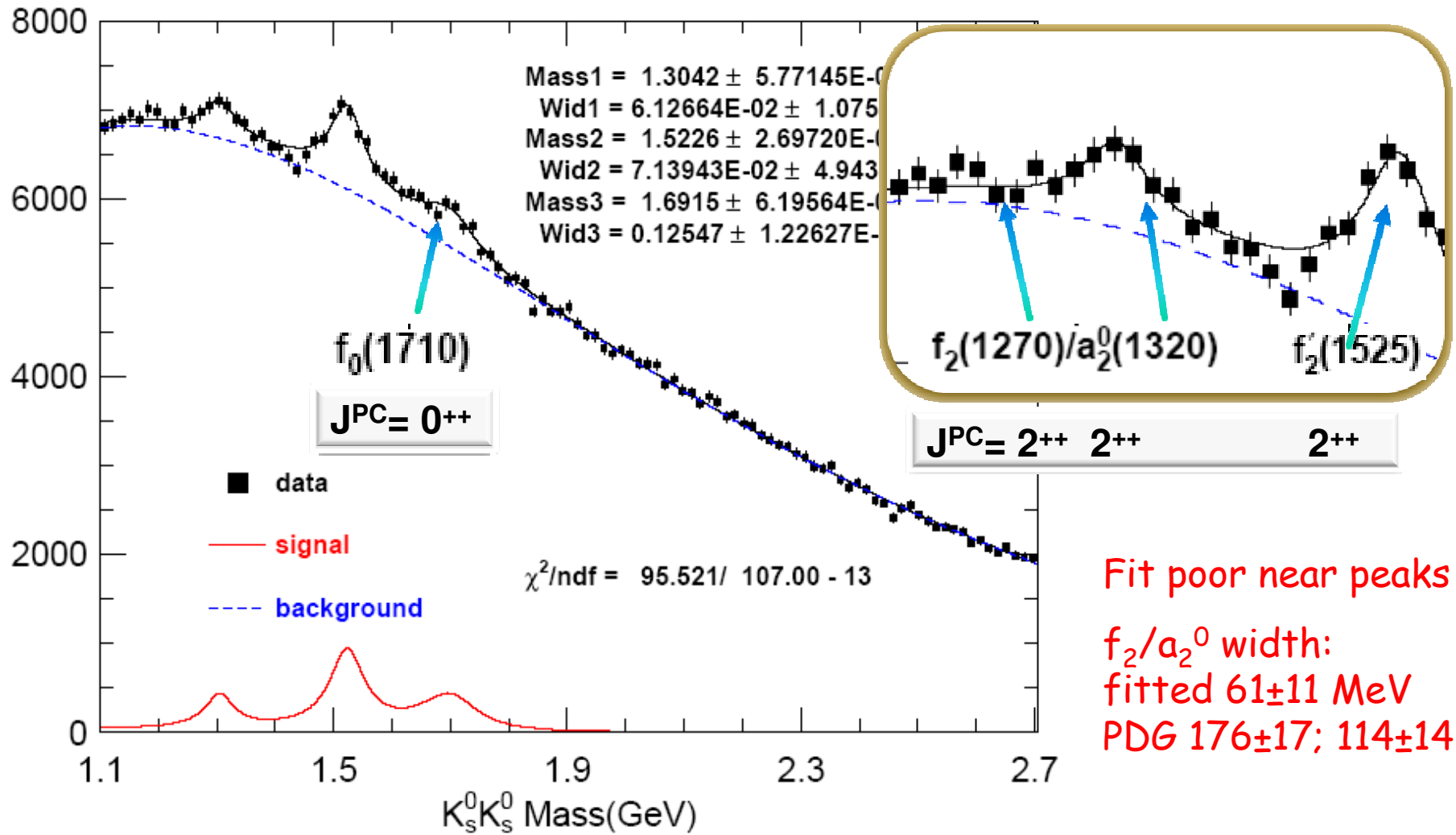
$$F(M) = \sum_{i=1}^3 C_i \left(\frac{m_{*,i} \Gamma_{d,i}}{(m_{*,i}^2 - M^2)^2 + m_{*,i}^2 \Gamma_{d,i}^2} \right)$$

Background

$$U(M) = A \cdot (M - 2m_{K_s^0})^B \cdot \exp\left(-C(M - 2m_{K_s^0})\right)$$

Health warning 1: (BW+free background) fit has strong correlations of fitted BW intensity, BW width and background shape. Long history - "bump hunting."

3-Incoherent BW+background fit

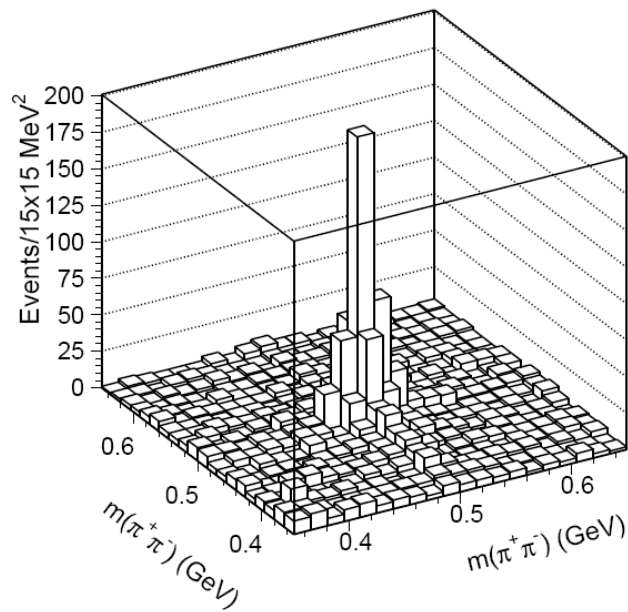


Fit poor near peaks

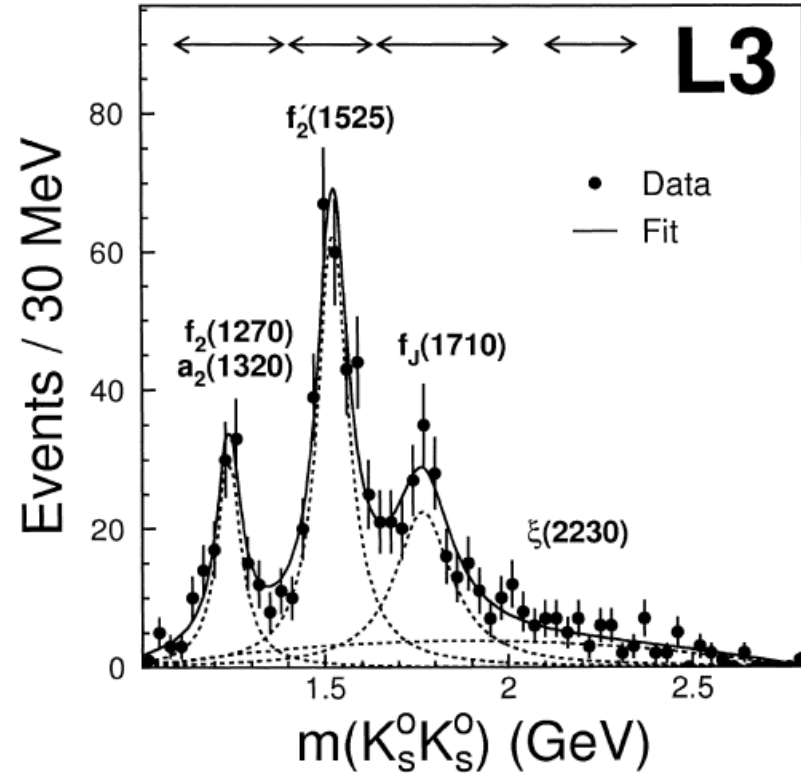
f_2/a_2^0 width:
 fitted 61 ± 11 MeV
 PDG 176 ± 17 ; 114 ± 14

Narrow peak in f_2, a_2^0 region: L3 $\gamma\gamma \rightarrow K_S^0 K_S^0$

Phys.Lett.B501:173-182,2001 (hep-ex/0010037)



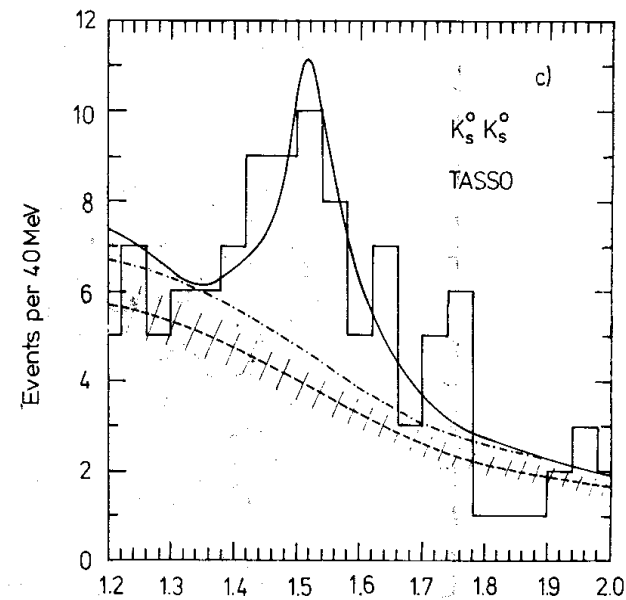
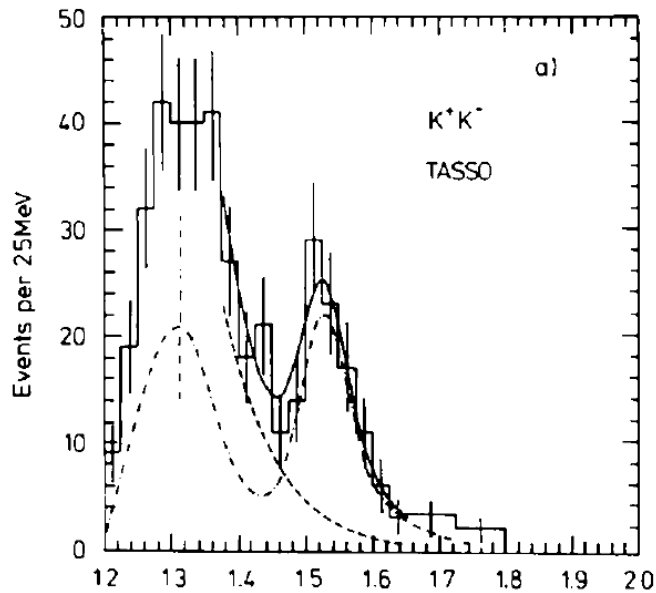
$\sim 4\sigma$ for $f_J(1710)$



	$f_2(1270)$ - $a_2(1320)$	$f_2'(1525)$	$f_J(1750)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Area	123 ± 22	331 ± 37	220 ± 55

Structure in f_2, a_2^0 region: TASSO $\gamma\gamma \rightarrow K^+K^-$ $\gamma\gamma \rightarrow K_s^0 K_s^0$,

Phys Lett **121B** (1983) 216



Strong enhancement ~ 1300 in K^+K^- , not in $K_s^0 K_s^0$. Both see peak ~ 1500

Health warning 2: $f_2(1270), a_2(1320), f_2'(1525)$ all have same $J^P=2^+$.

MUST interfere in mass spectrum - phase dependent on $\gamma q\bar{q}$ couplings

Fit $M(K_s^0 K_s^0)$ by adding coherent Breit-Wigners + smooth background

DFaiman, HJLipkin, HRRubinstein Phys Lett **59B** (1973) 269

	Coherent 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	$(\frac{2}{3} \times \frac{2}{3} + \frac{1}{3} \times \frac{1}{3}) \frac{1}{2}$	$(\frac{2}{3} \times \frac{2}{3} - \frac{1}{3} \times \frac{1}{3}) \frac{1}{2}$	$\frac{1}{3} \times \frac{1}{3}$
Amplitude ratio	5 BW	-3 BW	2 BW

$$rate(M) = a * | 5*BW(f_2^{1270}) \pm 3*BW(a_2) + 2*BW(f_2^{1525}) |^2 + b * | BW(f_0^{1710}) |^2 + c * U(M)$$

BW is Relativistic Breit-Wigner function:

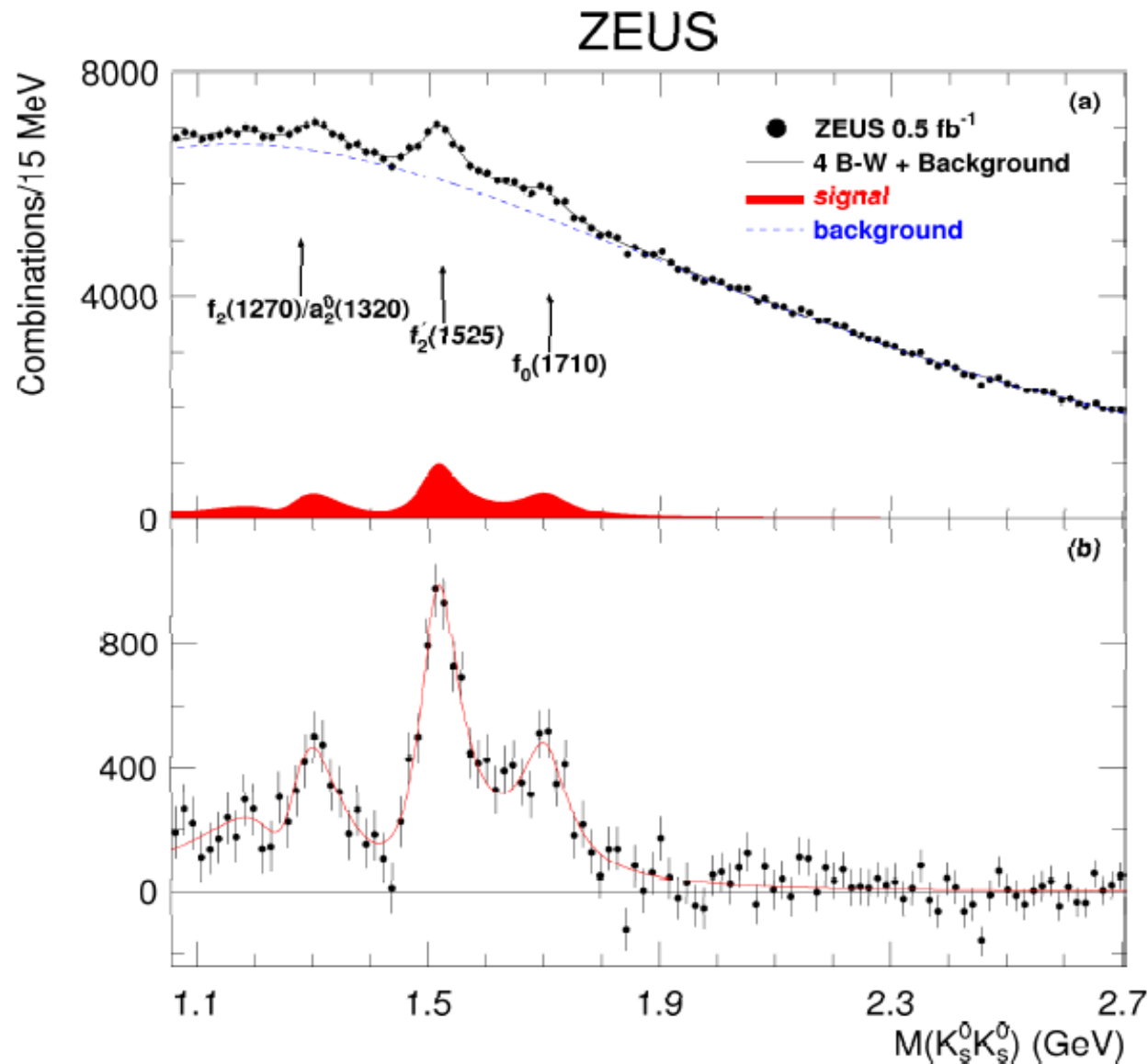
$$F(M) = \frac{m\sqrt{\Gamma}}{m^2 - M^2 - im\Gamma}$$

a_2 coeff +3 for K^+K^- ,
-3 for $K_s^0 K_s^0$

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Assumes 2+ states
couple direct to γ

Coherent BW fit



χ^2 /NDF improves:

Incoherent fit
96/95

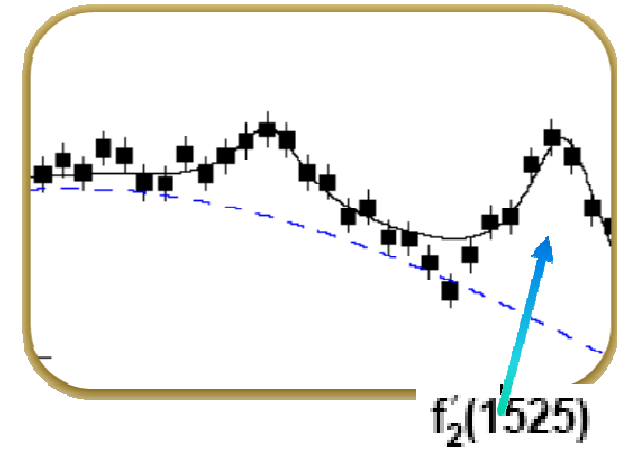
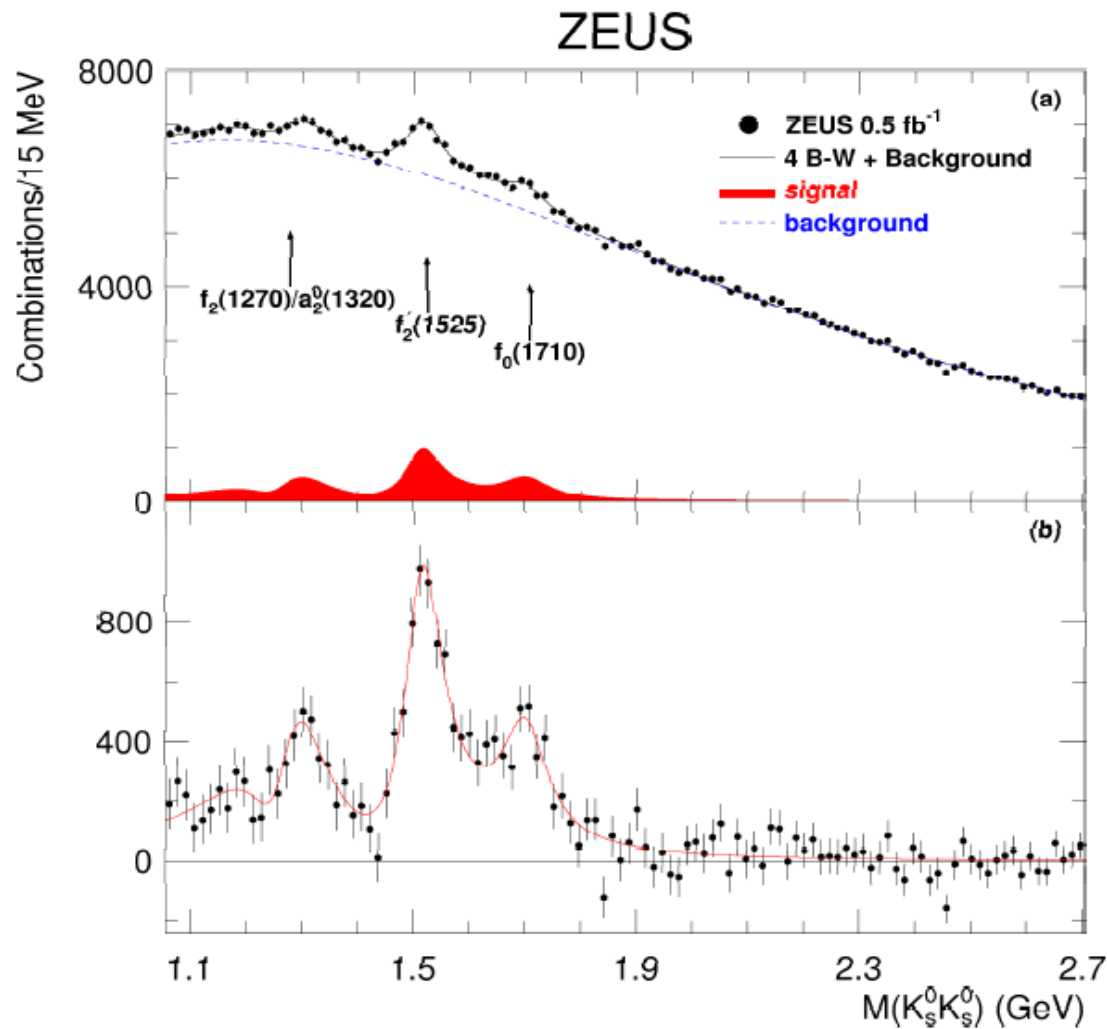
Coherent fit 86/97

3 σ improvement

**In this fit $J^P=2^+$
states couple direct
to exchanged
photon**

**Fit without $f(1710)$
162/97 - strongly
disfavoured**

Compare coherent and incoherent fits



χ^2/NDF improves:
 Incoherent fit
 96/95
 Coherent fit 86/97

3 σ improvement

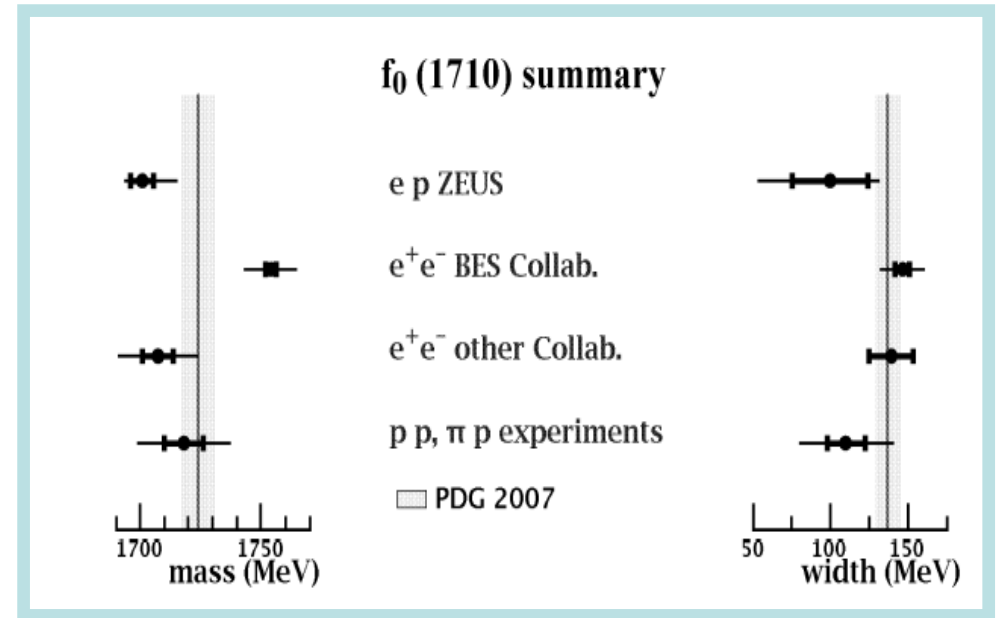
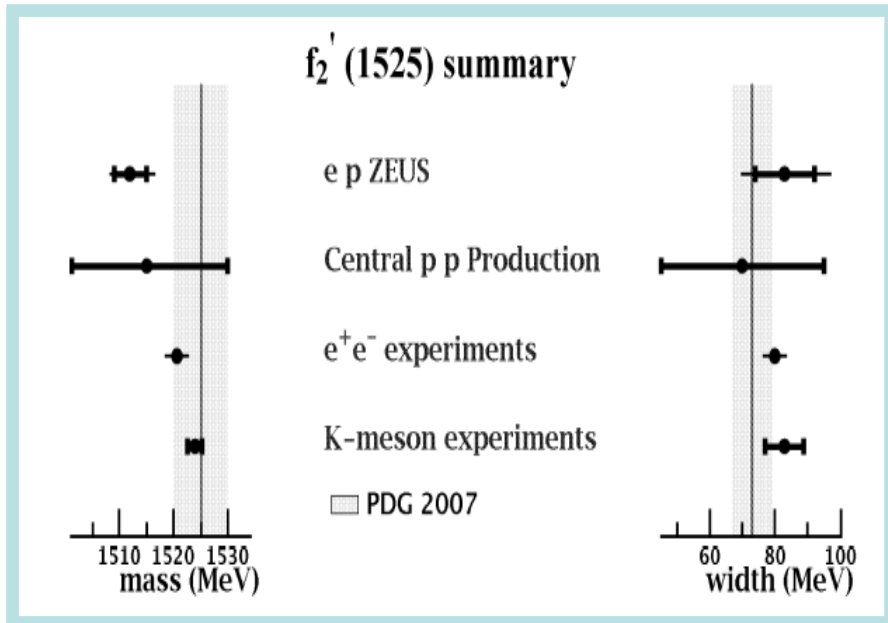
Coherent fit: compare Particle Data Group

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	$73 \pm 6_{-5}$
$f_0(1710)$	$1701 \pm 5^{+9}_{-2}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

Mostly good agreement. Widths OK but a_2 mass still low

$f_2'(1525)$ and $f_0(1710)$ comparisons

State	$M(\text{fit})$	$\Gamma(\text{fit})$	$M(\text{PDG})$	$\Gamma(\text{PDG})$
$f_2'(1525)$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	$73 \pm 6_{-5}$
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$f_0(1710)$	1701 \pm 5 ⁺⁹ ₋₂	100 \pm 24 ⁺⁷ ₋₂₂	1724 \pm 7	137 \pm 8

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Conclusions:

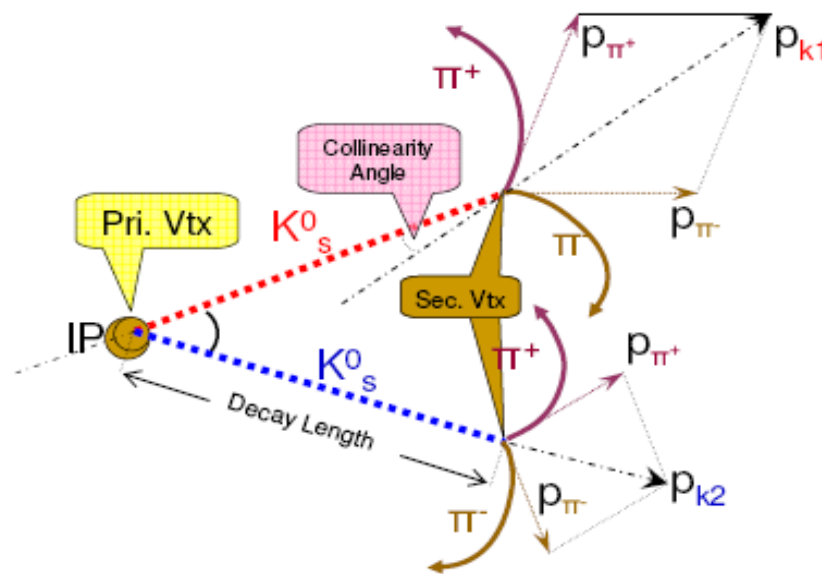
High statistics $K_s^0 K_s^0$ study of $J^{PC}=\text{even}^{++}$ states

Coherent production of three $J^{PC}=2^{++}$ states. Negative f_2/a_2 interference suggests coupling to exchanged photon

$f_0(1710)$ clearly observed. Not a glueball if the same state as $f_J(1710)$ seen in $\gamma\gamma$

Backup slides

$K_S^0 K_S^0$ states observation principles



Two V0 candidates

Particle	Main Decay	Mass (GeV)	Decay Length (cm)	Lifetime (10^{-8} sec)
K_S^0	$\pi^+ \pi^-$	0.497	2.68	0.89
Λ	$p^+ \pi^-$	1.112	7.89	2.63