Inclusive $K^0_s K^0_s$ 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 ($Q^2 < 1$ GeV^2), rest DIS
672418 $K^0_s K^0_s$ pairs

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

$\phi(1020)$ meson ($J^{PC} = 1^{--}$) decays 83% via $\phi \to K\overline{K}$

49% $\phi \to K^+K^-$, 34% $\phi \to K^0\overline{K}^0$ (strangeness eigenstates)

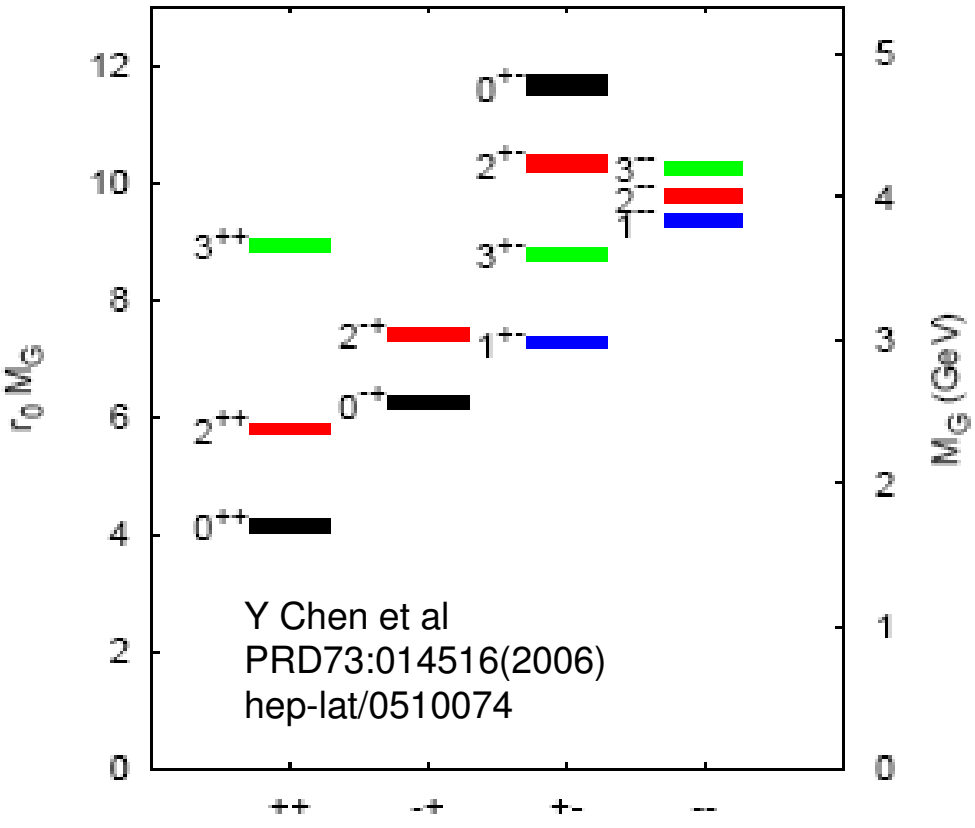
After 10^{-10}s one K^0 decays as K^0_s (CP eigenstate)

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:

$J^{PC} = 0^{++}$ 1710±50±80 MeV

$J^{PC} = 2^{++}$ 2390±30±120 MeV

Four states found with $J^{PC} = 0^{++}$
$f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$
?? 3 qqbar + glueball or mixed

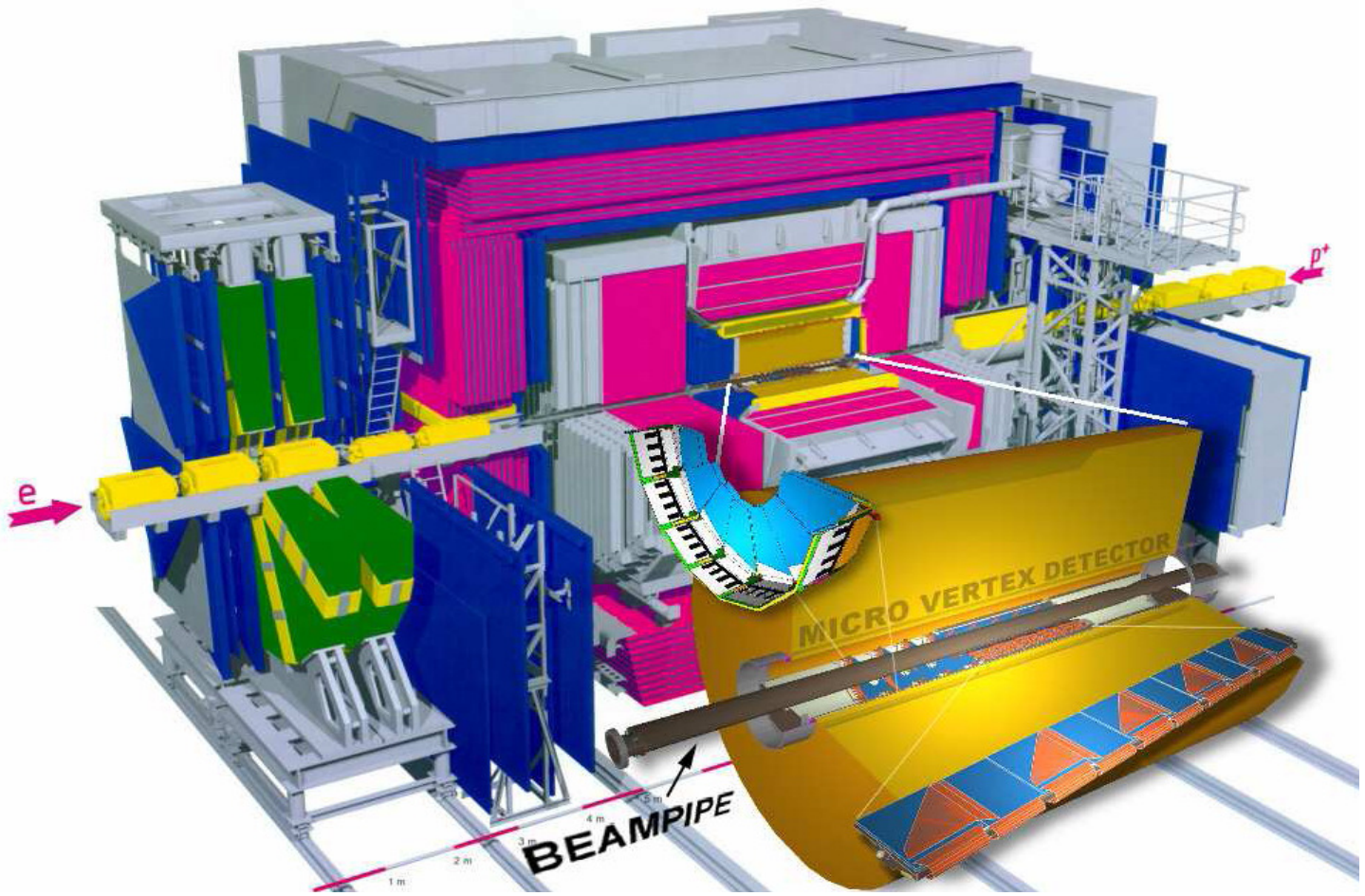
Produced as leading hadrons in resolved photoproduction or in fragmentation

qqbar: Produced as leading hadrons in direct photoproduction or in fragmentation

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

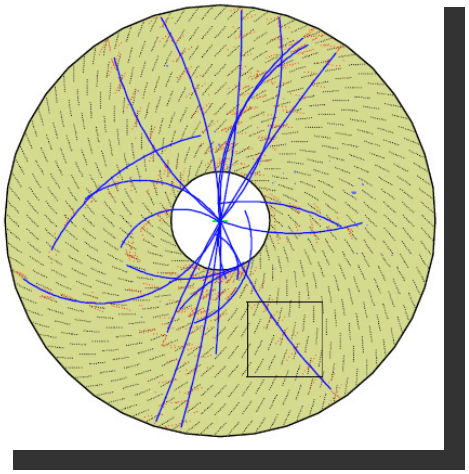
ZEUS at HERA

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

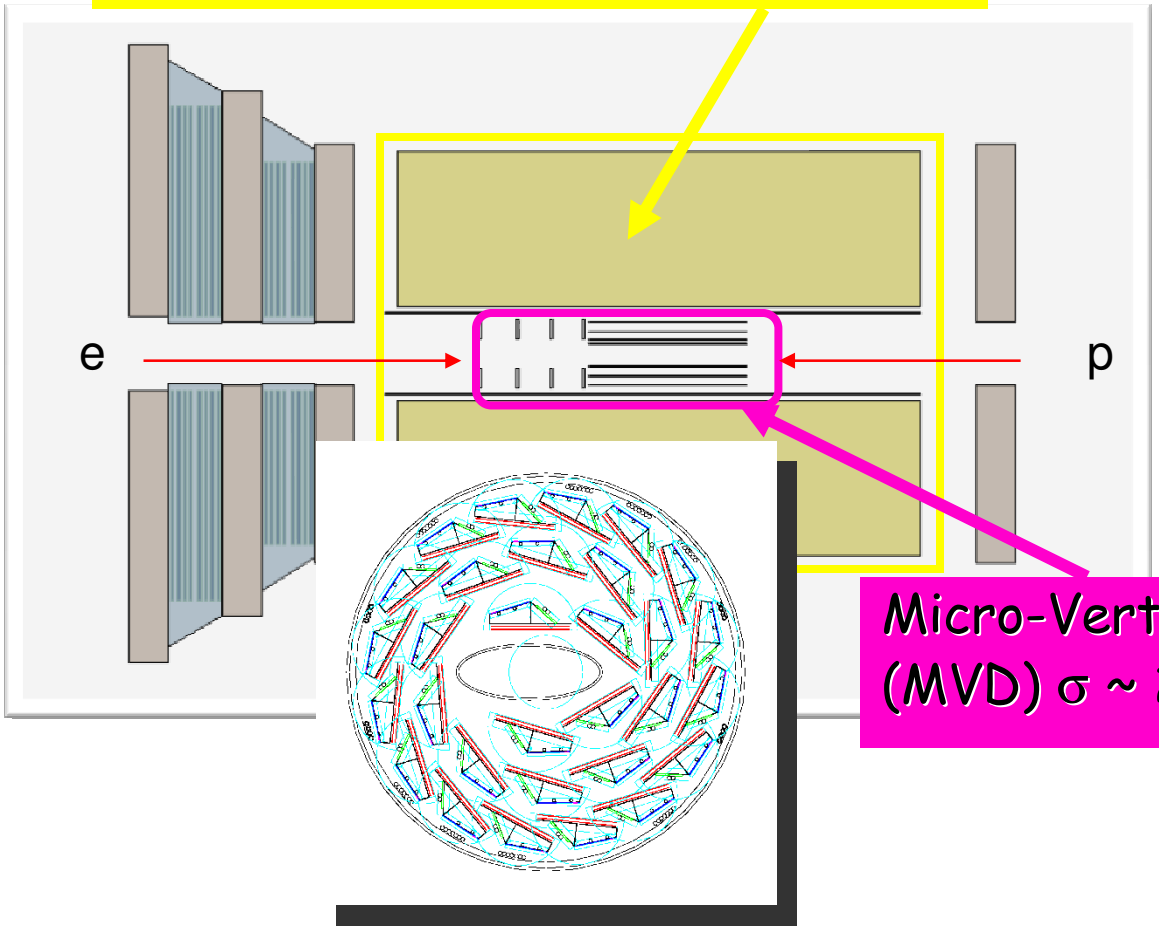


Tracking Detectors

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



B = 1.4 T



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

$K^0_s \rightarrow \pi^+\pi^-$ selection

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

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

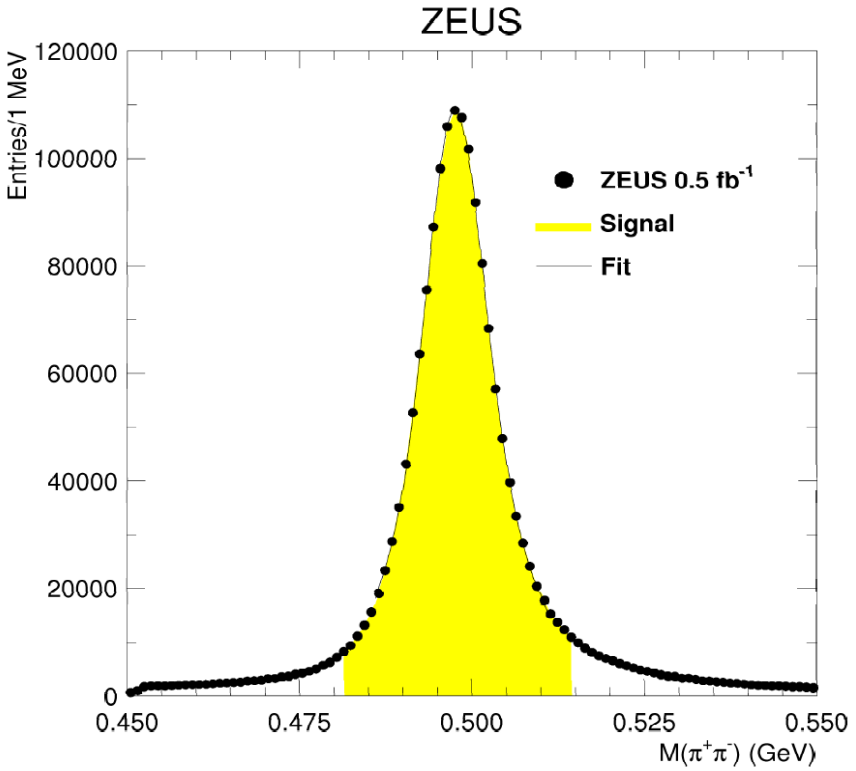
Decay colinearity < 0.12 (2d), 0.24 (3d)

Decay length < 30 cm (peak length 2 cm)

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

672418 $K^0_sK^0_s$ pairs

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



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

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

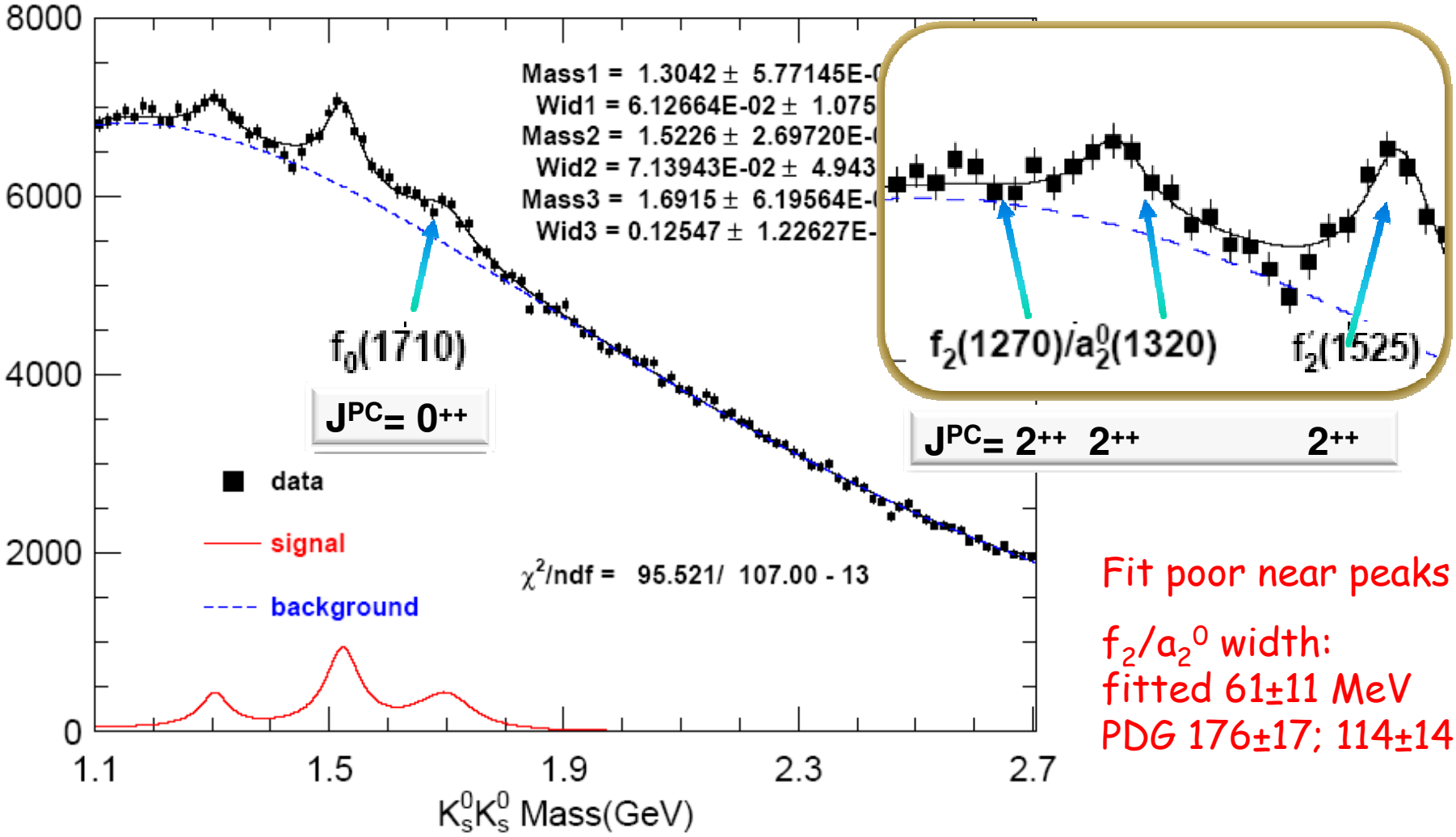
$$F(M) = \sum_{i=1}^{3} C_i \left(\frac{m_{*,i}\Gamma_{d,i}}{(m_{*,i}^2 - M^2)^2 + m_{*,i}^2\Gamma_{d,i}^2} \right)$$

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

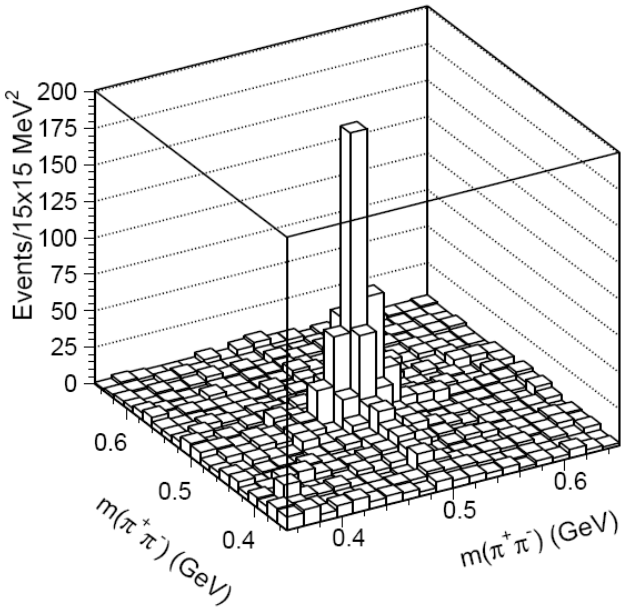


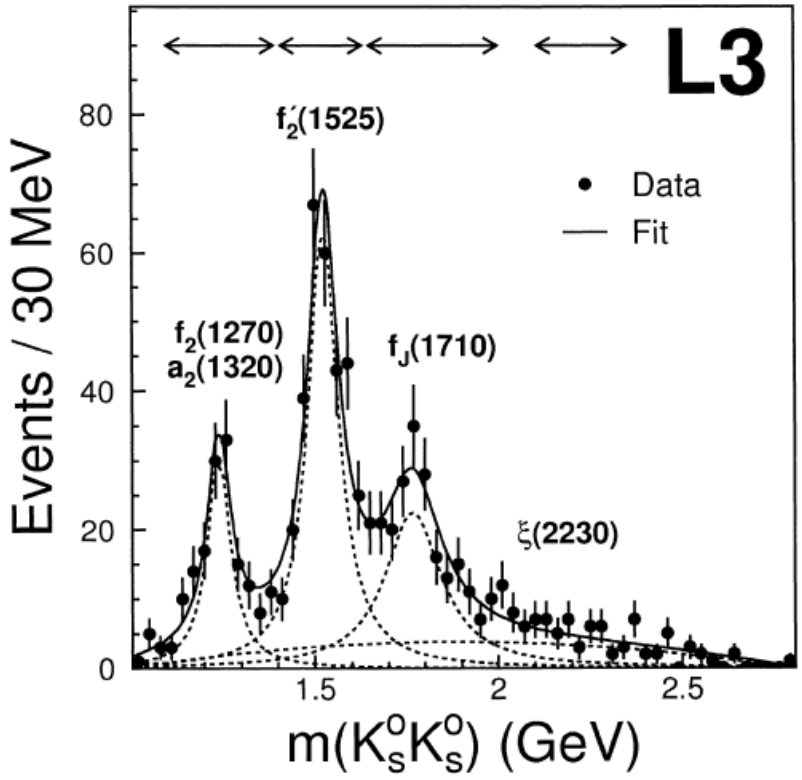
Fit poor near peaks

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 $\gamma\gamma \rightarrow K^0_s K^0_s$

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



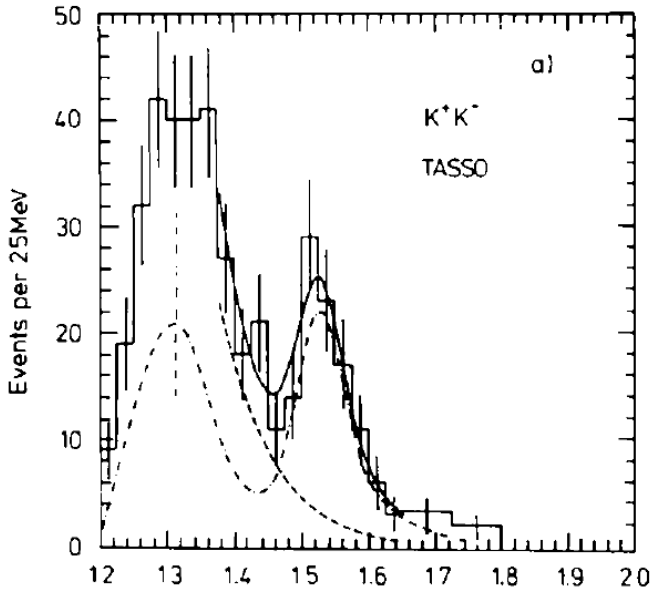


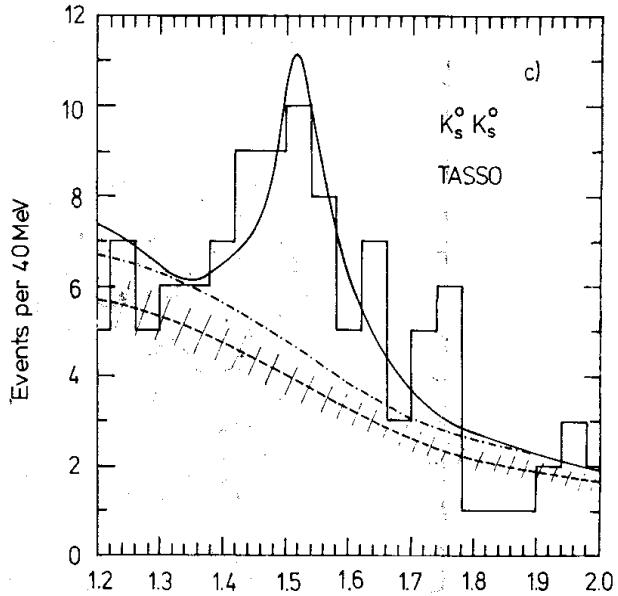
~4σ for $f_J(1710)$

	$f_2(1270)$-$a_2(1320)$	$f_2'(1525)$	$f_J(1750)$
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 $\gamma\gamma \to K^+K^-$ $\gamma\gamma \to K^0_S K^0_S$,

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





Strong enhancement ~1300 in K^+K^-, not in $K^0_S K^0_S$. 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 $M(K^0_s K^0_s)$ 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

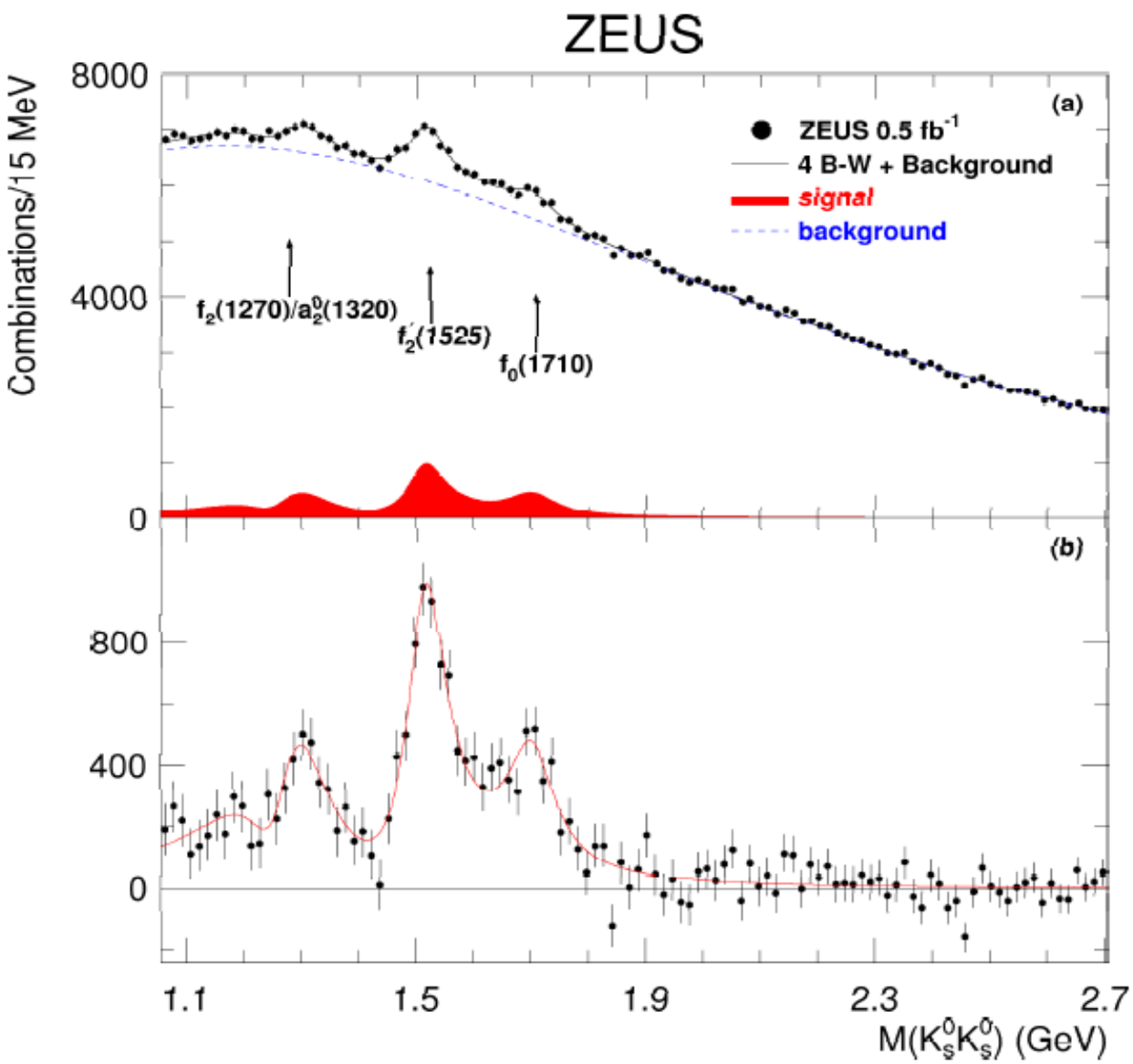
$$rate(M) = a * | 5*BW(f_2^{1270}) \pm 3*BW(a_2) + 2*BW(f_2^{1525})|^2 + b * |BW(f_0^{1710})|^2 + c * U(M)$$

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 $K^0_s K^0_s$

Assumes 2^+ states couple direct to γ



Coherent BW fit

χ^2/NDF improves:

Incoherent fit 96/95

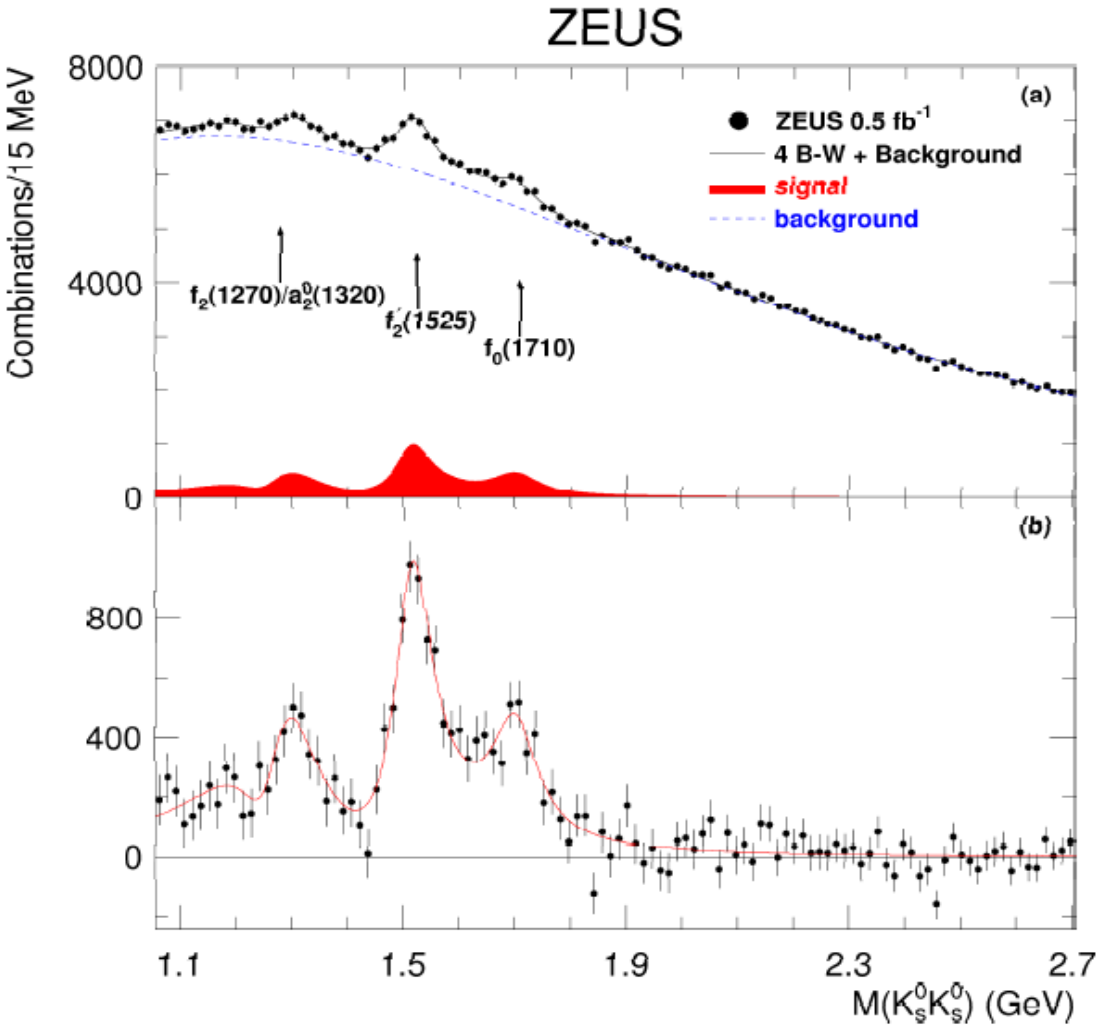
Coherent fit 86/97

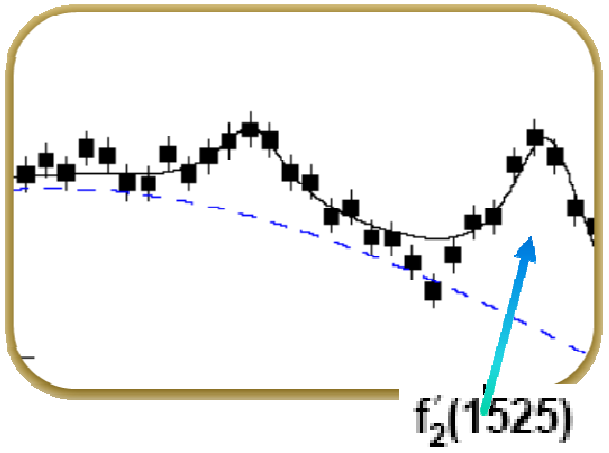
3σ improvement

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
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3σ 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
$f_2'(1525)$	$1512\pm3^{+1.4}_{-0.5}$	$83\pm9^{+5}_{-4}$	1525±5	73^{+6}_{-5}
$f_0(1710)$	$1701\pm5^{+9}_{-2}$	$100\pm24^{+7}_{-22}$	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(fit)	Γ(fit)	M(PDG)	Γ(PDG)
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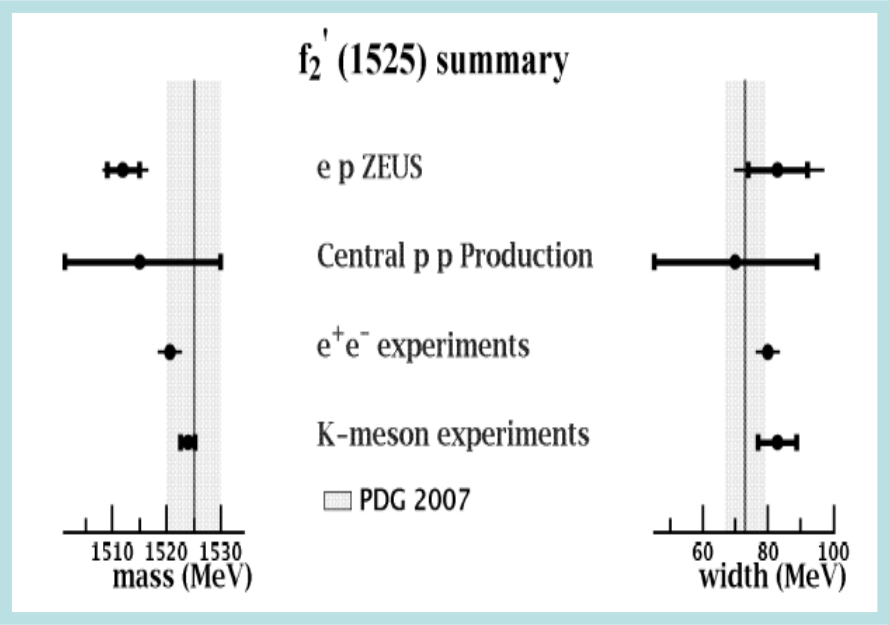

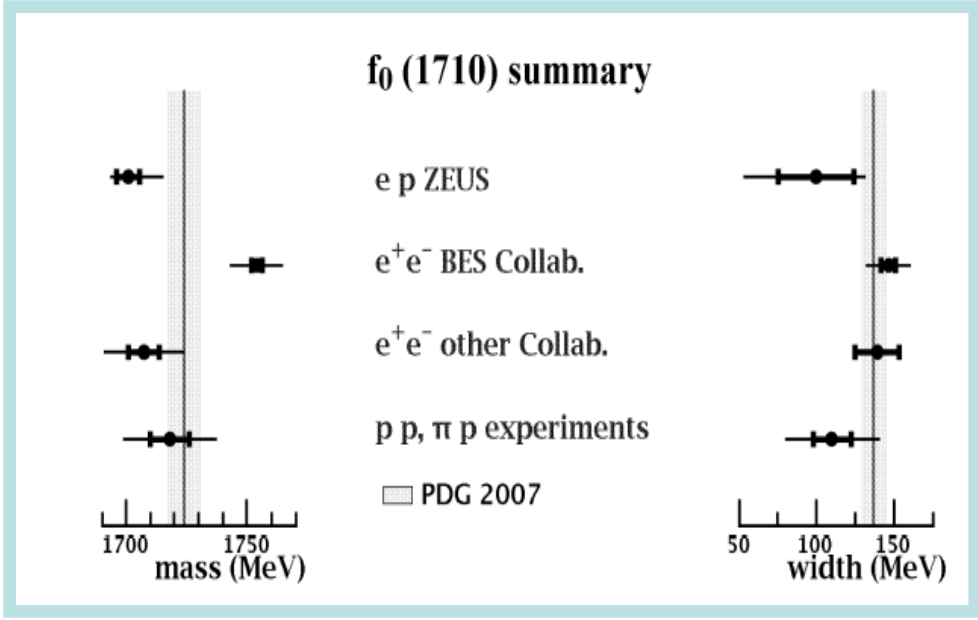

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Conclusions:

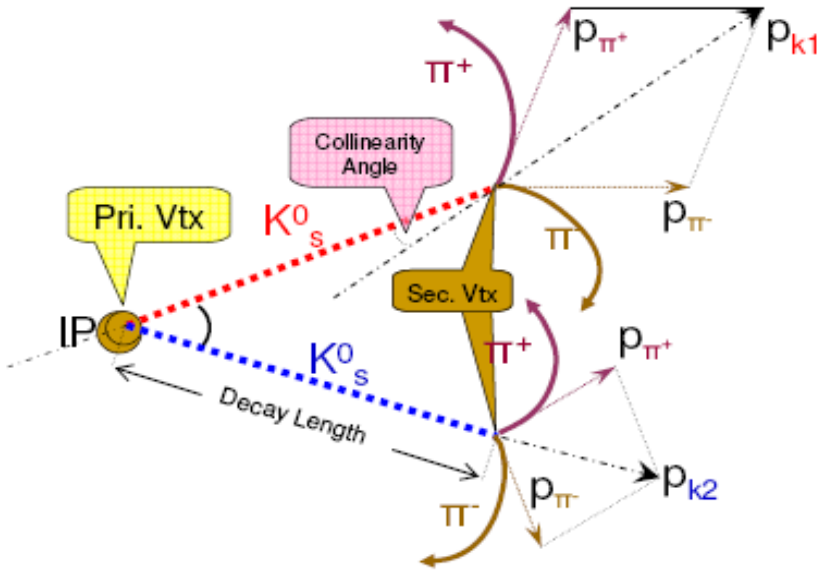
High statistics $K^0_sK^0_s$ study of $J^{PC}=even^{++}$ states

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

$K^0_s K^0_s$ states observation principles



Two V0 candidates

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