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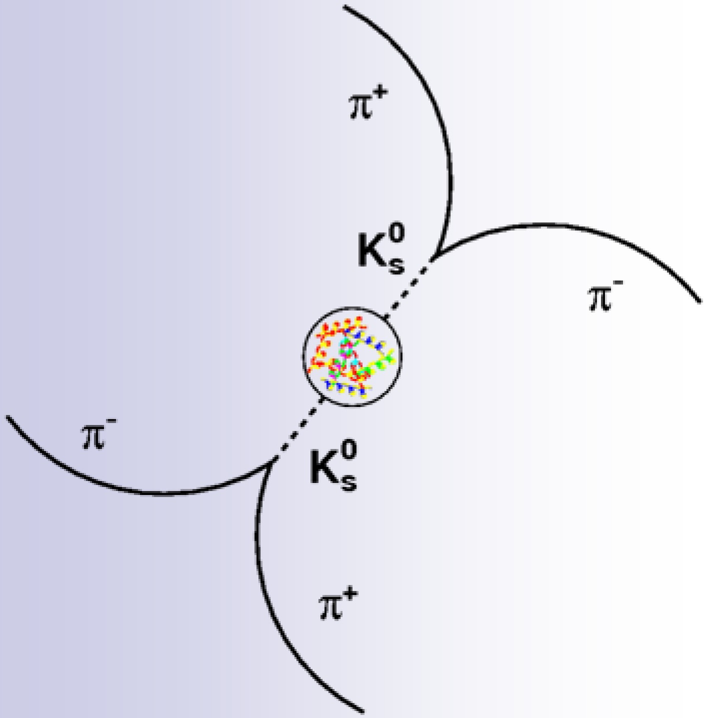
Burkard Reisert (MPP)
for ZEUS

$K_s^0 K_s^0$ Resonance Production at ZEUS



Introduction

Previous Results

Experimental Details

$K_s^0 K_s^0$ spectra

Summary & Conclusion

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 glueballs (gg), hybrids ($q\bar{q}g$) and mixed states
- The 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 $q\bar{q}$ nonent
- Lattice calculations predict that the 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
- $f_0(1710)$ is considered to be a possible glueball candidate
- The $K_S^0 K_S^0$ system can couple to $J^P = 0^+$ and 2^+

➔ $K_S^0 K_S^0$ is a good place to search for the lightest 0^+ glueball

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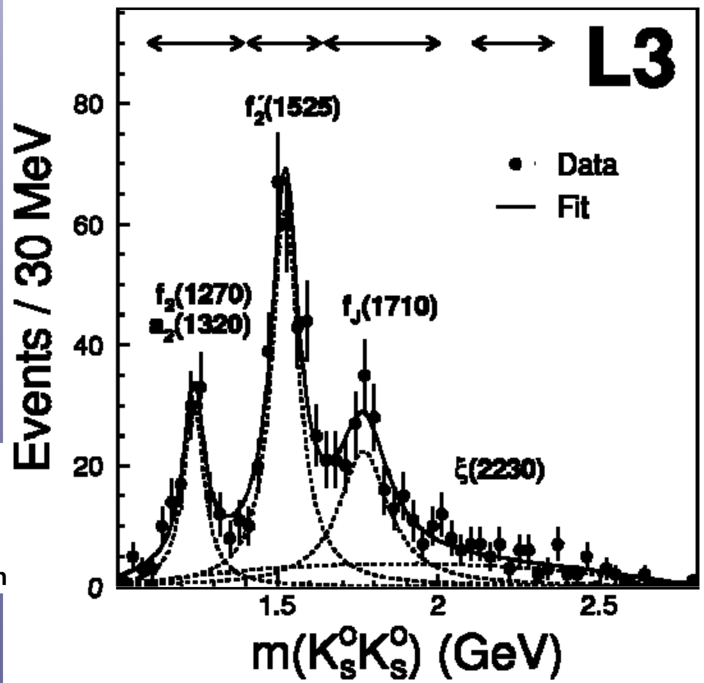
L3 $K^0_S K^0_S$ Result

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

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 ~4 s.d. is seen

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

$f_2'(1525)$ parameters consistent with PDG

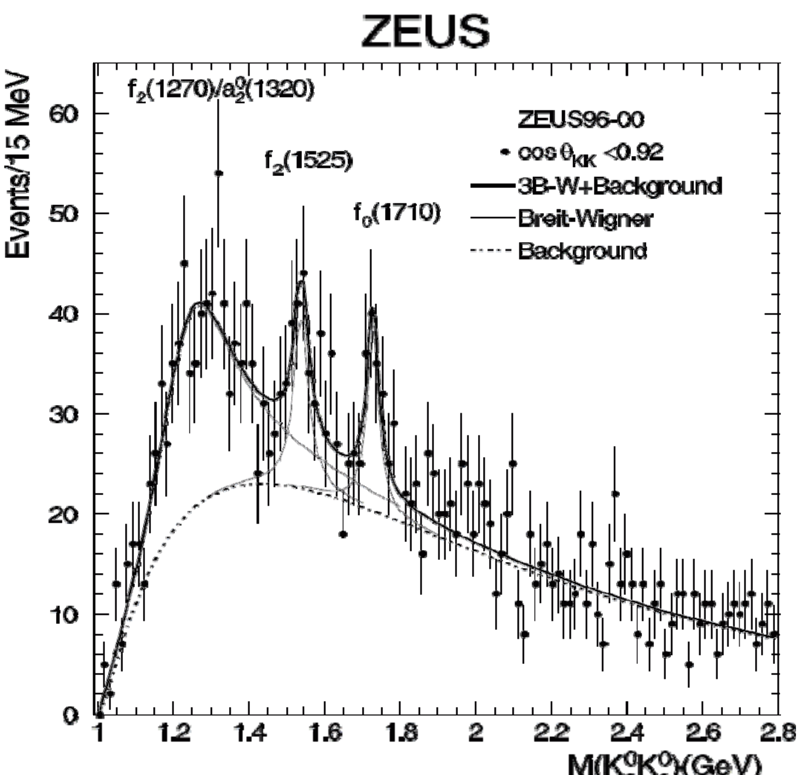
	$f_2(1270)/a_2(1320)$	$f_2'(1525)$	$f_0(1710)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Events	123 ± 22	331 ± 37	221 ± 55

Previous ZEUS $K^0_S K^0_S$ Result

ZEUS observed indications of $f_2'(1525)$ and $f_0(1710)$ decaying into $K_S^0 K_S^0$

In inclusive deep inelastic scattering (DIS) HERA 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 ≤ 3 s.d.

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

The present analysis was performed on the full HERA I & HERA II sample (~ 0.5 fb^{-1})

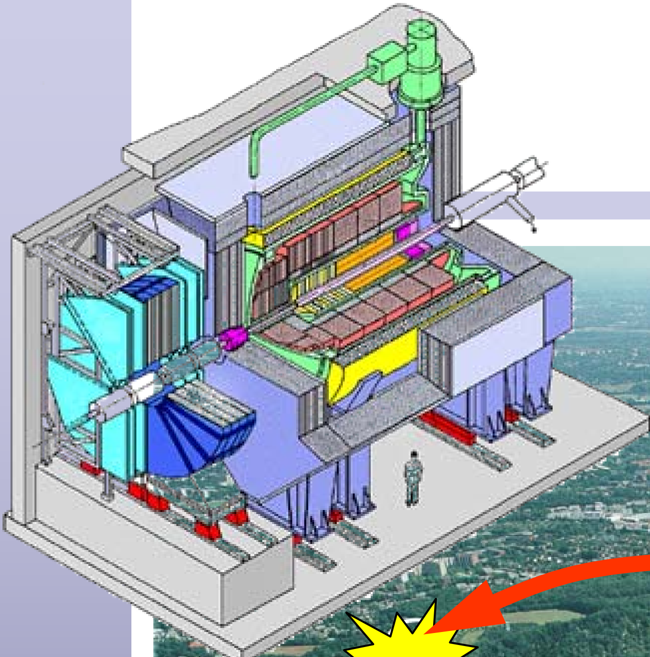
$$e^{\pm} p \rightarrow K_S^0 K_S^0 + X$$

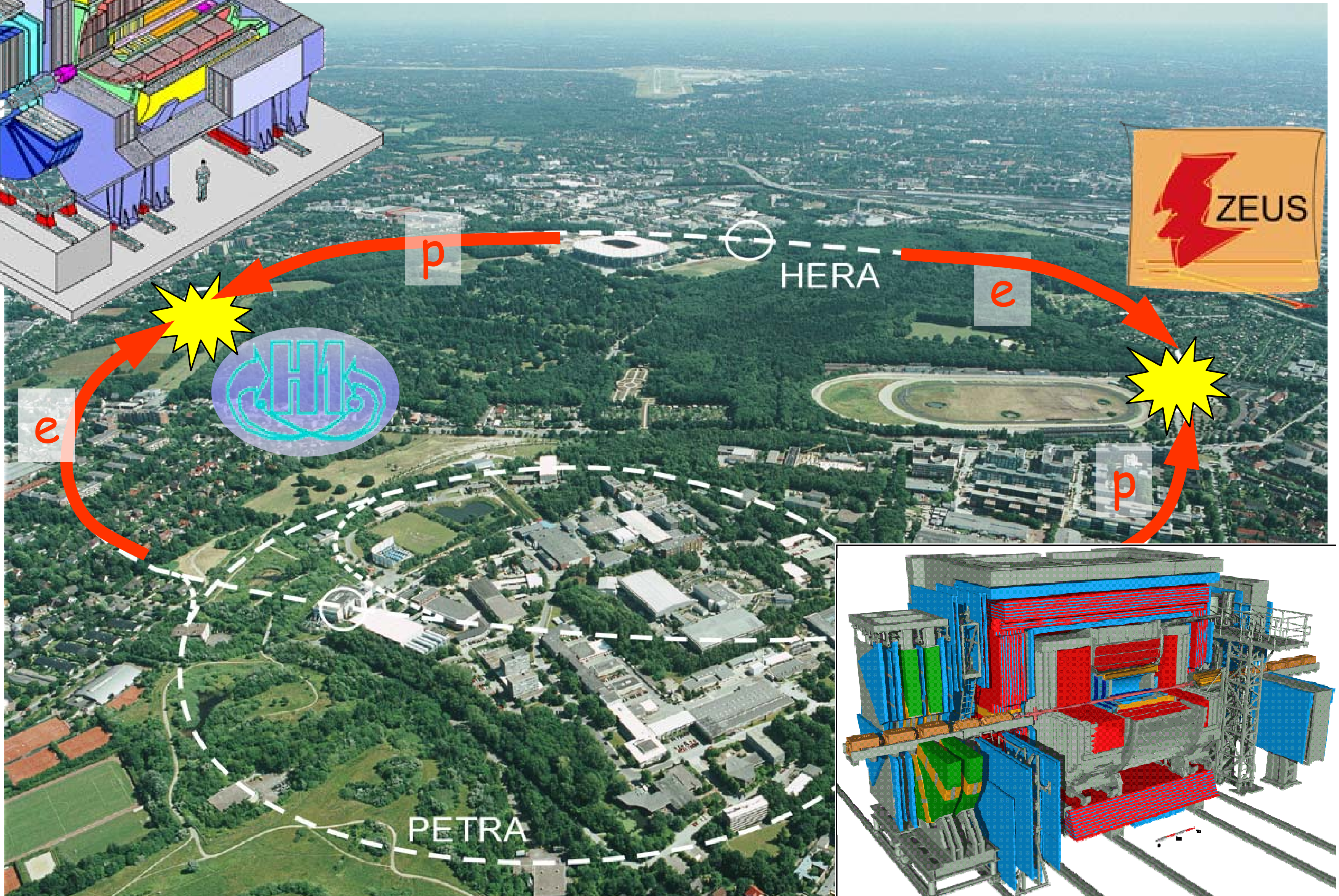
The kinematic region included both photoproduction (PHP) ($Q^2 < 1$ GeV^2)

and DIS ($Q^2 > 1$ GeV^2)

Sample dominated by PHP events

HERA Accelerator





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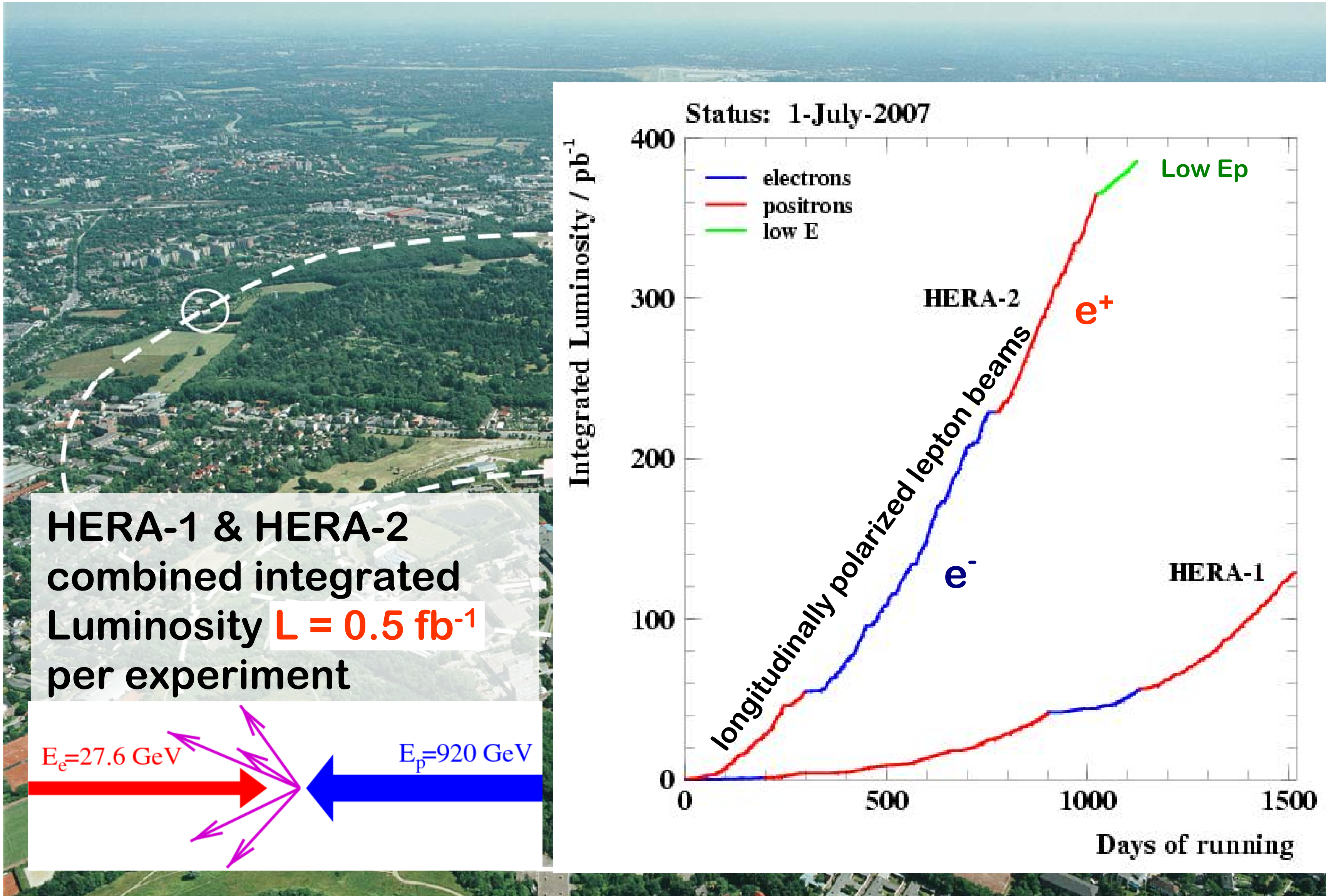
HERA Accelerator Performance



HERA-1 & HERA-2 combined integrated Luminosity L = 0.5 fb^{-1} per experiment

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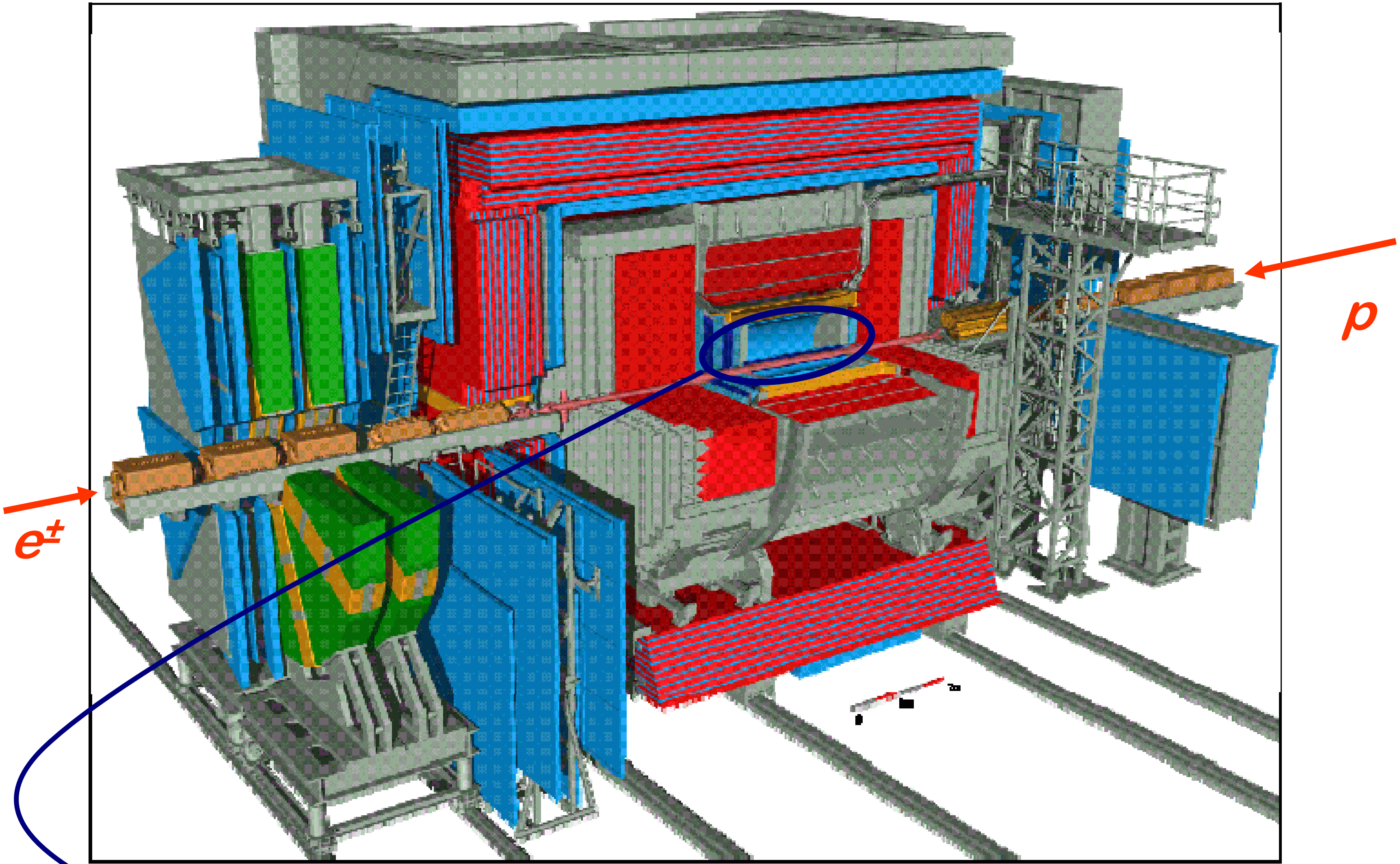
ZEUS Detector



Tracker: R=80cm, B = 1.43 T, 72 wire layers,

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Experimental Details

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

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

Events with ≥ 2 V_0 candidates were selected

No explicit trigger requirement applied for selecting $K_S^0 K_S^0$ events

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

DIS sample triggered by requiring $e^{\pm}$ in the calorimeter

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

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

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

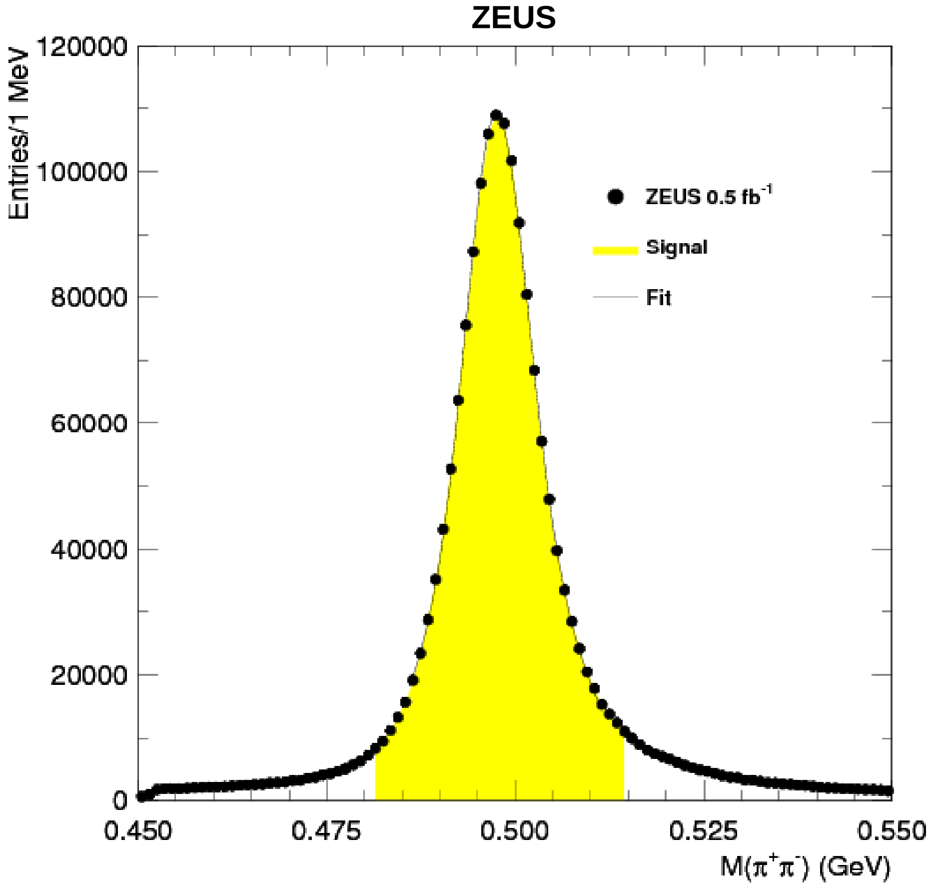
K^0_S Mass Distribution

M($\pi^+\pi^-$) distribution for events with ≥ 2 K_S^0 candidates

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

No. of K_S^0 candidates in signal window ~ 1,258,400

Clean K_S^0 signal; background ~8% (estimate from 1st pol. Fit)



K_S^0 mass and width determined by fitting central region with double Gaussian

M($K_S^0K_S^0$) = 497.49 MeV consistent with PDG

σ = 4.1 MeV consistent with detector resolution

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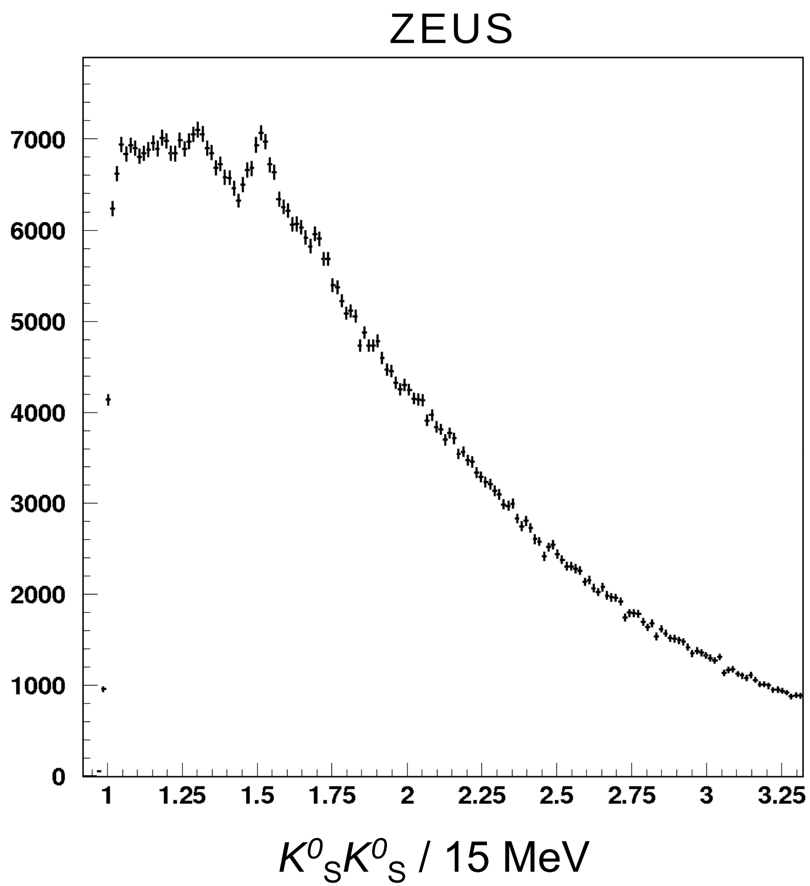
Fitting Procedure

Two K_S^0 candidates are combined to reconstruct the $K_S^0\, K_S^0$ invariant mass distribution



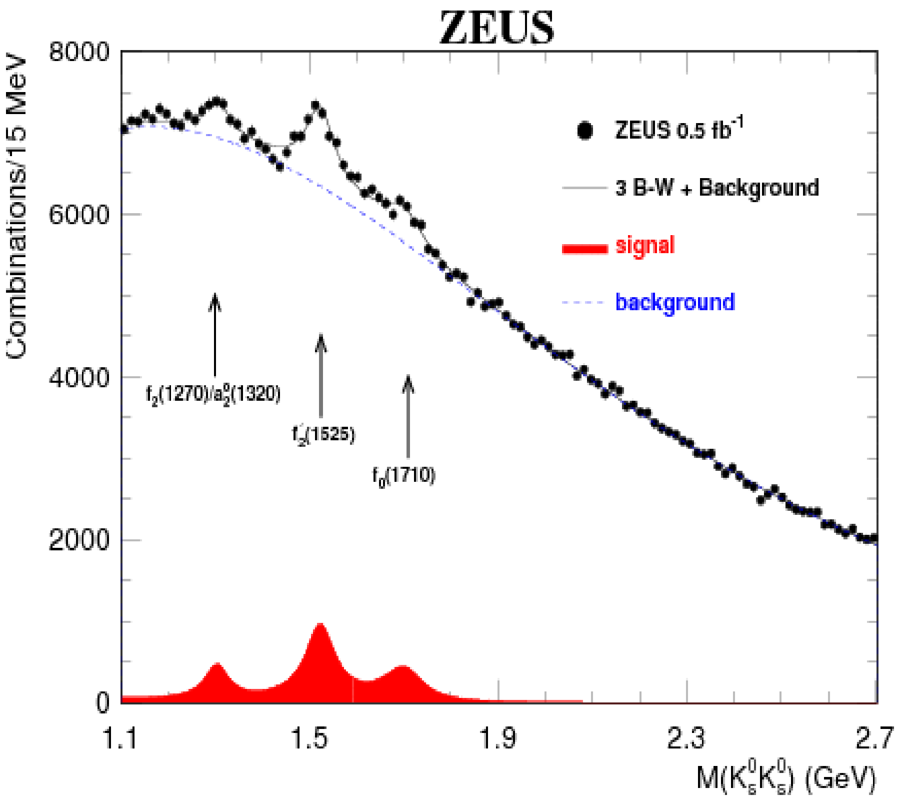
3 enhancements seen around
1.3, 1.5, 1.7 GeV
No state seen heavier then 1.7 GeV

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

$$A(m - 2M_{K_S^0})^B \exp\left(-C\left(m - 2M_{K_S^0}\right)\right)$$

A,B,C are free parameters
m(K_S^0) is the PDG K_S^0 mass
Mass resolution below 1.8 GeV ~12 MeV << resonance widths
➔ not included in fit

$K^0_S K^0_S$ Mass Spectrum & Incoherent Fit



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

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

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 = $K_S{}^0 K_S{}^0$ invariant mass

Goodness of fit is OK χ^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 ➔ $f_0(1710)$ is required

TASSO $K^0_S K^0_S$ Result

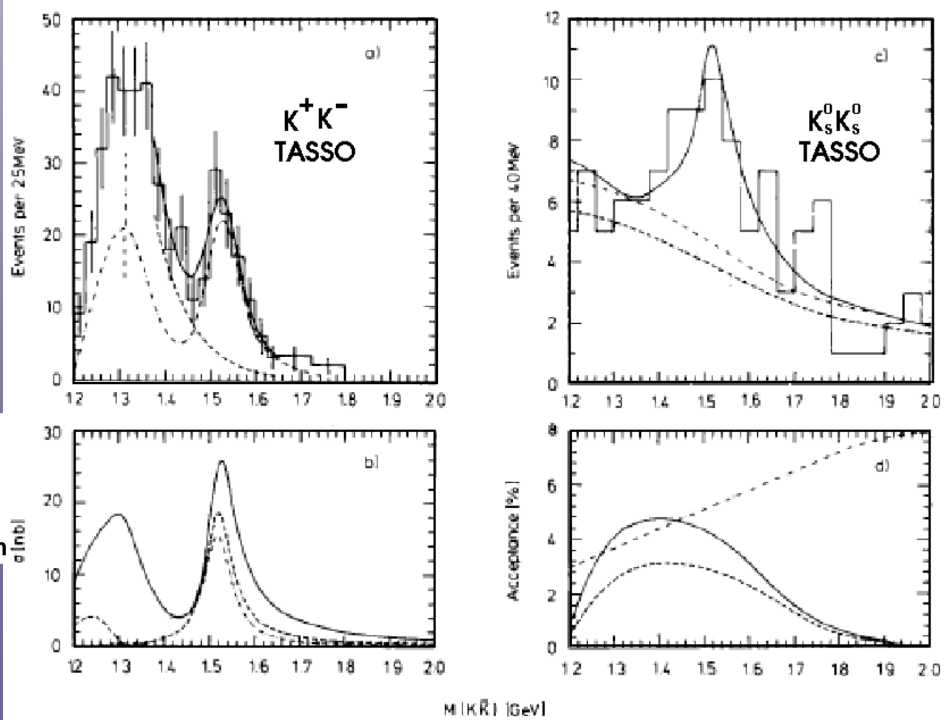
The old TASSO experiment at the PETRA e^+e^- collider studied in two-photon collisions the exclusive reactions $\gamma\gamma \rightarrow K^+K^-$, $K_S^0K_S^0$

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($K_S^0K_S^0$)

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 $K_S^0K_S^0$

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

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M($K^0_S K^0_S$) Fit 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	$C_1 = 5$	$C_2 = -3$	$C_3 = 2$

➔The appropriate function to fit the M($K_S{}^0 K_S{}^0$) spectra for an electromagnetic production process assuming SU(3) symmetry is H.J. Lipkin, private communication

$$F(m) = a\left[5\cdot \mathrm{BW}\left(f_2(1270)\right) - 3\cdot \mathrm{BW}\left(a_2(1320)\right) + 2\cdot \mathrm{BW}\left(f_2(1525)\right)\right]^2$$

$$+ b\left[\mathrm{BW}\left(f_0(1710)\right)\right]^2 + c\cdot \mathrm{background}$$

a, b, c are free parameters

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

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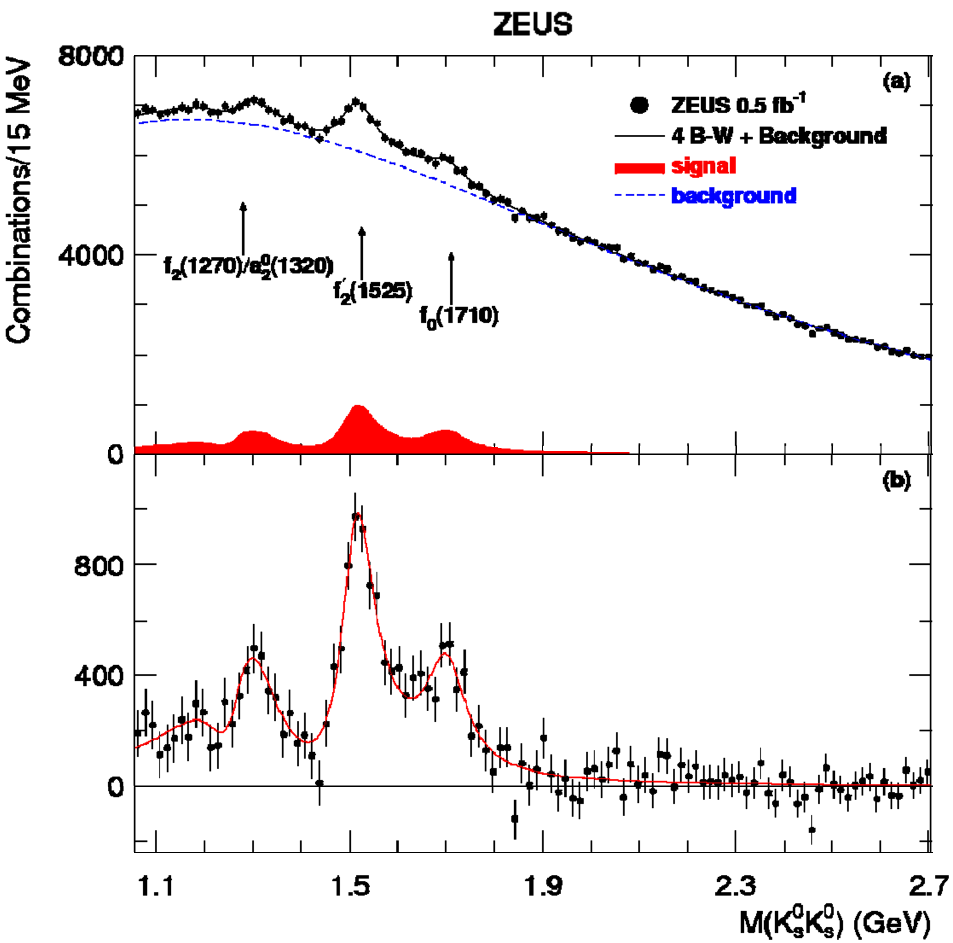
$K^0_S K^0_S$ Spectrum & Interference Fit



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

Bottom plot background subtracted $M(K_S{}^0 K_S{}^0)$ spectrum with fitted BW functions.

Good fit χ^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 ~ 5σ significance
Fit without $f_0(1710)$ strongly disfavoured χ^2/ndf = 162/97

Table of Fit Results

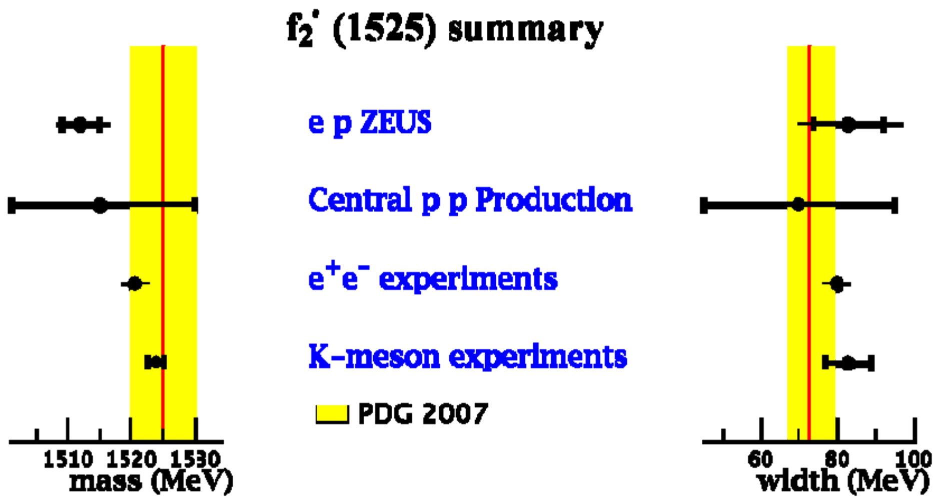
Fit	No interference		Interference		PDG 2007 Values	
χ^2/ndf	96/95		86/97			
in MeV	Mass	Width	Mass	Width	Mass	Width
$f_2(1270)$	1304 ± 6	61 ± 11	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$			1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+5}_{-3}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

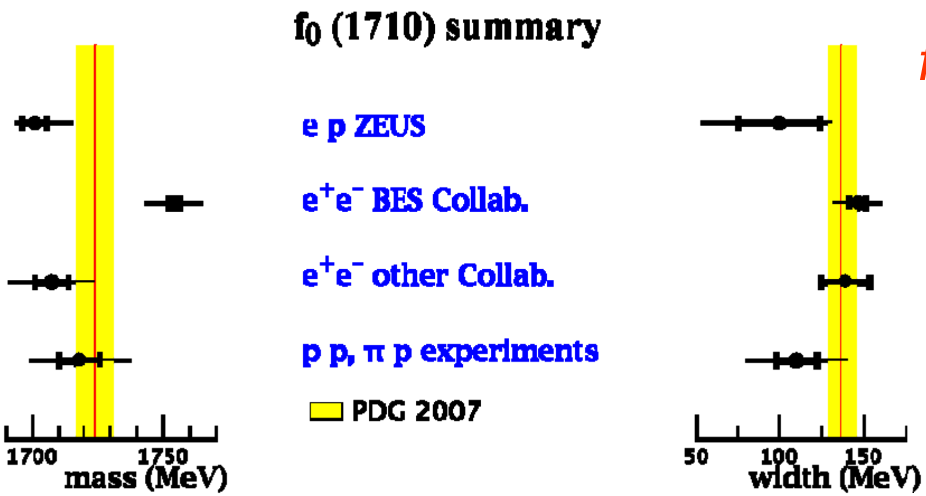
Incoherent fit yields narrow width for $f_2(1270)/a_2(1320)$: 61 ± 11 MeV
Similar to the L3 incoherent fit: $\Gamma(f_2(1270)/a_2(1320))$ = 78 ± 19 MeV

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)

Mass & Width of $f'_2(1525)$ and $f_0(1710)$





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

J/ψ or $\psi(2S) \rightarrow (\gamma$ or $\omega) + f_0(1710)$

significantly above other experiments including older J/ψ radiative decays

Conclusions

- $K_S^0 K_S^0$ final states studied in *ep* collisions at HERA with ZEUS
- Observed 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 $\gamma\gamma \rightarrow K_S^0 K_S^0$ (TASSO, L3) it is unlikely to be pure glueball since photons can couple in the partonic level only to charged quarks

Backup Slides

- Systematic uncertainties
- Deep inelastic scattering

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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 ± 0.1%
- Track angles by ± 0.5%
- Accepted $\pi^+\pi^-$ mass range around K_S^0 peak
- Collinearity cuts

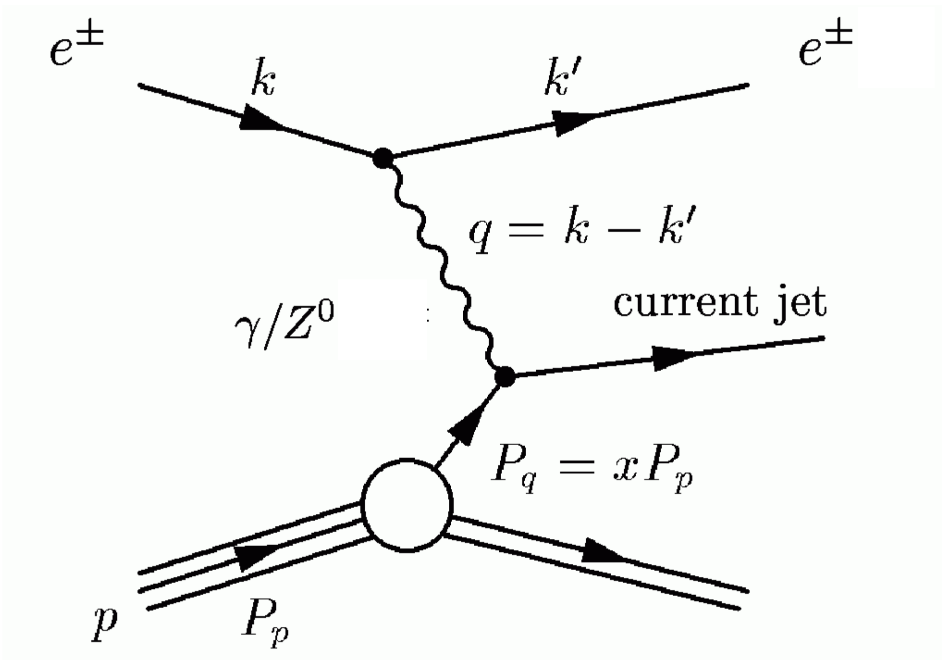
Fitting procedure changed: use maximum likelihood instead of χ^2 fit

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.

Deep Inelastic Scattering



Kinematic Variables

- **4-momentum transfer resolving power** $Q^2 = -q^2 = -(k-k')^2$
- **Bjørken scaling variable momentum fraction of struck parton** $x = \dfrac{Q^2}{2p\cdot q}$
- **Inelasticity:** $y = \dfrac{p\cdot q}{p\cdot k}$

Center of mass energy $\sqrt{s}$**:** $s = (k+p)^2$ **relation for fixed s:** $Q^2 = sxy$

- **Neutral current DIS cross section expressed by structure functions:**

$$\frac{d^2\sigma^{e^\pm p\to e^\pm X}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\underbrace{\left(1+(1-y)^2\right)}_{Y_\pm = 1\pm(1-y)^2}\cdot\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2)\right)$$

valence & sea quarks (F_2) — gluons (F_L) — valence quarks (xF_3)