Resonance searches at HERA

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on behalf of the
H1/ZEUS Collaborations

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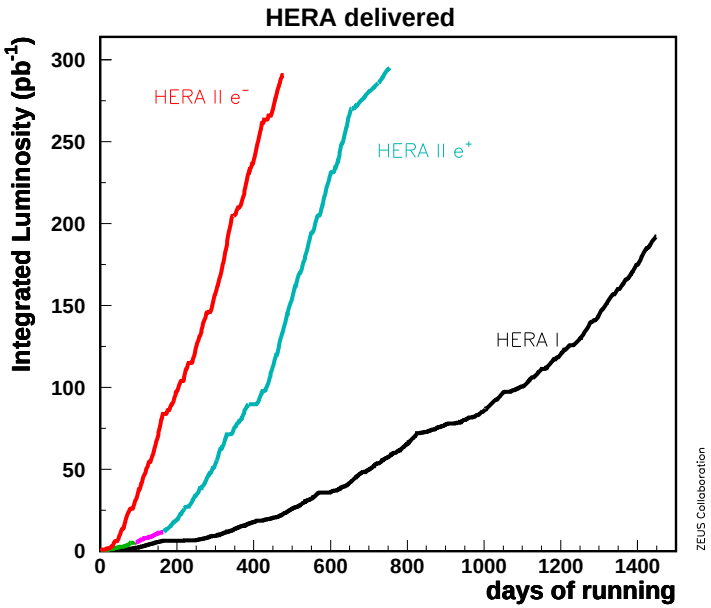
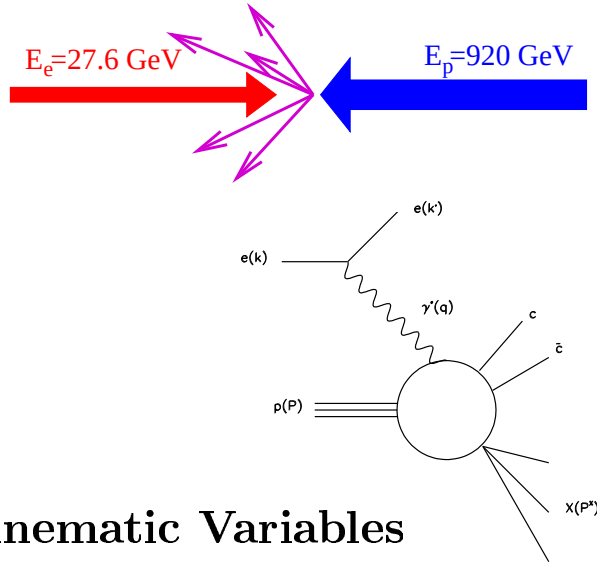
- Glueball search in the $K^0_S K^0_S$ system
- Charm pentaquark search in $D^* p$
- Excited charm and charm-strange mesons
- Summary

Introduction: HERA, luminosity, kinematic variables





	$e \Rightarrow$	$\Leftarrow p$
	$27.6\ GeV$	$820 - 920\ GeV$
	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	$\sim 370\, pb^{-1}$

Kinematic Variables

(Four-momentum transfer)^2 : $Q^2 = -q^2 = -(k - k')^2$

Bjorken-x scaling variable: $x = \frac{Q^2}{2\ P{\cdot}q}$

Fraction of e energy transfer to p in p RF: $y = \frac{P{\cdot}q}{P{\cdot}k}$

(γ p CMS energy)^2 : $W^2_{\gamma p} = (P+q)^2 \cong 4\ E_e\ E_p\ y$

Two kinematic regimes:

Deep Inelastic Scattering (DIS) $Q^2 > 1 GeV^2$

Scattered e visible in main detector

Photoproduction (PHP) $Q^2 < 1 GeV^2$; $< Q^2 > \approx 3 \cdot 10^{-4}$

No scattered e in main detector $\Rightarrow$ quasi-real photon

Motivation for glueball search in the $K^0_S K^0_S$ system

- 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 ($q\bar{q}g$)
- Scalar meson sector ($J^{PC} = 0^{++}$) 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
- Chiral symmetry predicts that the glueball decays predominantly to $s\bar{s}$
- The BES e^+e^- experiment observes a ratio $\pi\pi/K\bar{K} \approx$ **0.41** for $f_0(1710)$

$\Rightarrow$ $f_0(1710)$ **is a possible glueball candidate**

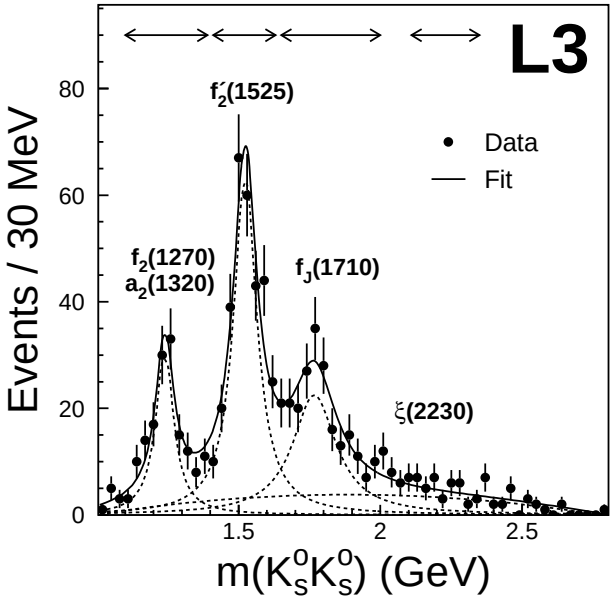
The $K^0_S K^0_S$ **system couples to** $J^{PC} = 0^{++}, 2^{++}, 4^{++}$**,...(Bose symmetry)**

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

$\gamma\gamma \to K^0_S K^0_S$ results

The exclusive reaction $\gamma\gamma \to K^0_S K^0_S$ was studied by L3 at LEP and TASSO at PETRA

L3(Phys.Lett.B501,173,2001) saw 3 peaks attributed to $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and $f_0(1710)$



The tensor meson $f_2'(1525)$ is dominant; $f_0(1710)$ signal $\approx$ 4 s.d.

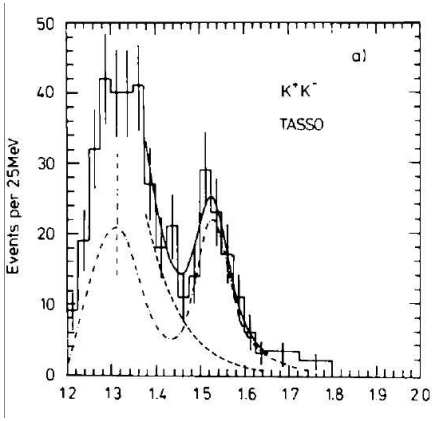
Maximum likelihood fit with 3 BW functions

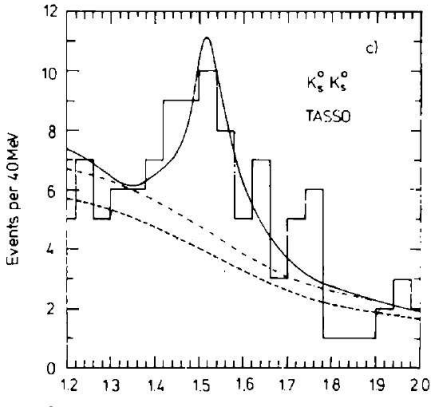
	$f_2(1270)/a_2(1320)$	$f_2'(1525)$	$f_0(1710)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Events	123 ± 22	331 ± 37	221 ± 55

TASSO (Phys.Lett.B121,216,1983): $\gamma\gamma \to K^+K^-, K^0_S K^0_S$

Strong $f_2(1270)/a_2(1320)$ enhancement in $m(K^+K^-)$

No $f_2(1270)/a_2(1320)$ in $m(K^0_S K^0_S)$; $f_2'(1525)$ in both spectra





Results interpreted by interference effects between 3 $J^{PC} = 2^{++}$ states:

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

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

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

ZEUS $K^0_S K^0_S$ analysis

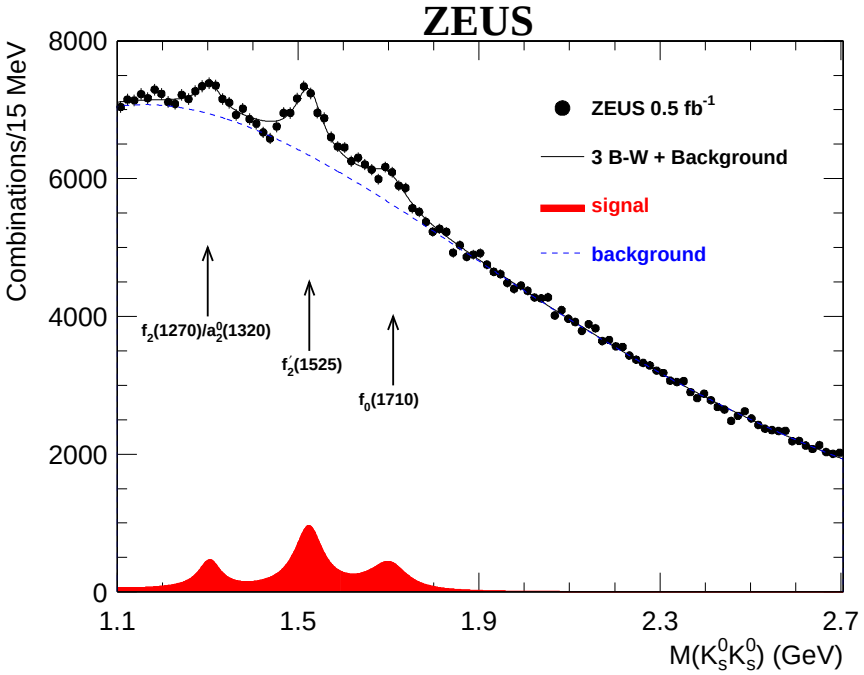
Full PHP+DIS data ($\approx$ 0.5 fb^{-1}) $e^{\pm}p \to K^0_S K^0_S + X$ **PRL 101,112003 (2008)**

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

K^0 signal window for $M(K^0_S K^0_S)$ analysis: $481 - 515$ **MeV**
($\approx 672,000$ $K^0_S K^0_S$ pairs)

Fit $m(K^0_S K^0_S)$ to incoherent sum of 3 resonances $f_2/a_2, f_2', f_0(1710)$:

$F(m) = C_R(\frac{M_R\Gamma_R}{(M_R^2-m^2)^2+M_R^2\Gamma_R^2})$ **and smooth background**



$U(m) = m^A exp(-Bm)$; A, B **free parameters**

$C_R =$ **Amplitude of resonance R**

$M_R =$ **Mass of resonance R**

$\Gamma_R =$ **Variable width of resonance R**

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

$\chi^2/ndf = 96/95$

Bad fit without $f_0(1710)$ $\Rightarrow$ $f_0(1710)$ required

Dip between f_2/a_2 and f_2' not reproduced

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

$\Rightarrow$ **Fit the $m(K^0_S K^0_S)$ spectra as in TASSO**

Assume: **SU(3) symmetry**

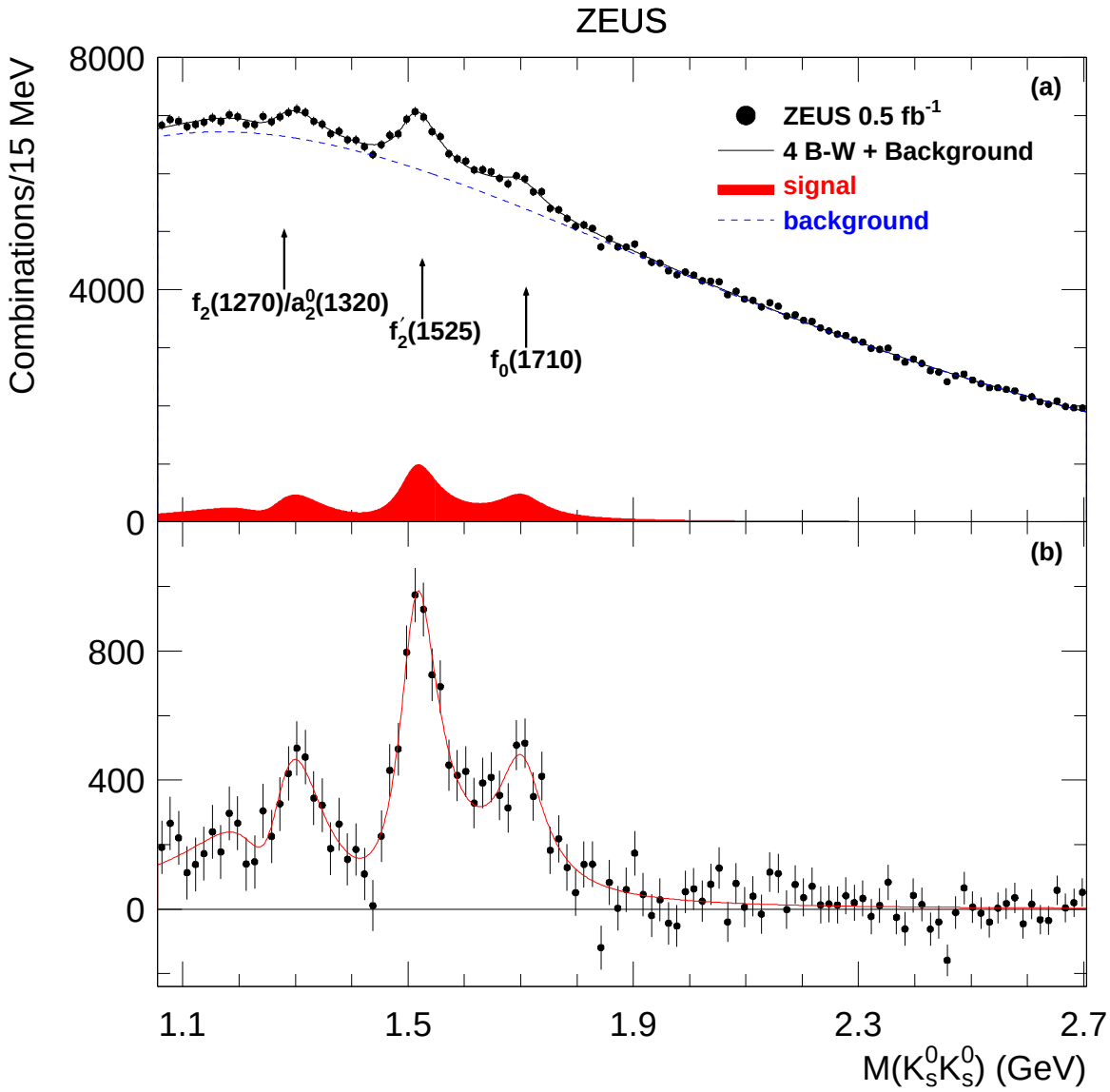
Direct coupling of 2^{++} states to exchanged photon

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

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 $\approx 5\sigma$ 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
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+9}_{-2}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

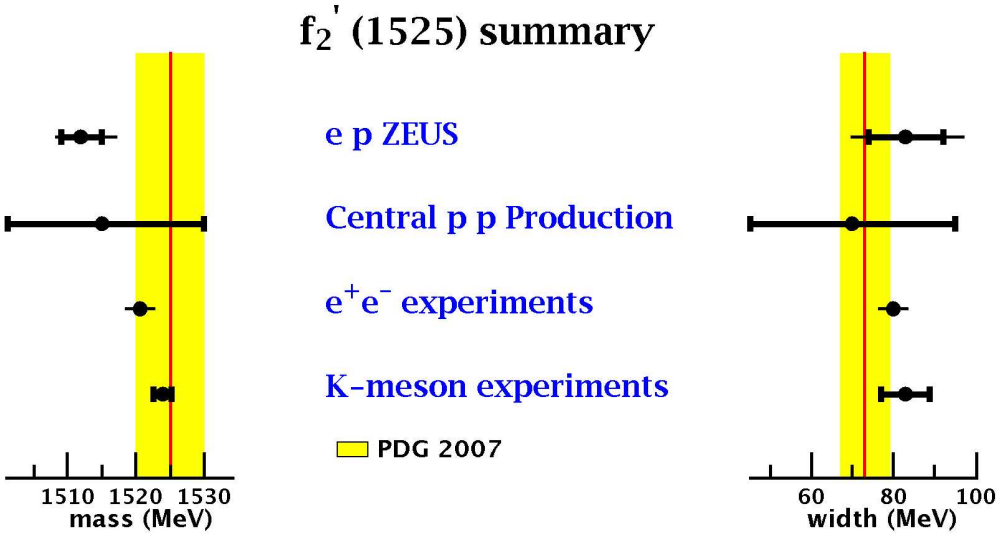
Incoherent fit yields narrow width for $f_2(1270)/a_2(1320)$: 61 ± 11 MeV

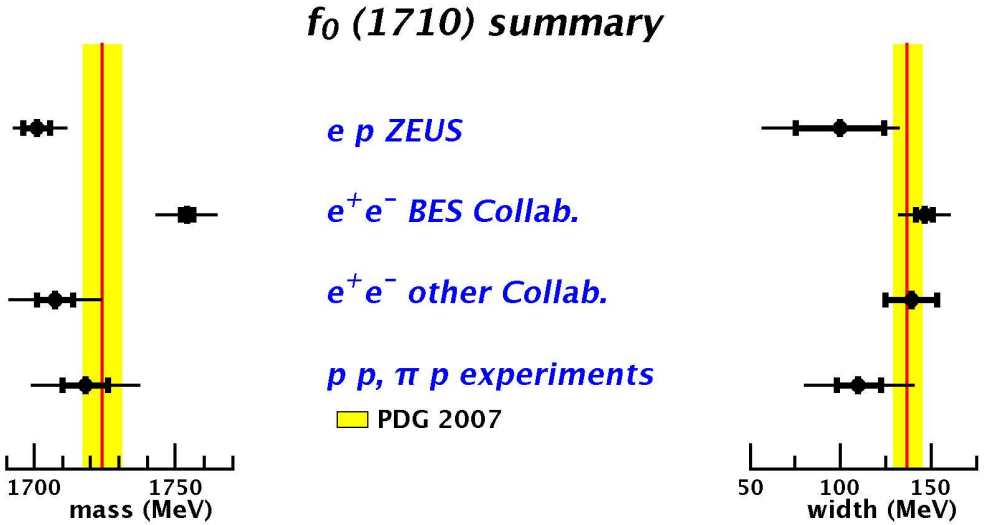
Similar to the L3 incoherent fit: $\Gamma(f_2(1270)/a_2(1320)) = 78 \pm 19$ MeV

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:

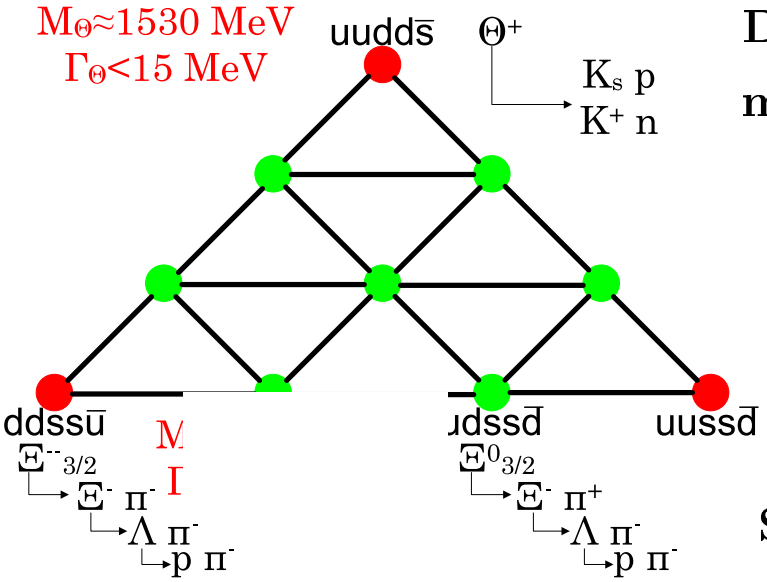
J/ψ **or** $\psi(2S) \to (\gamma$ **or** $\omega) + f_0(1710)$

significantly above other experiments

including older J/ψ **radiative decays**

$\Rightarrow$ **More than one state (?)**

Charm pentaquark search in D^*p



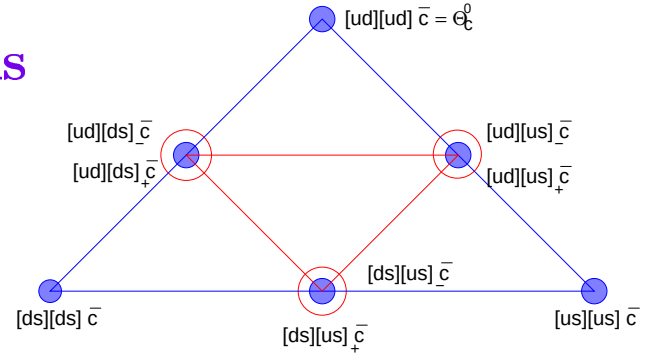
Diakonov et al. predicted in 1997 from Chiral Soliton model exotic $5q$ baryon anti-Decuplet

$\Theta^+(1530)$ cannot be made of qqq as required by the naive quark model

QCD does not forbid 5-quark states such as $uudd\bar{s}$

Since 2003 Θ^+ signals reported by several experiments

If $\Theta^+ = uudd\bar{s}$ exists, heavy pentaquarks, such as $\Theta_c^0 = uudd\bar{c}$ should also exist



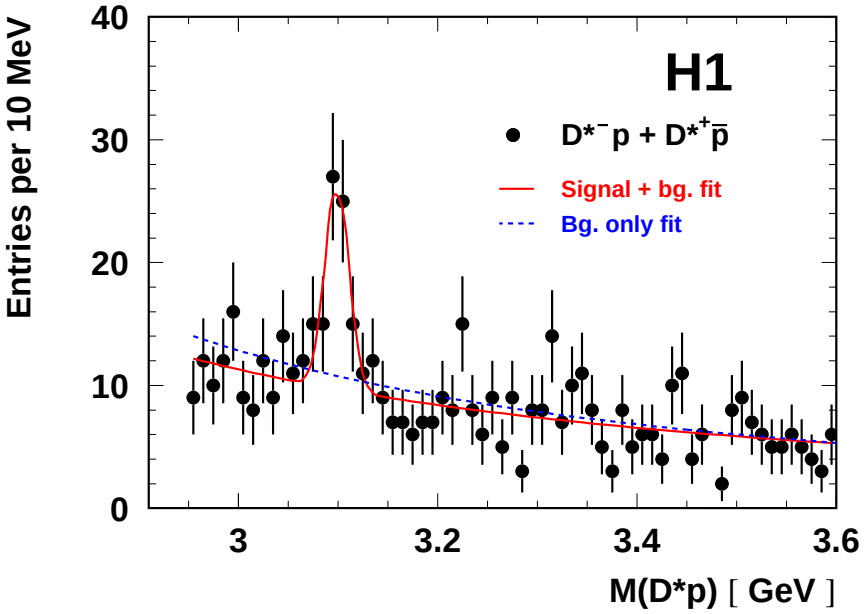
Jaffe-Wilczek and Wu-Ma predicted $M(\Theta_c^0) \approx 2.7$ GeV
$\Rightarrow$ too light to decay to D mesons

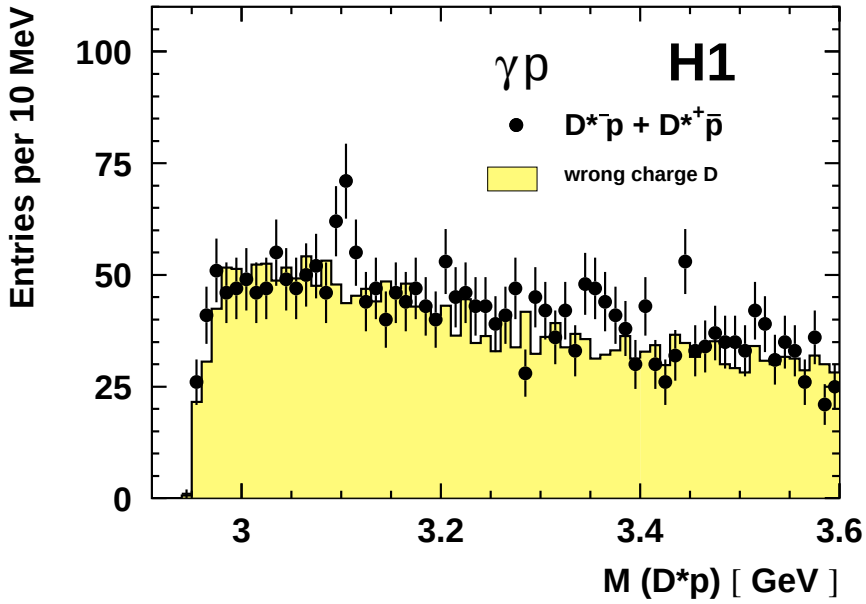
Karliner-Lipkin and Cheung predicted
$M(\Theta_c^0) \approx 2.9 - 3.0$ GeV $\Rightarrow \Theta_c^0$ can decay to D^-p (+c.c.)

If $M(\Theta_c^0) > M(D^{*\pm}) + M(p) = 2.95$ GeV, Θ_c^0 can decay to $D^{*-}p$ (+c.c.)

H1 and ZEUS at HERA searched for Θ_c^0 signal in $M(D^{*-}p)$ (+c.c.) spectra, where $D^{*-} \to D^0\pi_s^-$ (+c.c.)

H1 observation of Θ_c^0 at HERA I





In a DIS HERA I sample of ≈ 3400 $D^{*\pm}$ H1 saw a narrow resonance in $M(D^{*-}p)$ (+c.c.) in the D^0 decay mode $D^0 \to K^{\mp}\pi^{\pm}$ at a mass
$M = 3099 \pm 3(stat.) \pm 5(syst.)$ MeV **A. Aktas et al., Phys. Lett. B 588, 17 (2004)**

The measured Gaussian width $12 \pm 3(stat.)$ MeV is compatible with experimental resolution

The signal consists of 50.6 ± 11.2 events

"roughly 1% of the total D^* production rate"

Signal (with large background) also seen in a photoproduction sample with $\approx$ same ratio to D^*

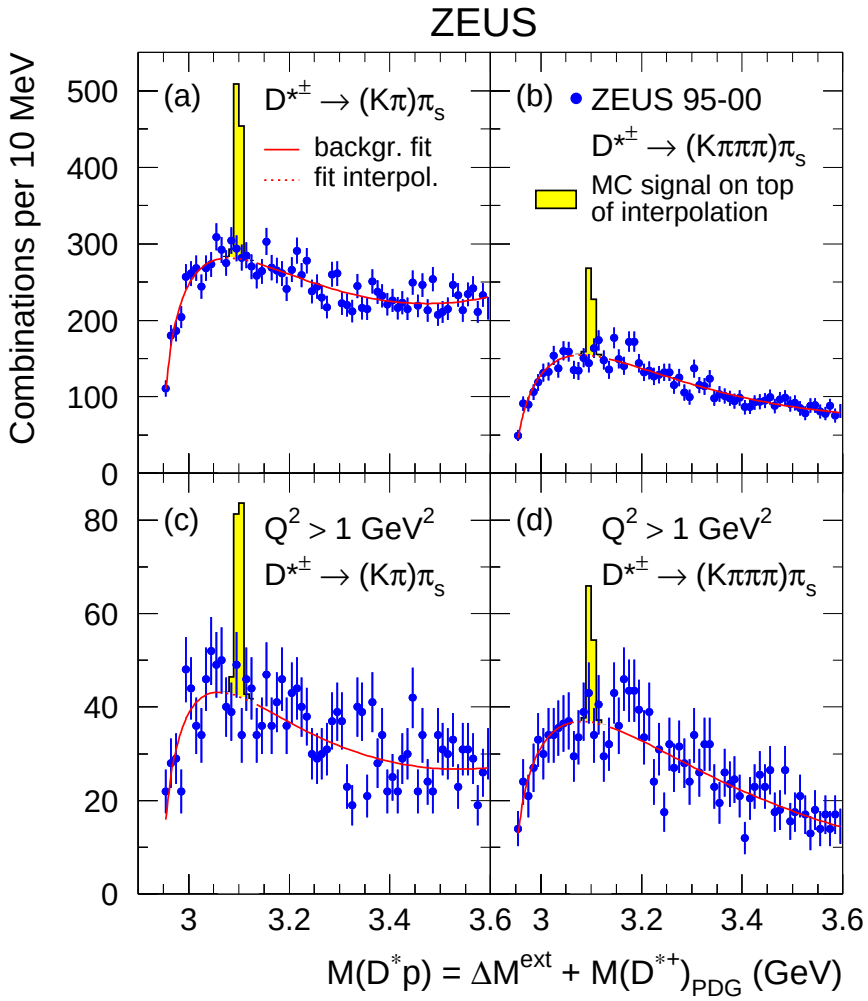
ZEUS search for Θ_c^0 at HERA I

$M(D^*p) = M(K\pi\pi_s p) - M(K\pi\pi_s) + M(D^{*+})_{\rm PDG}$ **Eur.Phys.J C38,29(2004)**

$D^0 \to K^-\pi^+ (\approx 42,700\ D^{*\pm})$ $D^0 \to K^-\pi^+\pi^+\pi^- (\approx 19,900\ D^{*\pm})$

Full sample

DIS sample



Yellow histograms are MC Θ_c^0 signals normalized to $\Theta_c^0/D^* = 1\%$ after H1 on top of a background fit (solid curves)

95% C.L. upper limits on $R(\Theta_c^0 \to D^*p/D^*)$ calculated in D^*p window 3.07-3.13GeV. A visible rate of $R = 1\%$ is excluded by 9 s.d. (5 s.d) for the full (DIS) sample. $R < 0.23\%$ $(< 0.35\%)$ for full (DIS) sample.

Acceptance-corrected limits: $< 0.37\%(< 0.51\%)$ for full (DIS) sample.

$f(c \to \Theta_c^0) \cdot B_{\Theta_c^0 \to\ D^*p} < 0.16\%$ $(< 0.19\%)$ for the full (DIS) combined sample

New H1 prel. Θ_c^0 search at HERA II (2008)

H1 excess in $M(D^*p)$ not confirmed by other experiments

- **ZEUS:** ≈ 63000 D^* (≈ 13500 **in DIS**)
- **BaBar:** > 750000 D^* **in B decays**
- **CDF:** 540000 D^* **in** $p\bar{p}$ **collisions**
- **ALEPH:** ≈ 5000 D^* **in Z decays**
- **FOCUS:** ≈ 35000 D^* **in** γBeO **collisions**

Full HERA II data, 348 pb^{-1}, DIS events

$D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm$ $\quad 15576 \pm 194$ D^*

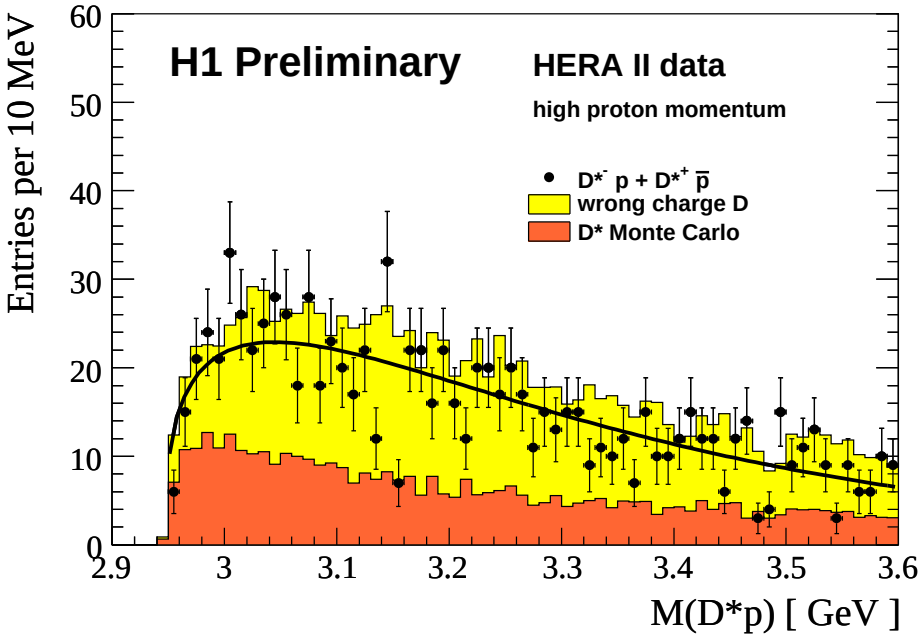
No D^*p peak around 3.1 GeV

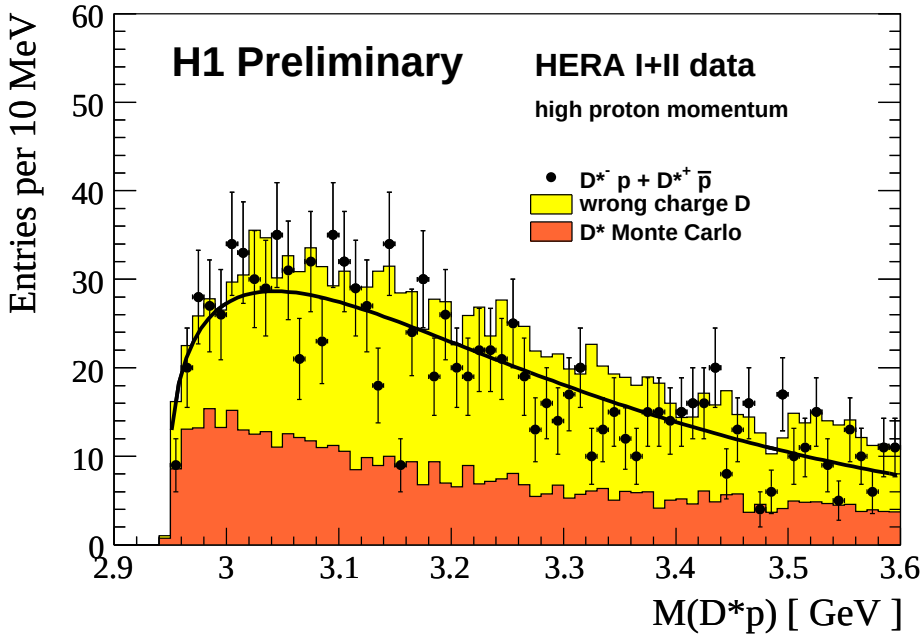
D^* MC + wrong charge D describe data

95% **CL limit** $N(D^*p)/N(D^*) < 0.1\%$

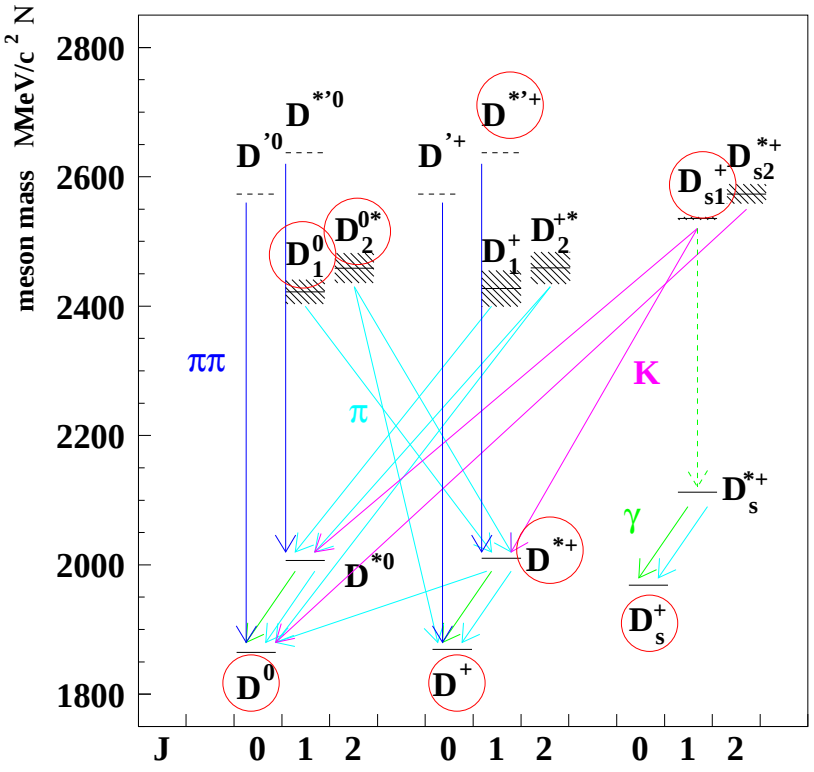
$\approx 1\%$ **in HERA I**

No signal for sum of HERA I + II data





Excited charm and charm-strange mesons



Large charm production cross section at HERA allows to search for excited charm states

Ground state charm mesons (D, D^*) well established

Look for orbitally excited states:

$D_1(2420)^0 \to D^{*\pm}\pi^{\mp}$ $\quad J^P = 1^+$

$D_2^*(2460)^0 \to D^{*\pm}\pi^{\mp}$ $\quad J^P = 2^{++}$

$D_2^*(2460)^0 \to D^{\pm}\pi^{\mp}$

$J^P = 1^+$ state cannot decay to $D\pi$

$D_{s1}(2536)^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$ $\quad J^P = 1^+$

Search for radially excited states:

$D^{*'}(2640)^{\pm} \to D^{*\pm}\pi^+\pi^-$ **(DELPHI)** $\quad J^P = 1^-$ **?**

ZEUS HERA I 1995 - 2000 (126 **pb**$^{-1}$) **DIS + PHP events**

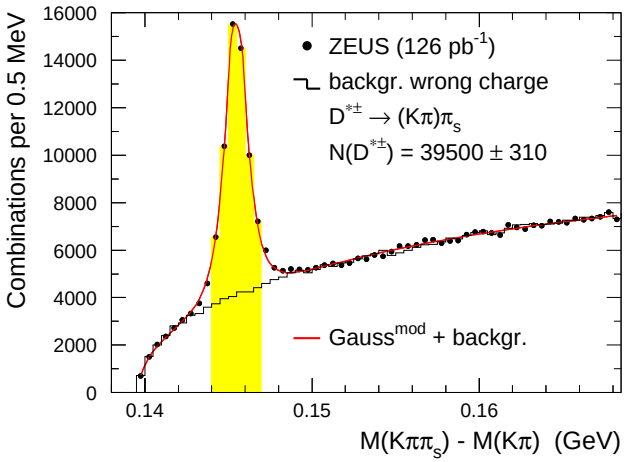
Eur.Phys.J C60,25(2009)

Ground state charm mesons

$D^{*\pm} \to D^0 \pi_s^{\pm}$

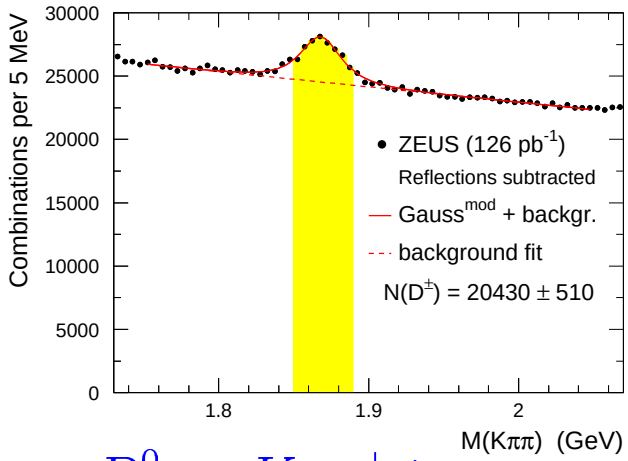
$D^0 \to K^-\pi^+ +$ **c.c.**

ΔM $39,500$ D^*



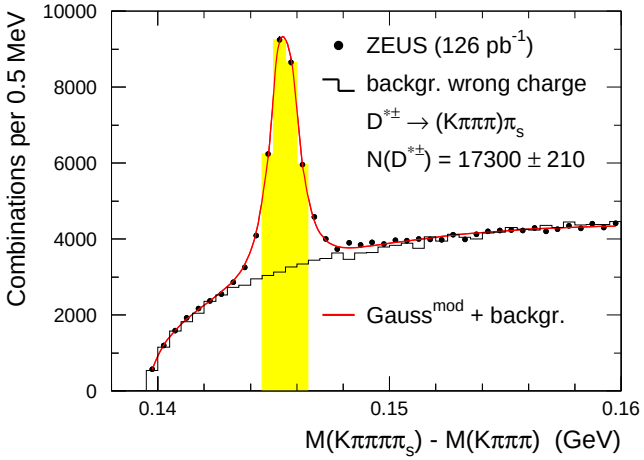
$D^+ \to K^-\pi^+\pi^+ +$ **c.c.**

$20,430$ D^+



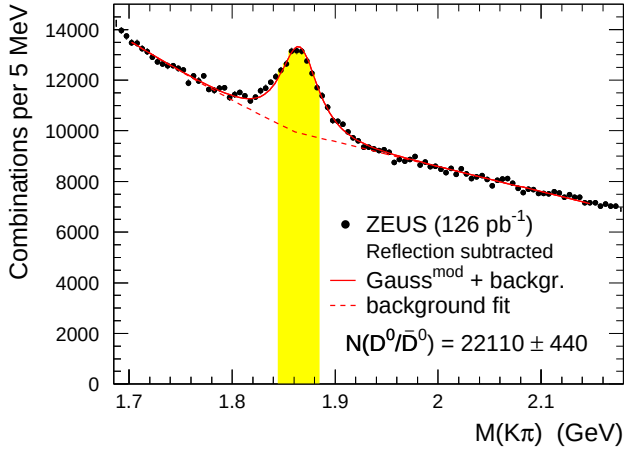
$D^0 \to K^-\pi^+\pi^+\pi^- +$ *c.c.*

ΔM $17,300$ D^*



$D^0 \to K^-\pi^+ +$ **c.c.**

$22,110$ D^0



Solid curves: fits to sum of modified Gaussian + background

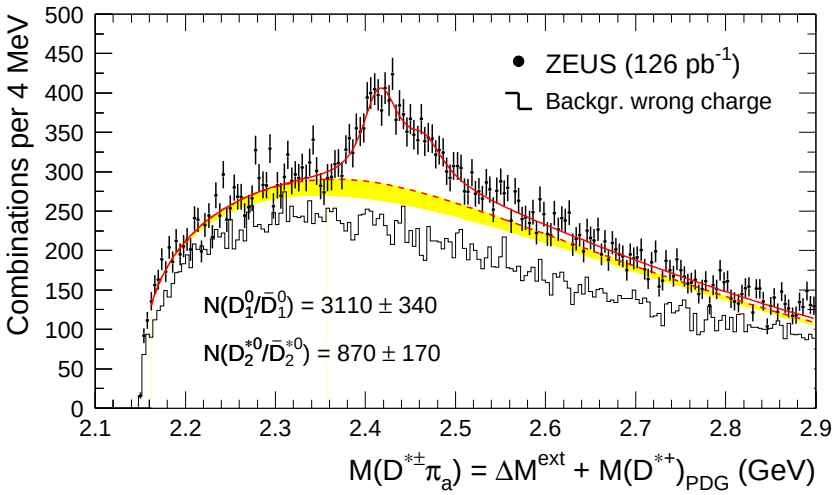
$Gauss^{mod} \sim exp(-0.5x^{1+\frac{1}{(1+0.5x)}})$

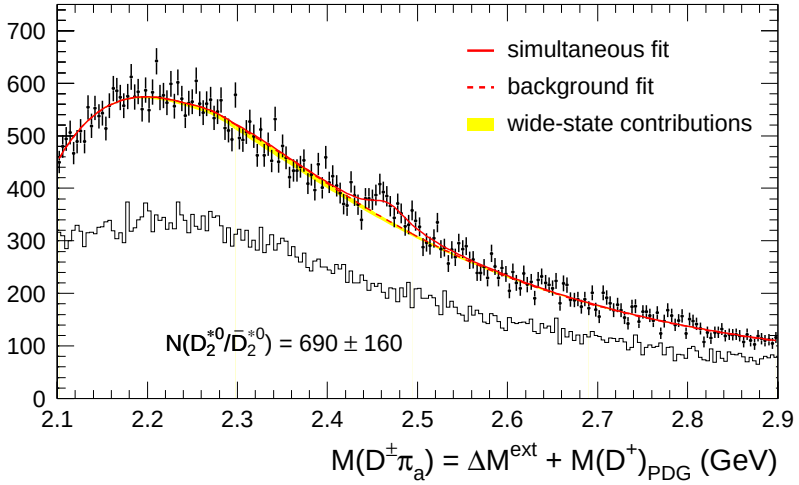
Histograms: ΔM distributions for wrong-charge combinations

Yellow bands: ranges used for excited charm mesons analysis

$D_1(2420)^0, D_2^*(2460)^0 \to D^{*\pm}\pi^{\mp}, D^{\pm}\pi^{\mp}$

Combine $D^{*\pm}/D^{\pm}$ with $\pi_e^{\mp}$





Plot $\Delta M^{ext} + M(D^{*\pm})_{PDG}$ **(dots)**

$$\Delta M^{ext} = M(K\pi\pi_s\pi_e) - M(K\pi\pi_s)$$

$$p_T(D^{*\pm}) > 1.35\ GeV,\ |\eta(D^{*\pm})| < 1.6$$

or: $\Delta M^{ext} = M(K\pi\pi\pi\pi_s\pi_e) - M(K\pi\pi\pi\pi_s)$

$$p_T(D^{*\pm}) > 2.80\ GeV,\ |\eta(D^{*\pm})| < 1.6$$

Difficult to separate D_1^0/D_2^{*0}

Plot $\Delta M^{ext} + M(D^{\pm})_{PDG}$ **(dots)**

$$\Delta M^{ext} = M(K\pi\pi\pi_e) - M(K\pi\pi)$$

$$p_T(D^{*\pm}) > 2.80\ GeV,\ |\eta(D^{*\pm})| < 1.6$$

As expected, only D_2^{*0} is seen

Solid curves: Simultaneous fit

Dashed curves: Background contribution

Histograms: Wrong-charge combinations

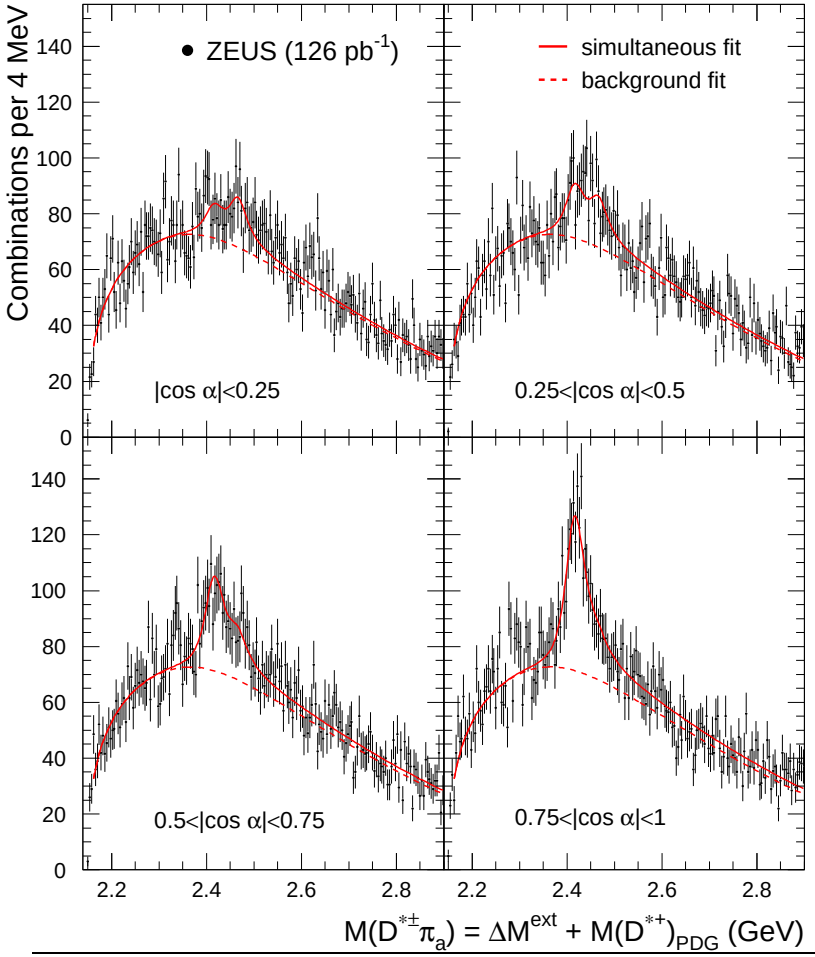
$D_1(2420)^0, D_2^*(2460)^0 \to D^{*\pm}\pi^{\mp}$ in helicity bins

$\Delta M^{ext} + M(D^{*\pm})_{PDG}$ **in 4 helicity** $|\cos(\alpha)|$ **intervals:**

$dN/d\cos\alpha \approx 1 + h\cos^2\alpha$

α is angle between π_e and π_s momenta in D^* rest frame

h is helicity parameter $h = 3\ (-1)$ **predicted for pure D-wave** D_1^0 (D_2^{*0})



D_1^0 contribution increases with $|\cos(\alpha)|$

dominates for $|\cos\alpha| > 0.75$

Solid curves: Simultaneous fit to 4 helicity $M(D^{*\pm}\pi^{\mp})$ regions and $M(D^{\pm}\pi^{\mp})$ histogram

Dashed curves: Background contribution

Data described well with 15 free parameters: signal yields, massses, D_1^0 width and helicity

Fitted masses agree with PDG

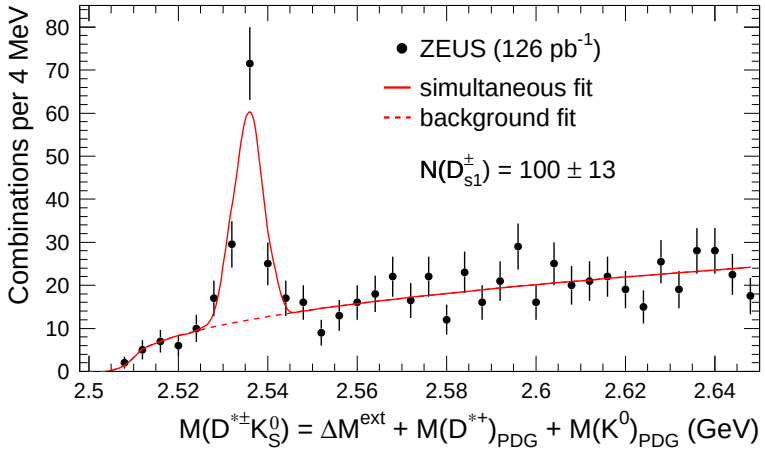
$\Gamma(D_1^0) = 53.2 \pm 7.2^{+3.3}_{-4.9}\, MeV (PDG: 20.4 \pm 1.7\, MeV)$

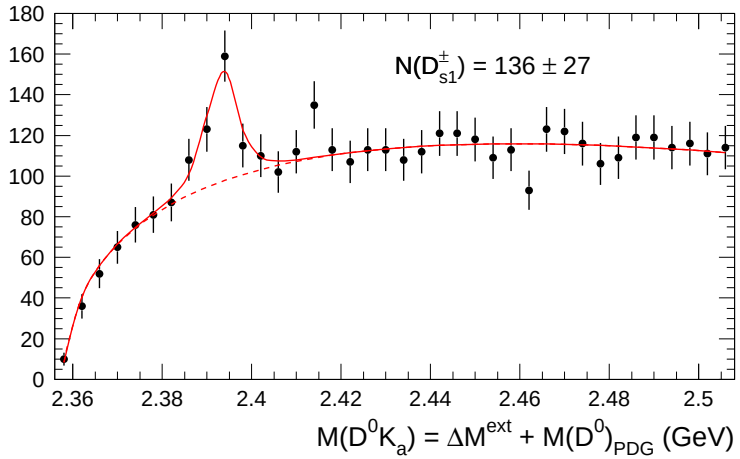
$h(D_1^0) = 5.9^{+3.0}_{-1.7}(stat.)^{+2.4}_{-1.0}(syst.)$ **(CLEO:** $2.74^{+1.40}_{-0.93}$**)**

Roughly consistent with pure D-wave (h=3)

$D_{s1}(2536)^{\pm} \to D^{*\pm}K^0_s, D^{*0}K^{\pm}$

Combine $D^{*\pm}$ with reconstructed $K^0_S \to \pi^+\pi^-$





Plot $\Delta M^{ext} + M(D^{*\pm})_{PDG} + M(K^0)_{PDG}$

$\Delta M^{ext} = M(K\pi\pi_s\pi^+\pi^-) - M(K\pi\pi_s) - M(\pi^+\pi^-)$ **or**

$\Delta M^{ext} = M(K\pi\pi\pi\pi_s\pi^+\pi^-) - M(K\pi\pi\pi\pi_s) - M(\pi^+\pi^-)$

Clear $D_{s1}(2536)^{\pm}$ signal

Plot $\Delta M^{ext} + M(D^0)_{PDG}$

$\Delta M^{ext} = M(K\pi K^{\pm}) - M(K\pi)$

Signal is feed-down from $D^+_{s1} \to D^{*0}K^+$

with $D^{*0} \to D^0\pi^0, D^0\gamma$ shifted down by 142 MeV

Solid curves: simultaneous unbinned likelihood fit

Dashed curves: background contribution

Fitted D_{s1} helicity parameter: $h(D_{s1}) = -0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$

Inconsistent with pure 1^+ D-wave (h=3)

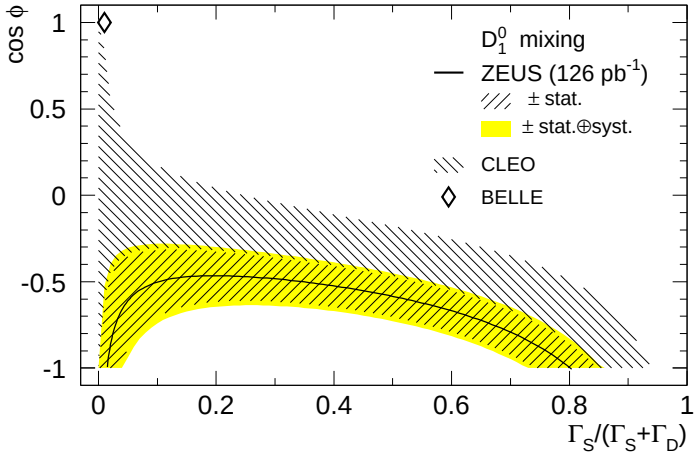
Barely consistent with pure 1^+ S-wave (h=0) $\to$ Significant S-D mixing

S-D wave mixing for D_1^0 and D_{s1}

For S-D wave mixing: $dN/d\cos\alpha \approx r + (1-r)(1+3\cos^2\alpha)/2 + \sqrt{(2r(1-r))}\cos\phi(1-3\cos^2\alpha)$

$r = \Gamma_S/(\Gamma_S+\Gamma_D)$; $\Gamma_{S/D}$ **is the S/D wave partial width**

ϕ **is relative phase between 2 amplitudes** $\Rightarrow \cos\phi = \dfrac{(3-h)/(3+h)-r}{2\sqrt{(2r(1-r))}}$



$\cos\phi$ **vs.** r **for ZEUS, CLEO BELLE:**

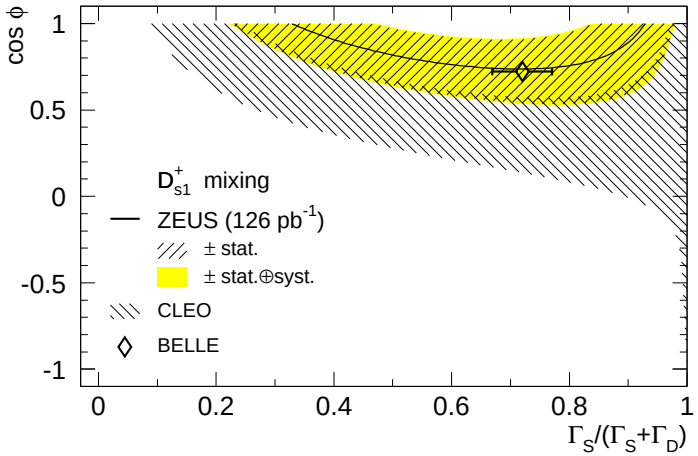
$D_1(2420)^0 \to D^{*+}\pi^-$ **decay**

Marginal overlap between ZEUS/CLEO ranges

BELLE consistent with pure D-wave

ZEUS favours negative $\cos\phi$ **and possible** $S-D$ **mixing**

Different environment; connection to larger width (?)



$D_{s1}(2536)^+ \to D^{*+}K_S^0$ **decay**

ZEUS range agrees nicely with BELLE

not inconsistent with CLEO: $h(D_{s1}) = -0.23^{+0.40}_{-0.32}$

Significant $S-D$ **mixing required**

Can be due to recently discovered $D_{s1}(2460)$ **with** $J^P = 1^+$

Branching ratios and fragmentation fractions

Using $f(c \to D^{*+})$, $f(c \to D^{+})$ previously measured by ZEUS:

$$\frac{B_{D_2^{*0} \to D^+ \pi^-}}{B_{D_2^{*0} \to D^{*+} \pi^-}} = 2.8 \pm 0.8(\text{stat.})^{+0.5}_{-0.6}(\text{syst.}) \qquad 2.3 \pm 0.6 \textbf{ (PDG)}$$

$$\frac{B_{D_{s1}^{+} \to D^{*0} K^+}}{B_{D_{s1}^{+} \to D^{*+} K^0}} = 2.3 \pm 0.6(\text{stat.}) \pm 0.3(\text{syst.}) \qquad 1.27 \pm 0.21 \textbf{ (PDG)}$$

Assuming I-spin conservation for D_1^0, D_2^{*0} and $B_{D_{s1}^{+} \to D^{*+} K^0} + B_{D_{s1}^{+} \to D^{*0} K^+} = 1$ yields fragmentation functions and strangeness suppression of excited D mesons

$$f(c \to D_{s1}^{+}) / f(c \to D_1^0) = 0.31 \pm 0.06^{+0.05}_{-0.04}$$

	$f(c \to D_1^0)[\%]$	$f(c \to D_2^{*0})[\%]$	$f(c \to D_{s1}^{+})[\%]$
ZEUS	$3.5 \pm 0.4^{+0.4}_{-0.6}$	$3.8 \pm 0.7^{+0.5}_{-0.6}$	$1.11 \pm 0.16^{+0.08}_{-0.10}$
OPAL	2.1 ± 0.8	5.2 ± 2.6	$1.6 \pm 0.4 \pm 0.3$
ALEPH			$0.94 \pm 0.22 \pm 0.07$

$\Rightarrow$ Frag. fractions for excited D mesons in ep and e^+e^- consistent

DELPHI saw a narrow peak in $D^{*\pm}\pi^+\pi^-$ at 2637 MeV; attributed to radially excited $D^{*\prime}$

No signal seen in ZEUS. Upper limit: $f(c \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.4\%$ (95% C.L)

Limit stronger than OPAL (0.9%)

Summary

- **ZEUS observed 3 enhancements in $M(K^0_S K^0_S)$ corresponding to $f_2(1270)/a_2(1320)$, $f_2'(1525)$, $f_0(1710)$**

Good fit by using interference between 2^{++} states as predicted by SU(3)

$f_0(1710)$ seen with 5σ significance; mass consistent with $J^{PC} = 0^{++}$ glueball

$f_0(1710)$ unlikely a pure glueball if same as in $\gamma\gamma \to K^0_S K^0_S$ (TASSO,L3)

- **H1 saw narrow $\Theta^0_c \to D^{*\pm} p^{\mp}$ signal at ≈ 3.1 GeV from ≈ 3400 $D^{*\pm}$**

No structure seen in ZEUS (PHP + DIS) from 62,600 D^*

ZEUS 95% C.L.: $R((\Theta^0_c \to D^* p)/D^*) < 0.23\%$

With higher statistics - no H1 Θ^0_c signal: $N(D^* p)/N(D^*) < 0.1\%$ (95% C.L.)

$\Rightarrow \Theta^0_c$ pentaquark at 3.1 GeV is ruled out

- **Sizeable production of excited D mesons at ZEUS ($D^0_1, D^{*0}_2, D^+_{s1}$)**

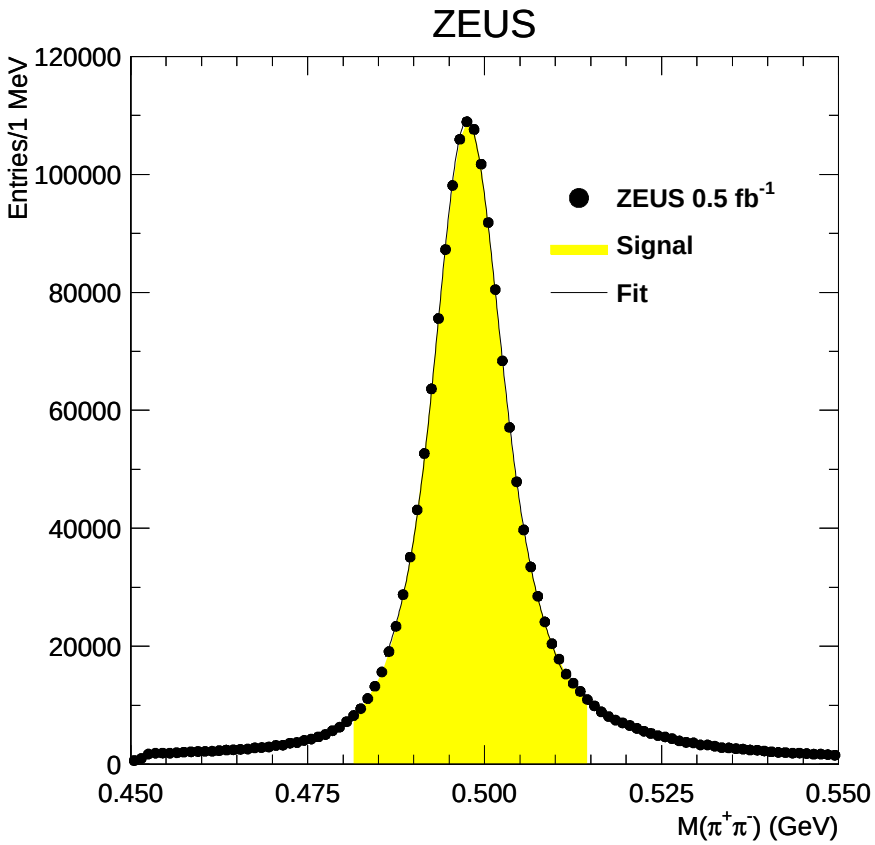
D^0_1 width is significantly above PDG (Larger S-wave admixture ?)

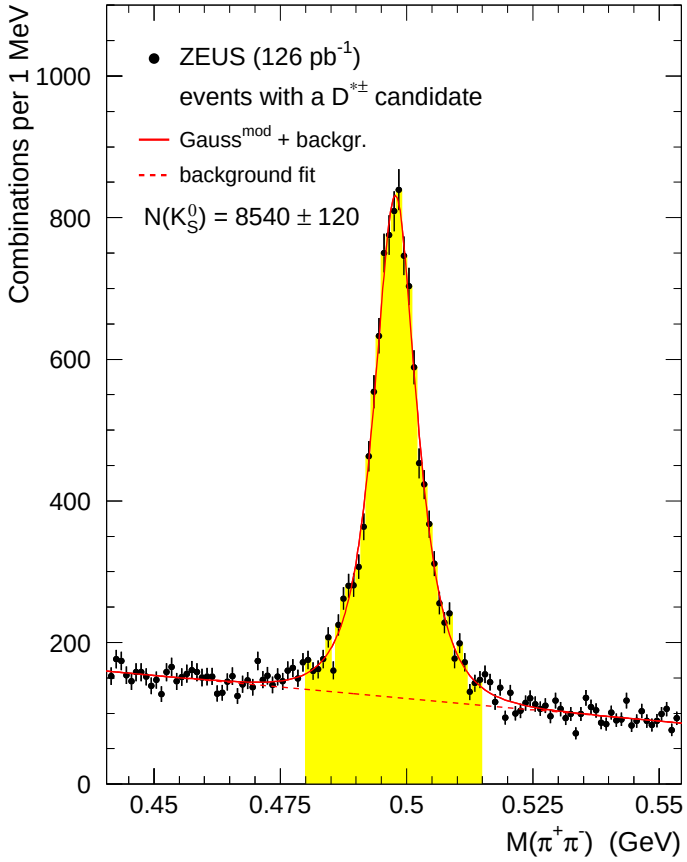
Frag. fractions of excited D mesons as in e^+e^- $\Rightarrow$ charm frag. universality

D^+_{s1} helicity consistent with BELLE and suggests significant S-D mixing

$f(c \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.4\%$ (95% C.L.)

Backup: K^0_S signal in $K^0_S K^0_S$ and D_{s1} analyses

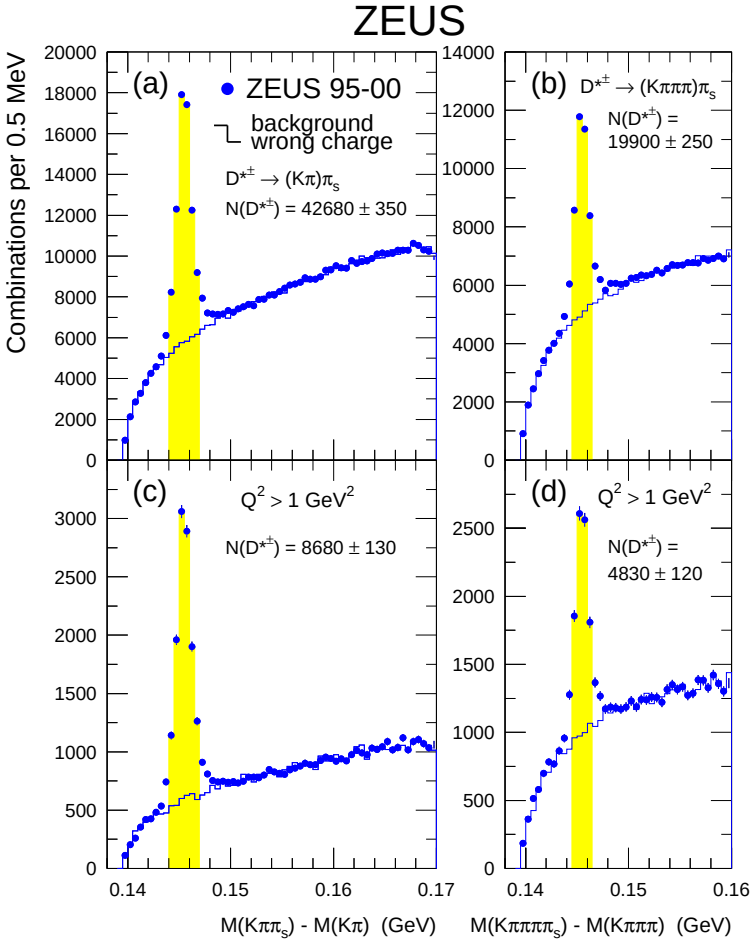




Backup: ZEUS search for the $\Theta_c^0 \to D^{*\pm} p^{\mp}$ pentaquark

ZEUS HERA-I data (126.5 pb^{-1}) **Eur. Phys. J. C38 (2004) 29**

$D^{*\pm} \to D^0 \pi_s^{\pm}$ $\quad \Delta M = M(D^{*\pm}) - M(D^0) \sim m_\pi$



$P_T(D^{*\pm}) > 1.35\,\mathbf{GeV}, \quad |\eta(D^{*\pm})| < 1.6$

Clean D^* signals in 2 D^0 decay modes

$D^0 \to K^-\pi^+$; $D^0 \to K^-\pi^+\pi^+\pi^-$ **(+ c.c.)**

Θ_c^0 searched for with D^*'s from yellow bands $N(D^{*\pm}) \approx 62,600$

For the DIS sub-sample $Q^2 > 1$ **GeV**^{2}
$N(D^{*\pm}) \approx 13,500$ **(x 4 of H1 sample)**

dE/dx calibrated with tagged $p(\bar{p})$ from Λ's

$$\chi^2 = \frac{(ln(dE/dx) - ln(dE/dx)_{expected})^2}{\sigma^2_{ln(dE/dx)}}$$

$p(\bar{p})$ candidates with $P_T > 0.15$ GeV selected by $Prob(\chi^2)_p > 0.15$; $A(Prob(\chi^2)_p > 0.15) = 85.0 \pm 0.1\%$

Two strategies for p-selection:

1) Low-P_p : $Prob(\chi^2)_p > 0.15$; $P < 1.35\,\mathbf{GeV}$; $dE/dx > 1.3$ **(Clean p's from dE/dx)**

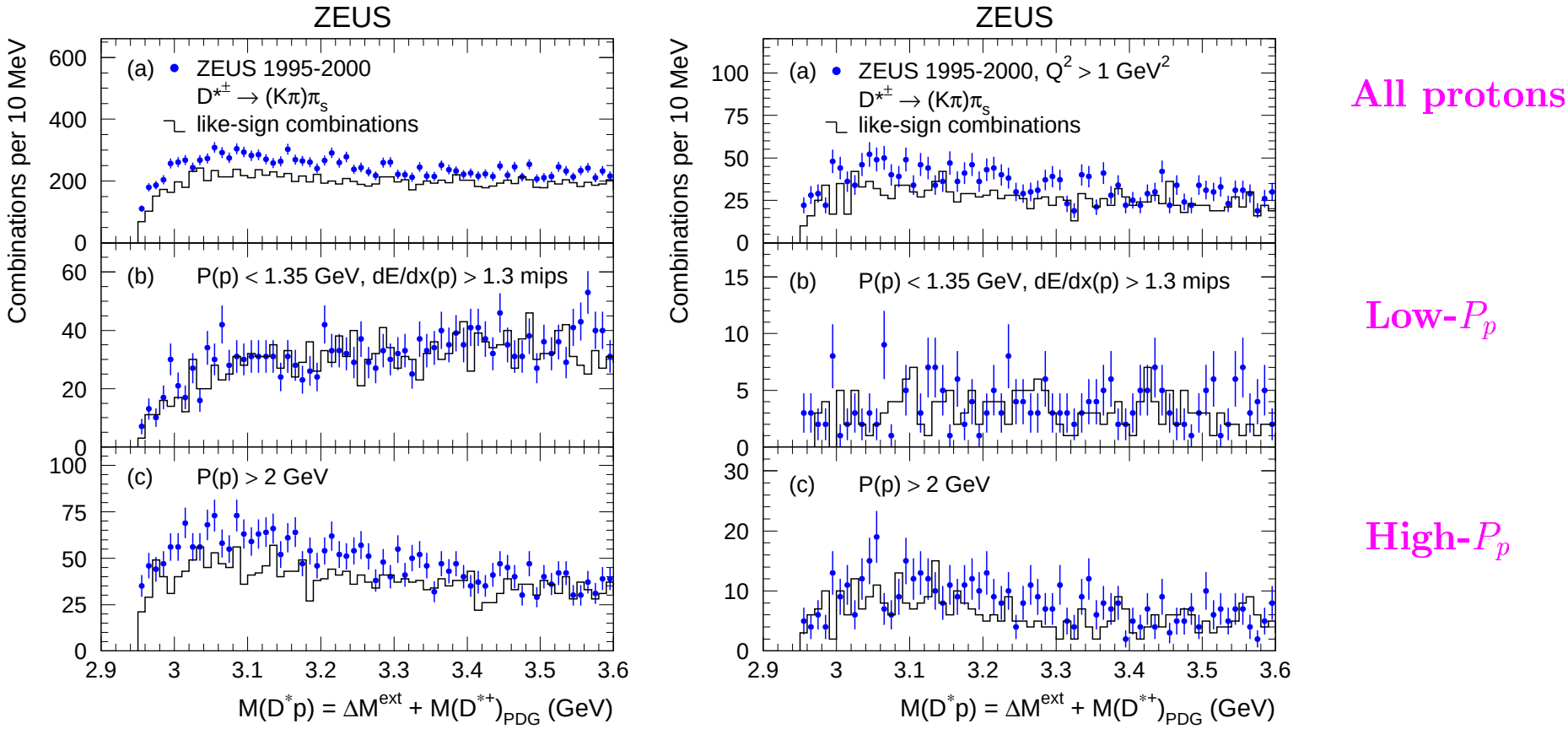
2) High-P_p : $Prob(\chi^2)_p > 0.15$; $P > 2\,\mathbf{GeV}$ **(Nicer H1 signal without dE/dx cut)**

Backup: ZEUS $M(D^*p)$ spectra for the $D^0 \to K^-\pi^+$ channel

$M(D^*p) = M(K\pi\pi_s p) - M(K\pi\pi_s) + M(D^{*+})_{\rm PDG}$

$M(D^*p)$ **resolution at** ≈ 3.1 **GeV is** ≈ 4 **MeV**

full sample **DIS sample**



All protons

Low-P_p

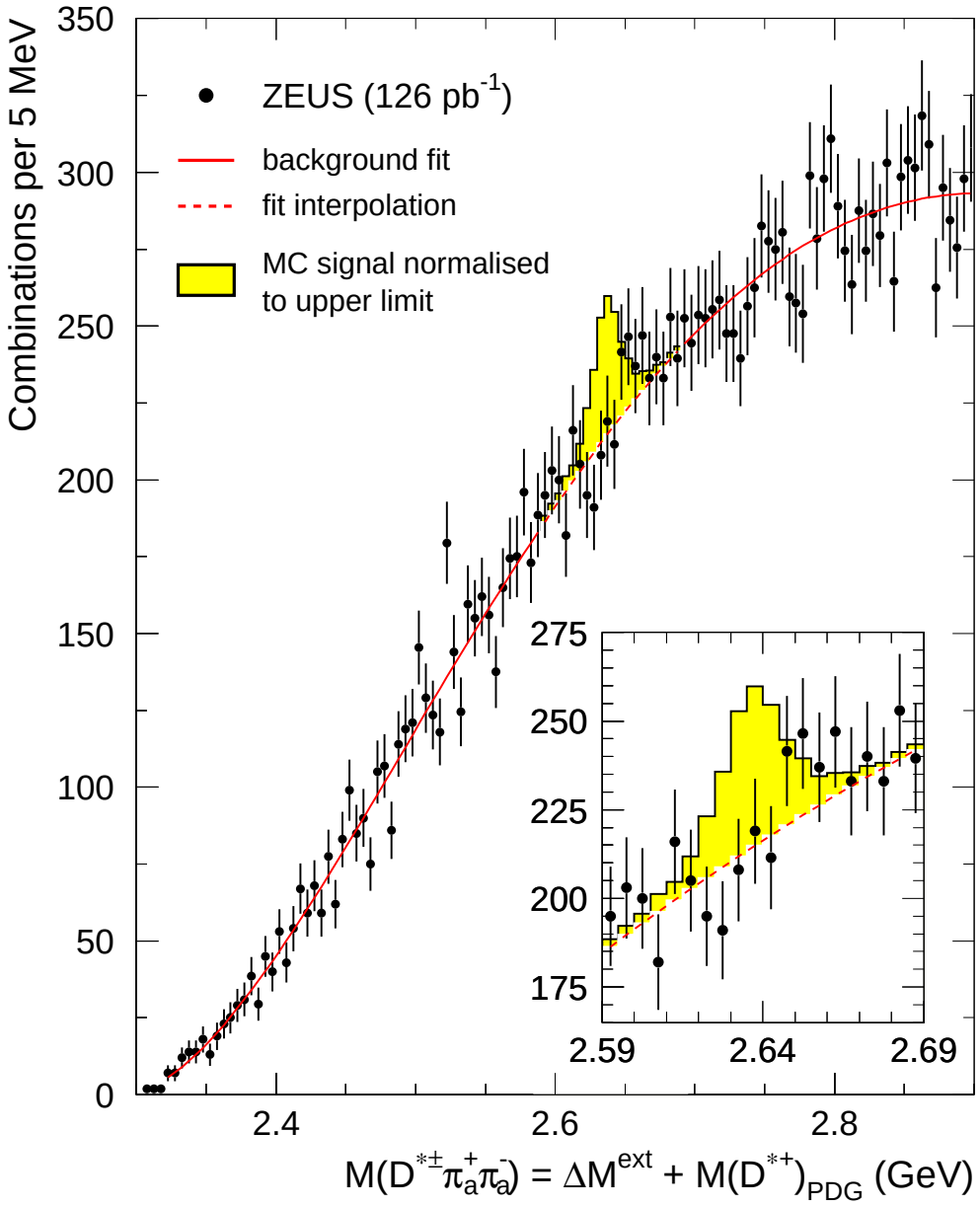
High-P_p

Histograms are $M(D^{*\pm}p^{\pm})$ **like-sign combinations**

No evidence for a signal at 3.1 **GeV** **(also in the** $D^0 \to K^-\pi^+\pi^+\pi^-$ **mode)**

$D^0 \to K^-\pi^+$ **analysis repeated with very similar cuts to H1** $\Rightarrow$ **no signal**

Backup: Search for radially excited $D^{*\prime\pm} \to D^{*\pm}\pi^+\pi^-$ meson



$\Delta M^{\rm ext} = M(K\pi\pi_s\pi_a^+\pi_a^-) - M(K\pi\pi_s)$ **or**

$\Delta M^{\rm ext} = M(K\pi\pi\pi\pi_s\pi_a^+\pi_a^-) - M(K\pi\pi\pi\pi_s)$

no DELPHI's or other signals

$N(D^{*\pm}\pi^+\pi^-)_{2.59-2.69} = 104 \pm 83$

correcting and using our $f(c \to D^{*+})$**:**

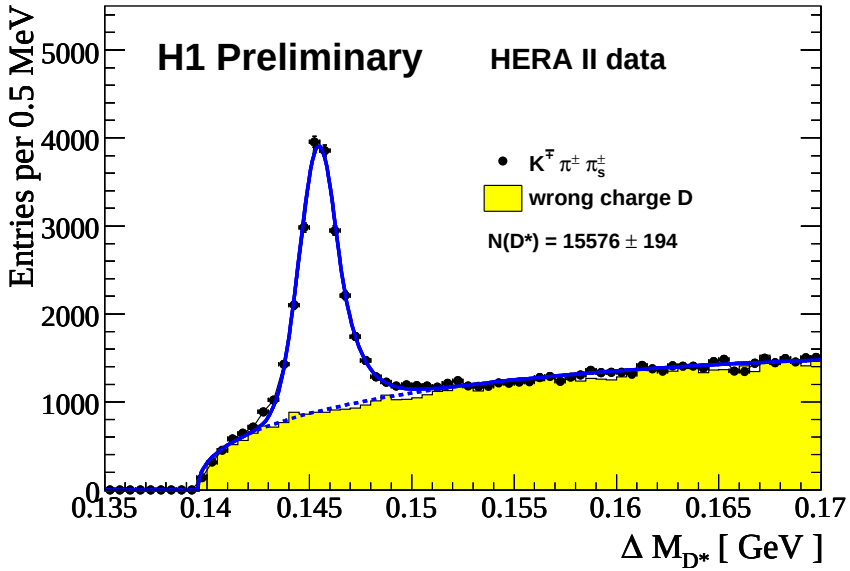
$f(c \to D^{*\prime+}) \cdot B_{D^{*\prime+}\to D^{*+}\pi^+\pi^-} < 0.4\%$

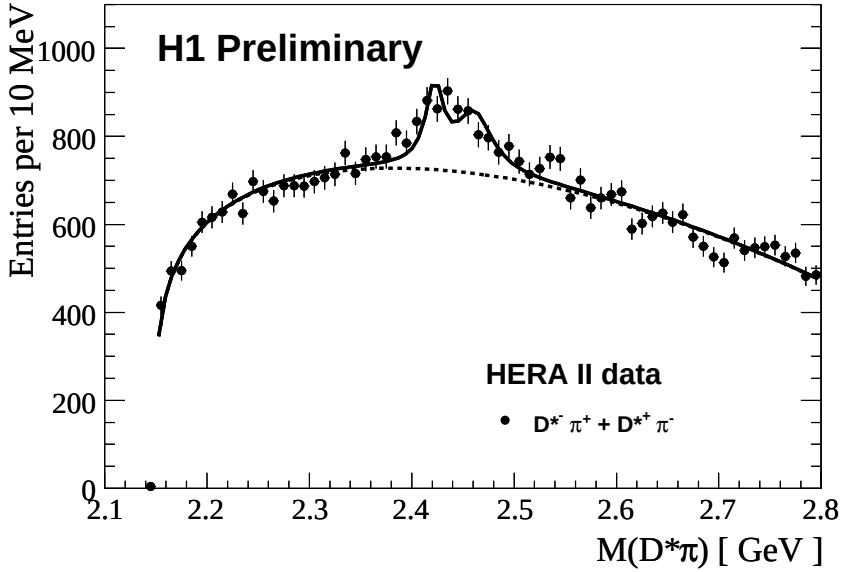
(95% C.L.)

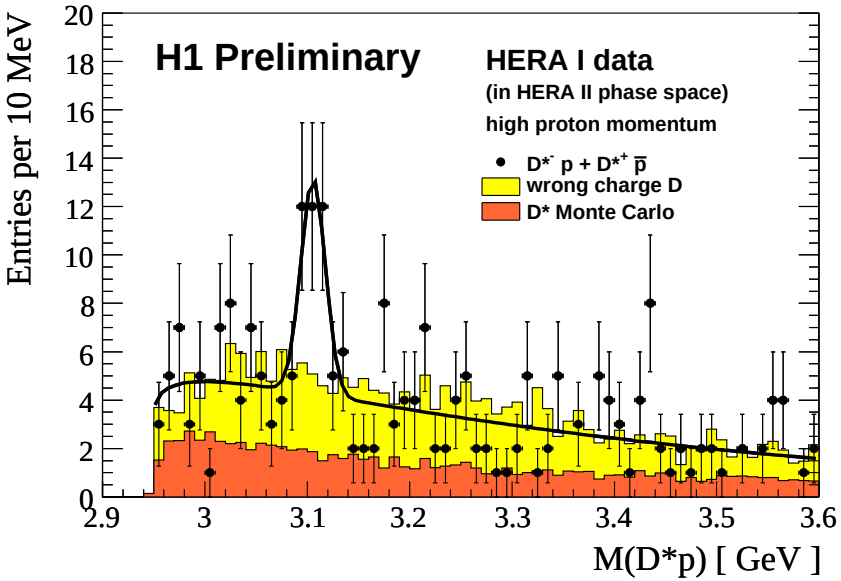
stronger than the 0.9% **OPAL limit**

	$R_{D^{*\prime+}\to D^{*+}\pi^+\pi^-/D_1^0,D_2^{*0}\to D^{*+}\pi^-}$
DELPHI, $Z^0 \to b\bar{b}, c\bar{c}$	$49 \pm 18 \pm 10\,\%$
OPAL, $Z^0 \to b\bar{b}, c\bar{c}$	$5 \pm 10 \pm 0.2\,\%$ $< 22\,\%$ (95% C.L.)
ZEUS, $ep \to c\bar{c}X$	$4.5 \pm 3.6^{+0.6}_{-0.7}\,\%$ $< 12\,\%$ (95% C.L.)

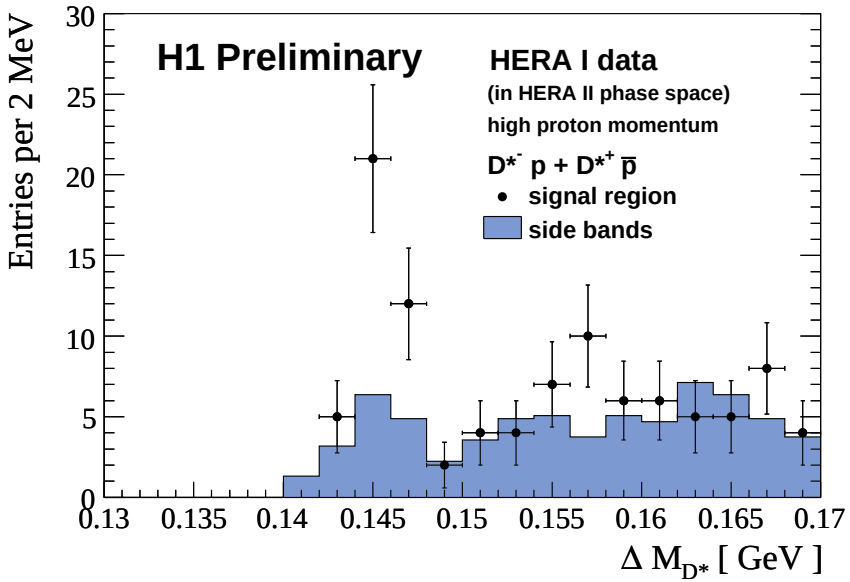
Backup: H1 D^*p

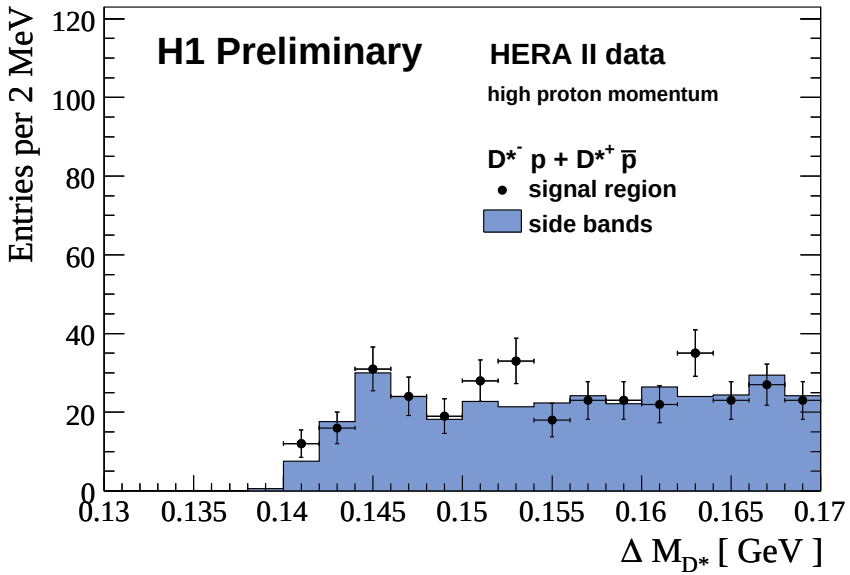

H1 Preliminary
HERA II data
$K^{\mp}\pi^{\pm}\pi^{\pm}_s$
wrong charge D
N(D*) = 15576 ± 194
Entries per 0.5 MeV
ΔM_{D^*} [GeV]


H1 Preliminary
HERA II data
$D^{*-}\pi^+ + D^{*+}\pi^-$
Entries per 10 MeV
M(D*π) [GeV]


H1 Preliminary
HERA I data
(in HERA II phase space)
high proton momentum
$D^{*-}p + D^{*+}\bar{p}$
wrong charge D
D* Monte Carlo
Entries per 10 MeV
M(D*p) [GeV]

Backup: H1 D^*p


H1 Preliminary
HERA I data
(in HERA II phase space)
high proton momentum
D*- p + D*+ p̄
signal region
side bands
Entries per 2 MeV
Δ M_D* [GeV]


H1 Preliminary
HERA II data
high proton momentum
D*- p + D*+ p̄
signal region
side bands
Entries per 2 MeV
Δ M_D* [GeV]