Production of the excited charm mesons D_1^0 and D_2^{*0} at HERA

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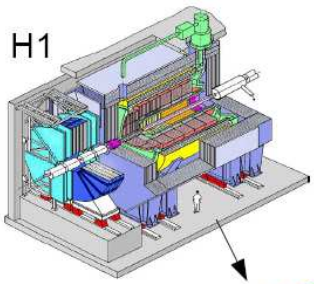
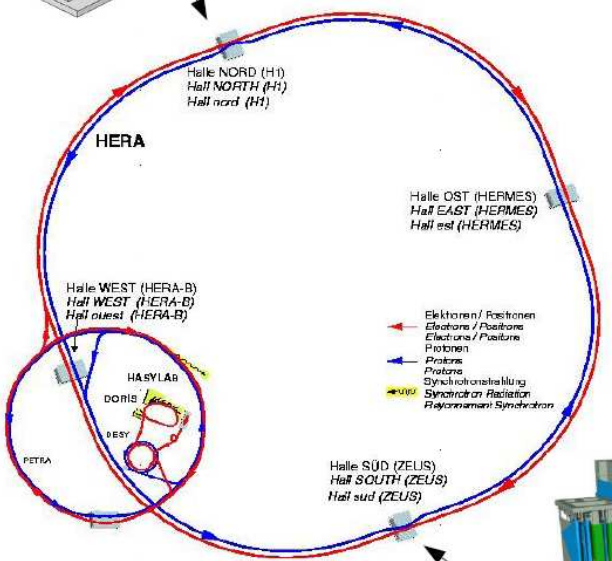
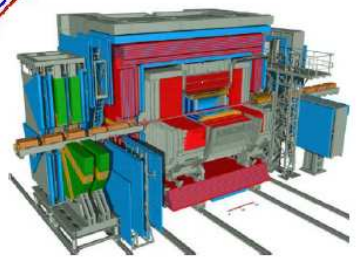


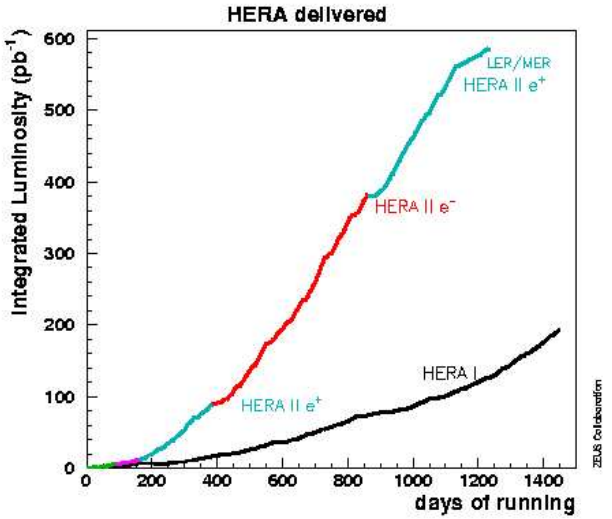
HERA collider



- Protons 920 GeV
- Electrons and positrons 27.6 GeV
- Operational: 1992 - 2007
- Two collider experiments: H1 and ZEUS
- ~500 pb^{-1} per experiment accumulated during HERA I and HERA II running periods

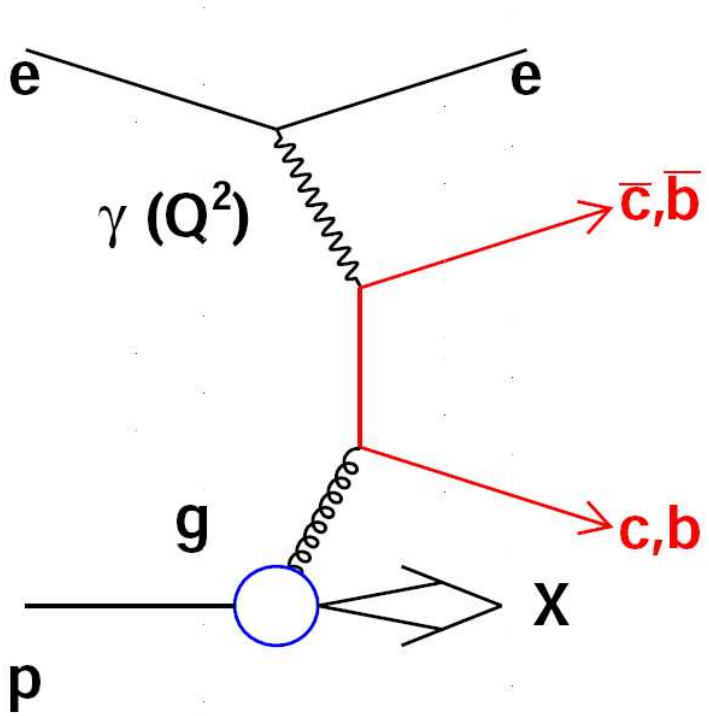


ZEUS



Luminosity

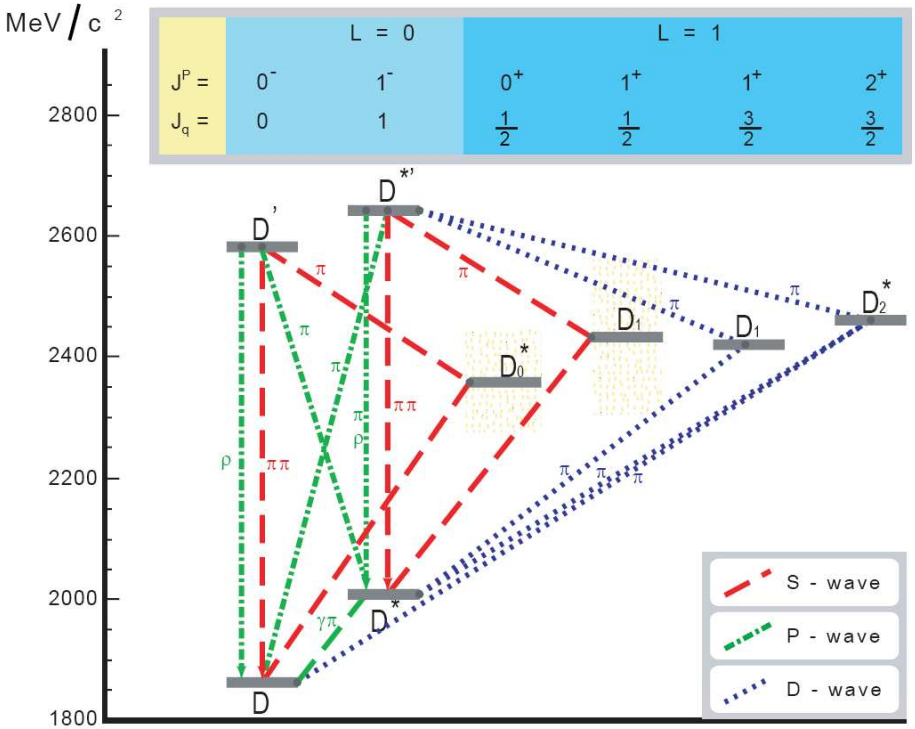
- HERA I: $\approx 126 pb^{-1}$
- HERA II: $\approx 370 pb^{-1}$



BGF (LO)

- Predominantly via Boson-Gluon Fusion (BGF)
- Well established ground state charm mesons D and D^*
- Charm cross section is high enough to study excited D mesons (EDM)

Theoretical predictions of EDMs



Godfrey and Isgur, 1985 (Heavy Quark Effective Theory HQET) – prediction of EDM states

- Known $1P$ narrow D_1, D_2^* states($\Gamma \sim 30MeV$):
  - $D_1(2420) - J^\pi = 1^+$
  - $D_2^*(2460) - J^\pi = 2^+$
- Poorly known $1P$ wide D_0^*, D_1 states ($\Gamma \sim 300MeV$):
  - $D_0^*(2400) - J^\pi = 0^+$
  - $D_1(2430) - J^\pi = 1^+$
- Poorly known or unknown orbitally and radially excited states D', $D^{*\prime}$

EDM reconstruction

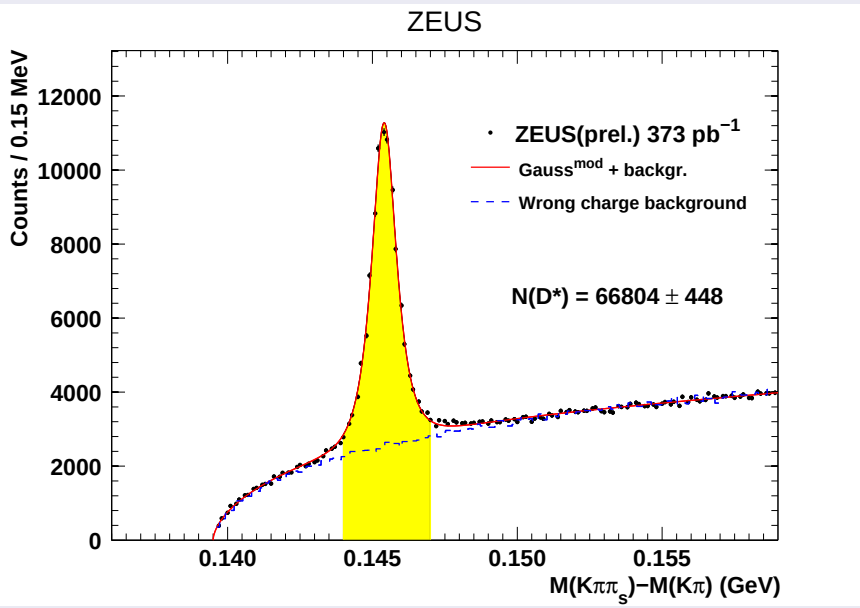
$D^{**} \to D^{*} \to D^{0}$

$$
\begin{aligned}
D_1(2420)^0 &\to D^{*\pm}\pi_a^{\mp} & \qquad D_2^*(2460)^0 &\to D^{*\pm}\pi_a^{\mp} \\
D^{*\pm} &\to D^0\pi_s^{\pm} & \qquad D^{*\pm} &\to D^0\pi_s^{\pm} \\
D^0 &\to K^{\mp}\pi^{\pm} & \qquad D^0 &\to K^{\mp}\pi^{\pm}
\end{aligned}
$$

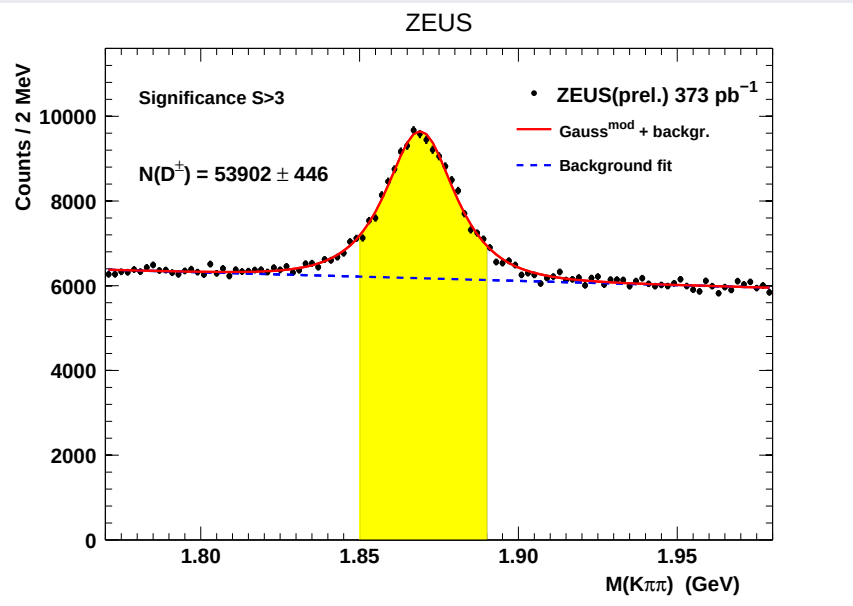
$D^{**} \to D^{\pm}$

$$
\begin{aligned}
D_2^*(2460)^0 &\to D^{\pm}\pi_a^{\mp} \\
D^{\pm} &\to K^{\mp}\pi^{\pm}\pi^{\pm}
\end{aligned}
$$

$D^{*\pm} \to D^0(K\pi)\pi_s$

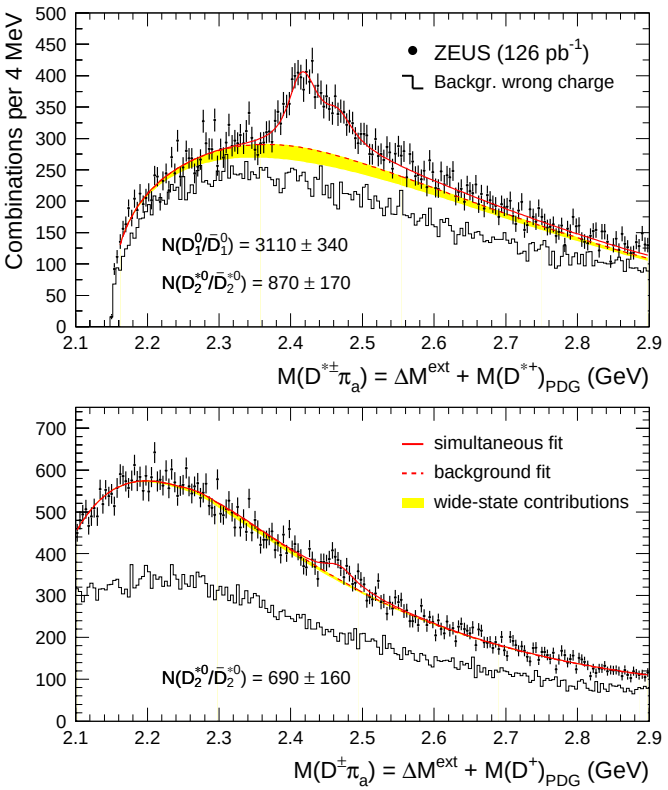


$D^{\pm} \to K\pi\pi$

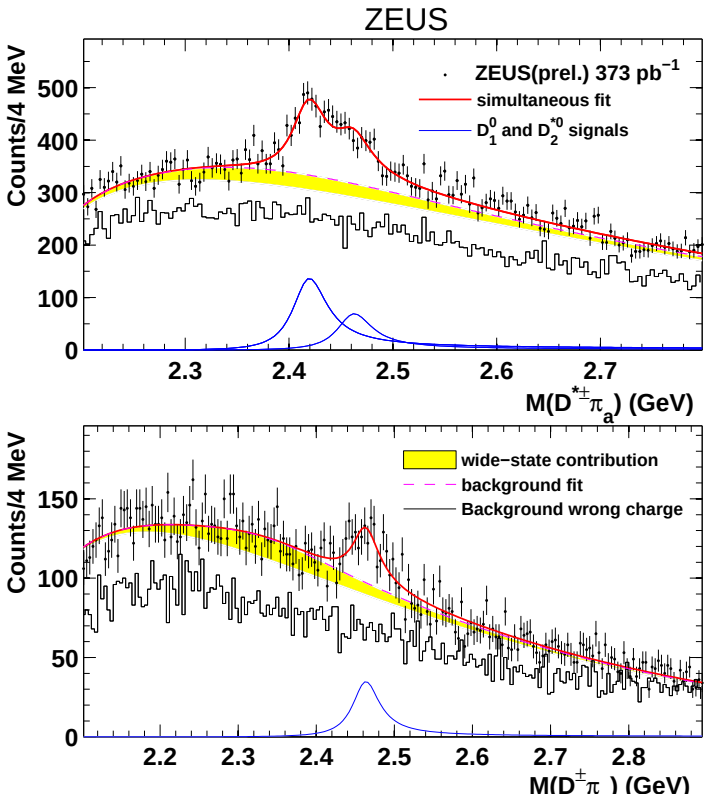


Excited charm mesons D_1^0 and D_2^{*0} at HERAI and HERAII

HERA I



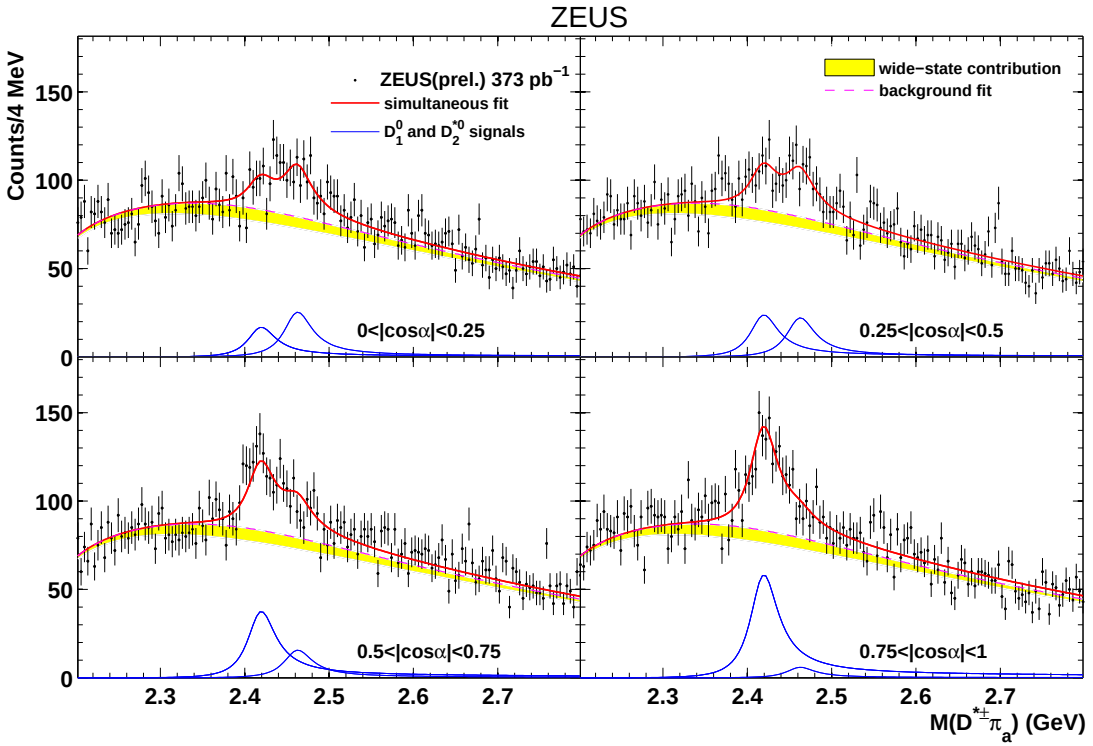
HERA II (prelim)



- Published: DESY-08-093; EPJ C 60(2009)25-45
- $D^{**} \rightarrow D^{*} \rightarrow D^0(K\pi), D^0(K\pi\pi\pi)$

- $D^{\pm}\pi$ signal – much better because of installed micro-vertex detector (MVD)
- $D^{**} \rightarrow D^{*} \rightarrow D^0(K\pi)$

Simultaneous fit of $D^*\pi$ mass spectra in 4 helicity bins



- Fitted $D_1(2420)^0$ and $D_2^*(2460)^0$ signals – relativistic Breit-Wigner functions ($L = 2$)
- Fitted wide state, $D_1(2430)^0$ – relativistic Breit-Wigner functions (mass and width fixed according to PDG, $L = 0$)

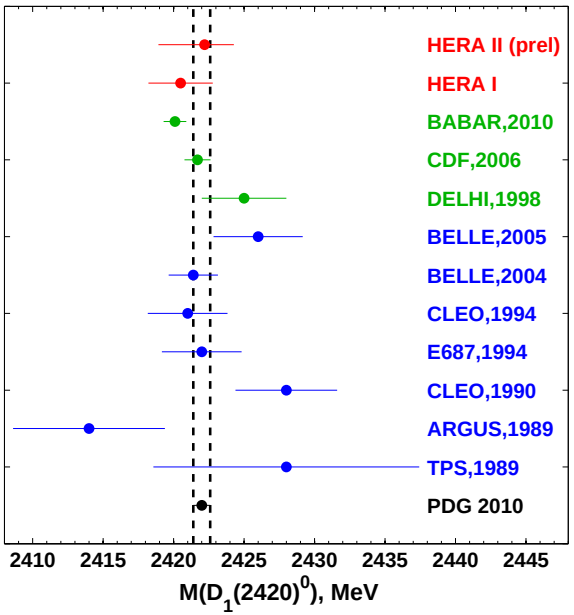
- Helicity angular parametrisation

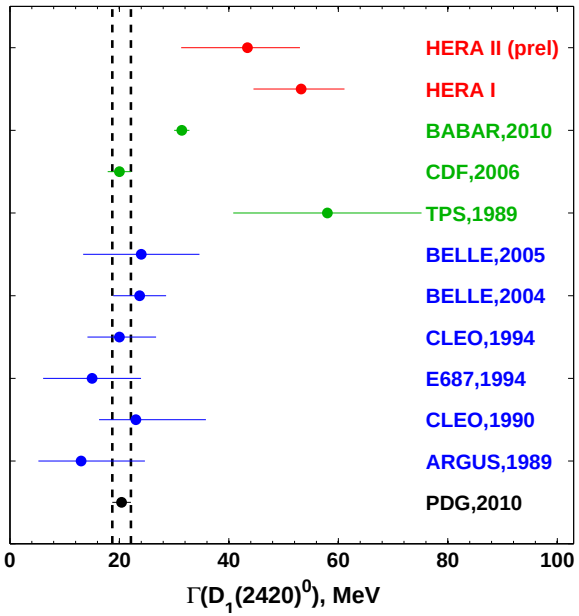
$$\frac{dN}{d\cos\alpha} \propto 1 + h\cos^2\alpha$$

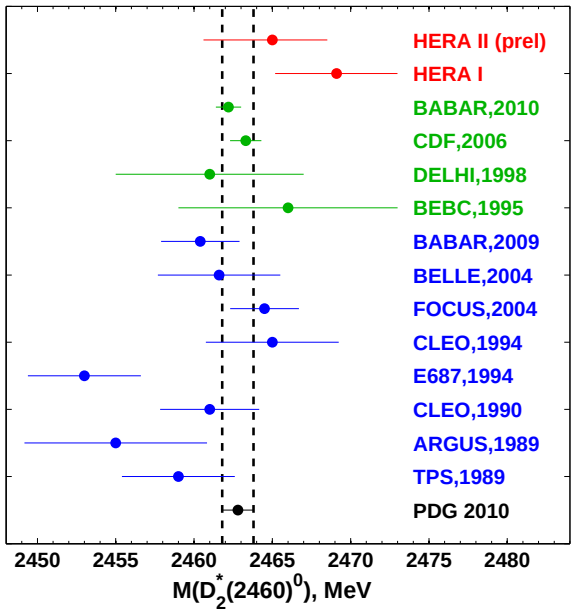
  - α – an angle between π_a and π_s momenta in the $D^{*\pm}$ rest frame
  - h – helicity parameter
- HQET predicts:
  - $h = 3$ for the 1^+ ($j = 3/2$): $D_1(2420)^0$ (pure D-wave)
  - $h = -1$ for the 2^+ ($j = 3/2$): $D_2^*(2460)^0$ (pure D-wave)
  - $h = 0$ for the 1^+ ($j = 1/2$): wide $D_1(2430)^0$ (pure S-wave)

$D_1(2420)^0$ and $D_2^*(2460)^0$ fit results and comparison

Parameter	HERAI	HERAII (prelim)	BABAR,2010	PDG,2010	PDG,2011
$M(D_1^0)$,MeV	$2420.5 \pm 2.1(stat) \pm 0.9(syst)$	$2422.2 \pm 1.7(stat)^{+1.2}_{-2.8}(syst)$	$2420.1 \pm 0.1(stat) \pm 0.8(syst)$	2422.0 ± 0.6	2421.3 ± 0.6
$\Gamma(D_1^0)$,MeV	$53.2 \pm 7.2(stat)^{+3.3}_{-4.9}(syst)$	$43.4 \pm 6.2(stat)^{+7.3}_{-10.4}(syst)$	$31.4 \pm 0.5(stat) \pm 1.3(syst)$	20.4 ± 1.7	27.1 ± 2.7
$h(D_1^0)$	$5.9^{+3.0}_{-1.7}(stat)^{+2.4}_{-1.0}(syst)$	$3.5^{+1.6}_{-1.0}(stat)^{+2.0}_{-0.8}(syst)$	5.72 ± 0.25	–	5.72 ± 0.25
$M(D_2^{*0})$,MeV	$2469.1 \pm 3.7(stat)^{+1.2}_{-1.3}(syst)$	$2465.0 \pm 3.3(stat)^{+1.2}_{-2.9}(syst)$	$2462.2 \pm 0.1(stat) \pm 0.8(syst)$	2462.8 ± 1.0	2462.6 ± 0.7
$\Gamma(D_2^{*0})$,MeV	$43(fixed)$	$43(fixed)$	$50.5 \pm 0.6(stat) \pm 0.7(syst)$	42.9 ± 3.1	49.0 ± 1.4
$h(D_2^{*0})$	$-1(fixed)$	$-1(fixed)$	-1	–	–







Points: blue – included into PDG2010 averaging, green and red (ZEUS) – not included

$S - D$ wave mixing

The general case of D- and S-wave mixing of 1^+ state:

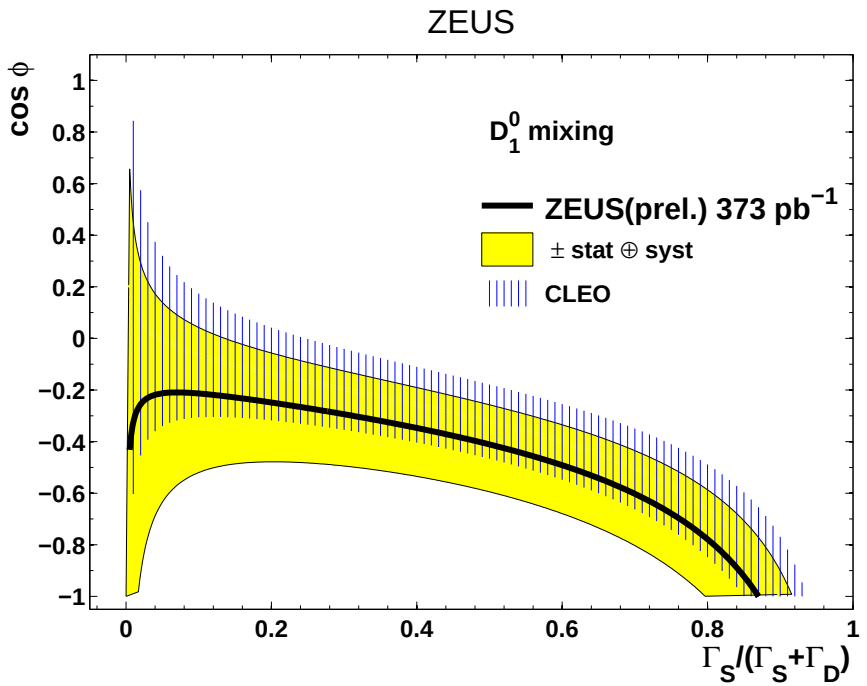
$$\frac{dN}{d\cos\alpha} \propto r + (1-r)(1+3\cos^2\alpha)/2 + \sqrt{2r(1-r)}\cos\phi(1-3\cos^2\alpha),$$

where

- $r = \frac{\Gamma_S}{\Gamma_S+\Gamma_D}$
- ϕ – the relative phase between two amplitudes

$\cos\phi$ can be expressed in terms of r and the measured helicity paramter, h:

$$\cos\phi = \frac{(3-h)/(3+h) - r}{2\sqrt{2r(1-r)}}$$



Summary

- The production of the excited charm mesons $D_1(2420)^0$ and $D_2^*(2460)^0$ in ep collisions was measured with the ZEUS detector at HERA using an integrated luminosity of 373 pb^{-1} (HERAII)
- The masses, widths and helicity parameters of these resonances were determined and compared with previous measurements, with theoretical expectations and with published ZEUS results of an independent sample with an integrated luminosity of 126 pb^{-1} (HERAI)
- The measured $D_1(2420)^0$ width is found to be above the world average value in both cases, consistent with a recent BaBar high-statistics result
- The measured $D_1(2420)^0$ helicity parameter allows for some mixing of S- and D-waves in its decay to $D^*\pi$ however the result is also consistent with the prediction for a pure D-wave decay