Spectroscopy of the excited charm mesons and measurement of fragmentation fractions

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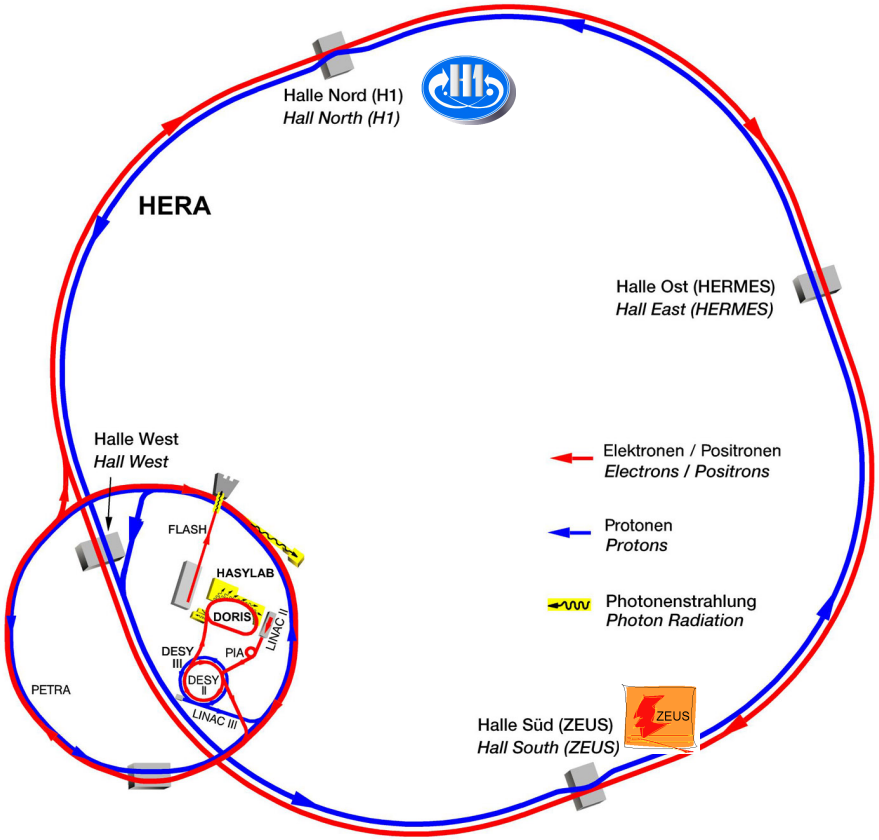
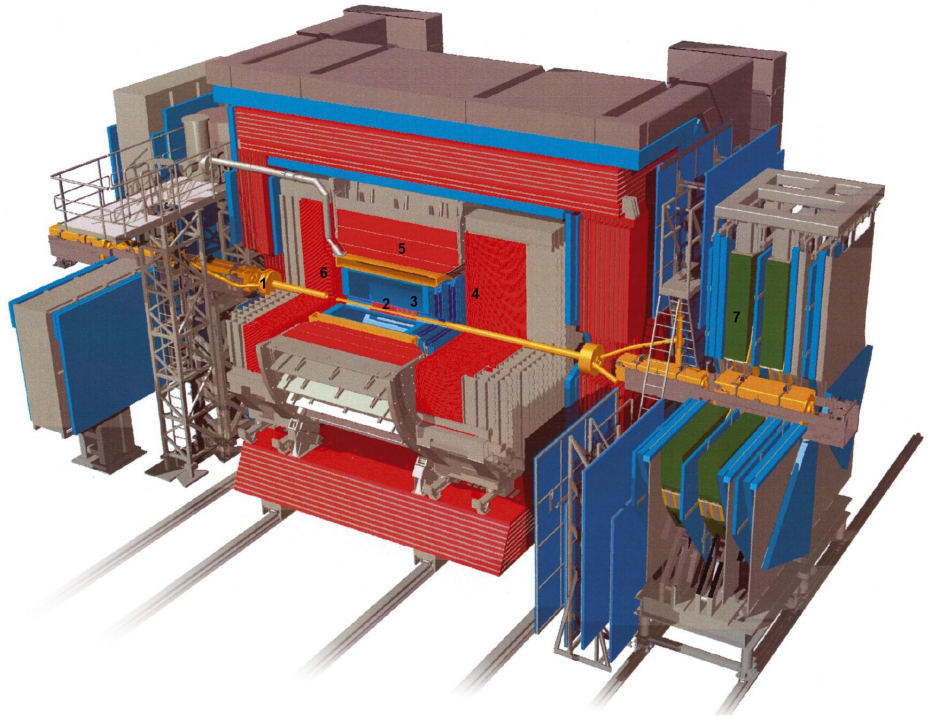
Outline:

1. Charm production at HERA
2. Measurement of charm fragmentation fractions
3. Excited charm spectroscopy

Introduction

HERA collider. ZEUS experiment.





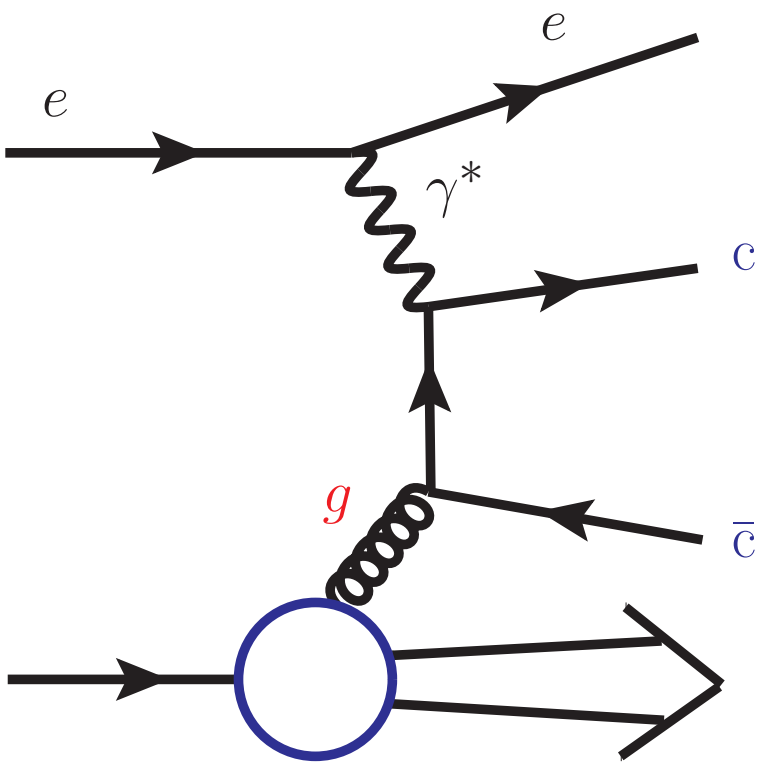
HERA storage ring:

- located at Hamburg, Germany;
- operated during 1992 — 2007;
- ep collisions;
- $\sqrt{s} = 300, 318$ GeV.

ZEUS collider experiment:

- Silicon microvertex detector;
- collected ~ 0.5 fb^{-1} of integrated luminosity.

Charm-quark production at HERA.



- charm production cross section can reach up to 30% of total inelastic cross section at HERA;
- rich physics program for study of charmed states.

Measurements of:

- meson masses, width and angular distributions;
- fragmentation fraction;
- test of fragmentation universality;
- and many more ...

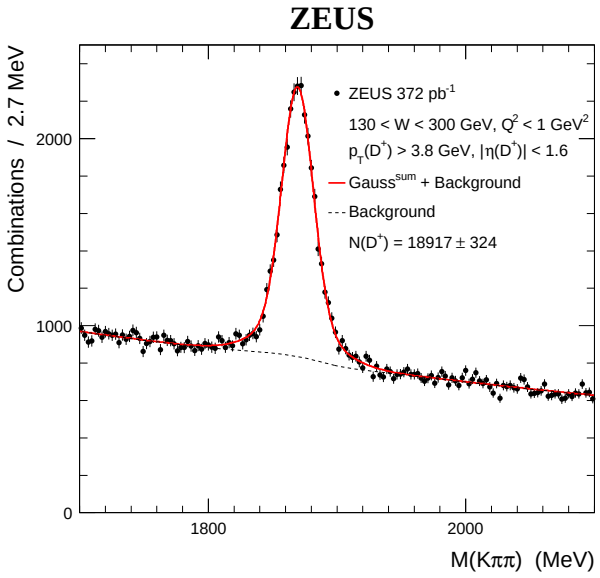
Charm fragmentation fractions in photoproduction

DESY-13-106

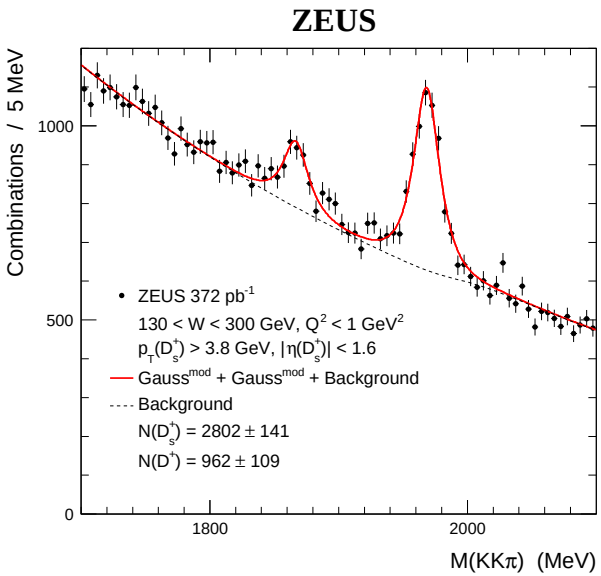
Accepted by JHEP

Reconstruction of $D^{\pm}$, $D_s^{\pm}$ mesons, Λ_c^+ baryon

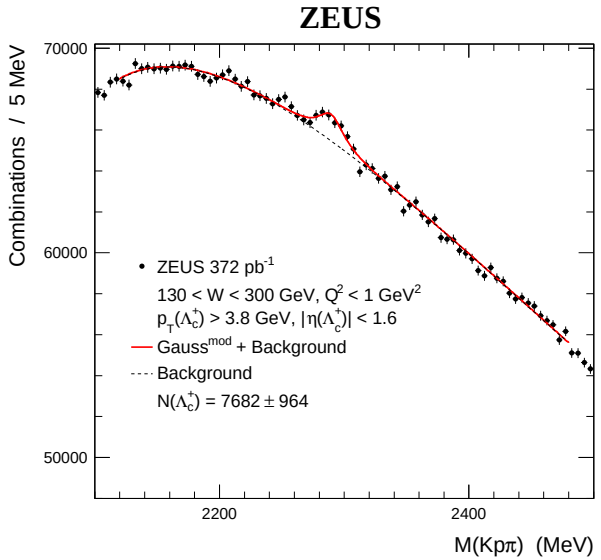
$D^+ \to K^-\pi^+\pi^+$



$D_s^+ \to \phi\pi^+ \to K^-K^+\pi^+$



$\Lambda_c^+ \to K^-p\pi^+$

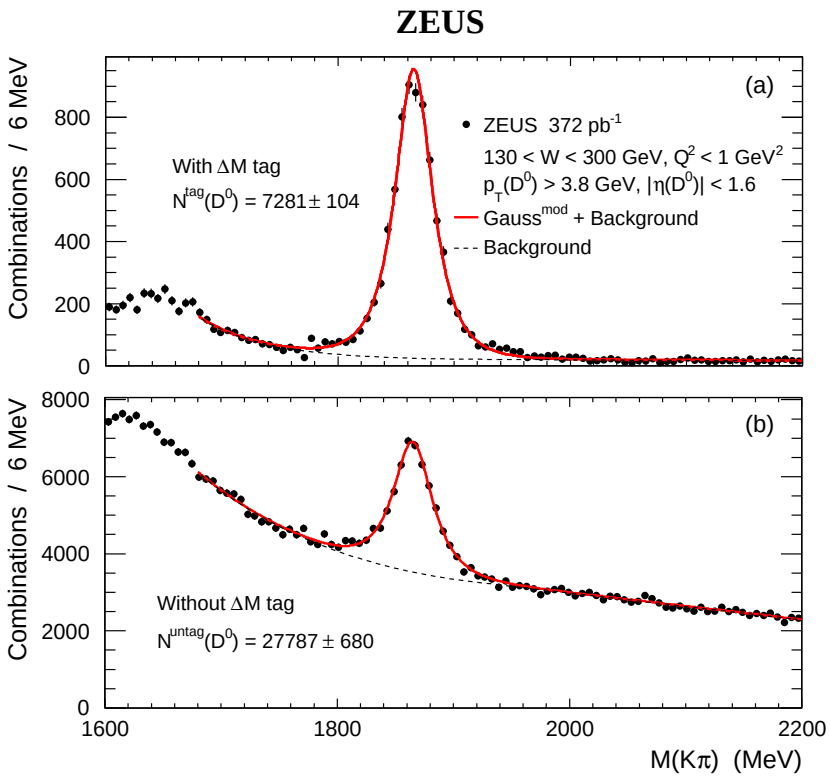


- $W = \sqrt{ys}$ - γp c.m. energy
- $Q^2 = -(l - l')^2$

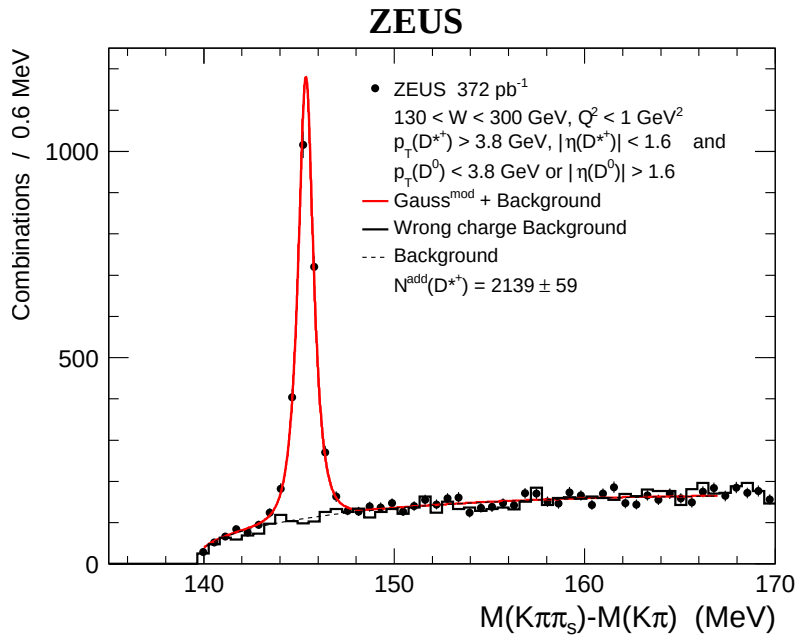
Total rate for the Ξ_c^+, Ξ_c^0, Ω_c^0 estimated from MC to be 14% of Λ_c^+

Reconstruction of D^0, D^* mesons

$$D^0 \to K^-\pi^+$$



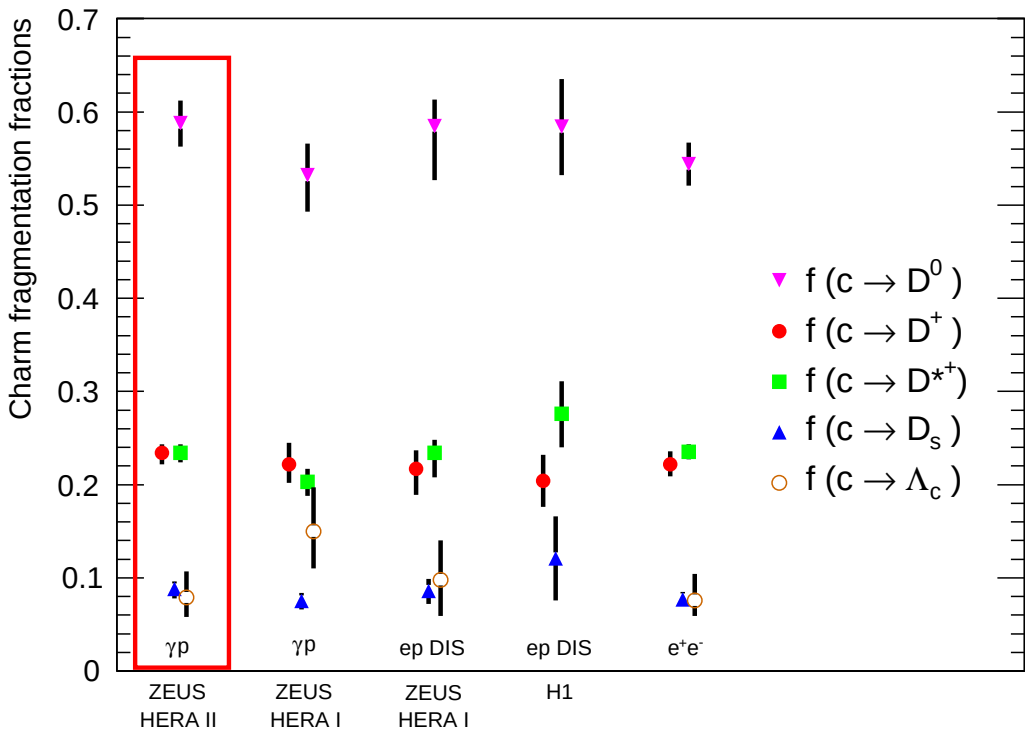
$$D^{*+} \to D^0\pi_s^+ \to K^-\pi^+\pi_s^+$$



Separation of D^0 candidates in two subsamples:

- D^0 originating from $D^{*+} \to D^0\pi_s^+$ (ΔM tag)
- without ΔM tag

Fragmentation fractions



$$f\left(c \to D, \ldots, \Lambda_c\right) = \frac{\sigma_{D,\Lambda_c}}{\sigma_{\mathrm{gs}}}$$

σ_{D,Λ_c} - hadron production cross section

$$\sigma_{\mathrm{gs}} = \sigma^{\mathrm{eq}}\left(D^+\right) + \sigma^{\mathrm{eq}}\left(D^0\right) + \sigma\left(D_s^+\right) + 1.14 \cdot \sigma^{\mathrm{eq}}\left(\Lambda_c\right)$$

- $Q^2 < 1\ \mathrm{GeV}^2$
- $130 < W < 300\ \mathrm{GeV}$
- $p_T\left(D, D^*, \Lambda_c\right) > 3.8\ \mathrm{GeV}$
- $\left|\eta\left(D, D^*, \Lambda_c\right)\right| < 1.6$

The data support the hypothesis that fragmentation is independent of the production process

Excited charm mesons

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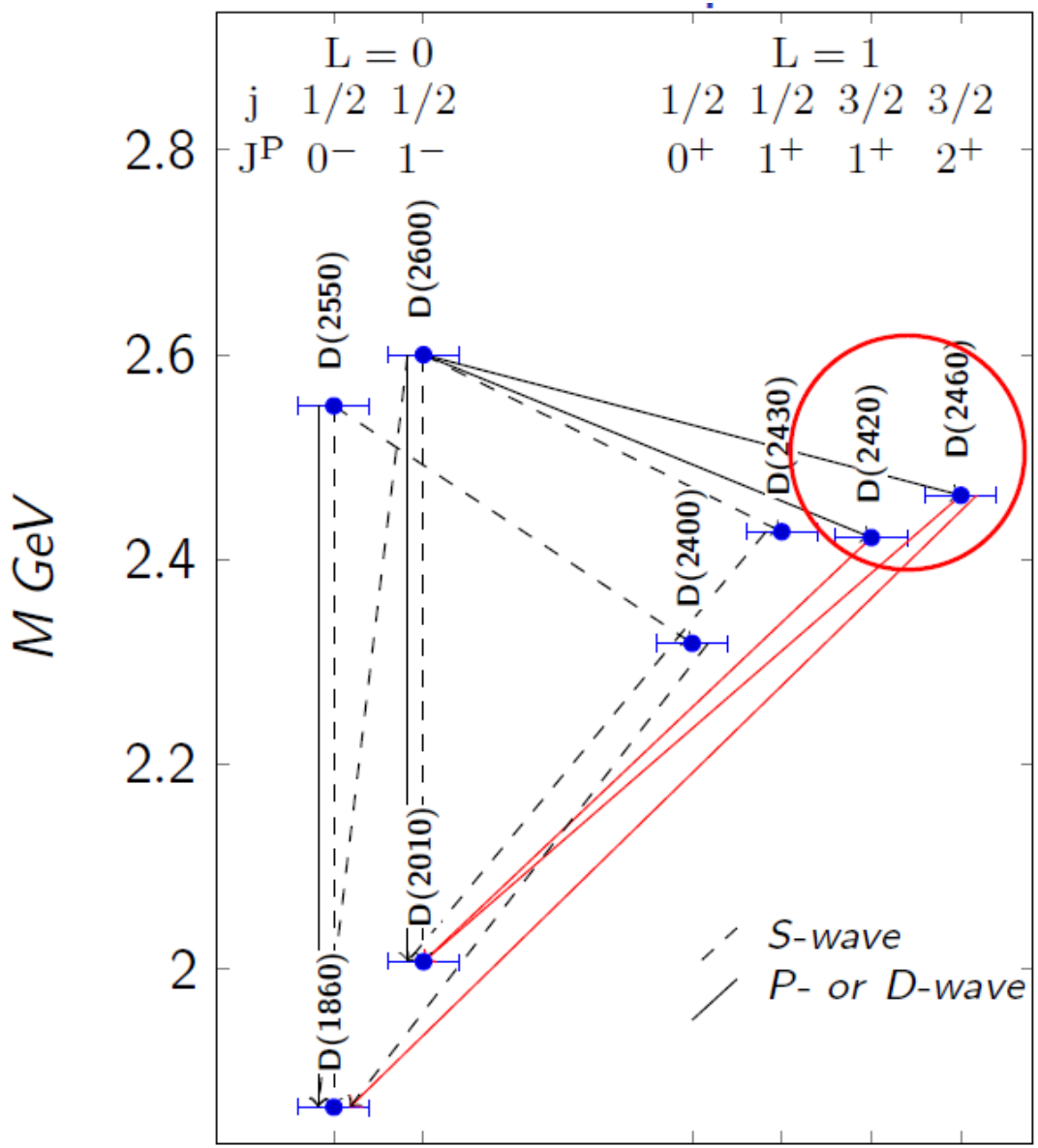
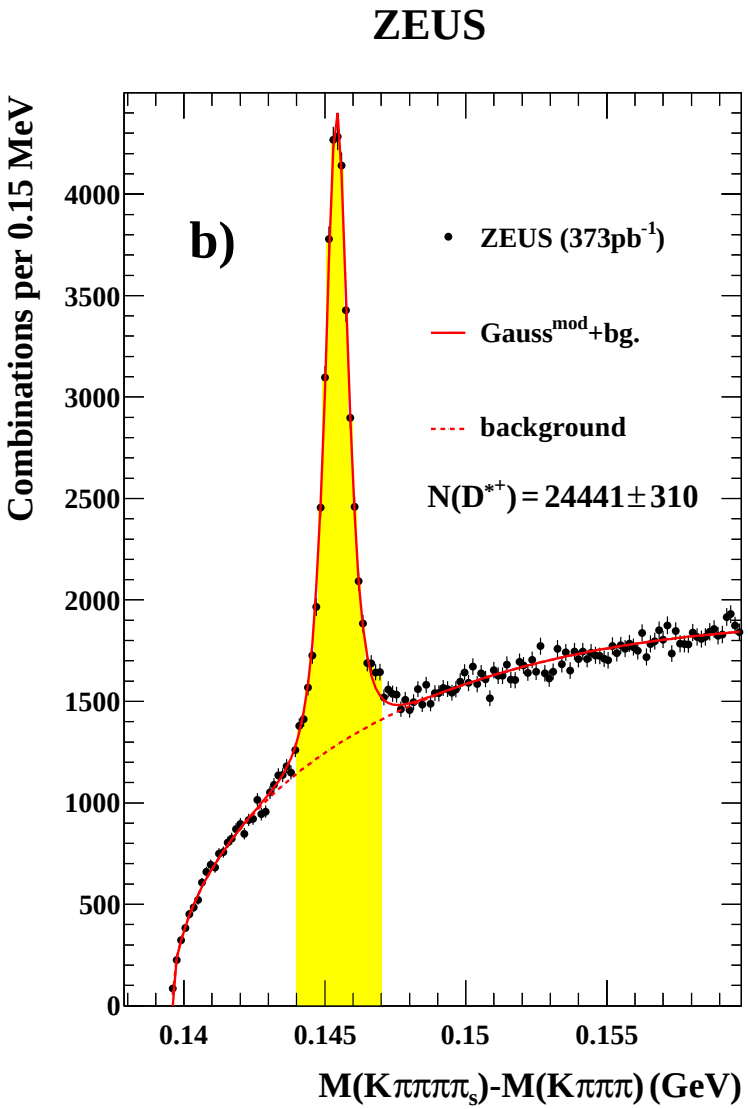
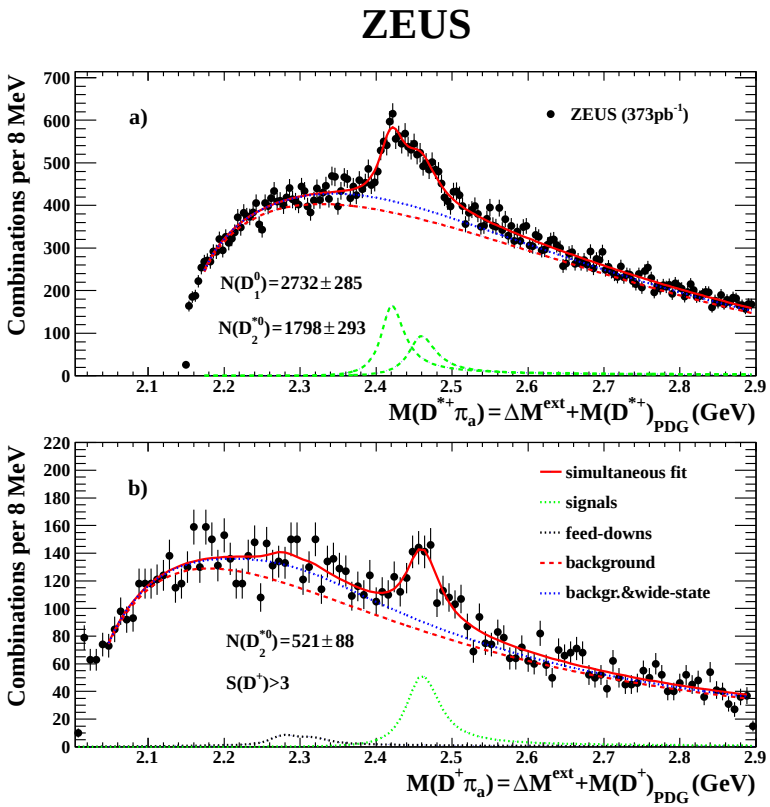


Neutral excited states

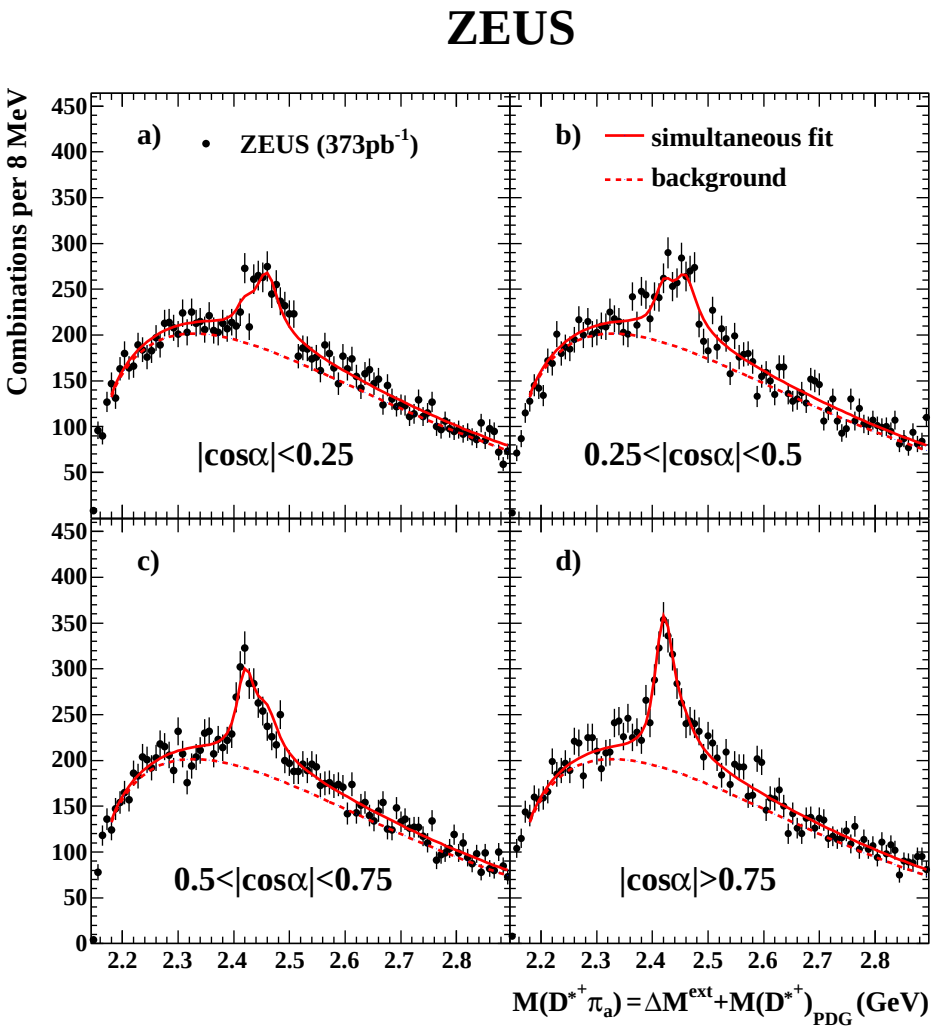
Reconstruction of D^{*+}, $D^{*+}\pi_a^-$ and $D^+\pi_a^-$





The solid curves are the result of a simultaneous fit.

Reconstruction of D_1^0, D_2^{*0}



The splitting into four bins helps to separate D_1^0, D_2^{*0}. Distribution in α, the angle between π_a and π_s in D^{*+} c.m., is predicted to be

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

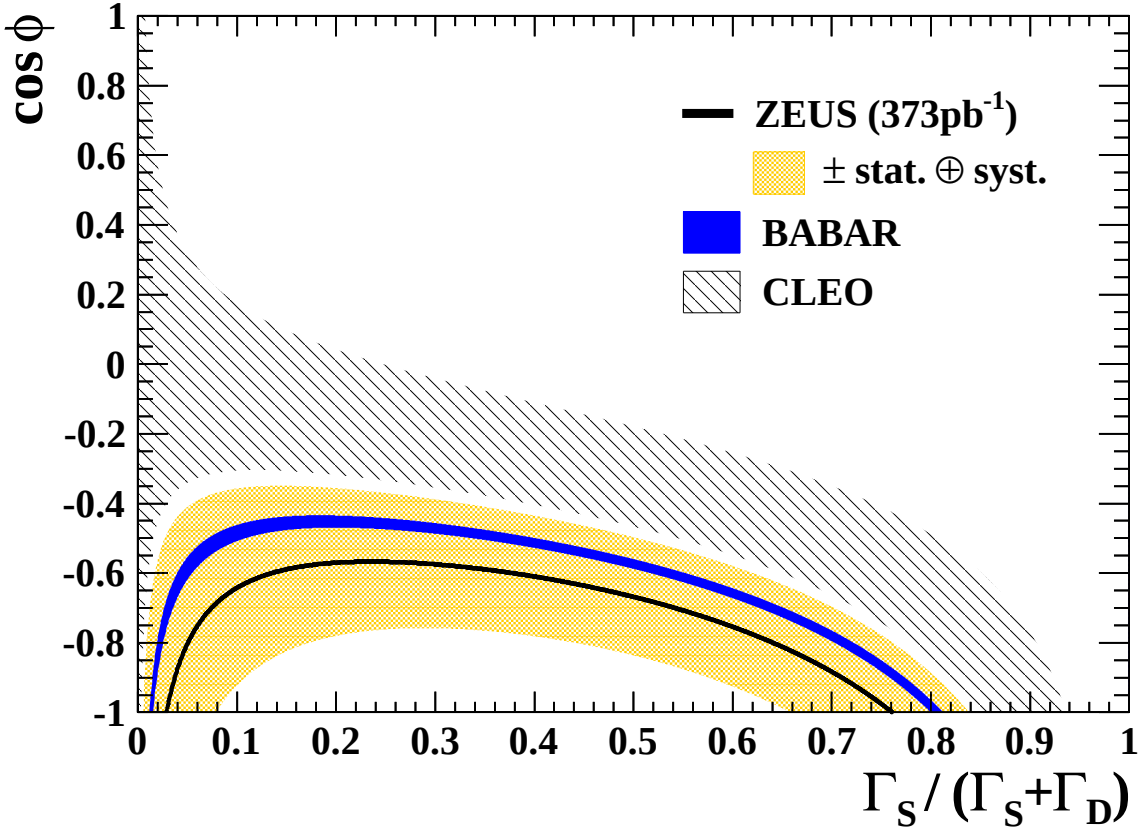
where h is a helicity parameter.

Neutral states spectroscopy measurements

	HERA II	HERA I	PDG
$M(D_1^0)$, MeV	$2423.1 \pm 1.5^{+0.4}_{-1.0}$	$2420.5 \pm 2.1 \pm 0.9$	2421.3 ± 0.6
$\Gamma(D_1^0)$, MeV	$38.8 \pm 5.0^{+1.9}_{-5.4}$	$53.2 \pm 7.2^{+3.3}_{-4.9}$	27.1 ± 2.7
$h(D_1^0)$	$7.8^{+6.7+4.6}_{-2.7-1.8}$	$5.9^{+3.0+2.4}_{-1.7-1.0}$	
$M(D_2^{*0})$, MeV	$2462.5 \pm 2.4^{+1.3}_{-1.1}$	$2469.1 \pm 3.7^{+1.2}_{-1.3}$	2462.6 ± 0.7
$\Gamma(D_2^{*0})$, MeV	$46.6 \pm 8.1^{+5.9}_{-3.8}$	43 fixed	49.0 ± 1.4
$h(D_2^{*0})$	-1 fixed	-1 fixed	

Measurements are consistent with PDG

Indication of S/D-wave mixing



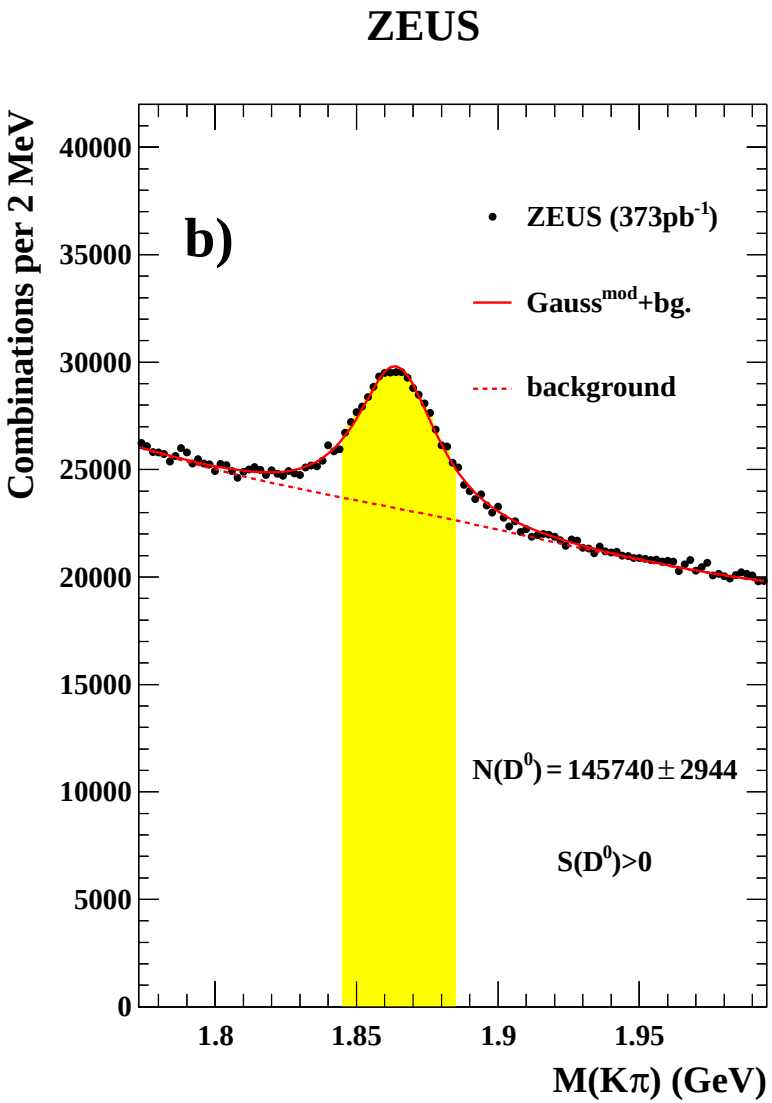
For mixed S/D-wave decay with the relative phase of S- and D-wave amplitudes ϕ and the fraction of S-wave

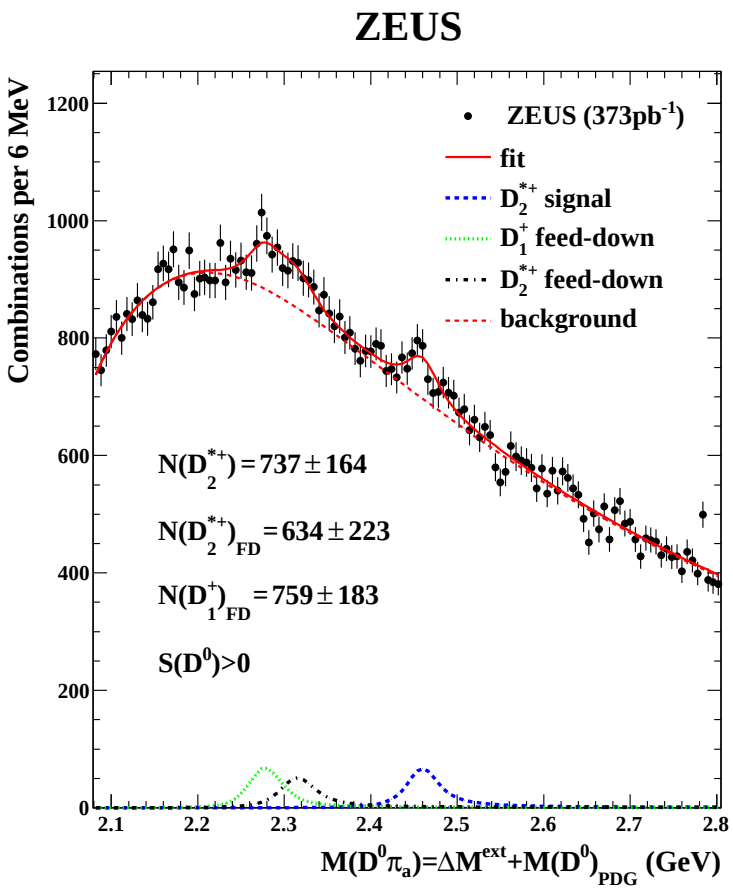
$$r = \frac{\Gamma_s}{\Gamma_s + \Gamma_D}$$

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

Charged excited states

Reconstruction of D^0 and $D^0\pi_a$





Charged states spectroscopy measurements

	HERA II	PDG
$M(D_1^+)$, MeV	$2421.9 \pm 4.7^{+3.4}_{-1.2}$	2423.4 ± 3.1
$\Gamma(D_1^+)$, MeV	25 fixed	25 ± 6
$h(D_1^+)$	3.0 fixed	
$M(D_2^{*+})$, MeV	$2460.6 \pm 4.4^{+3.6}_{-0.8}$	2464.4 ± 1.9
$\Gamma(D_2^{*+})$, MeV	37 fixed	37 ± 6
$h(D_2^{*+})$	-1.0 fixed	

First measurement of charged excited charmed mesons properties at HERA

Fragmentation fractions and branching ratios for excited states

	$f\left(c \to D_1^0\right)$	$f\left(c \to D_2^{*0}\right)$	$f\left(c \to D_1^+\right)$	$f\left(c \to D_2^{*0}\right)$
HERA II	$2.9 \pm 0.5^{+0.5}_{-0.5}$	$3.9 \pm 0.9^{+0.8}_{-0.6}$	$4.6 \pm 1.8^{+2.0}_{-0.3}$	$3.2 \pm 0.8^{+0.5}_{-0.2}$
HERA I	$3.5 \pm 0.4^{+0.4}_{-0.6}$	$3.8 \pm 0.7^{+0.5}_{-0.6}$		
OPAL	$2.1 \pm 0.7 \pm 0.3$	$5.2 \pm 2.2 \pm 1.3$		

- measurements of fragmentation fractions are most precise and support fragmentation universality;
- first measurements of $f\left(c \to D_1^+\right)$ and $f\left(c \to D_2^{*+}\right)$.

	$\frac{\mathcal{B}_{D_2^{*0} \to D^+ \pi^-}}{\mathcal{B}_{D_2^{*0} \to D^{*+} \pi^-}}$	$\frac{\mathcal{B}_{D_2^{*+} \to D^0 \pi^+}}{\mathcal{B}_{D_2^{*+} \to D^{*0} \pi^+}}$
HERA II	$1.4 \pm 0.3^{+0.3}_{-0.3}$	$1.1 \pm 0.4^{+0.3}_{-0.2}$
HERA I	$2.8 \pm 0.8^{+0.5}_{-0.6}$	
PDG	1.56 ± 0.16	$1.9 \pm 1.1 \pm 0.3$
MODEL A	2.280 ± 0.007	2.266 ± 0.015
MODEL B	$2.3 \ldots 3.0$	

- valuable contribution to the measurements of branching ratios.

Summary and conclusions

- ZEUS measurements of charmed states with about **3 to 4.5** larger than previous analyses statistics has been presented

- Determinations of
  - fragmentation fractions $f\,(c \to D, \ldots, \Lambda_c)$;
  - the data confirm universality of fragmentation with high precision.

  - spectroscopic properties of D_1 and D_2^* states;
  - fractions of c-quarks hadronising into D_1 and D_2^* **(including one of the first measurements of the** D_1^+ **)**;
  - ratios of branching fractions of the two decay modes of the D_2^{*0} and $D_2^{*\pm}$ states.