Measurement of charm fragmentation fractions in PHP and the production of the excited charm mesons at HERA

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(On behalf of the ZEUS collaboration)

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Charm meson spectroscopy

- **Charm systems are the most interesting case during the last decade, after unexpected discoveries (BaBar and Belle):**

2003: $D_{s0}^{*}(2317)^{+} \to D_{s}^{+}\pi^{0}$ and $D_{s1}(2460)^{+}$

2006-2007: $D_{s1}^{*}(2710)^{+}$ and $D_{sJ}^{*}(2860)^{+}$

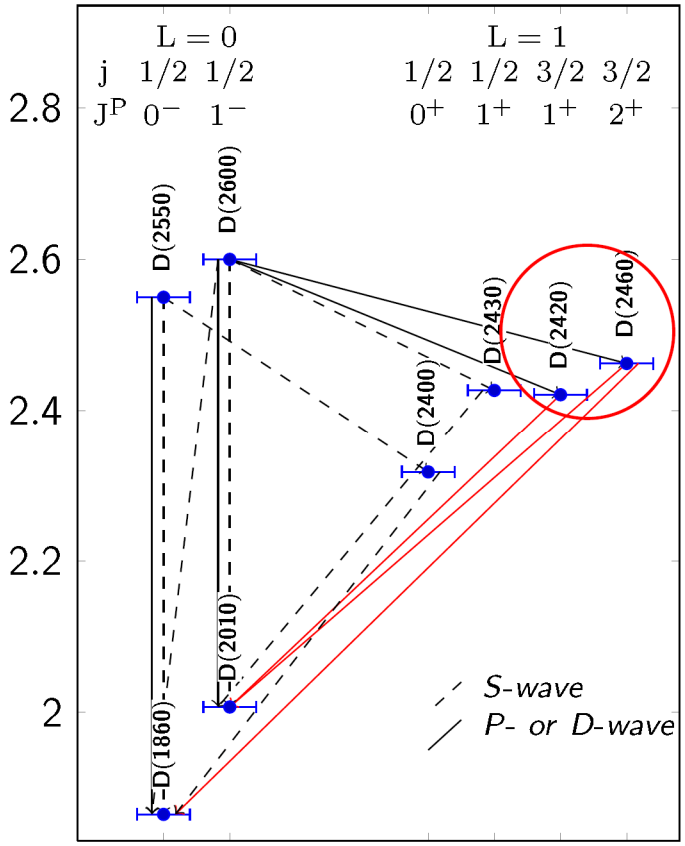
These states confirmed recently by LHCb.

- ***J = L + S***

L=0: Doublet with $(0^{-}, 1^{-})$: (D, D^{*})

L=1: Two doublets: $J^{P} = (0^{+}, 1^{+})$: (D_{0}^{*}, D_{1}')

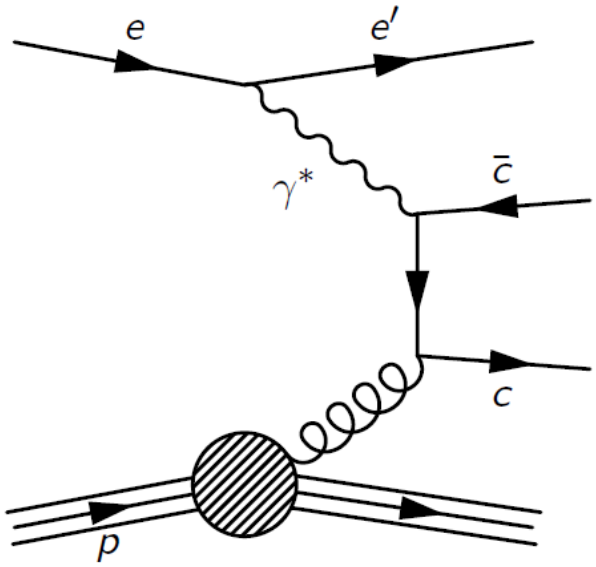
$J^{P} = (1^{+}, 2^{+})$: (D_{1}, D_{2}^{*})



Ground states: D^{0}, D^{*+} and D^{+}

Charm mesons at HERA

- boson-gluon fusion is a dominant process for the charm creation in DIS;
- charm contribution to the inclusive DIS cross section is up to 30% at HERA;
- charm production sensitive to the gluon density of the proton;
- possibility to test pQCD;
- better understanding of the charm is one of the key issues for LHC experiments;



New charm meson results from ZEUS

- **excited charm meson masses, widths, angular distributions, branching ratios and charm quark fragmentation fractions**

  measured for: $D_1^0(2420), D_2^{*0}(2460)$
  $D_1^+(2420), D_2^{*+}(2460)$

  these mesons were reconstructed in the decay channels with D^0, D^{*+} and D^+

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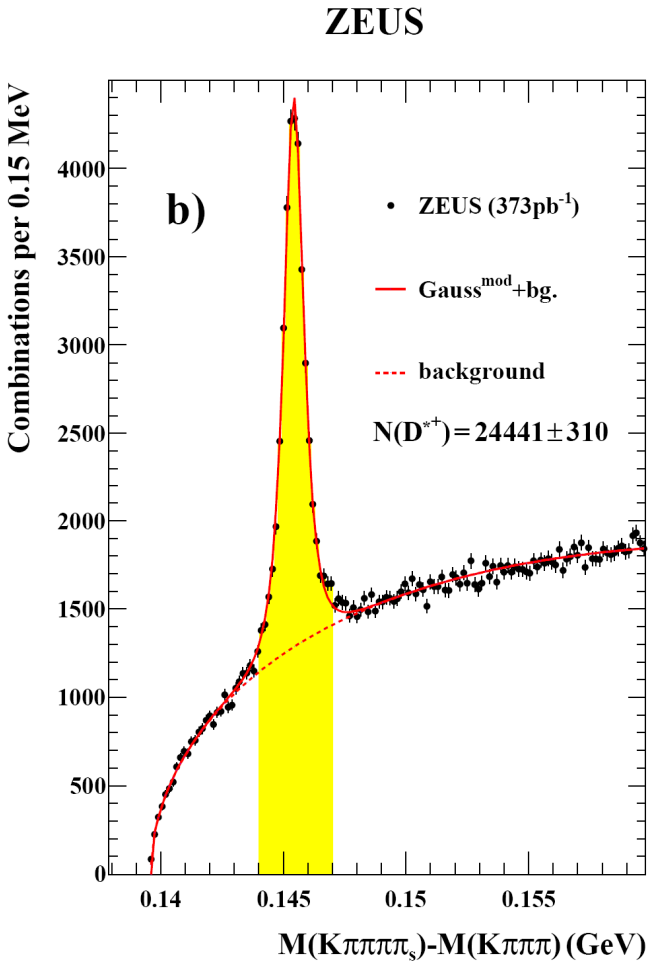
- **fractions of charm quarks hadronising as a particular charm hadrons**

  derived for: D^*, D^+, D^0, D_s^+ *and* Λ_c

- 373 pb^{-1} data sample (full statistics HERA II)

Excited Charm Production

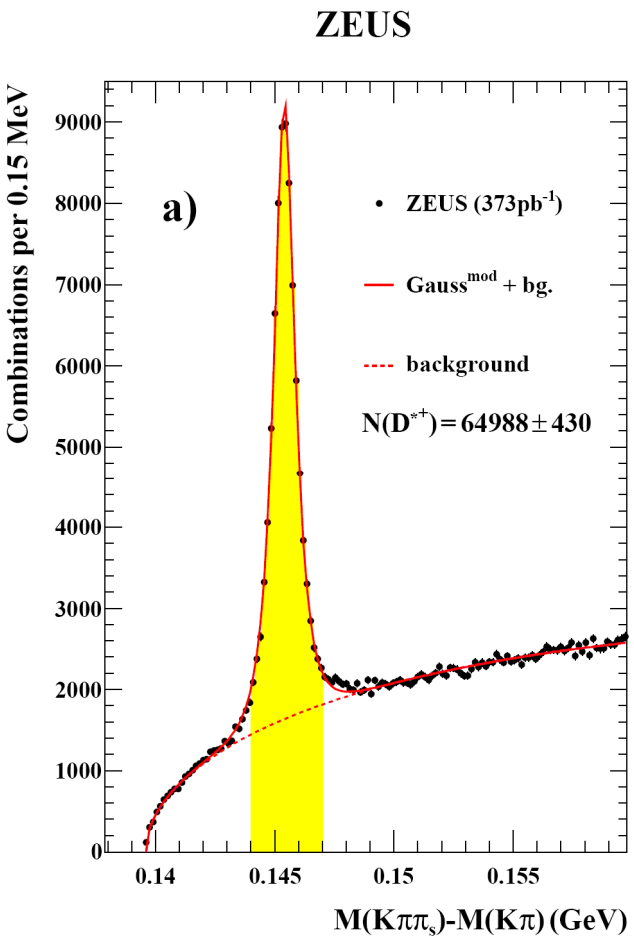
3-prong and 5-prong D^{*+} decay reconstruction



$D^{*+} \to K3\pi\pi_s$

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

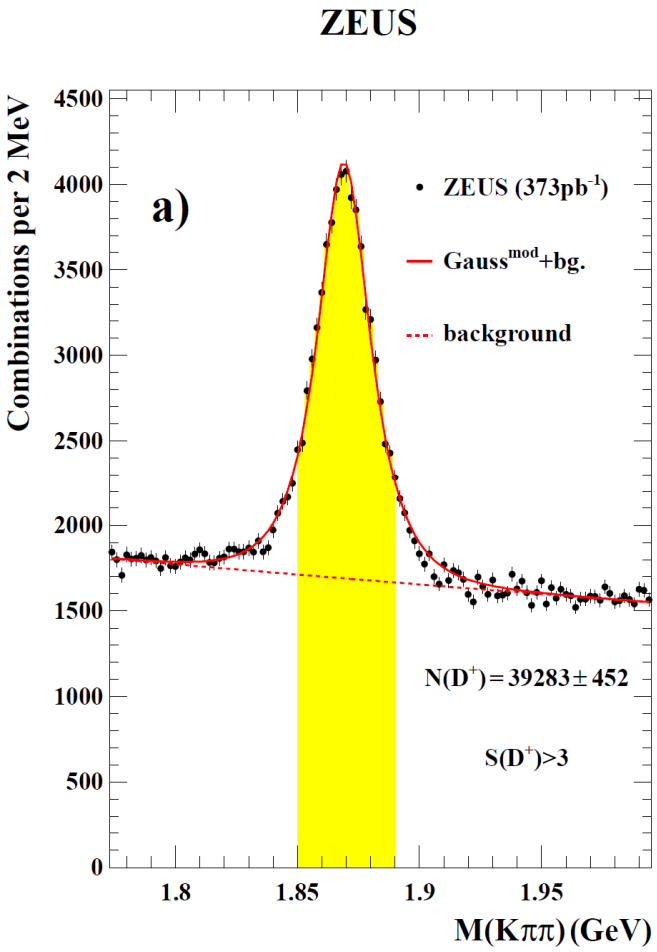
clear signal !
~90,000 D*+



Yellow area: D* in the mass range $0.144 < \Delta M < 0.147$ GeV combined with an additional track, assumed to be $\pi^{\pm}$

→ for the excited charm meson reconstruction;

D^+ and D^0 decay reconstruction

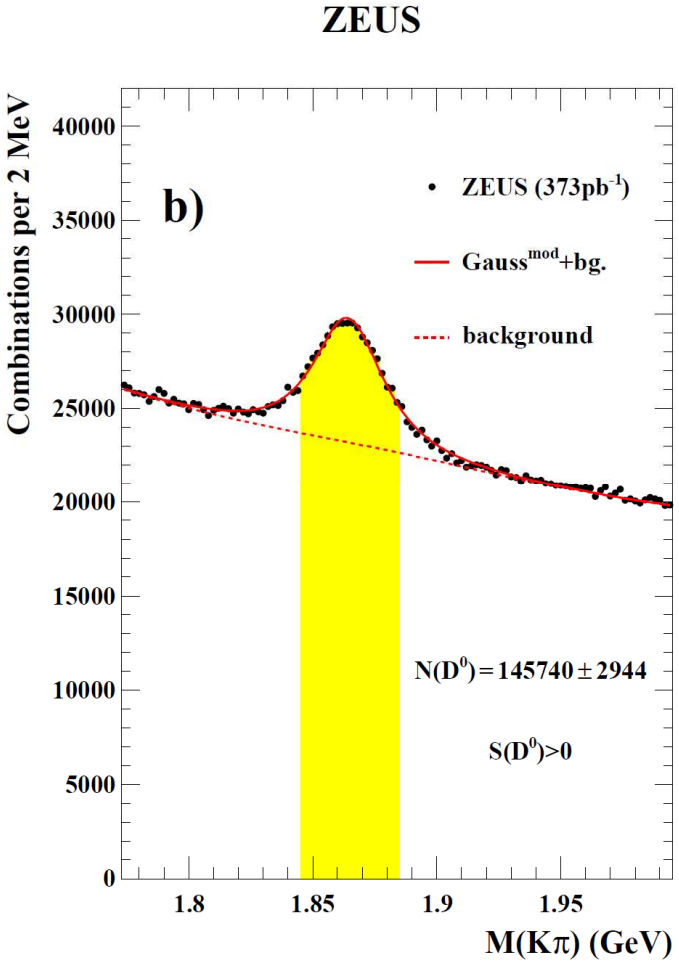


$D^+ \to K^-\pi^+\pi^+$

~40,000 D^+

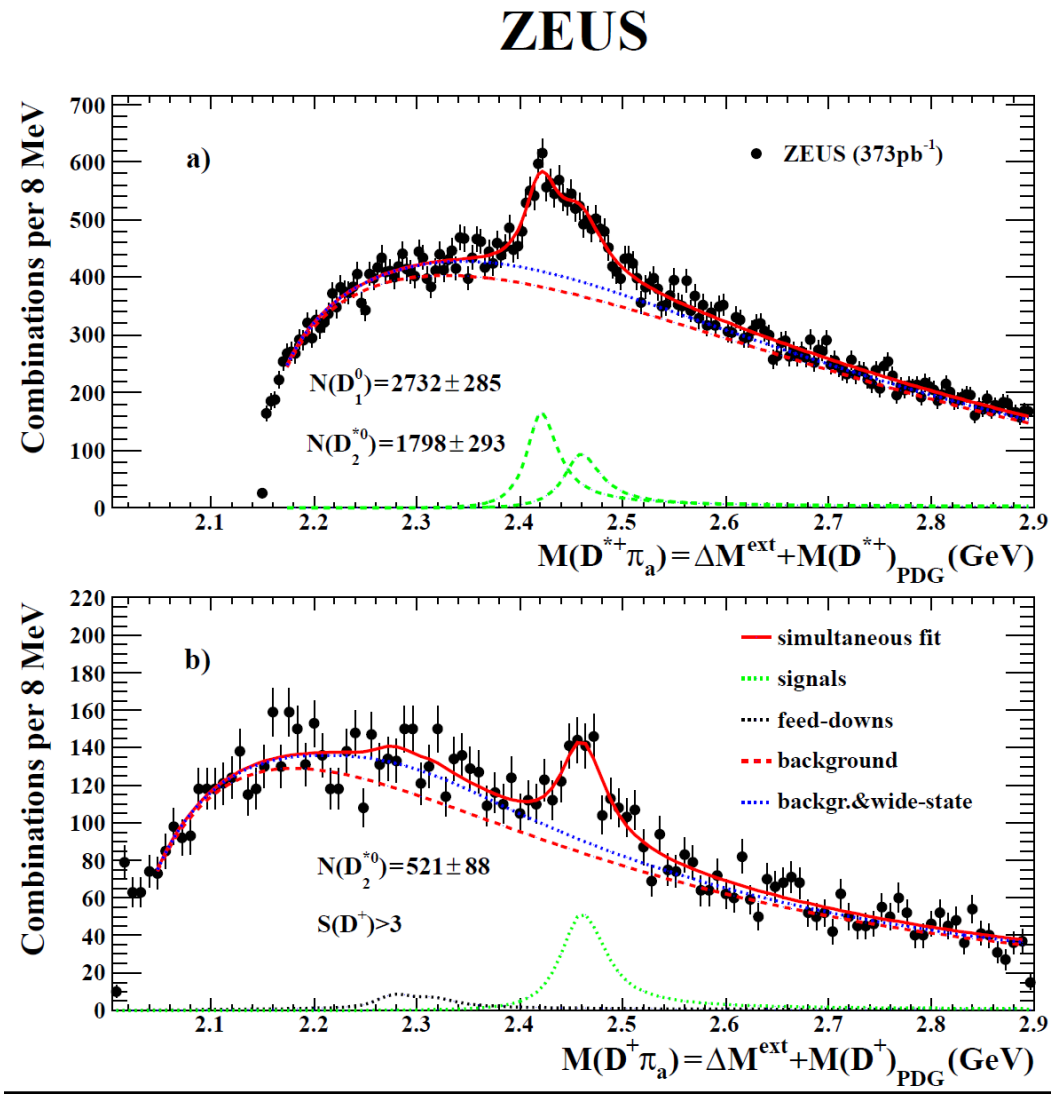
$D^0 \to K^-\pi^+$

~145,000 D^0



Yellow area: D^+ and D^0 in these mass ranges combined with additional $\pi^\pm$ for the excited charm meson reconstruction

$D^*\pi^-$ and $D^+\pi^-$ mass spectra

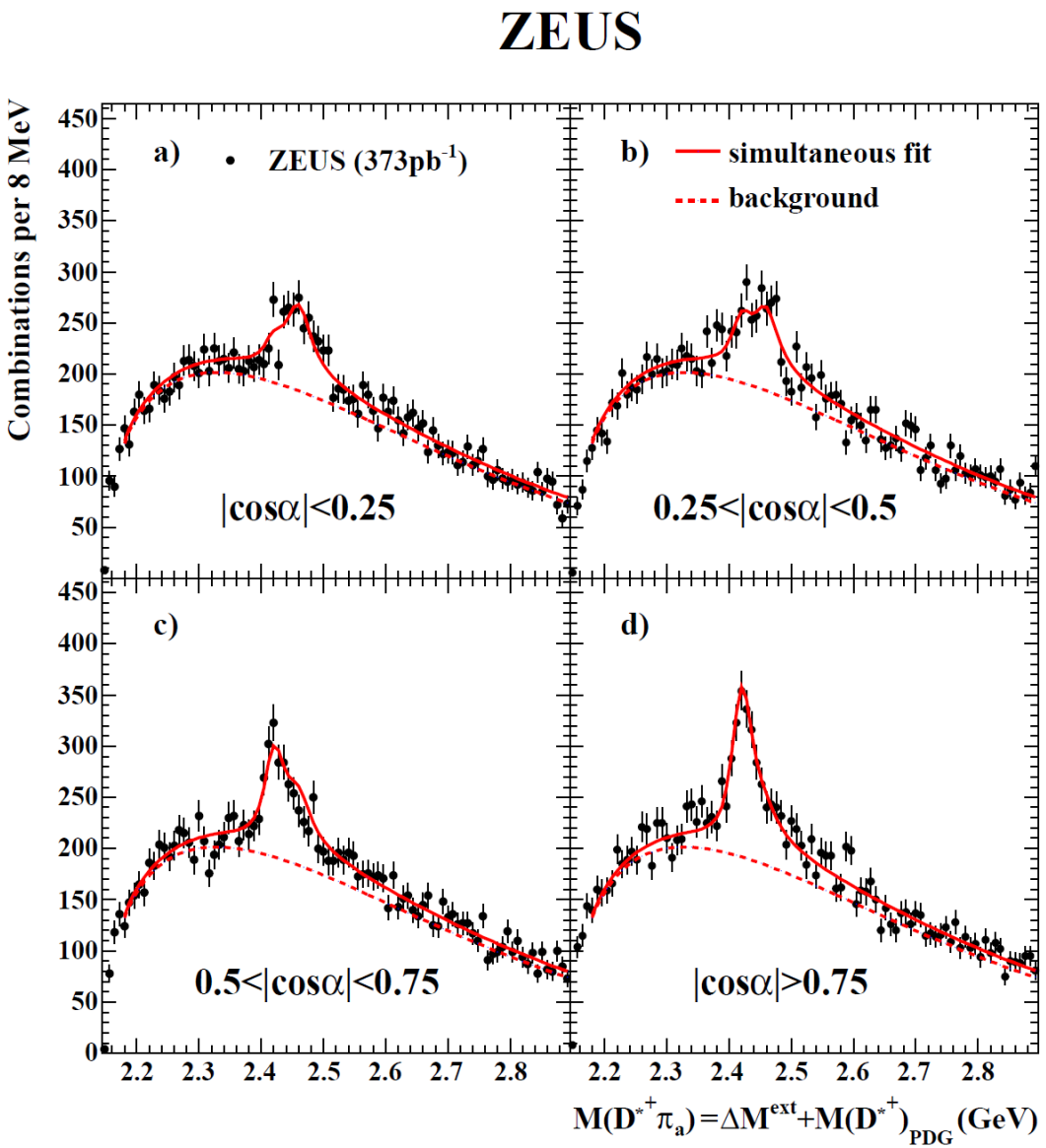


$$D_1^+ \to D^{*0}\pi^+$$

$$D_2^{*+} \to D^{*0}\pi^+$$

$$D_2^*(2460)^0 \to D^+\pi^-$$

$D^*\pi^-$ and $D^+\pi^-$ mass spectra in cosα bins



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

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

where h is a helicity parameter.

Results of the simultaneous fit for the yields, masses, widths and helicity parameters of the neutral D-mesons

	HERA II	HERA I	PDG
$N(D_1^0 \to D^{*+}\pi)$	2732 ± 285	3110 ± 340	
$N(D_2^{*0} \to D^{*+}\pi)$	1798 ± 293	870 ± 170	
$N(D_2^{*0} \to D^{+}\pi)$	521 ± 88 $(S(D^+) > 3)$	690 ± 160	
$M(D_1^0)$, 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

Results are compared to earlier ZEUS results at HERA I and PDG:

Good consistency with older results and PDG.!

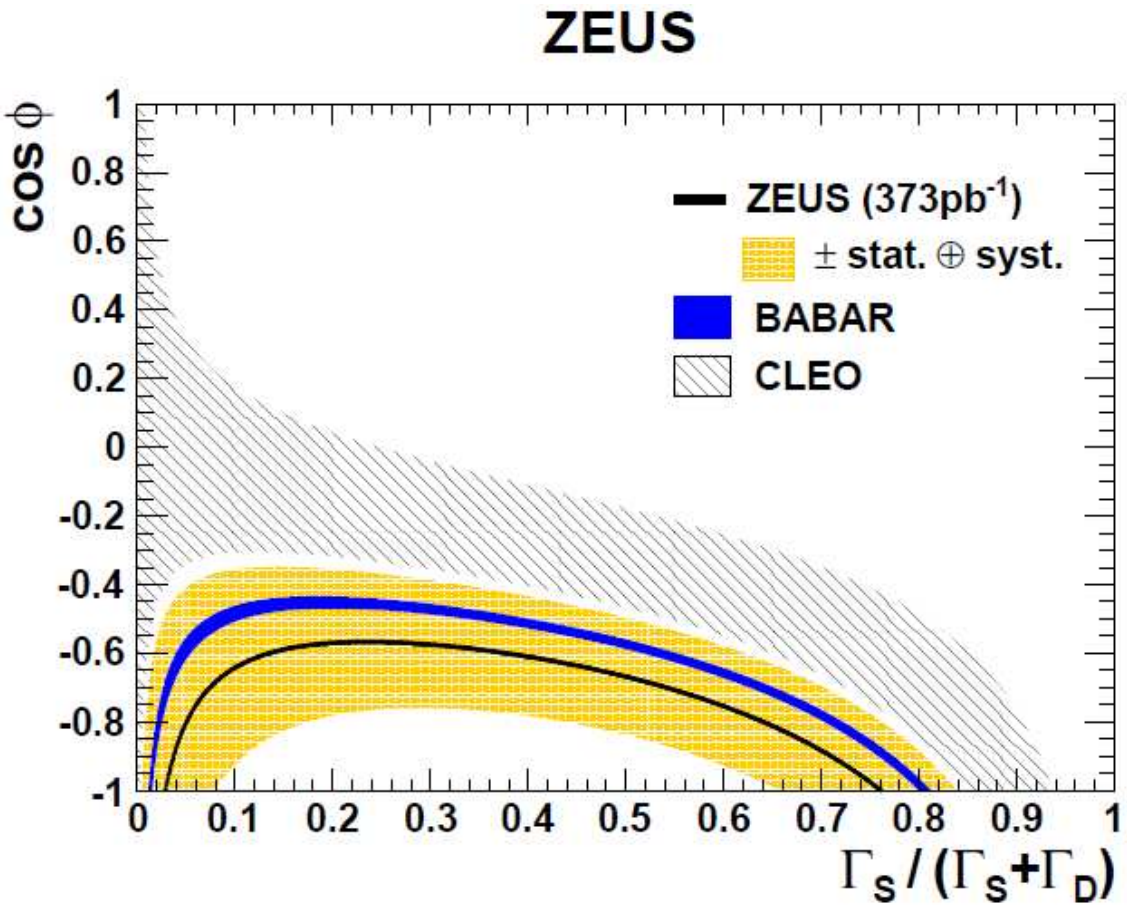
Results of the simultaneous fit for the yields, masses, widths and helicity parameters of the charged D-mesons

	HERA II	PDG
$N(D_1^+ \to D^{*0}\pi^+)$	759 ± 183	
$N(D_2^{*+} \to D^{*0}\pi^+)$	634 ± 223	
$N(D_2^{*+} \to D^0\pi^+)$	737 ± 164	
$M(D_1^+)$, 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	

Good consistency with PDG

Only few previous results on D_1^+ (BABAR and CLEO)

Indication of *S*- and *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 $r = \frac{\Gamma_S}{\Gamma_S+\Gamma_D}$:

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

Fragmentation fraction measurements

Fragmentation fractions: $f(c \to D) = \frac{N(D)}{N(c)}$

$$f(c \to D_2^{*0}) = 3.9 \pm 0.9(\text{stat.})^{+0.8}_{-0.6}(\text{syst.})\,\%$$

$$f(c \to D_1^{0}) = 2.9 \pm 0.5(\text{stat.}) \pm 0.5(\text{syst.})\,\%$$

$$f(c \to D_1^{+}) = 4.6 \pm 1.8(\text{stat.})^{+2.0}_{-0.3}(\text{syst.})\,\%$$

$$f(c \to D_2^{*+}) = 3.2 \pm 0.8(\text{stat.})^{+0.5}_{-0.2}(\text{syst.})\,\%$$

First measurements!

For comparison:

	$f(c \to D_1^0)$	$f(c \to D_2^{*0})$
HERA-I	$3.5 \pm 0.4^{+0.4}_{-0.6}$	$3.8 \pm 0.7^{+0.5}_{-0.6}$
OPAL[3]	$2.1 \pm 0.7 \pm 0.3$	$5.2 \pm 2.2 \pm 1.3$

ZEUS measurements of fragmentation fractions are the most precise and supports fragmentation universality.

Branching ratios

	$\frac{\mathcal{B}_{D_2^{*0}\to D^+\pi^-}}{\mathcal{B}_{D_2^{*0}\to D^{*+}\pi^-}}$	$\frac{\mathcal{B}_{D_2^{*+}\to D^0\pi^+}}{\mathcal{B}_{D_2^{*+}\to D^{*0}\pi^+}}$
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	$1.9 \pm 1.1 \pm 0.3$

Consistent with PDG and theoretical calculations* :

~ 2.3 for both ratios

* Phys. Rev. D 86 (2012) 054024

Measurement of charm fragmentation fractions in photoproduction

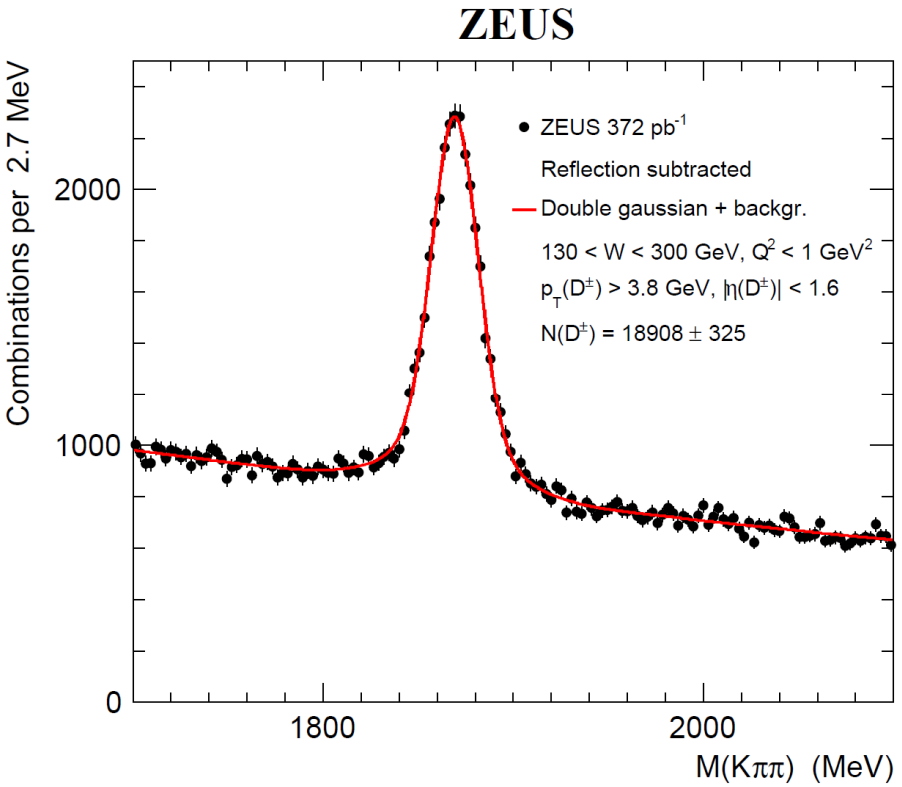
- **Determined fragmentation fractions of charm hadrons with HERA II data(372pb^{-1}), i.e. the probability of c-quark to hadronize into particular charm meson $f(c \to D^0, D^+, D_s^+, D^{*+}, \Lambda_c)$**

- **Kinematic range: transverse momentum $p_T(D^0, D^+, D_s^+, D^{*+}, \Lambda_c)$ and pseudorapidity $\eta(D^0, D^+, D_s^+, D^{*+}, \Lambda_c)$;**

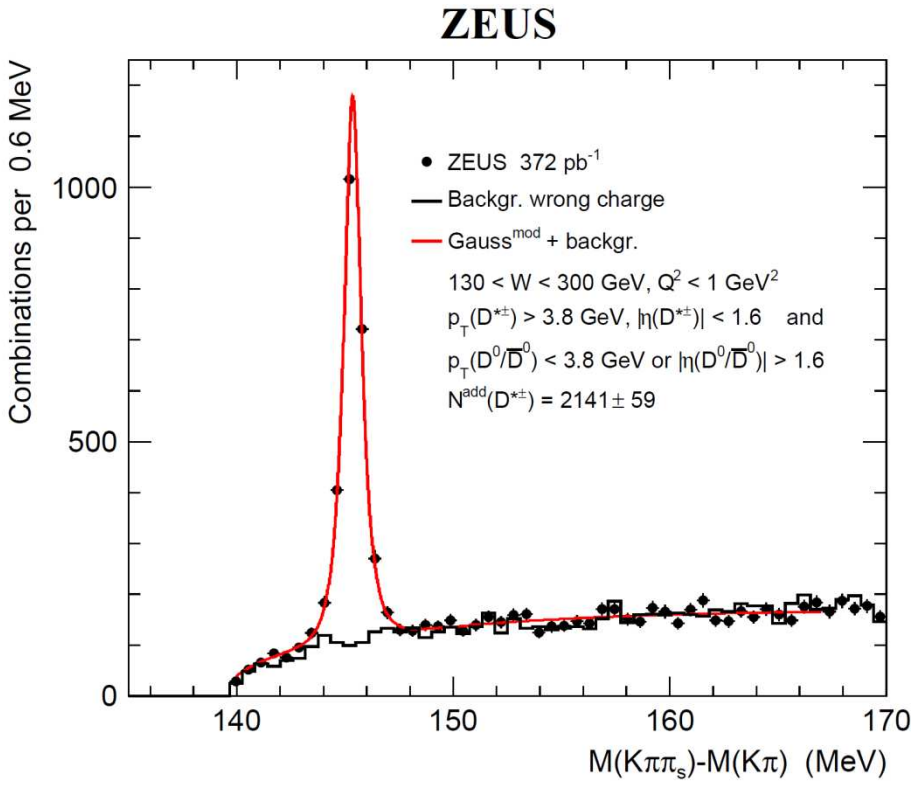
- **Significantly suppressed background using microvertex detector (MVD);**

D^+ and D^* spectra

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

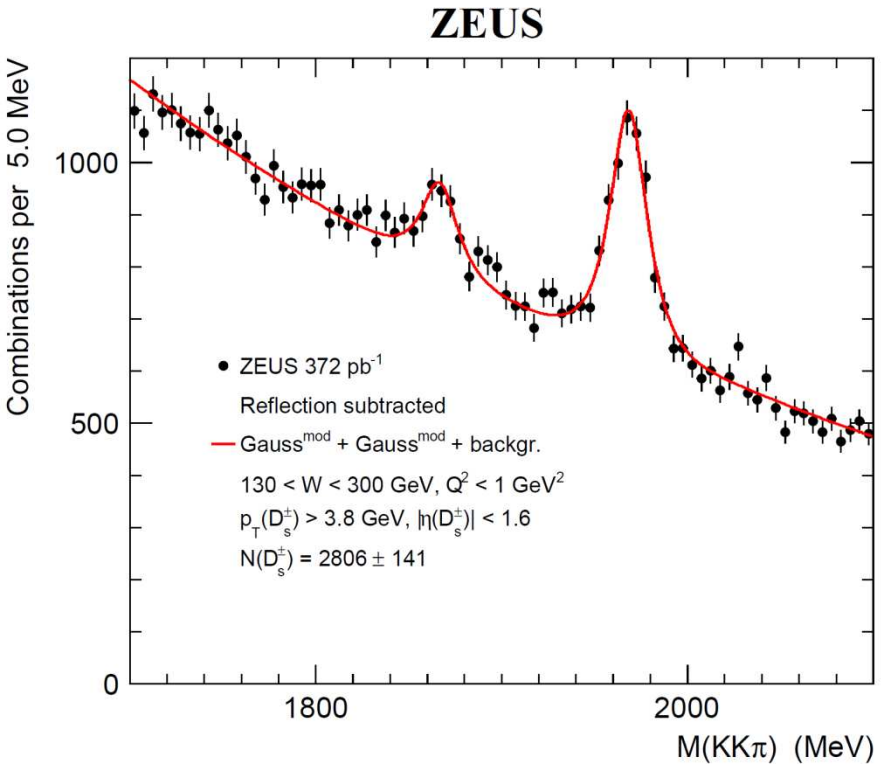


$D^{*+} \to D^0\pi_s^+ \to K^-\pi^+\pi_s^+$

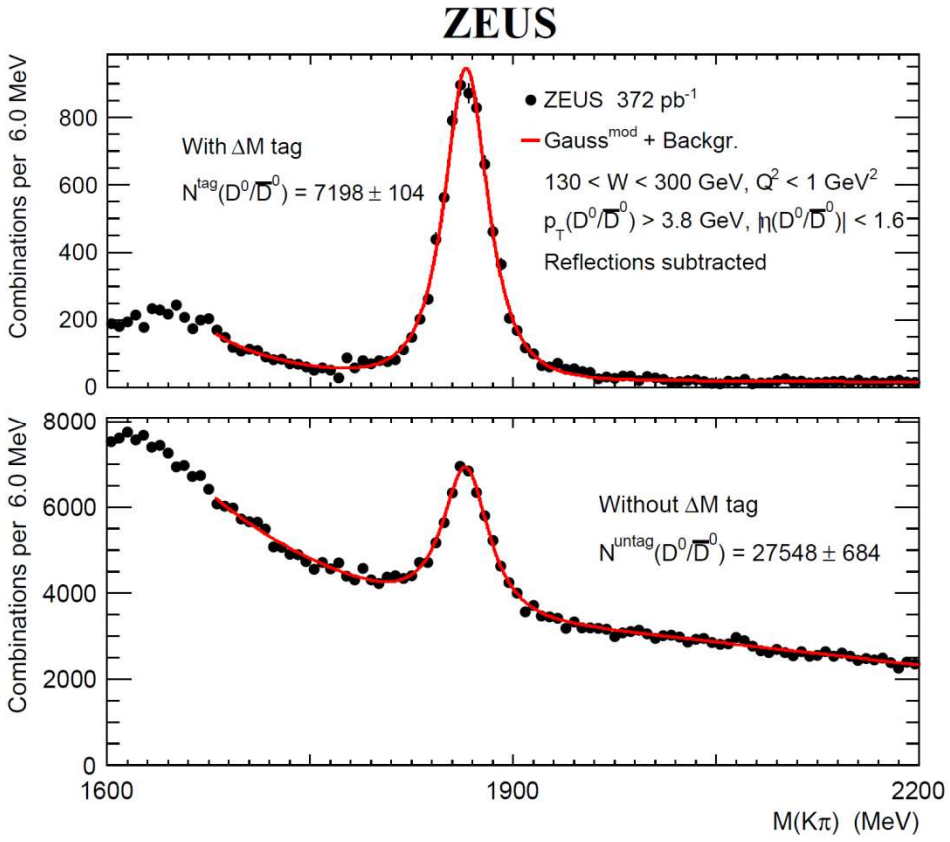


D^+ and D^* spectra

$D_s^+ \to \Phi^0\pi^+ \to K^+K^-\pi^+$



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



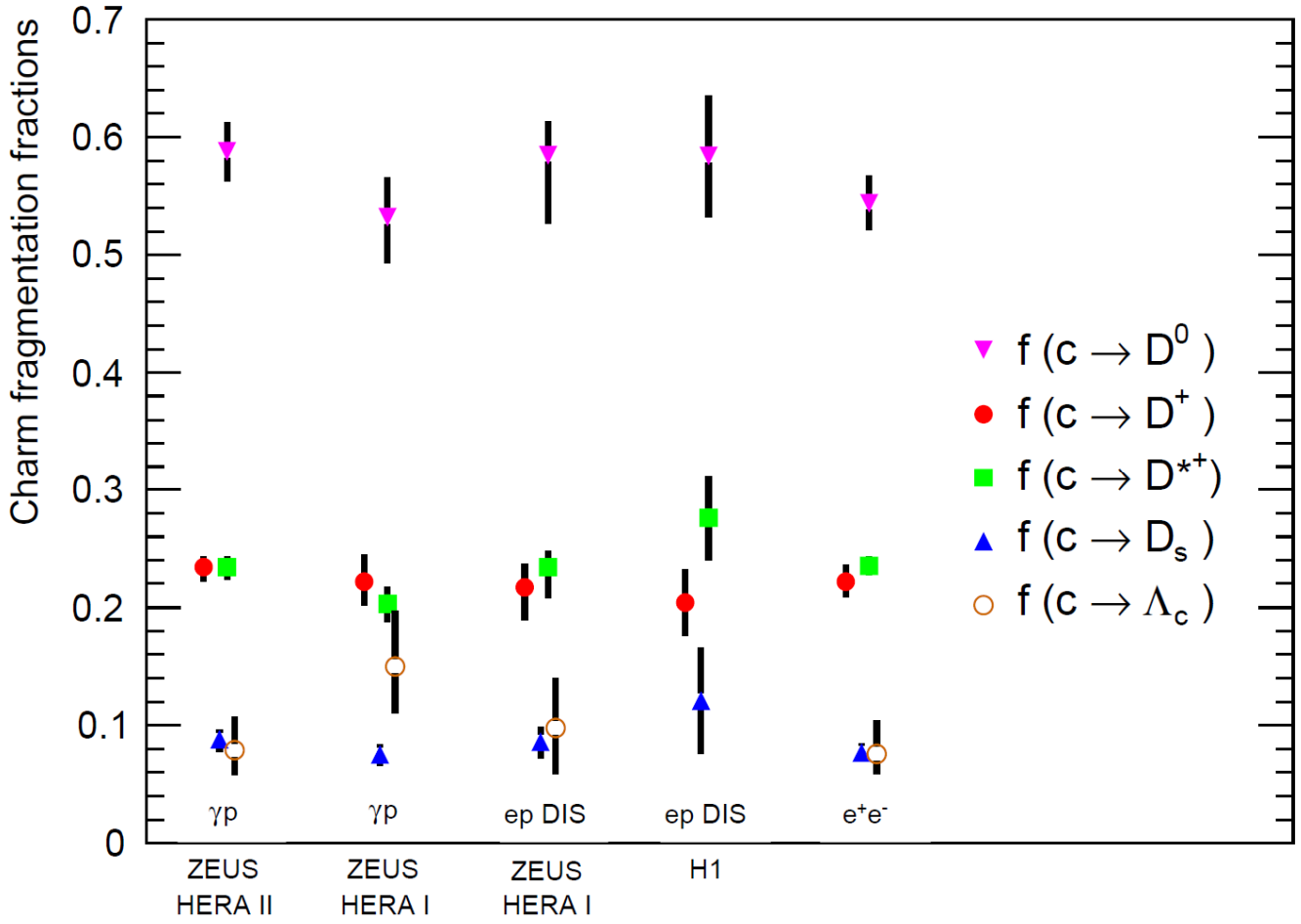
New results

	ZEUS (γp) (prel.) HERA II			ZEUS (γp) HERA I		
	stat.	syst.	br.	stat.	syst.	br.
$f(c \to D^+)$	0.232 ± 0.006	$^{+0.005}_{-0.006}$	$^{+0.009}_{-0.010}$	0.222 ± 0.015	$^{+0.014}_{-0.005}$	$^{+0.011}_{-0.013}$
$f(c \to D^0)$	0.590 ± 0.016	$^{+0.011}_{-0.007}$	$^{+0.013}_{-0.019}$	0.532 ± 0.022	$^{+0.018}_{-0.017}$	$^{+0.019}_{-0.028}$
$f(c \to D_s^+)$	0.089 ± 0.005	$^{+0.002}_{-0.007}$	$^{+0.005}_{-0.005}$	0.075 ± 0.007	$^{+0.004}_{-0.004}$	$^{+0.005}_{-0.005}$
$f(c \to \Lambda_c^+)$	0.078 ± 0.012	$^{+0.005}_{-0.009}$	$^{+0.024}_{-0.014}$	0.150 ± 0.023	$^{+0.014}_{-0.022}$	$^{+0.038}_{-0.025}$
$f(c \to D^{*+})$	0.234 ± 0.006	$^{+0.004}_{-0.004}$	$^{+0.005}_{-0.007}$	0.203 ± 0.009	$^{+0.008}_{-0.006}$	$^{+0.007}_{-0.010}$

The obtained precision is competitive with results in e+e- collisions!

	H1 (DIS) [2]			Combined e^+e^- data [5,6]			ZEUS (DIS) [3,4] HERA I		
	stat.$\oplus$syst.		br.	stat.$\oplus$syst.		br.	stat.	syst.	br.
$f(c \to D^+)$	0.204 ± 0.026	$^{+0.009}_{-0.010}$		0.222 ± 0.010	$^{+0.010}_{-0.009}$		0.217 ± 0.018	$^{+0.002}_{-0.019}$	$^{+0.009}_{-0.010}$
$f(c \to D^0)$	0.584 ± 0.048	$^{+0.018}_{-0.019}$		0.544 ± 0.022	$^{+0.007}_{-0.007}$		0.585 ± 0.019	$^{+0.009}_{-0.052}$	$^{+0.018}_{-0.019}$
$f(c \to D_s^+)$	0.121 ± 0.044	$^{+0.008}_{-0.008}$		0.077 ± 0.006	$^{+0.005}_{-0.004}$		0.086 ± 0.010	$^{+0.007}_{-0.008}$	$^{+0.005}_{-0.005}$
$f(c \to \Lambda_c^+)$				0.076 ± 0.007	$^{+0.027}_{-0.016}$		0.098 ± 0.027	$^{+0.020}_{-0.017}$	$^{+0.025}_{-0.023}$
$f(c \to D^{*+})$	0.276 ± 0.034	$^{+0.009}_{-0.012}$		0.235 ± 0.007	$^{+0.003}_{-0.003}$		0.234 ± 0.011	$^{+0.006}_{-0.021}$	$^{+0.007}_{-0.010}$

The fragmentation fractions of charm quarks are independent of the production process and supports the hypothesis of universality of heavy quark fragmentation



Conclusions

- **Charm systems are interesting in the light of recent progress on open charm spectroscopy;**
- **ZEUS continues to produce new interesting results in the field of charm meson spectroscopy in *ep*-collisions:**

  - ***excited charm studies: new measurements of masses, widths, helicity, ratios of branching fractions and the fractions of c-quarks hadronising into*** D_1 ***and*** D^*_2 ***states.***

  - ***production of*** D^0, D^+, D_s^+, D^{*+}, Λ_c ***: fragmentation fractions of charm quarks are independent of the production process;***
- **All results support the hypothesis that fragmentation proceeds independently of the hard sub-process.**