
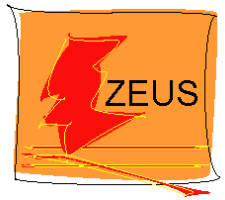

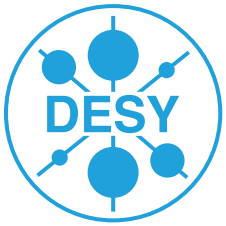

Production of the excited charm mesons D_1 and D_2^* at HERA

NPB 866, 229 (2013)

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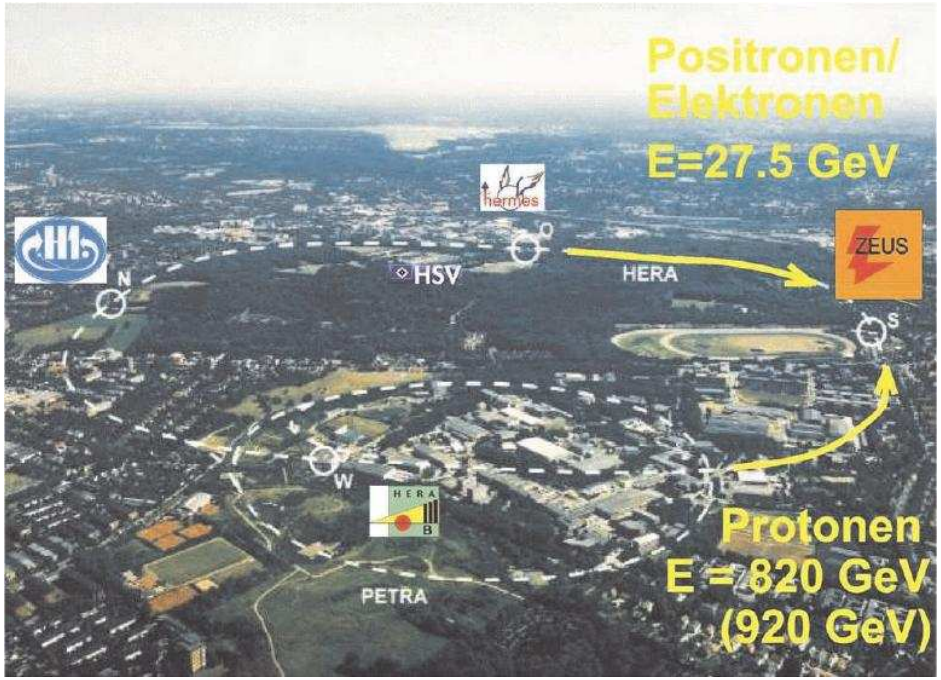
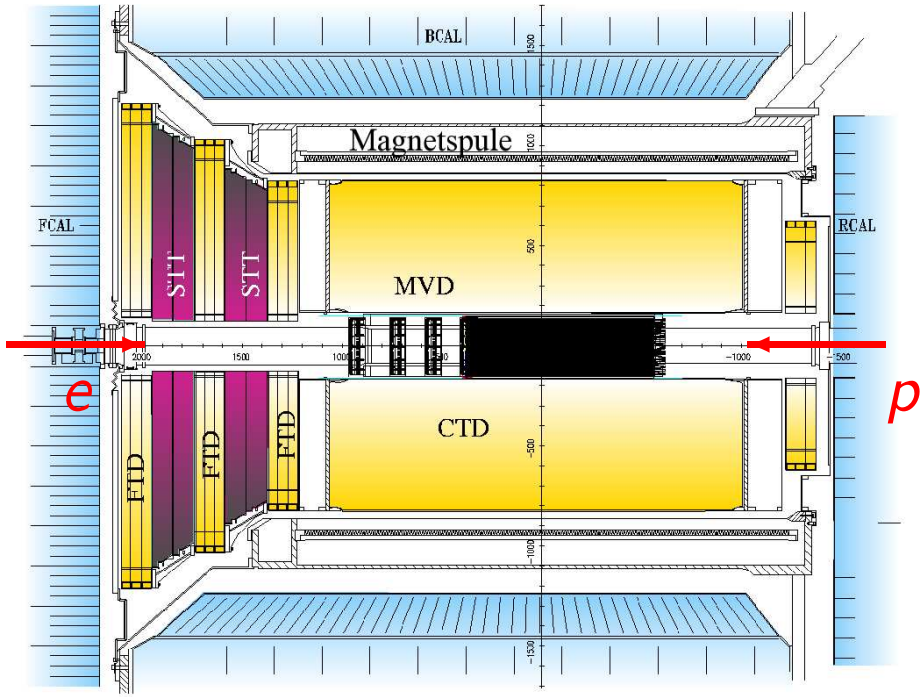
on behalf of the ZEUS collaboration

DIS2013, Marseille, France
April 22, 2013

Introduction

ZEUS at HERA





HERA:

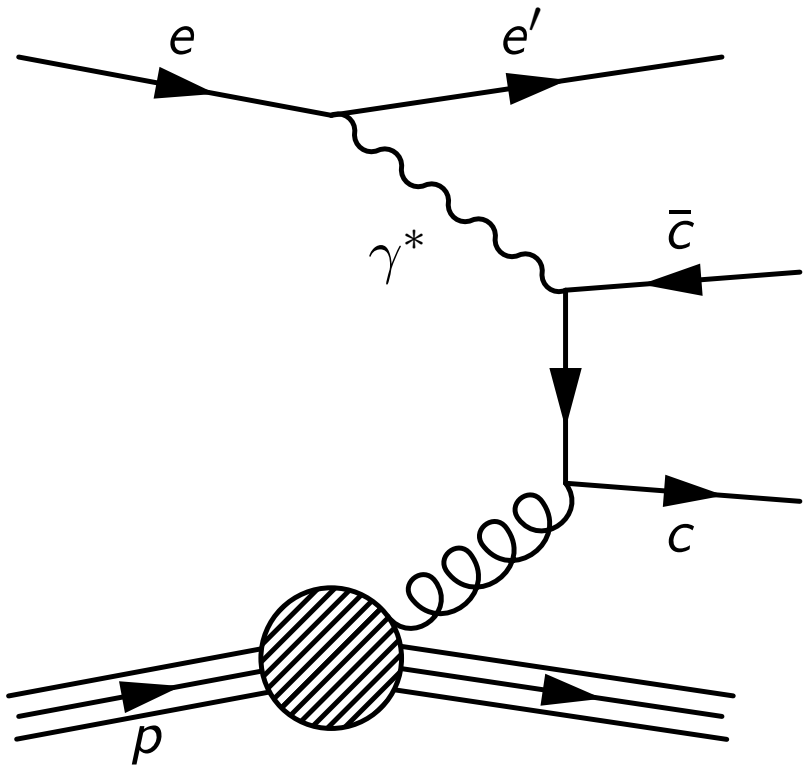
- Collider experiments: H1 and ZEUS;
- ep collisions at $E_{CMS} = 318\,\text{GeV}$.

ZEUS: $\sim 0.5\,\text{fb}^{-1}$ collected data,

- $130\,\text{pb}^{-1}$ between 1992 and 2000 (HERA-I);
- $370\,\text{pb}^{-1}$ between 2003 and 2007 (HERA-II).

Heavy quarks at HERA

Boson-gluon fusion:

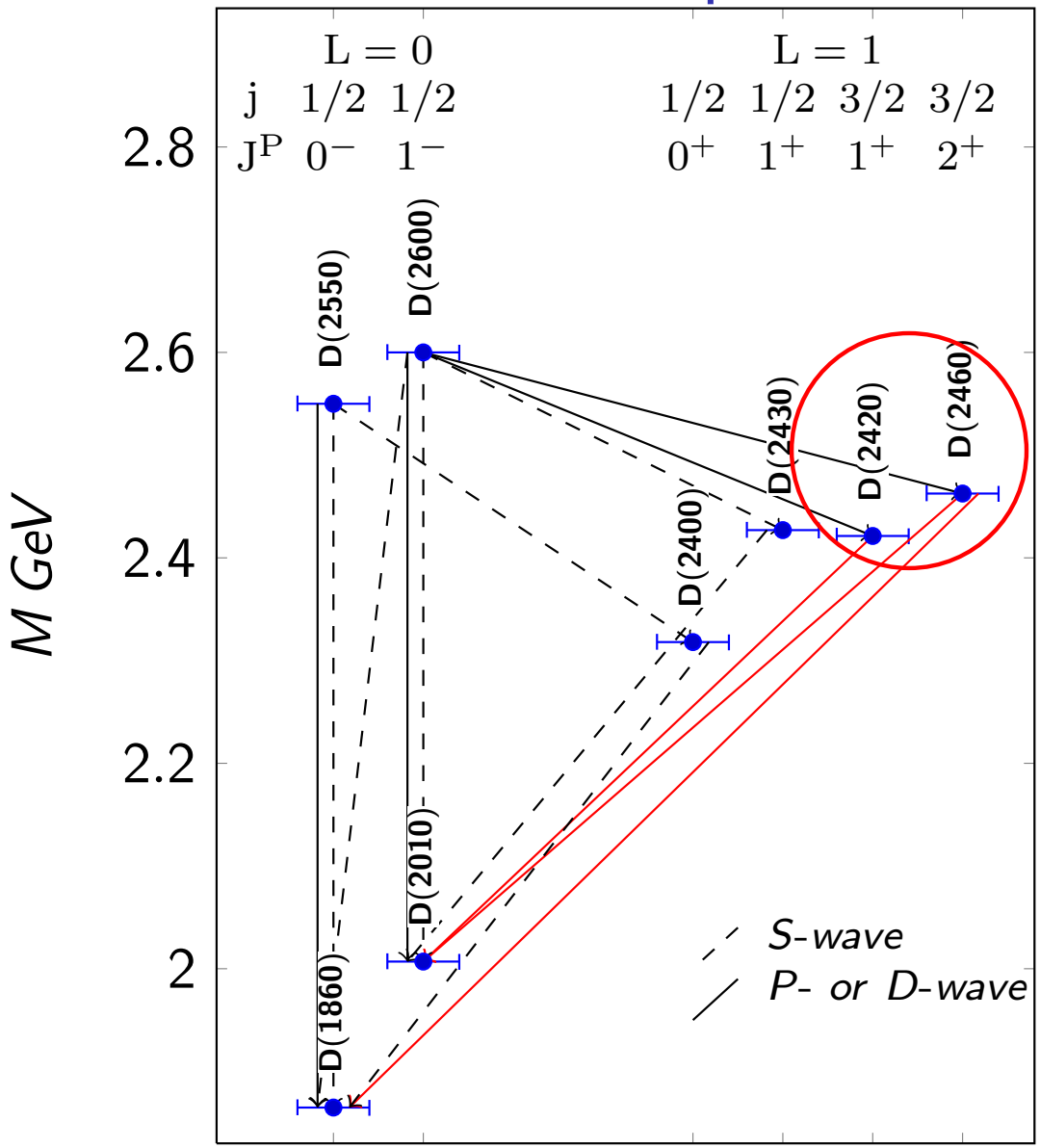


Up to $\sim 5 \times 10^9$ c-quarks: enough for ground and excited charm analysis.

The goal is to obtain:

- all possible excited charm meson masses, widths and angular distributions;
- branching ratios;
- charm quark fragmentation fractions.

Excited charm meson spectrum

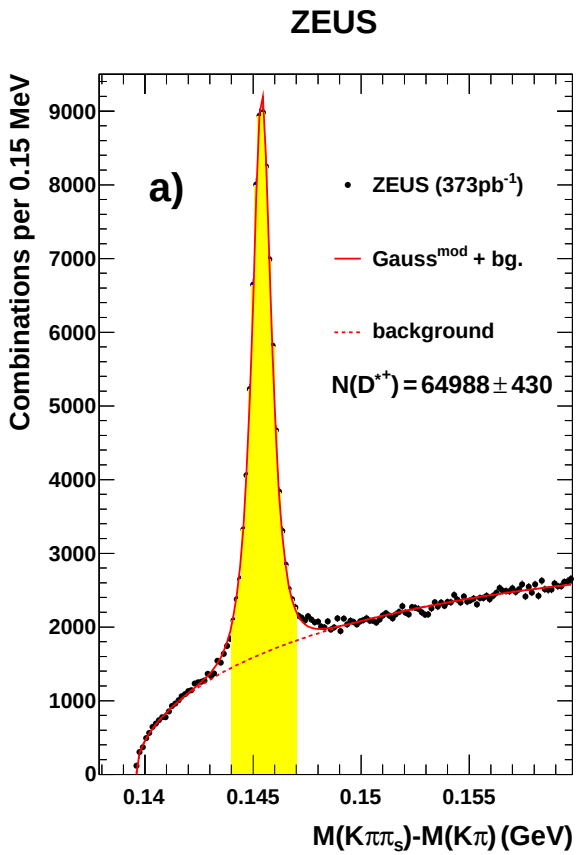


- Reconstructed states:
  $c\bar{u}$: $D_1^0(2420), D_2^{*0}(2460)$
  $c\bar{d}$: $D_1^+(2420), D_2^{*+}(2460)$
- The states were reconstructed in their decays to D^0, D^{*+}, D^+ ("ground" states) and pions.

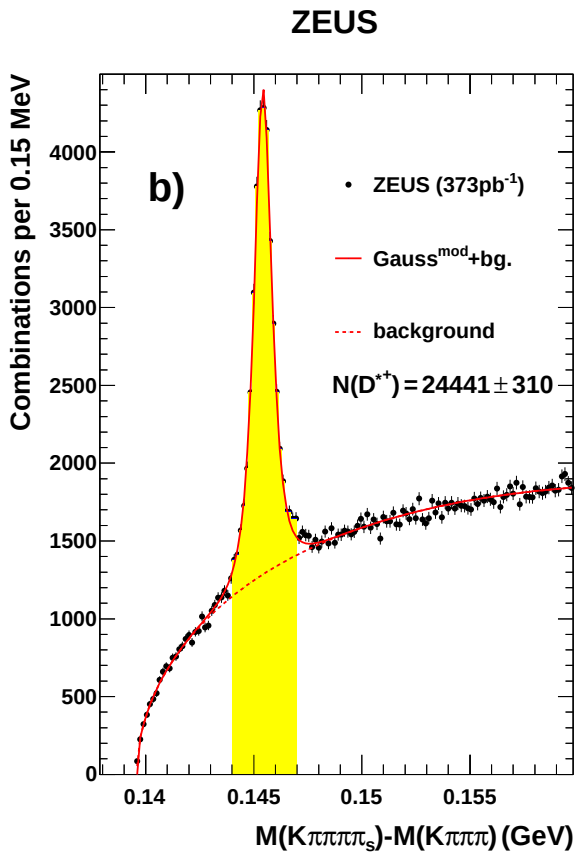
Ground state reconstruction

D^{*+} reconstruction

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



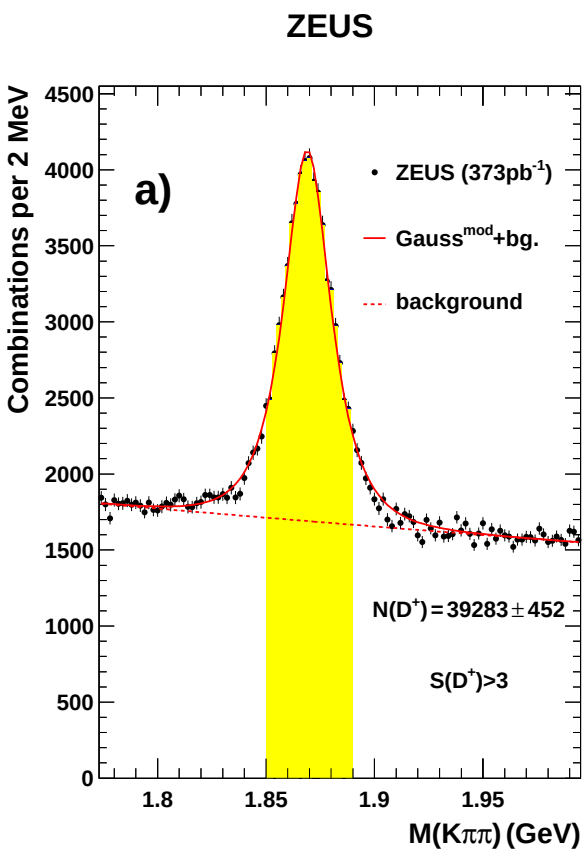
$D^{*+} \to K3\pi\pi_s$



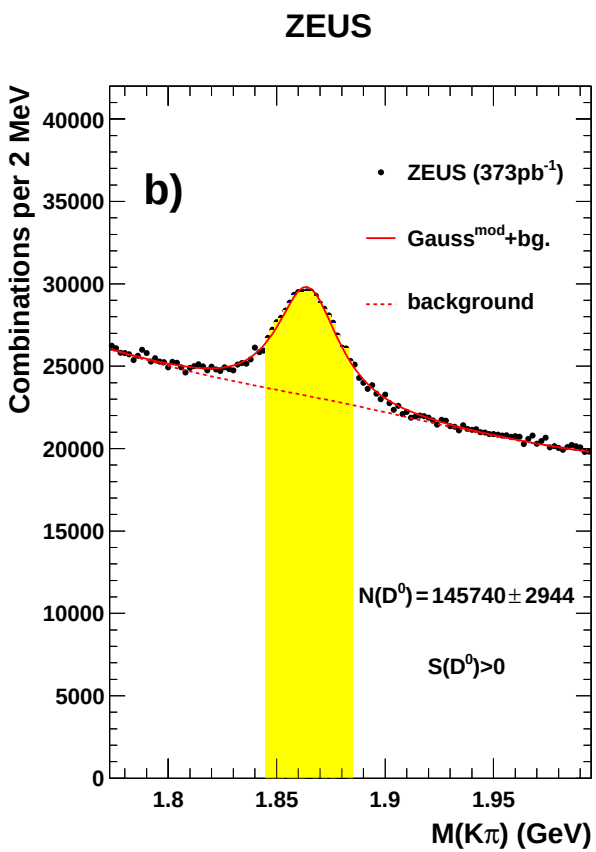
Almost 90000 D^{*+} candidates! Candidates from the mass window $(0.144 - 0.147$ GeV) are taken for the excited charm mesons analysis.

D^+ and D^0 reconstruction

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



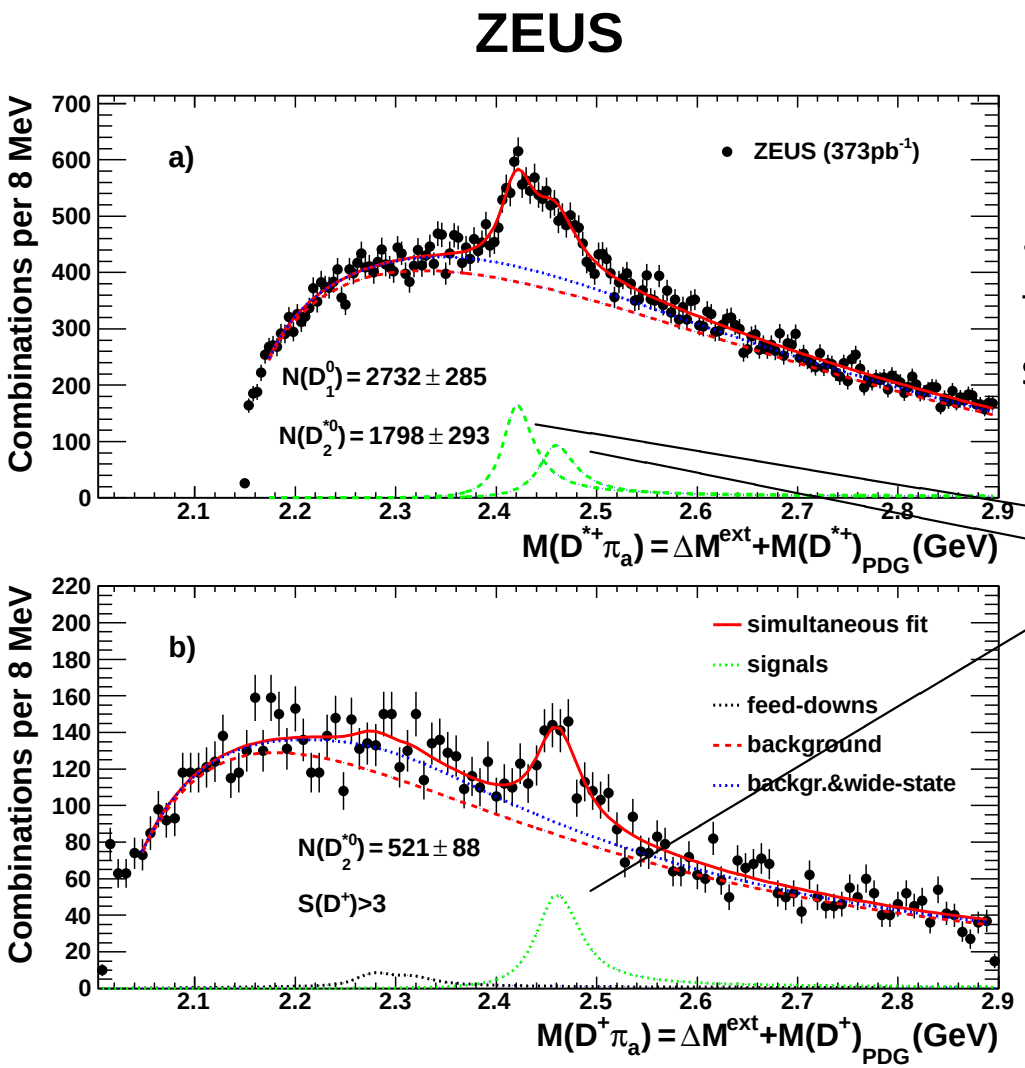
$D^0 \to K^-\pi^+$



MVD allows to use lifetime tagging of displaced vertices.

Neutral excited states

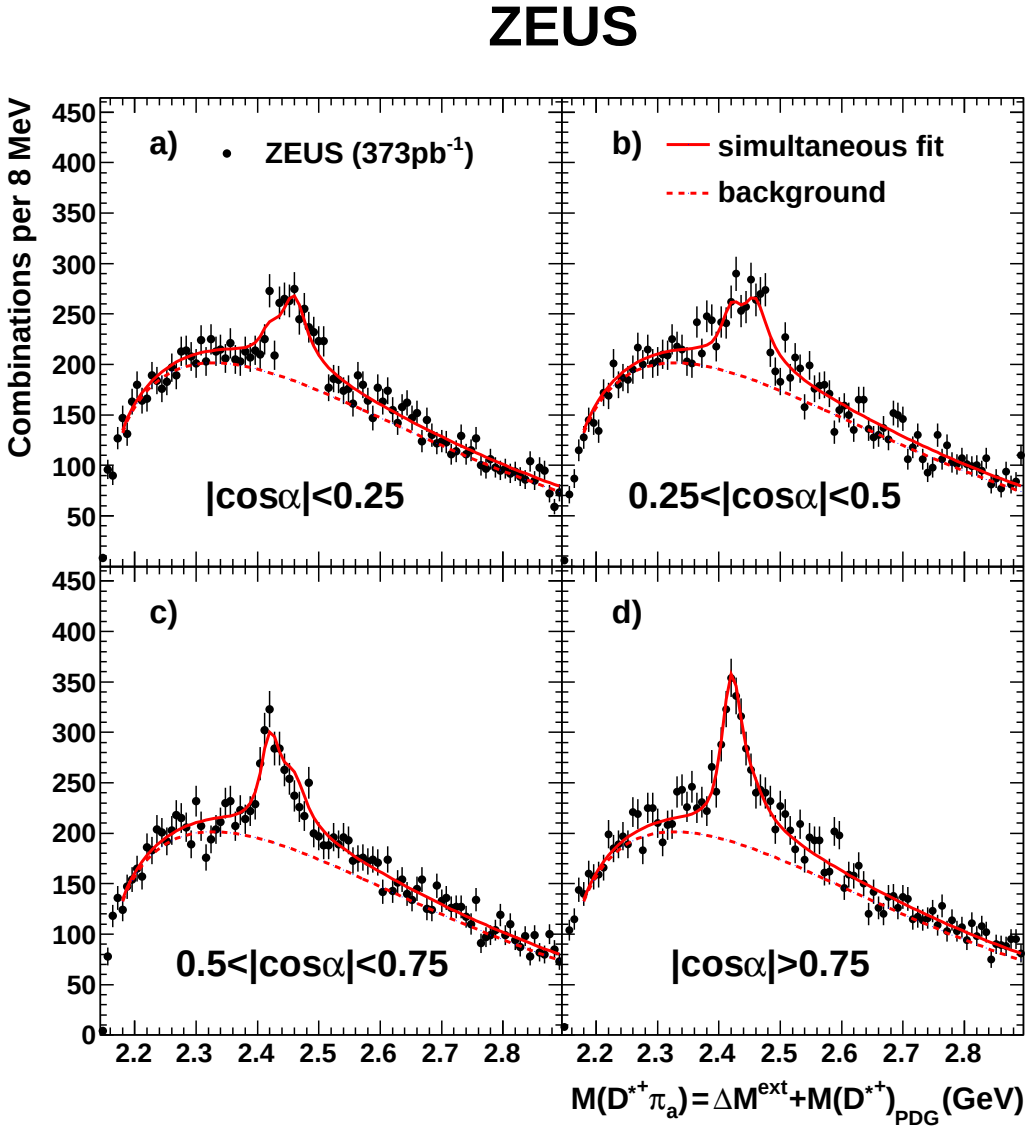
$D^{*+}\pi_a^-$ and $D^+\pi_a^-$ mass spectra and fit



The mass distributions $M(D^{*+}\pi_a)$ and $M(D^+\pi_a)$. The solid curves are the result of a simultaneous fit to the sum of:

- background contribution;
- D_2^{*0} and D_1^0 relativistic Breit-Wigner$\otimes$resolution;
- $D(2430)^0$ and $D(2400)^0$ wide states relativistic Breit-Wigner$\otimes$resolution.

$D^{*+}\pi_a^-$ mass spectra in $cos\alpha$ 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.

Neutral states spectroscopy results

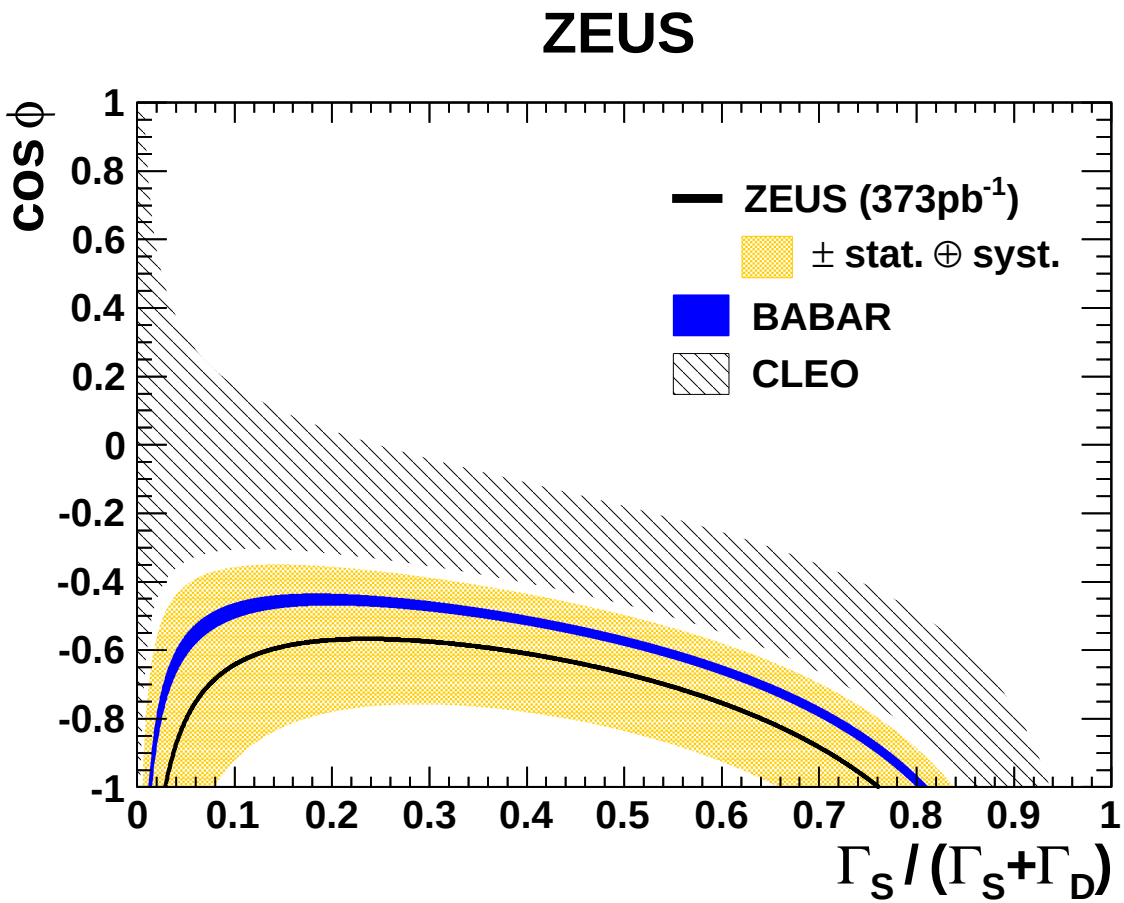
	HERA-II[1](this)	HERA-I[2]	PDG[3]
$M(D_1^0)$, MeV	$2423.1 \pm 1.5^{+0.4}_{-1.0}$	$2420.5 \pm 2.1 \pm 0.9$	2421.3 ± 0.6
$\Gamma(D_1^0)$, MeV	$38.8 \pm 5.0^{+1.9}_{-5.4}$	$53.2 \pm 7.2^{+3.3}_{-4.9}$	27.1 ± 2.7
$h(D_1^0)$	$7.8^{+6.7+4.6}_{-2.7-1.8}$	$5.9^{+3.0+2.4}_{-1.7-1.0}$	
$M(D_2^{*0})$, MeV	$2462.5 \pm 2.4^{+1.3}_{-1.1}$	$2469.1 \pm 3.7^{+1.2}_{-1.3}$	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	

[1]H. Abramowicz *et al.* ZEUS Collaboration, *Production of the excited charm mesons D_1 and D_2^* at HERA*, Nucl. Phys. **B** 866, 229-254, (2013).

[2]S. Chekanov *et al.* ZEUS Collaboration, *Production of excited charm and charm-strange mesons at HERA*, Eur. Phys. J. **C** 60, 25, (2009).

[3]J. Beringer *et al.*, Particle Data Group Collaboration, Review of Particle Physics (RPP), Phys. Rev. **D** 86 (2012) 010001.

Indication of S- and D-wave mixing

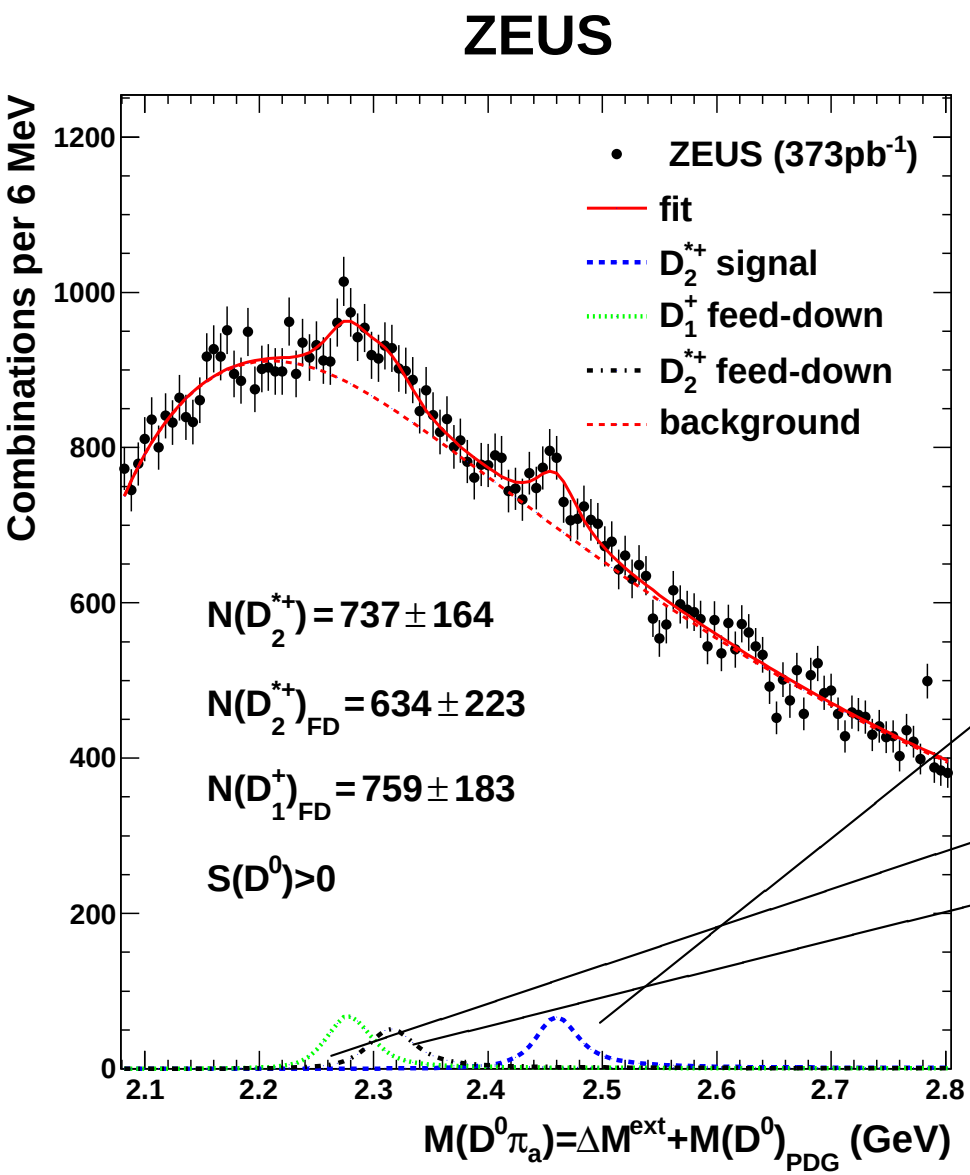


For mixed S/D-wave decay with the relative phase of S- and D-wave amplitudes ϕ and the fraction of S-wave $r = \frac{\Gamma_S}{\Gamma_S+\Gamma_D}$:

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

Charged excited states

$D^0\pi^+$ mass spectrum and fit



The solid curve is the result of a fit to the sum of:

- background contribution;
- D_2^{*+} relativistic Breit-Wigner⊗resolution;
- D_1^+ and D_2^{*+} feed-downs[a] ⊗resolution.

[a] Feed-downs, the peaking structures appearing in case of incomplete (e.g. missing π^0) reconstruction, are also used for measurements.

Charged states spectroscopy results

	HERA-II (this)	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 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 fixed	

- Only few previous results on D_1^+ (BABAR and CLEO);
- Good agreement with PDG.

Fragmentation fractions and branching ratios

Fragmentation fractions for excited charm mesons

Fragmentation fraction:

$$f(c \to D) = \frac{N(D)}{N(c)}.$$

Also:

$$f(c \to D^{**}) = \frac{N(D^{**})}{N(c)} = \frac{N(D^{**})}{N(D)} f(c \to D).$$

Extra assumptions on branching ratios, e.g. on sum of charged modes:
$\mathcal{B}_{D_2^{*0} \to D^+ \pi^-} + \mathcal{B}_{D_2^{*0} \to D^{*+} \pi^-} = \frac{2}{3}$.

Fragmentation fractions

	$f(c \to D_1^0)$	$f(c \to D_2^{*0})$	$f(c \to D_1^+)$	$f(c \to D_2^{*+})$
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[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;
- First measurements of $f(c \to D_1^+)$ and $f(c \to D_2^{*+})$.

[3] K. Ackerstaff *et al.*, Production of P wave charm and charm - strange mesons in hadronic Z^0 decays, Z. Phys. **C** 76 (1997) 425

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	$1.9 \pm 1.1 \pm 0.3$
Model A[4]	2.280 ± 0.007	2.266 ± 0.015
Model B[5]	$2.3 \ldots 3.0$	

[4] P. Colangelo et. al., New meson spectroscopy with open charm and beauty, Phys. Rev. **D** 86 (2012) 054024

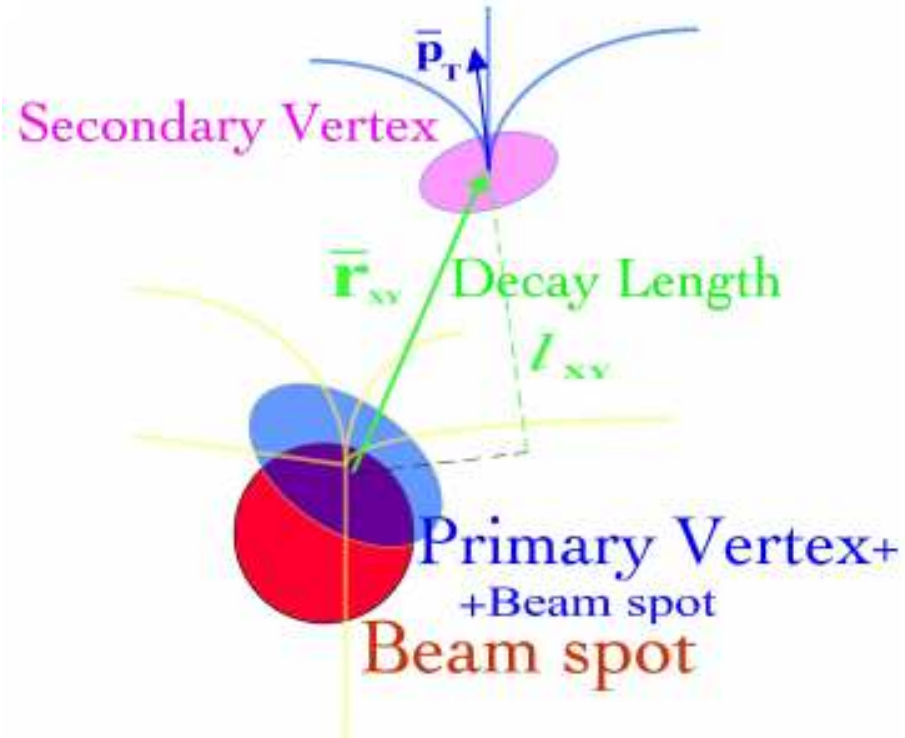
[5] A. F. Falk and M. E. Peskin, Production, decay, and polarization of excited heavy hadrons, Phys. Rev. **D** 49 (1994) 3320 and others

Conclusions

The following quantities were measured using HERA-II data:

- masses of D_1 and D_2^* states;
- widths of neutral states;
- the 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;
- helicity parameter of D_1^0, which favours mixing of S- and D-waves in its decays to $D^{*\pm}\pi^{\mp}$.

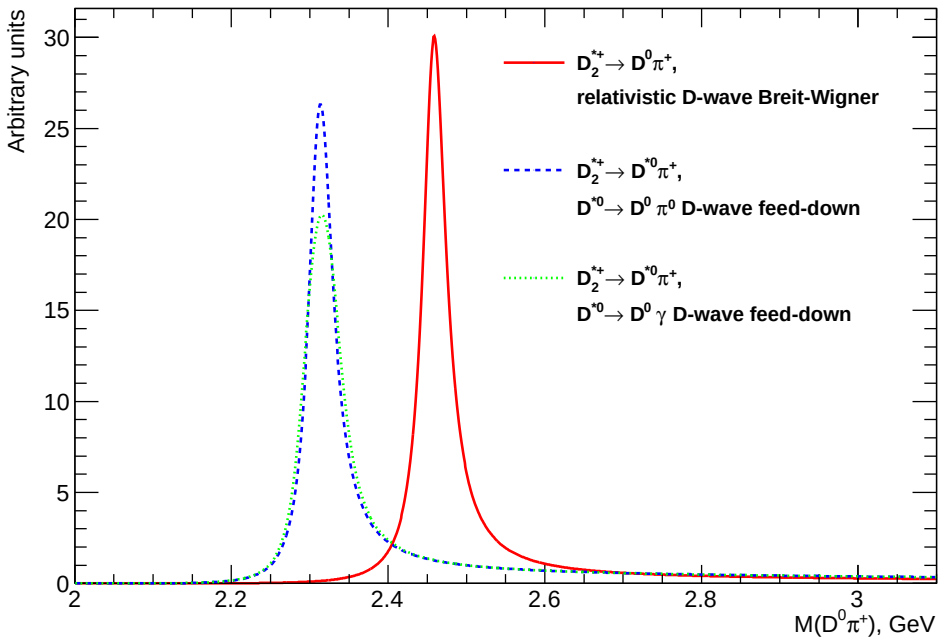
Backup:2D projected decay length significance



$$l_{proj.xy} = \vec{P}_{xy}(\vec{r}_{prim.xy} - \vec{r}_{sec.xy}),$$

$$S = \frac{l_{proj.xy}}{\sigma(l_{proj.xy})}$$

Backup:What are the feed-downs?



- Feed-downs are peaking structures that appear in incomplete reconstruction.
- The main condition for the feed-down appearance is an extremely restricted kinematic space for the missing particle.
- The reconstructed invariant-mass signal will be shifted from the nominal value and slightly distorted.

A special procedure has been developed to measure the mass parameters from the feed-down signals.